# Attenuating Excessive Sediment and Loss of Biotic Habitat in an Intensively Managed Midwestern Agricultural Watershed

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## Abstract
Portions of the 700 km$^2$ Elm Creek watershed in southern Minnesota have undergone watershed and channel improvements over the past decade to mitigate turbidity and biota impairment. Increased row cropping, artificial drainage, channel modifications and precipitation have cumulatively contributed to impairment and channel instability. Uplands that were once a prairie pothole landscape are now predominately drained corn-soybean fields, providing little hydrologic storage and sediment attenuation during peak runoff. Riparian degradation and channel discontinuity characterize much of lower Elm Creek. Wetlands have been restored in the upper watershed to reduce runoff and nutrient loading from croplands. Downstream, a 750 meter riparian corridor of Elm Creek was restored and the channel improved by oxbow reconnection, bluff and streambank protection. Monitoring will document erosion and sediment deposition within the reach and Index of Biotic Integrity (IBI) data will be collected to characterize fish and invertebrate communities in the stream.

## Introduction
Elm Creek is a tributary of the Blue Earth River (BER) which is the major contributor of nutrients and sediment to the Minnesota River Basin (MPCA 1994; Quade 2000; Magner et al. 2000) that is listed as impaired for nutrients and turbidity by the MPCA (2008). The 700 km$^2$ Elm Creek watershed has been the focus of several watershed management studies over nearly a decade to investigate methods of mitigating agricultural non-point source pollution. Elm Creek is impaired for turbidity and biota and is on the EPA 303(d) list. Intensive agriculture in the Blue Earth River Basin (BERB) is the major cause of turbidity and biota impairment. Reducing sediment and turbidity levels is important, not only to meet water quality standards, but to improve habitat of fish and aquatic organisms and to enhance aesthetic and recreational values (Newcombe and Jensen 1996; Zimmerman et al. 2003).

Over the past century, large-scale land cover change, drainage intensification and climate change have increased streamflow (Novotny and Stefan 2007), consequently increasing sediment supply and contributing to loss of fish habitat to Elm Creek. Although it is often assumed that land-use change occurred predominantly in the late 19th century, in fact there have been substantial land-use and drainage changes since 1980 with a large decline in perennial plant covers in favor of annual row crops. In Martin County, where the majority of Elm Creek lays, soybean acreage increased by two and half times and corn increased by one-third in the last half century, while hay fell to 1/7 of its 1960 land coverage. At the same time pasture land declined and cattle grazing occurs largely in riparian areas. Over 90% of the pre-European settlement wetland area has been drained; only 2% of the landscape in Martin County is covered by wetlands today. Consequently, uplands offer little opportunity for spring water storage and sediment attenuation during the season of typical peak runoff.

In addition to changes in the uplands, increased discharge and direct channel modifications have contributed to increased rates of channel adjustment. Channel straightening and widespread channelization at road crossings have exacerbated channel instability, contributing to entrenchment which leads to increased rates of bank collapse followed by channel widening as described in the Channel Evolution Model (Schumm et al. 1984). Although there likely will be an eventual return to equilibrium, stream channels in the Elm Creek basin remain largely unconnected to their floodplain (Lenhart 2008).

Excess sediment causes numerous ecological problems and contributes to filling of Lake Pepin on the Mississippi River (Waters 1995; Engstrom et al. 2009). Accumulation of fine sediment on the streambed decreases the diversity of biotic communities by burying coarse bed materials with fine sediment. This embeddedness reduces the heterogeneity of the streambed and niche availability for fish and invertebrates impacting colonization, feeding and shelter. In addition, woody debris, loss of habitat structure, and intermittent streamflow may contribute to low biotic integrity as well.

Sediment in Elm Creek originates from a combination of field and channel sources, although the exact percentages are unknown. Field erosion is a major contributor of sediment, although erosion rates have decreased since the early 20th Century (Knox 1977). Further reducing the impact of field erosion relative to channel erosion on downstream water bodies is the low sediment delivery rate of fields distant from streams compared to stream channel erosion (USEPA 1980). Much of the eroded field sediment is stored as *cumulic* soils on the toe of hillslopes, on floodplains and other low, accumulation spots on the landscape (Beach 1994). Channel erosion consists of both streambank erosion (defined by the active channel border) and bluff erosion, where the stream meanders into valley walls.

