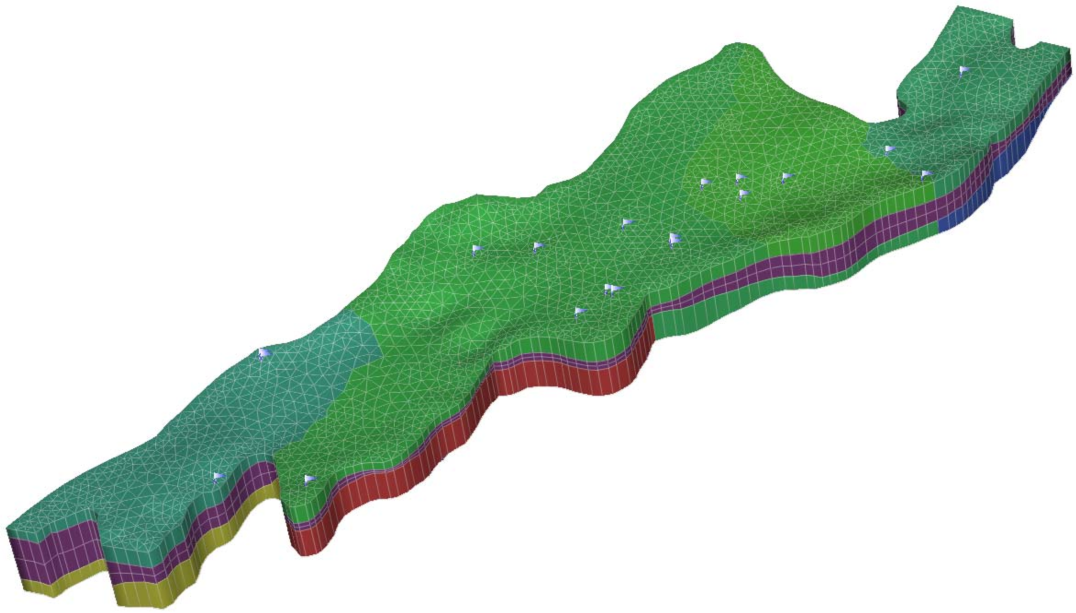
Numerical Groundwater Modeling in the Deep Creek Watershed



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Executive Summary

Numerical groundwater modeling in the Deep Creek watershed is part of the North Okanagan Groundwater Characterization and Assessment Project funded by the Canada-British Columbia (BC) Water Supply Expansion Program and the BC Ministry of Environment. The key objective of the numerical groundwater modeling component implemented at the University of British Columbia Okanagan (UBCO) is to integrate all available hydrogeological data to quantitatively assess groundwater flow, and gain insight into current and future groundwater resources. It is expected that the results from this project will support water planning and management efforts by the local communities in the North Okanagan including City of Armstrong and the Township of Spallumcheen.

The main valley bottom in the North Okanagan trends from the north end of Okanagan Lake north-northeast to Enderby. It contains both the Deep Creek watershed (230.1 km^2) which flows southwards to Okanagan Lake, and the Fortune Creek watershed (160.9 km^2) which flows northwards to the Shuswap River at Enderby. The boundary of the two watersheds is just north-east of the City of Armstrong. The groundwater system in the Deep Creek and Fortune Creek watersheds is complex, comprising 19 Quaternary unconfined and confined aquifers. Two major regional aquifers (Spallumcheen A and B) overlie each other in valley center. Early in the project, groundwater heads indicated groundwater flow from the Fortune Creek watershed to the Deep Creek watershed, and hence the original project boundaries were extended to include the Fortune Creek watershed.

To understand groundwater flow in this complex aquifer system, physical measurements and geochemical sampling were conducted in 2007-2008. A combination of hydrologic, hydrogeological, geochemical and modeling approaches was employed to quantify water fluxes, aquifer characteristics, groundwater flow, and groundwater recharge and discharge.

The following summarizes the key activities of the project:

- Stream flow measurements

Four continuous and six manual hydrometric stations were installed at the beginning of the project on Deep Creek and Fortune Creek to collect streamflow data. The continuous stations are operated from spring thaw (March/April) to fall (~November). For manual stations, streamflow measurements were conducted once per month or shorter intervals in the summer and once every other month in the winter.

- Monitoring of static water levels

Fifty-four wells were selected for static water level measurement. Forty-nine wells were measured manually once every two weeks in summer and once per month in winter.

- Water samples for chemical analysis

Groundwater (61 samples), surface water (19 samples) and precipitation (6 samples) were analyzed for full chemistry. These were combined with historical monitoring data of both surface and groundwater from the BC Ministry of Environment databases.

- Water samples for isotopic analysis

Both surface water and groundwater were also sampled for the isotopes of deuterium and oxygen. Sixty four water samples including 44 groundwater samples, 14 surface water samples and 6 precipitation samples were analyzed for stable isotopes in water.

- Data analyses

Physical data such as streamflow and groundwater heads were analyzed to understand groundwater flow, and surface water and groundwater interactions. Piper plots of the general geochemistry and deuterium-oxygen scatter plots of the isotope data were used to further understand groundwater flow between aquifers and water exchanges between surface water and groundwater systems.

- Groundwater modeling

The finite-element groundwater modeling package FEFLOW (Version 5.301) was employed to simulate steady-state groundwater flow in the two main confined aquifers within the main valley (Spallumcheen A and B). This helped to estimate mountain system recharge and overall groundwater flows in the main regional groundwater systems.

Through integrated analysis of hydrologic, hydrogeological, geochemical and modeling methods, we have the following major conclusions:

1. Groundwater vertical exchange between the two regional aquifers Spallumcheen A and Spallumcheen B is significant. Groundwater flow upwards from Spallumcheen B to Spallumcheen A in the Fortune Creek watershed, while this flow direction is reversed in the central part of Deep Creek watershed. The magnitude of this exchange represents about 30% of total recharge of Spallumcheen A.

2. Surface-groundwater interactions are important in the study area. Surface water and groundwater exchange both ways in the Hullcar and Sleepy Hollow areas of Deep Creek. Downstream of this aread, Deep Creek gains water from Otter Lake south. Fortune Creek has been found to contribute to groundwater at its origin, and receive groundwater in the main valley floor.

3. The physical data, geochemical data and simulation results all confirm that mountain system recharge is the major recharge source of the confined aquifers contributing 78% of the total. The modeled mountain system recharge varies from 5.0% to 6.6% of precipitation on the mountain areas. This results in model average mountain block recharge to the confined aquifers of about 3.6 % to 4.8% of precipitation.

4. About 34 % of groundwater discharges into surface water (Deep Creek, Otter Lake, and Fortune Creek) within the modeling area (5800 m^3/day). Groundwater within the regional aquifers contributes 45% (7800 m^3/d) to Okanagan Lake at the southern boundary of the modeling area.

5. Long-term groundwater level monitoring data show a general decline of groundwater heads in the main Spallumcheen A aquifers. This may raise a potential issue on long-term groundwater sustainability. The declines are most likely due to increased groundwater extraction.

Acknowledgements

During implementation of this project, we have received valuable support and assistance from various organizations and professionals. It would have been impossible to move the project to this stage without this support. We list their names here to express our sincere appreciation of their efforts.

Project Management

- Des Anderson, Trina Koch, Oleg Ivanov, Skye Thomson, MOE

Study Partners

- Township of Spallumcheen (TOS)
- City of Armstrong
- The residents of Spallumcheen and Armstrong
- John Pardell, TOS
- Terry Langlois, City of Armstrong
- Mayor Will Hansma, TOS
- Ron Christian, Splat'sin First nations
- North Okanagan Regional District
- Golder Associates

Associated Studies

- Dr. Pat Monahan
- Dr. Bob Fulton
- Greg Keller, Manitoba Geological Survey
- Dr. Allan Woodbury University of Manitoba

Aquifer Testing

- Sylvia Kenny and Vicki Carmichael, MOE, Colleen Gellein and Dr. Diana Allen, SFU

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- Trina Koch , Jeptha Ball, Skye Thomson, MOE
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Technical Review

- Vicki Carmichael, Oleg Ivanov, MOE
- Remi Allard, Sustainable Subsurface Solutions
- Dr. Brian Smerdon, CSIRO Land and Water

Chapter 1 Introduction

1.1 Water Resource Issues in the Okanagan valley

The Okanagan valley is situated in the semi-arid southern interior of British Columbia (BC). Due to population growth, increasing water demand and the possible impacts of climate change, there are growing concerns over shortages of water resources to meet the needs of future economic and social development in the valley. There is a general trend towards withdrawing more groundwater as stream water in the basin tributaries is nearly fully allocated or licensed.

Concerns have been raised over the quantity and quality of groundwater resources and how groundwater pumping may affect surface stream flows. There is a need for regional groundwater studies to understand groundwater availability and vulnerability and to examine possible impacts of groundwater extraction on future water supply and watershed processes.

A series of prior studies have examined water resource issues in the Okanagan at both large and local scales. A comprehensive basin-wide study initiated in 1969 jointly by the Province of British Columbia (BC) and the Government of Canada focused on various management aspects such as water quantity, water quality, waste treatment, socio-economics, limnology and fisheries (Consultative Board, 1974). This was the first comprehensive basin-scale water resource assessment of the Okanagan Basin. A subsequent climate change and adaptation study was conducted by various organizations to assess the impacts of climate change on basin water resources (Cohen and Kulkarni, 2001, Cohen et al., 2004).

Localized groundwater studies have been conducted by various consultants and are accessible through the Ecological Reports Catalogue (B.C. Ministry of Environment, 2009). A review of data sources for Okanagan water resources was completed concurrent to this study (Neilsen-Welch and Allen, 2007). Several academic or research studies have been completed or are in progress in other parts of the Okanagan Basin (e.g.: Groundwater Resources Research Group, Simon Fraser University).

The Okanagan Basin Water Supply and Demand study commenced in 2004 is a basin-wide study led by the Okanagan Basin Water Board and the BC Ministry of Environment. It aims to quantify water supply and demand under historical conditions and under various climate change and population growth scenarios. This study has run concurrent to the study described in this report.

1.2 Background and Objectives of This Study

The BC Ministry of the Environment obtained funding from the Canada - BC Water Supply Expansion Program in 2005 for a two-year study of the water resources that supply the Township of Spallumcheen and the City of Armstrong from within the Deep Creek watershed. As the aquifers underneath of the Deep Creek watershed extend to within the surface watershed boundaries of the Fortune Creek watershed, the project boundaries were extended to include the Fortune Creek watershed. This project is called the North Okanagan Groundwater Characterization and Assessment Project (NOGWCA). The key objectives were to undertake a comprehensive evaluation of the groundwater and surface water resources of the North Okanagan, and to provide management strategies for long-term water resource sustainability.

The NOGWCA project included: characterization of the principal hydrogeological units and aquifers (Monahan, 2006); geological depositional interpretations and an evaluation of the impact of these on trends in aquifer hydraulic properties (Fulton, 2006); three-dimensional aquifer geometry modeling (Keller, 2006); quantification of principle irrigation demands by the BC Ministry of Environment; sampling of background groundwater chemistry and general suitability; land use and planning modeling by the Geological Survey of Canada; and numerical groundwater modeling of the North Okanagan aquifers by UBC Okanagan.

These studies all contribute data towards a numerical groundwater model as shown in Figure 1.1. The numerical groundwater modeling component utilizes data and results from other components. Appendix 1.1 contains a summary of the studies and reports that have been undertaken during the NOGWCA study or provided to UBCO in support of the preparation of a groundwater model.

This report presents the work undertaken by UBCO in support of a numerical groundwater model of the North Okanagan. Due to the limited data available for model construction and calibration at the project start, significant effort was expended to collect data on surface water flows, groundwater flow and chemistry, and recharge rates. The followings present a brief description of key tasks undertaken by UBCO.

1.2.1 Field data collection

Field investigations undertaken by UBCO as part of the NOGWCA project included:

- Streamflow measurements in Deep Creek and Fortune Creek to determine locations of groundwater and surface water interaction and to quantify watershed budgets,
- Static groundwater level monitoring to provide data for aquifer assessment, water balance calculations, conceptual model development and numerical model

- Surface and groundwater sampling for geochemistry and isotopic analyses.

The detailed methods and results of these field investigations are presented in the following chapters as outlined in Section 1.3.

1.2.2 Hydrogeochemistry

Early work in the Deep Creek watershed indicated that physical measurements alone would likely not be sufficient to properly understand or quantify the groundwater regime in the North Okanagan. Physical measurements of hydraulic parameters and static water levels in various aquifers were limited. The quantity of recharge delivered to the valley bottom aquifers from the bedrock on the valley sides was identified as a potential source of significant uncertainty in the overall water budget.

A review of existing hydrogeochemical data stored within the BC Ministry of Environment water sample databases was undertaken. This, together with groundwater sampling undertaken from 2006 to 2008 provided data for hydrogeochemical interpretations. Samples of groundwater, surface water and precipitation were analyzed for general geochemistry, and environmental tracers, including stable isotopes and conservative ions.

Hydrogeochemical approaches were used as a means of:

- Understanding the overall conceptual model of groundwater flow within the study area,
- Providing hydrogeochemical assessments of groundwater flow directions,
- Understanding the groundwater exchanges between surface water and groundwater,
- Detecting and quantifying groundwater exchanges between aquifers, and
- Investigating recharge into unconfined and bedrock areas.

1.2.3 Numerical modeling

Numerical groundwater flow models bring together hydraulic head data and hydraulic properties (e.g.: hydraulic conductivities, storage coefficients) to simulate groundwater flows (Freeze and Cherry, 1979; Anderson and Woessner, 1992). Once calibrated and validated, numerical models can provide important quantitative information about groundwater recharge, groundwater exchange between aquifers and assessment of groundwater resources.

In this study, the finite element groundwater modeling software package (FEFLOW Ver. 5.301) was utilized. This report presents a steady state assessment of groundwater flow in the Deep Creek and Fortune Creek watersheds. The groundwater model considers the two main confined aquifers (Spallumcheen A and B) within the main valley stem of the North Okanagan area. Future modeling efforts are discussed in Chapter 6.

1.3 Report Contents

This report is divided into the following chapters:

Chapter 2 describes the general background characteristics of the watersheds including location, watershed characteristics, climate, hydrometric measurements, and current surface water and groundwater usage.

Chapter 3 introduces the subsurface geology including descriptions of the main hydrogeologic units. It presents groundwater level monitoring data and the interpretation of regional groundwater flow in the aquifer based on physical data.

Chapter 4 presents an analysis of the overall hydrogeochemistry of the North Okanagan. This is utilized to further understand the aquifer systems and to assist in deriving an overall conceptual model of the aquifers. A separate report in preparation by the MOE discusses the overall hydrogeochemistry from a water quality perspective.

Chapter 5 presents the steady state numerical groundwater modeling developed using FEFLOW including the conceptual groundwater flow model upon which the numerical model is based, the numerical model design, calibration, sensitivity analysis, and an assessment of overall groundwater resources.

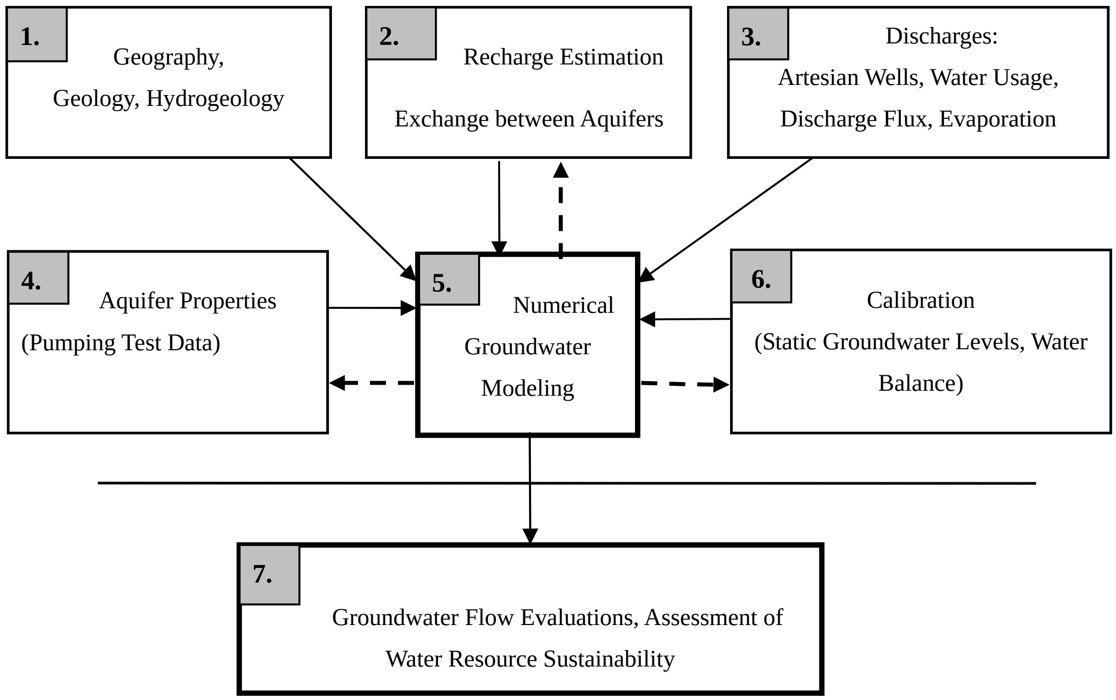


Fig.1.1 Key components and data sources used for groundwater evaluation

Chapter 2 Watershed Characteristics

Examination of geography, climate, geology, hydrogeology and social conditions within the study area watersheds is required for a comprehensive hydrological or hydrogeological study. This chapter presents a review of the relevant background data for the Deep Creek and Fortune Creek watersheds and summarizes their major characteristics. Some of these characteristics have previously been reported in other components of the NOGWCA project in more detail (e.g.: Monahan, 2006). References to other information sources are made when details are adequately covered in those other information sources, but information that is important to the UBCO component of the NOGWCA project is summarized in this chapter.

It should be noted that many of the wells located during the UBCO and MOE surveys for irrigation wells, artesian wells, for static water level monitoring wells and for geochemical sampling were not currently registered in the B.C. Ministry of Environment Water Wells Database. As such, a unified numbering system was developed for this study. Appendix 2.1 includes a summary table with identifying information such as B.C. MOE Well Tag Numbers for all wells used in the study. The BC Provincial well tag number system is abbreviated as WTN and the BC MOE Groundwater Observation Well Network well number system is abbreviated as O (e.g.: MOE observation well 117 is abbreviated as O117).

2.1 Location of the Study Area and General Topography

The Deep Creek watershed (DCW) and the Fortune Creek watershed (FCW) are two neighboring watersheds located in the southern interior of British Columbia (Figure 2.1). They lie between 50° 19' 56" and 50° 38' 29" N latitude and between 119° 1' 58" W and 119° 19' 59" W longitude. The DCW covers an area of 230.1 km^2 and is situated within the Okanagan Valley drainage that continues to the Columbia River system. FCW lies within the Shuswap River watershed system which ultimately joins with the Fraser River system. FCW has an area of 160.9 km^2. The DCW includes the limits of the City of Armstrong. The remainder of DCW and FCW are largely within the boundaries of the Township of Spallumcheen (Figure 2.1).

The two watersheds consist of relatively narrow flat valley bottoms at elevations of ~340 to 520 meters above sea level. The valley bottoms are bounded by rolling mountainous uplands that vary from 370 m to 1575 meters above sea level.

2.2 Climate

2.2.1 Data Sources

There are two sources of long term climate data located within the study area. The first is from a private weather station currently operated by Mr. Craig McKechnie in the valley bottom of DCW at 4376 Schubert Road within the Sleepy Hollow area of the Township of Spallumcheen. This station is located northwest of the City of Armstrong in the northern half of the study area (Figure 2.2). This station has been operated continuously since 1926 and records daily precipitation only. The second long term climate data record (precipitation and temperature, 1900 to 2004) close to the study area was collected at the Vernon Coldstream Ranch weather station operated by Environment Canada (Station ID: 1128580 , 482 m elevation) (Figure 2.2). This station is located approximately 20 km south of the study area.

A gridded (500m x 500m) climate data set has been prepared for the whole Okanagan Basin through collaboration between Environment Canada, Agriculture and Agri-food Canada, the British Columbia Ministry of Agriculture and the University of Lethbridge as part of a basin-wide assessment of agricultural irrigation requirements (Duke et al., 2008). This dataset is hereafter referred to as the Okanagan Climate Data Interpolator (OCDI). The extent of coverage of the climate grid within the study is shown in Figure 2.3.

In the preparation of the OCDI, all available climate data sets within the Okanagan basin were examined. It was determined that for the period of 1960 – 2006, there were sufficient long term records for a defensible spatial interpolation between stations to be done. Lapse rates for temperature and precipitation were estimated from both basin-wide historical data and from experimental measurements. The version used for consideration in this study is that prepared in April 2008, and provided to the UBCO study by Denise Neilsen of Agriculture and Agri-food Canada. The OCDI continued to be revised after the version supplied to UBCO.

The OCDI climate data set includes interpolated daily estimates of precipitation, maximum temperature and minimum temperature. Based upon this data, potential evapotranspiration is calculated using the Penman-Monteith method. Other summary statistics such as degree days and frost free periods have been calculated. The daily values within the original OCDI were further processed in this study to derive weekly and monthly averages and totals for the North Okanagan study area. The OCDI did not include all parts of the FCW, and data within the areas of the FCW not covered were estimated from the OCDI data.

2.2.2 Climate

The North Okanagan generally experiences hot, dry summer, with winter snowfall from

December to March, and a spring snowmelt. The frost free period ranges from 120 to 150 days in a calendar year (Zbeetnoff Agro-Environmental Consulting and Quadra Planning Consultants Ltd., 2006).

The sources of precipitation data were examined using cumulative precipitation departure. This is a measure of the difference between annual precipitation of a given year within a period of record to the average of the period of record. The difference between the two is totaled from year to year to give cumulative departure from average conditions. Successive below average years will lead to a declining trend in the cumulative departure curve.

The Schubert road private climate station recorded an average annual precipitation of 403 mm for the period of 1926-2005, and 421 mm in the period of 1960-2006 (Figure 2.3A). This station recorded the highest monthly precipitation in December, as snowfall, and the lowest monthly precipitation in April (Figure 2.3B). The cumulative precipitation departure for this station indicates lower than the long-term average precipitation from the early 1930’s to early 1960’s, after which precipitation is above average until 2001 (Figure 2.3A). A shorter period of below average rainfall occurred from 2001 to 2005.

The Vernon Coldstream Ranch station (Figure 2.4) recorded average precipitation of 429 mm/year from 1904 to 2004, and 465 mm/year from 1960-2004. Similar to the long term records from Schubert Road, the precipitation shows a decline in average precipitation until the 1960’s, followed by above average precipitation.

The OCDI indicates that overall, the study area experiences general increases in precipitation from south to north, and from valley bottom to mountain top. Long term annual average precipitation and potential evapotranspiration for valley bottom and mountain areas within the study area are presented in Figure 2.5 and 2.6, respectively. The average annual precipitation from 1960 to 2006 at valley bottom is ~494 mm/yr and in mountainous areas is ~611 mm/yr. The average potential evapotranspiration from 1960 to 2006 at valley bottom is ~929 mm/yr and in the mountainous areas is ~865 mm/yr. The potential evapotranspiration at the valley bottom is higher than that in the mountain areas due to the higher temperatures in the valley bottom.

A comparison of the OCDI and measured data was carried out of determining the average 1960 to 2006 precipitation as Schubert Road and Coldstream Ranch stations, and re-calculating the cumulative precipitation departure curves data for the period of record relative to the 1960-2006 average, zeroed at 1960 (Figure 2.7). The predicted OCDI and measured (Schubert Road) show good agreement.

Data from the OCDI was used to determine long term averages of precipitation for DCW and FCW for use in the basin water balance, recharge estimations and overall numerical modeling.

2.3 Surface Water

Deep Creek originates east of Mount Ida and west of Enderby (Figure 2.8). Deep Creek flows south in the Tohuk valley, and passes through the Hullcar and Sleepy Hollow areas before joining the main Okanagan Valley near the City of Armstrong. It then flows southwards through Otter Lake. Otter Lake is a small body of water with an area about 0.88 km^2 located in the centre of the DCW, south of the City of Armstrong, between stations DC4 and DC5. The lake water level is 347.2 meters above sea level as surveyed by UBCO in May, 2007. The mean depth of water is 3 meters and the maximum depth of water is 5 meters (http://www.sharphooks.com/tripplanner.aspx?subpage=lakeinfo&lake=otter+lake+(vernon)+-+south&lakeid=393). South of Otter Lake, Deep Creek discharges to Okanagan Lake.

Fortune Creek originates in the Shuswap Highlands adjacent to the Silver Star resort, and flows northwest to where it enters the valley floor just north of the City of Armstrong. Here it turns northeast and joins the Shuswap River at Enderby, and hence eventually enters into the Fraser River.

2.3.1 Hydrometric Data

There have been four historical hydrometric stations operational on DCW and two historical stations on FCW. Historical surface water hydrometric station information is summarized in Table 2.1 and the station locations are shown in Figure 2.8. The historical flow data of the stations referred to in Table 2.1 are presented in Appendix 2.2 and 2.3. All of these hydrometric stations were deactivated prior to the start of the NOGWCA project.

Three new automated hydrometric stations designed and installed by MOE staff were commissioned on Deep Creek in April of 2006. Water stage data are recorded by Thalimedes data loggers and these stations are managed by MOE staff. Staff gauge and data logger data was collected and processed in 2006 and 2007 by MOE staff, and the processed and corrected stage data was provided to this project. An additional automated hydrometric station was installed on Fortune Creek in the fall of 2007 through funding received from a Pacific Salmon Foundation project. This station was commissioned in Spring 2008.

Manual measurements of stream stages and water discharges were conducted at two week to one month intervals at these sites for development of rating curves so that water level data can be converted to discharge data (Figures 2.9, 2.10). In addition, manual measurements were also conducted in two additional sites along DCW, and four other sites along Fortune Creek.

2.3.2 Hydrometric data for Deep Creek

The 1970-1974 average Deep Creek historical discharge to Okanagan Lake (DH4, Figure 2.1) is $1.6 \pm 0.5\times10^7$ m^3/yr or 43,800 ± 13700 m^3/d. This is 0.49 ± 0.16 m^3/sec. There is no information on usage rates at that time to naturalize this hydrograph, but licensed extractions were 2.6×10^6 m^3/yr.

Flow rates were manually measured in 2007 and 2008. The automated hydrometric data is available for March to October 2007 (Figure 2.9). The manual and hydrometric station data show that Deep Creek gains groundwater in the stream reach from the hydrometric station site near Sleepy Hollow to the Okeefe Ranch golf course (Figure 2.9). This is most clearly seen in periods outside freshet (June to March). The gain is strongest between stations D4 and D5 located upstream and downstream of Otter Lake.

The average static water level of well 122, which is completed in a confined aquifer underlying Otter lake (Spallumcheen A aquifer) is 354.2 meters based on measured data since 2006. This is evidence of an upwards hydraulic gradient in the vicinity of Otter Lake (elevation 347.2 meters). Several artesian wells exist in the area south of Otter Lake. Local landowners have constructed ponds which encountered artesian conditions within 3 metres of surface and field drains were installed at regular intervals within the in agricultural fields in the region to drain excess groundwater to Deep Creek (various, personal communication, 2009). This groundwater discharge contributes 0.15 to 0.2 m^3/s (4.7×10^6 to 6.3×10^6 m^3/yr) to Deep Creek (Figure 2.9), and in times outside freshet represents the majority of the flow at the mouth of Deep Creek.

During 2007, the manual measurements for D4 located north of Otter Lake were in a location where there were abundant plants, and some flow measurements were below the detection limit of the hydrometric equipment. It is possible this station underestimated flow at D4 in 2007, and some of the inflow came in north of this station. The station location was moved in spring of 2009.

A best estimate of long term discharge can be made from the climate data in the OCDI and the measured outflow. The long term average (1960-2006) total precipitation volume for the Deep Creek watershed is $1.35 \pm 0.20\times10^8$ m^3/yr. The average of precipitation during 1970-1974 was $1.28 \pm 0.20\times10^8$ m^3/yr. The average (1970-1974) Deep Creek non-naturalized discharge to Okanagan Lake is about 0.45 m^3/s, which is about 1.43×10^7 m^3/yr. The average (1970-1974) discharge with the full licensed extractions added is therefore 1.7×10^7 m^3/yr. This would be the upper limit for a naturalized hydrograph. Based on the ratio of average precipitation volume in the years 1970-1974 to the average precipitation volume in the whole period 1960-2006 the best estimate for long term discharge from Deep Creek is 1.48×10^7 m^3/yr to 1.79×10^7 m^3/yr if naturalized using licensed extractions.

Discharge for the calendar year March 13, 2007 to March 12, 2008 was 7.9×10^6 m^3 which corresponds to an annual average rate of 0.25 m^3/s. This is not naturalized, and includes the effects of licensed extractions. Licensed extractions totaled 3.1×10^6 in 2007 m^3/yr. Total precipitation volume from 2007 is not available in the OCDI, but was estimated from OCDI data and precipitation measured at the Vernon North climate station and is 1.47×10^8 m^3/yr, which is close to the long term average.

Runoff after extraction in the Deep Creek watershed was therefore 12.1% of precipitation in 1970-74, compared to 5.4% in 2007. The total licensed surface water extraction has not changed by much. This suggests changes may have occurred in land use affecting runoff generation and there is likely increased extraction of surface and groundwater leading to a reduction in overall runoff reaching the mouth of Deep Creek.

2.3.3 Hydrometric data for Fortune Creek

A review of hydrological conditions in the FCW is included in Seebacher et al. 2007. In Fortune Creek, surface water is lost between the Reservoir Road water-intake site (FC1) and the location where Fortune Creek crosses Highway 97 (FC2) at times outside of freshet. Surface water flows are strong in Fortune Creek during freshet, and flow data is likely less accurate during the freshet period, and hence relative flows between stations are more difficult to interpret. Groundwater is gained in the reach below Highway 97 during winter time, but flows may still decrease downstream in summer time, likely due to withdrawal for irrigation (Figure 2.10).

Table 2.2 presents a reconstructed naturalized hydrograph data for Fortune Creek. Only one full year of data (1960) existed at the Stepney Road station. The measured Fortune Creek discharge at the Stepney hydrometric station (FH2, Figure 2.1) in 1960 was 3.24×10^7 m^3/yr (88,700 m^3/d or 1.027 m^3 /s). The hydrograph for Stepney was estimated by comparing the 1960 data from the Stepney road historical hydrometric station to the 1960 Armstrong North hydrometric station data and determining a monthly scaling factor. The scaling factor was used to scale up to estimate average flows during 1960-1984 at Stepney Road based on the monthly averages (1960-1984) from naturalized Armstrong North historical hydrometric station data (Seebacher et al. 2007). Naturalized monthly flow (m^3/s) is the natural flow which would be present in Fortune Creek without water withdrawals and total water extractions (m^3/s) is the amount of water removed by water licensees (1998-2006 average). The best estimate of 1960-1984 average naturalized flow is 3.0×10^7 m^3/yr, which is 30% of the total precipitation for the same period from the OCDI.

The best estimate of outflow at Stepney road using the manual measurements from March 2007 to March 2008 was 9.45×10^6 m^3/yr. This represents 8% of the total precipitation. With licensed extraction added back, the naturalized flow represents 11% of the total precipitation, indicating changes in the hydrology of the creek. Figure 2.10 indicates that the freshet in 2007 (1.5 m^3/s peak flows) was lower than the average peak flow (4.3 m^3/s for 1960-1984).

2.3.4 Okanagan Lake

Deep Creek terminates in the Armstrong Arm of Okanagan Lake. The mean and maximum depths of Okanagan Lake are 17 and 50 meters at Armstrong Arm (Nordin, 2005). The lake water level normally ranges between 341.2 m and 342.54 m above sea level, and is controlled by outlet structures at Penticton (Nordin, 2005).

Artesian conditions are noted in some wells immediately north of the lake shore, which indicates upwards hydraulic gradients and groundwater discharge to the lake. A further analysis is presented in Chapters 3 and 5.

2.4 Water consumption

Surface and groundwater usage data within the study area have been collected by UBCO and others. Water usage within DCW and FCW includes:

- Surface water usage for domestic, irrigation, land improvement, storage, watering and Waterworks Local Authority
- Groundwater usage by water districts or suppliers
- Groundwater usage by commercial enterprises
- Groundwater usage for irrigation
- Groundwater discharge to surface water from uncontrolled artesian wells
- Groundwater discharge to surface water from field drains

Returns to groundwater include:

- Agricultural and domestic irrigation return water
- Septic system discharge
- Irrigation return from spray irrigation of treated municipal wastewater

A summary of water consumption is presented in Table 2.3. The following sections outlines how measurements were obtained of these quantities or methodologies by which these amount were estimated.

2.4.1 Water district utilization

There are currently 14 independent Water Improvement Districts in the study area and four Municipal Water Utilities managed by the Township of Spallumcheen. A summary of the water district information is presented in Table 2.4.

The City of Armstrong (The City) manages water supply within its jurisdiction, and supplies water to some of the other districts and utilities as outlined in Table 2.4. The City supply relies upon both surface water obtained from intake structures on Fortune Creek and groundwater from wells. The City has two wells that are used to supplement their surface water during the periods of low water quality or quantity in Fortune Creek (Mike Klymchyk, Public Works Manager, City of Armstrong, personal communication, 2008).

2.4.2 Surface water usage

Deep Creek

Data on licensed surface water extractions were obtained from the Ministry of Environment Water Stewardship office (http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input). No attempt has been made to investigate actual water usage from the creek for irrigation. There are 28 licenses registered on Deep Creek. This information is summarized in Appendix 2.4. Total licensed extraction from Deep Creek is 3,087,900 m^3/yr (0.098 m^3/s).

No attempt was made within this study to estimate actual usage from Deep Creek. The only estimate of actual usage from this creek is reported by Swain (1994), with no reference to its origin. Swain (1994) reported that consumptive surface water uses from Deep Creek included 11.4 m^3/day (equivalent to 4200 m^3/yr) of domestic water supply withdrawals and 4685 m^3/day (equivalent to 1,710,000m^3/yr) of irrigation water supply withdrawals. This for estimated actual extraction represents 55% of total licensed withdrawals.

Fortune Creek

Licensed water consumption quantity and license purposes information were obtained from the Ministry of Environment Water Stewardship Division website (http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input) (Appendix 2.5). There are 22 licenses authorized on the creek. Total annual licensed extraction is 3,644,000 m^3/year.

No formal field survey was conducted to determine the actual utilization of authorized licenses on Fortune Creek.

The City of Armstrong uses Fortune Creek as its primary water supply. An intake structure, two large water holding and sediment settling reservoirs and a chlorination treatment system are located adjacent to Fortune creek at the head of Reservoir Road. The City of Armstrong maintains upland reservoirs adjacent to Silver Star Mountain to augment its water supply during summer months, and to maintain a reservoir of water for fire protection purposes. The release of water from the upland reservoirs is controlled manually on a bi-weekly or longer basis to augment water flow in Fortune Creek.

In 2008, the flow from Fortune Creek to the City water mains was controlled manually by adjustment of valves both on the upstream side of the reservoirs and on the downstream side of the holding reservoirs. These are adjusted daily, or more often, to match demand. Excess water within the holding reservoirs is returned to Fortune Creek.

Two deep wells located on Pleasant Valley road and adjacent to the City of Armstrong fire hall are used to supplement the surface water supply. The City switches to these groundwater sources during the spring freshet period when surface water quality is compromised by increased turbidity. The groundwater wells are also operated on a periodic basis in the remainder of the year when supply from Fortune Creek is insufficient to maintain operational water levels within the holding reservoirs on Reservoir Road. The groundwater wells are automatically turned on if the holding reservoirs fall below an acceptable operational capacity.

Surface water and groundwater consumption data from the City Armstrong was obtained from Mike Klymchuk, Public Works Manager for the period of 1999 to 2006. Surface water consumption from Fortune Creek is presented in Table 2.5. These data represent the total intake to the chlorination plant from Fortune Creek during the monthly period reported. The raw data from the “totalizing meter” located at the chlorination plant is divided by a factor of 2.2 to arrive at the water usage reported in the spreadsheet provided by the City. Neither confirmation of the settings on the metering system nor the reason for the factor of 2.2 has been provided. The data reported here are the raw meter readings divided by 2.2. The average annual usage from 1999-2006 is reported as 1,438,000 m^3/year

Other users extract water from Fortune Creek downstream of the City of Armstrong intake structure for both domestic and irrigation purposes. Anecdotal conversations with residents along Fortune Creek suggests that several of these licensed users no longer extract water from Fortune Creek due to low and erratic water levels within the upper creek reaches.

2.4.3 Groundwater usage

Groundwater in the study area is used for domestic water supply, irrigation, commercial and industrial purposes.

Irrigation wells survey

Irrigation requirements for most of the Spallumcheen Township are from the beginning of May to the second week of September, or a period of 130 days. Roughly 12% (1,932 ha) of the total farmland in the Township of Spallumcheen is currently irrigated, predominantly from groundwater (Zbeetnoff Agro-Environmental Consulting and Quadra Planning Consultants Ltd., 2006).

A door-to-door survey was conducted by MOE staff from September 2005 to October 2005 to gather information on irrigation and domestic supply wells. A total of 80 wells were located within the greater North Okanagan area, which includes some areas outside of the study boundary. The survey collected information on well location, well depth, construction details, pumping rates, and crop types. Some wells were metered and metered data were recorded and reported. For wells with no meters, water usage figures were estimated via integration of estimates of typical irrigation cycles, length of irrigation season, typical daily or weekly pumping durations and rated pump flow rates.

Fifty of the wells from the survey are located in the study area (Figure 2.11). The water usage purposes and quantities are presented in Table 2.6. The estimated annual total of groundwater consumption based on the survey data is 3,752,000 m^3/yr.

Water Districts

Eight water districts in the study area are known to rely in part or in whole on groundwater for their water supply. Water usage data were collected from:

- DWIMP study (Drinking Water Information Management Project)
- Okanagan Basin Water Supply and Demand study
- Directly from water districts via telephone enquiries by UBCO

In some cases, groundwater extraction rates were not available, and usage was estimated based upon per capita or per household water usage estimates. This information is presented in Table 2.7.

City of Armstrong Wells

Mike Klymchyk, Public Works Manager provided information about the groundwater consumption from the two wells operated by the City of Armstrong (Table 2.8).

2.4.4 Treated effluent water irrigation

Domestic and commercial wastewater from the Township of Spallumcheen and the City of Armstrong are collected in a wastewater treatment facility. The treated liquid effluent from the wastewater treatment plant is utilized for land based irrigation on land parcels within the Township of Spallumcheen. The areas under this irrigation are shown in Figure 2.12. In 2006, 4.9 km^2 of land received 8.2 $\times 10^5$ m^3 of treated wastewater. Table 2.9 shows the monthly distribution of treated municipal wastewater used for irrigation in 2006.

The majority of this water will undergo evapotranspiration and will not become part of the groundwater system. Irrigation returns have been estimated by the Okanagan Basin Agricultural Supply and Demand Study currently under way by Agriculture and Agri-food Canada (D. Neilsen) and the B.C. Ministry of Agricultrue (T. van der Gulik)

2.5 Population and economy

2.5.1 Population

Two major population centers are located in the study area: the City of Armstrong (population in year 2006: 4241) and the Township of Spallumcheen (population in year 2006: 4960). Population data for cities and townships is available at BC Stats, who compile data from Statistics Canada (source: http://www.bcstats.gov.bc.ca/data/pop/pop/mun/Mun1921_2006.asp) (Table 2.10). Population growth in the two communities from 1921 to 2006 is illustrated in the Figure 2.13.

The population was only 983 and 523 in Armstrong and Spallumcheen in 1921, respectively. The BC Stats projects that future population in the City of Armstrong and Spallumcheen Township is expected to reach 14508 in 2036 (Source: http://www.bcstats.gov.bc.ca/).

2.5.2 Economy

Forestry, agriculture, manufacturing and tourism are all important industries to the City of Armstrong and the Township of Spallumcheen. Agriculture is the most important industry in this area. Agricultural activity was reported on 16,264 ha encompassing 442 farms within the study area. The most numerous of the farming operation types are cattle operations, representing about 21% of all agricultural operations in the TOS. Other relatively important farm types include hay and forage operations (17.2%), horse and pony (15.2%), poultry (6.8%), and dairy (6.1%) (Zbeetnoff Agro-Environmental Consulting and Quadra Planning Consultants Ltd., 2006).

2.6 Summary

The followings are a brief summary for this chapter.

- The average annual precipitation from 1960 to 2006 at valley bottom is around 494 mm/yr and in mountainous areas is around 611 mm/yr based on the gridded climate data contained in the OCDI. The average annual precipitation from 1926 to 2005 at the valley bottom at a private weather station near the City of Armstrong is 403 mm which is about 90 mm less than that obtained from the data from OCDI.
- Surface water-groundwater interactions are evident in both creeks within the study area. Otter Lake and Okanagan Lake receive groundwater from the aquifers in the study area.
- Both surface water and groundwater are utilized by the communities for irrigation, drinking water and commercial usage, with irrigation use being the largest water consumption.

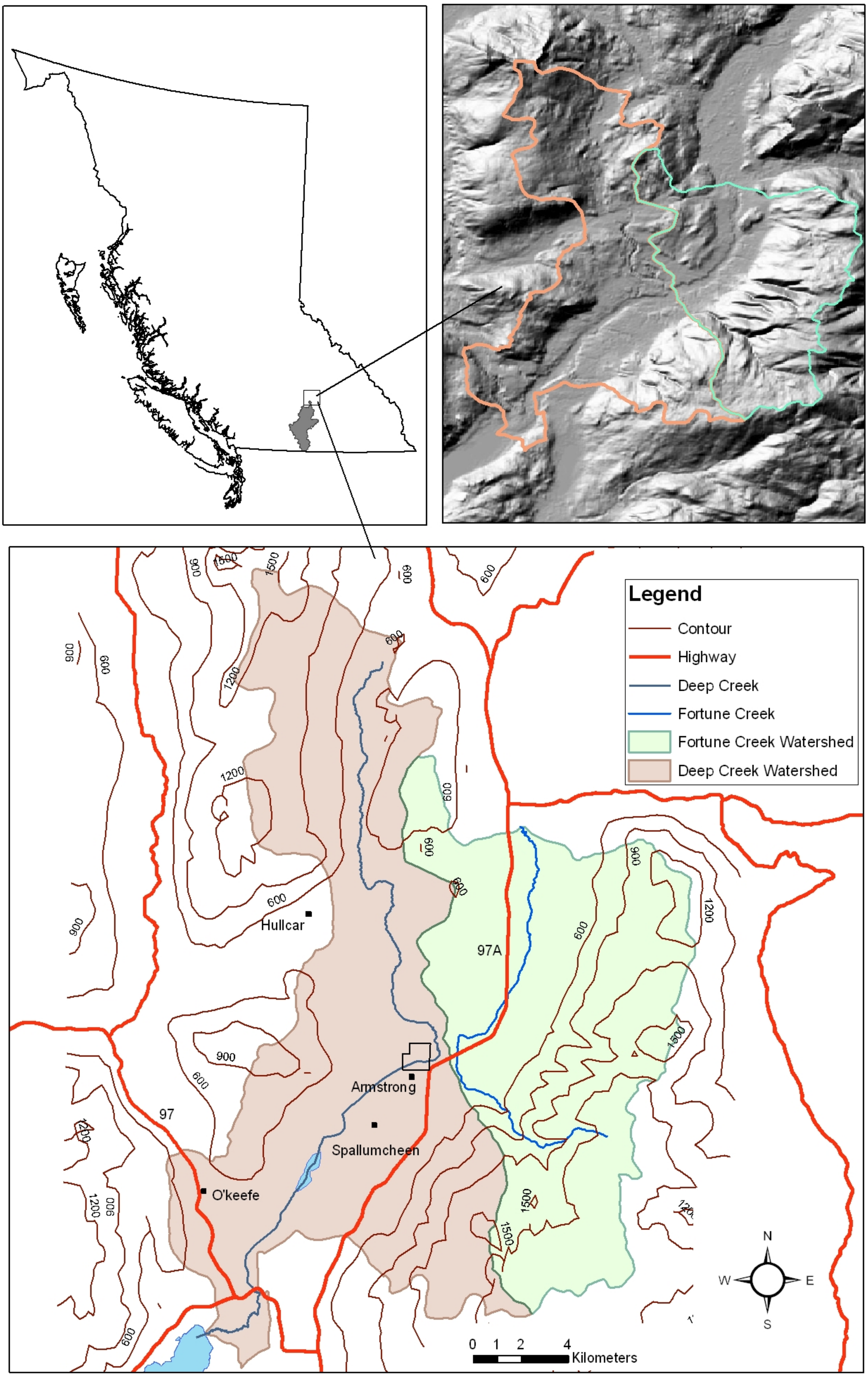


Figure 2.1: Location and topography of study area

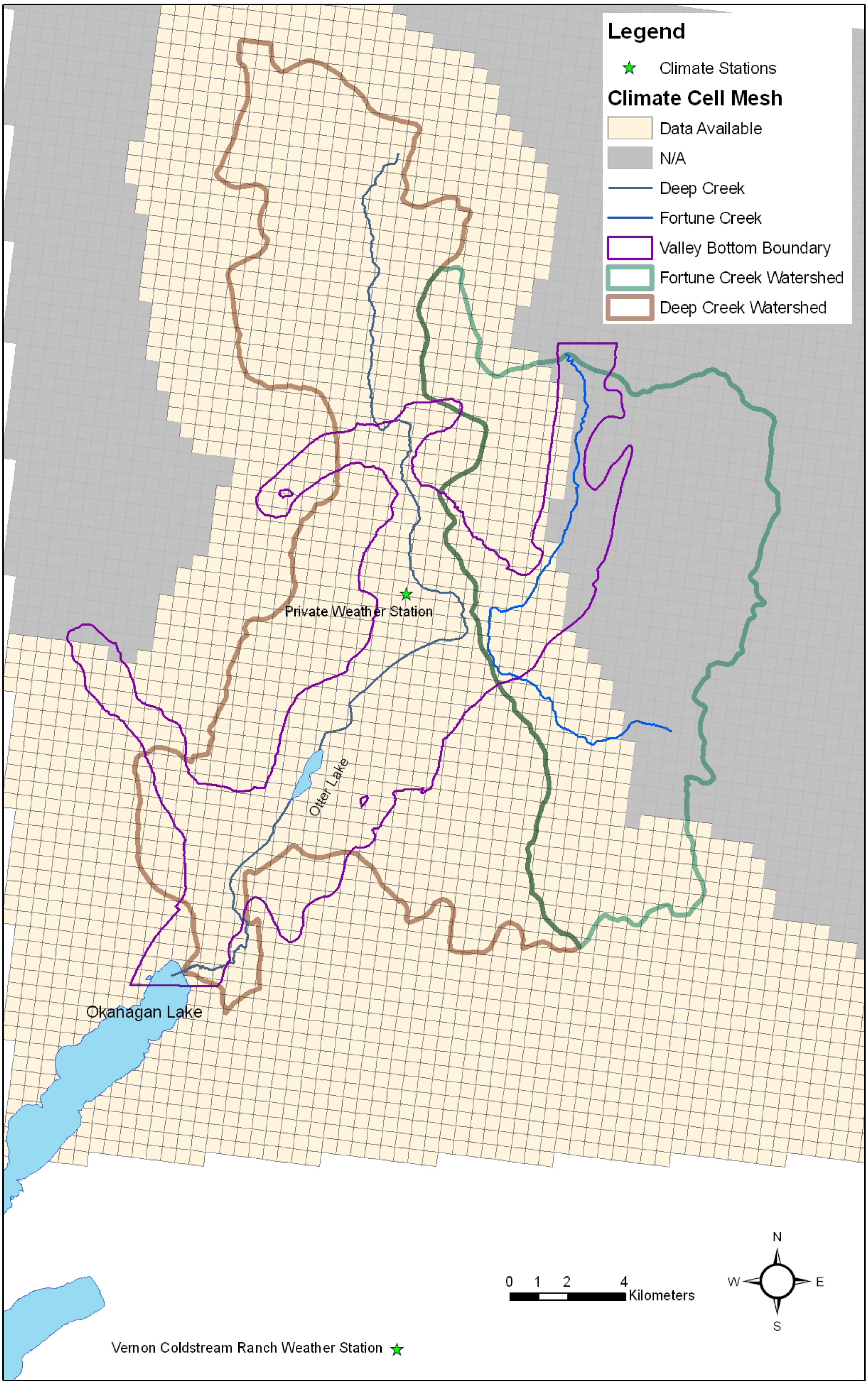


Figure 2.2: Climate data sources in the North Okanagan area including gridded (500m x 500m cells) climate data set coverage from the Okanagan Climate Data Interpolator (Duke et al., 2008)

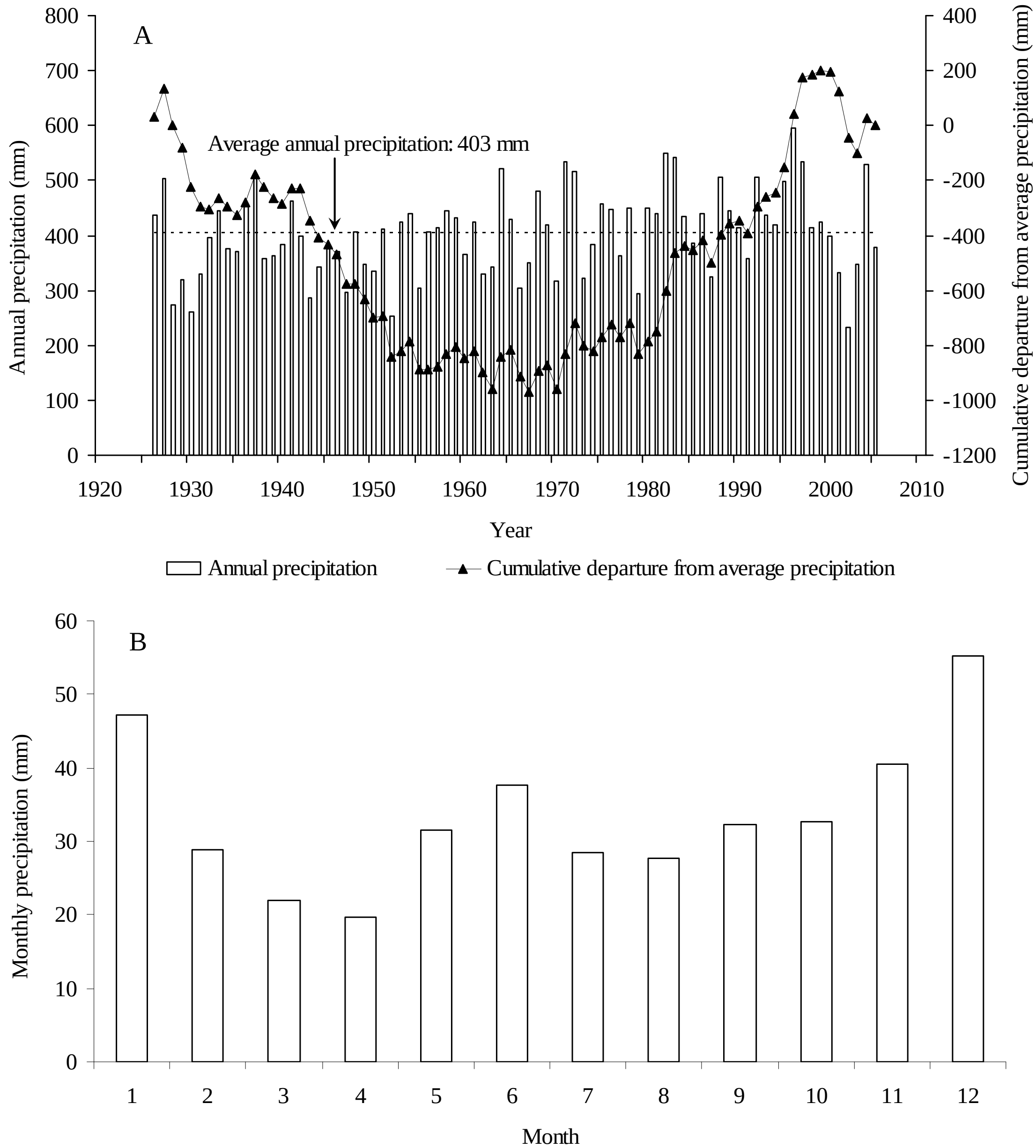


Figure 2.3 Climate data (1926 to 2005) from Schubert Road private weather station: A-Annual precipitation and the cumulative departure from average annual precipitation; B-Mean monthly precipitation (1926 to 2005).

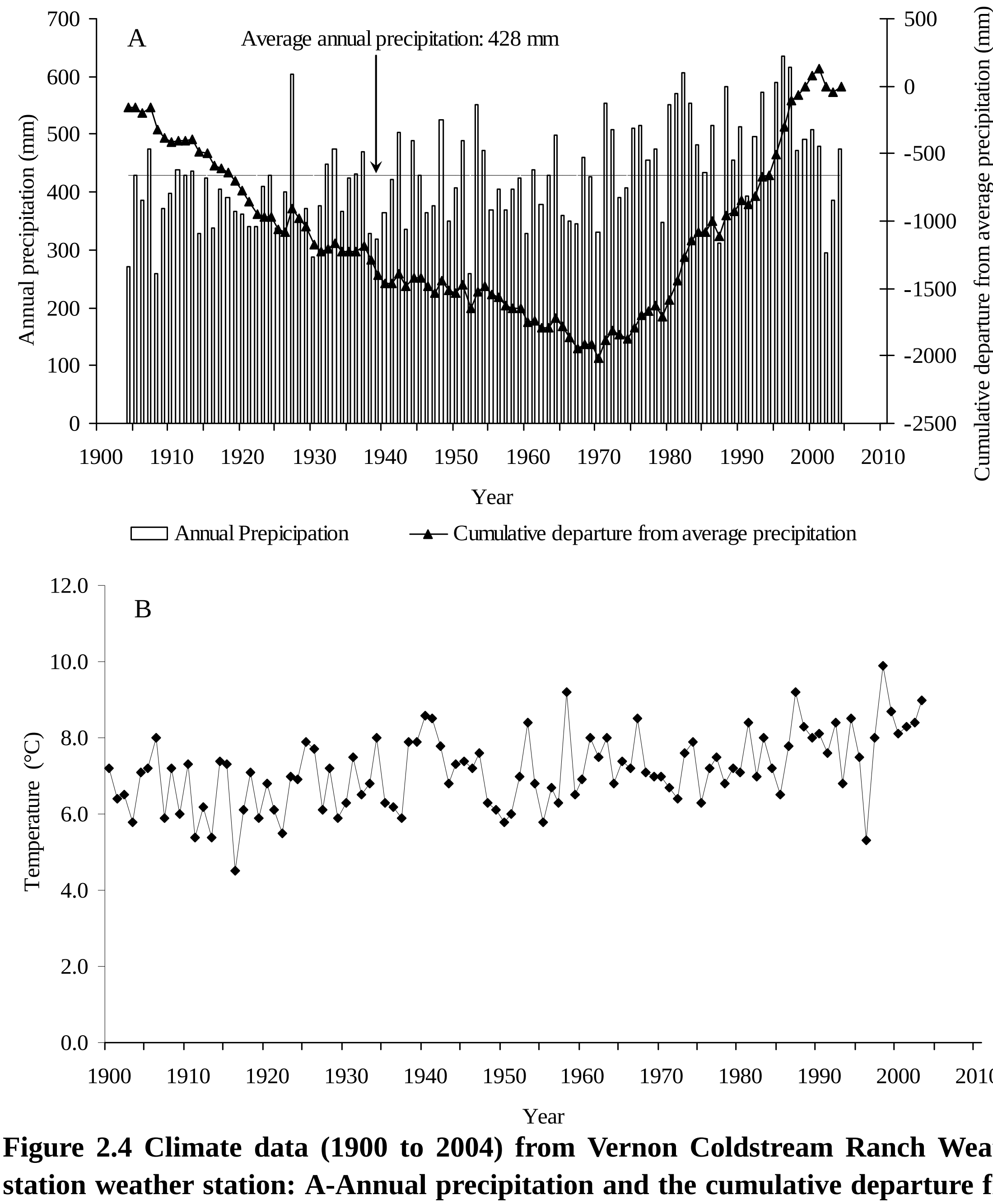


Figure 2.4 Climate data (1900 to 2004) from Vernon Coldstream Ranch Weather station weather station: A-Annual precipitation and the cumulative departure from average annual precipitation; B-Mean annual temperature

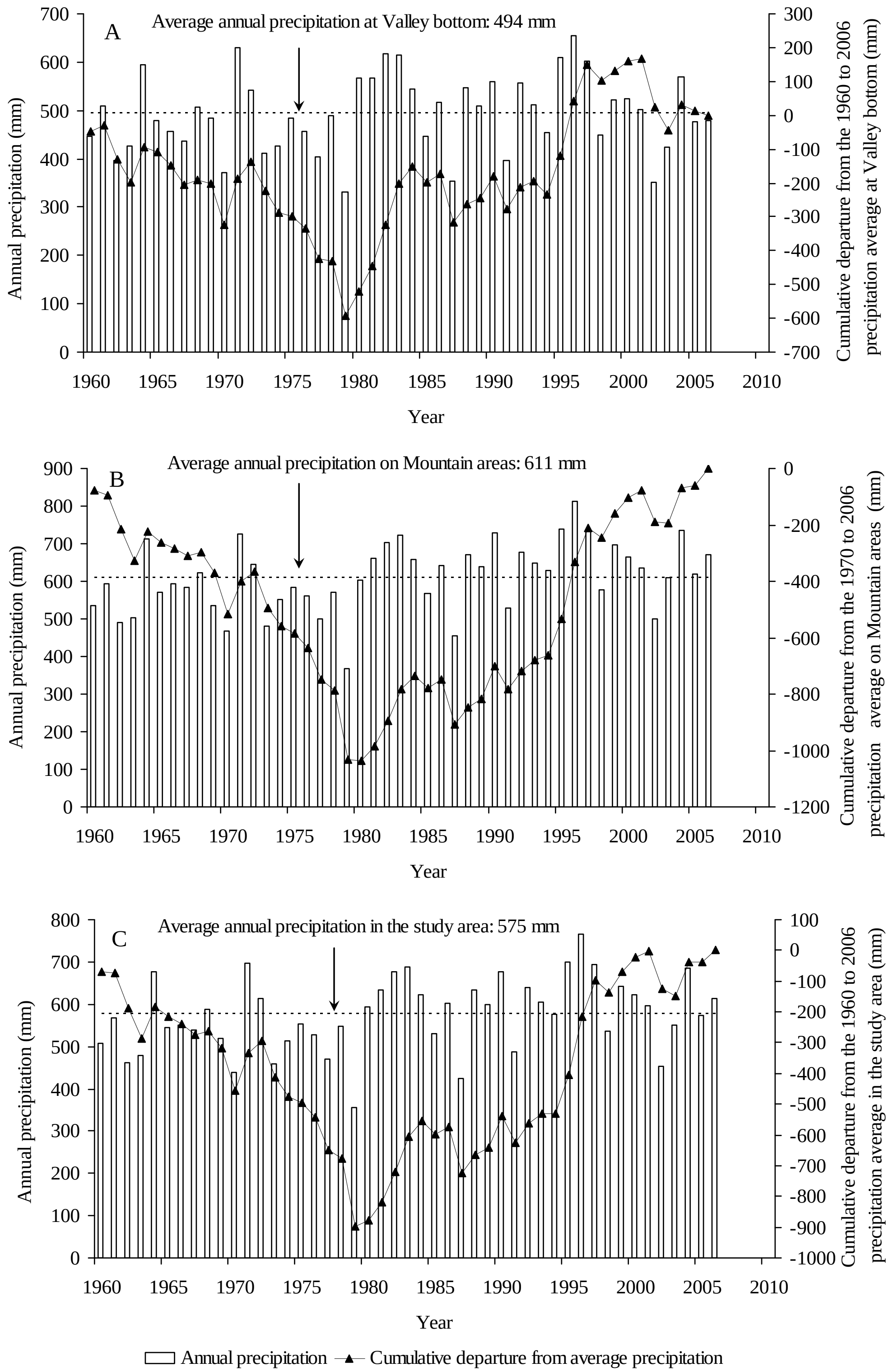


Figure 2.5 Climate data summaries (1960-2006) from Okanagan Climate Data Interpolator, annual precipitation and the cumulative departure from average annual precipitation: A-average at valley bottom; B-average within mountainous areas on either side of the main valley; C-averaged for whole the study area

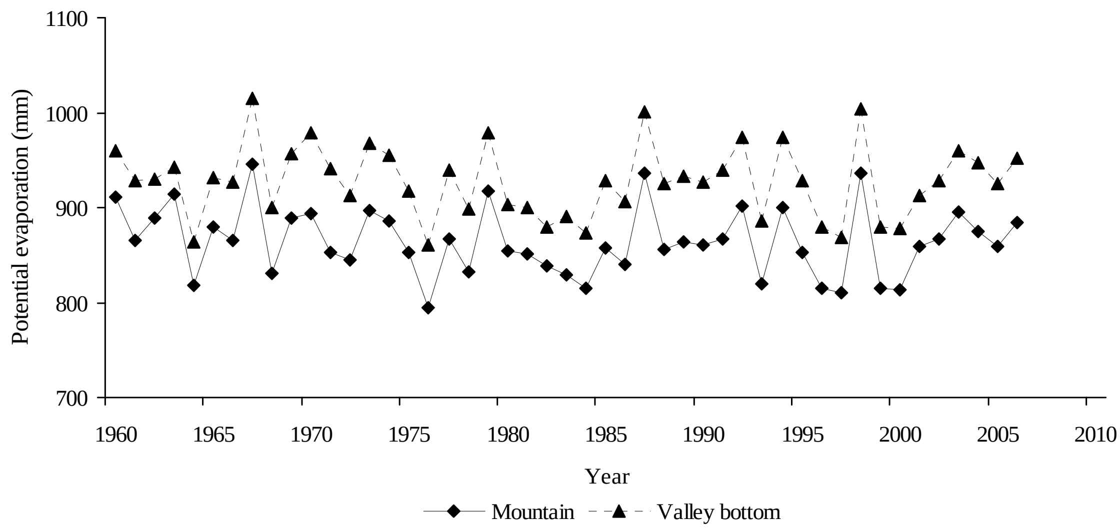


Figure 2.6 Calculated annual potential evapotranspiration using the Penman Montieth method in the Okanagan Climate Data Interpolator (1960 to 2006)

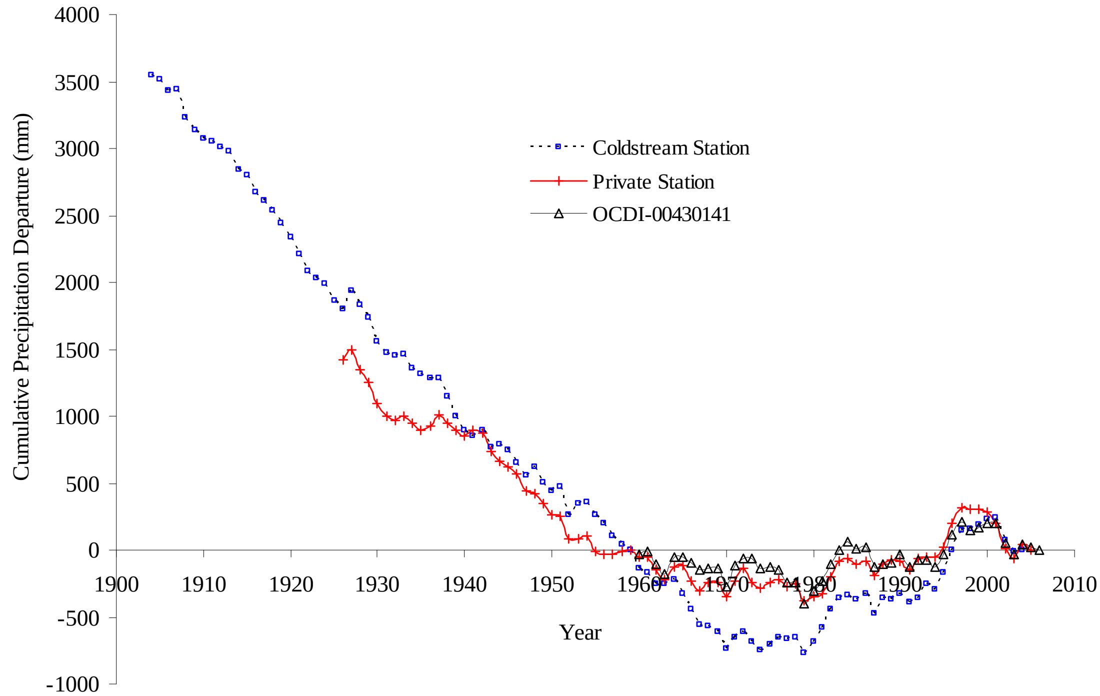


Figure 2.7 Cumulative precipitation departures from 1960-2005 average precipitation for Schubert Road climate station, the Vernon Coldstream ranch station, and the OCDI. Normalized to zero departure in 1960.

