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Cumulative Precipitation Departure from Average Characterizing Mountain System Recharge in Semi-arid North Okanagan, South Interior British Columbia, Canada

[1,2]Jianhua Ping, [2]Xiaohua Wei and [2]Craig Nichol
[1]School of Water Conservancy and Environment Engineering, Zhengzhou University,
100 Science Avenue, Zhengzhou, Henan, 450001, China
[2]Department of Earth and Environmental Sciences, The University of British Columbia,
Okanagan, 3333 University Way, Kelowna, British Columbia, Canada

Abstract: Mountain system recharge is the major source to the aquifers in the mountainous terrain within arid (semi-) areas. Cumulative precipitation from average is employed to describe mountain system recharge in North Okanagan based on the long term groundwater levels automatically observed by BC Ministry of Environment since 1970s and a gridded (500×500 m) climate data since 1960. The results indicated that mountain system recharge is a major contributor to the aquifers in the valley bottom. The deep aquifers are recharged by mountain system recharge and leakage from the moderate depth aquifer in the central portion of the main valley.

Key words: Mountain system recharge, groundwater levels, cumulative precipitation departure from average

INTRODUCTION

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 (Chaudhuri and Ale, 2014). Recharge is the most important factor in evaluating groundwater resources but it is often the most difficult parameter of a water balance to quantify (Carrera-Hernandez *et al*., 2012). 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 (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).

The North Okanagan comprising of Deep Creek watershed and Fortune Creek Watershed (Fig. 1) aquifer system is composed of valley bottom unconsolidated

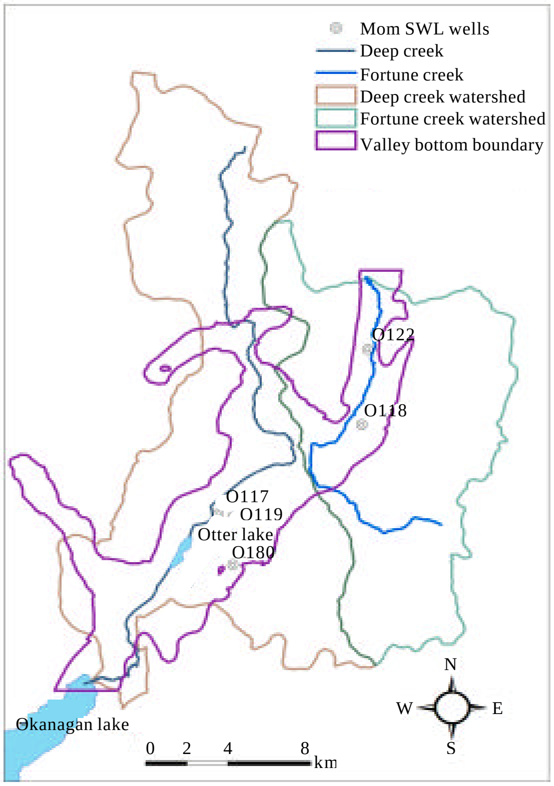

Fig. 1: Deep creek and fortune creek watersheds (North Okanagan) with MOE wells

Corresponding Author: Jianhua Ping, School of Water Conservancy and Environment Engineering, Zhengzhou University,
100 Science Avenue, Zhengzhou, Henan, 450001, China
Tel: (+86) 371-67783172 Fax: (+86)371-67781313

