Final Report

SUMMIT
ENVIRONMENTAL CONSULTANTS INC.
A Member of the Associated Engineering Group of Companies

Regional District of Okanagan Similkameen

Twin Lakes Aquifer Capacity Study

May 2010

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ENVIRONMENTAL CONSULTANTS INC.
A Member of the Associated Engineering Group of Companies

Summit Environmental Consultants Inc.
Suite 200 - 2800 29th Street
Vernon, British Columbia, Canada V1T 9P9

Tel 250.545.3672
Fax 250.545.3654
www.summit-environmental.com

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Regional District of Okanagan-Similkameen
101 Martin Street
Penticton, B.C. V2A 5J9

Attn: Mr. Andrew H.J. Reeder, P.Eng.
Engineering Services Manager

Dear Mr. Reeder:

Re: FINAL Twin Lakes Aquifer Capacity Study

Summit Environmental Consultants Inc. (Summit) is pleased to provide you with this final report on the above-noted study. The report presents the results of an aquifer capacity investigation to assess the sustainable yield of the Twin Lake Aquifer.

The final report addressed comments provide on the February 2010 draft report. We have appreciated the opportunity to assist you on this project and look forward to the chance for future collaboration.

Yours truly,

Summit Environmental Consultants Inc.

Bryer Manwell, M.Sc., E.I.T.
Hydrogeologist

Reviewed by:

PROFESSIONAL
PROVINCE OF
D. J. GELLER
#31660
BRITISH COLUMBIA
GEOSCIENTIST

Douglas Geller, P.Geo.
Senior Hydrogeologist

Attachment: Final report (two copies) and CD ROM

EXECUTIVE SUMMARY

In 2008-2009, the Lower Nipit Improvement District (LNID) requested assistance from the Regional District of Okanagan-Similkameen (RDOS) in determining the cause(s) of recent declines in lake levels and the potential effects of future development on the community and the environment. The resulting Twin Lakes Aquifer Capacity Study was funded through a planning grant obtained by LNID through the RDOS, with the terms of reference reviewed amongst LNID, B.C. Ministries of Environment and Transportation, and coordinated through the RDOS.

The Twin Lakes study area is located in a relatively small (24.5 km^2) upland basin on the west side of the Okanagan Valley between Penticton and Keremeos. Members of the community obtain their water supply from private wells or water intakes in Twin Lake. Seasonal use of water for irrigation has occurred for many years, beginning with ranching operations and then later with the development of the Twin Lakes Golf Course.

Previous water resource management-related studies in the Twin Lakes area date back to the 1960s and have continued in each decade since. The current study drew heavily on the work of these previous investigators. The most recent study (Golder-Summit 2009) comprised a groundwater balance analysis of the Twin Lake unconsolidated aquifer system, and was part of a basin-wide study for the Okanagan Water Supply and Demand Project.

The basic cycle of water movement through the basin consists of the following processes:

1. Precipitation as rain or snow falls on the surrounding uplands and in the valley bottom.
2. In spring, snowmelt produces runoff; in the upper part of the basin above Horn Lake, runoff supports the flow in Horn Creek; in some years, Horn Creek feeds directly to Horn Lake, in lower runoff years, Horn Creek losses to the ground exceed surface flows at some point above Horn Lake and thus are thought to recharge the aquifer system beneath the lakes.
3. Lakes receive input primarily from direct precipitation and Horn Creek runoff with little to no groundwater inflow; the lakes are believed to lose water to evaporation and through subsurface seepage to the unconsolidated aquifer system.
4. The surface catchment for Horn Lake is much larger than the catchment for Twin Lake; thus Twin Lake relies on excess surface flow from Horn Lake; when such flow is not available (as has been the case in recent years), the level of Twin Lake declines.
5. Groundwater flow is generally from south to north, beneath the lakes and exits the study area beneath Highway 3A near Trout Lake. Before groundwater exits the system, some of it is captured by pumping wells. Groundwater levels are generally deep enough that losses to groundwater evapotranspiration are believed to be minimal.

The objectives of the Twin Lakes Aquifer Capacity Study were to develop and refine a hydrogeological conceptual model, to assess the sustainable capacity of the aquifer system, assess the probable causes of lake level declines, and determine if there is enough water to support existing land uses, and whether or not additional water use required by future development is possible or advisable. In addition, we were specifically asked to investigate the water licences associated with the existing Horn Lake dam and associated works, as they relate to lake levels and what was approved by the provincial government, and also to provide an overview of potential ecosystem impacts caused by declining water levels.

To address the study objectives Summit completed the following:

- Conducted a field reconnaissance attended by hydrogeologists and a professional biologist;
- Documented ecosystem components and made water level measurements in the lakes and selected available wells;
- Interpreted well logs and pumping test information and developed a conceptual hydrogeological model including subsurface cross sections and groundwater flow analysis;
- Compiled and refined the existing groundwater balance analysis from the 2009 study;
- Adapted the 2009 groundwater balance analysis for use in future scenario modeling, incorporating climate change and increased water use;
- Estimated probable rates of groundwater capture (pumping) based upon existing information and on model-derived estimates;
- Reviewed storage and irrigation licences associated with Horn Lake and discussed same with B.C. Ministry of Environment staff;
- Applied the conceptual and water balance models combined with professional judgment in determining linkages between climate, water use, declining lake levels, and sustainable groundwater yield; and
- Developed a series of recommendations for improving water management within the Twin Lakes basin for consideration by RDOS, LNID and B.C. Ministry of Environment.

The main findings from the study included:

- Previous recommendations to conduct systematic collection of groundwater use and water level data have not been implemented; therefore, data are lacking to make predictions with a high degree of certainty;
- The estimated annual recharge o the Twin Lake unconsolidated aquifer is $1.15x10^6$ m^3 (570 US gpm); this compares with the estimated discharge through the system based upon a Darcy analysis of $1.14x10^6$ m^3 (570 US gpm);
- Estimated current groundwater capture rates from the aquifer range from 122 to 212 US gpm; which compares with a modeled estimate of 184 US gpm;
- Estimated future groundwater capture rates range from 169 to 416 US gpm;
- The current rate of capture is about 30% of the natural recharge and groundwater flow through the system; and
- Given the uncertainty of the data, and the sensitivity of the basin to short-term climate events such as droughts, the 30% capture rate should be considered the sustainable yield of the system; based on this, additional water demand from development may not be achievable in the long term.

Improving water management in the Twin Lakes basin will require the progressive adoption of an integrated land use and water management framework that may have voluntary as well as regulatory elements. Recommendations in this regard are provided as alternatives, and are summarized below in general order starting with voluntary or outcome-based measures and ending with regulatory measures:

1. Implement a pilot project to promote voluntary groundwater level and groundwater use measuring and reporting;
2. Establish a pair of groundwater observation wells along with surface water level stations in each of the two lakes;
3. Implement a pilot water demand management project including a benchmarking study on current water use;
4. Create a land-use designation identifying the Twin Lakes basin as “water-limited area” or “water conservation zone” to promote increased awareness to protect the resource;
5. Leverage potential funding sources to institute water-saving landscaping features for existing and new construction.
6. Develop a rural land use or sub-area plan with the objective being to protect the lake-aquifer system from further development that would increase groundwater usage beyond current levels.
    a. In the plan, identify levels of detailed hydrogeological study needed to support further development.
    b. Also provide an enabling mechanism to allow for peer-review of proponent-funded water availability studies.
7. Implement a voluntary water management plan similar to that developed recently in the Cowichan Basin on Vancouver Island.
8. Implement a formal water management plan similar to that attempted recently in Langley, B.C.
9. Work in partnership with OBWB and the provincial government to establish a pilot groundwater use regulation within the Twin Lake basin.

Our summary **key recommendations** are, at a minimum to implement the long-needed measurement of water use and water levels, implement some form of groundwater management as indicated in Section 7.2, and to work with the Ministry of Environment Water Stewardship Division in order to limit new surface licences and to reduce existing licenced use where and when possible.

ACKNOWLEDGMENTS

Summit would like to thank the following groups and individuals for their help in providing information to complete this study: Lower Nipit Improvement District, Regional District of Okanagan Similkameen, Twin Lakes Golf Course, Coral Brown, Denton Black, Betty Purdy, and Simon Siebens.

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1.0 INTRODUCTION

The Twin Lakes area (study area) is located on the west side of the Okanagan Valley between Penticton and Keremeos, B.C. and is accessed via Highway 3A (Figure 1). The Twin Lakes community is comprised of about 130 residences, and is made up of the Lower Nipit Improvement District (LNID), private ranches, a golf course and agricultural lands. There are three small lakes and one pond within the Twin Lakes area (Plate 1). These surface water bodies overlie a semi-confined unconsolidated aquifer. There is currently no surface water outlet from the Twin Lakes catchment.

The land users in the Twin Lakes area obtain their water supply from private groundwater wells or from water intakes in the Lower Twin Lake. Declining water levels in the lake and groundwater in the past few years have caused problems for water users. In some cases, the water level in the lake or the groundwater is now lower than the pump intakes, causing the property owner to switch from lake intakes to groundwater wells, or to drill new deeper groundwater wells.

In 2008-2009, the LNID requested assistance from the Regional District of Okanagan-Similkameen (RDOS) in determining the cause(s) of recent declines in lake levels and the potential effects of future development on the community and the environment. The resulting Twin Lakes Aquifer Capacity Study was funded through a planning grant obtained by LNID through the RDOS.

The Twin Lakes basin represents in many ways a smaller-scale version of the issues that concern residents throughout much of the Okanagan. Our climate is changing, there is significant climate variability ranging from very high to very low runoff years, land development pressures continue, and while water governance remains a complex undertaking. Against this backdrop, the Regional District of Okanagan-Similkameen (RDOS) and the LNID have obtained funding to prepare a state-of-the-basin report for the Twin Lakes catchment. Given the uncertainty in the groundwater - surface water interactions within the Twin Lakes area, and the concern of the residents, in October 2009 the RDOS issued a request for proposals (RFP) to complete an aquifer capacity study for the Twin Lakes area. This report will update older and sometimes inconclusive information with the latest climate and hydrologic data, and will lay the groundwork for effective water-based local government planning.

1.1 PROJECT OBJECTIVES

The primary objectives of this study are the following:

1 Review all available information and assess current and future uses of water;
2 Assess the current aquifer capacity,
3 State future constraints if the current capacity is not reached; and,

4 Recommend measures to ensure protection of the existing residents and the natural environment.

1.2 Scope of Work and Method

To achieve the above stated objectives we applied the following method:

1. Reviewed and summarized all pertinent past reports and information;
2. Performed a site visit on December 3, 2009, to assess the area to take water levels and GPS measurements, and discuss the project with the RDOS and LNID who also attended the visit;
3. Developed a hydrogeological conceptual model for the aquifer system;
4. Reviewed and estimated water consumption;
5. Performed both manual and spreadsheet assisted water balances to assess aquifer capacity;
6. Identified potential impacts; and,
7. Reported findings and provided recommendations (this report).

The following describes the method used in the current study to arrive at a reasonable estimate of aquifer capacity for the study area.

Site Visit

On December 3, 2009 Mr. Doug Geller P.Geo., Bryer Manwell M.Sc. E.I.T and Ms. Alexandra de Jong Westman, M.Sc., R.P.Bio. of Summit conducted an overview assessment of the Twin Lakes area. Ms. Betty Purdy (LNID), and Mr. Andrew Reeder (RDOS) accompanied the Summit team during the site visit. The visit included inspection of the area between Horn and Twin Lake, photographing the area, taking GPS and water level measurements at available groundwater wells and measuring lake stage at the Twin Lake gauge station. Appendix A presents a memo detailing the environmental assessment performed by Ms. De Jong Westman.

Review of Existing Reports and Development of a Hydrogeological Conceptual Model

All available maps, photos, and documents regarding water resource at the study area were gathered and reviewed. Refer to Section 1.3 for the list of pertinent documents reviewed. From available well logs and orthophotos a conceptual hydrological cross-section was created to help assess groundwater flow through the Twin Lakes Aquifer.

Water Balances

Although water management has been an issue in the Twin Lakes area for over 50 years, little measured data (i.e. stream flow measurements, climate data, lake evaporation, aquifer pumping rates, or groundwater and surface water levels) exists for the study area. To conduct the current aquifer capacity assessment estimates of variables such as precipitation, evapotranspiration and current and future groundwater capture (i.e. pumping, or extraction) have been made. To arrive at a reasonable estimates multiple methods for estimating both aquifer discharge and aquifer capture have will be presented.

An MS Excel-based spreadsheet groundwater balance analysis tool (GWBAT) developed by Golder-Summit for the OBWB Groundwater study (Golder-Summit 2009) was one method utilized in assessing aquifer capacity. The GWBAT is not a numerical model; however, it provides a first order approximation of groundwater budgets. Three scenarios analysed with the GWBAT for the Twin Lakes Aquifer study were as follows: 1) 1996-2006 a base-case scenario using historic precipitation data and current groundwater use patterns, 2) 2010-2040 future scenario using predicted precipitation data, expected carbon dioxide emissions, current use patterns and current efficiency trends, irrigating all arable land, and a high rate of population growth and 3) 2010-2040 future scenario using predicted precipitation data, reduced carbon dioxide emissions, current use patterns and current efficiency trends, irrigating with present conditions, and an expected rate of population growth. The future scenarios were selected from a much longer list of scenarios currently being evaluated for the Okanagan Basin Phase 2 Water Supply and Demand Project, with the future scenarios intended to bracket reasonably likely future water conditions.

