WATER SCIENCE SERIES

Groundwater Quality Assessment and Proposed Objectives for the Osoyoos Aquifer

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November 2019

No. 2019-06

The **Water Science Series** are scientific technical reports relating to the understanding and management of B.C.'s water resources. The series communicates scientific knowledge gained through water science programs across B.C. government, as well as scientific partners working in collaboration with provincial staff. For additional information visit: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series.

ISBN: 978-0-7726-7772-3

Citation:

Rathfelder, K. and L. Gregory, 2019. Groundwater quality assessment and proposed objectives for the Osoyoos Aquifer, Water Science Series: WSS2019-06, Province of British Columbia, Victoria.

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Cover Photographs:

Agricultural development on the lower and upper outwash terraces overlying the Osoyoos Aquifer adjacent to Osoyoos Lake, B.C. Photo source Linda Gregory (Gregory, 2014).

Acknowledgements

The authors gratefully appreciate the thorough review and constructive comments provided by Heather Thompson, Amy Sloma (ENV), Skye Thomson (FLNRORD) and John Pogson (FLNRORD) , technical input from Mike Sokal (ENV), and monitoring assistance from Nicole Pyett and Twyla Legault (FLNRORD).

EXECUTIVE SUMMARY

A groundwater quality assessment was conducted for the Osoyoos Aquifer (Aquifer 193), which is adjacent to the western shore of Osoyoos Lake in the southern end of the Okanagan Valley in British Columbia (B.C.). Land-use over the aquifer is dominated by agriculture covering about 70% of the aquifer area, and the Town of Osoyoos bisects the central portion of the aquifer. Groundwater is the main source of water supply for the Town of Osoyoos and for residents in adjacent rural areas.

The Osoyoos Aquifer is a surficial sand and gravel aquifer, generally about 5 to 15 m thick with a shallow groundwater table, typically about 3 to 6 m below the ground surface. Aquifer recharge is dominated by irrigation water in agricultural areas, which is sourced from Okanagan Lake. Because of the dry and desert climate of the Osoyoos Valley, recharge from precipitation is a minor contribution to the overall aquifer recharge. The aquifer sediments are generally well-draining and very conductive. Consequently, the aquifer is susceptible to contamination from overlying land-use practices.

Groundwater in the Osoyoos Aquifer flows into Osoyoos Lake with an average discharge of about 10,000 m^3/day. Soluble contaminants in groundwater will flow into Osoyoos Lake where they can potentially affect the aquatic habitat of the lake. Osoyoos Lake provides habitat to a variety of aquatic life, including both resident and anadromous fish species, and is important to the local economy and tourism industry for water-based recreation. The water quality of Osoyoos Lake is a long-term concern, especially for nutrient enrichment and eutrophication problems associated with phosphorus inputs. In 2012, the Province updated water quality objectives (WQOs) for Osoyoos Lake that included objectives for five nutrient enrichment parameters.

A groundwater quality assessment for the Osoyoos Aquifer was conducted by compiling and reviewing groundwater quality monitoring data and associated reports, and identifying and assessing point and non-point waste loads that potentially affect groundwater uses. The available groundwater monitoring data include samples collected by multiple agencies from 44 wells spanning more than 30 years. The groundwater quality database includes parameters for general chemistry, nutrients, metals, and limited data for pesticides. There are no monitoring data for organic compounds. Impacts to groundwater uses were assessed by comparing groundwater quality data to guideline values for drinking water supply, irrigation supply, and aquatic health in the receiving waters of Osoyoos Lake.

The overall groundwater quality throughout the Osoyoos Aquifer is generally within the Canadian drinking water guidelines for protection of human health. However, groundwater in the Osoyoos Aquifer is generally very hard, with high alkalinity and high total dissolved solids. There are a small number of exceedances of metals guidelines for drinking water and irrigation supply, which occur from natural sources and are localized in nature. These exceedances do not broadly affect groundwater uses of the aquifer.

Groundwater in the Osoyoos Aquifer is widely affected by elevated levels of nutrients. Nitrate was detected above the drinking water guidelines for protection of human health (10 mg-N/L) in some wells, and dissolved phosphorus occurs above the lake objective for protection of aquatic health (0.015 mg/L) in most samples. Monitoring data show elevated nutrient levels occur throughout much of the aquifer and have generally persisted over the past two decades, indicating the sources are distributed and permanent. The groundwater quality assessment evaluated a variety of potential nonpoint sources and land use activities including: fertilizer application in agricultural areas and residential landscaping; individual septic systems in rural areas; distributed discharges associated with the municipal landfill operations; land application of wastewater treatment plant effluent; and agricultural irrigation supply water from the lake. Associated nutrient loads have been estimated for most of these potential sources.

Groundwater quality objectives are proposed for the Osoyoos Aquifer to protect groundwater uses for drinking water supply and aquatic life protection in Osoyoos Lake. The proposed objective for nitrate is 10 mg-N/L, which is consistent with the Health Canada guideline for protection of human health and the B.C. source drinking water quality guideline. The proposed objective for dissolved phosphorus is 0.15 mg/L, which is consistent with the water quality objective for Osoyoos Lake after taking into account a 1:10 dilution in the transition from groundwater to surface water. These objectives should apply to the entire aquifer because the nutrient sources are varied and widely distributed, and because the aquifer is broadly vulnerable to contamination.

Proposed Groundwater Quality Objectives for Osoyoos Aquifer

Parameter	Objective Value	Notes
Nitrate	≤10 mg-N/L	Equal to the Health Canada guideline for protection of human health. Applicable to the entire aquifer.
Dissolved phosphorus	≤0.15 mg/L	Equal to the water quality objective for Osoyoos Lake after a 1:10 dilution in the transition from groundwater to surface water. Applicable to the entire aquifer.

The proposed groundwater objectives establish benchmarks for protecting groundwater uses in the Osoyoos Aquifer. The objectives and supporting information provide direction to government operations affecting groundwater quality, including oversight of permits and orders pertaining to waste discharges to groundwater, prioritization of groundwater quality characterization studies, and ongoing monitoring studies by government to assess objectives attainment. This report includes monitoring recommendations to assess objectives attainment, to improve estimates of nutrient flux into Osoyoos Lake, and to further investigate nutrient sources. In addition, the proposed objectives could also promote awareness of groundwater quality in the Osoyoos Aquifer, the importance of groundwater for domestic water supply, and the connections between groundwater and aquatic resources in Osoyoos Lake.

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ACRONYMS AND ABBREVIATIONS

ADS	Agricultural Drainage System
AO	Aesthetic Objective
B.C.	British Columbia
BOD	Biochemical Oxygen Demand
ECCC	Environment and Climate Change Canada
EMS	Environmental Monitoring System
ENV	Ministry of Environment and Climate Change Strategy
ET	Evapotranspiration
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
gpm	gallons per minute
GW	Groundwater
GWELLS	Groundwater Wells and Aquifer Database
ID	Identifier or Identification Number
LMWL	Local Meteoric Water Line
MAC	Maximum Acceptable Concentration
OW	Observation Well
SOLID	South Okanagan Lands Irrigation District
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
Town	Town of Osoyoos
TSS	Total Suspended Solids
WSA	*Water Sustainability Act*
WTN	Well Tag Number
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

1.1 Background

Groundwater is an increasingly important source of water in the Okanagan Basin of British Columbia (B.C.) providing nearly one quarter of the water needs (Summit , 2010). However, there are knowledge gaps about the sustainability of groundwater resources, groundwater quality, and the importance of groundwater to aquatic ecosystems. Groundwater resources were historically unregulated prior to 2016 when the Province began licensing groundwater use under the *Water Sustainability Act* (WSA). With increasing reliance on groundwater and an evolving regulatory structure, initiatives to characterize groundwater resources and to inform WSA implementation are prudent measures for sustainable management of groundwater in the Okanagan Basin.

The region adjacent to Osoyoos Lake at the southern end of the Okanagan Basin is a major agricultural production area and tourist centre that has experienced significant population growth over the past decade. The Town of Osoyoos sources municipal water supply from shallow groundwater wells and manages agricultural water supply, which is sourced from Osoyoos Lake. However, groundwater and surface water resources are interconnected. Agricultural irrigation supplied from the lake substantially affects groundwater levels in the shallow aquifer, which ultimately returns to Osoyoos Lake. Since the aquifer is shallow and conductive, overlying land use practices can affect groundwater quality and potentially impact groundwater uses for water supply and the receiving waters of Osoyoos Lake.

1.1 Groundwater Quality Objectives

In 1981, the B.C. Auditor General recommended the province develop a method of measuring its performance in safeguarding water quality. In response, the Ministry of Environment (now the Ministry of Environment and Climate Change Strategy) (ENV) developed protocols for setting water quality objectives for fresh and marine surface water, which are considered the safe conditions or threshold levels of a substance that will protect the most sensitive use of the water body (Prov. of B.C., 2013). The objectives establish a reference for assessing the state of water quality at a specific site and provide policy direction for protecting water quality. Water quality objectives have been set for more than 200 individual streams, lakes, or marine area (Province of British Columbia, 2017c).

Groundwater quality objectives are accepted regulatory practices in many Canadian and U.S. jurisdictions, but none are currently set in B.C. (Kohut & Pommen, 2005). Groundwater quality objectives in B.C. could augment surface water objectives in the following ways:

- guide the preparation of ENV permits, plans, and orders pertaining to the management of waste discharges that may affect groundwater quality (e.g. landfills);
- guide actions of other agencies and individuals who have a role in the regulation of activities that may affect groundwater quality;
- serve as benchmarks for assessing the effectiveness of protecting groundwater uses and quality;
- assist in maintaining high quality groundwater for existing and future groundwater uses, including the protection of human health and aquatic life;
- identify aquifers at risk of groundwater quality degradation; and,
- prioritize expenditures for groundwater characterization and monitoring.

1.2 Purpose and Scope

The overall purpose of this study is to assess the water quality of groundwater in the Osoyoos Aquifer and to evaluate potential implications to current and future groundwater uses. Based on the results of this assessment, groundwater quality objectives are proposed for the Osoyoos Aquifer to support ongoing management of water quality in the Osoyoos Aquifer and Osoyoos Lake by:

- establishing benchmarks for protection of groundwater uses;
- providing information and guidelines that help to inform permits and orders pertaining to waste discharges that affect groundwater quality;
- prioritizing groundwater quality characterization and ongoing monitoring studies by government to assess objectives attainment; and,
- promoting awareness of groundwater quality issues and providing incentives for reducing groundwater contaminants and protecting groundwater and surface water quality.

The scope of work for this study follows the framework for establishing groundwater quality objectives developed by Kohut and Pommen (2005):

1. *Identify and define groundwater quality issues of concern.* This report describes groundwater uses in Osoyoos Aquifer and summarizes relevant hydrogeological studies. This report identifies point and non-point waste loads that potentially affect groundwater uses, and reviews investigations on the effects of agricultural practices on groundwater quality.
2. *Conduct a groundwater quality assessment.* This study has compiled and summarized groundwater quality monitoring information collected by multiple agencies from 44 wells spanning more than 30 years and including more than 40 parameters. The data are presented through summary statistics, visual trends, and loading estimates to the Osoyoos Aquifer and Osoyoos Lake. The quality of groundwater is assessed by comparing the groundwater monitoring data to guideline values for the associated groundwater uses.
3. *Select appropriate water quality guidelines:* Groundwater quality objectives are based on the selection of water quality guidelines that express safe levels of substances for the most sensitive groundwater uses. Selected guidelines for the Osoyoos Aquifer are based on consideration of local uses of groundwater, which include drinking water and irrigation supply, and aquatic life uses in Osoyoos Lake, which receives groundwater discharge from the Osoyoos Aquifer.
4. *Set groundwater quality objectives.* The proposed groundwater quality objectives are designed to protect drinking water uses of groundwater and aquatic life protection in Osoyoos Lake. The report includes monitoring recommendations to assess groundwater quality and objectives attainment, and for studying and quantifying potential contaminant sources.

2. REGIONAL SETTING AND STUDY AREA DESCRIPTION

The Osoyoos Aquifer (Aquifer 193) is adjacent to the western shore of Osoyoos Lake in the southern end of the Okanagan Valley (Figure 1). Osoyoos Lake and the Osoyoos Aquifer are both transboundary water bodies straddling the Canada-U.S. border.

2.1 Climate

The climate of Osoyoos is dry with a low average annual precipitation of 323 mm. The Osoyoos area is Canada's only desert and there are unique flora and fauna referred to as the Osoyoos Arid Biotic Zone (Scudder, 1980). Precipitation occurs throughout the year with somewhat greater depths in late spring and late fall (Table 1). About 15% of the annual precipitation occurs as snow. Seasonal temperatures are variable, with cool to freezing temperatures in the winter, and hot temperatures in the summer. Due to hot and dry conditions during the summer growing season, irrigation water is used for agricultural crops and private lawns and gardens.

Table 1: Climate normals at the Environment Canada Osoyoos West climate station (1981-2010) in the Town of Osoyoos (see Figure 1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily Average (°C)	-0.7	1.6	6.6	11.1	15.2	18.7	21.9	21.4	16.5	10	3.7	-0.9	10.4
Daily Maximum (°C)	2	5.9	12.5	17.9	22.1	25.7	29.4	29.1	23.8	15.8	7.1	1.6	16.1
Daily Minimum (°C)	-3.4	-2.7	0.5	4.2	8.2	11.7	14.2	13.6	9	4.2	0.3	-3.4	4.7
Rainfall (mm)	14.3	17.7	22.3	24.1	37.1	41.7	24.6	17.3	14.9	18.5	28.2	18.8	279
Snowfall (cm)	14.6	4.6	1.7	0.1	0	0	0	0	0	0.1	5.7	17	43.8
Precipitation (mm)	28.8	22.3	24	24.2	37.1	41.7	24.6	17.3	14.9	18.6	33.8	35.8	323
Days with Precipitation > 5 mm	1.6	1.3	1.5	1.7	2.5	2.5	1.4	1.2	0.96	1.4	2.3	2.4	20.6

2.2 Topography and Drainage

The land surface over the Osoyoos Aquifer rises to the west forming a series of kettled outwash terraces that are about 200 to 400 m wide (e.g. see cover photo). The benches undulate and there are still several water filled kettles, although many of these are filled (Piteau Associates, 1989). The valley walls rise steeply above the outwash terraces, reaching an elevation over 1100 m, about 700-900 m above the valley floor (Figure 1).

A series of short, steep, and mostly unnamed streams drain the highland areas, however, there is limited information on surface flows. Peak flow in Strawberry Creek is reported at 0.5 m^3/min (0.3 cfs) during spring runoff (Brownlee & Kelley, 1961), but flow is seasonal and terminates before reaching Osoyoos Lake (Sarell et al., 2008). Similarly, surface flows in smaller neighboring stream courses and gullies that traverse the terraces are likely ephemeral and typically infiltrate into the permeable sediments before reaching Osoyoos Lake.

2.3 Land Use

Land use over the Osoyoos Aquifer is dominated by agriculture, covering about 70% of the 14 km^2 aquifer area. The region is a long-established and productive agricultural area, and much of the aquifer area is within a protected Agricultural Land Reserve (Figure 2). The Osoyoos area is known for commercial orchards including cherries, apricots, peaches and apples. There is also some vegetable production and recently there has been an increase in vineyards.

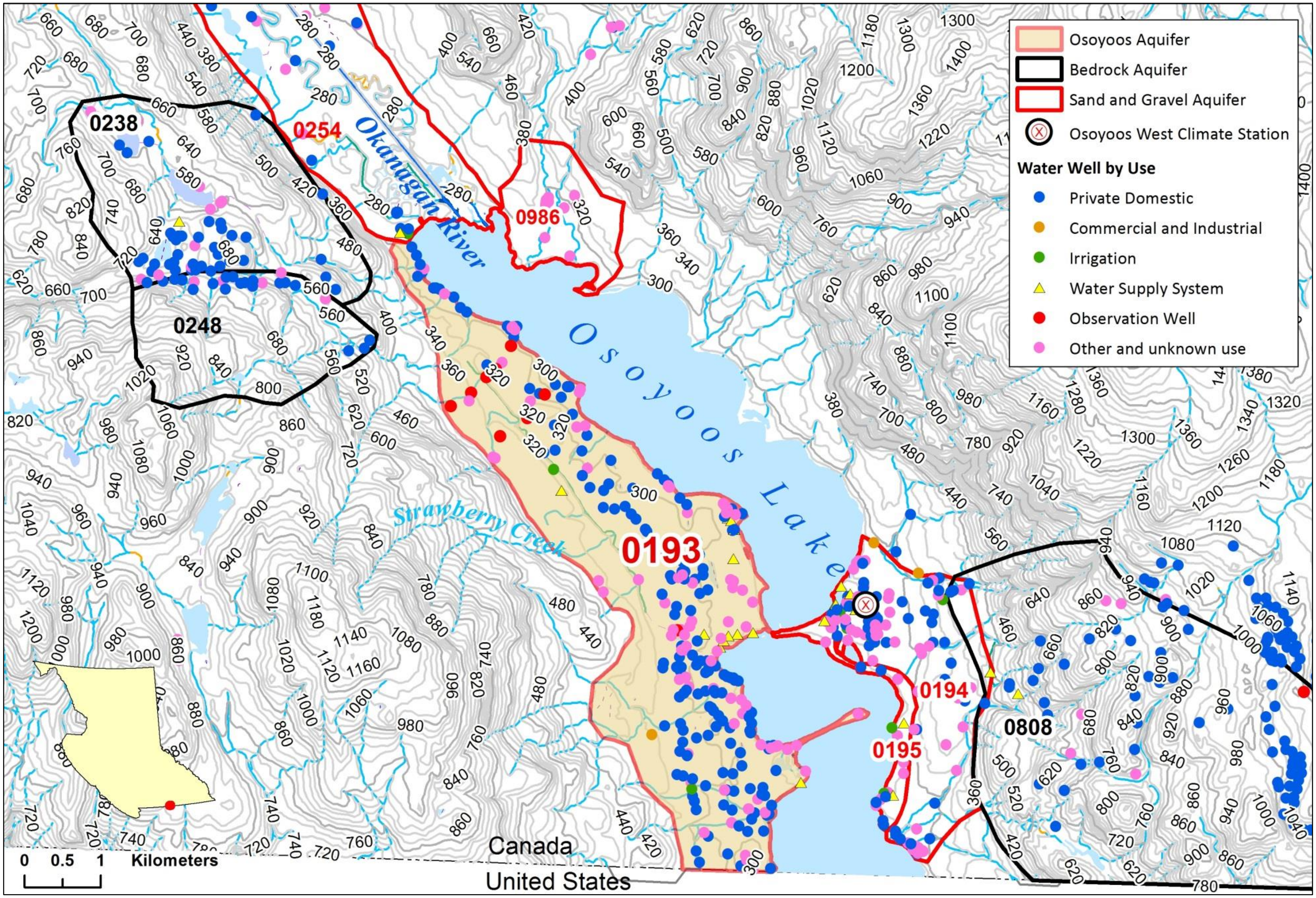

Figure 1: Study area location, topography, drainages, regional aquifers and water wells.

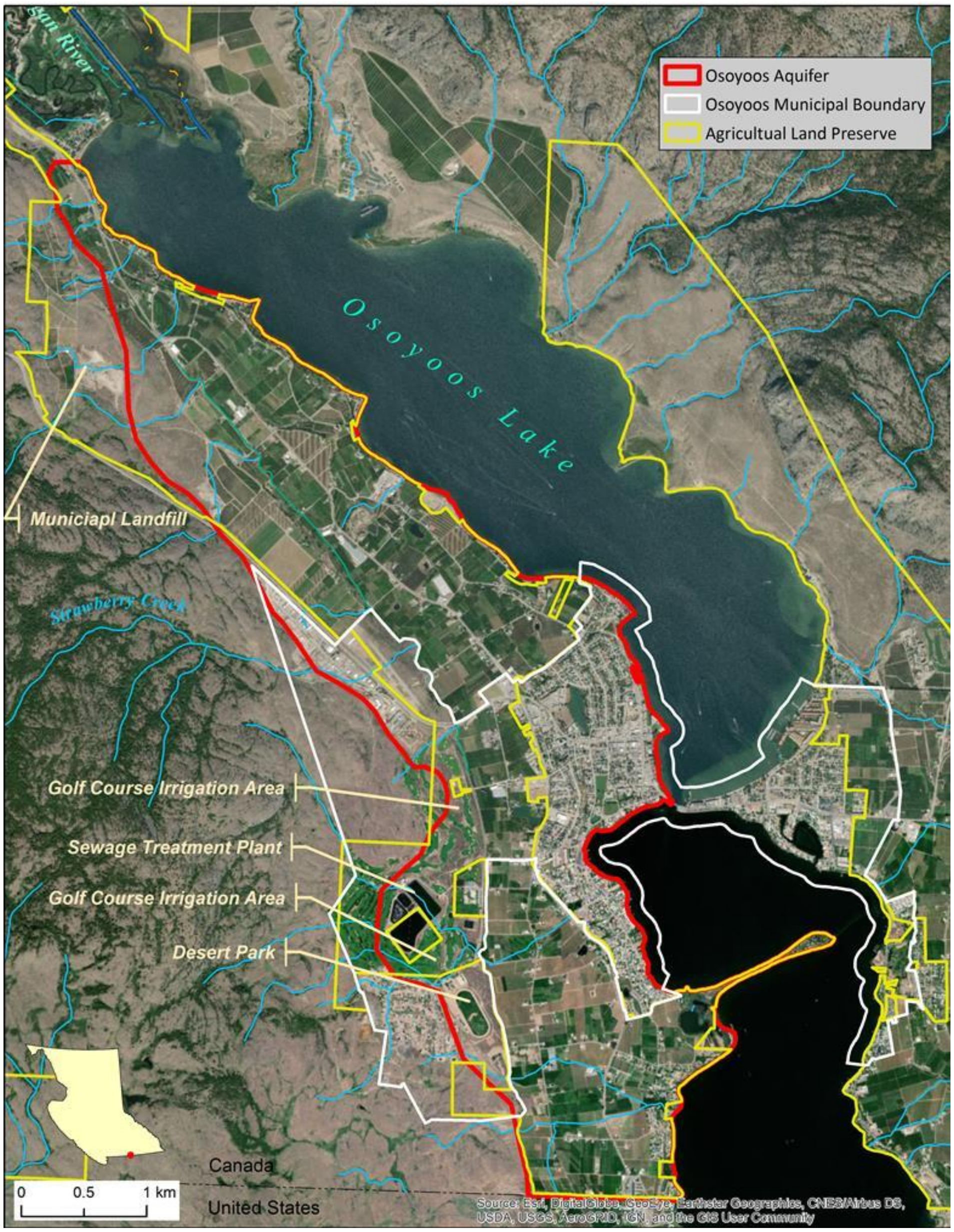

Figure 2: Municipal and agricultural land reserve boundaries overlying the Osoyoos Aquifer.

The Town of Osoyoos (Town) municipal boundary bisects the central portion of Osoyoos Aquifer and spans both sides of Osoyoos Lake. The Town and surrounding rural area have a permanent population of about 5000 and a summer seasonal population of about 9000 (KWL, 2014). Urban land uses cover about 20% of the aquifer area, which include residential (low, medium & high density), commercial (tourist, general and downtown), and industrial and institutional lands within the urban growth boundary. Major recreation facilities include two 18-hole golf courses in southwest Osoyoos and the Desert Park Recreation complex. Outside of the municipal boundary there are scattered rural residences and residences that line much of the shoreline.

Permitted facilities that potentially affect groundwater quality are the municipal landfill, the municipal sewage treatment plant, and associated irrigation areas at the golf courses, school, and recreation fields (Figure 2).

2.1 Osoyoos Lake

Osoyoos Lake is the southernmost in a series of inter-connected valley bottom lakes within the Okanagan River basin, which is a tributary to the Columbia River 127 km to the south. Osoyoos Lake is 16 km in length and comprised of three basins: a larger and deeper north basin; a smaller central basin; and an intermediate but shallower south basin (Figure 3). The lake has a surface area of 23 km^2 and a water residence time of approximately 0.7 years (Jensen et al., 2012).

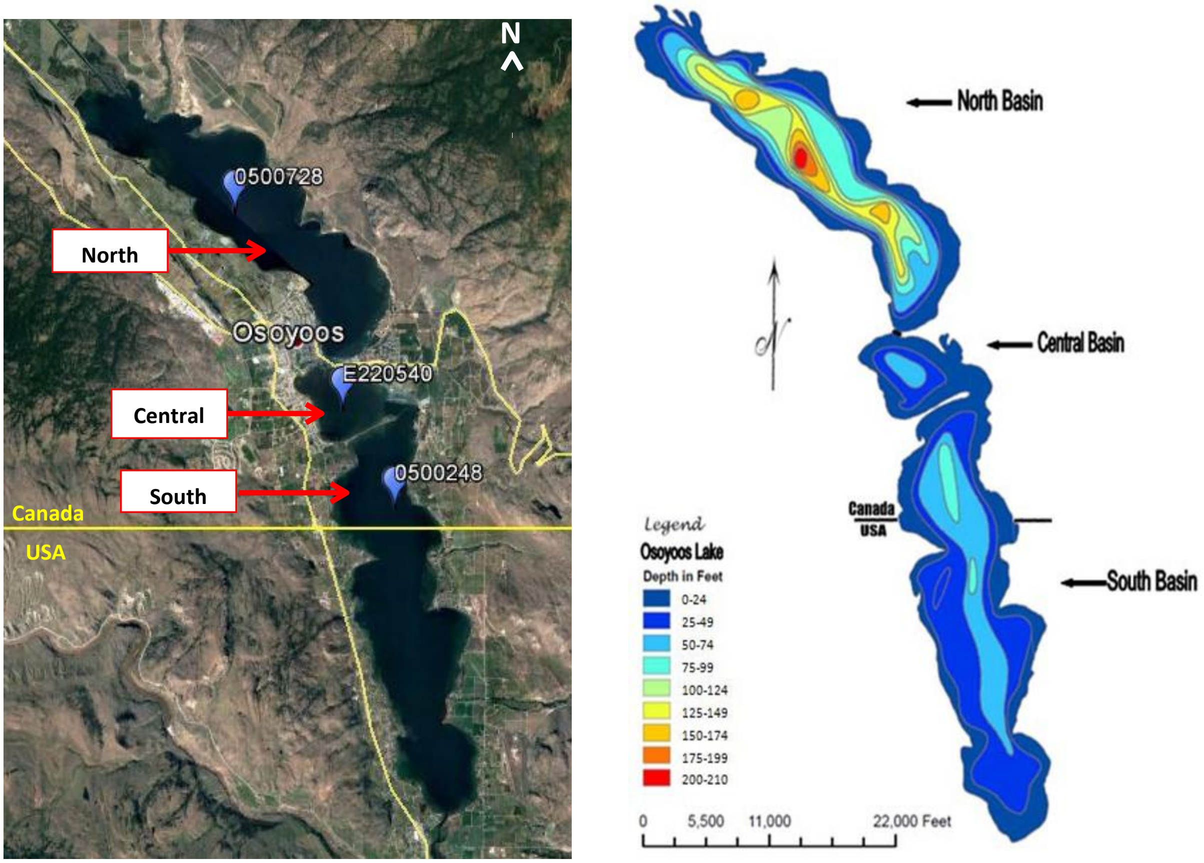

Figure 3: Satellite image of Osoyoos Lake basins and sampling sites (left, source: Sokal, 2017) and bathymetry contour map of Osoyoos Lake (right, source: Tran et al., 2011).

Osoyoos Lake provides important habitat to a variety of aquatic life, including both resident and anadromous fish species. There are 28 resident and non-anadromous fish species in the lake, providing good recreational fisheries. The lake also provides important rearing and migratory habitat for anadromous species including chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), and steelhead trout (*O. mykiss*). Water-based recreation is also popular and important to the local economy and tourism industry (Sokal, 2017).

2.2 Regional Aquifer Delineation and Groundwater Use

Five unconsolidated sand and gravel aquifers are delineated in the Osoyoos Valley and three confined bedrock aquifers are delineated in the adjacent mountains (Table 2 and Figure 1).

The Osoyoos Aquifer (#193) and aquifers #194 and #195 are shallow unconfined sand and gravel aquifers with moderate to high productivity, and high vulnerability to contamination from surface sources. Of these, the Osoyoos Aquifer is the largest and most heavily used.

Table 2: Characteristics of mapped aquifers in the Osoyoos area.

Aquifer Number	Size (km^2)	Aquifer Type*	Aquifer Material	Aquifer Classification**
193	14	4a	Sand & gravel	IIA
194	5.3	4a	Sand & gravel	IIA
195	0.5	4b	Sand & gravel	IIIB
254	22.3	1b	Sand & gravel	IA
986	2.1	4b	Sand & gravel	IIIB
238	7	6b	Bedrock	IIA
248	4.4	6b	Bedrock	IIIC
808	18.6	6b	Bedrock	IIA

* Aquifer type based on classification system described in (Wei et al., 2009):
1b = Fluvial or glaciofluvial aquifers along moderate order rivers
4a = Unconfined glaciofluvial outwash or ice contact aquifers
4b = Confined aquifers of glacial or pre-glacial origin
6b = Crystalline granitic, metamorphic, metasedimentary, meta-volcanic, and volcanic rock aquifers

** Provincial aquifer classification system (Berardinucci & Ronneseth, 2002)
Level of Development: I = high; II =moderate; III =low
Vulnerability to Contamination: A = high; B = moderate; C = low

There are two confined sand and gravel aquifers mapped on the east side of Osoyoos Lake (#195 and #986). These aquifers are small, lightly developed, and poorly characterized. Three bedrock aquifers in the mountains upland from the Osoyoos Valley (#238, #248, and #808) are mainly used for domestic supply as they have low to moderate productivity and low to moderate demand.

2.3 Groundwater Wells

There are over 350 active and abandoned wells in the Osoyoos Aquifer (Hodge, 1986), which include hand dug wells and drilled wells. Many are historical domestic wells that are no longer in use. Well construction reports and well logs are available from the provincial Groundwater Wells and Aquifer database (GWELLS) (Province of British Columbia, 2018). The information in GWELLS is submitted voluntarily and does not represent the full extent of groundwater development in the aquifer or active groundwater use.

This study considered groundwater data collected from more than 40 wells (Figure 4). These include monitoring or observation wells established by the ENV and the Ministry of Forest, Lands, Natural Resource Operations and Rural Development (FLNRORD), Environment and Climate Change Canada (ECCC), the Town of Osoyoos, and the Department of Geology at the University of Saskatchewan (Athanasopoulos, 2009). However, there is inconsistency in the naming convention and identification of the wells. In general, the wells are identifiable by a Well Plate Number that is physically attached to the well, which is cross-referenced to a Well Tag Number (WTN) in the GWELLS database. Groundwater quality data collected at individual wells is housed in the ENV Environmental Monitoring System (EMS) database and is referenced by a separate EMS number.

Appendix A summarizes the properties of the study wells used in this report, and lists the associated WTNs, EMS numbers, and other well characteristics. For consistency, the study wells are labelled as R1 to R56 and are shown on Figure 4. Although some wells are located outside of the Osoyoos Aquifer, the focus of this study is on groundwater quality in the Osoyoos Aquifer.

