CHENEY LAKE CEAP PROJECT: VALIDATION/CALIBRATION, STREAMFLOW

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Abstract AnnAGNPS was used to analyze some of the projects funded in 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 stages, for the water runoff and pollutant loads was done in a fixed order. This paper describes the streamflow calibration stage used to calibrate the runoff, why certain steps were necessary, the results, and insights as to what led to the results & 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 as a Special Emphasis Watershed in their 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).

The Annualized Agricultural Non-point Pollutant Source (AnnAGNPS) is a watershed-scale, water-quality, computer model (Bingner & Theurer, 2001a). It was used to predict water & pollutant loads (Bingner & Theurer, 2001b)—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 & management conditions as the benchmark scenario for calibration/validation and several alternative BMP scenarios. The first task required in the analysis was to calibrate & 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.

The total drainage area for the Cheney Lake watershed is 642,584 acres (1004 m^2) The watershed is dominated by 470,741 acres of agricultural landuse which consists of 9% irrigated cropland, 44% non-irrigated cropland, 21% rangeland, and the remaining landuse is non-agriculture (builtup, water, & 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 & baseflow whose source is groundwater, reappears in the river before it enters the reservoir. This paper describes a procedure used to calibrate a subwatershed upstream of 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 .m^2) to a drainage area of 518,618 acres (810 m^2). USGS streamflow measurements started 1 July 1965. Indicators for sediment load and chemicals have been measured since 1 November 1996.

AnnAGNPS predicts the direct runoff (water), suspended sediment, and chemicals (nutrients & pesticides) from their respective sources in the field and transports them 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, AnnAGNPS explicitly distinguishes the runoff and each pollutant's original location, yield, & load. Only a small fraction of the precipitation reappeared as streamflow in the river before it entered the reservoir.

The calibration/validation was done in a fixed sequence because the sediment load depends upon the runoff, the nutrients depend upon both the runoff & sediment load, and assessments depend upon thr runoff, sediment, & nutrient loads (Theurer et al, 2010; Bingner et al, 2010; French et al, 2010)).

NASH-SUTCLIFFE COEFFICIENT (NS)

Streamflow is measured daily without identifying what can 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 by months. Measured streamflow was summarized to match. Then a standard Nash-Sutcliffe (NS) coefficient was calculated (Moriasi et al, 2007) 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:

$$NS = 1 - (\hat{\sigma}/\sigma) \qquad (1)$$

Where: NS ≡ Nash-Sutcliffe efficiency coefficient, [nd];

$\hat{\sigma}$ ≡ standard deviation of estimated streamflow which is equal to the predicted runoff plus estimated baseflow), [nd];and

σ ≡ standard deviation of measured streamflow, [nd].

CALIBRATION/VALIDATION

Model predictions are sensitive to the application's temporal & spatial input data; i.e., the historical driving forces that cause the streamflow load statistics must be available for calibration/validation. This includes spatially-variable, daily precipitation when local thunderstorms may have had significant influence on the runoff. The project analysis found two major input requirements for streamflow integrity: 1) realistic spatially varied, daily

precipitation; and 2) accurate SCS runoff curve numbers (RCN) for antecedent moisture condition II (AMC-II).

The RCN is the single most important parameter, after actual precipitation that affects the rainfall/runoff relationship but is the most uncertain of the landuse input variables. Therefore the RCN was the most obvious choice for streamflow (water) calibration. Using the RCN without calibration would have resulted in much greater runoff than measured. Calibrating the maximum potential retention variable in the SCS runoff curve number procedure to match the average annual streamflow was the first task in the calibration/validation process.

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 calibration task. Total streamflow load was used as the basis for the NS index because streamflow are the measured statistics. Streamflow measurements include water from two sources: 1) direct runoff from storm events; and 2) baseflow coming from groundwater. Calibration factors for the SCS runoff curve numbers were used to determine a series of direct runoffs. Estimates of daily baseflow were added to the direct runoff to determine the total simulated streamflow. The maximum NS from this relationship was used to select the optimal calibration factor. The same historical climate dataset, the identical set of RCNs & its calibration factor was used to calibrate the sediment & nutrient loads.

