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ASSESSING TMDL IMPLEMENTATION IN THE MACATAWA WATERSHED, MI, USING SWAT

by

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ASSESSING TMDL IMPLEMENTATION IN THE MACATAWA WATERSHED, MI, USING SWAT

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Western Michigan University, 2004

Lake Macatawa, on the eastern shore of Lake Michigan, has been impaired by nonpoint source pollution from agriculture. A Total Maximum Daily Load (TMDL), developed by the Macatawa Area Coordinating Council and the Michigan Department of Environmental Quality, established a 60% reduction goal in phosphorus load by 2008. While agricultural best management practices have been implemented in the past three years, the local watershed organization has not had the means to evaluate the effectiveness of these practices, and to assess progress made towards the phosphorus reduction goal.

A simulation model, the Soil and Water Assessment Tool (SWAT) was chosen to simulate phosphorus load, and quantify the long-term effects of several agricultural management practices on water quality. A detailed land use/land cover map was produced from a 2002 Landsat ETM+ image. The model was calibrated for flow. Attempts were made to calibrate the model for sediments and phosphorus. Several scenarios - including wetland restoration, implementation of filter strips and no-till – were simulated over a 10-year period.

Results showed that only the implementation of no-till practices and filter strips throughout the watershed would bring a 60% reduction in phosphorus load. These results need to be further verified in the field to be used as partial basis of decision-making.

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Laurence Picq

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INTRODUCTION

Watershed Protection Approach

In the late 1980's, it became obvious that although regulation of point sources had brought significant improvements in water quality, a large number of water bodies remained impaired because of the continuing effects of nonpoint source pollution (NRC 2001). Since nonpoint source pollution is, by definition, difficult to regulate, a different approach was needed. In the last 10 years, the U.S. Environmental Protection Agency (EPA) has been promoting the "watershed protection approach" as the most logical basis for managing water resources (US EPA 1996, NRC 1999).

The watershed approach is characterized by decentralized decision-making, partnerships between local, state and federal agencies, stakeholder involvement, an integrated systems-perspective and continuous improvements based on sound science (US EPA 1997a, NRC 1999). This approach can save time and money (e.g. by coordinating monitoring efforts) and can lead to greater public support and awareness (US EPA 1996). The main attraction to watershed partnership is the collaborative approach to decision making (Leach *et al* 2002). As a result, watershed partnerships have multiplied in recent years, particularly following the recent introduction of Total Maximum Daily Load (TMDL) regulations.

Total Maximum Daily Load

The TMDL program is a return to ambient water quality standards (as opposed to effluent standards specified by the National Pollution Discharge Elimination System) (NRC 2001). It aims at improving water quality through regulation of both point and nonpoint sources. Although TMDL regulations were originally part of the 1972 Clean

Water Act, many states often ignored these regulations for pragmatic reasons, such as difficult implementation and monitoring of nonpoint sources. The EPA was forced to implement the TMDL rule following citizen lawsuits in the 1980's (Boyd 2000).

A TMDL is the calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards (US EPA 2000). It requires states to submit a list of impaired water bodies every two years, define pollutants and sources responsible for the impairment, establish the maximum amount allowable for the pollutant in order to meet water quality standards and allocate that amount between the various sources (US EPA 2000, NRC 2001). As such, the TMDL process poses significant challenges to state and local agencies because it requires large amounts of data and the use of modeling techniques that may be beyond the capabilities of local agencies (Boyd 2000, NRC 2001).

Macatawa Watershed Project

The Macatawa Area Coordinating Council (MACC) is a partnership between seven townships, local stakeholders and residents in Holland, MI. Through the Macatawa Watershed Project, the Michigan Department of Environmental Quality and the MACC have been working towards improving water quality in Lake Macatawa, considered to be one of the most nutrient-enriched lakes in Michigan (Walterhouse 1999).

In 1997, a MDEQ study concluded that water quality was impaired by excessive sediments and nutrients (phosphorus in particular). As a result, a phosphorus Total Maximum Daily Load (TMDL) program was finalized in 1998. The MACC has been implementing it since 2000. The goal of the TMDL is to reduce phosphorus load to Lake

Macatawa by 60% - from the current 138,500 lb/year to 55,000 lb/year - by 2008, thus bringing phosphorus concentrations in the lake down to an estimated 0.050 mg/L[1].

Statement of Problem

Most of the nutrient pollution comes from nonpoint sources, mainly agricultural activities. Since 2000, the Macatawa Watershed Project has been promoting the implementation of agricultural best management practices (BMPs). Some farmers, particularly those in the southern part of the watershed, have already put in place grassed waterways, filter strips, and grade stabilization structures, and have stopped tilling after harvesting corn.

However, the Macatawa Watershed Project has not had the means to assess the effectiveness of its actions, and therefore is unable to determine whether the TMDL goal can actually be reached by 2009.

The goal of this project was to provide an assessment of progress made towards phosphorus reduction as well as to predict and quantify the impact of agricultural best management practices on phosphorus load to Lake Macatawa.

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[1] The average phosphorus concentration for the period 1996/1997 was 0.127 mg/l.

MODELING WATER QUALITY

Water Quality in the U.S.

In the last 50 years, water pollution has become a major environmental, health and economic concern. Since the passage of the Clean Water Act in 1972, and the establishment of the National Pollution Discharge Elimination System (NPDES), point sources have been strictly regulated and now contribute less to overall water pollution (Boyd 2000). Nevertheless, approximately 40% of rivers and lakes in the US are still considered impaired, mainly because of nonpoint source pollution (US EPA 2000, NRC 2001). The number one nonpoint source of pollution in U.S. rivers and lakes is agriculture, while nutrients are the leading pollutants in lakes (US EPA 2000).

Nutrient concentrations have been increasing for the last 20 years (Heathwaite *et al* 1996). These trends have been attributed to the rapid increase in fertilizer and manure inputs (following an intensification of agriculture), urbanization and related increased population densities and surface imperviousness, and increased soil erosion caused by changes in land use (Carpenter *et al* 1998). In general, the over-application of fertilizers has radically altered nutrient cycles, causing phosphorus (P) and nitrogen (N) to accumulate in soils: in the United States, the phosphorus surplus is equal to 30 lb/acre/year (Sharpley *et al* 1999). Excess nutrients are then transported from soil to water either by erosion or leaching (Carpenter *et al* 1998, Sharpley *et al* 1999).

Eutrophication

Nutrient enrichment contributes to eutrophication of lentic water bodies, such as lakes and reservoirs. While eutrophication is a natural aging process for lakes, it has been greatly accelerated by human activities and is now the most common impairment of surface waters in the United States (US EPA 2000). Eutrophication is characterized by an increase in nutrient and suspended solids concentrations, a decrease in dissolved oxygen concentration and excessive blue-green algae growth. These changes in the ecosystem in turn lead to a reduction in aquatic biodiversity and may affect drinking water supplies and recreational activities (Heathwaite 1994, Newton and Jarrell 1999).

Phosphorus is often considered the limiting nutrient for plant growth in most freshwater bodies because it is usually present in small concentrations compared to plant needs (Heathwaite 1994). An increase in phosphorus concentration will accelerate plant growth and therefore eutrophication. A lake is considered eutrophic when total phosphorus (TP) is over 0.030 mg/L, and hypereutrophic when TP is over 0.100 mg/L (Newton and Jarrell 1999). Therefore, controlling phosphorus inputs to water bodies is required to reduce and manage eutrophication.

Phosphorus Research

Phosphorus comes from both point and nonpoint sources. Point sources include wastewater treatment plants, septic systems and industrial discharges. Total phosphorus concentration in point source discharges is strictly regulated under NPDES. Most phosphorus inputs come from nonpoint sources, such as agricultural and urban areas, while a small amount comes from naturally occurring phosphate deposits.

In the soil, phosphorus exists both in solid and solution phases. However, the majority of soil phosphorus is in the solid phase, either as phosphorus sorbed to soil particles or as organic phosphorus (Ward and Elliot 1995). As a result, phosphorus movement from soil to water is related to precipitation, soil erosion and management practices (Sharpley *et al* 1999). A large proportion of phosphorus (60 to 90% for cultivated lands) is usually transported by surface runoff but, in some cases, subsurface flow of dissolved phosphorus may also be an important pathway (Heathwaite and Sharpley 1999). The majority of phosphorus often comes from a small area of the watershed (10 to 20%, in particular zones near streams) during a few large storms (Soranno *et al* 1996, Heathwaite *et al* 2000, Gburek *et al* 2000). Overall, the amount of phosphorus introduced into water bodies is related to phosphorus soil concentration (Sharpley *et al* 1999)

Accepted measures to reduce phosphorus loss in surface runoff focus on controlling soil erosion through agricultural best management practices (BMPs), such as filter strips, grassed waterways and conservation tillage. These practices promote water infiltration and soil stability, thereby reducing runoff and soil erosion (USDA 1999). More recently, research has focused on the concept of critical source areas, i.e. areas where both source (i.e. high phosphorus levels or fertilizer inputs) and transport factors (i.e. erosion, runoff) coincide. Implementing best management practices in a watershed's critical source areas may represent a more efficient approach to reducing phosphorus loss (in sediment form) (Sharpley and Tunney 2000).

Modeling Water Quality

1. BMP assessment

The impact of best management practices on water quality can be estimated using either traditional monitoring methods or simulation models. Traditional BMP assessment requires long-term monitoring (pre- and post-BMP installation, usually a minimum of four years) and extensive data collection (Inamdar *et al* 2001, Rice *et al* 2002). Some studies have used paired watershed design (with control and treatment watersheds) and statistical tests to assess BMPs effects at the watershed scale (Meals and Hopkins 2002, Wang *et al* 2002).

Since long-term monitoring is labor and resources intensive, simulation models have been used. Models range from simple to complex. The choice of a model will depend on financial resources, the availability of data and the purpose of the study (NRC 2001). Although complex simulation models are more expensive to develop and use because of additional data requirements and training, they can provide comprehensive watershed assessments and represent an appropriate method to assess long-term effects of BMPs (Santhi *et al* 2001a, Ning *et al* 2002, Miller *et al* 2002).

2. BASINS

A large number of models have been developed in the last 20 years to predict pollutant movement from land to water (loading models) or the response of a water body to pollutant load (receiving models) (US EPA 1997a). In 1996, the EPA's Office of Water developed BASINS (Better Assessment Science Integrating point and Non point Sources) as a multipurpose environmental analytical tool for watershed management and TMDL development (US EPA 2001). By integrating environmental data (water quality, soils, land use, climate) and water quality models into a GIS framework (ArcView 3.2), BASINS allows users to perform comprehensive watershed assessments (US EPA 1997). Because BASINS provides a user-friendly interface that eases data entry, it has been criticized for providing a simplistic approach to modeling: an understanding of the scientific principles and requirements underlying each model is still required to produce valid results (Whittemore and Beebe 2000).

3. SWAT

Among the three watershed loading models available in BASINS (PLOAD, SWAT, HSPF), SWAT (Soil and Water Assessment Tool) was chosen for its intermediate complexity level: the model runs on a yearly to daily time step and data requirements, such as topography, land use and climate, are easily available.

SWAT was added to the latest BASINS version (released in June 2001). This model, created by the USDA Agricultural Research Service in the early 1990's, was originally developed to predict the impact of land management practices on water and pollutant yields in large complex watersheds (Neitsch *et al* 2002b). It models a number of climate, hydrological, nutrient, erosion and plant growth processes, such as runoff, evapotranspiration, sorption, sediment transport and nutrient uptake. In addition, SWAT includes the following databases: land cover/plant growth, tillage, pesticide, fertilizer and urban land types. These databases reduce data requirements and simplify data input. SWAT can be used to calculate water, sediment, nutrients and pesticides loadings at the watershed scale.

The EPA anticipates that this model will meet many modeling needs for TMDL development in predominantly agricultural watersheds (US EPA 2001). Few studies have so far been published to assess BASINS-SWAT modeling capabilities, in particular in the context of TMDL implementation (Santhi *et al* 2001a, Vaché *et al* 2002).

Objectives

The objectives of this study were to: (1) gather and/or produce all relevant watershed data for input into BASINS-SWAT; (2) simulate sediment and phosphorus loads under different agricultural management scenarios using SWAT, and (3) determine the best options for implementing the Macatawa Watershed's TMDL program.

The results of this study will support decision-making in the Macatawa Watershed and help the Macatawa Area Coordinating Council implement the phosphorus TMDL.

DESCRIPTION OF STUDY AREA

Physiography

The Macatawa watershed is a small watershed (175 mi^2) on the eastern shore of Lake Michigan (Figure 1). Lake Macatawa, in the center of the watershed, is a drowned river mouth: 0.25 to 2 km wide and approximately 8 km long. It is connected to Lake Michigan by a man-made channel. A shipping lane (depth: 6.5 m) is maintained by the U.S. Army Corps of Engineers. The Macatawa River is the main stream flowing into the east end of Lake Macatawa. Its several branches drain most of the watershed.

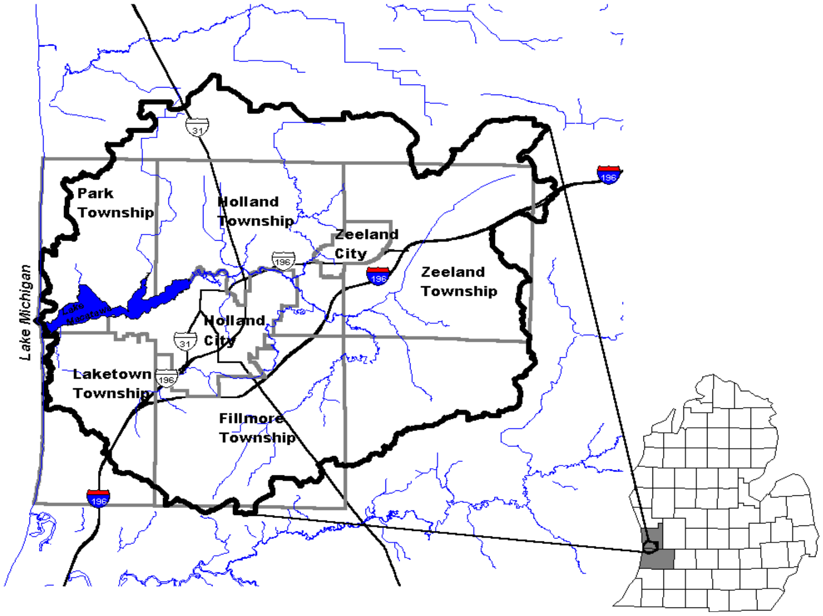

Figure 1. Map of the Macatawa Watershed

(Source: Macatawa Watershed Project documents 1997 – Used with permission of Sue Higgins, Chairman, Macatawa Area Coordinating Council, 08-24-04)

Soils in the watershed are varied and relatively fertile. In the western and central part of the watershed (34% of the area), sandy soils predominate; in the rest of the watershed, soils are mostly loam (see appendix A). Soils in the south are easily eroded. High sedimentation rates and turbid waters remain a problem in the watershed.