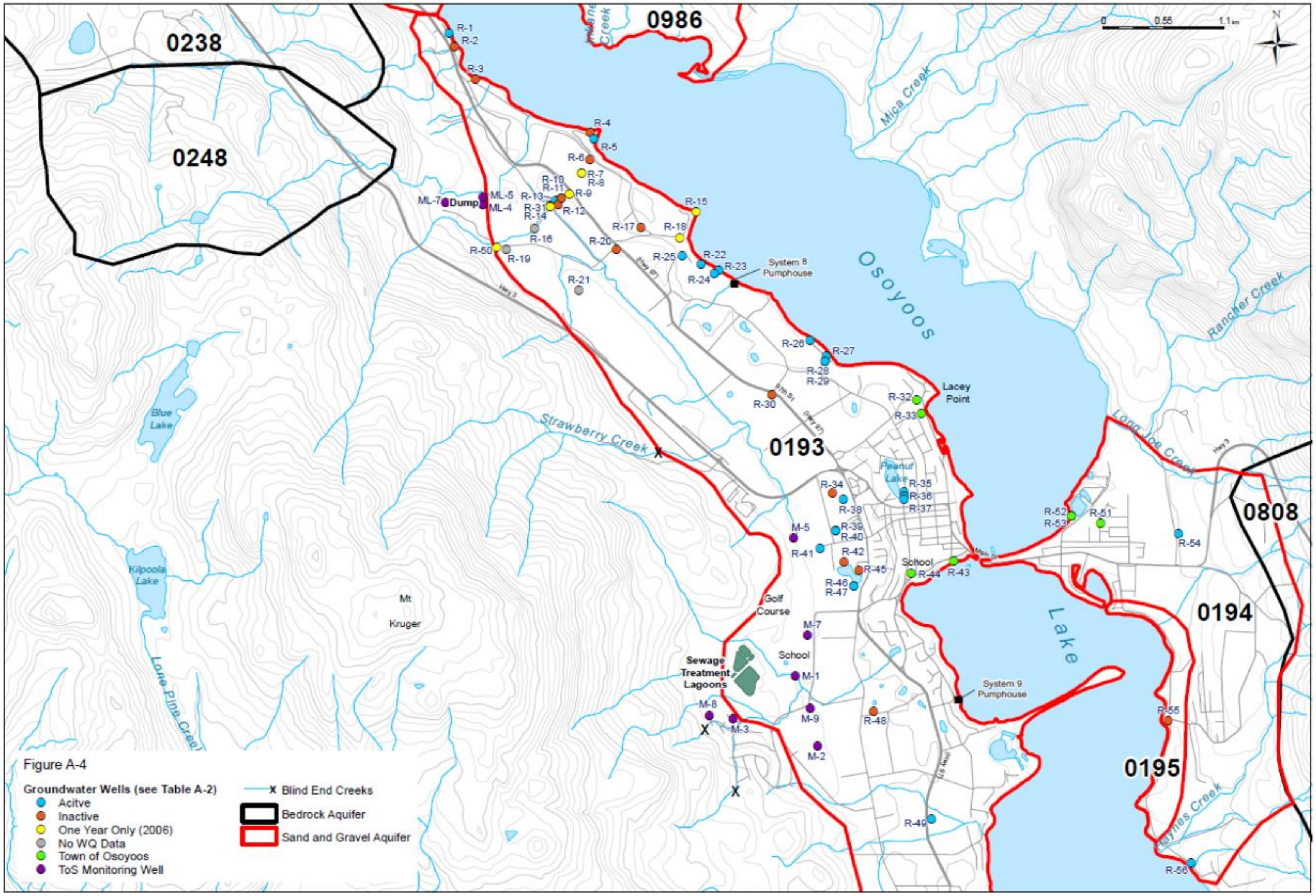

Figure 4: Location of study area wells with groundwater data (Source: Gregory, 2014).

3. OSOYOOS AREA HYDROGEOLOGY

3.1 Bedrock Geology

The regional bedrock geology in the Okanagan Valley is varied and complex, with an array of rock types, formations, and development sequences. The main types of bedrock in the study area and adjacent mountains are greenstone and greenschist metamorphic rocks from the Carboniferous to Permian periods (~250-350 million years old), and granodioritic intrusive rocks from the Jurassic period (~100-150 million years old) (Cui et al., 2017).

Although bedrock underlies the Osoyoos Aquifer and is important for water supply in upland areas, the bedrock aquifers are not a focus of this study. Bedrock beneath the Osoyoos Aquifer is not vulnerable to contamination from surface sources, and geochemical analyses suggest there is limited recharge to the Osoyoos Aquifer from upland bedrock flows (Wassenaar et al., 2011).

3.2 Surficial Geology

Surficial sediments in the valley bottom were deposited during glacial retreat from the Wisconsin glaciations that occurred 10,000 to 12,000 years ago (Nasmith, 1962). Surficial sediments in the Osoyoos Aquifer consist of sand and gravel outwash terraces from melt water streams, sand and gravel kettle outwash, and morainal deposits from melting ice blocks and glaciers (Figure 10). Dune and spit deposits occur along portions of the lakeshore near Haynes Point.

3.3 Surficial Soils

Wittneben (1986) identified the Rutland soil series on the west side of Osoyoos Lake covering much of the area from the lake to the mountains. Rutland soils, also likely occur on portions of the Osoyoos Aquifer. Below 20 cm, the Rutland soils consist of the loamy sand and gravel glaciofluvial deposits, whereas the Osoyoos soils do not contain gravels. Both soil series have high permeability and low water storage capacity, with naturally low levels of organic carbon and nitrogen. Consequently, crops must be heavily irrigated and fertilized, particularly with nitrogen and possibly phosphorus.

3.4 Osoyoos Aquifer Stratigraphy

Figure 5 shows six stratigraphic cross sections of surficial deposits in the Osoyoos Aquifer based on well logs in GWELLS, which have variable quality and consistency. The cross-sections show the aquifer is comprised of unconfined sands and gravel about 5 to 15 m in thickness. The sand and gravel deposits are somewhat thinner in the north-central portion (south of section B-B’) where an agricultural drainage system has been installed to improve drainage (Section 5.3.5). The surficial aquifer parallels the surface topography, sloping towards the lake and showing noticeable benches in the northern aquifer. Groundwater levels and gradients follow the surface topography, such that groundwater flows towards and discharges into Osoyoos Lake.

Beneath the sands and gravels are sandy silt and clay sediments described by Nasmith (1962) as lacustrine material deposited from glacial Lake Oliver. Piteau Associates (1989) described these underlying sediments as glacial till due to the occurrence of clay layers and traces of pebbles and gravel within the sandy silts. Confined sand and gravels below the silt/clay aquitard are encountered in a few deeper wells (e.g. Section E-E’), but the lateral extent of these deposits is unknown.

Very few wells in the Osoyoos Aquifer have been drilled to a depth that encountered the underlying bedrock. Consequently, the depth to bedrock and the thickness of the low permeability silt and clay aquitard is unknown over much of the aquifer.

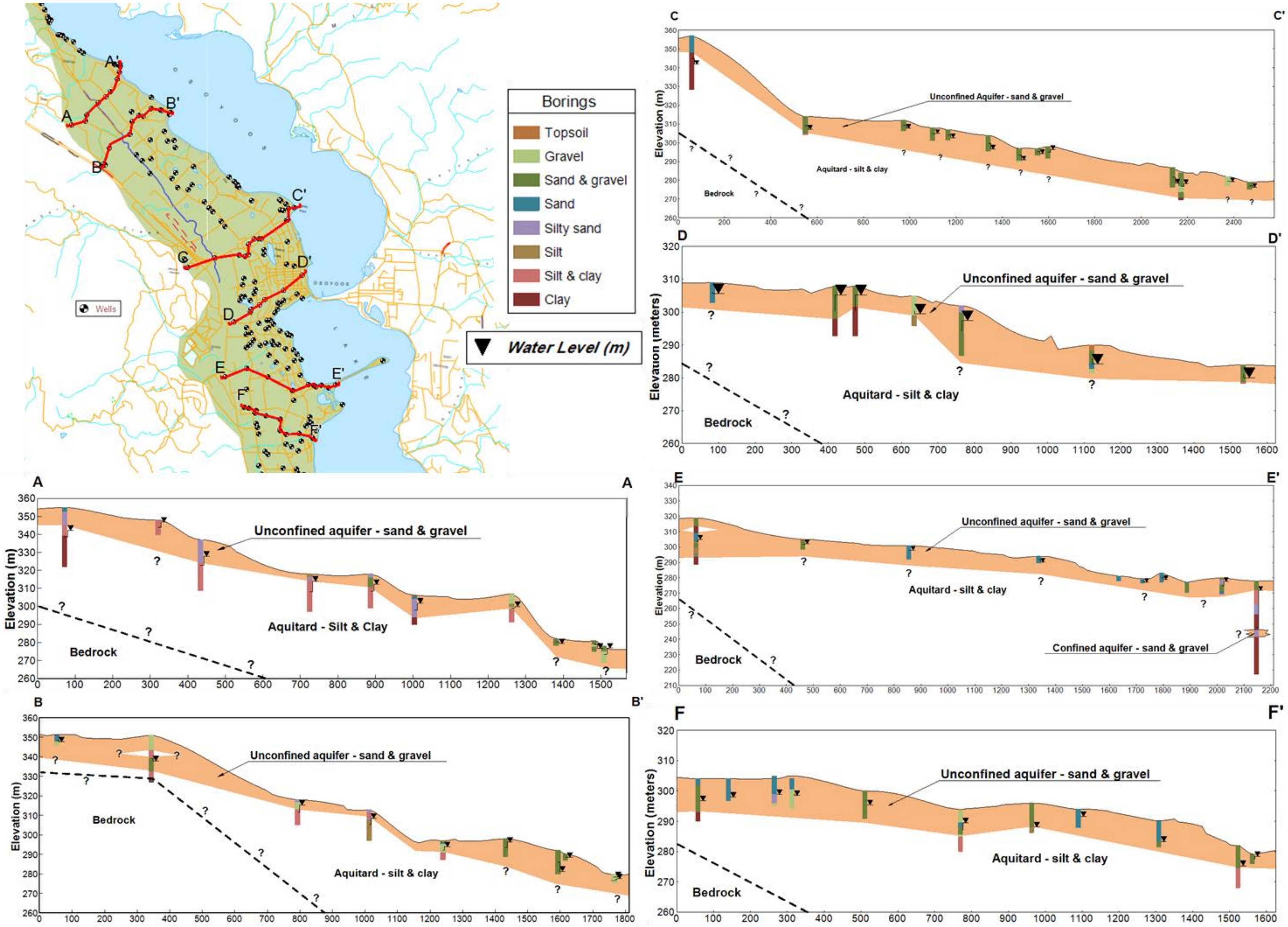

Figure 5: Stratigraphic cross-sections of surficial deposits in the Osoyoos Aquifer.

3.5 Groundwater Levels

Water well records in GWELLS include groundwater depth information measured at the time of drilling. The depth to groundwater throughout the aquifer is shallow, with an average depth of 4.6 m and a range of 0.3 to 14 m based on 230 well records.

Seasonal and long-term groundwater level information is available from one active and five inactive provincial observations wells (OWs) (Table 3). Plots of long-term monthly water depths show seasonal fluctuations occur within a relatively consistent range, especially before about 2008 (Figure 6). There are no visual long-term trends, but peak water levels appear lower after about 2008. OW 101 shows evidence of interference from nearby pumping wells after 2008. This well was decommissioned in 2017.

Table 3: Provincial observation wells with groundwater level monitoring data. Locations are shown in Figure 4.

Observation Well	Map Label	Status	Available Data
OW 96	R-42	Active	1969-2009 (monthly) 2009-present (hourly)
OW 101	R-9	Inactive	1969-2009 (monthly) 2009-2017 (hourly)
OW 100	R-12	Inactive	1969-2002 (monthly)
OW 102	R-6	Inactive	1969-2002 (monthly)
OW 105	R-20	Inactive	1969-2002 (monthly)
OW 107	R-17	Inactive	1969-2002 (monthly)

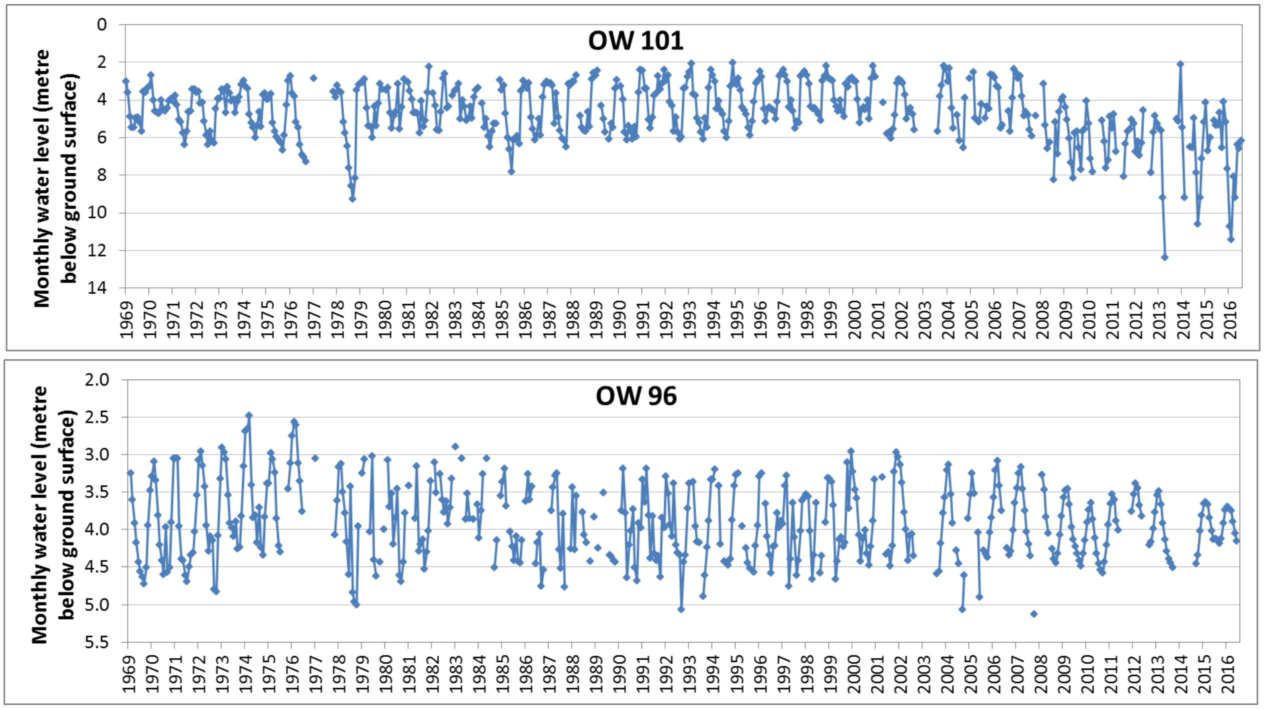

Figure 6: Long-term monthly depth to groundwater in provincial observation wells 96 and 101.

The average monthly depth to groundwater measured in the OWs show lowest groundwater levels occur in early spring and peak levels occur in mid to late summer (Figure 7). Rising groundwater during the spring and summer months is likely due to irrigation, as the timing coincides with the irrigation season and average precipitation is not sufficient to produce the observed water level rise.

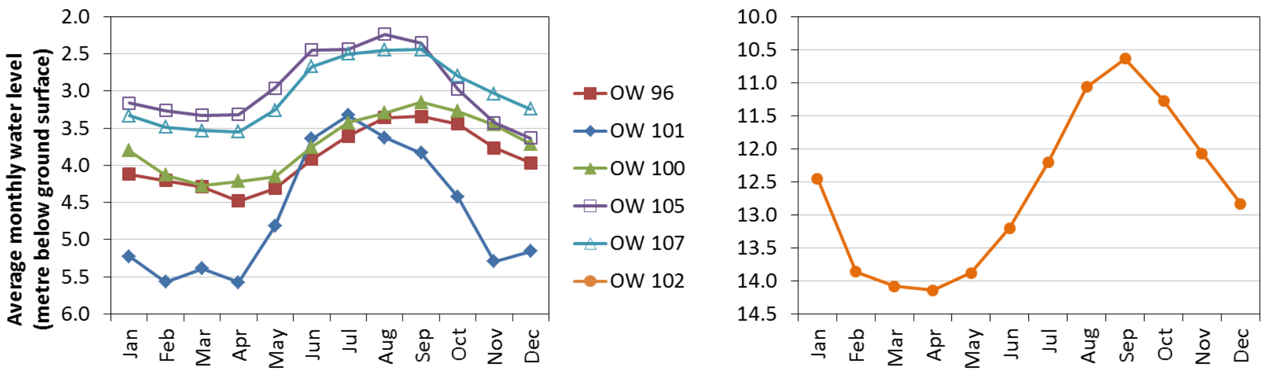

Figure 7: Average depth to groundwater in provincial observation wells in the Osoyoos Aquifer.

The magnitude of seasonal groundwater rise is variable with shallower wells showing an increase of about 1 m, and deeper wells showing changes of 2 to 3.5 m (Figure 7). This difference may reflect variability in porosity (specific yield), which typically decreases with depth. The timing of peak groundwater levels is also variable ranging from July to September, which may reflect the location of OWs relative to agricultural activities.

3.6 Aquifer Recharge

Recharge to the Osoyoos Aquifer may occur from: 1) infiltration and percolation of direct precipitation and snowmelt; 2) infiltration along stream channels; 3) infiltration of excess irrigation; and 4) subsurface flows from upland bedrock deposits referred to as mountain block recharge.

Recharge from Precipitation: A fraction of the annual precipitation (~320 mm) will recharge the shallow aquifer. Golder and Summit (2009) state that precipitation recharge ranges between 5 to 20% of precipitation throughout the Okanagan Basin, and is about 5% (16 mm) in the Osoyoos Valley. For the Osoyoos Aquifer, this equates to an annual rise in groundwater of about 0.1 to 0.32 m (specific yield of 0.05 to 0.2), which is much smaller than the observed water table changes of 1 to 3 m. In addition, daily groundwater level measurements available in OW 96 and 101 do not show consistent responses to precipitation events (Figure 8). Together, this information suggests infiltration of precipitation is not a significant component of recharge for the Osoyoos Aquifer.

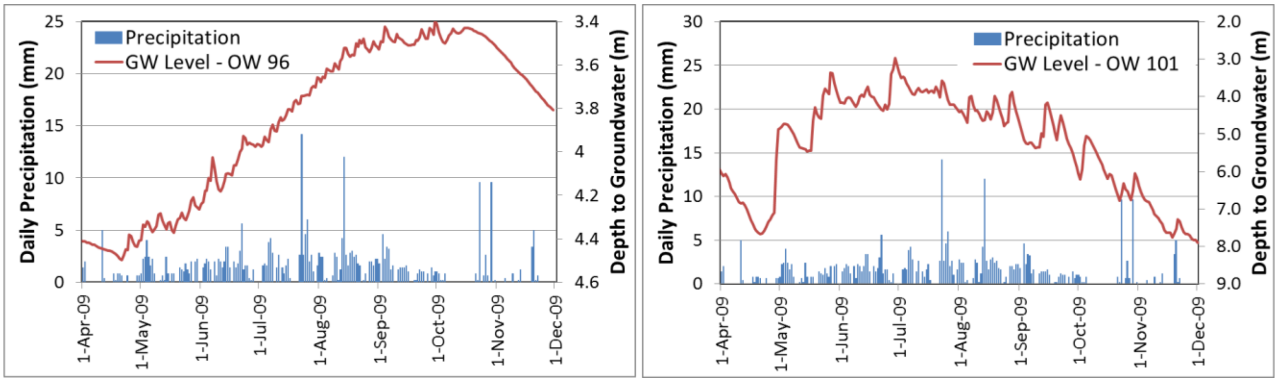

Figure 8: Comparison of daily precipitation and groundwater level measurements in observation wells 96 and 101. Precipitation measurements are from the Osoyoos West climate station.

Recharge from infiltration in stream channels: There is little quantitative information on streamflow in surface drainages that traverse the aquifer. Streamflow is seasonal during freshet and terminates before reaching the lake (Sarell et al., 2008). The infiltrating runoff provides recharge to the aquifer, but the quantity depends on the volume and duration of spring runoff. The OW measurements in Figure 7 show some increases in water levels during spring freshet (April-May), but also more substantial and sustained increases during the summer irrigation season (June-Sept). This suggests recharge from surface water infiltration is not the main source of aquifer recharge.

Recharge from irrigation and mountain block recharge: Athanasopoulos (2009) and Wassenaar et al. (2011) used isotopic analysis to investigate the sources of recharge to the aquifer. Precipitation samples collected throughout the Okanagan Valley and throughout the year were analyzed for isotopes of water (^{2}H and ^{18}O) to establish the local meteoric water line (LMWL) shown in Figure 9. The LMWL represents the changes in these isotopes over a year. In the Osoyoos area, the most negative values on the LMWL are from precipitation in late fall and early winter (October through December) and the highest values are from precipitation in late spring and summer (May through September).

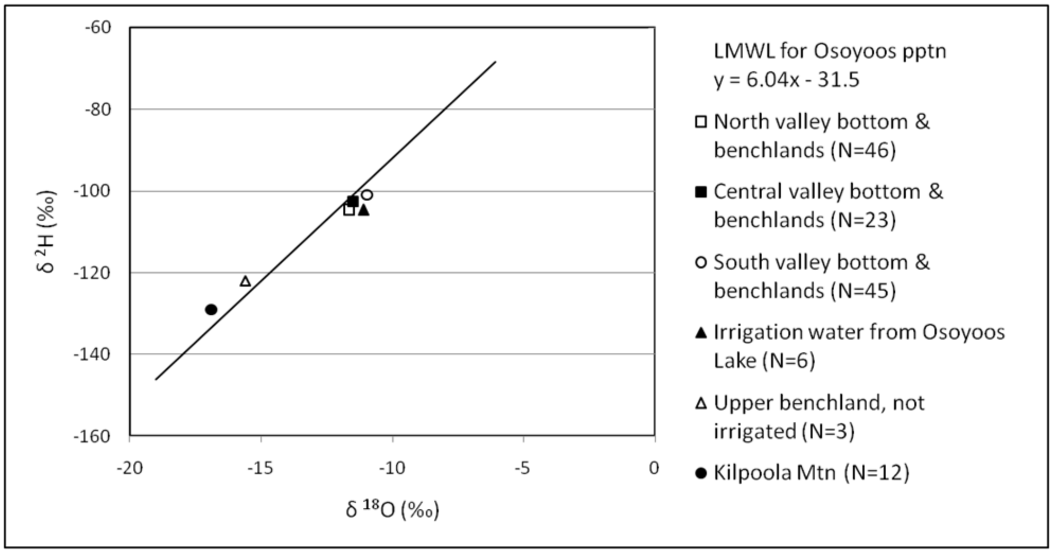

Figure 9: Comparison of isotopic signatures of groundwater, irrigation water, and precipitation. δ^2H (‰VSMOW) vs. δ^{18}O (‰VSMOW) for the Osoyoos West & East precipitation LMWL, the mean values for the north, central and south valley bottom and benchlands, the upper benchlands (1 location) and Kilpoola Mountain (outlier omitted). Prepared by Gregory (2014) as modified from Athanasopoulos, 2009. VSMOW is the Vienna Standard Mean Ocean Water, a standard defining the isotopic composition of fresh water.

Figure 9 relates the LMWL to mean isotopic signatures (mean levels of isotopes) of groundwater samples in different locations and the irrigation water from Osoyoos Lake. Athanasopoulos (2009) and Wassenaar et al. (2011) used these comparisons to assess the sources of recharge waters.

- **Highland Kilpoola bedrock aquifer**: The mean isotopic signature of groundwater samples from the Kilpoola bedrock aquifer are representative of precipitation signatures from late fall and winter, but more positive (Figure 9). This supports findings from Athanasopoulos (2009) and Wassenaar et al. (2011) that isotopic patterns in the highland bedrock aquifers occur from the combined effect of elevation and the prevalence of snowmelt or precipitation derived recharge.
- **Valley bottom surficial aquifers:** The isotopic signature of groundwater samples from the Osoyoos Aquifer (north, central and south valley bottom portions) and from irrigation water from the pump houses (Figure 9) were significantly different than the LMWL. This indicates

precipitation is not the main source of recharge water to the valley bottom aquifers, and that the valley bottom aquifers are not recharged by surface water or groundwater from the Kilpoola highlands (Wassenaar et al., 2011). However, the isotopic signature of groundwater from the valley bottom aquifers was similar to the irrigation water from Osoyoos Lake (Figure 9), which indicates irrigation water is a main source of recharge to the wells in the Osoyoos Aquifer.

3.7 Aquifer Hydraulic Properties

The aquifer hydraulic properties describe the aquifer's ability to store and transmit water:

- Hydraulic conductivity (K) is a measure of the aquifers capacity to transmit water.
- Transmissivity (T) is the product of the conductivity and the saturated aquifer thickness (b). It is commonly estimated from pumping tests or slug tests.
- Storativity (S) is the volume of water released from a confined aquifer per unit decline in hydraulic head per unit area. Specific yield (Sy) is the analogous parameter for unconfined aquifers. It is common to assume S = Sy, where S is estimated from pumping tests.

The hydraulic properties of the Osoyoos Aquifer have been estimated from pumping tests in Town of Osoyoos wells, #1 (R44), # 6 (R33) and # 7 (R32), and the Sunnyville Water Supply source well. These wells are in the southern portion of the aquifer near the lakeshore (see Figure 4). The estimated conductivity is on the order of 100 to 1000 m/d, which is representative of coarse sand and gravel and consistent with the lithology in the well logs (Table 4). The estimated specific yield ranges from about 0.04 to 0.09. This is lower than literature values for sands and gravels (0.1-0.3) (Johnson, 1967), which reflects the effects of drainage time and variability in soil texture.

Table 4: Osoyoos Aquifer properties estimated from pumping tests (Source: Carmichael et al., 2009).

Well tag number	Map label	Well type	Dominant Lithology	Aquifer thickness (m)	Transmissivity (m^2/d)	Conductivity (m/d)	Storativity
38799		Pumping	Gravel	2.8	750	260	
82357	R-32	Pumping	Clean sand & gravel	9.2	2000	430	
83016	R-33	OW	Coarse gravel & sand	7.4	1400	290	0.049
82358	R-44	Pumping	Clean coarse sand & gravel	5.2	2100	400	
19179		OW	Clean sand & gravel	8.7	3100	360	0.086
83016 (a)	R-33	Pumping	As above	7.3	2000	630	
unknown		OW		1.8	1400	780	0.091
83016 (b)	R-33	Pumping	As above	7.3	3700	1200	
unknown		OW		1.8	1900	1100	0.043
83016 (c)	R-33	Pumping	As above	7.3	1800	590	
unknown		OW		9.4	1600	170	0.045
			Average	6.2	1980	560	0.06
			Median	7.3	1900	430	0.05

Liskop and Allen (2005) conducted aquifer slug tests in three provincial OWs located on agricultural lands about 450 to 600 m from the lake. Two wells are completed in silty materials (OW 101, OW 105), and the third well (OW 96) is screened in sand and gravel. Hydraulic conductivity estimates from the slug tests (Table 5) are 2 to 4 orders of magnitude smaller than values from the pumping tests (Table 4), which partly reflects the finer grained aquifer materials in the test wells. The results also reflects the nature of slug tests, which typically produce lower conductivity estimates than pumping tests due to differences in the scale of the tests (Butler, 1998).

Table 5: Osoyoos Aquifer properties estimated from slug tests (Source: Liskop and Allen, (2005).

Observation Well	Map Label	Dominant Lithology	Number of Tests	Hydraulic Conductivity (m/d)			
				Minimum	Maximum	Average	Median
96	R-42	Gravel & coarse sand	12	0.029	1.11	0.9	0.97
101	R-9	Silty clay & fine gravel	6	0.24	0.45	0.34	0.34
105	R-20	Silty gravel	4	0.02	0.079	0.044	0.039

Collectively, the available information indicates the aquifer hydraulic parameters are representative of fine sands to gravels and are spatially variable. The hydraulic conductivity generally ranges from about 1 to 100 m/d, and the transmissivity generally ranges from about 10 to 3000 m^2/d.

3.8 Groundwater Discharge to Osoyoos Lake

Groundwater in the Osoyoos Aquifer flows toward the valley bottom, eventually discharging into Osoyoos Lake (Figure 10). Soluble contaminants present in groundwater will be conveyed by groundwater flow and eventually discharge into the lake (Rosenberry et al., 2015). Estimates of groundwater discharge are needed to quantify and assess the significance of contaminant loadings into the lake. However, quantifying groundwater discharge is difficult because groundwater flows are spatially and temporally variable. Three different methods for estimating groundwater discharge are compared in the following sections.

3.8.1 Seepage Measurements

In an unpublished report, Hii (1987) described the results of seepage measurements at 40 sites along Osoyoos Lake using seepage meters installed less than 12 m from the shoreline. Of the 40 sites, 15 are on the west side (W) and 16 are on the east (E) side (Figure 11). The remaining nine sites are shown in Figure 11 as unlabelled seepage sites, but are not discussed in this report.

Hii (1987) collected 28 to 60 seepage measurements at each site during six sample events between October 1985 and July 1987. There are no obvious spatial trends in the mean groundwater discharge on either side of Osoyoos Lake (Figure 12). However, in terms of total discharge, McNaughton (1991) concluded there was far less groundwater discharging into the north basin from the east side that was not cultivated or irrigated than from the west side. The mean discharge of sites in Figure 12 on the west side is about 20% greater than the mean discharge of east side sites (31.7 and 26.7 L/day/m^2), but there is substantial overlap of the confidence intervals.

Hii (1987) estimated the average daily groundwater discharge along the Canadian shoreline into Osoyoos Lake at roughly 18 million L/day or 18,000 m^3/day. This average daily discharge estimate does not address seasonal variability or spatial distribution. Using the proportion of mean seepage measurements from the west and east shores in Figure 12, an estimate for groundwater discharge from the Osoyoos Aquifer (west shore) is about 9,800 m^3/day, and about 8,200 m^3/day for groundwater discharge from the east shore.

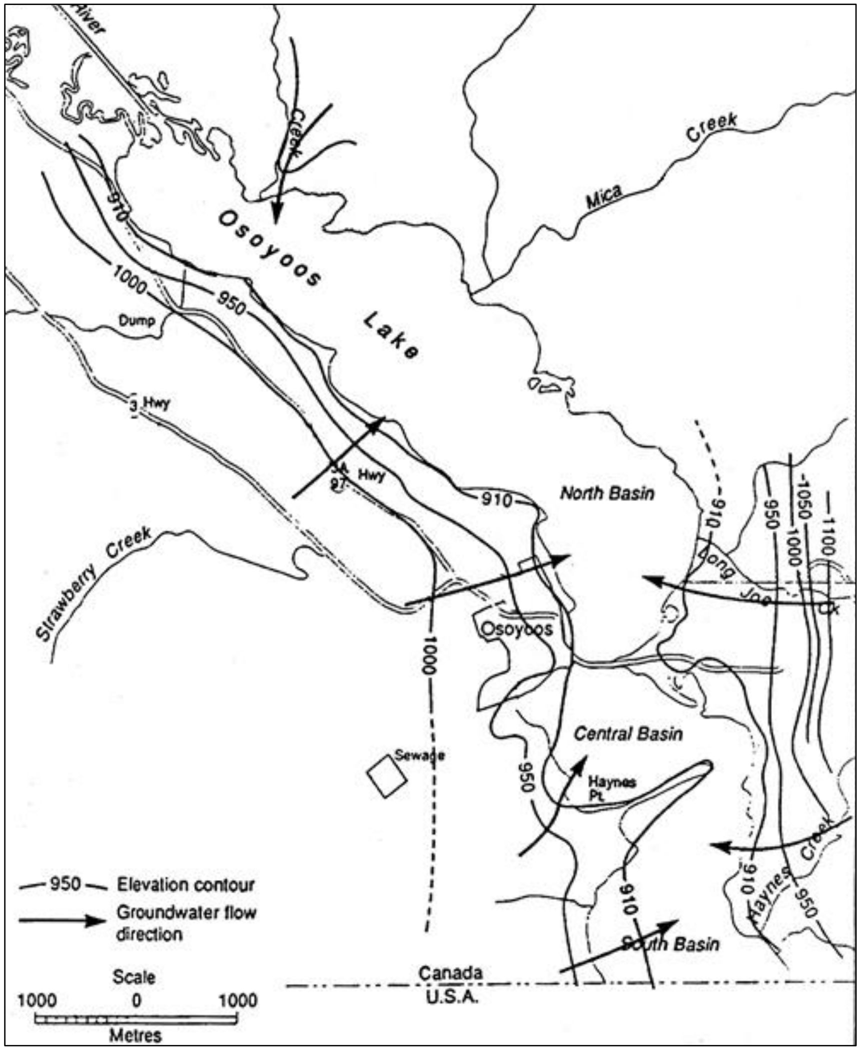

Figure 10: Groundwater level contour lines and directions of groundwater flow to Osoyoos Lake. Source: McNaughton (1991).

