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Monthly Groundwater Budget Analysis for the Oliver, B.C. Area (Aquifers 254, 255 and 256)

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Executive Summary

Aquifers 255, 254 and 256 form a linked chain of valley bottom aquifers located in the South Okanagan between Vaseux Lake to the north and Osoyoos Lake to the south. The study used existing information to develop a conceptual hydrogeological model of groundwater movement through these aquifers and to develop a monthly water budget that can be used to inform water allocation policies and decisions. The Oliver area is an important agricultural and tourism region and is home to approximately 6,000 people, most of whom rely on groundwater for drinking water. The climate is semi-arid with an average annual precipitation of 345 mm. The project objectives were to develop a conceptual groundwater model describing the regional movement of groundwater, a quantitative assessment of aquifer recharge and discharge, groundwater use and estimates of groundwater potentially available for licensing and identification of data gaps and monitoring activities for improving estimates of groundwater fluxes and availability.

The three aquifers can be thought of as an aquifer system comprised of mostly unconfined to semi-confined aquifers in a river valley (e.g. Type 1a or 1b as described in Wei et al 2009). Flow through the system is driven by the approximate 50 m difference in elevation between Vaseux Lake and Osoyoos Lake. Aquifer 255 is modeled to receive significant recharge from the combined surface water losses of Vaseux Lake, Vaseux Creek and the Okanagan River, and discharges to Aquifer 254 in the vicinity of Tuc-El-Nuit Lake in Oliver. Aquifer 254 receives its natural recharge from Aquifer 255, adjacent flow from Aquifer 256 and localized losses from the Okanagan River. Developed farmland throughout the area is irrigated primarily with surface water diverted at McIntyre Dam, and a component of recharge is modeled as irrigation return flow. Aquifer 256 is a less productive alluvial fan type aquifer (Type 3 of Wei et al) and is recharged by seasonal creek losses and potentially by upgradient inflow from Aquifer 254.

Groundwater wells have been developed and are in use in all three aquifers, with Aquifer 255 the most heavily used and Aquifer 256 the least used. The Town of Oliver supplies water to all of the municipal area and significant rural areas north and south of the Town centre. The Town also operates a number of wells completed in each of the three aquifers. Summary results of our groundwater budget analysis, 30% safety factor recommendation for potential groundwater availability and estimated existing groundwater use (dry year scenario) are provided in the table below.

<u>Dry Year</u> Groundwater Budgets and Potential Groundwater Availability (all in m^3/year)

Aquifer No.	**Estimated annual groundwater (GW) budget from water balance**	**Potential amount of GW available based on 30% as a Safety Factor**	**Existing estimated amount of GW used**
255	33,248,471	9,974,541	8,420,340
256	500,213	150,064	710,000
254	34,260,614	10,278,184	5,371,470

Water Licence Allocation Recommendations

We examined flow regulation and conservation flows in the Okanagan River and found that increases or decreases in groundwater extraction within the amounts in the middle column above are not likely to affect flow maintenance in the River. The difference between the minimum regulated River flow and suggested conservation flows is 2.5 m^3 /sec, which is 40,000 US gpm, whereas the maximum recommended groundwater available for Aquifer 254 is 0.3 m^3/sec or about 5,000 US gpm. The spreadsheet-based water budgets can be used to assess the relative impact of additional groundwater

extractions or the effects of changes to other input and output terms. However, it is important to recognize that these groundwater budgets are water balances and as such, changing an output will alter the balance and the system response functions (e.g. increase in induced surface recharge from pumping) are not represented within the spreadsheet, as they would be in a numerical model. Therefore, if a large extraction were added into the spreadsheet using the input sheet provided (say, 10,000 m^3/day or more), this would cause the tool to predict a change in storage, causing a decrease in aquifer thickness.

While it was not an objective of the current study to develop a water allocation tool with the water budget spreadsheet, we have assessed its potential applicability. The spreadsheet tool, together with the recommendations provided herein (e.g. site specific hydrogeological impact assessment, ongoing water level monitoring, additional aquifer characterization) should be used in combination to inform water allocation policies for each of the three subject aquifers. An individual licence application cannot be quantitatively assessed with a high degree of accuracy using the water budget tool because of the aforementioned limitations of the water balance, and also the uncertainty associated with the input and output terms is likely greater than the diversion from an individual well.

Recommendations for Further Study and Monitoring

The factors with the greatest overall influence on the groundwater budget are the following:

- Losses from flowing and standing water to Aquifer 255;
- Groundwater discharge to specific reaches of the Okanagan River (Aquifer 254, and also potentially Aquifer 255);
- Contributions from upgradient bedrock aquifers to all three study area aquifers (especially Aquifer 255 which is conceptually modeled to receive high flows from a bedrock aquifer associated with the Vaseux Creek catchment); and
- Aquifer thickness, aquifer width, hydraulic conductivity and groundwater discharge estimates that rely on an assumed hydraulic gradient.

The following recommendations are provided for Ministry consideration:

- Install two gauges in Vaseux Creek, one at the upgradient edge of the valley/unconsolidated aquifer and one just upstream of the Okanagan River confluence could be used to constrain monthly estimates of creek losses to the aquifer.
- Similarly, install gauges on the Okanagan River, perhaps at key times of the year (i.e. irrigation season and non-irrigation season or high water and low water) could be used to assess both losses and gains.
- It is also our opinion that a fully penetrating observation well in Aquifer 255 in the vicinity of where Vaseux Creek passes under Highway 97 would provide valuable insight into the groundwater flow regime in this area (this was also a recommendation from the Golder – Summit study) and information on aquifer vertical gradients degree of confinement of lower zones.
- Further, since there are few fully penetrating wells, additional deep boreholes in the other aquifers combined with detailed grain size analysis could help refine aquifer parameters.
- Review existing aquifer mapping and consider updating the boundaries of Aquifers 254 and 255.
- Establish environmental flow needs for the Okanagan River and use this information to develop allocation policies for shallow, unconfined groundwater sources.

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1. INTRODUCTION AND BACKGROUND

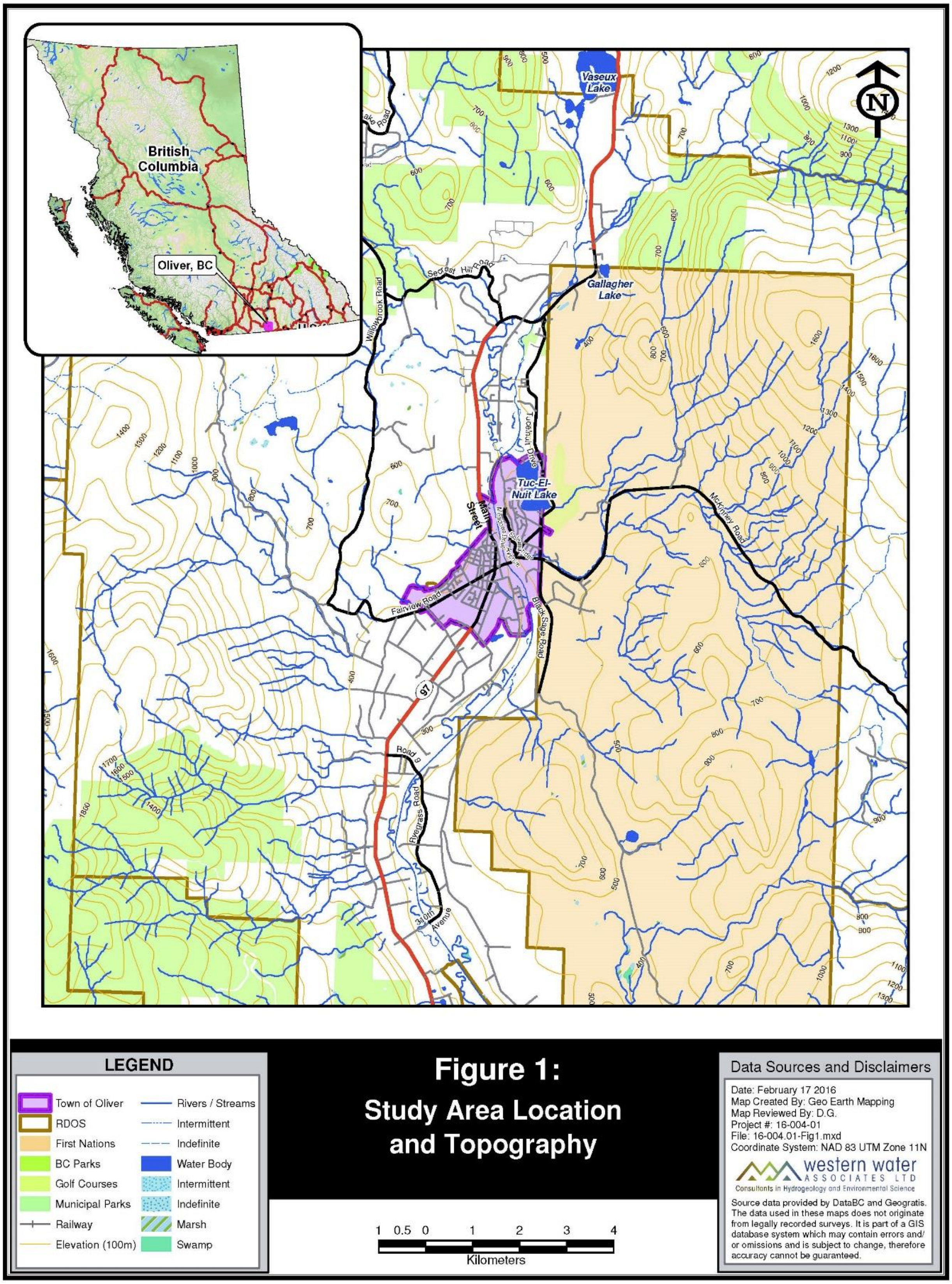
This report presents a conceptual hydrogeological model and monthly water budget analysis for aquifers located in the Oliver, B.C. area. The report was prepared by Western Water Associates Ltd. (WWAL) under contract to the B.C. Ministry of Environment (ENV).

1.1 Study Area and Project Objectives

For the purposes of this report, the Study Area is taken to be that part of the South Okanagan valley (Valley) bottom and adjoining areas lying between Vaseux Lake to the north and Oyosoos Lake to the south, comprising an area of approximately 60 km^2 (Figure 1). Oliver serves as an important centre of the South Okanagan agricultural and tourism economy and is home to approximately 4,000 residents in town, plus another 2,000 residing in outlying rural areas. The availability of groundwater and surface water resources is critical to the economy of the region and aquatic species within this part of the Okanagan watershed.

The objectives of this project are to:

- Development of conceptual groundwater model describing the regional groundwater movement in the study area, including groundwater recharge, interaction with surface waters, and groundwater use;
- Quantitative assessment of aquifer recharge and aquifer discharges, estimates of groundwater use, and estimates of water availability for groundwater licensing based on existing information; and
- Identification of data gaps and monitoring activities for improving estimates of groundwater fluxes and availability.



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Coordinate System: NAD 83 UTM Zone 11N

Source data provided by DataBC and Geogratis. The data used in these maps does not originate from legally recorded surveys. It is part of a GIS database system which may contain errors and/ or omissions and is subject to change, therefore accuracy cannot be guaranteed.

Figure 1 Project Location.

1.2 Overview of Previous Hydrogeological Studies

Owing to the semi-arid climate and the history of water use in the Oliver area, there have been a number of previous studies that are relevant to the water budget study. Table 1 below provides an overview of some of these studies, which will not be described in detail. A full list of references appears near the end of this report.

Table 1 Summary of relevant studies

Author(s) and Year	Title / Subject of Report	Brief Summary
Western Water Associates Ltd. (2015)	Source Water Assessment Town of Oliver Groundwater Supplies	Modules 1, 2, 7 and 8 of the Comprehensive Source to Tap Assessment Guideline
Western Water Associates Ltd. (2014)	Buchanan Road Wells Completion Report	Describes installation and testing of two new wells for Town of Oliver
Western Water Associates Ltd. (2012)	Assessment of Groundwater Under Direct Influence of Surface Water	Assessment following draft GUDI guidelines
Western Water Associates Ltd. (2011)	Review of Ambient Groundwater Quality Monitoring Networks	Assessed Provincial ambient groundwater monitoring well networks including the wells in the Oliver area
Summit Environmental (2010)	Senkulmen Industrial Park wells	Completion report for two high capacity production wells completed in Aquifer 255
Golder and Summit (2009)	OBWB Phase 2 Groundwater Study “Objectives 2 and 3”	Conceptual model and water budget analysis for unconsolidated aquifers in Okanagan valley including Oliver
Toews and Allen (2007)	Capture Zone and Recharge Modeling	Part of M.Sc. thesis (SFU)
Pacific Hydrology Consultants (2007)	Report on Covert Farms Production wells 1-4	Describes installation and testing of four high capacity irrigation wells completed in Aquifer 255
Golder Associates (2004)	Initial Steps of a Groundwater Protection Plan (Draft) Town of Oliver	B.C. Well Protection Toolkit study
Golder Associates (2004)	Completion report for Miller Road well for Town of Oliver	Production well drilling and testing report
TRUE Consulting (2002)	Town of Oliver Summary of Water Supply Wells and Background Information	A compilation of well logs and completion reports for older Town of Oliver wells

The 2009 Golder – Summit (2009) study for Okanagan Basin Water Board (OBWB) summarized aquifers in the study area as the “Vaseux - Osoyoos Lake Aquifer system” – which is described in more detail in Section 3 of this report.

The majority of this chain of valley-bottom aquifers is located along the mainstem Okanagan River and is in most places bisected by the Okanagan River channel. Recharge contributions to this aquifer system consist of recharge from upland bedrock areas, losses from flowing water and recharge from Vaseux Lake, return flows from irrigation, and losses from the Okanagan River, Vaseux Creek and Park Rill Creek (See Figure 2). The OBWB study attempted to re-map the aquifer extents based in part on well logs and on surficial mapping and topography and how these so-called “OBWB aquifers” compare to the currently mapped aquifers is illustrated in Figure 2. This figure also shows the location of selected high capacity water wells discussed in this report, Provincial observation wells, the Oliver climate station, and the Okanagan River gauge.

