Precision Conservation for Environmental Sustainability

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Abstract[1]

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 8.5 and 9.4 billion by 2025 and 2050, respectively 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.

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), 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. All this 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. This reduces 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 will also contribute to minimize that agrochemicals enter 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 were 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 the subwatershed and watershed level to reduce the amount of eroded sediment, nutrients and agrochemicals that end up in waterways. ***Precision Conservation*** as we have proposed is a set of spatial management practices that reduces soil erosion, and contributes to soil and water

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[1] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA, CSU, WSU and Denver University implies no approval of the product to the exclusion of others that may be suitable.

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, economical returns, and environmental sustainability.

Introduction

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 rich 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 want to postulate the idea that parallel improvements in ***Precision Conservation*** will also be needed to maintain the productivity of intensive agricultural systems and global sustainability.

Precision Conservation utilizes a set of technologies and procedures to link mapped variables with analytical capabilities to appropriate management actions. It requires the integration of spatial technologies: ***global positioning system*** (GPS), ***remote sensing***, 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). 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 water [surface and underground water resources]).

The 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 than those of less eroded soils. Depending on the degree of erosion, corn and soybean (*Glicine max* [L] merr.) yields can be reduced by about 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 to contribute to watershed sustainability. For example, it is important that when implementing buffers and other conservation practices we account for spatial variability of hydrological factors, agro-ecoregions, soil, hydrological properties, and other variable factors within the buffer areas to reduce the further transport of sediment. ***Precision Conservation*** and the integration of spatial technologies and analysis of spatial relationships can allow us to better account for spatial erosion variability and design of waterways, buffer, and/or other off-site conservation practices.

Management of Spatial Erosion Variability

The need to account for and to predict the spatial erosion variability has been reported (among others) by Wheeler (1990), Mitasova et al. (1995), Desmet and Govers (1996), Siegel (1996), Mitas et al.(1997) and Wang et al. (2000). These researchers acknowledge the need to account for topographic 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 Wischmeir (1974). They divided the slope into a number of irregular areas to account for specific area contributions. New technological advances in GIS, GPS, and remote sensing are facilitating the application of these complex calculations initially tried by Foster and Wischmeir (1974). Now we have algorithms that account for spatial erosion variability's 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 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 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 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 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, 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).

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 often emerges. If the relationship is strong, the regression equation can be used to predict maps of expected yield for another location or year.

Surface modeling and ***spatial data mining*** are cornerstones of the 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.

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.

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 only one rain drop 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 can be used to identify areas collecting water which may also have higher potential for denitrification rates (if finer clay soils) or higher potential for leaching rates (if coarser sandy soils). These kinds of analyses can contribute to management decisions to 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"). 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 **(Fig. 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 common sense 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. A “*map-ematical*” trick is used where the slope class map is multiplied by 10 then added to the flow class map to create a two digit code where the first digit identifies the slope class and the second digit the flow class.

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 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. 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.

Before we challenge 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 flowchart is used to summarize the model's logic and processing steps. Each map represents a step in the model's logic and each arrow represents an analysis operation. The sentences in the macro perform the model steps that derive the intermediate and final maps. This is a quick example of the potential use of GIS/GPS techniques to assess terrain and potential flow patterns.

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. The flowchart provides an effective means for communicating the processing steps to individuals with minimal GIS experience. The explicit linkage between the macro and the flowchart provides a common foothold for communication between the two perspectives—logical and code—of a GIS application. It also 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 AGNPS model (Young et al.1987) that 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. This 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 models (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 whit 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 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 that accounts for the 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 (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, 2001 b). 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 vs its gross area. In other words the riparian buffer effective area 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 can potentially 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 step with high flow “reaches” farther away.

Precision Conservation at a Site Specific field Scale

Precision farming techniques have the potential to increase agricultural production while reducing potential environmental impacts (Pierce, 1997; Bate, 2000; Lal, 2000; Delgado 2001a; Khosla et al.2002). Application of advanced technologies such as GPS, GIS, remote sensing, 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 farming 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 the US 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 economic advantage (Bausch and Delgado, 2003; Koch et al.2003).

