Evaluation of AnnAGNPS in cold and temperate regions

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Abstract Identification of the pollution sources and understanding the processes related to runoff generation and pollution transportation is effective for the water quality management and selection of the Best Management Practices. The ANNualized AGricultural Non-Point Source (AnnAGNPS) model was applied to a watershed in Southern Ontario to evaluate the hydrology and sediment component from the non-point sources. The model was run for two years (1998 to 1999); one year's data was used to calibrate and the second year's data was used for validation purposes. The model has under predicted runoff amount and over predicted the sediment yield. However, the simulated runoff and sediment yield compared fairly well with the observed data indicating that the model had an acceptable performance in simulation of runoff and sediment. The study is still in progress to assess its performance for estimation of TMDL and improvements needed for the model to use under Ontario conditions.
Keywords AnnAGNPS; best management practice; hydrology; non-point source pollution; sediment

Introduction

Intensive agricultural activities are potential sources of suspended sediment, nitrogen, phosphorus and pathogens. These are the main causes of non-point source (NPS) pollution at different tributaries in Ontario. A number on studies on the water quality and quantity are being carried out in the Grand River basin in Ontario, which is a tributary to Lake Erie (GRCA, 1998; GRIC, 1982). Those studies have indicated that both point and non-point pollution sources are adding pollutants to surface and groundwater. Pollution reduction from the point sources, such as industrial and municipal wastewater discharges at the basin area has improved during the past two decades. On the other hand, developing and understanding of the role of non-point sources and their effective control in the Grand River basin is less successful. Non-point agricultural source pollution has created many problems for Ontario's environment, especially in terms of water quality (GRCA, 1998). Different parts of the Grand River and its tributaries are currently experiencing low dissolved oxygen level, high nutrient and suspended sediment concentrations and degraded drinking water quality and habitat for fish and other aquatic organisms. For the purpose of assuring clean and safe use of surface water, it is required to identify those source areas responsible for the impairment of water bodies. According to Dickinson *et al.* (1990), targeting NPS pollution sources has the potential to triple pollutant reduction, and minimize the extent of area affected negatively by restrictive land practices. Once the target for pollution sources is specified and identified, the best management practices can be applied to reduce the pollutants and contaminants at watershed outlets. Watershed based NPS models have played an effective role to perform the above jobs from the last two decades. They are the important tools in the development of management strategies to ameliorate the effects on water quality from NPS pollution. The Grand River Conservation Authority (GRCA) of Ontario in Canada has recognized the need to improve the estimation of the amounts and timing of pollution from NPS entering the Grand River. Different models are being investigated for this purpose. The AnnAGNPS is one of them and is being evaluated in the Canagagigue

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subwatershed. The main objective of this study is to examine the applicability of the AnnAGNPS model on a watershed scale in the cold and temperate region of Canada.

AnnAGNPS model

The AnnAGNPS (Cronshey and Theurer, 1998) model is a continuous simulation, daily time step, watershed scale, pollutant loading model (Frank *et al.*, 1998) developed to simulate long-term sediment and chemical transport from ungaged agricultural watersheds. It can be used to locate the possible sources or areas that are responsible for the impairment of the water bodies. AnnAGNPS is a direct replacement for the single event model, AGNPS (Young *et al.*, 1989a,b) but retains many of the features of AGNPS (Yuan *et al.*, 2001). Bosch *et al.* (1998) described the model as flexible, accurate, and discretized. The hydrology part of the model is based on a water balance approach, which is based on a simple account of inputs and outputs of water during a day. Water inputs include rainfall, snowmelt, and irrigation water, while surface runoff, percolation, evapotranspiration, and drainage are the outputs. It is a distributed parameter model where the watershed is divided into several small scale areas named as "cells". The cells are often grouped into hydrologically similar areas. Generated runoff is routed through the in-cell watershed flow-system on a continuous basis, allowing moisture stored in the soil to be carried over from one day to the next. Soil moisture conditions are then used to calculate the SCS curve number (CN), which forms the basis of the surface and subsurface runoff quantities for that day.

