A RESEARCH EDITORIAL BY CONSERVATION PROFESSIONALS

Precision conservation for environmental sustainability

J.K. Berry, J.A. Delgado, R. Khosla, and F.J. Pierce

ABSTRACT: With continued population growth and increasing demands on water resources, precision conservation will have an increasing role during this new millennium. It has been reported that world population is expected to be about 9.4 billion by 2050, and that increases in crop yields will have to be achieved primarily from land that is currently under production since most of the world's arable land is already being cultivated. These increases in population growth and food and water demands will put increasing pressure for development of new more efficient technology and production practices that contribute to higher yields. Since intensive farming can potentially impact soil and water quality, parallel increases in new practices and technology contributing to improved soil and water conservation practices will be needed to help sustain and maintain the needed yield increases from agricultural systems.

Keywords: Agricultural sustainability, management zones, precision conservation, precision farming, remote sensing

We propose that precision conservation will have a key impact during the 21st century for soil and water conservation and global environmental sustainability. We define precision conservation as a set of spatial technologies and procedures linked to mapped variables directed to implement conservation management practices that take into account spatial and temporal variability across natural and agricultural systems. Although we acknowledge that there could be different degrees of precision conservation such as use of non-digital, non-GIS maps, and survey methods that can help in the application of spatial precision conservation practices, our definition is technologically based. Precision conservation as we have defined it will require the integration of spatial technologies such as global positioning systems (GPS), remote sensing (RS) and geographic information systems (GIS) and the ability to analyze spatial relationships within and among mapped data by three broad categories of surface modeling, spatial data mining and map analysis. The spatial technologies will be used to implement practices that contribute to soil and water conservation in agricultural and natural ecosystems.

Precision conservation can account for variability in topography, length, slope, hydrology, soil cover parameters and other chemical and physical properties to implement best conservation and management practices. These procedures can be used to reduce off-site transport of nutrients and sediments from fields to surrounding areas and help manage field off-site areas, buffer areas, water channels and other areas of the watershed. Not only will this reduce the further transport of sediments, but also will contribute to minimizing agrochemicals entry into water bodies. Precision conservation as we defined will be applied to agricultural fields, to range lands, forest, natural, and other ecosystems. Precision conservation can be applied in humid areas were water erosion is the driving process and in dry areas where wind erosion is the primary mechanism for off-site transport.

The final goal is to use precision conservation to evaluate management practices across several scales from site-specific to sub-watershed and watershed levels to reduce the amount of eroded sediment, nutrients and agrochemicals that end up in waterways. Precision conservation as proposed is a set of spatial management practices that reduces soil erosion, and contributes to soil and water conservation. We propose that as new technological advances are achieved the adaptation of precision conservation by land owners, managers, farmers, and extension personnel will be more widely implemented for higher efficiency of resource management, economic returns, and environmental sustainability.

A primary global concern during the new millennium is the impact of accelerated soil erosion on the economy and the environment (Pimentel et al., 1995; Lal, 1995) as well as increases in greenhouse gases and world population (Lal, 2000). The per capita arable land of 0.23 ha in 1995 is projected to be reduced by almost forty percent to 0.14 ha by 2050 when the population is expected to reach 9.4 billon (Lal, 2000). Since most of the world's arable land is already under cultivation (Baligar et al., 2001), a combination of intensive agriculture on prime soils and restoration of degraded land will be needed to increase and sustain yield productivity to meet the increasing demands in food production during the 21st century (Lal, 2000). We postulate that parallel improvements in precision conservation also will be needed to maintain the productivity of intensive agricultural systems and global sustainability.

Precision conservation utilizes a set of technologies and procedures that link mapped variables with analytical capabilities to appropriate management actions. It requires the integration of spatial technologies of global positioning system (GPS), remote sensing (RS), and geographic information systems (GIS) with the ability to analyze spatial data. Modern GPS receivers are used to establish positions on the earth within a few meters or even centimeters. Remote sensing is used to monitor existing landscape characteristics and conditions. GIS technology is used to encode, store, analyze and display the information obtained through GPS and remote sensing data collection (Burrough, 1986).

