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Department of
Earth Sciences

# GROUNDWATER AND HYDROGEOLOGICAL CONDITIONS IN THE OKANAGAN BASIN, BRITISH COLUMBIA
# A STATE-OF-THE-BASIN REPORT

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Prepared For:
Okanagan Basin Water Board
For Objective 1 of the Phase 2 Groundwater Supply and Demand Project

December, 2007

# EXECUTIVE SUMMARY

This report provides a compilation of hydrogeological knowledge for the Okanagan Basin to satisfy Objective 1 of the Groundwater Component of the Phase 2 Water Supply and Demand Project. The overall purpose of the Objective 1 work was to "develop a comprehensive State-of-the-Basin report that thoroughly documents the current state of knowledge of groundwater in the Okanagan Basin" (OBWB, 2007a).

This report identifies a number of information sources for obtaining groundwater-related information. The sources are described, and information that contributes to the understanding of regional hydrogeological processes in the Okanagan Basin is summarized. A synthesis of available information is then developed. Based on this synthesis, significant data gaps are identified and conclusions are made.

The following text summarizes the results and conclusions presented in this report.

- Sources for compiling groundwater-related data for the Okanagan Basin were identified under the following categories: Databases and Maps, Report Catalogues, Water Purveyors and Local Government, Consultant Reports, and Current Research and Knowledge.
- Many of the information sources identified provide potentially useful data regarding local-scale hydrogeology. Local-scale data was not compiled for this report.
- There are a number of regional-scale research projects that provide (or have the potential to provide) useful information regarding Okanagan Basin hydrogeology. Many of these research projects (summarized in this report based on unpublished information) are in preliminary stages, are ongoing, or are yet to be published.

- Figure i, below, presents a visual summary indicating areas of significant hydrogeological knowledge or ongoing research in the Okanagan Basin. Information regarding the individual topics noted on Figure i can be referenced within the body of this report in the section numbers identified.
- As part of the synthesis of available information, Aquifer Information Tables were developed for each aquifer identified by the BC MOE to be located within, or partly within, the Okanagan Basin (73 in total). These tables (in Appendix II of this report) provide summary information regarding aquifer dimensions, materials, hydraulic properties, and other data. The level of detail of available information is different for each of the aquifers.
- Based on the synthesis of information on regional hydrogeology and groundwater, the following general needs (i.e. data gaps) are evident:
  - Interpretations of stratigraphy (i.e., cross sections) and depositional environments for more areas within the Okanagan Basin.
  - Delineation (laterally and vertically) of identified aquifers and currently unmapped aquifers, based on current data and rigorous analysis.
  - Quantification of hydraulic properties of aquifers and aquitards across the Basin where these data have not previously been obtained.
  - An improved understanding of hydraulic connections between aquifers.
  - An improved understanding of recharge and discharge processes influencing the different aquifers (including surface water – groundwater interactions and subsurface processes).
  - Quantification of aquifer recharge/discharge due to different mechanisms.
  - Groundwater flow direction and gradient information (for unconfined, confined, and bedrock aquifers)

- In general, there is a high degree of uncertainty regarding hydrogeological conditions within most watersheds; only a few detailed hydrogeological studies have been undertaken to date. Thus, there will be limitations regarding the certainty of values for parameters used in future modelling work. Implications for hydrogeological modelling are discussed in Section 5.8 of the report. Section 5.7 identifies aquifer-watershed relationships which are relevant to modelling work for subsequent components of the Phase 2 Supply and Demand Project.
- Although some data gaps have been identified, available data provide a basis to initiate future Okanagan Basin hydrogeological investigations.
- It is evident, based on the large number of ongoing research projects, and the coordination of this research under the auspices of the Groundwater Assessment in the Okanagan Basin (GAOB) project, that there will be a significant increase in hydrogeological knowledge for the Okanagan Basin over the next decade. It will be important to consider current research for future water resources supply and demand studies.
- The information presented in this report is subject to all limitations noted within the report and appendices.

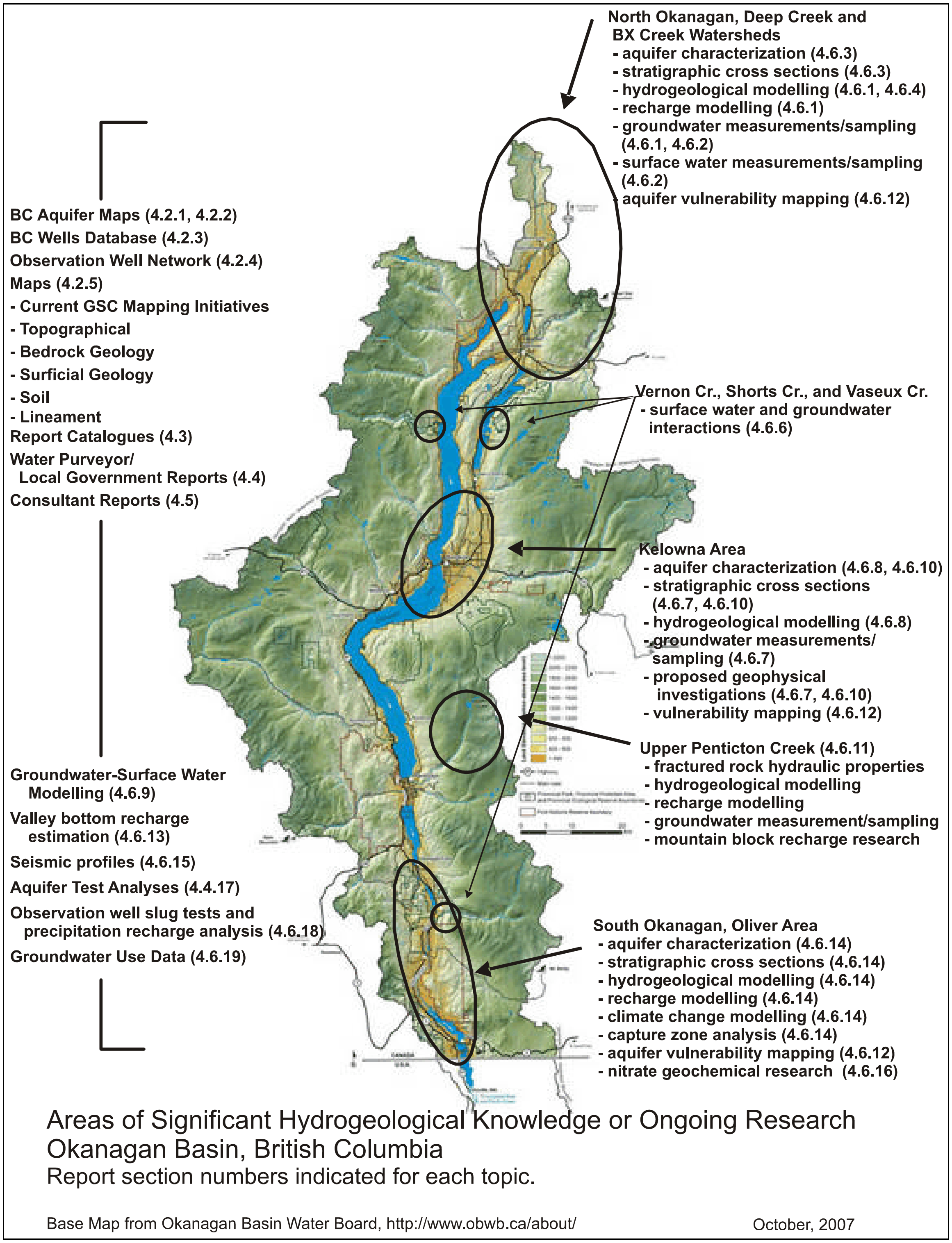


**Figure i: Map providing a visual summary of areas of hydrogeological knowledge and ongoing research in the Okanagan Basin**

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# 1 INTRODUCTION

The Okanagan Basin is a north-south trending valley located in south-central British Columbia. A mainstem river-lake system flows in a southerly direction in the valley bottom. Mountainous regions comprise the valley sides, and include precipitation catchment areas and watersheds. Figure 1 illustrates the location of the Okanagan Basin within British Columbia. Figure 2 shows the boundaries of the Okanagan Basin and mapped watershed areas considered in this project.

The Okanagan Basin has an arid climate and is well-populated. Thus, the long term sustainability of water resources in this region is an issue of concern. Concern regarding water resources was initially addressed in the 1970's, and a study, referred to as the 1974 Supply and Demand Study, was completed (see Section 3.1). More recently, ongoing water resources concerns and accelerated population growth identified the need to update the 1974 study to reflect current conditions/knowledge.

In 2004, the Okanagan Basin Water Board (OBWB) and the Province of B.C., in partnership with Environment Canada, Agriculture Canada, First Nations, and other stakeholders, initiated a basin wide study of surface water and groundwater resources. This project is referenced as the "Okanagan Basin Water Supply and Demand Project".

Phase 1 of the Okanagan Basin Water Supply and Demand Project was completed in May 2005 by Summit Environmental Consultants Ltd. (Summit, 2005, see Section 3.2). Phase 2 of this project was initiated in 2007 and consists of surface water and groundwater components. The groundwater component is further divided into specific "Objectives". This report satisfies "Objective 1" of the groundwater component of the Phase 2 Okanagan Basin Water Supply and Demand Project.

The scope of work for Objective 1 (defined in detail in Section 2) involved the compilation of available data and information regarding groundwater and hydrogeological conditions in the Okanagan Basin. The overall purpose of the Objective 1 work was to "develop a comprehensive State-of-the-Basin report that thoroughly documents the current state of knowledge of groundwater in the Okanagan Basin" (OBWB, 2007a).


**Figure 1: Map showing the location of the Okanagan Basin, British Columbia (from Summit, 2005).**

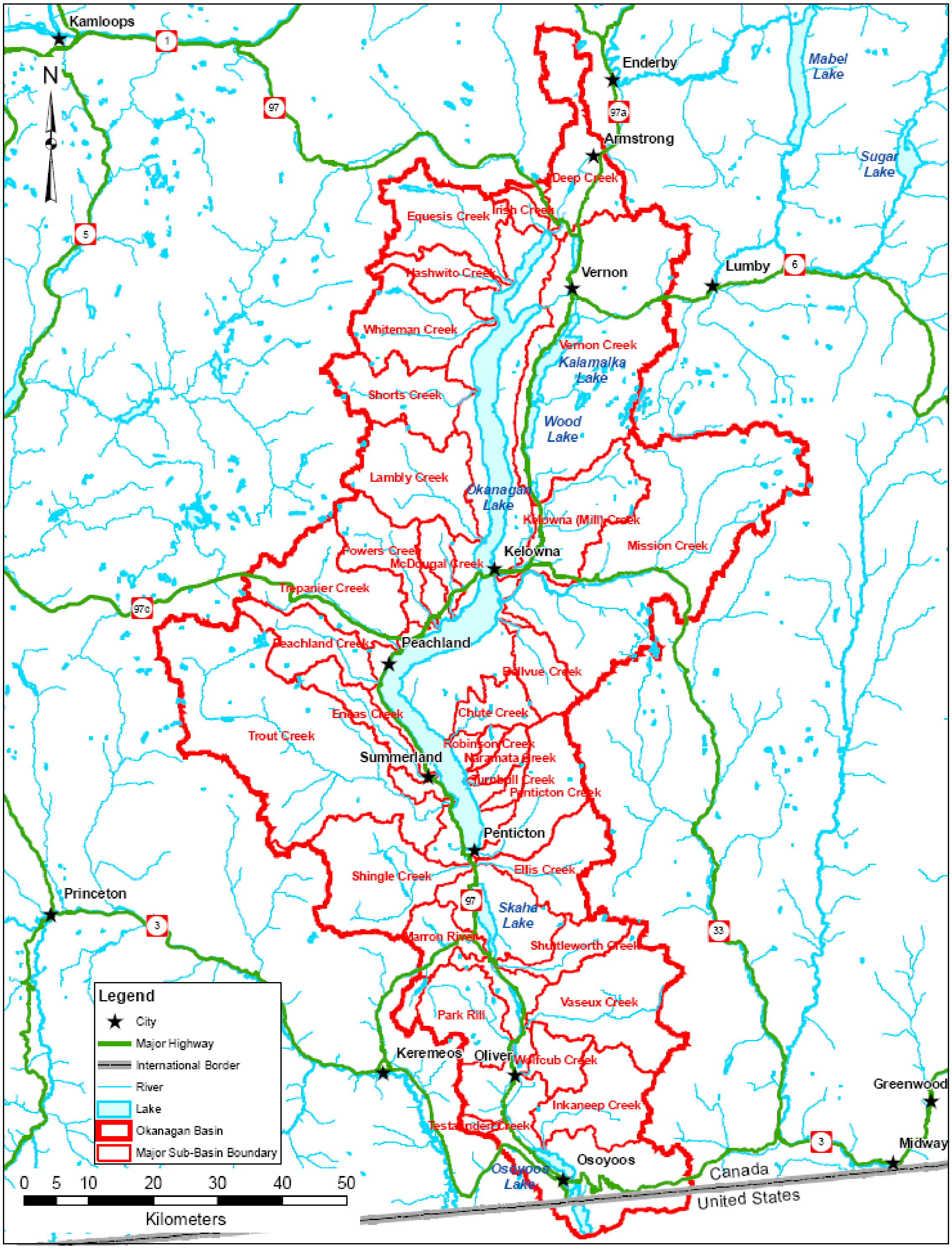


**Figure 2: Map showing Okanagan Basin and Watershed Areas (prepared by Summit, 2007).**

# 2 SCOPE OF WORK AND REPORT FORMAT

The general scope of work for this project was outlined in Contract OBWB 07-005; "Work Scope for Objective 1 of the Phase 2 Groundwater Study (Task 5.3)" (OBWBa, 2007). The overall purpose of the work was to "develop a comprehensive State-of-the-Basin report that thoroughly documents the current state of knowledge of groundwater in the Okanagan Basin."

The Phase 1 Okanagan Basin Water Supply and Demand Study (Summit, 2005) compiled a listing of available information sources for the development of an Okanagan Basin water information database, identified data gaps, and then, based on this information, presented recommendations for the Phase 2 Okanagan Basin Water Supply and Demand Project. This report builds upon the information presented in Summit (2005), and compiles relevant data and information to develop a basin-wide understanding of groundwater and hydrogeological conditions.

Key required tasks of the Objective 1 work were (from OBWB, 2007a):

- Review and become familiar with relevant previous and ongoing work;
- Review existing groundwater models and modelling efforts completed or underway for significant surficial aquifers including aquifers in the North Okanagan, Greater Kelowna, and Oliver areas;
- Obtain information on groundwater extraction rates and volumes, irrigation water use, and irrigation recharge - provided by the authors of a separate Phase 2 project component on Water Management and Use in the Okanagan Basin which is underway. (Note that, as these data were not available at the time of preparation of the final version of this report, they are not included. These data can be referenced in the Phase 2 Water Supply and Demand Project, Water Management and Use Component report);
- Prepare a comprehensive "State of the Basin" report for groundwater; and
- Summarize groundwater information identified during the study and not already listed in the Okanagan water information database, and enter the information into

the database. (Updates to the Okanagan Water Resources Information Database are provided under a separate cover to this report).

This report addresses the overall objective and the required tasks described above. The format of the report is described as follows:

- Section 3, Background, presents summaries of water supply and demand work that has previously been undertaken for the Okanagan Basin (in the 1970's and in 2005).
- Section 4 identifies available sources of information regarding groundwater in the Okanagan Basin and describes the contribution of each source to the understanding of Okanagan Basin hydrogeological processes.
- Section 5 presents a synthesis, developed on a basin-wide scale, of the available hydrogeological and groundwater information. The topics discussed in this section include: Okanagan Basin physiography and climate, bedrock geology, surficial geology, surficial soils, aquifer identification and properties, aquifer recharge and discharge, groundwater-watershed relationships, and implications for hydrogeological modelling. In developing the basin-wide synthesis of information, Aquifer Information Tables were created for each BC Ministry of Environment (MOE) Okanagan Basin aquifer (i.e., all BC MOE mapped aquifers). Basin-scale maps were also compiled. These tables and maps (included in Appendicies I and II) are referenced and described in Section 5.
- Section 6 presents a discussion regarding available information and data gaps in the understanding of basin-wide hydrogeological processes.
- Conclusions are presented in Section 7, limitations are noted in Section 8, and references are provided in Section 9.

Relevant figures and tables are included within this report to support the text. In addition, regional-scale relevant maps are provided in Appendix I, and the Aquifer Information Tables are provided in Appendix II.

The focus of this report is to compile information that contributes to a **basin-wide** or **regional** understanding of hydrogeological processes. In keeping with this focus, “regional” reports, projects, data, and research have been defined as:

(a) those that provide information for areas approximately equivalent to the scale/size of a watershed (or sub-basin). (watershed areas are outlined on Figure 2), and/or

(b) those that provide new and up-to-date information regarding specific hydrogeological concepts that could be extended to apply to other areas of the Okanagan Basin where data gaps exist.

Hydrogeological topics (i.e., topics related to groundwater) that are discussed in this report include:

- bedrock geology
- surficial geology
- surficial soil
- stratigraphy and depositional processes
- aquifer delineation
- aquifer properties
- aquifer recharge and discharge processes
- surface water – groundwater interactions
- conceptual and numerical models of geology and hydrogeology
- groundwater flow directions and gradients
- groundwater use

Information regarding surface water or hydrological processes (which are related to hydrogeological processes) is not discussed in detail in this report. Surface water related topics not examined in this report include:

- precipitation and snowpack data
- vegetation information (transpiration by plants)
- evaporation data

- climate data
- hydrological data (i.e. surface water)

Hydrochemical data (i.e., groundwater geochemistry) are not discussed (except where relevant to hydrogeology) as groundwater quality falls outside the scope of the project.

# 3 BACKGROUND

The following background information was obtained from Summit (2005) and from the Okanagan Basin Water Board (OBWB) website (http://www.obwb.ca/, OBWB, 2007b).

In 1969, an agreement, entitled the Canada-British Columbia Okanagan Basin Agreement, was signed. This Agreement provided the guidance for a four-year comprehensive preliminary study to provide information for the development and management of water resources in the Okanagan Basin. Subsequent research to satisfy the terms of the Agreement was completed by the year 1974 and involved a number of projects regarding many aspects of water supply and demand. The research completed is collectively referenced in this report as the “1974 Supply and Demand Study” (see Section 3.1 for an overview of this work). Based on the results of this research, a 50-year water resources management plan was developed for three economic growth projections.

By the mid-1990’s, it was evident that the economic growth projections of the Okanagan Basin Agreement had underestimated actual growth. In 1994, the BC MOE determined that only limited surface water resources remained available to be licensed for use. In addition, various government and non-government organizations, involved with water resources issues in the Okanagan Basin at that time, identified the need to gain an “updated understanding of the current status of water supply and use in the Basin” (Summit, 2005).

The commissioning of an updated water resources supply and demand project was subsequently initiated (in 2004) by the Province on behalf of the Provincial Deputy Ministers’ Committee on Drought, and in collaboration with the Okanagan Basin Water Board (OBWB) (Summit, 2005). The work plan was developed in at least two phases:

- Phase 1 Okanagan Basin Water Supply and Demand Project: this phase of the work involved information identification, information evaluation, and data gap analysis. Phase 1 was completed by Summit Environmental Consultants Ltd.

(Summit) and the results of the Phase 1 work were detailed in their report entitled: Okanagan Basin Water Supply and Demand Study: Phase 1, dated May 2005.

- Phase 2 Okanagan Basin Water Supply and Demand Project: this phase of the project is ongoing and involves an updated Okanagan water supply/demand analysis. Objective 1 of the groundwater component of the Phase 2 Okanagan Basin Water Supply and Demand Project is the subject of this report.

Both the 1974 and 2005 (Phase 1) supply and demand reports encompass many topics pertaining to water resources in the Okanagan Basin. Summaries of groundwater-related information from the 1974 Supply and Demand Study and the 2005 Phase 1 Water Supply and Demand Project are presented in the following sections.

### 3.1 1974 Supply and Demand Study – Groundwater Information

As outlined in Section 3, the 1974 Supply and Demand Study involved a number of research initiatives for a variety of water resources topics. Research topics included water quantity, water quality, waste treatment, socio-economics, limnology, fisheries, health, wildlife, forestry, and land use (Marr et al., 1974). This section provides a summary of the information presented in the 1974 Supply and Demand Study that is related to groundwater and hydrogeological conditions in the Okanagan Basin.

The following reports (obtained through EcoCat, see Section 4.3.1) were reviewed:

- *Main Report of the Consultative Board including the Comprehensive Framework Plan prepared under the Canada-British Columbia Okanagan Basin Agreement* (March, 1974). Author: B.E. Marr et al., 516 p. This report provides a comprehensive overview of all research completed for the 1974 Supply and Demand Study.
- *Canada - British Columbia Okanagan Basin Agreement - A Hydrogeological Study of the Okanagan River Basin - Tasks 38,39,40,41* (Sept., 1972). Authors: E.G., LeBreton, E.C. Halstead, and P.L Hall. This report provides information regarding the following 1974 Supply and Demand Study tasks:
  - Task 38: Selected Sub-Basin Geologic Surface Investigation
  - Task 39: Seismic Exploration of Groundwater Resources
  - Task 40: Groundwater Resource Exploration; Main Valley Deep Rotary Test Holes
  - Task 41: Instrumentation and Testing of Deep Wells
  - Task 47: Groundwater Evaluation / Report Preparation

A summary of the hydrogeological work completed as part of the 1974 Supply and Demand Study as outlined in the report by LeBreton et al. (1972) is provided below. It should be noted that, although some data from this 1974 study are useful (e.g., seismic profiles, borehole logs, and groundwater analytical data), the interpretation presented in the report does not necessarily reflect current knowledge.

The main objectives of the hydrogeological work were to (a) “estimate the groundwater flow into and from Okanagan Lake”, (b) “estimate the groundwater potential of the valley-fill deposits”, and (c) “determine the groundwater component of six selected sub-basins." Tasks 38, 39, 40, and 41, identified above were developed to satisfy these objectives.

Task 38 involved the study of 6 sub-basins (Vaseux Creek, Vernon Creek, Penticton Creek, Pearson Creek, Lambly Creek, and Greata Creek). The viability of groundwater as a water supply was assessed for each sub-basin. In general, sub-basins were determined to have low baseflows and the groundwater component compared to run-off (surface water) was considered small.

For Task 39, six seismic profiles were completed across the valley in the North Okanagan (4 profiles) and in the South Okanagan (2 profiles). (Seismic profiles across the Okanagan Basin are discussed further in Section 4.6.15). The profiles provided information regarding the depth of the bedrock surface in the Okanagan Basin as well as some information regarding stratigraphic layering of the valley fill deposits. These seismic profiles provided a basis for planning deep test-hole drilling (Task 40).

Task 40 (test-hole drilling) involved the drilling of nine boreholes and the installation of observation wells. Eight of the boreholes were drilled in the North Okanagan, and one borehole was drilled in the South Okanagan (near Okanagan Falls). Boreholes were drilled to depths of up to 370 m (1 215 feet). Well testing (Task 41) was subsequently completed for six of the wells to provide information on hydraulic properties of the well and aquifer.

Based on the test-hole drilling and well testing, rough estimates were made regarding total rate for groundwater movement towards Okanagan Lake (approximately 0.09 $m^3$/s), the overall groundwater potential for the valley fill deposits (in the range of 0.09 to 0.17 $m^3$/s), and potential well yields (average less than 1140 L/min, locally higher). The main source of recharge to aquifers was identified as precipitation.

## 3.2 Phase 1 Water Supply and Demand Project– Groundwater Information

The Phase 1 Water Supply and Demand Project report (Summit, 2005) presented an overview of groundwater data sources and some general information regarding hydrogeological knowledge in the Okanagan Basin. The following text summarizes some of the information presented in the Phase 1 report.

**Groundwater Data Sources:** The following key sources for groundwater information were identified in the Phase 1 Report (these are discussed in various sections of this report as noted):

- B.C. Aquifer Classification Maps (Section 4.2.2)
- 1974 Okanagan Basin Study (Section 3.1)
- MWLAP (currently BC MOE) Wells Database (Section 4.2.3)
- MWLAP NTS Reference Library (Section 4.3.2)
- MWLAP (currently BC MOE) Observation Well Network (Section 4.2.4); and
- Irrigation/Water District Capital Improvement Plans (not specifically discussed in this report, but referenced in Section 4.4).

The Phase 1 Report identifies the information available from the above-noted sources and discusses some of the limitations (groundwater-related information from this report is outlined below). Compilation of specific groundwater-related data from these reports and the development of a hydrogeological understanding for the Basin were not part of the scope of the Phase 1 report.

**Surface groundwater interactions:** At the time of preparation of the Phase 1 Report, information regarding the magnitude of surface-groundwater interactions was limited. Relative estimates of the general degree of interactions (i.e., low, moderate, or high) are cited in the Phase 1 report for some specific watershed areas. Specific studies to quantify surface-groundwater interactions, however, were not available at the time of preparation of the Phase 1 Report.

**Groundwater Use:** The Phase 1 report indicates that there are approximately 61 public water purveyors providing water services in the Okanagan Basin. The Phase 1 work involved contacting 45 of these water purveyors (the largest water providers were selected). Thirty-two of the water purveyors responded and provided information regarding groundwater usage in their area. The Phase 1 work also involved obtaining Improvement plans from water purveyors. Seven of the water purveyors provided Plans with useful groundwater information.

Updated groundwater use data is being obtained by Dobson Engineering Ltd. as a separate part of the Phase 2 Water Supply and Demand Project. This information is not yet available.

**Data Gaps:** Data gaps for groundwater information were discussed in the Phase 1 Report. A listing and discussion of these data gaps can be referenced in the Phase 1 Report. An updated discussion of data gaps with respect to current hydrogeological knowledge in the Okanagan Basin is provided in Section 6 of this report.

# 4 INFORMATION SOURCES

This section inventories and describes the information sources researched in compiling this report (sources dated up to October 31, 2007). Available information sources were identified through the Phase 1 Supply and Demand report, interviews, and internet searches. Table 1, below, lists the categories of information sources reviewed, and identifies their corresponding section in this report.

**Table 1: Summary Listing of Information Sources with Report Section Cross-References**

| Section Number | Information Source Category |
|---|---|
| 4.1 | Groundwater Assessment in the Okanagan Basin (GAOB) |
| 4.2 | Databases and Maps |
| 4.3 | Report Catalogues |
| 4.4 | Water Purveyors and Local Government |
| 4.5 | Consultant Reports |
| 4.6 | Current Research and Knowledge |

Within each category, specific relevant information sources were identified and are listed and described in this report. Summary tables, which provide at-a-glance information regarding the nature of the source, access location, responsible/affiliated organizations, and other information, are provided at the beginning of the sections for each specific information source.

## 4.1 Groundwater Assessment in the Okanagan Basin (GAOB)

The Groundwater Assessment in the Okanagan Basin (GAOB, initiated in 2004) project is an ongoing project being undertaken under the direction of Natural Resources Canada (NRC) and the BC Ministry of Environment (BC MOE) (formerly the BC Ministry of Water, Land and Air Protection). The overall project objective is to improve the understanding of groundwater resources within the Okanagan Basin.

The GAOB project does not provide funding for specific research (funding for individual research projects is obtained independently by the researcher), nor does it directly oversee specific research projects. Rather, under GAOB, a team of representatives from government and institutions works together to:

- review and provide some direction for ongoing research of groundwater in the Okanagan Basin. (Specific GAOB objectives for research can be referenced at http://ess.nrcan.gc.ca/2002_2006/gwp/p3/a5/index_e.php);
- discuss ongoing and future research needs;
- exchange information regarding ongoing Okanagan Basin research;
- facilitate the transfer of scientific information to local decision makers in a useful format; and
- facilitate the delivery of water resources information to the public.

The GAOB project encompasses all current groundwater research being undertaken for the Okanagan Basin (some of which has not been completed or is yet to be published). At the time of preparation of this report, a number of specific Okanagan Basin groundwater research projects were ongoing under the auspices of the GAOB project. These include ongoing research through universities, as well as government agency work to maintain/update existing databases and maps. This report presents summaries of the GAOB project work in subsequent sections.

## 4.2 Databases and Maps

Information databases and maps, which provide significant information regarding groundwater in the Okanagan Basin, are identified and discussed below. Each section describes the source, and outlines how the information from the source contributes to the overall/general understanding of groundwater in the Okanagan Basin.

A review of raw data available from some of the databases was not completed as part of this project.

### 4.2.1 BC Water Resources Atlas

| | |
|---|---|
| **Database Name or Data Category:** | **BC Water Resources Atlas (WRA)** |
| **Description:** | GIS based system that provides aquifer maps and information, water well information and other mapping information. |
| **Access Location/Report Reference:** | Water Resources Atlas: http://www.env.gov.bc.ca/wsd/data_searches/wrbc/<br><br>Berardinucci, J., and Ronneseth, K., 2002. *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*, BC MOE. |
| **Responsible Organization(s):** | BC Ministry of Environment, Victoria, BC |
| **Reference Citation (Section 9):** | BC MOE, 2007, WRA<br>Berardinucci and Ronneseth, 2002 |

The BC Water Resources Atlas is an on-line GIS based system that visually displays water resources information for British Columbia. The site is maintained by the BC MOE and can be accessed on-line at the address identified in the table above.

Information available through the BC Water Resources Atlas includes aquifer maps (i.e., BC Aquifer Classification Maps, see Section 4.2.2), general aquifer information, water well locations and access to well logs (see Section 4.2.3), as well as other general mapping information (e.g., topography, watershed areas). This website is useful for identifying aquifers and well locations within the Okanagan Basin, and provides some general information regarding aquifer use, aquifer vulnerability, and other data. It should be noted, however, that the information presented on this website is "currently under review and subject to verification".

Specific aquifer information available through the BC Water Resources Atlas includes aquifer reference number and location, a general description of aquifer materials, aquifer vulnerability, productivity and demand ratings (low, moderate, and high), and BC

MOE aquifer classification ratings (e.g., IC). Figure 3 illustrates the aquifer classification rating system used by the BC MOE.

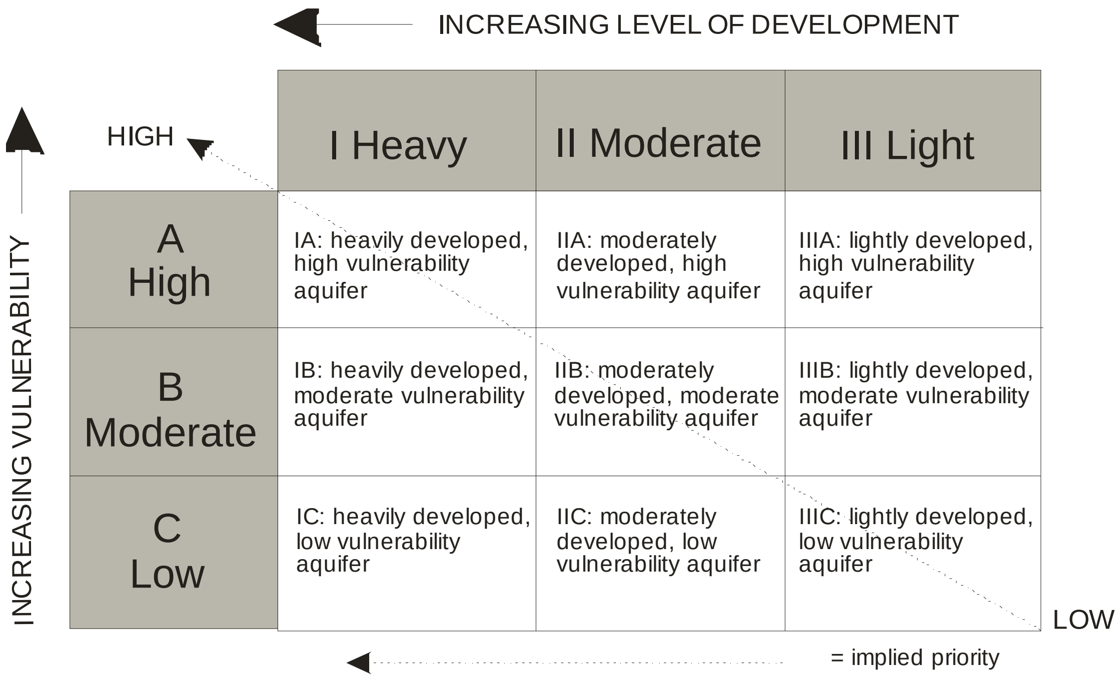


**Figure 3: BC MOE Aquifer Classification System - Diagram for Aquifer Rating. (from Berardinucci and Ronneseth, 2002).**

Further information regarding the development and use of the BC Aquifer Classification System can be referenced in the *Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater*, (Berardinucci and Ronneseth, 2002). Further discussion regarding the Aquifer Classification Maps is provided in Section 4.2.2.

