Applying spatial analysis for precision conservation across the landscape

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

ABSTRACT: Although new technologies such as precision farming will contribute to increasing yields per unit area, similarly soil and water conservation will be instrumental in maintaining these increases in productivity while reducing environmental degradation, off-site transport, and water pollution. Initially, 'precision conservation' was defined as the integration of spatial technologies such as global positioning systems (GPS), remote sensing, and geographic information systems (GIS) and the ability to analyze spatial relationships within and among mapped data. Surface modeling, spatial data mining and map analysis are three broad approaches that can be used to analyze layers of information to help develop and implement management practices that contribute to soil and water conservation in agricultural and natural ecosystems. In this paper, we expand the definition of precision conservation to a developing science that uses the new spatial technologies to link a system from a site specific location, to a field, to a set of fields (farm) to a regional scale. We also expand our discussion based on the status of precision conservation as it was shown by twenty six precision conservation papers presented at the 2004 Soil Science Society of America annual meeting. We propose that precision conservation will be a key science to contribute to the sustainability of our biosphere in this century.

Keywords: Agricultural sustainability, geographic information systems, global positioning systems, precision conservation, precision farming

Berry et al. (2003) established the term '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. This definition is technologically based. The Berry et al. (2003) definition requires the integration of spatial technologies such as global positioning systems (GPS), remote sensing, geographic information systems (GIS) and the ability to analyze spatial relationships within and among mapped data by three broad approaches of surface modeling, spatial data mining and map analysis. These spatial technologies can then be used to help implement conservation practices that contribute to soil and water conservation in agricultural and natural ecosystems. Since that manuscript was published, the Soil Science Society of America, Canadian Soil Science Society, Mexican Soil Science Society and the Division of Soil Water and Management and Conservation celebrated a joint symposium about "Precision Conservation in North America" at the November 1 to 4, 2004 annual meeting in Seattle, Washington. This symposium was well attended and had 10 oral and 16 poster presentations.

This paper addresses the fundamental considerations, underlying theory and practical expressions of the emerging concept of Precision Conservation and extends and links spatial analysis from site-specific to regional contexts. This was a key paper presented at the Symposium "Precision Conservation in North America" at the 2004 annual meeting of the Soil Science Society of America. At the symposium several researchers presented papers describing how precision conservation can be applied to soil management systems and the interactions with nutrient distribution, nutrient application to reduce NO_3-N leaching losses, and soil organic carbon (C) sequestration potential. The concept of precision conservation was also used and applied with conservation planning. Precision conservation was applied to erosion probability maps, erosion variability, identifying spatial patterns of erosion, and effect of erosion patterns on yield productivity. Precision conservation concepts were also applied to irrigation. Precision conservation will continue to link new technologies to assess how management practices can be more effective across different landscape positions to reduce the off site transport of nutrients, and to conserve the sustainability of the system.

Precision conservation links site specific properties of soil and crops with buffers, native areas, grass areas, and natural systems across the larger scale, integrating weather, hydrologic factors and spatial and temporal variability. For example, for nutrient managers, it is key to understand how these scales are linked to develop management decisions about what set of practices are best to minimize erosion and potential off-site transport of soil, nutrients, and other chemicals with the goals of maximum sustainability (*maintain higher yields*), economic returns for farmers (*viable practices*) and minimum negative off-site impacts. By evaluating how management and the hydrologic factors affect surface runoff versus tile movement across a region, managers can determine what set of practices will be best to implement over the field, set of fields, farm and/or region to reduce surface transport and tile movement.

Conservationists, nutrient managers, and other personnel can use spatial technologies such as remote sensing, GPS and GIS to increase their abilities to analyze spatial data and link mapped variables with appropriate management actions. Precision conservation integrates modern GPS receivers to establish positions on the earth surface within a few meters or even centimeters with geo-referenced remote sensing to monitor, landscape characteristics and conditions in order to conduct risk assessments and develop best management scenarios. GIS technology is

