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National Agri-Environmental Standards Initiative (NAESI)

Report No. 4-16

Non-Point Source Modelling and Scenario Gaming of the Raisin River Watershed

Technical Series 2008

Photos:
Bottom Left- clockwise
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Crop spraying: Corel CD photo # 95C2840
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NON-POINT SOURCE MODELLING AND SCENARIO GAMING OF THE RAISIN RIVER WATERSHED.

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NOTE TO READERS

The National Agri-Environmental Standards Initiative (NAESI) is a four-year (2004-2008) project between Environment Canada (EC) and Agriculture and Agri-Food Canada (AAFC) and is one of many initiatives under AAFC's Agriculture Policy Framework (APF). The goals of the National Agri-Environmental Standards Initiative include:

- Establishing non-regulatory national environmental performance standards (with regional application) that support common EC and AAFC goals for the environment
- Evaluating standards attainable by environmentally-beneficial agricultural production and management practices; and
- Increasing understanding of relationships between agriculture and the environment.

Under NAESI, agri-environmental performance standards (i.e., outcome-based standards) will be established that identify both desired levels of environmental condition and levels considered achievable based on available technology and practice. These standards will be integrated by AAFC into beneficial agricultural management systems and practices to help reduce environmental risks. Additionally, these will provide benefits to the health and supply of water, health of soils, health of air and the atmosphere; and ensure compatibility between biodiversity and agriculture. Standards are being developed in four thematic areas: Air, Biodiversity, Pesticides, and Water. Outcomes from NAESI will contribute to the APF goals of improved stewardship by agricultural producers of land, water, air and biodiversity and increased Canadian and international confidence that food from the Canadian agriculture and food sector is being produced in a safe and environmentally sound manner.

The development of agri-environmental performance standards involves science-based assessments of relative risk and the determination of desired environmental quality. As such, the National Agri-Environmental Standards Initiative (NAESI) Technical Series is dedicated to the consolidation and dissemination of the scientific knowledge, information, and tools produced through this program that will be used by Environment Canada as the scientific basis for the development and delivery of environmental performance standards. Reports in the Technical Series are available in the language (English or French) in which they were originally prepared and represent theme-specific deliverables. As the intention of this series is to provide an easily navigable and consolidated means of reporting on NAESI's yearly activities and progress, the detailed findings summarized in this series may, in fact, be published elsewhere, for example, as scientific papers in peer-reviewed journals.

This report provides scientific information to partially fulfill deliverables under the Biodiversity Theme of NAESI. This report was written by I. Wong, B. Booty, G. Benoy, C. Nielsen, P. Fong, and C. McCrimmon of Environment Canada. The report was edited and formatted by Denise Davy to meet the criteria of the NAESI Technical Series. The information in this document is current as of when the document was originally prepared. For additional information regarding this publication, please contact:

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NOTE À L’INTENTION DES LECTEURS

L’Initiative nationale d’élaboration de normes agroenvironnementales (INENA) est un projet de quatre ans (2004-2008) mené conjointement par Environnement Canada (EC) et Agriculture et Agroalimentaire Canada (AAC) et l’une des nombreuses initiatives qui s’inscrit dans le Cadre stratégique pour l’agriculture (CSA) d’AAC. Elle a notamment comme objectifs :

- d’établir des normes nationales de rendement environnemental non réglementaires (applicables dans les régions) qui soutiennent les objectifs communs d’EC et d’AAC en ce qui concerne l’environnement;
- d’évaluer des normes qui sont réalisables par des pratiques de production et de gestion agricoles avantageuses pour l’environnement;
- de faire mieux comprendre les liens entre l’agriculture et l’environnement.

Dans le cadre de l’INENA, des normes de rendement agroenvironnementales (c.-à-d. des normes axées sur les résultats) seront établies pour déterminer les niveaux de qualité environnementale souhaités et les niveaux considérés comme réalisables au moyen des meilleures technologies et pratiques disponibles. AAC intégrera ces normes dans des systèmes et pratiques de gestion bénéfiques en agriculture afin d’aider à réduire les risques pour l’environnement. De plus, elles amélioreront l’approvisionnement en eau et la qualité de celle-ci, la qualité des sols et celle de l’air et de l’atmosphère, et assureront la compatibilité entre la biodiversité et l’agriculture. Des normes sont en voie d’être élaborées dans quatre domaines thématiques : l’air, la biodiversité, les pesticides et l’eau. Les résultats de l’INENA contribueront aux objectifs du CSA, soit d’améliorer la gérance des terres, de l’eau, de l’air et de la biodiversité par les producteurs agricoles et d’accroître la confiance du Canada et d’autres pays dans le fait que les aliments produits par les agriculteurs et le secteur de l’alimentation du Canada le sont d’une manière sécuritaire et soucieuse de l’environnement.

L’élaboration de normes de rendement agroenvironnementales comporte des évaluations scientifiques des risques relatifs et la détermination de la qualité environnementale souhaitée. Comme telle, la Série technique de l’INENA vise à regrouper et diffuser les connaissances, les informations et les outils scientifiques qui sont produits grâce à ce programme et dont Environnement Canada se servira comme fondement scientifique afin d’élaborer et de transmettre des normes de rendement environnemental. Les rapports compris dans la Série technique sont disponibles dans la langue (français ou anglais) dans laquelle ils ont été rédigés au départ et constituent des réalisations attendues propres à un thème en particulier. Comme cette série a pour objectif de fournir un moyen intégré et facile à consulter de faire rapport sur les activités et les progrès réalisés durant l’année dans le cadre de l’INENA, les conclusions détaillées qui sont résumées dans la série peuvent, en fait, être publiées ailleurs comme sous forme d’articles scientifiques de journaux soumis à l’évaluation par les pairs.

Le présent rapport fournit des données scientifiques afin de produire en partie les réalisations attendues pour le thème de la biodiversité dans le cadre de l’INENA. Ce rapport a été rédigé par I. Wong, B. Booty, G. Benoy, C. Nielsen, P. Fong, and C. McCrimmon d’Environnement Canada. De plus, il a été révisé et formaté par Denise Davy selon les critères établis pour la Série technique de l’INENA. L’information contenue dans ce document était à jour au moment de sa rédaction. Pour plus de renseignements sur cette publication, veuillez communiquer avec l’organisme suivant :

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A modelling and scenario gaming approach was developed to assess the integration of land and water in the National Agri-Environmental Standards Initiative (NAESI) Biodiversity Theme. The Raisin River watershed was used as a pilot study. Six land use scenarios were created by the NAESI Biodiversity Theme based on biodiversity standards and include the potential natural vegetation (PNV), the ideal biodiversity (Ideal), the realistic biodiversity (Real), the current (Current), the agricultural intensification with limited biodiversity conservation (AgBio) and agricultural intensification with no conservation (AgNoCon) scenarios. Two non-point source models, AGNPS V5.0 and SWAT 2005, are used to evaluate the various land use scenarios and their impact on water quality, specifically the sediment and nutrients. The NAESI Land and Water Integration Decision Support System (LWIDSS) was created to assist in the evaluation processes. These processes include visualization of model results, scenario comparison, thematic mapping, visualization of model inputs, sensitivity analysis and pollutant source tracing. Because of its flexible design, the LWIDSS can be applied to other watersheds if sufficient data is available.

The key inputs of the two models include current land cover layer, precipitation, soil texture and digital elevation model data. Flow and water quality data are used to calibrate and validate the models. For SWAT, the calibration of the monthly flow for the Raisin River watershed at Williamstown from 1985 to 1994 resulted in a Nash-Sutcliffe Simulation Efficiency (NSE) and correlation coefficient (r) of 0.84 and 0.93, respectively. Similarly, the validation for the period from 1995 to 2004 show the NSE and r are 0.86 and 0.93, respectively. The observed and predicted sediment (TSS) means are 2.69 mg/L and 2.68 mg/L, respectively and the standard deviations of the observed and predicted values are 1.71 mg/L and 1.49 mg/L. As for total

nitrogen (TN), the NSE and r for the calibration period are 0.71 and 0.87, respectively. The model predictions are consistent with the observed values. The NSE and r for the validation period are 0.59 and 0.82, respectively. The model predictions of TN load also show good statistics during the validation phase. Finally, total phosphorus (TP) calibration resulted in an NSE and r of 0.44 and 0.81, respectively. The NSE and r for the validation period are 0.20 and 0.75, respectively.

The sediment data of the Raisin River watershed is limited in quantity and poor in quality. The sediment data constraints impacted the quality of the nutrients modelling results as the nutrients modelling is dependent upon the quality of the sediment modelling. For AGNPS, the average relative difference between the predicted and observed peak flows for thirteen events is 5.7%, which indicates the model results are good when compared to the observed data. For sediment and nutrients, it is difficult to validate the AGNPS results because samples were not taken at the peak flow periods.

With regards to scenario comparisons, AGNPS and SWAT yield similar results. Both models predict the lowest TSS, TN and TP for the PNV scenario followed by increasing values, in order, for the Ideal, Real, Current, AgBio and AgNoCon scenarios. As agricultural activities increase, the TSS, TN and TP increase, and vice versa. It is observed that the results of the AgBio and AgNoCon scenarios are very similar. This is due to the two models being applied at a watershed scale in this study. The land cover class rollup in both scenarios are very similar.

Pollutant sources can be tracked using AGNPS. The heavy rainfall event of September 8, 2004 was simulated and the sediment pollutant sources were tracked. It was found that most of the source regions occur near the outlet along either side of the main branch of the Raisin River. By applying modelling techniques to change the land cover type in SWAT, it is found that a 5 m filter strip provides the most optimal reduction in both sediment and nutrients at the outlet. This technique is useful and can help decision makers properly address these vulnerable areas.

When comparing the simulated results with the proposed ideal performance standards (IPS) of sediment and nutrients, it is found that TSS and TP for the Raisin River watershed are generally within the IPS guidelines but TN results are above the IPS. One possibility is that the soils in the Raisin River watershed have naturally high TN levels. Another possibility is that the high TN levels may be the result of long term over fertilization of crops.

1 INTRODUCTION

1.1 NAESI Background

Under Agriculture and Agri-Food Canada's (AAFC) Agriculture Policy Framework (APF), Environment Canada (EC) has committed to the development of environmental performance standards that will guide environmentally sustainable agricultural practices and management in support of common EC and AAFC goals for the environment. This standards development program is known as the National Agri-Environmental Standards Initiative (NAESI) and it consists of four themes: Air, Biodiversity, Pesticides, and Water. Standards developed within these themes will be non-regulatory quantitative or qualitative measures of desired environmental performance. In general, two different levels of performance standards are being developed: Ideal Performance Standards (IPS) specify the level of environmental quality necessary to maintain desired ecosystem integrity and Achievable Performance Standards (APS) specify the level of environmental quality that can be achieved using recommended, best available processes and technologies.

1.2 Land and Water Integration Project Background

Agricultural activities such as animal farming, grazing, plowing, pesticide spraying, irrigation and fertilizer applications can cause non-point source or diffuse pollution. Nutrients and sediment are two of the main agricultural pollutants affecting water quality that result from these activities. Nutrients such as phosphorus and nitrogen are minerals that can be applied to enhance plant growth and crop production. When they are applied in excess of crop needs, the excess nutrients are often attached to soil particles that can be carried by overland water runoff from land into the aquatic ecosystems. The nutrients can cause excessive algae and aquatic plant growth in rivers and streams; cloud the water; reduce the amount of sunlight reaching aquatic plants; cover fish spawning areas and food supplies; greatly increase the costs of water treatment; reduce swimming and water recreation activities; create a bad smell; kill fish; and accelerate aging of rivers and lakes. Besides fisheries and recreation effects, these pollutants also have harmful effects on drinking water supplies and wildlife. For example, high concentrations of nitrate in drinking water can cause newborns with a particular cyanotic condition called methemoglobinemia that is potentially fatal.

This project focuses on an important linkage between the NAESI Biodiversity and Water themes. For the Biodiversity Theme, performance standards for floral and faunal communities in terrestrial ecosystems are based on assessments and forecasts of land cover and land use in agricultural regions. For the Water Theme, performance standards for aquatic community structure in streams are based on assessments and forecasts of flow regime, sediment levels and nutrient concentrations. However, the physico-chemical condition of a stream is strongly affected by catchment characteristics, including land cover and land use, but also by basin shape, surficial geology and soil structure. Thus, land cover and land use patterns defined by the Biodiversity Theme to conserve terrestrial biodiversity will have profound impacts on both water quantity and quality, and aquatic biodiversity.

This project is also intended to ensure coherency in the development of standards by reconciling and integrating modeling approaches adopted by the Biodiversity and Water themes (and, potentially, by the Pesticides Theme). Scenario-based simulation modeling represents an approach by which performance standards can be developed in the absence of suitable or sufficient empirical data. For this project, the modeling involves examination of the impacts of habitat based standards (expressed as land cover and land use patterns) developed by the Biodiversity Theme on aquatic ecosystems. It also builds on ongoing NAESI Water Theme standards modeling work that is developing achievable performance standards for flow regimes, sediment levels and nutrient concentrations as a function of beneficial management practice (BMP) efficacy.

Six scenarios have been defined by the Biodiversity Theme to develop terrestrial biodiversity standards; the same scenarios will be integrated with watershed hydrology models to develop flow, sediment and nutrient performance standards in streams to protect aquatic biodiversity. In addition to maintenance of the status quo ("Current"), there are two scenarios that should result in improved environmental performance ("ideal" and "realistic"), two scenarios that consider greater agricultural intensification ("AgBio" with limited and "AgNoCon" without conservation practices) and a potential natural vegetation ("PNV") scenario. Differences between scenarios are primarily driven by the allocation of land to row cropping and the extent of woodlots and riparian zones. Validated and calibrated hydrologic models use these scenarios to estimate water quantity and quality parameters. These parameters are then used to forecast aquatic biodiversity according to empirically-derived relationships between flow, sediment and nutrient regimes and biotic condition. Benthic algal and invertebrate communities, as well as fish communities, function as the biotic endpoints of streams and rivers to gauge ecosystem integrity.

2 STUDY AREA

Previous studies indicate that contributions of sediment and nutrients by non-point sources such as agricultural activities are significant in the Eastern Ontario Model Forest (EOMF), one of the pilot study areas of the NAESI Biodiversity Theme. The Raisin River Watershed within the Raisin Region Conservation Authority (RRCA) has been selected to be the study area to understand the impact assessment of land and water integration, in particular to hydrology, sediment and nutrients (nitrogen and phosphorous). The rationale of the selection is that the

Raisin River watershed is highly agricultural, and the size of the drainage basin is suitable for non-point source (NPS) modelling.

The following description of the RRCA is extracted from the RRCA official website (RRCA, http://www.rrca.on.ca/) (RRCA, 2006). The RRCA encompasses an area of 1,680 square kilometers in Eastern Ontario and has jurisdiction over the Raisin, South Raisin, North Raisin, Beaudette and Delisle River basins in addition to a number of tributaries draining into the St. Lawrence River. Figure 1 illustrates the jurisdiction of the RRCA. The City of Cornwall is the largest populated urban area within the RRCA with a population of about 46,000 people and the total population within the RRCA is approximately 82,000 people. Although the demand for residential housing is on the rise with urban expansion and the public desire for rural living, agriculture remains the single major economic driver for the region.

Figure 1: Raisin Region Conservation Authority Jurisdiction [Source: RRCA website, http://www.rrca.on.ca/ (RRCA, 2006)]

Figure 2 illustrates the Raisin River watershed. This watershed encompasses the municipalities of North and South Glengarry, North and South Stormont, and the City of Cornwall. The Raisin River has a main branch (Figure 3), a south branch (Figure 4) and a north branch (Figure 5) totaling 809 km of streams of which 19 km flow through public lands. The total drainage of Raisin River watershed is about 58,000 ha with agriculture as its major land use. Soil along the Raisin River main branch is mostly clay loam and loam. The South Raisin River soils consist of silt loam, sandy loam, clay loam and even very fine sandy loam. The North Raisin River has some clay loam and sandy loam. In terms of woodlot size, of the 1577 stands in the Raisin River watershed, the largest is 1441 ha in size and the average size is 16.1 ha. About 68% and 33% of stream lengths have riparian cover on public and private land, respectively. The Raisin River is a sixth order stream system with 83% of the waterway classified as first through third order (i.e., headwater) streams. The Raisin River Watershed outlet is shown in Figure 6.

Figure 2: Raisin River Watershed [Source: RRCA website, http://www.rrca.on.ca/ (RRCA, 2006)]

Figure 3: Raisin River – Main Branch [Source: RRCA]

Figure 4: Raisin River – South Branch [Source: RRCA]

Figure 5: Raisin River - North Branch at Martintown [Source: RRCA]

Figure 6: Raisin River Watershed Outlet [Source: RRCA]

3 NON-POINT SOURCE MODELLING FOR RAISIN RIVER WATERSHED

This study focuses on the non-point source pollutants since they are the major contributor from agricultural activities. Non-point source pollution is often difficult to detect because of the intermittent releases of pollutants over large areas. This type of pollutant enters the receiving water body diffusely at intermittent rates corresponding to the occurrence of meteorological events. The correlation between the pollutant loading and rainfall event has been identified by Novotny and Chesters (1981). Geographic, geological, land cover conditions, infiltration, storage characteristics of the basin, soil permeability and other hydrological parameters all affect the transportation of non-point source pollutants. One important factor in studying non-point source pollution is the type of activities occurring on the land. Thus, non-point source pollution is heavily linked to land use. It should be noted that the hydrological, physical and chemical processes vary among land use categories and activities. In terms of agricultural issues, the entrainment, transport, and fate of sediment, nutrients (mainly N and P), and pesticides are largely influenced by the amount of water and the rate of water transport through and across the soil surface where precipitation, infiltration and surface runoff play major roles.

There are two basic approaches in modelling non-point source pollution. They are the so-called lumped-parameter models and the distributed-parameter concept models. The lumped-parameter models use the concept of homogeneous areas (i.e., it lumps the areas which exhibit similar characteristics together). This approach often uses the average to roll up to larger areas and the final form and magnitude of the parameters are often simplified to represent the model unit as a uniform system. Its limitation is that all homogeneous parameters and variables represent average values over the entire watershed. To overcome this, distributed models have been developed and introduced. The distributed approach divides the watershed into smaller homogeneous units and aggregates the results. These models often require larger computer power and storage because of their complexity and over-arching input/output requirements. In order to perform the modelling exercise effectively, much effort is spent on achieving the optimal grid size. One common factor for grouping and selecting grid size is based on the land cover type. To maintain a manageable grid size, in most cases, the assumption of uniformity is often violated. The hydrologic response unit is calculated by pro-weighting the parameter values in relation to land cover type. Thus, the land cover layer often dictates the grid size used in these types of models. Because these models deal with the spatial aspect, they are more superior to lumped-parameter models and provide results spatially. Some of these distributed models are event-based and some are continuous (time dependent). Because of their complexity, they require significant effort on model calibration and validation. In many cases, calibration can be difficult given that the runoff and water quality data are collected at only a few stations across the watershed.

Using the modelling approach to understand the non-point source pollutant problem is important for providing the assessment of the impacts of land-water integration. In addition, implementing a scenario gaming approach would allow decision makers an opportunity to understand the problem based on different possible scenarios and to make viable decisions to manage the problem more effectively and minimize the impacts.

The modelling survey report (Storey et al., 2006) identifies a number of candidate models that can be used in this study. Given the constraints of Canadian conditions and available data, some of these data intensive models are not suitable for this work. Based on the research of the report, the SWAT model and the AGNPS model were selected for this study. Both of these models are of the distributed-parameter type. The SWAT model is used for the continuous case whereas the AGNPS model is used for the single event case. These two models complement each other since the SWAT model can be used to evaluate the long term impact, while the AGNPS model can be used to examine the extreme wet storm events.

3.1 Soil and Water Assessment Tool (SWAT)

SWAT is the acronym for Soil and Water Assessment Tool, which is a river basin or watershed scale model developed for the USDA Agricultural Research Service (Arnold et al., 1998). SWAT Version 2005, the latest version of SWAT, is used in this study. SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc., are directly modeled by SWAT using this input data.

SWAT is a continuous time model (i.e., a long-term yield model). The model is not designed to simulate detailed, single-event flood routing. It is a process-based model that uses the CREAMS algorithms combined with the erosion (MUSLE) and groundwater/subsurface (GLEAMS) equations for estimating hydrology and water quality (primarily sediment, nutrients and pesticides). The model requires the studied watershed to be partitioned into homogenous hydrologic response units (HRU), (i.e., similar in soils, slope and land use). SWAT simulates hydrology, pesticide and nutrient cycling, bacteria transport, erosion and sediment transport. It uses a daily time step for simulations running from 1 to 100 years. An ArcView interface enables extraction of input parameters and provides visualization of model results.

In summary, SWAT is capable of predicting and assessing the impact of management on water, sediment and nutrients. It is a time continuous and physically based, distributed model that is designed to simulate water, sediment, and agricultural chemical transport on a watershed scale. It incorporates some of the previously developed models such as SWRRB, CREAMS, GLEAMS, EPIC and ROTO to predict the long term impact of different management scenarios and/or climate changes on watershed scale hydrology and non-point source pollution, mainly contributed by agricultural activities. It represents the full hydrological cycle that consists of interception, evapotranspiration, surface runoff, infiltration, soil percolation, lateral flow, groundwater flow, channel routing and snow melt processes. This model has been used and validated in many areas of the world especially in the United States. The major shortcomings of the SWAT model are the huge overheads in calibration and validation, and inherent problems when applied to regions with a large snowmelt and frozen ground component because of its simplistic snowmelt algorithms.

3.2 Agricultural Non-Point Source (AGNPS)

The Agricultural Non-Point Source (AGNPS) model (Young et al., 1986) is a distributed event-based model that simulates agricultural watersheds for a single storm event assuming uniform precipitation patterns. For this study, AGNPS Version 5 is used in conjunction with the ROS/AGNPS Interface version 2.1. AGNPS simulates surface runoff, sediment, and nutrient transport (nitrogen and phosphorus), primarily from agricultural watersheds. The nutrients nitrogen (N) and phosphorus (P) are essential for plant growth but contribute to surface water pollution if they find their way into the water body. Watersheds modelled by AGNPS must be divided into homogenous square working areas called cells. The hydrology in the model is calculated by the Soil Conservation Service (SCS) curve number approach. With this method, the infiltration is calculated simply by subtracting the runoff from the amount of rainfall with the runoff being calculated using the SCS curve numbers for each cell.

The Universal Soil Loss Equation (USLE) is used for predicting soil erosion for five different particle sizes (sand, silt, clay, small and large aggregates). The AGNPS model simulates the soil loss and sediment yield in a two-step process. First, the soil erosion is calculated and then compared to the sediment transport capacity of the flow. The eroded sediment is then routed based on a steady-state continuity equation for sediment transport and deposition described by Foster et al. (1980). Among the factors in the USLE, the soil erodibility factor is a measure of potential erosion of the soil and is a function of the soil texture; the vegetative cover factor estimates the effect of ground cover conditions and accounts for the effect of vegetation and land management on erosion rates resulting from canopy protection (reduction of rainfall energy effect).

The pollutant transport part of the model estimates transport of nitrogen, phosphorous and chemical oxygen demand (COD) throughout the watershed. It is divided into one part handling soluble pollutants and another part for sediment based pollutants. The methods used to predict nitrogen and phosphorus yields were developed by Frere et al. (1980).

As in most non-point source pollution models, the equations are based on the CREAMS model (Knisel, 1980). The nitrogen and phosphorus estimates are performed using relationships between chemical concentration, sediment yield and runoff volume. Soluble nitrogen and phosphorus in runoff waters represent the effects of rainfall, fertilization, solid waste and leaching from the soil in each cell. The contributions of soluble nutrients from each cell are calculated first within the cell and routed downstream. Once soluble nutrients reach concentrated flow, they are assumed to remain as constants. That is, the amount arriving in the overland flow from any particular cell is simply added to what is already present in the channel, with no losses of soluble nutrients allowed, except for the nutrient decay within the cell.

