Community Assistantship Program

An Attempt to Understand the Physical Hydrology of the Chippewa River Watershed

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Prepared in partnership with the Chippewa River
Watershed Project

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An Attempt to Understand the Physical Hydrology of the Chippewa River Watershed

By

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Executive Summary

Chippewa River Watershed (1.3 M acre) is very large compared to watersheds (<10,000 acre) in which SNAP model has been applied. Stream bank erosion estimation for large basins is difficult. RUSLE results indicate that regions with RUSLE $\leq T$ produce 90% of the sediments in the down stream basins. Lack of complete USDA soil classification data hampered documentation of entire watershed hydrology. The monitoring site network pattern makes it impossible to estimate load from watershed sub-basins. Lack of stream bank erosion data was a setback to successful SNAP modeling. Described in the report is methodology adopted to apply SNAP, its advantages, problems encountered and suggestion to overcome them.

Introduction and Background

Watershed Facts

The Chippewa River Watershed is located in the southwestern Minnesota. Portions of eight counties make up the watershed including Otter Tail, Grant, Stevens, Douglas, Pope, Swift, Kandiyohi and Chippewa (Figure 1). It drains a 1,331,200 acre (2,080 miles^2) basin. For monitoring purposes the Chippewa River Basin is divided into six tributaries/basins. There is also a small unmonitored sub-basin at the lower end. It constitutes 4.82% of the total watershed area.

Table 1 shows the acreage in each sub-basin. The East Branch (24.28%) covers the largest percentage of area followed by the Middle and Little Chippewa Rivers (19.33%) and the Upper Chippewa River (17.05%).

In 1990, the watershed had a population of 41,808. It rose by 3.39% to 43,227 in 2000. Chippewa and Kandiyohi counties contribute to over 50% of the total population.

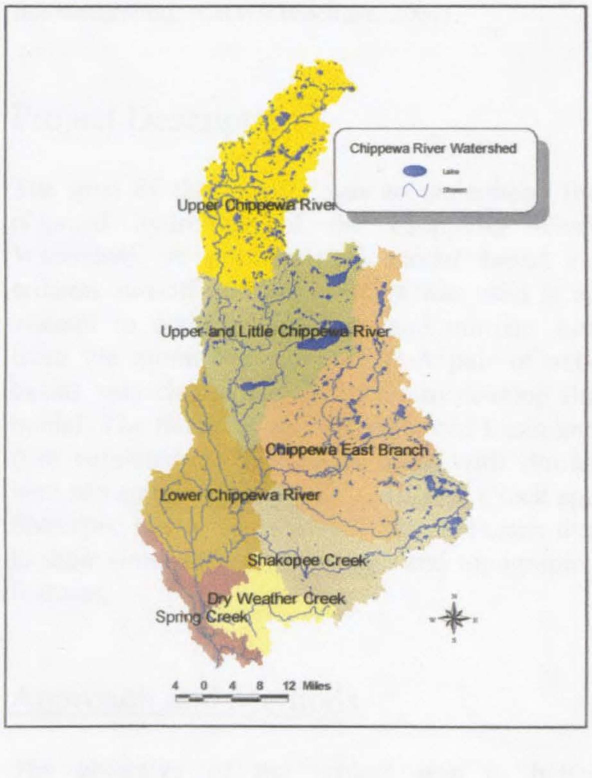

Figure 1: Chippewa River Watershed

Table 1: Chippewa River Tributaries/Sub-basins

Name	Acres	Percent Area
East Branch	323,767	24.28%
Middle Chippewa and Little Chippewa	257,712	19.33%
Upper Chippewa River	227,383	17.05%
Shakopee Creek	197,111	14.78%
Lower Chippewa River	195,443	14.66%
Dry Weather Creek	67,759	5.08%
Lower Unmonitored Region	64,300	4.82%
Chippewa River	**1,333,440**	**100.00%**

(Source: "Chippewa River Watershed", CRWP, Montevideo, unpublished document)

As seen in Table 2, agriculture is the primary land use in the watershed followed by grasslands. Grasslands are located predominantly around lakes and riverbanks.