1.3 PREVIOUS INVESTIGATIONS AND INFORMATION SOURCES

As noted above, water management has been a concern in the Twin Lakes area for many decades. Many researchers and concerned residents have gathered data on the area. Pertinent documents reviewed for this study included the following:

- Preliminary Report on Control of Surface Levels on Twin (Nipit) Lakes (Botham et. al. 1973);
- Letters to Lower Nipit Improvement District regarding proposed development in the Twin Lakes Area. 1981. (Van der Kamp G. 1981a and 1981b);
- Twin Lakes Basin Hydrogeological Study. Prepared for Twin Lakes Gold & Country Resort, Kaleden, B.C. (EBA 1994);
- Evaluation of groundwater quantity and quality from a well proposed to supply a six-lot subdivision at the south end of Twin Lakes Golf and R.V. Resort, southwest of Penticton. (Pacific 1994);
- Letter to Lower Nipit Improvement District c/o Mr. J. McPherson regarding licensing on Upper and Lower Twin Lake dated May 13, 1996 (Hare (MoE 1996);
- Assessment of groundwater availability, proposed residential subdivision, District Lot 259s, SDYD, Twin Lakes, British Columbia (Golder 1997);
- BC Lake Stewardship and Monitoring Program, Twin (Nipit) Lake 1999 – 2003, The Importance of Twin Lake and its Watershed (MoE 2004);
- Historical Groundwater Data Review and Groundwater Data Collection – Proposed Twin Lakes Golf Report Expansion, Twin Lakes, B.C.(EBA 2007);

- Personal communication via e-mail with Suki Sekhon regarding Twin Lakes Golf Report Groundwater Production Rates and Demand, sent Tuesday November 18, 2008. (Watterson D. 2008);
- Well capacity evaluation of main irrigation well, Twin Lakes Golf and Country Club, Kaleden, BC.(EBA 2009);
- Phase 2 Okanagan Water Supply & Demand Project: Surface Water Hydrology and Hydrologic Modelling Study "State of the Basin" Report.(Summit 2009a);
- Phase 2 Okanagan Water Supply and Demand Project: Main Report. Summit Environmental Consultants Ltd. (Summit 2009b);
- Phase 2 Okanagan Water Supply and Demand Project: Groundwater Objectives 2 and 3 Basin Study (Golder and Summit 2009);
- Pertinent surface water licenses; and
- Twin Lakes Resort Groundwater Supply-Demand and Impacts Summary. Letter to Mr. Suki Sekhon from Daniel Watterson. (EBA 2010).

Five documents were thought to be of significant value for detailed background information and have been included in the current report (Appendix E) for ease of reference. These reports are Botham 1973, Van der Kamp 1981a and 1981b, EBA 1994, and Hare (MoE 1996).

2.0 SITE DESCRIPTION

The overall study area is the catchment of the Twin Lakes basin south of Highway 3A, which comprises about 24.5 km^2. The detailed study area is taken to be the valley bottom area south of Highway 3A to the top of Horn Lake. The area includes Twin Lake, Horn Lake, the turtle pond (between Twin and Horn Lake), a golf course, residential development around Twin Lake, and the agricultural land (currently leased for ranching) surrounding Horn Lake (Plate 1). The detailed study area covers approximately 3.2 km^2, while the entire Twin Lakes catchment (including the upland areas) accounts for 0.3% of the Okanagan Basin area.

2.1 CLIMATE

The Twin Lakes area is affected by the rain shadow of the Cascade Mountains located to the southwest; therefore, precipitation in the area is below average for the interior of B.C. Environment Canada climate normals at the Summerland CDA (station ID 1127800, Environment Canada 2010) are presented (Table 1) as it is located at an elevation of 454 metres above sea level (masl). Even though Penticton is located geographically closer to the study area, the elevation of the Summerland station is more representative. The yearly average temperature is 9 degrees with a yearly precipitation rate of 327 mm. The study area is located at an elevation of approximately 790 masl; therefore, average temperature would be lower and precipitation would be expected to be slightly higher than at Summerland. See EBA 1994 (Table A-4) for climate values adjusted to 1200 masl (the upper part of the Twin Lakes catchment). Actual evapotranspiration and the moisture deficit were estimated to be 71% and 26% of the annual precipitation (EBA 1994), indicating limited aquifer recharge is occurring on the valley bottom.

For the GWBAT estimate of aquifer capacity we used gridded climate data files, which estimate daily temperature and precipitation values interpolated on a 500m x 500m. The gridded climate data were created from historic, current and projected climate data for the Okanagan basin Okanagan Climate Data Interpolation Model (Guy Duke, University of Lethbridge).

Table 1. Climate normals (1971-2000) for Summerland CDS climate station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature													
Daily Average (°C)	-2.5	0.2	4.7	9	13.6	17.4	20.5	20.2	15	8.8	2.4	-1.9	8.9
Standard Deviation	2.9	2.4	1.4	1.4	1.3	1.7	1.7	1.5	1.5	0.9	2.4	2.7	1.9
Precipitation													
Rainfall (mm)	8.3	9.9	16.4	25.6	35.9	36.2	30.2	30.5	20.2	17.6	18.9	11.6	261.2
Snowfall (cm)	21.8	11.9	2.6	0	0	0	0	0	0	0.4	8.7	22.4	67.9
Precipitation (mm)	29.7	20.9	18.6	25.6	35.9	36.2	30.2	30.5	20.2	18	27.5	33.4	326.5

2.2 GEOLOGY

Surficial geology consists primarily of kettled outwash deposits. Other surficial deposits in the area include the alluvial fan of Horn Creek and colluvium along the hillsides. Materials consists primarily of sand and gravel along with local deposits of silt and clay (see Section 3.2 for more detail regarding the hydrostratigraphy of the surficial deposits). Both Horn Lake and Twin Lake are deemed glacial Kettles and formed as a result of the last glacial ice retreat in the area (Nasmith 1980).

Bedrock geology beneath the site consists of Intermontane Cenozoic - Eocene undivided volcanic rocks of the Penticton Group - Marron, Kettle River, Springbrook, Marama and Skaha Formations (MoE 2010).

2.3 HYDROLOGY

Horn Lake (Upper Nipit) and Twin (Lower Nipit) Lake occupy a small headwater basin that is tributary to the larger Okanagan Basin, itself a headwater basin within the Columbia River drainage system in southern B.C. The total area of the Twin Lakes catchment above Highway 3A is approximately 24.5 km^2. The elevations in the Twin Lakes catchment range from 1550 masl in the upper watershed to 780 masl on the valley floor. Horn Creek is a second order stream originating in the upper watershed;

it has a catchment area of approximately 18.3 km^2, this catchment area accounts for 75% of the Twin Lakes watershed above Highway 3A (Plate 1). On Figure 2, note the relatively small area that drains directly to Twin Lake. Bear Creek is tributary to Horn Creek and in the upper watershed, both streams have been observed to flow year round. The lower reach of Horn Creek is ephemeral, only flowing during the snowpack melt (freshet), from about March to August (Summit 2009). That the streams typically flow year round in the upper watershed and only seasonally near the inlet to Horn Lake indicates that both Horn Creek and Bear Creek are losing to groundwater above Horn Lake.

During runoff Horn Creek discharges into the south end of Horn Lake (Plate 1 and Figure 2). Normal averaged yearly discharge of Horn Creek at the inlet to Horn Lake between 1996 and 2006 was estimated at 0.007 m^3/sec (Summit 2009a).

Horn Lake and Twin Lake sit at approximately 797 masl and 791 masl, respectively from a survey with a differential GPS during the site visit (December 3, 2009). A dam and sluice gate were built between Horn Lake and Twin Lake in the 1960s to store $2.47X10^5$ m^3 (200 acre-feet) on Horn Lake under the Conditional Licence No. 19011 (MoE 1973). Surface water flow between Horn Lake and Twin Lake occurs when the water level in Horn Lake is above the sluice gate. During the December 3, 2009 site visit Summit observed that the high water mark for Horn Lake on the wooden structure surrounding the sluice gate was approximately one metre (three feet) above the sluice gate (Photo 2). When Horn Lake stage (level) is above the sluice gate water flows into the Turtle Pond and subsequently water flows through a culvert which discharges into the southwest end of Twin Lake (Plate 1). There is no outlet for surface water from Twin Lake.

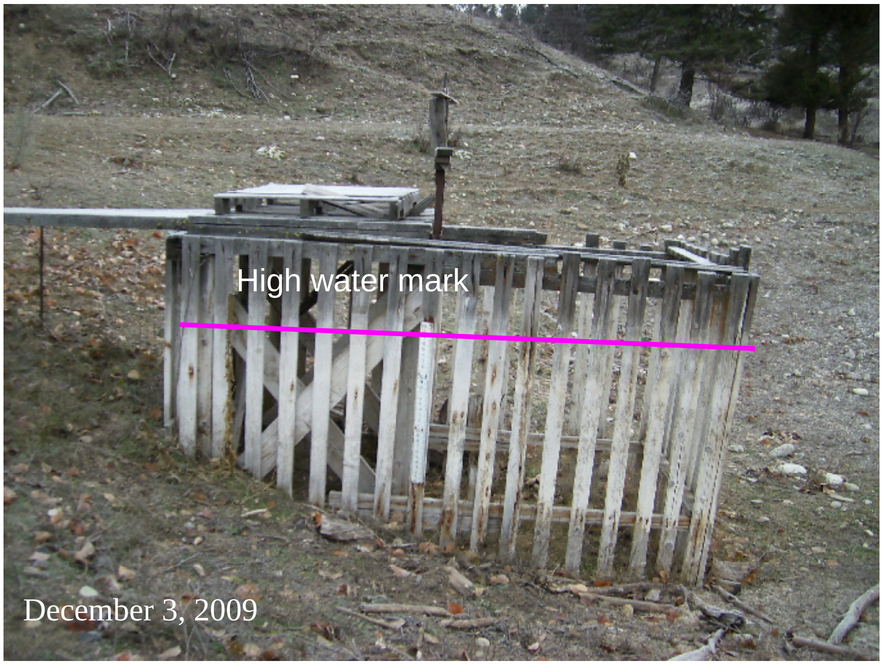

Photo 1. Protective wooden structure around sluice gate inlet.

A Bathymetric map of Twin Lake was created by the BC Lake Stewardship and Monitoring Society (2003) and provided to Summit by the Lower Nipit Improvement District (Mrs. Betty Purdy). From the Bathymetric Map (Figure 3) it is evident that Twin Lake is actually three smaller surface water bodies that join into one lake when the surface water level is 20 m above the lake base (connecting the south lobe and middle lobe) and 7 m above the lake base (connecting the north lobe and middle lobe) (Figure 3). From anecdotal evidence in the 1930s Twin Lake level was so low that the lake appeared as two lakes (Clifton W. pers comm. 2009).

Due to the proximity of Horn and Twin lakes to the headwaters of the basin, rapid and extremely variable water levels have been observed. Since the settlement of the Twin Lakes area periodic flooding has proved to be a problem for ranchers and residents. In the 1973 study titled 'Preliminary Report on Control of Surface Levels on Twin (Nipit) Lakes' J. Botham detailed the dry and wet climatic cycles and the subsequent water management strategies employed by residents in the Twin Lakes area. In 1965 the Lower Nipit Improvement District was incorporated; they have assumed responsibility for managing the level of Twin Lake so as to avoid flooding during wet cycles.

Horn Creek discharge is not currently measured; therefore, the hydrograph for the Similkameen was reviewed to facilitate a discussion of the effect of climate trends on yearly snowmelt (which directly affects stream discharge and groundwater levels). Although the Similkameen River may see more effects from coastal weather patterns, the hydrograph displays the overall response to climate in the region. Figure 4 presents the Similkameen River hydrograph at Nighthawk Washington (Environment Canada Station No. 08NL022) between 1929 and 2008 (Environment Canada 2010), the yearly average discharge is plotted along with a five-point moving average. This hydrograph shows the wet and dry cycles common in the region. In the last 10 years average yearly discharge has not been above 80 m^3/sec, whereas in the 1990s four years were above the 80 m^3/sec. The Similkameen hydrograph shows that the last ten years have been drier than average and the basin currently remains in this drier than average cycle.

Water level (lake stage) measurements were recorded for Twin Lake periodically between 1946 and 2009 (Figure 5). During Summit's site visit, the elevation of the old concrete sill (datum 1) and the new lake stage gauge (datum 2) were surveyed with a differential hand held GPS to an accuracy of +/- 30 cm. The old concrete sill represents the Water Survey of Canada (WSC) gauge station No. 08M148, established on Twin Lake in 1968. The level of the sill was considered to be the high lake stage (795.6 masl) and five feet below the sill (which corresponded to 12.6 ft on the WSC lake stage gauge plate adjacent to the McPherson pump house) was considered the low lake stage (794 masl). Since August 2007 the LNID has taken on monthly measurement of the lake stage (Figure 5).