Recent advancements that have demonstrated 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 and Koch et al. 2003). Users of ***SSMZ*** under irrigated continuous 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 also suggest that ***Precision Conservation Management Zones (PCMZ)*** may be a more viable approach with the stage of current technologies. We also want to postulate the idea that we could use ***SSMZ*** and ***PCMZ*** and that they will not necessarily overlap. We need to consider the data presented by Quine and Zhang (2002) and *previous* analyses of potential erosions (**Fig. 4**). It will probably be a combination of ***SSMZ*** and ***PCMZ*** that will maximize economic returns, resource use efficiency, and soil and water conservation practices.

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 $ha^{-1}y^{-1}$) in commercial field operations during the growing season. The Bausch and Delgado (2003) method saved 102 kg N $ha^{-1}y^{-1}$ 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 = 1.1). This remote sensing GIS/GPS tools can significantly ***maximize*** the N use 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

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. In the case of yield mapping, for example, it is now possible to transmit yield data from the combine to a base computer connected to a live Internet connection that can store, display, and analyze the data and its derivative information in real time, on-line. It is also 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. Robotic tractors are forthcoming that not only automate field operations but serve to measure ambient conditions of the soil, plant, or atmosphere as it maneuvers throughout a field. In its full expression, wireless networks will provide information on site-specific conditions in real time and allow for automated and/or remote control of field operations. Ultimately, any sensor or control device can be operated remotely and in real-time with wireless technologies.

There are many ideas of how to configure and manage a sensor and control network. Perhaps easiest to understand is the wireless Internet currently popular in Urban areas. In concept, wireless Internet provides 24/7 access to any electronic device within the coverage area that is equipped with a compatible radio. Since the bandwidth needed to communicate and transfer data from a sensor or controller is small, millions of sensors and controllers could be on-line within a given geographic area. To be successful, the remote devices must be very inexpensive, easy to deploy, and robust. A problem for agriculture is the availability of wireless networks for the low populated rural areas. Satellites may provide a partial answer but cellular phone and paging costs are still too high for real-time coverage.

New technologies appear capable of revolutionizing 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. The ultimate goal is a single-chip Mote with a volume less than a cubic millimeter and to stack Motes to facilitate more detailed applications. Called "smart dust" by their developers, Professors Kristofer Pister and Joseph Kahn of University of California at Berkeley, they are the size of specks of dust that can be scattered into the air and send back information from remote locations. Imagine the implications for ***Precision Conservation*** that smart dust may provided. Can future Motes be able to help us monitor conservation practices and inflows and outflows from fields and across natural systems and maybe even wind erosion patters? Can we use in the near future smart dust to trace specific erosion events across the watershed to obtain site specific information bout the pathways, flows, rate or transport and or erosion in a given erosion event?

Key to the self-organizing of Motes into a sensor network is the embedded software platform for Motes called TinyOS. TinyOS is an open source software platform and tool-chain developed by U. C. Berkeley and actively supported by a large community of users. There are numerous sensor applications already available with more forthcoming on the TinyOS open source web site.

Mote processor radio modules are commercially available. For example, Crossbow Technology, Inc ships three Mote Processor Radio module families that can be use in enduser and OEM applications. The newest modules provide a processor that runs TinyOS based code, two-way ISM band radio transceiver, and a logger memory capable of storing up to 100,000 measurements, feature a frequency tunable, FM radio capable with improved range, and are capable of over-air reprogramming of the Mote code. These are all great features if you desire low cost sensor web applications for agriculture.

The radios used in the Crossbow products are 433 Mhz and have a range of 500 to 1000 ft outdoors with line of sight. Using frequency hopping patterns, data are moved from one to another until they reach a base site that processes and stores the data. How these radios will perform in plant canopies will be of concern. However, Motes appear to be an inexpensive way to gather data on many aspects of crop production and processing and in tracking crops, particularly crop quality, from the field to the consumer. Motes should also greatly lower the cost of sensing and control and many are working to incorporate this technology in sensor networks of the future.

Within the last year, Intel launched a Mote project that, among other things, hopes to deliver easy to use Intel Mote sensor network kit within 2003. This should greatly increase the development of applications of Mote sensor networks for agriculture in the near future. 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.

