Prepared in cooperation with the Iowa Department of Natural Resources

Use of the Soil and Water Assessment Tool (SWAT) for Simulating Hydrology and Water Quality in the Cedar River Basin, Iowa, 2000–10

Scientific Investigations Report 2013–5002

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: Cedar River at Seminole Valley Park, Cedar Rapids, Iowa.

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KEN SALAZAR, Secretary

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Application rate	
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year [(kg/ha)/yr]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Use of the Soil and Water Assessment Tool (SWAT) for Simulating Hydrology and Water Quality in the Cedar River Basin, Iowa, 2000–10

By Kasey Hutchinson and Daniel Christiansen

Abstract

The U.S. Geological Survey, in cooperation with the Iowa Department of Natural Resources, used the Soil and Water Assessment Tool to simulate streamflow and nitrate loads within the Cedar River Basin, Iowa. The goal was to assess the ability of the Soil and Water Assessment Tool to estimate streamflow and nitrate loads in gaged and ungaged basins in Iowa. The Cedar River Basin model uses measured streamflow data from 12 U.S. Geological Survey streamflow-gaging stations for hydrology calibration. The U.S. Geological Survey software program, Load Estimator, was used to estimate annual and monthly nitrate loads based on measured nitrate concentrations and streamflow data from three Iowa Department of Natural Resources Storage and Retrieval/Water Quality Exchange stations, located throughout the basin, for nitrate load calibration. The hydrology of the model was calibrated for the period of January 1, 2000, to December 31, 2004, and validated for the period of January 1, 2005, to December 31, 2010. Simulated daily, monthly, and annual streamflow resulted in Nash-Sutcliffe coefficient of model efficiency (E_{NS}) values ranging from 0.44 to 0.83, 0.72 to 0.93, and 0.56 to 0.97, respectively, and coefficient of determination (R^2) values ranging from 0.55 to 0.87, 0.74 to 0.94, and 0.65 to 0.99, respectively, for the calibration period. The percent bias ranged from -19 to 10, -16 to 10, and -19 to 10 for daily, monthly, and annual simulation, respectively. The validation period resulted in daily, monthly, and annual E_{NS} values ranging from 0.49 to 0.77, 0.69 to 0.91, and -0.22 to 0.95, respectively; R^2 values ranging from 0.59 to 0.84, 0.74 to 0.92, and 0.36 to 0.92, respectively; and percent bias ranging from -16 for all time steps to percent bias of 14, 15, and 15, respectively.

The nitrate calibration was based on a small subset of the locations used in the hydrology calibration with limited measured data. Model performance ranges from unsatisfactory to very good for the calibration period (January 1, 2000, to December 31, 2004). Results for the validation period (January 1, 2005, to December 31, 2010) indicate a need for an increase of measured data as well as more refined documented management practices at a higher resolution. Simulated nitrate loads resulted in monthly and annual E_{NS} values ranging from 0.28 to 0.82 and 0.61 to 0.86, respectively, and monthly and annual R^2 values ranging from 0.65 to 0.81 and 0.65 to 0.88, respectively, for the calibration period. The monthly and annual calibration percent bias ranged from 4 to 7 and 5 to 7, respectively. The validation period resulted in all but two E_{NS} values less than zero. Monthly and annual validation R^2 values ranged from 0.5 to 0.67 and 0.25 to 0.48, respectively. Monthly and annual validation percent bias ranged from 46 to 68 for both time steps. A daily calibration and validation for nitrate loads was not performed because of the poor monthly and annual results; measured daily nitrate data are available for intervals of time in 2009 and 2010 during which a successful monthly and annual calibration could not be achieved.

The Cedar River Basin is densely gaged relative to other basins in Iowa; therefore, an alternative hydrology scenario was created to assess the predictive capabilities of the Soil and Water Assessment Tool using fewer locations of measured data for model hydrology calibration. Although the ability of the model to reproduce measured values improves with the number of calibration locations, results indicate that the Soil and Water Assessment Tool can be used to adequately estimate streamflow in less densely gaged basins throughout the State, especially at the monthly time step. However, results also indicate that caution should be used when calibrating a subbasin that consists of physically distinct regions based on only one streamflow-gaging station.

Introduction

An extensive network of U.S. Geological Survey (USGS) streamflow-gaging stations spans the State of Iowa, and although hydrologic information for these streamflow-gaging stations is provided on a near real-time basis, there is still a need for hydrologic information at ungaged locations. The USGS, in cooperation with the Iowa Department of Natural Resources (IDNR), conducted a study to estimate streamflow and nutrient loading at any point on a stream by developing a comprehensive approach using predictive tools and modeling. The ability to estimate streamflow and water quality can provide valuable information for environmental studies, hydraulic design, reservoir management, water management, urban studies, and recreation. This study focuses on the use of the Soil and Water Assessment Tool (SWAT) (Arnold and others, 1998; Neitsch and others, 2005) for making such estimates. The availability of varied and extensive land-management options in SWAT make it an ideal model for simulating streamflow and chemical fate and transport in agricultural basins.

While the scope of the project is statewide, the Cedar River Basin, located in central Iowa, was selected as the first basin to be modeled (fig. 1). Agriculture dominates land cover in the basin in the form of row crops, and artificial drainage is extensive (Iowa Department of Natural Resources, 2006a). The basin was removed from the State's 303(d) list for nitrate-nitrogen in 2008 because of Total Maximum Daily Load (TMDL) approval, but remains on the list for bacteria (Iowa Department of Natural Resources, 2008a), biological, low dissolved oxygen, mercury, and polychlorinated biphenyl (PCB) impairments (Iowa Department of Natural Resources, 2010a).

Purpose and Scope

This report describes the SWAT results of hydrology and water quality simulation, specifically the hydrology and nitrate load calibration (January 1, 2000, to December 31, 2004) and hydrology and nitrate load validation (January 1, 2005, to December 31, 2010) for the Cedar River Basin. The ability of SWAT to simulate streamflow and nitrate loads for the Cedar River Basin was tested as was the potential for making the same estimates for ungaged stream reaches in Iowa. This was done by creating an alternative scenario in which the model was calibrated and validated using only a subset of the streamflow-gaging stations used in the initial calibration and validation. The alternative scenario can indicate the level of reliability of SWAT to accurately predict streamflow in less densely gaged basins, which is more typical of other basins in the State. Model limitations were investigated and described.

Description of Study Area

Draining approximately 7,815 square miles, the Cedar River Basin extends from its headwaters in southern Minnesota to its outlet in southeastern Iowa at Columbus Junction where it joins, as the largest tributary, the Iowa River, (fig. 1) (Iowa Department of Natural Resources, 2006a; Squillace and others, 1996). Row-crop agriculture dominates the land cover in the form of corn and soybeans, and the basin is extensively artificially drained (Iowa Department of Natural Resources, 2006a). Artificial drainage includes open ditches and subsurface drainage tile, both designed to remove excess water from the soil subsurface. Confined and unconfined livestock operations that include beef and dairy cattle, hogs, sheep, and poultry are located throughout the basin (Iowa Department of Natural Resources, 2006a). Designated uses for the Cedar River include primary contact recreation, significant resource warm water, and drinking water supply (Iowa Department of Natural Resources, 2006a). There are 12 USGS streamflow-gaging stations, 3 IDNR Storage and Retrieval/Water Quality Exchange (STORET/WQX) stations, 4 Iowa State University (ISU) Ag Climate Network stations, and 22 National Weather Service (NWS) Cooperative Observer Program (COOP) stations, located within and surrounding the basin from which measured data have been acquired for this study (fig. 2, table 1).

Land Cover

The U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2008 Cropland Data Layer (CDL) (National Agricultural Statistics Service, 2008) was acquired and assessed to estimate land-cover types. The SWAT hydrologic response unit (HRU) definition tool was used to process the data and a threshold value was set so that land-cover types that occupied less than 5 percent of a subbasin were eliminated, with the remaining land-cover types being reapportioned to account for all of the land area of the subbasin. This resulted in row crops dominating the basin at 76 percent of the total land area, with 44 percent corn and 32 percent soybeans. The remaining basin land area is comprised of pasture at 11 percent, roadway at 8 percent, forested lands at 2 percent, and water, wetland, and developed land combined at 3 percent (fig. 3). The two largest urban areas in the basin include Waterloo and Cedar Rapids, Iowa (fig. 1), with smaller urban areas scattered throughout the basin.

Geology

The upper bedrock of the Cedar River Basin consists of Ordovician-age sandstone and dolostone, Silurian dolomites, and Devonian-age limestones (Squillace and others, 1996); the Silurian-Devonian and Ordovician systems are important aquifers within the basin and are used extensively for municipal, domestic, and industrial water supplies (Iowa Department of Natural Resources, 2006a; Squillace and others, 1996). Karst features that include caves, springs, and sinkholes, are prevalent in the northern part of the basin (Prior, 1991; Iowa Department of Natural Resources, 2006a). These conduits in the shallow bedrock can decrease and delay high peak flows, sustain flow during dry periods, and provide direct conduits for delivery of nitrate to aquifers (Baffaut and Benson, 2009; Iowa Department of Natural Resources, 2006a; Prior, 1991). Four distinct landform regions comprise the Cedar River Basin and include the Iowan Surface, the Southern Iowa Drift Plain, the Des Moines Lobe, and Iowa-Cedar Lowland (Prior, 1991; fig. 4). The Iowan Surface, primarily glacial drift with thin loess layers on ridges, makes up the eastern part of the basin.

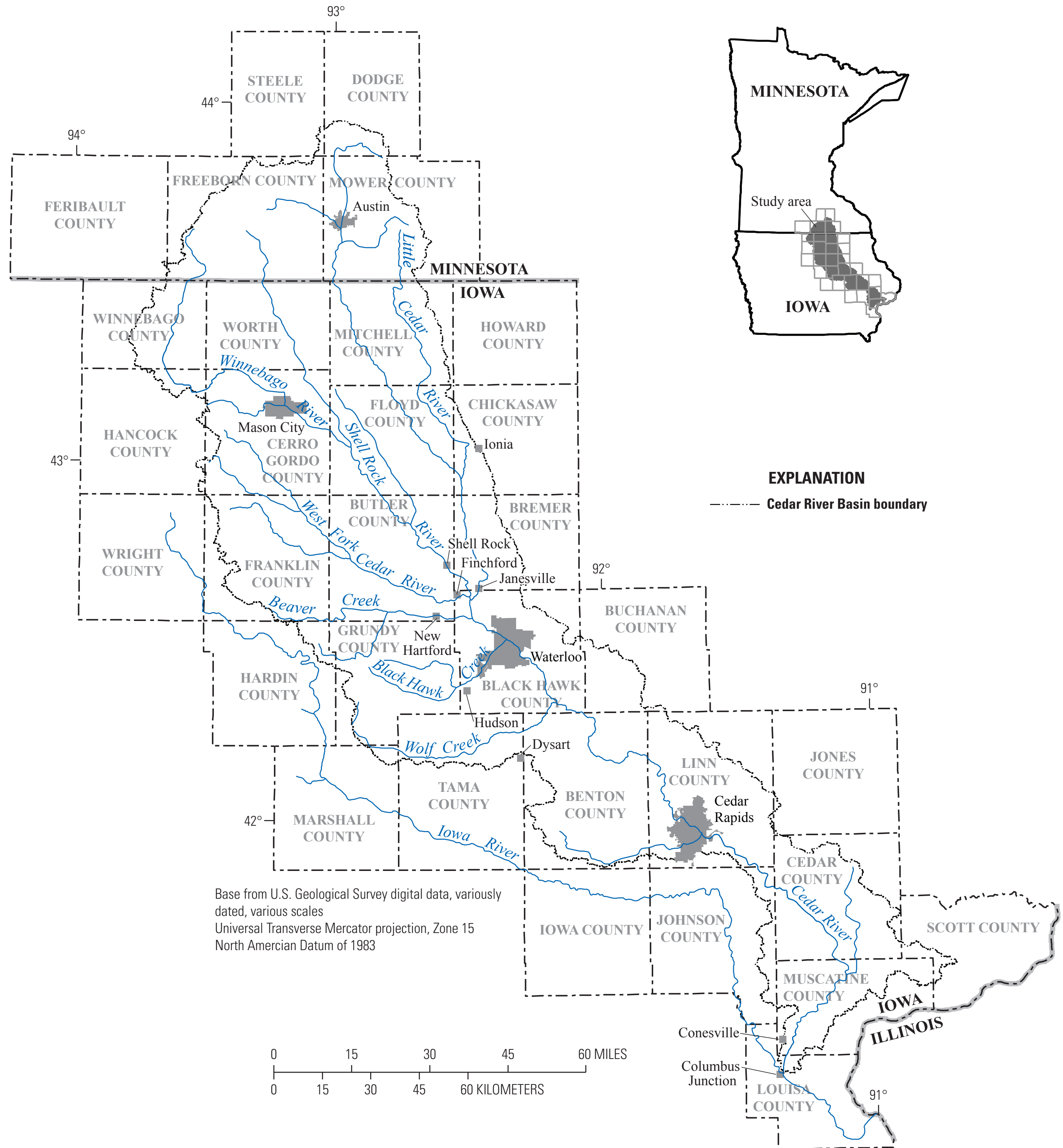

Figure 1. Location of the Cedar River Basin in Iowa and Minnesota.

Table 1. Sites from which measured data were used for model set-up, calibration, and validation purposes for the Cedar River Basin model, Iowa.

[STORET/WQX, Storage and Retrieval/Water Quality Exchange; min, minimum; max, maximum]

Map number (fig. 2)	Network	Site ID number	Site name and location	Measured parameter
1	U.S. Geological Survey	05457000	Cedar River near Austin, Minnesota	Streamflow.
2	U.S. Geological Survey	05459500	Winnebago River at Mason City, Iowa	Streamflow.
3	U.S. Geological Survey	05458000	Little Cedar River near Ionia, Iowa	Streamflow.
4	U.S. Geological Survey	05462000	Shell Rock River at Shell Rock, Iowa	Streamflow.
5	U.S. Geological Survey	05458900	West Fork Cedar River at Finchford, Iowa	Streamflow.
6	U.S. Geological Survey	05458500	Cedar River at Janesville, Iowa	Streamflow.
7	U.S. Geological Survey	05463000	Beaver Creek at New Hartford, Iowa	Streamflow.
8	U.S. Geological Survey	05464000	Cedar River at Waterloo, Iowa	Streamflow.
9	U.S. Geological Survey	05463500	Black Hawk Creek at Hudson, Iowa	Streamflow.
10	U.S. Geological Survey	05464220	Wolf Creek near Dysart, Iowa	Streamflow.
11	U.S. Geological Survey	05464500	Cedar River at Cedar Rapids, Iowa	Streamflow.
12	U.S. Geological Survey	05465000	Cedar River near Conesville, Iowa	Streamflow.
13	Iowa Department of Natural Resources STORET/WQX	10120001	Shell Rock River at Shell Rock, Iowa	Nitrite + Nitrate.
14	Iowa Department of Natural Resources STORET/WQX	10090001	Cedar River at Janesville, Iowa	Nitrite + Nitrate.
15	Iowa Department of Natural Resources STORET/WQX	10700001	Cedar River near Conesville, Iowa	Nitrite + Nitrate.
16	Iowa State University Ag Climate	A134309	Kanawha, Iowa	Solar Radiation, Wind Speed, Relative Humidity.
17	Iowa State University Ag Climate	A135879	Nashua, Iowa	Solar Radiation, Wind Speed, Relative Humidity.
18	Iowa State University Ag Climate	A131329	Cedar Rapids, Iowa	Solar Radiation, Wind Speed, Relative Humidity.
19	Iowa State University Ag Climate	A135849	Muscatine, Iowa	Solar Radiation, Wind Speed, Relative Humidity.
20	National Weather Service Cooperative Observer Program	210355	Austin, Minnesota	Precipitation, Max/Min Temperature.
21	National Weather Service Cooperative Observer Program	210075	Albert Lea, Minnesota	Precipitation, Max/Min Temperature.
22	National Weather Service Cooperative Observer Program	136103	Northwood, Iowa	Precipitation, Max/Min Temperature.
23	National Weather Service Cooperative Observer Program	132977	Forest City, Iowa	Precipitation, Max/Min Temperature.
24	National Weather Service Cooperative Observer Program	136305	Osage, Iowa	Precipitation, Max/Min Temperature.
25	National Weather Service Cooperative Observer Program	135230	Mason City, Iowa	Precipitation, Max/Min Temperature.
26	National Weather Service Cooperative Observer Program	131402	Charles City, Iowa	Precipitation, Max/Min Temperature.
27	National Weather Service Cooperative Observer Program	135952	New Hampton, Iowa	Precipitation, Max/Min Temperature.
28	National Weather Service Cooperative Observer Program	133584	Hampton, Iowa	Precipitation, Max/Min Temperature.