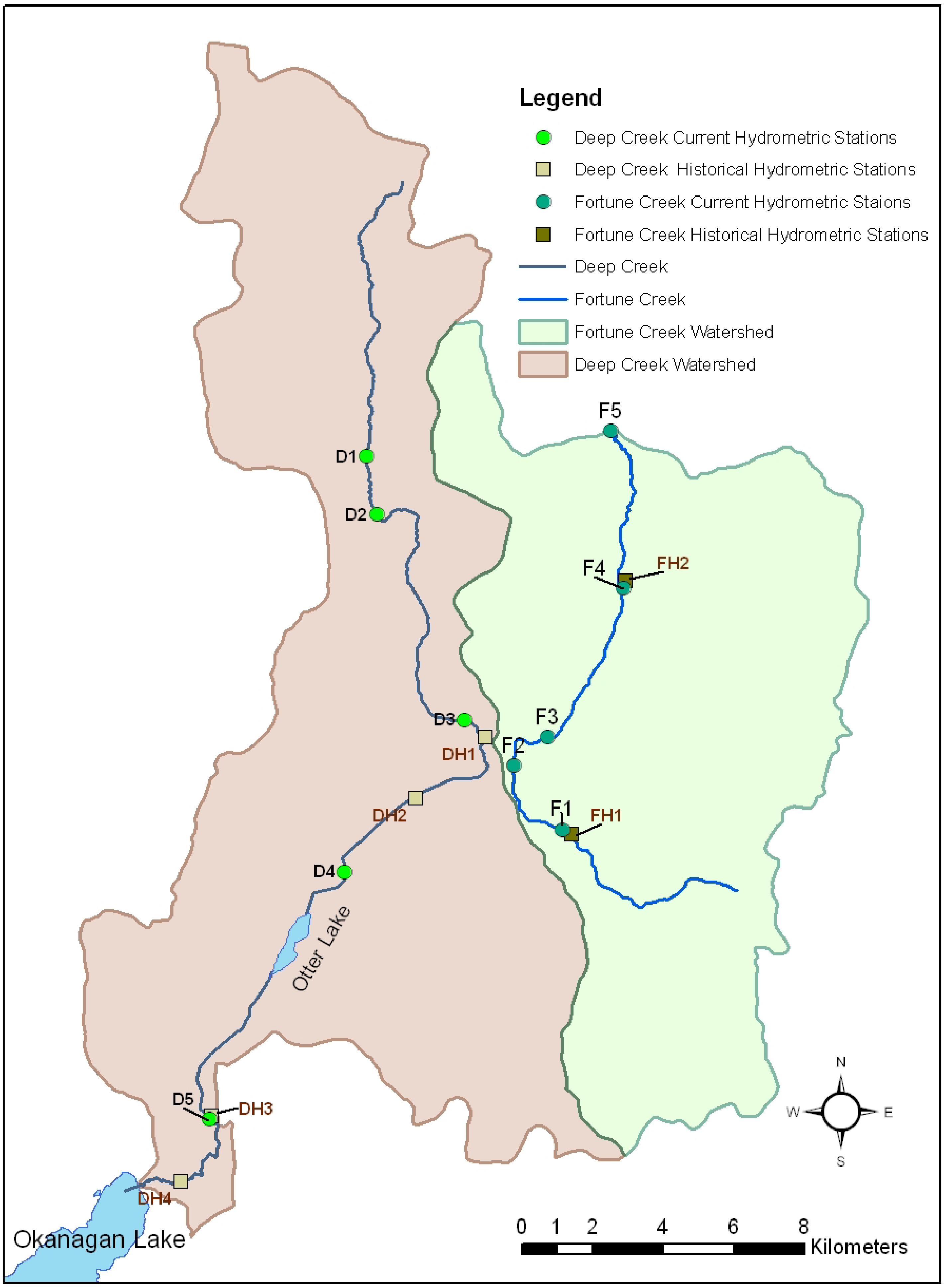


Figure 2.8 Locations of hydrometric and climate station in Deep Creek Watershed and Fortune Creek Watershed

Deep Creek Hydrometric Stations:
D1- Barber Road;
D2- Hullcar Road;
D3-Sleepy Hollow Road;
D4- Otter Lake Cross Road;
D5- Okeefe Ranch;
DH1- Historical Deep Creek at Young Road;
DH2- Historical Deep Creek at Armstrong;
DH3- Historical Deep Creek near Vernon;
DH4- Historical Deep Creek at the mouth;
Fortune Creek Hydrometric Stations:
F1- Reservoir road;
F2- Highway 97;
F3- McCallan;
F4- Stepney Cross Road;
F5- Back Enderby Road;
FH1- Historical Fortune Creek near Armstrong (at Reservoir Road);
FH2- Historical Fortune Creek at Stepney
(Historical hydrometric data from: http://www.wsc.ec.gc.ca/hydat/H2O/ index_e.cfm?cname=main_e.cfm)

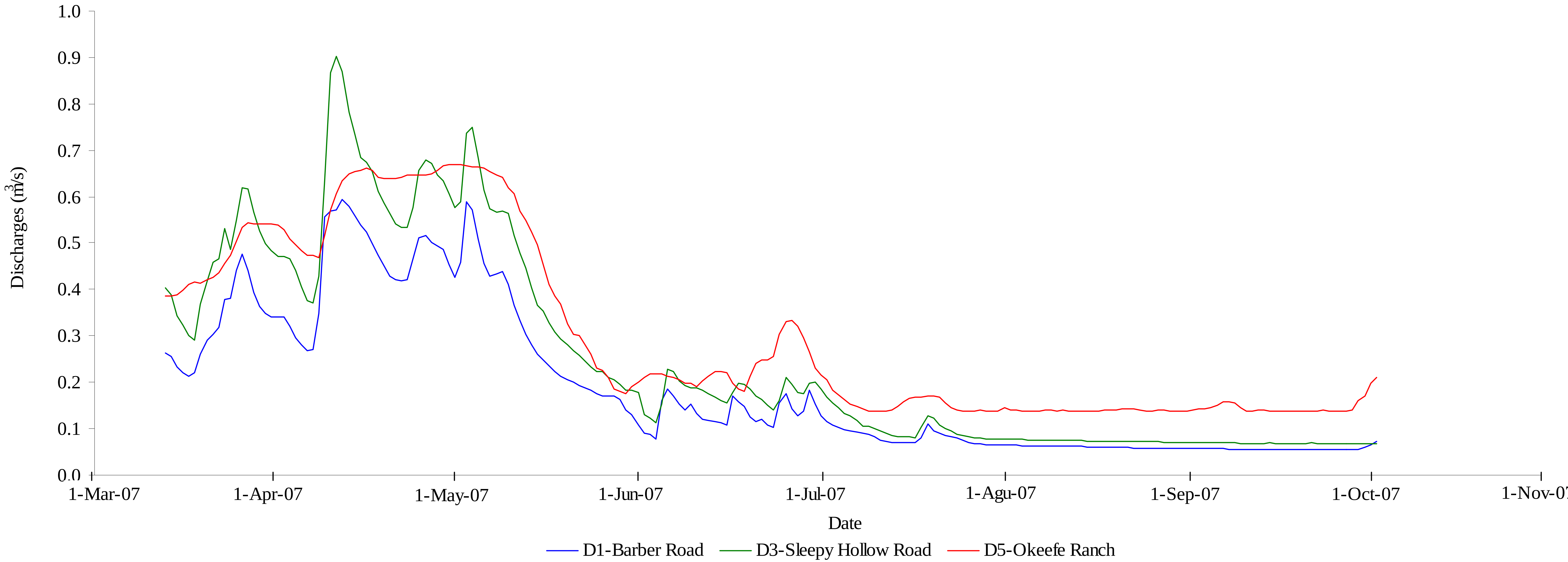


Figure 2.9-A Automatically measured streamflow discharges at three hydrometric stations on Deep Creek progressing downstream from March 13, 2007 to October 4, 2007

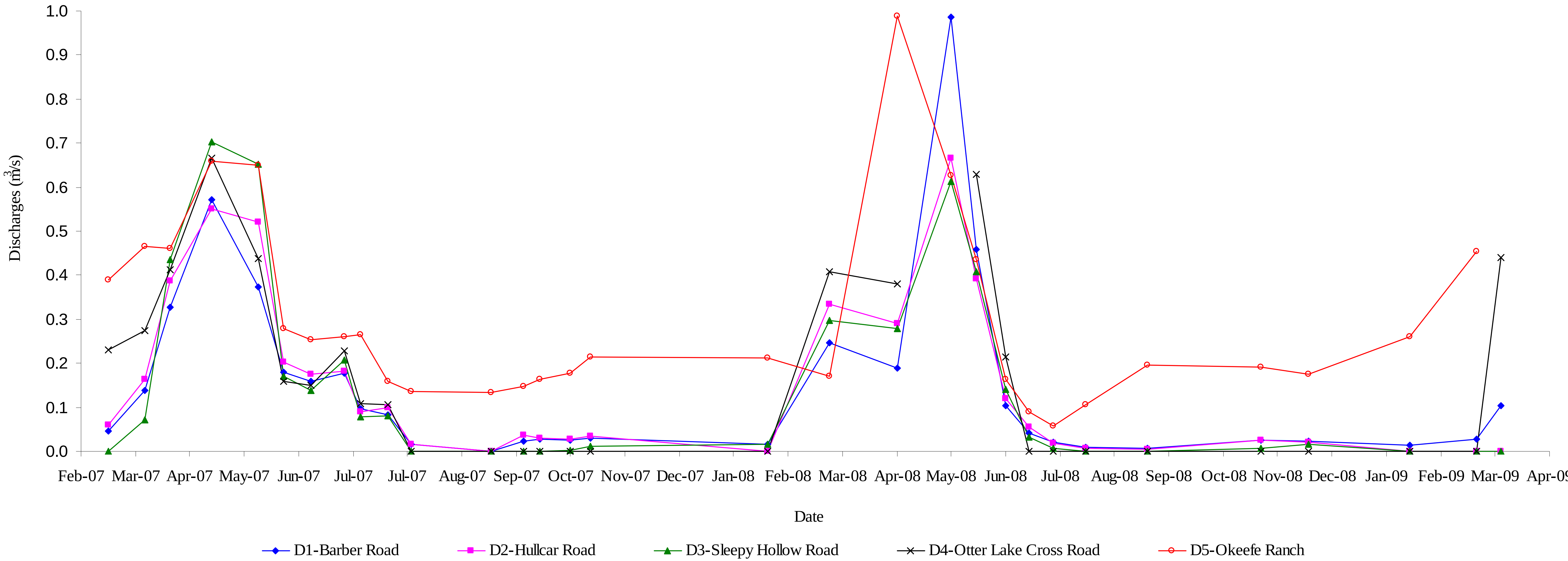


Figure 2.9-B Manual measured streamflow discharges at five hydrometric stations on Deep Creek progressing downstream from February 16, 2007 to March 25, 2009

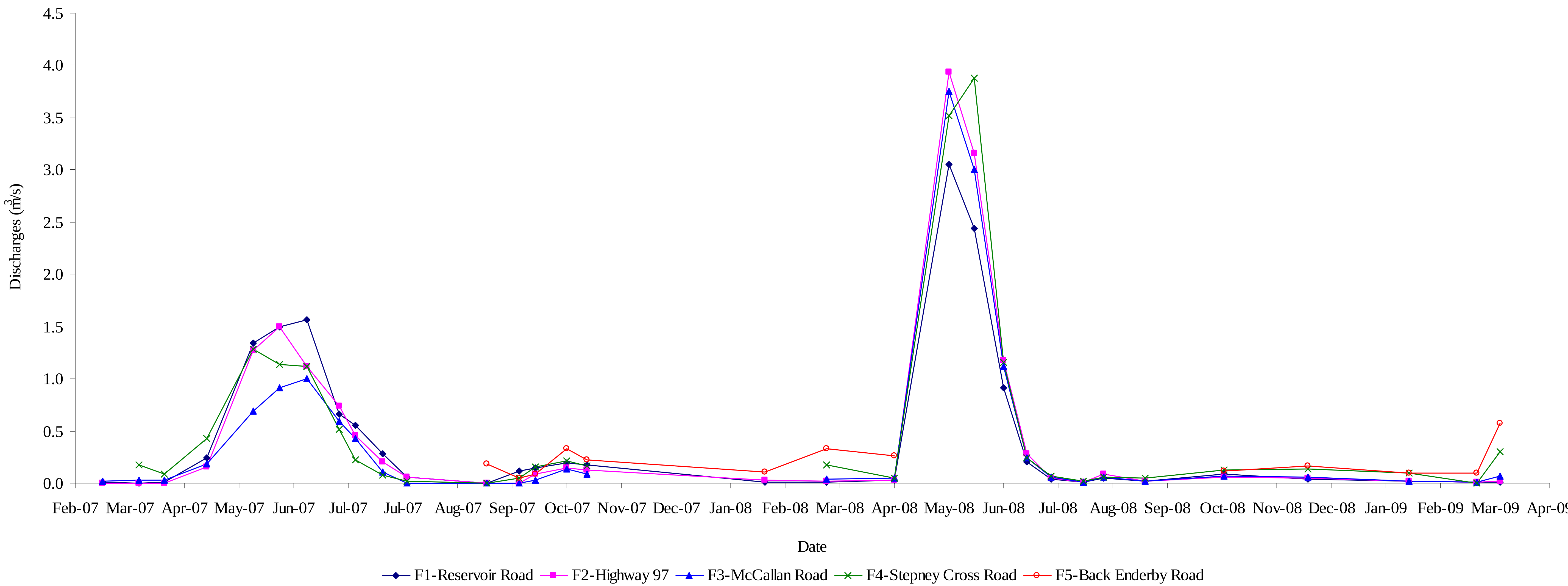


Figure 2.10 Manual measured streamflow discharges at five hydrometric stations on Fortune Creek progressing downstream from February 16, 2007 to March 25, 2009

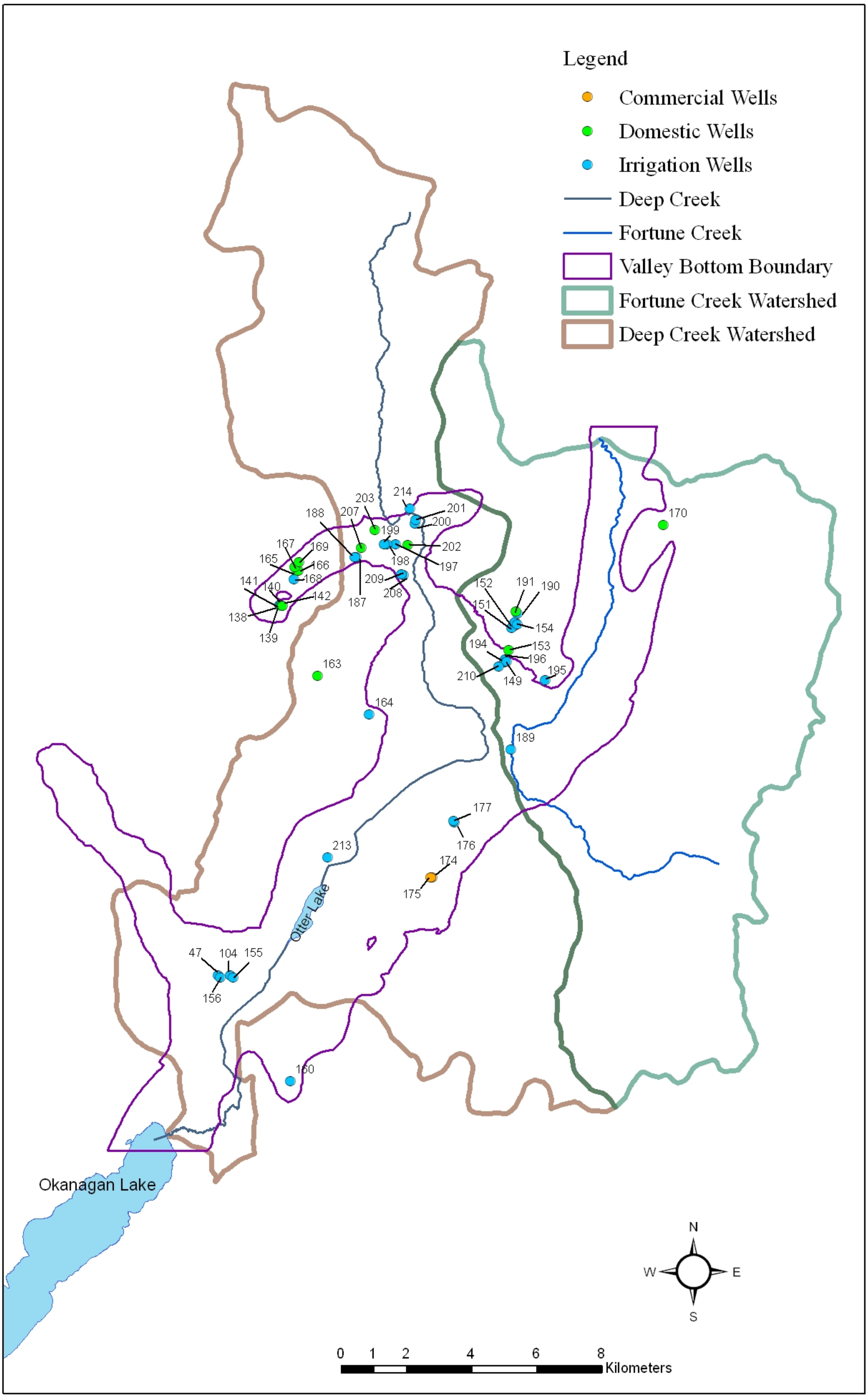


Figure 2.11 Spatial distribution irrigation, domestic and commercial wells located in a B.C. Ministry of Environment survey

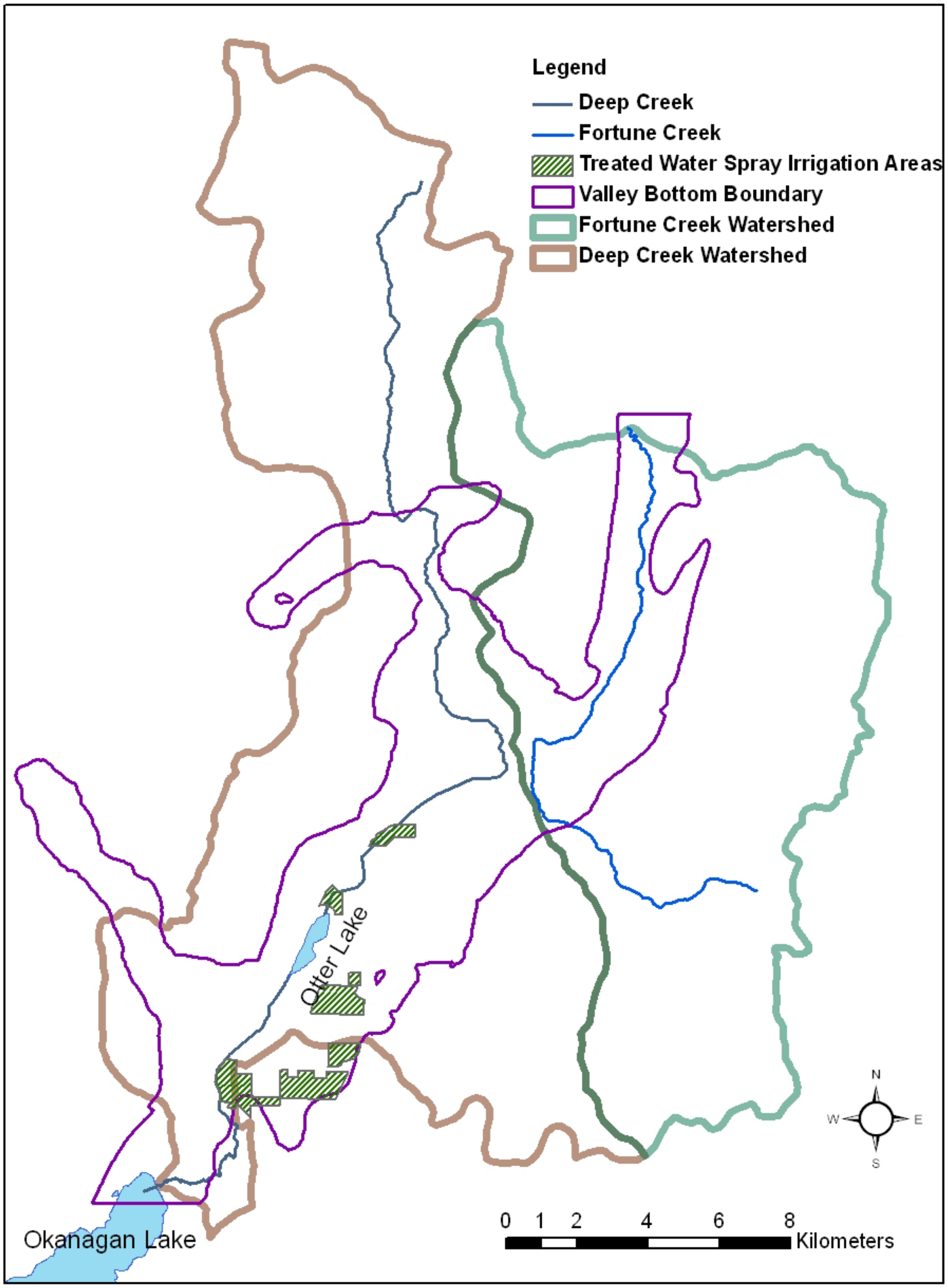


Figure 2.12 Treated municipal waste water spray areas for the City of Armstrong waste water treatment plant

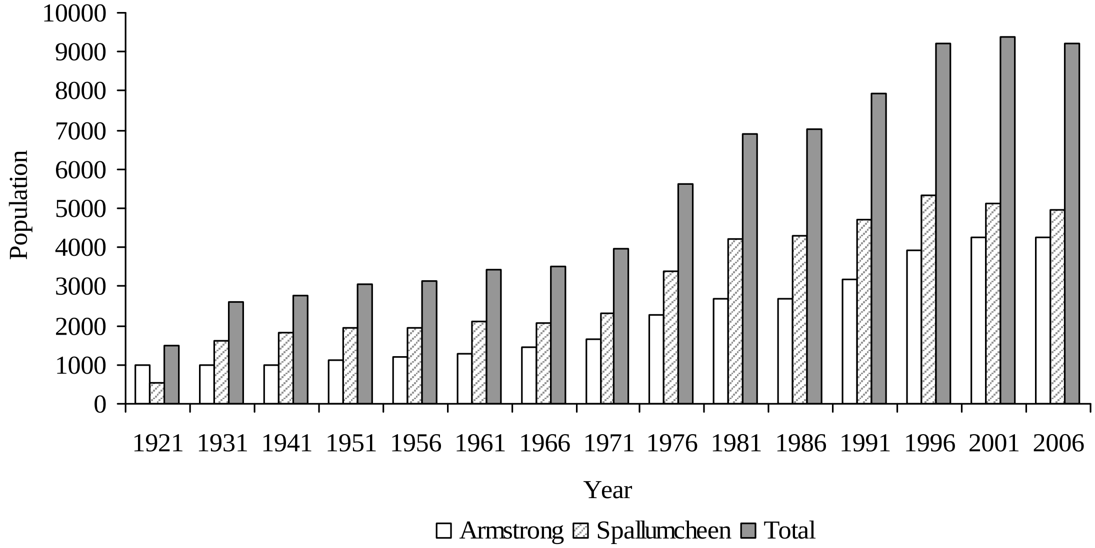


Figure 2.13 Historical populations in the City of Armstrong and the Township of Spallumcheen from 1921 to 2006

Table 2.1 Historical hydrometric stations on Deep Creek and Fortune Creek

Data Years	Station Name	Lat. N	Long. W	Gross Drainage Area Km^2
1970-1975	DEEP CREEK AT YOUNG ROAD	50°27'44"	119°10'39"	115
1951-1982	DEEP CREEK AT ARMSTRONG	50°26'46"	119°12'16"	135
1935-1950	DEEP CREEK NEAR VERNON (STATION NO. 3)	50°21'50"	119°16'55"	207
1969-1975	DEEP CREEK AT THE MOUTH	50°20'50"	119°17'36"	306
1911-1984	FORTUNE CREEK NEAR ARMSTRONG	50°26'18"	119°08'32"	41
1950-1961	FORTUNE CREEK AT STEPNEY	50°30'10"	119°07'25"	132

Table 2.2 Reconstructed naturalized hydrograph data for Fortune Creek

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average annual (m^3/s)	Total Volume (m^3/yr)
1960-1984 Armstrong North naturalized monthly flow (m^3/s)	0.086	0.075	0.09	0.522	3.416	2.405	0.533	0.149	0.169	0.178	0.151	0.101	0.659	2.1×10^7
1960-1984 Stepney Road naturalized monthly flow (m^3/s)	0.158	0.382	0.505	0.64	4.342	3.66	0.921	0.115	0.178	0.237	0.169	0.151	0.957	3.0×10^7
*Total water Usage (m^3/s)	0.042	0.037	0.041	0.048	0.063	0.082	0.117	0.106	0.056	0.043	0.04	0.038	0.060	1.9×10^6
Licensed Usage 2007 (m^3/yr)														3.0×10^6
Estimated 1960-1984 Average Outflow (m^3/yr)														2.7×10^7
Annual outflow from manual measurements 2007 (m^3/yr)														9.5×10^6
Total Precipitation (1960-1984 average) (m^3/yr)														1.0×10^8
Total Precipitation 2007 (m^3/yr)														1.2×10^8

*1998-2006 average value

Table 2.3 Summary of water usage in the study watersheds

Water usage		Domestic (m^3/ yr)				Irrigation (m^3/yr)	Other Uses (m^3/ yr)	Total (m^3/ yr)	Domestic (m^3/ yr)				Irrigation (m^3/yr)	Other Uses (m^3/ yr)	Total (m^3/ yr)
		Private	Local waterworks-City of Armstrong	Other Local waterworks	Subtotal	Estimated	Estimated	Estimated	Private	Local waterworks City of Armstrong	Other Local waterworks	Subtotal	Licensed	Licensed	Licensed
		Estimated	Estimated	Estimated	Estimated				Licensed	Licensed	Licensed	Licensed			
Surface water	Deep Creek	4,200[1]	N/A	N/A	4200	1,710,000[1]	488,300[2]	2,202,500	2,100	N/A	N/A	2,100	2,597,500	488,300	3,087,900
	Fortune Creek	N/A	1,438,000[3]	N/A	1,438,000	295,800[4]	N/A	1,733,800	N/A	3,095,000	253,500	3,348,500	295,800	N/A	3,644,300
	Total	4,200	1,438,000	N/A	1,442,200	2,005,800	488,300	3,936,300	2,100	3,095,000	253,500	3,350,600	2,893,300	488,300	6,732,200
Groundwater		575,000[5]	64,300[3]	1,375,100[6]	2,014,400	3,064,000[5]	113,000[7]	5,191,400	N/A						
Usage Total		579,200	1,502,300	1,375,100	3,456,600	5,069,800	601,300	9,127,700							
Irrigation Return		N/A	N/A	N/A	N/A	-1,267,500[8]	N/A	-1,267,500							
Treated water		N/A	N/A	N/A	N/A	-205,000[9]	N/A	-205,000							
Net Usage		579,200	1,502,300	1,375,100	3,456,600	3,597,300	601,300	7,655,200							

Notes:

1. Estimated actual usage (Swain 1994).
2. Licensed; other uses include Land improve, Storage and Watering.
3. Averaged measured usage (1999 to 2006) from City of Armstrong including water distributed to other licensed water districts: Highland Park, Lansdowne, Silver Star and Stardel. Data from Mike Klymchyk, Public Works Manager, City of Armstrong.
4. Licensed quantity. Actual usage not measured.
5. Estimation from MOE staff field survey.
6. Estimation by water districts (Table 2.7).
7. Estimation from MOE staff field survey, commercial water.
8. Estimated as 25% of irrigation quantity (there are no measured values).
9. Treated water data is based on year 2006 data from Mike Klymchuk, Public Works Manager of City of Armstrong. 818,000 m3/year used as irrigation with 25% irrigation return.
10. Negative means the water return to the watersheds.

Table 2.4 Water districts supply and usage information

No	District Name	Water Supply Source	Water usage
1	Canyon	Groundwater	35 houses, domestic, some farms
2	Eagle Rock	Groundwater	Domestic, farms
3	Grandview	Groundwater	Domestic
4	Highland Park	Water from City of Armstrong	Domestic , Other
5	Liard	Groundwater	97 residences, 1 farm, 1 commercial
6	Lansdowne	Water from City of Armstrong	Domestic , Other
7	Larkin	Groundwater	Big farms and industrial
8	Meighan Creek	Surface water - Meighan Creek	Domestic , Other
9	Mountain View	Groundwater	18 houses, Domestic, no farm, no commercial
10	Otter Lake	Groundwater	Irrigation, chicken farms
11	Silver Star	Water from City of Armstrong	Domestic , Other
12	Stardel	Water from City of Armstrong	Domestic , Other
13	Steele Springs	Surface water spring	Domestic, chicken farms
14	Stepney	Surface water-Fortune Creek	Domestic, farm, no irrigation
15	Hankey	Groundwater-Artesian well	Domestic
16	Pleasant Valley	Water from Armstrong	Domestic , Other
17	Round Prairie	Water from Armstrong	Domestic , Other
18	Stepping Stones	Greater Vernon Services Committee	Domestic , Other

Note: Hankey, Pleasant Valley, Round Prairie and Stepping Stones are municipal water utilities

Table 2.5 Total surface water extraction by the City of Armstrong (m^3) from Fortune Creek

Month \ Year	1999	2000	2001	2002	2003	2004	2005	2006
Jan	92,388	94,397	99,860	85,810	88,125	91,274	100,963	96,573
Feb	89,928	88,737	94,657	75,943	78,975	89,695	69,993	57,638
Mar	109,602	96,050	77,255	79,247	89,046	88,358	84,664	87,408
Apr	122,569	100,808	104,121	104,980	105,967	137,285	94,382	94,403
May	113,880	116,556	121,846	82,829	101,811	160,485	121,030	50,026
Jun	160,232	153,679	129,557	175,204	169,331	202,332	115,217	102,740
Jul	182,657	193,136	231,234	169,167	282,272	208,726	209,838	290,440
Aug	210,941	222,703	184,338	207,668	222,112	193,419	199,047	141,813
Sept	124,334	106,838	125,232	137,328	112,552	101,849	114,970	141,563
Oct	103,532	107,690	107,242	102,736	101,506	96,080	80,999	76,719
Nov	82,430	129,171	81,248	75,984	81,228	82,565	86,248	89,925
Dec	92,857	72,901	79,944	80,846	96,465	83,998	82,533	68,464
Total	1,485,350	1,482,666	1,436,534	1,377,742	1,529,390	1,536,066	1,359,884	1,297,712

Note:

1. The data in the table is for water provided to the City of Armstrong, and to 4 water districts (Highland Park, Lansdowne, Silver Star and Stardel).

Table 2.6 Summary of usage of groundwater from the BC Ministry of Environment well survey

Number	Usage Purpose	Quantity (m^3/yr)
35	Irrigation	3,064,000
13	Domestic	575,000
2	Commercial	113,000
Total		3,752,000

Table 2.7 Groundwater usage by water districts

District Name	Water Supply Source	Houses	Population	Water usage (m^3/yr)	Water Usage Information Source
Canyon	Groundwater	35	175	87,500	Estimation
Eagle Rock	Groundwater	NA	NA	291,000	Nora Ternier
Grandview	Groundwater	200	1,000	500,000	Estimation
Larid	Groundwater	97	485	243,000	Estimation
Larkin	Groundwater	NA	NA	101,000	OBWB
Mountain View	Groundwater	18	90	45,000	Estimation
Otter Lake	Groundwater	NA	NA	9,100	OBWB
Hankey	Groundwater	40	200	100,000	Estimation
Total	N/A			1,375,100	

Notes: Number of households supplied obtained from water districts. Number of persons supplied estimated from number of households using 5 persons per household. Water usage estimated using 500 m^3/yr per person. (http://www.earthcarecanada.com/FAQs/Water_FAQ.asp)

Table 2.8 City of Armstrong metered groundwater consumption from 1999 to 2006 (m^3)

Month \ Year	1999	2000	2001	2002	2003	2004	2005	2006
Jan	0	0	6	4	6,731	230	0	0
Feb	0	0	6,419	3,235	4,226	25	529	0
Mar	0	0	17,995	725	4,541	0	0	836
Apr	0	0	12,034	0	1,543	0	465	62,018
May	22,045	11,066	29,242	33,750	0	12,773	33,139	18,951
Jun	0	3,442	0	403	4,590	526	0	4,003
Jul	6,424	3,235	2,419	0	20,881	6,524	1,676	2,450
Aug	4,441	8,938	20,033	1,764	35,494	7,756	4,693	2,597
Sept	1,070	727	11,777	3,618	5,901	85	3,018	5,130
Oct	0	12	3,336	4,720	2,082	1,600	1,521	939
Nov	3,513	27	948	16,129	0	0	0	18,161
Dec	0	0	0	4,381	0	511	0	0
Total	37,493	27,447	104,209	68,729	85,989	30,030	45,041	115,085

Table 2.9 Treated sewage water used for irrigation purposes in 2006 (m^3)

Month	Discharge
Jan	0
Feb	0
Mar	0
Apr	0
May	42,559
Jun	83,724
Jul	360,497
Aug	307,667
Sep	23,800
Oct	0
Nov	0
Dec	0
Total	818,247

Table 2.10 Population projections for the City of Armstrong and the Township of Spallumcheen

Year	Population	Year	Population
2007	9,811	2022	12,164
2008	9,883	2023	12,350
2009	9,963	2024	12,531
2010	10,065	2025	12,713
2011	10,189	2026	12,891
2012	10,345	2027	13,064
2013	10,499	2028	13,234
2014	10,681	2029	13,405
2015	10,867	2030	13,576
2016	11,048	2031	13,741
2017	11,234	2032	13,901
2018	11,422	2033	14,056
2019	11,605	2034	14,207
2020	11,792	2035	14,357
2021	11,975	2036	14,508

Data Source: http://www.bcstats.gov.bc.ca/data/pop/pop/mun/Mun1921_2006.asp. http://www.bcstats.gov.bc.ca/

Chapter 3 Physical Hydrogeology

In this chapter, hydrogeological information such as the aquifer geometry, groundwater recharge, groundwater flow and discharge characteristics are examined. An understanding of these basic components and processes is needed to develop and calibrate a groundwater flow model for the study area.

3.1 Geological Setting

Geological and stratigraphic studies were commissioned as part of the NOGWCA project from Bob Fulton (Fulton, 2006) and Pat Monahan (Monahan, 2006). Further information has been drawn from earlier published work by Bob Fulton, Sandy Vanderburgh and from surface mapping and seismic reflection work by the Geological Survey of Canada.

Monahan (2006) conducted a stratigraphic analysis of the Okanagan basin in order to better delineate the aquifers of the North Okanagan. He constructed cross sections based upon:

- Well logs and ground surface elevation data from the MOE water well database,
- Well logs from other published reports from local government, MOE and Geological Survey of Canada reports
- Geophysical data from the Geological Survey of Canada, Simon Fraser University, and other independent sources,
- Geological Survey of Canada geological reports and maps

The finished product of his work was a report accompanied by a series of 19 cross sections covering the area from Okanagan Lake to the head of the Tohuk valley. Several cross sections were drawn based on Monahan (2006). The sections and section locations are included in Figures 3.1 and 3.2A to 3.2E. These are referred to in the discussions below.

A further detailed review of the Quaternary geological history and stratigraphy was undertaken by Fulton (2006). Keller (2006) then built a three-dimensional geological model based on the upper surface elevations ("tops") and lower surface elevations ("bases") of aquifers delineated in Monahan (2006). These 3-D layer surfaces were created with GoCad software, and exported in a series of other formats.

Overall Stratigraphy:

The valley fill can be broadly grouped into three packages of sediment (Fulton, 2006). The lowest contains layers of dense, sometimes reddish, coarse sands, or sands and gravels with layers sometimes described as "till" (Figure 3.2A). Some boreholes record organic debris in these layers, with descriptions ranging from "plant debris" to "lignite" to "coal" suggesting an older age for these sediments. A limited number of deep boreholes reach the full valley depth so direct information on these sediments is limited.

Seismic data indicates this lower package of sediments has an irregularly dipping upper surface, generally dipping towards the valley center from the east. The sediments above onlap this surface, indicating the lowest materials are unconformably overlain by the flat lying sequence above. Fulton (2006) interprets this as an erosional surface that was part of the Okanagan Center glaciations, which places these lower sediment packages with an age of greater than 65,000 years, but they may be from multiple glacial events. It is also possible they are pre-glacial Tertiary deposits (Fulton in Pullan, 1992)

Above the unconformity are flat lying sediments that are generally finer grained (including clays to fine sands) than the lower package. These flat lying sediments are sub-divided by the presence of organic material in a middle package, with distinct layers of organic debris noted in many boreholes in the study area, continuing down to the interface with the lower package. This middle package is interpreted as valley fill from between the penultimate Okanagan Center glaciations (>65,000 years) to the most recent Fraser Glaciation (20,000~11,000 years), which is supported by a radiocarbon date of the plant debris of 38,220 +/-370 radiocarbon years from Vanderburg (1993). The uppermost layer of the middle package is a coarser sandier layer which forms the main valley aquifer (Spallumcheen A). The presence of organic materials in borehole logs at the valley margins in areas such as the Okeefe and Hullcar valleys is used by Fulton (2006) to correlate the basal sedimentary layers in these valleys to the same time period as the Spallumcheen A aquifer, and to suggest lateral connections from them to the valley center (Figure 3.2C, 3.2D).

The topmost portion of the valley is filled with an upper package representing a complex range of sediments derived from the glacial and postglacial environments of the Fraser Glaciation. They include a large thickness of fine grained sediments related to a post-glacial lacustine environment, along with sand or sand and gravel outwashes from the glacial retreat. The most recent Holocene deposits sometimes overly these upper fine grained sediments.

The North Okanagan stratigraphy described by Monahan (2006) and Fulton (2006) has several locations where sediments are coarse enough or extensive enough to be considered aquifers. These have been divided into three classes: shallow, moderate and deep aquifer systems. Overall, there were 19 unconsolidated Quaternary aquifers identified within DCW and FCW.

3.1.1 Deep aquifer system

The deepest parts of the valley center include the Spallumcheen B, D, E aquifers of the lowest sediment package (Figure 3.2 A,B,C; Monahan, 2006, Section 5). These are grouped into the deep aquifer system because they are comprised of similar materials and have similar geologic characteristics (Figure 3.3). All of these aquifers lie beneath the unconformity surface that defines the top of this group. This unconformity separates the lower Okanagan Center sediments from interglacial sediments above.

Regional Spallumcheen B aquifer

The Spallumcheen B regional aquifer is comprised of coarse sands and gravels with thickness of 45 to 90 meters, and represents the top of the lowest package. It occurs at the depth from 200 to 340 meters below ground throughout the valley center. Monahan (2006) notes that Spallumcheen B sediments may cease in the far north of the study area in the FCW at observation well 54 (WTN 24093, O122) where the unconformity surface may have been eroded more deeply.

There are only 3 wells drilled through the Spallumcheen B aquifer, so the upper interface was located using seismic data in locations with no borehole data (Monahan, 2006). For modeling purposes, the Spallumcheen B aquifer is interpreted to be present throughout the North Okanagan Valley within the study area. This implies that Spallumcheen B has not been removed by over-deepening of the unconformity surface at any other locations.

A hydrogen sulphide odour (H_2S) was noted when water samples were taken in the MOE observation wells completed in the Spallumcheen B aquifer, indicating a long residence time and anoxic conditions. One value of hydraulic conductivity, 1.26×10^{-2} m/s (Kenny, 2005) is available from a series of slug tests performed on well 55 (WTN 24080, O118). This value is consistent with the description of Spallumcheen B as sand and gravel, but lies at the higher end of expected hydraulic conductivities.

Two of the three deep wells drilled through the Spallumcheen B aquifer reached several more layers below composed of sand and gravel interspersed with till. These lowest layers of permeable material are designated the Spallumcheen D and E aquifers and are identified separately in the FCW (Monhan, 2006). It is difficult to know the extent of these aquifers from the limited deep data in the DCW.

The Spallumcheen B, C and D aquifers can conceptually be grouped to act as a consistent set of permeable material that underlies the main moderate depth aquifers described below.

3.1.2 Moderate depth aquifers

Above the unconformity that marks the top of the Spallumcheen B aquifer, the sediments are an interglacial sequence of mixed sands, silts and clays, with organics present in many boreholes. This is a mixed package of sediments that varies within the area, but is generally finer at the top (silty clay, silt, sandy silt). In most locations it is dominantly silt with clay but in some locations it contains coarser materials at or near the base (silty sand up to sandy gravel).

Aquifer Spallumcheen C was identified within this package by Fulton (2006) and Monahan (2006) as identifiable sand to sandy gravel layers at selected locations within this sequence. Within FCW, this coarser grained material is 20 to 30 meters thick and present immediately above Spallumcheen B (Monahan, 2006; Sections 4,5,2). It is overlain by sandy silts, silts, or clay within FCW, making it distinct from aquifers above. It has thinned by the southern end of Section 18, and was not identified in Sections 2 or 3.

Between Armstrong and Otter Lake, this coarser layer is more difficult to identify due to the lack of deep wells. Monahan (2006) did not identify it in Section 11 (Figure 3.2A), as there are no deep wells. A deep well (WTN 20269) on the west side of Section 1 (Figure 3.2B) records 150 to 200 meters of silts interbedded with fine sands above Spallumcheen B. This layer contains abundant plant debris, which distinguishes these coarser materials from the underlying Spallumcheen B.

Moving south (Figure 3.2B,C; Sections 6,7,10,16), Spallumcheen C is only occasionally identified. Section 6 contains no wells to the appropriate depth, and within Section 7, only a thin layer (3 metres) of sand was found near the base of the City of Armstrong deep test well, at 247m depth. A thin layer of sandier material was identified in Figure 3.2C (Section 10), but at an elevation above that of Spallumcheen B and the other locations where Spallumcheen C was identified. South of Okeefe only one well was advanced to a depth that could provide information. Well WTN 19502 at the southern end of Section 16 records sandy silts and clay with silt, interbedded with occasional sand lenses from 17 meters to a depth of 300 meters (Monahan, 2006, Section 16). This extends to below the depth that Spallumcheen C was identified in other sections, and suggests that it is not present, or that any sandier materials are much more spatially restricted at the south of the valley than within FCW or at Section 1.

Within FCW, Spallumcheen C lies immediately above Spallumcheen B and would be hydrogeologically similar to Spallumcheen B. Within DCW, it is likely this “aquifer” represents discontinuous sandier material in these otherwise finer-grained valley fill sediments (Fulton, 2006), and that these sands are not regionally interconnected. Fulton (2006) proposes these spatially discontinuous coarser layers may have been generated from flushing of glacial debris in immediate post-glacial times after the Okanagan Center Glaciation, with coarser portions related to valley side tributaries. This may have been followed by valley side input of stream sediments to a main valley lake which contributed the silt and clay material that makes up the rest of this middle package (Fulton, 2006; Monahan, 2006). This middle package of sediments correlates laterally to coarser grained deposits at the base of the Okeefe valley (Figure 3.2C), which may suggest input of water and sediments from the Salmon River Valley to the west. This would have increased the sediment deposition rate to a lacustrine environment in Okanagan valley, and allowed the large thickness of sediments to accumulate over the ~45,000 years of interglacial time.

Regional Spallumcheen A aquifer

The top of the middle package of sediments is a sandier layer (silt with sand, silty fine sand, up to coarse sand) with plant debris termed Spallumcheen A by Fulton (2006) and Monahan (2006) (Figure 3.2A to E). The regional Spallumcheen A aquifer is the major aquifer within the study area. The depths of its top vary from 30 to 90 meters, but shallows to a depth of 12 to 20 meters below the Okeefe unconfined-confined aquifer at the south end of the valley. Its thickness ranges from 45 to 90 meters and exceeds 170 meters in a few wells in the valley center in some locations (Monahan, 2006). Artesian wells occur in the northern and central parts of the main Okanagan valley.

Spallumcheen A is the name given for this sandy layer within the valley center. However, the Spallumcheen A aquifer grades laterally into a series of other confined aquifers that are related, and are found at the valley sides in the Okeefe, Sleepy Hollow and Eagle Rock areas (Figure 3.2A to E). These aquifers tend to be coarser grained than the main body of Spallumcheen A, which is consistent with valley side erosion into a lake during an interglacial period (Fulton, 2006). The coarser sediment nature at the top of the middle package may be the result of diversion of the Salmon River into the Okanagan valley at this time (Fulton, 2006). The upper limit of this aquifer is in places the coarsest, and is marked by abundant organics. This may indicate that the start of the most recent glaciations was leading to more abundant coarse sediments from the surrounding hills, and to a flush of organics to the valley floor.

Spallumcheen A is interpreted as pre-Fraser glaciation (Fulton, 2006; Monahan, 2006). The top of this aquifer has an irregular surface, interpreted to be a glacial erosion surface. In several locations at the valley sides, the top of Spallumcheen A is overlain by tills (Figure 3.2D). In the Okeefe area compacted silts and compacted clays are logged above Spallumcheen A, and below glaciofluvial or glaciodeltaic sediments attributed to deposition from the Okeefe valley to the west (Figure 3.2C).

The majority of both drinking water supply wells and irrigation wells in the North Okanagan have been drilled into this aquifer. The hydraulic conductivity ranges from 2.64×10^{-5} m/s to 8.03×10^{-4} m/s based on the aquifer pumping tests conducted by Ministry of Environment (Carmichael et al., 2009). The specific storage is from 1.6×10^{-4} m^{-1} to 1.3×10^{-2} m^{-1} (Kenny, 2005).

Sleepy Hollow confined aquifer

Northwest of Armstrong, the valley side rises to the Hullcar area, through the Sleepy Hollow area (Figure 3.2D). The Sleepy Hollow B aquifer named by Monahan (2006) is a confined aquifer occurring at depths of 50 meters to 110 meters and consists of sands and gravels with a thickness up to 30 meters. Sleepy Hollow B joins into the Spallumcheen A aquifer at the valley side. Similar to the Spallumcheen A aquifer, this confined aquifer has an undulating upper surface. The presence of organic debris in Sleepy Hollow B helps to correlate it to Spallumcheen A. It is overlain in some locations by tills, which helps to place both Sleepy Hollow B and Spallumcheen A as prior to the Fraser glaciation. Above the tills overlying Sleepy Hollow B is an unconfined aquifer designated the Sleepy Hollow A aquifer.

Wells in Sleepy Hollow B are all actively used, and hence no static water level wells could be located. This lack of static water levels makes it difficult to analyze the hydraulic connections between the Sleepy Hollow unconfined and confined aquifers.

Hullcar confined aquifer

The Hullcar valley lies up to 150 m higher than the main Okanagan valley center (Figure 3.2D). Deep Creek incises a valley into the Hullcar and Sleepy Hollow sediments as it flows southeast towards the main valley. At the base of the Hullcar valley is a confined aquifer consisting of sands and some gravels, also overlain by tills in places. The origin of these sediments is still unclear, but Fulton (2006) proposes they may be derived from a tributary that flowed to the Okanagan valley at a similar time to the deposition of Spallumcheen A (Fulton, 2006; Monahan, 2006).

Further north along Deep Creek from Hullcar lies the Tohuk area (Figure 3.2D). The lower sediments in this area are coarser, and exhibit organic debris with an age similar to Spallumcheen A (21,500 radiocarbon years; Fulton, 2006).

The top of the Hullcar confined aquifer occurs from 15 to 50 meters below ground and it is up to a thickness of 25 meters. The depths of static water levels are from 5 to 25 meters below ground surface. Many wells have been drilled in this aquifer for irrigation and drinking water supply. Yields range from 3 to 40 litres per second (50 to 600 U.S. gallons per minute).

A new observation well (well 219, O384) with a depth at about 90.1 m was drilled by the BC MOE to investigate the geology between the Hullcar and Sleepy Hollow areas. The stratigraphy of this borehole indicates that there may be another aquifer existing between the Hullcar and Sleepy Hollow area (Oleg Ivanov, personal communication, 2009). Further information is needed to map the area linking the Hullcar and Sleepy Hollow areas.

Okeefe confined aquifer

The Okeefe valley links the Salmon River valley in the west to the main Okanagan valley in the area just north of the current north end of Okanagan Lake. The Okeefe C aquifer named by Monahan (2006) is a confined aquifer consisting of stream deposited sands and gravels over bedrock that connect from the base of the Okeefe valley to the west to the Spallumcheen A to the east. It represents stream deposition of coarser sediments coming from the Salmon River into an interglacial period lake in the main valley. There is no creek in the Okeefe valley at the moment, but it is likely the Salmon River flowed into the Okanagan at the time of Spallumcheen A.

Its thickness is up to 30 meters. The thickness of the overlying clay and silt that separate this aquifer from the overlying Okeefe A aquifer thins to the West to nothing where well 218 (WTN 24130) is located. This connects the confined Okeefe C with the overlying Okeefe unconfined aquifer.

3.1.3 Shallow aquifers

The Spallumcheen A and related aquifers were laid down at the end of the previous interglacial period. In rare cases, Monahan (2006) notes that small till areas lie on top of Spallumcheen A (Sleepy Hollow area, Eagle Rock area). The uppermost sediment package in the valley is therefore interpreted to be either from the Fraser Glaciation, or post-glacial.

The shallow aquifers system (Figure 3.5) consists of all the local shallow aquifers including the Eagle Rock unconfined and unconfined-confined aquifers, the Fortune Creek aquifer, the upper Okeefe aquifers and the Sleepy Hollow unconfined aquifer.

These represent coarser units in the overall sequence of glacial and postglacial sediments which infill above Spallumcheen A.

Eagle Rock unconfined-confined aquifer

The Eagle Rock aquifers named by Monahan (2006) are a confined-unconfined aquifer system (Figure 3.2B). The lowest portion of Eagle Rock A (deep confined aquifer) is connected to Spallumcheen A to the west, and is likely a coarser valley side infill from the pre-Fraser Spallumcheen A period. Higher up the valley side, Eagle Rock A continues to sands to sands and gravels interspersed with till layers that may represent valley side lake deposition adjacent to glacial ice, valley margin fan deposits or kame terrace deposits (Fulton, 2006). The total aquifer thickness of the Eagle Rock A ranges from several meters to 50 meters in the confined part and over 75 meters in the unconfined part (Monahan, 2006).

The unconfined Eagle Rock B aquifer lays on top and to the west of the main Eagle Rock A aquifer and represents post-glacial fan deposition of the sediments to the east. These overlie the finer silty clay lacustrine deposits that make up the valley center.

Against the valley side, the Eagle Rock A aquifer is connected to the overlying Eagle Rock B unconfined aquifer and receives recharge from the valley side. West of the highway, the Eagle Rock A aquifer is confined, and a layer of glaciolacustrine sediments separates the lower Eagle Rock A from the Eagle Rock B at surface.

Evidence of the Eagle Rock Unconfined (B) and Eagle Rock confined-unconfined (A) connection can be found in the historical chloride concentration of well 6 (WTN 25324). Chloride has been increasing in the confined portion of the aquifer (Figure 3.6) likely as the result of road salting activity in winter on the unconfined portion. These two aquifers have been considered together as part of the unconfined system due to their connection at the valley side.

Flowing artesian wells occur in the confined part of the aquifer in the west due to mountain system recharge (Le Breton, 1972, 1974; Livingstone, 1974). Well 7 (WTN 32340, O180) has measured static water levels since 1971 and provides data to interpret the hydrogeology of this aquifer. The depth to the static water level ranges from 5.7 meters to 12.6 meters.

Fortune Creek unconfined-confined aquifer

The water bearing materials of the Fortune Creek unconfined-confined aquifer consist of sands and gravels of up to 50 meters thickness (Figure 3.2A). A study of the Fortune Creek fan area is being undertaken under a separate project. This includes surficial mapping and a new reflection seismic profile conducted across the valley by the Geological Survey of Canada.

The lowest parts of the Fortune Creek aquifer may represent valley side deposition of coarser materials as kame terrace or proglacial outwash similar to Eagle Rock A and Sleepy Hollow B aquifers (Monahan, 2006) Other fan-like structures exist further north on the east side of the valley. The upper portion of the Fortune Creek fan immediately adjacent to the bedrock appears to be comprised of an intact Holocene alluvial fan or debris outflow deposited in immediate post-glacial times. This material has subsequently been incised by the post-glacial action of Fortune Creek. Multiple post-glacial stream channels have proceeded from valley side to the current valley center. Sands and gravels from the upper fan have been transported downstream by strong flows during spring runoff, leading to a series of channels infilled with coarser grained material cut into the underlying silts.

As indicated in Chapter 2, Fortune Creek loses surface water during the valley side to valley floor transition across the Fortune Creek fan. A portion of this water returns to Fortune Creek, and some does not return. Possible connection of the upper Fortune Creek aquifer to the underlying Spallumcheen A aquifer is explored further in Chapter 4. There may also be water exchange between Fortune Creek and Deep Creek via the former channel ways of the Fortune Creek fan.

Artesian wells located in the Fortune Creek unconfined-confined aquifer and Spallumcheen A aquifer occur at the valley center side of the fan complex. Drinking water supply wells WTN 62416 (Mountain View Improvement District) and WTN 68125 (Laird Improvement District) were completed in this aquifer (Monahan, 2006, personal communication with the Township of Spallumcheen).

Hullcar unconfined aquifer

The Hullcar valley lies in the northwest of study area with an average elevation of 520 meters above sea level, which is more than 150 meters higher than the main Okanagan valley (Fulton, 1975). The Hullcar unconfined aquifer is comprised of glaciofluvial sands and gravels and it includes kettle holes, indicating sedimentation during the waning of the last Fraser Glaciation. The sediments are interpreted as being derived from the Salmon River valley to the west (Fulton, 2006).

Its thickness ranging between 3 to 45 meters (Fulton, 1975; Monahan, 2006). Deep Creek deeply cuts across the Hullcar valley from northwest to southeast. The static water level depth varies from 2.5 to 7 meters based on measurements at wells 94 (WTN 57252), 95 and 96. Some wells are drilled in this aquifer to provide water for irrigation and domestic usage, though the majority of major wells are drilled to the Hullcar confined aquifer.

Sleepy Hollow unconfined aquifer

The Sleepy Hollow A aquifer named by Monahan (2006) is an unconfined aquifer in which the water bearing materials are surficial glaciofluvial and glaciodeltaic sands and gravels with a thickness up to 75 meters overlying clay and silt (Monahan, 2006). They have inclined bedding interpreted as due to foreset deposition. These are materials that represent distal portions of the deposition of the Hullcar unconfined aquifer. The geology of the area between Hullcar and Sleepy Hollow is complex, and merits further work to arrive at a detailed interpretation.

The topography of the aquifer drops from northwest to southeast as the Sleepy Hollow areas drops down towards the main valley floor. The static water level depth is from 3.9 to 43 meters. Deep Creek cuts the aquifers deeply within this area.

Okeefe unconfined aquifer

The main Okeefe valley spans between the Salmon River valley to the west, and the Okanagan valley to the east (Figure 3.2C). The Okeefe A aquifer named by Monahan (2006) is a completely unconfined aquifer comprising of glaciofluvial outwash and ice-contact deltaic deposits including sands and gravels interbedded with silts and clay (Fulton and Halstead, 1972; Fulton, 1975; Fulton, 2000; Monahan, 2006). The thickness of this aquifer is up to 120 meters, and at the western side, it is in contact with the underlying Okeefe C aquifer. The ground surface of the Okeefe unconfined aquifer is from 450 to 480 meters elevation above sea level, and the eastern edge of Okeefe A represents a steep drop to the main Okanagan valley (elevation ~350m) and the course of Deep Creek.

The average static water level depth is 18.1 meters based on the static water levels of WTN 45587. The sands and gravels are exploited for water supply within this area. Drinking water supply well (WTN 18897) for Grandview Flats Improvement District is drilled in this aquifer.

Okeefe unconfined-confined aquifer

This aquifer was named as Okeefe B by Monahan (2006), and fills the upper part of the valley along the course of Deep Creek east of the Okeefe valley. It has both unconfined and confined parts, and consists of sands and gravels interbedded with silts and clays. These deposit materials may have been distal portion of the glaciofluvial and glaciodeltaic sediments that formed an eastern part of Okeefe A, now separated by the action of Deep Creek (Fulton, 2006) or they may have partly come from slope failure of the thick Okeefe A deposits to the west (Fulton, 1975). The thickness is up to 36 meters.

The elevation of the top of this aquifer top floor is around 350 meters above sea level which is 100 meters lower than ground surface of the Okeefe A unconfined aquifer to the west. The Okeefe B aquifer is separated from Spallumcheen A by a variable thickness of fine grained sediments that can vary from clays, to compacted clays interpreted to be derived from the glacial environment. Monahan (2006) was able to map that the underlying Spallumcheen A aquifer becomes shallower at the southern end of the main valley, and may be in contact with the Okeefe B aquifer in the area south of Otter Lake. More discussion of this possible connection is investigated in Chapter 4 using geochemical methods.

The static water level depth generally lies closer to surface, and is around 6 meters. The static water levels in this aquifer are lower than that in aquifer Spallumcheen A within this area, indicating upwards groundwater flow from Spallumcheen A to Okeefe B. Several standing ponds with no surface water inflow or outflow exist south of Otter Lake, which are maintained by upwards groundwater flow.

3.2 General Hydrogeology

3.2.1 Regional Groundwater Recharge

Groundwater is a significant component of the total water resource within a watershed, and it commonly plays a key role in economic development, agricultural activity and ecologic protection, especially in arid and semiarid regions. Recharge is the most important factor in evaluating groundwater resources, but it is often the most difficult parameter of a water balance to quantify.

The North Okanagan aquifer system is composed of valley bottom unconsolidated aquifers surrounded by bedrock highlands of variable composition, geological history and geometric configuration. Recharge from the adjacent mountainous areas can includes both diffuse and localized recharge. Mountain system recharge (MSR) is frequently the dominant source of recharge to alluvial basins in the (semi-) arid Basin and Range province of the western United States, and has been a focus of recent research (e.g.: Gleeson and Manning, 2008; Manning and Solomon, 2005).

MSR consists of several components. Runoff from the mountains that creates localized recharge of water to the valley aquifer system at the mountain front is termed mountain-front recharge (MFR). Diffuse recharge to bedrock uplands leads to percolation through the mountain bedrock that reaches the valley basin via the movement of deep groundwater and is termed mountain-block recharge, (MBR). The acronym MFR has traditionally been utilized to describe both processes collectively but recent literature has moved to separate the terms MFR and MBR (Wilson and Guan, 2004, Wahi, 2005, Wahi et al., 2008). In the NOGWCA study area, MFR would result in water entering the local shallow aquifers with its source in the mountain areas and MBR represents the water entering the regional moderate and deep aquifers with its source in the mountain areas.

Recharge sources to the shallow aquifers include rainfall, snow-melt, irrigation return, septic field returns, surface water leakage and mountain system recharge. The inflow sources to the moderate and deep groundwater systems include downwards flow from the overlying shallow groundwater systems and recharge at the valley sides via mountain system recharge.

3.2.2 Regional Groundwater Flow

Contours of groundwater levels in the DCW and FCW aquifers were at times difficult to construct accurately due to the low spatial coverage of monitoring wells for static water levels. The uncertainty in well elevation data in the BC MOE wells database made interpretation of historic water level elevation data difficult. The groundwater flow directions in the central and northern parts of the Okanagan valley were determined from the available data. Figure 3.7 presents the static water levels data within aquifers Spallumcheen A and B. Groundwater within the main valley flows from north to south in the DCW, which indicate that groundwater within the regional aquifers ultimately flows into Okanagan Lake.

Vertical groundwater flow between aquifers Spallumcheen A and B is discussed in section 3.4.1 of this chapter.

3.2.3 Regional Groundwater Discharges

Discharge from the shallow aquifer systems involves phreatic groundwater evaporation, extractions by pumping, discharges to surface water, discharge at springs and flow into Okanagan Lake. Discharge from moderate aquifer systems occurs mainly from pumping and from upwards leakage to shallow aquifers and hence eventually into Okanagan Lake. Discharge from the deepest Spallumcheen B aquifer occurs from leakage upwards to moderate aquifers and from there likely to Okanagan Lake.

3.3 Static Water Level Monitoring

3.3.1 Locating static water level monitoring wells

There are five existing MOE observation wells located in the North Okanagan area (Figure 3.9). These five wells are datalogged by the MOE and records are largely continuous since the 1970s. The daily data is available from the Ministry of Environment Water Stewardship website (http://a100.gov.bc.ca/pub/gwl/disclaimerInit.do).

At the start of the study, it was determined that there were insufficient MOE groundwater monitoring wells for groundwater modeling given the complexities of the multi-layered aquifers and associated geological materials. Field surveys were undertaken by both MOE and UBCO personnel to locate more wells within the study area that were suitable for monitoring of static water levels. Wells were selected based on the following criteria:

- Completed with a known depth and screen interval;
- Not currently in use for water pumping, or in use for a defined time period such as during the summer irrigation season;
- Having suitable access at the well head to permit water level measurements with a standard water level tape;
- Located where access can be gained by permission of the well or land owner.

Locating suitable wells was a challenging and time consuming task. In spite of significant effort undertaken, only about 48 additional wells were located. Some of these wells are pumped at some times of the year, and thus records collected in this study are not continuous. Differential GPS surveying of all monitored wells was conducted to provide reference geodetic elevations of the monitoring ports. The locations of all the static water level monitoring wells are shown in Figure 3.8.

3.3.2 Static water level measurements

Static water level measurements were commenced in 2005, when 20 wells were located in the first survey. A single measurement was obtained at the time when the candidate well was first located. A program of regular static water level monitoring of the initial

20 wells located by April 2007 was instituted in May 2007. Static water levels were measured at two week intervals during the summer of 2007, and a monthly interval during the winter season of 2007-2008. The list of wells monitored varied over the study depending upon well usage, permission to obtain levels from the well owner, accessibility in winter time and other factors.

Detailed information about the monitoring wells and the associated static water level data are presented in Appendix 3.1 and Appendix 3.2, respectively. Historical monitoring data of the five MOE observation wells are presented in Appendix 3.3.

A separate survey by MOE staff (Trina Koch) was conducted to locate artesian wells within the study area, and to estimate any discharges. A number of the wells are free flowing when not in use for irrigation purposes. Well construction information and locations of artesian wells are presented in Appendix 3.4 and Figure 3.9. The wells located in this study represent a subset of the artesian wells in the study area. A larger number of wells was identified in the MOE water well records as being artesian, but not all of these wells remain in service, or remain artesian.

3.4 Groundwater Levels, Climate and Groundwater Flow

3.4.1 Regional confined aquifers

Five observation wells within the study area have been monitored by the MOE since the 1970s (Figure 3.8 and Appendix 3.1). The long term static water levels of these wells are discussed below. One well is located in Eagle Rock unconfined, one pair of adjacent wells are completed in aquifers Spallumcheen A and B in the central part of DCW, and one pair are completed in aquifers Spallumcheen A and B within the northern part of the main studied valley in FCW.

Spallumcheen A and B: central Deep Creek watershed

A pair of observation wells is located in the Spallumcheen A (well 42, WTN 24104, O119) and underlying Spallumcheen B (well 56, WTN 24062, O117) aquifers in the central part of northern Okanagan valley.

The seasonal static water level patterns of well 56 were similar to those of well 42 (Figure 3.10). However, the annual average static groundwater levels in well 42 were always higher than those in well 56 by approximately 1.5 meters. The difference in groundwater levels between two aquifers suggests an overall gradient downwards from Spallumcheen A into the deeper Spallumcheen B in this part of the valley.

MOE observation well 56 is located adjacent (about 90 meters laterally) to the production well 41(WTN 20648) with a depth at 190 meters. It is possible that a well 56 is affected by the pumping of the production well above.

Static water levels of wells 56 and 42 have been generally decreasing since 1971 (Figure 3.10). The groundwater levels in both wells decreased from the 1970's to early 1990's, following a similar pattern to the cumulative precipitation departure curve. The cumulative departure curve shown is derived from the average precipitation on the mountain areas, which represents the water entering the two regional aquifers via MSR. After the early 1990's the cumulative precipitation departure indicates above average precipitation for several years. Groundwater levels to show an upturn within one to two years. The groundwater levels from the mid 1990's to 2006 continue to reflect changes in cumulative precipitation, but remained more level than the cumulative precipitation departure. This may be due to pumping increases in the valley center with population growth.

It is also possible that the recent history of water levels is related to a decline in recharge to these two aquifer systems from spring snowmelt on the bedrock valley sides, or via the unconfined aquifers within the groundwater system. This would mean timing of precipitation, timing of snowmelt and some other combination of climate factors influenced recharge quantity independent of total precipitation.

The similarity of annual water level change patterns from these two wells suggests that the groundwater system in the valley center is capable of reaching equilibrium on an annual time scale. Vertical hydraulic gradients are maintained on an annual basis and represent a long term exchange of water vertically between Spallumcheen A and B.

Examination of the groundwater level differences on shorter time scales (daily, weekly, and monthly averages) between the two wells indicated that the water levels in well 42 are not always higher than in well 56 (Figure 3.11). The smallest differences in average monthly water levels occurred in July and August every year, which corresponds to the main irrigation season. Water levels in well 42 (Spallumcheen A) were lower than in well 56 (Spallumcheen B) for a short period in the months of July to August, 2004. At this time, the normally downwards groundwater gradient from Spallumcheen A to B was reversed and groundwater was then drawn upwards from Spallumcheen B to A. Groundwater levels increased again in September as the end of the irrigation season reduced groundwater pumping and water levels reach their highest annual levels in the period of January to March, 2005. This pattern is consistent with a steady vertical flow between Spallumcheen A and B maintained by recharge at elevation in the adjacent mountain block, temporarily altered by irrigation.

Estimation of the groundwater extraction for irrigation in the regions near to this pair of wells could be used to estimate normal groundwater flux from aquifer Spallumcheen A to B.

Spallumcheen A and B: Fortune Creek watershed

Wells 54 (WTN 24093, O122) and 55 (WTN 24080, O118) are both in the Spallumcheen B aquifer, located in the northern part of the study area (Figure 3.7). Well 54 is the most northerly well in the Spallumcheen B aquifer. At times, artesian conditions have been recorded at this well. The long term record of static water levels from these two wells is shown in Figure 3.12, and water levels are above those of well 56 to the south.

Water levels recorded in well 54 in the north were always lower than those in well 55, suggesting that there is a ground water divide in the Spallumcheen B aquifer system between the north and the centre of main valley.

The water levels in both wells have varied by up to 3 meters. The wells have not demonstrated a long-term decline in water levels as seen further south in Spallumcheen A and B (Figure 3.10). The water levels do show a correlation with annual precipitation and the cumulative departure from the average annual precipitation on mountain areas. Water levels decline from the 1970's to the early 1990's and then recover to levels similar to the 1970's. Water levels in the two northern wells appear to follow annual changes in precipitation, or to lag by one year. Changes in precipitation trends such as from 1979 (low) to 1980 (high) appeared in the water level record in 1981. Similar one year delays in aquifer response were seen in 1987 (low precipitation) and 1988 (lowest water level) and in 2002 (low precipitation) to 2004 (low water level). When seen at a monthly scale (Figure 3.13), the patterns of monthly static water levels in well 55 and well 54 were similar during the period of January 2004 to December 2005, but do not seem related to monthly precipitation. This may be associated with the 1 to 2 year lag in water levels appeared in the annually averaged data (Figure 3.12).

No MOE monitoring wells exist in Spallumcheen A in the FCW area. However, recent static water level measurements in a private well 26 (WTN 82463, surveyed) (Figure 3.14) in the Spallumcheen A aquifer indicated that groundwater levels in Spallumcheen A within the northern portion of the FCW were lower than those in Spallumcheen B. The water levels in this portion of Spallumcheen A and B are consistent with upwards flows from Spallumcheen B into Spallumcheen A. The depth of the Spallumcheen B (and C/D) aquifers in this area means their only source of recharge is the adjacent mountain block. This indicates that recharge to Spallumcheen B in FCW is primarily derived from MSR.

The reason for the change in the vertical flow direction in mid-valley cannot be determined from observed groundwater head data only. The balance of recharge to Spallumcheen A via unconfined aquifers and via MSR may alter the relative amounts of water entering Spallumcheen A and B at different parts of the valley. Further investigation of this in undertaken in Chapter 5.

There are insufficient static water level measurements in Spallumcheen A in the north of the FCW to determine if there is also a groundwater divide within Spallumcheen A.

The schematic vertical flow patterns in the central and northern parts of main valley are shown in Figures 3.15 and 3.16.

3.4.2 Local Aquifers

Eagle Rock unconfined-confined aquifer

Well 7 (WTN 32340, O180) is located in the Eagle Rock unconfined-confined aquifer. In an unconfined aquifer, groundwater levels generally vary with precipitation, pumping for irrigation and domestic use, and potential evaporation.

Water levels in this well generally followed the annual trends with precipitation from 1971 to 1997 (Figure 3.17). After 1997, the groundwater level began to decline, and the decline became a sharp decrease in 2001. The water levels after 2004 follow annual changes seen in the cumulative precipitation departure, but at an overall water level approximately 5m lower than before. The cumulative precipitation increased from 2002 onwards, but recovery of the water levels within the aquifer has not appeared to occur.

This significant decline in water levels may be the result of additional pumping of two commercial wells installed in Spallumcheen A close to this aquifer (well 174 at depth 80 metres and well 175 at 87 meters). The observation well reflects a change in the local flow pattern to supply these two wells with water. The link of water levels to pumping indicates that the Eagle Rock aquifer may provide water to Spallumcheen A by vertical leakage.

Detailed monthly precipitation and groundwater level data from 2004 to 2005 (Figure 3.18) suggests that groundwater levels have experienced fluctuations of up to 2 meters per year. The groundwater level increased from September to March. Groundwater levels decreased when irrigation started in April, and reached the lowest level in August at the end of the summer irrigation period.

Fortune Creek unconfined-confined aquifer

Well 100 (depth of 2.3 meters) is located in the Fortune Creek fan close to Fortune Creek and would be affected by precipitation and Fortune Creek water levels. The range of groundwater levels in this well was about 0.5 meters from June, 2007 to Sept. 2008 (Figure 3.19). Groundwater levels kept relatively stable from Jan to March with the snow cover and little evaporation. Both groundwater levels and Fortune Creek water levels went up from April to June with the snowmelt. The change in water levels in Fortune Creek during spring freshet in May and June can be up to a meter. At well 100, The water level declines in both years from July to September when Fortune creek water levels decline, and aquifer pumping for irrigation is highest..

Hullcar Unconfined aquifer

Figure 3.20 shows the groundwater level changes in well 93 located in the Hullcar unconfined aquifer at a depth of 6.1 meters. The range of water levels was 2.3 meters. The highest groundwater levels occurred in March as a result of snowmelt derived recharge. The groundwater level begins to drop from April onwards due to groundwater discharging to Deep Creek and water pumping for domestic supply and irrigation within the Hullcar valley.

Hullcar Confined aquifer

Wells 93 and 94 (WTN 57252) are located adjacent to each other, with well 93 in the upper unconfined aquifer, and well 94 (depth 20.5 meters) in the lower Hullcar confined aquifer. The confined aquifer is the more dominantly used aquifer for irrigation purposes. As indicated in Figure 3.21, groundwater levels in well 94 begin increasing in March and reach their highest levels in June. Water levels decline form July onwards due to pumping for irrigation and continue to fall until October. The range of groundwater levels was 0.8 meters which is relatively more stable compared with that observed in the Hullcar unconfined aquifer.

Okeefe unconfined aquifer

The groundwater levels in well 104 (WTN 45587) located in the Okeefe A unconfined aquifer at a depth of 91.4 meters is presented in Figure 3.22. The range of groundwater levels was about 0.9 meters. Groundwater levels drop starting in March until September due possibly to irrigation and commercial pumping. More data are needed to interpret water level changes in this aquifer.

Okeefe unconfined-confined aquifer

Figure 3.23 describes groundwater levels in well 106 at the depth at 8.6 meters which is completed in the Okeefe unconfined-confined aquifer. The groundwater level seems stable from March to June 2008. The groundwater dropped from July to August 2008.

3.5 Summary

The following is a brief summary of major findings from this chapter.

- The quaternary aquifers can be grouped into shallow, moderate and deep aquifer systems.
- The deeper Spallumcheen B, C and D aquifers can be considered together.
- Recharge sources to shallow aquifers are precipitation infiltration, irrigation return, surface water infiltration, mountain system recharge and leakage from Spallumcheen A. Discharges from shallow aquifers include evaporation, pumping, discharges to streams, leakage to Spallumcheen A and flow into Okanagan Lake.
- Moderate aquifers are recharged via mountain system recharge, leakage from shallow aquifers, leakage from deep aquifers in the north of main valley. Discharges are via pumping, leakage upwards to shallow aquifers, and leakage to deep aquifers in the central portion of the main valley.
- The deep aquifers are recharged by mountain system recharge and leakage from the moderate depth aquifer in the central portion of the main valley, Discharges include leakage to Spallumcheen A in the northern part of main valley and in the area adjacent to Okanagan Lake.
- Groundwater levels drop in the summer due to irrigation pumping in all shallow and moderate aquifers.
- Long term MOE records indicate water levels follow cumulative changes in precipitation. Groundwater pumping has affected water levels in the Eagle Rock area.
- Mountain system recharge is a major contributor to the deep regional aquifers.

