Predicting groundwater recharge in the Okanagan Basin: A comparison of three models

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ABSTRACT
Regional-scale groundwater recharge was predicted for the entire Okanagan Basin using the HELP model. Accuracy of the predictions was evaluated by comparison with two, independently derived, local-scale models to ensure local trends were captured in the regional model, and to compare different modelling methods. For the south Okanagan, results were compared to a high-resolution HELP/MODFLOW analysis, and were found to be similar (42mm/yr for local-scale, 34mm/yr for regional-scale). For the north Okanagan results were compared to the Richards' equation-based MIKE-SHE/MODFLOW analysis, and were found to vary significantly (7mm/yr for local-scale, 109mm/yr for regional-scale).

RÉSUMÉ
La recharge en eaux souterraines à l'échelle régionale a été prédite pour l'ensemble du basin de l'Okanagan à l'aide du code HELP. La validité des prédictions a été évaluée en comparant deux modèles indépendants à échelle locale pour s'assurer que les tendances locales étaient bien prises en compte dans le modèle régional, et également afin de comparer différentes méthodes de modélisation. Les résultats obtenus pour le sud de l'Okanagan ont été comparés à ceux d'une analyse HELP/MODFLOW de haute résolution, et nous avons déterminé qu'ils étaient semblables (42mm/an pour l'échelle locale, 34mm/an pour l'échelle régionale). Pour le nord de l'Okanagan, les résultats ont été comparés à ceux obtenus avec MIKE-SHE/MODFLOW basé sur la résolution des équations de Richard, et des différences significatives ont été observées (7mm/an pour l'échelle locale, 109mm/an pour l'échelle régionale).

1 INTRODUCTION

Groundwater recharge estimates are essential in determining the quantity and sustainability of a groundwater resource (deVries and Simmers 2002); however, recharge is a complex process resulting in spatially variable values that are difficult to measure, particularly at the regional scale and in semi-arid environments (Scanlon et al. 2002a). Regional scale, spatially-distributed, diffuse recharge estimates are often inferred by water balance or computer modelling approaches (Scanlon et al. 2002a, Scibek and Allen 2006, Jyrkama et al. 2002); although, there are a wide variety of methods available, some requiring data that are usually not available at a regional scale (Feyen et al. 2000). Also, regional scale recharge estimates must be reliable and straightforward to obtain, and adequately reflect local conditions to be effective for water use management.

This paper compares modelling approaches for predicting diffuse recharge to valley bottom aquifers in the semi-arid Okanagan Basin, British Columbia (BC). Modelling was undertaken using spatial datasets of varying resolution to obtain detailed recharge maps at the regional scale with the quasi-2D code HELP (Hydrologic Evaluation of Landfill Performance) (Schroeder et al. 1994). Regional recharge estimates were then compared with two, independently derived, local scale recharge models. In the south Okanagan, both the regional and local scale models used the same code, HELP; while in the north Okanagan, the local scale model was constructed using the Richards equation based MIKE-SHE code. Common raw datasets were used for all three models. The objectives of the study were to determine if the regional model effectively captures the local trends predicted by the local models, and to compare the modelling methods in respect of their ability to provide reasonable and consistent results.

2 OKANAGAN BASIN

The ~8 000 km^2 Okanagan Basin is located in south central BC, Canada (Figure 1). Increases in population, tourism, and agriculture (primarily orchards and vineyards) have led to an increased demand for water through the basin. Surface water sources in the basin are almost fully allocated, and many communities are turning to groundwater as a means of water supply. Unfortunately, little is known about the groundwater resources in the Okanagan, including the amount of recharge to the valley bottom aquifers.

The Basin is characterised by a long, north-south trending valley, extending from just north of Armstrong, nearly 200 km south, into Washington State (Figure 1). Upland plateaus and mountains surround the narrow valley, which is generally less than 5 km across. With mainly bedrock located along the valley sides and uplands, most of the valley bottom is filled with unconsolidated Quaternary sediments with a few areas of bedrock outcrop.

The Okanagan has a dry continental climate with mild winters and hot summers (Cohen et al. 2004). The valley bottom is semi-arid, with a climate gradient trending along the length of the valley from north to south. Mean annual air temperature ranges from 7.4°C in Vernon to 9.4°C in Oliver (Environment Canada 2006). The evapotranspiration gradient is opposite to the precipitation gradient, with less evapotranspiration in the north and more in the south. About 85% of precipitation in the Okanagan is lost through evapotranspiration (Cohen and Kulkarni 2001), and estimates of actual evapotranspiration from 1969 to 1977 (Stevenson 1978), show that average evaporation from May through to September in Armstrong (north Okanagan) was ~390 mm and in Summerland (south Okanagan) was ~630 mm.