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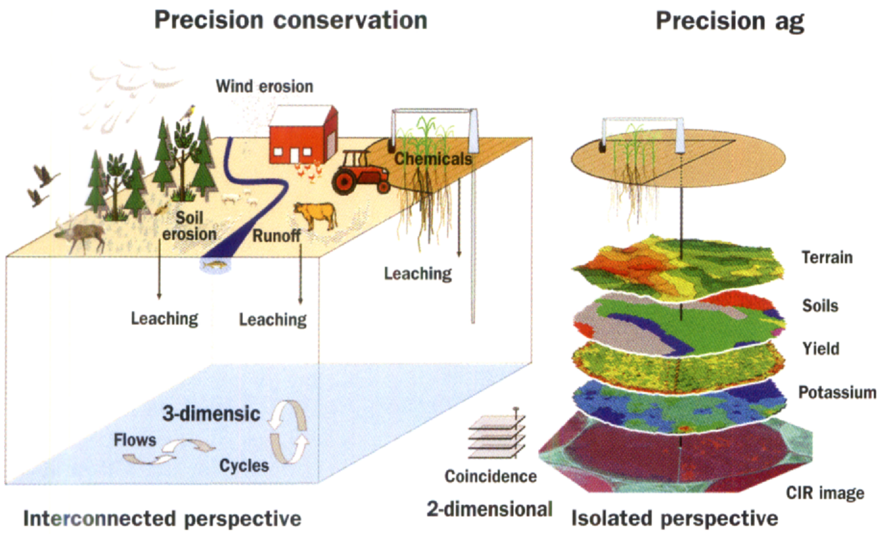
Figure 1
The site-specific approach can be expanded to a three dimensional scale approach that assesses inflows and outflows from fields to watershed and region scales.



As it is shown in Figure 1, precision conservation can be applied to the conservation of agriculture, forest, rangeland, and other ecosystems (air, soil and both surface and underground water). It is related to the emerging field of precision agriculture but has a broader scope and scale. Whereas many precision agriculture applications focus on spatial coincidence among map layers to maximized crop production, precision conservation focuses on interconnected cycles and flows of energy, material and water within three-dimensional contexts for ecosystem sustainability. In addition precision conservation's geographic extent encompasses agricultural fields and their surrounding landscapes composed of physical features (e.g., terrain, soil, water bodies, etc.), natural conditions (e.g., vegetation, wildlife, aquatic organisms, etc.) and system influences (e.g., climatic regimes, human infrastructure, management practices, etc.).

Erosion serves as an example of the more holistic approach engrained in precision conservation. Erosion processes can lead to alteration of soil physical and chemical properties, removal of important essential nutrients, and losses of soil organic matter and yield productivity (Lal, 1993; Lal et al., 1999). In general, erosion removes valuable topsoils and creates nutrient imbalances or toxicity problems due to newly exposed subsoil that has lower fertility (Lal et al, 1999). Olson et al. (1999) reported that corn (*Zea Mays* L.) grain yields of selected severally eroded soils of the Central United States averaged 18% lower yield than those of less eroded soils. Depending on the degree of erosion, corn and soybean (*Glicine max* [L] merr.) yields can be reduced by 20 to 50% (Langdale et al., 1979; White et al., 1985). If we are to meet the increasing demands for food during the 21st Century, we need to continue developing and implementing best management and conservation practices that prevent soil degradation/yield reduction.

As reported by Lal (1999), preservation of soil productivity and reclamation of degraded soils will be crucial during the 21st century. The goal is not only to reduce the off-site transport of nutrients and sediments but to improve and maintain overall soil productivity. Precision conservation has the potential to integrate site-specific field with off-site conservation practices that contribute to watershed sustainability. For example, it is important when implementing buffers and other conservation practices that we account for spatial variability of hydrological factors, agroecoregions, soil, hydrological properties, and other variable factors within the buffer areas. Precision conservation and the integration of spatial technologies and analysis of spatial relationships allows us to better account for spatial erosion variability and design of waterways, buffers, and/or other off-site conservation considerations.

Management of spatial erosion variability

The need to account for and to predict the spatial erosion variability has been widely reported by Wheeler (1990), Mitasova et al. (1995), Desmet and Govers (1996), Siegel (1996), Mitas et al.(1997), Wang et al. (2000) and others. These researchers acknowledge the need to account for topographically complex landscape units and to model the spatial and temporal erosion processes. The Universal Soil Loss Equation (USLE) was initially developed to assess soil erosion by calculating the average soil loss on slope sections (Wischmeier and Smith, 1965). USLE has been extensively used to assess soil erosion at a watershed scale by several scientists (Foster and Wischmeier, 1974; Williams and Berndt, 1972; Wilson, 1986).

One of the first attempts to assess spatial erosion losses by accounting for variability in slopes was conducted by Foster and Wischmeier (1974). They divided the slope into a number of irregular areas to account for differences in soil erosion. New technological advances in GIS, GPS, and remote sensing are facilitating the application of these complex calculations initially tried by Foster and Wischmeier (1974). Now we have algorithms that account for spatial erosion variabilities using GIS technology and digital elevation models (DEMs) that can assess topographical variability (Desmet and Govers, 1996).