The subsurface flow in AnnAGNPS considers either tile drainage or lateral subsurface flow and only occurs with the presence of an impervious layer within the soil profile. When the water table is below the drainage depth, lateral flow is calculated using Darcy's equation as described for lateral subsurface flow. AnnAGNPS utilizes the Revised Universal Soil Loss Equation (RUSLE, Renard *et al.*, 1997) for calculating the sediment delivery to a field edge when a runoff event occurs due to rainfall, irrigation, or snowmelt. The Hydro-geomorphic Universal Soil Loss Equation (HUSLE, Theurer and Clarke, 1991) is used to estimate the total sediment yield leaving each field to the stream reach after deposition. The model calculates nitrogen (N), phosphorus (P), and organic carbon (OC) concentrations within each field, using a mass-balance basis which is dependent upon soil moisture and the environmental cycles of the concerned area. Three sets of data are required to run AnnAGNPS. They are topographic data, soil and land-use related data, and climate data. Input data preparation is organized using the tools and/or models contained in the AnnAGNPS package.

Description of the study area

The Grand River is one of the largest rivers in Southern Ontario and is a tributary to Lake Erie. The selected watershed (Canagagigue Creek) is located in the northwest part of the Grand River basin. It is a minor tributary of the Grand River. The watershed has a total area of about 150 km^2 and is situated between the latitude of 43° 36′ N and 43° 42′ N and longitude 80° 33′ W and 80° 38′. About 80% of the land within the watershed is under agricultural activities and 10% is woodlot (Carey *et al.*, 1983). The area upstream of the Floradale Dam with a total contributing area of about 53 km^2 is selected. This selection was primarily based on the availability of observed flow and sediment data. These data were used for calibration and validation of the model. Figure 1 displays the studied subwatershed within Canagagigue watershed. The topography of the study area is flat to gently undulating with a slight slope towards the outlet in the south. 95% of the selected subwatershed area is under agricultural practices. A major portion of the watershed has 200 to 600 mm of loam or silt loam of the Huron and Harriston series overlying

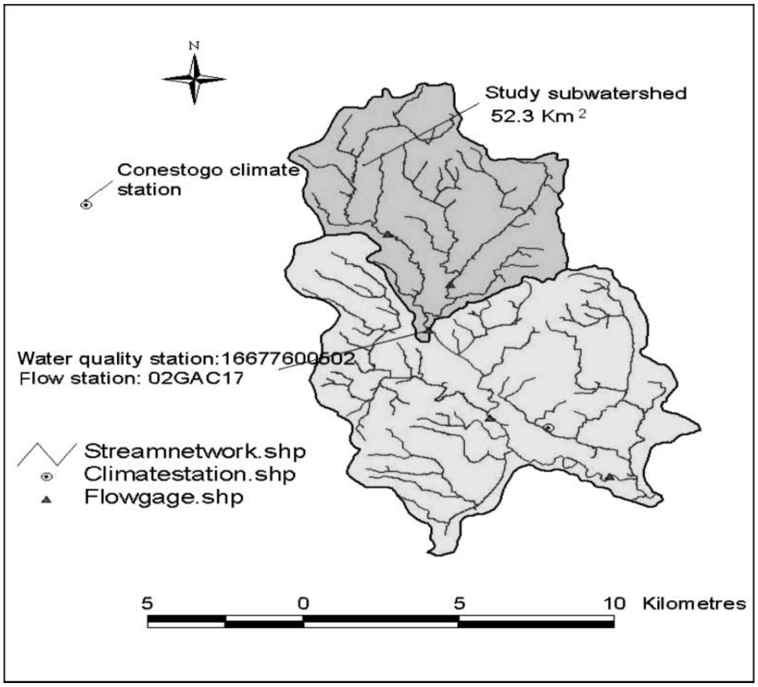

Figure 1 The location of the subwatershed inside Canagagigue watershed

a loam till (Presant and Wicklund, 1971; Hoffman *et al.*, 1963). Loam is the predominant soil type in the central portion of the catchment.

Agricultural practices include mixed farming with predominantly dairy farming and cropping of corn, small grains, some other row crops and hay. There are limited areas used to cultivate cash crops as most crops are grown for livestock feed (So and Singer, 1982). General tillage practices within the watershed vary from conventional tillage to moldboard plough. Agricultural lands of the study area are usually ploughed in October followed by tillage operations in May. Most of the farmers apply manure to agricultural land. Generally the manure is applied two times a year in April–May and July–November.

The average annual precipitation ranges from 750–1,000 mm, of which 100–200 mm falls as snow. The average annual temperature of the area is about 6.5°C and annual evaporation is about 65% of the annual precipitation. The major part of the evaporation occurs during the summer season. There are five flow gage stations and three water quality measuring stations situated in Canagagigue creek watershed area. The current study used the observed flow data from flow gage station (No. 02GAC17) and sediment data from quality gage station (No.16677600502) respectively. Positions of the gage stations are shown in Figure 1. The observed data including hourly flow rates and daily sediments rates are available during April 1 to October 31 in every year from 1998 to 2000.