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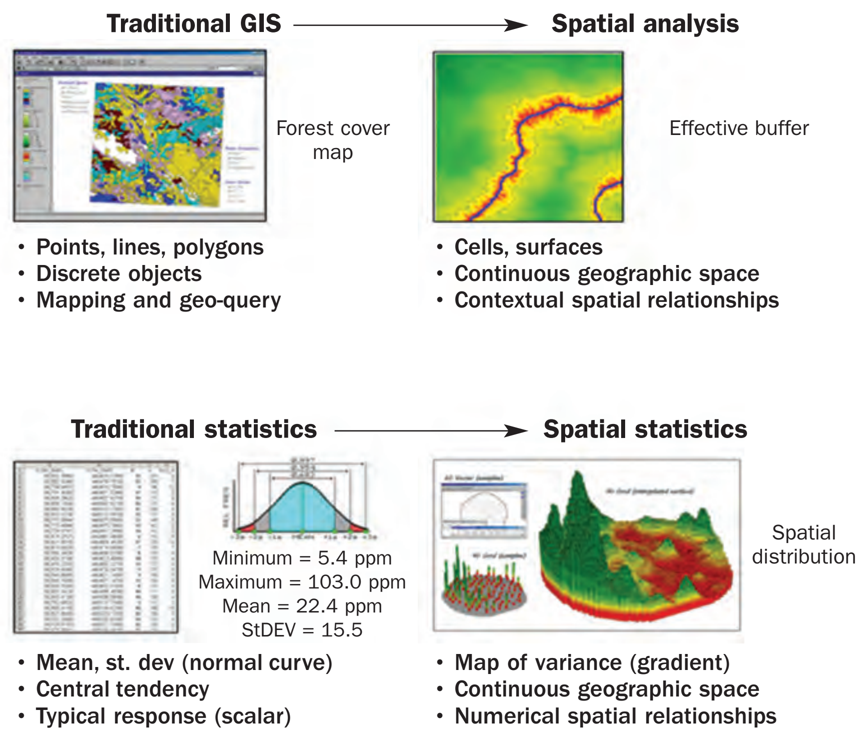
used to encode, store, analyze and display the information obtained through GPS and remote sensing data collection (Burrough, 1986). Precision conservation can be applied to the conservation of agriculture, forest, rangeland, and other ecosystems (air, soil, surface water and underground water resources).

Precision conservation, although related to the field of precision agriculture, has a broader scope and scale. Precision agriculture applications focus on spatial coincidence among map layers to maximize crop production. Precision conservation focuses on interconnected cycles and flows of energy, material, chemicals, and water to reduce environmental impacts, off-site transport, and water pollution. For example, precision conservation may consider variability to increase carbon sequestration at landscape positions that may have a higher sink capacity. Precision conservation's geographic extent encompasses agricultural fields and their surrounding 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.).

Figure 1
Spatial Analysis and Spatial Statistics are extensions of traditional, non-spatial ways of analyzing mapped data.



What geospatial technology is and isn't

For thousands of years we have used maps to show physical features of the landscape primarily for the purpose of navigation and transport. Precision conservation is a new way of conceptualizing and utilizing the spatial information contained in maps for management and conservation of the landscape, especially considering the areas of higher risk. Although this spatial information has long been the cornerstone of conservation research and practice, it was in a form that precluded the maximization of its use. However, with the advent of GIS technology in the early 1970's, mapped data have changed to digital representations that are linked to databases and to a wealth of new processing capabilities across the landscape.

Traditional GIS treats geographic space in a similar manner to our paper map legacy where points, lines and polygons are used to define discrete spatial objects, such as roads, wells, streams, ponds and lakes. In turn, these objects are linked to attributes in a database that describe their characteristics. The result is a tremendously useful system enabling users to make complex geo-queries of the information and then map the results. These capabilities are useful for describing current landscape attributes, but are limited in analytical capabilities for assessing spatial interactions and flows affecting conservation management. Trends in the movement from mapping to map analysis are identified in Figure 1.

Spatial analysis extends the basic set of discrete map features of points, lines and polygons to map surfaces that represent continuous geographic space as a set of contiguous grid cells. The consistency of this grid-based structuring provides a wealth of new analytical tools for characterizing "contextual spatial relationships", such as effective distance, optimal paths, visual connectivity and micro-terrain analysis. In addition, the grid structuring provides a mathematical/statistical framework by representing geographic space as a set of organized numbers, in a manner analogous to matrix algebra.

Traditional statistics is inherently non-spatial as it seeks to represent a data set by its typical response regardless of spatial patterns. The mean, standard deviation and other statistics are computed to describe the central tendency of the data in abstract numerical space without regard to the relative positioning of the data in real-world geographic space.