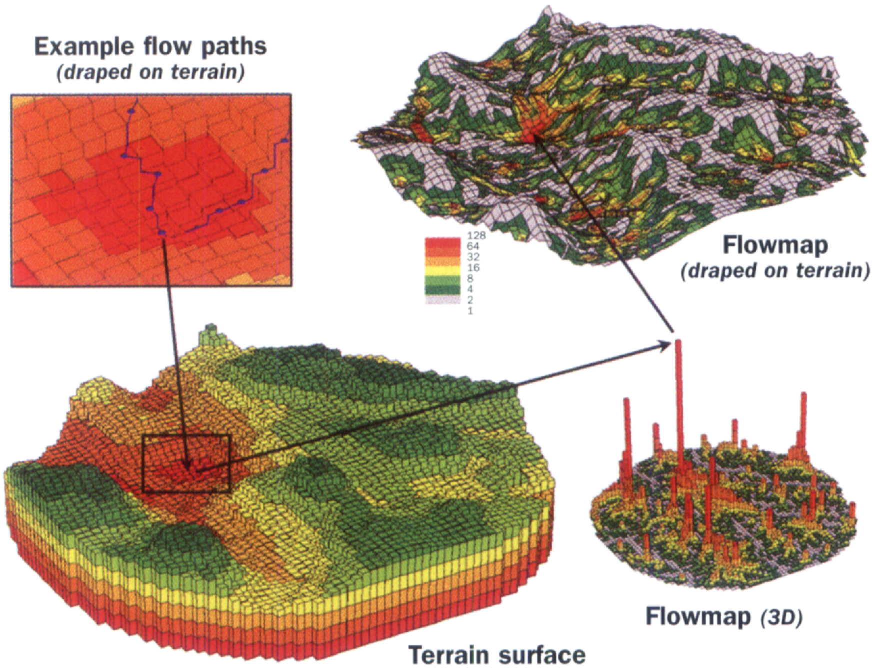
Spatial models for assessment of precision conservation

The ability to analyze spatial relationships within and among mapped data provides new insight into conservation applications. The analysis capabilities provided by GIS can be categorized into three broad categories: surface modeling, spatial data mining and map analysis (Berry, 1999 & 2003a). These new spatial techniques will contribute to new evaluation and application of precision conservation management practices providing new insight into site specific conservation applications.

Traditional non-spatial statistics involves fitting a numerical distribution (e.g., standard normal curve) to generalize the central tendency of a data set. The derived mean and standard deviation reflects the typical response and provides a measure of how typical it is. This characterization seeks to establish the central tendency of the data in terms of its numerical distribution without any reference to the spatial distribution of the data. In fact, an underlying assumption in most statistical analyses is that the data is randomly distributed in space. If the data exhibits spatial autocorrelation many of the analysis techniques are less valid.

Surface modeling on the other hand

Figure 2
Map of surface flow confluence.



involves the translation of discrete point data into a continuous surface that represents the geographic distribution of data. Surface modeling utilizes geographic patterns in a data set to further explain the variance. There are numerous techniques for characterizing the spatial distribution inherent in a set of point-sampled data but they can be characterized by three basic approaches:

- ***Point density*** mapping that aggregates the number of points within a specified distance (e.g., number of occurrences per hectare).
- ***Spatial interpolation*** that weight-averages measurements within a localized area (e.g., kriging).
- ***Map generalization*** that fits a functional form to the entire data set (e.g., polynomial surface fitting).

Environmental scientists collect point-sampled data to derive maps of pollution levels for a wide variety of variables, such as lead (Pb) concentration in the soil, carbon monoxide concentrations in the air and phosphorous levels in water bodies. In one of the oldest applications of surface modeling, meteorologists use geographic positioning of weather station data to generate temperature and barometric maps over large areas.

In contrast, spatial data mining seeks to uncover relationships within and among mapped data layers. These procedures include coincidence summary, proximal alignment, statistical tests, percent difference, level-slicing, map similarity, and clustering that are used in comparing maps and assessing similarities in data patterns (Berry, 2002).

Another group of spatial data mining techniques focuses on developing predictive models. For example, regression analysis of field plot data has been used for years to derive crop production functions, such as corn yield versus phosphorous, potassium and nitrogen levels. Spatial regression can be used to derive a production function relating mapped variables of corn yield and soil nutrients—similar to analyzing thousands of spatially consistent sample plots. In essence, the technique goes to a map location and notes the yield level (dependent variable) and the soil nutrient values (independent variables) and then quantifies the data pattern. As the process is repeated for thousands of map locations a predictable pattern between crop yield and soil nutrients may emerge.

Surface modeling and spatial data mining also defines developing field of spatial statistics. These procedures investigate the numerical relationships of spatial patterns inherent in mapped data. They are a natural extension of traditional statistics and focus on explaining variance by mapping and analyzing spatial distributions.

Simplified map analysis example

Map analysis procedures, on the other hand, investigate the spatial context among map features, characteristics and conditions, such as shape/pattern indices, effective distance, optimal path connectivity, visual exposure, and micro-terrain analysis. Many of these techniques focus on the relative positioning of map features and their connectivity. These techniques are cornerstone to modeling the cycles and flows involved in precision conservation.

