



Support Soil Conservation Practices by Identifying Critical Erosion Areas within an American Watershed Using the GIS-AGNPS Model

Xixi Wang and Peilian Cui¹

Abstract. Eroded soil from overland is one of the major nonpoint pollution sources in many watersheds. The subsequent sediment not only reduces conveyance capacity of streams and usable storage volume of reservoirs but it also adsorbs and transports pollutants into and impairs its receiving water bodies. These negative environmental impacts may be alleviated by reducing sediment loading, which is positively associated with soil erosion rate. Targeted to critical erosion areas, which have a soil erosion rate higher than the tolerable level (T value) of 4536 kg/ac-y (5 tons/ac-y), limited funds may be more efficiently used to control sediment. With this regard, it is necessary to identify these areas in a watershed using an efficient tool such as an ArcView GIS based AGNPS (AGriculture Non-Point Source) model. The objective of this study was to use the GIS-AGNPS model to identify erosion-source areas within the 7075-ha Lake Icaria watershed, located in the Adams County, Iowa. The simulation results indicated that under current conventional cultivation practices, approximately 20% of the watershed in size was incurring a soil erosion rate above the T value. However, iterative simulation results revealed that the erosion rates in more than 63% of these identified critical areas could be reduced to a magnitude less than the T value, provided that the cropping (C) factors corresponding to the conventional cultivation practices would be adjusted down by 25%.

Keywords. AGNPS, C factor, erosion, GIS, Iowa, T value, water quality modeling,

INTRODUCTION

Soils of the earth have been changing since the beginning of time. Natural changes in the earth's surface have brought devastation as well as the bounty of fertile topsoil upon which our civilization depends for food and fiber. Nevertheless, almost half of America's cropland is losing the invaluable topsoil faster than it can be replenished because of erosion, detachment and movement of soil particles (Dickey et al., 1997; Bhuyan and Kalita, 1999). Further, in a watershed, while soil erosion may occur along stream banks, on construction sites, and in lawns and streets, eroded soils in agricultural fields are cited as one of the major contributors to sediment loading (Chester and Schperow, 1985). Hence, soil erosion in agricultural fields has been widely studied and well documented (Baker et al., 1978; Laflen and Colvin, 1981; Laflen et al., 1981; Baker and Laflen, 1983; Dickey et al., 1997; Bhuyan et al., 2001).

¹ Respectively, Ph.D., P.E., Research Scientist, Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND 58202; and Software Programmer, Department of Space Studies, University of North Dakota, Grand Forks, ND 58202 (E-Mail/Wang: xwang@undeerc.org).

These studies indicated that the erosion rate across an agricultural field varied both spatially and temporally depending upon the characteristics of soil, land use/cover, topography, and climate. The subsequent sediment is either deposited in the field or on the beds of water bodies (e.g., streams, lakes, ponds, and/or reservoirs) or transported into downstream water bodies. In addition to lowering the conveyance capacity of streams and the usable storage volume of reservoirs, sediment is a pollutant in its own right (Senjem et al., 1996; Dickey et al., 1997) in that it increases turbidity in the water. The increased turbidity may limit light penetration and prohibit healthy plant growth on the water body bed, which serves as the ecological environment (i.e., spawning ground) and habitat of aquatic species. Blanketing much of the bed, sediment tends to destroy this ecological environment. Also, as an important carrier of various pollutants (e.g., nitrogen, phosphorus, and pesticides), sediment adsorbs and transports these pollutants into and impairs its receiving water bodies. For instance, nitrogen and phosphorous stimulate excessive algae growth in water bodies. When the algae decompose, they deplete dissolved oxygen from the water, reducing the number of life forms that are able to survive. Ouyang and Bartholic (1997) and Mohtar (2003) indicated that the impairment was positively associated with the sediment loading.

One of the major factors affecting sediment loading is the soil erosion rates in the contributing areas across the watershed. In general, an area with a higher erosion rate tends to contribute more to the sediment loading. For watersheds with significant row-crop lands, such as the 7075-ha study watershed of Lake Icaria, located in Adams County, Iowa, agricultural fields have an overall higher soil erosion rate than the areas with other land uses of grass, pasture, urban, and water. The areas with soil erosion rates higher than the tolerable level (T value) of 4536 kg/ac-y (5 tons/ac-y), the maximum soil loss rate that will permit a high level of crop productivity to be sustained economically and indefinitely, are cited as the critical soil erosion areas, whereas, the erosion rates in the severe soil erosion areas are higher than 6350 kg/ac-y (7 tons/ac-y) (Wischmeier and Smith, 1978; Senjem et al., 1996; Dickey et al., 1997; Reuter, 2000).

