Using SWAT to Evaluate Climate Change Impact on Water Resources: Case Study in Canagagigue Creek Watershed, Canada

CCTC 2013 Paper Number 1569694805

G. Golmohammadi[1], S.O. Prasher[1], A. Madani[1], R. Rudra[2]
[1] McGill University, Quebec, Canada
[2] University of Guelph, Ontario, Canada

Abstract

The impact of climate change on the hydrology of an agricultural watershed are predicted using the SWATDRAIN model. As an application of the SWATDRAIN model the impact of climate change on surface/subsurface flow is being evaluated in Canagagigue watershed located in 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 (2016-2044) is based on projections from SDSM downscaling based on historical weather data. With downscaling regional model results for the specified watershed, the future weather scenarios were the input for calibrated and validated hydrologic model, SWATDRAIN, for stream flow. The estimated future stream flows may have longer low flow periods that cause several annual water resources deficiency due to increased evapotranspiration. Warmer winter and hotter summers are expected during 2015-2044 and higher mean and variance of the amounts of precipitation in summer may be expected.

Keywords: Modeling, SWATDRAIN, Climate Change, Hydrology, Drainage

Résumé

L'impact des changements climatiques sur l'hydrologie d'un cours d'eau agricole peut être anticipé en utilisant le modèle SWATDRAIN. En tant qu'application du modèle SWATDRAIN l'impact des changements climatiques sur l'écoulement en surface et souterrain sera évalué sur la rivière Canagagigue située en Ontario, Canada. Ne considérant aucun changement sur l'occupation et l'utilisation du sol, le modèle est appliqué dans le but de simuler les changements annuels, saisonniers et mensuels sur l'écoulement en surface et souterrain à la source du cours d'eau sous les conditions climatiques actuelles et futures. Le scénario climatique considéré pour cette étude (2016-2044) est basé sur les projections du SDSM sous une réduction d'échelle basée sur les données de temps historiques. Avec les résultats pour le cours d'eau étudié et la réduction d'échelle, les futurs scénarios de temps météorologiques étaient les intrants pour le modèle hydrologique validé et calibré, SWATDRAIN, pour le débit du cours d'eau. Les estimations des futurs débits annoncent potentiellement de plus longues, basses périodes d'écoulement qui causeront de majeures défaillances en ressources en eau annuellement étant donné l'augmentation de l'évapotranspiration. Des hivers moins froids et des étés plus chauds sont anticipés entre 2015-2044 et de plus haute moyenne et variance du nombre de précipitations en été sont attendues.

1. Introduction

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 [1]. Studies in recent years have shown that important regional water resources are vulnerable to changes in both temperature and precipitation patterns [2]. It is primarily at the local and regional level that policy and technical measures could be taken to prevent, or reduce, the negative effects of climate change on the natural environment and society.

Predictions have been made that the Canadian climate, in general, will become warmer, and more variable [3]. 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 [4]. The impact on water resources in Canada as a result of climate change has been investigated by several institutional and government agencies [4]. In comparison to studies undertaken in larger river watersheds, small watershed scale studies are better able to capture local vulnerabilities to rapid and intense changes in climate [5].

The Soil and Water Assessment Tool (SWAT) model has been applied to several projects in the USA dealing with the impact of climate change on water supplies and reservoir operations [6], including: regional impacts of climate change on the recharge of groundwater to the Ogallala aquifer [7]; impact of climate change on water yields in a high-elevation, mountainous watershed [8]; impact of climate change on the Missouri River reservoir operation and water supply [9]; and surface water irrigation and riparian management influenced by climate change [10].