**Project Description**

Numerous projects have been implemented in the Elm Creek watershed to reduce excess sediment delivery to streams. The two projects in this study included wetland-perennial plant restoration in two watersheds located in the upper half of the basin and a multipurpose riparian restoration site in the lower third of the basin (Figure 1). Land-use is in the Elm Creek watershed is 85-90% row crop agriculture.

The upland project initiated in 2004 and 2005 restored 30-40 ha wetlands in combination with planting of mixed prairies grasses, shrubs, and trees in small watersheds ranging from 400-500ha. Their purpose was to capture rapid runoff from cultivated fields, reduce sediment carried to downstream waterbodies and remove excess nutrients (Lenhart 2008).

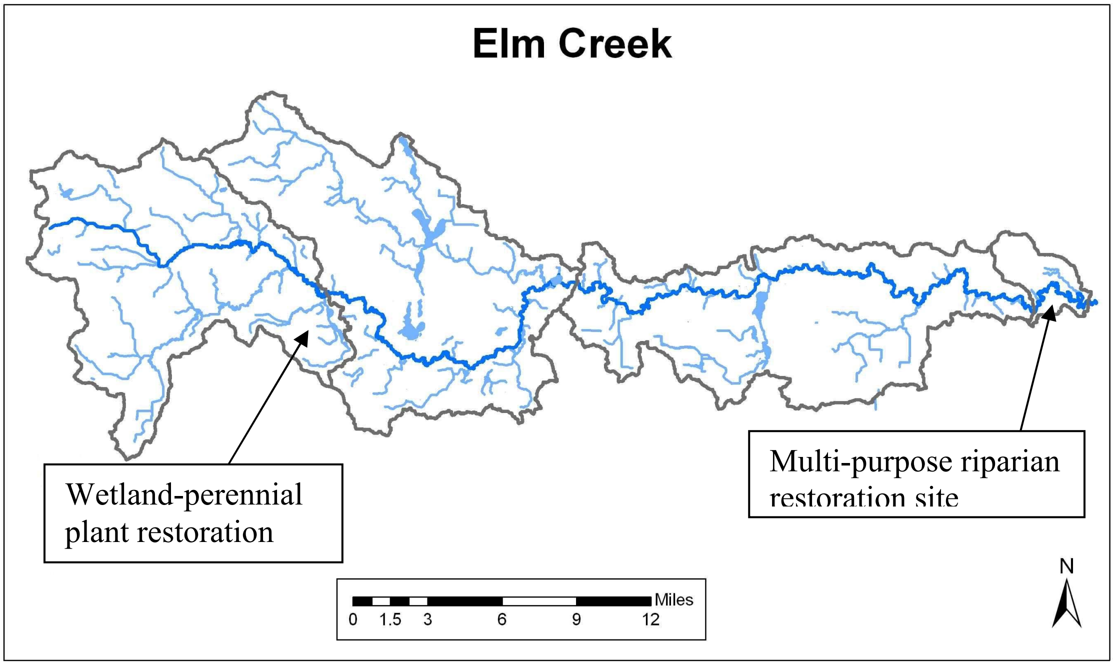


**Figure 1.** Location of projects in the Elm Creek watershed in southern Minnesota.

In the lower Elm Creek site, characterized by streambank instability and an entrenched channel with little floodplain connectivity, 750 meters of the riparian corridor were restored using an approach that integrated multifunctional agriculture with ecological restoration (Boody et al. 2005; Schultz et al. 2004). The project included floodplain reconnection by diversion of high flow into an oxbow, bluff and streambank protection and improved riparian grazing/vegetative management. The riparian corridor in the lower Elm Creek contains a well-defined valley that is principally used for grazing. Due to the cost and limited supply of large rock in southern Minnesota, large trees (cottonwood cut from the project site) were used to create in-channel fish structure and protect banks and bluffs from erosion. Coupled with channel re-shaping and willow plantings, the riparian terrace was planted to perennial forbs and grasses and fenced to limit the duration of cattle grazing in any given area. Rotational grazing is planned but has not been implemented to date. High value hardwood trees (white oak and black cherry) will be planted in the upper terraces with an alley-cropping systems of forbs and grasses with rows of willow and hybrid poplar at selected locations in the floodplain and terrace to demonstrate alternatives to row crops.

