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Research Article

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Isotopic conceptualization of groundwater system in semiarid mountain watersheds in the North Okanagan, British Columbia, Canada

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ABSTRACT

Because of important role hydrodynamic investigation in multi-layer aquifer system with complex surface system plays in water sustainability, multiple isotopic analysis including Deuterium, oxygen 18were employed to identify the groundwater recharge, mixing, surface water and groundwater interactions and mountain system recharge distributions in Northern Okanagan comprising of Deep Creek watershed and Fortune Creek watershed. The stable isotopic compositions profiles of surface waters indicate that Deep Creek obtains water from local and regional aquifers in dry seasons, Fortune Creek receives groundwater from regional aquifers in the main valley in drought and lose water in the upper of the fluvial fan in wet season. The stable isotopic data and plots qualify the groundwater mixing, exchange between aquifers, groundwater flow path. The sources to moderate regional aquifer were identified with isotopic data. Environmental isotopes provides significant and specific hydraulic information in hydrological studies.

Keywords: North Okanagan, Stable isotopes, surface water-groundwater interactions, Groundwater system, Mountain System Recharge

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INTRODUCTION

The benefits of using isotopic techniques into hydrogeological investigations are well known. Stable isotope ratios of oxygen ($\delta^{18}O$) and hydrogen (δD) are often employed to identify and estimate groundwater recharge sources, trace groundwater flow [1-7]. Nakaya et al (2007) applied stable isotopes of oxygen and hydrogen as natural tracers to study spatial separation of groundwater flow paths from a multi-flow system at a basin scale[8]. Both hydrodynamic and hydrochemical data can be used to conceptualize and model groundwater systems.

The Deep Creek watershed (DCW) and the Fortune Creek watershed (FCW) are two neighboring watersheds located in the southern interior of British Columbia (Figure 1). The DCW covers an area of 230 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 km^2. The two watersheds consist of relatively narrow flat valley bottoms (~5 km) 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.

Deep Creek originates east of Mount Ida and west of Enderby (Figure 1).

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 and into Okanagan Lake. However, 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 north and empties into the Shuswap River, and hence eventually enters into Fraser River. There are 19 Quaternary aquifers within the study area. The complexity of the aquifers was interpreted in previous studies [9]. The North Okanagan stratigraphy described by Monahan and Fulton has several locations where sediments are coarse enough or extensive enough to be considered aquifers.

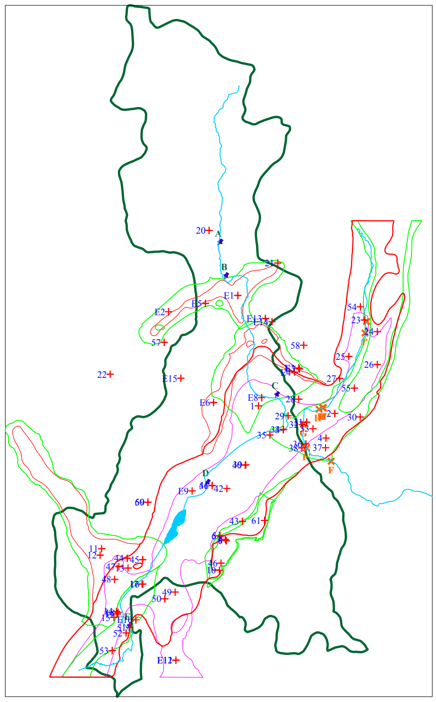


Figure 1 Distribution of isotopic samples in North Okanagan

DATA SAMPLING

Surface Water samples were collected for isotopic measurements in Deep Creek and Fortune Creek in August 2007, representing a summer period, and in October 2007 and November 2007, representing the winter period. These detailed data are presented in Appendix VI. The distributions are presented in Figure 1. Groundwater samples were collected for isotopic measurements from depths of 3.66 to 576.68 m in domestic, agricultural, Ministry of environment observation, artesian wells in August and September 2007, representing a summer period, and in October and November 2007, representing a winter time. The distributions are presented in Figure 1.

RESULTS AND DISCUSSION

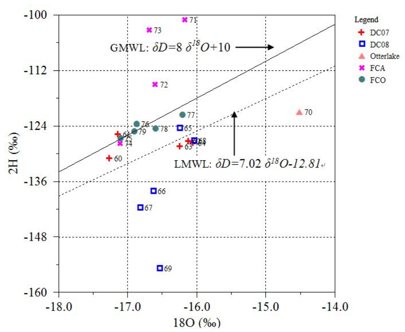
Isotopic Characteristics of meteoric water

It is difficult to get the local meteoric water line within the study area due to lack of precipitation samples. Fortunately, monthly precipitation collected for isotopic analysis for two years was conducted by Mr. Pathanasopous in Kelowna. The meteoric water line in Kelowna is d2H = 7.02d18O - 12.81; $R^2 = 0.97$; n = 17 (Pathanasopoulos, J. Hendry, unpublished data) represents the LMWL (local meteoric water line) within the study area.