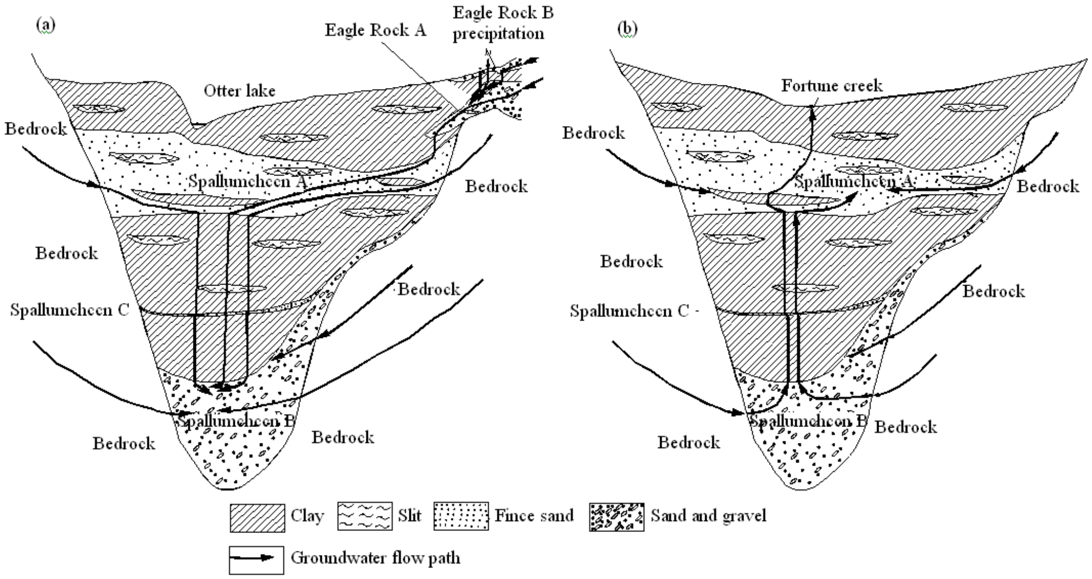

Fig. 2(a-b): Schematic vertical flow pattern in the (a) Central main valley and (b) Northern main valley

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. In the 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.

HYDROGEOLOGY CONDITIONS

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.

Contours of groundwater levels in the north 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. The schematic vertical flow patterns in the central and northern parts of main valley are shown in Fig. 2.

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.

Data: There are five existing MOE observation wells located in the North Okanagan area (Fig. 1). 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).

Five observation wells within the study area have been monitored by the MOE since the 1970s. 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 Deep Creek Watershed and one pair are completed in aquifers Spallumcheen A and B within the Northern part of the main studied valley in Fortune Creek Watershed.

A gridded (500×500 m) 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). Duke, D., Neilsen, D., Gulik, T.V. Ogeepogee Climate Dataset (OCD) April 2008 prepared by Guy Duke (University of Lethbridge), Denise

Neilsen (Agriculture and Agri-food Canada Summerland) and Ted van der Gulik, BC Ministry of Agriculture and Lands.

This dataset is hereafter referred to as the Okanagan Climate Data Interpolator (OCDI). 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 OCDI indicates that overall, the study area experiences general increases in precipitation from south to north and from valley bottom to mountain top. The average annual precipitation from 1960 to 2006 at valley bottom is ~494 mm year^{-1} and in mountainous areas is ~611 mm year^{-1}.

METHODOLOGY

The cumulative precipitation departure from average (mean or normal) precipitation is a concept sometimes used by climatologist and hydrologists to delineate precipitation trends (Knowles *et al.*, 2002). In mathematics, the result which is negative is often termed a cumulative precipitation deficit (Fenelon, 2000). The use of cumulative departure from the data mean is primarily in the areas of streamflows. It is rarely used in groundwater research (Weber and Stewart, 2004).

The cumulative precipitation departure from average is employed to elucidate the relationship between mountain system recharge and precipitation.

RESULTS AND DISCUSSION

Spallumcheen A and B (Central deep creek watershed): A pair of observation wells is located in the Spallumcheen A (WTN 24104) and underlying Spallumcheen B (WTN 24062, O117) aquifers in the central part of Northern Okanagan valley.

The seasonal static water level patterns of well O117 were similar to those of well O119 (Fig. 3). However, the annual average static groundwater levels in well O117 were always higher than those in well O119 by approximately 1.5 m. 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 O117 is located adjacent (about 90 m laterally) to the production well 41(WTN 20648) with a depth at 190 m. It is possible that a well O117 is affected by the pumping of the production well above.

Static water levels of wells O117 and O119 have been generally decreasing since 1971 (Fig. 3). 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

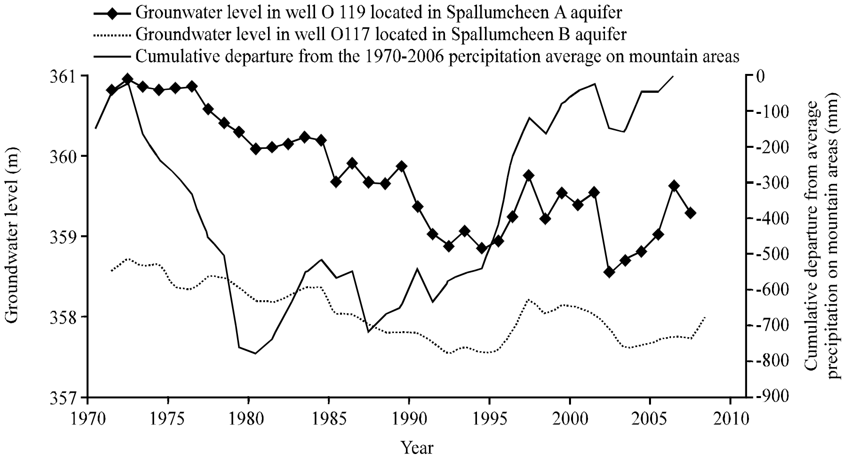

Fig. 3: Long-term static water level variations in well O119 (WTN 24104) and O117 (WTN 24062) in comparison to the cumulative precipitation departure from the 1970-2006 precipitation average on mountain areas (Precipitation data is from the Okanagan Climate Data Interpolator)

