BLANCHARD WATERSHED ANNAGNPS MODELING FINAL REPORT

Prepared for:

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EXECUTIVE SUMMARY

This report describes an interagency effort, funded under the authority of Section 516(e) of the Water Resources Development Act (WRDA) of 1996, to apply a watershed model, AnnAGNPS, to the Blanchard River Watershed, Ohio. The goal of the modeling effort was to predict direct runoff as well as sediment and nutrient loading from the highly agricultural watershed. A set of potential land management alternatives were evaluated to estimate the potential benefits in terms of reduced sediment and nutrient loading.

The watershed was represented in the model using data from several sources. A 30 m DEM was used to delineate the watershed into 3,830 subwatershed cells with an average area of 52 ha. Spatial information and attribute data from SSURGO and NASIS databases were used to define soil conditions. Stream channel geometry was based on a collection of surveyed cross-sections in the Blanchard and neighboring watersheds. A four-year crop and tillage rotation data layer was developed based on remote sensing data. Crop land management practices and fertilizer/manure application rates were defined in the model based on local knowledge. Point source loads from 13 permitted discharges were also included.

The model was calibrated against observed stream flow and water quality data for the period from 2002-2009. A model confirmation was also conducted using best available data from 1995-2001. For the calibration period, the model prediction of direct runoff was good, yielding R^2 and Nash-Sutcliffe model efficiencies (NSE) greater than 0.75 on an annual basis, and ranging from 0.63 to 0.69 on a monthly basis. Percent error and percent different calculations were both less than 20% and met the calibration target. Visual comparison of model results indicated an under-prediction of runoff in the late winter/early spring period, potentially attributed to the model's limitations in modeling a change in infiltration under frozen soil conditions.

The simulation of suspended sediment yield and loading was good, with NSE and R^2 values greater than 0.86 on an annual basis and near 0.40 on a monthly basis. Similar to the direct runoff predictions, the model under-predicted sediment during the late winter/early spring period. AnnAGNPS estimated that ephemeral gully erosion accounted for approximately 85% of the total landscape erosion in the watershed, while sheet and rill erosion amounted to the remaining 15%. The model simulated total phosphorus and total nitrogen loading in the watershed with less accuracy than direct runoff or suspended sediment.

A set of land management alternatives were run including tile drain management, conservation tillage, cover crops, conversion of crops to grassland, and improved nutrient management. A pre-settlement "all natural" watershed scenario was also developed. In general, all scenario runs showed reasonable reductions in suspended sediment. For example, the model estimated a suspended sediment loading reduction of 54% with a conversion of 10% of highest eroding cropland to grassland, and a 60% reduction for a combined management scenario involving conservation tillage, conversion of crop to grassland, and improved nutrient management. The model

predicted a sediment loading reduction of 99.8% under an all-natural watershed condition.

Simulation of phosphorus and nutrient loading reductions under proposed land management was reasonable for most scenarios. A cover crop scenario resulted in an estimated 25% reduction of total phosphorus and 39% reduction of total nitrogen. The model predicted that a 60% reduction of fertilizer application could result in a 21% decrease in total phosphorus and 60% decrease in total nitrogen loading. The model produced unexpected total phosphorus results for scenarios involving the conversion of cropland to grassland or forest. Model diagnostic runs suggest that phosphorus in non-crop land uses are represented almost entirely in a dissolved form which continually leaches out of cells during the simulation period. These results suggest that the phosphorus cycling algorithms within AnnAGNPS warrant further investigation.

This modeling exercise was a successful attempt at quantifying direct runoff and suspended sediment loading contributions from the Blanchard River watershed under baseline and potential management scenarios. The simulation of nutrient loading from the watershed under most management scenarios was informational; however, model nutrient calculations related to conversion of cropland to non-cropland land uses were problematic.

The application of AnnAGNPS to the Blanchard River watershed was a detailed analysis for a complicated problem over a larger watershed system. Because of the number of watershed cells and the complexity of supporting databases (e.g., crop and tillage rotations), a high level of resources was expended for model set-up, execution, and interpretation of model results. A simplified model configuration (e.g., smaller watershed or coarser spatial scale) which did not involve calibration may have required fewer resources.

The simulation of ephemeral gullies for delivery of sediments and associated nutrients is an important process captured in AnnAGNPS which is not an element of many other watershed models. However, additional empirical observations of ephemeral gully formation and erosion may help support the improvement of model process formulation. Simulation of nutrients within AnnAGNPS is less mature than algorithms, which model direct runoff and suspended sediment. Further investigation and testing of these processes would help to improve future applications of this model.

1. INTRODUCTION

This report describes an interagency effort, funded under the authority of Section 516(e) of the Water Resources Development Act (WRDA) of 1996, to apply a watershed model, AnnAGNPS, to the Blanchard River Watershed, Ohio.

1.1 BACKGROUND

The Western Lake Erie Basin (WLEB) is defined as a region in northwestern Ohio, northeastern Indiana, and southeastern Michigan which encompasses the Maumee River Basin as well as the Ottawa and Portage watersheds (Figure 1-1). The drainage area for the WLEB is approximately 7,372 mi^2 with the majority of land attributed to the Maumee River Basin (6,609 mi^2). The Maumee River flows into Lake Erie near Toledo, Ohio, and is considered the largest tributary source of suspended sediment to Lake Erie. Considerable attention has been focused on reducing erosion from this highly agricultural watershed to address water quality and dredging problems associated with sediment loading to the Maumee Bay.

Figure 1-1. Western Lake Erie Basin (WLEB) sub-watersheds (WLEB, 2008)

The U.S. Army Corps of Engineers (USACE) Great Lakes Region Districts (The Districts) are responsible for the maintenance of Great Lakes harbors and are tasked specifically with addressing sediment and associated pollutant loading from agricultural watersheds to Great Lakes harbors. The Districts have the authority under Section 516(e) of the Water Resources Development Act (WRDA) of 1996 (herein referred to as the 516(e) Program) and the Regional Sediment Management authority to promote and fund work which assists state and local watershed managers to evaluate, prioritize, and implement alternatives for soil conservation, sediment trapping, and nonpoint source pollution prevention. The Districts, in cooperation with the Great Lakes states, are working to develop sediment transport models for Great Lakes tributaries that discharge to Federal navigation channels or areas of concern (GLC, 2010).

In 2005 an interagency effort was conducted under the 516(e) Program to model the Upper Auglaize River Watershed, using the AnnAGNPS model, to determine sediment sources, contributing locations, and the effect of BMPs on rates of sediment delivery to the outlet of the watershed (USACE, 2005). This effort was an initial step in a proposed process to apply AnnAGNPS to each of the major Maumee River Basin watersheds and then link them to form a comprehensive basin-wide model, which would then be linked to a Lower Maumee River/Bay Model. The project described in this report is a continuation of the above effort to apply the AnnAGNPS model to a second 8-digit HUC sub-basin within the Maumee Basin called the Blanchard River watershed.

1.2 PROJECT OBJECTIVES

The desired outcome of the project was to develop a tool to support local stakeholder decision-making. The intent is that the tool will be used to assist local land managers in improving water quality by minimizing erosion and sedimentation problems in the watershed. It may be used to help federal and state agencies optimize an accelerated program of installing erosion control practices in the watershed or focus conservation measures on high-priority areas. Application of AnnAGNPS to the Blanchard River Watershed will benefit USACE-Buffalo District because it will advance the understanding of sediment and nutrient load contributions to the Maumee River and Lake Erie. The project will also increase the scientific and technical credibility of AnnAGNPS model and support broader USACE efforts in sediment reduction goals for Toledo Harbor. The primary goals of the project are to:

1) Simulate erosion, sediment delivery pathways and sediment delivery yields and loads in the watershed;
2) Simulate the export of nutrients from the watershed;
3) Project the potential benefits of conservation treatment strategies and best management practices; and
4) Support the larger conservation effort to reduce erosion in the Maumee Basin and reduce sediment and associated nutrient delivery to Toledo Harbor.

1.3 PARTNER AGENCIES

The project was led by LimnoTech in collaboration with the USACE-Buffalo District and the Engineer Research and Development Center of the U.S. Army Corps of Engineers (USACE-ERDC). Contributing partners included U.S. Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS Ohio); U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS); the

University of Toledo; Heidelberg University; and the U.S. Geological Survey (USGS) (Figure 1).

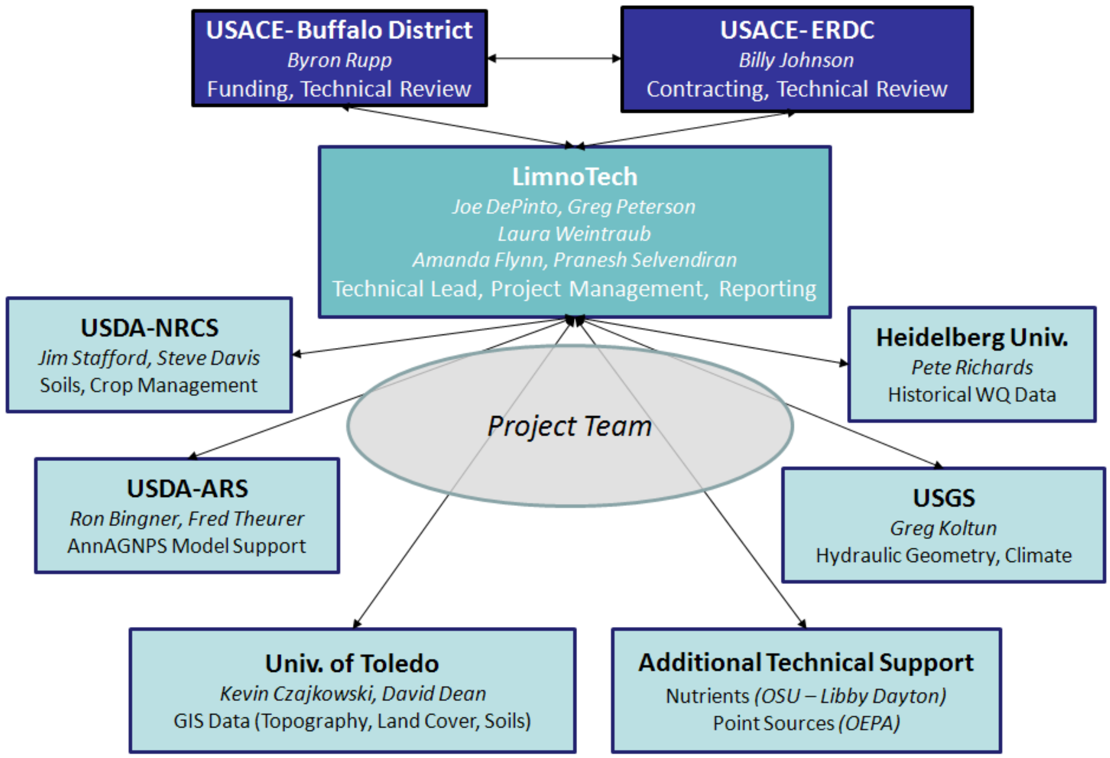

Figure 1-2. Project team for AnnAGNPS modeling in the Blanchard River Watershed, Ohio.

USACE (Buffalo District and ERDC) provided funding, contracting support, and technical review. The USDA provided support for model development and parameterization, primarily related to soils and crop management inputs. The USGS supported the development of channel geometry inputs and hydrograph separation of recorded flows. Heidelberg University provided historical flow and water quality records to support model calibration. The University of Toledo provided land cover, crop rotation, and tillage information based on remote sensing data. All team members provided local knowledge to support the model development and calibration, and participated in project status update meetings and document review.

1.4 PROJECT SCOPE

The following section outlines the major components of the project. Chapter 2 provides background on the Blanchard Watershed and Chapter 3 summarizes the AnnAGNPS model. Additional details regarding model development, calibration, and application are provided in Chapters 4 and 5.

1.4.1 Project Scoping and Model Selection

A project scoping report was developed and submitted to the USACE-Buffalo District in August, 2009. The report outlines the basis for the work, background information on watershed characteristics and stakeholders, and proposed steps for completing the project including model selection, data acquisition, model development and application, and technical transfer. Model selection for this project was driven by the previous 516(e) program modeling effort in the Upper Auglaize River Watershed (USACE, 2005). This effort was an initial step in a proposed process to apply detailed watershed models to each of the eight major Maumee River sub-basins and then link them to form a comprehensive basin-wide model. To maintain consistency between modeling efforts and to leverage the data and knowledge bases developed for the Upper Auglaize effort, AnnAGNPS was selected as the watershed model for the Blanchard River Watershed.

1.4.2 Work Plan Development and Project Initiation

As part of project initiation, a project work plan was developed by LimnoTech and distributed to all project team members. This document outlines the various steps of the project and identifies proposed contributions from various team members. A kick-off meeting was held to review and discuss the work plan. Data sources were identified, watershed characteristics were discussed, and action items to proceed with model development were defined.

1.4.3 Model Development, Calibration, and Application

The following model development steps were led by LimnoTech and supported by other project team members:

- **Data Acquisition**: Various data sources, specific to the Blanchard River Watershed, were identified and acquired for input to the model. These datasets include topography, soils, channel geometry, land use / land cover, climate, crop rotation and tillage, fertilizer application rates and practices, point sources, and observed stream flow and water quality. Specific details on each dataset are described more fully in Chapters 2 and 4.
- **Model Development:** The model was constructed using input data described above. Spatial data layers (e.g., soils, DEM, land use) were input to the ArcView GIS interface for AnnAGNPS. Other non-GIS data were input directly to the model (e.g., climate data, crop management schedules). Once all datasets were input, the model was run to produce preliminary output of flow, erosion, sediment yield, and sediment and nutrient loading at various points throughout the watershed. Additional details regarding model development are provided in Chapter 4.
- **Model Calibration:** Model calibration focused first on hydrology, then on suspended solids, and finally on nutrients. The calibration period included years with supporting meteorological input data, flow and water quality data (2002-2009). Simulated flow and water quality were compared with observed data, and model parameters were adjusted to improve calibration. Model calibration was evaluated using visual inspection of modeled output vs. data, and statistical error calculations (e.g., Nash-Sutcliffe efficiency). Chapter 5 contains additional details on the model calibration.

- **Model Application:** After model calibration, a set of illustrative management scenarios were run to evaluate the effects of conservation practices on erosion and sediment and nutrient delivery. The model predicted changes in sediment and nutrient delivery from the watershed outlet to the Auglaize River. Details regarding the management scenarios are included in Chapter 6.

1.4.4 Team Meetings and Reporting

The project team conducted two formal meetings in Findlay, OH:

- A project kick-off meeting was held on July 17, 2009.
- Calibration Review Meeting, June 4, 2010.

In addition to these broader team meetings, LimnoTech participated in a project update meeting with the USACE–Buffalo District on March 3, 2010, and presented project results at a 516(e) Program “All Hands” meeting on June 22, 2010. Both meetings were held in Ann Arbor, MI. Throughout the project, LimnoTech provided monthly status reports to USACE-Buffalo District which summarized project progress, challenges, and next steps.

1.4.5 Training and Outreach

A key component of 516(e) Program-sponsored projects is dissemination of the model and data sets to watershed stakeholders. Several watershed stakeholders attended the Calibration Review Meeting and were informed of the watershed modeling project. In addition to the project team, representatives from the following groups were in attendance:

- Putnam Soil and Water Conservation District
- Environmental Defense Fund
- Hancock Soil and Water Conservation District
- Blanchard River Watershed Partnership
- Ohio Department of Natural Resources – Division of Soil and Water Conservation

Group discussions helped frame the development of management scenarios to run with the model and identify potential opportunities for near-term or longer-term use of the analysis. Upon project completion, this report will be distributed to all interested stakeholders.

As part of the technical transfer, the AnnAGNPS model and accompanying datasets will be transferred to the USACE-Buffalo District, Great Lakes Commission, and the NRCS office in Findlay, OH. Arrangements may be made to distribute the model to other interested parties upon request.

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2. WATERSHED BACKGROUND

2.1 BLANCHARD WATERSHED

The 771-square-mile Blanchard River Watershed is located in northwestern Ohio and includes portions of Allen, Hancock, Hardin, Putnam, Seneca, and Wyandot Counties (Figure 2-1). The watershed comprises 7.1% of the Western Lake Erie Basin (WLEB) project area. The Blanchard River is a tributary of the Auglaize River, which drains into the Maumee River and eventually into Lake Erie near Toledo, OH. In general, the watershed is flat with 83% of the watershed having slopes of less than 2%. The Blanchard River Watershed includes portions of two Major Land Resource Areas as defined by USDA-NRCS – MLRA 99 (Erie-Huron Lake Plain of the Lake States Fruit, Truck Crop, and Dairy Region) and MLRA 111 (Indiana-Ohio Till Plain of the Central Feed Grains and Livestock Region) (NRCS, 2008). Soils within the western portion of the watershed (MLRA 99) are nearly level glacial lake plain with some scattered ridges of sandy soils. The eastern portion of the watershed (MLRA 111) is characterized by a gently undulating glacial till plain. Approximately 30% of the watershed is covered by nearly level and gently sloping areas of somewhat poorly drained Blount soils (USACE, 2008).

Prior to historical settlement, an estimated 42% of the watershed was covered in wetlands (NRCS, 2008). The majority of wetlands were drained and converted to agricultural lands in the early 1900s. Currently land use in the Blanchard Watershed is estimated to be 80.8% cultivated crops, 10.1% developed, 5.6% forest, 2.6% pasture and grassland, and < 1% open water and wetlands (OEPA, 2009). Within the cultivated lands, primary crops grown include corn (31.2%), soybeans (49.9%), wheat (15.9%), and hay (3%) (NRCS, 2008). The largest community within the watershed is Findlay with a population of approximately 45,000. From 1982 to 1997, the urban land in the watershed increased by 175% (NRCS, 2008). Other towns within the watershed include Ottawa and Bluffton.

The headwaters of the Blanchard River are in the southeast corner of the watershed. The river flows north and then turns west, just upstream of Findlay. Major tributaries of the Blanchard River include Cranberry Creek, Riley Creek, Ottawa Creek, Eagle Creek, Lye Creek, and The Outlet. According to a 2007 Ohio EPA assessment, approximately 35% of the 84 sampled sites are designated as impaired (USACE, 2008). Primary causes of impairment include habitat/flow alteration, siltation, organic enrichment, low oxygen, nutrient enrichment, and excess ammonia (NRCS, 2008). Nutrient impairments have been attributed to loads from agricultural areas, unsewered areas, and small wastewater treatment plants. Since 2001, wastewater treatment plant upgrades have been implemented for the Findlay and Bluffton wastewater treatment plants (NRCS, 2008). Conservation practices benefiting impairments include conservation tillage, conservation buffers, nutrient management, waste utilization, conservation cover, tree planting, and drainage water management (NRCS, 2008). Conservation tillage is practiced on 46% of the cultivated cropland within the watershed; however, the Blanchard River Watershed ranks last in percentage of conservation tillage as compared with the other seven watersheds within the Western Lake Erie Basin (NRCS, 2008).

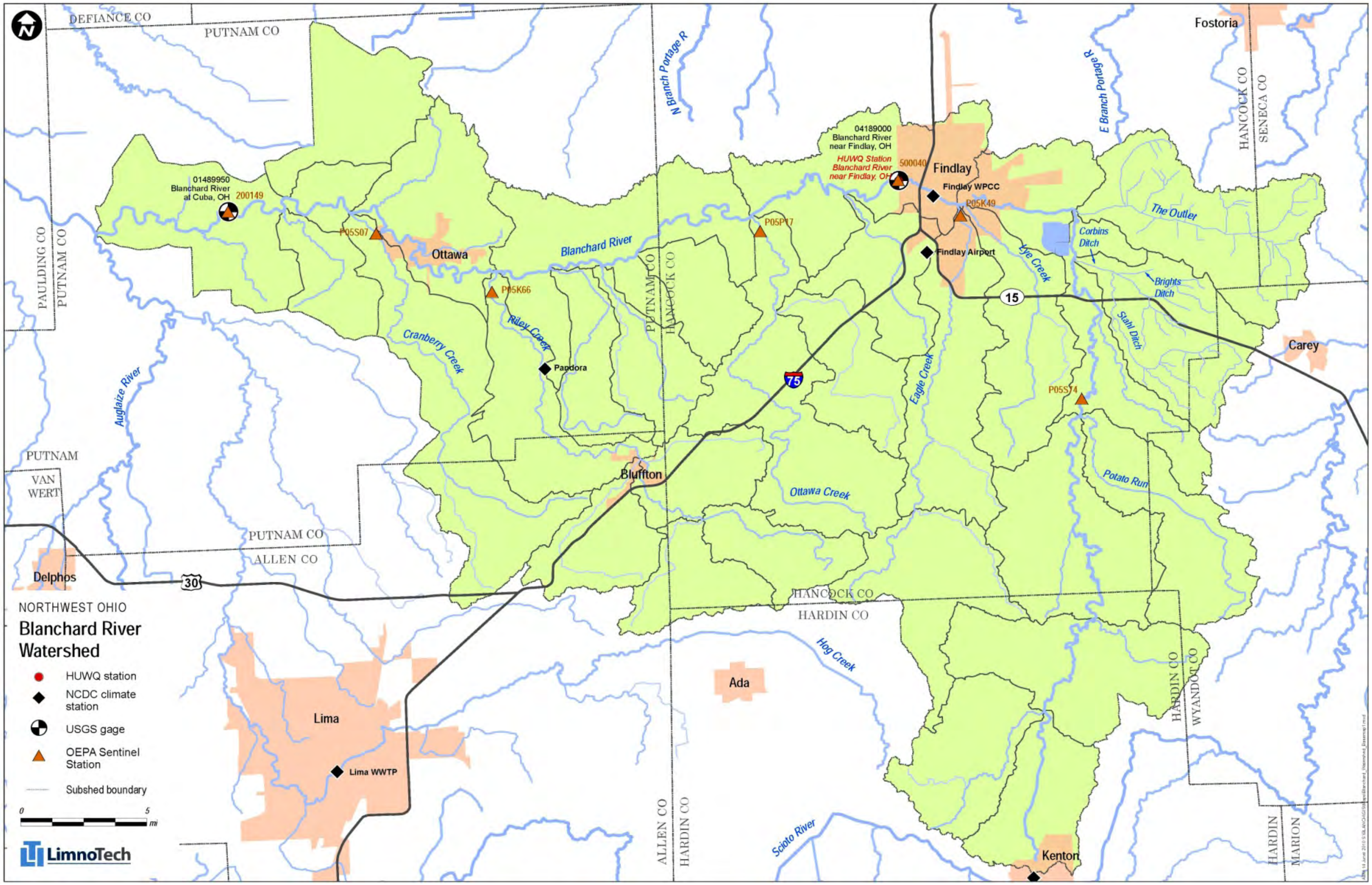

Figure 2-1. The Blanchard River watershed

2.2 CURRENT AND HISTORIC MONITORING STATUS

The following section describes observed data which are available for the Blanchard River watershed. These data will be used to compare with simulated flow and water quality during model calibration and confirmation.

2.2.1 Stream Flow

Daily streamflow measurements are available at the Findlay, OH, USGS gage (04189000) from 1923 to present. The watershed drainage area to this gage is approximately 346 square miles (45 % of the total watershed area). Daily streamflow records are also available at the Cuba, OH, USGS gage (01489950) for a shorter time period (2005-2007). The Cuba, OH, gage captures drainage from 745 square miles of watershed (97% of the total watershed). Both stations are shown in Figure 2-1.

2.2.2 Water Quality

Water quality data at varying levels of spatial and temporal resolution are available from two main sources, Heidelberg University and OEPA. The primary source of data for suspended sediment calibration was from a long-term monitoring data site in Findlay, OH, supported by Heidelberg University (station HUWQ in Figure 2-1). Concentration data for total suspended solids (TSS) and several nutrient species were collected on a daily basis from July 2007 to December 2009. The nutrient species sampled include total phosphorus (as P), soluble reactive phosphorus (as P), nitrite (as N), nitrate plus nitrite (as N), TKN (as N), and ammonia (as N). From the various nitrogen constituents, it is possible to also calculate a total nitrogen concentration for each day. These water quality data provide excellent temporal resolution for the calibration period. A limitation is that these data are only available for one watershed location.

A secondary water quality dataset from OEPA was also used to support model calibration and confirmation (OEPA stations in Figure 2-1). These data provide good spatial resolution; however, they are more temporally sparse than the Heidelberg University dataset. Streamflow and water quality were sampled at an approximate monthly frequency at seven (7) tributary and mainstem stations from 2005 to 2006 (Table 2-1).

Table 2-1. Summary of sentinel sites (OEPA, 2009)

Subbasin Name	*STORET ID*	*River Mile*	*Area (sq. mi.)*	*Number of Site Visits*	*Range of measured Flows (cfs)*
Blanchard River Headwaters	P05S74	75.57	140.8	24	0.585 – 371.
Blanchard River CR 140, USGS gage	500040	55.26	346	31	25.0 – 2260.
Eagle Creek	P05K49	0.45	61.4	24	0.378 – 136.
Ottawa Creek	P05P17	0.9	63	25	2.08 – 125.
Riley Creek	P05K66	1.2	85.6	25	3.07 – 41.2
Cranberry Creek	P05S07	1.64	45	24	0.050 – 151.
Blanchard River SR 115 @ Cuba, USGS gage	200149	9.05	745	24	21.0 – 8300.

2.3 ONGOING WATERSHED ACTIVITIES

Several activities which are ongoing within the Maumee Watershed and the WLEB have potential relevance to the application of AnnAGNPS to the Blanchard River Watershed. The current modeling work described in this report may help support these additional efforts to improve water quality in the watershed.

2.3.1 TMDL

A TMDL was developed for the Blanchard River Watershed and approved by U.S. EPA on July 2, 2009 (OEPA, 2009). The main causes for impairments which were addressed by the TMDL include nutrient enrichment (total phosphorus), low dissolved oxygen, siltation, habitat alteration, and pathogens. The TMDL provides an allocation of allowable loads of total phosphorus, fecal coliform, and sediment, and percent reductions of each load which would be required to meet water quality standards. More information on the TMDL can be found at the following website: (http://www.epa.state.oh.us/dsw/tmdl/BlanchardRiverTMDL.aspx). The AnnAGNPS watershed modeling could help inform actions related to the TMDL implementation.

2.3.2 Watershed Action Plans

The Blanchard River Watershed Partnership (BRWP) (http://www.blanchardriver.com/) is an active and organized watershed group within the basin with goals to preserve the natural and environmental aspects of the watershed, improve or maintain river water quality, and facilitate regional policy and development (NRCS, 2008). In December 2009, BWRP submitted a watershed action plan for The Outlet/Lye Creek region of the Blanchard River watershed. This was the first of potentially six action plans intended to guide land use and other implementation strategies to improve water quality. Specifically, this plan focused on nitrogen, phosphorus, and fecal coliform bacteria reduction goals that were in line with the TMDL. Proposed actions included filter strips, wetland development, drainage management, tree planting, nutrient management, field borders, residue management, and cover crops. As of summer 2010, The Outlet/Lye Creek Watershed Action Plan is under revision to include more detail regarding implementation of actions and sediment reduction goals. The BRWP next intends to develop a watershed action plan for Riley Creek. The AnnAGNPS modeling effort may provide opportunities for refinement or development of watershed action plans by helping quantify potential improvements of some proposed best management practices. It is important to note that the scale of the model application limits the resolution of BMPs considered.

2.3.3 Maumee Watershed SWAT Modeling

The University of Michigan is leading a multi-institutional project funded by NOAA-CSCOR to develop a forecasting framework for hypoxia in the central basin of Lake Erie. One element of this work is the development and application of a SWAT model to forecast the effects of land use and land management practices in the Maumee watershed on the delivery of nutrients and solids to the western basin of Lake Erie via the Maumee River. Dr. Nate Bosch, who developed this model with additional funding from the USACE, has already done a model transfer workshop in this model. By necessity, this model has been developed at a coarser scale than the AnnAGNPS application to the Blanchard and Upper Auglaize watersheds. For this reason, it would be valuable to compare the Blanchard watershed suspended solids and nutrient exports for the same time period and the same crop conditions and management practices. This would provide valuable information regarding the importance of scale and process formulation on predicting the outcome of best management practices that might be implemented in this watershed.

2.3.4 Lower Maumee River – Western Basin Lake Erie Modeling

With USACE-Buffalo District funding through Section 516(e) of the Water Resources Development Act (WRDA) of 1996, and through USACE’s Regional Sediment Management Authority, LimnoTech is developing and applying a linked hydrodynamic – sediment transport – water quality model for the lower Maumee River (below Waterville) through Maumee Bay and the entire western basin of Lake Erie (LMR-MB). Through its participation in the Western Lake Erie Basin Partnership and its responsibilities for the WRDA 516(e) and 204 programs, the USACE has been planning and working within the Maumee watershed to reduce the loading of solids and nutrients to the Maumee River and the western basin of Lake Erie. Most of the analysis to date has been focused on developing watershed models (e.g., Blanchard River watershed model) and other tools to assess the potential for various actions to reduce sediment and nutrient export from the land. There is a need, however, to quantitatively connect those watershed erosion and nutrient management efforts to important ecosystem endpoints in Toledo Harbor, Maumee Bay, and the western basin of the lake. The LMR-MB model has been developed to make that connection. The model demonstrates the quantitative relationship between sediment and nutrient loads and flows in the lower Maumee River and sedimentation within the Maumee River navigation channel, suspended solids distribution throughout the western basin, and the development of blue-green algal blooms in Maumee Bay and the rest of the western basin. This model can be used to predict the response of this receiving water body to land use changes, agricultural best management practices, and climate-driven hydrology within the Maumee watershed once it is linked to a watershed model such as described in this report. Even without that linkage, the LMR-MB model can be used to define the necessary load reductions to achieve sedimentation and water quality targets in the western basin of Lake Erie.