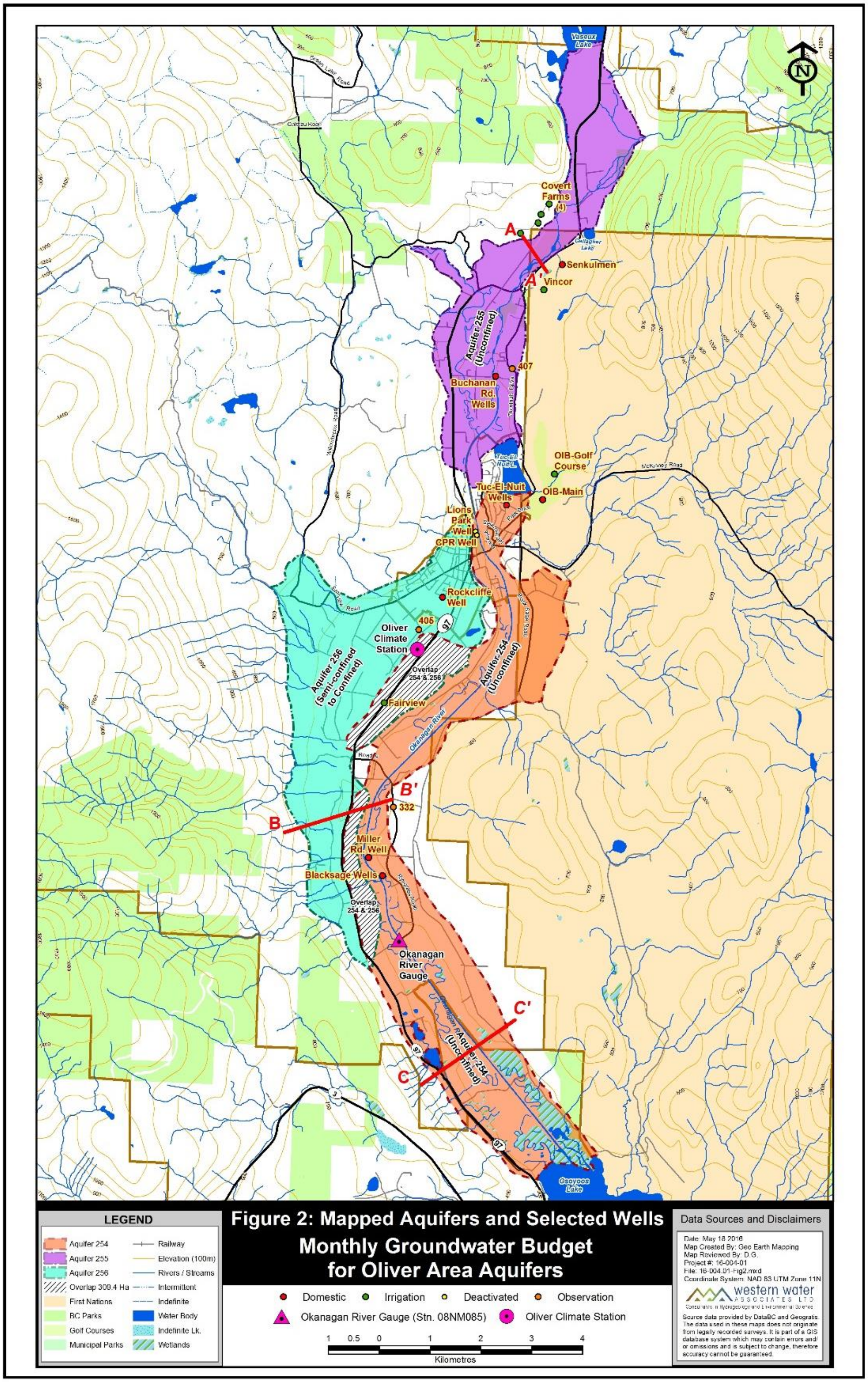


Figure 2   Mapped Aquifers and Selected Wells

1.3 Fundamental Concepts of Groundwater Budgets

This report will briefly review water budget concepts that are covered extensively in other reports and in the literature. Kohut (2014) provides Healy et al's (2007) broad definition of a water budget as "an accounting of the rates of water movement and change in water storage in all or parts of the atmosphere, land surface, and subsurface."

As applied in water management, a water budget is a tool to account for the movement and the uses of water on, through, and below the surface of the earth (AquaResource 2013). It answers the following types of questions:

- Where is the water?
- Where are the hydrologic elements located in the watershed?
- How does the water move between these hydrologic elements, including, the extent to which groundwater interacts with surface waters?
- What are the pathways through which water travels?
- What stresses affect water quantity in a watershed?
- Where are water users located and how much water are they using?
- What are the trends? Are water levels declining, increasing or remaining constant?
- How will additional groundwater withdrawals affect groundwater levels and surface water flows?

A key outcome of completing a water budget is an estimate of the various hydrologic components of a watershed under historical, current or future conditions. It is impossible to develop a water budget and sound water management policies and practices without an understanding of the hydrologic cycle. The components of the hydrologic cycle include precipitation, evapotranspiration, runoff, recharge, groundwater inflow and outflow, surface water inflow and outflow and change in storage.

Specific to groundwater resources, a groundwater budget is a summation of the inputs and outputs to an aquifer within a defined aquifer system or watershed. A groundwater budget becomes a "water balance" when the specific water budget terms are summed, with the calculated difference being taken as a change in storage. Sources of water to aquifers (inputs) are typically termed "recharge" whereas outputs are often termed "discharge" and both recharge and discharge may have multiple components that are both naturally occurring and human influenced. For connected aquifer systems, such as those in the Oliver study area, there are also components of groundwater inflow from upgradient aquifers and outflow to downgradient aquifers.

Kohut's (2014) Equation 1 provides the fundamental water budget equation:

Flow in – Flow out = change in storage

Water budgets are useful in managing groundwater resources because they can provide insights into potential or actual stresses on an aquifer system. Groundwater budget analysis is in turn tied to the concept of potential yield of aquifer systems through the development of such concepts as aquifer capacity, safe yield and sustainable yield.

The two simplest water budgets for aquifers involve estimating the recharge and/or estimating the natural discharge out of an aquifer system. Of the two, the discharge is more relevant to groundwater management. The recharge rate (particularly just that component of recharge from infiltrating precipitation) may or may not have any relationship to how much water can be withdrawn from an aquifer without causing a large imbalance in the system or other impacts, such as surface water depletion from groundwater extraction.

The simplest way to estimate recharge is to consider the hydrogeologic setting, and assume a percentage of average annual recharge is available to recharge groundwater. This percentage may range from a low of few percent in arid regions with deep groundwater resources to as much as 50 percent in wet climates with shallow permeable aquifers.

Hydrogeologists typically apply a form of Darcy's Law to calculate the volume of water discharging from an aquifer system under an assumed hydraulic gradient in the absence of pumping. Applying Darcy's Law requires the hydrogeologist to have an understanding of the aquifer thickness, width, hydraulic gradient and hydraulic conductivity, all of which can be determined through interpretation of well driller's logs or estimated based on literature data.

$$Q = KiA$$

where Q = discharge per unit time, K = hydraulic conductivity (length/time), i = hydraulic gradient and A = cross sectional area of aquifer through which flow occurs

The resulting flow (Q) is in theory the volume of flow required to sustain observed groundwater levels. A portion of this volume can, in theory, be captured by wells with the result being a reduction in groundwater storage and/or an increase in the rate of recharge.

The groundwater budget equation for the Oliver aquifer system is provided below and is essentially the same as Equation 5 in Kohut (2014) and is applicable to mostly unconfined alluvial aquifer systems along a major river valley:

$$R + Q_{GW}in = \Delta S_{GW} + Qbf + ET_{GW} + Q_{GW} + Q_{GW}out$$

Where:

R = recharge (from precipitation, irrigation return flows, and lakes/streams)

Q_{GW}in = groundwater inflow from upgradient

ΔS_{GW} = change in groundwater storage

Qbf = groundwater discharging to streams as baseflow

ET_{GW} = Groundwater evapotranspiration losses

Q_{GW} = Groundwater extraction

Q_{GW}out = groundwater outflow to downgradient aquifer or surface water feature

As explained later in the report, there are no data for the discharge to baseflow and this term is qualitatively assessed through the conceptual model on a broad scale only. There are sub-components to several terms (e.g. recharge), which we discuss in detail later in this report.

2. GENERAL PROJECT APPROACH

WWAL is familiar with the hydrogeology of the study area through past experience in conducting groundwater-related projects for OBWB, Town of Oliver, Osoyoos Indian Band and others. The general approach was to compile existing information pertinent to the water budget and conceptual hydrogeological model from prior studies, which we present in the following sections.

In creating the monthly water budgets for this project, we used the OBWB (Golder – Summit 2009) groundwater study as a starting point and then modified the water budget spreadsheets used in that study for the purposes of the current study. Specific water budget terms were based on either a re-analysis of existing information or adapted based on the different aquifer footprint areas used in the previous study as compared to the existing Provincial mapped aquifers 254, 255 and 256.

3. HYDROGEOLOGICAL SETTING OF OLIVER

3.1 Physiography and Drainage

The study area is located within the Bluebunch Wheatgrass and Ponderosa Pine Biogeoclimatic Zones. The hot, dry climate in these zones result in fragile ecosystems with limited plant productivity and soil development that support a diverse array of wildlife and plant species. Oliver's economy relies principally on agriculture and tourism, with the many wineries in the area creating a close link between these two sectors. Other land uses include residential, industrial, cultural, recreational and urban.

Topography of the area is dramatic. The valley bottom is relatively flat with elevations ranging between 300 and 330 masl. Its width fluctuates between about 1-6 km, with the narrowest section between Gallagher Lake and McIntyre Bluff and the widest section surrounding the Town's centre. The highest point to the southwest is Mt. Kobau at an elevation of 1,870 masl. The eastern valley sides rise more gradually through the Inkaneep Provincial Forest with the highest point being Mt. Baldy at 2,300 masl located about 40 km from the Oliver's Town centre. The western valley sides rise abruptly and are incised with drainage channels that flow into the valley bottom. These include Testalinden Creek, Hester Creek, Tinhorn Creek, Togo Creek and Reed Creek to the south, Park Rill to the north and unnamed ephemeral channels. About 10 drainage channels flow into the valley bottom from the eastern valley sides including Inkaneep Creek to the south, Atsiklak and Wolfcub Creeks to the north and numerous unnamed ephemeral channels. Vaseux Creek joins the Okanagan River north of Oliver and is believed to form a major source of recharge to the aquifer system.

The Okanagan River watershed generates runoff from rainfall and snow melt that contribute to recharge water in the aquifers. The Okanagan River flows freely in places but is highly channelized in other places. Many oxbow lakes (oxbows) exist along either side of the Okanagan River ("River") as a result of its channelized state. See Section 3.5 for discussion on the regulated flow of the River and suggested conservation flows. Tuc-El-Nuit Lake has a surface area of about 1 km^2 and is located northeast of the Oliver town centre. This lake marks the southern truncation of aquifer 255 and the northern extent of aquifer 254 although we see no reason for these two aquifers to be considered separate; they are one and the same. Tuc-El-Nuit Lake receives surface flow from the eastern highlands in its southeast section and drains into the River from its northwest section. The Town of Oliver and the Osoyoos Indian Band each operate moderate to high capacity drinking water supply wells in the vicinity of this lake, along with a private water utility supplying a mobile home park. Other lakes within the watershed include Gallagher Lake and small kettle lakes. Gallagher Lake is a kettle lake with no surface inflow or outlet, and has an area of 5.1 HA above aquifer 255.

The early work mapping the surficial deposits of the Okanagan Valley by Nasmith (1962) remains a primary reference used by most geological investigations today. Using the Nasmith maps as a basis, the surficial and bedrock geology of the Oliver area is summarized in the Golder (2004) and the Toews and Allen (2007) reports, and is very briefly described below. Section 2.7 of Toews and Allen (2007), provides a detailed discussion of the geology and hydrostratigraphy and will not be repeated here. WWAL (2015) also summarized hydrogeology in the Source Water Assessment for the Town's wells, which is available on the Town's website and Province's Ecocat site. Surficial geology governs the occurrence and behaviour of water in the water supply aquifers of the Okanagan River valley around Oliver. For the purposes of this assessment, these deposits are classified informally as belonging to the following four types of surficial material:

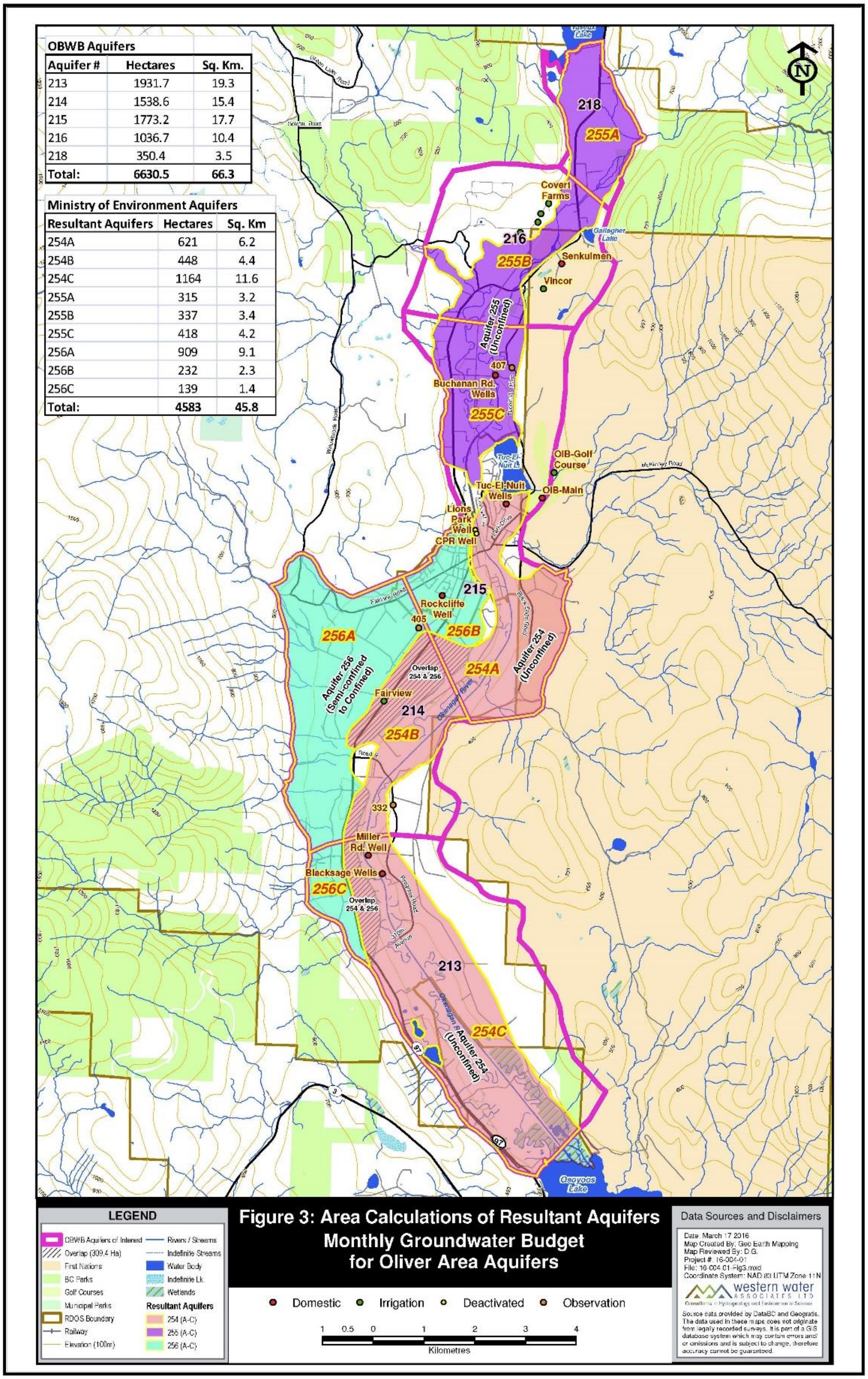
- Modern day Okanagan River floodplain deposits composed chiefly of silt, silty sand, and gravel;
- Alluvial fans and fan-delta complexes associated with the tributary streams entering the valley from the surrounding uplands;
- River terrace and stratified glacial drift sand and gravels associated with the most recent glaciation; and
- Outwash, moraine and ice-contact deposits occupying portions of the valley generally above the level of the main valley bottom. However, to the north of Oliver, it is possible that remnant ice-contact deposits exist in the vicinity of Vaseux Creek near the location of a former late Pleistocene ice dam.

Provincial aquifers 254 and 255 (Figure 2) typically have a relatively shallow water table, are classified as moderately to highly productive, and have a high vulnerability to potential contamination. These are both "IA" aquifers and as such would fall into a high priority for groundwater protection measures. Wells in and around Oliver as well as other areas in the South Okanagan with a long agricultural land use history exhibit elevated nitrate levels. Observed nitrate concentrations in the valley range from about 0.5 mg/L to more than 10 mg/L. There is some well log evidence to suggest that Aquifer 255 has both shallow and deeper water bearing zones and in places well logs show a silt/clay aquitard.

Provincial aquifer 256 is described as a confined to semi-confined system, and underlies portions of the Town and areas to the west of the Okanagan River (Figure 2). This aquifer, the source of water for the Town of Oliver Rockcliffe well, is in part associated with alluvial fans emanating from several creeks draining the west side of the valley, such as Testalinden and Hester creeks and may also be associated with buried glacial outwash deposits. The deeper part of the aquifer is relatively less vulnerable to potential contamination sources (although it is still impacted by nitrate, e.g. at the Fairview well), and likely sees considerably less overall groundwater demand than the two shallow aquifers 254 and 255. In fact, the Rockcliffe well and perhaps one or two irrigation wells are the only known high capacity wells in this fairly extensive aquifer.

The Oliver area aquifers, as mapped by ENV, were further assessed during the Phase 2 Okanagan Basin Water Supply and Demand (OKWSD) Project by Golder Associates and Summit Environmental (Golder-Summit 2009) (See Figure 3). In general, the aquifer system is moderately to highly productive, is unconfined or semi-confined and is moderately to highly vulnerable to contamination originating at the land surface. The total average annual groundwater flow (discharge) is over 6×10^7 m^3/year, making this one of the largest aquifer systems in the valley (see Table 10 of the Golder-Summit 2009 study).

