# Parson's Creek Watershed Modeling Report,
# Fond du Lac County, Wisconsin

## In support of Total Maximum Daily Loads for Sediment and Phosphorus in the Parson's Creek Watershed

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# CHAPTER 1. INTRODUCTION AND PROJECT OVERVIEW

The overall objective of this project is to assist in developing Total Maximum Daily Load (TMDL) allocations for phosphorus and suspended sediment in the 21.2 $km^2$ Parson's Creek watershed. To accomplish this task, sources of phosphorus and sediment export from the watershed were quantified through watershed model simulations. A modified version of the USDA Agricultural Research Service (ARS) Soil and Water Assessment Tool model (SWAT; version 4/18/2001), which was developed by Arnold et al. (1996), was applied to the Parson's Creek watershed to simulate daily stream flow, and suspended sediment and total phosphorus loads from non-point sources within the watershed. The model was validated with daily discharge and TSS and phosphorus loads from two USGS-WDNR monitoring stations that were located within the Parson's Creek watershed, which were operated from USGS water years 1998 to 2001. The Nash-Sutcliffe coefficient of efficiency (NSCE) and relative differences between simulated and observed flow and loads were used as the primary criterion to assess the validity of the model. Watershed simulations were conducted for the following scenarios: (1) Baseline 2000 conditions; and (2) alternative management or policy scenarios which were compared to the Baseline 2000 conditions. All scenarios utilized a 1992 to 2006 climatic period for SWAT simulations.

Figure 1 shows the watersheds, subwatersheds, land use and land cover, major streams and monitoring stations that were utilized in this project. The Parson's Creek watershed drains into the Fond du Lac River which empties into Lake Winnebago. These watersheds are part of the Upper Fox sub-basin, which itself is a part of the 16,500 $km^2$ Fox-Wolf basin which drains into Green Bay.

This report contains the following chapters which describe: (2) methods and SWAT inputs; (3) model calibration and assessment; (4) modeled results, and allocation of loads; (5) alternative scenarios; and (6) summary and conclusions.

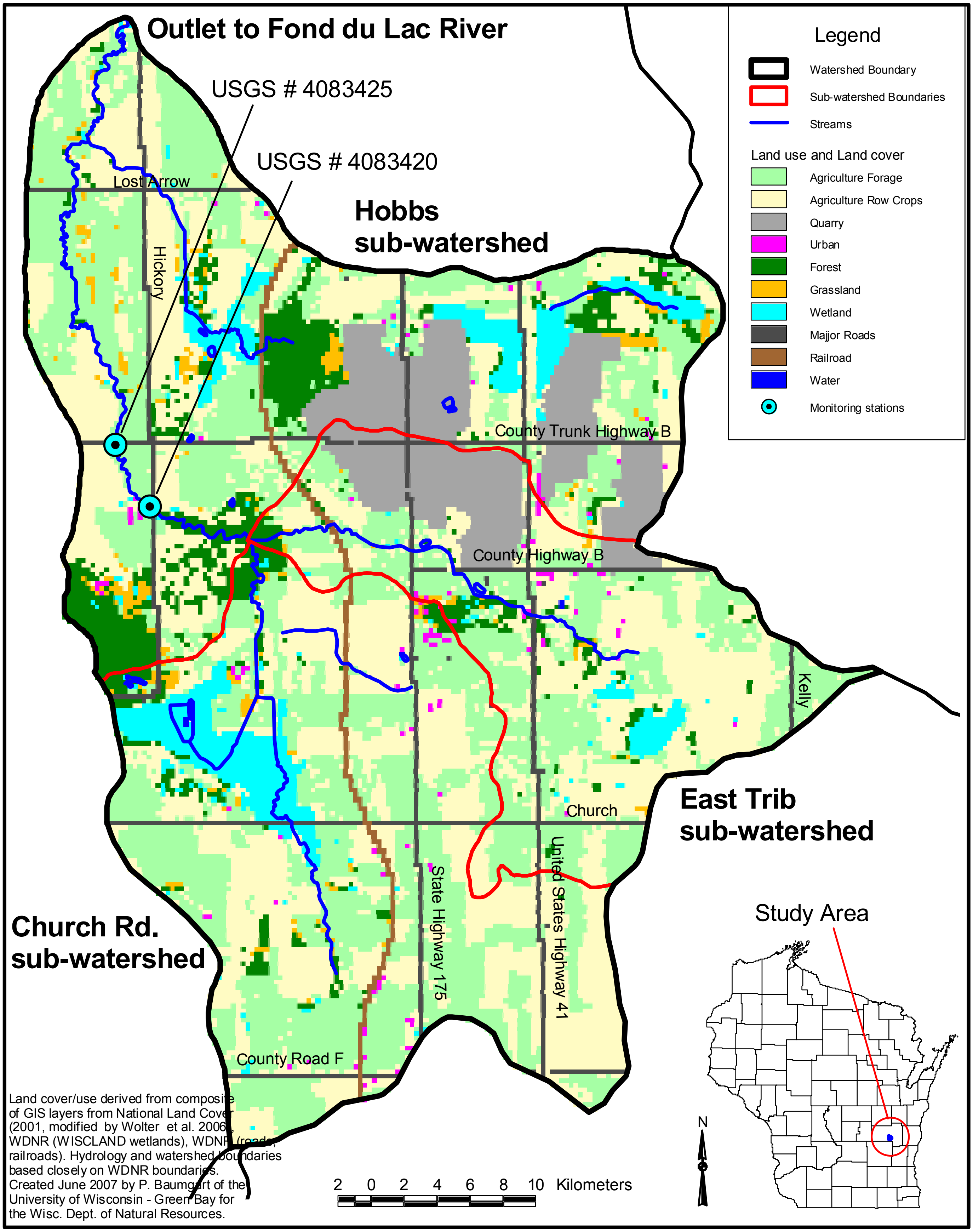


Figure 1. Parson's Creek Land Use and Land Cover (2001).

# CHAPTER 2. METHODS AND SWAT MODEL INPUTS

## APPROACH

The Soil and Water Assessment Tool (SWAT; Arnold et al. 1996, Neitsch et al. 2001) model requires numerous inputs including watershed boundaries, surface and groundwater hydrology, climatological data, soils, land use information, crops and other vegetation, and tillage and nutrient management practices. This chapter describes the methods used to supply inputs to the model. The model framework and many of the inputs utilized in this project are similar to those utilized by Baumgart (2005, 2007) for the Lower Fox River (LFR) sub-basin, where a more detailed description of the modeling methods can be found. Simulation periods included: 1992 to 2006 and subsets derived from this period.

**SWAT Model:** SWAT is a distributed parameter, daily time step model that was developed by the USDA-ARS to primarily assess non-point source pollution from watersheds and large complex river basins. SWAT simulates hydrologic and related processes to predict the impact of land use management on water, sediment, nutrient and pesticide export. With SWAT, a large heterogenous river basin can be divided into hundreds of subwatersheds; thereby, permitting more realistic representations of the specific soil, topography, hydrology, climate and management features of a particular area. In addition, point source loads and outputs from other models can be input to the model. Crop and management components within the model permit reasonable representation of the actual cropping, tillage and nutrient management practices typically used in Northeastern Wisconsin. Major processes simulated within the SWAT model include: surface and groundwater hydrology, weather, soil water percolation, crop growth, evapotranspiration, agricultural management, urban and rural management, sedimentation, nutrient cycling and fate, pesticide fate, and water and constituent routing. SWAT also utilizes the QUAL2e submodel to simulate nutrient transport. SWAT uses a separate input file for each subwatershed, hydrologic response unit, routing reach, soil, groundwater, pond/wetland, management practice, stream water quality reach, and chemical type. A more detailed description of this model can be found at the following Internet address: http://www.brc.tamus.edu/swat/.

**Subwatershed Configuration:** As illustrated in Figure 1, the Parson's Creek watershed was divided into 3 major hydrologic units (subwatersheds): (1) Hobbs; (2) Church Road; and (3) East Trib. These subwatersheds were further delineated into a total of 5 subwatersheds according to the placement of monitoring stations so that output from the model could coincide with measured flow and loads.

**Application of Geographical Information System:** ARCGIS, ARCVIEW and Spatial Analyst were used to construct, process and analyze a variety of GIS coverages to supply inputs to the SWAT model. All of these software programs were developed by Environmental Systems Research Institute, Inc. (ESRI). All raster-based layers were processed with a 30 square meter cell resolution. Where possible, GIS coverages were projected into WTM-NAD83/91 coordinates. The GIS data layers that were used to provide inputs to the SWAT model and to prepare GIS-based maps and analyzes are summarized in Table 2-1. Further details concerning the use of some of these GIS layers is described in the following section.

**Table 2-1. Sources of SWAT input data and GIS data layers used in SWAT simulations.**

| Data Type | Data Source | Data Description | Notes and Methods |
|---|---|---|---|
| Land cover | Wolter et al (2006) | Great Lakes land cover | 30 m land cover classification based on 2001 satellite imagery. Utilized as primary base land cover layer, with wetlands from WISCLAND, roads from WDNR, and quarries from a 2006 aerial DOP's overlaid to produce final land cover GIS layer. |
| | WDNR | WISCLAND land cover | 30 m land cover classification based on 1992-93 satellite imagery. Wetland areas utilized for final land cover GIS layer. |
| Hydrology | WDNR | 1:24k stream GIS layer | Subwatershed and routing stream channel lengths derived, and channel slopes were found by comparing to upland elevation contours |
| Watershed boundary | WDNR | 1:24k GIS watershed boundaries | Campground Creek watershed boundary split to add 3 subwatershed boundaries based on divisions by Michael Reif of WDNR. |
| Soils | NRCS GIS data; Link et al. 1973 paper document | SSURGO soil GIS layer from NRCS for Fond du Lac County | Intersected soils and subwatershed layers. Area-weighted averages for four-assumed depths were calculated for major HRU/landuse class within each subwatershed |
| Upland Soil slope | WDNR | 30 m Digital Elevation Model (DEM) | Intersected landuse and subwatershed layers, and tabulated area-weighted slopes with DEM for each major HRU/landuse class within each subwatershed |
| Topographic Maps & elevation contours | WDNR | USGS 1:24k Quadrangle Digital Raster Graphic Image - topographic maps | Primary DRG: 1974 Byron Township. General GIS background layer, contours, watershed boundaries, etc. |
| | Fond du Lac County Planning Dept | 4 foot elevation contours based on 2000 DTM | .Watershed boundaries and other characteristics. Digital Terrain Model (DTM) supplied, but not utilized due to time constraints. |
| Roads, railroads, counties | WDNR | Statewide road, railroad and county boundary layers | Roads and railroads merged with land cover layer to produce final land cover/use GIS layer. |
| Aerial photos | Fond du Lac County Planning Dept. | Spring 2005 Digital Ortho-photo (DOP) | All DOP's in Mr. SID compressed format. |
| | USDA-FSA (from Wisconsin View web site) | 2005 and 2006 Color DOP's | ("") Estimated extent of quarries, strip cropping, and used as general watershed image. |
| | WDNR (from Wisconsin View web site) | 1992 DOP | ("") |