Previous studies (Chester and Schperow, 1985; Tim et al., 1992) have indicated that sediment, originated from the eroded soils caused by the detrimental effects of agricultural practices, was a major nonpoint pollution source (NPS) for the America's water resources. Responding to the urgent need for a massive NPS pollution control program, Congress enacted several water quality protection legislations in 1972, including the Federal Water Pollution Control Act. As a result, researchers have been prompted to develop and test sound agricultural management practices, namely precision or site-specific agriculture (Copeland, 2000; Wang, 2001) and conservation tillage (Baker et al., 1978; Laflen and Colvin, 1981; Laflen et al., 1981), to alleviate soil erosion. However, besides jurisdictional and economic obstacles, controlling sediment is technically complex because its sources or soil erosion areas are often diffused over a large geographic area and are not readily identifiable. On the other hand, development of an effective sediment control program has to start with locating and prioritizing these sources because of limited federal and state cost-sharing funds. Hence, a cost-effective and easy-to-implement tool such as ArcView GIS (geographic information system) based AGNPS (AGriculture Non-Point Source) model is useful for the purposes of identifying

the critical and severe soil erosion areas within a watershed (Young et al., 1989; Tim et al., 1992; Jones et al., 1996; Mati et al., 2000).

The objective of this study was to use the GIS-AGNPS model to identify critical soil erosion areas in the Lake Icaria watershed. The results of this study may be used to guide the practices of the soil conservation and water quality protection for this watershed.

MATERIALS AND METHODS

The ArcView GIS-AGNPS Model

Computer simulation models may be cost-effective tools for examining soil erosion sources within a watershed. In the past two decades, several computer simulation models, namely EPIC (Erosion/Productivity Impact Calculator), ANSWERS (Area Nonpoint Source Watershed Environmental Response Simulation), and SWRRB (Simulator for Water Resources in Rural Basins), have been developed to estimate watershed responses to various rainfall events (Williams et al., 1985; Young et al., 1989; Spruill et al., 2000). Albeit, these models are inappropriate for identifying critical soil erosion areas because of a lumped structure (Wilson, undated).

On the other hand, the AGNPS model (version 5.0), developed by the U.S. Department of Agriculture (USDA), has a distributed structure (Young et al., 1989). This model has a capability to analyze and simulate runoff water quality from agricultural watersheds ranging in size from a few hectares to upwards of 20,000 ha. The model simulates runoff, sediment, nutrient and pesticide contributions from the overland to streams as a result of storm runoff and irrigation return flow (Young et al., 1989; Licciardello and Zimbone, 2002). Runoff is calculated in the model using a variation of the TR-55 method (USDA–SCS, 1986). Sediment loading is predicted by simulating upland erosion with the Modified Universal Soil Loss Equation (MUSLE) (Young et al., 1989; Jones et al., 1996), in conjunction with a sediment delivery ratio estimated by the equations that were developed and discussed by several researchers (Williams et al., 1971; Williams, 1975, 1977; Williams and Berndt, 1976, 1977; Ouyang and Bartholic, 1997). Sediment routing through a river reach is based on a modified Einstein deposition equation using the Bagnold suspended sediment formula for the transport capacity by particle size class (Bagnold, 1966; Young et al., 1989).

AGNPS requires that the study watershed be subdivided into approximately homogeneous smaller square areas (cells). The number of cells can be from a few to myriads, depending on data availability and the required simulation accuracy. In the model, each of the cells is uniquely characterized by a total of 22 input parameters covering topographic, soil, and land use factors (Young et al., 1989; Mankin et al., 2002). However, one limitation of distributed models such as AGNPS is that preparation of input data files and interpretation of simulation results may become overwhelming and time-consuming with increase in cell numbers (Tim and Jolly, 1994; Tim et al., 1995;

Tim, 1996; Liao and Tim, 1997; Mankin et al., 2002). This limitation mandates the need of a powerful tool to facilitate the application of AGNPS.

Geographic information system (GIS), designed to store, manipulate, retrieve, and display spatial and nonspatial data, can be such a tool. ArcView GIS, developed by the Environmental Systems Research Institute (ESRI) to be used primarily for desktop mapping and geographic data analysis and display, is perhaps the most widely used GIS software in the current marketplace. With more than 500,000 copies in use worldwide, ArcView provides users intuitive, easy-to-use, point-and-click interfaces for manipulating, querying, analyzing, modeling, and visualizing data from many different sources (ESRI, 2003). It allows users to quickly develop customized, enterprise-level applications and interfaces by adding standardized functions and operations, deleting and adding buttons, and attaching scrip to automate a process. The interfaces can be developed in Avenue and Microsoft Visual Basic computer programming languages and then employed to link ArcView GIS and other application software packages such as AGNPS. Coupled with ArcView GIS, the aforementioned limitation of applying AGNPS in practice was eliminated (Tim, 1996; Bhuyana et al., 2001; Wilson, undated).

The coupling was implemented by a graphic user interface (GUI) built in Avenue (Stratton, 1998). The GUI has four functional modules that generate AGNPS input parameters from user-specified ArcView GIS themes, create AGNPS input data files, control AGNPS model simulation, and extract and organize AGNPS model outputs for display. In conjunction with the ArcView interface of the soil and water assessment tool (SWAT) 2000 (Di Luzio et al., 2002), developed by the USDA Agricultural Research Service (ARS), the data generation module uses ArcView GIS themes on boundary, elevations, streams, land use, and soils to generate: 1) a fishnet (grid) theme for the watershed; 2) topographic, soil, and land use factors; and 3) other grid-cell-level information specified in the input data files. The generated fishnet theme provides the framework for storing the AGNPS grid-cell-level input parameters.