Sensitivity analyses have been carried out on the model and it has been calibrated and validated for Southern Ontario watersheds (Leon et al., 2004). It has also been extensively used by numerous Ontario Conservation Authorities as well as in other parts of Canada such as the Rocky Mountains of British Columbia. Calibration of the model requires very little effort as only a very small number of parameters (3-4) need to be adjusted once the model has been set up.

The main advantage of using the AGNPS model is that it is a robust model that has been successfully applied in many jurisdictions in the United States and Canada (Mostaghimi et al., 1997 and Leon et al., 2004). Since it has been applied successfully in Ontario, therefore it is an excellent choice for this study where the Raisin River watershed is in Eastern Ontario. When limited observed data is available, it makes sense to compare different scenarios on a relative basis. The AGNPS model excels in this arena. The goal is to evaluate the impact of different land cover scenarios as compared to the Current land cover scenario, on a relative sense. The other significant advantage in using the AGNPS model is that it has the capability to provide source tracing. This feature provides useful information to pinpoint the “hot spots” that requires management attention.

4 MODEL INPUT DATA FOR THE RAISIN RIVER WATERSHED

In this section, the model input requirements for both AGNPS and SWAT are discussed. Some of the inputs are similar or the same and others are different.

4.1 General Data Requirements

There are two types of data for the AGNPS model. Namely, they are watershed and grid data. Watershed data includes information for the entire watershed in the simulation. Examples of watershed data are size, number of grid cells, precipitation, duration of storm and storm intensity. Grid data includes information on values based on land cover, soil texture, topography and management practices within each grid cell. The Raisin River sub-watershed is divided into uniform grids in the AGNPS model. For each grid cell, inputs from geographical information system (GIS) mapping of land cover, soil and topography (digital elevation model) are automatically extracted. The size of each grid cell in this study is 1 x 1 kilometre.

SWAT 2005 is a comprehensive model that requires a diversity of information in order to run. The input data consists of both spatial data and non-spatial data. The mandatory spatial data includes the Digital Elevation Model, land cover or land use map layer and soil map layer. Key non-spatial data include Soil texture data (e.g., percentage of clay, silt and sand), land use and soil look up tables.

4.2 Precipitation Data (AGNPS and SWAT)

There are four rain gauges in the vicinity of the Raisin River watershed but none of them is located inside the watershed. These include Cornwall Ontario, Avonmore Ontario and Moose Creek (hourly) and Dalhousie Mills. Figure 7 shows the locations of these rain gauges. In the absence of a rain gauge inside the watershed, we were forced to use approximate values from these four rain gauges. Figure 8 shows the precipitation data for these four stations where Cornwall and Avonmore rain gauges have the most data available. All four rain gauge stations were used in SWAT.

Figure 7: Locations of rain gauge stations near the Raisin River watershed

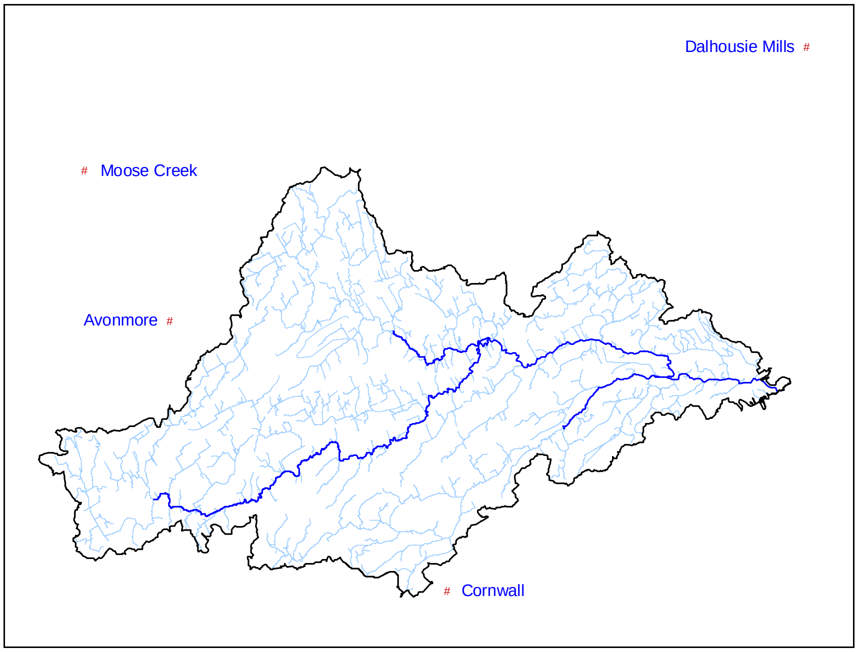
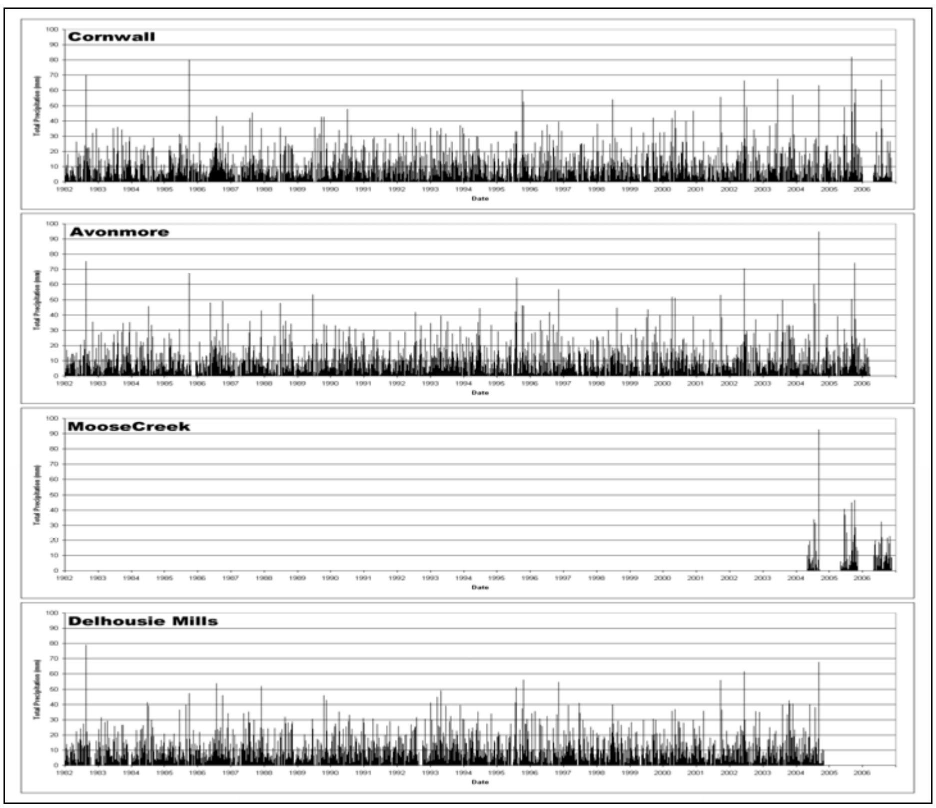


Figure 8: Precipitation Data for the four rain gauges near the Raisin River watershed



The AGNPS model was developed, tested and validated based on medium to large sized storm events. Therefore, median to large sized storm events in the Raisin River watershed were selected for this study. A total of thirteen storm events are chosen for this study. The general watershed data of these thirteen selected storm events is listed in Table 1.

Table 1: General Watershed Input data for Selected Events for AGNPS

Event (Date)	# Total Cells	Area base cell (ha)	Precipitation (mm)	Duration (hrs)	Energy intensity	Nitrogen in rain (mg/L)
Jun 8, 1987	3524	16	43	48	2.22	1
Jul 24, 1987	3524	16	84	48	9.83	1
Jun 16, 1993	3524	16	29	24	3.31	1
Jun 6, 1994	3524	16	43	48	2.25	1
Oct 21, 1995	3524	16	56	24	48.53	1
Mar 23, 1999	3524	16	34	48	13.31	1
Mar 27, 2000	3524	16	33	48	1.22	1
Jun 10, 2002	3524	16	78	48	42.18	1
Jun 14, 2002	3524	16	42	72	9.31	1
May 24, 2003	3524	16	50	72	2.29	1
Oct 26, 2003	3524	16	81	96	13.75	1
Sep 8, 2004	3524	16	81	24	59.77	1
Jun 16, 2005	3524	16	42	48	4.80	1

4.3 Current Land Cover Data

The current land cover data was generated by Spatial Works and is maintained by EOMF for the NAESI Biodiversity Theme. There are also other land cover data representing different scenarios and the discussion of these land cover layers will be discussed in the scenario section. The land cover layer was originally generated as an ESRI grid and has subsequently been converted to a polygon shapefile. The shapefile is a polygon representation of the grid layer for applications where grid data cannot be used. The data should be used in grid format (or exported raster format) wherever possible as this is the source data. Table 2 shows the breakdown of land use categories of the Raisin River watershed in percent area. Agriculture is the most dominant land use within the Raisin River watershed. Specifically, 10.98% of the area is for row crops, 21.29% of area is for hay and pasture, 6.96% is for cereal, 1.36% is for alfalfa and 2.37% for other intensive agricultural products such as orchard and horticulture.

These classes are further aggregated into AGNPS land cover classes to make the land cover map layer compatible with the AGNPS model. For the parameters that depend on the land cover information, a weighting mechanism is applied to calculate the land cover characteristics of each grid cell from a lookup table. The mechanism begins with extracting the land cover layer information for the intersection with every grid cell in the grid file, and then calculating the area for each attribute and its percentage with respect to the total area of the cell. This percentage is then used to retrieve the values for the selected field in the lookup table and calculate the value weight for the grid cell. Table 2 shows the lookup table for the land cover information. Similar roll up from the NAESI land cover classes to the SWAT land cover classes is also presented in Table 2.

Table 2: Current Land Cover Map Layer Descriptions

Detailed NAESI Class	AGNPS	SWAT	Percent Area
Ecosite FOC1 - Dry-Fresh Pine Coniferous Forest	Woods (dense)	Forest-Evergreen	0.02%
Ecosite FOC2 - Dry-Fresh Cedar Coniferous Forest	Woods (dense)	Forest-Evergreen	1.89%
Ecosite FOC3 - Fresh-Moist Hemlock Coniferous Forest	Woods (dense)	Forest-Evergreen	
Ecosite FOC4 - Fresh-Moist White Cedar Coniferous Forest	Woods (dense)	Forest-Evergreen	2.20%
Ecosite FOM1 - Dry Oak-Pine Mixed Forest	Woods (dense)	Forest-Mixed	
Ecosite FOM2 - Dry-Fresh White Pine-Maple-Oak Mixed Forest	Woods (dense)	Forest-Mixed	0.03%
Ecosite FOM3 - Dry-Fresh Hardwood-Hemlock Mixed Forest	Woods (dense)	Forest-Mixed	

Table 2: Current Land Cover Map Layer Descriptions

Detailed NAESI Class	**AGNPS**	**SWAT**	**Percent Area**
Ecosite FOM4 - Dry-Fresh White Cedar Mixed Forest	Woods (dense)	Forest-Mixed	0.48%
Ecosite FOM5 - Dry-Fresh White Birch-Poplar-Conifer Mixed Forest	Woods (dense)	Forest-Mixed	0.01%
Ecosite FOM6 - Fresh-Moist Hemlock Mixed Forest	Woods (dense)	Forest-Mixed	0.04%
Ecosite FOM7 - Fresh-Moist White Cedar-Hardwood Mixed Forest	Woods (dense)	Forest-Mixed	2.04%
Ecosite FOM8 - Fresh-Moist Poplar-White Birch Mixed Forest	Woods (dense)	Forest-Mixed	
Ecosite FOD1 - Dry-Fresh Oak Deciduous Forest	Woods (dense)	Forest-Deciduous	
Ecosite FOD2 - Dry-Fresh Oak-Maple-Hickory Deciduous Forest	Woods (dense)	Forest-Deciduous	
Ecosite FOD3 - Dry-Fresh Poplar-White Birch Deciduous Forest	Woods (dense)	Forest-Deciduous	0.91%
Ecosite FOD4 - Dry-Fresh Deciduous Forest	Woods (dense)	Forest-Deciduous	0.61%
Ecosite FOD5 - Dry-Fresh Sugar Maple Deciduous Forest	Woods (dense)	Forest-Deciduous	4.35%
Ecosite FOD6 - Fresh-Moist Sugar Maple Deciduous Forest	Woods (dense)	Forest-Deciduous	2.27%
Ecosite FOD7 - Fresh-Moist Lowland Deciduous Forest	Woods (dense)	Forest-Deciduous	1.66%
Ecosite FOD8 - Fresh-Moist Poplar-Sassafras Deciduous Forest	Woods (dense)	Forest-Deciduous	2.28%
Ecosite SWC1 - White Cedar Mineral Coniferous Swamp	Wetland	Wetlands-Forested	0.84%
Ecosite SWC2 - White Pine-Hemlock Mineral Coniferous Swamp	Wetland	Wetlands-Forested	0.06%
Ecosite SWC3 - White Cedar Organic Coniferous Swamp	Wetland	Wetlands-Forested	0.07%
Ecosite SWC4 - Tamarack-Black Spruce Organic Coniferous Swamp	Wetland	Wetlands-Forested	0.25%
Ecosite SWM1 - White Cedar Mineral Mixed Swamp	Wetland	Wetlands-Forested	1.26%
Ecosite SWM2 - Maple Mineral Mixed Swamp	Wetland	Wetlands-Forested	0.27%
Ecosite SWM3 - Birch-Poplar Mineral Mixed Swamp	Wetland	Wetlands-Forested	0.07%
Ecosite SWM4 - White Cedar Organic Mixed Swamp	Wetland	Wetlands-Forested	0.03%

Table 2: Current Land Cover Map Layer Descriptions

Detailed NAESI Class	AGNPS	SWAT	Percent Area
Ecosite SWM5 - Maple Organic Mixed Swamp	Wetland	Wetlands-Forested	0.02%
Ecosite SWM6 - Birch-Poplar Organic Mixed Swamp	Wetland	Wetlands-Forested	
Ecosite SWD1 - Oak Mineral Deciduous Swamp	Wetland	Wetlands-Forested	
Ecosite SWD2 - Ash Mineral Deciduous Swamp	Wetland	Wetlands-Forested	2.06%
Ecosite SWD3 - Maple Mineral Deciduous Swamp	Wetland	Wetlands-Forested	9.17%
Ecosite SWD4 - Mineral Deciduous Swamp	Wetland	Wetlands-Forested	2.36%
Ecosite SWD5 - Ash Organic Deciduous Swamp	Wetland	Wetlands-Forested	0.19%
Ecosite SWD6 - Maple Organic Deciduous Swamp	Wetland	Wetlands-Forested	0.80%
Ecosite SWD7 - Birch-Poplar Organic Deciduous Swamp	Wetland	Wetlands-Forested	0.02%
Fens	Wetland	Wetlands-Non-Forested	
Bogs	Wetland	Wetlands-Non-Forested	0.84%
Marshes	Wetland	Wetlands-Forested	0.89%
Thicket Swamp - Mineral	Wetland	Wetlands-Non-Forested	0.64%
Thicket Swamp - Organic	Wetland	Wetlands-Non-Forested	0.44%
Agriculture - Row Crops (Corn soybeans etc.)	Row crops	Agricultural Land-Row Crops	10.98%
Agriculture - Cereals (Wheat, Barley, etc.)	Small grains	Spring Wheat	6.96%
Agriculture - Hay, Pasture	Grass and pasture	Pasture	21.29%
Agriculture - Alfalfa	Short grass	Alfalfa	1.36%
Agriculture - Other intensive (Orchard, horticulture)	Farmsteads	Orchard	2.37%
Coniferous Forest Plantations (Cedar)	Woods (dense)	Forest-Mixed	0.06%
Mixed Forest Plantations	Woods (dense)	Forest-Evergreen	0.04%
Pine Plantation	Woods (dense)	Forest-Evergreen	0.99%

Table 2: Current Land Cover Map Layer Descriptions

Detailed NAESI Class	AGNPS	SWAT	Percent Area
Larch Plantation	Woods (dense)	Forest-Evergreen	0.06%
Spruce Plantation	Woods (dense)	Forest-Evergreen	0.98%
Poplar Plantation	Woods (dense)	Forest-Evergreen	0.65%
Tolerant Hardwood Plantation	Woods (dense)	Forest-Evergreen	0.04%
Cultural Meadow/Thicket stkg < 0.2	Meadow	Meadow Bromegrass	1.63%
Cultural Savannah stkg .2-.3	Short grass	Range-Grasses	0.24%
Cultural Woodland stkg > 3	Woods (dense)	Forest-Evergreen	0.26%
Hedgerows from SOLRIS	High grass	Range-Brush	1.19%
Water (Placeholder, no transition)	Water	Water	
Urban Areas (Placeholder, no transition)	Urban residential	Residential-Medium Density	1.89%
Rock Barren	Topsoil removal	Industrial	0.00%
Sand Barren (Placeholder, no transition)	Gravel and dirt	Industrial	0.61%
Road Right of Way	Street pavement	Transportation	4.35%
Transmission Lines	Fallow field	Transportation	0.64%
Railway	Gravel and dirt	Transportation	0.18%
Rural Developed	Farmsteads	Residential-Low Density	3.01%
Lakes	Water	Water	0.17%
Rivers	Water	Water	0.27%
Streams	Water	Water	0.72%

Both the SWAT and AGNPS models require the classes to be reclassified under their naming convention. Therefore, the NAESI land cover classes are further mapped to the SWAT and AGNPS land cover classes (see Tables 3 and 4). Figures 9 and 10 illustrate the break down in percent area of the current land cover layer for the SWAT and AGNPS models, respectively. Once the land cover layers are defined, their corresponding land cover parameters can then be defined.

Table 3: Percent Area of the Current Land Cover Classes in the SWAT Model

Land Cover Class	Percent Area (SWAT)
Agricultural Land-Row Crops	10.98%
Alfalfa	1.36%
Forest-Deciduous	12.07%
Forest-Mixed	7.14%
Industrial	2.66%
Meadow Bromegrass	1.63%
Orchard	2.37%
Pasture	21.29%
Range-Bush	1.19%
Range-Grasses	0.24%
Residential-Low Density	3.01%
Residential-Medium Density	1.89%
Spring Wheat	6.96%
Transportation	5.17%
Water	1.16%
Wetlands-Forested	16.30%
Wetlands-Non-Forested	3.98%

Table 4: Percent Area of the Current Land Cover Classes used in the AGNPS Model

Land Cover Class	Percent Area (AGNPS)
Fallow Field	0.64%
Farmsteads	5.38%
Grass and pasture	21.29%
Gravel and dirt	0.78%
High grass	1.19%
Meadow	1.63%
Row crops	10.99%
Short grass	1.60%
Small grains	6.96%
Street pavement	4.35%
Topsoil removal	0.00%
Urban residential	1.89%
Water	1.16%
Wetlands	20.28%
Woods (dense)	21.87%

Figure 9: SWAT Current Land Cover Layer

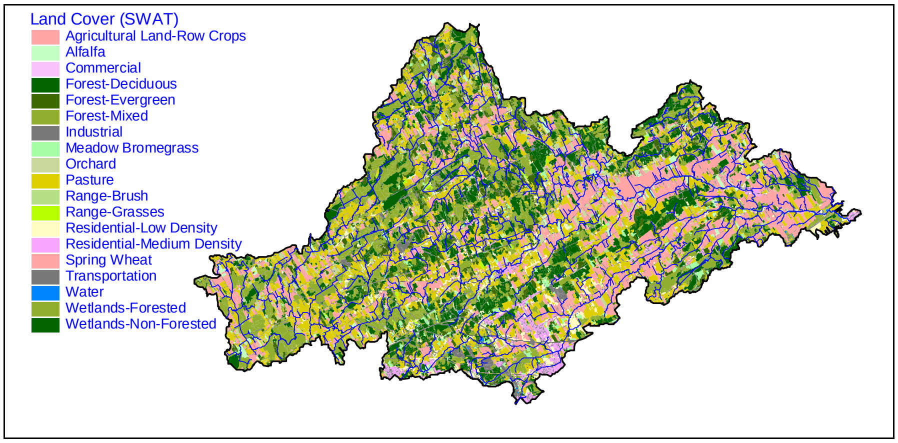
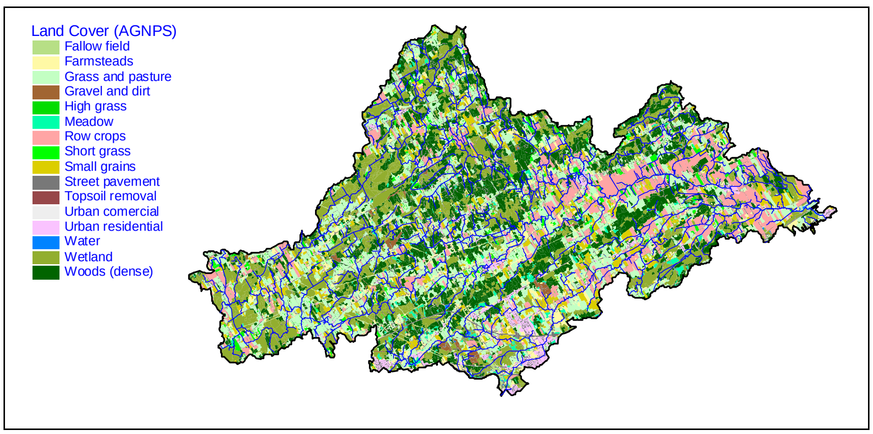


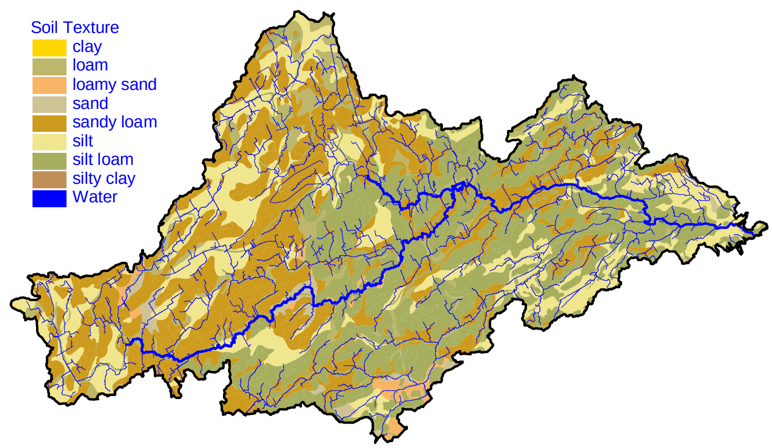
Figure 10: AGNPS Current Land Cover Layer



4.4 Soil Texture Data

Soil along the main river is mostly clay loam and loam with some silt loams, fine sandy loams, and muck interspersed. The North Raisin River drainage area has some clay loam and sandy loam and the South Raisin River has silt loam, sandy loam, clay loam, and very fine sandy loam which all have poor drainage except for one instance of loam with good drainage. Good drainage helps to create a healthier environment for plant growth and to provide drier field conditions so farm equipment can access the farm field throughout the crop production season. Healthy, productive plants have the potential to produce greater yields and more food. It also helps to reduce the year-to-year variability in crop yield, which helps reduce the risks associated with the production of abundant, high quality, affordable food. Improved access of farm equipment to the field provides more time for field activities that can help extend the crop production season, and help reduce crop damage at harvest. To this end, the soil data in the Raison River watershed exhibits a variety of poor to good drainage. Poor drainage causes soil erosion and it reduces land productivity, challenges agricultural sustainability, and degrades water quality and increases sediment. Soil data by county for Ontario compiled by Ontario Ministry of Agriculture, Food, and rural Affairs (OMAFRA) and Agriculture and Agri-Food Canada (AAFC) contains the spatial information of the percentages of clay, sand and silt. This information is then fed into the Soil Texture Triangle formula to compute a corresponding soil texture class. The soil texture classes used in AGNPS includes clay, silt clay, silty clay loam, silt, silt loam, loam, sandy loam, loamy sand, sand, sandy clay loam, sandy clay and clay loam. As in the case of land cover, the same mechanism is used to assign a weighted soil texture value for each grid cell. Figure 11 shows the soil texture layer for the Raisin River Watershed. Both the SWAT and AGNPS models use the same soil texture layer to generate the coefficients of the soil related parameters.