Table 1. Sites from which measured data were used for model set-up, calibration, and validation purposes for the Cedar River Basin model, Iowa.

[STORET/WQX, Storage and Retrieval/Water Quality Exchange; min, minimum; max, maximum]

Map number (fig. 2)	Network	Site ID number	Site name and location	Measured parameter
29	National Weather Service Cooperative Observer Program	130157	Allison, Iowa	Precipitation, Max/Min Temperature.
30	National Weather Service Cooperative Observer Program	134142	Iowa Falls, Iowa	Precipitation, Max/Min Temperature.
31	National Weather Service Cooperative Observer Program	138706	Waterloo, Iowa	Precipitation, Max/Min Temperature.
32	National Weather Service Cooperative Observer Program	132573	Eldora, Iowa	Precipitation, Max/Min Temperature.
33	National Weather Service Cooperative Observer Program	133487	Grundy Center, Iowa	Precipitation, Max/Min Temperature.
34	National Weather Service Cooperative Observer Program	134049	Independence, Iowa	Precipitation, Max/Min Temperature.
35	National Weather Service Cooperative Observer Program	138568	Vinton, Iowa	Precipitation, Max/Min Temperature.
36	National Weather Service Cooperative Observer Program	130600	Belle Plain, Iowa	Precipitation, Max/Min Temperature.
37	National Weather Service Cooperative Observer Program	131319	Cedar Rapids, Iowa	Precipitation, Max/Min Temperature.
38	National Weather Service Cooperative Observer Program	130213	Anamosa, Iowa	Precipitation, Max/Min Temperature.
39	National Weather Service Cooperative Observer Program	134101	Iowa City, Iowa	Precipitation, Max/Min Temperature.
40	National Weather Service Cooperative Observer Program	138266	Tipton, Iowa	Precipitation, Max/Min Temperature.
41	National Weather Service Cooperative Observer Program	135837	Muscatine, Iowa	Precipitation, Max/Min Temperature.

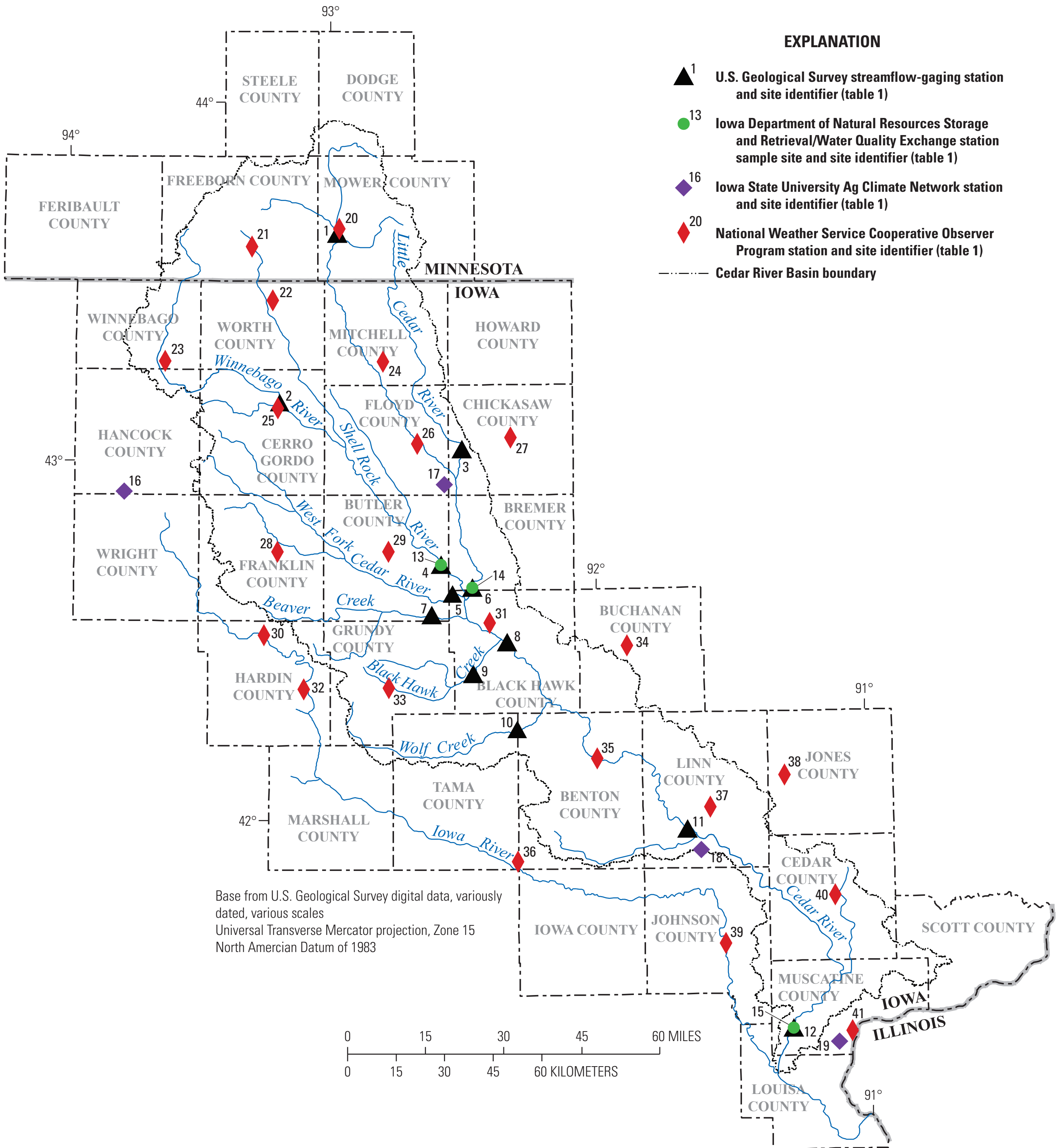

Figure 2. Locations of U.S. Geological Survey streamflow-gaging stations, Iowa State University Ag Climate Network stations, National Weather Service Cooperative Observer Program stations, and Iowa Department of Natural Resources Storage and Retrieval/Water Quality Exchange stations providing measured data for the Cedar River Basin model, Iowa.

Table 2. Selected Soil and Water Assessment Tool (SWAT) studies conducted in basins in Iowa.

[LSNT, late-spring nitrate test; FEM, farm-level economic model]

Study title	Authors	Study area (major basin)
Calibration and validation of SWAT for the Upper Maquoketa River watershed	Reungsang and others, 2005	Upper Maquoketa River (Maquoketa River Basin).
Evaluation of SWAT in simulating nitrate nitrogen and atrazine fates in a watershed with tiles and potholes	Du and others, 2006	Walnut Creek (Skunk River Basin).
Hydrologic evaluation of the soil and water assessment tool for a large tile-drained watershed in Iowa	Green and others, 2006	South Fork River (Iowa River Basin).
Water quality modeling for the Raccoon River watershed using SWAT	Jha and others, 2007	Raccoon River (Raccoon River Basin).
Economic and environmental impacts of LSNT and cover crops for nitrate-nitrogen reduction in Walnut Creek Watershed, Iowa, using FEM and enhanced SWAT models	Saleh and others, 2007	Walnut Creek Watershed (Skunk River Basin).
Modeling nitrate-nitrogen load reduction strategies for the Des Moines River, Iowa using SWAT	Schilling and Wolter, 2009	Des Moines River (Des Moines River Basin).
Targeting land-use change for nitrate-nitrogen load reductions in an agricultural watershed	Jha and others, 2010	Squaw Creek (Skunk River Basin).

It is characterized by long slopes, low relief, and well developed drainage (Prior, 1991). The Southern Iowa Drift Plain, which is predominantly glacial drift and loess, makes up the southern part of the basin. It is characterized by steeply rolling terrain, moderately well-drained soils, and broad, flat drainage divides (Prior, 1991). The Des Moines Lobe in the western part of the basin is characterized by poorly drained soils and low local relief with some distinct ridges. The dominant surficial material is glacial till with alluvium along the streams (Prior, 1991). The Iowa-Cedar Lowland (fig. 4), formerly part of the Alluvial Plains landform region, is located at the southern end of the basin at the confluence of the Cedar and Iowa Rivers (Iowa Department of Natural Resources, 2009).

Climate

Daily temperature and precipitation data from 22 NWS COOP stations located throughout and surrounding the basin were collected from January, 1, 1978, to December 21, 2010 (National Weather Service Cooperative Observer Program, 2001–12, 2009), for calculating statistical values of daily precipitation and temperature data for use in the SWAT weather generator. Average annual temperature, determined using data from stations located within the basin boundary (14 in total), ranges from 45 degrees Fahrenheit (ºF) in the northern part of the basin to 48 ºF in the southern part. The average annual precipitation ranges from 33.67 to 35.85 inches. The period of January, 1, 2000, to December 21, 2010, was selected for simulation, during which the average annual temperature and precipitation ranged from 45 ºF to 48 ºF and 33.89 to 38.20 inches, respectively.

Selected SWAT Studies in Iowa

Multiple SWAT studies have been done for Iowa basins (fig. 5, table 2) with a large focus on water budget and nutrient transport in agriculturally-dominated, artificially drained basins. Iowa has been identified as exporting some of the largest amounts of nitrates in the Midwest (Kalkhoff and others, 2001). Schilling and Libra (2000) estimated that 25 percent of the average annual nitrate delivered to the Gulf of Mexico is exported from Iowa. Many studies indicate that subsurface tile drainage increases nitrate losses from the basin by way of enhanced leaching through the soil profile with subsequent direct routing to surface water, often exceeding the U.S. Environmental Protection Agency (USEPA) drinking water regulation of 10 mg/L (David and others, 1997; Gilliam and others, 1999; Kladivko and others, 2004; Jaynes and others, 2001; Hu and others, 2007; Sui and Frankenberger, 2008). Subsurface tile drainage also has a profound effect on the hydrology of a basin (Eidem, and others, 1999; Jaynes, and others, 1999; Green and others, 2006), and becomes an essential component when balancing the hydrologic pathways (Kannan and others, 2006; Green and others, 2006; Saleh and others, 2007). Multiple factors such as fertilization rate and timing, soil type, drainage conditions, soil nitrogen content, drain-tile spacing and depth, and cropping systems affect nutrient dynamics (Randall and Goss, 2001; Gollamudi and others, 2007). Many studies have used SWAT because of its physical representation capabilities in conjunction with varied management options and a tile-drainage simulation component (Gollamudi and others, 2007).

Reungsang and others (2005) evaluated SWAT to simulate hydrology and nitrate levels in the Upper Maquoketa River Basin, located in northeast Iowa. The results of the study indicated that streamflow and nitrate as N loads could

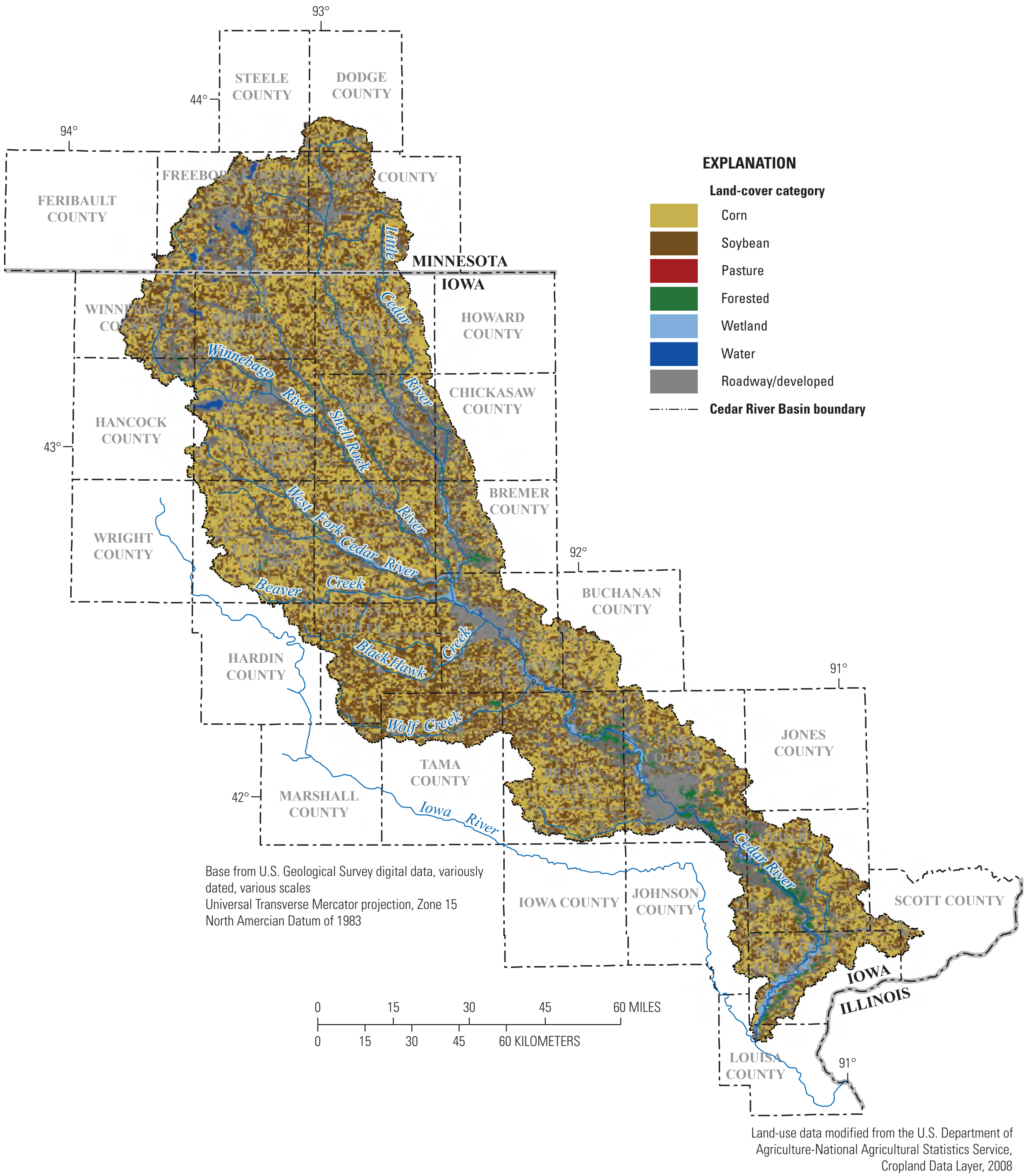

Figure 3. National Agricultural Statistics Service 2008 Cropland Data Layer land-cover categories in the Cedar River Basin, Iowa.