### 4.2.2 BC Aquifer Classification Maps and Supporting Information

| **Database Name or Data Category:** | **BC Aquifer Classification Maps, Draft Worksheets and Draft Spreadsheets** |
|---|---|
| **Description:** | BC Aquifer Classification Maps indicate aquifer extents and other general information such as aquifer ranking, vulnerability, productivity, and demand. Digitized aquifer map polygons show the mapped extent of the aquifer.<br><br>Draft Aquifer Classification worksheets and spreadsheets (ACW) provide some details regarding specific aquifer information and statistics. |
| **Access Location:** | BC Aquifer Classification Maps: http://www.env.gov.bc.ca/wsd/data_searches/wrbc/<br><br>Draft Worksheets and Spreadsheets (ACW): Unpublished data from BC Ministry of Environment, Victoria, BC, Science and Information Branch, Water Stewardship Division |
| **Responsible Organization(s):** | BC Ministry of Environment, Victoria, BC |
| **Reference Citation (Section 9):** | BC MOE, 2007, ACW<br>Berardinucci and Ronneseth, 2002 |

In developing the BC Aquifer Classification Maps (visual display available through the BC Water Resources Atlas, see Section 4.2.1), each aquifer delineated was assigned a reference number. These numbers are used throughout this report to identify aquifers associated with the different information sources; to provide a consistent referencing system for aquifer data. The reference numbers for the BC MOE aquifers within the

Okanagan Basin (73 in total[1]) are identified in Table 2 with their general Okanagan Basin location (i.e., north, central, south).

Aquifers mapped by the BC MOE were delineated using available water well records and knowledge regarding groundwater use (Berardinucci and Ronneseth, 2002). Digitized polygons, created for the development of the Aquifer Classification Maps, were obtained from the BC MOE (unpublished data, 2007) for use in preparing maps for this report (maps in Appendix I). Map 5 shows the locations of aquifers identified as unconfined by the BC MOE, Map 6 shows confined aquifer locations, and Map 7 illustrates bedrock aquifer locations. Note that for aquifers designated on Maps 5 and 6 as "unconfined" or "confined", the designation represents the main aquifer type. Many "confined" aquifers are partially or locally unconfined and vice versa.

Note that as new hydrogeological information is obtained (i.e., through future research, data analysis, and/or well drilling), the aquifer polygons shown on the maps in Appendix I may require modification. In addition, new aquifers will likely be identified and mapped in the future. Further limitations relating to the use of aquifer classification maps are discussed in Section 5.5.

The BC MOE aquifer mapping procedure involved the use of aquifer classification worksheets and spreadsheets to compile relevant data for each aquifer. Draft data compiled for the aquifers included location, size, aquifer materials, overlying and underlying materials, type of aquifer (confined, unconfined, or bedrock), and aquifer boundary information for most of the aquifers. Statistical information from the well logs

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[1] Aquifers within the Okanagan Basin are those mapped to be within or partially within the Okanagan Basin boundaries as defined on Figure 2. A total of 73 mapped aquifers have been identified (Table 2). Future aquifer mapping may indicate additional aquifers to those listed. In addition to the aquifers identified within the Basin, three aquifers (aquifers 109, 316, and 317) are currently mapped to be outside the Basin but in contact with the boundary. Aquifer 109 is confined aquifer at the north end of the Basin. Aquifers 316 (unconfined) and 317 (confined) are located at the east end of the Coldstream Valley. The BC Water Resources Atlas can be referenced for these aquifer locations.

such as mean/median well depth, static water level, and well yield is also presented on the draft aquifer classification worksheets/spreadsheets.

Draft Aquifer Classification Worksheets were obtained from the BC MOE (2007, ACW, unpublished data) for 67 of the 73 aquifers identified within the Okanagan Basin. Draft Aquifer Spreadsheets (providing detailed well log statistics) were available for 25 aquifers. Selected specific information from these worksheets and spreadsheets (as well as information from other sources) was used in developing Aquifer Information Tables for each of the 73 mapped aquifers within the Okanagan Basin. These tables are further discussed in Section 5.5 of this report and are included in Appendix II

**Table 2: Table identifying the mapped BC Aquifer numbers within (or partially within) the Okanagan Basin boundaries and their general Basin location.**

| North | Central | South |
|---|---|---|
| 102 | 297 | 193 |
| 103 | 298 | 194 |
| 104 | 299 | 195 |
| 105 | 300 | 238 |
| 106 | 301 | 248 |
| 107 | 302 | 254 |
| 111 | 303 | 255 |
| 346 | 304 | 256 |
| 347 | 305 | 257 |
| 348 | 306 | 260 |
| 349 | 344 | 261 |
| 350 | 345 | 262 |
| 351 | 358 | 263 |
| 352 | 461 | 264 |
| 353 | 462 | 265 |
| 354 | 463 | 266 |
| 355 | 464 | 267 |
| 356 | 465 | 268 |
| 357 | 466 | 269 |
| | 467 | 270 |
| | 468 | 808 |
| | 469 | 809 |
| | 470 | 810 |
| | 471 | |
| | 472 | |
| | 473 | |
| | 860 | |
| | 861 | |
| | 862 | |
| | 863 | |
| | 864 | |

#### 4.2.3 Wells Database

| Database or Data Category: | BC Wells Database |
|---|---|
| **Description:** | Electronic files of well logs (WL) and locations across B.C. |
| **Access Location:** | http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells.html |
| **Responsible Organization(s):** | BC Ministry of Environment, Victoria, BC |
| **Reference Citation (Section 9):** | BC MOE, 2007, WL |

The BC MOE Wells Database is accessible on-line at the address indicated in the above table. Each well log that is on file with the BC MOE has been digitized and assigned a well tag number (WTN)[2]. Using the WTN, the well log can be accessed through the Wells database. Well logs contain information regarding well location, well construction, well yield, static water level, and lithology observations with depth recorded by the driller at the time of drilling. Other searches (e.g., by location) can also be completed through the Wells Database search engines.

Well logs (WLs) provide some useful information for understanding hydrogeological conditions. The well yield, static water level, and lithology information can be used to assist in defining aquifer materials, aquifer depths/thicknesses, and confining layer characteristics. However, the information presented on the wells logs is of variable quality, and the accuracy of the information (provided by the water well driller) has not been confirmed or validated. In addition, the well logs on file with the wells database represent those that are voluntarily submitted by the driller and there is no legislative requirement to submit well logs to the provincial government database. As such, it is likely that there are more wells drilled within a given aquifer area than are indicated on the wells database. Experience in the North Okanagan (through the NOGWCA Project,

[2] Note that the Well Tag Number (WTN) is a unique well identifier; specific to the Well Database. Well Plate Numbers, which are inscribed on BC MOE well plates attached to water supply wells, do not correspond in numbering with WTNs.

Section 4.6.2) indicates that for every well on record, there may be as many as five that are unreported (Stewart, 2007, pers. comm.).

### 4.2.4 Observation Well Network Database

| Database or Data Category: | BC Observation Well Network |
|---|---|
| **Description:** | Database of water level data for BC Observation Wells |
| **Access Location:** | http://www.env.gov.bc.ca/wsd/data_searches/obswell/index.html |
| **Responsible Organization(s):** | BC Ministry of Environment, Victoria, BC |
| **Reference Citation (Section 9):** | BC MOE, 2007, OWN |

The BC MOE maintains an Observation Well Network (OWN) consisting of 158 wells across British Columbia. Water level data are collected from these wells throughout the year, and at (generally) regular time intervals, to observe groundwater level fluctuations in developed aquifers. Selected observation wells are sampled on a regular basis to obtain groundwater quality information.

Forty of the BC observation wells are present within the Okanagan Basin (see Table 3). Data from the observation wells can be obtained, graphed, and/or tabulated using the on-line system. Data are available for years dating from as early as the 1960's for some wells. Most data are month-end values of water level, but newer electronic dataloggers in some wells permit daily measurement of water level.

**Table 3: List of BC Observation Well Numbers within the Okanagan Basin (from BC MOE, 2007, OWN).**

| **General Location** | **Observation Well Number** |
|---|---|
| Armstrong | 117, 118, 119 |
| Cars Landing | 53, 54 |
| Eagle Rock | 180 |
| Enderby | 122 |
| Kalawoods (near Oyama) | 162, 172, 173, 174, 175, 176, 177 |
| Kelowna | 262 |
| Lumby | 294 |
| Meyers Flat | 282 |
| Mission Creek | 115 |
| Okanagan Mission | 305 |
| Oliver | 332 |
| Osoyoos | 96, 97, 100, 101, 102, 105, 107 |
| Rutland | 236 |
| Silver Star | 47, 322 |
| Summerland | 152, 153, 154, 158, 366, WW-1 |
| Tug Lake/Vaseux Lake | 348 |
| Vernon-BX Creek | 311 |
| Winfield | 57, 356 |
| | |
| **TOTAL NUMBER OF WELLS** | **40** |

### 4.2.5 Maps

| | |
|---|---|
| **Database or Data Category:** | **Maps** |
| **Description:** | Digital or hard-copy maps |
| **Access Location:** | **Topographical Maps**<br>Digital: General Map Data: TRIM, Digital Elevation Data – Geobase, 2007, USA Data – Washington Department of Natural Resources, 2007.<br>Hard Copy Topographical Maps available from distributors listed at: http://maps.nrcan.gc.ca/distribution_e.php<br><br>**Bedrock Geology**<br>Digital Geology Map of British Columbia: Tile NM11 Southeast BC, BC Ministry of Energy and Mines, GeoFile 2005-4, (Massey, et al., 2005). Map available at - http://www.em.gov.bc.ca/mining/geolsurv/publications/catalog/bcgeolmap.htm.<br>Hard Copy available from: Geological Survey of Canada Bookstores<br><br>GSC Open File 4375: Geology, Vernon, BC, Scale 1:50 000, Thompson, 2003.<br><br>Note: New GSC bedrock geology maps in progress, expected 2008. Email info-calgary@gsc.nrcan.gc.ca for more information.<br><br>**Surficial Geology**<br>Fulton, 1969. Digital data from NRCan Library, 2007 (http://ess.nrcan.gc.ca/esic/)<br>Nasmith, 1962. Digital data from GSC, unpublished data.<br>USA: Digital data from Washington Department of Natural Resources, 2007<br>Hard Copies (Canadian) available from: Geological Survey of Canada Bookstores<br><br>Note: New GSC surficial geology maps in progress, expected 2008. Email info-calgary@gsc.nrcan.gc.ca for more information.<br><br>**Soils**<br>Benchland and Highland soils: Digital from BC MOE ftp site (ftp://fshftp.env.gov.bc.ca/pub/outgoing/Soil_Data/CAPAMP)<br>Valley Bottom Soil: Digital from http://sis.agr.gc.ca/cansis/publications/bc/bc52/intro.html<br>Washington Soil: Washington Department of Natural Resources, 2007<br><br>Note: Current soil mapping work by BC Ministry of Agriculture and Lands is in progress (see Section 4.6.20).<br><br>**Aquifers**<br>Digital aquifer polygons: BC MOE (2007, unpublished data)<br><br>**Fault/Fracture Map**<br>Fault and Fracture Lineament Progress (Draft) Map: BC MOE (2007, unpublished data). Expected Completion 2008. |
| **Responsible Organization(s):** | Various as indicated by access locations (above) and text below. |
| **Ref. Citation:** | Various as indicated by access locations (above) and text below. |

At the time of preparation of this report, some of the above-noted maps were available in digital and/or hard copy format from the sources identified. Current mapping initiatives for bedrock geology, surficial geology, and soil, noted above and described below, were not available in final or digital format at the time of preparation of this report.

For the purposes of providing baseline map information in this report, the following maps were created by Summit Environmental Consultants Ltd. using available digital files and ArcGIS:

Map 1: Topography of the Okanagan Basin
Map 2: Bedrock Geology of the Okanagan Basin
Map 3: Surficial Geology of the Okanagan Basin
Map 4: Soils of the Okanagan Basin Benchlands and Highlands
Map 5: Unconfined Aquifers of the Okanagan Basin
Map 6: Confined Aquifers of the Okanagan Basin
Map 7: Bedrock Aquifers of the Okanagan Basin

These maps are provided as external figures to this report in Appendix I. For each of the maps created, selected attributes were included to provide the reader with an overview of the basic information available from the different map sources. Additional map attributes can be obtained through the above-noted websites and references. All maps produced show the boundaries of the Okanagan Basin, as well as the boundaries of the main sub-basins (watersheds) and residual areas (areas between watersheds where significant surface water is absent).

***Updates to Surficial Geology and Bedrock Geology Maps - GSC:***

The Geological Survey of Canada (GSC) is in the process of creating updated surficial geology and bedrock geology maps for the Okanagan Basin. This work builds upon previously completed surficial geology mapping work by Fulton (1975) and Nasmith (1962) and bedrock geology mapping by the GSC. The surficial geology maps are based on aerial photo interpretation as well as ground-truth data obtained during field mapping throughout the Okanagan (mapping work incorporated approximately 1500 new field observations). The maps will represent current knowledge and current theories regarding geological processes, but are unavailable at the time of preparation of this report.

To date, a bedrock geology map (1:125 000 scale) has been prepared in draft form and it is anticipated to be released in final form in 2008. The date of release of the surficial geology map has not been confirmed.

***Okanagan Basin Soil Survey – BC Ministry of Agriculture and Lands:***

At the time of preparation of this report, the BC Ministry of Agriculture and Lands was in the process of completing soil survey work across the valley bottom. The results of this work will provide soil mapping information to confirm/update existing maps. The scope of work for this soil study is outlined in Section 4.6.20.

***Okanagan Basin Fault and Lineament Mapping:***

Mapping of Okanagan Basin faults and fractures is currently being completed under the direction of the BC MOE (BC MOE, pers. comm.). A map entitled: “Okanagan Basin Fault and Fracture Mapping from Aerial, Satellite and DEM Imagery, Progress Map – Feb. 6, 2006” was prepared by McElhanney Consulting Services Ltd. (McElhanney Consulting Services Ltd., 2006). A portion of this progress map, selected to illustrate the mapping exercise, is included in this report as Figure 4. This map is expected to be finished in 2008, and will be available from BC MOE, Victoria.

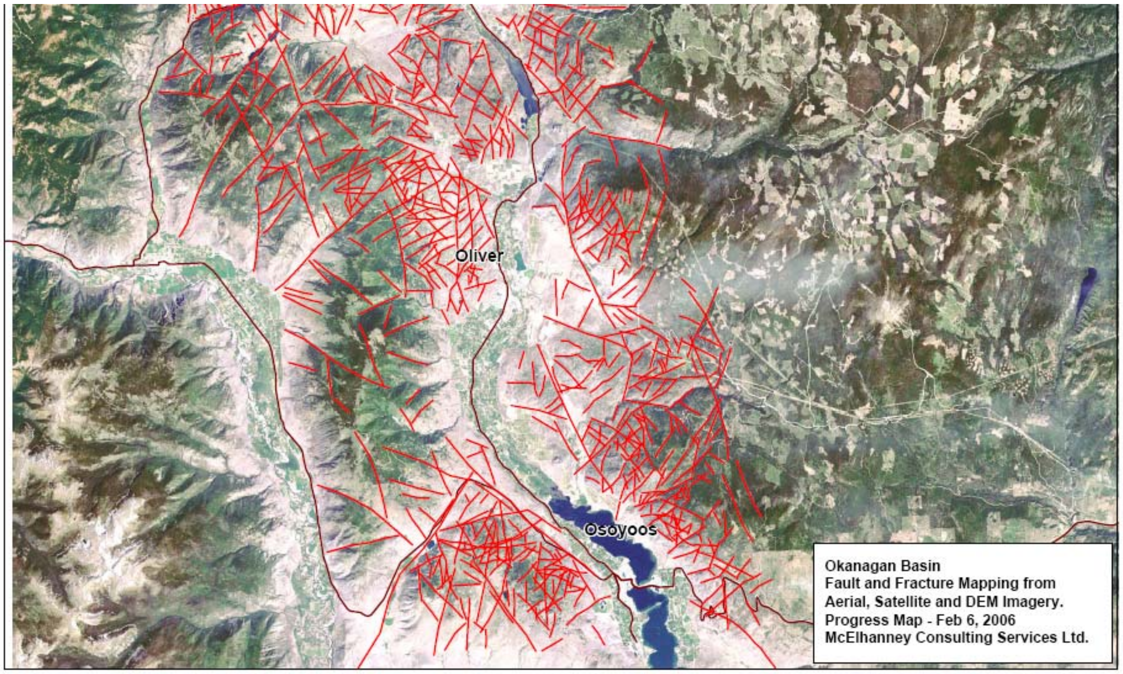



**Figure 4: Portion of "Okanagan Basin Fault and Fracture Mapping from Aerial, Satellite and DEM Imagery. Progress Map – Feb. 6, 2006. McElhanney Consulting Services Ltd. (map obtained from BC MOE, Penticton).**

## 4.3 Report Catalogues

The following sections describe three main report catalogues (EcoCat, BC Groundwater NTS Library, and the Okanagan Basin Water Resources Information Database) which are resources for identifying reports relevant to Okanagan Basin hydrogeology/groundwater. These catalogues provide listings and/or copies of hundreds of reports for many different water resource topics. “Reports” include documents such as maps, photos, proposals, laboratory and field analyses, field notes, applications, pumping/aquifer test data and results, and miscellaneous correspondence. Documents are public reports prepared by or for government, by consulting firms, by drilling companies, or by other private companies.

Many of the catalogued reports, data, and other documents provide potentially valuable information for local-scale areas (e.g., developments, individual residential wells, and municipal groundwater systems), but most do not address regional-scale hydrogeology (as defined in Section 2). As such, they are not reviewed in this report. Regional-scale reports identified through this work are limited to: previous Supply and Demand work (1974 and 2005), which is discussed in Sections 3.1 and 3.2 , and seismic profile work, discussed in Section 4.6.15.

Note that, due to the fact that much of the recent research pertaining to hydrogeology in the Okanagan basin is ongoing or not yet published (see Section 4.6), and the timeframe for government reports to be scanned into databases, all of the catalogued reports in Ecocat and the BC Groundwater NTS Library, are dated 2005 and earlier. As the Okanagan Basin Water Resources Information Database (OBWRID) was compiled based on these BC government catalogues, the reports identified in the OBWRID are also dated 2005 or earlier.

### 4.3.1 EcoCat

| **Database or Data Category:** | **EcoCat** |
|---|---|
| **Description:** | A BC MOE catalogue of electronic ecological reports |
| **Access Location:** | http://srmapps.gov.bc.ca/apps/acat/ |
| **Responsible Organization(s):** | BC Ministry of Environment, Victoria, BC |
| **Reference Citation (Section 9):** | BC MOE, 2007, EcoCat |

EcoCat is an on-line environmental reports catalogue that is maintained by the BC MOE. The catalogue contains all public ecological reports completed for or by the BC MOE. Keyword searches, searches by maps, and more advanced searches (e.g., by specific watershed, climatic zone, or fish habitat) provide lists of reports which can be downloaded.

At the time of preparation of this report (Fall 2007), the search for “Okanagan, Hydrogeology” identified 11 reports and a search for “Okanagan groundwater” identified 78 reports. Reports were dated from 1950 to 2003 and varied in content from smaller letters or inspection reports to large comprehensive regional reports. These reports were cross-referenced to the Okanagan Basin Water Resources Information Database (OBWRID, see Section 4.3.3) and reports were added where necessary to update the OBWRID.

### 4.3.2 BC Groundwater NTS Library

| Database Name or Data Category: | BC MOE Groundwater NTS Library |
|---|---|
| Description: | Library of information sources which are catalogued based on their National Topographic System (NTS) map sheet number. |
| Access Location: | BC Ministry of Environment, Victoria, BC Science and Information Branch, Water Stewardship Division |
| Responsible Organization(s): | BC Ministry of Environment, Victoria, BC |
| Reference Citation (Section 9): | BC MOE, 2007, NTS Library |

The BC MOE NTS Groundwater library contains over 5,600 groundwater-related reports (for British Columbia) dating from the late 1800's. Available reports include: "groundwater water supply reports, maps, photos, consultant reports, hydrogeologic studies, assessments, proposals, investigations, laboratory and field analyses, field notes, applications, contract work, environmental impact studies, pumping/aquifer test data and results and miscellaneous correspondence." (BC MOE, 2007, Water Stewardship Division website)

The documents contained in the Groundwater NTS Library are filed based on the 1:50,000 National Topographic System (NTS) map sheet numbers. The map sheet numbers for the Okanagan Basin include: 82E (3, 4, 5, 6, 11, 12, 13, and 14), and 82L (3, 4, 5, and 6). The NTS Master list can be obtained from:
http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/library.html.

Approximately 400 reports are listed for the above-noted NTS mapsheet numbers. In addition, approximately 40 "consultant reports" are also listed on a separate master list. Some of the BC Groundwater NTS Library documents for areas within the Okanagan Basin have been scanned into EcoCat (see Section 4.3.1) and are available on-line in digital form. The remaining hard copy reports may be obtained from, or reviewed at, the BC Ministry of Environment office, 3 rd floor, 2975 Jutland Road, Victoria, B.C.

### 4.3.3 Okanagan Basin Water Resources Information Database

| | |
|---|---|
| **Database Name or Data Category:** | **Okanagan Basin Water Resources Information Database (OBWRID)** |
| **Description:** | Database for Okanagan Basin water resources reports and references - the database inventories and describes water resources related information. |
| **Source/Access Location:** | CD can be obtained from the Okanagan Basin Water Board, Coldstream, BC.<br><br>CD was developed as part of the report: *Okanagan Basin Water Supply and Demand Study: Phase 1*, Summit Environmental Consultants Ltd., 2005. |
| **Responsible Organization(s):** | Okanagan Basin Water Board (OBWB)<br>(CD can be obtained from the OBWB) |
| **Reference Citation (Section 9):** | Summit, 2005 |

The Okanagan Basin Water Resources Information Database (OBWRID) was developed by Summit (2005), as part of the Phase 1 Okanagan Basin Water Supply and Demand Project. The database was created in Microsoft Access®. The following information is provided for each report/reference:

- Author
- Title
- Report date
- Full citation
- Access location for report and report format (i.e., digital/hard copy)
- Accessibility/availability rating
- General report content information (e.g., groundwater, surface water, type of research)
- Watershed (i.e., area) reference (database is not searchable by aquifer number)
- Brief description of report
- A relative evaluation and comments regarding report usefulness

The database can be searched, using selections from the above categories, to obtain report/reference listings for specified categories (e.g., reports dealing with groundwater modelling in the Vernon Creek watershed area).

At the time of initiation of this Objective 1 Groundwater Report, information for 249 reports/references had been entered into the database. Updates to the database, to include reports/references published since the 2005 Phase 1 Water Supply and Demand report, is a required task of this Objective 1 work. Updates to the OBWRID are provided under a separate cover to this report.

Note that data and information, which were unpublished or not public information at the time of preparation of this report (e.g., many NTS Groundwater Library reports), are not currently included in the database.

The database will be kept on file with, and updated as needed by, the Okanagan Basin Water Board, Coldstream, BC.

## 4.4 Water Purveyors and Local Government

Water use (including groundwater use in some areas) is governed or monitored under the direction of 61 water purveyors within the Okanagan Basin (Summit, 2005). Water purveyors (also referred to as Improvement Districts, Irrigation Districts, Water Districts, or Water Utilities) have information on file regarding groundwater use within their boundaries. Section 4.6.19 refers to groundwater use information collected for specific water purveyors within the Okanagan Basin as part of a separate Supply and Demand Project component.

In addition to groundwater use data, other hydrogeological reports and information may be on file with water purveyors or local governments (municipalities or regional districts). This information could include groundwater protection plans (GWPPs), Capital Improvement Plans, aquifer test data, borehole logs, or other reports or data. Of these information sources, GWPPs (typically prepared by consultants for water purveyors or local governments) can provide wider-area hydrogeological information as described below.

GWPPs provide a means to manage and protect groundwater resources. The development of a GWPP may be well-specific, aquifer-specific, or area-specific, but generally involves assessing the potential for contaminants to reach a potable water well. The GWPP involves six steps: forming a community planning team, defining a well protection area, identifying potential contaminants, developing management strategies, developing contingency plans, and monitoring results (BC MOE, 2000). Guidelines regarding GWPPs are provided in the Well Protection Toolkit (WPT) which has been published by the Province of British Columbia (BC MOE, 2000). Part of the development of a GWPP involves the compilation of geological and hydrogeological information for the study area. As such, GWPPs may provide a resource for hydrogeological information for specific areas of groundwater use within the Okanagan Basin.

At present, the Interior Health Authority (IHA), under the BC Ministry of Health, requests that a GWPP be completed by all water purveyors who use groundwater and have more than 300 connections in the Okanagan Valley (Golder, 2007, pers. comm.). This requirement is recent, and to date the IHA has focused on obtaining GWPPs for a small number of water purveyors. Some of the larger groundwater users in the Okanagan Basin (e.g. Kelowna Joint Water Committee) will have GWPPs which may be available by contacting the water purveyor or local government directly.

## 4.5 Consultant Reports

Various engineering or geoscience consulting companies have completed hydrogeological investigations throughout the Okanagan Basin for government-sector clients (e.g., municipalities, regional districts, and water improvement districts) and private-sector clients (e.g., developers and property owners). For the purposes of this report, the following consulting firms (identified by the BC MOE to be involved with hydrogeological work in the Okanagan Basin) were contacted to provide general information regarding the number of hydrogeological projects completed and the type of work undertaken. Further information regarding consultant reports may be obtained (at the consultant's discretion) by contacting the company directly.

Note that other consultants, not listed below, may also have conducted hydrogeological work in the Okanagan Basin. A full listing of engineering and geoscience consultants located in the Okanagan Basin can be obtained through the telephone directory.

- EBA Engineering Consultants Ltd. (EBA): EBA has completed local-scale pump/aquifer tests, drilling investigations, and sampling at sites within the Okanagan Basin. In addition, EBA has completed wider-area aquifer testing and analysis, groundwater resource evaluations, waste-water disposal assessments, aquifer analysis and modelling, well capacity testing, potable water testing, groundwater under the direct influence of surface water analyses (GUDI), production well design, and computer aquifer analysis.
- Golder Associates Limited (Golder): Hydrogeological work completed by Golder within the Okanagan Basin has included local-scale aquifer tests, drilling investigations, groundwater assessments, storm water disposal assessments, sewage disposal assessments and water well assessments. Golder has also completed wider-area groundwater protection and management plans and groundwater assessments. Specific wider-scale work has included the completion of groundwater assessments in the Kedleston and Spallumcheen areas, Phase I and II of the Groundwater Protection Plan for the Kelowna Joint

Water Committee, a hydrogeological assessment for BC Parks in the Kelowna area, work in the aquifers underlying Faulder and Summerland, and work consisting of groundwater assessments and groundwater protection plans for the Southern Okanagan area (Oliver and Osoyoos).

- Kala Groundwater Consulting Ltd. (Kala): Projects completed by Kala in the Okanagan Basin have included local-scale pumping tests, groundwater supply investigations (involving exploratory test drilling, well completion and safe yield evaluation), environmental assessments pertaining to on-site sewage effluent disposal, wellhead protection programs, and water quality analysis. Specific wider-scale work has included extensive groundwater supply and groundwater availability studies for the Glenmore-Ellison, South East Kelowna and Rutland Irrigation Districts. A groundwater availability study for the Osoyoos Indian Band at Osoyoos, BC, and a detailed pumping test program, in the Telicum Valley, Vernon, BC, have also been completed.
- Seacor Canada Ltd. (Seacor): Seacor has conducted hydrogeological work in the Okanagan basin. Projects have included local-scale pump/aquifer tests, drilling investigations, hydraulic conductivity testing, and water quality investigations.
- SNC Lavalin Environment Inc. (SLEI): SLEI has conducted hydrogeological work in the Okanagan Basin. These projects have included local-scale pump/aquifer tests, drilling investigations, and geochemical/contaminant assessments as well as wider-area groundwater use surveys.
- Summit Environmental Consultants Ltd. (Summit): Hydrogeological projects completed by Summit in the Okanagan Basin have included local-scale aquifer tests, drilling investigations, investigations on ground discharge of treated wastewater effluent, and investigations for subsurface disposal of storm water. Hydrogeological studies for larger groundwater development and management projects have included work for the Town of Oliver, Okanagan Falls Irrigation District, Willowbrook Utilities (near Okanagan Falls), the Regal Ridge development near Osoyoos, and a multi-phase groundwater development program for the Okanagan Nation Alliance (for a proposed Salmon fish hatchery

well field in Penticton). Specific wider-scale work has included the Trepanier Landscape Unit Hydrological Study (2004) and Phase 1 of the Okanagan Basin Water Supply and Demand Study.

## 4.6 Current Research and Knowledge

At the time of preparation of this report, a number of groundwater-related research initiatives were underway throughout the Okanagan Basin. This ongoing research will provide a significant contribution to the understanding of regional hydrogeological processes within the Okanagan Basin as it addresses some of the data gaps identified through Phase 1 of the Water Supply and Demand Project (Summit, 2005).

The following sections discuss ongoing hydrogeological research being completed by universities and government in the Okanagan Basin. As the current research remains largely unpublished, much of the information provided in this section was obtained through communication with individuals involved with the projects and/or from unpublished data or reports.

### 4.6.1 Surface Water and Groundwater Modelling – BX Creek

| | |
|---|---|
| **Descriptive Name of Project:** | **Surface Water and Groundwater Modelling – BX Creek** |
| **General Project Location:** | Silver Star Mountain, NE of Vernon, BC. |
| **Mapped Aquifers in study area (BC MOE, 2007):** | 348, 349, 350 and 351 |
| **Report Title (if available):** | *Linkages between upland water sources and valley bottom aquifers in a mountainous watershed* |
| **Report Date/Status:** | Journal manuscript in preparation (expected January 2008) |
| **Report Authors/Researchers:** | B.D. Smerdon, Post Doctoral Fellow, SFU<br>D.M. Allen, Associate Professor, SFU<br>M.A. Berg, B.Sc, SFU<br>E. Belland, undergraduate assistant, SFU<br>S. Grasby, GSC |
| **Affiliated Organization(s):** | Department of Earth Sciences, Simon Fraser University. |
| **Reference Citation (Section 9):** | Smerdon et al., in preparation. |

This research project involved conceptualizing and quantifying movement of water from upland and benchland areas to the valley bottom in the BX Creek watershed (area shown on Figure 5). The study used a combination of computer models (MODFLOW®, MIKE-SHE®) and water budget calculations to estimate groundwater recharge to valley bottom aquifers (BC MOE confined aquifer 348 and the lower part of BC MOE confined aquifer 349), as well as geochemical and isotopic data from wells and surface waters.

