Parameterization and Application of Agricultural Best Management Practices in a Rural Ontario Watershed Using PCSWMM

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Abstract

As agricultural production has continued to expand and intensify around the world, many models have been developed in an attempt to accurately predict the downstream impacts on water quality and quantity due to changes in on-farm management practices. In rural watersheds with complex stormwater conveyance systems, models designed for agricultural landscapes tend to inadequately represent the spatial and temporal resolution required in the simulation of hydraulic systems. The Storm Water Management Model (SWMM) was originally developed for urban watershed modelling, but its robust hydraulic simulation capabilities have been applied in conjunction with new tools developed within PCSWMM in order to simulate the downstream impacts of a suite of agricultural best management practices (BMPs) in a watershed in rural Ontario, Canada. Three simulation scenarios were run and results are reported for a single model subcatchment. Results show general agreement with literature reported nutrient reduction values, but more testing of these capabilities is required.

1 Introduction

Awareness of the environmental consequences resulting from agricultural production dates back at least to the 1920s with the publication of *Soil Erosion: A National Menace* (Bennett and Chapline 1928), which some consider the start of modern soil conservation (Renschler and Harbor 2002). The 1960s brought new awareness with the publication of *Silent Spring* (Carson 1962), which focused not on the denudation of agricultural lands, but instead on the downstream impacts of agricultural practices—specifically pesticide application—on wildlife. Around the same time came a more general increased awareness surrounding the issue of non-point source (NPS) pollution from agricultural lands, which eventually led to what were, perhaps, some of the first attempts to incentivize the adoption of agricultural best management practices (BMP)—such as conservation tillage—for purposes beyond soil conservation (Hayes and Young 1982; Logan 1993). More recently, water quality issues in the United States and Canada, such as the widespread contamination of groundwater with nitrates (e.g. Burkart and Stoner 2008) and coastal eutrophication from nitrates (e.g. McLellan et al. 2015) and phosphorus (e.g. Rousseau et al. 2013), continually bring agriculture and NPS pollution back into the public eye.

As agricultural production continues to expand and intensify, and awareness of its environmental impacts continues to increase, it is crucial for scientists and engineers to have the ability to adequately predict the effectiveness of agricultural

BMPs in controlling NPS pollution, as well as their economic feasibility (Rousseau et al. 2013; Xie et al. 2015). Since the 1970s, models have been used to help evaluate the benefits of BMPs to downstream waters, as they can provide predictions for water quantity and quality measures that can be compared with numeric standards. In the time since, numerous models have been developed in order to address the wide range of applications—sometimes niche—in which modelling efforts have been useful (USEPA 2005).

Even with this large selection of available models, it is not always possible to find a model that meets all of the requirements of a particular project. Case in point: in 2010, the Lake Huron Southeast Shores Executive Steering Committee (LHSESC—now Healthy Lake Huron: Clean Water, Clean Beaches Partnership) set out to develop a physically based model to assist in the location and prioritization of agricultural BMPs along the southeast shore of Lake Huron, based on the realization that, at that time, there was no model in existence that met all of the specific requirements laid out for modelling in rural Ontario (Emmons & Olivier Resources, Inc. and Computational Hydraulics International 2014). The desired model was required to have certain capabilities in order to accurately model the conditions unique to rural Ontario, including:

1. The ability to model natural, urban and agricultural landscapes at the field and regional scale with BMPs targeted to sediment, phosphorus and nitrogen;

2. The capacity to accurately simulate channels, culverts, bridges and stormwater network hydraulics;
3. The ability to change key input data seasonally to account for diverse crop stages and variability in certain hydrologic parameters over time;
4. The ability to simulate groundwater hydrology, including agricultural subsurface drainage;
5. The capacity to simulate sediment loading due to soil erosion; and
6. The ability to account for in-stream processes for phosphorus and nitrogen depletion.

In addition to these primary requirements, several secondary requirements were defined, including:

1. The ability to simulate snowmelt and spring runoff;
2. The ability to model the effects of backwater and reverse flows; and
3. The capacity to perform both event and continuous simulation modelling.

