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Research papers

Local-scale variability in groundwater resources: Cedar Creek Watershed, Wisconsin, U.S.A.

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ABSTRACT

A local-scale groundwater flow model representing an unconfined aquifer at the Cedar Creek Watershed in Wisconsin, U.S.A. was constructed to determine the effects on groundwater resources due to anthropogenic activities, climate variability, Lake Michigan stage, and finally, the treatment of surface water. The importance of this aquifer lies in its location on the sub-continental divide, which separates the Mississippi River Basin from the Great Lakes Basin, and its proximity to one of the largest surface water bodies, Lake Michigan. The groundwater aquifer model incorporating 4 layers and 18 different geologic zones simulated the influence of recharge on the local-flow regime by utilizing recharge estimates from the Soil-Water-Balance Code.

The steady-state simulation revealed that groundwater head in general was decreased toward the Lake Michigan with local variation caused by stream networks. In response to 2012 drought event, groundwater drawdown was not rehabilitated until spring 2013, implying that the aquifer required approximately 3–4 months until responding to meteorological drought. Additionally, variation in recharge caused to change in groundwater table throughout the entire aquifer simultaneously, but the effect of Lake Michigan stage on groundwater table was relatively minimal. Finally, a certain portion of streams in the Cedar Creek Watershed could be ephemeral. Switching from the RIVER to the DRAIN package for the implementation of ephemeral river and stream cells resulted in significant reduction of both groundwater head and flux, implying that realistic distribution of present groundwater head would resemble one simulated between RIVER and DRAIN packages.

1. Introduction

An increase in atmospheric concentration of greenhouse gases due to anthropogenic activities is predicted to be primary causes for significant changes in the global climate (Cox et al., 2000, Rosenberg et al., 1999). Over past decades, climate change has been growing concern globally because of its harmful effects on agricultural (e.g., crop productions) and water (surface/groundwater depletion) resources (Dragoni and Sukhija, 2008, Green et al., 2011, Mishra and Singh, 2010). Especially, Wisconsin adjacent to Lake Michigan is a leading state in agriculture and forestry, which can be heavily affected by future climate warming. Investigation of historical climate trends in Wisconsin indicates that since 1950 a statewide average increase in temperature and precipitation reached approximately 1 °C and 7–8 cm, respectively (Kucharik et al., 2010, Moran and Hopkins, 2002, Serbin and Kucharik, 2009, Veloz et al., 2011). Furthermore, until 2055, the climate in Wisconsin is predicted to transition to warmer and wetter; projected increase in temperature and precipitation is 2–5 °C and 3–4 cm, respectively, while the likelihood of severe weather events such as flooding and drought increases together (WICCI, 2011). Such changes could alter ecological landmarks (e.g., Cedarburg Bog) across the state as well as water resources including both surface and groundwater. Therefore, an adequate strategic plan for the integrated sustainable water management becomes essential.

Specific to evaluation of the groundwater resources, it is recognized that impacts of extreme meteorological events could eventually propagate to both surface and groundwater bodies (Green et al., 2011). Nevertheless, there is a lack of comprehensive assessment integrating all these interactions between water resources. As an example, when the impact of meteorological drought propagates to a groundwater

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aquifer, degree of the drought impact on the aquifer can vary both temporally and spatially depending on the scale of groundwater basins and their storage characteristics (Peters et al., 2006, van Lanen et al., 2013). Due to these complex interconnections between water resources, it is necessary to identify the linkage between precipitation, streamflow and groundwater. Groundwater flow models in conjunction with distributed recharge models can aid in elucidating such a dynamic linkage between groundwater bodies and other external forces from global climate change, anthropogenic impacts and variations in surface-water features (Candela et al., 2009, Hsu et al., 2007, Woldeamlak et al., 2007). The objective of this study was to characterize the local-scale groundwater aquifer in Cedar Creek Watershed in the state of Wisconsin (USA) responding to multiple external forces including anthropogenic activities, climate variability, Lake Michigan stage, and the treatment of surface water on groundwater resources. In order to achieve such a specific objective, the historical climatic variability, geologic information, and surface- and groundwater features were analyzed to identify recharge distribution. Then, the recharge distribution was implemented to a series of groundwater models, which was calibrated against 194 head targets. Subsequently, the calibrated groundwater models were utilized to evaluate groundwater resources in response to historical extreme weather events, anthropogenic pumping activities, projected variations in recharge due to future climate change, and surface-water features.

2. Cedar Creek Watershed

2.1. Geographical locations, populations, and land cover

In southeastern Wisconsin, U.S.A., the Cedar Creek Watershed is located approximately 30 km north of the City of Milwaukee (Fig. 1). The importance of the Cedar Creek Watershed lies in its location at the sub-continental divide separating the Mississippi River basin from the Great Lakes basin and also proximity to one of the largest surface water bodies, Lake Michigan. The watershed, which is a sub-basin of the Milwaukee River basin, drains large parts of Washington and Ozaukee Counties. In the Cedar Creek Watershed covering 334 km^2, the Cedar Creek stream (Green color), which is a relatively large tributary of the Milwaukee River (Blue color), flows eastward approximately 53 km from the sources at Big and Little Cedar Lakes to the outlet.

