Evaluation of a GIS-based watershed modeling approach for sediment transport

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Abstract: In order to improve water quality and restore impaired watersheds, managers need to make decisions using data that are able to gather. Data collection can be expensive, tedious and time consuming. Not all watershed managers have sufficient budgets to undertake such exercises. In such situations using modeling approach makes sense. The Sediment Nutrient Assessment Program (SNAP) is a functionally distributed model. It uses Geographic Information System (GIS)-based methodology employing commonly used Revised Universal Soil Loss Equation (RUSLE) to estimate the amount of erosion that can occur in the study area and Flux model for estimating the sediment transport. By adopting this methodology a modeler can estimate fractions of sediment contributions from the three landforms (upland, surface tiled, riparian). An intermediate result is mapping of areas producing erosion at rates above, below and equal to tolerable rates for each soil type. The model works best on smaller watersheds (<4,000 hectare) where staff have time and resources to inventory water quality. A good understanding of the watershed is needed to validate the model outputs. The model implementation is relatively cheap, cost effective and easy. Existing data and freely available information in the public domain are used for computations. It takes a multifaceted and holistic approach by integrating current, localized research literature, field surveys, water quality data, and GIS into one tool for refining watershed management decisions. The SNAP model serves as a first stage of analyzing as to how bad the sedimentation problem is with limited resources.

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1 Introduction

A watershed is defined as area of land that drains water, sediment and dissolved materials to a common receiving body or outlet. It is beneficial to study hydrologic processes at watershed scales because at such scale all inputs and outputs may be accounted for. Hydrologic processes such as precipitation, runoff, drainage and evapotranspiration need to be accounted for in order to develop the water budget of a watershed.

Studies have been done in which watersheds were continuously or periodically monitored to measure precipitation, flow, runoff and various other hydrologic parameters inside or at the edge of a watershed[1-3]. Although long term monitoring of watersheds provide valuable data for understanding their impacts on hydrologic processes, it is expensive and time consuming to conduct continuous field measurements[4-6].

Hydrologic models are simplified representations of hydrologic systems that allow us to study the functioning of watersheds and their response to various inputs. They

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allow us to predict the hydrologic response of watersheds[5]. For the most part, hydrologic models are based on a systems approach, and differ by how and to what extent each component of the hydrologic cycle is considered. Computer simulation models are a composite of mathematical relationships, some are empirical, and some are based on theory. As one attempts to explain or predict the impacts of watershed management practices on increasingly complex systems, more details and complexity are needed in model formulation. This can lead to development of models that must be calibrated by fitting parameters and relationships to local watershed conditions.

In order to improve water quality and restore impaired watersheds, managers need to make decisions using data that they are able to gather. Data collection can be expensive, tedious and time consuming. Not all watershed managers have sufficient budgets to undertake such exercises. Judgment can be based on experience, subjective and not always reliable. In such situations using modeling approach makes sense. Models combine gathered data and generalize some of the processes to estimate a net outcome. Models can predict outcomes based on input data and relationships between parameters. There are errors associated with models which can be largely depending on degree of simplification of relationships between parameters in the system[7,8]. Degree of simplification can be in computational precision or form, model logic, or temporal or spatial averaging. The more the simplification of understanding of a process, the more the uncertainty associated with predicted outcome.

For evaluation of viable watershed management options, sediment modeling at watershed scales is one of many important tools[9-12]. Sedimentation can lead to decreases in soil fertility and increases in turbidity levels and nutrient loading, causing water quality deterioration. Sediment in stream channels is mainly due to soil erosion caused by wind or water[5,13].

Sediment in streams is a major source of pollution. Watershed managers like to know the causes and sources of soil erosion in their watersheds. This helps them target Best Management Practices (BMPs) to curtail erosion. Soil erosion data gathered from experimental plots can be extrapolated over the entire watershed. However, such results may be misled for watersheds with heterogeneous land-use patterns and physical characteristics. The problem may be addressed either by establishing numerous observation plots over the watershed to capture variation in sediment loss across the area, or by employing simulation-modeling techniques[8]. The first option is usually a costly and time-dependent proposition, particularly where financial and human resources are limiting. In modeling, sediment loss under alternative management scenarios may be rapidly estimated at minimal cost. A primary requirement of simulation modeling is that the model input parameters be accurately quantified. Model input data can be obtained either directly from field measurements or derived from existing literature.

