Impact of Climate Change on Water Resources in an Agricultural Tile Drained Watershed

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ABSTRACT

SWATDRAIN model was developed by incorporation of subsurface flow model DRAINMOD, into a watershed scale surface flow model, SWAT (Soil and Water Assessment tool) to simulate hydrology and water quality of agricultural watersheds. The model is also capable of simulating hydrology under different agricultural management and climate scenarios. As an application of the SWATDRAIN model the impact of climate change on surface/subsurface flow is being evaluated in the Canagagigue watershed in southern Ontario, Canada. Under the assumption of no change in land cover and land management, the model is applied in order to simulate annual, seasonal and monthly changes in surface and subsurface flows at the outlet of the watershed under current and future climate conditions. The climate scenario under consideration in this study for 2015-2044 is based on CGCM2 for future climatic simulation.
INTRODUCTION

Changes in climate either long or short-term changes, can alter significantly the hydrological behavior of catchments. Climate change may exert extensive impacts on the natural hydrologic cycle and natural ecosystems, particularly in freshwater supply and water quality of water resources systems. Because of climate change, the patterns of precipitation, evaporation and streamflow quantity including surface flow and ground flow may change significantly, and thus cause changes in water supply from surface or ground water resources.

The hydrological cycle would be affected with more evaporation and more precipitation; however, the extra precipitation would be unequally distributed around the globe. Some parts of the world may see significant reductions in precipitation, or major alterations in timing of wet and dry seasons. The changes in hydrological behavior of watersheds caused by climate change will also affect nutrient transformation and transport characteristics (Bouraoui et al., 2004). Since hydrologic conditions vary from region to region, the influences of climatic change on local hydrological processes will differ within localities, even under the same climate scenarios (Zhang et al., 2007).

Predictions have been made that the Canadian climate, in general, will become warmer and more variable (Hengveld, 2000). Some recent examples of climate change impacts on water resources include melting of the permafrost in northern Quebec, rising sea levels in Atlantic Canada, glacial retreat in British Columbia, and prolonged drought in the Prairies (Mehdi et al., 2006). The soil and water Assessment Tool (SWAT) model has been applied to several projects in the U.S. dealing with the impact of climate change on water supplies and reservoirs operations (Arnold and Fohrer 2005), including regional impacts of climate change on the recharge of groundwater to the Ogallala aquifer (Rosenberg et al., 2000), the impact of climate change on water yields in a high-elevation, mountainous watershed (stonefelt et al., 2000), the impact of climate change on Missouri River reservoir operation and water supply (Hotchkiss et al., 2000), and surface water irrigation and riparian management influenced by climate change (Wollmuth and Eheart, 2000). Dayyani et al (2012) evaluated the effects of climate change under assumption of no changes in land cover and land management, based on projection from the Canadian Regional Climate Model (CRCM), on the hydrology and nitrogen pollution at the outlet of a 24.3 km$^2$ agricultural watershed in Quebec using the DRAIN-WARMF model.

MATERIALS AND METHODS

Watershed Description

The Grand River basin, located in the heart of the south western Ontario, includes all the land drained by the Grand River and its tributaries. This large basin of almost 7,000 square kilometers area in southern Ontario contributes about 10% of the drainage to Lake Erie. The studied watershed is Canagagigue Creek watershed near Floradale, located in the Grand River Basin in Southern Ontario. The Canagagigue Creek has a total drainage area of 143 square kilometers and is a minor tributary of the Grand River. It lies between latitude 43°36’ N and 43°42’ N and longitude 80°33’ W and 80°38’ W. This study targeted the upstream portion of the Canagagigue Creek west, roughly 18 km$^2$. The watershed is approximately 19 km long, 10 km wide, and is roughly triangular. The general slope is less than 1.5%. The topography of the watershed is flat to gently undulating with a slight slope towards the outlet in the south. The average elevation is 417 m. Figure 1 shows the location of Canagagigue Creek and subwatershed used in this study.
Daily weather data were obtained from the Fergus station. A flow gage station (02GA036) is located at the stream outlet of west branch of the watershed. The daily observations of streamflow rate measured at this station for period 1974-1984.

In addition to the weather data inputs, the SWAT model requires Digital Elevation Model (DEM), soils, land use and agricultural management data, if applicable. A DEM with a 100 m × 100 m spatial resolution was obtained from the Grand River Conservation Authority. The soil and land use classification across the watershed was defined by polygon shape files, provided by the Ontario Ministry of Agriculture and Food. The combination of landuse and soil type resulted in 118 HRUs. The soil surveys of Waterloo County presented by Presant and Wicklund (1971) and Wellington County presented by Hoffman et al (1963) indicated that the major portion of the watershed has 200 to 600 millimeters of loam or silty loam of the Huron and Harriston series overlying a loam till. In the northern part of the watershed, clay loam is predominant. Loam is the main soil type in the central portion of the watershed. In the south and southeastern sections, the soil types are characterized by moraine deposits of very fine sand and fine sandy loam with occasional layers of other material. The topography of the watershed is flat to gently undulating with a slight slope towards the outlet in the south.