Land Use

Agriculture represents the principal land use in the watershed: corn and soybean are the main crops, and livestock operations (swine, turkey, hen, dairy) are widespread throughout the area. Most fields have installed tile drainage either because of clay soils (in the south) or high water table (in the north).

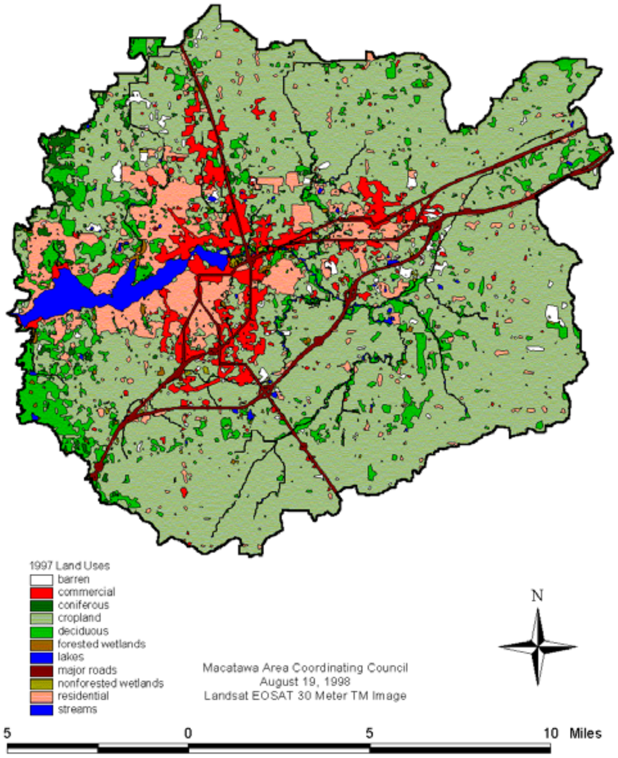

Figure 2. 1997 land use map of the Macatawa Watershed

(Source: Macatawa Watershed Project documents 1997 – Used with permission of Sue Higgins, Chairman, Macatawa Area Coordinating Council, 08-24-04)

Urban areas, located around Lake Macatawa, are centered on the cities of Holland (pop. 35,000) and Zeeland (pop. 5,800) (Focus 2002). Over 50,000 people live in the surrounding townships. Urban areas have been experiencing rapid growth in the last ten years, particularly in the north and central part of the watershed, as shown in table 1 (Focus 2002).

Table 1. Population change in the Macatawa Watershed

Township	**1990 census**	**2000 census**	**% change**
Zeeland	4,472	7,613	+ 70%
Holland	17,523	28,911	+ 65%
Park	13,541	17,579	+ 30%
Laketown	4,888	5,561	+ 14%
Fillmore	2,710	2,756	+ 1.7%

By comparison, population in Michigan grew by an average of 7% between 1990 and 2000 (Focus 2002).

METHODOLOGY

Land Use Classification

1. Introduction

Land use has an important influence on watershed hydrology. Changes in land use will affect runoff volume, streamflow, sediment yield and water quality (NRC 1999, Quiroga *et al* 1996). While many studies have evaluated the relationship between land use and water quality, this relationship is highly variable since it depends on local conditions (such as soil types and management practices) and the nature of land use changes (e.g. forest to agriculture, wetlands to urban).

In recent years, the integration of complex hydrologic and water quality models with geographic information systems has improved simulation accuracy by taking into account the spatial variability of different parameters, and has therefore contributed to a better understanding of the impact of land use changes on water quality (Haan and Storm 1996). However, adequate land use/water quality modeling still depends on the accuracy of land use data (Quiroga *et al* 1996).

The spatial resolution needed for land use data usually depends on the model requirements and the scale and purpose of the study. In studies of small watersheds with a relatively homogeneous land cover, land use data will often come from aerial photographs, local maps and/or ground survey (Inamdar *et al* 2001, Meals and Hopkins 2002, Vaché *et al* 2002). When large watersheds are modeled, satellite images are required to determine major land use categories (Chang *et al* 2001, Santhi *et al* 2001b, Tong and Chen 2002). The Macatawa Watershed is a small, mixed land use watershed. Producing a land use map of the watershed that adequately fits SWAT needs requires mixed sources of data: satellite imagery for determining major land use/land cover categories, and aerial photographs and ground survey data for additional detail, in particular in urban areas.

Land use/land cover is often analyzed using either the USGS classification system developed by Anderson *et al* (1976) or a classification scheme based on it (such as MIRIS, Michigan Resource Information System). The USGS classification system provides a standardized method for categorizing and naming land cover/land use depending on the spatial resolution of the map or image used. Land use/land cover categories are divided in four levels: level I and II correspond to general classes used in small scale maps or low resolution images while level III and IV correspond to very detailed categories for use with large scale aerial photographs (Lillesand and Kiefer 2000) as illustrated in table 2.

Table 2. Examples illustrating USGS land use/land cover classification system

Level I	Level II	Level III
1 Urban or built-up land	11 Residential 12 Commercial and services 13 Industrial	111 Single family 112 multifamily
2 Agricultural land	21 Cropland 22 Orchards, groves 23 Confined feeding operations	211 Cropland 212 Pasture land

2. Model requirements

SWAT databases include the following categories of land use/land cover:

a) Agriculture

SWAT includes a large database of land cover/plant growth parameters to simulate various hydrological and growth processes (Table 3). Detailed crop information is required to improve modeling accuracy, in particular when agriculture represents the major land use in the watershed. This land cover mapping requirement corresponds approximately to an Anderson level 3 or 4 classification. However, it should be noted that general classes, such as ‘agriculture’ or ‘orchards’, are also available in the model. Crops can be identified from either satellite images or aerial photographs.

b) Urban

The default urban land use database includes eight classes (Table 3) that correspond approximately to an Anderson level 2 or 3 classification. Users can modify and add new categories as needed provided runoff parameters are known. While general urban land use classes (such as residential or transportation) can be identified from satellite images, additional maps and/or higher resolution photographs are usually needed to accurately classify other urban land uses.

Table 3. Land use categories in SWAT databases

SWAT agricultural classes	SWAT urban classes	SWAT other classes
79 plant types: e.g. corn, winter wheat, bermudagrass, carrot, apple 11 generic agricultural covers: e.g. agricultural land – row crops orchard summer pasture.	Residential – high density Residential – medium density Residential – medium/low density Residential – low density Commercial Industrial Transportation Institutional	Forest – mixed Forest – deciduous Forest – evergreen Wetlands Wetlands – forested Wetlands – nonforested Water

c) Other

The SWAT land use database also includes a level 2 classification for forest and wetlands (Table 3).

3. Data sources

a) Remote sensing

A cloud-free, georeferenced, 2002 Landsat ETM+ image was purchased from the Basic Science and Remote Sensing Initiative (as it was called at the time) at Michigan State University in 2003. The Landsat ETM+ sensor has one 15-m resolution panchromatic band and six, 30-m resolution, spectral bands in the visible, near-infrared and mid-infrared (Lillesand and Kiefer 2000).

The image was taken relatively close to harvest time (September 30, 2002). The two main crops, corn and soybeans, are usually harvested mid- to end of October. However, it appeared that the majority of fields were not yet harvested therefore reducing classification errors (e.g. cropland classified as bare land).

b) *Crop information*

Information about the main crops grown in the Macatawa Watershed primarily came from USDA Farm Services Agencies (FSA) in Ottawa and Allegan counties, where most farmers certify their crops each year. Interviews with Michigan State Extension agents also provided additional information about certain agricultural activities, such as ornamentals and vegetables.

c) *Additional information*

Ancillary data included Allegan County Parcel Atlas book (2000), Ottawa County Land Atlas and Plat Book (2002), local maps, USGS 15' quadrangle maps (Holland East 1980, Holland West 1972, Hamilton West 1981) as well as 1998 orthophotos of the area available from the Michigan Geographic Data Library online (http://www.mcgi.state.mi.us/mgdl/).

4. Land use classification

The Landsat ETM+ image was analyzed using ERDAS Imagine® software. The image covered a larger-than-needed area of West Michigan. The first step consisted in defining an area of interest for the Macatawa Watershed. The image was overlaid with the roads shapefile available from the Michigan Geographic Data Library to provide a reference for ground survey and crop data.

The image was then categorized using supervised classification. In a supervised classification, the user first defines the spectral signatures of known land cover classes by selecting representative pixels (training sites). All pixels in the image are then assigned to the closest land cover class based on their spectral characteristics.

A combination of bands 4,3,2 (false color composite) and 5,4,2 were used to analyze the image: these combinations provided the best contrast between urban and agriculture, and allowed a clearer identification of crop types. A number of training sites were first developed to assist in the classification process.

a) Training stage

Training sites were developed as follows:

- Training sites for crops were chosen based on information provided by the Farm Services Agencies. The following crops – which account for over 95% of the total crop area - were identified: corn, soybean, winter wheat, alfalfa, blueberries, vegetables, ornamentals and fallow. Although oats was also grown in Allegan County, it covered a small area and had a spectral signature similar to that of winter wheat. Oats became classified as winter wheat.
- In urban areas, training sites were created for: high density residential, medium/low density residential, industrial/commercial and roads. Site selection was based on personal knowledge and various local maps of the area.
- Forest and wetlands training sites were delineated using maps and ground survey data.
- The signature for water was gathered from an unsupervised classification. In an unsupervised classification, pixels with similar spectral characteristics are

grouped together in clusters or classes. The user defines the maximum number of classes and needs to identify the classes defined.

Once all the signatures were created, the image was classified using the maximum likelihood parametric rule.

b) Smoothing

The resulting land use map was smoothed, using a focal majority filter, to eliminate small pixel groupings not representative of the main land use. For instance, an individual pixel classified as soybean could often be found in what was obviously a corn field. The minimum mapping unit was set at 3 pixels (0.27 ha). The land use classification is shown on Figure 3.

c) Accuracy assessment

The accuracy of the classification was evaluated using a 200-points, stratified random sample. Extensive ground survey data were collected 7 to 9 months after the satellite image was taken. While efforts were made to ensure that data were as accurate as possible, some errors must have nevertheless occurred, in particular for crops. Since it was not possible to get crop data from Farm Service Agencies for every field in the watershed, it was assumed during ground survey that a corn field in 2003 was most likely a soybean field in 2002 (soybean/corn being the most common rotation).

The error matrix (Table 4) showed that blueberries, wetlands and wheat were poorly classified, with only 50% of these areas correctly classified. This problem was already apparent at the training stage, in particular for blueberries. Since no training site was defined for brush or shrubs, blueberries appeared in small areas throughout the watershed. In addition, it was difficult to develop adequate training sites for blueberry orchards because many orchards were at different maturity stages and had a varying proportion of bare soil. Wetlands covered an unrealistically large area. This could be explained by the confusion between wheat and wetlands. Wheat would have been harvested at the time the image was taken. Wheat residues and wet soil became similar to a wetland signature.

The classification is as good as the number of classes identified. Overall, corn and soybean, which cover the largest area (34%) in the watershed, and urban areas (22%) were properly identified. The overall accuracy (86.5%) was considered reasonably adequate (Lillesand and Kiefer 2000).

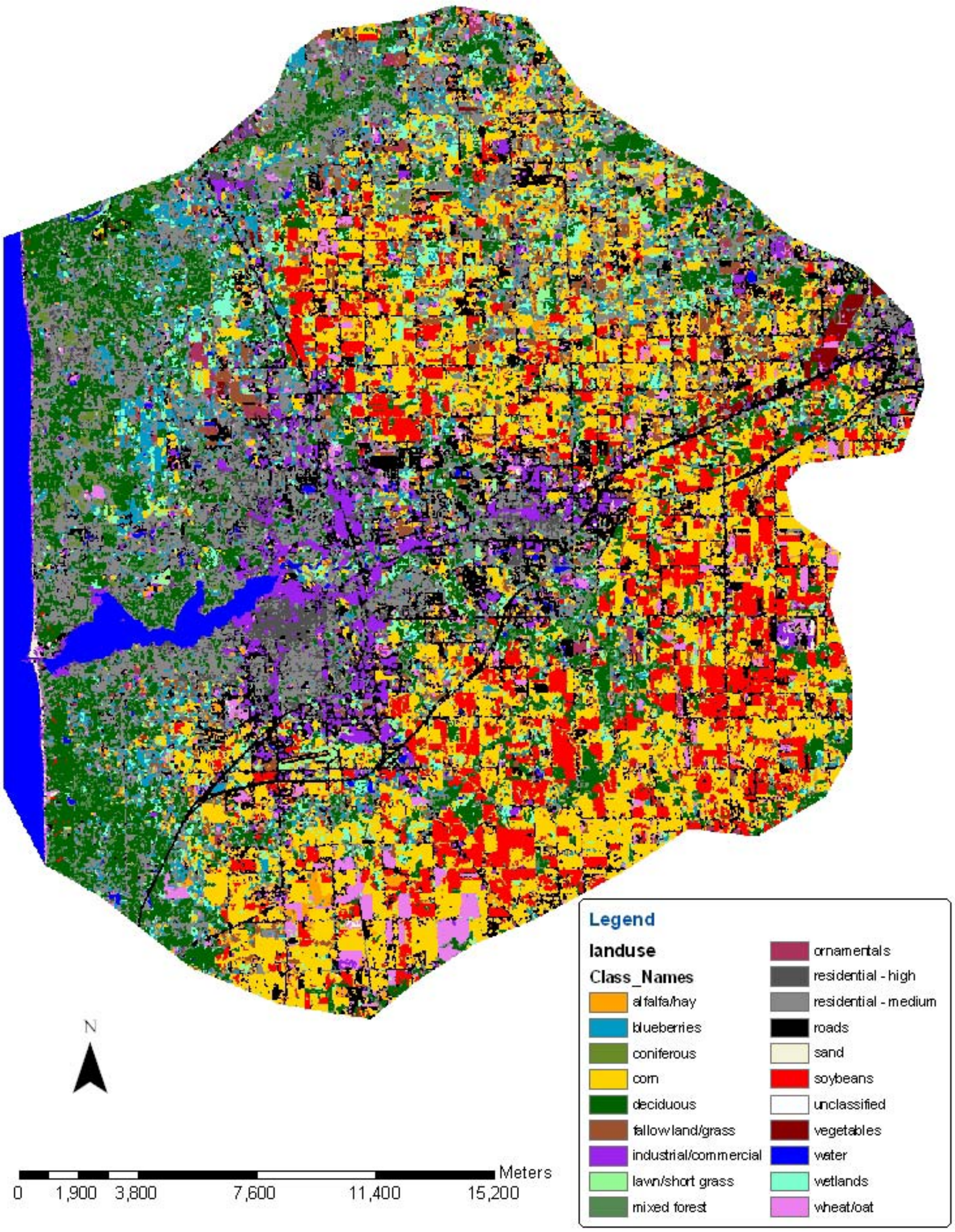

Figure 3. Supervised classification of 2002 Landsat ETM+ image – West Michigan

Table 4. Error matrix for supervised classification using stratified random sampling