In most soil and hydrologic simulation models several input parameters are required and their derivation can be a complex task depending on landscape variability. Manual extraction of input parameters can be tedious and error-prone, particularly with large watersheds. Consequently, many researchers have sought means to automate the process[14-16]. An increasingly popular approach involves use of GIS in which model input parameters can be easily generated from geographic databases. Integration of GIS with non-point source (NPS) pollution modeling can: (1) Identify environmentally sensitive areas in terms of NPS pollution potential based on model simulation results; (2) Produce useful information on changes in water quality following implementation of pollution reduction approaches; (3) Cost effectively evaluate alternative management strategies and programs for improved NPS pollution control[17-20].

Modeling soil erosion provides a sophisticated tool for selection of appropriate soil conservation practices. There are many soil erosion models, including the European Soil Erosion Model (EUROSEM)[16], the Water Erosion Prediction Project (WEPP)[21], the Limberg Soil Erosion Model (LISEM)[22], and the Chemical Runoff and Erosion from Agricultural Management System (CREAMS)[23] to name but a few. One of the most widely used erosion prediction models is the Revised Universal Soil Loss Equation (RUSLE). The RUSLE model has advantages because its data requirements are not too complex or unattainable, it is relatively easy to understand and apply, and it is compatible with GIS[24].

Linkage of GIS and erosion is made possible by the spatial format in which RUSLE factors are presented. These factors can be stored in GIS for each unit area inside a watershed for further calculations and graphical presentation of erosion.

This paper describes a hydrologic modeling approach involving GIS based RUSLE model application, its working intricacies, assumptions, advantages and limitations, and uses the Chippewa River watershed as an example case-study for the approach. The specific objectives of this research were to:

1) Document a modeling approach

2) Apply the approach to an agricultural watershed in Minnesota, United States to understand its benefits and shortcomings.

2 Model description

The Sediment and Nutrient Assessment Program (SNAP) modeling approach used in the study combines observed watershed inventories, information from GIS layers and potential erosion estimates (RUSLE) to quantify sediment and nutrient contributions from different landforms within watersheds.

The model is setup such that outlet stream monitoring data are combined with different GIS layers and soil classification data to create input information. Figure 1 describes the model setup. Broadly the model can be divided into three stages: input, process and output.

2.1 Input

Model inputs include soil classification data, identification of areas contributing to open tile intakes, riparian corridors and uplands, and stream monitoring data. Soil classification data include information on soil type and their C factor which are used in the process stage of the model for RUSLE analysis. Information on areas contributing to different landforms is derived using GIS and GPS (global positioning system). GIS layers of soil type, land use and stream and ditches are used as inputs for model simulation. A GPS survey of open tile intakes in the watershed is conducted to estimate the percentage of area contributing directly to the intakes. A survey should be such that it is representative of the watershed area.

2.2 Process

This stage of modeling involves computing and comparing estimated and measured sediment loadings. Estimated loadings are derived from RUSLE model and measured loadings are derived using the US Army Corps of Engineers' Flux model[25]. The RUSLE model gives estimate of sediment generated in the study area. The Flux model helps estimate the sediment transport. It is necessary to compare the two estimates to calculate the ratio of sediment reaching the watershed outlet to the sediment generated. These two estimates do not compare but complement each other in the SNAP modeling approach. It is necessary to have them both to calibrate the model to measured data rather than empirical formulae of just one of the estimates.