There are three sources of error when performing a calibration/validation: (1) input error; (2) measurement error; and (3) model error. Model error is what most people believe is measured by a NS. However, the other two sources of error frequently can be the major source of error. Or NS may not indicate errors but only differences if the measured data is not completely reliable. For example, the study for this paper attempted to determine a NS from streamflow data but since the model only calculates runoff, a major source of error is thought to be with the baseflow determination. In addition, subsequent model predictions of pollutant loads include suspended sediment. Suspended sediment's "measured data" is not from direct measurement but rather from turbidity and the turbidity had been related to small sample of measured suspended sediment load. Furthermore, particle-size measurements had not been associated with these sediment samples.

The first source of error has been found to be the most troublesome—input error, which is why the RCN's potential retention parameter was chosen to be the calibration candidate. For perfect calibration/validation, the driving forces (the weather) must match the resisting forces—the watershed's landscape resolution, soils, spatial & temporal landuse, channel geometry, etc. It is not practical to collect a complete set of watershed data over the same time period as the weather. There will always be a paucity of watershed data for validation.

Calibrating the potential retention parameter equally for all runoff curve numbers was considered the best course.

CLIMATE INPUT

The primary climate file must contain six weather parameters: (1) precipitation; (2) minimum air temperature; (3) maximum air temperature; (4) dew point temperature; (5) wind speed; and (6) sky cover, or cloud cover, or solar radiation. And it must be serially complete. Of the six weather parameters, the emphasis was placed on precipitation and which recorded statistics best represented the Cheney Watershed. A search of the National Climate Data Center resulted in selection of Cooperative Observation Program (COOP) station Hutchinson SW 10 (COOP ID- 143930) as the most serial complete for minimum & maximum air temperatures and precipitation within the Cheney Watershed. Other COOP stations were available, but not as serially complete as Hutchinson SW 10. The National Weather Service 1st Order station Wichita ICT (COOP ID- 148830) contained the remaining three weather parameters of sky cover, dew point and wind speed and were used to complete the required weather parameters from the primary climate file from 1/1/1965 through 12/31/1999.

Because precipitation is the weather parameter of emphasis climate data from a station at Stafford Ks was selected from 1/1/2000 through 12/31/2008. This station is managed by the Big Bend Water Management district and contained all six if the required weather parameters and is located near the center of the Cheney Watershed. The Stafford station elevation 1804, maximum, minimum temperature, precipitation and wind speed were used directly as collected from the Stafford station. Relative humidity was converted to dew point, sky cover is not collect, but Solar Radiation is collected in Langley and converted to BTU/h/Ft^2. Because the elevation of the Stafford station is 1804 and Hutchinson SW 10 is 1570 all maximum and minimum daily temperatures from 1/1/1965 through 12/31/1999 were converted to the Stafford station of elevation 1804. The final primary climate dataset was an amalgamation of Hutchinson SW 10 and Stafford corrected for elevations starting in 1/1/1965 through 12/31/2008.

Only daily precipitation was prepared for the secondary climate files. The 4.1 Km grid configuration developed by the NWS for NEXRAD was used to assign daily collected precipitation to their corresponding AnnAGNPS cell. NEXRAD developed precipitation used in this projected started 10/1/1995 through 12/31/2008. Additional ground based precipitation gauges along with satellite precipitation instrumentation to improve NEXAD derived precipitation estimates was completed in 2002 which significantly improved NEXRAD precipitation estimates. To complete the 43 year historical precipitation record from 1/1/1965 through 9/30/1995 and maintain the variability of precipitation within the watershed four additional NWS second order station historical precipitation records were assigned using the Thiessen polygon technique. In addition to Hutchinson SW 10, stations Hudson (COOP ID- 143847), Greensburg (COOP ID- 143239), Pratt 3W (COOP ID- 146549) and Kingman (COOP ID- 144313) were assign to their corresponding 4.1 Km NEXRAD secondary climate file to complete the historical precipitation data set from 1/1/1965through 12/31/2008.