The Lake Icaria Watershed

The Lake Icaria watershed, located in Adams County, Iowa, drains approximately 7075 ha into the 16-km long Lake Icaria (Figure 1). Topography of the watershed varies from gently sloping to moderately steep. Soils were developed primarily from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols. The predominant soil associations are Sharpsburg-Adair (nearly level to moderately steep), Macksburg-Winterset (nearly level to gently sloping), and Shelby-Sharpsburg (moderately sloping to steep). The soils were determined to have a moderate or low rate of water transmission.

Land use/cover in the Lake Icaria watershed primarily consists of grass and row crops (corn and soybean). The 1992 land cover data, derived from a satellite imagery by the Iowa Department of Natural Resources (Iowa DNR, 2001) at a mapping resolution of 900 m², indicated that 52.6% of the watershed was covered by grass or hay, 39.6% by row crops, 3.8% by waters, 2.3% by woody vegetation, 1.0% by barren/sparse vegetation,

and 0.7% by artificial/urban uses. Figure 1 shows the spatial distribution of these land covers in the watershed.

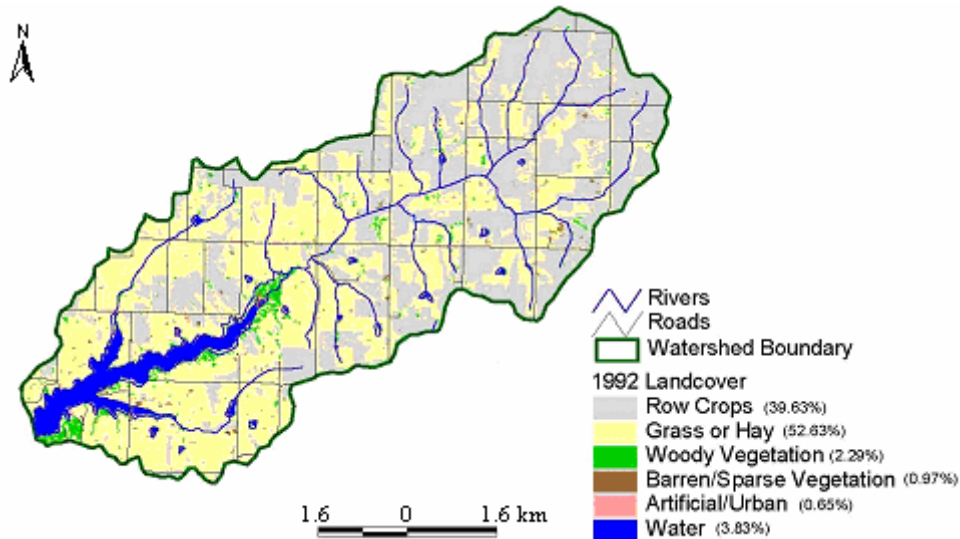


Figure 1. The boundary, streams, and land use/cover of the Lake Icaria watershed.

Watershed practices and the in-lake conditions have noticeably changed over the past decade. Following heavy rainfall and high wind events, the Lake Icaria could have a high turbidity (Iowa DNR, 2002). The vertical distributions of turbidity were significantly different from month to month, which might be caused by the deposition and suspension of sediment and other solids. In May, the turbidity monotonously increased from 5 NTU (nephelometric turbidity units) at the lake surface to 55 NTU at the 10-m depth, whereas, in July, it monotonously decreased from 30 NTU at the surface to 10 NTU at the 8-m depth but abruptly increased to 55 NTU at the 8.5-m depth. The distribution of July might be a result of high runoff generated from heavy rainfall events, transporting more sediment and other suspended solids into the first 6 m of water. In June, the turbidity reached its peak of 28 NTU at just above the 4-m depth, with an approximate uniform value of about 5 NTU at other depths. This pulse distribution might result from discharges from the sewer pipes with their outlets located at the 3–4-m depth. Throughout these three months, the lake had a vertically-averaged turbidity of higher than 10 NTU. The high turbidity of the lake water indicated soil erosion could be a problem for this watershed. Identifying and prioritizing the soil erosion areas in the Lake Icaria watershed would prompt developing cost-effective corrective measures for reducing the turbidity of the lake water, which will increase the existing water supply and recreational values of the Lake Icaria (Iowa DNR, 2002).

Model Set Up

The boundary for the Lake Icaria watershed was delineated using the 30-m national elevation dataset (NED) and the national hydrography dataset (NHD), obtained from the U.S. Geological Survey (USGS). NED was developed by merging the highest-resolution, best-quality elevation data available across the U.S. into a seamless raster format. As a

result of maturation, the USGS provides the 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous United States and 1:63,360-scale DEM data for Alaska (USGS, 2001a). NHD is a comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs, and wells (USGS, 2001b). Within NHD, surface water features are combined to form "reaches," which provide the framework for linking water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream and downstream order. NHD is based upon the content of the USGS Digital Line Graph (DLG) hydrography data integrated with the reach-related information from the U.S. Environmental Protection Agency's (EPA's) Reach File Version 3 (RF3). It supersedes DLG and RF3 by combining, expanding, and refining them. NHD is organized by the USGS 8-digit hydrologic cataloging units (HUCs).