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, DEM, GIS, GPS, and other new tools need to be incorporated to ***Precision Conservation*** models that can 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, among others, reliable weather and soil databases, remote sensing information, DEMs, 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 that will bring all of these tools together into a practical application with 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.

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Figures

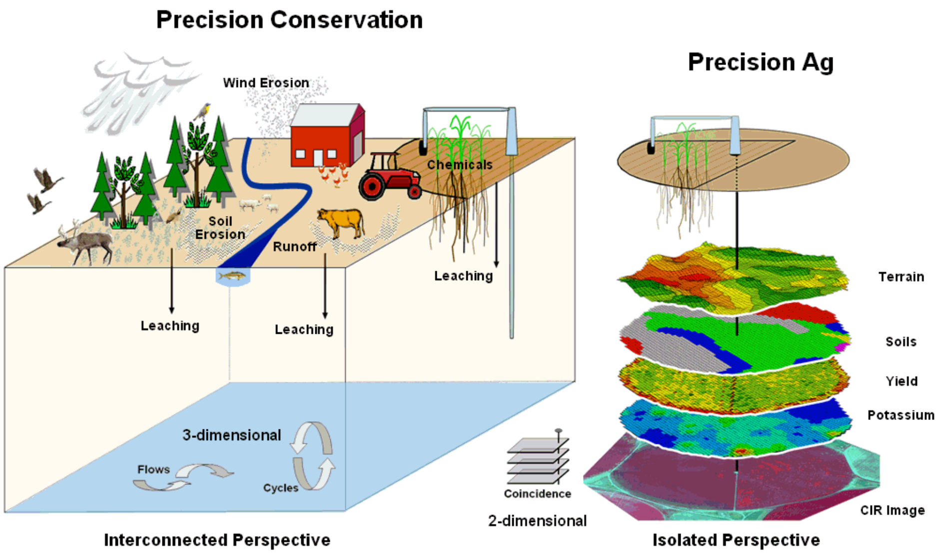

Figure 1. The site-specific approach can be expanded to a three dimensional scale approach that assess infows and outflows from fields to watershed and regional scales.

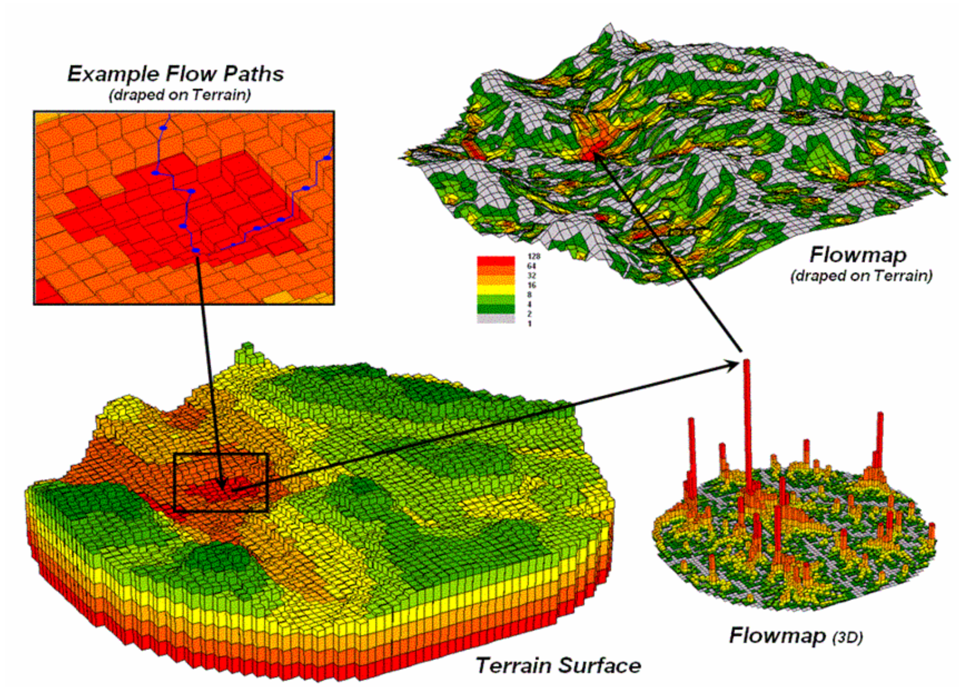

Figure 2. Map of surface flow confluence.

