SITE-SPECIFIC DECISION-MAKING BASED ON RTK GPS SURVEY AND SIX ALTERNATIVE ELEVATION DATA SOURCES: SOIL EROSION PREDICTIONS

C. S. Renschler, D. C. Flanagan

ABSTRACT. *Precision farming equipment based on Global Positioning Systems (GPS) enables landowners to gather spatially distributed topographic data in real-time kinematic (RTK) mode, which has the potential to be used in addition to or as substitute for commonly available topographic data sources (e.g., U.S. Geological Survey (USGS) topographic contour lines and/or digital elevation models). The latter are considered insufficiently accurate in their topographical representation of watershed boundaries, slopes, and upslope contributing areas to be able to meaningfully apply detailed process-based soil erosion assessment tools at the field scale. In this second of two articles discussing the usefulness of the available data sets from a decision-maker's perspective, the same comprehensive accuracy tests that were used for these topographical parameters are applied to the spatially distributed soil erosion assessment results simulated by the Water Erosion Prediction Project (WEPP) model supported by Geographic Information Systems (GIS). The impact of the accuracy of six alternative topographical data sources on predicting soil erosion rates using WEPP is compared to on-site soil erosion predictions using elevation measurements from a survey-grade RTK GPS with centimeter accuracy. Results show that the more precise topographic measurements with a photogrammetric survey or any differential GPS units yield more precise on-site soil loss predictions for individual raster cells (0.01 ha) and hillslope areas of interest (0.5 ha). However, the best WEPP predictions for average annual off-site runoff (–18.3% error) and sediment yield (–2.7% error) from upslope contributing areas of about 4 ha within the 30 ha watershed were achieved using the USGS 10 ft contours. These results demonstrate that in this case, the runoff and sediment yield predictions using DEMs based on the commonly available contour lines can be even better than those from the more precise and costly topographic data sets. The contours also allowed successful application of the WEPP model to identify all 11 hillslope areas of interest (0.5 ha) with soil loss (10) or deposition (1) problems that were initially mapped in the field as larger rills and sedimentation areas, respectively.*

Keywords. *Accuracy, Decision-making, Erosion, Global positioning systems, Modeling, Topography, Watershed, WEPP.*

One of the most fundamental requirements for modeling landscape topography and soil erosion processes is the accurate representation of topography. To be useful for decision-makers, soil erosion models must have simple data requirements, must consider spatial and temporal variability in hydrological and soil erosion processes, and must be applicable to a variety of regions with minimum calibration (Renschler and Harbor, 2002). Over the past few years, more land users have been able to gather more accurate site-specific information about soil, vegetation, and plant residue characteristics from precision farming techniques based on more accurate Global Positioning Systems (GPS) at a reasonable cost. Land users, such as precision farmers, utilize these spatially distributed GPS data mainly for applications such as yield monitoring and precision application of nutrient and pest management. Besides these main purposes of gathering soil and plant parameters for site-specific agricultural management support at a unique location (x and y), elevation data (z) are also recorded by a GPS data logger. However, these elevation data, which are continuously gathered on a moving vehicle in real-time kinematic (RTK) mode, have hardly been used in the past for best management practices (BMPs) in soil and water conservation.

As Clark and Lee (1998) and Wilson et al. (1998) demonstrated in different research projects, GPS elevation data have the potential to be used for topographic mapping as well as for topographic analysis such as flowpath, channel, and watershed delineation. Alternatively, geo-referenced commonly available data sources such as topographical maps, soil surveys, and rectified aerial photographs (orthophotos) are all readily available. These data sources depend on field surveys at a certain point of time in the past and are designed to be useful at the 1:24,000 scale of U.S. Geological Survey topographical maps (USGS, 2006). These data sets are usually available nationwide and are provided free of charge by U.S. federal agencies (USGS, 2006; NRCS, 2006). Renschler et

Submitted for review in June 2006 as manuscript number SW 6528; approved for publication by the Soil & Water Division of ASABE in February 2008.

The use of trade names does not imply endorsement by the University at Buffalo (SUNY) or the USDA Agricultural Research Service.

The authors are **Chris S. Renschler,** Associate Professor, Department of Geography, National Center for Geographic Information and Analysis (NCGIA), University at Buffalo – The State University of New York, Buffalo, New York; and **Dennis C. Flanagan, ASABE Member Engineer,** Agricultural Engineer, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, Indiana. **Corresponding author:** Chris S. Renschler, Department of Geography, National Center for Geographic Information and Analysis (NCGIA), University at Buffalo – The State University of New York, 116 Wilkeson Quad, Buffalo, NY 14261; phone: 716-645-2722, ext. 23; fax: 716-645-2329; e-mail: rensch@buffalo.edu.

  ISSN 0001–2351

al. (2002a) analyzed the impact of the accuracy of six alternative topographical data sources on watershed topography and delineation in comparison to GPS measurements of a survey-grade GPS with centimeter accuracy. The results demonstrated that the most accurate and expensive alternatives were most useful for determining elevation and slopes in the flow direction, while there was not much difference between alternative topographic data sources in obtaining upslope drainage areas and delineation of the channel network and watershed boundary. User-friendly soil erosion assessment tools such as the Geospatial Interface for the Water Erosion Prediction Project (GeoWEPP) model are capable of using these sources of information and precision farming data sets to support the decision-making process for sustainable land use and soil and water conservation (Renschler, 2003).

The Water Erosion Prediction Project (WEPP; Flanagan and Nearing, 1995; Flanagan et al., 2001) model is a physically based, continuous simulation, erosion prediction tool for use on personal computers. It was developed through a joint effort of several federal agencies, including the USDA Agricultural Research Service (ARS), USDA Natural Resources Conservation Service (NRCS), USDA Forest Service (FS), and the USDI Bureau of Land Management (BLM), to replace more empirically based technologies such as the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) and RUSLE (Revised USLE; Renard et al., 1997). WEPP simulates the important physical processes related to erosion by water, including infiltration, runoff, detachment by rainfall, detachment by flow, sediment transport, sediment deposition, plant growth, and residue decomposition and management. The model is applicable to small watersheds (<250 ha) as well as to individual hillslope profiles (Flanagan et al., 2001).

In order to assist users with application of WEPP to small watersheds, interfaces between the model and Geographic Information Systems (GIS) were created that allow use of spatial digital elevation data for an area to be automatically processed into hillslope profile and channel input slope files (Cochrane and Flanagan, 2003), ultimately culminating in two sets of WEPP-GIS tools. The first was the GeoWEPP software (Renschler et al., 2002b; Renschler, 2003), which is an ArcView 3.2 extension soon to migrate to be an ArcGIS 9 (ESRI, 2006) extension. The second is a web-based WEPP-GIS interface (Flanagan et al., 2004a, 2004b) that uses the open-source Mapserver environment (UNM, 2006). All of these WEPP interfaces rely on the TOPAZ (Topographic Parameterization; Garbrecht and Martz, 1997) digital landscape analysis tool to delineate channels, watersheds, and sub-basins.

Objectives

The main objective of this article is to analyze the impact of the accuracy of six alternative topographical data sources on predicting runoff and soil erosion rates using the WEPP model (Flanagan and Nearing, 1995). To test the applicability and accuracy of six alternative methods, seven data sets were obtained for a topographic analysis, and all results were compared to the most recently gathered and most precise available data set: a highly accurate survey-grade GPS unit in RTK mode. Instead of gathering data in optimal conditions (e.g., a sufficient number and optimum distribution of GPS satellites in view), all the GPS data sets were collected at the same time with a typical contour-parallel management pattern and speed within a three-day period without any extra GPS measurements along the fields, e.g., fences, ditches, or terraces. This allows comparing equipment performance under realistic farming conditions and an assessment of their fit for use in topographic analysis and watershed delineation (for a photo of the GPS platform on an all-terrain vehicle (ATV), refer to Renschler et al., 2002a).