Figure 11: Soil Texture Data for the Raisin River Watershed



4.5 Digital Elevation Model Data

The original Digital Elevation Model (DEM) is a 10 x 10 m grid and it is a product of the Ontario Ministry of Natural Resources (OMNR). The DEM was derived from OMNR Spot data. For the Raisin River watershed the original 10 x 10 m grid was too small for practical use with AGNPS. It was found that re-sampling the 10 x 10 m grid into a 100 x 100 m grid provided effective and satisfactory results in speed and accuracy in the models. In the case of SWAT, the original 10 x 10 m DEM was imported into the pre-processing SWAT ArcView (AVSWAT) interface and a masking polygon was created for the study area to focus only on the Raisin River watershed.

The details of the stream network, and the size and number of the sub-drainage areas are determined by defining the minimum drainage area. Strategic outlet points are added to match the location of monitoring stations which form the basis of comparison between the observed and model simulated flows, sediment and nutrients. An outlet point at the Raisin River watershed outlet was specified to extract useful model results at the outlet where sediment yield is the highest.

The main processes involving the DEM are clipping to the extents of the Raisin River watershed and performing the necessary watershed delineation. There are several tools (i.e., ArcView Extensions, TAR2DEM, etc.) with the capabilities to perform a watershed conditioning process to create depression-less elevation data and calculate flow accumulation values from a DEM. For this study, ArcView was used to clip the DEM to the extents of the Raisin River watershed. TAR2DEM was used to perform the watershed terrain analysis and calculate the drainage network to set up the files for the AGNPS model. For SWAT, we used AVSWAT to do the DEM pre-processing. Figure 12 shows the DEM (elevation & flow accumulation) resulting from the clipping and conditioning process for the AGNPS model. Figure 13 illustrates the watershed delineation by AVSWAT using the DEM data.

Figure 12: Watershed delineation of the Raisin River watershed to be used in the AGNPS Model

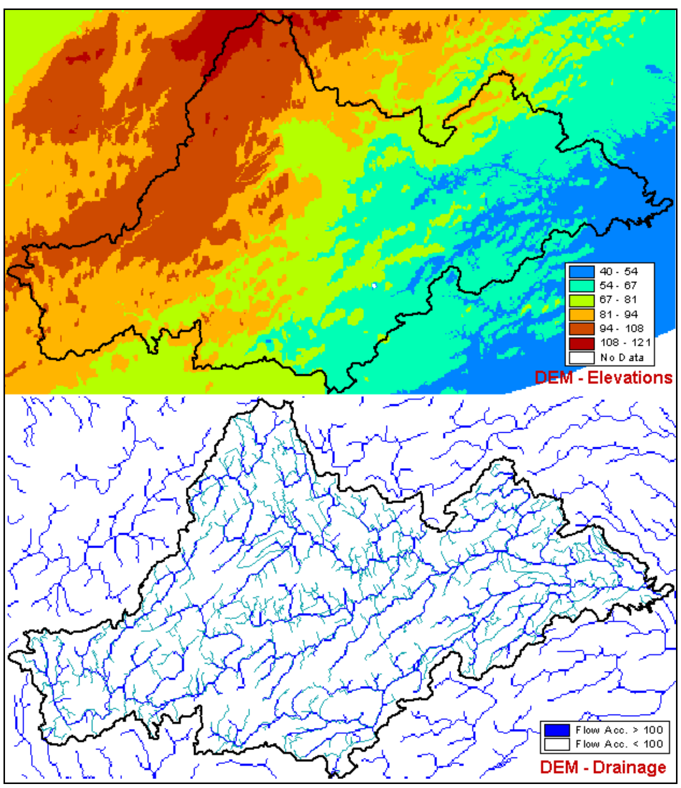


Figure 13: Watershed delineation of the Raisin River watershed to be used in SWAT

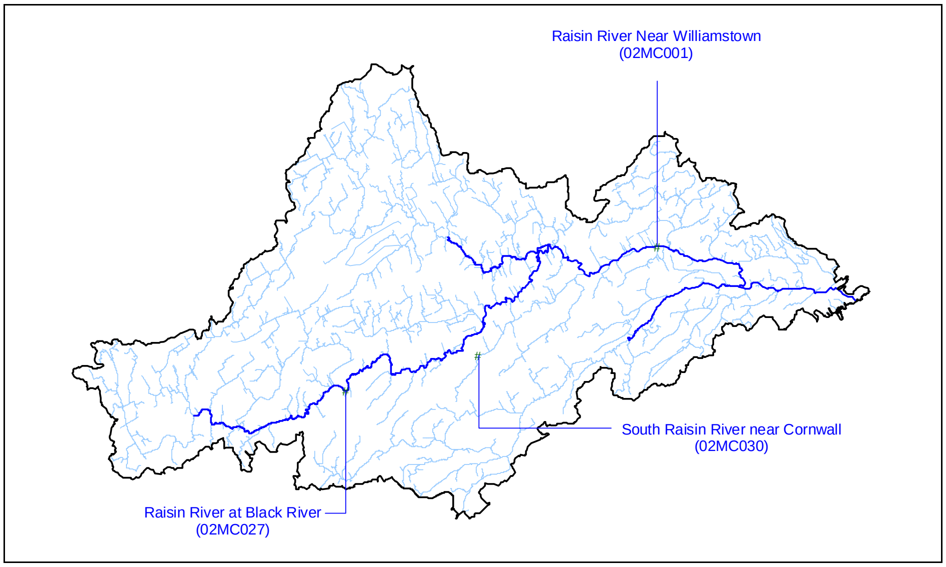
4.6 Flow Data (AGNPS and SWAT)

Three Water Survey of Canada (WSC) stream gauging (hydrometric) stations are located within the Raisin watershed (Figure 14):

- 02MC001, Raisin River near Williamstown,
- 02MC027, Raisin River at Black River,
- 02MC030, South Raisin River near Cornwall.

Of the above three stations, 02MC001 is nearest to the outlet and it is most suitable to be used for calibration and validation purposes. Station 02MC027 only has six years of data so it is not very useful. Station 02MC030 appears to drain only a very small area as it is located in the middle of a SWAT headwater sub-basin so is not useful for calibration purposes.

Figure 14: Locations of flow gages for the Raisin River Watershed



4.7 Water Quality Data (AGNPS and SWAT)

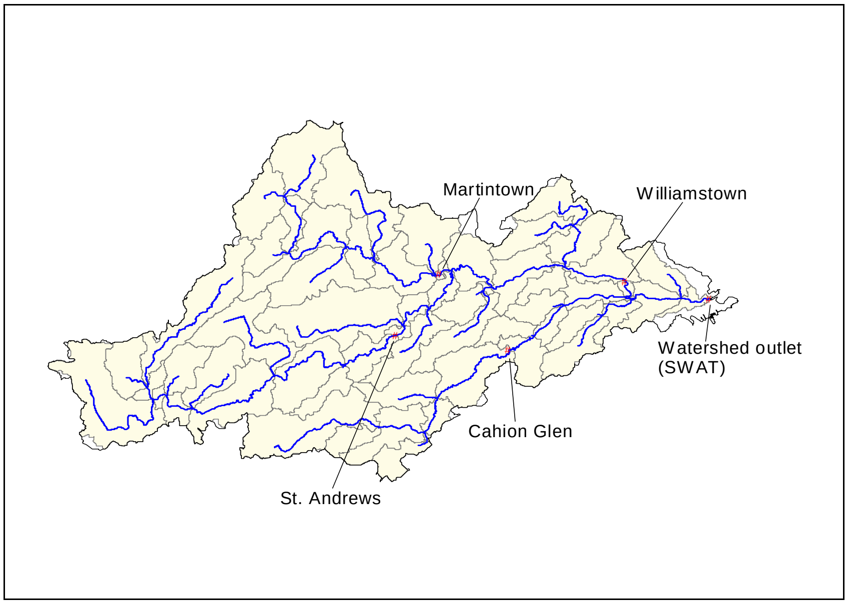
Water quality data for the Raisin River watershed is available at four provincial water quality monitoring network (PWQMN) stations from the Ontario Ministry of Environment and one from the RRCA's Tributary Network. The PWQMN stations are:

- Raisin River – St. Andrews (main branch upstream),
- Raisin River – Martintown (north branch),
- Raisin River – Cahion Glen (south branch),
- Raisin River – Williamstown (main branch downstream)

The only RRCA's Tributary Network station in the Raisin River watershed is the Raisin River Marina which is located at the mouth of the Raisin River (Raisin River Watershed Outlet).

The water quality data to be used in this study are the phosphorus and nitrogen data from the PWQMN stations and the sediment and phosphorus data from the RRCA station. They are used for calibration and validation purposes. It should be noted that the data is very limited in nature and it would be better if there was more data available for calibration and validation. Also, the MOE laboratory analytical accuracy for TP is in the order of plus or minus 6 µg/L. Consequently, it is not realistically possible to calibrate the model to anything better than this level of accuracy. Figure 15 shows the locations of the water quality stations (PWQMN and RRCA's Tributary Network).

Figure 15: OMOE's PWQMN and RRCA's Water Quality Stations



4.8 Fertilizer Application Rates

The 2001 Census of Agriculture Database compiled by Statistics Canada is available for this study. The Census of Agriculture data contains information on crops (e.g., number of farms, total growing area), landuse (e.g., total area), land management (e.g., area of irrigation, number of farms reporting fertilizer use), poultry and livestock (e.g., numbers of various animals, amount of manure produced annually) and on other farm operations (e.g., capital, expenses, equipment). However, it is not applicable for the models because the dataset is aspatial and makes it impossible to assign meaningful values spatially. Typical applications rates, used throughout most Ontario watersheds (TRCA, 2003), combined with information in the Eastern Ontario Water Resources Management Study Report (CH2M, 2001) were used for all land cover scenarios. Table 5 shows the fertilizer application rates used for the AGNPS and SWAT models.

Table 5: Fertilizer Applications Rates used for the AGNPS and SWAT Models

Land Cover Class	Nitrogen Application (kg/m^2)	Phosphorous Application (kg/m^2)
Fallow Field	0.00448	0.00224
Farmsteads	0.00448	0.00224
Grass and Pasture	0.00336	0.00056
Gravel and Dirt	0.0	0.0
High Grass	0.00336	0.00056
Meadow	0.0	0.0
Row Crops	0.015	0.00448
Short Grass	0.00673	0.00112
Small Grains	0.009	0.00336
Street Pavement	0.0	0.0
Topsoil Removal	0.0	0.0
Urban Commercial	0.0	0.0
Urban Residential	0.00336	0.00056
Water	0.0	0.0
Wetland	0.0	0.0
Woods	0.0	0.0

Specific fertilizer application rates of nitrogen and phosphorous on agriculture such as row crops are based on the report of Eastern Ontario Water Resources Management Study. The nitrogen recommendation is 115 kg/ha for corn. This is consistent with the data used in some other typical Ontario watersheds such as the Duffins Creek watershed (112 kg/ha) for row crop (TRCA, 2003). For other land cover types, the typical Ontario conditions are applied.

4.9 Hydrologic Response Units (SWAT)

Hydrologic Response Units (HRU) in the SWAT model subdivides the Raisin River watershed into areas having the same unique land use and soil combinations. It enables the SWAT model to properly deal with various evapotranspiration and other hydrologic conditions for different land cover and soil combinations. These land cover and soil combinations will provide an accurate estimate of the total runoff in the watershed, which in turn is a key driver in predicting water quality. In the Raisin River watershed, the threshold of 10% for land cover and soil is applied so that for each sub-basin any minor land use class or soil class making up less than 10% of the sub-basin is not included.

4.10 Climate Data (SWAT)

The SWAT model requires climate data inputs. The weather generator database in SWAT contains statistical data for different U.S. sites which can be used to generate representative daily climate data required by SWAT. The generated climate data can be used as the only source of climate data or can be used for missing observed data. The statistical data is based on a minimum of 20 years of climate data. The closest available station in the database to the Raisin River watershed is Canton, New York, which is approximately 67 km from the watershed centre. It is desirable to have a weather station closer to the watershed in the weather generator database. The watershed's closest weather station is Cornwall, Ontario, which is approximately 10 km from the watershed centre. Statistics were calculated for Cornwall for available parameters and were added to the weather generator database.

Statistics required for the weather generator include the following for each month:

- average daily precipitation and its standard deviation and skew
- probabilities of a wet day following a dry day and a wet day following a wet day
- average number of wet days in the month

- maximum ½ hour rainfall in entire period of record for the month
- average maximum and minimum daily air temperature and their standard deviations
- average daily solar radiation
- average daily dew point temperature
- average daily wind speed

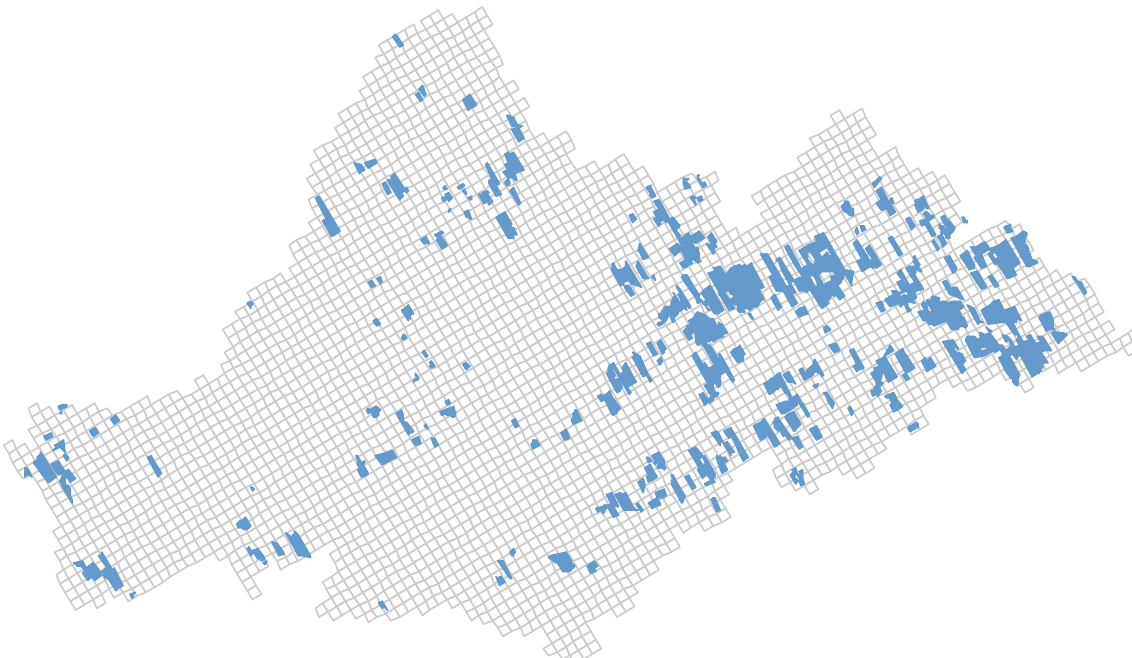
In addition to statistical weather data, the weather generator requires station information including title, latitude, longitude, elevation, and the number of years of ½ hour rainfall used to define the maximum.

The weather station for Cornwall, Ontario is the closest to the Raisin River watershed. This Environment Canada station (id number 6101874) has included measured daily precipitation, and maximum and minimum air temperature. Other required parameters such as solar radiation, dew point temperature, and wind speed were not available for Cornwall and the nearest Canadian stations with these parameters were Ottawa and Montreal. Since the Montreal and Ottawa climate stations are not closer than the Canton station, the Canton values for solar radiation, dew point temperature, and wind speed were used to essentially make a hybrid station that combines Cornwall and Canton data. Also, half an hour precipitation data was not available for any station closer than Canton so the maximum half an hour precipitation from Canton was used.

4.11 Tile Drainage (AGNPS)

The locations of tile drainage in the Raisin River watershed, which are provided by RRCA, are shown in Figure 16. The AGNPS grid model has been aligned with the tile drainage configuration to reflect the existence of the tile drainages in the watershed. However, additional information on the tile drain is required to model them using SWAT. This includes tile drain depth, amount of time to drain the soil to field capacity, and lag time between the drain and the outlet to the channel for each HRU. Therefore, tile drains were not modelled using SWAT.

Figure 16: Locations of tile drainage (grids in cyan colour)



5 CALIBRATION AND VALIDATION

5.1 SWAT

Typically, calibration and validation of water quality models are performed with data collected at the watershed outlet. However, in the Raisin River watershed, some of the observed data are not readily available at the outlet, so data from other sampling stations were used, as presented in sections 4.6 and 4.7. Table 6 lists the stations for the calibration and validation based on the current land cover layer.

Table 6: Calibration and Validation Based on the Current Land Cover

Parameter	Station	Data Source	Calibration Period	Validation Period
Flow (m^3/day)	WSC Station: 02MC001 near Williamstown	Water Survey of Canada	1985 - 1994	1995 – 2004
Total Suspended Sediment (mg/L)	RRCA Station: Raisin River Watershed Outlet	Tributary Outlet Sampling Database (RRCA)	2005 - 2006	-
Total Nitrogen Load (kg/day)	PWQ Stations: Downstream From Williamstown	OMOE	1985-1994	1995 – 2004
Total Phosphorus Load (kg/day)	PWQ Stations: Downstream From Williamstown	OMOE	1985-1994	1995 – 2004

The calibration was mainly done based on the following principles:

- Calibration followed the steps suggested in the SWAT 2000 user's manual with further calibration found in other study reports and papers. Calibration was done in steps: first water balance and stream flow, then sediment, and lastly nutrients
- Calibration based on comparison with observed values using Nash Sutcliffe Simulation Efficiency (NSE), means, correlation coefficient, and graphically. Graphical comparison was used mainly for low flow period comparison as the statistical comparison, especially NSE, isn't influenced much by the low flow values. Reasonable low flow simulations are desirable particularly for sediment and nutrient concentrations.

5.1.1 Flow Calibration

The best gauging station for flow data is the Williamstown flow station (02MC001), where data was collected from 1960 to 2005. Since the "Current" land cover scenario is used to calibrate the daily flow at that station, flow data from the more recent time period is used. In all, daily predicted flow values from 1980 to 2005 are generated. In this analysis, we allowed the first five years of simulation as a period of modelling equilibrium, and we started to calibrate flow values from 1985 to 1994 and validate flow values from 1995 to 2004.

The water balance and stream flow were calibrated first for average annual conditions. The water balance refers to the proportions of the total water yield which consists of the base flow and surface flow. The water balance components of the observed flow data were estimated using a FORTRAN computer program based on Arnold et al. (1995). The annual average base flow and surface flow ratios for the SWAT simulation were estimated at the flow gauge using the results from the SWAT output file. Only the sub-basins that drain to the flow gauge are used; the annual values for SURQ (surface flow), GWQ (groundwater flow), and WYLD (water yield) were multiplied by their drainage areas and then summed for the upstream sub-basins for each year resulting in runoff volumes. GWQ and SURQ cannot be used directly because in-stream precipitation, evaporation, transmission losses, etc. will alter the net water yield from that predicted by the WYLD variable in the HRU or sub-basin output file. Dividing the SURQ and GWQ sums by the WYLD sum will produce the surface and groundwater ratios; these ratios were averaged over the 1985 to 1994 period and then multiplied by the average flow rate from the SWAT output file, which contains the daily flow rate out of the sub-basin of interest which is approximately the location of the flow gauge, and then divided by the drainage area to get the average flows in units of mm.

The selection of the calibration parameters for flow calibration is based on the SWAT 2000 User's Manual and past experiences (Migliaccio et al., 2007; Arnold et al., 2000; Santhi et al., 2001; White and Chaubey, 2005). Model coefficients that were varied for calibration included ALPHA_BF, CN, SOL_AWC, ESCO, CH_K, GW_REVAP, and REVAPMN. An important part of the calibration was to ensure reasonable flow values during the summer months during low flow periods. Initial calibrations tended to produce inaccurate summer flows, such as having weeks with zero flow simulated. It was found that the groundwater parameters needed refinement to improve the summer low flow simulation. Further calibration of the flow rates involved the model parameters GWDELAY, ALPHA_BF, GWQMN, REVAPMN, GW_REVAP, SFTMP, SMTMP, SMFMX, SMFMN, TIMP, SNOCOVMX, ESCO, SURLAG, CN2, and SOL_AWC. Some of the parameters had little or worse effect when changed so were left at their default values. The calibrated parameters and their values are presented in Table 7.

Table 7: Hydrology Parameters used in the SWAT calibration

Hydrology Parameters	Name	Range	Calibrated Value
SFTMP	Snowfall temperature (°C)	-5 to 5	0.5
SMTMP	Snow melt base temperature (°C)	-5 to 5	0.9
TIMP	Snow pack temperature lag factor	0.01 to 1	0.15
SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover (mm H_2O)	> 0	25
ESCO	Soil evaporation compensation	0.01 to 1.0	0.5
SURLAG	Surface runoff lag coefficient	> 0	1.0
GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur (mm H_2O).	> 0	0.9
ALPHA_BF	Base alpha factor,	> 0	0.7
GW_DELAY	Groundwater delay time (days).	> 0	25
GW_REVAP	Groundwater "revap" coefficient.	0.02 to 0.2	0.2
CN2	Initial SCS runoff curve number for moisture condition II.		decrease 5
SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil).	> 0	increase 0.04

The calibration process of the daily predicted flow values was evaluated using two statistical measures: Nash-Sutcliffe simulation efficiency and correlation coefficient (r). The Nash-Sutcliffe simulation efficiency measures how well the model results agree with the observed values. The correlation coefficient indicates the strength of relationship between the modelled and observed values. Although it is desirable to have the correlation coefficient and the Nash-Sutcliffe simulation efficiency values as close to 1 as possible in the calibration process, they should be at least over 0.5 to be considered acceptable.

Figures 17 and 18 show the daily flow averaged monthly calibration and validation results for Raisin River at Williamstown, respectively. As shown in Figures 17 and 18, the simulated model flow rates and the observed values compare well and show a good correlation. Table 8 shows the calibration statistics of the monthly averaged flow from 1985 to 1994. The correlation coefficient and Nash-Sutcliffe simulation efficiency for the monthly calibration are 0.93 and 0.84, respectively. They show significant improvements when compared to the values at the start of the un-calibrated model. These values are greater than 0.5 and confirm reasonable model results. The validation was done for the period of 1995 to 2004. Table 8 also shows the statistics of the validation. The monthly correlation coefficient and Nash-Sutcliffe simulation efficiency for the validation are 0.93 and 0.86, respectively. These values are consistent with the calibration results.

