EXTENDING THE CONCEPT OF PRECISION CONSERVATION TO RESTORATION OF RIVERS AND STREAMS.

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ABSTRACT

Comprehensive water quality management in watersheds involves management of upland and riparian environments. Efforts to optimize environmental performance of agriculture through field-scale precision conservation should be complemented with riparian restorations to enhance capacities to assimilate contaminants and provide other ecosystem services. This paper's objective is to illustrate GIS technologies for management of riparian systems. Across the US, many agricultural streams and rivers are still in the midst of long-term geomorphic responses to hydrologic changes that accompanied agricultural settlement. These changes include artificial drainage systems, sediment accretion in valleys, stream straightening, and decreased transpiration by crops compared to native plant communities. These changes have caused increases in nutrient loadings, discharge and/or discharge velocities, and channel down-cutting and/or stream bank erosion. Our understanding of these geomorphic processes is well developed. However our capacity to manage these processes is limited not only because of the costs involved with many types of interventions, but also because mangers lack the tools to effectively target their efforts from a watershed perspective. GIS technologies could be developed to ensure that the types of restoration practices and the locations they are implemented are chosen based on economic and geomorphic criteria, thus increasing the likelihood of positive cost-benefit outcomes from restoration efforts. This paper illustrates several examples employing LiDAR topographic data, historical aerial photographs, and field surveys. Placement of wetlands, buffers riffles, drainage modifications, bank stabilization, and re-meandering are among the suite of potential tools for improved management of hydrology, riparian ecosystems, and stream geomorphology.

Keywords: LiDAR, river restoration, wetlands, riparian practices, watershed planning, precision conservation

INTRODUCTION

Management of water quality involves upland practices that retain nutrients and sediment within agricultural fields, and riparian practices placed to trap contaminants transported from uplands and thereby protect aquatic ecosystems. Precision conservation is based on an understanding of landscape processes, and applies that understanding to target conservation efforts in both upland and riparian settings to improve conservation performance. This paper is focused on precision conservation beyond the field scale, focusing on riparian practices and river restoration efforts. Approximately $15B was spent on nearly 3700 river restoration projects in the US from 1990 into 2004, but fewer than 10% of these projects included monitoring or evaluation (Bernhardt et al., 2005). Many river restoration projects focus on short (< 1 km) reaches, increasing the likelihood that projects focus on symptoms rather than causes of river management problems. American river systems are in the midst of a long term geomorphic response to changes in hydrology and sedimentation that accompanied agricultural settlement (Simon and Rinaldi, 2006; Walter and Merritts, 2008). These changes included artificial drainage systems, accretion of sediment from upland erosion in valleys, stream straightening, and decreased transpiration from land use conversion from native perennials to annual crops. Responses of rivers have included increased discharge, greater nutrient loads, bank erosion, downcutting and widening of channels. Our understanding of these processes has increased, and there are increasing calls in the scientific literature to leverage that understanding when undertaking projects to restore rivers and their riparian and aquatic ecosystems (Florsheim et al., 2008; Wohl et al., 2005). However, a toolbox of methods for assessment and appropriate placement of restoration practices is needed to put this concept into practice. The objective of this paper is to demonstrate a set of spatial technologies that can be used to assess river corridors and their tributary systems to provide information that can be used to appropriately place restoration practices based on an understanding of river-resource management priorities, hydrologic processes, and fluvial mechanics.

The examples discussed here are from artificially drained watersheds in the US Midwest, where concerns focus around nutrient loads, increasing rates of discharge and baseflow, and channel widening and bank erosion in response to increasing discharge. Practices that reduce nutrient loadings to surface waters from agricultural watersheds can improve the health of aquatic ecosystems and could provide pollution removal credits to help establish environmental markets (Hey et al., 2005). Reconstructed wetlands are one practice that could help reach water quality goals and provide nutrient trading credits. Under some conditions, wetlands could also help attenuate peak flood discharges. We demonstrate how detailed topographic data provided by a LiDAR (Light detection and ranging) survey can be analyzed to identify candidate wetland sites.