## Methods

We investigated sources of sediment in the Elm Creek basin through hydrologic and geomorphic studies at multiple scales, ranging from small, 2 $km^2$ headwater watersheds to the mouth of the 700 $km^2$ basin. Sediment reduction strategies were assessed at the restored wetland sites where field erosion was the major sediment source and at a riparian-corridor restoration project in lower Elm Creek, where channel erosion was the major source.

1. *Upper Elm Creek watershed study*

Hydrologic, sediment and nutrient data were collected at the sites of two restored wetlands, SHEEK (an acronym for the owners' names) and Kittleson. Flow was measured from surface channels and large subsurface tile pipes. Inflowing and outflowing sediment was measured as total suspended solids (TSS). Data were collected from 2005-2008, although the 2008-09 period analysis is not complete.

2. *In-stream sediment and geomorphology studies*

TSS, turbidity and organic matter data were collected at ten monitoring stations located across the Elm Creek basin in conjunction with stream geomorphology surveys conducted in Elm and Center Creeks from 2005-2007. This study is described in detail in Lenhart et al. (2009) and is not discussed here.

A series of geomorphic surveys were conducted between 2005-2007, identifying high rates of channel erosion as a major source of sediment in the lower main channel of Elm Creek(primarily through widening) (Lenhart 2008). This led to the identification of a riparian corridor restoration demonstration site and the implementation of an EPA 319 grant to address these issues.

3. *Riparian corridor management study*

Post-restoration monitoring will include surveys to document channel migration over time as well as deposition in the floodplain in 2010-2011. Equipment was installed to monitor sediment loss from bank erosion and sediment deposition on point bars and floodplains. Bank erosion pins, made of steel rebar were installed at three monitoring locations across the stream reach in 2008. Sediment deposition monitoring pads, consisting of clay pads enclosed by a wooden frame were placed at three different elevations, an active point bar, a bench at the 1-2 year flood elevation and the back-channel or oxbow that was reconnected in the project. Overbank flood frequency was estimated using stream gage data from 2002-2008, 2.6 river kilometers upstream of the demonstration site. Historic channel migration rates were estimated using 1938 aerial photos to obtain an estimate of long-term background rates of bank erosion. Index of biotic integrity data is being collected to characterize fish and invertebrate community diversity in Elm Creek. Biomass and productivity of the newly planted perennial crops will be monitored annually.

## Results

*1. Upper Elm Creek small watershed studies*

The two wetland complexes, SHEEK and Kittleson, greatly reduced peak flows and sediment load from their contributing watersheds. Peak discharge from adjacent farmland, carrying the majority of the sediment load, up to 1.5 $m^3$/second (cms) was reduced by 85%, while runoff from small storms, (rainfalls less than 5.0 cm per day), was reduced nearly 100%. TSS removal exceeded 90% for both wetlands, although the SHEEK wetland was more effective at reducing TSS and nitrogen, exporting less than 50% of the TSS exported by the Kittleson wetland, despite similarity in wetland and watershed size, restoration design and location (Figure 2). SHEEK likewise exhibited low levels of TSS in the discharge. TSS in wetland outflow was greatly reduced, compared to inflowing concentrations, with a flow-weighted mean concentration of 12.6 and 10.3 mg/l in 2005 and 2006 mg/l. 33% of samples contained no detectable TSS. TSS exported from the Kittleson wetland in 2005 (24.3 tons) represented less than 5% of the estimated inflowing TSS load (based on Universal Soil Loss Equation calculations), for a removal efficiency of greater than 95%. While inflowing TSS was predominantly inorganic sediment, TSS exiting the wetland contained large amounts of organic matter, particularly as primary productivity increased in late summer. Suspended volatile solids (SVS), (a measure of organic matter mass), comprised 13 to 100% of TSS in summer and fall outflow.