Next Generation Weather Data WSR-88D (NEXRAD) precipitation data was analyzed to determine if it had sufficient horizontal resolution, 152 grid cells - see Figure 1, and had been calibrated to precipitation on the ground. The Nation Weather Service (NWS) is making continued efforts to improve precipitation measurements which can be used at the watershed scale. In 2002, the NWS made improvements to NEXRAD precipitation collection with Stage

III, Digital Precipitation Array (DPA) products. These improvements had a positive impact on precipitation measurements which cover the Cheney Watershed. A complete report on DPA NEXRAD precipitation improvement is available at: http://www.nws.noaa.gov/oh/hrl/dmip/stageiii_info.htm. The NWS has long recognized the need to modernize the Cooperative Observer Program (COOP) which maintains long term historic climate data. A two phase strategy was started in 2000 to modernize and reduce error in the collection and use of NWS COOP data. A summary of this report is available at: http://www.nws.noaa.gov/om/coop/coopmod.htm.

Dr. Xingong Li, Department of Geography, University of Kansas, Lawrence, KS, was contracted by Kansas NRCS to report on the accuracy of NEXRAD precipitation between 1995 and 1999 for use with AnnAGNPS analysis in the Cheney Watershed. Findings from this investigation are 1) greatest NEXRAD precipitation error occurred in events less than 0.5 inches and 2) summer thunderstorms are not captured resulting in NEXRAD measured precipitation error. A complete report can be obtained by requesting report - Using NEXRAD Precipitation in AnnAGNPS to lyle.frees@ks.usda.gov.

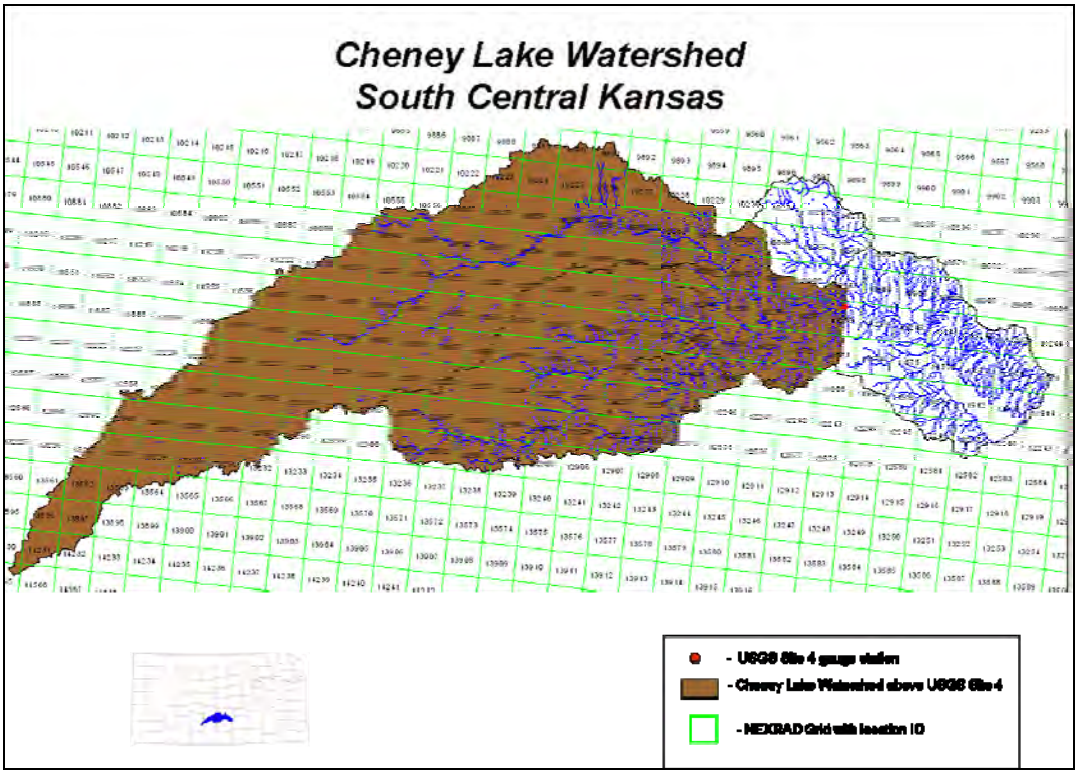

Figure 1 Cheney Lake Watershed with superimposed NEXRAD grid.

SIMULATION PERIOD

The calibration/validation time period was limited by the availability of reliable measured data—both input and streamflow & pollutant loads.