Groundwater exchanges between aquifers are complex and will be further analyzed using geochemical and modeling approaches in chapters 4 and 5.

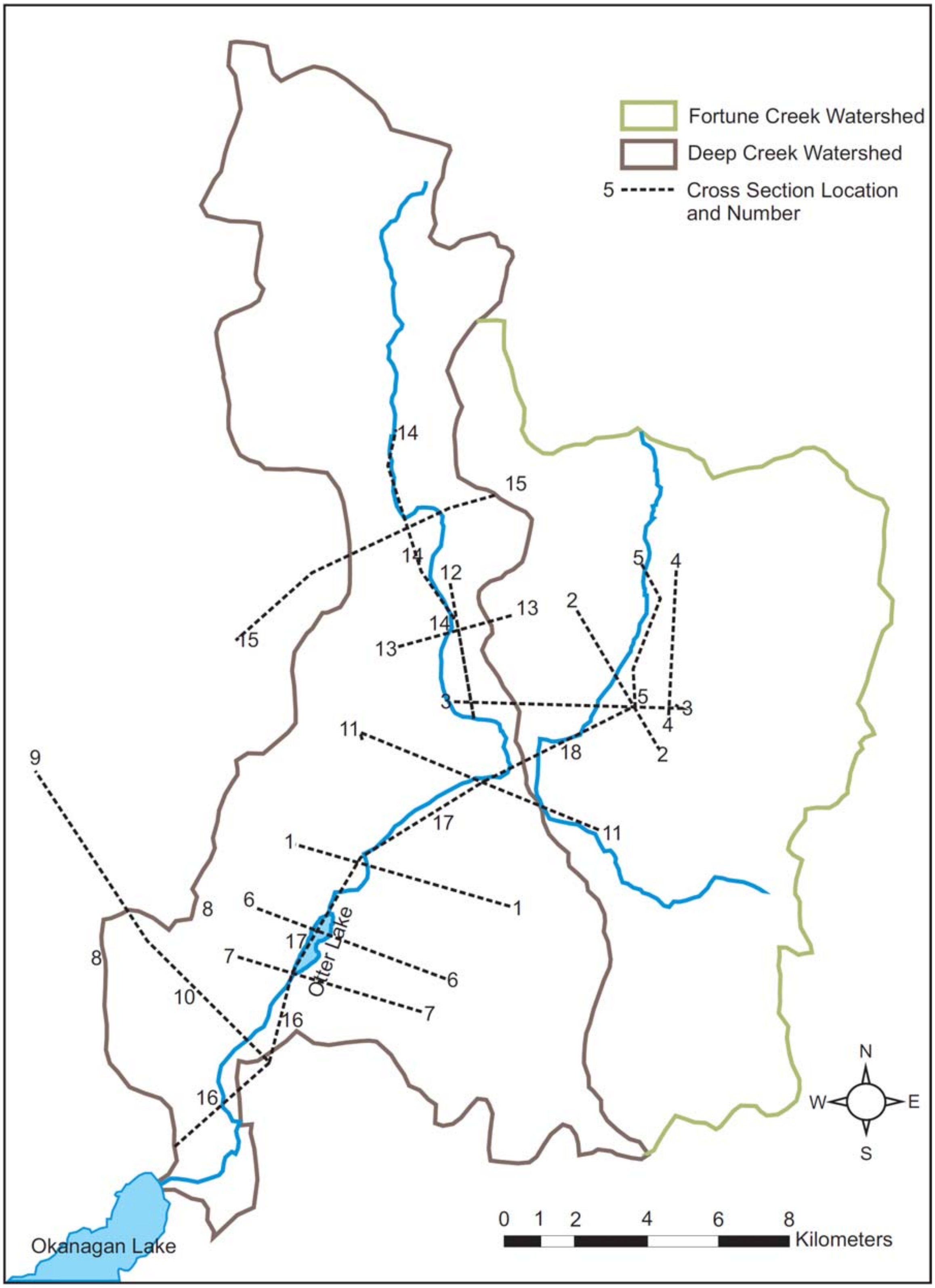


Figure 3.1 Locations of cross sections from Monahan (2006)

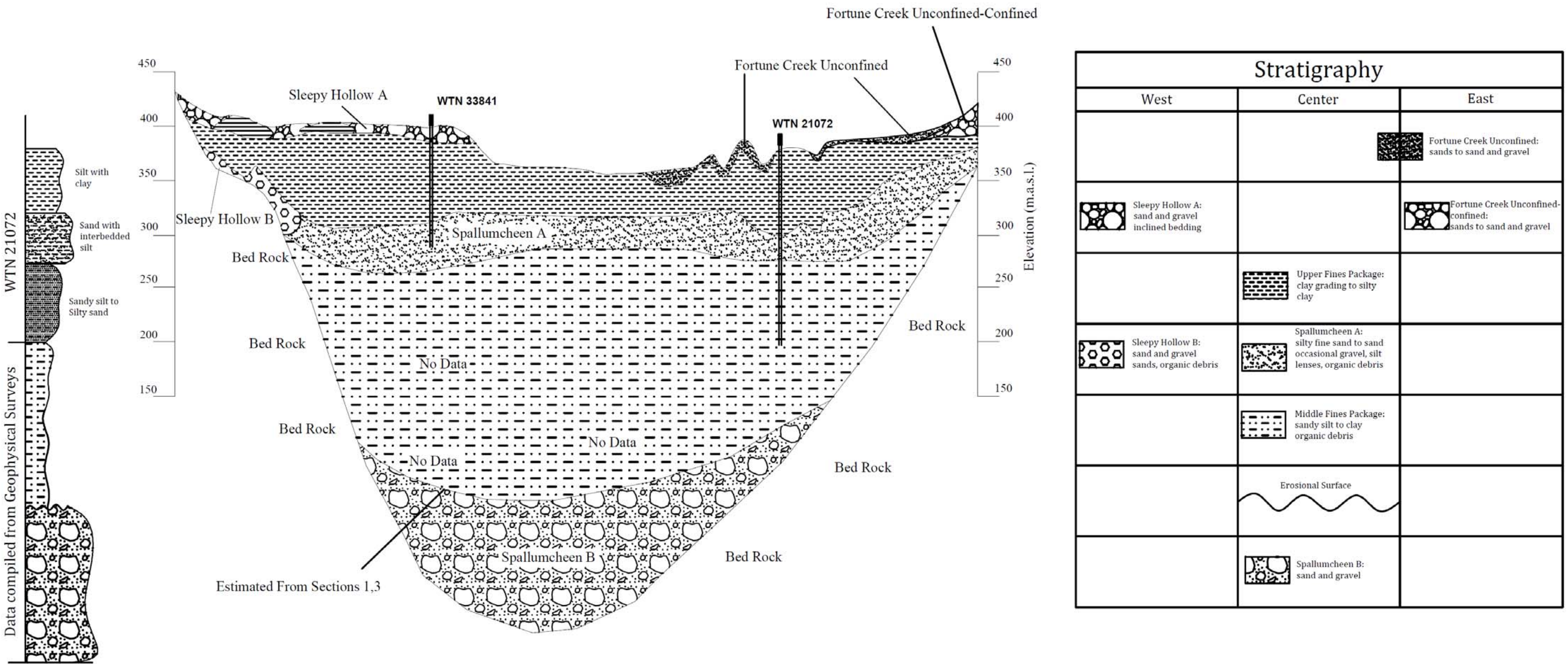


Figure 3.2A: Cross section of main valley north of the City of Armstrong (Cross Section 11, Figure 3.1).

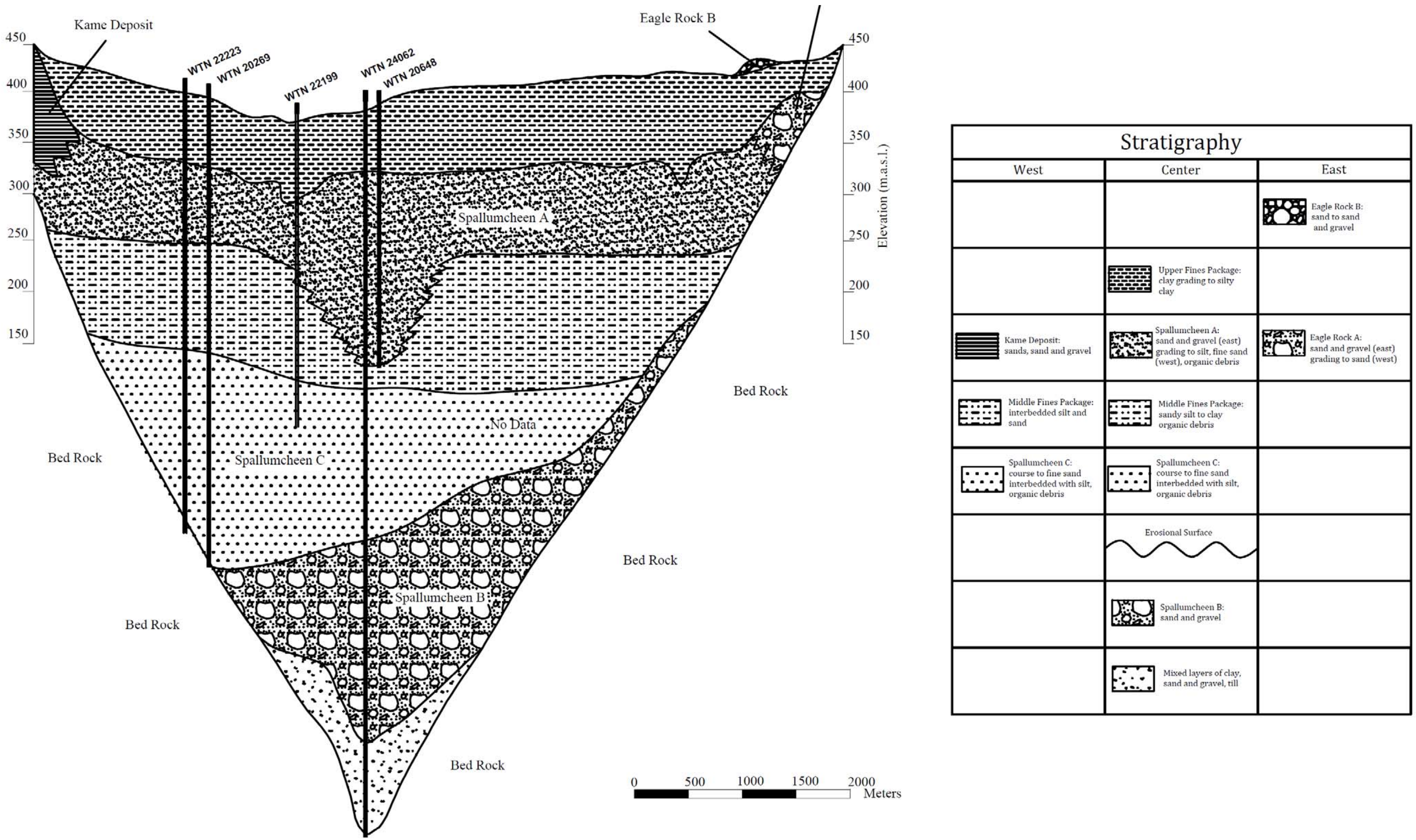


Figure 3.2B Cross section of main valley (Cross Section 1, Figure 3.1).

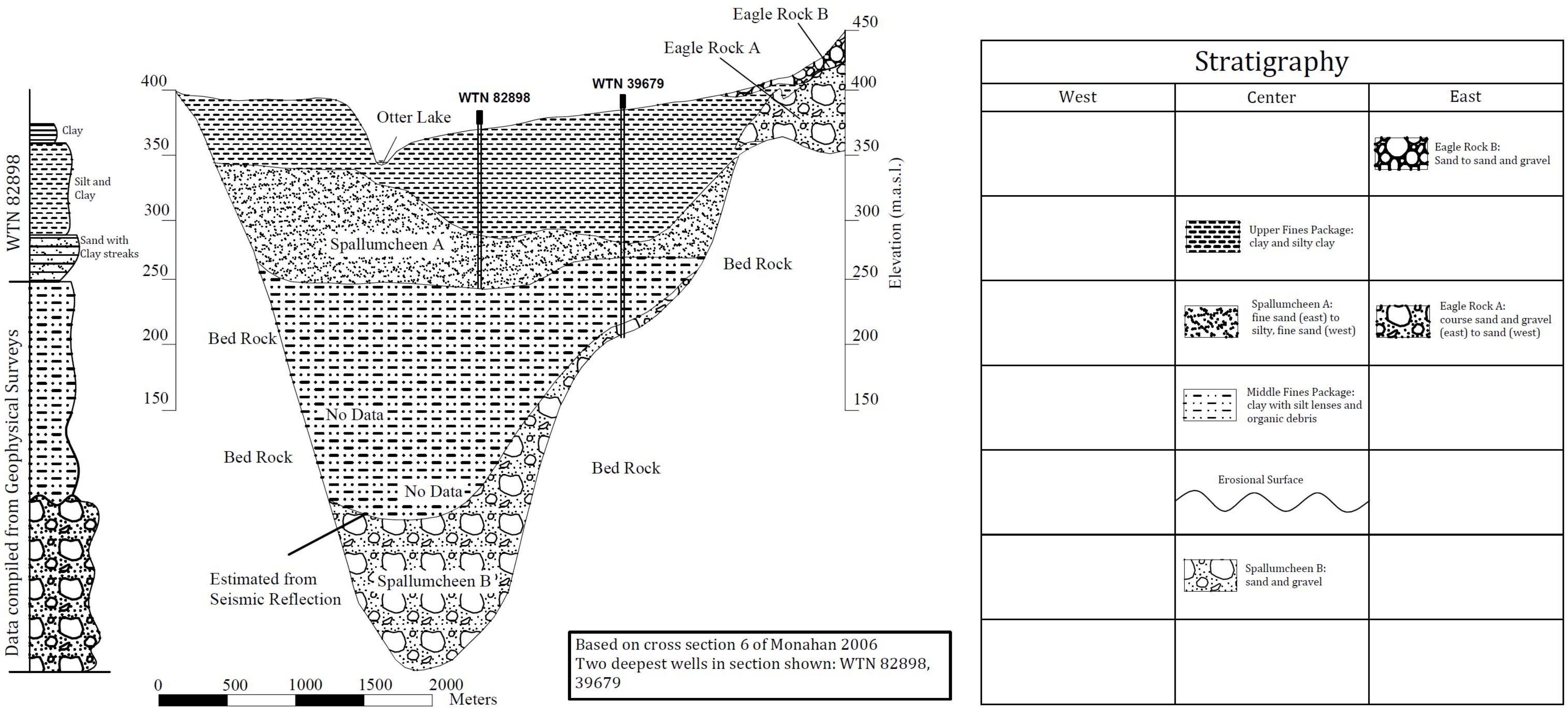


Figure 3.2C Cross section of the main valley including the Eagle Rock aquifers (Section 6, Figure 3.1).

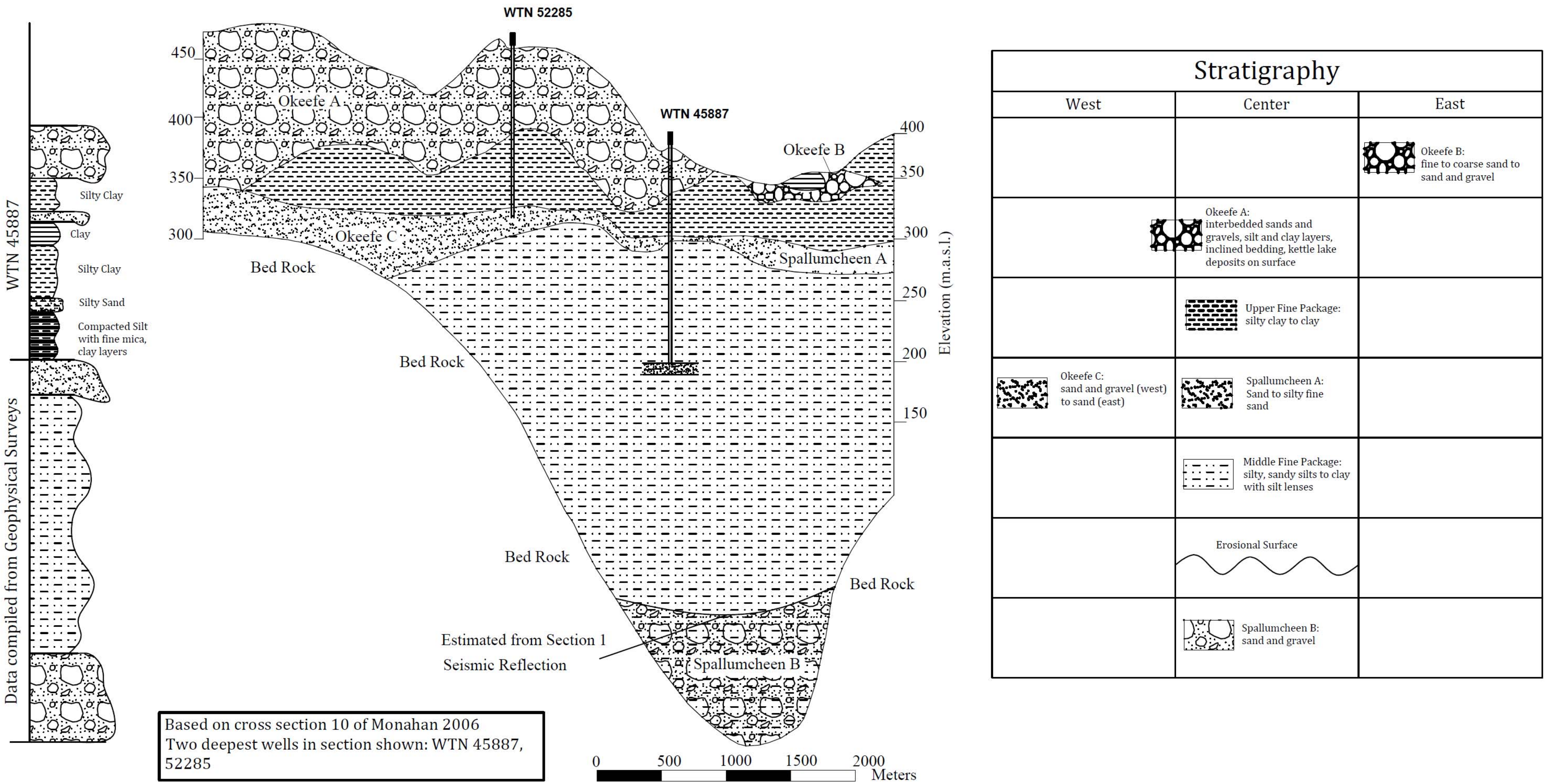


Figure 3.2D Cross section of Okeefe aquifers where they join the main valley (Cross Section 10, Figure 3.1).

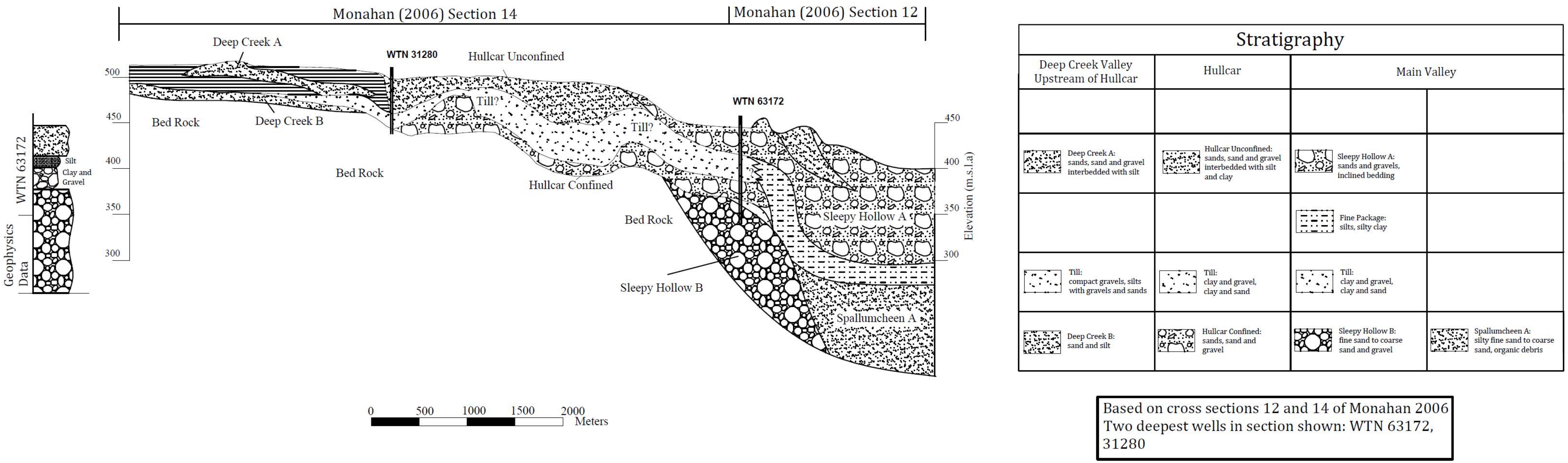


Figure 3.2E Cross section of Hullcar and Sleepy Hollow aquifers where they join the main valley (Cross Section 12/14, Figure 3.1). Cross Sections 12 and 14 join at WTN63172.

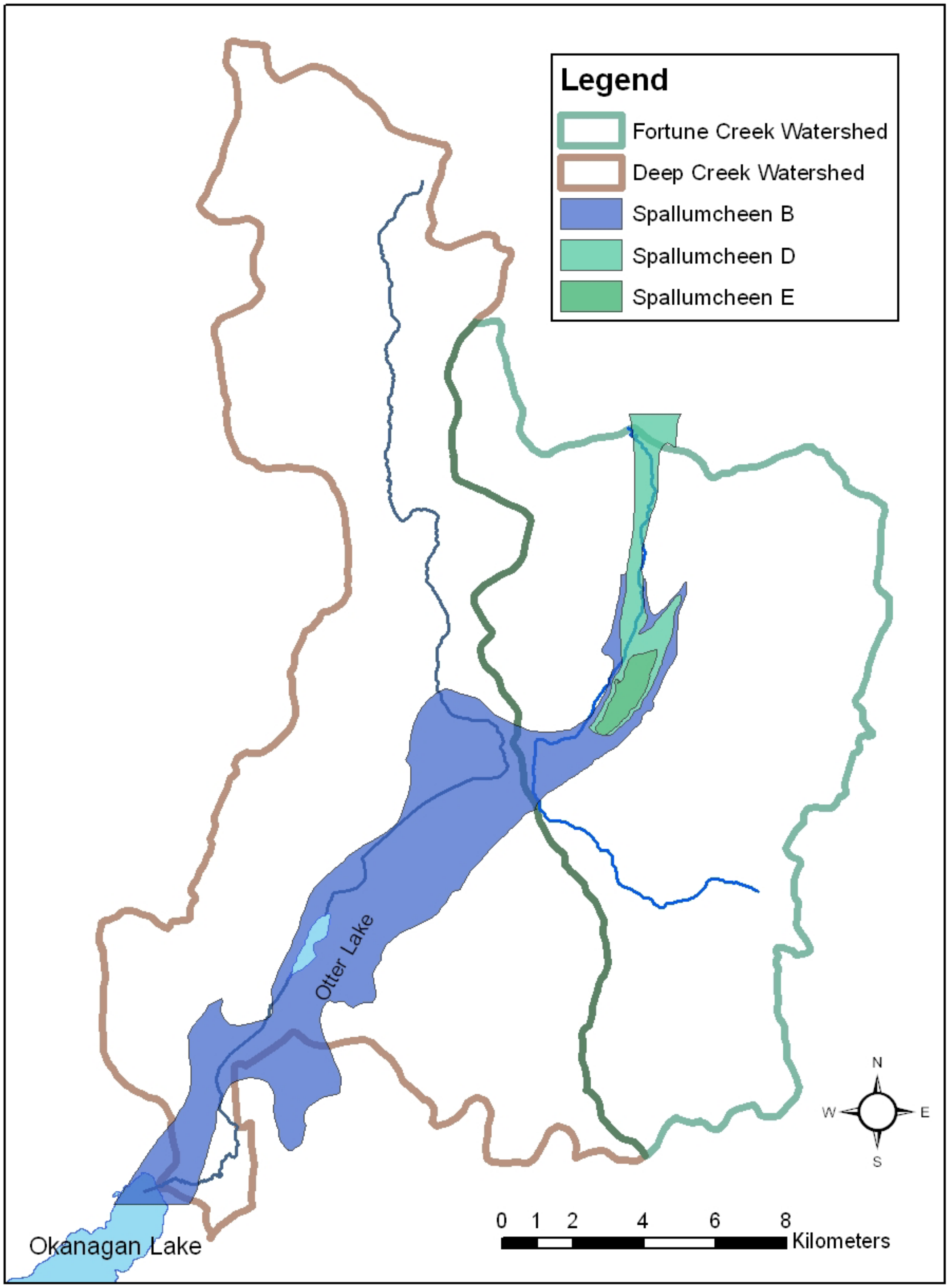


Figure 3.3 Deep Aquifers System

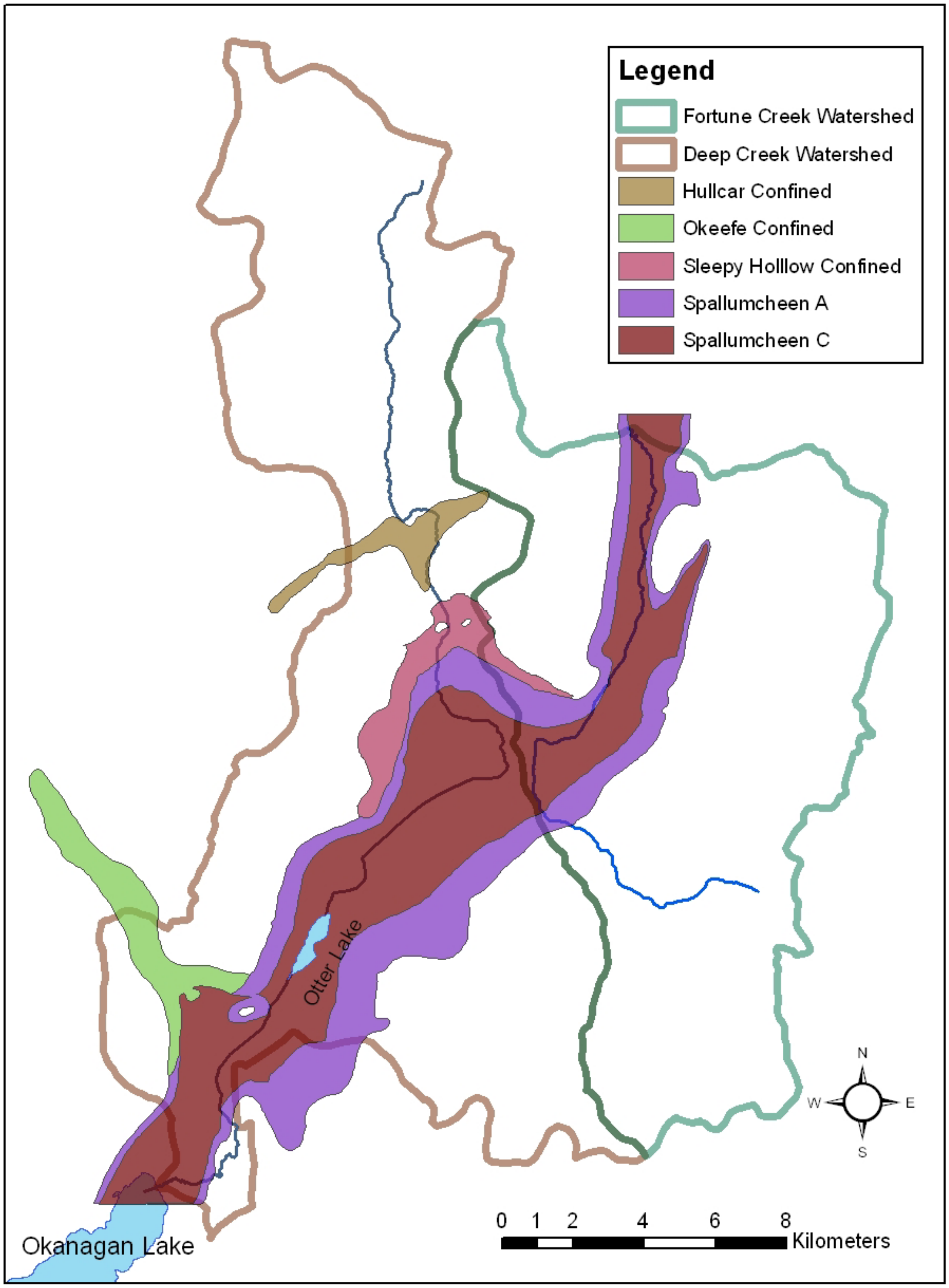


Figure 3.4 Moderate Aquifers System

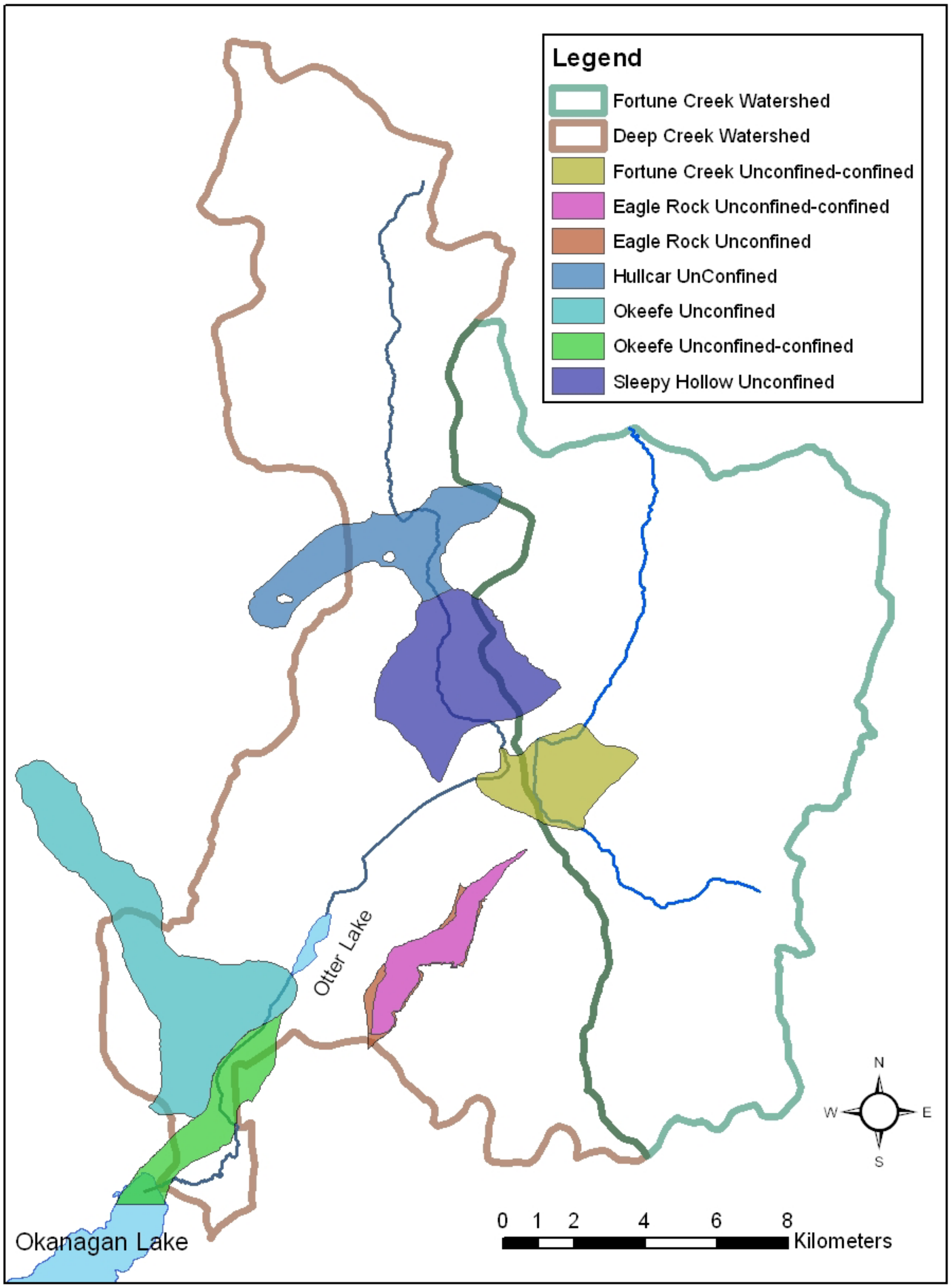


Figure 3.5 Shallow aquifers

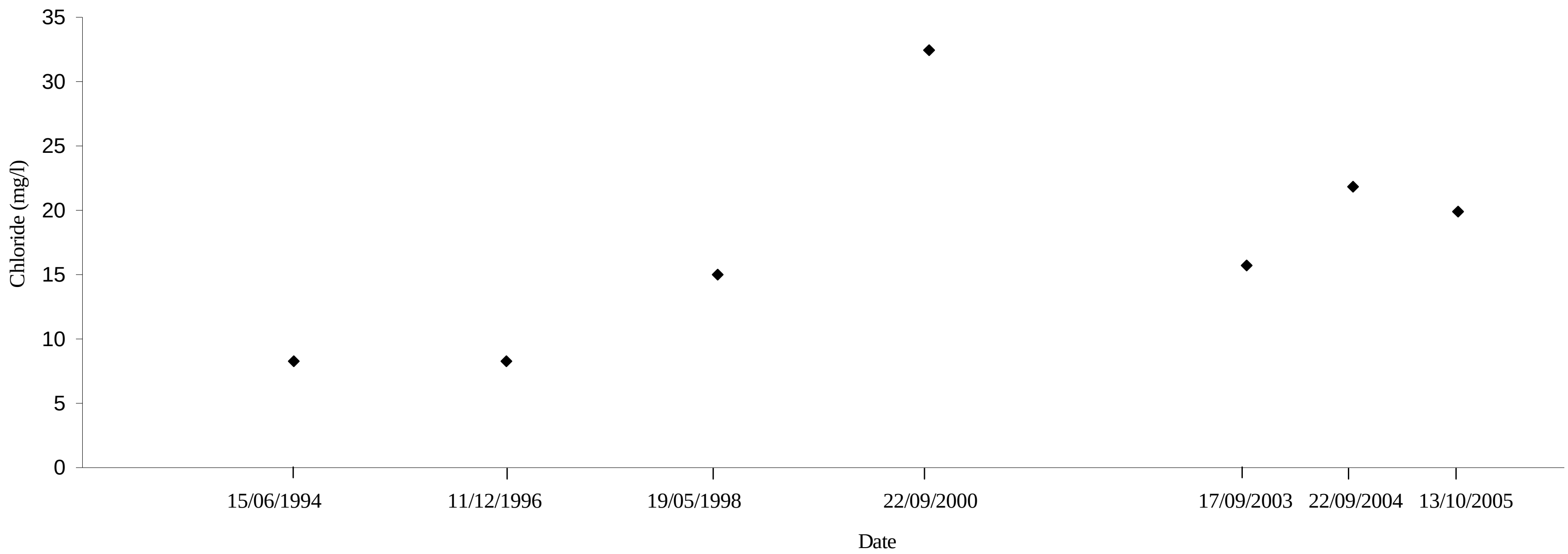


Figure 3.6 Chloride Concentrations in Well 6 (WTN: 25324) located in Eagle Rock unconfined-confined aquifer

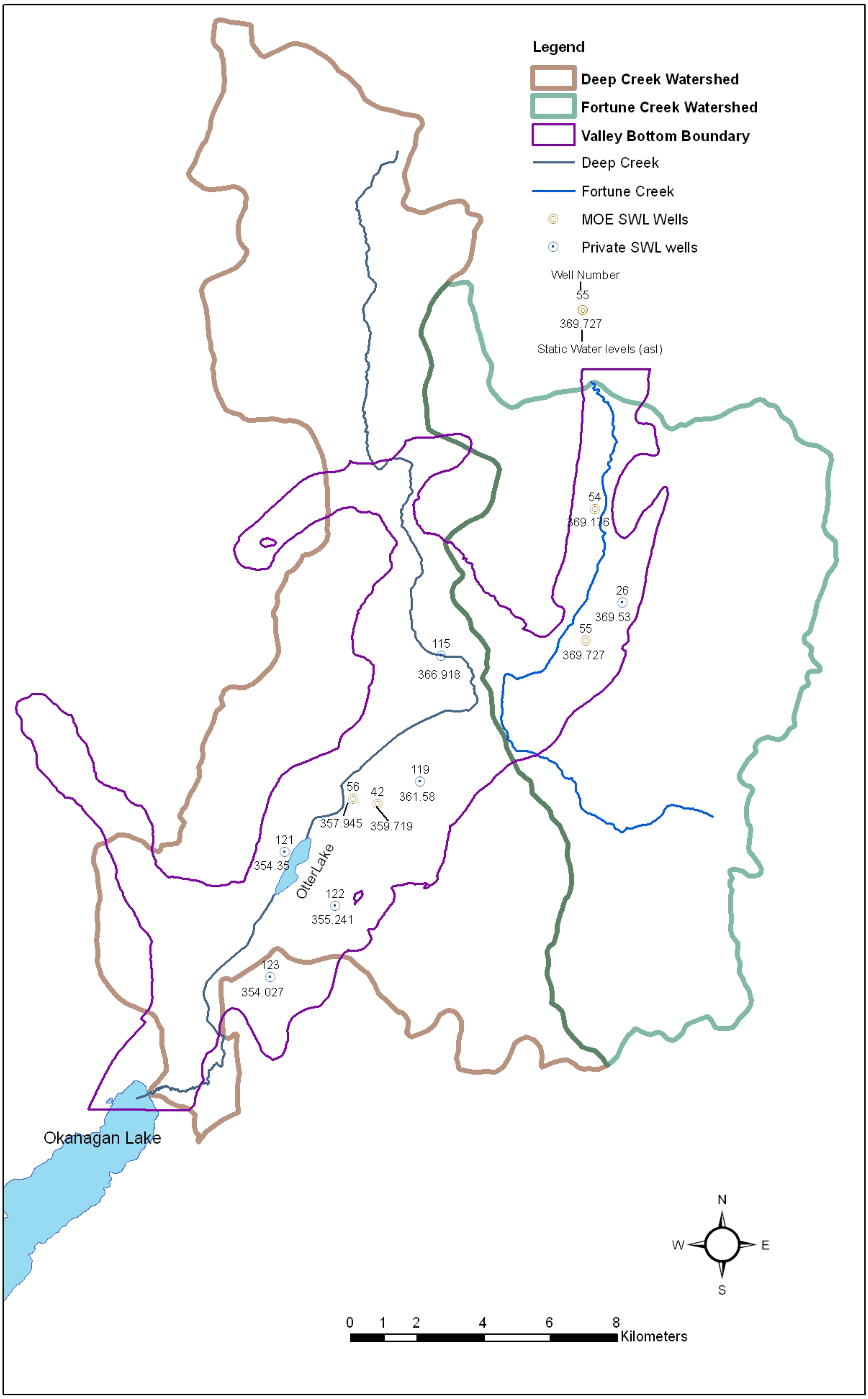


Figure 3.7 Static water levels of wells within Spallumcheen A and B in May ,2007

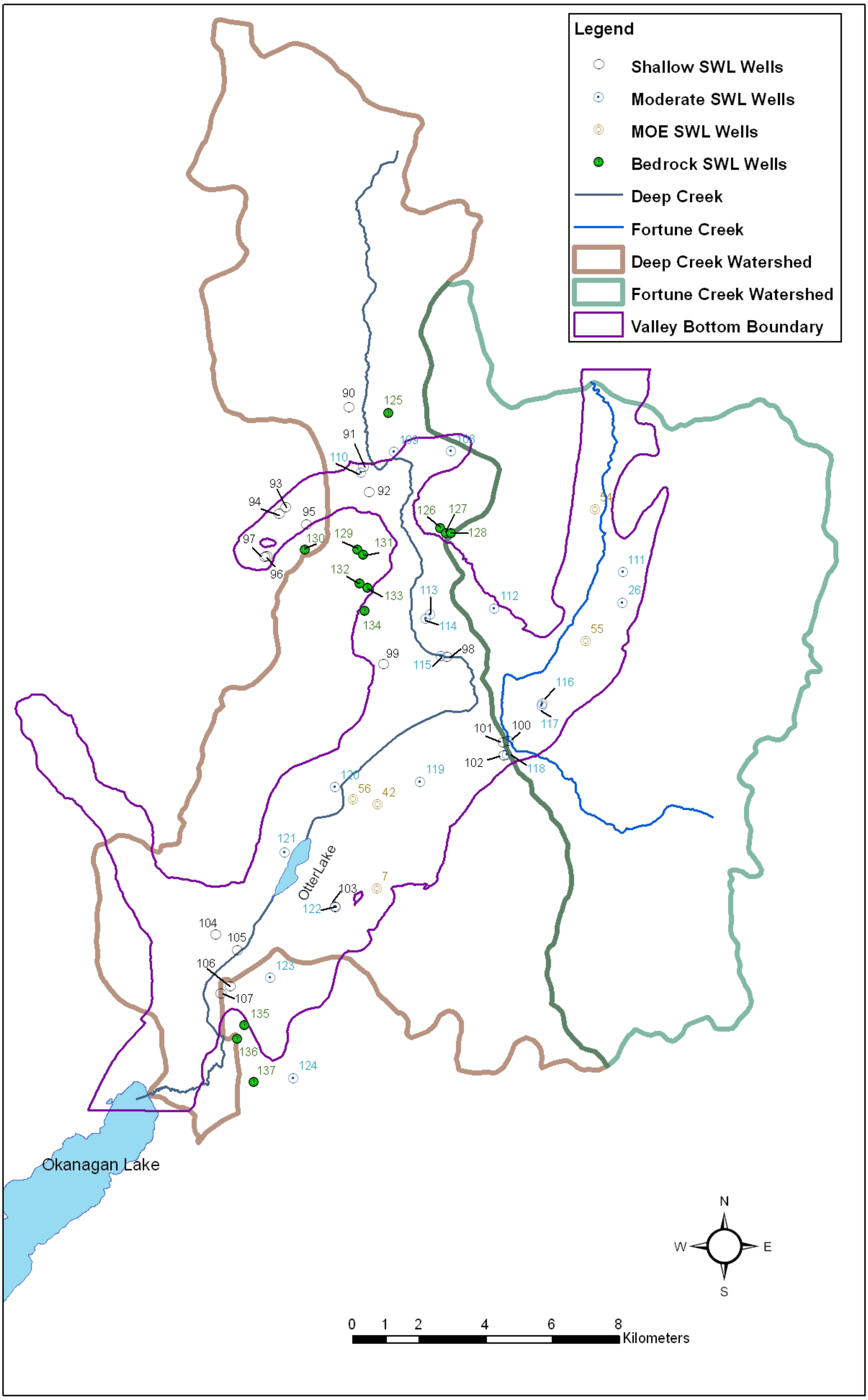


Figure 3.8 Locations of Static Water Level Observation Wells

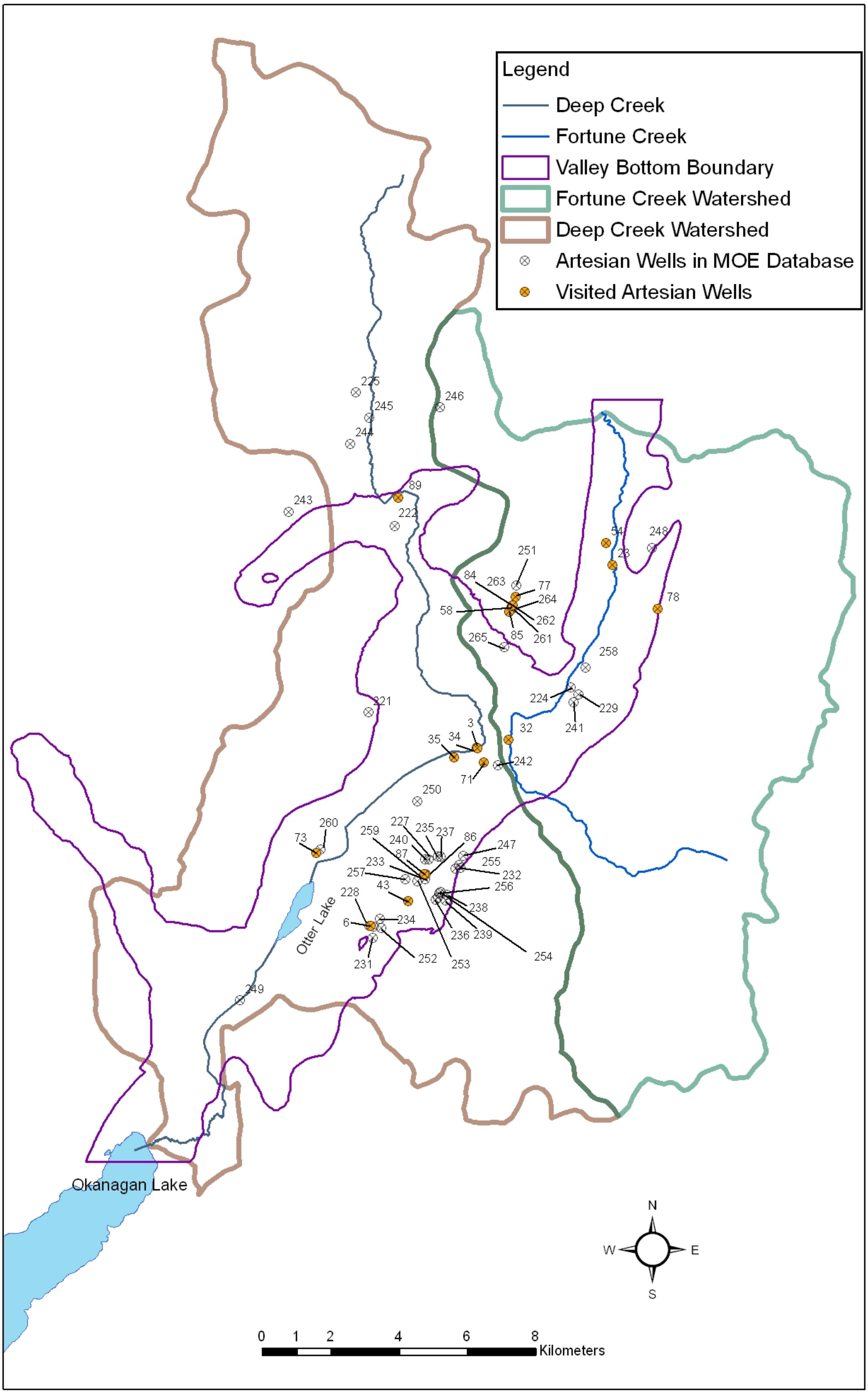


Figure 3.9 Artesian wells located in DCW and FCW in MOE study

Note: Well 35 had been artesian well in the MOE database, but it was not artesian well in 2007.

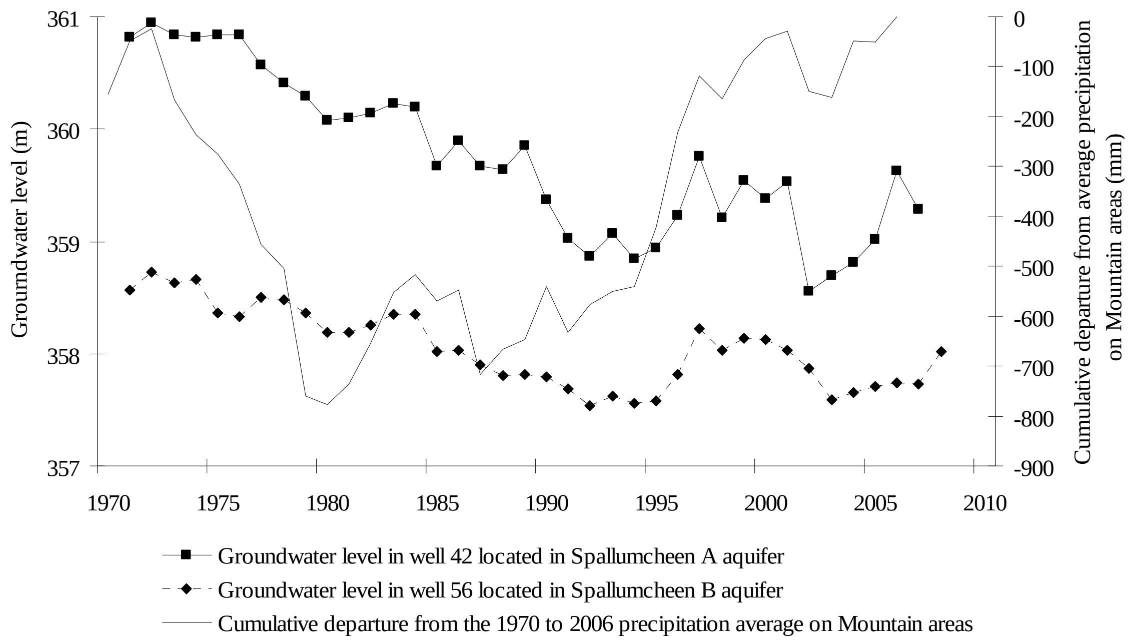


Figure 3.10 Long-term static water level variations in Well 42 (WTN 24104, O119) and Well 56 (WTN 24062, O117) in comparison to the cumulative precipitation departure from the 1970 to 2006 precipitation average on mountain areas (Precipitation data is from the Okanagan Climate Data Interpolator)

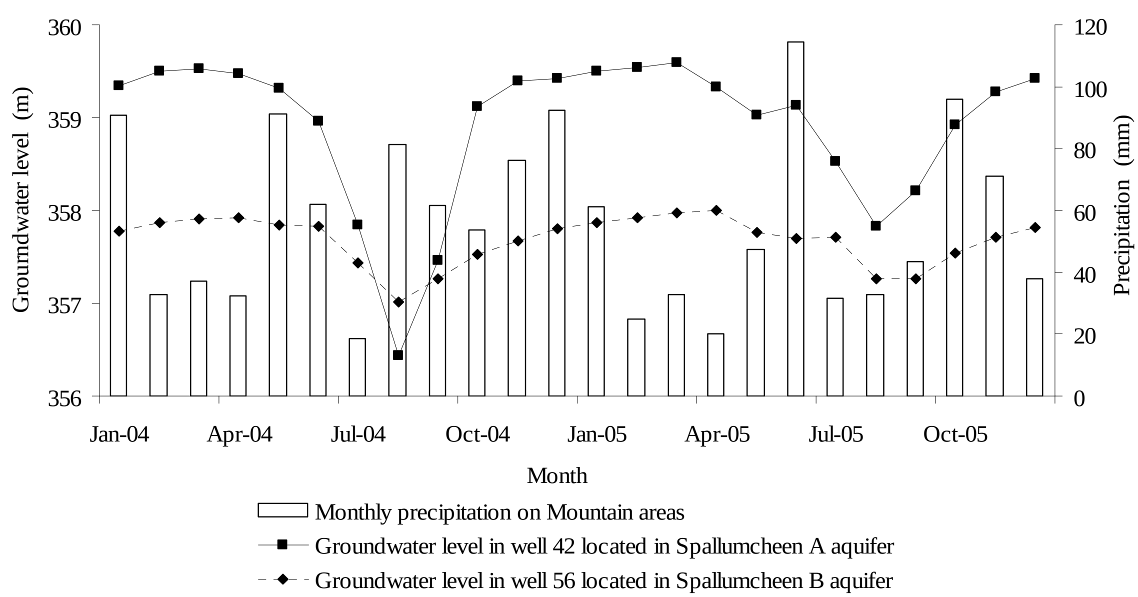


Figure 3.11 Monthly static water levels in Well 42 (WTN 24104, O119) and Well 56 (WTN 24062, O117) in comparison to monthly precipitation on mountain areas during the period of January 2004 to December 2005 (Precipitation data is from the Okanagan Climate Data Interpolator)

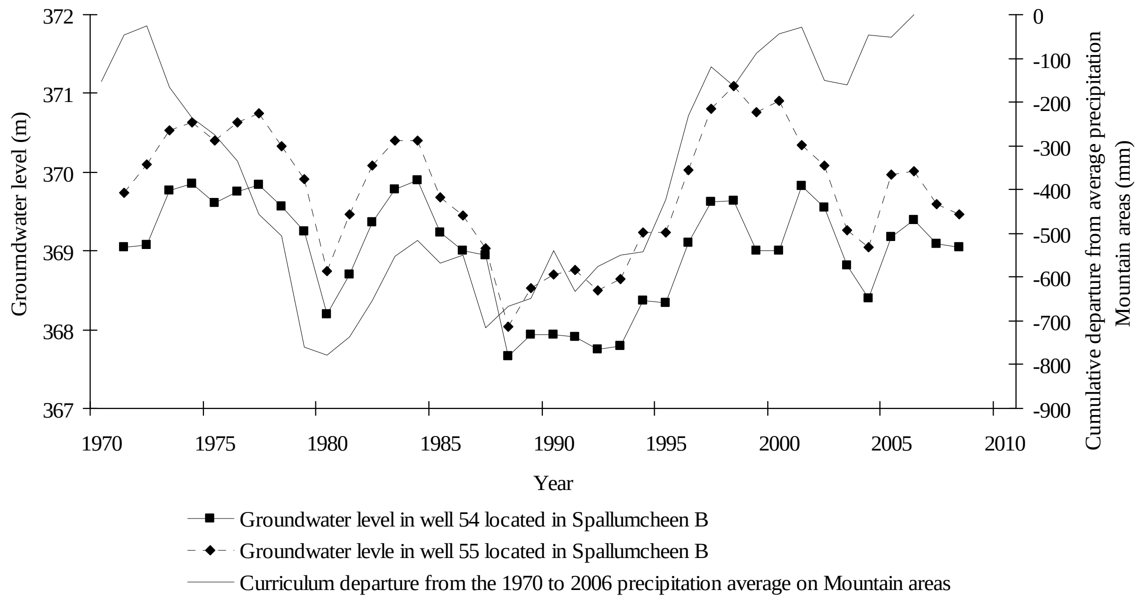


Figure 3.12 Long-term static water level variations of Well 54 (WTN 24093, O122) and Well 55 (WTN 24080, O118) in comparison to the cumulative precipitation departure from the 1970 to 2006 precipitation average on mountain areas (Precipitation data is from the Okanagan Climate Data Interpolator)

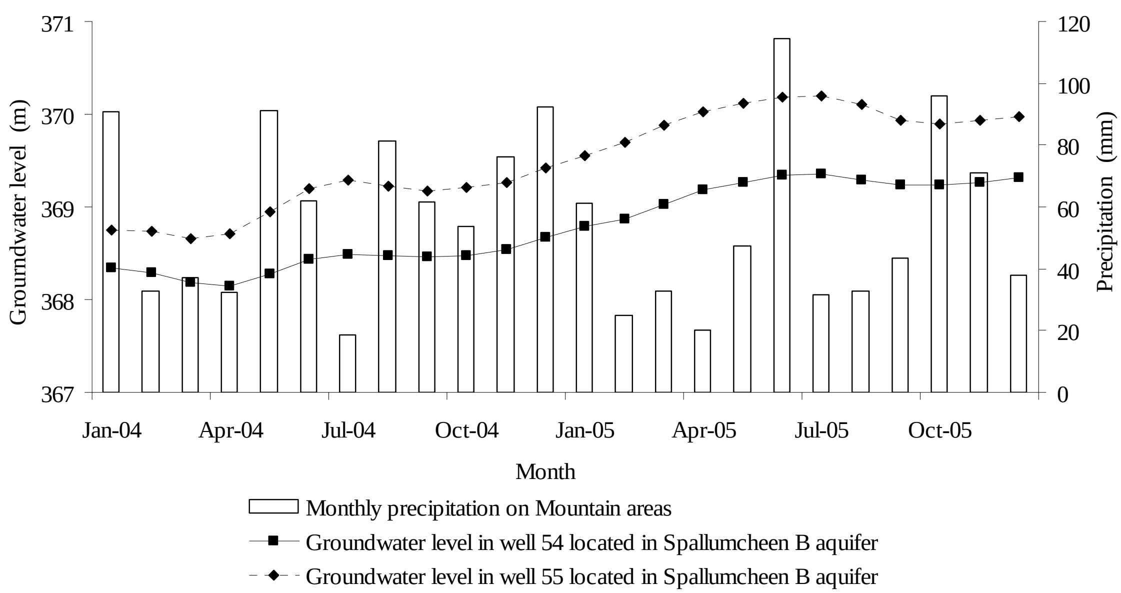


Figure 3.13 Monthly static water levels variation in Well54 (WTN 24093, O122) and Well 55 (WTN 24080, O118) in comparison to monthly precipitation on mountain areas during the period of January 2004 to December 2005 (Precipitation data is from the Okanagan Climate Data Interpolator)

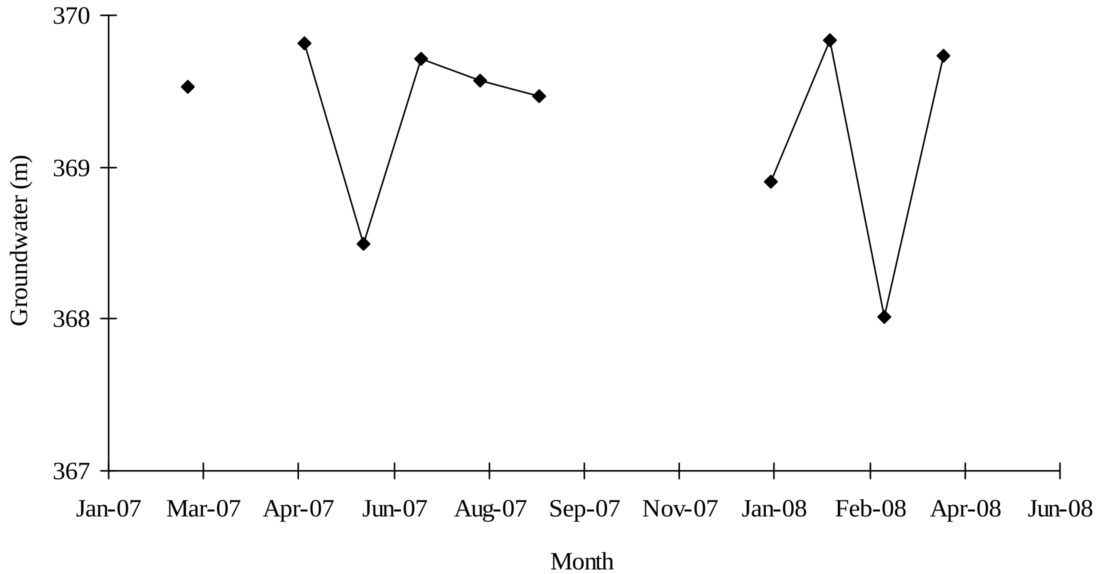


Figure 3.14 Static water levels variation in a private Well 26 (WTN 82463) located in Spallumcheen A aquifer during the period of March 2007 to April 2008

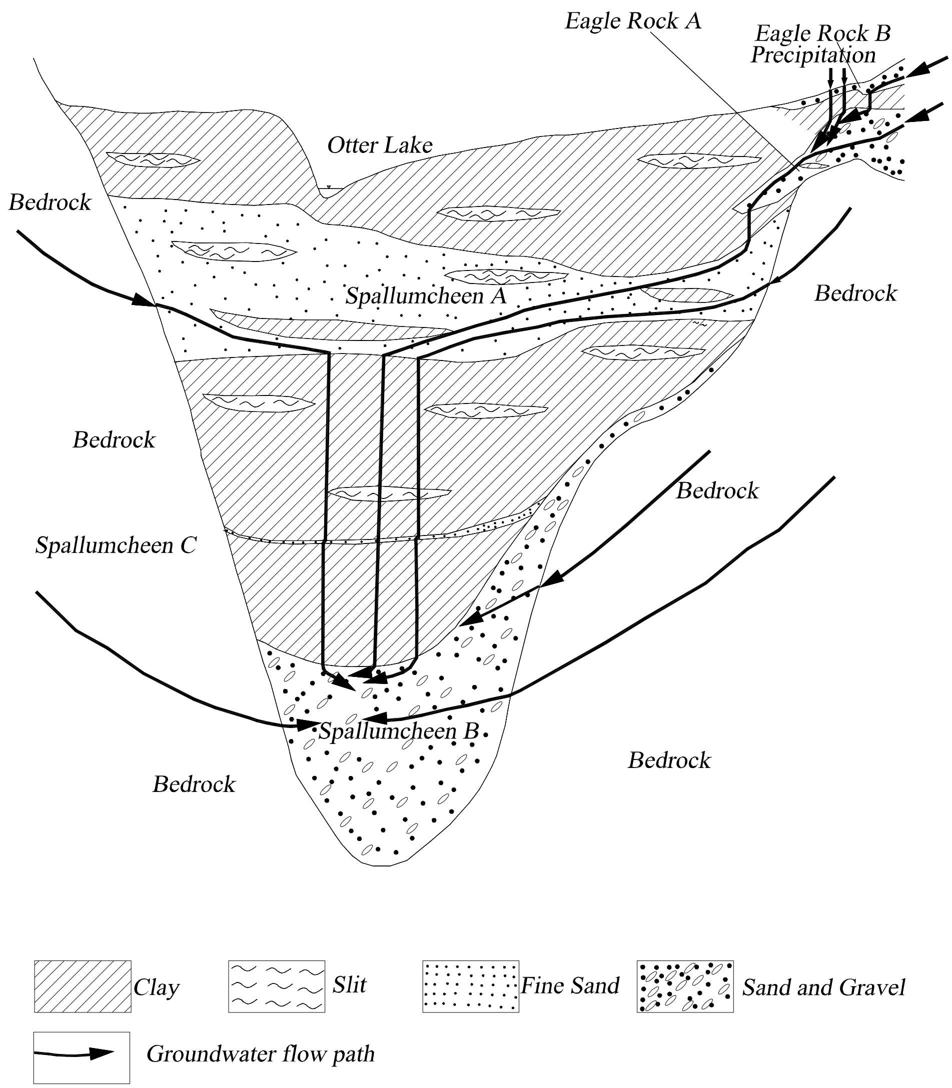


Figure 3.15 Schematic vertical flow pattern in the central main valley Section 1

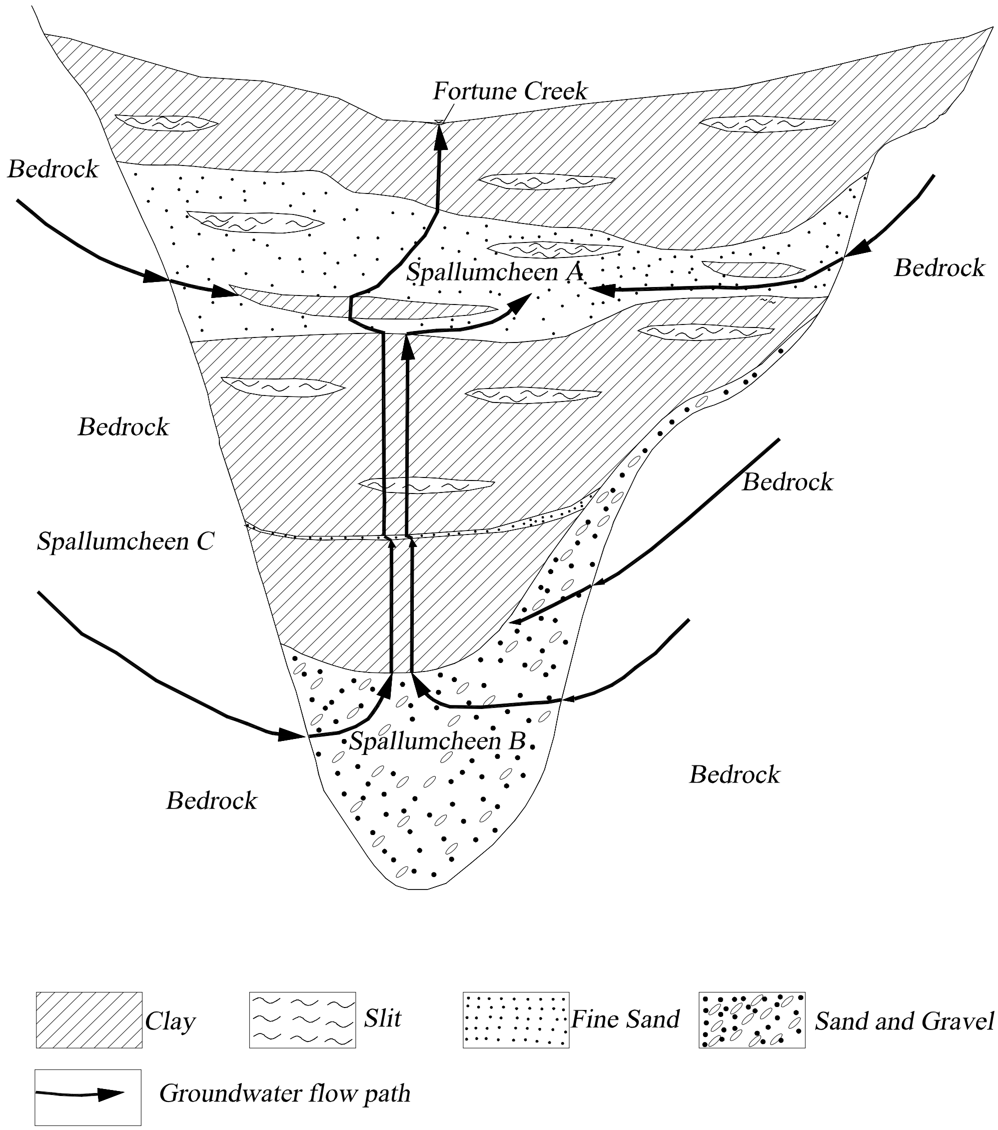


Figure 3.16 Schematic vertical flow pattern in the northern main valley Section 11 Figure3.2A

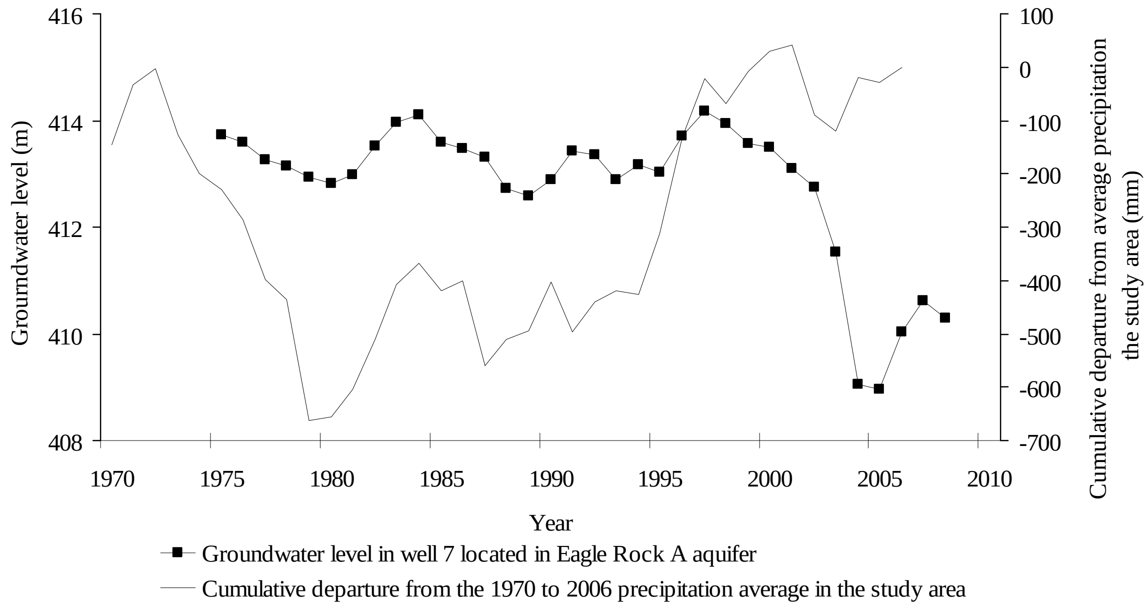


Figure 3.17 Long-term static water level variations in well 7 (WTN 32340, O180) in comparison to the cumulative precipitation departure from the 1970 to 2006 precipitation average in the study area (Precipitation data is from the Okanagan Climate Data Interpolator)

