# Factors affecting seasonal response of groundwater levels to depression-focused recharge in bedrock wells

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## Summary

Numerical groundwater modeling is an effective tool that provides insights into an aquifer system behavior and can be used for groundwater management decisions. To produce feasible predictions, groundwater models need to be calibrated, which requires reliable estimates of boundary conditions, such as recharge rates. Groundwater recharge has major effect on water balance of groundwater model but is often challenging to constrain. Calibration of watershed-scale groundwater models typically involves estimation of hydraulic parameters, such as hydraulic conductivity and specific storage coefficient. Although joint inversion of hydraulic properties and recharge rates is possible, it requires a large amount of observation data to resolve the non-uniqueness (Knowling and Werner 2017). Coupling surface and groundwater models has been recognized as an efficient way of accounting for the variability of recharge on a spatial and temporal scale (Lubczynski and Gurwin 2005). The common approach uses recharge calculated in soil water balance models and applies it to groundwater models as the upper boundary condition (Sophocleous and Perkins 2000, Jyrkama et al. 2002, Lubczynski and Gurwin 2005)

Hydraulic head data are commonly used to describe the dynamic state of the system and measure the success of model calibration by comparing simulated and observed values. Groundwater levels are relatively easy and inexpensive to collect, which makes them convenient and in the conditions of data scarcity the only measure of the groundwater model performance. However, due to inherent system heterogeneity and lack of constraints multiple models with different parameters can result in similar hydraulic head distributions. Therefore, it is important to understand how uncertainty in hydrogeological properties and boundary conditions are affecting the water level signal. The objective of this study is to test sensitivity of transient water level variation to recharge flux and subsurface hydrogeological properties using a 3-D groundwater model.

## Methods

The study area is the West-Nose Creek (WNC) watershed, located in the Canadian Prairies, which is characterized by a semi-arid climate. In the summer months, evapotranspiration exceeds precipitation, which makes snowmelt an important component of groundwater recharge (Hayashi and Farrow 2014). In the spring snowmelt runoff occurs over frozen or partially frozen ground and accumulates in numerous topographical depressions followed by soil thawing and rapid infiltration into the subsurface. To apply coupled modeling approach in this area, it is important to use the model that can account for processes dominant in the specific environment (Hayashi et al. 2010). The transient recharge in West Nose Creek watershed was estimated with Versatile Soil Moisture Budget (VSMB) model (Hayashi et al. 2010, Mohammed et al. 2013). In the latest implementation, VSMB allows estimation of depression-focused recharge by combining water balance of two 1-d models via runoff generated in the upland mode that is applied to depression simulation using topographic parameters of depressions and their catchments (Noorduijn et al. 2018). The spatially variable estimates were obtained by applying upscaling approach, utilizing the statistical probability of depressions parameters for main surficial geology types and universal relationship between depression capacity and depression area (Pavlovskii et al. 2017, Klassen et al. 2018). For each of the recharge time series, the model was run 196 times for fixed set of depression topographical parameters (depression area and catchment area) and the resulting recharge was obtained at each time step as a sum of recharge values for each realization, weighted by probability of depression topographical parameters in each sediment type. The climate data used for simulations was obtained from Spyhill and Woolliams Farm weather stations in 2007-2016 hydrological years. VSMB modeling was performed using the model parameters, calibrated by Noorduijn et al. 2018 at a field site, located in the WNC watershed.

The steady-state groundwater model of WNC watershed was developed by Niazi et al. 2017. The hydraulic conductivity field was conditioned to sand fraction map via four-point transfer function and calibrated using the steady-state observations of hydraulic head in the wells across watershed. They showed that the modeled piezometric heads are sensitive to spatial variability of long-term average groundwater recharge. The model was successfully calibrated using spatially variable recharge determined with baseflow-chloride mass balance approach; however, this method cannot account for temporal variability. In this study the model was modified to incorporate temporal variability. The hydraulic conductivity was calibrated in the steady-state mode, using the same technique as Niazi et al. 2017 and 10-year average recharge estimates, obtained with upscaled VSMB model results. Spatial variability was defined by four zones of different recharge time series, correspondent to two major surficial sediment types (moraine and stagnant ice moraine Fenton et al. 2013) and area around Spyhill and Woolliams Farm weather stations bounded by Thiessen polygons.