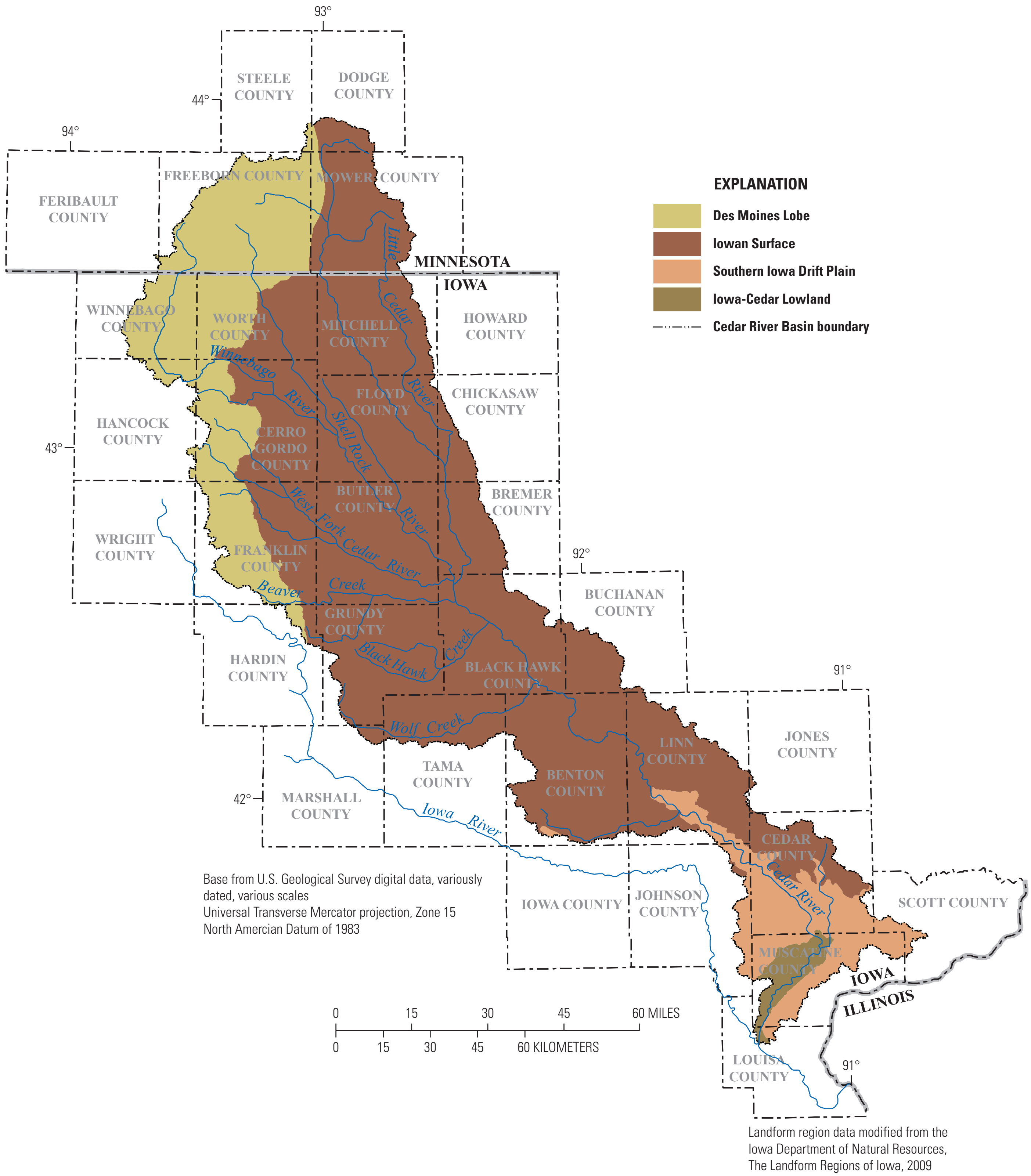

Figure 4. Landform regions of the Cedar River Basin, Iowa.

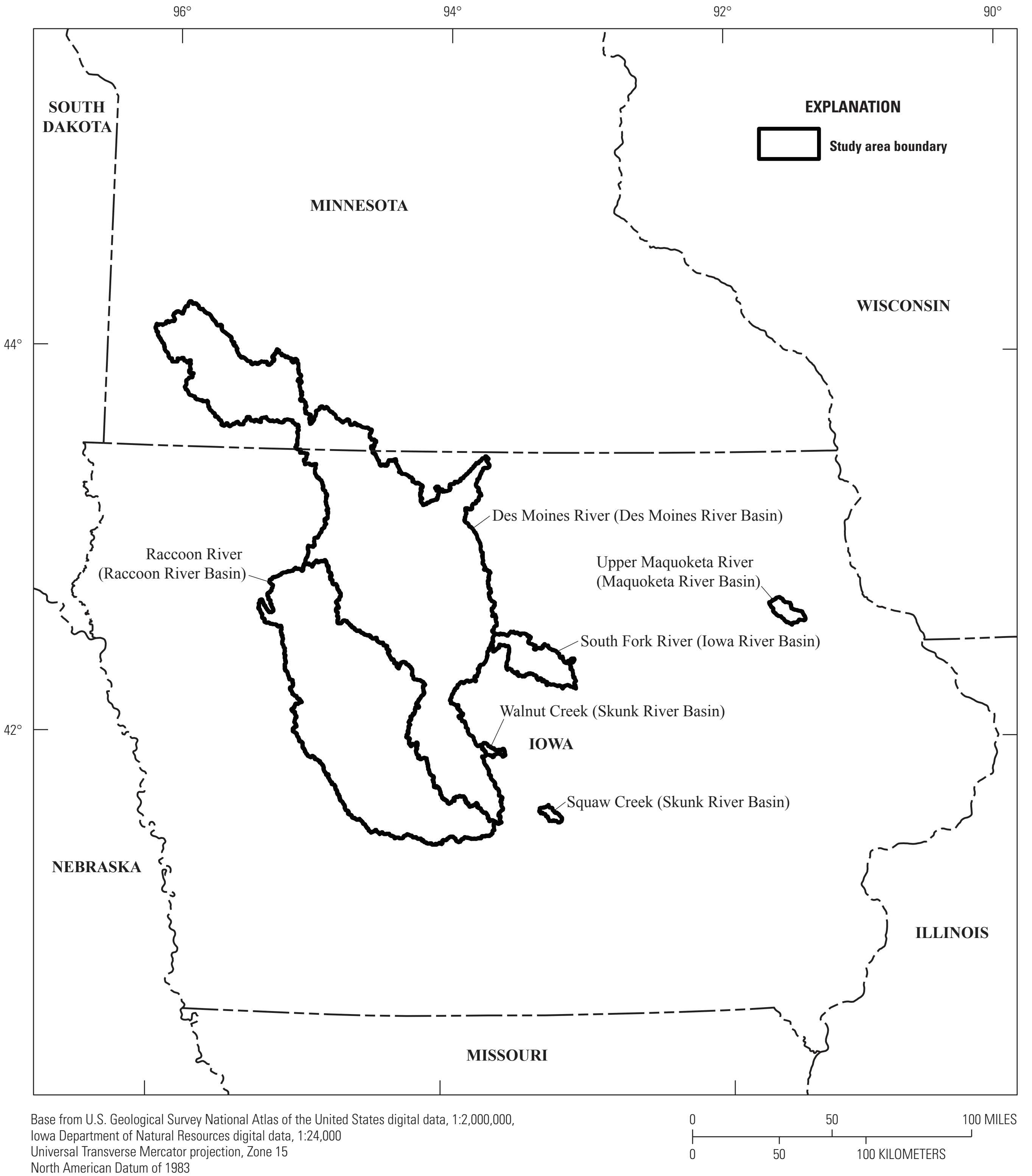

Figure 5. Locations of selected Soil and Water Assessment Tool studies conducted in basins in Iowa.

be replicated successfully by SWAT for the Upper Maquoketa River Basin. The study also illustrated the importance of climate inputs for model validation; results improved when a subset of the climate stations located within the basin were selected for climate data inputs.

Du and others (2006) evaluated SWAT in simulating nitrate and atrazine fates in the Walnut Creek Basin, a heavily artificially-drained agricultural basin located in the South Skunk River Basin in central Iowa. They compared an earlier version of SWAT (SWAT2000) with an upgraded version (SWAT-M) (Du and others, 2005) that incorporated tile drainage simulation, to assess the overall performance of SWAT, as well as the ability of the model to simulate subsurface flow. Simulation results improved with the modified version, and subsurface nitrate loads were reasonably simulated. Other SWAT work in Walnut Creek includes a study conducted by Saleh and others (2007) evaluating multiple best management practice scenarios for reducing nutrient and sediment loadings. Model simulations incorporating use of the late-spring nitrate test, cover crops, and a combination of the two methods reduced nutrient and sediment loadings from the basin.

Green and others (2006) evaluated the ability of SWAT to simulate hydrology in the South Fork River watershed of the Iowa River Basin located in central Iowa, an agricultural basin with extensive tile drainage. They determined that simulations with a tile flow component resulted in a water yield of 25.1 percent of precipitation, while simulations without a tile flow component resulted in 16.9 percent of precipitation. The tile flow scenario produced reasonable water-budget components, indicating that SWAT can be used for simulating tile flow and evaluating different management practices in agricultural basins.

Jha and others (2007) assessed the water quality of the Raccoon River Basin, an agricultural basin with substantial amounts of artificial drainage located in west-central Iowa. In their study, SWAT was calibrated and validated for streamflow, sediment, and nutrient loadings. The results of shifts in land-cover and management practices on loadings also were assessed. The model successfully predicted annual and monthly streamflow, as well as sediment, nitrate, organic nitrogen, organic phosphorus (P), and mineral P.

Schilling and Wolter (2009) used SWAT to evaluate nitrate-reduction strategies, including different spatial configurations, for TMDL purposes for the Des Moines River Basin in north-central Iowa. Their simulations indicated that reducing fertilizer application rates could achieve the required TMDL nitrate reduction; the most efficient simulated load reduction was achieved when targeting subbasins near the outlet of the basin, while the greatest simulated load reduction was achieved by targeting the highest yielding subbasins.

Jha and others (2010) used SWAT to evaluate the effects of four different land-use scenarios on nitrate loads in the Squaw Creek Basin, an agricultural basin and tributary of the South Skunk River in south-central Iowa. Their simulations indicated that targeting row crops on highly erodible land and headwater areas could provide efficient solutions for reducing nitrate loads. They also determined that targeting floodplains for grassland conversion did not prove to be as effective of an approach for reducing nitrate loads.

Methods

Model Description

SWAT, developed by the USDA Agricultural Research Service (ARS), is a physically-based, continuous time model that is designed to assess the effect of management and climate change on water, sediment, and agricultural chemical yields over long periods of time (Arnold and Fohrer, 2005; Jha and others, 2007; Gassman and others, 2007). The ArcGIS-ArcView extension ArcSWAT allows for the SWAT model to be executed within a geographic information system (GIS), and provides tools for developing and running the model (Gassman and others, 2007; Saleh and others, 2007).

SWAT can run at variable time steps and uses readily-available land-cover, climatic, soils, and topographic input data for simulating water budget, sediment yield, and nutrient fluxes (Gassman and others, 2007; Hu and others, 2007). Major components incorporated into the model include weather, hydrology, soil properties, land management, erosion, sediment transport, plant growth, nutrient and pesticide loading, bacteria transport, irrigation, and pond and reservoir storage (Gassman and others, 2007; Green and others, 2006). Hydrologic and climatic processes include precipitation, evapotranspiration, infiltration, surface runoff, groundwater flow, shallow aquifer flow, return flow, and transmission losses.

Input to SWAT is applied at different levels of detail that include the basin, subbasin, and HRU. The basin is first delineated into subbasins with each subbasin identified by a single reach (Garcia, 2009). Subbasins can be further delineated into HRUs, which consist of homogeneous land cover, management, and soil characteristics (Gassman and others, 2007). The HRUs are not represented spatially in SWAT but rather are percentages of the subbasins based on the unique combinations of characteristics (Gassman and others, 2007). The amount of water, sediment, nutrient, and pesticide loadings delivered to the main reach is calculated separately for each HRU and then summed to determine total subbasin water yield and constituent loadings (Neitsch and others, 2005). The resulting water yield and loads are then allocated to the corresponding subbasin reach of each subbasin, which then exit the subbasin at the outlet (Garcia, 2009). On delivery to the main channel, discharges and fluxes are kinematically routed downstream and chemical transformations are simulated in the stream and streambed, dividing this phase into water, sediment, nutrients, and organic chemicals (Garcia, 2009, Neitsch and others, 2005). Model output is provided for each subbasin outlet, including the designated whole-basin outlet.

Model Input

SWAT model version SWAT2009.exe revision 480 was used for this study. The ArcGIS 9.3.1 (Environmental Systems Research Institute, 2009) extension ArcSWAT version 2009.93.5 (Winchell and others, 2010) was used for model input generation and processing, which required incorporation of digital datasets representing elevation, land cover, soils, and climate. A digital elevation model was derived for Minnesota and Iowa from the USGS 30-m National Elevation Dataset (NED) (U.S. Geological Survey, 2009). The 2008 CDL from the USDA-NASS (National Agricultural Statistics Service, 2008), which contains crop-specific digital data layers, was used to describe land cover, allowing land cover to be categorized into specific agricultural land cover as compared to generic designations. The Soil Survey Geographic Database (SSURGO) from the USDA Natural Resources Conservation Service (NRCS) (Natural Resources Conservation Service, 2009) was used as soils input, providing detailed properties and distribution of soils in the study area. The hydrologic soils group, one of the SSURGO data attributes, represents relative infiltration rate of a soil (fig. 6) and is used in the NRCS curve-number (CN) method (Soil Conservation Service, 1986) for estimating surface runoff. Daily precipitation and maximum and minimum temperature data were obtained for 20 NWS COOP stations from the ISU, Department of Agronomy, Iowa Environmental Mesonet (IEM) (National Weather Service Cooperative Observer Program, 2001–12) for Iowa locations and for two NWS COOP stations from the National Climatic Data Center (National Weather Service Cooperative Observer Program, 2009) for Minnesota locations. Daily solar radiation, wind speed, and relative humidity data were obtained for four ISU Ag climate stations, provided by IEM (High Plains Regional Climate Center, 2001–12).

Average monthly nitrate loads for point sources were estimated for National Pollutant Discharge Elimination System (NPDES) permitted facilities in the basin (Iowa Department of Natural Resources, 2006a). Some discharge monitoring data and affiliated nitrate load estimates were provided by the IDNR (F. Amin, Iowa Department of Natural Resources, written and oral commun., 2010; L. Bryant, Iowa Department of Natural Resources, written and oral commun., 2010). Many of the facilities did not have available permit data; the Cedar River TMDL for nitrate (Iowa Department of Natural Resources, 2006a) report and the Total Maximum Daily Load for *Escherichia coli* (*E. coli*) report (U.S. Environmental Protection Agency, 2010) were used as guides for estimating total nitrogen effluent from each facility, from which nitrate loads were estimated for input into SWAT. In the absence of IDNR provided estimates, the design limit was used for facilities with a nitrogen design limit; for facilities without a design limit, constant nitrogen values were determined based on population (U.S. Census Bureau, 2000); and for facilities with controlled discharge, a combination of methods was used, allowing for nitrogen accumulation until time of discharge.

Potential evapotranspiration (PET), surface runoff, and routing methods, as well as land-management operations, must be selected in the model. In this case the Hargreaves method for estimating PET, which only requires temperature data for input, was selected (Hargreaves and others, 2003). Two methods for estimating surface runoff are provided in SWAT and include the Green and Ampt (Green and Ampt, 1911) 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 (Williams, 1969) and Muskingum method (McCarthy, 1938) 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). The ISU Extension Office recommends an application rate of 100–150 pounds per acre (lbs/ac) (112–168 kilograms per hectare (kg/ha)) of nitrogen for corn following soybeans (J. Faucett, ISU Extension Office, written and oral commun., 2011). Available data (National Agricultural Statistics Service, Census of Agriculture, 2007a, 2007b) suggests that the number of acres treated with fertilizer, as well as the number of cropland acres harvested, increased approximately 20 percent from 2002 to 2007 for those counties that constitute the Cedar River Basin. The 2008 CDL was used for representing land cover in this model. Land cover, and thus number of acres of land-cover type receiving fertilizer, is static, therefore the rates of fertilizer application were reduced by 20 percent for the calibration period (2000–04) to reflect the smaller number of cropland acres in 2002 relative to 2007. Depending on location within the basin, a fertilizer rate of 71 to 125 lbs/ac (80 to 140 kg/ha) of monoammonium phosphate (11-52-00: nitrogen-phosphorus-potassium) was applied before corn planting, and a fertilizer rate of 80 to

Table 3. Management operation schedule for corn and soybeans for the Cedar River Basin model, Iowa.