Model evaluation

Input data preparation

A Digital Elevation Model for the whole Canagagigue watershed was obtained from the Grand River Conservation Authority (GRCA). The DEM has 100 m resolution based on the contour data and digital terrain data from 1:1,000 OBMs (Ontario Base Map). Stream flow directions and the watershed and subwatershed boundaries are delineated by using the TOPAGNPS and AGFLOW modules of the AnnAGNPS Arc View interface. Cells were hydrologically determined by a user-defined critical source (CSA) area of 150 ha and a minimum source channel length (MSCL) of 250 m. Physical properties of each cell (area, length, and slopes) were determined by the AGFLOW module. Dominant soil and land use for each cell was predetermined by extrapolating the soil and land use shape files over the delineated subwatershed. The climate file was prepared based upon the historical data. The required parameters were the 2-year 24 hour rainfall, daily maximum and minimum temperatures, daily precipitation, dew point temperature, sky cover and wind speed. The Conestogo rain gauge station was selected for the historical rainfall and daily temperature data because it was the closest station to the selected area. It was difficult to obtain all the required climate parameters from one station; therefore some parameters (wind speed, sky cover, and dew point temperature) were obtained from the nearby weather station situated at the Elora research centre of the University of Guelph.

GIS layer for the soil and landuse were obtained from Ontario Ministry of Agriculture and Food (OMAF) soils and landuse database. This includes a series of county-wise geospatial soil survey data. The AnnAGNPS model has been developed in the USA where the model has the capability to extract most of the soil information from their SSURGO database provided by US Geological Survey (USGS). Therefore, the OMAF soils shape file was needed to rearrange for overlaying it with the delineated subwatershed. The entries in the attribute table for the soil shape file needed a Map Unit Symbol (MUSYM) parameter that should be identified by the model as respective soil group. Hence, the original attribute table of soil shape file was manipulated by adding the MUSYM to it. As there is no reference for this MUSYM in the Canadian conditions, MUSYM numbers were selected arbitrarily. Most of the physical properties of soils were obtained from the Canadian Soil Information System (CanSIS) website, Report No.35 of the Ontario soil survey (Hoffman *et al.*, 1963), and Report No.44 of the Ontario soil survey (Presant and Wicklund, 1971). Nine types of dominating soil have been found after extrapolating the soil shape file over the delineated watershed. Out of them, Burford soil (MUSYM 19A) has covered 31% and Brady soil (MUSYM 11A) has covered 21% of the study area.

The selected sub watershed consists of six types of dominated landuse. Each landuse type was included under a land use identifier during the input data preparation for the AnnAGNPS model. Mixed system (ID M) has covered 46%, corn system (ID C) has covered 32%, and Woodlot (ID Z) has covered 6% of the delineated study area. Most of the crop information and their management operations were collected from OMAF publication 811 (Agronomy guide for field crop). SCS curve number (CN) is one of the key hydrologic factors in obtaining accurate prediction of runoff and sediment yields (Yuan *et al.*, 2001). All the associated outputs transported through runoff are largely affected by the CN. The curve numbers for different hydrologic soil groups related to each crop operation have been selected from the National Engineering hand book section 4 (SCS, 1985).

Running AnnAGNPS

The AnnAGNPS model was run for the selected watershed for 2 years (1998–1999) on a daily basis. The observed flow and sediment rates from April 1 to October 31 in 1998 from the respective gage stations were used to calibrate the model. Similar data from April 1 to October 31 in 1999 of the same stations were used for validation purposes. Calibration to the model input was done by adjusting the sensitive parameters according to the field estimates to make the model predictions close to the actual conditions.

Un-calibrated run. Table 1 shows the monthly output (from April 1998 to October 1998) of runoff and sediment and the percentage of deviation from the observed data. The model has under predicted the runoff as the observed runoff is always more than the

Table 1 Comparison of observed and predicted monthly runoff for the year 1998 (uncalibrated)