Surface water

Evaporation results in characteristic heavy-isotope enrichment (Known as kinetic fractionation) in surface waters, owing to lower molecular diffusivities in air of water molecules containing the heavy isotope species. The sources of the surface water are rainfall, snowmelt and low-temperature groundwater, which indicate that the stable isotope value varies with the season changing and the isotope composition typically lie along more-or-less well-defined linear arrays in *δD and $\delta^{18}O$* space, termed LMWL(the same to local evaporation line). Unusual deviations of some surface water samples including sample 69, 71, 73 showed in Fig 3 suggest that the relative humidity, temperature in sites of these samples taken are the different from other locations, or some contaminants occurs in the water sampled. Otter lake water isotope composition lies below the LMWL indicate that the water evaporation result in the heavy isotopes enriched.

The samples taken in Deep Creek in 2007 and in Fortune Creek October 2007 seem lie around the GMWL and LMWL. Normally, the stable isotope oxygen-18 and deuterium values increase due to evaporation. In general, the isotope values increase in Deep Creek from upstream to down stream showed in Fig4 due to the evaporation. $\delta^{18}O$ increament slope between site B(hullcar area) and site C (sleeply hollow area) values is steep that other profiles and δD increment slope inverse from other profiles between Site B and Site D, which indicate that surface-groundwater interactions occurring groundwater recharge surface water happen between Site B and Site C at this time corresponding that the groundwater levels were higher than the surface water in this area at this time.



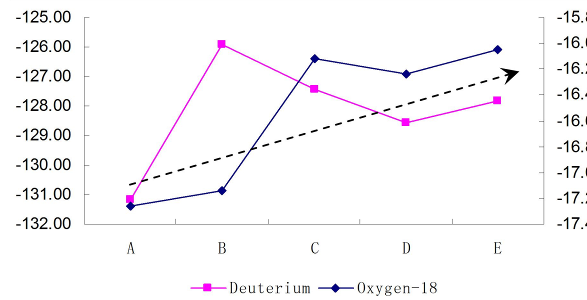


Fig.3Stable isotope composition of oxygen-18 Fig 4 Deep Creek oxgen-18 and Deuterium values profile vs. deuterium in surface water

The water isotope values profile sampled in Fortune Creek either in August and October occur with a "∧" shape between Site G (Fortune Creek at High way 97) and Site H (Fortune Creek at McCallum road) dramatically showed in Fig5 and Fig 6, which indicate that the surface-groundwater interactions happen in Fortune Creek. It is known that water lose in Fortune Creek Fan between Site F and Site G and the water come back which occurs as groundwater flow into Fortune Creek in site H from the hydrometric data. The isotope signature proves the hydrometric measurements.

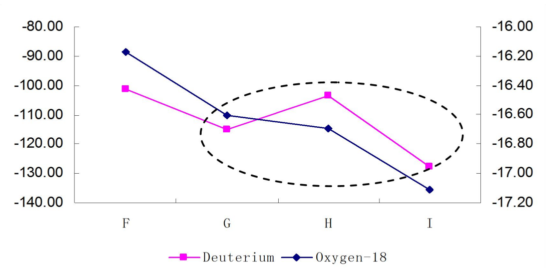


Figure 5 Fortune Creek deuterium and oxygen-18 profile in August 2007

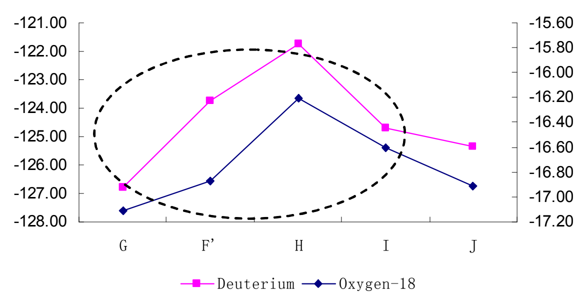


Figure 6 Fortune Creek deuterium and oxygen-18 profile in October 2007

Groundwater

Groundwaters generally reflect the isotopic signature of precipitation in the zones of recharge and movements, although individual reservoirs may acquire signatures reflecting their mean residence time and seasonal timing of inputs, as modified by mixing between other sources, such as river water, lake water or thermal water [10]. 59 goundwater samples were taken for isotopic analysis and the results are presented in Fig7.