[11-52-00, monoammonium phosphate]

Crop	Management operation	Date (for each year of simulation)
Corn	Manure application	April 1
	Tillage	April 18
	Fertilizer application, 11-52-00	April 20
	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	October 20
	Fertilizer application, anhydrous ammonia	November 1

Figure 6. Relative soil infiltration rates in the Cedar River Basin, Iowa.

161 lb/ac (90 to 180 kg/ha) of anhydrous ammonia was applied after soybean harvest.

Manure land application also was simulated for corn for spring and fall and these simulated amounts were estimated based on the livestock numbers reported in the 2007 Census of Agriculture (Ag Census) (National Agricultural Statistics Service, Census of Agriculture, 2007c-g) for the Minnesota part of the basin, and on IDNR GIS coverages of feedlots for the Iowa part of the basin (Iowa Department of Natural Resources, 2006b, 2006c). Manure rates also were decreased 20 percent for the calibration period (2000–04); a comparison of the livestock inventory from the 2002 and 2007 Ag Census indicates that livestock in the basin increased by approximately 20 percent from 2002 to 2007 (National Agricultural Statistics Service, Census of Agriculture, 2007c-g). Following the guidelines used in the Cedar River Watershed TMDL for *E. coli* report (U.S. Environmental Protection Agency, 2010), the livestock population for Minnesota subbasins was estimated by reducing the reported number of livestock per county (beef and dairy cattle, hogs, and sheep) by the proportion of subbasin within that county. The amount of manure distributed by way of grazing (beef and sheep only) also was reduced. Manure production rates by animal listed in the SWAT Input/Output File documentation, Version 2009 (Arnold and others, 2010), as well as area of land grazed, were then used to calculate subbasin manure input per acre from grazing.

To simulate tile flow, values must be 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. A GIS coverage representing soils that require tile drainage was obtained from the IDNR (fig. 7) (Iowa Department of Natural Resources, 2008b), and was overlain with the soils layer in SWAT to determine the soil types likely to be drained. Tile data were not available for the Minnesota part of the basin but the soils likely to be tiled as determined from the Iowa data were considered basinwide. Tile drainage was implemented for those HRUs characterized by soils likely to be drained, corn or soybean land cover, and low slopes (0–2 percent).

Streamflow data were obtained for each of the streamflow-gaging stations used in model calibration and validation from the National Water Information System (NWIS) Web service (table 1; U.S. Geological Survey, 2011). Nitrate concentration data and corresponding streamflow were obtained from three IDNR STORET/WQX (Iowa Department of Natural Resources, 2010b) stations for nitrate load calibration and validation.

Subbasin Delineation

Basin delineation is the first step in the model setup, and begins by using a Digital Elevation Model (DEM) and hydrography dataset to partition the basin into subbasins. A threshold value can be set by the user to control the density of the stream network and thus the resulting number of subbasins. In this case, the threshold was set so that the resulting subbasin boundaries would coincide with Hydrologic Unit Code (HUC) 12 boundaries. Some minor discrepancies occur because not all streamflow-gaging stations coincide with HUC 12 basin outlets. All streamflow-gaging stations used for calibration must be included as basin outlets so that simulated model output is provided at these locations for comparison to measured data. Sensitivities can be specified for land cover, soil, and slope to determine HRU distribution; in this case the sensitivity was set to 5 percent for each. Before HRU definition, slope was separated into four categories including less than 2 percent, 2 percent to 4 percent, greater than 4 percent to 9 percent, and greater than 9 percent (fig. 8). The final delineation resulted in a total of 14,234 HRUs and 227 subbasins (fig. 9); however, outlet 226 represents the farthest downstream streamflow-gaging station from the basin, USGS streamflow-gaging station Cedar River near Conesville, IA (table 1), and was thus selected as the whole basin outlet.

Model Calibration

Statistical Evaluation of Model Performance

The Nash-Sutcliffe coefficient of model efficiency (E_{NS}) (Nash and Sutcliffe, 1970), coefficient of determination (R^2), and percent bias (PBIAS) were selected for quantitatively evaluating model performance. The E_{NS} is a measure of how well the simulated values agree with the measured values, and can range between negative infinity and 1. The closer the value is to one the better the predictive power of the model. The E_{NS} model performance ratings proposed for all constituents by Moriasi and others (2007) was used to evaluate model calibration and validation and are as follows: “very good” if the monthly E_{NS} is greater than or equal to 0.75, “good” if the monthly E_{NS} is greater than or equal to 0.65 but less than 0.75, “satisfactory” if the monthly E_{NS} is greater or equal to 0.5 but less than 0.65, and “unsatisfactory” if the monthly E_{NS} is less than 0.5. Moriasi and others (2007) propose appropriate adjustments of these ratings for daily and annual time step evaluations, respectively, and note that shorter time steps (for example, daily) typically produce poorer results than longer time steps (for example, annual).

The R^2 value is the proportion of the variability in the measured data that is explained by the simulated data, and is a measure of the strength of the linear relation between predicted and measured values. It can range between 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 as satisfactory when comparing across multiple SWAT studies.

The PBIAS is a measure of the average tendency of overpredictions and underpredictions of the simulated data for the time period being evaluated (Bumgarner and Thompson, 2012;

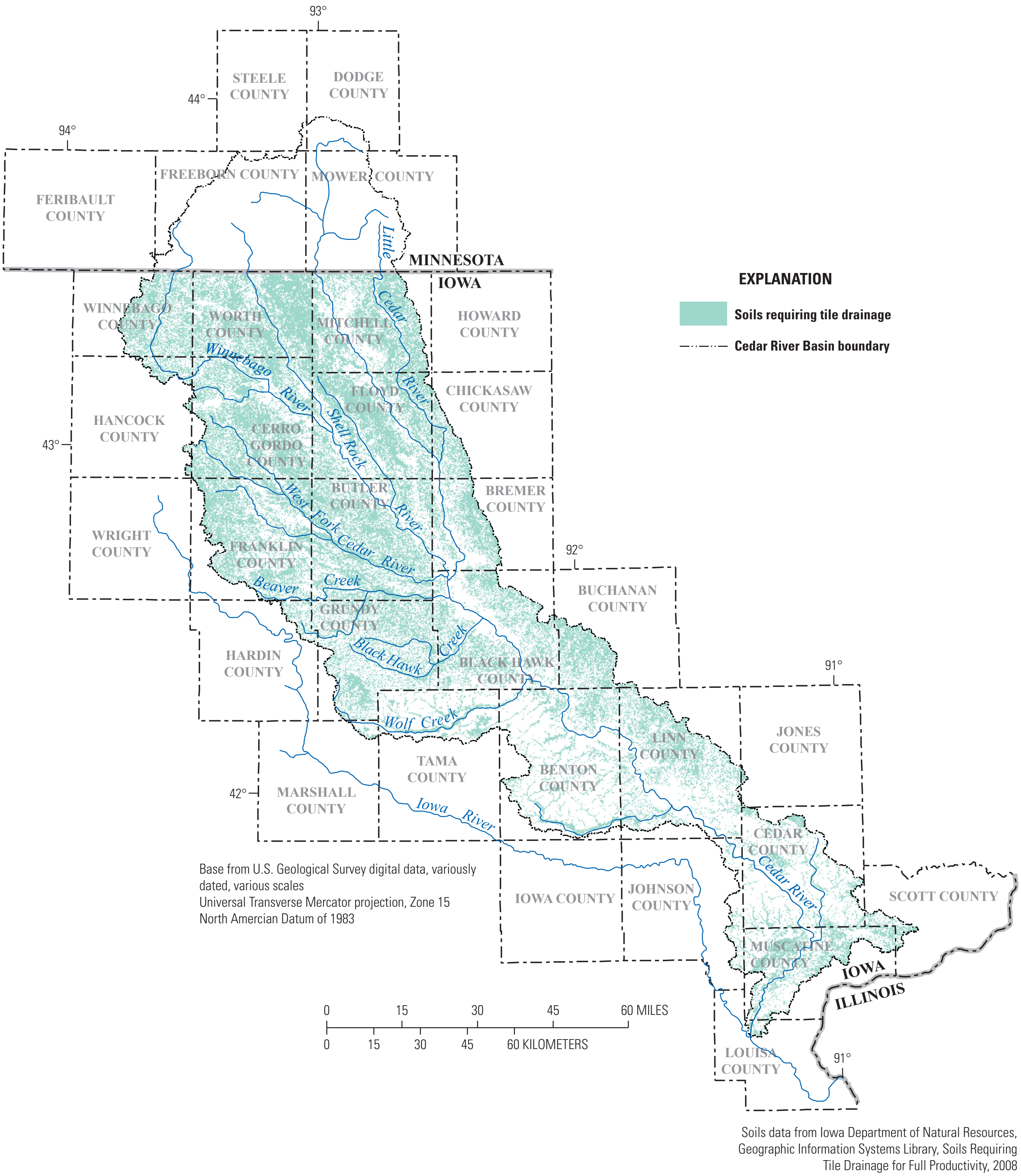

Figure 7. Soil types likely to be drained in the Iowa part of the Cedar River Basin, Iowa.

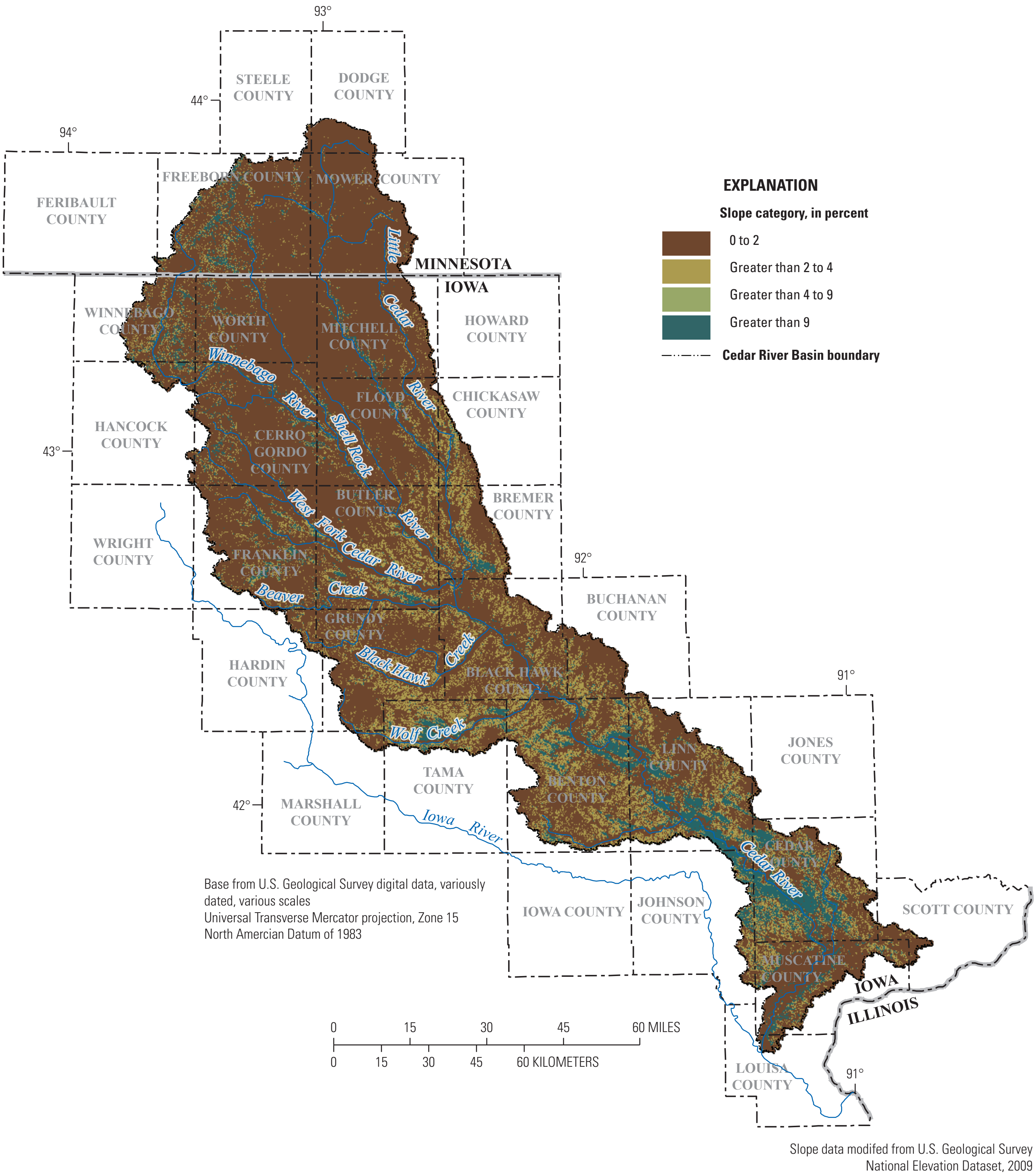

Figure 8. Percent slope for the Cedar River Basin model, Iowa.

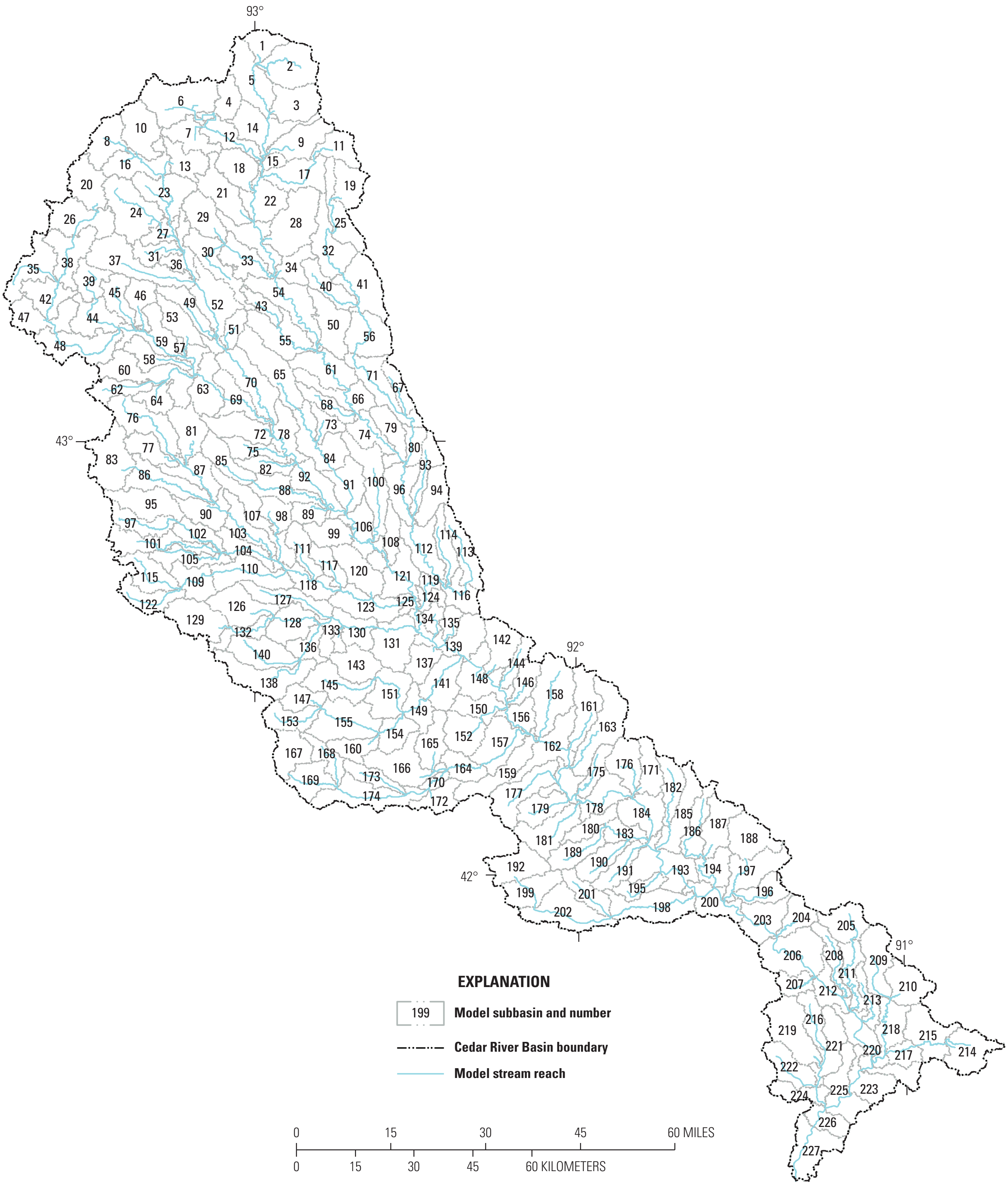

Figure 9. Subbasin delineation for the Cedar River Basin model, Iowa.

