Comparison of CANWET and HSPF for water budget and water quality modeling in rural Ontario

Syed I. Ahmed, Amanjot Singh, Ramesh Rudra and Bahram Gharabaghi

ABSTRACT

This study comparatively evaluates the Hydrological Simulation Program-FORTRAN (HSPF) model and the Canadian ArcView Nutrient and Water Evaluation Tool (CANWET) for non-point source pollution (NPS) management in rural Ontario watersheds. Both models were calibrated, validated, and applied to a 52 km² headwater rural watershed known as the Canagagigue Creek near Elmira in the Grand River basin, Ontario, Canada. A comparison of the simulated and observed values for stream flow, surface runoff, subsurface runoff, evapotranspiration, and sediment yield showed that BASINS/HSPF and CANWET models have similar capabilities to simulate various hydrological processes at the watershed scale. The seasonal stream flow comparison between observed and simulated values from HSPF and CANWET showed Nash-Sutcliffe efficiency (Nash-E) coefficients of 0.80 and 0.72, respectively. The monthly comparison between the simulated and observed stream flow yielded Nash-E coefficients of 0.88 and 0.94 for HSPF and CANWET, respectively. Overall, both models predicted the components of the annual, seasonal, and monthly water budget accurately. There was a considerable difference in the monthly simulated sediment yield by both models. This difference is consistent with the surface runoff variation predicted by both models. Both models predicted sediment yield with early winter and spring storms which is typical for southern Ontario.

Key words | modeling, sediment, water budget, water quantity

INTRODUCTION

In the last few years, researchers have attempted to address the problem of non-point source (NPS) pollution by combining the relationship between land management practices and water quality degradation. Under Tier 1 of the Ontario Source Water Protection Act by Ministry of Environment (MOE), Ontario, conservation authorities, and other government agencies are currently involved in assessment of water budget at watershed scale to quantify drinking water sources (MOE 2007). Two systems, the surface water system and groundwater system, are being analyzed and different tools have been researched for quantifying elements of both systems individually and in integration. Understanding the environmental conditions and watershed hydrological characteristics is the first step to quantify and protect the water resources of the area.

In the last few decades, the modeling approach has become more common to address the issue of water resources pollution from NPSs. Field monitoring studies have been limited due to their requirements of high financial and time investment. Hydrologic modeling approaches have been proven to be more versatile, as they have been effectively used to simulate a variety of environmental conditions and soil-water management practices needed to prevent water quality degradation (Saleh & Du 2004; Wang & Linker 2006; Walton & Hunter 2009). Some of the widely used watershed scale models are: AnnAGNPS (Bingner & Theurer 2005), Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998), Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al. 2001), and Canadian ArcView Nutrient...

The two models, HSPF and CANWET, were selected for comparison as well as application of these models for climatic conditions in Ontario. HSPF is a complex model for hydrologic and water quality simulations; whereas the CANWET model is considered as a relatively simple model for hydrologic processes and water pollutants. For example, HSPF calculates the surface runoff using hourly model for hydrologic processes and water pollutants. For CANWET model is considered as a relatively simple hydrologic and water quality simulations; whereas the CANWET model is considered as a relatively simple model for hydrologic processes and water pollutants. However, HSPF is a complex model for comparison as well as application of these models for climatic conditions in Ontario. HSPF is a complex model for hydrologic and water quality simulations; whereas the CANWET model is considered as a relatively simple model for hydrologic processes and water pollutants.

HSPF calculates the surface runoff using hourly model for hydrologic processes and water pollutants. It uses the concept of infiltration computed using Philip's equation (Philip 1957), and uses a storage routing technique to transport water from one reach to the next during stream processes. The CANWET model provides a continuous stream flow simulation using daily time steps using climatic data for water budget. It calculates the surface runoff by the Soil Conservation Services (SCS) Curve Number (CN) method (United States Department of Agriculture (USDA)-SCS 1972).

The surface water hydrology and sediment simulations of both the models are distributed based on multiple land use/cover scenarios; however, each land use area is considered as homogenous in regard to various attributes considered by the model. These two models do not spatially distribute the source areas, but simply aggregate the loads from each area into a watershed total at the specified outlet.

Both models operate under different complexities and are currently being used by various agencies and consultants in Ontario to address water budget issues for source water protection.