Increased discharge associated with annual cropping and a shift towards a wetter climate (Tomer and Schilling, 2009) has resulted in channel widening in the upper Midwest, particularly where floodplain water storage capacity is diminished by historical sedimentation (Leece, 1997; Yan et al., 2010). Channel widening occurs by bank erosion, which is a natural process that cannot be prevented and can be beneficial (Florsheim et al., 2008). However, where chronic levels of bank erosion are occurring, we hypothesize it is possible to manage this process naturally using riparian vegetation. We illustrate how an approach using aerial survey data from river corridors, including LiDAR topographic data, land use information, and aerial photography and video, could be used to test this hypothesis. These two examples serve as illustrations of the types of tools that could be developed for precision management in river restoration.

METHODOLOGY

Several types of spatial information are available to help develop the concept of precision watershed management and river restoration. Two that have significant potential and that we illustrate here are LiDAR and aerial imagery. LiDAR provides detailed, accurate topographic data (Bowen and Waltermire, 2002) but there have been few reports of its utility in agricultural watersheds in the scientific literature. Here, we used a terrain analysis of LiDAR data to site potential nutrient removal wetlands in Lime Creek, a tributary draining 6500 ha of cropland to Big Bureau Creek and the Illinois River. Aerial imagery we have worked with includes sequences of historical aerial photographs and video captured from a helicopter. This work was conducted in the South Fork of the Iowa River (Simon and Klimetz, 2008; Tomer et al., 2008a,b).

Siting wetlands

Nutrient interception wetlands are advocated for tile drained lands in the Midwest in order to reduce nutrient loads to the Mississippi River and the Gulf of Mexico (Burkart and James, 1999). However such sites must be located carefully to be sized appropriately and to avoid impeding drainage from up-gradient croplands. The wetland siting work extended results from Tomer et al., (2003) in which potential sites for nutrient interception wetlands were located in Tipton Creek Iowa, a tributary to the Iowa River’s South Fork. In that study, potential sites conformed to criteria defined by Iowa’s Conservation Reserve Enhancement

Program, and were identified using 30-m grid data from USGS's National Elevation Database. Here, we located wetlands using LiDAR data under the sole constraint not to impede drainage from substantial cropland areas up gradient, nor from roadways or farmsteads. LiDAR data were acquired in early 2009 and processed to obtain a 1 m grid elevation model of the watershed. The elevation data were manipulated to remove false drainage impoundments where roads crossed channels with >100 hectares (250 acres) of contributing drainage area. LiDAR data were detailed enough to allowed depths of drainage ditches to be estimated and mapped. At 30 m (100 ft) up-gradient of each road crossing, a shallow impoundment that was 2.4 m (8 ft) above the depth of the drainage ditch was simulated and tested to determine if surface drainage would be impeded upstream to the next up-gradient road crossing. If not, and if the drainage ditch did not follow closely alongside a roadway, then a second shallower impoundment was modeled that was 0.9 m (3 ft) above the depth of the drainage ditch. The area 'ponded' by the 0.9 m impoundment gave the estimated wetland area, and the initial area impounded by the 2.4 m provided an estimated buffer area, the area where tile drainage would be impeded by the wetland. Row cropping would no longer be possible in the buffer, and hence a conservation easement would be needed for both the wetland and the buffer. The buffer 'impoundments' were finally checked to ensure that farmsteads or adjacent were not affected.