Table 2: Land Use Classification

Land Use	Acres	Percent Area
Agriculture	980,021	73.50%
Grassland	148,575	11.14%
Forest	71,798	5.38%
Water	71,668	5.37%
Wetlands	37,042	2.78%
Urban or Residential	23,565	1.77%
Gravel pits or Exposed	724	0.05%
Unclassified	47	<0.01%
Total	**1,333,440**	**100.00%**

(Source: "Chippewa River Watershed", CRWP, Montevideo, unpublished document)

The Chippewa River Watershed Project (CRWP)

The Chippewa River Watershed Project is a cooperative partnership and citizen based approach aiming to improving water quality in the Chippewa River and its tributaries. CRWP is partially funded through a Clean Water Partnership Grant from the Minnesota Pollution Control Agency (MPCA). CRWP also relies on the volunteerism and commitment of its partners to achieve its aims.

The CRWP was formed in 1998 as a result of growing concern over the health of the Chippewa River Watershed. The need for a comprehensive review of water quality and water quantity problems resulted in a Phase I Diagnostic Study. The Study was funded by the MPCA and was completed in March 2001 and now Implementation Projects are going on. (CRWP brochure, 2001)

Activities of the CRWP

Citizens across the basin collect water quality data on the Chippewa River and its tributaries and report to the Watershed Project. Also the staff collect water quality samples for chemical analysis, conduct flow measurements, and collect samples for bio monitoring. The staff also tries to reach out to watershed residents through newsletters, brochures, meetings, classroom and community presentations, conferences, and displays. CRWP is also involved in providing funds for Best Management Practices (BMP) in the watershed. (CRWP brochure, 2001)

Project Description

The goal of this project was to understand the physical hydrology of the Chippewa River Watershed. A mathematical model based on erosion, run-off and precipitation was used in an attempt to estimate sediment and nutrient loss from the monitored sub-basins. A pair of sub-basins was chosen for the study to develop the model. The model is calibrated on one basin and then validated on the second basin with similar land use and topography. Dry Weather Creek and Shakopee Creek were the sub-basins chosen due to their similarity of hydrologic and topographic features.

Approach and Methods

The objective of the project was to better understand the hydrology of the entire watershed by testing a model that could eventually be used for the whole watershed. Many milestones were achieved which contributed to moving closer to this objective.

Described below is the model that was utilized to aid in the watershed restoration management process in the CRWP. The model helps in doing a cost-benefit analysis of the sediment reduction. It describes the sources and their relative impact on the watershed.

Sediment Nutrient Assessment Program (SNAP)

The basis for the SNAP model used in this project is a report authored by Klang and Kuehner. (2002) It is a very new method and has not been adequately peer reviewed yet. The original SNAP was developed on watersheds of around 10,000 acres. Part of the goal of this project was to learn if the model could be applied to much larger watersheds.

The methodology provides land use analysis by a logic process that combines "ground-truthed" watershed inventories with information from GIS coverages to explain sub watersheds and/or source types and loadings. The data is organized, calculated and analyzed in a Microsoft Excel spreadsheet.

Advantages of the Model

- Helps identify significant bank erosion contributions to the watersheds
- Relatively cheap and cost effective
- Ease of use
- Multifaceted and holistic approach Integrates current and localized research literature, field surveys, water quality data, and GIS into one tool for refining watershed management decisions
- Allows managers to target BMPs and set realistic goals

Disadvantages of the Model

- Works best on smaller watershed (<10,000 acre) where staff has the time and resources to inventory water quality
- Minor watershed must be homogeneous in nature
- Moderate margin of error
  Model is not meant to quantify but to describe sources and their relative impact on the watershed
- Model has spring runoff limitations
  RUSLE is used mainly as a summertime erosion runoff model and therefore does not work well when there are heavy spring snowmelt conditions.
  (Klang and Kuehner, 2002)

The SNAP model uses data derived or collected using different tools and techniques. The CRWP monitors the daily flow of streams. It has data-loggers installed at various locations along the river and its tributaries to do so. CRWP also monitors the Total Suspended Particle (TSS) and phosphorus (total and ortho). Samples of water are collected periodically during the monitoring season (April 1st – September 30th) and sent to the laboratory for analysis of these compounds. This data along with daily flow data is used for computing total load in the stream for the monitoring season. FLUX is the software that is used for this computation.