## WATERSHED DELINEATION AND HYDROLOGY

**Watershed Delineation:** The 1:24,000 statewide watershed boundary GIS layer provided by the Wisconsin Department of Natural Resources (WDNR) for the Campground Creek watershed boundary was split to produce the Parson's Creek watershed boundaries shown in Figure 1. A Digital Raster Graphic (DRG) version of the 1974 Byron Township 1:24,000 U.S. Geological Survey (USGS) topographic map obtained from the WDNR and a 4 foot contour interval shapefile from the Fond du Lac County Planning Department were used as background layers within ARCVIEW to assist in adding the boundaries to the original shape file. In addition to the manual delineation process, the ARCVIEW interface for SWAT was applied to the 30-meter digital elevation model (DEM) to automate the delineation process and to clear up any questionable boundaries. The Parson's Creek watershed boundary and sub-watershed boundaries were closely based on divisions supplied by Michael Reif of the WDNR in shapefile format. The final subwatershed delineation displayed in Figure 1 was then used to create subwatershed-specific model inputs by overlaying this boundary layer with other GIS layers.

## CLIMATOLOGICAL INPUTS

**Climatological Data:** The USGS weather station located at the upstream monitoring station within the watershed was the source of measured daily precipitation data to the SWAT model (Figure 1). Simulated temperature and precipitation data were not used. The precipitation data from the USGS station was supplemented with data from other sites as summarized in Table 2-2.

**Table 2-2. Sources of climatological data used in SWAT simulations.**

| Data Type | Data Source | Data used in Simulations | Notes and Methods |
|---|---|---|---|
| Climate | Wisconsin State Climatology Office | Daily precipitation and minimum and maximum temperature | Fond du Lac Cooperative NWS Observer weather station, supplemented with Appleton Coop. NWS Observer station and Green Bay NWS station data as needed. 1970 to 2006 precip and temperature. |
| | USGS - Wisconsin | Daily precipitation and sub-daily rainfall intensity | USGS tipping bucket rain gauge at Parson's Creek station (Dec. 1997 to June 2001) |
| | USDA-ARS | Statistical summary climatic data for SWAT weather generator | Portage, Wisconsin climate data |

# SOILS

Area-weighted average values for subwatershed soil parameters required by SWAT were created by processing the Fond du Lac County digital soil survey and tables obtained from the NRCS web site according to the procedure described by Baumgart (1998, 2005). This procedure was judged to be better than assuming that the soil parameters associated with the dominant soil series in a subwatershed are representative of an entire subwatershed. Area-weighted average values for soil parameters including: USLE K-factor; NRCS hydrologic group; available water capacity; saturated conductivity; clay, silt and sand percentages; organic carbon and bulk density were generated for each subwatershed. Scripts (macros) were used to automatically export subwatershed-specific soil files into a SWAT compatible text file format for all subwatersheds in a single operation. This operation was also done for routing reach, hydrologic response unit and subwatershed input files.

**Soil Phosphorus Levels**: Mean soil test phosphorus (P) data from Fond du Lac County are shown in Table 2-3. Data are from Combs et al. (1996) and the University of Wisconsin Soil Testing Lab.

**Table 2-3. Mean Soil Test Phosphorus in Fond du Lac County and Estimated Values for Parsons Creek Watershed.**

| | Soil Bray-P1 (ppm) | |
|---|---|---|
| ***Period*** | **Fond du Lac County** | **Parson's Creek** |
| 1974-77 | 31 | 26.4 |
| 1977-81 | 34 | 28.9 |
| 1982-85 | 38 | 32.3 |
| 1986-90 | 42 | 35.7 |
| 1990-04 | 52 | 44.2 |
| 1995-99 | 45 | 38.3 |
| 2000-04 | 48 | 40.8 |
| Assumed Baseline Soil P | | 40.0 |

Soils in the project area generally have lower clay content, and should therefore have slightly lower Soil Test P values than the county average. For example, mean soil test P values were 35 ppm for Theresa soils and 70 ppm for Ripon soils (2000-04 data). Therefore, it was assumed that the mean soil-test P value was 40 ppm under baseline conditions within the watershed, based on applying an adjustment factor of 0.85 to an average of the 1995-99 and the 2000-04 Fond du Lac County means, and then rounding down to 40 ppm. The selected baseline condition soil P level should be representative of those present during the calibration/validation period of 1998 to June 2001. Site-specific information was not readily available because nutrient management plans are not public documents.

# GENERAL LAND USE AND MODELING METHODS

**Land Cover Analysis with Great Lakes Basin Land Use/Cover Image:** Land cover within the watershed was primarily determined from the 2001 Great Lakes landuse/land cover image, which was obtained from Wolter et al. (2006). This layer was augmented by overlaying: 1) wetland areas from the WISCLAND land cover image; 2) roads and railroads from the WDNR; and 3) quarries that were manually delineated from a USDA-FSA 2006 aerial photograph. This classified land cover image was then reclassified to generate the following land cover/uses which were modeled with SWAT: agriculture (row crops, forage), urban, shrubland or grassland, forest, wetland, roads and railroads, and quarries and related businesses. Areas classed as water were minimal, so this class was simply ignored and the area displaced to the urban class to keep the total area the same.

Areal land cover and landuse for each of the subwatersheds in the watershed are summarized in Tables 2-4 and 2-5, which is also illustrated in Figure 1. Agricultural and quarries were the most prevalent land uses in the watershed, followed by forests, wetlands, and roads or railroads.

**Table 2-4. Major Landuse/Land Cover in Parsons Creek Watershed: 2001* (sq. km).**

| | Ag** | Urban | Shrubland | Forest | Wetland | Quarry* | Road & Railroad | Total |
|---|---|---|---|---|---|---|---|---|
| **Hobbs** | 5.46 | 0.03 | 0.22 | 0.99 | 0.49 | 1.06 | 0.38 | **8.65** |
| **Church Rd.** | 6.25 | 0.05 | 0.08 | 0.28 | 0.58 | 0.00 | 0.38 | **7.64** |
| **East Trib** | 3.57 | 0.04 | 0.03 | 0.19 | 0.12 | 0.69 | 0.27 | **4.90** |
| **TOTAL** | **15.28** | **0.12** | **0.33** | **1.47** | **1.20** | **1.75** | **1.04** | **21.19** |

**Table 2-5. Major Landuse/Land Cover Proportions in Parson's Creek Watershed: 2001*.**

| | Ag** | Urban | Shrubland | Forest | Wetland | Quarry* | Road & Railroad |
|---|---|---|---|---|---|---|---|
| **Hobbs** | 63.1% | 0.4% | 2.6% | 11.5% | 5.7% | 12.3% | 4.4% |
| **Church Rd.** | 81.9% | 0.7% | 1.1% | 3.7% | 7.7% | 0.0% | 5.0% |
| **East Trib** | 72.7% | 0.7% | 0.6% | 3.9% | 2.5% | 14.0% | 5.5% |
| **TOTAL** | **72.1%** | **0.6%** | **1.6%** | **6.9%** | **5.7%** | **8.3%** | **4.9%** |

* Quarry areas updated to 2006
** Equal proportions of row crops and alfafa/hay crops (50% each)

Seven major land use categories were modeled with methods that are described in greater detail later in this section. These land covers were further divided into 13 major groups of hydrologic response units (HRU's) which were directly modeled in the following fashion:

| | | |
|---|---|---|
| | Agriculture - Dairy | |
| 1 | | Conventional tillage practice (CT) |
| 2 | | Mulch-till (MT30) |
| 3 | | No-till (NT) |
| | Agriculture - Cash crop | |
| 4 | | Conventional tillage practice (CT) |
| 5 | | Mulch-till (MT30) |
| 6 | | No-till (NT) |
| 7 | Shrubland or Grassland | |
| 8 | Forest | |
| 9 | Wetland | |
| 10 | Roads and railroads | |
| 11 | Urban | |
| 12 | Barnyard | |
| 13 | Quarries and related businesses | |

HRU's represent areas within a subwatershed that are similar in a hydrologic or management sense, but are not necessarily contiguous. For this project, HRU's are the total area in the subwatershed with a particular land use and/or management. No single specific farming practice could be used to model the entire watershed; therefore, various proportions of six possible agricultural practices (6 major HRU's) were used to simulate what occurred in each subwatershed. For simplicity, every subwatershed was modeled as though it contained the 13 major HRU's in the order shown above, except when quarries were not present. However, in order to simulate the crop rotations that were modeled (dairy: corn, alfalfa and soybean; cash crop: corn and soybean), additional HRU's were required so that all phases of a crop rotation could be simulated in a single model run. In this way, model output from a single simulation could be directly compared to measured data. Each subwatershed contained 30 or 31 HRU's. Alternatively, separate model runs would be required to simulate each phase of a crop rotation. A GIS overlay operation was used to derive the proportional area of the major HRU's within each of the modeled subwatersheds. The next section describes how the agricultural areas were further divided into 6 agricultural HRU's. Where a subwatershed did not contain all of the landuses, the area of the non-existent land use was assigned a negligible value (0.0000001).

