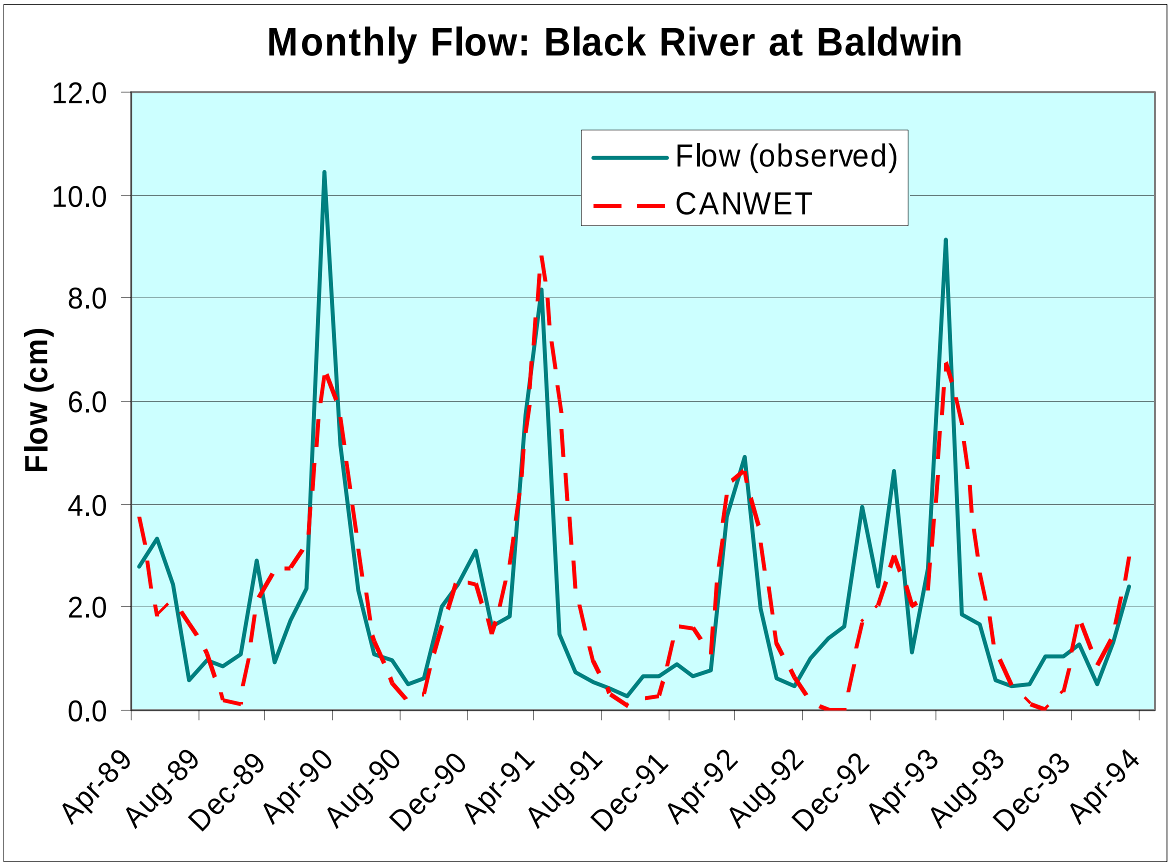
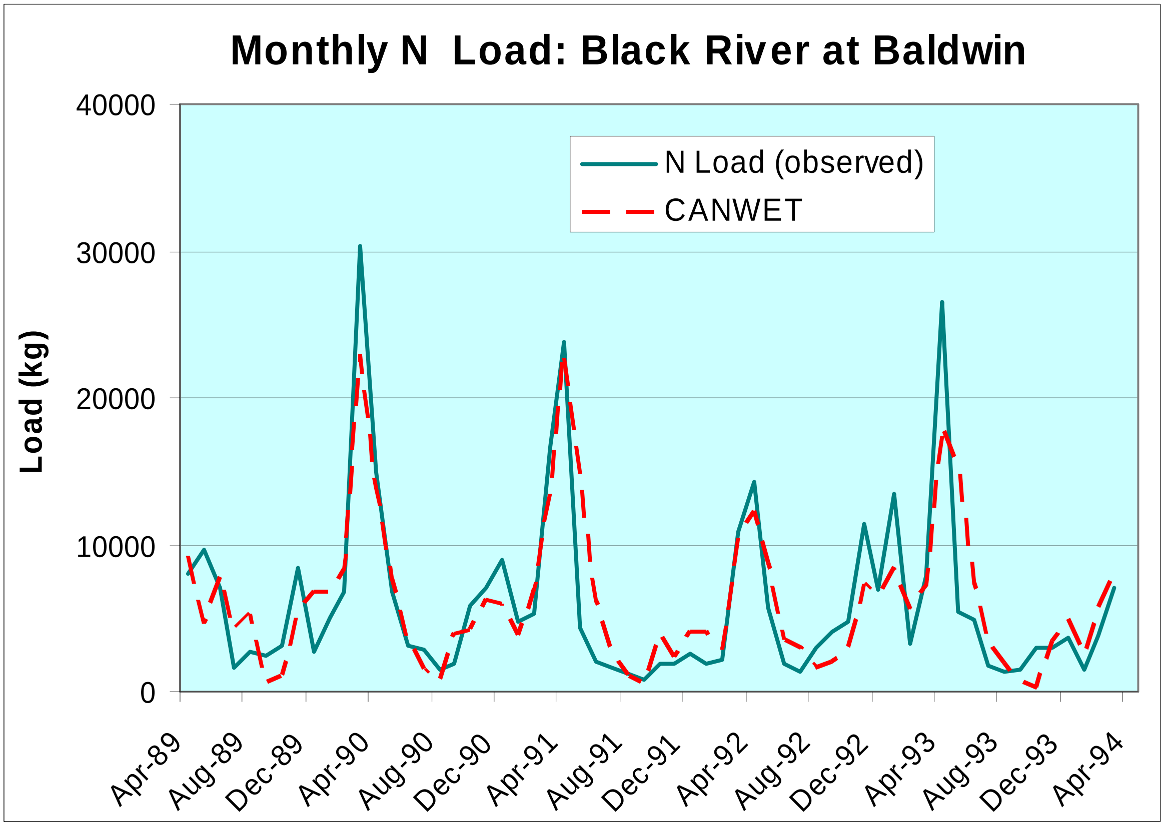