Figure 2 shows the distribution of the main soil types and land use characteristics of studied watershed. The area is composed of about 80% of agricultural land use and about 10% woodlots (Carey et al., 1983). The rest of the watershed is covered by urban areas, fallow land, and rivers and lakes.
**SWATDRAIN model development**

The DRAINMOD model was incorporated into the SWAT model's subsurface hydrology module as an alternative method for simulating tile drainage, water table depth, and soil moisture content. The main program of the integrated model, referred to as SWATDRAIN, is a modified version of the main program of SWAT. A new subroutine, termed DrainM.f, was written and incorporated into the SWAT model to affect the modifications by integrating the DRAINMOD model approaches to subsurface hydrology, including predicting tile drainage, water table depth and stored water in the profile in the SWATDRAIN model. The newly developed SWATDRAIN model is based on the DRAINMOD subsurface hydrology simulation and the SWAT surface hydrology simulation. Figure 1 demonstrates the SWATDRAIN modeling procedure.

SWATDRAIN computes the soil water balance, on a daily basis, for each HRU in every subbasin. For the first day of the simulation, all calculations were made on the SWAT model and the results, including the surface hydrology parameters, were ready for the first day and for all HRUs. According to the presence or the absence of a drainage system in each HRU across the watershed, it is termed drained or non-drained, respectively. Next, DRAINMOD is used for tile drained HRUs of the watershed to simulate subsurface hydrology in an unsaturated zone. For this reason, the main surface hydrology parameters calculated by SWAT (e.g. evapotranspiration, runoff and infiltration) on an HRU basis would be passed on to DRAINMOD through the intermediary of the DrainM.f subroutine added to the SWAT source code. DRAINMOD which is now part of SWAT code would compute subsurface hydrology parameters for the same day as the surface hydrology parameters were calculated by SWAT. After simulating the subsurface drainage, water table depth, and soil moisture content, the values of these parameters are used in SWAT. Lastly, DRAINMOD and SWAT were incorporated to collectively simulate the hydrology on a watershed scale. This newly developed model integrated a SWAT-driven surface flow and a DRAINMOD driven subsurface flow to improve the accuracy and efficiency of this new model.

**Climate data**

The climate data used in this study were provided by previous research (Rong et al., 2009), and climate change modeling is not part of this study. In this study, In order to develop future weather scenarios for the watershed, CGCM2 in scenario A2 was selected for future climatic condition simulation (Rong et al., 2009).

The climate parameters used to run SWATDRAIN model are precipitation and min/max temperature from Fergus station in Ontario. SDSM downscaling tool is calibrated and validated using the historical local weather variables, daily mean precipitation and daily maximum and minimum temperature. The generated climate change scenarios by SDSM were entered as the weather input of calibrated and validated SWATDRAIN model. Stream flow at the outlet of the watershed for future were then simulated, and compared to the historical measurements.

**RESULTS AND DISCUSSION**

The climate-change impact on hydrology of the Canagagigue Creek watershed was estimated by running the SWATDRAIN model using climate data from 1974 to 2044. SWATDRAIN was calibrated and validated for 1974-1984 at the same watershed.

Figure 2 shows the scatter plot of measured and predicted monthly precipitation values for a part of the historical period (1974-1984). The observed data are taken from Fergus station close to the study area. A coefficient of determination of 0.83 indicates a good correspondence between predicted and observed precipitation values.
The average monthly total precipitation and averaged seasonal total precipitation for the historical period and for future period are presented in Figure 2. The monthly graph of precipitation indicates that in months such as June, July and August the future monthly total amounts of precipitation were greater than those in the historical period, particularly in June. In other months, the average monthly total precipitations for future were less than those historical data. In seasonal graph of PCP it is obvious that in summer the future precipitation was greater than historical, while in the other three seasons the future amounts were less.

The average monthly and seasonal streamflow during historical and future were compared to see the monthly change pattern, which is presented in graphs. The monthly graph shows that the highest monthly streamflow for the observed historical period was April, but for the simulated future it was March. This may be explained by the fact that snowmelt is occurring earlier as compared to the historical period. Therefore, earlier snowmelt might occur due to climate change in future and causes the flow peaks move to earlier months. It is clear from surface/subsurface graph that the decrease in flow during April is mainly the results of a decline in surface flow, which supports the hypothesis of snowmelt before April.
CONCLUSIONS

Regarding the future weather change, warmer winters and hotter summers might be expected. Obvious higher amount of annual monthly mean precipitation might be expected in summer, and thus heavy rainfall might occur. Summer might be the most dramatically altered season in precipitation due to the high variances in months from June to August.

REFERENCES


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