Although no statistical evaluation can be made due to a limited data set, comparing the Twin Lake stage graph and the hydrograph for the Similkameen River shows similar long-term trends. The wet cycle of the early 1950s is reflected in a lake stage above the high water mark. Whereas during the dry cycle of the late 1960s the lake stage was below the normal low water mark. 1972 saw the highest average yearly discharge on the Similkameen (Figure 4) and this compares well with the sudden rise of the Twin Lake stage in that year (Figure 5). In recent years the stage of Twin Lake has remained over 0.6 m (2 ft) below what was established as the normal low water mark. Since 2007 the lake stage has been on a continuous decline (Figure 5). During the 1960s and until 1971 water was pumped directly from the lake by licence holders. The last pumping of Twin Lake by the LNID reportedly occurred in 1998 as directed by the MoE. Although pumping of the Twin Lake has not occurred since 1998, the lake stage continues to decline. This declining trend is likely the result of a combination of nearby groundwater extraction (capture) and lower than average snowmelt runoff in recent years (see Appendix D for further discussion).

3.0 HYDROGEOLOGICAL CONCEPTUAL MODEL

Past investigations of water resources in the Twin Lakes area have focused on developing a conceptual model of groundwater flow. The following sections present our understanding of the aquifer properties and groundwater flow.

The B.C. Ministry of Environment (MoE) has mapped the unconsolidated Twin Lakes Aquifer called MoE Aquifer 261 IIB (11) and the underlying bedrock aquifer as MoE Aquifer 260 IIB (11). The demand, productivity and vulnerability of MoE Aquifer 261 is classified as moderate for all three characteristics. Demand, productivity and vulnerability for MoE Aquifer 260 are low, low and moderate, respectively. In the recent report issued by Golder and Summit (2009) for the Okanagan Basin Water Board Phase 2 Okanagan Water Supply and Demand Project: Groundwater Objectives 2 and 3 Basin Study, the Twin Lakes aquifer is designated as OBWB Aquifer 221.

3.1 AQUIFER EXTENT

The footprint of the unconsolidated aquifer (valley bottom area, 2 km^2) is small (8%) relative to the size of the catchment above Highway 3A (24.5 km^2). The Twin Lakes Aquifer is bounded by bedrock to the east and west and by a groundwater divide to the south of Horn Lake. To the north the aquifer is inferred to discharge through the Marron Valley to a downgradient bedrock aquifer (OBWB Bedrock Aquifer SK2) which recharges Skaha Lake directly. The inferred groundwater flow direction is from south to north and groundwater movement is topographically-driven. The average width of the Twin Lakes Aquifer is taken to be 415 m and the length of the aquifer between the groundwater divide (south boundary) and Highway 3A is 5 km. The total length of the aquifer is approximately 8 km. An average aquifer thickness of 20 m was assigned within the study area from assessment of well logs (MoE 2010).

During test pumping performed at the Twin Lakes Golf Resort in 1994 and 2009, negative boundary effects were evident (EBA 1994 and EBA 2009). These boundaries are interpreted to represent the east and west bedrock no flow aquifer boundaries. From the empirical test pumping data and evaluation of the geomorphology of the Twin Lakes Aquifer, it is evident the aquifer is bounded and of limited lateral extent.

A low divide separates this catchment from Park Rill, which drains east and then southeast toward Meyers Flat (Willowbrook), another small groundwater basin within RDOS in a similar setting that has experienced problems with low groundwater levels in recent years (Summit 2006). A small component (estimated by Summit to be $8.76X10^4$ m^3/year) of natural subsurface outflow may exit the basin to the east toward Park Rill; however, the majority of the natural groundwater outflow is to the north toward Trout Lake and the Marron Valley. At times of high water, the location of the Park Rill low divide may shift westward, thus temporarily increasing the subsurface outflow to the east.

Being a closed (i.e. no surface outlet) upland basin with a relatively small catchment area, the Twin Lakes hydrologic system is characterized by relatively rapid response to stresses such as extraction or climate variability. To help illustrate the hydrogeological conceptual model, a cross-section of the subsurface running the length of the Twin Lakes Aquifer within the study area was created (Plate 2). The cross-section was developed based on mapped bedrock geology and water well driller's logs (reports) provided on the B.C. MoE Water Resources Atlas (MoE 2010). From the conceptual cross-section three different hydrostratigraphic layers are evident with the Twin Lakes Aquifer. These layers have been deemed Twin Lakes Aquifer A, B and C. Twin Lakes A is the predominant formation within the aquifer and is comprised of interbedded sand and gravel with minor silt layers. Twin Lakes B is made up of laterally discontinuous interbedded sand and gravel with partial cementation, and little to no fine material. Twin Lakes C is characterized as interbedded fine to coarse sand and silty sand, with little to no gravel.

3.2 GROUNDWATER – SURFACE WATER CONNECTION

Our current hydrogeological conceptual model of the Twin Lakes Basin represents the groundwater and surface water (lakes) as one connected system. The following observations support the hypothesis that groundwater and surface water are connected:

1. No continuous aquitard is evident from the well driller's logs (MoE 2010);
2. There is an apparent downward vertical hydraulic gradient when comparing paired neighbouring wells;
3. From test pumping results, wells completed in both the shallow (lake connected formation) and the deeper formation indicate that the aquifer behaves as one semi-confined (leaky) aquifer; and
4. Bortham (1973) describes observing, after a dry climatic cycle, snow melt recharge from the upland areas first recharging the aquifer and then, once the aquifer had been recharged, recharge to the lake in the subsequent year.

The following paragraphs provide more detail for the rationale behind considering the groundwater and surface water hydraulically connected.

Two distinct water levels are evident within the Twin Lakes Aquifer and are associated with hydrostratigraphic Units A, B and C (Plate 2). Twin Lakes Aquifer A generally has shallow static water levels; whereas Twin Lakes B and C generally have deeper static water levels. Based on comparison of several neighbouring well pairs, the downward vertical hydraulic gradient between the upper and lower formation is quite strong (between 1 and 4 m/m). From assessment of aquifer properties estimated by test pumping wells completed in both the shallow and deeper formations (Carmichael et. al. 2009) it is evident that the Twin Lakes Aquifer behaves as one semi-confined (leaky) aquifer.

From Botham's 1973 report, Horn Creek has been observed in a rising flood stage for several days before reaction occurred at Horn Lake; indicating high groundwater absorption. In 1971 precipitation was above average; however, Twin Lake level only rose two feet. The bulk of the snowmelt was apparently accounted for in recharging the groundwater aquifer, which had been depleted during the preceding dry cycle. This observation is critical in understanding that the lakes and aquifer are one inseparable system.

3.3 WATER LEVELS AND HYDRAULIC PROPERTIES

Currently, no groundwater level monitoring (observation) wells exist in the Twin Lakes Aquifer. The nearest MoE observation Well is No 282 located in the Park Rill catchment at Meyers Flat (Willowbrook). The hydrograph for observation well No. 282 between January 1983 and April 2008 is presented in Figure 6. The hydrograph shows that from 1997 until 2006 water levels declined. As of 2008 groundwater level at Meyers Flat remained 8 m below the peak water level observed in 1997. The Meyers Flat observation well shows good correlation with the patterns seen on the Similkameen hydrograph (Figure 4). The groundwater levels within the Twin Lakes Aquifer would likely have followed a similar trend to the observation well No. 282, as both aquifers are recharge-limited and experience relatively high capture (pumping) rates. The Twin Lakes aquifer transmissivity is estimated at $1.14X10^{6}$ m^{3}/yr and the hydraulic conductivity of the aquifer is estimate at $3.11X10^{-4}$ m/sec. Refer to Section 4.2 for more details on the derivation of these estimates.

3.4 WATER QUALITY

Geochemical data collected during test pumping wells in the area suggests that groundwater in the deeper formation has undergone longer flow paths as ion exchange has likely occurred (Pacific 1994, EBA 1994, EBA 2009). There appears to be little anthropogenic impact on the aquifer as nitrate and chloride levels at the Main golf course well are relativity low at <0.01 mg/l and 7.2 mg/l, respectively (EBA 2009).

3.5 OVERVIEW OF GROUNDWATER AND SURFACE WATER RECHARGE AND DISCHARGE PROCESSES

In adapting the OBWB Phase 2 groundwater study methodology for evaluating current and future scenarios of the Twin Lakes Aquifer the hydrogeological conceptual model used for the Phase 2 OBWB Groundwater Supply and Demand Study (Golder – Summit 2009) was also incorporated. The conceptual model describing groundwater recharge, groundwater flow and groundwater discharge in the Basin are described below.

Within all of the Okanagan Basin, including the study area, upland areas (i.e. above an elevation of approximately 800 masl) account for a very large portion of the Basin footprint, and most groundwater recharge is generated above this elevation.

Groundwater recharge and subsurface flow are topographically-driven by the substantial elevation difference between the highland areas and the base of the Valley. Spring snowmelt (freshet surface water runoff) produces significant seasonal variability in streamflow and in turn, groundwater recharge through infiltration from stream losses.

Recharge to the unconsolidated aquifer system in the base of the Twin Lakes valley is partially via contributions from the shallow upland bedrock aquifers within adjoining area(s) immediately upgradient. Natural recharge to the unconsolidated aquifer system is also through infiltration of streamflow and probably lake bed seepage. For assessment of aquifer capacity the recharge from the shallow upland aquifer zone to the unconsolidated system is assumed to be constant, whereas infiltration of streamflow is seasonally variable and proportional to surface water runoff, with the majority occurring immediately following snowmelt and surface water runoff.

3.6 TEMPORAL CHANGES IN GROUNDWATER LEVELS

As noted above there are currently no provincially-monitored observation wells in the Twin Lakes Aquifer. Therefore, evaluating changes in water level over time is based on water level measurements made during various groundwater investigations, including the current study, and from driller's well logs. Table 2 summarizes groundwater level measurements recorded in the reviewed documents. At DW3 and WTN 53185 (see Plate 1 for locations) an approximate three metre and two metre decline in the water level is apparent between the 1980s (when the wells were drilled) and 2009. An approximate 2 m decline in water level was observed between June and September 1994 at the Twin Lakes Golf Course wells "C1" and "Domestic Well" (EBA 1994). The rapid drop in water level at the golf course is likely due to pumping of the Golf Course Main irrigation well during this three month time interval. Assuming a porosity of 0.25, a one to three-metre decline in groundwater level represents a significant volume of water ($2.53X10^5$ m^3 to $5.75X10^5$ m^3 or $6.7X10^7$ US gal to $1.5X10^8$ US gal) removed from aquifer storage between Horn Lake and Highway 3A. This decline in water level is likely due to a combination of reduced recharge (climate) and increased use (pumping).

Table 2. Twin Lake Aquifer groundwater level measurements.

Well Name and Well Tag Number (WTN) if known	**DW3 (58440)**	**C1 Well**	**Hwy Well**	**DW1**	**DW2**	**Domestic Well (83151)**	**South Well (62716)**	**WTN 53185**
Assumed formation monitored (Unit A, B or C)	**A**	**C**	**A**	**C**	**C**	**A**	**C**	**C**
Elevation of top of casing	799.83	809.45	779.27	804.97	808.43			
Depth to water (m)								
October 19, 1984 (m)								24.99
September 22, 1988 (m)	5							
March 3, 1994 (m)								27.2
June 7, 1994 (m)		27.03	10.47			5.76	41.45	
September 21, 1994 (m)		27.61	11.01			8.24	42.00	
January 11, 2007 (m)			11.62			5.18		
December 3, 2009 (m)	7.10	28.92	12.13	24.41	19.11			
Water level elevation (masl)								
September 22, 1988	795							
June 6, 1994		782.4	768.8					
September 21, 1994		781.8	768.3					
January 11, 2007			767.7					
December 3, 2009	793	780.5	767.1	781	789			
Max Change in WL (m)	**2.1**	**1.9**	**1.1**			**2.5**	**0.5**	**0.7**

Notes: All water levels are measured from below top of casing.

3.7 OVERVIEW OF OBWB GROUNDWATER BALANCE MODEL

To assist the assessment of aquifer capacity the Groundwater Balance Analysis Tool (GWBAT) was utilized. The GWBAT is a spreadsheet custom-designed by the OBWB Supply and Demand Groundwater Study Project Team. The purpose of the tool is to enable calculation of time-series values of groundwater flow for discrete aquifer systems based upon simplified conceptual groundwater models and estimated or modeled inputs and outputs. The GWBAT is not a numerical model but a first order approximation, however, the tool is useful when there are limited data to support a more sophisticated numerical model, as is that case in the current study. Below is a very brief summary of the GWBAT components and assumptions; for a detailed description refer to Appendix C or Golder-Summit (2009).

GWBAT Components

The spreadsheet has seven basic components including the following:

1. Aquifer Description Component (aquifer width, length, porosity, etc.)
2. Aquifer Characteristics Component (Darcy flow)
3. Water Balance Component (Difference between inputs and outputs)
4. Comparison Component (comparison between Darcy flow and water balance component)

GWBAT Assumptions

Several assumptions were incorporated into the spreadsheet (GWBAT Tool) over the designed trial time periods.

1. Contributions of recharge from adjacent bedrock systems were assigned a constant value;
2. Temporal changes in infiltration from surface flow were apportioned by applying a monthly adjustment factor to monthly precipitation; and,
3. The solution is non-unique; therefore, different inputs can yield a similar solution. Therefore, professional judgment is inherently required to use the tool.

4.0 TWIN LAKES AQUIFER DISCHARGE ESTIMATES

To arrive at a reasonable estimate of aquifer discharge two methods were used: 1) catchment water balance approach, and 2) groundwater flow analysis approach.

