features

Impacts of Climate Change on Groundwater in BC

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Groundwater, often referred to as the "hidden" resource, is an important natural resource in British Columbia. In areas where surface water supplies are unavailable (eg, some Gulf Islands), fully allocated (eg, parts of the Okanagan Valley), too costly to develop, of marginal quality, or require expensive treatment, groundwater is often a viable and cost-effective source of water supply.

Furthermore, groundwater also has a critical role in maintaining stream flows during summer months, which sustain fish habitat, aquatic ecosystems, and the animals that depend on them. Yet, despite the economic and ecological importance of groundwater, very little has been reported on how climate change might affect groundwater resources in the future.

This article briefly focuses on some potential impacts of climate change on groundwater, encompassing groundwater recharge, groundwater levels, and the resource itself. This topic, particularly in the context of BC, has been a focus of a research program at Simon Fraser University (SFU) over the past decade, and has formed the basis of several SFU Masters theses and collaborative projects between SFU, the University of British Columbia, and Environment Canada. The projects have focused on the historical analysis of natural variations in groundwater levels across the province, modeling recharge and groundwater-streamflow interaction under scenarios of climate change, and the development of an overall understanding of climate-groundwater-surface water interactions in BC.

Potential Impacts of Climate Change on Groundwater

Undertaking a climate change impacts assessment on a groundwater system is complicated because, ultimately, atmospheric change drives hydrologic change, which, in turn, drives hydrogeologic change. The latter requires detailed information about the subsurface; information that is traditionally difficult to obtain and sparse for much of BC. Each aquifer has unique physical properties (ie, the geology), geometry (ie, the control on broad flow patterns), and the nature of connection with surface

water (ie, can be a highly dynamic water source and sink for groundwater). Thus, to determine the potential impacts of climate change for a particular aquifer, a detailed characterization is needed, with suitable quantification of the water budget components. This if often achieved through use of site- or region-specific numerical models of groundwater flow. This type of case-by-case approach is entirely unreasonable given the number of aquifers in BC. However, through a combination of detailed case studies and a general understanding of both anticipated climatic and hydrologic impacts along with an understanding of the responses of aquifers, it is reasonable to forecast, at least in a general fashion, how groundwater systems might respond to climate change in different regions of the province.

To date, four case studies in BC have been completed to quantify potential impacts of future climate change on groundwater recharge and groundwater levels. The detailed results from all of these studies can be found in the various papers and associated MSc theses. These include the Grand Forks aquifer in the south central interior, the Oliver region of the South Okanagan, the Abbotsford-Sumas Aquifer in southwest BC, and the Gulf Islands on the west coast. The study areas represent a range of current hydro-climatic regimes, spanning wet to semi-arid to arid, and focus on both alluvial aquifers and bedrock aquifers. The same overall methodology and computer codes were used to assess climate change impacts in each aquifer system, although over the course of these studies techniques were refined, bringing in greater spatial resolution, a wider selection of global climate models (GCM) and downscaling methods, and more rigorous modeling techniques.

Direct recharge via precipitation was modeled for each time period using predicted shifts in climate as input to a hydrologic (recharge) model. Spatially-distributed recharge estimates were generated using unique combination of physical parameters that influence recharge. These included soil (and its depth layering), vegetation, slope and water table depth. In Oliver, irrigation return flow was explicitly incorporated into the recharge model. For all but the Gulf Islands case study, the recharge estimates were then applied to three dimensional transient groundwater flow models representative of each aquifer. All models were calibrated using historical groundwater level observations. Groundwater levels for current and future time periods were simulated using Visual MODFLOW.

Overall, the models showed relatively small impacts of climate change on 1) groundwater recharge (a few percent different from current rates) and 2) groundwater levels (only a few centimetres). But, these case studies served an important role in increasing our understanding of how sensitive groundwater systems are to climate change, what the controlling factors are and, most importantly, what the limitations are for undertaking such studies.