Table 8: SWAT Flows Calibration & Validation Statistics at Williamstown

Type	Statistics Function	Stat. Value
1985 - 1994		
Calibration	Nash-Sutcliffe Simulation Efficiency	0.84
Calibration	r	0.93
1995 - 2004		
Validation	Nash-Sutcliffe Simulation Efficiency	0.86
Validation	r	0.93

Figure 17: Monthly Flows Calibration for WSC Station (2MC001) Williamstown from 1985-1994

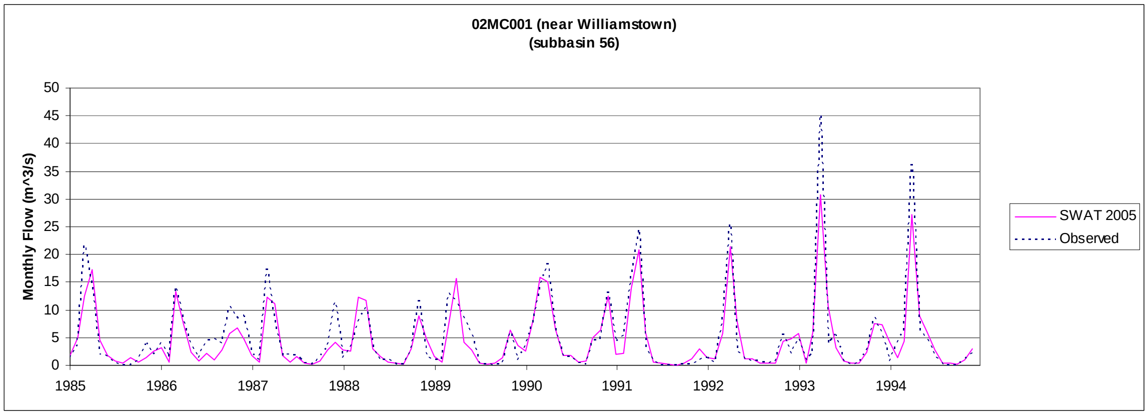
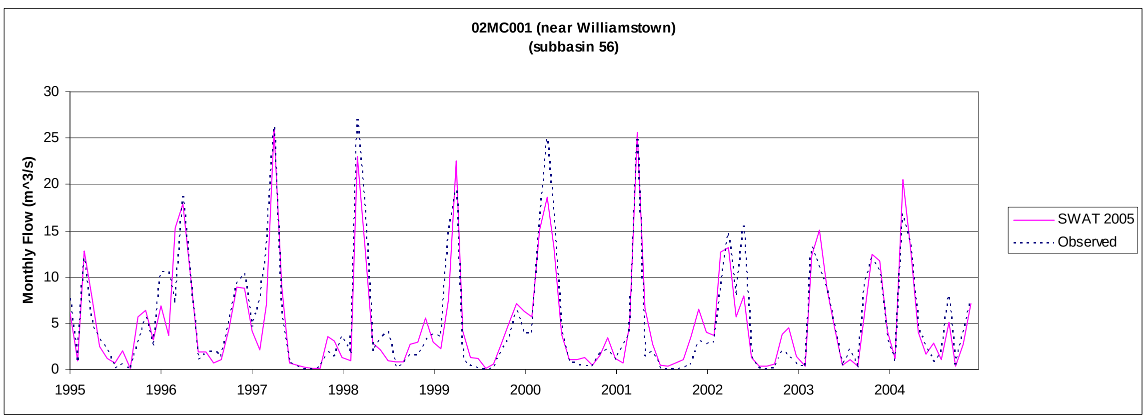


Figure 18: Monthly Flows Validation for WSC Station (2MC001) Williamstown from 1995-2004



5.1.2 Sediment Calibration

Sediment calibration was difficult given the small number of observations and only having observations during the summer periods. Calibration of sediment is also difficult since at the Raisin River watershed outlet there is a positive relationship between the predicted flow and sediment in that as flow increases sediment concentration also increases, but the same cannot be said for observed flow (Raisin River at Williamstown) and observed sediment (Raisin River Watershed Outlet). Also, one operation that can significantly affect sediment transport is the tillage operations but the tillage practices data were not known and cannot be directly applied to the model.

The sediment data is very limited in both quantity and quality. The RRCA has started to collect data from the outlet of the tributaries to the St. Lawrence River since 2004 in its tributary outlet sampling database. However, sediment data is only available for the Raisin River Watershed Outlet starting in 2005. We use both 2005 and 2006 TSS data for calibration. Validation of the sediment calibration can be performed if there are more sediment data available for a reasonable period. There is a total of twenty-one observations for TSS and eleven of them have remark code as "<3 mg/L". Thus, the uncertainty is very high in the calibration process of TSS. We decided to set the "< 3 mg/L" values equal to half the detection level, i.e., 1.5 mg/L. This is a widely used approach because it avoids the biases in approaches such as ignoring the below detection limit values entirely, assigning zero to the below detection or assigning the values to the detection level (Helsel, 1990). Table 9 shows the list of sediment calibrated parameters and their values.

Table 9: Sediment Parameters applied in the SWAT calibration

Sediment Parameter	Name	Range	Calibrated Value
PRF	Sediment routing peak rate adjustment factor	>=0	0.5
SPEXP	Exponent parameter for calculating sediment reentrained in channel sediment routing.	1 to 2	1.3

Figure 19 shows the daily observed and SWAT simulated sediment concentration for 2005 and 2006 at the outlet of the Raisin River watershed. Table 10 shows the calibration statistics. Although the correlation coefficient of the calibration is 0.37, the small sample size and the large number of sample points below the detection limit make it difficult for any in-depth analysis. However, since the F-value of 2.82 is greater than the F-critical value of 0.11, the regression is significant. The observed and predicted means are 2.69 mg/L and 2.68 mg/L, respectively. The standard deviations of the observed and predicted values are 1.71 mg/L and 1.49 mg/L. An ANOVA test was performed to test against any significant difference between the observed and predicted means. The results indicated that at the 5% significance level, there is no difference between the observed and predicted means. Therefore, the simulation sediment results are satisfactory given the data constraints.

Figure 19: Daily Sediment (TSS) Calibration at Raisin River Watershed Outlet.

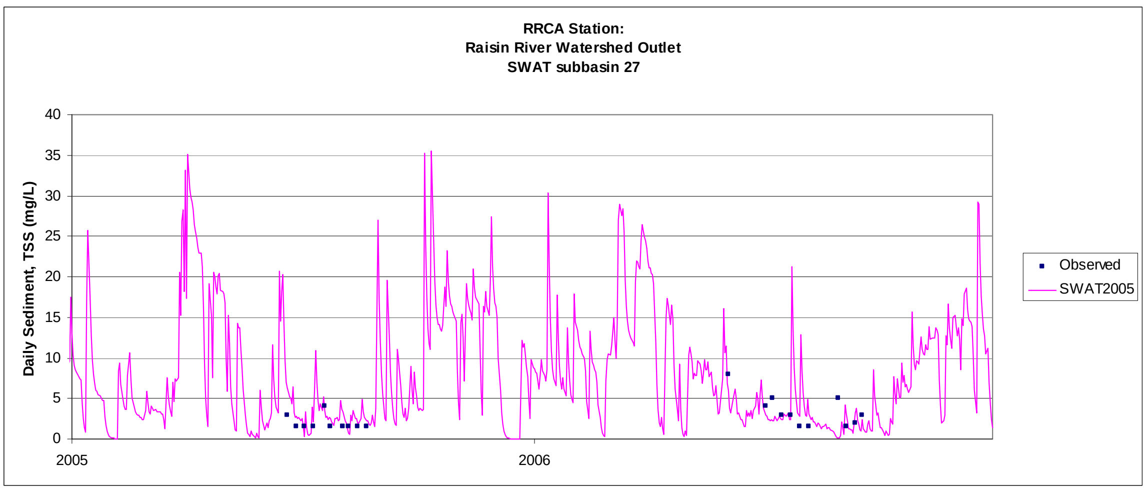


Table 10: Daily Sediment Calibration & Observed Statistics (2005-2006) at Raisin River Watershed Outlet

Type	Statistics Function	Calibration	Observed
Daily	r, F-value, F-critical, n	0.37, 2.82, 0.11, 21	N/A
Daily	Mean	2.68 mg/L	2.69 mg/L
Daily	standard deviation	1.49 mg/L	1.71 mg/L

5.1.3 Nutrient Calibration

After the sediment calibration was done, the next step was to calibrate the nutrients. Total nitrogen (TN) and total phosphorus (TP) were the parameters used for nutrient calibration. Nutrient observations were available for 5 stations in the watershed for different nitrogen and phosphorus components, which were summed to get TN and TP. The simulated TN is the sum of the SWAT values for nitrate (NO_3), nitrite (NO_2), ammonium (NH_4), and organic nitrogen (ORGN). The observed TN was not available directly, so it was obtained by summing the observed values for nitrate, nitrite, and total kjeldahl nitrogen. However, the observed TP was available. Simulated TP was obtained by summing the SWAT outputs for mineral phosphorus (MINP) and organic phosphorus (ORGP).

The observed TN and TP data are available in the Ontario Ministry of Environment's PWQMN dataset. Most data were collected monthly and the current dataset is provided up to 2004. Not all months had measurements every year and data were typically missing more in winter months. For consistency, the nutrient calibration and validation time periods used are the same ones used for flow calibration and validation periods. Thus, the calibration and validation periods are from 1985 to 1994 and from 1995 to 2004, respectively.

Parameters that were changed for calibration were ERORGP, GWSOLP, and FRT_KG for the row crop landuse. The calibrated values are presented in Table 11. It should be noted that organics are transported to the stream attached to sediment. Since there are very few sediment observations, the calibration of sediment and therefore organics should be viewed with caution.

Table 11: Nutrient Parameters applied in the SWAT calibration

Nutrient Parameter	Name	Range	Calibrated Value
ERORGP	Phosphorus enrichment ratio for loading with sediment	>=0	0.3
GWSOLP	Groundwater soluble phosphorus concentration	>=0	0.005
FRT_KG for AGRR landuse only	Fertilizer N and P applied to row crops were adjusted	>=0	decrease 25%

Figure 20 illustrates the monthly observed and SWAT calibrated total nitrogen load for 1985-

1994 at Williamstown of the Raisin River watershed. Table 12 displays the statistics of the TN load calibration and validation. The Nash-Sutcliffe Simulation Efficiency and the correlation coefficient for the calibration period are 0.71 and 0.87, respectively. The model predictions are consistent with the observed values. The validation is done for the period from 1995 to 2004 and is shown in Figure 21. The Nash-Sutcliffe Simulation Efficiency and the correlation coefficient for the validation period are 0.59 and 0.82, respectively. The model predictions of TN load also show good statistics during the validation phase.

Figure 22 illustrates the monthly observed and SWAT calibrated TP load for 1985-1994 at Williamstown of the Raisin River watershed. Table 12 displays the statistics of the TP load calibration. The Nash-Sutcliffe Simulation Efficiency and the correlation coefficient for the calibration period are 0.44 and 0.81, respectively. The model predictions are consistent with the observed values. The validation is done for the period from 1995 to 2004 for the same location as shown in Figure 23. The Nash-Sutcliffe Simulation Efficiency and the correlation coefficient for the validation period are 0.20 and 0.75, respectively.

Although higher statistical values in Nash-Sutcliffe Simulation Efficiency and the correlation coefficient are desirable, the sediment data constraints impacted the quality of the nutrients modelling results as the nutrients modelling is dependent upon the quality of the sediment modelling. The calibration and validation of both TN and TP loads show good results, especially the TN loads. When more sediment data become available, the model can be re-calibrated and re-validated for better performance.

Figure 20: Monthly Total Nitrogen Load Calibration (1985-1994) at Williamstown, Raisin River Watershed

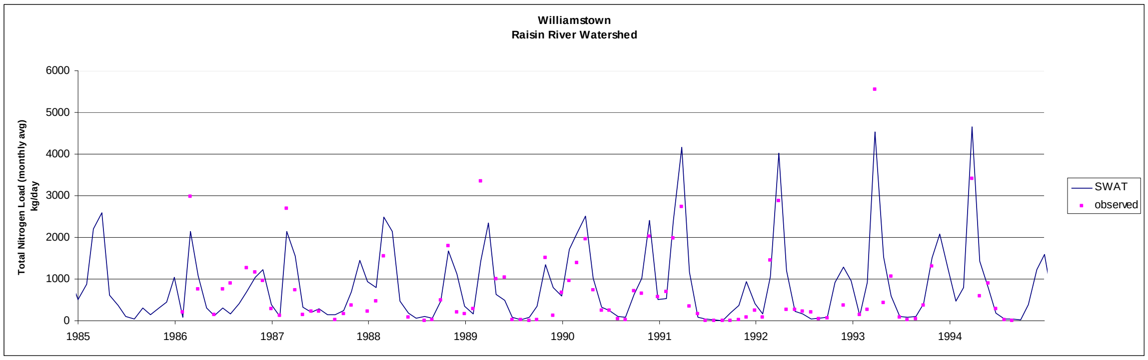


Figure 21: Monthly Total Nitrogen Load Validation (1995-2004) for Williamstown, Raisin River Watershed

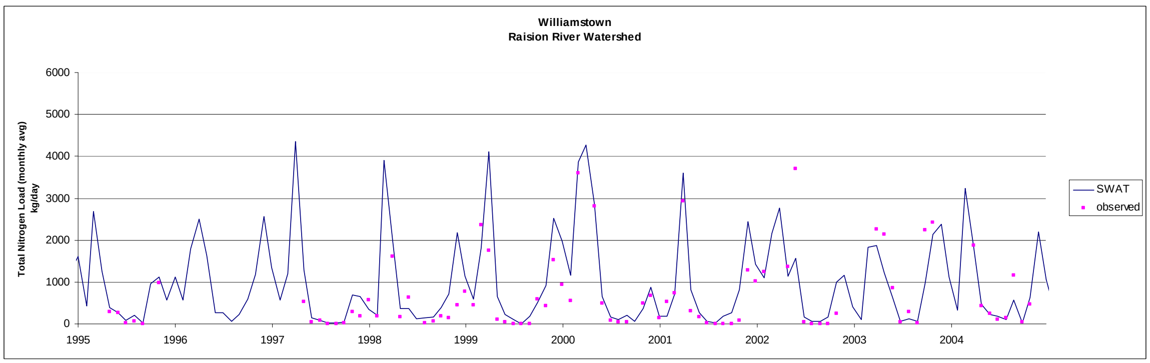


Figure 22: Daily Total Phosphorus Load Calibration (1985-1994) for Williamstown, Raisin River Watershed

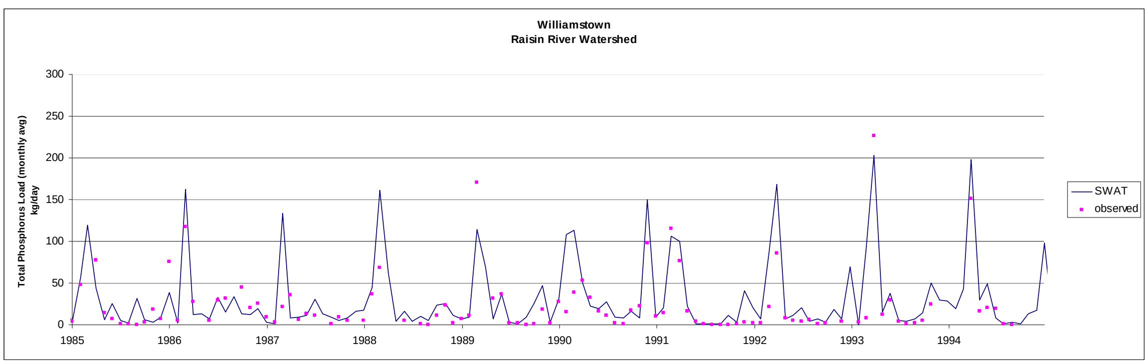


Figure 23: Daily Total Phosphorus Load Validation (1995-2004) for Williamstown, Raisin River Watershed

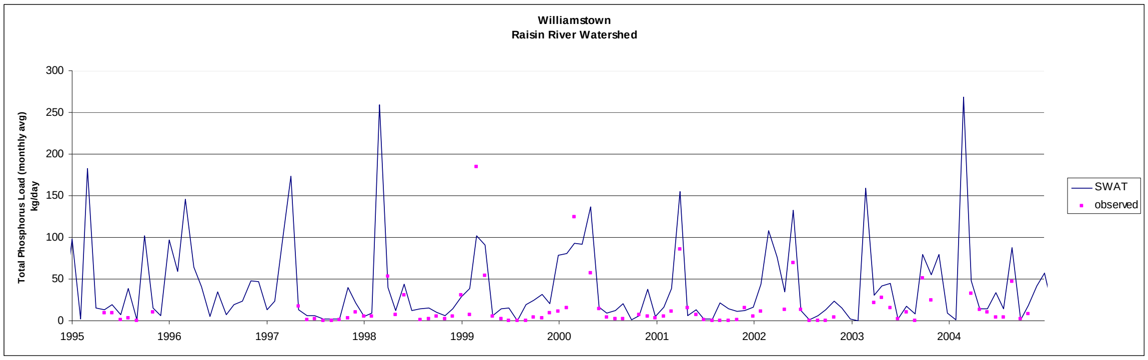


Table 12: Monthly SWAT Nutrient Loads Calibration & Validation Statistics

Type	Statistics Function	Stat. Value
Nitrogen		
1985-1994		
Calibration	Nash-Sutcliffe Simulation Efficiency	0.71
Calibration	r	0.87
1995-2004		
Validation	Nash-Sutcliffe Simulation Efficiency	0.59
Validation	r	0.82
Phosphorus		
1985-1994		
Calibration	Nash-Sutcliffe Simulation Efficiency	0.44
Calibration	r	0.81
1995-2004		
Validation	Nash-Sutcliffe Simulation Efficiency	0.20
Validation	r	0.75

5.2 AGNPS

The calibration and validation of the AGNPS model follows a similar approach as the SWAT model. A total of thirteen rainfall events are examined between 1987 and 2005. Since the event-based AGNPS model generates single values for the extreme events, the calibration is done by comparing the peak flow to the observed data at the Raisin River near the Williamstown station. Since the surface runoff is the dominant transport driver for both sediment and nutrients, it is critical that the downstream runoff is calibrated properly. Rainfall is the most sensitive parameter in the AGNPS runoff component. Since all four of the meteorological stations are all outside of the Raisin River watershed, it is necessary to calibrate the rainfall for all events separately. Table 13 shows the range of precipitation for the four stations and calibration is done to adjust the rainfall within the ranges to provide the closest peak flow as compared to the observed data. The average relative difference between the predicted and observed peak flows for the thirteen events range is 5.7% and it indicates the model results are good when compared to the observed data.

Table 13: Peak Flow Calibration of the AGNPS Model for the Current Land Cover

Event (Date)	Precip-itation Range (mm)	Final Precip-itation Value used (mm)	Pred. Peak Flow (m^3/s)	Obs. Peak Flow (m^3/s)	Rel. Diff. between Pred. & Obs. Peak Flow	Sediment Yield (tonnes)	Soluble N (mg/L)	Soluble P (mg/L)
Jun 8, 1987	43 – 47	43	10.29	9.39	0.10	704	0.29	0.01
Jul 24, 1987	76 – 84	84	12.06	15.10	-0.20	1257	0.10	0.00
Jun 16, 1993	29 – 33	29	8.96	7.68	0.17	384	0.50	0.01
Jun 6, 1994	39 – 43	43	10.59	14.10	-0.25	707	0.29	0.01
Oct 21, 1995	50 – 56	56	6.93	13.40	-0.48	976	0.04	0.01
Mar 23, 1999	30 – 34	34	20.60	26.30	-0.22	728	0.41	0.01
Mar 27, 2000	29 – 33	33	26.64	42.30	-0.37	561	0.42	0.01
Jun 10, 2002	73 – 78	78	45.61	49.40	-0.08	2245	0.11	0.00
Jun 14, 2002	40 – 49	42	47.00	44.70	0.05	794	0.30	0.01
May 24, 2003	49 – 55	50	19.91	13.00	0.53	737	0.24	0.01
Oct 26, 2003	73 – 81	81	38.94	39.10	0.00	1084	0.11	0.00
Sep 8, 2004	78 – 86	81	50.80	50.10	0.01	3185	0.11	0.00
Jun 16, 2005	39 – 49	42	34.87	35.00	0.00	612	0.30	0.01
Average					**0.057**			

For the sediment calibration in the AGNPS model, there is only one observation available to validate the sediment model results and it is at the outlet of the Raisin River. The AGNPS sediment concentration for the June 16, 2005 event is 217 mg/L and the observed total dissolved sediment (TDS) is 292 mg/L on June 21, 2005. The numbers are reasonably close given that the sampling date was several days after the event and also only one sample was available.

For nutrients, it is difficult to validate the model results because samples were not taken at the peak flow period. Usually at peak flow, after the storm, the large quantity of water dilutes the nutrients and makes the concentrations decrease. The AGNPS model concentrations of both soluble N and P are low with soluble P being close to zero (Table 13). However, the AGNPS model has been validated extensively in Ontario (Leon et al., 2004). Based on the success of that validation and that the Raisin River watershed is in Ontario, it can be deduced that the nutrient model results are satisfactory. Since the event driven model is mainly used to evaluate and compare various scenarios in the relative term as opposed to absolute term, it is more interesting to analyze the scenario results. An additional advantage in using the AGNPS model is its ability to perform source tracing to identify “hotspots”. The results of source tracing can be used to determine areas for best management practices (BMP).

6 LAND COVER SCENARIO GAMING

6.1 Introduction

The NAESI Biodiversity Theme produces a number of land cover scenarios that are based on biodiversity standards, agricultural practices and best management practices (BMP). The calibrated AGNPS and SWAT models were applied to various NAESI Biodiversity Theme scenarios. There are six land cover scenarios for the Raisin River watershed. The PNV scenario is a vegetation structure that would become established if all natural successional sequences were completed without interference by man under the present climatic and edaphic conditions (including those created by man) (Tüxen, 1956). The two biodiversity conservation scenarios, Ideal and Realistic, adopt existing BMPs and conservation direction for the region to improve landscape condition for biodiversity. Specifically, the Ideal scenario is where a high uptake/adoption of conservation direction and best management practices are predicted for the benefit of water and habitat conservation whereas the Realistic scenario, with a lower rate of uptake, focuses on conservation activities currently associated with agriculture. The two agricultural intensification scenarios, AgBio and AgNoCon, integrate agricultural policy and encourage cultivation of all productive lands using conventional technology and inputs. Specifically, the AgBio scenario is where intensification occurs with some limited constraints to conserve water and wildlife habitat whereas the AgNoCon scenario is an intensification scenario that does not consider conservation values on private lands. In addition, there is a status quo "Current" scenario which reflects the current land use situation. Detailed discussion of the land cover scenarios can be found in the NAESI biodiversity detailed land modelling report (Neave et al., 2007).

Table 14 shows the breakdown (in percentages) of the land cover types for the six scenarios. Figure 25 shows the distribution of the top 18 land cover types of the six land cover scenarios. As shown in Table 15 and Figure 24, row crops are at 10.98% for the Current scenario, they decreases to 6.38% in the Ideal scenario, but are predicted to increase to 43.4% in the AgNoCon scenario. This dramatic change in land use will cause considerable change in non-point source pollution and requires the use of models. Specifically, we use AGNPS to study the extreme event situation and SWAT to investigate the long term impact. The scenario comparisons were performed using the current land cover as the base.

