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Integrated Land and Water Scenarios of the Raisin River Watershed Using the SWAT Model

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This paper investigates the linkage between Canada's National Agri-Environmental Standards Initiative (NAESI) Biodiversity and Water themes by studying how patterns in terrestrial habitat, generated through land cover scenario modelling, influence water quality and quantity in the Raisin River watershed in southeastern Ontario. NAESI developed nonregulatory performance standards that define ideal and achievable levels of environmental quality. The indicators used to investigate the scenario risks included sediment and nutrient concentrations. The SWAT (Soil and Water Assessment Tool)-2005 model was calibrated and validated from 1985 to 2006 for current land cover and five other scenarios: potential natural vegetation (PNV); high biodiversity conservation (HBC); moderate biodiversity conservation; agricultural intensification with limited application of conservation direction; and agricultural intensification with no consideration of conservation direction (ANC). Scenario comparisons are provided for the average annual flow, and concentrations of total suspended sediment (TSS), total nitrogen, and total phosphorus for five watershed locations. The PNV scenario predicted the lowest total flows, and sediment and nutrient concentrations, and the ANC scenario predicted the highest sediment and nutrient concentrations. The SWAT median values for the HBC, "Current," and ANC scenarios at the outlet all exceeded the Ideal Performance Standards, except for the median TSS concentration of the HBC scenario.

Key words: **nonpoint source pollutants, integrated modelling, scenario, biodiversity, water quality**

Introduction

Agriculture and Agri-Food Canada's (AAFC) Agriculture Policy Framework (APF) was launched in 2002. The objective was to establish Canadian leadership in food safety, innovation, and environmentally responsible food production in the world. Hence, the environment is one of the key elements in APF. Environment Canada, under a five-year memorandum of understanding with AAFC, has committed to the development of environmental performance standards that will guide environmentally sustainable agricultural practices and management in support of common Environment Canada 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 nonregulatory quantitative or qualitative measures of desired environmental performance. In general, two different levels of performance standards are being developed: 1. Ideal Performance Standards (IPS) that specify the level of environmental quality necessary to maintain desired ecosystem integrity, and 2. Achievable Performance Standards (APS) that specify the level of environmental quality that can be achieved using recommended, best available processes, practices, and technologies. Science-based assessments are being conducted to guide development of these standards in which they are practical and consistent science-based benchmarks to help guide the design of farm practices in achieving environmental outcomes.

This paper 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 physicochemical condition of a stream is strongly affected by catchment characteristics, including land cover and land use, as well as 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.

The NAESI Biodiversity theme produced a number of land cover scenarios that are based on biodiversity standards, agricultural practices, and best management practices (BMP). A total of six land cover scenarios have been defined in 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

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maintenance of the status quo ("Current"), there are two scenarios that should result in improved environmental performance (HBC [high biodiversity conservation] and MBC [medium biodiversity conservation]), two scenarios that consider greater agricultural intensification (ALC [agricultural intensification with limited application of conservation direction] and ANC [agricultural intensification with no consideration of conservation direction]), and a potential natural vegetation (PNV) scenario. Intensification for the purposes of this analysis is focused on changes in land cover and therefore land use, rather than changes in agricultural practices directly. Thus, 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. The modelling results are used in developing achievable performance standards for flow regimes, sediment levels, and nutrient concentrations as a function of BMP efficacy.

Methods

Study Area

Previous studies indicate that contributions of sediment and nutrients by nonpoint 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. Since the Raisin River watershed, which is within the Raisin Region Conservation Authority (RRCA) and EOMF, is predominantly an agricultural watershed, it has been selected to be the study area for the impact assessment of land and water integration, particularly for hydrology, sediment, and nutrients.

Figure 1 illustrates the Raisin River watershed and Table 1 summarizes some characteristics of the watershed. This watershed encompasses the municipalities of North and South Glengarry, North and South Stormont, and the City of Cornwall (Raisin Region Conservation Authority 2006). It has a main branch, a south branch, and a north branch totalling 809 km of streams of which 19 km flow through public lands. The total drainage of the Raisin River watershed is about 58,000 ha. 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.

Nonpoint Source Modelling

This study focuses on the nonpoint source pollutants since they are the major contributor from agricultural activities. Nonpoint 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, infiltration, storage characteristics of the basin, soil permeability, and other hydrological parameters all affect the transportation of nonpoint source pollutants. The land use activities also strongly affect the hydrological, physical, and chemical processes that impact the nonpoint source pollutants. In terms of agricultural issues, the entrainment, transport, and fate of sediment, nutrients (mainly nitrogen, N, and phosphorus, 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.

