Historical trends and future projections of groundwater levels and recharge in coastal British Columbia, Canada

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ABSTRACT

Climate change has the potential to put added stress on coastal aquifers that are already experiencing increasing development pressures. Reduction in natural recharge owing to changes in the frequency, amount and duration of precipitation, and increased temperature, in combination with rising sea level, coastal erosion and storm surges are all potential threats. In this study, historical groundwater levels were examined for selected observation wells in the south coastal region of British Columbia, Canada, to gain a better understanding of historical trends. Over a common period (1976-1999), negative trends in groundwater level dominate most records, and appear to be related to longer term negative regional trends in precipitation, although variable trends are evident at the shorter time periods used for this study. To explore potential consequences of varying recharge on groundwater quality, water chemistry data from selected monitoring wells on one island were examined. Chloride concentrations are observed to vary annually in one well by up to 4000 mg/L. Projections for future climate from one global climate model (CGCM1) were used as input to a recharge model to study the sensitivity of recharge to shifts in precipitation and temperature predicted for the region. The recharge model was driven by a stochastic daily weather series, calibrated to historic climate data. Daily weather series represent historic climate, and two future time periods (2020s) and (2050s). Simulated recharge increases progressively in the future using this particular global climate model; however, precipitation projections for this region of British Columbia are highly uncertain. Both positive and negative shifts in annual precipitation are predicted using a range of global climate models. Ongoing research is attempting to integrate results from various global climate models and sea level change into a groundwater flow and transport model.

INTRODUCTION

With substantial changes in global climate predicted over the next century, there is growing concern about the impacts of climate change on water resources worldwide. Coastal aquifers, in particular, may experience significant stress due to climate change because of their increased risk of salinization and because these regions are already experiencing high development. Reduction in natural recharge, owing to changes in the frequency, amount and duration of precipitation, and increased temperature, in combination with rising sea level, coastal erosion and storm surges are all potential threats to these highly sensitive coastal aquifers. Shifts in the interface under climate change might be anticipated in areas where recharge will lessen, given that sea level is expected to rise under future climate scenarios.

This study consisted of three parts: 1) Trends in historical groundwater levels were examined for the south coastal region of British Columbia, Canada; 2) Water chemistry data from selected monitoring wells were examined to explore potential consequences of varying recharge on groundwater quality; and 3) Recharge was simulated for both historic and future time periods, based on the projections for shifts in precipitation and temperature obtained from one global climate model (GCM). The results are discussed in terms of uncertainty in GCM predictions for this region.

The region is mountainous with topography ranging from sea level up to 450 m above sea level. The climate is characterized by cool dry summers and humid mild winters; mean annual precipitation ranges from 658 mm to 983 mm. About 80% of the mean annual precipitation (mostly as rain) falls in October to April and less than 10% of the mean annual precipitation falls during the summer months (i.e. June to August). Mean monthly temperature on the islands generally ranges between 3.7°C to 4.2°C in winter (i.e. November to January), increasing to a range of 17.0°C to 18.4°C in summer.

Groundwater in fractured rock is the main source of potable water source. Groundwater recharge occurs during the winter months (November to March). Consequently, the natural groundwater levels in these coastal aquifers show a seasonal high during winter or early spring (January), and generally decline from spring to late fall to their lowest levels in September. During the summer months, when recharge rates are at their lowest and when population increases due to summer residents and tourists, the groundwater resource is at higher risk for deterioration of quality (increases salinity) and quantity (dry wells). Groundwater levels have been found to be sensitive to changing climate conditions, as evidenced by strong apparent correlation between groundwater levels and El Nino Southern Oscillation (ENSO) cycles.

METHODS

Trend Analysis

All available observation well groundwater level records that cover the time period from 1980 or earlier until at least the year 1999 were extracted from the BC Ministry of Environment website. Records with more than 20% missing data were excluded. Ultimately, five observation well records were used to represent the Gulf Islands study region (Obs. Wells 126, 127, 128, 258 and 268, with depths ranging from 30 to 312 m) (Note of total of 37 wells were available for analysis at the provincial scale). A common period from 1976 to 1999 was chosen for analysis. The starting year coincides with the shift to the positive phase of the Pacific Decadal Oscillation (PDO), a situation that is predicted to become more dominant in the future climate. Temporal trends of groundwater levels were calculated using the non-parametric Spearman’s rank correlation coefficient, rs, and a p-value of <0.05 to determine whether the trend was significant. Trends for the observation well levels were calculated for annual series of each individual calendar month.

Groundwater Quality Monitoring

Twenty two wells on Saturna Island were monitored for chemistry over the period 2002 to 2007. These wells reflect a range of water chemistry characteristics (e.g. evidence of saltwater intrusion ranging to fresh groundwater). Wells were sampled monthly from June 2002 to October 2003, and every six months thereafter until April 2007. Among other water quality parameters, chloride concentration was measured as a primary indicator of salinity.