The aquifer system in Oliver is considered an important contributor to baseflow in the mainstem Okanagan River, particularly in the southern half of the study area. Because large portions of the aquifer system are relatively shallow and unconfined in most places, there is a high degree of inter-connectedness between groundwater and surface water. The seasonal pattern of groundwater exchange between the river and the aquifer is not well understood.



OBWB Aquifers		
Aquifer #	Hectares	Sq. Km.
213	1931.7	19.3
214	1538.6	15.4
215	1773.2	17.7
216	1036.7	10.4
218	350.4	3.5
Total:	6630.5	66.3

Ministry of Environment Aquifers		
Resultant Aquifers	Hectares	Sq. Km
254A	621	6.2
254B	448	4.4
254C	1164	11.6
255A	315	3.2
255B	337	3.4
255C	418	4.2
256A	909	9.1
256B	232	2.3
256C	139	1.4
Total:	4583	45.8

Data Sources and Disclaimers

Date: March 17 2016
Map Created By: Geo Earth Mapping
Map Reviewed By: D.G.
Project #: 16-004-01
File: 16-004-01-Fig3.mxd
Coordinate System: NAD 83 UTM Zone 11N

Source data provided by DataBC and Geogratis. The data used in these maps does not originate from legally recorded surveys. It is part of a GIS database system which may contain errors and/ or omissions and is subject to change, therefore accuracy cannot be guaranteed.

Figure 3 Comparison of Aquifer Areas

3.2 Climate and Determination of Normal, Wet and Dry Years

The most recently available 30 - year Environment Canada climate normal data for 1981 to 2010 from the Oliver station are presented in Table 2 (Station location shown on Figure 2). Climate normal depict average data over the period of record and show that nearly 90% of annual precipitation falls as rain and also that May and June are the wettest months, which is typical of much of the B.C. Interior. Long term average annual precipitation is approximately 345 mm. The study area is considered semi-arid.

Table 2. Climate normal data from the Environment Canada Oliver station (1981-2010).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature													
Daily Average (°C)	-1	1.3	6.2	10.7	15	19	22	21	16	9.3	3	-1	10.1
Standard Deviation	2.4	2.4	1.4	1.2	1.4	1.3	1.8	1.3	1.7	1.1	2.5	2.7	1.9
Daily Maximum (°C)	1.5	5.3	12	17.6	22	26	30	29	24	15	6.5	1.3	15.9
Daily Minimum (°C)	-3.6	-2.8	0.4	3.8	7.7	11	14	13	8.1	3.1	-0.5	-4	4.3
Extreme Maximum (°C)	16	17	24	30.6	37	38	43	39	36	29	20	16	
Precipitation													
Rainfall (mm)	14	18	22.8	28	37	44	32	23	19	20	26	19	303
Snowfall (cm)	14	5	1.4	0	0	0	0	0	0	0.2	4.2	18	42.7
Precipitation (mm)	28	23	24.1	28	37	44	32	23	19	20	30	37	345
Extreme Daily Rainfall (mm)	21	28	15.2	40	51	34	50	61	29	16	20	25	

Station ID: 1125760 Elevation: 315.2 m

For the purposes of this study, we have defined a “dry” year as any year in which total precipitation is less than 276 mm, i.e. less than 80% of normal. A “normal” year would see precipitation ranging from 276 to 414 mm and a “wet” year would see precipitation above 414 mm (i.e. 20% or more average precipitation). We are interested in the 11 year period utilized in the OBWB study (1996-2006), and based on the above criteria and historical climate data for Oliver, we have assigned each year as being either dry, normal or wet. Within this 11 year period, it can be seen that the period from 1996 to 1999 was somewhat wetter than normal (all above average precipitation), and 2000 to 2003 was drier than normal, and from 2004 to 2006 was close to normal. Multi-year climate cycles affect groundwater levels, and in particular the late 1990s wet cycle followed by the early 2000s dry cycle are both evident on a number of observation wells in the valley. Table 3 provides the climate classification assigned to each of the years assessed between 1996 and 2006.

The classifications appear to be supported by Vaseux Creek flow data, also presented in Summit (2009), which followed the same general wet, dry, normal pattern over the 11 year period. As explained later, we chose three of the years, 1998, 2003 and 2006 to reasonably represent wet, dry, and normal conditions, respectively. These years are simply reference years for the water budget and are thought to represent the typical range of climate conditions for the study area. Any year exhibiting similar seasonal and annual precipitation patterns to the three reference years can be classified as wet, dry or normal (Table 3).

Table 3: 1996-2006 Climate Data and Classification for Oliver

Year	Precipitation (nearest 1 mm)	Classification
1996	403	Normal
1997	376	Normal
1998	456	Wet
1999	366	Normal
2000	246	Dry
2001	305	Normal
2002	218	Dry
2003	244	Dry
2004	417	Wet
2005	276	Normal
2006	388	Normal

3.3 Surficial Geology

Present-day understanding of surficial geology is largely based on the work of Nasmith (1962), who grouped study area surficial deposits into four main categories:

- Okanagan River floodplain deposits. Closely associated with the river, the materials comprise sand, silt and wetland soils. These materials are found throughout much of the study area and extend from surface down to perhaps 10-20 m below ground surface;
- Alluvial fans and deltaic sands. These are erosional and depositional features of the present day streams draining into the valley. Materials range from silty sand to large gravel. The most significant fan type deposit is on the west side of Oliver and is associated with Fairview Creek;
- Fluvial terrace and channel deposits. These are primarily glacio-fluvial materials, and form portions of the underlying sedimentary package within and around Oliver; and
- Outwash terrace deposits. These sediments originated during deglaciation and are found in the upper bench areas near Oliver. Composed largely of layered sand and gravel.

3.4 Mapped Aquifers, Aquifer Types and Descriptions

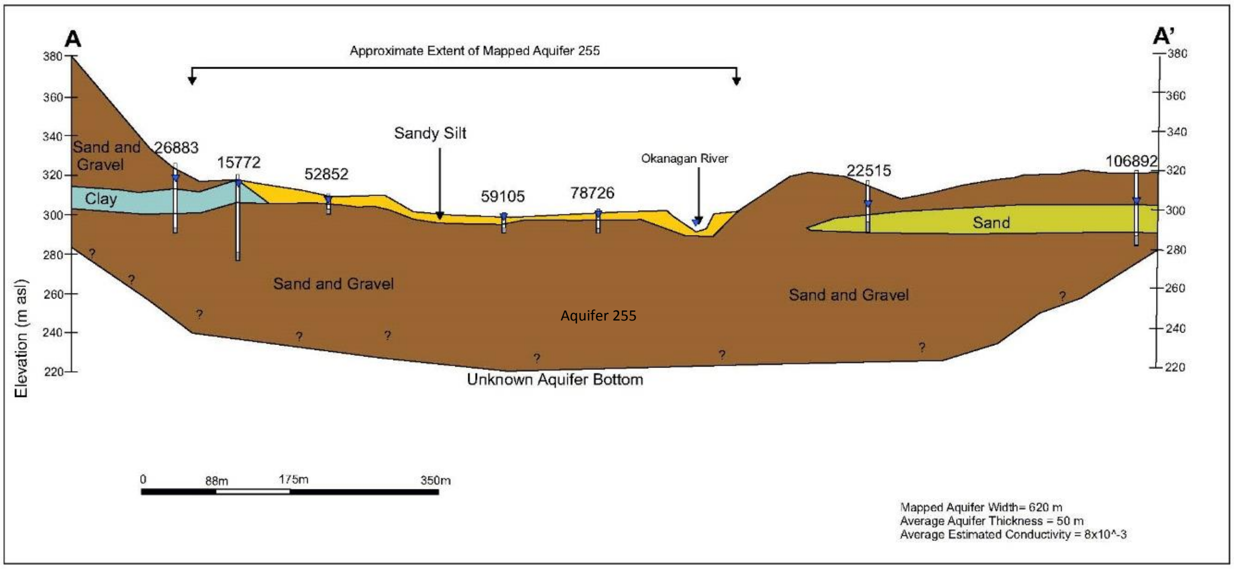
Three mapped aquifers occur within the study area and are described below, from north to south. The extent of the mapped aquifers along with locations of a few key wells is depicted in Figure 2, and Figure 3 shows the extent of the OBWB mapped aquifers compared to the ENV mapped aquifers. Figures 4, 5, and 6 portray transverse subsurface cross sections through all three of the mapped aquifers in the study area (section locations are indicated on Figure 2).

Aquifer (255) is situated at the north end of the system, immediately south of Vaseux Lake, at a relatively narrow portion of the Valley where coarse-grained alluvial fan deposits associated with Vaseux Creek exist. We consider this aquifer to be the key to the entire system as recharge to and flow through this aquifer plays a significant role in driving groundwater movement through the valley south to Osoyoos Lake. The aquifer is recharged by Vaseux Lake and Vaseux Creek as well as the Okanagan River. The narrowing of the Valley at this location causes water levels to back up and rise to near the ground surface around the lake, where the gradient is relatively flat. At the southern limits of this aquifer the hydraulic gradient becomes steeper as water is transferred to the south, towards locations where the valley and its aquifer become significantly wider. Mean annual flow through the northern part of the system was estimated by Golder – Summit to be on the order of 4.24×10^{7} m^3 in the north (Aquifer 255), decreasing to 3.21×10^7 m^3 to the south (Aquifer 254). The estimated groundwater discharge through Aquifer 255 was found to be the fourth largest in the Okanagan Valley. The aquifer 255 estimated mean annual discharge is equivalent to approximately 21,000 US gpm or 1,344 Litres/second. Section 3.0 describes the three aquifers in more detail.

Aquifer 255 extends from the south end of Vaseux Lake to Tuc-El-Nuit Lake and is composed of a combination of deeper glacio-fluvial and terrace deposits and shallower Okanagan River floodplain deposits. The aquifer occurs under unconfined to semi-confined conditions and ranges in thickness to 40 m or more north of Oliver. Aquifer 255 is believed to have the following main characteristics:

- Potentially the most productive of the study area aquifers;
- Discharges to Aquifer 254, which we consider the southern extension of the same aquifer;
- Located proximal to the above described major sources of surface water recharge, and with better water quality than aquifers to the south; and
- Potentially the most heavily used of the study area aquifers.

Aquifer 255 is classified (Kreye et al 1998) by B.C. as a IA aquifer, meaning it is highly productive, heavily developed and highly vulnerable to contamination originating at the land surface.



Mapped Aquifer Width= 620 m
Average Aquifer Thickness = 50 m
Average Estimated Conductivity = 8x10^-3

Figure 4 - Cross Section A-A' In Aquifer 255

Date: March 2016	Image Source:		WWAL Project: 16-004-01
Drawn by: AMF	Checked by: BM	Client: B.C. Ministry of Environment	

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Figure 4 Cross-section through a portion of Aquifer 255.

Aquifer 256 is found west of the Okanagan River from the Town of Oliver urban area south. This aquifer is believed to be formed in alluvial fan deposits, and occurs under semi-confined conditions, and discharges to the base of the valley (Aquifer 254 and/or river). Aquifer 256 is believed to have the following characteristics:

- A locally productive aquifer supporting only a few higher capacity wells;
- Exhibits localized land-use impacts (e.g. higher nitrate concentrations); and
- Likely sees the lowest use of the study area aquifers.

Owing to its semi-confined nature and less-intensive use, Aquifer 256 is classified by B.C. as a IIIC aquifer meaning it is lightly developed and has relatively low vulnerability to contamination. Recharge is thought to be a combination of losses from seasonal creeks flowing across the aquifer area, as well as infiltration of irrigation return flow and in the northern part of the aquifer, inflows from connected Aquifer 254. The components of recharge are not well understood.

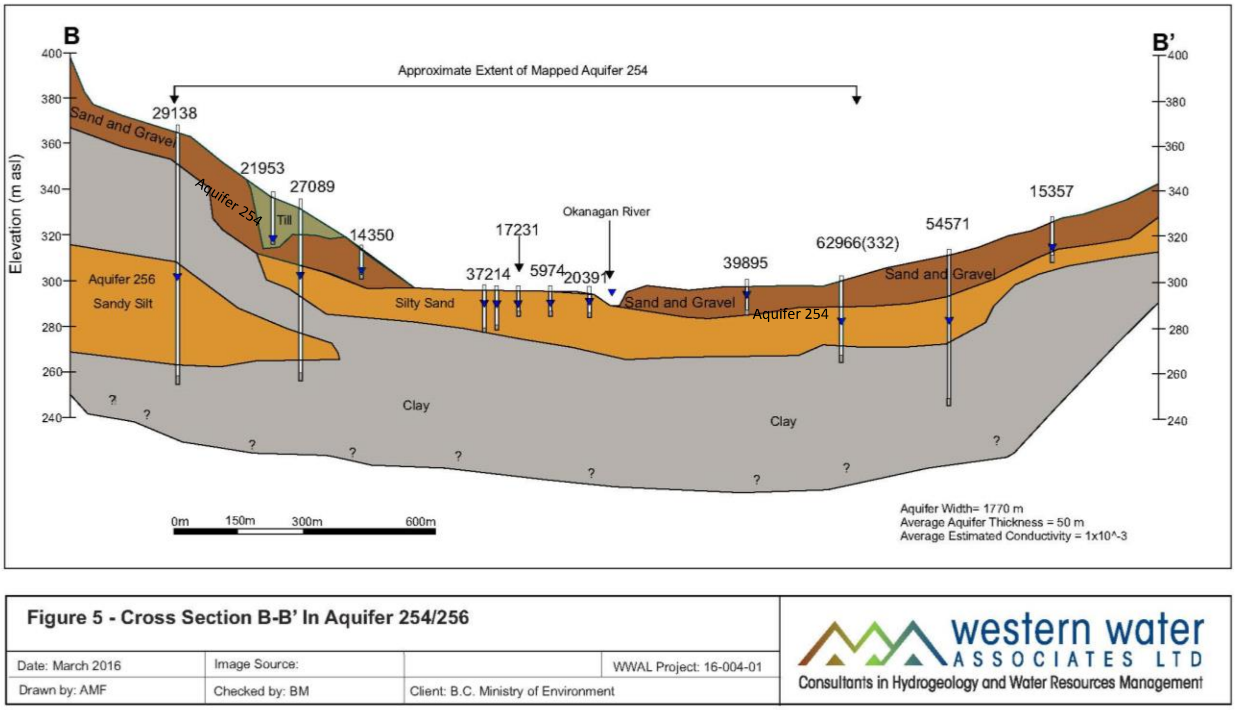

Figure 5 Cross-section through a portion of Aquifers 254 and 256.

As noted above, Aquifer 254 is thought to be the southern continuation of Aquifer 255 and extends south from Tuc-El-Nuit Lake to Osoyoos Lake. The mostly unconfined aquifer is composed of Okanagan River floodplain deposits, and in places, glacio-fluvial deposits and is thought to be connected to adjacent Aquifer 256. Aquifer 254 is believed to have the main characteristics:

- Also a highly productive aquifer supporting a number of municipal wells;
- Located within historically agricultural and urban areas; and
- Likely the second most heavily used aquifer in the study area.

Like Aquifer 255, Aquifer 254 is classified by B.C. as a IA aquifer.