**Non-agricultural Rural Land Areas:** Non-agricultural rural areas were modeled as HRU's designated as grassland/shrubland, forest, wetlands, urban, and road or railroad surfaces and right-of-ways. These HRU's were assigned values from SWAT's crop data sets for pasture, forest, wetland, lawn and grass data sets, respectively. Those areas that were classified as quarries were simulated with an HRU that produced little surface water, but substantial water to recharge the shallow aquifer. However, it is possible that relatively large quarries in the watershed divert water away from portions of Parsons Creek, and it is likely that they affect groundwater flow paths, perhaps, significantly so.

**Forested Areas:** Comparisons with aerial photographs showed that the land cover image understated the amount of forested areas, particularly along narrow riparian corridors and scattered forested areas throughout the watershed. To compensate for the understated forested area, and to provide more accurate inputs to SWAT, the proportions shown in Table 2-5 were increased by a factor of 1.5 for the Hobbs subwatershed and 1.85 for Church Road and East trib subwatersheds. These factors were based on similar differences that were observed in the LFR sub-basin between estimates of forested areas with WISCLAND and those estimated with landuse GIS layers produced by Brown County and Outagamie County.

# AGRICULTURAL LANDUSE AND MODELING METHODS

SWAT requires detailed information regarding land use management practices. For example, the type of crop, the date it was planted and harvested, tillage practices and dates, fertilizer applications and dates, and NRCS curve number for each period, are just some of the information that is input into SWAT's management files. This section briefly describes how some of these inputs were obtained. Detailed methods are described by Baumgart (2005).

**Agricultural Crop and Tillage Methodology:** Two types of agricultural crop rotations were simulated: dairy and cash crop, although the latter was minimized because most of the acreage is under a dairy operation (Tollard 2007) and the agricultural land cover within the subwatershed consists of about 50% forage crops. A six year crop rotation that is typical for dairy farm operations in Northeastern Wisconsin was used to simulate dairy operations. The six year rotation consisted of: (year 1) corn grain; (year 2) soybean; (year 3) corn silage; (years 4-6) alfalfa. A nurse crop such as oats was not "grown" in the fourth year because SWAT cannot simulate two crops growing simultaneously. This rotation was chosen to ensure equal proportions of forage and row crops were simulated. A two year crop rotation consisting of corn grain followed by soybean was used to simulate cash crop operations. Soybean was assumed to also represent other potential row crops such as wheat or oats grown solely as a grain crop.

The agricultural HRU's consisted of two potential farming practices under all conditions/scenarios:

1) 98%: Dairy-based (6 year rotation: corn grain, soybean, corn silage, alfalfa, alfalfa, alfalfa)
2) 2%: Cash crop (2 year rotation: corn grain, soybean).

At any given time, not all farm fields are in the same year or phase of the rotation. To represent average conditions, 1/6 of the dairy farm fields were assumed to be in each of the six years of the rotation. Therefore, it was necessary to simulate the different phases of each crop rotation by representing each phase as a separate HRU. The same procedure was followed for the cash crop rotation resulting in a total of 24 agricultural HRU's, not counting the barnyard HRU. Alternatively, the results of six model simulations would have to be averaged to represent average conditions in each subwatershed.

**Tillage Practices and Crop Residue Levels - Transect Survey:** Three tillage practices were simulated: a) conventional tillage with fall moldboard plow as the primary tillage implement for corn and fall chisel plow for soybean; b) mulch till, with chisel plow tillage in fall for corn (not highly twisted shank) and field cultivator in spring for soybean; and c) no-till. Field cultivator and disk tillage operations were also included prior to planting under the conventional and mulch till classes that were simulated.

The following primary tillage practices were assumed for each of the three simulated tillage classes:

**Table 2-6. Primary tillage practices utilized in SWAT simulations**.

| tillage | corn or end of alfalfa rotation | soybean |
|---|---|---|
| conventional practice (CT) | fall moldboard plow | fall chisel plow |
| mulch till (MT) | fall chisel plow | spring field cultivator, or disk |
| no-till (NT) | none | none |

Conservation Technology Information Center (CTIC) Conservation Tillage Reports for Fond du Lac County were analyzed to determine the primary tillage practice inputs to SWAT (Table 2-7). These "Transect Survey" reports were based on statistical sampling procedures of farm fields to estimate residue levels present shortly after spring planting, as well as other information. Data were supplied by Paul Tollard of the Fond du Lac County Land Conservation Department and Sara Walling of the Wisconsin Department of Agriculture, Trade and Consumer Protection. The data were analyzed with the Transect 2.16 software program produced by Purdue Research Foundation, Purdue University.

The level of residue in existing corn fields (present crop), as indicated in the Transect survey data, were assumed to be appropriate because dairy operations are dominant in this watershed, and soybean residue levels are more likely to be associated with cash-grain operations which are more likely to utilize conservation tillage practices. Four residue categories were initially assigned based on the percent residue present and the level of no-till or ridge-till practiced: conventional tillage (CT: 0-15%); limited mulch tillage (MT15: 15-30%); standard mulch tillage (MT30: >30%); and no-till or ridge-till (NT). The tillage/residue data were further combined into three categories for input to SWAT by reapportioning the MT15 category equally into the CT and MT30 categories (Table 2-7). In this way, only three types of tillage practices needed to be simulated, while some credit was still given to tillage practices that left 15-30% residue, but did not exceed the 30% residue level required to be classified as mulch till. To increase the number of available data points, data gathered in 1999, 2000 and 2001 were combined and utilized for the Baseline Scenario. The resulting residue levels that were input to SWAT for baseline conditions were 73% CT, 24% MT and 3% NT.

**Table 2-7. Fond du Lac County conservation tillage levels.**

| Year | CT | MT | NT |
|---|---|---|---|
| 1999 | 77% | 21% | 2% |
| 2000 | 63% | 34% | 5% |
| 2001 | 79% | 19% | 1% |
| 2002 | 68% | 30% | 3% |
| 2003 | 62% | 32% | 6% |
| 2005 | 74% | 19% | 7% |
| 2006 | 69% | 22% | 9% |
| Assumed 2000 Baseline Conditions (1999-2001 mean) | 73% | 24% | 3% |

**Erosion Control Practice, P-factor:** The P-factor was set at 0.4 for strip cropping along the contour of slopes. The implementation rates input to SWAT were estimated to be 7.4% in the Church subwatershed and 3.6% in the East Trib subwatersheds. These estimates were based on 2005 and 2006 aerial photographs which showed consistent implementation of strip cropping on the same fields; plus some strip cropping was also apparent in a 1992 aerial photograph.

**Nutrients and Nutrient Management:** The following assumptions concerning commercial fertilizer and manure applications were utilized as model inputs under Baseline conditions and other scenarios. Dairy rotation model inputs are summarized below, and the basis for these assumptions directly follows.

*Dairy rotation* - tillage options: moldboard plow, chisel or mulch till, no-till

Baseline condition Scenario (1 yr corn grain, 2$^{nd}$ yr soybean, 3$^{rd}$ yr corn silage, 3 years alfalfa):

1 corn grain - 150 lbs/acre of 9-23-30 at planting; 9 t/acre manure in spring, 5.3 t/acre in fall
1 soybean - 150 lbs/acre (168 kg/ha) of 9-23-30 at planting; 10.7 t/acre manure in fall
1 corn silage - 150 lbs/acre (9-23-30 at planting); apply 9 t/acre manure in spring
3 alfalfa - 2nd year 19 lbs/acre (17 kg/ha) of 0-11-45; apply 16 t/acre manure in fall of third year (it was assumed that only 10% of farmers apply 180 lbs/acre of 0-11-45; hence, the rate of 19 lbs/acre of commercial fertilizer applied)

Manure application rates shown above are based on dry manure. It is assumed that application rates for liquid manure are equivalent on a phosphorus mass basis. The total phosphorus concentration in fresh manure was assumed to be 0.1375% on a wet weight basis. This value was based on the 1998-2000 average statewide nutrient content of solid dairy manure samples that were submitted to the University of Wisconsin Soil Testing Lab (6.3 lbs $P_2O_5$/ton wet manure; n=799; data courtesy of John Peters, director of UW Soil and Forage Analysis Lab). In general, phosphorus levels in dairy manure may have peaked around 2000, with a decline thereafter.

Manure application rates were assumed to be 45 t/acre over a typical 6 year dairy crop rotation for all scenarios, which translates to 7.5 t/acre/year. This rate is slightly lower than the 50 t/acre utilized for the LFR sub-basin modeling project under the 2000 baseline conditions, but more than the 38 t/acre that was assumed for the LFR sub-basin 1992 baseline conditions (Baumgart 2005). The rationale for this difference is that farms in the Parson's Creek watershed have not expanded as much as the major farms in the LFR sub-basin.

<u>Manure incorporation (depth of application)</u>: Under baseline conditions (~1998 to 20001, roughly 70% of manure was on a daily haul basis, and was not intentionally worked in within three days (Becky Wagner, Fond du Lac LWCD agronomist, personal communication, 2007). The remaining 30% was either spread, or injected and/or incorporated within three days. However, these numbers have changed dramatically as manure storage was added, so Wagner estimated that by 2007 roughly 70% of manure is now incorporated within 3 days and 30% is hauled on a daily basis without intentional incorporation. Therefore, it was assumed that under the Baseline 2000 Scenario, 70% of the manure was surface applied; that is, not intentionally incorporated within three days of application. This value was changed to 15% for all a potential future scenarios. Within the SWAT model, surface applied fertilizer/manure is assumed to be mixed into the surface soil layer (10 mm, or 0.4 inches thick in SWAT), and the remainder mixed into the next layer, which was set to a thickness of 203 mm (8 inches) for this project.

*<u>Cash crop rotation (corn & soybean)</u>* - tillage options: moldboard plow, chisel mulch till, no-till

The following information summarizes the crop rotations and fertilizer applications for cash crop farms modeled under Baseline conditions and potential scenarios. The basis for these model inputs directly follows the summary.

Baseline condition Scenario (1 year corn, 1 year soybean):

1 year corn: 125 lbs/acre anhydrous ammonia prior to planting; 240 lbs/acre of 9-23-30 at planting (269 kg/ha)

1 year soybean: 150 lbs/acre of 9-23-30 at planting(168/258 kg/ha); (note that this amount of nitrogen was not necessary for soybean but was kept to ensure the growth of modeled crops was correct)

Under a nutrient management alternative scenario whereby soil test phosphorus and total phosphorus in the soil were assumed to no longer increase, no commercial starter fertilizer that contained phosphorus was added to soybean and a minimal rate of commercial starter fertilizer was added to corn at planting to boost corn yields under certain conditions.