HSPF is a comprehensive, conceptual, and continuous watershed model designed for simulation of watershed hydrology and water quality. It is an analytical tool with application in planning, designing, and operating of water resources systems (Bicknell et al. 2001). HSPF has also been extensively used for hydrological and total maximum daily load (TMDL) modeling (Al-Abed & Whiteley 2002; Singh et al. 2005). HSPF has generally been used to assess the effects of land-use change, reservoir operations, point or NPS treatment alternatives, flow diversions, etc. (Van Liew et al. 2003; Saleh & Du 2004; Mishra et al. 2007). It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment–chemical interactions (Fontaine & Jacomino 1997; Whittemore & Beebe 2000). HSPF is also applicable to many watersheds and the adjustment of various parameters is possible for various climatic and site-specific conditions (Carrubba 2000). A study by Chung et al. (2011) was conducted to evaluate the effects of climate change and urbanization on hydrologic behavior and water quality using the HSPF model in Anyangcheon watershed in Korea. The model was able to simulate the significant effect of urbanization on water quality as compared to low flow conditions; whereas climate change has a major effect on stream flow rate.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) (US Environmental Protection Agency (USEPA) 2001) integrates GIS (Geographic Information System), data analysis, and a modeling system to support watershed based analysis and TMDL development (Lahlou et al. 1998). HSPF/BASINS have also been used as prediction tools for in-stream bacterial concentration in the watershed by Paul et al. (2004). A sensitivity analysis to determine the parameters that most influence the coliform predictions showed that maximum storage of coliform bacteria over the pervious land segment and amount of surface runoff affected the bacterial concentration. This study emphasized the importance of parameterization of sensitive parameters to obtain better results (Geurink & Ross 2006). Also, the method used for the calibration of HSPF is important as reported by Gutierrez-Magness & McCuen (2005).

The CANWET model is the Canadian version of the Generalized Watershed Loading Function (GWLF) model developed by Haith et al. (1992). The model uses the concept of HSPF in a simplified form (Haith 2006) as well as a land use based approach for hydrologic simulations with limited parameters, making the application of the model simple. The CANWET/GWLF models have been used for hydrology and NPS pollution simulations from watersheds (Benham et al. 2005; ShuKuang et al. 2006). A theoretical comparison of a number of watershed models including HSPF and GWLF was done by Borah & Bera (2005). They concluded that the HSPF model is more comprehensive compared to CANWET, involves a large number of variables, and uses complex approaches in simulating watershed hydrology and pollutants.
Saleh & Du (2004) evaluated and compared HSPF and SWAT models within BASIN 4.0 using daily and monthly measured flow, sediment, and nutrient loading for a watershed in Texas. The results showed that SWAT simulated average daily flow, sediment, and nutrient loading better than HSPF when compared with the measured values for the calibration and verification periods. However, HSPF was found to be a better predictor of temporal variations of daily flow and sediment. HSPF under-predicted nutrient loads due to its limited ability to incorporate detailed information regarding farm management.

The performances of HSPF and SWAT were also compared by Van Liew et al. (2003) for eight nested watersheds in southern Oklahoma, to assess simulated stream flow under various climatic conditions. This study showed that HSPF performed better on the watersheds used for calibration and SWAT produced better results on the validation watersheds when compared with the observed flow data. Overall, SWAT simulated better results (−1.3%) for stream flow volumes than HSPF (−8.2%). The difference in the simulated results by SWAT and HSPF was attributed to approaches used for the simulation of the runoff process.

HSPF presents volume-dependent discharge from a stream based on stage, surface area, volume, and discharge entries in a function table (FTABLE). A study was conducted by Staley et al. (2005) to evaluate the flow predictions of HSPF in FTABLEs using computer-based data and field measurements for Pigg River watershed in southern Virginia. The simulated FTABLEs showed similarities in stage-discharge curves for the bankfull range and differences at floodplain depths. In addition, use of field data did not show any improvement in the simulated average daily outflows as compared to use of the computer-based data. This study suggests that computer-based data can be used for similar conditions without loss of accuracy; however, it was also emphasized that it should be determined if use of field data could improve the accuracy for various conditions and watershed sizes. Shenk et al. (2012) also found that application of the HSPF model to simulate nutrient and sediment load poses challenges for efficient simulation of Best Management Practices (BMPs) in large-scale watersheds, and can be improved by combined upgrading of segmentation, input data, and model calibration. A recent study by Singh et al. (2012) using the CANWET model on the Canagagigue Creek watershed stated that the hydrologic processes and water budget components need more detailed and accurate calculation. However, the CANWET model was found to be a useful tool to simulate hydrologic processes at watershed scale on an annual ($R^2 = 0.89$), seasonal ($R^2 = 0.68$), and monthly ($R^2 = 0.68$) basis.

Now with the availability of models with varied complexities in use and approach, the question of how much complexity do we need for water budgeting and NPS pollution assessment arises? The present study was conducted to compare the hydrology and sediment components of a complex model (HSPF) and a relatively simple model (CANWET) to describe water budget and sediment yield, and to identify the strengths and weaknesses of each model.

In this study, the integrated watershed models BASINS 4.0/HSPF and CANWET were applied to simulate the flow and sediment transport for the Canagagigue Creek watershed in southern Ontario. Basic hydrologic units in the models were constructed from the combination of land use groups, soil type, and hydrologic characteristics. The main objective of this study was to provide a watershed-modeling framework for estimating hydrological processes and sediment loads from watershed, and to compare results from both models to provide the reductions needed to meet the NPS pollution standard in Ontario climatic conditions.