4.1 CATCHMENT WATER BALANCE APPROACH

By understanding the rate of natural recharge a preliminary assessment of the natural groundwater balance is possible (Alley et all 1999). The majority of precipitation within the Twin Lakes basin will fall as snow at elevations greater than 800 masl during the cooler months and subsequently melt during the spring/summer melt (freshet) which typically occurs in April or May in the Twin Lakes basin. This freshet water will partition to surface water runoff (i.e. creek discharge), evaporation, transpiration by plants, and recharge to groundwater. Using a simple mass balance, represented by Equation 1 below, we can estimate the net volume of groundwater recharge in the Twin Lakes basin. The following presents the catchment water balance method.

$$P = SR + AET + GWR \qquad \text{Equation 1}$$

Where:

P = average annual precipitation (m^3yr)

SR = average annual surface water runoff (m^3/yr)

PET = average annual potential evapotranspiration (m^3/yr)

AET = average annual actual evapotranspiration (m^3/yr)

GWR = average annual groundwater recharge (m^3/yr)

Parameters for the water catchment water balance were taken from the Phase 2 OBWB Water Supply and Demand - Groundwater Study. The parameters were derived from available climate data and Table 3 summarizes the groundwater recharge estimates above Horn Lake. Values in Table 3 are annual average values for the period of 1996 to 2006 for the Twin Lakes Basin, and are based on Golder – Summit (2009).

Table 3. Summary of catchment water balance parameters (annual averages (1996 to 2006).

Median Elevation	Aquifer Area (m^2)	P (m^3/yr)	SR (m^3/y)	PET (m3/y)	AET (m^3/y)	GWR (m^3/yr)
1349	1.6E+07	1.1E+07	1.4E+06	1.4E+07	8.2E+06	1.4E+06

Assuming 15% of groundwater recharge reports to the deeper bedrock fracture flow system average annual recharge from the upland to the Twin Lakes unconsolidated aquifer is estimated to be 1.4 $X10^6$ m^3/yr multiplied by 85% or **1.15$X10^6$ m^3/yr (570 USpgm).** In 1981 Van der Kamp estimated aquifer recharge based on stream inflow and precipitation to be approximately $8X10^5$ m^3/yr (400 USgpm) and in 1994 EBA estimated aquifer recharge to be $1.5X10^6$ m^3/yr (750USgpm), the latter figure presented as a five-year return dry period. The 1994 EBA higher-end estimate was 1,800 US gpm, which is not supported by the data.

4.2 GROUNDWATER FLOW ANALYSIS APPROACH

To hone in on an accurate estimate of aquifer recharge to the Twin Lakes unconsolidated aquifer we applied the empirically-derived Darcy's Law (flux) (Equation 2).

The following form of Darcy's Law was utilized:

$$Q = -KiA$$ Equation 2

Where:

Q = Discharge [$length^3$/time]

K = hydraulic conductivity [length/time]

i = hydraulic gradient (dimensionless) [length/length]

A = cross sectional area (aquifer width {W} * saturated thickness {b}) [$length^2$]

Inputs for the Darcy flow calculation were derived from assessment of past test pumping events, evaluation of the hydraulic gradient of the aquifer and measurement of the aquifer geometry, and were slightly modified from the values in Golder-Summit (2009).

Hydraulic conductivity (K) is typically the most significant aquifer property controlling the solution to the Darcy equation. It is more challenging to accurately determine bulk K than the thickness, hydraulic gradient or the porosity (all of which can be measured or estimated relatively accurately). For the current study Summit evaluated estimates of hydraulic conductivity from past test pumping data that had been summarized by the MoE (Carmichael et. al. 2009). Four test pumping events were summarized in Carmichael's compendium for the study aquifer. In determining the most representative hydraulic conductivity we applied the technique described by Neville (2008). First, one visual outliner was removed from the estimates (New Hwy Well). The outlier estimate varied by more than an order of magnitude from the other three estimates. This significant difference indicating it is potentially completed in a zone not characteristic of the formation or is potentially influenced by some other boundary condition not evident in the other three tests. Potentially the aquifer formation changes as the Twin Lakes aquifer merges with the upgradient aquifer to the west of the New Hwy Well. The remaining three estimates of hydraulic conductivity were observed to converge. This convergence of aquifer estimates satisfies the assumptions inherent in the Theis (and Cooper-Jacob) analytical model, used to derive these estimates. The geometric mean of the convergent hydraulic conductivities was then calculated. Table 4 summarizes the hydraulic properties derived from the MoE data.

Table 4. Summary of Twin Lakes Aquifer hydraulic properties MoE (2009).

Well Tag Number (WTN)	**55199**	**62716**	**46711**	**83151**
Well Name	New Hwy Well	South Well	Unknown	Main Well
Test date	9/22/1994	3/2/1994	6/23/1981	9/22/1994
Well depth (m)	26.5	51.8	29.3	25.9
Static water level (m)	3.4	41.6	7.6	7.7
Long term well yield (L/s)	16	3	3	25
Transmissivity, T (m2/d)	5043	757	117	457
Aquifer thickness at the well site b (m)	23.1	10.2	7.9	16
Hydraulic conductivity k (m/day) from T/b	218	74	15	29
Hydraulic conductivity k (m/sec)	2.53E-03	8.59E-04	1.72E-04	3.30E-04
		Geometric mean (excluding the outlier, WTN 55199)		3.11E-04

Note: the New Hwy Well (in green font) yields a hydraulic conductivity an order of magnitude different from the other three estimates and was considered an outlier and not used in the mean calculation.

Saturated thickness was interpreted based on cross sections developed from the BC MoE driller's well logs (MoE 2010). The elevation of wells was estimated from the digital elevation model (DEM, accurate to +/- 10 m) and based on the GPS location listed on the drillers' logs except for wells located with differential GPS during Summit's site visit. Aquifer width and length were constrained by the physical limits of the aquifer as mapped by the MoE (see Plate 1 for aquifer width outline). Specifically, the width was assigned as the average width of the aquifer measured perpendicular to the inferred groundwater flow direction. Gradients were determined using two methods; measurement of the topographic gradient and calculation of the hydraulic gradient, based on water level data.

Table 5 summarizes the Darcy analysis inputs. From the groundwater flow analysis approach the Twin Lakes Aquifer discharge is estimated at **$1.14X10^6 m^3/yr$** (570 US gpm).

The percent difference between the catchment approach and the groundwater flow approach is 5%, suggesting that we have arrived at a reasonable estimate of groundwater discharge within the Twin Lakes Aquifer. This value falls between the low estimate of Van der Kamp 1981 and the more optimistic estimate of EBA 1994.

Table 5. Summary of input parameters for the groundwater flow analysis.

Parameter	Symbol and Unit	Estimated Values
Hydraulic conductivity	K (m/sec)	3.11E-04
Hydraulic gradient	i (dimensionless)	0.014
Aquifer width	w (m)	415
Aquifer thickness (saturated thickness)	b (m)	20
Cross sectional aquifer area	A (m^2)	8300
Transmissivity	T (m^2/sec)	6.22E-03
Discharge	**Q (m^3/yr)** **(USgpm)**	**1.14E+06** **570**

5.0 WATER EXTRACTION (CAPTURE) ESTIMATES

Snowmelt is the principal source of recharge in the Twin Lakes basin and both groundwater and surface water (Horn and Twin Lake) are essentially part of the same reservoir for storage of the snowmelt water. As noted in the previous studies, water extraction (capture) of either groundwater or surface water in the Twin Lakes basin will affect the quantity of the other, as they are hydraulically connected.

Surface water and groundwater capture for agricultural, recreation (golf course) and domestic use occur in the Twin Lakes area. The earliest surface water extraction licence was granted by the provincial government in 1904 on Horn Creek, with significant licenses for storage and diversion granted in the late 1940s following a record runoff. In the last forty years land use has changed from agriculture to more recreational and domestic use. The 1950s brought a wet climatic cycle and flooding in the Twin Lakes basin was a problem. Surface water from the Twin Lakes Basin was diverted to Park Rill; however, flooding became a concern there as well. In the 1950s ranching was the principal land use around Horn and Twin lakes. In the 1960s Twin Lakes Golf Resort began pumping groundwater. The 1960s marked a return to dry climate conditions and by 1966 the pumping of Twin Lakes by the TL Ranch ended as the lake stage fell below the pump intake pipe. The early part of the 1970s saw another wet cycle (Figure 3) and the Lower Nipit Improvement District (formed in 1965) was charged with managing the Twin Lake stage. A dry cycle occurred thought the 1980s and into the early part of the1990s. Since 1998 we have entered another dry cycle. Although surface water pumping has not occurred since 1998, Twin Lake stage has been on a continuous rate of decline of 0.3 m/year (1 ft/year) since at least 2007. However, during this time groundwater extraction has been continuous and very high during the irrigation season.

Although other hydrological investigators have recommended monitoring water extraction (capture) (Van der Kamp 1981 and EBA 1994) no formal monitoring of either surface water or groundwater levels or use has occurred, although relative to some of the other locations examined in the OBWB Phase 2 Groundwater Study, the data availability is good. The following sections detail the available information on surface water withdrawal and estimates of groundwater capture in the Twin Lakes basin.

5.1 SURFACE WATER

There are several surface water diversion licences for Horn Creek (via Horn Lake) and Twin Lake and one significant storage license on Horn Lake; these are summarized in Table 6. It is interesting to note that if all current surface water licences were used 80% of the average Twin Lakes basin groundwater recharge would be used. The Hare letter (MoE 1996) (see Appendix E) provides a useful review of how the licences are administered. Note that the Comptroller of Water Rights (MoE) has issued an order that restricts water diverted from Twin Lake when the lake stage is below the low lake level (12.6 feet at the WSC gauge). Since monitoring of the lake level resumed in 2007 the lake has remained at least two feet below the low lake level. Therefore, many of these conditional licences on Twin Lake cannot be used. We suspect these licences have been replaced by unlicensed groundwater withdrawals. For more discussion on the surface water licences on Horn and Twin lakes refer to the Frequently-Asked Questions (Appendix D).

5.2 GROUNDWATER

As groundwater use is not currently regulated within the province of British Columbia there is no system of measurement and reporting of groundwater capture from the Twin Lakes Aquifer. In his letter to the Lower Nipit Improvement District dated October 21, 1981 Dr. Garth Van der Kamp, a prominent Canadian hydrogeologist, stated:

> "It is imperative that the pumping rates be recorded for the withdrawal from the lower lake and from the wells in the golf course area. A reliable estimate of the sustainable yield of the watershed cannot be obtained without this data."

Almost 30 years have passed since this letter was written and still no systematic record of pumping rates at the Twin Lakes Golf Resort or other Twin Lakes area wells has been made. With that being said, credible estimates of current and future groundwater withdraw have been made in an attempt to assess the capacity of the Twin Lakes Aquifer. Groundwater capture estimates have been estimated manually by Summit and modeled by RHF Systems Ltd. for the OBWB Phase 2 groundwater supply and demand study.

Table 6. Summary of surface water licenses in the Twin Lakes area. (from MoE 2010)