**<u>Dietary Phosphorus Management Scenario (25% reduction in dietary phosphorus)</u>:** Dietary phosphorus in dairy livestock frequently exceeds the required amount. Research has shown that existing levels of phosphorus in the diet of dairy cows can be substantially reduced without adverse health effects to cows. In a Wisconsin study, Ebeling et al. (2002) found that reducing phosphorus in the diet of dairy cows by avoiding excess supplements in the dairy ration greatly reduced the measured level of phosphorus in the corresponding manure, and the subsequent load of dissolved phosphorus in runoff from fields where the manure was applied.

The precise average dietary phosphorus level of dairy cattle in the watershed is not known for the Baseline 2000 scenario. However, in a nutrient mass balance study conducted by Erb (2000) within the LFR sub-basin,, most of the dairy farms surveyed in the Apple and Ashwaubenon watersheds aimed for 0.52% to 0.54% phosphorus in the milking cow ration. Examples of a 25% reduction could be: 0.55% to 0.41%, or 0.51% to 0.38%, or 0.41% to 0.34%. These examples of dietary phosphorus reductions still provide a margin of safety, for Powell et al. (2001) found that most studies showed that problems in dairy cattle don't appear until dietary phosphorus falls below 0.3%. Also, the U.S. National Research Council (NRC 2001) recommends dietary phosphorus levels of between 0.32% (55 lbs/day of milk) to 0.38% (120 lbs/day of milk) for dairy cows.

According to UW-Ext. Agronomist Kevin Erb (personal communication 2004), dietary P levels for dairy cows were 0.42% in 1992, 0.52% in 1997-98, and 0.42-0.46% in 2003 (on a per cow basis). As of 2003, small farms were generally around 0.52%, while larger farms were below 0.42%. On a per acre basis, the average in 2003 was around 0.46%. For the dietary phosphorus management scenario, a drop of 25% from the 0.52% level observed in 1997-98, to 0.39% seemed achievable. Therefore, a 25% reduction in the level of phosphorus in the dairy cow feed was selected for this scenario. For this scenario the 25% decrease in dietary phosphorus fed to lactating cows was assumed to correspond to a reduction in manure phosphorus from all dairy livestock of 25%. The precise form of phosphorus that would be reduced under the scenario is unknown, so both mineral and organic phosphorus levels in applied manure were reduced by 25%, to a total wet weight concentration of 0.103%.

## RIPARIAN BUFFER STRIPS IN RURAL AREAS

Vegetative buffer strips (VBS), also known as vegetative filter strips, or riparian buffers strips, or filter strips can reduce sediment and nutrient loads to waterways. A VBS is defined as "a strip or area of herbaceous vegetation situated between crop land, grazing land, or disturbed land (including forest land) and environmentally sensitive areas" (Natural Resource Conservation Service, 1999). Although the primary goal of installing a VBS may be to reduce sediment and nutrient loadings to waterways, additional potential benefits include the ability to moderate water temperature, maintain and improve wildlife distribution and diversity, and to reduce human impact in urban environments.

A measure of a VBS's impact and effectiveness in reducing sediment and nutrient delivery to waterways is its trapping efficiency. Trapping efficiency measures the percentage of a given constituent load (e.g., sediment, phosphorous) which the VBS prevents from reaching the adjoining waterway. For example, if a VBS receives a sediment load of 100 kg from adjacent agricultural land and retains 70 kg its trapping efficiency would be 70%.

**Method for Simulating Reductions due to VBSs in Rural Areas:** The trapping efficiency and overall impact from VBS's along streams in rural areas was simulated using essentially the same method as applied in the Restoration and Compensation Determination Plan for the Lower Fox River/Green Bay Natural Resource Damage Assessment (NRDA-RCDP, Stratus 2000; Baumgart 2000); and further modified by Baumgart (2005) for the LFR sub-basin SWAT model framework. Existing riparian forested areas were not as well delineated with the land cover image utilized in this project compared to the county landuse layers available in the latter project. Therefore, a somewhat simpler GIS-based system of identifying existing riparian VBS's and potential new VBS's adjacent to agricultural land was utilized in this project.

Reductions from agricultural areas due to VBS's were simulated internally within the modified version of the SWAT model. VBS trapping efficiency was varied according to the average soil hydrologic group within each subwatershed, rather than using a single fixed value. The width of installed VBS's was assumed to average 10 meters per side. Potential VBS impact zones along streams were identified as areas within 100 meters of a stream under agricultural landuse (90 meter effectiveness zone, plus 10 buffer width). Only streams identified in the 1:24k hydrology layer provided by the WDNR were included in this portion of the analysis. A GIS method similar to that outlined in the NRDA-RCDP to estimate the potential agricultural land that could be impacted by adding VBS's was utilized for this purpose. However, areas that were already buffered were not included, because they had already been accounted for as natural buffers. With the methodology employed in this VBS-modeling effort, the combined suspended sediment reduction within the assumed VBS-affected area that is associated with both the up slope VBS impact zone (90 m assumed effective range) and the VBS width of 10 m on each side of a stream, is about 54%, 49% and 45% for hydrologic group A, B and C soils respectively. The combined phosphorus reduction is about 49%, 45% and 40% for hydrologic group A, B and C soils respectively.

## MODELING LOADS FROM URBAN AREAS

**Urban Areas:** The buildup and washoff option was selected as the method to simulate urban loads from impervious surfaces in SWAT. The buildup/washoff method incorporated in SWAT is similar to that usesd in the Storm Water Management Model (SWMM, Huber and Dickinson 1988). Because measured loads from different urban sources were not available within the project area, all urban areas were lumped into one class and simulated as medium density residential areas. For the pervious portion of the urban HRU, phosphorus and sediment loadings were simulated by assuming that these areas are in grass with some fertilizer added, and an appropriate SWAT management routine was developed to simulate the runoff and loadings from these areas. Detailed information describing the methods and inputs for urban areas are provided in Baumgart (2005).

## SIMULATING BARNYARD CONTRIBUTIONS

To simulate daily runoff and phosphorus export from barnyards within the SWAT model, an HRU that simulated grazing animals, forage crop, and manure deposition was established in each subwatershed to represent barnyard areas in the same fashion that is described in more detail by Baumgart (2005). Existing barnyard load estimates served as a basis for model calibration. Simulated daily manure loads from the barnyard HRU were annualized and adjusted to fit: 1) measured values at the upper and lower USGS monitoring stations, and 2) estimated average annual values throughout the rest of the watershed. For calibration purposes (2000 Baseline conditions), it was assumed that a majority of the difference in phosphorus load between the upper and lower USGS monitoring stations (1998-2001) was due to barnyard/feedlot runoff. For other locations, the average annual phosphorus loads were based on estimates that were reported in the Fond du Lac River Priority Watershed Project (WDNR 1997) for the Campground Creek watershed, and applied on an area-weighted basis to each of the subwatersheds. These phosphorus loads were estimated with the Wisconsin Barnyard Runoff Model (BARNY). BARNY is a modified version of the USDA Agricultural Research Service Feedlot Runoff Model (Young et al. 1982).

**Effect of barnyard/feedlot runoff BMP controls:** Stuntebeck and Bannerman (1998) measured an 85% and 87% reduction in the phosphorus loads contributed to Otter Creek and Halfway Prairie Creek, respectively, from two barnyards after BMPs were installed to control manure runoff. Based on this research, and the fact that some measurable losses will occur unless a barnyard is replaced with a confined operation, an 80 to 90% reduction in phosphorus load was assumed when barnyard BMP controls were implemented. For the purposes of estimating the impact of barnyard BMPs, it was assumed that the phosphorus load from the major barnyard source between the upper and lower USGS monitoring stations was reduced by 90% because a larger load ought to be able to be reduced by a greater amount on a relative basis. All other barnyard loads were reduced by 80%. While some reductions may be less than these values, a 100% reduction in phosphorus loads would be expected when a barnyard was no longer in use, or it was replaced with a confined system.

## WETLAND SIMULATION

Wetlands were simulated in all three subwatersheds with the SWAT wetland/pond subroutine. Surface area inputs were based on the area classified as wetlands along the major stream network in the landuse/land cover image. Based on GIS analysis, it was estimated that approximately 12%, 30% and 20% of the upland agricultural areas in the Hobbs, Church Road and East Trib subwatersheds flowed through these riparian wetlands.

**WETLAND sub-model modification:** Modifications of the SWAT2000 program code (4/18/2001 version) were made by Baumgart (2005) to create the version of the model that was applied in this project. An additional modification was made to the SWAT code for this project. In a December, 2006 letter to the SWAT model developers, the SWAT Midwest American User's Group (SMAUG) had documented that the pond/wetland routine did not function correctly:

> "Water infiltrated through ponds, wetlands, and channels is not included as groundwater recharge in the model. Instead, this water gets "trapped" in the shallow aquifer storage, never to be released. E.g., when ponds are added to the model, total water yield declines by the same amount that shallow aquifer storage increases - which continues to increase indefinitely. are described in this chapter."

No response has been received regarding this problem yet. The same problem documented by SMAUG had to be dealt with when wetland inputs were added to the subwatersheds to represent the effect of riparian wetlands on surface water, and in particular, ground water recharge. Numerous attempts were made to fix the routine by modifying the model code; however, the only "fix" that seemed to help was to simply add the groundwater seepage back to the surface water flow near the end of the wetland subroutine (wetlan.f):

```
      !! compute seepage depth for HRU water balance
       twlwet = wetsep / cnv
!     **** Modified **** ADDED wet seepage back to total flow
      qdr = qdr + twlwet
!     **** End of change*****
```

For the purposes of this project, this temporary "fix" worked reasonably well; however, it was not ideal as some odd effects seemed to occur with either low, or high seepage rates. The modified SWAT executable was named SWAT2007w, with the "w" signifying the wetland modification.