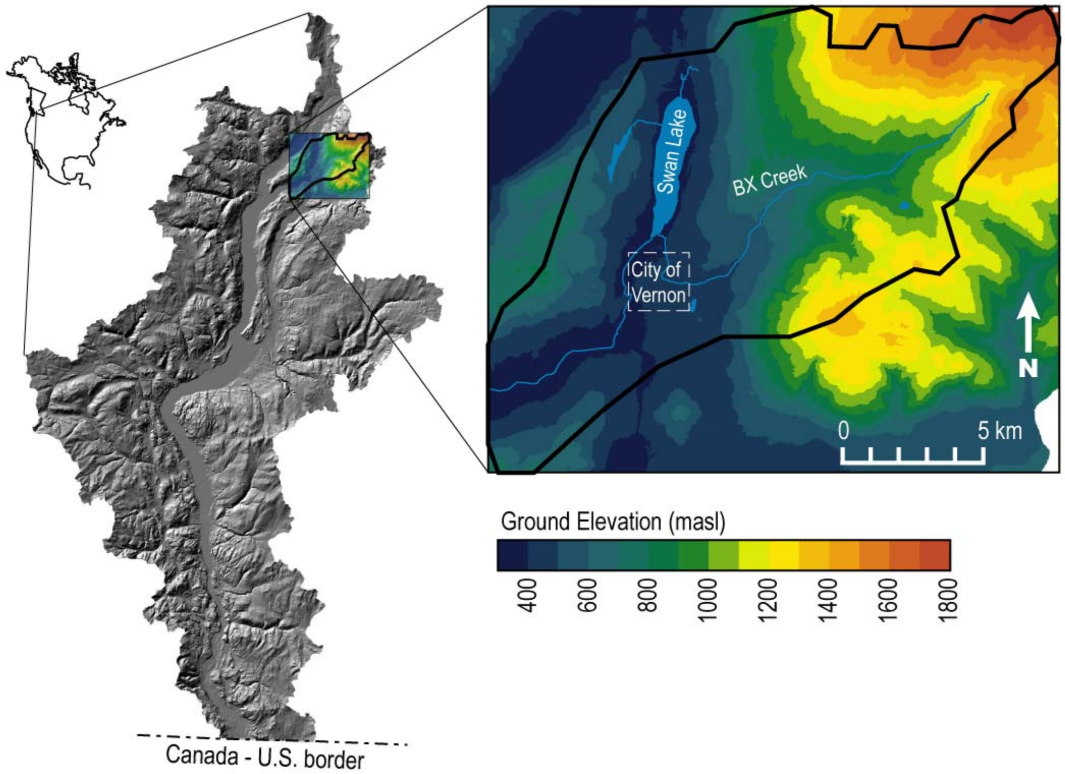



**Figure 5: Map illustrating the location of the study area for the BX Creek Surface Water and Groundwater Modelling Study (from Smerdon et al., in prep.).**

Groundwater recharge estimates were simulated with the MIKE-SHE® model for the valley bottom area, and by a simple water budget calculation for the upland area (see Figure 6a). The MIKE-SHE® model considered precipitation, evapotranspiration, overland flow, and infiltration through the unsaturated zone. Upland area water budget calculations considered seasonal precipitation, evapotranspiration, and streamflow in BX Creek.

In general, simulation results indicated groundwater recharge estimates varied from 0 to 200 mm/yr, with an average of 22 mm/yr in the valley bottom and 40 mm/yr in the upland areas. Details of the estimated spatial distribution of recharge across the study area are illustrated on Figure 6b. The recharge values provided for this report and indicated on Figure 6 are based on preliminary simulations. SFU continues to work on quantifying recharge in the BX Creek area (Liggett, in prep., see Section 4.6.13).

The spatially-distributed recharge values for the valley bottom and upland areas were combined as input to a larger-scale groundwater flow model. Steady-state groundwater flow was simulated with MODFLOW®. MODFLOW® simulations were completed to verify the groundwater recharge estimates for published values of hydraulic conductivity (based on material type) for the surficial deposits and bedrock geology of the area. The MODFLOW® model simulated steady-state hydraulic heads with 4% error (RMS), and illustrates the linkage between upland water sources and valley bottom aquifers. Groundwater flow to the valley bottom aquifers occurs across the eastern boundary and was determined to come from (a) upslope areas of a confined aquifer (upper portion of BC MOE aquifer 349), contributing 60% of the groundwater flux; and, (b) upland bedrock areas (BC MOE aquifers 350 and 351), contributing 40%. Recharge to the valley bottom aquifer is due to the combination of subsurface groundwater flux from upland areas, as illustrated in Figure 6c, and direct recharge to the valley bottom.

In general, modelling results indicated that the majority of groundwater flow to the valley bottom aquifers occurs through a relatively narrow alluvial fan aquifer extending from the upper BX Creek valley, and that BX Creek loses water as it enters the valley bottom.

Future work in the BX Creek watershed will build upon the groundwater modelling work and will involve comparison of results to water chemistry and stable isotope data. Thirty-one groundwater samples have been collected across benchland and highland areas and were analyzed for major ions and stable isotopes of oxygen and hydrogen. Preliminary results indicate that identifiable differences are observed between highland and benchland groundwater when both isotope and other geochemical data are considered.

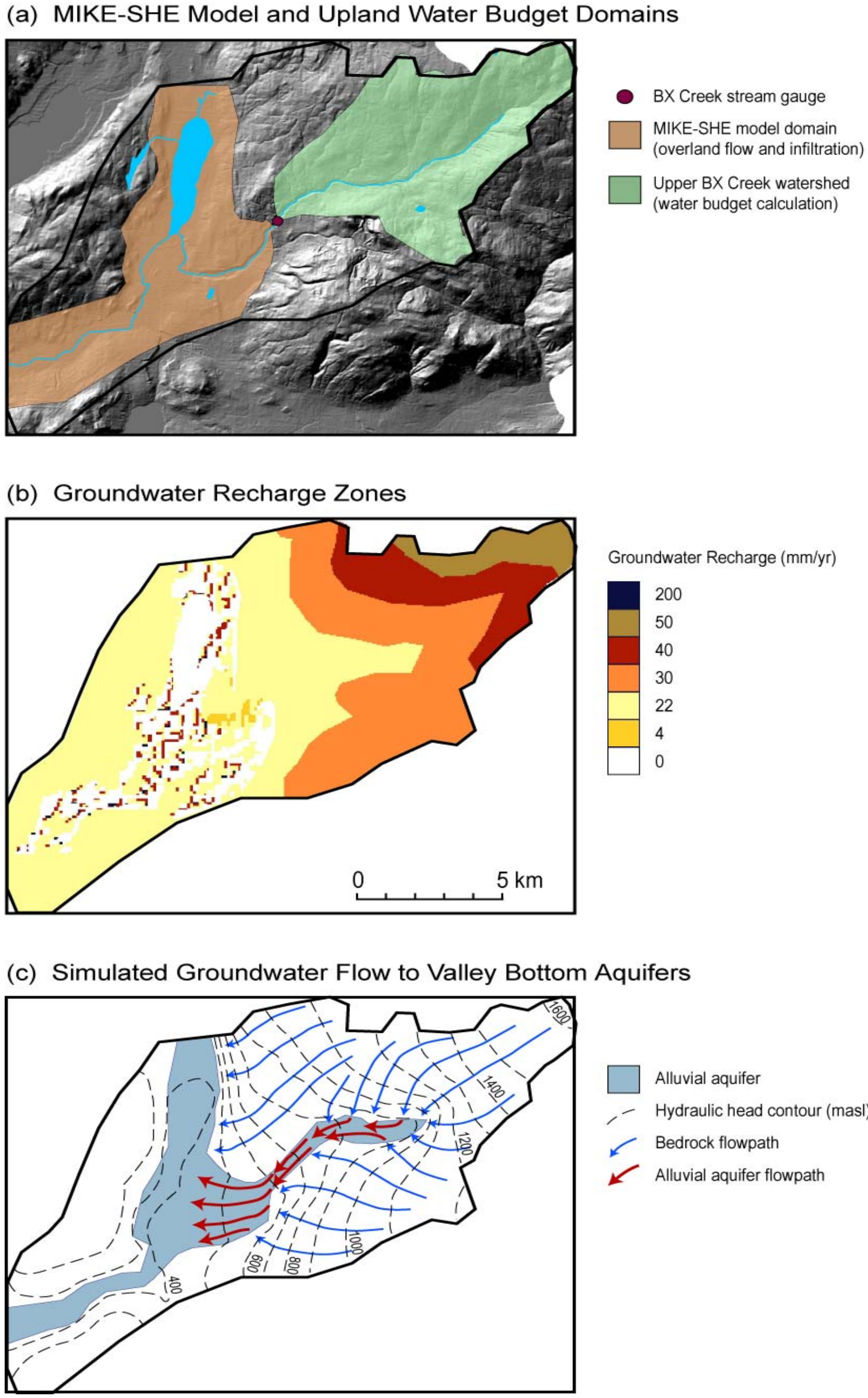



**Figure 6:** **Illustrations of model/calculation domains and results for the BX Creek Surface Water and Groundwater study. Figure 6a illustrates domain boundaries for MIKE-SHE and water balance calculations. Figure 6b illustrates the spatial distribution of groundwater recharge results. Figure 6c illustrates the MODFLOW simulated groundwater flow paths. (from Smerdon, et al., in prep.).**

### 4.6.2 North Okanagan Groundwater Characterization and Assessment Project (NOGWCA)

| | |
|---|---|
| **Descriptive Name of Project:** | **North Okanagan Groundwater Characterization and Assessment Project (NOGWCA)** |
| **General Project Location:** | North Okanagan (Vernon, Armstrong, Enderby Spallumcheen areas), Deep Creek and Fortune Creek watersheds. |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database):** | 102, 103, 104, 106, 111, 353, 354, 355, 356, and 348 (also other aquifers outside the Okanagan Basin boundaries) |
| **Report Titles (if available):** | This project involves a number of different components which will be presented as separate reports.<br>Completed Reports (see Section 4.6.3):<br>• *North Okanagan Aquifer Mapping Project*, Monahan, 2006, unpublished.<br>• *Geological Depositional Interpretations and the Impact of these on Trends in Hydraulic Properties of Identified Aquifers in the Deep Creek Drainage Basin, North Okanagan Valley*, Fulton, 2006, unpublished.<br>• *3D Aquifer Model of the Deep Creek/BX Creek Watersheds, British Columbia, Canada*, Keller, 2007, unpublished. |
| **Report Date/Status:** | Completed reports: Monahan (2006, unpub.), Fulton (2006, unpub.), Keller (2007, unpub.)<br>Other reports: In progress, expected Spring 2008. |
| **Report Authors/Researchers:** | T. Stewart, BC MOE, Water Stewardship – Okanagan<br>D. Anderson, BC MOE, Water Stewardship – Okanagan<br>Dr. C. Nichol, Dr. J. Ping, Dr. A. Wei, UBCO<br>Greg Keller, University of Manitoba<br>Dr. Patrick Monahan, Monahan Petroleum Consulting<br>Dr. Bob Fulton<br>Dr. Diana Allen (technical advisor), SFU |
| **Project Management:** | D. Anderson, BC MOE, Penticton – Project Manager<br>T. Stewart, BC MOE, Penticton – Project Coordinator |

| | |
|---|---|
| **Affiliated/Contributing Organization(s):** | BC MOE (Penticton and Victoria), City of Armstrong, Golder Associates, Natural Resources Canada, North Okanagan Regional District, Simon Fraser University (Dept. of Earth Sciences), Spallumcheen Township, UBCO (Dept. of Chemistry, Earth & Environmental Sciences) |
| **Reference Citation:** | Various unpublished reports as indicated above.<br>Stewart, T., 2007, pers. comm. or unpublished data |

The North Okanagan Groundwater Characterization and Assessment Project (NOGWCA) was initiated in April 2005 and is funded by the Canada-British Columbia Water Supply Expansion Program and the BC Ministry of Environment. The NOGWCA project was formed as part of, and is directly related to, the GAOB project (described in Section 4.1). The overall goal of the project is to provide a framework for water resources management in the Deep Creek watershed and portions of the lower Fortune Creek watershed. Originally the scope of the project included the BX Creek watershed. However, ground water modelling work in the BX Watershed has since been completed by researchers at SFU (see Section 4.6.1).

The NOGWCA project involves two main “phases” which are being completed concurrently: (a) general groundwater characterization and (b) numerical modelling. Key components of the NOGWCA project, relevant to this report and which have been initiated to date, are (T. Stewart, pers. comm., 2007):

- Aquifer characterization and depositional/stratigraphic interpretation work in the North Okanagan by Monahan (2006), Fulton (2006), and Keller (2007). These projects are discussed in Section 4.6.3 of this report.
- Groundwater modelling in the Deep Creek watershed (see Section 4.6.4) and Fortune Creek watershed (see Section 4.6.5).
- Groundwater and surface water related investigations (discussed below).

This section of the report provides a description of groundwater and surface water related work of the NOGWCA project being completed through BC MOE, Penticton. This work has involved: surveys to locate water wells, surface and ground water sampling and measurement, and aquifer tests.

A survey of irrigators was completed. The survey identified 22 irrigators using a total of 88 irrigation wells. Of the wells discovered, 17 are artesian. Forty of the identified wells have been designated as “static water level” wells and have been geodetically surveyed (as part of the NOGWCA project) for future modelling purposes. The water levels in the “static water level” wells are measured every two weeks. Five BC Ministry of Environment observation wells (numbers 122, 117, 118, 119, and 180) are also located within the study area. Water levels in observation wells may be measured more frequently.

To date, over 70 wells have be sampled for major ions, sulphate, nitrate, phosphate and general chemistry. Thirty of these wells have also been sampled for oxygen, deuterium and carbon 14 isotopes. All of the water quality data, except for the isotopic data, are available on the BC Environmental Monitoring System data warehouse (EMS) (Contact – Trina Stewart, BC MOE, Penticton).

To collect surface water data, five sites along Deep Creek, and four sites along Fortune Creek, are stream gauged every two weeks. All of the stream gauge sites have been sampled for water quality. The stream gauge sites have been geodetically surveyed for numerical modelling purposes.

The above-noted data will be used for numerical modelling and as baseline data for ongoing research (i.e., in the Deep Creek watershed study, Section 4.6.4, and the Fortune Creek watershed study, Section 4.6.5). In addition, isotopic water chemistry data will be used to assess the origin of the water from artesian wells. Various mapping outputs will be generated as a result of the modelling and data analysis. A report presenting the results of the work is expected to be available through the BC MOE by May 2008.

Data collected through the NOGWCA project will be used for the development of a Land Use Allocation Model (LUAM). This model uses land use planning software and environmental science to provide a tool useful to regional planners. GIS layers, including aquifers (Monahan, 2006, and Keller, 2007), vulnerability mapping (Liggett, 2007), septic field usage, cadastral mapping, and the Official Community Plan (OCP, NORD), are included in the model.

#### 4.6.3 North Okanagan Stratigraphy and Aquifer Mapping

| | |
|---|---|
| **Descriptive Name of Project:** | **North Okanagan Stratigraphy and Aquifer Mapping** |
| **General Project Location:** | North Okanagan (Vernon, Armstrong, Enderby Spallumcheen areas), Deep Creek Watershed. |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 102, 103, 111, 353, 354, 356, and 348.<br>(Other BC MOE mapped aquifers are also included but are not within the Okanagan Basin boundaries) |
| **Report Title (if available):** | *North Okanagan Aquifer Mapping Project*, by P.A. Monahan, 2006, unpublished report presented to Water Stewardship Division of the BC MOE.<br><br>*Geological Depositional Interpretations and the Impact of these on Trends in Hydraulic Properties of Identified Aquifers in the Deep Creek Drainage Basin*, North Okanagan Valley, Fulton, 2006, unpublished report, presented to Water Stewardship Division of the BC MOE.<br><br>*3D Aquifer Model of the Deep Creek/BX Creek Watersheds*, British Columbia, Canada, Keller, 2007, unpublished report presented to Water Stewardship Division of the BC MOE). |
| **Report Date/Status:** | Unpublished reports as noted above. |
| **Report Authors/Researchers:** | R.J. Fulton<br>G. Keller, Contractor, Winnipeg, MB<br>P.A. Monahan, Monahan Petroleum Consulting |
| **Affiliated Organization(s):** | BC MOE, Penticton Office |
| **Reference Citation (Section 9):** | Fulton, 2006, unpublished report<br>Keller, 2007, unpublished report<br>Monahan, 2006, unpublished report<br>Stewart, 2007, pers. comm. or unpublished data |

As part of the North Okanagan Groundwater Characterization and Assessment Project (NOGWCA, see Section 4.6.2), three reports were commissioned by the Water Stewardship Division of the BC MOE to develop a better understanding of stratigraphy and aquifers in the North Okanagan, Deep Creek watershed.

- A report prepared by Monahan (2006, unpublished) presents the results of detailed data analysis from borehole/well logs and seismic profiles to map the aquifer system within the study area.
- A subsequent report by Fulton (2006, unpublished) reviews the aquifer delineation work by Monahan and suggests “probable geological contexts” for the unconsolidated deposits forming the aquifers.
- Keller, 2007 (unpublished), digitized the cross section and mapping work by Monahan to develop a preliminary 3-dimensional digital model of the aquifer system.

The following text summarizes results from the above-noted reports:

Monahan (2006) developed 19 cross sections across the study area which identify bedrock depth and stratigraphic layering of different types (e.g., based on grain size, organic content, or other attributes) of unconsolidated deposits within the valley bottom. The cross sections were developed based on seismic profiles, water well records, and borehole logs. Each cross section illustrates the depths of different types of unconsolidated materials and provides an interpretation of the depths and extents of aquifers. Maps illustrating the cross section locations, aquifer areal delineations, well locations, and other information were also prepared by Monahan. At the time of preparation of this report, these cross sections and maps were available in hand-drawn format (scanned onto CD) and are not reproduced here.

Monahan identified 20 distinct aquifers or permeable units within the study area. Table 4 lists the aquifers delineated and named by Monahan (2006) with their corresponding BC MOE aquifer numbers (note some of the aquifers are located outside the boundaries of the Okanagan Basin as mapped for this project, e.g., 108, 109). Fifteen of the identified aquifers are mapped on Figure 7 (map obtained from BC MOE). Figure 7 illustrates the significant vertical aquifer overlap within the study area.

Fulton (2006) developed theories to explain the geological context and depositional environments for the unconsolidated sediments in the North Okanagan. Work completed by Fulton involved a review of the “conceptual” aquifers delineated by Monahan (2006). The aquifers are discussed in the context of the geological evolution of the Okanagan Valley Fill (unconsolidated deposits present in the Okanagan Valley).

Fulton examined information/data regarding the Okanagan Valley Fill deposits to:

- differentiate glacial from non-glacial sediments,
- provide approximate ages for the sediment units (aquifers, “permeable units”, and aquitards)
- distinguish different depositional environments, and
- assess/predict trends in grain size and aquifer dimensions which could lead to inferences of hydraulic property trends.

Some of the information obtained from Monahan (2006) and Fulton (2006) has been incorporated into the Aquifer Information Tables for the unconsolidated aquifers of the North Okanagan (Appendix II). Further details can be referenced in the cited reports.

Work to develop a preliminary 3-dimensional geological model based on the work by Monahan (2006) was completed by Keller (2007). Keller’s work involved the digitization (assisted by BC MOE, Penticton) of maps and cross sections provided by Monahan. The 3-dimensional model developed by Keller included 17 of the aquifers identified by Monahan. It was concluded in the Keller report that the preliminary 3-D model required additional data (i.e., more cross sections and a better understanding of geological context) to improve the visual representation of the system.

**Table 4: BC MOE Aquifer Numbers corresponding to Mapped Aquifers Identified by Monahan (2006).**

| BC MOE Aquifer Number | Corresponding Aquifer Named by Monahan (2006) |
|---|---|
| 102 | Hullcar Confined |
| 103 | Hullcar Unconfined |
| 108 | Tuhok Unconfined |
| 109 | Tuhok Confined A<br>Tuhok Confined B |
| 111 | Spallumcheen A<br>Spallumcheen B<br>Spallumcheen C<br>Spallumcheen D<br>Spallumcheen E |
| 353 | Eagle Rock A<br>Eagle Rock B |
| 354 | O'Keefe A<br>O'Keefe B<br>O"Keefe C |
| 356 | Sleepy Hollow A<br>Sleepy Hollow B |
| None specified | Fortune Creek Permeable Unit<br>(mapped by Monahan, 2006, to extend into Deep Cr. watershed at the east side, near Fortune Cr). |
| None specified | Deep Creek Aquifers (poorly defined aquifers north and upstream of Hullcar Valley) |
| None specified | Crossman Permeable Unit<br>(NE of Deep Creek watershed, near aquifer 109) |

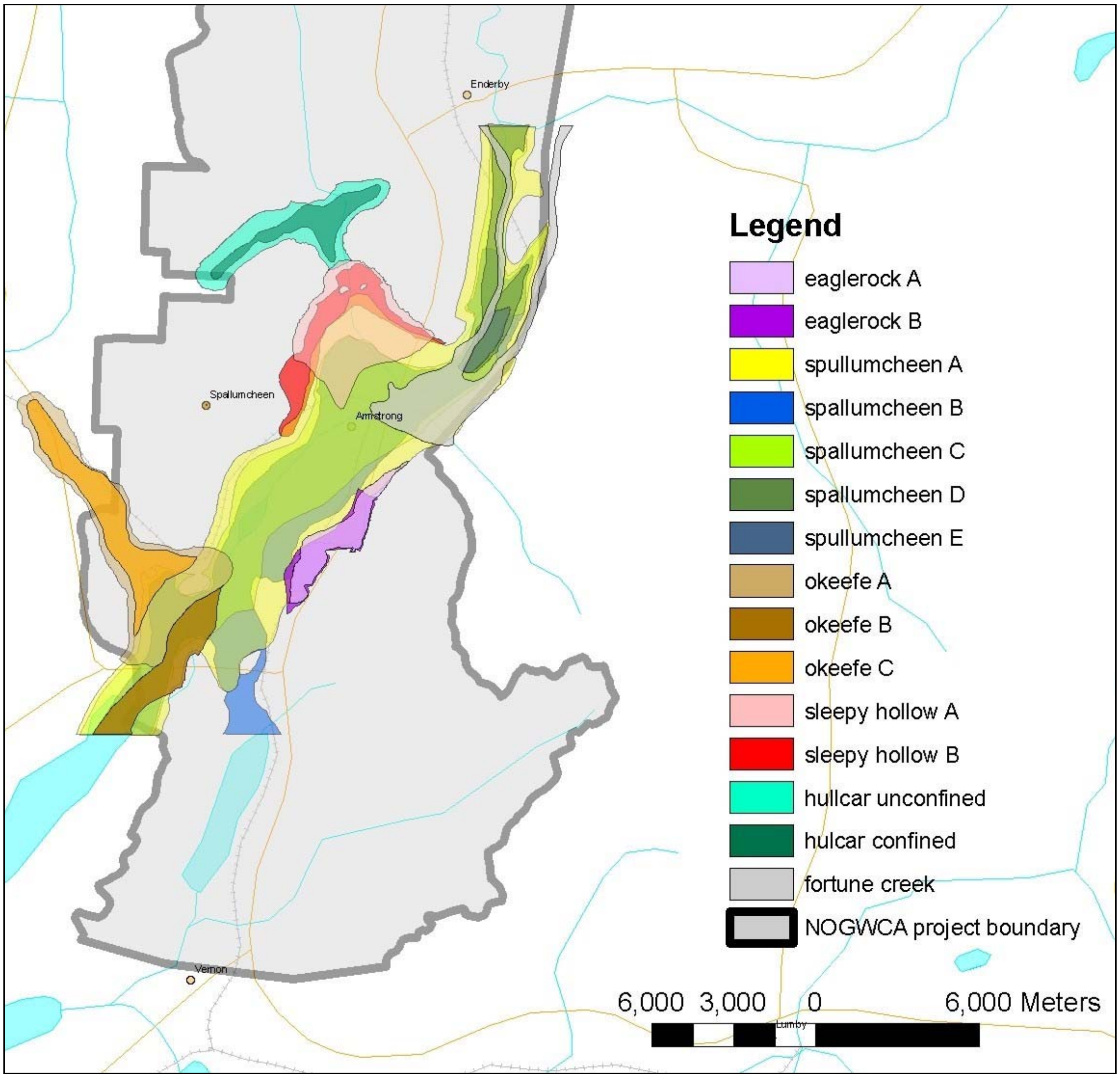



**Figure 7: Map illustrating areal extents and overlap of aquifers in the North Okanagan. Map based on work by Monahan (2006), Fulton (2006), and Stewart (2006). (map obtained from BC MOE, 2007, unpublished data).**

### 4.6.4 Groundwater Modelling – Deep Creek Watershed

| | |
|---|---|
| **Descriptive Name of Project:** | **Groundwater Modelling for the Deep Creek Watershed** |
| **General Project Location:** | Deep Creek watershed, North of Vernon, BC |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 102, 103, 104, 105, 106, 107, 111, 348, 353, 354, 355, 356 |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | Expected Spring 2008 |
| **Report Authors/Researchers:** | J. Ping, Post Doctoral Fellow, UBCO<br>A. Wei, Associate Professor, UBCO<br>C. Nichol, Assistant Professor, UBCO.<br>D. Allen, technical advisor, SFU |
| **Affiliated Organization(s):** | Department of Chemistry, Earth & Environmental Sciences, University of British Columbia Okanagan. |
| **Reference Citation (Section 9):** | Ping, Wei, and Nichol, 2007, in progress<br>Ping, 2007, (unpublished data)<br>Wei, 2007, (pers. comm. or unpublished data)<br>Nichol, 2007, (pers. comm. or unpublished data) |

This Deep Creek watershed modelling study is being completed by UBCO as part of the larger North Okanagan Groundwater Characterization and Assessment (NOGWCA) Project (see Section 4.6.2). The Deep Creek watershed area is shown on Figure 8.

This UBCO study involves developing a groundwater flow model for the Deep Creek watershed and verifying/calibrating the model using geochemical data, streamflow measurements, and water level data. The conceptual hydrogeological model will make use of detailed 3-dimensional geological and aquifer characterization work by Monahan, 2006, and further 3-D geological modelling in GoCad® by Keller, 2007 (this work by Monahan, 2006 and Keller, 2007, is reviewed in Section 4.6.3 of this report). The conceptual model will be developed based on this geological/aquifer information as well as groundwater recharge and discharge data. Model development will also be aided by an analysis of geochemical and isotopic data from groundwater and surface water.

A mixing cell model (MCM) will be applied to trace groundwater flow pathways, as well as identify areas where aquifers are in hydraulic communication with other aquifers or surface water. Ultimately, the numerical hydrogeological model will be solved using the computer code FEFLOW®. Model simulations will be carried out for existing conditions and for future scenarios as deemed appropriate by the final level of data certainty. FEFLOW® modelling is anticipated to be completed in Spring 2008.

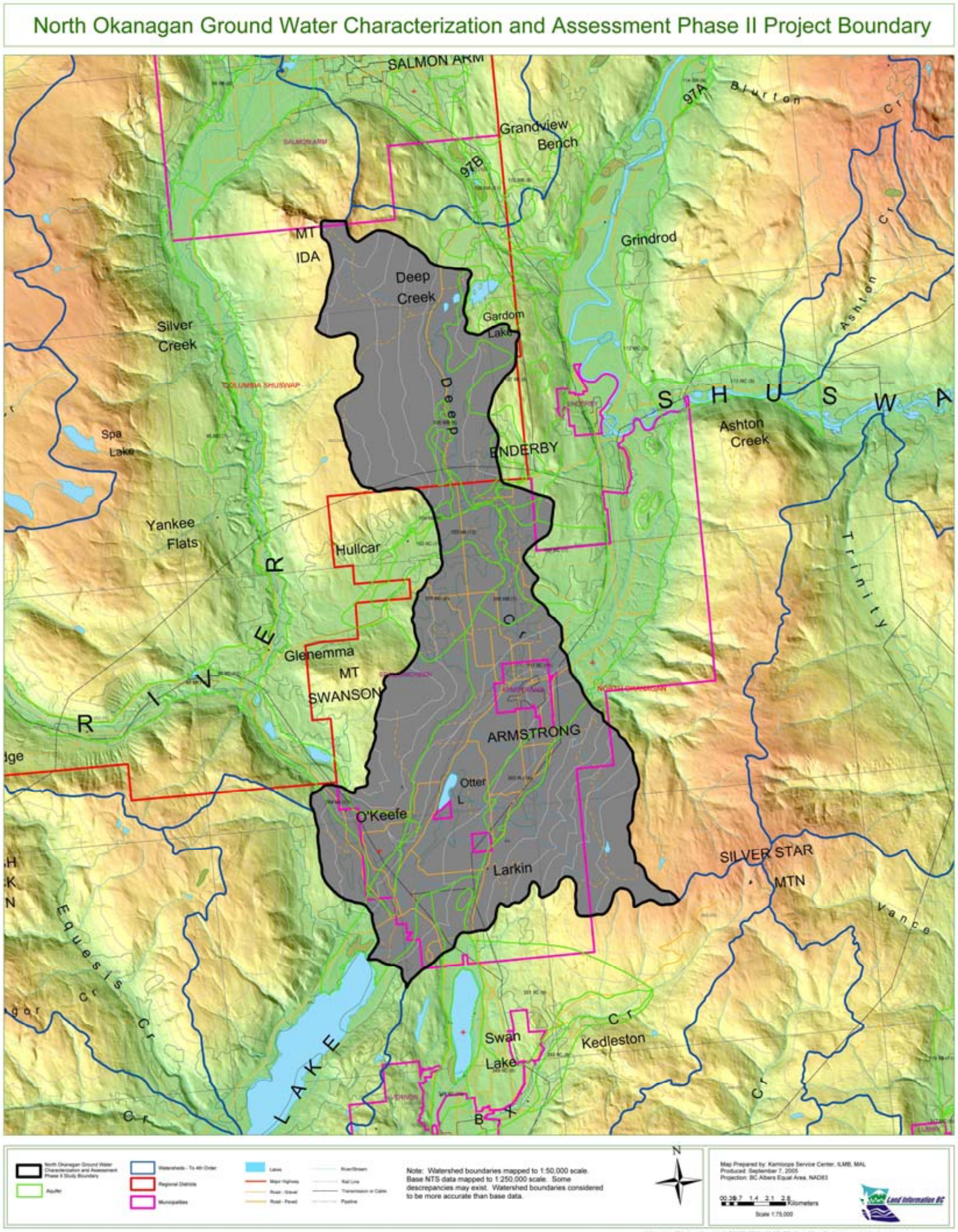



**Figure 8: Map showing area of Deep Creek watershed (from Nichol, 2007, unpublished data).**

#### 4.6.5 Groundwater and Fish Habitat Study – Fortune Creek Watershed

| | |
|---|---|
| **Descriptive Name of Project:** | **Groundwater and Fish Habitat Study – Fortune Creek Watershed** |
| **General Project Location:** | Northeast of Okanagan Basin, NE of Armstrong and East of Enderby. |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 111, 106, 107<br>(Identified aquifers are those within the Okanagan Basin that are reported to extend into the Fortune Creek watershed. Other mapped aquifers are also present within the Fortune Creek watershed). |
| **Report Title (if available):** | Scoping Report to Pacific Salmon Foundation (Report 1) |
| **Report Date/Status:** | Report 1 - Scoping Report to Pacific Salmon Foundation – April 2007.<br><br>Report 2 - In progress, expected 2010. |
| **Report Authors/Researchers:** | E. Jochum, MSc. Candidate, UBCO (Report 2)<br>C. Nichol, Assistant Professor, UBCO (Reports 1 and 2)<br>T. Seebacher, MSc., Research Assistant, UBCO (Report 1)<br>A. Wei, Associate Professor, UBCO (Reports 1 and 2) |
| **Affiliated Organization(s):** | Department of Chemistry, Earth & Environmental Sciences, University of British Columbia, Okanagan |
| **Reference Citation (Section 9):** | Nichol, 2007, (pers. comm. or unpublished data)<br>Jochum, et al., 2007 |

The Fortune Creek Watershed (area shown on Figure 9 is outside the surface water boundaries of the Okanagan Basin, but hydrogeological data indicate that groundwater within the Fortune Creek Watershed moves into the Okanagan Basin (i.e., into the Deep Creek Watershed). As such, an overview of research work being completed in the Fortune Creek area has been presented in this report.

The research was initiated in 2006, in response to fisheries concerns within Fortune Creek, which flows into the Shuswap River. To date, a scoping study (January to April, 2007) presented a literature review, water sampling, and stream flow measurements.

Future components of this research will include: detailed groundwater and surface water sampling (in fall 2007 and spring 2008), geophysical measurements, and examination of surface water – groundwater interactions using methods such as forward looking infra-red imaging (expected completion in 2008). The interactions of the Fortune Creek and Deep Creek aquifers will be further investigated as part of the NOGWCA Deep Creek aquifer modelling (see Section 4.6.2).