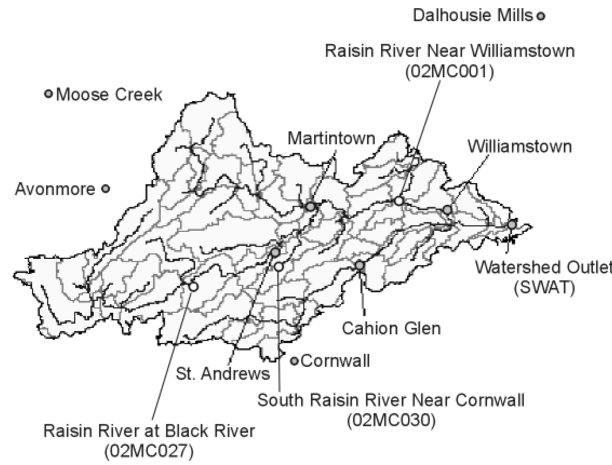

Fig. 1. Raisin River watershed.

Using the modelling approach to understand the nonpoint 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 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 Soil and Water Assessment Tool (SWAT) model (Arnold et al. 1998) was identified as the top candidate model for this study. In addition, the SWAT model is widely used in soil erosion prevention and control, nonpoint source pollution control, and regional management in watersheds. It has been calibrated in a number of watersheds in the Great Lakes basin with similar land use, soils, and climatic conditions.

SWAT is a river basin or watershed scale model developed for the United States Department of Agriculture, Agricultural Research Service (Arnold et al. 1998), that

TABLE 1. Raisin River watershed characteristics

Area [a]	57,982 ha
Land use [a]	Mainly agriculture
Soil type [a]	*Main branch* → Mostly clay loam and loam → Some silt loams, fine sandy loam and muck *North branch* → Mostly loam and muck → Some Clay loam and sandy loam *South branch* → silt, sandy, clay, very fine sandy loam
Steam flow [a]	809 km of steams (<20 m width) which 19 km flow through public lands. Annual discharge near Williamstown is 5.1 m^3/s
Fishery resources [a]	Warm water fishery: 43 species Cool water site: Mottled sculpins River redhorse and bridle shiner are classified as special concern by SARA and COSEWIC
Woodlot size [a]	1,577 stands Largest: 1,441 ha Average: 16.1 ha
Riparian forest [a]	68.4% on public land 33.5% on private land
Population	~82,000 residences 45,640 reside in city of Cornwall
Topography	Watershed elevation range: 50 to 120 m Distance 31 km, slope 0.2%
Outlet location	45.1262N, 74.4920W

Average climatic conditions (Cornwall ON) [b]		*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
	Temperature (°C)	-8.8	-7.3	-1.3	6.5	13.9	18.7	21.6	20.4	15.5	9.1	2.6	-4.9
	Precipitation (mm)	81.7	63	67.5	81	82.9	88	92.6	93.2	102.4	82.4	86.5	80.8

[a] Data from Raisin River Conservations Authority (2007)
[b] Data from Environment Canada (2006).

can be used 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. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT is physically based and requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. In this study, the SWAT Version 2005 was used.

Input Data for the SWAT Model

Precipitation data. There are four rain gauges in the vicinity of the Raisin River watershed but none of them are located inside the watershed. These gauge locations include Cornwall, Avonmore, Moose Creek (hourly), and Dalhousie Mills and are shown in Fig. 1. In the absence of a rain gauge inside the watershed, we used average approximate values from these four rain gauges.

Current land cover 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% is for hay and pasture, 6.96% is for cereal, 1.36% is for alfalfa, and 2.37% is for other intensive agricultural products such as orchard and horticulture. These NAESI land cover classes are reclassified into SWAT land cover classes to make the land cover map layer compatible with the SWAT model (see Table 2). Once the land cover layers are defined, their corresponding land cover parameters can then be defined.

Soil texture data. Soil data by county for Ontario compiled by the Ontario Ministry of Agriculture and Food and AAFC contain 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 SWAT include 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. The SWAT model uses the same soil texture layer to generate the coefficients of

TABLE 2. Percent area of the current land cover classes in the SWAT model

Land cover class	*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-nonforested	3.98

the soil-related parameters.

Digital elevation model data. The original digital elevation model is a 10 by 10 metre grid and it is a product of the Ontario Ministry of Natural Resources. For SWAT, the original 10 by 10 metre digital elevation model was imported into the preprocessing SWAT ArcView interface (Di-Luzio et al. 2002), and a masking polygon was created for the study area to focus only on the Raisin River watershed. A total of sixty subbasins were generated in the process as shown in Fig. 1.

Flow data. Three Water Survey of Canada stream gauging (hydrometric) stations are located within the Raisin watershed (Fig. 1). They are Station 02MC001 (Raisin River near Williamstown), Station 02MC027 (Raisin River at Black River), and 02MC030 (south Raisin River near Cornwall).