While the previous companion article analyzed the effect of alternative data gathering methods solely on watershed topography and delineation (Renschler et al., 2002a), this article evaluates the accuracy of each of the alternatives in obtaining elevation data and using their topographic parameters for soil erosion prediction at three decision-maker's scales of interest. The areas that decision-makers would be interested in assessing, i.e., Total Maximum Daily Loads (TMDLs) of small watersheds and best management practices (BMPs) along channels, are here referred to as "contributing areas of interest." In this study, the latter category would include the entire watershed scale (30 ha; see W-2 in fig. 1) and its channel contributing hillslope areas (>4 ha; approximately similar size as neighboring W-11 in fig. 1). At a more detailed scale, a decision-maker may be interested in site-specific locations to mitigate selected areas of concern, or "hillslope areas of interest" (0.5 ha), for the optimization of BMP locations. The most detailed resolution possible, but hardly considered by a decision-maker for making any location-based land cover change, would be the single-raster cells, or "hillslope locations of interest" (0.01 ha). Out of practical reasons for decision-makers, the six alternative topographic data methods were paired in three groups of similar applicability and costs:

- Alternative A: two methods that are (1) nationwide applicable and (2) include additional costs.
- Alternative B: two methods that are (1) local/regional dependent and (2) include additional costs.
- Alternative C: two methods that are (1) nationwide applicable and (2) include no costs.

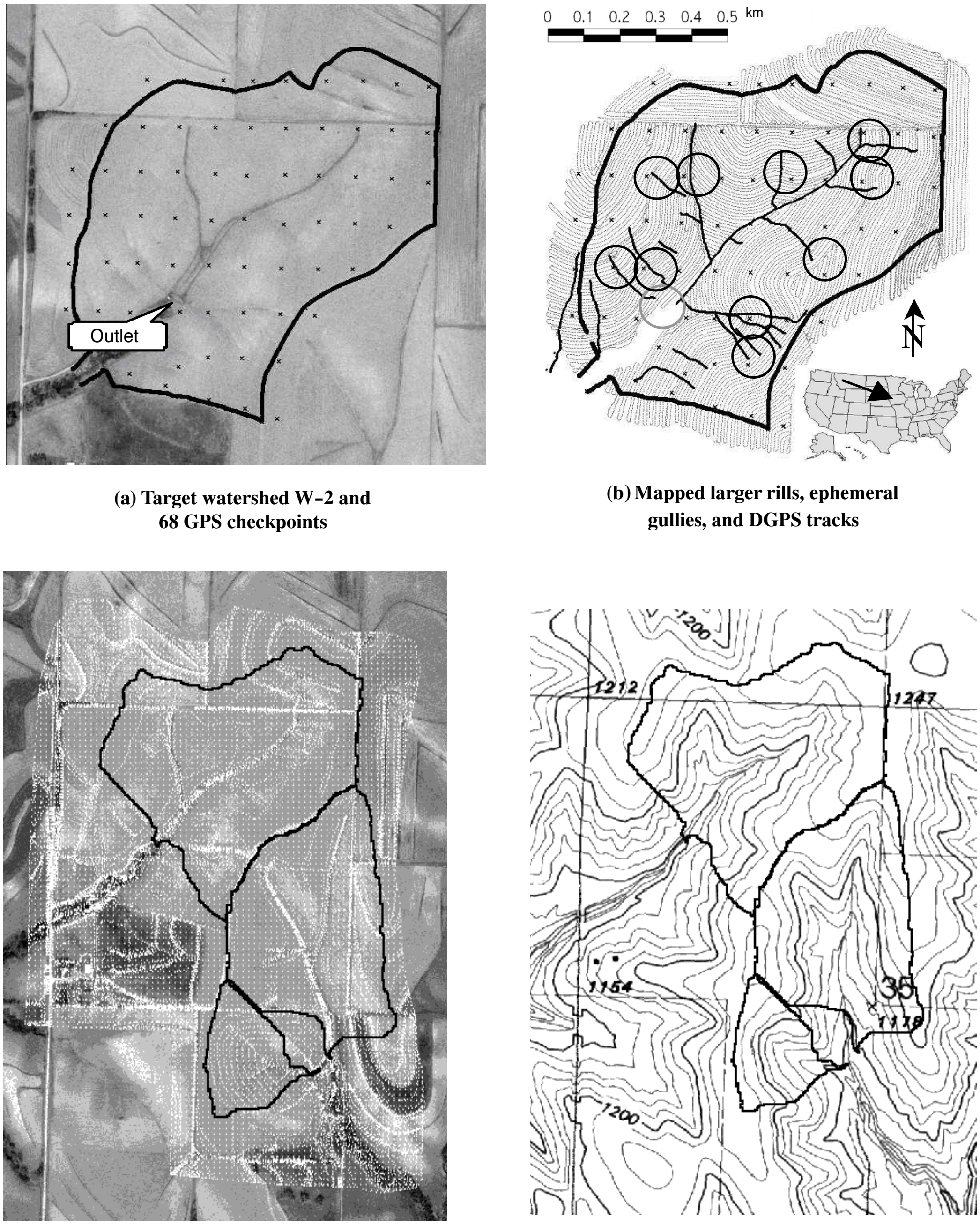
Materials

Test Site Location

The test site for this accuracy assessment study was a 30 ha watershed (W-2) in continuous corn with a conventional tillage rotation at the Deep Loess Research Station in Treynor, Iowa (Kramer et al., 1999) (fig. 1). This experimental watershed enables not only the accuracy tests of topographical characteristics based on the various available terrain data sets, but also the effects of these different topographical data sets on the accuracy of surface runoff and sediment yield predictions. The observed runoff and sediment discharges at the outlet of this fairly large, entirely agricultural-use watershed W-2 and its smaller neighboring W-11 (an area that would represent a channel contributing hillslope area for W-2) provide the opportunity to compare these measurements with the soil erosion model predictions (Renschler and Harbor, 2002; Cochrane and Flanagan, 1999).

DGPS Surveys

The pseudo-range GPS units commonly used in precision farming provide on-the-go elevation data, although at a much lower accuracy. Like carrier-phase receivers, they use the



(a) Target watershed W-2 and 68 GPS checkpoints

(b) Mapped larger rills, ephemeral gullies, and DGPS tracks

(c) Triangular irregular network (TIN) points

(d) USGS 10 ft contour lines in topographic map

Figure 1. Field surveys of target watershed W-2 at Treynor, Iowa, with (a) GPS checkpoints; (b) GPS locations of large rills, ephemeral gullies, and field management tracks; (c) photogrammetric derived TIN, and (d) USGS topographical map with watershed boundaries for watersheds W-2 (northernmost), W-1, and W-11 (southernmost). In figure 1a, the delineation of the target watershed was performed by visual interpretation and was intentionally beyond the actual watershed to gather additional GPS measurements surrounding the watershed to avoid interpolation boundary effects. Due to accessibility, no GPS measurements were taken below the gully headcut and discharge measurement station at the outlet of watershed W-2. In figure 1b, circles indicate hillslope areas of interest (0.5 ha) with accelerated soil loss (black circles) and deposition (gray circle).

differential GPS (DGPS) technique (Tyler et al., 1997) to improve accuracy beyond the level that can be obtained from satellite signals alone. Most pseudo-range DGPS (hereafter referred to as DGPS) receivers used in U.S. agriculture today utilize one of two types of broadcast differential correction signals (U.S. Coast Guard correction beacon and wide-area DGPS correction network; for details, see Renschler et al., 2002a). Two DGPS units were mounted on each of the ATVs, with four separate antennas and data loggers (Renschler et al., 2002a). The coordinated DGPS RTK measurements took place by operating both ATVs with a typical management speed (10 km h^{-1}) and a 5 to 10 m distance between vehicles as they traversed all management strips in contour-parallel (~4 m spacing) in the 30 ha watershed W-2. In addition to the DGPS RTK data sets, the watershed boundary, lines of preferred surface flow (such as larger rills, ephemeral gullies, and defined channels), and a more or less regular raster of 68 checkpoints were mapped for accuracy testing of all available elevation data sets to represent these watershed characteristics at these locations (Renschler et al., 2002a).

The most accurate, survey-grade GPS systems that are commercially available are alleged to be as accurate as conventional topographic surveys when operated in a stop-and-go data collection mode (Clark and Lee, 1998). The skill level required to successfully complete an RTK GPS survey is high. Therefore, it was desired to investigate other DGPS units and software packages designed such that non-surveyors are able to gather, process, and analyze spatially distributed information with a minimum of additional expertise.

In this study, the four different DGPS data sets were collected from four DGPS receiver setups mounted on two ATVs during a three-day period just before seedbed preparations on 28 to 30 March 2000 (Renschler et al., 2002a). The DGPS systems mounted on the vehicles included one survey-grade RTK DGPS using a local base station for correction (the most accurate GPS unit, referred to as RTK GPS), one survey-grade DGPS operating in a lower-accuracy mode with Coast Guard beacon correction (DGPS (B)), and two systems commonly used for precision farming applications: one a virtual base station (Ag-DGPS (V)) and one with the Coast Guard correction (Ag-DGPS (B)).