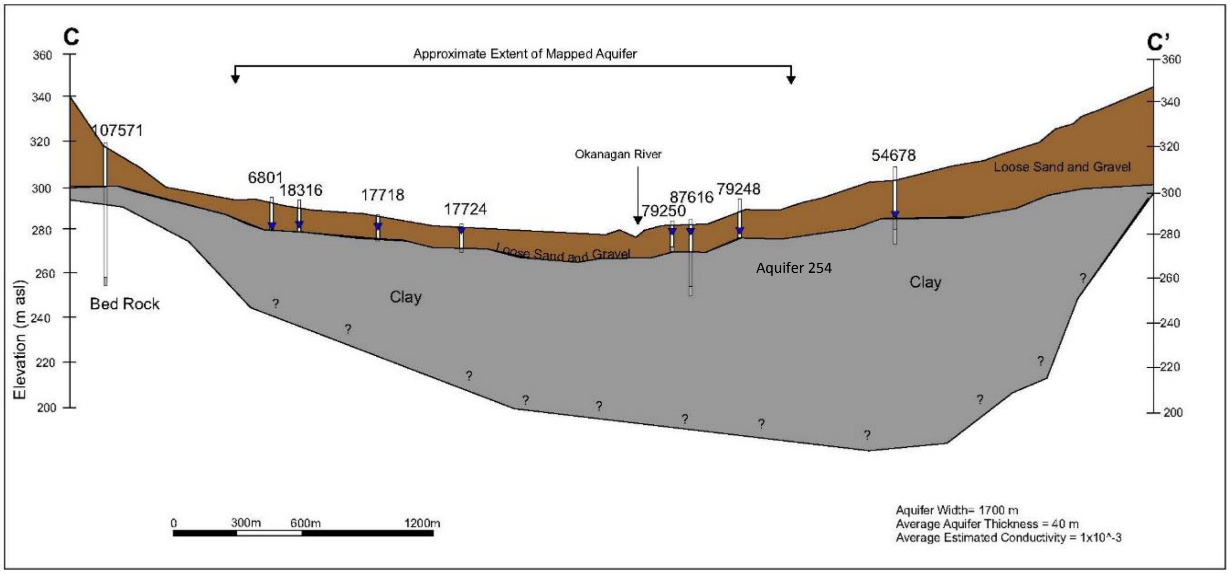

Figure 6 - South Cross Section C-C' In Aquifer 254

Date: March 2016	Image Source:		WWAL Project: 16-004-01
Drawn by: AMF	Checked by: BM	Client: B.C. Ministry of Environment	

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Figure 6 Cross–section through a portion of Aquifer 254.

3.5 Okanagan River Flow, Flow Regulation and Conservation Flows

It is beyond the scope of this study to review in detail the hydrology and fisheries values of the Okanagan River, which have received considerable study elsewhere, and is ongoing (Lars Uunila, pers. comm 2016). The Okanagan River is the primary drainage of the Okanagan Valley. The river bi-sects the study area flowing from north to south between Vaseux Lake and Osoyoos Lake. Flow in the river through Oliver is driven by the approximate 50 m elevation difference between the two lakes, with the stream gradient steeper in the northern half of the study area and gentler in the southern half. The river flow is altered by the presence of McIntyre dam, the canal diversion, a series of drop structures, and channelization through much of the area. The active hydrometric station (ID 08NM085) for the river is located at Road 18 south of all of the Town of Oliver wells and most of the groundwater extraction in the study area (see Figure 2). This gauge has a period of record dating back to 1944 with some gaps in the period of record in the 1940s and 1950s.

Summit (2002) developed an Excel – based model that attempted to reconstruct the natural hydrograph of the Okanagan River at four points of interest in the basin including Oliver by estimating the geometry of the pre-dam (early 1900s) outlet to Okanagan Lake and developing a rating curve. Using a data set from the 1940s to late 1990s, the flow reconstruction showed that regulated flows are higher between January and May (due to lake releases prior to freshet for flood control), lower from June to September and about the same from October to December (the typical early baseflow period). However, natural flow would be maintained throughout the year by the gradual draining of Okanagan Lake and as such, the late fall flows (natural or regulated) in Oliver would typically derive from a combination of groundwater discharge as well as continuing lake discharges. Groundwater discharge to the River likely has a modest influence on flow, and locally, along specific reaches, may play a more significant role in providing a source of seasonally cool water in late summer.

3.5.1 River Flow Statistics

As noted above, discharge in the Okanagan River is regulated throughout the year through operation of the Okanagan Lake dam. Mean annual regulated flow at the Oliver station is 5.22 x 10^8 m^3 or about 16.5 m^3/sec. River discharge is influenced by releases from upland reservoirs as well as from the valley bottom lakes (principally Okanagan Lake), and varies considerably from year to year depending on snowpack and snowmelt-driven runoff characteristics (Summit 2009). A graph of the daily flow (Figure 7) recorded in 2015 (a dry year) portrays a low flow of about 7-8 m^3/sec compared with an average baseflow of about 10 m^3/sec. Note, 2015 was a dry year with little snow pack resulting in a relatively early and more abrupt onset of baseflow (starting early July) compared to mean flows, which exhibit a more gradual recession in summer and fall. The period of record for this gauge is 1944-2016. Mean monthly flows range from approximately 10 m^3/sec in January to 38 m^3/sec in June. By comparison, Summit's (2002) range of estimated natural mean monthly flows was approximately 9 to 44 m^3/sec at Oliver. Discharge in the 2015 dry year were still well above the conservation flows discussed in Section 3.5.2.

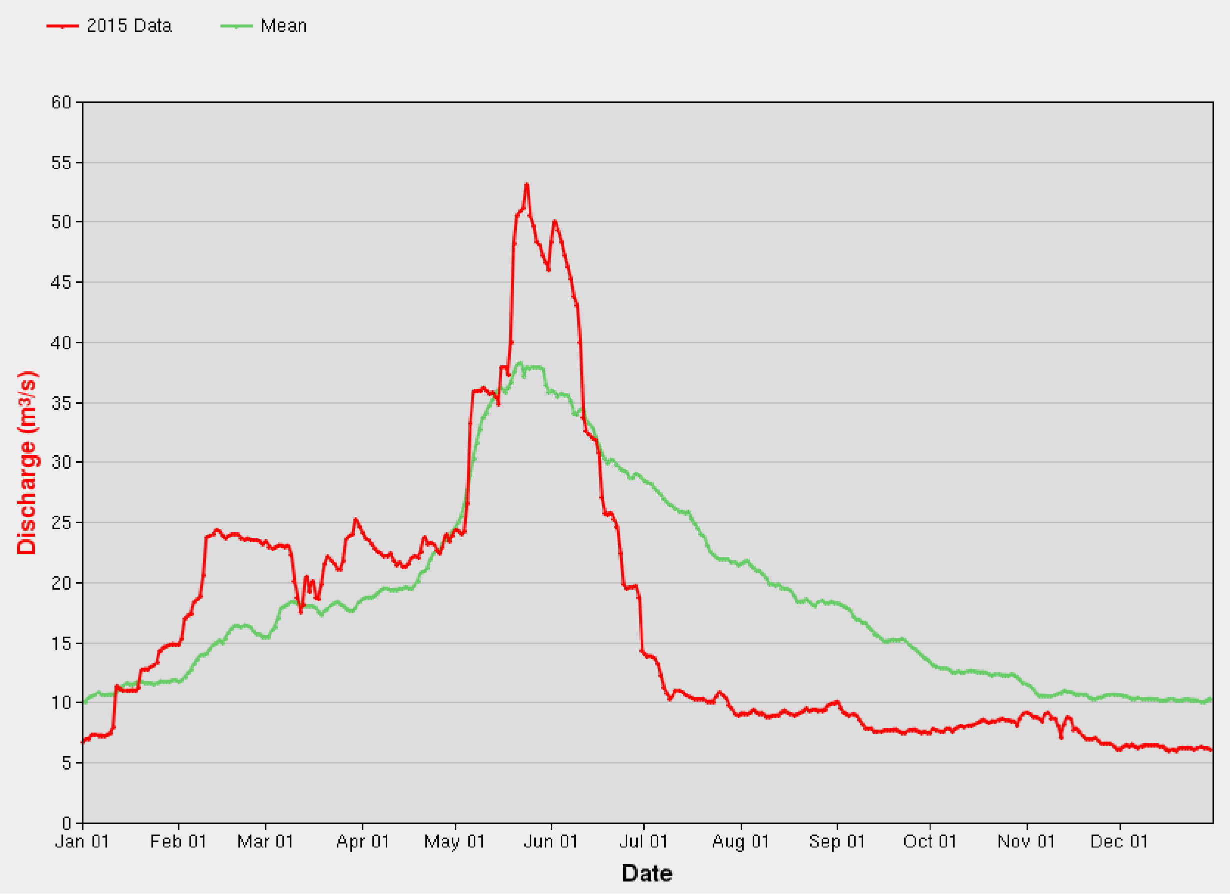


Figure 7 Okanagan River Discharge at Oliver: 2015 and Mean 1944-2015 Daily Discharge.

3.5.2 Operational Guidelines and Conservation Flows

Operational guidelines provided to WWAL by MFLNRO currently in place for the river (measured at the gauge south of Oliver at Road 18, Station 08NM085, Figure 7 range from a minimum of 5.0 m^3/sec to a maximum of 28.3 m^3/sec until freshet (May-June), when daily flows as high as 80 to 100 m^3/sec are observed depending on the runoff volumes in the basin. It is our understanding that these flow guidelines consider both cross-border agreements with water managers in the U.S. as well as fisheries values. The Fish Water Management Tool and Guidebook for Water Managers (ESSA 2013 and currently in revision) provides further details on the main fish-water management objectives for Okanagan Lake and the Okanagan River. For Oliver, the main management objectives are flood control (keeping flow < 96 m^3/sec), sockeye incubation flows of < 30 m^3/sec from November to April/May, minimum flows of 6 m^3/sec to protect domestic and agricultural intakes and to maintain recreational navigability (ESSA 2002).

A 2001 report by Northwest Hydraulic Consultants provided suggested conservation flows for Kokanee Salmon and Rainbow Trout that could be applied basin-wide. These flows were based on specified percentages of mean monthly flow. Table 4 summarizes the results of implementing these suggested flows at the Okanagan River Road 18 gauge. This information suggests that current operational guidelines provide a significant safety margin with respect to suggested conservation flows in that the guidelines meet or exceed the conservation flows in all months, typically by a significant margin (at least 2.5 m^3/sec). These are relatively large numbers (i.e. 2.5 m^3/sec is equivalent to about 40,000 US gpm). As such, increases or decreases in groundwater extraction patterns are not likely to directly affect flow maintenance in the river.

Table 4 Okanagan River regulated flows and suggested conservation flows.

Month	Operational Guideline regulated flow range (m^3/sec)	Approximate mean monthly flow (m^3/sec)	Suggested conservation flow (m^3/sec)
October	9.9 to 15.6	13	2.6
November	5.0-28.3	12	2.4
December	5.0 to 28.3	11	2.2
January	5.0 to 28.3	10	2.0
February	5.0 to 28.3	12	2.4
March	5.0 to 28.3	15	3.0
April	5.0 to 28.3	18	3.6-8.3
May	5.0 to 28.3	25	12.5-25
June	N.G.	38	38
July	N.G.	30	12
August	8.5 to 28.3	22	6.6
September	9.9 to 15.6	18	3.6-4.5

Notes: N.G. = no guideline

Suggested conservation flows based on percentages provided in NHC (2001); these may be outdated

3.6 Summary of Conceptual Hydrogeological Model of Groundwater Movement

As described earlier in this section, regional groundwater flow in the study area is believed to be driven by the southward topographical gradient, which is the ~ 50 m difference in elevation between Vaseux Lake (326 masl) and Osoyoos Lake (276 masl). The aquifer system receives significant recharge in its northern portions from surface water sources including Vaseux Lake, Vaseux Creek and the Okanagan River, and natural discharge through aquifer 255 is considered to be the highest of the three study area aquifers. The other main sources of recharge includes irrigation return flow and infiltration of precipitation. The main sources of discharge are groundwater extraction and discharge to downgradient aquifers and/or water bodies. The basic process from a conceptual standpoint is summarized below:

- Aquifer 255 is recharged, primarily by adjacent connected surface water sources and upland shallow bedrock flow reporting to the valley bottom from the Vaseux Creek catchment. Additional recharge is provided by irrigation return flow, and irrigation water is derived from a combination of Okanagan River canal water and large capacity groundwater wells.
- Net groundwater flow from Aquifer 255 discharges to Aquifer 254.
- Aquifer 254 flows south and receives lateral recharge from Aquifer 256 and ultimately discharges to the Okanagan River and wetland complexes north of Osoyoos Lake,; locally, there may be places where the Okanagan River loses water to the aquifer, especially at times of high surface flow and groundwater levels depressed by pumping.
- Groundwater is closer to the surface in the southern part of Aquifer 254 whereas static water levels are deeper to the north. Groundwater evapotranspiration likely plays a role in the groundwater budget of Aquifer 254.
- Aquifer 256 is recharged by infiltration of seasonal creeks and irrigation return flow and discharges to Aquifer 254. It may also receive some lateral inflow from the northeast from deeper portions of Aquifer 254.

4. OVERVIEW OF HISTORICAL AND EXISTING WELL DEVELOPMENT IN OLIVER

Early water use in the valley was typical for the earlier part of the 20th century. Farmers dug ditches or shallow wells to obtain the water they needed to irrigate crops and to feed livestock. The Province of B.C. constructed the dam at McIntyre Bluff and the original irrigation canals in the 1920s as part of the South Okanagan Lands Project, later (1964) turning the water works over to the locally run South Okanagan Lands Irrigation District (SOLID). Once water diversions began, agriculture grew as the irrigated acreage increased. During the early SOLID years, the first groundwater wells were constructed to facilitate system expansion (e.g. Town of Oliver Fairview well). Locals also commonly drank water diverted by the canal and in the earlier years, the surface water was not treated and eventually residents of the area and the Town of Oliver turned to groundwater wells to supply domestic drinking water. In 1989, the Towns of Oliver and Osoyoos assumed responsibility for the SOLID system. Today there are more than 500 wells recorded in the study area, according to provincial data base records. However, it is believed that many more unreported wells, including large capacity irrigation wells, are in existence and in use today. The Town of Oliver supplies agricultural water and domestic drinking water to approximately 80% of the lands in the study area, with the Osoyoos Indian Band water system (groundwater-based) supplying much of the remaining domestic supply along with a few small water systems. The Town of Oliver has completed twinning of almost all of its water system such that drinking water is supplied by wells and irrigation water is supplied mostly by canal water and supplemented with groundwater.

4.1 Well Inventory

We conducted a search of water wells in the Provincial WELLS database and summaries of these wells appear in the report Appendix. For ease of presentation, we screened the search to only provide results for wells with reported yields of 100 US gpm (6.3 L/sec) or greater in the report Appendix. A second screening was performed to identify the number of shallow and dug wells, which we define as being 7.5 m (25 ft) or less in depth. Table 3 below summarizes the results of this screening. As Table 5 below indicates, nearly one-half of reported wells are shallow, dug wells. Many of these are believed to not be in use.

Table 5 Number of shallow and deep wells in the WELLS database with reported yields greater than 100 gpm.

Aquifer	Shallow Wells (<25')	Deep wells (>25')	Total Wells
254	123	145	268
255	155	193	348
256	12	49	61

4.2 Known Large Capacity Wells and Reconciling Groundwater Use

Based on information in our files and Provincial WELLS database well records, we compiled a listing of known large capacity wells in each aquifer. From this, it appears that Aquifer 255 is the most heavily developed and used followed by Aquifer 254, and then by Aquifer 256, which appears to be only lightly developed. Demand on all the aquifers is mitigated by the extensive irrigation supplied by Okanagan River water, diverted by the Town of Oliver at McIntrye Dam. Even with the relatively extensive supply of surface water, there are locations particularly in the northern part of the study area as well as in the southern part of the area near Blacksage that rely on groundwater wells.

For this study, WWAL researched area high capacity wells that are believed to be operated regularly and these formed the basis for our groundwater extraction estimates. There are likely additional wells that are not registered in Provincial databases or known by the authors. For this reason, the estimates of groundwater extraction as provided herein may need to be updated once existing well sources are licenced under the Water Sustainability Act Regulation of 29 February 2016. The report Appendix includes a table summarizing known high capacity wells with information on estimated withdrawals organized by aquifer unit, along with an explanation of how we apportioned monthly production volumes.

4.3 Groundwater Level Monitoring

The Province of B.C. maintains three active groundwater observation wells in the study area, one completed in each of the three subject aquifers. The well locations are shown in Figure 2. Groundwater level hydrographs over the range of available records are shown in Figures 8, 9, and 10. Not all records were available on the observation well website at the time of this study. For this project, Ministry staff provided WWAL with additional data that had not been posted to the website. Below each graph we provide brief comments on any observable trends or changes, and potential influences on those trends. The slightly different appearance of the graphs is due to WWAL constructing the graphs for wells 332 and 405 from excel data provided by the Ministry whereas the graph for well 407 is from the complete data set on the observation well website.