Point of Diversion Number	LICENSE NO.	PRIORITY DATE	LICENSE STATUS	STREAM NAME	LICENSEE	PURPOSE	QUANTITY	UNITS	QUANTITY (m3/yr)
PD71982	C110869	19960328	ABANDONED	Twin Lakes (Lower)	WILSON DUANNE R & NANCY J	DOMESTIC	500	GD	
PD53857	C066339	19871028	ABANDONED	Twin Lakes (Lower)	BROWN RICHARD E	DOMESTIC	500	GD	
PD53860	C066301	19870511	ABANDONED	Twin Lakes (Lower)	CARTER M F	DOMESTIC	500	GD	
PD53861	C066302	19870511	ABANDONED	Twin Lakes (Lower)	PURDY LLOYD & BETTY	DOMESTIC	500	GD	
PD53862	C066303	19870511	ABANDONED	Twin Lakes (Lower)	OUELLETTE LAWRENCE J	DOMESTIC	500	GD	
PD53846	C041537	19730227	CURRENT	Twin Lakes (Lower)	TWIN R RANCH LTD	LAND IMPROVE	0	TF	
PD53849	C041537	19730227	CURRENT	Twin Lakes (Lower)	TWIN R RANCH LTD	LAND IMPROVE	0	TF	
PD53846	C052034	19300505	CURRENT	Twin Lakes (Lower)	TWIN R RANCH LTD				
PD55526	C060398	19831205	CURRENT	Horn Creek	TWIN R RANCH LTD	LAND IMPROVE	200	AF	246,700
PD53845	C052997	19040930	CURRENT	Horn Creek	BONSON CHRIS J & CHERYLE J	IRRIGATION	24.5	AF	30,221
PD53868	C062298	19840926	CURRENT	Horn Creek	WHITEHEAD WAYNE ARVID	STORAGE	120	AF	148,020
PD53868	F051116	19491118	CURRENT	Horn Creek	MACINNES IRENE J & MICHAEL C	STORAGE	200	AF	246,700
PD53869	C052034	19300505	CURRENT	Horn Creek	FORESTS & RANGE MINISTRY OF	IRRIGATION	30	AF	37,005
PD53846	F054114	19490518	CURRENT	Twin Lakes (Lower)	LOWER NIPIT IMPROVEMENT DISTRICT	IRRIGATION	188	AF	232,416
PD62976	C070494	19910126	CURRENT	Twin Lakes (Lower)	PARSONS MICHAEL C & ELAINE A	DOMESTIC	500	GD	692
PD69803	C108485	19940803	CURRENT	Twin Lakes (Lower)	MORAN MONICA L	DOMESTIC	500	GD	692
PD78846	C120260	20041216	CURRENT	Twin Lakes (Lower)	CLARK GLEN D	DOMESTIC	500	GD	692
PD79421	C121273	20050929	CURRENT	Twin Lakes (Lower)	ELLIS HARRY M & DOREEN N	DOMESTIC	500	GD	692
PD64380	C070506	19910818	CURRENT	Twin Lakes (Lower)	LOWER NIPIT IMPROVEMENT DISTRICT	DOMESTIC	500	GD	692
PD62186	C070451	19900906	CURRENT	Twin Lakes (Lower)	TWIN R RANCH LTD	DOMESTIC	500	GD	692
PD61583	C070423	19900522	CURRENT	Twin Lakes (Lower)	TWIN R RANCH LTD	DOMESTIC	500	GD	692
PD61633	C070429	19900613	CURRENT	Twin Lakes (Lower)	JONES GAIL E	DOMESTIC	500	GD	692
PD53848	C058304	19810721	CURRENT	Twin Lakes (Lower)	LOWER NIPIT IMPROVEMENT DISTRICT	DOMESTIC	500	GD	692
PD53851	C054798	19800201	CURRENT	Twin Lakes (Lower)	GEARY TERENCE G & ELIZABETH A	DOMESTIC	500	GD	692
PD53852	C051607	19780630	CURRENT	Twin Lakes (Lower)	MERKEL DONALD C & LORRAINE B	DOMESTIC	500	GD	692
PD53853	C053834	19790523	CURRENT	Twin Lakes (Lower)	KLINE B JUNE	DOMESTIC	500	GD	692
PD53854	C053687	19790703	CURRENT	Twin Lakes (Lower)	PECK FRANCES L & LAUREL A F	DOMESTIC	500	GD	692
PD53859	C066300	19870511	CURRENT	Twin Lakes (Lower)	BJORNSTAD HEATHER & MILLER KENELM	DOMESTIC	500	GD	692
PD53855	C051608	19780630	CURRENT	Twin Lakes (Lower)	WEBB NANCY L ET AL	DOMESTIC	500	GD	692
PD53856	F050905	19751006	CURRENT	Twin Lakes (Lower)	LEE PATRICIA	DOMESTIC	500	GD	692
PD53858	C052415	19781010	CURRENT	Twin Lakes (Lower)	REEDER ANDREW H J & JODIE L	DOMESTIC	500	GD	692
PD53863	C066304	19870511	CURRENT	Twin Lakes (Lower)	HARTLEY SHAUN R & MCBETH ERIN L	DOMESTIC	500	GD	692
PD53864	C066305	19870511	CURRENT	Twin Lakes (Lower)	TOL HELENA E	DOMESTIC	500	GD	692
PD53865	F051117	19750709	CURRENT	Twin Lakes (Lower)	AIKEN S RANCHES LTD	DOMESTIC	3500	GD	4,842
PD53866	F052740	19790305	CURRENT	Twin Lakes (Lower)	ROUTLEDGE JOHN W & ZLATA	DOMESTIC	500	GD	692
PD53867	C054799	19800331	CURRENT	Twin Lakes (Lower)	ROYAL CITY TIRE & AUTO CENTRE LTD	DOMESTIC	500	GD	692

5.2.1 Manual Estimates of Groundwater Capture

The following section provides the rationale for the current and potential future groundwater capture estimates for the Twin Lakes Aquifer. Currently, groundwater is captured by the Twin Lakes Golf Resort and residences surrounding Twin Lakes, with the golf course considered the largest groundwater user in the basin. It appears that irrigation of agricultural lands is not occurring or only occurring on a few small acreages and so most of the water is used for domestic indoor and outdoor and the golf course.

Estimates of Twin Lakes Golf Resort Groundwater Capture

As noted above no formal records have been kept regarding groundwater pumping at the golf course. To arrive at a reasonable estimate two sources of data were compared: 1) direct estimate of water use made by Twin Lakes' hydrogeologist (EBA), and 2) adapting average estimates of golf course water use in the Okanagan Basin to the Twin Lakes Golf Resort (Summit 2010, and Dobson 2008).

From correspondence provided to Summit between Suki Sekhon (Twin Lakes Golf Resort) and Daniel Watterson (EBA) average golf course water use during the summer season ranges from 450 USgpm to 1000 USgpm (Watterson and Sekhon pers. comm. 2008, and EBA 2010). The upper estimate is based on the number of sprinkler heads in use multiplied by the rate at which each head can flow. Apparently, this flow rate has been maintained 24-hours a day for weeks at a time.

It is estimated that golf courses within the Okanagan Basin comprises approximately 5% of the water use (Dobson 2008). The average golf course water application is estimated at 960 mm during the irrigation season (Summit 2009b). This estimate assumes water is diverted for 24 hours a day, but irrigate only at night, storing water during the day. Twin Lakes golf course water demand is likely no less than 960 mm and might be considerably more, because they do not store water and we understand that irrigation occurs throughout the day and night. The climate at Twin Lake is semi-arid; therefore, the application rate at the Twin Lakes Resort could be as much as 2000 mm. The approximate irrigated area for the golf course is 40.7 ha. Multiplying the area by the estimated lower and upper application rates provides annual groundwater capture estimates of between $4.1X10^5 m^3$/yr (200 USgpm equivalent) and $8.1X10^5$ m^3/yr (400 USgpm equivalent). These estimates of groundwater capture were used in the manual calculations.

EBA (2010) stated that future water use for the golf course will drop to 250 USgpm during the irrigation season after certain irrigation efficiencies are implemented. Summit is concerned that this estimate is too optimistic (low) since current water use is unmonitored. Therefore, in our manual estimates of future golf course groundwater capture we have kept the golf course usage at the current estimated rates. For an accurate picture of groundwater capture in the future, continuous metering of all operating golf course wells is critical. Only through this method can it be shown that future combined domestic and irrigation use will be less than current demand.

Estimates of Domestic and Agricultural Groundwater Capture

For the GWBAT estimate of aquifer capacity, modeled groundwater extraction estimates provided by R.H.F Systems was used (see Section 5.2.2 and Appendix C for details). The following provides a summary of the manual estimate of domestic groundwater capture.

There are currently approximately 130 lots surrounding Twin Lake (Plate 1) Partial year residency is common in the area and it is estimated that approximately 25 residents occupy the area year round (Brown C. pers. comm. 2010). Assuming average residential use of 2,300 L/day (0.42 USgpm) maximum residential groundwater capture will occur in the summer months and is estimated at 130 lots multiplied by 0.42 USgpm or 54 USgpm. During the off-season residential use is estimated to be 90% less than the summer months or approximately 6 USgpm. The annual average rate of groundwater capture for domestic use is estimated to be 26 USgpm (Table 7).

Future residential development is currently in the planning stages for the Twin Lakes Golf Resort, and there is potential for development to occur in the remaining lots around Twin Lake and at Horn Lake. EBA (2010) estimate groundwater capture for the Twin Lakes Resort future residential development as 96 USgpm annual average and this is used as a lower estimate for future development. For full build out around Horn and Twin lakes Summit estimated the addition of 112 more single family residences. This would add an additional (0.42 USgpm multiplied by 112) 47 USgpm of average annual capture. The future estimate for total annual average capture is [96 USgpm (Golf Course) + 26 USgpm (existing domestic) + 47 USgpm (potential future domestic)] **169 USgpm**.

Since the land surrounding Horn Lake is designated agricultural, Summit has included an annual average capture estimate of 102 USgpm for agriculture in the future upper estimate. This agricultural estimate is based on 660 mm/year applied to 73 ha of agricultural acreage to the northeast and northwest of Horn Lake (area calculated from RDOS parcel map, RDNO 2010).

The resultant groundwater capture estimates are provided on Table 7.

Table 7. Estimates of Groundwater Extraction from the Twin Lakes Aquifer.

Manual Existing Extraction Estimates (USgpm)				Manual Future Extraction Estimates (USgpm)				
Lower estimates				**Lower estimates**				
Month	Golf Course	Domestic (existing)	Total	Golf Course	Domestic (existing)	Domestic (future)	Agricultural (future)	Total
J	0	6	6	0	6	20	0	26
F	0	6	6	0	6	20	0	26
M	50	6	56	50	6	20	0	76
A	50	6	56	50	6	20	0	76
M	200	55	255	200	55	100	0	355
J	200	55	255	200	55	100	0	355
J	200	55	255	200	55	100	0	355
A	200	55	255	200	55	100	0	355
S	200	55	255	200	55	20	0	275
O	50	6	56	50	6	20	0	76
N	0	6	6	0	6	20	0	26
D	0	6	6	0	6	20	0	26
Annual Average	96	26	**122**	96	26	47	0	**169**
Upper Estimates				**Upper Estimates**				
Month	Golf Course	Domestic (existing)	Total	Golf Course	Domestic (existing)	Domestic (future)	Agricultural (future)	Total
J	0	6	6	0	6	60	0	66
F	0	6	6	0	6	60	0	66
M	75	6	81	75	6	60	0	141
A	75	6	81	75	6	60	0	141
M	400	55	455	400	55	163	240	858
J	400	55	455	400	55	163	240	858
J	400	55	455	400	55	163	240	858
A	400	55	455	400	55	163	240	858
S	400	55	455	400	55	163	240	858
O	75	6	81	75	6	60	20	161
N	0	6	6	0	6	60	0	66
D	0	6	6	0	6	60	0	66
Annual Average	185	26	**212**	185	26	103	102	**416**

Modeled Estimates (only considers outdoor pumping)					
1996 to 2006			**2010 to 2040 Scenario 4**		
Month	Annual Average m3/yr	Annual Average USgpm	Month	Annual Average m3/yr	Annual Average USgpm
J	0.0.E+00	0	J	7.5.E+02	4
F	0.0.E+00	0	F	6.8.E+02	4
M	0.0.E+00	0	M	7.5.E+02	5
A	4.7.E+03	29	A	1.5.E+04	91
M	5.4.E+04	332	M	7.2.E+04	440
J	7.7.E+04	469	J	8.8.E+04	540
J	1.0.E+05	614	J	1.1.E+05	673
A	9.0.E+04	548	A	9.5.E+04	580
S	4.2.E+04	260	S	4.7.E+04	289
O	4.6.E+02	3	O	5.5.E+03	34
N	0.0.E+00	0	N	7.2.E+02	4
D	0.0.E+00	0	D	7.5.E+02	5
Total	3.7.E+05	**184**	Total	4.4.E+05	**218**

5.2.2 Modeled Estimates of Groundwater Capture

For the estimate of aquifer capacity based on the GWBAT, estimates of groundwater use and irrigation return flow for the Twin Lakes Aquifer were supplied by RHF Systems Ltd. and were based on the Okanagan Water Demand Model (OWDM) (Van der Gulik et al, 2008), which is a GIS-based model that estimates water demand based on crop type, seasonal crop development and spatial distribution of data layers which characterize topography, surface and subsurface hydrology, crop distribution, irrigation management practice and soils. The yearly average groundwater use for the Twin Lakes Aquifer for the 1996 to 2006 and 2010 to 2040 Scenario 4 were 184 USgpm and 218 USgpm, respectively.

6.0 TWIN LAKES AQUIFER GROUNDWATER BALANCES

To assess the long term capacity of an aquifer, estimates of the percent of groundwater captured are necessary. To hone in on a reasonable percent groundwater capture Summit performed water balances both with the assistance of the Groundwater Balance Analysis Tool (GWBAT) and manually.

6.1 GWBAT ESTIMATES OF PERCENT GROUNDWATER CAPTURE

The GWBAT was briefly described is Section 2.3 and more detail on the development, application, and assumptions of the GWBAT may be found in Appendix C. It is important to note that the water balance results are non-unique solutions. As such alternative values of unconsolidated aquifer properties, anthropogenic inputs and outputs, and adjustment factors could be used to achieve a reasonable balance. The factors used involved interpretation of available data and professional judgment.

Four estimates of percent groundwater capture were made with the GWBAT. The four estimates were as follows:

- OBWB aquifer characterization run from 1996-2006 (Golder-Summit 2009) – base case;
- Summit aquifer characterization run from 1996-2006;
- Summit aquifer characterization run from 2010 – 2040, OBWB future scenario 4; and
- Summit aquifer characterization run from 2010 – 2040, future scenario 9.

The two future scenarios provide upper and lower estimates for the water demand over the 31-year periods. Refer to Appendix C for the assumptions of the two scenarios. The precipitation data utilized in the future scenarios were extracted from gridded climate data files produced by the Okanagan Climate Data Interpolation Model.

6.2 MANUAL ESTIMATES OF PERCENT GROUNDWATER CAPTURE

Manual estimates were developed for both the catchment area water balance and the Darcy flow estimates of groundwater discharge. A total of eight manual estimates were calculated based on the lower and upper bound groundwater capture estimates.

It is clear from analysis that at the present, on an annual basis, a large portion of the potential groundwater outflow from the Twin Lakes basin is captured by pumping wells at a rate that may be approaching the sustainability of the system, depending on whether there is a wet or a dry climate cycle occurring. Refer to the next section for more detail regarding the findings.

7.0 WATER BALANCE FINDINGS

A total of 16 results of percent groundwater capture were made from manual and GWBAT assisted estimates. Summit's estimates were also compared to those made in 1994 by EBA. A summary of all input parameters and the resultant percent capture are presented in Table 8.