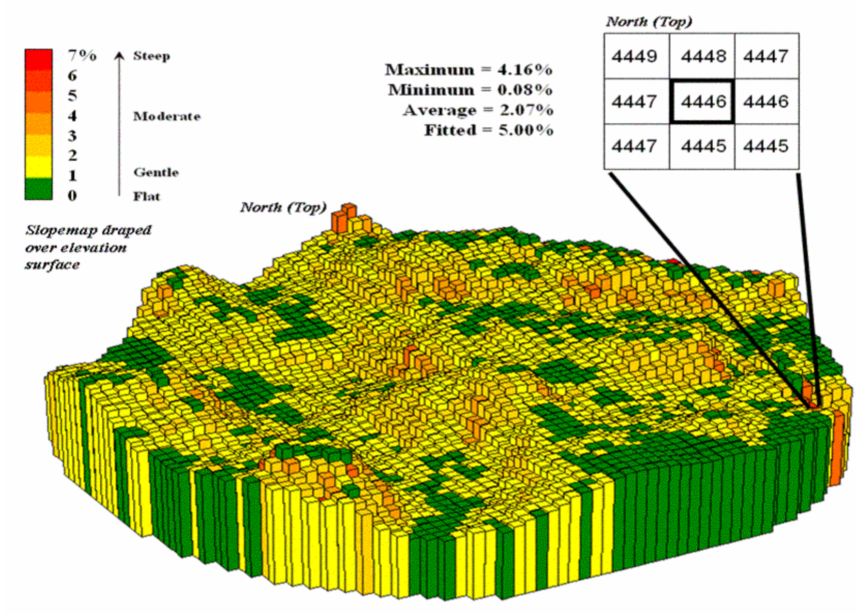

Figure 3. Calculation of slope considers the arrangement of elevation differences.

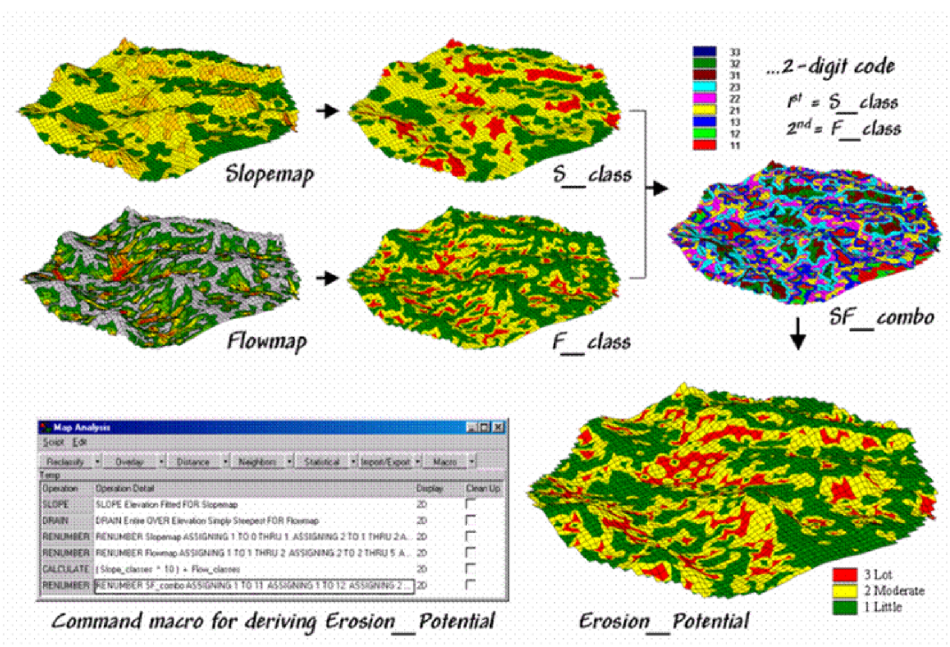

Figure 4. Areas of gentle, moderate and steep slopes (S_class) are combined with areas of light, moderate and heavy flows (F_class) into a single map (SF_combo) that is reclassified to identify areas of little, moderate and lot erosion (Erosion_potential)