Quantifying the impact of predicted climate change on groundwater recharge to fractured rock aquifers

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Background

This study demonstrates the use of the HELP model (Schroeder *et al*., 1994), driven by predicted daily weather data, to quantify the impact of climate change on recharge amount to fractured bedrock aquifers.

With significant changes expected in global climate over the next century, there has been growing concerns on its impacts on water resources, especially groundwater, worldwide (Hengeveld, 2000). The Gulf Islands (GI) region (Fig.1) in Canada is used to demonstrate the methodology, but a similar methodology has been applied in other areas and may provide a means to estimate recharge under scenarios of climate change in other regions. Groundwater within fractured sedimentary rock aquifers of the Upper Cretaceous Nanaimo Group serves as the main potable water supply to the inhabitants. However, sustainability of the water supply is threatened by increasing residential development and high water usage coupled with low recharge during the summer months.

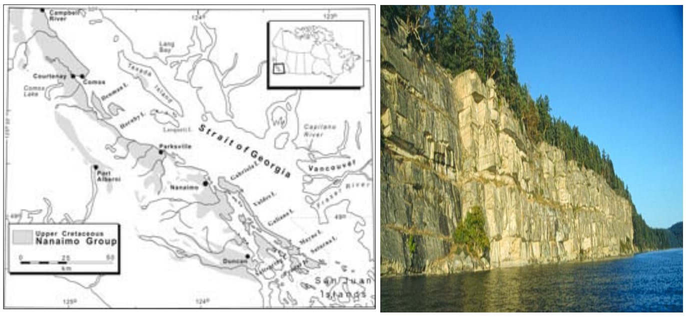
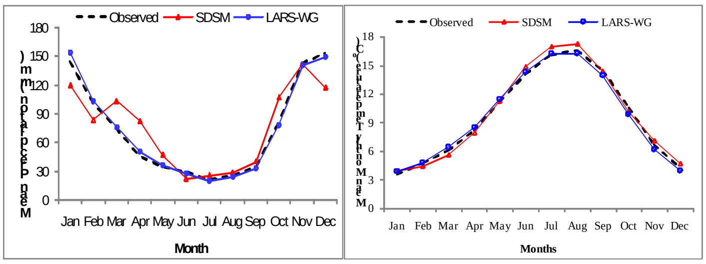


Fig. 1. GI region showing exposure of the Nanaimo Group sedimentary rocks (after Mustard, 1994); Sandstone exposure

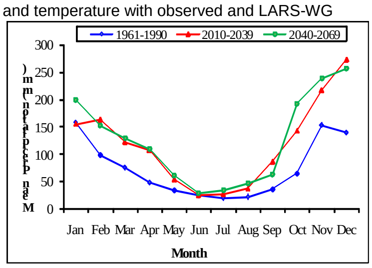
Climate Change Modelling

Current (1961-1990) and future (2001-2069) climates were simulated from the first version Coupled Global Climate Model (CGCM1) predictor variables using Statistical Downscaling Model (SDSM) version 3.1 (Wilby and Dawson, 2004). SDSM had some difficulties in accurately downscaling monthly mean temperatures and precipitation (Figs. 2a and b). Hence, the output was passed through the Long Ashton Research Station Weather Generator (LARS-WG), which produced a good fit to both the observed temperature and precipitation (Fig. 2a and b) and was, consequently, used for simulating future weather data for the recharge estimations.



ig. 2. Comparing SDSM current precipitation and temperature with observed and LARS-WG

Future monthly precipitation patterns (Fig. 3) on the islands are similar to the current. The current annual precipitation is predicted to increase by 52% and 65% in 2010-2039 and 2040-2069, respectively. Mean monthly temperature is predicted to rise by 1.14ºC in the 2020's and 2.05ºC by 2070



ig. 3. Predicted future precipitation of GI

HELP Recharge Methodology

HELP recharge modelling involved creating different vertical percolation columns that account for soil permeability and thickness, depth to water table, and permeability of fractured vadose zone media. Average estimates were used to create recharge zones in ArcGIS that allowed spatial and temporal integration of recharge results.