In the context of these requirements, the confounding factors for model selection necessitating the development of new tools were primarily related to (a) the level of detail and rigor required in hydraulic routing due to the possibility of backwater and reverse flows in flat landscapes; and (b) the importance of accurate representation of stormwater conveyance systems on the landscape, including networks of municipal drains within rural areas. Informed by many reviews and comparisons of models (notably USEPA 2005), the U.S. Environmental Protection Agency's (USEPA) stormwater management model, SWMM, was ultimately chosen over models more typically used in rural areas (e.g. SWAT, HSPF) due to its high spatial and temporal resolution modelling capabilities and its explicit physical representation of channel and pipe hydraulics.

The ultimate goal of this project was to develop a model that met all of the project requirements, and to apply this model to five priority coastal watersheds along the southeast shore of Lake Huron totalling roughly 500 km² in area—which together are referred to as the Rural Stormwater Management Models (RSWMM). This paper focuses on requirement (1) of this project: the use of a field-scale, GIS based methodology for model parameterization and process representation of a suite of BMPs in SWMM and the resulting model simulations using PCSWMM—a decision support system for SWMM (James et al 2010)—within one of these priority watersheds. A brief overview of the watershed model is given, followed by a description of the methodology. Finally, three simulation scenarios applying three different agricultural BMPs will be demonstrated, along with the results of their application within a subcatchment.

2 Methodology

2.1 Study Area

The Bayfield North watershed is located on the southeastern shore of Lake Huron (Figures 1 and 2) between Goderich and

Bayfield. It is a 39 km² agricultural watershed entirely within the jurisdiction of the Ausable Bayfield Conservation Authority (ABCA). The watershed is drained by municipal drainage systems, including drainage ditches, tile drains and water and sediment control basins (WASCOB), to twenty small streams draining westerly to Lake Huron. The streams are locally referred to as the North Gullies due the eroded ravines and the longest stream in the watershed is Gully Creek.

Figure 1 Location of the Bayfield North watershed.

Figure 2 Location of monitoring stations used for model construction and calibration.

The most dominant land cover category in the watershed is agriculture (57%) and the main crops cultivated are soybeans, corn and winter wheat. Approximately 28% of the watershed is forested. Urbanization is limited to rural residential and cottage developments (8%) throughout the watershed and along the lakeshore. The watershed soils are clay loams, silt loams, loams and sandy loams. The mean annual temperature of the watershed is 7.8 °C with mean monthly temperatures ranging from –5.8 °C in January to 20.7 °C in July. Mean annual precipitation ranges from about 1 000 to 1 250 mm at nearby weather stations with historical records. The longest stream, Gully Creek, is 10 km long and flows northwesterly at a relatively constant grade of 2.8% from its headwaters (280 m above sea level) to its outlet into Lake Huron (176 m above sea level).

The streams in the North Bayfield watershed are cold water fisheries that are important habitats for fish species at risk, such as Redside Dace. The observed nitrate and total phosphorus concentrations at the primary sampling location range from 0.7 mg/L to 38.7 mg/L and 0 mg/L to 5.4 mg/L respectively. The maximum observed nitrate concentration exceeds the Canadian Water Quality Guideline (CWQG) of 3 mg/L (CCME 2012), and the maximum observed total phosphorus concentration exceeds the Provincial Water Quality Objectives (PWQO) of 0.03 mg/L (MOEE 1994).

2.2 Model Description

SWMM

The USEPA's Storm Water Management Model (SWMM) has undergone significant periodic upgrades since its original release in 1971, most recently with the release of the SWMM5 engine in 2005. SWMM is a rainfall–runoff model capable of both single event and continuous simulation of runoff quantity and quality from urban and rural landscapes (Metcalf and Eddy, Inc. et al. 1971; James et al. 2010). Hydrology is simulated by treating each catchment as a nonlinear reservoir using Manning's equation and lumped continuity; hydraulics can be simulated by solving the complete Saint-Venant equations (i.e. dynamic wave routing); and water quality can be simulated using one of several forms of buildup and washoff equations for pollutants, with treatment or depletion occurring through the use of mathematical decay expressions (Huber and Dickinson 1992). Although SWMM is a spatially lumped model at the subcatchment scale, discretization of subcatchments is possible to a fine scale and thus, depending somewhat on the level of discretization relative to the size of the study area, SWMM can also be considered distributed or semi-distributed (Sun et al. 2014). Rainfall can be temporally distributed down to minute-scale time steps, as well as spatially distributed if data from more than one gauge is available. Daily values for average windspeed and minimum and maximum temperatures are required for the simulation of snowmelt and snow accumulation, and daily evaporation rates are required to simulate evaporative (E) and evapotranspirative (ET) losses from storage devices (i.e. water surfaces) and subcatchments (i.e. vegetated surfaces) respectively. These daily evaporation rates are used as upper limits

on the E and ET rates in lieu of a process based representation of these processes. The simulation time steps are defined separately for routing, runoff and reporting; typical values are on the order of seconds, minutes and hours respectively (Huber and Dickinson 1992; James et al. 2010).