2.3.5 Flood Mitigation General Investigation

Flooding is a recurring problem in the Blanchard River watershed because of cumulative impacts of flat topography, wetland draining, and development of floodplain areas. Flooding in the watershed typically corresponds to extreme weather events. Rainfall amounts ranging from 5 to 10 inches during the period of August 20-25, 2007, which occurred at various watershed locations, led to record flooding (NRCS, 2008). This event caused significant economic damages, the loss of property, and one fatality. Flood control levees or diversions have not been constructed in the watershed. An extensive rural drainage system (tile drains and ditches) exists within the watershed and contributes substantially to flooding problems in the watershed. Major flood areas in the watershed are within the cities of Findlay and Ottawa. USACE Buffalo District is funding a General Investigation (GI) study to evaluate potential flood mitigation efforts. This project involves coordination with community and township trustees to discuss flooding concerns and development of an ecosystem-based approach for flood mitigation. The effort intends to explore opportunities for watershed-wide ecosystem restoration through wetlands, diversions to flood plains, or other actions. Though the AnnAGNPS watershed model is not a flood-focused hydrodynamic model, it may helpful to quantify the benefits and potential quality improvements of proposed actions by evaluating current flow volumes, defining the best areas for increased infiltration, or estimating the flood-related benefits of BMPs.

3. ANNAGNPS MODEL BACKGROUND

This chapter provides an overview of the AnnAGNPS model including key features, a summary of algorithms, and input data requirements.

3.1 OVERVIEW AND CAPABILITIES

AGNPS (Agricultural Non-Point Source) is a suite of computer models that predicts nonpoint source pollutant loadings within agricultural watersheds (Figure 3-1). AnnAGNPS is one component (or module) of AGNPS and is a replacement of the single-event version (AGNPS). AnnAGNPS is a watershed-scale, continuous simulation model that operates on a daily time step and is designed to predict the impact of management on water, sediment, nutrients, and pesticides in agricultural watersheds. AnnAGNPS incorporates several components of other models, including the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model, the Erosion Productivity Impact Calculator (EPIC) model, and the Trace Element Transport - Transient-State Solute Transport (TETRANS) model (Das et al., 2008; Bingner et al., 2009).

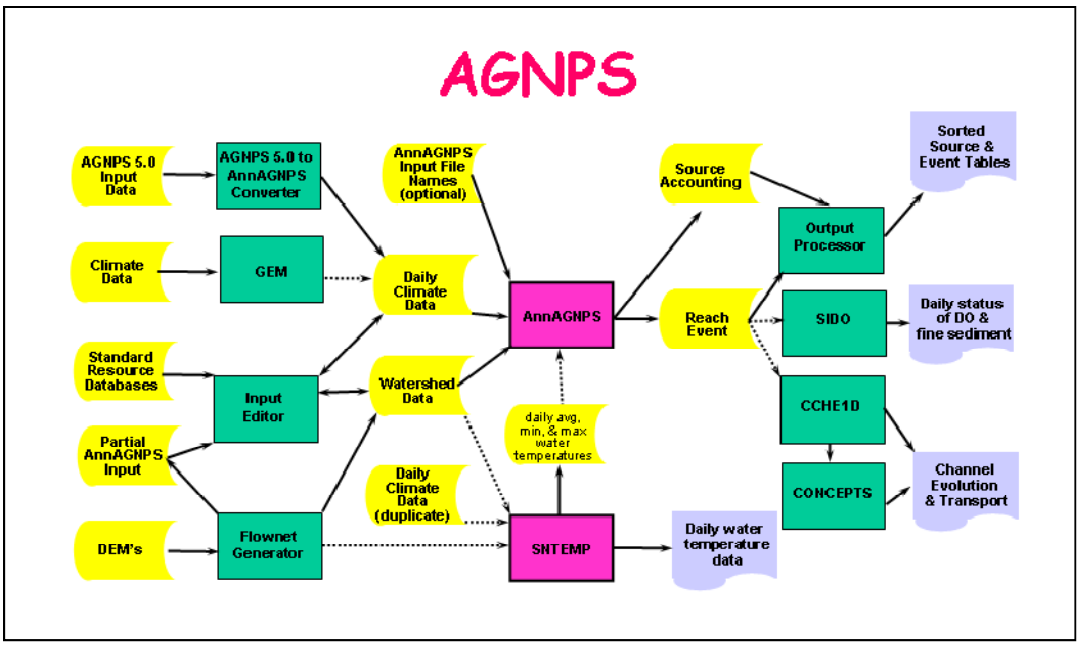

Figure 3-1. The suite of modeling components contained within AGNPS (Bingner et al., 2009)

Major model components include weather, hydrology, sediments, nutrients, pesticides, plant growth, and land management. Agency support for AnnAGNPS is provided by USDA. The model is a non-proprietary, public domain model with an open source code that can be accessed and downloaded by any individual at the following web site:
http://www.wsi.nrcs.usda.gov/products/w2q/h&h/tools_models/agnps/index.html

AnnAGNPS is primarily a watershed model and has a limited simulation of receiving water processes (e.g., first-order decay). The general features of AnnAGNPS include the simulation of watershed surface hydrology, sediment loading, nutrient loading, pesticide loading, point sources, and simplified reach routing. Special features include the simulation of ephemeral gully erosion, bed and bank erosion, feedlots, impoundments, crop growth and irrigation, tile drains, and agricultural management practices. The following sections briefly describe the algorithms for calculating watershed runoff, suspended sediment yield, and nutrient loading.

3.1.1 Hydrology

Total runoff calculated by AnnAGNPS includes direct surface runoff, subsurface drainage flow (from tile drains), and subsurface lateral flow. AnnAGNPS does not calculate groundwater (base flow) that would be considered a slow return flow to a neighboring stream (Yuan et al., 2006). The algorithms to model daily direct surface runoff are based on the SCS curve number technique (SCS, 1972). The basis of these calculations is the empirical curve number parameter, C_n, which typically ranges from 30 to 100. Lower curve numbers indicate a low runoff potential, while larger numbers represent conditions for increased runoff potential. AnnAGNPS does not use a constant curve number for the entire simulation period, but rather adjusts it each day based on a soil moisture balance. The calculation accounts for water inputs (precipitation, snow melt, irrigation) and subtracts surface runoff from the previous time step, percolation out of the soil layer, potential evapotranspiration, subsurface lateral flow, and tile drainage flow.

For each land use / land cover category, the model requires an initial C_{n2} value for antecedent moisture conditions based on the soil wilting point, field and soil hydrologic group C_n, and field capacity. During a simulation, C_{n2} may change because of an operation that makes a significant change to the land surface such as harvest or active crop growth. The impacts of tillage on soil hydraulic properties, and resulting C_n values, are not accounted for in AnnAGNPS.

Total runoff calculated within AnnAGNPS is an undifferentiated mixture of overland flow over the watershed and shallow flow through the upper soil. Shallow flow (interflow) is accounted for as lateral subsurface flow and subsurface drainage (tile drainage) in the model. These flows out of watershed cells are assumed to be added to the reach the same time as runoff. The model does not account for lateral flow between cells. Lateral subsurface flow is computed under saturated conditions only, based on Darcy's equation, and is therefore a function of saturated hydraulic conductivity (*KSAT*) and the calculated hydraulic gradient (approximated by the local surface topographic slope).

Tile drainage flow is calculated based on the Hooghoudt equation, which assumes steady constant flow occurs through the soil to the drains (Bingner et al., 2009). This calculation is a function of the saturated layer hydraulic conductivity (*KSAT*), the distance between tile drains, pipe depth and diameter, depth to impervious layer, and the calculation of soil moisture as discussed previously. If the soil moisture does not exceed field capacity, then there is no subsurface flow into the tile drains.

3.1.2 Suspended Sediment

AnnAGNPS calculates two sources of erosion and sediment yield from a watershed: sheet and rill erosion, and ephemeral gully erosion. A modified version of the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) is used to calculate sheet and rill erosion (Bingner et al., 2009):

$$PErosion = EI \times LS \times C \times P$$

where:

PErosion = total potential erosion from a cell,
EI = erosion index (a product of the total storm energy and maximum 30-minute intensity),
K = the soil erodibility factor,
LS = the hillslope length and steepness factor,
C = cover management factor, and
P = the support practices factor.

To provide spatial and temporal variation of management practices within a watershed, each AnnAGNPS cell can have different RUSLE parameters (Bingner et al., 2009). The *LS* factor is determined based on DEM data, whereas *C* and *P* are internally calculated based on model inputs such as crop rotation, tillage, soil, and land use. AnnAGNPS has an option to input *C* or *P* values directly, overwriting the internally calculated value.

AnnAGNPS can recalculate *LS*, *C* and *P* factors as frequently as every 15 days to reflect changing crop management conditions. For each unique soil, the *K* factor is calculated or provided by user input. During the simulation, the *EI* and *K* factors may be adjusted on a daily basis based on storm precipitation and frozen conditions, respectively.

The calculated *PErosion* is compared to the amount of thawed soil available for erosion, and the lesser of the two quantities is then multiplied by the sediment delivery ratio to determine the amount of sediment delivered to the edge of the field. Sediment delivery, the total sediment volume delivered from the field to the channel after sediment deposition, is calculated with the Hydrogeomorphic Universal Soil Loss Equation, HUSLE (Theurer and Clarke, 1991), and utilizes the time of concentration (*Tc*) determined from watershed topography parameters. HUSLE calculations are based on RUSLE parameters described above, drainage area, volume of water runoff, and peak discharge. AnnAGNPS simulates sheet and rill deposition of five sediment classes (clay, silt, sand, and small and large aggregates) based on particle density and fall velocity (Bingner et al., 2009).

Erosion control practices have had significant impact on reducing sheet and rill erosion, leaving ephemeral gully erosion to be a dominant source of cropland erosion in many watersheds (Bingner et al., 2009). Most ephemeral gullies that form in croplands are tillage-induced. AnnAGNPS uses the tillage-induced ephemeral gully erosion model (TI-EGEM), an enhanced version of EGEM, to estimate sediment production from ephemeral gullies (Gordon et al., 2007; Gordon et al., 2008). During

AnnAGNPS set-up, a spatial distribution of potential ephemeral gully (PEG) locations is mapped based on an user-specified Compound Topographic Index (CTIndex) and watershed topography. The TI-EGEM technology provides an integrated approach for simulating ephemeral gully erosion. The headcut is induced and moves up the length of the pathway with varying widths, depths and migration rates as a result of management practices, watershed characteristics, and climatic effects. If the shear stress for a given runoff event exceeds the erosion threshold of the soil, incision is initiated at PEG locations in the form of headcut, and erosion occurs. The erosion threshold, or the critical shear stress of the soil, is calculated based on prior land use subfactors and soils clay content (Bingner et al., 2009). Other input parameters that influence ephemeral gully erosion include Manning’s roughness, erosion depth, and soil bulk density.

Sediment transport within watershed reaches is based on the Einstein deposition equation and uses the Bagnold equation (Einstein and Chien, 1954; Bagnold, 1966). All sediment yield and entrained bank and bed materials are transported as sediment load within the stream system (Bingner and Theurer, 2002). AnnAGNPS simulates routing of five sediment classes (clay, silt, sand, and small and large aggregates) based on particle density and fall velocity (Bingner et al., 2009).

3.1.3 Nutrients

AnnAGNPS uses a mass-balance approach to dynamically calculate nitrogen and phosphorus concentrations in each field and to track subsequent movement downstream. NRCS-developed soil databases are used to describe each cell or field in AnnAGNPS, while RUSLE crop information is used by AnnAGNPS along with additional parameters to describe how the crop uses nutrients from the soil. AnnAGNPS chemical routing processes for the fate and transport of nitrogen and phosphorus have been updated to account for partitioning between absorbed and dissolved states. The model does not mechanistically simulate instream processing of nutrients. Rather, the fate of instream nutrients is controlled by a "reach nutrient half life" parameter, which is specified for both nitrogen and phosphorus.

3.1.3.a Nitrogen

AnnAGNPS incorporates a simplified version of the full nitrogen cycle that tracks only major nitrogen transformations of mineralization from humified soil organic matter and plant residues, crop residue decay, fertilizer inputs, and plant uptake. Three pools of soil nitrogen are considered: stable organic N, active organic N (mineralizable N), and inorganic N. Losses (cell output pathways) include soluble inorganic N in runoff, leaching, denitrification, and sediment-bound organic N from soil erosion. The nitrogen mineralization equation is adapted from the EPIC model (Sharpley and Williams, 1990); plant uptake of N is modeled with a simple crop growth stage index with adaptations for soil profile nutrient uptake from the TETRANS model (Corwin, 1995); and residue return and decomposition equations are based on RUSLE (Renard, et al., 1997).

3.1.3.b Phosphorus

The AnnAGNPS phosphorus (P) module extracts P from a cell into surface runoff (a transport process) while maintaining an appropriate soil mass balance of P in a cell by horizon or computational layer. The module is not a detailed chemical model of P in the soil, but instead simulates the effect of P adsorption that controls P availability and partitioning into runoff. The mass balance portion of the model is a simplification of the EPIC P model (Sharpley, et al., 1984; Sharpley and Williams, 1990), where P is partitioned into organic P and mineral P. Mineral P is further broken down into labile P, active mineral P, and stable mineral P (absorbed P that is "fixed" or relatively irreversibly chemisorbed to the soil adsorption complex or as discrete insoluble P minerals). The amount of P available for extraction into runoff is dictated by an empirical distribution coefficient, *Kd*, that partitions P between the soluble and absorbed phases. *Kd* is a linear partitioning coefficient which represents the ratio of the mass of absorbed phosphorus to the mass of phosphorus in solution. *Kd* is set within the model code to be equal to 4.0 (unit-less), though the most recent documentation lists a *Kd* value of 0.175. Sediment-bound P, consisting of organic P and both active and stable mineral P, is extracted through erosion of the clay-size fraction of soil.

Important model input parameters related to nutrient dynamics include initial soil concentration, fertilizer application rates (both chemical and manure), soil characteristics, crop-specific parameters, and reach nutrient half-life. These parameters can all be adjusted as part of the calibration process.

3.2 MODEL APPLICATION

The technical expertise or skill level required of the model user to develop and apply the model is at an "advanced" level, requiring knowledge and competence in GIS, ArcView, and watershed processes. A low to moderate level of technical support for the model is available to model users. Model developers can be directly contacted for technical support on a case-by-case basis. In addition, training sessions have been given in the past, and the materials for the training sessions are available for download; however, the training materials alone do not provide sufficient information on model theory, development and application.

During an AnnAGNPS model set-up, a watershed is subdivided into watershed cells that are either grid-based and square, or amorphous in shape and hydrologically based. The size of watershed cells is determined based on user-specified thresholds for drainage areas and channel lengths. Each watershed cell is represented by homogenous land use (dominant), soil characteristics, and land management (crop rotation/tillage), which are assigned during the input development process. Each watershed cell is spatially explicit, meaning that it has an exact spatial location within the watershed representation in AnnAGNPS. The model simulates the quantities of runoff, sediment, nutrients, and pesticides leaving each watershed cell on a daily basis. The runoff and pollutants are routed (using a simplified method) to a downstream point and through the watershed via simulated rivers.

An AnnAGNPS feature of particular note is source tracking, which quantifies the fraction of a pollutant loading at the watershed outlet from user-identified watershed source locations (e.g., specific cells, reaches, feedlots, point sources, and gullies) (Figure 3-2). Output is expressed on an event basis for selected stream reaches and as source accounting or allocation (contribution to outlet) from land or reach components over the simulation period. This feature can be used to better understand the impact of specific land management practices on various source load reductions.

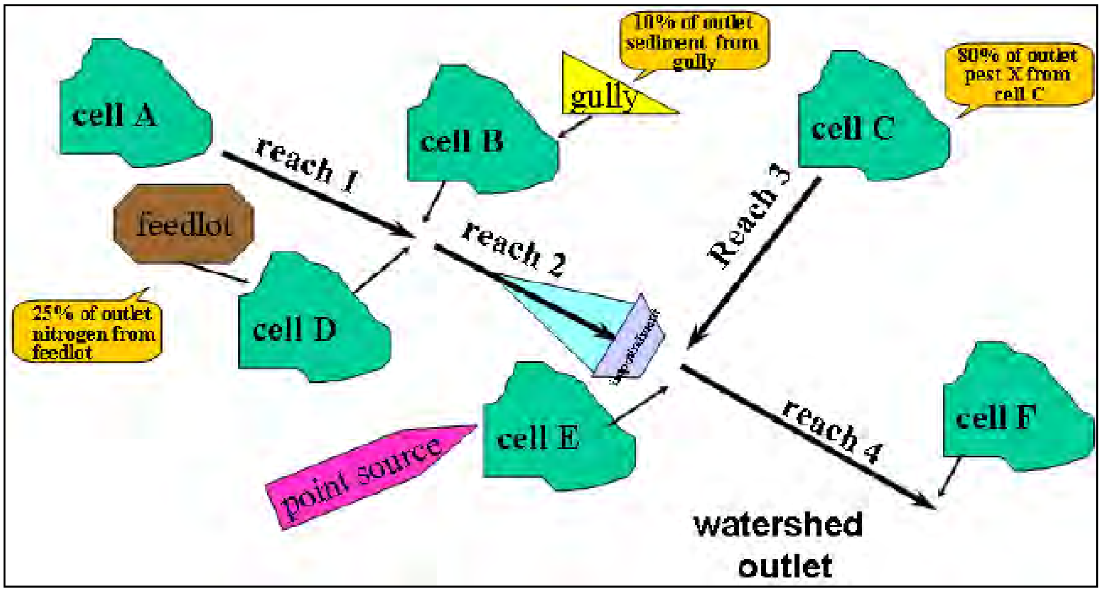

Figure 3-2. Example of the source tracking in AnnAGNPS (Bingner et al., 2009)

The impacts of watershed management practices on runoff, sediment, and nutrients can be simulated using various land management alternatives and BMPs. Specific, mechanistic algorithms allow for simulation of crop rotations, contour farming, cover crops, no-till farming, nutrient application management, and tree plantings. Other BMPs and land management practices that can be simulated indirectly include conservation tillage, grassed waterways, field borders, filter strips, residue management, and strip cropping. Impoundments, tile drainage, and irrigation can be modeled directly in AnnAGNPS.

3.3 INPUT REQUIREMENTS

The data requirements for AnnAGNPS are extensive but can generally be met with datasets from various public sources such as USGS, Environmental Protection Agency (EPA), National Oceanic and Atmospheric (NOAA) National Climatic Data Center (NCDC), state environmental agencies, and local agricultural extension programs. Model inputs include a digital elevation model (DEM); climate data (daily precipitation, minimum and maximum air temperature, dew point, sky cover, wind speed and direction); soils; land use/land cover (LULC); crop rotations; crop management schedules including tillage and fertilizer applications; reach geometry; and point source inputs of sediments and nutrients.

As mentioned above, AnnAGNPS is one component in the AGNPS suite of computer models. Consequently, there are several linkages that are supported within the AGNPS framework. The tools and/or models linked to AnnAGNPS include TOPAZ (Topographic Parameterization) for watershed delineation; SNTEMP (Stream Network Temperature Model) for water temperature simulation in the stream network; SIDO (Sediment Intrusion and Dissolved Oxygen Model) to predict sediment accumulation and DO status for salmonid redd habitat; CONCEPTS (Conservational Channel Evolution and Pollutant Transport System), a stream corridor model designed to predict and quantify bank and bed processes as well as riparian vegetation on channel morphology and pollutant loadings; and CCHE1D (Center for Computational Hydroscience and Engineering – One-Dimensional Channel Model), which is a stream network watershed scale model (Bingner et al., 2009). NRCS also plans to revise HU/WQ (Hydrologic Unit/Water Quality Model), which serves to prepare input and display output for pollutant loading models.

3.4 ARCVIEW INTERFACE

The hardware and software computing requirements for AnnAGNPS are moderate and reasonable. The AnnAGNPS model interface contains three components: a GIS-based tool for input data development and visualization, an Input Editor, and a stand-alone, post-processing tool. The GIS-based tool is an ArcView Interface that supports model input development (i.e., DEM, watershed delineation, soils, land use, and climate station assignment), execution, and output post-processing. The ArcView Interface provides some automation of input data preparation; however, the tool's limitations include dependence on TOPAGNPS, a submodel of TOPAZ (Topographic Parameterization), to perform the watershed delineation and parameterize the watershed cells. Unfortunately, TOPAGNPS has inherent array limitations on the DEM raster's number of rows and columns, and therefore limits the resolution of the DEM with implications for model domain size.

Overall, AnnAGNPS visualization tools are limited. Map-based visualization of output includes an overlay of modeled hydrology, sediment or nutrient yields, and loads on an annual average basis over the watershed cell map. The interface does not include time series plots, statistical summaries, or the capability to compare model results with observed data. The Input Editor, a dialog-based graphical user interface (GUI), provides a method to parameterize, edit, import, and export the main text-based input file. The Summarization Tool to Evaluate AnnAGNPS Data (STEAD) is a stand-alone, post-processing tool that exports and summarizes precipitation and modeled output (e.g., flow, sediment, nitrogen, phosphorus, and organic carbon) on a daily, monthly, or annual basis. The STEAD program does not compare modeled results with observed data.

3.5 APPLICATION HISTORY

The application history of the AnnAGNPS model consists of a moderate level of application to a range of watersheds across the United States as well as watersheds in Europe (Licciardello et al., 2007), Australia (Baginska et al., 2003), Africa (Leon et al., 2003), and China (Hong et al., 2005). For example, Parajuli et al. (2009) applied

AnnAGNPS to two small subwatersheds in the Cheney Lake watershed in south-central Kansas, and Polyakov et al. (2007) applied AnnAGNPS to a small watershed in the Hanalei River basin located on the Hawaiian Island, Kauai. As mentioned above, AnnAGNPS was applied to the Upper Auglaize River watershed as part of an effort funded by the 516(e) Program (USACE, 2005). This watershed is approximately half the size of the Blanchard River watershed. The AGNPS registered users also represent a wide range of entities, including federal governments, universities, and private consulting firms.

4. TECHNICAL APPROACH AND IMPLEMENTATION

This chapter describes the various elements of input data and model development. It also describes the strategy used for model calibration.

4.1 DATA AND MODEL DEVELOPMENT

4.1.1 Watershed Cell Delineation

One of the first steps of model development is characterization of watershed topography. The Blanchard watershed is flat; therefore a high-quality digital elevation model (DEM) is essential to accurately represent watershed subcatchment boundaries, land slope, and river reaches to support simulation of erosion. First a 10 meter DEM published by the Ohio EPA division of Emergency and Remedial Response was considered. However, given the size of the Blanchard watershed, the resolution of the 10 meter DEM exceeded the computational limit of the DEDNM module in the ArcView interface. Therefore, a coarser, 30 meter DEM was obtained from National Elevation Dataset hosted by the USGS and used to define the watershed. The source DEM was georeferenced to "NAD 1983 HARN StatePlane Ohio North FIPS 3401" projection using "D_North_American_1983_HARN" datum.

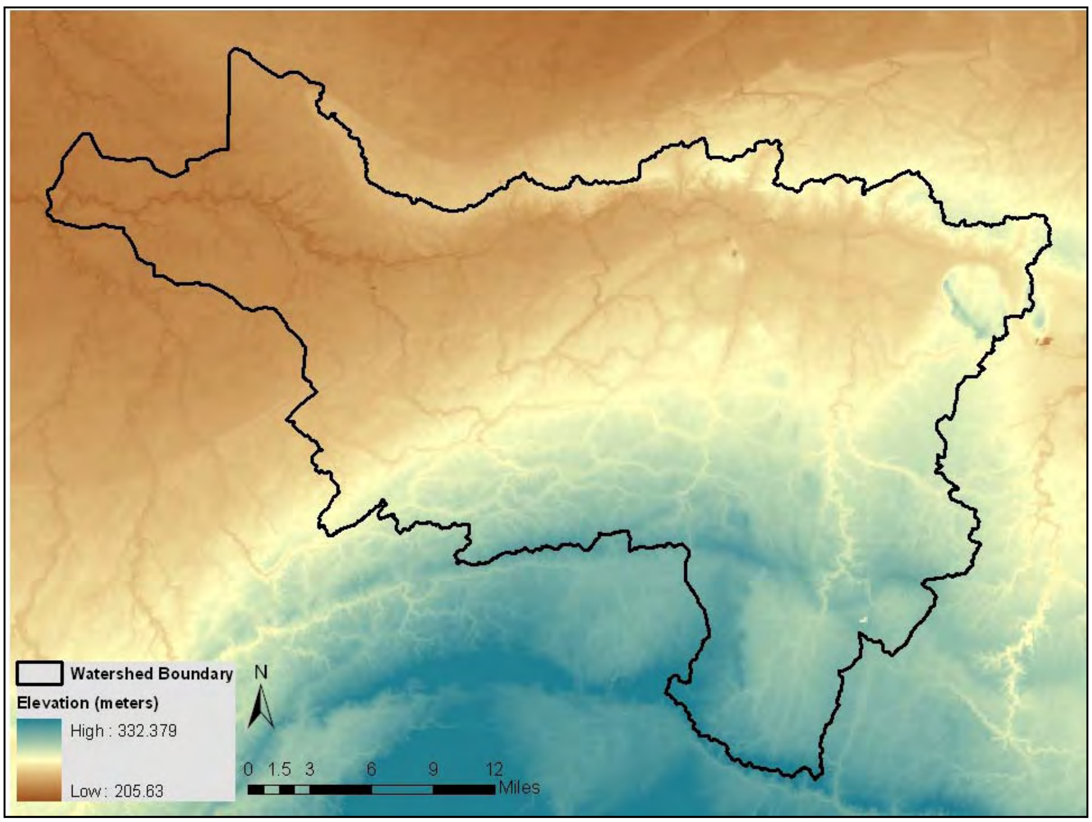

Figure 4-1. 30 m DEM used in the development of AnnAGNPS model of the Blanchard watershed

In conjunction with the DEM, a high-resolution (1:24,000 scale) stream network dataset of the Blanchard watershed was obtained from the National Hydrography

Dataset (NHD). To minimize uncertainty related to flat topography and a relatively coarse DEM, the stream network was burned into the DEM by lowering stream elevation by 0.75 m in relation to the neighboring grid cells. This method of forcing known stream topography into a DEM ensures that flow is forced through cells that correspond to the true locations of stream. The modified DEM was used as an input layer in the ArcView interface to define watershed and subwatershed (cell) boundaries.

The pre-processed DEM was input to the ArcView interface, and the TOPAGNPS module was used to perform elevation data pre-processing, hydrographic segmentation and channel network definition, and topographic parameterization. The level of resolution of the model watershed (i.e., size and number of cells) was defined by setting the critical source area (CSA) and minimum source channel length (MSCL) parameters. CSA and MSCL values of 65 and 80, respectively, resulted in a hydrographic segmentation of 3830 AnnAGNPS cells or subwatershed units. The average cell size is 52 ha (128.5 acres). The level of spatial resolution for the Blanchard River watershed is similar to the Upper Auglaize AnnAGNPS application. For example, the Upper Auglaize model had 1833 cells, with an average size of 47 ha, for a watershed that is approximately half the size of the Blanchard Watershed.