Reference data / Classified data	water	lawn/short grass	coniferous	deciduous	mixed forest	wetlands	corn	soybrans	alfalfa	sand	bluberries	fallow land	wheat/oat	vegetables	ornamentals	residential-medium	residential-high	industrial/ commercial	roads	total	User's accuracy (%)
water	9																			9	100
lawn/short grass		3																		3	100
coniferous			1																	1	100
deciduous				25			1													26	96
mixed forest					4															4	100
wetlands		1				4							2							7	57
corn		2					32	3				2								39	82
soybeans								17												17	100
alfalfa									3				1							4	75
sand										0										0	-
blueberries							1				4	3				1				9	44
fallow land												7								7	100
wheat/oat		1							1	1			3							6	50
vegetables														1						1	100
ornamentals												1			0					1	-
residential-medium			1			1										28		1		31	90
residential – high																	5			5	100
industrial/ commercial																		6		6	100
roads							3												21	24	88
total	9	7	2	25	4	5	37	20	4	1	4	13	6	1	-	29	5	7	21	200	
producer's accuracy (%)	100	43	50	100	100	80	86	85	75	-	100	54	50	100	-	97	100	86	100		

Overall accuracy: 86.5%　　Overall Kappa statistics = 0.849

d) Refining classification

A few classes were refined to correct obvious mistakes. Using Arc/Info 8.3 and the Spatial Analyst extension, two new land use classes (schools and recreational, i.e. golf courses, parks) were digitized using reference information from maps and orthophotos. Mobile home parks, often classified as roads, were re-defined as residential-high density. Finally, because they represent a major crop in Park Township, large blueberries orchards were re-defined based on ground survey data and plat books. Some misclassified wetlands were changed to agricultural land based on ground survey data and information from USDA FSA.

While blueberries and high-density residential areas increased by a couple of hundred hectares, changes in other land use categories were minor (see Table 5).

Table 5. Comparison of land use areas before/after edits

Supervised classification		***After editing supervised classification***	
land use	**area (ha)**	**land use**	**area (ha)**
unclassified	28767.33	unclassified	28767.33
lawn/short grass	893.79	lawn/short grass	878.67
coniferous	287.28	coniferous	287.28
deciduous	9039.87	deciduous	8995.59
mixed forest	1243.17	mixed forest	1241.37
corn	13456.71	corn	13539.78
water	3204.81	water	3202.74
alfalfa/hay	1540.53	alfalfa/hay	1510.38
roads	8270.01	schools	318.96
sand	113.94	roads	7812.09
blueberries	2960.1	sand	119.61
fallow land/grass	2525.58	blueberries	3196.53
wheat/oat	1956.33	fallow land/grass	2483.64
ornamentals	382.05	wheat/oat	1892.61
wetlands	2468.43	ornamentals	373.32
residential - medium	10572.48	wetlands	2200.5
vegetables	235.26	residential-medium	10370.34
industrial/commercial	2065.68	vegetables	228.24
residential - high	1855.17	industrial/commercial	1970.64
soybeans	6021.36	residential-high	2083.05
		soybeans	6013.71
		recreational	373.5
Total	**97859.88**	**Total**	**97859.88**

e) Accuracy assessment for updated land use

The previous accuracy assessment was updated based on the refined land use categories. The overall accuracy did not significantly change; it improved slightly to 87.5%. It should be noted that, since the previous accuracy assessment was based on a stratified random sample, the random points did not account for the area covered by the new categories (schools and recreational) and the re-defined blueberry orchards. Therefore, it would have been more appropriate to conduct a separate accuracy assessment, with a new set of points. However, this was not done because of time constraints, and technical difficulties with ERDAS. In addition, while the overall accuracy from a second assessment would likely be better, the improvement might not be significant enough to justify the time spent on it.

This work certainly illustrates the time and cost issues associated with data requirements for water quality modeling, and the difficulty for local agencies to actually use models.

5. Results

The final 2002 land use/land cover map, clipped to the Macatawa Watershed's boundaries, is shown on Figure 4.

A comparison with the 1997 land use map (produced for the Macatawa Watershed Project) shows that, although agriculture remains the main land use in the Macatawa Watershed, cultivated areas have decreased dramatically in the last 5 years and are being replaced by urban development (Table 6). Residential areas and roads (impervious surfaces) have increased significantly. While these figures may contain a degree of error, they nevertheless illustrate the rapid urbanization of the watershed and related loss of agricultural land. This change is related to the rapid population growth experienced by several townships in the watershed (see Table 1) (Focus 2002).

Table 6. Land use change in the Macatawa Watershed

Land use	***Percentage of watershed area***		***Percent change***
	1997 *	***2002***	
Agriculture	68	47	- 21
Residential	9	16.5	+ 7.5
Commercial/industrial	5	5.5	+ 0.5
Roads	3	13	+ 10
Water	3	2	- 1
Deciduous Forest	9	11	+ 2
Coniferous Forest	1	1.5	+ 0.5
Other (barren, wetlands)	2	3.5	+ 1.5

*Figures taken from the Macatawa Watershed Project documents (Higgins and Kosky 2000) – accuracy not known

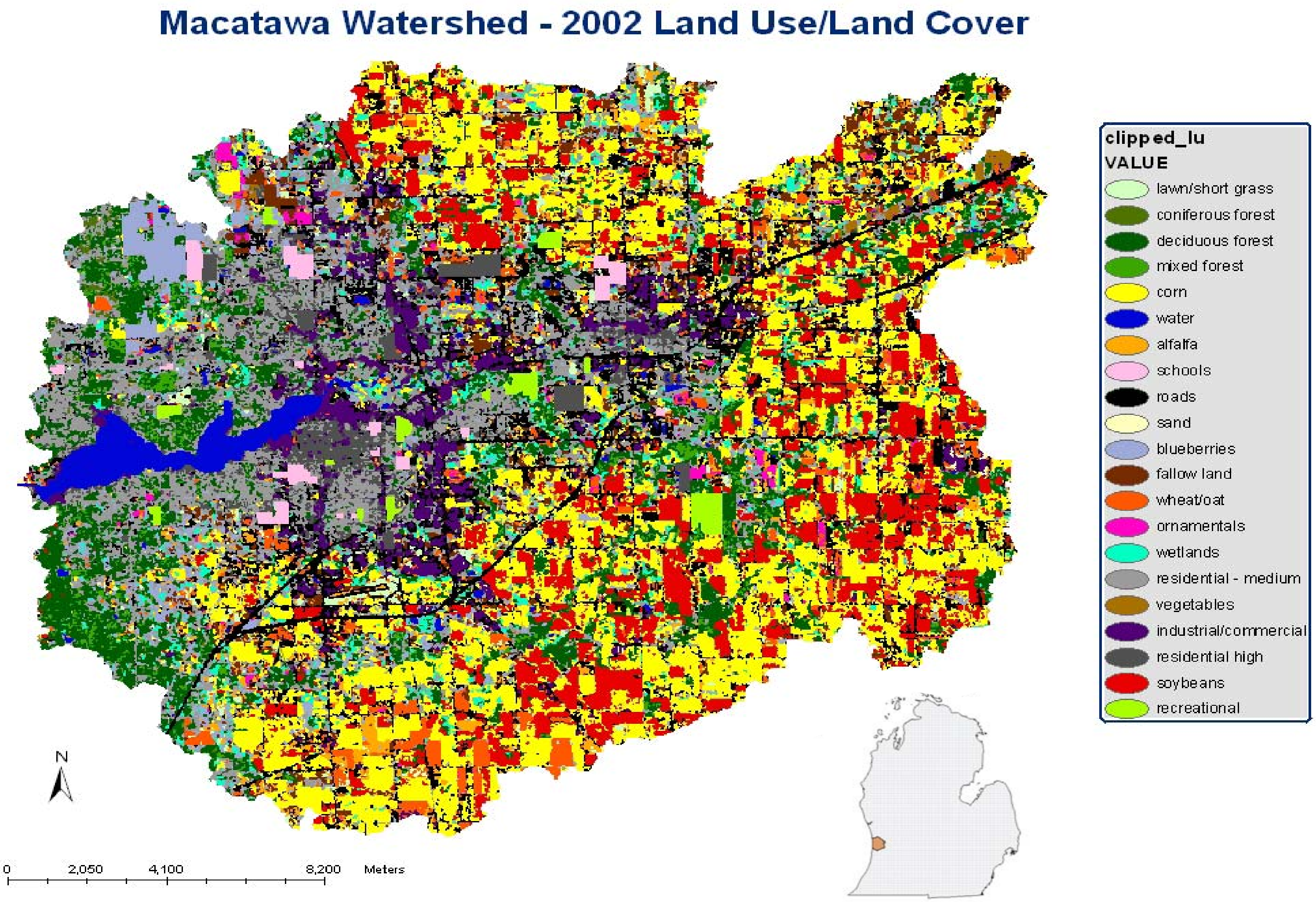

Figure 4. Final 2002 land use map of the Macatawa Watershed

SWAT Modeling

Once the 2002 land cover map was completed, topographical, soil and climatic data were processed for input into SWAT. The following section describes data input.

1. Data input & processing

   a) *Topography, soil and land use*

Hydrographic, elevation and soil maps were processed through the BASINS-ArcView interface:

- A 30x30m digital elevation model (DEM) for Allegan and Ottawa counties was downloaded from the Michigan Geographic Data Library.
- The National Hydrography Dataset (stream network) and the State Soil Geographic Database (STATSGO) layers were available in the BASINS database.
- All layers were projected using Universal Transverse Mercator Zone 16

While SWAT allows grid-cell modeling through programming, all SWAT-GIS interfaces, including BASINS, divide a watershed into subbasins (Neitsch *et al* 2002b). Using the Automatic Watershed Delineation tool in BASINS, the watershed was delineated and subdivided into subbasins based on topography. A 300-ha threshold area - selected because it resulted in an intermediate level of detail - produced a subdivision into 85 subbasins (Figure 5). Point source outlets were also added at this stage, using the point source database available in BASINS.

Once subwatersheds were defined, the land use and soil maps were processed using the Land Use and Soil Definition tool: grid maps were clipped to the watershed boundaries and re-classified using SWAT classes. They were then overlaid to determine the different land use/soil combinations present within each subbasin.

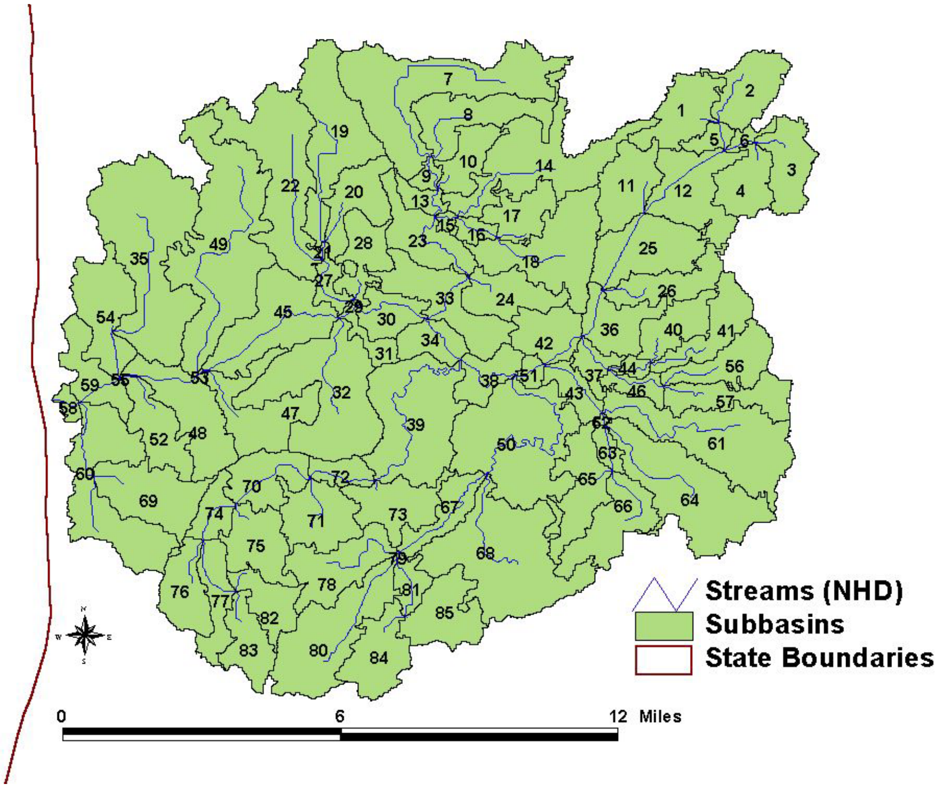

Figure 5. Delineated subbasins in the Macatawa Watershed

The final step consisted in defining the distribution of Hydrologic Response Units (HRUs). HRUs are defined as unique soil/land use/management combinations within subbasins (Neitsch *et al* 2002b). HRUs, the smallest spatial units used by SWAT, allow better modeling of evapotranspiration and other hydrologic processes depending on land uses and soils. Two options are available: selecting the dominant land use and soil (i.e. one HRU per subbasin), or defining multiple hydrologic response units for each subbasin. The latter option was chosen to account for the variety of land uses present in the Macatawa Watershed. The land use threshold was set at 8% (i.e. land uses that cover less than 8% in a subbasin are eliminated) because it represented the mean value available; the soil threshold was set at 10% (suggested value). In total, 469 HRUs were created in the watershed (see example Table 7).