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

Water quality data. Water quality data for the Raisin River watershed was available at four provincial water quality monitoring network (PWQMN) stations from the Ontario Ministry of Environment and one from the RRCA's tributary network. Figure 1 shows the locations of the water quality stations (PWQMN and RRCA's tributary network). The PWQMN stations are the St. Andrews Station (main branch upstream), Martintown Station (north branch), Cahion Glen Station (south branch), and Williamstown Station (main branch downstream). The only RRCA tributary network station was the Raisin River Marina at the mouth of the Raisin River (Raisin River watershed outlet).

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

Fertilizer application rates. Fertilizer applications rates, used throughout most Ontario watersheds (Toronto and Region Conservation Authority 2003), combined with information in the *Eastern Ontario Water Resources Management Study Report* (CH2M HILL 2001) were used for all land cover scenarios as shown in Table 3.

Climate data. 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 was Cornwall, Ontario, which is approximately 10 km from the watershed centre. Statistics were calculated for Cornwall for available parameters and were added to the

TABLE 3. Fertilizer applications rates used for the SWAT model[a]

Land cover class	*Nitrogen application (kg/m^2)*	*Phosphorus 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

[a] Data from: Toronto and Region Conservation Authority (2003); CH2M HILL (2001).

Results and Discussion

SWAT Calibration and Validation

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 the other sampling stations were used. Table 4 lists the stations for the calibration and validation based on the current land cover layer. The calibration was mainly done based on the following two principles:

1. Calibration followed the steps suggested in the SWAT 2005 users' 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;
2. Calibration was based on comparison with observed values using NSE (Nash-Sutcliffe simulation efficiency), means, correlation coefficient, and graphically. Graphical comparison was used mainly for low flow period comparison since the statistical comparison, especially NSE, is not influenced much by the low flow values. Reasonable low flow simulations are desirable, particularly for sediment and nutrient concentrations.

Flow calibration. The best gauging station for flow data was the Williamstown flow station (02MC001), where data were collected from 1960 to 2005. Since the Current land cover scenario was used to calibrate the daily flow at that station, flow data from the more recent time period was used. In all, daily predicted flow values from 1980 to 2005 were 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 subbasins that drain to the flow gauge were 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 subbasins for each year resulting in runoff volumes. GWQ and SURQ cannot be used directly because instream precipitation, evaporation, transmission losses, etc., will alter the net water yield from that predicted by the WYLD variable in the hydrologic response unit or subbasin 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 contained the daily flow rate out of the subbasin of interest, which was approximately the location of the flow gauge, and then divided by the drainage area to get the average flows in units of millimetres.

The selection of the calibration parameters for flow calibration was based on the SWAT 2000 uers' manual and past experiences (Arnold et al. 2000; Santhi et al. 2001; White and Chaubey 2005; Migliaccio et al. 2007). 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 a worse effect when changed so were left at their default values. The calibrated parameters, definitions, and their values are presented in Table 5.

TABLE 4. Calibration and validation based on the current land cover [a]

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
TSS (mg/L)	RRCA Station: Raisin River Watershed Outlet	Tributary outlet sampling database (RRCA)	2005–2006	—
TN Load (kg/day)	PWQ Stations: Downstream from Williamstown	OMOE	1985–1994	1995–2004
TP Load (kg/day)	PWQ Stations: Downstream from Williamstown	OMOE	1985–1994	1995–2004

[a] WSC = Water Survey of Canada; RRCA = Raisin River Conservation Authority; PWQ = Provincial Water Quality; OMOE = Ontario Ministry of the Environment.

TABLE 5. 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: NSE and correlation coefficient (*r*). The NSE 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 NSE values as close to 1 as possible in the calibration process, they should be at least over 0.5 to be considered acceptable.

Figures 2 and 3 show the daily flow averaged monthly calibration and validation results for the Raisin River near Williamstown, respectively. As shown in Fig. 2 and Fig. 3, the simulated model flow rates and the observed values compare well and show a good correlation. Table 6 shows the calibration statistics of the monthly averaged flow from 1985 to 1994. The correlation coefficient and NSE for the monthly calibration were 0.93 and 0.84, respectively. They show significant improvements when compared with the values at the start of the uncalibrated model. These values were greater than 0.5 and confirm reasonable model results. The validation was done for the period of 1995 to 2004. Table 6 also shows the statistics of the validation. The monthly correlation coefficient and NSE for the validation are 0.93 and 0.86, respectively. These values are consistent with the calibration results.