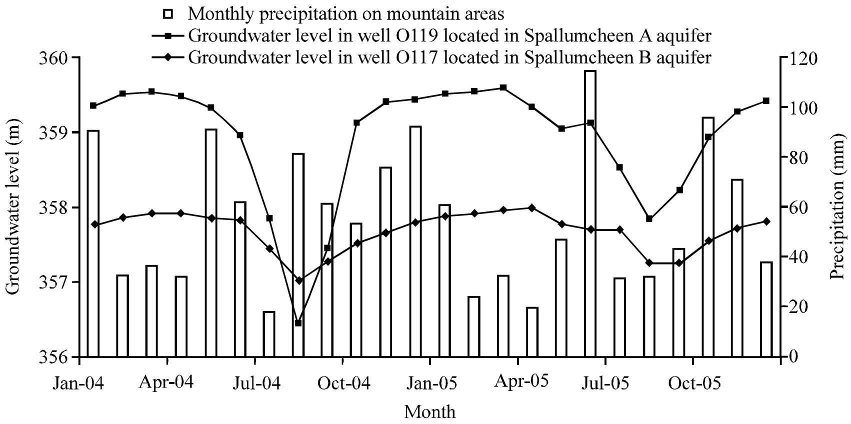

Fig. 4: Monthly static water levels in well O119 (WTN 24104) and O117 (WTN 24062) in comparison to monthly precipitation on mountain areas during the period of January 2004 to December 2005 (Precipitation data is from the Okanagan Climate Data Interpolator)

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 O119 are not always higher than in well O117 (Fig. 4). 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 O119 (Spallumcheen A) were lower than in well O117 (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 O122 (WTN 24093) and O118 (WTN 24080) are both in the Spallumcheen B aquifer, located in the northern part of the study area (Fig. 1). 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 Fig. 5 and water levels are above those of well O117 to the south.

Water levels recorded in well O122 in the north were always lower than those in well O118, 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 m. The wells have not demonstrated a long-term decline in water levels as seen further south in Spallumcheen A and B (Fig. 3). 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

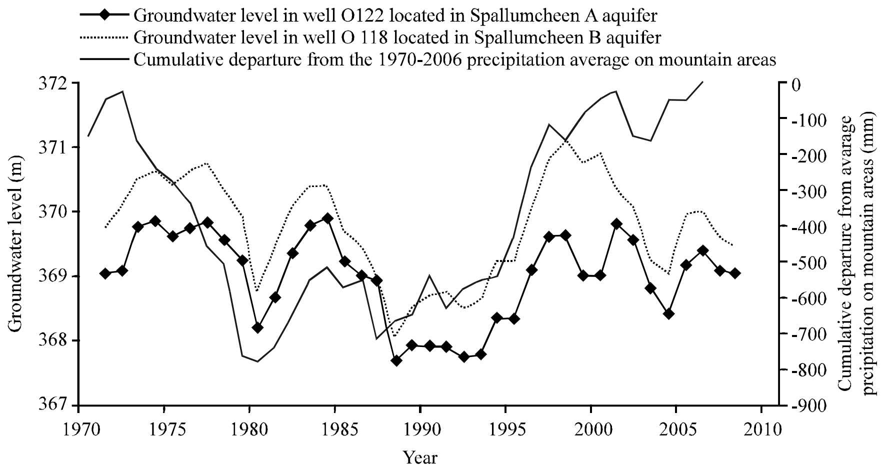

Fig. 5: Long-term static water level variations of well O122 (WTN 24093) and O118 (WTN 24080) in comparison to the cumulative precipitation departure from the 1970 to 2006 precipitation average on mountain areas (Precipitation data is from the Okanagan Climate Data Interpolator)