<u>Observation Well 405 Comments</u>: Groundwater levels appear relatively stable over the approximate five year period of record except for 2015-16, which could be a response to increased pumping. This observation well is located within a few hundred metres of the Town of Oliver's Buchanan Rd well site. Pumping from this well site increased following completion of new wells in 2014 that effectively doubled the rate of extraction, which can be seen in the response of the observation well. This is the likely cause of the apparent drawdown recorded in 2015 but will need to be monitored in the coming years to determine if recovery occurs following summer peak use. The pumping tests on the newly completed Buchanan Road wells for Oliver occurred in 2013 and it is possible that the drawdown response for that year is reflected in the hydrograph. Therefore, this observation well can be considered as monitoring the effects of an aquifer with nearby pumping wells.

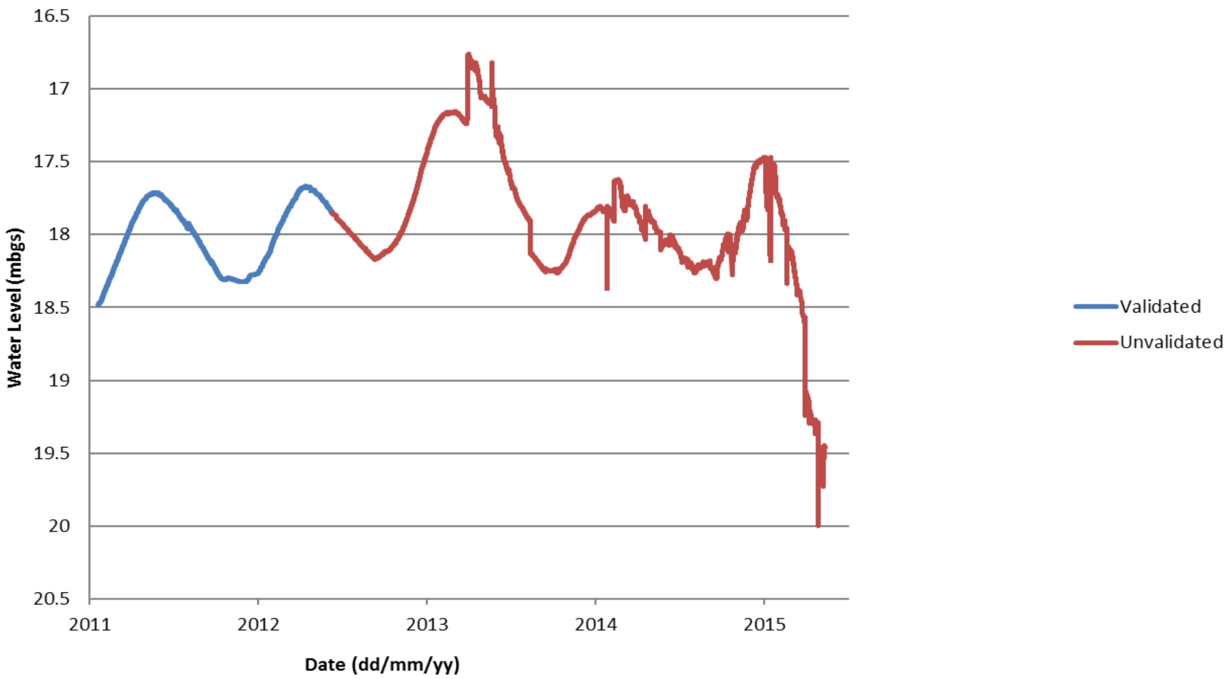


Figure 8 Historical groundwater elevations at Observation Well 405 (Aquifer 255).

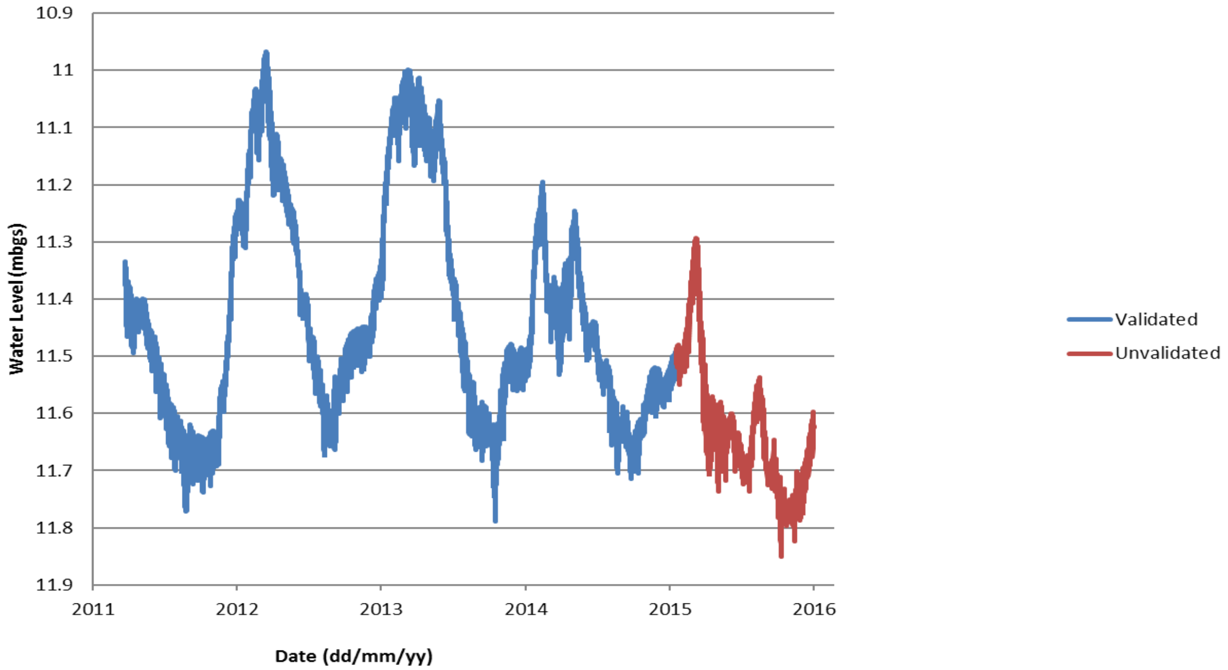
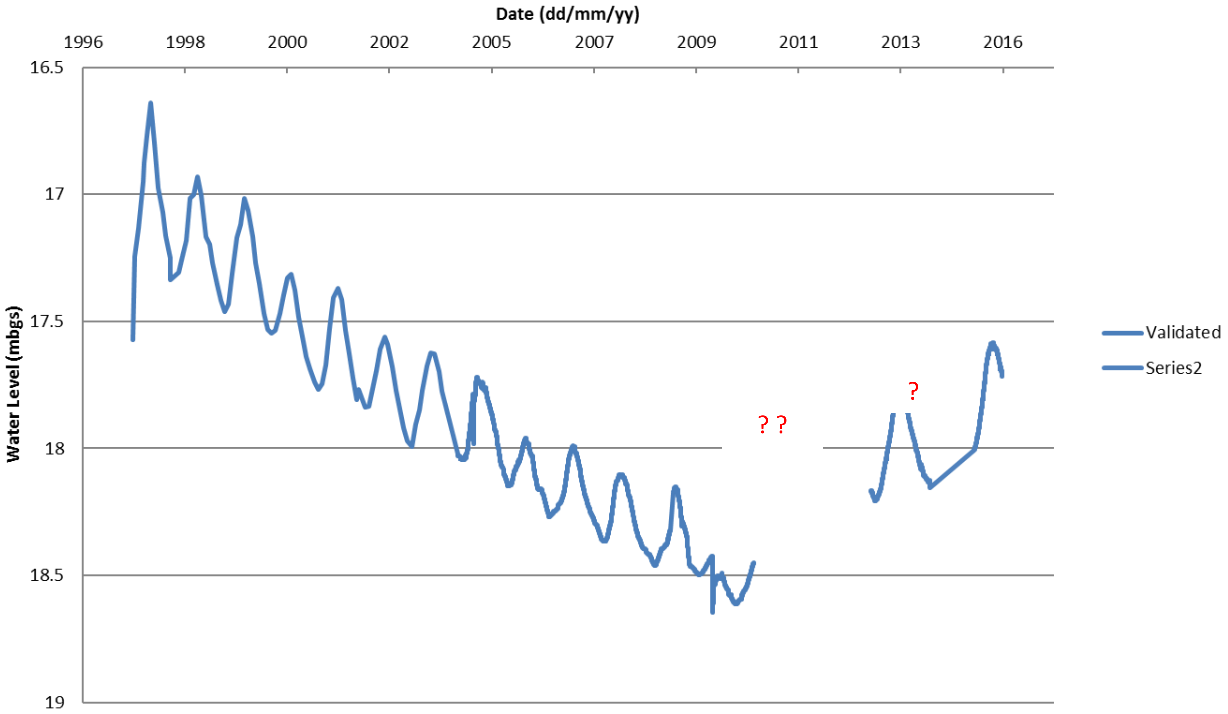


Figure 9 Historical groundwater elevations at Observation Well 407 (Aquifer 256).

Observation Well 407 comments: A slight decreasing water level trend is apparent in the approximate five-year period of record. The overall change seasonally is less than 1 metre. Overall groundwater levels appear stable over the period of record depicted.



Note: there is a gap in the data from 2010 to 2013, and a second shorter gap in 2014 as indicated by question marks

Figure 10 Historical groundwater elevations at Observation Well 332 (Aquifer 254).

Observation Well 332 Comments: The cause of the slow but steady decline (a step-down of about 0.1 to 0.3 m/year) that continued from the late 1990s until 2011 is not known. A possible influence on the apparent water level recovery is the cessation of pumping from the Town of Oliver's Lion's Park and CPR wells located north of the observation well (and completed in Aquifer 254). Oliver has shifted production to Aquifer 255 (Buchanan Rd, see Observation well 405 comments). However, the previous period of decline suggests that prior to cessation of pumping at Lion's Park and CPR that water was slowly being removed from storage in this unconfined aquifer.

5. SOURCES OF DATA FOR COMPONENTS OF THE GROUNDWATER BUDGET

Sources of spreadsheet input of key terms in the groundwater budget are described below:

- Inputs: groundwater inflow from upgradient, precipitation recharge, irrigation return flow, and river/stream losses as well as inferred flow from upgradient bedrock aquifers
- Outputs: groundwater extraction, groundwater discharge to surface water, and evapotranspiration
- Change in storage: This value was calculated in the spreadsheet and compared against records of Provincial Observation Wells 332, 405 and 407 in order to obtain a reasonable range in saturated thickness (water level) variation. Note that we did not attempt to match the synthetic hydrographs created by the spreadsheets with the Provincial observation wells due to the lack of overlap between the period of record in the wells versus the period of record used in the water balance analysis.

5.1 Groundwater Inflow From Upgradient Aquifers

Values for this water budget term were largely taken from the Golder – Summit (2009) report. For portions of aquifers 255 and 254 that are narrower than as mapped by the Golder – Summit study, we modified the groundwater inflow estimate. This estimate was derived from application of Darcy's Law for unconsolidated aquifers, and used assumed hydraulic conductivity, hydraulic gradient and aquifer porosity values. For bedrock contributions to valley bottom aquifers (sometimes thought of as mountain block recharge), this was taken to be a proportion of the estimated recharge to the bedrock aquifer reporting to the adjacent unconsolidated aquifer and applied evenly throughout the year (a simplifying assumption). Recharge to bedrock was based upon an agreed upon AET:PET ratio of 0.6 for the Okanagan basin study for upland areas, and the equation RR = TP – RO – AET, where RR equals bedrock recharge, TP is total annual precipitation, RO is annual runoff and AET is the actual evapotranspiration. Recharge was further taken to be equal to discharge through bedrock as recharge to the valley bottom. There is considerable uncertainty in this term, see Section 6.4 for discussion.

5.2 Precipitation Recharge

Values for precipitation recharge were taken directly from the Golder – Summit (2009) report but adjusted for the different aquifer footprint areas of Aquifer 254, 255 and 256. As explained in that document, the infiltration from precipitation was estimated by applying an infiltration factor to the monthly average precipitation value and then computing the area (footprint) of the aquifer in question. For the Oliver area, 5% was used. Based on an average 345 mm of average annual precipitation this amounts to approximately 17.25 mm of precipitation infiltration as a component of aquifer recharge. This component of recharge, like the aquifer recharge from streams (5.3 below) is subject to considerable uncertainty but this term has less influence of the water budget.

5.3 Aquifer Recharge From Streams

As no new information is available to refine this parameter, this term was based on the values provided in the Golder-Summit (2009) report. The approach used in that study used stream gradient and inferred hydraulic conductivity of underlying materials to develop a series of stream interaction factors. From this, the infiltration was taken as a fraction of the total surface flow as determined in the OBWB surface water hydrology report (Summit 2009). As explained in the conceptual model for the current study, it is believed that Aquifer 255 recharge is primarily from the combined losses of Vaseux Creek and Okanagan River and the flow through Aquifer 255 in effect drives the water balance for the entire aquifer system. Vaseux Creek alone has a mean annual discharge of 1.53 m^3/sec (Summit 2009), which translates to annual discharge in the 5×10^7 m^3 range, and likely significant volumes of water seep into the ground from the creek through much of the year. The creek bed conductivity was based on visual examination of the creek, which is largely coarse grained gravel and cobbles as well as local knowledge that the creek "flows subsurface" in the summer and fall. Similar estimates were made for seasonal streams recharging Aquifer 256.

5.4 Groundwater Use (extraction)

To develop reasonable values for estimates of monthly groundwater use, we reviewed the modeled groundwater extraction values used in the Golder – Summit (2009) water balance analysis. These groundwater extraction estimates were supplied by the Okanagan Water Demand Model (OWDM, van der Gulik et al 2008). However, in reviewing the demand model estimates and comparing these to our records of known larger capacity wells operated by the Town of Oliver, Osoyoos Indian Band, and farms in the area (particularly Aquifer 255), we determined that the modeled groundwater extraction rates were likely low, perhaps by as much as an order of magnitude for Aquifer 255 (See Table 6).

Table 6: Comparison of groundwater extraction estimates from the OWDM and this study.

	Groundwater Extraction Comparison			
		(all values in m^3)		
MOE#	**OBWB aquifer #**	**Peak (July) monthly extraction for July (OWDM)**	**Extraction from known wells (this study)**	**Difference**
255	216	154,000	1,980,000	-1,826,000
254	215	217,000	1,236,000	-1,019,000
256	214	162,000	315,000	-153,000

Accordingly, we derived empirical estimates of groundwater extraction, shown in Table 7 and explained below.

1) First, we established groundwater extraction estimates for the probable highest demand month of July, starting with Town of Oliver records from 2015 (a hot and dry year), and then summed the nominal flow rates of known large capacity wells in each aquifer. Comparisons are shown in the Appendix.
2) Second, the assumed peak monthly demand was then calculated as 125% of the total from the known large wells for Aquifer 255 (where there are significant areas around Gallagher Lake not served by Town of Oliver) and assumed to be 100% of the total for Aquifers 254 and 256 (where Oliver supplies most of the water).
3) Third, we then applied seasonal factors in a similar fashion as used in the Golder-Summit (2009), with the bulk of the extraction occurring during the months of May to September.
4) Fourth, we assumed no outdoor water use or irrigation for the months of October to March and assigned relatively uniform (and low) rates of groundwater extraction for this six month period, based in part on domestic water usage and well operating flows as recorded by the Town of Oliver.
5) Finally, we adjusted demand values for normal and wet years to equal 90% and 80% of the estimated dry year demand. The tables below compile and summarize this information. The total estimated groundwater extraction from the three aquifers on an annual basis may range from 12,000,000 to 14,500,000 m^3, of which 55% is from Aquifer 255. This is notable in that 255 is proximal to the upgradient recharge zone of the study area.

Table 7: Estimated monthly groundwater use for dry, wet, and normal precipitation years.