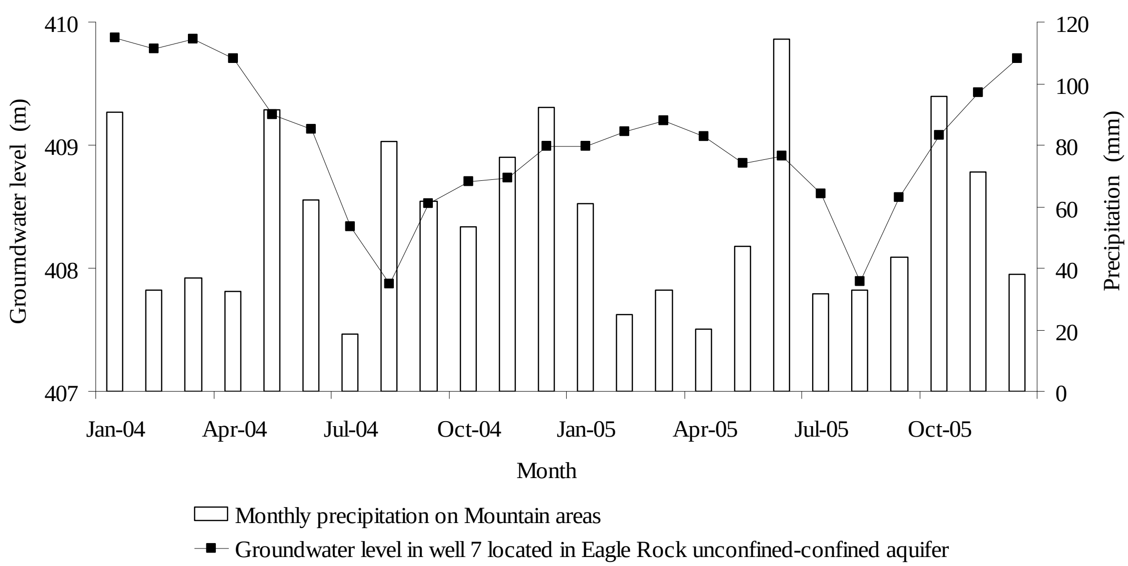


Figure 3.18 Monthly static water level variations in well 7 (WTN 32340, O180) in comparison to monthly precipitation in the study area during the period of January 2004 to December 2005 (Precipitation data is from the Okanagan Climate Data Interpolator)

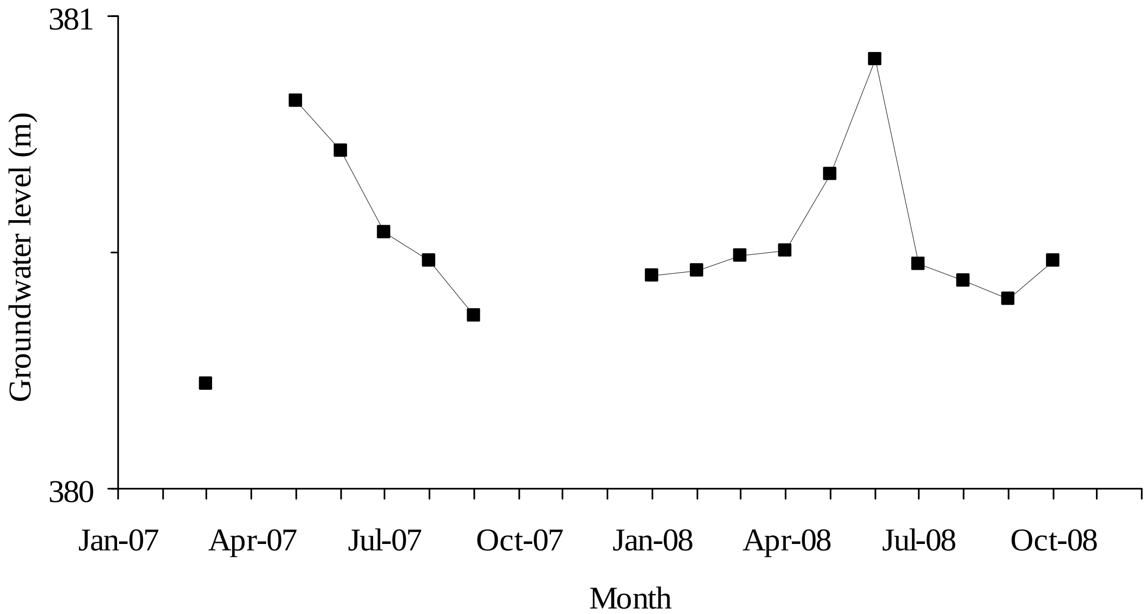


Figure 3.19 Static water level variations in Well 100 located in Fortune Creek unconfined-confined aquifer during the period of March 2007 to October 2008

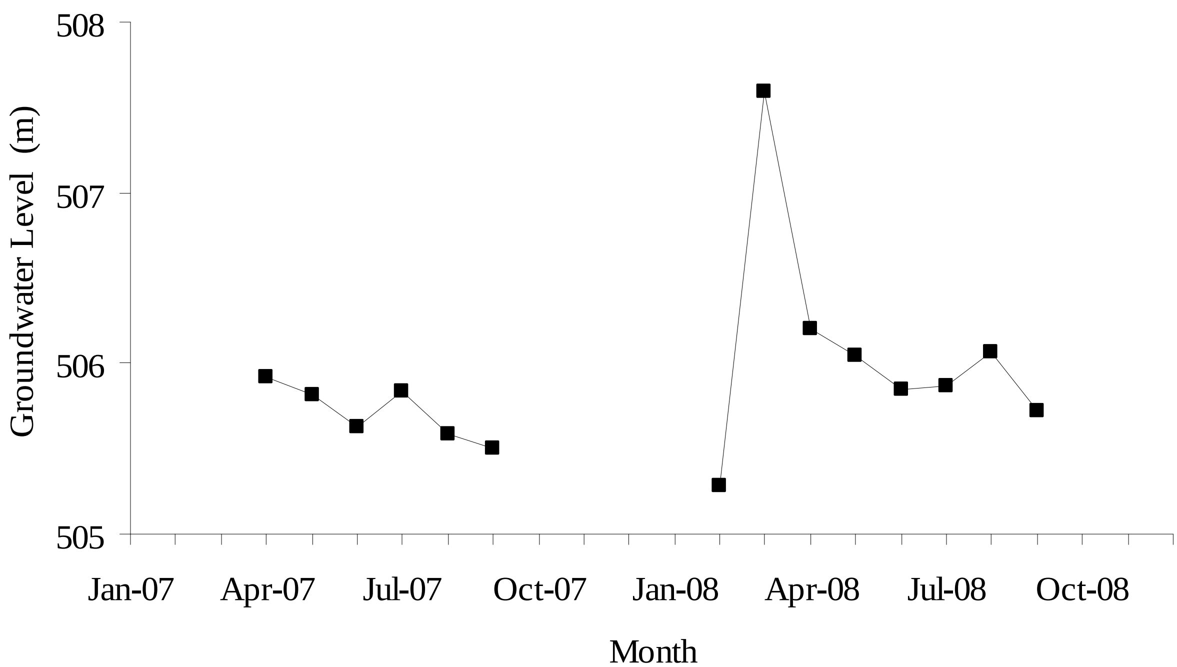


Figure 3.20 Static water level variations in Well 93 located in Hullcar unconfined aquifer during the period of April 2007 to September 2008

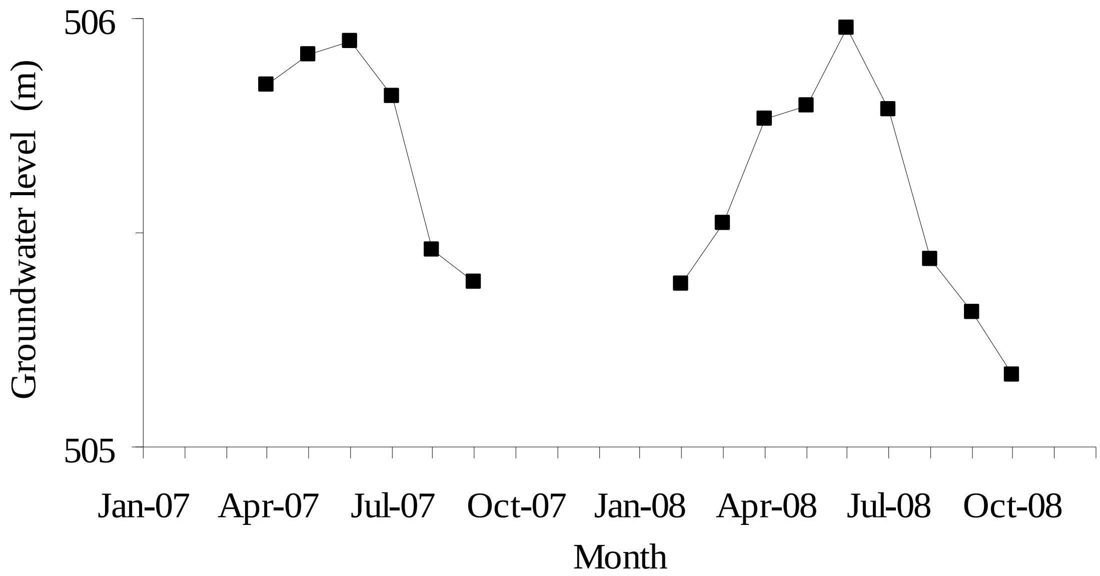


Figure 3.21 Static water level variations in Well 94 located in Hullcar confined aquifer during the period of April 2007 to October 2008

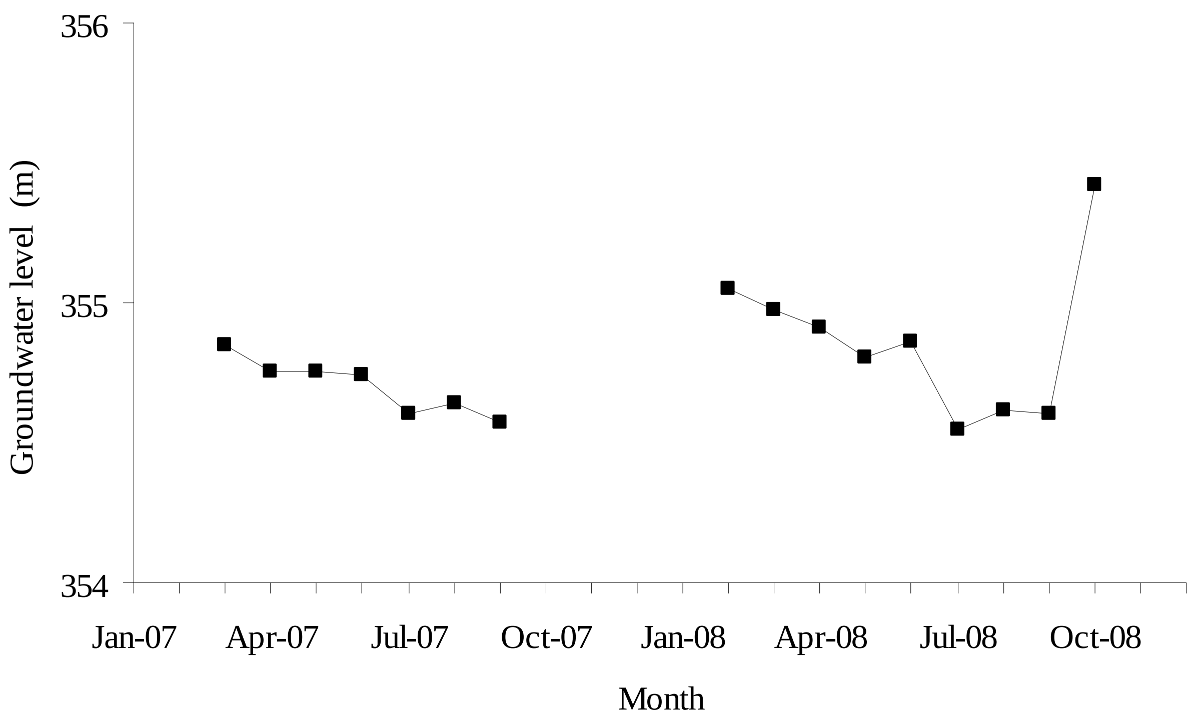


Figure 3.22 Static water level variations in Well 104 located in Okeefe unconfined aquifer during the period of Mar 2007 to October 2008

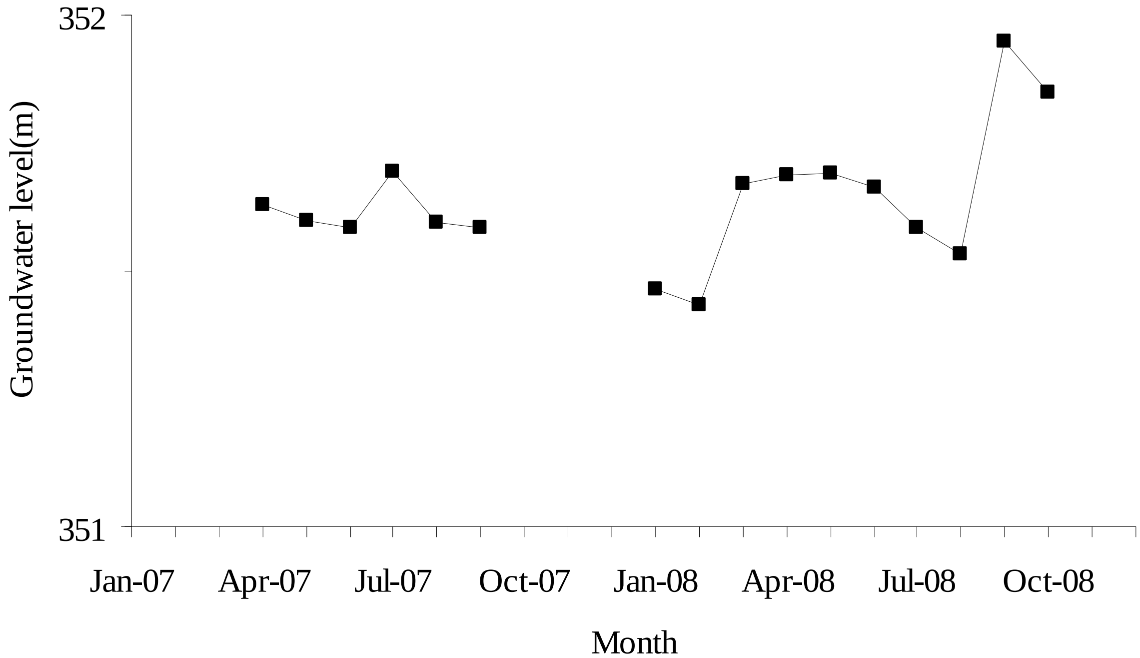


Figure 3.23 Static water level variations in Well 106 located in Okeefe unconfined-confined aquifer during the period of Mar 2007 to October 2008

Chapter 4: Geochemical Evaluation of Surface Water and Groundwater

The Deep Creek and Fortune Creek watersheds have a complex arrangement of aquifers. The proper determination of a conceptual model of groundwater flow and a quantitative numerical groundwater model requires more information than is available from purely physical measurements. In this study, hydrogeochemical data from major ions and stable isotopes were used to investigate the hydrogeological connections between aquifers, to assess surface-groundwater interactions, to delineate groundwater flow paths, to identify groundwater recharge sources and to understand the distribution of mountain system recharge (MSR) to regional aquifers within the Fortune Creek and Deep Creek watersheds. Major ion geochemistry can be used to provide a general characterization of a groundwater system whereas isotopic approaches provide a more detailed description and confirmation of chemical methods. These data are used to support model simulations presented in Chapter 5.

4.1 Background and Theory

Groundwater chemical and isotopic signatures are determined by the initial chemistry and isotopes of external waters entering an aquifer system and by the subsequent mixing, or chemical reactions with minerals comprising the aquifer and aquitard materials.

Hydrochemical data from major ion chemistry and isotopic studies can be utilized to analyze groundwater recharge and flow (Panno et al., 1994; Mazor, 2004; Coetsiers and Walraevens, 2006) and to characterize groundwater flow (Fritz et al., 1990; Howard and Mullings, 1995; Plummer et al., 2004; André et al., 2005; Pilla et al., 2006; Dilsiz, 2006; Mayo et al., 2007; Lu et al., 2007).

4.1.1 Major Ion Chemistry

Six major constituents or ions (Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, $HCO3^{-}$, SO_4^{2-}) and four parameters (total dissolved solids (TDS), electrical conductivity, pH, and temperature) are reported in groundwater studies. These are sufficient for studying the major geochemical processes in most aquifers and their relationship with hydrologic systems. Major ions can be also utilized to identify spatial variability which provides insight into aquifer heterogeneity and connectivity (Murray, 1996; Rosen and Jones, 1998; André et al., 2005; Pilla et al., 2006; Lu et al., 2007).

Precipitation has very few dissolved ions. Precipitation water begins reacting with soil minerals at the ground surface and continues to change along the groundwater flow path. The dissolved ions in a groundwater sample represent the cumulative history of all the reactions with minerals in soils and aquifers and biological activity from the recharge location to the groundwater sample location.

Major ion geochemical data are interpreted using a variety of methods to compare groundwater chemistries. Total concentrations of any constituent can be used to delineate waters of different origin, or the relative travel distance of a particular package of water from its recharge source (e.g.: a progressive change in concentration along a flowpath). Geochemical interpretation tools that utilize the relative proportions of the major ions such as Piper plots can be found in most hydrogeology textbooks. In a Piper plot, the relative proportions of the major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and the major anions (HCO_3^{-}, SO_4^{2-}, Cl^{-}) are plotted in two trilinear plots and projected to a central portion of the graph. This serves to separate waters with different overall characters, termed facies, which can be linked to groundwater source and to groundwater age. Groundwater mixing will plot as straight lines on a Piper plot between the two end members.

4.1.2 The isotopic composition of water

A brief summary of the major processes and methods used for the interpretation of stable isotopes in regional groundwater studies is included here to provide background for the isotopic studies conducted in the north Okanagan aquifer systems.

In nature, there are two stable isotopes of hydrogen (^{1}H and ^{2}H/D) and three stable isotopes of oxygen (^{16}O, ^{17}O, ^{18}O). The stable isotopes of oxygen and hydrogen are widely used as tracers in hydrologic science for water characterization (Clark and Fritz, 1997; Mazor, 2004; Gammons et al., 2006). Water occurs with nine isotopically different water molecules. Only three occur in nature in easily measurable concentrations: $^{1}H_2{}^{16}O$, $^{1}H_2{}^{18}O$, and $^{1}HD^{16}O$ (Araguás- Araguás et al., 2000).

The isotopic composition of a water sample is expressed in comparison to the isotopic composition of ocean water. An internationally agreed upon sample of ocean water has been selected, called the Standard Mean Ocean Water (SMOW), and all other samples are analyzed relative to it (Craig, 1961a, 1961b).

The isotopic composition of water is first determined by mass spectrometry or laser-based methods, and then is expressed in per mil (1 part in 1000, shown as ‰) deviations from the SMOW standard. These deviations are reported as δD, for deuterium, and $\delta^{18}O$ for ^{18}O:

$$\delta = \frac{R_{sample} - R_{SMOW}}{R_{SMOW}} \times 1000 \qquad \text{Equation 4.1}$$

Where, R is the $^{18}O/^{16}O$ or D/H ratio.

Water with less deuterium than the SMOW has a negative δD and water with more deuterium than the SMOW has a positive δD. The same is true for $\delta^{18}O$ (Mazor, 2004).

The benefits of incorporating oxygen and deuterium isotopic techniques into hydrogeological investigations are based on their conservative (non-reactive) nature. Major ion chemistry continuously evolves due to geochemical reactions along flow paths, which makes quantitative evaluation of groundwater mixing more difficult without the use of a full reactive transport geochemical model (eg: PhreeqC). In contrast, the stable isotope ratios of oxygen ($\delta^{18}O$) and hydrogen (δD) are primarily conservative. These isotopes are often employed to identify and estimate groundwater recharge sources, and to trace groundwater flows (Lee et al, 1999; Wilcox et al., 2004; Palmer et al., 2007; Baillie et al., 2007; Blasch and Bryson, 2007). Nakaya et al (2007) applied stable isotopes of oxygen and hydrogen as natural tracers to study the spatial separation of groundwater flow paths within a multi-layer system at a basin scale. Radioactive isotopes such as ^{3}H, ^{14}C and ^{36}Cl are employed to estimate groundwater residence times (Mazor, 2004; Lu et al., 2006; Dilsiz, 2006; Mayo et al., 2007).

In recent years, quantitative hydrogeochemical modeling has been used in parallel with physical methods to calibrate or/and validate groundwater flow modeling. Kalin and Long (1993) used the computer code NETPATH to simulate steady-state and transient isotope transport as a calibration and validation tool for a regional groundwater flow model. NETPATH was also employed by Kalin and Long (1994) to model hydrogeochemical evolution and validate hydrologic flow modeling. Sanford et al (2004) applied hydrochemical data to help calibrate groundwater flow model parameters. Dahan et al (2004) utilized a multi-variable mixing cell model as a tool to calibrate and validate a hydrogeologic groundwater model.

4.1.3 Isotopic characteristics of natural waters

Meteoric water, or water derived from precipitation, is the original source for water in the hydrologic cycle of any particular drainage basin. Characterization of the isotopes in atmospheric water is the precondition for studying origins and movement of groundwater and surface water through a watershed using isotopic techniques.

Stable isotopes in precipitation are measured on a global scale by the International Atomic Energy Agency (IAEA) via the global network of isotopes in precipitation sampling stations (GNIP). There are 25 GNIP stations in Canada, but none are located near the study area.

Water evaporated from the ocean surface has an isotopic composition different from the ocean water from which it was derived. This primary oceanic evaporation fractionates the isotopes of the water between ocean and atmosphere. Evaporation favours lighter isotopes, and hence atmospheric water has negative δD and $\delta^{18}O$ in comparison to the oceanic source. The degree of fractionation is temperature dependant, with less fractionation occurring at higher temperatures.

A second fractionation of isotopes occurs as water condenses from atmospheric water to fall on the land or ocean surface as precipitation. These condensation and precipitation processes generally favour heavier isotopes. Precipitation is thus generally isotopically heavier than the atmospheric humidity from which it is derived. Precipitation therefore varies across continental land masses by distance from the ocean and elevation with precipitation generally isotopically lighter further inland. A further effect of altitude leads to lighter isotopes at higher elevations.

Craig (1961) analyzed approximately 400 water samples from river and lake water, rain, and snow from diverse geographic locations across the globe. He found that all of the data, except for those from lakes, plotted along a line defined by the equation 4.2:

$$\delta D = 8\ \delta^{18}O + 10 \qquad \text{Equation 4.2}$$

The above equation became known as the global meteoric water line (GMWL) which traces the isotopic compositions of natural waters originating from atmospheric precipitation that have not been subjected to evaporation at ground surface.

Within a particular watershed, isotopes are fractionated by their distance inland, the average temperatures, and the range of elevations considered. Local watersheds develop a range of isotopes in precipitation which define a Local Meteoric Water Line of similar slope to the GMWL. As noted above, isotopes in precipitation are generally lighter (δD *or* $\delta^{18}O$ more negative) during colder weather in winter or at higher elevations within a watershed.

Groundwater stable isotopic composition is determined by specific hydrologic conditions in recharge source areas. Oxygen and deuterium isotopes are generally conservative within groundwater, and the isotopic composition of a particular aquifer generally represents the long-term average isotopic composition of recharge. Hydrologic processes along the groundwater flow path can result in isotopic changes due to mixing of groundwater from different sources. Additional fractionation of isotopes within groundwater can occur due to processes such as evaporation directly from unconfined groundwater, evaporation from vadose zones and by interactions with other connected water bodies such as rivers, lakes, waste water or thermal water (Gibson et al., 2005).

4.2 Sampling Design and Laboratory Analysis

Water samples were taken from precipitation, surface water and groundwater in both 2007 and 2008. Descriptions of water sampling and laboratory analyses are presented below.

4.2.1 Precipitation sampling

A literature survey and survey of Okanagan databases and prior studies was made to determine historical precipitation chemistry monitoring programs with data on precipitation chloride. This included the (National Atmospheric Chemistry Database/Precipitation Chemistry Database system (NAtChem program, Canadian) and the National Atmospheric Deposition Program/National Trends Network (NADP/NTN, United States).

No historical samples of precipitation chemistry, or precipitation sampling data for isotopes were located within the North Okanagan study area. Historical records of federal and provincial government precipitation monitoring programs were located for data collected from Kamloops and Kelowna. A summary of data available are presented in Table 4.1.

Recently, monthly averaged precipitation samples were collected in Kelowna for isotopic analysis for two years by Panagiota Athanasopoulos from the University of Saskatchewan under the supervision of Dr. Jim Hendry. A local meteoric water line (LMWL) for Kelowna is reported in Athanopoulous (2009).

To compare the isotopes of precipitation in the North Okanagan to those in Kelowna, three precipitation sampling stations were deployed in the North Okanagan and two stations in Kelowna at the UBC Okanagan campus. Each station consisted of a 1 litre high density polyethylene (HDPE) sample bottle equipped with a collection funnel. Mineral oil was used to suppress evaporation of the sample from within the bottle. The collection stations were not equipped with any special provisions for collecting snow, and thus winter samples are less representative than summer samples.

4.2.2 Surface water Sampling

The BC Ministry of Environment (MOE) chemical sample database was searched for all historical surface water samples from Deep and Fortune Creeks. No historical water chemistry data were not located for Fortune Creek.

Deep Creek

Water samples were collected for chemical analysis and isotopic analysis on August 14th, 2007.

Fortune Creek

1) Water samples were collected for chemical analysis on March 16th, 2007.
2) Water samples were collected for chemical and isotopic analysis on August 14th and October 24th, 2007.

The surface water sampling locations are shown in Figures 4.1 and 4.2, respectively.

4.2.3 Groundwater Sampling

A review was conducted of historical groundwater samples located in the MOE geochemistry database. It was determined that many of the historical groundwater samples did not report a full range of major ions, and hence could not be used for comparative geochemical analysis using Piper plots. Na^+ and K^+ were the results most often absent from the reported analyses. A total of 21 historical samples with sufficiently complete analyses were located. New groundwater samples were collected by both MOE and UBC Okanagan during the project. These groundwater samples were collected from wells ranging from 4 to 577 meters in depth and represent a mixture of domestic, agricultural irrigation, MOE observation wells and artesian wells.

Groundwater samples were taken from regional and local aquifers within the study area.
The main sampling efforts were conducted in March 2007 for groundwater chemistry only, and in August and September 2007, and in October and November 2007, for both general hydrogeochemistry and D/O isotopes. Each well was purged prior to sampling of

a minimum of three standing well volumes using either the dedicated groundwater pump installed in the well, or using a submersible groundwater sampling pump (Grundfos Redi-flo2). The deepest MOE observation wells were purged for 8 hours prior to sampling which may not represent a full three well volumes in the very deepest wells.

Thirty two wells were sampled from the regional aquifers consisting of 29 wells within Spallumcheen A and 3 wells in Spallumcheen B. Seventeen wells were sampled within the quaternary aquifers excluding regional aquifers and ten wells were sampled from the shallow fractured bedrock. The groundwater sampling locations are presented in Figures 4.3 and 4.4.

4.2.4 Analysis

Samples from 2007 were analyzed for general hydrogeochemistry by Maxxam Analytics who were under a contract to the MOE in 2007. D/O stable isotopes were analyzed at three locations. Some were analysed on an instrument jointly owned by Environment Canada and the University of Saskatchewan. The instrument is a Los Gatos Research Liquid Water Analyzer model 908-0008 coupled to a CTC LC-PAL liquid auto-sampler. Analysis was conducted according to the method outlined in Lis et al (2008).

Some of the deuterium data from the first analysis by the Saskatchewan Los Gatos instrument were not within the normal range of groundwaters. Recent experience with the new Los Gatos analysers has indicated that dissolved organic acids can sometimes lead to anomalous results (Steve Tayler, University of Calgary, Dirk Kirste, SFU, 2009, personal communications).

These samples were re-analysed at the University of Calgary Stable Isotope laboratory. The $^{2}H/^{1}H$ and $^{18}O/^{16}O$ ratios of low TDS water samples are determined using a high temperature “pyrolysis” reactor coupled to an isotope ratio mass spectrometer in continuous flow mode. The system is comprised of a Finnigan Mat TC/EA reactor interfaced to a Finnigan Mat Delta+XL mass spectrometer via a Conflow-III open split/interface. Approximately 100nL of water is injected into the septum port of the TCEA using an A200S liquid autosampler (CTC). Upon injection the water rapidly vapourizes and is carried down into the hot zone of the TCEA with the helium carrier. H_2O is quantitatively converted to $H_{2(gas)}$ & $CO_{(gas)}$ at 1400 ˚C as the water vapour interacts with the glassy carbon packing of inside the TCEA. After conversion, all gases are swept through a small, acid gas trap, the TCEAs GC (90˚C) and finally into the ion source via the Conflow-III open split. Measurement of $\delta^{2}H$ and $\delta\,^{18}O$ are made in two separate sequences, optimizing the ion source first for HD and then for ^{18}O respectively. Raw data is corrected for drift and normalized to the international VSMOW-VSLAP scale using LIMs (USGS) (http://www.ucalgary.ca/uofcisl/files/uofcisl/ TCEA-Delta_water.doc).

The major ion and isotopic chemistry were input to the geochemical analysis program Aquachem (Waterloo Hydrogeologic Inc., Version 5.1) for preparation of Piper plots and other plots to assist groundwater chemical interpretation.

4.3 Results and Discussion

4.3.1 Precipitation chemistry

The chemical and isotopic results for precipitation samples are presented in Tables 4.2 and 4.3, respectively. The rainfall samples are bulk precipitation samples that include both wet and dry deposition of material. All precipitation samples were collected in winter, and some stations indicated elevated chloride concentrations. This is consistent with the dispersal of road salt as aerosols. Road salt is dominantly the mineral halite (NaCl). Dispersal of road salts over large distances (10's of kms) has been noted at other precipitation sampling locations in Canada (David McTavish, Environment Canada, personal communication, 2008).

The results of isotopic sampling of precipitation are discussed in Section 4.46 below.

4.3.2 Surface water chemistry

Five samples for chemical analysis were collected from Deep Creek and fourteen water samples from Fortune Creek. A summary of the major ions, pH, conductivity and TDS is presented in Table 4.4 and the isotopic results are in Table 4.5.

Deep Creek

Historical chloride concentrations in Deep Creek indicate the concentration of chloride has been steadily increasing from ~5 mg/L in early 1970's to current peak concentrations of 15 to 20 mg/L at the Okeefe Ranch hydrometric station (Figure 4.5). Within each year, concentrations were highest during early spring snow melt, and decreased over the summer. The chloride concentration of 8 mg/L observed at the Okeefe Ranch hydrometric station (D5) in August 2007 is consistent with the historical trend.

Profiles of chemistry along Deep Creek are shown in Figures 4.6 and 4.7. EC, TDS, chloride and sulfate values generally increased downstream especially between Location D2 (Hullcar hydrometric station) to Location D3 (Sleepy Hollow hydrometric station). This pattern indicates a source of water soluble salts discharging into the river within the Hullcar/Sleepy Hollow areas. Previous investigators (Le Breton, 1972, 1975; Monahan, 2006) have noted that Hullcar aquifers/permeable units contribute water to Deep Creek, at least during dry years. Water actively discharges from the Hullcar confined aquifer at Steele Springs (Groundwater sample 82). Chloride increases by a factor of 7 and sulfate by a factor of 4 between D2 and D3.

EC and TDS decreased from Location D3 to Location D4 due to influence of two tributary creeks, and through the start of groundwater discharge to the valley center north of Otter Lake. Between Locations D4 and D5, the concentration of chloride decreased further, whereas sulfate increased slightly. Surface water flow measurements (Chapter 2) indicate a significant increase in the flow of Deep Creek between Locations D4 and D5 (0.15 to 0.2 m^3/s) due to strong groundwater contributions from the underlying aquifers. The surface water chemical data indicated this groundwater contribution resulted in dilution of the overall chloride concentration in Deep Creek, but an increase in sulfate. Comparison of groundwater and surface water chemistry is presented in Section 4.3.4.

The Deep Creek and Fortune Creek major ion geochemical data indicates Ca^{2+} and HCO_3^- ions dominated the water sampled in this study (Table 4.4, Figure 4.6). The water type was Ca-HCO_3 in August, 2007 which is typical for surface waters, where Ca^{2+} and HCO_3^- ions result from dissolution of calcite ($CaCO_3$) in soils and aquifers. There were also higher concentrations of Mg^{2+} and SO_4^{2-} in some samples.

Fortune Creek

Interpretation of the water chemistry of Fortune Creek is complicated by anthropogenic discharges to the creek along its reach. An artesian well completed in Spallumcheen A is located immediately downstream from Location F2 (Highway 97 hydrometric station, Figure 4.1), and it overflows into the creek for most of the year. Multiple ditches and drains from adjacent properties feed into the creek, some of which have been observed to have strong odours consistent with manure waste at certain times of year. Observations during summer water sampling and fish enumeration studies have indicated the creek becomes very tightly overgrown with plants, and flow becomes nearly stagnant at several locations along the creek. This is typical of a nutrient rich environment.

The water type at Location F1 (Reservoir hydrometric station) was Ca-HCO_3 (Figure 4.8) which is typical for natural water unaffected by other processes. This water type continues up to Location F7, then the water type starts to change. It becomes a Ca-SO4 type by Location F4 (Stepney hydrometric station) during the March sampling period.TDS, chloride and sulfate values generally increased from upstream to downstream (Figures 4.9 and 4.10). The shapes of the TDS plots appear similar to chloride and sulfate values plots, both showing an increase between Locations F6 and F7. Between these locations, water from a discharge pipe on the northeast side has been noted on occasion to have a strong manure smell.

Chloride values at Reservoir road (F1) where Fortune Creek leaves the bedrock and enters the valley floor were consistent over time (0.5 mg/L). Downstream locations were an order of magnitude higher in both chloride and sulfate in March than in August and October 2007. The increased Cl could be the result of road salts applied to Highway 97 that is contained in March snowmelt runoff. As noted above, winter precipitation samples in the Kelowna and North Okanagan areas had elevated chloride values. Chloride concentrations in Fortune creek during the freshet were similar to those in Deep Creek (~20 mg/L). The higher sulfate values point to a source other than road salts. Sulfate can be a component of cattle waste (Williams et al., 1999) as can Cl, and hence the increased concentrations during spring runoff may be the result of snowmelt carrying an increase in cattle waste to Fortune Creek.

4.3.3 Groundwater chemistry

The raw groundwater chemistry data are presented in Tables 4.6. Detailed data about the sampled wells (depth, aquifer, location etc) are presented in Appendix 2.1. The overall chemical composition of groundwater was plotted in a Piper plot as shown in Figure 4.11. General groundwater facies analysis is presented in Table 4.7.

The groundwater plots show the following four main hydrochemical facies:

- a calcium bicarbonate facies in most of the sampled wells;
- a sodium bicarbonate facies in the wells in Spallumcheen B, one of the bedrock wells (well 57) and one well (well 25) in Spallumcheen A aquifer located in the northeast part of the main valley;
- a magnesium bicarbonate facies in four samples (wells 11, 13, 14 and 15) taken from groundwater in the Okeefe unconfined aquifer and three wells (wells 16, 17 and 18) located the Okeefe B aquifer; and
- a magnesium sulfate facies with very high TDS in 2 wells (wells 59 and 60) located in the bedrock aquifers.

Overall Pattern

Figure 4.11 indicates that the majority of the Spallumcheen A aquifer samples create recognizable patterns in the cation portion. The first pattern (Line A) includes wells from the Fortune Creek aquifer, Eagle Rock and a portion of Spallumcheen A. These wells plotted at similar locations to the surface water samples reported in Figure 4.8. The second pattern is the trend between the Spallumcheen A aquifer wells to those from Hullcar confined and Spallumcheen B (Line B), which are more dominantly Na+K. These wells cluster as a Na-HCO3 type. The third pattern (Line C) is the trend between the majority of Spallumcheen A samples to the wells in the Okeefe aquifers, which contain higher Mg concentrations.

The anion portion indicates that most waters fractionated between bicarbonate and sulfate. Samples from Eagle Rock, one sample from Okeefe B, and one bedrock sample demonstrated higher proportions of chloride.

Bedrock aquifers

Five wells (wells 57 to 61) completed in bedrock were sampled for chemical analysis. There were three different geochemical characteristics.

Well 57 has a drilled depth of 159.7 m and is located on the mountainside adjacent to the Hullcar valley. It had a sodium bicarbonate facies with low chloride and sulfate concentrations of 1.1 mg/l and 3 mg/l, respectively.

Wells 58 and 61 indicated a calcium bicarbonate water facies, suggesting that precipitation infiltration was their main water source.

Wells 59 and 60 had higher chloride at 4.4 mg/l and 25.8 mg/l, and sulfate at 950 mg/l and 2190 mg/l, respectively. They both plot in the magnesium sulfate facies.

Spallumcheen B

The water facies of groundwater in the Spallumcheen B aquifer is sodium bicarbonate (wells 54 to 56, Figure 4.11, label D). A sodium bicarbonate signature is characteristic of older groundwater where sodium has been dissolved from silicate minerals which have slow mineral dissolution kinetics and sulfate has been removed by reduction of sulfate to sulphide. A similar water character is seen in the bedrock well 57. Hydrogen sulfide odour was also noted during sampling in wells 54 to 56. The low sulfate concentrations reported at wells 54 to 56 along with the pH values over 7 indicated that sulfate reduction by organic carbon occurred following the equation described below:

$$SO_4^{2-} + 2C_{organic} + 2H_2O \rightarrow H_2S + 2HCO_3^- \qquad \text{Equation 4.4}$$

The low concentrations of all species reported for well 55 in Spallumcheen B is consistent with two other analyses conducted in 1985 and 1988. All three wells in Spallumcheen B contained fewer dissolved solids than occurred in most of the Spallumcheen A wells.

Similar low concentrations of sulfate were reported in bedrock well 57, located adjacent to the Hullcar area, which plotted with the Spallumcheen B wells on the Piper plot (Figure 4.11).

Spallumcheen A

Wells 23 to 53 are completed in the Spallumcheen A aquifer. The groundwater facies of these wells are calcium bicarbonate.

Wells 23, 24 and 25 from Spallumcheen A are located in the northeast end of the main valley in the Fortune Creek Watershed. These three wells lie along the trend in cations labeled as B on Figure 4.11 towards enrichment in sodium seen in the samples from Spallumcheen B (Figure 4.11, label D). Groundwater head measurements reported in Chapter 3 indicated an upward hydraulic gradient from Spallumcheen B to A in this region. The higher sodium, lower sulfate Spallumcheen B water (D) mixing into Spallumcheen A water would produce a mixing line similar to trend line labeled B in the center plot area. These results, together with the overall chemistry in the Fortune Creek Watershed support that there is a consistent upward water flux from Spallumcheen B to A.

Unconfined aquifers

Nineteen groundwater samples were taken from wells located in the unconfined aquifers (Eagle Rock unconfined-confined, Okeefe unconfined and unconfined-confined, Fortune Creek unconfined-confined, and Sleep Hollow unconfined aquifers).

The water facies of groundwater samples taken in Eagle Rock (wells 5 to 10), Sleepy Hollow A (well 1), and Fortune Creek (wells 2 to 4) were calcium bicarbonate which indicates that precipitation infiltration is the main source to the groundwater within these aquifers.

Eagle Rock unconfined-confined aquifer

Groundwater samples in the Eagle Rock aquifers (wells 6, 7, 9, 10, 43) generally plotted with Spallumcheen A waters, but did contain increased chloride. Well 61 is located in shallow bedrock immediately upgradient of the Eagle Rock aquifer reported the second highest chloride concentration (31 mg/L). It is possible that either a source of chloride exists in the bedrock adjacent to Eagle Rock and the increased chlorides in the unconfined sections are the result of a mixture of precipitation based recharge, and mountain block recharge or that halite from road salting of Highway 97 contributes chloride to the recharge.

Hullcar and Sleepy Hollow unconfined aquifers

At the time of the 2007 groundwater chemistry sampling, no wells within the Hullcar unconfined aquifer were located where permission to sample was granted. As a result, no samples of groundwater for full general chemical analysis were obtained.

Water within the Hullcar confined aquifer shows some similarities to the water within Spallumcheen B, and falls along the trend line B in the cation portion of the Piper plot. This is also where the bedrock well 57 plots. This may indicate the Hullcar confined aquifer receives a portion of its recharge from older groundwaters via mountain system recharge processes, similar to the Spallumcheen B aquifer.

Okeefe unconfined and unconfined-confined aquifers

Wells 11 to 15 are located in the Okeefe unconfined (Okeefe A) aquifer. The water facies for these wells was magnesium bicarbonate, except that of well 12 which was calcium bicarbonate. Wells 16 to 19 are located in the Okeefe unconfined-confined (Okeefe B) aquifer and these samples had a calcium bicarbonate facies. No samples were obtained for the deeper confined Okeefe C aquifer. Wells 11 to 15 reported chloride between 0.7 to 5.5 mg/L and sulphate of 64-100 mg/L. Wells 16-18 had chloride between 0.5 and 1 mg/L and sulphate between 120 and 162 mg/L. These sulphate values are higher than sulphate values further to the north in Spallumcheen A and Eagle Rock aquifers, which are typically < 50 mg/L.

The wells in Okeefe unconfined and unconfined-confined aquifers are located on the line labeled C in the cations portion of Figure 4.11. This suggests there was a source of enriched magnesium water which contributes to the Okeefe unconfined and unconfined-confined aquifers. Adjacent to this area are the bedrock wells 59 and 60 which demonstrated a strong magnesium sulfate signature (Figure 4.11 label E). Mixing of bedrock water with a higher magnesium and sulfate with Spallumcheen A type or precipitation recharge would produce the trend labeled C.

4.3.4 Comparison of surface and groundwater chemistry

Groundwater in the Spallumcheen A aquifer in the Fortune Creek watershed is low in chloride (<0.5 to 1.1 mg/L). Surface water samples from station F2 onwards in Fortune Creek ranged from 18.7 to 23.8 mg/L in the March 2007 sampling. This exceeds the groundwater chloride, and thus groundwater is not the sole source of this chloride.

Fortune creek chloride values in the August and October samplings are closer to the range of groundwater. This suggests that surface-based discharges such as springtime runoff from roads or fields is the source of the spike in chloride in spring.

In August, the majority of flow in Deep Creek is derived from groundwater discharge (0.15 to 0.2 m^3/s) in the area from Otter Lake south to Okanagan Lake. Concentrations of chloride in groundwater in the aquifers adjacent to Deep Creek (0.5 to 4.2 mg/L) in this area are lower than those in Deep Creek (8 to 20 mg/L, Figure 4.5), and therefore groundwater discharges in this area are not the source of the historical increases of chloride in Deep Creek.

The increase in chloride concentrations in Deep Creek is therefore most likely the result of an increase in chloride within the watershed over time. The higher concentrations in March correspond to the melting of winter snow in the valley bottom, and hence may be the result of road salt usage within the watershed. The inter-annual increase may also indicate an increase over time of chloride from other sources such as wastewater or industrial discharges.

In section 4.3.2 it was noted that the influx of groundwater to Deep Creek between stations D4 and D5 leads to a decrease in chloride, and an increase in sulphate. This is consistent with the higher concentrations of sulphate found in the wells adjacent to Deep Creek noted in the discussion of the Okeefe aquifers above. Wells surrounding the lower portion of Deep Creek range from ~65 to ~160 mg/L sulphate, which is above the ~75 mg/L sulphate reported at D4. The source of this increased sulphate in the groundwater is not yet fully determined, but may originate from the bedrock to the north west where very high sulphate values were recorded in bedrock wells 59 and 60.

4.3.5 Summary of Groundwater Chemistry

The key processes identified from groundwater chemistry analysis can be summarized as follows:

- Groundwater interactions between Spallumcheen A and B in the Fortune Creek watershed are sufficiently long lived to have created a consistent chemical trend between the aquifers;
- Bedrock contributes recharge to both Spallumcheen B and Hullcar confined aquifers;
- Groundwater chemistry in the region of the Okeefe Unconfined and Unconfined-confined aquifers may result from mixing of several sources.

These processes are further investigated using the stable isotope data.

4.3.6 Isotopic composition of precipitation

Results for the precipitation samples collected in this study for the North Okanagan valley and the UBCO campus are presented in Figure 4.12. These samples were compared to both the global meteoric water line (GWML) (Dansgaard, 1964) and a local meteoric water line (LMWL) from Kelowna. The meteoric water line determined for precipitation at the valley bottom in Kelowna is $\delta D = 7.03\delta^{18}O - 12.68$; $R^2 = 0.97$; $n = 17$ (Athanasopoulos, 2009).

The reported LMWL for Kelowna is located to the right of the GMWL, and has a slightly lower slope. These deviations are consistent with partial evaporation of raindrops in a relatively dry atmosphere occurring below the cloud base (Araguás-Araguás et al., 2000). This process is found where the climate is arid and semi-arid which is consistent to the average annual precipitation of 320 mm in Kelowna (Environment Canada, October 2009).

The limited number of precipitation samples collected from the North Okanagan and Kelowna areas in this study are consistent with the LMWL reported for Kelowna. A more comprehensive precipitation sampling effort would be required to derive a local meteoric water line for the North Okanagan. However, the reported samples are sufficient to confirm that valley bottom precipitation is not likely to be very different from the Kelowna LMWL.

4.3.7 Isotopic composition of surface water

$\delta^{18}O$ and δD values fractionate when water is subjected to evaporation, resulting in heavy isotope enrichment in the remaining water. The trend of the remaining water would plot to the right of the LMWL at a lower slope, and is termed a Local Evaporation Line (Clark and Fritz, 1997). Surface water isotopic data were plotted in Figure 4.13, with the GMWL and LMWL from Figure 4.12 for comparison. The samples taken in Deep Creek in August 2007 and in Fortune Creek in August 2007 and October 2007 seemed to line up around the GMWL and LMWL which indicate that these waters ultimately came from precipitation.

Deep Creek

The August 2007 isotope values increased in Deep Creek from upstream to downstream, moving from close to the GMWL toward enrichment in ^{18}O (Figure 4.14). There is little change in the Deep Creek isotopes despite the groundwater inflow south of Otter Lake between D4 and D5.

The Deep Creek samples above and below Otter lake (D4, D5) are more consistent, and thus the Otter Lake result indicates a more detailed sampling of the lake waters would be needed for an average lake composition to be determined.

Fortune Creek

Based on streamflow data, water is lost in the valley side alluvial fan of Fortune Creek downstream of Site F1 (Reservoir Road Hydrometric Station). A portion of the water is returned to Fortune Creek by Site F2 (Highway 97 Hydrometric Station) and further water comes back as groundwater discharge by Site F3 (McCallum Hydrometric Station). An artesian well drilled to Spallumcheen A discharges to the Creek immediately downstream of site F2.

Data from Fortune Creek showed different characteristics between the August 2007 and October 2007 samplings (Figure 4.13). The October 2007 samples were consistent with the slope of the GMWL. The samples do not systematically change going downstream, but vary up and down near the GMWL (Figure 4.13). The values show a similar irregular trend going downstream (Figure 4.16). This would be consistent with the evolution of water chemistry as several side creeks carrying precipitation sourced surface water enter Fortune Creek between sites F2 and F9 (Figure 4.2).

The isotopic values in August 2007 are distributed along a horizontal trend with a spread in ^{18}O values with little change in D. They trend from higher oxygen isotope values (-16) to lower and closer to the GMWL progressing downstream from F2, F3 to F4. The initial value at F1 falls to the right of the LMWL for Kelowna, which suggests some degree of evaporative fractionation. The flow from Fortune Creek in the summer is augmented with reservoir water from the City of Armstrong reservoirs located adjacent to Silver Star Mountain. The trend towards the GMWL progressing downstream may represent a change to water more dominated by other surface waters from side creeks that do not have evaporative fractionation, or to the contribution of groundwaters.

4.3.8 Isotopic composition of groundwater

The results of isotopic analysis are presented in Table 4.8. The isotopic compositions of all groundwater samples are plotted in Figure 4.17-A. In general, the isotopic values of water in the deeper confined aquifers are lower than those in unconfined groundwater (Table 4.8). A number of samples can be seen to depart from the GMWL and LMWL.

The evolution of isotopes in the North Okanagan system can be understood by following the evolution of isotopes from recharge areas, and areas up gradient to discharge at Okanagan Lake.

The following areas are discussed:

(a) Bedrock
(b) Hullcar to Sleepy Hollow to Spallumcheen A near Armstrong;
(c) Groundwater in the Fortune Creek watershed to the central Deep Creek watershed near Armstrong;
(d) Where (b) in Fortune Creek watershed and (c) meet at Armstrong and Spallumcheen A and Fortune Creek interact;
(e) Middle valley of Spallumcheen A where Eagle Rock and Spallumcheen A interact;
(f) The area where Okeefe unconfined and unconfined-confined and the southern part of Spallumcheen A meet.

This follows water from the mountains to the discharge at the south end of the main valley. In order to identify the specific hydrodynamic connections, the isotopic data in Figure 4-17A is presented again for three subareas, the Fortune Creek watershed area, the Central Deep Creek watershed and the Okeefe Area at the southern part of the valley (Fig. 4.17-B, 4.17-C). The isotopic compositions of groundwater samples with that of surface water comparison in these areas distributes in Figure 4.17-B, 4.17-C.

Groundwater in Bedrock aquifers

MSR is believed to be the main source to the groundwater located in the moderate and deep aquifers at the valley bottom. The isotopic values of the groundwater in the bedrock on either side of the valley are important to understand this process and as such, eight wells completed in bedrock were sampled. These bedrock wells are completed at depths between 19.2 and 91.4 meters. Residential bedrock wells most likely sample the upper parts of the fractured bedrock system.

The δD and $\delta^{18}O$ compositions of water in bedrock wells distribute around the LMWL which indicates that the original source to these groundwaters is atmospheric precipitation. The values range from being the lowest per mil values (well 59) to wells close to the composition of the surface water within the watershed (wells 60, 76, 78 and 79). The number of residences with wells located on the adjoining bedrock is low, and bedrock wells are rare. Too few wells were located in this study to determine the effects of altitude on isotopic composition.

Samples from wells 59 and 60 were taken in two wells close together that are reported to both be 91 metres deep. Chloride (4.4 mg/L, 25.8 mg/L) and sulfate (950 mg/L, 2190 mg/L) in these wells were elevated above other groundwater samples. Their major ion chemistry plotted at similar locations on the Piper plot (Figure 4.11). They had quite different isotopic values (Figure 4.17A), and plot at either end (bottom left 59; top right 60) of the cluster of wells around the GMWL. This suggests that the reported depth information may not be correct.

Hullcar aquifers to Sleepy Hollow to Spallumcheen A at Armstrong

Wells 22 and 66 are located in the western portion of the Hullcar valley and were the only two confined Hullcar aquifer wells sampled. The isotopic values at well 22 are similar to Spallumcheen B and the isotopic composition a well 66 is halfway between well 22 and signature of shallow bedrock wells. This points to a bedrock component to the water within the Hullcar confined aquifer.

Further groundwater sampling and analysis of stable isotopes in groundwater in this region is required for the hydrogeochemistry of the Hullcar region to be determined. The region between Hullcar to Sleepy Hollow contains some of the most complex geology in the area (Monahan, 2006).

The Hullcar aquifers pass to the Sleepy Hollow aquifers, which join Spallumcheen A north west of the City of Armstrong. Wells 28, 29 and 34 in Spallumcheen A are those closest to Sleepy Hollow. All plot close to bedrock signatures from wells 78 and 79.

Well 3 is located within sands adjacent to Deep Creek, that form an aquifer above Well 34. Both are artesian wells, indicating water flow is upwards from both Spallumcheen A and the shallower aquifer materials. Well 3 may be located within a continuation of the

Sleepy Hollow unconfined aquifer. Well 3 and well 34 plot close to each other, with well 3 showing some oxygen enrichment.

Groundwater in Fortune Creek Watershed and central Deep Creek Watershed

Water enters into groundwater in the Fortune Creek watershed either via MSR from the valley sides or possibly via direct recharge from surface water at the Fortune Creek fan. Groundwater samples taken in the Spallumcheen A aquifer comprised 21 wells sampled in October 2007 (Figure 4.17-B). The majority of wells sampled in October, 2007 are in the main valley stem of Spallumcheen A and lie along a pattern between the GMWL and the Kelowna LMWL. The isotopes of Spallumcheen A water in the main valley is consistent with the isotopes from bedrock wells on either side. It suggests aquifer Spallumcheen A obtains a portion of its water from Mountain System Recharge.

Three MOE observation wells from Spallumcheen B were sampled, two of which are in the FCW. Isotopes in both the Spallumcheen B and Hullcar confined aquifers fall at the depleted end of the GMWL/LMWL (Figure 4.17-B). This suggests that Spallumcheen B and parts of the Hullcar confined aquifer derive their recharge from upper elevations in the bedrock mountain system on either side. The groundwater isotopic values were higher in the Spallumcheen A aquifer than in the Spallumcheen B, which indicates that the temperature of the originating groundwater in Spallumcheen A is higher than the originating groundwater source for Spallumcheen B. The low isotope values in Spallumcheen B indicate suggest that the water is mainly derived from higher elevation sources than the water contained in the shallow fractured bedrock that is accessed for domestic supply by wells on the valley side.

Within the Fortune Creek watershed, groundwater head measurements indicated that water flows southwards in Spallumcheen A, and the head gradient is upwards from both Spallumcheen A and B. Groundwater heads in both Spallumcheen A and B are higher than Fortune Creek. This exchange was seen in chemistry data and is repeated in the isotope data. The isotopes of wells in Spallumcheen A in FCW (wells 23, 25, 26, 27, Group A Figure 4.17-B) fall between the adjacent bedrock well (78), and the three Spallumcheen B wells (54, 55, 56).

This indicates a contribution of Spallumcheen B water depleted in isotopes (wells 54 and 55) upwards into Spallumcheen A in sufficient proportion to bring the signature of Spallumcheen A in this area closer to the Spallumcheen B signature. Wells on the west side (25, 27) are closer to the Spallumcheen B signature, whereas the wells on the east side (23, 26, 30) trend closer to a bedrock signature (78) indicating increasing contributions of mountain recharge further south. Well 30 is located at the location of a fan structure on the valley side, and plots closest to the bedrock signature.

Fortune Creek Fan and Armstrong

At the boundary of the Fortune Creek and Deep Creek watersheds, the Spallumcheen A aquifer (wells 28, 29, 31, 32, 33, 34, 35, 36, 38, 71) are overlain by Fortune Creek and the Fortune Creek aquifer (well 4), as well as Deep Creek, and a similar shallow aquifer close to its channel (Well 3). Spallumcheen A receives flow from Spallumcheen A upgradient in the Fortune Creek watershed (wells 27, 30) and from the west from Hullcar/ Sleepy Hollow (28, 29, 34).

Flow measurements indicate Fortune Creek loses water in the area of the Fortune Creek fan. Wells in the area of the Fortune Creek fan indicate the possibility of groundwater recharge via the Fortune Creek Fan. Only one well location was obtained within the Fortune Creek unconfined aquifers created by the movement of alluvial materials downstream by Fortune creek. Well 4 is located east of Fortune creek within a former channel. Its isotopic signature falls within the values obtained from Fortune Creek. This suggests that measured water losses from Fortune Creek are at least partly passing into the shallow unconfined deposits created by the former channels of Fortune Creek.

Well 38 is the closest Spallumcheen A well to the location of the Fortune Creek fan. Its isotopic signature falls between that of the Spallumcheen A wells upgradient Fortune Creek Watershed (25, 26, 27, 31, 33) and the Spallumcheen A well 30. The signature of well 4 is quite different, which suggests Fortune Creek water does not proceed westwards into Spallumcheen A. The main losses of water from Fortune Creek aquifer occur closer to the eastern edge of the valley. The next well on that side of the valley is well 74, which is discussed below.

Wells on the downgradient side of Armstrong (wells 35, 71, 38) fall in between the more oxygen depleted Spallumcheen A wells from FCW (e.g.: wells 25, 26, 27, 31, 33) and the more oxygen enriched wells from the Sleepy Hollow side of Armstrong (wells 28,29,24, 70).

Spallumcheen A in Middle Valley

Deep wells in the center of the main valley between Armstrong and Otter Lake were more difficult to locate. Wells 42, 73, and 74 are a mix of groundwater from up-gradient. Wells 42 and 73 located in the center of the valley fall in the middle of the Spallumcheen A signature, similar to that of well 71 on the downgradient side of Armstrong.

Well 74 is located closer to the eastern side of the valley, just upgradient of the Eagle Rock aquifer. Its signature is closer to that of the surface water from Fortune Creek. It may indicate that the main part of the Fortune Creek Fan closest to the eastern side of the valley does recharge part of Spallumcheen A. This water proceeds southwards along the margin of the valley but does not mix further out in the valley center. More samples along the eastern edge of the valley are required.

The east side of the valley had one well in the Eagle Rock aquifer (well 43), and one in bedrock (well 61). The isotopes in well 43 fall to the upper right of the cluster of wells defining the character of Spallumcheen A. These samples are the least depleted, and plot near to samples obtained from shallow bedrock wells. Well 61 falls within the center of the signature of the Spallumcheen A wells.

No isotope samples were obtained in 2007 from wells located within the main part of the

Eagle Rock aquifer.

Spallumcheen A and Okeefe Aquifers

As Spallumcheen A approaches the south end of the valley, it is overlain by the Okeefe unconfined-confined aquifer, which is in turn overlain to the west by the Okeefe unconfined aquifer. Examination of cross sections 16 and 17 in Monahan (2006) indicates that the Spallumcheen A aquifer and Okeefe Unconfined-confined aquifer come close together in this area. The hydraulic gradient is upwards from Spallumcheen A to the Okeefe Unconfined-confined aquifer. Groundwater heads and the chemistry (particularly sulphate) indicate that groundwater in the Okeefe valley flows into the Spallumcheen A aquifer south of Otter Lake. Water in the area north of Okanagan Lake is expected to represent a mixture of groundwater flowing south in Spallumcheen A, and groundwater flowing from the west from Okeefe.

Groundwater samples for isotopes were taken from the Okeefe aquifers, Spallumcheen A underneath the Okeefe aquifers and from bedrock near the Okeefe area. Groundwater within the Okeefe valley is a mixture of surface water derived from the Salmon River to the west, direct surface recharge within the Okeefe valley, and MSR to the Okeefe valley from the bedrock highlands on either side. The isotopic compositions of samples 12, 14 and 15 from the Okeefe Unconfined aquifer are distinct from other groundwater samples and plot to the right of the LMWL line (Figure 4.17-C). There are too few samples to determine the mechanism that fractionates these samples in this manner, but it may relate to a different LMWL for the Salmon river valley, evaporation processes within the Okeefe area, or changes to the isotopic composition of the groundwater due to the presence of the Okanagan fault in this area.

The Spallumcheen A wells show isotopic signatures consistent with MSR and the upgradient wells. Well 45 is downgradient of bedrock well 60, and these plot together, indicating MSR is contributing to Spallumcheen A. Water in wells 49, 50 on the east side of the Spallumcheen A aquifer distribute around the GMWL and LMWL similar to well 73 from upgradient. The isotopic composition of Spallumcheen A well 53 downgradient of the intersection of the Okeefe aquifers distributes between bedrock well 59 and the upgradient Spallumcheen A signature (49, 50) and the Okeefe unconfined wells, which suggests that the groundwater downgradient of the intersection in Spallumcheen A is a mixture of the water in the Okeefe unconfined and bedrock aquifers.

The distribution of isotopes in wells 16, 17, 18, 19 to the right of the LMWL indicates that the groundwater in the Okeefe Unconfined-confined aquifer is most likely a mixture of up gradient water coming from Spallumcheen A and water similar to that reported for the Okeefe unconfined aquifer. The geochemical and isotopic data support an upwards flow from Spallumcheen A to Okeefe Unconfined-confined aquifer.

4.4 Summary

The key conclusions of this chapter are the following:

- Mountain System Recharge is a significant recharge source to the regional

- Spallumcheen A obtains groundwater from Spallumcheen B in the Fortune Creek Watershed at the north of the study area.
- Water infiltrating within Fortune Creek fan may recharge Spallumcheen A.
- Additional sampling is required in the Hullcar and Sleepy Hollow areas to resolve the hydrogeochemistry and hydrogeology of this area.
- The unconfined aquifers in the Hullcar and Sleepy Hollow areas contribute to Deep Creek and to Spallumcheen A in the main valley.
- There is upwards flow from Spallumcheen A to the Okeefe Unconfined-confined aquifer.
- Deep Creek gains water from Spallumcheen A and Okeefe aquifers south of Otter Lake.
- The geochemical and isotopic data indicate lateral inflow from the Okeefe valley.