The Lake Icaria watershed is located within the HUC of 10240010. Both of NED and NHD use a geographic coordinate with the unit of decimal degree, horizontally referenced to the North American Datum of 1983 (NAD83). In this study, the NED and NHD for the Lake Icaria watershed were projected to Zone 15 of the Universal Transverse Mercator 1983 (UTM-1983) using the ArcView Extensions of Grid Projector and Projection Utility Wizard, respectively. To improve the delineation accuracy and efficacy, a polygon mask theme, which is slightly larger than the Lake Icaria watershed boundary, was visually created from the projected NHD using ArcView. The ArcView Interface for SWAT 2000 (Di Luzio et al., 2002) was used to delineate the accurate boundary for the watershed. In the Watershed Delineation dialogue box of the interface, the DEM grid was specified as the projected NED, the Focusing watershed area option specified as the polygon mask theme, and the Burn_in option specified as the projected NHD.

Following the Processing of the DEM to remove sinks, the best Threshold Area of 7.5 ha for stream definition was determined by trial and error to make the delineated stream network closely match that presented by the NHD, which was assumed to be accurate. The watershed or the lake outlet was visually defined from the NHD, displaying the Lake Icaria and its drainage network. The results consisted of an accurate watershed boundary theme, along with the delineations and associated parameters of its 408 subbasins. The boundary theme was fed into the data generation module of the GIS-AGNPS GUI to generate the fishnet theme with a cell size of 2.5 ac (100 m × 100 m), from which the 7075 model input cells were created. Figure 2 shows the fishnet theme with cells merged to show the modeled land uses. The land uses were derived from reclassifying the 1992 land cover data obtained from the Iowa DNR (Figure 1).

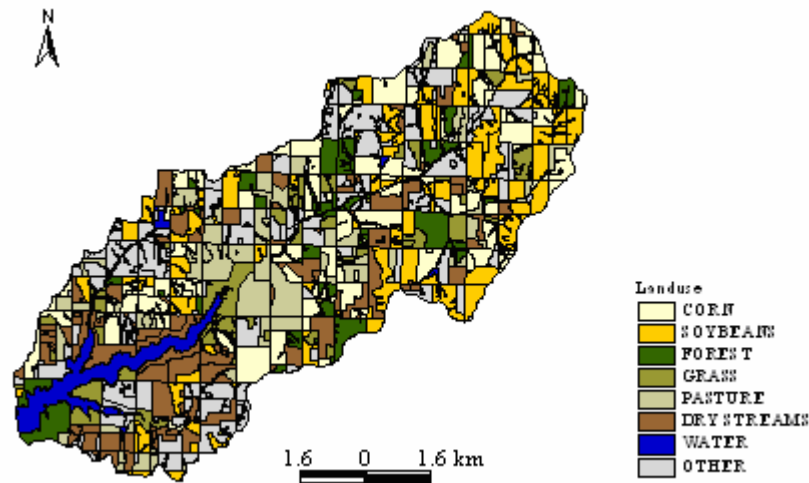


Figure 2. The 100-m fishnet for the Lake Icaria watershed with cells merged to show the modeled land uses.

The AGNPS topographic parameters, including flow direction, receiving cell number, land slope, slope shape, slope length, and channel type, were determined from the NED using the data generation module. The module generated an elevation grid theme with the fishnet cell size of 100 m by resampling the 30-m NED and derived and stored these topographic parameters automatically. The AGNPS soil parameters, namely soil texture number and soil erodibility factor, and land-use parameters, namely NRCS runoff curve number, MUSLE C (cropping) and P (conservation practice) factors, Manning’s overland flow factor, and surface condition constant, were extracted from the state soil geographic (STATSGO) database and the 1992 land cover data (Figure 1). Although the soil survey geographic (SSURGO) data base (USDA–NRCS, 1995) was preferred because it provides the most detailed level of information and was designed primarily for farm and ranch, landowner/user, township, county, or parish natural resource planning and management, it was unavailable for Adams County when the study was conducted.

Using the ArcView Interface for SWAT 2000, the hydrologic response units (HRUs), portions of a subbasin that possess unique land use/management/soil attributes (Neitsch et al., 2002a,b), were defined from the STATSGO and the land cover data for each of the 408 subbasins. The results included both the soil and land use parameters required by the AGNPS but stored subbasin by subbasin in several attribute tables associated with a subbasin polygon theme. Using the data generation module, these results were area-weighted to generate the input data for each of the 7075 cells by overlaying the fishnet theme and the subbasin polygon theme.