Alternative A

As an alternative to the expensive, survey-grade RTK GPS system, alternative A provided the next most accurate terrain information. A low-altitude photogrammetric survey was conducted by a contractor for the test site in 1997 and consisted of points in a triangular irregular network (TIN). Alternative A also included a precision agriculture DGPS (Ag-DGPS) RTK unit with a nationwide available correction signal from a virtual base station provider (Omnistar).

Alternative B

Alternative B was either a single survey-grade GPS or a less expensive precision agriculture DGPS unit. Both units obtained a correction signal from the closest U.S. Coast Guard/Corps of Engineers beacon station (about 25 km to Omaha, Nebraska). Much of the crop-producing area of the U.S. is within range of one or more stations in this correction network; however, the accuracy of the correction degrades with increasing distance from the correction station. Thus, alternative B would only be of localized application, usable within the effective range of Coast Guard beacon station corrections.

Alternative C

Alternative C, the no-cost option, used either contour lines from topographic maps or a 30 m raster DEM, both provided by the U.S. Geological Survey (USGS, 2006). The U.S. National Map Accuracy Standards allow 10 ft contour lines on a topographic map at the 1:24,000 scale that have no more than 10% of randomly tested elevation points with errors of more than 1.5 times the distance between contours (BoB, 1947). The 30 m Level 1 DEM (9 points per ha) is the less accurate of the two commonly available DEM sources. For more details about these three alternatives, see Renschler et al. (2002a).

Methods

Topographic Data Processing

The available topographic data sets were originally stored as line (contour lines only) and point measurements (TIN and all other GPS data sets). The 30 m raster DEM was simply converted to a 10 m DEM (Arc command RESAMPLE), while all other data sets in line and point format were converted to a 10 m raster through an interpolation procedure specifically designed for terrain applications (Arc command TOPOGRID) in the Geographical Information System (GIS) ArcGIS (ESRI, 2006). The topographic parameters elevation, upslope drainage area, and slope in the flow direction were investigated. In this study, the commonly available TOPAZ software (Garbrecht and Martz, 1997) was used for deriving these parameters as well as the watershed boundary delineation and flowpaths draining into channels. DEM pixels with a contributing area of 4 ha and larger were marked as potential channel cells for each of the data sources. The dataset-delineated drainage patterns came closest to the field survey mapping of gullies and defined channels when a critical source area (CSA) of 4 ha was chosen for delineating channels in the watershed. Renschler et al. (2002c) analyzed the impact of raster sizes ranging from 4 to 30 m on watershed area and other topographic parameters for this particular interpolation algorithm. The analysis revealed that the 10 m resolution provided the best support for interpolating the DEMs for the Treynor experimental watersheds (e.g., an interpolation of smaller grid size would require additional information between contours or TIN points).

WEPP Model Input

As in previous WEPP watershed simulation studies at Treynor, Iowa (Cochrane and Flanagan, 1999; Renschler and Harbor, 2002), the soil erosion assessment with WEPP (version 2002.7) in this study was applied to the experimental watershed W-2. The WEPP model required daily observed climate records from 1985-1990 to simulate a continuous corn rotation under conventional tillage. The soil parameters were prepared to represent the conditions of a silt loam soil series (Marshall-Monona-Ida-Napier) developed on deep loess (Karlen et al., 1999; Kramer et al., 1999). The Geospatial Interface for WEPP (GeoWEPP) currently offers two methods to predict surface runoff and sediment yields at two different scales (Renschler et al., 2002b; Renschler, 2003): the watershed method and the flowpath method. While the watershed method enables the simulation of small watersheds with representative hillslopes for contributing areas, the flowpath method allows assessing the soil erosion and deposition pattern in landscapes (Renschler, 2003). The application of the flowpath method has the advantage of predicting spatially distributed erosion patterns within the watershed. This method creates soil erosion maps by simulating all possible flowpaths contributing to a channel independently and weighting the soil loss and deposition along each flowpath by its contributing area and flowpath length (Cochrane and Flanagan, 2003). In contrast to the flowpath method and its results for the hillslope areas, the watershed method considers channel processes, routing the runoff and sediment to the watershed outlet. The accuracy of the elevation data as well as their derivatives such as slope, upslope drainage area, channel network, and watershed boundary were evaluated by comparing them with the field survey of these features (Renschler et al., 2002a).

Accuracy Assessment

The accuracy tests were performed on the basis of average annual event-based runoff for the watershed outlet and average annual sediment yields into channels (watershed method) and soil loss/deposition pattern on hillslopes (flowpath method). A total of three different spatial scales were selected to be representative for various decision-making procedures: "contributing areas of interest" that include channel contributing hillslope areas (>4 ha) and the entire watershed scale (30 ha), selected areas of concern or "hillslope areas of interest" (0.5 ha), and single raster cells or "hillslope locations of interest" (0.01 ha). These three scales represent areas that are relevant to on- and off-site assessment in soil and water conservation. While it is highly unlikely that a precision farmer would consider changing the land use for a single hillslope location of interest (10 × 10 m) based on a high soil loss prediction, the hillslope areas of interest (7 × 7 raster cells) are sufficiently large to be considered for either economic or soil and water conservation reasons.

High soil loss regions predicted by WEPP do not necessarily indicate anything about the presence of ephemeral gullies, since the WEPP hillslope simulations conducted using the flowpath method only compute interrill and rill detachment or deposition. However, the observations of larger rills and/or ephemeral gullies in the field give an indication of apparent soil erosion problem hot spots. These areas are usually where concentrated flow may lead to increased soil loss. In order for WEPP to simulate ephemeral gully erosion accurately, these ephemeral gullies have to be delineated as channels in the WEPP model parameter setup. However, the mapped larger rills and/or ephemeral gullies in the watershed W-2 were not permanent features and were therefore not identified as channels for the average annual soil loss predictions with WEPP.

In addition to the visual comparisons, three quantitative tests were performed to compare average annual soil loss and deposition based on each of the alternatives with the predictions from the most accurate data obtained by the survey-grade RTK GPS measurements.

Comparisons of Hillslope Locations of Interest (Single Raster Cells)

Instead of using all the survey-grade GPS RTK data in the less accurate kinematic mode, additional GPS data were collected with the same system at the highest accuracy level (non-kinematic mode). At 68 checkpoints that were distributed as a more or less regular lattice over the watershed area (figs. 1a and b), individual readings were averaged at the same location (one reading per second over at least 30 s). From these 68 checkpoints, 33 checkpoints (or hillslope locations of interest) were within the common (overlapping) area of all watershed areas delineated by the seven data sets. For these 33 locations, averages and standard deviations (SD) of the 10 m raster data were determined. To compare an alternative data set with the most accurate data set, the coefficient of determination (CD; r^2), root mean square error (RMSE), and model efficiency (ME) were used as accuracy measures.

The RMSE by definition is given by:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}} \tag{1}$$

where n is the number of observations, P is the "representative" or predicted model value at a given point i (e.g., elevation from less accurate equipment), and O is the "true" or observed value at the same point i (e.g., elevation from more accurate survey-grade RTK GPS).

The ME method (Nash and Sutcliffe, 1970) is usually used to gauge the performance of a series of model results in comparison to observed values:

$$\text{ME} = 1 - \frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \tag{2}$$

where $\overline{O}$ is the mean of all observed values.

ME can range from −∞ to 1, and the closer the value is to 1, the better the model representation. Negative ME values indicate that the fit is poor and unacceptable (in fact, the average of all observations would be a better predictor).

In addition to the 33 checkpoints at selected locations, a pixel-to-pixel comparison between the 10 m raster data layers was calculated and mapped as a continuous layer. This allowed evaluating the difference between alternative methods and the best available data (RTK elevations) within the common (overlapping) watershed areas. The absolute error (AE) is the difference between the "true" or observed value (O) and the "representative" or predicted model value (P) for a value (e.g., elevation) at a given pixel. This test was chosen to show the relative accuracy of all other data sets to the two most accurate data sets (RTK GPS and alternative A TIN), which were expected to have the least AE due to their vertical accuracy (table 1).

Comparison of Hillslope Areas of Interest (Pixel Neighborhoods)

In contrast to the one-dimensional approach of comparing a series of checkpoints and the two-dimensional approach of a pixel-to-pixel comparison, a new filter was developed to evaluate the spatially distributed RMSE and ME for the central pixel within an $n \times m$ pixel rectangular area. The root mean square error filter value (RMSEFV) is derived as:

Table 1. Topographic data sources and vertical accuracies.