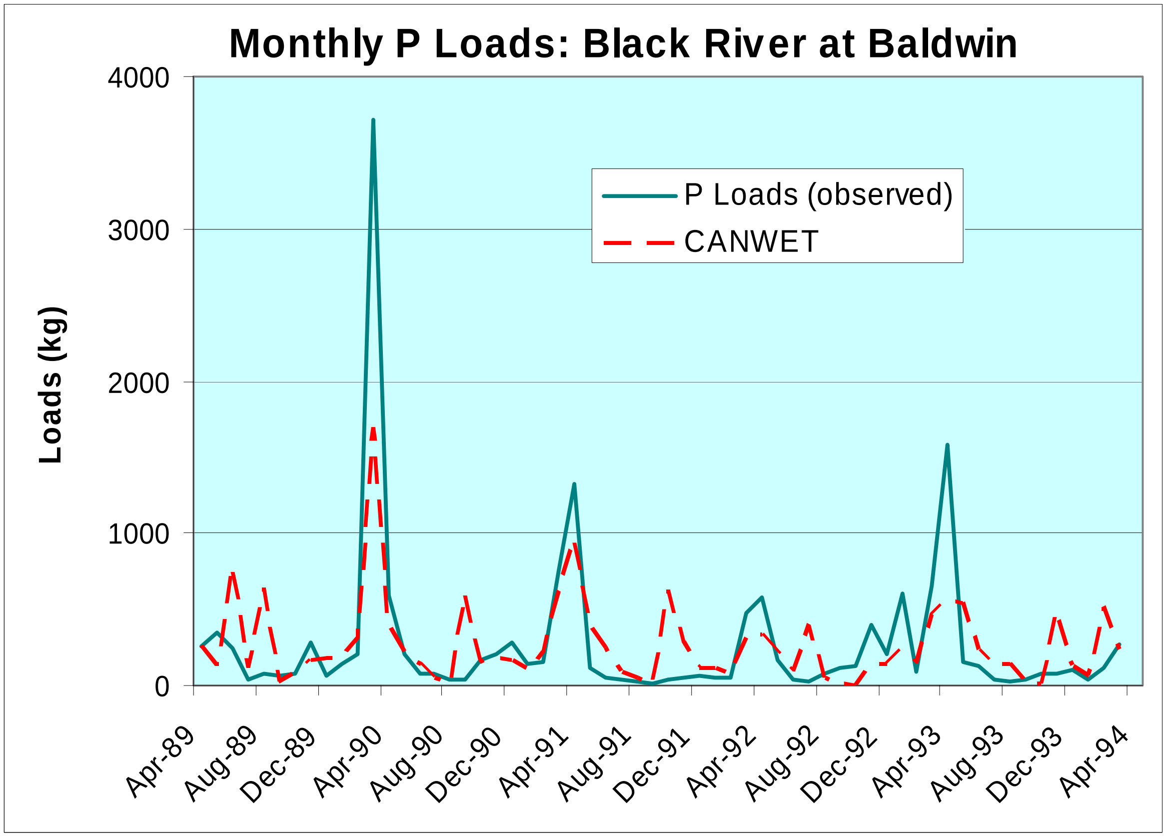
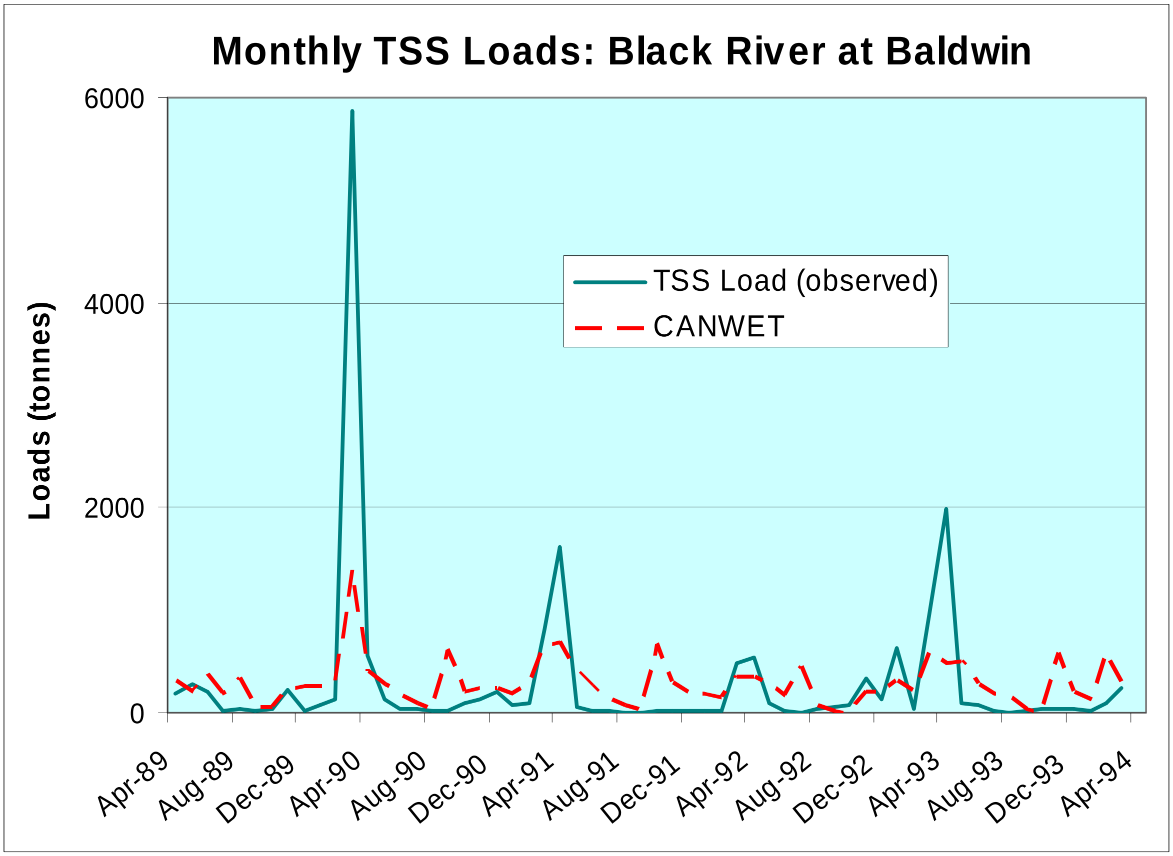
APPENDIX A:

BLACK RIVER CALIBRATION PLOTS


Monthly Flow: Black River at Baldwin
Flow (cm)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Flow (observed)
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94


Monthly N Load: Black River at Baldwin
Load (kg)
40000
30000
20000
10000
0
N Load (observed)
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94


Monthly P Loads: Black River at Baldwin
Loads (kg)
4000
3000
2000
1000
0
P Loads (observed)
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94


Monthly TSS Loads: Black River at Baldwin
Loads (tonnes)
6000
4000
2000
0
TSS Load (observed)
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94

APPENDIX B:

COMPARATIVE STUDY: CANWET, SWAT AND HSPF ON GRAND RIVER SUB-CATCHMENT

9th Environmental Engineering Specialty Conference
9e Conférence spécialisée sur le génie de l'environnement

Toronto, Ontario, Canada
June 2-4, 2005 / *2-4 juin 2005*

EV-156

PROTECTING ONTARIO'S SOURCE WATERS FROM DISTRIBUTED CONTAMINANT SOURCES

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ABSTRACT: Since the 1980s, awareness has grown of the wide-ranging impacts of sediments and sediment-bound pollutants in streams, including impacts on downstream fisheries, recreation activities, reservoirs, harbours, and drinking water intake facilities. The main contaminants of concern include sediments and associated pollutants (e.g. phosphorus, heavy metals, pesticides, and bacteria). The sources of these contaminants include distributed or nonpoint sources in rural watersheds. The selection of effective source water protection strategies requires delineation of significant contaminant sources in the watershed and determination of their relative contribution to downstream loadings. To ascertain significant nonpoint sources of downstream contaminants requires an extensive network of sophisticated and/or labour intensive monitoring, which has not been possible primarily for economic reasons; and/or a reliable method to predict the significant sources. In the last few decades, a wide variety of distributed hydrological models have been developed that can predict downstream contaminant loadings on the basis of distributed characteristics of the upstream watershed and describe the transport of contaminants in the stream system. A few of these watershed models, including CANWET, AnnAGNPS, and SWAT were evaluated in a watershed in Southern Ontario for predicting runoff. The models were run for five years (1990 to 1994). The data for 1990 was used to initialize the models for a continuous calibration run using the 1991 to 1992 data. The outputs for 1993 and 1994 were used to validate the models. Strengths and weaknesses of the models and their accuracy of predictions are discussed.

1. INTRODUCTION

The concerns relating to sediments and sediment bound pollutant movement in streams are extensive. Sediment bound pollutants include nutrients, heavy metals, pesticides, and bacteria. The combination of sediment and these contaminants can impact a variety of water related activities, including downstream fisheries, recreational activities, reservoirs, harbours and drinking water intake facilities. Increased sediment loads and nutrients associated with sediment transport can affect local aquatic life by degrading habitat and causing eutrophication (USEPA, 2000). Additionally, heavy metals, pesticides and bacteria loading in streams and rivers adversely affect the quality of surface drinking water sources. The impairment of water quality and quantity is as a result of impacts of industrialization, urbanization and agriculture, including nonpoint sources in rural watersheds (Davies & Mazumder, 2003).