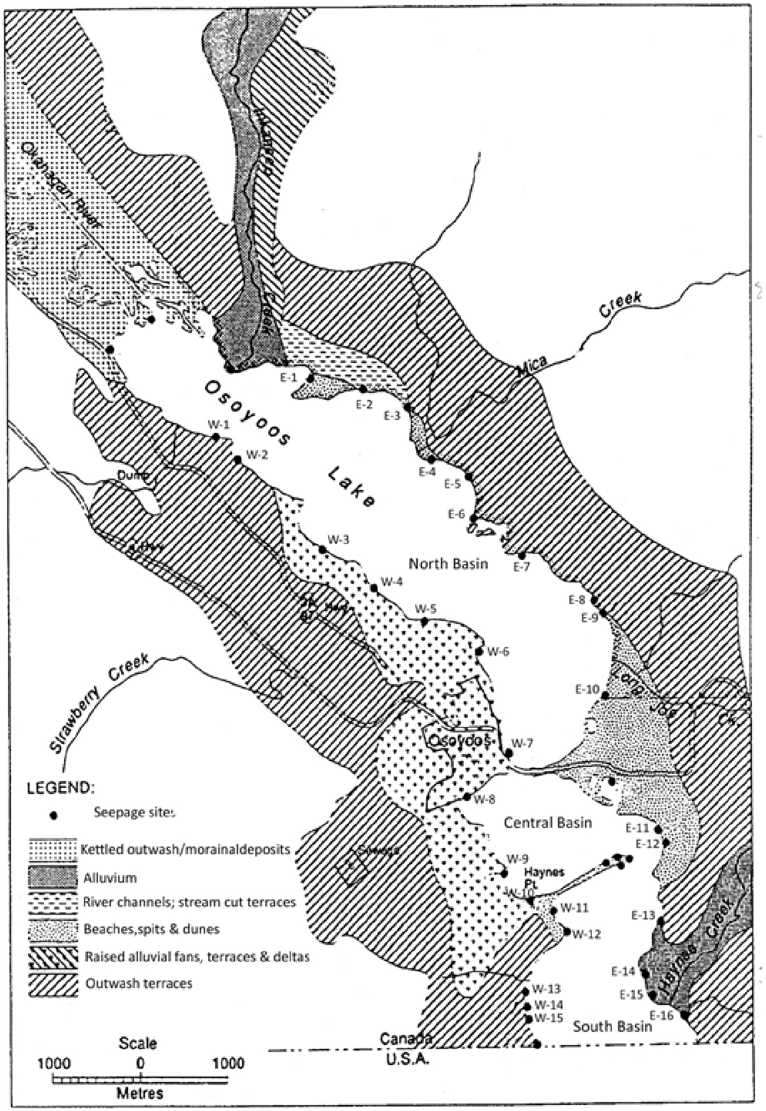

Figure 11: Location of seepage study sites on the west (W) and east (E) sides of the Osoyoos Lake (Hii, 1987). Each site is approximately 6 m from shore. Additional sites not discussed in this report are shown. Source: Gregory (2014).

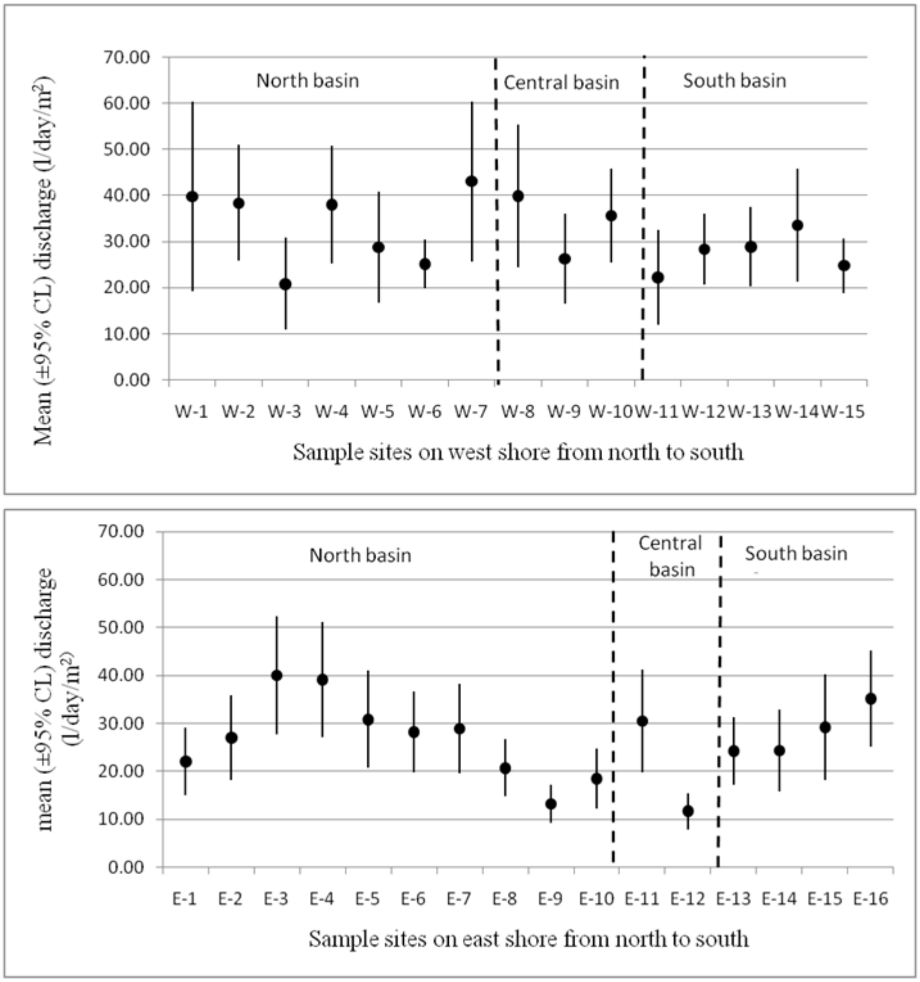

Figure 12: Mean of groundwater seepage measurements at individual measurement sites in the north, central & south basins of the shoreline of Osoyoos Lake as reported by Hii (1987). Top plot: West shore sites. Bottom plot: East shore sites. See Figure 11 for site locations. Note, raw data were not available for this report. Consequently, confidence limits are obtained as an estimate using ± 2 times the standard error (SD/√N). Source: Gregory (2014).

3.8.2 Darcy Flux Calculation

Darcy's law relates the groundwater discharge to the hydraulic gradient and the hydraulic conductivity:

$$Q = -KAJ \qquad \text{(Eq. 1)}$$

where Q is the groundwater discharge (volume/time); K is the hydraulic conductivity (length/time); J is the hydraulic gradient (i.e., slope of the water table) (dimensionless); and A is the cross-sectional area of flow (i.e., perpendicular to the direction of flow) (length^2).

Piteau Associates (1989) used Darcy's law to estimate a summertime groundwater discharge from the western bench assuming an average saturated thickness of 1 m, an average hydraulic gradient of 5%, and a hydraulic conductivity of 0.0003 m/s (~26 m/day). The estimated discharge on a lineal basis is 0.015 L/s/m, which extrapolated over the entire aquifer length, gives an aquifer discharge of 13,900 m^3/day during the summer growing season.

These estimates were refined by separately applying Darcy's law along six aquifer sections (Figure 13) and using information from GWELLS to estimate the saturated thickness and hydraulic gradients in each section (Appendix C, Table C1). The discharge estimates range from 8,000 to 23,000 m^3/day during the irrigation season, and between 3,000 to 8,000 m^3/day during non-growing season. Largest discharges are adjacent to the north basin (Section A-A') where the saturated thickness and hydraulic gradients are largest. The average year-round groundwater discharge ranges between 5,000 to 16,000 m^3/day, which brackets the discharge estimates from seepage measurements (~10,000 m^3/day).

Figure 13: Aquifer sections used in Darcy flux calculations.

3.8.3 Water Balance Calculations

Groundwater discharge to the lake can be estimated with a groundwater budget (Eq. 2), provided all other groundwater inflows, outflows, and the change in groundwater storage over a specified time period (Δt) are known.

$$\text{Volume In}\big|_{\Delta t} - \text{Volume Out}\big|_{\Delta t} = \text{Change in groundwater storage}\big|_{\Delta t} \qquad \text{(Eq. 2)}$$

Piteau Associates (1989) used this approach to develop a monthly soil water budget for the west bench, considering only precipitation and irrigation as the aquifer inflows, and evapotranspiration (ET) and groundwater discharge as the aquifer outflows. Piteau calculated an annual soil moisture surplus of 847.7 mm over a 500 m wide bench, which represents the aquifer recharge from precipitation and irrigation in excess of ET. Assuming there is no change in aquifer storage on an annual basis, this surplus depth equates to a lineal groundwater discharge of 0.0134 L/s/m, which extrapolated over the aquifer length, gives an estimated groundwater discharge of 144.5 L/s or about 12,500 m^3/day.

An updated aquifer water budget was developed for calendar year 2013 using data available from Town of Osoyoos reports (Appendix B). This extends the approach by Piteau Associates by considering monthly inputs and outputs, as well as recharge and withdrawals from municipal sources. Water budget results show an estimated recharge to the aquifer of about 2,700,000 m^3 with the vast majority from irrigation sources (Appendix B). Estimated municipal contributions from outdoor water use and recycled water disposal are comparatively small at about 300,000 m^3, which are offset by municipal withdrawals.

The estimated recharge of 2,700,000 m^3 equates to an average groundwater discharge into Osoyoos Lake of 7,400 m^3/day, assuming there is no change in aquifer storage on an annual basis. This estimate is smaller than estimates from seepage measurements and near the low range of the Darcy flux estimates. However, there are unaccounted inputs and outputs that could affect the water budget results. These include surface water runoff during spring freshet, which infiltrate into the aquifer before reaching the lake, losses from the municipal water distribution system, and unaccounted pumping from private wells.

3.8.4 Summary of Aquifer Discharge Estimates

Table 6 summarizes estimates of groundwater discharge from the Osoyoos Aquifer. Seepage meters provide a direct measurement of groundwater flux, but measurements must be extrapolated over the lakebed to obtain estimates of total aquifer discharge. Darcy flux estimates are based on aquifer properties, but are sensitive to the value of hydraulic conductivity, which is spatially heterogeneous. The water budget accounting is based on an assessment of aquifer recharge and groundwater use, but there are unaccounted inputs and outputs that may be significant.

Table 6: Summary of groundwater discharge estimates from the Osoyoos Aquifer into Osoyoos Lake.

Method (source)	Irrigation season daily discharge	Non-growing season daily discharge	Year-round average daily discharge
Seepage measurements (Hii, 1987)			9,800 m^3/day *
Darcy flux – low estimate (Table C1)	7,800 m^3/day	2,800 m^3/day	5,300 m^3/day
Darcy flux – high estimate (Table C1)	23,000 m^3/day	8,400 m^3/day	16,000 m^3/day
Water budget (Piteau Associates, 1989)	1.3 m^3/day/m (14,000 m^3/day**)		
Water budget (Appendix B)			7,400 m^3/day

* Estimated west shore contribution from reported Canadian sourced groundwater discharge of 18,000 m^3/day

** For assumed aquifer length of 10,750 m

For all methods, the average daily discharge ranges from 5,300 to 16,000 m^3/day with a median of about 9,000 m^3/day. For comparison, the mean discharge of the Okanagan River into Osoyoos Lake ranges from 500,000 to 3,000,000 m^3/day (6 to 35 m^3/s) (Jensen et al., 2012). Thus, the estimated groundwater contributions to Osoyoos Lake along the western Canadian shoreline represent less than 2% of the surface inflows from Okanagan River. Collectively groundwater discharge analyses indicate:

- average daily discharge from the Osoyoos Aquifer to Osoyoos Lake is on the order of 10,000 m^3/day;
- groundwater discharge varies significantly in space and time;
- groundwater discharge is greater from the west shore than the east shore, which is attributed to greater contributions of irrigation on the western shore;
- groundwater discharge is greater during the spring and summer seasons, coinciding with the irrigation season; and
- cumulative groundwater contributions to Osoyoos Lake are minor in comparison to surface water contributions from the Okanagan River.

3.9 Groundwater Travel Time

The rate of travel for soluble contaminants in groundwater can be conservatively estimated by an average interstitial groundwater velocity, which assumes there is no retardation from sorption to aquifer sediments. The average interstitial groundwater velocity is expressed by:

$$\bar{v} = \frac{Q}{A\theta} = -\frac{KJ}{\theta} \qquad \text{(Eq. 3)}$$

where $\bar{v}$ is the average pore velocity and θ is the soil porosity. The groundwater pore velocity in the Osoyoos Aquifer ranges from <1 to about 16 m/day, assuming a range of hydraulic conductivity from 1 to 100 m/d, a range of hydraulic gradient from -0.01 to -0.04, and an average porosity of 0.25. An average pore velocity for the aquifer is estimated to be on the order of 1 to 10 m/d.

The average time of travel for soluble contaminants across the full width of the aquifer (~1400 m) is approximately 9 months, but could be as high as four years along flow paths where the conductivity and hydraulic gradient are low (Table 7). Average travel time estimates in Table 7 indicate soluble contaminants in groundwater generally discharge to Osoyoos Lake in less than a year, and typically within a single growing season (6 months) depending on travel distance.

Table 7: Estimates for groundwater travel time.

Pore velocity (m/d)	Groundwater travel time (months) for distance in metres				
	200 m	400 m	600 m	1000 m	1400 m
1	7	13	20	33	47
5	1.7	2.7	5.0	6.7	9.3
10	0.7	1.3	2.0	3.3	4.7

4. WATER USE AND SOURCES

4.1 Water Use and Sources

In the Okanagan Basin, agricultural water use accounts for more than half of the regional demand (55%), followed by indoor and outdoor domestic uses, which accounts for almost a third of the regional demand (Table 8). Recreational, industrial, and commercial water uses make up less than 20% of the regional demand. Water use in the Osoyoos area is similar to regional use, with agricultural and outdoor domestic use accounting for the large majority of the local water demand.

Several water supply sources are used to meet water demand in the Osoyoos area (Table 8). Within the municipal boundary, groundwater wells supply all domestic (indoor and outdoor), commercial, and industrial water uses. Reclaimed water is used for outdoor irrigation of parks and golf courses within the municipal boundary. Outside of the municipal boundary, agricultural water supply is sourced from Osoyoos Lake. A combination of lake water, municipal well water, and private well water is used for domestic and other water uses outside of the municipal boundary.

Table 8: Categories and percentage of water use in the Okanagan Basin (Summit , 2010) and corresponding water supply sources in the Osoyoos area.

Water Use	Water use in Okanagan Basin (%)	Water Source in Osoyoos Area	
		Municipal Boundary (urban areas)	**Irrigation Systems #8 & 9 (rural areas)**
Agriculture	55		• Irrigation system, lake inlets (irrigation season) • Private wells
Domestic – outdoor	24	Town of Osoyoos Municipal System (groundwater wells)	• Irrigation system, lake inlets (irrigation season) • Municipal system (municipal groundwater wells) • Private wells
Domestic – indoor	7		
Commercial	4	Town of Osoyoos Municipal System (groundwater wells)	
Industrial	2		
Institutional	1		
Golf courses	5	Reclaimed wastewater	
Parks & open spaces	5	Other systems – local wells	

4.2 Town of Osoyoos Water Supply

The Town of Osoyoos manages water supply in three separate service areas: 1) Municipal service area; 2) Irrigation System 8; and 3) Irrigation System 9 (Figure 14). There is some overlap in the municipal and irrigation service areas on the west side. Within these service areas, the Town uses three main sources of water supply (Table 8):

1. **Lake water** – Agricultural demand is the dominant water use and is sourced directly from Osoyoos Lake. Lake water also provides some domestic supply in Irrigation Systems 8 and 9 during the irrigation season.
2. **Groundwater** – Municipal wells provide water for domestic, commercial, and industrial users within the municipal boundary. Municipal wells also supply rural domestic users in Systems 8 and 9 during the non-irrigation season. The Town of Osoyoos also uses local wells to supply irrigation water for some community parks and recreation areas (TRUE, 2010).
3. **Reclaimed wastewater** – Treated wastewater supplies irrigation water to the golf courses and some local parks.

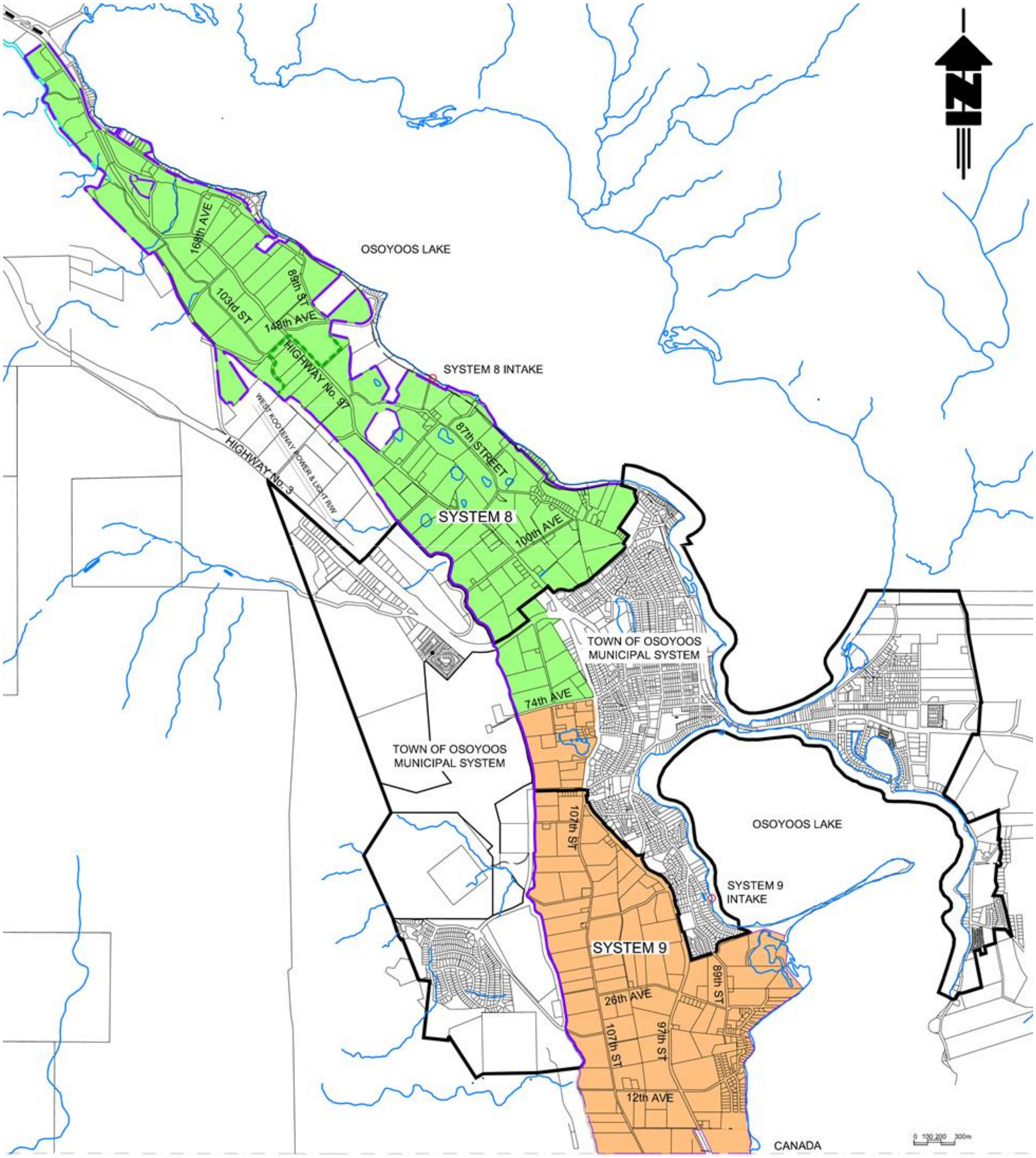

Figure 14: Water service areas in the Osoyoos Aquifer. Source: Town of Osoyoos (2016).

4.2.1 Municipal System

The Town of Osoyoos municipal water system is sourced by six groundwater wells (No. 1, 3, 4, 5, 6, 8) located on both sides of Osoyoos Lake (Figure 4, note Appendix A cross references the municipal well numbers to map IDs and WTNs). A seventh well (No. 7) is capped and not in use. Well No. 2 was decommissioned in May 2017 (Town of Osoyoos, 2017). The pumping capacities of the six active wells range from 18 L/s (295 US gpm) to 75 L/sec (1200 US gpm). Groundwater supplied by the municipal wells provides the highest water quality of the Town's water systems and is the principal source of domestic water supply (TRUE, 2010).

Total annual consumption from the municipal system ranged from 2.1 Mm^3 (2.1 million m^3) to 2.5 Mm^3 during 2004 to 2016 (Figure 15). The annual consumption has remained relatively constant over the past 15 years despite a concurrent 16% increase in the permanent population (Town of Osoyoos, 2017). Outdoor domestic water use during the summer season (Figure 16) accounts for a large majority of the total municipal demand, consistent with regional water use information (Table 8).

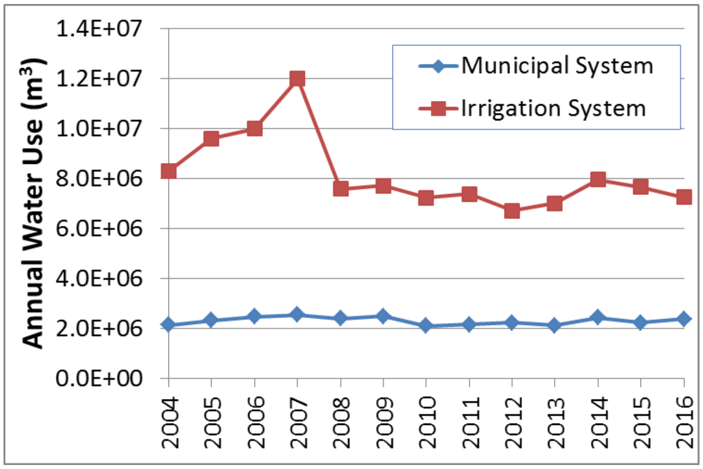

Figure 15: Annual water consumption from the municipal and irrigation Systems. Source: Town of Osoyoos (2017).

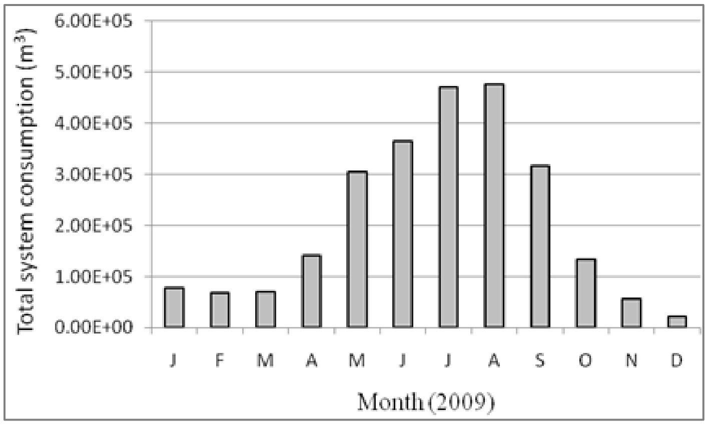

Figure 16: Total monthly water consumption in 2009 from the six Town of Osoyoos wells. Figure from Gregory (2014) based on information from the Town of Osoyoos (2010).

4.2.2 Irrigation Systems

Prior to 1990, the South Okanagan Lands Irrigation District (SOLID) owned and operated Irrigation Systems 8 and 9. The province dissolved SOLID in 1990, transferring ownership to the Town of Osoyoos. The Osoyoos Irrigation District provides water to 600 hectares (1500 acres) and 500 domestic connections in Systems 8 and 9.

During the irrigation season from mid-April to mid-October, Systems 8 and 9 are supplied by water pumped directly from Osoyoos Lake through two separate lake intakes (Figure 14). The lake water is treated by chlorination, but this treatment does not fully comply with the Interior Health Authority requirements for chorine contact time and removal or inactivation of parasites (e.g. Giardia and

Cryptosporidium) (Town of Osoyoos, 2016). In accordance with Interior Health requirements, the Town issues a boil water advisory during the irrigation season for residents within Systems 8 and 9.

The lake intakes are only in use during the irrigation season. Outside of this period, the municipal system (Well No. 6) supplies water for domestic connections in Systems 8 and 9. To address the boil water advisories in rural areas, the Town is taking steps towards the year-round use of the municipal system for domestic connections in Systems 8 and 9. This requires construction of 'twin' water distribution systems (Town of Osoyoos, 2016b).

Total annual consumption from the irrigation system ranged from 7,000,000 m^3 to 12,000,000 m^3 between 2004 to 2016 (Figure 15), about 3 to 5 times the consumption from the municipal system. Water consumption in System 8 is about 150% of System 9, based on 2014 and 2015 information (Table 9). Water consumption for domestic purposes in Systems 8 and 9 is comparatively small, about 5% of the total annual consumption.

Table 9: Water consumption in Systems 8 and 9 in 2014 and 2015. Source: Town of Osoyoos (2015, 2016, 2017).

Period	Service Area	Water Source	Water Consumption (m^3)		
			2014	2015	2016
Irrigation Season (April 15 – Oct 15)	System 8	Lake Inlet	5,081,000	4,544,000	4,341,000
	System 9	Lake Inlet	2,876,000	2,906,000	2,874,000
Non Irrigation Season (Oct 15 – April 15)	Systems 8 and 9	Well No. 6	236,000	215,000	160,000

Irrigation use between 2008 and 2016 has been relatively steady at roughly 7,500,000 m^3/yr (Figure 15). This equals an average application rate over the combined service areas (611 ha) of 12,300 m^3/ha/yr, or an average depth of 1.23 m/yr. The average irrigation over both service areas is more than three times the average annual precipitation (0.34 m/yr).

Prior to 2008, irrigation consumption in 2004-2007 was comparatively higher than in 2008-2015, consistently above 8,000,000 m^3/yr (Figure 15). Reduced irrigation demand after 2008 may be influenced by a shift towards vineyards, which have roughly one-third the water demand of orchards based on a 2006 Town of Osoyoos metering pilot program (Athanasopoulos, 2009).

4.3 Wastewater and Reclaimed Water Systems

The Town of Osoyoos operates a wastewater and sanitary sewer system for all areas within the municipal boundary, and priority areas outside of the municipal boundary including Haynes Point, the Osoyoos Indian Band on the east side of the lake, and a recent major NW extension. This last project reduced the use of individual septic systems by shoreline residents from Lacey Point to Willow Beach (Osoyoos & District Museum and Archives, 2012). Other residents in rural areas north and west of the Town and the residents south of the Town rely on individual septic systems and leach fields.

Wastewater collected in the municipal sewer system is treated at the Osoyoos wastewater treatment plant (WWTP) located near the golf course on the parks and recreation land to the south-west of the Town (Figure 4). The WWTP is an aerated sewage treatment lagoon system that includes three aeration cells, two effluent storage basins, one chlorine contact basin, and associated pumping and lifts stations (KWL, 2014). Treated effluent from the WWTP is disposed to land. During the summer months, reclaimed water is used to irrigate turf areas at the Osoyoos golf course, nearby school areas, and other parks and recreation facilities. During the winter, effluent is stored in holding basins.

Table 10 lists WWTP influent and effluent volumes between 2009 and 2017. Future WWTP influent and effluent volumes are projected to steadily increase and there is a concern that irrigation areas are not adequate for full disposal of treated wastewater (KWL, 2014).

Table 10: WWTP influent and effluent volumes. Source: TRUE (2014, 2018b), KWL (2014).

Year	WWTP Influent Volume (m^3)	WWTP Effluent Volume (m^3)		
		Reclaimed Water used for Irrigation	Diversion to Infiltration Beds	Total
2009	740,900	741,000		741,000
2010	752,700	661,900		661,900
2011	733,900	746,100		746,100
2012	768,700	728,400		728,400
2013	803,400	740,500	69,000 (Desert Park)	809,500
2014	821,400	812,500	27,700 (Desert Park)	840,200
2015	793,000	778,300		778,300
2016	827,900	650,800	47,300 (Desert Park)	698,100
2017	848,900	684,100	61,500 (Desert Park) 44,500 (Tree Farm site)	790,100

The Town's Operational Certificate authorizes the use of infiltration facilities to dispose of surplus effluent quantities. Accordingly, in 2012 the Town constructed infiltration beds in a stormwater detention basin and former sand pit south of the Desert Park. The design infiltration capacity is 500 m^3/day (TRUE, 2012). Additional infiltration capacity is discussed in the 2017 annual report, referred to as the former Tree Farm site, but no detail of these facilities is provided. Effluent has been diverted to infiltration beds in four of the last five reporting periods (Table 10), often to mitigate surplus effluent resulting from maintenance operations such as the liner replacement in Cell #3 in 2018. Effluent disposal in the infiltration beds is considered a temporary measure to reduce surplus effluent, but it appears to be more common after 2013. To meet projected increases in effluent volume, the Town plans to extend irrigation supply works to the airport area (TRUE, 2018a).

4.4 Individual Groundwater Users

The number and type of private wells currently in use for local water supply is unknown due to the legacy of unregulated groundwater use and voluntary submission of well records to the Province. With the WSA coming into force in February 2016, all new and existing non-domestic groundwater users are required to obtain a water license. All new and licensed wells will be registered in the provincial GWELLS database.

Historically, private wells were the primary source of individual domestic supply in rural areas, with more than 350 active and abandoned wells reported in 1985 (Hodge, 1985). The number of legacy wells still in use is unknown, but is likely small as most rural residences are within the service areas of Irrigation Systems 8 & 9.

Private irrigation wells likely remain in use as there are developed agricultural areas outside of the Irrigation System service areas and because there are irrigation wells listed in the GWELLS database. The Town may also use local wells to supply irrigation water for some community parks and recreation areas (TRUE, 2010). All existing non-domestic supply wells are required to be licensed under the WSA, but there are no approved licenses as of June 2019.

5. GROUNDWATER QUALITY ASSESSMENT

5.1 Groundwater Quality Assessment Approach

The groundwater quality assessment examines groundwater quality parameters and associated waste loads, and identifies parameters that potentially impact the beneficial uses of groundwater. The assessment approach follows the framework outlined by Kohut & Pommen (2005).

1. **Establish groundwater uses:** Determine key beneficial uses of groundwater, including uses in receiving waters of groundwater discharges. Identify associated water quality guidelines and objectives for the groundwater uses.
2. **Characterize waste loads:** Identify contaminant sources and assemble applicable data for waste discharges, including all point and non-point discharges to the aquifer. Assemble and map water quality data for groundwater, aquifers, soils, and surface receiving waters as appropriate. Characterize the present contaminants, concentrations, and waste loads, and estimate future waste loads.
3. **Water quality assessment:** Evaluate effects of present and future waste loads on groundwater quality and assess potential impacts on groundwater uses through comparisons to applicable water quality guidelines.

5.2 Groundwater Uses and Guidelines

Groundwater uses considered in this assessment are:

- **Drinking water supply** – The Town of Osoyoos relies solely on groundwater for drinking water and municipal supply. Outside of the Osoyoos municipal boundary, groundwater provides a portion of drinking water supply. This includes an unknown number of individual domestic wells and contributions from the municipal supply wells during a portion of year.
- **Aquatic life in Osoyoos Lake** – Groundwater in the Osoyoos Aquifer flows into Osoyoos Lake. These discharges and associated contaminants potentially affect the water quality and aquatic life of the receiving waters in the lake.
- **Irrigation water supply** – Although irrigation supply is largely sourced from Osoyoos Lake, irrigation supply wells are potentially active both within and outside of the irrigation district service area. No irrigation wells are currently licensed in the Osoyoos area and the number of active irrigation wells is unknown.

Although recreational uses in Osoyoos Lake are potentially affected by groundwater discharges from the Osoyoos Aquifer, the water quality guidelines for recreational uses are generally less sensitive than aquatic life guidelines. Groundwater uses for recreation were not considered in this assessment.

Water quality guidelines are maximum levels (numeric values) of water quality parameters that express province-wide policy guidance for protecting water quality. The guideline values depend on both the water quality parameter and the specific water use. Guideline values for drinking water uses are from the *Summary of Water Quality Guidelines: Drinking Water Sources* (B.C. ENV, 2017a). Guideline values for irrigation water supply and aquatic life uses are from the *British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture, Summary Report* (B.C. ENV, 2017b), or if no approved guidelines were available, they were taken from *British Columbia Working Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture* (B.C. ENV, 2015).

5.3 Contaminant Sources

Sources of contaminants that potentially impact groundwater uses are from non-point (diffuse) waste discharges to the Osoyoos Aquifer. They include the Town's regional landfill, the Town's domestic sewage treatment lagoons and reclaimed wastewater disposal areas, individual septic systems, agricultural activities (orchards and vineyards with some vegetable crops), and urban landscaping. These sources are also the origin of waste loads in groundwater discharges to Osoyoos Lake, which occur as distributed discharges and at two outfalls from an agricultural drainage system.

The following sections describe the potential contaminant sources, including a description of the available monitoring data for assessing and estimating the potential waste loads.

5.3.1 Solid Waste Disposal Site

The regional landfill is located on the Osoyoos West Bench about 3 km north of the Town of Osoyoos (Figure 4). The Town of Osoyoos has operated a landfill at this location for more than 60 years.

The landfill accepts four types of general waste: construction waste, commercial waste, compostable and yard wastes, and municipal wastes. The site also accepts liquid and sludge waste from septic and holding tanks. Separation and composting of organic wastes was initiated in 2007.

