Upper Cedar River Watershed SWAT Model Report

Prepared for
Upper Cedar Watershed Management Improvement Authority

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Executive Summary

The Upper Cedar River watershed (UCW) is part of the Upper Mississippi Region and spans portions of southern Minnesota and north-central Iowa (Figure: Location Map). The UCW is approximately 1,685 square miles (1,078,400 acres) and lies in portions of seven counties in Iowa, the majority within Mitchell, Floyd and Bremer.

The Upper Cedar Watershed Management Improvement Authority (UCWMIA) have undertaken the development of a Soil and Water Assessment Tool (SWAT) model for the UCW system. The scope of this project is to use SWAT to simulate hydrologic and nutrient dynamics on a continuous simulation to identify priority watersheds that could be targeted for potential system changes or Best Management Practices (BMPs) needed to meet water quality standards in the Iowa.

This report is a summation of the application of the SWAT model and evaluation of nutrient load on a subwatershed scale. The report is divided into the following sections:

Executive Summary – Provides an overview of the report

Project Background – Summarizes the background of the project highlighting that the scope of this project is to simulate hydrologic and nutrient dynamics on a continuous simulation to quantify the impact that potential system changes or BMPs would have on the hydrology and nutrient impairment within the watershed.

Watershed Characteristics – Presents current information about the watershed relating to land use/ land cover, topography, soils, hydrology and farming practices.

Model Selection, Development and Performance – Describes the selection method used to select a SWAT model as the preferred modeling tool for this watershed; how and where data were compiled; and how the model was calibrated and validated.

Conclusion – Summarizes the project and provides recommendations.

Project/ Modeling Framework

Model Selection

To complete the project, the Agricultural Non-Point Sources Pollution Model (AGNPS), Hydrological Simulation Program – Fortran (HSPF), and the SWAT models were evaluated for use on this project.

After reviewing the list of available watershed data, desired model criteria, and the scope of the project, which requires a model that simulates nutrients on a continuous, basin-wide scale, and the intended use of the model, SWAT emerged as the model of choice.

Model Development

The model was developed in three major steps. These steps were completed as follows and are summarized described below:

1. Compile Data
2. Model Construction
3. Perform Model Calibration and Validation

Data Assessment

Various sources of data were available for land use, soils, topography, climate, land management, stream flow, water quality and infrastructure, as described above. Nutrient data were the most limited. Stream flow data were reviewed from the U.S. Geological Survey stream gages. Monthly averages of stream flow data from 1990 to 2010 were used to calibrate and validate the model.

Model Construction

The model was constructed in three key steps: watershed delineation, land use, and soils integration. The watershed delineation was completed by loading the Digital Elevation Model (DEM) into SWAT. Fifty (50) subbasins and the outlet to the Upper Cedar River watershed were defined. The land use and soil definitions were defined by loading the National Land Cover Data (NLCD) land use and Soil Survey Geographic (SSURGO) soil data layers, respectively. Once each subbasin was defined they were furthered divided into Hydrologic Response Units (HRU). After the HRUs were developed, land management practices, such as fertilizer application, crop rotations, and tillage operations were added. Lastly, climate data and point source data were added and the model was executed using default parameter data.

Model Performance

SWAT simulated results were compared to observed data to determine whether the model simulations provided a reasonable representation of actual conditions. The model was calibrated and validated to available flow data. Several statistical methods were used to evaluate the model's performance.

Conclusion

The UCWMIA undertook the application of a SWAT model to simulate the Upper Cedar watershed system. The scope of this project was to use SWAT to simulate hydrologic and nutrient dynamics on a continuous simulation to identify priority subwatersheds to target for system changes or BMPs needed to meet water quality standards in Iowa. Using the calibrated SWAT model, priority rankings were assigned to each subwatershed based on total nitrogen and phosphorous load, in addition to flood ranking.

Project Background

In addition to addressing future flooding concerns, the UCWMIA also placed emphasis on tackling the prevalent nutrient problems that plague much of Iowa. Iowa is one of the leading producers of nitrates in the Midwest, largely thought to be exacerbated by the heavy use of subsurface tile drainage.

To address these issues on the watershed scale, the Soil and Water Assessment Tool (SWAT) was selected to model the Upper Cedar system. The scope of this project was to use the SWAT model to simulate hydrologic and nutrient dynamics on a continuous simulation to identify potential system changes or Best Management Practices (BMPs) needed to meet proposed nutrient water quality standards.

The following sections describe the Upper Cedar watershed model including: model selection, application and performance; and use for identifying priority subwatersheds.

Watershed Characteristics

The Upper Cedar Watershed (UCW) is part of the larger Cedar River Watershed and encompasses 1,685 square miles – an exceptionally large geographic area. The Upper Cedar has its headwaters in the State of Minnesota. Of the entire UCW, 58% is within the State of Iowa. Approximately 18 square miles are in Black Hawk County, 174 square miles are in Bremer County, 5 square miles are in Butler County, 81 square miles are in Chickasaw County, 210 square miles are in Floyd County, 405 square miles are in Mitchell County, and 80 square miles are in Worth County (refer to Location Map in Appendix A). The 2010 Census reported a total population of 31,203 for all of the 25-Iowan communities that are at least partially within the UCW.