The contamination of local water bodies from non-point source pollution in small agricultural watersheds is a concern both in North America and globally. Studies have been completed in the UK and NZ illustrating the significance of non-point source pollution in these small basins (Caruso, 2001; Mainstone & Schofield, 1996). Additionally, the US EPA notes that agriculture is the leading source of pollution in assessed rivers and streams, contributing 48% of reported water quality problems in impaired rivers and streams (USEPA, 2000). In a Canadian context and on a smaller scale, the degradation of water quality and quantity is an ongoing concern in the Grand River Basin, located in Southern Ontario (Balachandran, 1979; Carey et al.

1982; So & Singer, 1982). The selection of effective source water protection strategies requires delineation of significant contaminant sources in the watershed and determination of their relative contribution to downstream loading. In this way, critical areas can be identified where “the greatest improvement to an impaired water resource can be obtained for the least investment” (Maas et al, 1985).
The use of models to predict the hydrological responses in a watershed is common practice for water resource management. Modelling scenarios that can determine significant non-point sources of contamination are an important tool for source water protection. The identification of these sources without models requires an extensive network of sophisticated and/or labour intensive monitoring, which is generally not economically viable. A wide variety of watershed-based models are available for determining the impacts of non-point source pollution in a small watershed. These hydrological models can predict downstream contaminant loadings on the basis of the characteristics of the upstream watershed and describe the transport of contaminants in the stream system. The models in this study are examples of how GIS technology can be partnered with hydrological modeling. The linking of models with a GIS database can help organize relevant information effectively and allow management of water resources on a watershed scale. However, it is essential that the application of a model in an area outside of where it is originally developed be tested. In some cases, the inherent assumptions, constants and algorithms in the model may require modification to better represent a new climate regime or unique physiographic characteristics in the study area.

2. OBJECTIVES

The main goal of this study is to evaluate the performance four watershed based models in a small agricultural watershed, considering the hydrologic portion of the model only. Establishing the strengths and weaknesses of the hydrological portion of a watershed model is essential. The nutrient and sediment transport in a watershed model relies on the hydrologic response determined by the predicted water balance and flow. The watershed models evaluated in this study are SWAT, CANWET, and AnnAGNPS. The strengths and weaknesses of the models are discussed following the application of each model to the Upper Canagagigue Creek, a tributary of the Grand River, in Southern Ontario. The models are run for five years (1990 to 1994). The data for 1990 is used to initialize the model for a continuous calibration run from 1991 to 1992. The years 1993 and 1994 are used to validate the models.

3. BACKGROUND

Canagagigue Creek is a minor tributary of the Grand River in southern Ontario. The climate is temperate; long-term mean temperature for the Grand River basin ranges from 6-9 °C and long-term mean annual precipitation range from 84cm to 88cm, with 10 cm to 20 cm of the overall precipitation falling as snow (So & Singer, 1982). The entire basin drainage area is roughly 143 km^2 with predominantly silt loam soils (Watt et al., 1989). This study focuses on the Upper Canagagigue Creek sub-basin, upstream of Floradale, which has a drainage area of 53 km^2. Canagagigue Creek is located between 43°36’N-43°42’N latitude and 80°33’W longitude. The minimum elevation of the study area is 366m, the maximum elevation is 470m and the average elevation is 417 m (Figure 1). The physiography of the area can be considered “typically Canadian” as it was formed by glaciation and the topography is flat to gently undulating with an average slope of 1.5% (Carey et al. 1983). The average annual evaporation in the area is about 65% of the annual precipitation (Rudra, 2000), with most evaporation occurring during the summer months. The predominant land use in the area is agricultural, with primary crops of corn and grains. There are also small areas of pasture, woodland and low intensity development (Watt et al., 1989; Carey et al. 1983). The primary source of contamination in the Upper Canagagigue Creek is agricultural runoff. The study area is located upstream of Elmira and does not have impacts of the industrial effluent from Elmira or the Elmira Water Pollution Control Plant (Carey et al. 1982). The main contaminants of concern as a result of these agricultural activities are sediment, nutrients, pesticides, organic matter and bacteria.

The DEM of Upper Canagagigue is presented in Figure 1. This area was selected due to the availability of weather and flow data at the Woolwich Dam and Reservoir monitoring station.