Month	Ppt. (mm)	Sim_runoff (mm)	Obs_runoff (mm)	Deviation (%)	Sim_sed (ton)	Obs_sed (ton)	Deviation (%)
Apr-98	42.70	2.68	8.60	− 68.80	13.02	3.14	315.37
May-98	26.30	0.08	0.43	− 81.98	2.29	0.01	16,090.24
Jun-98	45.80	2.24	4.44	− 49.56	212.69	84.93	150.43
Jul-98	15.40	0.01	0.11	− 88.11	1.19	0.38	215.44
Aug-98	86.40	10.08	20.12	− 49.91	141.30	59.65	136.88
Sep-98	10.30	0.02	0.03	− 38.38	0.60	0.00	19,746.03
Oct-98	18.20	0.09	0.05	65.04	2.98	0.09	3,097.11
Total	202.40	15.20	33.79	− 55.01	374.07	148.21	152.40

simulated runoff. However, the daily simulated runoff amount follows the same pattern of the observed amount. The total simulated runoff for the run period is 15.2 mm where the observed runoff was 33.8 mm. AnnAGNPS doesn't account for the base flow and this may be a reason for this variation. The model has under predicted the runoff by 55% which is without the base flow separation and this could be a reasonable range for an uncalibrated run of a model. Climate data shows that 1998 was comparatively a dry year and thus the runoff amounts in May, July, September and October are comparatively low. Runoff regression analysis gives the best-fit equation $y = 1.84x$ and coefficient of determination $R^2 = 0.89$. This is in the reasonable range for an un-calibrated hydrology submodel and hence indicates that the AnnAGNPS model is capable of simulating hydrology components under watershed conditions.

Simulated sediment in 1998 indicates that AnnAGNPS has over predicted the sediment yield in all months. Specially May and September are showing a huge deviation between the simulated and observed data. Simulated sediment yield is comparatively less in these months but the observed data has shown almost negligible values. It might happen due to the problem of observed data recording. The runoff on these months is also low. Runoff amounts do not affect the soil loss results directly as the rainfall amounts are used in RUSLE to determine an erosion index value for each storm. This is because RUSLE uses this rainfall and runoff factor in the calculation of soil loss and it is only determined when AnnAGNPS predicts runoff occurring for an event (Yuan *et al.*, 2001). However, the overall error in sediment prediction is 152.4%. Sediment regression analysis gives the best-fit equation $y = 0.4x$ and coefficient of determination $R^2 = 0.89$. This result indicates that the sediment sub model did an acceptable job of predicting sediment in 1998 without calibration though there are some unexpected deviations.

Calibrated run. Though AnnAGNPS has predicted the hydrology and sediment component fairly well with some exceptions, the simulated data varies with the observed data and thus needed the calibration to bring them more close to each other. Table 2 shows the monthly simulation results and the deviation from the observed data after calibration for both runoff and sediment. It has been seen that the simulated runoff has increased and the sediment yield has been decreased by a small amount. For sediment, due to the observed data in May and September, a huge deviation between the simulated and observed value still exists. Coefficient of determination (R^2) values between the simulated and observed amount of runoff and sediment are 0.93 and 0.91 respectively.

On average, analysis shows that the hydrology component of the model consistently under predicted runoff and over predicted sediment yield. This may happen as the model doesn't have a good groundwater component and the groundwater flow is not simulated properly by the model. For the calibration phase, model simulated runoff amount has been slightly increased and the final result appeared to be in an acceptable range.

Table 2 Comparison of observed and predicted monthly runoff for the year 1998 (calibration phase)

Month	Ppt. (mm)	Sim_runoff (mm)	Obs_runoff (mm)	Deviation (%)	Sim_sed (ton)	Obs_sed (ton)	Deviation (%)
Apr-98	42.70	3.54	10.49	− 66.24	11.91	3.14	279.81
May-98	26.30	0.19	0.55	− 64.78	3.58	0.02	23,067.57
Jun-98	45.80	3.58	4.44	− 19.21	218.97	84.93	157.81
Jul-98	15.40	0.06	0.11	− 43.56	0.69	0.38	81.42
Aug-98	86.40	11.99	20.17	− 40.57	130.19	59.65	118.25
Sep-98	10.30	0.15	0.03	394.88	0.74	0.00	24,549.11
Oct-98	18.20	0.54	0.07	698.41	3.95	0.09	4,144.90
Total	202.40	20.06	35.85	− 44.04	370.02	148.21	149.66

The erosion sub model still over predicts sediment yield for the year 1998 after calibration. However, considering the unavailability of very precise and detailed data for watershed, results could be considered in the acceptable range.