Table 14: Land Cover Type Percentages for the Six Scenarios

NAESI	Ideal	Realistic	Current	AgBio	AgNoCon	PNV
Ecosite FOC1 - Dry-Fresh Pine Coniferous Forest	0.02%	0.02%	0.02%	0.02%	0.02%	0.00%
Ecosite FOC2 - Dry-Fresh Cedar Coniferous Forest	1.90%	1.89%	1.89%	1.05%	1.05%	0.00%
Ecosite FOC4 - Fresh-Moist White Cedar Coniferous Forest	2.20%	2.20%	2.20%	1.02%	1.02%	21.12%
Ecosite FOM7 - Fresh-Moist White Cedar-Hardwood Mixed Forest	2.04%	2.04%	2.04%	1.19%	1.19%	
Ecosite FOM2 - Dry-Fresh White Pine-Maple-Oak Mixed Forest	0.03%	0.03%	0.03%	0.00%	0.00%	0.00%
Ecosite FOM3 - Dry-Fresh Hardwood-Hemlock Mixed Forest	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%
Ecosite FOM4 - Dry-Fresh White Cedar Mixed Forest	0.48%	0.48%	0.48%	0.30%	0.30%	0.00%
Ecosite FOM5 - Dry-Fresh White Birch-Poplar-Conifer Mixed Forest	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%
Ecosite FOM6 - Fresh-Moist Hemlock Mixed Forest	0.04%	0.04%	0.04%	0.03%	0.03%	0.23%
Ecosite FOD3 - Dry-Fresh Poplar-White Birch Deciduous Forest	0.91%	0.91%	0.91%	0.51%	0.51%	5.11%
Ecosite FOD8 - Fresh-Moist Poplar-Sassafras Deciduous Forest	8.45%	4.94%	2.28%	1.90%	1.49%	
Ecosite FOD4 - Dry-Fresh Deciduous Forest	0.61%	0.61%	0.61%	0.40%	0.40%	22.84%
Ecosite FOD5 - Dry-Fresh Sugar Maple Deciduous Forest	4.35%	4.35%	4.35%	3.14%	3.14%	
Ecosite FOD6 - Fresh-Moist Sugar Maple Deciduous Forest	2.27%	2.27%	2.27%	1.49%	1.49%	10.41%
Ecosite FOD7 - Fresh-Moist Lowland Deciduous Forest	1.66%	1.66%	1.66%	0.82%	0.82%	2.05%
Ecosite SWC1 - White Cedar Mineral Coniferous Swamp	0.85%	0.85%	0.84%	0.69%	0.69%	10.45%
Ecosite SWC3 - White Cedar Organic Coniferous Swamp	0.07%	0.07%	0.07%	0.07%	0.07%	
Ecosite SWM1 - White Cedar Mineral Mixed Swamp	1.26%	1.26%	1.26%	1.01%	1.01%	
Ecosite SWM4 - White Cedar Organic Mixed Swamp	0.03%	0.03%	0.03%	0.03%	0.03%	
Ecosite SWC2 - White Pine-Hemlock Mineral Coniferous Swamp	0.06%	0.06%	0.06%	0.02%	0.02%	0.06%

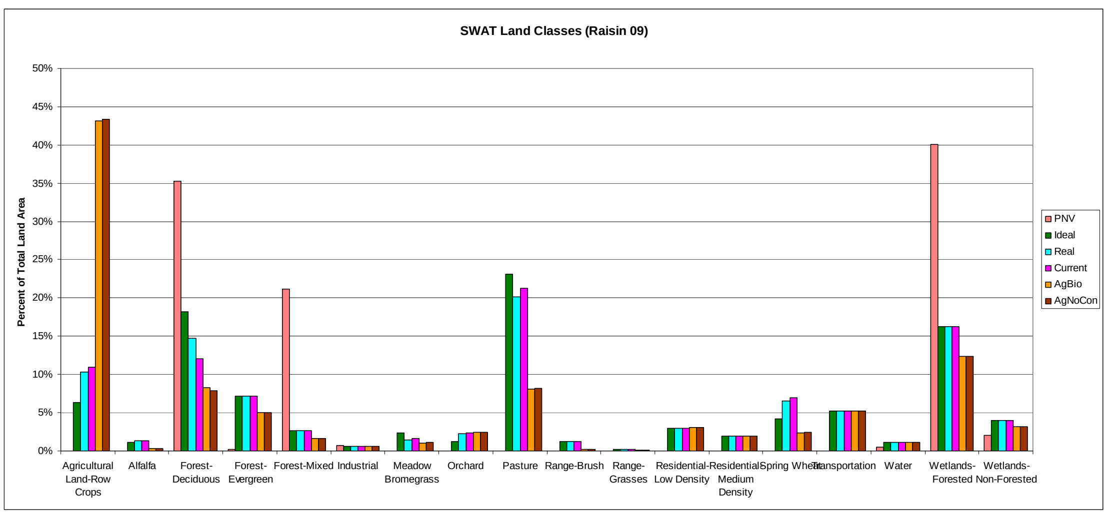
Table 14: Land Cover Type Percentages for the Six Scenarios

NAESI	Ideal	Realistic	Current	AgBio	AgNoCon	PNV
Ecosite SWC4 - Tamarack-Black Spruce Organic Coniferous Swamp	0.25%	0.25%	0.25%	0.25%	0.25%	0.38%
Ecosite SWM2 - Maple Mineral Mixed Swamp	0.27%	0.27%	0.27%	0.23%	0.23%	0.00%
Ecosite SWM3 - Birch-Poplar Mineral Mixed Swamp	0.07%	0.07%	0.07%	0.07%	0.07%	0.00%
Ecosite SWM5 - Maple Organic Mixed Swamp	0.02%	0.02%	0.02%	0.02%	0.02%	0.00%
Ecosite SWD2 - Ash Mineral Deciduous Swamp	2.07%	2.07%	2.06%	1.22%	1.22%	16.97%
Ecosite SWD3 - Maple Mineral Deciduous Swamp	9.17%	9.17%	9.17%	6.81%	6.81%	
Ecosite SWD5 - Ash Organic Deciduous Swamp	0.19%	0.19%	0.19%	0.19%	0.19%	
Ecosite SWD6 - Maple Organic Deciduous Swamp	0.80%	0.80%	0.80%	0.80%	0.80%	
Ecosite SWD4 - Mineral Deciduous Swamp	2.36%	2.36%	2.36%	1.31%	1.31%	0.00%
Ecosite SWD7 - Birch-Poplar Organic Deciduous Swamp	0.02%	0.02%	0.02%	0.02%	0.02%	0.00%
Bogs	0.84%	0.84%	0.84%	0.84%	0.84%	0.86%
Marshes	0.89%	0.89%	0.89%	0.89%	0.89%	7.16%
Thicket Swamp – Mineral	0.64%	0.64%	0.64%	0.64%	0.64%	1.16%
Thicket Swamp – Organic	0.44%	0.44%	0.44%	0.44%	0.44%	
Agriculture – Row Crops (Corn soybeans etc.)	6.38%	10.38%	10.98%	43.19%	43.40%	0.00%
Agriculture - Cereals (Wheat, Barley, etc.)	4.17%	6.53%	6.96%	2.35%	2.41%	0.00%
Agriculture - Hay, Pasture	23.16%	20.12%	21.29%	8.12%	8.14%	0.00%
Agriculture – Alfalfa	1.14%	1.28%	1.36%	0.34%	0.34%	0.00%
Agriculture - Other intensive (Orchard, horticulture)	1.28%	2.21%	2.37%	2.41%	2.44%	0.00%
Coniferous Forest Plantations (Cedar)	0.06%	0.06%	0.06%	0.06%	0.06%	0.00%
Mixed Forest Plantations	0.04%	0.04%	0.04%	0.02%	0.02%	0.00%
Pine Plantation	0.99%	0.99%	0.99%	0.97%	0.97%	0.00%
Larch Plantation	0.06%	0.06%	0.06%	0.06%	0.06%	0.00%
Spruce Plantation	0.99%	0.98%	0.98%	0.99%	0.99%	0.00%
Poplar Plantation	0.65%	0.65%	0.65%	0.65%	0.65%	0.00%
Tolerant Hardwood Plantation	0.04%	0.04%	0.04%	0.04%	0.04%	0.00%
Cultural Meadow/Thicket stkg < 0.2	2.30%	1.41%	1.63%	1.03%	1.13%	0.00%
Cultural Savannah stkg .2-.3	0.21%	0.23%	0.24%	0.13%	0.13%	0.00%

Table 14: Land Cover Type Percentages for the Six Scenarios

NAESI	Ideal	Realistic	Current	AgBio	AgNoCon	PNV
Cultural Woodland stkg > 3	0.26%	0.26%	0.26%	0.15%	0.15%	0.00%
Hedgerows from SOLRIS	1.19%	1.19%	1.19%	0.16%	0.16%	0.00%
Rock Barren	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sand Barren (Placeholder, no transition)	0.61%	0.61%	0.61%	0.61%	0.61%	0.68%
Road Right of Way	4.35%	4.35%	4.35%	4.35%	4.35%	0.00%
Transmission Lines	0.64%	0.64%	0.64%	0.64%	0.64%	0.00%
Railway	0.18%	0.18%	0.18%	0.17%	0.18%	0.00%
Rural Developed	3.01%	3.01%	3.01%	3.04%	3.04%	0.00%
Water (Placeholder, no transition)	1.89%	1.89%	1.89%	1.90%	1.90%	0.51%
Lakes	0.17%	0.17%	0.17%	0.17%	0.17%	
Rivers	0.27%	0.27%	0.27%	0.27%	0.27%	
Streams	0.71%	0.72%	0.72%	0.72%	0.71%	

Figure 24: Comparison of Land Cover Types for the six scenarios in SWAT



6.2 Scenario Analyses and Comparisons

6.2.1 SWAT Result and Discussion

The main objective in this study is to assess the impact of each of the land cover scenarios on water. It is well known that sediment and nutrients are the key drivers of poor surface water quality. The hydrology is important in that it transports the sediment and nutrients downstream. Therefore, it is essential to understand the hydrology, the sediment and the nutrient concentrations for the different scenarios. Figures 25 – 28 illustrate the SWAT predicted annual means of flow, total suspended sediment (TSS), TN and TP at five locations in the Raisin River watershed. These locations are St. Andrews (main branch), Williamstown (main branch downstream), Raisin River Outlet, Cahion Glen (south branch) and Martintown (north branch) as shown in Figure 15. The soil and the Current land cover profiles of the sub-basin for the five locations are listed in Tables 15 and 16, respectively. The simulations are from 1985 to 2006 for the current base case and the five land cover scenarios. It can be seen that the two biodiversity cases have lower values than the current base case but the two agricultural intensification scenarios have much higher values in sediment and nutrients (TN and TP). As expected, the PNV scenario shows the lowest values in sediment and nutrients.

Table 15: SWAT Soil texture profile for the five locations

SWAT Soil Texture	Martintown Area in ha (% drainage)	Cahion Glen Area in ha (% drainage)	St. Andrews Area in ha (% drainage)	Williamstown Area in ha (% drainage)	Raisin River Watershed Outlet Area in ha (% drainage)
Silt Loam	2283 (18.3%)	4759 (62.1%)	1826 (12.2%)	11555 (28.4%)	20036 (36.5%)
Sandy Loam	5700 (45.8%)	1814 (23.7%)	7829 (52.3%)	17361 (42.6%)	19828 (36.1%)
Silt	3160 (25.4%)	376 (4.9%)	3945 (26.3%)	8610 (21.1%)	11107 (20.2%)
Loam	1307 (10.5%)	97 (1.3%)	635 (4.2%)	2433 (6%)	2542 (4.6%)
Sand		211 (2.8%)	554 (3.7%)	559 (1.4%)	791 (1.4%)
Loamy Sand		411 (5.4%)	186 (1.2%)	220 (0.5%)	631 (1.1%)

Table 16: SWAT Current Land use profile for the five locations

SWAT Land Use (Current)	Martintown Area in ha (% drainage)	Cahion Glen Area in ha (% drainage)	St. Andrews Area in ha (% drainage)	Williamstown Area in ha (% drainage)	Raisin River Watershed Outlet Area in ha (% drainage)
Pasture	2269 (18.2%)	1696 (22.1%)	3949 (26.4%)	8931 (21.9%)	11821 (21.5%)

Table 16: SWAT Current Land use profile for the five locations

SWAT Land Use (Current)	Martintown Area in ha (% drainage)	Cahion Glen Area in ha (% drainage)	St. Andrews Area in ha (% drainage)	Williamstown Area in ha (% drainage)	Raisin River Watershed Outlet Area in ha (% drainage)
Wetlands-Forested	2356 (18.9%)	588 (7.7%)	3462 (23.1%)	7151 (17.6%)	8743 (15.9%)
Forest-Deciduous	1676 (13.5%)	719 (9.4%)	1062 (7.1%)	5005 (12.3%)	6676 (12.2%)
Agricultural Land-Row Crops	829 (6.7%)	460 (6%)	888 (5.9%)	4071 (10%)	5911 (10.8%)
Forest-Evergreen	1466 (11.8%)	319 (4.2%)	910 (6.1%)	3334 (8.2%)	3985 (7.3%)
Spring Wheat	774 (6.2%)	744 (9.7%)	917 (6.1%)	2512 (6.2%)	3845 (7%)
Transportation	560 (4.5%)	731 (9.5%)	769 (5.1%)	1877 (4.6%)	2823 (5.1%)
Wetlands-Non-Forested	651 (5.2%)	352 (4.6%)	799 (5.3%)	1743 (4.3%)	2244 (4.1%)
Residential-Low Density	153 (1.2%)	696 (9.1%)	386 (2.6%)	843 (2.1%)	1637 (3%)
Forest-Mixed	628 (5%)	72 (0.9%)	447 (3%)	1357 (3.3%)	1474 (2.7%)
Orchard	393 (3.2%)	62 (0.8%)	423 (2.8%)	1171 (2.9%)	1323 (2.4%)
Residential-Medium Density	40 (0.3%)	649 (8.5%)	122 (0.8%)	312 (0.8%)	1031 (1.9%)
Meadow Bromegrass	131 (1.1%)	275 (3.6%)	191 (1.3%)	474 (1.2%)	894 (1.6%)
Alfalfa	160 (1.3%)	9 (0.1%)	209 (1.4%)	669 (1.6%)	760 (1.4%)
Range-Brush	162 (1.3%)	43 (0.6%)	190 (1.3%)	554 (1.4%)	666 (1.2%)
Water	113 (0.9%)	77 (1%)	137 (0.9%)	433 (1.1%)	626 (1.1%)
Industrial	35 (0.3%)	174 (2.3%)	75 (0.5%)	172 (0.4%)	346 (0.6%)
Range-Grasses	53 (0.4%)	2 (0.03%)	38 (0.3%)	130 (0.3%)	132 (0.2%)
Total	**12450**	**7667**	**14974**	**40738**	**54934**

Figure 25: Scenario Comparison for average flow (m^3/L) at the five locations within the Raisin River Watershed

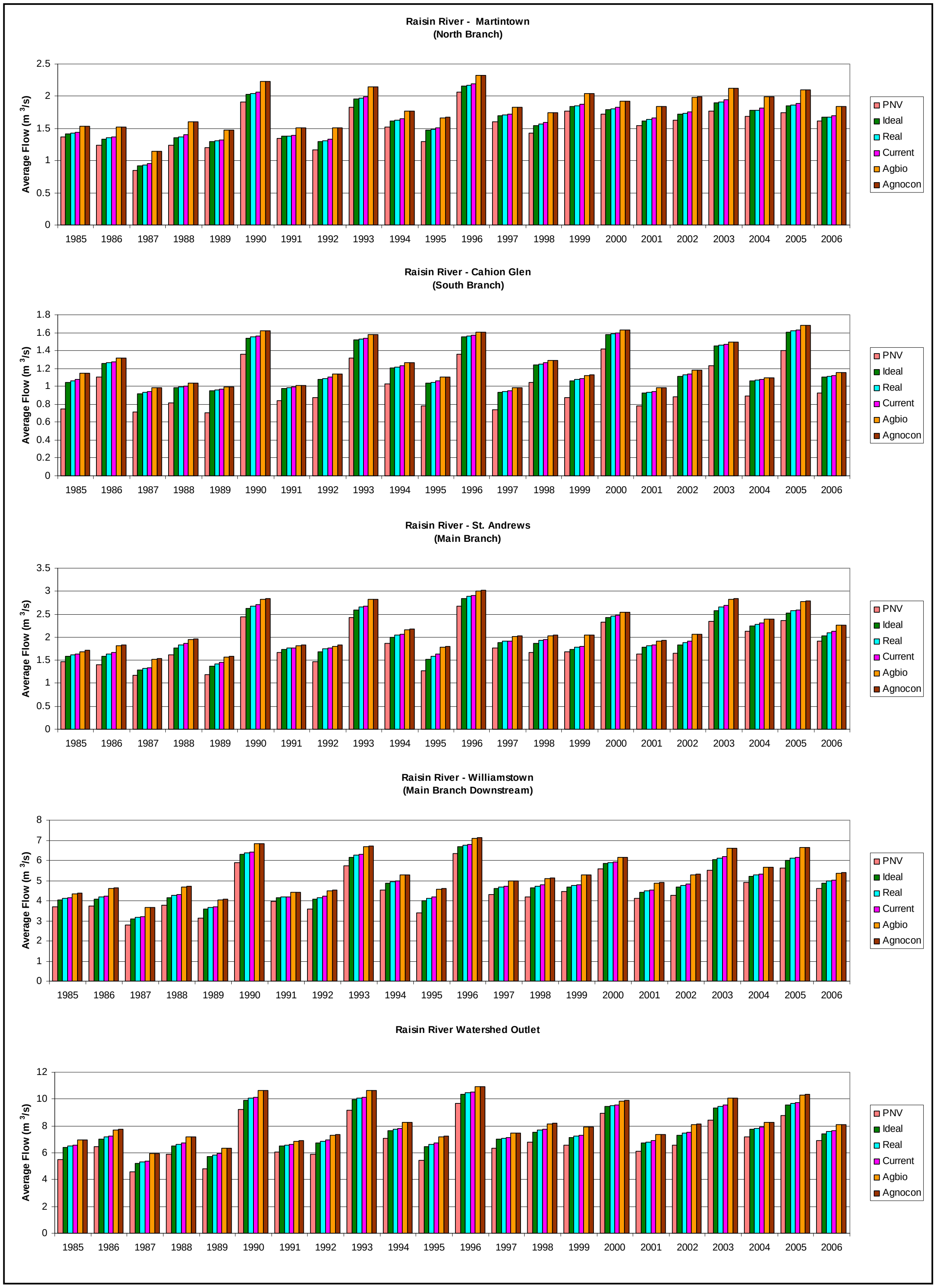


Figure 26: Scenario Comparison for TSS (mg/L) at the five locations within the Raisin River Watershed

Figure 27: Scenario Comparison for TN (mg/L) at the five locations within the Raisin River Watershed

Figure 28: Scenario Comparison for TP (mg/L) at the five locations within the Raisin River Watershed

The flow, TSS, TN and TP annual averages for the five locations are listed in Table 17. The relative changes between the Current and the other five scenarios are listed in Table 18.

Table 17: The flow, TSS, TN and TP annual averages for the six scenarios for the five locations within Raisin River Watershed

Average Annual					Scenarios		
Parameter	Location	PNV	Ideal	Realistic	Current	AgBio	AgNoCon
Flow (m^3/s)	Martintown	1.52	1.62	1.63	1.65	1.81	1.81
	Cahion Glen	0.99	1.19	1.20	1.21	1.25	1.25
	St Andrews	1.83	1.98	2.03	2.05	2.16	2.18
	Williamstown	4.46	4.82	4.90	4.95	5.30	5.32
	Outlet	6.93	7.63	7.73	7.81	8.25	8.27
TSS (mg/L)	Martintown	4.46	5.54	8.27	8.60	14.51	14.52
	Cahion Glen	3.12	4.43	4.59	4.65	5.27	5.28
	St Andrews	4.50	4.83	5.47	5.43	12.60	12.66
	Williamstown	3.61	5.48	6.12	6.28	7.86	7.88
	Outlet	3.82	6.42	6.92	7.05	8.48	8.49
TN (mg/L)	Martintown	0.82	1.19	1.37	1.44	3.17	3.17
	Cahion Glen	1.34	1.98	2.11	2.15	3.50	3.51
	St. Andrews	0.86	1.32	1.47	1.48	3.17	3.25
	Williamstown	0.98	1.60	1.85	1.90	3.33	3.36
	Outlet	1.07	1.75	1.95	2.00	3.35	3.37
TP (mg/L)	Martintown	0.0096	0.0251	0.0304	0.0336	0.0852	0.0855
	Cahion Glen	0.0205	0.0750	0.0780	0.0784	0.1228	0.1231
	St. Andrews	0.0103	0.0258	0.0303	0.0318	0.0820	0.0839
	Williamstown	0.0122	0.0426	0.0525	0.0560	0.1050	0.1063
	Outlet	0.0147	0.0540	0.0607	0.0636	0.1126	0.1134

Table 18: Relative changes of the flow, TSS, TN and TP annual averages between the scenarios and current land cover for the five locations within Raisin River Watershed

Average Annual Realative to Current			Scenarios			
Parameter	Location	PNV	Ideal	Realistic	AgBio	AgNoCon
Flow (m^3/s)	Martintown	-7.9%	-1.8%	-1.2%	9.7%	9.7%
	Cahion Glen	-18.2%	-1.7%	-0.8%	3.3%	3.3%
	St Andrews	-10.7%	-3.4%	-1.0%	5.4%	6.3%
	Williamstown	-9.9%	-2.6%	-1.0%	7.1%	7.5%

Table 18: Relative changes of the flow, TSS, TN and TP annual averages between the scenarios and current land cover for the five locations within Raisin River Watershed

Average Annual Realative to Current		Scenarios				
Parameter	**Location**	**PNV**	**Ideal**	**Realistic**	**AgBio**	**AgNoCon**
TSS (mg/L)	Outlet	-11.3%	-2.3%	-1.0%	5.6%	5.9%
	Martintown	-48.1%	-35.6%	-3.8%	68.7%	68.8%
	Cahion Glen	-32.9%	-4.7%	-1.3%	13.3%	13.5%
	St Andrews	-17.1%	-11.1%	0.7%	132.0%	133.1 %
	Williamstown	-42.5%	-12.7%	-2.6%	25.2%	25.5%
	Outlet	-45.8%	-8.9%	-1.8%	20.3%	20.4%
TN (mg/L)	Martintown	-43.1%	-17.4%	-4.9%	120.1%	120.1 %
	Cahion Glen	-37.7%	-7.9%	-1.9%	62.8%	63.3%
	St. Andrews	-41.9%	-10.8%	-0.7%	114.2 %	119.6 %
	Williamstown	-48.4%	-15.8%	-2.6%	75.3%	76.8%
	Outlet	-46.5%	-12.5%	-2.5%	67.5%	68.5%
TP (mg/L)	Martintown	-71.4%	-25.3%	-9.5%	153.6 %	154.5 %
	Cahion Glen	-73.9%	-4.3%	-0.5%	56.6%	57.0%
	St. Andrews	-67.6%	-18.9%	-4.7%	157.9 %	163.8 %
	Williamstown	-78.2%	-23.9%	-6.3%	87.5%	89.8%
	Outlet	-76.9%	-15.1%	-4.6%	77.0%	78.3%

From the SWAT model scenario results, the PNV scenario is the lowest in flow, sediment and nutrients concentration. At the other extreme, the AgNoCon scenario predicts the highest in sediment and nutrients concentrations. In general, the following order of scenarios is ranked from the lowest to the highest flow, sediment and nutrients concentrations: PNV, Ideal, Realistic, Current, AgBio and AgNoCon.

Martintown has the highest change in flow when comparing the AgNoCon scenario with the Current scenario (9.7%) and Cahion Glen has the lowest relative change (3.3%) in flow for the same comparison. Both Martintown and St. Andrews exhibit large increases of TSS, TN and TP concentrations when comparing the AgNoCon scenario with the Current scenario. In the case of St. Andrews, the model predicts an increase of 133.1% in TSS, 119.6% in TN and 163.8% in TP concentrations, respectively. On the other hand, the PNV, Ideal and Realistic scenarios show reduction of the sediment when compared to the Current scenario. For instance, at the outlet, PNV predicts a reduction of 45.8% in TSS, 46.5% in TN and 76.9% in TP. Cahion Glen exhibits small relative changes among all locations because of its heavy anthropogenic activities, i.e., City of Cornwall. Therefore, the changes in land cover classes are relatively small in the scenarios when compared to the other areas such as the north branch and the main branch.

The highest annual average sediment concentrations are found in Martintown and the outlet while the highest nutrient concentrations are located at Cahion Glen and the outlet. Martintown and the outlet predict 8.6 mg/L and 7.05 mg/L of TSS in the Current scenario, respectively. Cahion Glen and the outlet predict an annual average of 2.15 and 2.00 mg/L of TN in the Current scenario, respectively. Similarly, Cahion Glen and the outlet predict an annual average of 0.0784 and 0.0636 mg/L of TP in the Current scenario, respectively. The Raisin River Watershed Outlet has consistently high annual average sediment and nutrients concentrations among all the locations.

In summary, as agricultural activities increase, the flow, TSS, TN and TP increase, and vice versa. The PNV scenario, because it is potential natural vegetation, predicts the lowest in flow, TSS, TN and TP concentrations. At the other extreme, the AgNoCon scenario predicts the highest in flow, TSS, TN and TP concentrations. It is observed that the results of the AgBio and AgNoCon scenarios are very similar. This is due to the SWAT model being applied at a watershed scale in this study. The land cover class rollup in both scenarios are very similar. It is recommended that local scale models be applied to further assess the impact at the local scale level.

