DAILY ESTIMATES OF SOIL EROSION AND RUNOFF IN IOWA

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Abstract
The largest water quality impairment in the Midwest US is farmland sediment. Yet few understand the severity or impact of erosion. The project objective is to estimate, at the township level (~10 X 10 km), daily soil erosion and runoff for Iowa and to deliver a map to the public showing daily soil erosion estimates. WEPP, a daily simulation model, is used to compute soil erosion and surface runoff. WEPP uses break point precipitation obtained by Doppler radar and other weather data from an Iowa Weather network. The National Resources Inventory data points provide soils, topography, cropping and soil management information required for running WEPP. Daily estimates illustrate a high level of spatial variability in runoff and erosion related to topography, rainfall characteristics, soils and crop management practices.

Additional Keywords: radar, WEPP, NRI

Introduction
Sediment from eroded cropland is Iowa's biggest water quality problem. Soil erosion affects everyone in the state. Erosion reduces soil productivity (Craft *et al.,* 1992; Pierce *et al.,* 1984), and causes a range of downstream impacts. Estimates for off-site (related to downstream sediment damage) and on-site (associated with direct effects on eroded land) costs, in the U.S., range in the billions of dollars annually (USDA, 1987), with annual off-site and on-site costs estimated at $17 billion and $27 billion, respectively (Pimentel *et al.*, 1995).

Soil erosion is dependent on rainfall characteristics, soil type, topography, soil and crop management, and soil conservation practices (Hudson, 1995). Because these factors vary across the landscape, soil erosion losses are spatially variable, and often to a surprising degree. Localized soil erosion losses can be extreme, as experienced in north-east Iowa in 1999 (Ballew and Fischer, 1999). Localized heavy rainstorms are a relatively common occurrence in Iowa. Ideally, areas most prone to severe damage should be prioritized for erosion control measures, to minimize further damage and productivity losses.

Current erosion and runoff modelling is typically limited in spatial extent due to the use of field measurement for precipitation data. The use of Doppler radar significantly expands the possible areas over which the models can be applied as nearly the entire United States is covered with high quality radar data. The use of this data also allows us to build a high-resolution database of rainfall patterns. Limited research/observation suggests spatial rainfall patterns over fairly small areas (ie. county-size or smaller) may be both distinct and stable (Keuhnast *et al.*, 1975; Causey, 1953). Features or areas associated with higher rainfall may also be more prone to intense rainstorms (Keuhnast *et al*., 1975). Most importantly, those areas more prone to erosion losses and in need of greater soil conservation measures could be precisely identified, allowing better targeting of priority areas for enhanced soil conservation measures that cannot currently be identified with existing soil erosion prediction technology.

Materials and Methods
A system capable of making and presenting daily estimates of soil erosion and runoff contained a number of elements. These elements included: erosion model selection; soil, slope, and management database development; climate database development; statewide application at township scale; map product development; and communication network development.

Erosion model selection

WEPP is a process-based daily simulation computer program for predicting soil erosion by water from virtually any land - rural, urban, rangeland, cropland, construction site, housing development etc. (Flanagan and Nearing, 1995). It is capable of making daily erosion predictions across a wide range of land management systems.

WEPP requires input data files to generate daily estimates of soil loss and water runoff from hillslope profiles. The four basic input files for model simulations are climate, slope, soil, and management. Slope, soil and management files can be developed based on the NRI data available for each NRI point in Iowa. Doppler radar and the Iowa Environmental Mesonet can provide the needed climate data to make daily erosion estimates using WEPP. With this data, WEPP can be operated on a daily basis, developing runoff and erosion maps at various scales everyday.

Soil, slope, and management database development

The NRI is the best source of publicly available soil, slope, and cropping/management input data required for this project. The NRI is a longitudinal survey of all non-federal land in the U.S. and has been conducted every 5 years since 1982 by the Natural Resources Conservation Service of the U.S. Department of Agriculture in cooperation with the Statistical Laboratory at Iowa State University. The NRI collects information on land cover and use, soil erosion, prime farmland soils, wetlands, habitat diversity, selected conservation practices, and related resource attributes. The 1997 NRI contains information on 34,120 points in Iowa, of which 17850 could be used for this project. Details on the NRI survey design and objectives can be found in Nusser and Goebel (1997). NRI data such as soil, slope, and management is only publicly available at the county level, but a confidentiality agreement was entered into allowing the project access to township level (~10 km x ~10 km) data. Some data assumptions, detailed below, were necessary to make use of this data.