## PHOSPHORUS ROUTING - ALTERNATIVE TO QUAL2e

A problem was discovered near the end of the project, whereby the sum of the phosphorus loads at the subwatershed level was less than the load routed to the watershed outlet. The problem was traced to the addition of chlorophyll within SWAT to the main routing channels whenever the in-stream water quality sub-model QUAL2e is utilized. SWAT also adds the phosphorus associated with this chlorophyll to the main channel, but doesn't keep the mass balance correct by subtracting the phosphorus from other pools. In the LFR sub-basin model, Baumgart (2005) overcame this problem by reducing the phosphorus content in the algae, which is not an ideal solution, but better than the default of having excessive phosphorus added to the stream whenever QUAL2e is used. Unfortunately, the small sizes of some of the subwatersheds, particularly those that served as connecting points between USGS monitoring stations and the main subwatersheds, seemed to contribute excessive phosphorus-associated chlorophyll even with the values that were utilized in the LFR model.

To correct this problem, the QUAL2e sub-model was disabled in the "cod" file, which normally means that the amount of phosphorus exiting a channel is the same as the amount that enters. Instead, an earlier modification by Baumgart to the SWAT model "noqual.f" code simply routed the organic and sediment-attached phosphorus through the channels in a similar way that it does for sediment. The square route of the ratio between the sediment transported out of a channel and the sediment entering the channel was applied to organic and sediment-attached phosphorus. Soluble phosphorus was routed through the system without any loss. An alternative solution was also tried where the phosphorus content of the algae was reduced to essentially zero. However, the model output was sufficiently different than earlier results that the model might have needed to be re-calibrated. Also, the solution of utilizing the modified model code has the advantage of coupling phosphorus to stream bank sediment contributions.

This problem of the phosphorus in-balance associated with chlorophyll and the QUAL2e submodel was addressed in a letter by the SMAUG to SWAT model developers in December 2006. No solution or response has been received regarding this problem yet.

# CHAPTER 3. MODEL CALIBRATION AND ASSESSMENT

## OVERVIEW

Model calibration involves adjusting model inputs within acceptable ranges to obtain a good fit between observed and simulated values. Model assessment involves applying a previously calibrated model to a data set other than that used to calibrate the model, and then determining whether there is a good fit between observed and simulated values. The data set utilized during the validation phase can be either a different location or a different time period than that used to calibrate the model. The model must be able to provide reliable estimates (validated) during the assessment phase before it can be applied to provide reliable estimates and predictions of suspended sediment and phosphorus loads. This chapter describes how well the model was able to estimate flow, and suspended sediment and phosphorus loads. All results reported here were simulated with a version of the SWAT2000 model (USDA-ARS version 4/18/2001) that was modified for the LFR sub-basin TMDL project (Baumgart 2005).

The USGS Parson's Creek monitoring stations were used as the primary calibration and validation sites for stream flow, suspended sediment loads and phosphorus loads (Figure 1). The upstream monitoring site (USGS #04083420) was located at the intersection of the stream and Hickory Road, and the most downstream station (USGS #04083425) was located about 500 m downstream at the intersection with CTH B. These stations were jointly funded by the USGS and WDNR, and operated from Dec. 1997 to June 30, 2001. Drainage areas of 12.94 $km^2$ and 14.67 $km^2$ were calculated for the upstream and downstream stations, respectively. Another USGS station located between these two stations was not utilized for model assessment. Average daily flow, and loads of phosphorus and suspended sediment were calculated by the USGS for this period. Loads were not calculated for the period between July 16, 1999 and Feb. 22, 2000 because stream bank stabilization construction was conducted within the stream during this period. A 1998 to 2000 data set of 29 runoff events that the USGS calculated for the purposes of evaluating non-point contamination (Stuntebeck 2007) was also used for assessing the validity of the model. The event periods were changed slightly because the SWAT model computes loads on a daily basis — an extra day or two was often added to the event period.. Most of the data obtained for the USGS stations were provided in digital format, both on an event basis, and on a daily basis by Todd Stuntebeck of the USGS, Madison, Wisconsin.

The model was first calibrated for baseflow. After the model was successfully calibrated for baseflow, the model was tested to see how well it performed in predicting stream flow, and loads of suspended sediment and phosphorus. In this chapter, calibration and validation of the model for baseflow is discussed first. The next section describes the model validation/assessment phase where the model is tested to see if it can provide reasonable estimates without calibrating for flow, TSS or phosphorus.

## CALIBRATION - BASEFLOW HYDROLOGY

The Parson's Creek watershed has somewhat similar soils to those of the Duck Creek watershed, which is located within the LFR sub-basin (Hydrologic group B to C soils). Therefore, SWAT model inputs that were utilized by Baumgart (2005, 2007) for the Duck Creek watershed were initially applied to the project area. However, stream baseflow in the Duck Creek watershed, although higher than many other LFR watersheds, was substantially lower than in the project watershed. Much of the project area lies over or near the Niagara escarpment (Newport 1962, Link et al. 1973). Springs, seeps, fracture traces, shallow depth to the fractured bedrock (e.g., Knowles series 20 to 42" to bedrock, Link et al. 1972), and other features are evidently serving as sources to groundwater recharge to Parson's Creek, thereby increasing stream baseflow above what would be expected given the low to moderately permeable soils that are typical to this watershed. Preliminary investigations of stream flow in Parson's Creek revealed that baseflow comprised about 63% of total stream flow. Therefore, the first step prior to validating the model for stream flow, TSS loads and phosphorus loads was to ensure that the simulated stream baseflow was similar to the observed proportions.

Flow from the downstream Parson's Creek USGS station for the 1998 to 1999 water years was utilized to calibrate the baseflow percentage. Flow from the 2000 to 2001 water years then served as validation data for the simulated baseflow percentages, as did flow from the upper station. Once that was done, the simulated flows and loads were compared to the USGS values to assess the validity of the model without calibrating for stream flow or loads of TSS and phosphorus. Base flow analysis was conducted using a computer program developed by Arnold et al. (1995). Based on the second iteration with this computer program, base flow comprised approximately 63% of stream flow at the downstream USGS station during the calibration period. Initial baseflow and groundwater related inputs were based on the Duck Creek watershed, which has about 30 to 35% baseflow.

Based on analysis with the baseflow program, the initial inputs were altered to increase the Parson's Creek base flow proportion by: 1) reducing the alpha factor to 0.1 for most areas, and somewhat lower values for wetlands and forested areas; and 2) lengthening the groundwater delay to 100 days. As previously mentioned, wetlands were added to each of the subwatersheds. Wetlands also acted to slow stream flow and as potential recharge areas which increased the computed baseflow proportions. The last modification was to decrease the curve number multiplier factor from the value of 0.97 that was used in the Duck Creek watershed to 0.92. This change decreased the proportion of surface water runoff versus water that percolated through the soil and was available as groundwater recharge to the stream. Although the infiltration rates and hydrologic groups of many of the soil series in both watersheds are similar, it seemed that reducing the curve number helped to simulate the direct infiltration effects potentially caused by some of the karst features in the Parson's Creek watershed. Alternatively, additional total seepage in ponds or wetlands could've been used to increase the simulated effect of these features. However, as previously mentioned, there were problems with the wetland and pond sub-routines that precluded putting greater emphasis on them in the model. After the calibration adjustments (and the changes in the following paragraph), the simulated base flow proportion was 58% during the calibration period and 59% during the validation period, compared to 62% and 64% for the observed baseflow percentage at the downstream station. For the entire flow period, simulated baseflow comprised 61% at both the upstream and downstream stations, compared to the observed proportions of 63 and 64%, respectively.

Two additional changes were made to accommodate site-specific needs. The USGS had placed the three monitoring stations in the watershed to estimate the effect of BMPs that were to be installed on a farm with a significant barnyard runoff problem. Consequently, this major barnyard source of phosphorus had to be accounted for. The barnyard procedure was discussed in the previous methods section. This portion of the calibration did not affect the USGS upstream station, and associated comparisons with simulated loads. The other additional change was made to account for climatic differences due to latitude. The evapotranspiration (ET) coefficient the author had applied in the past to decrease ET in LFR sub-basin watersheds, had seemed less necessary in the Green Lake watershed located south of the LFR sub-basin and west of the Parson's Creek watershed. Therefore the ET coefficient was also increased from the 0.806 value utilized for the LFR sub-basin (Baumgart 2005) to 0.836 because of the similarity in latitude with the Green Lake watershed. These changes had minimal effect on base flow proportions. Comparisons between simulated and observed flow, and TSS and P loads were then made using this version of the model which was now calibrated for baseflow proportion.

# MODEL ASSESSMENT/VALIDATION

Simulated and observed stream flow volumes, TSS loads and phosphorus loads from 29 runoff events which occurred between 1998 and 2000 were compared to assess the validity of the model and its ability to make reliable predictions of runoff events. The coefficient of determination ($R^2$), as determined through linear regression analysis, the Nash-Sutcliffe coefficient of efficiency (NSCE; Nash and Sutcliffe 1970), and relative differences were used to assess the ability of the model to match observed values. A NSCE value of 1 indicates a perfect fit. Statistical measures for the runoff events are summarized in Table 3-1 for the upstream and downstream USGS stations, and they indicate that there was an acceptable level of correspondence between simulated and observed events. However, the relative differences could use some improvement, particularly at the upstream station.

**Table 3-1. Simulated and observed flow, TSS loads and phosphorus loads from 29 runoff events at Parson's Creek (1998 - 2000). Without model adjustment.**

| | Upstream | | | Downstream | | |
|---|---|---|---|---|---|---|
| | $R^2$ | NSCE | Rel. Diff. | $R^2$ | NSCE | Rel. Diff. |
| **Flow** | 0.86 | 0.83 | 26.5% | 0.87 | 0.85 | 16.3% |
| **TSS** | 0.92 | 0.87 | 31.6% | 0.91 | 0.83 | 20.5% |
| **Phosphorus** | 0.91 | 0.85 | 25.8% | 0.89 | 0.78 | 11.0% |

Annual simulated and observed flows, TSS loads and phosphorus loads are summarized in Table 3-2 and 3-3 for the upstream and downstream USGS stations, respectively. As previously stated, TSS and phosphorus loads were not calculated from July 16, 1999 to Feb. 22, 2000, and flow and loads were only calculated up to June 30, 2001. The NSCE, $R^2$, and relative differences were used to assess the ability of the model to match observed values. However, the NSCE and $R^2$ are not robust when there are only four data points/years. In general, there was a reasonable fit between the observed and simulated totals, especially since the calibration parameters were largely unchanged from that utilized by Baumgart (2005, 2007) for the LFR sub-basin (except parameters related to baseflow). Total stream flow was quite close, and the relative difference ranged from +21% to +32% for total loads. However, the simulated TSS and phosphorus total loads were all higher than the observed loads. With the exception of the first year, the annual loads were nearly always higher, and sometimes much higher than the observed loads.