For example, surface flow over an elevation map can be modeled and used in determining an erosion potential map as described in the following simplified case study (Berry, 2003b). It is common sense that water, if given its head, will take the steepest downhill path over a terrain surface. GIS utilizes an analogous procedure placing a drop of water at a location on an elevation surface and allowing it to pick its path down the surface in a series of steepest downhill steps. As each map location is traversed it gets the value of one added to it. As the paths from other locations are considered, the areas sharing common paths get increasing larger values (one + one + one, etc.).

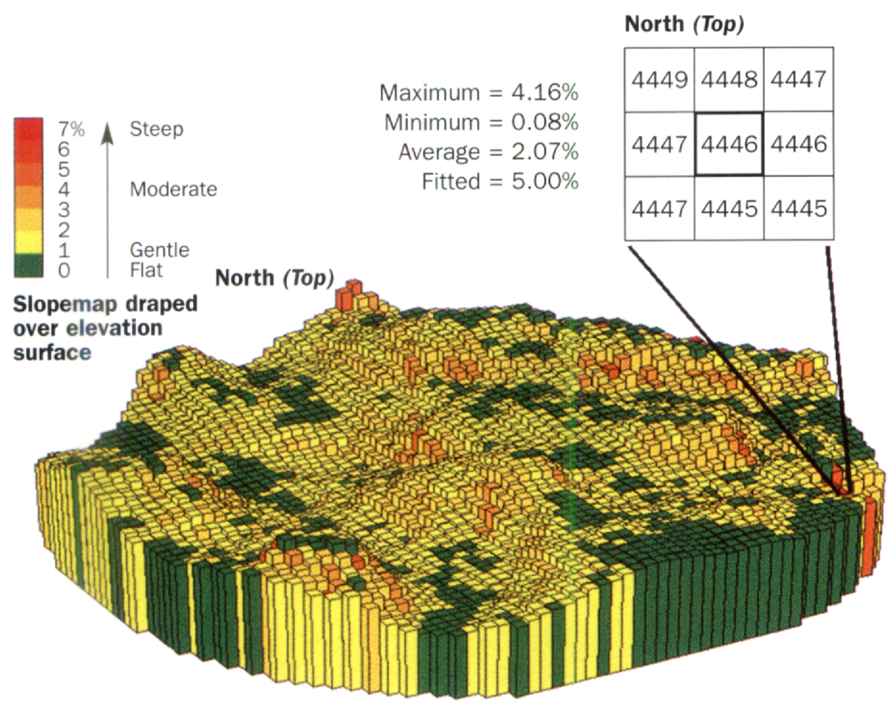
Figure 2 shows a 3-D grid map of the elevation surface and its resulting flow confluence. The enlarged inset on the upper-left shows the paths taken by a couple of drops into a slight depression. The paths are based on the assumption that water will follow a route that chooses the steepest downhill step at each "grid cell step" along the terrain surface. The inset in the lower-right of the figure shows the considerable inflow into the depressions as high peaks in the 3D display. The high value indicates that a lot of uphill locations are connected to this location.

The upper-right portion of figure 2 shows the "Flowmap" draped over the terrain surface. The gray tone on ridges of the surface indicate locations where minimal flow occurs—all flow is away. The green and yellow tones identify areas with increasing number of paths, or confluence of water. The red areas identify locations of pooling with large amounts of water collecting—depressions in the terrain surface. The flow map identifies surface water confluence throughout a field with larger numbers indicating locations with lots of uphill contributors. However, surface flow is just one factor for determining where applied chemicals and materials are likely to concentrate, as well as fine soil particles and organic residue.

We proposed that these types of analysis

Figure 3

Calculation of slope considers the arrangement of elevation differences.



can be used to identify areas collecting water which may also have higher potential for denitrification rates (in case of finer clay soils) or higher potential for leaching rates (in case of coarser sandy soils). Such analyses can contribute to management decisions that increase yields, nutrient use efficiency and soil and water conservation.

The procedure can be extended for a simple "erosion potential" model by considering terrain slope, a neighborhood map analysis operation that calculates the inclination of a surface. In mathematical terms, slope equals the difference in elevation (termed the "rise") divided by the horizontal distance (termed the "run"). The process is analogous to taking the derivative of a two-dimensional equation except it is reporting the rate of change along a three-dimensional terrain surface.

As shown in Figure 3, there are eight surrounding elevation values in a 3 x 3 roving window. Individual slope lines through the center cell are computed to identify the *Maximum, Minimum* and *Average* slope values as reported in the figure. Note that the large difference between the maximum and minimum slope (0.08 to 4.16%) suggests that the overall slope is fairly variable. An alternative technique is calculated by "fitting a plane" to the elevation values by minimizing the deviations from the plane to the nine individual values. In the example, the *fitted* slope is 5.00% and is a good indicator of the overall slope for the location.