One limiting set of input data was the availability of spatially varied measured weather data since the watershed was over 1000 square miles. NEXRAD precipitation data for Cheney Lake has been available only since 1997. This early NEXRAD data was found not to as precise for watershed modeling as desired because the grid spacing was too coarse to capture local thunderstorms and its correlation to precipitation reaching the ground was not satisfactory. Still, it was used for the beginning years of simulation but is recognized as a possible source of input error.

Another set of limiting data was the measured pollutant loads near the outlet. Although reliable streamflow measured data was available well before 1997, stations were started & decommissioned and the main station location was changed in the latter 1990's. The main station was chosen and corrections made for its different locations to the watershed's outlet.

The final simulation period for calibration/validation selected was from 1 January 1997 through 31 December 2008.

RUNOFF, BASEFLOW, & STREAMFLOW

Currently AnnAGNPS predicts only runoff and pollutant loads. Streamflow is more than runoff. This difference must be recognized whenever calibrating/validating watershed model output with USGS measured streamflow.

Streamflow, as used by the U.S. Geological Survey (USGS, includes all water passing a gauging station regardless of its originating source. There are two sources for streamflow: (1) baseflow which comes from the groundwater, but not all groundwater appears in the stream as baseflow; and (2) runoff which comes directly from storm events as surface water and quick return flow. Quick return flow is near-surface, lateral flow that reappears the stream during the surface runoff. Quick return flow can significantly increase runoff as a result of tile drainage. The average annual streamflow for Site 4, corrected to the outlet, was 2.085701 [in]. Among many other statistics predicted by AnnAGNPS, is the average annual runoff. The estimated average annual baseflow must always be equal to or greater than zero and is the difference between measured streamflow and predicted runoff.

Baseflow, which can be significant or even dominate streamflow, must be estimated when calibrating/validating. An analysis of the gauging station's streamflow clearly showed significant baseflow between runoff events. Furthermore, it indicated that the baseflow fluctuated according to wet & dry periods, although the fluctuation had a time lag because the water has to percolate vertically through the vadose zone and then move laterally as groundwater before the channel intercepts the top portion of the groundwater as baseflow.

Three different baseflow procedures were studied. The chosen procedure was approximated as a constant portion and a varying portion. To keep the baseflow independent from the runoff estimated by AnnAGNPS, the varying portion of baseflow was assumed to be a function of the precipitation. It became obvious, after studying the behavior of the runoff, baseflow, and associated NS's while trying to calibrate/validate, that determining baseflow, particularly its fluctuation, has a significant impact on the magnitude of the NS.

Eckhardt (2005) proposed the general form of a digital filter considering a digital filter parameter and a baseflow value which is a maximum value of long term ratio of baseflow to total streamflow.

$$B_d = \frac{[(1-\beta)\alpha B_{d-1}] + [(1-\alpha)\beta S_d]}{[1-(\alpha\beta)]} \tag{2}$$

Where: B_d ≡ current day's baseflow, [cfs];
S_d ≡ current day's streamflow, [cfs];
α ≡ digital filter parameter; and
β ≡ long term ratio of baseflow to total streamflow.

Kyoung et al's (2005) substituted the relationship between runoff & baseflow for streamflow in Equation 2:

$$B_d = [\alpha B_{d-1}] + \left\{\left[\frac{(1-\alpha)}{(1-\beta)}\right]\beta R_d\right\} \tag{3}$$

Where; α & β are as above and R_d ≡ current day's runoff.

OPTIMIZATION

The procedure used to find the best runoff/baseflow was done by optimizing the Nash-Sutcliffe (NS) efficiency coefficient in two stages: (1) determining the optimal constant baseflow ratio for all potential runoffs for runoff curve numbers between 0 & 100; (2) determining the optimum runoff, using its previously determined optimal constant baseflow ratio.

Table 1 shows the: (1) average annual runoff; (2) average annual baseflow corresponding to an average annual streamflow of 2.085701 [in]; (3) NS; and (4) optimal constant baseflow ratio for selected RCN calibration coefficients. Only selected runoffs are shown because there are physical & mathematical limits for the RCN calibration coefficient. Runoff is limited to the average annual precipitation which corresponds to a Cn II=100 and a RCN=0. The mathematical upper limit for the coefficient is when the daily values for all runoff curve numbers would have an initial abstraction less than the corresponding rainfall. For this dataset, the average annual precipitation is 30.3215 [in] and the maximum RCN calibration coefficient for zero runoff is 40.