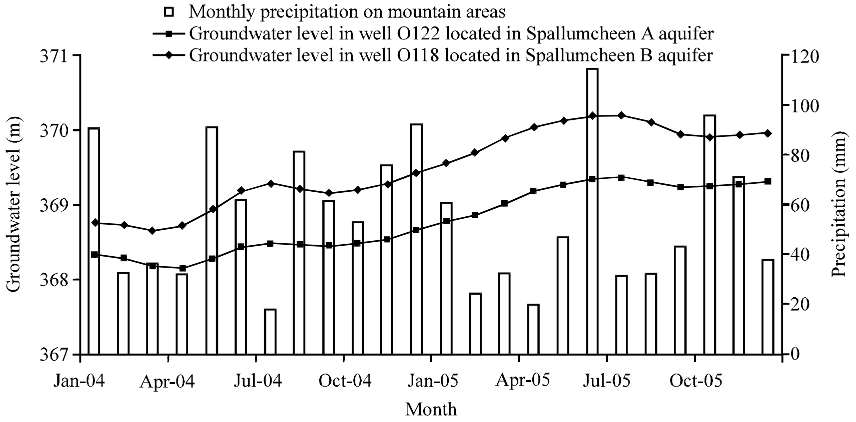

Fig. 6: Monthly static water levels variation in well O122 (WTN 24093) and O118 (WTN 24080) in comparison to monthly precipitation on mountain areas during the period of January 2004 to December 2005 (Precipitation data is from the Okanagan Climate Data Interpolator)

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 (Fig. 6), the patterns of monthly static water levels in well O118 and well O122 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 (Fig. 5).

No MOE monitoring wells exist in Spallumcheen A in the FCW area. However, recent static water level measurements in a private well 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.

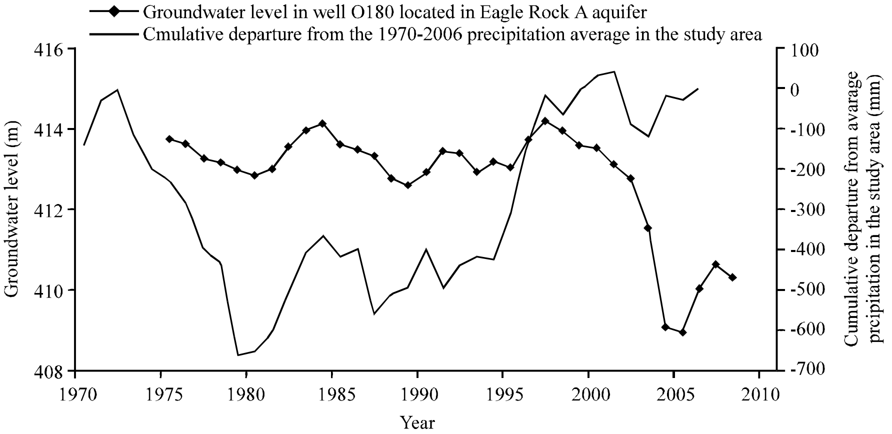

Fig. 7: Long-term static water level variations in well O180 (WTN 32340) in comparison to the cumulative precipitation departure from the 1970-2006 precipitation average in the study area (Precipitation data is from the Okanagan Climate Data Interpolator)

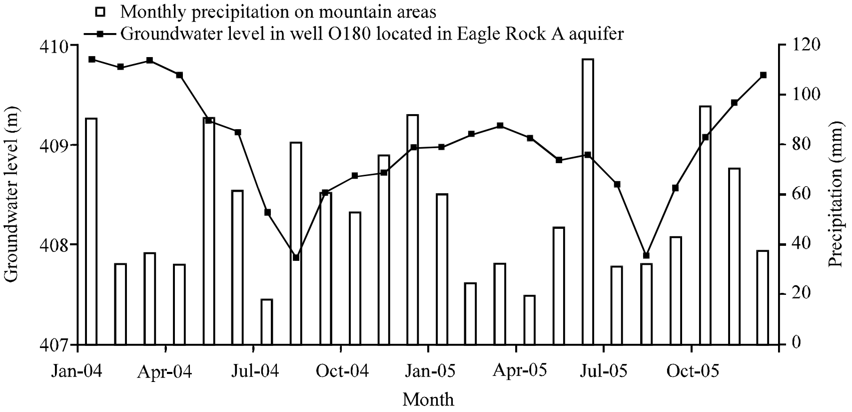

Fig. 8: Monthly static water level variations in well O180 (WTN 32340) in comparison to monthly precipitation in the study area during the period of January 2004 to December 2005 (Precipitation data is from the Okanagan Climate Data Interpolator)

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.

Eagle Rock A aquifer: Well O180 (WTN 32340, O180) is located in the Eagle Rock A 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 1971-1997 (Fig. 7). 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 5 m 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 m and well 175 at 87 m). 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 (Fig. 8) suggests that groundwater levels have experienced fluctuations of up to 2 m 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.

CONCLUSIONS

- 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

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