CHENEY LAKE CEAP PROJECT: VALIDATION/CALIBRATION, SEDIMENT

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Abstract Sediment originating from the landscape has been referred to as wash load because it generally consists of fine sediment (clays & silt size particles). Sheet & rill and concentrated flow & gully erosion are the known causes that result in wash load. Sheet & rill erosion is largely due to raindrop intensity while concentrate flow erosion is due to headcut migration and tractive stress. AnnAGNPS uses RUSLE to predict the sheet & rill erosion but relies upon TIEGEM for ephemeral gully erosion which has been clearly noted within ARS as needing additional research to extend its applicability. Instream sediment load is only indirectly measured and its measurements include bed & bank sediment sources. This paper explains how the wash load was predicted for the Chaney Lake watershed in Kansas using USGS streamflow measurements and wash load predictions using AnnAGNPS.

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.

The total drainage area for the watershed is more than 1,000 sq. mi. The watershed is dominated by agricultural landuse consisting of cropland and rangeland. The average annual precipitation varies from close to arid to nearly humid. The average annual precipitation is 29 inches for the entire watershed. Only a small fraction of the precipitation reappears as streamflow in the river before it enters the reservoir.

The Annualized Agricultural Non-point Pollutant Source (AnnAGNPS) watershed-scale, water-quality, computer model (Bingner & Theurer, 2001) predicts water, 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. After calibrating the total streamflow, the next task was to calibrate & validate the suspended sediment because sediment-borne pollutants are subject to the accuracy of sediment predictions.

Model predictions are sensitive to the application's temporal & spatial input data; i.e., the historical driving forces that cause a sequence of suspended sediment load statistics must be available for calibration/validation. All water-borne sediment originates from two basic physical processes: 1) sheet & rill erosion; or 2) concentrated flow erosion. Concentrated flow erosion

can be attributed to either gullies in the field or from the bed & bank in the stream system. AnnAGNPS recognizes these three sources and they are: 1) sheet & rill erosion; 2) gully erosion in the fields; and 3) bed & bank erosion in the stream system.

Suspended sediment loads originating from sheet & rill erosion and ephemeral gully erosion are predicted by AnnAGNPS; and an independent geomorphic analysis was done to estimate the contribution of bed & bank erosion to the suspended sediment load. Sheet & rill erosion was estimated by the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1997) procedure, which is accepted as a reliable model for sheet & rill erosion. Ephemeral gully erosion was estimated with the recently developed Tillage-Induced Gully Erosion Model (TIGEM).

On site investigations for gullies in the fields were conducted, aerial photos studied, and nearly one-thousand (1,000) ephemeral gullies were identified within the watershed. All were headcut-type gullies and most had not much drainage area to their mouths. Ephemeral gully erosion became the choice for suspended sediment calibration.

The Nash-Sutcliffe (NS) efficiency index (Moriasi et al, 2007) was used as the criterion for the goodness-of-fit and also was the final step in the suspended sediment calibration task. Total suspended sediment load was used as the basis for the NS index. Calibration factors for ephemeral gully erosion were used to determine a series of suspended sediment loads. The maximum NS from this relationship was used to select the optimal calibration factor. The same historical climate dataset, the identical set of SCS runoff curve numbers (RCN) & its calibration factor, and this ephemeral gully erosion calibration factor was used to calibrate the nutrient loads.

The total drainage area for the Cheney Lake watershed is 642,584 acres (1004 sq. mi.) 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 (built-up, 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 29 inches for the entire watershed if irrigation applications are included. Slightly more than 2 inches of streamflow reappears in the river before it enters the reservoir.

AnnAGNPS predicts the direct runoff (water), suspended sediment, and chemicals (nutrients & pesticides) from their 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 constituents original location, yield, & load.

Gullies can be formed either by headcuts migrating upstream or by channel entrenchment. Either process can create gullies in the field. Headcuts can exist in well-defined channels and are classified as gullies but are neither ephemeral nor are the direct result of agricultural operations.

The primary function of the adaption of REGEM (Gordon et al, 2006 and Gordon et al, 2007) within AnnAGNPS as TIEGEM was to recognize both the spatial & temporal variability of the landuse in each field.