The NRI gives the soil name, which enables determination of basic soil properties such as soil texture, soil organic matter, and cation exchange capacity through the use of the SOILS5 database (USDA, 2000). These basic properties allow determination of rill and interrill erodibility, critical shear, and baseline hydraulic conductivity using the equations presented in Alberts *et al.* (1995). An albedo of 0.23 and an initial saturation of 75% is used for all soils files. The WEPP slope file uses the slope and slope length given in the NRI. The slope is assumed to be a uniform slope.

Data on crops being grown were only given for the 4 years from 1994 to 1997, so a 4-year rotation was assumed and extrapolated to the current year. This means that the crops in year 2004 are the same as those in 2000 and 1996. The four-year NRI period gives a total of 71,400 crop/plant years over this 4-year period. For corn and soybeans the state was split into its 9 traditional climate zones (dividing the state into thirds north-south and east-west). This enables different corn and soybean plant parameters such as yield for each climate zone, an option that was not used on the other plant species due to their small areal coverage and the desire for a relatively small management file database. Statewide corn planting is set at April 30, soybeans at May 5.

The WEPP plant "grass" is used to represent grass, hay, or pasture. Pasture areas are grazed at 1 cow per acre from May 1 to October 15. Hay is cut 3 times per year with typical Iowa yields. Wheat, barley, and oats are spring planted small grains in Iowa, with wheat and barley practically non-existent (<0.10% of plant years) and oats contributing a very small amount (1.3% of plant years). These 3 crops are all represented as the same plant in WEPP with spring wheat being planted later than oats or barley.

Land management methods are not given in the NRI, however the C value used in the Universal Soil Loss Equation (Wischmeier and Smith 1978) is given. It can be computed as

$$C=A/(RKLSP) \quad (1)$$

Where A is soil erosion, R is the USLE rainfall factor, K is a soil erodibility factor, LS is a length slope factor, and P is a conservation practice factor. K and P values are given in the NRI and LS can be computed from the topographic information. Usually, the mulch remaining in a field is a major and direct indicator of C values.

Six levels of tillage that left varying levels of mulch and the corresponding tillage tools that made up each level of mulch are given in Table 1. The order of the severity of tillage (in terms of residue burial) was moldboard plow>chisel plow>disk>field cultivator>planter. It was assumed that these 6 tillage levels encompassed the range that is used, and well represented the normal ways that these tillage tools are used.

Table 1. C Values for various mulch levels and crops with different tillage options

Mulch Level	Soybeans	Corn	Corn Silage	Barley and Oats	Wheat	Sorghum
No-Till	0.02	0.02	0.03	0.02	.02	.02
Very High Mulch	0.08	0.03	0.11	0.04	.03	.03
High Mulch	0.19	0.08	0.14	0.08	.05	.06
Medium Mulch	0.30	0.13	0.23	0.16	.12	.12
Low Mulch	0.33	0.17	0.27	0.21	.18	.19
Fall Moldboard Plow	0.35	0.18	0.29	0.26	.23	.26
No till - No tillage except by planter						
Very High Mulch - Fall chisel plow, 1 spring field cultivate, plant						
High Mulch - Fall chisel plow, 1 spring disk, 1 field cultivate, plant						
Medium Mulch - Fall chisel plow, 2 spring disk, 1 field cultivate, plant						
Low Mulch - Fall moldboard plow, 1 field cultivate, plant						
Fall Moldboard Plow - Fall moldboard plow, 2 spring disk, 1 field cultivate, plant						

For each crop/plant, with the exception of grasses, trees and vegetables, C values are computed for that plant grown continuously with 6 levels of tillage, leaving various mulch levels (Table 1). For the various mulch levels, WEPP is used to compute an average annual soil loss for a “Unit Slope” (72.6 feet long at 9% slope) for a given soil of broad extent in Iowa, and for up-and-down hill tillage. The computed soil loss is divided by the USLE K value and the Rainfall factor (the LS factor is 1) to compute the C value for that particular crop/plant with that particular tillage. These values are shown in Table 1. All grass and trees are computed to have C values of 0.01.

For rotations, the rotations and mulch levels are chosen that would produce the best match to the C value given in the NRI. There were some limits as to what we could choose. Since there were always 4 crops/plants in the NRI, the tillage system for all 4 years was not allowed to vary by more than one mulch level up or down (see Table 1). For example, if the NRI had a C value of 0.19 for a corn-soybean-corn-oats rotation, the best fit might be medium mulch for corn and soybeans, and low mulch for oats, giving an average C value of slightly more than 0.19. It is difficult to separate corn from corn silage. If the NRI C value cannot reasonably be approximated with corn because corn C values were too low, then corn silage was attempted to see if improvements were made. If so, corn silage is used rather than corn. Corn silage is an important crop in Iowa, but of far less importance than corn for grain.