Land Use/Land Cover

The Upper Cedar Watershed is a 'working watershed', with more than 75 percent of the total land area associated with agricultural activities (refer to 2006 Land Cover map in Appendix A) and Table 1. Historically the region was dominated by prairies, but since European settlement, the area has remained primarily agricultural, with corn and soybeans as the dominant crops.

Table 1. Land use (as listed in the 2006 National Land Cover Dataset, NLCD)

National Land Cover Land Dataset (2006)	Area (sq miles)	Percent Area of Total Area
Open Water	10	0.6%
Developed, Open Space	105	6.2%
Developed, Low Intensity	29	1.7%
Developed, Medium	5	0.3%
Developed, High Intensity	2	0.1%
Barren Land	1	0.0%
Deciduous Forest	44	2.6%
Evergreen Forest	1	0.0%
Mixed Forest	0	0.0%
Shrub/Scrub	0	0.0%
Grasslands/Herbaceous	98	5.8%
Pasture/Hay	58	3.4%
Cultivated Crops	1301	77.2%
Woody Wetlands	25	1.5%
Emergent Herbaceous	7	0.4%
TOTAL	***1685***	***100.0%***

Topography

Elevation in the Upper Cedar ranges from approximately 1,440 feet above sea level (in Mower County, MN) to 850 feet (watershed outlet in Black Hawk County, IA). The topography is characterized by gentle slopes, with an average of 1.8% based on analysis of a 30 m DEM. A map depicting the elevations within the Upper Cedar can be found in Appendix A entitled Elevation Relief.

Topography can be a driving factor for selecting feasible BMPs for improving water quality and flood reduction. Certain BMPs are better suited for rolling terrain (e.g. constructed wetlands) while others can be implemented in flat terrain (e.g. cover crops). Therefore, slope can be used when prioritizing areas for specific types of BMP projects.

Soils

Soils within the watershed are generally poorly to somewhat poorly drained. Small patches of sandy loam and clay loam soils are present within the central and northeast parts of the watershed, which are moderately to poorly drained, respectively. Similarly, most of the soils have medium to low infiltration. Much of the agricultural fields are artificially drained via subsurface drain tiles.

The prevailing soils associations were captured in Natural Resources Conservation Service (NRCS) U.S. General Soil Map (STATSGO2) database. Until 2006, these data were referred to as the State Soil Geographic (STATSGO) database. It consists of a broad based inventory of soils and non-soil areas.

The NRCS updates soils survey datasets on a regular basis, providing the data online through the Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov/). For use on this project, the Soil Survey Geographic (SSURGO) dataset was used as discussed under Model Application.

Hydrology

Surface water in the Upper Cedar Watershed is dominated by the river and stream network with few large open bodies of water. The entire watershed has more than 2,500 miles of streams based on the National Hydrology Dataset (24K GIS dataset); approximately 1,550 miles of the stream network are within Iowa.

Within the Iowa portion of the Upper Cedar Watershed, 15 impairments were identified as a requiring a TMDL for a Category 5 Impairment along 11 stream segments in the DNR's final 2012 Integrated Report (approved by the EPA on April 24, 2013). The impaired segments are portions of the following streams: Burr Oak Creek, Cedar River, Deer Creek, Little Cedar River, Otter Creek, Rock Creek, Spring Creek and Turtle Creek.

Climate

The climate of the UCW has marked seasonal variations due to the latitude and interior continental location. The average monthly temperatures at Osage range from 15°F in January to 72°F in July (1981-2010, Midwestern Regional Climate Center, Osage USC00136305). The highest recorded temperature was 107°F in July of 1936 and the lowest recorded temperature was -35°F, occurring twice, once in January of 1912 and once in February of 1996. The average total annual precipitation between 1983-2013 (excluding years with missing records) was 35.6 inches. Additional precipitation stations within the Upper Cedar include Charles City, IA, Northwood, IA, and Austin, MN.

Farming Practices

As previously mentioned, land use within the watershed is predominately agricultural. Farming practices associated with agricultural land use generally consists of a rotation of corn and soybeans. Within the Iowa portion of Upper Cedar Watershed, corn and soybeans are the dominant cultivated crops comprising 57.3% and 41.0% of the total crop land, respectively, based on the 2013 USDA Cropland Data Layer. Many landowners adopt a corn/soybean annual crop rotation to increase corn yields and reduce nitrogen application expenses. Table 1 shows the percent coverage of the major crop types within the Iowa portion of the Upper Cedar watershed, again based on the 2013 USDA Cropland Data Layer.