Mapping river corridor conditions

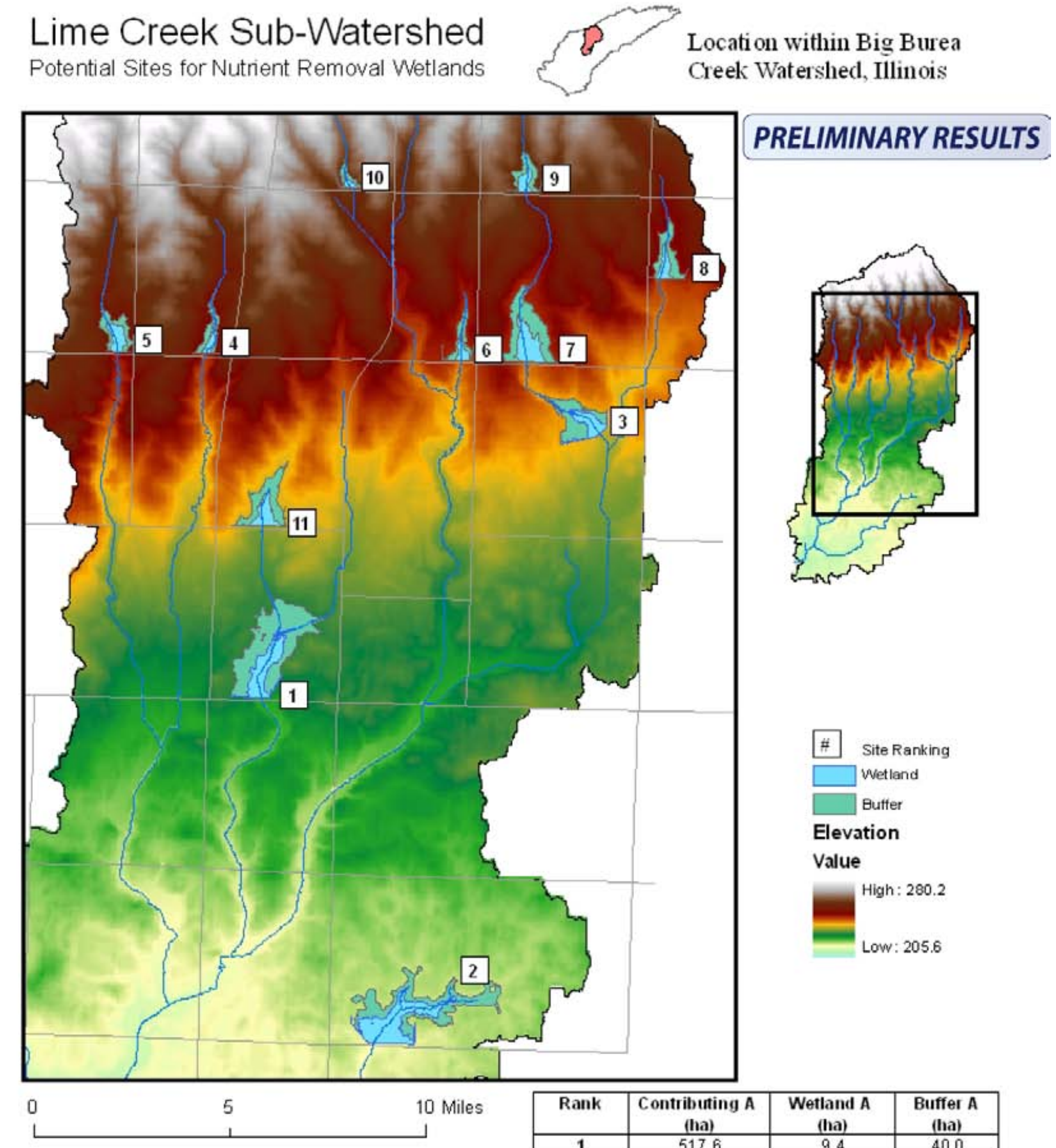
Our second illustration comes from of the South Fork of the Iowa River. Changes in the stream channels were mapped by digitizing stream courses shown in aerial photographs taken in 1939 and 2002 (Yan et al., 2010). This involved digitizing a single line down the center of the stream course. To further pursue this work, both stream banks were digitized in aerial photographs taken in 2006 and in 2008. This provided an opportunity to evaluate bank movement that resulted from significant flooding that occurred in 2008. We overlaid stream bank positions in the two years, and polygons that were formed by this overlay were classified as areas of bank accretion or of bank erosion. Results are preliminary but we can readily compare the differences in bank movement in areas under pasture and areas under conservation reserve program plantings.

