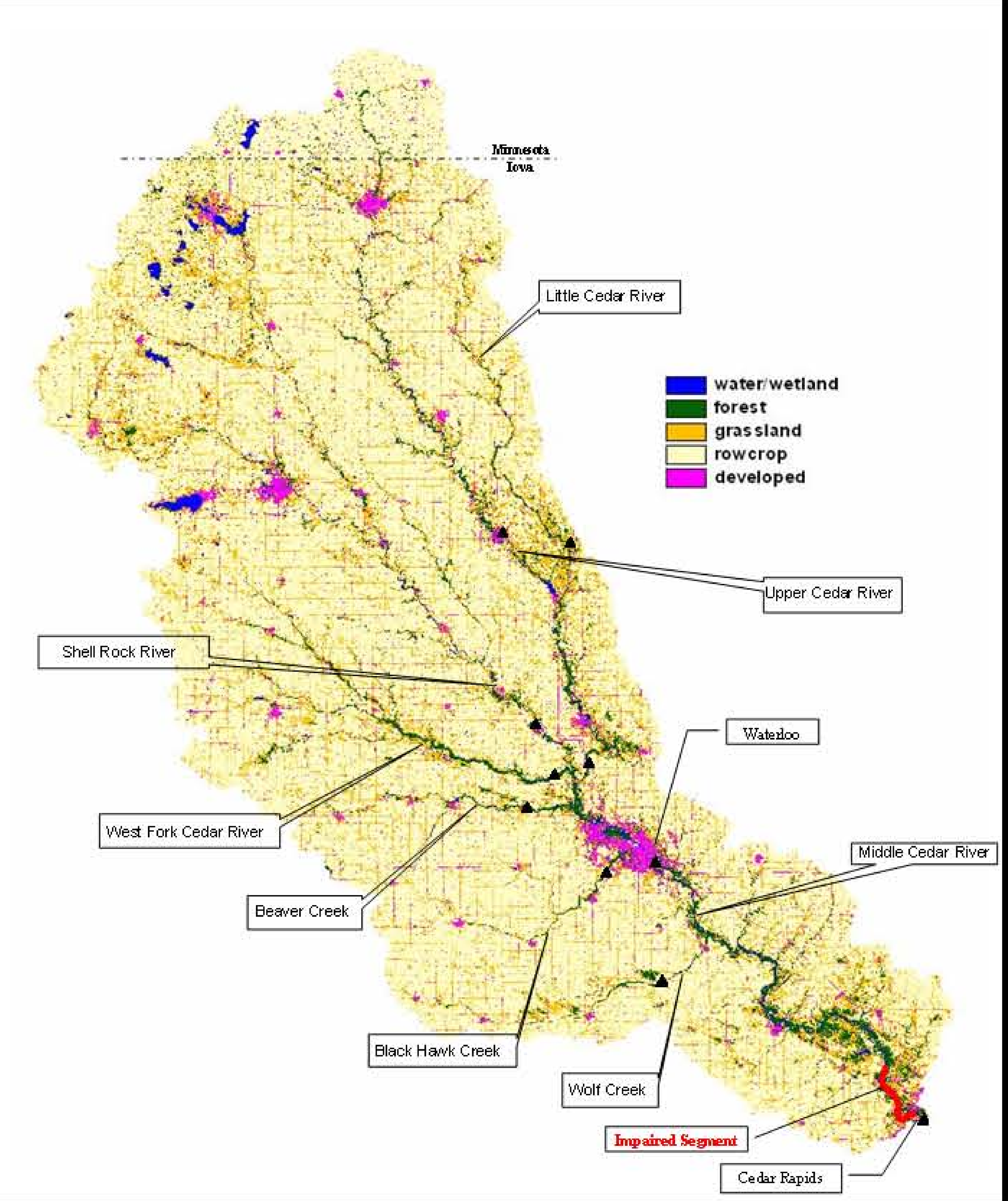
Surface-water modeling in support of establishing Total Maximum Daily Loads for nitrate in the Cedar River Basin, Iowa

Daniel Christiansen[1], Douglas Schnoebelen[1], & Chad Fields[2]
1: U.S. Geological Survey, Iowa Water Science Center, 2: Iowa Geological Survey Bureau