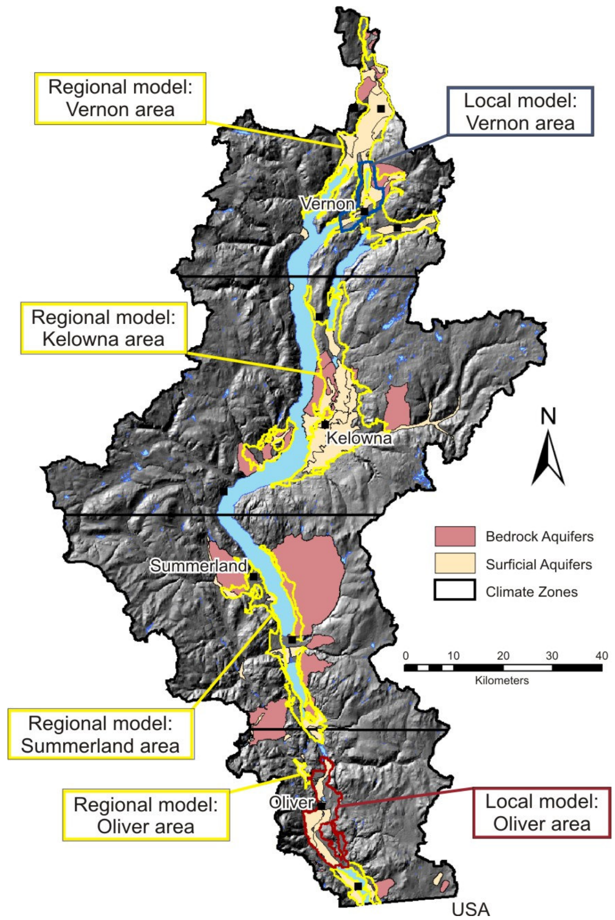

Figure 1. Okanagan Basin with modelling areas.

3 METHODS

3.1 Regional (Spatial) Recharge Modelling with HELP

The Hydrologic Evaluation of Landfill Performance (HELP) code was developed for the United States Environmental Protection Agency in 1984 to evaluate and compare the water balance components of various landfill cover designs (Schroeder et al. 1994). HELP solves a series of soil water balance equations for a layered column of material using a weather series as input to the top of the model. For recharge simulations, the base of the column is set equal to the depth of the water table, and leakage simulated through the bottom of the soil column is considered representative of direct recharge to the groundwater system.

The HELP code requires a weather series, soil properties, and soil column data as input, and accounts for the effects of surface storage, runoff, evapotranspiration, snowmelt, infiltration, vegetation growth, soil moisture storage, lateral subsurface drainage, and unsaturated vertical drainage. Detailed descriptions of all inputs and equations can be found in the supporting documentation for HELP (Schroeder et al. 1994).

Spatially variable recharge was simulated in the Okanagan utilising six, spatially variable inputs, which included climate, soil type, vadose zone type, depth to water table, leaf area index (LAI), and evaporative zone depth. The inputs were grouped into a number of categories of similar values and mapped within ArcGIS. Combinations of these six variables yielded unique HELP columns, and a HELP model was run for each combination. The recharge results were then applied to all areas containing that particular combination of variables, thus yielding a map of recharge, similar to the approaches of Scibek and Allen (2006), Jyrkama et al. (2002), Croteau (2006), and Toews (2007). Detailed recharge modelling methods for the regional model can be found in Liggett (2008).

Four valley bottom areas were considered for this study: the Vernon, Kelowna, Summerland, and Oliver areas (Figure 1). Only the valley bottom was modelled to restrict the study to areas of low slope, where runoff was likely a negligible process. Additionally, there is a lack of water well data, used to determine the depth to water table, in the upland areas. Only the Oliver and Vernon areas are considered in this paper; results from Summerland and Kelowna are found in Liggett (2008).

The Okanagan was divided into four zones of different climatic conditions, similar to those used by Neilsen (Personal Communication) (Figure 1). For each zone, daily temperature (measured), precipitation (measured), and solar radiation (calculated) data were used from 1961 to 1990 (Neilsen Personal Communication). Median quarterly humidity and annual windspeed was calculated from Environment Canada (2006) hourly data at each of the four stations. Unfortunately, hourly data were unavailable for 1961 to 1990; consequently, median quarterly humidity was calculated from 1994 to 2006 data for Vernon and Summerland, and from 1971 to 2004 data for Kelowna. As well, no hourly humidity data were available for the Oliver area; therefore, the median quarterly humidity and annual windspeed was calculated with hourly data from Osoyoos with 1994 to 2006 data.