**MATERIALS AND METHODS**

The watershed for this study is located in the Grand River basin in Ontario, Canada. The Grand River starts from south of Georgian Bay and ends in Lake Erie, winding 300 km through heartland of southern Ontario between longitude 79°30’ W, and 80°57’ W and latitude 42°51’ and 44°13’ N. The draining area of Grand River and its tributaries is about 6,965 km². The Canagagigue Creek watershed selected for this study is a subwatershed of Grand River. The upper Canagagigue Creek watershed, upstream of the Floradale reservoir, is located between 43°56’ N–43°42’ N latitude and 80°33’ W–80°38’ longitude, and drains approximately 52 km² (Figure 1). About 79.4%
of the watershed area is under agriculture land use, 11.3% forest and wetlands, 9% pasture, 0.2% built up, and 0.1% is open water. About 95% of the area has slope less than 5%. The dominant soil in the watershed is categorized as silt and silt loam.

The two models, HSPF and CANWET, selected for comparison of water budget analysis and sediment simulations were evaluated for the Canagagigue Creek watershed. The surface water loadings for both models are distributed in the sense that they allow multiple land use/cover scenarios, but each area is assumed to be homogenous in regard to various attributes considered by the model. Additionally, the models do not spatially distribute the source areas, but simply aggregate the loads from each area into a watershed total. The brief description of models on hydrologic and sediment simulation approaches is presented in the following sections.

**Hydrological Simulation Program-FORTRAN (HSPF)**

HSPF uses information such as the time history of rainfall, temperature, evaporation, and parameters related to land use patterns, soil characteristics, and agricultural practices to simulate watershed processes. The result of the simulation is a time history of runoff rate, sediment load, and nutrient and organic chemical concentrations at any point in a watershed. HSPF simulates three types of sediment classes (sand, silt, and clay), water quality processes on pervious and impervious land surfaces, in the streams, and well-mixed impoundments (Donigian et al. 1984). HSPF also simulates surface runoff, interflow, base flow, snowpack depth, snowmelt, evapotranspiration (ET), groundwater recharge, dissolved oxygen, biochemical oxygen demand (BOD), pesticides, pH, ammonia, nitrate-nitrite, organic nitrogen, phosphorus, and sediment detachment and transport.

The HSPF has three main modules, PERLAND, IMPLAND, and RCHRES. PERLAND represents permeable (non-urban agricultural and forest) lands, IMPLAND impermeable (urban/developed) lands, and RCHRES streams/rivers in the watershed. In the HSPF, the surface runoff is estimated using an hourly time step and the Philip’s infiltration equation. The model uses a storage routing technique to route water from one reach to the next during stream processes. For the sediment simulations, it uses the model developed by Negev (1967).

The BASINS has made HSPF input sequences easier and provided advanced interaction with input sequence and graphical representation of the output. WinHSPF assists the user in the building of a user control input (UCI) file from GIS data, especially from the BASINS system. Also, HSPF may be run from within WinHSPF and input...
sequences may be modified, thus creating simulation scenarios. WinHSPF also assists the user in building the necessary dataset for hydrologic calibration using the United States Geological Survey (USGS) Expert System (HSPEXP). WDMUtil, a tool built inside BASINS, is used to prepare input data for WinHSPF and manages WDM files which contain input and output time-series data needed for HSPF. For the multiple runs, HSPF requires manual tracking of time-series datasets from all scenarios at multiple locations for several constituents. GenScn (Generation and analysis of model simulation Scenarios), developed by the USGS, helps to facilitate the display and interpretation of output data derived from model applications (Kittle et al. 1998). GenScn also provides advanced interaction with the HSPF input sequence and integrated analysis capabilities.

HSPF requires six meteorological time-series datasets to simulate stream flow. These include precipitation, minimum and maximum air temperature, dew point temperature, evaporation, wind speed, and solar radiation. In this study, the input time series were developed for 9 years (1991–1999). Recorded daily precipitation, air temperature, and wind speed data were obtained from the Grand River Conservation Authority (GRCA), Ontario. The potential ET time series provides a maximum limit for the ET demand. The ability of the model to simulate stream flow is limited by the accuracy of both precipitation and ET time-series inputs.

For the application of CANWET and HSPF the Canagigue Creek watershed, upstream of the Floradale reservoir and downstream of the confluence of the two tributaries (draining eastern and western parts of the watershed) was delineated and discretized into sub-basins using the automatic delineation tool available in the EPA-BASINS (United States Environmental Protection Agency (USEPA) 2001). The three GIS layers, 10 m resolution digital elevation data, land use grid layer, and soils grid layer were obtained from GRCA. A 100 ha threshold area was selected for stream definition. The land uses were classified into agriculture, hay/pasture, forest, and urban. The calibration parameters for both the models and the possible range were adopted from the previous studies completed on these models (Haith et al. 1992; USEPA 2000; Anonymous 2004).

Canadian ArcView Nutrient and Water Evaluation Tool (CANWET)

The CANWET (Anonymous 2004) Version 3.0 is a GIS-based model and has two main modules, Rural and Urban. The Rural module is similar to the PERLAND module of HSPF and the Urban is similar to the IMPLAND. The CANWET model provides a continuous stream flow simulation using daily time steps for weather data and water balance calculations. It uses SCS CN approach for surface runoff generation and the universal soil loss equation (USLE) (Wischmeier & Smith 1965) for soil erosion calculations. Monthly calculations are made for sediment and nutrient loads based on the sum of daily water balance values for a given month. The sediment yield is computed by using an area based delivery ratio approach. Spatial routing is not available in Version 3.0 of CANWET. For subsurface loading, the model acts as a lumped parameter model using a daily water balance methodology. Daily water budgets are computed for the unsaturated zone, as well as the saturated subsurface zone, where infiltration is simply computed as the difference between precipitation and snowmelt minus surface runoff and ET. ET is determined by the Hamon method (1961), using daily weather data and a cover factor dependent upon land use.