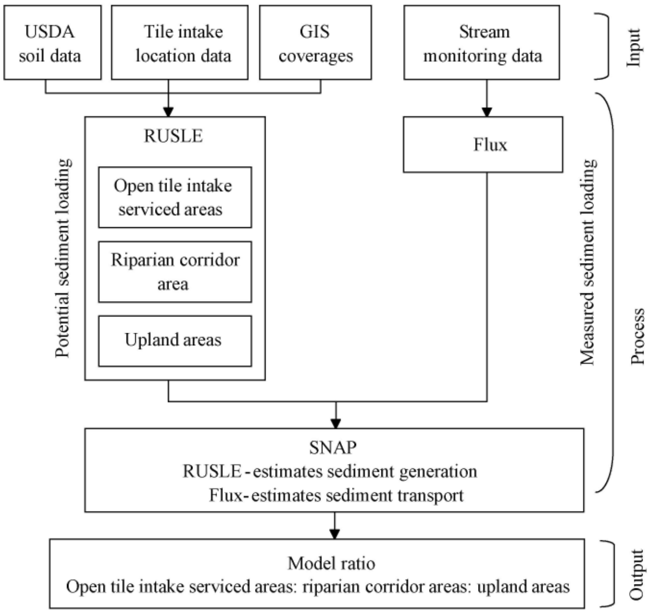

Figure 1 Flowchart of SNAP modeling process

2.2.1 RUSLE analysis

Analysis includes dividing a watershed into three landforms: uplands areas not serviced by open tiles, riparian corridors, and areas served by open tile. These three landforms serve as Hydrologic Response Units (HRUs) having unique hydrologically sensitive properties.

Each HRU reacts in a unique manner to the watershed processes such as runoff, sediment generation and sediment transport. A survey needs to be conducted at the beginning of the modeling exercise to estimate percentage area served by open tile intakes in the watershed. Tile intakes must be identified on a map using a GPS. Sites need to be visited to estimate the area directly serviced by the intakes. The watershed should be divided into several sections to have a representative sample of location and density of open tile intakes. The open tile intakes have a different hydrologic movement mechanism for water compared to the other two landforms. Once the water enters an open tile intake, it flows directly to the mouth of the tile drain. There are no delivery losses in the process causing a higher delivery ratio for the sediments in water. Using GIS, the water features in the watershed are buffered to 30 m. This buffered area serves as the riparian corridor. Area served by open tile intakes is calculated by multiplying the uplands by the percentage land serviced by open tile intakes. The rest of the area is considered as uplands. Once identified, RUSLE estimates of sediment generation can be computed for these three categories of land features.

The RUSLE is represented by the simple equation:

$$A = R * K * LS * C * P \tag{1}$$

Where: A is the predicted average annual soil loss from interrill (sheet) and rill erosion from rainfall and associated overland flow; R is the factor for climate erosivity; K is the factor for soil erodibility; LS is the L and S factors jointly represent the effect of slope length, steepness, and shape on sediment production; C is the factor for cover and management; P is support practices.

RUSLE estimates soil loss from sheet and rill erosion caused by rainfall and its associated overland flow. Like most erosion models, it is based on detachment limiting conditions designed to evaluate hill-slopes. Empirical models such as the RUSLE are based on coefficients computed or calibrated on the basis of measurement and/or observation and they cannot describe nor simulate the erosion process as a set of physical phenomena. In contrast to process-based models that consider erosion processes individually, RUSLE has a lumped equation structure that does not explicitly consider runoff, processes of detachment, transport or deposition individually, but rather combines these processes. As with most empirical models, the RUSLE is not event responsive, providing only an annual estimate of soil loss. It aggregates the processes of rainfall-runoff, and how these processes affect erosion, as well as the heterogeneities in inputs such as vegetative cover and soil types.

Yoder et al. [26] have illustrated the expected accuracy of the RUSLE factors and results. The total erosion per year estimate has at least 25% error in it. This error is significant and is unacceptable when estimating erosion for, critical decision making such as the life of a reservoir. But with limited time, money and data, the RUSLE erosion estimates can be used for qualitative analysis.

Returning to the SNAP methodology, using RUSLE, sediment load is computed for each landform. Data are available from various sources for computing sediment load using RUSLE. NRCS-USDA distributes soil erodibility data from its Minnesota website http://www.mn.nrcs.usda.gov/soils/ken/hel/mnhel2001.pdf. The data are in tabular form sorted by county. Tables include Map Symbol, Map Unit Name, T, K, C, R and LS values. Soil data for the counties can be downloaded from the Soil Survey Geographic (SSURGO) database. The data are 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 are available from the USDA. The USDA assigns a single value for C factor for the entire county. A more accurate soil loss estimate can be achieved by using different values according to different land use type. Soil classification data, land use data and soil erodibility data are joined together using GIS software. Once the tables are joined, RUSLE is calculated using GIS functionalities. Area for each soil classification polygon is computed using the X-tools GIS extension. Total soil loss in tons/year is calculated by combining RUSLE estimated soil loss for all polygons. The RUSLE values are compared with the T values supplied by the NRCS-USDA. A map of RUSLE-T is made and data are classified as positive, zero and negative.