Growing season start and end days were determined by identifying days for which the mean daily temperature was above (or below) 10°C and 5°C for 5 consecutive days. The median start and end dates from the 10°C and 5°C degree scenarios in each climate zone was entered into the HELP model.

Two, comprehensive, 1:20 000 digital soils maps were available for the north and south valley bottom of the Okanagan. A saturated hydraulic conductivity (K) was assigned to each soil horizon in the soil surveys based on soil texture properties within HELP (Schroeder et al. 1994). Soil horizons were considered as gravel when the percentage of coarse fragments was above 50%. A vertical, depth weighted, harmonic average was calculated to produce a single hydraulic conductivity for each soil type in the Okanagan.

The soil types were divided into four groups for input into HELP. Group 1 contained all soil types from the minimum conductivity to the 1st quartile, group 2 contained all soil types with a conductivity from the 1st quartile to the median, and so on. Based on the soil texture properties within HELP (Schroeder et al. 1994), conductivity, porosity, wilting point, and field capacity were assigned to each soil group.

Depth to water table through the valley bottom was interpolated using 1 512 wells selected out of 2 948 from the BC Ministry of Environment (MoE) WELLS database as representative of the water table. The water level in each well was first converted to elevation to determine the water table elevation map. Due to the uneven distribution of wells, control points were added in areas of limited well information and along the boundary of the valley bottom. Water elevations were assigned to these points based on the observed relationship between the water elevation (h) in each water well and the elevation of the ground surface (z) at each well location:

$$h = 0.9825z \tag{6.1}$$

In some locations, control points were manually assigned a water elevation based on topography and the trend of the water table elevation in the immediate area. Control points were also added along lakes and rivers with a water elevation equal to the ground elevation at that location.

The water table elevation map was interpolated with the nearest neighbour method on a 50 m grid. The interpolated water table elevation map has an RMS error of 1.6 m, and a normalised RMS of 5% when compared to measured values. The depth to water was calculated by subtracting the water table elevation map from the ground elevation map.

The depths to water table throughout the Okanagan were grouped into four categories. Like the soils, Group 1 contained all areas where the depth to water ranged from the minimum depth to the 1st quartile; Group 2 contained all areas where the depth ranged from the 1st quartile to the median; and so on. The median depth to water was calculated for each group and used to represent the water table depth for each.

Unfortunately, due to the distribution of well data, it was difficult to use the recorded well lithologies to assign and interpolate conductivity values throughout the Okanagan. Therefore, the parent material from the soils map was selected to spatially represent the conductivity of the vadose zone. The parent materials were grouped into three categories and assigned hydraulic parameters based on the soil texture properties in Schroeder et al (1994).

Leaf Area Index (LAI) is the ratio of upper leaf surface area to the surface area of the land upon which the vegetation grows, and is used in HELP to calculate evapotranspiration. LAI was estimated from 30 m resolution Landsat 5 TM imagery acquired on August 8, 2005 and Landsat 7 ETM+ imagery acquired on July 3, 2001 (Soffer et al. Personal Communication). The range of LAI values throughout the valley was from 0 to 8; however, 87% of the area had an LAI of < 2. According to the documentation (Schroeder et al. 1994), HELP is insensitive to LAI values above 5. Therefore, LAI was split into two groups from 0 to 1, and 2 to 8, and assigned mid-LAI values of 0.5 and 3.5, respectively.

The HELP model is sensitive to evaporative zone depth (EZD) (Croteau 2006), which is the depth to which water can be removed from the soil column by evaporation or transpiration (Schroeder et al. 1994). This depth is dependent on both the soil texture and the vegetation (Shah et al. 2007), and must be explicitly specified within HELP. Each of the different land cover types in the Okanagan were grouped into four categories and assigned representative evaporative zone depths (as described in Liggett 2008).

The spatially varying input parameters (e.g., soil, vadose zone, etc.) for all four regions identified (Vernon, Kelowna, Summerland, and Oliver) were discretized into 50x50m cells and combined in ArcGIS. Considering all possible combinations of input parameters, there were 841 unique HELP columns for the entire study area. For each column, a 30 year simulation, plus a 60 or 150 year model spin-up was completed. These spin-up times were used to allow for an adequate initialization of soil moisture, storage, and recharge and were created by repeating the 1961-1990 data series three to five times (Liggett 2008).