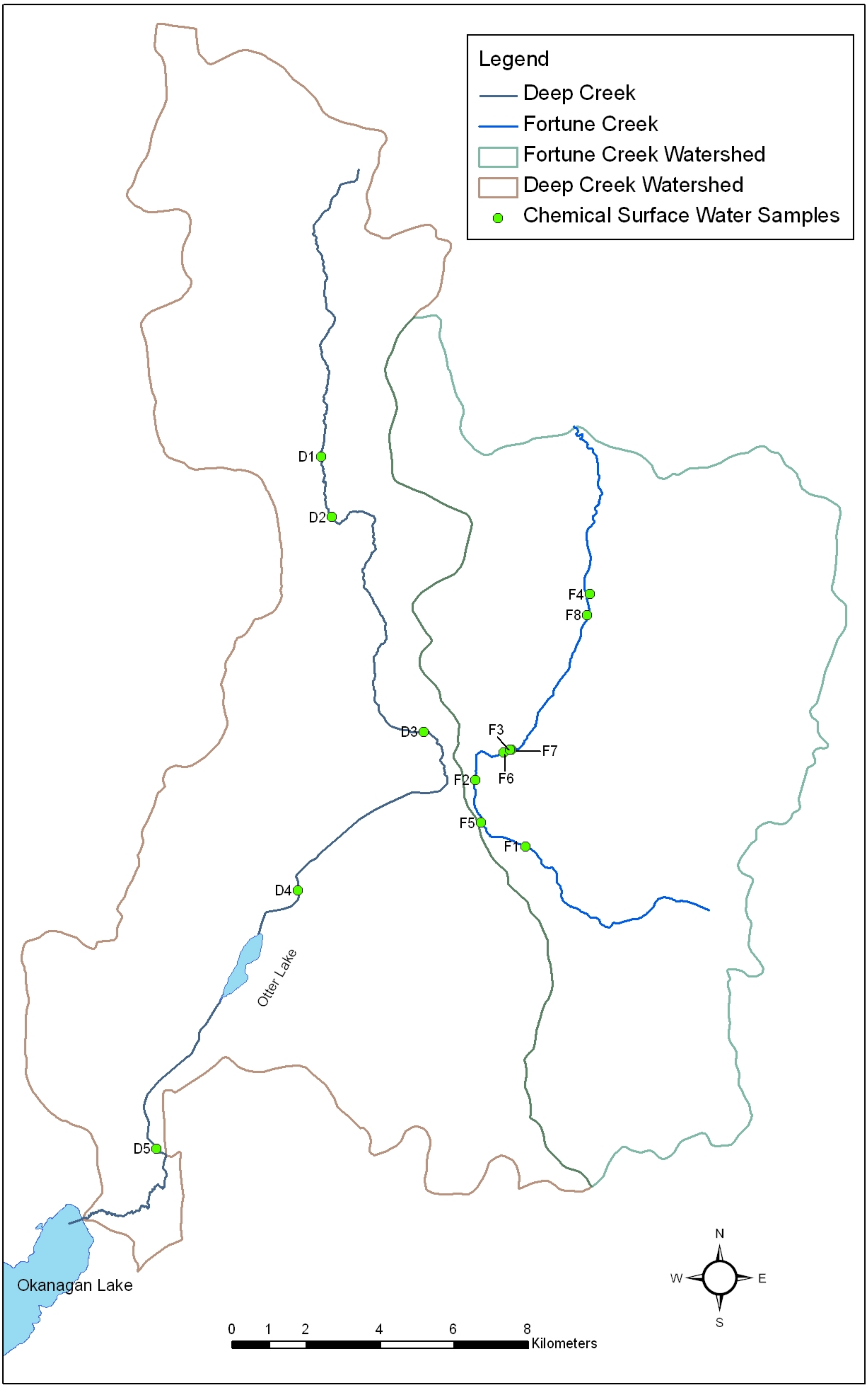


Figure 4.1 Surface water sampling locations for chemical analysis

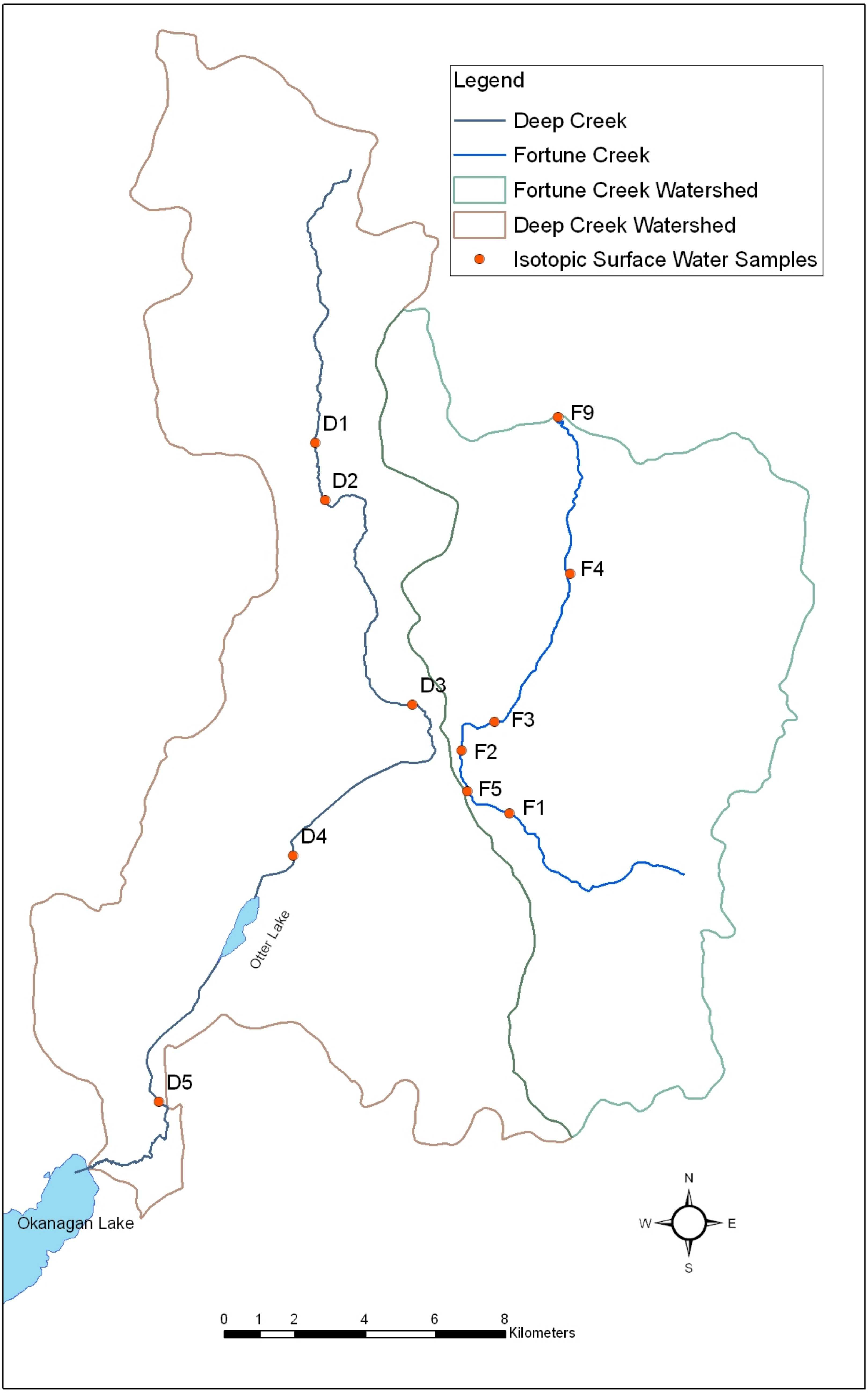


Figure 4.2 Locations of surface water samples for isotopic analysis

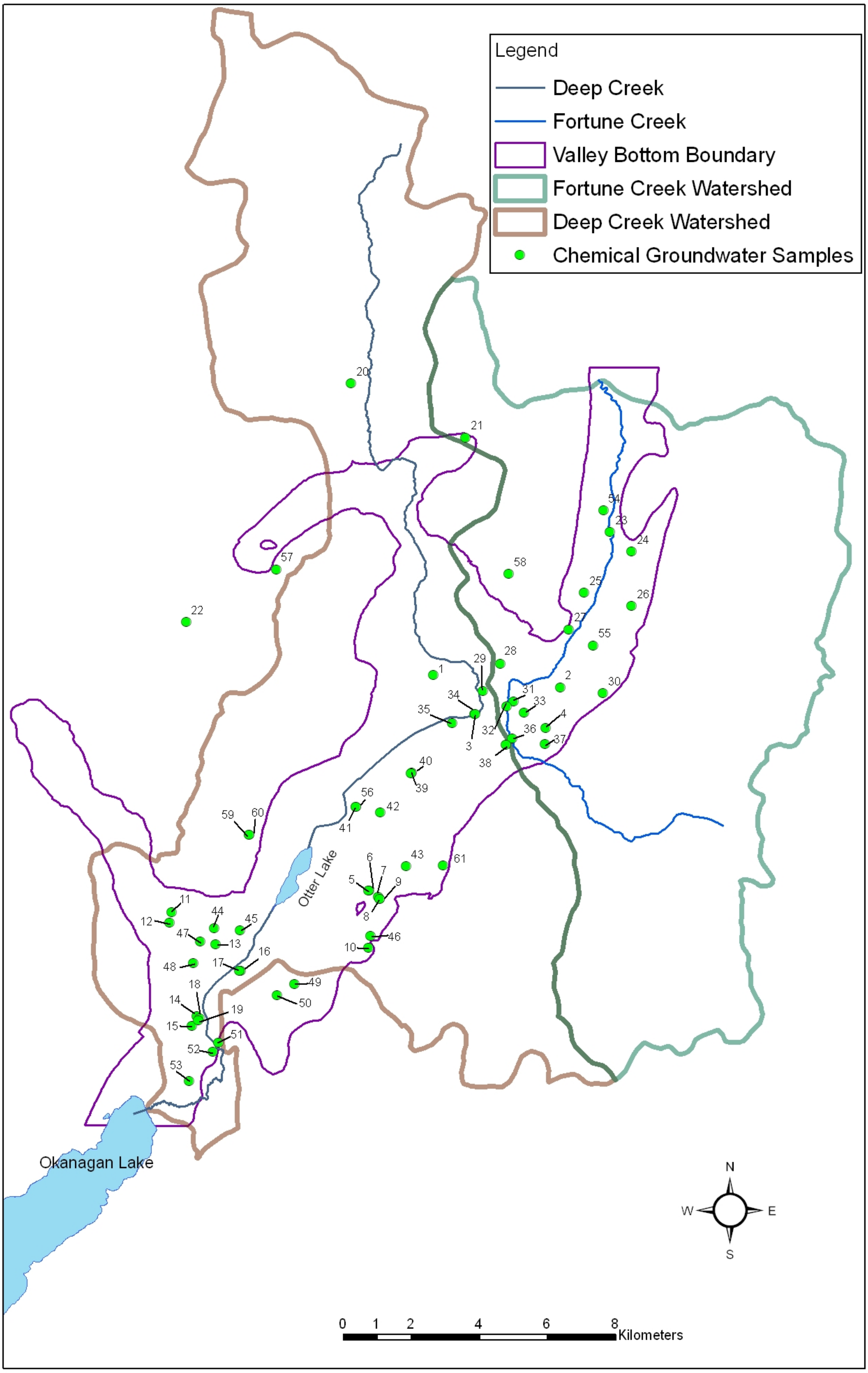


Figure 4.3 Groundwater chemical sampling locations

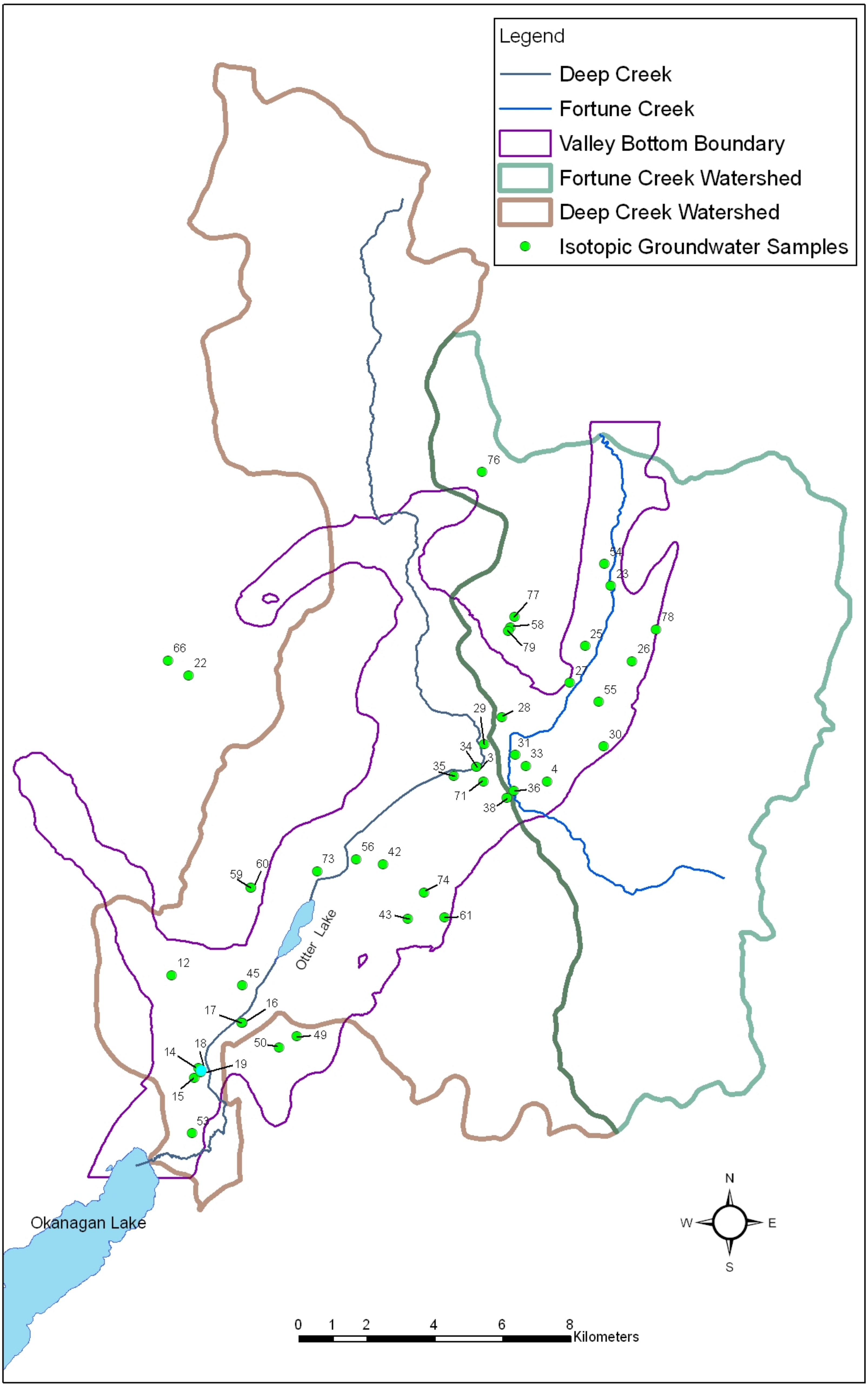
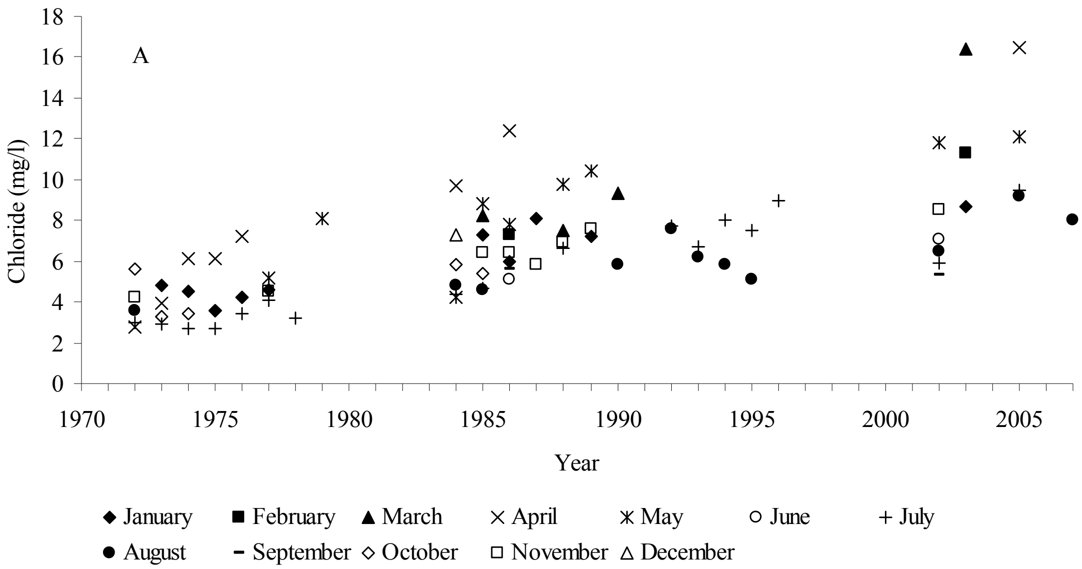


Figure 4.4 Groundwater isotopic sample locations



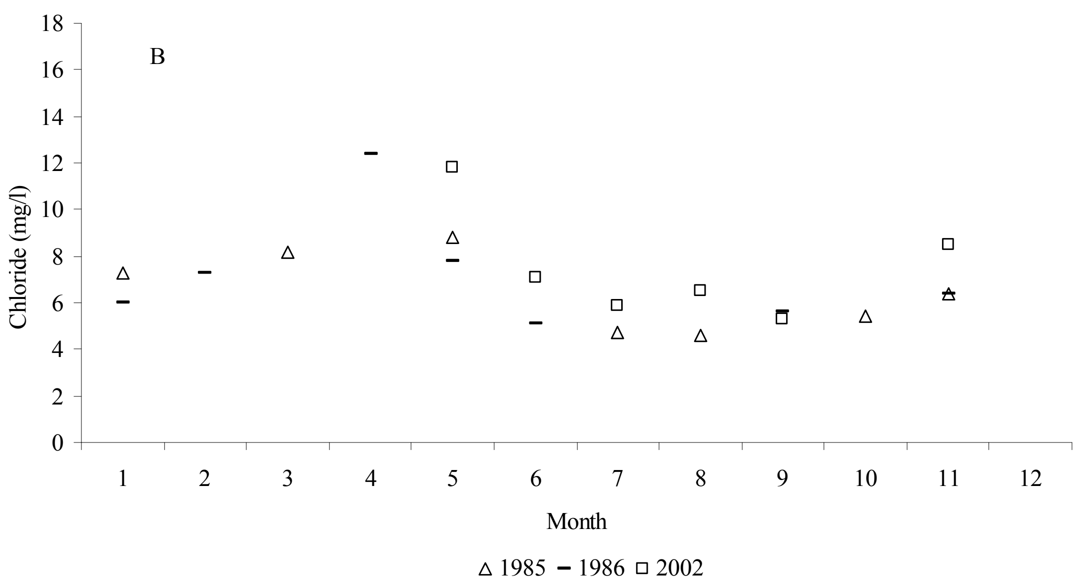


Figure 4.5 Historical chloride concentrations at Deep Creek At The Mouth historical hydrometric station (DH4)
(A) All data (B) Monthly chloride concentrations variation in 1985, 1986, and 2002

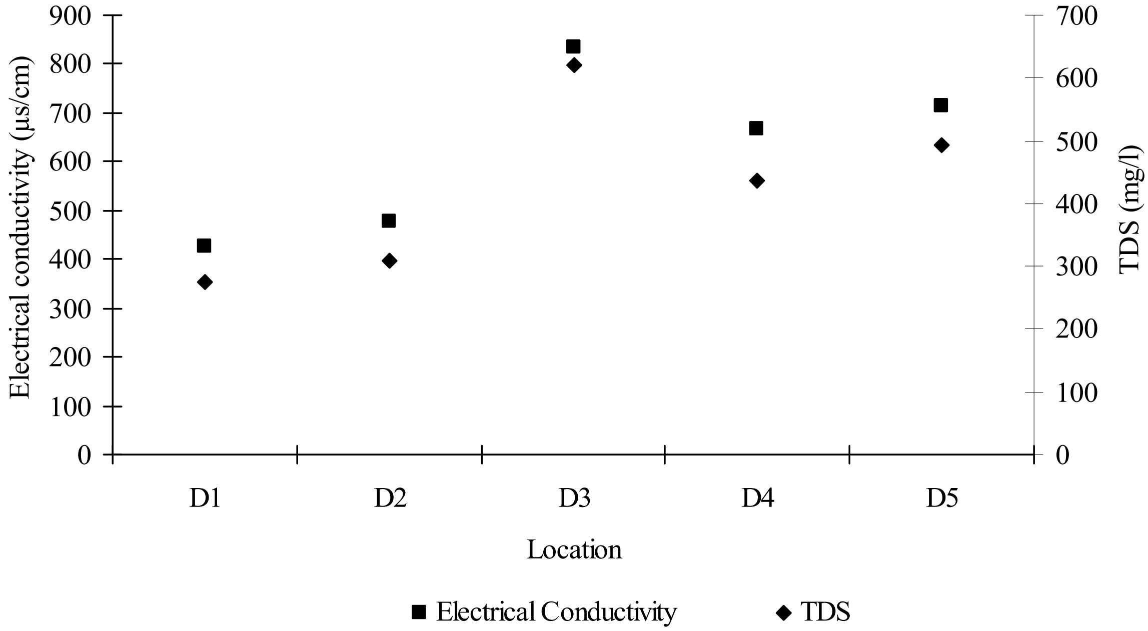


Figure 4.6 Total dissolved solids and electrical conductivity profiles from upstream to downstream in Deep Creek (August 2007). Refer to figure 4.2 for station locations.

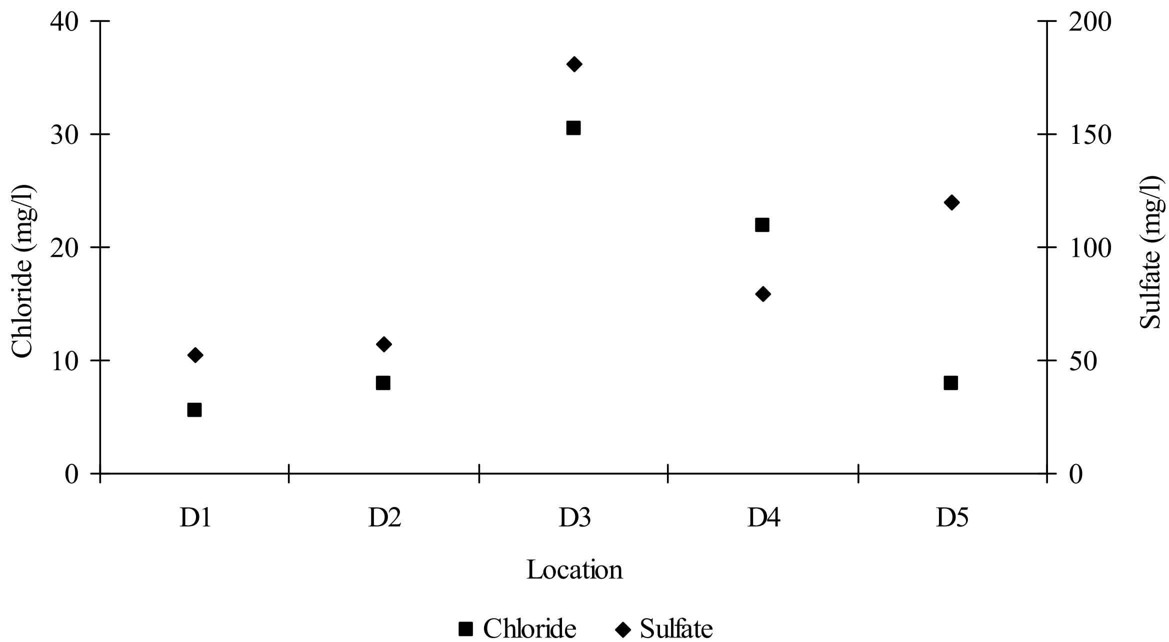


Figure 4.7 Chloride and sulfate concentrations profiles from upstream to downstream in Deep Creek (August, 2007). Refer to figure 4.2 for station locations.

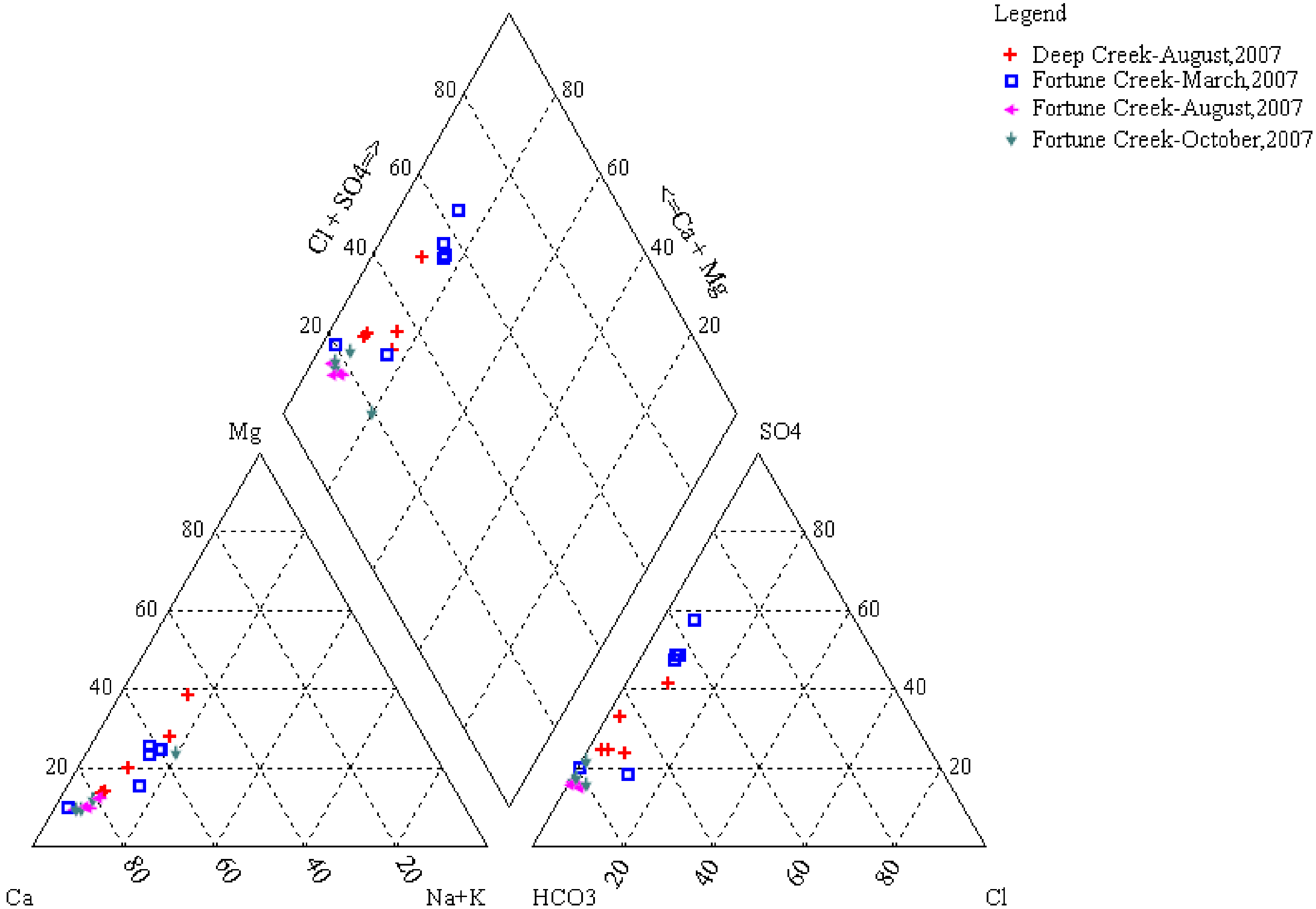


Figure 4.8 Piper plot of water chemistry in Deep and Fortune Creeks in March, August and October 2007

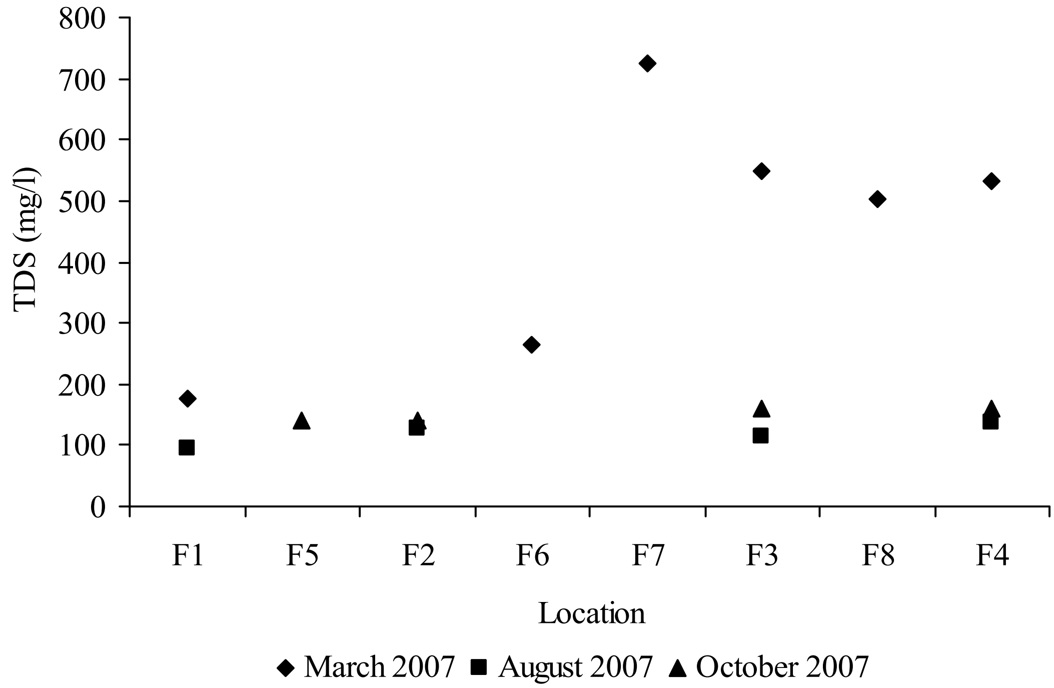


Figure 4.9 Total dissolved solids profiles from upstream to downstream in Fortune Creek in March, August and October 2007. Refer to Figure 4.2 for station locations.

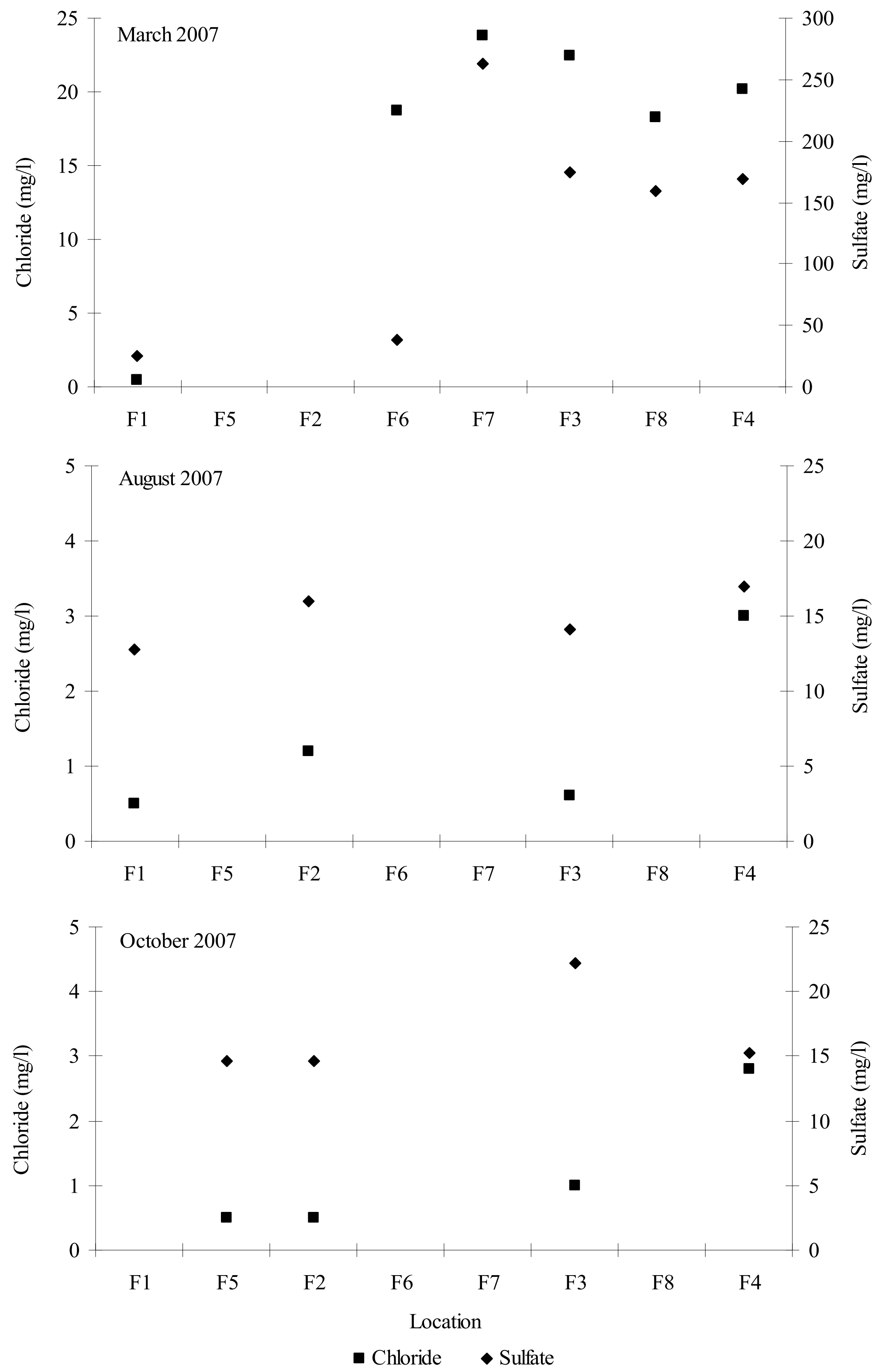


Figure 4.10 Chloride and sulfate concentrations from upstream to downstream in Fortune Creek in March, August and October 2007. Refer to Figure 4.2 for station locations.

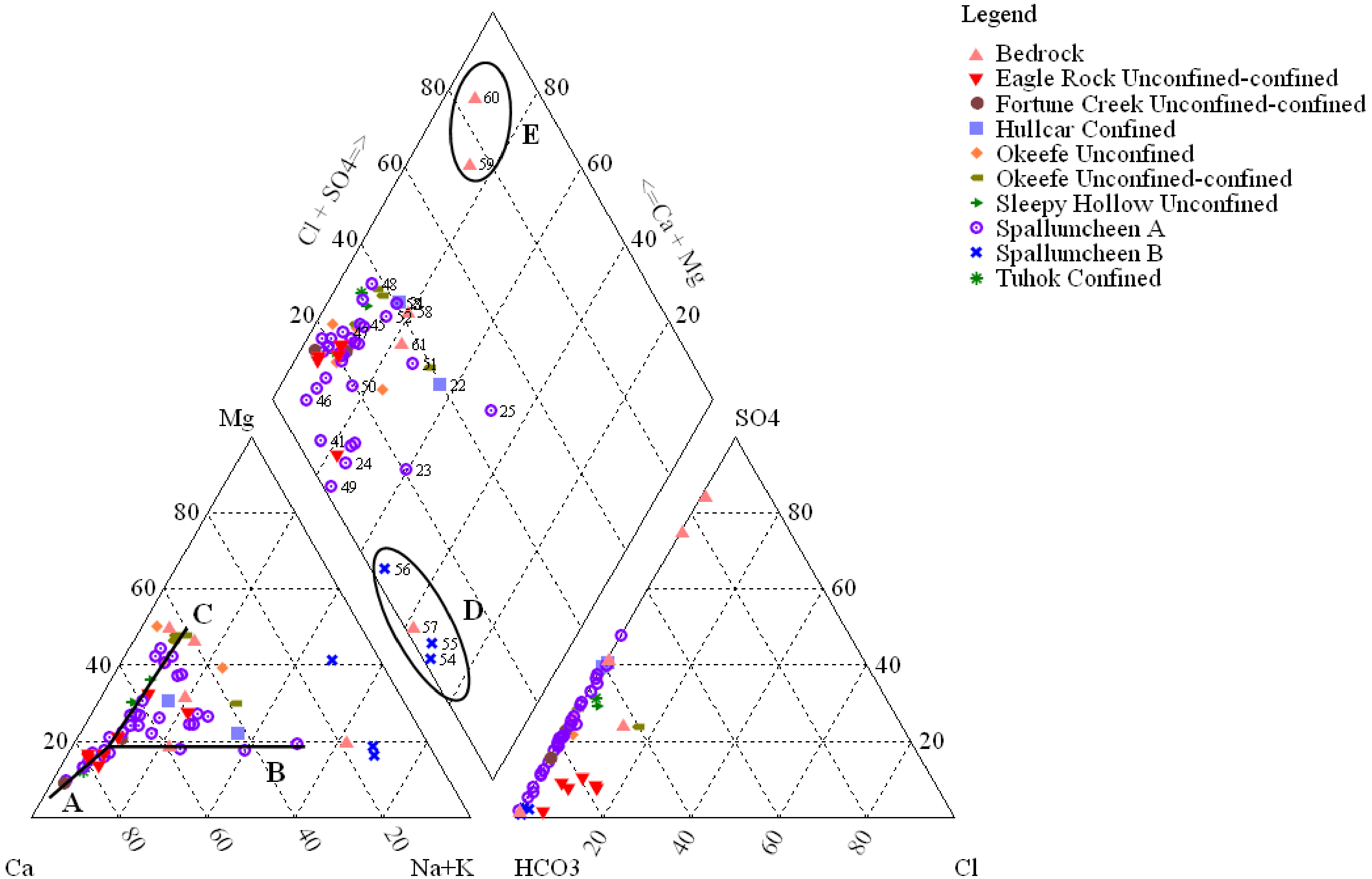


Fig.4.11 Piper plot of groundwater chemistry by aquifer groups

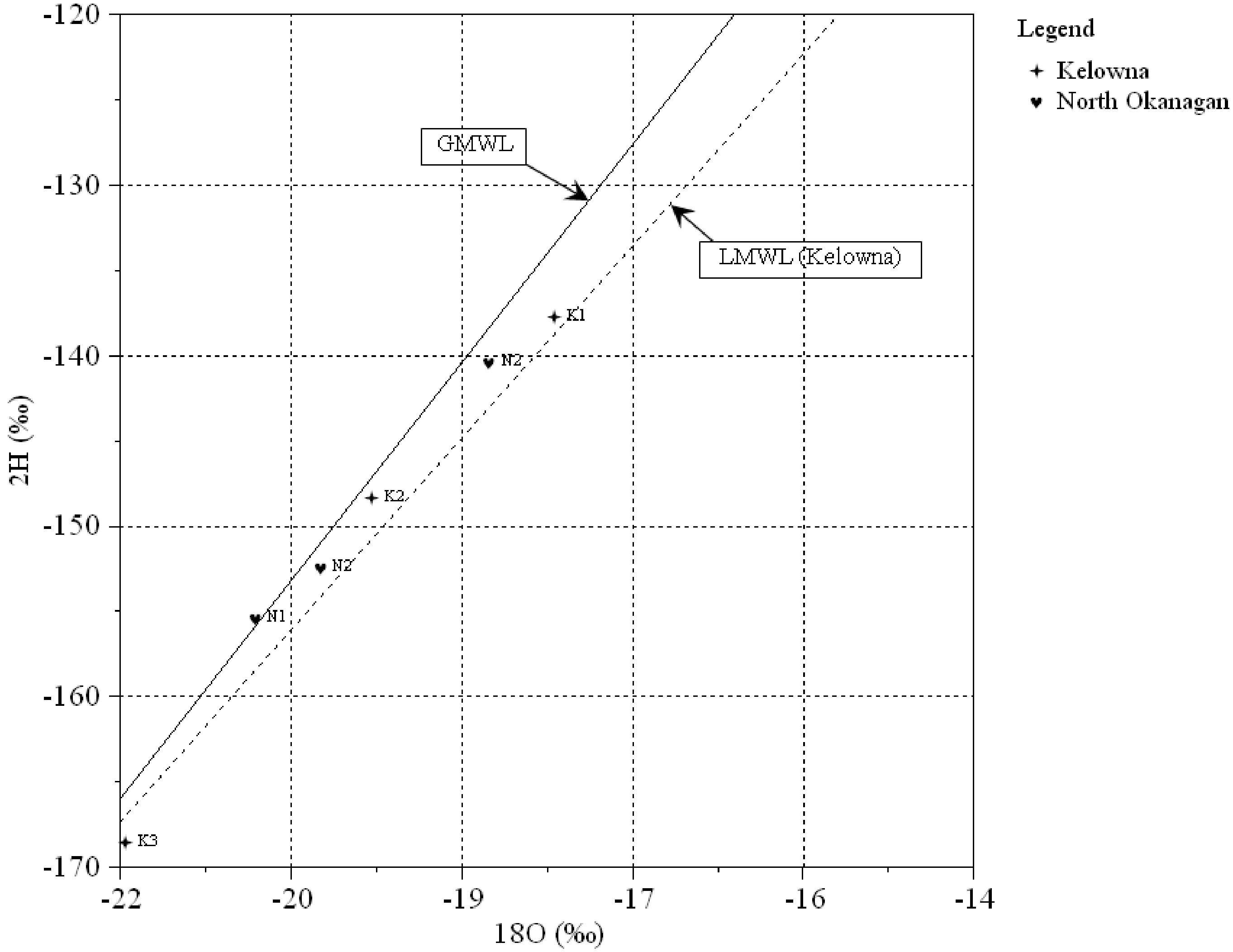


Figure 4.12 Stable isotope composition of deuterium vs. oxygen-18 in precipitation. LMWL from Athanasopoulos (2009)

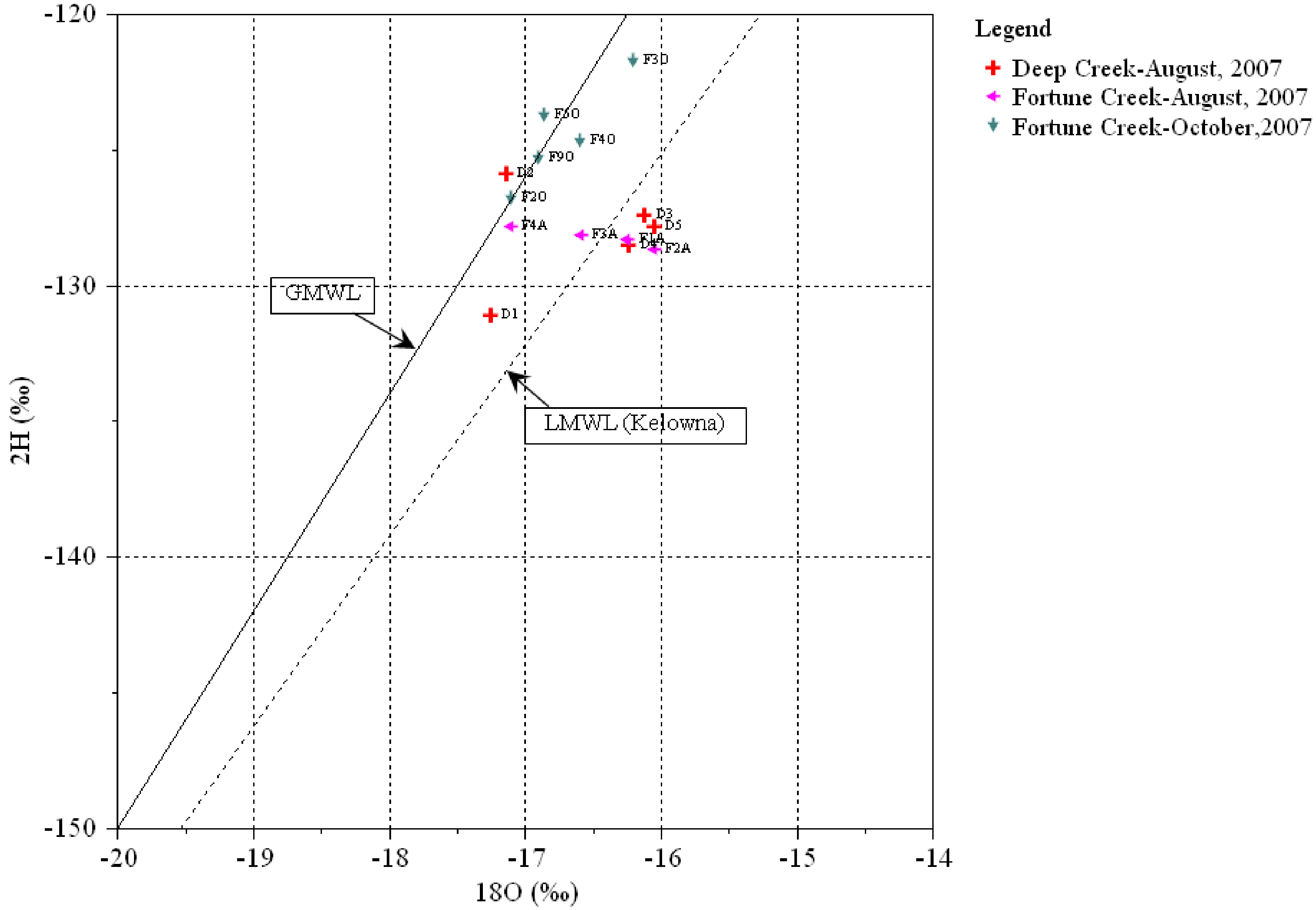


Fig.4.13 Stable isotope composition of deuterium vs. oxygen-18 in surface water. LMWL from Athanasopoulos (2009).

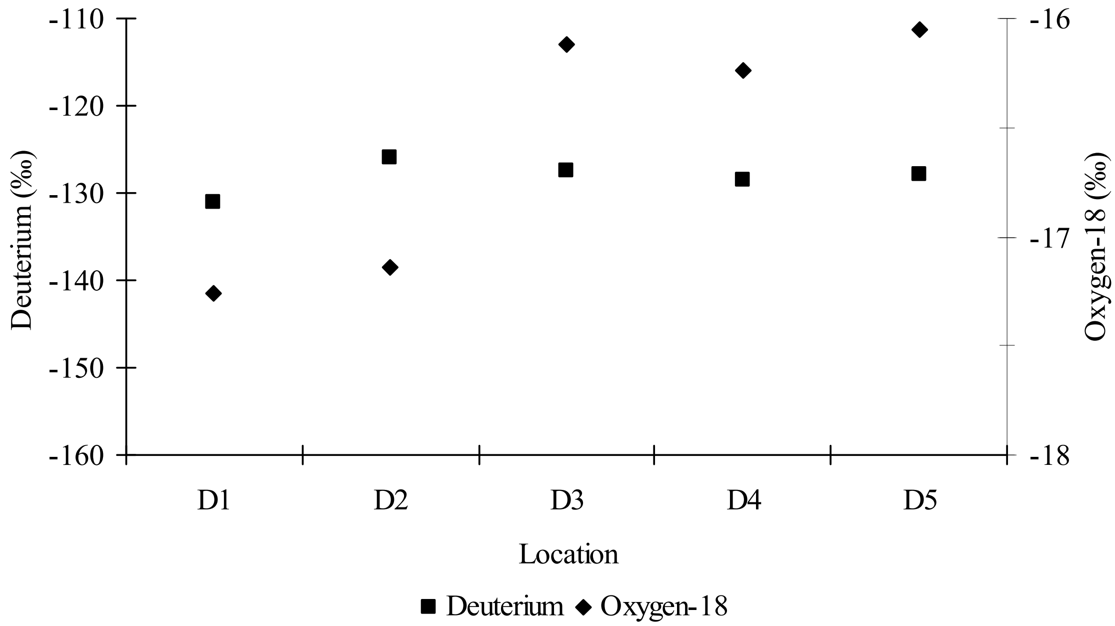


Figure 4.14 Deep Creek oxygen-18 and deuterium profiles from upstream to downstream in August 2007

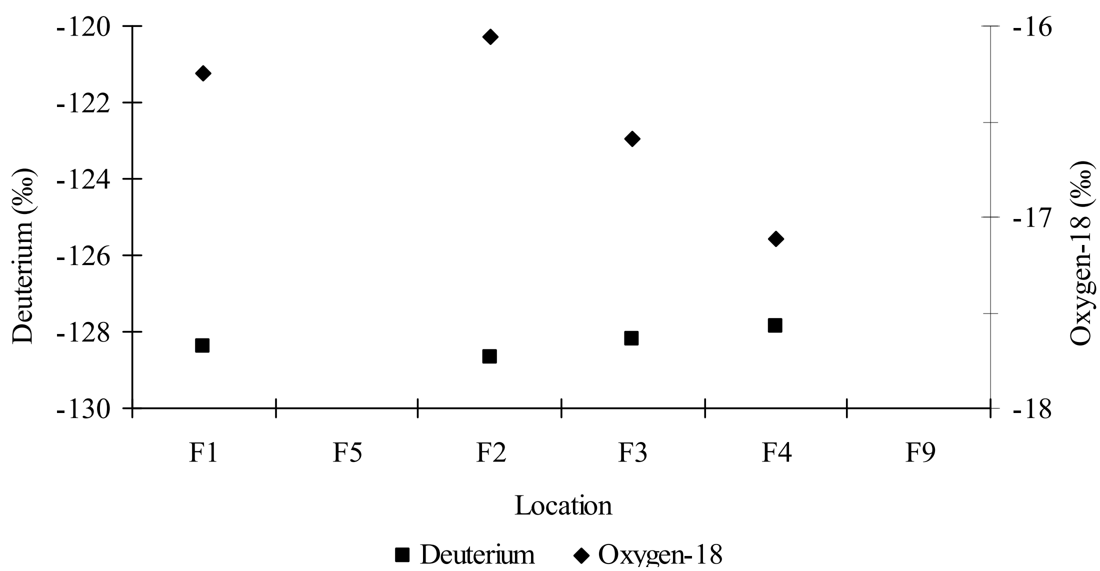


Figure 4.15 Fortune Creek deuterium and oxygen-18 profile from upstream to downstream in August 2007. Refer to Figure 4.2 for station locations.

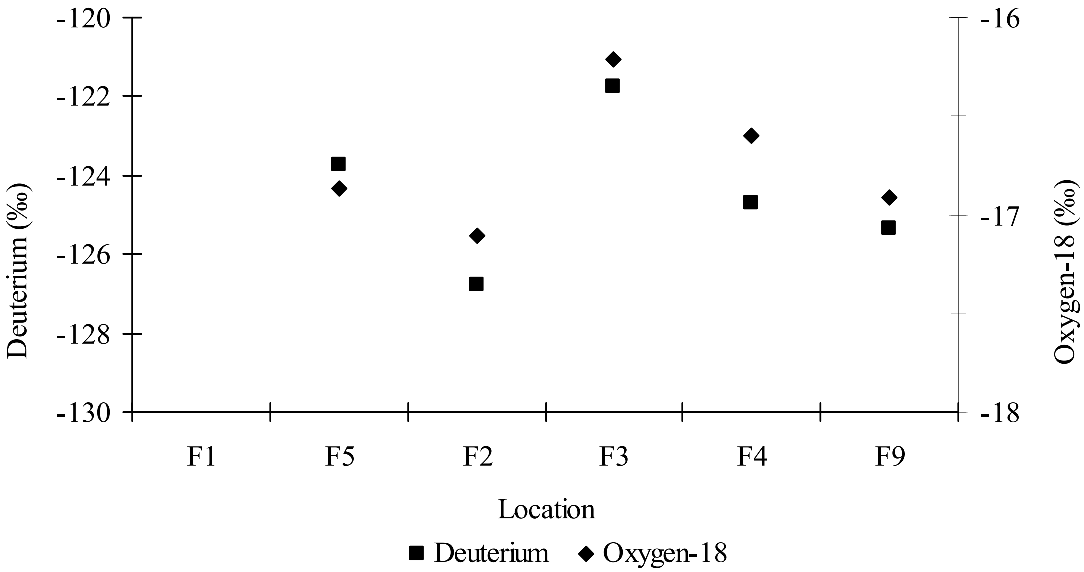


Figure 4.16 Fortune Creek deuterium and oxygen-18 profiles from upstream to down stream in October 2007. Refer to Figure 4.2 for station locations.

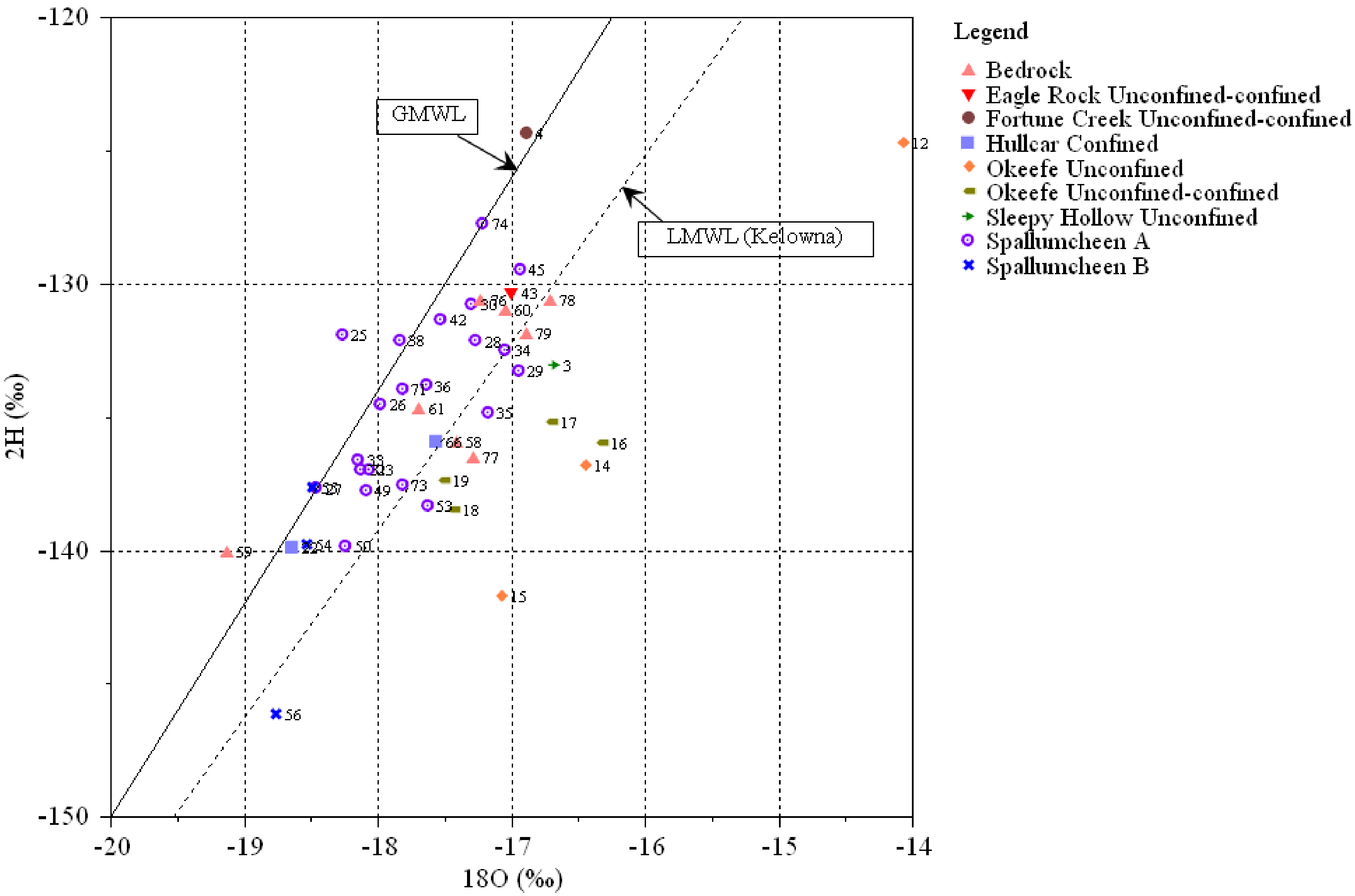


Figure 4.17-A Deuterium and oxygen-18 composition of all groundwater samples. LMWL from Athanasopoulos (2009).

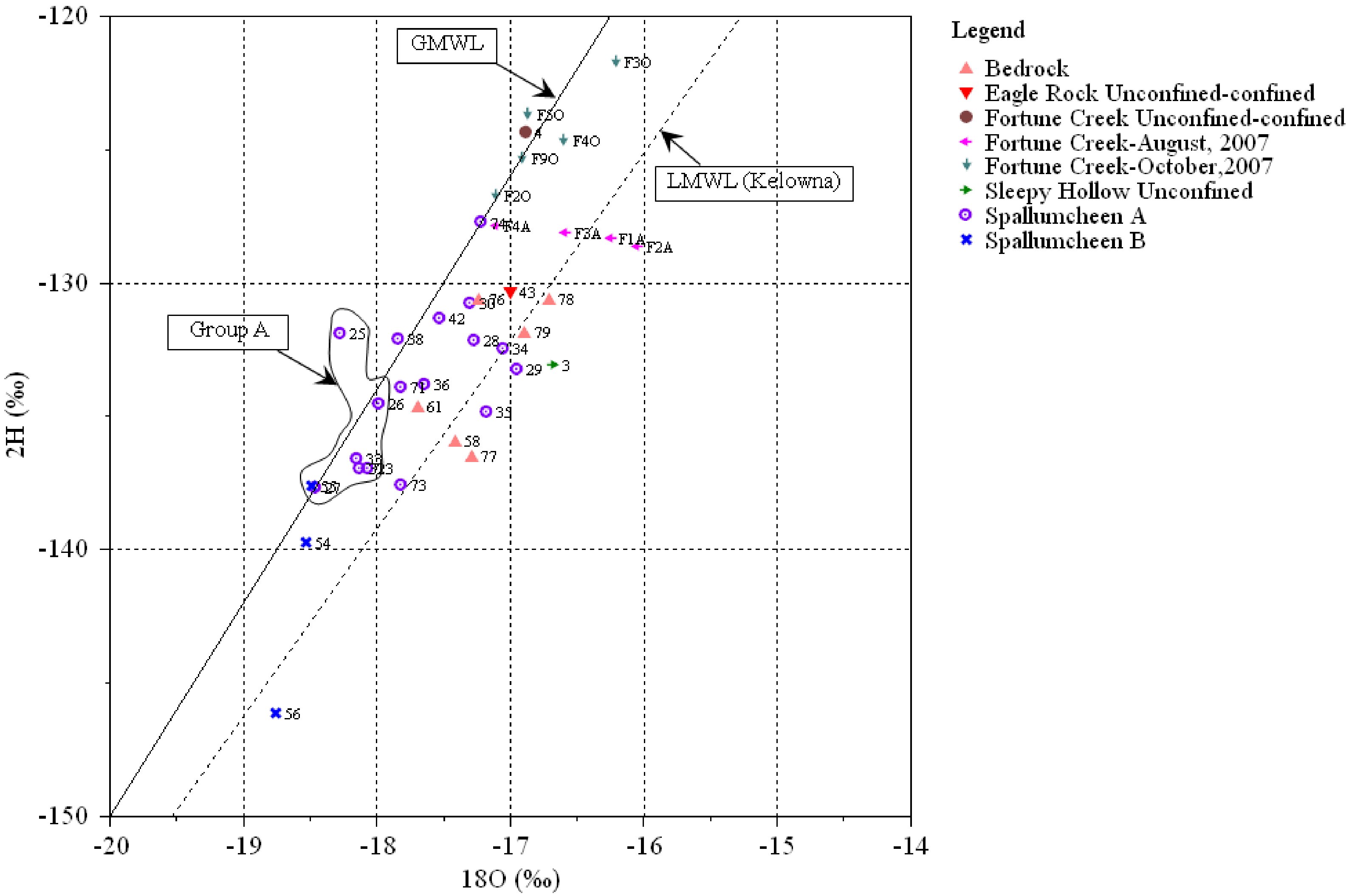


Figure 4.17-B Deuterium and oxygen-18 plot of surface water and groundwater samples in Fortune Creek Watershed and central Deep Creek Watershed. LMWL from Athanasopoulos (2009).

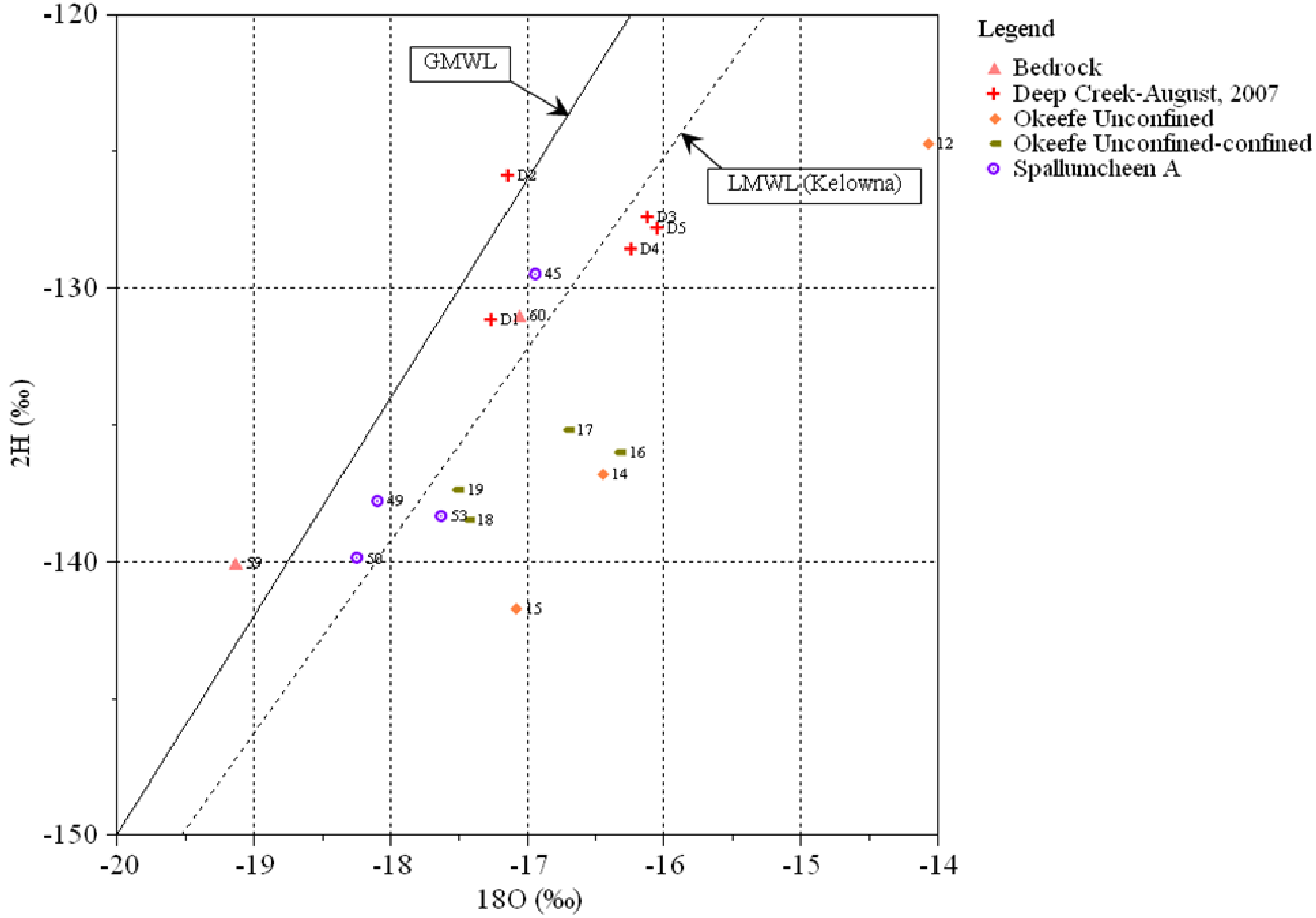


Figure 4.17-C Deuterium and oxygen-18 plot of surface water and groundwater samples in the Okeefe area. LMWL from Athanasopoulos (2009).

Table 4.1 Available precipitation sampling data near the North Okanagan region

Station	BCPMCABC1KLW	BCPMCABC1KML	BCPMCABC2KML
Location	Kelowna Airport	Kamloops Airport	Kamloops Westsyde Acid Rain
Latitude	49.9611	50.7056	50.7675
Longitude	-119.3778	-120.4433	-120.3464
Elevation(m)	431	346	355
Dates of Operation	10/21/1986-05/10/1997	02/21/1984-11/05/1985	01/14/1986-12/19/1989
Parameters	Bulk Chemistry	Bulk Chemistry	Bulk Chemistry

Note:
The Kamloops station moved in 1985.

Table 4.2 Results of chemical analysis of precipitation (mg/L)

ID	Location	Na	K	Mg	Ca	Cl	SO_4	Alkalinity as HCO_3
N1	Rain gauge Stepney X-road	25.10	0.95	0.35	1.68	48.44	0.36	5.94
N2	Rain gauge Township office	0.56	0.42	0.04	0.83	1.22	0.52	3.81
N3	Rain gauge Purple Springs	5.57	0.56	0.21	3.06	9.23	0.15	9.75
K1	UBCO November-Dec 7, 2007	0.35	0.21	0.04	1.60	0.49	0.39	5.49
K2	UBCO Dec 7 2007 -Jan 4, 2008	1.23	0.50	0.02	0.93	2.00	0.39	5.03
K3	UBCO Jan 4-31, 2008	1.95	0.71	0.03	1.68	2.81	0.46	6.10

Note: N1 in Fortune Creek Watershed from November 2007 to January, 2008;
N2 in the central Deep Creek Watershed from November 2007 to January, 2008;
N3 in the north Deep Creek Watershed from November 2007 to January, 2008;

Table 4.3 Results isotopic analysis of precipitation

ID	Location	δD	$\delta^{18}O$
N1	Rain gauge Stepney X-road	-155.44	-20.73
N2	Rain gauge Township office	-152.47	-20.12
N3	Rain gauge Purple Springs	-140.37	-18.54
K1	UBCO November-Dec 7, 2007	-137.74	-17.93
K2	UBCO Dec 7 2007 -Jan 4, 2008	-148.40	-19.64
K3	UBCO Jan 4-31, 2008	-168.57	-21.95

Note: N1 in Fortune Creek Watershed from November 2007 to January, 2008;
N2 in central the Deep Creek Watershed from November 2007 to January, 2008;
N3 in the north Deep Creek Watershed from November 2007 to January, 2008;

Table 4.4 Results of chemical analysis of surface waters (mg/L[1*])

ID	EMS	Sample Date	Conductivity (uS/cm)	TDS	Na	K	Mg	Ca	Cl	SO_4	HCO_3[2*]	NO_3	F
D1	E267912	29/8/2007	428	276	6.76	5	8.06	77	5.5	52.5	199.5	0.09	0.28
D2	E267911	29/8/2007	479	310	7.72	6	9.33	84.4	7.9	57.5	212.1	0.17	0.28
D3	E267910	29/8/2007	833	620	21.7	8	24.4	141	30.4	181	276.4	0.01	0.30
D4	E267909	29/8/2007	665	436	25	7	25.8	86	21.9	79.3	289.3	0.20	0.30
D5	E267908	29/8/2007	715	494	24.1	8	38.3	76.9	8	120	299.7	0.21	0.31
F1M	E265934	16/3/2007	255	176	2	<0.1	3.54	52.4	<0.5	24.7	126.6	0.08	0.11
F6M	E265929	16/3/2007	430	264	11.4	10	8.8	65.9	18.7	38.3	185.6	0.31	0.12
F7M[3*]	BCD	16/3/2007	939	726	29.2	7	33.3	135	23.8	263	207.6	8.74	0.28
F3M	E265925	16/3/2007	776	548	22.7	10	24.5	111	22.5	175	198.8	5.28	0.22
F8M	E265927	16/3/2007	718	504	24.7	8	23.8	95.1	18.3	159	183.3	4.32	0.20
F4M	E265924	16/3/2007	752	532	26.4	8	25.4	103	20.2	169	204.8	4.43	0.20
F1A	E265934	14/08/2007	163	96	1.41	1	1.98	31.5	<0.5	12.8	82.6	0.03	0.07
F2A	E267907	14/08/2007	216	126	2.43	3	2.76	38.6	1.2	16	104.3	0.22	0.07
F3A	E265925	14/08/2007	196	114	2.26	2	2.65	36.7	0.6	14.1	98.3	0.12	0.06
F4A	E265924	14/08/2007	239	138	4.07	2	3.99	42.7	3	17	120.6	0.24	0.07
F2O	E269465	24/10/2007	190	140	1.62	1.78	2.18	33	<0.5	14.6	94.6	0.06	0.05
F5O	E269464	24/10/2007	180	140	1.25	1.52	1.99	31.3	<0.5	14.6	88.0	0.01	0.05
F3O	E265925	24/10/2007	220	160	2.55	2.09	3.13	36.5	1	22.2	102.0	0.07	0.06
F4O	E265924	24/10/2007	210	160	6.32	4.75	5.65	22.8	2.8	15.2	100.0	0.02	0.08

Note: 1* except Conductivity

2* calculated from Alkalinity as HCO3

3* a pipe discharges below Fortune Creek

Table 4.5 Results of stable isotopic analysis of surface waters

ID	EMS	Sample Date	Water Type	δD	$\delta^{18}O$	Analysis Method
D1	E267912	14/08/2007	Deep Creek	-131.16	-17.26	U of S Los Gatos
D2	E267911	14/08/2007	Deep Creek	-125.92	-17.14	U of S Los Gatos
D3	E267910	14/08/2007	Deep Creek	-127.42	-16.12	U of S Los Gatos
D4	E267909	14/08/2007	Deep Creek	-128.56	-16.24	U of S Los Gatos
D5	E267908	14/08/2007	Deep Creek	-127.84	-16.05	U of S Los Gatos
F1A	E265934	14/08/2007	Fortune Creek	-128.36	-16.25	U of C IRMS
F2A	E267907	14/08/2007	Fortune Creek	-128.68	-16.05	U of C IRMS
F3A	E265925	14/08/2007	Fortune Creek	-128.17	-16.59	U of C IRMS
F4A	E265924	14/08/2007	Fortune Creek	-127.88	-17.11	U of S Los Gatos
F2O	E269465	24/10/2007	Fortune Creek	-126.78	-17.11	U of S Los Gatos
F5O	E269464	24/10/2007	Fortune Creek	-123.72	-16.87	U of S Los Gatos
F3O	E265925	24/10/2007	Fortune Creek	-121.75	-16.21	U of S Los Gatos
F4O	E265924	24/10/2007	Fortune Creek	-124.68	-16.60	U of S Los Gatos
F9O	E269463	24/10/2007	Fortune Creek	-125.35	-16.91	U of S Los Gatos

Table 4.6-A Results of chemical analysis of groundwater (mg/L*)

ID	Sample Date	pH	Conductivity (uS/cm)	TDS	Na	K	Mg	Ca	Cl	SO_4	HCO_3**	NO_3	F	Aquifer
1	02/08/1983	7.5	915	646	24		48.20	122.0	22.0	194	564.5	0.002	0.6	SA
2	15/08/2007	8.2	463	298	9.75	6	13.7	77.4	<0.5	53.4	235.2	<0.002	0.2	FC
3	16/03/2007	8.3	498	318	11		22.20	75.6	<0.5	50	262.2	0.002	0.4	SA
4	25/10/2005	6.6	383	243	3		4.20	71.0	1.0	28	199.3	0.550	0.1	FC
5	13/10/2005	8.1	366		5.17		7.67	66.3	8.4	15	189.0	0.777	0.09	EA
6	13/10/2005	8.2	530		13.4		15.60	86.6	19.9	26.1	262.3	0.288	0.14	EA
7	11/09/2000	8.1	84		4		2.60	8.0	1.9	<0.5	50.7	0.006	0.04	EA
8	13/10/2005	8.1	499		10.9		10.80	82.5	24.9	16.4	219.4	4.418	0.11	EA
9	26/07/2005	7.9	361	263	5.4		8.93	72.3	12	14.1	206.7	1.85	0.1	EA
10	27/07/2005	7.5		279	12		18.70	55.1	2.15	51	204.8	0.05	0.5	EA
11	26/07/2005	8.1	550	510	6		42.80	65.5	1.1	74	318.4	0.043	0.3	OA
12	13/08/2007	8.2	560		11.2	7	33.5	67.4	5.5	62.3	285.5	<0.002	0.28	OA
13	13/08/2007	8.1	580	529	14		35.00	55.7	2.6	64	364.5	0.080	0.3	OA
14	13/08/2007	8.2	750		16.7	7	52.9	81.2	<0.5	110	361.3	<0.002	0.33	OA
15	13/08/2007	8.3	630		36.1	9	35.7	56.1	0.7	84.1	306.5	0.005	0.42	OA
16	13/08/2007	8.3	760		18.9	9	52.9	75.5	1	152	313.4	<0.002	0.34	OB
17	14/08/2007	8.2	810		16.4	9	56.7	90.8	0.6	162	337.5	0.005	0.3	OB
18	14/08/2007	8.1	800		16.6	7	57.6	87.6	<0.5	119	386.4	<0.002	0.33	OB
19	14/08/2007	8	1100		84.7	11	45.2	96.8	61.1	118	390.6	7.79	0.42	OB
20	24/05/2007	8.2	638	N/A	10		9.89	116.0	6.9	96.0	262.1	0.597	0.23	TC
21	08/04/1995	8.1	690		34		33.60	97.9	3.8	165	305.4	N/A	N/A	HC
22	06/11/2007	8.2	820	520	76.5	5	25	79.7	1.7	165	320.7	<0.002	0.67	HC
23	16/03/2007	8.3	332	206	33		7.54	30.9	<0.5	34	165.4	0.003	0.4	SPA
24	04/03/2007	8.2	289	184	18.2		6.77	36	<0.5	12.7	195.7	N/A	N/A	SPA

Table 4.6-B Results of chemical analysis of groundwater (mg/L*)

ID	Sample Date	pH	Conductivity (uS/cm)	TDS	Na	K	Mg	Ca	Cl	SO_4	HCO_3**	NO_3	F	Aquifer
25	09/12/2007	8.3	680	430	81.6	4.1	16.3	42.7	1.1	157	219.5	<0.002	0.39	SPA
26	24/10/2007	8.3	350	240	4.93	6.1	7.76	57.2	0.8	24.1	183.7	0.007	0.13	SPA
27	13/11/2007	8.3	370	220	8.74	6.1	12.5	55	0.7	48.4	172.1	<0.002	0.16	SPA
28	13/11/2007	8.2	620	390	8.57	6	17.1	98.8	2.5	101	261.7	0.002	0.31	SPA
29	13/11/2007	8.2	510	320	10.1	6.6	19.3	73.9	1	52.9	252.1	<0.002	0.34	SPA
30	24/10/2007	8.1	470	310	3.92	4.9	10.5	80.7	0.6	48	231.6	0.337	0.13	SPA
31	29/10/2007	8.3	460	300	6.57	8.2	13	66.7	0.7	57.5	216.9	<0.002	0.22	SPA
32	16/03/2007	8.3	447	290	12.6		14.5	66.4	<0.5	53.6	268.1	0.002	0.3	SPA
33	05/11/2007	8.3	530	350	11.7	6.5	18.7	72.5	0.7	80.1	238.5	0.006	0.27	SPA
34	16/03/2007	8.3	549	348	14.6		23.00	74.6	<0.5	58.1	280.5	0.007	0.32	SPA
35	11/10/2007	8.2	530	350	10.4	6.2	20.6	81.8	1.1	54.8	262.5	0.005	0.35	SPA
36	05/11/2007	8.2	280	160	1.97	2.9	4.34	45.7	<0.5	23	140.1	0.005	0.11	SPA
37	26/07/2005	7.8	239	146	2		2.81	43.2	0.6	20	111.8	0.110	0.1	SPA
38	05/11/2007	8.2	300	180	2.57	3.3	5.66	51.9	0.5	28.3	151.2	0.004	0.14	SPA
39	10/08/2000	8.1	568	353	32		16.70	59.6	1.2	31	313.8	N/A	0.4	SPA
40	12/12/2000	8.1	544	352	32		18.40	55.3	1.3	34	311.9	0.050	0.4	SPA
41	26/07/2005	8.3	380	217	14		9.60	45.3	0.8	9	227.4	1.000	0.2	SPA
42	10/10/2007	8.2	248	164	4.2	3	5.45	43.4	<0.5	13.1	136.6	<0.002	0.15	SPA
43	26/09/2007	8.2	280		4.23	3	4.74	46.2	14.1	10.1	128.3	0.137	0.13	EA
44	12/11/2003	8.0	567	350	15		28.90	53.2	4.2	70	274.3	0.030	0.4	SPA
45	13/08/2007	8.2	610		13.7	6	36.2	73.1	0.6	93.5	284.8	0.144	0.31	SPA
46	29/09/2003	7.3	235	150	4.39		4.88	35.3	0.95	7.6	141.7	0.12	0.1	SPA
47	01/04/1983	8.3	655	590	13		39.10	77.8	2.0	92	369.0	N/A	N/A	SPA
48	13/08/2007	8.2	870		15.3	6	57.6	105	1.1	174	369.8	<0.002	0.26	SPA

Table 4.6-C Results of chemical analysis of groundwater (mg/L*)

ID	Sample Date	pH	Conductivity uS/cm	TDS	Na	K	Mg	Ca	Cl	SO_4	HCO_3**	NO_3	F	Aquifer
49	13/08/2007	8.2	350		18.9	7	11.8	41.1	<0.5	2.1	209.8	0.86	0.37	SPA
50	13/08/2007	8.2	810		31	12	31.5	116	1.7	79.6	427.8	1.36	0.28	SPA
51	28/03/2003	7.9	772	504	49		25.00	72.7	4.4	136	315.9	0.010	0.5	SPA
52	27/03/2003	7.9	825	574	33		42.40	91.1	1.5	165	368.4		0.5	SPA
53	16/08/2007	8.3	860		31.3	11	47.3	99.1	3.8	180	345.1	0.004	0.36	SPA
54	16/08/2007	8.9	337	196	59.4	7	7.58	11.1	1.5	<0.5	202.2	<0.002	0.38	SPB
55	17/08/2007	9.6	94	48	11.3	5	2	2.4	<0.5	<0.5	36.2	0.003	0.2	SPB
56	26/09/2007	8.6	563	314	70.9	7	33.7	15.2	1.8	6.2	354.6	<0.002	0.36	SPB
57	19/06/1991	8.4	638		99		16.40	25.6	1.1	3	288.7	0.080		BR
58	26/09/2007	8.2	920		48.3	5	44.6	114	2.6	202	359.7	0.005	0.53	BR
59	17/08/2007	7.8	2100		89.6	10	169	237	4.4	950	391.9	0.255	0.4	BR
60	17/08/2007	7.7	3500		76.5	11	343	493	25.8	2190	478.0	0.052	0.43	BR
61	11/10/2007	8	664	434	36.5	3	17	88.5	31.4	80.3	270.5	<0.002	1.09	BR

Note: * except Conductivity

** calculated from Alkalinity as HCO3

Note: BR-Bedrock aquifers; EA-Eagle Rock Unconfined-confined aquifer; FC-Fortune Creek Unconfined-confined aquifer; HU-Hullcar Unconfined aquifer; HC-Hullcar Confined aquifer; OA- Okeefe Unconfined aquifer; OB-Okeefe Unconfined-confined aquifer; SLA-Sleepy Hollow Unconfined aquifer; SPA-Spallumcheen A aquifer; SPB-Spallumcheen B aquifer; TC-Tuhok confined aquifer

Table 4.7 Water facies of groundwater

ID	Water type	ID	Water type	ID	Water type	ID	Water type
1	Ca-HCO3	17	Mg-HCO3	33	Ca-HCO3	49	Ca-HCO3
2	Ca-HCO3	18	Mg-HCO3	34	Ca-HCO3	50	Ca-HCO3
3	Ca-HCO3	19	Ca-HCO3	35	Ca-HCO3	51	Ca-HCO3
4	Ca-HCO3	20	Ca-HCO3	36	Ca-HCO3	52	Ca-HCO3
5	Ca-HCO3	21	Ca-HCO3	37	Ca-HCO3	53	Ca-HCO3
6	Ca-HCO3	22	Ca-HCO3	38	Ca-HCO3	54	Na-HCO3
7	Ca-HCO3	23	Ca-HCO3	39	Ca-HCO3	55	Na-HCO3
8	Ca-HCO3	24	Ca-HCO3	40	Ca-HCO3	56	Na-HCO3
9	Ca-HCO3	25	Na-HCO3	41	Ca-HCO3	57	Na-HCO3
10	Ca-HCO3	26	Ca-HCO3	42	Ca-HCO3	58	Ca-HCO3
11	Mg-HCO3	27	Ca-HCO3	43	Ca-HCO3	59	Mg-SO4
12	Ca-HCO3	28	Ca-HCO3	44	Ca-HCO3	60	Mg-SO4
13	Mg-HCO3	29	Ca-HCO3	45	Ca-HCO3	61	Ca-HCO3
14	Mg-HCO3	30	Ca-HCO3	46	Ca-HCO3		
15	Mg-HCO3	31	Ca-HCO3	47	Ca-HCO3		
16	Mg-HCO3	32	Ca-HCO3	48	Ca-HCO3		

Table 4.8-A Result of stable isotopic analysis of groundwater

Well ID	EMS	Sample Date	δD	$\delta^{18}O$	Analysis Method	Aquifer
3	E265932	11/10/2007	-133.10	-16.68	U of S Los Gatos	SA
4	E258749	24/10/2007	-124.37	-16.89	U of S Los Gatos	FC
12	E267834	13/08/2007	-124.73	-14.07	U of C IRMS	OA
14	E267824	13/08/2007	-136.85	-16.45	U of C IRMS	OA
15	E267831	13/08/2007	-141.75	-17.08	U of C IRMS	OA
16	E267829	13/08/2007	-136.01	-16.32	U of C IRMS	OB
17	E267830	14/08/2007	-135.23	-16.70	U of C IRMS	OB
18	E267825	14/08/2007	-138.49	-17.43	U of C IRMS	OB
19	E267826	14/08/2007	-137.39	-17.51	U of C IRMS	OB
22	E269604	07/11/2007	-139.94	-18.64	U of S Los Gatos	HC
23	E265926	10/10/2007	-136.99	-18.07	U of S Los Gatos	SPA
25	E269570	13/11/2007	-131.95	-18.27	U of C IRMS	SPA
26	E265922	24/10/2007	-134.55	-17.98	U of S Los Gatos	SPA
27	E269569	13/11/2007	-137.70	-18.46	U of S Los Gatos	SPA
28	E269566	13/11/2007	-132.17	-17.27	U of S Los Gatos	SPA
29	E269567	05/11/2007	-133.28	-16.95	U of S Los Gatos	SPA
30	E258755	24/10/2007	-130.79	-17.30	U of S Los Gatos	SPA
31	E269503	29/10/2007	-137.00	-18.13	U of S Los Gatos	SPA
33	E269565	05/11/2007	-136.65	-18.15	U of S Los Gatos	SPA
34	E265933	11/10/2007	-132.51	-17.05	U of S Los Gatos	SPA
35	E258753	11/10/2007	-134.88	-17.18	U of S Los Gatos	SPA
36	E269564	05/11/2007	-133.84	-17.64	U of S Los Gatos	SPA
38	E269563	05/11/2007	-132.16	-17.84	U of S Los Gatos	SPA
42	1400958	10/10/2007	-131.35	-17.53	U of S Los Gatos	SPA
43	E268964	26/09/2007	-130.37	-17.00	U of C IRMS	EA
45	E267835	16/08/2007	-129.48	-16.94	U of C IRMS	SPA
49	E267833	13/08/2007	-137.78	-18.09	U of C IRMS	SPA
50	E267828	13/08/2007	-139.89	-18.24	U of C IRMS	SPA
53	E267823	16/08/2007	-138.33	-17.63	U of C IRMS	SPA
54	1400962	16/08/2007	-139.80	-18.53	U of S Los Gatos	SPB
55	1400964	17/08/2007	-137.67	-18.49	U of S Los Gatos	SPB
56	1400957	26/09/2007	-146.18	-18.76	U of S Los Gatos	SPB
58	E269006	10/10/2007	-135.97	-17.41	U of S Los Gatos	BR
59	E267836	17/08/2007	-140.06	-19.13	U of C IRMS	BR
60	E267837	17/08/2007	-131.00	-17.05	U of S Los Gatos	BR
61	E269284	10/10/2007	-134.68	-17.69	U of S Los Gatos	BR
66	E269605	08/11/2007	-135.94	-17.56	U of S Los Gatos	HC
71	E262830	11/10/2007	-133.96	-17.82	U of S Los Gatos	SPA

Table 4.8-B Results of stable isotopic analysis of groundwater

Well ID	EMS	Sample Date	δD	$\delta^{18}O$	Analysis Method	Aquifer
73	E266363	11/10/2007	-137.59	-17.82	U of S Los Gatos	SPA
74	E268963	11/10/2007	-127.77	-17.22	U of S Los Gatos	SPA
76	E269603	8/11/2007	-130.62	-17.23	U of S Los Gatos	BR
77	E269263	11/10/2007	-136.52	-17.29	U of S Los Gatos	BR
78	E269285	11/10/2007	-130.64	-16.71	U of S Los Gatos	BR
79	E262375	26/09/2007	-131.87	-16.89	U of S Los Gatos	BR

Note:

U of S Los Gatos means University of Saskatchewan Los Gatos instrument method;
University of Calgary IRMS means University of Calgary IRMS method;
BR- Bedrock aquifers;
EA- Eagle Rock Unconfined-confined aquifer;
FC- Fortune Creek Unconfined-confined aquifer;
HU- Hullcar Unconfined aquifer;
HC- Hullcar Confined aquifer;
OA- Okeefe Unconfined aquifer;
OB- Okeefe Unconfined-confined aquifer;
SLA-Sleepy Hollow Unconfined aquifer;
SPA-Spallumcheen A aquifer;
SPB-Spallumcheen B aquifer.