Table 2: Iowa Portion of the Upper Cedar Watershed Cropland (2013 USDA Crop Land Data Layer)

Crop*	Percent of all cropland
Corn	57.3%
Soybeans	41.0%
Alfalfa	1.2%
Other Hay/Non Alfalfa	0.2%
Peas	0.1%

**Barley, Oats, Sweet Corn, Rye, Sorghum, Spring Wheat, Winter Wheat, and Other Crops each individually account for less than 0.1% of the total cropland.*

Model Selection, Development, and Performance

Model Selection

A range of simple to detailed hydrologic and water quality models are available. Many of these are public domain models, developed and supported by various government agencies. Private models, for sale by software companies, are also available. Drawbacks with private models include the cost, technical support, and limited access to the technical foundations. Based on the preference of using a public domain model and the requirement to use a tool that directly integrates GIS data, the list of potential models for selection was greatly reduced. The most viable models included Agricultural Nonpoint Sources (AGNPS), Hydrological Simulation Program - Fortran (HSPF), and the Soil and Water Assessment Tool (SWAT). When considering the large-scale scope of the project area as well as the available watershed data, and furthermore the planning intent, SWAT was selected as the most appropriate model.

The U.S. Geological Survey and the Iowa DNR used SWAT to simulate streamflow and nitrate loads within the Cedar River Basin (Hutchinson et al, 2013). The Cedar basin is relatively densely gaged in comparison to other watersheds in Iowa, and the goal of the project was to assess the ability of SWAT to model both gaged and ungaged watersheds in the state. The model was calibrated for 2000-2004 and then validated for 2005-2010. A modified version of this SWAT model was used in this study to focus specifically on the Upper Cedar Watershed and water quality.

SWAT is a physically-based water quality simulation model that operates on a user-selected daily, monthly, or yearly time step. It is a basin-scale model developed by United States Department Agriculture (USDA) - Agricultural Research Service (ARS), in Temple, Texas (Neitsch, Arnold, Kiniry, & Williams, 2005). SWAT was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in complex watersheds with varying soils, land use, and management conditions over long periods of time. The SWAT model components include: hydrology, weather, sedimentation, crop growth, nutrients, pesticides, and agricultural management.

The strength of the SWAT modeling approach is in the emphasis on landscape scale analysis of pollutant loadings with a powerful GIS-based interface. This yields a direct association between land use activities and water quality impacts to engage stakeholders in management efforts. The SWAT model also provides a unifying assemblage of data, a detailed understanding of the source of pollutants, an ability to simulate existing and future scenarios, and a foundation for analyzing adaptive management efforts to improve water quality over time.

ArcGIS 10.2 for Desktop (Environmental Systems Research Institute, 2014) and the extension ArcSWAT2012.10_2.16 (released 9/9/14) was used for model input generation and processing.

Model Development

The model was developed in three major steps. These steps were completed as follows and are described in more detail below:

1. Compile Data
2. Model Construction
3. Model Calibration and Validation

Data Compilation

Available monitoring data are critical to constructing a watershed model which accurately simulates the watershed. Data were compiled from project partners as well as various state and federal agencies.

It should be noted that even though the UCWMIA only has authority in the Iowa portion of the UCW, the entire watershed was modeled for accuracy.

Soils

The Natural Resources Conservation Service (NRCS) Division of the USDA maintains a database of soils data. This database is referred to as the Soil Survey Geographic (SSURGO) dataset (USDA-SSURGO). The SSURGO dataset is the most detailed soil mapping produced by the NRCS.

Land Use/ Land Cover

The National Land Cover Database (NLCD) coverage from 2001 was acquired from the United States Geologic Survey (USGS) Multi-Resolution Land Characteristics Consortium (MRLC) (USGS, 2001). NLCD data consists of land use and land cover classification data primarily based on interpretation of aerial photography and elevation data. Coverage for the NLCD area includes several class codes used to identify land use and land cover. The most common NLCD coverage in the UCW is agricultural.

Land Management

Landcover and crop information was obtained from the National Cropland Dataset. This dataset is created by the USDA, and the National Agricultural Statistics Service using satellite imagery to provide acreage estimates for different land use types. For the Upper Cedar SWAT model, the 2011 Cropland Data layer was selected because it had a higher resolution than earlier years (each cell size is 30 meter rather than 56 meter) and 2011 exhibited non-drought/flooding conditions. This dataset was used to determine all of the land cover types, except for agricultural areas with corn and soybean crops present.

Corn and soybeans are the dominate crops within the Upper Cedar and many farmers use crop rotations and modify their management practices accordingly (e.g. change fertilizer rates yearly). To determine the location of different crop rotations within the Upper Cedar, four years for the Cropland Data layer were combined (2010 – 2013). For simplicity, only the dominate crop rotations considered. MSA consulted with the County Soil and Water conservationists (NRCS) who recommended including continuous corn, a two year cycle of corn and soybeans (CSCS), and a three year cycle of corn, corn, and then soybeans

(CCS). Any other rotations were assigned to a dominant rotation. An example crop distribution is shown the map entitled 2013 Crop Distribution in Appendix A.