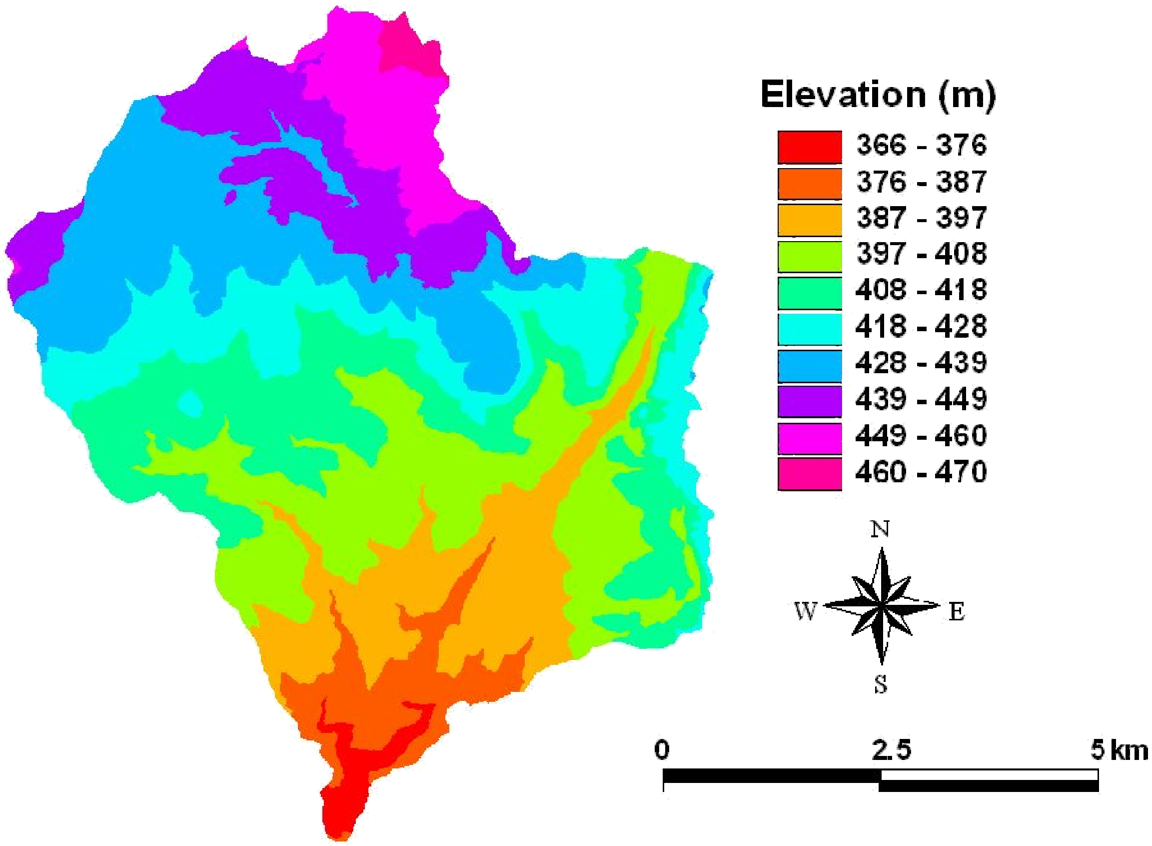

Figure 1: DEM for Upper Canagagigue Creek

4. MATERIALS AND METHODS

The variety of models available for the prediction of hydrologic response and sediment transport in a watershed allows the user to select an appropriate model for their task. Therefore, models are evaluated and compared in order to establish their strengths and weaknesses so that the best model for each scenario can be used. The selection of a model often depends on the problem definition, the resources available to the analyst, and the time frame available (Haan et al., 1982). More specifically, Haan et al. (1982) outline the four criteria that should be considered for model selection as:

1. accuracy of prediction
2. simplicity of the model
3. consistency of parameter estimates
4. sensitivity of results to changes in parameter values

With respect to these criteria, the model with the minimum error variance, simplest concepts, the least number of parameters to be estimated and the least sensitivity to parameters that are difficult to measure is best.

Model Descriptions

The Canadian ArcView Nutrient and Water Evaluation Tool CANWET (Greenland, 2004) has been developed by Greenland International Consulting Ltd. for application in continuous models for watershed scale nutrient management, drainage plans and source water protection. The CANWET model is comprised of two main modules, the nutrient-loading module and the best management practices assessment module. The nutrient-loading module combines aspects of distributed and lumped parameter modeling. The model allows for different land use/cover scenarios for surface water loadings. Parameters are calculated using weighted averages of watershed characteristics over the basin area. Sub-surface loadings are calculated using daily water balance and lumped parameter methodology. CANWET uses daily temperature and precipitation data inputs in the Hamon Method to predict potential evapotranspiration. This model uses the SCS curve number method to determine runoff and the Universal Soil Loss Equation for sediment transport. Phosphorous loading in CANWET is representative of the relationship between phosphorous transport and sediment transport. CANWET also allows the user to specify point source loading and water extractions. The best management practices assessment module (PREDICT) can be used to determine the impact of implementing a system of management practices on the downstream sediment and nutrient loads in a watershed. The cost of management practices can also be included in the evaluation so that the best allotment of resources can be determined.

The Annualized Agricultural Non-Point Source Pollution Model AnnAGNPS (Bingner & Theurer, 2003) is a daily based continuous simulation watershed-scale model. The model is applied first by partitioning the basin into homogenous land areas with respect to soil type, land use and land management. Areas can be of any shape, including hydrologically based or square grid. The model is able to simulate surface water, sediment, nutrients, and pesticides leaving the land areas (cells) and their subsequent travel through the watershed. Surface runoff depth is computed by using curve number (CN) method while sediment is determined using the Revised Universal Soil Loss Equation (RUSLE). Special components are included to handle concentrated sources of nutrients (feedlots and point sources), concentrated sediment sources (gullies), and added water (irrigation). The model can be used to evaluate non-point source pollution from agricultural watersheds. It can compare the effects of implementing various conservation alternatives over time within the watershed. Alternative cropping and tillage systems, fertilizer, pesticide, and irrigation application rates, point source loads and feedlot management can be evaluated.

Soil and Water Assessment Tool SWAT (Neitsch et al., 2002) is a watershed scale continuous model that operates on a daily time step. The objective of the model is to predict the long-term impacts in a large basin of management and also timing of agricultural practices within a year. It can also help in assessing the environmental efficiency of BMP's and alternative management policies. Surface runoff can be estimated either by the CN method or the Green & Ampt infiltration approach. SWAT also has the capability to simulate channel losses, runoff in frozen soils, snow melt, or capillary rise. Sediment yield is computed for each sub basin with the Modified Universal Soil Loss Equation. A simplified EPIC approach is used to simulate crop growth. The chemicals considered include nutrients and pesticides. Nutrient loadings to the channel are calculated from the concentrations in the upper soil layer and the runoff volumes. Uses of phosphorous and nitrogen by crops are estimated using a supply and demand approach. The nitrogen module also includes processes like mineralization, de-nitrification, and volatilization. Phosphorous association with sediment phase is considered in the phosphorous module.