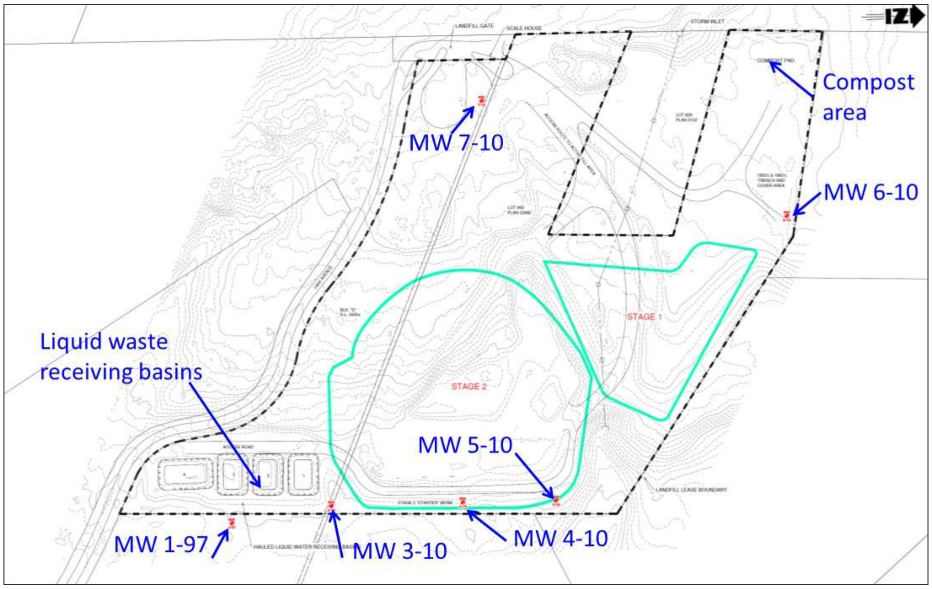

Figure 17: Osoyoos landfill site layout and location of groundwater monitoring wells (modified figure from TRUE, 2018b).

The liquid and sludge waste from septic and holding tanks is trucked to the landfill site where it is weighed and added to one of three unlined disposal lagoons (Figure 17, Figure 18). The wastes are de-watered and the sludge is disposed of in the landfill. Addition of the wastes and drying/infiltration follows a rotation cycle in each lagoon: two months of loading followed by four months of de-watering and infiltration, and then sludge removal. Approximately 20 m^3 of sludge is removed from each lagoon two times per year for a total of about 100 to 150 m^3 per year. Following completion of the NW municipal sewer system extension in 2012, the volume of liquid waste added to the lagoons is approximately 2000 m^3/year (Figure 18). The difference in volume of liquid waste added to the lagoons and the volume of sludge removed suggests that over 90% of the wastes are liquids, or about 1900 m^3/year. These liquid wastes either infiltrate or evaporate while in the lagoons, but the quantity of liquid that percolates to groundwater is unknown.

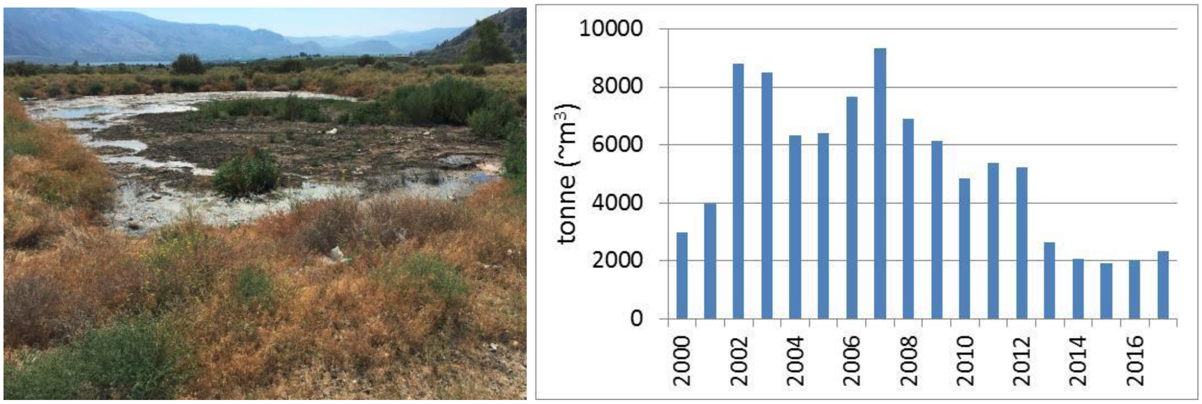

Figure 18: Liquid waste receiving basin at the Osoyoos Landfill (left), and volume of liquid wastes added to the disposal lagoons (right). Source: (TRUE, 2018b; B.C. ENV, 2018).

The operating permit requires groundwater monitoring. There are six monitoring wells along the site perimeter (Figure 17); four wells along the down-gradient perimeter, one on the eastern perimeter (MW 6-10), and one is up-gradient of the landfill (MW 7-10). The monitoring wells are sampled monthly for water levels, and twice a year for water quality analyses, but some wells are not sampled due to lack of water. There are no monitoring results for MW 1-97 and MW 6-10 in the 2012 to 2017 annual reports, which affects the assessment of groundwater immediately downgradient from the septic receiving basins and the compost area (TRUE, 2014b; 2015b; 2016b; 2017b; 2018b).

Appendix D (Table D1) lists groundwater quality monitoring results from the 2012 to 2017 annual reports. The data indicate the landfill is not a source of a broad spectrum of metals and phosphorus, which were typically not detected in groundwater or present at levels below guideline values. However, monitoring data for nitrate and chloride show variable results. Nitrate levels were often low to moderate in down-gradient monitoring wells, but very high levels above drinking water guidelines were occasionally measured, indicating the landfill is periodically a source of nitrate to groundwater. Moderate nitrate and chloride levels were also measured in an up-gradient well, which suggests possible sources from active vineyards upslope from the landfill.

Samples collected from the septic waste receiving basins in 2013, 2014 and 2015 show very high levels of ammonia and organic nitrogen, and low levels of nitrate, which is typical of wastewater. Ammonia that percolates into the ground is subject to nitrification, which suggests the receiving basins could be a potential source of nitrate in groundwater. However, there is no groundwater monitoring information adjacent to the receiving basins to assess this source.

5.3.2 Domestic Sewage and Reclaimed Wastewater

Treated effluent (reclaimed water) from the Town's WWTP is disposed through irrigation of golf course turf and other park and landscape areas. Effluent from the WWTP typically meets the operating requirements for biochemical oxygen demand (BOD) and total suspended solids (TSS) (Table D2).

The Town's operating certificate requires water quality monitoring of treated effluent prior to disposal. Nutrients (nitrogen and phosphorus) and chloride are the main parameters of concern for the reclaimed water. Monitoring data show total nitrogen in the reclaimed water ranges from about 15 to 25 mg/L, with Total Kjeldahl nitrogen as the dominant form (Figure 19). Nitrate regularly spikes above guideline levels during the warmer summer months, which promotes nitrification. The total phosphorus concentration in reclaimed water ranges from about 2 to 8 mg/L, but the dissolved fraction is unknown. Two samples were analyzed for chloride, showing concentrations of 223 and 230 mg/L, which are near guideline levels. These monitoring results suggest reclaimed water may be a potential source of nitrate, chloride and possibly phosphorus in groundwater, if it is able to percolate to the groundwater table. Potential flow paths to groundwater occur when irrigation rates exceed the agronomic needs of the turf grass, or when reclaimed water is disposed directly to groundwater through infiltration basins.

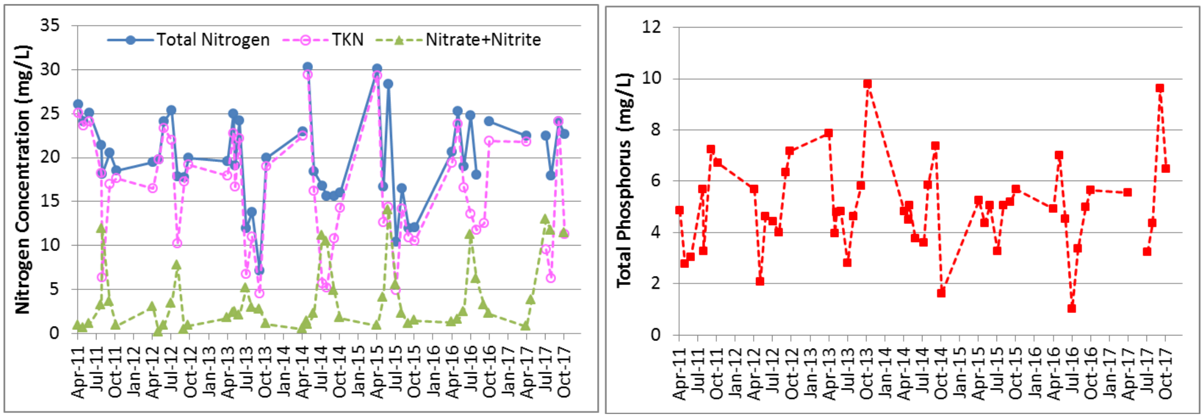

Figure 19: Nitrogen and phosphorus concentration in reclaimed water used for irrigation. Source: EMS database site number E207444.

The Town's operating permit further requires groundwater monitoring to assess potential impacts to groundwater from WWTP operations (Figure 20) Sites MW1-01, MW2-01 and MW3-01 are the initial locations installed downgradient of the WWTP. Historical data from these wells (1982 to 1992) are generally within drinking water guidelines, but there are occasional spikes in chloride and nitrate at MW1-01, which have been associated with failing liners in the WWTP. Liners of the WWTP cells have been replaced at various times between 1978 and 2010 and some of the cells were likely leaking prior to liner replacement (TRUE, 2014a).

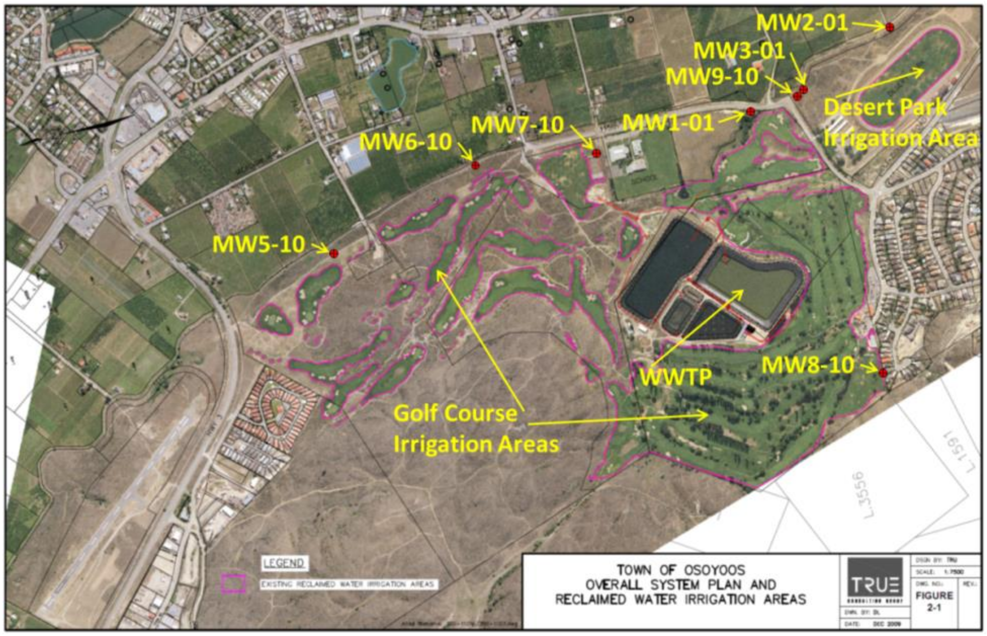

Figure 20: Location of groundwater monitoring wells and effluent disposal areas near the WWTP. Modified from TRUE (2017a).

The groundwater monitoring program was expanded in 2010 to include monitoring down-gradient from irrigation areas at the golf course and recreation fields. Well MW3-01 was replaced by MW9-10 and four additional wells (M5-10, M6-10, M7-10 and M8-10) were constructed (Figure 20). All seven wells are measured monthly for water levels and are sampled twice per year for water quality provided there is enough water to collect a sample. Recent monitoring results from 2012 to 2017 are tabulated in Appendix D (Table D3). During this period, MW2-01 and MW6-10 were not sampled due to lack of water, with the exception of one sample for MW2-01.

The WWTP groundwater monitoring data suggest nitrate, phosphorus and chloride could be entering groundwater from portions of the golf course irrigation areas or from upgradient sources, potentially at increasing levels and above the drinking water guidelines. There is no groundwater monitoring to assess effects from operation of the Desert Park Infiltration facility. The available WWTP monitoring data are discussed in Sections 5.7 and 5.8.

5.3.3 Individual Septic Systems

The NW sewer extension completed in 2012 extended the municipal sewer line along the lakeshore north of the municipal boundary. This allowed about 130 lakeshore properties outside of the municipal boundary to connect to the municipal system, including the Elenko Residence, and the Willow Beach Mobile Home Park and campground (Osoyoos & District Museum and Archives, 2012). However, remaining rural residences outside of the municipal boundary, including properties north and west of Town, and properties south of Town still rely on individual septic systems.

Typical septic systems include a septic tank for settling of solids and anaerobic decomposition with liquid overflow draining to a buried leach field comprised of perforated pipe or open bottom chambers. Waste in the septic tank is periodically pumped and trucked away for offsite disposal. Effluent in the leach field drains into the soil and may reach the groundwater table where it is a potential source of contaminants for groundwater and the surface waters that receive groundwater discharges. For example, Epp (1985) found leachate from septic systems near the east shore of Osoyoos Lake received inadequate treatment, resulting in the migration of leachate into groundwater and subsequently into Osoyoos Lake. Reducing septic system discharges to Osoyoos Lake from shoreline residents was a main motivation for the NW sewer extension project (Osoyoos & District Museum and Archives, 2012).

Nitrate is the main focus of septic system discharges because nitrogen removal in the leach field is generally low, typically in the range of 1 to 15% (Viers et al., 2012). Nitrogen in the septic tank effluent that enters the leach field is dominated by ammonium, which is subject to nitrification (conversion to nitrate) in the aerobic soil layer below the leach field. Therefore, most of the nitrogen in the septic tank effluent is likely to reach the groundwater table as nitrate. In addition to nitrate, septic fields can be a source of other groundwater contaminants, including phosphorus, potassium, sodium, sulphate, and emerging contaminants (U.S. EPA, 2002; Robertson, 2008; Schaider et al., 2016). The numerous individual septic systems in rural portions of the Osoyoos Aquifer are potentially a significant source of nitrate and other contaminants to the shallow aquifer.

5.3.4 Agricultural Activities

Fertilizers applied in agriculture areas are a source of nutrients in groundwater, particularly nitrate and possibly phosphorus. Athanasopoulos (2009) analyzed the general types of fertilizers used in the Osoyoos area, which is summarized below. There is no detailed information on the current quantities of fertilizers used.

The main agricultural crops are soft fruit trees, apple orchards, grapes and some vegetables. Different quantities and types of fertilizers are used on the different crops. For fruit trees, the dominant fertilizer is urea on its own or blended. Ammonium nitrate (34-0-0), once heavily used in the 1980's, is no longer widely used. Other fertilizers for fruit trees include ammonium sulphate, calcium nitrate and other orchard blends. Urease-inhibited urea is applied to grapes and orchard blends (19-5-17) and are added to vegetables. Fertilizer is applied to fruit trees in spring and after bloom and there are multiple applications for vegetables.

The influence of fertilizer application on groundwater quality in the Osoyoos Aquifer has been studied over three decades and there is a substantial body of monitoring data that indicates agricultural areas are a significant source of nutrients in the shallow aquifer, primarily nitrates and to a lesser extent phosphorus. Sections 5.7 and 5.8 describe the monitoring data and groundwater quality assessment for nitrate and phosphorus

Pesticides (insecticides and herbicides) applied to agriculture areas are also potential contaminants to groundwater. Pesticides, including fungicide, herbicides and insecticides, are not routinely monitored in the Osoyoos Aquifer and adjacent surface waters. Available monitoring data are sparse, primarily from special studies in early 1990's. McNaughton (1991) and Murry and York (1993) measured 15 priority pesticides in groundwater samples from wells on both sides of Osoyoos Lake and the lake itself. No values exceeded Health Canada drinking water quality or aquatic life water quality guidelines (Table D4). McNaughton (1991) found detectable levels of five pesticides, and Murry and York (1993) measured trace amounts or detectible levels of nine pesticides. A follow up survey of growers conducted after the pesticide sampling study found that a majority of pesticide detections did not correlate with actual pesticide use, likely because of the location of sampling sites relative to farm operations and the focus on 'priority' pesticides for analysis (McBeth, 1994).

Although pesticide application in agricultural areas could potentially impact groundwater quality, the available pesticide monitoring information for the Osoyoos Aquifer is outdated. There is insufficient monitoring data or information on current pesticide use to complete a groundwater quality assessment for pesticides.

5.3.5 Agricultural Drainage Systems

Two agricultural drainage systems (ADS) are present in the north-central portion of the aquifer (Figure 21). They were constructed to protect orchards from excess irrigation in shallow portions of the aquifer where the depth to the underlying silt layer is generally less than seven feet (Brownlee & Kelley, 1961). The drainage systems collect groundwater from beneath agricultural lots and discharge directly into Osoyoos Lake at two outfalls (Figure 21). The total length of each system is approximately 1.5 km, each draining an area of roughly 0.20 km^2 (Athanasopoulos, 2009).

As part of a study on nitrate characterization in agricultural drainage, Athanasopoulos (2009) measured flow rates and nitrate levels in the ADS between 2006 and 2008; phosphorus was not measured. The available data indicate the ADS is a point source discharge into Osoyoos Lake for nitrate and potentially phosphorus and other constituents associated with agricultural activities. Sections 5.7 and 5.8 describe the available data and loading estimates.

5.3.6 Municipal Area Sources

Potential sources of contaminants to groundwater from urban development within the municipal areas includes the excessive or poorly timed fertilizer and pesticide application on residential landscaping and leaky municipal sewer lines. However, there is no local information available to assess the influence of these potential groundwater contamination sources.

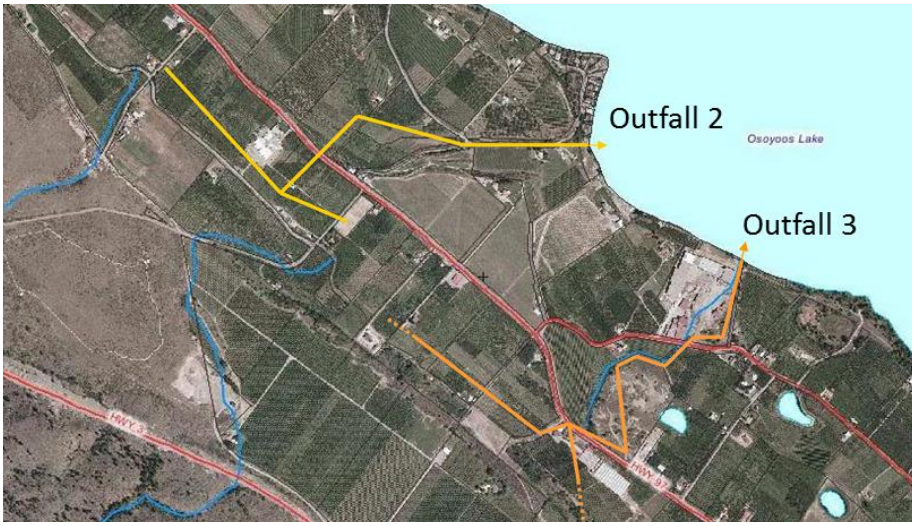

Figure 21: Location of agricultural drainage systems in the northern portion of the aquifer. Source: (Athanasopoulos, et al., 2011)

5.4 Water Quality Studies and Monitoring Data

5.4.1 Osoyoos Lake Water Quality Studies and Objectives

The water quality of Osoyoos Lake has been a long-term concern to residents and water resource managers (Jensen et al., 2012). The main water quality issues in the lake are:

- nutrient enrichment, primarily from phosphorus;
- high phytoplankton growth and heavy algae blooms, resulting in low water transparency and poor aesthetic water quality; and,
- low levels of dissolved oxygen, which can negatively impact aquatic biota and enhance internal recycling of phosphorus.

Prior to the 1970’s, population growth in the Okanagan Basin corresponded with nutrient enrichment of the basin's lakes and associated water quality degradation. Discharge of phosphorus rich wastewater effluent was the main cause of nutrient enrichment with lesser contributions from agricultural activities, forest harvesting, septic tanks, and soil erosion (Jensen & Epp, 2002). Beginning in the 1970’s, efforts to reduce phosphorus loads from wastewater, septic system, agricultural, and other point and nonpoint sources helped to produce significant reductions in phosphorus concentrations in Osoyoos Lake (Jensen & Epp, 2002). A water quality objective for total phosphorus was developed in 1985 (5 to 15 μg/L), applicable in all Okanagan Basin lakes (Nordin, 1985).

In 2012, the ENV completed a detailed water quality assessment of Osoyoos Lake to review and update the lake water quality objectives (Jensen et al., 2012). Analysis of multi-decadal monitoring data found:

- Improved water quality and reduced phosphorus levels in the north basin, generally meeting or close to the water quality objective of 15 μg/L.
- Year to year variability in phosphorus levels are associated with spring freshet flow rates in the Okanagan River. Greatest phosphorus levels tend to occur in years with high Okanagan River discharge, and lower phosphorus levels occur when freshet flows are below normal.
- Internal phosphorus loads contribute to increasing phosphorus and decreasing oxygen levels throughout the summer growing season and fall. Internal phosphorus loadings are the main cause of poor water clarity and low to anoxic oxygen levels in the central and south basins.

- Phosphorus loading from point and non-point sources decreased between 1985 and 2010, particularly from septic systems, agricultural runoff, and wastewater system discharges (Jensen et al., 2012). Phosphorus contributions from groundwater were considered negligible based on the assumption that phosphorus mobility in soils is limited.

Jensen et al. (2012) revised the water quality objectives for Osoyoos Lake to include five nutrient enrichment parameters (Table 11). Compliance with the objectives is only measured in the north basin, except for total phosphorus, which has compliance measured in all three basins. Consistent attainment of the objectives in the north basin is expected to promote the long-term goal of water quality improvements in the central and south basins.

Table 11: Summary of Osoyoos Lake water quality objectives and 2015 attainment sampling data (Sokal, 2017).

Variable	Objective Value	Timing	2015 Attainment		
			North Basin	**Central Basin**	**South Basin**
Dissolved oxygen	≥5.8 mg/L at 15 m depth	on August 15th	4.62 mg/L (sampled on Aug 19)	*0.0 mg/L (on Aug 19)*	*0.0 mg/L (on Aug 19)*
Total phosphorus	≤15 µg/L	Spring (February -March)	8.00 µg/L	8.60 µg/L	9.90 µg/L
Phytoplankton chlorophyll-a	≤4.0 µg/L	Seasonal mean (May to Sept)	2.96 µg/L	*2.94 µg/L*	*3.47 µg/L*
Secchi depth	≥3.5 m	Seasonal mean (May to Sept)	4.8 m	*4.28 m*	*4.62 m*
Cyanobacteria biomass	≤700 mm^3/m^3 mean; ≤2000 mm^3/m^3 max	Seasonal mean (May to Sept)	mean = 443 mm^3/m^3 max = 1364 mm^3/m^3	--	--

Legend =	Met objective	Did not meet objective	*No objective or no data*

The ENV evaluated objectives attainment for Osoyoos Lake in 2015 (Sokal, 2017). Moderately dry conditions in 2015 resulted in below normal discharge in the Okanagan River, which tends to reduce nutrient loads and phosphorus concentrations in the lake. This supported attainment of water quality objectives for all parameters except for dissolved oxygen in the north basin (Table 11). However, the oxygen levels remained above the critical level of 4 mg/L in mid-August (Sokal, 2017).

The 2015 attainment study also showed ongoing nutrient enrichment in the shallower central and south basin. Phosphorous concentrations increase throughout the summer and early fall in bottom waters of the central and south basins due to anoxic conditions, which promotes the internal recycling of phosphorus from bottom sediments (Jensen et al., 2012). The attainment report recommends continued monitoring in the central and south basin to understand long-term water quality trends, as well as additional efforts to understand and manage anthropogenic phosphorous inputs to the lake, including groundwater inputs (Sokal, 2017).

5.4.2 Groundwater Quality Studies and Monitoring

Groundwater quality investigations in the Osoyoos Aquifer span over 30 years beginning with monitoring studies in the 1980's. Initial studies focused on characterizing nitrate levels through regional private well sampling and the construction and sampling of monitoring wells (Hodge, 1985; Hodge, 1986). Between 1985 and 1989, more than 80 sites were sampled for nitrate and major ions at various times. High nitrate concentrations occurred in a large percentage of wells, often exceeding the Health Canada drinking water quality guideline of 10 mg-N/L (Hodge, 1989). Nitrate sources were associated with agricultural activities, as many wells with high nitrate levels were located immediately within orchards, and wells with low nitrate levels were in areas of little agricultural activity (Piteau Associates, 1989).

Groundwater quality issues identified in the 1980s prompted subsequent investigations. In the early 1990's, several studies focused on environmental monitoring of pesticides (Murray & York, 1993; McNaughton, 1991) and pesticide use and groundwater vulnerability to pesticides (McBeth, 1994). ECCC conducted a groundwater monitoring program at more than 10 sites in the Osoyoos Aquifer from 1996 to 2010 with a focus on characterizing and monitoring elevated nitrate levels. In the late 2000s, researchers from the University of Saskatchewan conducted a detailed hydrogeologic assessment and nitrate source analysis using stable isotope analyses (Athanasopoulos, 2009; Wassenaar et al., 2011).

In 2011, the FLNRORD conducted a review of the groundwater-monitoring network and an assessment of monitoring activities (Western Water, 2011). The contractor recommended continuation of monitoring activities with some adjustment in monitoring locations and suggested "more frequent and comprehensive" monitoring is warranted. The FLNRORD continues to monitor a subset of wells on an annual basis with the most recent sampling in 2018.

5.4.3 Groundwater Monitoring Data

There is a large amount of groundwater quality information from the Osoyoos Aquifer. Multiple agencies have collected water quality data from 44 wells between 1985 and 2018. Most data are from the ENV/FLNRORD monitoring programs, which are available from the provincial EMS database. These monitoring data have been combined with datasets collected by ECCC and Athanasopoulos (2009), as well as data available in the Town of Osoyoos reports.

The available monitoring data include more than 40 water quality parameters, but not all parameters were analysed at all sites and different parameters were analysed at different times. The parameters include general water quality chemistry (anions, cations), nutrients (nitrogen, phosphorus), and a range of metals. There are limited, older data for pesticides/herbicides. The datasets do not include analyses for hydrocarbons. The datasets from ECCC and Athanasopoulos (2009) include fewer parameters, as the focus of these studies was on nitrate characterization and associated general water quality chemistry. Collectively, there are thousands of groundwater quality data from multiple agencies since 1985, which are combined for this assessment and are summarized in Table 12.

5.5 Groundwater Quality Assessment for General Chemistry

Groundwater in the Osoyoos Aquifer is high in total dissolved solids (TDS) and specific conductance due mainly from calcium and bicarbonate, with contributions from chloride and sulphate and other anions and cations (Table 12, Figure 22). Dissolved ions occur naturally in groundwater from contact with sediments and bedrock, and from human sources including fertilizers, septic systems and de-icing chemicals. There is no health-based drinking water guideline for TDS, but high levels may affect taste, and suitability for irrigation supply. Health Canada has set a drinking water aesthetic objective (AO) for TDS at 500 mg/L, which is exceeded in more than half of the groundwater monitoring data. Somewhat lower ranges of TDS occur at wells in the central and southern portion of the aquifer (R35 to R45), possibly from the influence of surface waters or lower use of inorganic fertilizers. There are occasional exceedances of provincial guidelines for TDS in irrigation supply.

Table 12: Summary of groundwater quality monitoring data collected from private and provincial monitoring wells in the Osoyoos Aquifer. The summary results are a compilation of information collected by the FLNRORD and ENV, ECCC, and Athanasopoulos (2009).

Parameter (units)	Sampling Period**	No. samples	Range	Mean*	Median*	Guidelines				Exceedance number (%)			
						D.W. MAC	D.W. AO	Aquatic Life	Irrig. Supply	D.W. MAC	D.W. AO	Aquatic Life	Irrig. Supply
General Chemistry													
Alkalinity (mg/L as $CaCO_3$)	1985-2018	621	105 - 525	281	275								
Hardness (mg/L as $CaCO_3$)	1989-2018	270	182 - 640	348	339								
Specific Conductance (μS/cm)	1985-2018	429	292 - 1740	778	758				1200 [2,5]				8 (2%)
Total Dissolved Solids (mg/L)	1985-2018	450	160 - 1590	522	509		500 [4]		800 [2,5]		236 (52%)		16 (4%)
pH	1985-2018	601	5.8 - 8.6	7.9+	7.8			6.5-9 [1]				10 (2%)	
Cations													
Calcium - total & dis.# (mg/L)	1987-2018	409	35 - 226	104	105								
Magnesium - total & dis.# (mg/L)	1987-2018	341	8 - 97	25.7	21.5								
Sodium - dissolved (mg/L)	1987-2018	402	13 - 148	29.0	24.4		200 [4]				0 (0%)		
Potassium - dissolved (mg/L)	1987-2018	446	2.6 - 43	6.5	5.7								
Anions													
Bicarbonate (mg/L)	2006-2018	115	150 - 498	341	340								
Sulphate (mg/L)	1987-2018	451	10 - 308	73	64		500 [3,4]				0 (0%)		
Chloride (mg/L)	1987-2018	630	3.9 - 180	24.5	17.8		250 [3,4]	150 [1]	100 [1]		0 (0%)	6 (1%)	14 (2%)
Fluoride - total & dis.# (mg/L)	1997-2018	95	0.05 - 1.8	0.36	0.35	1.5 [3,4]			1.0 [1]	1 (1%)			1 (1%)
Nutrients													
Ammonia (mg-N/L)	1985-2018	427	<0.005 - 4.6	0.12	0.01			1.77 [1,7]				1 (0%)	
Nitrite (mg-N/L)	1987-2018	394	<0.002 - 2	0.04	0.006	1.0 [3,4]		0.06 [1,7]		1 (0%)		6 (2%)	
Nitrate++ (mg-N/L)	1985-2018	727	<0.002 - 62	8.9	7.1	10 [3,4]		3 [1,7]		233 (32%)		584 (80%)	
Total Kjeldahl Nitrogen (mg-N/L)	1985-2018	300	<0.07 - 14	0.72	0.45								
Phosphorus - total (mg/L)	1985-2015	418	0.005 - 6.5	0.33	0.15		0.01 [3,8]	0.015 [9]				382 (93%)	
Phosphorus - dissolved (mg/L)	1985-2018	440	<0.002 - 2	0.15	0.08			0.015 [9]				387 (88%)	
Metals													
Aluminum - dissolved (mg/L)	1987-2018	219	0.0003- 0.37	0.047	0.003	9.5 [3]		0.05 [1]		0 (0%)		8 (4%)	
Antimony - total & dis.# (μg/L)	1992-2018	311	0.02 - 0.28	0.14	0.13	6 [4]		9 [2]		0 (0%)		0 (0%)	
Arsenic - total & dis.# (μg/L)	1985-2018	307	0.54 - 23	4.26	2.8	10 [3,4]		5 [1]	100 [1]	31 (10%)		56 (18%)	0 (0%)
Barium - total & dis.# (mg/L)	1990-2018	334	0.022 - 1.1	0.11	0.094			1 [2]				2 (1%)	
Beryllium - total & dis.# (μg/L)	2002-2018	145	<0.01 - 0.04	0.032	0.03			0.13 [2]	100 [2]			0 (0%)	0 (0%)
Boron - total & dis.# (mg/L)	1992-2018	313	<0.008 - 0.7	0.088	0.080	5 [3,4]		1.2 [1]	1-2 [1,5]	0 (0%)		0 (0%)	0 (0%)
Cadmium - total & dis.# (μg/L)	2002-2018	140	<0.003 - 0.57	0.049	0.040	5 [3,4]		0.42 [1,6]	5.1 [2]	0 (0%)		1 (0%)	0 (0%)

Parameter (units)	Sampling Period**	No. samples	Range	Mean*	Median*	Guidelines				Exceedance number (%)			
						D.W. MAC	D.W. AO	Aquatic Life	Irrig. Supply	D.W. MAC	D.W. AO	Aquatic Life	Irrig. Supply
Chromium - total & dis.# (µg/L)	2004-2018	141	0.10 - 13	2.4	1.2	50 [4]		8.9 [2]	4.9 [2]	0 (0%)		4 (3%)	20 (14%)
Cobalt - total & dis.# (µg/L)	2003-2018	141	0.01 - 1.2	0.11	0.09			4 [1]	50 [2]			0 (0%)	0 (0%)
Copper - total & dis.# (mg/L)	2003-2018	142	0.0001 - 1.1	0.026	0.0055		1.0 [3,4]	0.01 [1,6]			1 (1%)	27 (19%)	
Iron - total & dis.# (mg/L)	1987-2018	428	<0.001 - 0.95	0.082	0.012		0.3 [3,4]	0.35 [1]			20 (5%)	19 (4%)	
Lead - total & dis # (µg/L)	2003-2018	142	0.0063 - 4.3	0.26	0.090	10 [3,4]		13.5 [1,6]		0 (0%)		0 (0%)	
Lithium - total & dis.# (µg/L)	2003-2018	125	3.3 - 15	7.8	7.6				2500 [2]				0 (0%)
Manganese - total & dis # (µg/L)	1992-2018	468	0.1 - 7890	110	3.0	120 [4]	20 [4]	1700 [1,6]	200 [2]	38 (8%)	54 (11%)	4 (1%)	14 (3%)
Molybdenum - total & dis.# (µg/L)	2003-2018	140	2.5 - 16	8.0	7.1	250 [3]		1000 [1]	30 [1]	0 (0%)		0 (0%)	0 (0%)
Nickel - total & dis.# (µg/L)	2003-2018	141	0.06 – 4.2	1.2	1.0			150 [2,6]	200 [2]			0 (0%)	0 (0%)
Selenium - total & dis.# (µg/L)	2003-2018	142	0.04 - 5.4	1.1	0.80	10 [3]		2 [1]	10 [1]	0 (0%)		15 (11%)	0 (0%)
Uranium - total & dis.# (µg/L)	2003-2018	137	1.6 - 30	9.1	7.4	20 [4]		8.5 [2]	10 [2]	5 (4%)		56 (41%)	43 (31%)
Zinc - total & dis.# (mg/L)	1997-2018	218	0.0001 – 0.3	0.02	0.004		5 [3,4]	0.13 [1,6]	5 [1]		0 (0%)	7 (3%)	0 (0%)

D.W. MAC = Drinking water objective – Maximum acceptable concentration. This guideline addresses human health concerns.