Unconfined groundwater

Thirteen groundwater samples for stable isotopic analysis were taken in unconfined aquifers which include Hullcar Unconfined, Fortune Creek, Okeefe A and Okeefe B. Oxygen-18 values occur at the range from -14.03 to -17.83 and deuterium values occur with a range from -99.54 to -148.25. Isotopic compositions of sample 1, 2, 3 and 4 taken in aquifer Hullcar Unconfined lie dispersedly on the cross

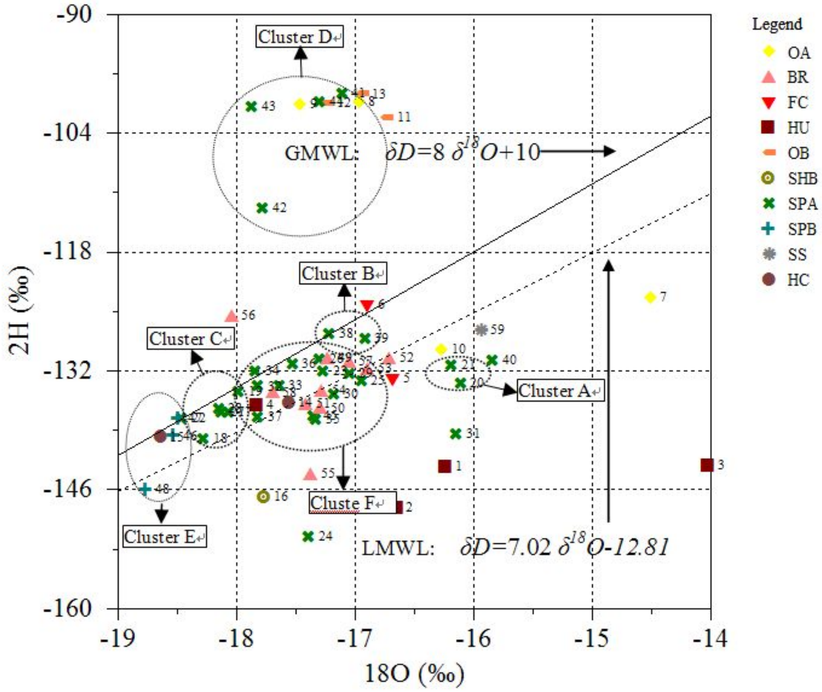


Figure 7 Scatter plot of *δD versus $\delta^{18}O$* in groundwater samples

plot of *δD and $\delta^{18}O$*. Normally, the isotopic values should be close and the isotopic compositions should distribute closely. The isotopic values of sample 1, 2, 3 are lower than what of sample 1, and the isotopic compositions lie below the LMWL, which indicate that sample 1,2,3 have contaminants proved by the higher chloride and sulfate values of the tree samples caused by the close Cow Farm. The Sample 4 lies close to the LMWL, which suggest that the groundwater comes from modern cycling water.

The distribution of isotopic compositions groundwater samples including Sample 7 to 13 in Okeefe A and Okeefe B aquifers occurs dramatically in Fig 7. The compositions of sample 8,9 taken in Okeefe B and sample 11, 12 ,13 taken in Okeefe A lie above the LMWL with large deviations and the isotopic values are pretty higher than other ones taken in the same aquifers, mainly cause that these groundwater are formed by the mixture of thermal water and modern cycling water, which proved by sample 41 with highest isotopic values taken in a geothermal well at the depth of 650 feet.

The *δD* value of sample 6 is -124.37, which is higher than what of sample 5 located in the same aquifer Fortune Creek Unconfined result that the sample 6 was taken in a well located in clay and silt without sand and very little water inside of the well.

Confined groundwater

46 groundwater samples were taken in confined aquifers including aquifer Hullcar Confined, Sleepy B, Spallumcheen A and Spallumcheen B. The results are distributed in Fig 7. In general, the isotopic values of confined groundwater are higher than what in unconfined. Oxygen 18 values occur from -99.52 to -155.61 and deuterium values appear from -15.84 to -18.76. The samples taken in July 2008 isotopic values seem unusual, which is discussed in the below sections.

The samples which are sample 14, 15 and 16 and 59 taken in Hullcar Confined aquifer. The isotopic compositions of sample 14 and 15 distribute close to GMWL and LMWL which indicate that the groundwater origin is atmospheric water although the values are lower result that the Mountain System Recharge is a significant source. The δD and $\delta^{18}O$ value of groundwater sample 59 taken from one tank pumping from Steele Spring is -127.37 and -15.94 respectively. The chloride and sulfate of sample 59 are 19.4 mg/l and 112.3 mg/l, which the high chloride and sulfate suggest that the water in the tank contaminated by other source which enhance the stable isotopes values. It is necessary to sample Steele Spring again to study the origin water of Steele Spring.