5. RESULTS AND DISCUSSION

Model Calibration

Calibration is defined by Watt (1989) as "the process of adjusting model parameters to reduce the differences between simulated and observed flows to levels that are deemed acceptable." The calibration is not expected to achieve a "perfect fit" since that would imply that all the error is associated with the model, when in fact, all data does contain some error. Model calibration is completed using continuous runs over a three year data set. The first year is used to stabilize the model and only the model output for the years 1991 and 1992 are analyzed. Factors used to calibrate flow data in the Canagagigue watershed include evapotranspiration adjustment factors, ground water recess coefficient and CN curves. These factors are used to calibrate the model using both graphical and visual techniques.

The CANWET model allows the user to adjust monthly evapotranspiration factors in order to better predict the monthly stream flow. Also, CANWET uses the evapotranspiration factors as a surrogate to represent the decrease in stream flow during the winter months when the water is frozen. Rudra et al. (2000) recommend that the mean annual evapotranspiration for watersheds in this area be 65% of the mean annual precipitation. Rudra et al. (2000) also state that most of the mean annual evapotranspiration occurs during the growing season (May-Sept). The models are calibrated with these recommendations as a guide. The ground water recess coefficient is another parameter used to calibrate the model for Canagagigue Creek. The recommended range for this parameter is 0.1 to 1, with a coefficient of 0.04 was found to be the best fit for pilot studies completed for the CANWET model in three small watersheds (Greenland, 2004). In the CANWET model, the CN values are weighted by relative land use area over the total basin area. The CN values in the CANWET calculations have been slightly modified from original USDA values to better represent Canadian conditions. The major limitation of the original SCS method is that it specifically excludes runoff from snow melt and frozen ground (Watt, 1989) which means that in its original form the method is not applicable to Southern Ontario conditions. Lower CN values can be used for Canadian conditions to increase infiltration and decrease runoff. CN values are also assigned by weighted area according to land use area in each basin; therefore, the output of this model is most sensitive to changes made to the CN curves representing the most common land use type.

Figure 2 shows the comparison of the observed flows to the model predicted flows for the calibration at Woolwich Dam. These results indicate that the CANWET model has the capability to reproduce the hydrograph well for most of the calibration period. There are some indications that CANWET has difficulty with snow melt and also lags slightly when modeling peak flows. However, the overall trends for the non-snow months are generally well represented. The overall volume of flows for the calibration period matches to 99% accuracy even though some of the peaks are not accurately represented.

AnnAGNPS does not have a base flow component and therefore the monthly average includes zero flow days. However, AnnAGNPS performs well in following the overall trends in hydrologic response in the watershed. If desired, the user can add an appropriate base flow to the predicted flow depth for this model, but for the purposes of comparison in this study the model output is not altered in this way. The results for the SWAT model calibration indicate that this model can accurately reproduce the hydrograph for the calibration period. The SWAT model calibration shows “good” response to snow melt and runoff from frozen ground and the stream flow during the winter and spring months is represented well.