Table 7. Extract from the Land Use and Soil distribution report

		Area [ha]	**Area [acres]**	**%Wat.Area**	**%Sub.Area**
SUBBASIN	# 3	437.1239	1080.155	1	
LANDUSE:					
	Soybean-->SOYB	70.7681	174.8715	0.16	16.19
	Corn-->CORN	147.3387	364.0814	0.34	33.71
	Forest-Deciduous-->FRSD	105.0144	259.4959	0.24	24.02
	Transportation-->UTRN	114.0026	281.7062	0.26	26.08
SOIL:					
	MI006	366.9247	906.6892	0.84	83.94
	MI022	70.1992	173.4658	0.16	16.06
HRUs:					
14	Soybean-->SOYB/MI022	25.8269	63.8197	0.06	5.91
15	Soybean-->SOYB/MI006	44.9412	111.0519	0.1	10.28
16	Corn-->CORN/MI006	147.3387	364.0814	0.34	33.71
17	Forest-Deciduous-->FRSD/MI006	105.0144	259.4959	0.24	24.02
18	Transportation-->UTRN/MI022	44.3723	109.6461	0.1	10.15
19	Transportation-->UTRN/MI006	69.6304	172.0601	0.16	15.93

b) Climate

Once subbasins and HRUs were defined, the SWAT interface and project opened. Before all input data could be written into the model, climate data had to be imported. Daily values are required for precipitation, temperature, solar radiation, wind speed and relative humidity. These values can either by loaded from a file or simulated using the Weather Generator model (Di Luzio *et al* 2002a).

Thirty years of temperature and precipitation records from three gages in and outside the watershed (Holland, Allegan and Grand Haven) were obtained from the National Climatic Data Center website (http://www.ncdc.noaa.gov) and formatted for input into SWAT. Solar radiation, wind speed and relative humidity as well as missing temperature and rainfall records were simulated. The closest weather generator station available in the SWAT database was South Haven (Coop Id 207690).

c) *Additional data*

Once climate data were entered, all initial input values for SWAT were processed.

Input data are divided into 12 databases: soil (.sol), weather generator (.wgn), subbasin (.sub), HRU (.hru), main channel (.rte), groundwater (.gw), water use (.wus), management (.mgt), soil chemical (.chm), pond/wetlands (.pnd), stream water quality (.swq) and basin (.bsn). Most databases contain default values. However, additional data were used as much as possible to define conditions particular to the Macatawa Watershed, such as crop rotation and management practices (see Appendix E).

- Annual phosphorus loads from the four main point sources[2] were provided by the Macatawa Watershed Project. Loads did not vary significantly over the last decade. Therefore, an average daily load was calculated for the relevant subbasins and entered as constant point source loading.
- Initial soil phosphorus concentration was gathered from one farmer's soil test dataset; average soil concentrations were provided by the MSU Cooperative Extension Service in Allegan (Wylie 2003).
- Information about management practices, such as crop rotation, tillage, tile drainage, fertilizer application, were obtained through interviews with a farmer (Dykhuis 2003), the watershed technician (Van Den Bosch 2003) and Michigan State University Extension agents (Krupp 2003, Wylie 2003).

2. Calibration

Once all input data for SWAT were processed, the model was calibrated.

Calibration is the process of adjusting parameter values so as to optimize model performance (Watts 1997). Although SWAT can be used in ungauged watersheds, it

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[2] Mead Johnson & Co, Flint Ink/CDR, Holland Wastewater Treatment Plant, Zeeland Wastewater Treatment Plant

was clear that calibration in this case was required after the first trial run. Calibration was conducted in several steps: first hydrology, then sediment and phosphorus.

The model was run using the following options (Set Up and Run SWAT dialog box):

- Rainfall/runoff routing: daily curve number
- Rainfall distribution: skewed normal
- Potential ET method: Penman-Monteith
- Channel water routing method: variable storage
- Crack flow, channel degradation, stream water quality and lake water quality processes were not active (default).

d) Flow calibration

Observed streamflow data were available from the USGS gage (# 04108800), located on the Macatawa River, which drains the eastern part of the watershed (Figure 6).

Flow calibration was done first on a yearly average basis, then on a monthly average basis. The model was run for six years, from 1987 to 1992. These years were selected because there were few missing records in the temperature and rainfall files. These years covered wet (1990), dry (1989) and average (1991) years as to precipitation.

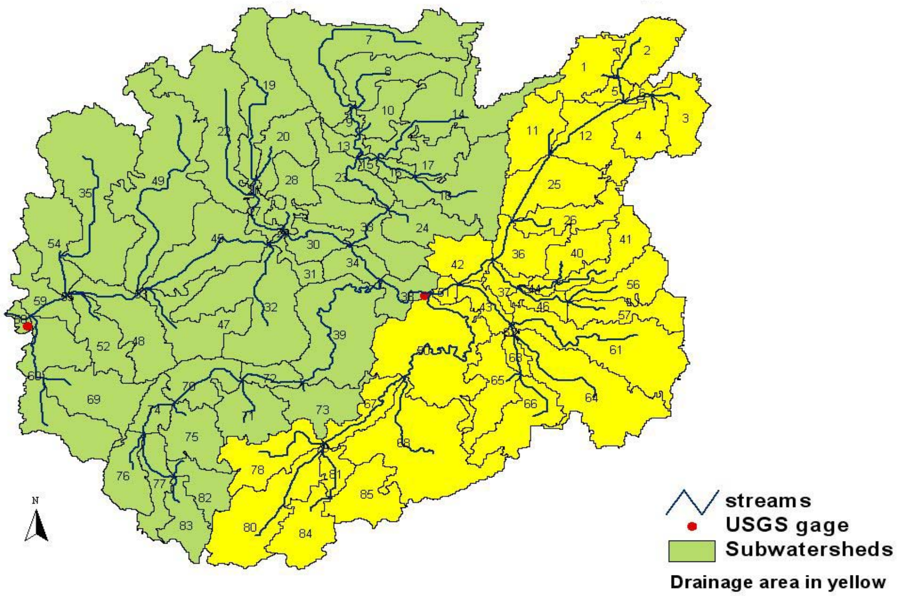

Figure 6. Drainage area of USGS gage 04108800

Various parameters in the groundwater, HRU, soil, management and basin database were adjusted to improve fit between observed and simulated flow (see Appendix D).

The model predictions were evaluated using two parameters: coefficient of determination (r^2) and Nash-Sutcliffe coefficient of efficiency (Ens). The coefficient of determination r^2 measures the strength of the relationship between observed and simulated values while Ens is a measure of the goodness-of-fit between observed and simulated values. The closer r^2 and Ens are to 1, the better the model predictions.

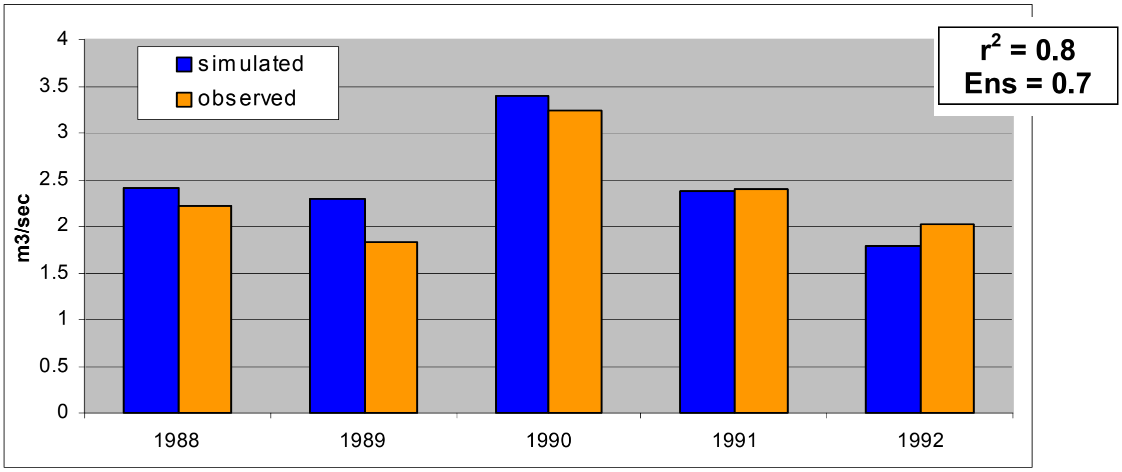

Figure 7. Yearly average flow calibration

On an annual basis, model predictions were good. The mean simulated annual flow was within 5% of the mean observed flow for the period

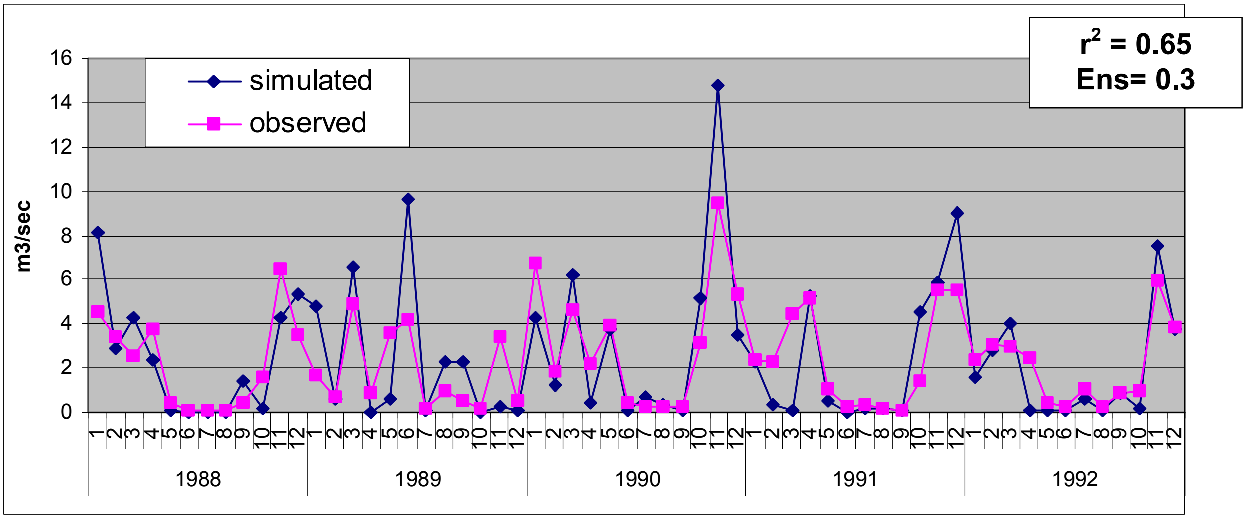

Figure 8. Monthly average flow calibration

On a monthly basis, SWAT appeared to overestimate high flow events. However, the relationship between observed and simulated monthly flow remained relatively strong (r^2 = 0.65). Ens is more sensitive to outlying values on a single event (Earth Tech 2000). The low value for Ens could be an indication that the climate data used in the model were not entirely representative of conditions in the watershed since some of the input data (e.g. wind speed) were simulated. Since phosphorus load assessment was conducted on an annual basis, flow simulation was considered to be adequate.

e) Sediment calibration

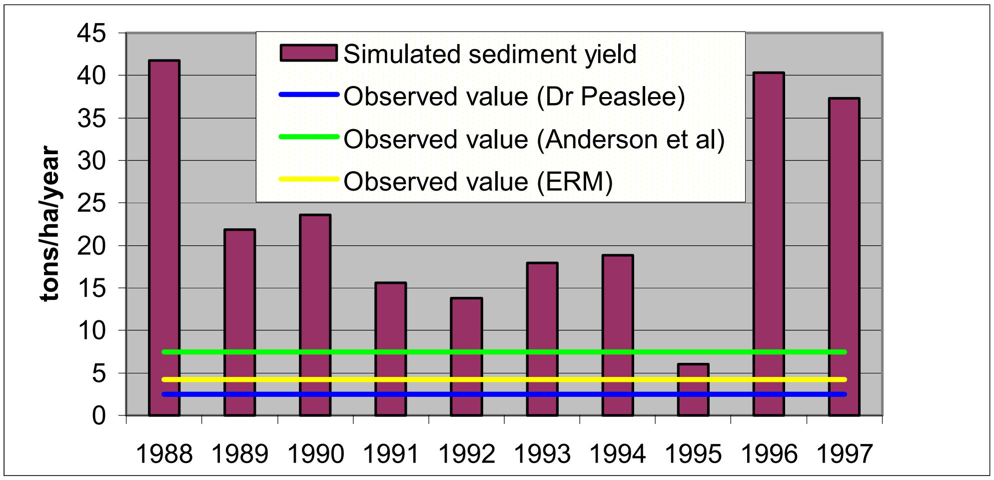

Figure 9. Yearly average sediment yield calibration

Because only three observed values, based on one-time observations, were available to calibrate sediment yield, the model was run over a 10-year period to better represent sediment yield variation.

- Dr Rabe, an environmental consultant from ERM, sampled two points in the lake in fall 1997 and calculated a sedimentation rate of 500 tons/day, or 4.2 tons/ha/year.
- Dr Peaslee, from Hope College, collected sediment cores for a separate study in early 2004 and estimated a sedimentation rate of 1cm/year. Assuming a soil density of 1.55 g/cm3, this rate was converted to 2.5 tons/ha/year.
- A 1978 study found that sedimentation rates for Lake Macatawa ranged from less than 1 cm to 5.3 cm/year with an average rate of 3 cm/year (Anderson *et al* 1978). The average value (converted to 7.5 tons/ha/year) is shown on figure 9.

All parameters used in the Modified Universal Soil Loss Equation were decreased to their lowest possible value. Other parameters, such as edge-of-field filter strip, were also modified. Nevertheless, simulated sediment yield remained very high across the run period. Simulated sediment load was on average approximately three to ten times more than observed values.