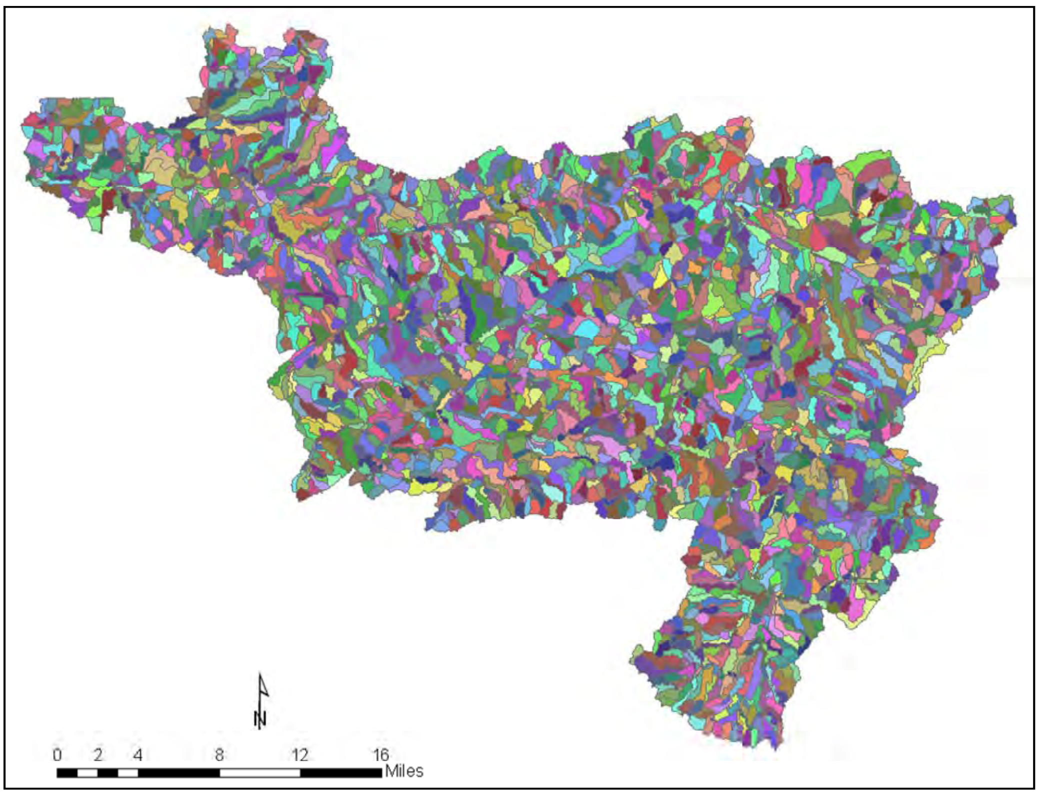

Figure 4-2. Final Blanchard Watershed AnnAGNPS model cell delineation

4.1.2 Soils Classification and Attributes

Both spatial and soil attribute datasets were obtained and processed for input to AnnAGNPS. The spatial data layer was developed from digital data available through the NRCS Soil Survey Geographic Database (SSURGO) program. All six counties in the Blanchard Watershed (Hancock, Putnam, Wyandot, Seneca, Hardin, Allen) had SSURGO data available for use in this project. The six counties were spatially merged and then clipped to the watershed delineation to reduce data volume and to include only the soils present in the watershed (Figure 4-3). A unique soil identification name was assigned to each soil type and then correlated to the soil attribute data using the unique soil identification name. The original six-county dataset contained 622 soils with unique soil identification names.

Soil attribute data from the National Soil Information System (NASIS), available for all six countries, were provided by NRCS in a text file format. The soil attribute data, which include USLE and RUSLE K-factor, field capacity, and wilting point, were incorporated and reformatted to fit the requirements of AnnAGNPS and thinned to include only the soil map units located in the watershed. The thinning process involved consolidating individual soil classifications which had the same name and/or the same attribute values but differing map unit IDs because they were located in different counties. This process eliminated differences in data attributes between counties and reduced the amount of data to be edited. Where necessary, new map unit symbols were developed. Attributes for these selected representative map units were then edited for completeness for use with AnnAGNPS.

A number of soils have dual drainage classifications as designated by the Hydrologic Soils Grouping (HSG) A, B, C or D. The designations of B/D or C/D indicate that the soils are B or C if they have subsurface drainage installed, and are D soils if they do not have subsurface drainage. AGNPS requires that a single HSG be specified in the soil attribute data input section. NRCS indicated that most soils have subsurface drainage installed in northwest Ohio, and recommended that all dual classification soils be assigned to the better drainage class (e.g., B/D would become B). Some data attributes were not populated in NASIS and needed to be developed for use with the model. These attributes included bulk density, clay ratio, silt ratio, sand ratio, K-factor, wilting point, and field capacity. NRCS was consulted regarding the missing attribute data and provided values based on best professional judgment to fill in the data gaps.

After clipping the spatial data and aggregating soils with common names and soil attributes, the spatial data layer was intersected with the AnnAGNPS watershed cell layer. A single, dominant soil was assigned to each watershed cell based on the most prominent soil type within that cell. This process yielded the representation of 179 unique soils in the model, and attribute data were developed for each of these soil types. Figure 4-3 and Table 4-1 summarize the dominant soils by percent areas within the watershed.

Figure 4-3. Map of the merged, six-county soil layer for the Blanchard watershed

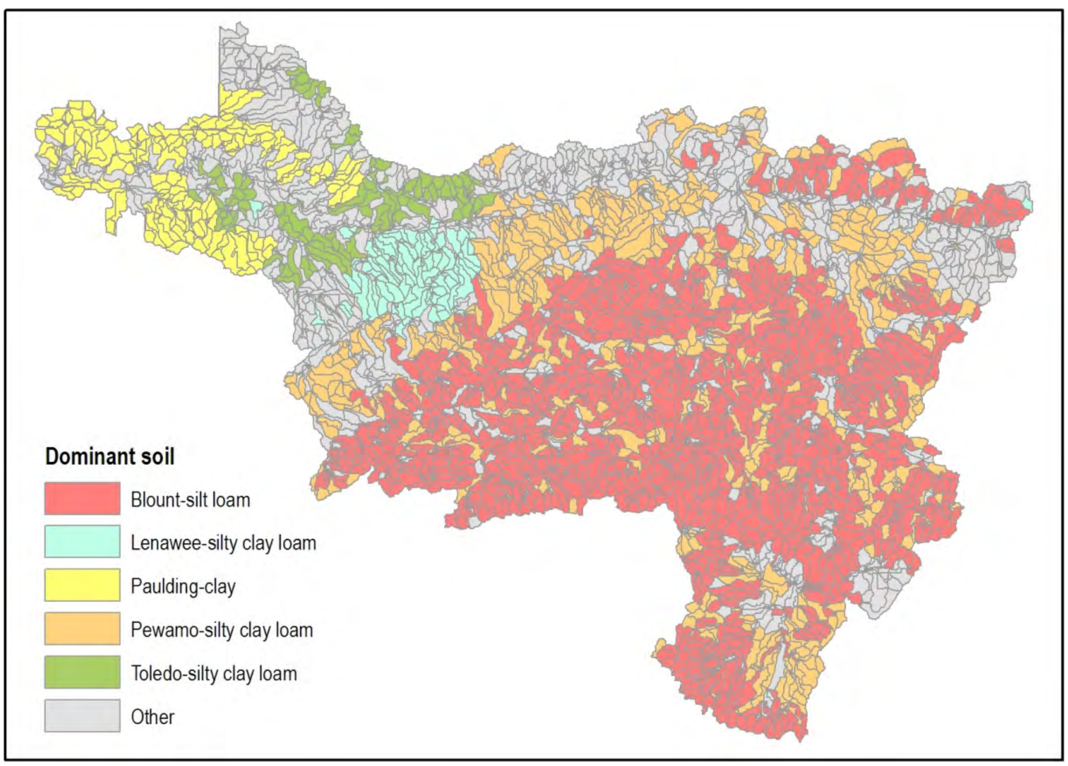

Figure 4-4. Map of dominant soils assigned to each watershed cell

Table 4-1. Summary of dominant soils by percent area of the Blanchard watershed

Soil Name	*Soil Type*	*% Area*
Blount	silt loam	41.38%
Pewamo	silty clay loam	19.83%
Paulding	clay	6.45%
Toledo	silty clay loam	3.37%
Lenawee	silty clay loam	3.33%
All Other Soils		25.65%

4.1.3 Hydraulic Geometry

Hydraulic geometry data required for AnnAGNPS include bankfull depth, bankfull width and valley width. AnnAGNPS computes each of these characteristics as a function of drainage area by means of power equations that must be developed and supplied by the user.

Ideally, data used to develop hydraulic geometry power equations should represent channels that have not undergone hydromodification and cover a reasonable spatial domain within the watershed. Power equations for the Blanchard River watershed were determined with cross-section data from both the Blanchard and Upper Auglaize watersheds. Although the USGS has surveyed select cross-sections in the Blanchard River and its tributaries, most of the cross-sections were surveyed upstream of the Findlay stream gage, and many were surveyed near bridge openings and developments (making them not ideal for this analysis). A total of eight Blanchard watershed cross-sections were selected that represented undisturbed channels. Each cross-sectional profile was analyzed to determine bankfull depth (hydraulic depth at bankfull) and bankfull width (width at top of bank). The location of each cross-section and its upstream drainage area were determined using GIS. A GIS shapefile of the 100-year recurrence flood plain, developed by Federal Emergency Management Agency (FEMA), was used to estimate valley width. As a supplement to the sparse Blanchard River watershed data, channel survey data for 16 cross-sections obtained from the neighboring Upper Auglaize watershed were also used to develop power equations for application in AnnAGNPS model.

Data for each cross-section were then plotted to determine the parameters of the bankfull depth and width and valley width equations. Log-transformed drainage areas were regressed with log-transformed bankfull depths and widths and valley widths (Figure 4-5). The following equations relating drainage area to width at bankfull, depth at bankfull, and valley width were input to AnnAGNPS:

$$W_b = 22.86\ A^{0.44}$$

$$D_b = 2.60\ A^{0.144}$$

$$W_v = 125.74\ A^{0.4147}$$

Where:

A = drainage area, in square miles
W_b = width at bankfull, in feet
D_b = depth at bankfull, in feet
W_v = valley width, in feet

These equations are similar to those used for the Upper Auglaize River watershed (USACE, 2005).

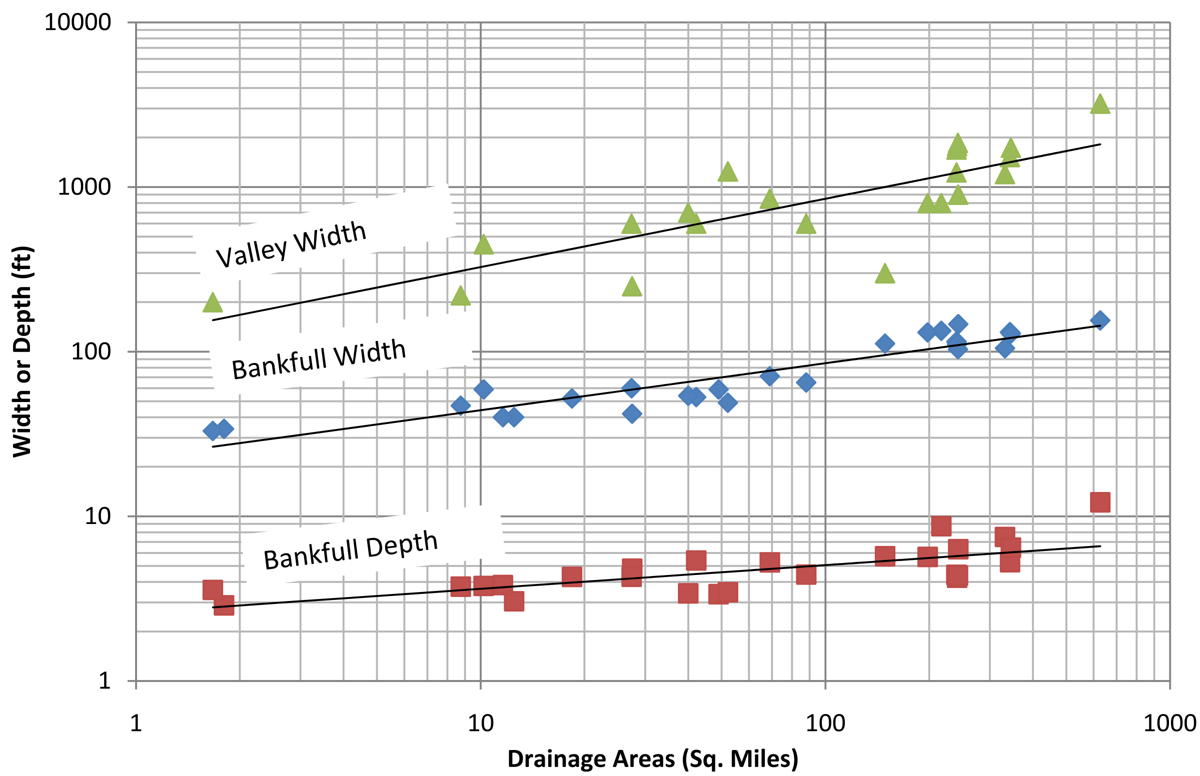

Figure 4-5. Regression of hydraulic geometry characteristics vs. drainage area

4.1.4 Land Use / Land Cover and Tillage Data

Input data used to characterize agricultural and non-agricultural land use and land cover within AnnAGNPS are complex. As an overview, the model used spatial data representing a four-year rotation of crops and associated tillage for all regions identified as "cropland." All other "non-cropland" land uses were defined as static, and did not vary during the four-year rotation. The following three sections describe the acquisition and processing of these datasets for the Blanchard River watershed.

4.1.4.a Land use and land cover

Landuse/landcover datasets were generated for 2005, 2006, 2007, and 2008 by the University of Toledo using a series of remote-sensing processing steps in the ERDAS IMAGINE software package. The raw LANDSAT images were georectified and mosaiced to form a single image that encompassed the Blanchard Watershed. Within ERDAS, training classes were developed to represent the various landcover classes based on pixel coloration values. A supervised classification was run with a maximum likelihood classification to develop landcover classes for the entire watershed. The data were in raster format and included roughly 16 discrete classifications.

For use in AnnAGNPS, the classifications were simplified by LimnoTech. Each original dataset was clipped to the Blanchard watershed extent, and data were reclassified to be consistent with one of the eight classes including four static landcover classes (commercial, residential, water, and forest) and four non-static rotating crop classes (corn, fallow [alfalfa hay], soybeans, and wheat) (Table 4-2).

Table 4-2. Original and simplified land use / land cover classifications

2007 Original Landcover Data Classes	*Final Landcover Data Classes*
Hi-Intensity Urban Bare Land	Commercial
Mid-Intensity Urban Lo-Intensity Urban Open Developed	Residential
Water	Water
Forest Wetland Scrub	Forest
Corn	Corn
Hay	Fallow
Soybeans	Soybean
Wheat	Wheat
Unclassified	Unclassified

Data for some years included unclassified areas which typically corresponded with commercial, residential, or roads areas. These regions were identified and assigned an appropriate classification. Data gaps for missing roads data were filled with a road line data layer obtained from the Bureau of Transportation Services (BTS), which was buffered at 3.7 meters to create a polygon representing average road width. Additional gaps for commercial and residential areas present in the 2005-2007 datasets were filled with the more complete 2008 data.

The final land use classes used in the model, and the proportion of area of each category are shown in Table 4-3. The interim product at this point in model set-up was four discrete spatial land use / land cover data layers for the years 2005, 2006, 2007, and 2008. Section 4.1.5 below describes how these data were transformed for input to AnnAGNPS.

Table 4-3. Land use categories, the area and the percent areas of each category represented in AnnAGNPS

	Modeled in AnnAGNPS	
Landuse	***Area (acres)***	***% Area***
Commercial	4,132	0.8%
Crop	401,797	81.5%
Forest	38,734	7.9%
Residential	44,987	9.1%
Roads	110	0.02%
Water	3,277	0.7%
Grand Total	493,037	100%

4.1.4.b Tillage development

For each cropland area and year in the rotation, the model requires a corresponding tillage operation. Spatial tillage data based on remote sensing imagery were obtained from the University of Toledo for 2006, 2007 and 2008. The raw LANDSAT images were georectified and mosaiced to form a single image that encompassed the Blanchard Watershed. Within ERDAS, training classes were developed to represent the various tillage classes based on pixel coloration values. Validation was performed on the classification using transect data for the tillage classes from the USDA transect observation. The three predominant tillage types practiced in the watershed include no till (NT), mulch till (MT), and traditional till (TT). For all the years available, there were “unclassified” categories where tillage data were not available. To address the missing data, a breakdown of tillage practices for each crop type was summarized for each year with available data. Unclassifiied tillage areas were assigned to the dominant tillage type for each crop type.

Remotely sensed tillage data were not available for 2005; therefore, it was necessary to develop an estimated spatial tillage layer to correspond with the 2005 cropland data layer. An attempt was made to identify any apparent tillage patterns using spatial analysis of tillage and land cover data for 2006, 2007, and 2008 data; however, no apparent patterns emerged.

Each year NRCS collects county transect data at approximately 400 points within the watershed over predetermined routes. The transect data include a survey of crop and tillage at each point. These data were obtained from the NRCS for the years 2006 – 2009 and compared with a summary of remotely sensed data for the corresponding years. Although the data sets did not directly correspond, each provided a similar range of tillage practices for each crop. Tillage information for 2005 was derived as an average of 2006 – 2009 NRCS transect summary data for corn, wheat and soybean crops. Spatially derived tillage practices corresponding to fallow for the years 2006 – 2008 were used for 2005. Because the transect data summaries did not provide spatial referencing, the estimated 2005 tillage layer was randomly applied throughout the watershed based on crop type. A summary of the final tillage layer corresponding to each crop type for 2005 – 2008 is shown in Table 4-4. The interim product at this point in model set-up was four discrete spatial tillage data layers for the years 2005, 2006, 2007, and 2008. Section 4.1.5 below describes how these data were transformed for input to AnnAGNPS.

Table 4-4. Breakdown of final tillage categories used in AnnAGNPS corresponding to different crop type and rotation years

Crop	*Tillage*	*2005*	*2006*	*2007*	*2008*
Corn	NT	11%	42%	20%	9%
	MT	1%	14%	31%	26%
	TT	88%	44%	49%	66%
Soybean	NT	54%	58%	46%	34%
	MT	6%	17%	33%	22%
	TT	40%	25%	21%	43%
Wheat	NT	50%	97%	84%	48%
	MT	21%	3%	10%	19%
	TT	29%	0.11%	6%	33%
Fallow	NT	82%	94%	82%	69%
	MT	9%	5%	11%	13%
	NT	9%	2%	8%	18%

4.1.5 Crop Management Schedules

To evaluate crop management in the Blanchard River watershed, AnnAGNPS required a management schedule for each watershed cell to describe crop rotations, tillage operations, different methods of crop establishment and management, and fertilizer application. As described in Section 4.1.4 above, the crops represented in the model include corn, alfalfa hay (fallow), soybean, and wheat, and the tillage operations represented in the model include no-till, mulch till, and conventional till. The various crop/tillage combinations represented in the model are listed in Table 4-5 below.

Table 4-5. Combinations of crops and tillage operations represented in the Blanchard River Watershed AnnAGNPS model

Crop/Tillage ID	*Crop/Tillage Description*
CM	Corn-Mulch Till
CN	Corn-No Till
CT	Corn-Traditional Till
FM	Fallow-Mulch Till
FN	Fallow-No Till
FT	Fallow-Traditional Till
SM	Soybean-Mulch Till
SN	Soybean-No Till
ST	Soybean-Traditional Till
WM	Wheat-Mulch Till
WN	Wheat-No Till
WT	Wheat-Traditional Till

After the landcover and tillage data processing was completed, four land use layers and four tillage layers for the years 2005 to 2008 were used to generate a single a four-year rotating landcover/tillage dataset for input to AnnAGNPS. This dataset was created using the Spatial Analyst extension for ArcGIS. Each land use and tillage class was assigned a unique numeric code (with text identifiers), and a combined crop and tillage sequence corresponding to each of the four years (2005 – 2008) was assigned to each cropland cell.

This final spatial layer was intersected with AnnAGNPS watershed cells to assign a dominant crop rotation and tillage sequence for each cell. Each unique sequence of a 4-year crop and tillage rotation represents a unique management schedule. For example, a management schedule for a four-year rotation and tillage sequence of no-till soybean and conventionally tilled corn (SNCTSNCT) consists of soybean no-till in year one, corn conventional till in year two, soybean no-till in year three, and corn conventional till in year four.

Initially, the data input process resulted in 779 individual management schedules for the Blanchard River watershed. An effort was made to reduce the number of unique management schedules for more efficient model set-up and execution. Crop rotations/tillage sequences that represented only a small number of cells were reassigned to an ID corresponding to a dominant or frequently occurring crop rotation/tillage sequence. For example, if the management schedule ID SNCTSMCT was assigned to only a few cell or fields, it was reassigned to a management schedule identity that was similar and had more occurrences, such as SNCTSNCT. In addition, some unrealistic crop/tillage sequences were also reassigned to a more realistic crop/tillage sequence. For example, FNFTFNFT would have been reassigned as FNFNFNFN. Using this reassignment approach, the number of unique management schedule ID's were reduced from 779 to 414. Management schedules were then developed for the 414 unique management schedule identities and input to the model. Table 4-6 provides a summary of the most common crop/tillage rotations derived for the AnnAGPNS modeling.

Table 4-6. Dominant crop rotation/tillage sequences by area represented in the Blanchard River Watershed model

Field ID	*Total Area (acres)*
CTCNWNCT	16,460
SNCTSNCT	11,572
CTSNCTSN	8,942
FNFNFNFN	8,637
CTCNCTSN	8,296
CTSNWNCT	7,623
CTCNWNCM	7,054
Other	333,186
Total Crop Area	*401,770*

In addition to the spatially defined aspect of the management schedule (i.e., crop and tillage), other elements of the management schedule were input manually. These data included planting time, harvest time, fertilizer application, tile drains operations , and a curve number that represents the condition of the field based on the type of crop and the type of tillage. Tile drains were assumed to be installed in every crop field in the Blanchard watershed at an invert depth of 36 inches and a drain rate of 0.375 inch/day. Information to support this aspect of each management schedule was derived from files developed for the Upper Auglaize watershed application as well as personal communication with NRCS (Stafford, 2010). Section 4.1.8 describes fertilizer application in greater detail.

Table 4-7 shows a sample management schedule for a four-year rotation of soybean and corn with both no-till and conventional till operations.

Table 4-7. Example management schedule for AnnAGNPS

Schedule Name	*Event Date (Month)*	*Event Date (Day)*	*Event Date (Rotation Year)*	*Event New Crop ID*	*Event Fertilizer Application ID*	*Management Operation ID*	*Tile Drain Controlled Status*	*Tile Drain Control Depth (inches)*
Soybean-No Till	11	1	1			No Operation	On	36
Soybean-No Till	5	10	2	Plant Soybean	Phosphorus Application	Drill Soybeans, No- Till	On	36
Soybean-No Till	10	10	2			Harvest	On	36
Corn-Traditional Till	11	1	2			Moldboard Plowing	On	36
Corn-Traditional Till	5	1	3			Tandem Disk Harrow	On	36
Corn-Traditional Till	5	5	3			Tandem Disk Harrow	On	36
Corn-Traditional Till	5	7	3		Manure Application	Manure Application Injection	On	36
Corn-Traditional Till	5	10	3	Plant Corn	Phosphorus Application	Double Disk Corn	On	36
Corn-Traditional Till	6	10	3		Nitrogen Sidedress Application	Anhydrous Fertilizer Application	On	36
Corn-Traditional Till	10	20	3			Harvest	On	36
Soybean-No Till	11	1	3			No Operation	On	36
Soybean-No Till	5	10	4	Plant Soybean	Phosphorus Application	Drill Soybeans, No- Till	On	36
Soybean-No Till	10	10	4			Harvest	On	36
Corn-Traditional Till	11	1	4			Moldboard Plowing	On	36
Corn-Traditional Till	5	1	5			Tandem Disk Harrow	On	36
Corn-Traditional Till	5	5	5			Tandem Disk Harrow	On	36
Corn-Traditional Till	5	7	5		Manure Application	Manure Application Injection	On	36
Corn-Traditional Till	5	10	5	Plant Corn	Phosphorus Application	Double Disk Corn	On	36
Corn-Traditional Till	6	10	5		Nitrogen Sidedress Application	Anhydrous Fertilizer Application	On	36
Corn-Traditional Till	10	20	5			Harvest	On	36

4.1.6 Climate

Daily precipitation, minimum and maximum air temperature, dew point temperature, sky cover, wind speed, and wind direction data are required by the AnnAGNPS model to perform continuous simulations. Climate data used with AnnAGNPS can be historical, synthetically generated, or a combination of the two. For this project, historical climate data were obtained from the National Climatic Data Center (NCDC) for six climate stations for the period between 1995 and 2009 (see Table 4-8, and Figure 2-1). Climate data for 1995 through 2006 were downloaded from BASINS (Better Assessment Science Integrating Point and Nonpoint Sources), which is a USEPA-sponsored multipurpose environmental watershed analysis system that provides continuous time series of preprocessed NCDC data for precipitation, air temperature, wind speed, solar radiation, potential evapotranspiration, dew point, and cloud cover (USEPA, 2008). Data for 2007 through 2009 were downloaded directly from NCDC and required additional preprocessing to fill in gaps. Missing data for short periods of time (1-7 days) were filled using interpolation between two valid points. All other missing data were filled using data from nearby climate stations. It should be noted that the Bellefontaine climate station is outside the Blanchard watershed; however, data from this station were used to fill in data gaps for the Kenton climate station, given the proximity to Kenton.

Table 4-8. Blanchard River Watershed climate stations used in AnnAGNPS

Station Name	*COOP ID*	*Latitude*	*Longitude*
Findlay FAA Airport	332786	41.0136	-83.6686
Findlay WPCC	332791	41.0461	-83.6622
Kenton	334189	40.6489	-83.6061
Lima WWTP	334551	40.7247	-84.1294
Pandora	336405	40.9542	-83.9617
Bellefontaine	330563	40.3500	-83.7667

Key climate parameters (e.g., daily precipitation, minimum and maximum air temperature) were available from all six climate stations. Each watershed cell was assigned a climate station (and corresponding precipitation and temperature data) based on the Thiessen Polygon Method. This method divides a watershed into polygons with a climate station centered in each polygon, and assigns a corresponding station to each watershed cell within that polygon.

Other climate input parameters required by AnnAGNPS (e.g., dew point temperature, sky cover, wind speed, and wind direction) were not measured at every NCDC climate station. Therefore, data collected at the Findlay Airport climate station for these parameters were assigned to each cell within the watershed.

4.1.7 Ephemeral Gullies

AnnAGNPS simulates erosion from both sheet and rill, and ephemeral gully sources. Ephemeral gullies are erosional features, typically larger than rills, that form due to concentrated flow. Ephemeral gullies may be erased by normal tillage practices, but once formed they tend to reform in the same location from year to year. As determined for the adjacent Upper Auglaize watershed (USACE, 2005), it is likely that the Blanchard River watershed experiences notable sediment erosion generated from ephemeral gullies in the watershed. An automated gully erosion tool available within the AnnAGNPS Arcview interface was used to identify potential ephemeral gully locations within the watershed, and the tillage induced ephemeral gully erosion model (TI-EGEM) within AnnAGNPS was used to calculate ephemeral gully erosion.

Potential ephemeral gully (PEG) sites in the watershed were mapped within the AnnAGNPS-ArcView interface. The PEG tool used the 30 meter DEM to generate a Compound Topographic Index (CTIndex or CTI) for each pixel of the grid. The CTI is a function of upstream contributing area and slope of the landscape area, and represents the tendency of a land area to accumulation of water in this place. Once the CTI values were generated, the PEG tool applied a user-specified CTI threshold value to identify potential gully sites at locations where the threshold levels are exceeded. Only croplands were considered for gully erosion. Figure 4-6 shows a map of 140 PEG sites mapped for the Blanchard River watershed.

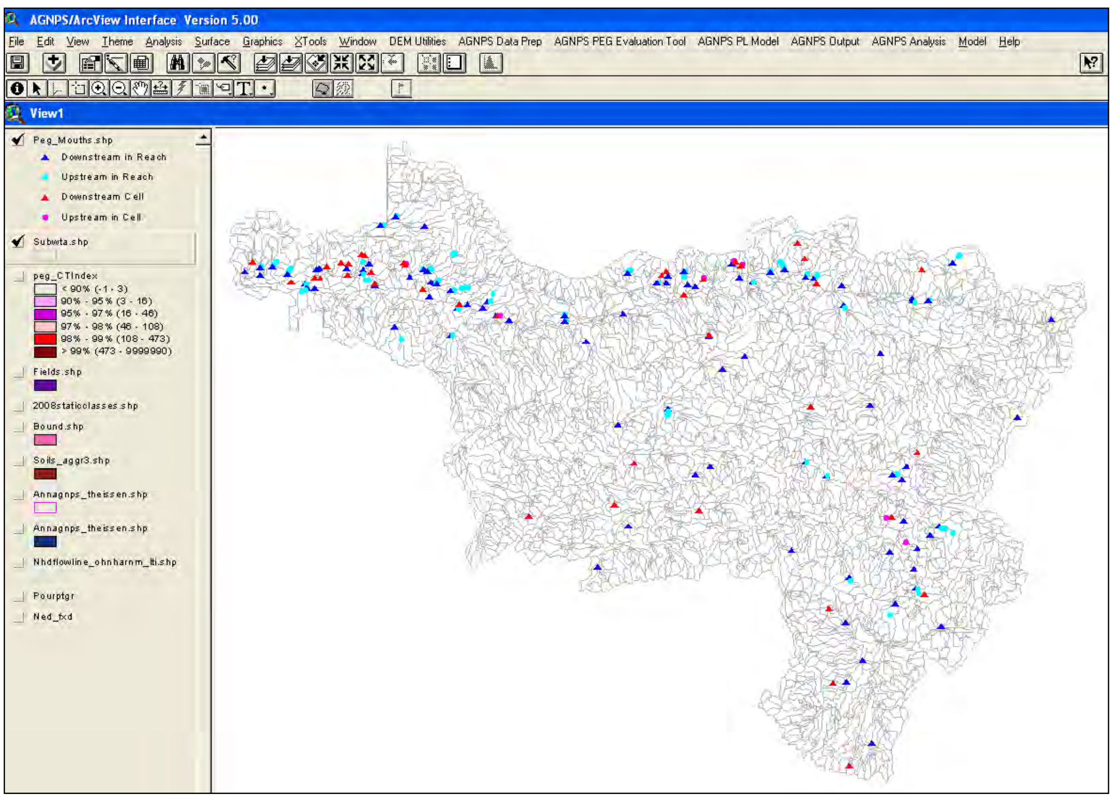

Figure 4-6. Potential ephemeral gully sites mapped for the Blanchard Watershed using a 30 m DEM and CTIndex value of 99.69%

Following mapping of PEG mouth locations, the PEG tool extracted information required to simulate erosion such as contributing area, slope, and the type of land use and soil. This information was then imported into AnnAGNPS, and the model employed the tillage induced ephemeral gully erosion model (TI-EGEM), an enhanced version of EGEM, to estimate sediment production from ephemeral gullies (Gordon et al., 2007; Gordon et al., 2008).