The authors have developed a new model, SWATDRAIN, by integrating a field scale subsurface flow model, DRAINMOD [11], with a watershed scale surface flow model, SWAT (Soil and Water Assessment Tool), to simulate the hydrology and water quality of agricultural watersheds. In this modeling approach, surface flow transport is simulated using SWAT; while DRAINMOD is used to model subsurface. The integrated model was calibrated and validated for an agricultural watershed in Quebec using daily stream flow and nitrogen data measured from 1994 to 1996 [12]. The calibration and validation results showed that the model was able to simulate the monthly stream flow and nitrate-N loads well, with a coefficient of determination and Nash-Sutcliffe efficiency greater than 0.86 for both calibration and validation periods [12]. The model also is capable of simulating hydrology and nitrate loading under different agricultural management and climatic scenarios.

The objective of this study was to evaluate the effect of climate change (under an assumption of no change in land cover and land management), based on projections using the SWATDRAIN model.

2. Materials and methods

2.1. Site 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 Canagagigue Creek watershed near Floradle, 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, and is about 25 kilometers northwest to the city of Guelph, Ontario. The area includes part of Peel and Pilkington Township in Wellington County and part of Woolwich Township in Waterloo County.

Based on the availability and credibility of observed flow data at the Floradle gauge station (Figure1) this study targeted the upstream portion of the Canagagigue Creek, roughly 53 km2. 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 subwatersheds used in this study.

The outlet of the entire watershed is close to the town of Floradle. A flow gage station (02GAC17) are located at the stream outlet of the watershed. The observed data including hourly flow rates are available during for the period 1989-2000. Figure 2 shows the distribution of the main soil types in the watershed. The soil surveys of Waterloo County presented by [13] and Wellington County presented by [14] 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.

Figure 2 demonstrates the land use characteristics of studied watershed. The area is composed of about 80% of agricultural land use and about 10% woodlots [15]. The rest of the watershed is occupied by urban areas, fallow land, and rivers and lakes.