Although these results were the best simulation that could be achieved, they cannot be considered satisfactory. Input data for sediment processes were either inaccurate or incomplete. In addition, observed data included only one-time measurements: such measurements are more representative of immediate climatic conditions (e.g. loading following a storm) than actual, long-term sediment loadings.

f) Phosphorus calibration

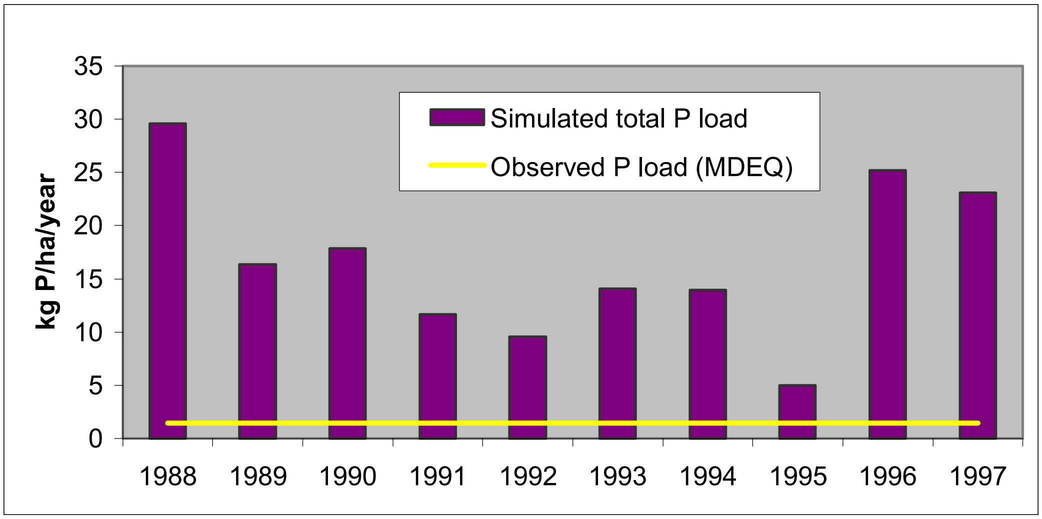

Figure 10. Yearly average phosphorus load calibration

Because phosphorus strongly adsorbs to soil particles, phosphorus load is directly related to sediment load. The inaccurate sediment calibration obviously affected phosphorus calibration. As for sediment calibration, the observed phosphorus load was limited to the MDEQ study in 1996/1997: the total phosphorus load calculated was 62,757 kg/year (or 1.44 kg/ha/year). However, it must be noted that the MDEQ reduced the influence of a record flow event in June 1997 to calculate a phosphorus load more representative of an average year (Walterhouse 1999). This change clearly impacted calibration results: the SWAT simulation showed the peak in phosphorus and sediment load in June 97 following the precipitation event (Figure 11).

The model was run both on a yearly and monthly average (for 1995-1997 only) to show seasonal variations in phosphorus load and to provide a comparison with the MDEQ study. A few parameters were adjusted. In particular, initial phosphorus soil concentration values were all decreased to the average value of 100 ppm. However, no attempt was made to fit phosphorus load within the following observed values (it would have been impossible considering sediment load).

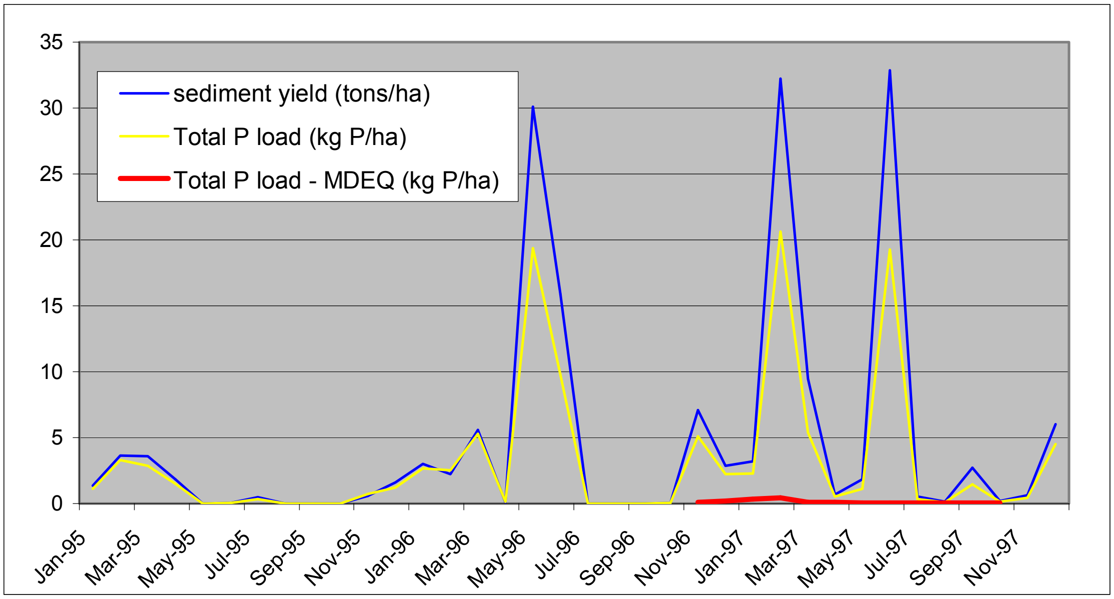

Figure 11. Average monthly phosphorus and sediment calibration

Similar to the sediment calibration results, the simulated total phosphorus load was on average two to twelve times more than observed values.

3. <u>Scenarios</u>

Once the model was calibrated, the model was run for a period of 10 years for six BMP scenarios (Table 8 and Appendix F).

SWAT models BMPs in the following manner (Neitsch *et al* 2002b):

- Filterstrips: Edge-of-field filterstrips are applied to the smallest spatial unit available: the hydrologic response unit. The only value required is the width (in meters) of the filterstrip. In most cases, HRUs will be larger than fields.
- No-till: Management practices are also applied at the HRU level. The tillage operation (November 15) included after corn harvesting was removed: soybeans were planted directly into residue corn stalks. The parameter BIO_MIX was increased to 0.7 to reflect the increase in

biological activity when soil is less frequently disturbed (Neitsch *et al* 2002a)

- Grassed waterways: They can only be modeled at the subbasin level. The Manning's "n" value for the main channel (CH_N2) was increased from default value 0.14 to 0.24 to account for the increase in channel flow roughness (Bracmort *et al* 2003).

Table 8. Agricultural BMP scenarios

Scenario number & name	Description	Notes
#1 - Current	Includes all BMPs implemented in the Macatawa Watershed between 2000 and 2003: - filter strips - no till - grassed waterways - Zeeland West wetland area	Does not include three grade stabilization structures. See appendix F for more information on BMP location and size. Source: Macatawa Watershed Project listing 2003
#2 – Filter30	- BMPs from scenario 1 - 30-m wide filter strip applied to the largest corn or soybean HRU per subbasin	The 30-m filter strip corresponded to the average width of all implemented filter strips (excluding one 100-m outlier).
#3 - Wetland	- BMPs from scenario 1 - 30-m wide filter strip applied to the largest corn or soybean HRU per subbasin - Restoration of a 131.5 ha (325 acres) agricultural property into wetlands	The wetland area is located over three subbasins (25, 26, 36). Restoration of this property will be undertaken by the Macatawa Watershed Project in the coming years.
#4 – No-till	- BMPs from scenario 1 - 30-m wide filter strip applied to the largest corn or soybean HRU per subbasin - Restoration of a 131.5 ha (325 acres) agricultural property into wetlands - Tillage operation removed in two HRUs per subbasin whenever possible (one corn and one soybean)	
#5 – No-till only	- BMPs from scenario 1 - Restoration of a 131.5 ha (325 acres) agricultural property into wetlands - Tillage operation removed in two HRUs per subbasin whenever possible (one corn and one soybean)	
#6 – Filter10	- BMPs from scenario 1 - 10-m wide filter strip applied to the largest corn or soybean HRU per subbasin - Restoration of a 131.5 ha (325 acres) agricultural property into wetlands - Tillage operation removed in two HRUs per subbasin whenever possible (one corn and one soybean)	The 10-m filter strip scenario was added to provide a more conservative approach. It also provided an estimate of the impact of filter strip width on sediment and phosphorus loads.

As of 2003, BMPs implemented in the watershed cover a small area of the watershed (approximately 6%)[3]. The most comprehensive scenarios (#4 and #6) cover most of the agricultural area in the watershed (approximately 83% of the total cropland). Although

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[3] This percentage is likely an overestimate considering the way SWAT models filterstrips.

they are likely unrealistic considering the current pace of BMP implementation, they nevertheless provide a valuable estimate of phosphorus load reductions in the best case scenario.

Table 9. BMP area under different scenarios

Scenario #	Name	Total area affected (ha)	% watershed area
1	Current	2819.01	6.45
2	Filter30	12310.48	28.18
3	Wetland	12441.98	28.48
4	No-till	17218.37	39.44
5	No-till only	16483.24	37.46
6	Filter10	17218.37	39.44

Note: For filterstrips, the area calculated correspond to the area of the HRU where a filterstrip is applied, not to the area of the filterstrip itself.

RESULTS AND DISCUSSION

Sediment and Phosphorus Loads

For each scenario, the average annual sediment and phosphorus loads were calculated and compared to base conditions in the watershed, i.e. no actions taken. Results are presented in tables 10 and 11, and figures 12 and 13.

Agricultural best management practices implemented in the last three years reduced sediment load by 10% and phosphorus load by 8%. If BMP implementation continues at approximately the same pace in the coming years, it seems unlikely that the 60% goal reduction in phosphorus load will be met.

The restoration of 325 acres of agricultural land into wetlands also brought a small decrease in both sediment and phosphorus loads (about 4% less than scenario 2). However, considering that the wetland area corresponds to only 0.3% of the total watershed area, this action - and restoration of wetlands in general - could result in valuable reductions in phosphorus and sediment loads.

Edge-of-field filter strips provided a significant reduction in both sediment and phosphorus loads, although the reduction was not proportional to the width of the filter strip. A 30-m filter strip (scenario 4) only reduced phosphorus load by an additional 15% compared to a 10-m filterstrip (scenario 6). No-till practices could also bring a sizeable reduction in sediment and phosphorus loads (-35%, scenario 5) although not as important as filter strips (-66%, scenario 3).

The largest reduction in sediment (-71%) and phosphorus loads (-65%) occurred when all practices were implemented, with the best results obtained using the 30-m filter strip (scenario 4).

Table 10. Sediment load (tons/ha/year) under different scenarios

Year	Base	Scen. 1	Change (%)	Scen. 2	Change (%)	Scen. 3	Change (%)	Scen. 4	Change (%)	Scen. 5	Change (%)	Scen. 6	Change (%)
1	41.77	39.80	-4.73	28.42	-31.95	27.16	-34.98	26.37	-36.87	33.06	-20.85	29.43	-29.54
2	21.89	19.44	-11.17	9.48	-56.68	8.31	-62.02	6.97	-68.15	16.57	-24.31	11.38	-48.02
3	23.60	21.22	-10.08	6.94	-70.58	6.13	-74.02	5.19	-78.02	14.08	-40.33	9.27	-60.71
4	15.62	14.07	-9.93	4.84	-69.01	4.32	-72.36	3.31	-78.81	8.35	-46.58	5.62	-64.01
5	13.83	12.50	-9.63	4.27	-69.16	3.83	-72.29	3.15	-77.23	8.43	-39.06	5.57	-59.75
6	17.91	15.93	-11.06	7.34	-59.03	6.47	-63.86	5.45	-69.55	13.65	-23.75	9.20	-48.60
7	18.86	17.03	-9.67	5.77	-69.38	5.10	-72.97	4.57	-75.77	12.52	-33.59	8.23	-56.35
8	6.02	5.32	-11.54	2.29	-61.86	2.02	-66.50	1.43	-76.31	3.41	-43.28	2.33	-61.23
9	40.34	36.67	-9.10	11.16	-72.35	9.98	-75.27	8.25	-79.56	21.63	-46.39	14.44	-64.20
10	37.32	32.82	-12.05	16.13	-56.79	13.96	-62.59	10.14	-72.84	24.06	-35.53	16.53	-55.71
Mean	**23.7**	**21.5**	**-9.89**	**9.66**	**-61.68**	**8.73**	**-65.69**	**7.48**	**-71.31**	**15.58**	**-35.37**	**11.20**	**-54.81**

Table 11. Phosphorus load (kg/ha/year) under different scenarios

Year	Base	Scen. 1	Change (%)	Scen. 2	Change (%)	Scen. 3	Change (%)	Scen. 4	Change (%)	Scen. 5	Change (%)	Scen. 6	Change (%)
1	29.60	27.95	-5.56	17.69	-40.22	16.82	-43.18	16.00	-45.94	22.00	-25.66	18.75	-36.66
2	16.36	14.71	-10.09	7.01	-57.18	6.18	-62.23	5.01	-69.37	11.69	-28.58	8.09	-50.57
3	17.85	16.23	-9.04	6.02	-66.29	5.34	-70.09	4.41	-75.27	10.41	-41.65	7.17	-59.84
4	11.69	10.72	-8.27	4.31	-63.09	3.90	-66.66	3.13	-73.25	6.34	-45.74	4.60	-60.62
5	9.56	8.78	-8.14	3.47	-63.75	3.12	-67.42	2.59	-72.92	5.83	-39.01	4.07	-57.40
6	14.10	12.99	-7.87	7.25	-48.57	6.57	-53.38	5.75	-59.21	10.55	-25.14	7.95	-43.64
7	13.95	13.00	-6.81	6.17	-55.76	5.60	-59.85	5.11	-63.36	9.59	-31.28	7.18	-48.58
8	4.99	4.62	-7.44	2.68	-46.19	2.46	-50.76	2.09	-58.04	3.34	-33.11	2.66	-46.57
9	25.18	23.60	-6.27	10.07	-60.01	9.01	-64.21	8.01	-68.19	15.01	-40.40	11.25	-55.31
10	23.07	21.15	-8.34	11.85	-48.64	10.20	-55.79	8.26	-64.22	15.47	-32.94	11.56	-49.88
Mean	**16.63**	**15.38**	**-7.78**	**7.65**	**-54.97**	**6.92**	**-59.36**	**6.04**	**-64.98**	**11.02**	**-34.35**	**8.33**	**-50.91**

Note: Results of each scenario were compared to the base (no BMP applied) condition. Precipitation weighted means were also calculated. For phosphorus load, they were not significantly different from the above means. For sediment load, they were slightly below the above means.