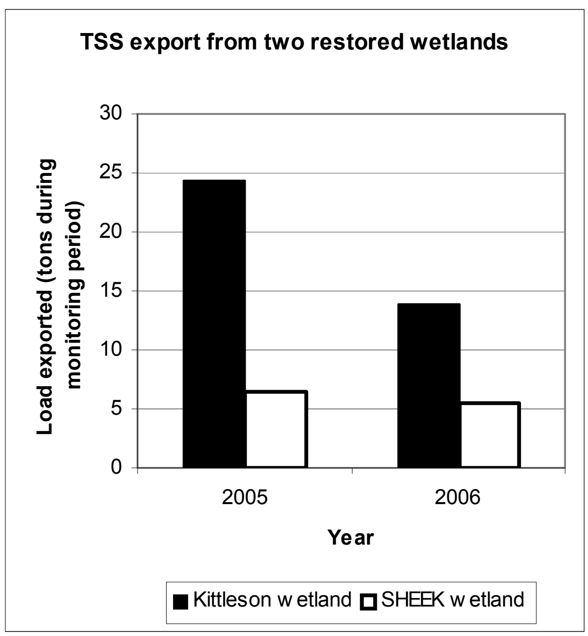


**Figure 2:** Sediment discharge (approximated by tons of TSS) from two restored wetland-perennial vegetation complexes from March-November of 2005-2006. While both removed approximately 90% of incoming inorganic sediment, the SHEEK wetland (white) was more effective, due to its two-cell design and a larger total storage volume to drainage area ratio.

*2. In-stream sediment processing: sources and sinks*
Both turbidity and TSS levels increased moving in a downstream direction, though the increase was very non-linear at high flows. Elm Creek flows through Creek Lake, which acts as both a sediment source and a sink, depending on flow conditions. Downstream of the lake, turbidity was greatly increased. Since the lake is filled with much sediment, it is not that effective at trapping sediment. At high flows sediment is re-mobilized contributing to downstream sediment loads, with deposition occurring as flow drops off. Downstream of Creek Lake, the drainage area increases considerably with a resultant increase in stream power, bank height and sediment loading from streambanks in the vicinity of the stream restoration demonstration site.

In many Elm Creek reaches, fine sediment has accumulated on top of the streambed, with an average depth of 0.33 meters measured at all survey sites. The sites with the most fine sediment aggradation were located in over-widened ditches and reaches upstream of wetlands and lakes. Aggradation of fine sediment is thought to impact biotic habitat by burying coarse bed material needed by fish for spawning and feeding. However little biotic data is available in Elm Creek to verify the impacts of fine sediment on IBI scores.

*3. Riparian corridor management study in lower Elm Creek*
The restoration project altered the sediment budget for this reach by decreasing the most extreme rates of outer bend erosion (exceeding 1.8m/year) and increasing floodplain deposition by the re-establishment of a bench at the bankfull elevation in the formerly entrenched channel and the reconnection of the back-channel oxbow (Table 1). Based on preliminary estimates, streambank erosion exceeds floodplain deposition within the reach by hundreds of tons per year indicating that the channel is a net source of sediment in this reach. Prior to the restoration project, flooding of the back-channel oxbow occurred approximately every 5 years while now it is every 1 to 2 years based on flood frequency calculations from the nearest stream gage. Based on preliminary estimates, deposition on the bankfull bench removes less sediment than the side channel oxbow because of a smaller depositional surface area. These estimates will evolve over time as further monitoring data becomes available.

**Table 1.** Estimated changes to sediment budget at the stream restoration demonstration site, a 750m reach in lower Elm Creek, Minnesota.

| **Sediment source** | **Pre-project rate (tons/yr) for reach** | **Post-project rate (tons/yr) for reach** |
|---|---|---|
| Streambank erosion rate within study reach (outer bends) | 500 – 5000 | 1000-3000 |
| Side-channel deposition | <300 | 500-1500 |
| Bankfull bench deposition | 0 | >100 – 200 |

* *Based on preliminary calculations from bank erosion pin monitoring from 2008-2009 and sediment deposition on clay monitoring pads since August 2009.*

The restoration also increased stream sinuosity at high flows and introduced additional large woody debris to the stream, providing additional habitat structure for fish and invertebrates. No biotic measurements have been made, but are planned for 2010-2011.

**Discussion**
The Elm Creek sediment reduction projects demonstrate how optimal sediment attenuation practices vary by watershed position and sediment sources. In the headwaters, where a greater proportion of the total sediment load comes from field erosion, the wetland-perennial plant complexes were very effective at removing sediment from agricultural runoff. The wetlands reduced outgoing sediment loads by as much as 90%, although they were net sources of organic matter that contributed slightly to turbidity and TSS loads downstream. The wetlands varied in effectiveness due to wetland design and the storage volume/watershed drainage area ratio. The SHEEK wetland contained a large back basin, up to 3 meters deep that provided an additional settling basin before emptying into a smaller wetland that then discharged downstream.