Moriasi and others, 2007; Gupta and others, 1999). A PBIAS 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). Model performance for nitrogen is considered very good if the PBIAS is between 0 and +/-25 percent, good if the PBIAS is between +/-25 and +/-40 percent, satisfactory if the PBIAS is between +/- 40 and +/-70 percent, and unsatisfactory if the PBIAS is +/-70 percent or greater (Moriasi and others, 2007).

The variables E_{NS}, R^2, and PBIAS are defined as follows:

$$E_{NS} = 1 - \frac{\left[\sum_{i=1}^{N} (q_{obs,i} - q_{sim,i})^2\right]}{\left[\sum_{i=1}^{N} (q_{obs,i} - \bar{q}_{obs})^2\right]} \tag{1}$$

$$R^2 = \frac{\left[\sum_{i=1}^{N} (q_{obs,i} - \bar{q}_{obs})(q_{sim,i} - \bar{q}_{sim})\right]^2}{\left[\sum_{i=1}^{N} (q_{obs,i} - \bar{q}_{obs})^2\right]\left[\sum_{i=1}^{N} (q_{sim,i} - \bar{q}_{sim})^2\right]} \tag{2}$$

$$PBIAS = \frac{\sum_{i=1}^{N} (q_{obs,i} - q_{sim,i})}{\sum_{i=1}^{N} q_{obs,i}} * 100 \tag{3}$$

where

- $q_{obs,i}$ is the measured streamflow at the *i*th time step;
- $q_{sim,i}$ is the simulated streamflow at the *i*th time step;
- $\bar{q}_{obs}$ is the measured mean streamflow for the time period;
- $\bar{q}_{sim}$ is the simulated mean streamflow for the time period; and
- N is the number of observations.

Hydrology Calibration

A 5-year and 6-year period that included wet and dry years were selected for model calibration (January 1, 2000, to December 31, 2004) and validation (January 1, 2005, 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 and others, 2010) to match simulated to measured streamflow at each of the 12 USGS streamflow-gaging stations listed in table 1 and shown in figure 2. Calibration was first completed for average annual conditions, followed by average monthly, and finally daily conditions, starting with the farthest upstream streamflow-gaging station for each tributary and moving downstream to the next consecutive streamflow-gaging station. Performance was evaluated by determining the E_{NS}, R^2 of the linear regression, and the PBIAS for each streamflow-gaging station. A total of 16 streamflow parameters were designated as sensitive and thus manually adjusted for calibration. The selected hydrology parameters and parameter descriptions are listed in table 4. The final hydrology calibration values are listed in table 5.

Table 4. Soil and water assessment tool (SWAT) hydrology calibration parameters and parameter descriptions for the Cedar River Basin model, Iowa.

[SCS, Soil conservation service; mm, millimeters; mm water/mm soil, millimeters of water per millimeters of soil; ET, actual evapotranspiration]

SWAT calibration parameter (units)	Parameter description
CN2 (dimensionless)	SCS runoff curve number for moisture condition II.
SOL_AWC (mm water/mm soil)	Available water capacity
ESCO	Soil evaporation compensation factor; accounts for the effect of cracking, crusting, and capillary action by adjusting the depth distribution used to the meet the soil evaporative demand.
REVAPMN (mm)	Amount of water required in the shallow aquifer for percolation to the deep aquifer or movement of water to the unsaturated zone to occur.
GWQMN (mm)	Threshold depth of water in the shallow aquifer required for return flow to occur.
GW_REVAP	Regulates movement of water between the shallow aquifer and root zone.
ALPHA_BF (days)	Base-flow recession constant.
CNCOEF	Plant ET curve number coefficient.
OV_N (days)	Manning’s “n” for overland flow.
CH_N1	Manning’s “n” for tributary channels.
CH_N2	Manning’s “n” for the main channel.
SURLAG (days)	Surface lag coefficient.
GW_DELAY (days)	Delay time for aquifer recharge.
DDRAIN (mm)	Depth to subsurface drains.
TDRAIN (hours)	Time to drain the soil to field capacity.
GDRAIN (hours)	Time between transfer of water from the soil to drain tile and drain tile to the reach.
DEP_IMP (mm)	Depth to an impervious layer in the soil profile; necessary for tile flow.

Nitrate Load Calibration

Nitrate concentration and corresponding streamflow for the calibration (2000–04) and validation period (2005–10) were collected from three Iowa STORET/WQX Water Quality

Table 5. Soil and Water Assessment Tool final hydrology calibration values for the Cedar River Basin model, Iowa.

[MN, Minnesota; IA, Iowa; CN2, Moisture condition II curve number; SOL_AWC, Soil available water capacity; ESCO, Soil evaporation compensation factor; REVAPMN, Threshold depth of water in the shallow aquifer for "revap" to occur; GWQMN, Threshold water level in shallow aquifer required for return flow to occur; GW_REVAP, Revap coefficient; ALPHA_BF, Base-flow recession constant; CH_N1, Manning's "n" value for the tributary channels; CH_N2, Manning's "n" value for the main channel; OV_N, Manning's "n" value for overland flow; SURLAG, Surface runoff lag time; GW_DELAY, Groundwater delay; DDRAIN, Depth to subsurface drain; TDRAIN, Time to drain soil to field capacity; GDRAIN, Drain tile lag time; DEP_IMP, Depth to impervious layer in soil profile; ICN, Daily curve number calculation method; CNCOEF, Plant ET curve number coefficient; ET, actual evapotranspiration]

Streamflow-gaging station	Calibrated parameter value								
	CN2	SOL_AWC	ESCO	REVAPMN	GWQMN	GW_REVAP	ALPHA_BF	CH_N1	CH_N2
Cedar River near Austin, Minnesota	-8	-	0.8	1.02	0	0.02	0.1	0.04	0.04
Winnebago River at Mason City, Iowa	-8	+0.01	0.75	0.98	0.1	0.02	0.1	0.04	0.04
Little Cedar River near Ionia, Iowa	-6	-	0.8	0.87	0.1	0.02	0.1	0.025	0.025
Shell Rock River at Shell Rock, Iowa	-8	-	0.95	0.93	0.1	0.02	0.1	0.025	0.025
West Fork Cedar River at Finchford, Iowa	-8	-	0.85	1	0	0.02	0.1	0.04	0.04
Cedar River at Janesville, Iowa	-8	-	0.80	1	0	0.02	0.1	0.025	0.025
Beaver Creek at New Hartford, Iowa	-8	+0.02	0.85	0.97	0	0.02	0.1	0.045	0.045
Cedar River at Waterloo, Iowa	-6	-	0.85	1.35	0	0.02	0.1	0.025	0.025
Black Hawk Creek at Hudson, Iowa	-6	+0.02	0.85	1	0	0.02	0.5	0.025	0.025
Wolf Creek near Dysart, Iowa	-2	-	0.85	1	0	0.02	0.1	0.025	0.025
Cedar River at Cedar Rapids, Iowa	-6	-	0.85	1.35	0	0.02	0.1	0.025	0.025
Cedar River near Conesville, Iowa	-4	-	0.80	1	0	0.02	0.1	0.03	0.03

Streamflow-gaging station	Calibrated parameter value								
	OV_N	SURLAG	GW_DELAY	DDRAIN	TDRAIN	GDRAIN	DEP_IMP	ICN	CNCOEF
Cedar River near Austin, Minnesota	0.12	2	62	1,200	36	72	1,200	1	0.3
Winnebago River at Mason City, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
Little Cedar River near Ionia, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
Shell Rock River at Shell Rock, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
West Fork Cedar River at Finchford, Iowa	0.12	2	62	1,200	36	96	1,200	1	0.3
Cedar River at Janesville, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
Beaver Creek at New Hartford, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
Cedar River at Waterloo, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
Black Hawk Creek at Hudson, Iowa	0.12	2	62	1,200	36	96	1,200	1	0.3
Wolf Creek near Dysart, Iowa	0.12	2	62	1,200	36	96	1,200	1	0.3
Cedar River at Cedar Rapids, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3
Cedar River near Conesville, Iowa	0.12	2	62	1,200	36	72	1,200	1	0.3

Table 6. LOADEST statistical modeling results for each streamflow-gaging station for the Cedar River Basin model, Iowa, 2000–10.

[N., number; obs., observations; ln, natural logarithm; L, daily load in kilograms per day; Q, centered mean daily streamflow in cubic feet per second; SS, seasonality parameter (2π*decimal years (centered)); Ave., average; m., monthly; Std., standard; dev., deviation; a., annual; Est., estimated; res., residual; var., variance; R^2, coefficient of determination; %, percent]

Streamflow-gaging station	N. obs.	Regression model	Ave. m. load (tons)	Std. dev. (tons)	Ave. a. load (tons)	Std. dev. (tons)	Est. res. var.	R^2 (%)
Shell Rock River at Shell Rock, Iowa	126	$\ln(L) = 9.97 + 1.36*\ln Q - 0.140*\ln Q^2 + 0.284*\sin(SS) + 0.263*\cos(SS)$	848	1,112	9,707	3,915	0.1383	94
Cedar River at Janesville, Iowa	110	$\ln(L) = 10.3 + 1.37*\ln Q - 0.163*\ln Q^2 + 0.176*\sin(SS) + 0.281*\cos(SS)$	945	1,195	10,735	4,543	0.1379	93
Cedar River near Conesville, Iowa	117	$\ln(L) = 11.6 + 1.71*\ln Q - 0.320*\ln Q^2 + 0.318*\sin(SS) + 0.533*\cos(SS)$	5,036	6,352	60,436	37,841	0.4398	82

Database stations (Iowa Department of Natural Resources, 2010b), that correspond to three USGS streamflow-gaging stations, listed in table 1 and shown in figure 2. These data are a compilation of single grab samples collected on a monthly basis. Continuous average monthly and yearly nitrate loads were estimated for the period of record from the grab samples using the USGS Load Estimator (LOADEST) regression model (Runkel and others, 2004). Provided a time series of discrete measured streamflow and constituent concentrations, LOADEST can be used to develop a regression model for estimating constituent loads in streams and rivers (Runkel and others, 2004). There are three statistical methods that the model uses to estimate constituent loads. In this case, the Adjusted Maximum Likelihood Estimation (AMLE) method was used. The form of the regression model used to generate continuous loadings is user-selected and the option for allowing LOADEST to select the best regression model was selected in this case (table 6). There were no sample values below analytical detection limits. The resulting estimated time-series data were then used in place of measured data for completing the annual and monthly nitrate calibration and validation. The LOADEST statistical modeling results are listed in table 6.

Nitrate load calibration was completed by manually adjusting parameter values within their acceptable ranges to match simulated nitrate loads to LOADEST nitrate loads. Calibration was first completed for average annual conditions followed by average monthly conditions. Performance was evaluated by determining the E_{NS} and R^2 values for each Iowa STORET/WQX Water Quality Database station. A total of four nutrient parameters were manually adjusted for calibration. The selected parameters, parameter descriptions, and final nitrate calibration parameter values are listed in table 7. Management operations also were considered calibration parameters (table 3).

Table 7. Soil and water assessment tool (SWAT) nitrate calibration parameters, parameter descriptions, and final calibration values for the Cedar River Basin model, Iowa.

[°C, degrees Celsius; day-1, per day; NH_4, ammonium; NO_2, nitrite; N, nitrogen; P, phosphorus]

SWAT calibration parameter	Parameter description	Final calibrated value
CDN	Denitrification exponential rate coefficient; controls rate of denitrification	0.6
RS4	Rate coefficient for organic N settling in the reach at 20 ºC (day-1)	0.1
BC1	Rate constant for biological oxidation of NH_4 to NO_2 in the reach at 20 ºC in well-aerated conditions (day-1)	0.5
CMN	Rate factor for humus mineralization of active organic nutrients (N and P)	0.0001

Model Limitations

Measurement errors that can affect model performance include resolution of land cover, assumed static land cover through the simulation period, resolution and availability of land management operation data and application at the subbasin to basinwide level, availability of nitrate data, model-estimated average measured yearly and monthly nitrate values, and distribution of point measurements of precipitation and temperature across the basin.

The CDL was selected to represent land cover because of the great detail that is provided for the land cover-classes, specifically agricultural crops. However, the resolution of the CDL is coarser (57 meters (m)) relative to other land-cover layers that could have been used. This could cause overestimation or underestimation in certain land-cover types, thus affecting rainfall-runoff calculations.

Land cover was considered static through time and thus changes were not accounted for, including years in which management operations would have been altered because of short-term events such as flooding. For example, the timing of the 2008 floods allowed for some crops to actually be replanted later in the season.

In addition to fertilizer and manure data being compiled and published every 5 years, the amount of estimated corn and soybean acres affects the estimated manure application rates. In an attempt to compensate for manure application rate increases through time, as suggested by NASS data, higher rates were applied during the validation period relative to the calibration period. Manure and fertilizer rates also can change from year to year depending on a number of factors and this is not captured in 5-year compilations. Other operations such as planting, tillage, and harvest may be altered from field to field as well as from year to year. However, because of the lack of this information as well as the time requirement for implementing management operations at a finer resolution than at the subbasin, and sometimes basinwide, level for the Cedar River Basin, generalized management operations that were uniform from year to year had to be applied.

Monthly grab-sample data were available for only three nutrient stations, limiting the data available for calibration. In addition, the monthly data were used to estimate average monthly and yearly values. Measurement errors could occur in the grab-sample results that were used to estimate monthly and annual measured loads. Additional errors are introduced in the model (LOADEST) used to make these average measured estimates for use in calibration.

There are also errors inherent to the model, such as systematic errors that result simply from the limitations of model parameters and equations to replicate the processes occurring in the basin. In addition, for SWAT specifically, precipitation and temperature point data are distributed in space across the basin, with subbasins receiving point values of the closest climate station, instead of a gradient being applied across the basin based on the available point values. Isolated precipitation events can cause over estimation of rainfall, while events occurring between streamflow-gaging stations might cause the model to under-predict rainfall amounts, affecting the amount of rainfall-produced-runoff from an HRU.

