CHENEY LAKE CEAP PROJECT: VALIDATION/CALIBRATION, NUTRIENTS

Lyle D. Frees, KS State Agronomist, USDA-NRCS, Salina, KS, lyle.frees@ks.usda.gov; Fred D. Theurer, Agricultural Engineer, USDA-NRCS; Ronald L. Bingner, Agricultural Engineer, USDA-ARS; Lisa French, Project Coordinator, Cheney Lake Watershed Inc, Kansas

Abstract The Annualized Agricultural Non-point Pollutant Source (AnnAGNPS) was used to analyze some of the Special Emphasis Watershed during the Conservation Evaluation Assessment Program (CEAP). Its major finding was the significance of ephemeral gully erosion. In order to ensure confidence in its findings, a sequence of calibration in steps for the water runoff and pollutant loadings was done in a fixed order. This paper describes the calibration stages used to calibrate the nutrients, why certain steps were necessary, the results, and insights as to what led to the results and what can or should be done to improve the results.

INTRODUCTION

The Cheney Lake Reservoir is a major source of water for the city of Wichita, KS, and is located in south central Kansas near the town of Hutchinson. It was chosen by the United States Department of Agriculture (USDA) as a Special Emphasis Watershed in its Conservation Effects Assessment Project (CEAP) to evaluate the importance of specific agricultural conservation-related problems and the impacts of these problems on water quality that would be overlooked by the larger-scale, national assessment. A final report was submitted to USDA (Frees et al, 2009).

AnnAGNPS is a watershed-scale, water-quality, computer model (Bingner & Theurer, 2001a). It was used to predict water, suspended sediment and nutrient loads—from their originating locations in the field downstream to the reservoir. This was done for several best management practice (BMP) scenarios. These scenarios included the present landuse and management conditions as the benchmark scenario for calibration/validation and several alternative BMP scenarios. The first task required in the analysis was to calibrate and validate the benchmark scenario's streamflow (water) because all model predictions of water-borne pollutants are subject to the accuracy of the water predictions i.e. if the streamflow predictions do not reflect the measured statistics, then the validity of the water-borne sediment, chemical and sediment-borne chemical predictions will be uncertain.

Model predictions are sensitive to the application's temporal and spatial input data; i.e., the historical driving forces that are the cause of the nutrient load statistics, must be available for calibration/validation. This paper incorporates all the findings in relationship to streamflow and suspended sediment findings by Fred Theurer (Theurer; et al, 2010) and (Bingner; et al, 2010). Total nitrogen and total phosphorous are the two nutrients reported in the paper. It is recognized that dissolved and attached nutrients are also pollution issues in streams which require separated and distinct mitigation practices to alleviate their pollution concern.

The Nash-Sutcliffe (NS) efficiency coefficient was used as the criterion for the goodness of fit and also was the final step in the total streamflow nutrient calibration task. Total nutrient load in the streamflow was used as the basis for the NS index. These nutrient measurements include

water from two sources: 1) direct runoff nutrients from storm events; and 2) baseflow nutrients coming from groundwater. Estimates of daily baseflow nutrients were added to the direct runoff nutrients to determine the total simulated nutrients. The same historical climate dataset, the identical set of Runoff Curve Number (RCN) and the runoff and erosion calibration factors were used to calibrate the nutrient runoff.

The total drainage area for the Cheney Lake Watershed is 642,584 acres (1004 mile^2) The watershed is dominated by 470,741 acres of agricultural landuse which consists of 9 percent irrigated cropland, 44percent non-irrigated cropland, 21percent rangeland, and the remaining landuse is non-agriculture (built-up, water, and woodland). The average annual rainfall varies from a low of 25 inches at the west (top) end of the watershed to a high of 32 inches at the east (outlet) end, and averages 30 inches for the entire watershed. Slightly more than 2 inches of streamflow, which is a combination of surface runoff and baseflow whose source is groundwater, reappears in the river before it enters the reservoir while less than 1 inch of runoff is a part of the total streamflow. This paper describes a procedure used to calibrate a subwatershed upstream of United States Geological Survey (USGS) Gauging Station ID 07144780. The subwatershed is called Site 4 and drainage area above the outlet is 517,080 acres (808 m^2). USGS Gauging Station ID 07144780 has been continuously monitored since July 1965 although the station was relocated upstream in February 1996 from a drainage area of 567,840 acres (887 mile^2) to a drainage area of 518,618 acres (810 mile^2). USGS streamflow measurements started July 1, 1965. Indicators for sediment load and chemical measurements have been measured since November 1, 1996.