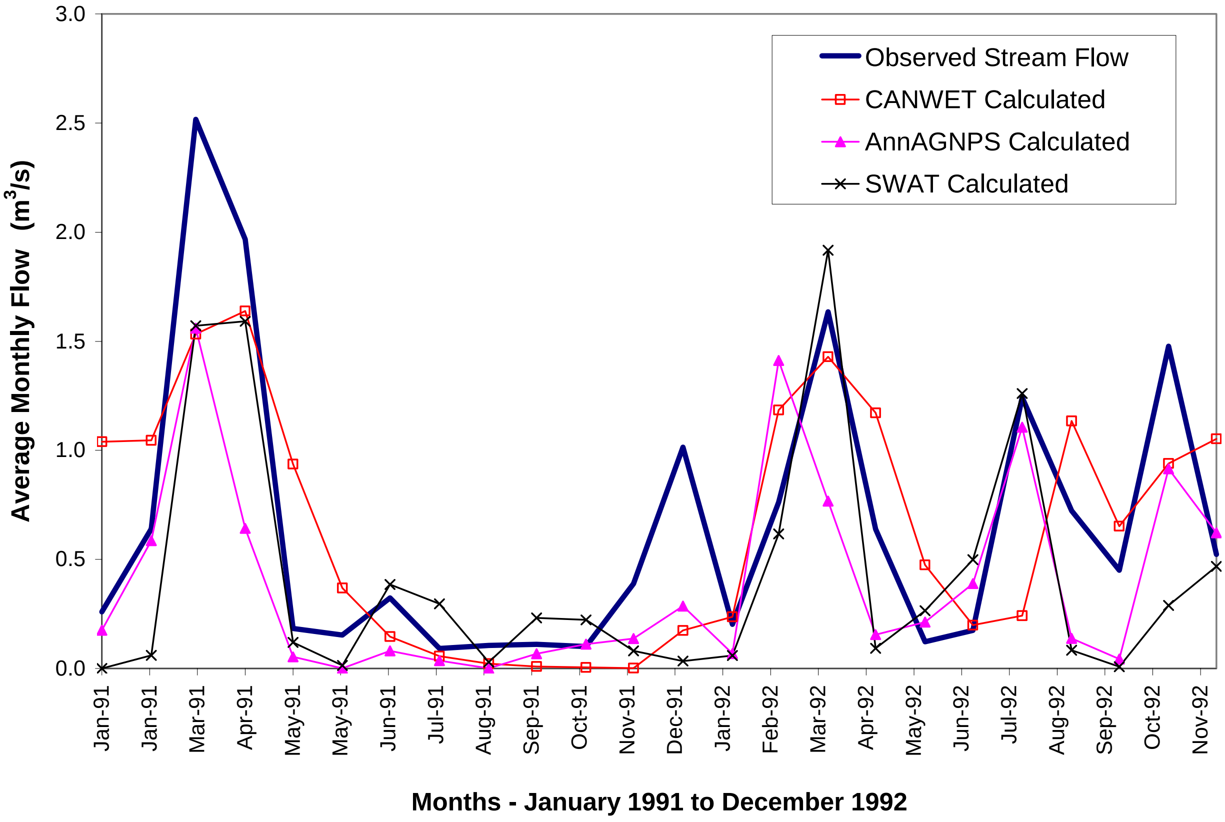

Figure 2: Observed and simulated average monthly stream flow for Canagagigue Creek at Floradale (calibration)

Evapotranspiration is an important part of the water balance for long term continuous models used for watershed management. Rudra et al. (2000) recommend that the percent of precipitation “lost” to evapotranspiration is approximately 65% in the study area, based on hydrologic data collected for study.

The calibrated CANWET model predicts a yearly value of 73.2% precipitation lost to evapotranspiration. The calibrated AnnAGNPS model predicts at value of 73.6% precipitation lost to evapotranspiration. The over prediction of these watershed models for evapotranspiration in the study area indicates that the evapotranspiration portion of the water balance is likely being used as a surrogate for other hydrologic behaviour (e.g.: in the case of CANWET, for winter freeze). More study is required in this area in order to correctly establish the role of potential evapotranspiration in watershed scale modeling.

Model Validation

The last 3 years of the data set are used to validate that the model is accurately calibrated for the study area. Once again, the first year of data is used to initialize the model for the continuous run, and the results are analyzed for 1993 and 1994 only. Validation with an independent period of the continuous data set for observed flows indicates how well the model parameters represent the real world. This step assesses the ability of the calibrated model to make accurate predictions for the study area. Figure 3 is an example of a validation of the CANWET and AnnAGNPS models for 1993 to 1994. The validation step indicated that the calibrated SWAT, CANWET and AnnAGNPS models performed well and can be used with confidence for future flow predictions.

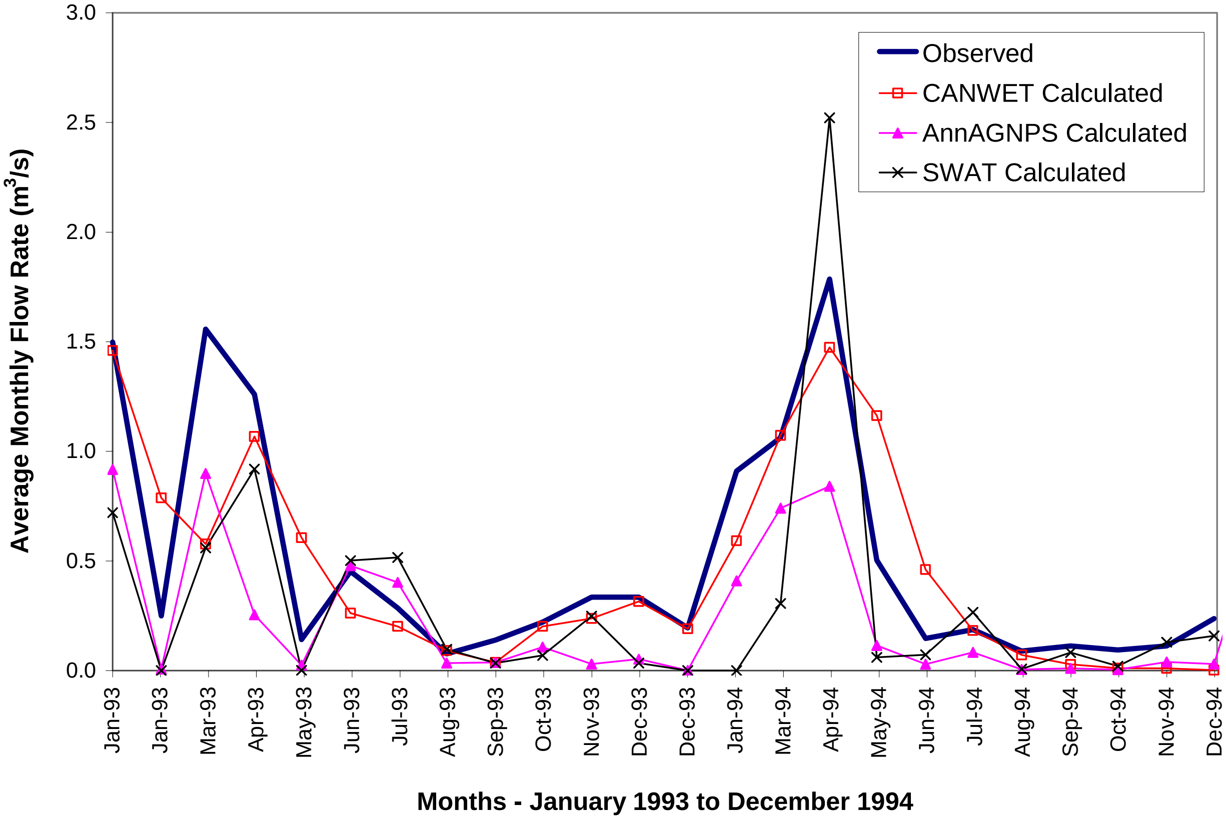

Figure 3: Observed and Simulated average monthly stream flow for Canagagigue Creek at Floradale (validation)