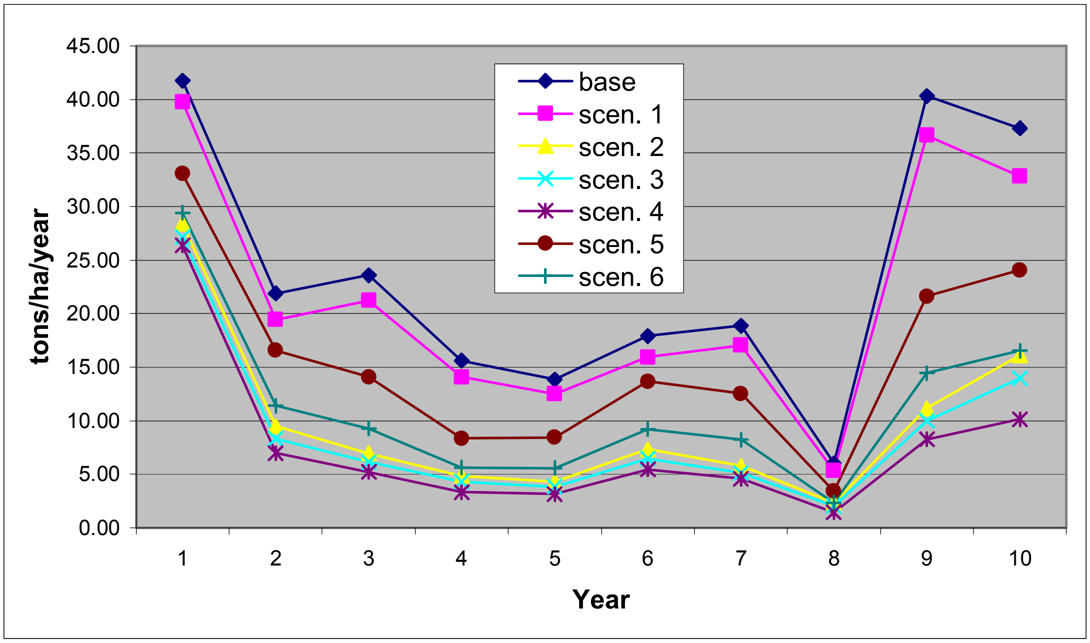

Figure 12. Sediment load under different scenarios

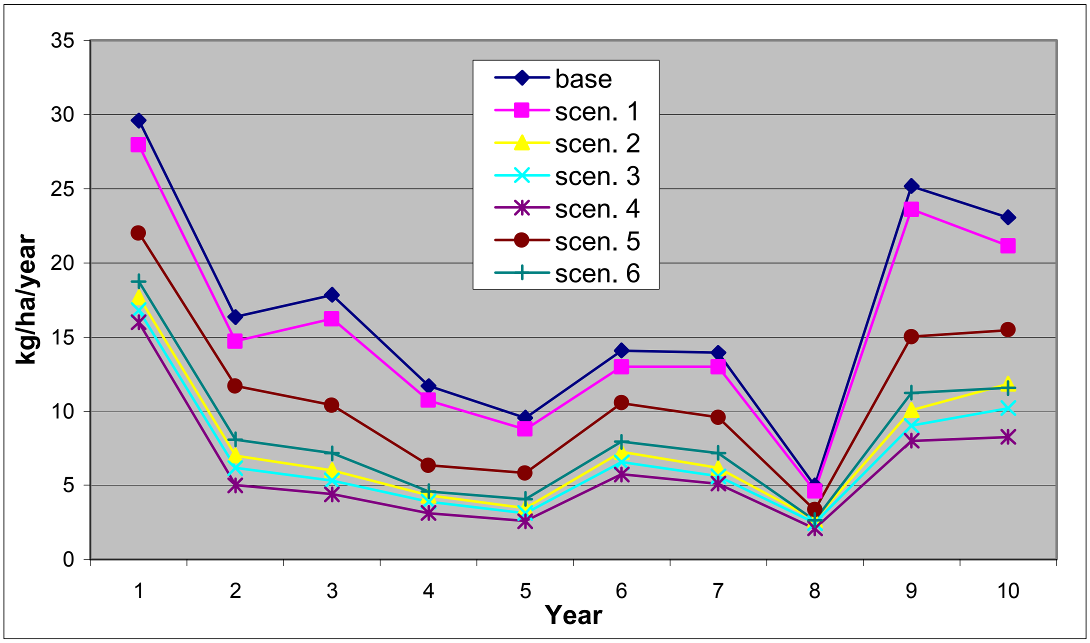

Figure 13. Phosphorus loads under different scenarios

Distribution of Sediment and Phosphorus Loads

Base conditions

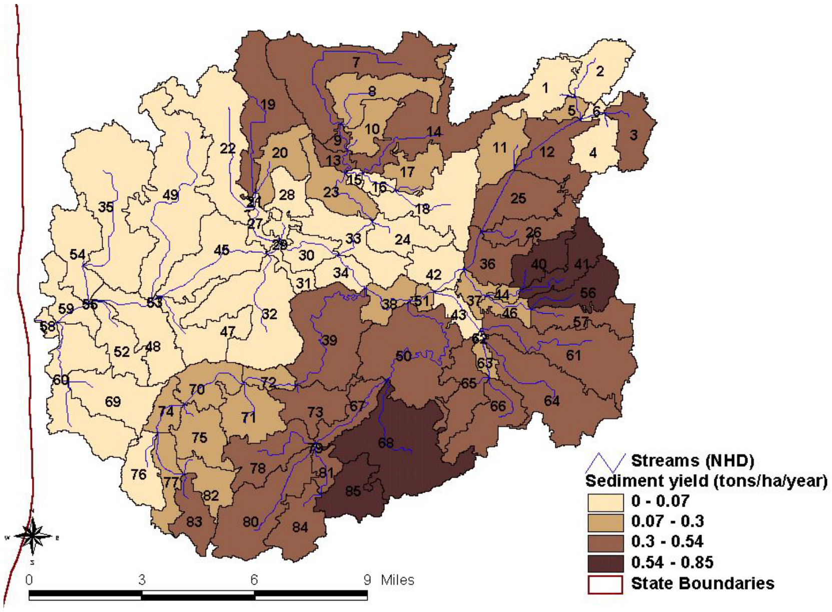

Figure 14. Sediment load per subbasin

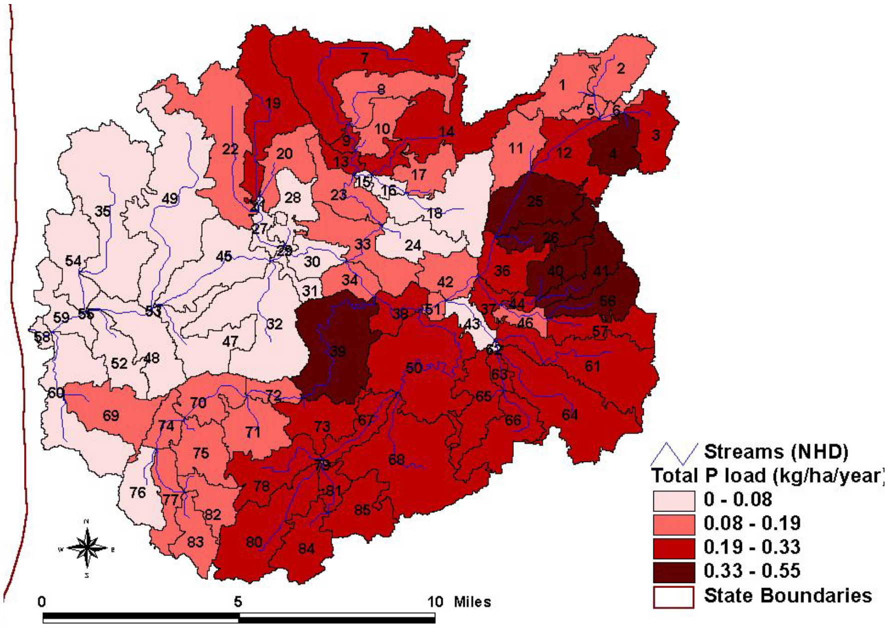

Figure 15. Total phosphorus load per subbasin

Scenario 4

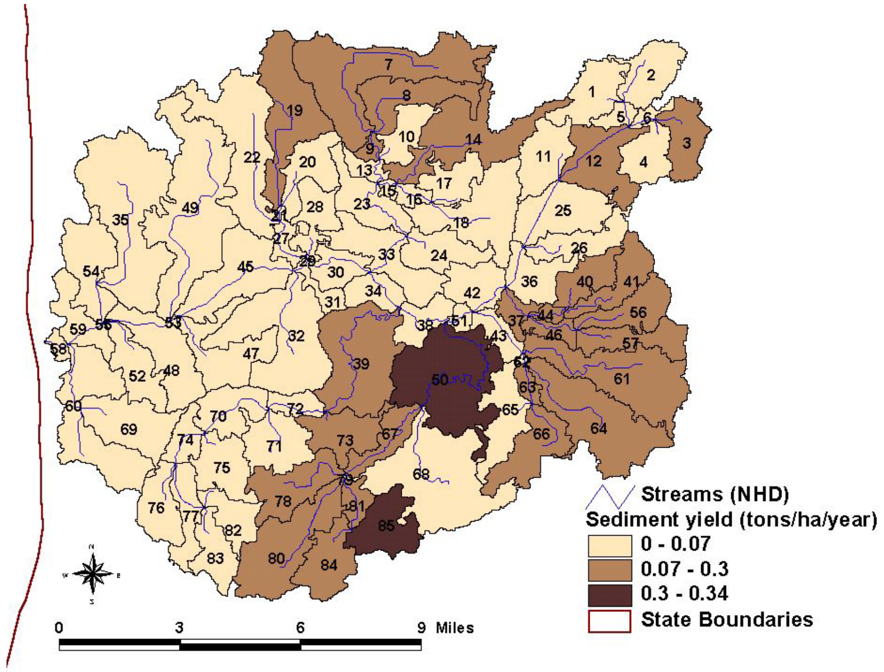

Figure 16. Sediment load per subbasin

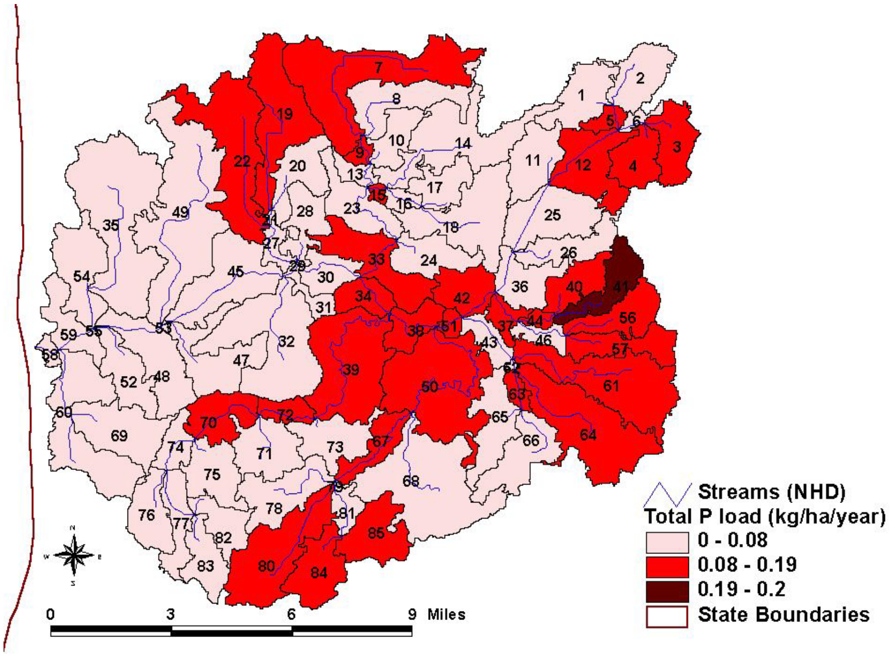

Figure 17. Total phosphorus load per subbasin

The simulation results confirm that most of the phosphorus and sediment pollution comes from agricultural areas, in particular those located on clay and loam soils. While there is a strong correlation between high sediment load and high phosphorus load, some of the highest loading subbasins are different: for instance, sediment load is high in subbasins 68 and 85 while phosphorus load is high in subbasins 39 and 4. This difference could be related to soil types. The highest phosphorus loadings are all occurring on soil class MI006, the only soil in the watershed with a silty clay texture (Appendix A).

Under the best-case scenario (scenario 4), reductions in sediment and phosphorus load appear to be evenly spread throughout the watershed. This should be expected since BMPs were applied consistently in each subbasin. Sediment yield remains relatively high in two subbasins – and surprisingly, one of them (50) was not in the highest category under base conditions. The highest phosphorus loading now only occurs in subbasin 41, which also had the highest load (0.55 kg/ha/year) under base conditions.

Water Quality Standards

Simulation results could also provide an estimate of whether water quality standards in the Macatawa Watershed would be met in the best-case scenario. However, the simulated concentration values should only be taken as rough estimates considering the large difference between observed and simulated loads at the calibration stage. To determine the sediment and phosphorus concentrations, the mean annual total load for the 10-year simulation period was divided by the mean annual water yield for the same period for the whole watershed.

Table 12. Average annual sediment and phosphorus loads and concentrations

		Scenarios					
	base	**1.current**	**2. filter30**	**3. wetland**	**4. notill**	**5. notill only**	**6. filter10**
mean flow (m3)	6.46E+08	6.45E+08	6.45E+08	6.51E+08	6.53E+08	6.53E+08	6.53E+08
mean sediment load (tons)	1034309.84	936859.44	421497.12	380620.54	326314.72	679344.01	488508.17
mean P load (kg)	725524.25	670616.53	333738.10	301772.20	263272.68	480788.21	363226.63
Sed. conc. (mg/l)	1601.80	1451.40	653.07	584.50	499.89	1040.67	748.33
Total P conc. (mg/L)	1.12	1.04	0.52	0.46	0.40	0.74	0.56

Recently, to address the continuing issue of eutrophication, the EPA has developed numerical criteria for nutrients in rivers and streams (including total phosphorus, total nitrogen, chlorophyll a and turbidity), and in lakes and reservoirs (TP, TN, chlorophyll a, secchi depth) for 17 ecoregions in the United States. These criteria were developed to provide a starting point for states to develop more refined criteria (US EPA 2002a).

1. <u>Sediment</u>

The EPA criteria use two measures related to sediment: secchi depth for lakes and turbidity for streams and rivers. However, no quantitative criteria have been established for total suspended solids either nationwide or in the State of Michigan (US EPA 2002b, MDEQ 1999). The EPA recommended criteria for suspended solids aims at protecting aquatic life by limiting reduction in photosynthetic activity (US EPA 1986). In Michigan, the rule states that:

> *"The waters of the state shall not have any of the following unnatural physical properties in quantities which are or may become injurious to any designated use: (a) turbidity, […], (f) settleable solids, (g) suspended solids"* (MDEQ 1999).

Therefore, it is difficult to determine whether the Macatawa Watershed would meet water quality standards using simulation results. While a 70% reduction in TSS load would certainly improve conditions for aquatic life and other designated uses, only monitoring data could correctly assess the improvement in water quality in streams and lake.

2. <u>Phosphorus</u>

The recommended total phosphorus concentration for rivers and streams for EPA Ecoregion VII (mostly glaciated dairy region, including western Michigan) is 0.033 mg/L (US EPA 2002b). The lowest simulated total P concentration (0.400 mg/L) is over 10 times the recommended criteria value. The Macatawa Watershed would fail to meet EPA recommended water quality standards. Even if we take into account the fact that the original simulated mean total phosphorus load was approximately ten times more than observed values, water quality standards for total P in streams would still not be met (US EPA 2002b).