Spatial statistics, on the other hand, extends traditional statistics on two fronts. First, it seeks to map the variation in a data set to show where unusual responses occur, instead of focusing on a single typical response. Secondly, it can uncover "numerical spatial relationships" within and among mapped data layers, such as deriving data zones (e.g., clustering) within an agricultural field or generating a prediction map (e.g., regression) of crop yield based maps of soil nutrients and other driving variables.

An example of the use of geospatial technology

Map analysis. A GIS's ability to characterize the numerical and contextual relationships within mapped data serves as the cornerstone of management decisions in precision conservation. Spatial analysis operations have the potential to integrate site-specific management actions with site-specific conservation practices and also with off-site conservation practices that can contribute to watershed sustainability. For example, since water will take the steepest downhill path over a terrain surface, surface flow over an elevation map can be modeled and used in creating an erosion potential map (Berry, 2003a, 2003b). We could use GIS to conduct a series of analogous procedures, 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.

An example of a 3-D grid map showing flow confluence is shown in Figure 2. In this example the elevation surface (vertically exaggerated) shows the paths taken by a couple of drops into a slight depression. The inset shows a location where a cell shows that 451 uphill locations contribute surface runoff to the lowest location. This high value indicates a link between this cell and a large number of uphill locations. The flow map can be draped over the elevation surface showing the locations where all flow is away (gray tone on ridges), areas with greater confluence of water (blue and green tones) and areas of heavy flows where large amounts of water could potentially form gullies (red areas).

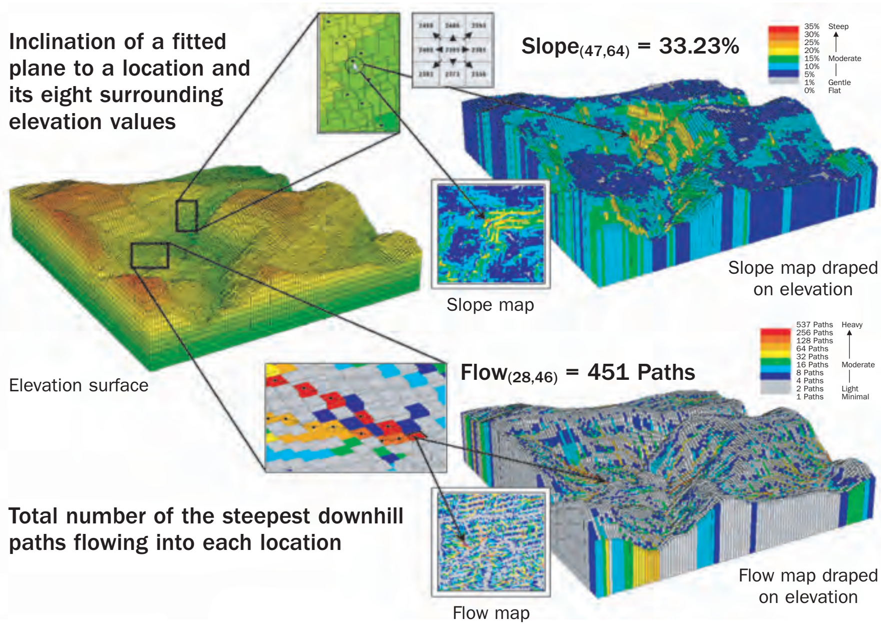
In this example, the surface flow is just one factor for determining where erosion is likely to occur, but it can be extended to simple "erosion potential" by considering the slope. This GIS slope procedures based on the difference in elevation divided by the horizontal distance uses a neighbor spatial analysis to calculate the surface inclination at each grid cell. As shown in the upper portion of Figure 2, there are eight elevation values in a three-by-three roving window surrounding each grid location. The most commonly used slope algorithm uses a fitted plane to the localized elevation values that minimizes the deviations from the plane to the nine individual elevation values. The *fitted* slope for the example location is 33.23 percent and is a good indicator of the overall steepness at that location.

The slope map characterizes the relative energy of water flow at a location, while the confluence values on the flow map identify the volume of flow. It is common sense that as energy and volume increases, so does erosion potential. The maps of slope and flow can be combined to develop a simple erosion potential map. While the sequence of processing shown in the top portion of Figure 3 might appear as an unfamiliar way of thinking with maps, the underlying assumptions are quite straightforward.