In addition, we acquired helicopter video of stream bank conditions for approximately 150 km of channels in late fall of 2006 and 2008. At this writing the 2008 video imagery is still being analyzed, but analysis of the 2006 imagery was completed. Analysis of video is a process of manual interpretation of both video and maps. The 2006 imagery was evaluated for bank stability and land cover conditions near the stream edge to determine how bank stability was influenced by vegetative cover. The extent of the riparian buffer was evaluated qualitatively from aerial photographs. Accounting for the extent of the riparian cover helps to explain the distribution of stable and unstable outside banks. A simple "scale," based on observed percent cover were divided in to four categories; no buffer, minimal buffer (sparse vegetation), some buffer (<50% cover), and full buffer (100% cover).

RESULTS

Siting wetlands

The process to identify potential nutrient interception wetlands in Lime Creek in Illinois identified 11 candidate sites that could be considered for wetland reconstructions (Fig. 1). All of the wetland areas were at least 0.6% of the contributing area (and at most 4.1%). The sites were ranked according to contributing area, in descending order. The contributing-area rank was discounted if the wetland was "too large" (by 10% if 2-3% of the contributing area; 20% if 3-5% of the contributing area; larger than 5% would probably be dropped from consideration), or if the buffer area removed from production was 'too large' for the wetland (by 10% if the buffer was 2-3 times the wetland size, by 20% if 3-5 times the wetland size). These scoring deductions were arbitrary and could be adjusted, but some ranking of the sites that considers these sizing factors would be helpful if participation in a wetland program is sought through a bidding process. The results (Figure 1) are preliminary pending site visits, landowner expression of interest, and final survey and engineering design data. Results indicate that 34% of the Lime Creek watershed (2233 ha) could be serviced by nutrient removal wetlands. The 11 wetlands total 54.6 ha; including buffer areas the total is 159 ha. However, the wetland area could be reduced to 41 ha (101 ac, or <2% of the contributing area) without reducing the uplands serviced, because several possible sites share tributaries (Fig. 1). Including buffers these wetland areas sum to 5.5 percent of the contributing areas. Note that buffers would probably be removed from row-crop production, but could be converted to land uses that do not require good drainage but that can provide an economic return, including bioenergy crops, forage, and/or wildlife habitat.



Ranking of potential wetlands is based on contributing area. The contributing area score is discounted if the wetland area is too large in comparison to contributing area or if the wetland area is too small is comparison to the buffer area. See accompanying text for details.

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Rank	Contributing A (ha)	Wetland A (ha)	Buffer A (ha)
1	517.6	9.4	40.0
2	408.7	16.7	39.7
3	333.8	4.4	13.7
4	265.9	1.7	4.8
5	236.5	3.4	7.6
6	259.6	7.3	19.7
7	170.6	2.5	8.0
8	152.0	1.8	4.9
9	151.8	2.1	5.6
10	148.1	0.9	2.4
11	117.7	4.4	12.7

Figure 1. Potential sites for placement of nutrient interception wetlands, with a tentative ranking of the sites.

Mapping river corridor conditions

Evaluation of channel movement between 1939 and 2002 (Yan et al., 2010) showed that the sinuosity of two main South Fork tributaries, Tipton and Beaver Creeks, both decreased by about 17%, while that of the South Fork's main channel was only about 6%. The difference was attributed to greater efforts to straighten the two tributary streams. Evaluating historical sedimentation along the South Fork, Yan et al. (2010) also showed that bank heights were increased by an average of about 1 m due to accretion of sediment in the alluvial floodplain that originated from agricultural erosion (since about the 1850s). Accretion of sediment near the stream clearly increases the susceptibility of stream banks to erosion. It is important to realize there is a historical reason for bank instability when evaluating data on bank conditions and bank movement.

Evaluation of aerial video taken in fall 2006 showed 65% of the South Fork of the Iowa River is unstable with a large part of the outside banks mass wasting. This can be attributed to either the land use adjacent to the river banks, or the degree of vegetative buffer zones along the bank tops themselves (Fig. 2) Sites containing a full buffer zone had 83% of their sites without dominant (<50%) mass wasting, around 67% of them had less then 25% of the outside banks failing. Sites with no buffer, minimal buffer, and some buffer all had a majority of their outside banks failing. All categories without a full buffer zone had less then 20% of their outside banks with stable banks. It is important to note that 17% of banks under full cover had dominant (>75%) wasting of banks (Fig. 2), which highlights bank erosion is a natural process and that cover of vegetation may only reduce chronic rates of bank erosion, rather than halt bank erosion.