Extraction total numbers in m^3

Aquifer 255	**dry year**	**normal year**	**wet year**	**Aquifer 254**	**dry year**	**normal year**	**wet year**	**Aquifer 256**	**dry year**	**normal year**	**wet year**
	e.g. 2015	***95%***	***85%***		***e.g. 2015***	***0.95***	***0.85***		***e.g. 2015***	***0.95***	***0.85***
January	50,000	47,500	42,500	January	50,000	47,500	42,500	January	30,000	28,500	25,500
February	50,000	47,500	42,500	February	50,000	47,500	42,500	February	30,000	28,500	25,500
March	50,000	47,500	42,500	March	50,000	47,500	42,500	March	30,000	28,500	25,500
April	495,150	470,393	420,878	April	309,240	293,778	262,854	April	65,000	61,750	55,250
May	990,300	940,785	841,755	May	618,480	587,556	525,708	May	100,000	95,000	85,000
June	1,584,450	1,505,228	1,346,783	June	989,550	940,073	841,118	June	100,000	95,000	85,000
July	1,980,570	1,881,542	1,683,485	July	1,236,900	1,175,055	1,051,365	July	120,000	114,000	102,000
August	1,782,510	1,693,385	1,515,134	August	1,113,270	1,057,607	946,280	August	90,000	85,500	76,500
September	1,287,360	1,222,992	1,094,256	September	804,030	763,829	683,426	September	55,000	52,250	46,750
October	50,000	47,500	42,500	October	50,000	47,500	42,500	October	30,000	28,500	25,500
November	50,000	47,500	42,500	November	50,000	47,500	42,500	November	30,000	28,500	25,500
December	50,000	47,500	42,500	December	50,000	47,500	42,500	December	30,000	28,500	25,500
	8,420,340	7,999,323	7,157,289		5,371,470	5,102,897	4,565,750		710,000	674,500	603,500
Sources of Information											
Town of Oliver water use summaries 2012 to 2015											
Review of large capacity irrigation well log information (mainly for aquifer 255)											

5.5 Irrigation Return Flow

Values for return flow were taken directly from the Golder – Summit (2009) report but were not adjusted for the different aquifer footprint areas of Aquifer 254, 255 and 256 as these modeled values are relatively low relative to other water budget parameters. As explained in the 2009 document, the irrigation return flow was typically determined by the OWDM to be a percentage of total irrigation demand from surface water and groundwater and values were generated by the OWDM. Even though it is possible that groundwater extraction was underestimated in the prior study, we did not adjust the return flow values as they are based on modeled irrigation volumes from both surface water and groundwater sources.

5.6 Water Tables Losses From Evapotranspiration (ET)

These values were taken from the Golder-Summit (2009) study and adjusted for mapped aquifer footprint areas. Water tables losses due to evapotranspiration were estimated based on a maximum annual potential loss of 1 m at the lowest valley elevations and adjusted to reflect decreasing ET losses with increasing depth to groundwater. Aquifer 255 (where static groundwater levels are typically deeper than 5 m) ET losses were estimated to be 0 to 10 cm whereas in the southern portions of Aquifer 254, where groundwater is closer to the surface, the estimated ET losses ranged from 68 to 90 cm.

5.7 Monthly Change in Storage

This value was calculated in the spreadsheet and expressed as a net change in aquifer thickness, which is also a surrogate for water level change. The calculation was based on aquifer volume and porosity. Porosity was based upon literature values for sand and sand and gravel mixtures.

5.8 Groundwater Discharge to Downgradient Aquifer or Surface Water Body

This term is calculated after the sum of all the inputs and outputs and change in storage, and are quantified against the groundwater inflow term. The net groundwater discharge from Aquifer 254 can be inferred to report to Osoyoos Lake and the Okanagan River north of the lake (with some losses to evapotranspiration as estimated in the spreadsheet and described in 5.6 above), but no discrete calculations of groundwater discharge to these water bodies were made within the water budget spreadsheet. The Okanagan River hydrograph represents regulated flow year – round and therefore does not permit baseflow separation techniques to be applied. Multiple gauges along the river through the study area might provide further insight into these surface water – groundwater relationships. Methods to facilitate this are described in the Westwold report by Bennett (2012).

6.0 MONTHLY WATER BUDGETS

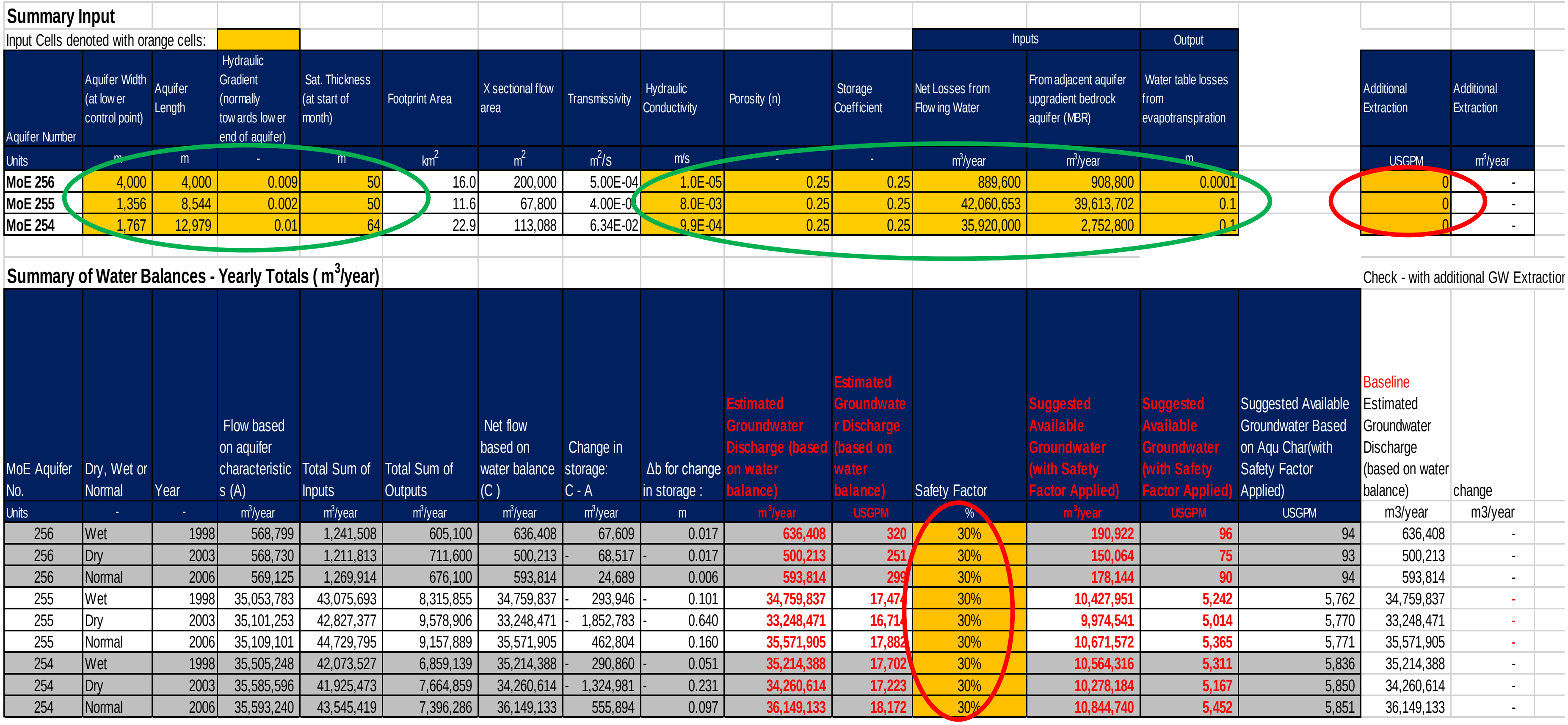
6.1 Spreadsheet Description

The spreadsheet used for this study takes a modified form of the “Groundwater Balance Analysis Tool” (GWBAT) spreadsheet developed in the 2009 Golder – Summit study. Several modifications were made to the spreadsheet, including the following:

- New/revised aquifer areas; and limited to three aquifers (255, 254, 256);
- New/revised Darcy Flow calculations;
- Revised values for groundwater extraction;
- Creation of an input sheet where variables can be changed by the user;
- Addition of a “new groundwater extraction” input; and
- Elimination of extraneous terms and cells that were proposed in the original tool but not applicable to the current study.

The three aquifer spreadsheets are linked to each other (255 and 256 report to 254) and each have seven basic components including the following:

1) **Aquifer Description Component:** This is information contained in boxes at the top of the spreadsheet, such as subject aquifer name, type, water level response type, aquifers which communicate with the subject aquifer, approximate elevation at the centroid of the aquifer and Stream Interaction and Precipitation Infiltration factors. The Precipitation Infiltration Factor relates to what fraction of precipitation falling on the footprint area of the unconsolidated aquifer, will actually recharge the aquifer. The Stream Interaction Factor relates to what fraction of streamflow is lost as infiltration (recharge) to an unconsolidated aquifer beneath the stream/creek.
2) **Aquifer Characteristics Component (A)**: This section is the upper-most 11 lines of the spreadsheet and represents the physical characteristics of the aquifer and the basis for a Darcy's Law calculation. Aquifer input parameters included are: hydraulic conductivity, saturated thickness, gradient, width, length, and porosity. For reference the spreadsheet calculates the white cells (footprint area, cross-section flow area, transmissivity, and storage at beginning of the trial period). The values are from the Golder-Summit study. Some thickness values were adjusted in order to achieve a balance as explained in this report.
3) **Surface Features Component (B)**: This section of the spreadsheet has not been used in the current assessment, it is "hidden" in the spreadsheets provided. It is intended for future use to facilitate the quantification of such water balance influences such as domestic water withdrawals, sewage disposal to ground and storm water discharge to ground, all of which could be related to population (if need be).
4) **Water Balance Component (C):** This section of the spreadsheet accounts for all estimated recharge and discharge influences on the aquifer and calculates a monthly flow estimate, independently of the Darcy's Law calculation in (A). Recharge (input) is treated as positive and discharge (output, for example extraction) is negative.
5) **Comparison Component (D):** This section of the spreadsheet calculates the difference between the Darcy's Law calculation in (A) and the Water Balance (C). The net difference between the two is treated as a monthly change in aquifer storage. A positive number is treated as an increase in storage and a negative number as a decrease. The change in storage is subsequently applied over the footprint area of the aquifer and, accounting for influence of porosity on storage volume, a change in saturated thickness for the aquifer system is determined. The change in thickness is transferred to the starting saturated thickness in the next column representing the next month.
6) **Graph of Saturated Thickness Component (Page 2):** This is a graphical representation of the data output from the spreadsheet model, specifically the temporal trend of saturated thickness throughout the 11-year trial time period. The graph provides immediate feedback of changes made to input parameters in Component A and can be used as a visual tool for sensitivity analysis. Over a specified time period, the difference between the calculated flow in the unconsolidated aquifer and the combined predicted recharge from adjacent aquifer systems plus other gains and losses is representative of the change in the volume of water stored in the aquifer over the time period. The change in volume of water stored was applied to the footprint area of the aquifer and, accounting for the influence of porosity on storage volume, a change in saturated thickness for the aquifer system was determined. This change in saturated thickness is plotted on a graph for the entire 11-year trial period on Page 2.
7) **Input Page and Summary Water Balances:** This worksheet allows the user to modify certain values in each aquifer using the identified yellow highlighted cells. These include physical aquifer characteristics, water balance terms, the recommended safety factor (30% used) and additional groundwater extraction. Figure 11 below depicts this summary worksheet.



Summary Input

Input Cells denoted with orange cells:

Aquifer Number	Aquifer Width (at lower control point)	Aquifer Length	Hydraulic Gradient (normally towards lower end of aquifer)	Sat. Thickness (at start of month)	Footprint Area	X sectional flow area	Transmissivity	Hydraulic Conductivity	Porosity (n)	Storage Coefficient	Inputs Net Losses from Flowing Water	Inputs From adjacent aquifer upgradient bedrock aquifer (MBR)	Output Water table losses from evapotranspiration	Additional Extraction	Additional Extraction
Units	m	m	-	m	km^2	m^2	m^2/s	m/s	-	-	$m^3/year$	$m^3/year$	m	USGPM	$m^3/year$
MoE 256	4,000	4,000	0.009	50	16.0	200,000	5.00E-04	1.0E-05	0.25	0.25	889,600	908,800	0.0001	0	-
MoE 255	1,356	8,544	0.002	50	11.6	67,800	4.00E-0	8.0E-03	0.25	0.25	42,060,653	39,613,702	0.1	0	-
MoE 254	1,767	12,979	0.01	64	22.9	113,088	6.34E-02	9.9E-04	0.25	0.25	35,920,000	2,752,800	0.1	0	-

Summary of Water Balances - Yearly Totals ($m^3/year$)

Check - with additional GW Extractio

MoE Aquifer No.	Dry, Wet or Normal	Year	Flow based on aquifer characteristics (A)	Total Sum of Inputs	Total Sum of Outputs	Net flow based on water balance (C)	Change in storage: C - A	Δb for change in storage :	Estimated Groundwater Discharge (based on water balance)	Estimated Groundwater Discharge (based on water balance)	Safety Factor	Suggested Available Groundwater (with Safety Factor Applied)	Suggested Available Groundwater (with Safety Factor Applied)	Suggested Available Groundwater Based on Aqu Char(with Safety Factor Applied)	Baseline Estimated Groundwater Discharge (based on water balance)	change
Units	-	-	$m^3/year$	$m^3/year$	$m^3/year$	$m^3/year$	$m^3/year$	m	$m^3/year$	USGPM	%	$m^3/year$	USGPM	USGPM	m3/year	m3/year
256	Wet	1998	568,799	1,241,508	605,100	636,408	67,609	0.017	636,408	320	30%	190,922	96	94	636,408	-
256	Dry	2003	568,730	1,211,813	711,600	500,213	- 68,517	- 0.017	500,213	251	30%	150,064	75	93	500,213	-
256	Normal	2006	569,125	1,269,914	676,100	593,814	24,689	0.006	593,814	299	30%	178,144	90	94	593,814	-
255	Wet	1998	35,053,783	43,075,693	8,315,855	34,759,837	- 293,946	- 0.101	34,759,837	17,474	30%	10,427,951	5,242	5,762	34,759,837	-
255	Dry	2003	35,101,253	42,827,377	9,578,906	33,248,471	- 1,852,783	- 0.640	33,248,471	16,714	30%	9,974,541	5,014	5,770	33,248,471	-
255	Normal	2006	35,109,101	44,729,795	9,157,889	35,571,905	462,804	0.160	35,571,905	17,882	30%	10,671,572	5,365	5,771	35,571,905	-
254	Wet	1998	35,505,248	42,073,527	6,859,139	35,214,388	- 290,860	- 0.051	35,214,388	17,702	30%	10,564,316	5,311	5,836	35,214,388	-
254	Dry	2003	35,585,596	41,925,473	7,664,859	34,260,614	- 1,324,981	- 0.231	34,260,614	17,223	30%	10,278,184	5,167	5,850	34,260,614	-
254	Normal	2006	35,593,240	43,545,419	7,396,286	36,149,133	555,894	0.097	36,149,133	18,172	30%	10,844,740	5,452	5,851	36,149,133	-

Figure 11 Summary Input Worksheet and Summary Wet/Dry/Normal Year Water Balances.

Notes*: The orange cells circled in green are the overall aquifer input values that can be changed by the user. The orange cells circled in red are values that can be varied by the user. For example, an annual extraction rate for Aquifer 255 can be entered and the spreadsheets will then average this extraction rate across 12 months. Similarly, the recommended safety factor of 30% (30% of water budget available for groundwater development) can be modified by the user. The result of changing one or more of these values is the graph of saturated thickness will likely change as the water balance has been changed. However, since this is not a physical/dynamic flow model, the spreadsheet cannot produce a response such as increased recharge from surface water due to groundwater pumping, which underscores the need for site-specific hydrogeological impact assessment for new groundwater extractions as explained in the text.*

Assumptions: Several assumptions were incorporated into the spreadsheet modeling over the 11-year trial period from which the three year scenarios are presented.