6.2.2 AGNPS Results and Discussion

Tables 19 to 26 summarize the results of the AGNPS scenario analyses. The downstream peak flow, sediment yield, soluble nitrogen and soluble phosphorus for the Current and the five NAESI Biodiversity Theme land cover scenarios are presented in two different table formats. The first format lists the absolute AGNPS model results (Tables 19, 21, 23, and 24). The second format compares the various land cover scenarios with the current base case for the downstream peak flow, sediment yield, soluble nitrogen and soluble phosphorus (Tables 20, 22, 24, and 26). It can be seen that the downstream peak flow, sediment and nutrients show consistent trends in that the PNV land cover scenario generates the lowest peak flow, the lowest sediment yield as well as the lowest nutrients in sediment. As compared to the Current scenario for the thirteen storm events, the PNV scenario predicts a reduction of the peak flow between 47.0% and 97.1% at Williamstown, a decrease in sediment yield from 77.4% to 92.1% at the outlet, a decrease in "nitrogen in sediment" between 62.2% and 90.2% at the outlet, and a decrease in "phosphorus in sediment" between 50% and 100% at the outlet. Similarly, the Ideal scenario predicts a reduction of the peak flow between 6.1% and 24.0%, a decrease in sediment yield from 4.0% to 15.3%, a decrease in "nitrogen in sediment" between 0% and 19.6%, and a decrease in "phosphorus in sediment" between 0% and 50%. The Realistic scenario is the third lowest in terms of peak flow, sediment yield and nutrients in sediment, and it also showed modest improvement over the current land cover case. The Current scenario has slightly higher values than the Realistic scenario. The AgBio scenario shows the second highest values in peak flow, sediment and nutrients. The AgNoCon has the highest values in peak flow, sediment and nutrients. As compared to the current base case using the thirteen storm events, the AgNoCon scenario predicts an increase in the peak flow between 14.3% and 57.7%, an increase in sediment yield from 9.2%

to 47.1%, an increase in "nitrogen in sediment" between 0% and 43.6%, and an increase in "phosphorus in sediment" between 0% and 54.5%. In addition, the results of AgBio and the AgNoCon scenarios are very close and both are much higher than the Current scenario.

Table 19: AGNPS Peak Flow Rates Scenario Results at Williamstown (m^3/s)

Event	PNV	Ideal	Realistic	Current	AgBio	AgNoCon
Jun 8, 1987	3.54	9.10	9.71	10.29	13.00	13.12
Jul 24, 1987	3.87	10.95	11.51	12.06	15.48	15.65
Jun 16, 1993	1.50	7.81	8.39	8.96	11.50	11.61
Jun 6, 1994	3.64	9.38	9.99	10.59	13.35	13.47
Oct 21, 1995	0.20	5.27	6.08	6.93	10.57	10.93
Mar 23, 1999	5.97	18.53	19.59	20.60	25.12	25.33
Mar 27, 2000	14.11	25.02	25.85	26.64	30.32	30.46
Jun 10, 2002	11.74	40.86	43.25	45.61	55.49	55.92
Jun 14, 2002	19.69	43.06	45.07	47.00	55.47	55.83
May 24, 2003	6.99	18.03	18.99	19.91	24.06	24.24
Oct 26, 2003	11.21	35.12	37.04	38.94	46.93	47.32
Sep 8, 2004	15.20	47.62	50.22	52.80	63.84	64.44
Jun 16, 2005	15.44	32.22	33.57	34.87	40.62	40.86

Table 20: AGNPS Peak Flow Rates Scenario Comparison with Current land cover base case at Williamstown

Event	PNV	Ideal	Realistic	AgBio	AgNoCon
Jun 8, 1987	-65.6%	-11.6%	-5.6%	26.3%	27.4%
Jul 24, 1987	-67.9%	-9.2%	-4.6%	28.4%	29.8%
Jun 16, 1993	-83.3%	-12.8%	-6.4%	28.3%	29.6%
Jun 6, 1994	-65.6%	-11.4%	-5.7%	26.1%	27.2%
Oct 21, 1995	-97.1%	-24.0%	-12.3%	52.5%	57.7%
Mar 23, 1999	-71.0%	-10.0%	-4.9%	21.9%	23.0%
Mar 27, 2000	-47.0%	-6.1%	-3.0%	13.8%	14.3%
Jun 10, 2002	-74.3%	-10.4%	-5.2%	21.7%	22.6%
Jun 14, 2002	-58.1%	-8.4%	-4.1%	18.0%	18.8%
May 24, 2003	-64.9%	-9.4%	-4.6%	20.8%	21.7%
Oct 26, 2003	-71.2%	-9.8%	-4.9%	20.5%	21.5%
Sep 8, 2004	-71.2%	-9.8%	-4.9%	20.9%	22.0%
Jun 16, 2005	-55.7%	-7.6%	-3.7%	16.5%	17.2%

Table 21: AGNPS Sediment Yield Scenario Results at Raisin River Watershed Outlet (tonnes)

Event	PNV	Ideal	Realistic	Current	AgBio	AgNoCon
Jun 8, 1987	104	888	911	925	1008	1010
Jul 24, 1987	380	1587	1643	1684	1917	1922
Jun 16, 1993	111	489	506	522	599	601
Jun 6, 1994	106	892	915	929	1015	1017
Oct 21, 1995	215	1333	1449	1572	2291	2312
Mar 23, 1999	190	920	981	1028	1327	1335
Mar 27, 2000	60	703	728	742	832	834
Jun 10, 2002	324	2784	3064	3259	4670	4704
Jun 14, 2002	220	981	1046	1090	1398	1405
May 24, 2003	111	926	955	972	1077	1079
Oct 26, 2003	271	1361	1448	1510	1914	1924
Sep 8, 2004	367	3934	4353	4645	6784	6834
Jun 16, 2005	185	762	798	823	983	986

Table 22: AGNPS Sediment Yield Scenario Comparison with Current land cover base case at the Raisin River Watershed Outlet

Event	PNV	Ideal	Realistic	AgBio	AgNoCon
Jun 8, 1987	-88.8%	-4.0%	-1.5%	9.0%	9.2%
Jul 24, 1987	-77.4%	-5.8%	-2.4%	13.8%	14.1%
Jun 16, 1993	-78.7%	-6.3%	-3.1%	14.8%	15.1%
Jun 6, 1994	-88.6%	-4.0%	-1.5%	9.3%	9.5%
Oct 21, 1995	-86.3%	-15.2%	-7.8%	45.7%	47.1%
Mar 23, 1999	-81.5%	-10.5%	-4.6%	29.1%	29.9%
Mar 27, 2000	-91.9%	-5.3%	-1.9%	12.1%	12.4%
Jun 10, 2002	-90.1%	-14.6%	-6.0%	43.3%	44.3%
Jun 14, 2002	-79.8%	-10.0%	-4.0%	28.3%	28.9%
May 24, 2003	-88.6%	-4.7%	-1.7%	10.8%	11.0%
Oct 26, 2003	-82.1%	-9.9%	-4.1%	26.8%	27.4%
Sep 8, 2004	-92.1%	-15.3%	-6.3%	46.0%	47.1%
Jun 16, 2005	-77.6%	-7.4%	-3.0%	19.4%	19.8%

Table 23: AGNPS Nitrogen in Sediment Scenario Results at Raisin River Watershed Outlet (kg/ha)

Event	PNV	Ideal	Realistic	Current	AgBio	AgNoCon
Jun 8, 1987	0.011	0.056	0.056	0.056	0.056	0.056
Jul 24, 1987	0.034	0.090	0.090	0.090	0.101	0.101
Jun 16, 1993	0.011	0.034	0.034	0.034	0.045	0.045
Jun 6, 1994	0.011	0.056	0.056	0.056	0.056	0.056
Oct 21, 1995	0.022	0.067	0.078	0.078	0.112	0.112
Mar 23, 1999	0.011	0.056	0.067	0.067	0.078	0.078
Mar 27, 2000	0.011	0.045	0.045	0.045	0.045	0.045
Jun 10, 2002	0.022	0.146	0.157	0.168	0.235	0.235
Jun 14, 2002	0.022	0.067	0.067	0.067	0.090	0.090
May 24, 2003	0.011	0.056	0.056	0.056	0.067	0.067
Oct 26, 2003	0.022	0.078	0.090	0.090	0.112	0.112
Sep 8, 2004	0.022	0.202	0.213	0.224	0.314	0.314
Jun 16, 2005	0.011	0.045	0.056	0.056	0.067	0.067

Table 24: AGNPS Nitrogen in Sediment Scenario Comparison with Current land cover base case at the Raisin River Watershed Outlet

Event	PNV	Ideal	Realistic	AgBio	AgNoCon
Jun 8, 1987	-80.4%	0%	0%	0%	0%
Jul 24, 1987	-62.2%	0%	0%	12.2%	12.2%
Jun 16, 1993	-67.6%	0%	0%	32.4%	32.4%
Jun 6, 1994	-80.4%	0%	0%	0%	0%
Oct 21, 1995	-71.8%	-14.1%	0%	43.6%	43.6%
Mar 23, 1999	-83.6%	-16.4%	0%	16.4%	16.4%
Mar 27, 2000	-75.6%	0%	0%	0%	0%
Jun 10, 2002	-86.9%	-13.1%	-6.5%	39.9%	39.9%
Jun 14, 2002	-67.2%	0%	0%	34.3%	34.3%
May 24, 2003	-80.4%	0%	0%	19.6%	19.6%
Oct 26, 2003	-75.6%	-13.3%	0%	24.4%	24.4%
Sep 8, 2004	-90.2%	-9.8%	-4.9%	40.2%	40.2%
Jun 16, 2005	-80.4%	-19.6%	0%	19.6%	19.6%

Table 25: AGNPS Phosphorus in Sediment Scenario Results at Raisin River Watershed Outlet (kg/ha)

Event	PNV	Ideal	Realistic	Current	AgBio	AgNoCon
Jun 8, 1987	0.000	0.022	0.022	0.022	0.034	0.034
Jul 24, 1987	0.011	0.045	0.045	0.045	0.056	0.056
Jun 16, 1993	0.000	0.011	0.022	0.022	0.022	0.022
Jun 6, 1994	0.000	0.022	0.022	0.022	0.034	0.034
Oct 21, 1995	0.011	0.034	0.034	0.045	0.056	0.056
Mar 23, 1999	0.011	0.034	0.034	0.034	0.045	0.045
Mar 27, 2000	0.000	0.022	0.022	0.022	0.022	0.022
Jun 10, 2002	0.011	0.078	0.078	0.090	0.112	0.123
Jun 14, 2002	0.011	0.034	0.034	0.034	0.045	0.045
May 24, 2003	0.011	0.022	0.022	0.022	0.034	0.034
Oct 26, 2003	0.011	0.045	0.045	0.045	0.056	0.056
Sep 8, 2004	0.011	0.101	0.112	0.112	0.157	0.157
Jun 16, 2005	0.011	0.022	0.022	0.022	0.034	0.034

Table 26: AGNPS Phosphorus in Sediment Scenario Comparison with the Current land cover scenario at the Raisin River Watershed Outlet

Event	PNV	Ideal	Realistic	AgBio	AgNoCon
Jun 8, 1987	-100.0%	0%	0%	54.5%	54.5%
Jul 24, 1987	-75.6%	0%	0%	24.4%	24.4%
Jun 16, 1993	-100.0%	-50.0%	0%	0%	0%
Jun 6, 1994	-100.0%	0%	0%	54.5%	54.5%
Oct 21, 1995	-75.6%	-24.4%	-24.4%	24.4%	24.4%
Mar 23, 1999	-67.6%	0%	0%	32.4%	32.4%
Mar 27, 2000	-100.0%	0%	0%	0%	0%
Jun 10, 2002	-87.8%	-13.3%	-13.3%	24.4%	36.7%
Jun 14, 2002	-67.6%	0%	0%	32.4%	32.4%
May 24, 2003	-50.0%	0%	0%	54.4%	54.5%
Oct 26, 2003	-75.6%	0%	0%	24.4%	24.4%
Sep 8, 2004	-90.2%	-9.8%	0%	40.2%	40.2%
Jun 16, 2005	-50.0%	0%	0%	54.5%	54.5%

6.3 Integrated Modelling Approach to Pollutant Source Tracing

One of the advantages of the AGNPS model over other non-point source models is its ability to trace pollutants back to their source. By pinpointing the major pollution sources, or hot spots, the AGNPS model assists decision makers to focus corrective actions at those locations.

It was observed that the September 8, 2004 storm produced the highest amount of sediment yield. In particular, the AgNoCon scenario predicted a total of 6,834 tonnes of sediment at the outlet of the Raisin River being generated by this extreme event. It is of interest to trace back to where the origins ("hot spots") of these sediments are. Figure 29 illustrates the results of the sediment source tracing at the Raisin River outlet. The cells with darker colours are the source cells that contribute the most to the sediment load at the outlet. It is identified that most of the source regions occur near the outlet along either side of the main branch. Similar pollutant source tracing was done for "nitrogen in sediment" and "phosphorus in sediment" as shown in Figures 30 and 31.

Figure 29: Sediment Source Tracing for the AgNoCon Scenario for the rainfall event on September 8, 2004

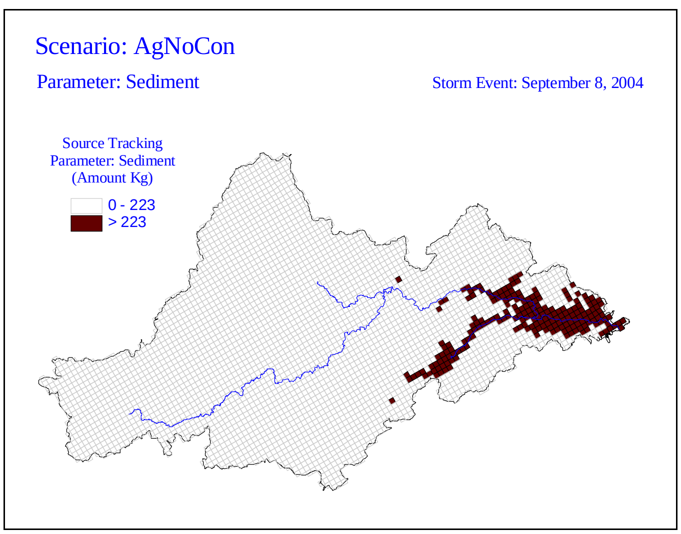


Figure 30: "Nitrogen in Sediment" Source Tracing for the AgNoCon Scenario for the rainfall event on September 8, 2004

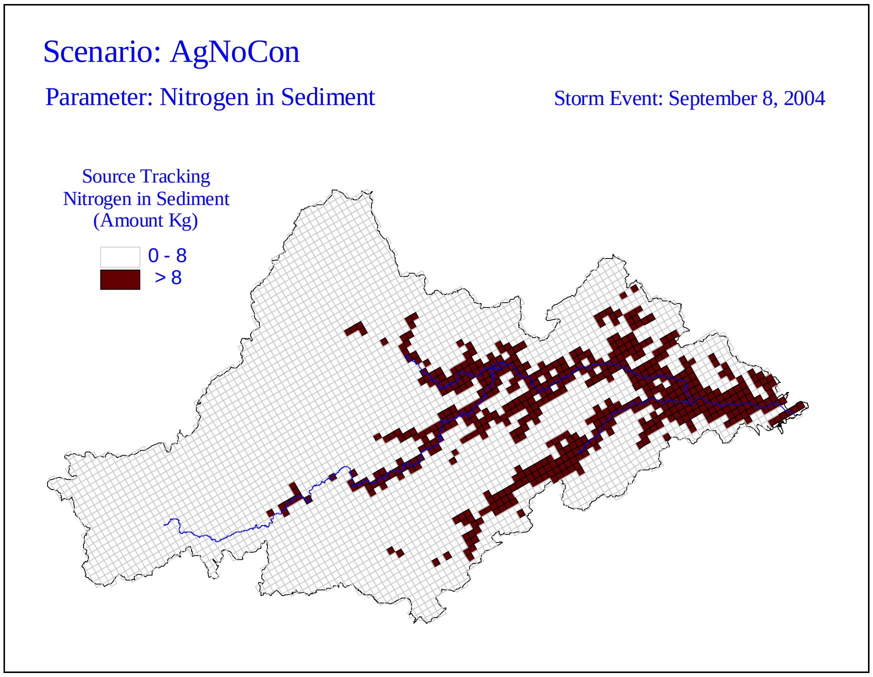
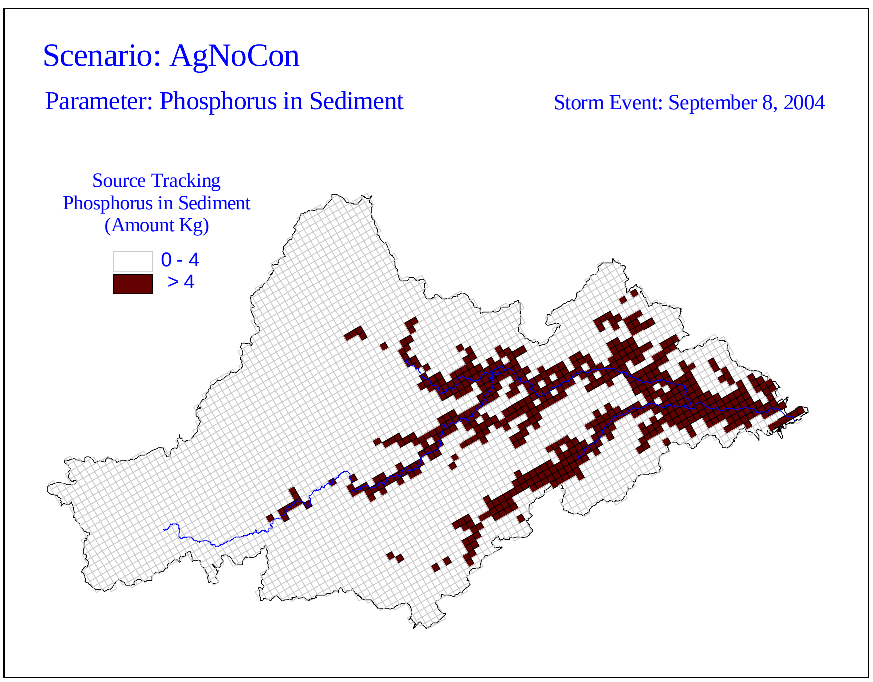


Figure 31: "Phosphorus in Sediment" Source Tracing for the AgNoCon Scenario for the rainfall event on September 8, 2004



Since the "hot spots" of the sediment source tracing from the AGNPS model for the extreme rainfall event are known, we can apply modelling techniques to change the land cover type and understand the impacts. The idea is to apply AGNPS to identify hot spots and then to use the SWAT model to assess long term impacts. The integration of the two non-point source models complements each other. Figure 32 illustrates the schematic of the integrated modelling approach. In the SWAT model, the filter strip option was activated for 5m, 10m, 15m, 20m, 25m and 30m at the high sediment yield "hot spots" as identified in Figure 29. Two scenarios, Current and AgNoCon, were used to assess the impact of the filter strip option. The SWAT results were collected as shown in Tables 27 to 29. It can be seen that the decrease of sediment yield is proportional to the filter strip length. The initial 5m filter strip provides the largest decrease in sediment and nutrients concentrations for both the Current and AgNoCon scenarios. For instance, using a 5 m filter strip will reduce TSS, TN and TP concentrations for the Current land cover scenario by 3%, 5.8% and 3.8%, respectively. This information is useful and can help decision makers properly address these vulnerable areas.

Figure 32: Schematic of the Integrated Modelling Approach

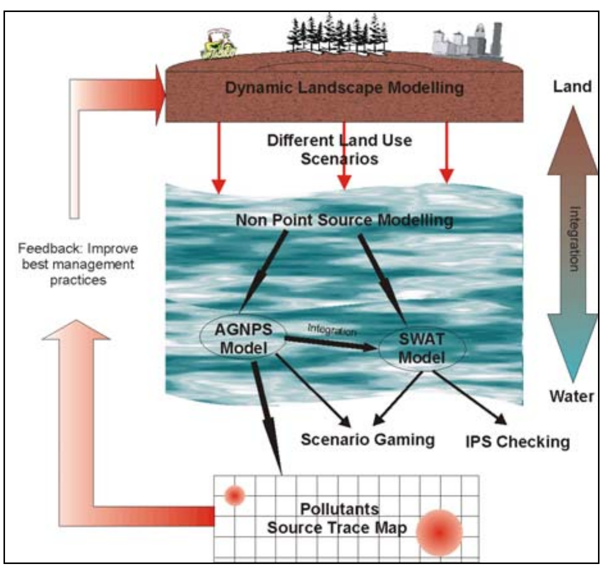


Table 27: SWAT Filter Strip Analysis Results for TSS (filter strips applied to high sediment yield "hot spots" identified by AGNPS pollutant source tracing)

Filter strip	Current		AgNoCon	
	Avg TSS (mg/L) at the Outlet	% change	Avg TSS (mg/L) at the Outlet	% change
None	7.05	-	8.49	-
5m	6.84	-3.0%	8.34	-1.8%
10m	6.81	-3.4%	8.32	-2.0%
15m	6.78	-3.8%	8.30	-2.2%
20m	6.76	-4.1%	8.29	-2.4%
25m	6.74	-4.4%	8.27	-2.6%
30m	6.73	-4.5%	8.26	-2.7%

Table 28: SWAT Filter Strip Analysis Results for TP (filter strips applied to high sediment yield "hot spots" identified by AGNPS pollutant source tracing)

Filter strip	Current		AgNoCon	
	Avg TP (mg/L) at the Outlet	% change	Avg TP (mg/L) at the Outlet	% change
None	0.0636	-	0.1134	-
5m	0.0599	-5.8%	0.1066	-6.0%
10m	0.0594	-6.6%	0.1057	-6.8%
15m	0.0590	-7.2%	0.1050	-7.4%
20m	0.0587	-7.7%	0.1045	-7.8%
25m	0.0585	-8.0%	0.1040	-8.3%
30m	0.0583	-8.3%	0.1037	-8.6%

Table 29: SWAT Filter Strip Analysis Results for TN (filter strips applied to high sediment yield "hot spots" identified by AGNPS pollutant source tracing)

	Current		AgNoCon	
Filter strip	Avg TN (mg/L) at the Outlet	% change	Avg TN (mg/L) at the Outlet	% change
None	2.004	-	3.375	-
5m	1.927	-3.8%	3.240	-4.0%
10m	1.917	-4.3%	3.220	-4.6%
15m	1.908	-4.8%	3.204	-5.1%
20m	1.900	-5.2%	3.189	-5.5%
25m	1.893	-5.5%	3.176	-5.9%
30m	1.886	-5.9%	3.163	-6.3%

6.4 Comparison of SWAT Results with Ideal Performance Standards

One of the goals in the land and water integration is to check the Raisin River watershed modelling results against the NAESI's Ideal Performance Standards (IPS). The Ideal Performance Standards (draft) of TSS (Culp et al., 2008), TN and TP (Chambers et al., 2008) for Ontario are 4.1, 1.07 and 0.024 mg/L, and for Quebec are 3.6, 0.66 and 0.027 mg/L, respectively. However, most of the data points for the IPS development are in southwestern Ontario. Since Raisin River watershed is located in southeastern Ontario and is near the Quebec border, the Quebec IPS for sediment and nutrients are also used for comparison. Table 30 lists both average and median SWAT model results of TSS, TN and TP; and uses both the IPS of Ontario and Quebec as a basis for comparison.

It is observed that the average model values are much higher than the median model values. Although PWQ stations were designed to collect samples monthly, samples in some years were not collected in all months, especially winter months. For example, the months from May to November have on average 33% more samples for phosphorus at Williamstown than for the months from December to April. Thus, the observed data are biased towards snow fall and snow melt months. This would result in missing the large loads of sediment and nutrients occurring during spring snowmelt. Also, sudden storm events that are captured in the model can also be missed since measurements are only once per month. The end result is that the average will be higher than the median because of the high values of extreme events during model simulation.