It became very clear that the original SCS runoff curve numbers for antecedent condition II (Cn II) were too high, possibly to ensure conservative designs of hydraulic structures; i.e., they are too high for purposes of estimating risk analyses. The first clue is that the runoff associated with a RCN coefficient of 1, which would result in Cn II, exceeds the measured streamflow. Using the SCS runoff curve numbers without calibration would have resulted in much greater runoff than measured. The second indicator is that there is a large volume of streamflow unrelated to precipitation and its subsequent runoff. This was baseflow originating from groundwater which

fluctuates as a result of varying precipitation, infiltration, & eventual water percolating into the vadose zone.

Figure 2 shows the difference between input runoff curve numbers and the calibrated runoff curve numbers. While the end point differences are zero, the maximum difference is at the input Cn II=60 where the calibrated Cn II=38.9.

Table 1 RCN calibration coefficients showing the resulting runoff and baseflow for a streamflow=2.085701 [in]; also shown is the constant baseflow percentage for the optimal NS. The highlighted RCN calibration coefficient is the optimum runoff/baseflow.

RCN Calibration Coefficient	**Average Annual Runoff**	**Average Annual Baseflow**	**Nash-Sutcliffe (NS)**	**Optimal Constant Baseflow Ratio**
	[in/yr]	[in/yr]	[nd]	[%]
0.000000	30.321500	0.000000	-150.102	10
1.000000	2.346837	0.000000	-0.890	100
1.114457	2.085701	0.000000	-0.665	100
1.250000	1.823480	0.262221	-0.302	95
1.500000	1.445250	0.640451	0.107	95
1.750000	1.163172	0.922529	0.318	95
2.000000	0.947912	1.137789	0.416	95
2.125000	0.858778	1.226923	0.439	95
2.250000	0.779845	1.305856	0.452	95
2.375000	0.709761	1.375940	0.458	90
2.437500	0.677898	1.407803	0.459	85
2.453125	0.670134	1.415567	0.460	85
2.468750	0.662720	1.422981	0.460	85
2.500000	0.647938	1.437763	0.460	85
2.531250	0.633215	1.452486	0.460	80
2.550000	0.618842	1.466859	0.460	80
2.625000	0.591709	1.493992	0.460	80
2.750000	0.542110	1.543591	0.458	75
3.000000	0.456950	1.628751	0.450	70
4.000000	0.242613	1.843088	0.403	65
10.000000	0.014783	2.070918	0.299	40
20.000000	0.000545	2.085156	0.290	40
30.000000	0.000028	2.085673	0.290	40
40.000000	0.000000	2.085701	0.289	40

The optimal constant baseflow ratio for each RCN calibration coefficient depends upon the ratio of the constant portion to the total baseflow. Optimal constant baseflow ratios were determined for all calibration coefficients. These optimal ratios varied systematically as a function of the RCN calibration. Figure 3 shows how the NS for the runoff curve number calibration coefficient equal to 2.550000 varies with respect to these ratios expressed as a percentage.

The optimal constant baseflow ratio for RCN calibration coefficient equal to 2.550000 occurs at a constant percentage of 80%. The same optimal constant baseflow ratio procedure for each potential RCN calibration coefficient was used in the second stage of the optimization process to match the expected streamflow.