The maps of slope and flow can be combined to develop a simple erosion potential model. While the sequence of processing shown might appear unfamiliar, the underlying assumptions are quite straightforward as depicted in Figure 4. The "slopemap" characterizes the relative energy of water flow at a location, while the confluence values on the "flowmap" identify the "volume" of flow. It is logical that as energy and volume increase, so does erosion potential.

The first step in the model classifies slope into three relative steepness classes—1 = Gentle, 2 = Moderate and 3 = Steep for the "S_class" map. The next step does the same thing for relative flow classes—1 = Light, 2 = Moderate and 3 = Heavy for the "F_class" map. The third step combines the slope and flow class maps for a "SF_combo" map that identifies all combinations.

For example, on the slope/flow combination map, the category "33 Steep: Heavy Flow" (dark blue) identifies areas that are relatively steep (S_class = 3) and have a lot of uphill locations contributing water (F_class = 3). Loosened soil under these circumstances is easily washed downhill. However, category "12 Gentle; Moderate Flow" (light green) identifies locations with much less erosion potential. In fact, deposition (the opposite of erosion) occurs in areas of gentle slope, such as category "11 Gentle; Light Flow" (dark red).

The final step interprets the slope/flow combinations into a set of simplified "Surface Transport Erosion Potential" classes of Little, Moderate and Lot. Note that the red areas indicating a lot of potential erosion align with the sides of sloping terrain, whereas the green areas indicating little erosion potential are at the flat tops and bottoms of the terrain surface. Of particular concern are red areas near the edge of the field where materials are easily washed off the field and could enter streams.

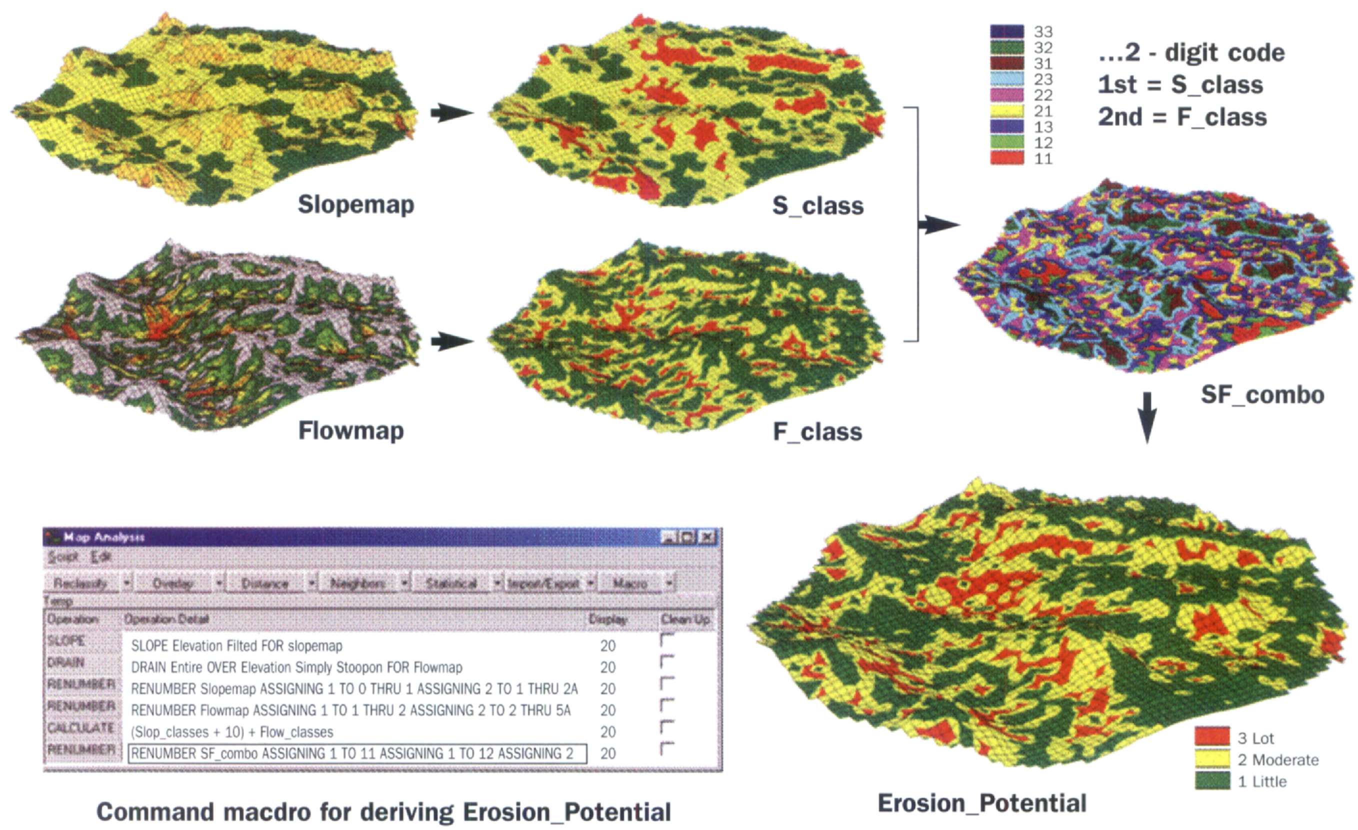
Modeling soil erosion potential is a good example of precision conservation application that can be used to identify potential vulnerable spots for runoff and sediment and agrochemical transport out of the field so producers might consider covering these high sensitive edge areas with grasses or buffers or use other viable mitigation practices. However, before challenging the scientific merit of the simplified example that does not take into consideration covered plant biomass, soil type, drainage, hard pans, soil depth, and method of planting (eg. presence of furrows or beds), or other important variables, note the basic elements of the GIS modeling approach in Figure 4.