The NSCE and $R^2$ statistics for monthly simulated and observed flow, TSS loads and phosphorus loads are also listed in Tables 3-2 and 3-3 for the upstream and downstream USGS stations, respectively. NSCE values ranged from 0.78 to 0.85, indicating a good fit between observed and simulated monthly flow and loads.

**Table 3-2. Simulated and observed stream flow, TSS and phosphorus loads (water years 1998-2001). Upstream USGS monitoring station: without adjustment to MUSLE.**

| Stream | Flow (mm) observed | Flow (mm) SWAT | Relative Diff. | TSS (ton) observed | TSS (ton) SWAT | Relative Diff. | Phosphorus (kg) observed | Phosphorus (kg) SWAT | Relative Diff. |
|---|---|---|---|---|---|---|---|---|---|
| WY1998 | 186 | 187 | 0.6% | 923 | 855 | -7.4% | 1,546 | 1,522 | -1.6% |
| WY1999 | 174 | 178 | 2.6% | 273 | 558 | 104.8% | 651 | 1,026 | 57.7% |
| WY2000 | 124 | 154 | 23.9% | 126 | 267 | 110.9% | 385 | 653 | 69.6% |
| WY2001 | 190 | 181 | -4.9% | 203 | 336 | 65.7% | 640 | 934 | 46.0% |
| TOTAL | 675 | 701 | 3.8% | 1,525 | 2,016 | 32.2% | 3,222 | 4,135 | 28.4% |

**Statistics: R-squared and Nash-Sutcliffe Coefficient of Efficiency (NS): 1998 to 2001.**

| | Flow R-sq. | Flow NS | TSS R-sq. | TSS NS | Phosphorus R-sq. | Phosphorus NS |
|---|---|---|---|---|---|---|
| Annual | 0.94 | 0.64 | 0.89 | 0.69 | 0.95 | 0.61 |
| Monthly | 0.82 | 0.82 | 0.87 | 0.85 | 0.86 | 0.85 |

**Table 3-3. Simulated and observed stream flow, TSS and phosphorus loads (water years 1998-2001). Downstream USGS monitoring station: without adjustment to MUSLE.**

| Stream | Flow (mm) observed | Flow (mm) SWAT | Relative Diff. | TSS (ton) observed | TSS (ton) SWAT | Relative Diff. | Phosphorus (kg) observed | Phosphorus (kg) SWAT | Relative Diff. |
|---|---|---|---|---|---|---|---|---|---|
| WY1998 | 202 | 187 | -7.6% | 1,118 | 951 | -14.9% | 2,107 | 1,830 | -13.1% |
| WY1999 | 188 | 178 | -5.4% | 336 | 627 | 86.4% | 896 | 1,277 | 42.4% |
| WY2000 | 135 | 154 | 14.4% | 165 | 312 | 88.9% | 642 | 928 | 44.5% |
| WY2001 | 199 | 180 | -9.4% | 235 | 405 | 72.3% | 802 | 1,360 | 69.6% |
| TOTAL | 724 | 699 | -3.4% | 1,855 | 2,295 | 23.8% | 4,447 | 5,395 | 21.3% |

**Statistics: R-squared and Nash-Sutcliffe Coefficient of Efficiency (NS): 1998 to 2001.**

| | Flow R-sq. | Flow NS | TSS R-sq. | TSS NS | Phosphorus R-sq. | Phosphorus NS |
|---|---|---|---|---|---|---|
| Annual | 0.98 | 0.64 | 0.90 | 0.72 | 0.85 | 0.55 |
| Monthly | 0.83 | 0.83 | 0.86 | 0.82 | 0.81 | 0.78 |

Overall, the model was able to estimate flow, and to a lesser degree, loads of TSS and phosphorus at the upstream and downstream monitoring stations with a reasonable degree of accuracy during the 1998 to 2001 USGS water year period. The model is therefore judged to be valid by the author of this report, and can be applied to reliably predict flow and loads of TSS and phosphorus from the Parson's Creek watershed. However, there was a tendency for the model to overstate phosphorus and TSS loads during events, and during most years. Because of this tendency, a slight adjustment to the leading coefficient of the Modified Universal Soil Loss Equation (MUSLE) was made to reduce the TSS load, and thereby reduce the sediment-associated phosphorus load. Since the model had already been validated, and because the adjustment is relatively minor, it was felt that there was no need to validate the model again with another data set.

**Revised Model:** A slight adjustment to the leading coefficient of the MUSLE equation was made to reduce the overall TSS load, and thereby reduce the sediment-related phosphorus load, recognizing that this change might reduce other statistical measures.. The leading coefficient was decreased from 0.0245 to 0.0188. The results that follow are based on this adjustment.

As shown in Table 3-4, the relative differences between simulated and observed event loads were improved with the revised model.

**Table 3-4. Simulated and observed 29 runoff events at Parson's Creek (1998 - 2000). After adjustment of the MUSLE.**

| | Upstream | | | Downstream | | |
|---|---|---|---|---|---|---|
| | $R^2$ | NSCE | Rel. Diff. | $R^2$ | NSCE | Rel. Diff. |
| **Flow** | 0.86 | 0.83 | 26.5% | 0.87 | 0.85 | 16.3% |
| **TSS** | 0.92 | 0.78 | 1.2% | 0.91 | 0.73 | -6.1% |
| **Phosphorus** | 0.90 | 0.79 | 7.8% | 0.90 | 0.71 | -3.5% |

Annual simulated and observed flows, TSS loads and phosphorus loads for the revised model are summarized in Tables 3-5 and 3-6 for the upstream and downstream USGS stations, respectively. In general, the fit between the observed and simulated phosphorus and TSS totals improved as the relative differences now ranged from -2% to +12%. Relative differences also improved on an annual basis. However, these improvements come with a tradeoff. Monthly NSCE and $R^2$ statistical measures are reduced (Tables 3-5 and 3-6), as they are for the event loads shown in Table 3-4. Overall, the slightly revised model with improved relative differences is believed to be a better solution than the original model because getting the long-term loads correct is judged to be better than improved monthly statistics.

**Table 3-5. Simulated and observed stream flow, TSS and phosphorus loads (water years 1998-2001). Upstream USGS monitoring station: with adjustment to MUSLE leading coefficient.**

| | Flow (mm) | | Relative | TSS (ton) | | Relative | Phosphorus (kg) | | Relative |
|---|---|---|---|---|---|---|---|---|---|
| **Stream** | **observed** | **SWAT** | **Diff.** | **observed** | **SWAT** | **Diff.** | **observed** | **SWAT** | **Diff.** |
| **WY1998** | 186 | 187 | 0.6% | 923 | 659 | -28.6% | 1,546 | 1,311 | -15.2% |
| **WY1999** | 174 | 178 | 2.6% | 273 | 430 | 57.8% | 651 | 890 | 36.8% |
| **WY2000** | 124 | 154 | 23.9% | 126 | 206 | 63.1% | 385 | 573 | 48.9% |
| **WY2001** | 190 | 181 | -4.9% | 203 | 260 | 28.3% | 640 | 819 | 28.1% |
| **TOTAL** | 675 | 701 | 3.8% | 1,525 | 1,555 | 2.0% | 3,222 | 3,594 | 11.6% |
| **Statistics: R-squared and Nash-Sutcliffe Coefficient of Efficiency (NS): 1998 to 2001.** | | | | | | | | | |
| | **R-sq.** | **NS** | | **R-sq.** | **NS** | | **R-sq.** | **NS** | |
| **Annual** | 0.94 | 0.64 | | 0.89 | 0.74 | | 0.95 | 0.77 | |
| **Monthly** | 0.82 | 0.82 | | 0.87 | 0.78 | | 0.86 | 0.82 | |

**Table 3-6. Simulated and observed stream flow, TSS and phosphorus loads (water years 1998-2001). Downstream USGS monitoring station: with adjustment to MUSLE leading coefficient.**

| | Flow (mm) | | Relative | TSS (ton) | | Relative | Phosphorus (kg) | | Relative |
|---|---|---|---|---|---|---|---|---|---|
| **Stream** | **observed** | **SWAT** | **Diff.** | **observed** | **SWAT** | **Diff.** | **observed** | **SWAT** | **Diff.** |
| **WY1998** | 202 | 187 | -7.6% | 1,118 | 745 | -33.4% | 2,107 | 1,599 | -24.1% |
| **WY1999** | 188 | 178 | -5.4% | 336 | 492 | 46.3% | 896 | 1,125 | 25.6% |
| **WY2000** | 135 | 154 | 14.4% | 165 | 249 | 50.3% | 642 | 832 | 29.5% |
| **WY2001** | 199 | 180 | -9.4% | 235 | 325 | 38.3% | 802 | 1,198 | 49.4% |
| **TOTAL** | 724 | 699 | -3.4% | 1,855 | 1,810 | -2.4% | 4,447 | 4,754 | 6.9% |
| **Statistics: R-squared and Nash-Sutcliffe Coefficient of Efficiency (NS): 1998 to 2001.** | | | | | | | | | |
| | **R-sq.** | **NS** | | **R-sq.** | **NS** | | **R-sq.** | **NS** | |
| **Annual** | 0.98 | 0.64 | | 0.90 | 0.70 | | 0.85 | 0.63 | |
| **Monthly** | 0.83 | 0.83 | | 0.86 | 0.73 | | 0.81 | 0.74 | |

**<u>Overall Model Assessment - Flow, Sediment and Phosphorus</u>:** A comparison between precipitation, observed flow and simulated flow indicates that the model was capable of adequately estimating stream flow over a fairly wide range of soil moisture conditions (graph not shown). The model was also able to predict suspended sediment and phosphorus loads reasonably well. Simulated loads were reasonably close to observed loads. Statistical comparisons between simulated and observed flow, TSS loads and phosphorus loads on an event, monthly and annual basis support the conclusion that the model as applied in this project can predict flow, suspended sediment and phosphorus loads from the Parson's Creek watershed with an acceptable degree of accuracy. Although better model performance is always preferred, the author believes the model can be expected to provide acceptable phosphorus and TSS load estimates for this watershed.