The first step in the model classifies slope

Figure 2

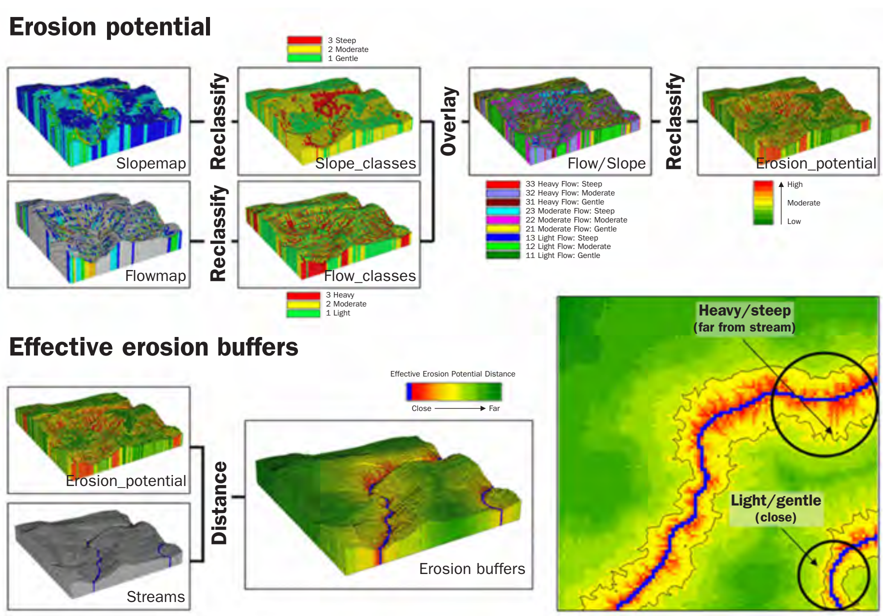
Maps of surface flow confluence and slope are calculated by considering relative elevation differences throughout a project area.



into three relative steepness classes: 1 = Gentle, 2 = Moderate and 3 = Steep for the slope classes map. The next step does the same thing for relative flow classes: 1 = Light, 2 = Moderate and 3 = Heavy for the flow classes map. The third step combines the maps of slope and flow classes for a slope/flow map that identifies all existing combinations of slope and flow classes. In combining the two maps, the flow classes map is multiplied by 10 then added to the slope classes map to create a two digit code where the first digit identifies the flow class and the second digit the slope class.

Figure 3

Effective erosion buffers around a stream expand and contract depending on the erosion potential of the intervening terrain.



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

The final step in determining erosion potential interprets the slope/flow combinations for simplified surface transport erosion potential map containing a gradient of susceptibility for erosion from 9 = Low (green) through 1 = High (red). 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 a field, or other actively disturbed area, where materials can be easily washed off and enter the waterways. These are good simple precision conservation techniques that can be used to identify potential hot spots for runoff and sediment and agrochemicals transport out of the field so producers may want to cover these high sensitive edge areas with grasses or buffers along the edge of the fields or use other viable practices.

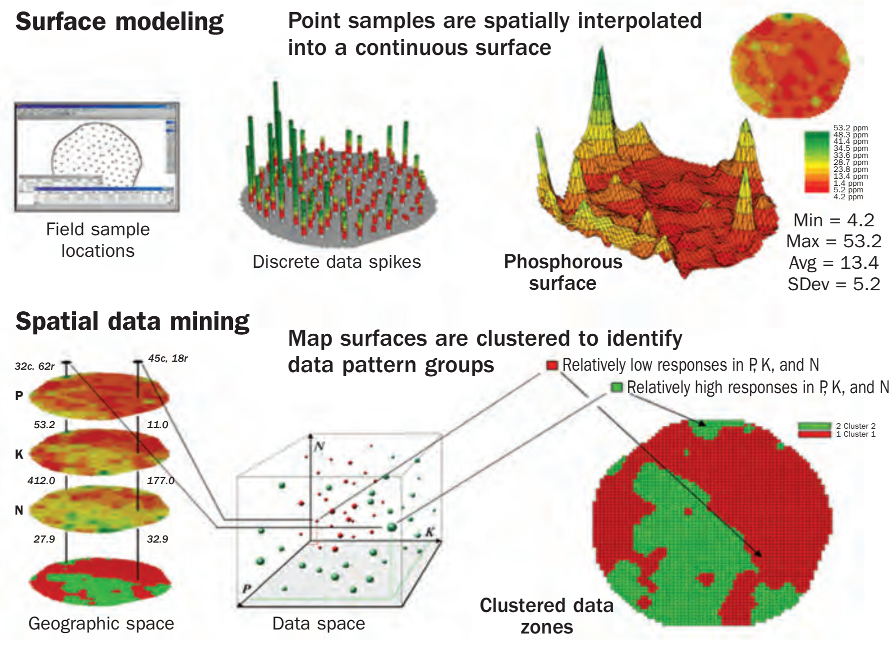
Buffers. Traditionally, protective buffers based on simple geographic distance from a stream are used to shield sensitive waterways from sediment and chemical loading. However, the erosion potential map can be used to identify effective erosion buffers around waterways that respect the intervening terrain (bottom portion of Figure 3). These variable-width buffers are wider under high erosion conditions and are narrower under low erosion conditions. The algorithm for deriving effective distance moves away from the stream as a series of wavefronts, noting the relative erosion potential at each step. An area of high erosion potential causes the wave-front to extend farther in geographic space than an area of low erosion potential. The result is an erosion buffer map that constricts and expands as a function of the intervening conditions.