Recharge Simulation for Historic and Future Time Periods

Recharge simulations were undertaken for the Gulf Islands to estimate historic recharge and potential future recharge under projected climate change conditions. The quasi-two-dimensional, deterministic, water-routing HELP (USEPA) hydrological model (Schroeder *et al*. 1994) was used for recharge simulations. Different vertical percolation profiles were constructed to represent unique recharge zones, defined by mapping and classifying soil type and thickness, depth to water table, and vadose zone permeability across the islands. The recharge model was driven by a stochastic daily weather series, calibrated to historic climate data. Daily weather series represent historic climate, and two future time periods (2020s) and (2050s). Shift factors were applied to the historic weather series based on downscaled temperature and precipitation predictions from one global climate model (CGCM1) (Boer *et al*. 2000).

RESULTS

Trends

Trends in groundwater levels are shown in Figure 1. Observation wells on Mayne Island and Denman Island show negative trends year-round. They are more strongly negative in the first half of the year, but not statistically significant. The well on Galiano Island has significant negative trends from June to September. Long-term climate analyses indicate negative precipitation trends for the winter recharge season in the area; however, shorter time series, such as that used in this study, indicate more variable monthly precipitation trends with mainly increasing precipitation for the winter half year and a more common signal of negative precipitation trends in the summer. The causes for negative trends in groundwater level are thus uncertain, and are thought to reflect a combination of negative precipitation and human influences due to pumping despite the placement of these observation wells away from populated areas.

Water Quality

Average chloride concentrations in the monitoring wells range from 6-2690 mg/L and vary seasonally (from a few mg/L to roughly 200 mg/L) in 15 of the 22 wells. In seven wells, the variability exceeds 300 mg/L, with one well showing a maximum variability of 4000 mg/L over the 5 year monitoring period. Chloride concentrations appear to be inversely correlated to groundwater levels. Whether this relation is due to freshening during the winter months or increased salinization during the summer months cannot be determined due to high noise in the data. The annual variability in recharge and groundwater quality suggests that shifts in recharge due to climate change could possibly result in shifts in water quality.

Historical and Future Recharge

Simulated historical spatially distributed mean annual recharge ranges between 184 to 537 $mm \cdot year^{-1}$ representing between 20% and 60% of the mean annual precipitation. More than half of the precipitation from December to June contributes to recharge whereas less than 40% of precipitation from July to November contributes to recharge. Highest recharge on the islands is in December, whereas the lowest often occurs in between July and October.

Future mean annual recharge on the islands is predicted to increase by 16–94% and 31–111% in the 2010–2039 and 2040–2069 time periods, respectively based on the single GCM model used (Figure 2). The proportion of precipitation received as mean annual recharge is projected to increase from the current fraction (44%) by 7% and 8% in the 2020s and 2050s, respectively.

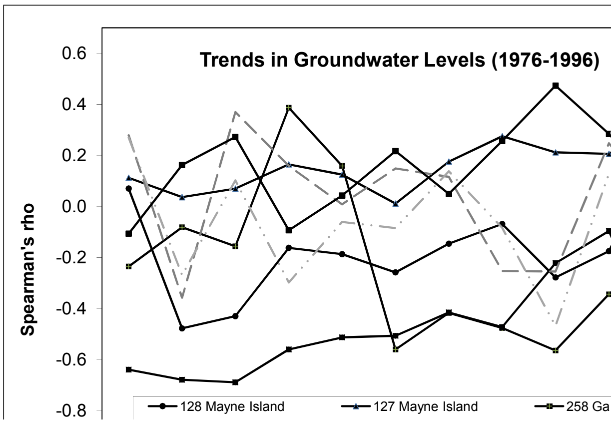

Figure 1. Trends in groundwater level (1976-1996)

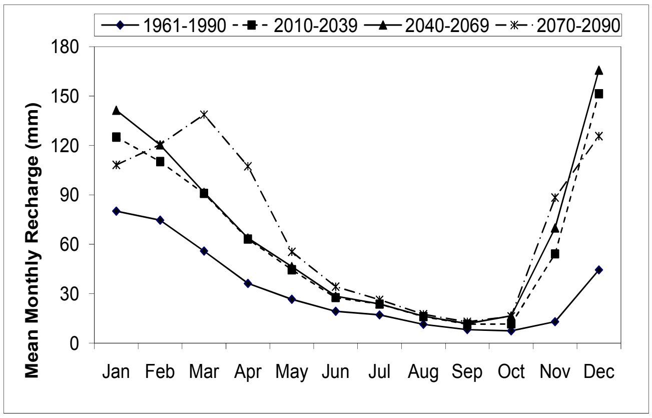

Figure 2. Simulated monthly recharge for current and future CGCM1 time periods.

DISCUSSION AND CONCLUSIONS

The contribution of precipitation to recharge is predicted to increase by up to 8% by 2070 based on the results of one GCM using one emissions scenario, namely CGCM1. Recent research in this coastal region of BC has compared recharge simulated using a similar approach, but with four other GCMs (CGCM3.1, ECHAM5, PCM1 and CM2.1). Both increases and decreases relative to historic recharge were simulated depending on time period and model. By the 2080's, the range of model predictions spanned -10.5% to +23.2% relative to historic recharge. This uncertainty in recharge predictions suggests that a range of GCMs should be considered for water management planning. As part of ongoing work, results from these other GCMs are being compared, and recharge from each used as a boundary condition to a three dimensional, density-dependent, groundwater flow and transport model to study the effects of climate change on salinity distributions under scenarios of climate change, including rising sea level.

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