Since these IPS are determined by the median values of the observed data, we compare the median values of the 1985-2006 model results of TSS, TN and TP at Martintown, Cahion Glen, St. Andrews, Williamstown and the outlet with the IPS (Table 30). The results for the Current scenario indicate that the TSS median values of the SWAT model for all locations except at the

Outlet are below the TSS Ontario IPS. For TP, the locations of Martintown, St. Andrews and Williamstown meet both of the TP Ontario IPS and the TP Quebec IPS. However, for TN, all locations are above the TN IPS for both Ontario and Quebec. It is possible that the soils in the Raisin River watershed have naturally high TN levels or they may be the result of long term over fertilization of the crops. Since some of the results suggest that sediment and nutrients in the Raisin River watershed do not meet the Ideal Performance Standard, it is important that the Achievable Performance Standard (APS) should be developed to handle the local conditions of the watershed.

Table 30: Comparison of SWAT average and median results with the Ideal Performance Standards for sediment and nutrients

	TSS (mg/L)		% of days below IPS (TSS)		TN (mg/L)		% of days below IPS (TN)		TP (mg/L)		% of days below IPS (TP)	
	Avg	**Med**	**Ont**	**Queb**	**Avg**	**Med**	**Ont**	**Queb**	**Avg**	**Med**	**Ont**	**Queb**
IPS Target			**4.1**	**3.6**			**1.07**	**0.66**			**0.024**	**0.027**
PNV												
Martintown	4.46	0.16	76%	74%	0.82	0.70	71%	46%	0.0096	0.0088	100%	100%
Cahion Glen	3.12	1.34	74%	72%	1.34	1.48	30%	20%	0.0205	0.0108	78%	80%
St. Andrews	4.50	0.15	76%	74%	0.86	0.80	69%	32%	0.0103	0.0090	98%	99%
Williamstown	3.61	0.60	73%	71%	0.98	0.91	61%	24%	0.0122	0.0102	96%	98%
Outlet	3.82	0.86	72%	70%	1.07	1.03	53%	21%	0.0147	0.0114	87%	91%
Ideal												
Martintown	5.54	0.54	70%	68%	1.19	0.96	59%	28%	0.0251	0.0139	73%	75%
Cahion Glen	4.43	2.79	58%	56%	1.98	1.61	23%	9%	0.0750	0.0400	42%	44%
St. Andrews	4.83	0.41	71%	69%	1.32	1.11	47%	23%	0.0258	0.0133	72%	75%
Williamstown	5.48	2.88	59%	56%	1.60	1.33	28%	11%	0.0426	0.0198	58%	61%
Outlet	6.42	3.78	52%	48%	1.75	1.47	20%	7%	0.0540	0.0295	44%	48%
Real												
Martintown	8.27	2.85	56%	54%	1.37	1.19	41%	16%	0.0304	0.0143	70%	72%
Cahion Glen	4.59	3.07	56%	54%	2.11	1.84	14%	5%	0.0780	0.0403	43%	45%
St. Andrews	5.47	1.43	65%	63%	1.47	1.27	36%	16%	0.0303	0.0141	69%	71%
Williamstown	6.12	3.60	54%	50%	1.85	1.63	16%	8%	0.0525	0.0211	54%	58%
Outlet	6.92	4.37	48%	45%	1.95	1.73	12%	5%	0.0607	0.0310	43%	47%
Current												
Martintown	8.60	3.23	55%	52%	1.44	1.25	35%	15%	0.0336	0.0147	68%	70%

Table 30: Comparison of SWAT average and median results with the Ideal Performance Standards for sediment and nutrients

	TSS (mg/L)		% of days below IPS (TSS)		TN (mg/L)		% of days below IPS (TN)		TP (mg/L)		% of days below IPS (TP)	
	Avg	**Med**	**Ont**	**Queb**	**Avg**	**Med**	**Ont**	**Queb**	**Avg**	**Med**	**Ont**	**Queb**
Cahion Glen	4.65	3.13	55%	53%	2.15	1.85	14%	5%	0.0784	0.0405	43%	44%
St. Andrews	5.43	1.49	65%	63%	1.48	1.28	36%	16%	0.0318	0.0142	68%	70%
Williamstown	6.28	3.82	52%	49%	1.90	1.69	15%	7%	0.0560	0.0219	53%	56%
Outlet	7.05	4.52	47%	44%	2.00	1.77	12%	5%	0.0636	0.0321	42%	45%
AgBio												
Martintown	14.51	10.1	25%	22%	3.17	3.28	6%	5%	0.0852	0.0317	45%	47%
Cahion Glen	5.27	4.40	48%	46%	3.50	3.55	4%	3%	0.1228	0.0742	34%	35%
St. Andrews	12.60	7.51	33%	30%	3.17	3.14	7%	5%	0.0820	0.0269	48%	50%
Williamstown	7.86	6.05	38%	34%	3.33	3.37	4%	3%	0.1050	0.0485	36%	38%
Outlet	8.48	6.49	35%	32%	3.35	3.39	3%	2%	0.1126	0.0622	29%	32%
AgNoCon												
Martintown	14.52	10.1	25%	22%	3.17	3.29	6%	5%	0.0855	0.0318	45%	47%
Cahion Glen	5.28	4.42	48%	46%	3.51	3.56	4%	3%	0.1231	0.0746	34%	35%
St. Andrews	12.66	7.56	33%	30%	3.25	3.24	6%	5%	0.0839	0.0271	48%	50%
Williamstown	7.88	6.09	38%	34%	3.36	3.40	4%	3%	0.1063	0.0488	36%	38%
Outlet	8.49	6.52	35%	32%	3.37	3.42	3%	2%	0.1134	0.0623	29%	32%

6.5 Sensitivity Analysis

It is important to understand how sensitive the additional buffer on land cover type is to the model outputs. In this study, the sensitivity analysis that was done involved studying the effects of using filter strips of different sizes in the SWAT model. Filter strips, ranging in widths from 5 metres to 30 metres, were added to agricultural row-crop lands throughout the Raisin River watershed for both the Current and AgNoCon land use scenarios. A SWAT model run was performed for each one of the filter strip sizes (all other model inputs were held constant). Tables 31 and 32 shows the sensitivity results of TSS, TN and TP simulation for the Raisin River Watershed outlet. It can be seen that as the filter strip buffer increases, all of TSS, TN and TP decreases. The biggest relative change of the sediment occurs at 30m. However, the biggest rate of decrease of the nutrients, both TN and TP, occurs at 5m. It is observed that the TSS concentration is sensitive to the increasing buffer length, especially in the case of the AgNoCon scenario. However, the TN and TP are sensitive to the first 5m of the filter strip and the rates are diminishing as the lengths are increasing.

Table 31: Current scenario - Sensitivity Analysis for applying filter strips to the agricultural row-crop lands throughout the Raisin River Watershed

Filter Strip	Avg TSS (mg/L) at the Outlet	% change	Avg TP (mg/L) at the Outlet	% change	Avg TN (mg/L) at the Outlet	% change
Without filter strip option	7.05	-	0.064	-	2.00	-
5 m	6.60	-6.4%	0.050	-21.9%	1.83	-8.5%
10 m	6.38	-9.5%	0.046	-28.1%	1.75	-12.5%
15 m	6.15	-12.8%	0.044	-31.3%	1.68	-16.0%
20 m	5.84	-17.2%	0.043	-32.8%	1.61	-19.5%
25 m	5.35	-24.1%	0.041	-35.9%	1.55	-22.5%
30 m	4.43	-37.2%	0.040	-37.5%	1.50	-25.0%

Table 32: AgNoCon scenario - Sensitivity Analysis for applying filter strips to the agricultural row-crop lands throughout the Raisin River Watershed

Filter Strip	Avg TSS (mg/L) at the Outlet	% change	Avg TP (mg/L) at the Outlet	% change	Avg TN (mg/L) at the Outlet	% change
Without filter strip option	8.49	-	0.113	-	3.37	-
5 m	8.18	-3.7%	0.059	-47.8%	2.70	-19.9%
10 m	7.99	-5.9%	0.047	-58.4%	2.36	-30.0%
15 m	7.75	-8.7%	0.038	-66.4%	2.06	-38.9%
20 m	7.40	-12.8%	0.031	-72.6%	1.78	-47.2%
25 m	6.65	-21.7%	0.026	-77.0%	1.51	-55.2%
30 m	3.06	-64.0%	0.022	-80.5%	1.25	-62.9%

6.6 Data Gap

Data gap problems make it difficult to carry out the non-point source modelling work. Some data are required for model inputs and some are required for the purpose of calibration and validation. Non-point source models require extensive data such as land cover, soil, meteorological, fertilizer, flow and water quality data. It is essential to have the correct and up-to-date data in place to ensure the effectiveness of the modelling exercise. However, some of these data are limited in amount and some of them have spatial and temporal problems. The WSC flow gauging stations are not located in the same vicinity as the water quality stations. This makes it difficult to accurately calculate the pollution loads such as those for sediment and nutrients at a location. Multiple datasets do not have the same time frame so this makes the calibration and validation difficult. The sediment data is available only at the outlet of the Raisin River watershed for 2005 - 2006 and the 2006 flow data is not yet available. Therefore, the 2006 sediment data cannot be used for calibration and validation without the flow data at the same time frame. In addition, the sediment data was sparse and only available for the summer months which decreases the confidence in the sediment calibration and the predictions for non summer months and for other years. Since nutrients are directly affected by sediment predictions, then it becomes difficult to calibrate the nutrients and decreases the confidence in the nutrient calibration.

SWAT is a U.S. model and its weather generation stations database contains only U.S. information. A new weather generation station was built for Raisin River Watershed for this study. However, some of the weather data still comes from the U.S. because there is no Canadian weather station closer than the U.S. station that collects information such as solar radiation, dew point temperature, and wind speed.

There is limited data on tile drain depth, amount of time to drain the soil to field capacity, and lag time between the drain and the outlet to the channel for each HRU. It is not possible to model tile drainage in SWAT given the current data constraints.

The 2001 Census of Agriculture Database compiled by Statistics Canada is available for this study. However, the data itself is not applicable for the models because of its aspatial nature and it is available only for large soil landscape units and thus makes it impossible to assign meaningful values to the grid cells (AGNPS) and the HRUs (SWAT). Some of the larger landuse groups are row crops and pasture which both have fertilizer application. Fertilizer applications had to be estimated using values from previous studies for other watersheds (refer to section 4.8) which introduces uncertainty to the nutrient simulations.

Initial soil concentrations of nutrients, which are another important part of nutrient simulation, were also not known and were estimated using the default values in the SWAT model. Because SWAT is a US based model and the defaults may not be as applicable to Canadian soils.

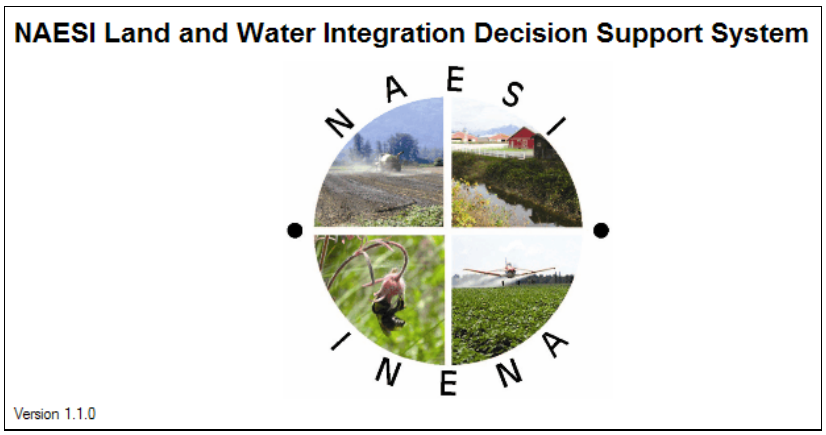
Crop rotation can affect all simulated parameters of flow, sediment and nutrients, but due to a lack of data and for modelling simplicity, this was not simulated.

7. THE NAESI LAND AND WATER INTEGRATION DECISION SUPPORT SYSTEM (NAESI LWIDSS)

7.1 Motivation

Water quality modelling is a large and complex process requiring great quantities of input and generating vast amounts of output because of its nature of trying to simulate real-world processes. Dealing with such sums of data, both inputs and outputs, can be daunting to those who are trying to understand and extract knowledge and information from them. Not all modelling programs contain tools for visualizing the results, comparing multiple sets of results, performing post-analysis or managing/organizing the data from different model runs. Typically, after running the models, different software are employed to look at the output and to do further statistical analysis and these can be time consuming procedures by themselves. It is apparent that it would be very useful to have an integrated set of tools in a single software system that performs these tasks. This would make those doing modelling more productive by allowing them to examine the results in a more efficient manner. More time can be spent on modelling and less time on manipulating data to move it into a software program. This is the motivation behind developing the NAESI Land and Water Integration Decision Support System (the NAESI LWIDSS). Even though the NAESI project is the genesis of the LWIDSS, it can be applied to other similar modelling work. The NAESI LWIDSS integrates the SWAT (Soil and Water Assessment Tool) and the single-event version of AGNPS (Agriculture Non-Point Source) models. Figure 33 shows the NAESI LWIDSS splash screen.

Figure 33: NAESI Land and Water Integration Decision Support System Splash Screen



7.2 Features of NAESI LWIDSS

The NAESI LWIDSS captures most of the analytical processes of the NAESI land/water integration. Due to the complexity of the models and the existing tools to setup the input files, the execution of the non-point source models and their related input file setup functions are excluded from the LWIDSS (meaning they are run standalone outside of the LWIDSS just like they normally would). However, the LWIDSS can be used to assist during the calibration and validation phase of the modelling process by providing visualization tools to compare the predicted model results to the observed data. Refer to "Appendix B: Project Setup" of the

LWIDSS user guide (Wong and Fong, 2008) for details on getting the model outputs into the LWIDSS. The value-added features provided by the LWIDSS are visualization of model results, scenario comparison, thematic mapping, visualization of model inputs, sensitivity analysis and pollutant source tracing.

The LWIDSS handles two models: SWAT 2005 and AGNPS (single event version). The sources of the model and software are listed in Table 33.

Table 33: Sources of the model and software used in the LWIDSS

Model/Software	Source
SWAT 2005	www.brc.tamus.edu/swat/soft_model_2005soft.html
AVSWAT-X	www.brc.tamus.edu/swat/avswat.html This is an ArcView Interface to the SWAT model. **Requirements**: ArcView 3.1 or later and ArcView Spatial Analyst Extension.
AGNPS	www.wsi.nrcs.usda.gov/products/w2q/h&h/tools_models/agnps/index.html.
ROS AGNPS Interface & AGNPS model package	Contact Dr. Luis Leon (lfleonvi@uwaterloo.ca).

7.2.1 Visualization of the Modelling Results

After a model has been run, one typically would like to take a look at the results. The NAESI LWIDSS has many functions for looking at the SWAT and AGNPS model outputs in a variety of different ways that includes graphs and tables (Figure 33). Model results are also organized by scenario, spatial location (sub-basin outlet in the case of SWAT and grid cell for AGNPS) and by parameter (e.g., flow, TSS, TN and TP). This makes it easier for one to find the results of interest. Because SWAT is a time-continuous model, the NAESI LWIDSS also has functions for defining the time period to view and for summarizing the results (averages) by month or by year. During the process of calibration and validation of the model, one needs to be able to compare the predicted model output with the observed values. The system provides facilities for plotting the observations over the model results (Figure 35).

Figure 34: Viewing AGNPS model results for total sediment yield at the watershed outlet for the Current scenario.

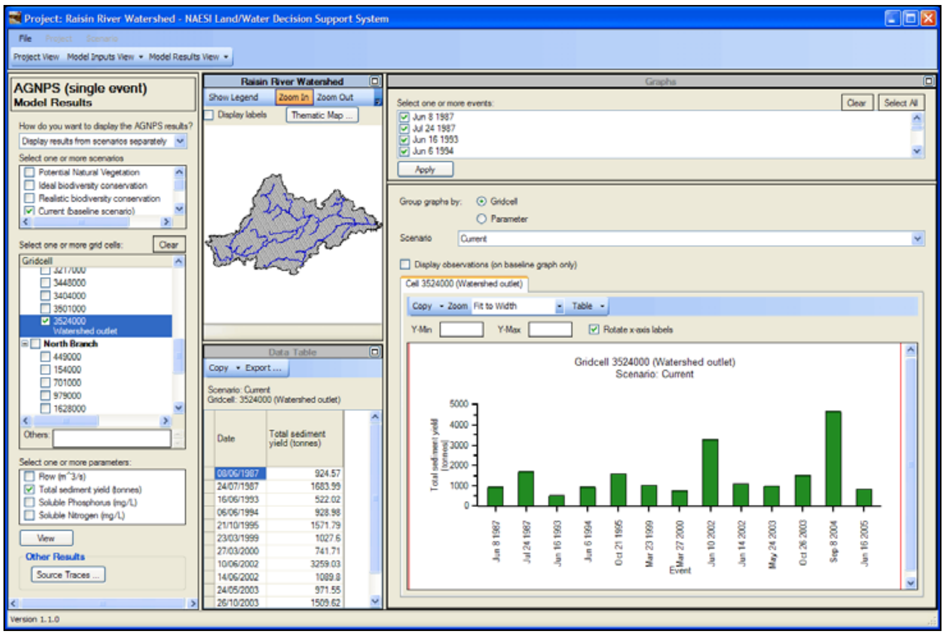
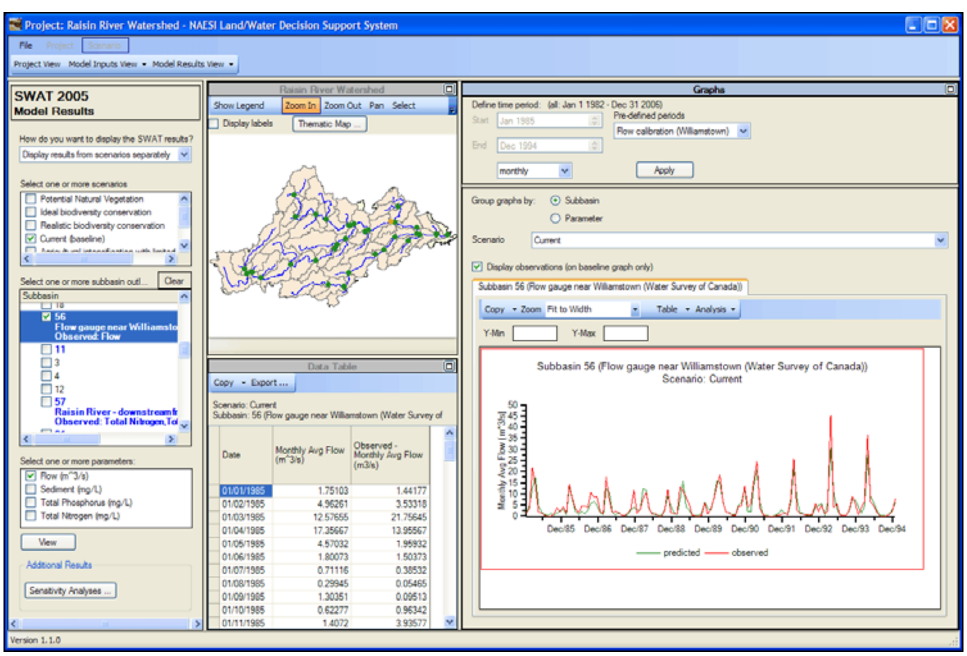


Figure 35: Comparing the observed flow with the SWAT model predictions.

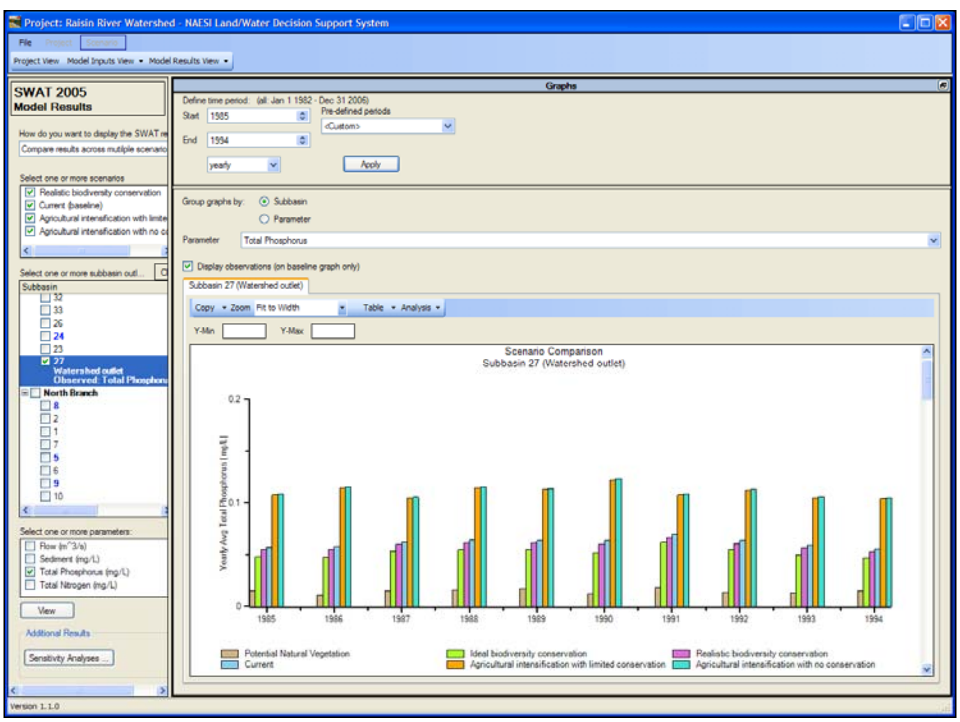


Because no one software can possibly have all the functions one may require, the NAESI LWIDSS has ways of exporting the model output into other software using copy and paste or CSV files. Graphs can also be copied into reports or presentations.

7.2.2 Scenario Comparison

Scenario gaming and comparison is an important feature in the NAESI LWIDSS. This module assists the user to compare more than one set of model results to observe how different scenarios affect the output. In this study, each of the six scenarios contains a different land use map for the Raisin River watershed. In the NAESI LWIDSS, model results are plotted on the same graph with each scenario in its own graph series (Figure 36). A comparison table is also provided to give a numeric view of the differences. Results of the scenario comparison can be extracted from the NAESI LWIDSS and can be summarized in the report.

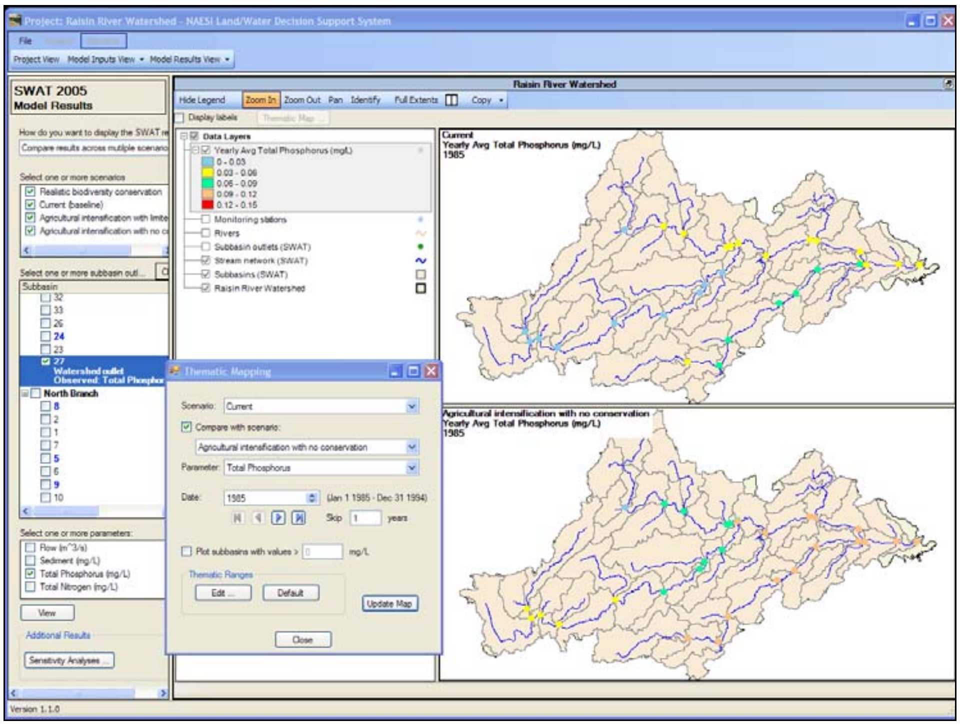
Figure 36: Comparing SWAT model results for total phosphorus across the six land use scenarios.