Selected significant preliminary results of the Fortune Creek watershed research are outlined below:

- Stream flow measurements indicate that Fortune Creek consistently loses water to groundwater along its flow path from where it first flows onto the valley floor on a debris fan. Then, further downstream, the creek begins to re-gain some of this water from groundwater.
- Geochemical analysis and measured water levels indicate that the two aquifers known as Spallumcheen A (BC Aquifer 111, shallow confined) and Spallumcheen B (also currently identified as BC Aquifer 111, deeper confined) are hydraulically connected (i.e., groundwater flows vertically between the two aquifers). These two aquifers are interpreted to extend across both the Fortune Creek and Deep Creek Watershed areas.
- Water level data indicate lateral groundwater flow between the Fortune Creek and Deep Creek watersheds. A preliminary estimate from streamflow data suggests that at times, 30% of the streamflow within Fortune Creek (located outside the Okanagan Basin) enters the Okanagan Basin as groundwater (i.e., through the aquifer system).
- After the spring freshet until the end of the irrigation season in the fall, the stream loses water along its length.

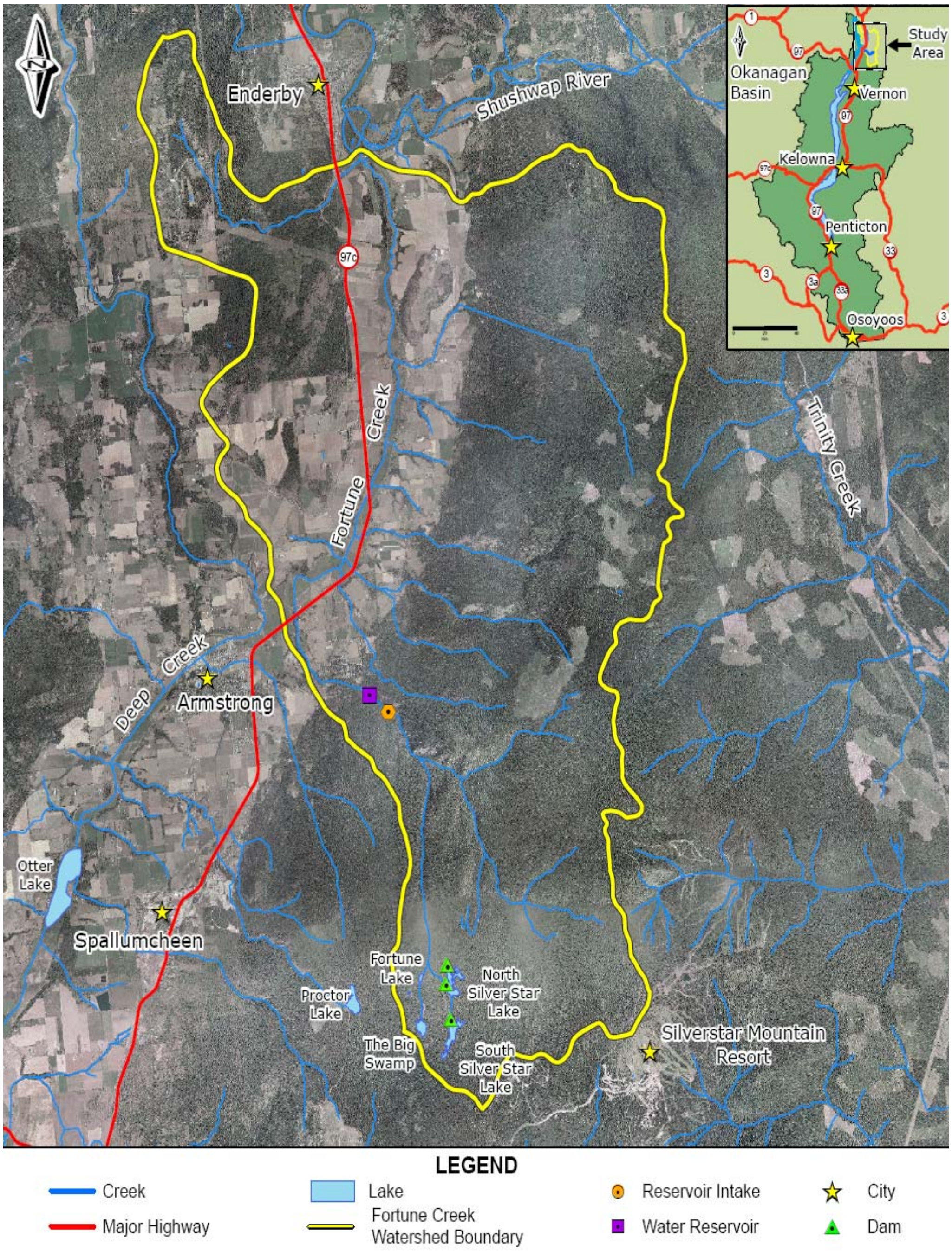



**Figure 9: Map showing boundaries of the Fortune Creek Watershed study area (from Nichol, 2007, unpublished data).**

### 4.6.6 Surface-Groundwater Interactions – Okanagan Basin

| | |
|---|---|
| **Descriptive Name of Project:** | **Surface Water - Groundwater Interactions and the Functioning of Aquatic Ecosystems:**<br>**a) Surface water and groundwater interactions in alluvial fan deposits: Okanagan Basin**<br>**b) Effects of surface water and groundwater interactions on salmon spawning and rearing habitat: Okanagan River north of Oliver, BC** |
| **General Project Location:** | a) Upper Vernon Creek (north), Shorts Creek (central), Vaseux Creek (south).<br><br>b) Okanagan River north of Oliver, BC and south of McIntyre Dam/Vaseux Lake – natural and setback sections of the river. |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | a) Vernon Creek – 344, Shorts Creek – 358, Vaseux Creek – 255<br><br>b) Okanagan River north of Oliver – 255 |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | PhD. Thesis, In preparation (expected 2010) |
| **Report Authors/Researchers:** | N. Neumann (PhD candidate), P.J. Curtis and A. Wei, UBCO<br>D. Allen, SFU<br>H. Wright, Okanagan Nation Alliance |
| **Affiliated Organization(s):** | Department of Chemistry, Earth & Environmental Sciences, University of British Columbia Okanagan.<br><br>Department of Earth Sciences, Simon Fraser University<br><br>Fisheries Department, Okanagan Nation Alliance |
| **Reference Citation (Section 9):** | N. Neumann, 2007, pers. comm. or unpublished data |

As indicated above, two separate studies are underway through UBCO which involve surface and groundwater interaction within the Okanagan Basin. These are described below (information provided by Neumann, pers. comm.).

a) Surface water and groundwater interactions in alluvial fan deposits: Okanagan Basin.

This ongoing research involves the study of surface water and groundwater interactions at three locations within the Okanagan Basin where surface water (from creeks) flows across alluvial fan deposits at the valley margins. Areas investigated were: Upper Vernon Creek (a complex surface water – groundwater system in an area where a larger community has a high reliance on water resources), Shorts Creek (a smaller alluvial fan delta where the creek flows directly into Okanagan Lake), and Vaseux Creek (a large, coarse-grained fan where the creek is known to "dry up" in mid-summer).

Field work to date has involved stream discharge measurements at selected locations along the length of each creek to determine their losing or gaining status on the alluvial fans. Geochemical work has involved the collection of samples in the creeks, tributaries, nearby lakes, and/or local domestic wells for analysis of major ions. For each of the study areas, field data and numerical modelling will be used to assess the physical and chemical modifications that occur, both instream and downstream, through surface water – groundwater interactions.

It is anticipated that this research will contribute to developing a sound conceptual understanding of surface water – groundwater interactions in similar alluvial fan systems throughout British Columbia. It will also provide information on the contributions of groundwater recharge through streambed infiltration on fans.

b) Effects of surface water and groundwater interactions on salmon spawning and rearing habitat: Okanagan River north of Oliver, BC.

The work was initiated in response to concerns expressed by the Okanagan Nation Alliance and the Department of Fisheries and Oceans regarding Chinook spawning behaviour within the Okanagan River. This research investigates the hypothesis that localised groundwater exchange at the riverbed has implications regarding the locations where Chinook deposit their eggs. Changes to the surface water – groundwater interactions within the river bed over time may affect Chinook spawning behaviour as well as egg survival.

Data collection for this study has involved the installation of piezometers (groundwater monitoring/sampling wells) at different depths and locations in the bed of Okanagan River in areas of mapped Chinook and sockeye salmon spawning habitat. Measurements of groundwater flux (direction and magnitude) have been collected. Geochemical work has involved the collection of samples from the piezometers and the river to be analysed for major ions. Modelling work will be completed using the field measurements and incorporating other available data such as streambed sediment studies.

Complementary work is being completed separately by the Okanagan Nation Alliance. This work includes aerial thermal imaging and bed temperature monitoring to identify areas of groundwater inflow.

### 4.6.7 Geological Survey of Canada Research – Kelowna Area

| | |
|---|---|
| **Descriptive Name of Project:** | **Developing a 3-D Geological Model for the Kelowna Area.** |
| **General Project Location:** | Kelowna Area and Westside |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473 (Kelowna and Mission Cr.)<br><br>301, 302, 303, 304, 305, 306 (Westside) |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | In preparation, expected completion fall 2008. |
| **Report Authors/Researchers:** | S. Grasby, GSC, Calgary<br>S. Paradis, GSC, Quebec<br>C. Deblonde, GSC, Calgary |
| **Affiliated Organization(s):** | Geological Survey of Canada (GSC) |
| **Reference Citation (Section 9):** | S. Grasby, (2007) pers. comm. |

A 3-D geological model will be developed for the Kelowna area (possibly including both the east and west sides of Okanagan Lake). The model will incorporate geological information obtained from an 80 m deep well recently drilled in the Mission Creek area. Samples of sediment core obtained during the drilling of this well will be analyzed to obtain age dates to assist in the stratigraphic interpretation for the area. The geological model will also incorporate data from proposed seismic surveys (expected to be completed in 2008), and updated surficial and bedrock geology mapping information (see Section 4.2.5).

To develop the 3-D model, all newly collected/compiled geological information will be combined with lithology information from existing well records (BC Wells database) to create a series of geologic cross sections. The cross sections will be digitized using SVM (support vector machine). The cross sections will then be combined and compiled to develop a 3-D geologic model illustrating stratigraphic layers. The model will be digitized to allow for 3-D visualization. The 3-D model is expected to be available by fall 2008.

Future work will involve developing an improved understanding of the characteristics, and vertical and lateral extents, of aquifers within the study area. This work will involve the use of groundwater chemistry data collected by the GSC from 63 wells. A 3-dimensional groundwater flow model of the Kelowna area will be developed by SFU beginning in 2008; using the GSC geologic model as a framework. Section 4.6.8 describes that upcoming project in more detail.

Updates to the mapped aquifers (BC Aquifer Classification Database) may be made based on the new geological model and/or future hydrogeological research in the area.

### 4.6.8 Groundwater –Surface Water Modelling – Kelowna Area

| | |
|---|---|
| **Descriptive Name of Project:** | **Developing a 3-D Groundwater Model for the Kelowna Area including Mission Creek.** |
| **General Project Location:** | Kelowna Area and Mission Creek |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473 (Kelowna and Mission Cr.) |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | N/A, project to be initiated in January 2008. |
| **Report Authors/Researchers:** | D. Allen, and M. Jodrey (M.Sc. student), SFU |
| **Affiliated Organization(s):** | Department of Earth Sciences, SFU<br>Geological Survey of Canada (GSC) |
| **Reference Citation (Section 9):** | Allen, D., 2007, pers. comm. |

A 3-D groundwater flow model will be developed for the Kelowna area; including the Mission Creek valley. The model will incorporate geological information obtained from Geological Survey of Canada research as described in Section 4.6.7 (above), as well as other available data/reports for the Kelowna area

This research is in a very preliminary stage. The current scope of work includes developing a 3-D groundwater flow model that encompasses Mission Creek, and using that model, not only to investigate groundwater flow within the watershed, but also to investigate the thermal characteristics of the area. The Kelowna area is experiencing significant growth in the installation of geothermal systems, and these systems have the potential not only to interfere with each other, but also to thermally pollute nearby streams if warmer (or colder) groundwater discharges to them.

The model will be constructed using FEFLOW®, which is capable of simulating both groundwater flow and heat transport. To provide additional data to this model, temperature sensors may be placed in stream sediments at various locations along Mission Creek (and other smaller creeks).

### 4.6.9 Groundwater – Surface Water Modelling – Okanagan Basin

| | |
|---|---|
| **Descriptive Name of Project:** | **Hydrogeological Research – Okanagan Basin (to be defined)** |
| **General Project Location:** | Okanagan Basin |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | To be determined |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | N/A, project to be initiated in January 2008. |
| **Report Authors/Researchers:** | L. Neilson-Welch (PhD candidate), and D. Allen, SFU<br>C. Nichol, UBCO<br>R. Allard, Golder |
| **Affiliated Organization(s):** | Department of Earth Sciences, SFU<br>Golder Associates |
| **Reference Citation (Section 9):** | Neilson-Welch, 2007, pers. comm.<br>Allen, 2007, pers. comm. |

The study will involve a basin-wide approach to quantifying the potential contributions of groundwater from upland catchments. The research will be undertaken by L. Neilson-Welch (SFU) and will encompass the development of a conceptual model for groundwater flow in mountainous areas. Conceptual model development will be supported through detailed modelling case studies in several catchments throughout Okanagan Basin. Model development will be aided by geochemical and stable isotopic analysis to determine potential sources to groundwater recharge from uplands, streams, and valley bottom. Numerical models (e.g., MIKESHE® and/or FEFLOW®) will be developed to explore groundwater recharge and interaction with surface water from upland catchments to the valley bottom. The research will serve to advance our understanding of mountainous watersheds, advance modelling approaches in such watersheds, and support local efforts to quantify the basin water balance components.

#### 4.6.10 Stratigraphy and Geological History – North Kelowna

| | |
|---|---|
| **Descriptive Name of Project:** | **Stratigraphy and Quaternary Geological History, Kelowna** |
| **General Project Location:** | North Kelowna, near UBCO Campus |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 463, 464, 469, 470, 472 |
| **Report Title (if available):** | Hydrogeostratigraphy of a Quaternary Valley-fill Sequence, Central Okanagan Valley, British Columbia (In preparation) |
| **Report Date/Status:** | In preparation, expected completion 2008. |
| **Report Authors/Researchers:** | Skye Thomson, MSc. Student, UBCO<br>Robert Young, Associate Professor, UBCO |
| **Affiliated Organization(s):** | UBC Okanagan, Earth and Environmental Sciences Program |
| **Reference Citation (Section 9):** | Thomson, 2007, pers. comm.<br>Young, 2007, pers. comm. |

The Quaternary stratigraphic and geological history of the Okanagan Valley is incomplete and requires further assessment. Existing information is based on limited geologic exposures, borehole information and isolated geophysical surveying. This research project will re-evaluate the valley-fill architecture of a north-south trending tributary valley to the main Okanagan trench, near the UBCO campus and Kelowna airport.

The study area comprises approximately a 5 $km^2$ area adjacent to the UBCO campus. The proposed research involves the development of a series of geologic cross sections for the study area through lithologic, geophysical and biostratigraphic correlations. High resolution seismic reflection surveying (proposed for the study area), in conjunction with known borehole lithologies, will allow for a better understanding of post-glacial depositional environments. It is anticipated that this research will contribute to the identification and delineation of aquifer units in the area.

Research is based on the following:

- Observations of core from several privately owned waterwells and other boreholes recently drilled within the study area.
- Additional borehole data from the MOE Groundwater Database and GSC Reports.
- Shallow high resolution seismic profiles (will be completed in the study area to provide geologic data to approximately 100 m depth).

A total of two cross sections are being developed for the study area (north-south and east-west trending profiles). Once the cross sections are developed they will be used to assess the geological context of the deposits, enhance aquifer description, and contribute to our understanding of Cordilleran paleohydrology and deglaciation.

#### 4.6.11 Mountain Block Recharge Through Fractured Rock– Upper Penticton Creek

| | |
|---|---|
| **Descriptive Name of Project:** | **Investigation of mountain block recharge through a fractured mountainous bedrock aquifer** |
| **General Project Location:** | Upper Penticton Creek, Naramata and Penticton Creek Watersheds |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 298 |
| **Report Title (if available):** | Estimating Groundwater Recharge to a Headwater Catchment as a Basis for Mountain Block Recharge (MBR) Modelling: An Integrated Surface Water – Groundwater Modelling Study. |
| **Report Date/Status:** | Ph.D. Thesis, In progress. |
| **Report Authors/Researchers:** | H. Voeckler, PhD Student, SFU<br>D. Allen, Associate Professor, SFU<br>Y. Alila, Associate Professor, UBC<br>M. Journeay, GSC |
| **Affiliated Organization(s):** | Department of Earth Sciences, Simon Fraser University.<br>Department of Forestry, University of British Columbia<br>Geological Survey of Canada |
| **Reference Citation (Section 9):** | Voeckler (2007), pers. comm. or unpublished data |

In a mountainous watershed (such as the Okanagan Basin), recharge to valley bottom aquifers (i.e., confined or unconfined aquifers within the unconsolidated materials), occurs at the valley margins from stream channels (called mountain front recharge - MFR) and in the subsurface through the bedrock of the surrounding mountains. Recharge to aquifers which comes through the bedrock of the surrounding mountains is referred to as Mountain Block Recharge (MBR) (see Figure 10). The contribution (i.e., quantification) of MBR to valley bottom aquifers of the Okanagan Basin has not been estimated to date.

Research through SFU and UBC by Voeckler (in progress) will investigate surface hydrology and hydrogeology in a small headwater catchment (UPC 241) of the Penticton Creek 1st order watershed (Figure 11). A surface water model will be developed using DHSVM (distributed hydrology soil vegetation model, Washington State University), and will estimate loss of water to the deep bedrock (i.e., bedrock recharge) using estimates of bedrock permeability derived from a detailed fracture mapping and parameter estimation (i.e., permeability) modelling. The spatial recharge results will be used as input data for a groundwater simulation of the UPC 241 headwater catchment. Once a reasonable groundwater flow field is generated, the results (e.g., adjusted bedrock permeabilities and recharge) will be used for the construction of a regional groundwater flow model from the upland to valley bottom for estimating Mountain Block Recharge to the Okanagan Basin.

Some specific objectives of this research are (Voeckler, 2007, pers. comm.):

- Characterize the fractured bedrock using field measurements of fracture location, orientation, and properties (e.g., persistence, aperture) within the Naramata and Penticton Watersheds;
- Compute estimates of bulk permeability of the fractured bedrock using a discrete fracture network (DFN) model, which involves statistical generation of fracture networks and subsequent flow modelling using the fracture field data;
- Investigate scale effects on bedrock permeability by comparing outcrop measured fractures to lineament mapping data (available from the GSC, see section 4.2.5), remote sensing data, and GIS data;
- Develop and calibrate a local-scale surface water model for the alpine headwater catchment UPC 241;
- Estimate groundwater recharge to the bedrock through the surface water modelling study;

- Develop and calibrate a local-scale groundwater model for the alpine headwater catchment UPC 241;
- Develop a regional-scale groundwater flow model;
- Estimate MBR to the Okanagan Basin;
- Investigate impacts of logging on groundwater recharge, as the UPC 241 watershed is currently 50% logged.

As part of this study, three bedrock wells were drilled in the UPC 241 watershed in July 2007. Two wells are situated in the upper watershed (one 30m deep and one 50 m deep), and one is situated at the base of the watershed (30 m deep). The wells are currently instrumented with pressure transducers and dataloggers. One well will be converted to a BC MOE provincial observation well. The wells will be logged using geophysical probes, and hydraulically tested in summer 2008.

Groundwater levels, chemistry and isotope samples have been collected from these three bedrock wells, in addition to shallow soil piezometers located along transects in the watershed. An additional shallow piezometer transect is planned.

Selected significant preliminary results are (from Voeckler, 2007, pers. comm.):

- Results to date indicate that both larger faults/lineaments and smaller matrix fractures contribute to bedrock permeability.
- Preliminary estimates indicate bedrock hydraulic conductivity on a local scale (e.g., due to smaller fractures in the rock matrix) is in the order of $10^{-6}$ to $10^{-7}$ m/s.
- Bedrock hydraulic conductivity in the study area is higher in the North-South direction which may correspond to the trend of major lineaments/faults in the area.
- Hydraulic conductivity due to larger lineaments/faults is in the order of $10^{-4}$ m/s.

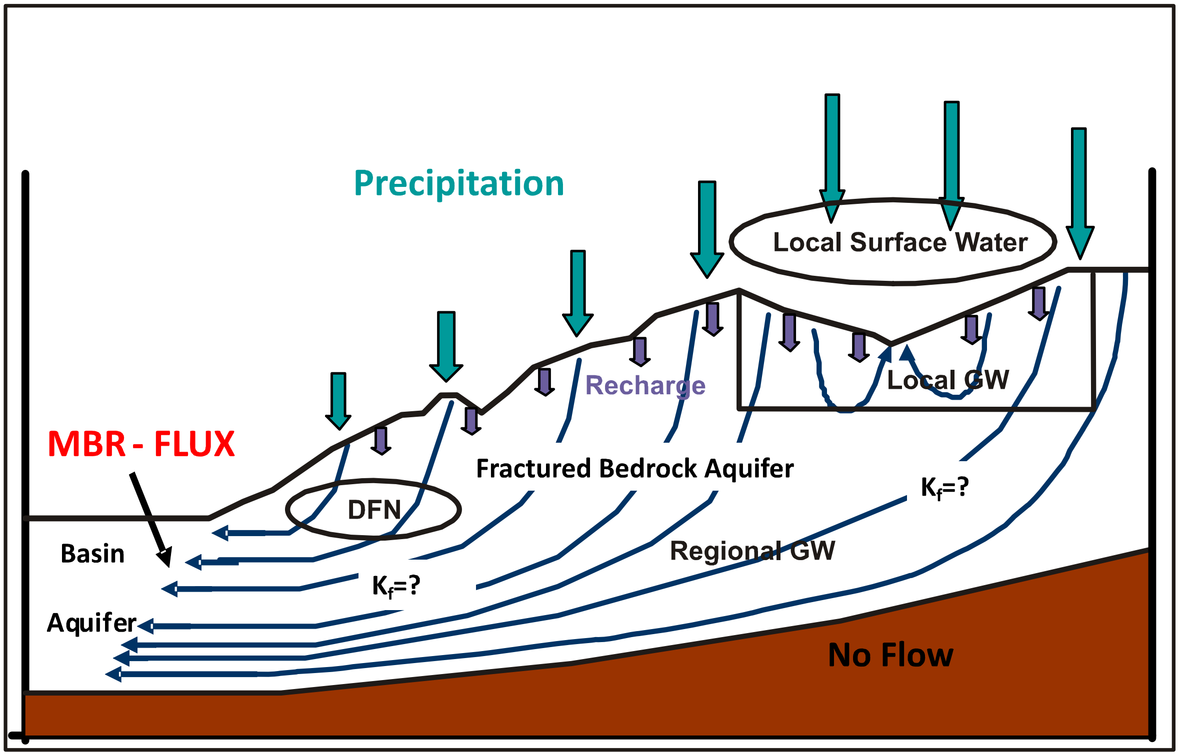



**Figure 10: Cross section showing the groundwater flow and Mountain Block Recharge (MBR) entering into the basin aquifer (from Voeckler, unpublished data).**

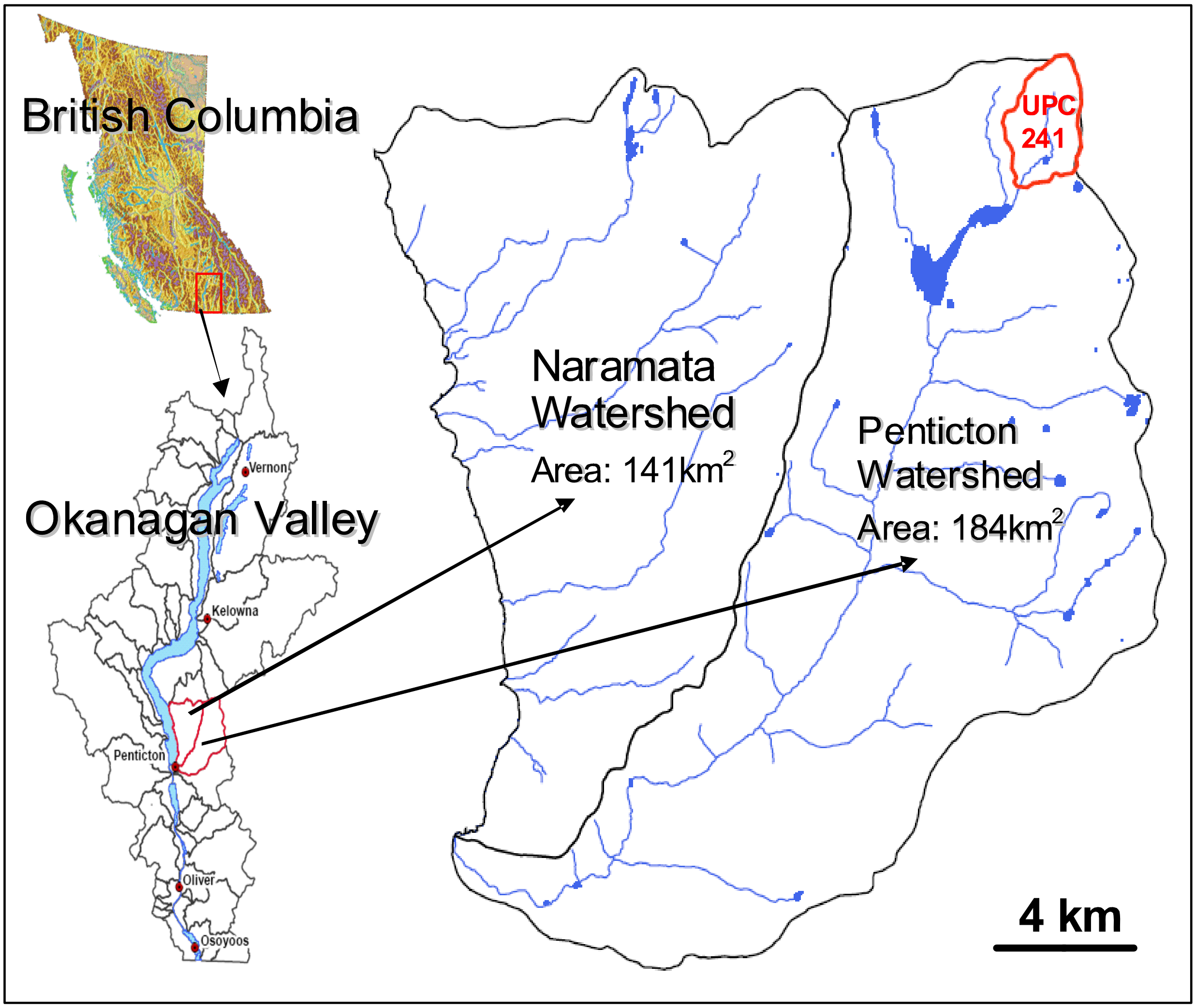



**Figure 11: Map showing study area for work by Voeckler.**

#### 4.6.12 Aquifer Vulnerability Mapping

| | |
|---|---|
| **Descriptive Name of Project:** | **Aquifer Vulnerability Mapping and Land Use Planning** |
| **General Project Location:** | Oliver and Vernon, BC |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 256, 254, 255, 257 |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | Preliminary vulnerability maps for Oliver and Vernon have been created and delivered to the municipal planning committees.<br>MSc. Thesis, In progress (expected Spring 2008) |
| **Report Authors/Researchers:** | J. Liggett, MSc. Student, SFU<br>D.M. Allen, Associate Professor, SFU<br>M. Journeay, S. Denny and S. Talwar, Geological Survey of Canada |
| **Affiliated Organization(s):** | Department of Earth Sciences, Simon Fraser University.<br>Natural Resources Canada<br>Smart Growth on the Ground |
| **Reference Citation (Section 9):** | Liggett, 2008, pers. comm. or unpublished data. |

Aquifer vulnerability maps illustrate the spatially distributed potential for an aquifer to become impacted from ground surface contaminants. The vulnerability mapping procedure uses calculations to estimate how easily contaminants, if present at the ground surface, could percolate downward to an aquifer. Aquifer vulnerability maps can provide valuable information for municipalities (for land use planning, sustainable development, aquifer protection, and monitoring) to minimize potential impacts to groundwater resources.

Aquifer vulnerability mapping was completed for the Oliver and North Okanagan areas of the Okanagan Basin. Future aquifer vulnerability mapping has been proposed for the

Kelowna area. For each area, relative vulnerability ratings were determined using the DRASTIC vulnerability mapping method (Aller et al., 1987). The DRASTIC method assumes a contaminant at the ground surface moves conservatively downwards through the subsurface at a rate equal to water. Input parameters for the DRASTIC® model are: **D**epth to water table, net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of the vadose zone, and aquifer hydraulic **C**onductivity. Ranges within each characteristic are rated from one (low) to ten (high) based on their relative contribution to vulnerability. Each characteristic is then multiplied by a set weight, and all seven inputs are added together to produce a final relative aquifer vulnerability rating (for spatial mapping). Figure 12 provides an aquifer vulnerability map for the Oliver area.

Preliminary maps for both Oliver (between Vaseux Lake and Osoyoos Lake) and North Okanagan (Okanagan and Kalamalka Lake to Enderby) extend from the valley bottom into the upland areas. More detailed, larger-scale, mapping of the Oliver valley bottom area was subsequently completed.

The vulnerability map for electoral district C in the Oliver area was subsequently used in the Land Use Allocation Model (LUAM) that was developed by the Geological Survey of Canada as part of the Smart Growth on the Ground initiative in Oliver. The vulnerability (aquifer susceptibility) maps are included in the Concept Plan for Oliver (http://www.sgog.bc.ca/uplo/SGOGOLApp5.pdf).

The vulnerability map for the Vernon area has also been included in the Land Use Allocation Model for that area and is currently being used for land use planning.