The sentences in the macro perform the model steps that derive the intermediate and final maps. A GIS macro enables entering, editing, executing, storing and retrieving individual operations that comprise an application. For example, the erosion model could be extended to consider soil type, vegetation cover and seasonal effects by adding additional command lines. The explict expression of complex spatial processing into a series of commands lines provides a whole new paradigm for conservation research and technology transfer.

Spatial erosion variability

New advances are allowing the use of GIS, remote sensing and non-point source pollution models to identify and evaluate the potential uses of hydrological models (Bhuyan et al., 2003). These models can be used to evaluate the sediment losses for a watershed and its sub watersheds. Bhuyan et al. (2003) in their study used the AGricultural NonPoint Source pollution (AGNPS) model (Young et al., 1987) that

Figure 4
Areas of gentle, moderate, and steep slopes (S_class) are combined with areas of light, moderate and heavy flows (F_class) into a single map (SF_combo) that is reclassified to identify areas of little, moderate, lot erosion (Erosion_Potential).



divides the watershed into small discrete square cells. These cells, representing the variability in agricultural practices, are characterized with several input parameters that include: aspect/flow direction, slope, slope shape, slope length, soil erodibility factor (k-factor), C-factor, conservation practice factor (P-factor), soil texture, fertilizer availability, pesticide indicator, and other parameters. The method used by Bhuyan et al. (2003) to assess runoff and sediment yield uses sediment yields calculated from a modified USLE (Wischmeier and Smith, 1978) and runoff volume calculated by the SCS-CN method (SCS, 1968). The field-scale model Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS, Smith and Williams, 1980) was used to calculate the pollutant level and chemical transport part.

Bhuyan et al. (2003) used several databases to run the model including digital elevation model (DEM) fields. They concluded that this modeling process was effective for small watersheds and that remote sensing with GIS reduced the time needed to evaluate the watershed. Gertner et al. (2002) reported that by using finer interpolations of the digital elevation model (DEM) we can improve spatial resolution which reduces variability for predicting the topographic factor of slope length (L) and steepness (S).

Another model used to simulate sediment yield and agricultural non-point source pollution is the Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1993). FitzHugh and Mackay (2001) used the SWAT model and reported that data aggregation affected model behavior differently depending on whether the watershed was sediment source limited or transport limited. They concluded that it is important to characterize stream channel processes and to improve the selection of sub-watershed size to match SWAT.

Quine and Zhang (2002) evaluated the effect of spatial erosion on soil properties and crop yield. They found that the effect of spatial erosion on yield was complex. Eroded areas where nutrients were depleted had lower yields; but on some areas with high soil aggregation also showed low yields. A forty-year simulation predicted that future effects of spatial erosions will be more extreme and will continue to reduce crop yields (Quine and Zhang, 2002). These studies clearly show the need for precision conservation practices that can effectively evaluate spatial erosion from intensive cropping systems and response with practical viable applications.

Assessment of the uncertainty of spatial erosion variability

Several researchers have reported the importance of understanding the spatial prediction and uncertainty assessment of factors that affect spatial soil erosion (Wang et al., 2000; Hatch et al., 2001). Hatch et al. (2001) reported that site-specific management will be potentially more effective when hydrological watersheds are complemented with agroecoregions within a watershed. It is also important to conduct a complete hydrological analysis since some watersheds, while not susceptible to erosion, may be significantly affected by tile drainage. In other words, a precision conservation three-dimensional management scheme accounting for erosion, soil erodibility, tile drainages and NO_3-N leaching is needed.