The gully erosion process in AnnAGNPS, as described in Gordon et al., 2008, can be conceptualized as follows. For a given runoff event, a hydrograph is constructed at the mouth or outlet of the cell. The flow rate at a given location within the cell is proportional to the upstream drainage area, depending on the length of the gully. Once the flow rate at the mouth of the cell exceeds the erosion threshold level of the soil, incision is initiated in the form of a headcut. This headcut will first incise down to the tillage depth, an erosion-resistant layer, and then the headcut migrates upstream at a rate proportional to the concentrated flow rate. Erosion processes cease at any given location once the local flow rate drops below the threshold for soil erosion via headcut migration or expansion of the gully width. Following the runoff event, the cell may be re-tilled, thus obliterating the developed gully and reactivating the initial erosion process at the cell outlet. If the tillage does not occur, the physical characteristics of the existing gully are carried forward in time, until another runoff event occurs, which may or may not modify the gully.

The detachment capacity of the flow, *DC,* is defined as:

$$DC = k_d(\tau - \tau_c)$$

where k_d is the soils erodibility coefficient, τ is the boundary shear stress, and τ_c is the critical sheer stress for the soil. It is used to calculate the depth of erosion (*DE*) as:

$$DE = t\frac{DC}{\delta_s}$$

where *t* is the timestep, and δs is the soil bulk density.

For each timestep, there are three possible sources of sediment available for transport within a gully section: 1) incoming sediment from upstream sections; 2) internal sediment due to headcut migration and/or channel widening within a gully section; and 3) previously deposited sediment that resides on the bed within the gully section. Sediment flux leaving a gully section, *C,* is calculated with the following general equation (units = *Mg*):

$$C = C_u + \Delta w\ \Delta L\ S_D\ \delta_s\ P_x\ \pm wLD_d\delta_d\frac{P_x}{n}$$

where C_u is the sediment flux from upstream; Δw and ΔL refer to the changes in gully width and length during the time step; S_D and δ_s refer to the scour depth and soil bulk density; P_x is the proportion by mass of each particle size class; *w* and *L* are the width and length of the gully; D_d and δ_d are the thickness and bulk density of the sediment deposit in a gully section, respectively; and *n* is the number of time steps during which headcut migration is occurring.

The following input model parameters / assumptions were used to simulate ephemeral gully erosion:

- Manning's *n* for concentrated flow within the gully was set to the default value of 0.04;

- The *Nachtergaele* algorithm was chosen so that model would internally calculate gully width, w, as a function of discharge;
- Scour depth, S_D, was assumed to be equal to the tillage depth of 20 cm;
- The soil critical shear stress, $\tau_{c,}$ was internally calculated by the model;
- The headcut migration erodibility coefficient, $k_{d,}$ was internally calculated by the model; and
- A sediment delivery ratio of 0.4 was assumed, which is the ratio of gully's yield at its mouth to its yield at its receiving stream.

4.1.8 Feedlots, Manure, and Fertilizer Application

Nutrient application in the watershed can be a result of confined feedlot sources, manure deposition in pasture areas, or manure and/or chemical fertilizer application in cropland areas.

The dominant type of livestock in the watershed are pigs, and most are raised in a confinement operation or feedlot rather than in a grazing and pasturing system (NRCS, 2008). There are an estimated 148 confined livestock operations that do not have discharge permits, and only three confined livestock operations that do have discharge permits. Efforts were made to obtain both basic and detailed information on feedlot operations in the Blanchard River Watershed. A list of basic data needs required by the model was compiled and sent to local agricultural extension agencies including the Ohio USDA. However, feedlot data for the watershed are virtually non-existent, and consequently were not explicitly included in the model. NRCS suggested that the key source of manure nutrient application in the watershed is via manure application to cropland rather than confined point sources, which have likely been addressed (Davis, 2009).

Sufficient data were available to incorporate the quantity of manure generated by livestock in the watershed into the model. Estimates of total annual manure production in the watershed, including nutrient availability of N and P from the manure, are provided in the Blanchard River Watershed Rapid Assessment Report (NRCS, 2008). Almost all of the manure generated in the watershed is utilized to supply nutrients for crop production. To account for the manure generated and applied within the watershed, every acre of conventional-till corn was assumed to first receive N and P available through manure application. The remainder of the crop nutrient requirements for conventionally tilled corn as well as other crops (soybean, alfalfa, wheat) and tillage systems were met through the application of commercial fertilizer.

Model inputs of fertilizer application were based on the information available from the previous AnnAGNPS model application to the Upper Auglaize watershed. Because farming practices are similar among the watersheds, it was assumed that the fertilizer application rates and timing specified in the Upper Auglaize would also apply to the Blanchard River watershed. Table 4-9 provides a summary of the fertilizer applications specified in the Blanchard River Watershed AnnAGNPS model. Several key assumptions are as follows:

- Conventionally tilled corn was assumed to have a pre-plant application of manure, followed by a nitrogen and phosphorus application at planting, then a sidedress nitrogen application just prior to the rapid growth period;
- Mulch till and no-till corn were assumed to have a nitrogen and phosphorus application at planting, then a sidedress nitrogen application just prior to the rapid growth period;
- For soybeans, a phosphorus application was specified at planting for all tillage systems. Soybeans are able to fix atmospheric nitrogen (convert atmospheric N_2 to a biologically available form called ammonia (NH_3)) and do not generally require additional nitrogen fertilizer applications;
- Wheat was assumed to have a nitrogen and phosphorus application at planting, then a sidedress nitrogen application just before substantial growth occurs; and
- For alfalfa, a phosphorus application was specified at planting for all tillage systems. Alfalfa is also able to fix atmospheric nitrogen, and it was assumed that no additional fertilizer applications would be required. If an alfalfa field was allowed to senescence and regrow a second or third year, it was assumed that a phosphorus application would occur early in the growing season. The timing of fertilizer applications for alfalfa varied based on whether the alfalfa was a summer or spring alfalfa, and the type of crop and tillage system preceding the alfalfa planting.

Table 4-9. Summary of fertilizer applications specified in the management schedules developed for the Blanchard River Watershed

Crop	*Description*	*Fertilizer Type*	*Time Applied*	*Nitrogen (lbs/acre)*	*P_2O_5 (lbs/acre)*
Corn	Preplant nitrogen and phosphorus application	Manure	May 7	40	30
Corn	Preplant phosphorus application	Commercial	May 10	0	15
Corn	Nitrogen and phosphorus application at planting	Commercial	May 10	40	50
Corn	Sidedress nitrogen application	Commercial	June 10	180	0
Soybeans	Phosphorus application at planting	Commercial	May 10	0	30
Wheat	Nitrogen and phosphorus application at planting	Commercial	October 13	20	51
Wheat	Sidedress nitrogen application	Commercial	March 10	60	0
Alfalfa	Phosphorus application at planting for summer alfalfa.	Commercial	August 1 or August 25	0	65
Alfalfa	Phosphorus application at planting or initial regrowth.	Commercial	April 15, May 1 or May 3	0	65

4.1.9 Point Sources

AnnAGNPS provides the option to input point source contributions of flow, nitrogen, phosphorus, and organic carbon, but not point source contributions of solids. Point source input data are limited to constant loading rates for discharge flow and nutrients for entire simulation period. An initial search based on information provided in the Blanchard River Watershed TMDL helped identify the largest dischargers (OEPA, 2009). Flow and nutrient data for the 18 largest dischargers were downloaded from the USEPA Envirofacts Permit Compliance System (EPA PCS) database for 1995-2009. Based on a data inventory, only 13 of the 18 dischargers contained sufficient information to estimate representative inputs to the model. For each of the 13 dischargers, an average flow, total nitrogen (TN) and total phosphorus (TP) concentration were calculated for each year reported and for the entire period 1995-2009. The data for each discharger were evaluated to determine if there were trends in the flow or nutrient concentrations discharged. Any outliers were removed from the dataset. An average, representative concentration for the 1995 to 2009 time period was selected and input to the model (Table 4-10).

Table 4-10. Summary of the point source input values

Facility	*NPDES Permit No.*	*Cell ID for Point Source Input*	*Flow (cfs)*	*Total Nitrogen (mg/L)*	*Total Phosphorus (mg/L)*
Arlington WWTP	OH0053171	8623	0.31	5.07	2.37
Beaverdam WWTP	OH0021318	13632	1.55	0.35	1.71
Findlay WWTP	OH0025135	2672	16.7	7.18	0.58
Dunkirk WWTP	OH0048321	7102	0.62	0.35	0.79
Forest WWTP 1	OH0025151	5601	0.05	0.86	1.44
Forest WWTP 2	OH0025151	5602	0.17	1.45	1.46
Ottawa WWTP	OH0026921	1332	2.2	4.36	0
Pandora WWTP	OH0021148	1282	0.34	3.73	0
Putnam Stone	OH0038482	12132	0.27	0	0.07
Rawson WWTP	OH0047791	10411	1.27	0.02	0.94
Shelly Materials	OH0003603	5861	0.7	0	0.03
Vanlue WWTP	OH0020397	4082	0.2	0.43	0
Bluffton WWTP	OH0020851	12302	1.36	13.95	2.17

4.2 DEVELOPMENT AND INTEGRATION OF WINMODEL FRAMEWORK

To assist with model development and calibration, an effort was made to interface AnnAGNPS with *WinModel*, a model management tool developed by LimnoTech (Redder, 2008). *WinModel* provides an integrated collection of model processing, visualization, and linkage tools. It is programmed in Visual Basic 6, and has been interfaced with multiple surface water and watershed modeling packages (e.g., EFDC, BLTM, HSPF, WARMF, WASP5, FEQ, RCA, ECOMSED, SWMM). Visualization capabilities available for all supported models include spatial and temporal profiles, model-data comparisons, cumulative frequency distributions, one-to-one plots, and map-based visualization. *WinModel* also provides flexible options for comparing model results with site-specific water quality standards. The *WinModel* toolbox has undergone rigorous testing, is being further developed to interface with additional models, and is being enhanced to include new visualization features. *WinModel* significantly improves model development, calibration, and application efficiency, and the toolbox serves a valuable role as a communication and education tool for client and stakeholder groups.

The integration of AnnAGNPS into the *WinModel* framework focused on providing options for efficient output post-processing and visualization (not pre-processing tasks). These features include spatial and temporal plotting and mapping, efficient evaluation of model and data, multiple scenario comparison, and time aggregation capabilities (daily to monthly, monthly to annual). The AnnAGNPS source code was modified to output key parameters in a binary format, and a utility was developed to transfer binary output to *WinModel*. Model output and observed streamflow and water quality data were added to a standard *WinModel* project database. Testing was performed to ensure that results were correctly transferred from AnnAGNPS to the *WinModel* interface for visualization.

5. MODEL CALIBRATION AND CONFIRMATION

This chapter presents results of the AnnAGNPS model application to the Blanchard River watershed. First, the calibration strategy is presented. Then, calibration and confirmation results are shown for flow, suspended sediment, and nutrients. Finally, discussions are presented regarding model diagnostics and comparisons of AnnAGNPS output with other watershed modeling efforts in the region.

5.1 CALIBRATION STRATEGY

Model calibration involves the process of comparing model predictions for state variables of interest to site-specific measurements and iteratively adjusting model parameters (e.g., model coefficients, initial soil conditions) to achieve an acceptable fit between predicted and observed values. The process of model calibration is important not only in terms of optimizing the model fit to available field data, but also in terms of developing a better conceptual understanding of how the physical system behaves and responds under different environmental conditions. A successful model calibration/confirmation provides confidence to the managers in the model's ability to predict the system response to various management actions.

Because of a lack of observed flow and water quality data, the application of AnnAGNPS to the Upper Auglaize watershed did not involve calibration (USACE, 2005). The model developers of AnnAGNPS state that this model is typically not applied to gaged watersheds where calibration would be possible (Bingner and Theurer, 2002). Baginska et al. (2003) noted that although AnnAGNPS can be applied in data-poor watersheds, the need for calibration should be recognized to help understand model output uncertainty and expose the importance of model parameterization.

Given the availability of flow and water quality data for the Blanchard River watershed, a model calibration and confirmation was conducted in a logical order and included several steps. The goal of the effort was to improve model performance to the extent possible, given data and model limitations.

5.1.1 Model Performance in Uncalibrated Mode

AnnAGNPS was first set up and run in an uncalibrated mode. Model performance was assessed relative to observed conditions. A sensitivity analysis was conducted to identify which model parameters should receive the most attention during calibration.

5.1.2 Calibration Time Period

A calibration time period (2002-2009) was selected based on best available data for system forcing functions (e.g., meteorology, land use) and observed flow and water quality. As described in Section 2.2, the majority of data available for calibration were collected at Findlay, OH, which is a watershed point representative of the upper ~45% of the watershed. Because the most comprehensive water quality data were available for 2007 to 2009, the water quality calibration focused on this time period.

5.1.3 Calibration Sequence and Process

The calibration process followed a logical order according to model parameters (or coefficients) which depend on each other and also account for the most sensitive model parameters. Hydrology calibration was conducted first, and model performance was evaluated at different timescales (e.g., annual, seasonal, monthly, daily basis). Then suspended sediment was calibrated in terms of concentration and loads (annual, seasonal, and monthly). Finally, the model was calibrated for nitrogen and phosphorus species, considering both instream concentrations and loads (annual and monthly).

During calibration, model predictions were compared with site-specific measurements, and the goodness of fit was evaluated using both visual and statistical techniques. Next, a set of model parameters were adjusted within an acceptable range using best professional judgment. The set of potential model parameters to adjust were based on both a sensitivity analysis intended to identify which parameters have the greatest influence on model output, and a review of calibration parameters adjusted during previous applications of AnnANGPS. The model was re-run, and results were reviewed to determine if the calibration had improved. The process continued until it was determined that the best possible calibration had been reached, given available data and model limitations. Though calibration progressed in three major phases (i.e., hydrology, sediment, nutrients), some iteration did occur. For example, during calibration of sediment and/or nutrients, it was necessary to go back and make small adjustments to the hydrology calibration.

5.1.4 Statistical Metrics and Sensitivity Analysis

The general metrics for calibration/confirmation included visual and statistical (e.g., coefficient of determination [R^2] and the Nash-Sutcliffe model efficiency coefficient [*NSE*]) comparison of simulated and observed data. The following equations were used to compute these model efficiency criteria:

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right)^2$$

and

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

where *O* = observed values and *P* = predicted values. Table 5-1 presents a range of model efficiency classifications for AnnAGNPS based on monthly simulated and observed values. A general target of model calibration/confirmation for AnnAGNPS modeling of the Blanchard River watershed was calculated R^2 and *NSE* values greater than 0.75.

Table 5-1. Model efficiency classification for AnnAGNPS calibration (adapted from Parajuli et al., 2009)

Class	*R2, NSE for flow, sediment, total phosphorus*
Excellent	> 0.9
Very good	0.75 – 0.89
Good	0.50 – 0.74
Fair	0.25 – 0.49
Poor	0.00 – 0.24
Unsatisfactory	< 0.00

5.1.5 Model Confirmation

After model calibration, a model confirmation was performed by running the model without changing any model parameters for a second time period. The model confirmation time period (1995 – 2001) provides adequate data sets for forcing functions and observed conditions. Forcing functions specific to the confirmation period were used for this additional model evaluation.

5.2 CALIBRATION AND CONFIRMATION RESULTS

5.2.1 Direct Runoff

AnnAGNPS models total runoff as the aggregation of direct runoff, direct subsurface drainage flow (from tile drains), and subsurface lateral flow. AnnAGNPS does not calculate a groundwater (baseflow) that would be considered a slow return flow to a neighboring stream (Yuan et al., 2006).

The hydrology component of AnnAGNPS was calibrated by adjusting the curve number (CN), which is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The initial curve numbers input to the model were based on the Upper Auglaize model application. During calibration, the curve numbers were adjusted consistently across all hydrologic soil groups and cover types. The initial runoff simulated was too high; therefore, curve numbers were decreased from the initial curve number inputs through several iterations to increase infiltration and achieve a satisfactory hydrology calibration. The final calibrated curve numbers in the Blanchard River watershed model are summarized in Table 5-2 below.

Table 5-2. Summary of curve numbers by land use in the calibrated Blanchard River Watershed model

Land Use	*Curve Number ID*	*HSG A*	*HSG B*	*HSG C*	*HSG D*
Commercial	Urban_(72%_imp)	84	91	94	96
Crop	Row_Crop_(C_CR_Good)	67	77	84	88
Crop	Row_Crop_(C_T_Good)	65	74	81	84
Crop	Row_Crop_(SR_Good)	70	81	88	92
Crop	Row_Crop_(SR_Poor)	75	84	91	94
Forest	Woods_(Good)	33	58	73	80
Residential	Residential_(30%_imp)	60	75	84	89
Roads	Roads_(Paved_w/ditch)	75	84	91	94

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.
Poor: Factors impart infiltration and tend to increase runoff.
Imp: Denotes imperious land area.
C: Contoured
CR: Crop residue
T: Terraced
SR: Straight row

Calibration involved a comparison of simulated direct runoff with observed data. Daily streamflow measurements are available at the Findlay, OH, USGS gage (04189000) from 1923 to present. The watershed drainage area to this gage is approximately 346 square miles (45% of the total watershed area). Daily streamflow records are also available at the Cuba, OH, USGS gage (01489950) from 2005 to 2007. The Cuba, OH, gage captures drainage from 745 square miles of watershed (97% of the total watershed). Both stations are shown in Figure 2-1. The drainage area ratio method was used to fill data gaps for the Cuba streamflow data using data from the Findlay gage (1995-2004 and 2008-2009). Streamflow was estimated by multiplying the ratio of the drainage area for the site of interest and the drainage area for a nearby streamflow-gaging station by the streamflow for the nearby streamflow-gaging station (Emerson et al., 2005). It is important to note that this technique provides only “estimated” flow during the data gap periods.

To calibrate direct runoff, rather than the total streamflow measured by USGS, it was necessary to perform a hydrograph separation on observed streamflow data. Two different hydrograph separation programs, HYSEP (Sloto and Crouse, 1996) and PART (Rutledge, 1998), were used to separate the baseflow component from the runoff component represented in streamflow. Then only the runoff component in observed streamflow was compared to AnnAGNPS simulated runoff for the calibration period (2002-2009) and the confirmation period (1995-2001).

The calibration of runoff resulted in a “good” to “very good” calibration based on statistical comparison and visual comparison of estimated “observed” data and simulated runoff (Table 5-3). As expected, statistical results are better for longer time periods. The annual NSE and R^2 values are greater than 0.75 for both Findlay and Cuba; however, at monthly and daily time scales the NSE and R^2 are not quite as good as the annual statistics and range from 0.52 to 0.69.

Table 5-3. Cuba and Findlay runoff NSE and R2 statistics for the calibration period (2002-2009)

	Cuba				*Findlay*			
	NSE		*R^2*		*NSE*		*R^2*	
Time	*HYSEP*	*PART*	*HYSEP*	*PART*	*HYSEP*	*PART*	*HYSEP*	*PART*
Annual	0.79	0.83	0.86	0.85	0.84	0.76	0.86	0.83
Monthly	0.69	0.66	0.69	0.67	0.67	0.63	0.68	0.69
Daily	0.60	0.59	0.60	0.59	0.52	0.52	0.53	0.52

The estimated "observed" and simulated annual average runoff volume at Cuba and Findlay were also evaluated. The percent error and the percent difference between the estimated "observed" and simulated were also calculated to evaluate model performance. Percent error is a measure of accuracy that quantifies how accurate the simulated model result is compared to the observed measure.

$$\%error = \frac{(model - observed)}{observed} \times 100$$

Percent difference is calculated to determine the similarity of the measurements and is used to evaluate the absolute difference between simulated and observed results.

$$\%difference = \frac{|model - observed|}{\left|\frac{model - observed}{2}\right|} \times 100$$

A target of less than 20% for the percent error and percent difference was set for the hydrology calibration. The percent error and percent difference at Cuba ranged from 3.2 to 7.1 and 3.1 to 6.9, respectively (Table 5-4). The percent error and percent difference at Findlay ranged from -5.0 to -0.82 and 0.83 to 5.2, respectively (Table 5-5). The calibration statistics were both less than 20% and met the calibration target.

Table 5-4. Estimated "observed" and simulated annual average runoff volume (ac-ft/day) at Cuba for the calibration period (2002-2009)

Year	*HYSEP*	*PART*	*AnnAGNPS*	*Percent Error (w/HYSEP)*	*Percent Error (w/PART)*	*Percent Difference (w/HYSEP)*	*Percent Difference (w/PART)*
2002	809	842	942	16.4%	11.8%	15.1%	11.2%
2003	1,660	1,765	1,696	2.2%	-3.9%	2.1%	4.0%
2004	1,173	1,194	1,308	11.5%	9.6%	10.9%	9.1%
2005	1,558	1,666	1,404	-9.9%	-15.8%	10.4%	17.1%
2006	1,417	1,412	1,415	-0.14%	0.23%	0.14%	0.23%
2007	1,743	1,821	1,842	5.7%	1.2%	5.5%	1.1%
2008	1,508	1,600	1,777	17.8%	11.1%	16.4%	10.5%
2009	796	771	1,040	30.8%	35.0%	26.7%	29.8%
2002-2009	*1,333*	*1,384*	*1,428*	*7.1%*	*3.2%*	*6.9%*	*3.1%*

Table 5-5. Estimated "observed" and simulated annual average runoff volume (ac-ft/day) at Findlay for the calibration period (2002-2009)

Year	*HYSEP*	*PART*	*AnnAGNPS*	*Percent Error (w/HYSEP)*	*Percent Error (w/PART)*	*Percent Difference (w/HYSEP)*	*Percent Difference (w/PART)*
2002	376	391	433	15.3%	10.8%	14.2%	10.2%
2003	771	824	733	-4.9%	-11.0%	5.16%	11.7%
2004	545	554	565	3.8%	1.9%	3.7%	1.9%
2005	744	815	611	-18.0%	-25.1%	19.7%	28.7%
2006	665	692	681	2.4%	-1.6%	2.4%	1.6%
2007	883	899	792	-10.3%	-11.9%	10.8%	12.6%
2008	700	743	777	10.9%	4.5%	10.3%	4.4%
2009	369	358	420	13.6%	17.2%	12.7%	15.9%
2002-2009	*632*	*660*	*626*	*-0.83%*	*-5.0%*	*0.83%*	*5.2%*

In addition to calculating statistics, model performance was evaluated using visual comparison of estimated "observed" and simulated runoff at annual, monthly, and daily time scales at Cuba (Figures 5-1 to 5-3) and Findlay (Figures 5-4 to 5-6). Overall, the model tends to slightly over-predict flows at Cuba and slightly under-predict flows at Findlay. The model tends to under-predict runoff during late winter/early spring time periods, and over-predict low flows during the summer and early fall months (Figures 5-2, 5-3, 5-4, and 5-5).

The under-prediction of runoff during the late winter/early spring months can be explained by the lack of a complete suite of "winter routines" in AnnAGNPS. At this time, AnnAGNPS includes only a simple snowpack/snowmelt algorithm for the "winter routines" that is based on rain/snow precipitation separation at 32 °F and a degree-day snowmelt equation. A frozen soil algorithm has not been incorporated into the model, which results in an under-prediction of runoff whenever a frozen soil layer existed (Theurer, 2010). When a watershed experiences a precipitation event under frozen soil conditions, infiltration and percolation are typically lower and the potential for runoff is increased. By not capturing this phenomenon, the model under-predicts runoff during temperature conditions which would result in frozen soil conditions. The over-prediction of runoff in the summer is likely caused by an over-compensation by the model and the calibration technique to make up for the under-prediction of runoff during the late winter/early spring. In addition, it is possible that the model may also be underestimating evapotranspiration during the higher temperature months; however, the model showed minimal sensitivity to the adjustment of evapotranspiration-related parameters.

An additional consideration when evaluating runoff model performance is the inherent uncertainty in hydrograph separation techniques. HYSEP and PART hydrograph separation methods are meant for the long-term evaluation of baseflow and runoff and are not meant to be used with certainty at time scales shorter than a few months.

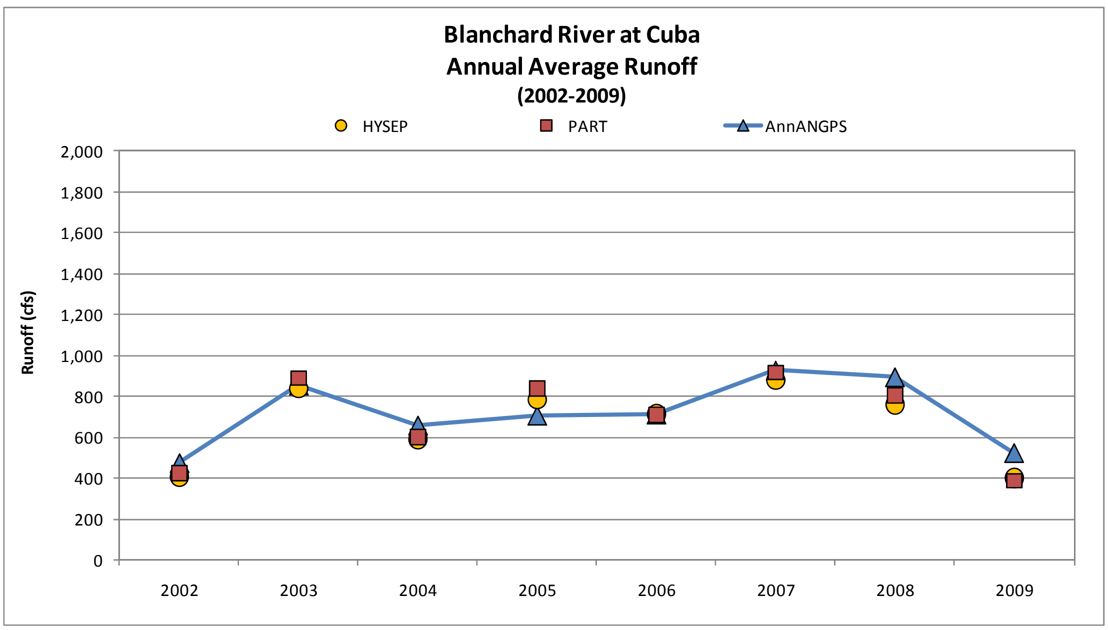

Figure 5-1. Annual average simulated direct runoff at Cuba compared with estimated "observed" direct runoff for the calibration period (2002-2009)

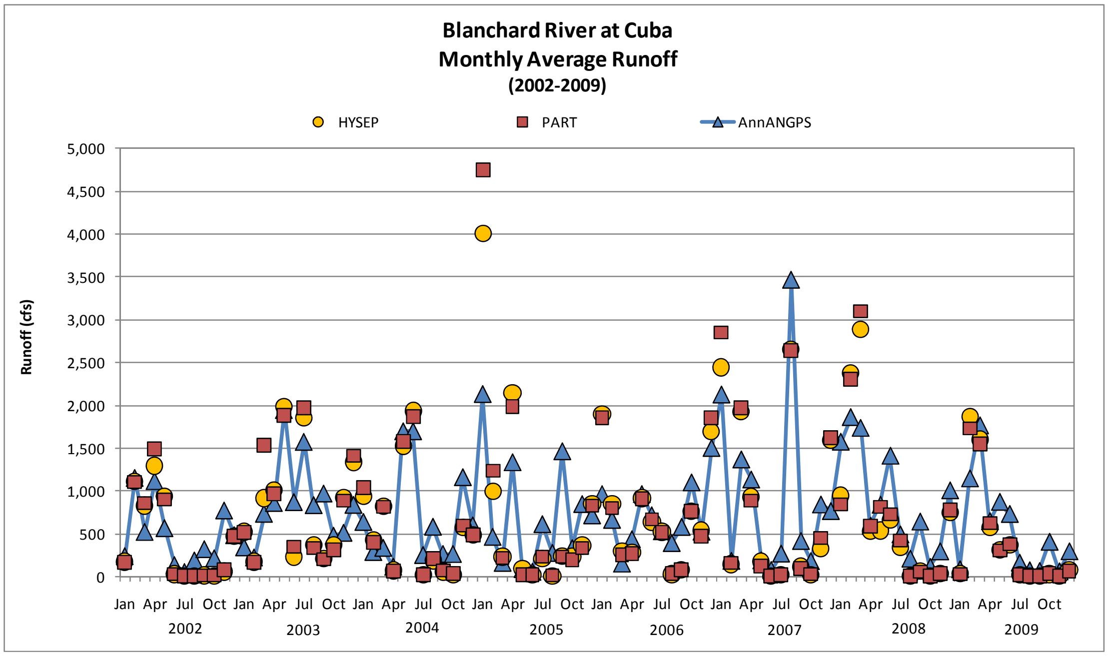

Figure 5-2. Monthly average simulated direct runoff at Cuba compared with estimated "observed" direct runoff for the calibration period (2002-2009)