The storm data and the model simulation control parameters (Young et al., 1989) were specified through the GUI dialogue box of Initial Watershed Data for AGNPS (Stratton, 1998). Using the historical data observed at a local meteorology station,

Stratton determined that an SCS (soil conservation service) Type II storm (USDA-SCS, 1986; Chow et al., 1988; Kellems et al., 2003) tended to cause noticeable soil erosions in the geographic location, where the Lake Icaria watershed is located. The storm has a 6-h precipitation of 120.7 mm and a rainfall and runoff erosivity index R of 2437.3 MJ-mm/ha-h-y (143.2 ft-ton-in/ac-h-y). The index is comparable with the value of 3000 MJ-mm/ha-h-y (176 ft-ton-in/ac-h-y) presented by USDA and EPA (1975) and Foster (1981, 1999). These storm data were input into the GIS-AGNPS model as well.

RESULTS AND DISCUSSION

The row crops in the Lake Icaria watershed were either corn or soybean. Until today, the agriculture land has been being cultivated with the conventional mold board plow and disk (Jain et al., 1994; Stratton, 1998). Under this conventional cultivation, C factors were determined to be 0.26 and 0.31 for the corn and soybean fields, respectively (Baker and Laflen, 1983; Jain et al., 1994; Stratton, 1998; Mcgregor and Cullum, 1999; and Reuter, 2000). The annual soil erosion was simulated for the conventional cultivation (Figure 3).

Figure 3 showed an obvious spatial pattern of soil erosion in the Lake Icaria watershed. First, the erosion was closely associated with the land use and cover. Row crops of both corn and soybean resulted in a higher erosion rate than the other land uses. For a given crop, the erosion rate varied from one cropland area to another. Overall, the soybean fields had higher erosion rates than the corn fields. Further, six erosion strips existed in the northern portion of the watershed, whereas in the southern portion, an almost continuous erosion strip extended from the southeast to the northwest. The upstream (northeastern) portion of the watershed had erosion areas denser than the downstream (southwestern) part. Between the upstream and the midstream and between the midstream and the downstream existed two strips with soil erosion rates lower than the T value.

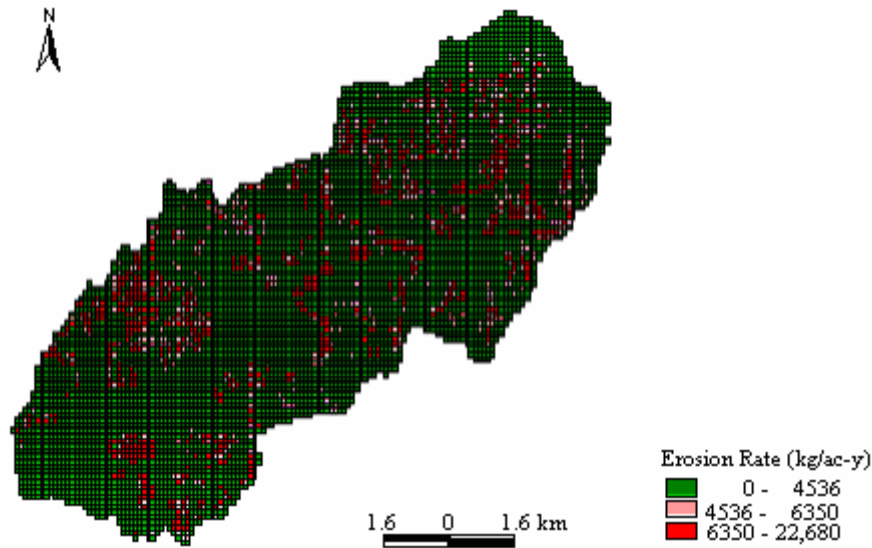


Figure 3. Simulated soil erosion rates within the Lake Icaria watershed under the current conventional cultivation practices.

This spatial pattern might be interpreted by examining the land use/cover of the watershed (Figures 1 and 3). The predominant land cover in the upstream was soybean, while corn was widely planted in the midstream, and dry streams spreaded out in the downstream. Between the upstream and the midstream and between the midstream and downstream were forest, grass, or pasture. The simulation results indicated that approximately 552 ha (7.8%) of the Lake Icaria watershed was incurring a critical soil erosion and 863 ha (12.2%) was incurring a severely critical soil erosion. The remaining 5,660 ha (80%) had a soil erosion rate lower than the T value (Figure 3).

The soil erosion rates might be reduced through lowering the C factors by implementing conservation cultivation practices, such as low-till, no-till, and residue management (Baker and Laflen, 1983; Dickey et al., 1997; Montas et al., 1999). These conservation practices might reduce the C factors by up to 40% from the conventional cultivation practices (Reuter, 2000). To evaluate effects of C factors on reducing soil erosion rates in the Lake Icaria watershed, the C factors for corn and soybean fields in these identified critical and severely critical soil erosion areas were arbitrarily adjusted down 25% to 0.20 and 0.23 (arbitrary cultivation), respectively. The soil erosion under this arbitrary cultivation was simulated using the GIS-AGNPS model, and the simulated erosion rate reductions are shown in Figure 4.