Hydrology and Water Quality Simulation

Hydrology Calibration and Validation Results

Daily, monthly, and annual E_{NS}, R^2, and PBIAS values, along with descriptive statistics, were determined for hydrology calibration, January 1, 2000, to December 31, 2004 (fig. 10, table 8), and validation, January, 1, 2005 to December 31, 2010 (fig. 11, table 9), for all 12 USGS streamflow-gaging stations ("streamflow-gaging station" will be referred to as "station" for the entire results section); please refer to table 1 and figure 2 for cross-referencing station names and locations. Results indicate that SWAT is capable of predicting hydrology; calibration E_{NS} and R^2 values are greater than 0.5 for all locations and time steps with the exception of the Cedar River near Austin, MN, station with a daily E_{NS} of 0.44. The monthly calibration and validation E_{NS} for the Cedar River at Austin, MN, station indicates good model performance whereas monthly calibration and validation E_{NS} values indicate very good model performance for all other locations. Monthly PBIAS results indicate satisfactory to very good model performance.

Annual calibration E_{NS} values range from 0.56 for the Cedar River near Austin, MN, station to 0.97 for the Winnebago River at Mason City, IA, station while annual calibration R^2 values range from 0.65 for the Cedar River near Austin, MN, station to 0.99 for the West Fork Cedar River at Finchford, IA, station and the Cedar River near Conseville, IA, station. Annual calibration PBIAS ranges from -19 percent for the Shell Rock River at Shell Rock, IA, station to 10 percent for the Black Hawk Creek at Hudson, IA, station.

Monthly calibration E_{NS} values range from 0.72 for the Cedar River near Austin, MN, station to 0.93 for the Cedar River near Conesville, IA, station while monthly calibration R^2 values range from 0.74 for the Cedar River near Austin, MN, station to 0.94 for the Cedar River at Waterloo, IA, station and the Cedar River at Cedar Rapids, IA, station. Monthly calibration PBIAS ranges from -16 percent for the Shell Rock River at Shell Rock, IA, station to 10 percent for the Black Hawk Creek at Hudson, IA, station.

Finally, daily calibration E_{NS} values range from 0.44 for the Cedar River near Austin, MN, station to 0.83 for the Cedar River near Conesville, IA, station while daily calibration R^2 values range from 0.55 for the Cedar River near Austin, MN, station to 0.87 for the Cedar River at Cedar Rapids, IA, station. Daily calibration PBIAS ranges from -19 percent for the Shell Rock River at Shell Rock, IA, station to 10 percent for the Black Hawk Creek at Hudson, IA, station.

Although monthly validation results indicate good to very good model performance the annual validation E_{NS} dropped below zero for the Shell Rock River at Shell Rock, IA, station (-0.22), and below 0.5 for the Winnebago River at Mason City, IA, station. Outside of these exceptions, annual validation E_{NS} values range from 0.59 for the Little Cedar River near Ionia, IA, station to 0.95 for the West Fork Cedar River at Finchford, IA, station. Annual validation R^2 values range from 0.36 for the Winnebago River at Mason City, IA, station to 0.92 for the Black Hawk Creek at Hudson, IA, station. Annual validation PBIAS ranges from -16 percent for the Shell Rock River at Shell Rock, IA, station to 15 percent for the Black Hawk Creek at Hudson, IA, station.

Monthly validation E_{NS} values range from 0.69 for the Cedar River near Austin, MN, station to 0.91 for the Little Cedar River near Ionia, IA, station while monthly validation R^2 values range from 0.74 for the Wolf Creek near Dysart, IA, station to 0.92 for the Little Cedar River near Ionia, IA, station. Monthly validation PBIAS ranges from -16 percent for the Shell Rock River at Shell Rock, IA, station to 15 percent for the Black Hawk Creek at Hudson, IA, station.

Table 8. Hydrology calibration (January 1, 2000, to December 31, 2004) results for each streamflow-gaging station for the Cedar River Basin model, Iowa.

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

				Measured				Simulated			
	E_{NS}	R^2	PBIAS	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)
Cedar River near Austin, Minnesota											
Daily	0.44	0.55	4%	43	15,000	325	122	4	16,951	313	108
Monthly	0.72	0.74	4%	48	2,328	325	142	13	2,162	310	142
Annual	0.56	0.65	4%	166	457	325	393	188	482	313	220
Winnebago River at Mason City, Iowa											
Daily	0.69	0.75	-3%	17	7,550	359	127	1	7,098	370	142
Monthly	0.88	0.89	-3%	28	2,510	359	151	14	2,247	366	146
Annual	0.97	0.98	-3%	237	555	359	249	232	546	370	299
Little Cedar River near Ionia, Iowa											
Daily	0.66	0.68	-16%	12	7,530	197	61	4	4,520	228	87
Monthly	0.88	0.89	-15%	18	1,636	196	70	7	1,241	226	122
Annual	0.83	0.96	-16%	84	303	197	202	137	338	228	217
Shell Rock River at Shell Rock, Iowa											
Daily	0.65	0.78	-19%	142	23,900	1,175	475	66	24,226	1,405	650
Monthly	0.89	0.90	-16%	174	8,236	1,173	549	94	7,037	1,387	825
Annual	0.68	0.92	-19%	657	1,774	1,174	901	955	2,063	1,404	1,138
West Fork Cedar River at Finchford, Iowa											
Daily	0.80	0.81	-8%	32	11,300	539	210	23	6,992	583	268
Monthly	0.92	0.92	-8%	64	2,959	537	219	47	3,051	570	305
Annual	0.93	0.99	-8%	381	939	539	407	446	927	583	468
Cedar River at Janesville, Iowa											
Daily	0.67	0.76	-6%	183	20,900	1,173	498	27	30,053	1,242	477
Monthly	0.89	0.90	-5%	219	8,056	1,172	542	45	7,081	1,235	602
Annual	0.91	0.93	-6%	577	1,698	1,173	1,202	774	1,862	1,242	1,089
Beaver Creek at New Hartford, Iowa											
Daily	0.70	0.71	-9%	9	4,780	191	75	24	2,896	208	111
Monthly	0.83	0.84	-9%	21	920	190	81	34	698	201	131
Annual	0.74	0.82	-9%	120	260	191	179	160	301	208	167
Cedar River at Waterloo, Iowa											
Daily	0.75	0.85	-7%	340	57,100	3,444	1,760	180	54,738	3,704	1,769
Monthly	0.92	0.94	-7%	628	19,412	3,437	1,863	269	18,414	3,649	2,141
Annual	0.93	0.98	-7%	2,175	4,837	3,443	2,924	2,578	5,086	3,703	3,225
Black Hawk Creek at Hudson, Iowa[1]											
Daily	0.66	0.67	10%	6	5,450	125	50	3	1,793	113	37
Monthly	0.92	0.86	10%	14	793	124	57	12	489	105	63
Annual	0.84	0.97	10%	83	191	132	122	54	187	120	119

Table 8. Hydrology calibration (January 1, 2000, to December 31, 2004) results for each streamflow-gaging station for the Cedar River Basin model, Iowa.—Continued

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

	E_{NS}	R^2	PBIAS	Measured				Simulated			
				Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)
Wolf Creek near Dysart, Iowa[2]											
Daily	0.55	0.58	3%	7	8,360	123	40	0	1,977	120	49
Monthly	0.91	0.84	2%	13	975	126	44	7	525	118	75
Annual	0.83	0.74	-3%	54	214	125	117	52	187	130	141
Cedar River at Cedar Rapids, Iowa											
Daily	0.82	0.87	-8%	326	61,800	4,200	2,240	275	54,385	4,565	2,391
Monthly	0.92	0.94	-8%	722	21,148	4,193	2,372	494	20,069	4,488	2,654
Annual	0.91	0.98	-9%	2,716	6,172	4,200	3,639	3,211	6,208	4,564	3,939
Cedar River near Conesville, Iowa											
Daily	0.83	0.86	-7%	660	69,200	5,052	2,760	357	55,091	5,424	3,252
Monthly	0.93	0.93	-7%	1,029	22,207	5,045	2,839	667	21,365	5,336	3,392
Annual	0.94	0.99	-7%	3,568	7,092	5,052	4,249	3,811	7,318	5,424	4,504

[1]Measured data was unavailable for 2000 and a part of 2001; calibration statistics are based on a total of 1,212 measured daily values.

[2]Measured data was unavailable for 2000 and a part of 2001; calibration statistics are based on a total of 1,326 measured daily values.

Finally, daily validation E_{NS} values range from 0.49 for the Cedar River near Austin, MN, station to 0.77 for the Cedar River at Waterloo, IA, station and the Cedar River at Cedar Rapids, IA, station while daily validation R^2 values range from 0.59 for the Cedar River near Austin, MN, station to 0.84 for the Cedar River at Waterloo, IA, station. Daily validation PBIAS ranges from -16 percent for the Shell Rock River at Shell Rock, IA, station to 14 percent for the Black Hawk Creek at Hudson, IA, station.

There were decreases and increases in the E_{NS} and R^2 values for the validation period relative to calibration. The E_{NS} values for all time steps for calibration and validation for the model outlet, the Cedar River near Conesville, IA, station ranged from 0.72 to 0.94, while R^2 values ranged from 0.79 to 0.99. The model performance based on the statistical measures is good to very good with the noted exceptions.

Nitrate Calibration and Validation Results

The annual and monthly E_{NS}, R^2, and PBIAS values were determined for nitrate calibration and validation and are listed in table 10. The calibration period resulted in E_{NS} and R^2 values greater than 0.6 for all time steps at all three locations with the exception of the monthly calibration E_{NS} for the Cedar River at Janesville, IA, station (0.28). Annual calibration E_{NS} values range from 0.61 for the Cedar River at Janesville, IA, station to 0.86 for the Shell Rock River at Shell Rock, IA, station while annual calibration R^2 values range from 0.65 to 0.88 for the same locations, respectively. Annual calibration PBIAS ranges from 4 percent for the Cedar River near Conesville, IA, station to 7 percent for the Cedar River at Janesville, IA, station.

Monthly calibration E_{NS} values for the Shell Rock River at Shell Rock, IA, station (0.65), and the Cedar River near Conesville, IA, station (0.82) indicate good to very good model performance. The monthly calibration R^2 values for the Shell Rock River at Shell Rock, IA, station and the Cedar River near Conesville, IA, station were 0.77 and 0.81, respectively. Although the monthly calibration E_{NS} for the Cedar River at Janesville, IA, station indicates unsatisfactory model performance, the monthly R^2 value of 0.65 indicates satisfactory performance for this location. The monthly calibration PBIAS ranges from 4 percent for the Cedar River near Conesville, IA, station to 7 percent for the Cedar River at Janesville, IA, station, indicating very good performance.

Annual and monthly E_{NS} values for the validation period were all below zero, with the exception of the monthly validation E_{NS} for the Shell Rock River at Shell Rock, IA, station (0.39) and the monthly validation E_{NS} for the Cedar River at Janesville, IA, station (0.1) indicating that the measured mean is actually a better predictor than the model; the model cannot accurately simulate nitrate loads for the 2005–10 time period. Annual validation resulted in R^2 values of 0.48, 0.27, and 0.25 for the Shell Rock River at Shell Rock, IA, station, the Cedar River at Janesville, IA, station, and the Cedar River near Conesville, IA, station, respectively, while monthly validation

Table 9. Hydrology validation (January 1, 2005, to December 31, 2010) results for each streamflow-gaging station for the Cedar River Basin model, Iowa.

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

				Measured				Simulated			
	E_{NS}	R^2	PBIAS	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)
Cedar River near Austin, Minnesota[1]											
Daily	0.49	0.59	-4%	49	11,500	350	175	18	8,405	375	162
Monthly	0.69	0.80	-4%	58	1,606	349	227	35	2,322	376	239
Annual	0.71	0.74	-4%	222	462	349	346	287	515	375	360
Winnebago River at Mason City, Iowa											
Daily	0.74	0.76	4%	27	10,400	464	241	25	8,899	467	243
Monthly	0.87	0.87	4%	63	2,795	464	315	47	2,388	466	297
Annual	0.23	0.36	4%	314	582	464	467	355	594	466	471
Little Cedar River near Ionia, Iowa											
Daily	0.62	0.63	-14%	17	21,400	265	116	21	10,100	312	135
Monthly	0.91	0.92	-14%	26	2,551	265	174	32	2,110	312	204
Annual	0.59	0.82	-14%	183	396	265	251	216	429	312	289
Shell Rock River at Shell Rock, Iowa											
Daily	0.62	0.75	-16%	247	46,400	1,539	831	130	34,326	1,833	950
Monthly	0.79	0.86	-16%	289	9,999	1,538	1,111	210	10,186	1,831	1,234
Annual	-0.22	0.50	-16%	1,095	2,024	1,539	1,521	1,398	2,403	1,832	1,733
West Fork Cedar River at Finchford, Iowa											
Daily	0.58	0.77	-7%	43	23,300	955	492	40	20,694	1,034	473
Monthly	0.79	0.84	-7%	64	5,315	954	570	61	5,946	1,032	746
Annual	0.95	0.75	-7%	528	1,279	955	1,057	683	1,327	1,034	1,069
Cedar River at Janesville, Iowa											
Daily	0.72	0.77	-3%	281	51,400	1,579	840	100	31,254	1,677	759
Monthly	0.87	0.89	-3%	322	10,778	1,581	1,129	134	10,200	1,677	1,117
Annual	0.81	0.83	-3%	1,157	2,176	1,579	1,548	1,315	2,185	1,677	1,529
Beaver Creek at New Hartford, Iowa											
Daily	0.66	0.69	6%	26	15,700	443	213	28	10,771	423	197
Monthly	0.84	0.85	6%	38	2,917	443	297	42	2,242	422	274
Annual	0.82	0.85	6%	183	635	443	508	218	610	422	437
Cedar River at Waterloo, Iowa											
Daily	0.77	0.84	-1%	710	104,000	5,366	3,040	406	98,175	5,588	2,818
Monthly	0.87	0.88	-1%	38	2,917	443	297	42	2,242	422	274
Annual	0.76	0.77	-1%	3,432	7,351	5,365	5,492	3,957	7,235	5,587	5,327
Black Hawk Creek at Hudson, Iowa											
Daily	0.58	0.68	14%	9	10,600	381	192	13	13,667	331	130
Monthly	0.79	0.81	15%	11	2,102	384	244	20	2,408	331	199
Annual	0.81	0.92	15%	138	597	385	456	110	532	331	377

Table 9. Hydrology validation (January 1, 2005, to December 31, 2010) results for each streamflow-gaging station for the Cedar River Basin model, Iowa.—Continued

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

	E_{NS}	R^2	PBIAS	Measured				Simulated			
				Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)
Wolf Creek near Dysart, Iowa											
Daily	0.58	0.66	12%	13	9,400	362	182	11	10,877	323	130
Monthly	0.72	0.74	13%	21	2,001	362	239	17	2,194	322	203
Annual	0.82	0.90	12%	100	625	362	399	100	528	323	374
Cedar River at Cedar Rapids, Iowa											
Daily	0.77	0.82	-3%	916	138,000	6,771	3,940	572	119,717	7,151	3,885
Monthly	0.86	0.87	-3%	1,506	46,453	6,765	5,190	926	41,168	7,141	5,270
Annual	0.84	0.86	-3%	3,801	10,139	6,770	7,016	4,710	9,722	7,150	7,230
Cedar River near Conesville, Iowa											
Daily	0.72	0.79	2%	983	119,000	8,490	5,170	890	132,077	8,510	4,803
Monthly	0.85	0.86	2%	1,658	47,687	8,475	6,087	1,496	47,275	8,497	6,259
Annual	0.85	0.88	2%	4,327	12,935	8,488	9,145	5,128	11,867	8,508	9,099

[1]Measured data is missing for December 10, 2009, to December 31, 2009; validation statistics are based on 2,147 measured daily values.

resulted in R^2 values of 0.67, 0.5, and 0.54 for the same locations, respectively. PBIAS results ranged from 46 percent for the Shell Rock River at Shell Rock, IA, station to 68 percent for the Cedar River near Conesville, IA, station for monthly and annual time steps.