For each of the 841 simulations, tables of monthly totals, annual totals, average monthly, and average annual recharge and evapotranspiration values were created for the 1961-1990 timeframe. The average monthly and average annual tables were imported into ArcGIS and linked to the location of each unique HELP column to produce spatially-distributed maps of average monthly and average annual recharge conditions.

3.2 Local scale Recharge Modelling in Vernon

Smerdon et al. (2008) used the Richards equation based MIKE-SHE code to estimate spatial recharge for the Vernon area in the northern Okanagan (Figure 1). MIKE-SHE is an integrated hydrologic modelling system designed to simulate all major aspects of the hydrologic cycle including evapotranspiration, overland flow, unsaturated flow, groundwater flow, channel flow and interactions between these processes

Smerdon et al. (2008) utilised the unsaturated, overland flow, and evapotranspiration components of MIKE-SHE to simulate spatially-distributed recharge in the Vernon area for similar water table conditions as the current study. These recharge values were then used in a MODFLOW model to explore the linkage between upland water sources and valley bottom aquifers. One-dimensional unsaturated flow through the vadose zone and, thus, recharge, were simulated using Richards' equation. Recharge was calculated spatially based on a 100x100m grid for the valley bottom area. Unlike HELP however, runoff was routed from one cell to the next.

Similar datasets were used in both the regional study and the local Vernon study by Smerdon et al. (2008). These include the soil survey, LAI data, BC WELLS database, and land use. Also similar to the regional HELP model, soil and vadose zone types were grouped into areas of similar properties, creating 13 unique areas of material types. Two zones of LAI and four zones of rooting depths following the same spatial patterns as the regional model LAI and evaporative zone depths were input into the local model. Like the regional model, the two zones of LAI were assigned maximum values of 0.5 and 3.5; and adjusted manually (linear decrease) to account for the absence of leaves in the winter months. The evaporative zone depths used in the local model were 50 cm less for three categories, because these represent rooting depths as opposed to evaporative zone depths. Like the LAI parameter, the maximum rooting zone depths were adjusted slightly for the winter months. Finally, the depth to water table was determined from wells in the region, and formed the lower boundary condition for each 100x100m grid cell.

The same 30 years of measured climate data as the regional HELP model, i.e., from 1961 to 1990, were used in the local MIKE-SHE model. Spatial recharge was calculated for each grid cell. Unlike HELP, which produces cumulative monthly and annual values, MIKE-SHE produces a ‘snapshot’ of the recharge for the output days specified. Daily leakage through each column, or recharge, was output every 30 days for 30 years from 1961 to 1990 inclusive, and post-processed to generate average monthly and average annual recharge values (Smerdon et al. 2008). Thus, the day selected may not be representative of average monthly values for recharge.

Similar to the study by Toews (2007) in Oliver (discussed following), the spatial recharge results from MIKE-SHE were input into a steady-state MODFLOW groundwater flow model. The model incorporated water balance contributions from the upland areas (estimated based on a broad-scale water budget) and was adequately calibrated to the hydraulic head data from the WELLS database.

3.3 Local scale Recharge Modelling in Oliver

Toews (2007) used the HELP code to estimate spatially-distributed diffuse valley-bottom recharge and the potential changes under scenarios of predicted climate change within the Oliver region of the south Okanagan (Figure 1). That study used the same raw spatial datasets as the current study; however, data manipulation and modelling approach differed as described below.

For climate data, Toews (2007) utilised the LARS-WG weather generator to stochastically generate 200 years of calibrated daily maximum and minimum temperature, precipitation, and solar radiation, rather than using recorded weather data. Average annual precipitation and temperature were similar for the regional and local studies. Only the last 100 of the 200 years of data were used for recharge analysis to allow for an adequate spin-up time for soil moisture (Toews 2007).

Similar to this study, Toews (2007) considered six spatially-varying physical input parameters, including soil drainage, soil texture, evaporative zone depth, LAI, surface slope, land cover and depth to water. The runoff curve number was calculated for each column using soil drainage, soil texture, land cover and slope.

Unlike the regional recharge model, which contains only two layers for each HELP column, the local Oliver study considered multiple soil horizons representing spatial and depth weighted average soil profiles for all soil types on a 100 x 100m grid cell basis (Toews 2007). In addition, the hydraulic properties of each soil type were calculated with hierarchical pedotransfer functions (Toews 2007). The hydraulic properties of the bottommost soil horizon were used to represent the vadose zone, and this layer was extended to the water table depth at the bottom of the HELP column.