FLUX

FLUX is an interactive program for estimating loadings or mass discharges passing a tributary or outflow monitoring station over a given period. These estimates can be used in formulating reservoir nutrient balances over annual or seasonal averaging periods. The function of the program is to collect event samples to estimate mean (or total) loading over the complete flow record between two dates. (*Empirical Methods for Predicting Eutrophication in Impoundments*, Report 4, Phase III: Application Manual, 1987)

Other Data

Precipitation data for SNAP was collected from the US Geological Survey (USGS) monitor located along the Chippewa River and CRWP rain gauges at each sub-basin. The Minnesota Department of Natural Resource (DNR) provided land use and US Department of Agriculture (USDA) soil classification data. Geographic Information System (GIS) was an integral part of the modeling process. GIS is a computer system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data related to positions on earth's surface. It has become a powerful tool for presenting spatial information. (Nangia et al., 2001) Arc View GIS software was used for deriving information needed for estimating sediment load distribution.

RUSLE

The USDA has developed Revised Universal Soil Loss Equation (RUSLE) for estimating sheet erosion from a field. It estimates erosion in tons per acre per year based on five factors. The equation is expressed as follows:

$$A = R * K * LS * C * P \text{ (ton/acre/year)}$$

- A: the predicted average annual soil loss from interrill (sheet) and rill erosion from rainfall and associated overland flow. Units for factor values are usually selected so that A is expressed in tons per acre per year.

- R: the factor for climate erosivity. R factor values represent the average storm El value from a 22-year record period. R accounts for the amount of rainfall and the peak intensity sustained over an extended period of time and is the number of rainfall erosion index (El) units in an average year's rainfall.

- K: the factor for soil erodibility. K values represent the susceptibility of soil to erosion and the amount and rate of runoff. K is a measure of the soil loss rate per erosion unit for a specific soil as measured on a unit plot. The unit plot is an erosion plot 72.6 feet long on a uniform 9 percent slope managed in continuous clean till fallow.

- LS: The L and S factors jointly represent the effect of slope length, steepness, and shape on sediment production. RUSLE represents the combined effects of rill and interrill erosion. Rill erosion is primarily caused by surface runoff and increases in a downslope direction because runoff increases in a downslope direction. Interrill erosion is caused primarily by raindrop impact and is uniform along a slope. Therefore, the L factor is greater for those conditions where rill erosion tends to be greater than interrill erosion. The LS factor is a measure of sediment production. Deposition can occur on concave slopes where transport capacity of the runoff is reduced as the slope flattens. This deposition and its effect on sediment yield from the slope is considered in the supporting practices P factor.

- C: the factor for cover and management. C represents the effect of plants, soil cover, soil biomass, and soil disturbing activities on soil erosion. C is the ratio of soil loss from an area with specified cover and management to that from an identical area under tiled continuous fallow management.

- P: the factor for support practices. P represents the impact of support practices on erosion rates. P is the ratio of soil loss from an area with supporting practices in place to that from an identical area without any supporting practices. Supporting practices include contour farming, cross-slope farming, buffer strips, strip cropping, and terraces.