2.2.2 FLUX analysis

The total sediment loads computed using RUSLE need to be balanced against the measured amounts (Figure 1). 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. The Flux program requires continuous flow data for the period for which loadings or mass discharges are estimated. There are six methods for estimating the loading and managers must identify the method most suitable for their nutrient and region.

Once we have the measured sediment load estimates from the Flux model and estimated sediment loads from the RUSLE analysis, we can compare the two. Since the monitoring season is based on six months (April-September) in the Midwest United States and RUSLE is based on twelve months, RUSLE output needs to be normalized for the monitoring season via a normalization factor. The normalization factor in our case was 2 (12 months/6 months). Additionally, RULSE gives an estimate of the potential erosion that can occur in the watershed and not the actual amount of sediment that reaches the monitoring station. A model ratio based on the ratio of sediment delivered as compared to the sediment eroded is used to compare the RUSLE estimated potential erosion with the sediment measured at the monitoring station.

Using model ratios, the loads computed using RUSLE are balanced against measured loads. Since the three landforms have different rates of delivery of sediment to the stream, different model ratios are needed to estimate each landform's contribution to the total sediment being delivered. When broken down into its landscape components, a SNAP equation becomes:

$$\begin{gathered}(R_u * A_u * M_u * N)+(R_{st} * A_{st} * M_{st} * N)+ \\ (R_r * A_r * M_r * N)+S=Flux\end{gathered} \tag{2}$$

Where: R is average load computed using RUSLE (ton/acre); A is area (acre); M is model ratio; N is normalization factor (annual runoff/monitor season runoff); S is stream bank erosion (tons); $Flux$ is load computed using $Flux$ (ton). Subscripts u: upland, st: surface tiled and r: riparian.

2.3 Output

Broad ranges of model ratios can be found from the literature review of research carried out in the region. Based on University of Minnesota research and as reported in Seven Mile Creek Watershed diagnostic study report[27], the ranges for the Upper Mississippi River Basin are:

Uplands: 0-20% Riparian Corridors: 50%-100%

Open-tile Intakes: 10%-40% Stream banks: 0-100%

Using these ranges the values on left-hand side of Equation (2), sediment generation estimates can be balanced against Flux results. Numerous combinations of numbers for model ratios can balance the equation. Not all of them are correct. Since the model ratio ranges are very broad and numerous combinations are possible, a validation of model ratios is needed. The numbers obtained for model ratios by balancing Equation (2) are applied to sub-basins or similar basins to check if the Equation (2) balances satisfactorily there as well. If the numbers being used for balancing the equation hold good for all sub-basins in the watershed or for similar basin then we may conclude that the model ratios are correct.

The model ratios help in estimating the amounts of sediment being contributed by the three landforms. The managers can then use this information for prioritizing the BMP efforts in landforms that generate the most sediment loadings.

2.4 SNAP model limitations

There are a few limitations of the SNAP model. The model works well in some years, but in extremely wet or dry years the Flux results do not compare well with RUSLE's long-term average predictions. It works better in smaller setting where the watershed's physical characteristics are similar and works best when it is coupled with a monitoring plan that informs the user by isolating two first order watersheds with minimal bank erosion sources to calibrate and validate the upland runoff delivery ratios. Then the user can apply it in a watershed that has bank erosion and solve for the unknown quantity of erosion. Because the model combines RUSLE (a long-term average prediction) and Flux, a seasonal regression based prediction for one year and climatic events that may or may not be in normal ranges (considering volume, intensity and timing), the source partitioning estimates have a wide range of variability. This is a good, inexpensive tool when a decision-maker has GIS capability, but should not be assumed to be accurate beyond the limits of either model (i.e.: RUSLE and Flux).

3 Model application

This part of the paper describes the implementation of SNAP modeling approach to the Chippewa River Watershed for sediment budgeting. A pair of sub-basins from the Chippewa River Watershed was chosen to implement the model. The model was calibrated on one basin and validated on the second basin with similar land use and topography.