A major outcome from the past decade of research is an appreciation for the huge amount of uncertainty in these predictions. Uncertainty arises from the GCM itself (ie, how well does a particular model predict climate both in the past and into the future) and at each step throughout the modeling process: the downscaling process; the recharge modeling; and the groundwater flow modeling. Such a sequence of models can serve to augment model error, thus contributing to overall uncertainty in predictions. In fact, the cumulative model uncertainty is likely so high as to offset any uncertainty in what the actual changes in climate might be!

General Responses of Aquifers to Climate Change

Considering some of the challenges and uncertainty in attempting to model climate change impacts directly (as done in the case studies), taking a more holistic perspective of "general" hydrologeologic response has helped elucidate potential impacts, from a practical sense. Groundwater systems in the interior regions of BC will be particularly sensitive to climate change owing to the strong dependence of rates of evapotranspiration, snow accumulation and snowmelt on temperature, and shifts in the timing and amount of precipitation. Higher spring temperatures will kick-start the growing season, and lead to increased rates of evapotranspiration. Higher summer and early fall temperatures will limit groundwater recharge even more than presently observed. In the winter, loss of winter snowpack and timing of snowmelt in the spring can potentially have significant impacts on the amount and timing of spring runoff, and these shifts will consequently influence groundwater recharge both in the valley bottom and in the upland areas. From an agricultural perspective, groundwater is an important source of irrigation water in some interior regions. Hotter, drier summers combined with a greater demand for produce and a longer growing season may pose significant water stress on such areas, particularly where surface water sources are limited and where population growth is high (eg, Okanagan). A consequent impact will be a lowering of groundwater levels in some areas as groundwater is extracted to meet higher demands for water.

A direct consequence of reductions in groundwater level, brought about either by increased extraction or lower recharge, is a reduction in summer baseflow to stream corridors. Although changes in recharge could amount to only a few millimeters per year, when summed across an entire aquifer, this could lead to significant loss of stored groundwater and, consequently, a significant reduction in the contribution of groundwater to baseflow. Furthermore, a shift in peak stream flow will occur due to earlier snowmelt. The consequent longer baseflow period will demand a higher groundwater contribution to sustain the flow.

In glacierized catchments, glacier-fed rivers are likely to experience a shift from a glacial regime with high flows in mid and late summer to a regime that responds to the summer dry period with streamflow recession, low flows and increased temperatures. In such areas, groundwater will become an increasingly important source of water for sustaining baseflow during the summer months. Therefore, summer low flows in the streams may be exacerbated by the decreasing groundwater levels and diminished glacier cover, and streamflow may become inadequate to meet economic needs such as domestic consumption, irrigation, as well as ecological functions such as in-stream habitat for fish and other aquatic species.

Shifts in the timing of river discharge may have a strong impact on groundwater levels, particularly in valleys that have major rivers flowing through them. Peak flow in many BC rivers is predicted to shift to an earlier date, and there will be a prolonged and lower baseflow period. Parts of the Grand Forks valley aquifer that are strongly connected to the river have been shown to have the largest climate-driven changes. As the river peak flow shifts to an earlier date in the year, groundwater levels shift by the same interval.

In coastal regions, changes in recharge can be anticipated to result in not only impacts to water levels, but to water quality as well. Coastal aquifers are highly sensitive to hydrologic stress because of the complex chemical and physical interactions between fresh water and ocean water. The impacts associated with global climate change are expected to cause global sea level rise, which will undoubtedly slowly affect the position of the saltwater-freshwater interface in many coastal aquifers.

The higher incidence of extreme events is another very important factor. Heavy rain events generally result in less groundwater recharge, because the ground is not able to absorb the precipitation fast enough. This will lead to greater runoff, more flooding, etc, which can be difficult to quantify accurately in hydrologic models. Similarly, extended periods of drought lead to dry soil conditions, which in some cases can result in less groundwater infiltration. So even though BC, as a whole, is expected to become wetter, some of this additional precipitation may fall as heavy rainfall and, consequently, the amount of recharge could decrease

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