- T: soil loss tolerance. T is not part of RUSLE but is used with RUSLE to establish a benchmark for evaluating the predicted erosion rate from an existing or planned conservation system. T is the average annual erosion rate that can occur with little or no long-term degradation of the soil resource on the field. When the computed soil sheet and rill erosion is assumed to be adequate. When computed the soil erosion rate exceeds the T value, sheet and rill erosion is considered to be excessive and additional conservation treatment is needed. Soil loss tolerance values (T) are assigned to each soil map unit by the Natural Resource Conservation Service (NRCS).
(RUSLE, Technical Guide, USDA-NRCS-MN)

NRCS-USDA distributes soil erodibility data from its Minnesota website http://www.mn.nrcs.usda.gov/soils/ken/hel/mnhel

2001.pdf. The data is in tabular form sorted by county. It includes Map Symbol, Map Unit Name, T, K, C, R and LS values. A practice factor of 1 was assumed for the entire watershed. This assumption was made after discussions with the local NRCS staff. The reason for choosing the value of 1 for P was that, according to the local NRCS staff, there were few contour farming, cross-slope farming, buffer strips, strip cropping or terraces in the area. Soil data for the counties was downloaded from the Soil Survey Geographic (SSURGO) database. The data is available, in Arc View GIS shape file format, for free download at http://www.ftw.nrcs.usda.gov/ssur_data.html. Values for C factor corresponding to land use for the watershed were developed based on NRCS recommendations. These values were used instead of values supplied by the USDA PDF file. The USDA assigns a single value for C factor for the entire county. A more accurate soil loss estimate was achieved by using different values according to different land use type.

Using Arc View GIS software soil classification data, land use data and soil erodibility data were joined together. Once the tables were joined RUSLE was calculated using Arc View GIS. Acreage for each soil classification polygon was computed and then a total soil loss in tons/year was calculated. The RUSLE values were compared with the tolerable soil loss (T) values supplied by the NRCS-USDA. A map of RUSLE-T was made and data was classified as positive, zero and negative values of RUSLE-T. (Figure 3)

SNAP requires average RUSLE values and acreage for the watershed. Each watershed needs to be divided into riparian corridors, areas served by open tile and uplands. In order to estimate area served by open tile intakes in the watershed a survey was conducted in the beginning of the project. Tile intakes were identified on maps using Global Positioning System (GPS) and by visiting the sites estimates were made of the area directly serviced by the intakes. This exercise took several days. The sub-watersheds were divided into several sub-sections to have a representative sample. Thirty fields in each sub-watershed were used for tile intake estimates. Using GIS the water features in the sub-basin were buffered by 100 feet. This area served as the riparian corridor. Area served by open tile intakes was calculated by multiplying the uplands by the percentage land that open tile intakes serviced. The rest of the area was considered as uplands. RUSLE was computed for these three categories of land features.

Soil erosion loads from the FLUX program were used to balance sediment values derived from the RUSLE program. Microsoft Excel spreadsheets were used to evaluate the data.

To overcome dynamic changes of and differences in climate, soil types, slopes, geomorphology of the watershed and cropping techniques a few key assumptions are made:

- Since the monitoring season is based on six months and RUSLE is based on 12 months, RUSLE needs to be normalized for the monitoring season via normalization factor.
- A model ratio is loosely based on the ratio of sediment delivered as compared to the sediment eroded, but also includes a correction factor for other assumptions on normalizing yearly rainfall averages and variations in rainfall intensity.
- The modeler must make judgment in the first watershed and check/confirm them in the second watershed prior to proceeding on with the assumed Delivery ratios.

(Klang and Kuehner, 2002)

When broken down into its landscape components a SNAP equation becomes:

$$(R_u \cdot A_u \cdot M_u \cdot N) + (R_{st} \cdot A_{st} \cdot M_{st} \cdot N) + (R_r \cdot A_r \cdot M_r \cdot N) + S = FLUX \qquad (1)$$

where

R: Average load computed using RUSLE (ton/acre)

A: Area (acre)

M: Model ratio

N: Normalization factor (annual rainfall/monitor season rainfall; or annual runoff/monitor season runoff)

S: Stream bank erosion (ton)
FLUX: Load computed using FLUX (ton)

Subscripts
u: Upland
st: Surface tiled
r: Riparian

In order to solve the above equation the values for stream bank erosion (S) and the model ratio (M) need to be determined. In Klang and kuehner's case, they selected a watershed where S was known to be close to 0 and then solved for M. In the case of Dry Weather Creek and Shakopee Creek S was known to be significant but the actual value was unknown. With S equal a high-unknown value SNAP is impossible to compute without further investigation.