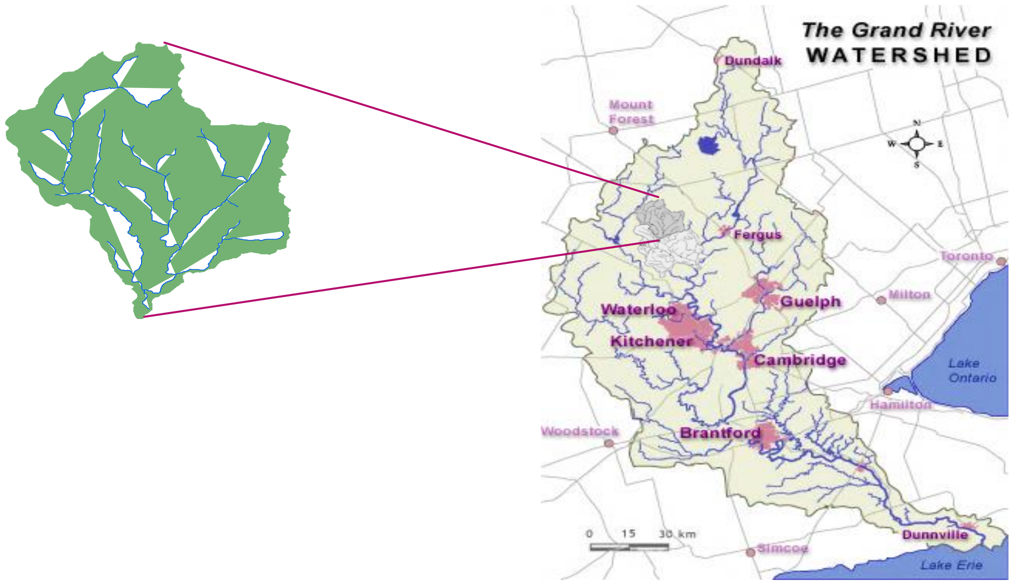

Figure1. Location of the study area in Grand River Basin and the river network

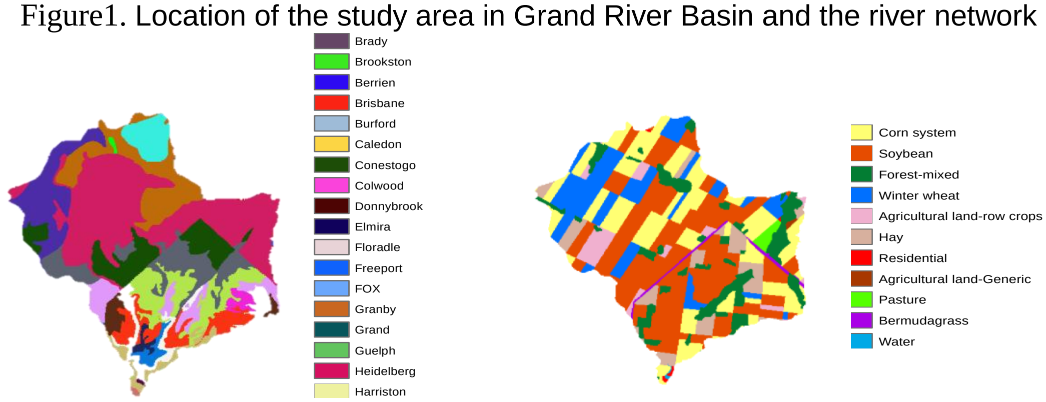

Figure 2. Soil and land use classifications.

2.2. SWATDRAIN model description

The DRAINMOD model was incorporated into the Soil and Water Assessment tool (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. The changes have been made to the percmain.f subroutine. One subroutine, termed DrainMod.f, was written and incorporated into the SWAT model to effect the modifications using the DRAINMOD model approach 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. Figure1 demonstrates the SWATDRAIN modeling procedure.

According to the presence, or the absence, of a drainage system in each HRU across the watershed, it is termed drained or non-drained. Next, DRAINMOD was to be used for tile drained HRUs of the watershed to simulate subsurface hydrology in an unsaturated zone. DRAINMOD would then compute subsurface hydrology parameters for the same day as the surface hydrology parameters were calculated by 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.

3. Statistical Downscaling Model (SDSM)

One of the widely used tools to evaluate the impacts of global warming is General Circulation Model (GCM). Due to coarse spatial resolution of GCMs downscaling techniques are used to drive the regional climate information from global climate data. In this study, the Statistical DownScaling Model (SDSM) was used to estimate the local scale temperature and precipitation data series. The historical local predictands of SDSM for Fergus station in Ontario including the daily precipitation (Pmean), maximum and minimum daily temperature (Tmax and Tmin) were collected for the period from 1975-1983. Observed historical data was downloaded from NCEP (National Centers for Environmental Prediction) for both historical and future periods. After calibration and validation of SDSM, downscaled GCM scenarios for the future were generated (2015 – 2044). The generated climate change scenarios by SDSM were used as input data for calibrated SWATDRAIN model in Canagagigue Watershed. Stream flow at the outlet of the watershed for the future was predicted.

4. Results and Discussion

Time series graphical of plot of daily and monthly streamflow during calibration and validation period is illustrated in Figure 1 to Figure 3.

The calibration and validation model performance results for the daily and monthly time steps are resented in Table 1.

Table 1. Monthly and daily streamflow calibration and validation statistics of the measured and simulated data

Calibration	Validation

Index	Monthly	Daily	Monthly	Daily
R^2	0.93	0.68	0.76	57.00
PBIAS	7.30	4.39	12.88	14.25
NSE	91.74	67.85	0.73	52.36

The calibrated SWAT-Drain model was used to simulate the future stream flow rate at the outlet of the watershed. The current results are for only the business as usual scenario and other scenarios are under investigation at this stage. The initial evaluation of the model for long term predictions are promising and it is expected that SWAT-DRAIN model can produce results with similar accuracy for other scenarios.