For each combination of corn and soybeans (or continuous corn, continuous soybeans) that was used, a variation of the management operation schedule in Table 3 was used. Fertilizer application rates were scaled based on data from the USGS (Hutchinson et al, 2013) as well as the Iowa Nutrient Reduction Strategy plan (http://www.nutrientstrategy.iastate.edu/; updated September 2014).

Table 3. Management operation schedule for corn and soybeans

Crop	Management Operation	Date (for each year of simulation)
Corn	Manure application (swine and beef)	April 1
	Tillage	April 18
	Plant/begin growing season	April 25
	Harvest and kill	October 15
Soybean	Plant/begin growing season	May 5
	Harvest and kill	October 15
	Manure application (swine and beef)	October 20
	Fertilizer application, anhydrous ammonia	November 1

Flow Data

Stream flow data are available from three USGS gage stations located within the Iowa portion of the Upper Cedar. Table 4 summarizes the USGS gages (water quality and water quantity) within the Upper Cedar.

Table 4: USGS Gages (water quality and water quantity) within the Upper Cedar Watershed

USGS ID	Site Name	Latitude	Longitude	County	River Mile	Gage currently collecting stream discharge data	Beginning date of discharge record	Ending date of discharge record	Water Quality Data Available	Notes
05457700	Cedar River at Charles City, IA	43.062472	-92.673245	FLOYD	252.9	Y	10/1/1964	present	Yes	Water quality sampling includes pH, nitrate plus nitrite, dissolved oxygen, and others. 20 nutrient samples between 4/26/1988 and 9/25/2012.
05458500	Cedar River at Janesville, IA	42.648316	-92.465186	BREMER	207.7	Y	10/1/1904	present	Yes	Water quality sampling includes pH, nitrate plus nitrite, dissolved oxygen, and others. 22 nutrient samples between 4/27/1988 and 9/25/2012.
05457505	Cedar River at Osage, IA	43.283472	-92.8525	MITCHELL		Y	4/16/2010	present	No	
05458300	Cedar River at Waverly, Iowa	42.73722	-92.47009	BREMER		Y	8/30/2000	present	No	
05457500	Cedar River at Mitchell, IA	43.317469	-92.879363	MITCHELL		N	7/1/1933	9/30/1942	No	
05457000	Cedar River near Austin, MN	43.6372222	-92.9744444	MOWER		Y	6/1/1909	present	Yes	Water quality sampling includes suspended sediment and a few others.
05457200	Cedar River at 100th St near Lyle, MN	43.5142222	-93.0028611	MOWER		N	--	--	Yes	Only water quality sampling. Water quality sampling includes nitrate, nitrite, suspended sediemnt, ammonia, and others.
05457778	Little Cedar River near Johnsburg, MN	43.5144444	-92.7552778	MOWER		N	--	--	No	Only peak flow measurements (28 in total).
05458000	Little Cedar River near Ionia, IA	43.03328	-92.503544	CHICKASAW	6.4	Y	10/1/1954	present	Yes	Water quality sampling includes pH, nitrate plus nitrite, dissolved oxygen, and others. 4 nutrient samples between 7/23/1988 to 8/18/2009.
05455940	Cedar River at Lansing, MN	43.7463889	-92.9583333	MOWER		N	--	--	No	Only peak flow measurements (7 in total).

Data Assessment for Modeling

As described above, various forms of data are available for land use, soils, topography, climate, land management, stream flow, water quality and infrastructure. Nutrient data are the most limited for model construction.

Application of the SWAT model to the UCW includes acknowledgement of data issues and limitations. Errors due to data can have significant impact on the accuracy of the model results. Where there were data gaps, model defaults were used to support the modeling effort, where necessary. These defaults were based on researched values in the SWAT model, SWAT manuals and/or conclusions of literature research, and modeling experience. The key to making the most successful use of a SWAT model is to calibrate the model to observed flow.

Model Construction

The watershed delineation was completed by loading the previously described DEM into SWAT. SWAT uses the DEM to delineate the stream location and subbasin boundaries. HUC-12 subbasin boundaries were used as guides for the subwatershed delineations (see Subwatershed map in Appendix A). Additionally, three HUC-12 watersheds were artificially split so as to provide an outlet at the stream gage locations for use during calibration and validation. Thus, a total of fifty (50) subwatersheds and the outlet to the Cedar River were defined.

The soils data were from the SSURGO database, which included the type of soil, their infiltration capacity, water retention capacity, and other soil characteristics. These data assisted in simulating runoff, sediment transport and vegetation potential (for crop growth simulation) in SWAT. The land use, soil and slope (derived from the DEM) data were reclassified using the SWAT land cover classes, the state soil identifiers and the calculated land slopes and then superimposed in SWAT. This resulted in each watershed having subbasin of specific land use, soils and slope (e.g. corn/Oran/0-0.5%).

With the characteristics of each subbasin defined, the hydrologic response unit (HRU) distribution was selected. HRUs were defined using the default 'land use percentage over subbasin area' of five (5) percent and 'soil class percentage over land use area' of five (5) percent and 'slope class percentage over the land use area' of five (5) percent. This resulted in 3491 unique HRUs. For each HRU, water flux and transport of sediment and nutrients are simulated in the SWAT model and then routed through a subwatershed, i.e., water and chemicals are transported from one subwatershed to the next, depending on flow characteristics.