On the other hand if a sub watershed of Dry Weather Creek, where S equals a known quantity were identified (and if this basin had relevant monitoring data) then perhaps SNAP could proceed.

On its most basic level a SNAP equation is:

$$(R \cdot A \cdot M \cdot N) + S = FLUX \qquad (2)$$

Thus, the equation for a sub-basin would be:

$$(R_{sub} \cdot A_{sub} \cdot M_{sub} \cdot N) + S_{sub} = FLUX_{sub} \qquad (3)$$

where
M_{sub}: basin-wide model ratio

Subscript
Sub: Section of watershed

Assuming that the sub-basin was homogeneous to the rest of the basin one could solve for M_{sub}, and then apply M_{sub} into the larger basin's equation. This would then leave S_{DWC} to be the only unknown.

$$(R_{DWC} \cdot A_{DWC} \cdot M_{sub} \cdot N) + S_{DWC} = FLUX_{DWC} \qquad (4)$$

Subscript:
DWC: Dry Weather Creek

Once the stream bank erosion of the Dry Weather Creek (S_{DWC}) is known we can solve equation 1 for the three model ratios (M_u, M_{st} and M_r).

Once solved we can validate the model ratio values by applying them to another similar basin (i.e. Shakopee Creek).

Unfortunately, no such smaller basin in Dry Weather Creek had been monitored.

Results & Discussion

The tile intake survey was the first step in data collection for the hydrologic study (Figure 2). The average of data collected from 30 fields in each of the two sub-basins found that the area serviced by open tile intakes in the Shakopee Creek was 5.7% of the area and 4.7% in the Dry Weather Creek area. These numbers are lower than percentages found in eastern Minnesota. As the land prices fall it becomes more and more impractical to lay tiles for drainage. There are even fewer tiles per acre laid in the Dakotas (west of Minnesota). The rudimentary method employed for the tile intake survey greatly depends on the surveyor's judgment and experience. Although the survey was done before the crop started to grow tall, the percentages can vary, to a certain degree, from person-to-person. The tile intake survey relied on the markers posted by the intake by the field owners. It is not certain that all the intakes were marked.

The next step was the analysis of RUSLE results. Due to lack of soil classification data for Pope, Grant, Otter Tail and Kandiyohi counties RUSLE could only be computed for portions of the watershed. As seen in Figure 3 there is a very large portion of watershed in these counties. The rolling topography of these counties is such that it could significantly impact the overall load of the watershed. In addition, the land has proportionally more grasslands, forests and lakes than the rest of the watershed. Lakes serve as sediment ponds and impact the water quality. While grass and trees reduce erosion. CRWP water quality data gathered from these areas seems to support that lakes and diverse land use are buffering the highly erodable areas in these regions.