Method (applicability)	Data Set	Data Type (correction signal)	Equipment and Method Used	Vertical Accuracy	Points (ha^{-1})
Most accurate	RTK GPS	Survey-grade GPS (2nd unit as base station)	Ashtech Z-Surveyor (two units) RTK	~2-6 cm	~900
Alternative A	TIN	Triangular irregular network	Aerial photogrammetry (1997)	~1 m	~90
	Ag-DGPS (V)	Precision Ag-GPS (virtual base)	Trimble AgGPS124	~2 m	~900
Alternative B	DGPS (B)	Survey-grade-GPS (beacon base)	Trimble Pathfinder Pro XRS	~2 m	~900
	Ag-DGPS (B)	Precision Ag-GPS (beacon base)	Starlink Invicta 210A	~2 m	~900
Alternative C	10 ft DLG	10 ft contour lines, USGS	Aerial photogrammetry (1952/1956)	~4.5 m	n.a. (lines)
	30 m DEM	30 m DEM raster, USGS	High-altitude photogrammetry (1970)	~7 m	~9 (lattice)

$$\text{RMSEFV}_{x,y} = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(P_{ij} - O_{ij}\right)^2}{n * m}} \quad (3)$$

where x and y are the coordinates of the central pixel of an ($n \times m$)-sized filter, n is the number of pixels in the x-direction, and m is the number of pixels in the y-direction.

The filter to derive the model efficiency filter value (MEFV) can be described mathematically as:

$$\text{MEFV}_{x,y} = 1 - \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(P_{ij} - O_{ij}\right)^2}{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(O_{ij} - \bar{O}_{nm}\right)^2} \quad (4)$$

where parameters x, y, n, m, P, i, and O are defined as in the RMSEFV, and $\bar{O}$ is the mean of all observed values of the ($n \times m$)-sized filter.

RMSEFV and MEFV were applied as filters with $n = 7$ by $m = 7$ pixels to ensure a sufficiently high number of samples ($7 \times 7 = 49$ samples). The practical reason to apply this filter was to analyze the spatial distribution of more and less accurate areas. Analogous to the approach of test limits described for the pixel-to-pixel comparison, the filters were applied to compare the different alternatives. Note that alternative B had an area with missing values for the Ag-DGPS (B), which was thus masked and therefore not included in any spatial analysis of alternative B.

Results and Discussion

Contributing Areas of Interest (>4 to 30 ha)

The outline of the watershed boundary based on the location of the watershed outlet (as set on the delineated channel closest to the existing discharge measurement station; fig. 2) indicates that all data sets except the 30 m DEM data match more or less the outlined watershed boundary mapped in the field. A quantitative analysis of the total watershed area demonstrates the best fit of the derived watersheds based on the most accurate RTK GPS (30.1 ha; 0.3% error), TIN (30.4 ha; 1.3% error), and freely available DLG 10 ft contour line data set (29.2 ha; –2.6% error). The delineation of the DEM pixels with a contributing area of at least 4 ha indicates potential channel cells for each of the data sources (fig. 2). The drainage patterns came closest to the field survey mapping of gullies and defined channels when a critical source area (CSA) of 4 ha was chosen for delineating channels in the W-2 watershed. A minimum source channel length (MSCL) of 30 m was set very low to delineate, as much as possible, potentially preferred pathways to channels that have a CSA larger than 4 ha. The drainage patterns of the RTK GPS, the TIN, and the DLG data sets showed the best visual agreement with the mapped gullies and channels. Due to uncertainties in the central portion of the watershed (possibly caused by the shadow effect of the hidden beacon corrections), the two other DGPS data sets have areas with parallel flow rather than a single channel outline. The 30 m DEM drainage pattern and watershed boundary differ greatly from the observed features in the watershed.

WEPP simulation results of the watershed method for the W-2 and W-11 watershed outlet demonstrate that the average annual surface runoff over the six-year period was better predicted for the larger watershed W-2 (table 2). Even though the

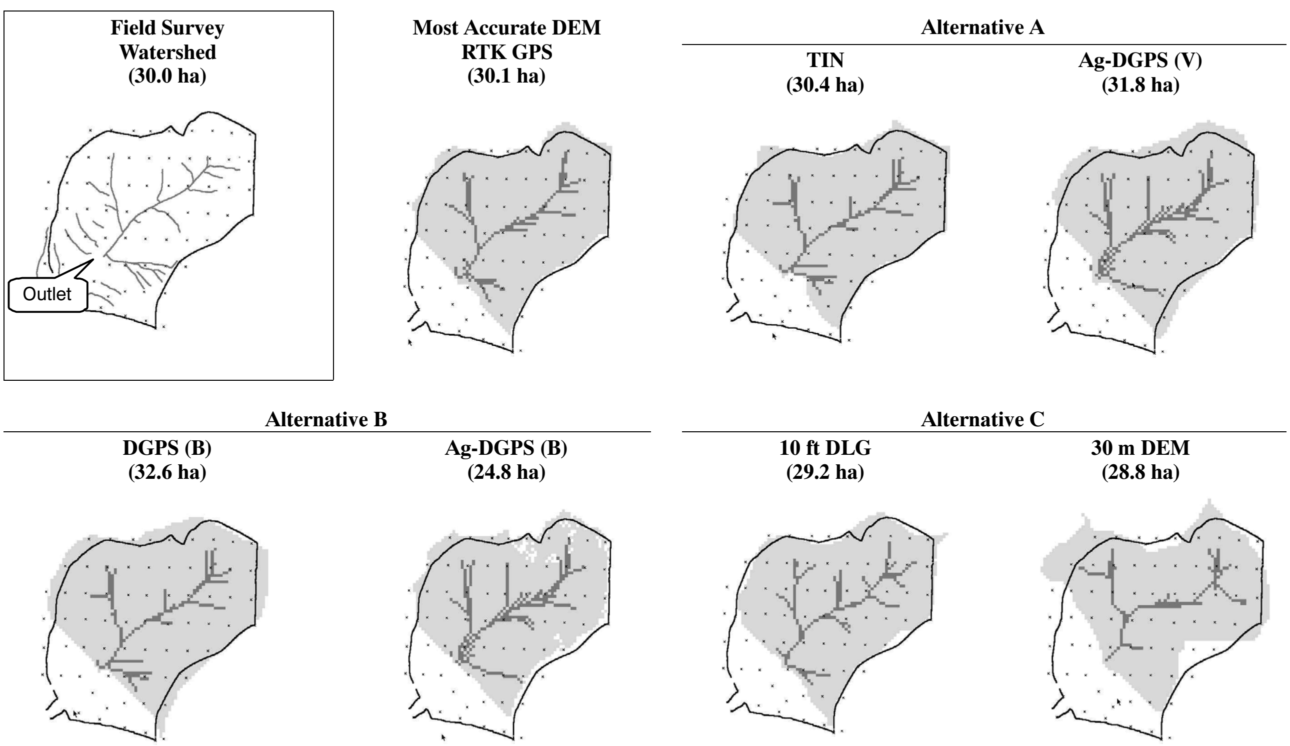


Figure 2. Comparison of observed larger rills and ephemeral gullies with DEM delineated channels and watershed boundary. Note that delineated channels include also preferred flow lines with a contributing area >0.4 ha.