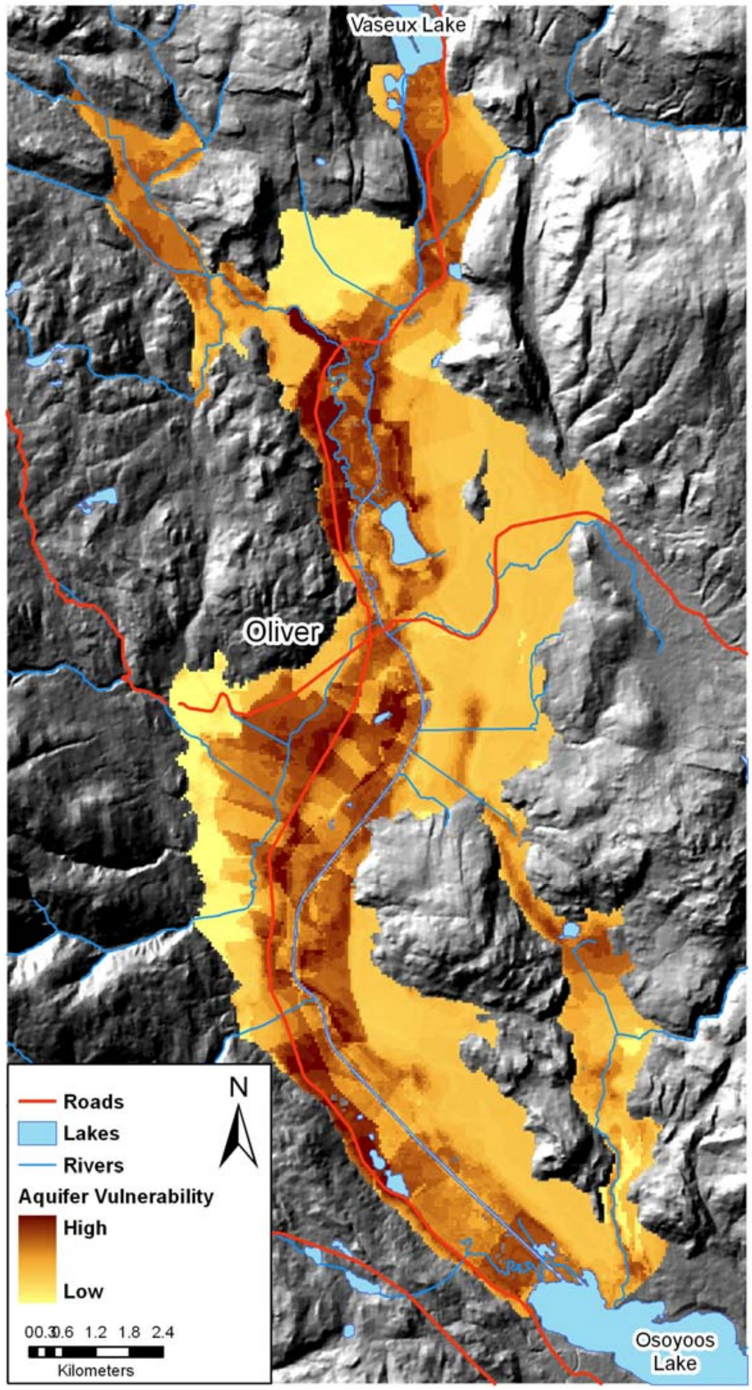



**Figure 12: Vulnerability Map created for Oliver Area (from Liggett, 2008, with permission).**

### 4.6.13 Okanagan Basin Valley Bottom Recharge Modelling

| | |
|---|---|
| **Descriptive Name of Project:** | **Okanagan Basin Valley Bottom Recharge Modelling** |
| **General Project Location:** | Okanagan Basin, valley bottom |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | All valley bottom aquifers (see Map 5, Map 6, and Map 7, Appendix I) |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | MSc. Thesis, J. Liggett, In progress (expected Spring 2008) |
| **Report Authors/Researchers:** | J. Liggett, MSc. Student, SFU<br>D.M. Allen, Associate Professor, SFU |
| **Affiliated Organization(s):** | Department of Earth Sciences, Simon Fraser University. |
| **Reference Citation (Section 9):** | Liggett, 2008, pers. comm. or unpublished data. |

Ongoing research for this project involves deriving estimates of groundwater recharge throughout most of the Okanagan Basin valley bottom (from Vernon to Osoyoos). Regional estimates of direct recharge (i.e., recharge due to the infiltration of precipitation) were obtained using the Hydrologic Evaluation of Landfill Performance (HELP) code (Schroeder et al., 1994 and Berger, 2004); a 1 D water balance code which simulates drainage (i.e., recharge) out of the bottom of a column of materials.

To develop the input parameters for the HELP® code, available information for the study area was reviewed to identify and define categories/classes of soil texture, water table depth, vadose zone material, leaf area index, and evaporative zone depth. One dimensional soil / aquifer columns were then created to represent each combination of these parameters. The HELP® code was applied to each of the representative soil columns to estimate recharge. Results of the HELP® calculations were then applied spatially over the valley bottom, corresponding to mapped areas representing the different one-dimensional columns. Results from the recharge modelling, which are anticipated to provide estimated recharge rates for unconfined valley bottom aquifers, are not currently available (anticipated in January 2008). Results will be compared with other estimates of valley bottom recharge derived independently (e.g., BX Creek MIKE SHE® modelling described in Section 4.6.1).

#### 4.6.14 Groundwater and Climate Change Modelling – Oliver Area

| | |
|---|---|
| **Descriptive Name of Project:** | **Groundwater and Climate Change Modelling** |
| **General Project Location:** | Oliver, BC |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | 254, 255, 256, 257 |
| **Report Title (if available):** | Modelling the Effects of Climate Change on Groundwater in Oliver, British Columbia (Toews, 2007, in prep.)<br><br>Aquifer Characterization, Recharge Modelling and Groundwater Flow Modelling for Well Capture Zone Analysis in the Oliver Area of the Southern Okanagan, BC. (Toews and Allen, 2007) |
| **Report Date/Status:** | As noted above. |
| **Report Authors/Researchers:** | Toews, M.T., MSc. Student, SFU<br>Allen, D.M., Associate Professor, SFU |
| **Affiliated Organization(s):** | Department of Earth Sciences, Simon Fraser University. |
| **Reference Citation (Section 9):** | Toews, 2007, in prep.<br>Toews and Allen, 2007 |

The study area for the research was located between Vaseux Lake (north end) and Osoyoos Lake (south end) and included the valley bottom and benchland areas. The Town of Oliver is located in the middle of the study area. Figure 13 shows the study area boundaries.

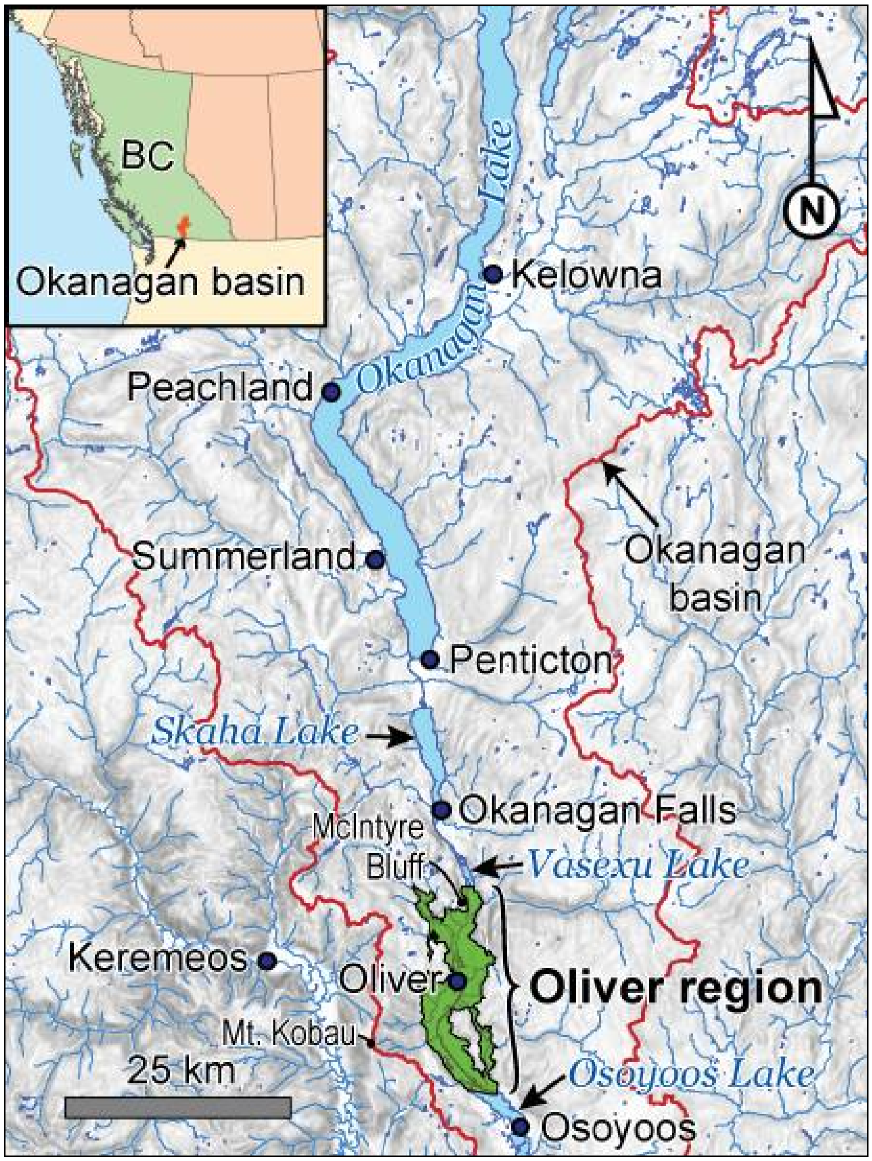



**Figure 13: Map showing the location of the study area for the Oliver region modelling (from Toews, 2007, with permission)**

The overall purpose of the research was to “quantify the impacts of climate change on recharge and groundwater resources in an arid region of British Columbia”. The following text outlines the main components of the research that provide contributions to the understanding of Okanagan Basin hydrogeology.

- **Stratigraphy and Aquifer Characterization**

  This component of the research involved a literature review and data analysis to develop a detailed understanding of the geological conditions and stratigraphy for the study area. The elevation of the bedrock surface was interpreted to range from 0 to 100 m above sea level. Overlying the bedrock, valley fill deposits are reported to consist of “Pleistocene-age glaciolacustrine silt and clay overlain by glaciofluvial sand and gravel” (Toews and Allen, 2007). Figure 14 represents a conceptual understanding of general stratigraphy across the study area. Detailed geological cross sections were developed by Toews and are reproduced here as Figure 15.

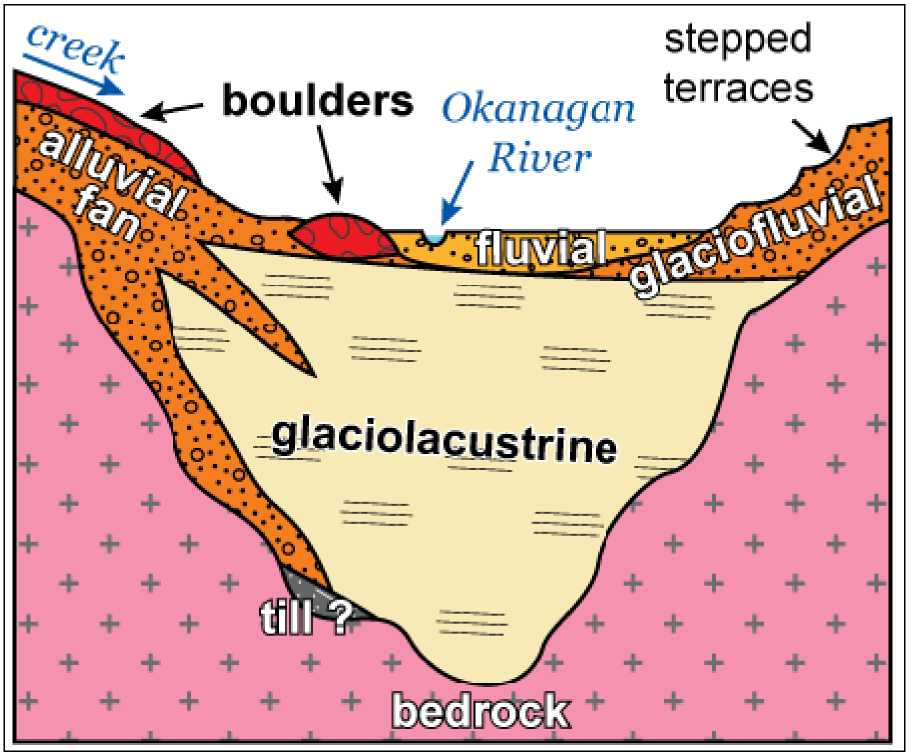



**Figure 14: Generalized stratigraphy from the Oliver study area (from Toews, 2007, with permission).**

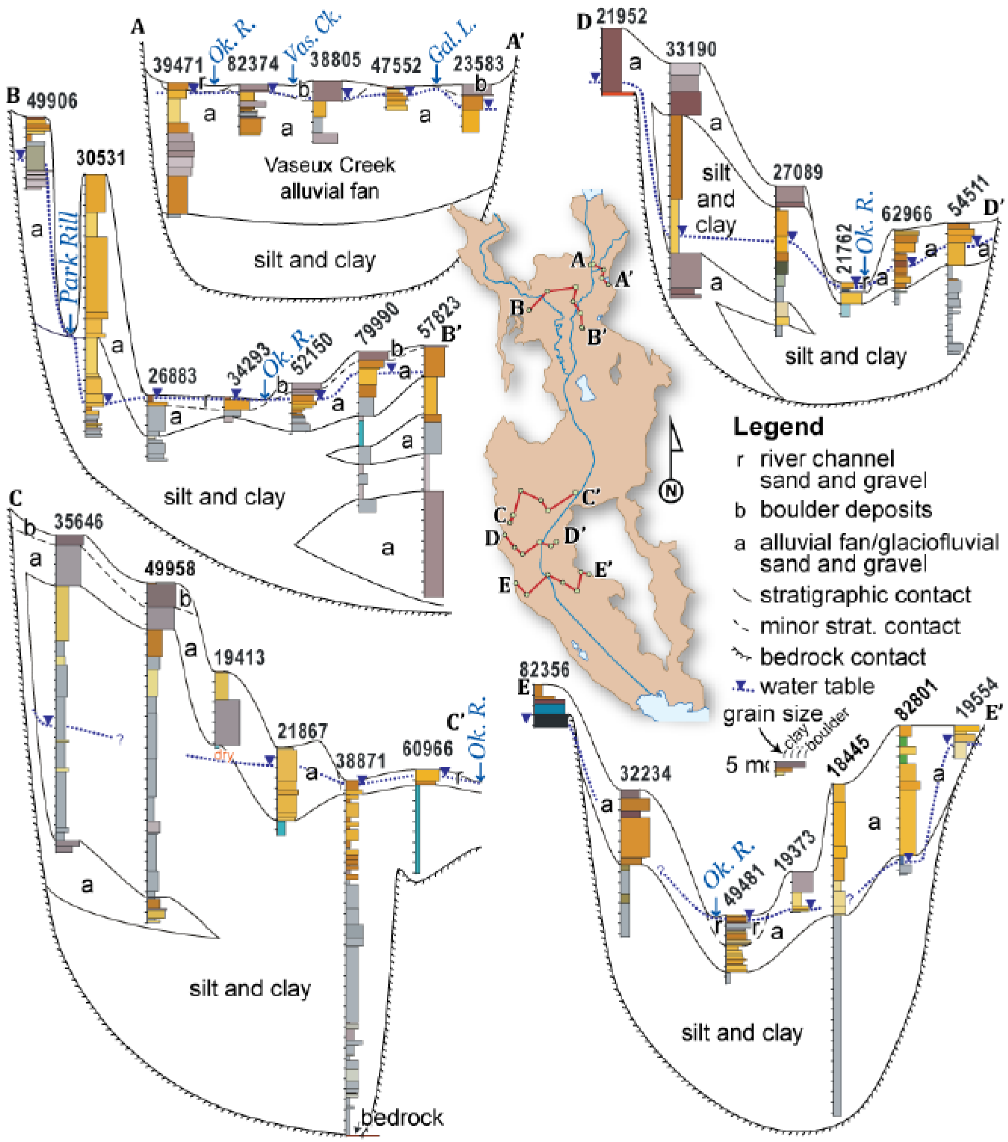



**Figure 15: Cross-Sections through the Oliver region from Toews, 2007 (with permission).**

With respect to water-bearing geological units, the aquifer delineation work completed by Toews (2007) builds upon aquifer information provided in the BC Aquifer Classification Maps database. BC MOE aquifer numbers 254, 255, 256, 257 are within the study area. In general, Toews identifies a main unconfined sand and gravel aquifer (a combination of the BC MOE aquifers) in the valley bottom; adjacent to the Okanagan River. (Figure 16 illustrates the interpreted saturated thickness of the upper sand and gravel aquifer across the study area). Deeper confined sand and gravel aquifers, comprised of alluvial fan deposits, are identified along the valley margins.

Aquifer hydraulic properties of transmissivity, aquifer thickness, hydraulic conductivity and specific yield are tabulated by Toews (2007) for eleven specific municipal wells within the study area and can be referenced in Toews (2007).

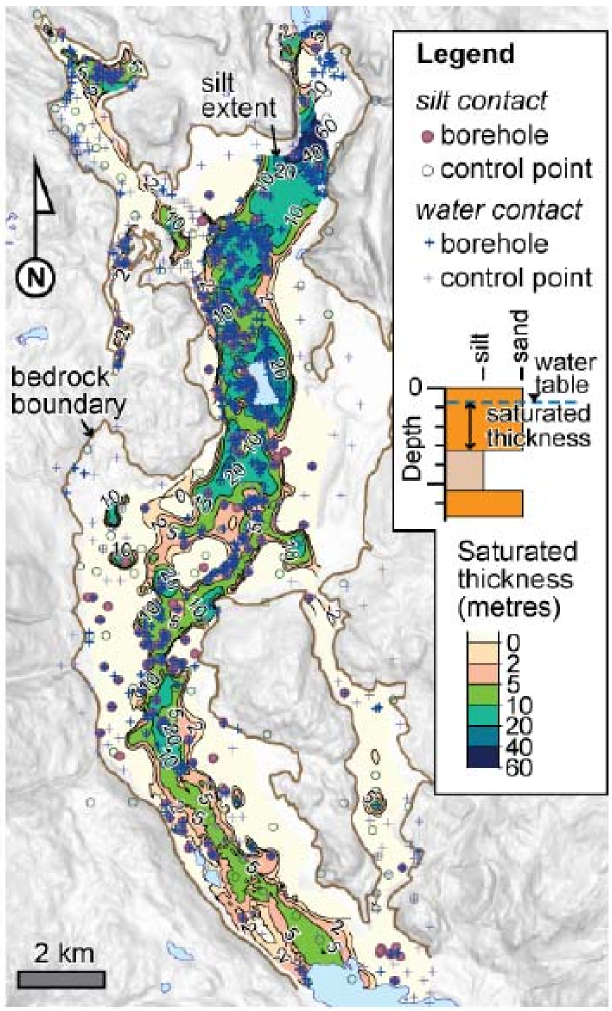



**Figure 16: Saturated thickness of upper sand and gravel aquifer in the Oliver study area, estimated by Toews, 2007.**

- **Recharge Modelling**

  The effects of local, regional, and total precipitation on recharge was estimated using the hydrology model HELP® (Hydrologic Evaluation of Landfill Performance, Schroeder et al., 1994 and Berger, 2004). This model mathematically calculates the amount of recharge through a soil column based on input parameters related to precipitation, other climate data, soil/aquifer characteristics, and ground cover characteristics.

  The results indicated that regional precipitation events had a significantly greater influence on recharge compared to smaller-scale local precipitation events. The mean annual recharge rates had a median of 45mm/yr which corresponded to approximately 20% of the annual precipitation. Figure 17 illustrates the recharge and run off results. When recharge due to irrigation was added to the calculations, net recharge in the irrigation districts ranged from 250 to 1000 mm/yr.

  The yearly variability of recharge and the influence of climate change on recharge was also investigated for the study area and involved a detailed statistical analysis of climate data. The procedures and results of this component of the research can be referenced in Toews (2007) and Toews and Allen (2007).

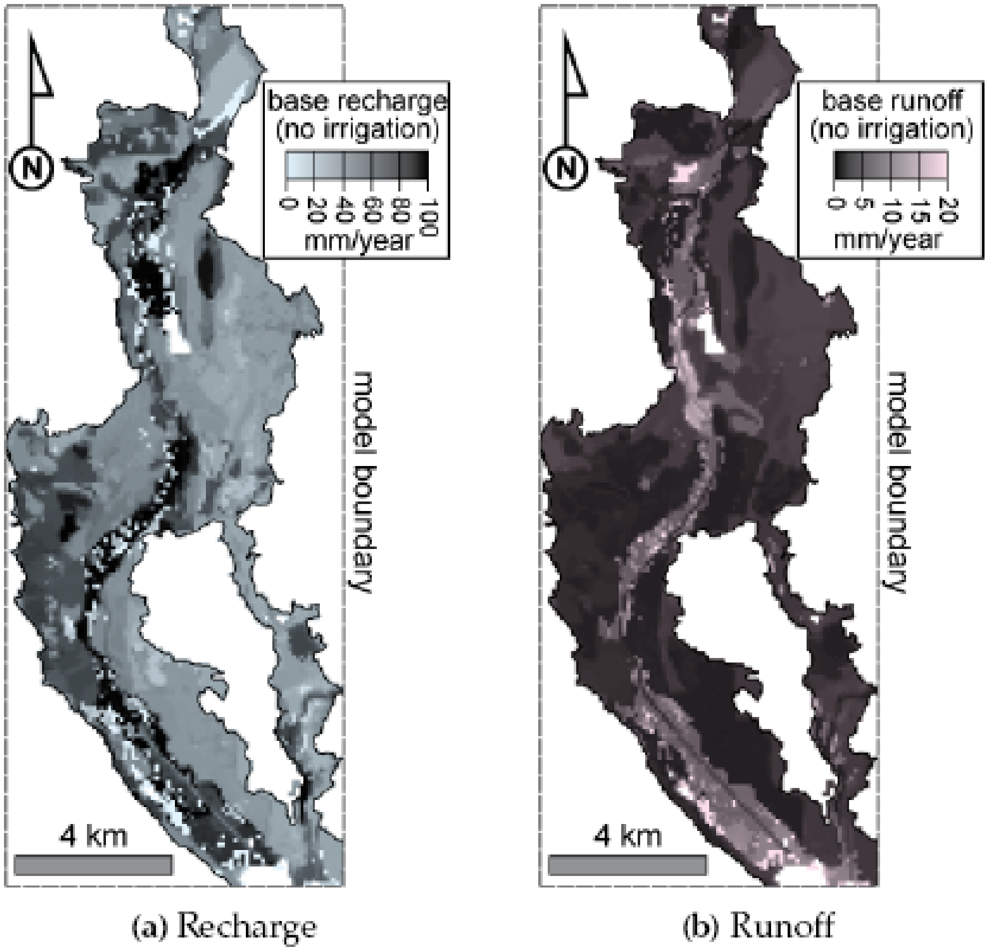



**Figure 17: "Base" mean annual recharge and runoff (without irrigation). From Toews, 2007 (with permission).**

- **Groundwater Flow Modelling**

A 3-dimensional numerical groundwater flow model was constructed and used to simulate hydrogeological conditions across the Oliver study area. Steady-state and transient simulations were completed and the results were calibrated to observed water level (hydraulic head) data. Input values for ground surface recharge were obtained through the recharge study outlined above. At the local scale, a model was developed to investigate well capture zones in for the Town of Oliver municipal wells.

The results of this modelling indicated that groundwater in the study area is significantly linked to water levels in Okanagan River and bounding lakes. The simulated water table surface ranged from 280 to 355 m a.s.l. A slight rise in water table was indicated near the benchland areas. Direct recharge to the aquifer (from precipitation), as well as recharge from irrigation return flow were indicated to be significant. Projected scenarios based on the impacts of future climate change indicated a potential rise in the median water table elevation of 17 cm (in the 2050's) and 35 cm (in the 2080's).

Well capture zones were delineated in a probabilistic fashion using the results of 30 stochastic simulations. Well capture zones for some production wells appear to coincide reasonably well with fixed radius capture zones determined previously. However, for other production wells, there are significant differences in the captures zone predicted from this study and previous fixed radius methods. The capture zones will be forwarded to the Town of Oliver for use in local planning. The fixed radius capture zones are shown on a map in the Concept Plan developed as part of the Smart Growth on the Ground initiative. (http://www.sgog.bc.ca/uplo/SGOGOLApp1.pdf).

### 4.6.15 Seismic Profiles

| | |
|---|---|
| **Descriptive Name of Project:** | **Various seismic profiles** |
| **General Project Location:** | Okanagan Basin |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | Various aquifers located along seismic profile transects. See individual reports (cited below) for specific transect locations. |
| **Report Title (if available):** | Various reports listed below |
| **Report Date/Status:** | Various as indicated below |
| **Report Authors/Researchers:** | Various as indicated below |
| **Affiliated Organization(s):** | Various as indicated below |
| **Reference Citation (Section 9):** | Various as indicated below |

A number of seismic profiles have been completed across the Okanagan Valley. The seismic profiles provide information, in variable detail, regarding bedrock depth and stratigraphic layering. An example of a seismic profile is provided as Figure 18 (from Monahan, 2006).

A listing of seismic profile references compiled during research for this report is provided below. References to these seismic profiles were obtained from LeBreton (1972), Monahan (2006), and Toews (2007). The seismic profiles were not acquired nor reviewed as part of this report.

- MacAulay and Hobson, 1972: Seismic refractions survey that provides information on bedrock surface only (cited in Monahan, 2006).
- LeBreton, 1972: Seismic reflection surveys produced for the 1974 Supply and Demand Study (see Section 3.1). Four profiles were located in the North Okanagan, and two were located in the South (see Figure 19 and Figure 20). Profiles show bedrock and principle reflectors (cited in Monahan, 2006).
- Mullins et al., 1990: Seismic reflection profiling near Kalamalka Lake (cited in Toews, 2007).

- Pullan, et al., 1992. High resolution seismic reflection surveys across the North Okanagan. Profiles show “fine details of the sedimentary fill in the Okanagan Valley” (Monahan, 2006).
- Eyles et al., 1990: Seismic reflection profiling across Okanagan Lake (cited in Toews, 2007).
- Vanderburgh, 1993; Vanderburgh and Roberts, 1996. Analysis of high resolution seismic reflection data for the North Okanagan (cited in Monahan, 2006).

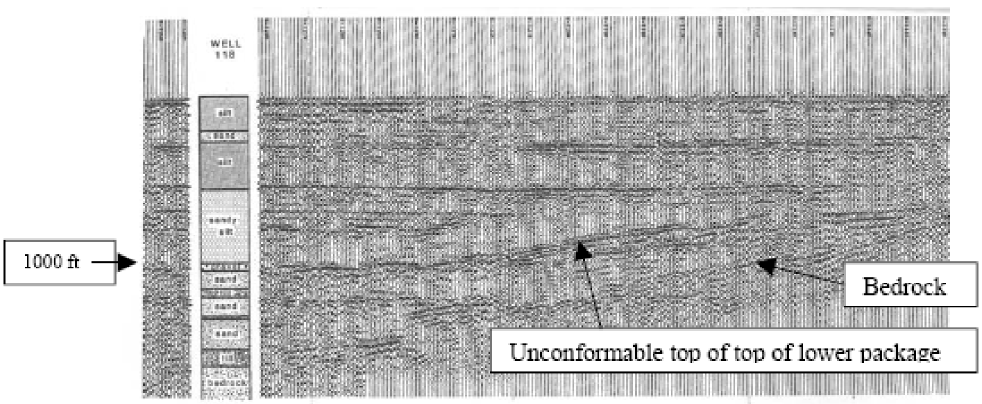



**Figure 18: Example of part of a high resolution seismic profile (from Pullan, et al., 1992) for the Okanagan Valley Fill, showing correlation with a borehole log.**

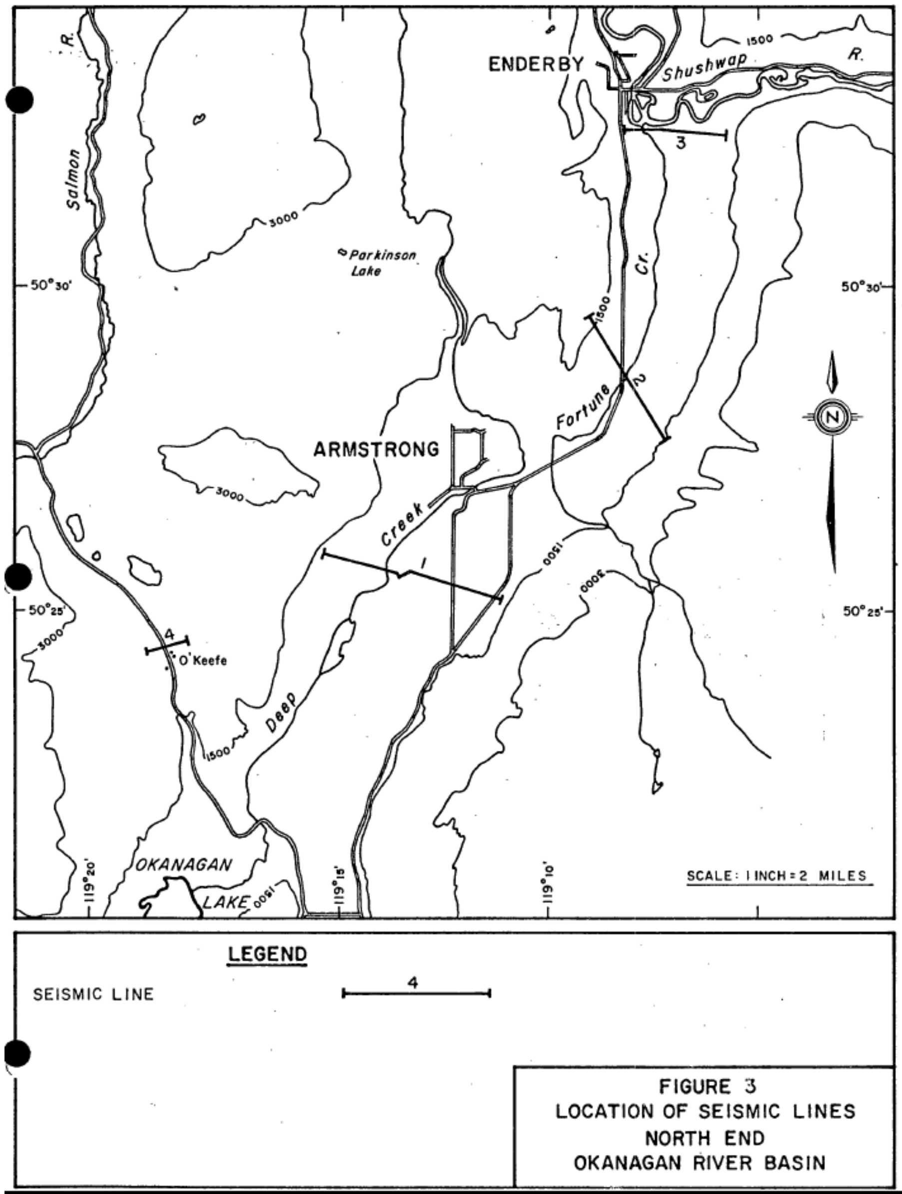



**Figure 19: Map illustrating seismic profiles completed across the North Okanagan during the 1974 Supply and Demand Study (from LeBreton, 1972).**

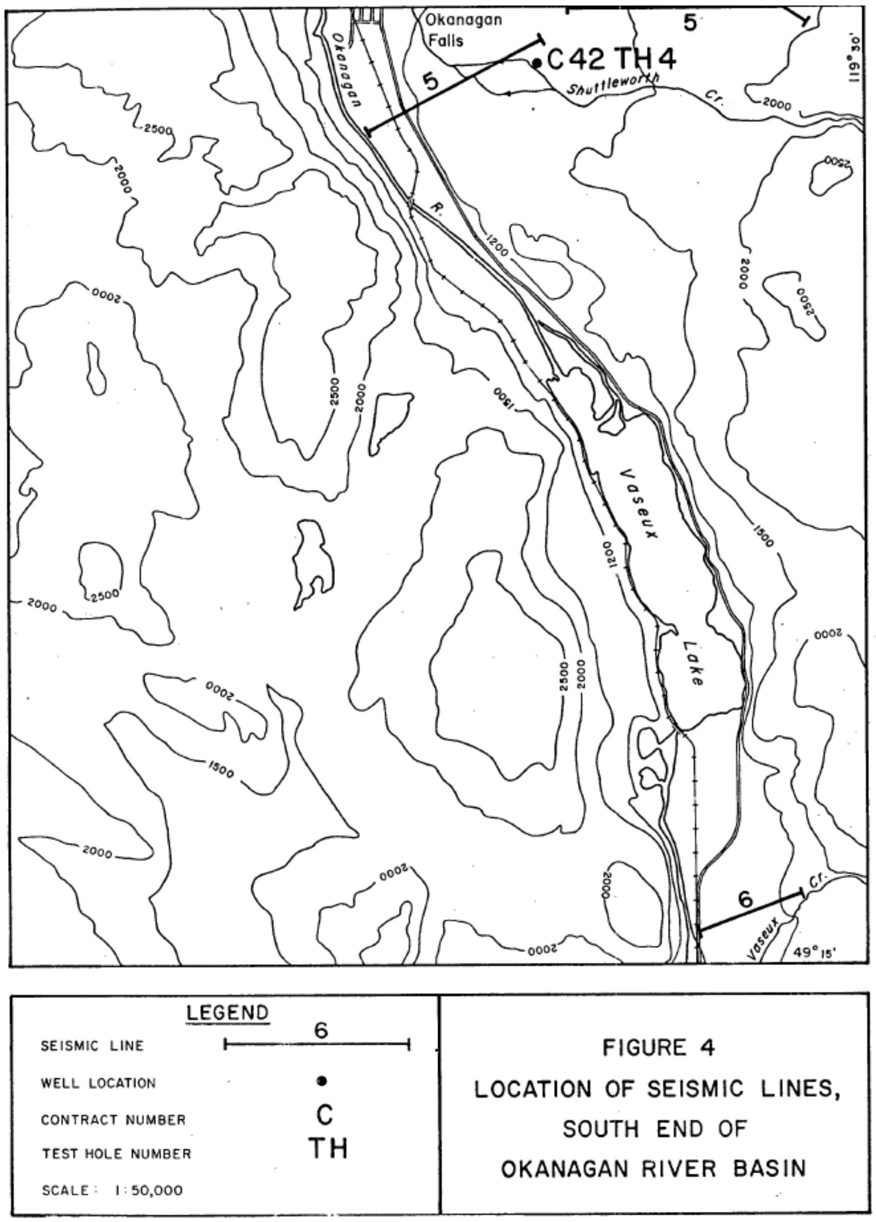



**Figure 20: Map illustrating the locations of seismic profiles completed in the South Okanagan during the 1974 Supply and Demand Study (from LeBreton, 1972).**

### 4.6.16 Groundwater and Drainage Study – South Okanagan Basin

| | |
|---|---|
| **Descriptive Name of Project:** | **Groundwater and Drainage Study with Geochemical Analysis** |
| **General Project Location:** | South Okanagan Basin |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | Inferred 193<br>Possibly 194 and 254 |
| **Report Title (if available):** | In progress |
| **Report Date/Status:** | Expected completion: first phase, spring 2008)<br>Second phase to commence Spring 2008 |
| **Report Authors/Researchers:** | P. Athanasopoulos, MSc. Student, U of S<br>M.J. Hendry, U of S<br>L. Wassenaar, NWRI<br>D. Neilsen, Agriculture and Agri-Food Canada |
| **Affiliated Organization(s):** | University of Saskatchewan (U of S)<br>Agriculture and Agri-Food Canada<br>National Water Research Institute (NWRI), Environment Canada, Saskatoon. |
| **Reference Citation (Section 9):** | Athanasopoulos, 2007, pers. comm. or unpublished data.<br>Athanasopoulos, et al., 2007, unpublished data. |

In the rural Osoyoos area, agriculture, specifically, tree fruit orchards and a small, yet increasing, number of vineyards, is the primary economic activity. Previous studies conducted within the rural Osoyoos area indicate that agricultural activities have resulted in elevated levels of nitrate in shallow groundwaters.