It should be noted that another calibration data set was tried to see how well it worked. Initially, the fit between the observed and simulated TSS and phosphorus loads was better than that produced with the default calibration data set from the LFR sub-basin on an annual, monthly and event basis. However, further investigation revealed that the TSS and phosphorus yields from the Hobbs subwatershed were quite low, and the simulated effect from conservation tillage was also much lower than expected. The MUSLE calibration parameters in this data set were obviously outside the bounds of acceptability. However, the fact that the fit was much better may reveal a potentially better calibration solution than the one selected for this project.

# CHAPTER 4. MODEL RESULTS - SUSPENDED SEDIMENT AND PHOSPHORUS LOADS

## WATERSHED AND SUBWATERSHED CONTRIBUTIONS

**Watershed Contributions:** Simulated average annual loads at the Parson's Creek watershed outlet were 678 metric ton of suspended sediment and 1,835 kg of phosphorus under Baseline 2000 conditions (1992-2006 climate).

**Subwatershed Loads by Landuse:** Simulated average annual suspended sediment and phosphorus source loads, as routed to the subwatershed outlet, are summarized by subwatershed in Table 4-1 for each major landuse type (Baseline 2000 conditions, 1992-2006 climate).

**Table 4-1. Parson's Creek simulated sediment and phosphorus subwatershed loads, by landuse. Baseline 2000 conditions.**

**Suspended Sediment Average Annual Load in Metric Ton**

| Subwatershed | Ag | Barnyard | Urban | Grassland | Forest | Wetland | Road/Railroad | Quarries | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| **Hobbs** | 176 | 1 | 1 | 0 | 2 | 0 | 2 | 7 | **189** |
| | 93.2% | 0.7% | 0.6% | 0.1% | 0.8% | 0.2% | 0.8% | 3.5% | |
| **Church Rd.** | 292 | 1 | 2 | 0 | 0 | 0 | 2 | 0 | **297** |
| | 98.3% | 0.2% | 0.5% | 0.0% | 0.2% | 0.2% | 0.6% | 0.0% | |
| **East Trib** | 157 | 0 | 1 | 0 | 0 | 0 | 2 | 4 | **165** |
| | 95.1% | 0.2% | 0.7% | 0.0% | 0.2% | 0.1% | 1.0% | 2.6% | |
| **TOTAL** | **625** | **2** | **4** | **0** | **2** | **1** | **5** | **11** | **650** |
| **% TOTAL** | **96.0%** | **0.3%** | **0.6%** | **0.1%** | **0.4%** | **0.2%** | **0.8%** | **1.7%** | |

**Phosphorus Average Annual Load in Kilogram**

| Subwatershed | Ag | Barnyard | Urban | Grassland | Forest | Wetland | Road/Railroad | Quarries | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| **Hobbs** | 456 | 278 | 1 | 6 | 8 | 3 | 11 | 24 | **786** |
| | 58.0% | 35.3% | 0.2% | 0.7% | 1.0% | 0.4% | 1.4% | 3.0% | |
| **Church Rd.** | 555 | 55 | 2 | 1 | 2 | 3 | 10 | 0 | **628** |
| | 88.3% | 8.8% | 0.4% | 0.2% | 0.4% | 0.4% | 1.5% | 0.0% | |
| **East Trib** | 330 | 36 | 2 | 1 | 2 | 1 | 8 | 14 | **393** |
| | 83.9% | 9.2% | 0.5% | 0.2% | 0.5% | 0.2% | 2.0% | 3.7% | |
| **TOTAL** | **1,340** | **369** | **6** | **8** | **12** | **6** | **29** | **38** | **1,807** |
| **% TOTAL** | **74.2%** | **20.4%** | **0.3%** | **0.4%** | **0.7%** | **0.3%** | **1.6%** | **2.1%** | |

The percent load associated with each major landuse is also listed, so load contributions can be compared on a relative basis. Although these loads are from the subwatershed outlets, the total loads are nearly the same as the loads that were routed to the watershed outlet. The reason for this similarity is that the simulated contributions from stream bank erosion are roughly equal to sediment deposition losses in the stream channel as the constituent loads are routed to the watershed outlet. The simulated contributions from stream bank erosion are about 8.1% of the suspended sediment load and 2.3% of the phosphorus load at the watershed outlet. At the subwatershed outlet level, agricultural sources contribute about 96% of the simulated sediment load, and 95% of the phosphorus load. Loads from other sources are relatively insignificant. Simulated barnyard sediment loads are very low because the barnyard component of the model was calibrated for phosphorus, rather than both constituents because it was difficult to match BARNY-derived loads of sediment and phosphorus at the same time.

# CHAPTER 5. EVALUATION OF ALTERNATIVE SCENARIOS

This chapter describes how the SWAT model was applied to simulate the impact of implementing alternative policy changes, or scenarios, as well as the outcome of these scenarios compared to current practices. Eight major alternative scenarios were developed and simulated, and a combination of scenarios was also simulated. To determine the simulated impact of implementing alternative scenarios, the validated model was applied to the watershed for a 15 year climatic period (1992-2006). All scenarios were compared to the Baseline 2000 Scenario to evaluate the impact because this time frame coincided with the model validation period and intensive monitoring by the USGS that occurred primarily from 1998 to 2001. The following section describes each alternative scenario and how the model was applied to simulate the impact on sediment and phosphorus load export from the Parson's Creek watershed.

## DEVELOPMENT OF ALTERNATIVE SCENARIOS

The following alternative scenarios were developed, simulated, and then compared to modeled output from the Baseline 2000 Scenario.

**1. Conservation tillage - current levels versus reduced tillage intensity:** Under this scenario, the area of land dedicated to conservation tillage (i.e., reduced tillage practices) increases from estimated 2000 Baseline levels of:

24% mulch till, 3% zone-till or no-till, and 73% conventional tillage
to:
70% mulch-till, 20% zone-till or no-till, and 10% conventional tillage.

It should be noted that the baseline levels were based on county averages from 1999 to 2001. It is likely that the proportion of conservation tillage in the Parson's Creek watershed was lower, for the amount of cash-grain crops was, and still is much lower than the remainder of Fond du Lac County. In general, farm fields from cash-grain operations usually have a higher level of conservation tillage than dairy operations.

**2. Manure incorporation - Increase proportion of applied manure that is incorporated within 72 hours to 85%:** The level of manure incorporated immediately or within 72 hours was assumed to be 30% under 2000 Baseline conditions, with the remainder spread as needed without intentional incorporation. Current levels are likely reversed (70% incorporated). These estimates were provided by Becky Wagner, agronomist with the Fond du Lac County Land and Water Conservation Department.

3. **Nutrient Management - Dietary Phosphorus in Dairy cow feed ration reduced by 25%, with a 90% implementation rate:** In this scenario, phosphorus in the dairy cow feed ration was reduced by 25%, compared to 2000 levels. At levels estimated for the year 2000, this reduction translates to roughly a 25% reduction in manure phosphorus concentrations. The fertilizer/manure input file was adjusted accordingly to simulate this scenario. A detailed justification of these assumptions is described in Baumgart (2005). A 90% implementation rate implies that 90% of the total manure produced and applied in the watershed contained 25% less phosphorus due to an associated reduction of phosphorus in the dairy feed ration.

**4. Barnyard or feedlot BMP's implemented:** For the purposes of estimating the impact of barnyard BMPs, it was assumed that the phosphorus load from the major barnyard source between the upper and lower USGS monitoring stations was reduced by 90% because a larger load ought to be able to be reduced by a greater amount on a relative basis. It was assumed that all other barnyard loads were reduced by 80%.

**5. Streambank stabilization:** For this scenario, it was assumed that unstable eroding streambanks were stabilized sufficiently enough that streambank contributions to the total sediment and phosphorus loads were relatively minor.

**6. Strip cropping along the contour:** Current implementation rates of strip cropping along the contour of steeper agricultural land were assumed to increase to 20% compared to the estimated 2000 Baseline levels of 7.4% in the Church Road subwatershed, 3.6% in the East Trib, and 0.0% in the Hobbs subwatersheds.

**7. Vegetative Buffer strip (VBS) implementation:** In this scenario, it was assumed that VBS's were installed on 100% of streams that were adjacent to crop land and were delineated by the AV-SWAT GIS model, which is somewhat greater than that shown in the WDNR 1:24k hydrology layer.

**8. Nutrient Management - Nearly Stabilize Soil-test phosphorus level at current average of 40 ppm (Bray P1):** This scenario simulated the estimated effect of a comprehensive nutrient management plan which requires that phosphorus inputs be limited to crop agronomic needs, thereby stabilizing soil-test phosphorus levels such that they remain at the current average level.

In this scenario, a number of management changes were instituted to ensure that soil phosphorus levels did not increase over time due to net gains from fertilizer and manure applications. Therefore, phosphorus levels in the dairy feed ration were reduced by 25% to decrease the potential for increasing soil phosphorus levels. This reduction in dietary phosphorus is the same as that used in the low dietary phosphorus dairy feed ration scenario. No supplemental phosphorus in the form of starter fertilizer was added to the soybean crop. No supplemental phosphorus in the form of commercial fertilizer was added to the alfalfa crop. As was done for the 2000 Baseline Scenario, commercial fertilizer was applied at crop agronomic needs (i.e., harvest removal rates) for corn under the cash crop rotation. Under the dairy crop rotation, only the minimal recommended starter rate of 87 lbs/acre of 9-23-30 (Kelling et al. 1998) was initially applied to the corn crop. When soil nutrients are sufficient to meet crop needs, starter fertilizer still boosts yields slightly under the right conditions. Soil phosphorus levels still increased, so 80% of the recommended starter was added to corn planted under the dairy rotation. Even these steps were not enough to stabilize simulated soil phosphorus levels, which continued to increase, although at a much lower rate than before. However, it is also possible that the total amount of manure that is actually applied in the watershed (or the phosphorus content in the manure), is sufficiently less than assumed under the Baseline conditions such that there is no real surplus after these steps are taken to stabilize soil phosphorus.