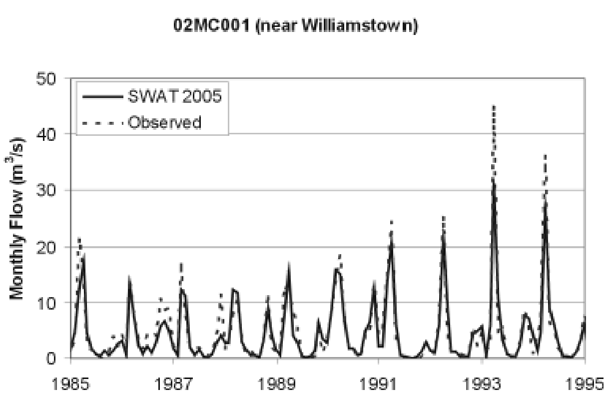

Fig. 2. Monthly flows calibration for Water Survey of Canada station (2MC001) Williamstown from 1985 to 1994.

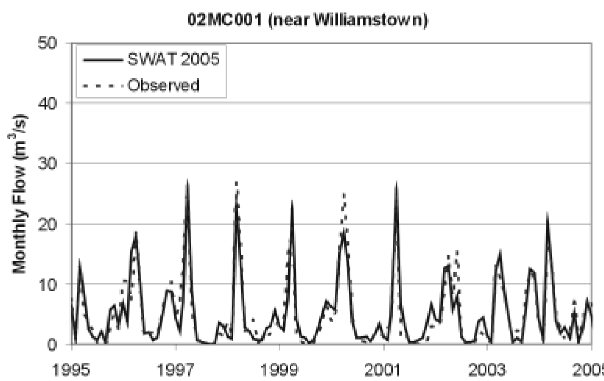

Fig. 3. Monthly flows validation for Water Survey of Canada station (2MC001) Williamstown from 1995 to 2004.

TABLE 6. SWAT flows calibration and validation statistics near Williamstown[a]

Type	*Stat. function*	*Stat. value*
1985–1994		
Calibration	NSE	0.84
Calibration	*r*	0.93
1995–2004		
Validation	NSE	0.86
Validation	*r*	0.93

[a] NSE = Nash-Sutcliffe simulation efficiency; *r* = correlation coefficient.

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 because 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. The same cannot be said for observed flow (Raisin River near Williamstown) and observed sediment (Raisin River watershed outlet). Also, one operation that can significantly affect sediment transport is the tillage practices; however these data were not known and cannot be directly applied to the model.

TABLE 7. 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

The sediment data are very limited in both quantity and quality. The RRCA started to collect data from the outlet of the tributaries to the St. Lawrence River in 2004 in its tributary outlet sampling database. However, sediment data is only available for the Raisin River watershed outlet starting in 2005. We used both 2005 and 2006 total suspended sediment (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 21 observations for TSS, and 11 of them have a remark code "<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 7 shows the list of sediment calibrated parameters and their values.

Figure 4 shows the daily observed and SWAT simulated sediment concentrations for 2005 and 2006 at the outlet of the Raisin River watershed. Table 8 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 and 2.68 mg/L, respectively. The standard deviations of the observed and predicted values are 1.71 and 1.49 mg/L, respectively. An analysis of variance (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 was no difference between the observed and predicted means. Therefore, the simulation sediment results are satisfactory given the data constraints.

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 five 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. The observed TN was not available directly, so it was obtained by summing the observed values for nitrate, nitrite, and total Kjeldahl nitrogen. Observed TP was available and simulated TP was obtained by summing the SWAT outputs for mineral phosphorus and organic phosphorus.

The observed TN and TP data are available in the Ontario Ministry of the 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 the 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 land use; the calibrated values are presented in Table 9. 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.

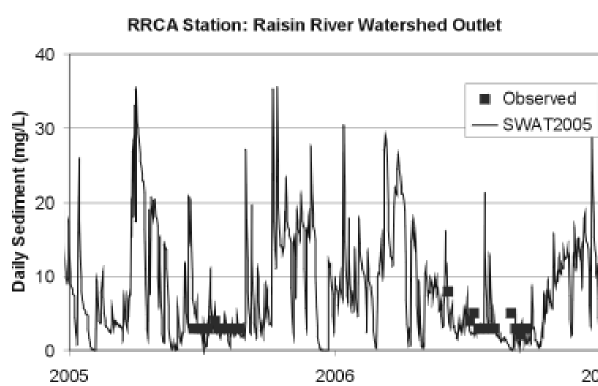

Fig. 4. Daily sediment (TSS) calibration at Raisin River watershed outlet.

TABLE 8. 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

TABLE 9. 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[a]	Fertilizer N and P applied to row crops were adjusted	>=0	decrease 25%

[a] For AGRR land use only.