Seasonal fluctuations of water levels in the bedrock wells can serve as an indicator of inter-annual recharge variability (Hayashi and Farrow 2014). Long term water level records from the Rocky View Well Watch network (RVWW, Little et al. 2016) show, that water levels respond to seasonal recharge variations. However, the seasonal pattern can vary even in the nearby wells, screened at the same depth and with same general lithology. The sensitivity of transient water level variation to recharge flux and subsurface hydrogeological properties was tested using the WNC groundwater model by forcing it with multiple scenarios of recharge and assessing the water levels at the 11 locations from observation wells in RVWW network and several strategically placed observation points with different hydrogeologic properties across the model. Different recharge scenarios were simulated by running VSMB with the alternative set of input parameters: flux from the bottom layer of depression and flux through the frozen ground.

## Results and discussion

The average recharge for watershed was obtained by taking average weighted by area occupied by surficial geology types and area around weather stations bounded by Thiessen polygons. The correlation between simulated recharge and baseflow measured at the West Nose Creek gauging station is reasonable for most years (Figure 1b). The average annual recharge in 2007-2016 is presented on Figure 1c, where spatial variability is defined by surficial geology map and interpolation between Spyhill and Woolliams stations. Due to differences in recharge, modeled by VSMB using Spyhill and Woolliams climatic data, there is transition of the average recharge value at the Thiessen polygons boundary. The area of higher simulated recharge within same polygon is attributed to stagnant ice moraine surficial geology, and lower to moraine surficial geology. Stagnant ice moraine estimates of recharge are higher due to the higher mean depression capacities in comparison to moraine sediment type (Pavlovskii et al. 2020).

Figure 2 shows the comparison of modeled daily recharge time series with relative water levels in the observation wells from the RVC network screened in the bedrock aquifer. The time series of the water level are characterized by a rapid rise in early spring, slightly delayed in comparison to the start of the modeled recharge event, followed by a peak in late summer to early fall, and winter recession. The selected wells show strong correlation between annual recharge and water level rise, with Pearson's correlation coefficients equal to 0.87 and 0.7 in wells 215 and 325 respectively (Figure 2 c,d).