Table 2. Observed and simulated watershed size, average annual runoff, and sediment yields for the watershed method (W-2 and W-11) and flowpath method (W-2) at Treynor, Iowa, based on different 10 m DEM data sets.[a]

Method	Data Set	Watershed Size		Average Annual Runoff		Average Annual Sediment Yield	
		ha	% error	mm year^{-1}	% error	t ha^{-1} year^{-1}	% error
Watershed method for W-2 (contributing area 30.0 ha)							
	Observed	30.0	n.a.	40.2	n.a.	6.6	n.a.
Alternative A	TIN	30.0	0.0	34.2	-14.9	10.1	53.0
Alternative C	10 ft DLG	29.1	-3.0	40.9	1.7	15.4	133.3
	30 m DEM	29.9	-0.3	41.4	3.0	15.2	130.3
Watershed method for W-11 (contributing area 5.9 ha; similar to contributing flowpath areas for W-2)							
	Observed	5.9	n.a.	50.7	n.a.	14.6	n.a.
Alternative A	TIN	5.7	-3.4	40.2	-20.7	16.8	15.1
Alternative C	10 ft DLG	6.3	6.8	41.1	-18.9	16.6	13.7
	30 m DEM	6.8	15.3	47.0	-7.3	19.9	36.3
Flowpath method for W-2 (contributing flowpath areas >4 ha; compared to observed data set for W-11)							
Most accurate	RTK GPS	30.1	0.3	35.4	-30.2	11.7	-19.9
Alternative A	TIN	30.4	1.3	34.7	-31.6	10.2	-30.1
	Ag-DGPS (V)	31.8	6.0	28.1	-44.6	5.0	-65.8
Alternative B	DGPS (B)	32.6	8.6	28.4	-44.0	7.2	-49.3
	Ag-DGPS (B)	24.8	-17.3	36.0	-29.0	10.9	-25.3
Alternative C	10 ft DLG	29.2	-2.6	41.4	-18.3	14.2	-2.7
	30 m DEM	28.8	-4.0	37.4	-26.2	9.7	-33.6

[a] Note that the observed watershed area for 30.0 ha watershed W-2 is compared with the total flowpath contributing area for W-2; the observed average annual runoff and sediment yields for 5.9 ha watershed W-11 are comparable to amounts expected to be contributed by flowpath contributing area into W-2 channels (data for comparison was taken from Renschler et al., 2002c, where alternatives in B were not available). Note also that watershed areas for flowpath and watershed methods may differ due to the fact that the contributing areas for the representative hillslopes are rectangular and rounding may lead to smaller discrepancies.

runoff was up to 20% underpredicted for the smaller W-11 watershed, the 15% overpredicted average annual sediment yields were much better than those for W-2. The erodibility parameters for the channels could have been possibly optimized further to match the observed values at W-2, but since the focus of this study was the soil loss prediction on the hillslope contributing areas (>4 ha), the simulation results for W-11 (5.9 ha) were assumed to be acceptable as a comparison basis for the various elevation data sets' flowpath method erosion results. The delineation errors of areas for both watersheds based on the TIN data set and the commonly available 10 ft DLG were less than 7% (table 2).

Even though the flowpath contributing area was predicted quite well through the GPS data sets, all of them showed an underestimation of average annual event runoff by at least 30% of the observed 50.7 mm year^{-1} (table 2). One possible reason for the differences between observed and predicted runoff is lateral subsurface flow contributions from the hillslopes to the channel. WEPP v2002.7 only predicts overland flow due to surface runoff and does not properly track any lateral subsurface flow that may exit the hillslopes and enter the channel. On steep topography such as this watershed in Iowa, a substantial amount of water may have moved in this manner.

While the watershed method allows predicting the runoff and sediment yield for the outlet based on representative hillslopes (aggregation of information BEFORE running the model), the flowpath method predicts the runoff and sediment contribution for the hillslopes into the channels based on interpolating all possible hillslope flowpaths (aggregation of information AFTER running the model). The average annual event-based sediment yield predictions for contributions from the hillslopes into the channels (5.0 t ha^{-1} year^{-1} to 14.2 t ha^{-1} year^{-1}) were within the range of the observed 6.6 t ha^{-1} year^{-1} for the 30 ha W-2 watershed and 14.6 t ha^{-1} year^{-1} for the adjacent 6 ha W-11 watershed. Since both experimental watersheds were comparable due to the same land use and soils characteristics for the simulation time period, W-11 with a relatively short channel was therefore a good indicator for expected sediment yields directly from hillslopes (see also Renschler and Harbor, 2002). The reduced observed average annual sediment yield for W-2 indicates the relatively large amount of sediment that is deposited (likely only temporarily) in the channel network. Surprisingly, the 10 ft DLG (2.7% underestimation) and the DGPS (19.9% underestimation) predictions showed the best results for predicting the average annual event-based sediment yield from the hillslopes into the channels (table 2). While site-specific decision-making at the watershed scale is important for the off-site assessment of agricultural watersheds, a more detailed analysis of particular hillslope locations will help to decide which hillslope areas to select to mitigate increased sediment contributions, e.g., with the location of best management practices (BMPs) such as buffer-strips or field borders (Renschler and Lee, 2005).

Hillslope Areas of Interest (0.5 ha)

The soil loss and deposition predictions for the most accurate RTK GPS data set perfectly identified the erosion and deposition problem regions of the eleven selected hillslope areas of interest at the 0.5 ha scale (fig. 3). All ten hillslope areas of interest with increased soil erosion as well as the one area with increased sediment deposition were indicated correctly and matched the visual survey. There were also at least three areas of erosion that were predicted using the RTK GPS data set but were not necessarily identified as a larger rill or

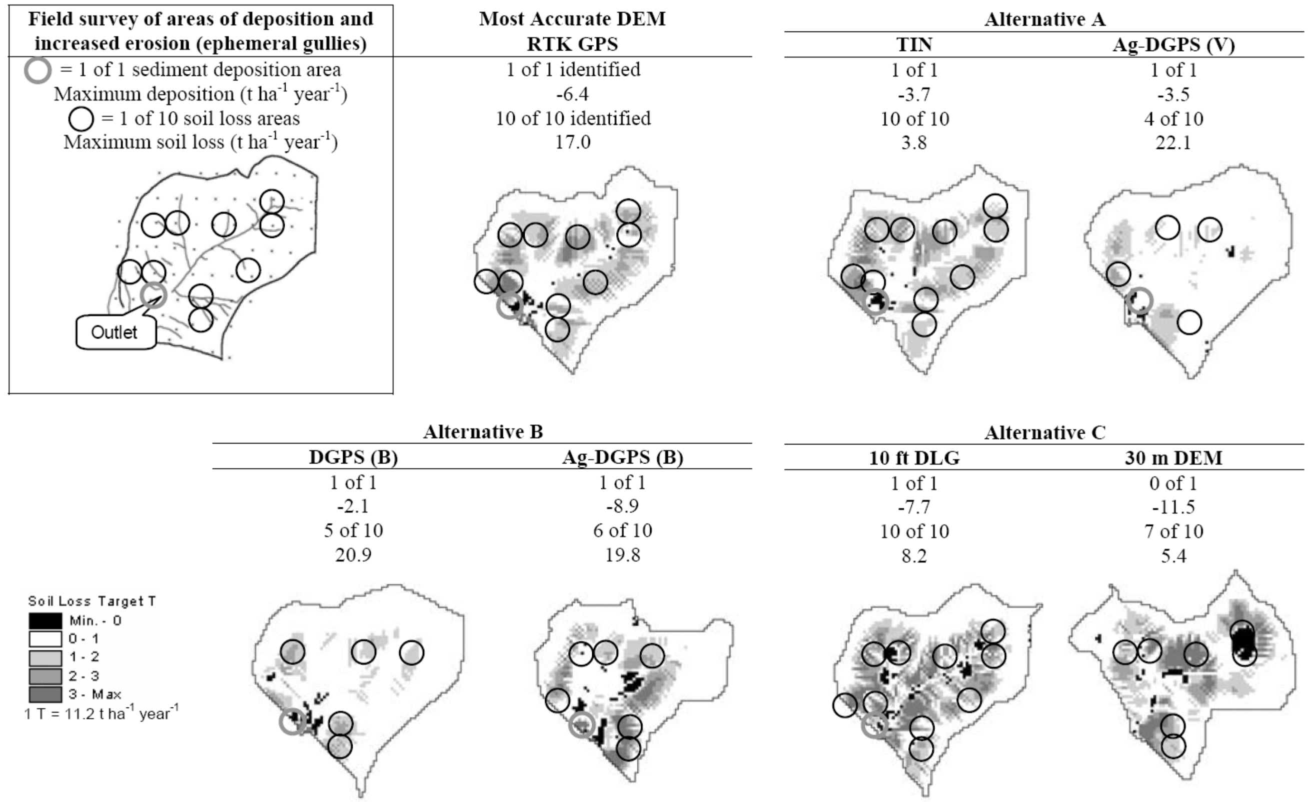


Figure 3. Field survey of observed larger rills and ephemeral gullies and simulated average annual soil loss for 0.5 ha hillslope areas of interest. Note that soil loss is mapped relative to tolerable soil loss target T (11.2 t ha^{-1} year^{-1}). Hillslope locations with T < 0 (black) indicate deposition, 0 < T < 1 (white) indicate tolerable soil loss, and T > 1 indicate soil loss greater than 11.2 t ha^{-1} year^{-1}. Circles in observed and most accurate data sets indicate hillslope areas of interest for increased deposition (gray circle) and increased soil loss (black circles). Note that the northeast area of alternative B was masked due to equipment failure of Ag-DGPS (B).

ephemeral gully in the field. While both the TIN- and the DLG-based predictions successfully indicated all hillslope areas of interest successfully, both of them have limitations. The TIN-based predictions have relatively low estimates of extreme soil loss and deposition. The DLG-based predictions instead show at least four more areas of potential deposition. This is based on the fact that the interpolated contour lines allow a smooth transition from hillslopes to the channel area that increases the likelihood of deposition areas along the channels. The other DGPS-based predictions were less successful in indicating the hillslope areas of interest due to deformed watershed boundary and terrain characteristics. This was also apparent in the predictions based on the 30 m DEM data set.