AnnAGNPS predicts the direct runoff (water), suspended sediment, and chemicals (nutrients and pesticides) from its respective sources in the field throughout the watershed to the outlet. It is capable of identifying how much of each pollutant, at any point in the stream system, originated from anywhere in the watershed. To accomplish this task, it was necessary to explicitly distinguish between each constituent's original location, yield and load.

NASH-SUTCLIFFE COEFFICIENT (NS)

Nutrients are measured daily without identifying what came from runoff versus baseflow. AnnAGNPS calculates the runoff associated with rainfall events, but approximates the runoff hydrograph for each rainfall event. This hydrograph approximation was considered sufficiently accurate to summarize runoff nutrients by months. Measured nutrients were summarized to match. Then a standard Nash-Sutcliffe (NS) coefficient was calculated using these monthly summaries while accounting for baseflow.

The estimated runoff plus baseflow for each month's summary was identical to the streamflow for every NS calculation. The NS was calculated as:

$$NS = 1 - \left(\hat{\sigma}/\sigma\right) \tag{1}$$

Where: NS ≡ Nash-Sutcliffe efficiency coefficient, [non dimensional units (nd)];
$\hat{\sigma}$ ≡ standard deviation of the estimated total nutrient which is equal to the predicted runoff plus estimated baseflow nutrient), [nd]; and
σ ≡ standard deviation of the measured total nutrient, [nd].

CALIBRATION/VALIDATION

There are three sources of error when performing a calibration/validation exercise, 1) model error; 2) measurement error; and 3) input error. The most obvious source of error is model error and that is what most people believe is measured by a NS. However, the other two sources of error frequently can be the major source of errors. For example, this paper is attempting to determine a NS from streamflow measured nutrient data while the AnnAGNPS model only predicts runoff nutrients. A major source of error is also thought to be with the baseflow nutrient determination. The measured streamflow nutrient data is not from direct measurements of nutrients but rather from an in stream sensor which measures turbidity which is used to calculate nutrient concentrations. The coefficient of determination ($R^{2)}$ for total nitrogen is 0.414, and the R^2 for total phosphorous is 0.845 (Christensen, et al, 2006).

The third error source for nutrients has been found to be the most challenging—input error. There are five (5) separate nutrient input data categories required: 1) crop data nutrients, 2) soils data, both organic and inorganic forms, 3) applied fertilizer, both organic and inorganic forms, 4) feedlot data, and 5) rainfall nitrogen. The organic and inorganic forms of nitrogen and phosphorous are not routinely analyzed for soils making it difficult to use measured soils' data. The crop data nutrients where calculated using published Kansas State University data for each crop type grown in the watershed. There is the opportunity to optimize the NS in relationship to crop residue nutrient data, but no optimization of the NS was conducted at this time. Soils data needed for soil nutrient initialization contained in the simulations period data section are not commonly collected. Two soil nutrient layers or required: the top 20 centimeters (cm) and 20 cm to the bottom of the profile. Inorganic nitrogen is commonly collected for the top 20 cm and for the 20 to 60 cm second soils' layer. Inorganic phosphorous would be the other commonly collect nutrient, but for only the top 20 cm layer. The 20 cm to the bottom of the soils profile is not collected. The organic nitrogen and organic phosphorous soil nutrients for both soil layers were calculated as a function of soil organic matter. Organic nitrogen = organic matter ratio X 90000 and organic phosphorous = organic matter ratio X 15000. The following table contains the initialization values used for soil nutrients.

Both commercial and manure fertilizer were nutrient inputs accounted for using common rates, form and timing for each crop and rotation. It is important to note soluble phosphorous from a feedlot is not correctly accounted for in the verification output files within the AnnAGNPS executable version 5.00.m.116.

Table 1 Soils Global Nutrient Initialization.