Enhancements

Several additional functionalities were introduced as part of this project. One of these functionalities, the ability to provide monthly multipliers which facilitate the seasonal modification of certain SWMM inputs, was incorporated as a modification to the SWMM code itself in order to satisfy project requirement (3). Along with additional subsequent code modifications, this modified SWMM engine eventual became known as the OpenSWMM engine (CHI 2015). In order to satisfy project requirement (5), the modified universal soil loss equation (MUSLE) was incorporated into the PCSWMM interface. Daily sediment yield is calculated outside of the SWMM engine, and then these daily estimates are distributed based on SWMM-predicted runoff per the wet period time step (CHI 2014). The resulting estimated total suspended solids (TSS) concentration is then routed conservatively into the hydraulics as a pollutant inflow at the subcatchment outlet, at which point treatment expressions can be applied to represent settling or filtration processes, just as with other SWMM pollutants.

2.3 Observed Data

Streamflow Data

Meteorological data including precipitation, air temperature and wind speed was collected using a DAVIS Vantage Pro2 weather station. The weather station also provided a calculated estimate of reference evapotranspiration using the Penman–Monteith equation. Five months of these data (2013-05-01 to 2013-09-30) collected at three monitoring locations (Figure 2 above), along with gauged streamflow at two monitoring locations (also Figure 2 above) were used for flow calibration, with meteorological data for April used for model warmup. One location had a permanent gauge (GULGUL5), while the other location had a temporary gauge (GULGUL7) that was installed and operated as part of this project. Not enough streamflow data were available at this time to use as a validation dataset.

Water Quality Data

Water quality samples were collected at both flow monitoring locations and analysed for total suspended solids (TSS), nitrogen (nitrate nitrogen, $\text{NO}_3\text{-N}$, nitrite nitrogen, $\text{NO}_2\text{-N}$, and total Kjeldahl nitrogen, TKN), and phosphorus (soluble reactive phosphorus, SRP, and total phosphorus, TP). Other water quality indicators were also reported (e.g. ammonium-N, dissolved oxygen), but were not used in model parameterization. Samples were collected using an ISCO automated sampler at the permanent gauge, and grab samples were collected at the temporary gauge. All viable reported concentrations between May 2013 and September 2013 were used for model calibration. Not enough water quality data were available at this time to perform model validation.

2.4 Model Setup

Spatial Datasets

A portion of the Bayfield North watershed, the Gully Creek subwatershed, has been the subject of both past and ongoing modelling efforts involving the uses of SWAT and imWEBs (Keizer 2014). Partly as a result of these efforts, along with the data collection efforts of the Healthy Lake Huron: Clean Water, Clean Beaches Partnership, a relatively robust GIS dataset was available for use in model parameterization. These data provided by the ABCA included:

- hydrography: digitized watershed boundaries, streams, ditches, municipal drains;
- soil texture (derived from Hoffman et al. 1952);
- land cover, a modified and discretized version of the *Provincial Land Cover (2000) Data Base* (Smyth 2002), to include agricultural fields and associated cropping and management metadata;
- transportation: digitized roads, culverts and, bridges, including surveyed elevations and measured dimensions;
- digital elevation model (DEM) at 1 m horizontal resolution; and
- aerial photographs at 0.2 m resolution.

Subcatchments were initially delineated using ArcHydro (Maidment 2002) and the 1 m DEM, followed by manual verification in PCSWMM based on contours and aerial photos, resulting in 178 subcatchments having an average of 22 ha, a median of 15.5 ha, and a range of 1.5 ha to 95 ha in area. A slope raster derived from the DEM was used to initialize the subcatchment slopes within a subcatchment. Infiltration parameters derived from the work of Rawls et al. (1982) were defined for each subcatchment based on the soil texture. Erosion parameters were defined for each soil texture, where the fractions of clay, silt and sand within each soil texture class are derived from the median value of the range of each particle size within a given texture class (as defined by the USDA soil texture classification (Shirazi and Boersma 1984) and the *K*-factor for MUSLE was derived from the work of Wall et al. (1997).