The quantitative filter test for RMSE and ME demonstrates the relative difference of acceptance areas among alternative data sets in comparison to the most accurate RTK GPS data. The RMSE filter map with an acceptance of an RMSE < 1 (fig. 4) shows that both alternatives in A and the DGPS (B) of alternative B have similar acceptable predictions for upper hillslope areas around the watershed boundary. However, most of the map has RMSE of 1 and higher. The MEFV shows its strength when using an ME > 0 (fig. 4); in this case, the TIN data set shows the largest area of agreement with the RTK GPS data. It is now clear that both alternatives in A are more accurate than alternatives in B. Even though the 10 ft DLG was able to identify the hillslope areas of interest, both alternatives in C show almost no agreement within the watershed in comparison to the soil loss predictions based on the RTK GPS unit. This indicates that the more a decision-maker would demand quantitative estimates for smaller areas within a watershed, the more likely one needs to invest in more accurate topographic measurement systems such as a RTK GPS, a photogrammetric derived TIN, or an Ag-DGPS (V) system.

Hillslope Locations of Interest (0.01 ha)

If a site-specific decision-maker requires exact soil loss estimates for each raster cell or hillslope location of interest, one has to investigate at the scale of 0.01 ha. An absolute error analysis of a raster cell-based analysis indicates that both alternatives in A have the largest agreement when allowing a maximum absolute error of 50% of the average annual soil loss based on the most accurate RTK GPS unit (fig. 5). The TIN has the best coverage, while the Ag-DGPS (V) and DGPS (B) seem to have problems, particularly on the mid-slope areas. The remaining alternatives indicate only reliable quantitative soil loss estimates below 50% absolute error for the upper hillslope areas in a raster cell to cell comparison. The main problem here lies in the combination of errors in the slope and upslope (contributing) areas for each raster cell.

A comparison of slopes and upslope areas for all three alternative data sets with the most accurate RTK GPS data for the 33 selected checkpoints is shown in table 3. While Renschler et al. (2002a) demonstrated that the averages for elevation of the GPS data sets at a given location were relatively close to each other (within about a 1.5 m margin that corresponds to the accuracy levels given by the manufacturers),

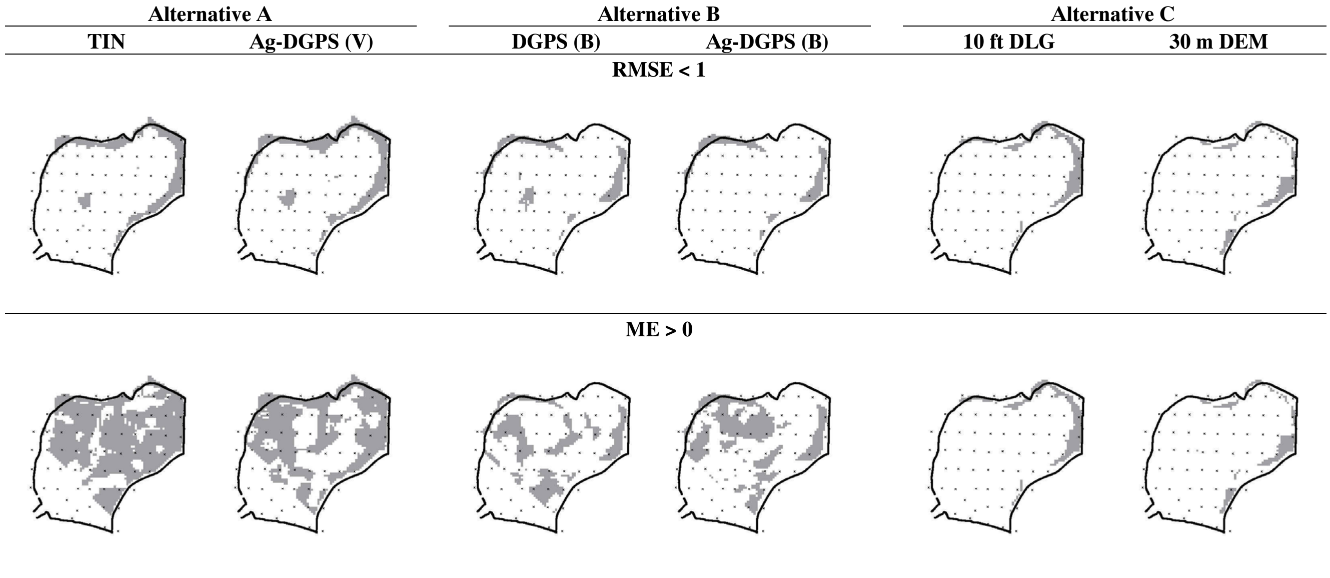


Figure 4. Root mean square error (RMSE) and model efficiency (ME) of simulated average annual soil loss comparing a 7 × 7-pixel neighborhood of different data sources with the most accurate data (RTK GPS). Shaded areas indicate an acceptable RMSE < 1 and ME > 0.

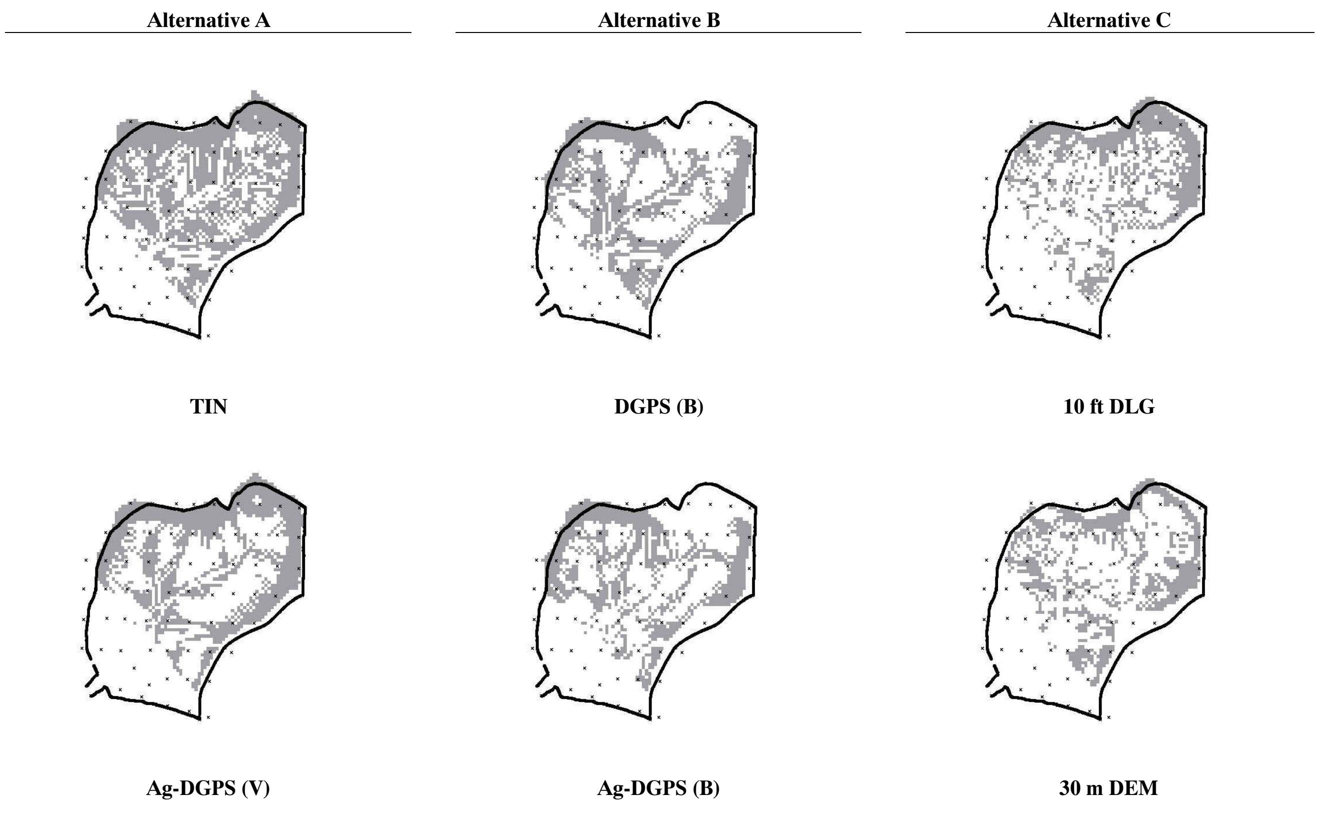


Figure 5. Absolute error (AE) of simulated average annual soil loss comparing each pixel of different data sources with the most accurate data (RTK GPS). Shaded areas indicate an acceptable AE < 0.5. Note that the northeast area of the alternative B analysis was masked due to equipment failure of Ag-DGPS (B).