D.W. AO = Drinking water objective – Aesthetic objective. This guideline addresses non-health based issues such as taste, colour, and odour.

dis. = dissolved

Irrig. = Irrigation

* For samples above the laboratory detection limit.

** Sampling spans the indicated year range, but sampling did not occur at all stations and in all years.

+ Obtained by determining the log of the mean of the antilogs of all the values.

++ Combined results for nitrate and nitrate+nitrite.

Where samples were analyzed for both total and dissolved concentration, total concentration values are used in the statistical summary.

[1] B.C. Approved water quality guidelines (B.C. ENV, 2017b)

[2] B.C. Working water quality guidelines (B.C. ENV, 2015). For chromium, values are for Cr(III), which is the smaller of

[3] B.C. Water quality guidelines for drinking water sources (B.C. ENV, 2017a). Applicable before treatment.

[4] Health Canada (2019) drinking water quality guideline.

[5] Crop dependent. Conductivity and TDS value is for slightly tolerant crops. Boron value is for moderately sensitive crops.

[6] Hardness dependent. Copper value assumes hardness > 250 mg/L. A hardness of 250 mg/L is assumed in guideline calculations for fluoride, cadmium, lead, manganese, and zinc.

[7] Long-term average water quality guideline. Ammonia value is for pH=7 and T=15 C. Nitrite is for Cl in the range of 4 to 6 mg/L.

[8] Health Canada has not established drinking water objectives for phosphorus. B.C. has established phosphorus guidelines for drinking water sources from surface waters to reduce risk of algae blooms. Because groundwater sources are not at risk for algae blooms, groundwater measurements are not compared to the B.C. guideline.

[9] B.C. has established a site specific objective for total phosphorus (0.015 mg/L) in Osoyoos Lake for protection of aquatic life (Jensen et al., 2012). Groundwater measurements of total and dissolved phosphorus are compared separately to the lake objective, as only the dissolved form is considered mobile in groundwater and a potential source to the lake.

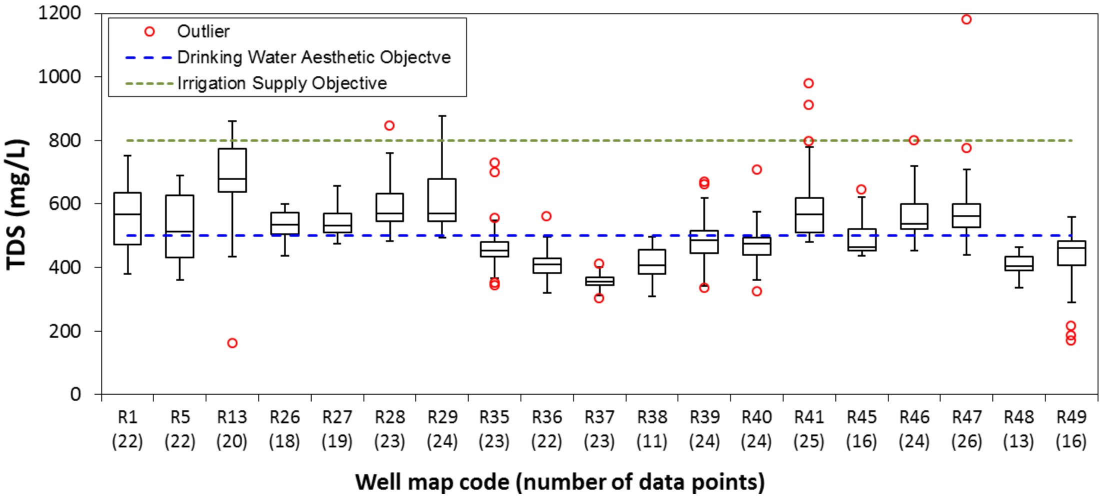

Figure 22: Box plots of groundwater TDS concentration data collected between 1985 and 2018 at sampling locations shown in Figure 4.

Piper diagrams illustrate the dominance of calcium and bicarbonate in recent monitoring data (Figure 23), which is consistent with piper plots presented by Athanasopoulos (2009) and Western Water (2011). Elevated levels of calcium is reflected by high water hardness consistently exceeding 200 mg/L $CaCO_3$ equivalent (Table 12), which is classified as hard to very hard. High hardness does not pose health concerns, but may cause aesthetic issues including unpleasant taste, water spots on glassware, and scale formation in pipes, plumbing fixtures and well screens. Health Canada has not set an AO for water hardness. Hardness does affect various water quality guidelines for aquatic life protection.

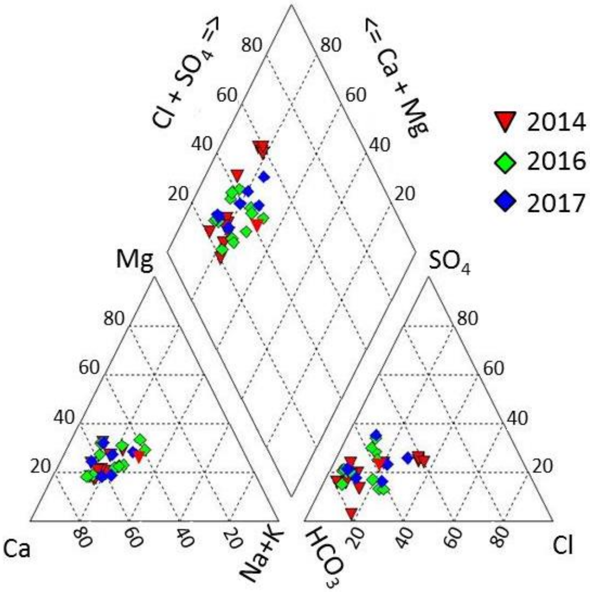

Figure 23: Piper diagram showing the chemical composition of recent groundwater samples.

Other inorganic ions with established water quality guidelines include sodium, sulphate, chloride, and fluoride (Table 12). With only one exception, none exceeded drinking water guidelines, and only chloride had occasional exceedances of irrigation supply and aquatic life guidelines. There are a limited number of exceedances of the pH aquatic life guideline of less than 6.5, mostly within urban areas (Table 12). The reason is unknown, but they represent less than 2% of all pH measurements.

Summary and Assessment for General Chemistry: The overall groundwater quality throughout the Osoyoos Aquifer is within drinking water guidelines for parameters describing the general groundwater chemistry. However, the groundwater is very hard, has high alkalinity and high dissolved ion content. High alkalinity and hardness are consistent among the sampling sites.

5.6 Groundwater Quality Assessment for Metals

The 'metals' category in Table 12 includes those metals with established water quality guidelines. Groundwater samples have been analyzed for both dissolved metal concentrations (filtered prior to analysis) and total metal concentrations (unfiltered). Samples collected before 2009 were typically analyzed for both dissolved and total metals, and samples collected after 2009 are only analyzed for dissolved metals. In this assessment, the monitoring results for dissolved and totals metals are combined, using the total concentration results in cases where samples have been analyzed for both total and dissolved metals.

Comparison to Drinking Water Guidelines: The following four metals had exceedances of Health Canada drinking water guidelines (Table 12).

Arsenic: Monitoring results for arsenic exceed the Health Canada Maximum Acceptable Concentration (MAC) in 10% of the samples. Nearly all exceedances (43 of 44) occur in two wells, R1 and R5, which are both close to the lakeshore in the northern portion of the aquifer. The source of arsenic is from natural origins caused by the erosion of aquifer sediments, which is common in glacial aquifer systems (Warner & Ayotte, 2014). Excluding R1 and R5, monitoring results from all other wells show arsenic levels are below the Health Canada MAC, with only one exceedance in hundreds of samples spanning over 30 years. These monitoring data indicate the majority of the aquifer is not at risk for elevated levels of arsenic in drinking water supply. Individual well owners should be aware that arsenic levels above the MAC are possible in isolated pockets, and should have their water tested and take appropriate measures to reduce health risks.

Manganese: Health Canada updated drinking water guidelines for manganese in May 2019, reducing the AO from 50 to 20 μg/L and introducing a health based MAC of 120 μg/L. The new MAC focuses protection on infants who are at risk from consumption of tap water, especially infants consuming formula made with tap water. For adults and older children, "short-term exposure to manganese in drinking water slightly above the guideline is unlikely to cause negative health effects (Health Canada, 2019b)." Monitoring results for manganese exceed the MAC in 38 samples (8% of measurements), but are concentrated in four wells occurring in two areas. There were 27 exceedances in well R37 in the central portion of the aquifer (27 of 30 samples), and nine exceedances (9 of 9 samples) in wells R10, R11, and R17, which are clustered in silty areas in the northern portion of the aquifer. Wells R36 and R38 each had one exceedance of the MAC. Like arsenic, the source of elevated levels of manganese is from geologic origins, a characteristic of glacial aquifer systems (Warner & Ayotte, 2014). High manganese levels are also reported in municipal wells No. 4 (R33) and No. 8 (R43), which is in the same proximity as R37 in the central portion of the aquifer. The Town sometimes limits production from these wells to reduce manganese levels in the municipal supply (Town of Osoyoos, 2016).

Health Canada reduced the manganese AO to address complaints of discoloured water and staining of fixtures and laundry. Monitoring results for manganese exceed the AO in 54 samples (11% of measurements), with the majority (38 of 54) occurring in the four wells that exceeded the MAC guideline. The remaining AO exceedances are occasional one or two time events occurring in 10 different wells (R1, R9, R12, R14, R28, R36, R38, R47, R48, and R49). These wells are located in the northern and central portions of the aquifer in general proximity to the four wells with exceedances of the MAC.

The majority of the monitoring results for manganese are below both the AO and MAC guidelines. However, data show exceedances of the MAC are possible, particularly in the central and northern portions of the aquifer. Individual well owners should be aware of potential health concerns for infants and should have their water tested and take appropriate measures to reduce risks

Uranium: Monitoring results for uranium exceed the Health Canada MAC (20 μg/L) in five samples (4% of measurements). The main health concern from exposure to uranium is inflammation of the kidneys (nephritis), however, little is known about the long term health effects from exposure to low levels of uranium through drinking water (Health Canada, 2019; Warner & Ayotte, 2014). Uranium in groundwater occurs naturally from the erosion of aquifer sediments, primarily shale fragments. Warner and Ayotte (2014) found more frequent exceedance of uranium drinking water guidelines occur in glacial aquifer systems where bicarbonate concentrations exceed 300 mg/L and sulfate concentrations exceed 30 mg/L, conditions that typify the Osoyoos Aquifer. However, the Osoyoos monitoring data also shows all five exceedances of the uranium MAC were isolated to a single well, R13, which has not been sampled since 2009. This suggests the majority of the aquifer is not at risk for elevated levels of uranium in drinking water supply.

Iron: Monitoring results for iron exceed the Health Canada AO drinking water guideline (0.3 mg/L) in 20 samples (5% of measurements). Elevated levels of iron are not a health concern, but can causing staining of clothes and undesirable taste. Monitoring results show 18 of the 20 exceedances were measured in well R37 and 2 were measured in the nearby well R38. Apparently, this portion of the aquifer is subject to reducing conditions that promote elevated levels of iron and manganese. Excluding these wells, there are no other exceedances of the iron AO in the monitoring records.

Comparison to Irrigation Supply and Aquatic Life Guidelines: Water quality guidelines for irrigation supply are exceeded in greater than 10% of samples for chromium, manganese, and uranium. Most exceedances are concentrated in localized areas of the aquifer and there is a potential to affect food supplies if groundwater from these areas is used to irrigate food crops. However, the location of active irrigation wells is unknown and the number may be small as irrigation supply is widely sourced from Osoyoos Lake. Additional information on groundwater use for irrigation supply is needed to fully assess the exceedances of irrigation supply guidelines. Ongoing implementation of groundwater licensing requirements will help to fill these data gaps.

Table 12 shows a high percentage of exceedances of the aquatic life guidelines for arsenic, copper, selenium, uranium, and iron. The aquatic life guidelines are not applicable within the aquifer but rather in Osoyoos Lake, which receives aquifer discharges. Because there is no evidence that these parameters are impairing aquatic health in the lake, the exceedances of the aquatic life guidelines within the aquifer is not an issue of concern.

Summary and Assessment for Metals: Groundwater monitoring results for metals exceed Health Canada drinking water guidelines in wells from three main areas of the Osoyoos Aquifer

- elevated arsenic above the MAC in near shore samples in the northern portion of the aquifer near wells R1 and R5;
- elevated manganese above the MAC in the central portion of the aquifer in wells R37, R36 and R38, and in the north-central portion of the aquifer in wells R10, R11, and R17;
- elevated uranium above the MAC in the north-central portion in well R13; and
- elevated iron above the AO in the central portion of the aquifer in wells R37 and R38.

These metals are often found at elevated levels in glacial aquifer systems like the Osoyoos Aquifer, and occur from natural origins through erosion of aquifer sediments. Excluding the wells listed above, the majority of groundwater monitoring results for metals are below drinking water guidelines, which include hundreds of groundwater samples collected over several decades. The results indicate the majority of the Osoyoos Aquifer is not at risk for elevated levels of metals in drinking water supplies, but exceedances are possible and well owners should periodically test the water for metals.

Exceedances of irrigation supply guidelines for metals could not be fully assessed because there is not enough information on groundwater use for irrigation supply. Exceedances of aquatic life guidelines for metals are not an issue of concern because there is no evidence that metals are impairing aquatic life in Osoyoos Lake.

5.7 Groundwater Quality Assessment for Nitrogen Compounds

5.7.1 Nitrogen Cycle

The nitrogen cycle (Figure 24) occurs on local, regional and global scales, with reactive nitrogen compounds moving among the atmospheric, terrestrial, and aquatic components (Galloway et al., 2003). The only non-reactive form of nitrogen is N_2. The reactive nitrogen compounds include:

- inorganic reduced forms (e.g., ammonia [NH_3], ammonium [NH_4^+]);
- inorganic oxidized forms (e.g., nitrogen oxide [NO_x], nitrous oxide [N_2O], nitrite [NO_2^-] and nitrate [NO_3^-]); and
- organic compounds (e.g., urea, amines, proteins and nucleic acids).

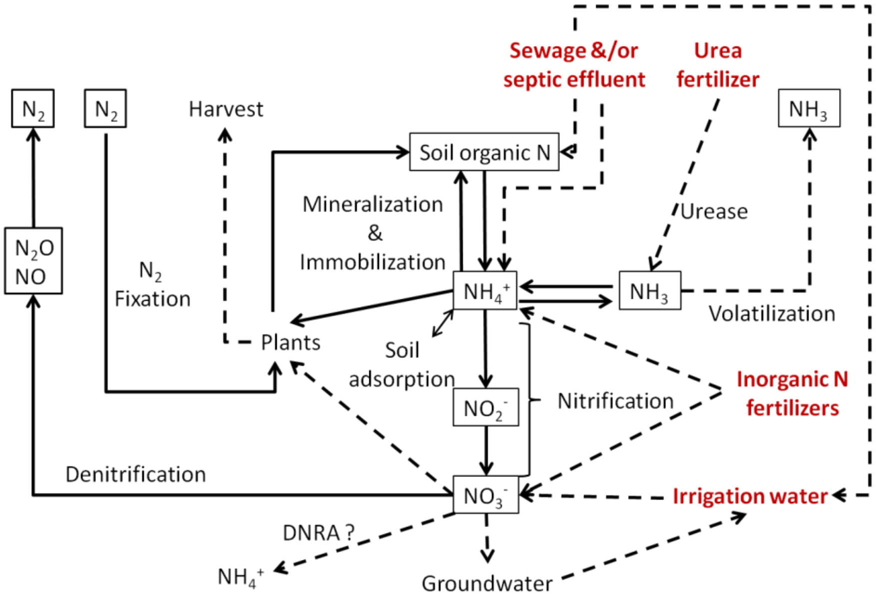

Figure 24: The general nitrogen cycle is shown by solid lines with the different forms of nitrogen in boxes. The surface waters (rivers, lakes and oceans) are excluded but obtain nitrogen compounds from overland flow and groundwater discharge. The sources of nitrogen to the Osoyoos Aquifer are in red and the probable fates of these sources are shown by dashed lines. DNRA = dissimilatory nitrate reduction to ammonium. Source: Gregory (2014).

The nitrogen transformation processes that are important in the Osoyoos Aquifer are:

- ***Mineralization*** - the process where soil microbes convert organic nitrogen in manure, sewage effluent, plant residue, and other organic materials into inorganic reduced nitrogen (NH_3, NH_4^+). Mineralization occurs readily in warm, well-drained and aerated moist soils.

- ***Nitrification*** - the process where ammonium is converted by soil microbes to nitrate. It is a two-step process ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$) but the second step occurs rapidly such that nitrite is not significantly found in the soil column. Nitrification is most rapid when the soil is warm, moist, and well drained and aerated; conditions that are common in the Osoyoos Aquifer during the growing season. Using chemical and stable isotope analyses, Athanasopoulos (2009) showed that nitrate in groundwater and the ADS is predominately derived from nitrification of inorganic fertilizers and was not derived from septic or manure sources, nor from mixing of fertilizer nitrogen and septic/manure nitrogen. Volatilization of NH_3 derived from fertilizer nitrogen also occurred, which can be significant when soil pH is high and when weather conditions are hot (Athanasopoulos, 2009).
- ***Denitrification*** - the process where microbes convert nitrate to gaseous forms of nitrogen (NO, N_2O, N_2) to allow O_2 to become available for microorganisms. Denitrifying bacteria require very low oxygen and therefore is more common in poorly drained saturated soils. The bacteria also require a source of organic carbon, which can be the limiting constraint for denitrification. Athanasopoulos (2009) found some evidence of localized denitrification in a limited number of groundwater samples, but noted that conditions in the study area were generally not favourable for natural remediation by denitrification.

5.7.2 Significance of Nitrate in Groundwater

The accumulation of nitrate in aquifers beneath agricultural lands is well documented (Burkart & Stoner, 2007; Dubrovsky et al., 2010; Puckett, et al., 2011). Inorganic fertilizer use has increased substantially since 1945 (20-fold in the U.S.), corresponding to increasing trends of nitrate levels in groundwater (Puckett et al., 2011). Nitrate is the most plant available form of nitrogen and is highly soluble and mobile in groundwater. It can persist in groundwater for long periods. Because of its mobility, shallow unconfined aquifers are susceptible to nitrate contamination from leaching, particularly well-drained aquifers underlying agricultural areas like the Osoyoos Aquifer.

High levels of nitrate in drinking water are a health risk, especially for young children. Nitrate is digested into the more toxic nitrite, which bind with hemoglobin molecules forming methaemoglobin. An excess of methaemoglobin limits the uptake and release of oxygen resulting in a condition referred to as methaemoglobinaemia or blue-baby disease (Health Canada, 2013). Health Canada has set the drinking water guideline at 10 mg-N/L based on methaemoglobinaemia as the endpoint of concern.

Groundwater in shallow alluvial aquifers eventually discharges to surface waters including streams, wetlands and lakes. When high levels of nitrate accumulate in an aquifer, the resulting nitrate loads to surface waters from groundwater discharges can be substantial, particularly in baseflow to streams. Increased nutrient levels in surface waters potentially contribute to eutrophication, which affects the health and abundance of fish and other components of surface water ecosystems (Dubrovsky et al., 2010). B.C. has established nitrate water quality guidelines to protect aquatic life. The 30-day average concentration to protect freshwater aquatic life is 3.0 mg-N/L (B.C. ENV, 2017b). However, the drinking water criterion (10 mg-N/L) is the initial focus for discussion in the following assessment because there is substantial dilution in the transition from groundwater to surface water.

5.7.3 Nitrogen Monitoring Data

This study considers groundwater monitoring data from various sources including ENV/FLNRORD, ECCC, Athanasopoulos (2009), and the Town of Osoyoos. However, the selected parameters and quality control procedures differ among these sources. The available nitrogen data include ammonia, nitrate, nitrite, nitrate+nitrite, Total Kjeldahl nitrogen (TKN), organic nitrogen, and total nitrogen (TN), which is the sum of the inorganic and organic forms of nitrogen. For this assessment, nitrate data are combined with the nitrate+nitrite data because nitrite is not detected in nearly three-fourths of the samples (detection limit 0.002 to 0.005 mg/L), and if present, nitrite concentrations are small and insignificant in comparison to nitrate concentrations.

TKN is a measure of organic nitrogen plus ammonia, but the ammonia levels (Table 12) indicate it is a small part of the TKN. Even with a small contribution of ammonia, the organic nitrogen (TKN minus ammonia) is a minor part of the reactive nitrogen in the groundwater. Nitrate is by far the major form of reactive nitrogen in the Osoyoos Aquifer (Table 12) and is also the major nitrogen constituent of concern. For these reasons, this assessment focuses on nitrate-nitrogen.

5.7.4 Groundwater Nitrate Monitoring Data

Groundwater monitoring data for nitrate are available from 43 wells throughout the aquifer spanning over three decades. Samples were typically collected once per year, generally in the late summer and fall, but there is no consistency in the collection timing. The seasonal timing of sample collection was not considered in this assessment, although groundwater nitrate levels are likely influenced by the seasonal nutrient application.

Box plots of groundwater nitrate data show variability in nitrate levels throughout the aquifer (Figure 25). Some wells have median nitrate levels near or above the drinking water MAC. Other wells show low to moderate nitrate levels with narrow ranges of about 2 to 8 mg-N/L. About one-third of all nitrate data exceed the drinking water MAC and 80% exceed the provincial aquatic life guideline (Table 12). 92% of nitrate results exceed 1 mg-N/L, which is considered a background level for nitrate in glacial aquifer systems (Dubrovsky et al., 2010; Warner & Ayotte, 2014). Nitrate concentrations above background levels are suggestive of sources from human activities.

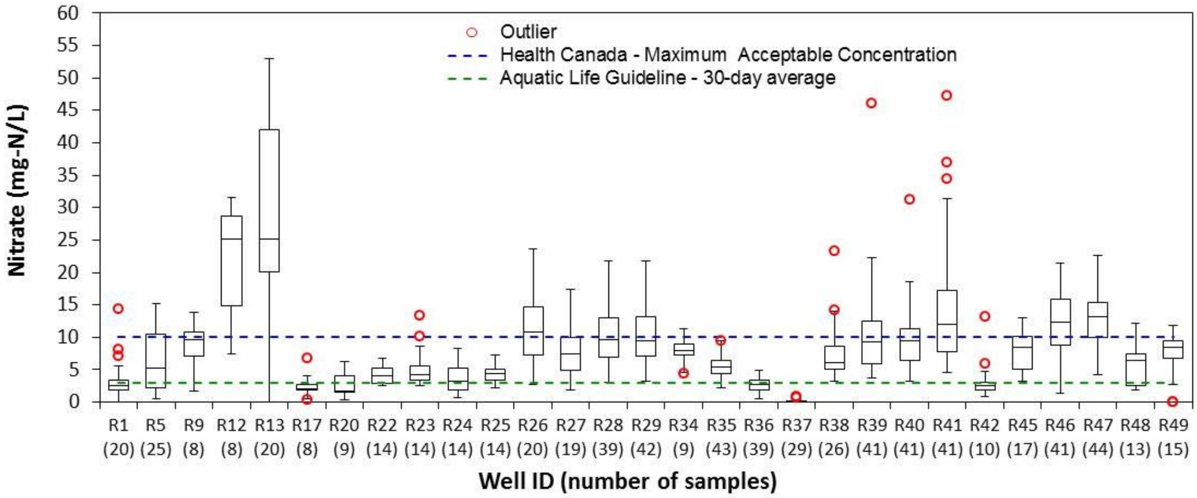

Figure 25: Box plots of groundwater nitrate concentration data collected between 1985 and 2018 at sampling locations shown in Figure 4.

The available nitrate data span a wide period and have trended over time. High levels of nitrate in the aquifer during the 1980's and 1990's have trended downward (Figure 26) and Athanasopoulos (2009) noted that 50% of groundwater samples in her study exhibited a decreasing trend and that nitrate concentrations in the ADS decreased three-fold between 1997 and 2008. This decrease is attributed to improved fertilizer use and management and possibly a shift to increased vineyard production, which requires less fertilizer application. After 2000, the range of nitrate measurements is relatively steady between 0 to 20 mg-N/L, and recent sampling after 2014 show occasional exceedance of the drinking water MAC. Figure 26 also shows periods of intensive sampling in the 2000's when investigations by

ECCC and Athanasopoulos (2009) were active. FLNRORD continues to monitor groundwater quality on an annual basis but at progressively fewer locations as development pressures have reduced access and availability of monitoring wells. Six wells were sampled by FLNRORD in 2018.

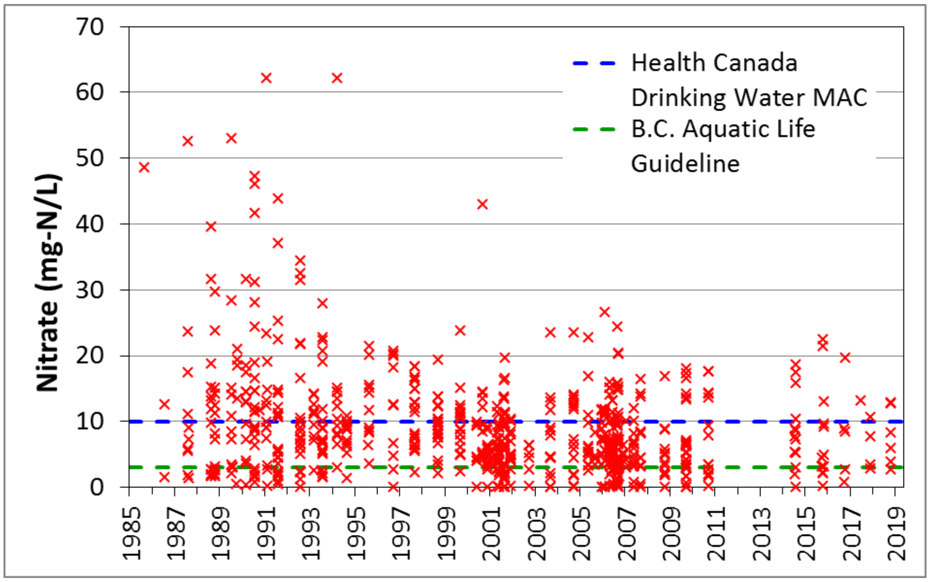

Figure 26: Nitrate time series measurements throughout the Osoyoos Aquifer.

Figure 27 and Figure 28 show time series plots of nitrate monitoring data from the northern and southern half of the aquifer, respectively. The data include FLNRORD monitoring data from active and inactive wells, data from special studies by ECCC and Athanasopoulos (2009), and data available from the Town of Osoyoos reports.

In the northern portion of the aquifer, residential homes are concentrated along the shoreline where water supply is provided by the Town of Osoyoos municipal and irrigation systems, but an unknown number of private domestic wells are still in use. Long-term monitoring results from near-shore domestic wells R1 and R5 (Figure 27A) show low to moderate nitrate levels (1 to 4 mg-N/L) over much of the last decade, which are below the drinking water MAC but indicative of anthropogenic inputs. This may reflect improved agricultural practices in upgradient areas or the influence of the residential sewer connections to the NW municipal sewer system extension completed in 2012.

Away from the shoreline, agriculture is the dominant land use and several wells located in agricultural areas show significant long-term downward trends in nitrate levels (R9, R12, and R13), and nitrate levels that are generally below 6 mg-N/L (R17, R20, and R22 to R25) (Figure 27B, C, D). Unfortunately, these wells have not been sampled since about 2010 so that current nitrate levels throughout much of this agricultural area are unknown.

Recent data are available from a group of near shore wells (R26 to R29) that are down-gradient from agricultural activities. Time series plots for these wells mirror downward nitrate trends prior to 2010 as observed in other wells, but also show somewhat increasing nitrate levels after 2010 with a few samples exceeding the drinking water MAC (Figure 27E). This indicates elevated nitrate levels persist in this portion of the aquifer where agricultural is the dominant land use.

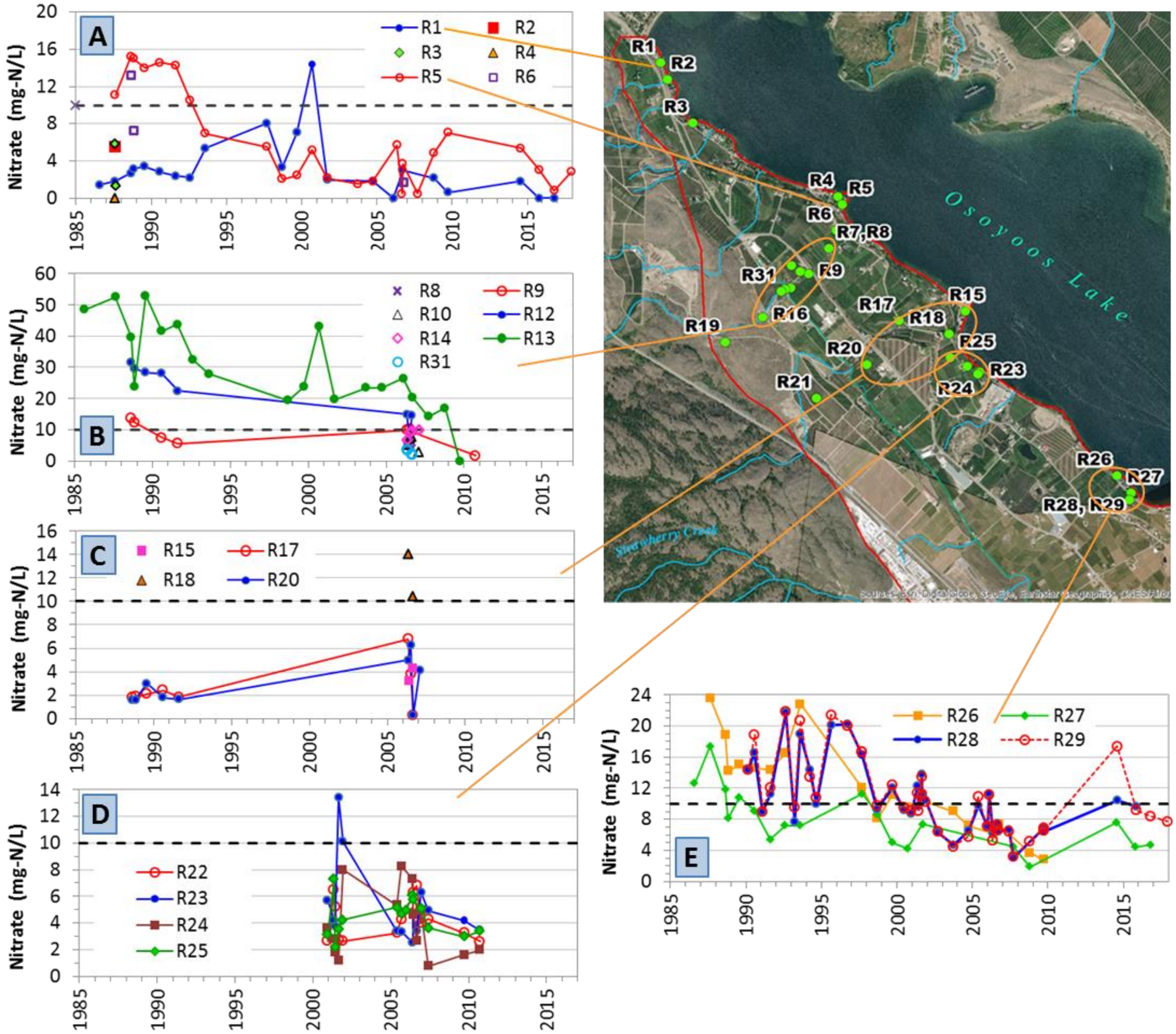

Figure 27: Nitrate time series plots from wells in the northern portion of the Osoyoos Aquifer. The horizontal dashed line is the Health Canada drinking water MAC.