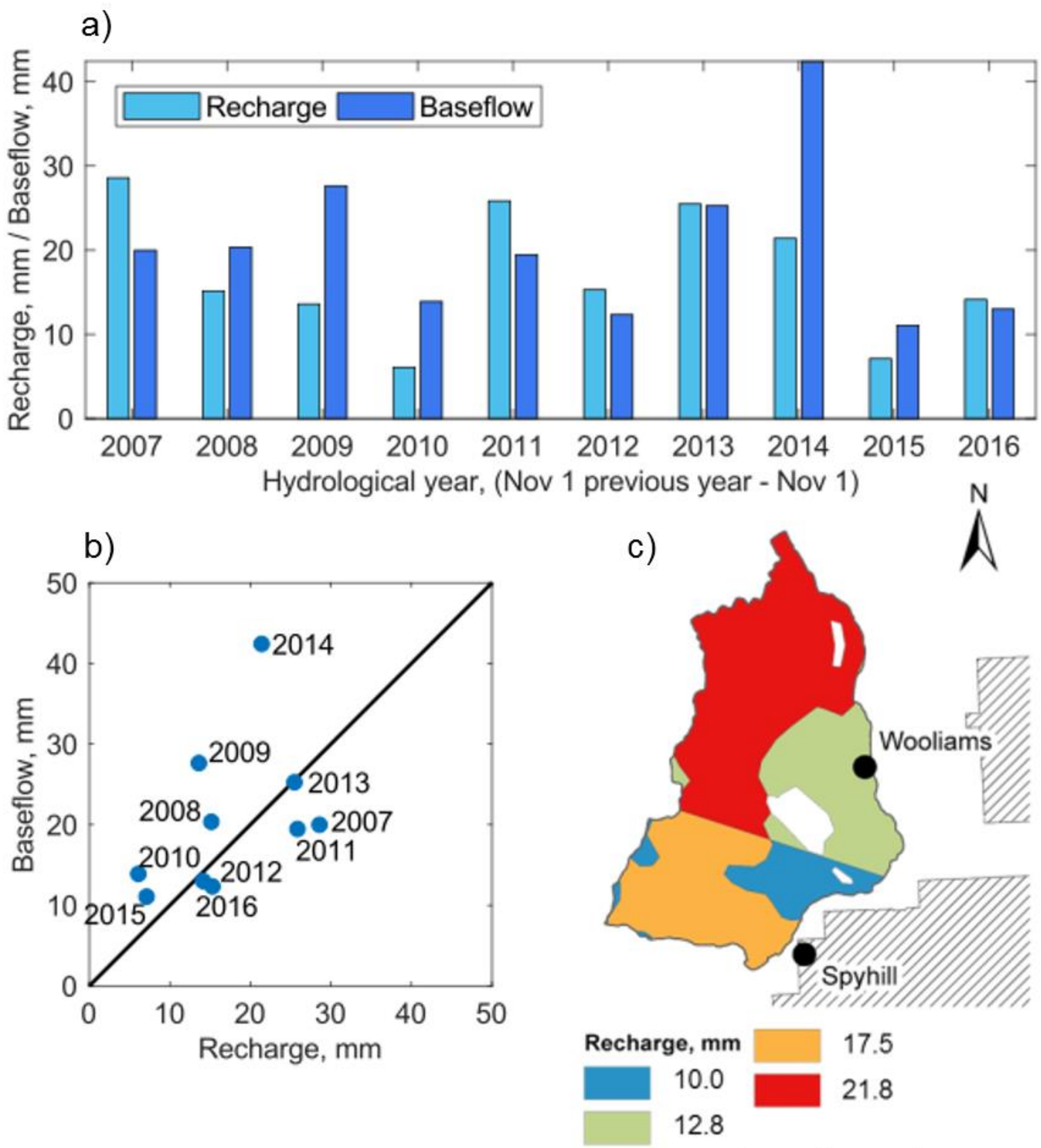
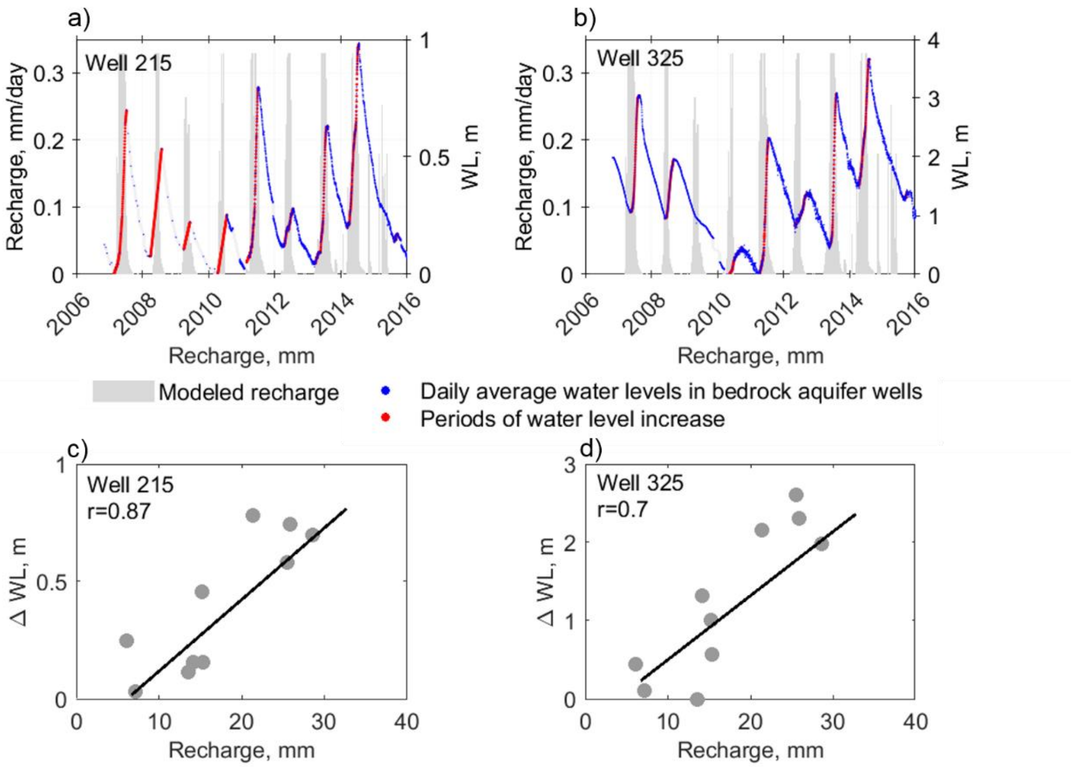