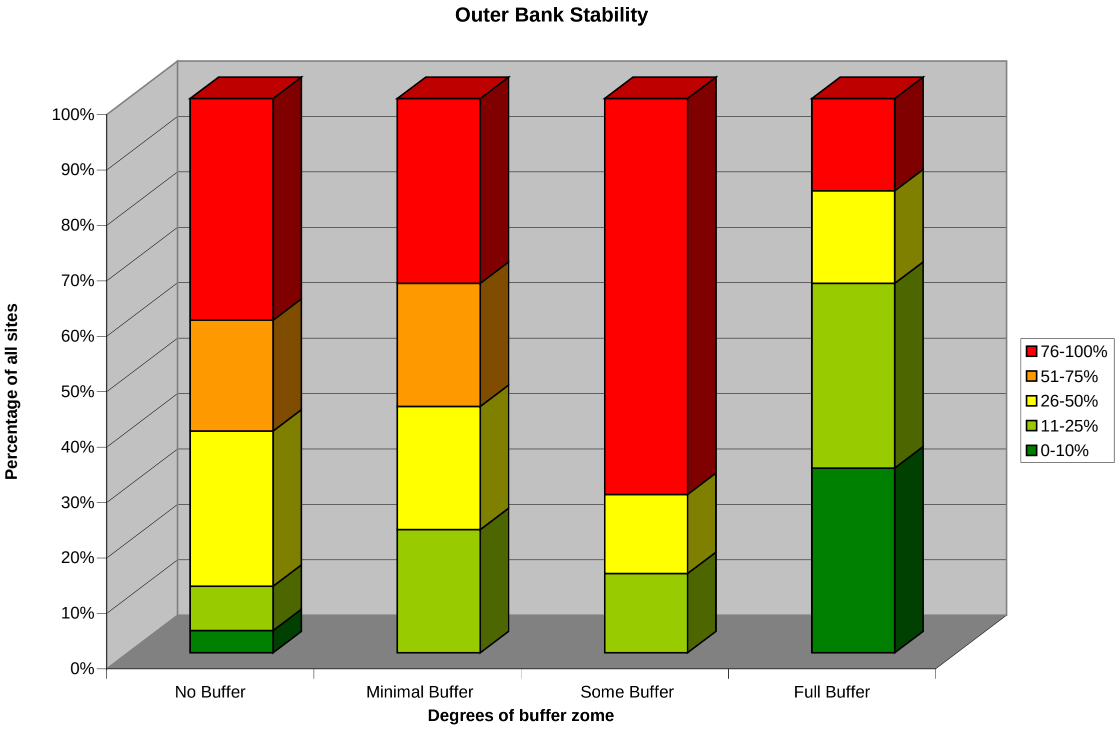

Figure 2. Proportion of outer (cut) banks that were actively eroding along the South Fork Iowa River in fall 2006, under different amounts of vegetative cover (buffer). No and minimal buffer indicate where bank vegetation was fully or nearly denuded, often due to heavy grazing or farming. Some buffer indicates at least 50% cover, while full buffer indicates 100% cover.

The importance of vegetative cover in determining bank stability is further highlighted by comparing maps of bank movement between 2006 and 2008 at two sites, one under Conservation Reserve Program (CRP) cover and the other under continuous (non-rotational) summer grazing (Fig. 3). Most of the bank movement observed during these two years would have occurred during large floods that occurred during June 2008 and resulted in the closure of every bridge crossing Tipton Creek. It is clear from the comparison that non-grazed grass cover provided protection from bank failure very high flows.