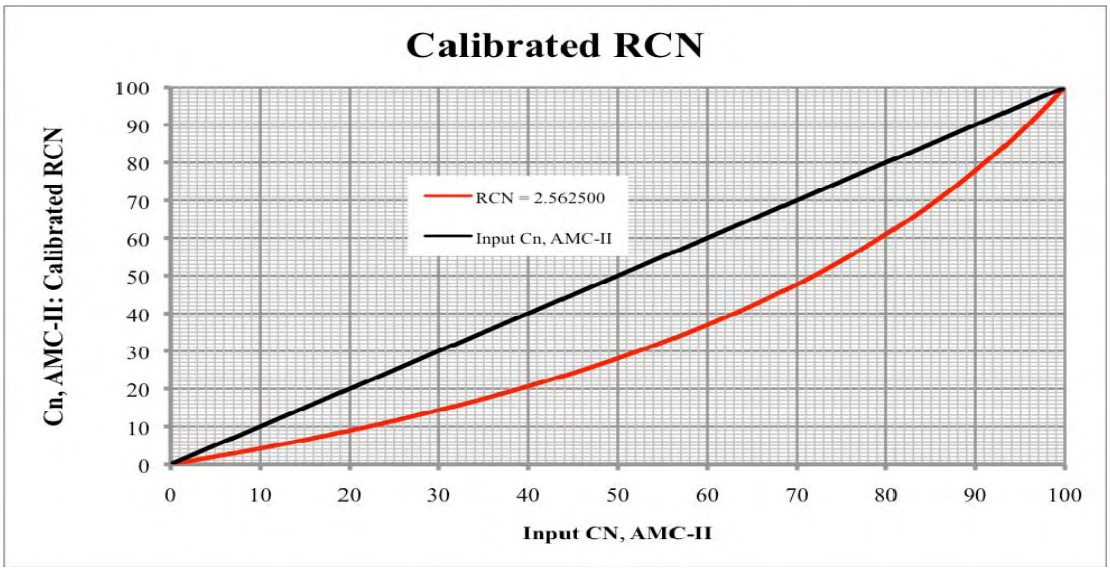

Figure 2 Difference between input and calibrated runoff curve numbers for RCN=2.550000.

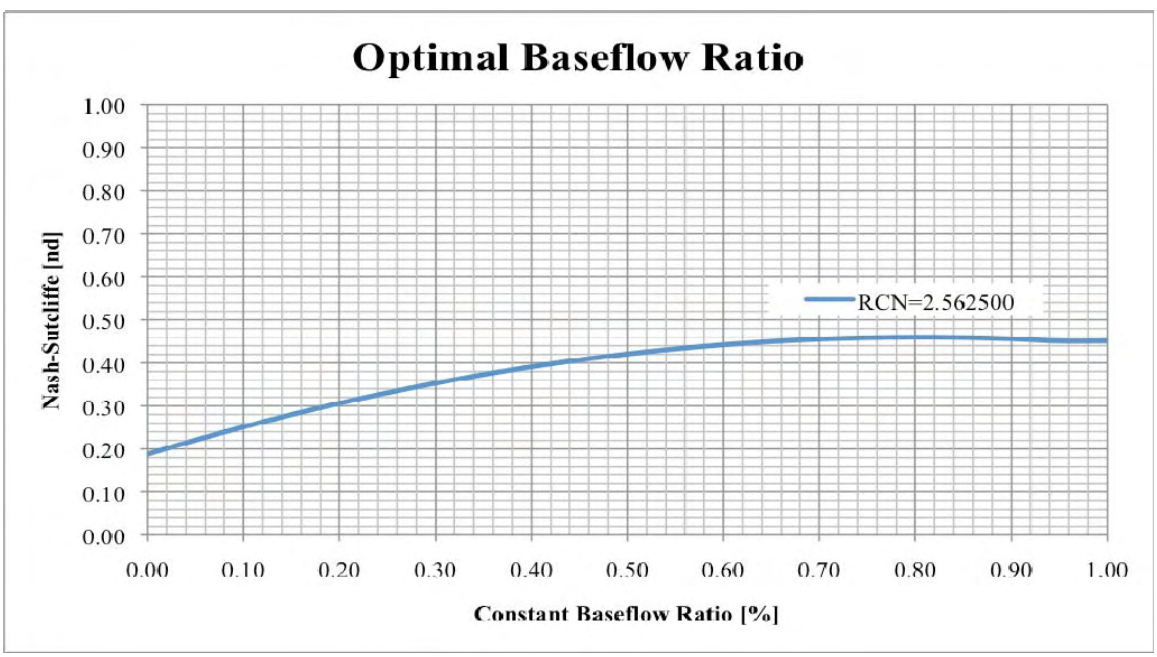

Figure 3 Baseflow ratios for RCN=2.550000; the optimal constant baseflow ratio percentage occurs at 80%.