7.2.3 Thematic Mapping

In the NAESI LWIDSS, graphs and tables are good for displaying results at a sub-basin or a grid cell, depending on the model. However, this can be a poor method of trying to understand what the results are showing on a much broader spatial scale, say, across the entire watershed. The technique of thematic mapping can be employed in this situation. One version of thematic mapping colours or shades areas of a map based on which one of the pre-defined ranges their values fall into. In this project, the areas are the sub-basin outlets or grid cells and the values are the model results such as sediment or phosphorus. Thematic mapping allows regions of low and high values (i.e., hotspots) to be spotted quickly and spatial patterns to be identified, as shown in Figure 37.

Figure 37: Thematic mapping total phosphorus in the Raisin River Watershed for the Current and "Agricultural intensification with no conservation" scenarios.



7.2.4 Visualization of Model Inputs

Reviewing the input data of the model is also an important aspect in the overall modelling process. It allows one to check and possibly confirm whether or not the results produced from the model seem reasonable. Going back and examining the input data can also help to get some insight into why one is getting certain results when they may be expecting something different.

The NAESI LWIDSS contains functions not only to display the model inputs for SWAT and AGNPS, but also to perform some simple analysis on the inputs. More specifically, the DSS focuses on the spatial input data (e.g., soil and land use maps) and generates summary information on the soil or land use composition (i.e., the percentage taken up by each soil or land use class) for the entire watershed or for selected sub-basins.

For example, as the results in Table 17 and Figure 28 show, the annual averages for total phosphorus at Cahion Glen (south branch, SWAT Sub-basin 60) are greater than those at Martintown (north branch, SWAT Sub-basin 58) for the Current scenario. The functions found in the NAESI LWIDSS can be used to help explain why this may be the case. A land use composition analysis is first done for sub-basin 58 plus its drainage sub-basins. The results can be copied and placed elsewhere, for example, into Excel. Next, the same composition analysis is done for sub-basin 60 plus its drainage sub-basins. When comparing the landscape make-up for both these areas (Figures 38 and 39), there are higher percentages of wetlands (24% vs. 12%) and forests (30% vs. 14%) along the north branch than the south branch. The south branch contains greater areas of fertilizer use (39% vs. 36%) and residential (18% vs. 2%). It would appear that along the south branch there are potentially more sources of pollutants.

Figure 38: Land use composition for the Martintown drainage sub-basin.

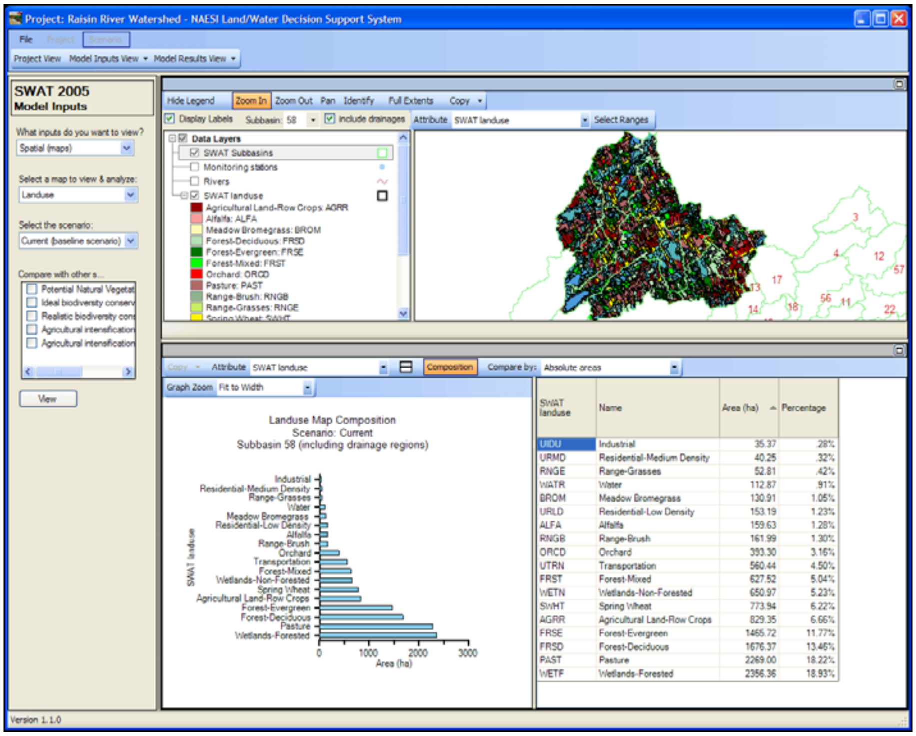
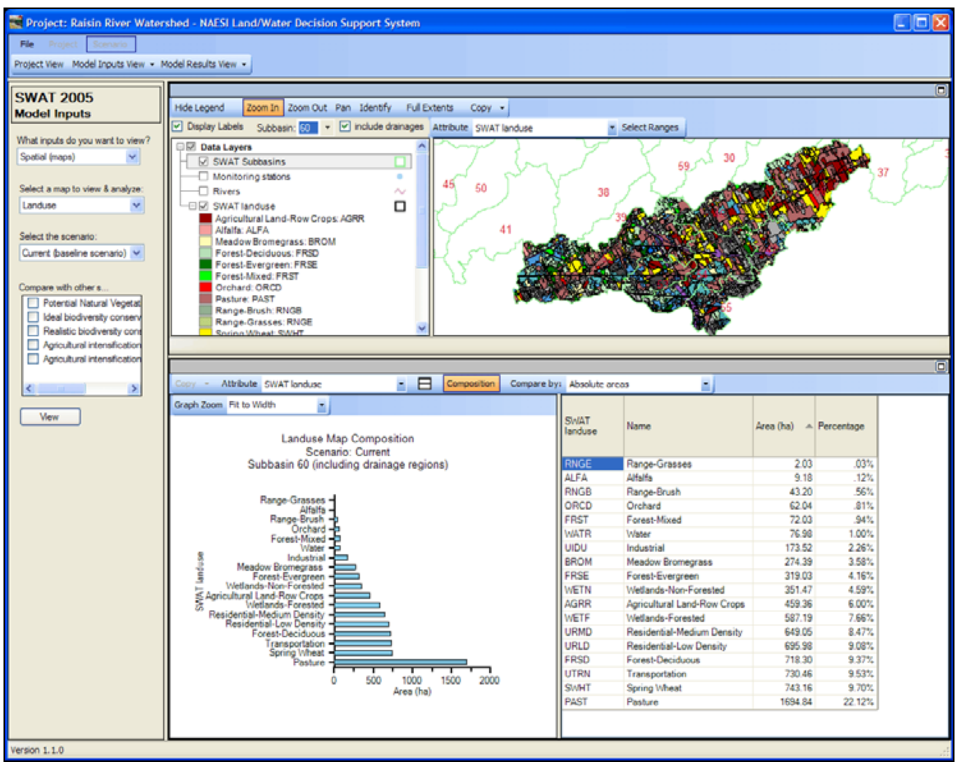
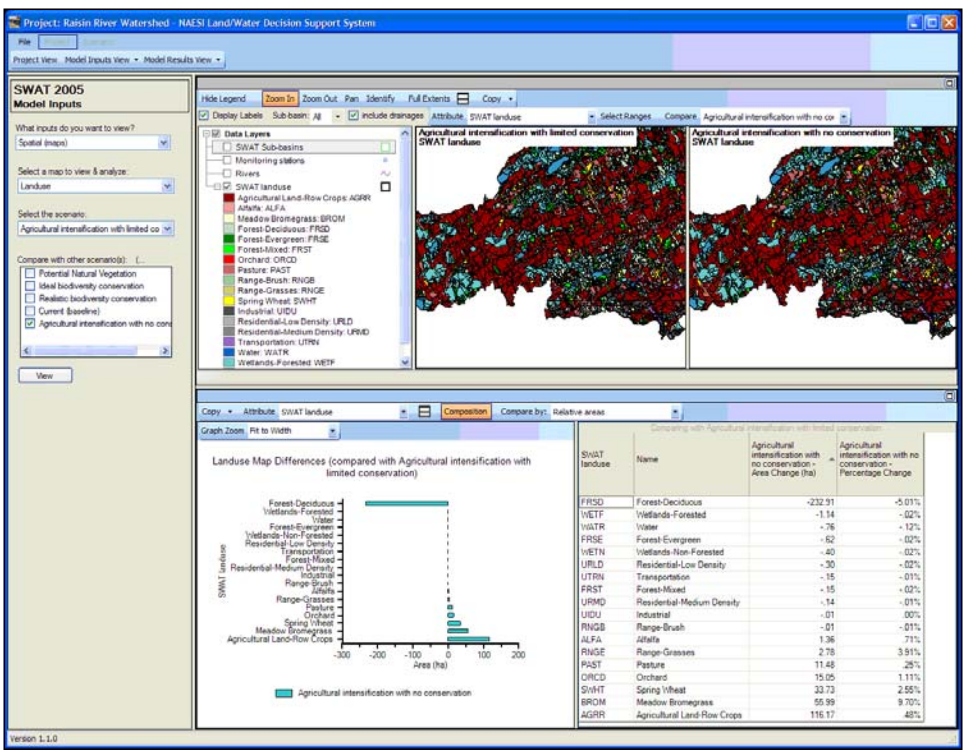


Figure 39: Land use composition for the Cahion Glen drainage sub-basin.



As another example, Table 17 and Figure 28 also indicate that the model results for the two agricultural intensification land use scenarios (limited conservation and no conservation) are very close to each other. The NAESI LWIDSS can be used to show the difference in areas (and also the relative change) for each of the land use types between these two scenarios over the entire watershed (Figure 40). The results reveal that there is very little difference in terms of land use area between the two scenarios. Most of the land use types have a relative change of less than 1% and the most any one has is just under 10%. This would then seem to explain why the model results for the two agriculture scenarios are so similar to one another.

Figure 40: Comparing Raisin River Watershed's land use composition for the two agricultural intensification scenarios.

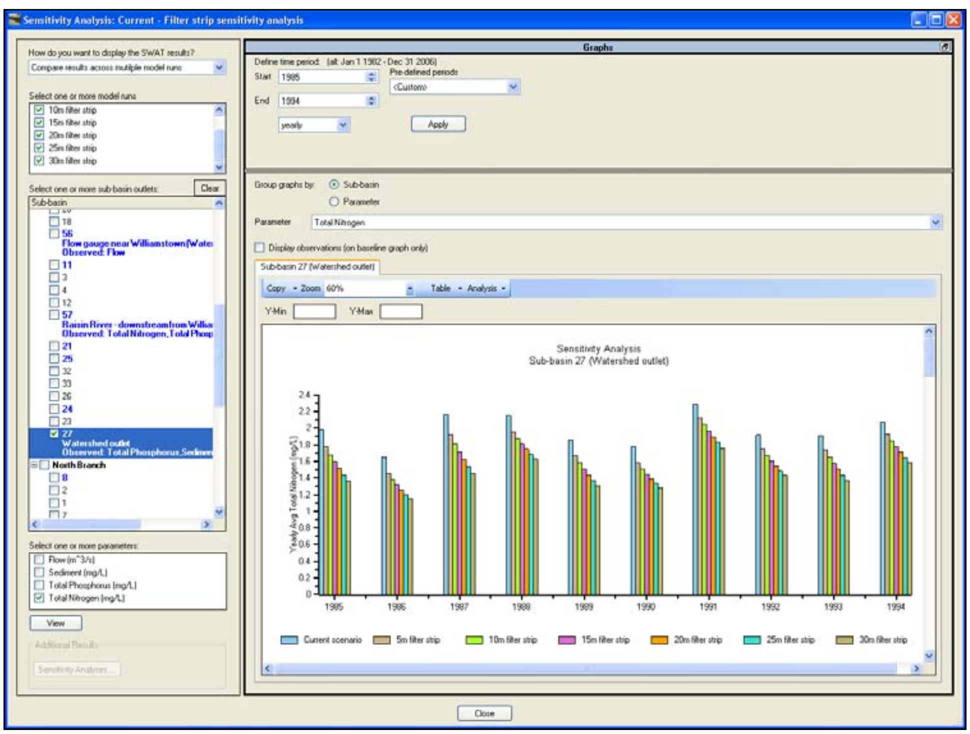


7.2.5 Sensitivity Analysis

Sensitivity analysis is an essential part in any modelling work. Model's variables are studied to evaluate the effects of varying a model's inputs on the outputs. Results from sensitivity analyses can be examined within the NAESI LWIDSS using many of the tools previously mentioned. For example, scenario comparison graphs can be used to show how the model results change as one of the model's variables is varied (here, a model run is treated as a "scenario"). In addition, the system can act as a repository for the analysis results that can lead to better data organization.

One sensitivity analysis that was done for the NAESI project involved studying the effects of including filter strips in the SWAT model. Filter strips, ranging in widths from 5 metres to 30 metres, were added to agricultural row-crop lands throughout the Raisin River watershed for the current land use scenario (Figure 41). A SWAT model run was performed for each one of the filter strip sizes (all other model inputs were held constant). The NAESI LWIDSS showed that the greater the filter strip size, the less sediment, phosphorus and nitrogen were predicted at the sub-basin outlets.

Figure 41: SWAT model results for total nitrogen after the application of filter strips.



The next step is to select the "best" filter strip width to use in Best Management Practices (BMP). The NAESI LWIDSS contains such a tool that can assist with this task. Briefly, one or more "targets" (e.g., sediment, phosphorus or nitrogen) are chosen to identify the pollutants that are trying to be reduced and then search criteria are defined to set up the rules used in selecting a filter strip width (e.g., the filter strip that caused the biggest drop in the target).

7.2.6 AGNPS Pollutant Source Tracing

The AGNPS model has the capability of finding the sources of pollution (i.e., sediments, nutrients) in any given grid cell after the model has been run. In addition, the amounts of pollutants contributed by the source locations to the target grid cell can also be computed (Figure 42). This information can then be used as a guide to employ BMPs at source locations that contribute the greatest amount of pollutants.

For the this study, after the sources of pollution to the outlet of the Raisin River watershed were identified using AGNPS source tracing, two methods of pollution reduction were tested. One is the aforementioned filter strips and the other is land use change. In the latter case, various percentages of agricultural row-crop lands (10%, 20%, 50% and 100%) at the source locations were converted into forest. After each one of these methods was applied, the AGNPS and/or SWAT models were then re-run. All of the results, including the ones from source tracing, were brought into the NAESI LWIDSS for review (Figures 42 and 43).

Figure 42: Results from an AGNPS source tracing run. Red grid cells are source locations that contribute more then 223 kg of sediment to the watershed outlet.

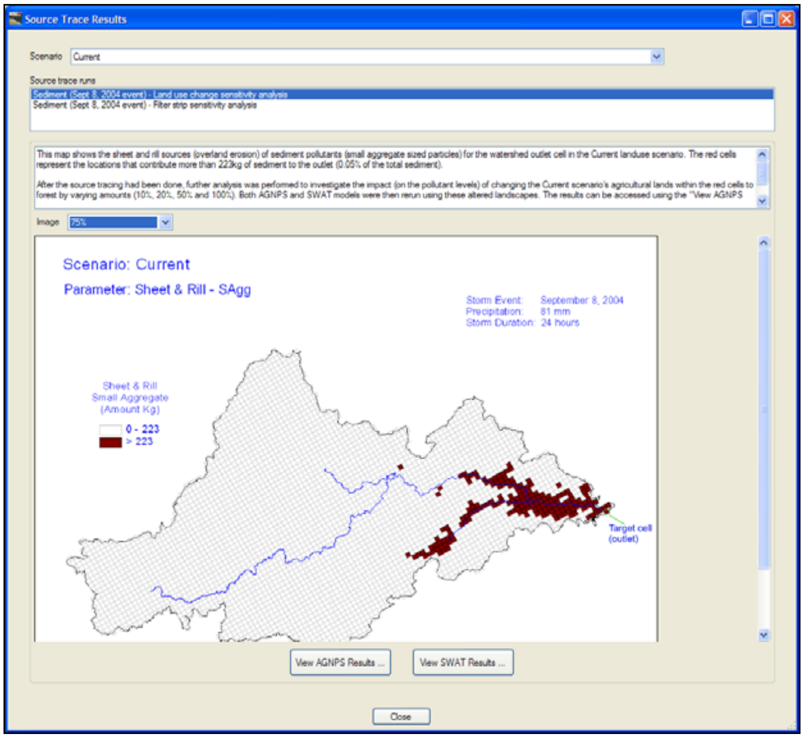
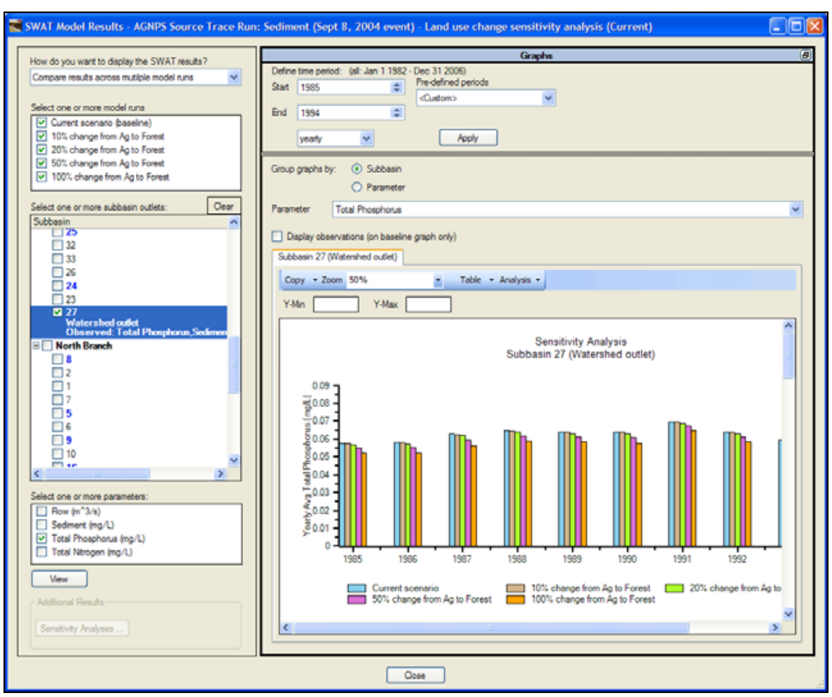


Figure 43: SWAT model results for total phosphorus after changing some agriculture row-crop lands to forest at the source locations.



7.3 Open Architecture and External Linkages

Since the structure of the NAESI LWIDSS is built on the WILDSPACE framework (Wong et al., 2003), it can store and retrieve model inputs and outputs, scenario gaming information and link seamlessly with other systems or models such as the AAFC's NAHARP Wildlife Habitat Indicator System. The design of the NAESI LWIDSS facilitates integration of diverse information, ranging from various land use scenario map layers, to soil texture map layer, to Digital Elevation Model data, and to water quality data. The NAESI LWIDSS is designed to provide an opportunity to query a variety of databases, to visualize spatial and/or temporal patterns, and to analyze model input data and output results using the DSS customized tools. Inherent to the NAESI LWIDSS architecture are relational databases with common design structures for data integration to be used in the modelling and scenario gaming framework. The use of modelling and scenario gaming will allow decision-makers to explore potential responses of land and water integration to hypothetical situations, i.e., to answer the "what-if" question.

The use of common data structures avoids data duplication. Modelling data and results such as land use scenarios, sediment and nutrients from the NAESI LWIDSS can feed directly into NAHARP Wildlife Habitat Indicator System and vice versa. In addition, the design of the NAESI LWIDSS is flexible so it can integrate other multidisciplinary and/or multimedia models such as the NAHARP's models into the system. Other possible linkages include providing modelling and scenario information to AAFC's NLWIS system by web services; reusing the DSS approach for other priority studies such as Lake Winnipeg Initiatives; and feeding the modelling results as inputs to other models such as Water Quality Index.

8 CONCLUSIONS AND RECOMMENDATIONS

The integration of the land and water project was aimed at evaluating the capability of the

AGNPS and SWAT models in modelling the flow, sediment and nutrients for various NAESI Biodiversity Standards scenarios in one of its pilot study areas, Raisin River Watershed within the Eastern Ontario Model Forest. In spite of data gap problems and limitations, the calibration of the models was reasonably successful. The calibrated models were used to identify the impact of the various land cover scenarios on water quality, in particular, sediment and nutrients (nitrogen and phosphorus). Results of the models were incorporated into the NAESI Land and Water Integration Decision Support System to effectively view model inputs and results, compare scenarios, thematic map, analyze sensitivity, and trace pollution sources.

The SWAT model provided results in a continuous time frame. Using SWAT, the PNV scenario predicts the largest reduction in sediment and nutrient concentrations as compared to the Current scenario. The Ideal scenario also shows some significant reduction and the Realistic scenario indicates modest reduction in both sediment and nutrients. The two agricultural intensification scenarios, AgBio and AgNoCon, predict significant increases in both sediment and nutrients. In particular, the AgNoCon scenario predicts the highest increase among all the land use scenarios.

In the case of AGNPS, the most serious storm event was September 8, 2004. Source tracing of pollutants showed a clear picture where the most vulnerable areas are for sediment and nutrient runoff. The SWAT model can be used to evaluate the benefit of adding filter strips to these areas. It was found that a 5 m filter strip provides the most optimal reduction in both sediment and nutrients.

The results of the SWAT models can also be used to compare with the Ideal Performance Standards. It was found that TSS and TP for the Raisin River watershed are in general within the IPS guidelines but TN results are above the IPS. One possibility is that the soils in the Raisin River watershed have naturally high TN levels. Another possibility is that the high TN levels may be the result of long term over fertilization of the crops.

If data gaps mentioned in this report can be filled then model calibration can likely be improved and confidence in the predictions increased. In particular, more observed data is required. Other valuable data would include actual fertilizer application rates, soil nutrient concentrations, crop rotation cycles, detailed tile drainage data and a field verified DEM that would allow for more accurate watershed delineation. In addition, the current manual calibration of the models might be improved by using some automated calibration techniques. Refinement of other model characteristics such as basin size, land use and soil thresholds could improve calibration results as well.

The NAESI LWIDSS framework can be used to determine the impact assessment of various land use scenarios on sediment and nutrients. Most of the integration process is captured in the DSS and can be used for other similar watersheds if appropriate data is available. The results of the modelling and scenario gaming can be linked with other systems using a common data exchange interface. Although the DSS is currently not fully automated, the system is completely capable of assisting in the assessment process. With further development in the future, the system can become more automated. Future work should build on this framework, to improve on scenario gaming through dynamic modelling, sensitivity analysis of individual parameters, automation of calibration and validation, fully integrate models within the DSS, and complete the feedback loop among models. This will allow the user to input specific land use decisions to investigate impacts on both water quality and elements of biodiversity. Potential linkages to other government programs include NAHARP, WEBs, Lake Winnipeg and GeoConnections.

The current NAESI LWIDSS is a desktop system. It is recommended that future generations of the NAESI LWIDSS should consider some web presence. This will ensure its interaction among other systems such as NLWIS. Specifically, the DSS should support three types of clients: the Intranet, the Extranet and the Internet. The Intranet refers to the implementation of a system using Internet technologies within the department, rather than external connections to the global Internet. Though similar to the Intranet, the Extranet provides access to departmental resources for a different set of users, predominantly those representing partner agencies or stakeholders. Finally, the Internet provides access to summarized information, including tables, graphs and maps generated as a result of web service queries.

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