For the HELP simulations, Toews (2007) assigned unique parameters as described above to each grid cell rather than grouping each of the input parameters into a set number of categories as was the approach with the regional model. A unique HELP model was run for each of the 10 102 grid cells.

Toews (2007) used the recharge results as input to both steady state and transient groundwater flow models for the Oliver region to investigate impacts of future predicted climate change on groundwater levels. The steady-state model was calibrated against the measured hydraulic heads in the WELLS database, and for pumping tests reported in the area. The good calibration results support the range of recharge values used in the model for measured ranges of hydraulic properties, which were determined from pumping tests, and assigned to the various hydrostratigraphic units.

4 RESULTS

Recharge results for the Vernon and Oliver areas from both the regional and local models are shown in Table 1, Figures 2, 3, and 4. Results for Kelowna and Summerland can be found in Liggett (2008).

Table 1: Average recharge results for Vernon and Oliver.

	Vernon		**Oliver**	
	Local	Regional	Local	Regional
Annual	6	109	42	37
% Precipitation	1.3	24	14	12
January	0.1	7.7	3.2	2.8
February	0.2	7.1	3.0	2.9
March	1.2	12.6	2.8	3.9
April	1.1	13.0	3.3	4.0
May	0.5	9.2	4.0	3.6
June	0.5	8.4	3.9	3.1
July	0.3	9.5	4.1	2.9
August	0.3	9.8	4.0	2.9
September	0.3	9.0	3.7	2.7
October	0.3	8.7	3.7	2.7
November	0.6	8.7	3.5	2.9
December	0.4	7.8	3.7	2.9

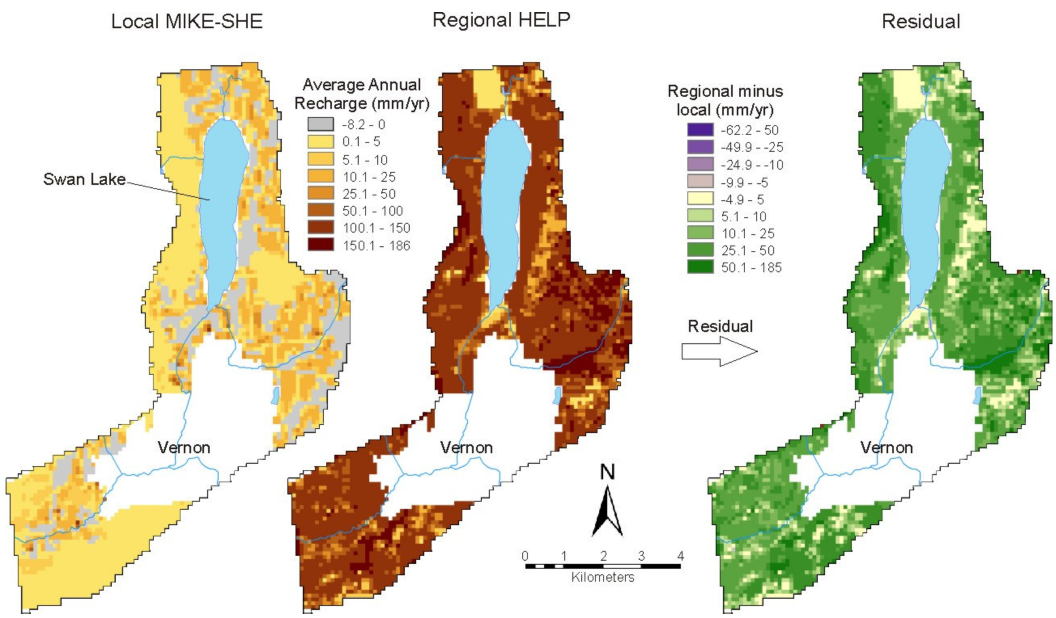

Figure 2. Comparison of recharge from local MIKE-SHE and regional HELP models in Vernon.