The upper and lower estimates of percent groundwater captured from the Twin Lakes Aquifer above Highway 3A are **21%** (Summit manual existing lower capture estimate) and **73%** (Summit manual future upper capture estimate). This means that nearly one-fourth and potentially up to three fourths of all the natural groundwater flow through the aquifer is captured by pumping. These are high values for a bounded aquifer located in a recharge zone. The 5-year excessive dry period percent capture was estimated in 1994 by EBA to be **34%**. Estimates of percent capture made by three independent hydrogeologists: Richard Guiton (EBA 1994), Pattie Amison (Golder-Summit 2009), and Bryer Manwell (Summit 2010, current study) are all within the same order magnitude.

In their 1994 report EBA stated:

> "…a significant increase in water usage could potentially cause significant changes in basin storage, therefore we do not recommend permitting any significant net increase in water usage. "

It is difficult to establish a hard number for sustainable aquifer capture expressed as a percent of the water balance (recharge or discharge). Factors affecting the sustainability of aquifer capture are whether the aquifer is a discharge or recharge area, if there is year round recharge or limited recharge occurring, and if the aquifer is limited in areal extent. The Twin Lakes Aquifer is located in a recharge area, aquifer recharge is limited to the snowmelt, and the aquifer is limited in areal extent. These factors, along with the current groundwater pumping have created a situation where Summit believes the Twin Lakes Aquifer is at or near its sustainable capacity. With groundwater and surface water levels susceptible to prolonged decline, due to climate cycles and pumping, it appears that 200

USgpm or 30-35% of the aquifer discharge is an upper limit for groundwater capture in the Twin Lakes Aquifer, on a long-term annual average basis.

In the RDOS Request for Proposals some Frequently Asked Questions (FAQ) Regarding the Twin Lakes Aquifer were presented. Summit has provided opinion on the most reasonable answers to these questions in Appendix D.

Table 8. Aquifer discharge estimates and resultant percent capture for the Twin Lakes Aquifer.

			Modeled				Manual			
Parameter	**Symbol and Unit**	**EBA 1994**	**OBWB - GWBAT Golder-Summit 2009 (1)**	**OBWB - GWBAT Summit 2010 (1)**	**OBWB - GWBAT Summit 2010 (2)**	**OBWB - GWBAT Summit 2010 (3)**	**Summit 2010 Manual (existing, lower capture estimate)**	**Summit 2010 Manual (existing, upper capture estimate)**	**Summit 2010 Manual (future, lower capture estimate)**	**Summit 2010 Manual (future, upper capture estimate)**
Hydraulic conductivity	K (m/sec)	3.09E-03	1.20E-04	3.11E-04	3.11E-04	3.11E-04	3.11E-04	3.11E-04	3.11E-04	3.11E-04
Hydraulic gradient	i	0.01	0.01	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Aquifer width	w (m)	300	415	415	415	415	415	415	415	415
Aquifer thickness (saturated thickness)	b (m)	15	51	18.5	19	20.3	20	20	20	20
Cross sectional aquifer area	a (m2)	4500	21165	7678	7885	8425	8300	8300	8300	8300
Transmissivity	T (m2/sec)	4.63E-02	6.12E-03	5.75E-03	5.91E-03	6.31E-03	6.22E-03	6.22E-03	6.22E-03	6.22E-03
porosity		0.3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Darcy's	Q (m3/yr)	4.40E+06	8.06E+05	1.08E+06	1.11E+06	1.14E+06	1.14E+06	1.14E+06	1.14E+06	1.14E+06
Catchment Basin average	Q (m3/yr)	3.60E+06	1.35E+06	1.15E+06	1.15E+06	1.15E+06	1.15E+06	1.15E+06	1.15E+06	1.15E+06
Catchment Water Balance (5-yer excessive dry period)	Q (m3/yr)	1.50E+06								
Darcy's	Q (USgpm)	2200	403	538	553	569	570	570	570	570
Catchment Basin average	Q (USgpm)	1800	677	576	576	576	576	576	576	576
Catchment Water Balance (5-yer excessive dry period)	Q (USgpm)	750								
Total Capture (m3/yr)		5.12E+05	3.68E+05	3.68E+05	4.36E+05	4.06E+05	2.44E+05	4.24E+05	3.38E+05	8.32E+05
Total Capture yearly averaged (USgpm)		256	184	184	218	203	122	212	169	416
% Total Capture (Darcy Flux Est)		12%	46%	34%	39%	36%	**21%**	37%	30%	**73%**
% Total Capture (Catchment average)		14%	27%	32%	38%	35%	21%	37%	29%	72%
% Total Capture (Catchment 5-year excessive dry period)		34%								

Notes:

(1) Estimates based on GWBAT 1996 to 2006.

(2) Estimates based on GWBAT 2010 - 2040 Scenario 4.

(3) Estimates based on GWBAT 2010 - 2040 Scenario 9.

7.1 FUTURE GROUNDWATER AVAILABILITY (SUSTAINABLE AQUIFER YIELD)

The most important concept to understand with respect to groundwater sustainability is that water pumped from a groundwater system (which we term capture) must come from somewhere and necessarily causes a change in the linked surface water-groundwater system.

Possible sources of water for capture are (1) more water entering the groundwater system (increased recharge), (2) less water leaving the system (decreased discharge), and (3) removal of water that was stored in the system. In the Twin Lakess basin, it is likely that groundwater capture to date has caused a change in the system that involves all three of the above processes, occurring to different degrees throughout the year.

Pumping water from aquifers that are hydraulically connected with surface water bodies can have a significant effect on those bodies by reducing groundwater discharges to surface water or increasing surface water losses to ground. This potential drop in groundwater level caused by pumping (drop in pressure head) may cause outflow from those surface water bodies into the groundwater system. A strong downward vertical hydraulic gradient is evident at multiple pairs of neighbouring wells around Twin Lake, for example between WPNs 61111 and 46711 and WPNs 58440 and 61153 (see Plate 1 for well locations).

Aquifers, including even the relatively small Twin Lakes system, contain large volumes of groundwater in storage, which allows the possibility of using aquifers for temporary storage, that is, managing inflow and outflow of groundwater in storage in a manner similar to surface water reservoirs. For example, most recharge typically occurs in spring and most capture occurs in summer. Incomplete recovery of groundwater levels following periods of pumping, or a succession of lower water levels from one year to the next are an indication of such storage being used. Various terms are used to describe such situations, including groundwater depletion, groundwater decline, or simply "mining" the resource.

Continuing large withdrawals of water from an aquifer often result in undesirable consequences. The most common of these consequences almost always involve an impact to the end users of the resource, which may include surface water and associated ecological systems, surface water users, and groundwater users. The effects of groundwater development may require many years to become evident. Thus, there is an unfortunate tendency to forego the data collection and analysis that is needed to support informed decision making until after problems materialize. This is why one of the key recommendations in this report is to establish a dedicated groundwater level observation well(s) located at a strategic and accessible location so that continuous data can be collected and shared. It is not too late to implement monitoring.

We close this discussion of groundwater sustainability by highlighting some common misrepresentations that are sometimes seen in hydrogeologic reports:

1. That rapid recovery of water levels following pumping is an indication of aquifer productivity or sustainable yield;
2. That the sustainable yield is equal to the estimated average annual recharge or discharge;
3. That sustainable yield can be adequately demonstrated by determining the "safe yield" of a well based upon interpretation of a pumping test and application of a standard procedure such as Evaluating Long Term Capacity according to the B.C. CPCN Guidelines; and
4. That sustainable yield is possible in all groundwater basins.

- **Rapid recovery = high productivity**. In reporting favourable results from a pumping test, hydrogeologists sometimes point out that rapid recovery of water levels in a well after pumping are an indication of aquifer productivity or confirmation of sustainable yield, which may or may not be the case. It is our experience that such observations almost always neglect to consider the proportion of drawdown caused by well inefficiency (which can be estimated with pumping test data). Such well losses are almost immediately recovered upon cessation of pumping, whereas the losses (drawdown) caused in the aquifer recover more slowly, except when the pumping rate is low relative to aquifer transmissivity. Even a relatively small residual amount of drawdown (incomplete recovery) is potentially significant – it means water was removed from storage, and recharge is either not occurring or occurring too slowly or at too great a distance from the well to be detected.

- **Sustainable yield = recharge rate**. Another common and potentially misleading concept presented in hydrogeological reports is that the average annual recharge (or its counterpart in "balanced" aquifers, groundwater discharge or Darcy flow) represents the limit of sustainable yield of a groundwater system. In most cases, it is practically impossible for wells to capture all of the water entering or leaving an aquifer, and therefore such high usage typically results in increased recharge to the aquifer from stream, lake or wetland seepage and/or removal of water from storage. Unfortunately, there is no universally agreed upon "safe" groundwater capture limit, expressed as a percentage of average annual recharge or discharge, but in our opinion, the likely range for the Twin Lakes system is on the order of 30%. This opinion is based on the estimate of current capture (200 USgpm), which is close to but probably greater than 35% of natural groundwater discharge on a long-term annual basis. Also, surface water-groundwater system is showing signs of stress (i.e. out of balance), in part due to continued groundwater withdrawal as well as climate change.

- **"Safe Yield" of a well cannot be equated to the sustainable yield of an aquifer system**. Evaluating the long-term capacity of a well based upon application of the province's CPCN Guidelines (Allen et al 1999) is typically used to demonstrate adequate groundwater well capacity, and was specifically developed to support applications to create water utilities. The long-term well capacity in such systems must be such that after 100 days of continuous pumping, the well must still be capable of supplying the water system peak demand. Even though this is a useful technique to conservatively rate a well in order to properly size a water system, this method is not the same as examining the water balance of an aquifer system using conceptual, analytical or numerical modeling.

- **Sustainable yield is possible?** Finally, in assessing the sustainable yield of the Twin Lakes Aquifer, this study must assume that there is some level of groundwater pumping that, if maintained, can allow the system to reach a new state of equilibrium. This new state of equilibrium could be measured and defined simply in terms of stabilized surface and groundwater levels, but would be more difficult to measure against other criteria such as protection of groundwater-dependent ecosystems, no constraints on existing surface water licenses, or water quality. In the absence of such information, it is very difficult to determine an appropriate percentage of the natural groundwater balance (recharge or discharge) that can sustainably be extracted for consumptive use. In New South Wales, Australia a default allowance equal to 30% of the long-term average net annual recharge is provided for ecological systems (Kalf and Woolley 2005). If this default value has some validity in the semi-arid Okanagan, this then suggests an upper limit of 70%, but only in a system that is showing signs of stability and equilibrium, which is not the case with Twin Lakes. Therefore, we have been more conservative in our appraisal and consider a more realistic and practical value of sustainable capture to be in the range of 30-35% of the net groundwater budget, which translates to an annual average extraction rate of approximately 200 US gpm (with seasonal use patterns extending above and below this average value). This value is within the range estimated for the current rate of extraction (122 to 212 US gpm) but lower than the estimate for the upper future estimate (416 US gpm). More data and numerical modeling would be required to refine these values further. As noted in the limitations section, the spreadsheet-based tool (GWBAT), the modeling and judgment applied should be considered as a first-order approximation of the available groundwater capacity on a long-term basis. We believe that the concordance of three different hydrogeological investigators is significant, and helps underscore the reliability of our estimate. Because the actual sustainable yield of the Twin Lakes aquifer is so dependent on relatively short-term variations in climate and precipitation, we believe it is prudent to base the yield estimate on the prevalence of dry cycles and not on infrequent wet cycles.

In reaching our finding with regard to the sustainable capacity of the aquifer and lake system, in accordance with Section 5.4 of the RFP we have considered the following with regard to existing licenses, the *BC Right to Farm Act* {RSBC 1996 Ch 131}, and the lack of provincially – legislated groundwater use controls:

- It has been noted in this report that some existing water licenses cannot be used in some years due to low lake levels, and that holders of such licenses, in some cases, have likely drilled wells to provide more reliable access to water;
- There are not any current restrictions on well drilling other than wells must comply with Phase 1 of the Groundwater Protection Regulation, which requires that certain minimum construction standards are met and that wells are installed by qualified and registered well drillers;
- For new development, the RDOS subdivision servicing bylaw does not explicitly require hydrogeological reports that assess groundwater sustainability, potential interference between wells or between wells and licensed surface water, nor is there typically an independent peer review done on the "proof of water" studies conducted by developers; and
- The *Right to Farm Act* in BC protects what are referred to as "normal farm practices"; however, it is not known if such legislated protections include access to sufficient water resources (assuming no license exists that is appurtenant to the farm or agricultural land in question); in the absence of groundwater legislation, we suspect there are no protections afforded to farmland with regard to access to usable quantities of groundwater.

7.2 GROUNDWATER MANAGEMENT RECOMMENDATIONS

Our analysis found that the sustainable yield of the Twin Lakes aquifer and surface water system has either been reached or has possibly been exceeded. This is not, however, an entirely new finding, as the limits of the resource have previously been identified by qualified hydrogeologists (Van der Kamp 1981 and EBA 1994). Our analysis of future scenarios confirms that the potential exists for additional groundwater capture by currently-allowed land uses. Therefore, it appears that the opportunity exists for an integrated approach to groundwater management to be developed that may involve a combination of voluntary and regulatory measures intended to protect the limited resource.