the coefficient of determination (CD) of the slope at a given location was lower for the Ag-DGPS (B) measurements and the commonly available data (table 3). While the CD and ME for the TIN were greater than 0.80 for slopes at a given location, these values dropped to 0.03 and –0.02, respectively, for the upslope areas. Instead, the alternative B DGPS (B) slopes had a CD of 0.70 and ME of 0.13, and a surprising 0.96 and 0.95 for upslope areas. Even the other alternative B showed a CD of 0.92 and ME of 0.47 for predicting upslope areas. The C alternatives performed rather poorly for the 33 selected checkpoint comparison of slopes and upslope areas.

Table 3. Slopes and upslope areas in flow direction at 33 checkpoints based on different data sets.[a]

Method (applicability)	Data Set	Slopes CD	Slopes RMSE	Slopes ME	Upslope Contributing Areas CD	Upslope Contributing Areas RMSE	Upslope Contributing Areas ME
Alternative A	TIN	0.8560	0.1479	0.8007	0.0253	3.0772	-0.0221
	Ag-DGPS (V)	0.5101	0.3743	-0.2768	0.0033	8.7387	-7.2429
Alternative B	DGPS (B)	0.7011	0.3081	0.1295	0.9584	0.6719	0.9524
	Ag-DGPS (B)	0.2535	0.4321	-0.7123	0.9229	2.2495	0.4666
Alternative C	10 ft DLG	0.1325	0.5522	-1.6784	0.2393	3.1303	-0.0471
	30 m DEM	0.1446	0.4551	-0.8188	0.0800	3.4976	-0.3072

[a] For averages and standard deviations, see Renschler et al. (2002a); CD = coefficient of determination (r2), RMSE = root mean square error, and ME = model efficiency.

Table 4. Soil loss in flow direction at 33 checkpoints based on different data sets.

Method (applicability)	Data Set	Average Annual Soil Loss (t ha^{-1} $year^{-1}$)	Standard Deviation (%)	CD (r^2)	RMSE	ME
Most accurate	RTK GPS	10.91	9.67	n.a.	n.a.	n.a.
Alternative A	TIN	10.85	9.40	0.5237	0.6403	0.4624
	Ag-DGPS (V)	5.23	4.62	0.2402	0.9224	-0.1156
Alternative B	DGPS (B)	5.94	4.93	0.4092	0.8070	0.1275
	Ag-DGPS (B)	9.22	11.31	0.2000	1.0193	-0.3921
Alternative C	10 ft DLG	14.28	15.49	0.0732	1.4777	-1.8187
	30 m DEM	15.30	12.89	0.2609	1.1236	-0.8297

Table 5. Overall ranking of average annual runoff, sediment yield, and soil erosion predictions at various scales of interest.[a]

		Contributing Areas of Interest, >4 ha			Hillslope Areas of Interest, 0.5 ha			Hillslope Locations of Interest, 0.01 ha (100 m^2)			
Method (applicability)	Data Set	Area	Runoff	Sediment Yield	Circles	Moving filter		All pixels	33 selected pixels		
Most Accurate	RTK GPS	1	4	2	1	RMSE	ME	AE	CD	RMSE	ME
Alternative A	TIN	2	5	4	2	2	1	1	1	1	1
	Ag-DGPS (V)	5	7	7	7	1	2	2	4	3	3
Alternative B	DGPS (B)	6	6	6	6	3	4	3	2	2	2
	Ag-DGPS (B)	7	3	3	4	4	3	4	5	4	4
Alternative C	10 ft DLG	3	1	1	2	5	5	5	6	6	6
	30 m DEM	4	2	5	5	6	6	6	3	5	5

[a] Methods of comparison to the most accurate RTK GPS data set: RMSE = root mean square error, ME = model efficiency, and AE = absolute error.

In terms of soil loss predictions at the 33 checkpoints, the averages and standard deviations showed large differences among alternatives (table 4). While the RTK GPS and the TIN produced the best average values in this regard, the other alternatives were scattered around these averages in a wide range. The TIN and DGPS (B) showed the best results with the highest CDs, the lowest RMSEs, and positive ME values. The best alternative was the TIN, which had an ME of 0.46 for soil loss. All other alternatives performed comparatively poorly for the selected 33 checkpoints.

Soil Erosion Predictions across Scales

A comprehensive ranking of performance of all alternatives across scales indicated that the TIN data offers the best alternative compared to the survey-grade RTK GPS measurements at all scales of interest (table 5). Surprisingly, the commonly available 10 ft contour lines from USGS are the next best alternative if one were only interested in runoff and sediment yield predictions of smaller subwatersheds larger than 4 ha and the identification of critical areas within the 30 ha watershed. The TIN and the Ag-DGPS (B) offer the best soil loss prediction at smaller scales.

A ranking of all the alternatives providing topographic information through elevation and their products for the point scale, such as slopes, upslope areas, and soil loss, reveals a very comprehensive picture about error or uncertainty propagation through the data processing. The TIN and DGPS (B) data sets show the most consistent ranking among the top three positions in the comparison with the most accurate RTK GPS data (table 6). Assuming that the variability of weather, soils, and land cover parameters are negligible, and that the soil loss in this watershed can be considered as a function including the slope and upstream contributing areas at a particular location, it seems that accurate representation of these combined two parameters provides the basis for accurate soil loss prediction. Therefore, the TIN and DGPS (B) come in as the two top alternatives compared to the RTK GPS measurements for elevation and its derivatives in the data processing and modeling sequence.

We are aware that the methodology presented here was tested on only one small watershed with steep slopes, typical of highly erodible land, but atypical of many of the agricultural lands in the U.S. to which WEPP might be applied. The results in much flatter terrain would have been significantly influenced by the DGPS measurement variations due to GPS satellites in view and the availability of beacon correction signals (distance to beacon).

Summary and Conclusions

The use of digital topographic data from commonly available data sources and precision farming GPS data offers soil and water conservation decision-makers the possibility of

Table 6. Overall ranking of quantitative values on elevation, slopes, upslope areas, and soil loss for 33 checkpoints (hillslope locations of interest) based on different data sets.[a]

Method (applicability)	Data Set	Elevation[b]			Slopes			Upslope Areas			Soil Loss			Overall Cumulative Ranks		
Most Accurate	RTK GPS	CD	RMSE	ME	CD	RMSE	ME	CD	RMSE	ME	CD	RMSE	ME	CD	RMSE	ME
Alternative A	TIN	1	4	4	1	1	1	5	3	3	1	1	1	8	9	9
	Ag-DGPS (V)	3	2	2	3	3	3	6	6	6	4	3	3	16	14	12
Alternative B	DGPS (B)	2	1	1	2	2	2	1	1	1	2	2	2	7	6	6
	Ag-DGPS (B)	5	3	3	4	4	4	2	2	2	5	4	4	16	15	13
Alternative C	10 ft DLG	4	5	5	6	6	6	3	4	4	6	6	6	19	21	21
	30 m DEM	6	6	6	5	5	5	4	5	5	3	5	5	18	21	16

[a] CD = coefficient of determination (r^2), RMSE = root mean square error, and ME = model efficiency.
[b] See quantitative values in Renschler et al. (2002a).

using this topographic data for running soil erosion prediction tools such as the Water Erosion Prediction Project (WEPP) model. The analysis of accurate topographical representation in the raw elevation data, the discretization of topographical parameters, the distributed simulation output, and the simulation results for the watershed outlet are critical to site-specific decision-making. In addition to the choice of the target raster size and the most appropriate interpolation algorithm, the variability of elevation representation, topographical parameter discretization, their impact on model predictions, and comparison with observed values based on a wide range of available data sources need to be investigated in each watershed analysis using GIS.