Figure 5 illustrates the monthly observed and SWAT calibrated TN load for 1985 to 1994 at Williamstown of the Raisin River watershed. Table 10 displays the statistics of the TN load calibration and validation. The NSE and correlation coefficient for the calibration period are 0.71 and 0.87, respectively. The model predictions are consistent with the observed values. The validation was done for the period from 1995 to 2004 and is shown in Fig. 6. The NSE 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 7 illustrates the monthly observed and SWAT calibrated TP load for 1985 to 1994 at Williamstown of the Raisin River watershed. Table 10 displays the statistics of the TP load calibration. The NSE 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 was done for the period from 1995 to 2004 for the same location as shown in Fig. 8. The NSE and the correlation coefficient for the validation period are 0.20 and 0.75, respectively.

Although higher statistical values in NSE and the correlation coefficient are desirable, the sediment data constraints impacted the quality of the nutrient modelling results since the nutrient 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 recalibrated and revalidated for better performance.

TABLE 10. Monthly SWAT nutrient load calibration and validation statistics

Type	*Stat. function*	*Stat. value*
Nitrogen		
1985-1994		
Calibration	NSE	0.71
Calibration	*r*	0.87
1995-2004		
Validation	NSE	0.59
Validation	*r*	0.82
Phosphorus		
1985-1994		
Calibration	NSE	0.44
Calibration	r	0.81
1995-2004		
Validation	NSE	0.20
Validation	*r*	0.75

[a] NSE = Nash-Sutcliffe simulation efficiency; *r* = correlation coefficient.

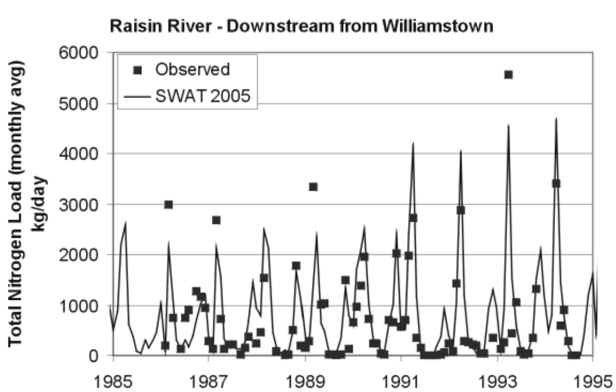

Fig. 5. Monthly total nitrogen load calibration (1985–1994) at Williamstown, Raisin River watershed.

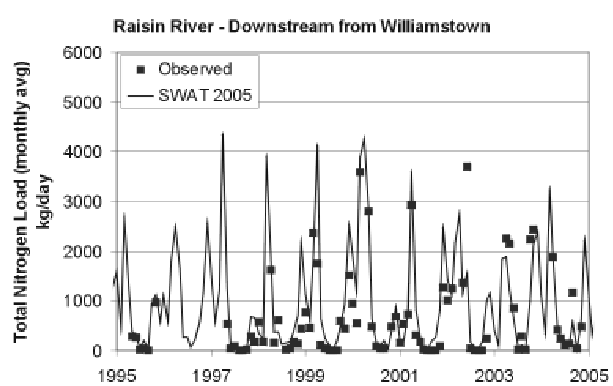

Fig. 6. Monthly total nitrogen load validation (1995-2004) for Williamstown, Raisin River watershed.

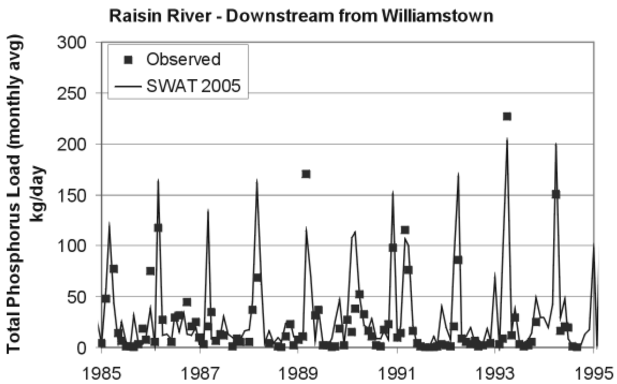

Fig. 7. Daily total phosphorus load calibration (1985-1994) for Williamstown, Raisin River watershed.

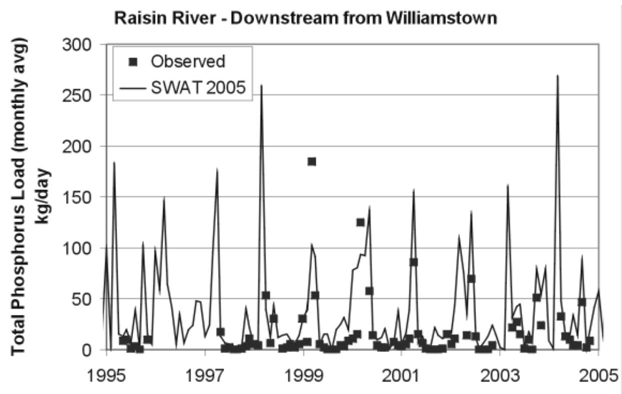

Fig. 8. Daily total phosphorus load validation (1995-2004) for Williamstown, Raisin River watershed.