Chapter 5 Numerical Groundwater Modeling

This chapter first presents the development of a conceptual groundwater flow model of the North Okanagan aquifer system. The complex hydrogeology in the region of Hullcar and Sleepy Hollow makes a numerical model of the whole groundwater system including all the aquifers challenging. A regional steady state numerical groundwater model was developed which includes the main regional aquifers Spallumcheen A and B, and the main recharge processes.

5.1 Conceptual Groundwater Flow Model

5.1.1 Modeling Area and Aquifers

The modeling area covers the main valley center and extends over 87 km^2 (Figure 5.1). The model extends from the north end of Okanagan Lake to a constriction of the main valley within the Fortune Creek watershed north of the location of well 54.

The main valley system was conceptually divided vertically into three hydrogeological units representing the Spallumcheen A aquifer at the top, a package of lower permeability materials underlying Spallumcheen A, and a lowest package of permeable materials primarily based upon Spallumcheen B (Figure 5.2).

The use of Spallumcheen A as the upper model layer recognizes that the sediments above Spallumcheen A grade upwards throughout the main valley to clayey silts of lower hydraulic conductivity. The main valley system is in many places artesian, and hence recharge from surface to Spallumcheen A is likely limited in the valley center. A model of groundwater resources based upon groundwater flow in Spallumcheen A and the aquifers below it is therefore considered conservative. It omits the potential for recharge in the valley center or the possibility of pumping wells to draw water vertically from the finer grained materials above within in the main valley area. The model would not be appropriate for the study of local scale processes such as the detailed interactions of the two creeks with the main groundwater system.

Within the valley center, the Spallumcheen A and B aquifers are considered to be continuous throughout the modeling area. Spallumcheen A is represented by a continuous model layer of variable thickness and elevation as determined from cross sections (Monahan, 2006; Keller, 2006). Spatial coverage in the cross sections of Monahan (2006) was sufficient to define the extent of Spallumcheen A, but at times additional information was used to define the aquifer boundaries. Monahan (2006) noted that the top of Spallumcheen A is gradational, and hence in some cases adjacent wells can report the start of significant sand at slightly different elevations.

The material between Spallumcheen A and B was discussed in Section 3.1.2. It is a mixed package of finer grained sediments that varies within the modeling area. Within FCW, and in one cross section within DCW (Figure 3.2C), a coarser unit was identified within this package. There is insufficient data to give it a spatially explicit permeable layer within a numerical model. There are no aquifer tests available as there are no wells completed in any of these layers. This middle package of sediments would have different lateral and vertical hydraulic conductivities based upon the vertical layering observed in the boreholes. The lateral hydraulic conductivity of the middle package would also be difficult to assess based upon the potentially discontinuous nature of the coarser materials within a finer silt matrix. The model therefore conceptually combines the lateral water flow from within this package and the underlying Spallumcheen B package together. The model contains a uniform, isotropic middle layer with low permeability, appropriate to the finer grained end of the silts to clays observed in the middle package.

The lower layer based on Spallumcheen B is modeled as a continuous model layer with thickness and elevation estimated from Monahan (2006), who based the Spallumcheen B location on data from well logs supplemented by seismic reflection data. Spallumcheen B is encountered in a limited number of deep boreholes, and thus information on its continuity and geometry is limited.

Similarly, beneath the Spallumcheen B aquifer, there are other, deeper aquifers such as Spallumcheen D and E, particularly within the FCW. These are not represented explicitly in the model as layers. Their potential influence on deep lateral flow is represented by the basal model layer based upon Spallumcheen B. The modeled lower layer of the aquifer package therefore acts as an "under-drain" to the Spallumcheen A aquifer, and includes components of lateral water flow that may result from permeable layers within Spallumcheen C and deeper aquifers.

5.1.2 Hydraulic Properties

Aquifer test data from all prior aquifer tests in the North Okanagan area were compiled and analyzed by the Ministry of Environment (MOE) (Kenny, 2005). The majority of aquifer test data located were for wells located within the greater North Okanagan area including outside the area covered by the groundwater model. Data from aquifer tests conducted on 5 wells located within the boundaries of the modeling area were considered when determining the hydraulic properties of the materials in the modeling area (Figure 5.1 and Table 5.1).

The tests conducted within Spallumcheen A showed that hydraulic conductivities range from 2.6×10^{-4} m/s to 8.0×10^{-4} m/s. The hydraulic conductivity of the Spallumcheen A aquifer was varied spatially based upon the geological features. The model assumes that it is isotropic without significant vertical anisotropy.

Only one set of tests was located for a well completed in Spallumcheen B. Slug testing of well 55 (MOE O118, WTN 24080) indicated hydraulic conductivity values ranging from 7.2×10^{-3} m/s to 1.3×10^{-2} m/s, suggesting that the hydraulic conductivities of Spallumcheen B are relatively higher than Spallumcheen A. This is consistent with the geological logs which report Spallumcheen B as composed of sands and gravels. The saturated hydraulic conductivities of coarse sands and gravels were estimated to be from

2.5×10^{-4} m/s to 6.3×10^{-4} m/s (Table 5.2) based upon the lithological descriptions contained in borehole logs, and compilations of lithology based hydraulic conductivity values contained within EPA (1986). The water bearing materials of Spallumcheen B were also considered to be isotropic for the model.

There are no aquifer tests conducted in the low permeability material between Spallumcheen A and B. The estimation of hydraulic conductivities is presented in Table 5.3 based upon the lithological descriptions of these materials in the well logs (EPA 1986).

Based on the descriptions above, the modeling aquifers and the middle fine grained aquitard package are represented in the model as heterogeneous and isotropic. The spatial subdivisions of the model area for the aquifers Spallumcheen A and B are shown in Figures 5.3 and 5.4.

5.1.3 Boundary conditions

1) Upper and Lower Boundaries

It is known that Spallumcheen A gains groundwater from the Eagle Rock aquifers, the Sleepy Hollow A unconfined aquifer, the Okeefe A and B unconfined-confined aquifers, and the Fortune Creek unconfined-confined aquifers. The choice of Spallumcheen A as the main modeled layer meant that groundwater exchanges between local unconfined aquifers, surface waters and Spallumcheen A were treated as vertical flux boundaries to the Spallumcheen A aquifer, with values based on field data and numerical calculations conducted outside the model (Figure 5.5).

This first model structure captures the major features of the North Okanagan aquifer system and allows for an assessment of overall aquifer system water resources. It allows an assessment of the relative contribution of MSR and local recharge through unconfined portions of the aquifer system. It does not provide for detailed assessment of water flows in the local unconfined aquifers.

Evidence of surface water and groundwater interactions have been presented in Chapters 2, 3 and 4. The model does not explicitly calculate surface water and groundwater interaction within the model itself.

Groundwater level measurements from static water level measurements conducted during this study, or groundwater levels from historical well records were used to determine vertical hydraulic gradients between the unconfined portions of the aquifers above, and the underlying Spallumcheen A aquifer. These calculations are based upon steady state conditions within these valley side aquifers being maintained.

The lower boundary of the model is the contact of the Spallumcheen B aquifer with the underlying low hydraulic conductivity clays or bedrock. The model simplifies the entry of water into Spallumcheen B by considering that all water enters Spallumcheen B laterally, and that no water enters via the bottom boundary.

2) Horizontal Boundaries

The locations of lateral boundary segments within the model are shown in Figures 5.3 and 5.4.

Constant head Boundaries

Section 1: The constant head at Okanagan Lake was established from water level measurements. As outlined in Chapter 2, the water levels in Okanagan Lake normally range between 341.2 meters and 342.5 meters above sea level, with an average water level of 341.9 meters above sea level. Measurements of water levels in Spallumcheen A in the vicinity of the lake indicate that there is an upwards gradient, and several artesian wells are located near the head of the lake. The groundwater level in Spallumcheen A at the north end of Okanagan Lake was assigned to be 1.0 meters higher than the lake level.

There are only three wells located within Spallumcheen B, and all three are in the northern half of the modeling area. The groundwater level in Spallumcheen B in the vicinity of Okanagan Lake is not directly known. In FCW, Spallumcheen B water levels are approximately 20 metres higher than water levels of Fortune Creek. In the central portion of the main valley, the groundwater levels in well 42 (O119, WTN: 24104) located in Spallumcheen A are about 1.7 meter higher than in well 56 (O117, WTN: 24062) located in Spallumcheen B. In DCW, the water level in Deep creek close to well 56 area is about 348.7 meters, which is about 10 meters lower than that in well 56 in August, 2007. It was presumed that the downwards groundwater head gradient from Spallumcheen B to A observed in the middle of the valley continued south, but diminished towards the lower end of the valley adjacent to Okanagan Lake. The groundwater level in Spallumcheen B was therefore assumed to be 0.5 meters higher than the lake water level.

Section 2: The constant head boundary at the northeast of the model extent (section 2, Figures 5.3 and 5.4) was determined from measured static water levels. The head values for both Spallumcheen A and B were derived from the observation data from monitoring well 54 (O122, WTN: 24093) located in Spallumcheen B. The constant head in Spallumcheen B was set based on water level data from this well. There are no other wells monitored at the same location of well 54 (Figure 5.4) which are completed in Spallumcheen A. However, the static water level of well 26 (WTN 82463) in Spallumcheen A located between wells 54 and 55 (O118) has been manually measured since March 2007. The groundwater head in Spallumcheen A at the constant head boundary was estimated by comparing the static water levels between wells 26, 54 and 55. Spallumcheen A was estimated to be 0.5 meters lower than in well 54. The groundwater head in Spallumcheen A and B at this location are about 20 meters higher than Fortune Creek.

Lateral Flux Boundaries

Sections 3 to 16: Lateral boundary sections 3 to 16 were assigned as lateral flux boundaries (Figures 5.3 and 5.4) to accommodate MSR to the valley center, and inflows from adjacent aquifer systems. Each flux section corresponds to a section of adjacent bedrock, or a valley side unconsolidated aquifer. The characterization of each boundary segment is presented in Tables 5.4 and 5.5.

Mountain System Recharge

One of the main conclusions of the field investigations is that the system includes a proportion of recharge derived from the bedrock on either side of the main valley, which is responsible for the artesian conditions noted in the valley center (Figure 3.3). The bedrock sides of the valley maintain groundwater flow through fractures in the bedrock system, which bring recharge from the bedrock on either side of the valley down to the valley center.

MSR is the major source of recharge to the valley center within mountainous terrain (Plummer at al., 2004; Wilson and Guan, 2004; Wahi et al., 2008). MSR is composed of both mountain block recharge (MBR) and mountain front recharge (MFR). Traditionally, MSR recharge is from the rainfall or snowmelt infiltration formed on the mountainous areas bordering the adjacent valley bottom basin aquifers as well as from runoff from the mountain highlands. MSR reaches the valley through two mechanisms: (1) lateral groundwater flow within the deep bedrock system from the mountainous areas to the valley bottom aquifers (MBR), and (2) vertical infiltration of creeks or direct runoff at the margins of the valley bottom basin (MFR) (Wilson and Guan, 2004; Wahi et al., 2008).

In this study, MFR is defined as the water entering the local valley side aquifers through the surface runoff infiltration at the mountain front transition and the water entering the local shallow aquifers via shallow subsurface flow. MBR represents the water entering the regional moderate and deep aquifers such as Spallumcheen A and B aquifers via flow in the deep fractured bedrock (Figure 5.6).

There is little information in the literature to assist in determining how to distribute MFR/MBR when multiple aquifers are contained within the adjacent valley. In the North Okanagan, two scenarios occur: the valley aquifers consist of the two confined aquifers only (Figure 5.6A); and the valley aquifers consist of one or more valley side unconfined aquifers with the two confined aquifers below (Figure 5.6B). In the first case, all MSR is assumed to be delivered to the valley center as MBR, and is distributed between Spallumcheen A and B. When a valley side aquifer is present (Figure 5.6B), then a portion of MSR is assigned to MFR. This contributes to the valley side unconfined aquifer, and the remaining MSR is assigned to MBR between the two confined aquifers. The flux downwards within the unconfined aquifers has been assigned in the model as a vertical recharge (Section 5.1.3). The unconfined aquifers gain this water by either direct vertical recharge in the valley bottom, or the lateral MFR that comes from the valley side.

The description of lateral boundary sections is presented in tables 5.4 and 5.5. The groundwater model obtains MSR via sections 3 to 12 (Figures 5.4 and 5.5). Each section has the corresponding MSR shown in Figure 5.7 and corresponding interpretations are presented in Table 5.6.

The connections between the watershed and aquifer components within the groundwater model area are conceptually shown in Figure 5.8.

5.1.4 Groundwater Flow Conditions

In this project, the model was assumed as a steady state system in which recharges and discharges are in equilibrium. A quasi steady state approach was used to divide the year into two periods: a summer period in which irrigation pumping is active; and a winter period in which no irrigation groundwater demand is present. The system was modeled separately at steady state for two times during the period in August, 2007 and February, 2008. This assumes that the duration of transient flow effects due to the changing pumping rates are short lived, and the aquifers reach steady state with a few months of the change in overall conditions. All other forms of recharge or discharge are also assumed to be constant over the year. This approach does not capture the full transient nature of the real groundwater system, but allows the steady state modeling approach to take some advantage of data from summer and winter to assist in model calibration.

The real groundwater system is under transient conditions in which system recharges and discharges are not in equilibrium so that there is a net change with time. This report only conducted the steady state groundwater simulations described above and leaves the transient simulations to the next phase of the project when more data is available.

5.2 Numerical Model Design

The conceptual model of groundwater flow in the study area discussed above was translated into a quasi-three-dimensional, steady state groundwater flow. The numerical model was developed with the FEFLOW finite element groundwater modeling package (Wasy Gmbh, Version 5.3.1).

5.2.1 Spatial Discretization

The mesh used in the modeling is shown in Figure 5.9, and a cross section is shown in Figure 5.10. The modeling area is first designated within a superelement mesh which outlines the major spatial features of the model such as the layering, boundary locations, wells, rivers and changes in hydraulic conductivity.

The lower hydraulic conductivity materials included between the upper Spallumcheen A and lower permeable units was split into 2 model layers to facilitate the use of a fixed flux boundary to direct MSR into the upper and lower permeable layers only. The model therefore had four layers, with layers 2 and 3 having the same hydraulic properties.

The North Okanagan represents a steep sided, U shaped bedrock valley (Chapter 3). FEFLOW permits the use of multiple layers, but layers may not be truncated laterally, and all layers must physically extend to the model edges as shown in Figure 5.10. The 2nd to 4th layers in the model must extend to the same lateral extent as the top layer of the model. The model width was set to the width of the top of the Spallumcheen A aquifer.

This layer structure therefore includes the lower permeable layer out to the full lateral dimensions of the model grid. This lower layer represents lateral permeability generated by Spallumcheen B and any permeable materials within Spallumcheen C. This structure was utilized as it permits the use of a lateral flux boundary to assign a proportion of the total MSR to this layer.

The model layer also includes aquifer material not actually present underneath the outer edges of the modeling area. The hydraulic properties of Spallumcheen B were therefore altered to make the down-valley transmissivity of the model layer representative of the down-valley transmissivity of the aquifer. The outer edges could have been set to the hydraulic conductivity of bedrock, but it was felt that the change in overall groundwater head across-valley was minimal.

The finite element mesh used for calculation was generated automatically using the automatic TMesh (Delaunay) option (Dyer, 2007). This feature is able to alter the finite element mesh density around specified points and lines features such as the locations of pumping, artesian, and observed wells. Generation of smaller elements (mesh refinement) around important parts of the modeling area allows for greater numerical stability and accuracy in areas of important groundwater flow. The mesh was also refined along the model boundaries as to the majority of water entering the groundwater system enters through the boundaries, and thus more. The resultant mesh used in the modeling is shown in Figure 5.9, comprising 16140 elements and 10845 nodes within the four layers. The model cross section corresponding to the hydrogeological cross section shown in Figure 5.2 is shown in Figure 5. 10.

5.2.2 Error and Convergence Criteria

The error tolerance is 0.001 and the error norms were selected as “Euclidean L2 integral (RMS) NORM” (Diersch, 2005).

5.2.3 Iterative Solver Settings

The preconditioned Lanczos BiCGSTABP-Postconditioned bi-conjugate gradient stable method was chosen. The error tolerance was set to 0.001 and the error norms were “Euclidean L2 integral (RMS) NORM” (Diersch, 2005).

5.2.4 Wells

Active wells used in the model included both pumping and flowing artesian wells (Figure 5.3 and Table 5.7). Groundwater pumping rates for irrigation and artesian flow rates were obtained from field door to door surveys of irrigation uses by MOE staff and other sources as discussed in Chapter 2. Drinking water supply data were partially provided by City of Armstrong, the Township of Spallumcheen, the Okanagan Basin Water Board, and partially collected through this project.

Static water level observation wells were included in the model for use within model calibration (Figure 5.3, Figure 5.4 and Table 5.8). An analysis was carried out of the groundwater levels derived from historical well records contained with the BC MOE water well database. Static water level wells monitored in this program were surveyed by differential GPS during the study. These surveyed water levels were compared to the water levels derived from the well elevation and depth to water data included in the water well database data for the surveyed wells. It was found that the correlation was poor for these wells where the true elevations were known. A similar scatter was found for other unsurveyed wells in the database where water level and well elevation data were present. The uncertainty in well location, well elevation, and the uncertain nature of the original water level measurements meant that the uncertainty in this historical data was relatively large compared to the change in head over the whole area (~28 metres), and to the head difference between Spallumcheen A and B (~0 to 1.5 metres). The historical data were judged to be inappropriate for use in the model calibration (Figure 5.11).

5.2.5 Initial Hydrogeological Parameters

The hydrogeological parameter of interest in the steady state model is hydraulic conductivity. The parameter values employed in this model were obtained from the aquifers tests and literature values for materials of similar grain size to those identified in the cross sections of Monahan (2006). The hydraulic conductivity division of the model area for the aquifers Spallumcheen A and B is shown in Figures 5.4 and 5.5. The initial parameters are presented in Table 5.9.

5.2.6 Estimation of Vertical Flux Quantities

Groundwater discharges vertically upwards into the Okeefe unconfined-confined aquifer (Okeefe B named by Monahan, 2006), into Deep Creek, into Fortune Creek and into Otter Lake. The top surface of the Spallumcheen A aquifer was therefore subdivided into regions which represent the different areas where flow is either upwards to surface or downwards (Figure 5.5).

Darcy’s law was employed to determine the water exchange rates between Spallumcheen A and the unconfined aquifers, creeks and Otter Lake. Within each region (Figure 5.5), data was gathered from cross sections (Monahan, 2006), from the water wells database, and from field measurements. The extent of material overlying Spallumcheen A was estimated from surficial geology maps and well log information contained within the MOE water wells database. The hydraulic conductivity of geological materials was estimated from Table 5.3, and the hydraulic gradient was estimated from either measured or historical water level data.

A summary of the calculations are presented in Table 5.10. All vertical exchanges were considered to be steady state.

5.2.7 Estimation of Lateral Flux Quantities

The bedrock highlands on either side of the valley center was sub-divided into areas of bedrock contributing to the valley center, and total volumes of MSR generated within these areas was evenly spread along the corresponding boundary of that bedrock area and valley center aquifers.

A variety of physical, chemical, and numerical methods are reported in the literature as having been utilized to quantify MSR over the past five decades. These techniques include: water balances; chloride mass balances; numerical modeling; environmental tracers, precipitation-runoff studies, temperature profile methods and others. Flint et al. (2002) summarized methods applied in Yucca Mountain for estimating recharge to the mountain block. Wilson and Guan (2004) reviewed a wide variety of the methods employed to estimate MSR in arid and semiarid regions. MSR can also be estimated by chloride mass balance methods (Wilson and Guan, 2004; Gates et al., 2008). Other geochemical tracers have been employed to improve the conceptual and quantitative understanding of MSR (Wahi, 2005; Wahi et al., 2008).

There are few existing estimates of MSR in the North Okanagan from previous studies. Chloride mass balance methods were attempted to determine MSR. However, chloride in precipitation data is not available for the study area, and anthropogenic chloride use within the watershed confounds attempts to calculate a recharge rate. A conservative hydrogeochemical mixing model was also attempted to determine MSR. However, there was insufficient data from mountain areas to constrain the geochemical signature of mountain groundwaters.

Explicitly modeling the groundwater flow in bedrock on either side of the valley by including the mountain bedrock within the model domain was not considered. Recent efforts within the Okanagan Basin Water Board Supply and Demand study included groundwater modeling of the general bedrock and valley geometry of the Okanagan Basin using typical dimensions and best estimated or measured hydraulic parameters for the bedrock. These models were insufficient to constrain the flow of groundwater from the bedrock (R. Allard, per comm., 2008). Estimation of lateral groundwater flows from the bedrock highlands on either side of the model in this study would therefore be dependent upon the rate of recharge determined for the adjacent mountain block from efforts external to the numerical groundwater model.

It was therefore decided that MSR would be applied to the sides of the valley center aquifers as a lateral flux boundary, which makes it explicit that this recharge volume is calculated outside the numerical model. A total recharge volume was calculated from multiple mountain sub-areas adjacent to the main valley and this recharge volume is distributed to the lateral edge of the valley basin.

An estimate of the initial recharge rate was therefore derived from recent studies in North America within semi-arid climates including:

- Anderholm (2000) estimated the average annual recharge rate of 22 mm which is equal to 4.3%of the mean annual precipitation of 510.5 mm for the middle Rio Grande Basin.
- A numerical modeling approach by Wilson and Guan (2004) was utilized to estimate an MSR rate of 26 mm to the west slope of the Sandia Mountains,

Based on the similarity of the climate of these study areas and the Okanagan, a recharge rate of 5% of mean annual precipitation was assumed for the initial MSR rate. Average annual precipitation from 1960-2006 was calculated for different mountain areas (Figure 5.6) using data from the Okanagan Climate Data Interpolator (OCDI).

The detailed MSR contributions to valley bottom aquifers are presented in Table 5.11. The proportion of total MSR assigned to MFR and MBR from each mountain area are presented in Table 5.11. This is based upon the method of splitting MSR into MFR and MBR outlined in Figure 5.6.

Averaged across the whole mountain area, total MBR represents 71% of total MSR. The remaining 29% of MSR is distributed to the unconfined portions of the valley side aquifers. Initially, 50% of MBR was distributed to Spallumcheen A and the other 50% of MBR was distributed to Spallumcheen B. The ratio of Spallumcheen A lateral inflow to total lateral inflow was adjusted during model calibration.

These MSR inflows were assumed to be evenly distributed over the year. The extent of groundwater level fluctuations within the mountain blocks on either side of the valley are small compared to the hundreds of metres of elevation difference between Spallumcheen A/B aquifers and the recharge zone. This would suggest that fluctuations MSR into these deeper aquifers directly from the bedrock can be treated as steady over the year. MFR to the local unconfined aquifers may be more variable during the year.

5.3 Calibration

The hydrogeological conditions in August, 2007 including static water levels, pumping rates and artesian well flow rates were utilized as the primary starting point to build and calibrate the model. The hydrogeological conditions without irrigation pumping in February, 2008 were used for the winter period. The parameters representing hydraulic conductivities, and calculated boundary fluxes were assumed to be constant between summer and winter conditions.

5.3.1 Calibration Criteria

Aquifer hydraulic conductivities, the percent of precipitation forming MSR, the relative split of MBR between Spallumcheen A and Spallumcheen B and the calculated boundary fluxes were all adjusted to calibrate the model. Groundwater heads generated within the model were compared to measured groundwater heads from static water level observation wells. As noted above, the degree of scatter in water level data derived from historical well records was found to be unsuitable for these records to be of use in calibration.

The calibration criteria were:

- Minimization of the error between simulated and measured static water levels

The model root mean squared (RMS) error and the residuals for each well are less than 10% of the variability of the groundwater heads across the model domain (10% of 28 meters is 2.8 meters).

- Vertical water flow between Spallumcheen A and B

Analyses of measured water levels (Chapter 3) and geochemistry (Chapter 4) identified areas of the aquifer system where vertical exchanges between Spallumcheen A and B are active. The model had to re-create these conditions appropriately. In the northern part of the modeling area (FCW), water flows upwards from Spallumcheen B to A (e.g.: wells 26 and 55). In the central part of the modeling area, water flows from Spallumcheen A to B (wells 42 and 56).

- Inflows or outflows via north constant head (boundary section 2)

The constant head boundary located in the northern part of the model creates the possibility of water entering or leaving the system via the northern constant head boundary through Spallumcheen A or B. Groundwater head measurements in Spallumcheen B within the FCW confirmed a groundwater divide (Chapter 3), and hence the northern constant head boundary was required to demonstrate a small outflow, or close to zero inflow in the lowest model layer. Field data could not determine if a groundwater divide exists in Spallumcheen A, so the upper model layer was required to show a low, or near zero flux of water at the constant head.

- Mountain System Recharge

MSR was not changed to more than 10% of the total annual precipitation on the mountain areas. Based on the description that averaged across the whole mountain area, total MBR represents 71% of total MSR, MBR was not allowed to exceed 7.1% of total annual precipitation. The proportion of MBR entering Spallumcheen A as a percentage of the total MBR was varied.

- Summer / Winter conditions

The initial model calibration was to conditions in the summer period with irrigation pumping. Groundwater heads are higher in winter with the absence of groundwater pumping. The same recharge and hydraulic conductivity must appropriately re-create the observed groundwater heads under the winter conditions of lower pumping.

5.3.2 Calibrated Model

The trial-and-error calibration procedures are presented in Figure 5.12. Comparisons between simulated conditions and field measurements were performed for static groundwater levels, groundwater flow directions, MSR, and summer/winter conditions.

1) Calibrated hydraulic conductivities

The calibrated hydraulic conductivities of aquifers Spallumcheen A and B are presented in Table 5.12. The best fit was obtained with the hydraulic conductivity of the low permeability layer between Spallumcheen A and B as 1×10^{-8} m/s. The low number of aquifer tests and the overall uncertainty of geometry of the aquifers and aquitards made model calibration difficult.

2) Modeled groundwater levels

The comparison of computed and observed static groundwater levels for the best calibrated model are presented in Table 5.13 and Figure 5.13 for the summer period (August, 2007 model). The difference in hydraulic heads between simulated and measured values is shown in Figure 5.14. The variations of the differences between the measured and simulated groundwater levels ranged from -1.4 and 1.7 meters (Table 5.13). Figure 5.13 shows that the simulated groundwater heads distributed closely around the 1:1 straight line and the differences were less than 2.8 meters which is 10% of the variation of the groundwater head across the model domain (Figure 5.14). In short, the calibrated model demonstrates acceptable qualitative and quantitative comparisons of the simulated and observed groundwater heads and groundwater levels.

The mean error (ME), mean absolute error (MAE) and root mean squared error (RMS) were -0.2, 0.7 and 0.9 meters respectively, which were less than 10% of the variability of the change in groundwater heads across the model domain from field data (10% of 28 m is 2.8m). The ratio of RMS error to the total head loss in the model system is 0.032.

3) Groundwater flow directions

The modeled groundwater flow directions are shown in Figures 5.15 to 5.18.

In Spallumcheen A water flows from mountain areas and aquifers Sleepy Hollow B and Okeefe C to the valley centre. Water flows from the north to south and ultimately into Okanagan Lake (Figures 5.15 and 5.16). The calibrated model has a small water inflow into the modeling system from the north constant head boundary as the aquifer Spallumcheen A extends to Shuswap River basin.

The general groundwater flow directions of Spallumcheen B are from the north to the south. The model ceases at the boundary of Okanagan Lake where the aquifer geometry is assumed to continue under the lake. Ultimately, water from within Spallumcheen B must flow upwards to Spallumcheen A, and then enter Okanagan Lake.

There is a groundwater divide in Spallumcheen B in the FCW between wells O118 and O122, and some water leaves the model via the north constant boundary as shown in Figures 5.17 and 5.18. This is consistent with the field data.

4) MSR and MBR

The calibrated MSR was 5.5% of total precipitation of the mountain area. MBR from this MSR was determined as per Table 5.11 for each boundary section. Across the model, the total MBR is 13450 m^3/d which is 4.0% of the total precipitation volume of 332300 m^3/d that falls on the mountain areas. The total precipitation on each contributing mountain area is different. The contribution of MBR to the valley aquifers represented between 18 mm/yr to 29 mm/yr of precipitation depending on the elevation of the mountain areas.

5) Summer/Winter conditions

There was no irrigation pumping wells operating in February, 2008. The irrigation pumping wells were turned off from the calibrated model (August, 2007) so that observed static water level data from Feb, 2008 could be used to check the model calibration. Lower pumping rates lead to an increase in groundwater head across the modeling area. The ME, MAE values for comparison of computed and observed static water levels are presented in Table 5.14. The RMS error was 1.0 m, which is less than 2.8 meter criteria.

The change between summer and winter conditions was most affected by hydraulic conductivities within the model. High hydraulic conductivity of the main aquifers would require a high recharge to sustain the observed groundwater heads. Higher hydraulic conductivity of the main aquifers leads to smaller changes in groundwater heads between summer and winter conditions. This helped to constrain the balance between total recharge and hydraulic conductivity.

5.3.3 Water mass balance analysis

The water mass balance of the August modeling period is presented in Table 5.15.

The total groundwater recharge to the two aquifers is 17300 m^3/d. MBR is 13450 m^3/d, which is 77.7 % of total recharge (Figure 5.19.). Recharge from unconfined aquifers is 2470 m^3/d, which equals 14.3 % of total recharge. Other model inflows total 1380 m^3/d and account for 8% of total inflows (Figure 5.19.).

The total groundwater discharge is 17300 m^3/d of which 7860 m^3/d is groundwater flow at the southern boundary of the model to under Okanagan Lake. This represents 45.4% of total discharge (Figure 5.20). This water would eventually discharge upwards to Okanagan Lake. Groundwater discharging to surface water systems within the model boundaries including Deep Creek, Fortune Creek and Otter Lake is 5850 m^3/d, which accounts for 33.8 % of total discharge. In total, about 80% of groundwater discharges into surface water systems (lakes and rivers), Groundwater pumping and flow from artesian wells is 2870 m^3/d or about 16.6% of total groundwater discharge. The discharge amounts from the other sources total 720 m^3/d, about 4.2 % of total groundwater discharge (Figure 5.20).

Total water entering aquifer Spallumcheen A in August 2007 was estimated to be 16850 m^3/d of which recharge via MBR is 46 %, and water leakage upwards from Spallumcheen B is 31%. Thus, MSR direct to Spallumcheen A, or via Spallumcheen B is the major source of groundwater in the this aquifer. Unconfined recharge from the Eagle Rock aquifers, Fortune Creek unconfined-confined aquifer, O'Keefe unconfined aquifer and Sleepy Hollow unconfined aquifer are 7.7 %, 6.2 %, 0.2 % and 0.6% respectively. Water flux flowing to the northeast via the constant head boundary in FCW is 2.6 % (Figure 5.21.).

The distribution of water fluxes leaving from Spallumcheen A are shown in Figure 5.22. The majority of the 16850 m^3/d of total throughflow in Spallumcheen A is water leakage from Spallumcheen A to B (29.6%). Discharge into Deep Creek and Fortune Creek are the next largest flows, and represent 13.6% and 18.7% respectively. Natural discharges into Okanagan Lake, Okeefe B, Otter Lake and Fortune Creek Fan are 15.1%, 2.7%, 2.4% and 0.9% respectively. The other discharges are anthropogenic: groundwater pumping (16.1%); and flow at artesian wells (0.9%), Thus, a significant portion of the discharge of Spallumhceen A is water flowing into Okanagan Lake and the Fortune Creek system.

The total groundwater flow within aquifer Spallumcheen B is 10700 m^3 per day of which recharge via MSR constitutes 53.5% and vertical water leakage from Spallumcheen A is 46.5% (Figure 5.23). This water flows into Okanagan Lake (49.7%) or leaks vertically from Spallumcheen B to A (49.3%). Lateral outflow via the constant head at the north-east boundary 1.0% is a small proportion of the overall flow (Figure 5.24).

5.3.4 Sensitivity Analysis of Model of August, 2007 conditions

Sensitivity analysis allows an assessment of the uncertainty in the modeled parameters and an indication of which parameters most affect the model outputs.

For this model, the main model input parameters altered within the calibration process comprised: the total volume of MBR determined as a percentage of total mountain area precipitation; the distribution of MBR between Spallumcheen A and B; lateral hydraulic conductivities within the upper and lower layers; the hydraulic conductivity of the middle unit of fine grained materials; inflows to Spallumcheen A from unconfined aquifers calculated outside the model; and water leaving from the system to unconfined aquifers and surface waters. These parameters were varied systematically, and the calculated and observed groundwater heads were compared.

RMS values between the modeled and measured heads were determined for variations of the parameters above. The resultant RMS values in response to the variation of the model parameters are shown in Figures 5.25 and 5.26, and Table 5.16.

1) Comparison of MBR, hydraulic conductivities, vertical flux recharges and discharges

In general, the model is most sensitive to MBR. Hydraulic conductivities of aquifers is the second most sensitive parameter. Recharge from the unconfined aquifers is the third, and sinks which represent groundwater leaving from the system to unconfined aquifers and surface water is the fourth.

The model is least sensitive to the hydraulic conductivity of the fine grained sediment package, modeled as an aquitard, separating Spallumcheen A and B (Table 5.16).

As indicated above in Section 5.3.2, the calibrated MSR if 5.5% of precipitation resulting in MBR as 4.0 % of precipitation. The RMS error varies from 1.85 to 2.78 meters as the total MBR changed from 0.9 to 1.2 times the calibrated value. A criterion of RMS error being less that 10% of the total head change in the model requires RMS error less than 2.8 meters. Thus, the variation of model RMS with changing MBR indicates that the MBR ranges from 3.6% to 4.8% (MSR 5% to 6.6%) of precipitation in the mountain areas. More detailed information on the different mountain regions is presented in Table 5.17.

The RMS error varied from 2.0 to 2.6 meters with the change of hydraulic conductivities of aquifers from 0.8 to 1.4 times (Tables 5.14 and 5.16), but the water flow directions both horizontally and vertically did not match the field measured data at either end of this range. The RMS values were reasonable when hydraulic conductivities were within 0.9 to 1.1 times the calibrated values.

The RMS values were generally reasonable when vertical flux recharges calculated and entered as vertical flux boundaries were varied within 0.4 to 1.8 times of the calibrated values. However water flow directions between Spallumcheen A and B did not match the measured data when vertical flux recharges were less than the calibrated values. The acceptable values of vertical fluxes were from 1.0 to 1.8 times of the calibrated vertical flux recharge values.

The RMS error was within the reasonable range when vertical flux discharges values were changed from 0.6 to 1.4 times the calibrated values. However, the water flow directions in both Spallumcheen A and B did not match the measured data when vertical flux discharges were greater than 1.1 times of the calibrated values. Based on this, vertical discharges calculated as fluxes likely range from 0.6 to 1.1 times of the calibrated values.

The RMS error was acceptable when the hydraulic conductivity of the aquitard between Spallumcheen A and B was within 0.2 to 2.0 times of the calibrated hydraulic conductivity. However, the water flow directions did not match the measured data when hydraulic conductivities of the aquitard were less than 0.8 times of the calibrated values. So the reasonable range of hydraulic conductivity of aquitard is from 0.6×10^{-8} to 2.0×10^{-8} m/s.

2) Distribution of MBR between Spallumcheen A and B

The uncertainty of the percentage of total MBR recharging to Spallumcheen A or B was assessed. The initial distribution was that 50% of MBR reported to Spallumcheen A, and 50% to Spallumcheen B. The resultant RMS error values in response to the variations of the MBR distribution percentages to Spallumcheen A (volume of recharge to Spallumcheen A/ total MBR volume) are presented in Figure 5.26 and Table 5.18.

The RMS error values are acceptable with the percentage of total MBR assigned to Spallumcheen A from 50% to 80%. However, the vertical water flow directions did not match the measured data when these values were assigned. The reasonable range of total MBR recharging to Spallumcheen A is from 60% to 65%.

In summary, the model performed reasonably well according to above comparisons on static water levels, ME, MAE, RMS and sensitivity analysis.

5.4 Model Limitations

A series of assumptions were made in the model that may impact upon them model results and their interpretation.

The model only considers water that reaches the main Spallumcheen A aquifer. Precipitation on the main valley floor within areas of Spallumcheen A overlain by finer grained materials is not considered in the model. While these sediments are not conducive to pumping, they do contribute to the overall watershed groundwater balance. Upwards fluxes from Spallumcheen A are thus calculated external to the model, and are not part of the direct model calculations.

The model presented in a quasi three dimension steady state assessment of two conditions (summer, winter). It is reliant upon the assumption that all inflows and outflows other than irrigation pumping are at steady state over the year. Actual irrigation wells pumping in summer would derive water laterally from Spallumcheen A, and from above and below from storage in the lower permeability materials located above and below Spallumcheen A. The model does not include the influence of storage in the layers overlying Spallumcheen A, and hence only considers flow upwards from below.

The model has allotted inflow from the Sleepy Hollow/ Hullcar area based upon limited assessments of lateral flow via Darcy's law calculations. These fluxes have not been compared in detail to an independent recharge assessment or water balance of the Hullcar/Sleepy Hollow area.

5.5 Summary

The key conclusions of this chapter are the following:

- Mountain Block Recharge is the main source of inflow to the modeled groundwater system, representing 78 % of total inflows. The corresponding MBR rates was 4% of total precipitation, which represents from 18 mm/yr to 29 mm/yr in the mountain regions;
- The distribution of MBR between the regional aquifers was solved to be 60-65% to Spallumcheen A and 35-40% to Spallumcheen B;
- Current utilization of groundwater during the summer period, when groundwater pumping is at a maximum, represents 16.6 % of the total through flow of the aquifer system.

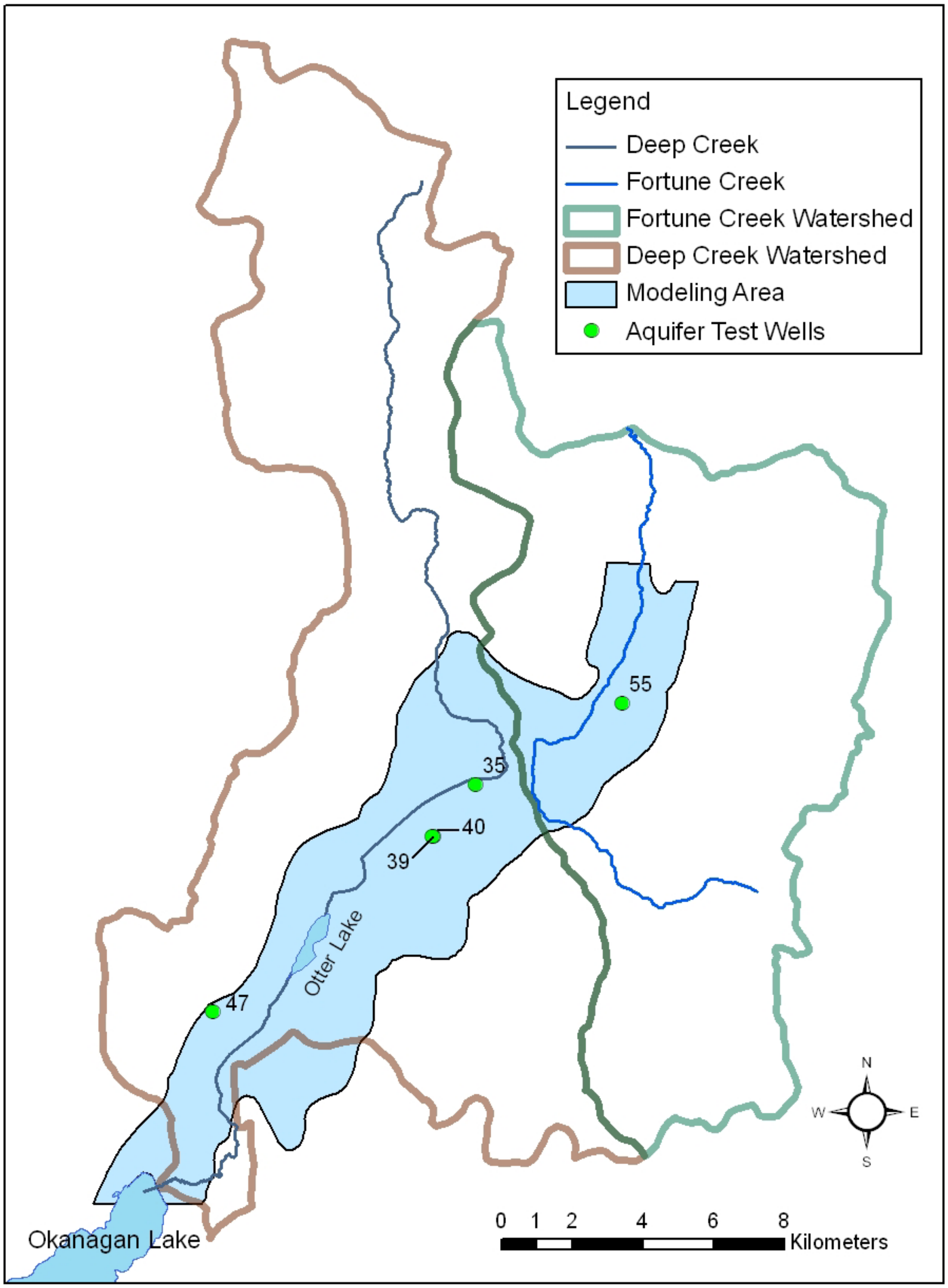


Figure 5.1 The modeling area and the locations of the wells for which aquifer test data is available

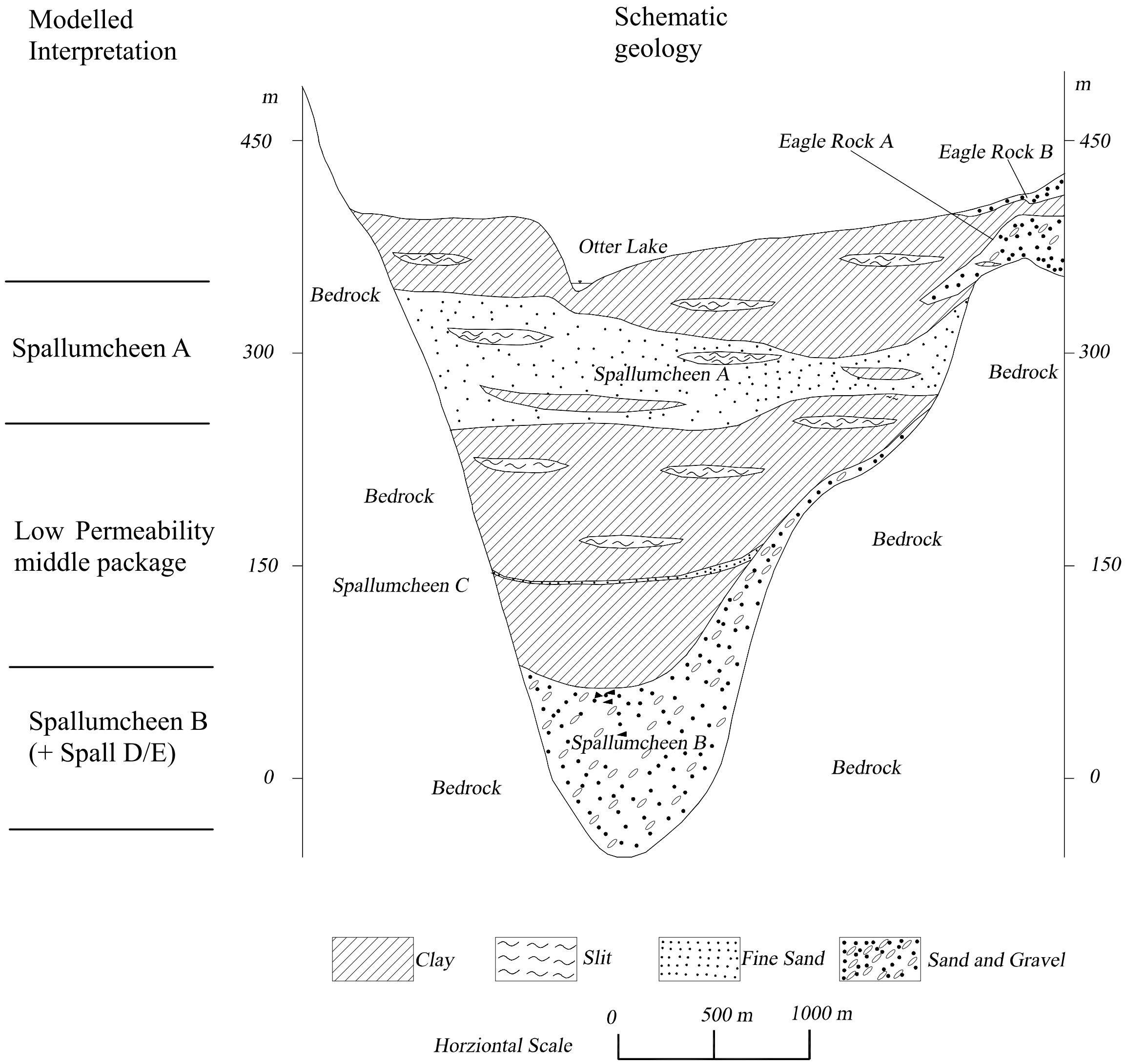


Figure 5.2 Schematic hydrogeological cross section of the main valley and interpretation for modeling

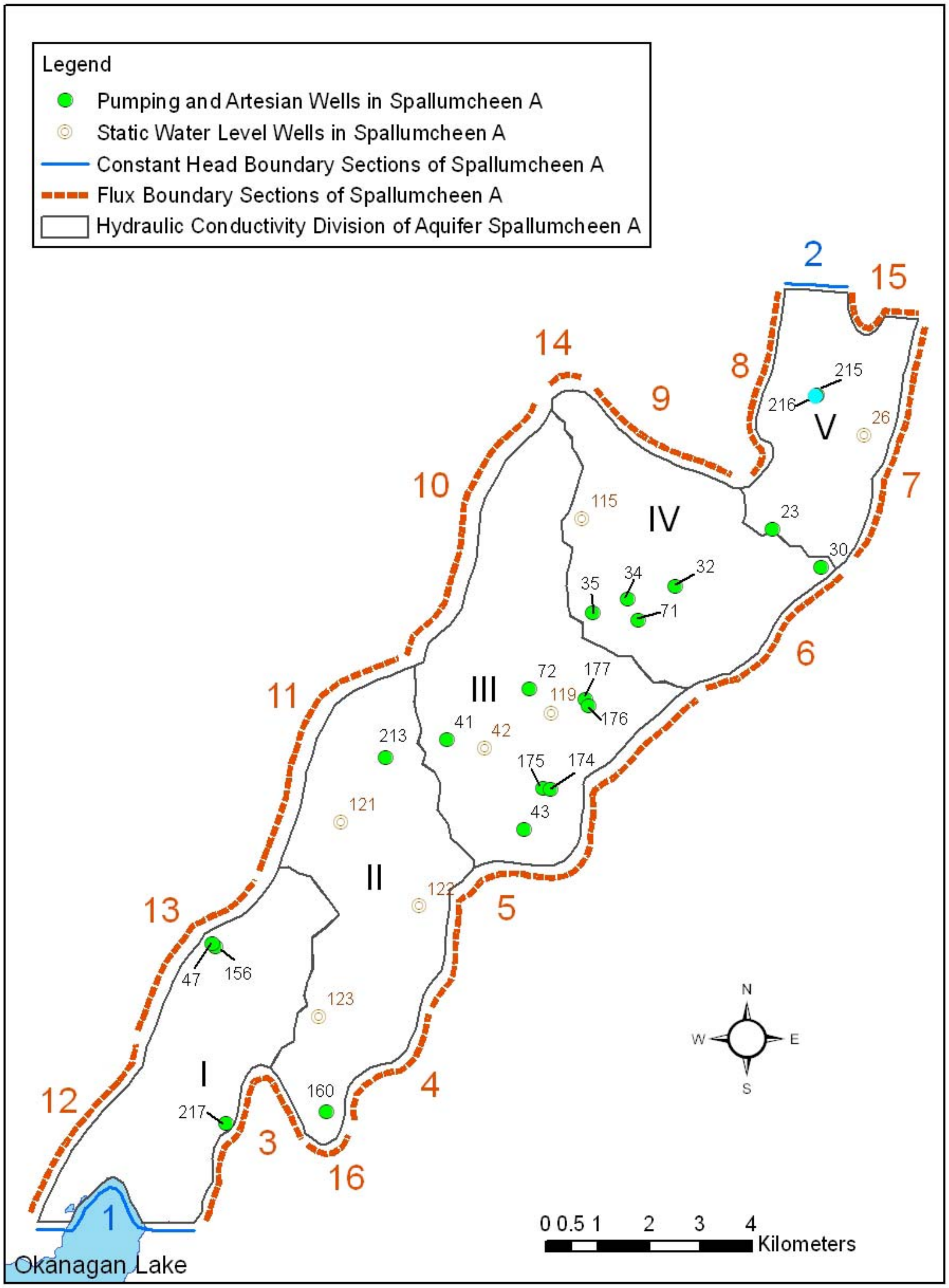


Figure 5.3 Conceptual hydrogeological model of the aquifer Spallumcheen A

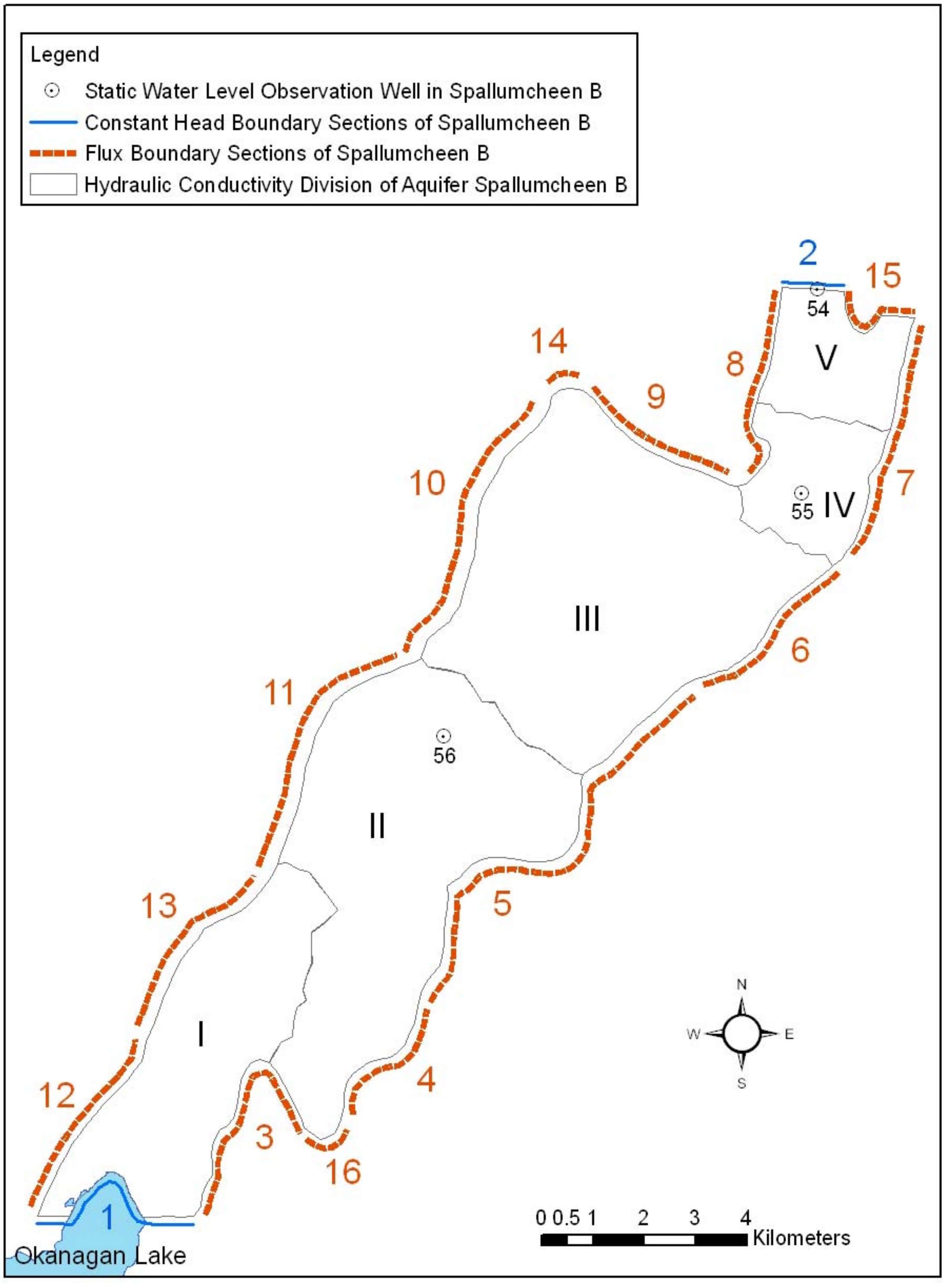


Figure 5.4 Conceptual hydrogeological model of the Spallumcheen B aquifer

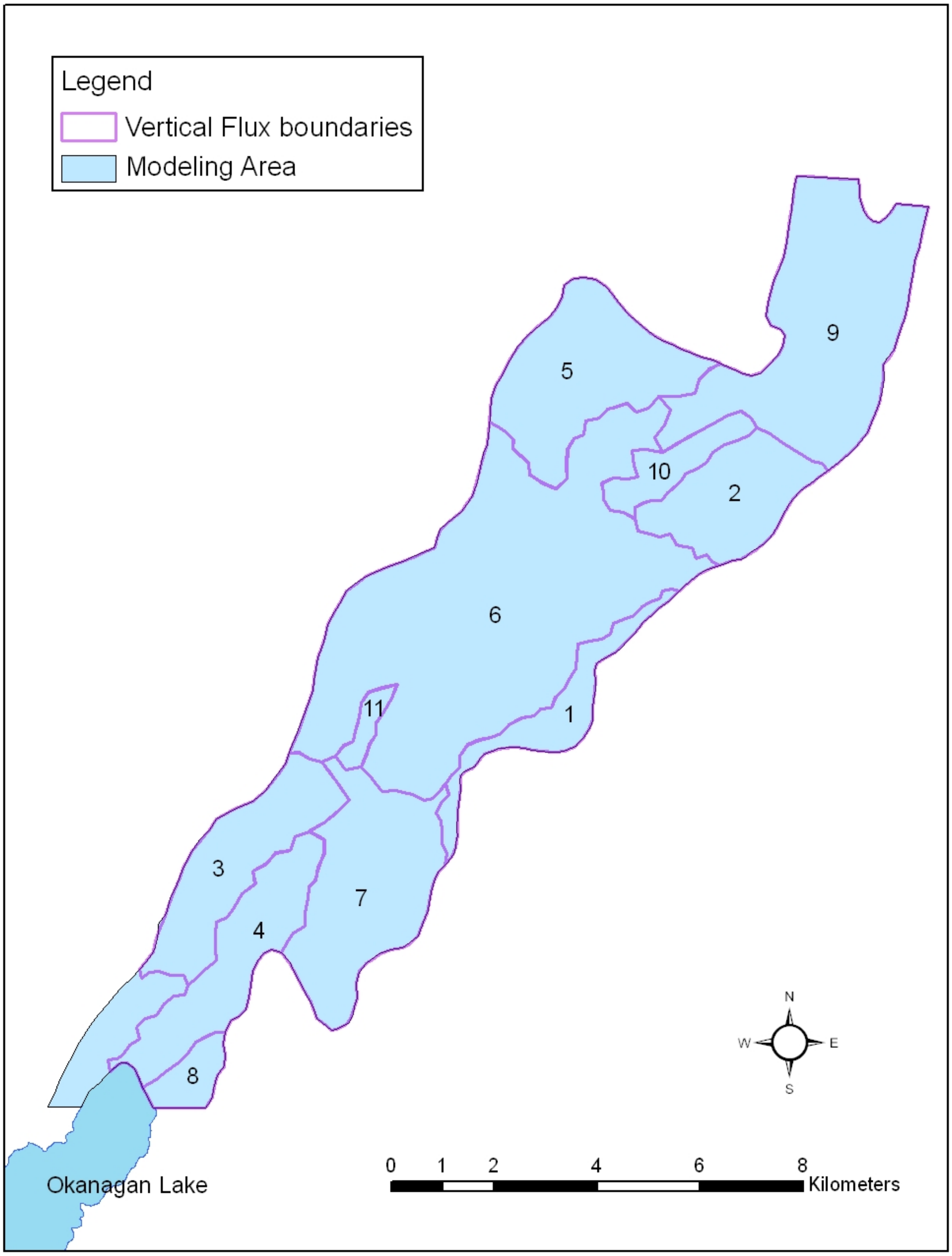


Figure 5.5 Areas of model with vertical flux boundaries for Spallumcheen A

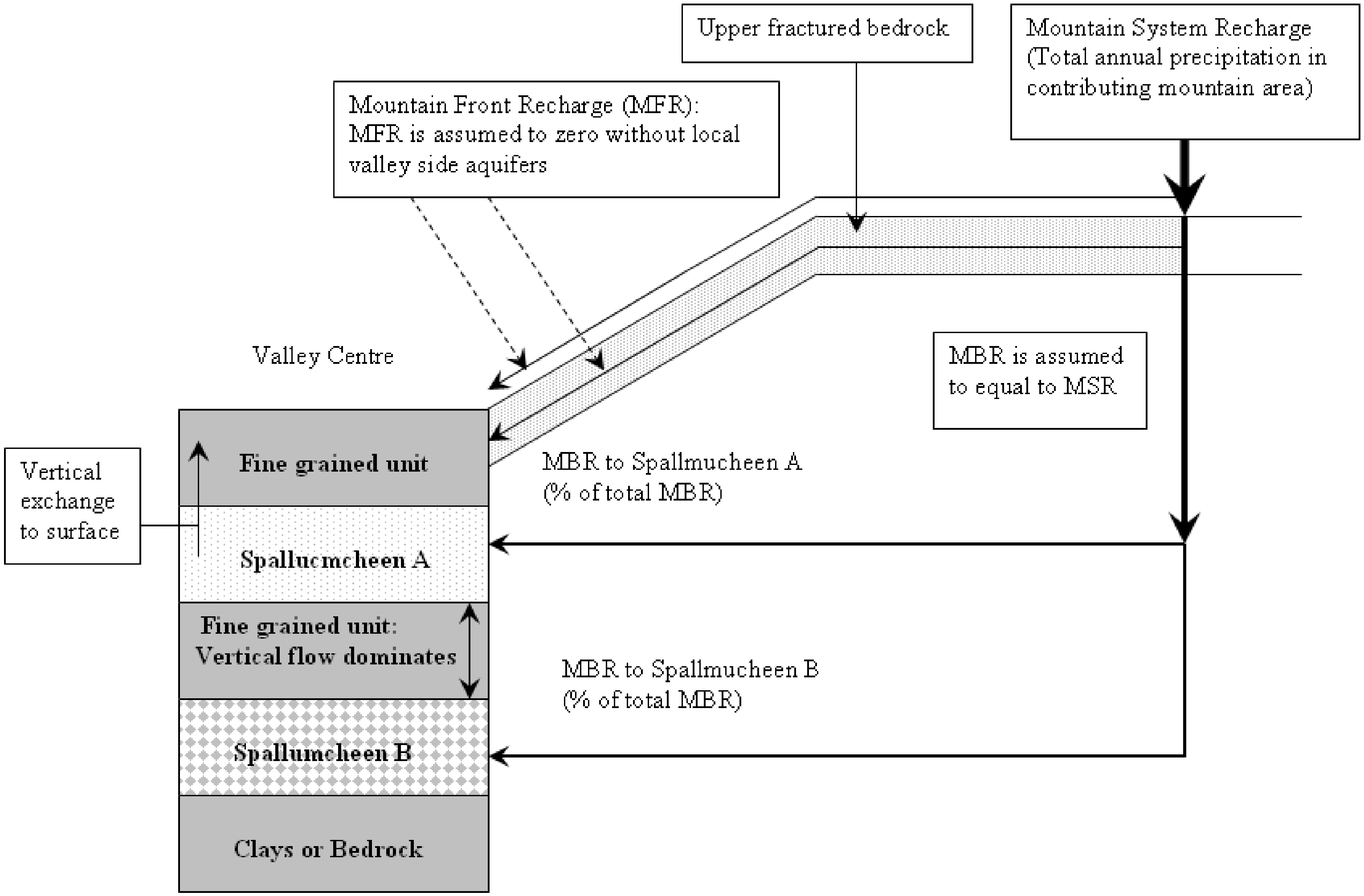


Figure 5.6A: Conceptual division of valley center sediments and main recharge processes via mountain system recharge without local valley side aquifers