Groundwater samples taken in aquifer sapllumcheen A comprise of 23 samples collected in 2007 and 6 samples collected in 2008. The isotopic compositions of these sample lie above the LMWL with large deviations which present that the deuterium are pretty high showed in Fig 7. The deuterium values of cluster D comprising sample 41 to 44 range from -112.98 to -99.52 and the oxygen-18 values of sample 41 to 44 cover a range from -17.11 to -17.87. The isotopic Sample 41 taken in the geothermal well at the depth of 650 feet indicates that there is a potential fault lying underneath O'Keefe area. The isotopic values of sample 44 are close to what of sample, mainly result that the Okanagan Fault lies underneath the well taken for sample 44. The higher deuterium values of sample 42 and 43 suggest that there is a potential fault below the wells for sample 42 and 43, which the thermal water come from the fault is a source to the groundwater in aquifer Spallumcheen A. The isotopic deuterium and oxygen-18 ratios of sample 24 are pretty lower than other ones, especially, deuterium value, probably result of the analysis error or pollution of the relative higher chloride and sulfate than the average values. The isotopic compositions of the other ones except sample 41 to 44 and 24 distribute around the GMWL and the LMW, which absolutely suggest that the atmospheric water is the source to groundwater except the thermal water. Cluster C including sample 17, 18, 19, 22 locates in the north-east of the main valley with lower isotopic values which deuterium value range from -140.14 to -134.55 and oxygen-18 range from -17.98 to -18.46 showed in Fig7, mainly result that groundwater in aquifer Spallumcheen B with lower isotopic values flows up to recharge the groundwater in Aquifer Spallumcheen A, corresponding to the analysis of groundwater regime in chapter 3.Cluster A comprising of sample 21 and 22 sets in the north of the main valley set in the sleepy hollow area. The isotopic composition distribute showed in F13 indicate the heavy isotopes enriched. Cluster B including sample 38 and 39 located in Eagle Rock, of which the isotopic compositions are different from other ones.The deuterium values ranging from -146.18 to -137.67 and the oxygen-18 values ranging from -18.76 to -18.49 of the groundwater samples in Aquifer Spallumcheen B. The isotopic compositions distribute around the GMWL and LMWL, which suggest this groundwater origin comes from atmospheric precipitation. The average oxggen-18 value of sample 46, 47, 48 is -18.59 and the average deuterium value of these samples is -141.22. The average deuterium of except cluster D and sample 24 is -134.27 and the average deuterium of these samples is -17.36 in aquifer Spallumcheen A.

Groundwater in Bedrock aquifers

It is very important to get the isotopic values of the groundwater in the bedrock aquifers to study the hydrologic cycle on the mountain due that Mountain System Recharge is the main source to the groundwater located in the moderate and deep aquifers at the valley bottom. It is expected to take samples in the from shallow wells to deep wells gradually to characterize hydrologic cycle using isotopic techniques

The depths of groundwater samples taken in bedrock aquifers range from 19.15 to 91.4 meters. The δD and $\delta^{18}O$ values cover ranges from -144.28 to -125.66 and -18.04 to -16.71 respectively. The isotopic compositions of these samples except sample 56 and 57 distribute around the LMWL closely showed in Figure 7, which indicate that the original source to these groundwaters is atmospheric precipitation. The isotopic values of sample 56 and 57 seem odd, probably cause of contaminants which proved by the high chloride values at 4.4 mg/l, 25.8 mg/l and sulfate at 950 mg/l, 2190 mg/l respectively.

CONCLUSION

In this study, precipitation, surface water and groundwater were sampled to analyze isotopic compositions to study hydrological cycle, detect surface water and groundwater interactions, identify the sources to groundwater, investigate water exchange between aquifers and trace groundwater flow path.

The isotopic evidence of surface water profiles suggest that groundwater system exchange water with surface water systems. The specific groundwater-surface water interactions were found as following:

(1)Deep Creek gains groundwater from local unconfined aquifers including Hullcar unconfined and Sleepy Hollow A aquifers in upper Deep Creek watershed, receives water from Spallumcheen A when it joins into the main Okanagan Valley near Armstrong, and obtains water from Okeefe B unconfined aquifer when it enters Okeefe Valley in the drought summer periods;

(2)Fortune Creek loses water to Fortune Creek unconfined aquifer in the upper fluvial fan and gains water from Fortune Creek unconfined aquifer in the lower fan, receives water from Spallumcheen A in the main valley in the wet and dry periods;

The sources to and flow path of groundwater were identified based on the chemical and isotopic analysis. The detailed processes were summarized as follows:

(3)The original sources of groundwater were atmospheric water; Groundwater in Spallumcheen B upwards recharge Spallumcheen A in the North part of Fortune Creek Watershed; Fortune Creek fan gains water from Fortune Creek at the upper of the fan; groundwater flow upwards from spallumcheen A to Fortune Creek fan at the end of Fortune Creek fan; Groundwater in Spallumcheen A flow from North to South in the Main Okanagan Valley.

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