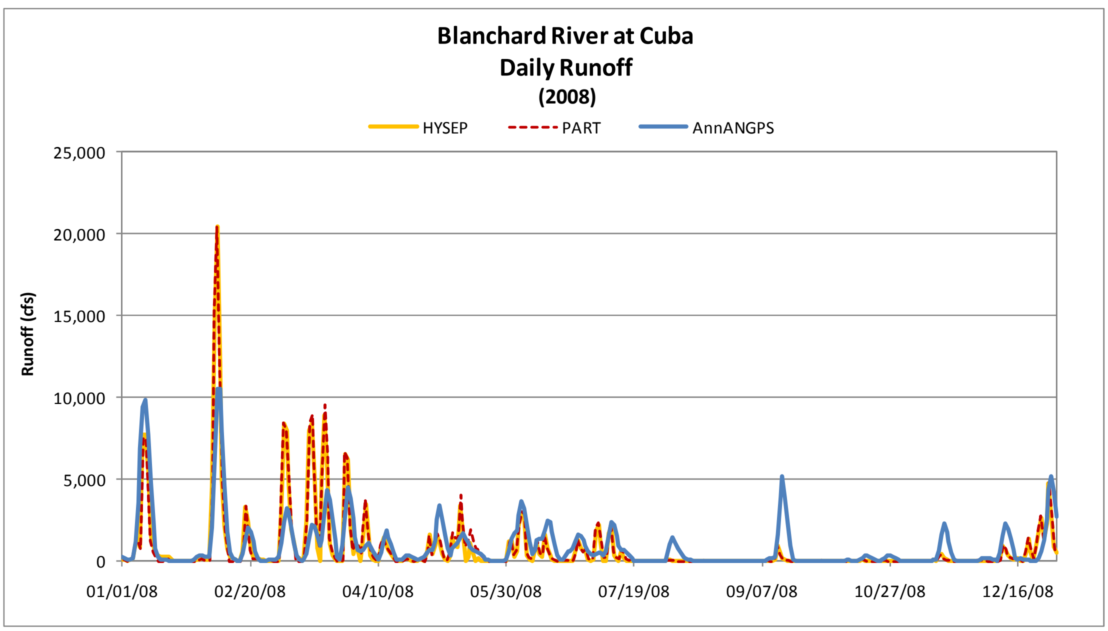

Figure 5-3. Representative daily simulated direct runoff at Cuba compared with estimated "observed" direct runoff for 2008

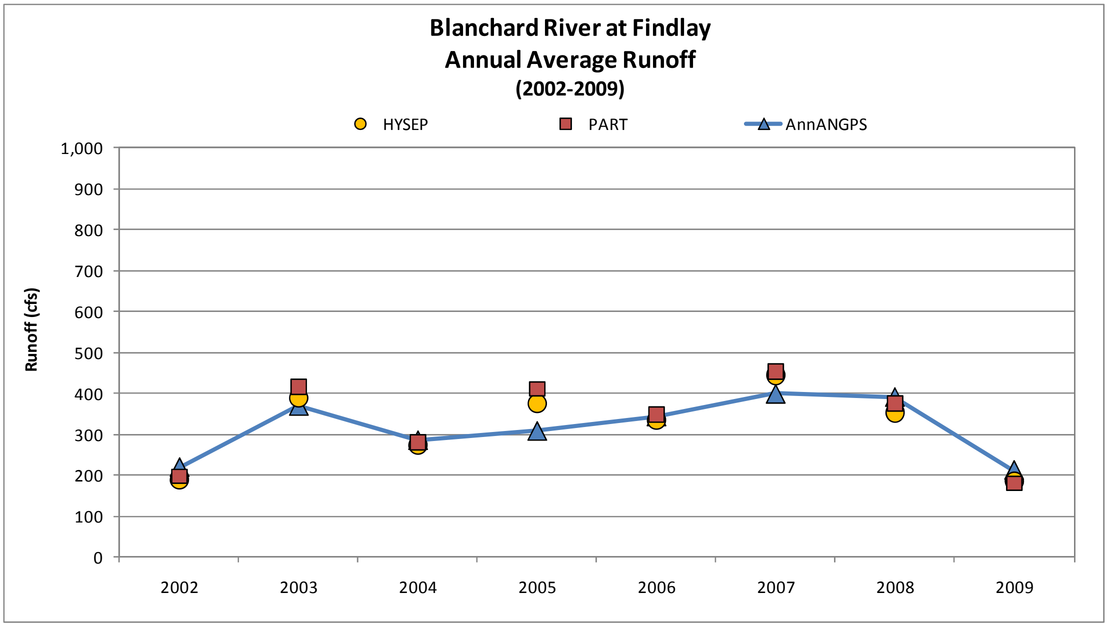

Figure 5-4. Annual average simulated direct runoff at Findlay compared with estimated "observed" direct runoff for the calibration period (2002-2009)

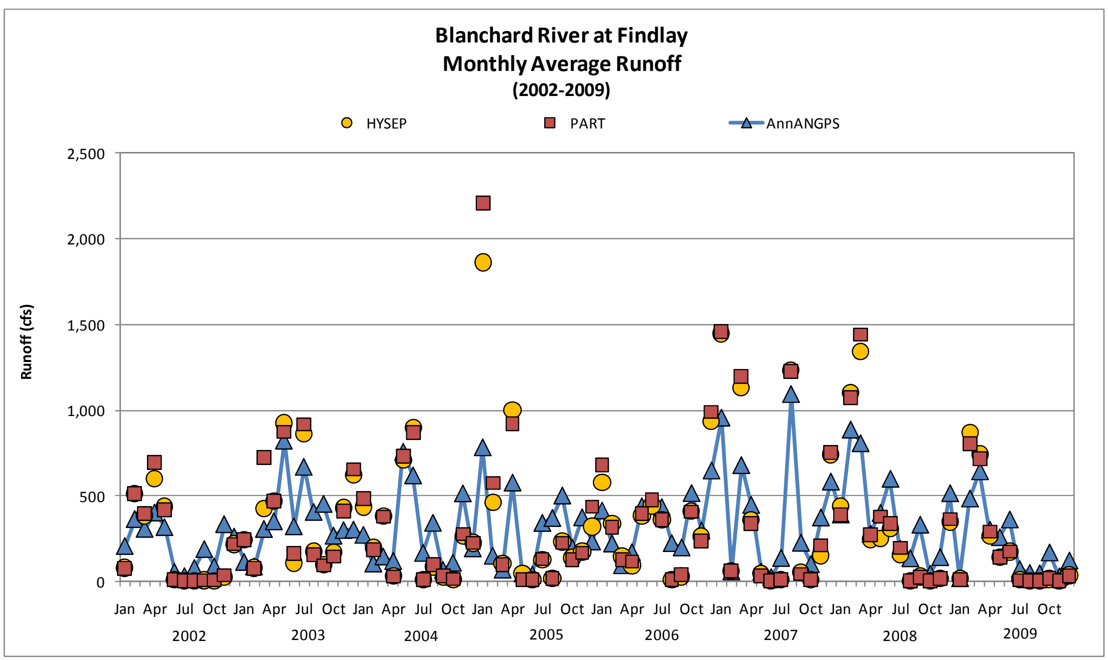

Figure 5-5. Monthly average simulated direct runoff at Findlay compared with estimated "observed" direct runoff for the calibration period (2002-2009)

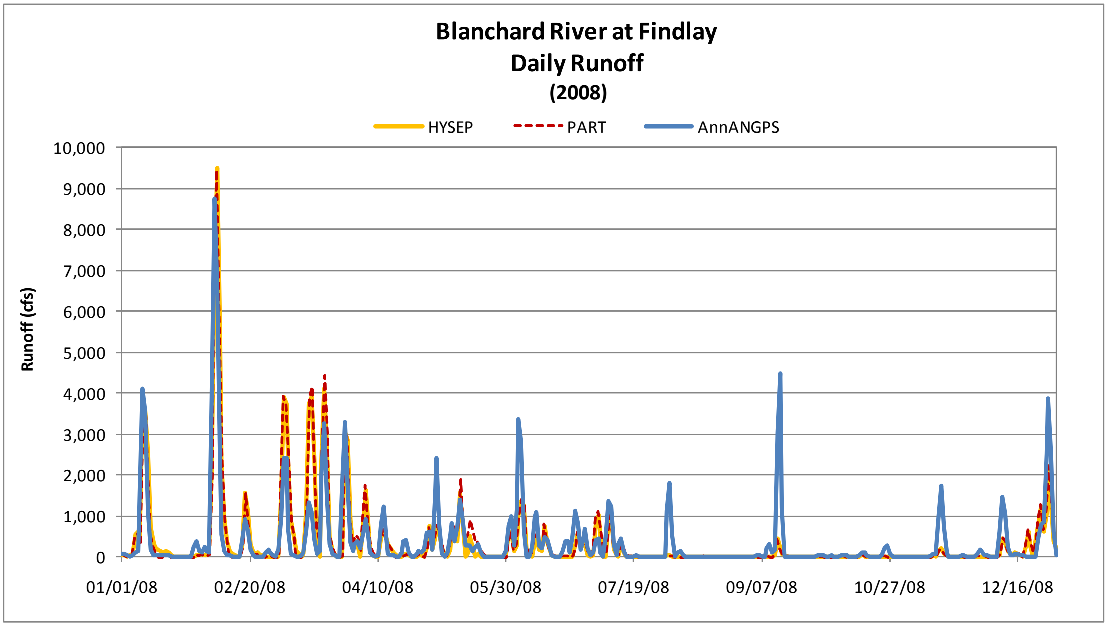

Figure 5-6. Representative daily simulated direct runoff at Findlay compared with estimated "observed" direct runoff for 2008

The Blanchard River Watershed AnnAGNPS model was also evaluated for a confirmation period that covered the time period 1995 to 2001. For these simulations, model parameters were not adjusted, and only time series forcing functions (e.g., climate) were modified to correspond with the confirmation time period. Model results yielded NSE index values less than 0.50 for both Cuba and Findlay, and R^2 values greater than 0.75 for the annual statistic and greater than 0.50 for the monthly statistic (Table 5-6). Based on the classifications presented in Table 4-12, confirmation results using the R^2 statistic would be considered fair to excellent, depending on timescale. With the NSE statistic, confirmation results would be considered unsatisfactory to poor.

Table 5-6. Cuba and Findlay runoff NSE and R2 statistics for the confirmation period (1995-2001)

	Cuba				*Findlay*			
	NSE		*R^2*		*NSE*		*R^2*	
Time	*HYSEP*	*PART*	*HYSEP*	*PART*	*HYSEP*	*PART*	*HYSEP*	*PART*
Annual	-2.26	-1.69	0.97	0.91	-1.49	-1.02	0.93	0.88
Monthly	0.06	0.15	0.66	0.53	0.33	0.39	0.66	0.60
Daily	0.28	0.31	0.42	0.42	0.21	0.24	0.47	0.47

Overall, the model consistently over-predicts runoff at Cuba and Findlay during the confirmation period. The percent error and the percent difference statistics calculated for Cuba and Findlay are all greater than 20% and also show that the simulated runoff is greater than the "observed" runoff as estimated by both HYSEP and PART (Table 5-7 and Table 5-8).

Table 5-7. Estimated "observed" and simulated annual average runoff volume (ac-ft/day) at Cuba for the calibration period (1995-2001)

Year	*HYSEP*	*PART*	*AnnAGNPS*	*Percent Error (w/HYSEP)*	*Percent Error (w/PART)*	*Percent Difference (w/HYSEP)*	*Percent Difference (w/PART)*
1995	611	608	1,116	82.8%	83.6%	58.5%	59.0%
1996	939	1,083	1,435	52.8%	32.5%	41.8%	27.9%
1997	1,397	1,449	2,006	43.6%	38.4%	35.8%	32.2%
1998	1,067	1,031	1,746	63.6%	69.3%	48.2%	51.5%
1999	530	584	963	81.8%	64.7%	58.1%	48.9%
2000	745	759	1,167	56.8%	53.8%	44.2%	42.4%
2001	637	654	1,034	62.4%	58.3%	47.6%	45.1%
1995-2001	*846*	*881*	*1,352*	*59.8%*	*53.5%*	*46.0*%	*42.2*%

Table 5-8. Estimated "observed" and simulated annual average runoff volume (ac-ft/day) at Findlay for the calibration period (1995-2001)

Year	*HYSEP*	*PART*	*AnnAGNPS*	*Percent Error (w/HYSEP)*	*Percent Error (w/PART)*	*Percent Difference (w/HYSEP)*	*Percent Difference (w/PART)*
1995	284	282	545	92.3%	93.1%	63.4%	63.3%
1996	436	503	654	49.9%	30.1%	39.3%	26.3%
1997	649	673	837	29.1%	24.4%	25.4%	21.4%
1998	496	479	744	50.1%	55.4%	40.4%	43.4%
1999	246	271	451	83.5%	66.3%	58.0%	49.6%
2000	346	352	509	47.3%	44.2%	38.3%	36.2%
2001	296	304	451	52.4%	48.5%	41.4%	39.3%
1995-2001	*393*	*409*	*599*	*52.3*%	*46.3*%	*41.5*%	*37.2*%

Model performance was also evaluated during the confirmation period, 1995 to 2001, using visual comparison of estimated "observed" and simulated runoff at annual, monthly time scales at Cuba (Figures 5-7 to 5-8) and Findlay (Figures 5-9 to 5-10). The consistent over-prediction of runoff at Cuba and Findlay during the confirmation period could be attributed to several possible explanations. The Blanchard River Watershed model was developed based on current land use data (2005-2008) and current agricultural practices (crop types/tillage operations/tile drains). The land use and agricultural practices likely changed to some degree between the 1995 to 2001 time period and the 2002-2009 time period. In addition, only two years of streamflow data for a more recent time period (2005-2007) were available for Cuba, the station closest to the watershed outlet. Consequently, observed runoff was estimated for the remaining years, and this process could have introduced additional uncertainly into the data-model comparison.

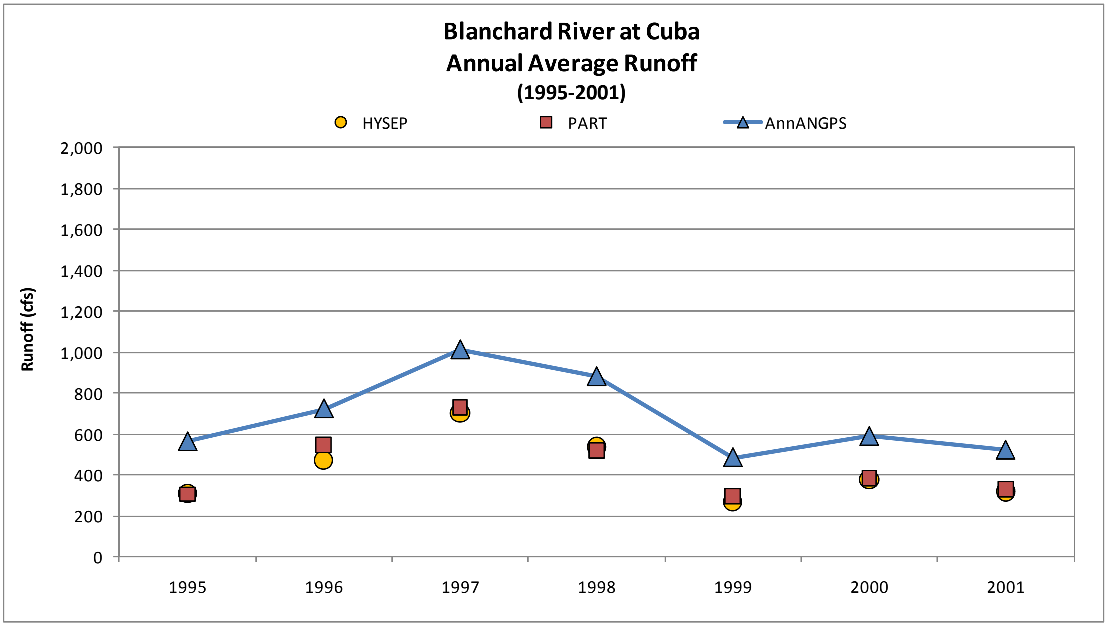

Figure 5-7. Annual average simulated direct runoff at Cuba compared with estimated "observed" direct runoff for the confirmation period (1995-2001)

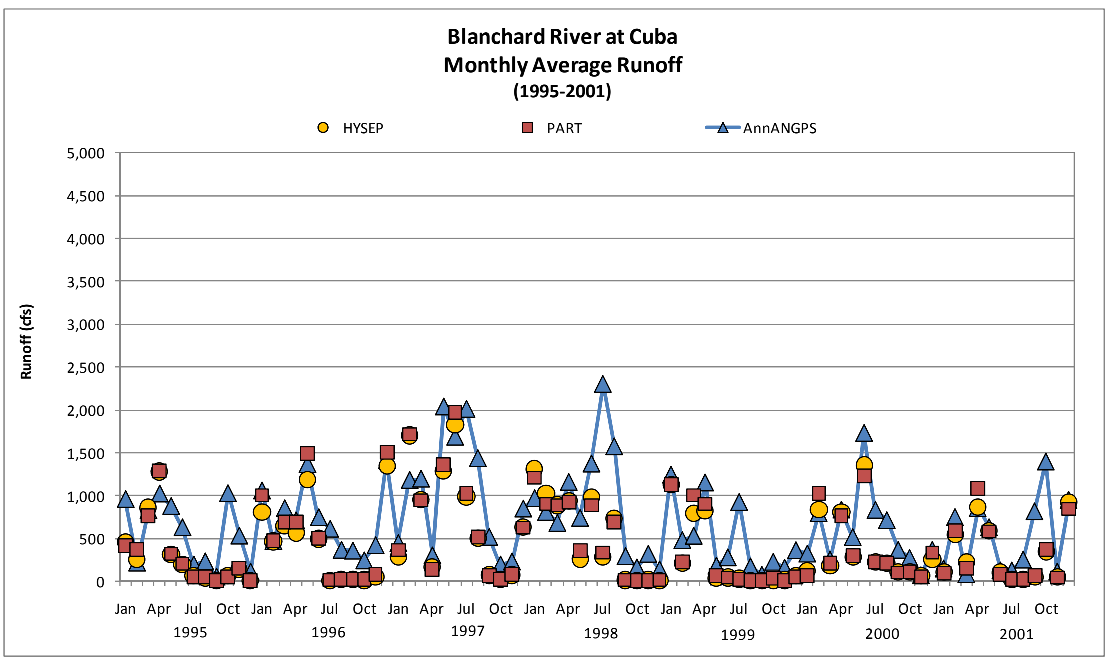

Figure 5-8. Monthly average simulated direct runoff at Cuba compared with estimated "observed" direct runoff for the confirmation period (1995-2001)

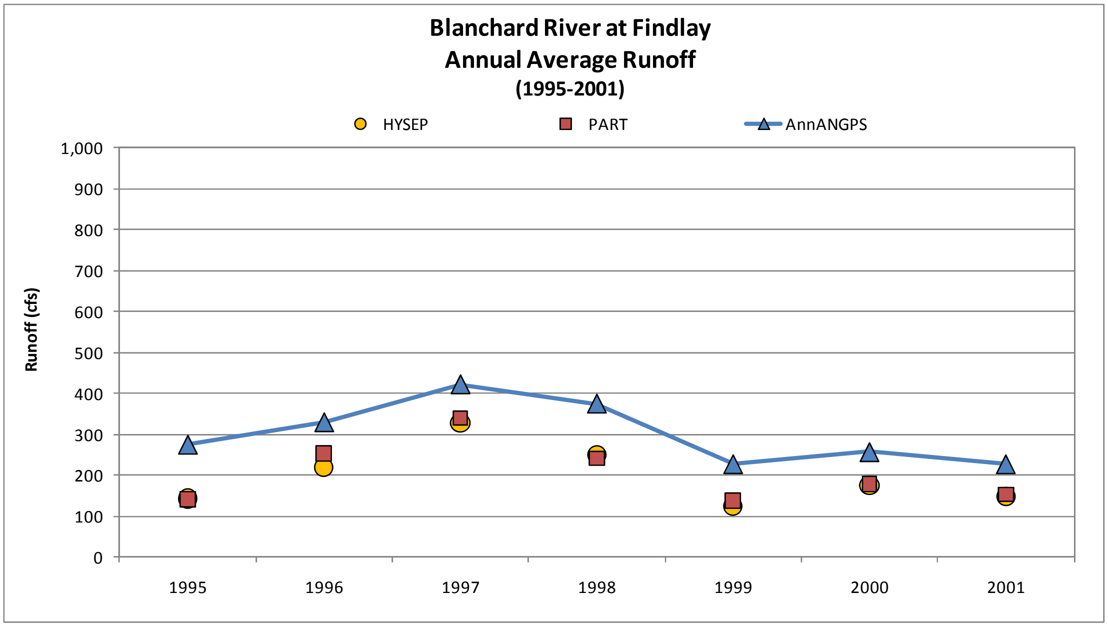

Figure 5-9. Annual average simulated direct runoff at Findlay compared with estimated "observed" direct runoff for the confirmation period (1995-2001)

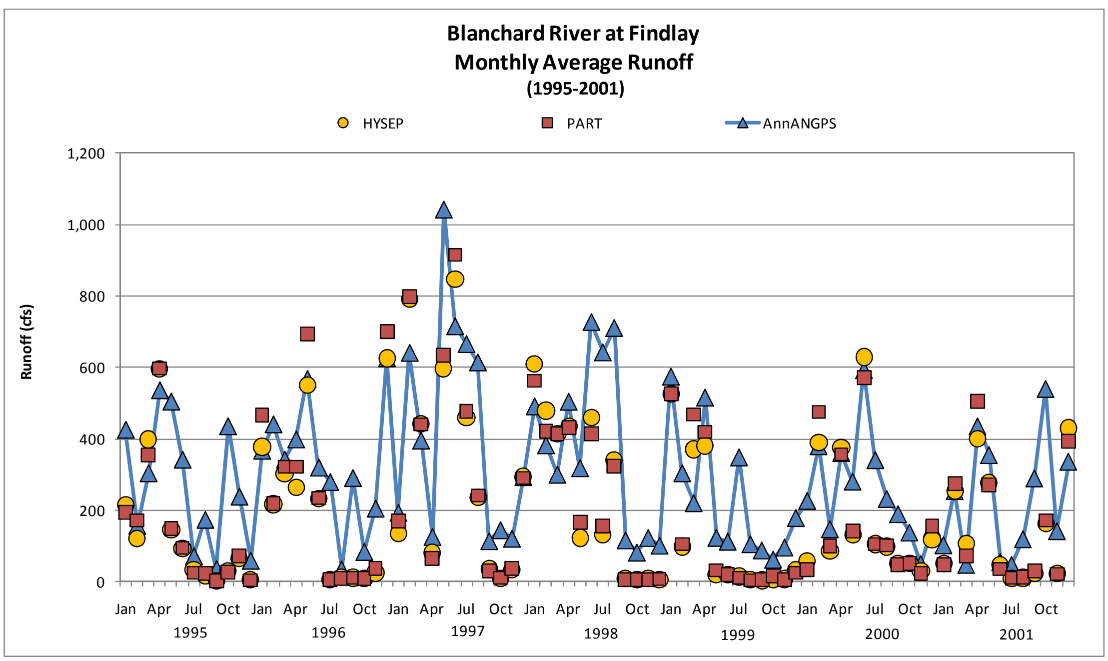

Figure 5-10. Monthly average simulated direct runoff at Findlay compared with estimated "observed" direct runoff for the confirmation period (1995-2001)

Overall, the model performance during the calibration period was determined to range from "good" to "very good," based on NSE, R^2, percent error, percent difference and visual observations. The model performance is satisfactory, and the user can be confident that the model can simulate reasonable runoff values for current conditions in the watershed. However, model performance during the confirmation was not satisfactory, as the NSE, percent error, percent difference and visual observations indicated that the model consistently over-predicts runoff during the confirmation time period. The model performance is satisfactory, and the user can be confident with simulated runoff values for current conditions in the watershed. The model should not be relied upon to estimate absolute runoff values for time periods before 2002.

5.2.2 Suspended Sediment

AnnAGNPS utilizes the widely used Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) for the calculation of sediment loss (erosion) from each cell as a result of precipitation-generated runoff. Sediment loss predicted by the RUSLE is the rate of sheet and rill erosion from the landscape, and is typically greater than the final amount of sediment delivered to the stream. The Hydro-geomorphic Universal Soil Loss Equation (HUSLE) is used to estimate total sediment yield, the net quantity of sediment reaching the stream after deposition (Theuer and Clarke, 1991). As mentioned in Section 4.1.8, AnnAGNPS employs the TIEGEM model to estimate ephemeral gully erosion, and the HUSLE equation is applied to estimate sediment delivery ratio and the amount of ephemeral gully sediment delivered to the stream. Alternatively, HUSLE calculations can be overridden by user-supplied value of sediment delivery ratio.

Sediment loads estimated by the model were calibrated to the observed loads at the Findlay gaging station. Total suspended sediment (TSS) concentrations were measured at the USGS gage (04189000) near Findlay from July 2007 to December 2009. Daily average TSS concentrations were multiplied with average flow to estimate the daily TSS load. Model predicted annual average sediment load was calibrated to the measured annual average loads at the Findlay gage.

The RUSLE algorithm utilized in AnnAGNPS has been thoroughly researched and applied to many watersheds. However, models to predict gully erosion are less mature and have been applied to far fewer watersheds. It was assumed that the model's prediction of erosion from sheet and rill sources was acceptable. At the recommendation of AnnAGNPS developers, the calibration of suspended sediment focused solely on the parameters which influence the prediction of ephemeral gully erosion. No calibration adjustments were made to parameters which influence sheet and rill erosion. Calibration focused on adjusting the number of potential ephemeral gully sites, which was determined to be the most sensitive parameter controlling the prediction of ephemeral gully erosion. The number and distribution of sites were adjusted until the predicted sediment load matched the observed loads at Findlay gage (Figure 4-6). A total of 140 gullies in cropland cells were included in the final calibration run.

Calibration statistics for suspended sediment calibration are shown for annual monthly and daily time periods in Table 5-9. The model prediction of annual sediment resulted in "very good" calibration based on the NSE and R^2 statistics of 0.86 and 90, respectively. The model performance was less robust at monthly and daily time scales resulting in statistical criteria ranging from fair to good. The model behavior is consistent with findings from other studies that AnnAGNPS is more suited for predicting annual average conditions rather than shorter events and time scales.

Table 5-9. Calibration statistics including NSE and R2 calculated for model predicted and observed sediment during the calibration period (2007-2009)

Time	*NSE*	*R^2*
Annual	0.86	0.90
Monthly	0.39	0.40
Daily	0.50	0.51

Similar to hydrology, the percent error and the percent difference between the estimated observed and predicted values of sediment were also calculated to evaluate model performance. The percent error and the percent difference statistics, calculated over the entire calibration period (2007 – 2009), were both well within the calibration target of 20% set for sediment (Table 5-10).

Table 5-10. Estimated observed and simulated annual average sediment load at Findlay for the calibration period (2007-2009)

Year	*Observed TSS Load*	*Simulated TSS Load*	*Percent Error*	*Percent Difference*
2007	11,306	16,149	42.8%	35.3%
2008	71,116	58,479	-17.8%	19.5%
2009	42,481	50,288	18.4%	16.8%
2007-2009	*124,903*	*124,916*	*0.01%*	*0.01%*

The model was able to capture the temporal variations in sediment load reasonably well. As shown in Figure 5-11 and Figure 5-12, the model predicted elevated sediment discharge corresponding to episodic sediment peaks observed in the measured data. However, the magnitude of the model response varied compared to the observed data during different seasons of the year. As summarized in Figure 5-13, the model over-predicted sediment loads during winter and early spring months and under-predicted during the summer months. This behavior is consistent with the seasonal pattern of predicted hydrology described in Section 5.1.1. Therefore, the winter/spring under-prediction and summer over-prediction can be attributed to the hydrology predictions of the model.