This simplified example does not take into consideration plant density, soil type, drainage, infiltration, saturation, hard pans, soil depth, or other important variables affecting erosion severity. However, it is sufficient to illustrate the basic elements of the GIS modeling approach encapsulated in Figure 3. The flowchart is used to summarize the model's logic with each map representing a logical step and each line representing an analysis operation. At each step, an analytical operation is employed from GIS's robust toolbox of capabilities for assessing spatial relationships.

The reclassify operations in the model identify the most critical steps as they imply calibration and weighting judgments that translate mapped data into a decision context. For example, the slope values that define the cutoffs between gentle, moderate and steep classes greatly influence erosion potential and eventually the delineation of the erosion buffers. These steps require expert knowledge and science within the discipline of the application within a spatial context.

This situation is the most limiting factor in applying map analysis. Most of our current knowledge base has focused on spatially aggregated science, as the map analysis tools were not available for research or practical application. Now that software and powerful PC computers are readily available and the necessary data sets are coming online, our scientific understanding of calibrations and weights of spatial models is emerging as the most limiting factor in precision conservation.

Figure 4
Surface modeling is used to derive map surfaces that utilize spatial data mining techniques to investigate the numerical relationships in mapped data.



The processing steps of a model are entered into a GIS macro that facilitates 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. The flowchart provides an effective means for communicating the processing steps to individuals with minimal GIS experience. The explicit linkage between the command macro and the flowchart provides a common foothold for communication between the two perspectives—logical and code—of a GIS application. It also provides an entirely new paradigm for conservation research, technology transfer, management practice and regulation.

Characterizing spatial distributions

The ability to analyze spatial relationships provides new insight for conservation applications. The *spatial analysis* capabilities provide information on the contextual relationships among map features, such as slope, flow, and effective distance. These procedures are defining a new "map-mathematics" that exploits the digital nature of modern maps. For example, slope is a direct extension of the derivative in traditional mathematics as it summarizes the change in elevation (rise) over the change in distance (run). Similarly, surface flow can be thought of as a spatial extension of the integral function as it accumulates paths over a three dimensional surface.

The *spatial statistics*, on the other hand, extend traditional statistics by focusing on the numerical relationships within and among map variables. The evolving field can be subdivided into two broad approaches—surface modeling and spatial data mining (Berry, 1999; 2003a).

Surface modeling involves the translation of discrete point data into a continuous surface that represents the geographic distribution of data. Traditional non-spatial statistics involves an analogous process when fitting a numerical distribution (e.g., standard normal curve) to generalize the central tendency of a data set. The derived mean and standard deviation reflect the typical response and provide 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 non-spatial analysis techniques are less valid.

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 techniques:

• *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), and

• *Map generalization* that fits a functional form to the entire data set (e.g., polynomial surface fitting).

Precision agriculture uses spatial interpolation to derive maps of soil nutrient levels based on a set of soil samples collected throughout a field (Figure 4). The geographic coordinates for each sample point can be coupled with laboratory results to generate a three-dimensional view of the sample measurements to visualize the spatial pattern. Spatial interpolation uses nearby samples to estimate the localized responses throughout a field and map the phosphorous surface in this example. Note that the average is 13.4 ppm, which falls in the light red band in the plot and that there are numerous locations that are significantly above and below the average. A fertility program based on the average and applied equally over the entire field would probably apply too much in many areas and too little in others.