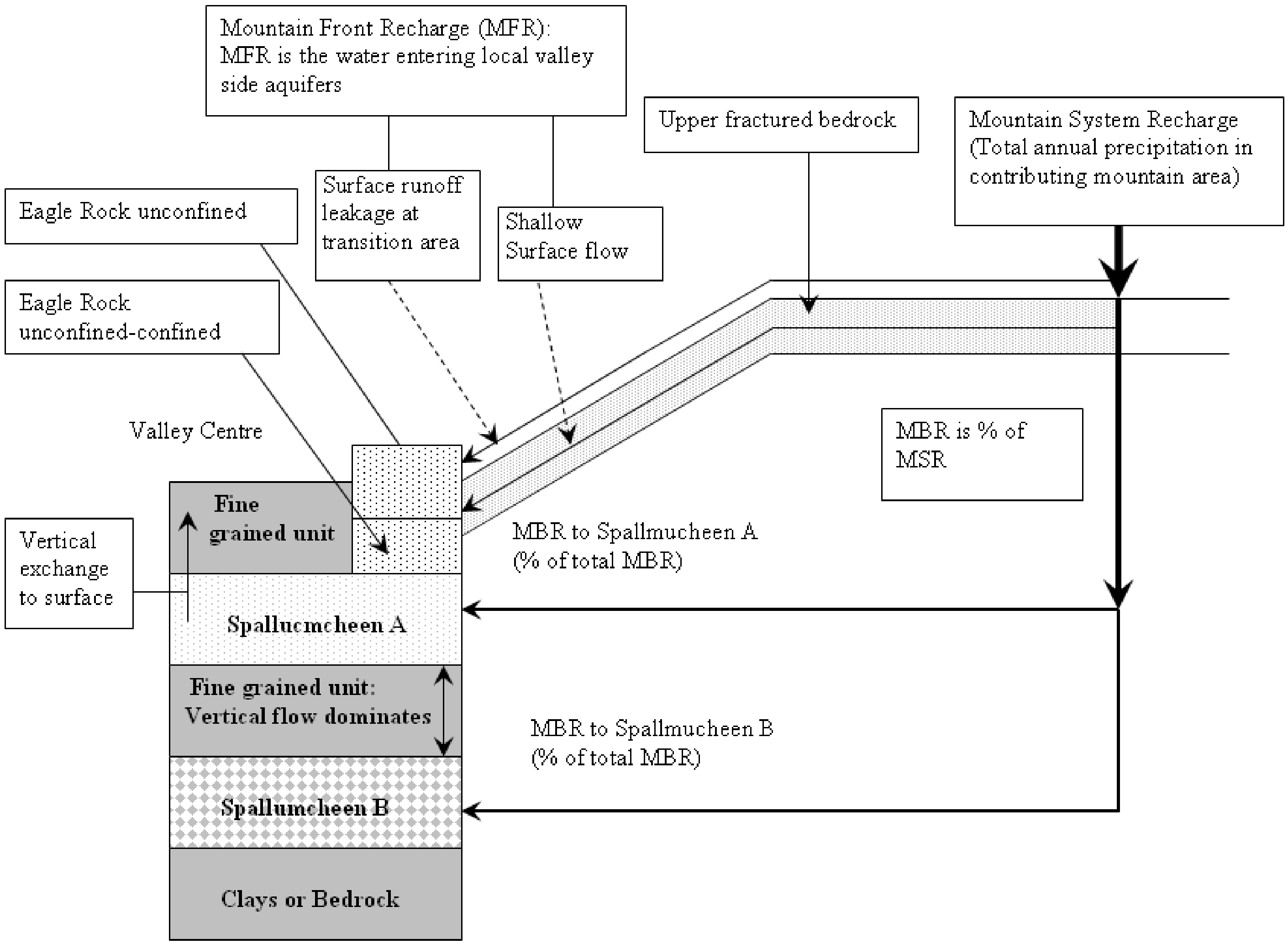


Figure 5.6B: Conceptual division of valley center sediments and main recharge processes via mountain system recharge with local valley side aquifers. Eg: Eagle Rock aquifers

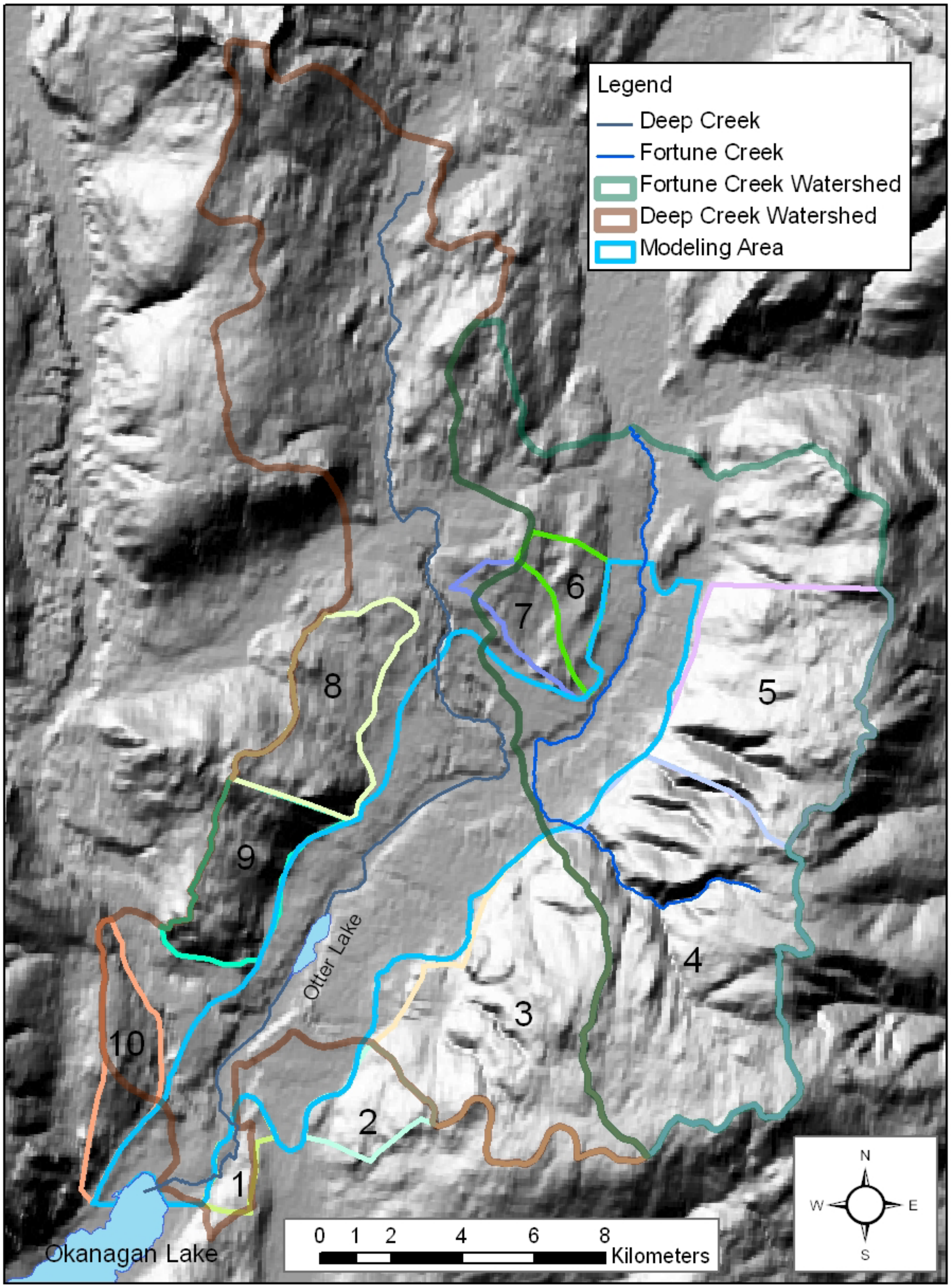


Fig 5.7 Mountain areas contributing to mountain system recharge

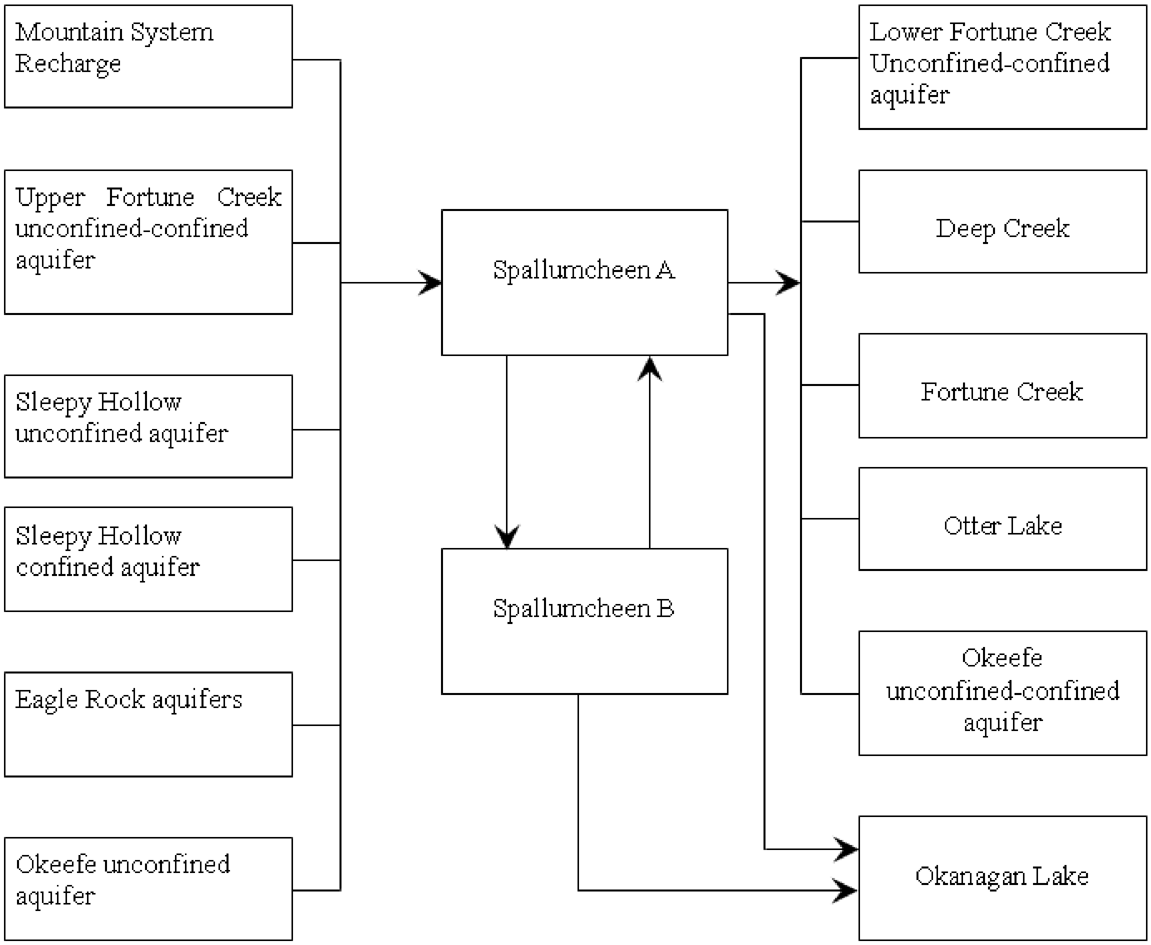


Figure 5.8 Conceptual water connections between aquifers

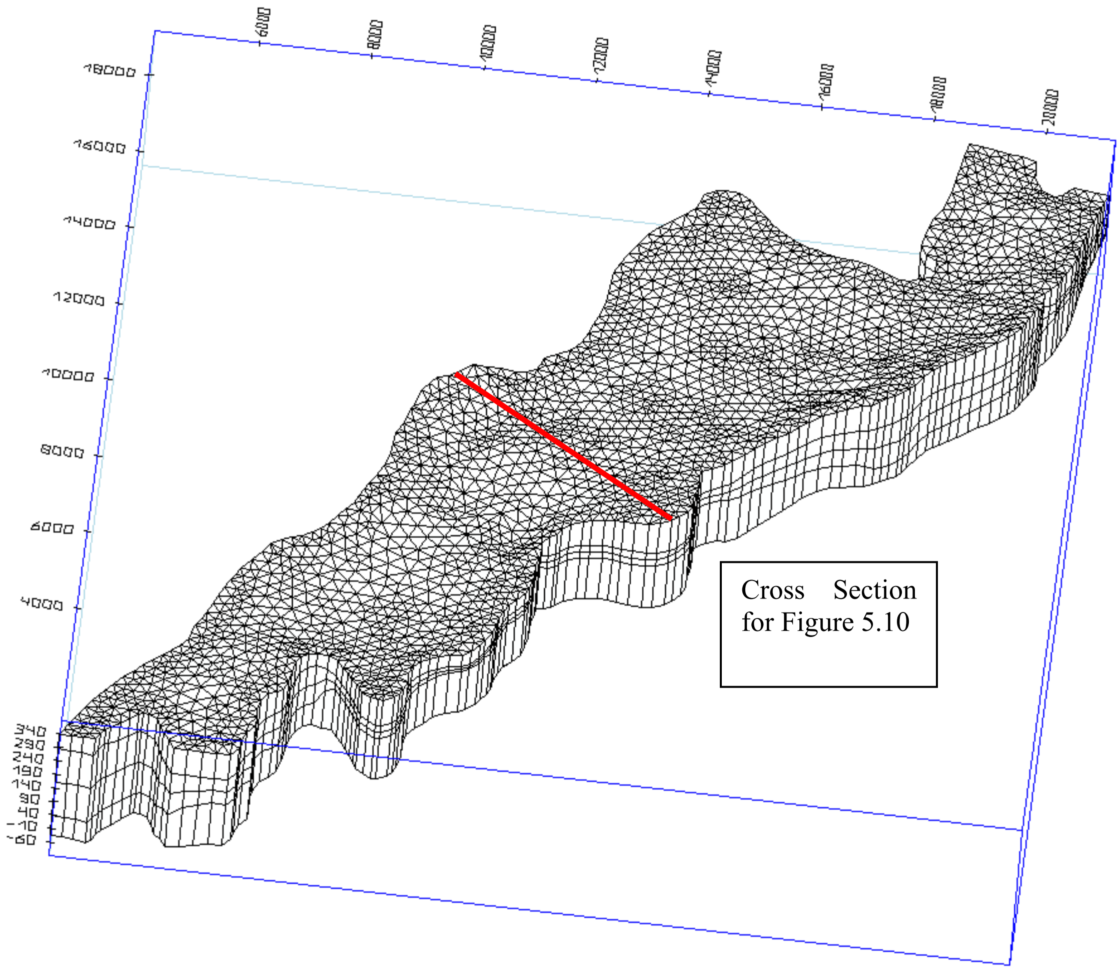


Figure 5.9 Perspective view of model mesh geometry as developed with FEFLOW

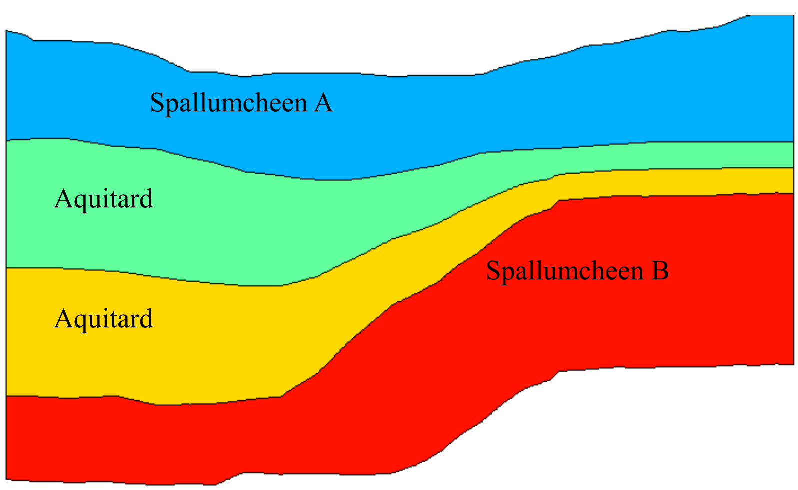


Figure 5.10 Model Cross Section corresponding to Geological cross section in Figure 5.2

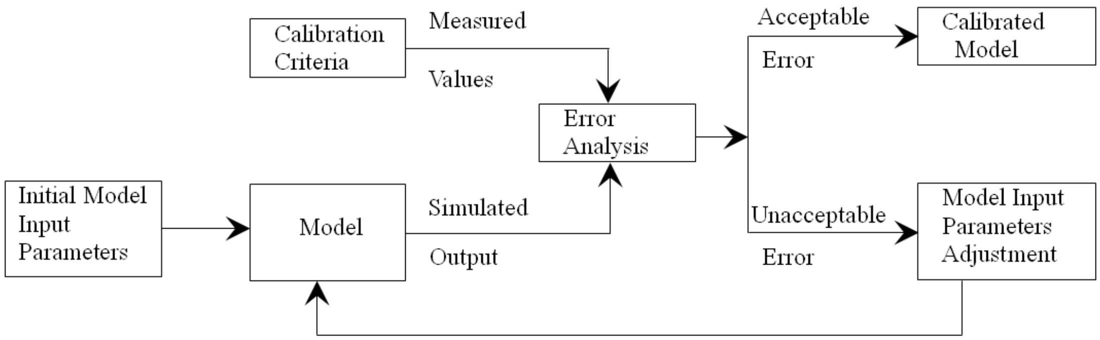


Figure 5.12 Trial-and-error calibration flow chart

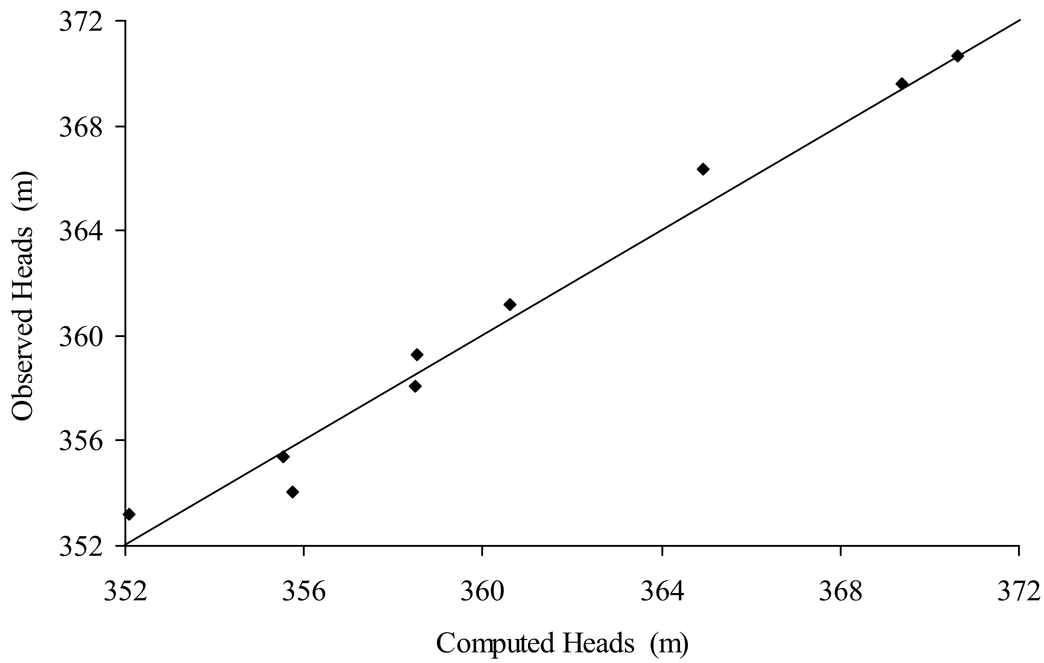


Figure 5.13 Comparison between measured and simulated static water levels of Model in August, 2007

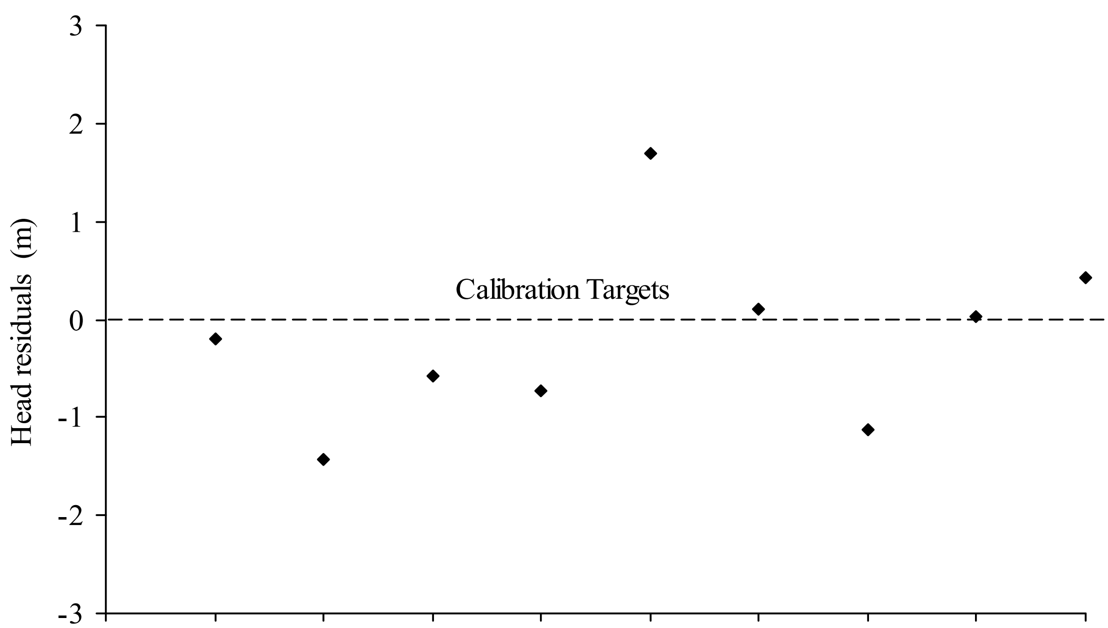


Figure 5.14 Residuals of measured and simulated static water levels at calibration targets in August, 2007

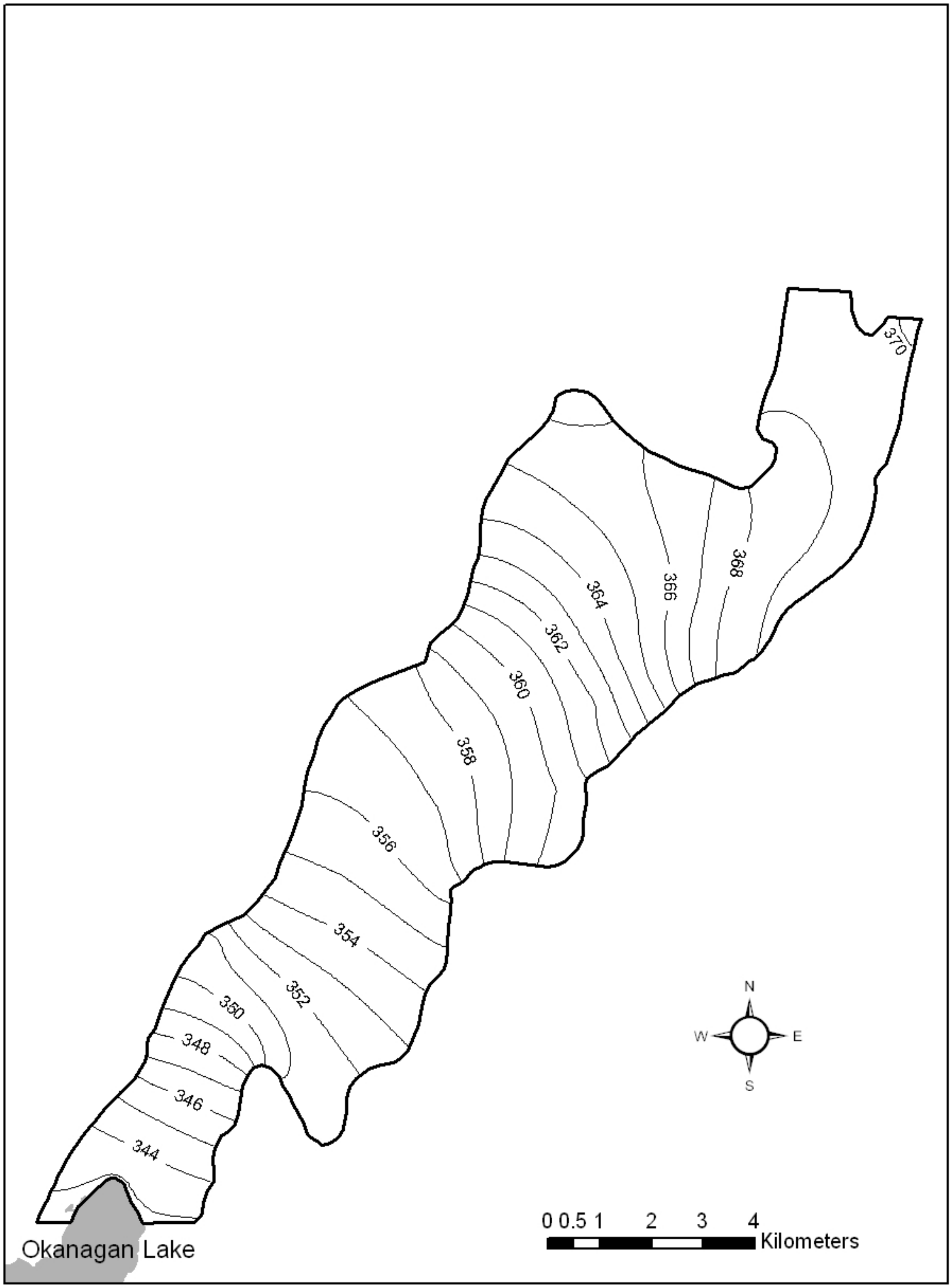


Figure 5.15 Modeled groundwater head contours in aquifer Spallumcheen A of model in August, 2007

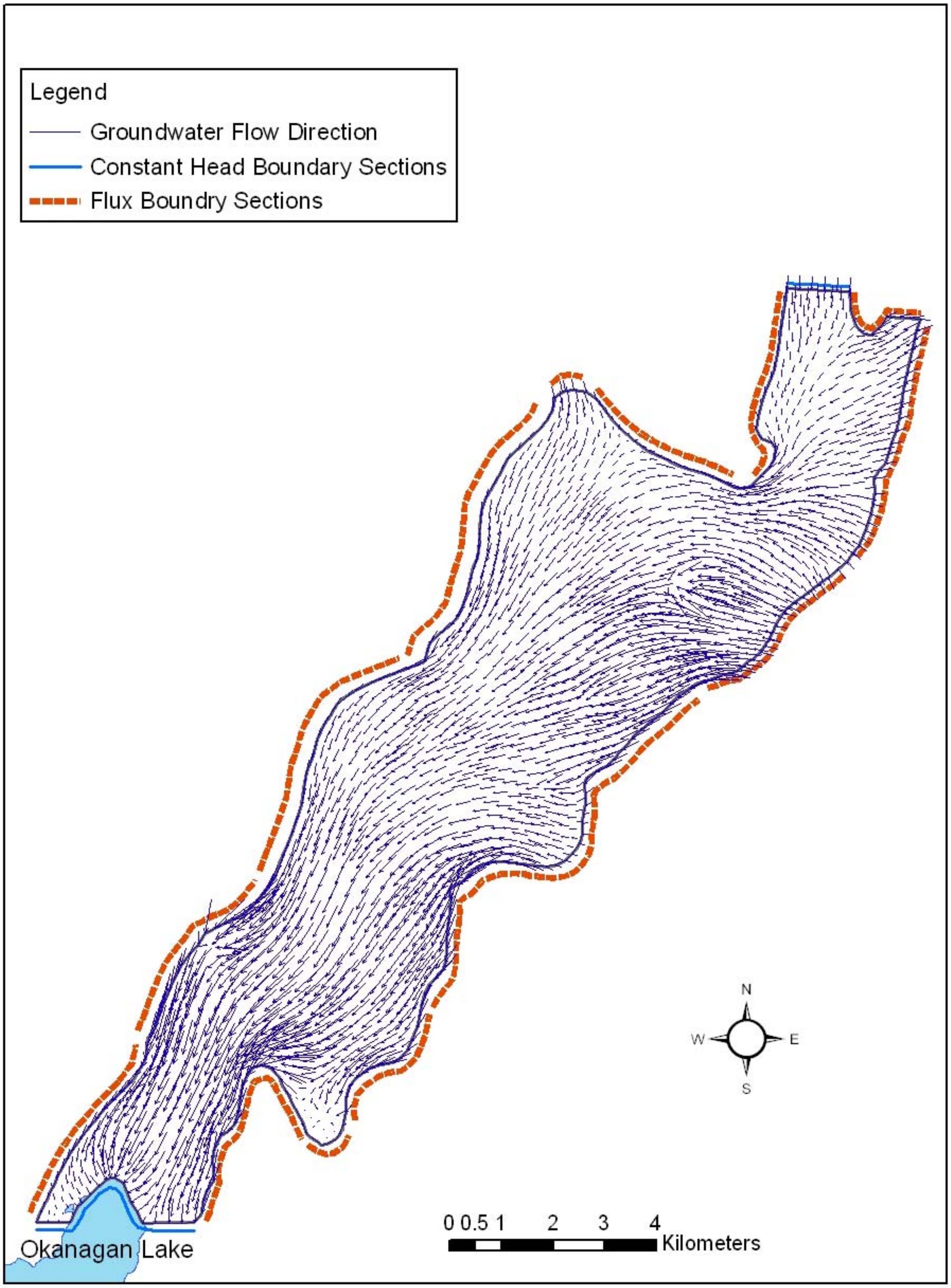


Figure 5.16 Groundwater flow directions in aquifer Spallumcheen A of model in August, 2007

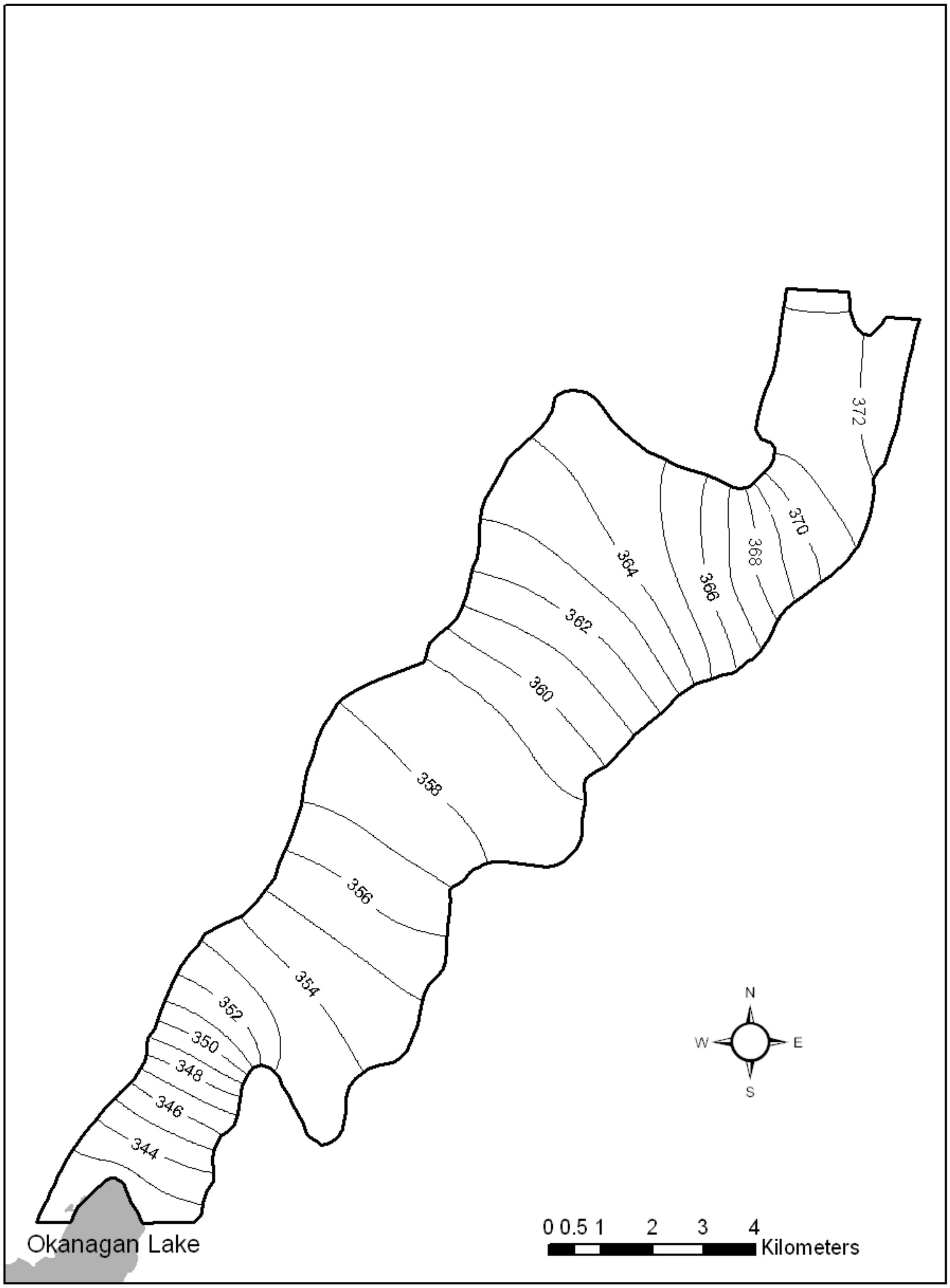


Figure 5.17 Modeled groundwater head contours of aquifer Spallumcheen B of model in August, 2007

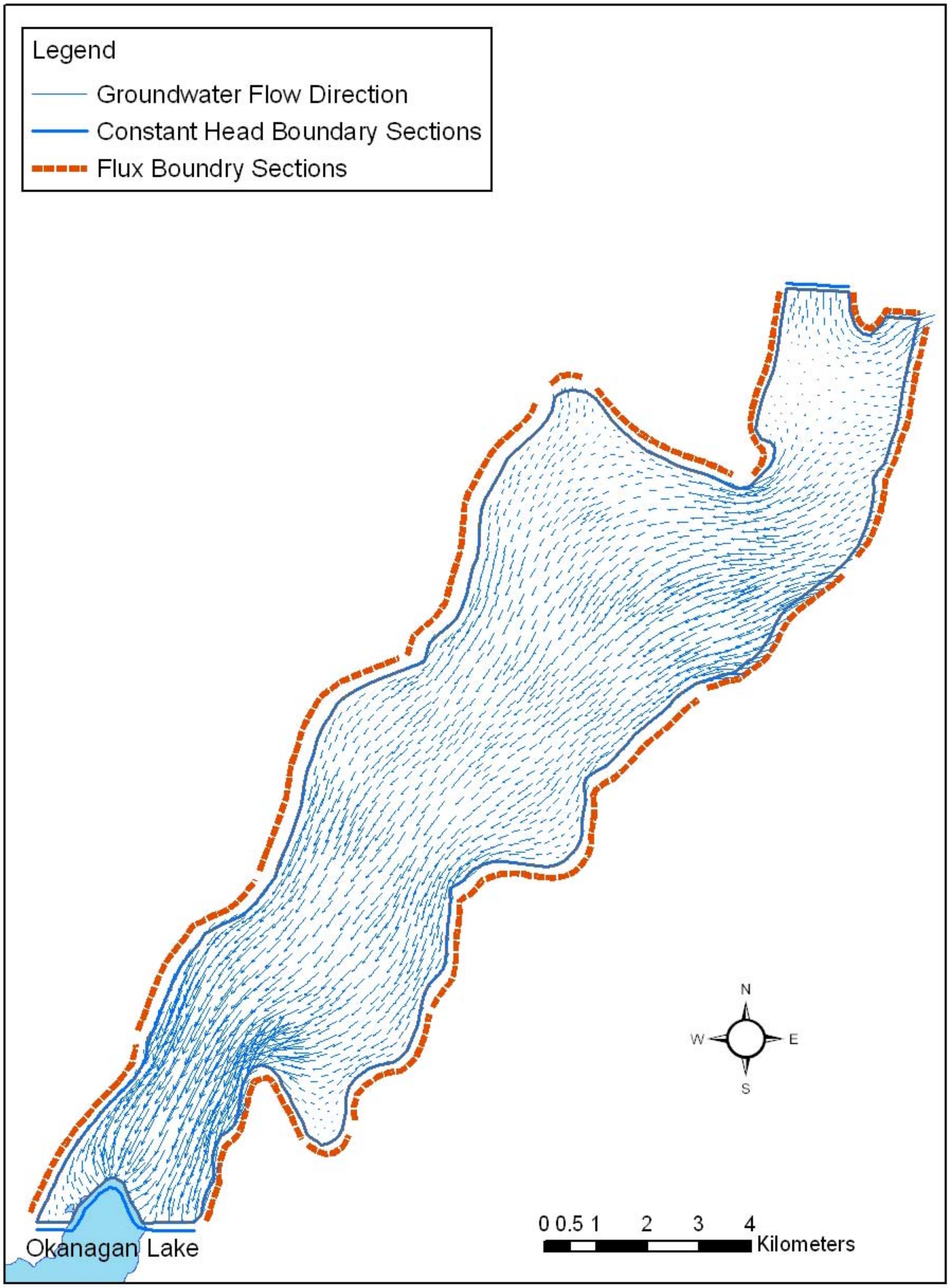


Figure 5.18 Groundwater flow directions in aquifer Spallumcheen B of model in August, 2007

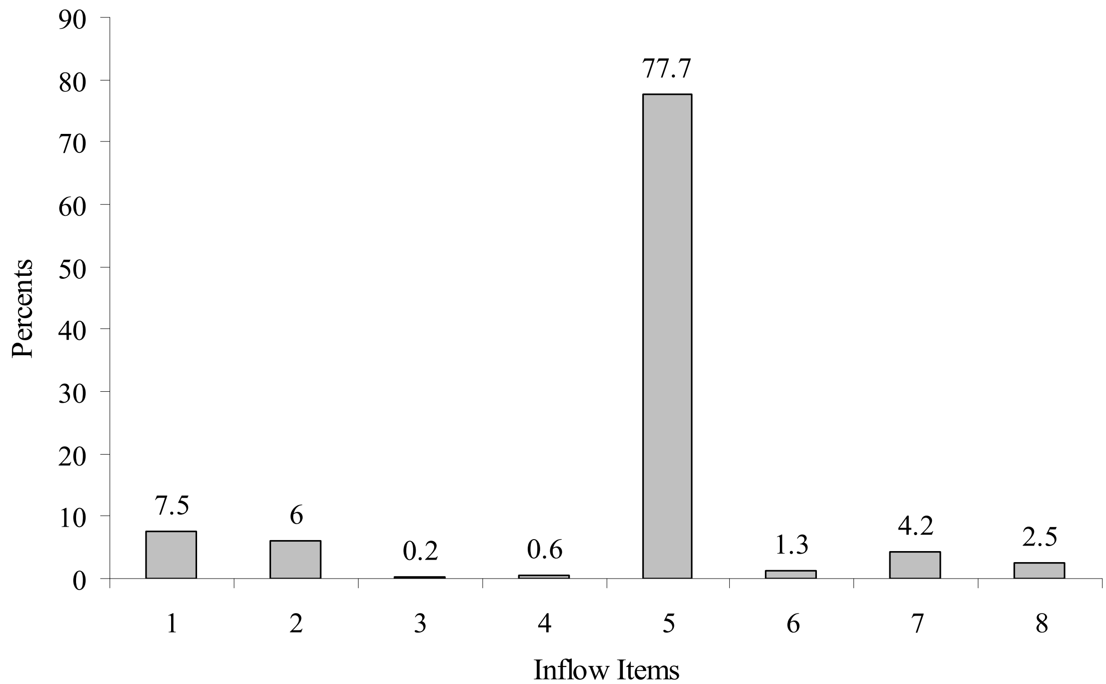


Figure 5.19 Inflows to modeled groundwater system of model in August, 2007

1-Vertical inflow from Eagle Rock aquifer;
2-Vertical inflow from upper Fortune Creek unconfined aquifer;
3-Vertical inflows from Okeefe unconfined aquifer;
4-Vertical inflows from Sleepy Hollow unconfined aquifer;
5-Lateral inflow from Mountain System Recharge;
6-Lateral inflows from Sleepy Hollow confined aquifer;
7-Lateral inflow from Okeefe C confined aquifer;
8-Laternal inflows via north constant head boundary

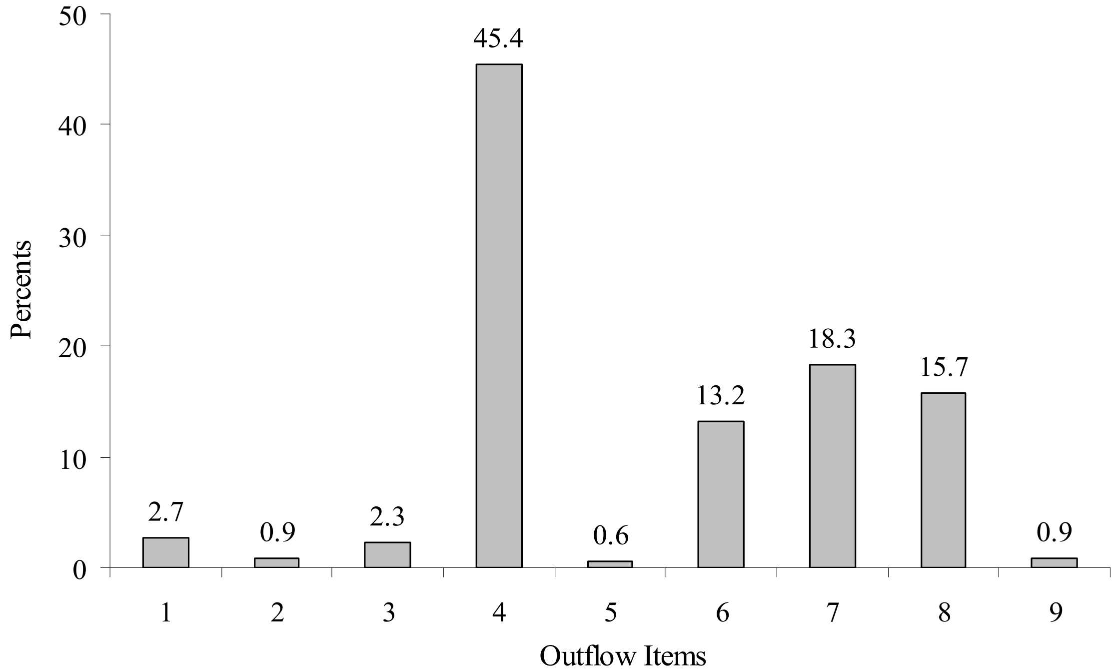


Figure 5.20 Outflows from modeled groundwater system of model in August, 2007

1-Discharge into Okeefe unconfined-confined aquifer;
2-Discharge into lower Fortune Creek unconfined-confined aquifer;
3-Discharge into Otter Lake;
4-Discharge into Okanagan Lake;
5-Discharge via north constant head boundary;
6-Discharge into Deep Creek;
7-Discharge into Fortune Creek;
8-Pumping;
9-Artesian flows

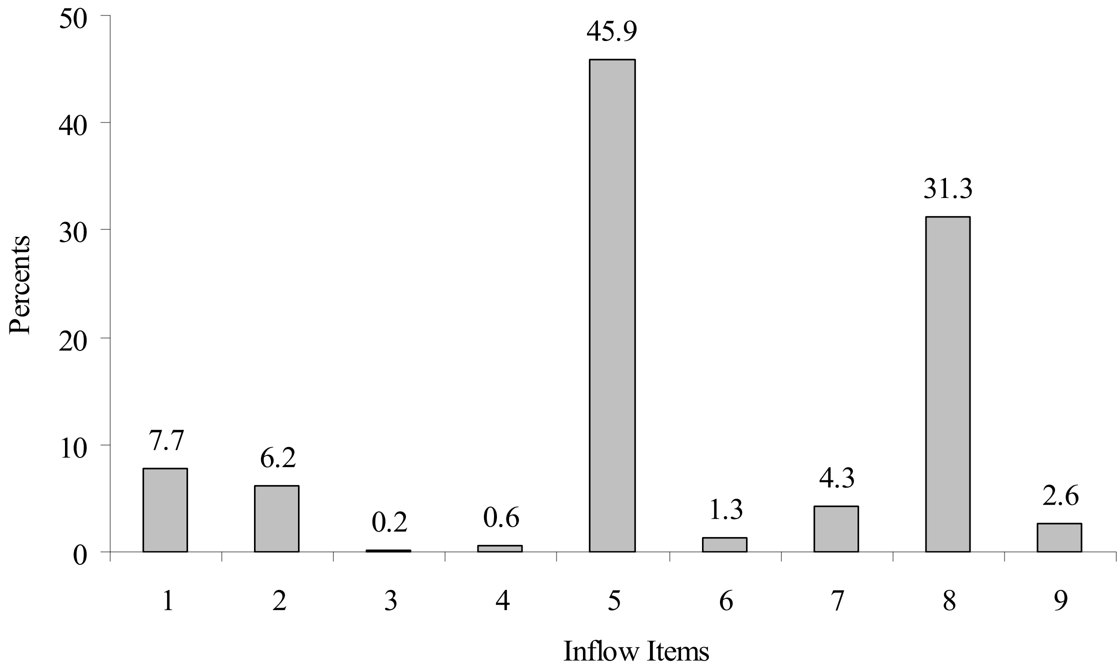


Figure 5.21 Inflows to aquifer Spallumcheen A of model in August, 2007

1-Vertical inflow from Eagle Rock aquifers;
2- Vertical inflow from upper Fortune Creek unconfined-confined aquifer;
3- Vertical inflow from Okeefe unconfined aquifer;
4-Vertical inflow from Sleepy Hollow Unconfined;
5- Lateral inflows from Mountain System Recharge;
6-Lateral inflows from Sleepy Hollow confined aquifer;
7-Lateral inflows from Okeefe C;
8-Vertical exchange from Spallumcheen B;
9- Lateral inflow from constant head boundary to north.

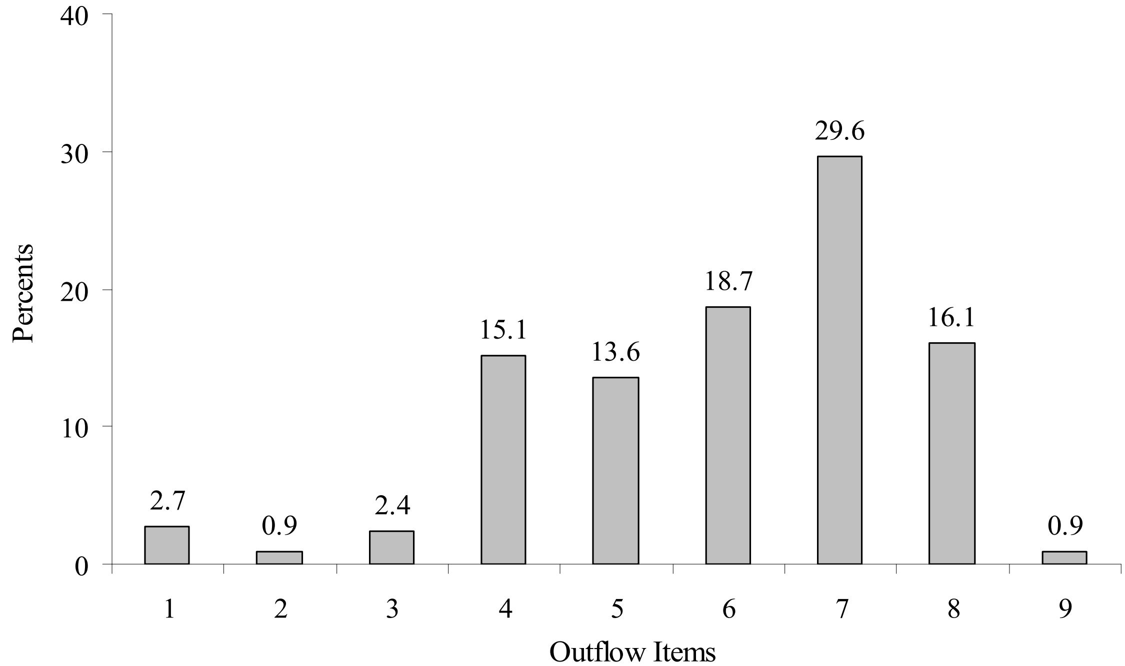


Figure 5.22 Mass flows out of aquifer Spallumcheen A of model in August, 2007

1-Discharge into Okeefe unconfined-confined aquifer;
2-Discharge into lower of Fortune Creek unconfined-confined aquifer;
3-Discharge into Otter Lake;
4-Discharge into Okanagan Lake;
5-Discharge into Deep Creek;
6-Discharge into Fortune Creek;
7-Discharge into Spallumcheen B aquifer;
8-Pumping and artesian flows

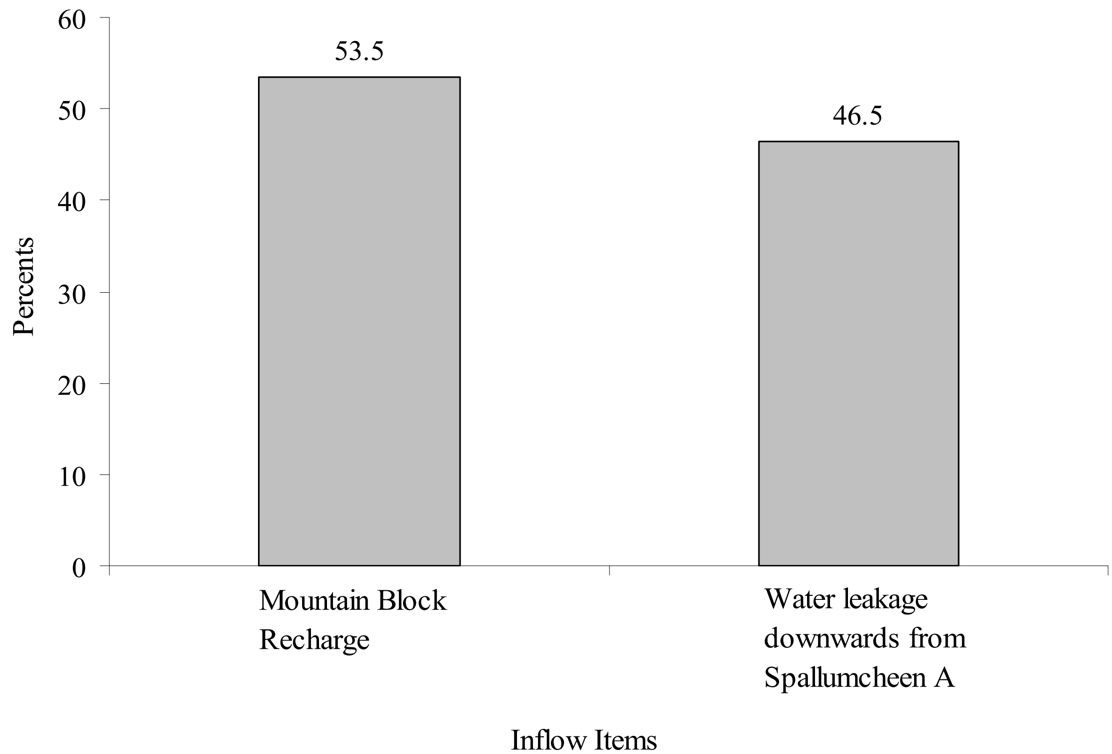


Figure 5.23 Inflows to aquifer Spallumcheen B of model in August, 2007

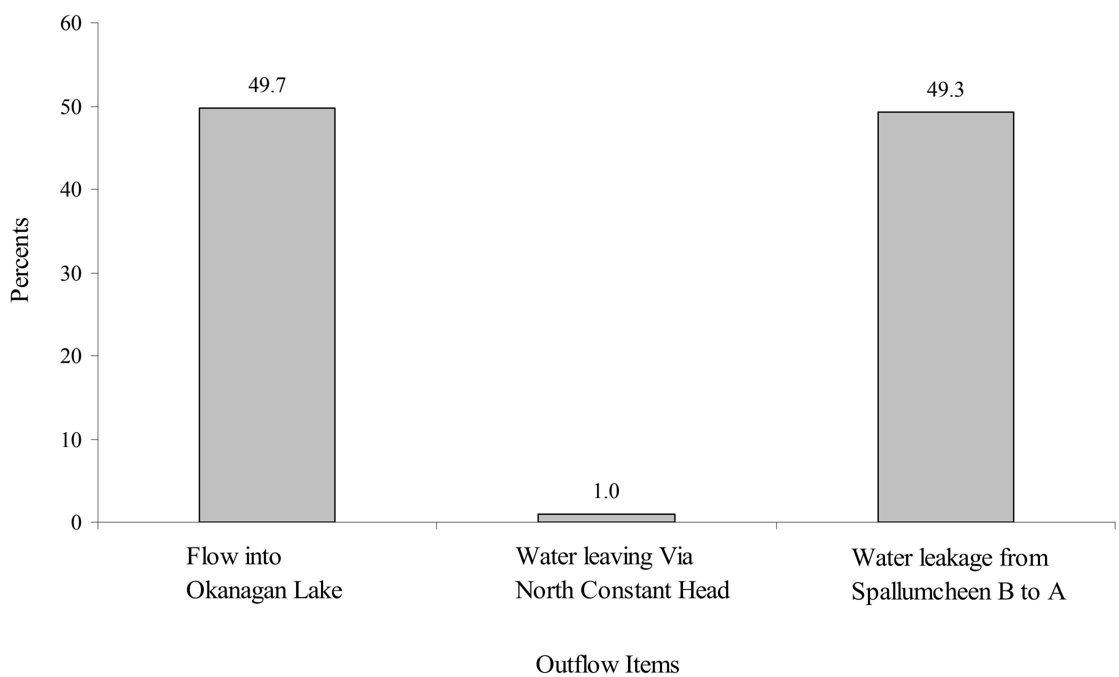


Figure 5.24 Mass flows out of aquifer Spallumcheen B of model in August, 2007

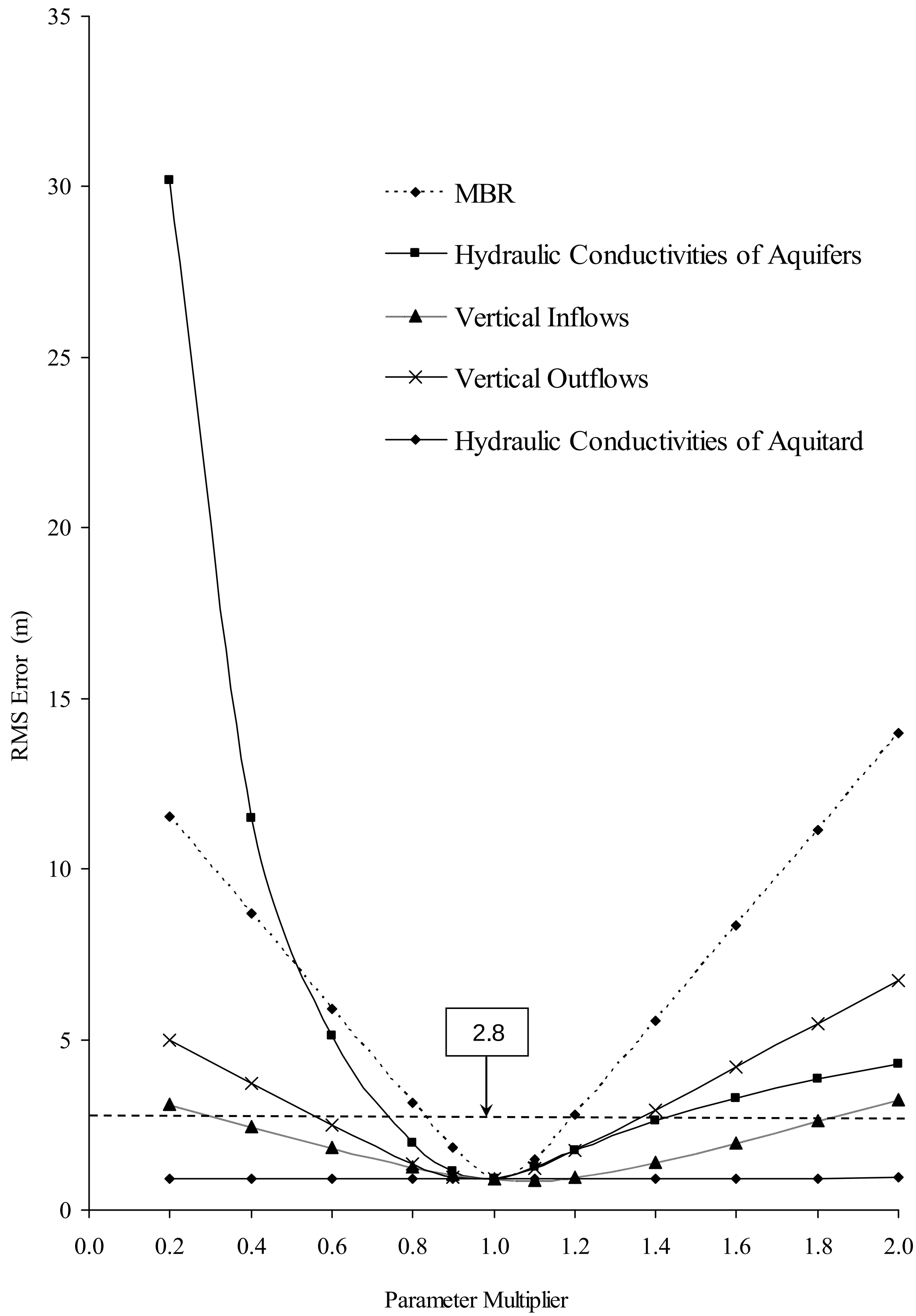


Figure 5.25 Simulated changes in RMS error in hydraulic heads resulting from changes in parameter values of model in August, 2007

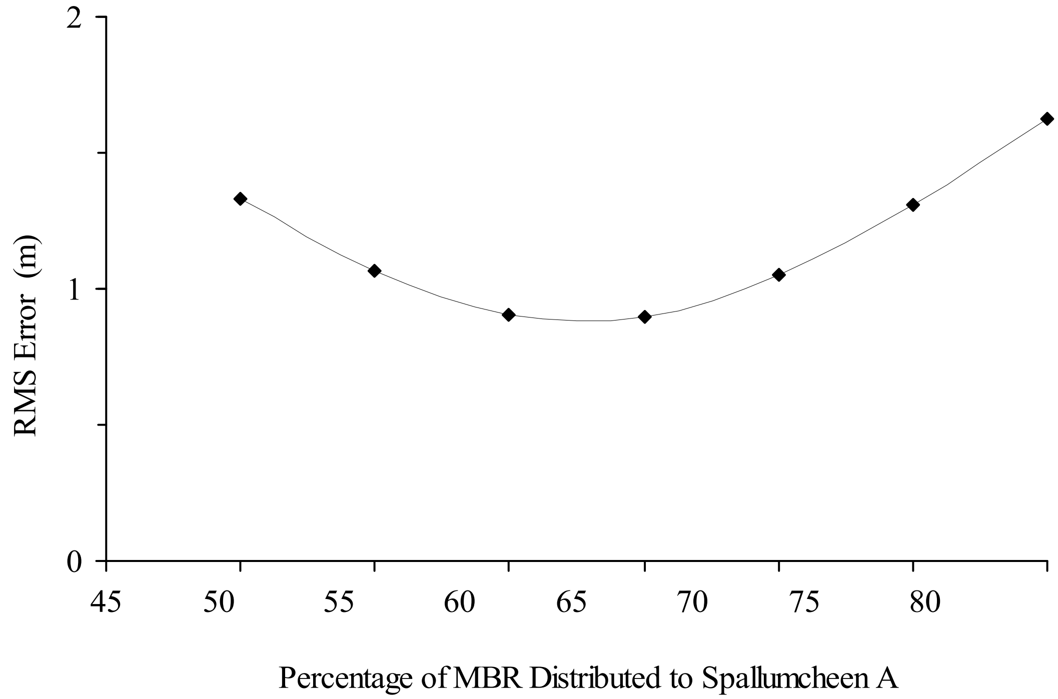


Fig 5.26 Changes in model RMS error in hydraulic heads resulting from changes in MBR distribution to aquifer Spallumcheen A of model in August, 2007

Table 5.1 Hydraulic conductivities from aquifer tests

Well No	Aquifer	Drawdown Test: Theis (m/s)			Drawdown Test: Jacob (m/s)		
35	Spallumcheen A	2.94E-04			2.96E-04		
39	Spallumcheen A	6.07E-04			8.03E-04		
40	Spallumcheen A	4.78E-04			5.50E-04		
47	Spallumcheen A	2.64E-05			3.23E-05		
		Slug Test Hydraulic conductivity (m/s)					
55	Spallumcheen B	Slug-in1	Slug-in2	Slug-in3	Slug-out1	Slug-out2	Slug-out3
		7.24E-03	1.17E-02	1.03E-02	9.34E-03	8.13E-03	1.26E-02

Note: Data from Kenny (2005).

Table 5.2 Estimated saturated hydraulic conductivities for coarse sands and gravels

Grain-Size Class or Range	Hydraulic Conductivity, *K* (m/S)					
	Degree of Sorting			Silt Content		
	Poor	Moderate	Well	Poor	Moderate	Well
Coarse sand to fine gravel	4.1E-04	5.1E-04	N/A	3.8E-04	3.2E-04	2.5E-04
Coarse sand to medium gravel	5.1E-04	N/A	N/A	4.1E-04	3.2E-04	2.5E-04
Coarse sand to coarse gravel	6.3E-04	N/A	N/A	4.8E-04	3.5E-04	3.2E-04

Source: EPA (1986).

Table 5.3 Estimated saturated hydraulic conductivities for fine-grained materials

Grain-Size Class	Saturated Hydraulic Conductivity, *K* (m/s)
Clay	<3.2E-09
Silt, clayey	3.2E-06 - 1.3E-05
Silt, slightly sandy	1.6E-05
Silt, moderately sandy	2.5E-05 - 2.9E-05
Silt, very sandy	3.2E-05 - 3.8E-05
Sandy silt	3.8E-05
Silty sand	4.4E-05

Source: EPA (1986).

Table 5.4 Description of horizontal boundary conditions employed in layer 1 representing Spallumcheen A (Section locations are shown in Figure 5.3)

Sections	Boundary Type	Hydrogeological Character	Interpretation
1	Constant Head	Discharge	Okanagan Lake
2	Constant Head	Discharge	Estimation from Well O122
3	Flux	Recharge	MSR From Mountain Area 1
4	Flux	Recharge	MSR From Mountain Area 2
5	Flux	Recharge	MSR From Mountain Area 3
6	Flux	Recharge	MSR From Mountain Area 4
7	Flux	Recharge	MSR From Mountain Area 5
8	Flux	Recharge	MSR From Mountain Area 6
9	Flux	Recharge	MSR From Mountain Area 7
10	Flux	Recharge	MSR From Mountain Area 8
11	Flux	Recharge	MSR From Mountain Area 9
12	Flux	Recharge	MSR From Mountain Area 10
13	Flux	Lateral Inflow	Inflow From Okeefe C
14	Flux	Lateral Inflow	Inflow from Sleepy Hollow B
15	Flux	Zero Flux	No flow where aquifer pinches out
16	Flux	Zero Flux	No flow at the water divide

Table 5.5 Description of horizontal boundary conditions employed in the second model layer representing Spallumcheen B (Section locations are shown in Figure 5.4)

Sections	Boundary Type	Hydrogeological Character	Interpretation
1	Constant Head	Discharge	Continuation under Okanagan Lake
2	Constant Head	Discharge	Set from Well 55 (O122)
3	Flux	Recharge	MSR From Mountain Area 1
4	Flux	Recharge	MSR From Mountain Area 2
5	Flux	Recharge	MSR From Mountain Area 3
6	Flux	Recharge	MSR From Mountain Area 4
7	Flux	Recharge	MSR From Mountain Area 5
8	Flux	Recharge	MSR From Mountain Area 6
9	Flux	Recharge	MSR From Mountain Area 7
10	Flux	Recharge	MSR From Mountain Area 8
11	Flux	Recharge	MSR From Mountain Area 9
12	Flux	Recharge	MSR From Mountain Area 10
13	Flux	Lateral Inflow	MSR from Bedrock under Okeefe Confined
14	Flux	Lateral Inflow	Water from Bedrock under Sleepy Hollow Confined
15	Flux	Zero Flux	No flow where the aquifer pinches out
16	Flux	Zero Flux	No flow at the water divide

Table 5.6 Mountain system recharge distribution to potential aquifers

Mountain Area	Mean Annual Precipitation (mm/yr)	Contributions to Aquifers
1	452	Spallumcheen A and B
2	556	Spallumcheen A and B
3	746	Eagle Rock aquifers, Spallumcheen A and B
4	742	Fortune Creek unconfined-confined aquifer, Spallumcheen A and B
5	742	Spallumcheen A and B
6	543	Spallumcheen A and B
7	543	Sleepy Hollow aquifers, Spallumcheen A and B
8	539	Sleepy Hollow aquifers, Spallumcheen A and B
9	559	Spallumcheen A and B
10	500	Spallumcheen A and B

Note: Mean Annual Precipitation data is from the Okanagan Climate Data Interpolator (OCDI).

Table 5.7 Pumping rates and artesian wells flow rates used in the model

NOGWCA Well No	WTN	Flow rate in August, 2007 (m^3/d)	Flow rate in February, 2008 (m^3/d)
Pumping Wells			
35	38650	0	0
72	81601	90	0
177	122	170	0
176	142	150	0
213	N/A	60	0
175	N/A	200	200
174	N/A	100	100
156	N/A	180	0
160	NA/	360	0
47	41502	460	0
30	62416	110	110
41	20648	220	220
215	76254	30	30
216	83441	30	30
217	9184	20	20
Artesian Wells			
32*	169	550	20
23	58716	20	20
34	N/A	30	30
43	N/A	50	50
71	N/A	40	40
Total	N/A	2870	870

*Note: In summer time, irrigation system is operated in well 32.

Table 5.8 Static water level wells used in the model

NOGWCA Well No.	WTN	SWL in August, 2007 (masl)	SWL in February, 2008 (masl)	Aquifer
26	82463	369.567	369.839	Spallumcheen A
115	45422	366.374	367.207	Spallumcheen A
119	N/A	361.201	361.899	Spallumcheen A
42	24104	359.264	360.254	Spallumcheen A
121	N/A	354.054	354.403	Spallumcheen A
122	N/A	355.424	356.122	Spallumcheen A
123	N/A	353.184	353.882	Spallumcheen A
54*	24093	370.300	370.242	Spallumcheen B
55	24080	370.624	370.463	Spallumcheen B
56	24062	358.049	358.646	Spallumcheen B

Note:
a) Well 54 is not used in the calibration but was used to set the northern constant head boundary (Section 2), the static water levels except well 54, 55 and 56 were measured on August 22, 2007 and February 13, 2008.
b) All static water level wells were surveyed to mm accuracy using corrected differential surveying.
c) Static water levels of well 54, 55 and 56 were auto measured by Ministry of Environment and the water levels were averaged in August, 2007 and February, 2008.

Table 5.9 Initial hydraulic conductivity estimates for main regional aquifers

Sub-areas	Hydraulic conductivities of Spallumcheen A ($x10^{-4}$ m/s)	Hydraulic conductivities of Spallumcheen B ($x10^{-4}$ m/s)
I	1.3	1.9
II	2.1	1.9
III	3.6	1.9
IV	1.4	1.9
V	3.6	1.9

Note: The hydraulic conductivities of sub-areas II, III and V of Spallumcheen B were lower than what of Spallumcheen A because modeled Spallumcheen B is physically extended to the model edges, which leading to part of Bedrock with low hydraulic conductivities were included in modeled Spallumcheen B.

Table 5.10 Estimation of water exchange with Spallumcheen A via vertical boundaries as outlined in Figure 5.3

Vertical Boundary Region		Description of Hydrogeological Processes	Exchange Areas (m^2)	NOGWCA Well No.	Thickness of aquitard (m)	Max water exchange (m^3/d)	Min water exchange (m^3/d)
Inflows	1	Eagle Rock aquifer vertical leakage	3,147,700	7,122	60	2700	270
	2	Upper Fortune Creek Unconfined-confined aquifer vertical leakage	5,230,000	118,102	30	1470	147
	3	Okeefe unconfined aquifer (Okeefe A) vertical leakage	6,138,300	104,123	60	80	8
	5	Sleepy Hollow unconfined aquifer leakage	8,328,500	98,115	38	230	23
Outflows	4	Discharge to Okeefe unconfined-confined aquifer (Okeefe B)	5,819,300	106,107,123	20	870	87
	6	Flow upwards into Deep Creek	28,453,700	115,42,119	45	4860	486
	7	Flow upwards into Deep Creek	9,035,500	121,122,123	30	1540	154
	8	Flow upwards into Deep Creek	1,376,400	123	30	240	24
	9	Flow upwards into Fortune Creek	13,957,600	26,54,55	66	3670	367
	10	Flow upwards into lower Fortune Creek Unconfined-confined aquifer	2,054,200	N/A	30	580	58
	11	Flow upward into Otter Lake	712,400	121	12	300	30

Note: Min water exchange using lower estimate of hydraulic conductivity of aquitard at 10^{-9} m/s;

Max water exchange using higher estimate of hydraulic conductivity of aquitard at 10^{-8} m/s.