Version 3.0 of the CANWET model allows monthly and seasonal variation in CN, ET coefficient, recession coefficient, and seepage coefficient. The seepage coefficient provides the possibilities of discharge and recharge from neighboring aquifers. This version can also be run for a single basin or aggregated basin simulation; however, spatial routing is not yet available.

Model calibration

Prior to the application of a hydrological simulation model to a specific area, calibration of the model is very important because most of the hydrological models are developed mainly from statistical analysis of hydrologic/pollutants data collected from a specific location and they may not effectively perform for other regions. Existing land use, soil conditions, and management practices significantly affect the hydrology and soil erosion rates of an area (Drohan et al. 2003; Kaleita et al. 2007). Also, long-term simulations
of hydrologic models have been helpful in evaluation of management practices as they capture the temporal variability of NPS loads by incorporating a wide range of climate and land conditions (Borah & Bera 2004).

Calibration is an iterative procedure of parameter evaluation and refinement. Good calibration should result in parameter values that are within an acceptable range for the watershed and climatic conditions and produce the best overall agreement between simulated and observed output response. HSPF and CANWET calibrations were accomplished by adjusting sensitive input parameters to reproduce realistic watershed behavior well enough to meet the modeling objectives.

**HSPF**

The main dominant parameters governing the water balance are LZSN (lower zone soil moisture storage), INFILT (index to infiltration capacity), and LZETP (lower zone ET). If the amount of percolation to groundwater is small, actual ET is adjusted to change the runoff component of the water balance. LZSN represents the primary soil moisture storage and root zone in the soil profile, and the major portion of actual ET occurs from the LZSN. Increasing LZSN resulted in increased actual ET and decreased surface runoff. Therefore, LZSN is a sensitive parameter for estimation of annual water balance. INFILT governs the division of precipitation into upper zone soil moisture storage (UZSN), LZSN, and to the groundwater. An increase in INFILT resulted in an increase in water infiltrating into the lower zone and groundwater zone resulting in a decrease in surface runoff, and an increase in actual LZSN storage and ET. Therefore, INFILT is one of the most sensitive parameters for calibration of HSPF for water balance and shape of hydrograph.

LZETP was another important parameter evaluated carefully for calibration. An increase in LZETP resulted in an increase in actual ET from the lower zone; therefore, any change of LZETP will result in a corresponding change in runoff amount. INTFW, the Interflow parameter, has minimum effect on runoff amount but it has significant impact on the shape of the hydrograph. An increase in the INTFW value resulted in a decrease in peak flow and prolonged recession of the hydrograph. KRER (coefficient in the soil detachment equation) is the major parameter that controls the availability of sediment on the land surface. KRER is related to the erodibility of soil type, soil surface conditions, and to the K factor in the USLE.

**CANWET**

The model was set up for the upper Canagagigue Creek watershed in such a way that the basic parameters (e.g., CN) were not supplied directly and the values extracted by the model’s ArcView interface were used. However, the adjustment factors associated with these parameters were then fine-tuned to mimic temporal variability in the parameters for the study watershed. The key parameter associated with surface runoff estimation and used by the model for the considered land uses was CN. The model extracted CN values from the three GIS layers using the ArcView interface provided with the model, and the values were 75, 63, 34, and 80 for crop land, hay/pasture, forest, and urban land, respectively.

CANWET also has an option that allows the user to adjust CN values monthly to accommodate seasonal effects. Such adjustments are essential for proper simulation of watershed hydrologic behavior in Ontario. For example, frozen soil conditions, prevalent during winter seasons, and freeze-thaw cycles, common during spring seasons, tend to reflect very poorly drained conditions and can generate significant runoff. On the other hand, the soils drain and dry out significantly during summer and early fall periods and produce little or no surface runoff. In various modeling approaches, using an infiltration approach to estimate surface runoff, the seasonal conditions have been represented by temporally varying saturated hydraulic conductivity (Schroeter 1996; Al-Abed & Whiteley 2002). A similar approach has been adopted in CANWET for the monthly and seasonal adjustment of CN values. The monthly CN adjustment factors used in this study to represent seasonal changes in CN are presented in Table 1.

A groundwater recession coefficient is used in CANWET to estimate the subsurface (groundwater) contribution to stream flow. This coefficient allows the removal of a fraction of water available in saturated storage. The recession coefficient was also varied seasonally, as shown in Table 1. The model also provides an option to vary groundwater seepage coefficient monthly for simulating the possible
movement to or from a deep aquifer system. In this study, monthly values of groundwater seepage coefficient were set to zero for all the months other than November and December (0.3) to account for the threshold base flow in the stream.