This study demonstrates that not only the accuracy of the data source but also the appropriate handling and consequent analysis of topographical data within the GIS model environment have an impact on useful prediction results. This study illustrates that survey-grade RTK GPS data, a photogrammetric survey (TIN), to some extent precision farming-type differential GPS, and even interpolated DEMs based on commonly available 10 ft contour lines from USGS topographic maps can be used for effective soil loss estimates in small watersheds. The results show that the more precise topographic measurements with an RTK GPS, a photogrammetric survey (TIN), and DGPS yield more precise on-site soil loss predictions at all scales ranging from individual raster cells (0.01 ha) and hillslope areas (0.5 ha) to small watersheds (>4 ha). The results at the small watershed scale demonstrate that DEMs based on USGS 10 ft contour lines from commonly available data can be as good as the most accurate data sets (RTK GPS or TIN) in predicting average annual off-site runoff (–18.3% error) and sediment yield (–2.7% error) with the WEPP model for the upslope contributing areas of 4 ha or larger within the 30 ha watershed. As with the RTK GPS and TIN data sets, the contours also allowed successful identification of all 11 hillslope areas of concern with known soil loss (10) or deposition (1) problems. In addition to this visual inspection of hillslope areas of interest, at the individual raster cell scale, two newly developed statistical filters utilizing the root mean square error (RMSE) and Nash-Sutcliffe model efficiency (ME) values allowed visualization and quantification of the spatially distributed accuracy in predicting the observed values within the watershed (TIN had largest area with ME > 0 when compared with RTK GPS). An overall ranking based on quantitative values for predicted elevations, slopes, upslope areas, and simulated soil loss values for 33 checkpoints revealed that the best alternative sources of topographic data to substitute for survey-grade RTK GPS were the photogrammetric survey (TIN) or the DGPS with a beacon correction.

Acknowledgements

We want to thank Bernard A. Engel of the Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana, for the discussion of the results. We also want to acknowledge Kenneth A. Sudduth, Robert L. Mahurin, and Michael J. Krumpelman of the USDA-ARS Cropping Systems and Water Quality Research Unit, Columbia, Missouri, for their efforts in gathering the RTK GPS field data. The authors especially want to thank Larry A. Kramer, who just recently retired from the USDA-ARS Deep Loess Research Station at Treynor, Iowa, for his service and contributions to establish extremely valuable long-time soil erosion measurement series for the experimental watersheds. The College of Arts and Sciences, University at Buffalo, and the USDA ARS National Soil Erosion Research Laboratory provided financial assistance to publish this research.

References

BoB. 1947. *United States National Map Accuracy Standards.* Revised 17 June 1947. Washington, D.C.: U.S. Bureau of the Budget.

Clark, R. L., and R. Lee. 1998. Development of topographical maps for precision farming with kinematic GPS. *Trans. ASAE* 41(4): 909-916.

Cochrane, T. A., and D. C. Flanagan. 1999. Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. *J. Soil Water Cons.* 54(4): 678-685.

Cochrane, T. A., and D. C. Flanagan. 2003. Representative hillslope methods for applying the WEPP model with DEMs and GIS. *Trans. ASAE* 46(4): 1041-1049.

ESRI. 2006. *ArcInfo 8 – User's Guide.* Ver. 8. Redlands, Cal.: Environmental Systems Research Institute, Inc. Available at: www.esri.com/software/arcgis/arcinfo/. Accessed 17 June 2006.

Flanagan, D. C., and M. A. Nearing, eds. 1995. USDA-Water Erosion Prediction Project: Hillslope profile and watershed model documentation. NSERL Report No. 10. West Lafayette, Ind.: USDA-ARS National Soil Erosion Research Laboratory.

Flanagan, D. C., J. C. Ascough II, M. A. Nearing, and J. M. Laflen. 2001. Chapter 7: The Water Erosion Prediction Project (WEPP) Model. In *Landscape Erosion and Evolution Modeling*, 145-199. R. S. Harmon and W. W. Doe III, eds. New York, N.Y.: Kluwer Academic / Plenum Publishers.

Flanagan, D. C., J. R. Frankenberger, C. S. Renschler, and B. A. Engel. 2004a. Development of web-based GIS interfaces for application of the WEPP model. In *Proc. ISCO 2004: 13th Intl. Soil Conserv. Org. Conf.*, Paper No. 419. Brisbane, Queensland, Australia: International Soil Conservation Organization.

Flanagan, D. C., J. R. Frankenberger, and B. A. Engel. 2004b. Web-based GIS application of the WEPP model. ASAE Paper No. 042024. St. Joseph, Mich.: ASAE.

Garbrecht, J., and L. W. Martz. 1997. TOPAZ: An automated digital landscape analysis tool for topographic evaluation, drainage identification, watershed segmentation, and subcatchment parameterization: Overview. ARS-NAWQL 95-1. Durant, Okla.: USDA-ARS.

Karlen, D. L., L. A. Kramer, D. E. James, D. D. Buhler, T. B. Moorman, and M. R. Burkart. 1999. Field-scale watershed evaluations on deep-loess soils: I. Topography and agronomic practices. *J. Soil Water Cons.* 54(4): 693-704.

Kramer, L. A., M. R. Burkart, D. W. Meek, R. J. Jaquis, and D. E. James. 1999. Field-scale watershed evaluations on deep-loess soils: II. Hydrologic responses to different agricultural land management systems. *J. Soil Water Cons.* 54(4): 705-710.

Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part I. A discussion of principles. *J. Hydrol.* 10(3): 282-290.

NRCS. 2006. Geospatial data gateway. Washington, D.C.: USDA Natural Resources Conservation Service. Available at: http://datagateway.nrcs.usda.gov/. Accessed 20 February 2008.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder, coordinators. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. Agriculture Handbook No. 703. Washington, D.C.: USDA.

Renschler, C. S. 2003. Designing geo-spatial interfaces to scale process models: The GeoWEPP approach. *Hydrol. Processes* 17(5): 1005-1017.

Renschler, C. S, and J. Harbor. 2002. Soil erosion assessment tools from point to regional scales: The role of geomorphologists in land management research and implementation. *Geomorphology* 47(2-4): 189-209.

Renschler, C. S., and T. Lee. 2005. Spatially distributed assessment of short- and long-term impacts of multiple best management practices in agricultural watersheds. *J. Soil Water Cons.* 60(6): 446-456.

Renschler, C. S., D. C. Flanagan, B. A. Engel, L. A. Kramer, and K. A. Sudduth. 2002a. Site-specific decision-making based on RTK GPS survey and six alternative elevation sources: Watershed topography and delineation. *Trans. ASAE* 45(6): 1883-1895.

Renschler, C. S., D. C. Flanagan, B. A. Engel, and J. R. Frankenberger. 2002b. GeoWEPP: The geospatial interface to the Water Erosion Prediction Project. ASAE Paper No. 022171. St. Joseph, Mich.: ASAE.

Renschler, C. S., T. Cochrane, J. Harbor, and B. Diekkrüger. 2002c. Regionalization methods for watershed management: Hydrology and soil erosion from point to regional scales. In *Sustaining the Global Farm*, 1062-1067. D. E. Stott, R. Mothar, and F. Steinhard, eds. West Lafayette, Ind.: International Soil Conservation Organization.

Tyler, D. A., D. W. Roberts, and G. A. Nielsen. 1997. Location and guidance for site-specific management. In *The State of Site-Specific Management for Agriculture*, 161-182. F. J. Pierce and E. J Sadler, eds. Madison, Wisc.: ASA, CSSA, SSSA.

UMN. 2006. MapServer. Minneapolis, Minn.: University of Minnesota. Available at: http://mapserver.gis.umn.edu. Accessed 17 June 2006.

USGS. 2006. USGS geographic data download. Washington, D.C.: U.S. Geological Survey. Available at: http://edc.usgs.gov/geodata/. Accessed 4 June 2006.

Wilson, J. P., D. J. Spangrud, G. A. Nielsen, J. S. Jacobsen, and D. A. Tyler. 1998. Global positioning system sampling intensity and pattern effects on computing topographic attributes. *SSSA J.* 62(5): 1410-1417.

Wischmeier, W. H., and D. D. Smith. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. Agriculture Handbook No. 537. Washington, D.C.: USDA.