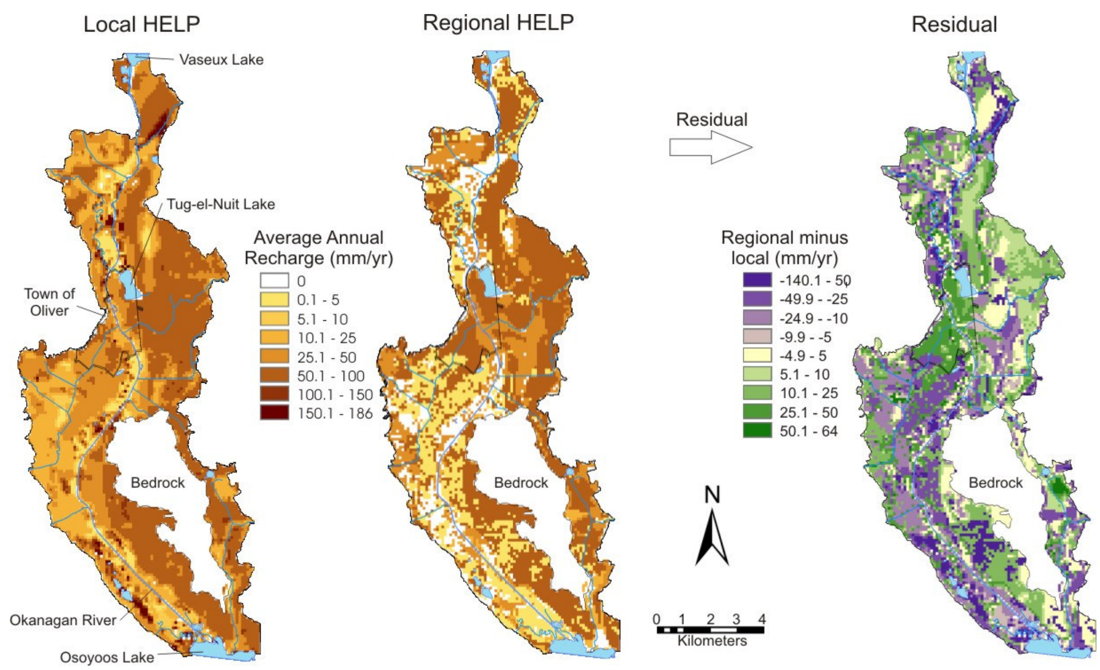

Figure 3. Comparison of recharge from local and regional HELP models in Oliver.

For the local Vernon MIKE-SHE model, average annual recharge varied from -8 mm/yr (i.e., upwards flux of water, no recharge) to 135 mm/yr (Figures 2 and 4a, b) with a spatial average of 6 ± 8 mm/yr (Table 1). Although the maximum average annual recharge for the local model was 135 mm/yr, only 21 100 x 100 m cells had values above 40 mm/yr. Considering only the overlapping areas between the regional and local models, the average annual recharge in the regional model varied from 1 mm/yr to 186 mm/yr, with a spatial average of 109 ± 40 mm/yr. The average annual recharge represents 1.3% and 24% of the average annual precipitation for the local and regional Vernon models, respectively. The residual map and histogram between the regional and local models are shown alongside the individual results for these models in Figures 2 and 4a, b.

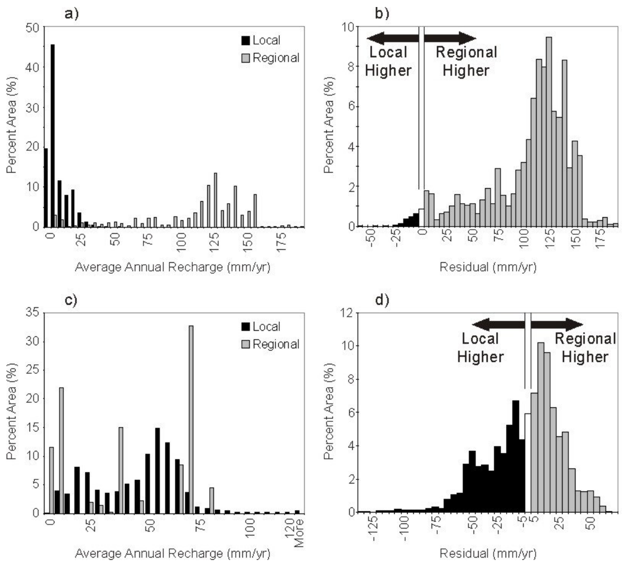

Figure 4 a) Histogram of average annual recharge results from the local and regional Vernon MIKE-SHE and HELP models. b) Residual from regional map minus the local map in Vernon. c) Histogram of average annual recharge results from the local and regional Oliver HELP models. d) Residual of from regional map minus the local map in Oliver.

For the local Oliver HELP model, average annual recharge varied from 0 mm/yr to 199 mm/yr (Figures 3 and 4c, d) with a spatial average of 42 ± 22 mm/yr (Table 1). Considering only the overlapping areas between the regional and local models, the average annual recharge in the regional model varied from 0 mm/yr to 78 mm/yr, with a spatial average of 37 ± 29 mm/yr. The spatial average annual recharge represents 14% and 12% of the average annual precipitation for the local and regional Oliver models, respectively. The residual map and histogram between the regional and local models are shown alongside the individual results for these models in Figures 3, and 4c, d.