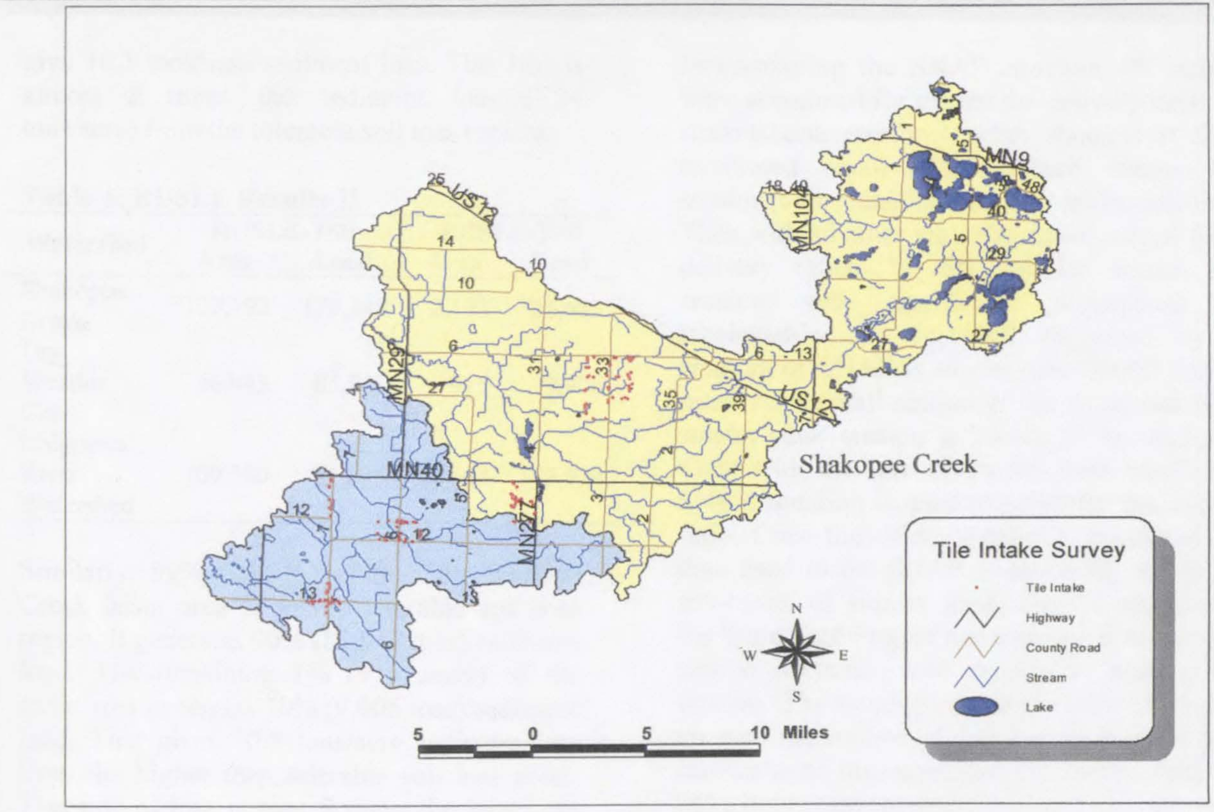

Figure 2: Open Tile Intake Survey

Table 3 summarizes the area and total load estimated to come from the two main watersheds.

Table 3: RUSLE Results-I

Watershed	Area (Acre)	Load (Ton)
Shakopee Creek	129,295	192,031
Dry Weather Creek	67,858	95,854
Chippewa River Watershed*	795,034	255,009

*Watershed area for which RUSLE was computed.

The area for which RUSLE could be computed was 60% of the entire watershed. If we closely look at the Shakopee and the Dry Weather Creeks, in Figure 3, we see that majority of the sediment load comes from the regions with tolerable soil loss. Table 4 shows a break down of the area and load for the two sub-watersheds.

Ninety eight percent (127,192 acres) of the Shakopee Creek basin area is in the tolerable soil loss region. It contributes 89% (170,348 tons) of the total load. Only 2% (2,103 acres) of Shakopee Creek contributes the other 11% (21,683 tons) of the sediment load into the river. Thus, higher than tolerable soil loss areas

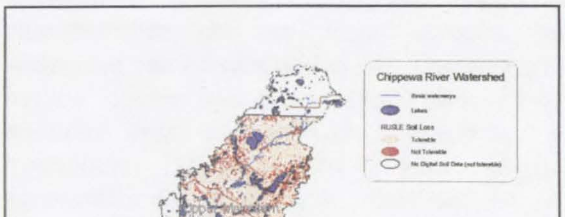

Figure 3: RUSLE Results

give 10.3 tons/acre sediment loss. This loss is almost 8 times the sediment loss (1.34 tons/acre) from the tolerable soil loss regions.