In a similar manner, environmental scientists collect point-sampled data to derive maps of pollution levels for a wide variety of variables, such as lead 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.

While surface modeling seeks to map the data pattern of a single variable, *spatial data mining* procedures seek to uncover relationships within and among mapped data layers, such as the ones generated through surface modeling. 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).

Identifying data patterns

The bottom portion of Figure 4 illustrates using clustering to subdivide a field into data zones. The map surfaces identify the data patterns in geographic space that can be characterized by their relative responses in "data space." In the example, this linkage can be conceptualized as a box with the phosphorous (P), potassium (K) and nitrogen (N) forming the axes. The three nutrient values for a grid cell on the surface maps identify a point in data space. The distance between any two points corresponds to the similarity in the grid cells' data patterns—if they are close together, they have similar nutrient composition. The computer uses the relative 'data distances' between all points to classify the field into data zones. The result are clustered data zones with each containing grid cells that are as similar as possible (minimal intra-cluster distance) while at the same time as different as possible between zones (maximum inter-cluster distance). The spatial pattern can be used to formulate prescription maps that can be used to vary management actions, such as fertilizer application that varies throughout a field.

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. In a GIS, 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 often emerges. If the relationship is strong, the regression equation can be used to predict maps of expected yield for another location or year. These GIS analyses can be used to conduct rapid analysis for N fertilization budgets. Initial N before planting can be accounted to make spatial N fertilizer recommendations.

Current applications and research trends

Pennock (2005) reported that precision conservation is being used for co-management of carbon and nitrogen on the Canadian Prairies. He suggested the use of precision conservation to account for variability across the landscape in carbon and nitrogen dynamics. He identified the need for application of precision conservation by professional agronomists to contribute to the reduction of greenhouse gasses from the Canadian Prairies. Pennock (2005) contends that by using precision conservation, managers could target the areas that have the higher aggregate carbon sequestration potential, such as those landscape positions in the upper slope. Additionally they have found that in Canada the lower slope positions are the areas of higher nitrous oxide (N_2O) emissions. These areas will be targeted to implement practices that increase the N use efficiency with potential to reduce the hot spot N_2O contributions from these landscape positions.

Goddard (2005) presented an overview of precision conservation in Canada. He also reported on the need to integrate landscape position to implement conservation practices. He suggests that land forms in Canada may be a way to characterize spatial variability of soil properties and crop responses to identify risks. The application of computer models to assess the nutrient or erosion scenarios across spatial variability will be an approach to precision conservation.

Several studies have reported that tillage practices can contribute to moving soil particles down slope (Lindstrom et al., 1990; Govers et al., 1994). Papiernik et al. (2005) states that the effect of this erosion exposes the calcareous subsoil and mixes it with the surface soil reducing wheat yields by 50 percent or more and that conservation practices can reduce this erosion. Another method to manage the eroded positions across slopes was discussed by Terra et al. (2005). They reported that we can use conservation systems of no-till and cover crops with or without manure to increase soil carbon sequestration in the most eroded landscape positions. There is potential to use soil management system and landscape position interactions for soil and water conservation (Balkcom et al., 2005; Terra et al., 2005).

Schumacher et al. (2005) reported that we can use ^{137}Cs to identify spatial patterns of erosion for use in precision conservation. They stated, that since topography drives erosion process due to tillage, we could use ^{137}Cs to estimate the soil displacement across landscape positions. This information in conjunction with erosion models can be used to evaluate spatial maps reflecting past erosion that can be useful to plan conservation practices. They recommended practices such as localized cover crops, supplemental carbon inputs from manure, extract crop residue, or municipal sludge, and reduced tillage. We propose there is potential to use new technologies such as remote sensing, GPS, and GIS to evaluate biomass production and erosion potential in developing precision conservation approaches that increase conservation across the landscape.

Mueller et al. (2005) reported on the potential to develop erosion probability maps using logistic regression. They suggested that precision technologies and logistic regression analysis are excellent tools for developing erosion indices. Dosskey et al. (2005) reported on the potential of designing conservation buffers using precision information. There is potential to use remote sensing to improve and develop conservation management practices for precision conservation by assessing the erosion potential, hydrological flows, and potential for off-site transport.