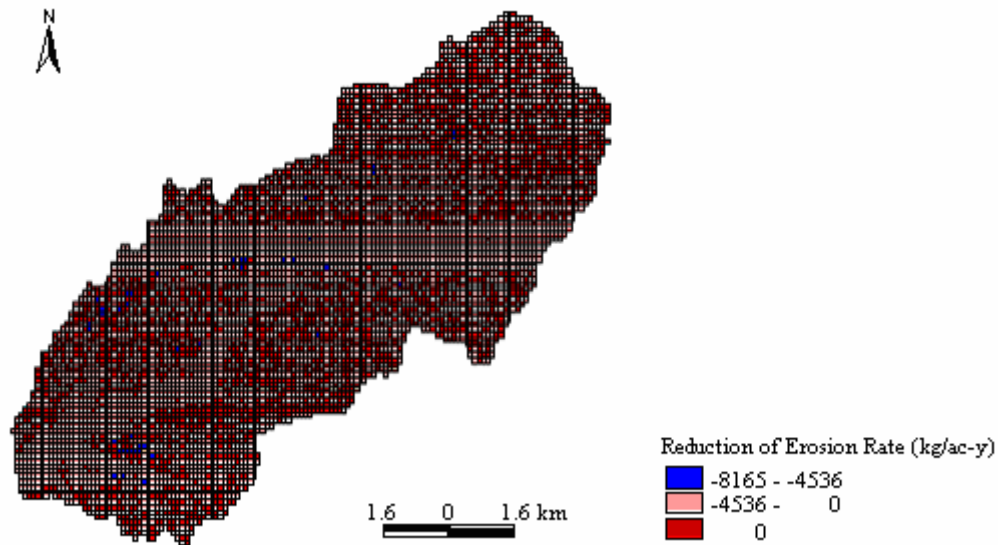


Figure 4. Simulated soil erosion rate reduction under the arbitrary cultivation within the Lake Icaria watershed from the current conventional cultivation practices.

Under this arbitrary cultivation, the soil erosion rates in the critical and severe soil erosion areas shown in Figure 3 would be reduced by up to 8165 kg/ac-y (9 tons/ac-y) (Figure 4). In contrast to the conventional cultivation, the arbitrary cultivation would reduce the identified critical and severe soil erosion areas by 27.9 % and 36.0%, respectively. A t-test indicated that these reductions were statistically significant at a significance level of 0.01 (p value = 0+).

By further adjusting the C factors for the remaining critical and severe soil erosion areas down an additional 25%, these areas would be further reduced by 21.2% and 34.5%, respectively (not shown). Iteration of this process would generate the C factor reductions that might be required in particular areas to eliminate these critical and severe soil erosion areas. However, the more reduction in C factors might imply that more conservation measures such as no-till would be needed. For the Lake Icaria watershed, reducing these critical and severe soil erosion areas might significantly lower the sediment loading into the Lake Icaria.

SUMMARY AND CONCLUSIONS

It is necessary to use a cost-effective and easy-to-implement tool such as the ArcView GIS-AGNPS model to identify and prioritize the critical and severe soil erosion areas in the 7075-ha Lake Icaria watershed. For the identified critical and severe soil erosion areas in this watershed, this study also examined effects of the hypothetical practices that would result in a 25% reduction of the C factors on reducing soil erosion rates to a magnitude of less than the T value of 4536 kg/ac-y (5 tons/ac-y). The simulation results indicated that under the current conventional cultivation practices, 552 ha (7.8%) of the study watershed was incurring a critical soil erosion and 863 ha (12.2%) was incurring a

severe critical soil erosion. Mapping of these results revealed an obvious spatial pattern, self-explained by the land use/cover. The northeastern portion of the watershed had erosion areas denser than the southwestern part, and the areas under row crops had an overall higher erosion rate than the ones under forest, grass, pasture, and waters. The identified critical and severe soil erosion areas could be reduced by 27.9% (241 ha) and 36.0% (199 ha), provided that the C factors corresponding to the conventional cultivation practices would be adjusted down by 25%. Iteration of this process indicated that further reducing the C factors by additional 25% would further reduce the soil erosion rates in these identified critical and severe soil erosion areas in the Lake Icaria watershed to a magnitude of less than the T value. The results and the GIS-AGNPS model presented in this paper may be used to guide the research, planning, and practice of soil conservation and water quality protection for the Lake Icaria watershed.