After inputting watershed land use, soils, slope and land management information were completed, the SWAT View was used to enter weather data and to define the coefficients. Climate data from stations within the watershed were used for the climatological data.

Potential evapotranspiration (PET), surface runoff, and routing methods, as well as land-management operations, must also be selected in the model. In this case the Hargreaves method for estimating PET, which only requires temperature data for input, was selected. Two methods for estimating surface runoff are provided in SWAT and include the Green and Ampt equation and the CN method.

The CN method, which estimates surface runoff based on hydrologic soil group, land cover, and antecedent moisture condition, was selected. The variable-storage and Muskingum method are available for simulating channel routing. Both methods are variations of the kinematic wave model. The Muskingum method was selected because it improved the timing of peak flows relative to the variable-storage routing method.

For simplification, a corn-soybean rotation was implemented basinwide, and includes fertilizer and manure applications (Table 3). Manure land application also was simulated for corn for spring and fall.

Artificial drainage by way of subsurface drain tiles constitutes the majority of the Upper Cedar . To simulate tile flow, values were set for the depth to subsurface drains (DDRAIN), the time to drain the soil to field capacity (TDRAIN), and the time between the transfer of water from the soil to the drain tile, and then from the drain tile to the reach (GDRAIN). In addition, initiation of tile flow requires that a depth to impervious layer (DEP_IMP) be set at approximately the same depth as the tile drain. During model calibrartion, however, it was instead determined that using the max rooting depth provided more representative tile flow. The max rooting depth was calculated by determining the max rooting depth (soil characteristic) for each HRU. Because subsurface tile drainage is so prevalent within the watershed, tiles were applied basinwide. Tile parameters are listed below in Table 5.

Table 5. Upper Cedar Tile Flow Parameters

Parameter	Units	Calibrated Model
DDRAIN	mm	1200
TDRAIN	hours	36
GDRAIN	hours	72
DEP_IMP	mm	2030

Model Performance

The model results were compared to observed data to determine whether the model simulations provided a reasonable representation of actual conditions. Standard SWAT calibration practices were followed for stream flow calibration and validation. Calibration and validation for the Charles City stream gage had to be modified slightly since there was a gap in the recorded data from 1998 through 2000.

The USGS has collected water quality data at five locations in the Upper Cedar, three of which are in Iowa. Sampling is typically not continuous, but can provide a snapshot view in time of water quality. Station information can be found in Table 4, and site specific data can be obtained from the USGS National Water Information System (NWIS):

Calibration and Validation

Calibration and validation is an essential part of the modeling process, especially when working with a complex model and when covering such a large study area. Calibrating validates the model outputs so that results can be trusted with a greater degree of certainty. While models are always limited by the quality and quantity of input data, calibrating and validating can go a long way in closing the gap on reliable results when compared with measured data.

Flow

The most commonly used parameter for initial calibration and validation of SWAT models is streamflow. A 10-year and 11-year period that included wet and dry years were selected for model calibration (January 1, 1990 to December 31, 1999) and validation (January 1, 2000 to December, 31, 2010), respectively. The initial group of calibration parameters was selected based on previous published studies that assessed the sensitivity of parameters for Iowa, as well as other Midwestern agricultural basins. Calibration was completed by manually adjusting parameter values within their acceptable ranges (Arnold et al, 2010) to match simulated to measured streamflow at two of the USGS streamflow gage stations. The selected parameters are described in Table 6.

Table 6. SWAT model calibration parameters

Parameter	Summary
ALPHA_BF	Base flow alpha factor (days).
ESCO	Soil evaporation compensation factor.
GW_REVAP	Groundwater revap coefficient. As GW_REVAP approaches 0, movement of water from the shallow aquifer to the root zone is restricted.
GWQMN	Threshold depth of water on the shallow aquifer required for return flow to occur (mm H_2O).
REVAPMIN	Threshold depth of water in the shallow aquifer for revap or percolation to the deep aquifer to occur (mm H_2O).
SURLAG	Surface runoff lag coefficient.

After an iterative process, those parameters were manually adjusted to produce a flow-calibrated SWAT model of the Upper Cedar. The final parameter values, along with the default values are summarized in Table 7.

Table 7. Upper Cedar watershed SWAT Model Calibration Parameters

Parameter	Units	Default	Calibrated Model
ALPHA_BF	days	0.048	0.9
ESCO		0.95	0.7
GW_REVAP		0.02	0.05
GWQMN	mm	1000	300
REVAPMIN	mm	750	400
SURLAG	days	2	2

Calibration was completed for average monthly conditions, starting with the upstream streamflow gaging station (Charles City) and moving downstream to the next consecutive streamflow gaging station (Janesville). Performance was evaluated by determining the coefficient of determination, Nash-Sutcliffe efficiency, root mean square error, and the percent bias for both streamflow gaging stations. The model was considered calibrated when the statistical results were within acceptable range for both the calibration and validation periods.