Table 5.11-A Initial Mountain System Recharge and Distribution

Mountain Areas	Area (m^2)	Average Annual Precipitation (mm/yr)	5.0% of Volume(m3/d)	MSR	Contribution to Potential Aquifers	Interpretation of Initial Distribution of MSR	MBR Volume (m3/yr)
1	3,453,467	452	214	MSR_1=MBR_1	MBR_1 contributes SPA and SPB	50% of MSR_1(MBR_1) enters SPA and 50% of MSR_1 (MBR_1) enters SPB	214
2	6,216,619	556	474	MSR_2=MBR_2	MBR_2 contributes to SPA and SPB	50% of MSR_2(MBR_2) enters SPA and 50% of MSR_2 (MBR_2) enters SPB	474
3	35,950,169	746	3,676	MSR_3=MFR_3+ MBR_3	MFR_3 contributes to Eagle Rock aquifers, MBR_3 contributes to SPA and SPB	MFR_3 is equal to one third of total MSR_3, MBR_3 equals to two thirds of MSR_3, % MBR_3 enters into SPA, 50% of MBR_3 enters SPB	2,451
4	53,509,916	742	5,438	MSR_4=MFR_4+ MBR_4	MFR_4 contributes to Fortune Creek aquifer and MBR_4 contributes to SPA and SPB	MFR_4 equals to one third of total MSR_4, MBR_4 equals to two thirds of MSR_4, 50 % of MBR_4 enters SPA and 50 % of MBR_4 enters SPB	3,626
5	32,339,320	742	3,287	MSR_5=MBR_5	MBR_5 contributes to SPA and SPB	50% of MSR_5(MBR_5) enters SPA and 50% of MSR_5 (MBR_5) enters SPB	3,287
6	5,593,737	543	416	MSR_6= MBR_6	MBR_6contributes to SPA and SPB	50% of MBR_6 enters into SPA, 50% of MBR_6 enters SPB	416

Table 5.11-B Initial Mountain System Recharge and Distribution

Mountain Areas No.	Area (m^2)	Precipitation (mm/yr)	5.0 Percents of Volume(m3/d)	MSR	Contribution to Potential Aquifers	Interpretation of Initial Distribution of MSR	MBR Volume (m3/yr)
7	5,593,737	543	416	MSR_7=MFR_7+ MBR_7	MFR_7 contributes to Sleepy Hollow aqufiers, MBR_7contributes to SPA and SPB	MFR_7 is equal to MBR_7,50% of MFR_7 enters Sleepy Hollow A , 50% of MFR_7 enters Sleepy Hollow B, 50% of MBR_7 enters into SPA, 50% of MBR_7 enters SPB	208
8	15,064,550	539	1,113	MSR_8=MFR_8+ MBR_8	MFR_8 contributes to Sleepy Hollow aqufiers, MBR_8contributes to SPA and SPB	MFR_8 is equal to MBR_8,50% of MFR_8 enters Sleepy Hollow A , 50% of MFR_8 enters Sleepy Hollow B, 50% of MBR_8 enters into SPA, 50% of MBR_8 enters SPB	371
9	12,781,877	559	978	MSR_9=MBR_9	MBR_9 contributes to SPA and SPB	50% of MSR_9 (MBR_9) enter SPA, 50% OF MSR_9 (MBR_9) enters SPB	489
10	8,796,042	500	603	MSR_{10}= MBR_{10}	MBR_{10} contributes to SPA and SPB	50% of MSR_{10} (MBR_{10}) enter SPA, 50% OF MSR_{10} (MBR_{10}) enters SPB	301
Total	179,299,433	N/A	16,600	N/A	N/A	N/A	11,800

N/A-Not Applicable

Table 5.12 Hydraulic conductivities of calibrated steady state model

Sub-areas	Hydraulic conductivities of Spallumcheen A (x10^{-4} m/s)	Hydraulic conductivities of Spallumcheen B (x10^{-4} m/s)
I	1.2	1.6
II	1.4	1.8
III	0.67	0.90
IV	0.91	0.55
V	1.7	0.52

Table 5.13 Observed and simulated static water levels for the period of August, 2007

Wells	Observed SWL (masl)	Simulated SWL (masl)	Error	Absolute Error
26	369.567	369.360	-0.207	0.207
115	366.374	364.940	-1.434	1.434
119	361.201	360.616	-0.585	0.585
42	359.264	358.530	-0.734	0.734
121	354.054	355.754	1.700	1.700
122	355.424	355.522	0.098	0.098
123	353.184	352.062	-1.122	1.122
55	370.624	370.645	0.020	0.020
56	358.049	358.473	0.424	0.424

Table 5.14 Comparison of observed and simulated static water levels for the period of February, 2008

Wells	Observed SWL (masl)	Simulated SWL (masl)	Error (m)	Absolute Error (m)
26	369.839	369.613	-0.226	0.226
115	367.207	366.188	-1.019	1.019
119	361.899	362.195	0.296	0.296
42	360.254	359.983	-0.271	0.271
121	354.403	357.238	2.835	2.835
122	356.122	356.959	0.837	0.837
123	353.882	353.665	-0.218	0.218
55	370.463	370.432	-0.031	0.031
56	358.646	358.865	0.219	0.219

Table 5.15 Simulated water mass balance for the period of August 2007

	Balance items	Spallumcheen A		Spallumcheen B		Modeling Groundwater System (m^3)	
		Amount (m^3)	Percentage	Amount (m^3)	Percentage	Amount (m3)	Percentage
Inflows	Eagle Rock leakage	1,300	7.7	N/A	N/A	1,300	7.5
	Fortune Creek Unconfined-confined leakage	1,040	6.2	N/A	N/A	1,040	6.0
	Okeefe Unconfined leakage	30	0.2	N/A	N/A	30	0.2
	Sleepy Hollow Unconfined leakage	100	0.6	N/A	N/A	100	0.6
	Mountain Block Recharge	7,730	45.9	5,720	53.5	13,450	77.7
	Flux from Sleepy Hollow confined	220	1.3	N/A	N/A	220	1.3
	Flux from Okeefe confined	720	4.3	N/A	N/A	720	4.2
	Water leakage upwards from Spallumcheen B	5,270	31.3	N/A	N/A	N/A	N/A
	Water leakage downwards from Spallumcheen A	N/A	N/A	N/A	46.5	N/A	N/A
	Water flux from North Constant head	440	2.6	N/A	N/A	440	2.5
	Total	16,850	100.0	10,700	100.0	17,300	100.0
Outflows	Discharge into Okeefe Unconfined-confined	460	2.7	N/A	N/A	460	2.7
	Discharge into end of Fortune Creek Unconfined-confined	150	0.9	N/A	N/A	150	0.9
	Discharge into Otter Lake	400	2.4	N/A	N/A	400	2.3
	Flow into Okanagan Lake	2,540	15.1	5,320	49.7	7,860	45.4
	Water leaving Via North Constant Head	N/A	N/A	110	1.0	110	0.6
	Groundwater discharge into Deep Creek	2,290	13.6	N/A	N/A	2,290	13.2
	Groundwater discharge into Fortune Creek	3,160	18.7	N/A	N/A	3,160	18.3
	Water leakage from Spallumcheen B to A	N/A	N/A	5,270	49.3	N/A	N/A
	Water leakage from Spallumcheen A to B	4,980	29.6	N/A	N/A	N/A	N/A
	Pumping	2,710	16.1	N/A	N/A	2,710	15.7
	Artesian flow	160	0.9	N/A	N/A	160	0.9
	Total	16,850	100.0	10,700	100.0	17,300	100.0

N/A= Not Applicable

Table 5.16 Variation of model RMS error in response to changes in model input parameters for the period of August, 2007 (unit: m)

Multipliers	MSR	Hydraulic Conductivity of aquifers	Vertical Recharges	Vertical Discharges	Hydraulic Conductivity of aquitard
0.2	11.519	30.205	3.086	4.965	0.938
0.4	8.705	11.482	2.444	3.709	0.909
0.6	5.901	5.113	1.826	2.480	0.899
0.8	3.134	1.986	1.271	1.356	0.898
0.9	1.847	1.117	1.049	0.956	0.899
1.0	0.902	0.902	0.902	0.902	0.902
1.1	1.478	1.268	0.869	1.239	0.905
1.2	2.777	1.752	0.963	1.755	0.908
1.4	5.531	2.614	1.400	2.939	0.916
1.6	8.333	3.294	1.977	4.181	0.924
1.8	11.146	3.831	2.603	5.443	0.934
2.0	13.964	4.264	3.249	6.712	0.943

Table 5.17 Simulated ranges of total Mountain Block Recharge rates

Mountain areas	Average Annual Precipitation 1971-2005* (mm/yr)	Minimum Recharge Rate (mm/yr) (3.6%of Precipitation)	Maximum Recharge Rate (mm/yr) (4.8% of precipitation)
1	452	16	22
2	556	20	27
3	746	27	36
4	742	27	36
5	742	27	36
6	543	20	26
7	543	20	26
8	539	19	26
9	559	20	27
10	500	18	24

*Data from Okanagan Climate Data Interpolator

Table 5.18 Changes in model RMS error in response to proportion of total mountain block recharge flowing to aquifer Spallumcheen A for the period of August 2007

Flow to Spall A / Total MBR	0.5	0.55	0.6	0.65	0.7	0.75	0.8
RMS	1.331	1.066	0.902	0.895	1.049	1.308	1.622

Note: Distribution of MBR 65% to Spallumcheen A and 35% to Spallumcheen B represents the best fit.

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Appendix 1.1: Summary of data reported or provided to UBC Okanagan

Report Data	Author/Source	Material Type	Received
Geological mapping	Pat Monahan, NOGWCA Contractor	Report	April, 2006
3-D geological model	Greg Keller, Manitoba Geological Survey, NOGWCA Contractor	Report, electronic GoCad and shape files	June, 2006
Geological mapping interpretation	Bob Fulton, NOGWCA Contractor	Report	Sept, 2006
Irrigator usage survey	Ministry of Environment (MOE), Trina Koch	Spreadsheet: well locations, estimated usage	May, 2007
Artesian well survey	MOE, Trina Koch	Spreadsheet: locations and estimated discharge	2007
Bedrock lineament maps	Geological Survey of Canada	Images	June, 2007
Drinking Water Information Management Project (DWIMP)	MOE	Spreadsheet: water usage data	Oct 2007
Observation well testing and recharge characterization of the Okanagan basin, BC. (2005)	Simon Fraser University	Data Final report	Aug 2007 April 2008
Use of well pumping tests to evaluate the transmissive properties of unconsolidated and bedrock aquifers in the northern Okanagan Basin, BC, 2005(1)	MOE	Report Revised data(1)	June 2007 April 2008
Water District usage data	Okanagan Basin Water Board (OBWB)	Data for 2006: 3 districts only	March 2008
Aquifer parameters peport #3(2): Title pending	MOE	Spreadsheet (2)	April 2008
Gridded and interpolated Okanagan climate data	Okanagan land use and agricultural water demand study	Database of daily precipitation, min/max temperature and calculated potential evapotranspiration, SQL programming	April 2008
Kelowna precipitation isotopic data: unpublished data.	Personal communication, Panagiota Athanasopoulos and Dr. Jim Hendry, University of Saskatchewan	Equation of meteoric water line	February 2008
Hydrometric stations: installation and operation	MOE	Flow data for Deep Creek (3 stations) and Fortune Creek (1 Station)	Ongoing

Notes:
(1) Aquifer testing methodologies were revised in Aquifer parameters report #3. The dates for the first two reports represent the dates of final revisions to the reports.
(2) Spreadsheet in progress as per February 2007, which does not include final adjustments to testing methodology.

Appendix 2.1-A Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	Chemistry	Isotopes	SWL	Artesian	Pumping	Depth (m)	Aquifer
1	52444		X					344039	5592375	X					64.01	SLA
2		E267763						347783	5592007	X					45.72	FC
3	62738	E265932		X				345260	5591231	X	X		X		12.19	FC
4	68116	E258749		X				347350	5590805	X	X				24.38	FC
5	25325	E258742		X				342162	5586041	X					51.82	EA
6	25324	E249037		X				342145	5586034	X					51.51	EA
7	32340	1400951		X				342421	5585857	X		X		X		EA
8	25326	E249039		X				342462	5585795	X					48.77	EA
9	30690	E258741		X				342458	5585791	X					51.85	EA
10	19383	E258736		X				342129	5584355	X						EA
11	18897	E258740		X				336360	5585404	X					91.74	OA
12		E267834						336287	5585090	X	X				99.06	OA
13	45000		X					337653	5584457	X						OA
14		E267824						337085	5582347	X	X					OA
15		E267831						336960	5582053	X	X				22.86	OA
16		E267829						338377	5583680	X	X				36.58	OB
17		E267830						338348	5583678	X	X				35.66	OB
18		E267825						337168	5582290	X	X				21.34	OB
19		E267826						337133	5582220	X	X				3.66	OB
20		E266644						341624	5600938	X						TU
21	83440	E258763		X				344990	5599346	X					76.81	HC
22		E269604						336780	5593923	X	X				91.44	HC
23		E265926						349230	5596565	X	X		X		100.58	SPA
24	26983	E265923		X				349865	5595999	X					103.02	SPA
25		E269570						348469	5594789	X	X				54.86	SPA
26	82463	E265922		X			X	349864	5594395	X	X	X			85.34	SPA
27		E269569						348022	5593711	X	X				56.69	SPA
28		E269566						346014	5592701	X	X				53.34	SPA
29		E269567						345494	5591891	X	X				115.82	SPA
30	62416	E258755		X				349027	5591833	X	X				44.20	SPA

Appendix 2.1-B Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	Chemistry	Isotopes	SWL	Artesian	Pumping	Depth (m)	Aquifer
31		E269503						346405	5591583	X	X				60.96	SPA
32	169	E265931		X			X	346186	5591456	X			X		62.48	SPA
33		E269565						346715	5591259	X	X				91.44	SPA
34		E265933						345267	5591213	X	X		X		46.63	SPA
35	38650	E258753		X				344602	5590952	X	X			X		SPA
36		E269564						346365	5590514	X	X				81.08	SPA
37	68114	E258750		X				347330	5590332	X					60.96	SPA
38		E269563						346170	5590320	X	X				85.34	SPA
39	82382			X				343418	5589499	X					85.34	SPA
40	81601		X					343393	5589484	X					86.41	SPA
41	20648		X					341770	5588488	X				X	190.50	SPA
42	24104	1400958		X			X	342493	5588340	X	X	X			179.83	SPA
43		E268964						343254	5586743	X	X		X		198.12	SPA
44	82350		X					337616	5584937	X					152.70	SPA
45		E267835						338368	5584870	X	X				73.15	SPA
46	38270	E258743		X				342207	5584702	X					73.15	SPA
47	41502		X					337203	5584533	X				X		SPA
48		E267832						336995	5583909	X	X				198.12	SPA
49		E267833						339963	5583286	X	X				91.44	SPA
50		E267828						339453	5582958	X	X				106.68	SPA
51	18863	E247043		X				337733	5581558	X					50.29	SPA
52	56610	E258730		X				337558	5581294	X					39.01	SPA
53		E267823						336878	5580433	X	X				38.10	SPA
54	24093	1400962		X			X	349035	5597209	X	X	X	X		318.82	SPB
55	24080	1400964		X			X	348741	5593240	X	X	X			478.53	SPB
56	24062	1400957		X			X	341772	5588491	X	X	X			576.68	SPB
57	69233		X					339425	5595473	X					159.72	BR
58		E269006						346259	5595333	X	X		X		25.91	BR
59		E267836						338627	5587672	X	X				91.44	BR
60		E267837						338627	5587672	X	X				91.44	BR

Appendix 2.1-C Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	Chemistry	Isotopes	SWL	Artesian	Pumping	Depth(m)	Aquifer
61		E269284						344338	5586783	X	X				91.44	BR
62								342335	5597669		X				9 to 18	HU
63	45563							341404	5597454		X				36.00	HU
64								343067	5597074		X					HU
65							X	340360	5596735		X				11.75	HU
66		E269605						336188	5594363		X				91.44	HC
67								343271	5595722		X				30.00	SLB
68								344086	5594039		X				103.00	SPA
69								343894	5593844		X				72.00	SPA
70								344651	5592626		X				59.00	SPA
71		E262830						345468	5590802		X		X		64.62	SPA
73		E266363						340567	5588150		X		X		53.64	SPA
74		E268963						343728	5587531		X				80.77	SPA
75							X	339965	5580109		X				52.00	SPA
76		E269603						345431	5599920		X				30.48	BR
77		E269263						346383	5595650		X		X		60.96	BR
78		E269285						350558	5595285		X		X		67.06	BR
79	63174	E262375		X				346205	5595239		X			X	57.91	BR
80							X	341958	5594963		X				19.15	BR
81							X	342197	5594842		X				37.00	BR
82								342972	5597436		X					HC
83	1263							346204	5595208				X		12.19	
84	16909							346292	5595362				X		12.50	
85	21210							346311	5595391				X		4.27	
86	53902							343765	5587528				X		80.77	
87								343728	5587531				X	X	86.87	SA
88								346285	5595757					X	60.96	
89	31281							342958	5598539				X		30.78	
90							X	341644	5600274			X			10.00	DA

Appendix 2.1-D Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	Chemistry	Isotopes	SWL	Artesian	Pumping	Depth (m)	Aquifer
91							X	342073	5598475			X			21.00	HU
92								342234	5597722			X			18.50	HU
93							X	339737	5597260			X			6.14	HU
94	57252				X	X	X	339538	5597069			X			20.45	HU
95							X	340360	5596735			X			11.75	HU
96	19260?						X	339173	5595799			X			11.45	HU
97							X	339115	5595782			X			26.10	HU
98							X	344584	5592762			X			12.70	SLA
99								342685	5592541			X			62.60	OA
100	39792		X	X				346419	5590229			X			2.26	FC
101								346273	5590201			X			41.60	FC
102								346285	5589802			X			13.80	FC
103							X	341233	5585241			X			11.50	EB
104	45887		X	X				337641	5584429			X		X	91.44	OA
105								338293	5583936			X			14.00	OB
106	9081?						X	338075	5582869			X			8.66	OB
107							X	337798	5582644			X			17.30	OB
108	29167		X	X				344707	5598952			X			49.38	HU
109	63182				X	X	X	342994	5598929			X			40.00	HC
110	58527		X	X				342016	5598292			X			29.79	HC
111								349865	5595323			X				SLB
112							X	346014	5594224			X		X	121.92	SPA
113								344087	5594039			X			103.00	SPA
114								343947	5593911			X			75.00	SPA
115	45422		X	X				344396	5592782			X			79.86	
116								347445	5591371			X			94.10	SPA
117								347429	5591295			X			93.50	SPA
118								346390	5589818			X				SPA
119							X	343782	5589012			X		X	51.50	SPA
120								341230	5588851			X			26.00	SPA

Appendix 2.1-E Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	chemistry	Isotopes	SWL	Artesian	Pumping	Depth(m)	Aquifer
121	68480?						X	339709	5586892			X			49.99	SPA
122	41511?						X	341227	5585265			X			100.00	SPA
123								339286	5583122			X			46.00	SPA
124			X					339965	5580109			X			52.00	SPA
125							X	342823	5600096			X			61.00	BR
126	63184		X	X				344379	5596644			X			29.40	BR
127	63185		X	X				344557	5596489			X			122.53	BR
128	63186		X	X				344705	5596484			X			109.73	BR
129	57310				X	X	X	341898	5595994			X			100 +	BR
130	40342?							340318	5595992			X			95.00	BR
131	2077?						X	342077	5595830			X				BR
134	62405?						X	342109	5594161			X			30.00	BR
135							X	338494	5581699			X			128.00	BR
136							X	338299	5581282			X			18.00	BR
137							X	338790	5579994			X			27.30	BR
138								339098	5595907					X	15.24	HU
139								339116	5595909					X	15.24	HU
140								339136	5595898					X	21.34	HU
141								339155	5595888					X	21.34	HU
142								339168	5595888					X	21.34	HU
143								338188	5595753					X	21.34	HU
144								338246	5595653					X	21.34	HU
145	62395							338226	5595439					X	74.68	HU
146	62396							338269	5595356					X	56.08	HU
147	41506							338413	5595980					X	52.73	HU
148	19193							338982	5595949					X	10.67	HU
149								346017	5594232					X	121.92	SLB
150		E262374						346287	5595280					X	25.91	SLA

Appendix 2.1-F Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	chemistry	Isotopes	SWL	Artesian	Pumping	Depth(m)	Aquifer?
151		E262376						346292	5595362					X	39.62	SLA
152		E262379						346311	5595391					X	39.62	SLA
153	63174							346116	5594518					X	57.91	SLA
154								346378	5595309					X		SLA
155	45688							337653	5584457					X	90.22	OA
156								337266	5584467					X	140.21	SA
157	52379	E262369						340003	5579968					X	39.62	SLB
158	52341	E262370						339997	5579966					X	54.86	SLB
159	52444	E262371						340055	5579674					X	64.01	SLB
160								NA	NA					X	27.43	SLB
161								339623	5581284					X	27.43	SLB
162		E262372						338036	5581930					X	48.77	OB
163		E262373						340242	5593725					X	63.09	SLA
164		E262368						341846	5592538					X	40.23	SLA
165		E262366						339639	5596966					X	19.81	HC
166	50316							339668	5596974					X	18.29	HC
167	27577							339548	5597066					X	18.29	HC
168		E262367						339537	5596702					X	18.29	HU
169	62423							339691	5597234					X	15.24	HU
170								350859	5598363					X	158.50	SLA
171	82938				X	X		350844	5598704					X	152.40	SLA
172	62444				X	X		350794	5598707					X	48.77	FC
173	82722				X	X		350772	5598602					X	97.54	SLA
174	53902?							343765	5587528					X	80.77	SPA
175								343728	5587531					X	86.87	SPA
176	142							344450	5589236					X	85.34	SLA
177	122							344438	5589276					X	85.34	SLA
178								344873	5589657					X	85.34	SLA
179		E262319						337849	5594653					X	21.34	HU
180		E262320						338211	5595099					X	21.34	HU

Appendix 2.1-H Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	chemistry	Isotopes	SWL	Artesian	Pumping	Depth(m)	Aquifer
181		E262321						338042	5594971					X	21.34	HU
182		E262322						337865	5594947					X	11.28	HU
183		E262323						337908	5594572					X	36.58	HU
184	82425	E262324						338007	5594585					X	48.77	HU
185		E262359						337338	5594914					X	100.58	HC
186		E262360						338014	5594432					X		N/A
187		E262361						341446	5597375					X	67.06	HC
188		E262362						341386	5597381					X	67.06	HC
189		E262363						346182	5591459					X	62.48	FC
190								346383	5595650					X	60.96	SLA
191								346337	5595702					X	60.96	SLA
192								346285	5595757					X		N/A
193								345927	5595646					X		N/A
194	63174?							345983	5594157					X		SLB
195								347244	5593612					X		SLA
196		E262380						346051	5594174					X	64.62	SLA
197	41474							342642	5597771					X	38.40	HC
198	46540							342391	5597775					X	47.24	HC
199	44872							342299	5597779					X	36.88	HC
200	751							343248	5598420					X	60.35	HC
201								343255	5598516					X	44.20	HC
202	76133	E262364						343031	5597761					X	42.06	HC
203		E262365						342007	5598212					X	33.83	HC
204								341567	5597415					X	51.51	HC
205								N/A	N/A					X	82.30	HC
206	31281?							342958	5598539					X	45.11	HC
207								N/A	N/A					X		N/A
208	9216							342883	5596832					X	93.27	HC
209	48180							342835	5596863					X	93.27	HC
210		E262539						345807	5594022					X	51.82	SLA

Appendix 2.1-I Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	chemistry	Isotopes	SWL	Artesian	Pumping	Depth(m)	Aquifer
211								344015	5575777					X	24.38	N/A
212								339948	5583859					X	273.10	N/A
213								340567	5588150					X	53.64	N/A
214		E262540						343078	5598870					X	34.75	HC
215	76254		X					348941	5595184					X		SPA
216	83441		X					348916	5595152					X		SPA
217	9184		X					337479	5581059					X		SPA
218	24130		X					335193	5586440							
219								343124	5596575					X		HC
220	68125		X					347341	5589842					X		
221	9104		X					342082	5592260				X		62.48	
222	9293		X					342851	5597704				X		0.00	
223	13612		X					344109	5586855				X		2.44	
224	16484		X					348012	5592985				X		9.45	
225	17425		X					341718	5601607				X		2.13	
226	20288		X					342226	5585995				X		35.97	
227	22179		X					343842	5587969				X		84.12	
228	22973		X					342121	5586030				X		50.29	
229	23647		X					348235	5592791				X		59.44	
230	24094		X					344632	5587702				X		36.58	
231	25323		X					342206	5585670				X		25.91	
232	26446		X					344777	5587727				X		8.23	
233	28187		X					343743	5587391				X		85.34	
234	28968		X					342414	5586236				X		25.30	
235	29195		X					344125	5588056				X		67.06	
236	30998		X					344047	5586787				X		73.15	
237	31069		X					344207	5588056				X		60.35	
238	39190		X					344395	5586929				X		54.86	
239	39436		X					344343	5586772				X		70.10	
240	45769		X					343752	5587959				X		93.88	

Appendix 2.1-J Information of wells used in the report

No	WTN	EMS	WTN Available	WTN from EMS	WTN by UTM	UTM Checked	Surveyed	Easting	Northing	chemistry	Isotopes	SWL	Artesian	Pumping	Depth(m)	Aquifer
241	58716		X					348082	5592565				X		40.84	
242	62415		X					345872	5590721				X		48.77	
243	62425		X					339764	5598114				X		54.86	
244	62427		X					341549	5600111				X		79.25	
245	62446		X					342107	5600876				X		24.99	
246	62477		X					344178	5601172				X		109.73	
247	63165		X					344864	5588064				X		182.88	
248	63187		X					350374	5597074				X		94.79	
249	63205		X					338322	5583845				X		53.95	
250	69041		X					343513	5589670				X		79.25	
251	82451		X					346410	5595980				X		27.43	
252	82467		X					342460	5585962				X		11.58	
253	82515		X					343517	5587319				X		76.81	
254	82517		X					344192	5587028				X		54.25	
255	82519		X					344744	5587798				X		90.22	
256	82520		X					344158	5586972				X		58.52	
257	82607		X					343158	5587381				X		93.27	
258	82892		X					348437	5593580				X		51.82	
259	85478		X					343728	5587531				X		86.26	
260	85558		X					340690	5588259				X		53.64	
261	94089		X					346287	5595280				X		25.91	
262	94090		X					346292	5595362				X		39.62	
263	94093		X					346311	5595391				X		39.62	
264	94098		X					346204	5595208				X		57.91	
265	94403		X					346051	5594174				X		64.62	

Note: SWL –Static water level observation wells; DA-Deep Creek Confined aquifer; BR-Bedrock aquifers; EA-Eagle Rock Unconfined-confined aquifer; FC-Fortune Creek Unconfined-confined aquifer; HU-Hullcar Unconfined aquifer; HC-Hullcar Confined aquifer; OA- Okeefe Unconfined aquifer; OB-Okeefe Unconfined-confined aquifer; SLA-Sleepy Hollow Unconfined aquifer; SLB-Sleepy Hollow Confined aquifer; SPA-Spallumcheen A aquifer; SPB-Spallumcheen B aquifer.

Appendixes 2.2 Monthly mean discharges (m^3/s) for the periods at each station on Deep Creek

DEEP CREEK AT YOUNG ROAD													
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD
1970	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.007	0.010	0.005	0.002
1971	0.007	0.012	0.020	0.294	0.514	0.207	0.045	0.008	0.008	0.011	0.014	0.011	0.096
1972	0.013	0.014	0.316	0.794	1.37	0.265	0.173	0.035	0.049	0.053	0.087	0.059	0.270
1973	0.026	0.036	0.302	0.209	0.260	0.096	0.025	0.009	0.009	0.025	0.020	0.026	0.087
1974	0.034	0.059	0.156	0.720	0.889	0.263	0.068	0.010	0.007	0.021	0.028	0.024	0.190
1975	0.013	0.008	0.024	0.398	1.11	0.277	0.063	0.014	0.014	0.013	NA	NA	0.164
DEEP CREEK NEAR VERNON (STATION NO. 3)													
1935	NA	NA	NA	NA	1.64	0.703	0.563	0.315	0.239	NA	NA	NA	NA
1936	NA	NA	NA	1.60	1.83	0.519	0.252	0.132	0.176	NA	NA	NA	NA
1937	NA	NA	NA	1.41	1.40	0.541	0.260	0.155	0.152	NA	NA	NA	NA
1938	NA	NA	NA	0.932	0.632	0.187	0.118	0.110	0.139	NA	NA	NA	NA
1939	NA	NA	0.471	1.00	0.711	0.405	0.229	0.111	0.141	NA	NA	NA	NA
1940	NA	NA	0.599	0.977	0.930	0.337	0.126	0.108	0.120	NA	NA	NA	NA
1941	NA	NA	NA	0.606	0.424	0.260	0.107	0.074	0.238	NA	NA	NA	NA
1942	NA	NA	NA	0.504	0.668	1.08	0.569	0.325	0.256	NA	NA	NA	NA
1943	NA	NA	NA	1.38	0.879	0.426	0.201	0.178	0.089	NA	NA	NA	NA
1944	NA	NA	NA	0.740	0.644	0.387	0.161	0.140	0.200	NA	NA	NA	NA
1945	NA	NA	NA	NA	1.65	0.697	0.218	0.102	NA	NA	NA	NA	NA
1946	NA	NA	NA	0.920	1.88	0.670	0.286	0.182	0.183	NA	NA	NA	NA
1947	NA	NA	NA	0.677	0.709	0.288	0.176	0.144	0.167	NA	NA	NA	NA
1948	NA	NA	NA	0.797	2.58	1.45	0.421	0.305	0.302	NA	NA	NA	NA
1949	NA	NA	NA	1.53	1.49	0.583	0.225	0.218	0.329	NA	NA	NA	NA
1950	NA	NA	NA	0.599	0.923	0.478	NA	NA	NA	NA	NA	NA	NA
DEEP CREEK AT THE MOUTH													
1969	------	------	------	------	------	------	------	------	------	------	0.297	0.319	0.063
1970	0.294	0.339	0.550	0.521	0.482	0.209	0.147	0.139	0.187	0.232	0.296	0.268	0.305
1971	0.254	0.370	0.457	0.642	1.39	0.850	0.373	0.117	0.157	0.211	0.282	0.312	0.451
1972	0.302	0.320	1.36	1.49	2.48	0.776	0.313	0.216	0.280	0.377	0.409	0.420	0.731
1973	0.358	0.356	1.35	0.610	0.776	0.302	0.081	0.083	0.205	0.297	0.326	0.358	0.426
1974	0.518	0.517	0.598	0.956	1.95	0.723	0.224	0.117	0.180	0.277	0.230	0.336	0.553
1975	0.308	0.228	0.392	1.02	2.02	0.687	0.152	0.194	0.250	0.342	------	------	0.479
DEEP CREEK AT ARMSTRONG													
1951	NA	NA	NA	NA	0.742	0.183	0.055	0.013	0.048	NA	NA	NA	0.088
1952	NA	NA	NA	0.880	1.07	0.403	0.107	0.030	0.043	NA	NA	NA	0.211
1953	NA	NA	NA	0.074	0.175	0.120	0.064	0.024	0.026	NA	NA	NA	0.040
1954	NA	NA	NA	0.387	0.691	0.402	0.161	0.081	0.083	NA	NA	NA	0.151
1955	NA	NA	NA	NA	0.536	0.241	0.094	0.033	0.012	NA	NA	NA	0.083
1956	NA	NA	NA	0.754	0.830	0.188	0.050	0.023	0.024	NA	NA	NA	0.156
1957	NA	NA	NA	NA	0.874	0.166	0.047	0.040	NA	NA	NA	NA	0.135
1958	NA	NA	NA	NA	0.815	0.159	0.030	0.003	NA	NA	NA	NA	0.131
1959	NA	NA	NA	NA	0.966	0.307	0.089	0.049	0.107	0.138	0.200	0.111	0.188
1960	0.066	0.078	0.500	1.05	0.919	0.308	0.043	0.025	0.028	0.057	0.096	0.066	0.270
1961	NA	NA	NA	NA	0.539	0.062	0.016	0.015	0.023	NA	NA	NA	0.057
1962	NA	NA	NA	0.301	0.297	0.101	0.024	0.019	0.020	NA	NA	NA	0.064
1963	NA	NA	NA	NA	0.241	0.031	0.026	0.018	0.020	NA	NA	NA	0.042
1964	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1965	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1966	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1967	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1968	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1969	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1970	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1971	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1972	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1973	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1974	NA	NA	NA	NA	NA	0.302	0.120	0.017	0.034	0.022	0.035	0.044	0.146
1975	0.047	0.044	0.243	0.678	1.46	0.426	0.078	0.016	0.029	0.041	0.065	0.064	0.267
1976	0.068	0.071	0.148	0.598	0.875	0.229	0.078	0.277	0.188	0.167	0.140	0.157	0.250
1977	0.084	0.196	0.260	0.356	0.271	0.084	0.017	0.008	0.023	0.040	0.070	0.076	0.123
1978	0.082	0.085	0.401	1.02	1.35	0.237	0.071	0.023	0.060	0.047	0.056	0.041	0.290
1979	0.027	0.045	0.203	0.245	0.365	0.064	0.017	0.012	0.021	0.025	0.031	0.041	0.092
1980	0.034	0.060	0.290	0.100	0.086	0.099	0.018	0.009	0.038	0.050	0.045	0.057	0.074
1981	0.069	0.194	0.278	0.313	0.468	0.320	0.133	0.010	0.016	0.039	0.090	0.100	0.169
1982	0.062	0.122	0.524	1.13	1.72	0.194	0.417	0.128	0.112	0.093	0.088	0.127	0.395

Appendix 2.3 Monthly Mean Discharges (m^3/s) for the period of January 1950 - December 1961 on Fortune Creek

Fortune Creek at Stepney													
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	PERIOD
1950	----	----	----	0.201	3.250	----	0.321	0.133	0.064	----	----	----	----
1951	----	----	----	1.050	6.960	2.740	1.130	0.120	0.103	----	----	----	----
1952	----	----	----	1.590	----	----	0.591	0.131	0.090	----	----	----	----
1953	----	----	----	0.300	2.790	3.350	0.634	0.119	0.116	----	----	----	----
1954	----	----	----	0.169	7.250	8.760	2.350	0.240	0.223	----	----	----	----
1955	----	----	----	0.179	2.210	8.150	3.440	0.106	0.059	----	----	----	----
1956	----	----	----	1.070	5.460	4.590	0.501	0.118	0.120	----	----	----	----
1957	----	----	----	----	5.990	1.240	0.258	0.091	0.037	----	----	----	----
1958	----	----	----	----	----	----	0.219	0.018	0.021	----	----	----	----
1959	----	----	----	----	----	----	----	0.060	0.484	----	----	----	----
1960	0.347	0.649	0.982	1.910	4.520	2.930	0.588	0.044	0.082	0.102	0.091	0.079	----
1961	----	----	----	----	----	----	----	----	----	----	----	----	----
Fortune Creek near Armstrong													
1911	------	------	------	------	------	------	------	------	0.135	0.078	0.06	0.019	0.025
1912	0.014	0.035	0.04	0.128	2.35	1.82	0.53	0.155	0.134	0.073	0.057	0.042	0.449
1913-1958 Not Available													
1959	------	------	------	------	3.59	3.17	0.595	0.127	0.438	1.03	0.476	0.178	0.832
1960	0.17	0.122	0.156	1.56	------	1.93	0.305	0.035	0.065	0.059	0.068	0.035	0.372
1961	0.025	0.032	0.049	0.189	5.19	2.77	0.175	0.06	0.037	0.252	0.095	0.037	0.748
1962	0.023	0.075	0.061	1.38	4.06	2.61	0.25	0.144	0.116	0.24	0.332	0.241	0.797
1963	0.103	0.074	0.062	0.975	4.1	1.34	0.464	0.064	0.05	0.042	0.062	0.061	0.621
1964	0.044	0.04	0.04	0.069	3.32	5.53	0.971	0.507	0.733	0.646	0.233	0.125	1.02
1965	0.092	0.105	0.095	1.15	4.75	2.43	0.363	0.198	0.264	0.199	0.204	0.15	0.837
1966	0.09	0.062	0.062	0.367	2.46	1.35	0.611	0.089	0.018	0.06	0.098	0.078	0.448
1967	0.064	0.06	0.035	0.044	2.74	3.76	0.183	0.037	0.005	0.019	0.099	0.064	0.593
1968	0.052	0.073	0.119	0.173	1.82	2.73	0.264	0.093	0.369	0.265	0.27	0.108	0.526
1969	------	------	------	0.931	3.45	1.11	0.477	0.051	0.158	0.351	0.277	0.151	0.584
1970	0.074	0.056	0.031	0.048	2.28	0.873	0.069	0.04	0.057	0.06	0.039	0.015	0.306
1971	0.016	0.089	0.069	0.272	4.47	3.35	0.567	0.05	0.036	0.029	0.028	0.028	0.753
1972	0.028	0.024	0.093	0.166	3.73	2.69	0.8	0.142	0.152	0.168	0.124	0.074	0.685
1973	0.051	0.05	0.046	0.138	2.93	0.904	0.134	0.053	0.031	------	------	------	0.369
1974	0.125	0.053	0.067	1	4.81	3.79	0.677	------	------	------	------	------	0.885
1975-1976 Not Available													
1977	------	------	------	------	------	------	------	------	0.03	0.042	0.028	0.02	0.013
1978	0.02	0.012	0.026	0.393	2.9	2.19	0.264	0.089	0.298	0.172	0.107	0.061	0.546
1979	0.029	0.018	0.021	0.059	2.79	0.863	0.152	0.046	0.04	0.004	0.016	0.013	0.341
1980	0.012	0.003	0.014	1.05	2.7	1.6	0.298	0.096	0.167	0.095	0.139	0.117	0.525
1981	0.179	0.128	0.093	0.29	4	2.46	0.975	0.12	0.076	0.16	0.208	0.101	0.738
1982	0.065	0.066	0.063	0.119	2.91	3.07	1.29	0.254	0.143	0.151	0.082	0.053	0.693
1983	0.048	0.054	0.134	0.657	3.59	1.68	0.536	0.109	0.205	0.068	0.181	0.069	0.615
1984	0.082	0.051	0.058	0.282	1.82	3.93	0.668	0.072	0.08	0.043	0.024	0.013	0.591

Appendix 2.4-A Licensed extraction of water from Deep Creek by license

License No	WR Map Point Code	Purpose	Quantity	Units	Quantity (m^3/yr)	Qty Flag	Rediv Flag	Licensee	Licence Status	Process Status	Priority Date YYYYMMDD
F016833	8594 AA (PD59134)	Domestic	1000	GD	1382	M	N	FANKHAUSER HANS & IDA L 573 DEEP CREEK RD ENDERBY BC V0E1V3	Current	N/A	19510810
F044268	82.L.045.3.1 A (PD59370)	Domestic	500	GD	691	T	N	LONGSTAFF BARRY R BOX 723 ARMSTRONG BC V0E1B0	Current	N/A	19070208
C042529	82.L.045.3.1 B (PD59363)	Irrigation	60	AF	74009	M	N	WILLIAMSON HILDA K 2600 YOUNG RD ARMSTRONG BC V0E1B4	Current	N/A	19730730
C042529	82.L.045.3.1 D (PD59361)	Irrigation	60	AF	74009	M	N	WILLIAMSON HILDA K 2600 YOUNG RD ARMSTRONG BC V0E1B4	Current	N/A	19730730
C042530	82.L.045.3.1 B (PD59363)	Irrigation	15	AF	18502	T	N	WILLIAMSON HILDA K 2600 YOUNG RD ARMSTRONG BC V0E1B4	Current	N/A	19730730
C045650	82.L.054.2.2 E (PD59338)	Irrigation	100	AF	123348	T	N	REGEHR DOUGLAS & ELAINE 5042 SCHUBERT RD ARMSTRONG BC V0E1B4	Current	Sec. 18 Amendment	19740212
C045651	82.L.054.2.2 E (PD59338)	Irrigation	30	AF	37004	T	N	REGEHR DOUGLAS & ELAINE 5042 SCHUBERT RD ARMSTRONG BC V0E1B4	Current	Sec. 18 Amendment	19740212
C052891	82.L.034.4.1 D (PD59759)	Irrigation	27.14	AF	33477	T	N	O'KEEFE RANCH & INTERIOR HERITAGE SOC BOX 955 VERNON B C V1T6M8	Current	N/A	19470528
C052892	82.L.034.4.1 D (PD59759)	Irrigation	6	AF	7401	T	N	O'KEEFE TIERNEY BOX 429 VERNON B C V1T6M3	Current	N/A	19470528
C052893	82.L.034.4.1 D (PD59759)	Irrigation	6	AF	7401	T	N	DELISIMUNOVIC JOSIP & JADRANKA 415 ST ANNES RD ARMSTRONG BC V0E1B5	Current	N/A	19470528
C062271	82.L.054.2.2 D (PD59337)	Irrigation	100	AF	123348	T	N	HANSON STEPHEN L & MARY L 4144 HULLCAR ROAD ARMSTRONG BC V0E1B4	Current	N/A	19840313
C069206	82.L.034.4.3 K (PD59735)	Irrigation	55.75	AF	68767	T	N	KLOPPENBURG BROS FARMS LTD 4590 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	19431202
F013130	82.L.034.2.3 A (PD59796)	Irrigation	417.6	AF	515102	M	N	OKANAGAN INDIAN BAND 12420 WESTSIDE RD VERNON BC V1H2A4	Current	N/A	19300718
F015901	82.L.034.4.1 C (PD59755)	Irrigation	136	AF	167754	T	N	OKANAGAN INDIAN BAND 12420 WESTSIDE RD VERNON BC V1H2A4	Current	N/A	19491109

Appendix 2.4-B Licensed extraction of water from Deep Creek by license

License No	WR Map Point Code	Purpose	Quantity	Units	Quantity (m^3/yr)	Qty Flag	Rediv Flag	Licensee	Licence Status	Process Status	Priority Date YYYYMMDD
F016833	8594 AA (PD59134)	Irrigation	10	AF	12335	M	N	FANKHAUSER HANS & IDA L 573 DEEP CREEK RD ENDERBY BC V0E1V3	Current	N/A	19510810
F021312	82.L.034.4.3 H (PD59733)	Irrigation	10.75	AF	13260	T	N	BLOOMFIELD DANIEL S 4580 LARKIN X RD COMP 22 RR 3 ARMSTRONG BC V0E1B0	Current	N/A	19431202
F021502	82.L.034.4.1 E (PD59757)	Irrigation	89	AF	109780	T	N	HAMMING HOLSTEINS LTD 9344 HWY 97 N VERNON BC V1H1W9	Current	N/A	19530519
F021503	82.L.034.4.3 K (PD59735)	Irrigation	100	AF	123348	T	N	KLOPPENBURG BROS FARMS LTD 4590 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	19530519
F021505	82.L.034.4.1 F (PD59753)	Irrigation	43.7	AF	53903	T	N	HAMMING HOLSTEINS LTD 9344 HWY 97 N VERNON BC V1H1W9	Current	N/A	19530519
F044268	82.L.045.3.1 A (PD59370)	Irrigation	47.1	AF	58097	T	N	LONGSTAFF BARRY R BOX 723 ARMSTRONG BC V0E1B0	Current	N/A	19070208
F049529	82.L.034.4.1 F (PD59753)	Irrigation	142.8	AF	176141	T	N	HAMMING HOLSTEINS LTD 9344 HWY 97 N VERNON BC V1H1W9	Current	N/A	19530519
F052953	82.L.034.4.1 D (PD59759)	Irrigation	46.9	AF	57850	M	N	O'KEEFE RANCH & INTERIOR HERITAGE SOC BOX 955 VERNON B C V1T6M8	Current	N/A	19530519
F052953	82.L.034.4.1 E (PD59757)	Irrigation	46.9	AF	57850	M	N	O'KEEFE RANCH & INTERIOR HERITAGE SOC BOX 955 VERNON B C V1T6M8	Current	N/A	19530519
C103556	82.L.044.2.4 H (PD64179)	Irrigation Local Auth	110	AF	135683	T	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19910611
F052952	82.L.034.4.1 E (PD59757)	Irrigation Local Auth	27.6	AF	34044	T	N	NORTH OKANAGAN REGIONAL DIST(GVS W) ATTN: GVS WATER MANAGER 9848 ABERDEEN RD COLDSTREAM BC V1B2K9	Current	N/A	19530519
F064274	82.L.044.2.4 G (PD59524)	Land Improve	0	TF	0	T	N	DEEP CREEK IMPROVEMENT DIST C/O FRED FINDLAY 1493 ITTER LAKE RD ARMSTRONG BC V0E1B5	Current	N/A	19490607
C062163	8594 Q5 (PD59136)	Land Improve	5	AF	6167	M	N	R'ANN CHIRA ECOSYSTEMS INC 1429 DEEP CREEK RD RR3 ENDERBY BC V0E1V3	Current	Sec. 18 Amendment	19830426
C062163	8594 S5 (PD59137)	Land Improve	5	AF	6167	M	N	R'ANN CHIRA ECOSYSTEMS INC 1429 DEEP CREEK RD RR3 ENDERBY BC V0E1V3	Current	Sec. 18 Amendment	19830426

Appendix 2.4-C Licensed extraction of water from Deep Creek by license

License No	WR Map Point Code	Purpose	Quantity	Units	Quantity (m^3/yr)	Qty Flag	Rediv Flag	Licensee	Licence Status	Process Status	Priority Date YYYYMMDD
C066582	82.L.045.1.3 M (PD59424)	Land Improve	0	TF	0	M	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19561018
C042531	82.L.045.3.1 B (PD59363)	Storage	15	AF	18502	T	N	WILLIAMSON HILDA K 2600 YOUNG RD ARMSTRONG BC V0E1B4	Current	N/A	19730730
C045652	82.L.054.2.2 E (PD59338)	Storage	30	AF	37004	T	N	REGEHR DOUGLAS & ELAINE 5042 SCHUBERT RD ARMSTRONG BC V0E1B4	Current	Sec. 18 Amendment	19740212
C103556	82.L.044.2.4 H (PD64179)	Storage	110	AF	135683	T	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19910611
C064226	82.L.034.4.1 D (PD59759)	Watering	70	AF	86344	T	N	SPALLUMCHEEN ESTATES LTD BOX 218 VERNON BC V1T6M2	Current	N/A	19841212
C064257	82.L.034.4.1 D (PD59759)	Watering	160.86	AF	198418	T	N	SPALLUMCHEEN ESTATES LTD BOX 218 VERNON BC V1T6M2	Current	N/A	19470528
Total	N/A	N/A	N/A	N/A	3,087,900	N/A	N/A	N/A	N/A	N/A	N/A

Notes: Descriptions of each Unit for Appendix 2.4,

- AF (acre-feet per annum)
- GD (gallons per day)
- TF (total flow) - a unit shown against non-consumptive purposes for which the total flow of the source is authorized to pass through the licensed works

Appendix 2.5-A Licensed extraction of water from Fortune Creek by license

License No	WR Map Point Code	Purpose	Quantity	Units	Quantity (m^3/yr)	Qty Flag	Rediv Flag	Licensee	Licence Status	Process Status	Priority Date YYYYMMDD
F004898	82.L.045.1.4 B (PD59390)	Domestic	3500	GD	4836	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	18900106
F004899	82.L.045.1.4 B (PD59390)	Domestic	500	GD	691	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	18911111
F004902	82.L.045.1.4 B (PD59390)	Domestic	500	GD	691	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	18911111
C045635	82.L.045.1.3 K (PD59399)	Irrigation	20	AF	24670	T	N	POPOFF GERALD G 1665 WHITAKER RD ARMSTRONG BC V0E1B8	Current	N/A	19750307
C057306	82.L.045.3.4 A (PD60197)	Irrigation	18	AF	22203	T	N	MACAULAY PHILIP G & ELIZABETH K 1411 STEPNEY CROSS RD ARMSTRONG BC V0E1B8	Current	N/A	19790704
C057514	82.L.045.3.4 B (PD60196)	Irrigation	45	AF	55507	T	N	TO BE DETERMINED C/O WATER REVENUE UNIT PO BOX 9340 STN PROV GOVT VICTORIA BC V8W9M1	Pending	Apportionment Pend	19800829
F048861	82.L.045.3.1 J (PD59375)	Irrigation	11.2	AF	13815	T	N	MILLER JEFFERY C 4134 LANDSDOWNE RD ARMSTRONG BC V0E1B3	Current	N/A	19700817
F048862	82.L.045.3.1 H (PD59377)	Irrigation	40	AF	49339	T	N	FOWLER ALFRED 3790 HWY 97A ARMSTRONG B C V0E1B8	Current	N/A	19640511
F048865	82.L.055.1.2 F (PD60002)	Irrigation	95.6	AF	117921	T	N	STANDBRIDGE ERNEST H & ELAINE M 5162 HWY 97A N ARMSTRONG BC V0E1B8	Current	N/A	19700805
F049255	82.L.045.3.1 K (PD59373)	Irrigation	10	AF	12335	T	N	POTHOVEN WILLIAM & TILDA 9765 CREAMERY RD ARMSTRONG BC V0E1B8	Current	N/A	19620524
C002286	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	1.83E+08	GY	690838	T	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19020621
C019215	82.L.045.1.4 B (PD59390)	Waterworks Local Auth	3650000	GY	13817	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	19490718
C019430	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	1.83E+08	GY	690838	T	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19491010
C033449	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	1.1E+08	GY	414503	T	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19570129

Appendix 2.5-B Licensed extraction of water from Fortune Creek by license

License No	WR Map Point Code	Purpose	Quantity	Units	Quantity (m^3/yr)	Qty Flag	Rediv Flag	Licensee	Licence Status	Process Status	Priority Date YYYYMMDD
C033451	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	3285000	GY	12435	T	N	SPALLUMCHEEN TOWNSHIP OF 4144 SPALLUMCHEEN WAY SPALLUMCHEEN BC V0E1B6	Current	N/A	19650826
C033453	82.L.045.1.4 B (PD59390)	Waterworks Local Auth	10767500	GY	40759	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	19650826
C033455	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	8030000	GY	30397	T	N	HIGHLAND PARK WATERWORKS DISTRICT C/O B WEINTZ 4768 SCHUBERT RD ARMSTRONG BC V0E1B4	Current	N/A	19650826
C033457	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	9490000	GY	35924	T	N	SPALLUMCHEEN TOWNSHIP OF 4144 SPALLUMCHEEN WAY SPALLUMCHEEN BC V0E1B6	Current	N/A	19650826
C033545	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	7117500	GY	26943	T	N	LANSDOWNE WATERWORKS DISTRICT C/O ALFRED BENNETT 4420 LANSDOWNE RD ARMSTRONG BC V0E1B3	Current	N/A	19650826
C042043	82.L.045.1.4 B (PD59390)	Waterworks Local Auth	13322500	GY	50431	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	18911111
C049565	82.L.045.1.4 B (PD59390)	Waterworks Local Auth	13322500	GY	50431	T	N	SILVER STAR WATERWORKS DISTRICT C/O RALPH LEYENHORST 4444 LARKIN CROSS RD ARMSTRONG BC V0E1B6	Current	N/A	19770520
C063519	82.L.045.1.4 C (PD59391)	Waterworks Local Auth	3.39E+08	GY	1284958	M	N	ARMSTRONG CITY OF CORY CLEMENT WATER/WAST TECH. PO BOX 40 ARMSTRONG BC V0E1B0	Current	N/A	19810615
Total	N/A	N/A	N/A	N/A	3,644,300	N/A	N/A	N/A	N/A	N/A	N/A

Notes: Descriptions of each Unit for Appendix 2.5 are as follows,

- AF (acre-feet per annum)
- GD (gallons per day)
- GY (gallons per year)

Appendix 3.1-A Information of Static Water Level wells

NO	WTN	Owner	Address	Easting	Northing	Elevation (m)	Stick-up (m)	Depth (m)	Aquifer
90	NA			341644.319	5600274.292	530.244	0.20	10.00	DA
91	NA	Community Hall	Corner Hullcar/ Deep C.	342072.723	5598474.856	517.640	0.80	21.00	HU
92	NA			342234.000	5597722.000	513.800	N/A	18.50	HU
93	NA			339737.205	5597259.723	508.708	1.12	6.14	HU
94	57252			339538.454	5597069.243	511.126	0.18	20.45	HU
95	NA			340360.056	5596735.025	522.474	0.40	11.75	HU
96	NA			339172.618	5595799.238	510.217	0.50	11.45	HU
97	NA			339115.271	5595781.970	510.276	0.75	26.10	HU
98	NA			344583.516	5592761.626	372.106	0.25	12.70	SLA
99	NA			342685.000	5592541.000	412.300	0.50	62.60	SLA
100	39792			346418.636	5590228.666	381.822	0.44	2.26	FC
101	NA	Armstrong Landfill1	MW4	346273.000	5590201.000	373.640	0.72	41.60	FC
102	NA	Armstrong Landfill4	MW10A	346285.000	5589802.000	388.880	0.82	13.80	FC
7	32340	MOE	MOE	342481.908	5585805.155	422.506	2.24	48.77	EA
103	NA	Gov. Well	1151 Thomas Hayes Rd.	341233.245	5585241.022	397.229	0.80	11.50	EB
104	45887			337640.573	5584428.744	373.552	0.60	91.44	OA
105	NA			338293.000	5583936.000	354.200	0.80	14.00	OA
106	NA			338074.609	5582869.487	357.859	0.90	8.66	OB
107	NA			337797.529	5582644.403	362.359	0.30	17.30	OB
108	29167			344706.919	5598951.518	513.271	0.80	49.38	HC
109	NA			342994.076	5598928.534	521.751	0.60	40.00	HC
110	58527			342015.653	5598292.181	507.588	0.80	29.79	HC
111	NA			349865.000	5595323.000	382.000	N/A	N/A	SLB
26	82463			349864.435	5594395.364	382.029	0.30	110.34	SPA
112	NA			346013.617	5594223.813	405.424	0.40	121.92	BR
113	NA			344087.000	5594039.000	437.800	0.42	103.00	SPA
114	NA			343947.000	5593911.000	441.200	0.40	75.00	SPA
115	45422			344396.432	5592781.983	378.382	0.25	79.86	SPA
116	NA			347445.000	5591371.000	388.000	N/A	94.10	SPA
117	NA			347429.000	5591295.000	389.000	N/A	93.50	SPA
118	NA	Armstrong Landfill3	MW10B	346390.000	5589818.000	388.840	0.89		SPA

Appendix 3.1-B Information of Static Water Level wells

NO	WTN	Owner	Address	Easting	Northing	Elevation (m)	Stick-up (m)	Depth (m)	Aquifer
119	NA			343781.571	5589012.221	393.014	0.55	51.50	SPA
120	NA			341230.000	5588851.000	365.000		26.00	SPA
42	24104	MOE	MOE	342492.987	5588340.487	391.577	0.61	179.83	SPA
121	NA			339708.538	5586891.521	389.448	0.80	49.99	SPA
122	NA			341226.625	5585264.897	396.462	0.10	100.00	SPA
123	NA			339286.150	5583121.899	391.572	0.50	46.00	SPA
124	NA			339964.53	5580108.713	400.841	0.75	52	SPA
54	24093	MOE	MOE	349035.49	5597208.592	370.9	1.19	318.82	SPB
55	24080	MOE	MOE	348741.18	5593239.889	384.52	0.985	478.54	SPB
56	24062	MOE	MOE	341771.94	5588491.405	375.053	0.696	576.68	SPB
125	NA			342822.56	5600096.38	554.647	0.6	61	BR
126	63184			344379.23	5596644.041	500.49	0.55	29.4	BR
127	63185			344557.37	5596488.763	499.042	0.52	122.53	BR
128	63186			344704.92	5596484.008	507.367	0.55	109.73	BR
129	NA			341898.29	5595994.095	569.038	0.1	100 +	BR
130	NA			340318	5595992	545	0.33	95	BR
131	NA			342077.27	5595829.635	555	0.1		BR
132	NA			341958.37	5594963.108	524.573	0.4	19.15	BR
133	NA			342196.9	5594842.33	523.187	0.4	37	BR
134	NA			342108.63	5594160.716	500.494	0.5	30	BR
135	NA			338493.59	5581698.963	399.444	0.6	128	BR
136	NA			338298.81	5581281.742	380.01	0.2	18	BR
137	NA			338789.65	5579993.67	408.962	0.5	27.3	BR

Note: DA-Deep Creek Confined aquifer; BR-Bedrock aquifers; EA-Eagle Rock Unconfined-confined aquifer; FC-Fortune Creek Unconfined-confined aquifer; HU-Hullcar Unconfined aquifer; HC-Hullcar Confined aquifer; OA- Okeefe Unconfined aquifer; OB-Okeefe Unconfined-confined aquifer; SLA-Sleepy Hollow Unconfined aquifer; SLB-Sleepy Hollow Confined aquifer; SPA-Spallumcheen A aquifer; SPB-Spallumcheen B aquifer.

Appendix 3.2-A Static water level data Unit (m)

Date / Well	Mar-15 2007	Apr-11 2007	May-18 2007	Jun-15 2007	Jul-14 2007	Aug-22 2007	Sep-05 2007	Oct-15 2007	Nov-17 2007	Dec-10 2007	Jan-22 2008	Feb-13 2008	Mar-18 2008	April29/30 2008	May-14/15 2008	Jun-11 2008	Jul-16 2008	Aug-13 2008	Sep-14 2008	Oct13/14 2008
90	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.3	NA	2.41	1.61	0.41	0.4	0.352	0.642	1.143	NA	1.92
91	NA	NA	NA	NA	NA	NA	NA	NA	NA	14.4	14.335	14.33	14.1	13.7	NA	NA	NA	NA	NA	13.19
92	NA	NA	NA	NA	NA	NA	NA	NA	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
93	NA	2.79	2.895	3.084	2.875	3.126	3.205	NA	NA	NA	NA	3.425	1.115	2.51	2.66	2.866	2.845	2.642	2.99	NA
94	NA	5.28	5.212	5.18	5.308	5.666	5.742	NA	NA	NA	NA	5.745	5.605	5.36	5.329	5.15	5.34	5.69	5.81	5.96
95	NA	NA	NA	NA	NA	NA	NA	NA	6.6	NA	6.577	9.735	6.25	6.13	NA	NA	NA	NA	NA	7.85
96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.36	4.18	4.05	3.999	4.344	7.47	9.401	7.41	5.82
97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.45	4.23	4.03	3.992	4.248	6.495	7.922	6.38	5.73
98	NA	NA	NA	NA	NA	NA	NA	NA	4.25	NA	4.271	4.113	3.905	3.89	NA	NA	NA	NA	NA	4.41
99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	43.09	43.091	43.178	NA	NA	NA	NA
100	1.6	NA	1	1.107	1.28	1.341	1.456	NA	NA	NA	1.372	1.36	1.33	1.32	1.156	0.915	1.346	1.382	1.42	1.34
101	7.3	NA	7.344	7.458	7.601	7.804	NA	NA	NA	NA	NA	NA	NA	7.31	7.369	7.464	NA	NA	NA	NA
102	13.06	NA	12.555	12.519	12.504	12.657	NA	NA	NA	NA	NA	NA	NA	NA	12.282	12.278	12.481	12.834	NA	13.5
7	9.171	9.264	9.642	9.801	10.496	NA	NA	NA	9.684	9.765	10.007	10.089	9.922	NA	NA	NA	NA	NA	NA	NA
103	NA	NA	NA	NA	NA	NA	NA	NA	6.4	NA	5.7	5.649	5.61	4.49	4.886	5.262	5.91	6.461	7.01	7.36
104	18.7	18.8	18.795	18.81	18.95	18.912	18.981	NA	NA	NA	NA	18.499	18.58	18.64	18.745	18.688	19.002	18.933	18.95	18.13
105	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	sawdust	NA	NA	NA	NA	NA	NA
106	NA	NA	6.262	6.275	6.164	6.266	6.276	NA	NA	NA	6.396	6.425	6.19	6.17	6.167	6.196	6.275	6.328	5.91	6.01
107	NA	NA	NA	NA	NA	NA	NA	NA	13.2	NA	13.002	12.995	12.86	NA	12.903	12.887	13.009	13.115	NA	NA
108	NA	NA	18.123	17.582	23.979	26.328	26.526	NA	NA	NA	17.311	17.24	17.385	17.27	NA	NA	NA	NA	NA	17.04
109	NA	NA	NA	NA	NA	NA	NA	NA	18.5	NA	18.522	18.375	18.25	18.04	NA	NA	NA	NA	NA	18.3
110	NA	NA	4.891	4.987	5.056	5.178	5.243	NA	NA	NA	5.491	5.505	5.195	4.98	4.921	4.807	4.933	5.005	5.22	5.23
111	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.663	3.91	4.466	4.909	5.27	7.41
26	12.5	NA	12.214	13.531	12.314	12.462	12.561	NA	NA	NA	13.124	12.19	14.02	12.3	NA	NA	NA	NA	NA	14.18
112	NA	26.7	26.6	26.691	26.679	26.665	26.689	NA	NA	NA	26.855	26.99	27.1	NA	27.106	27.101	27.042	26.976	26.83	26.82
113	NA	NA	NA	NA	NA	NA	NA	NA	NA	62	62.012	61.331	60.895	no water	NA	NA	NA	NA	NA	NA
114	NA	NA	NA	NA	NA	NA	NA	NA	NA	61	61.173	NA	60.922	NA	NA	NA	NA	NA	NA	36.85
115	NA	NA	11.464	11.573	11.872	12.008	11.864	NA	NA	NA	11.255	11.175	11.12	11.1	11.104	11.41	12.079	12.41	11.94	11.62
116	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	N`A	14.074	14.15	14.04	14.28
117	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	16.859	17.951	18.496	NA	NA
118	21.8	NA	21.551	21.531	21.589	21.742	NA	NA	NA	NA	NA	NA	NA	21.4	29.395	21.347	21.468	21.742	NA	22.16
119	NA	NA	NA	NA	NA	NA	NA	NA	31.4	NA	NA	31.115	31.1	31.09	NA	NA	NA	NA	NA	32.08
120	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.556	8.938	8.978	NA	NA
42	31.127	31.007	31.351	31.929	32.035	32.542	32.275	31.604	30.801	30.766	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
121	35.1	34.98	35	35.14	35.194	35.394	35.355	NA	NA	NA	35.102	35.045	34.92	34.95	34.956	35.061	35.477	35.604	35.36	35.28
122	NA	NA	NA	NA	NA	NA	NA	NA	41.5	NA	41.398	40.34	41.221	NA	NA	NA	NA	NA	NA	42.64
123	NA	NA	NA	NA	NA	NA	NA	NA	37.67	NA	37.66	37.69	37.545	37.59	NA	NA	NA	NA	NA	NA
124	NA	NA	NA	NA	NA	NA	NA	NA	23.67	NA	NA	19.97	18.885	17.44	18.201	18.588	35.431	39.344	NA	29.59
54	0.592	0.592	0.525	0.48	0.466	0.72	0.761	0.792	0.77	0.79	0.71	0.65	0.66	NA	NA	NA	NA	NA	NA	NA
55	13.895	13.895	13.808	13.763	13.706	14.051	14.111	14.16	14.111	14.14	14.11	14.05	14.07	NA	NA	NA	NA	NA	NA	NA
56	16.38	16.36	16.41	16.55	16.67	17.2	17.27	16.772	16.637	16.53	NA	NA	16.34	NA	NA	NA	NA	NA	NA	NA
125	NA	NA	NA	NA	NA	NA	NA	NA	4.95	NA	5.202	4.65	4.58	4.14	NA	NA	NA	NA	NA	6.15
126	NA	6.4	7.665	7.607	7.633	7.852	7.935	NA	NA	NA	7.108	6.94	6.86	1.83	6.635	6.203	6.29	6.431	6.7	7.99
127	NA	NA	1.943	2.819	3.57	5.654	6.186	NA	NA	NA	8.075	8.07	8.02	7.59	7.568	7.457	7.488	7.665	7.88	4.25

Appendix 3.2-B Static water level data Unit (m)

Well \ Date	Mar-15 2007	Apr-11 2007	May-18 2007	Jun-15 2007	Jul-14 2007	Aug-22 2007	Sep-05 2007	Oct-15 2007	Nov-17 2007	Dec-10 2007	Jan-22 2008	Feb-13 2008	Mar-18 2008	April29/30 2008	May-14/15 2008	Jun-11 2008	Jul-16 2008	Aug-13 2008	Sep-14 2008	Oct13/14 2008
128	NA	5.79	6.495	6.504	6.636	6.987	7.12	NA	NA	NA	2.915	2.642	2.43	6.43	1.703	1.921	2.618	4.034	4.57	6.75
129	NA	NA	NA	NA	NA	NA	NA	NA	25.45	NA	25.703	29.615	23.905	29.09	NA	NA	NA	NA	NA	36.49
130	NA	NA	NA	NA	NA	NA	NA	NA	8	NA	7.892	5.13	2.89	20.22	NA	NA	NA	NA	NA	14.37
131	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	17.06	NA	NA	NA	NA	NA	NA	NA
132	NA	NA	NA	NA	NA	NA	NA	NA	15	NA	22.412	16.35	17.25	15.74	NA	NA	NA	NA	NA	19.59
133	NA	NA	NA	NA	NA	NA	NA	NA	11	NA	9.331	9.16	11.74	21.32	NA	NA	NA	NA	NA	16.27
134	NA	NA	NA	NA	NA	NA	NA	NA	25.4	NA	25.308	14.33	13.46	13.98	NA	NA	NA	NA	NA	45.09
135	NA	NA	NA	NA	NA	NA	NA	NA	29.19	NA	29.311	NA	29.285	29.36	24.7	Collapsed	Collapsed	Collapsed	NA	NA
136	NA	NA	NA	NA	NA	NA	NA	NA	1.25	NA	1.259	1.18	0.9	0.98	0.992	1.154	1.157	1.093	0.98	0.91
137	NA	NA	NA	NA	NA	NA	NA	NA	1.32	NA	1.305	1.27	0.94	1.25	1.227	1.31	1.824	1.901	2.05	1.99

Appendix 3.3 Annual average historical monitoring data of 5 auto-monitored observation wells

WTN / Year	24062 (O117)	24080 (O118)	24104 (O119)	24093 (O122)	32340 (O180)
1971	358.567	369.739	360.813	369.045	N/A
1972	358.724	370.095	360.941	369.077	N/A
1973	358.626	370.530	360.844	369.773	N/A
1974	358.662	370.637	360.813	369.854	N/A
1975	358.365	370.400	360.838	369.612	413.727
1976	358.330	370.636	360.839	369.752	413.590
1977	358.504	370.753	360.573	369.846	413.270
1978	358.478	370.332	360.408	369.559	413.155
1979	358.361	369.914	360.292	369.252	412.945
1980	358.195	368.747	360.076	368.193	412.826
1981	358.189	369.471	360.099	368.694	412.988
1982	358.253	370.080	360.142	369.364	413.514
1983	358.351	370.399	360.227	369.781	413.968
1984	358.348	370.403	360.191	369.893	414.109
1985	358.023	369.685	359.665	369.230	413.600
1986	358.029	369.455	359.900	368.999	413.471
1987	357.904	369.033	359.670	368.940	413.316
1988	357.800	368.033	359.641	367.665	412.732
1989	357.819	368.522	359.856	367.930	412.584
1990	357.798	368.706	359.365	367.931	412.894
1991	357.686	368.754	359.025	367.910	413.430
1992	357.538	368.501	358.861	367.751	413.364
1993	357.618	368.638	359.065	367.798	412.897
1994	357.556	369.228	358.848	368.362	413.179
1995	357.574	369.232	358.944	368.347	413.037
1996	357.816	370.033	359.227	369.106	413.717
1997	358.219	370.800	359.757	369.616	414.177
1998	358.032	371.092	359.214	369.636	413.935
1999	358.135	370.757	359.544	N/A	413.577
2000	358.123	370.911	359.376	N/A	413.493
2001	358.027	370.348	359.529	369.820	413.096
2002	357.865	370.077	358.554	369.557	412.748
2003	357.592	369.262	358.697	368.810	411.526
2004	357.654	369.049	358.811	368.400	409.056
2005	357.708	369.962	359.020	369.183	408.949
2006	357.745	370.008	359.631	369.399	410.030
2007	357.734	369.593	359.284	369.087	410.628
2008	358.017	369.469	N/A	369.039	410.284

Appendix 3.4 Information of Visited Artesian wells

NO	WTN	Easting	Northing	Depth (meter)
43		343254	5586743	198.12
61		344338	5586783	91.44
86	53902	343765	5587528	80.77
87		343728	5587531	86.87
73		340567	5588150	53.64
71		345468	5590802	64.62
34		345267	5591213	46.63
3	62738	345260	5591231	12.19
32	169	346185	5591456	62.48
83	1263	346204	5595208	12.19
78		350558	5595285	67.06
58		346259	5595333	25.91
84	16909	346292	5595362	12.50
85	21210	346311	5595391	4.27
77		346383	5595650	60.96
88		346285	5595757	60.96
23		349230	5596565	100.58
54	24093	349035	5597208	318.82
89	31281	342958	5598539	30.78