6. CONCLUSIONS

It is very important that the hydrological functionality of a model is established before it is used for sediment or nutrient modeling, since the hydrologic relationships are the building blocks of the model algorithms. The performance of models developed outside of Canada in Canadian conditions is also an area that requires ongoing and extensive research. For example, some of the models outlined in this study incorporate the SCS curve method to estimate runoff (AnnAGNPS, CANWET, and SWAT). This method should be used with caution for Canadian applications as this method is not immediately applicable to areas with snow and frozen ground. The AnnAGNPS model does not include a base flow component and tend to consistently underestimate the actual observed flows in the study area. The addition of this component may be one way to improve the estimates of stream flow using this model. Additionally, the AnnAGNPS model is very sensitive to some input parameters (i.e. runoff curve numbers). This sensitivity indicates that input parameters must be selected very carefully. The analysis and comparison of the models did indicate that future work is required in the area of evapotranspiration as it is incorporated into watershed models. This is a very important parameter of the water budget, especially for long term continuous simulations. Specifically, investigation into the evapotranspiration algorithms in the CANWET model will be performed. This research is required for the clarification of the role of potential evapotranspiration in watershed scale modeling. Additionally, some models developed outside of Canada are not as “user-friendly” as they could be since they do not accept climatic and/or water quality data in standard Canadian format and S.I. units for input. Further development and enhancement of these watershed-scale modeling tools will improve our scientific capabilities for protecting our water resources.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Balachandran, G. 1979. Grand River Basin Water Management Study Grand River Study Team technical report series report #6: An evaluation of three selected watershed models for use in water resources management studies in the Grand River basin. Prepared for the Grand River Implementation Committee. Ministry of the Environment, Toronto, Ontario.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle (Jr.), T.H. Jobes & A.S. Donigian (Jr.). 2001. Hydrological Simulation Program – Fortran (HSPF). Version 12, User’s Manual. Aqua Terra Consultants, Mountain View, CA.

Bingner, R.L. & F.D. Theurer. 2003. AnnAGNPS Technical Processes Documentation.

Caruso, B.S. 2001. Risk-based targeting of diffuse contaminant sources at variable spatial scales in a New Zealand high country catchment. Journal of Environmental Management, Vol. 63, pp. 249-268.

Carey, J.H., M.E. Fox, B.G. Brownless, J.L. Metcalfe, P.D. Mason and W.H. Yerex. 1983. The Fate and Effects of contaminants in Canagagigue Creek-1. Stream ecology and identification of major contaminants. Environment Canada. Scientific series No.135. 37p.

Davies, J.M. & A. Mazumder. 2003. Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources. Journal of Environmental Management, Vol. 68, pp. 273-286.

Greenland International Consulting Ltd. 2004. CANWET (Version 1.0) Canadian Arcview Nutrient and Water Evaluation Tool USER’S GUIDE. Collingwood, ON.

Haan, C.T., H.P. Johnson, & D.L. Brakensiek (Eds). 1982. Hydrologic Modeling of Small Watersheds. ASAE Monograph, Number 5 in a series. American Society of Agricultural Engineers. Michigan, USA.

Maas, R.P., M.D. Smolen and S.A. Dressing. 1985. Selecting critical areas for nonpoint-source pollution control. Journal of Soil and Water Conservation, January-February 1985.

Mainstone, C.P. & K. Schofield. 1996. Agricultural management for nonpoint pollution control, with particular reference to the UK. European Water Pollution Control, Vol. 6, No. 3, pp. 21-30.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams & K.W. King. 2002. Soil and Water Assessment Tool Theoretical Documentation. Version 2000.

Rudra, R.P., W.T. Dickinson, H.R. Whiteley, J.D. Gayner and G.J. Wall. 2000. Selection of Appropriate Evaporation Estimation Technique for Continuous Modeling. Journal of the American Water Resources Association, Vol. 36, No. 3, pp. 585-594.

So, S.K. & S.N. Singer. 1982. Grand River basin water management study technical report series Report #27: Rural non-point source pollution and control, prepared for the Grand River Implementation Committee. Ontario Ministry of the Environment, Toronto, Canada.

United States Department of Agriculture (USDA). 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). Agricultural Research Service, Agriculture Handbook No. 703.

United States Environmental Protection Agency (USEPA). 2000. National Water Quality Inventory – Chapter 2: Rivers and Streams. Available online: http://www.epa.gov/305b/200report/

Watt, W.E., K.W. Lathem, C.R. Neill, T.L. Richards, J. Rousselle (Eds.). 1989. Hydrology of Floods in Canada: A Guide to Planning and Design. National Research Council Canada, Associate Committee on Hydrology.