3.1 Material and methods

3.1.1 Site description and water quality data

The Chippewa River Watershed (Figure 2) is located in southwestern Minnesota. Portions of eight counties make up the watershed including Otter Tail, Grant, Stevens, Douglas, Pope, Swift, Kandiyohi and Chippewa counties. It drains a 5,387 km^2 basin. For monitoring purposes, the Chippewa River Basin is divided into six tributaries/basins (Table 1 and Figure 2). 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 2000, the watershed had a population of 43,227. As seen in Table 2, agriculture is the primary land use in the watershed, followed by grasslands. Grasslands are predominantly around lakes and riverbanks.

The Chippewa River Watershed Project (CRWP) monitors daily flow of streams from all sub-basins via data-loggers installed at various locations along the river. The CRWP also monitors the Total Suspended Solid particle (TSS) and phosphorus (total phosphorus and orthophosphate). Water samples are periodically collected by the CRWP staff during the monitoring season (April 1st – September 30th) and sent to the laboratory for analyses. Using the Flux model, these

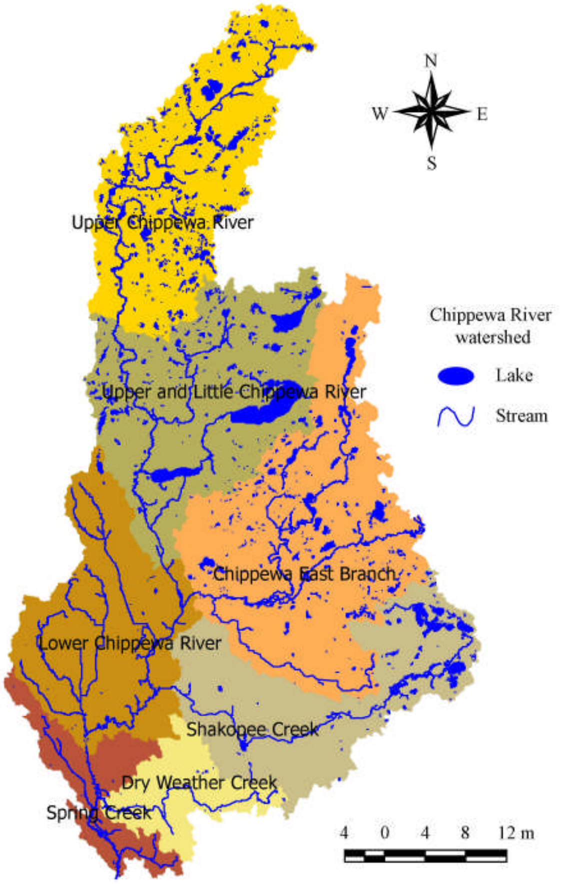

Figure 2 Chippewa River watershed

Table 1 Names of Chippewa River tributaries and sub-basins and their respective areas.

Name	Area/km^2	Percent area/%
East Branch	1,310	24.28
Middle Chippewa and Little Chippewa	1,043	19.33
Upper Chippewa River	920	17.05
Shakopee Creek	798	14.78
Lower Chippewa River	791	14.66
Dry Weather Creek	274	5.08
Lower Unmonitored Region	260	4.82
Chippewa River	5,396	100.00

Note: “Chippewa River Watershed”, CRWP, Montevideo, unpublished document[28].

Table 2 Chippewa River watershed landuse classification

Land use	Area/km^2	Percent area/%
Agriculture	3966	73.50
Grassland	601	11.14
Forest	291	5.38
Water	290	5.37
Wetlands	150	2.78
Urban or Residential	95	1.77
Gravel pits or Exposed	3	0.05
Unclassified	0.2	<0.01
Total	5396	100.00

Note: “Chippewa River Watershed”, CRWP, Montevideo, unpublished document[28].

data along with daily flow data were used for computing total load in the stream for the monitoring seasons. Precipitation data for running SNAP were collected from the Minnesota State Climatology Office. The Minnesota Department of Natural Resource provided land use and USDA soil classification data. Arc View GIS software was used for deriving information needed for estimating sediment load distribution.