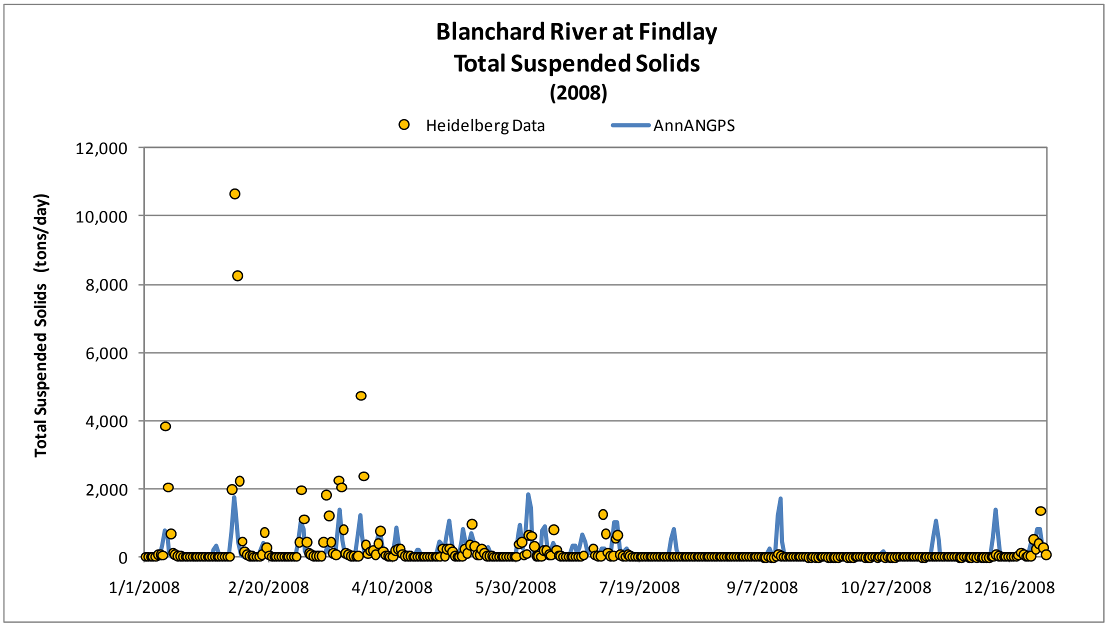

Figure 5-11. Representative daily simulated suspended sediment load at Findlay compared with estimated "observed" load for January 2008 to December 2008

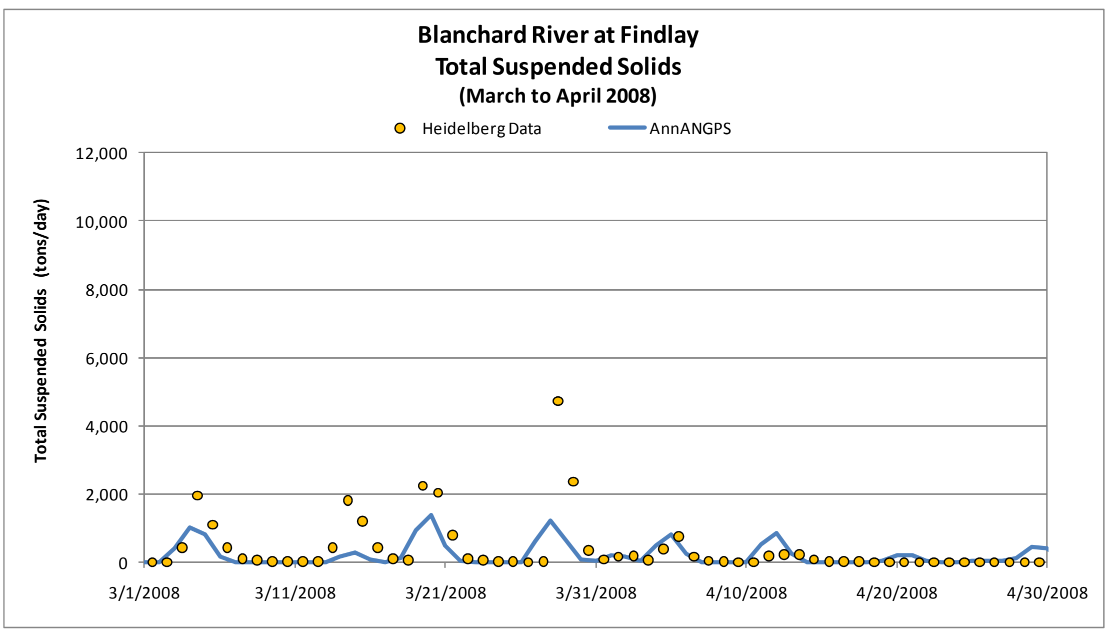

Figure 5-12. Representative comparison of daily simulated and estimated "observed" total suspended sediment load at Findlay (March 2008 to April 2008)

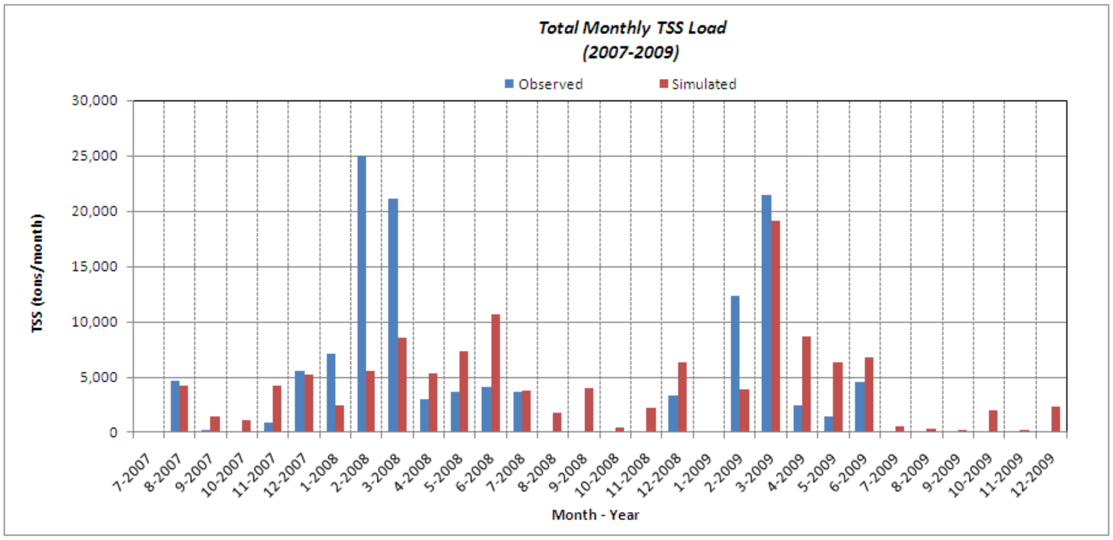

Figure 5-13. Monthly average simulated and observed total suspended sediment loads at Findlay during the calibration period (2007-2009)

AnnAGNPS predicted the majority of suspended sediment in the Blanchard River watershed to originate from ephemeral gully erosion. The estimated ephemeral gully erosion accounted for approximately 85% of the total landscape erosion, while sheet and rill erosion amounted to remaining 15%. These results are similar to the Upper Auglaize watershed modeling where ephemeral gully erosion accounted for 72% of the total watershed erosion (USACE, 2005). Figure 5-14 provides a spatial representation of total sediment yield in the watershed, aggregated for 2007 in units of tons/acre/year.

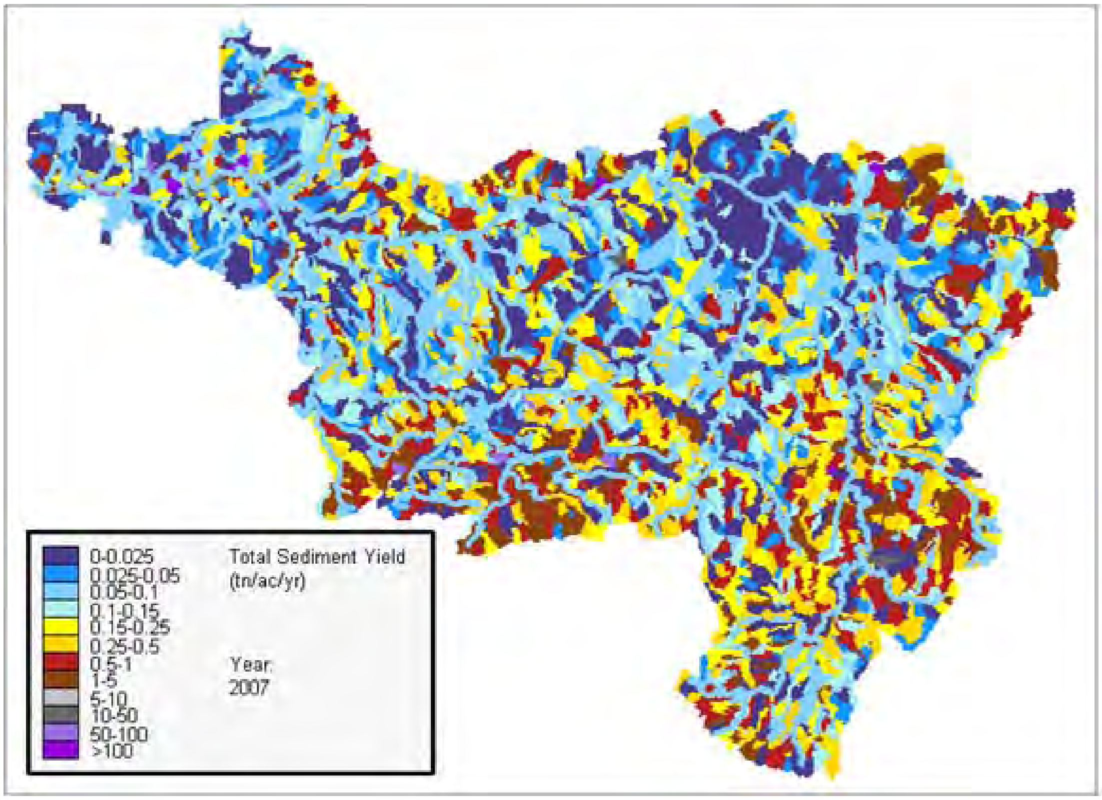

Figure 5-14. Watershed map of simulated annual total sediment yield during 2007.

5.2.3 Nutrients

This section describes calibration of AnnAGNPS for both total phosphorus and total nitrogen.

5.2.3.a Phosphorus

The phosphorus cycle represented in AnnAGNPS is a simplified version of the phosphorus cycling that occurs in the real world. AnnAGNPS tracks major phosphorus transformations of mineralization from humified soil organic matter and plant residues, crop residue decay, fertilizer inputs, and plant uptake. Four pools of soil phosphorus are represented in the model (Binger et al., 2009):

- organic phosphorus
- labile – inorganic phosphorus readily available for plant uptake (soluble or dissolved);
- active – inorganic phosphorus that can be desorbed from soil (exchangeable); and
- stable – inorganic phosphorus that is insoluble and cannot readily be desorbed from soil (refractory).

Phosphorus is represented in both soluble (or dissolved) and sorbed (or particulate) states in the model. AnnAGNPS accounts for potential losses of phosphorus from the system through plant uptake, as soluble inorganic phosphorus exported in runoff and sediment-bound phosphorus transported with eroding soil (Binger et al., 2009).

The phosphorus component of AnnAGNPS was calibrated by adjusting the initial soil concentrations. Default values of zero were the starting point for the initial soil concentrations. The phosphorus initial soil concentrations were adjusted based on concentrations set in the Upper Auglaize model application for existing conditions (Davis and Stafford, 2009) and cropland soil test data for the Sandusky River Watershed (Baker, 2010). Total soil phosphorus was assumed to be composed of 50% organic and 50% inorganic in both the first and second soil layers. The final calibrated initial soil phosphorus concentrations in the Blanchard River Watershed model are summarized in Table 5-11. Fertilizer application rates were not adjusted in the calibration of phosphorus.

Table 5-11. Initial soil phosphorus concentrations in the Blanchard River Watershed model

Land Use Category	*Input parameter*	*Soil Layer*	*Value (ppm)*
Crop	Initial Soil Organic P	First Soil Layer (Top 8 inches)	37
	Initial Soil Organic P	Second Soil Layer (> 8 inches)	18
	Initial Soil Inorganic P	First Soil Layer (Top 8 inches)	37
	Initial Soil Inorganic P	Second Soil Layer (> 8 inches)	18
Non-Crop	Initial Soil Organic P	First Soil Layer (Top 8 inches)	16
	Initial Soil Organic P	Second Soil Layer (> 8 inches)	8
	Initial Soil Inorganic P	First Soil Layer (Top 8 inches)	16
	Initial Soil Inorganic P	Second Soil Layer (> 8 inches)	8

Heidelberg University measured instream phosphorus concentrations on an almost daily basis at the Findlay, OH USGS gage station (04189000) from July 2007 to December 2009. The nutrient species sampled include total phosphorus (as P) and soluble reactive phosphorus (as P). These water quality data provide excellent temporal resolution for the calibration period, but are spatially limited due to the single watershed station. A secondary water quality dataset from OEPA, streamflow and water quality from seven stations (2005-2006), was used to support model calibration and confirmation (Table 2-1). These data provide better spatial resolution; however, they are more temporally sparse than the Heidelberg University dataset (Figure 2-1).

Observed data were translated into loads by multiplying daily average streamflow and daily average concentrations. When sufficient data were available, instantaneous loads were also calculated and compared with daily averaged loads. Although during a storm event instantaneous loads were generally higher than the daily average load, it was determined that the use of daily averaged loads was reasonable, especially considering the other sources of uncertainty in the model (e.g., no representation of baseflow contributions).

Model performance for total phosphorus simulation was evaluated based on statistical comparison and visual comparison of observed data and simulated total phosphorus. Table 5-12 shows that the NSE values range from an annual value of 0.08 and a daily value of 0.31, which would be considered a "poor" calibration classification (see Section 4.2). The R^2 values ranging from a monthly value of 0.28 to an annual value of 0.46 would be considered a "fair" calibration.

Table 5-12. NSE and R^2 statistics for total phosphorus calibration (2007-2009)

Time	*NSE*	*R^2*
Annual	0.08	0.46
Monthly	0.18	0.28
Daily	0.31	0.39

The percent error and percent difference for the calibration period is slightly greater than 20%, which can be considered a "good" result (Table 5-13). The load comparisons and the percent error and percent difference statistics for 2007 and 2008 indicate that the model is performing very well during this time period; however, the load comparison and percent error and percent difference statistics for 2009 suggest that model is significantly over-predicting phosphorus.

Table 5-13. Observed and simulated annual average total phosphorus loads at Findlay (2007-2009)

Year	*Observed TP Load (lbs/yr)*	*Simulated TP Load (lbs/yr)*	*Percent Error*	*Percent Difference*
2007[1]	138,694	141,510	2.03	2.01
2008	459,947	441,474	-4.02	4.10
2009	213,391	440,818	107	69.5
2007-2009	*812,032*	*1,023,802*	*26.1*	*23.1*

[1] A complete annual dataset was not available; load represents a partial year.

Figures 5-15 to 5-16 provide a visual comparison of simulated and estimated "observed" total phosphorus. The daily time series plots (Figure 5-15 and 5-16) show an under-prediction of total phosphorus load at Findlay in 2008. These results directly correspond with model performance related to an under-prediction of direct runoff and total suspended sediment during late winter/early spring and an over-prediction during the summer and early fall months as discussed in Sections 5.1.1 and 5.1.2 (Figure 5-17). This correspondence is expected due to the high adsorption of capacity of phosphorus with transported sediment.

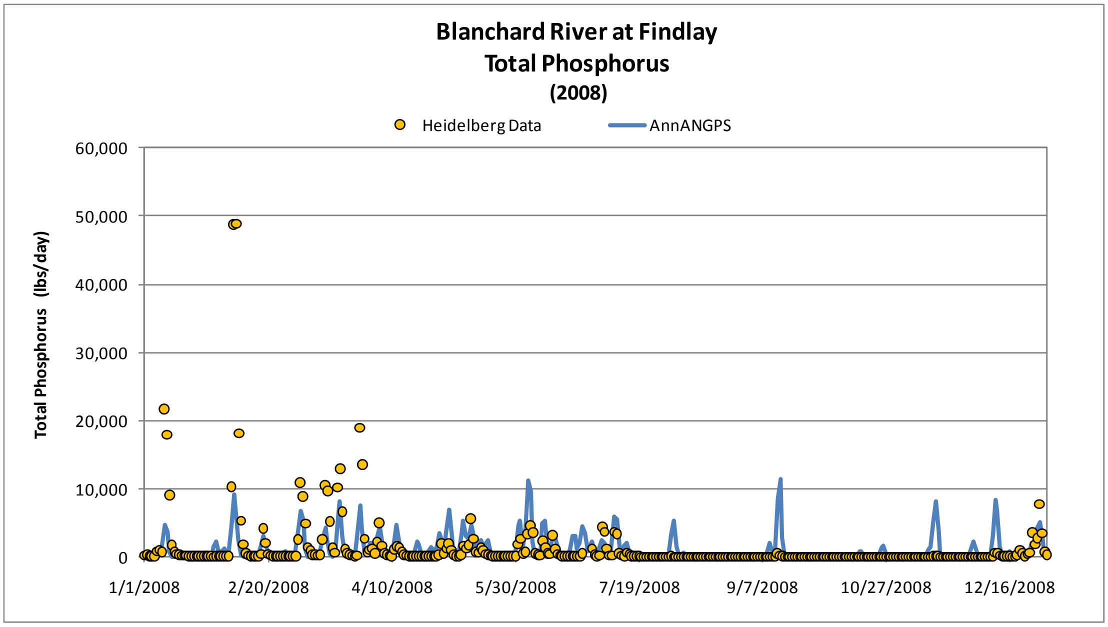

Figure 5-15. Representative comparison of daily simulated and estimated "observed" total phosphorus at Findlay (January 2008 to December 2008)

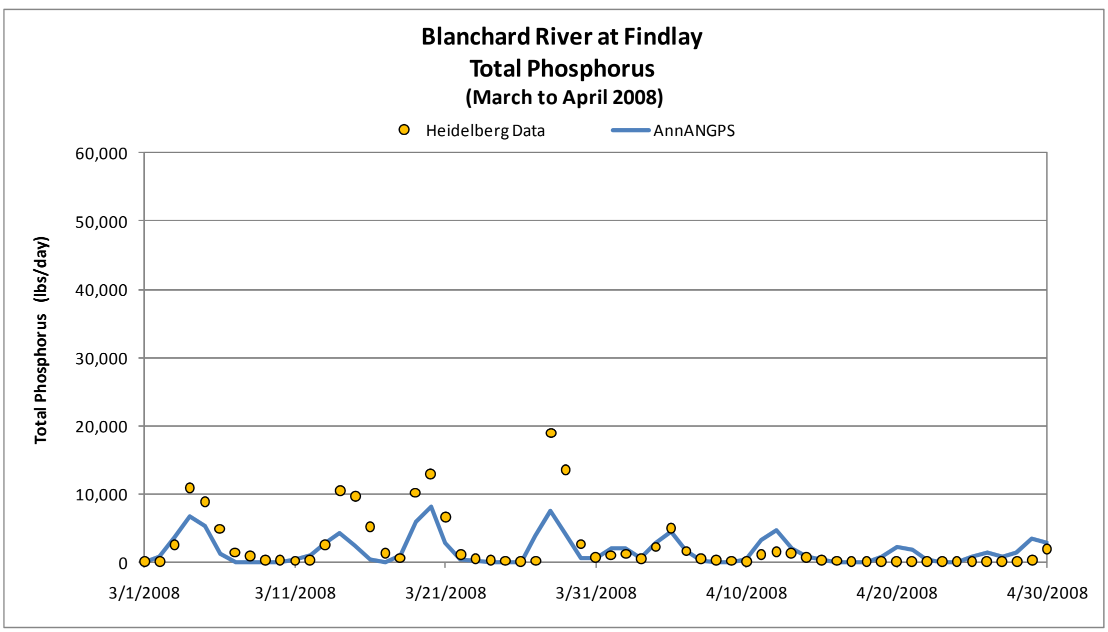

Figure 5-16. Representative comparison of daily simulated and estimated "observed" total phosphorus at Findlay (March 19, 2008 to April 11, 2008)

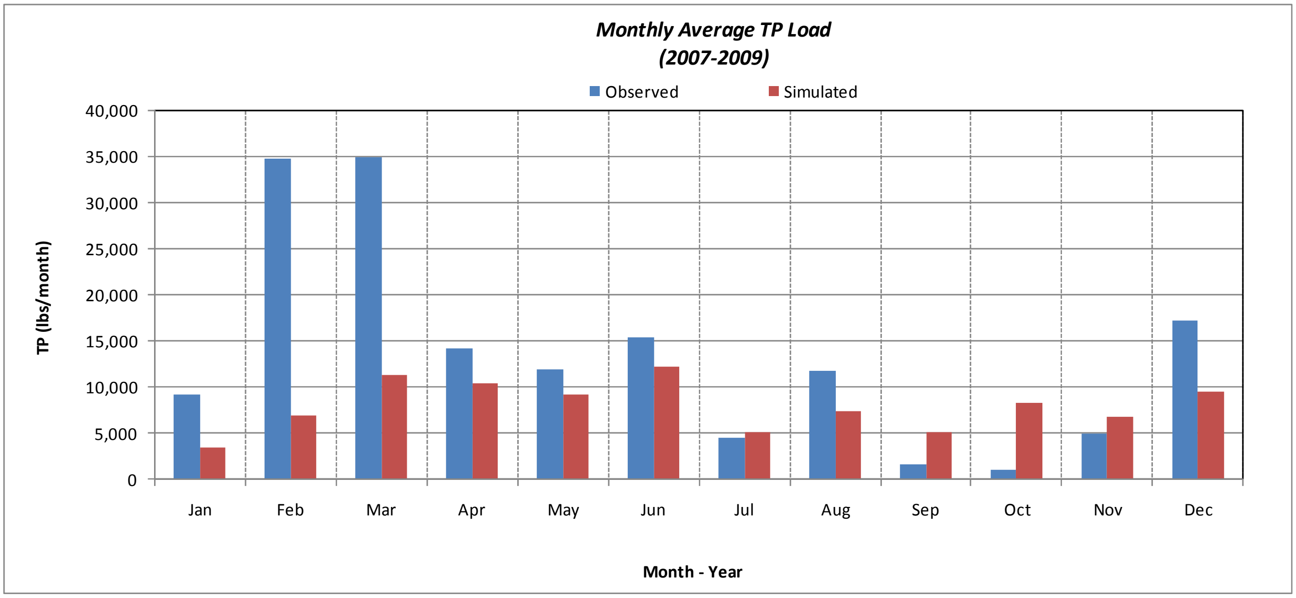

Figure 5-17. Monthly average observed and simulated total phosphorus loads at Findlay (2007-2009)

Figure 5-18 provides a spatial representation of total phosphorus yield in the watershed, aggregated for 2008.The model predicted total phosphorus yield to range from 0 to 5 lbs/acre/year for much of the watershed. Localized cells with higher total phosphorus yield are noted in brown (30-35 lb/acre/year) or purple (>50 lb/acre/year).

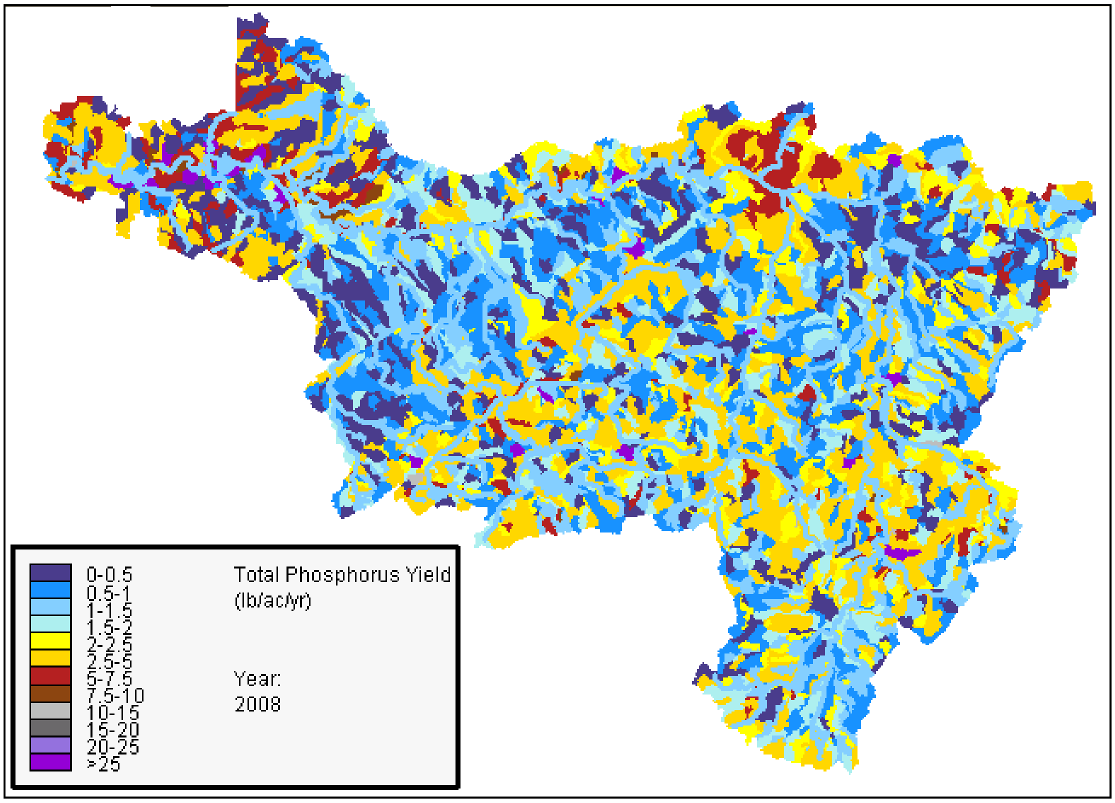

Figure 5-18. Watershed map of annual simulated total phosphorus yield during a selected year (2008)

5.2.3.b Nitrogen

The nitrogen cycle represented in AnnAGNPS is a simplified version of nitrogen cycling that occurs in the real world. AnnAGNPS tracks only major nitrogen transformations of mineralization from humified soil organic matter and plant residues, crop residue decay, fertilizer inputs, and plant uptake. Three pools of soil nitrogen are considered (Binger et al., 2009):

- stable organic nitrogen;
- active organic nitrogen (mineralizable N); and
- inorganic nitrogen (nitrate, nitrite and ammonium).

Nitrogen is represented in both soluble (or dissolved) and sorbed (or particulate) states in the model. AnnAGNPS accounts for potential losses of nitrogen from the system as soluble inorganic nitrogen exported in runoff or leaching, inorganic nitrogen loss through denitrification, and sediment-bound organic nitrogen transport with eroding soil (Binger et al., 2009).

Total nitrogen was calibrated by adjusting the initial soil concentrations and fertilizer applications rates. The nitrogen initial soil concentrations were adjusted from a default value of zero based on concentrations set in the Upper Auglaize model application for existing conditions (Davis and Stafford, 2009). Total soil nitrogen was assumed to be composed of 50% organic and 50% inorganic in the first soil layer, and approximately 30% organic and 70% inorganic in the second soil layer.

Nitrogen loads were also calibrated by adjusting fertilizer application rates of nitrogen to corn and wheat crops. Fertilizer application rates were adjusted upward from maintenance rates (which did not provide a good prediction) towards the upper end of typical rates for corn and wheat crops (OSU Agricultural Extension, 2010). The final calibrated model inputs for initial soil nitrogen concentrations and fertilizer applications rates for corn and wheat are summarized in Table 5-14 and Table 4-9, respectively.

Table 5-14. Initial soil nitrogen concentrations in the Blanchard River Watershed model

Land Use Category	*Input parameter*	*Soil Layer*	*Value (ppm)*
Crop	Initial Soil Organic N (ppm)	First Soil Layer (Top 8 inches)	25
	Initial Soil Organic N (ppm)	Second Soil Layer (> 8 inches)	10
	Initial Soil Inorganic N	First Soil Layer (Top 8 inches)	25
	Initial Soil Inorganic N	Second Soil Layer (> 8 inches)	25
Non-Crop	Initial Soil Organic N	First Soil Layer (Top 8 inches)	10
	Initial Soil Organic N	Second Soil Layer (> 8 inches)	5
	Initial Soil Inorganic N	First Soil Layer (Top 8 inches)	10
	Initial Soil Inorganic N	Second Soil Layer (> 8 inches)	10

Similar to phosphorus, Heidelberg University measured nitrogen on an almost daily basis at the Findlay, OH, USGS gage station (04189000) from July 2007 to December 2009. The nutrient species sampled include nitrate plus nitrite (as N), TKN (as N), and ammonia (as N). Total nitrogen was calculated as an aggregation of TKN and nitrate plus nitrite concentrations. These water quality data provide excellent temporal resolution but are limited spatially. Secondary water quality data from OEPA were used to support model calibration and confirmation (Table 2-1). These data provide better spatial resolution; however, they are more temporally sparse than the Heidelberg University dataset (Figure 1).

Observed data were translated into loads by multiplying daily average streamflow and daily average concentrations. When sufficient data were available, instantaneous loads were also calculated and compared with daily averaged loads. Although during a storm event, instantaneous loads were generally higher than the daily average load, it was determined that the use of daily averaged loads was reasonable, especially considering the other sources of uncertainty in the model (e.g., no representation of baseflow contributions).

Model performance for total nitrogen simulation was evaluated based on statistical comparison and visual comparison of observed data and simulated total nitrogen. Table 5-15 shows that the NSE values range from an annual value of -0.87 and a daily value of 0.28, which would be considered a "poor" to "fair" calibration classification (see Section 4.2). The R^2 values ranging from a monthly value of 0.24 to an annual value of 0.92 would be considered a "fair" to "excellent" calibration.

Table 5-15. NSE and R^2 statistics for total nitrogen calibration (2007-2009)

Time	*NSE*	*R2*
Annual	-0.87	0.92
Monthly	0.10	0.24
Daily	0.28	0.34

The percent error and percent difference for the calibration period are approximately -36% and 44%, respectively (Table 5-16). These results suggest a "fair" calibration in consideration of a 20% error target. The load comparisons and the percent error and percent difference statistics indicate that the model is consistently under-predicting total nitrogen.