Three municipalities, Cedarburg (Ozaukee County), Jackson (Washington County), and, Richfield (Washington County) are within the Cedar Creek Watershed with the majority of the population residing in rural areas with water supply relying on private wells. Since 2000, the population within the two counties has increased approximately 5% with a vast majority of the population increasing in urban areas. In contrast, the rural population has increased less than 1% (Crowe, 2014).

Regarding land cover delineated by Homer et al. (2015), Cedar Creek Watershed is dominated by agricultural land (90%) (Fig. S1). Forests and wetlands (Cedarburg Bog and Jackson Marsh) cover approximately 6% of the watershed area. All the agricultural, forested and wetlands serve as the most effective pathway for groundwater recharge in the Cedar Creek Watershed. The urban lands (Cedarburg, Jackson, and Richfield) covering less than 3% are continuously growing, coinciding with increase in both population and municipality. This urbanized land becomes the least susceptible to recharge because almost all precipitated water is directly diverted to surface water features as runoff or surface discharge.

2.2. Surface glacial geology and hydrostratigraphy

In the Cedar Creek Watershed, surficial geology is dominated by glacial deposits; outwash sediments such as sands, gravels, and subglacial silts and clays. The highly variable surficial unconfined aquifers include glacial land formations such as hummocks and hollows, kettles, and moraines (Syverson, 1988). Especially, the western portion in the watershed lies at the confluence of the Green Bay and Lake Michigan lobes of the Laurentide ice sheet.

The surface of western Washington County is covered by the

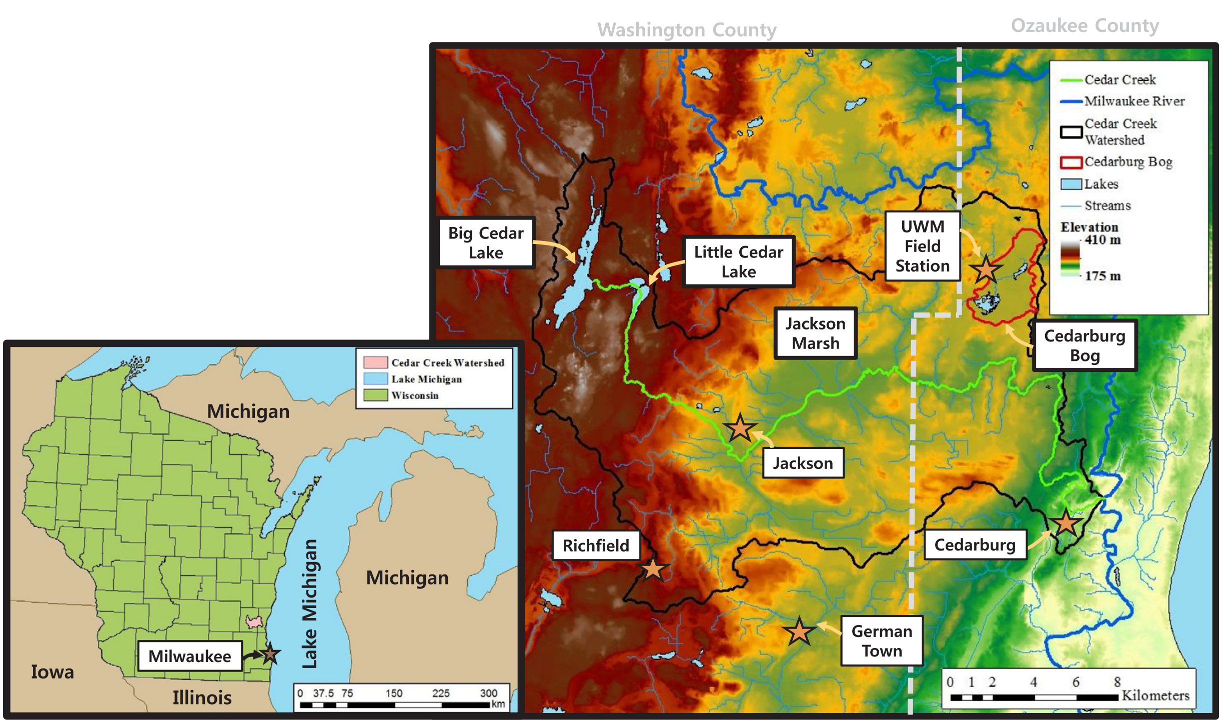

Fig. 1. Location of Cedar Creek watershed in Wisconsin state, U.S.A. The DEM map is sourced from the U.S. Geological Survey National Elevation Dataset (http://viewer.nationalmap.gov/viewer/). The Cedar Creek watershed and Cedarburg bog is outlined in black and red lines, respectively. Surface water features including Milwaukee river, small tributaries and lakes are shown in blue, but the Cedar Creek stream crossing the center of the watershed is delineated in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)