Table 4: RUSLE Results-II

Watershed	RUSLE-T≤0		RUSLE-T>0	
	Area	Load	Area	Load
Shakopee Creek	127,192	170,348	2,103	21,683
Dry Weather Creek	66,943	85,948	915	9,906
Chippewa River Watershed	709,380	81,035	85,654	173,974

Similarly, 99% (66,943) of the Dry Weather Creek basin area is in the tolerable soil loss region. It generates 90% (85,948 tons) sediment load. The remaining 1% (915 acres) of the basin area generates 10% (9,906 tons) sediment load. That gives 10.8 tons/acre sediment loss from the higher than tolerable soil loss areas. This rate of loss is over 8 times the loss from the tolerable soil loss regions (1.28 tons/acre).

The above discussed findings clearly indicate that areas that have soil loss less than the tolerable rate of loss (RUSLE≤T) need to be addressed to reduce nutrient and sediment drainage into water. The rate of loss might be tolerable but the amount of sediment being drained into the river significantly detracts from water quality. The problem needs to be seen from the water quality rather than soil quality perspective to address the pollution concerns.

The SNAP helps assess contributions from three land categories (riparian corridors, areas served by open tile intakes and uplands). It has successfully been implemented at small sized watersheds (<10,000 acres). There is a lot of diversity visible in the Chippewa River watershed. The upper half of the watershed is predominantly hilly with less agricultural land and more water features (like streams and lakes), grasslands and forests. The lower portion of the watershed is mostly under agricultural use. This makes application of SNAP difficult. Creators of SNAP suggest dividing large watershed into smaller homogeneous sub-watersheds to help capture diversity, compute delivery ratios and validate SNAP results.

In computing the SNAP equation all variables were accounted for except the delivery ratios and stream bank erosion. Earlier attempts at SNAP monitored small basins where stream bank erosion was either minimal or easily calculated. Then with all other variables fitted, solved for the delivery ratios. In this instance stream bank erosion was significant, widespread and incalculable. An approach suggested by the creators of SNAP is to compute SNAP delivery ratios for a small section of the watershed where stream bank erosion is known to be negligible. Then with the rate of stream bank erosion set SNAP equation is used to solve for the delivery ratio. Once the delivery ratio is calculated it is then used in the SNAP equation for the greater sub-basin, of similar physiology. Unfortunately, the Watershed Project had monitored no two such similar sections, with negligible stream bank erosion. The monitoring station network was set up with the motive of monitoring flow in major tributaries of the watershed. No major watershed has a homogeneous composition. Each watershed contains a complex mixture of soil types, landscapes, climatic regimes, land use characteristics, and agricultural systems. Each watershed can be subdivided into agroecoregions having similar soil types, landscapes, climatic regimes, crop and animal productivity, and hydrologic characteristics. The physical, agronomic, and hydrologic characteristics of a watershed can then be described and represented using a few relatively homogeneous agroecoregions. Had monitors been placed according to agroecoregions in the watershed there could possibly have been regions monitored where stream bank erosion was known to be negligible.

Conclusions

At the project onset it was not certain that all objectives proposed in the project description would be accomplished. The project gave some insight into the hydrology of the watershed. The RUSLE helped understand that regions with RUSLE≤T collectively produce 90% of the sediments in the down stream basins. This alone can be very useful for water resources decision-makers. The SNAP modeling constraints highlighted the need for more monitoring. The monitoring should be based on an agroecoregion basis. This will help capture the water quality changes with watershed physiology. Lack of USDA soil classification data for many counties in the watershed hampered understanding the characteristics and hydrological phenomenon taking place in those portions of the watershed. Lack of stream bank erosion data was a setback to successful SNAP modeling. The SNAP results could have helped do a cost-benefit analysis for cutting sediment drainage into the river.

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