Groundwater monitoring wells in the southern portion of the aquifer are influenced by a variety of land use activities, including urban development (wells R35, R36, R37), agricultural areas (wells R42, R45, R48, R49), wastewater irrigation (R41, MW5-10), or a combination of these activities (Figure 28).

Wells R35, R36 and R37 are closely spaced wells located in residential areas adjacent to Peanut Lake. These wells are designed to assess groundwater quality at three depth intervals: shallow (R37, 8.6 m), intermediate (R36, 10.6 m) and deep (R35, 13.4 m). Monitoring results (Figure 28A) show a strong association between nitrate concentration and sampling depth, with smallest nitrate concentrations measured in the shallow well (R37) and highest nitrate concentrations (~3 to 10 mg-N/L) in the deep well (R35). Increasing nitrate levels with depth suggests groundwater monitoring results are influenced by mixing and dilution with lake water from Peanut Lake, with more dilution occurring in the shallower well. The nitrate levels in the deeper and intermediate wells are consistently below the drinking water MAC, but generally in a moderate range (~2 to 6 mg-N/L) indicating persistent anthropogenic inputs. The potential upgradient sources include urban, agricultural and wastewater irrigation land uses.

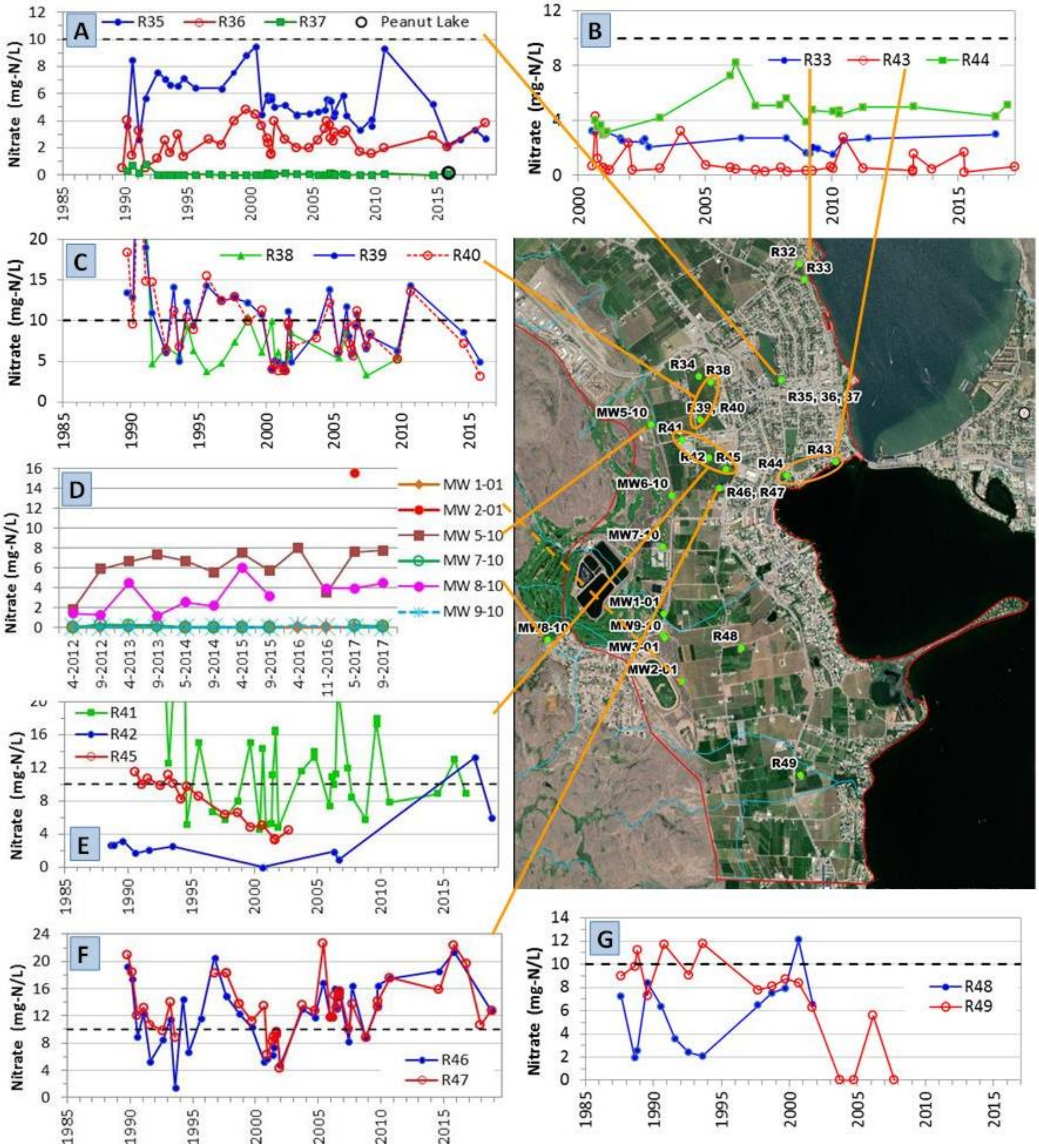

Figure 28: Nitrate time series plots from wells in the southern portion of the Osoyoos Aquifer. The horizontal dashed line is the Health Canada drinking water MAC.

Wells R33, R43, and R44 are Town of Osoyoos water supply wells. The Town regularly monitors the wells for nitrate levels and publishes results in annual water reports (Town of Osoyoos, 2017). Reported nitrate levels in these wells are consistently below the Health Canada MAC, ranging from less than 1 to about 5 mg-N/L (Figure 28B). The nitrate concentrations are fairly steady over time, but the levels in individual wells are influenced by mixing and dilution with lake water that is drawn into the wells. Western Water (2012) showed water supply from the municipal wells is a mixture of groundwater and lake water and the ratio is associated with well depth, distance from shore, and pumping quantity.

Water supplies from wells that are closer to shore (R33 and R43) have a greater proportion of lake water drawn into the well, which is reflected by lower nitrate concentrations due to dilution. In comparison, well R44 is further from the shoreline, resulting in a lower proportion of lake water drawn into well and water quality that is more reflective of the upgradient groundwater, including higher levels of nitrate.

Monitoring wells R38, R39, R40, and R41 are within agricultural areas that are sandwiched between downgradient municipal areas and up-gradient wastewater irrigation areas. Monitoring data from these wells (Figure 28C, E) show nitrate levels consistently above 4 mg-N/L and generally within a range of about 4 to 14 mg-N/L over a 30-year time span. This implies a persistent, long-term source likely associated with agricultural activities. Similarly, nitrate data from R46 and R47 are consistently in the range of 4 to 20 mg-N/L and frequently exceed the drinking water MAC (Figure 28F). Wells R42 and R45 are in the same area but show lower and downward trending nitrate levels prior to 2007 (Figure 28E). Two recent samples from R42 in 2017/18 show an increase in nitrate levels above 4 mg-N/L. Collectively, plots from these wells indicate moderate to high levels of nitrate, sometimes exceeding the drinking water MAC, persist in this portion of the aquifer and may be increasing in some wells.

Disposal of WWTP effluent on the golf course irrigation areas could potentially contribute to nitrate concentrations observed in the down-gradient monitoring wells within the agricultural and urban areas. However, the WWTP groundwater monitoring data are not definitive and show variable nitrate results (Figure 28D). Low nitrate levels near or below the detection limit were consistently measured between 2012 and 2017 in wells MW1-01, MW7-10 and MW9-10. In contrast, two wells, MW5-10 and MW8-10, show moderate nitrate levels in the range of 2 to 8 mg/L, both with a visually increasing trend over time. However, well MW8-10 is up-gradient of the golf course, indicating the nitrate source is not related to reclaimed water irrigation and is from other up-gradient sources. Nitrate measured in a single sample from well MW 2-01 in 2017 was above the drinking water MAC at 15.6 mg-N/L. Higher nitrate levels in MW5-10 and MW2-01 were also accompanied by higher chloride concentrations often exceeding the drinking water AO (250 mg/L), which is suggestive of WWTP effluent. All other monitoring wells had low chloride levels, typically below 30 mg/L. Collectively, the WWTP groundwater monitoring data show inconsistent results. Data from three monitoring wells indicate disposal of WWTP effluent is not impacting groundwater quality, while data from three other wells suggests nitrate and chloride could be entering groundwater from portions of the golf course irrigation areas or from upgradient sources, potentially at increasing levels.

Wells R48 and R49 are inactive monitoring wells within agricultural areas in the south end of the aquifer. Both wells show moderate to high nitrate concentration prior to 2001, diminishing to low levels in R49 around 2003-07 (Figure 28G). The current nitrate levels throughout the south end of the aquifer are unknown, which includes large areas of agricultural land use, rural residential areas, and areas downgradient from wastewater irrigation and infiltration facilities at the Desert Park.

5.7.5 Nitrogen Loading Estimates

Existing and future nitrogen loads to the Osoyoos Aquifer and Osoyoos Lake cannot be quantified with a high level of confidence from available information. The following are approximations and qualitative evaluations of nitrogen loadings.

Agricultural loads to Osoyoos Aquifer: Fertilizer application in agricultural areas is the major source of nitrogen loads to the aquifer. Growers primarily use synthetic inorganic fertilizers, including ammonium sulphate, calcium nitrate, and orchard blends. Ammonium nitrate widely used in the 1980’s and early 90’s is less commonly used and the use of manure for fertilizer is not common (Athanasopoulos, 2009). Application rates for fruit trees is reported to roughly range from 40 to 200 kg-N/ha/yr, and less for apple orchards (<70 kg-N/ha/yr) and vineyards (about 40 kg-N/ha/yr) (Athanasopoulos, 2009). The fraction of nitrogen application that leaches to groundwater could be in the range of 20 to 60% depending on crop type (Viers et al., 2012). Assuming an average nitrogen application rate of 70 kg/ha/yr over 600 ha, a gross estimate of nitrogen loads to the aquifer ranges from about 8,400 to 25,000 kg-N/yr. Future loads are likely to be similar to current loads, provided there is no major shift in agricultural production and practices.

Wastewater irrigation loads to Osoyoos Aquifer*:* Irrigation areas for reclaimed wastewater are potential sources of nitrogen loads if the application rates exceed ET demand or if local soil conditions allow for rapid percolation to the water table (Section 4.3). A monthly water budget for 2013 suggests application rates may exceed ET demand by about 20%, based on average monthly information (Appendix B). For 2013, this amounted to about 175,000 m^3 of aquifer recharge from reclaimed wastewater. Total nitrogen levels in the reclaimed water supply ranges from 15 to 25 mg-N/L (Figure 19). However, only a fraction of this will reach the groundwater table as turf grass is efficient at sequestering nitrogen (Viers et al., 2012). This is somewhat supported by the Town's groundwater monitoring program, which has measured low nitrate concentrations below 2 mg-N/L in monitoring wells downgradient of the golf course. However, a few wells, including one upgradient of the golf course show moderately high nitrate in the range of 2 to 7 mg-N/L. Assuming 10 to 40% of the applied nitrogen may leach past the root zone, the estimate for nitrogen loading from reclaimed water irrigation ranges between 250 to 1750 kg/year. This estimate depends greatly on the irrigation rate relative to the ET demand. Future loads from wastewater irrigation will depend on disposal practices and the area available for irrigation. The existing loading rates will likely remain unchanged or could increase because of increasing influent to the WWTP with increasing population (TRUE, 2012; KWL, 2014).

Wastewater infiltration loads to Osoyoos Aquifer*:* The Town disposes of surplus wastewater effluent in infiltration beds near Desert Park in accordance with their Operational Certificate. Effluent disposal in the infiltration facility is considered a temporary measure to reduce surplus but has occurred in four of five years between 2013 and 2017 with an average volume of about 50,000 m^3/year (Table 10). The average total nitrogen concentration in the wastewater effluent is in the range of 10 to 20 mg-N/L (Figure 19), resulting in a potential nitrogen load of 500 to 1000 kg/year. Because wastewater infiltration is not a routine practice, these potential loadings may or may not occur in any given year. Future loads depend on the need for disposal of surplus effluent. Loads could remain at current levels or increase if adequate irrigation area is not available.

Municipal landfill loads to Osoyoos Aquifer: Potential nitrogen loadings from the landfill area include leakage from the landfill cells, infiltration from the composting area, and leakage from the sludge and septic waste disposal lagoons. However, data are not available to estimate nitrogen loads from the landfill and composting areas. Groundwater monitoring data from the 2012-17 suggest there is some degree of nitrogen loading, as TN concentrations typically range from low to moderate levels (1-8 mg-N/L) and are occasionally measured at very high levels above 100 mg-N/L (Table D1).

The volume of liquid waste added to the waste disposal lagoons in 2014 was 2000 m^3, with about 2% removed as sludge. Nearly all the liquid waste either evaporates or infiltrates into the subsurface, but the proportion is unknown. A TN concentration of 194 mg/L was measured in the lagoon in 2014, but a fraction of this is subject to settling or volatilization such that the concentration of dissolved nitrogen reaching groundwater is expected to be less. Assuming half of the liquid waste infiltrates to groundwater, and further assuming a dissolved nitrogen concentration in the range of 50 to 100 mg/L, a gross estimate of nitrogen loading from the disposal lagoons is on the order of 50 to 100 kg/yr.

Septic system loads to Osoyoos Aquifer: Nitrogen in septic system effluent is dominated by ammonium, which is subject to nitrification in the aerobic soil layer below the leach field. There is generally limited removal of nitrogen in the leach field in the range of 1 to 15% (Viers et al., 2012).

Therefore, a majority of the nitrogen in the septic tank effluent is likely to reach the groundwater table as nitrate. Athanasopoulos (2009) estimated the nitrate-N loading from individual septic wastes at roughly 7 kg- N/year/household, assuming complete oxidation of organic nitrogen to nitrate. The calculation is based on an average TN concentration in the effluent of 53 mg/L, an average effluent volume of 140 L/day/person, and an average 2.5 persons/household. For comparison, Viers et al. (2012) conservatively estimated nitrate loading from septic systems at 4.125 kg/person/year, which is about 10 kg-N/year/household for an average 2.5 person household.

Rural residences outside of the municipal boundary rely on individual septic systems except for lakeshore residence north of the municipal boundary that have connected to the NW sewer extension. Information about the number of active systems is not readily available, which could be in the range of 100 to 300 or more based on the number of lots and population estimates outside of the municipal boundary (KWL, 2014). Based on these values, the estimated nitrogen loading from septic systems is between 700 to 3000 kg-N/yr. Future loads from septic systems are uncertain. They could increase with significant residential development in rural areas or could decrease if the Town further expands sewer service to rural areas.

Municipal area loads to Osoyoos Aquifer: There is substantial outdoor water use within the municipal boundary during the summer growing season and associated fertilizer use and nitrogen leaching from residential landscaping is a potential load to the aquifer. These loads have not been estimated due to lack of information on the amount of landscape area and the types and quantities of fertilizers applied to these areas.

Leakage from municipal sewer lines and holding basins is another possible source of nitrogen loading. Hydraulic loading calculations for the holding basins indicate that unaccounted losses are roughly balanced by potential evaporation losses suggesting limited losses from the holding basins (TRUE, 2018a; 2017a; 2016a). There is no information on losses or spills from sewer lines during dry weather conditions and therefore could not be estimated.

Irrigation system loads to Osoyoos Aquifer: Large volumes of lake water are used for agricultural irrigation. Although lake water has low concentrations of nitrogen, the large volume of water used for irrigation cumulatively results in a meaningful nitrogen load to the aquifer. A monthly water budget for 2013 (Appendix B) suggests about 40% of the irrigation water recharges the aquifer, or roughly 2,700,000 m^3/yr. Lake monitoring information indicates an average TN concentration in the north and central basins over the growing season is roughly 0.28 mg/L (Sokal, 2017). However, a fraction of this nitrogen is subject to uptake. Assuming 20 to 60% of the nitrogen leaches to the groundwater table, a gross estimate of nitrogen loads from irrigation water is in the range of 150 to 450 kg-N/yr. Future loadings would likely remain relatively unchanged, in the absence of significant changes to current irrigation practices, irrigation demand, or nitrogen levels in Osoyoos Lake.

Agricultural drainage system loads to Osoyoos Lake: Athanasopoulos (2009) measured flow rates and nitrate levels in the ADS between 2006 and 2008 (Figure 29). Measured flows ranged from 2 to 18 L/s at outfall 2 (northern system) and from 0.01 to 8 L/s at outfall 3 (southern system). The flows generally correspond to the irrigation cycle, increasing over the summer/early fall and decreasing over the winter/spring. Measured nitrate concentrations at the two outfalls were variable, ranging from 1 to 10 mg-N/L (Figure 29). Nitrate levels at outfall 3 generally correspond to flow rate, increasing during the growing season and decreasing in the non-growing seasons. The pattern was different at outfall 2 where nitrate levels appear to decrease or remain stable during the growing season and increase in the non-growing season.

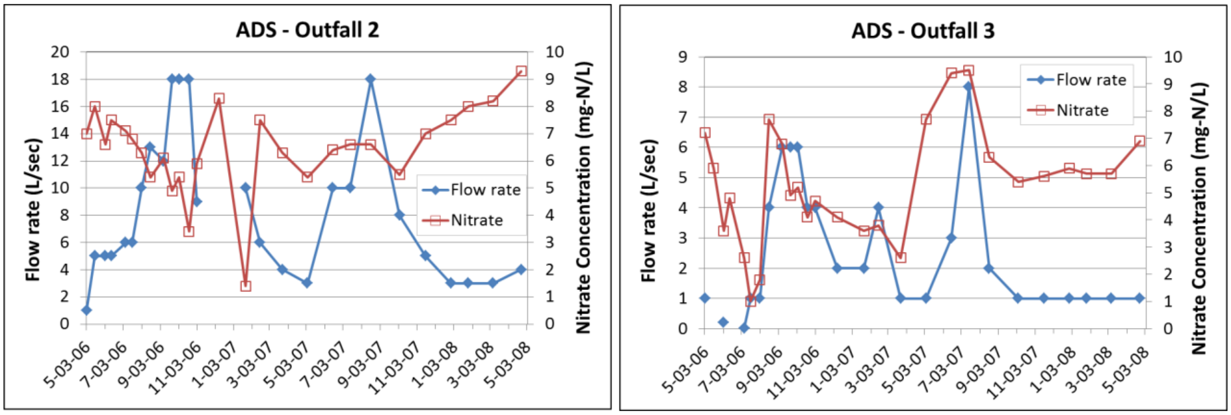

Figure 29: Measured flows and nitrate concentration at agricultural drainage system outfalls to Osoyoos Lake. Source: (Athanasopoulos, 2009).

Flow rates and nitrate concentration measured at the ADS outfalls provide nitrate loadings estimates from the ADS. Calculated daily nitrogen loads vary from about 0 to 10 kg-N/day, with generally much greater loads at outfall 2 (Figure 30). Loading rates tend to correspond to the irrigation cycle, increasing in the summer and decreasing in the winter. The estimated total annual nitrogen load to Osoyoos Lake is about 1500 kg-N/year at outfall 2, and about 400 kg-N/year at outfall 3. This is a direct point source to Osoyoos Lake.

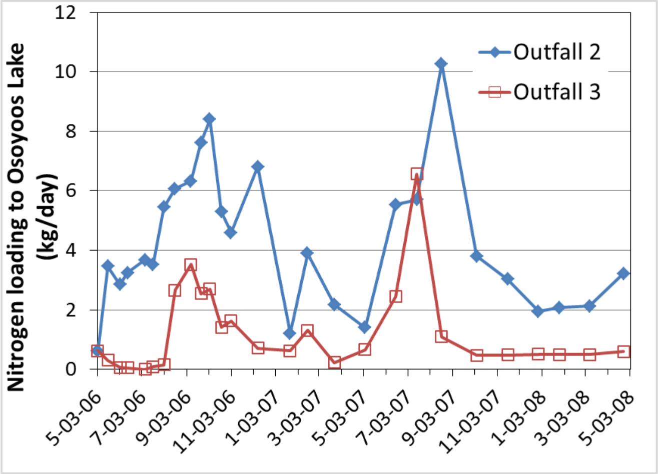

Figure 30: Nitrogen loads to Osoyoos Lake from agricultural drainage systems. Loads are calculated from flow and nitrate measurements by Athanasopoulos (2009).

The current loads from the ADS are unknown as regular flow and water quality measurements from the outfalls are not available after 2008. A single water quality sample was collected from discharge at outfall 3 in December 2017, measuring nitrate at 4.7 mg-N/L. This is similar to nitrate levels measured in December 2006 (4.1 mg-N/L) and 2007 (5.9 mg-N/L), which suggests nitrogen loads in Figure 30 persist and may continue indefinitely into the future.

Groundwater discharge loads to Osoyoos Lake: Estimates of nitrogen loads in groundwater discharge to Osoyoos Lake were determined with median groundwater discharge values along six aquifer sections (Figure 13) and estimates of groundwater nitrate concentrations from monitoring information (see Appendix C, Table C2). The estimated loads range from about 8,000 to 23,000 kg-N/year. There are many inherent uncertainties in these load estimates, which are gross approximations.

Summary of nitrogen load estimates: The loading estimates indicate agricultural fertilizer application is the dominant source of nitrogen loads to the Osoyoos Aquifer (>80%) with lessor contributions from septic systems and reclaimed water irrigation (Table 13). There are unaccounted loads from the landfill and urban contributions from residential landscaping.

Assuming negligible denitrification in the aquifer, 90% of the nitrogen loads emanating from the aquifer is by nonpoint source groundwater discharge into Osoyoos Lake, and about 10% is from point source discharge through the ADS. The total estimated nitrogen load to Osoyoos Lake roughly balances with the estimated loads to the aquifer, indicating the Lake and downstream waterbodies are the main receiving waters of nitrogen loads to the aquifer.

Table 13: Summary of estimated nitrogen loads to Osoyoos Aquifer and Osoyoos Lake.

Source	**Nitrogen Load (kg-N/year)**			**Fraction of total median load**
	Low estimate	High estimate	Median estimate	
Loads to Osoyoos Aquifer				
Agricultural fertilizer application	8,400	25,000	16,700	84%
Reclaimed wastewater irrigation	250	1,750	1,000	5%
Wastewater infiltration at Desert Park*	500	1000	750	
Municipal Landfill – sewage ponds	50	100	75	<1%
Municipal Landfill – compositing and landfill cells	No estimate	No estimate		
Septic systems	700	3,000	1,850	9%
Irrigation supply	150	450	300	2%
Municipal area residences and leaky sewer lines	No estimate	No estimate		
Total nitrogen load to Osoyoos Aquifer	**9,550**	**30,300**	**19,925**	
Loads to Osoyoos Lake				
Groundwater discharge	8,250	23,000	15,650	89%
Agricultural drainage system	1,900	1,900	1,900	11%
Total nitrogen load to Osoyoos Lake	**10,150**	**24,900**	**17,550**	

* Occurs irregularly in years when facilities are in use. Loading estimate from effluent infiltration is not included in the total aquifer load, but is shown to indicate potential loads in years when the facilities are in use.

5.7.6 Nitrate – Water Quality Assessment

Information and awareness of nutrient management has led to a reduction of very high nitrate concentrations measured in the 1980/90's. Moderate to high nitrate concentrations above the drinking water MAC persist and may be increasing in portions of the aquifer, particularly in the central portion where there is confluence of potential sources from agriculture, residential development, and wastewater irrigation. Additional source analyses and targeted monitoring is needed to better identify the nitrogen sources and to reduce uncertainties in the loading estimates.

Future nitrogen loads to the aquifer are likely to remain at current levels or could possibly increase because of the widespread fertilizer use in agricultural areas, and the potential increases in urban related sources (residential landscaping, wastewater effluent) with projected increases in population. Factors that could potentially reduce nitrogen loads are a reduction in agricultural production, source control measures to reduce fertilizer applications in urban areas, and reductions in the individual septic systems.

5.8 Groundwater Quality Assessment for Phosphorus

5.8.1 Phosphorus Cycle

Phosphorus moves within and between the terrestrial and aquatic systems via physical, chemical and biological processes. The gaseous component is negligible. Phosphorus in soil occurs in inorganic and organic forms (Brady & Weil, 2002), which are shown as general compartments on the right and left of Figure 31, respectively. Soluble phosphorous that is readily available to plants from soil moisture is predominately in the form of dissolved phosphate and is generally reported as orthophosphate. Orthophosphate in soil moisture occurs as $H_2PO_4^-$ in acidic conditions, PO_4^{3-} in very alkaline conditions, and HPO_4^{2-} in intermediate (pH 6 to 8) conditions (Brady & Weil, 2002). Dissolved phosphorus also includes the calcium-based phosphates (Brady and Weil, 2002).

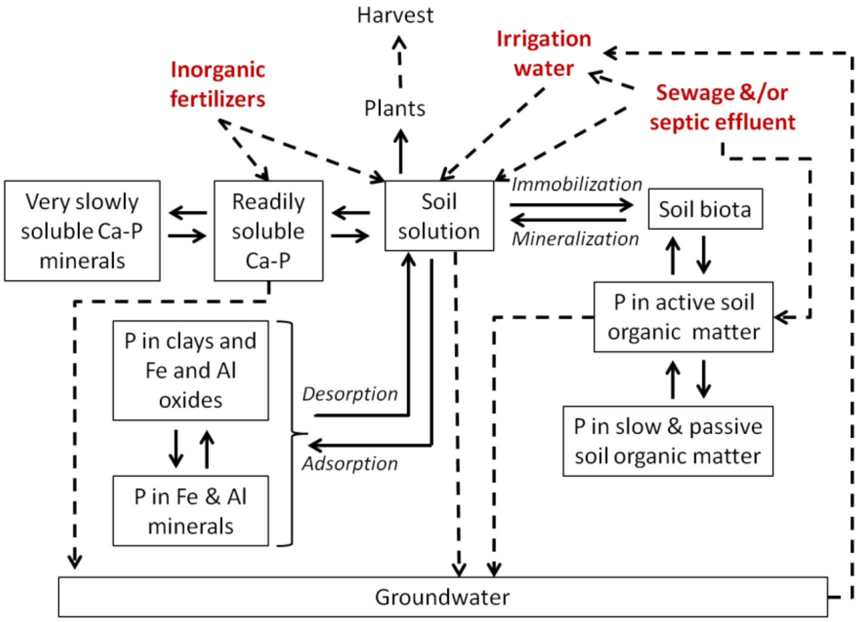

Figure 31: The general phosphorus cycle is shown by solid lines with the different compartments for phosphorus in boxes. The surface waters (rivers, lakes and oceans) are excluded but obtain phosphorus compounds from overland flow, subsurface flow and groundwater discharge. The sources of phosphorus to the land over the Osoyoos Aquifer are in red and the probable fates of these sources are shown by dashed lines. Source: Gregory (2014).

Although orthophosphate is soluble in water, it readily binds or adsorbs to soil particles, particularly in soils with clay particles or soils that are rich in fine-grained iron oxides or calcium carbonate (Domagalski & Johnson, 2012). Concentrations of soluble phosphorus in groundwater are often low, and where elevated levels occur, it is often associated more with natural geologic sources rather than anthropogenic sources (Dubrovsky et al., 2010). As a result, phosphorus is commonly assumed to be adsorbed and unavailable for movement in groundwater (Holman et al., 2008; USGS, 2017). This is reflected in groundwater sampling protocols that frequently omit phosphorus, such as studies in the Osoyoos Aquifer by ECCC and Athanasopoulos (2009). Western Water (2011) recommended discontinuing phosphorus analyses in the ambient networks, including the Osoyoos Aquifer, and the assessment of surface water quality objectives for Osoyoos Lake neglected groundwater contributions based on its assumed immobility (Jensen et al., 2012).

While adsorption mechanisms retard phosphorus mobility in the subsurface, soils have a limited capacity to store phosphorus. Once the capacity of soil to adsorb phosphorus is exceeded, the excess phosphorus will dissolve or remain in solution, where it can then move more freely with soil moisture and percolate downward to an aquifer. Conditions that can limit phosphorous adsorption include the lack of available surface area on mineral oxides and clay particles, low oxygen levels, high pH above 7, and excess application of soluble phosphorus (Domagalski & Johnson, 2012).

There is growing awareness that phosphorus mobility in groundwater systems is significant in certain settings and associated groundwater discharges to streams and lakes can be an important source of phosphorus loadings to surface waters (Holman et al., 2008; Lewandowski et al., 2015; Meinikmann et al., 2015). Documented cases of phosphorus mobility in groundwater systems occur from a variety of phosphorus sources, including: manure and inorganic fertilizer use in agricultural areas (Dubrovsky et al., 2010; Domagalski & Johnson, 2012); land application of wastewater (McCobb et al., 2003; USGS, 2017); septic system discharges (Robertson et al., 1998; Robertson & Harman, 1999); and natural geologic sources (Kelly et al., 1999). There is also evidence that phosphorus sorption is reversible such that desorption of accumulated phosphorus in soils can be a persistent and long-term source to groundwater and surface water bodies (Walter et al., 1996; Robertson, 2008).

The potential for phosphorus mobility in the Okanagan Basin was recognized in a 2009 agronomic and environmental survey of soil chemical and physical properties (Kowalenko et al., 2009). The study found most Okanagan-Similkameen soils had high to very high phosphorus contents with limited phosphorus binding capacity relative to Lower Fraser Valley soils. The study concluded that attention is required for appropriate application rates of phosphorus amendments and management practices that minimize the potential for phosphorus transport to surface water.

5.8.2 Significance of Phosphorus in Groundwater

Health Canada has not established drinking water objectives for phosphorus as common environmental levels of phosphorus in drinking water supplies from both surface and groundwater sources is not a heath concern. B.C. has established an aesthetic guideline for total phosphorus (0.01 mg/L) in lakes used as a source of drinking water supply to protect against algae growth (Nordin, 2001). While Osoyoos Lake does provide drinking water supply for rural residences during the irrigation season, any exceedance of the aesthetic guideline for phosphorus does not pose a health concern unless there was a formation of potentially toxic algae blooms. B.C. has also established an ambient recreational water quality guideline for total phosphorus (0.01 mg/L) to ensure safe water clarity (Prov. of B.C., 2017d).

The main interest and issue of concern regarding phosphorus inputs to groundwater is the possible movement of phosphorus in groundwater discharges to Osoyoos Lake and the contribution of these inputs to eutrophication of the Lake. Phosphorus enrichment of Osoyoos Lake is a long-term issue of concern. B.C. has established water quality objectives for the lake, including a springtime objective for total phosphorus of 0.015 mg/L, and objectives for water clarity and algae production (Table 11). Although the site-specific objective for phosphorus in Osoyoos Lake is greater than the guideline values for protection of drinking water supply and recreational uses, it is considered protective of the most sensitive uses of the lake (Jensen et al., 2012).

The Osoyoos Lake water quality objectives report and recent attainment report did not consider groundwater sources of phosphorus to the lake because phosphorus sources from fertilizer application were considered to be limited, and because phosphorus mobility in groundwater was assumed negligible. However, both reports include recommendations to improve understanding and estimates of nonpoint nutrient sources to the lake. The following assessment supports this recommendation by summarizing the available phosphorus monitoring data from the aquifer, by evaluating the potential groundwater contribution of phosphorus to Osoyoos Lake, and by identifying potential phosphorus sources to the aquifer.

5.8.3 Phosphorus Data Summary

FLNRORD has monitored phosphorus levels in the Osoyoos Aquifer since 1985. Data are available for total phosphorus, total dissolved phosphorus, and ortho-phosphate. The ortho-phosphate data, however, are not considered further in this assessment because the data are not recent (they were collected only until September 2001), the number of data are limited in comparison to data for total and dissolved phosphorus, and because 62 of the 74 analyses were less than the detection limit of 0.05 mg/L.

There are more than 400 samples of total and dissolved phosphorus collected concurrently from the aquifer since 1985 (Table 12). For most samples the concentration of dissolved phosphorus is similar to the concentration of total phosphorus (Figure 32), indicating a high fraction of the total phosphorus is in the dissolved phase. Because the dissolved form of phosphorus will migrate with groundwater flow, there will be a net contribution of phosphorus to the lake from groundwater discharges. In addition, groundwater quality data indicate a large majority of measured phosphorus concentrations exceed the Osoyoos Lake objective (Table 12).