Cropland Soils Global Nutrient Initialization				
		0-20 cm layer		20 cm to bottom of profile
Initial Inorganic N		7.0		2.0
Initial Inorganic P		29.0		1.0
Initial Organic Matter		0.007		0.0035
Initial Organic N		630.0		315.0
Initial Organic P		105.0		52.5
Non-Cropland Soils Global Nutrient Initialization				
		0-20 cm layer		20 cm to bottom of profile
Initial Inorganic N		1.0		1.0
Initial Inorganic P		1.0		1.0
Initial Organic Matter		0.025		0.015
Initial Organic N		2250.0		1350.0
Initial Organic P		375.0		225.0

Rainfall nitrogen concentration was also considered as a nutrient input. The National Atmospheric Deposition Program collects precipitation for concentration of nitrogen at various sites throughout the United States. The 1997 through 2008 annual average nitrogen concentration is 1.59 parts per million (ppm). When over or under nutrient predictions occur, it is impossible to know which nutrient input needs adjustment in order to calibrate the model. For this study all nutrients were adjusted proportionally when over or under predictions occurred.

SIMULATION PERIOD

The calibration/validation time period was limited by available measured nutrient data 1997 - 2008.

TOTAL NITROGEN AND PHOSPHORUS NUTRIENTS IN RUNOFF AND BASEFLOW

AnnAGNPS is concerned only with storm events and associated runoff and pollutant loads. Streamflow is more than runoff. This difference must be recognized whenever calibrating/validating watershed model output with USGS measured nutrients. Measured nutrients, as defined by the USGS, includes all nutrients passing a recording gauge regardless of its originating source. There are two sources for streamflow nutrients: 1) baseflow nutrients which originates from the groundwater, but not all groundwater appears in the stream as baseflow, and 2) runoff nutrients which originates from storm events as surface water and quick return flow. Starting in January 1997, a continuous water-quality monitoring system was established by USGS to describe the water quality in the Cheney Lake Watershed. Regression equations were developed to measure daily load and concentration for a number of water quality constitutions (Christensen, et al, 2006). Total nitrogen and total phosphorus were selected for analysis with AnnAGNPS in this report. Starting on November 10, 1998 an in stream sensor

which measured turbidity was installed which resulted in improved estimates of daily total nitrogen and phosphorus loads. Occasionally, the sensor which measured turbidity was inoperable. When this occurred the daily load was supplied by the discharge based equation. Daily calculated nutrient loads were aggregated to monthly loads for analysis.

The method used to separate baseflow nutrients from runoff is to determine total nutrients in streamflow and subtract baseflow nutrient from streamflow nutrients to arrive at runoff nutrients. Nutrients contained in the baseflow will be in the dissolved form. Mean concentrations for 1997-2000 nutrients in baseflow were collected by USGS (Milligan, et al, 2001) and were used as the baseflow concentration for the study period January 1, 1997 through December 31, 2008. The mean baseflow nutrient concentration used for this report was 1.0 ppm for total nitrogen and 0.10 ppm for total phosphorous. Monthly baseflow has been calculated for Site 4 on an acre foot basis; monthly baseflow load was calculated for nitrogen and phosphorus.

The following table contains the 1997 through 2008 average annual streamflow total nitrogen, baseflow total nitrogen and runoff total nitrogen load:

Table 2 Distribution of baseflow and runoff total nitrogen.

1997-2008 Average Annual Total Nitrogen (TN)		
USGS measure TN load lbs/acre	**Baseflow TN lbs/acre**	**Runoff TN lbs/acre**
0.88	**0.33**	**0.55**

The following table contains the 1997 through 2008 average annual streamflow total phosphorous, baseflow total phosphorus and runoff total phosphorous load:

Table 3 Distribution of baseflow and runoff total phosphorous.

1997-2008 Average Annual Total Phosphorous (TP)		
USGS measure TP load lbs/acre	**Baseflow TP lbs/acre**	**Runoff TP lbs/acre**
0.10	**0.03**	**0.07**

NS NUTRIENT RESULTS

The 1997 through 2008 NS for total nitrogen was **0.59** and for total phosphorous was **0.47** which were based on the monthly measured versus monthly AnnAGNPS predicted loads. These ratings are marginally satisfactory for a goodness of fit between measured versus predicted. There is a greater degree of uncertainty between discharge estimated total nitrogen and phosphorus and turbidity sensor measured nutrient loads. Coupling this with the National Weather Service's Next Generation Weather Data WSR-88D (NEXRAD) estimated precipitation improvements being initiated in 2002, a NS analysis for total nitrogen and phosphorous was completed for January 1,

2002 through December 31, 2008. The 2002 through 2008 NS for total nitrogen was **0.76**, and total phosphorous was **0.55** which are significantly improved, illustrating the value of improved input data within AnnAGNPS to predict water quality constituents.