USGS turbidity measurements included occasional suspended sediment measurements for correlation between turbidity & suspended sediment concentration. Particle size determination of suspended load was not done.

RUSLE has been thoroughly research, improved, & validated (Renard et al, 1997). The bed & bank erosion was studied for this particular watershed and is the lesser source of erosion of the three possible sources. Field investigations were conducted and evidence of many ephemeral gullies were found and documented in the Cheney lake watershed. Recent aerial photos were studied and nearly 1,000 scars were identified as potential ephemeral gullies.

OPTIMAL WASH LOAD

Total Suspended Sediment Load The total sediment load at a given location in the stream system is composed of bed load & suspended load. Bed load is the sediment that is moving along the bed by sliding or saltation and is of little interest when analyzing wash load because it is mainly comprised of coarser material that likely originates from within the stream system. However any fine material that originates from the bed & bank must be addressed since its physical behavior may be identical to the wash load originating from the landscape. Wash load originating from the landscape generally is comprised of the finer fraction because most all of the eroded coarser material is deposited within the fields before the sediment is transported to the receiving reach.

There are only two sources for sediment loads transported by water in a watershed: (1) wash load originating entirely from the landscape; and (2) stream material load originating entirely from within the stream system. Each source can have two different erosion processes contributing to the sediment. Landscape contributes sediment from: (1) sheet & rill erosion; and (2) gully concentrated flow erosion. The stream material load contributes sediment from: (1) bed material load, which tends to be coarser than wash load; and (2) bank material load which consists mostly of older alluvial deposits. As a result of soil and water conservation practices installed during the twentieth century, ephemeral gully erosion now dominates erosion and is the major source of wash load in many fields.

Figure 1 shows a typical ephemeral gully developing in a Kansas cropland located near Wichita, Kansas and the same field three months later. Nearly 1000 such ephemeral gullies were estimated to reoccur each year within the Cheney Lake watershed.

Within the Cheney Lake watershed, ephemeral gullies are estimated to be the cause of 84% of the landscape erosion and to yield 79% of the wash load.

Figure 2 is a plot of the ephemeral gully coefficient versus the Nash-Sutcliffe efficiency coefficient using the following conditions for 1997 through 2008:

1. The Nachtergaele ephemeral gully width algorithm (Nachtergaele et al, 2002) was chosen to estimate gully width because, in addition to formal research supporting its use (Nachtergaele and Poesen, 1999, and Nachtergaele et al, 2005), it gave the best calibration results;

Figure 1 Left-hand photo shows an ephemeral gully developing in field shortly after planting; right-hand photo was taken further down slope in the field and two months later after additional headcut migration & subsequent growth of vegetation. Faint outline of wheel tracks within gully can be seen beginning at downstream end at left-central of photo and progressing to the right to near center of photo before turning directly upslope towards ridge line.

2. The RCN calibration coefficient was set at 2.5625 (Theurer et al, 2010) which results in 0.630127 [in] of average annual runoff and 2.085701 [in] of average annual streamflow measured at the watershed outlet;
3. Bank erosion was set equal to 5,167 [tons] (USDA-NRCS, 2007) as estimated in geomorphological studies;
4. Total suspended sediment load was set equal to 25,385.12 [t] as estimated by the turbidity measurements at the gauge and the bed material contribution was allowed to vary to match the total suspended load (bed & Bank); or
5. Bed & bank material load was held constant at 5167 [t] (USDA-NRCS, 2007) and the total suspended sediment load was allowed to vary (Bank Only).

Two different stream source erosion algorithms were analyzed: (1) bed & bank material where the contribution from the bed was allowed to vary to match the total suspended sediment load at the outlet (25,385.12 [t] from 1997 through 2008); and (2) bed & bank material load was held constant at 5,167 [t] and the total suspended sediment load was allowed to vary.

Figure 3 shows the resulting wash loads as a function of the NS.

DISCUSSIONS AND CONCLUSIONS

The development of calibration techniques for wash loads requires an evaluation of the distinct sources of erosion within a watershed. Within Cheney Lake watershed the biggest uncertainty was in the production of ephemeral gully sediment loads, since many of the processes are still

being researched and developed into modeling algorithms. In addition, ephemeral gullies are not readily observed in the field by watershed planners because of their lack of visibility within croplands. The development of the ephemeral gully width is one of the most sensitive parameters within AnnAGNPS affecting sediment. With a calibration of this component, better evaluations of conservation practices targeted for sheet and rill erosion and ephemeral gully erosion can be developed.