Data for constructing the percolation columns were obtained from 1) water well database, 2) soil maps, and 3) intrinsic aquifer vulnerability maps (Denny et al., 2007).

48 percolation vertical columns (e.g. Fig 4) were created from the data, based on a combination of three aquifer media classes (less fractured sandstone, interbedded mudstone sandstone, and fractured zone), four different soil classes (clay, topsoil, glacial till, and gravelly sand), and four water depth classes for the HELP recharge estimations.

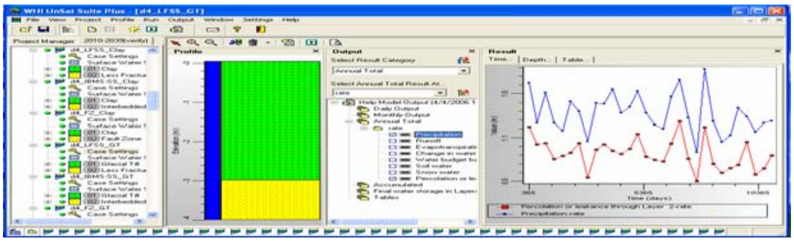


Fig. 4. HELP interface displaying percolation column and results after model runs

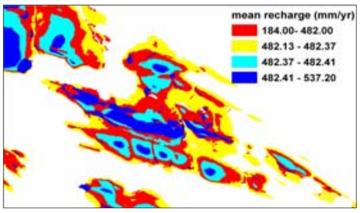


Fig. 5. Estimated current spatial recharge to Mayne Island (Quartile ranges shown)

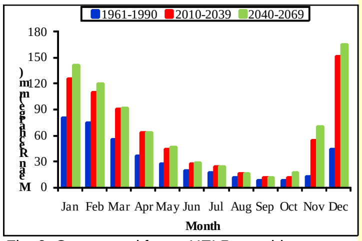


Fig. 6. Current and future HELP monthly recharge estimates to of the Gulf Islands

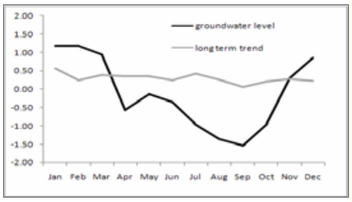


Fig. 7. Seasonality and monthly trends in groundwater levels for an observation well on Mayne Island.

Discussion

Current spatially distributed recharge to the aquifers (Fig. 5) ranges between 184 to 537 mm/yr (or 14 to 41 mm/month) representing between 20% to 60% of the mean annual precipitation. The estimate is higher in comparison to previous estimates based on hydrograph and water balance approaches, and suggests that HELP may be over-estimating recharge due to runoff under-estimation.

Notwithstanding the seemingly high estimates, both the seasonality of recharge and potential shifts in recharge due to climate change are thought to be representative. Mean monthly recharge pattern (Fig. 6) is similar to the temporal distribution of precipitation and the response of the aquifer, as suggested by observation well hydrographs, and is also consistent with the estimates (Fig. 7).

Future mean annual recharge on the islands is predicted to increase by 7% and 8% in the 2020's and 2050's, respectively. Interestingly, a statistical analysis of trends in monthly groundwater levels using observation well data on Mayne Island suggests a weak but positive trend in all months over the period 1976-1996 (Fig. 7), which may be evidence of a climate shift that is already occurring.

Conclusions

1. Recharge to fractured rock aquifers on the GI was estimated using HELP columns that accounts for spatial variability of soil and aquifer media properties.
2. Spatially distributed mean annual recharge to the GI is estimated to be in the range of 184 to 537 mm/year and is predicted to increase in future; up to 8% by 2070. Over half of precipitation from December to June contributes to recharge, while less than 40% contribute to recharge from July to November.
3. HELP appears to under-predict runoff and potentially over-estimate recharge, despite attempts to ensure that the factors influencing runoff (curve number and slope) were duly considered. Consequently, caution should be exercised when using this recharge model. However, even if its accuracy is problematic, its use for examining sensitivity to climate change can be exploited as demonstrated in this work.

cknowledgements

hanks to Megan Surette, Murray Journeay and Shannon Denny for providing some of the data for the work, and the conference organisers for sponsoring this presentation.

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