The ET was also adjusted temporally to represent realistic ET conditions for the study area as shown in Table 1. Based on the soil texture and depth of soil profile, the value of unsaturated available water storage was assumed to be 10 cm. The initial saturation on April 1 (the starting date for the simulation) was estimated to be 3 cm. The beginning of April is generally snow melting time and the soil conditions are close to field capacity.

### Analysis

Calibration of flow and sediment components was undertaken by adjusting certain model parameters to obtain an agreement of within ±10%, as suggested in the BASINS (USEPA 2000), between observed and simulated output responses. In this study, the calibration focused on the comparison between observed and simulated daily, monthly, and annual stream flow. All of these comparisons were performed for a proper calibration of hydrology and sediment parameters. The available observed flow data include continuous flow records at the gauge sites for the entire time period.

Graphical and statistical procedures applied in this calibration process include the following:

1. Time-series plot of observed and simulated values for flow. The plot visually evaluates the agreement between the simulated and observed values.
2. Observed vs. simulated scatter plots, with a 45° linear regression line displayed, for values of stream flow. Scatter plots include calculation of a correlation coefficient, along with the slope and intercept of the linear regression line; thus the graphical and statistical assessments are combined.
3. Percent error difference (monthly and annual) for the observed and simulated stream flow.

The outputs of the calibrated models were compared for the water budget components, stream flow, and total suspended sediment load (TSS) on annual, seasonal, monthly, and daily time frames. The annual analysis was based on the year starting from December of the previous year to November of the current year. For the seasonal analysis, the year was divided into four seasons: Spring from March 1st to May 31st, Summer from June 1st to September 30th, Fall from October 1st to November 30th, and Winter from December 1st to February 28th or 29th. The comparative evaluation used both statistical and graphical approaches. Statistical tests include the Nash-Sutcliffe efficiency coefficient (Nash-E) (Nash & Sutcliffe 1970) and correlation coefficient ($R^2$), and the graphical approach used a scatter diagram. The annual results were also compared using a percent error method.

### RESULTS AND DISCUSSION

#### Comparison for annual water budget and stream flow

The comparison of averaged annual components of water budget (surface runoff, subsurface runoff, and ET) simulated by HSPF and CANWET are shown in Figure 2. The average annual rainfall for the 9-year study period (1991–1999) was 820 mm. The wettest year was 1992 (1,036 mm), and the driest year was 1998 (549 mm). The HSPF and CANWET simulated water budget was very similar to the observed data. The models’ predicted annual ET values were also
very similar to the observed ET values. However, HSPF
simulated surface runoff was 21% of the precipitation as
compared to 12% by CANWET. Also, CANWET simulated
28% subsurface flow (interflow + groundwater flow) as com-
pared to 20% by HSPF. Overall, the outputs of both models
revealed that the water budget components were compar-
able with the observed data. The results reported by
Dickinson & Rudra (2006) also found similar division of
rainfall into ET, surface runoff, and subsurface from the
watersheds with medium textured soils in Ontario.

Figure 3 shows the comparison of the annual stream
flow simulated by HSPF and CANWET with the observed
stream flow. These data show that the stream flow simulated
by both the models compares well with the observed stream
flow over the 9-year period (1991–1999). When averaged
over the 9-year period, HSPF overestimated the annual
stream flow by 2.5% and CANWET underestimated by
1.3%. This indicates that the models are similar in simulat-
ing average annual stream flow. Both the models either
over predicted annual stream flow (1992) or under predicted
(1998 and 1999) during wet years. The models slightly over-
predicted (CANWET 10% and HSPF 19%) the stream flow
in the wettest year (1992). However, these models did well
in predicting the stream flow for the driest year (1998) of
the study period. In addition, for the driest year CANWET
simulated (250 mm) annual stream flow was very close to
the observed annual stream flow (228 mm); and HSPF simu-
lated 219 mm of annual stream flow.

The comparison between the annual observed and simu-
lated stream flow yielded a Nash-E of 0.77 for HSPF and
0.82 for CANWET. Also, the determination coefficient
between the annual simulated and observed daily stream
flow was 0.77 for HSPF and 0.83 for CANWET. These
data indicate that models' results are similar for the simu-
lation of water budget and stream flow; however, the
simulation results on an annual basis were slightly better
for the CANWET model than for the HSPF model.

Comparison for seasonal water budget and stream flow

Figure 4 presents the comparison of average seasonal water
budget simulated by both models. The data given in
Figures 4(a) and 4(b) clearly show that during the winter
period HSPF predicted higher surface runoff (8.1 cm) and
ET (2.2 cm) than that predicted by CANWET, surface
runoff (4.2 cm) and ET (0.5 cm). Overall, CANWET pre-
picted higher groundwater recharge for all the seasons
than simulated by HSPF except for summer. Also,
CANWET predicted a higher amount of ET (35.5 cm) than
HSPF (27.1 cm) during summer. For the fall season, both
models have similar predictions. Figures 4(c) and 4(d)
describe the percentage contribution of various components of the water budget simulated by HSPF and CANWET during various seasons. The amount of averaged annual ET simulated by HSPF (467 mm) and CANWET (499 mm) compared well with the ET value (500–567 mm) available in literature for southern Ontario conditions (Dickinson & Diwu 2000; Rudra et al. 2000; McLaughlin 2001). These comparisons suggest that both models slightly underestimated actual ET. The overall analysis of the seasonal water budget shows good agreement among ET, surface runoff, and subsurface runoff simulated by both models. Comparison of groundwater flow simulated by these models for various seasons shows that groundwater flow was a major part of the water budget in spring (32.7%) and summer (35.9%) for HSPF (Figures 4(c) and 4(d)). CANWET-simulated groundwater flow showed significant contribution during winter (28.1%) and spring (43.2%). The surface runoff values of the HSPF and CANWET models show that the summer season was predicted better by HSPF (8.9%) as compared to the CANWET simulated value (0.4%). Also, HSPF showed a consistent trend in predicting the surface runoff for the study period (Figure 4(c)). Overall, spring and winter contributions of groundwater flow and surface runoff predicted by these models were typical for southern Ontario.