At the present time, it appears that most of the water use in the basin is derived from unlicenced groundwater pumping, for which there are no current provincial requirements to measure or report use, or ways to limit usage based upon a government-controlled allocation system. Many of the existing surface water licences cannot be used due to low water levels of Twin Lake. In part, these licenses have been and possibly will continue to be replaced by unlicensed groundwater wells.

Existing groundwater users can expected to be impacted in times of future water shortage, some more than others. For example, owners of relatively shallow wells that do not penetrate the full thickness of the aquifer may see lower water levels in future years that eventually could affect well yield or even cause some wells to "go dry." The solution in such cases would be well deepening so that the full thickness of the aquifer is available to each user. However, as noted in this report, deeper wells may have correspondingly deeper static water levels due to a prevailing downward vertical hydraulic gradient.

The Twin Lakes Aquifer is relatively thick (20 metres or more) and as of late 2009, groundwater levels appear to be within or perhaps within 90 percent of historic levels. A groundwater decline on the order of 5 metres (25% decline) would likely start causing impacts to be felt by users and downgradient receptors of groundwater discharge. Such a decline can be prevented or delayed by implementing a coordinated effort. The continuing progression of subdivision of large holdings (i.e. 20 ha) parcels into small acreages and hobby farms that use significant water for both indoor, outdoor irrigation and stock watering purposes, such as has occurred in nearby Willowbrook, could lead to 25% declines, or the more severe groundwater declines seen at Meyers Flat (Figure 6).

The following series of recommendations are based in part on elements of the recently-published Groundwater Bylaws Toolkit (OBWB 2009). The recommendations require adoption of an integrated land use and water management framework, which may have voluntary as well as regulatory elements. Recommendations are presented in the form of alternatives described in general order of increasing complexity under three broad categories, with the simplest and easiest to implement tools presented first, and progressing toward more involved and complex undertakings.

Voluntary measures relying upon data gathering and sharing, education/outreach, and cooperation amongst stakeholders

- Implement a pilot project to **voluntarily measure and report groundwater use** (monthly); include all golf course wells and as many other private domestic and irrigation wells as possible. This project should run for at least one full year to establish a baseline. The OBWB is in the process of developing an online water use reporting tool; this tool could potentially be available for the pilot project.
- Implement this report's recommendations with regard to other data collection activities, including the **establishment of groundwater observation wells, and monitoring of lake levels and Horn Creek flows**. Leverage potential funding and in-kind support available through the OBWB and BC Ministry of Environment to establish at least one and ideally two dedicated groundwater observation wells located on easily accessible land somewhere between Twin Lake and Highway 3A. The minimum program would involve one well, monitoring Twin and Horn Lake levels, and Horn Creek flows near the former gauging station.

The recommended program would include a second observation well, a precipitation station, and also include Trout Lake levels.

- Implement a **pilot demand management project** that would establish a benchmark of current water use and then seek to reduce use by an agreed-upon percentage within a certain timeframe.
- Establish a land-use designation consistent with the Local Government Act that identifies Twin Lakes as a "**water-limited area" or a "water conservation zone**" and use this designation (which would initially place no further conditions on allowable land uses), as a means to educate community members on the importance of reducing water usage – both household and outdoor. This process would be similar to establishing a well protection area for the purpose of preventing groundwater pollution, except in this case, the main purpose is protecting groundwater quantity.
- Consider leveraging potential local government or grant funding to help pay for **water-saving landscaping such as xeriscaping** for both existing and new construction.

Regulatory measures relying primarily on land-use and development controls (e.g. bylaws)

- Develop a **Rural Land Use Plan or a similar Sub-Area Plan** for Twin Lakes with a major objective being to protect the aquifer-lake system by prohibiting further subdivision and development that would increase groundwater usage beyond currently-estimated levels.
- In the Plan, **outline the levels of detailed study** that would be required in order for any further subdivisions or rezonings to be considered. Such studies could be tied to and be required to contribute to (at least in part) the implementation of additional data collection as outlined in this study. A provision could also be included that would require that **proponents pay for a peer-review** (coordinated by the regional district) of any hydrogeological studies conducted to support a proposed rezoning or subdivision, or other regulated land use application that would require increased groundwater capture.
- As a possible **short-term or temporary** measure (until such a time that other recommendations can be implemented), consider either a **moratorium or an outright ban on further land subdivisions or OCP amendments** (e.g. rezoning) that would allow for increased development necessitating additional groundwater capture.

Regulatory or quasi-regulatory measures relying primarily on water-management related controls

We envision at least three possible approaches to implementing a water management planning framework for Twin Lakes, and other similar areas within the South Okanagan-Similkameen region. Each of these can be integrated with land-use planning changes and increased water monitoring and data collection, and such integration is critical regardless of which approach is taken. The potential regulatory or quasi-regulatory water management approaches are described briefly below.

- Implement a **voluntary Water Management Plan** (WMP) modeled after the Cowichan Basin Water Management Plan. Such an effort would be a partnership between all of the major stakeholders within the Twin Lakes Basin, and potentially coordinated by the regional district with support from BC MoE and other ministries. Such a Plan would not be implemented under Part 4 of the Water Act (see Langley discussion, below) and therefore would remain largely voluntary. The Plan would expand on the recommendations provided here, and might include for example a detailed drought response plan that is coordinated with drought plans that exist or may be developed elsewhere in the Okanagan. Another feature might include reserving water for existing agricultural lands, if the intent of the existing OCP is to remain (i.e. protect agricultural lands from development). One potential drawback of an entirely voluntary program would be that in the event of a severe drought, if one or more key water users withdraws participation and does not cut back on water usage, the Plan could fail when it was most needed. For more information on the Cowichan Basin Water Management Plan, please refer to Page 54 of the Groundwater Bylaws Toolkit.

- Implement a **formal Water Management Plan**, as provided for under Part 4 of the B.C. Water Act. In terms of process, a formal WMP would be similar to a voluntary plan, except that it would need to be formally led by the responsible local government (in this case, RDOS) and to be adopted the Plan would require Cabinet approval. The Township of Langley Water Management Plan is highlighted on Pages 52-53 of the Groundwater Bylaws Toolkit, and to date is the best example of this process in B.C. Although a formal WMP could result in enforceable regulations, it is likely the process would take longer and cost more than a voluntary plan. (Langley's Plan is still not finalised and has been in development since approximately 2004.) However, the Langley Plan has benefited from partial provincial funding, and considerable staff support from the Water Stewardship staff at BC MoE and other organizations and ministries.

- Work in partnership with the OBWB and the provincial government to establish a **pilot Groundwater Use Regulation** within the Twin Lakes area. The pilot project would incorporate the province's Living Water Smart (LWS) and Wate Act Modernization (WAM) initiatives, which intend to regulate "large" groundwater withdrawals in "priority areas" by 2012. We understand that as part of the WAM process, discussions are underway that would identify the Okanagan Basin as one "priority area" in the province where certain groundwater use regulations could be pilot-tested for possible broader implementation. If this is the case, it is our opinion that Twin Lakes would represent a good area for a pilot project. The project may include elements of what has previously been proposed in Langley, for example, private well metering, mandated summertime sprinkling restrictions, other demand management measures, land use regulations like those outlined above, expanded groundwater monitoring, using stormwater to recharge the aquifer, and so on.

In closing this section, the concept of risk management should be discussed within the context of managing land use and water resources. This study and the ones that preceded it have demonstrated the limited nature of water resources in the Twin Lakes basin. Only when the limit is approached or exceeded are the consequences of past decisions realised. We have recommended that land use planning for this area be based upon the presumption of relatively frequent dry climate cycles. If the water supply situation worsens, there is no alternative supply (such as a municipal source) anywhere nearby that can be used to support the ongoing needs of the community. The combination of relatively high uncertainty about the limits of the resource, and the high consequences of over-use, suggest that a conservative approach to land use planning is warranted until more information is available that reduces both the uncertainty and the consequences.

8.0 ASSUMPTION AND LIMITATIONS

That three independent hydrogeological investigators arrived at similar results is encouraging; however, there are several assumptions and therefore limitations associated with the current investigation. The most significant limitation is that no real pumping data exists. Groundwater capture has been estimated based on assumed or modeled use and professional judgment. Another limitation is the lack of water level measurements surveyed to a common datum, in both groundwater and the surface water bodies (Horn Lake and Twin Lake). To better understand the changes in storage for the study aquifer water level measurements in both surface water and groundwater should be monitored.

For the future scenarios, climate data are modeled, the reliability of modeled data can only be proven after the fact. The future scenarios, however, are based on the full range of scenarios being evaluated for the entire Okanagan Basin, and therefore are considered a reasonable approximation.

It is important to note that the GWBAT water balance results are non-unique solutions, and as such alternative values of unconsolidated aquifer properties, anthropogenic inputs and outputs, and adjustment factors could be used to achieve reasonable balances.

Table 9 provides a qualitative assessment of uncertainty associated with the inputs used to calculate the percent aquifer capture. Note the most uncertainty lies in the capture estimates and the assessment of basin wide precipitation.

Table 9. Uncertainty matrix.

Parameter	Level of uncertainty
Hydraulic conductivity	Low
Hydraulic gradient	Low
Aquifer width	Low
Aquifer thickness (saturated thickness)	Medium
Cross sectional aquifer area	Medium
Transmissivity	Medium
porosity	Low
Precipitation	Medium to High
Horn Creek discharge	Medium
Catchment basin groundwater discharge	Medium to High
Darcy flow groundwater discharge	Medium
Total groundwater capture	Medium to High

9.0 CONCLUSIONS AND RECOMMENDATIONS

Garth Van der Kamp, one of Canada's most esteemed academic researchers in hydrogeology visited the Twin Lakes area and evaluated the water balance situation of the basin nearly 30 years ago (Van der Kamp 1981a and 1981b). Dr. Van der Kamp concluded that the water resources of the Twin Lakes basin are finite, he calculated recharge and discharge at 400 USgpm, and that the sustainable capacity of the lake-aquifer system had already likely been reached during the 1970s. Put more succinctly, during climate cycles that are drier than long-term normal conditions, the basin is likely already over-subscribed in terms of water licenses and unlicensed groundwater pumping. Even the most senior licenses can not be used in some years due to a lack of water.

Van der Kamp also made a number of key recommendations that unfortunately were never implemented, including a) measuring the amount of groundwater pumping, particularly from the golf course wells and measuring groundwater levels in wells relative to a surveyed datum, b) systematically monitoring lake levels throughout the year relative to a surveyed datum c) restoring hydrometric streamflow monitoring on Horn Creek and installing a weather station to measure precipitation, and d) conducting a detailed water balance analysis based upon the hydrologic and climate data collected. To date, a, b and c have not been done, or only partially done. The current Summit study is an attempt at (d), based upon the best-available information that in part must rely upon modeled values, or values that are arrived at on the basis of professional judgment. It is important to understand that the Twin Lake water balance, while reasonable, is not based on all of the data as recommended by Dr. Van der Kamp. Therefore, the estimates contained in this report are subject to change and should be examined in the future if and when the recommendations in this report, which are similar to Dr. Van der Kamp's, are implemented. However, the fundamental conclusions of Dr. Van der Kamp are still considered valid, except that we will add the following: *there is **not enough water for existing users during dry climate cycles**, and planners and developers alike should base their decisions upon the dry cycles and not count on unpredictable and infrequent wet cycles to make up the shortfall.*

Increased rates of groundwater capture (extraction) will only come at the expense of surface water licenses. During wetter-than-normal climate cycles, there is likely enough water for all existing users and also less demand for water due to adequate precipitation. However, the storage capacity in the basin is limited by the maximum spill elevations of the lakes and the ability of the groundwater system to absorb excess recharge. These times of surplus, unfortunately, cannot be counted on to make up for the dry cycles and therefore, the land use in the basin needs to be based on planning for the dry cycles. If this is to be the case, then allowing further land uses that will result in groundwater development will only further exacerbate the problems seen during the dry cycles.

Currently, there remains an unresolved issue between the LNID and the MoE regarding elevation of the channel between Horn Lake and the Turtle Pond (Plate 1). If intentional or unintentional rework of the channel has occurred since the dam was approved, and if the channel bottom now sits at a higher elevation than the originally licensed elevation there could potentially be more water available to flow from Horn Lake through the sluice gated culvert to points downstream. However, during discussion with the Steve Rowe of the MoE it was stated to Summit that there is no requirement in the license or under the Water Act to maintain the channel to a specific elevation between Horn Lake and Twin Lake (Pers. Comm. Rowe S. 2010).

From the current investigation Summit makes the following recommendations:

1. Measure groundwater pumping rates and well water levels, specifically from the golf course wells;
2. Work with the MoE to establish observation wells in both the upper (A) and lower (B or C) Twin Lakes Aquifer layers. Summit recommends using WTN 58440 for the upper formation and WTN 62716 for the lower formation;
3. Continue monitoring Twin Lake stage and establish a formal gauging station on Horn Lake and monitor both lake level relative to the same surveyed datum;
4. Restore a hydrometric streamflow monitoring station on Horn Creek and install a weather station to measure precipitation;

5. If new wells are to be drilled they should fully penetrate the aquifer and wells should not cross-connect the A, B and C layers;
6. Future planning of development in the Twin Lakes area should be based on an assume prevalence of dry climate cycles so as not to further over extend the water resources in the area;
7. Work with the MoE – Water Stewardship branch to limit any new surface water licensing and reduce licensing where possible;
8. Use tools in the B.C. Groundwater Bylaws toolkit and limit development in areas that are groundwater limited. **Do not permit any significant net increase in water usage; Consider implementing the management alternatives presented in Section 7**;
9. Limit outdoor watering, and promote xeriscaping ;
10. Develop a drought plan for what should be done if water levels continue to decline; and
11. Initiate public education regarding the sustainability of groundwater use in the area and consider implementing conservation measures and a mechanism to resolve water use conflicts, possibly through a collaborative water management process that is voluntary.