Table 5-16. Observed and simulated annual average total nitrogen at Findlay (2007-2009)

Year	*Observed TN Load (lbs/yr)*	*Simulated TN Load (lbs/yr)*	*Percent Error*	*Percent Difference*
2007[1]	2,245,312	1,540,201	-31.4	37.3
2008	4,669,374	2,700,872	-42.2	53.4
2009	3,495,630	2,436,897	-30.3	35.7
2007-2009	*10,410,315*	*6,677,969*	*-35.9*	*43.7*

[1] A complete annual dataset was not available; load represents a partial year.

Figure 5-19 and 5-20 provide a visual comparison of simulated and estimated "observed" total nitrogen. The daily time series plots (Figure 5-19 and Figure 5-20) show that during 2008, the model is under-predicting total nitrogen load at Findlay. Similar to what was observed in the runoff simulation, the model tends to under-predict total nitrogen during late winter/early spring and over-predict total nitrogen during the summer and early fall months (Figure 5-21). This correspondence is expected as total nitrogen yield, and loading is dependent upon watershed hydrology and surface runoff.

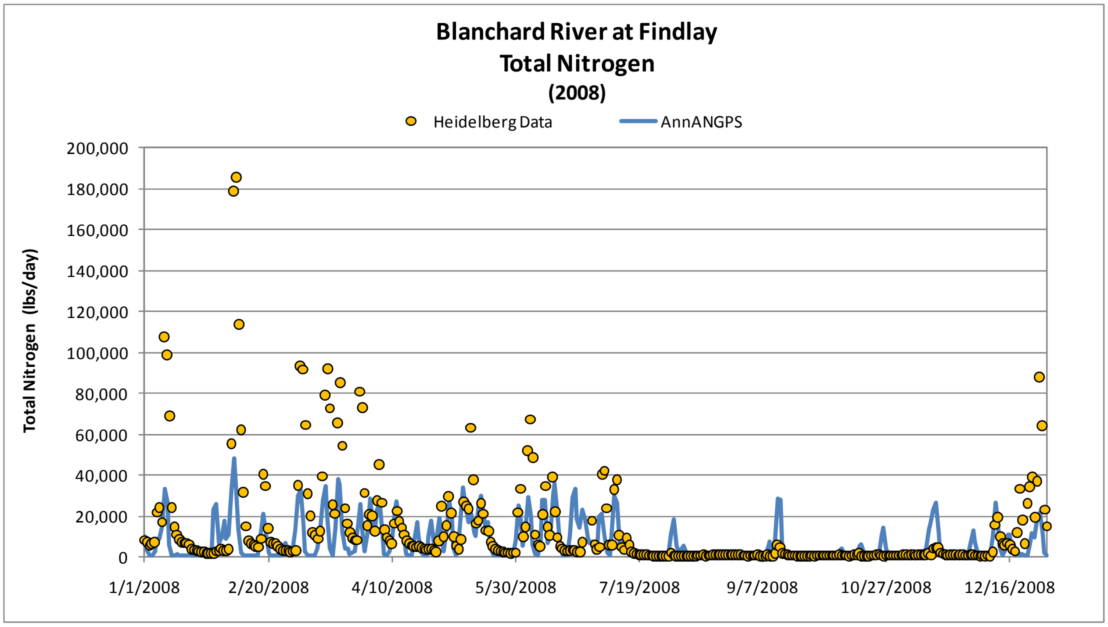

Figure 5-19. Representative comparison of daily simulated and estimated "observed" total nitrogen at Findlay (January 2008 to October 2008)

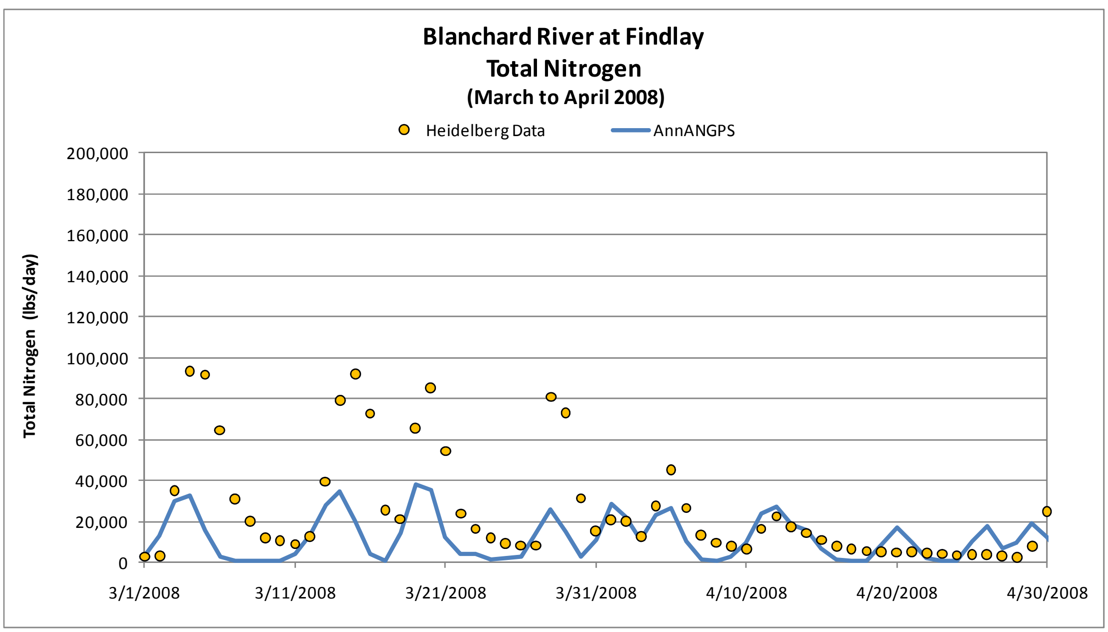

Figure 5-20. Representative comparison of daily simulated and estimated "observed" total nitrogen at Findlay (March 19, 2008 to April 11, 2008)

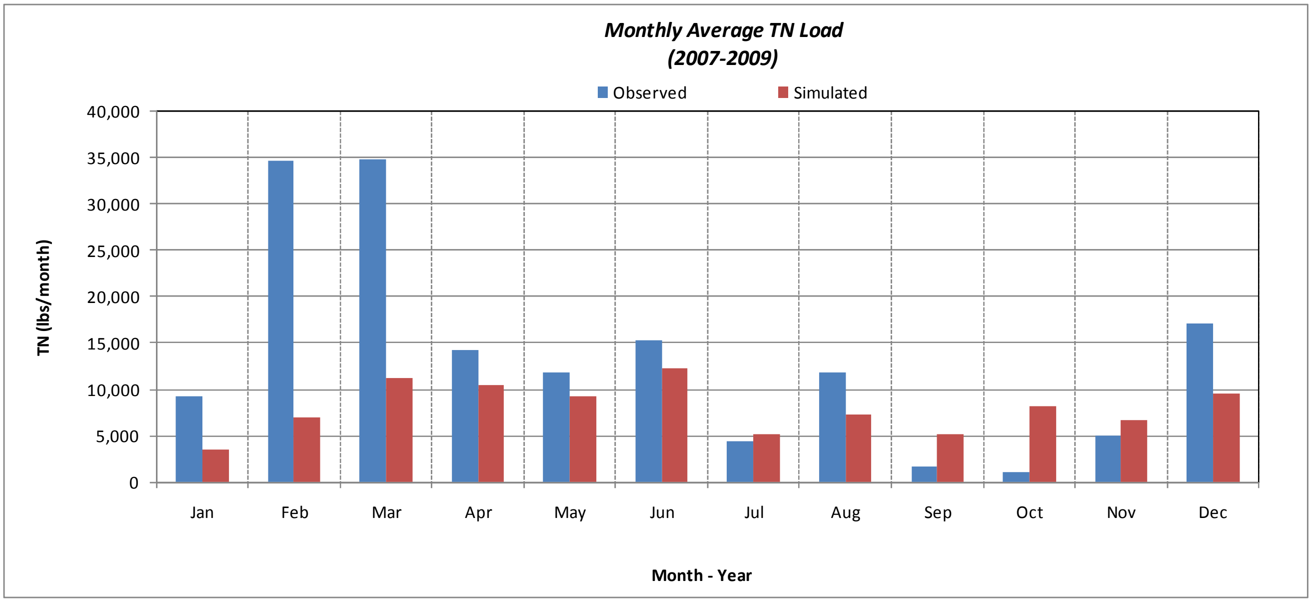

Figure 5-21. Monthly average observed and simulated total nitrogen loads at Findlay (2007-2009)

Figure 5-21 provides a spatial representation of total nitrogen yield in the watershed, aggregated for 2008.The model predicted total nitrogen yield to range from 0 to 30 lbs/acre/year for much of the watershed. Localized cells with higher total nitrogen yield are noted in red (50-60 lb/care/year), brown (60-70 lb/acre/year), or purple (>100 lb/acre/year).

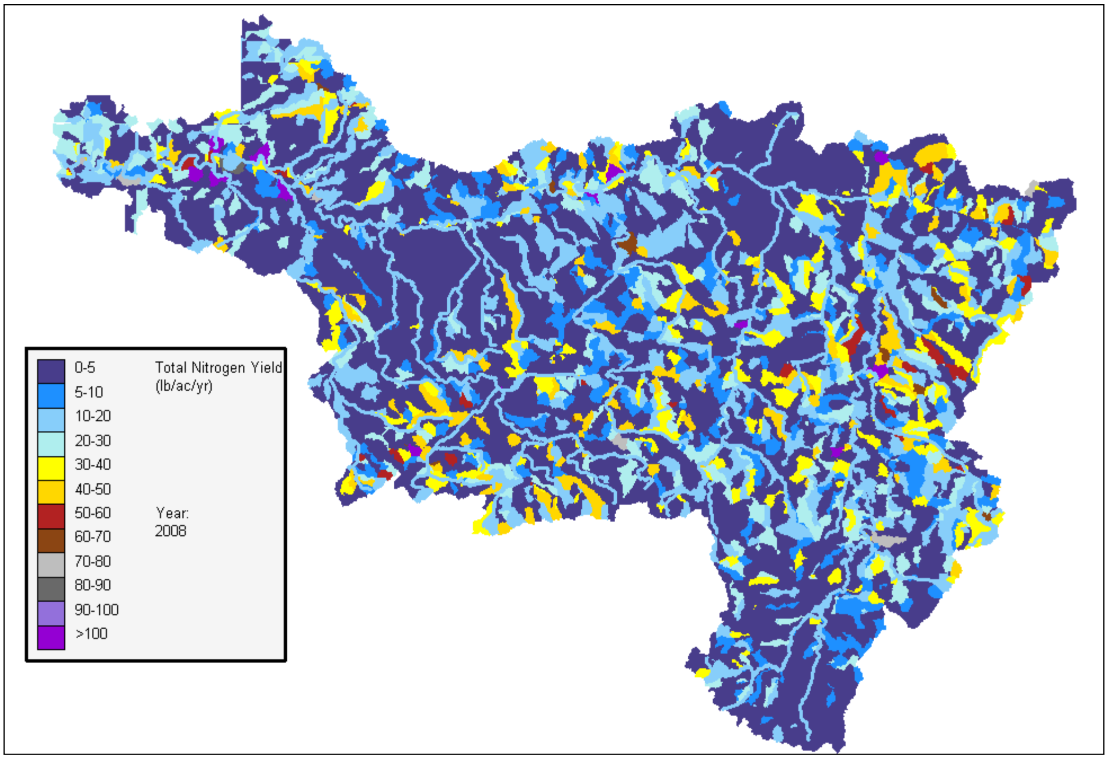

Figure 5-22. Watershed map of annual simulated total nitrogen yield during a selected year (2008)

5.3 MODEL DIAGNOSTICS AND SENSITIVITY ANALYSES

Diagnostic tests and sensitivity analyses model runs were performed to determine the most sensitive parameters that could be adjusted for calibration and to understand how sensitive the model is to changes in specific parameter input values. These runs helped focus the calibration process and supported the interpretation of model results.

For hydrology, the curve number, the minimum and maximum interception evaporation, and the tile drain rate parameters were evaluated. Adjustment of the curve number (CN) through a range of ± 5 of the initial curve number inputs for each hydrologic soil group (A, B, C, and D) and specific cover type indicated that hydrology was quite sensitive to this parameter. Adjustment of the minimum and maximum interception evaporation parameters within ranges of 0.003 to 0.010 and 0.012 to 0.019 inches resulted in either almost no change or a very small change in hydrology. These parameters represent the maximum amount of expected precipitation subject to evaporation prior to infiltration at 100% and 0% relative humidity, respectively. The tile drain rate parameter, which represents the daily reduction in height of the water table, was adjusted from 0 to 0.5 inches per day, and model results indicated moderate.

Model sensitively to parameters related to ephemeral gully erosion prediction were examined by adjusting the number of ephemeral gullies, critical shear stress, the nickpoint erodibility rate, and the delivery ratio. The critical shear stress and the nickpoint erodibility rate were varied within a reasonable range based on values reported in the literature (Gordon et al., 2007). The delivery ratio was varied from 20% to 80%. The numbers of gullies were varied by specifying different CTI values for DEM in the ArcView interface. Of these parameters, the model is most sensitive to the number of potential ephemeral gully sites. Varying the number of sites from 140 to 1445 resulted in a predicted sediment loading that was several folds higher. Although less sensitive than the number of potential ephemeral gully sites, increasing or decreasing the critical shear stress generally resulted in decreased or increased sediment loading, respectively, at the outlet. The model responded to an increase in nickpoint erodibility rate and sediment delivery ratio as higher sediment output .

A sensitivity analysis was conducted for the following nutrient parameters: initial soil concentrations, inorganic and organic fractions, non-crop annual root mass, and fertilizer application rates. The model showed significant sensitivity to the initial soil phosphorus concentrations. For example, when non-crop land use initial soil phosphorus concentrations were decreased from the calibrated values, the model responded with a significant decrease (more than half) in phosphorus yield from the watershed and loading at the outlet. The model also showed sensitivity to initial soil nitrogen concentrations with increases in initial concentrations resulting in a fair increase in nitrogen yield from the watershed and loading at the outlet. Adjustment of fertilizer application rates resulted in a moderate change in phosphorus and nitrogen loadings.

The model showed a moderate sensitivity to a change in the proportion of inorganic and organic phosphorus fractions from 50:50 to 20:80. The model responded with an increase in particulate phosphorus and an overall decrease in phosphorus loading at the outlet. When the non-crop annual root mass (i.e., the average annual live root mass in the top 4 inches of soil), was increased by a factor of two, the model responded with only a slight change in phosphorus loading, therefore indicating little sensitivity.

5.4 COMPARISON WITH OTHER MODELING EFFORTS

5.4.1 Regional SWAT Model

As mentioned in Section 2.3, a SWAT model has recently been applied to the entire Maumee Basin including the Blanchard Watershed. The two models were applied at different spatial scales and across different time periods. SWAT represented the Blanchard River watershed with 19 subbasins with an average area of 10,571 ha, and the model was run for a period from 1998 to 2005. As described above, the AnnAGNPS application of the Blanchard River watershed included 3830 subwatersheds (cells) with an average size of 52 ha, and the calibration period focused on the years of 2002 to 2009 to correspond with available datasets. Other differences to note are that the SWAT application used less detailed crop rotation and tillage data and was calibrated to a time period which did not correspond with the water quality data collected at Findlay, OH, by Heidelberg University. Alternatively, SWAT model predictions were compared with Heidelberg data collected at the downstream Waterville site.

However, despite differences in model configuration, it is interesting to compare the predictions from the two models. Output from SWAT was obtained (Bosch, 2010) and a comparison of predicted flow and loadings for each model is provided in Table 5-17. The results show a very similar prediction for average daily mean streamflow; however, it is important to note that streamflow predictions by SWAT include surface runoff and baseflow, whereas AnnAGNPS is limited to direct runoff only (surface runoff and tile drain flow). AnnAGNPS is predicting slightly higher suspended sediment load. This could be partially due to the fact that AnnAGNPS predicts contributions of erosion from ephemeral gully erosion in addition to sheet and rill sources, whereas SWAT only considers the latter. Total phosphorus loads predicted by AnnAGNPS are slightly higher than SWAT, which likely corresponds with the suspended sediment predictions described above (e.g., adsorbed P loads are highly correlated with sediment loads). Total nitrogen load predictions from AnnAGNPS are slightly less than predicted by SWAT. In general, both models are predicting flow, suspended sediment, and nutrient loading within a similar range.

Table 5-17. Comparison of AnnAGNPS and SWAT output at the watershed outlet

Simulated at Watershed Outlet	*AnnAGNPS (1998- 2005)*	*SWAT (1998 - 2005)*
Average Daily Mean Streamflow (m^3/s)	19	19
Average Suspended Sediment Load (tons/yr)	192,901	115,413
Average TP Load (tons/yr)	426	353
Average TN Load (tons/yr)	3,843	5,512

5.4.2 Upper Auglaize AnnAGNPS Model

Model predicted parameters of suspended sediment were compared with AnnAGNPS results reported for the Upper Auglaize watershed (USACE, 2005). The model predicted that watershed average rate of sheet and rill erosion is in close agreement with the value reported for the Upper Auglaize (Table 5-18). The total rate landscape erosion predicted by the model for the Blanchard (5.27 t/ac/yr) is twice as much compared to the value for the Upper Auglaize watershed (2.47 t/ac/yr). This is due to the relatively higher rate of gully erosion predicted for Blanchard compared to the Upper Auglaize watershed (Table 5-18). The watershed average sediment yield to streams and the loading rate at watershed outlet are comparable to the values simulated for the Upper Auglaize. The amount of sediment leaving the Blanchard watershed is significantly greater due to the watershed being almost twice as large and the slightly higher loading rate at the watershed outlet.

Table 5-18. Comparison of AnnAGPNS output for the Blanchard River and Upper Auglaize River watersheds

Item	*Blanchard*	*Upper Auglaize*	*Units*
Watershed Average Sheet and Rill Rate of Erosion	0.80	0.71	t/ac/yr
Watershed Average Ephemeral Gully Rate of Erosion	4.48	1.77	t/ac/yr
Watershed Average Total Rate of Erosion	5.27	2.47	t/ac/yr
Watershed Total Tons of Erosion	2,599,810	524,200	t/yr
Watershed Sediment Yield to Streams	1.18	0.97	t/yr
Sediment Loading Rate at Watershed Outlet	0.41	0.31	t/ac/yr
Sediment Loading Amount to Watershed Outlet	200,175	65,070	t/yr

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6. MODEL MANAGEMENT APPLICATION

Once the model was calibrated, the next step was to explore the potential water quality benefits of implementing best management practices (BMPs) and land management practices. The following sections describe a set of management scenarios that were defined based on stakeholder input and a summary of model results.

6.1 MANAGEMENT SCENARIO DESCRIPTIONS

Table 6-1 describes common BMPs and land management practices, noting the practices that can be directly represented in AnnAGNPS and those that cannot and must be implemented using an indirect method.

Table 6-1. Management Alternatives in AnnAGNPS

BMP and Land Management Practices	*Description of BMP/Land Management Practices*	*AnnAGNPS Representation*
Conservation Tillage	Any tillage/planting system which leaves at least 30 % of the field surface covered with crop residue after planting has been completed.	Indirect
Conservation Crop Rotation	Grow a sequential crop series for environmental benefits (balance fertility demands, avoid excessive soil nutrient depletion, maximize plant residue left on a field to reduce erosion).	Mechanistic
Contour Farming	Plowing, planting, cultivating, and/or harvesting in a direction parallel to (rather than perpendicular to) elevation contour lines. Contour rows slow surface runoff, helps prevent soil erosion, and promote water infiltration to the soil.	Mechanistic
Cover Crops	Any crop grown to provide soil cover, regardless of whether it is later incorporated into the soil. Cover crops are grown primarily to prevent soil erosion by wind and water.	Mechanistic
Grassed Waterways	Natural / constructed vegetated channels near cropland where water concentrates or flows off fields. Helps prevent gully formation and erosion. May also trap sediment in surface runoff and absorb chemicals and nutrients.	Indirect
Field Borders	Vegetation installed along field perimeters to reduce sediment, nutrients, pesticides, and bacteria in surface runoff as it passes through.	Indirect
Filter Strips	Vegetation installed along channel segment edges to reduce sediment, nutrients, pesticides, and bacteria in surface runoff as it passes through.	Indirect
No-Till Farming	Grow crops from year to year without disturbing the soil through tillage. Can increase the amount of water in the soil and decrease erosion.	Mechanistic
Nutrient Management	Manage the amount, source, placement, form and timing of the application of plant nutrients and soil amendments.	Mechanistic
Residue Management	Grow a specific crop to maximize plant residue left on a field to reduce soil erosion.	Indirect
Strip cropping	Alternate strips of closely sown crops (hay, wheat, small grains) with strips of row crops (corn, soybeans, cotton, sugar beets). Reduces soil erosion and nutrient loss.	Indirect

Through coordination with project team members and local stakeholders, a set of possible management scenarios was developed while considering constraints with the project resources and model configuration. These scenarios are only a subset of possibilities that could be run with the model, but they do provide an illustration. A brief description of each scenario is provided below, and model results are presented in Section 6.2.

6.1.1 Drain Management

The baseline scenario assumes that tile drain flow occurs throughout the year. An alternative scenario was constructed in which all tile drains were removed from the watershed. This scenario evaluates the effect of tile drains in the export of sediment and nutrients from the watershed.

6.1.2 Conservation Tillage

The base case scenario assumes a distribution of conventional and conservation tillages (no-till and mulch till). A scenario was developed in which existing mulch till and no till were left unmodified, and every acre of conventional till was converted to mulch till. This scenario evaluates the benefits of implementing conservation tillage throughout the watershed.

6.1.3 Cover Crops

The base case assumes no cover crops within the watershed. Cover crops can be an efficient management tool to control soil erosion. A scenario was constructed in which cover crops were applied to every acre of conventional till in the watershed. Comparison with the base case will provide a bound on the benefits that can be expected from a cover crop management practice.

6.1.4 Crop Conversion to Grassland

BMPs of particular interest in the watershed include filter strips, riparian buffers, and wetlands. Unfortunately, AnnAGNPS does not provide a direct mechanism to discretely represent these BMPs within the model. Because the model required each cell to have only one dominant land use, it is not possible to convert a fraction of a watershed cell (e.g., the edge of a crop field, or a buffer along a stream) into a non-crop, natural land cover.

To support a similar, but simplified analyses, a scenario was constructed which converts the highest eroding cropland cells into a grassland. For this run, 9.4% of the watershed cropland with the highest erosion was converted. A second run was configured to convert a random 9.5% of the cropland cells to grassland to illustrate the benefits of targeted vs. random implementation of BMPs.

6.1.5 Improved Nutrient Management

Recently a lot of focus has been placed on fertilizer applications in the region and the potential impacts in high levels of soluble reactive phosphorus (SRP) reaching Lake Erie. It is suspected that fall/winter fertilization is a common practice in the agricultural community due to favorable soil, cost, and climate conditions. It is also suspected that fall/winter fertilization can lead to greater runoff and transport of nutrients due to lack of plant uptake and lack of incorporation due to soil compaction. Three different scenarios were constructed to evaluate the change in nutrient loading, if fertilizer application rates were reduced to 80%, 60% and 40% of the base case levels. The base case as well as the reduced nutrient application scenarios assumed that fertilizer application was done in the spring. Due to labor involved in manipulating input files, current project resources did not allow for a thorough evaluation of the change in nutrient loading under spring only, fall/winter only, or combined spring and fall/winter fertilizer application. Setting up these scenarios could be done under future efforts.

6.1.6 All Natural Watershed

There may be interest to look at the erosion potential of the watershed under pre-settlement conditions. A scenario was constructed in which all cropland cells were converted to a forest land cover. Though this is not a realistic management scenario for consideration, this scenario could provide insight regarding flow and constituents loadings under pre-settlement as compared to current day conditions.

6.1.7 Combined Management Scenario

To understand the cumulative benefits of implementing multiple BMPs, a scenario was constructed which combines the conservation tillage, conversion of crop to grassland, and improved nutrient management scenarios described above. First the 9.4% of the cropland with the highest erosion as converted to grassland, then conservation tillage was applied to all remaining cropland with conventional tillage. Finally, the fertilizer application rates were reduced to 40% of base levels. Model output from this scenario will provide an upper bound on the benefits that can be obtained for sediment and nutrient load reduction, given extensive BMP implementation.

6.2 MANAGEMENT SCENARIO RESULTS

The management scenario runs were a baseline calibration run that extended from 1995 to 2009 and used actual rainfall, land use and field and nutrient management inputs. Results from this simulation served as a base case to compare against the alternative simulations of various agricultural management practices.

6.2.1 Suspended Sediment

The base run produced an annual average runoff of 329.1 mm (12.96 inches) and an annual average sediment erosion of 5.273 tons/acre/yr. Ephemeral gully erosion was the dominant source, accounting for 4.478 tons/acre/yr, and sheet and rill erosion accounted for 0.795 tn/acre/yr (Table 5-19).The gross landscape erosion was 2,599,810 tons/yr, of which 200,177 tons/yr (or 8%) is delivered at the outlet of the watershed. This delivery ratio suggests that although a large amount of sediment is displaced in the watershed, only a small proportion of eroded sediment is delivered to the stream.

A comparison of sediment loading for the various alternative management scenarios is shown in Table 6-2 and Figure 6-1 on an annual average basis over the entire simulation period (1995 – 2009). Sediment loading refers to the amount of sediment that moves through stream channel and reaches the watershed outlet.

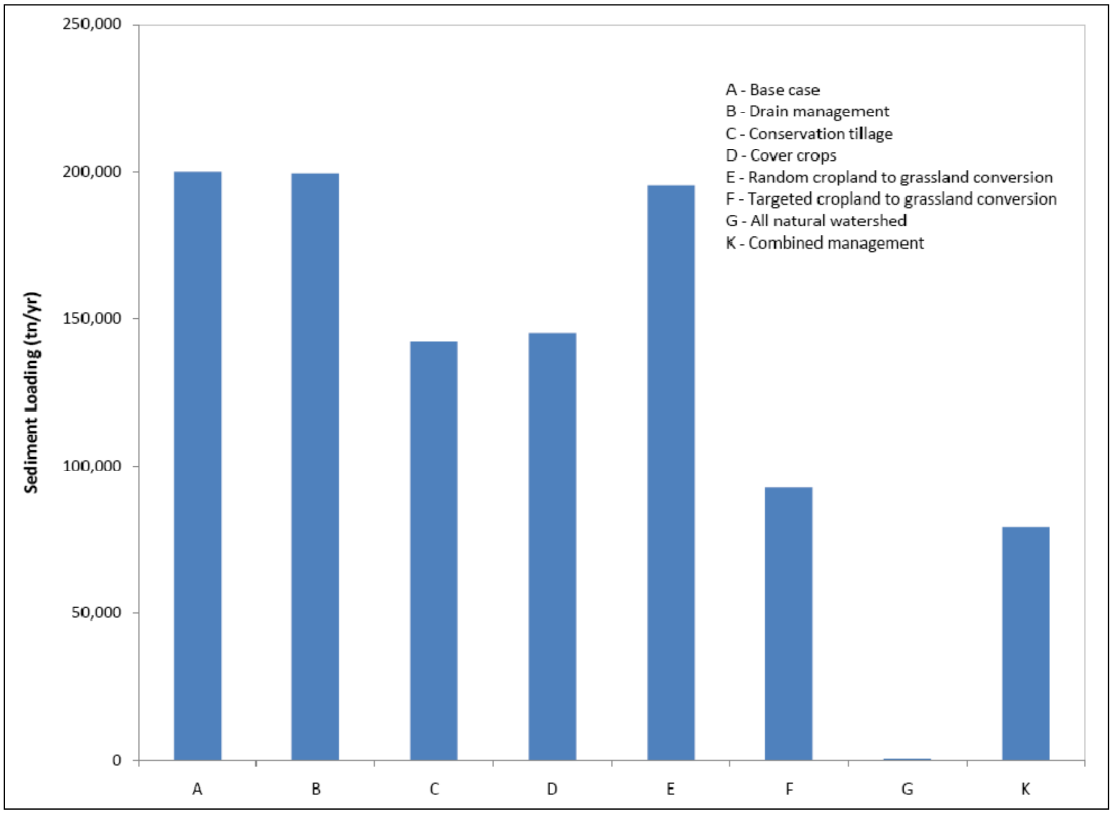

Figure 6-1. Average annual simulated sediment loading at watershed outlet for base case and management scenarios (1995-2009)

For Scenario B, the model predicted a marginal change in erosion and sediment erosion when the tile drains were turned off. With tile drains turned off, the model predicted a slight increase in sheet and rill erosion, ephemeral gully erosion, and sediment yield. Surprisingly, the model predicted a very slight *decrease* in sediment loading at the watershed outlet (0.3%). Direct runoff calculated by AnnAGNPS is a combination of both surface runoff and tile drain flow. Turning of tile drains resulted in an increase of surface runoff from 11.27 inches to 11.58 inches, and a decrease in subsurface volume from 1.69 inches to 0.01 inch. However, the net water yield for Scenario B was slightly lower (11.59 in) as compared to the base case (12.96 in). This lower overall yield likely contributed to the overall lower sediment load at the watershed outlet.