REFERENCES

- Bagnold, R.A. 1966. An approach to the sediment transport problem from general physics. Prof. Paper 422, *J. U.S. Geol. Surv.*, Reston, Va.
- Baker, J.L., J.M. Laflen, and H.P. Johnson. 1978. Effects of tillage systems on runoff losses of pesticides: A rainfall simulation study. *Transactions of the ASAE* 21: 886–892.
- Baker, J. L., and J. M. Laflen. 1983. Water quality consequences of conservation tillage. *J. Soil and Water Cons.* 5: 186–193.
- Bhuyan, S. J., and P. K. Kalita. 1999. Predicting soil loss for three tillage systems in Kansas. In *Proc. 1999 ASAE Annual International Meeting/CIGR World Congress*, Sheraton Center, Toronto, Ontario, Canada.
- Bhuyan, S.J., L.J. Marzen, J.K. Koelliker, J.A. Harrington, and P.L. Barnes. 2001. Assessment of runoff and sediment yield using remote sensing, GIS, and AGNPS. *J. Soil and Water Cons.* 57(6): 201–210.
- Chester, G., and L.J. Schperow. 1985. A primer on nonpoint pollution. *J. Soil and Water Cons.* 40(1): 9 – 13.
- Chow, V.T., D.R. Maidment, and L.W. Mays. 1988. *Applied Hydrology*. McGraw-Hill, Inc.
- Copeland, C. 2000. Water quality initiatives and agriculture: Report to the Congress RL 30437. The Congress, Washington D.C.
- Di Luzio, M., R. Srinivasan, J.G. Arnold, and S.L. Neitsch. 2002. ArcView Interface for SWAT2000—User’s Guide. Grassland, Soil and Water Research Laboratory, Agricultural Research Service; Black Research Center, Texas Agricultural Experiment Station.
- Dickey, E.C., D.P. Shelton, and P.J. Jasa. 1997. NebGuide – Residue management for soil erosion control. Published by the Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska – Lincoln. Available at <http://www.ianr.unl.edu/pubs/fieldcrops/g544.htm>. Accessed on November 20, 2003.
- ESRI. 2003. ArcNews. ESRI International User Conference Issue, 25(2).

- Foster, G.R. 1981. Rainfall and runoff erosivity index R by geographic location. Available at <http://pasture.ecn.purdue.edu/~abe325/week.8/effects.html>. Accessed on November 19, 2003.
- Foster, G.R. 1999. Revised universal soil loss equation (RUSLE). In *Proc. Sino-American Workshop on Sediment Management in Agricultural Watersheds*. Oxford, MS., December 6 – 9, 1999.
- Iowa DNR. 2001. Lake Icaria watershed land cover. Available at <http://wqm.igsb.uiowa.edu/activities/lake/icaria.htm>. Accessed on November 18, 2003.
- Iowa DNR. 2002. Lake Icaria. Available at <http://wqm.igsb.uiowa.edu/activities/lake/icaria.htm>. Accessed on November 13, 2003.
- Jain, D. K., U. S. Tim, and R. W. Jolly. 1994. A spatial decision support system for livestock production planning and environmental management. *App. Eng. in Agri.*, 11(5): 711–719.
- Jones, D.S., D.G. Kowalski, and R.B. Shaw. 1996. Calculating revised universal soil loss equation (RUSLE) estimates on Department of Defense lands: A review of RUSLE factors and U.S. Army land condition – trend analysis (LCTA) data gaps. Published by the Center for Ecological Management of Military Lands, Department of Forest Science, Colorado State University. Available at <http://www.cemml.colostate.edu/files/tps-96-8.pdf>. Accessed on November 19, 2003.
- Kellems, B.L., R. Johnson, and F. Sanchez. 2003. Design of emerging technologies for control and removal of stormwater pollutants. In *Proc. Water World & Environmental Resources Congress 2003*. Philadelphia, PA., June 2003.
- Laflen, J.M., and T.S. Colvin. 1981. Effect of crop residue on soil loss from continuous row cropping. *Transactions of the ASAE* 24: 605 – 609.
- Laflen, J.M., W.C. Moldenhauer and T.S. Covin. 1981. Conservation tillage and soil erosion on continuously row-cropped land. In *Proc. Production with Conservation in the 80's*, 7 – 81. St. Joseph, Mich.
- Liao, H., and U.S. Tim. 1997. An interactive modeling environment for nonpoint – source pollution control. *J. Amer. Water Resources Assoc.* 33(3): 1 – 13.
- Licciardello, F., and S.M. Zimbone. 2002. Runoff and erosion modeling by AGNPS in an experimental mediterranean watershed. In *Proc. 2002 ASAE Annual International Meeting/CIGR XVth World Congress*, Chicago, Illinois, July 28 – 31, 2002.
- Mankin, K.R., R.D. DeAussen, and P.L. Barnes. 2002. Assessment of a GIS-AGNPS interface model. *Transactions of the ASAE* 45(5): 1375 – 1383.
- Mati, B.M., R.P.C. Morgan, F.N. Gichuki, J.N. Quinton, T.R. Brewer and H.P. Liniger. 2000. Assessment of erosion hazard with the USLE and GIS: A case study of the upper Ewaso Ng'iro North Basin of Kenya. *JAG* 2(2): 1 – 9.
- Mcgregor, K. C. and R. F. Cullum. 1999. Crop residues reduce soil erosion. In *Proc. 1999 ASAE Annual International Meeting/CIGR World Congress*, Toronto, Ontario, Canada.
- Mohtar, R.H. 2003. Estimating effect of water erosion. Available at <http://pasture.ecn.purdue.edu/~abe325/week.8/effects.html>. Accessed on November 19, 2003.
- Montas, H. J., A. Shirmohammadi, J. S. Butler, and T. W. Chu. 1999. Decision support for precise BMP selection in Maryland. In *Proc. 1999 ASAE Annual International Meeting/CIGR World Congress*, Toronto, Ontario, Canada.

- Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams, and K.W. King. 2002a. Soil and Water Assessment Tool – Theoretical Documentation (Version 2000). Grassland, Soil and Water Research Laboratory, Agricultural Research Service; Black Research Center, Texas Agricultural Experiment Station.
- Neitsch, S.L., J.G. Arnold, J.R. Kiniry, R. Srinivasan, and J.R. Williams. 2002b. Soil and Water Assessment Tool – User’s Manual (Version 2000). Grassland, Soil and Water Research Laboratory, Agricultural Research Service; Black Research Center, Texas Agricultural Experiment Station.
- Ouyang, D., and J. Bartholic. 1997. Predicting sediment delivery ratio in Saginaw Bay watershed. In *Proc. The 22nd National Association of Environmental Professionals Conference*, 659 – 671. Orlando, FL., 19 – 23 May.
- Reuter, H.I. 2000. Soil and water conservation project: Rockwood case study. Available at <http://www.hnm.de/hp/kassi/swc%20project.htm>. Accessed on November 20, 2003.
- Senjem, N.B., J.F. Moncrief, G.W. Randall, and S.D. Evans. 1996. Sediment problems and solutions for the Minnesota River. Published by the University of Minnesota Extension Service. Available at <http://www.extension.umn.edu/distribution/naturalresources/DD6671.html>. Accessed on November 20, 2003.
- Spruill, C.A., S.R. Workman, and J.L. Taraba. 2000. Simulation of daily and monthly stream discharge from small watersheds using the SWAT model. *Transactions of the ASAE* 43(6): 1431 – 1439.
- Stratton, S.M. 1998. An integrated assessment of watershed land use impacts on aquatic ecosystem. M.S. thesis. Ames: Iowa State Univ., microfiche.
- Tim, U.S., S. Mostaghimi, and V. O. Shanholtz. 1992. Identification of critical nonpoint pollution source areas using geographic information systems and water quality modeling. *Water Resources Bulletin* 28 (5): 877–887.
- Tim, U.S., and R. Jolly. 1994. Evaluating agricultural nonpoint-source pollution using integrated geographic information systems and hydrologic/water quality model. *J. Environ. Qual.* 23(1): 25–35.
- Tim, U.S., R. Jolly, and H. Liao. 1995. Impact of landscape feature and feature placement on agricultural nonpoint-source pollution control. *J. Water Resources, Planning, and Management* 121 (6): 463–470.
- Tim, U.S. 1996. Coupling vadose zone models with GIS: Emerging trends and potential bottlenecks. *J. Environ. Qual.* 25(3): 535–544.
- USDA and EPA. 1975. Rainfall and runoff erosivity index R by geographic location. Available at http://weather.nmsu.edu/teaching_Material/soil350/erosion_laboratory.htm. Accessed on November 26, 2003.
- USDA–SCS. 1986. Technical Release 55: Urban Hydrology for Small Watersheds. Available at <http://www.wcc.nrcs.usda.gov>. Accessed on November 26, 2003.
- USDA–NRCS. 1995. Soil Survey Geographic (SSURGO) Data Base: Data Use Information. National Cartography and GIS Center, Fort Worth, TX.
- USGS. 2001a. National elevation dataset. Available at <http://gisdata.usgs.net/NED/default.asp>. Accessed on November 20, 2003.
- USGS. 2001b. National hydrography dataset. Available at <http://nhd.usgs.gov>. Accessed on November 20, 2003.
- Wang, X. 2001. Integrated spatial decision support system for precision agriculture. Ph.D. diss., Agricultural & Biosystems Engineering Dept., Iowa State Univ., Ames.

- Williams, J.R., E.A. Hiler, and R.W. Baird. 1971. Prediction of sediment yields from small watersheds. *Transactions of the ASAE* 43(4): 1157–1162.
- Williams, J.R. 1975. Sediment routing for agricultural watersheds. *Water Resources Bulletin* 11(5): 965–974.
- Williams, J.R., and H.D. Berndt. 1976. Determining the universal soil loss equation's length–slope factor for watersheds. In *Erosion and Solid Matter Transport in Inland Waters*, 217 – 225. IAHS–AISH Publication No. 122.
- Williams, J.R. 1977. Sediment delivery ratios determined with sediment and runoff models. In *Erosion and Solid Matter Transport in Inland Waters*, 168–179. IAHS–AISH Publication No. 122.
- Williams, J.R., and H.D. Berndt. 1977. Sediment yield prediction based on watershed hydrology. *Transactions of the ASAE* 44(6): 1100–1104.
- Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. SWRRB, A simulator for water resources in rural basins. *ASCE J. Hydrol. Eng.* 111(6): 970–986.
- Wilson, J.P. undated. GIS-based land surface/subsurface modeling: New potential for new models? Published by the Geographic Information and Analysis Center, Department of Earth Sciences, Montana State University. Available at http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/wilson_join/wilson.html. Accessed on November 26, 2003.
- Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses – A guide to conservation planning. Agriculture Handbook No. 537. U.S. Department of Agriculture, Washington, D.C.
- Young, R.A., C.A. Onstad, D.D. Bosch, and W. P. Anderson. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. *J. Soil Water Cons.*, 3:168–173.