Model validation. Model validation is considered to be a final check on the performance of the model under certain conditions. Runoff amount and sediment yield data in 1999 at the outlet of the watershed were used to validate the model. The model outputs of runoff and sediment yield using 1999 climate data were compared to the observed data and are displayed in Table 3, Figures 2 and 3. The simulated runoff is still under predicted compared to the observed amount. Simulated runoff amount is 48.88 mm whereas the observed runoff amount is found to be 55.9 mm. Simulated runoff is only higher than the observed data in September. The deviation percentage is very high in August. There was more rainfall in that month within one week (Julian day 216 to 223). A management operation was also performed (culti weed) during this period which disturbed the soil and as a result, there was less runoff. The total percentage of deviation for the whole year was 13%. There was more rainfall found in 1999 than in 1998 which resulted in more runoff in the validation phase. The best fit equation for runoff is $y = 1.153x$ and the coefficient of determination $R^2 = 0.83$. Thus it could be concluded that the model consistently under predicted the runoff. From the above statements, it can be better described that the model can simulate the runoff component in an efficient way.

The deviation of simulated sediment from the observed was 103%, which shows the model is over predicting the sediment yield in the validation phase too. The best fit equation shows the relation $y = 0.45x$ and the coefficient of determination (R^2) is 0.79. The validation results show the improvement in sediment prediction by the model. The deviation percentage did not change abruptly as was found in the year 1998 for both the un-calibrated and the calibrated run. Hence we can say that the model can simulate the sediment component effectively.

Table 3 Comparison of observed and predicted monthly runoff for the year 1999 (validation phase)

Month	Ppt. (mm)	Sim_runoff (mm)	Obs_runoff (mm)	Deviation (%)	Sim_sed (ton)	Obs_sed (ton)	Deviation (%)
Apr-99	34.90	4.87	7.09	− 31.23	23.37	16.79	39.20
May-99	61.00	3.22	3.20	0.80	48.15	25.88	86.02
Jun-99	103.70	16.35	17.84	− 8.37	131.57	61.72	113.16
Jul-99	62.10	8.05	7.48	7.51	36.80	22.95	60.39
Aug-99	44.40	1.59	0.18	768.50	19.99	8.26	141.97
Sep-99	62.40	4.12	2.23	85.21	64.14	34.75	84.58
Oct-99	65.50	10.68	17.91	− 40.35	88.08	32.30	172.68
Total	434.00	48.88	55.93	− 12.59	412.10	202.65	103.35

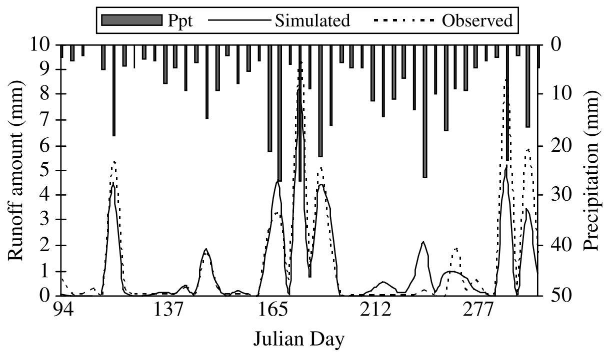

Figure 2 Comparison of simulated and observed amount of runoff (validation phase)

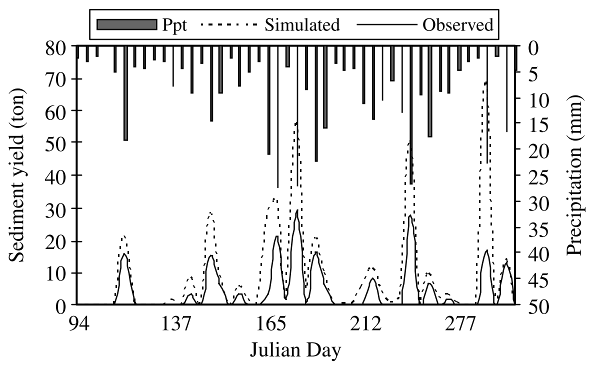

Figure 3 Comparison of simulated and observed amount of sediment yield (validation phase)

Conclusion

The AnnAGNPS model was evaluated on a watershed in Southern Ontario where the weather is cold and temperate. The model performance was calibrated and validated for the hydrology and sediment component from the non-point sources with the observed parameters. The model was applied from 1998 to 1999 on a daily basis. Depending on the availability and compilation of observed data, the model simulated hydrology and sediment component was calibrated from April 1998 to October 1998 and validated using independent data from April 1999 to October 1999. The model under predicted the simulated runoff and over predicted the sediment yield. Runoff curve number is the most sensitive parameter in the model as it has a greater impact on runoff than other parameters and runoff controls the detachment and transportation of other components from a watershed. Calibration and validation results show that the model is capable of simulating the runoff amount and sediment yield fairly well for a cold and temperate region like Ontario. Selection of the model input parameters needs careful attention especially while running for a long term period, as it is much too sensitive to input parameters.

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