GIS can also be used to model and evaluate non-point sources of pollutants in the vadoze zone (Corwin et al., 1998; Hall et al., 2001). Shaffer and Delgado (2002) reported the need to evaluate surface, tile and leaching transport of nutrients as well as taking into consideration spatial variability. Delgado (1998; 1999; 2001b) reported spatial variability of residual soil NO_3-N at harvesting across several vegetable and small grain fields. On average residual soil NO_3-N for center pivot irrigated barley, canola, and potato grown on a loamy sand zone was measured at 20, 44 and 109 kg N ha^{-1}, respectively, which was lower than that measured for the sandy loam zone (42, 51, and 136 kg N ha^{-1}, respectively). The amounts of NO_3-N leached from the irrigated barley, canola, and potato at the loamy sand zone were 32, 39 and 91 kg N ha^{-1} respectively, higher than that of the sandy loam zone (29, 13, and 72 kg N ha^{-1}, respectively). The NLEAP model was able to simulate this spatial variability on soil residual soil NO_3-N and NO_3-N leaching (Delgado, 2001b). Modeling best management practices and GIS can be used to evaluate the effect of spatial variability on NO_3-N transport and dynamics across regions (Hall et al., 2001; Delgado, 2001a).

Precision conservation: Off-site field case scenario

Riparian buffers are good conservation practices that can be used to reduce runoff from sediment and pollutants from agricultural fields. Dosskey et al. (2002) reported that in order to use riparian buffers effectively we need to consider the site-specific effective area of the buffer versus its gross area. In other words, the effective area riparian buffer will be site specific depending on several factors affecting the flow of sediment and pollutants from the site specific buffer surrounding area. This is another good example for the need to apply precision conservation for environmental sustainability. Other factors that need to be considered to determine the effectiveness of the buffer is the effect of non-uniform flow through the filter buffer or concentrated flow in site-specific areas of the buffer.

The Riparian Ecosystem Management Model (REMM) can be used to evaluate buffers of different shapes and soil depths (Lowrance et al., 2000). There is the need to develop models that can evaluate the spatial variability of buffer systems and complex scenarios presented by Dosskey et al. (2002). The previous discussion of spatial data analyses potentially can be applied to the evaluation of flows within a buffer area based on erosion potential. The width of a buffer around a stream depends on the intervening conditions with areas of high erosion potential effectively "reaching" farther away from the stream.

Precision conservation at a site-specific field scale

Precision farming has the potential to increase agricultural production while reducing environmental impacts (Pierce and Nowak, 1999; Bate, 2000; Lal, 2000; Delgado, 2001a; Khosla et al., 2002). Application of advanced technologies such as GPS, RS, GIS, variable rate technology (for seeds, nutrients, irrigation, pesticides, etc.) and yield monitoring to quantify and manage agricultural field variability has been referred to as precision agriculture, or site-specific management. Although the introduction of yield monitors in combination with the availability of GPS in the early 1990's greatly accelerated the initial adoption of precision agriculture, only about 12 percent of U.S. farmers are using some form of precision agricultural management practices (Gallup Poll, 2000). The main challenge associated with adoption and proliferation of precision agricultural practices has been its economic feasibility. Although there are quite a few studies that demonstrate environmental advantages of utilizing precision agriculture (Hornung et al., 2003; Khosla et al., 2002; Khosla and Alley, 1999; Bausch and Delgado, 2003) a very few studies have shown substantial economic advantage (Bausch and Delgado, 2003; Koch et al., 2003).

Recent advancements that have demonstrated a more cost effective and less time consuming way to manage variability is the use of site-specific management zones (SSMZ) based on yield history, soil color from aerial photographs, topography, and the producers' past management experiences (Fleming et al., 1999; Khosla et al., 2002; Koch et al., 2003). Users of site-specific management zones under irrigated corn in Northeastern Colorado have maintained or increased grain yields, increased N use efficiency by 20 to 200%, and increased net economical return to land and management by \$17 to \$30 ha^{-1} (Khosla et al., 2002; Koch et al., 2003).

We suggest that "Precision Conservation Management Zones" might be a viable approach with the stage of current technologies. It will probably be a combination of site-specific management zones and precision conservation management zones that will maximize economic returns, resource use efficiency, and soil and water conservation practices, at least in the near term.

Remote sensing can also improve the N management and in-season application of N (Scharf et al., 2002; Bausch and Diker, 2001; Bausch and Delgado, 2003). Ground-based remote sensing, GIS and a revised N Reflectance Index (NRI) (Schleicher et al., 2003) were used to improve in-season N management of corn in a commercial sprinkler-irrigated field. Bausch and Delgado (2003) reported that this site-specific N management system applied 52% less N than that used by the farmer (214 kg N ha^{-1} yr^{-1}) in commercial field operations during the growing season. The Bausch and Delgado (2003) method saved 102 kg N ha^{-1} yr^{-1} with equivalent savings of about \$55.00 ha^{-1} per season. On average Bausch and Delgado (2003) used almost the equivalent to one year total farmer traditional N fertilizer application to produced two years of commercial corn without reduction of yields (Bausch & Delgado total N applied 2 years / traditional practices total N applied 1 year = 0.95). The use of GPS/RS/GIS tools can significantly maximize N efficiency of corn systems without reducing grain yield for commercial applications and minimize NO_3-N leaching and offsite transport of N (Bausch and Delgado, 2003).