Research is currently being conducted in the rural Osoyoos area to characterize the potential source(s) of shallow groundwaters and evaluate the origin and fate of nitrate in the shallow groundwaters and tile drains in this area. The research couples several techniques: aqueous geochemistry; stable isotope analysis: $\delta^{15}N$ and $\delta^{18}O$ of nitrate, $\delta^{2}H$ and $\delta^{18}O$ of waters, and $\delta^{2}O$ of dissolved oxygen; water level data; and $^{3}H/^{3}He$ age dating. The research is focused in the north portion of rural Osoyoos (west of Osoyoos Lake) where shallow groundwaters beneath agricultural fields are collected in two tile drainage systems and discharged into Osoyoos Lake. The results of the research will be used to determine extent of nitrate contamination of shallow groundwaters, the source and age of this nitrate contamination, and the impact of the groundwater and tile drain systems on Osoyoos Lake. In addition, monitoring is being conducted to characterize the isotopic signature ($\delta^{2}H$ and $\delta^{18}O$ of surface waters) of the Okanagan river basin system from the north end of Okanagan Lake to Oroville, USA.

The scope of the research includes, but is not limited to:

- installation of 8 new monitoring wells to augment the existing monitoring well network (20 wells) , and to support long-term monitoring of the network.
- collection and analysis of groundwater samples from the valley bottom, groundwater from bedrock wells in the upland areas to the east and west of the study area, surface water (12 sites), precipitation (3 sites along the basin) and agricultural tile drainage (2 drains).
- monitoring of groundwater levels in monitoring wells.
- slug testing at 4 selected wells to determine the hydraulic conductivity of aquifer materials.
- measuring $^{3}H/^{3}He$ from 9 groundwater samples to determine the age and residence time of the water (and nitrate) in the groundwater.

#### 4.6.17 Draft Aquifer Test Analyses – Okanagan Basin

| | |
|---|---|
| **Descriptive Name of Project:** | **Draft Aquifer Test Analyses**<br>**a) Okanagan Basin Group**<br>**b) North Okanagan Group** |
| **General Project Location:** | Okanagan Basin |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | a) Okanagan Basin: 193, 254, 256, 260, 261, 262, 264, 265, 267, 268, 269, 270, 298, 299, 300, 301, 344, 346, 347, 350, 351, 352, 353, 354, 461, 463<br><br>b) North Okanagan: 102, 103, 104, 111, 346, 347, 348, 349, 350, 351, 352, 353, 354.<br>Note that aquifer test data is also available for approximately 49 wells in "unmapped" aquifers. |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | BC MOE, in prep, expected 2008 |
| **Report Authors/Researchers:** | V. Carmichael, Science and Information Branch<br>Water Stewardship Division,<br>Ministry of Environment, Victoria, BC |
| **Affiliated Organization(s):** | BC MOE<br>SFU (D. Allen, reviewer) |
| **Reference Citation (Section 9):** | BC MOE, 2007, draft aquifer test data. |

The BC MOE has completed the analysis of data for 121 aquifer tests (also referred to as pump tests) across the Okanagan Basin (identified in this report as the Okanagan Basin Group) and 88 aquifer tests across the northern end of the Basin (identified in this report as the North Okanagan Group). Tests were completed in wells within the aquifers identified in the table above. In addition, a number of the tests were completed for wells within unmapped aquifers. All wells tested are identified by their well tag numbers (WTN).

The analysis of the aquifer test data was provided in draft form at the time of preparation of this report. The data analysis has been incorporated into this report to provide order of magnitude estimates of aquifer parameters of hydraulic conductivity and, where available, storativity/specific yield. Geometric averages of the parameter data for each aquifer have been incorporated into the Aquifer Information Tables (Appendix II). Once the final reports are completed by BC MOE, the Aquifer Information Tables may require updates/modification.

Note that the draft aquifer test data for unmapped aquifers has not been compiled for this report.

### 4.6.18 Observation Well Slug Testing and Recharge Analysis – Okanagan Basin

<table>
<tr><td>Descriptive Name of Project:</td><td colspan="3">Observation well testing and recharge of the Okanagan Basin, BC</td></tr>
<tr><td>General Project Location:</td><td colspan="3">Okanagan Basin</td></tr>
<tr><td rowspan="15">Mapped Aquifers in Study Area (from BC Aquifer Classification Database)</td><td>OBS Well #</td><td>Location</td><td>Aquifer Number</td></tr>
<tr><td>96</td><td>Osoyoos</td><td>193</td></tr>
<tr><td>101</td><td>Osoyoos</td><td>193</td></tr>
<tr><td>105</td><td>Osoyoos</td><td>193</td></tr>
<tr><td>118</td><td>Armstrong</td><td>Inferred 111</td></tr>
<tr><td>119</td><td>Armstrong</td><td>Inferred 111</td></tr>
<tr><td>154</td><td>Summerland</td><td>297</td></tr>
<tr><td>162</td><td>Oyama</td><td>Unmapped</td></tr>
<tr><td>172</td><td>Oyama</td><td>Inferred 345</td></tr>
<tr><td>174</td><td>Oyama</td><td>Inferred 345</td></tr>
<tr><td>180</td><td>Armstrong</td><td>Inferred 353</td></tr>
<tr><td>236</td><td>Rutland</td><td>Kelowna area</td></tr>
<tr><td>282</td><td>Myer's Flat</td><td>Near 257 (unmapped)</td></tr>
<tr><td>332</td><td>Oliver</td><td>Unmapped</td></tr>
<tr><td>356</td><td>Winfield</td><td>Inferred 344</td></tr>
<tr><td>Report Title (if available):</td><td colspan="3">Observation well testing and recharge characterization of the Okanagan Basin, BC</td></tr>
<tr><td>Report Date/Status:</td><td colspan="3">Liskop and Allen, 2005</td></tr>
<tr><td>Report Authors/Researchers:</td><td colspan="3">T. Liskop and D. Allen, SFU<br>Report prepared for BC MOE (V. Carmichael, Science and Information Branch<br>Water Stewardship Division,<br>Ministry of Environment, Victoria, BC)</td></tr>
<tr><td>Affiliated Organization(s):</td><td colspan="3">Simon Fraser University<br>BC MOE</td></tr>
<tr><td>Reference Citation (Section 9):</td><td colspan="3">Liskop and Allen, 2005; Liskop, 2004.</td></tr>
</table>

The study involved a preliminary investigation aimed at characterizing the aquifer media surrounding provincial monitoring wells in Okanagan Valley using slug testing methods, analyzing groundwater level fluctuations using a cumulative precipitation departure (CPD) graph, and using the hydrographs to estimate recharge using the water table fluctuation (WTF) method. The hydraulic conductivities determined from slug testing were on the order of ~$10^{-7}$ m/s for silty clay aquifers, and ~$10^{-3}$ m/s for sand and gravel aquifers, but there was considerable variability depending upon which analytical method was used for analysis (Table 3.2, Liskop and Allen, 2005). Nonetheless, the values obtained from slug testing correspond well with published values of hydraulic conductivities for similar materials.

The cumulative precipitation departure method indicated that six wells in the study area are primarily recharged by precipitation (Table 5). The WTF method yielded questionable results due to uncertainty in specific yield values which are needed for the WTF method. Mean monthly recharge rates, estimated for only a sub-set of wells, ranged between 24 mm and 318 mm. These values are considered highly uncertain (Liskop and Allen, 2005), and other methods are needed to validate the range.

**Table 5: Summary of observation wells directly influenced by precipitation (from Liskop, 2004)**

| Obs Well No. | Location | Recharged by Precipitation |
|---|---|---|
| 118 | Armstrong | Yes |
| 119 | Armstrong | Yes |
| 162 | Kalawoods | Yes |
| 180 | Eagle Rock | Yes |
| 236 | Rutland | Yes |
| 282 | Myer's Flats | Yes |
| 96 | Osoyoos | No |
| 101 | Osoyoos | No |
| 105 | Osoyoos | No |
| 154 | Summerland | No |
| 172 | Oyama | No |
| 174 | Kalawoods | No |

### 4.6.19 Groundwater Use Data Collection – Okanagan Basin

| | |
|---|---|
| **Descriptive Name of Project:** | **Groundwater Use Data Collection** |
| **General Project Location:** | Okanagan Basin |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | Many aquifers throughout the Okanagan Basin, potentially all of them. |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | Dobson Engineering Ltd., in prep, expected 2007/08. Report part of the Phase 2 Supply and Demand Study. |
| **Report Authors/Researchers:** | Dobson Engineering Ltd. |
| **Affiliated Organization(s):** | Dobson Engineering Ltd. |
| **Reference Citation (Section 9):** | Dobson, 2007, pers. comm. or unpublished data. |

Data regarding groundwater use is being collected through a separate component of the Phase 2 Water Supply and Demand Project being completed by Dobson Engineering Limited (Dobson). Data compilation by Dobson is underway, but the information is not yet available. Contributions to this component of the project will include data from BC Ministry of Agriculture and Lands regarding groundwater use for irrigation and their estimates of recharge from irrigation water (Van der Gulik, 2007, pers. comm.).

### 4.6.20 Soil Survey – Okanagan Basin

| | |
|---|---|
| **Descriptive Name of Project:** | **Soil Survey – Okanagan Basin** |
| **General Project Location:** | Okanagan Basin, various sampling locations |
| **Mapped Aquifers in Study Area (from BC Aquifer Classification Database)** | Valley bottom aquifers (specific aquifers numbers may be determined upon completion of the project) |
| **Report Title (if available):** | N/A |
| **Report Date/Status:** | In progress, expected 2008 |
| **Report Authors/Researchers:** | Contact: E. Kenny, AAFC or O. Schmidt, BCAL |
| **Affiliated Organization(s):** | BC Ministry of Agriculture and Lands (BCAL)<br>Agriculture and Agri-Foods Canada (AAFC)<br>BC Agriculture Council (BCAC)<br>BC MOE<br>Environment Canada<br>UBCO |
| **Reference Citation (Section 9):** | Schmidt, 2007, pers. comm. |

This research was initiated in 2007 and is ongoing. The study involves the following tasks:

- Excavation of soil pits (to 1 m depth) at 56 sites in the Okanagan, Similkameen, and Shuswap areas.
- Soil classification at these sites to be used for the verification of, or integration with, existing soil maps.
- Field soil permeability testing using a Guelph permeameter.
- Collection of soil samples from the test pits for laboratory testing of saturated hydraulic conductivity for correlation with field measurements.
- Laboratory testing of soil samples for available water storage capacity.
- Analysis of soil samples, from the soil pits and from other test areas, for fertility (nutrients) and chemical parameters.

Results of the research are not currently available.

# 5 SYNTHESIS OF AVAILABLE INFORMATION

The following presents a synthesis of the available information presented in this report as it is relevant to the regional understanding of hyrogeological conditions in the Okanagan Basin.

## 5.1 Okanagan Basin Physiography and Climate

The Okanagan Basin is a north-south trending valley located in south-central British Columbia. The Basin is approximately 185 km in length; extending from the headwaters of Deep Creek (at the north end) to approximately 5 km south of the Canada-US border (to Zozel Dam). The width of the Basin averages approximately 40 km, but extends to up to 70 km in the central portion. The approximate area of the basin is 8,046 $km^2$ (Summit, 2005).

The highland areas forming the boundaries of the Basin average between approximately 1,200 m and 1,500 m a.s.l. (Summit, 2005). The topographic relief from the valley bottom to the mountainous areas surrounding the Basin is variable but is approximately 1,100 m (Toews, 2007). The elevation of the valley bottom is approximately 340 m a.s.l.

The Basin lies within the Thompson Plateau and Okanagan Highland physiographic regions (Roed and Greenough, 2004). Most of the Okanagan Basin is located within the Thompson Plateau region. The Thompson Plateau consists of volcanic and sedimentary rocks, metamorphosed and/or intruded by granitic rocks, which were uplifted, eroded, and subjected to lava flows, to create a flat or “plain” like surface (Roed and Greenough, 2004). Subsequent erosion into these “plains” by glacial and fluvial systems created the existing Okanagan Basin topography.

Some higher elevation areas at the eastern side of the Okanagan Basin lie within the Okanagan Highlands physiographic region. This region consists of moderately rugged mountains which are comprised mainly of metamorphic rocks of the Monashee Gneiss and granitic rocks (Roed and Greenough, 2004). Glacial activity also influenced the existing terrain and topography of the Okanagan Highlands area.

In the valley bottom, a mainstem river-lake system flows to the south. Okanagan Lake is the largest water body within this system; covering an area of approximately 351 $km^2$ (Summit, 2005). Other major water bodies in the valley include Kalamalka Lake, Wood Lake, Skaha Lake, Vaseux Lake and the Okanagan River. Smaller lakes are present throughout the Basin in the valley bottom and highland areas. There are 31 main tributaries which flow from the upland areas in the valley sides to the mainstem river-lake system. These tributaries are associated with the sub-basins or watersheds indicated on Map 1, Appendix I. Numerous other minor tributaries have also been mapped within the Okanagan Basin (see Map 1). Further information regarding surface water and drainage within the Okanagan Basin can be referenced in Summit (2005) and LeBreton et al. (1974). Other reports regarding surface water in the Okanagan Basin will be available through report catalogues (Section 4.3) or other sources. A detailed review of surface water or hydrological data and available hydrological reports was not within the scope of this project.

The climate within the Okanagan Basin is complex and five biogeoclimatic zones have been identified (Summit, 2005). On a basin-wide scale, annual precipitation averages approximately 600 mm/year (Summit, 2005). Precipitation, however, varies from north to south, east to west, and with elevation (Summit, 2005, Toews, 2007; Liskop and Allen, 2005). For example, in the valley bottom, precipitation decreases from approximately 450 mm/yr in the north to approximately 300 mm/yr in the south (LeBreton, et al., 1974). Average temperature, length of growing season, and frost-free period increase from north to south in the Basin (LeBreton, 1974).

A detailed review of available climate data and climate references was not within the scope of this project. Research cited within this report that considers climate data includes: LeBreton (1974), Liskop and Allen (2005), and Toews (2007). In addition, detailed studies of Okanagan Basin climate data are presented in the following references: Cohen and Neale (2006), Cohen, et al. (2004), and Cohen and Kulkarni (2001). Other information may be available through Environment Canada, BC Ministry of Environment, Agriculture Canada, BC Ministry of Agriculture and Lands, farmwest.com, or other resources.

## 5.2 Bedrock Geology

An understanding of bedrock geology and fault/fracture networks is important to assess groundwater flow through fractured rock. For the purposes of this report, selected attributes from the digital bedrock geology map, (Massey, et al., 2005), are presented on Map 2, Appendix I. As indicated in Section 4.2.5, larger-scale, 1:50 000, mapping work has also been completed by the GSC for the Vernon area. In addition, current fault/fracture maps are being developed under the direction of the BC MOE (Section 4.2.5) based on lineament analysis. Voeckler (in progress) has compiled fracture attributes based on outcrop measurements for the Naramata and Penticton Creek Watersheds and has derived estimates of bedrock permeability based on discrete fracture flow modelling.

Roed and Greenough (2004) present an overview of Okanagan Basin bedrock geology and theories regarding geological evolution.

In general, bedrock present in the Okanagan Basin outcrops in the benchland and highland areas surrounding the valley bottom. Bedrock on the eastern side of the basin in the highland areas generally consists of faulted and fractured, metamorphosed, and intruded rock forming the Monashee Gneiss Shuswap Rocks (Roed and Greenough, 2004). These rocks are separated from bedrock on the western side of the valley by the Okanagan Valley Fault (which trends approximately north to south through the valley bottom, approximately through the centre of Okanagan Lake). Bedrock on the western side of valley generally consists of younger metamorphosed and intruded volcanic and sedimentary rocks (various named formations). This overview is a simplification of the complex bedrock geology in the area. The bedrock geology maps referenced in Section 4.2.5 should be consulted for details.

Data regarding the depth to bedrock (i.e., bedrock elevation) has been mapped in the Oliver area (Toews, 2007, Section 4.6.14) and in the North Okanagan (Monahan, 2006, Section 4.6.3). Future work in the Kelowna area (by the GSC, Section 4.6.7, and Thomson and Young, Section 4.6.10) may provide bedrock surface information in this area.

## 5.3 Surficial Geology

An understanding of surficial geology, Quaternary geological evolution and depositional processes is important to assess groundwater flow through unconsolidated materials in the Okanagan Basin. As discussed in Section 4.2.5, new Okanagan surficial geology mapping work is in progress by the GSC. For the purposes of this report, selected attributes from digitized previous surficial geology maps (Fulton, 1969, and Nasmith, 1962) are presented on Map 3, Appendix I.

Roed and Greenough (2004) present an overview of Okanagan Basin surficial geology. In general, older surficial deposits consist of glacial or inter-glacial sediments (till, glaciolacustrine, glaciofluvial, terrace, kettle terrace, outwash terrace, or morainal deposits, meltwater channels). Modern deposits include alluvial fans, deltas, and fluvial deposits. Surficial geological deposits and underlying unconsolidated materials exhibit variability in grain size distribution and density (Fulton, 2006) suggesting variability in hydraulic properties.

Current theories regarding Quaternary geologic history and depositional environments have been developed or are in progress for the North Okanagan (Section 4.6.3), Kelowna area (Sections 4.6.7 and 4.6.10) and South Okanagan (Section 4.6.14).

## 5.4 Surficial Soils

Knowledge of soil characteristics can provide information to assess surface recharge due to precipitation or snowmelt. Selected attributes of soil texture (coarse fragment content), drainage, and perviousness are indicated on a soil map compiled (using digital files) for this report which is included as Map 4, Appendix I. Map 4 presents soil information for the benchland and highland areas only, due to the regional-scale of the map, and is intended to present an example of the type of soil information available. Soil data are also available in detail at the local scale in the valley bottom. In general, the map indicates significant soil variability across the mapped area for the attributes shown (coarse fragment soil texture, drainage, and perviousness – these attributes are defined on Map 4).

Ongoing work by BC Ministry of Agriculture and Agriculture and Agri-Foods Canada involves soil survey work for sampling areas within the Okanagan Basin (Section 4.6.20). The results of this work, once completed, will be used to confirm/augment existing soil maps.

Liggett (in progress, Sections 4.6.12 and 4.6.13) used soil characteristics in the HELP® model for development of vulnerability maps as well as for the assessment/quantification of valley bottom recharge. Toews (2007, Section 4.6.14) also used soil characteristics in developing recharge estimates using the HELP® model in the Oliver area.

## 5.5 Aquifer Identification and Properties (Aquifer Information Tables)

As discussed previously in this report, aquifer identification and mapping, based on areas of groundwater use, well records, and other information, has been completed across the Okanagan Basin by the BC MOE. The aquifer mapping initiative provides an inventory of identified aquifers within the Okanagan Basin and some information regarding the aquifers (location, size, demand, vulnerability, and productivity). The mapping was initiated in the early 2000's, based on information available at that time. Maps 5, 6, and 7 (Appendix I) illustrate the locations of unconfined, confined, and bedrock aquifers, respectively (as categorized on Draft Aquifer Classification Worksheets provided by the BC MOE).

The following comments are provided regarding the identification and mapping of aquifers in the Okanagan Basin.

- Recent and ongoing geological research is providing new information to allow for the refinement of aquifer characterization and delineation at some areas within the Okanagan Basin. Recent stratigraphic interpretation models for the North Okanagan (Monahan, 2006, and Fulton, 2006, Section 4.6.3) have indicated that many of the previously defined aquifers in this area can be sub-divided into a number of distinguishable aquifer units. For example, Monahan (2006) identified five distinguishable aquifers within BC MOE aquifer 111. In addition, work by Monahan (2006) and Fulton (2006) has redefined the lateral boundaries of some aquifers. Other ongoing or recently completed research in North Kelowna (Thomson and Young, 2007, Section 4.6.10) and the Oliver Area (Toews, 2007, Section 4.6.14) may provide a basis to re-map and confirm the boundaries of aquifers identified within these areas.
- New surficial geology mapping (Section 4.2.5) may provide updated information to assist in the re-definition of shallow aquifers across the Okanagan Basin.
- Some mapped aquifers within the Okanagan Basin have been defined based on a very limited data set. For example, aquifers 465 and 468 (Kelowna area), have been delineated based on a single borehole/well log.

- The aquifers have been classified based on information from the BC MOE as "unconfined", "confined", or "bedrock" types (BC MOE, 2007, ACW). For some aquifers, the ACWs indicate that both confined and unconfined conditions occur at different locations across the aquifer expanse. The aquifer type of unconfined, confined, or bedrock represents the main type of aquifer (i.e., an unconfined aquifer may be locally confined but is still identified as unconfined or vice versa). Except in areas where detailed stratigraphic analysis has been completed (e.g., in the North Okanagan), there is limited information to specifically indicate confined and unconfined locations within a partially confined aquifer.
- There are likely aquifers in the Okanagan Basin that have not been identified or mapped (unmapped aquifers). Some data regarding groundwater in unmapped aquifers are available in the BC MOE, aquifer test analyses, 2007; see Section 4.6.17. Other data may be available through water purveyors, local governments, consultants, or other sources. Data regarding unmapped aquifers have not been compiled for this report. These data, however, may be important for subsequent groundwater work during the Phase 2 Water Supply and Demand Project.

With consideration of the comments noted above, this report has used the BC MOE aquifer identification numbers as a reference point when presenting the information sources in Section 4.6 (Current Research and Knowledge). The applicable BC MOE aquifer identification numbers are indicated in the tables at the beginning of each sub-section within Section 4.6. For other information sources identified in Sections 4.2, 4.3, 4.4, and 4.5, specific aquifer numbers are not indicated as most of these sources provide information for many areas across the Basin.

The BC MOE aquifer identification numbers also provide a basis for the organization and compilation of aquifer-specific hydrogeological information. As such, for the purposes of this report, Aquifer Information Tables have been developed for each BC MOE mapped aquifer in the Okanagan Basin and are included in Appendix II (in order of BC MOE aquifer number). For each aquifer, a table presents summary information and references (extracted or inferred from the information sources cited in this report) regarding:

- Aquifer Identification (BC MOE number, Location, BC MOE Classification, and Aquifer Type)
- Aquifer Dimensions (size, thickness, depth to bottom)
- Stratigraphy and Geology (aquifer materials, overlying materials, underlying materials, depositional environment or bedrock type)
- Well Log Statistics (number of wells in aquifer, well depth, yield, depth to water)
- Aquifer Hydraulic Properties and Information (hydraulic conductivity, transmissivity, storativity/specific yield, hydraulic communication with other aquifers, and recharge processes)
- Other Aquifer Information (geological or hydrogeological models, geochemical data, static water level data, associated watersheds)

The Aquifer Information Tables are based on the information available at the time of preparation of this report; at the level of detail presented in this report. Information presented in the Aquifer Information Tables represents data compiled from available sources of aquifer-specific hydrogeological information (e.g. BC MOE Water Resources Atlas, Draft Aquifer Classification Worksheets, and Wells Database), and current research. A review of local-scale reports (i.e., from report catalogues) was not completed to obtain specific aquifer information for the tables. Some of the information presented in the Aquifer Information Tables has been inferred for this report, and ongoing research continues to provide new data. Thus, the tables should be used in conjunction with an independent and detailed review of available data.

New information, through ongoing research and data collection, will be obtained in the future and modification of these tables will be required. As discussed above, new aquifers may be identified (i.e., currently unmapped aquifers), aquifer boundaries may be modified, or more representative values of aquifer properties may be measured.

Further discussion regarding the limitations of the information presented in the Aquifer Information Tables is provided at the end of Appendix II.

## 5.6 Aquifer Recharge and Discharge

**Aquifer Recharge:**

Groundwater recharge to aquifers within the Okanagan Basin can be categorized into six general types (inferred from Voeckler, 2007): (A) direct recharge due to precipitation, (B) recharge from creeks/lakes, (C) mountain block recharge, (D) irrigation recharge, (E) recharge due to leakage from, or hydraulic connection with, another aquifer, and (F) recharge from anthropogenic discharges of water such as septic discharges, urban pipe leakage. These recharge types are illustrated on Figure 21. Available data to quantify recharge values for these different types are discussed below.

***Type A: Direct recharge due to precipitation.*** Aquifer recharge due to infiltration of precipitation (type A) has been quantified by Toews (2007), Section 4.6.14, and Smerdon, et al. (2007), Section 4.6.1. Research by Toews (2007) calculated a median valley bottom recharge rate for the Oliver area (South Okanagan, aquifers 254 and 255) at 45 mm/yr (this value is approximately 20% of the annual precipitation). Smerdon (2007) estimated average recharge in the BX Creek area (North Okanagan) to be 22 mm/yr for the valley bottom (aquifer 348 and lower part of 349) and 40 mm/yr in the upland area (upper part of aquifer 349 and aquifers 350 and 351). Liskop (2004) and Liskop and Allen (2005) assessed whether precipitation contributed to aquifer recharge at twelve BC MOE Observation Wells (see Section 4.6.18). Estimates of surface recharge due to precipitation are not currently available for other locations within the Okanagan Basin.

No estimates are currently available for bedrock aquifers; however, such estimates are forthcoming as part of the study by Voeckler (2007). Regional direct recharge data, applicable to unconfined aquifers in the valley bottom, from Liggett, in progress, (Section 4.6.13), will also be available in the future (anticipated January 2008). Recharge values obtained by Toews (2007) and Smerdon et al. (2007) may be useful to extend to other areas within the Okanagan Basin where similar conditions exist.

***Type B: Recharge from Creeks/Lakes.*** Ongoing research by Neumann (2007) (Section 4.6.6), may, in the future, provide some information regarding groundwater recharge from creeks. Data are not currently available. Similarly, research by Neilson-Welch (in progress, Section 4.6.9) may also provide estimates of groundwater recharge for valley side catchments. Recharge to/from Fortune Creek (Jochum, et al., 2007, Section 4.6.5) is indicated to affect Okanagan Basin Aquifers in the North.

***Types C: Mountain Block Recharge.*** Current research by Voeckler (2007), Section 4.6.11, may provide information to quantify mountain block recharge. Data are not currently available. For comparison purposes, in the Salt Lake Valley of Utah, about 22% of the whole water budget for the valley aquifer enters through MBR from the adjacent Wasatch Mountain Range (Wilson and Guan 2004). Based on a synthesis of data from various watersheds in the southern USA, the amount of MBR (mm/year - percentage of precipitation) varies from 0.6% to 38% (Voeckler, personal communication).

***Type D: Irrigation Recharge.*** Irrigation recharge values calculated by Toews (2007) ranged from 250 to 1000 mm/year for the irrigated areas modelled. Other calculations to estimate irrigation recharge across the Okanagan Basin (BC Ministry of Agriculture and Lands, in progress, Van der Gulik, 2007, pers. comm.) are being compiled through a separate water use component of the Phase 2 Water Supply and Demand Project.

***Type E: Recharge from other aquifers (leakage or hydraulic connection).*** Stratigraphic models for the North Okanagan (Monahan, 2006, and Fulton, 2006, Section 4.6.3), North Kelowna (Thomson and Young, 2007, in prep., Section 4.6.10), and the Oliver Area (Toews, 2007, Section 4.6.14) may provide a basis to qualitatively assess the potential for aquifer recharge due to leakage or hydraulic connections.

Information regarding confining layer properties, such as thickness and grain size, may provide an indication regarding the potential for vertical leakage. Only limited information regarding confining layer properties is available as indicated on the Aquifer Information Tables, Appendix II.

Inferences regarding possible hydraulic connections between aquifers are summarized on the Aquifer Information Tables (based on available stratigraphic analysis and/or proximity to other aquifers). Groundwater flux between aquifers, however, has not been quantified.

***Type F: Recharge from anthropogenic additions to groundwater (e.g. storm sewer leakage, other urban pipe leakage, septic discharges, or other sources).*** Local municipal studies may provide information to provide an indication of the potential for aquifer recharge due to anthropogenic sources. Reports may be available from local governments, consultants, and/or water purveyors.

**Aquifer Discharge:**

Aquifer discharge mechanisms include: discharge to creeks/lakes, discharge from aquifers due to aquifer leakage or hydraulic connection with other aquifers, or discharge due to pumping of wells.

Discharge due to pumping of wells has been quantified for a number of locations throughout the Okanagan Basin (see Section 4.6.19).

Research to date has not quantified aquifer discharge rates (discharge to surface water bodies or discharge to other aquifers). Estimates of aquifer discharge to mainstem rivers and lakes may be calculated based on knowledge or estimates of aquifer hydraulic properties, groundwater flow gradients, and the aquifer area in contact with the river/lake. These calculations have not been completed for this report, however, data required to perform the calculations may be extracted from the Aquifer Information Tables, Appendix II, or references identified on the tables.

Ongoing research by Neumann (2007), Section 4.6.6, may, in the future, provide some information regarding aquifer discharge to creeks. Current research by Voeckler, et al., (2007), Section 4.6.11, may provide information to quantify discharge from fractured rock aquifers comprising the valley sides to aquifers within the valley fill deposits (also termed Mountain Block Recharge).