The effect of conservation tillage, a combination of mulch and till, applied to every acre cropland in the watershed resulted in substantially lower landscape erosion, which in turn resulted in reduced sediment loading at the watershed outlet compared to the existing condition or base case. The model predicted a sediment load reduction of 29% if conservation tillage practices were employed in the entire watershed (Scenario C). Similarly, the model predicted that planting cover crops on every acre of conventionally tilled cropland tillage could result in a sediment load reduction of 27% (Scenario D).

One key action of the conservation reserve program (CRP) is conversion of highly erodible agricultural land to long-term vegetative cover such as grasses, trees, filter strips or riparian buffers. Farmers receive an annual rental payment, and cost sharing is provided to establish vegetative cover (NRCS, 2010). A random conversion of 9.4% of the cropland area to grassland (Scenario E) resulted in an overall 2%, reduction of sediment load. In contrast, when the upper 9.5% of the highest eroding cells were targeted and converted to grassland (Scenario F), the model predicted a sediment load reduction of 54%.

A scenario in which all cropland cells were converted to forest (Scenario G) suggested a possible 99% reduction in sediment loading. Although this is not a realistic management scenario, it was developed as a reference. In addition to significant erosion reduction, the model predicted an approximate 50% reduction in annual runoff volume.

A final scenario (K) was developed to explore the potential cumulative benefits of combining the actions of Scenarios C, F, and J. The model predicted that a targeted conversion of 9.4% of the highest eroding cells to grassland along with implementation of conservation tillage to every remaining cropland acre and fertilizer application amounting to 40% of the base levels could result in a 60% reduction in sediment loading.

Table 6-2. Summary of sediment results of management alternatives simulated by AnnAGNPS

Scenario ID	*Scenario*	*Runoff volume [in]*	*Gross Sheet and Rill Erosion [t/ac/yr]*	*Gross Ephemeral Gully Erosion [t/ac/yr]*	*Sediment Yield [t/ac/yr]*	*Sediment Loading at Outlet [t/ac/yr]*	*% Loading Reduction*
A	Base case	12.96	0.795	4.478	1.180	0.406	
B	Tile drains turned off	11.93	0.797	4.569	1.195	0.405	0.30%
C	Conservation tillage	11.69	0.638	2.908	0.846	0.289	29%
D	Cover crops applied to every acres of conventional till	11.68	0.424	3.599	0.870	0.295	27%
E	9% of the random cropland cells converted to grassland	12.77	0.747	4.357	1.120	0.396	2%
F	10% of the highest eroding cells converted to grassland	12.75	0.67	0.951	0.494	0.188	54%
G	All Natural Watershed	6.40	0.004	0.000	0.001	0.001	99.8%
H	Fertilizer 80% of base case	12.96	0.795	4.478	1.180	0.406	0%
I	Fertilizer 60% of base case	12.96	0.795	4.478	1.180	0.406	0%
J	Fertilizer 40% of base case	12.96	0.795	4.478	1.180	0.406	0%
K	Combined Management Scenario	11.35	0.539	0.966	0.457	0.161	60%

Figures 6-2 to 6-5 provide spatial output of selected management scenarios along with the base case run. Sediment yield refers to the amount of eroded sediment that is transported across the landscape and reaches the channel.

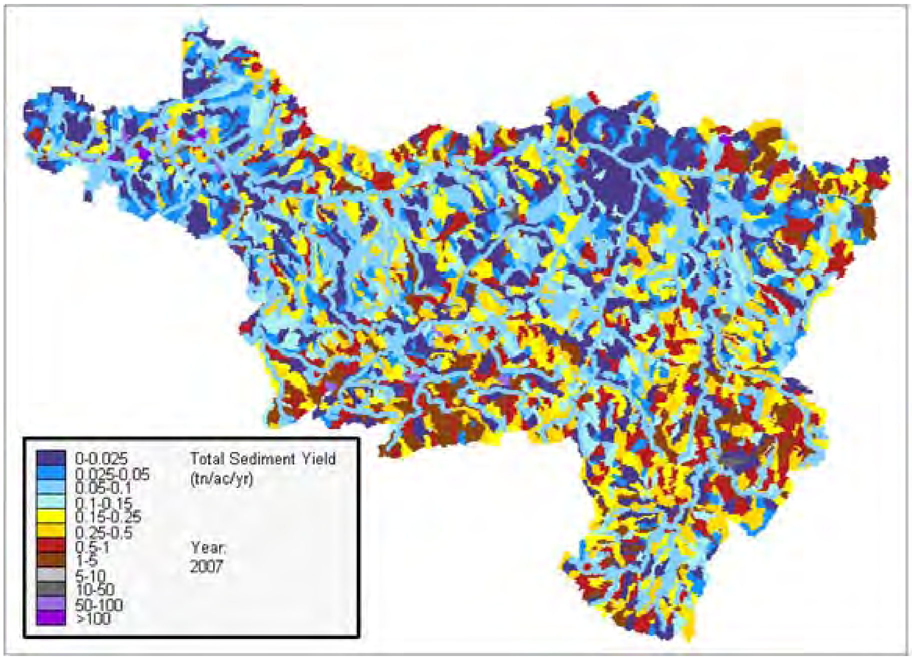

Figure 6-2. Spatial distribution of sediment yield to streams for Scenario A (base case)

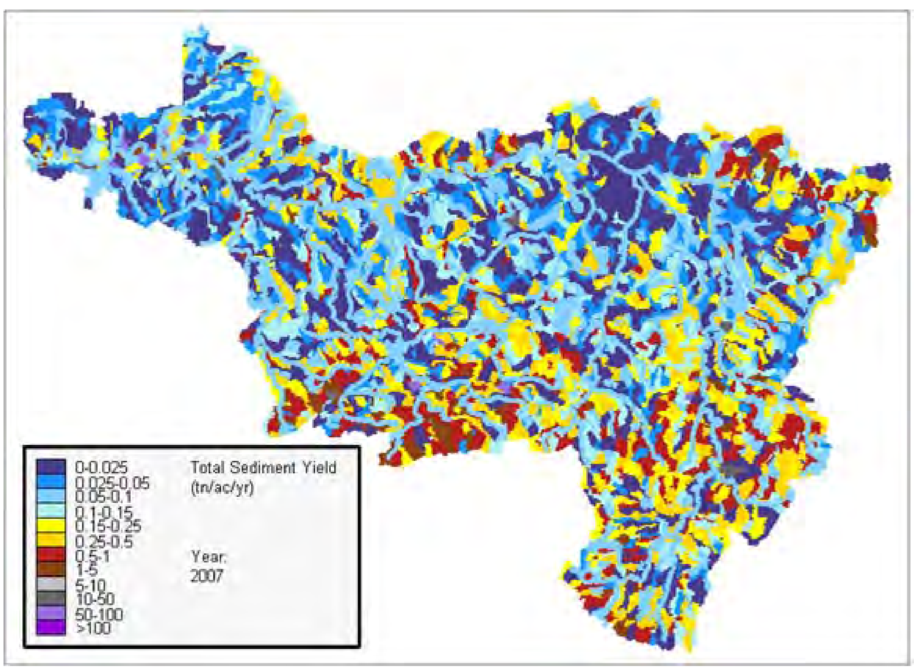

Figure 6-3. Spatial distribution of sediment yield to streams for Scenario C (conservation tillage)

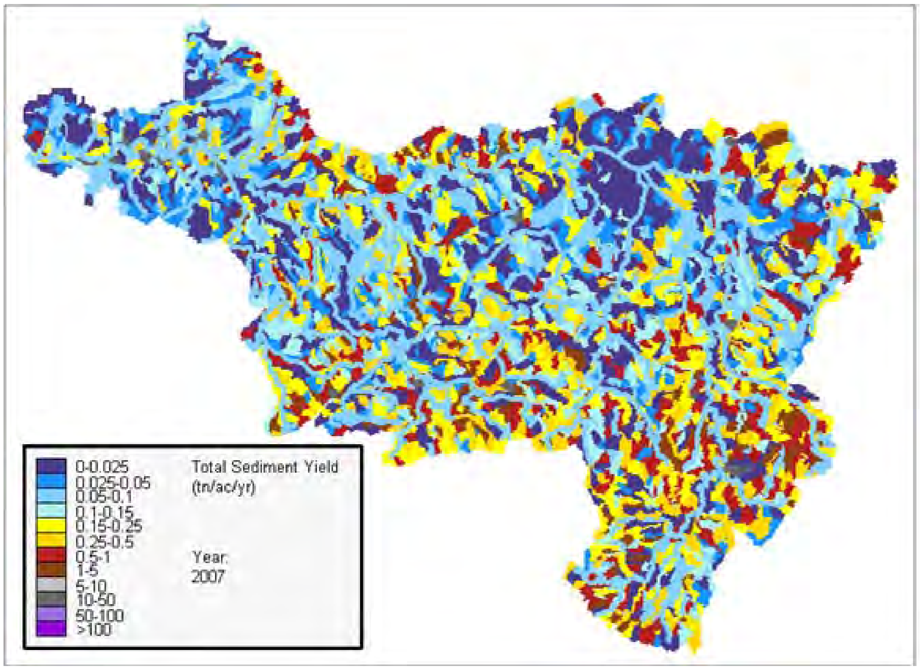

Figure 6-4. Spatial distribution of sediment yield to streams for Scenario F (targeted cropland to grassland conversion)

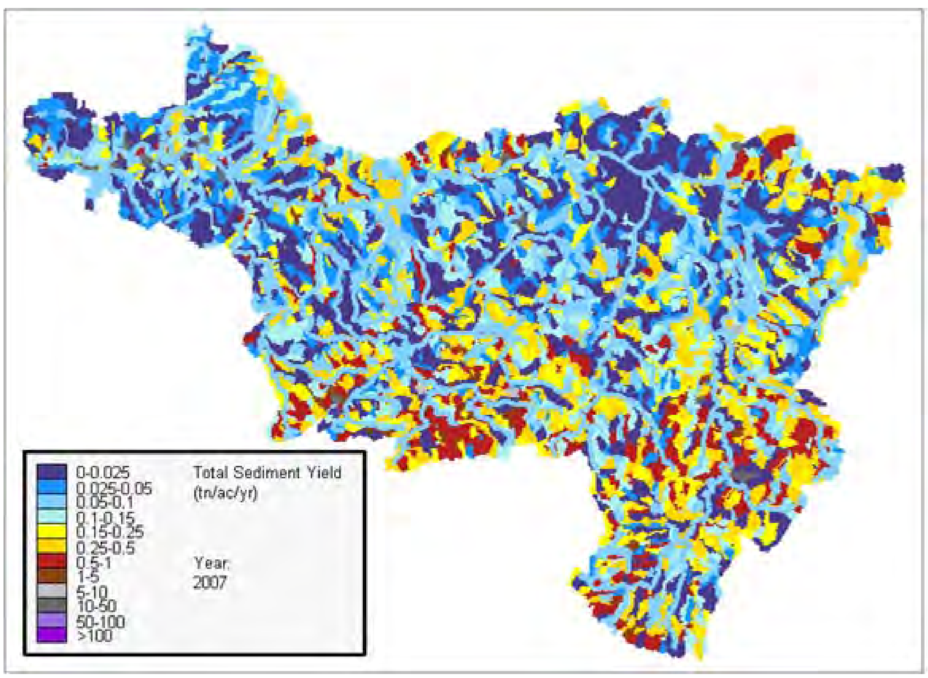

Figure 6-5. Spatial distribution of sediment yield to streams for Scenario K (combined management scenario)

6.2.2 Phosphorus

A comparison of total phosphorus loading for the base case run and the ten management runs is summarized below in Figure 6-6 and Table 6-3. Phosphorus loading refers to the amount of phosphorus that moves through stream channels and reaches the watershed outlet.

For the base case (Scenario A), the model calculated an annual average total phosphorus yield of 1.93 lb/ac/yr and an annual average load of 476 tons/yr at the watershed outlet. In general, the management scenarios with various land practices resulted in a decrease in the total phosphorus load at the watershed outlet. The model predicted that implementation of conservation tillage (Scenario C) and cover crops (Scenario D) would result in potential total phosphorus reductions of 13% and 25%, respectively. Reduction of fertilizer application from 80% to 40% of baseline levels (Scenarios H, I, J) resulted in a potential total phosphorus yield reduction ranging from 8% to 21%.

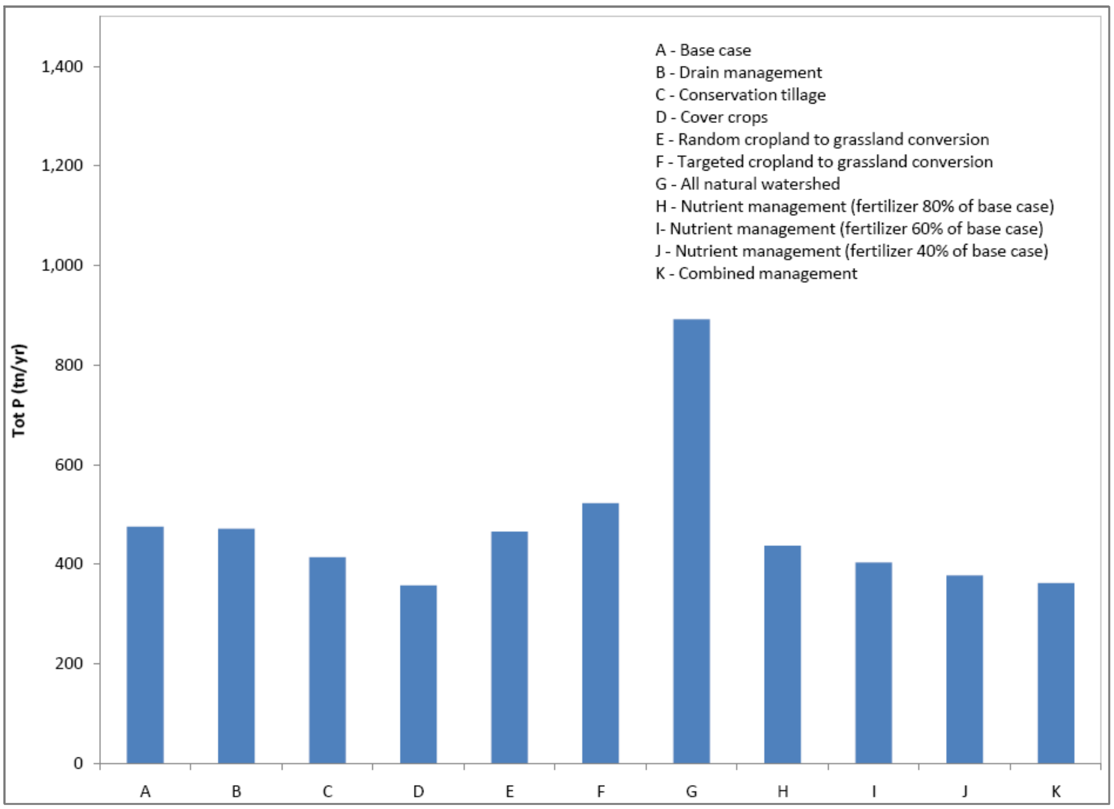

Figure 6-6. Average annual simulated total phosphorus loading at watershed outlet for base case and management scenarios (1995-2009)

Table 6-3. Simulated total phosphorus loading at the watershed outlet each management scenario (1995-2009)

Scenario ID	*Scenario*	*Phosphorus Loading at Outlet (lb/ac/yr)*	*Phosphorus Loading at Outlet (tons/yr)*	*% Reduction*
A	Base case	1.93	476	-
B	Tile drain management	1.91	471	-1%
C	Conservation tillage (mulch till and no-till)	1.68	414	-13%
D	Cover crops applied to every acre of conventionally tilled field	1.45	357	-25%
E	9% of the random cropland cells converted to grassland (pasture)	1.89	465	-2%
F	10% of the highest eroding cells converted to grassland (pasture)	2.12	523	10%
G	All cropland converted to forest	3.62	892	88%
H	Fertilizer 80% of base case	1.77	437	-8%
I	Fertilizer 60% of base case	1.63	403	-15%
J	Fertilizer 40% of base case	1.53	378	-21%
K	Combined management scenario	1.47	362	-24%

Two of the management scenarios produced unexpected results with respect to phosphorus yield. The management scenario that simulates a conversion of all cropland to forest (Scenario G) resulted in an 88% ***increase*** in total phosphorus load at the outlet. In addition, scenarios with random (Scenario E) and targeted (Scenario F) conversion of cropland to grassland resulted in slight decrease or moderate increase in total phosphorus yield. These unexpected results were evaluated in detail. Model inputs were reviewed to check for errors and for realistic input parameter values that would impact the phosphorus simulation. In addition, several diagnostic and sensitivity analyses were run to try to understand the reason for the unexpected and unrealistic model results.

The diagnostic and sensitivity analyses included adjustments to initial soil phosphorus concentrations for the non-crop land uses, and an increase in annual live root mass for the non-crop land use, forest. The initial soil phosphorus concentrations for non-crop land use were decreased substantially from the calibrated value of 32 ppm (inorganic plus organic) in the first soil layer and 16 ppm in the second soil layer, to 2 ppm (inorganic plus organic) in the first soil layer and 1 ppm in the second soil layer. The decrease was incorporated into both the base case run and the forest management scenario and rerun. The model responded with a significant decrease (more than half) in phosphorus yield from the watershed and loading at the outlet. Phosphorus loading from various land use types was reviewed and evaluated. The non-crop annual root mass input parameter for forest was also evaluated by increasing the base value two times. The model responded with only a slight decrease in phosphorus loading at the outlet.

Based on these diagnostic runs and others, it is suspected that phosphorus in non-crop land uses (forest, commercial, residential, roads) is represented almost entirely in a dissolved form and continually leaches out of the cells throughout the simulation period. This suggests that phosphorus is not being sufficiently utilized by plants in the non-crop land uses, and that phosphorus may be continually re-equilibrating with the stable and active pools providing a supply of labile (or dissolved) phosphorus in the model. These results suggest that the phosphorus cycling algorithms within AnnAGNPS warrant further investigation.

The conversion of the 10% highest eroding cropland cells to pasture (Scenario F) resulted in a decrease in the watershed phosphorus ***yield*** from 3.06 lb/ac/yr in the base case to 2.44 lb/ac/yr in the targeted cropland conversion, which is an expected response. In contrast and unexpectedly, the model predicted a 10% increase in total phosphorus ***loading*** at the watershed outlet between the base case and the targeted conversion of cropland to pasture (Table 6-3). A review of model inputs, parameters impacting the phosphorus simulation, and model results was conducted. This evaluation indicated that the cell or catchment portion of the model is responding as expected to improved field conditions with an increase in infiltration (subsurface flow) and an overall decrease in total surface runoff. Likewise, the phosphorus yield from the watershed decreased. However, the model's routing of phosphorus loads did not respond as expected for Scenario F, and a higher phosphorus load was delivered to the watershed outlet even with less total runoff and less phosphorus yield from the watershed. Further investigation of the model inputs, phosphorus algorithms, and chemical routing is required to fully understand the results of the targeted cropland conversion management scenario.

6.2.3 Nitrogen

A comparison of total nitrogen loading for the base case run and the ten management runs is summarized below in Figure 6-7 and Table 6-4. Nitrogen loading refers to the amount of nitrogen that moves through stream channels and reaches the watershed outlet.

For the base case (Scenario A), the model calculated an annual average total nitrogen yield of 16.1 lb/ac/yr and an annual average load of 3,968 tons/yr at the watershed outlet. In general, the management scenarios with various land practices resulted in a decrease in the total nitrogen load at the watershed outlet. The highest reduction in total nitrogen loading, a 96% reduction, was predicted for Scenario G (conversion of all cropland to forest). The model predicted a 75% reduction of total nitrogen for the combined management scenario (K), and a 39% reduction for the cover crop scenario (D). A moderate decrease of 24% was predicted for the conservation tillage management scenario (C). Fertilizer reduction scenarios (H, I, J) resulted in an estimation of potential total nitrogen yield to range from 20% to 60%. Random (Scenario E) and targeted (Scenario F) conversion of cropland to grassland resulted in potential reductions of total nitrogen loading of 9% and 15% respectively. In terms of nitrogen, these two scenarios were the least effective in decreasing the total nitrogen load at the watershed outlet.

The tile drain management scenario (B) that assumed all tile drains were turned off all the time resulted in a slight increase (1%) in total nitrogen load at the watershed outlet. The nitrate component in nitrogen is transported primarily in the dissolved form and is highly mobile. If surface runoff is increased from a lack of tile drainage, the dissolved nitrogen on the surface can easily be transported to a nearby stream.

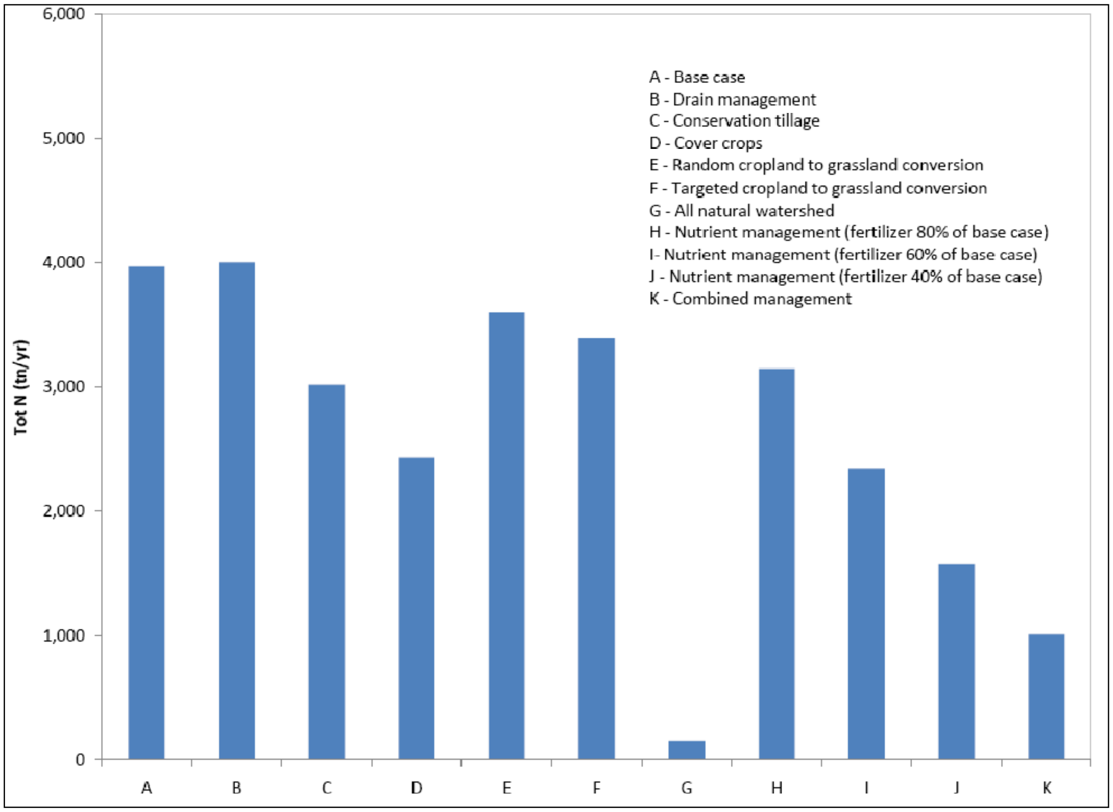

Figure 6-7. Average annual simulated total nitrogen loading at watershed outlet for base case and management scenarios (1995-2009)

Table 6-4. Simulated total nitrogen loading at the watershed outlet for each management scenario (1995-2009)

Scenario ID	*Scenario Description*	*N (lb/acre/yr)*	*N (tons/yr)*	*% Reduction*
A	Base case	16.1	3,968	-
B	Tile drain management	16.2	4,004	1%
C	Conservation tillage (mulch till and no-till)	12.2	3,018	-24%
D	Cover crops applied to every acre of conventionally tilled field	9.9	2,432	-39%
E	9% of the random cropland cells converted to grassland (pasture)	14.6	3,598	-9%
F	10% of the highest eroding cells converted to grassland (pasture)	13.7	3,390	-15%
G	All cropland converted to forest	0.63	155	-96%
H	Fertilizer 80% of base case	12.8	3,146	-21%
I	Fertilizer 60% of base case	9.5	2,349	-41%
J	Fertilizer 40% of base case	6.4	1,571	-60%
K	Combined management scenario	4.1	1,008	-75%

7. PROJECT SUMMARY AND CONCLUSIONS

7.1 SUMMARY

This report documents the application of a watershed model, AnnAGNPS, to the Blanchard River watershed in Ohio. The model adequately simulates runoff and suspended sediment as compared to observed conditions. Less confidence is placed on the simulation of total nitrogen and total phosphorus loading. A set of potential land management alternatives were explored with the model to estimate possible benefits of actions such as conservation tillage, cover crops, conversion of cropland to grassland, and fertilizer reduction practices. Not all desired management alternatives (e.g., filter strips) could be modeled directly within AnnAGNPS.

One conclusion of this work is that although modeling a watershed at a fine scale is beneficial to explore the benefits of localized changes in land management, it comes at a high price in terms of human and computational resource requirements.

7.2 MODEL LIMITATIONS AND CHALLENGES

The modeling results described above demonstrate the model's capability to simulate flow, suspended sediment, and nutrient loading in the Blanchard River watershed. However, during the model application, several model challenges and limitations were identified:

- AnnAGNPS is best suited to watersheds that range from small to medium (<1,000 square miles). Model set-up was difficult because of preprocessing tools having limits on level of detail for DEM that could be used to create a delineation.
- AnnAGNPS does not include a simulation of the groundwater component of streamflow. This may be important to effectively model a watershed with significant groundwater contributions or notable subsurface inputs of nitrogen to adjacent streams. AnnAGNPS requires the application of a hydrograph separation program to observed streamflow to allow for comparison of simulated and observed flow. This procedure introduces additional uncertainty in evaluating model performance.
- AnnAGNPS does not simulate the potential impacts of frozen soil in the late winter/early spring months on surface runoff. This contributed to an under-prediction of direct runoff as well as sediment and nutrient loading during the late winter/early spring periods.
- A high level of human and computational resources is required to set up and run AnnAGNPS simulations. The user interface lacks efficient preprocessing tools and tools to post process model results are limited. For example, the set-up of a management scenario involving modification of crop rotation management schedules would take approximately 6+ labor hours. Simulation time on a relatively fast machine would be 16 hrs for a 15-year simulation.

- There has not been extensive testing of AnnAGNPS nutrient cycling algorithms, and the model produced surprising results. Specifically, the model showed dramatic increases in phosphorus for conversion to non-crop land uses. The model appears to be extremely sensitive to initial soil concentrations of phosphorus, and the unexpected results could be related to either uptake or partitioning algorithms.
- Although some land management practices can be simulated directly (i.e., the model has a specific input or algorithm), others must be represented indirectly. For example, it is not possible to directly specify filter strips as a portion of a watershed cell. Instead, the user must convert one more cells to a different land use, and this approach has limitations related to scale.
- To represent point sources, AnnAGNPS only provides the option to enter a single, constant value for the entire simulation period.
- Although one advantage of AnnAGNPS is its capability to simulate ephemeral gully erosion in watersheds, there has not been extensive application and testing of ephemeral gully erosion algorithms, and uncertainty exists within the TIEGEM algorithm and its user-controlled inputs. The critical relationships for calculating critical shear, the nickpoint erodibility coefficient, and the headcut migration erodibility coefficient are based on data available for soils from Mississippi Delta, and may not represent a wider range of agricultural soils.
- The use of a relatively coarse 30 m resolution DEM is another source of error related to ephemeral gully erosion because higher resolution topographic data would result in a greater likelihood of identifying more realistic nickpoint locations. Nickpoint locations identified by the model could not be verified because of a lack of field data for the Blanchard watershed. Another limitation is that the model does not consider the influence of soil properties when determining the location of the mouth of ephemeral gullies.
- AnnAGNPS technical documentation of TIEGEM algorithms identified several limitations associated with the identification of and relationships for ephemeral gully width, soil resistance to gully erosion (including a definition of non-erosive layers), effects of root mass and aboveground vegetation on erosion resistance, ephemeral gully networks, and effects of subsurface flow on ephemeral gully erosion. Errors introduced due to any combination of these topics can lead to large errors for the prediction of ephemeral gully erosion.

7.3 RECOMMENDATIONS FOR FUTURE WORK

Several recommendations for potential future work include:

- Development of additional detailed management scenarios that were beyond the current available resources for this project, such as:
    - Seasonal variations of tile drain operation;

  - Seasonal variation of nutrient application to capture the possible implications of fall fertilization as compared to spring fertilization;
  - Additional variation of management scenarios which focus on more or less areas of the watershed converted to conservation tillage, cover crops, or grassland.

- Investigation and refinement (if warranted) of the phosphorus mass balance in crop and non-crop land use areas;
- Investigation and ground-truthing of ephemeral gully erosion algorithms;
- Use of the model to help support the development of watershed action plans such as those under development by the Blanchard River Watershed Partnership. This work may require simulation of a smaller subwatershed region of the Blanchard at a higher level of spatial detail; and
- Application of additional fine-scale models to other watersheds within the Maumee Basin (e.g., Tiffin), and coordination with modeling efforts downstream to characterize sediment and nutrient transport in the lower Maumee River and Toledo Harbor.

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