Three subcatchment parameters were determined based on land use. Percent impervious surface was approximated using typical impervious percentages for each land use category, and was determined not to be a sensitive model parameter due to the dominance of pervious area in the landscape upstream of the monitoring station used for calibration. Manning's roughness for pervious surfaces was defined for each land use using values from reports by the U.S. Army Corps of Engineers (USACE 1998) and the Soil Conservation Service (1986), and according to Rossman (2010). Depressional storage was also defined according to Rossman (2010) where possible, and was otherwise estimated by assuming a linear relationship with Manning's roughness based on the suggestion of Onstad (1984) that a correlation exists between these attributes. The roughness of hydraulic elements was estimated based on conduit material using values obtained from

Chow (2009) and the American Society of Civil Engineers (Bizier 2007).

Pollutants

Seven pollutants were simulated: sand, silt, clay, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, TKN and SRP. Of these, sand, silt and clay are simulated through PCSWMM's MUSLE routine, and the remainder were simulated using SWMM's washoff equations. Additionally, four pollutants were calculated using PCSWMM's Derive functions: total nitrogen (TN), total suspended solids (TSS), particulate phosphorus (PP), and total phosphorus (TP).

TSS was represented in three parts (sand, silt and clay) to facilitate a more accurate representation of sediment and phosphorus removal via settling than would be possible by simply defining TSS as a pollutant. In this way, a separate treatment expression can be defined for each part. Following a model run, TSS was derived as:

$$\text{TSS} = \text{Sand} + \text{Silt} + \text{Clay} \quad (1)$$

Phosphorus was considered to be present in two pools: particulate and dissolved (Wetzel 2001). Particulate phosphorus (PP) was derived as:

$$\text{PP} = \text{Sand} * P_{\text{Sand}} + \text{Silt} * P_{\text{Silt}} + \text{Clay} * P_{\text{Clay}} \quad (2)$$

where P_{Sand} , P_{Silt} and P_{Clay} represent the phosphorus content of each particle size, derived from the work of Dong et al. (1983).

The dissolved phosphorus pool was assumed to consist of soluble reactive phosphorus (SRP), often referred to dissolved inorganic phosphorus (Wetzel 2001), and soluble unreactive phosphorus (SUP). While SUP may constitute a non-negligible fraction of total phosphorus (Jarvie et al. 1999; Wetzel 2001), the observed water quality data was only reported for SRP and TP and as such it was not possible to determine the relative magnitude of SUP. Thus, the dissolved component of phosphorus was assumed to be represented solely by SRP as:

$$\text{TP} = \text{PP} + \text{SRP} \quad (3)$$

Due to observed correlation between SRP and flow rate at selected sampling locations, SRP was parameterized using the Rating Curve form of the washoff equation as suggested by James et al. (2010).

Nitrogen was assumed to be completely accounted for by $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and TKN. Due to the observed absence of correlation between any of the nitrogen components and flow rate at selected sampling locations, these pollutants were parameterized using the event mean concentration (EMC) form of the washoff equation. Since all three were reported as mg/L of nitrogen, total nitrogen was derived as:

$$\text{TN} = \text{NO}_2\text{-N} + \text{NO}_3\text{-N} + \text{TKN} \quad (4)$$

as supported by Kadlec and Knight (1995) and Wetzel (2001).

It is also possible to define concentrations for groundwater outflow in SWMM, although the model does not allow for

seasonally variable concentrations. These concentrations were defined for $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, TKN and SRP using the average concentration of those samples taken during baseflow conditions.

2.5 Model Calibration

Calibration was performed for a continuous simulation period from 2013-05-01 to 2013-09-30 for flow data and water quality samples taken at the permanent monitoring location. The temporary monitoring location was not used, due in part to the low number of grab samples taken, and because the timing of the sampling did not line up with peak flows as well as at the permanent location. Calibrations were performed using the sensitivity based radio tuned calibration (SRTC) tool in PCSWMM. The SRTC tool allows users to define tolerances for parameter uncertainty in SWMM layers, and performs model runs at the extremes of this uncertainty range. Once model runs are complete, radio sliders are used to adjust the individual parameters within the pre-defined uncertainty tolerances and the user is able to dynamically observe the predicted model response, including model performance statistics (if observed data has been imported). The resulting parameters can then be passed back into the model to replace the existing parameters, or they can be used to define a new scenario (Finney and Gharabaghi 2011).