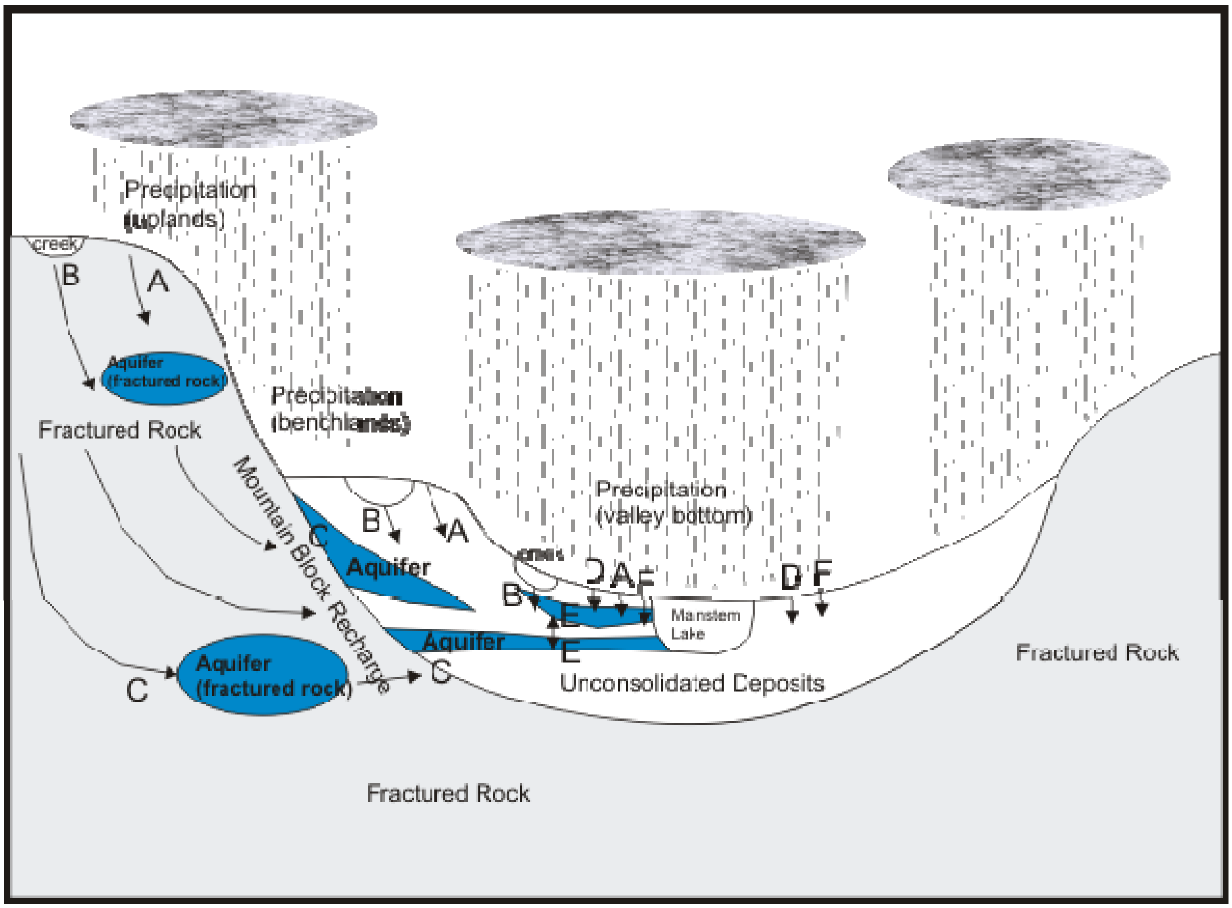



**Figure 21: Schematic drawing showing a simplification of different aquifer recharge scenarios for mountainous watersheds. Type A = direct recharge due to precipitation, Type B = recharge from creeks, Type C = mountain block recharge, Type D = irrigation recharge, Type E = recharge due to leakage from, or hydraulic connection with, another aquifer, Type F = recharge due to other anthropogenic sources such as septic discharge, urban pipe leakage, or other sources.**

## 5.7 Aquifer – Watershed Relationships

In order to assess aquifers in the context of the complete hydrologic cycle, the aquifer-watershed relationship has been examined. In plan view, as illustrated on Maps 5, 6, and 7 (Appendix I), aquifers may extend across one or more watershed areas or residual areas (residual areas are areas between watersheds where significant surface water is absent). The watershed(s) and residual areas associated with each aquifer are indicated on the Aquifer Information Tables, Appendix II.

Conversely, individual watersheds/residual areas may encompass one or more mapped aquifers. The following tables (Table 6 and Table 7) list the aquifer numbers associated with each Okanagan Basin watershed and residual area.

Table 6 and Table 7 also reference "Node" numbers. The node numbers (indicated on Maps 5, 6, and 7, Appendix I), were assigned to specific point locations within the Okanagan Basin (representing watersheds or residual areas) by Summit, 2007 (Map 1, Summit, 2007). The node numbers were assigned in anticipation of future modelling work for the Phase 2 Water Supply and Demand Project, and are not directly relevant to this report.

Note that as new information regarding aquifer extent and unmapped aquifers becomes available, modifications to the table below and the Aquifer Information Tables would be required.

**Table 6:** **Watershed – Aquifer Relationships (based on watershed boundaries indicated on Maps 5, 6, and 7, Appendix I). Note that aquifers listed represent the main aquifers within the defined areas as indicated on Maps 5, 6, and 7. Small portions of other aquifers may also be present. Aquifer Type: X indicates main aquifer type indicated by BC MOE, 2007, ACW.**
***These aquifers have recently been redefined and re-delineated through work by Monahan (2006) and Fulton (2006).**

| WATERSHED (clockwise starting at North end of Okanagan Basin) | NODE Number (from [3]Summit, 2007, Map1) | AQUIFERS IN WATERSHED AREA | Unconfined | Confined | Bedrock |
|---|---|---|---|---|---|
| Deep Creek | 3 | *102 | | X | |
| | | *103 | X | | |
| | | 104 | | | X |
| | | 105 | | | X |
| | | 106 | | | X |
| | | 107 | | | X |
| | | *111 | | X | |
| | | 348 | | X | |
| | | *353 | X | | |
| | | *354 | X | | |
| | | 355 | | | X |
| | | *356 | X | X | |
| Vernon Creek | 12 | 344 | | X | |
| | | 345 | X | | |
| | | 346 | X | | |
| | | 347 | | X | |
| | | 348 | | X | |
| | | 349 | | X | |
| | | 350 | | | X |
| | | 351 | | | X |
| | | 352 | | X | |
| | | 464 | | X | |
| | | 470 | | | X |
| | | 471 | | | X |
| Kelowna (Mill) Creek | 20 | 463 | | X | |
| | | 464 | | X | |
| | | 467 | X | | |
| | | 470 | | | X |
| | | 472 | | | X |

[3] Summit, 2007, Map 1, The Okanagan Basin In British Columbia, produced by BdJ, May 2007.

| WATERSHED (clockwise starting at North end of Okanagan Basin) | NODE Number (from [3]Summit, 2007, Map1) | AQUIFERS IN WATERSHED AREA | Unconfined | Confined | Bedrock |
|---|---|---|---|---|---|
| Mission Creek | 22 | 461 | | X | |
| | | 462 | X | | |
| | | 463 | | X | |
| | | 464 | | X | |
| | | 466 | X | | |
| | | 473 | | | X |
| Bellevue Creek | 24 | 462 | X | | |
| | | 463 | | X | |
| | | 464 | | X | |
| Chute Creek | 34 | 298 | | | X |
| Robinson Creek | 38 | 298 | | | X |
| Naramata Creek | 40 | 298 | | | X |
| Turnbull Creek | 44 | 298 | | | X |
| Penticton Creek | 46 | 298 | | | X |
| | | 269 | | | X |
| Ellis Creek | 52 | 269 | | | X |
| | | 270 | | X | |
| Shuttleworth Creek | 60 | 263 | | | X |
| | | 264 | | X | |
| | | 265 | | X | |
| Vaseux Creek | 66 | 255 | X | | |
| Wolfcub Creek | 71 | 254 | X | | |
| Inkaneep | 78 | None | | | |
| Testalinden Creek | 76 | 254 | X | | |
| | | 256 | | X | |
| Park Rill | 69 | 255 | X | | |
| | | 257 | X | | |
| | | 260 | | | X |
| | | 262 | | X | |
| Marron River | 55 | 260 | | | X |
| | | 261 | X | | |
| Shingle Creek | 51 | 266 | | X | |
| | | 267 | | X | |
| Trout Creek | 42 | 297 | X | | |
| | | 299 | X | | |
| | | 300 | | | X |
| Eneas Creek | 36 | 299 | X | | |
| | | 300 | | | X |
| Peachland Creek | 32 | 860 | X | | |
| | | 861 | | | X |
| Trepanier Creek | 30 | 862 | | X | |
| | | 863 | | | X |
| | | 864 | | X | |
| Powers Creek | 28 | 302 | | X | |
| | | 304 | | | X |

| WATERSHED (clockwise starting at North end of Okanagan Basin) | NODE Number (from [3]Summit, 2007, Map1) | AQUIFERS IN WATERSHED AREA | Unconfined | Confined | Bedrock |
|---|---|---|---|---|---|
| McDougal Creek | 26 | 303 | | X | |
| | | 305 | | | X |
| | | 306 | | X | |
| Lambly Creek | 18 | None | | | |
| Shorts Creek | 16 | 358 | X | | |
| Whiteman Creek | 14 | 357 | X | | |
| Nashwito Creek | 10 | None | | | |
| Equesis Creek | 8 | None | | | |
| Irish Creek | 5 | *111 | | X | |

**Table 7:** **Residual Area – Aquifer Relationship (based on residual area boundaries indicated on Maps 4, 6, and 7, Appendix I). Note that aquifers listed represent the main aquifers within the defined areas as indicated on Maps 5, 6, and 7. Small portions of other aquifers may also be present. Aquifer Type: X indicates main aquifer type indicated by BC MOE, 2007, ACW.**
***These aquifers have recently been redefined and re-delineated through work by Monahan (2006) and Fulton (2006).**

| RESIDUAL AREA (clockwise starting at North end of Okanagan Basin) | NODE Number (from [4]Summit, 2007, Map1) | AQUIFERS IN RESIDUAL AREA | Unconfined | Confined | Bedrock |
|---|---|---|---|---|---|
| E-1 | 7 | *111 | | X | |
| | | 347 | | X | |
| E-2 | 13 | 347 | | X | |
| | | 464 | | X | |
| | | 468 | | X | |
| | | 469 | | X | |
| | | 470 | | | X |
| | | 471 | | | X |
| E-3 | 21 | 464 | | X | |
| | | 465 | | X | |
| | | 467 | X | | |
| E-4 | 23 | 462 | X | | |
| | | 463 | | X | |
| | | 464 | | X | |
| E-5 | 25 | 463 | | X | |
| | | 464 | | X | |
| E-6 | 35 | 298 | | | X |
| E-7 | 39 | 298 | | | X |
| E-8 | 41 | 298 | | | X |
| E-9 | 45 | 298 | | | X |
| E-10 | 50 | 298 | | | X |
| E-11 | 54 | 263 | | | X |
| | | 264 | | X | |
| | | 268 | | | X |
| | | 270 | | X | |
| E-12 | 63 | 255 | X | | |
| | | 264 | | X | |
| | | 265 | | X | |
| E-13 | 65 | 255 | X | | |
| E-14 | 68 | 254 | X | | |
| | | 255 | X | | |
| E-15 | 72 | 254 | X | | |
| E-16 | 75 | 254 | X | | |

[4] Summit, 2007, Map 1, The Okanagan Basin In British Columbia, produced by BdJ, May 2007.

| RESIDUAL AREA (clockwise starting at North end of Okanagan Basin) | NODE Number (from [4]Summit, 2007, Map1) | AQUIFERS IN RESIDUAL AREA | Unconfined | Confined | Bedrock |
|---|---|---|---|---|---|
| E-17 | 79 | 194 | X | | |
| | | 195 | | X | |
| | | 808 | | | X |
| | | 809 | | X | |
| | | 810 | | | X |
| W-23 | 77 | 193 | X | | |
| | | 238 | | | X |
| | | 248 | | | X |
| | | 254 | X | | |
| | | 256 | | X | |
| W-22 | 74 | 254 | X | | |
| | | 256 | | X | |
| W-21 | 70 | 254 | X | | |
| | | 255 | X | | |
| | | 256 | | X | |
| W-20 | 67 | 255 | X | | |
| W-19 | 62 | None | | | |
| W-18 | 61 | 260 | | | X |
| W-17 | 57 | 260 | | | X |
| | | 261 | X | | |
| W-16 | 56 | None | | | |
| W-15 | 53 | 267 | | X | |
| W-14 | 49 | None | | | |
| W-13 | 43 | 297 | X | | |
| W-12 | 37 | 297 | X | | |
| | | 300 | | | X |
| W-11 | 33 | 860 | X | | |
| | | 861 | | | X |
| W-10 | 31 | 860 | X | | |
| | | 861 | | | X |
| | | 862 | | X | |
| W-9 | 29 | 302 | | X | |
| | | 304 | | | X |
| | | 862 | | X | |
| | | 863 | | | X |
| W-8 | 27 | 301 | | X | |
| | | 302 | | X | |
| | | 303 | | X | |
| | | 305 | | | X |
| W-7 | 19 | 303 | | X | |
| | | 305 | | | X |
| | | 306 | | X | |
| W-6 | 17 | 358 | X | | |
| W-5 | 15 | 357 | X | | |
| | | 358 | X | | |
| W-4 | 11 | 357 | X | | |
| W-3 | 9 | None | | | |

| RESIDUAL AREA (clockwise starting at North end of Okanagan Basin) | NODE Number (from [4]Summit, 2007, Map1) | AQUIFERS IN RESIDUAL AREA | Unconfined | Confined | Bedrock |
|---|---|---|---|---|---|
| W-2 | 6 | *111 | | X | |
| W-1 | 4 | *111 | | X | |
| | | *354 | X | | |

## 5.8 Implications for Hydrogeological Modelling

Hydrogeological modelling involves the development of a scaled geological representation to investigate groundwater flow. A model domain is developed which consists of the geological representation, specified hydraulic properties for the geological units (aquifers and aquitards), and assigned boundary conditions (to represent both the physical and hydraulic boundaries of aquifer, as well as surface water bodies, and direct recharge). Once the model is developed, it can be solved mathematically (numerically or analytically) to assess groundwater levels, groundwater flow directions, hydraulic gradients, and other hydrogeological aspects. Such models can also be used to simulate well capture zones, and potential interaction with surface waters. Hydrogeological modelling provides a useful tool for the assessment of groundwater resources.

Based on the current knowledge of the hydrogeological conditions in the Okanagan Basin, as presented in this report, the following text provides a discussion of some of the possible considerations or implications for hydrogeological modelling. Note that the influence of the some of the modelling implications discussed below will depend on the purpose and level of detail of the hydrogeological model.

***Development of Geological Representation - Aquifer and Aquitard Delineation:*** In developing a model domain, it is important to accurately represent geological unit dimensions.

- As discussed in Section 5.5, aquifer mapping by the BC MOE was completed based on knowledge of groundwater use, water well records, and a limited consideration of geological conditions/topography. The aquifer maps provide a preliminary indication regarding the areal extents of aquifers. The development of model domains using the BC MOE aquifer maps, however, should be completed with consideration of the limitations of the mapping as discussed in Section 5.5.

- Available data regarding the thickness and depth of aquifers is limited except for locations where detailed stratigraphic analysis has been completed (e.g., North Okanagan, Section 4.6.3, Central Okanagan, in progress, Sections 4.6.7 and 4.6.10, and South Okanagan, Section 4.6.14).
- Available data regarding the areal extent, thickness, depth, and continuity of confining layers (or aquitards) is limited, except for locations where detailed stratigraphic analysis has been completed (sections identified above).
- Available data regarding bedrock depth (beneath unconsolidated materials) is limited, except for locations where bedrock contour mapping has been completed (e.g. North Okanagan, Section 4.6.3, and South Okanagan, Section 4.6.14).

***Hydrogeological Boundary Conditions:*** Typically, in developing a hydrogeological model, boundary conditions are defined for the limits of the model domain as "impermeable", "specified groundwater flux", or "specified hydraulic head". Pumping wells, creeks, and lakes are also represented as boundary conditions.

- Impermeable boundaries for aquifer systems in hydrogeological modelling are often specified to coincide with topographical divides (based on the assumption that "groundwater mimics topography"). In the Okanagan Basin, however, many of the mapped aquifers extend across more than one watershed area. As such, the topographical surface water divides may not indicate groundwater divides. Preliminary information for the Fortune Creek watershed (Section 4.6.5) has shown that groundwater in aquifer(s) within this watershed crosses the watershed boundary to the south-west and enters the Deep Creek watershed. Similar situations may occur at other areas where aquifers extend across more than one drainage sub-basin (watershed).
- In developing groundwater flux boundary conditions, knowledge regarding aquifer recharge and discharge is necessary. Different types or mechanisms of aquifer recharge and discharge and available research results are discussed in Section 5.6 of this report.

- With respect to groundwater recharge, some data are available (or will be available in the future) to quantify recharge to shallow aquifers due to precipitation and irrigation (i.e., at the ground surface boundary) (see Section 5.6). Aquifer recharge due to other mechanisms (from creeks/lakes, from mountain block recharge, and due to leakage from, or hydraulic connection with, other aquifers) has not been quantified in the Okanagan Basin.
- Aquifer discharge mechanisms include discharge to creeks/lakes, discharge from aquifers due to aquifer leakage or hydraulic connection with other aquifers, or discharge due to pumping of wells. Discharge due to pumping of wells has been quantified for a number of locations throughout the Okanagan Basin (see Section 4.6.19). Other discharge processes have not been quantified.

- Data to define specified hydraulic head boundaries are related to surface water elevation and have not been compiled for this report.

***Aquifer Hydraulic Properties:*** In developing a model domain, it is important to accurately represent the hydraulic properties of the geological units (aquifers and aquitards). Hydraulic properties required include: hydraulic conductivity or transmissivity, storage properties (storativity or specific yield), porosity, and anisotropy (see Glossary for definitions).

- The Aquifer Information Tables, Appendix II, provide a summary of aquifer hydraulic property estimates (for hydraulic conductivity, transmissivity, storativity/specific yield) that were reviewed during the preparation of this report. As indicated in Section 5.5, and in the limitations provided at the end of Appendix II, estimates for aquifer hydraulic properties are not available for all aquifers, and some of the values presented were obtained from “draft” or unpublished data.
- Due to a lack of data, the Aquifer Information Tables do not indicate values for aquifer porosity and provide only limited information for anisotropy for some aquifers in the South Okanagan (aquifers 254, 255, 256, and 257).

- There are likely local-scale reports on file (on databases/catalogues identified in Section 4) that could provide additional data for hydraulic properties and/or provide values for hydraulic properties where no values are indicated on the Aquifer Information Tables.
- Based on the variability of aquifer test data for different wells screened within the same aquifer (BC MOE, 2007, draft aquifer test analyses), as well as detailed analysis of aquifer depositional environments in the north Okanagan (Fulton, 2006, Section 4.6.3), it is inferred that there could be significant variability of hydraulic properties within an aquifer. Variability in hydraulic properties within an aquifer may be caused by vertical and/or horizontal changes in grain size and/or density.

# 6 INFORMATION SUMMARY AND DATA GAPS

Figure 22 is a visual summary indicating areas of significant hydrogeological knowledge and areas of ongoing research in the Okanagan Basin. Information regarding the individual topics noted on Figure 22 can be referenced in the section numbers identified.

Figure 22 illustrates that a number of information sources and research projects provide data which extend regionally across the Okanagan Basin. Figure 22 also illustrates that area-specific research has been mainly focussed on populated areas within the North (Vernon area), Central (Kelowna Area), and South (Oliver Area) areas of the Okanagan Basin. In addition, some specific ongoing research is being completed for alluvial fan areas of Vernon Cr., Shorts Cr., and Vaseux Cr., and on a bedrock area in the Penticton Creek watershed. Many areas along the valley bottom, as well as most of the upland areas, however, have not been the subject of focussed hydrogeological research.

The following discussion references relevant data and current research (presented on Figure 22 and as outlined in this report), and considers significant data gaps in the context of developing an understanding of the regional hydrogeology of the Okanagan Basin. The following discussion is intended to provide an overview of available information and data gaps to assist in completing future Phase 2 Water Supply and Demand Project work, and/or to assist in understanding uncertainties in available data.

Note that most of the Okanagan Basin research that provides significant contributions to the understanding of regional hydrogeology was ongoing or was not published at the time of preparation of this report. Many potentially useful results have not been compiled and/or are not publicly available. Thus, some data gaps will be addressed, or partially addressed, once ongoing research is completed.

***Bedrock Geology:***

- Available bedrock geology mapping information is presented on Map 2, Appendix I. Bedrock geology is currently being re-mapped by the GSC (Section 4.2.5).

- Bedrock lineament mapping has been initiated (under the direction of the BC MOE) for the Okanagan Basin (Section 4.2.5). Once completed, this map will provide useful and current information which will contribute to the understanding of fractured rock aquifers in the Okanagan Basin. Lineament data are being compared with outcrop measurements of fracture characteristics (Voeckler, et al., 2007).
- Data regarding the depth to bedrock (i.e., bedrock elevation) have been mapped in the Oliver area (Toews, 2007, Section 4.6.14) and in the North Okanagan (Monahan, 2006, Section 4.6.3). Future work in the Kelowna area (by the GSC and Thomson and Young, UBCO, Section 4.6.10) may provide bedrock surface information. Bedrock surface contour mapping has not been completed at other areas of the Okanagan Basin. More complete mapping of the bedrock surface would assist in developing stratigraphic cross sections to assess aquifer thicknesses and depths.

***Surficial Geology:***

- Available surficial geology mapping information is presented on Map 3, Appendix I. Surficial geology is currently being re-mapped by the GSC (Section 4.2.5). Once completed, this map will provide useful and current information which may contribute to the delineation of aquifers (laterally and vertically) and the development of stratigraphic cross sections.

***Surficial Soil:***

- Surficial soil mapping has been completed for the Okanagan Basin (Map 4, Appendix I) and provides information regarding soil type, drainage, perviousness, and other attributes which may provide information to assess direct recharge to the Okanagan Basin.
- Current soil survey research involving soil sampling, classification, mapping contributions, and soil property/chemistry measurements for the Okanagan Basin is being completed through the BC Ministry of Agriculture and Lands and Agriculture and Agri-Foods Canada (see Section 4.6.20).

***Stratigraphy and depositional processes:***

- An understanding of stratigraphy and depositional processes provides valuable information for identifying aquifers/aquitards and their dimensions, and for assessing hydraulic properties, possible connections between aquifers, and recharge/discharge processes. Stratigraphic cross sections and assessments of depositional processes have been developed in detail across the North Okanagan (by Monahan, 2006, and Fulton, 2006, Section 4.6.3) and in the Oliver area (Toews, 2007, Section 4.6.14). Ongoing research in the Central Okanagan (by Thomson and Young, Section 4.6.10, and the GSC, Section 4.6.7) will provide useful information to characterize aquifers in these locations.
- Research and data compilation to assess stratigraphy and depositional processes is needed in many areas across the Okanagan Basin valley bottom, as well as benchland and upland areas where unconsolidated sediments are present.

***Aquifer/Aquitard delineation:***

- Specific knowledge/data regarding dimensions of individual aquifers are summarized on the Aquifer Information Tables, Appendix II. The Aquifer Information Tables can be reviewed to indicate data gaps for specific aquifer delineation information.
- As discussed in this report (Sections 4.2.2 and 5.5), much of the aquifer delineation work completed to date (i.e., BC MOE Aquifer Classification Maps), although completed extensively across the Okanagan Basin, is based on limited analysis of water well records, groundwater use data, and surficial geology/topography data. Detailed aquifer delineation work has been completed in the North Okanagan (Monahan, 2006) and Oliver area (Toews, 2006). Aquifers in other areas of the Okanagan Basin, however, have not been subject to rigorous analysis to confirm/modify boundaries, depths, thicknesses, or other attributes.

- As indicated previously in this report, a number of unmapped aquifers are indicated to be present within the Okanagan Basin. Delineation of these aquifers would be required to completely represent the hydrogeological system in the Okanagan Basin.
- Except for areas where detailed stratigraphic analysis has been completed, limited information has been compiled to delineate confining layers or aquitards.

***Aquifer properties:***

- Specific knowledge/data regarding individual aquifers is summarized on the Aquifer Information Tables, Appendix II. Data for all hydraulic properties are not available for every aquifer identified throughout the Okanagan. The Aquifer Information Tables can be reviewed to indicate data gaps for specific aquifers.
- Aquifer properties of hydraulic conductivity and transmissivity have been preliminarily defined for many of the aquifers within the Okanagan Basin by the Draft Aquifer Test Analyses provided by the BC MOE (Section 4.6.17). Storativity/specific yield are defined for a few aquifers based on these data. These aquifer properties will be further refined once the Final Aquifer Test Analyses are available. Estimates of hydraulic conductivity are also available for some provincial observation wells (Liskop and Allen, 2005).
- Unmapped aquifer hydraulic properties have not been compiled.
- The hydraulic parameters of confining layers or aquitards have not been defined through previous or ongoing research. (Toews, 2007, Section 4.6.14, provides model-calibrated values for some hydraulic properties of a glaciolacustrine silty clay aquitard beneath aquifers in the Oliver area).
- Data have not been compiled to assess aquifer anisotropy for most aquifers. Toews (2007) presents model-calibrated anisotropy ratios ($K_h/K_v$) for aquifers in the Oliver area (these anisotropy ratios are indicated on the Aquifer Information Tables).

***Aquifer Recharge and Discharge processes:***

- Ongoing research will provide a contribution to the understanding of direct recharge of precipitation to the shallow aquifers within the Okanagan Basin. Aquifer Recharge due to precipitation has been estimated by Toews (Section 4.6.14), for the Oliver area, and Smerdon et al. (Section 4.6.1), for the BX Creek area. Future work by Liggett (Section 4.6.13) will provide estimates of direct recharge to the valley bottom (unconfined) aquifers. Ongoing research by Voeckler (Section 4.6.11) may provide information to characterize direct recharge to fractured rock in the Penticton Creek watershed.
- Recently completed research by Toews, Section 4.6.14, provides, some information to understand the contribution of irrigation to recharge of shallow aquifers in the Okanagan Basin.
- BC Ministry of Agriculture and Lands will provide irrigation recharge values for the Okanagan Basin for a separate component of the Phase 2 Water Supply and Demand Project (Van der Gulik, 2007, pers. comm.).
- Recharge of shallow confined aquifers or partially confined aquifers due to precipitation has not been investigated.
- Information regarding recharge/discharge from/to creeks or lakes has not been quantified. (Current research by Neumann, Section 4.6.6, may provide preliminary data regarding these processes).
- Aquifer recharge/discharge due to leakage or hydraulic connections between aquifers has not been quantified to date.
- Mountain block recharge has not been assessed. Ongoing research by Voeckler, et al. (2007, in progress), may provide data regarding this aquifer recharge process.

***Surface water – groundwater interactions:***

- There are no data available to date to quantify surface water – groundwater interactions within the Okanagan Basin. Ongoing research by Neumann (in progress, Section 4.6.6) may provide preliminary data to assess surface water –

groundwater interactions near streams on alluvial fans at Shorts Cr, Vaseux Cr., and Vernon Cr.

- Aquifer discharge to surface water in the mainstem river-lake system in the valley bottom has not been specifically quantified/measured.
- The discharge of water from areas of bedrock adjacent to mainstem lakes has not yet been identified.

***Conceptual and numerical models of geology and hydrogeology:***

- Conceptual 3-dimensional models have been or will be developed for stratigraphy and geology in the North Okanagan (Monahan, 2006, Fulton, 2006, and Keller, 2007, Section 4.6.3), Oliver area (Toews, 2007, Section 4.6.14), Kelowna area (GSC, in progress, Section 4.6.7) and North Kelowna (Thomson and Young, in progress, Section 4.6.10). The geology of other areas of the Okanagan Basin, however, has not been modelled.
- Hydrogeological models have been developed and solved numerically for the BX Creek area (Smerdon, et al., in prep., Section 4.6.1) and Oliver area (Toews, 2007, Section 4.6.14).
- Future hydrogeological modelling will be completed for the Deep Creek watershed (Ping, et al., in progress, Section 4.6.4), Upper Penticton Creek watershed and Penticton areas (Voeckler, in progress, Section 4.6.11), and the Kelowna area (Jodrey, Section 4.6.8). Future regional-scale Okanagan Basin modelling will also be completed by Neilson-Welch, Section 4.6.9, and through subsequent components of the Phase 2 Water Supply and Demand Project.

***Groundwater flow directions and gradients:***

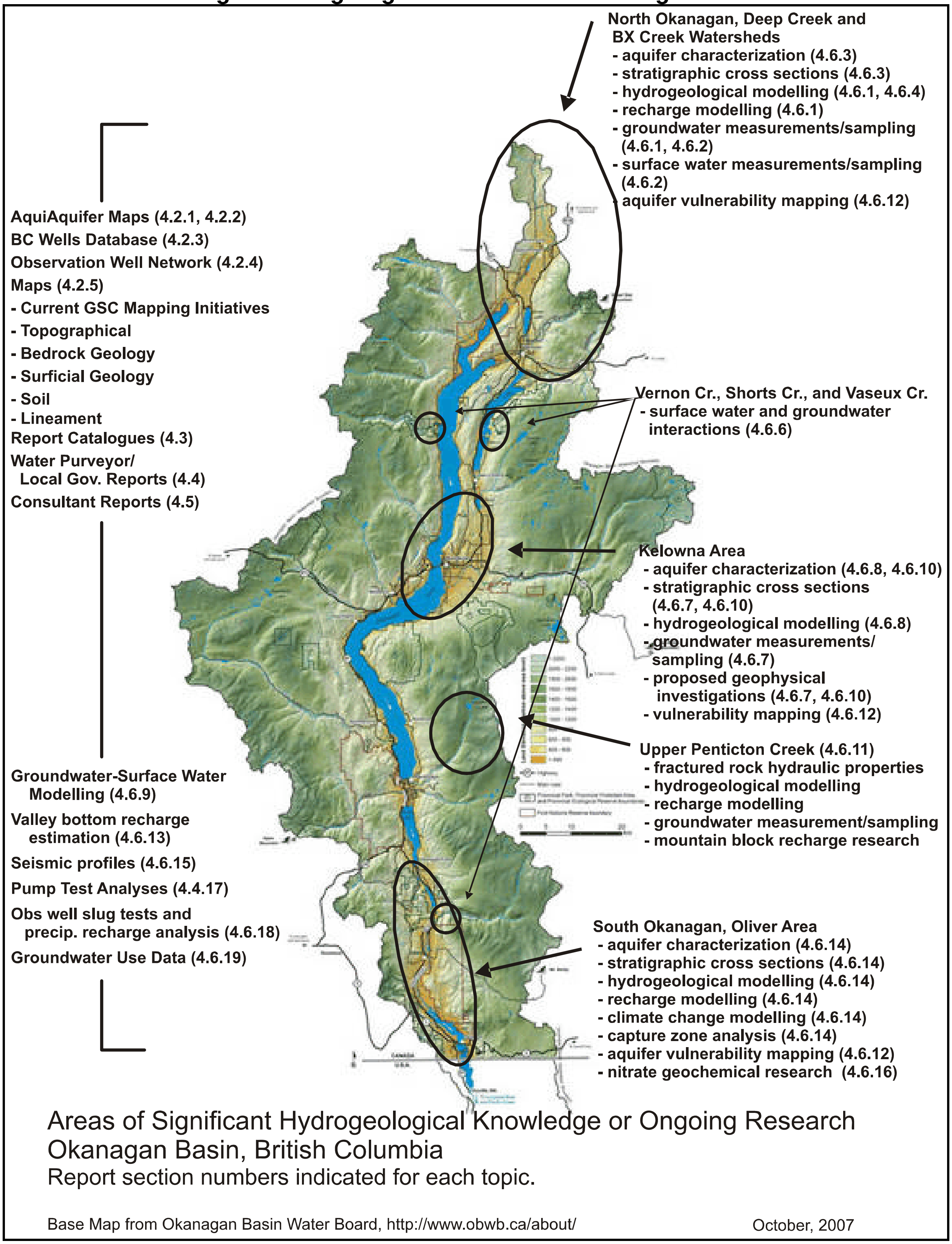
- Groundwater flow directions and gradients are not well defined for many areas across the Okanagan Basin. Toews (2007, Section 4.6.14) presents water level contour diagrams for the Oliver area. Some data regarding groundwater flow direction and gradients may be available for the North Okanagan (as part of the NOGWCA project, Section 4.6.2).

- Groundwater flow directions and gradients in deeper/confined aquifers have not been assessed.