Nitrate loads substantially were underestimated for the validation period. There was a notable increase in measured data values basinwide from 2007 to 2010; however, this was not reflected in model results even though simulated fertilizer and manure rates were increased for the validation period relative to the calibration period. Heavy precipitation events during this period resulted in large simulated exports of nitrogen in the organic and ammonia forms, while nitrate loads substantially were underestimated.

Alternative Hydrology Scenario Calibration and Validation

The Cedar River Basin is a densely gaged basin; 12 USGS streamflow-gaging stations were used in this study for hydrology model calibration and validation purposes. Successful calibration can be more difficult for basins that are not as densely gaged, resulting in decreased agreement between simulated results and measured data. An alternative hydrology calibration scenario was run to represent the situation with regard to streamflow-gaging station density, and thus calibration points, for application to other Iowa basins. This was done by removing a subset of the streamflow-gaging stations that had been incorporated in the first calibration; locations removed include the Cedar River near Austin, MN, station, the Winnebago River at Mason City, IA, station, the Little Cedar River near Ionia, IA, station, the Beaver Creek at New Hartford, IA, station, the Wolf Creek near Dysart, IA, station, and the Black Hawk Creek at Hudson, IA, station. Removing these streamflow-gaging stations left only those streamflow-gaging stations on the main stem of the Cedar River; if a basin has few streamflow-gaging stations they will more likely be

Table 10. Nitrate load calibration (January 1, 2000, to December 31, 2004) and validation (January 1, 2005, to December 31, 2010) results for selected streamflow-gaging stations for the Cedar River Basin model, Iowa.

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; %, percent]

	Calibration			Validation		
	E_{NS}	R^2	PBIAS	E_{NS}	R^2	PBIAS
Shell Rock River at Shell Rock, Iowa						
Monthly	0.65	0.77	5%	0.39	0.67	46%
Annual	0.86	0.88	5%	-6.80	0.48	46%
Cedar River at Janesville, Iowa						
Monthly	0.28	0.65	7%	0.10	0.50	60%
Annual	0.61	0.65	7%	-6.35	0.27	60%
Cedar River near Conesville, Iowa						
Monthly	0.82	0.81	4%	-0.20	0.54	68%
Annual	0.76	0.78	6%	-2.73	0.25	68%

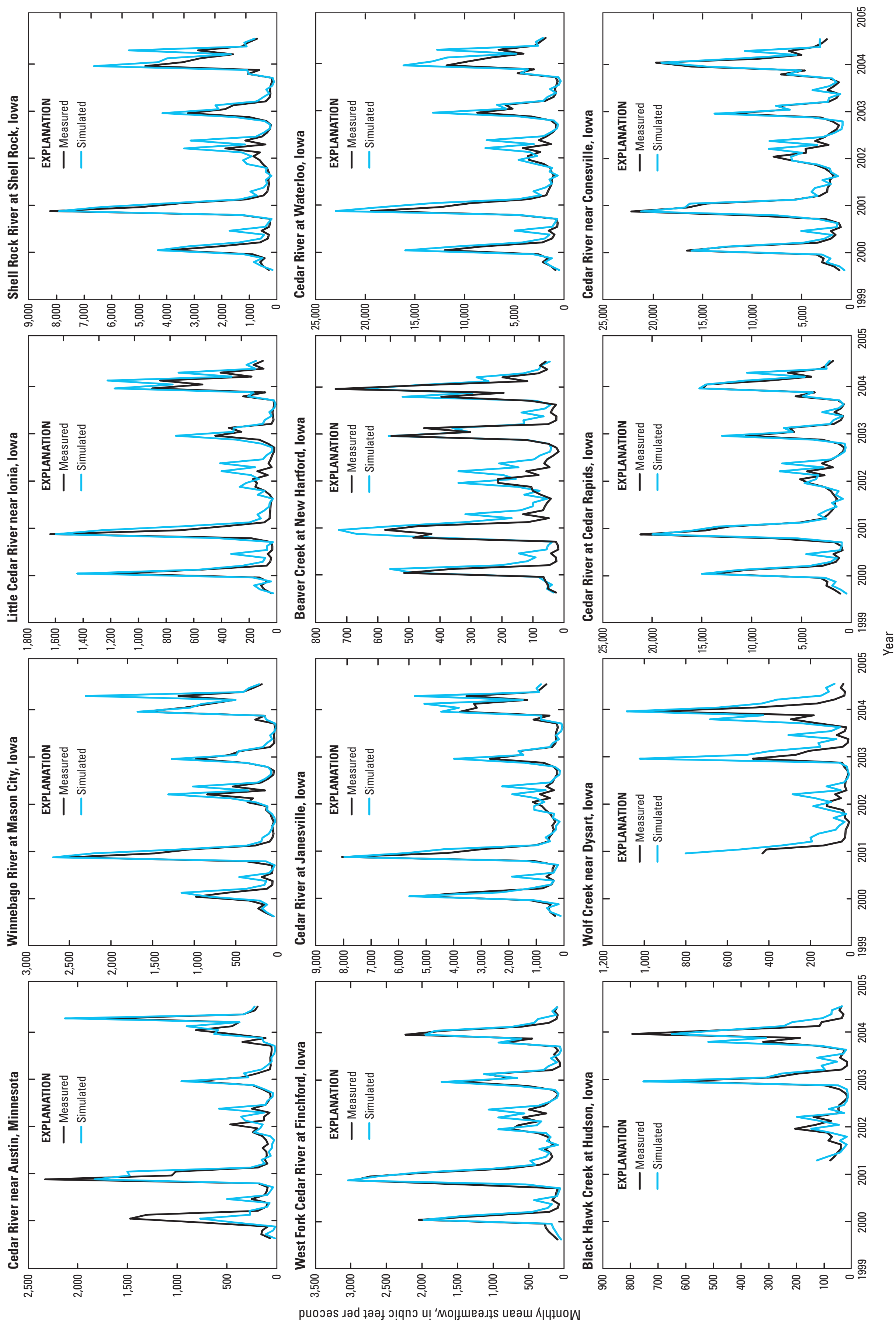

Figure 10. Calibration plots of measured and simulated monthly mean streamflow for each streamflow-gaging station in the Cedar River Basin model, Iowa.

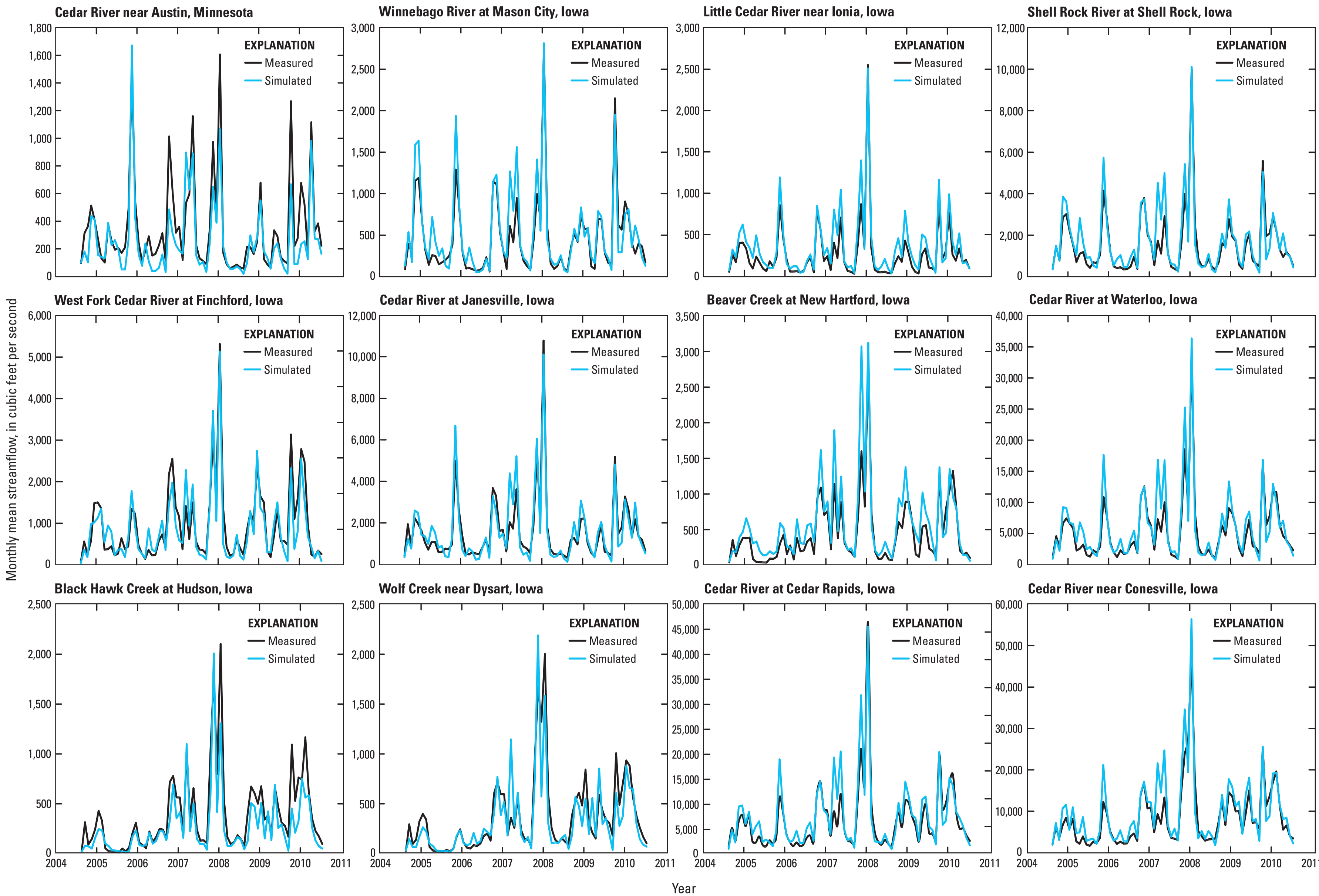

Figure 11. Validation plots of measured and simulated monthly mean streamflow for each streamflow-gaging station in the Cedar River Basin model, Iowa.

Table 11. List of streamflow-gaging stations used for the original and alternative scenario calibrations, and the streamflow-gaging stations used in place of the removed streamflow-gaging stations for calibration in the alternative scenario for the Cedar River Basin model, Iowa.

Original calibration locations	Alternative scenario calibration locations	New calibration point for alternative scenario
Cedar River near Austin, Minnesota		Cedar River at Janesville, Iowa.
Winnebago River at Mason City, Iowa		Shell Rock River at Shell Rock, Iowa.
Little Cedar River near Ionia, Iowa		Cedar River at Janesville, Iowa.
Shell Rock River at Shell Rock, Iowa	Shell Rock River at Shell Rock, Iowa	
West Fork Cedar River at Finchford, Iowa	West Fork Cedar River at Finchford, Iowa	
Cedar River at Janesville, Iowa	Cedar River at Janesville, Iowa	
Beaver Creek at New Hartford, Iowa		Cedar River at Waterloo, Iowa.
Cedar River at Waterloo, Iowa	Cedar River at Waterloo, Iowa	
Black Hawk Creek at Hudson, Iowa		Cedar River at Waterloo, Iowa.
Wolf Creek near Dysart, Iowa		Cedar River at Cedar Rapids, Iowa.
Cedar River at Cedar Rapids, Iowa	Cedar River at Cedar Rapids, Iowa	
Cedar River near Conesville, Iowa	Cedar River near Conesville, Iowa	

located on the main stem of the river rather than the smaller tributaries. The subbasins originally calibrated for hydrology based on the removed streamflow-gaging stations were instead calibrated based on the retained streamflow-gaging station locations farther downstream. Thus, subbasins originally calibrated on streamflow-gaging station data from the Cedar River near Austin, MN, station and the Little Cedar River near Ionia, IA, station were calibrated based on streamflow-gaging station data from the Cedar River at Janesville, IA, station; subbasins originally calibrated on streamflow-gaging station data from the Winnebago River at Mason City, IA, station were calibrated based on streamflow-gaging station data from the Shell Rock River at Shell Rock, IA, station; subbasins originally calibrated based on streamflow-gaging station data from the Beaver Creek at New Hartford, IA, station and the Black Hawk Creek at Hudson, IA, station were calibrated based on streamflow-gaging station data from the Cedar River at Waterloo, IA, station; and subbasins originally calibrated based on streamflow-gaging station data from the Wolf Creek near Dysart, IA, station were calibrated based on streamflow-gaging station data from the Cedar River at Cedar Rapids, IA, station. Locations used for calibration and validation purposes for the original and alternative scenarios are listed in table 11.

$E_{NS,}$ R^2, and PBIAS values were determined for hydrology calibration, 2000–04 (table 12), and validation, 2005–10 (table 13), for all streamflow-gaging stations to see how well values at the removed locations, calibrated based on alternative streamflow-gaging stations, compared to results when all streamflow-gaging stations were used. Monthly E_{NS} values indicate good to very good model performance for all locations for calibration and validation. However, the monthly calibration PBIAS for the Winnebago River at Mason City, IA, station (-30 percent), and subsequently the Shell Rock River at Shell Rock, IA, station (-28 percent), indicates unsatisfactory model performance. The monthly calibration and validation PBIAS for all other locations indicates satisfactory to very good model performance.

Calibration resulted in annual E_{NS} values ranging from 0.29 for the Winnebago River at Mason City, IA, station to 0.92 for the West Fork Cedar River at Finchford, IA, station and annual calibration R^2 values ranging from 0.65 for the Cedar River near Austin, MN, station to 0.99 for the West Fork Cedar River at Finchford, IA, station and the Cedar River near Conesville, IA, station. Annual calibration PBIAS ranges from -31 percent for the Winnebago River at Mason City, IA, station to 8 percent for the Black Hawk Creek at Hudson, IA, station.

Monthly calibration E_{NS} values range from 0.70 for the Cedar River near Austin, MN, station to 0.91 for the Cedar River at Cedar Rapids, IA, station and the Cedar River near Conesville, IA, station while monthly calibration R^2 values range from 0.72 for the Cedar River near Austin, MN, station to 0.93 for the Cedar River at Cedar Rapids, IA, station. Monthly calibration PBIAS ranges from -30 percent for the Winnebago River at Mason City, IA, station to 14 percent for the Black Hawk Creek at Hudson, IA, station.

Daily calibration E_{NS} values range from 0.39 for the Cedar River near Austin, MN, station to 0.81 for the Cedar River near Conesville, IA, station while daily calibration R^2 values range from 0.56 for the Wolf Creek near Dysart, IA, station to 0.86 for the Cedar River at Cedar Rapids, IA, station. The daily calibration PBIAS ranges from -31 percent for the Winnebago River at Mason City, IA, station to 8 percent for the Black Hawk Creek at Hudson, IA, station.

Table 12. Hydrology calibration (January 1, 2000, to December 31, 2004) results for each streamflow-gaging station for the alternative scenario for the Cedar River Basin model, Iowa.