Hydrologic and Hydraulic Calibration

The most sensitive hydrologic parameters, and those used for calibration, were determined to be pervious depressional storage, pervious Manning's roughness, subcatchment slope, subcatchment width, and the three parameters used in the GreenAmpt infiltration equation. For calibration of stream discharge, hydraulic parameters were not found to be as sensitive as hydrologic parameters and, with the exception of Manning's roughness, hydraulic parameters were generally constrained by survey data and field observations.

Flow data was calibrated for daily and monthly mean flows (Figure 3). Model performance was measured using the coefficient of determination (i.e. R^2) and Nash–Sutcliffe model efficiency (Nash and Sutcliffe 1970), shown in Table 1. July of 2013

had relatively few storm events, and no large storm events, so calibration for those months proved difficult. Overall, the calibration resulted in a good fit with observed daily and monthly mean flows for the simulation period, with $\text{NSE} = 0.77$ and $R^2 = 0.82$.

Table 1 Model calibration performance statistics and monthly mean flows for 2013.

Period	NSE	R^2	Mean Flow (m^3/s)	
			Predicted	Observed
May	0.42	0.89	0.082	0.104
June	0.31	0.53	0.061	0.048
July	N/A	N/A	0.019	0.009
August	0.92	0.98	0.053	0.050
September	0.74	0.94	0.053	0.026
Overall	0.77	0.82	0.054	0.047

Water Quality Calibration

Water quality indicators (parameterized as *pollutants* in SWMM) were calibrated based on monthly and overall nutrient loading for $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, TKN and SRP. The number of usable samples is summarized in Table 2.

Table 2 Summary of water quality samples.

Pollutant	Number of usable samples
$\text{NO}_2\text{-N}$	12
$\text{NO}_3\text{-N}$	47
SRP	46
TSS	46
TKN	47
TP	47

Water quality sampling tended to be both sporadic and clustered (i.e. coincident with particular storm events), providing limited observed data for calibration. For pollutants found to have concentrations correlated to flow, observed loading was estimated by first developing regressions between the concentration of individual samples with flow at the time of sampling. These regressions were then used to interpolate concentrations for all observed flows on an hourly time step, and the resulting

Figure 3 Observed and predicted hydrographs for daily mean discharge in 2013.

concentrations were multiplied by flow and by the length of the time step to yield a mass load. If no significant correlation existed, an event mean concentration (EMC) was computed for the entire simulation period. EMCs are computed as:

$$EMC = \frac{\sum_{i=1}^n Q_i C_i}{\sum_{i=1}^n Q_i} \quad (5)$$

where:

- Q_i = volumetric discharge corresponding to sample i ,
- C_i = nutrient concentration in sample i , and
- n = total number of samples.

For $\text{NO}_3\text{-N}$, the relationship between concentration and flow varied significantly both within and between events, so concentrations were instead interpolated serially.

Because the MUSLE routine in PCSWMM only takes into account field derived sediment and thus excludes other sources of sediment (e.g. channel bed and bank, and gully erosion), calibration was not performed directly for TSS; rather, observed concentrations were used as checks to ensure that MUSLE-predicted sediment yields were not in excess of measured in-stream loads. Consequently, TP was also not calibrated because predicted TP loads are dependent in the model on predicted particulate phosphorus (PP) loads, which were derived based on an estimated fraction of TSS loads (using the work of Dong et al. 1983). Predicted and observed loads for the four remaining water quality indicators are shown in Table 3.

Table 3 Monthly predicted and observed nutrient loads for 2013.

		Period					Total
		May	June	July	August	September	
$\text{NO}_2\text{-N}$ load (tonnes)	Predicted	4.9	2.0	0.30	5.6	1.9	15
	Observed	5.6	2.7	0.42	2.1	2.4	13
	% Error	-13%	-26%	-29%	166%	-18%	12%
$\text{NO}_3\text{-N}$ load (tonnes)	Predicted	1 062	444	67.0	1076	374	3 023
	Observed	1 770	1 045	105	416	669	4 004
	% Error	-40%	-58%	-36%	159%	-44%	-24%
SRP load (tonnes)	Predicted	5.6	2.3	0.34	7.1	2.5	18
	Observed	4.0	1.3	0.25	23.0	6.2	35
	% Error	42%	79%	33%	-69%	-60%	-49%
TKN load (tonnes)	Predicted	50	25	4.9	34	17	131
	Observed	27	12	1.9	67	34	141
	% Error	82%	115%	156%	-49%	-50%	-8%