## ALTERNATIVE SCENARIOS - RESULTS

The simulated impact of alternative scenarios on average annual sediment and phosphorus loads at the outlet of the Parson's Creek watershed, relative to the Baseline 2000 Scenario, are summarized in Table 5-1 (1992 to 2006 climatic conditions). According to the model predictions, it would take the following suite of BMP's to reach nearly a 52% reduction in the suspended sediment load: 1) mulch-till (70%) and no-till or zone-till (20%); 2) stabilizing all substantial sources of stream bank erosion; 3) strip cropping along the contour of 20% of all agricultural cropland in the watershed; and 3) VBS's along all of the delineated stream network adjacent to crop land. Conservation tillage had the greatest impact of any single scenario on suspended sediment reduction. Seven of the BMP scenarios listed in Table 5-1 would be required to reach a similar 52% reduction in the simulated phosphorus load, and all eight BMP scenarios would provide an estimated 54% reduction in the phosphorus load.

**Table 5-1. Simulated impacts of Alternative Scenarios on suspended sediment and phosphorus loads at Parson's Creek watershed outlet.**

| | | Simulated Mean Annual Load | | Simulated Reduction as % | | Cumulative Scenario Loads | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | TSS (tons) | Phos. (kg) | TSS | Phos. | TSS (tons) | Phos. (kg) | % Reduced TSS | % Reduced Phos. |
| | **BASELINE 2000 CONDITIONS** | **678** | **1,835** | 0.0% | 0.0% | 678 | 1,835 | 0.0% | 0.0% |
| **1** | Conservation Tillage (70% Mulch-till, 20% Zone or no-till, 10% conventional till). | 483 | 1,624 | -28.8% | -11.5% | 483 | 1,624 | -28.8% | -11.5% |
| **2** | Increase Manure Incorporation to 85% of Manure (85% incorporate, 15% spread). | 675 | 1,633 | -0.4% | -11.0% | 472 | 1,386 | -30.3% | -24.5% |
| **3** | Reduce Phosphorus in Feed Ration by 25%, assume 90% implementation. | 678 | 1,655 | 0.0% | -9.8% | 472 | 1,265 | -30.3% | -31.1% |
| **4** | Barnyard/Feedlot BMPs: install on all or most important sources. | 678 | 1,557 | 0.0% | -15.2% | 472 | 1,048 | -30.3% | -42.9% |
| **5** | Stream Bank Erosion Controls, decrease erosion from stream banks to minimal levels. | 623 | 1,792 | -8.1% | -2.3% | 410 | 1,011 | -39.5% | -44.9% |
| **6** | Strip Cropping along Contours (USLE P-factor adjusted); increase to 20% in all subwatersheds. | 617 | 1,744 | -8.9% | -4.9% | 365 | 958 | -46.1% | -47.8% |
| **7** | VBS: Vegetated Buffer Strips, install VBS's to 100% of stream network adjacent to Ag areas. | 621 | 1,708 | -8.4% | -6.9% | 327 | 886 | -51.7% | -51.7% |
| **8** | Stablize Phosphorus Levels in Soil as much as possible, without reducing total appled manure; implement on 90% of acres. | 678 | 1,591 | 0.0% | -13.3% | **327** | **844** | **-51.7%** | **-54.0%** |
| | **Total with ALL Above Scenarios** | **327** | **844** | **-51.7%** | **-54.0%** | | | | |

**<u>Subwatershed Alternative Scenario Loads by Landuse</u>:** Simulated average annual suspended sediment and phosphorus source loads, as routed to the subwatershed outlet, are summarized by subwatershed in Table 5-2 for each major landuse type (All Alternative Scenarios, 1992-2006 climate). The percent load and percent area associated with each major landuse are also listed, so load contributions can be compared on a relative basis. Although these loads are from each of the subwatershed outlets, the total loads are nearly the same as the total loads routed to the watershed outlet shown in Table 5-1. The contributions from stream bank erosion are assumed to be minimal in the combined Alternative Scenario.

**Table 5-2. Parson's Creek simulated sediment and phosphorus subwatershed loads, by landuse. Simulated impact of implementing all 8 Alternative Scenarios.**

| Suspended Sediment Average Annual Load in Metric Ton | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subwatershed | Ag | Barnyard | Urban | Grassland | Forest | Wetland | Road/Railroad | Quarries | TOTAL |
| **Hobbs** | 83 | 1 | 1 | 0 | 2 | 0 | 1 | 6 | **94** |
| | 87.6% | 1.1% | 1.2% | 0.2% | 1.7% | 0.5% | 1.5% | 6.2% | |
| **Church Rd.** | 144 | 1 | 2 | 0 | 0 | 0 | 2 | 0 | **148** |
| | 96.9% | 0.3% | 1.0% | 0.0% | 0.3% | 0.3% | 1.1% | 0.0% | |
| **East Trib** | 75 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | **82** |
| | 91.2% | 0.4% | 1.4% | 0.0% | 0.4% | 0.1% | 1.7% | 4.7% | |
| **TOTAL** | **301** | **2** | **4** | **0** | **2** | **1** | **4** | **10** | **325** |
| **% TOTAL** | **92.8%** | **0.6%** | **1.2%** | **0.1%** | **0.7%** | **0.3%** | **1.3%** | **3.0%** | |

| Phosphorus Average Annual Load in Kilogram | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subwatershed | Ag | Barnyard | Urban | Grassland | Forest | Wetland | Road/Railroad | Quarries | TOTAL |
| **Hobbs** | 228 | 48 | 1 | 6 | 8 | 3 | 11 | 23 | **327** |
| | 69.8% | 14.6% | 0.4% | 1.7% | 2.3% | 0.9% | 3.3% | 7.0% | |
| **Church Rd.** | 276 | 19 | 2 | 1 | 2 | 3 | 9 | 0 | **313** |
| | 88.3% | 6.1% | 0.7% | 0.4% | 0.7% | 0.8% | 3.0% | 0.0% | |
| **East Trib** | 163 | 12 | 2 | 1 | 2 | 1 | 8 | 14 | **202** |
| | 80.9% | 6.1% | 0.8% | 0.4% | 0.9% | 0.3% | 3.8% | 6.9% | |
| **TOTAL** | **668** | **79** | **5** | **8** | **12** | **6** | **28** | **37** | **842** |
| **% TOTAL** | **79.3%** | **9.4%** | **0.6%** | **0.9%** | **1.4%** | **0.7%** | **3.3%** | **4.4%** | |

## MARGIN OF SAFETY

Some of the implicit margins of safety that apply to the simulated scenarios are listed below:

1) With implementation of sediment-related reduction scenarios, the simulated reduction in suspended sediment ought to be greater for the combined bedload and suspended sediment load because the larger particles associated with bedload are more easily reduced by most BMP's. The model was calibrated for the suspended sedimented sediment load (bedload not included), so the simulated reductions from the implementation of most BMPs were based on the finer particles associated with suspended sediment rather than the coarse particles associated with bedload.
2) Conservation tillage/residues levels under Baseline conditions were likely lower because average Fond du Lac County levels were assumed, and Parson's watershed has much less cash crop operations where conservation tillage was more likely to be adopted in the past.
3) Contour strip cropping should have a larger impact as a conservative modeling approach was utilized whereby the USLE P factor was not fully adjusted across the watershed to account for presumably higher rates of soil erosion where strip crops were typically placed.
4) No grassed waterways were simulated, so installing them would increase the actual reduced load of sediment and phosphorus to the stream.
5) Soil phosphorus could be reduced, not just stabilized, through nutrient management (more evenly distribute manure and use manure to replace commercial P fertilizer as mush as possible, lower commercial P fertilizer, transport manure to cash-crop fields, etc.).

# CHAPTER 6. SUMMARY AND CONCLUSIONS

The following points summarize the major findings and conclusions of this project:

1) The LFR SWAT model was calibrated and validated to baseflow in Parson's Creek. This refined model performed satisfactorily when applied to the Parson's Creek watershed during the validation period that was examined in this project. The simulated monthly hydrograph preserved the peaks and recessions of the observed hydrograph. Simulated monthly, annual and total water yields were generally in good agreement with observed yields

2) Although the unadjusted model produced acceptable results, the leading coefficient of the MUSLE was adjusted to obtain a closer match with total loads. The adjusted model was able to predict suspended sediment and phosphorus event loads reasonably well at the upper and lower USGS monitoring stations. Direct comparisons between individual events and monthly statistical measures support the conclusion that the model can be applied to predict suspended sediment and phosphorus loads at the subwatershed and watershed scale with an acceptable degree of accuracy.

3) A simulations of all eight alternative scenarios showed a 52% decrease in sediment load and a 54% decrease in phosphorus load from the Parson's Creek watershed. The largest reductions related to BMP's were obtained through wide-scale implementation of conservation tillage, barnyard controls and nutrient management.

4) When comparing the simulated impact of implementing BMPs, caution should be used so as to not place too much emphasis on small differences. Small differences may be dwarfed by known and unknown sources of error.

**Conclusion:** Direct comparisons between individual events, statistical measures and graphical relationships support the conclusion that the model can be applied to predict sediment and phosphorus loads at the subwatershed and watershed scale with an acceptable degree of accuracy. Therefore, I conclude that the SWAT model, as applied in this project, can be reliably used as a tool to make improved management decisions.

Models of all types should primarily be judged by a criterion that is based on whether we can make better decisions with the model, or without it. In my judgement, the SWAT model as applied in this project meets that criterion. However, the most important tools are the skills and decision making abilities of the resource manager(s) who must be aware of the limitations of each model they rely on. Limitations that potentially affect SWAT-simulated results include potential input errors, inappropriate assumptions and an inability to mimic all of the complex processes and interactions which affect sediment and phosphorus delivery to streams, and nutrient and sediment transport to the watershed outlet. The numerous interactions between climatological factors, plants, soil, nutrients, soil organisms, and management practices are difficult to comprehend, let alone accurately predict. Models are limited by our understanding of the system and our ability to provide accurate, representative inputs at the appropriate scale.

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