5 DISCUSSION

5.1 Regional to Local Comparison in North Okanagan

The local MIKE-SHE model in Vernon predicted much lower recharge compared to the regional HELP model (Figures 2, and 4a, b). The spatially averaged annual recharge in the regional model (109 mm/yr) was over an order of magnitude higher than the local model (6 mm/yr), representing a difference of 103 mm/yr.

Although there was a difference in the absolute value of recharge between the MIKE-SHE and the HELP models, a comparison of the monthly distribution of recharge in the Vernon area suggests that the timing of recharge throughout the year is similar (Table 1). Both models show a peak in recharge in March and April and a minimum in January and February.

The significant difference in recharge between HELP and MIKE-SHE was directly due to differences in the simulation of evapotranspiration. Actual evapotranspiration (AET) estimates were compared for the summer months (May to September) in 1969 to 1973; from MIKE-SHE and HELP, to measured Agriculture and Agri-Food Canada (AAFC) data (Stevenson 1978), and calculated AAFC data from daily climate measurements (Neilsen Personal Communication) (Figure 5). As the AET values from Stevenson (1978) and Neilsen (Personal Communication) were calculated for a complete vegetative ground cover, only areas with a high LAI category (3.5) in the local and regional models (implying denser vegetation) were compared with the measured data. The average AET values from all areas of the model domains (i.e., high and low LAI) are also shown in Figure 5.

From the comparison of AET values (Figure 5), HELP was found to significantly under-predict AET in the Vernon area and, thus, over-predict recharge. These findings are consistent with other studies (Scanlon 2002b, Khire et al 1997), which found HELP over-predicts recharge by under-predicting AET, especially in semi-arid areas (Khire et al. 1997, Scanlon 2002b). This under-prediction of AET in HELP could be due to the algorithms used to predict AET, or may be related to under-estimating the evaporative zone depth. The HELP code does not account for upward water flux; therefore, it is essential that the evaporative zone depth be defined at an appropriate depth below which ET cannot occur. This depth must be explicitly specified and is commonly unknown or, at least, uncertain.

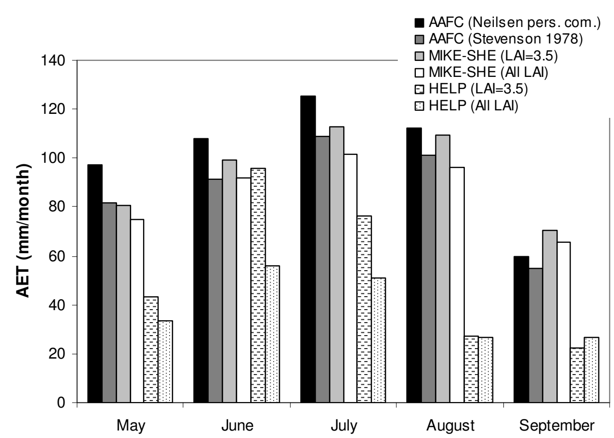

Figure 5. Actual evapotranspiration for the Vernon area.

Another possible explanation for model discrepancy is runoff, although this accounts for much less difference than the calculation of AET. Some localised areas were highly affected by runoff in the local MIKE-SHE model and resulted in high recharge (up to 134 mm/yr) for isolated cells due to the effects of ponding in small depressions. The importance of this localised, depression-focused recharge in semi-arid areas is well known in other regions (e.g., deVries and Simmers 2002, Scanlon et al. 2002a); however, the extent to which this process affects recharge in the Okanagan is unknown. Notwithstanding these observations, there was no trend of higher recharge downslope than upslope across the map area, which suggests that the runoff factor could be localized.

In summary, the absolute values of recharge were very different between the local MIKE-SHE model and the regional HELP model, suggesting that there was a consistent error in the recharge calculation from each code. The most likely explanation is a difference in AET due to methods of solution and uncertainties in establishing the evaporative zone depth in HELP. Runoff appears not to be a significant factor in the differences between the models. There was also little spatial correlation between the local and regional models. Based on the comparison of AET values to observed and calculated data, it appears that MIKE-SHE predicts recharge more accurately than HELP. Thus, for relatively heterogeneous soil and vadose zone properties, and dry climate of the north Okanagan, HELP was found to overestimate recharge, which echoes findings in similar studies.