- Contributions of recharge from adjacent bedrock systems were assigned a constant value equivalent to the total annual recharge determined for the bedrock aquifer, divided by 12 to derive a monthly amount. Balancing began with the full value of recharge, but was reduced for some aquifers. This was the methodology applied in the OBWB study by a team of five hydrogeologists with consensus agreement from the coordinating committee.
- Temporal changes in infiltration from surface flow were apportioned by applying a monthly adjustment factor to monthly precipitation. A stream loss factor and other adjustment factors were also applied.
- The monthly precipitation adjustment factor was determined for each of the 132 months over the 11-year trial period by dividing the actual amount of precipitation recorded during a specific month at the Coldstream climate station (which has the longest period of record in the basin), by the mean monthly value for that same month at the station, and multiplying by the 0.05 factor for low elevation locations (350 m or lower), and for the aquifer footprint area. We simply applied the OBWB data which used the Coldstream station data over the entire basin due to precipitation infiltration being a small factor in the overall water balance of low-elevation unconsolidated aquifers. The infiltration numbers using the Oliver station data could be substituted; this would likely result in requiring more input from losses from flowing water. Since these are both estimates, we did not substitute the Oliver station data.
- To account for snow accumulation and freshet surface water runoff, the monthly precipitation factor for consecutive months from November through April was cumulatively added and then divided by six (the number of months), to determine a relative average monthly amount.
- Freshet surface water runoff was assigned as streamflow over the freshet period, during April through August. Additional contributions to streamflow via rainfall were also assigned, using the precipitation adjustment factor.
- Precipitation during September was directly attributed to surface water runoff.
- Precipitation during October, November, December, January, February and March was assigned to snow accumulation for the following year snowmelt and freshet surface water runoff.
- Changes to saturated thickness were made by adding to the thickness of the bottom layer in the sediment profile, as the thickness of the top layers could not vary substantially from the stratigraphic layering noted in available borehole logs (few wells penetrate to the base of aquifers 254/255/256).

The above assumptions are reflected in the calculation formulae used in each spreadsheet. Each aquifer analysis started with the same template into which the unique values for that aquifer were copied and pasted into the appropriate cells.

6.2 Updating and Extending the Spreadsheets

The water budget spreadsheets can be easily updated with new information. This new information, for example, might consist of more detailed aquifer physical characteristics (updated as shown in Figure 11), or refined estimates of mountain block recharge (i.e. inflow from upgradient bedrock aquifers), the updating for which would have be performed within each individual aquifer worksheet. The groundwater extraction term is based on best current estimates and can be updated once existing groundwater uses are licenced under the new regulations. Although the Oliver aquifer system is not thought to be highly sensitive to climate, a different climate data set for a different time period (e.g. from 2007 to 2027) and the spreadsheets could simply be extended into the future to the desired date.

We have provided a separate worksheet that clearly shows input data in highlighted cells. The user can start with this worksheet in updating the water budget information.

6.3 Discussion on Water Budget Results

Groundwater budgets fall in the 10^5 to 10^7 m^3/year range. Recall that mean annual regulated flow in the Okanagan River at Oliver is on the order of 5 x 10^8 m^3, naturalized annual flow of 5x 10^7 m^3 in Vaseux Creek, and groundwater extraction is estimated to be in the 1 x 10^6 m^3 range for the two most productive aquifers (255 and 254). Therefore, the estimated aquifer water budgets appear reasonable in that they fall between the high surface flow values and the estimated amount of groundwater extraction, and this coupled with relatively stable groundwater levels in observation wells suggests that the limits of groundwater capacity have not been reached. Figure 12 provides a graphical comparison between regulated Okanagan River flows, and modeled groundwater flow and extraction for Aquifer 254 that shows how there are order-of-magnitude differences between extraction and groundwater flow and between groundwater flow and regulated surface flow. These findings do not mean that the resource does not require careful management because there have been signs of stress from a water quality standpoint (WWAL 2011; 2015), and one observation well (332) did exhibit a long term declining trend for a number of years.

The following paragraphs briefly review the water balance results for each of the three study area aquifers with comments also touching upon implications in dry years, wet years and normal years. Figure 11 summarizes the water budget information. For details refer to the individual spreadsheets attached to this report.

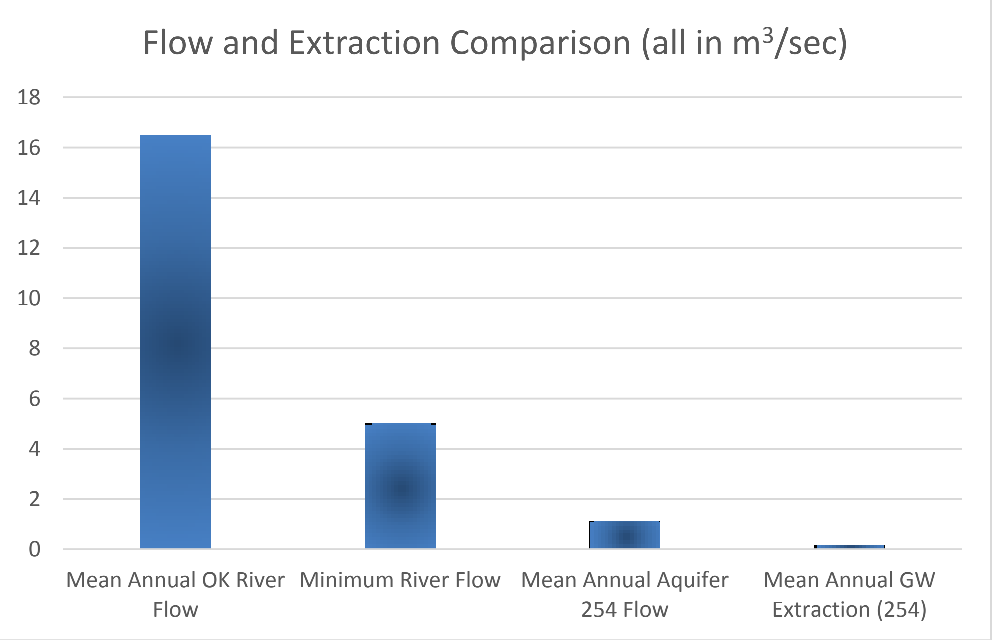


Figure 12 Comparison of Surface Flows, Groundwater Flow and Groundwater Extraction.

Aquifer 255

As noted above, as the aquifer in the upgradient position and located proximal to three major sources of recharge (Vaseux Lake, Vaseux Creek and Okanagan River), recharge to and flow through this aquifer likely drives the groundwater flow in the rest of the system between Vaseux and Osoyoos Lakes.

Figure 11 depicts a summary of the dry, normal and wet year water balance estimates for Aquifers 254, 255 and 256. Based on the water balance estimates it appears that approximately 20% of the Aquifer

255 water budget (i.e. annual discharge through the aquifer) is captured by wells on an annual basis. Aquifer storage is on the order of 1.5 x 10^8 m^3 based on the conceptual model and aquifer geometry. We concur with the aquifer classification of IA as the aquifer is heavily developed with numerous high capacity wells that are known, and potentially, other wells that remain undocumented.

Aquifer 256

Aquifer 256 covers a relatively large area but appears to play a less significant role in the Oliver area groundwater system. Consequently, as a result of the conceptual model, and our assessment of the aquifer and estimation of inputs and outputs, its water budget is approximately two orders of magnitude less than the other two study area aquifers. Water levels in the observation well appear stable. Existing use of this aquifer appears quite low but relative to the water budget, groundwater use on an annual basis approaches 100% of the Aquifer 256 water budget. This suggests that there may be unaccounted sources of recharge to this aquifer, such as lateral inflows from portions of Aquifer 254.

Aquifer 254

The water budget of aquifer 254 depends to a large degree on the amount of inflow provided by Aquifers 255 and 256. The Town of Oliver's transition (in approximately 2012) away from using the CPR and Lions Park wells has lessened the demand on this aquifer in recent years. Interestingly, we note that observation well 332 has since showed signs of a water level recovery, but we do not know if there is a connection between reduced demand and higher water levels given the distance between the unused wells and the observation well (> 1 km). Flow through Aquifer 254 is estimated to be nearly as large as flow through Aquifer 255. Estimated groundwater extraction on an annual basis is about 15% of the Aquifer 254 water budget.

6.4 Analysis of Uncertainty and Limitations

While we believe that the groundwater budget estimates reflect best available current knowledge, there remains uncertainty due to the inability to accurately measure factors such as contributions from upgradient bedrock aquifers, precipitation recharge, losses from surface water to ground, return flows, and groundwater extraction. Due to the high volumes, the water budgets are most sensitive to changes in losses from flowing water and inputs from upgradient aquifers.

The water balance analysis process showed that some aquifer balances were sensitive to relatively small changes in the input parameters, such as flow from upgradient aquifers, or changes in extraction. In addition, a limited sensitivity analysis of the effect of the AET factor (influences bedrock aquifer water budget) on water balances was conducted for each bedrock aquifer for the Golder – Summit 2009 study. The AET / PET ratio was was adjusted from the 0.6 value upwardly to a maximum factor of 0.7 for this analysis, and also examined the influence on water balances of setting negative bedrock recharge values to zero. Increasing the AET factor resulted in higher numbers of bedrock aquifers having zero or negative recharge values. A few of the limitations stated in the Golder – Summit 2009 are broadly applicable to the Oliver groundwater budgets study and summarized below.

The spreadsheet model allows for the determination of approximate water balance for individual aquifers based on an analytical solution and is not a numerical model that solves the partial-differential equation that governs groundwater flow for each aquifer in space and time. The analytical solution is based on application of Darcy's Law and is founded on a number of assumptions that are subject to limitations as follows:

- The Basin is a regional water system and significant simplifications were required to account for topography and complexity of stratigraphic layering. Based on best estimates, single values have been applied to large aquifer areas for each of the input parameters, including hydraulic

conductivity, hydraulic gradient, depth to groundwater at centroid, aquifer width and thickness, and porosity. All other things being equal, the greater the quantity of data available for a single aquifer may not necessarily produce more representative values for these input parameters;
- Flow between bedrock and unconsolidated aquifers was assumed to be evenly distributed throughout the year (constant flux) based on the assumption that groundwater flow through the shallow upland aquifer is in a steady-state of equilibrium and that the dynamics of the equilibrium are at a time scale in the order of hundreds of years;
- Stream losses were assigned based on an assumed temporal distribution throughout the year, with the added assumption that creek base flow was constant and that infiltration was not directly proportional to streamflow, but was relatively higher during freshet and relatively lower during the winter period. Gains within the streams were not considered. Stream loss and gain is one of several topics of potential future research in the Basin; and
- Detailed accounting of temporal gains and losses between creeks and aquifers is currently not achievable due to limited data on stream loss in creeks within the study area. The merits of completing site-specific surveys to determine creek channel slope/geometry and hydraulic head in creeks and in aquifers in the areas are worth considering to constrain inputs to Aquifer 255.

4.4 Significant Data Gaps

The main data gaps affecting this study included:

- Limited borehole information for wells that penetrate the full thickness of aquifers. These are needed to characterize saturated thickness and bulk hydraulic conductivity values;
- Limited information on the thickness of alluvium or unconsolidated sediments above bedrock at hydrometric stations, such that the relative proportion of streamflow, baseflow and aquifer flow, can be more accurately determined;
- Further analysis of the natural (unregulated) flow of the Okanagan River flow at the Road 18 gauge could potentially allow for further analysis of baseflow;
- Limited streamflow data that would enable streams gains and losses, especially during baseflow recession, to be determined (requires measurements of streamflow at multiple locations); in addition, the amount of stream or river flow induced to flow into aquifers near pumping wells has not been quantified;
- Aquifer 255 does not have an observation well closer to its major sources of recharge in the Vaseux Creek area;
- Limited information on groundwater extraction and individual well flow rates;
- Relatively short term groundwater level data are available and one well (332) has a gap in the data record.

7.0 CONCLUSIONS AND RECOMMENDATIONS

One desired outcome for this study was to provide guidance on potential future allocation of groundwater licenses. This section discusses the current situation and provides possible approaches for making future allocation decisions. The Province of B.C. is in the early stages of licensing existing groundwater uses into the new licensing scheme under the 29 February 2016 Water Sustainability Regulation. There are two key data outputs that will be derived from this process: 1) total licensed groundwater use (should be determined monthly and not just annually) and 2) actual groundwater use (once the reporting requirements are enacted under the regulations). While we believe the groundwater extraction estimates in the water budgets developed for this study are reasonable and likely accurate to within an order of magnitude or less, the actual use values will better inform the water budget and future allocation process.

The following sections provide guidance on allocation for each of the three study area aquifers. Before we discuss each aquifer, we provide a series of over-arching recommendations applicable to the Oliver area aquifers.

7.1 Overall Findings and Recommendations

1. On an average annual basis, assuming the estimates of inputs and outputs are reasonably accurate, there is likely additional groundwater available that could be developed in some locations without causing water level declines or unacceptable well interference. However, because of the high agricultural demand on groundwater and surface water during the irrigation season, additional allocation of groundwater for irrigation purposes (or any use concentrated in the summer month) should be reviewed in greater detail than year-round uses for municipal drinking water or other uses.
2. The difference between minimum regulated flow in the Okanagan River and suggested conservation flows is on the order of 2.5 m^3/sec, which is about 40,000 US gpm. The surface water flow volumes are a full order of magnitude above groundwater budgets, and due to flow regulation in the Okanagan River (that maintain more than the minimum recommended conservation flows). As such, it would require an improbably large increase (say, greater than 20,000 US gpm) in groundwater extraction to negatively impact surface flows in the Okanagan River within the study area.
3. Notwithstanding #2 above, it is possible that on a local or river reach scale, high rates of groundwater extraction have the potential to alter patterns of natural groundwater discharge and so could have an effect on surface water temperatures at times of the year. Such effects should be addressed on a site-specific or project-specific basis, for example, as part of the terms of reference for a B.C. Environmental Assessment or a hydrogeological study that would be used to support a high capacity well licence application.
4. The groundwater budgets appear as water balances and as such any significant change to inputs would need to be offset by a change in outputs. Because the water budgets are not a dynamic flow model, if groundwater extraction rates are significantly increased, this will be reflected in a continuing reduction in the aquifer saturated thickness in the spreadsheet tool. The only way to “re-balance” the water budget would be to alter the aquifer physical properties or to increase recharge; however, in practice, it is often observed that the system finds a new equilibrium and water tables level off following an increase in extraction if the system is able to remain in balance.
5. The groundwater budgets have potential applicability to assessing larger-scale groundwater withdrawals of 50 to 75 L/sec or more (75 L/sec and more are subject to a Provincial EA), but we believe that the effects of smaller individual well groundwater withdrawal licence applications are better assessed through a site-specific hydrogeological impact assessment prepared to support the licence application, or perhaps more relevant, in a forward casting assessment of the potential incremental and cumulative effects of continuing to allow new groundwater licences within a given aquifer. This assessment would need to consider potential impacts on existing groundwater users (e.g. well interference), potential changes in surface water – groundwater interaction (as determined in a field investigation or through numerical modeling) as well as the aforementioned peak season stress on the aquifer system. The spreadsheets could provide an indicator of a potential concern if the water budget indicates a declining aquifer thickness (declining water level).

6. Water allocation decisions should not be made strictly based on the potentially available groundwater to develop values provided, but in concert with continuing to track trends in observation well levels, as well as monitoring actual groundwater use as well sources come into compliance with the regulations. Importantly, it is our opinion that the spreadsheet tool should not be used in isolation to assess an individual licence application because the level of uncertainty in the spreadsheet likely exceeds the amount of diversion under an individual licence.
7. We recommend allocation decisions be informed by policy based on the recommendations provided herein for each aquifer, and also by the results of additional aquifer characterization, including but not limited to impact assessments by licence applicants, and also by continuing to monitor groundwater use and observation well groundwater levels. One potential policy to consider would be to assess available surface water supply availability based on existing licenced flow (and storage), and environmental flow needs (established base on achievable objectives for habitat, flow, and temperature) and then administer additional groundwater extraction as an extraction of surface water (if any is deemed available) given the relatively shallow and unconfined nature of the study area aquifers.
8. Below, we will apply a recommended 30% “safety factor” in making preliminary estimates of potentially available groundwater for development. This value is taken to be 30% of the remaining estimated groundwater budget in the water balance. It is based, in part, on our own subjective professional opinion. However, it is informed by discussions in a paper by Kalf and Wolley (2005) which suggested a default value of 30% of pre-development water be reserved for ecological purposes (i.e. 70% of the recharge or water budget is potentially available for development). In the case of an already developed basin, allowing 70% of the groundwater budget to be developed is not advisable. Therefore, we settled on a 30% value.