3.1.2 RUSLE analysis

Data were collected from various sources for computing potential sediment load using RUSLE. The USDA-NRCS soil erodibility data for Chippewa County were used for estimating *T*, *K*, *C*, *R* and *LS* factor values. A practice factor (*P*) of 1 was assumed for the entire watershed. This assumption was made after discussions with the local NRCS staff. A *P* value of 1 was chosen because there were few contour farmed, cross-slope farmed, buffer stripped, strip cropped or terraced fields in the watershed. Soil data for the counties were downloaded from the Soil Survey Geographic (SSURGO) database. An *R* factor of 115 was used for watershed. This was based on a literature review and discussions with the local NRCS staff. The R factor represents the effect that ponded and puddled water has on raindrop erosion. Adjusted *K* factor values were for soils in the southwestern Minnesota (0.28 adjusted to 0.26, 0.20 adjusted to 0.17, 0.32 adjusted to 0.30, and 0.24 adjusted to 0.22. -9.00 representing wetlands and lakes were not included in analysis). *LS* values were used from the soil survey information for the contributing counties.

Soil classification data, land use data and soil erodibility data were spatially joined together using Arc View GIS software. Once the tables were joined, RUSLE was calculated using Equation (1) in Arc View GIS. Area for each soil classification polygon was computed and then a total soil loss in tons/year was calculated. The RUSLE values were compared with *T* values provided by the USDA-NRCS. A map of RUSLE-*T* was made and data were classified as positive, zero and negative values of RUSLE-*T* (Figure 3).

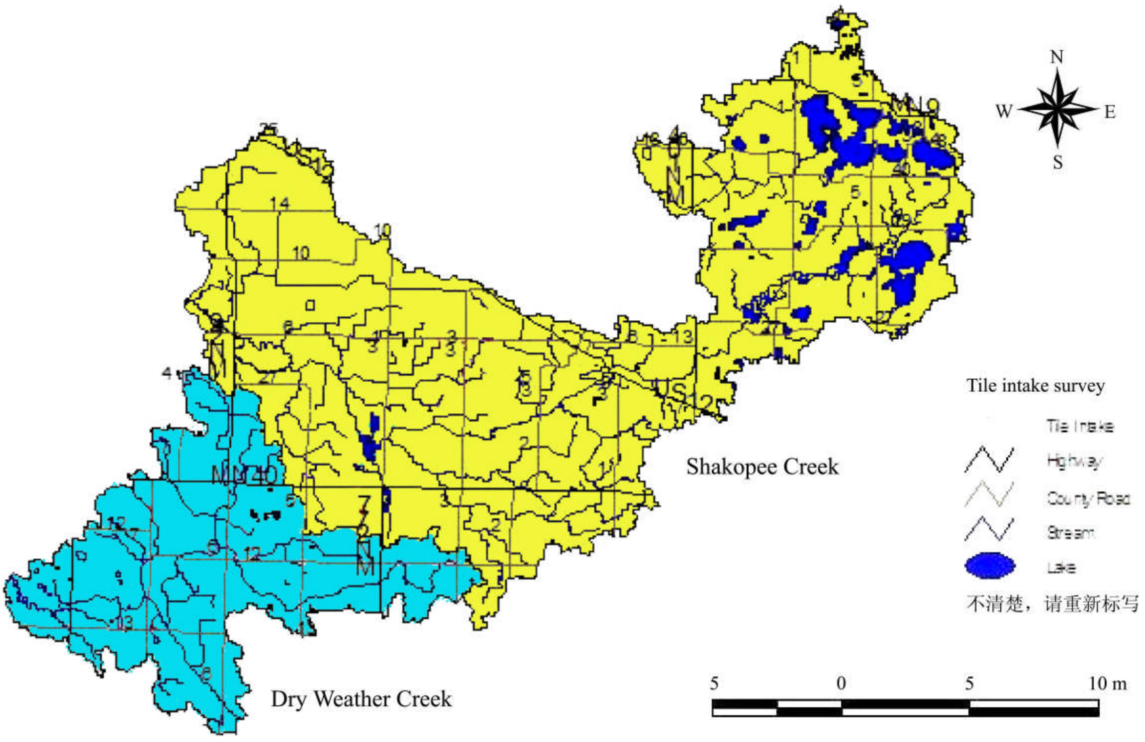

Figure 3 Open tile intake survey

The objective was to better understand the hydrology of the entire Chippewa River watershed by calibrating the SNAP model on a portion of the watershed. The SNAP could then be applied to the entire watershed. The model was to be calibrated on the Dry Weather Creek sub-basin and validated on the Shakopee Creek sub-basin (Figure 3). These sub-basins were independently monitored and had water quality data available for analysis. An open tile intake survey was carried out at these sub-basins to estimate the percentage area serviced by them.