Impacts of Land Cover Scenarios on Aquatic Ecosystems

The development of a land cover scenario was based on the application of a series of spatially-explicit rules. Land cover rules for the various scenarios were based on land use trends, and the current suite of potential BMPs that are designed to conserve biodiversity and impact land cover. The rules impact broad land use categories (riparian, wetland, forest cover, pasture/hay, cropland), and land cover characteristics including location, configuration, composition, and management. The impact of land ownership (public versus private lands) was defined by varying the probability of land use change as a result of conservation/resource values. Rules were applied under a spatial hierarchy to ensure logical application (because many rules overlap). Rules were applied to the current landscape with an assumption of an immediate effect, but did not consider temporal impacts across ecosites. The biodiversity theme habitat-based standards derived through multiple lines of evidence including landscape metrics, habitat models, and the outcomes of population analysis were used as indicators to assess the quality of a given scenario.

Four alternative scenarios have been developed with the goal of demonstrating the impact of land use decisions on elements of biodiversity. The scenarios include two biodiversity conservation scenarios, and two agricultural intensification scenarios for comparison with the Current land cover and PNV scenarios. The two biodiversity conservation scenarios, HBC and MBC, adopt existing BMPs and conservation direction for the region to improve landscape condition for biodiversity. The HBC 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 MBC scenario, with a lower rate of uptake, focuses on conservation activities currently associated with agriculture. The two agricultural intensification scenarios, ALC and ANC, integrate agricultural policy and encourage cultivation of all productive lands using conventional technology and inputs. The ALC scenario is where intensification occurs with some limited constraints to conserve water and wildlife habitat, whereas the ANC 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. The PNV scenario is a vegetation structure that would be present with only natural disturbance and therefore the absence of anthropogenic land cover changes across the watershed.

Figure 9 shows the distribution of the more notable land cover types of the six land cover scenarios. Small land cover types (less than 5% of total area for all scenarios) that do not vary much between scenarios are not shown in Fig. 9 and include alfalfa, industrial, meadow bromegrass, orchard, range-brush, range-grasses, residential-low density, residential-medium density, transportation, wetlands-nonforested, and water. Figure 10 shows the spatial distribution of land use for each scenario with similar land uses grouped together. Row crops are at 10.80% for the Current scenario, they decrease to 10.38% in the MBC scenario, 6.38% in the HBC scenario, and 0% in the PNV scenario, but are predicted to increase to 43.19% in the ALC scenario and 43.40% in the ANC scenario. This dramatic change in land use will cause considerable change in nonpoint source pollution and requires the use of a model to assess the long term impact of water quality from these land cover scenarios. The scenario comparisons were performed using the current land cover as the base case.

Land cover scenario analyses and comparisons. The main objective in this paper was to assess the impact of each of the land cover scenarios on 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. The study locations are St. Andrews (main branch), Williamstown (main branch downstream), Raisin River Outlet, Cahion Glen (south branch), and Martintown (north branch)