Generally, if wetlands are situated strategically on the landscape with a sufficiently large storage volume to contributing drainage area ratio, they should be effective sediment reduction tools in the Blue Earth Basin of Minnesota and similar watersheds in the upper Midwestern United States. The main challenge with using wetland restoration as a tool for sediment attenuation is the number and land area of wetlands that would be required to reduce sediment measurably at the mouth of larger river basins, such as the Blue Earth, Minnesota and Mississippi Rivers. Lack of funding for large-scale wetland restoration and expansion of perennial vegetation cover (both native species and crops) is a barrier to as well.

Moving downstream, past the Creek Lake watershed merger on Elm Creek, channel erosion becomes a larger source of sediment in relation to field erosion with increasing bank erosion hazard and occasional bluff erosion. The riparian corridor demonstration site was designed to address downstream, in-channel sediment sources and enhance floodplain connectivity. While preliminary indications are that it has been successful at doing so, there are problems with attempting to control channel erosion both from a technical and financial standpoint. Streambank restoration projects can be very expensive, often totaling $100,000s of dollars. In comparison this project cost $30,000 for construction plus donated staff time from government and university staff. Stream restoration sites need to be selected carefully, and if intended for sediment reduction, should target large bluffs and outer stream bends that are large net sediment sources. This raises the question of what is “natural” or typical for a rate of bank erosion in this region, which can be addressed through measuring long-term bank erosion rates using historic aerial photo and map measurements.

Despite some difficulties, streambank and bluff erosion control projects have several advantages over field erosion control purely from the standpoint of reducing sediment to downstream waters. Riparian corridor restoration projects directly address the sediment sources with the highest sediment delivery rate to streams, since nearly 100% of eroded streambank sediment is delivered to a stream. In contrast, field erosion in southern Minnesota often has a sediment delivery ratio of <10% - 35% (Beech 1994). Therefore, although streambank erosion projects are more costly per project than individual field erosion control measures, they could be more cost effective at removing sediment if viewed as the cost per ton of sediment removed from downstream rivers. Perhaps more importantly there is increasing evidence that channels are the main source of sediment in the Minnesota River basin (Thoma et al. 2005; Engstrom et al. 2009; Gran et al. 2009) demanding that more work to be done to control channel erosion from both streambanks and bluffs.

**Stream Biota Issues**

Excess sediment has numerous detrimental biological impacts in streams (Waters 1995), including increased turbidity as well and embeddedness of coarse streambed materials needed for spawning and other life cycle functions of aquatic organisms. While little is currently known on the direct effect of bedded sediment on fish and invertebrate IBI scores, more will be known in upcoming years. Biotic diversity will only become more important in Minnesota, as the Minnesota Pollution Control Agency is moving towards biotic standards for streams, away from the traditional chemical and nutrient standards. Consequently future river restoration projects will more often be required to directly show improvements to fish and invertebrates IBIs.

**Conclusion**

Much has been learned from the Elm Creek studies about the effectiveness of restored wetland-perennial plant complexes and stream restoration for sediment yield reduction. Both can be effective sediment attenuation tools if designed properly and placed strategically in the right landscape position. Yet, many unanswered questions remain. Data on sediment delivery ratios is needed at different scales ranging from the headwaters to larger basins (10,000s $km^2$) to plan the optimal location for sediment attenuation practices. Clearly, soil conservation practices in flat fields that are distant from the main channel will have less immediate impact on stream sediment load, although they could be justified for sustaining soil productivity. Less is known about the effectiveness of different stream restoration techniques, such as root wad revetments, streambank bioengineering and side-channel reconnection. The sediment and nutrient reduction of these practices needs to be better quantified in terms of net load reduction as well as cost per mass of sediment or nutrient removed. Ongoing work at the Elm Creek demonstration site will help provide answers to some of these questions. However, further research aimed at quantifying the cost-benefit of stream restoration practices for stream biotic integrity improvement will become more essential as the State of Minnesota makes stream IBI a higher priority.

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