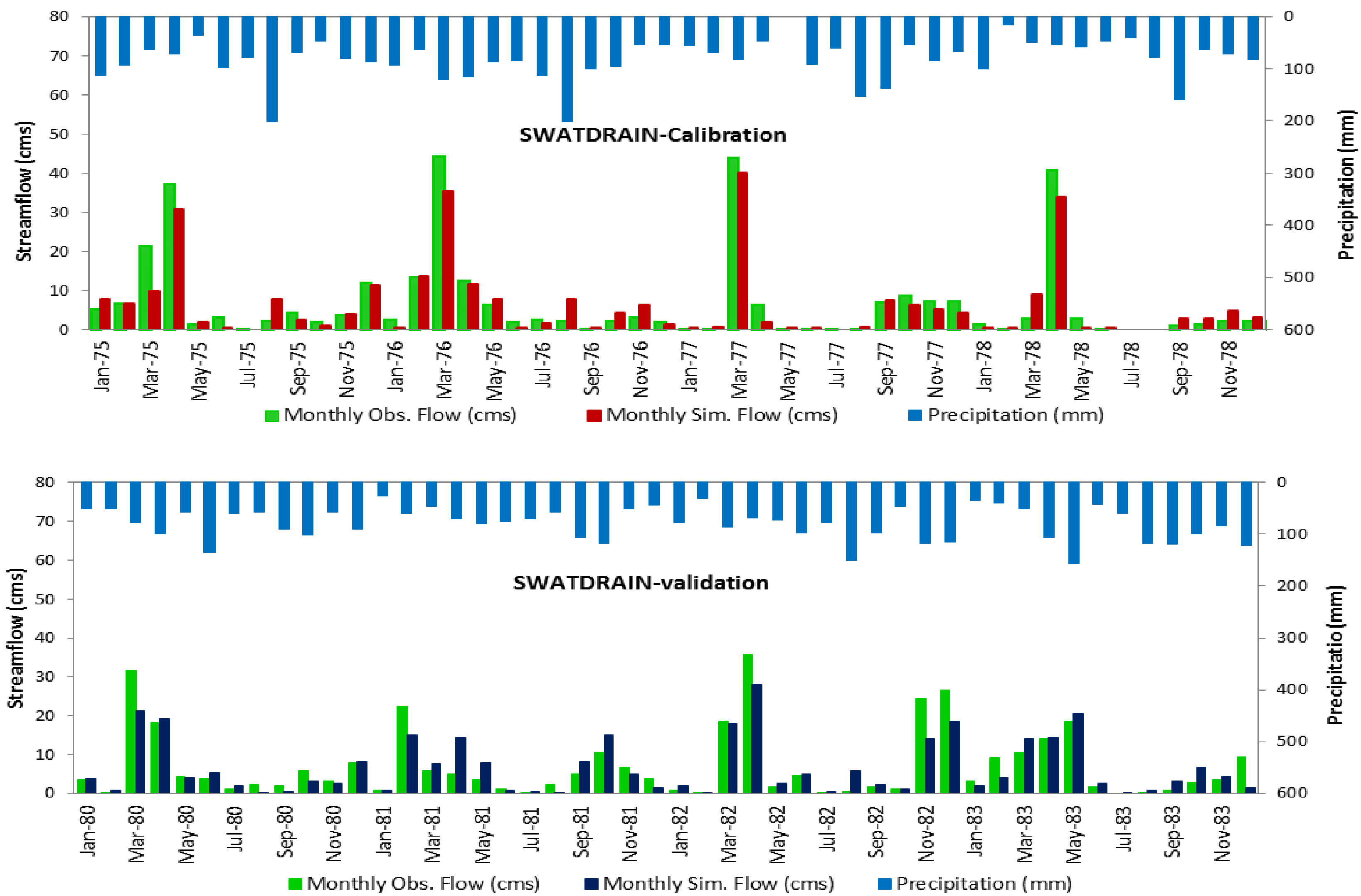

Figure 2. Monthly streamflow for Canagagigue watershed during calibration and validation period