To further evaluate the performance of the HSPF and CANWET models, simulated seasonal stream flows were compared with the observed seasonal stream flow for the entire simulation period (Figure 5). This comparison generated Nash-E of 0.80 for HSPF and 0.72 for CANWET. This indicated that both models showed similar performance for simulation of seasonal hydrology in Ontario conditions. These data also show that both models did not exhibit a consistent pattern for the winter season. For most of the years, HSPF under-predicted the stream flow. CANWET performed better than HSPF for the prediction of stream flow values for spring and summer seasons. During wet summer seasons (1992 and 1993), HSPF over-predicted and CANWET slightly under-predicted the stream flow which affected the overall performance of the models for the summer season. For the fall season, the predicted stream flow by HSPF matched better with the observed stream flow compared to the stream flow predicted by CANWET.

To evaluate the overall seasonal performance of these models, averaged over the entire study period, predicted

![Figure 4](https://iwaponline.com/wqrj/article-pdf/49/1/53/380006/53.pdf)
and observed stream flows are shown in Table 2. These data show that the percent difference between averaged observed and predicted stream flow were −2.2 and 3.9 for CANWET and HSPF, respectively, indicating that both models have similar seasonal stream flow prediction capabilities. These values also show that CANWET did better on a seasonal basis than HSPF. In addition, HSPF could not adequately simulate stream flow during the spring (−29.3%) and summer (47.4%) seasons. This could be due to the higher ET in spring and lower ET in summer simulated by HSPF as shown in Figure 4(c). However, HSPF performed better than CANWET for simulation of stream flow for fall (0.5%) and winter (−2.9%) periods. Overall, CANWET performed better than the HSPF for the simulation of stream flow. The Nash–E between the average observed and simulated stream flow by the CANWET and HSPF models was 0.99 and 0.92, respectively. Also, the determination coefficient \((R^2)\) of 0.99 and 0.94 between the simulated and observed CANWET and HSPF simulated flows, respectively, support the better performance of CANWET. The observations in southern Ontario reveal that most of the stream flow during summer results from the subsurface (groundwater) contribution. Therefore, the observations imply that CANWET performed more realistically in simulating the subsurface flow in spring and summer than HSPF.

### Comparison of monthly water budget and stream flow

The performance of HSPF and CANWET was also evaluated for water budget components on a monthly basis from 1991 to 1999. However, the data shown in Figure 6(a) and 6(b) are for only 2 years (1991–1992). The analyses of monthly results indicate that ET is at minimum during winter and fall months; and monthly simulated ET varied

<table>
<thead>
<tr>
<th>Season</th>
<th>Precipitation (cm)</th>
<th>Stream flow (cm)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>CANWET</td>
</tr>
<tr>
<td>Winter</td>
<td>18.65</td>
<td>11.41</td>
<td>10.76</td>
</tr>
<tr>
<td>Spring</td>
<td>18.57</td>
<td>15.14</td>
<td>15.55</td>
</tr>
<tr>
<td>Summer</td>
<td>32.38</td>
<td>4.16</td>
<td>4.11</td>
</tr>
<tr>
<td>Fall</td>
<td>12.38</td>
<td>3.23</td>
<td>3.10</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Winter = December, January, and February; Spring = March–May; Summer = June–September; Fall = October–November.
from 0 to 3.9 cm during these months. However, ET started accumulating more during spring and reached up to 6.4 cm in May 1996 by HSPF. CANWET also showed up to 9.5 cm ET in May 1991 (a wet month, above average rainfall). As anticipated, summer months were found to be the highest ET producing months for both models. HSPF simulated peak ET (9.8 cm) in August 1991 and CANWET gave the peak ET values of 6.7–17.1 cm in July 1993. The trends for ET were found to be similar for both models during wet and dry months; however, CANWET predicted higher ET during summer months when compared with the predicted values from HSPF for these months.

The trends of simulated groundwater contribution to stream flow by CANWET and HSPF were similar and realistic. Both models produced maximum groundwater contribution in November, December, March, and April, and minimum contribution during summer months. The range of groundwater flow for summer months was 0.1–3.8 cm for HSPF and 0.2–3.5 cm for CANWET, respectively.