Statistical Analysis Methods

*Coefficient of determination (*R^2*)*

The R^2 value indicates the consistency with which measured versus predicted values follow a linear best-fit line (Equation 1). R^2 only describes how much of the measured dispersion is explained by the prediction, and therefore R^2 is not suggested to be used alone (Maidment, 1993). R^2 values range from 0 and 1, and the closer the value is to 1, the better the linear correlation between measured and simulated values (Kalin and Hantush, 2006). Gassman and others (2007) considered an R^2 value of greater than 0.5 satisfactory when comparing across multiple SWAT studies.

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

where *O* is the observed (measured) value, *P* is the predicted (simulated) value, and *n* is the number of events. The over-bar denotes the mean (measured or predicted) for the evaluation time period.

*Nash–Sutcliffe model efficiency index (*E*)*

The *E* indicates how well the simulated values agree with the measured values (Nash and Sutcliffe, 1970), and is estimated using Equation 2. The *E* ranges from negative infinity (poor model) to 1.0 (perfect model). The *E* model performance ratings proposed by Moriasi and others (2007) was used to evaluate model calibration and validation and are as follows: “very good” if the monthly *E* is greater than or equal to 0.75, “good” if the monthly *E* is greater than or equal to 0.65 but less than 0.75, “satisfactory” if the monthly *E* is greater or equal to 0.5 but less than 0.65, and “unsatisfactory” if the monthly *E* is less than 0.5.

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

where *O* is the observed (measured) value, *P* is the predicted (simulated) value, and *n* is the number of events. The over-bar denotes the (measured or predicted) mean for the entire time period of the evaluation.

Root mean square error (RMSE)

The RMSE (Equation 3) summarizes the average error between measured and predicted variates using the same units as those variates. The smaller the RMSE, the better the performance of the model; a value of zero represents perfect simulation of the measured data. However, there is no absolute value suggested for RMSE (Moriasi et al., 2007). The RMSE indicates the bias (deviation of the actual slope from the 1:1 line) compared with the random variation that may occur (Willmott, 1984).

$$\text{RMSE} = \left(\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n} \right)^{0.5} \quad (3)$$

where RMSE is the root mean squared error, *O* is the observed (measured) value, *P* is the predicted value and *n* is the number of events.

Percent Bias (PBIAS)

The PBIAS (Equation 4) is a measure of the average tendency of over-predictions and under-predictions of the simulated data for the time period being evaluated (Bumgarner and Thompson, 2012). A value of 0.0 indicates ideal performance, while positive values indicate underestimation bias and negative values indicate overestimation bias (Moriasi and others, 2007). Model performance for streamflow is considered "very good" if the PBIAS is between 0 and plus or minus (+/-) 10 percent, "good" if the PBIAS is between +/- 10 and +/- 15 percent, "satisfactory" if the PBIAS is between +/- 15 and +/- 25 percent, and "unsatisfactory" if the PBIAS is +/-25 percent or greater (Moriasi and others, 2007).

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^{n} (O_i - P_i) * (100)}{\sum_{i=1}^{n} O_i} \right] \quad (4)$$

where PBIAS is the percent bias, *O* is the observed (measured) value, *P* is the predicted (simulated) value, and *n* is the number of events.

Results

Two gage sites within Iowa were selected as streamflow calibration and validation sites.