Open tile intakes were digitally mapped using GPS measurements. Sites were visited to estimate the area directly serviced by the intakes. The sub-basins were divided into several sub-sections to have a representative sample. Thirty fields in each sub-basin were used for tile intake area estimation.

Using GIS the water features in the sub-basin were buffered to 30 meters. This area served as the riparian corridor for SNAP. 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.

3.2 Results and discussion

The results of tile intake survey data collected from 30 fields in each of the two sub-basins found that open tile intakes serviced 5.7% area in the Shakopee Creek sub-basin and 4.7% area in the Dry Weather Creek sub-basin. These numbers are lower than those found in eastern 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 crops grew tall, the percentages could vary 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 4 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 sediment 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 settling ponds and impact the water quality while grass and trees serve as buffers and reduce erosion. The CRWP gathered water quality data from these areas seems to support the finding that the lakes and diverse land use are buffering the highly erodable areas in these regions.

The area for which RUSLE could be computed was 60% of the entire watershed. For Shakopee and the Dry Weather Creek sub-basins in Figure 4, majority of the sediment load comes from the regions with tolerable soil loss rates. Table 3 shows a break down of the area and load for the two sub-watersheds.

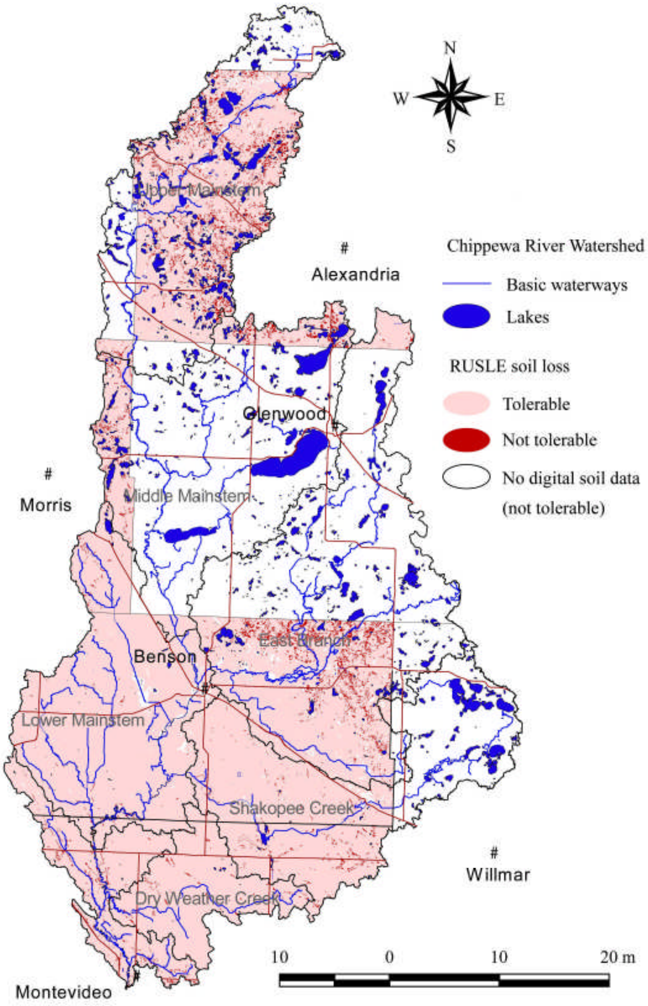

Figure 4 RUSLE results

Table 3 RUSLE results-I

Watershed	Area/km^2	Load/Ton
Shakopee Creek	523	192,031
Dry Weather Creek	275	95,854
Chippewa River Watershed*	3217	255,009

Note: *Watershed area for which RUSLE was computed.