Climate database development

Two separate sources were used for WEPP weather input. The Iowa Environmental Mesonet, a network of meteorological observation stations recording wind speed, temperature and solar intensity throughout the state supplies the non-precipitation data. Spatial resolution of this data is limited to the 9 traditional climate zones (described above) because this data is already being distributed and because it is believed that greater spatial resolution of this data will have little impact on simulation accuracy.

The National Weather Service’s (NWS) nationwide network of WSR-88D radars (Crum *et al.* 1998), known as NEXRAD, gathers precipitation data in real time, covering the state of Iowa through stations in Davenport and Des Moines, Iowa; Minneapolis, Minnesota; Omaha, Nebraska; La Crosse, Wisconsin; and Sioux Falls, South Dakota. They survey the atmosphere around them every 6 minutes and are capable of providing basic data (Level II) with resolution of 1 degree in azimuth and one kilometer in range. This Level II data would be ideal for erosion simulation as erosion events are strongly impacted by short, intense rainfall periods often lasting five minutes or less. However computational demands, current NWS data distribution procedures, and budget constraints dictate the innovative combination of two currently available precipitation products; high quality National Centers for Environmental Prediction (NCEP) 1 hour data and NWS 15 minute Level III (degraded from Level II) NEXRAD data to obtain 15 minutes rainfall product in a 4×4 km^2 grid (which overlays the Hydrologic Rainfall Analysis Project (HRAP) projection grid (Fulton *et al.*, 1998; Reed and Maidment, 1999).

Our main radar rainfall input is NCEP Stage IV Multisensor Radar Product. This product is originally distributed as a data of national coverage with 1-hour time resolution, 4×4 km^2 space resolution and with 1 hour delay. NCEP product is derived from a radar reflectivity vs. rainfall rate (Z-R) relationship with quality control correction algorithms applied (Fulton *et al.*, 1997). This product is then merged with rain gauge measurements using mean field bias correction by the Kalman filter algorithm (Anagnostou *et al*., 1998). The merged radar–gauge product is then further processed separately by each River Forecast Center (RFC), often involving a significant degree of human interaction (Fulton *et al.*, 1998). Iowa is under the North Central and Central RFC. After decoding the data for each site, we apply quality control algorithms and construct 5-minutes reflectivity maps for each site. Next, we transform the maps to the HRAP coordinate system and merge to obtain reflectivity product for the entire state. After applying the commonly used NEXRAD Z-R relationship (Fulton *et al.*, 1998) we obtain the rainfall product for our area.

At this point we have 2 rainfall products of the same coverage and coordinate system. One of them (NCEP), consists of hourly accumulation information, while the time resolution of the other (NEXRAD Level III) is 15 minutes. Integrating the NEXRAD data files to 1-hour accumulation and comparing with the NCEP maps we observe significant differences between those two rainfall estimates. This discrepancy comes from the fact that NCEP data is multisensor, i.e. it is build out of radar data as well as from rain gauge data and the other data set is created using only the degraded radar information. Also, radar data used for the NCEP product was subject to several quality control procedures that cannot be applied to the NEXRAD Level III data due to their degraded quantization (only 8 effective levels of reflectivity.) Although the NEXRAD Level III rainfall product is of inferior quality compared to the NCEP product, it provides good qualitative information about 15-minutes rainfall distribution within the hour of the NCEP estimate. Thus, we distribute the 1-hour NCEP accumulation into four 15-minutes accumulations according to the 15-minutes NEXRAD Level III rainfall estimates for each HRAP grid cell. As a result, we obtain 15-minutes rainfall product with the same 1-hour accumulation as the NCEP product.

To better understand our precipitation product quality we performed a limited validation (Krajewski and Smith, 2003). For our comparisons we used the Iowa City Airport Piconet (Krajewski *et al*., 2003) and the AMSR-E rain gauge network. The piconet is a high density rain gauge network implemented in an approximately 2×2 km^2 area with 10 sites equipped with dual tipping bucket gauges (Krajewski *et al*., 1998). The AMSR-E network is a similar network of 25 sites spaced on approximately a 5×5 km^2 grid with dual tipping bucket platforms. Both networks are located approximately 80 km from the Davenport WSR-88D (KDVN) NEXRAD radar and over 150 km from the Des Moines WSR-88D (KDSM). At a monthly aggregation, the radar and raingauge have on average a 1:1 correlation with some scatter about the line.