7.2 Aquifer 255 Water Budget and Future Development Implications

As noted in the report, Aquifer 255 is likely the most heavily used of the three Oliver area aquifers. The aquifer is also located in an area that receives significant recharge via surface water losses. Because of this, the aquifer exhibits relatively good groundwater quality compared to locations further south (WWAL 2015). For purposes of this discussion, the “annual water budget” is the estimated groundwater flow based on the water balance.

There are no signs that the aquifer is under a high degree of stress from a water quantity standpoint. Observation well water levels appear stable over the past several years except there may be a hydraulic response to increased pumping locally by the Town of Oliver that will need to be monitored. There are no anecdotal reports of wells going dry. Existing groundwater extraction during the peak month of groundwater use (July) is approximately 65% of the estimated groundwater budget for that month (dry year) and on a long term annual basis is about 20% of the groundwater budget. Relatively less of the lands overlying the aquifer are served by the Town of Oliver and so there is greater potential for future applications for groundwater licenses in Aquifer 255 relative to areas further south.

We believe that increased extraction will induce more recharge from the Okanagan River into the aquifer, and possibly more recharge from Vaseux Creek (though some losses form the latter may occur through an unsaturated zone and so would not be influenced by drawdown). Until more information is available, we recommend that future licenses limit July monthly extraction to current levels (once groundwater use is verified under the reporting requirements of the WSA regulations) and limit annual extraction to 30% (the “Safety Factor”) of the annual water budget, which is an annual equivalent to $1.05 \times 10^7 m^3$. Given our current status of information, and assuming our estimates of existing use are representative, considerably more groundwater capacity could potentially be developed from Aquifer

255 but less capacity is potentially available during the irrigation season. On an annual basis, there is the potential to develop approximately 1 x 10^7 m^3 groundwater annually or an average of about 5,000 US gpm or approximately 0.3 m^3/sec.

We also note that licensing of some existing groundwater sources in this aquifer could be reviewable under the Environmental Assessment Act. Such reviews could include additional quantitative hydrogeological investigation and analysis that would inform updates to the water budget and conceptual model. See Section 7.1 above and Section 7.4 for further discussion. Aquifer 255 appears to be more extensive than currently mapped based on a review of available well logs (see Cross Section A-A’ Figure 4). WWAL can provide shape files upon request if government wishes to modify the existing aquifer maps.

7.3 Aquifer 254 Water Budget and Future Development Implications

As noted in the report, Aquifer 254 is likely the second most heavily used of the three Oliver area aquifers. The aquifer is located downgradient of Aquifer 255 and downgradient of historically developed land for agriculture and urban land uses. Because of this, the aquifer exhibits relatively good groundwater quality but not as good as Aquifer 255 (WWAL 2015).

There are no signs that the aquifer is under a high degree of stress from a water quantity standpoint. However, until recently, the observation well (#332) exhibited a slow but steady decline which is suggests some stress on the system. Observation well water levels appear to be recovering, possibly due to changes in Town of Oliver well usage that effectively have shifted production from Aquifer 254 to 255. There are no anecdotal reports of wells going dry. Existing groundwater extraction on a long term annual basis is about 15% of the groundwater budget but peak (July) extraction in a dry year (2003) is approximately 42% of the water budget. Most of the lands overlying the aquifer are already supplied with domestic and irrigation water by the Town of Oliver and so there is likely less potential relative to Aquifer 255 for additional large scale groundwater development due to the availability of supply.

We believe that increased extraction from Aquifer 254 would induce recharge from the Okanagan River into the aquifer, where drawdown is great enough to increase gradients, and reduce downgradient discharge to surface water where gradients are not reversed. Until more information is available, we recommend that future licenses limit July monthly extraction to 65% of the water budget similar to Aquifer 255 (once groundwater usage is verified under the reporting requirements of the WSA regulations) and limit annual extraction to 30% of the annual water budget, which is equivalent to approximately $1.06 \times 10^7 m^3$.

Given this, and assuming our estimates of existing use are good, considerably more groundwater capacity could potentially be developed from Aquifer 254 but less capacity is potentially available during the irrigation season. On an annual basis, there is the potential to develop approximately 1 x 10^7 m^3 groundwater annually or an average of about 5,000 US gpm or 0.3 m^3/sec.

As is the case with Aquifer 255, we note that licensing of some existing groundwater sources in this aquifer could be reviewable under the Environmental Assessment Act. Such reviews could include additional quantitative hydrogeological investigation and analysis that would inform updates to the water budget and conceptual model. The water quality effects, if any, from increased extraction would also be assessed for the larger regulated withdrawals. The aquifer appears to cover a slightly larger area than currently mapped. See Cross Sections B-B’ and C-C’ Figures 5 and 6.

7.4 Aquifer 256 Water Budget and Future Development Implications

This study and the water budget analysis suggests that Aquifer 256 is the least developed of the three aquifers, but could have a more limited water budget that might be approaching its limits. On an annual basis, based on our estimates of inflow and outflow, it appears that groundwater extraction consumes

100% or more of the water budget. However, observation well water levels appear relatively stable and there are no reports of declining well water levels or well yields. As mentioned above, it is likely that there is unaccounted recharge entering the aquifer, possibly as lateral inflow from portions of Aquifer 254, perhaps a greater degree of mountain block recharge from bedrock, or potentially pumping – induced recharge from surface water and/or Aquifer 254. Applying the safety factor suggests that only about 150,000 to 190,000 m^3 /year is available for groundwater development, which is less than 100 US gpm, or about 0.01 m^3/sec.

Owing to the existing land base already served by the Town of Oliver water system, there are likely few drivers for significant additional large scale groundwater development in this aquifer. In recent years, the Town converted its Fairview well from domestic (drinking water) purposes to agricultural and therefore it is possible that extraction from the aquifer could increase slightly. We recommend that future groundwater licenses be examined on a case-by-case basis since the water budget suggests the potential capacity has already been reached. We note that drawdown from pumping wells in this aquifer likely induce recharge from Aquifer 254 where extraction occurs relatively close to the contact between the two aquifers. For this reason, it is likely that additional groundwater can be developed from Aquifer 256 in some locations without causing well interference problems or year-to-year water level declines. Potentially elevated nitrate (potentially in excess of 10 mg/L locally) should be considered in allocation decisions. Given the uncertainty is higher in this less developed aquifer, it is reasonable that a larger scale proposed development (i.e. 30 L/sec or more per well) should receive a thorough review and be supported by a detailed impact analysis prior to a licence being issued for a new groundwater use (post-Feb 29 2016).

7.5 Future Study and Monitoring Recommendations

The recommendations provided in this section assume that future studies will be informed by the in-process licensing of existing groundwater wells in the study area and that monitoring of water levels in the three observation well continues without interruption over the next several years. As already noted, the factors with the greatest overall influence on the groundwater budget are the following:

- Losses from flowing and standing water to Aquifer 255;
- Groundwater discharge to specific reaches of the Okanagan River (Aquifer 254, and also potentially Aquifer 255);
- Contributions from upgradient bedrock aquifers to all three study area aquifers (especially Aquifer 255 which is conceptually modeled to receive high flows from a bedrock aquifer associated with the Vaseux Creek catchment); and
- Aquifer thickness, aquifer width, hydraulic conductivity and groundwater discharge estimates that rely on an assumed hydraulic gradient.

The following recommendations are provided for Ministry consideration:

R1 Install two gauges in Vaseux Creek, one at the upgradient edge of the valley/unconsolidated aquifer and one just upstream of the Okanagan River confluence could be used to constrain monthly estimates of creek losses to the aquifer.

R2 Similar gauges installed on the Okanagan River, perhaps at key times of the year (i.e. irrigation season and non-irrigation season or high water and low water) could be used to assess both losses and gains.

R3 It is also our opinion that a fully penetrating observation well (possibly with multiple completions at varying depths) in Aquifer 255 in the vicinity of where Vaseux Creek passes under Highway 97 would provide valuable insight into the groundwater flow regime in this area (this was also a recommendation from the Golder – Summit study); as well as provide further information on shallow and deep aquifer zones and degree of confinement.

R4 Further, since there are few fully penetrating wells, additional deep boreholes in the other aquifers combined with detailed grain size analysis could help refine aquifer parameters.

R5 Review existing aquifer mapping and consider updating the boundaries of Aquifers 254 and 255.

R6 Establish environmental flow needs for the Okanagan River and use this information to inform allocation policies and decisions for shallow, unconfined groundwater sources.

R6 Finally, a detailed well water level survey throughout at least one full water year could help confirm hydraulic gradients.

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APPENDIX A - KNOWN HIGH CAPACITY WELLS IN THE OLIVER AREA

Aquifer 255

Well owner	Well name or #	WPN or WTN	Depth (ft)	Diameter (In)	Reported Yield (US gpm)	yield (m3/day)	type
Covert Farms	PW1	15772	132	12	1,100	5,988	IRR
Covert Farms	PW2	15773	122	12	1,295	7,049	IRR
Covert Farms	PW3	15774	134	16	400	2,177	DOM
Covert Farms	PW4	15777	129	16	1,525	8,301	IRR
Covert Farms		26883		8	800	4,355	IRR
OIB	Golf Course			8	250	1,361	IRR
OIB	Main wells (2)			8	500	2,722	DOM
Vincor		47003	180	8	735	4,001	IRR
BC Fruit Growers		46717			730	3,974	IRR
BC Fruit Growers		53817			768	4,180	IRR
Town of Oliver	Buchanan Dom.	29356	78	16	1000	5,443	DOM
Town of Oliver	Buchanan AG.	29354	73	10	600	3,266	IRR
TOTAL (peak season use)					**9,703**	**52,815**	
ASSUMED TOTAL = 125% OF THE largest wells					**12,129**	**66,019**	
Aquifer 254							
Town of Oliver	Tuc El Nuit 2		47	12	1200	6,532	DOM
Town of Oliver	Tuc El Nuit 3		45	10	650	3,538	DOM
Town of Oliver	Fairview				425	2,313	IRR
Doers		30557			800	4,355	IRR
Evans		20391			800	4,355	IRR
Town of Oliver	Blacksage 1	49481	84	16	2000	10,886	DOM/IRR
Town of Oliver	Blacksage 2	24513	50	16	400	2,177	DOM/IRR
Town of Oliver	Blacksage	23793	102	8	200	1,089	DOM/IRR
Town of Oliver	Miller Rd		59	16	1100	5,988	DOM/IRR
TOTAL PEAK SEASON USE					**7575**	**41,232**	
Aquifer 256							
Town of Oliver	Rockcliffe well		80	16	1500	8,165	DOM
Town of Oliver	Fairview well			8	425	2,313	IRR
TOTAL PEAK SEASON USE					**1925**	**10,478**	

APPENDIX B – WELL INVENTORY INFORMATON

Well Inventory Appendix: All Wells within Aquifer 255 with reported yield of 100+USgpm.

Well Tag Number	Well Owner	Static water level (ft)	Depth Drilled (ft)	Yield (USgpm)	Formation (UNC/BR)
20402	Jack Knodel	5	14	2000	UNC
82374	Deer Park Estates Mobiile Home Park	13	74.9	1250	
21131	Sundial Motel	4	18	1000	UNC
39471	Covert Holdings Ltd	15	213	835	UNC
26883	George Covert	4	106	800	UNC
25809	George Covert	4	106	800	UNC
53187	BC Fruit Growers Associations	1	73	768	UNC
47003	Inkameep Winery Proj	61	180	735	UNC
46717	BC Fruit Growers Associations	6	70	730	UNC
21827	Wallace Smith	13	20	600	UNC
79225	David Holmes Smith		26	500	
79206	Ken Moore		30	500	
21136	Merlin Phelps	20	25	500	UNC
20414	Cyril Heady	18	28	500	UNC
188	Oliver Trout Farms	5	45	500	UNC
21873	South Okanagan Lands Irrigation District	7	114	402	UNC
53199	BC Fruit Growers Associations	7	71	370	UNC
76687	Arnie Elcert	40	100	350	
110316	Richards	39.7	77	300	
14108	F. Selig		14	300	UNC
61069	Living Styles Inc.	6	79	250	UNC
99289	Friesen	3	35	200	
90588	Kane	8.5	57.5	200	UNC
82375	Deer Park Estates Mobiile Home Park	9	78	200	
57823	K Moore	100	402	200	UNC
89174	Gallagher Lake Campground	22	98.5	150	

82597	David Ward	2	78	150	
49935	Theo Brouwer		105	150	UNC
21968	George Covert	5	18	150	UNC
20397	Terrey Serell	10	16	125	UNC
106892	Vincor Int. Inc.	49	120	120	
105476	Gill	6.5	55	100	
97300	Blue Terrace Vineyard	28	56	100	UNC
87393	Remillard	24	100	100	
84757	Radies		320	100	
83003	Ocean Highway Heavy Haul Inc	22	59.5	100	
82996	Riverside Resort and Campsite	3	78	100	
79990	Blue Terrace Vineyard	35	256	100	
58135	Walter Barisoff	5	37	100	UNC
54602	Hovin and Minchin	42.5	79	100	UNC
47711	Leighton	11	77	100	UNC
47302	Kozlovic	48	118	100	UNC
47145	C Niessen	1	50	100	UNC
44077	Gerald E Niessen	5	24	100	UNC
39960	D Shipley	3	60	100	UNC
37907	Levant	14	40	100	UNC
36123	C Overton	4	65	100	UNC
27477	McGowan Investments	8	28	100	UNC
22942	Louis Schonberger	6	14	100	UNC

Note: this table does not include several non-database well logs in WWAL files.

Well Inventory Appendix: All Wells within Aquifer 256 with reported yield of 100+USgpm.

Well Tag Number	Well Owner	Static water level (ft)	Depth Drilled (ft)	Yield (USgpm)	Formation (UNC/BR)
82376	Town of Oliver	79.9	79.9	1500	
19582	Jack Walker	6	16	1000	UNC
21867	Town of Oliver	30	140	425	UNC
104536	Prov. of B.C.	59.8	84.9	100	UNC
21124	P Falkenhot	42	50	100	UNC

Well Inventory Appendix: All Wells within Aquifer 254 with reported yield of 100+USgpm.

Well Tag Number	Well Owner	Static water level (ft)	Depth Drilled (ft)	Yield (USgpm)	Formation (UNC/BR)
49481	Town of Oliver	7	110	1400	UNC
84724	Town of Oliver	20	59	1092	
29205	Town of Oliver		0	1000	UNC
22554	Ralph Dieno	6	10	1000	UNC
52995	Osoyoos Indian Band	17	61	937	UNC
47304	Cherry Grove Estates	17	59	854	UNC
30557	L. Doers		25	800	UNC
20391	Dave Evans	5	16	800	UNC
23078	Solid	8	48	790	UNC
83008	Town of Oliver	11	47	700	
57022	L Martiniuk	12	58	700	UNC
5960	South Okanagan Lands Irrigation District	11	52	700	UNC
51107	Town of Oliver	12	45	627	UNC
79249	Randy Toor	18	25	500	
72594	Osoyoos Indian Band	10	95	500	
22329	A.T. Hewitt	2	14	500	UNC
20387	Art Colman	14	19	500	UNC
21867	Town of Oliver	30	140	425	UNC
24513	Town of Oliver	8	49	400	UNC
23076	Corp Village of Oliver	7	24	300	UNC
6000	Used By Haynes Corp		0	300	UNC
16860	T. Lipkovits	2	10	250	UNC
84705	Osoyoos Indian Band		57	240	
23793	Town of Oliver	6	109	200	UNC
29913	Manual Dutra	4	35	120	UNC
22403	Ed Hintz	6	18	120	UNC
29027	Village of Oliver	8	35	114.5	UNC
97839	Boclair	10	79	100	UNC
40942	Ron Venables	2	34	100	UNC

37098	Frank Skukale	9	86	100	UNC
34759	Frank Skukale	8	49	100	UNC
30566	B Weins	2	21	100	UNC
22170	Norris Wheeler	17	26	100	UNC
21124	P Falkenhot	42	50	100	UNC