Abstract

Excessive nutrients (nitrogen and phosphorus) in surface waters are of concern in Iowa and other States across the Midwest. A 12-mile reach of the Cedar River upstream of Cedar Rapids, Iowa is listed on the Iowa Section 303d list as impaired by nitrate-nitrogen. In addition, nitrogen in the Cedar River may contribute to excessive nutrients transported to the Gulf of Mexico and subsequent hypoxic condition. The Cedar River Basin in east-central Iowa upstream of Cedar Rapids drains an area of 6,500 square miles, and is approximately 93 percent agricultural. Total maximum daily loads (TMDLs) for nitrate in the impaired reach need to be established and calculated for various flow conditions. Surface-water models can be a powerful tool for assessing TMDL calculations and scenarios. This investigation used a combination of the hydrodynamic model Diffusion Analogy Flow (DAFLOW) developed by the U.S. Geological Survey (USGS) and the water-quality model Water Quality Analysis Simulation Program, (WASP), developed by the U.S. Environmental Protection Agency. Modeling was performed for the period from January 1, 2001 to December 31, 2004 based on available flow and water-quality data. An overview of the DAFLOW and WASP model boundaries and setup are presented. A conceptual modeling schematic using USGS streamflow measurement stations as boundaries, and water quality collection sites as inputs, was used to determine scale and size of models. The DAFLOW and WASP models provided a good framework for predicting responses of hydrodynamic and water-quality parameters. In general, modeling showed good agreement with known water-quality and flow data, provided estimates of "hot spots" for nitrate in the basin, and showed elevated nitrate levels throughout much of the basin. The statistical Coefficient of Efficiency (COE) between the observed and the predicted model runs for the DAFLOW model was approximately 86% or 0.86, and for the WASP model was approximately 78% or 0.78. A value of 0.7 to 0.8 indicates a good fit for a streamflow simulation. A value of 0.5 typically indicates a good fit for stream nutrient export simulations. The models can be used for TMDL development and implementation procedures to target future application of best management practices (BMPs) to maximize reduction in nitrogen load at the watershed scale.



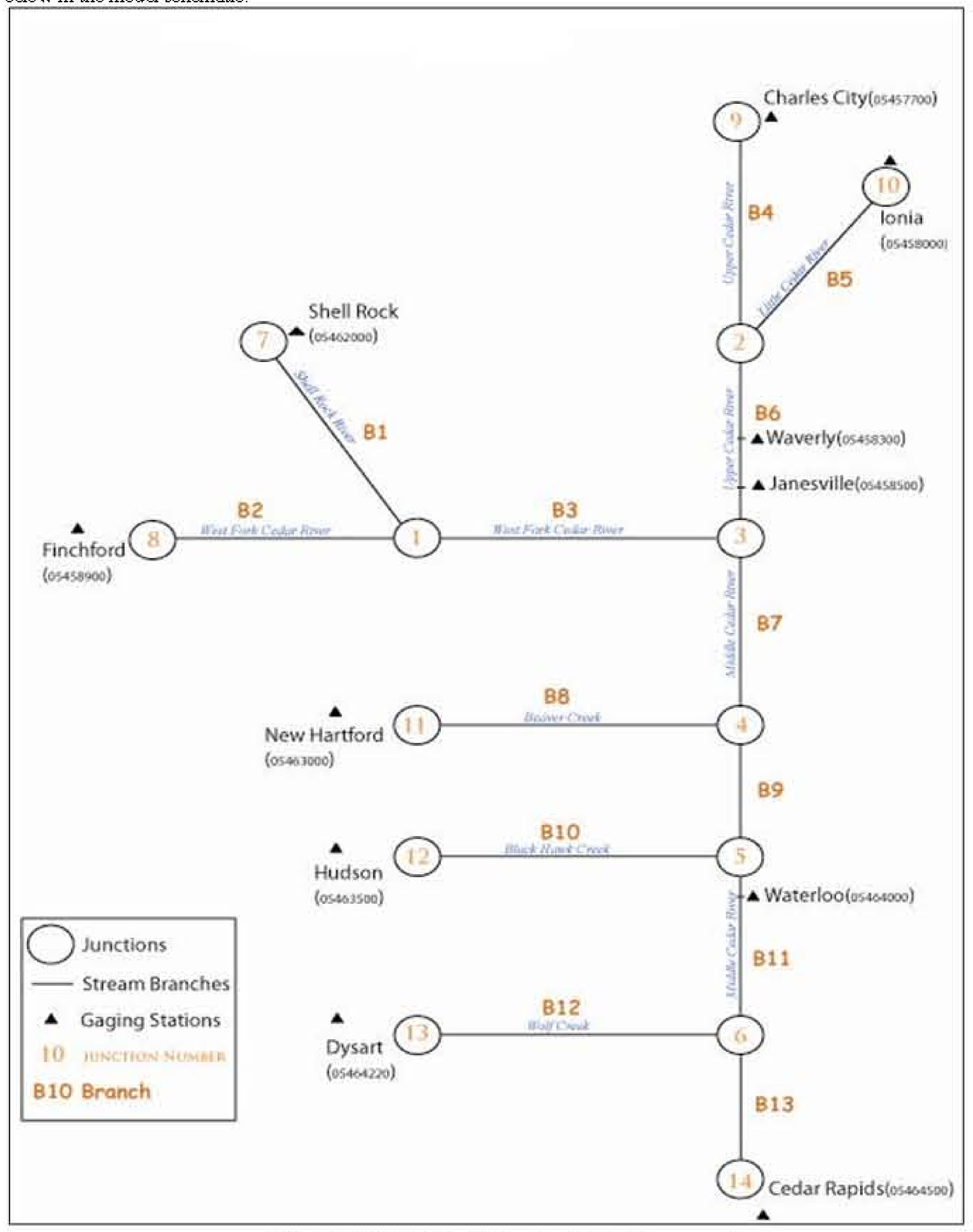
Landsat imagery of landuse in the Cedar River basin