For the fall months (October–November) water budget data show that CANWET predicted consistently higher groundwater flow than the HSPF simulated groundwater flow. However, HSPF predicted some decent contributions in these months for the above average rainfall years (1991, 1992, and 1996) (Figures 3, 6(a) and 6(b)).

Analysis of HSPF simulated surface runoff showed a general trend of higher flows during January (1.5–5.4 cm) and March–April (0.1–10.1 cm) (Figures 6(a) and 6(b)). The CANWET model also produced a similar pattern of surface runoff in these months; however, CANWET simulated surface runoff values were comparatively lower than the HSPF simulated values.

An analysis of the wettest and driest years in the study period indicated that these models successfully simulated the water budget components (Figure 6). For the year 1992 (wet year), HSPF predicted a typical partition of precipitation into ET, groundwater, and surface runoff contribution of southern Ontario. In the case of CANWET, water
budget was more dependent on ET and groundwater contribution. For the dry year of 1998, both models showed similar trends as ET was the significant part of the water budget from April to September. However, there was also some contribution of groundwater flow in March and April. In addition, there was minimum contribution of surface runoff in all the months of this dry year other than April.

Examination of the components of the monthly water budget also showed that simulated ET contributed more than 80% of the water budget during months from July and September; surface runoff ranging from 30 to 46% in February, November, and March; groundwater flow contributing from 70 to 80% in January, April, and December by both models.

The monthly comparison of surface runoff simulated by HSPF and CANWET, when averaged over the years, showed that proportionate monthly surface runoff was produced by both models (Figures 7(a) and 7(b)); however, there was discrepancy in the amount produced. These differences could be due to the use of one CN in the CANWET model for one type of land use for the entire simulation period. However, it is possible to change the parameters related to the infiltration rate temporally during the simulation period in the HSPF model. In this study, the infiltration parameters in the HSPF model were adjusted to reduce the infiltration rate during winter and early spring periods (to accommodate frozen conditions) resulting in a higher amount of runoff during these months as shown in Figure 7(a).

The monthly simulated water budget averaged over the 9-year study period showed similar results for both models (Figure 7) with peak ET demands during June or July and minimal ones during winter months (December, January, and February). CANWET over-predicted ET by approximately 12% more than the ET simulated by HSPF during summer months (June–September). Nevertheless as discussed earlier, the annual ET simulations of both models are within the permissible range.

The results shown in Figure 7 also indicate that there are variations in simulated monthly subsurface flow within the seasons. CANWET simulated a higher amount of subsurface flow during late winter and early spring months (March and April) and less subsurface flow during summer months. This could be due to the adoption of the single-tank approach in the CANWET model. For subsurface flow computation, ET uses the moisture that is available in the tank which results in limited moisture remaining to contribute to subsurface flow, whereas HSPF uses a two-tank approach and the amount of groundwater being used for ET can be calibrated.

The comparison of the monthly stream flows simulated by HSPF and CANWET were compared with the observed stream flow for the study period (1991–1999) (Figure 8). These results showed a good agreement between observed and simulated stream flow, and generated a Nash-E of 0.70 and 0.67 for HSPF and CANWET, respectively. However, HSPF performed better than the CANWET because of more temporal control over the variables that mimic monthly variations in the processes. Also, the correlation coefficients of the simulated and observed stream flows were found to be 0.80 and 0.70 for HSPF and CANWET, respectively.

Figure 9 shows the comparison of simulated monthly stream flow, averaged over the 9-year study period, with the observed stream flow. These results indicate that both models did a good job in simulating stream flow. Specifically, CANWET results showed a consistency
throughout the year with the observed stream flow data. HSPF underestimated stream flow for the months of March and April, and overestimated for the summer months. The comparison also yielded a Nash-E of 0.88 and 0.94 when simulated monthly stream flow by HSPF and CANWET, respectively, was compared with the observed monthly stream flow.

**Daily stream flow analysis**

An analysis was conducted for the evaluation of the models for the simulation of daily stream flow. The comparison between daily observed and simulated stream flow by HSPF and CANWET were conducted for the 9-year simulation period (1991–1999), and were also statistically analyzed. Due to the extensive amount of daily data for this analysis, only 3-years (1991–1993) of the study are shown in Figure 10. The Nash-E for the daily observed and simulated stream flow was 0.33 and 0.17 for HSPF and CANWET, respectively. The correlation coefficients between the simulated and observed daily stream flow were also low, 0.35 for HSPF and 0.28 for CANWET. The scatter diagram between daily observed stream flow and simulated daily HSPF and CANWET stream flows (Figure 11) did not show strong relation between daily simulated and observed data; however, both models produced similar trends. HSPF performed reasonably due to better control of simulation of temporal variability of subsurface flow contribution to the stream flow. In addition, the peaks of daily stream flows were satisfactorily captured by both models.

**Sediment simulation**

The annual soil erosion by HSPF was compared with the annual soil erosion simulated by USLE and multiplied by the sediment delivery ratio (SDR) of 0.36 based upon the model given by Renfro (1975). HSPF simulates upland
erosion as delivered to the stream. Since CANWET uses USLE for simulation of upland soil erosion, the erosion output produced by CANWET was multiplied by the SDR of the watershed (0.36) to achieve upland sediment delivered to the stream as suggested by USEPA (USEPA 2006). Figure 12 shows the comparison of annual upland erosion simulated by HSPF and CANWET from 1993 to 1995. The outputs for upland sediment delivered to the stream are in close agreement with HSPF producing slightly higher sediment than CANWET.