***Groundwater use:***

- Groundwater use data are being compiled for a separate component of the Phase 2 Water Supply and Demand Project, but are not yet available.

**Figure 22: Map providing a visual summary of areas of hydrogeological knowledge and ongoing research in the Okanagan Basin.**



# 7 CONCLUSIONS/SUMMARY

This report provides a comprehensive summary of hydrogeological knowledge for the Okanagan Basin to satisfy Objective 1 of the Groundwater Component of the Phase 2 Water Supply and Demand Project. The report identifies a number of potential information sources for obtaining groundwater-related information and presents overviews of regional-scale, relevant, current, and ongoing hydrogeological research for the Okanagan Basin.

The following general conclusions are made regarding available information and data gaps:

- Potential information sources for compiling groundwater-related data for the Okanagan Basin were identified under the following categories: Databases and Maps, Report Catalogues, Water Purveyors and Local Government, Consultant Reports, and Current Research and Knowledge.
- The review of available information sources indicated that hundreds of groundwater-related reports (ranging from letters and laboratory reports, to larger more detailed studies) have been completed since approximately the 1950's. In general, the information provided in these catalogued reports is for local-scale projects (as defined in the scope of work, Section 2). Local-scale information is potentially useful for site-specific investigations and may be compiled using the databases, catalogues, and other sources referenced in this report.
- Regional-scale investigations for the Okanagan Basin mainly consist of recent and ongoing hydrogeological research being completed through universities and/or government. These research projects (summarized in Section 4.6) include: recent bedrock and surficial geology mapping, hydrogeological and geochemical modelling, surface water – groundwater modelling/assessment, groundwater sampling and measurements, aquifer characterization and mapping, stratigraphic/geological interpretations, recharge modelling, and aquifer test analyses. Some of the current research is applicable across the basin as a

whole. Other research projects are focussed; mainly on populated areas in the North, Central, and Southern Okanagan Basin.

- Relevant previously completed regional work is limited to the 1974 Supply and Demand Study (Section 3.1), the 2005 Phase 1 Supply and Demand work (Section 3.2), seismic profile work (from various sources, Section 4.6.15), and existing geological and soil maps (Section 4.2.5).

In general, the review of available information sources indicated that there are a number of regional-scale research projects that provide (or have the potential to provide) useful information regarding Okanagan Basin hydrogeology. Many of these research projects, however, are ongoing or yet to be published.

Data gaps related to developing a regional understanding of hydrogeological processes were discussed in Section 6. In general, the following needs are evident:

- Interpretations of stratigraphy (i.e., cross sections) and depositional environments for more areas across the Okanagan Basin.
- Delineation, laterally and vertically, of aquifers (previously identified or currently unmapped) based on current data and rigorous analysis.
- Quantification of hydraulic properties of aquifers and aquitards across the Basin where these data have not previously been obtained.
- An improved understanding of hydraulic connections between aquifers.
- An improved understanding of recharge and discharge processes influencing the different aquifers (including surface water – groundwater interactions and subsurface processes).
- Quantification of aquifer recharge/discharge due to different mechanisms.
- Groundwater flow direction and gradient information (for unconfined, confined, and bedrock aquifers)

Modelling work (conceptual and numerical), drilling investigations, field measurements, seismic/geophysical investigations, and soil and groundwater sampling and analysis, are examples of tools which can be used to address some of the datagaps identified above.

In general, based on the available information, there is a high degree of uncertainty regarding hydrogeological conditions within most watersheds – only a few detailed studies have been undertaken to date. Thus, there will be limitations regarding the certainty of values for parameters used in any future modelling work that is carried out in those areas. Future water supply modelling (e.g. through subsequent components of the Phase 2 Water Supply and Demand Project) should consider all uncertainties in developing groundwater models.

Although some data gaps have been identified, available data nevertheless provide a basis to initiate future Okanagan Basin hydrogeological investigations including future Phase 2 Water Supply and Demand Project work.

It is evident, based on the large number of ongoing research projects, and the coordination of this research under the auspices of the GAOB project, that there will be a significant increase in hydrogeological knowledge for the Okanagan Basin over the next decade. It will be important to consider current research for future water resources supply and demand studies to ensure that results and conclusions based on hydrogeological knowledge are as accurate as possible.

# 8 LIMITATIONS

This report has been prepared for Contract OBWB 07-005; "Work Scope for Objective 1 of the Phase 2 Groundwater Study (Task 5.3)" (OBWB, 2007a). The overall purpose of the work was to "develop a comprehensive State-of-the-Basin report that thoroughly documents the current state of knowledge of groundwater in the Okanagan Basin."

The focus of this report is to compile information which contributes to a **basin-wide** or **regional** understanding of hydrogeological processes. In keeping with this focus, "regional" reports, projects, data, and research have been defined as:

(a) those that provide information for areas approximately equivalent to the scale/size of a watershed (or sub-basin), and/or

(b) those that provide new and up-to-date information regarding specific hydrogeological concepts that could be extended to apply to other areas of the Okanagan Basin where data gaps exist.

With respect to the information sources referenced in this report, and the data compiled for the synthesis of information, the following general limitations are noted.

- The information presented in this report is current up to October 2007. Research toward increasing the understanding of hydrogeological conditions in the Okanagan Basin was ongoing at the time of preparation of this report. Future results of ongoing research may provide information which affects the content or conclusions of this report.
- Many of the sources for Okanagan Basin hydrogeological information consist of ongoing/unpublished research or "draft" data. Once these research projects are completed or published, final results may affect the content of this report.
- This report relies heavily on information and data collected, presented, communicated, and provided by others as referenced. The writer does not guarantee the accuracy of this information.

- Databases used and referenced in this report may have inherent errors and are subject to their own set of limitations.
- Limited data compilation was completed to summarize information for the purposes of this report (e.g., in the Aquifer Information Tables). The data compilation work completed does not represent a rigorous analysis of raw data.
- Inferences, where presented in this report, were made to provide a preliminary basis for understanding Okanagan Basin hydrogeology. The inferences presented are based on limited review of the information sources and do not represent a scientific analysis of all available data.

Further specific limitations are also noted on Maps in Appendix I, on the Aquifer Information Tables in Appendix II, within specific sections of this report, and on specific tables and figures throughout the report.

# 9 REFERENCES

Aller, L., Bennet, T., Lehr, J., Petty, R., and Hackett, G., 1987. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings. EPA-600/2-87-035, National Water Well Association, Dublin, Ohio/EPA Ada. Oklahoma.

Athanasopoulos, P., Hendry, M.J., Wassenaar, L., and Neilsen, D., 2007, pers. comm. or unpublished data.

BC Ministry of Agriculture and Lands (BCAL), Irigation Supply and Demand Project, in progress.

BC MOE, 2000, Well Protection Toolkit (WPT)

BC MOE, 2007, Draft Aquifer Classification Worksheets (ACW) and Spreadsheets, unpublished data.

BC MOE, 2007, EcoCat, BC Ministry of Environment Ecological Reports Catalogue. http://srmapps.gov.bc.ca/apps/acat/

BC MOE, 2007, draft aquifer test analyses, unpublished

BC MOE, 2007, NTS Library, BC Ministry of Environment, Victoria, BC, Science and Information Branch, Water Stewardship Division.

BC MOE, 2007, Water Stewardship Division website: http://www.env.gov.bc.ca/wsd/

BC MOE, 2007, Observation Well Network (OWN), http://www.env.gov.bc.ca/wsd/data_searches/obswell/index.html

BC MOE, 2007, personal communication or unpublished data

BC MOE, 2007, Water Resources Atlas (WRA), http://www.env.gov.bc.ca/wsd/data_searches/wrbc/

BC MOE, 2007, Well Logs (WL), BC Wells Database, http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells.html

Berardinucci, J., and Ronneseth, K., 2002. Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater, BC Ministry of Water, Land and Air Protection (now BC MOE).

Berger, K., 2004. The Hydrologic Evaluation of Landfill Performance (HELP) model: engineering documentation for HELP 3.80 D – Enhancements compared to HELP 3.07. Tech. Rep., Institute of Soil Science, University of Hamburg.

Cohen, S. and T. Kulkarni (eds.). 2001. Water management & climate change in the Okanagan Basin. Project A206, submitted to Climate Change Action Fund, Natural Resources Canada, Ottawa, 75 pp.

Cohen, S., D. Neilsen and R. Welbourn (eds.). 2004. Expanding the dialogue on climate change & water management in the Okanagan Basin, British Columbia. Final Report, Project A463/433, submitted to Climate Change Action Fund, Natural Resources Canada, Ottawa, 230 pp.

Cohen, S. and T. Neale (eds.). 2006. Participatory integrated assessment of water management and climate change in the Okanagan Basin, British Columbia. Vancouver: Environment Canada and University of British Columbia.

Dobson, D., 2007, personal communication or unpublished data, Okanagan groundwater use data, Dobson Engineering Ltd.

Eyles, N., Mullins, H.T., 1991. The seismic stratigraphy of Okanagan Lake, British Columbia; a record of rapid deglaciation in a deep “fiord-lake” basin. Sedimentary Geology 73, 13-41.

Fulton, R.J., 1965. Surficial Geology – Vernon. Geological Survey of Canada Map 1245A Scale 1:126,720.

Golder Associates Ltd. (Golder), 2007, personal communication.

Grasby, S., 2007, personal communication, Kelowna area geological research, by Deblonde, C., Grasby, S., and Paradis, S., Geological Survey of Canada.

Jochum, E., Nichol, C., Seebacher, T., and Wei, A., 2007. Report 1 - Scoping Report to Pacific Salmon Foundation – April 2007.

Keller, G., 2007, unpublished. 3D Aquifer Model of the Deep Creek/BX Creek Watersheds, British Columbia, Canada., report prepared for BC Ministry of Environment.

LeBreton, E.G., Halstead, E.C., and Hall, P.L., 1972. Canada – British Columbia Okanagan Basin Agreement – A Hydrogeological Study of the Okanagan River Basin – Tasks 38, 39, 40, 41 (Sept. 1972).

Liggett, J., and Allen, D.M., 2007, personal communication or unpublished data. Okanagan Basin valley bottom recharge modelling, Department of Earth Sciences, Simon Fraser University.

Liskop, T., 2005, Observation Well Testing and Recharge Characterization of the Okanagan Basin, British Columbia. Unpublished, B.Sc. thesis, Department of Earth Sciences, Simon Fraser University, Burnaby, BC.

Liskop, T. and Allen, D., 2005. Observation Well Testing and Recharge Characterization of the Okanagan Basin, BC. Report prepared for BC Ministry of Water, Land and Air Protection, April 2005.

Marr, B.E., et al., 1974. Main Report of the Consultive Board including the Comprehensive Framework Plan prepared under the Canada-British Columbia Okanagan Basin Agreement. 516p.

MacAulay, H.A., Hobson, G.D., 1972. A seismic refraction survey of the North Okanagan and south Shuswap Valleys. GSC Paper 72-8, Part A, Geological Survey of Canada.

Massey, N.W.D., MacIntyre, D.G., Desjardins, P.J., and Cooney, R.T., 2005. Digital Geology Map of British Columbia: Tile NM11 Southeast B.C., B.C. Ministry of Energy and Mines, GeoFile 2005-4.

McElhanney Consulting Services Ltd., 2006. Okanagan Basin Fault and Fracture Mapping from Aerial, Satellite and DEM Imagery, Progress Map – Feb. 6, 2006, prepared by McElhanney Consulting Services Ltd., prepared for BC Ministry of Environment.

Monahan, P.A., 2006. North Okanagan Aquifer Mapping Project., prepared for BC Ministry of Environment., unpublished.

Mullins, H.T., Eyles, N., Hinchey, E.J., 1990. Seismic reflection investigation of Kalamalka Lake: a “fiord lake” on the Interior Plateau of southern British Columbia. Canadian Journal of Earth Sciences 27, 1255-1235.

Nasmith, H., 1962. Late Glacial History and Surficial Deposits of the Okanagan Valley, British Columbia. B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 46, 46p.

Neumann, N., 2007, personal communication or unpublished data, Surface water – groundwater interaction research, Okanagan Basin, by Neumann, N., Curtis, P.J., and Wei, A. (UBCO), Allen, D., (SFU), and Wright, H., Okanagan Nation Alliance.

Nichol, 2007, personal communication or unpublished data, Fortune Creek Watershed research by Jochum, E., Nichol, C., Seebacher, T, and Wei, A., University of British Columbia Okanagan, Department of Chemistry, Earth and Environmental Sciences.

Nichol, C., Ping, J., and Wei, A., 2007, personal communication or unpublished data, Deep Creek Watershed research. University of British Columbia Okanagan (UBCO), Department of Chemistry, Earth and Environmental Sciences.

Okanagan Basin Water Board, 2007a, Contract OBWB 07-005; Work Scope for Objective 1 of the Phase 2 Groundwater Study (Task 5.3).

Okanagan Basin Water Board, 2007b, website, http://www.obwb.ca/

Pullan, S.E., Hunter, J.A., Burns, R.A., and Good, R.L., 1992. "Optimum offset" shallow seismic reflection profiles from the Okanagan Valley, British Columbia. Geological Survey of Canada, Open File 2545, 22p.

Roed, M.A., and Greenough, J.D., editors, Okanagan Geology, British Columbia. Kelowna Geology Committee, 2004. 220p.

Schmidt, O., BC Ministry of Agriculture and Lands, 2007, personal communication.

Schroeder, P. R., Dozier, T.S., Zappi, P.A., McEnroe, B.M, Sjostrom, J.W., Peyton, R.L., 1994. The Hydrologic Evaluation of Landfill Performance (HELP) model: Engineering documentation for version 3. EPA/600/R-94/168b, U.S. Environmental Protection Agency Office of Research and Developement, Washington, DC, USA.

Smerdon, B.C., Allen, D.M., Berg, M.A., Belland, E., and Grasby, S., in preparation. Linkages between upland water sources and valley bottom aquifers in a mountainous watershed. Department of Earth Sciences, Simon Fraser University.

Stewart, T., 2007, pers. comm., or unpublished data, BC Ministry of Environment, Penticton.

Summit Environmental Consultants Ltd., 2005. Okanagan Basin Water Supply and Demand Study: Phase 1, May 2005.

Summit Environmental Consultants Ltd., 2007. Map 1, The Okanagan Basin in British Columbia, produced by BdJ, May 2007.

Thomson, S., and Young, R., 2007, personal communication, stratigraphy research in North Kelowna, Department of Chemistry, Earth and Environmental Sciences, University of British Columbia Okanagan.

Thompson, R.I., 2003. Geology, Vernon, British Columbia, GSC Open File 4375.

Toews, M.W., 2007, in preparation. Modelling the Effects of Climate Change on Groundwater in Oliver, British Columbia, unpublished MSc. Thesis., Department of Earth Sciences, Simon Fraser University.

Toews, M.W., and Allen, D.M., 2007. Aquifer Characterization, Recharge Modelling and Groundwater Flow Modelling for Well Capture Zone Analysis in the Oliver Area of the Southern Okanagan, BC. Draft Report to Water Stewardship Division, Ministry of Environment, Victoria, BC.

Vanderburgh, S., 1993. Basin architecture of the north Okanagan Valley fill, British Columbia. Ph.D. thesis, Simon Fraser University, 8888 University Driver, Burnaby, BC.

Vanderburgh, S., Roberts, M.C., 1996. Depositional systems and seismic stratigraphy of a Quaternary basin; north Okanagan Valley, British Columbia. Canadian Journal of Earth Sciences 33, 917-927.

Van der Gulik, T., BC Ministry of Agriculture and Lands, 2007, personal communication.

Voeckler, H., 2007. In progress or personal communication.

Voeckler, H., Allen, D. (SFU), and Alila, Y. (UBC), 2007, personal communication or unpublished data. Estimating Groundwater Recharge to a Headwater Catchment as a Basis for Mountain Block Recharge (MBR) Modelling: An Integrated Surface Water – Groundwater Modelling Study.

Wei, M., Ronneseth, K, Allen, D., Kohut, A.P., Turner, B., and Grasby, S. Types and general characteristics of aquifers in the Canadian Cordillera Hydrogeologic Region. In: Proceedings 8th Annual Canadian Geotechnical Society - International Association of Hydrogeologists Joint Conference, OttawaGeo2007: The Diamond Jubilee Conference, Ottawa, October 21-24, 2007.

Wilson, J.L. and Guan, H., 2004, Mountain-block hydrology and mountain front recharge. In: J.F. Hogan, F.M. Phillips, and B.R. Scanlon (Eds.), Groundwater Recharge in a Desert Environment, The Southwestern United States, Water and Science Application 9, American Geophysical Union, p. 113-137.

# 10 GLOSSARY

**Glossary Source**:
http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/gwbc/appendices/glossary.html

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**ALLUVIAL DEPOSITS** — The general name for all sediments, including clay, (**ALLUVIUM**) silt, sand, gravel or similar unconsolidated material deposited in a sorted or semi-sorted condition by a stream or other body of running water, in a stream bed, floodplain, delta or at the base of a mountain slope as a fan.

**AMBIENT GROUND WATER FLOW** — The rate of flow and direction of flow of ground water under unpumped, natural conditions.

**ALLUVIAL FANS** — A fan shaped deposit of detrital material deposited by a stream where it emerges from a steep mountain slope or from an upland onto a less steeply sloping terrain.

**ANION** — A negative electricity charged ion such as a nitrate or chloride ion.

**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.)

**AQUIFER DEPLETION** — Aquifer depletion occurs when ground water is withdrawn from an aquifer at a rate greater than it can be replenished.

**AQUIFER TEST** — A test conducted by pumping a well to determine aquifer or well characteristics.

**AQUIFER VULNERABILITY** — A measure of how vulnerable an aquifer is to contamination.

**AQUIFER VULNERABILITY MAPPING** — Mapping the vulnerability of an aquifer to contamination from sources. Vulnerability mapping does not consider the type of land use above an aquifer, only the intrinsic vulnerability of the aquifer, typically based on the type, thickness, and extent of geologic materials overlying an aquifer, depth to water, and type of aquifer materials.

**ARTESIAN AQUIFER** — See Confined Aquifer.

**ARTESIAN WELL** — A well obtaining its water from an artesian or confined aquifer in which the water level in the well rises above the top of the aquifer. The water level in a flowing artesian well rises above the land surface.

**BASE FLOW** — The sustained low flow in a stream. Generally base flow is the inflow of ground water to the stream.

**BEDROCK** — Rock underlying soil and other unconsolidated material.

**CAPTURE ZONE** — The land area that contributes ground water to or recharges a pumping well.

**CATION** — A positive electrically charged ion such as a sodium or calcium ion.

**COEFFICIENT OF STORAGE** — See Storage Coefficient.

**COLLUVIAL DEPOSITS** — Weathered, unconsolidated materials transported and deposited by gravity.

**CONFINED AQUIFER** — Confined is synonymous with artesian. A confined aquifer or an artesian aquifer is an aquifer bounded both below and above by beds of considerably lower permeability than that existing in the aquifer itself. The ground water in a confined aquifer is under pressure that is significantly greater than that existing in the atmosphere.

**CONFINING BED** — A bed of impermeable material stratigraphically adjacent to one or more aquifers. Confining bed is now used to replace terms such as "aquiclude", "aquitard" and "aquifuge".

**CONTAMINANT** — Solute which, through human action, intrudes into the hydrologic cycle.

**CONTAMINANT PLUME** — Contaminants which encroach into a ground water system are moved down gradient. The area of the aquifer containing the degraded water which resulted from the migration of a pollutant is called a contaminant plume.

**CONTAMINATION** — Impairment of natural water quality by chemical or bacterial pollution as a result of human activities. The degree of contamination allowed before an actual hazard to public health is created will depend upon the intended end use, or uses of the water.

**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.

**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.

**DRIFT (GLACIAL)** — Glacial drift includes all rock material in transport by glacier ice, the deposits made by glacier ice and all materials mainly of glacial origin deposited in the sea or in glacial melt water bodies including materials rafted in by ice bergs or transported indirectly in the water itself. Glacial drift therefore includes till, rock fragments and stratified drift.

**DRILLED WELL** — A well that is constructed with a drilling rig, such as an air rotary or cable tool drilling rig.

**DUG WELL** — A well that is dug by hand or excavated by backhoe. Dug wells are usually shallow.

**EVAPOTRANSPIRATION** — Loss of water from a land area through transpiration of plants and evaporation from the soil.

**FAULT** — A fracture in the earth's crust along which dislocation has taken place so that the rocks on one side of the fault have been displaced in relation to those on the other side.

**FLOODPLAIN** — The flat land adjacent to a river, formed by deposition of fluvial materials.

**FLOWING ARTESIAN WELL** — A well where the water level is above the ground surface.

**FLUVIAL DEPOSITS** — Deposits related to a river or stream.

**FRACTURE** — A break or crack in the bedrock.

**GEOMORPHOLOGY** — Geomorphology is the science dealing with the origin and evolution of land forms.

**GLACIAL DRIFT** — See Drift (Glacial).

**GLACIO-FLUVIAL DEPOSITS** — Deposits related to the joint action of glaciers and melt water streams.

**GROUND WATER** — Water in the zone of saturation, that is under a pressure equal to or greater than atmospheric pressure.

**GROUND WATER CATCHMENT AREA** — An area contributing natural replenishment (recharge) of the ground water regime. It may include localized discharge areas.

**GROUND WATER DIVIDE** — The uppermost boundary of a ground water basin.

**GROUND WATER MINING** — Permanent depletion of ground water reserves.

**GROUND WATER 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.

**HANGING VALLEY** — Where the valley floor of a tributary stream lies or "hangs" above the floor of the main valley. Hanging valleys may occur where the main valley has been glaciated.

**HARDNESS** — When hard water is used with soap it will form an insoluble residue and hard water will form a scale in utensils in which the water has been allowed to evaporate. Hardness is mainly caused by calcium and magnesium ions. Hardness is generally expressed in mg/L calcium carbonate (Ca CO3).

**HETEROGENEOUS DEPOSIT** — Non-uniform structure and composition throughout the deposit.

**HOMOGENEOUS DEPOSIT** — Structure or composition of the deposit is uniform throughout.

**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.

**ICE CONTACT DEPOSITS** — Drift sediment deposited in contact with its supporting ice.

**IGNEOUS ROCKS** — Rocks that solidified from molten or partly molten materials, that is from a magma or lava.

**IMPERMEABLE** — Impervious to flow of fluids.

**INCRUSTATION** — Mineral matter deposited by water. One of the major causes of well failure is the chemical and biological incrustation of well screen through precipitation of calcium and magnesium carbonates or sulphate's. The precipitation of iron and manganese compounds and slime producing iron bacteria will also plug well screens.

**INDURATED** — A compact rock hardened and solidified by post depositional chemical and physical alterations.

**INFILTRATION RATE** — The rate at which water permeates the pores or interstices of the ground.

**INTERMONTANE VALLEY** — A valley located between or surrounded by mountain ranges, mountains or mountainous regions.

**ISOTROPIC** — Exhibiting properties with the same values in all directions.

**KETTLE** — A closed depression made in 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.

**LEACHATE** — Fluid percolating through a land fill.

**LEVEL OF GROUND WATER DEVELOPMENT** — The level of ground water use of an aquifer relative to the aquifer's ability to replenish itself.

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

**MARINE DEPOSITS** — Mostly silt and clay materials deposited under a marine environment.

**MEDIAN** — Being in the middle or in an intermediate position.

**MELTWATER CHANNEL** — A channel shaped by water coming from the melting of snow or glacier ice.

**MESOZOIC** — Geologic era preceding the Cenozoic Era. The Mesozoic Era was a time when the rocks of the Triassic, Jurassic and Cretaceous Systems were deposited.

**METAMORPHIC ROCKS** — Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.

**MONADNOCK** — From Mount Monadnock in New Hampshire (1893). A Monadnock is an isolated hill standing conspicuously above a peneplain. (A peneplain is a land surface worn down to an area of low relief by stream erosion and mass wasting.

**MORAINE** — An accumulation of unsorted unstratified glacial drift mainly till, deposited by glacial ice. Drift deposited in the flanks of a valley glacier form a lateral moraine. Glacial deposits which have accumulated at the front of a glacier form a terminal moraine. Deposits of drift which have been dragged along beneath the ice form ground moraine.

**OBSERVATION WELL** — A well constructed for the objective of undertaking observations such as water levels, pressure readings and ground water quality.

**OROGENY** — The deformation of the earth's crust to form mountains.

**OUTWASH DEPOSITS** — Stratified drift deposited by meltwater streams flowing away from melting ice.

**OVERBURDEN** — The layer of fragmental and unconsolidated material including loose soil, silt, sand and gravel overlying bedrock, which has been either transported from elsewhere or formed in place.

**OVERLAND RUNOFF** — That part of precipitation flowing overland to surface streams.

**PALAEOZOIC** — Geological era preceding the Mesozoic Era. The Palaeozoic is a major division of geologic time and it includes in descending order the Permain, Carboniferous, Devonian, Silurian, Ordovician and the Cambrian.

**PERCHED WATER TABLE** — A separate continuous body of ground water lying (perched) above the main water table. Clay beds located within a sedimentary sequence, if of limited aerial extend, may have a shallow perched ground water body overlying them.

**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.

**pH** — A numerical measure of the acidity or alkalinity of water ranging from 0 to 14. Neutral waters have pH near 7. Acidic waters have pH less than 7 and alkaline waters have pH greater than 7.

**PHYSIOGRAPHY** — Physical geography.

**PIEZOMETER** — Pressure reading and measuring instrument connected to a short sealed off length of a drill hole or hydrogeologic unit.

**PIEZOMETRIC SURFACE** — Imaginary surface defined by the elevation to which water will rise in wells penetrating confined aquifers.

**PLATEAU** — An elevated land surface of large areal extent where the surface is nearly level.

**PLEISTOCENE** — The period following the Pliocene during which an ice sheet covered the greater part of North America. Named by Lyell in 1839.

**POLLUTION** — Contamination of the environment with objectionable or offensive matter.

**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.

**POTENTIAL WELL YIELD** — An estimate of well yield generally above the existing yield rate or test rate, but considered possible on the basis of available information, data and present well performance.

**PUBLIC INVOLVEMENT** — The process by which the views of all parties interested in a proposed government decision are integrated into the decision-making process. It is a dynamic process that attempts to identify, record, analyze and synthesize ideas, concerns, needs and values before recommendations are given to government decision makers.

**PUMPING INTERFERENCE** — The condition occurring when a pumping well lowers the water level in a neighbouring well.

**PUMPING TEST** — A test conducted by pumping a well to determine aquifer or well characteristics.

**QUATERNARY** — The period of geologic time that follows the Tertiary. The Quaternary includes the Pleistocene and Recent Periods and is part of the Cenozoic Era.

**RADIUS OF INFLUENCE** — The radial distance from a pumping well to the point where there is no drawdown of the water table or piezometric surface. This point marks the edge of the cone of depression around the pumping well.

**RECHARGE AREA (GROUND WATER)** — 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.

**SALINE GROUND WATER** — Ground water consisting of or containing salt.

**SALT WATER INTRUSION** — Movement of salty or brackish ground water into wells and into aquifers previously occupied by fresh or less mineralized ground water either through upconing or sea water encroachment.

**SANDPOINT** — A well pipe with a screen, equipped with a hardened, conical point at the bottom, that is driven into the ground to tap shallow ground water.

**SANDSTONE** — A sedimentary rock composed of mostly sand sized particles.

**SANITARY SURFACE SEALS** — A grouted annular space around the well casing which usually extends from the land surface to several metres deep. The sanitary well seal functions to prevent any contaminated surface and near surface water from seeping down the side of the well to the aquifer.

**SATURATED ZONE** — The subsurface zone in which all voids are ideally filled with water under pressure greater than atmospheric.

**SEA WATER ENCROACHMENT** — The lateral landward movement of sea water into wells and freshwater aquifers.

**SEDIMENTARY ROCKS** — Rocks formed from consolidation of loose sediments such as clay, silt, sand, and gravel.

**SHALE** — A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

**SPECIFIC CAPACITY** — The rate of discharge of a water well per unit of drawdown. Specific capacity can be expressed as L/s/m of drawdown.

**SPECIFIC CONDUCTANCE (GROUND WATER)** — The ability of a water sample to conduct an electric current. Specific conductance is related to the concentration of dissolved solids in a water sample. A rapid determination of TDS of a water sample can be made by measuring the electrical conductance.

**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.

**STORAGE COEFFICIENT** — Volume of water stored or released from a column of aquifer with unit cross section under unit change in head.

**SURFICIAL DEPOSITS** — Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.

**SUSTAINED YIELD** — Rate at which ground water can be withdrawn from an aquifer without long-term depletion of the supply.

**TERTIARY** — Geologic period of the Cenzoic Era and that period prior to the Quaternary.

**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.

**TOTAL DISSOLVED SOLIDS (TDS)** — Concentration of total dissolved solids (TDS) in ground water expressed in milligrams per litre (mg/L), is found by evaporating a measured volume of filtered sample to dryness and weighing this dry solid residue.

**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 DEPOSITS** — 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.

**UPCONING** — Upward movement of salty or brackish ground water into wells and into aquifers previously occupied by fresh or less mineralized ground water.

**UNSATURATED ZONE** — The zone between the land surface and the water table. The pore spaces, interstices, contain water at less than atmospheric pressure, and also air and other gases. Perched ground water bodies (local saturated zones) may exist in the unsaturated zone.

**VARVE** — Laminated clays and fine grained sediments of glacial origin deposited in lakes during the retreat of glacial ice. Each lamina or varve has a thicker coarser layer and a finer layer which represent a years seasonal cycle of deposition. Varve is the Swedish word for cycle.

**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.

**WELL DEVELOPMENT** — This operation helps make water enter the well more easily and can make the difference between a satisfactory and an unsatisfactory well. Different techniques for well development can be used, the aim is to remove the smaller sized particles from the aquifer surrounding the well screen and to provide a coarser filter zone around the screen. The smaller sized particles are drawn into the well screen and can then be removed by bailing or pumping.

**WELLHEAD PROTECTION** — Protection of the recharge (or capture zone) area of a pumping well.

**WELL INTERFERENCE** — When the area of influence, or the cone of depression around a water well comes into contact with or overlaps that of a neighbouring well pumping from the same aquifer and thereby causes additional drawdown or drawdown interference in the wells.

**WELL POINTS** — Also referred to as sand points, gravel points,are used in shallow permeable unconfined (usually) aquifers generally less than 30 feet deep. Well points consist of a short length of screened pipe with a sharp point on the bottom end. As the pipe is driven into the ground, additional lengths of pipe are added to the top end. Sand points are also available with a check valve at the lower end to enable the pipe to be washed down in sand and fine gravel aquifers. Water can be pumped down the pipe and it passes out the check valve at the bottom and washes the sand up the hole to the ground surface.

**WELL SEALS** — Cover for the top of the well.

**WELL SCREEN** — A cylindrical filter used to prevent sediment from entering a water well. There are several types of well screens, which can be ordered in various slot widths, selected on the basis of the grain size of the aquifer material where the well screen is to be located. In very fine grained aquifers, a zone of fine gravel or coarse sand may be required to act as a filter between the screen and the aquifer.

**WELL YIELD** — The volume of water discharged from a well in litres per minute (L/min), litres per second (L/s) or cubic metres per day ($m^3$/day).

**ZONE OF SATURATION** — See Saturated Zone.

# 11 LIST OF ACRONYMS

ACW – Draft Aquifer Classification Worksheets

BC MOE – British Columbia Ministry of Environment

GIS – Geographic Information System

GSC – Geological Survey of Canada

LUAM – Land Use Allocation Model

MCM – Mixing Cell Model

MWLAP – British Columbia Ministry of Water Land and Air Protection

NOGWCA – North Okanagan Groundwater Characterization and Assessment

NORD – North Okanagan Regional District

NTS – National Topographic System

OBWRID – Okanagan Basin Water Resources Information Database

OCP – Official Community Plan

OWN – Observation Well Network

SFU – Simon Fraser University

UBCO – University of British Columbia Okanagan

WL – Water Well Logs

WPT – Well Protection Toolkit

WRA – Water Resources Atlas

WTN – Well Tag Number

# Appendix I

## Maps

# Appendix II

## Aquifer Information Tables
## And Limitations