10.0 REFERENCES[1]

Alley, W.M., Reily, T.E., Ranke, O.L. 1999. Sustainability of Groundwater Resources. U.S. Geological Survey Circular 1186. Accessed on-line at http://pubs.usgs.gov/circ/circ1186/htnl/cover.html.

Botham, J., Livingston, E., and Paget, A.F. 1973. British Columbia Ministry of Environment (MoE) (then Department of Lands, Forest, and Water Resources, Water Rights Branch Kelowna BC 1973. Preliminary Report on Control of Surface Levels on Twin (Nipit) Lakes (report & correspondence).

British Columbia Lake Stewardship Society and the Ministry of Environment (then Ministry of Water, Land, and Air Protection). 2004. BC Lake Stewardship and Monitoring Program, Twin (Nipit) Lake 1999 – 2003, The Importance of Twin Lake and its Watershed.

British Columbia Ministry of Environment (MoE). 2010. Water resources atlas. Accessed on-line at: http://www.env.gov.bc.ca/wsd/data_searches/wrbc/

Brown, Coral. 2010. Long time resident of the Twin Lake area and member of the Lower Nipit Improvement District. Personal communication with Bryer Manwell (Summit) on February 23, 2010.

Carmichael, V.; Allen, D.M.; Gellein, C.; Kenny, S.. 2009 Compendium of Aquifer Hydraulic Properties from Re-evaluated Pumping Tests in the Okanagan Basin, British Columbia.

Clifton, Wade. 2009. Personal communication on December 3, 2009 during Summits site visit. Rancher who leases the land surrounding Horn Lake.

Dobson Engineering Ltd. (Dobson). 2008. Phase 2 Okanagan Water Supply and Demand Project: Water Management and Use Study. Prepared for OBWB in June 2008.

EBA Engineering Consultants Ltd. (EBA). 1994. Twin Lakes Basin Hydrogeological Study. Prepared fro Twin Lakes Gold & Country Resort, Kaleden, B.C., Report No. 0808-88654.

EBA Engineering Consultants (EBA). 2007. Historical Groundwater Data Review and Groundwater Data Collection – Proposed Twin Lakes Golf Report Expansion, Twin Lakes, BC. Letter report No. K23100051.

EBA Engineering Consultants (EBA). 2009. Well capacity evolution of main irrigation well, Twin Lakes Golf and Country Club, Kaleden, BC. Report No. K23100051.003 prepared for Twin Lakes Golf Course Ltd.

EBA Engineering Consultants (EBA). 2010. Twin Lakes Resort Groundwater Supply-Demand and Impacts Summary. Letter to Mr. Suki Sekhon from Daniel Watterson, dated January 14, 2010.

Environment Canada. 2009. Canadian Climate Normals between 1951-1980 accessed on-line at http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html

Golder Associates Ltd. 1997. Assessment of groundwater availability, proposed residential subdivision, District Lot 259s, SDYD, Twin Lakes, British Columbia. Letter report prepared for Mar-Wil Investments on December 12, 1997.

[1] Bolded references are included in Appendix E.

Golder Associates Ltd. and Summit Environmental Consultants Ltd. 2009. Phase 2 Okanagan Water Supply and Demand Project: Groundwater Objectives 2 and 3 Basin Study. Prepared for: Okanagan Basin Water Board.

Hare A. 1996. (B.C. MoE). Letter to Lower Nipit Improvement District regarding water licensing. Dated May 13, 1996.

Kalf, F. and D. Wolley 2005. Applicability and methodology of determining sustainable yield in groundwater systems. J. Hydrogeology (2005) 13:295-312.

Nasmith H. 1980. Bulletin No. 46. Late Glacial History and Surficial Deposits of the Okanagan Valley, British Columbia. B.C. Ministry of Energy, Mines, and Petroleum Resources. (reprint, originally published in 1962).

Neville C. 2008. Senior Hydrogeologist with S.S. Papadopoulos & Associates, Inc. Presented a short course on "Critical Thinking in the Interpretation of Aquifer Tests." Course sponsored by the International Association of Hydrogeologists, Canadian National Chapter. November 7, 2008, Vancouver B.C.

Okanagan Basin Water Board. 2009. Groundwater Bylaws Toolkit, An Appendix to the Green Bylaws Toolkit. Accessed on-line at: http://www.obwb.ca/fileadmin/docs/groundwater_bylaws_toolkit.pdf

Pacific Hydrogeology Consultants Ltd. (Pacific) 1994. Evaluation of groundwater quantity and quality from a well proposed to supply a six-lot subdivision at the south end of Twin Lakes Golf and R.V. Resort, southwest of Penticton. Letter report for Project No. T706101, prepared for Twin Lakes Golf and R.V. Resort on March 25, 1994.

Regional District of Okanagan Similkameen (RDNO). 2010. Parcel Map Viewer. Accessed on-line at: http://www.rdosmaps.bc.ca/imf51002/imf.jsp?site=rdos_public

Rowe, Steve. 2010. Personal communication on February 26, 2010 during phone conversation with Douglas Geller (Summit). Water Stewardship Officer, B.C. Ministry of Environment.

Summit Environmental Consultants Ltd. (Summit) 2006. Installation and testing of water supply Well # 2 – Willowbrook Utilities Ltd., Oliver, BC. Project No. 213003.01, prepared for TRUE Consulting Group and Willowbrook Utilities Ltd.

Summit Environmental Consultants Ltd. (Summit) 2009a. Phase 2 Okanagan Water Supply & Demand Project: Surface Water Hydrology and Hydrologic Modelling Study "State of the Basin" Report. Prepared for OBWB.

Summit Environmental Consultants Ltd. (Summit) 2009b. DRAFT of Phase 2 Okanagan Water Supply and Demand Project: Main Report. Prepared for the OBWB in December 2009.

Van der Gulik, T., D. Neilsen, and R. Fretwell. 2008. Okanagan Water Demand Model (also known as the Irrigation Water Demand Model).

Van der Kamp G. 1981a. Letter to Lower Nipit Improvement District regarding proposed development in the Twin Lake Area. October 21, 1981.

Van der Kamp G. 1981b. Letter to Lower Nipit Improvement District regarding proposed development in the Twin Lake Area. November 13, 1981.

Watterson D. 2008. Personal communication via e-mail with Suki Sekhon regarding Twin Lakes Golf Resort Groundwater Production Rates and Demand, sent Tuesday November 18, 2008.

11.0 GLOSSARY AND ACRONYMS

AET – Actual evapotranspiration. The quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration.

Anthropogenic inputs and outputs – Human–influenced activities which influence the groundwater balance. In the context of this study anthropogenic inputs and outputs considered were pumping and irrigation return flow.

Aquifer – An aquifer is a formation, group of formations or part of a formation containing enough saturated permeable material to produce significant amounts of water to wells and springs. (See also confined aquifers or artesian aquifers and unconfined aquifers.)

BC MoE – British Columbia Ministry of Environment.

Bedrock – Rock underlying soil and other unconsolidated material.

DEM – Digital Elevation Model.

Deep–seated bedrock fracture–flow system – Bedrock (inferred to be below approximately 50 m below ground surface) that has few and/or poorly connected fractures. The system may hold large amounts of water in storage, but due to the constraints of deep–seated fracture flow much it is not typically economical to extract this water from storage.

Discharge area – An area where ground water and water in the unsaturated zone is released to the ground surface, to surface water or to the atmosphere.

Discharge boundary – A linear constant head boundary where groundwater discharges to a surface water body, for example a lake or a stream.

Drawdown – The variation in the water level in a well prior to commencement of pumping compared to the water level in the well while pumping. In flowing wells drawdown can be expressed as the lowering of the pressure level due to the discharge of well water.

Ephemeral stream – A stream which flows only after rain or snow-melt and has no baseflow component.

ET – Evapotranspiration.

Evapotranspiration – Loss of water from a land area through transpiration of plants and evaporation from the soil.

Fracture – A break or crack in the bedrock.

Fractured bedrock aquifer – An aquifer where the majority of groundwater flows through cracks and fractures in the rock.

Freshet – A sudden, rapid increase in water levels in a stream, caused by heavy rains and/or melting snow. In the Okanagan, freshets are usually associated with spring–time conditions.

Gridded climate data – Surfaces of daily temperature and precipitation values interpolated on a 500m x 500m a grid which were created from historic, current and projected climate data for the Okanagan basin.

Groundwater – Water in the zone of saturation, that is under a pressure equal to or greater than atmospheric pressure.

Groundwater divide – The uppermost boundary of a ground water basin.

Groundwater table – That surface below which rock, gravel, sand or other material is saturated. It is the surface of a body of unconfined ground water at which the pressure is atmospheric.

GWBAT – Groundwater Balance Analysis Tool. A spreadsheet–based groundwater balance model used within this study in order to reconcile water balance terms based on Darcy's Law with water balance terms derived from climate data.

Hydraulic conductivity – Hydraulic conductivity is a measure of the ability of a fluid to flow through a porous medium determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient – The slope of the ground water level or water table.

Hydraulic head – The level to which water rises in a well with reference to a datum such as sea level.

Hydrogeology – Study of ground water in its geological context.

Hydrograph – A graphical plot of changes in elevation of water or flow of water with respect to time.

Hydrologic cycle – The continued circulation of water between the ocean, atmosphere and land is called the hydrologic cycle.

Impermeable – Impervious to flow of fluids.

K – Hydraulic conductivity.

Kettle – A closed depression made in glacial drift by a mass of underlying ice melting.

Lacustrine deposits – Sediments laid down in a lake. Includes gravelly deposits at the margin and clay in deeper water. Sediments commonly show seasonal banding or varve clays.

Lithology – All the physical properties, the visible characteristics of mineral composition, structure, grain size etc. which give individuality to a rock.

No–flow boundary – A boundary across which the groundwater discharge is assumed to be zero. In the context of this study, groundwater divides were assumed to be no-flow boundaries.

Observation well – A well constructed for the objective of undertaking observations such as water levels, pressure readings and ground water quality.

OBWB – Okanagan Basin Water Board.

Okanagan Hydrology Model – A version of the Okanagan Water Accounting Model which has been calibrated against data provided by the Okanagan groundwater and surface water studies.

Okanagan Water Demand Model – A model which combines gridded climate data, land use information, estimates of AET, crop type and irrigation system type in order to generate water demand scenarios.

Outwash deposits – Stratified drift deposited by meltwater streams flowing away from melting ice.

PET – Potential Evapotranspiration. A measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply.

Permeability – The property of a porous rock, sediment or soil for transmitting a fluid, it is a test of the relative ease of fluid flow in a porous medium.

Permeable – The property of a porous medium to allow the easy passage of a fluid through it.

Porosity – The volume of openings in a rock, sediment or soil. Porosity can be expressed as the ratio of the volume of openings in the medium to the total volume.

Precipitation Adjustment Factor – A factor derived by dividing the total monthly precipitation at the Environment Canada Coldstream Ranch Climate Station by the long-term mean of the total monthly precipitation at the same station.

Precipitation Infiltration Factor – The percentage of the total annual precipitation anticipated to infiltrate into the aquifer. Varies with the approximate centroid elevation of an aquifer.

Pumping test (or test pumping) – A test conducted by pumping a well to determine aquifer or well characteristics.

Recharge area – An area where water infiltrates into the ground and joins the zone of saturation. In the recharge area, there is a downward component of hydraulic head.

Residual – Remainder. In the context of the Okanagan Water Supply and Demand Study, the surface water study calculated groundwater discharge by difference after accounting for other water budget terms.

RFP – Request for proposal. A document soliciting contract proposals.

RO – Total annual surface runoff.

RR – Residual recharge. In this study, represents recharge to the shallow upland

Runoff – That part of precipitation flowing overland to surface streams.

Saturated thickness – The distance from the groundwater table to the bottom of an aquifer.

Static water level – The level of water in a well that is not being influenced by ground water withdrawals. The distance to water in a well is measured with respect to some datum, usually the top of the well casing or ground level.

Surficial deposits – Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.

Till – Till consists of a generally unconsolidated, unsorted, unstratified heterogeneous mixture of clay, silt, sand, gravel and boulders of different sizes and shapes. Till is deposited directly by and underneath glacial ice without subsequent reworking by meltwater.

Topography – The configuration of a surface including its relief and the position of its natural features.

TP – Total annual precipitation.

Transmissivity – Rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values can be expressed as square metres per day (m^2/day), or as square metres per second (m^2/sec).

Transpiration – The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface.

Unconfined aquifer – An aquifer in which the water table is free to fluctuate under atmospheric pressure.

Unconsolidated aquifer – Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other material which have either been formed in place or have been transported in from elsewhere.

Water balance (Hydrologic budget) – A record of the outflow from, inflow to, and storage in a hydrologic unit like an aquifer, drainage basin etc.

Watershed – A catchment area for water that is bounded by the height of land and drains to a point on a stream or body of water, a watershed can be wholly contained within another watershed.

Water table – See Ground water table.