In Shakopee Creek, 98% (515 km^2) of the basin area is in the tolerable soil loss region (Table 4). It contributes 89% (170,348 tons) of the total load. Only 2% (8.5 km^2) of Shakopee Creek contributes the remaining 11% (21,683 tons) of the sediment load into the river. Thus, areas with higher than tolerable soil loss rate give 2551 tons/km^2 sediment loss. This loss is almost eight times the sediment loss (331 tons/km^2) from the tolerable soil loss regions.

Table 4 RUSLE results-II

Watershed	RUSLE-T≤0		RUSLE-T>0	
	Area/km^2	Load/Ton	Area/km^2	Load/Ton
Shakopee Creek	515	170,348	8.5	21,683
Dry Weather Creek	271	85,948	3.7	9,906
Chippewa River Watershed	2871	81,035	347	173,974

Similarly, 99% (271 km^2) of the Dry Weather Creek basin area is in the tolerable soil loss region. It generates 90% (85,948 tons) of the sediment load. The remaining 1% (3.7 km^2) of the basin area generates 10% (9,906 tons) of the sediment load. That is 2,677 tons/km^2 sediment loss from the higher than tolerable soil loss (RUSLE-T>0) areas. This rate of loss is over eight times the loss from the tolerable soil loss regions (317 tons/km^2).

The findings indicate that areas that have soil loss less than the tolerable rate of loss (RUSLE≤T) need to be addressed to effectively reduce nutrient and sediment inputs into streams and rivers in the test watersheds. The rate of loss is tolerable from a crop production standpoint but the amount of sediment delivered to the river significantly detracts from water quality. The problem needs to be seen from the water quality rather than soil quality standpoint to address the pollution concerns.

The model was calibrated on the Dry Weather Creek sub-basin. It was assumed that the sub-basin in representative of the entire watershed and that if the model was calibrated on the sub-basin, the model ratios (M) will be applicable to the Chippewa River Watershed. In Equation (2) the potential erosion rate (R) was a known variable, area (A) had been estimated using GIS, the RUSLE erosion rate (R) was normalized (N) and sediment load from the basin was estimated using Flux. Model ratio (M) and streambank erosion (S) were the only two unknowns. The model ratios vary within the range described in methodology of the modeling approach. The major task was to estimate streambank erosion to solve Equation (3). A survey of the sub-basin concluded that the sub-basin had a very variable streambank erosion rate. There were locations where erosion was extremely high and locations where erosion was close to zero. In such a circumstance the only option left was to look for a sub-basin where streambank erosion did not vary as much and was easy to estimate.

Unfortunately, the Watershed Project had not monitored two such similar sections, with constant streambank erosion. The monitoring station network was set up with the motive of monitoring flow in major tributaries of the watershed. None of the sub-basins was homogeneous with accountable streambank erosion.

This was an initial and limited effort to apply the SNAP approach to the Chippewa River watershed. There is much room for improvement. There were intermediate results obtained that helped understand the vulnerable regions in the watershed. But the exercise highlighted the shortcomings of the model and should be of help to managers considering implementation of SNAP to their watershed.

4 Conclusions

The SNAP model was applied to the two Chippewa River watershed sub-basins. The model was to be calibrated on the Dry weather Creek sub-basin and validated on the Shakopee Creek sub-basin. Had estimates of stream bank erosion been available for the calibration sub-basin, the Equation (2) could have been balanced. But lack of stream bank erosion information hindered the calibration process. Some intermediate results gave valuable information about the sediment generation in and delivery from the watershed.

The open tile intakes service 5.7% area in Shakopee Creek and 4.7% area in the Dry Weather Creek. The RUSLE analysis helped understand that regions with RUSLE estimated erosion rates less than the tolerable soil loss collectively produce 90% of the sediments in the down stream basins. This information can be very useful for water resources decision-makers. The SNAP modeling constraints highlighted the need for more monitoring. A monitoring network should be setup such that it helps capture the water quality changes within the watershed. Lack of USDA soil classification data for many counties in the watershed hampered an understanding of the characteristics and hydrological phenomenon taking place in those portions of the watershed.

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