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

				Measured				Simulated			
	E_{NS}	R^2	PBIAS	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)	Min streamflow (ft^3/s)	Max streamflow (ft^3/s)	Mean streamflow (ft^3/s)	Median streamflow (ft^3/s)
Cedar River near Austin, Minnesota											
Daily	0.39	0.57	2%	43	15,000	325	122	4	22,012	319	107
Monthly	0.7	0.72	3%	48	2,328	325	142	14	2,148	315	146
Annual	0.55	0.65	2%	166	457	325	393	194	490	319	223
Winnebago River at Mason City, Iowa											
Daily	0.5	0.74	-31%	17	7,550	359	127	11	9,810	472	193
Monthly	0.78	0.88	-30%	28	2,510	359	151	19	2,378	466	220
Annual	0.29	0.93	-31%	237	555	359	249	312	665	472	415
Little Cedar River near Ionia, Iowa											
Daily	0.66	0.69	-18%	12	7,530	197	61	5	4,506	231	90
Monthly	0.88	0.89	-17%	18	1,636	196	70	9	1,256	230	123
Annual	0.8	0.96	-17%	84	303	197	202	140	339	231	220
Shell Rock River at Shell Rock, Iowa											
Daily	0.54	0.75	-29%	142	23,900	1,175	475	71	27,358	1,514	714
Monthly	0.82	0.9	-28%	174	8,236	1,173	549	103	7,248	1,496	980
Annual	0.37	0.89	-29%	657	1,774	1,174	901	1,051	2,177	1,514	1,265
West Fork Cedar River at Finchford, Iowa											
Daily	0.8	0.81	-9%	32	11,300	539	210	24	7,066	589	268
Monthly	0.9	0.91	-10%	64	2,959	537	219	45	3,055	575	312
Annual	0.92	0.99	-9%	381	939	539	407	455	938	589	472
Cedar River at Janesville, Iowa											
Daily	0.64	0.75	-7%	183	20,900	1,173	498	32	32,825	1,254	479
Monthly	0.87	0.89	-6%	219	8,056	1,172	542	55	7,153	1,247	611
Annual	0.89	0.93	-7%	577	1,698	1,173	1,202	785	1,862	1,254	1,097
Beaver Creek at New Hartford, Iowa											
Daily	0.72	0.72	-12%	9	4,780	191	75	24	4,266	214	111
Monthly	0.8	0.82	-9%	21	920	190	81	32	700	207	135
Annual	0.65	0.81	-13%	120	260	191	179	168	307	214	174
Cedar River at Waterloo, Iowa											
Daily	0.69	0.83	-11%	340	57,100	3,444	1,760	198	60,635	3,834	1,830
Monthly	0.89	0.92	-10%	628	19,412	3,437	1,863	302	18,639	3,777	2,245
Annual	0.85	0.97	-11%	2,175	4,837	3,443	2,924	2,710	5,194	3,833	3,369
Black Hawk Creek at Hudson, Iowa[1]											
Daily	0.67	0.68	8%	6	5,450	125	50	3	1,793	113	37
Monthly	0.74	0.79	14%	14	793	124	57	13	521	107	66
Annual	0.87	0.97	8%	83	191	132	122	56	185	122	124

Table 12. Hydrology calibration (January 1, 2000, to December 31, 2004) results for each streamflow-gaging station for the alternative scenario for the Cedar River Basin model, Iowa.—Continued

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

	E_{NS}	R^2	PBIAS	Measured Min streamflow (ft^3/s)	Measured Max streamflow (ft^3/s)	Measured Mean streamflow (ft^3/s)	Measured Median streamflow (ft^3/s)	Simulated Min streamflow (ft^3/s)	Simulated Max streamflow (ft^3/s)	Simulated Mean streamflow (ft^3/s)	Simulated Median streamflow (ft^3/s)
Wolf Creek near Dysart, Iowa[2]											
Daily	0.53	0.56	1%	7	8,360	123	40	0	1,794	121	52
Monthly	0.75	0.83	6%	13	975	126	44	9	514	118	78
Annual	0.82	0.74	-4%	54	214	125	117	52	185	130	142
Cedar River at Cedar Rapids, Iowa											
Daily	0.78	0.86	-12%	326	61,800	4,200	2,240	263	57,987	4,690	2,450
Monthly	0.91	0.93	-10%	722	21,148	4,193	2,372	474	20,250	4,612	2,722
Annual	0.85	0.98	-12%	2,716	6,172	4,200	3,639	3,345	6,306	4,689	4,081
Cedar River near Conesville, Iowa											
Daily	0.81	0.85	-10%	660	69,200	5,052	2,760	371	56,998	5,546	3,292
Monthly	0.91	0.92	-8%	1,029	22,207	5,045	2,839	643	21,476	5,455	3,420
Annual	0.89	0.99	-10%	3,568	7,092	5,052	4,249	3,937	7,440	5,546	4,646

[1]Measured data was unavailable for 2000 and a part of 2001; calibration statistics are based on a total of 1,212 measured daily values.

[2]Measured data was unavailable for 2000 and a part of 2001; calibration statistics are based on a total of 1,326 measured daily values.

Annual validation E_{NS} values range from -0.91 for the Shell Rock River at Shell Rock, IA, station to 0.95 for the West Fork Cedar River at Finchford, IA, station while annual validation R^2 values range from 0.38 for the Winnebago River at Mason City, IA, station to 0.92 for the Black Hawk Creek at Hudson, IA, station. Annual validation PBIAS ranges from -23 percent for the Shell Rock River at Shell Rock, IA, station to 15 percent for the Black Hawk Creek at Hudson, IA, station.

Monthly validation E_{NS} values range from 0.68 for the Cedar River near Austin, MN, station to 0.90 for the Little Cedar River near Ionia, IA, station while monthly validation R^2 values range from 0.74 for the Wolf Creek near Dysart, IA, station to 0.92 for the Little Cedar River near Ionia, IA, station. Monthly validation PBIAS ranges from -23 percent for the Shell Rock River at Shell Rock, IA, station to 15 percent for the Black Hawk Creek at Hudson, IA, station.

Daily validation E_{NS} values range from 0.43 for the Cedar River near Austin, MN, station to 0.75 for the Cedar River at Waterloo, IA, station and the Cedar River at Cedar Rapids, IA, station while daily validation R^2 values range from 0.60 for the Cedar River near Austin, MN, station to 0.83 for the Cedar River at Waterloo, IA, station. Daily validation PBIAS ranges from -23 percent for the Shell Rock River at Shell Rock, IA, station to 14 percent for the Black Hawk at Hudson, IA, station.

The E_{NS} values for all time steps for calibration and validation for the model outlet, the Cedar River near Conesville, IA, station ranged from 0.71 to 0.91, while R^2 values ranged from 0.78 to 0.99, both just a slight drop from the original scenario. Although E_{NS} and R^2 values decrease for most locations and time steps relative to the original scenario, there are increases in these values for some locations. The Winnebago River at Mason City, IA, station is the location for which there is the greatest decrease in performance relative to the original scenario for the calibration and validation periods; the greatest decrease in model performance for this location is at the annual time step. In addition, this location, along with the Shell Rock River at Shell Rock, IA, station are the only locations to drop from satisfactory or better model performance to unsatisfactory model performance as indicated by the monthly calibration PBIAS.

A decrease in values from the original scenario was expected and can be attributed to a number of factors, such as projecting calibration parameters from one subbasin to another subbasin that has vastly different physical characteristics or land cover and management practices, or both. For example, the Winnebago River at Mason City, IA, station drains part of the Des Moines lobe landform region, while the rest of the subbasin is physically defined as Iowan Surface. This could explain the substantial decline in model performance for this location relative to the original scenario. As an additional example, the subbasins contributing directly to the Cedar River at Waterloo, IA, station have distinct physical differences from those subbasins contributing to the Black Hawk Creek at Hudson, IA, station and Beaver Creek at New Hartford, IA, station which were calibrated based on the Cedar

Table 13. Hydrology validation (January 1, 2005, to December 31, 2010) results for each streamflow-gaging station for the alternative scenario for the Cedar River Basin model, Iowa.

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

	E_{NS}	R^2	PBIAS	Measured Min streamflow (ft^3/s)	Measured Max streamflow (ft^3/s)	Measured Mean streamflow (ft^3/s)	Measured Median streamflow (ft^3/s)	Simulated Min streamflow (ft^3/s)	Simulated Max streamflow (ft^3/s)	Simulated Mean streamflow (ft^3/s)	Simulated Median streamflow (ft^3/s)
Cedar River near Austin, Minnesota[1]											
Daily	0.43	0.60	-5%	49	11,500	350	175	17	10,418	369	141
Monthly	0.68	0.79	-6%	58	1,606	349	227	32	2,313	368	244
Annual	0.70	0.75	-5%	222	462	349	346	278	500	368	364
Winnebago River at Mason City, Iowa											
Daily	0.61	0.75	-17%	27	10,400	464	241	28	11,078	542	276
Monthly	0.81	0.85	-17%	63	2,795	464	315	62	2,621	541	357
Annual	-0.57	0.38	-17%	314	582	464	467	391	680	542	550
Little Cedar River near Ionia, Iowa											
Daily	0.62	0.64	-15%	17	21,400	265	116	18	10,058	305	126
Monthly	0.90	0.92	-15%	26	2,551	265	174	32	2,091	305	197
Annual	0.54	0.83	-15%	183	396	265	251	206	422	305	287
Shell Rock River at Shell Rock, Iowa											
Daily	0.53	0.73	-23%	247	46,400	1,539	831	136	36,904	1,888	951
Monthly	0.73	0.85	-23%	289	9,999	1,538	1,111	203	10,415	1,886	1,301
Annual	-0.91	0.49	-23%	1,095	2,024	1,539	1,521	1,415	2,438	1,888	1,817
West Fork Cedar River at Finchford, Iowa											
Daily	0.58	0.77	-8%	43	23,300	955	492	39	20,811	1,028	463
Monthly	0.79	0.84	-8%	64	5,315	954	570	56	5,997	1,026	730
Annual	0.95	0.75	-8%	528	1,279	955	1,057	687	1,325	1,028	1,060
Cedar River at Janesville, Iowa											
Daily	0.67	0.75	-6%	281	51,400	1,579	840	88	31,677	1,666	738
Monthly	0.84	0.87	-5%	322	10,778	1,581	1,129	122	10,234	1,667	1,126
Annual	0.72	0.78	-6%	1,157	2,176	1,579	1,548	1,307	2,191	1,666	1,512
Beaver Creek at New Hartford, Iowa											
Daily	0.53	0.65	4%	26	15,700	443	213	32	15,655	426	187
Monthly	0.83	0.83	4%	38	2,917	443	297	42	2,199	425	287
Annual	0.83	0.84	4%	183	635	443	508	223	610	425	441
Cedar River at Waterloo, Iowa											
Daily	0.75	0.83	-4%	710	104,000	5,366	3,040	398	97,998	5,589	2,744
Monthly	0.86	0.88	-4%	38	2,917	443	297	603	32,065	5,584	3,753
Annual	0.74	0.77	-4%	3,432	7,351	5,365	5,492	3,904	7,150	5,588	5,413
Black Hawk Creek at Hudson, Iowa											
Daily	0.57	0.68	14%	9	10,600	381	192	12	13,639	328	130
Monthly	0.79	0.82	15%	11	2,102	384	244	17	2,385	328	193
Annual	0.82	0.92	15%	138	597	385	456	114	524	328	375

Table 13. Hydrology validation (January 1, 2005, to December 31, 2010) results for each streamflow-gaging station for the alternative scenario for the Cedar River Basin model, Iowa.—Continued

[E_{NS}, Nash-Sutcliffe coefficient of model efficiency; R^2, coefficient of determination ; PBIAS, percent bias; ft^3/s, cubic feet per second; %, percent]

	E_{NS}	R^2	PBIAS	Measured Min streamflow (ft^3/s)	Measured Max streamflow (ft^3/s)	Measured Mean streamflow (ft^3/s)	Measured Median streamflow (ft^3/s)	Simulated Min streamflow (ft^3/s)	Simulated Max streamflow (ft^3/s)	Simulated Mean streamflow (ft^3/s)	Simulated Median streamflow (ft^3/s)
Wolf Creek near Dysart, Iowa											
Daily	0.58	0.66	11%	13	9,400	362	182	11	10,877	323	132
Monthly	0.71	0.74	11%	21	2,001	362	239	18	2,224	322	199
Annual	0.83	0.89	11%	100	625	362	399	102	527	322	375
Cedar River at Cedar Rapids, Iowa											
Daily	0.75	0.80	-5%	916	138,000	6,771	3,940	562	119,364	7,188	3,849
Monthly	0.84	0.86	-5%	1,506	46,453	6,765	5,190	915	41,389	7,178	5,238
Annual	0.79	0.82	-5%	3,801	10,139	6,770	7,016	4,723	9,757	7,187	7,293
Cedar River near Conesville, Iowa											
Daily	0.71	0.78	0%	983	119,000	8,490	5,170	770	133,136	8,456	4,704
Monthly	0.84	0.85	0%	1,658	47,687	8,475	6,087	1,661	47,291	8,444	6,387
Annual	0.85	0.88	0%	4,327	12,935	8,488	9,145	5,041	11,793	8,455	9,134

[1]Measured data is missing for December 10, 2009, to December 31, 2009; validation statistics are based on 2,147 measured daily values.

River at Waterloo , IA, station parameters; the Cedar River at Waterloo, IA, station has a large urban contribution.

Summary

The U.S. Geological Survey, in cooperation with the Iowa Department of Natural Resources, used the Soil and Water Assessment Tool to simulate streamflow and nitrate loads within the Cedar River Basin, Iowa. The goal was to assess the ability of the Soil and Water Assessment Tool to estimate streamflow and nitrate loads in gaged and ungaged basins in Iowa. The Cedar River basin model uses measured streamflow data from 12 U.S. Geological Survey streamflow-gaging stations for hydrology calibration. The nitrate calibration was based on a small subset of the locations used in the hydrology calibration and uses nitrate concentration and corresponding streamflow from three Iowa Storage and Retrieval/Water Quality Exchange STORET/WQX stations. Streamflow and nitrate loads were calibrated for the period of January 1, 2000, to December 31, 2004, and validated for the period of January 1, 2005, to December 31, 2010.

Daily, monthly, and annual E_{NS}, R^2, and PBIAS values were determined for hydrology calibration and validation for all 12 streamflow-gaging station locations and illustrate the capability of SWAT for predicting hydrology; calibration E_{NS} and R^2 values are greater than 0.5 for all locations and time steps with the exception of the Cedar River near Austin, MN, streamflow-gaging station while PBIAS results indicate satisfactory to very good performance for all locations. Monthly validation E_{NS} values indicate good to very good performance, while PBIAS results range from satisfactory to very good.

The nitrate load calibration period resulted in annual and monthly E_{NS} and R^2 values greater than 0.6 for the Shell Rock River at Shell Rock, IA, streamflow-gaging station and the Cedar River near Conesville, IA, streamflow-gaging station with monthly values indicating good to very good performance, respectively. Although the annual and monthly calibration R^2 for the Cedar River at Janesville, IA, streamflow-gaging station were greater than 0.6, the monthly calibration E_{NS} indicated unsatisfactory performance. PBIAS results for the calibration period range from 4 percent for the Cedar River near Conesville, IA, streamflow-gaging station to 7 percent for the Cedar River at Janesville, IA, streamflow-gaging station. Monthly and annual validation E_{NS} values indicate that the measured mean is actually a better predictor than the model and that the model cannot accurately simulate nitrate loads for the 2005–10 time period. Nitrate loads were substantially underestimated for the validation period. A major limitation for successful nitrate load calibration is applying uniform management operations year to year, basinwide. While management operations such as planting and fertilizer application will vary from field to field and from year to year, lack of this information as well as the time requirement for implementing management operations at a finer resolution requires generic application. Depending on the year this could cause substantial differences between actual and simulated management operations.

An alternative hydrology calibration scenario was run to represent the situation with regard to streamflow-gaging station density, and thus calibration points, for application to other Iowa basins. This scenario involved removing a subset of the streamflow-gaging stations that had been incorporated in the first calibration retaining only those streamflow-gaging stations located on the main stem of the Cedar River. As expected, E_{NS} and R^2 values were highest for the original scenario in which all locations were used. However, statistical values remained high in the alternative scenario. For many of the locations and time steps, modifications of the calibration parameters had minimal effects on the results. Monthly results indicate good to very good model performance for all locations with only two exceptions for the calibration period. Decreases in model performance can be attributed to a number of factors, such as projecting calibration parameters from one subbasin to another subbasin that has vastly different physical characteristics or land cover and management practices, or both. Results indicate that SWAT can be used to adequately estimate streamflow in less densely gaged basins throughout the state, especially at the monthly time step, but that caution should be used when calibrating a location based on one with known physical dissimilarities.

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