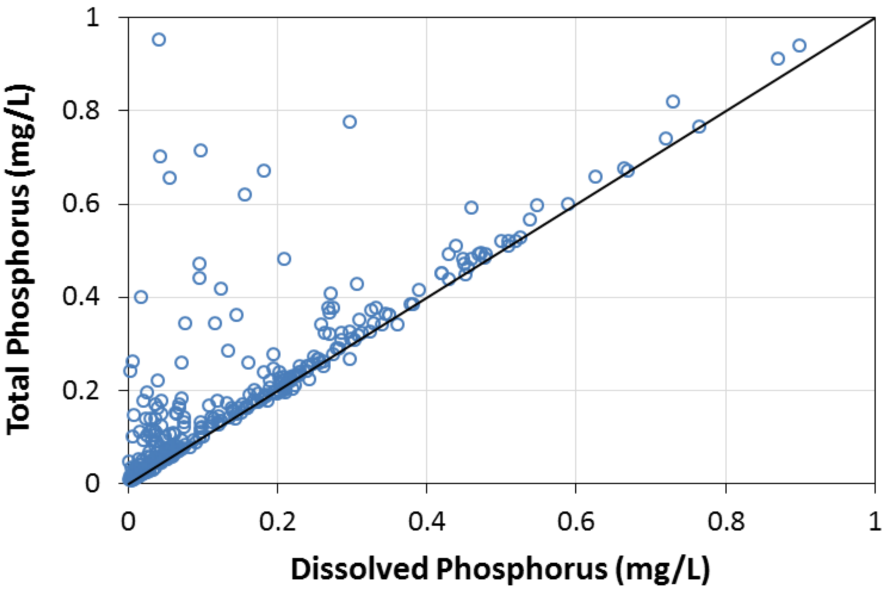

Figure 32: Comparison of dissolved and total phosphorus concentration in groundwater samples from the Osoyoos Aquifer.

Box plots of phosphorus monitoring data show variability in phosphorus levels throughout the aquifer (Figure 33). Lowest ranges of phosphorus are more prevalent in the middle portion of the aquifer. Greatest ranges in phosphorus occur at the northern end of the aquifer and adjacent to the central and south basins. Median phosphorus levels exceed the Osoyoos Lake objective in nearly all wells, often by more than an order of magnitude. A time series plot of phosphorus data collected throughout the aquifer shows some reduction of high levels above 0.6 mg/L in the 1980’s and 1990’s (Figure 34). However, monitoring results after 2010 show groundwater phosphorus levels persist well above the lake objective ranging above 0.2 mg/L.

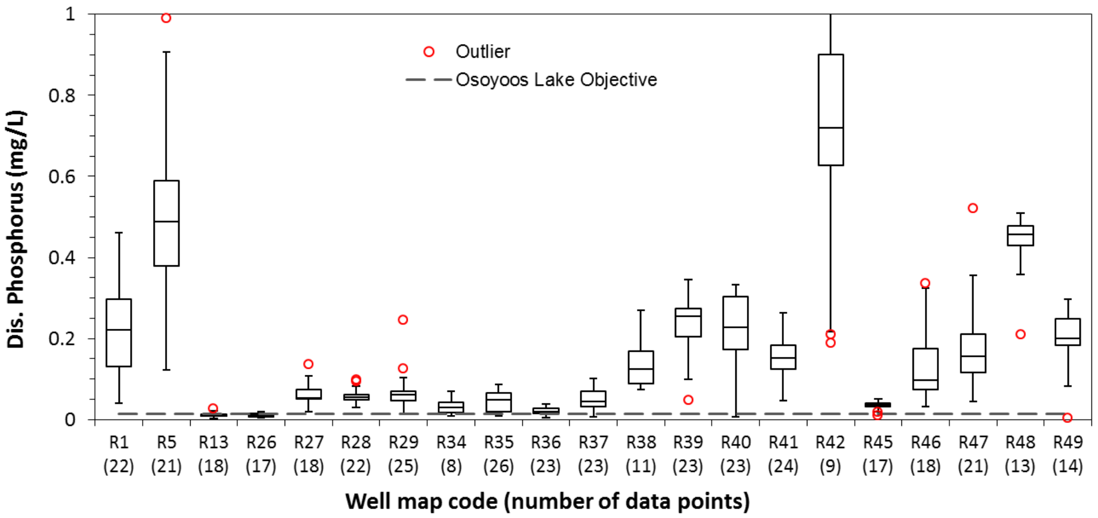

Figure 33: Box plots of groundwater phosphorus concentration data collected between 1985 and 2018 at sampling locations (map codes) shown in Figure 4.

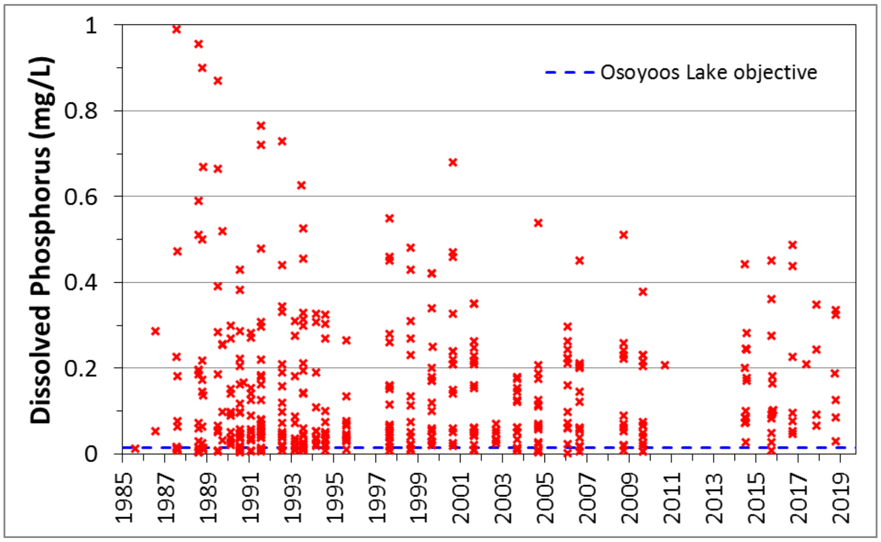

Figure 34: Time series of dissolved phosphorus measurements in the Osoyoos Aquifer.

Figure 35 and Figure 36 show phosphorus monitoring results from individual wells. In the northern half of the aquifer, phosphorus levels in two domestic wells, R1 and R5, show a long-term decline from high levels in the 1980's/90's (Figure 35A). Recent monitoring results after 2010 show consistently low phosphorus levels in R1, close to the lake objective. In contrast, phosphorus levels in R5 have stayed comparatively high, consistently between 0.2 to 0.6 mg/L, which is more than 10x the lake objective. The possible sources of phosphorus include local septic system discharges and fertilizer use in agricultural or residential areas.

The remaining wells in the northern portion of the aquifer are in agricultural intensive areas. Unfortunately, wells around R6 to R24 (Figure 35B) do not have recent monitoring results because the wells are either inactive or samples were not analyzed for phosphorus. Monitoring results before 2010 show variable phosphorus concentrations ranging from 0.002 to 0.2 mg/L, which spans a range from below the lake objective (<0.015 mg/L) to more than 10x the lake objective (>0.15 mg/L) Current levels of phosphorus in groundwater throughout this agriculturally dominant area are unknown.

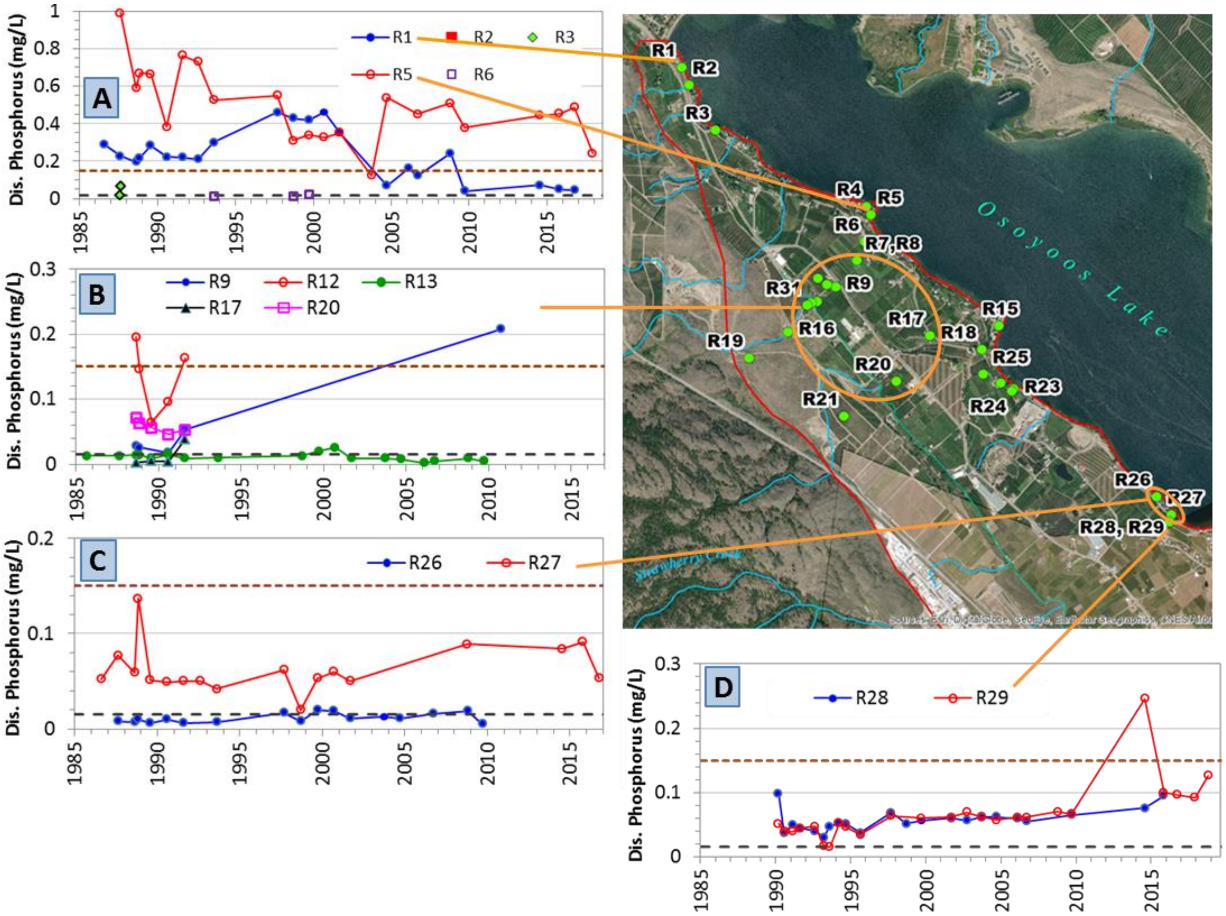

Figure 35: Phosphorus time series plots from wells in the northern portion of the Osoyoos Aquifer. The black horizontal dashed line is the Osoyoos Lake phosphorus objective (0.015 mg/L) and the brown horizontal dashed line is 10x the objective value (0.15 mg/L).

Recent monitoring results after 2010 are available from three near shore wells (R27 to R29). Phosphorus concentrations in these wells are moderately high, ranging from 0.02 to 0.1 mg/L, or about 5x the lake objective (Figure 35C, D). The data also suggest visually increasing trends in phosphorus. The source of phosphorus appears to be from agricultural activities, as this is the dominant upgradient land use.

Groundwater phosphorus levels in the southern portion show greater variability (Figure 36), which may reflect the wider variety of land use activities.

Phosphorus concentrations in the three multi-level monitoring wells (R35, R36, R37) adjacent to Peanut Lake are low to moderate, ranging from 0.02 to 0.1 mg/L (Figure 36A). Like nitrate, there is an association between phosphorus concentrations and sampling depth. The lowest phosphorus concentration is measured in the shallow well (R37) due from mixing and dilution with surface water. Variable and erratic phosphorus levels were measured in the intermediate depth well (R36), and highest phosphorus concentrations were from the deepest well (R35). Phosphorus levels in R35 show a long-term visually increasing trend with concentrations well above the lake objective. This suggests a persistent and possibly increasing upgradient source of phosphorus, potentially including municipal, agricultural, or golf course irrigation sources.

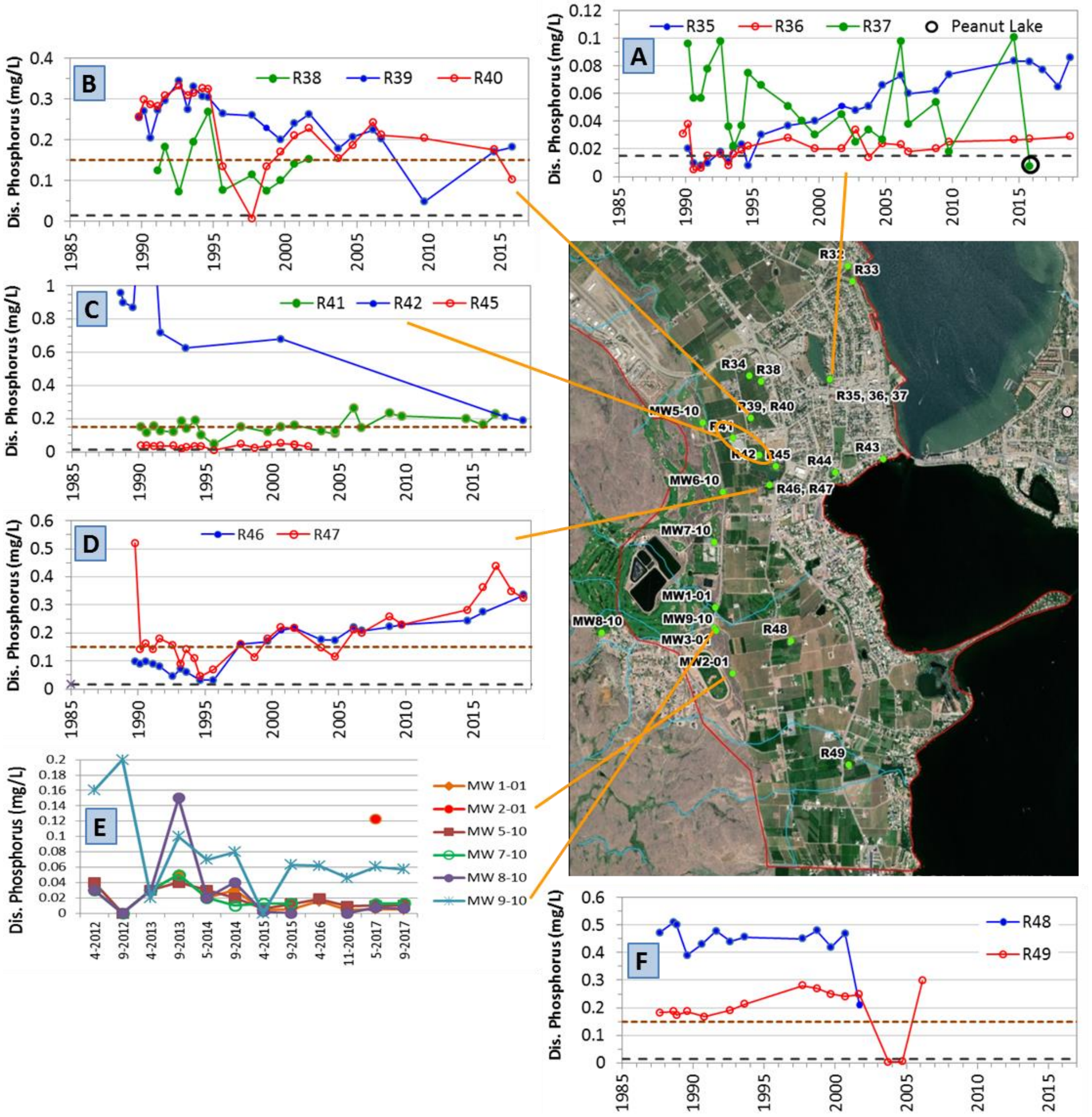

Figure 36: Phosphorus time series plots from wells in the southern portion of the Osoyoos Aquifer. The black horizontal dashed line is the Osoyoos Lake phosphorus objective (0.015 mg/L) and the brown horizontal dashed line is 10x the objective value (0.15 mg/L).

Monitoring results from wells in agricultural areas between downgradient municipal areas and up-gradient wastewater irrigation areas are shown in Figure 36B, C and D. This portion of the aquifer has the largest phosphorus concentrations in recent and current monitoring, with most results after 2005 exceeding 10x the lake objective. The time series plots show both visually decreasing trends in phosphorus levels (R39, R40, R42) and visually increasing trends (R41, R46, R47). The high levels of phosphorus and increasing trends in some wells are consistent with high levels of nitrate measured in this portion of the aquifer. This further supports the presence of persistent and possibly increasing nutrient sources in this portion of the aquifer where there are both agricultural and urban land use activities.

Monitoring data from the WWTP monitoring wells are shown in Figure 36E. Dissolved phosphorus concentrations in most wells display downward trends, with most results showing phosphorus levels below 0.01 mg/L. There are two exceptions. Phosphorus concentrations in MW9-10 are typically greater than other wells and are generally at moderate levels at about 0.06 mg/L. Phosphorus measured in the single sample from MW2-01 was comparatively high, which is consistent with the nitrate results and suggestive of WWTP effluent sources. With the exception of results from MW2-01 and MW9-10, the WWTP monitoring wells generally suggest that reclaimed water irrigation areas are not a significant source of phosphorus in the aquifer.

R48 and R49 are inactive monitoring wells within agricultural areas in the south end of the aquifer. Both wells show moderate to high phosphorus levels over 0.2 mg/L prior to 2007 (Figure 36F). Current levels of dissolved phosphorus throughout much of the south end of the aquifer are unknown, including areas downgradient from wastewater irrigation and infiltration facilities at the Desert Park.

5.8.4 Phosphorus Loading Estimates

Phosphorus loading to the Osoyoos Aquifer and Osoyoos Lake cannot be quantified with a high level of confidence from the available information compiled in this report. The following are approximations and qualitative evaluations of phosphorus loadings.

Agricultural loads to Osoyoos Aquifer: There is poor understanding about the amount of phosphorus in fertilizer applications and no quantitative loading estimates are attempted. Although manure application is a significant source of phosphorus, manure fertilizer use is not common. Synthetic fertilizers used for fruit trees include urea (34-0-0), ammonium sulphate, calcium nitrate, which have no phosphorus content. However, these may be blended with mixed fertilizers called orchard blends (e.g., 19-5-17) that contain some phosphorus. Additionally, mixed fertilizers (e.g., 14-16-10) are used for vegetable crops, which receive multiple applications per year (Athanasopoulos, 2009).

Monitoring results in areas dominated with agricultural land use show variable phosphorus levels. (Figure 35, Figure 36). A few wells show low concentrations close to the lake objective, but these are generally domestic wells close to the lakeshore (R1, R4, R26), or are inactive wells that show historical data (R13, R45). Several other wells with recent monitoring data show moderate to high phosphorus levels in the range of 0.05 to 0.5 mg/L, which indicates the presence of soluble phosphorus in the agricultural dominated portions of the aquifer. These sources are presumably from fertilizer application, but more work is needed to quantify phosphorus application rates and rule out other potential sources.

Reclaimed wastewater irrigation loads to Osoyoos Aquifer: Total phosphorus levels in the reclaimed water supply are high, ranging from 2 to 8 mg/L (Figure 19). The reclaimed water irrigation is a potential source of groundwater phosphorus if irrigation application rates exceed ET demand or if local soil conditions allow for rapid percolation to the water table (Section 4.3). However, groundwater monitoring information downgradient from the golf course generally show low levels of dissolved phosphorus (Figure 36E) with most recent results below 0.06 mg/L. This suggests phosphorus in the wastewater effluent is either not soluble, is adsorbed to aquifer sediments, or the turf grass is effectively sequestering most of the applied phosphorus.

Irrigation application rates could exceed ET demand by about 20% based on a 2013 monthly water budget (Appendix B), which equates to about 175,000 m^3 of aquifer recharge from reclaimed wastewater. Also, groundwater monitoring information in Figure 36E indicates average dissolved phosphorus concentrations are in the range of 0.03 to 0.08 mg/L. The resulting phosphorus loads to the aquifer range between 5 to 17 kg/year. However, these are approximations based on limited monitoring information that should be refined with additional monitoring and analyses.

Wastewater infiltration loads to Osoyoos Aquifer*:* The Town disposes of surplus wastewater effluent in infiltration beds near Desert Park in accordance with their Operational Certificate. Effluent disposal in the infiltration facility is a temporary measure to reduce surplus but has occurred in four years between 2013 and 2017 with an average volume of about 50,000 m^3/year (Table 10). The average total phosphorus concentration in the wastewater effluent is in the range of 2 to 6 mg/L (Figure 19), resulting in a potential total phosphorus load of 100 to 300 kg/year. However, these loads are for total phosphorus and an unknown and significant fraction of this load would be sequestered to sediments in the infiltration facility. There is no groundwater monitoring directly downgradient of the infiltration facilities to assess these loadings. Also, wastewater infiltration is not a routine practice and these potential loadings may or may not occur in any given year. Future loads depend on the need for disposal of surplus effluent.

Municipal landfill loads to Osoyoos Aquifer: It is not possible to estimate phosphorus loading from the landfill and composting areas because the volume of leakage is unknown and groundwater-monitoring data for phosphorus are below detection limits (Table D1).

Liquid waste added to the waste disposal lagoons is a potential source of phosphorus, as some fraction of the liquid will infiltrate into the subsurface. However, there is no phosphorus monitoring data from the septic ponds, or groundwater monitoring information immediately downgradient of the ponds. The volume of liquid waste added to the waste disposal lagoons in 2014 was 2000 m^3, and typical levels of total phosphorus in septic system effluent ranges from 7 to 17 mg/L (U.S. EPA, 2002). But the volume of liquid and the concentration of phosphorus reaching the aquifer would be much smaller. Using conservative estimates of 1000 m^3/yr and 1.0 mg/L of dissolved phosphorus, the estimated total phosphorus load to the aquifer is 1.0 kg/yr. This limited assessment suggests the landfill cells, compositing area, and waste disposal lagoons are not a significant source of phosphorus to the aquifer.

Septic system loads to Osoyoos Aquifer: Estimates of phosphorous loading in typical residential wastewater range from 1 to 2 grams/person/day (U.S. EPA, 2002), or 0.9-1.8 kg/household/yr for an average 2.5 person household. Phosphorus retention in the septic system leach field is difficult to determine. Reported removal rates for phosphorus in septic systems are wide ranging (0-100%), but dissolved phosphorus effluent plumes can migrate to groundwater and surface waters, and these plumes can persist for long periods (Epp, 1985; Robertson et al., 1998; U.S. EPA, 2002; Robertson, 2008). Phosphorus removal rates in the Osoyoos Aquifer may be on the low end based on the presence of coarse grained aquifer materials and a high ratio of dissolved to total phosphorus in monitoring data. Assuming an average removal rate for phosphorus of 50% and the presence of 100 to 300 active septic systems, an approximation for phosphorus loadings to the Osoyoos Aquifer is between 45 to 270 kg/yr.

Residential area loads to Osoyoos Aquifer: An assessment of water use patterns in the Town of Osoyoos (Urban Systems, 2015) states the largest contributor to high water consumption is summer season lawn irrigation, particularly at single family residential dwellings. Fertilizer use in these outdoor residential areas is a potentially significant source of phosphorus loads to the aquifer. These loads could not be estimated due to lack of information on the amount of landscape area and nutrient application rates.

Irrigation system loads to Osoyoos Aquifer: Large volumes of lake water are used for agricultural irrigation, which is the primary source of aquifer recharge. Although lake water has low concentrations of phosphorus, the large volume of water used for irrigation cumulatively creates a potentially significant phosphorus load to the aquifer. A monthly water budget for 2013 suggests about 40% of the irrigation water recharges the aquifer, or roughly 2,700,000 m^3/yr. Lake monitoring information suggests an average total phosphorus concentration in the north and central basins over the growing season is roughly 0.02 mg/L (Sokal, 2017). However, a fraction of this phosphorus is subject to uptake. Assuming 20 to 60% of the phosphorus leaches to the groundwater table, a gross estimate of phosphorus loads from irrigation water is in the range of 11 to 32 kg/yr. Future loadings would likely remain relatively unchanged, in the absence of significant changes to current irrigation practices, irrigation demand, or phosphorus levels in Osoyoos Lake.

Agricultural drainage system loads to Osoyoos Lake: Athanasopoulos (2009) monitored flows and nitrate levels in the ADS, but did not include phosphorus measurements. Consequently, there is no long-term information of phosphorus levels in the ADS. In December 2017 a single water quality sample was collected in outflows near outfall 3, measuring dissolved phosphorus at 0.113 mg/L. Assuming a combined average annual flow of 10 L/s and average phosphorus concentrations from 0.05 to 0.1 mg/L, a very rough phosphorus loading estimate from the ADS ranges from about 15 to 30 kg/yr.

Groundwater discharge loads to Osoyoos Lake: Estimates of phosphorus loads in groundwater discharge to Osoyoos Lake were determined with median groundwater discharge values along six aquifer sections (Figure 13) and estimates of groundwater phosphorus concentrations from monitoring information (Appendix C, Table C3). The resulting load estimates range from about 200 to 680 kg/year, but there are large uncertainties inherent is these load estimates.

Summary of phosphorus load estimates: The summary of phosphorus loading estimates in Table 14 is incomplete because several unaccounted loads are potentially significant especially, fertilizer application in agricultural and residential areas. There is a lack of information on phosphorus application associated with fertilizer use in both agricultural and urban areas, as well as groundwater monitoring data for dissolved phosphorus.

Table 14: Summary of estimated total phosphorus loading to Osoyoos Aquifer and Osoyoos Lake.

Source	**Phosphorus Load (kg/year)**		
	Low estimate	High estimate	Median estimate
Loads to Osoyoos Aquifer			
Agricultural fertilizer application	No estimate, potentially significant		
Reclaimed wastewater irrigation	5	17	11
Wastewater infiltration at Desert Park*	80	240	160
Municipal Landfill – sewage ponds	No estimate, likely small		
Municipal Landfill – compositing and landfill cells	No estimate		
Septic systems	45	270	158
Irrigation supply	11	32	22
Municipal area residences and leaky sewer lines	No estimate, potentially significant		
Total phosphorus load to Osoyoos Aquifer	**61**	**319**	**190**
Loads to Osoyoos Lake			
Groundwater discharge	200	680	440
Agricultural drainage system	17	33	25
Total phosphorus load to Osoyoos Lake	**217**	**703**	**465**
* Occurs irregularly in years when facilities are in use. Loading estimate from effluent infiltration is not included in the total aquifer load, but is shown to indicate possible loads in years when the facilities are in use.			

Estimates of phosphorus loads to Osoyoos Lake are variable, ranging from about 200 to 700 kg/yr. In comparison, the average TP load to the lake from the Okanagan River between 1984 and 2009 is about 14,000 kg/yr (range is 4,000 to 50,000 kg/yr). This indicates phosphorus contributions to the lake from groundwater are small in comparison to the river inputs, but may comprise up to 5 to 10% of the Okanagan River load in low flow years.

5.8.5 Phosphorus – Water Quality Assessment

Phosphorus is not a water quality parameter of concern for groundwater because there is no human health or aesthetic issues of concern, and because phosphorus mobility in groundwater is often assumed to be retarded by sorption to aquifer sediments. However, long-term monitoring data collected throughout the Osoyoos Aquifer shows a high fraction of phosphorus in groundwater is in the dissolved and mobile form, and that the concentration of the dissolved phosphorus in the majority of samples exceeds the water quality objective in the lake, often by more than an order of magnitude. Visually increasing trends in phosphorus levels in some wells suggests there are persistent and possibly increasing phosphorus inputs in portions of the aquifer.

The main issue of concern with phosphorus is from groundwater discharge to Osoyoos Lake and the contribution of phosphorus inputs to eutrophication of the Lake. The loading estimates above indicate phosphorus inputs from the Osoyoos Aquifer are small in comparison to the loads from the Okanagan River, and may comprise up to 5 to 10% of the river load in low flow years. However, considering there are other aquifers adjacent to the lake that may also contribute phosphorus loadings, the groundwater contributions are not necessarily insignificant as previously assumed, and warrant consideration and assessment as part of the overall eutrophication management of the lake. Additional source analyses and targeted monitoring is needed to better identify the phosphorus sources to groundwater, and to improve phosphorus loading estimates to the lake.

6. GROUNDWATER QUALITY OBJECTIVES AND RECOMMENDATIONS

6.1 Basis for Setting Objectives

The following general guidance on setting water quality objectives provided a basis for development of proposed groundwater objectives for the Osoyoos Aquifer.

Water quality objectives are developed to protect the most sensitive water use (B.C. ENV, 2011). The B.C. approved water quality guidelines for the most sensitive water use should be adopted as the preliminary water quality objective for each water quality variable for a site. At sites with atypical water quality characteristics or ecological receptors, the B.C. approved water quality guidelines may be modified up or down to account for site-specific factors (B.C. ENV, 2011). In general, objectives should be reasonable, workable and usable (adapted from CCME, 2015).

Guidance from Kohut and Pommen (2005) state groundwater quality objectives should protect drinking water use as a minimum. All other direct groundwater uses (e.g., from a well, spring, or in a groundwater discharge area) that exist or that could reasonably exist in the future should also be protected, which include aquatic life, wildlife, aquaculture, irrigation, livestock water, recreation, and industrial. Where groundwater is flowing into surface waters that support aquatic life, groundwater quality objectives should protect aquatic life in the surface water from sub-lethal effects, as a minimum, as well as protecting the other designated uses of the surface water, taking account any attenuation and dilution that may occur in the transition from groundwater to surface water (Kohut & Pommen, 2005). For example, generic guidelines for aquatic life protection specified in Schedule 6 of the *Contaminated Sites Regulation* assume a minimum 1:10 dilution (B.C. ENV, 2017).

Short-term and long-term groundwater quality objectives may be used where existing water quality does not suit all desired water uses, and it is feasible to improve the groundwater quality over time. The short-term objectives would protect water uses to a certain degree until the long-term objectives can be achieved (Kohut & Pommen, 2005). As there may be considerable lag time for groundwater contamination to occur, consideration might also be given to establishing "early warning" objectives that are less than the long-term objectives. Early warning values can act as a trigger to detect increasing contaminant concentrations prior to the degradation of a beneficial use (Kohut & Pommen, 2005).

6.2 Proposed Groundwater Quality Objectives for the Osoyoos Aquifer

The most sensitive uses of groundwater from the Osoyoos Aquifer are drinking water supply, irrigation water supply, and aquatic life in the receiving environment of Osoyoos Lake. The water quality assessment in Section 5 evaluated the suitability of groundwater for these uses by assembling available water quality data and reports and comparing this information to applicable water quality guidelines.

The water quality assessment indicates nitrogen and phosphorus levels in groundwater exceed water quality guidelines in a high percentage of samples, including recent samples that demonstrate a persistence of high levels of nutrients in portions of the aquifer as well as increasing trends at some locations. The water quality assessment also identified potential sources of nutrient loads to the aquifer and estimated current loads, where possible. A qualitative evaluation of future loads suggests that in the absence of management actions, future loads are not likely to decrease substantially and could increase with increasing population or expansion of agricultural activities. Collectively, this information indicates nitrogen and phosphorus loads to the aquifer potentially impair current and future groundwater uses. To protect these uses, groundwater quality objectives are proposed for nitrate and phosphorus.

The water quality assessment also identified several other parameters with a high number of exceedances of water quality guidelines, including TDS, arsenic, manganese, copper, and uranium. However, groundwater quality objectives are not proposed for these parameters because exceedances of the Health Canada MAC are limited to isolated pockets of the aquifer, and exceedances of the Health Canada AO do not pose health concerns. In addition, there is not enough information to assess exceedances of the irrigation supply objectives, and there is no evidence that exceedances of aquatic life objectives for metals are impairing aquatic life in Osoyoos Lake.

6.2.1 Groundwater Quality Objective for Nitrate

Groundwater uses potentially affected by elevated levels of nitrate in the Osoyoos Aquifer are drinking water supply and aquatic health in receiving waters of Osoyoos Lake. The Health Canada MAC for nitrate is 10 mg-N/L for protection of human health, and the B.C. guideline for protection of aquatic life is 3 mg-N/L. Although the aquatic life guideline is smaller, its application to the aquifer should consider a dilution factor in the lake (a minimum of 10-fold is specified in the Contaminated Sites Regulation), which would increase a potential objective value in the aquifer above 10 mg-N/L. In addition, nitrogen is not the limiting nutrient in the lake. Therefore, drinking water supply is the most sensitive groundwater use affected by elevated nitrate levels.