2.6 Parameterization of Agricultural BMPs

Dynamic Field Shapefile

Within the model, since the subcatchments are generally much larger than individual farm fields, field scale changes in model parameters are not explicitly represented. However, it was desirable that field level changes hydrology and nutrient loading be reflected accurately at the subcatchment scale. To overcome this, a schema was developed in which the changes in hydrologic parameters predicted to occur as the result of implementing BMPs on a particular field are passed back into the model as changes in the subcatchment parameters using area weighted averages. In

this way, the process by which BMPs are implemented could be performed outside of the SWMM engine itself, allowing for more flexibility in future modifications of the process and avoiding the need to modify the SWMM code.

Within PCSWMM, SWMM layers are represented spatially as GIS shapefiles, with model parameters corresponding to shapefile attributes. To implement BMPs on a field scale, a separate shapefile containing polygons representing farm fields is required. In the case of the Bayfield North watershed, this field shapefile was created by modifying the polygons contained in an existing land use shapefile. Setting up BMPs using a field shapefile is facilitated by the ability within PCSWMM to (a) define enforced value lists for attributes; (b) group attributes into customizable categories; and (c) *auto-express* attributes, which is essentially the ability to define the values of an attribute using an expression. These expressions (auto-expressions) can optionally involve the use of values from one or more of the other attributes in the same shapefile. Auto-expressions were used in conjunction with both user defined and enforced value attributes to develop a network of interdependent attributes that auto-updated a set of dependent attributes based on the selection or *implementation* of a BMP on a field polygon.

The following six agricultural BMPs can be added to a model using the fields layer to provide pollutant removal, as categorized as avoid or control practices in the *Agricultural BMP Handbook for Minnesota* (Minnesota Department of Agriculture 2012):

1. Avoid practices:
 - conservation cover;
 - contour farming; and
 - cover crops.
2. Control practices:
 - conservation tillage;
 - grassed waterways; and
 - terracing.

Pollutant Reduction Mechanisms

While it would have been possible to simply assign reduction coefficients (i.e. empirical removal efficiencies) for a particular BMP's impact on water quality indicators based on literature values alone, it was desirable to also represent a BMPs impact on runoff rates and volumes as well. To represent the theoretical treatment capabilities of BMPs, the schema was set up such that the activation of a BMP affects relative changes in certain SWMM hydrologic input parameters. First, parameters in the Fields layer are initialized via area weighting from the subcatchments following calibration. Second, BMPs are activated in the Fields layer. Auto-expressions built into the model change and then change the treatment mechanisms assumed for each BMP, summarized below with typical reduction values in Table 4. The overall mechanisms vary between the BMP types as follows:

- conservation cover: lowers erosion with permanent vegetation and reduces nutrient applications;

- contour farming: lowers erosion by directing flow across the slope;
- cover crops: lower erosion with temporary vegetation and reduces nutrient leaching;
- conservation tillage : lowers erosion by retaining residue and vegetation;
- terracing: lowers erosion with reduced slope length; and
- grassed waterways: lower soil erosion with permanent vegetated conveyance.

Table 4 Median values of pollutant reduction by agricultural BMPs as reported in the literature.

BMP	Typical Ave Annual Reduction (%)			Treatment Mechanisms to Achieve Typical Pollutant Reduction						
	TSS	TP	TN	MUSLE C-factor	MUSLE P-factor	MUSLE LS-factor	Manning's Roughness	Depressional Storage	Catchment Slope	
Conservation Cover	90	75 ²	85 ²	X			↑	↑		
Contour Farming	59 ⁷	30 ⁸	20 ⁸		X	X		↑		↓
Cover Crops	83 ⁶	29 ²	52 ³	X						
Conservation Tillage	63 ⁴	70 ³	62 ³	X			↑	↑		
Terracing	75 ¹	77 ²	N/A		X	X		↑		↓
Grassed Waterways	36 ³	13 ⁵	6 ³		X		↑			