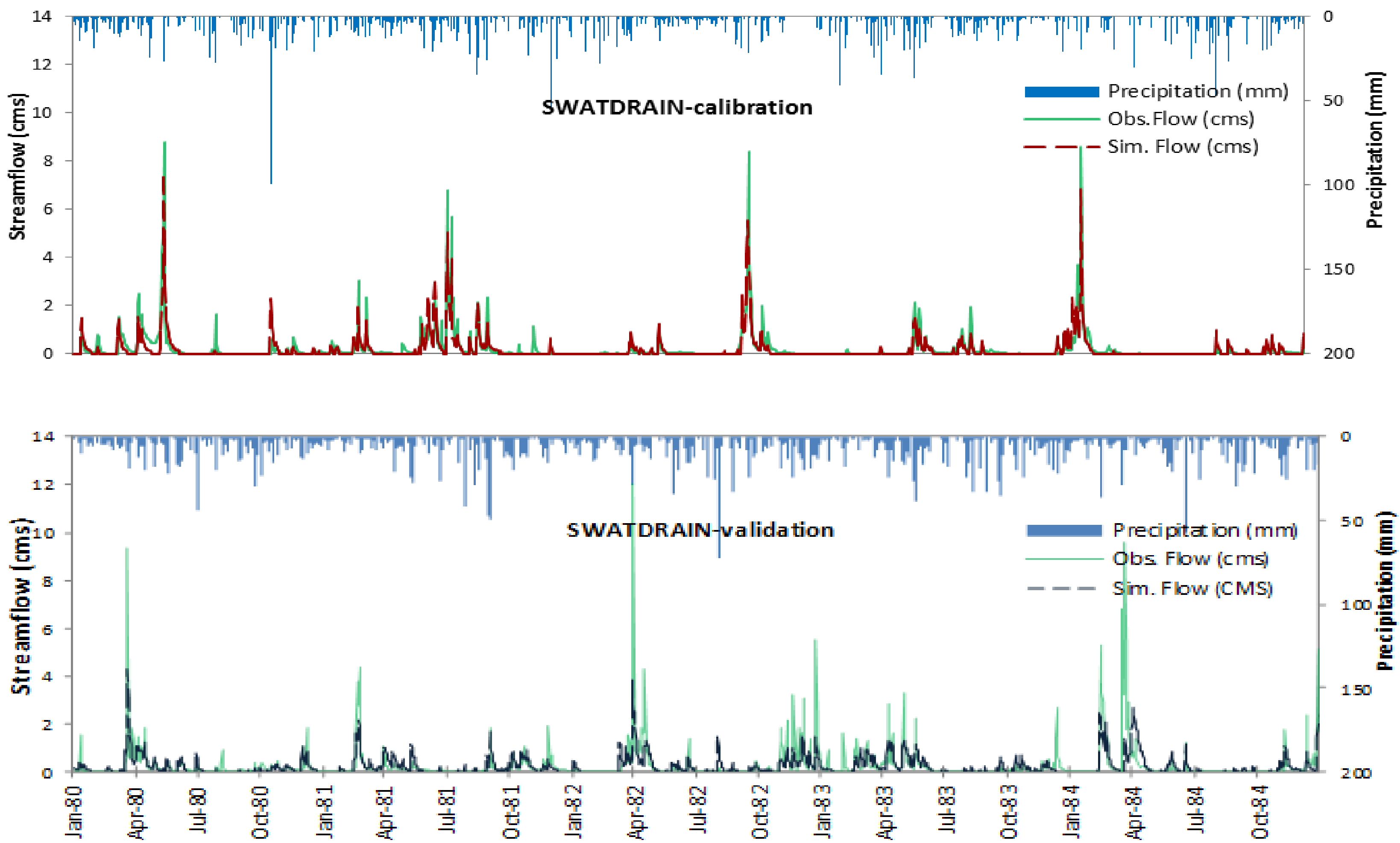

Figure 3. Daily streamflow for Canagagigue watershed during calibration and validation period

5. References

[1] Zhang, X., R. Srinivasan and F. Hao, 2007. "Predicting hydrologic response to climate change in the Luohe River basin using the SWAT model." *Transactions of the ASABE*, Vol 50, Iss 3, pp. 901-910.