Computation is carried out at the University of Iowa within two hours after midnight for the day that the data is valid. After data has been transferred to Iowa State University by FTP, breakpoint precipitation data is calculated. If total daily accumulation is less than 5 mm, only one breakpoint is created, reducing unnecessary processor usage. This breakpoint precipitation and climactic data is then added to the WEPP climactic database. Precipitation totals for an HRAP cell greater than 0 will trigger an insertion in the WEPP database signalling that the HRAP cell requires processing by WEPP. The daily rainfall totals per HRAP cell are then downloaded to the web server and displayed as in Figure 1.

State-wide application at the township scale

To successfully run a model of this complexity at tens of thousands of data points, significant software automation is needed. At 0:30 local time, a script executes to download the radar data via FTP. If the data has not been successfully transferred by 10:30, an email warning is generated and the script terminates.

Before the WEPP model can run, the non-precipitation data must be linked to the precipitation data by assigning the corresponding climactic zone non-precipitation data to the correct HRAP cells. After completion, a python script executes checking the WEPP database for HRAP cells that need to be processed (precipitation occurred). Runs continue until the WEPP database contains no more cells needing to be run. Because of the differing resolutions of input data, i.e. the 4 km x 4 km HRAP cells and the ~10 km x ~10 km townships containing management data, input data does not align perfectly. To overcome this problem each HRAP cell is assigned to the township that contained its centroid. This creates a problem correlating NRI points with HRAP climate information, so all possible HRAP cells in a township are run against all NRI locations in a township. All these runs are averaged for output.

After the previous python script executes, another python script will execute and search the WEPP output for erosion and runoff events for the previous day. When an event is found, it makes an entry in the WEPP database. After all the output is processed and entered into the database, an aggregation is done to the township level and this is uploaded to the web server. May 4, 2003, which is shown in the figures, had rainfall throughout the state and required runs for nearly every combination in the domain. Twelve hours of computer runtime were required for this run. This time is primarily input/output limited and a new hard disk system should significantly speed operations.

Results and Discussion

Considerable work remains in reporting the results of this project. The two areas with significant work remaining are the development of map products and a communication network to disseminate the results of this work.

Current and future map products

There are currently 3 types of map products distributed to the website: estimated daily and monthly rainfall with a 4 km x 4 km HRAP grid size (daily cumulative given in Figure 1), average runoff in each township (Figure 2), and the average soil loss in each township (Figure 3). We are also producing some variations of these maps - ie. maximum runoff and maximum estimated soil loss in each township. Currently we are developing a suite of maps that will display soil erosion and the components affecting soil erosion, such as rainfall, antecedent soil moisture, land cover, slope, and soil type. It is important for the public to understand that many factors affect erosion and understand that high spatial variability of soil loss is to be expected. This information is important for financial resource targeting to solve most critical erosion and runoff problems.