We can use precision farming information to develop conservation plans at a field level to improve soil and water conservation practices (Kitchen et al., 2005; Lerch et al., 2005). The precision conservation plan that they proposed for their study field varies according to the precision information obtained across this field. They reported that using precision conservation is unique and will have national and international applications.

Sadler et al. (2005) reported using precision information to conserve irrigation water. This form of precision conservation of water resources can contribute to conservation of up to 50 percent in applied water or averages from eight to 20 percent savings in water depending on the regions.

Meisinger and Delgado (2002) stated that a principle for managing nitrate (NO_3-N) leaching is managing irrigation. Managing irrigation is important when we have spatial variability in soil texture across a field. Usually the fields that have this spatial variability will be managed uniformly, which leads to higher NO_3-N leaching losses from the more sensitive field areas. Precision irrigation as reported by Sadler et al. (2005) has the potential to contribute to lower NO_3-N leaching losses, thus potential higher N use efficiencies.

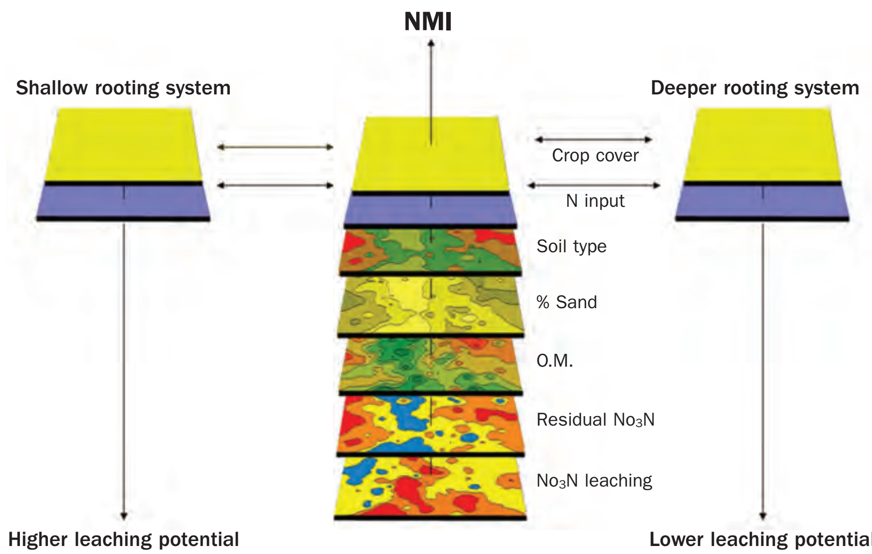
Delgado (1999; 2001) reported on spatial variability of residual soil NO_3-N and NO_3-N leaching. Bausch and Delgado (2003) reported that remote sensing can be used to manage this spatial variability and increase N use efficiencies by increasing the synchronization of fertigations with the higher times of N uptake demand. They reduced N applications to corn by half, using remote sensing techniques, without reducing yields in commercial fields in Colorado. Delgado and Bausch (2005) reported that by using these remote sensing techniques and increasing N use efficiencies by almost fifty percent the NO_3-N leaching was reduced by about 47 percent. They reported that productivity zones delineated using precision agriculture technologies identify areas within corn production fields that differed in residual soil NO_3-N and NO_3-N leaching potential. Delgado et al. (2005) reported that site specific management zones can also reduce NO_3-N leaching losses. They reported that site-specific management zones characterized the variability of factors that affect NO_3-N leaching and demonstrated that applying N fertilizer in accordance with the productivity potential of the management zone can reduce NO_3-N leaching. They proposed that GPS, GIS, remote sensing and modeling technologies can contribute to delineation of more efficient site specific management zones that consider hydrological factors to lower NO_3-N leaching losses.