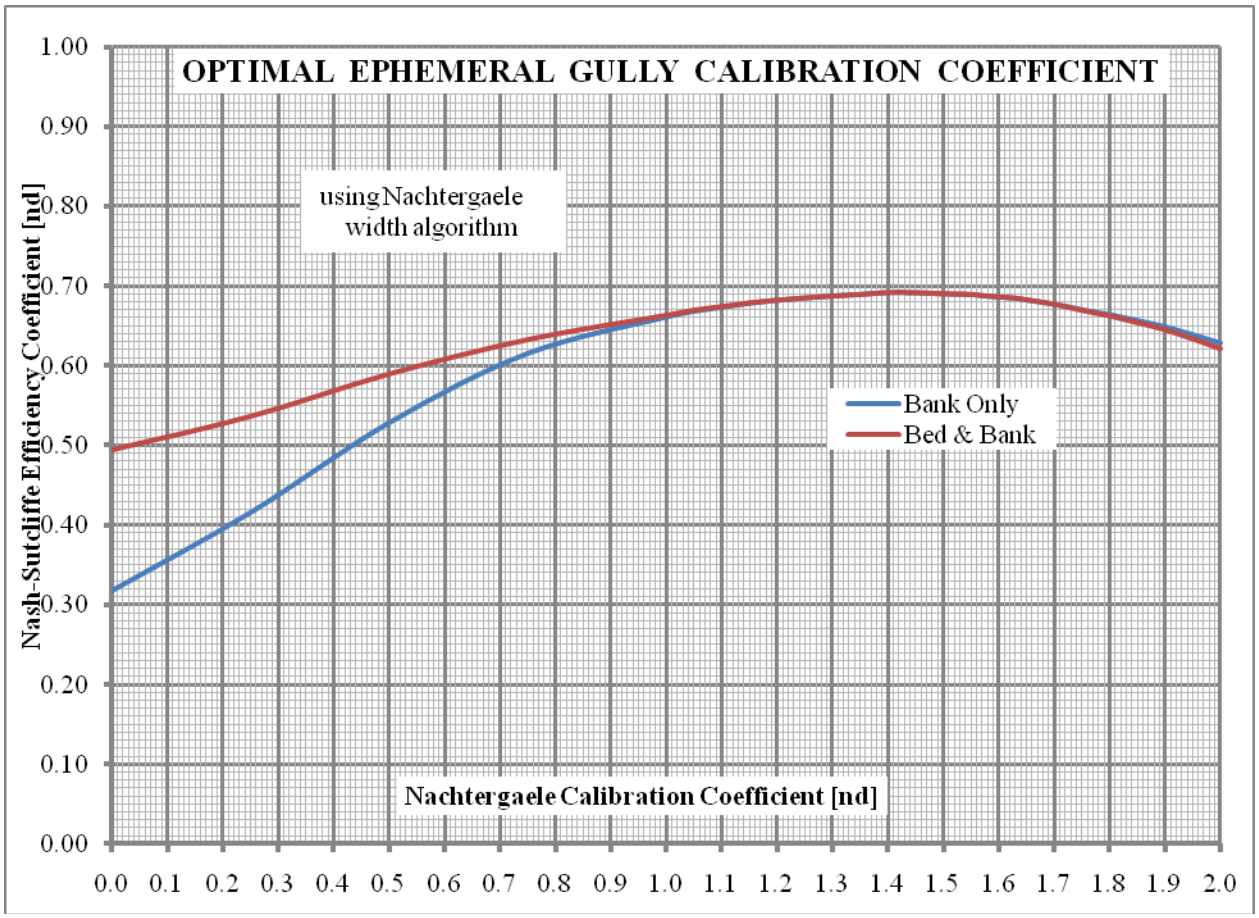

Figure 2 Evaluation of the ephemeral gully coefficient using an optimal calibration coefficient approach.

Assessments of sheet and rill erosion can be reliably attained using RUSLE technology. Concentrated flow erosion from the bed and bank was a source of wash load, but was less important in Cheney Lake watershed. Estimates of bed and bank wash load were obtained and included in the calibration for the watershed.