Cedar River near, Cedar Rapids, IA

Cedar Rapids municipal wells, Ground water under the influence

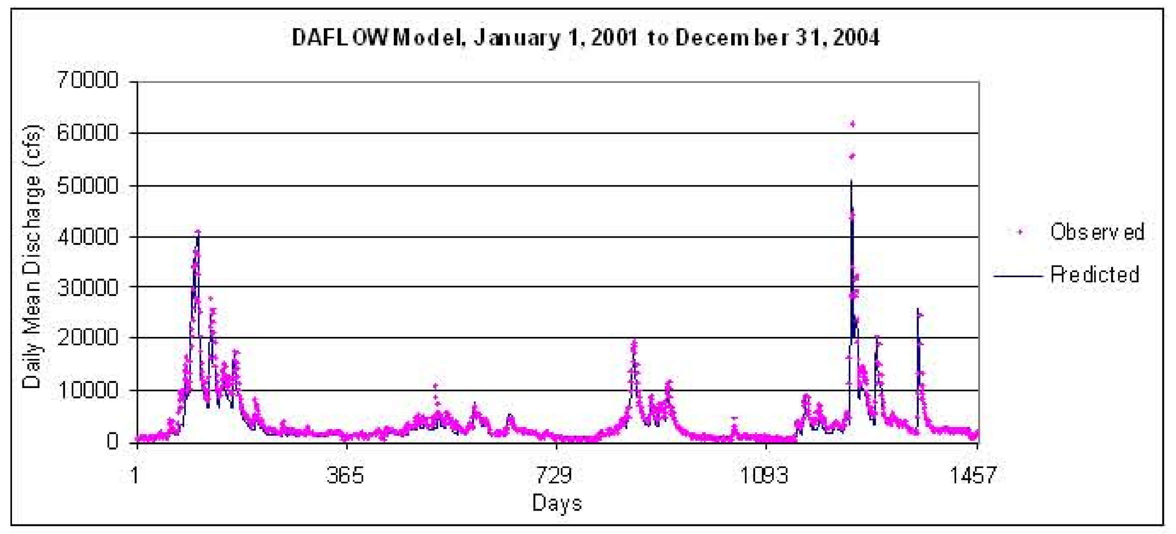
Model Setup

DAFLOW used streamflow data from USGS stream gages for the period of January 1, 2001 to December 31, 2004. Streamflow data were reconstructed, as needed, from discontinued gaging sites in the Basin. Reconstructed data were developed for Black Hawk Creek at Hudson (USGS station 05463500) and Wolf Creek at Dysart (USGS station 05464220). Regression equations were developed for each of these two gages by relating daily-value discharge from each gage to those of another gage with a corresponding record for the selected time period. Using the regression equations, daily values were estimated for these two gages for the selected time periods of unavailable data within the 4 calendar-year period. The stream gages within the Cedar River Basin that were used in the DAFLOW model are shown below in the model schematic.