Figure 1. a, b - area-weighted modeled recharge at the WNC in comparison with measured baseflow, c -map of the spatial distribution of modeled groundwater recharge




Figure

Figure 2. a, b – measured water levels in the bedrock wells at WNC and area-weighted modeled recharge; c,d – correlation between modeled annual recharge and water-level rise in bedrock wells in the WNC

Time series of groundwater levels, simulated using 3D groundwater model are similar to water levels, measured in the observation wells (Figure 3). Although seasonal variations are very distinct in the modeled water level fluctuations, the recharge signal is dampened, and head series produced by the same model with different recharge scenarios do not vary drastically between each other.

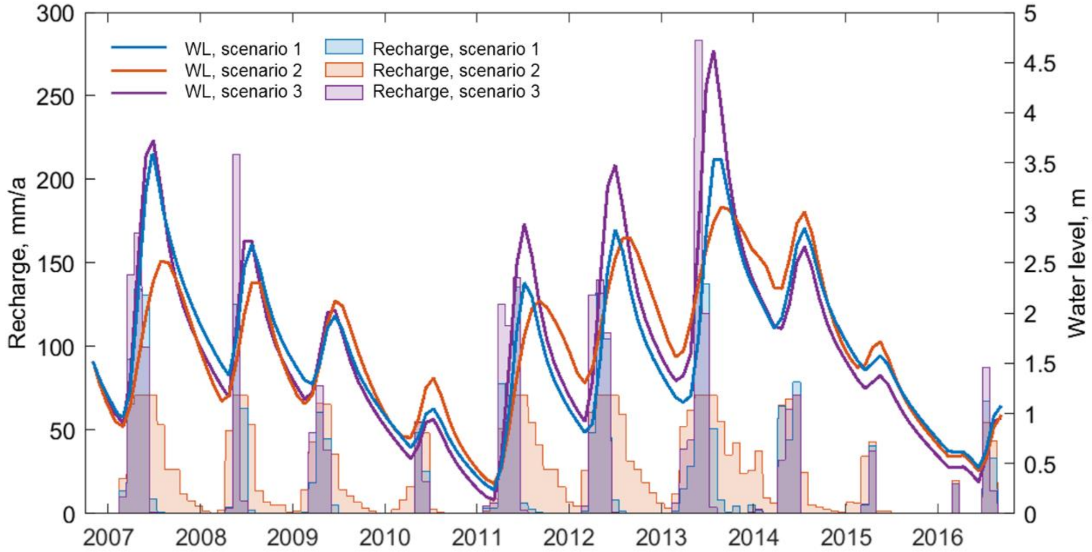



Figure 3. Different scenarios of simulated recharge and modeled using 3D groundwater model water levels at one location

## Conclusions

Groundwater recharge is an important parameter that is required as top boundary of the groundwater models. It is necessary to constraint the recharge to get reliable model predictions. This study demonstrates the applicability of the coupled modeling approach to watershed scale study. Observations indicate that there is strong influence of hydrogeological parameters (hydraulic conductivity) around the well on the transient water level response. The recharge signal is dampened at the bedrock wells, with degree of dampening dependent on the diffusivity of the formation and sediments above. Due to the dampening effect, groundwater model forced with different recharge time series can have similar amplitude and timing of seasonal head fluctuations.

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