¹Hanway and Laflen 1974

²Iowa Nutrient Reduction Strategy 2013

³Houston Engineering 2013

⁴Iowa State University Midwest Plan Service 2000

⁵Almendinger and Ulrich 2012

⁶Sharpley et al. 1991

⁷Van Doren et al. 1951

⁸Tomlinson et al. 2003

Auto-expressions were developed specifically for each treatment mechanism and BMP combination in Table 4. The relative change in a given parameter was determined from a variety of sources. For the MUSLE C- and P-Factors, values were derived explicitly from RUSLE and USLE documentation (Renard et al. 1997; Wall et al. 1997; Stone and Hilborn 2012). While guidance for the modification of some of the hydrologic parameters also came from these sources, the relative change in these parameters was ultimately determined empirically using a hillslope-scale model calibrated to achieve the median pollutant reduction percentage found in the literature referred to in Table 4. Details of this process and the final auto-expressions are provided in Section 5.2 and Appendix B.2 of the project report available online at <http://www.ruralstormwater.com/docs/Rural-Stormwater-Management-Model-Report-FINAL-low-res.pdf>.

For example, when a user changes the tillage practice of a field from conventional to conservation tillage, the logic within the auto-expressions:

1. Checks to make sure the land use of that field is agricultural (and not, for example, woodland), else none of the dependent attributes are changed;
2. Checks if other BMPs are also assigned to that field, and takes the maximum resulting values for each dependent attribute; and

3. Modifies Manning's roughness, depressional storage, and the MUSLE C-factor based on the literature suggestions and RUSLE/MUSLE documentation (see Table 4 above).

At this point, the user is free to pass these attribute changes to MUSLE parameters, pervious Manning's roughness, pervious depressional storage, and slope back into the subcatchments of the SWMM model using the area weighting tool in PCSWMM.

3 Results and Discussion

The predicted performance of three agricultural BMPs (conservation tillage, conservation cover and contour farming) was assessed using separate simulation scenarios. BMPs were applied to four fields (all cultivated in soybeans under conventional tillage in 2013) that intersect one 89 ha subcatchment (model element SGulyC39) in the easternmost (upstream) portion of the watershed. Together, these fields comprise 54.5 ha (61.2%) of the subcatchment area. The remaining 34.5 ha were in winter wheat (24.1%), corn (10.2%), woodland (3.3%), and grass/weeds (1.2%). Results for simulated runoff volume, TSS load, TP load, and TN load for the base condition scenario were compared with the results for each of the three BMP scenarios, as summarized in Table 5.

Table 5 Comparison of selected water quantity and water quality predictions for May 2013 to September 2013 for four management scenarios.

Simulation Scenario	Runoff Volume (m ³)	TSS load (kg/ha)	TP load (kg/ha)	TN load (kg/ha)
Base Conditions	64 610	149	0.81	12.3
Conservation Tillage	58 550	91	0.50	9.1
% Reduction	9%	39%	38%	26%
Conservation Cover	61 190	118	0.65	10.6
% Reduction	5%	21%	20%	14%
Contour Farming	64 260	113	0.63	12.3
% Reduction	1%	24%	22%	0.2%

Due to the dependency on multiple field specific variables, including slope, and also because the subcatchment parameters are the lumped representation of other land uses, these results are difficult to assess without field or subcatchment level monitoring data. However, the reduction percentages for TSS, TP and TN appear to be generally in line with the values from Table 4 above.

4 Conclusions

This project set out to develop a model that could meet a set of requirements based on criteria specific to rural Ontario, and to apply that model to five priority watersheds. Focusing on project objective 1, this paper outlined the model construction and calibration for one of these priority watersheds using PCSWMM, and attempted to evaluate the performance of the model in simulating the impacts of assigning three agricultural best management practices to several fields within a model

subcatchment. Results show that SWMM was able to accurately represent the hydrologic response of a rural watershed, and that it is possible to use SWMM to predict nutrient and sediment loading from agricultural landscapes. Water quality calibrations were adequate, and model performance can likely be improved with the incorporation of additional streamflow and water quality data for use in calibration and validation.

The GIS based schema developed for parameterizing field-based agricultural BMPs shows promise as a user friendly methodology that facilitates the modification of model parameters in a structured but customizable fashion. More testing is needed to determine the method's accuracy in predicting the downstream water quality and quantity impacts of BMPs. However, this methodology could be applied as it has been developed to assess the relative impacts of BMP implementation as part of a BMP or site prioritization process.

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