DAFLOW Model Schematic

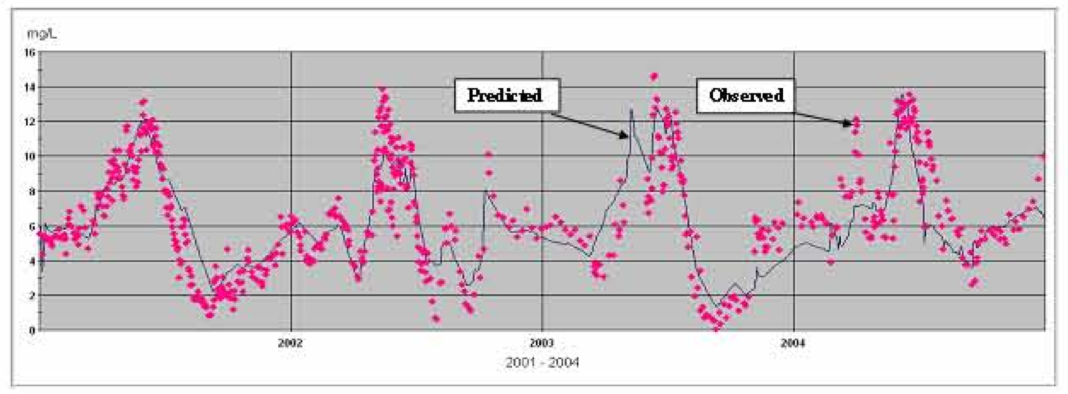
For initial calibration, the DAFLOW model was run for the 3-month period August 1, 2002 to October 31, 2002. This period was selected because there were no variations in storm sequencing or other anomalies among streamflow data. Then, DAFLOW was tested on streamflow data for calendar year 2002. Finally, the DAFLOW model was run on streamflow data for a 4-year period (January 1, 2001 to December 31, 2004). The 4-year period had a typical range of streamflow values for this area of the state. The hydrograph below shows the model predicted versus the observed data for streamflow at Cedar Rapids, Iowa, for the entire 4-year period. This calibrated streamflow data was used as input into the WASP model as the hydrodynamic linkage.



DAFLOW Final Model Run

Discharge and Sample Collection site

The WASP model was schematically set up similar to DAFLOW, with added nodes along stream lengths for better dispersion. All available nitrate data were added for initial boundary conditions along all boundary locations. This included all USGS and Iowa Geological Survey (IGS) water samples from synoptic and longer term monitoring studies. Typically, the amount of nitrite and ammonia is small (a few tenths of milligrams per liter) when compared to nitrate (milligrams per liter) in a stream. The nitrate concentration data used were reported as dissolved (filtered) concentrations in milligrams per liter. All nitrogen-containing compounds were reported as equivalent amount of elemental nitrogen (milligrams per liter as N). Water temperature was set to a default 20 degrees Celsius in the model. WASP was run for the 4-year period using the available nitrate data. The graph below shows observed versus model predicted nitrate concentrations.