Delgado (2001) reported on the potential to use modeling to evaluate the effects of best management practices (BMPs) on NO_3-N leaching including variability across fields. We could use GIS tools to conduct evaluations of BMPs on a regional basis (Delgado and Follett, 2004; Hall et al., 2001; Wylie et al., 1994). Shaffer and Delgado (2002) reported that there is a need to develop a nitrate leaching index that integrates site and off-site factors. Figure 5 shows an example of how spatial properties will affect spatial NO_3-N leaching. There is potential to use GIS to develop a nitrogen index that accounts for management factors and that integrates spatial information with the effects of management practices on N dynamics, use efficiencies, losses and on NO_3-N leaching (Delgado, 2004a, 2004b; Shaffer and Delgado, 2002; Figure 5). We could use GIS, GPS and modeling technologies to evaluate site specific field scenarios or NO_3-N leaching across a region (Figure 6). Figure 6 shows a case scenario with a new NLEAP-GIS version. The model can conduct an evaluation considering spatial field variability or be used to evaluate the NO_3-N leaching potential in the field and outside the field. The model can be used to do a site specific location in a field or a simulation for a complete field with different soil types. A simulation can also be done for a field or its surrounding area or for multiple fields at once (Delgado, 2004a, 2004b; Figure 6).

Renschler and Lee (2005) reported on the spatially distributed assessment of short and long term impacts of BMPs within a watershed. They used a modeling approach to evaluate the effect of BMPs. The watershed evaluation allowed the determination of effects of topography, soils and land management across the watershed. It contributed to estimation of erosion, soil loss, runoff, and sediment yields within the watershed. Renschler and Lee (2005) reported that this evaluation then allows land managers to develop scenarios that can identify the hot spots within a watershed and develop management practices to reduce offsite transport.

Figure 5

A concept of a nitrogen management index that integrates spatial information with effects of management practices on nitrogen (N) dynamics and on nitrate -N (NO_3-N) leaching.

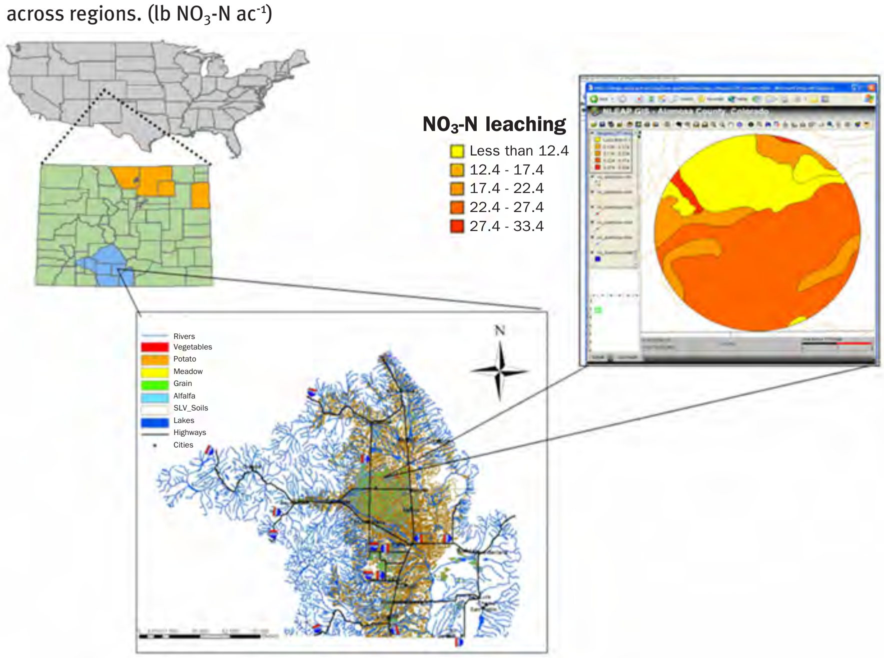


Summary and Conclusion

With new tools we can evaluate in space and time how management practices contribute to reducing offsite transport of nutrients at a field scale and linking these management practices to a watershed scale. We could use these new tools to identify landscape risk areas, helping us to make management decisions to implement conservation practices. Precision conservation will contribute to better management of our resources for air, soil, and water. As we advance with new and/or improved models, the integration from field scale to the watershed level will be easier to evaluate. There is the need to continue the development and calibration of models that can integrate all of this information. It is clear that GIS, GPS have advanced significantly during the last ten years, contributing to a more precise evaluation of natural resources and to the development of precision conservation applications. These recent advances in precision conservation provide several examples on how we can use spatial tools. These new tools for spatial analysis and statistics are changing conservation research and management. We conclude that precision conservation will use these spatial technologies to improve the conservation of our natural resources and to maintain the sustainability needed in this century.

Figure 6

A stand alone NLEAP geographic information system can be used to evaluate the effects of management practices on nitrogen (N) dynamics, transformations and nitrate-N (NO_3-N) leaching across regions. (lb NO_3-N ac^{-1})



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