For lakes and reservoirs, the EPA recommends a TP concentration of 0.01475 mg/L. The TMDL goal for Lake Macatawa is a TP concentration of 0.05 mg/L. Therefore, even if this goal is achieved, EPA standards will not be met (US EPA 2002a).

While Michigan has a numerical total phosphorus criteria for point source discharges (1 mg/L), the general nutrient standard states that:

> *“nutrients shall be limited to the extent necessary to prevent stimulation of growths of aquatic rooted, attached, suspended and floating plants […] which are or may become injurious to the designated uses of the waters of the state” (MDEQ 1999).*

Even in the best-case scenario, the total phosphorus concentration still indicates eutrophic conditions, therefore it is likely that the Macatawa Watershed would not be able to comply with Michigan water quality standards.

Discussion

If agricultural best management practices continue to be implemented at the same pace in the coming years as they are now, it is unlikely that the Macatawa Watershed TMDL goal will be met. Modeling results show that only a widespread implementation of no-till practices and large filter strips would bring a 60% reduction in phosphorus load to Lake Macatawa. No-till could be implemented by farmers and should be actively promoted within the farming community. Filter strips are one of the most effective methods for reducing phosphorus and sediments. However, they do not give farmers any direct benefits and represent a more costly option. Nevertheless, filter strips should be promoted whenever possible. Finally, small wetland restoration along streams at different points in the watershed may provide some valuable reduction in phosphorus load.

While complete BMP implementation at the watershed scale is unrealistic, it could be possible to target BMP implementation in critical source areas of phosphorus load, such as agricultural areas located on silty clay soils (soil type MI006) in the center and eastern side of the watershed. Focusing future actions in these areas could represent the most cost-efficient solution.

While it is necessary to keep in mind the uncertainties associated with the modeling process, results from the SWAT model provide an estimate of the impact of common agricultural best management at the watershed scale. Many other practices, such as restoring riparian buffer strips, were not simulated and could provide a significant reduction in phosphorus inputs to the lake. New nutrient management regulations could also lead to improvements in water quality.

According to the results (see Figure 14 and 15), urban areas do not contribute much to sediment and phosphorus loadings. However, urban runoff may sometimes contribute more to the annual phosphorus load than agricultural areas, in particular during dry years (Soranno *et al* 1996, Winter and Duthie 2000). Impervious surfaces produce much more runoff than agricultural areas; this runoff drains directly into a stream or lake whereas runoff from cultivated areas, in particular away from riparian zones, will be partially attenuated before reaching a waterbody (Soranno *et al* 1996, Tong and Chen 2002). Therefore, it would be useful to determine the long-term impact of rapid urban development on water quality in the Macatawa Watershed.

Limitations

The results should be taken with caution as they contain a large degree of uncertainty associated with data input, sampling data and the SWAT model itself.

1. Data input

Although many data inputs used in SWAT were specific to the Macatawa Watershed, they might not always adequately account for spatial and temporal variability within the watershed. While detailed datasets would improve simulation results, they are not often available.

a) Climate

The Holland weather station, in the center of the watershed, provided the most important data input for simulation of all hydrological processes. However, one weather station is not enough to represent spatial and temporal variations in precipitation throughout a watershed, even though the watershed is not very large. Although stations in Allegan and Grand Haven were also included, the model used only the closest station to each subbasin, i.e. Holland. In addition, depending on the years, the amount of missing data for the Holland station varied from a few days to a few months (e.g. in 1997), therefore affecting the accuracy of the simulation.

b) *Soil phosphorus*

Similarly, phosphorus levels in the soil are extremely variable, even within fields. The soil phosphorus concentration value used represents average conditions in the watershed. Better soil concentration data would improve the simulation of phosphorus and sediment transport processes, and provide a more accurate location of critical source areas, i.e. high phosphorus level field located along streams.

c) *Management practices*

Tilling equipment and fertilizer applications (type, timing and amount) vary from one farmer to the next. Management practices used in the simulation were based on average practices and may vary across the watershed: for instance, dairy, poultry and turkey farmers will use different types of manure while farmers without livestock may use commercial fertilizer. While the chemical composition of different types of manure may not completely affect nutrient processes, it may nevertheless have some impact on results at the watershed scale.

2. Sampling data

Model calibration was made more difficult because of the limited amount of observed water quality data. Sediment load measurements came from two one-time sampling tests and a small 1978 study (Anderson *et al* 1978). The phosphorus load value was calculated from a one-year study by MDEQ. While the MDEQ's study covered one full year, results were skewed as one large rain event was not accounted for; therefore, sampling results could not be compared to simulation data.

Increasing monitoring data would allow a better calibration of the model and would provide more confidence in the model's results.

3. SWAT model

Several problems occurred while entering data into SWAT; not all of them were resolved in a satisfactory manner.

BASINS did not process properly the land use grid format (the reclassified land use showed a hole of missing data). This seems to be a rare problem for which BASINS developers have not yet found a solution. The land use grid was converted to a shapefile format for processing.

The STATSGO soil dataset for the Macatawa Watershed includes water as a soil category. SWAT can only reclassify this category when the STATSGO dataset from Texas is also downloaded into the SWAT database. Nevertheless, an error message appeared when the model was writing the input data; this problem was never properly fixed. The only way to fully process the STATSGO dataset was to reclassify the lake area as a soil (not water).

Finally, processes such as channel erosion, in-stream nutrient processes and sediment resuspension were not simulated because input data were not available. These processes could have a long-term impact on water quality.

CONCLUSIONS AND RECOMMENDATIONS

Lake Macatawa, a coastal lake in Western Michigan, has been eutrophic for over thirty years. In 1997, the Michigan Department of Environmental Quality determined that water quality of the lake was impaired by phosphorus and suspended solids. As a result, in accordance with the 1972 Clean Water Act, a phosphorus Total Maximum Daily Load (TMDL) was developed for the Macatawa Watershed in 1998. The Macatawa Area Coordinating Council (MACC), the local metropolitan planning organization, has been charged with implementing the TMDL through the Macatawa Watershed Project. In the past four years, the MACC has promoted the implementation of agricultural best management practices. While several practices, in particular no-till, filterstrips and grassed waterways, have been used, the MACC has not had the means to assess the effects of its actions on water quality. Using a watershed simulation model, the Soil and Water Assessment Tool (SWAT), this study estimated the impact of several agricultural best management practices on sediment and phosphorus loads, and on water quality in the Macatawa Watershed.

A land use/land cover map was first produced through supervised classification of a 2002 Landsat ETM+ image. This map confirmed the rapid urbanization (18% increase in urban areas in 5 years) of the Macatawa Watershed due to population growth, although cropland remains the main land use in the watershed (47% of total area).

Six agricultural best management practices scenarios were simulated for a ten-year period. The modeling results led to the following conclusions:

1. The current pace of BMP implementation would not be sufficient to achieve the 60% reduction goal in phosphorus load by 2009. Only a widespread implementation of filterstrips and no-till practices would bring in such a

phosphorus load reduction. In the short term, the best option would be to focus best management practices in critical sources areas, i.e. fields located on silty clay soils (soil class MI006) in the center and eastern part of the watershed.

2. Even in the best-case scenario, with a widespread BMP implementation, the Macatawa Watershed would not be able to comply with either Michigan water quality standards or the recent EPA recommendations for total phosphorus concentrations in lakes and streams. However, it should be noted that the TMDL goal was set to bring Lake Macatawa from extremely hypereutrophic condition to hypereutrophic (MDEQ 1999). Managing eutrophication is a slow process that cannot be easily achieved within the 8-year period allocated to most TMDLs.

This project, done in cooperation with the Macatawa Watershed Project, contributes to a better understanding of the impact of agriculture and BMPs on water quality. However, due to constraints of data and financial resources, simulation results contain a certain level of uncertainty. While the Macatawa Area Coordinating Council may be able to use this study as a partial basis for decision-making, further studies need to be conducted.

Recommendations

- As the Macatawa Watershed becomes more developed, it will be necessary to assess the impact of urban areas on water quality. While an urbanization scenario was originally considered, it proved difficult to implement under the current SWAT set-up. This work should nevertheless be conducted in the future to provide a long-term perspective on water quality in the Macatawa Watershed, and to support local land use planning.
- Extensive monitoring data (such as long-term sediment load, soil phosphorus level and accurate BMP locations) need to be collected on a regular basis to assess the

uncertainty of modeling results and to determine the impact of BMP implementation for effective management of TMDL.

- The Macatawa Watershed Project has had limited financial, technical and personnel resources to implement the TMDL program and has often relied on volunteer work to carry out specific actions, such as wetland restoration. This lack of resources may limit the successful implementation of TMDLs in many small watersheds. Therefore, the EPA should provide consistent financial and technical assistance to local government agencies in order to assess the feasibility and effectiveness of TMDLs.
- The simulation results showed that the TMDL goal could only be achieved through watershed-wide implementation of several BMPs but, even in this unrealistic best-case scenario, the Macatawa Watershed would not likely be able to meet either Michigan or EPA water quality standards. Thus, it is necessary for the EPA to develop pilot studies to evaluate the feasibility of achieving water quality standards with available financial resources in the context of the TMDL program and timeline. Otherwise, success of TMDL implementation and water quality management by local governments would be uncertain, unrealistic, and difficult.

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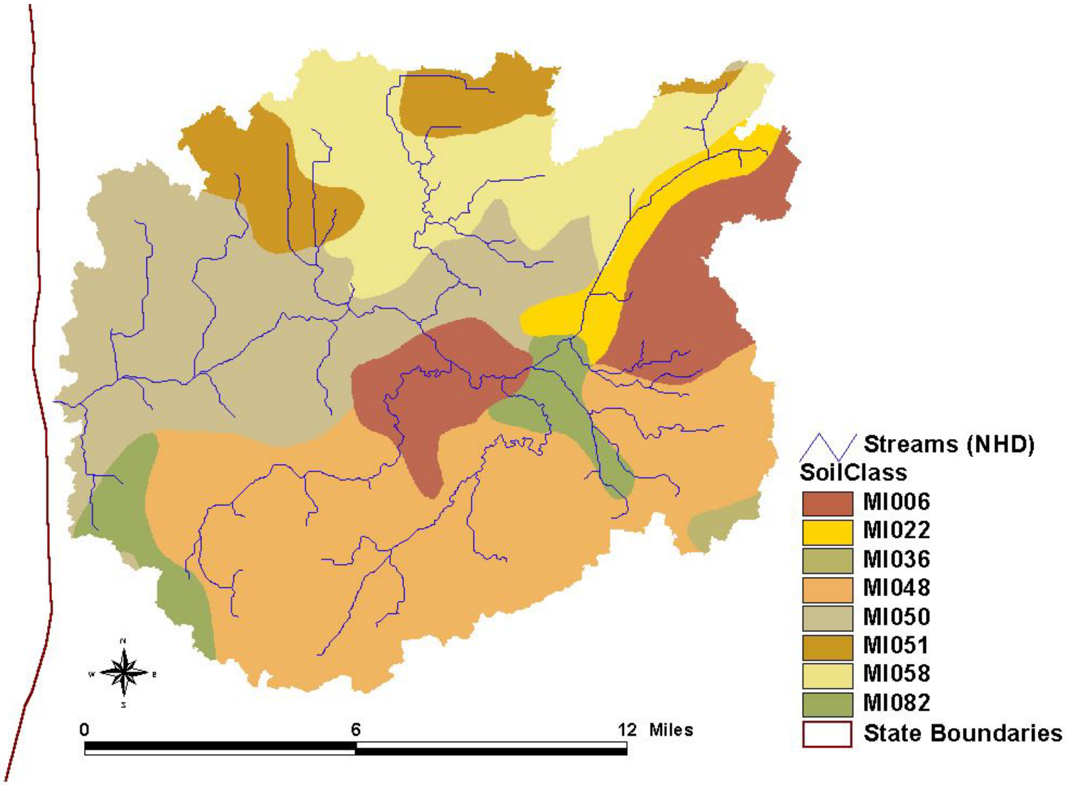
APPENDICES

Appendix A

Soils in the Macatawa Watershed



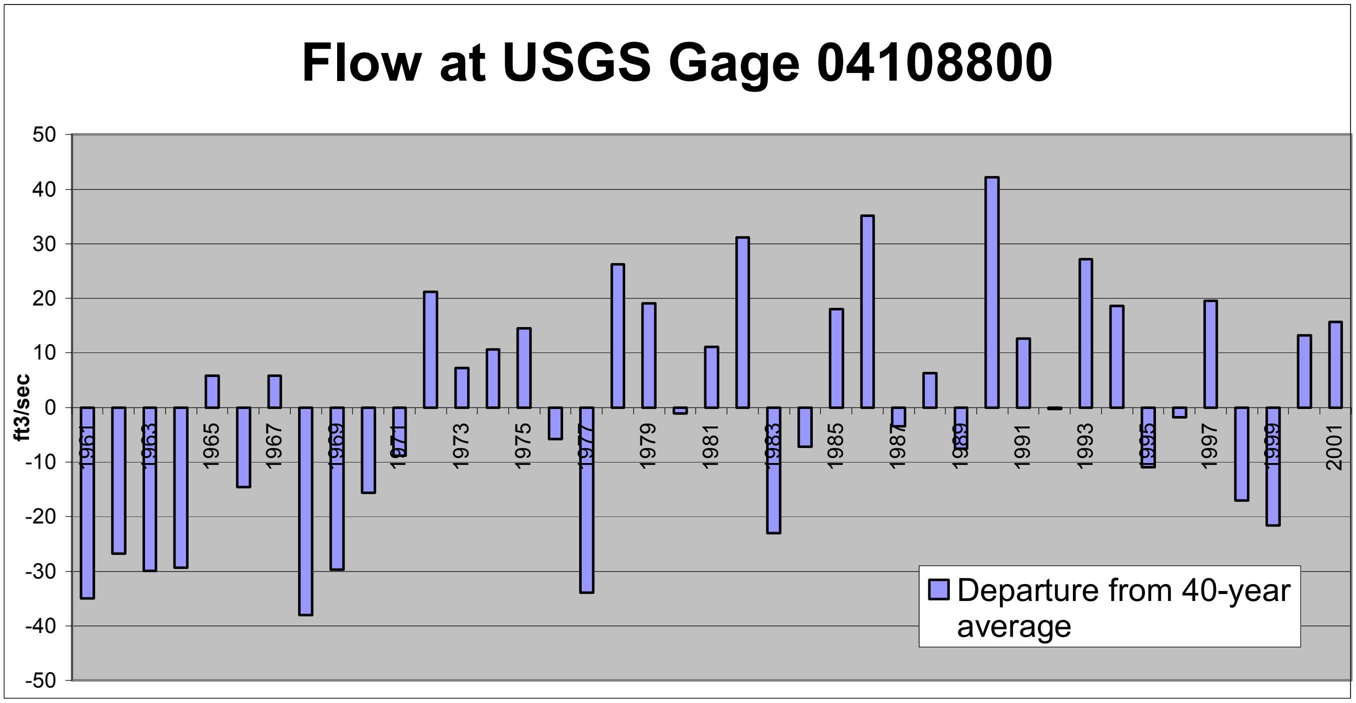
Stmuid	Name	Area[%]	Soil Group	Texture
MI050	Grattan	24.54	A	S, S, S
MI022	Houghton	3.46	A	muck
MI051	Granby	7.09	A	SL, LS, COS
MI058	Perrington	15.01	C	L, CL, CL, CL
MI006	Blount	11.09	C	L, SIC, SICL, SICL
MI036	Capac	0.58	C	L,CL, L
MI048	Capac	32.89	C	L,CL, L
MI082	Gilford	5.34	B	FSL, SL, LS, S