Water quality guidelines for the most sensitive use provide the basis for setting water quality objectives, but there is flexibility in setting objectives by allowing modifications based on consideration of site-specific conditions or use of alternative approaches. The following options were considered:

1. Set the nitrate objective equal to Health Canada MAC (10 mg-N/L). This is a direct application of the principle of adopting existing guidelines for the water quality objective. It is the least subjective and likely the most justifiable approach as it directly assigns a concentration level to

the aquifer that is considered protective of human health. However, this approach does not compel anti-degradation in aquifer areas where nitrate levels are below the objective (i.e., there is an assumed allowable contamination capacity up to the 10 mg-N/L). In addition it does not consider the nature of contaminant transport in groundwater systems, which can exhibit time lags between the release of nutrients into the aquifer and the impacts to groundwater uses at pumping wells.

2. Establish a precautionary nitrate objective below the Health Canada MAC (5 mg-N/L) to provide early detection of increasing contaminant concentrations. The rationale of a precautionary objective is to provide adequate response time to trigger proactive measures at upgradient locations. These measures could include increased monitoring activities, and changes in land use practice or operating procedures by permit holders, to protect beneficial uses at the downgradient locations. Precedence for precautionary objectives includes the assessment of nitrate contamination in the Hullcar Aquifer, which recommended setting "water objectives that include target nitrate precautionary thresholds (3-5 mg-N/L)" (Brandes et al., 2017), and the State of Washington, which has promulgated early warning objectives (Washington State, 1990). A precautionary objective of 5 mg-N/L is consistent with recommendations in the Hullcar Aquifer report and with Washington State procedures (Washington State, 2005) that set the early warning objective to one-half of the sum of the criteria level (10 mg-N/L) plus background levels (~0-2 mg-N/L).

The proposed groundwater objective for nitrate is 10 mg-N/L. This value was selected over the lower objective of 5 mg-N/L because the Town of Osoyoos and Interior Health currently use the Health Canada MAC as the standard of protection and a lower precautionary objective that is not a legally enforceable health standard could potentially be construed as an unsupported and unworkable objective. In addition, a precautionary objective of 5 mg-N/L is to some extent obsolete as nitrate levels already exceed 5 mg-N/L in many wells, including high nitrate levels above 10 mg-N/L in areas upgradient of the municipal wells. This should be sufficient impetus to increase monitoring and nutrient management activities in order to protect groundwater use for drinking water supply.

The proposed groundwater objective for nitrate should apply to the entire Osoyoos Aquifer because sources of nitrate occur from a variety of land use activities throughout the aquifer, and because the characteristics of this aquifer (shallow and permeable unconfined sediments) make it particularly vulnerable to nitrate contamination and unfavourable for denitrification. In addition, the number and location of private domestic wells that are still in use is unknown, and potentially occur throughout rural portions of the aquifer.

6.2.2 Groundwater Quality Objective for Phosphorus

The only groundwater use that is potentially affected by elevated levels of dissolved phosphorus is aquatic life in Osoyoos Lake. Phosphorus enrichment of Osoyoos Lake is a long-term issue of concern that has prompted B.C. to establish water quality objectives for the lake, including an objective for total phosphorus of 0.015 mg/L, and objectives for water clarity and algae production (Table 11). Although phosphorus loadings to the lake from the Osoyoos Aquifer are small in comparison to loadings from the Okanagan River, they are not negligible as assumed in the objectives reports, particularly if combined with phosphorus loads from the east shore aquifers and aquifers along the U.S. portion of the lake. Groundwater contributions are a net source of phosphorus loadings to the lake that potentially contribute to ongoing eutrophication issues and the related effects on the aquatic ecosystem.

The proposed groundwater quality objective for dissolved phosphorus is 0.15 mg/L. This value is consistent with the lake objective after considering a 1:10 dilution that may occur in the transition from groundwater to surface water. This dilution factor is consistent with guidance from the *Contaminated Sites Regulation* (B.C. ENV, 2017). The proposed groundwater objective is also expressed in terms of dissolved phosphorus rather than total phosphorus used in the lake objective, as only the dissolved form is considered mobile in groundwater.

The proposed groundwater objective for dissolved phosphorus should apply to the entire Osoyoos Aquifer as monitoring data show high levels of dissolved exceeding the proposed objective occur throughout the aquifer. In addition, the potential sources of phosphorus occur from a variety of land use activities that are also distributed throughout the entire aquifer, including residential development in municipal areas, agricultural activities throughout the agricultural preserve, individual septic systems in rural areas, and land application of treatment plant effluent.

6.3 Monitoring and Potential Future Studies

Ongoing groundwater monitoring is needed to assess objectives attainment. The current FLNRORD monitoring locations and annual monitoring frequency should be retained as the minimum level of effort for assessing objectives attainment. However, the number of active monitoring locations has decreased over time and is now between 5 to 8 locations with many concentrated in the central portion of the aquifer. The FLNRORD should consider increasing the number, distribution, sampling frequency, and reliability of long-term monitoring wells. These efforts would increase information about the nutrient distribution in the aquifer and improve the assessment of objectives attainment. Locations where additional groundwater monitoring could be considered are:

- agricultural areas in the northern and southern portion of the aquifer, particularly areas with intensive agricultural activity where there are no current active monitoring wells or historical monitoring information;
- locations downgradient of residential development in the southern portion of the aquifer, including the Divided Ridge Community above Desert Park, near shore residential areas within the municipal boundary, and in the rural area at the southern end of the aquifer; and
- locations associated with WWTP activities including areas immediately downgradient of treatment plant, the effluent disposal areas at groundwater infiltration facilities, and additional monitoring locations adjacent to irrigation areas at the golf course and community fields.

The FLNRORD should consider expanding monitoring goals to improve estimation of nutrient fluxes to Osoyoos Lake. This could include two efforts: 1) improving information on nearshore groundwater gradients and nutrient levels by measuring groundwater elevation and nutrient concentrations at dedicated nearshore monitoring wells spaced along the entire aquifer; and 2) measuring flow and nutrient levels in the ADS near the outfalls to Osoyoos Lake. Groundwater levels and ADS flows should be measured more frequently using automated methods (e.g., hourly, daily), while nutrient concentration could be measured less frequently (monthly, quarterly).

The FLNRORD could further consider a short-term monitoring program (1 to 3 years) to identify nutrient sources and improve nutrient loading estimates from specific land use activities. This monitoring would be limited to groundwater nutrient levels (nitrate and phosphorus) associated with specific land use activities or transects through multiple land uses listed below. Because of the shallow and permeable nature of the aquifer, the sampling sites could use small diameter wells installed with traditional drilling methods, or possibly monitoring systems installed with drive-point technology as an approach for reducing monitoring costs. Quarterly or monthly monitoring should be considered, and the targeted land uses could include:

- agricultural areas with dominant crop types (stone fruit, grapes, vegetables);

- residential and commercial development areas with concentrated areas of well-maintained outdoor landscaping;
- rural residential areas with a concentrated use of individual septic systems; and
- areas associated with WWTP activities and effluent disposal.

Source analyses could also be supported by grower and municipal residential surveys to assess nutrient use including type and quantity, and possibly associated pesticide use, as well as assessments to quantify use of individual septic systems in rural areas. Current groundwater use from private domestic wells and irrigation should also be assessed.

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APPENDIX A. STUDY AREA WELL INFORMATION

Well ID (map code)	EMS Number	WTN	Other Name	Monitoring Agency or Report				Aquifer Number	Last sample date	Ground Elev. (masl)	Well depth (m)	Depth to static water level (m)	Aquifer material at screen
				FLNRORD / ENV	Env Can	ToO	A (2009)						
R-1	E207129	19166	P/D	x				0193	Oct-2016	283	6.1	2.7	G*
R-2	E207128	18253	P/D	x				0193	Aug-1987		4.9	3.1	G*
R-3	E207130	15015	P/D	x				0193	Aug-1987		7	4	sand*
R-4	E207147	37486	P/D	x				0193	Aug-1987		9.1	4.3	G*
R-5	E207131	16758	P/D	x			25?	0193	Oct-2016	283	7		SG
R-6	1401086	22713	OBS 102	x			26	0193	Oct-2006	303	15.9	7	silt
R-7			USGD				27a (S)	0193	Aug-2006	305	5		SS
R-8			USGD				27c (D)	0193	Sep-2006		12		SS
R-9	1401084	22731	OBS 101	x			28	0193	Sep-2010	321	20	4	silt
R-10			USGD				29a (S)	0193	Feb-2007	318	7		silt
R-11			USGD				29b (D)	0193	Sep-2006		19		silt
R-12	1401083	22733	OBS 100	x			30	0193	Sep-2006	318	18.9	5.8	Silt
R-13	E207133	14402	P/D	x				0193	Sep-2009	320	8.2	5.5	SG
R-14			USGD				31	0193	Feb-2007	321	9		silt
R-15		79237	P/D				32	0193	Sep-2006	281	4		SG
R-16	1401082	22773	OBS 99	x				0193			28.3	9.1	SG
R-17	1401091	22706	OBS 107	x			35	0193	Sep-2006	296	9.8	3.1	Silt (&G)
R-18			P/D				37	0193	Sep-2006	290			SG
R-19	1501055	22779	OBS 98	x				0193			32.9	12.8	silt & clay
R-20	1401089	22702	OBS 105	x			39	0193	Feb-2007	320	13	2.7	Silt & G
R-21	1401087	22782	OBS 103	x				0193					
R-22			Hartmann P2		x		42	0193	Sep-2010	287	6		SG
R-23			Hartmann P3		x		43	0193	Sep-2010	274	3		SG
R-24			Hartmann P4		x		44	0193	Sep-2010	279	6		SG
R-25		19464	Hartmann		x		46	0193	Sep-2010	300	8.2	7.3	SG
R-26	E207135		P/D	x			52?	0193	Sep-2009	280	4		SG
R-27	E207163	23677	P/D	x				0193	Oct-2016	280	3.1	1.5	G
R-28	E208018	93982	A-1 (P-1) D	x	x		54a	0193	Nov-2015	284	10.2	6.6	SG
R-29	E208019	93982	A-1 (P-2) S	x	x		54b	0193	Dec-2017	284	8.9	6.6	SG
R-30	E208021		A-3	x				0193	Aug-1992	315	5		SG
R-31			P/D				57	0193	Sep-2006	323			

Well ID (map code)	EMS Number	WTN	Other Name	Monitoring Agency or Report				Aquifer Number	Last sample date	Ground Elev. (masl)	Well depth (m)	Depth to static water level (m)	Aquifer material at screen
				FLNRORD / ENV	Env Can	ToO	A (2009)						
R-32	E258457	82357	ToO Well #7			x		0193		284	19.5	7.9	SG
R-33	E258456	83016	ToO Well #6			x		0193		283	14.3	5.8	SG
R-34	E208028		B-6	x				0193	Aug-1995	308	7.8		SG
R-35	E208022	93983	B-1A	x	x		61	0193	Dec-2017	287	13.4	4.6	SG
R-36	E208023	93984	B-1B (P-2) D	x	x		62a	0193	Oct-2015	287	10.6	4.6	SG
R-37	E208024	93984	B-1B (P-3) S	x	x		62b	0193	Oct-2015	287	8.6	4.6	SG
R-38	E208033	93990	B-9	x	x			0193	Sep-2010	306	7.1	5.7	SG
R-39	E208029	93989	B-7 (P-1) D	x	x		66a?	0193	Nov-2015	308	10.7	6.7	SG
R-40	E208030	93989	B-7 (P-2) M	x	x		66b	0193	Nov-2015	308	8.7	6.7	SG
R-41	E208027	93987	B-5	x	x		70	0193	Oct-2016	307	6.9	5.5	SG
R-42	1401093	22769	OBS 96	x			72	0193	Jun-2017	308	10.7	4.	SG
R-43	E258423	82359	ToO Well #8			x		0193		280	14.3	2.1	SG
R-44	E258422	82358	ToO Well #1			x		0193		279	9.2	1.5	SG
R-45	E208026	93986	B-4	x				0193	Sep-2002	305	6.3	4.4	SG
R-46	E208031	93991	B-8 (P-1) D	x	x		74a	0193	Oct-2015	304	7.2	5	SG
R-47	E208032	93991	B-8 (P-2) S	x	x		74b	0193	Dec-2017	304	6.1	5	SG
R-48	E207173		P/D		x			0193	Sep-2001				
R-49	E207165	5152		x				0193	Sep-2007	296	6.1	2.4	sand
R-50		89835					38[a]	0193		427	6		Ob
R-51	E258424	83013	ToO Well #3			x		0194		279	16.2	2.4	SG
R-52	E258426	83014	ToO Well #4			x		0194		280	23.8	2.4	SG
R-53	E258425	83105	ToO Well #5			x		0194		280	26.5	3.0	SG
R-54	E207152	18647	P/D	x				0194	Sep-06		10.4	8.2	S
R-55	E207162	14602	P/D	x				0195	Sep-01		3.7	2.7	SG
R-56	E207166	19613	P/D	x				0194	Sep-09		4.3	1.5	SG

FLNRORD = Ministry of Forest, Lands, Natural Resource Operations, and Rural Development
ENV = Ministry of Environment and Climate Change Strategy
EnvCan = Environment Canada
ToO = Town of Osoyoos
USGD = University of Saskatchewan Geology Department
A (2009) = (Athanasopoulos, 2009)
EMS = Environmental Monitoring System database
OBS = Observation well database
P/D = private domestic
WTN = Well tag number
D = deep
M = middle
S = shallow
G = gravel
SG = sand and gravel
SS = sandy silt
Ob = overburden
BR = Bedrock

The last sample date does not include the samples in 2006 by Athanasopolus (2009) or the on-going data collecting from the ToO wells

APPENDIX B. ESTIMATED OSOYOOS AQUIFER WATER BUDGET FOR 2013

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm) [1]	18.9	5.3	12.6	15.6	19.5	41.5	4	15.9	50.7	7	20.7	13.3	225
Eto (mm) [2]	15	27	64	90	147	153	191	157	101	55	24	14	1038
Water use, Irrigation systems 8 & 9 (m^3) [3]				287000	767000	1399000	1469000	1413000	1074000	593000			7,002,000
Irrigation + Precipitation, systems 8 & 9 (mm) [4]				63	145	270	244	247	226	104			
Surplus, Irrigation Systems 8 & 9 (mm) [5]				0	0	117	54	90	125	49			
Contribution to GW from excess irrigation, Irrigation systems 8 & 9 [6]				0	0	717251	326579	550522	766276	300030			**2,660,658**
Precipitation surplus – non growing season (mm) [7]	3.9	0	0								0	0	
Contribution to GW from precipitation, non-growing season (m^3) [8]	54560	0	0								0	0	**54,560**
Reclaimed water use for irrigation (m^3) [9]		38	24020	76720	107654	115493	159517	139303	65339	52274	636		740,994
Reclaimed water irrigation + precipitation (mm) [10]		5	46	121	167	200	223	207	140	79	22		
Surplus, reclaimed water irrigation use (mm) [11]		0	0	31	20	47	32	50	39	24	0		
Contribution to GW from excess irrigation with reclaimed water (m^3) [12]		0	0	22408	14579	34098	23007	36300	28620	17234	0		176,246
Reclaimed water diverted to infiltration beds (m^3) [13]		4500	15500	15000	5000				2500	15000	11000		69,000
Total contribution to GW from reclaimed water (m^3)		4500	15500	37408	19579	34098	23007	36300	31948	31734	11000		245,074

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Municipal system water use (m^3) [14]	67825	59347	67825	118693	254343	313689	406948	406948	262821	110215	42390	16956	2,128,000
Groundwater withdrawal from west side municipal wells (m^3) [15]	-9495	-8309	-9495	-16617	-35608	-43916	-56973	-56973	-36795	-15430	-5935	-2374	**-297,920**
Estimated contribution to GW from outdoor use in municipal areas (m^3) [16]	0	0	0	1935	8717	11684	16347	16347	9141	1511	0	0	**65,683**
Total net contributions to groundwater (m^3)	**44,386**	**-4,402**	**5,326**	**21,539**	**-9,855**	**715,981**	**304,891**	**542,127**	**767,942**	**316,743**	**4,641**	**-2,543**	**2,706,775**

[1] Environment Canada climate data from Osoyoos CS. Monthly depth is the accumulated daily total precipitation.

[2] Eto = Reference ET from Osoyoos West Station, source: http://farmwest.com/

[3] Total 2013 water use for systems 8 & 9 as reported in (Town of Osoyoos, 2015). Monthly consumption is estimated by proportion of 2009 monthly consumption reported by Gregory (2014). All water use assumed for irrigation, as rural domestic consumption is small in comparison to irrigation use.

[4] Irrigation depth calculated for the combined service area of 611 ha.

[5] Surplus is Precip + Irrigation – ET. Actual ET is crop dependent; ET = Eto x Kc, where the crop coefficient (Kc) ranges from 0.8 to 1.2 for applies, cherries and stone fruits, and from 0.5 to 0.8 for grapes (Tam, et al., 2005). An area average Kc=1 is assumed as information on crop acreages is not available.

[6] Groundwater volume is the surplus depth over the combined service area of 611 ha.

[7] Surplus is Precip – ET, where no crop dependency or irrigation is assumed in the non-growing season (Kc=1).

[8] Groundwater volume is the surplus depth over a total aquifer area (1399 ha).

[9] Reclaimed water disposal volume excluding 69,000 m^3 diverted to infiltration beds (TRUE, 2014a).

[10] Reclaimed water irrigation depth calculated for an irrigation area of 73 ha (golf course, ball diamonds, play fields) (TRUE, 2014a).

[11] Surplus = Precip + Irrigation – ET. A crop coefficient of Kc=1 is assumed for turf.

[12] Groundwater volume is the surplus depth over a reclaimed water irrigation area (73 ha).

[13] Based on the design flow rate 500 m^3/d and the reported period of use (TRUE, 2014a). All water diverted to the infiltration beds is assumed to recharge the aquifer.

[14] Total 2013 water use for the municipal system as reported in (Town of Osoyoos, 2015). Monthly consumption is estimated by proportion of 2009 monthly consumption reported by Gregory (2014).

[15] Municipal wells #1, 6, and 8 are in the Osoyoos Aquifer and produce approximately 30% of the municipal supply (Town of Osoyoos, 2015). Water from the wells are a mix of groundwater and surface water. Water from well #1 is more similar to groundwater, and water from wells #6 and 8 is more similar to surface water (Western Water, 2012). We assumed 50% of the pumped water is from the aquifer. Therefore, 15% of the total municipal consumption is withdrawn from the Osoyoos Aquifer.

[16] Outdoor water use in municipal area is estimated at 50% of total municipal consumption (Section 0). We assumed 5% of the municipal consumption greater than 80,000 m^3/month is returned to the aquifer from outdoor irrigation.

APPENDIX C. GROUNDWATER AND NUTRIENT FLUX ESTIMATES TO OSOYOOS LAKE

The following tables show estimated groundwater discharge and nutrient loadings from the Osoyoos Aquifer to from the Osoyoos Lake. The estimates are developed individually for aquifer sections shown in Figure 13 of the main report.

Table C1: Darcy flux estimates of groundwater discharge to Osoyoos Lake.

Section	Period	Conductivity (m/day)		Length (m)	Saturated depth (m)	Hydraulic gradient	GW Discharge (m^3/day)	
		Low Estimate	High Estimate				Low Estimate	High Estimate
A-A'	Irrigation	10	30	2150	3	0.04	2580	7740
	Non-growing				2	0.03	1290	3870
B-B’	Irrigation	5	15	2000	3	0.025	750	2250
	Non-growing				2	0.02	400	1200
C-C’	Irrigation	10	30	2200	2.5	0.03	1650	4950
	Non-growing				1.5	0.01	330	990
D-D’	Irrigation	10	30	1650	2.5	0.03	1240	3710
	Non-growing				1.5	0.01	250	740
E-E’	Irrigation	10	30	1450	2	0.03	870	2610
	Non-growing				1	0.02	290	870
F-F’	Irrigation	10	30	1300	1.5	0.035	683	2048
	Non-growing				1	0.02	260	780
Aquifer Length	Irrigation			10750			7770	23300
	Non-growing						2820	8450
	Yearly Ave						5290	15900

Table C2: Estimated nitrogen loads to Osoyoos Lake in groundwater discharges.

Section	Period	Nitrate concentration (mg-N/L)		Median GW Discharge (m^3/day)	Nitrogen Load (kg-N/day)	
		Low Estimate	High Estimate		Low Estimate	High Estimate
A-A'	Irrigation	1	2	5160	5.2	10.3
	Non-growing			2580	2.6	5.2
B-B’	Irrigation	2	6	1500	3.0	9.0
	Non-growing			800	1.6	4.8
C-C’	Irrigation	4	10	3300	13.2	33.0
	Non-growing			660	2.6	6.6
D-D’	Irrigation	3	14	2400	7.2	33.6
	Non-growing			480	1.4	6.7
E-E’	Irrigation	2	4	1740	3.5	7.0
	Non-growing			580	1.2	2.3
F-F’	Irrigation	2	4	1365	2.7	5.5
	Non-growing			520	1.0	2.1
Aquifer Length	Irrigation Season – Daily Load (kg-N/day)				34.8	98.3
	Non-growing Season – Daily Load (kg-N/day)				10.5	27.7
	Average Annual Daily Load (kg-N/day)				22.6	63.0
	Total Annual Load (kg-N/yr)				**8250**	**23000**

Table C3: Estimated phosphorus loads to Osoyoos Lake in groundwater discharges.

Section	Period	Dis. Phosphorus concentration (mg/L)		Median GW Discharge (m^3/day)	Dis. Phosphorus Load (kg/day)	
		Low Estimate	High Estimate		Low Estimate	High Estimate
A-A'	Irrigation	0.02	0.04	5160	0.10	0.21
	Non-growing			2580	0.05	0.10
B-B’	Irrigation	0.1	0.4	1500	0.15	0.60
	Non-growing			800	0.08	0.32
C-C’	Irrigation	0.05	0.2	3300	0.17	0.66
	Non-growing			660	0.03	0.13
D-D’	Irrigation	0.1	0.3	2400	0.24	0.72
	Non-growing			480	0.05	0.14
E-E’	Irrigation	0.05	0.2	1740	0.09	0.35
	Non-growing			580	0.03	0.12
F-F’	Irrigation	0.05	0.2	1365	0.07	0.27
	Non-growing			520	0.03	0.10
Aquifer Length	Irrigation Season – Daily Load (kg-P/day)				0.8	2.8
	Non-growing Season – Daily Load (kg-P/day)				0.3	0.9
	Average Annual Daily Load (kg-P/day)				0.5	1.9
	Total Annual Load (kg-P/yr)				**200**	**680**

APPENDIX D. OSOYOOS AQUIFER MONITORING DATA FROM PUBLISHED REPORTS

Table D1: Results of groundwater monitoring adjacent to the Osoyoos landfill. Source: (TRUE, 2013b; 2014b; 2015b; 2016b; 2018b).

MW ID	Sample Date	TDS (mg/L)	Hardness (mg/L)	Chloride (mg/L)	Nitrate+ Nitrate (mg-N/L)	Ammonia (mg-N/L)	TKN (mg-N/L)	Total Nitrogen (mg-N/L)	Dissolved Phosphorus (mg/L)
MW 3-10	9-2013	518	724	53.4	<0.01	0.037	2.59	2.59	<0.2
	11-2016	566	438	53.5	0.017	0.168	4.78	4.79	<0.2
	5-2017	526	418	45.1	<0.01	0.41	6.91	6.91	<0.05
	9-2017	537	364	34.4	0.017	0.12	2.85	2.87	<0.05
MW 4-10	4-2012	482	921	14.6	0.16	0.06	1.7	1.86	<0.2
	9-2012	512	1880	16.8	1.94	0.06	6.1	8.04	<0.2
	4-2013	556	837	20.1	6.12	0.034	1.56	7.68	<0.2
	9-2013	509	397	19.4	0.17	0.051	3.16	3.33	<0.2
	9-2014	531	426	17.1	<0.01	0.031	0.57	0.571	<0.2
	5-2017	527	384	23.2	<0.01	0.229	0.46	0.46	<0.05
	9-2017	517	371	22.5	<0.01	0.131	1.80	1.80	<0.05
MW 5-10	4-2012	869	823	841	33	0.04	0.93	33.9	<0.2
	9-2012	1410	1370	137	104	0.071	0.28	104	<0.2
	4-2013	1690	1300	109	103	0.038	2.25	105	<0.2
	9-2013	1860	1620	130	110	0.105	3.36	113	<0.2
	5-2014	1010	1310	138	1.96	0.045	3.32	4.28	<0.2
	9-2015		827	217	5.74	<0.02			
	5-2017	918	730	188	0.85	0.108	1.95	2.80	<0.05
	9-2017	888	549	136	0.097	0.087	1.18	1.28	<0.05
MW 7-10 upgradient	4-2012	735	548	140	3.31	0.04	0.49	3.8	<0.2
	9-2012	796	456	146	1.69	<0.02	0.43	2.12	<0.2
	4-2013	747	541	140	4.08	<0.02	0.33	4.41	<0.2
	9-2013	748	529	152	3.64	<0.02	0.5	4.14	<0.2
	5-2014	772	559	153	2.96	<0.02	0.27	3.23	<0.2
	9-2014	836	555	141	3.22	0.036	0.32	3.54	<0.2
	4-2015	742	530	173	3.12	<0.02	0.26	3.37	<0.2
	9-2015		551	156	1.91	<0.02			
	4-2016	764	501	149	2.81	0.137	0.25	3.05	<0.2
	11-2016	732	536	139	2.03	0.027	0.19	2.23	<0.02
	5-2017	737	554	162	0.03	0.091	0.65	0.68	<0.05
	9-2017	726	471	132	1.74	0.038	0.36	2.10	<0.05
Septic Pond	9-2013			223	0.99	210	324	325	
	4-2014			425	<0.1	98.4	184	184	
	4-2015			346	0.24	109	198	199	
	9-2015			550	<1.0	409	1420	1420	

TDS = Total dissolved solids; TKN = Total Kjeldahl nitrogen (organic nitrogen and ammonia nitrogen)

Table D2: Results of WWTP effluent quality monitoring prior to storage. Source: (TRUE, 2013a; 2014a; 2015a; 2016a; 2017a, 2018a).

Year or Requirement	**BOD-5 (mg/L)** Range of monthly samples, (number of exceedances of permit requirements)	**TSS (mg/L)** Range of monthly samples, (number of exceedances of permit requirements)	**Total Phosphorus** (mg/L)	**Total Nitrogen** (mg/L)
2012	<10-32 (0 exceedances)	3-19 (0 exceedances)	4.22 (January) 12.6 (July)	34.8 (January) 37.7 (July)
2013	<10-18 (0 exceedances)	<1 – 19 (0 exceedances)	3.71 (January) 5.4 (July)	31.9 (January) 16.9 (July)
2014	<10-273* (2 exceedances)	<1-37 (0 exceedances)	5.48 (January) 14.1 (July)	37.2 (January) 23.6 (July)
2015	<6-93 (1 exceedance)	<2-39 (0 exceedances)	4.25 (January)	30.8 (January)
2016	<5-38 (0 exceedances)	5-32 (0 exceedances)	4.75 (January) 5.17 (July)	33.4 (January) 6.5 (July)
2017	23.2-98.6 (5 exceedances)	6-76.8 (1 exceedance)	5.36 (January) 5.99 (July)	39.9** (January) 23.6**(July)
Permit Requirement	<45	<60	--	--

* One exceedance sample exceeded holding time

** calculated as the sum of reported TKN, nitrate, and nitrite nitrogen

Table D3: Results of WWTP groundwater quality monitoring. Source: (TRUE, 2013a; 2014a; 2015a; 2016a; 2017a, 2018a).

MW ID	**Sample Date**	**Hardness (mg/L)**	**Chloride (mg/L)**	**Nitrate (mg-N/L)**	**Ammonia (mg-N/L)**	**Total dissolved phosphorus (mg/L)**
MW 1-01	4-18-2012	717	8.79	0.017	0.07	0.03
	9-11-2012	567	12.3	<0.02	0.052	<0.02
	4-9-2013	679	10.1	<0.01	0.03	0.03
	9-24-2013	672	10.2	<0.01	0.023	0.05
	5-13-2014	753	8.9	0.02	0.062	0.02
	9-30-2014	833	10.9	<0.01	<0.02	0.03
	4-15-2015	664	13.8	<0.01	0.077	0.004
	9-30-2015	713	10.1	<0.01	<0.02	0.005
	4-26-2016	698	14.1	<0.01	0.112	0.016
	11-1-2016	722	11	<0.014	0.071	0.004
	5-9-2017	711	9.56	<0.011	0.094	0.0054
	9-12-2017	620	11.1	<0.10	0.025	0.005
MW 2-01	5-9-2017	583	190	**15.6**	0.031	0.123
MW 5-10	4-18-2012	870	44.9	1.83	0.02	0.04
	9-11-2012	551	241	5.93	0.043	<0.2
	4-9-2013	696	229	6.67	0.02	0.03
	9-24-2013	633	**272**	7.34	0.025	0.04
	5-13-2014	642	183	6.71	0.057	0.03
	9-30-2014	689	228	5.61	<0.02	0.02
	4-15-2015	2050	173	7.56	0.077	0.006
	9-30-2015	827	217	5.74	<0.02	0.012
	4-26-2016	704	**256**	8.06	0.088	0.019

MW ID	Sample Date	Hardness (mg/L)	Chloride (mg/L)	Nitrate (mg-N/L)	Ammonia (mg-N/L)	Total dissolved phosphorus (mg/L)
	11-1-2016	729	**251**	3.56	0.078	0.009
	5-9-2017	665	240	7.65	0.033	0.0099
	9-12-2017	627	**269**	7.78	<0.02	0.0105
MW 7-10	4-18-2012	509	4.64	0.081	0.03	0.03
	9-11-2012	194	10.6	0.364	0.036	<0.2
	4-9-2013	349	5.18	0.245	<0.02	0.03
	9-24-2013	564	6.15	0.184	0.047	0.05
	5-13-2014	266	5.21	0.018	0.02	0.02
	9-30-2014	1080	9.65	<0.02	0.048	0.01
	4-15-2015	623	7.17	<0.01	0.085	0.013
	9-30-2015	551	7.02	0.062	<0.02	0.013
	5-9-2017	356	7.08	0.216	0.029	0.0127
	9-12-2017	501	7.18	0.136	<0.02	0.013
MW 8-10	4-18-2012	2010	28.2	1.45	0.03	0.03
	9-11-2012	1180	23.7	1.3	0.044	<0.2
	4-9-2013	1590	30.2	4.56	0.038	0.03
	9-24-2013	983	14.3	1.22	0.027	0.15
	5-13-2014	1970	26.7	2.59	0.038	0.02
	9-30-2014	974	14.5	2.21	0.035	0.04
	4-15-2015	1670	36.1	6.05	0.078	0.002
	9-30-2015	1790	26.7	3.16	<0.02	<0.002
	4-2016					
	11-1-2016	1950	30.2	3.95	0.061	<0.002
	5-9-2017	1980	20.2	3.99	0.03	0.0074
	9-12-2017	1220	16.1	4.51	<0.02	0.0062
MW 9-10	4-18-2012	651	1.83	0.135	0.16	0.16
	9-11-2012	148	2.12	0.041	0.192	0.2
	4-9-2013	179	1.99	0.019	0.203	0.02
	9-24-2013	160	2.46	0.072	0.06	0.1
	5-13-2014	183	1.77	0.027	0.187	0.07
	9-30-2014	149	1.64	0.132	0.12	0.08
	4-15-2015	150	3.75	<0.01	0.205	<0.002
	9-30-2015	364	1.86	<0.02	0.197	0.063
	4-26-2016	152	2.97	0.248	0.184	0.062
	11-1-2016	152	2.39	0.149	0.152	0.05
	5-9-2017	316	1.86	0.08	0.174	0.0606
	9-12-2017	312	1.81	0.0092	0.146	0.0572

Table D4: Pesticide monitoring data in wells on the west side of Osoyoos Lake, 1991 and 1993.

Pesticide Class	**McNaughton (1991) N = 23**	**Murray & York (1993) N=38**	**Health Canada** (2013)	**CCME** (2018)
	Results	**Results**	**Max. Allowable Conc. (µg/L)**	**Long term aquatic life guideline (µg/L)**
Fungicide				
Captan		0.4 - 0.51 (2)		1.3
Herbicides				
Atrazine	ND (all)	Trace – 1.0 (20)	5	1.8
EPTC	ND (all)			
Simazine	0.14 – 2.1 (4)	Trace – 6.4 (23)	10	10
Terbacil		Trace (5)		
Insecticides				
Carbaryl	ND (all)		90	0.2
Carbofuran	ND (all)		90	1.8
Diazinon	ND (all)	Trace – 0.08 (11)	20	
Dimethoate	0.12 (1)	Trace (6)	20	6.2
DNOC		Trace – 0.04 (3)		
Guthion		Trace (6)	Banned in Canada in 2007	
Malathion	ND (all)	Trace (4)	190	
P,P’-DDT	0.02-0.1 (3)		Banned for agricultural use in 1972	
P,P’-DDE	0.02 (1)			
P,P’-DDD	0.01 (1)			