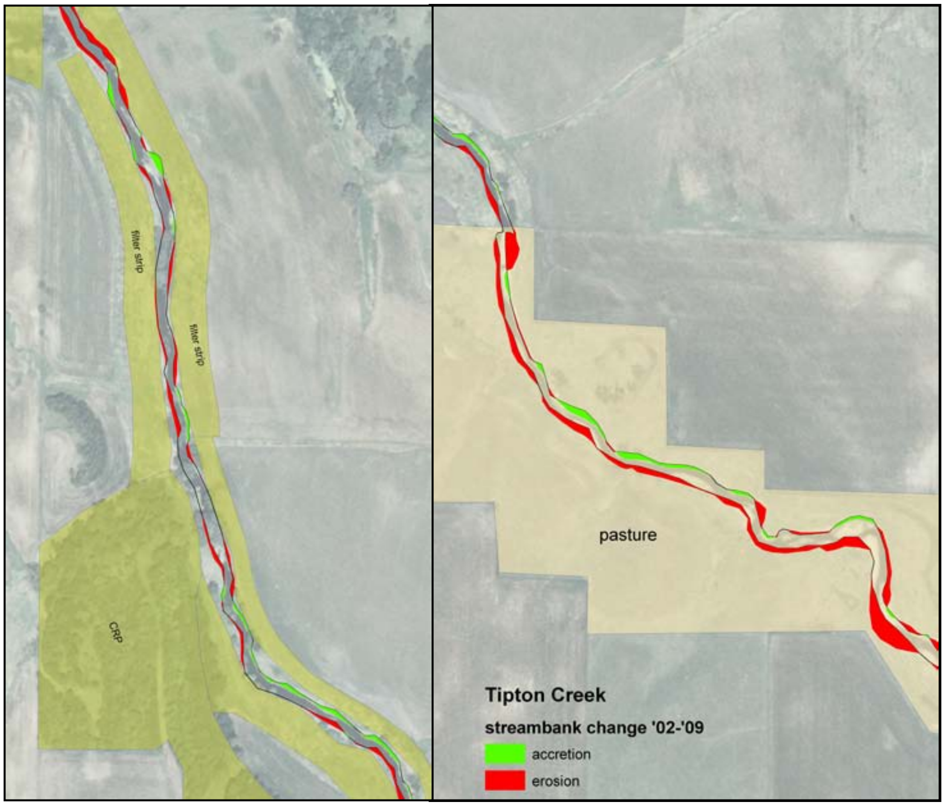

Figure 3. Contrasting amounts of bank movement resulting from 2008 floods in an area under conservation reserve program (CRP) cover (left, showing little bank movement), versus land use under continuously grazed pasture (right, showing wide areas of bank lost. Tipton Creek is a tributary to the South Fork of the Iowa River. (Scale: 800 m from top to bottom of photos)

CONCLUDING DISCUSSION

River restoration projects should be aimed to understand and manage natural processes throughout the entire river network including tributary and headwater streams (Wohl et al., 2005). These examples from tile-drained Midwest watersheds provide just a glimpse of the many different ways that geographic data sources and analyses could be brought together to inform on river management needs, and provide alternatives to identify, prioritize and place restoration practices appropriately within the river system.

Riparian zones are a small but critical fraction of the landscape that regulate nutrient flows, water regimen, and provide ecological function and biological diversity. Many different practices can be placed within river networks to restore or enhance these functions. Nutrient removal wetlands offer the possibility to restore nutrient processing and other ecological functions on agricultural landscapes. Our results show how new sources of terrain data can help identify sites to restore wetland function in agricultural working landscapes efficiently. Understanding historical changes to rivers may be critical to managing current bank conditions and riparian land use in the context of long term changes that rivers are undergoing, in response to a legacy of human impacts (Florshiem et al., 2008; Walter and Merritts, 2008). Geographic analyses can help us document changes in stream courses, channel widths, sinuosity and stream gradients along a river course, ensuring that we can apply an understanding of river processes to predict secondary responses to management actions being considered.

LiDAR offers a potentially powerful tool to document current channel and river network conditions, while aerial imagery can be used document current cover conditions and, where historical sequences are available, understand how the river has changed historically. We are investigating the utility of mapping bank heights and stream gradients with LiDAR data, which could simplify tasks such as identifying appropriate lengths of drainage ditches that could be converted to two-stage ditches (NRCS, 2007), and evaluating and mitigating ongoing impacts along and below straightened (and hence steepened) channel reaches. We hypothesize tools could be developed to bring geographic analyses, ecological assessment, and engineering design together for more holistic river management.

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