Furthermore, the monthly sediment yields simulated at the outlet by HSPF and CANWET were compared, and considerable differences were found in the monthly simulated sediment yield by both models. The difference is consistent with the surface runoff variation predicted by both models (Figure 12). In addition, HSPF has a module for in-stream sediment deposition and scouring which makes the simulation dynamic for in-stream sediment routing. However, in the absence of continuous observed data, it is not possible to predict which model is simulating better monthly sediment yield. Both models predicted sediment with early winter storms (January) and spring storms (March–May), which is typical behavior of watersheds in southern Ontario. The sediment yield predicted by both models was due to the wet conditions in the watershed which increased the contributing area during these periods. The simulated sediment yield is minimal during the rest of the year because of lower flows in these periods. Overall, this modeling study for sediment shows that the hydrologic behavior of the watershed controls the sediment transport and sediment yield.

The HSPF model also simulates TSS on a daily basis which was compared with the available 18 observations for the study period. Figure 13 reveals that observed data points fall on the non-peak flow days and therefore, give the base suspended sediment values in the stream. The simulated TSS also showed base values during the times when...
observed TSS data were available. Figure 13 also shows that the peaks in TSS were simulated accordingly when there were peaks in stream flow. Therefore, the trend for TSS is justified, whereas the quantitative verification needs further investigation with the observed data. Figure 14 gives the comparison of annual erosion and sediment yield simulated by HSPF and CANWET for the period 1993–1995. It is obvious from Figure 14(a) and (b) that HSPF simulated erosion and sediment yield was higher than the erosion and sediment yield simulated by CANWET. Since CANWET does not produce daily sediment loads in the version we used in this study, it may be the reason that CANWET predicted results are underestimated. Therefore, CANWET cannot be used for TMDL evaluation whereas HSPF has the capability of evaluating TMDL at the watershed scale.

The study has shown the ability of these models to predict the hydrologic behavior and sediment yield for climatic conditions in Ontario with limited observed data. It is anticipated that the availability of continuous observed sediment data and comparison with simulated sediment results by these models would produce better guidelines for management practices in the area.

Figure 12 | Comparison of observed and HSPF simulated TSS concentration (a) and load (b) for the period 1994–1995.
CONCLUSIONS

The study concludes the following:

- Both HSPF and CANWET effectively partitioned annual precipitation into ET, surface runoff, and subsurface flow which is representative of the watersheds with medium soils in southern Ontario conditions. Therefore, either of the models may be used for analysis of annual water budget.
- Both models simulated components of seasonal water budget compatible with observed components (Nash-E 0.80 and 0.72 for HSPF vs. observed stream flow and CANWET vs. observed stream flow, respectively). The simulated groundwater flow and surface runoff by these models also show a typical pattern for southern Ontario.

Figure 13 | Comparison of monthly erosion (a) and sediment yield (b) simulated by HSPF and CANWET for the period 1993–1995.
Also, averaged seasonal simulated stream flow over the 9-year period showed high Nash-E of 0.91 and 0.99 for HSPF and CANWET, respectively. Therefore, seasonal comparison also supports that either of the two models can be used for seasonal water budgeting.

- These models predicted monthly water budget components realistically representing hydrology of watersheds in southern Ontario. The monthly simulated stream flow comparison with observed stream flow rendered good correlation (Nash-E = 0.70 and 0.67 for HSPF vs. observed stream flow and CANWET vs. observed stream flow, respectively). Apparently HSPF better predicts monthly water budgeting than CANWET as it has more temporal control of hydrologic parameters.

- The daily comparison of HSPF and CANWET simulated stream flow with observed stream flow showed a Nash-E of 0.35 and 0.17, respectively. Since correlation of HSPF with observed stream flow is more promising, HSPF may be preferred over CANWET for daily simulations depending upon the accuracy level required.

- The upland erosion simulation is comparable for both models with HSPF relying on USLE for calibration. HSPF has a strong in-stream component for sediment routing and therefore, sediment yield prediction may be more reliable. The conclusion could not be drawn between the two studied models for the prediction of sediment yield because few observed data were available to verify the models’ outputs.

- HSPF needs a higher level of expertise for its application compared to that required for the application of CANWET. The number of variables controlling hydrology and sediment in HSPF outnumber the variables needed for CANWET.

ACKNOWLEDGEMENTS

The study was sponsored by the Ministry of Agriculture and Food, Ontario, and Greenland International Consulting, Collingwood, Ontario, Canada, through a grant provided to the University of Guelph, Guelph, Ontario. The study was accomplished by joint venture of Greenland International and the University of Guelph.

REFERENCES


McLaughlin, N. 2001 Improving Nitrogen Leaching predictions within the MCLONE4 Program. MSc Thesis, University of Guelph, Guelph, Ontario.


First received 23 August 2012; accepted in revised form 12 December 2012. Available online 27 August 2013