DISCUSSIONS AND CONCLUSIONS

The NS can and should be improved, but the improvements are largely depended upon improvements in estimated nutrient measurements and AnnAGNPS input data. The first, most likely source of loss of ability to duplicate measured results, is to make certain that AnnAGNPS inputs sufficiently describe the spatial and temporal variables. Second, better and more frequent direct measurements of sediment and nutrients should be made whenever water quality is important, including particle-size measurements. Third, improve initialization of background soil organic and inorganic nutrients which better reflect spatial variability within the watershed. Fourth, a baseflow feature that addresses the percolation into the vadose zone, groundwater movement, and interception of the top of the water table by the channel is needed within AnnAGNPS, if a complete analysis of dissolved chemicals is important or when calibrating or validating.

It is important to note that 38percent of the total nitrogen load and 30percent of the total phosphorous average annual load is derived from base flow. While it is still important to improve AnnAGNPS baseflow routines on a monthly basis the average annual baseflow estimates are most likely correct. The rainfall nitrogen concentration is 1.59 ppm which exceeds the base flow concentration. The 1.0 ppm total nitrogen load is very close to being considered "background" concentration. It will require a different suite of conservation practices to address reductions of nutrient loads originating as baseflow from runoff derived nutrient loads.

REFERENCES

Bingner, R.L. and F.D. Theurer. (2001a). AGNPS 98: a suite of water quality models for watershed use. *In Proceedings of* Sediment: Monitoring, Modeling, and Managing, Pgs. , 7th Federal Interagency Sedimentation Conference, Reno, NV. 8 pp.

Bingner, R.L. and F.D. Theurer. (2001b). AnnAGNPS: estimating sediment yield by particle size for sheet and rill erosion. In Proceedings of Sediment: Monitoring, Modeling, and Managing, Pgs. , 7th Federal Interagency Sedimentation Conference, Reno, NV. 7 pp.

Bingner, R.L., F.D. Theurer, L.D. Frees, & L. French. 2010. Cheney Lake CEAP Project validation/calibration: sediment. *In Review*. In Review. In Proceedings of the Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling (JFIC 2010) June 27-July 1, 2010, Las Vegas, NV. 12pp.

Christensen, V.G., Jian, Xiaodong, and Ziegler, A.C. (2000). Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995–99: U.S. Geological Survey Water-Resources Investigations Report 00–4126, 36 p.

Christensen, V.G., Graham, J.L. Milligan, C.R., Pope, L.M., and Ziegler, A.C. (2006). Water quality and relation to taste-and-odor compounds in the North Fork Ninnescah River and Cheney Reservoir, south-central Kansas, 1997-2003: U.S. Geological Survey Scientific Investigations Report 2006-5095, 43 p.

Frees, Lyle, Lisa French, and Fred Theurer. (2009). Conservation Effects Assessment Program: Special Emphasis Watersheds, Cheney Lake Watershed, Kansas. 17 March 2009. USDA, NRCS, Kansas. 50 pp.

French. L., L.D. Frees, F.D. Theurer, & R.L. Bingner. 2010. Cheney Lake CEAP Project: conservation practice effects assessment. *In Review*. In Review. In Proceedings of the Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling (JFIC 2010) June 27-July 1, 2010, Las Vegas, NV. 12pp.

Milligan, C.R., and Pope, L.M. (2001). Occurrence of phosphorus, nitrate, and suspended solids in streams of the Cheney Reservoir Watershed, south-central Kansas, 1997–2000: U.S. Geological Survey Water-Resources Investigations Report 01–4199, 22 p.

Pope, L.M., and Milligan, C.R. (2000). Preliminary assessment of phosphorus transport in the Cheney Reservoir watershed, south-central Kansas, 1997–98: U.S. Geological Survey Water-Resources Investigations Report 00–4023, 29 p.

Theurer, F.D., R. L. Bingner, L.D. Frees, & L. French. 2010. Cheney Lake CEAP project validation/calibration: streamflow. In Review. In Proceedings of the Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling (JFIC 2010) June 27-July 1, 2010, Las Vegas, NV. 9pp.