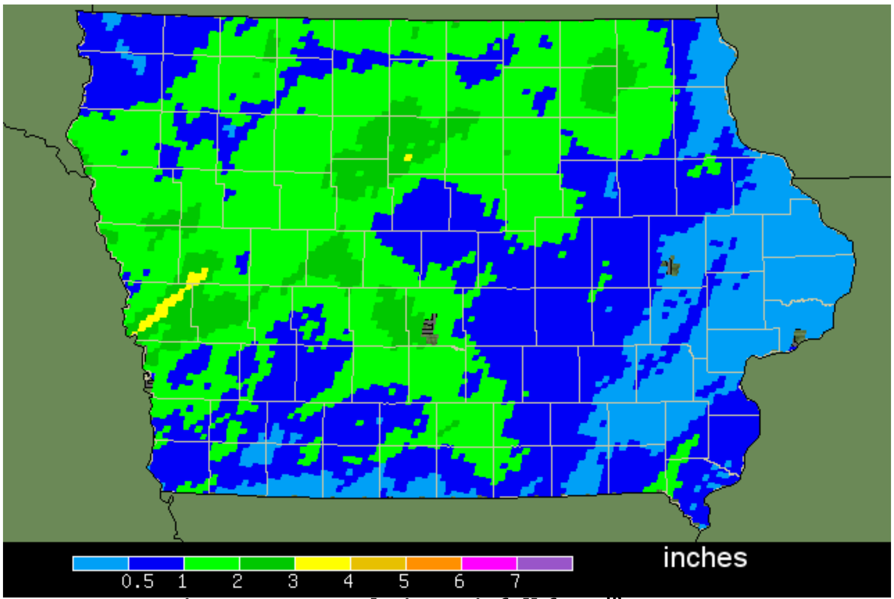

Figure 1. Cumulative rainfall for 4th May 2003

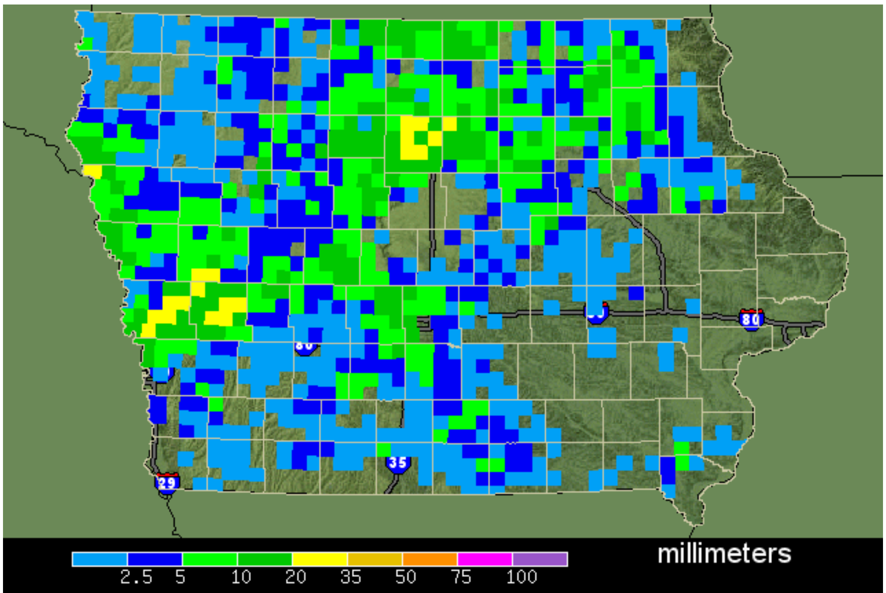

Figure 2. Average runoff for 4th May, 2003

Map access

The resulting rainfall, erosion, and runoff maps are hosted on a public server. The website to access our data is http://wepp.mesonet.agron.iastate.edu

Conclusions

This research project effectively demonstrates the valuable results that can come from integrating a number of different datasets, only one of which was specifically designed for this project. There are, however, some limitations using data that is not specifically designed for a project. The use of NRI data limits the spatial and temporal resolution of our data and limits our ability to field verify our results. First, we want to develop a land management dataset using remotely sensed data at the field level. This would allow us to obtain results at a finer resolution, would allow us to field verify our results, and would allow us to obtain a better confidence interval for the estimates. Second, we want to develop a finer spatial and temporal resolution precipitation map, this is anticipated within one to two years using Level II NEXRAD data and faster computers. These two new inputs would allow erosion modelling on a field scale level based on management and a near field scale level based on weather data, which is the resolution for which the WEPP model was designed.

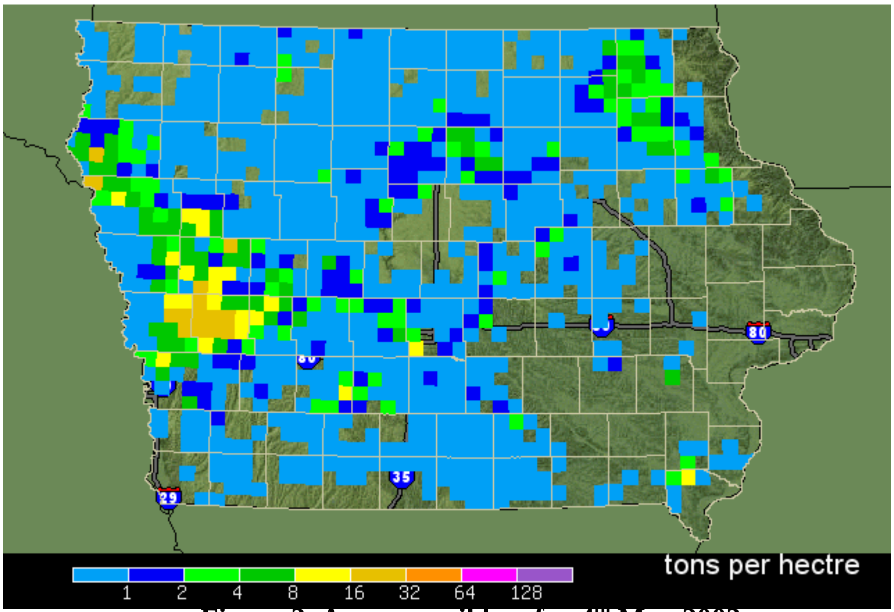

Figure 3. Average soil loss for 4th May 2003

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