Telecommunications and precision conservation

Precision conservation as we defined *(technologically based)* will benefit from novel advances in the areas of telecommunications and micro technology. New breakthroughs in these areas will contribute to deliver real-time information that can help managers and practicing conservationists in making better *"real-time"* decisions contributing to environmental conservation. We believe that the field of telecommunications and micro-technology will have future applications to the areas of soil and water conservation. Following are some examples on the state of these technologies and their potential application.

Advances in wireless radio communications and miniaturization of electronics has made it possible to develop robust sensors, data loggers, control, and telemetry technologies that can be produced and deployed over a range of conditions at very affordable prices. It is possible to manage irrigation systems using sensors that measure soil and/or plant water status and transmit that information by telemetry to a control device that regulates the timing and amount of an irrigation application either in fixed irrigation systems or center pivots. A grower's entire irrigation system for all fields and crops can be managed on-line on the Internet. In the case of yield mapping, it is now possible to transmit yield data from the combine to a base computer via a live Internet connection that can store, display, and analyze the data and its derivative information in real time, online manner.

Evolving technologies appear capable of revolutionizing these sensor and control networks. Imagine a quarter-sized wireless smart sensor that fits anywhere, can be reprogrammed remotely, and can self organize into a sensor network to move data from one sensor to another until it reaches a data processing location. Initially developed by researchers at University of California at Berkeley and Intel, Motes are tiny wireless sensors only a few cubic centimeters in size and consist of an application-specific sensor board and a wireless controller board in a hermetically sealed enclosure. Called "smart dust" by their developers, Professors Kristofer Pister and Joseph Kahn of University of California at Berkeley, these dust-sized micro-dataloggers can be scattered into the air and send back information from remote locations.

A recent example application for agriculture was reported by Intel in which they outfitted a vineyard in British Columbia with 16 pager-sized sensors spaced about 33 feet apart to monitor microclimates to help prevent against frostbite, mold and other problems. They take temperature and other weather measurements every five minutes and pass them on to neighboring sensors until they reach a main server. As the availability and capabilities of wireless networks improves and micro-technology advances there will be new potential users such as practicing conservationists, extension personnel, consultants, farmers, and others that could apply these tools for precision conservation.

Summary and Conclusions

It is clear that continued population growth and demand by water resources will put increasing pressure for intensive agriculture of already cultivated prime lands during the 21st century. Management of natural and agricultural systems will need to be more efficient if we are to maintain sustainability while we maximize and sustain agricultural production. Demands for water resources will increase while irrigated systems that are so important due to their higher yields will have to be more efficient. We postulate that precision conservation will be a significant key component of global sustainability for the 21st century. Although there are several current limitations to applying these new technologies, we believe that as new tools and technologies become less expensive, they will be more available and the internet will serve to transfer key information and to train technicians and personnel in the use of these tools at any connected location.

It is important that we continue to develop new advances in soil and water conservation for conservation of agricultural lands, natural resources and for the reclamation of degraded soils. Due to the complexity of spatial variability of erosion and nutrient cycles, we need to continue the development, test and calibration of viable and reliable holistic quantitative models and assessment tools that can allow us to evaluate the effects of best management practices on soil and water conservation. It is important that these tools can be flexible enough to be applied at a site-specific level, and over a watershed scale. Remote sensing, GIS, GPS and other new tools need to be incorporated to precision conservation models to provide quick assessment evaluations.

We propose that precision conservation will be a key for sustainability of global agricultural systems during the 21st century contributing to: 1) maintain and or increase prime land productivity; 2) improve efficiency of resource management; 3) reclaim degraded soils by accounting and managing spatially degraded soil variability; 4) conserve and improve soil quality; 5) increase carbon sequestration; 6) reduce off-site transport of soil nutrients, agrochemicals, and sediments.

We postulate that precision conservation will be a tool that will use layers of GIS information including reliable weather and soil databases, remote sensing information, digital terrain data, and other information with erosion and hydrological models to conduct site-specific simulation across field and natural ecosystems. Precision conservation will be a key component bringing all of these tools together into practical applications with the potential to contribute to the sustainability of prime lands while maximizing agricultural productivity. The use of servers and the Internet will serve as tools that will allow the quick assessment of the newest model and databases versions. Extension personnel, consultants, farmers, and other users will benefit from quick access to future precision conservation tools.

Endnote

Names are necessary to report factually on available data; however, the U.S. Department of Agriculture neither guarantees nor warrants the standard of the concepts and/or products presented, and the use of the name by the USDA, CSU, WSU and Denver University implies no approval to the exclusion of others that may be suitable.

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