[2] Lahmer, W., B. Pfützner and A. Becker, 2001. "Assessment of land use and climate change impacts on the mesoscale." *Physics and Chemistry of the Earth*, Vol. 26, Iss. 7, pp. 565-575.

[3] Hengeveld, H.G., 2000. Projections for Canada's Climate Future: A Discussion of Recent Simulations with the Canadian Global Climate Model. Climate Change Digest Special Edition CCD 00-01. Meteorological Service of Canada Environment Canada, Downsview, Ontario.

[4] Mehdi, B., L. Connolly-Boutin, and C.A. Madramootoo, 2006. "Coping with the Impacts of Climate Change on Water Resources: A Canadian Experience." *World Resource Review Journal.* Vol. 18, Iss. 1, pp. 62-83.

[5] Chang, H., B. Evans and D. Easterling, 2001. "The Effects of Climate Change on Stream Flow and Nutrient Loading." *Journal of the American Water Resources Association*, Vol. 37, Iss. 4, pp. 973-985.

[6] Arnold, J. and N. Fohrer, 2005. "SWAT2000: Current Capabilities and Research Opportunities in Applied Watershed Modelling." *Hydrological Processes*, Vol. 19, Iss. 3, pp. 563-572.

[7] Rosenberg, N., D. Epstein, D. Wang, L. Vail, R. Srinivasan and J. Arnold, 1999. "Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region." *Climatic Change*, Vol. 42, Iss. 4, pp. 677-692.

[8] Stonefelt, M., T. Fontaine and R. Hotchkiss, 2000. "Impacts of Climate Change on Water Yield in the Upper Wind River Basin." *Journal of the American Water Resources Association*, Vol. 36, Iss. 2, pp. 321-336.

[9] Hotchkiss, R., S. Jorgensen, M. Stone and T. Fontaine (2000). "Regulated River Modeling for Climate Change Impact Assessment: The Missouri River." *Journal of the American Water Resources Association*, 36(2): 375-386.

[10] Wollmuth, J. and J. Eheart, 2000. "Surface Water Withdrawal Allocation and Trading Systems for Traditionally Riparlan Areas." *Journal of the American Water Resources Association*, Vol. 36, Iss. 2, pp. 293-303.

[11] Skaggs, R. W. (1980). "DRAINMOD Reference Report." Methods for Design and Evaluation of Drainage-Water Management Systems for Soils with High Water Tables. USDA-SCS, South National Technical Center, Fort Worth, Texas 329.

[12] Dayyani, S., S. O. Prasher, C. A. Madramootoo and A. Madani, 2009. "Development of DRAIN-WARMF Model to Simulate Flow and Nitrogen Transport from an Agricultural Watershed." *Journal of Agricultural Water Management*, Vol. 98, pp. 55-68.

[13] Presant, E. W., and R. E. Wicklund. (1971). Soils of Waterloo County, report no. 44 of the ontario soil survey Canada Department of Agriculture and Ontario Department of Agricuture.

[14] Hoffman, D. W., Matthews, B. C., and R. E. Wicklund. (1963). Soil survey of wellington county ontario, report no.35 of the ontario soil survey Canada Department of Agricuture and Ontario Department of Agricuture.

[15] Carey, J. H., M. E., Fox, B. G., Brownlee, J. L., Metcalfe, P. D., Mason, and W. H. Yerex. 1983. The Fate and Effects of Contaminant in Canagagigue Creek 1. Stream Ecology and Identification of Major Contaminants. Environment Canada Scientific Series No. 135. Burlington, Ontario: Environment Canada, Inland Waters Directorate.