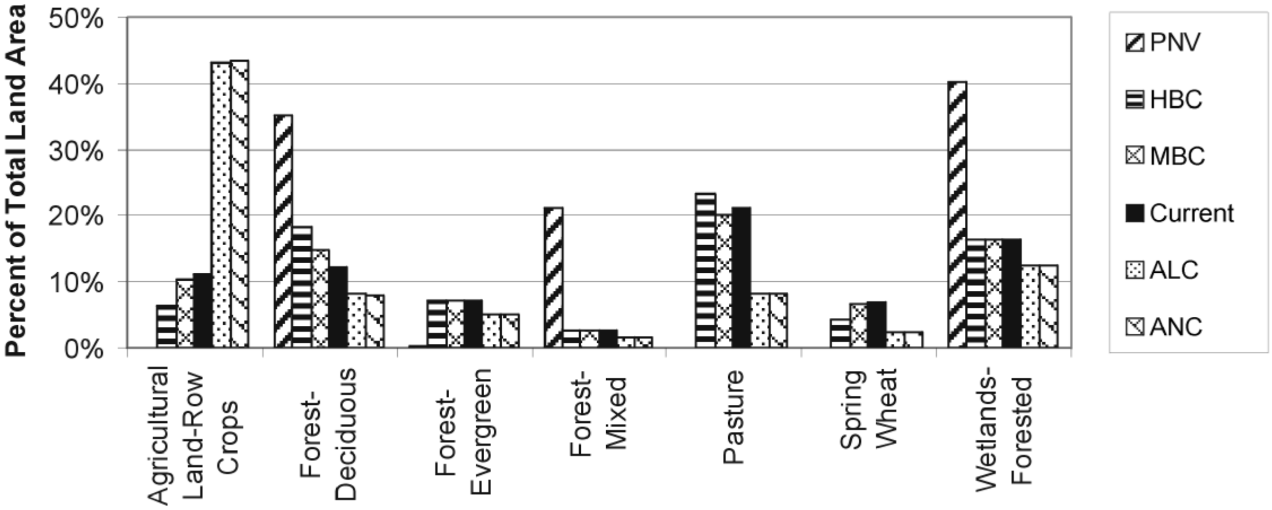

Fig. 9. Comparison of notable SWAT land cover types for the six scenarios.

as shown in Fig. 1. The simulations are from 1985 to 2006 for the current base case and five other land cover scenarios.

Table 11 displays the actual SWAT model scenario results. 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 showed the lowest values in sediment and nutrients. At the other extreme, the ANC scenario predicts the highest in sediment and nutrient concentrations. In general, the following order of scenarios is ranked from the lowest to the highest flow, and sediment and nutrient concentrations: PNV, HBC, MBC, Current, ALC, and ANC. The highest annual average sediment concentration was found in Martintown and the outlet with the highest nutrient concentrations was located at Cahion Glen and the outlet. Martintown and the outlet predict 8.6 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 had consistently high annual average sediment and nutrient concentrations among all of the locations.

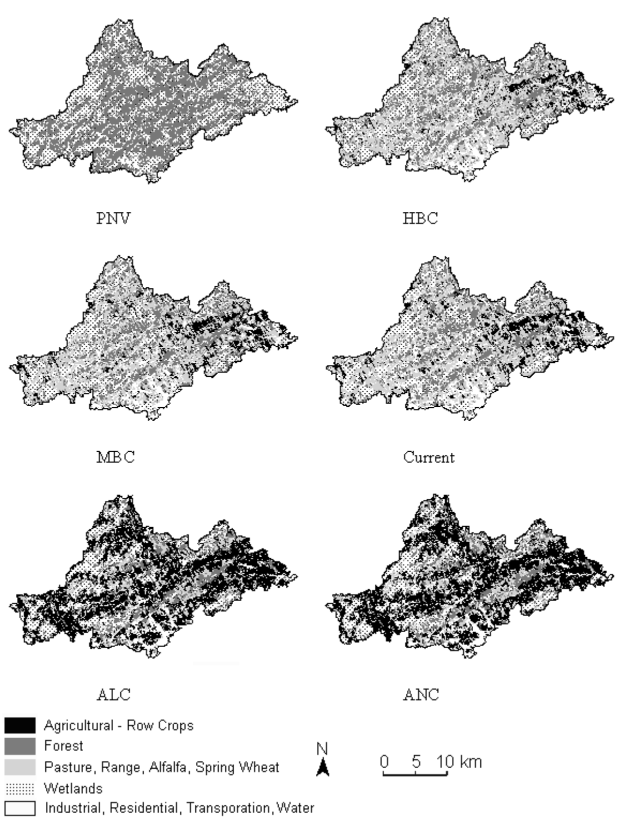

Fig. 10. Spatial comparison of SWAT land cover types for the six scenarios.

Next, we compared the Current land use scenario with other scenarios on a relative basis. Martintown had the highest change in flow when comparing the ANC scenario with the Current scenario (9.7%), and Cahion Glen had the lowest relative change (3.3%) in flow for the same comparison. Both Martintown and St. Andrews exhibited large increases of TSS, TN, and TP concentrations when comparing the ANC scenario with the Current scenario. In the case of St. Andrews, the model predicted an increase of 133.1% in TSS, 119.6% in TN, and 163.8% in TP concentrations, respectively. On the other hand, the PNV, HBC, and MBC scenarios showed reduction of the sediment when compared with the Current scenario. For instance, at the outlet, PNV predicted a reduction of 45.8% in TSS, 46.5% in TN,

TABLE 11. Flow, TSS, TN, and TP annual averages for the six scenarios at five locations within the Raisin River watershed

Parameter (average annual)	*Location*	*Scenarios*					
		PNV	*HBC*	*MBC*	*Current*	*ALC*	*ANC*
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

and 76.9% in TP. Cahion Glen exhibited small relative changes because of its heavy anthropogenic activities, i.e., City of Cornwall. Therefore, the changes in land cover classes upstream of Cahion Glen were relatively small in the scenarios when compared with the other areas such as the north branch and the main branch.