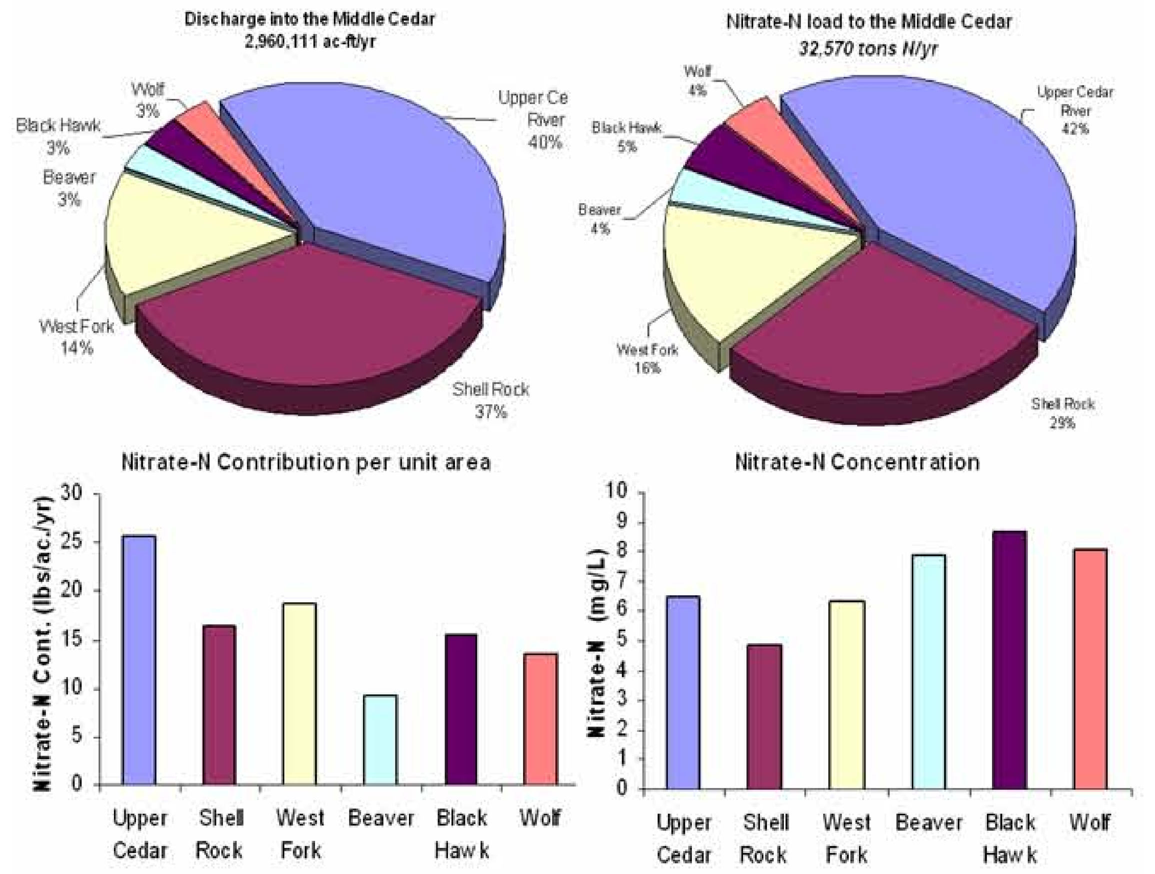


WASP Final Model Run

Model Results

Tributaries

All six major tributaries of the Cedar River above the impaired segment were modeled for discharge, nitrate concentration, and nitrate load. These include the Upper Cedar River, Shell Rock River, West Fork Cedar River, Beaver Creek, Black Hawk Creek, and Wolf Creek. Excluded in these results is the Middle Cedar River, as both discharge and nitrate loads are influenced by the upper six tributaries.



The figure above shows the estimated contribution of average flow and nitrate load to the Middle Cedar River, along with nitrate-N loads, contributions per unit area, and concentrations from each of the six major tributaries.

Model results indicate that during 2001-2004, the Upper Cedar River was the largest contributor of both flow and nitrate to the Middle Cedar River. Both discharge and nitrate loads were connected to watershed size. Nitrate concentrations were inversely related to watershed size, with the highest concentrations measured at the smallest tributaries. This is likely because of nitrate dilution from deeper baseflow contributions in deeper cut (larger) streams. In addition, larger streams have a greater portion of nitrogen in the organic form.

The Shell Rock River had substantially smaller amounts of nitrate load than discharge would indicate. The decrease in nitrate concentration in the Shell Rock River could be because of a dam located upstream of the gaging stations. Biological processes such as algal and plant uptake in the dam waters may decrease the amount of nitrate exported from the river.