OPTIMUM RUNOFF

Figure 4 shows how the NS varied as a function of runoff which varied as a function of the RCN calibration coefficient. The NS was determined as a function of the measured and the predicted streamflow. The predicted streamflow was the sum of each RCN calibrated coefficient's runoff and its associated optimal constant baseflow ratio.

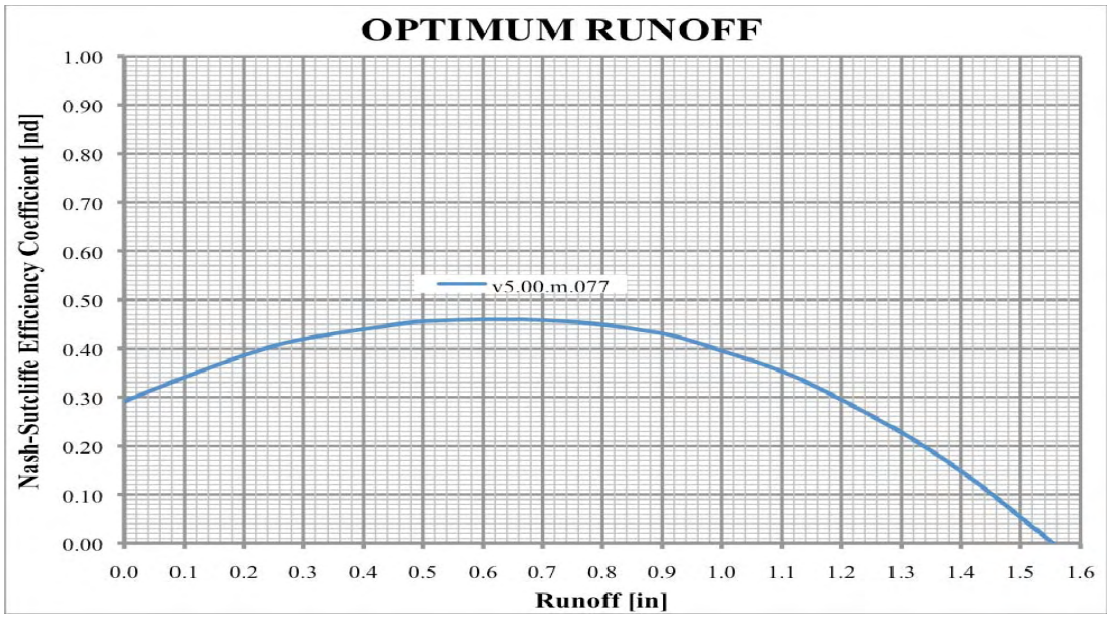

Figure 4 Optimum runoff for Cheney Lake, Site 4.

Figure 4 optimum runoff occurs at a runoff of 0.618842 [in] (see Table 1) whose RCN calibration coefficient is 2.550000 and the NS is 0.43.

DISCUSSIONS AND CONCLUSIONS

Nash-Sutcliffe: The NS can be improved. To understand how to improve the NS, it is necessary to understand the three sources of error. The first most likely source of error is the input. To better duplicate measured results, the user must make certain that the input sufficiently describes the spatial & temporal variables. Spatial resolution of the precipitation data is important when local thunderstorms could pass between NEXRAD grid points. Also important, the user must determine the runoff curve numbers so that they can be used for evaluation studies. Second source of errors is to obtain better, more direct measured pollutant loads, by taking more frequent direct measurements of sediment & nutrients whenever water quality is important, including particle-size measurements. Then when the input and measured output is reliable, the model errors can be determined and their algorithms corrected, improved, or enhanced.

RCN Coefficient Calibration: The large difference between the input & calibrated runoff curve numbers suggest that something more than calibration should be done. This potential problem can be attribute to a combination of three possible causes: (1) KS-NRCS' runoff curve numbers are meant for design of hydraulic structures and are too high for evaluation purposes; (2) the

default setting for antecedent condition II at 50% of the soil's available moisture is not compatible with KS-NRCS' runoff curve numbers; and (3) the engineering soil properties obtained from NRCS' NASIS soil database are not accurate. KS-NRCS should review their official SCS runoff curve numbers, especially when the purpose is for evaluation as opposed to design.

Baseflow Determination: 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.

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