Better information on the location of gullies is also needed to improve the assessment of gully erosion conservation practices. Since the evolution of ephemeral gullies can vary widely based on management, soil properties, topography, and climate, better decision support tools are needed to integrate these components and aid management decisions. Improved climate and runoff information is also critical for assessing sediment loads, which has been discussed by Theurer et al (2010).

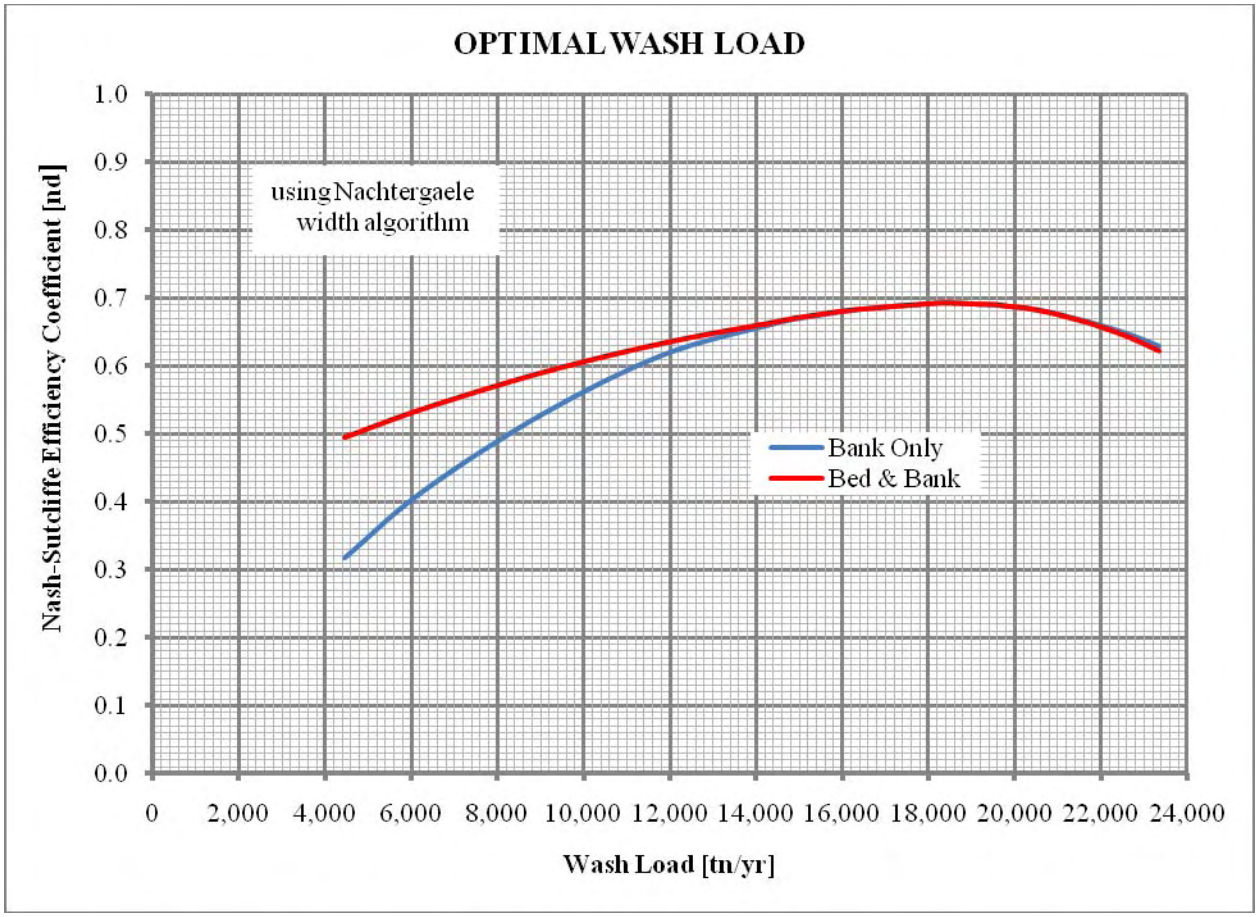

Figure 3 Determining the wash load using an optimal Nash-Sutcliffe coefficient.

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