Texture codes:

S	sand	L	loam	C	clay
SL	sandy loam	LS	loamy sand	CL	clay loam
SIC	silty clay	FSL	fine sandy loam	COS	coarse sand
SICL	silty clay loam				

Appendix B

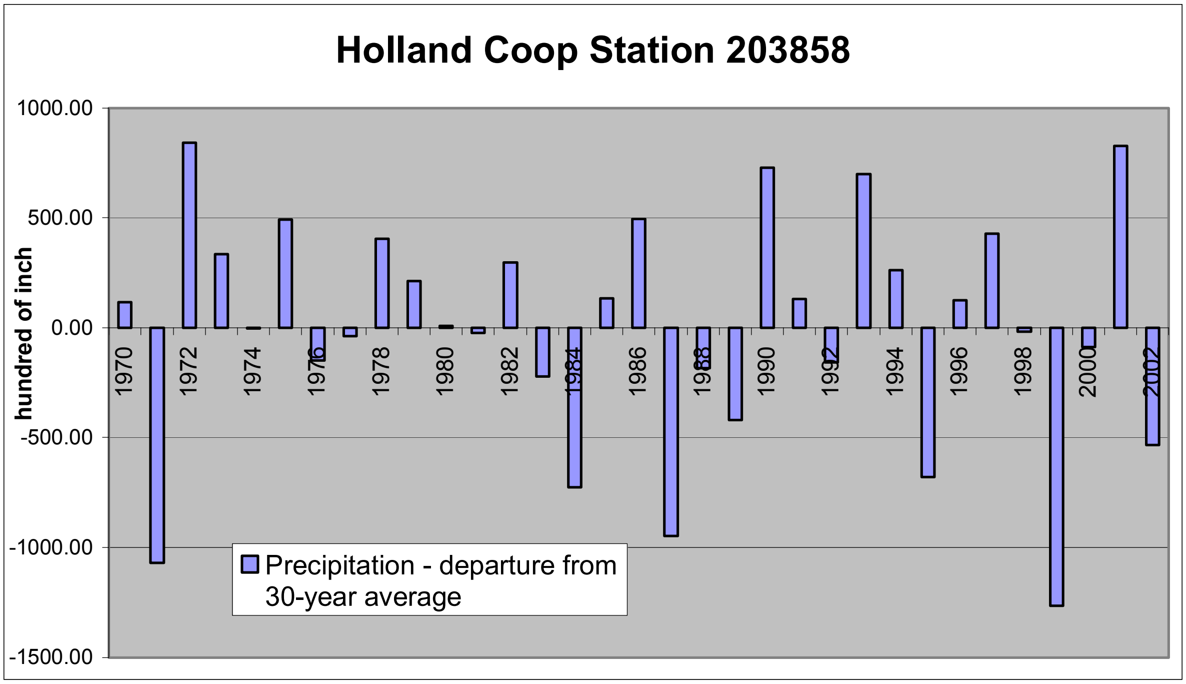
Streamflow at USGS Gage 04108800



Source: USGS Water Resources of Michigan (http://waterdata.usgs.gov/nwis)

Appendix C

Annual Precipitation at Holland Weather Station



Source: National Climatic Data Center (http://www.ncdc.noaa.gov)

Appendix D

Calibration Data

	parameter	definition	default	range/values tried	final value
Flow	ESCO	soil evaporation compensation factor	1		0.7
	CN2	runoff curve number	varies		lowest allowed for all land uses
	SOL_AWC	available water capacity of soil layer	varies		+0.04
	SMTMP	snow melt base temperature	0.5	0.7	0.5
	SMFMX	melt factor for snow on June 21	4.5	2.8-4.3	4.1
	SMFMN	melt factor for snow on December 21	4.5	1.85-2.3	2.1
	TIMP	snow pack temperature lag factor	1	0.85, 0.9	0.8
	GWQMN	threshold depth of water for return flow	0	50-200	110
	GW_REVAP	'revap' coefficient	0.02	0.05-0.1	0.08
	REVAPMN	threshold depth of water for revap or percolation	1	0.5-0	0
	RCHRG_DP	deep aquifer percolation fraction	0	0.3	0.3
	ALPHA_BF	baseflow alpha factor	0.048	0.03-0.08	0.048
	GW_DELAY	groundwater delay time	31	100	31
	CH_K2	effective hydraulic conductivity	0	0.7	0.7

Appendix D - Continued

Sediment	USLE_P	USLE equation support practice factor	1		0.5
	USLE_C	factor for water erosion applicable to land cover	0.2 cropland		0.15
	USLE_K	soil erodibility factor	varies	Decreased by 0.03 to 0.08	varies
	APM	peak rate adjustment factor for sediment routing (subbasin)	1	0.5-0.75	0.5
	PRF	peak rate adjustment factor for sediment routing (main channel)	1	0.5-0.75	1
	RSDCO	residue decomposition coefficient	0.05	0.02-0.1	0.05
	SLSUBBSN	average slope length	varies	Decreased by 21 to 41	varies
	SLOPE	average slope steepness	varies	Decreased by 0.01 to 0.04	varies
	FILTERW	width of edge-of-field filter strip	0		0.7-2
	RSDIN	initial residue cover	0	500	0
	BIO_MIX	biological mixing efficiency	0.2	0.15-0.3	0.3
Phosphorus	PPERCO	phosphorus percolation coefficient	10	13	10
	UBP	phosphorus uptake distribution parameter	20	25-30	30
	BIO_MIX	biological mixing efficiency	0.2	0.15-0.3	0.3
	.chm	initial soil concentration	0	LABP: 20-35 ORGP: 105-225 as per soil test	LABP: 20 ORGP: 80 (average values)

(Neitsch *et al* 2002a)

Appendix E

Final Parameters Values for SWAT Calibration

- **SWAT INPUT: CROP.DAT**

Parameter	Value used	Land use	Default value
USLE_C	0.15	Corn/SB/CELR	0.2
	0.008	ALFA	0.1
	0.001	AGRL	

- **SWAT INPUT: .HRU**

Parameter		Value used	Default value	Where applicable (subbasins, land use or HRU)
ESCO		0.7		
SLSUBBSN	slope 0-2%	80 m	121.951 m	
	slope 1-2%	70 m	121.951 m	
	slope 2-3%	60 m	91.463	
	slope 3-5%	50 m	91.463	Sub 5, 60, 34
	slope 7%	40 m	60.976	Sub 58
SLOPE		0.016	0.018	Sub 3, 25, 36, 69, 74
		0.015	0.017	Sub 31, 48, 50, 7
		0.015	0.016	Sub11, 42, 54
		0.018	0.02	Sub 51
		0.017	0.019	Sub 30
		0.025	0.029	Sub 13
		0.023	0.027	Sub 4
		0.028	0.032	Sub 5
		0.022	0.025	Sub 6, 9
		0.02	0.021	Sub 12, 23
		0.02	0.022	Sub 15
		0.03	0.034	Sub 34
		0.022	0.026	Sub 38
		0.02	0.024	Sub 39
		0.02	0.023	Sub 62
FILTERW		1.5	0	SB/CORN/WWHT
		0.7	0	ALFA/AGRL/UTRN/UCOM
		2	0	BLUE
DDRAIN		900	0	Sub 50 & 39–CORN–MI006/MI048 Sub 7, 8, 14, 19–CORN-MI058
TDRAIN		48	0	sub 61, 68, 71, 73–CORN–MI048
GDRAIN		55	0	sub 38, 40, 41-CORN–MI006

- **SWAT INPUT: .SOL**

Parameter	Value used	Default value	Where applicable (subbasins, lland use or HRU)
SOL_AWC	+0.04		top and second layer - all soils/land use
	+0.02		third and fourth layer - all soils/land use
USLE_K	0.35	0.43	MI006
	0.3	0.37	MI058
	0.28	0.32	MI048
	0.28	0.32	MI036
	0.17	0.20	MI082

Appendix E - Continued

- **SWAT INPUT: .BSN**

Parameter	Value used
SMTMP	0.5
SMFMX	4.1
SMFMN	2.1
TIMP	0.8
SPEXP	1
APM	0.5
UBP	30
PRF	0

- **SWAT INPUT: .GW**

Parameter	Value used	Where applicable
GWQMN	110	all
GW_REVAP	0.08	all
REVAPMN	0	all
RCHRG_DP	0.3	All HRUs except below
	0	CORN/SB-MI048 CORN MI058

- **SWAT INPUT: .RTE**

CH_K2: 0.7

- **SWAT INPUT: .CHM**

Land use	Parameter	Value used
All corn/SB	LABP	20
	ORGP	80
All WWHT	LABP	10
	ORGP	40
All ALFA/BLUE/CELR	LABP	7
	ORGP	35
All AGRL	LABP	5
	ORGP	15

Note: 20 ppm minimum, 100 ppm average, 50 to 500 ppm range (Wylie 2003)

- **SWAT INPUT: POINT SOURCES**

		Constant daily loading (kg/day)	
Point source	**Location**	**Soluble P**	**Organic P**
Mead Johnson	subb 18	0.4	0.021
Flink Ink - CDR	subb 45}	15.137	0.796
Holland WWTP	subb 45}		
Zeeland WWTP	subb 24	1.365	0.072

Appendix E - Continued

- **SWAT INPUT: .MGT**

Parameter	Value used	Where applicable
BIOMIX	0.15	CORN/SB
USLE_P	0.4	CORN/SOYBEAN/WWHT/CELR
	0.55 (0.35)	UCOM (subb 5, 60, 58, 34 where slope >3%)
	0.6	all other land uses

Curve numbers	Soil Group		
CN2/CNOP Planting	**A**	**B**	**C**
Corn	61	70	77
SB	58	67	76
WWHT	58	69	77
Till CNOP	64	72	78
ALFA	35	58	71
BLUE	35	58	72
AGRL	35	58	71
FRSD	35	55	70

Scenarios:

Rotation	Year	Date	Operation	Detail
Corn/Soybean rotation	Year 1	29-Apr	Fertilizing	Swine manure - 50 kg/ha
		5-May	Tilling	Disk Chisel
		6-May	Tilling	Field Cultivator/Soil finisher
		15-May	Planting CORN	
		1-Nov	Harvest/Kill CORN	
		15-Nov	Tilling	Generic fall plowing
	Year 2	25-May	Planting SB	
		20-Oct	Harvest/Kill SB	
		15-Nov	Fertilizing	Swine manure - 112 kg/ha
		20-Nov	Tilling	Deep Ripper Subsoiler

Corn/Soybean/Winter wheat rotation	Year 1	29-Apr	Fertilizing	Swine manure - 50 kg/ha
		5-May	Tilling	Disk Chisel
		6-May	Tilling	Field Cultivator/Soil finisher
		15-May	Planting CORN	
		1-Nov	Harvest/Kill CORN	
		15-Nov	Tilling	Generic fall plowing
	Year 2	25-May	Planting SB	
		20-Oct	Harvest/Kill SB	
		20-Nov	Tilling	Deep Ripper Subsoiler
	Year 3	15-Sep	Planting WWHT	
		Oct-1	Fertilizing	Dairy Manure 100 kg/ha
	Year 4	20-Jul	Harvest/Kill WWHT	

Appendix E – Continued

Buleberry	Year 1	30-Apr	Begin growing season - BLUE
		25-Jul	Harvest only
		30-Oct	Kill/End of growing season

Alfalfa	Year 1	25-Apr	Begin growing season - ALFA
		1-Jun	Harvest only
		6-Jul	Harvest only
		16-Aug	Harvest only
		30-Sep	Harvest only
		30-Oct	Kill/End of growing season

- **SWAT INPUT: .PND**

Parameters	Sub. 1, 2	Sub 4, 16	Sub 5	Sub 11	Sub 52	Sub. 60	Sub. 59
PND_FR	0.8	1	0.6	0.2	0.7	0.6	1
PND_PSA	1	1	1	0.5	0.8	1.5	163.3
PND_PVOL	0.9	0.9	0.9	0.4	0.7	1	100
PND_VOL	0.9	0.9	0.9	0.4	0.8	1	100

Parameter	Value used	Where applicable
PSETL1	13	Sub. 1, 2, 4, 5, 11, 16, 52, 59, 60
PSETL2	10	
IPND1	April	
IPND2	November	
ND TARG	15	

Appendix F

Scenario 1: BMP Information

- FILTERSTRIPS

	Filter strips	
HRU (subbasin, land use, soil)	**Actual size (length x width) in meters**	**Width value used (meters)**
78 – corn – MI048	137 x 47 30 x 411	100
41 – soybean – MI006	186 x 45	45
69 – corn – MI048	655 x 55	55
48 – no crop available	265 x 9 262 x 22	Not included
80 – corn – MI048	1390 x 21 106 x 30 381 x 14 212 x 15	20
65 – soybean – MI048	704 x 15 201 x 15	15
68 – soybean – MI048	251 x 30 1112 x 30	30
61 – soybean – MI048	503 x 15	15

- NO TILL

	No till / crop residue management	
HRU (subbasin, land use, soil)	**Actual area in ha**	**Actual area of HRU used**
84 – soybean – MI048	70	58
48 – no crop available	21	Not included
3 – soybean – MI022	18	26
7 – soybean – MI051	101	105
66 – soybean – MI048	85	94
81 – corn – MI048	93	105

- GRASSED WATERWAYS

Included in subbasins 80, 84, 64, 65, 66