Comparison of SWAT model results with Ideal Performance Standards. One of the goals in the land and water integration was to check the Raisin River watershed modelling results against NAESI IPS that are based on reference conditions and statistical analyses of historical datasets. The provisional IPS for TSS (Culp et al. 2008), TN, and TP (Chambers et al. 2008) for Ontario are 4.1, 1.07, and 0.024 mg/L, respectively. Table 12 lists the median SWAT model results of TSS, TN, and TP for HBC, Current, and ANC scenarios, and uses the IPS of Ontario as a basis for comparison.

Since the IPS are determined by the median values of the observed data, we used the median values of the 1985 to 2006 model results of TSS, TN, and TP at Martintown, Cahion Glen, St. Andrews, Williamstown, and the outlet for comparison. The results for the Current scenario indicated that the TSS median values of the SWAT model for all locations, except at the outlet, were below the TSS Ontario IPS. The HBC scenario showed a reduction in sediment and nutrient concentrations, and the ANC scenario exhibited an increase in sediment and nutrient concentrations as compared with the Current scenario. The SWAT median values of the HBC/Current/ANC scenarios at the watershed outlet for TSS, TN, and TP are 3.78/4.52/6.52 mg/L, 1.47/1.77/3.42 mg/L, and 0.0295/0.0321/0.0623 mg/L, respectively. The provisional IPS of TSS, TN, and TP for Ontario are 4.1, 1.07, and 0.024 mg/L, respectively. The comparison of the SWAT median values for the HBC, Current and ANC scenarios at the outlet indicated that the model results exceeded the IPS except for the ideal TSS. Since the results at the outlet suggest that sediment and nutrients in the Raisin River watershed do not meet the IPS, it is recommended that some BMP strategies be implemented such as stream buffer strips reduction, and/or jurisdiction targets be developed to improve the water quality.

Conclusions

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

Besides the PNV scenario, the HBC scenario also showed some significant reduction, and the MBC scenario indicated modest reduction in both sediment and nutrients. The two agricultural intensification

TABLE 12. Comparison of SWAT median results of the HBC, Current, and ANC scenarios with the Ideal Performance Standards (IPS) for sediment and nutrients

	HBC			*Current*			*ANC*		
	TSS (mg/L)	*TN (mg/L)*	*TP (mg/L)*	*TSS (mg/L)*	*TN (mg/L)*	*TP (mg/L)*	*TSS (mg/L)*	*TN (mg/L)*	*TP (mg/L)*
IPS	4.1	1.07	0.024	4.1	1.07	0.024	4.1	1.07	0.024
Martintown	0.54	0.96	0.0139	3.23	1.25	0.0147	10.1	3.29	0.0318
Cahion Glen	2.79	1.61	0.0400	3.13	1.85	0.0405	4.42	3.56	0.0746
St. Andrews	0.41	1.11	0.0133	1.49	1.28	0.0142	7.56	3.24	0.0271
Williamstown	2.88	1.33	0.0198	3.82	1.69	0.0219	6.09	3.40	0.0488
Outlet	3.78	1.47	0.0295	4.52	1.77	0.0321	6.52	3.42	0.0623

scenarios, ALC and ANC, predicted significant increases in both sediment and nutrients. In terms of biodiversity standards and direction, the HBC scenario predicted a substantial reduction in sediment and nutrients as compared with the current land use condition. BMPs such as stream buffer strips can be put in place with the biodiversity standards to provide the optimal results to achieve pollutant reduction with minimum impact to agricultural activities. The scenarios with increased conservation practices only reflect land use changes, i.e., increased natural cover. However, other practices such as no till would change the results. The results indicated that the TSS median values of the SWAT model for the Current scenario, for all locations except at the Outlet, were below the TSS Ontario IPS. For TP, the locations of Martintown, St. Andrews, and Williamstown met the TP IPS. However, all locations were above the TN IPS. It is possible that the soils in the Raisin River watershed have high TN levels naturally or maybe as a result of long term over fertilization of the crops.

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Symbols and Abbreviations

AAFC	Agriculture and Agri-Food Canada
ALC	Agricultural intensification scenario with limited application of conservation direction
ANC	Agricultural Intensification scenario with no consideration of conservation direction
APF	Agriculture policy framework
BMP	Best management practices
EOMF	Eastern Ontario Model Forest
GWQ	Groundwater flow
HBC	High biodiversity conservation scenario
IPS	Ideal performance standards
MBC	Moderate biodiversity conservation scenario
NAESI	National Agri-Environmental Standards Initiative
NSE	Nash-Sutcliffe simulation efficiency
PNV	Potential natural vegetation scenario
PWQMN	Provincial water quality monitoring network
r	Correlation coefficient
RRCA	Raisin Region Conservation Authority
SURQ	Surface flow
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended sediment
WYLD	Water yield

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