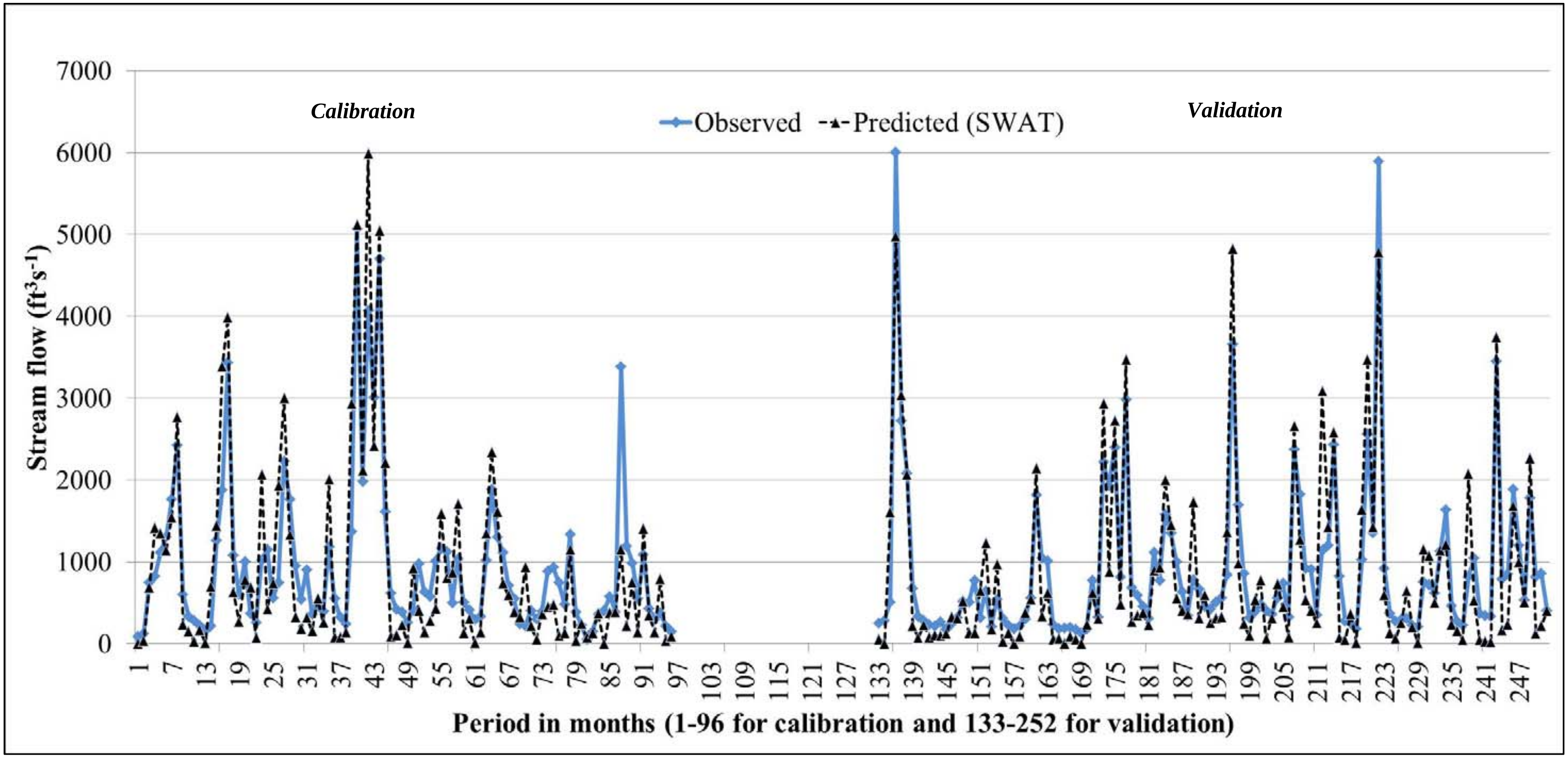
Unfortunately there was data missing between October 1998 and February 2001 for the Charles City stream gage. Thus, the years from 1998-2000 were removed from the calibration/validation analysis.

Results are summarized in Table 8 below and in the graphs below.

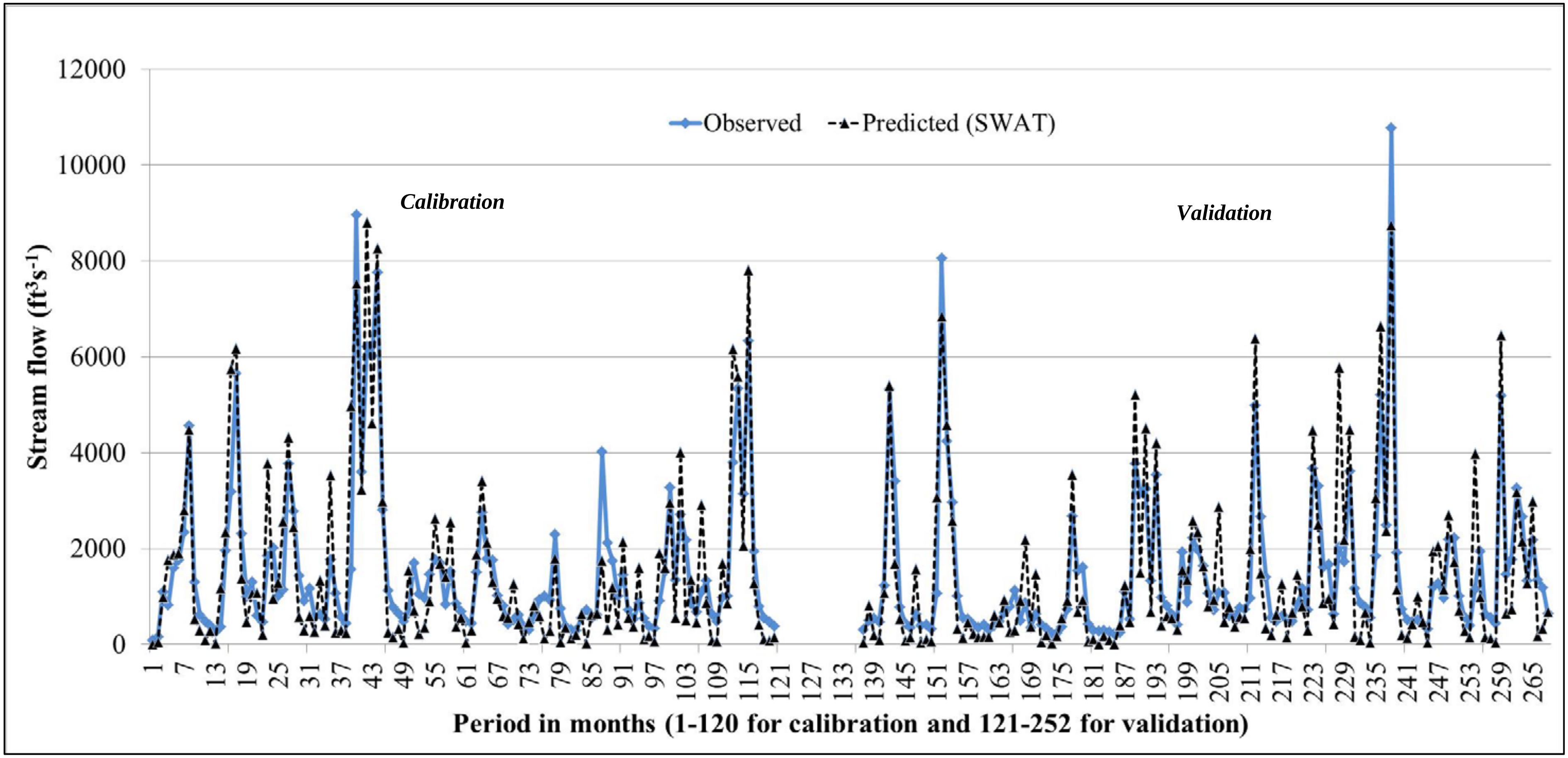
Table 8. Hydrology calibration results for monthly streamflow averages