5.2 Regional to Local Comparison in South Okanagan

Overall, the regional recharge map indicated lower recharge for the Oliver area by an average of 5 mm/yr compared to the local model results. A two sample t-test showed that these results were significantly different at the 95% confidence interval. Although statistically different, practically, 5 mm/yr (2% of average annual precipitation) would be considered a rather small uncertainty in recharge modelling. There are a number of differences in modelling approach that may account for the slightly lower recharge predicted by the regional model as discussed below.

First, in the regional model deeper evaporative zone depths were utilised relative to those assigned by Toews (2007) which allow for more evapotranspiration, thus lowering recharge to the aquifer. Secondly, the hydraulic conductivity values used in regional model for the soil and vadose zone materials were an order of magnitude lower than those used in the local model. Lower conductivity values may result in slower water movement through the evaporative zone, allowing for more evaporation and less recharge. Another difference was that the local model had multiple soil horizons rather than one composite soil layer. Also, the bottommost soil horizon was extended to the water table in the local model, whereas the parent material of the soil was extended to the water table in the regional model.

The regional recharge map of the Oliver area was more variable spatially than the local recharge map (Figure 3). This was primarily due to the method of grouping the gradational input variables into a set number of categories for the regional modelling. Areas along the input category boundaries show an abrupt change in recharge, even though there may be only a slight difference in the actual input property and the recharge.

While there were many spatial variations in recharge between the regional and local maps, the error was randomly distributed across the area, and appeared normally distributed with a mean of -5 mm/yr and a median of 1 mm/yr (Figures 3, and 4c, d). Generally, both the local and regional recharge distributions show the same trend in recharge, with more recharge on the eastern side of the valley, and less recharge along the river and the west side of the valley.

In summary, the average annual recharge for both models was similar, suggesting that HELP provides consistent results at these two spatial scales. Differences in monthly recharge were likely due to the differences in how the properties and distribution of the subsurface materials were represented in each of the models. Spatially, the recharge follows a similar trend through the Oliver area; however, there are many differences in the spatial pattern in localized areas. Thus, for the relatively homogeneous soils and vadose zone material, and the dry climate of the south Okanagan, the two HELP models were found to represent recharge similarly.

Although the local recharge results by Toews (2007) were used in a steady state flow model, recharge and hydraulic conductivity are highly correlated, and calibrating flow models to head data only identifies the ratio between recharge and conductivity (Scanlon et al. 2002a). Therefore, it is possible for Toews (2007) to have calibrated the steady model with the recharge values from HELP by only slightly adjusting the hydraulic conductivity of the sediments in the subsurface, as these can vary over several orders of magnitude. This suggests that the absolute values of recharge fluxes obtained from both the local and regional HELP models remain uncertain, and results from the model comparison in Vernon suggest these estimate may not be accurate.

6 CONCLUSIONS

Recharge is an important component of the groundwater budget, and estimates are critical for effective groundwater management. However, accurate measurements are difficult to obtain due to the spatial variability of recharge, particularly over large regions. Extrapolating local recharge measurements to the regional scale can be difficult due to variations in climate, physical, and biological characteristics of the land surface; therefore, regional scale recharge estimates are often obtained from computer models. Additionally, regional scale recharge estimates must be reliable and straightforward to obtain, and adequately reflect local conditions to be most effective for local water use management and assessment of groundwater resources.

In Vernon, where different codes were used to model recharge (i.e., HELP and MIKE-SHE), there was a significant difference between the recharge predicted by each model in both spatial extent and absolute values of recharge. It appears as though HELP under-predicted actual evapotranspiration, which resulted in an over-prediction of recharge; this was most noticeable in the summer months. These findings indicate that the recharge results from HELP through the entire Okanagan, including the local Oliver model, may be similarly over-estimated. The relative distribution of recharge throughout the year was consistent between the local and regional model, indicating that although HELP over-predicted recharge, the changes in distribution throughout the year were similar.

In Oliver, where the same code was used to model recharge (i.e., HELP), there was a subtle difference in the spatial pattern of recharge between the local and regional models. However, these differences were randomly distributed across the area and relatively normally distributed, indicating that there was not a systematic difference in the two modelling approaches. Overall, the average annual recharge was essentially the same between the two models. The comparison of the two Oliver models showed that locally, recharge was highly variable and the regional scale model did not capture the same trends as the local scale model; however, when averaged spatially, the recharge from both the regional and local scale studies was similar, indicating there was little difference between the regional and local scale models. These findings illustrate the uncertainty of recharge model results at a localized scale using different methods. From a water management perspective, regional recharge maps provide an adequate overall estimate of diffuse recharge and the general trend across an area; however, there may be less certainty when examining the recharge maps on a very localized scale.

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