The large discrepancy in load per area for Beaver Creek is because of the smaller flow per unit area than the other streams, although it has one of the higher concentrations (Fig. 15). The smaller load in Beaver Creek is potentially due to the wetland areas near the mouth of the river. These wetland areas convert nitrate nitrogen to organic nitrogen, and remove the nitrate from the system. Wetlands also evaporate and transpire much of the water near the surface of the land.

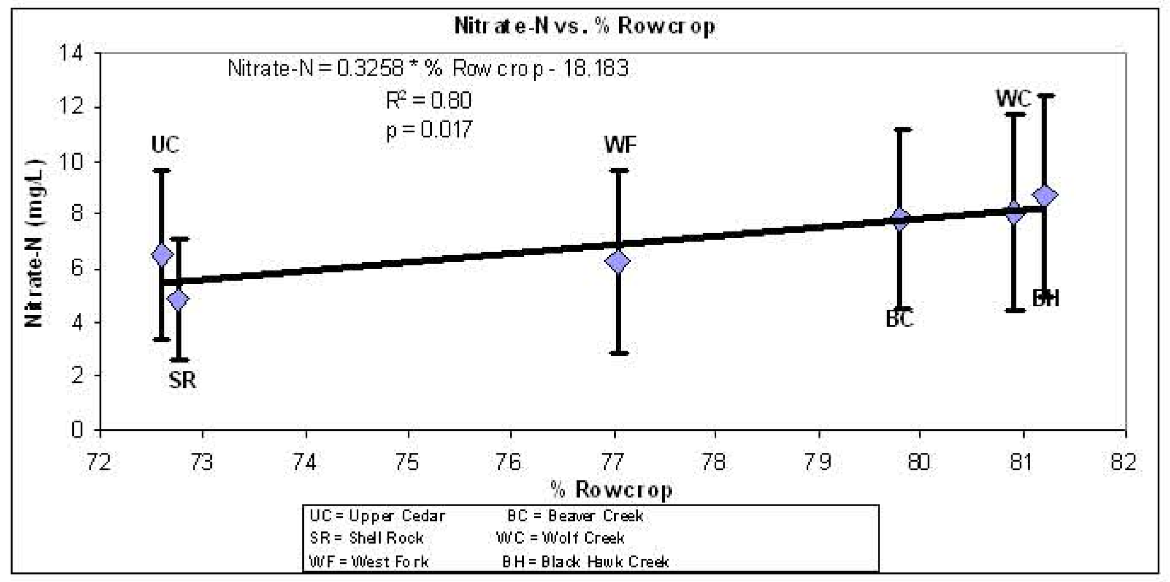
Cedar River

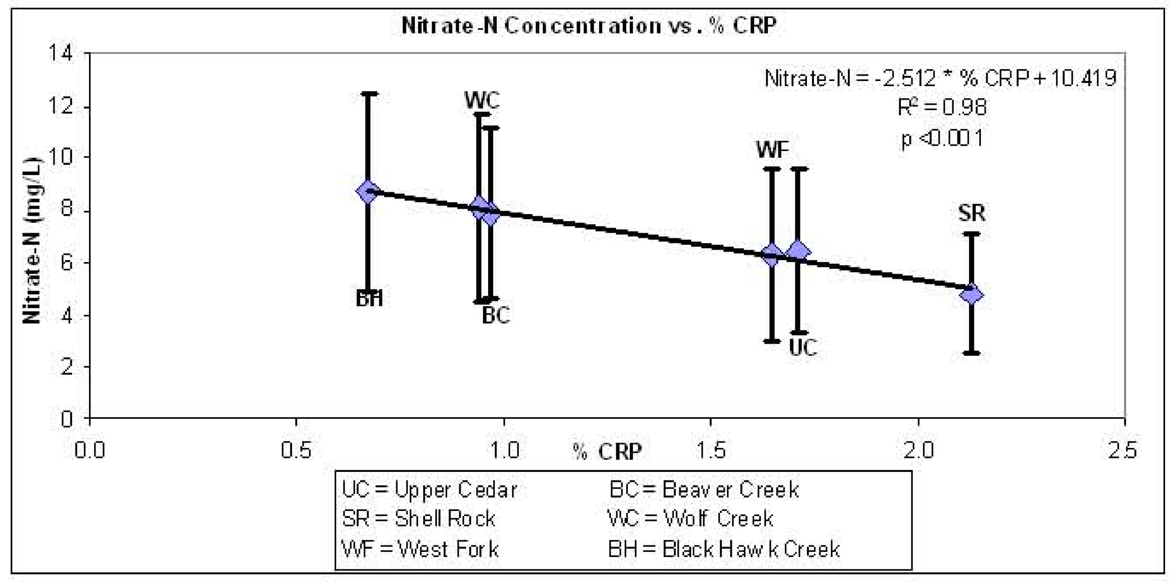
The entire Cedar River, including the Middle Cedar River, was modeled to the downstream end of the listed segment. Model results are as follows:

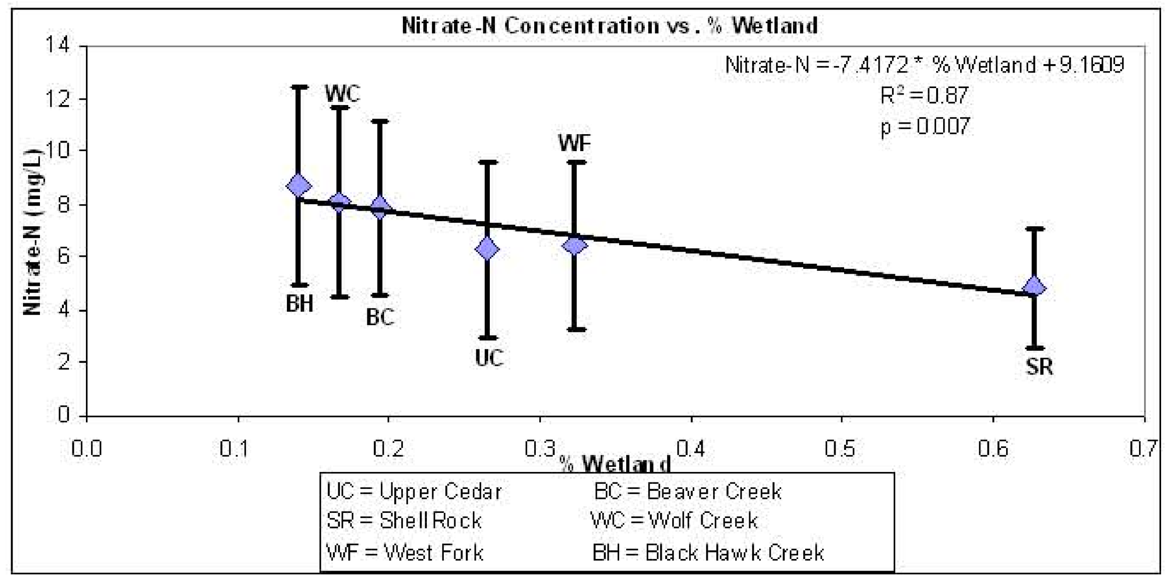
Discharge = 2,683,908 acre-feet/year
Nitrate-N load = 28,561 tons/year
Watershed contribution = 13.7 pounds/acre/year
Daily mean concentration = 6.1 milligrams/Liter

Watershed contribution and daily mean concentration of the entire Cedar River are towards the lower range when comparing with the values from the major tributaries. This is expected, as concentration and watershed contribution is comprised of a mixture of the tributaries and the contribution from the Middle Cedar River.

The model results indicate that the load of nitrate-nitrogen entering the Middle Cedar River is greater than the load of nitrate leaving the Middle Cedar by 4,000 tons annually, or 12%. A large majority of the reduction is most likely because of plant uptake, evaporation, transpiration, and industry decreasing the discharge of the water. Annual water discharged from the Middle Cedar River had a 10% reduction from water entering the Middle Cedar River. In addition, monitoring data indicates that a further decrease in nitrate might also be due to the doubling (10% to 20%) of nitrogen in the organic form in the main channel of the Cedar River.







Results compared to agricultural practices

93% Agricultural landuse in the basin

Contact Information

Daniel Christiansen, dechrist@usgs.gov, Douglas Schnoebelen, djschnoe@usgs.gov,
http://ia.water.usgs.gov/
Office Phone#319-337-4191

USGS science for a changing world