Calibration (1990-1999)	R^2	*E*	RMSE	PBIAS
Charles City	0.79	0.66	15.5	3.1%
Janesville	0.79	0.70	24.6	1.0%
Validation (2000-2010)	R^2	*E*	RMSE	PBIAS
Charles City	0.82	0.78	13.0	6.9%
Janesville	0.79	0.73	22.6	2.5%

Graph 1: Observed versus predicted streamflow for calibration and validation periods at Charles City, Iowa



Graph 2: Observed versus predicted streamflow for calibration and validation periods at Janesville, Iowa



Evaluation of Nutrients

Using the UCW calibrated SWAT model, a five year average from 2003 to 2007 was used to determine total nitrogen and total phosphorous load (lbs/ac) for each subwatershed. Evaluation of a 10-year average to the five-year average yielded little difference. A five-year span from 2003-2007 was selected for use in prioritizing watersheds because it is the most recent data available and does not take in to account the 2008, which caused an abnormal flush of nutrients. Below, the weighted watershed averages are presented in Table 9.

Table 9. Simulated nitrogen and phosphorous loads, weighted over the entire watershed.

	2003-2007	2001-2010	2008
Nitrogen load (lb/ac)	**29.5**	30.6	56.4
Phosphorous load (lb/ac)	**2.2**	2.3	4.2

The goal of this exercise was to determine nutrient loads on a per watershed basis. Nutrients have historically been a principal concern within the watershed, and the state of Iowa proposes a state-wide reduction to the Mississippi River by 45 percent.

Future work could use the calibrated Upper Cedar SWAT model to simulate the effect with the addition of BMPs, modified land use, and/or changes in subsurface drainage. This effort cannot be completed until decisions are made about which watersheds will be selected and what changes will be made.

Conclusion

The UCWMIA undertook the application of a SWAT model to simulate the Upper Cedar watershed system. The scope of this project was to use SWAT to simulate hydrologic and nutrient dynamics on a continuous simulation to identify priority subwatersheds to be targeted for improvement with the hope of having sizable impact should changes or BMPs be implemented.

The model was subdivided to approximately align with the HUC-12 watershed boundaries, and calibrated (1990-1999) and validated (2000-2010) to streamflow using USGS gages near Charles City and Janesville. Land use was derived from the USDA-NRCS Cropland Data layer incorporating the years 2009-2012 (30 m grid resolution), simplifying crop rotations to the following: continuous corn, corn/soybean, and corn/corn/soybean. Any other crop types/rotations were assigned to one of these dominant rotations. Drain tiles were applied across all land within the watershed, and a uniform set of management practices was applied to all cropped areas based on crop type (e.g. tillage type and timing, fertilizer application quantity and timing, planting/harvesting timing, etc). Parameters were adjusted manually to better correlate with observed streamflow records.

A base output of this model was used to determine which subwatersheds had the highest nitrogen and phosphorous loading on a per acre basis in order to prioritize watersheds for future work. Figures in Appendix A display the annual nitrogen and phosphorous loadings from the HUC-12 watersheds. Note that nutrient loadings are highly dependent on the input parameters within the SWAT model. As precise data is not available for the entire watershed, the model was built under basic assumptions (e.g. all landowners applying fertilizer on the same day every year), which results in over-/under-predicting output values for any discrete sampling period. However, the model is useful in comparing the relative contribution of nutrient loading in comparison to other subwatersheds within the Upper Cedar.

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Appendix A: Figures