2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Demonstrating Benefits of Conservation Grasslands on Water Quality
PROJECT MANAGER: James E. Almendinger
AFFILIATION: Science Museum of Minnesota, St. Croix Watershed Research Station
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WEBSITE: www.smm.org/scwrs/
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 5(d)

APPROPRIATION AMOUNT: $374,000

Overall Project Outcome and Results

This study used sediment accumulation rates in 26 lakes in southern and western Minnesota as a measure of the delivery of eroded soil and phosphorus from watershed uplands to the lakes. Accumulation rates were calculated for the periods 1963-1986 and 1986-2007 to characterize sediment and phosphorus delivery before and after 1986, when many agricultural lands were converted to grasslands as part of the Conservation Reserve Program (CRP). Inorganic sediment accumulation rates decreased with increasing area of conservation grassland in the watershed. This linear relation explained only about 20% of the variance, leaving substantial unexplained scatter. The relation predicted that sediment accumulation would decrease by 3-4% for every 10% of cropland converted to grassland. Consideration of wetland sediment traps within the watershed did not measurably improve the relationship, nor did consideration of soil erodibility, slope, or flow accumulation factors. The decrease in sediment phosphorus accumulation rates as a function of increasing grassland area was not statistically significant at the $p = 0.05$ level. Diatom analyses demonstrated biotic change in selected lakes over time. In two of these lakes the change appeared to be driven by lake-water phosphorus concentrations, which declined in the post-1986 period perhaps in response to increased grassland area. In the absence of substantial land-cover change, inorganic sediment accumulation increased by about 20% and sediment phosphorus increased by about 35%, indicating that other factors were influential. These factors could include changes in annual rainfall, artificial drainage, in-lake sediment transport processes, and lag effects in transport from uplands to lowlands.

We conclude that this study demonstrated a fundamental incoherence between field-scale parameters influencing erosion and watershed-scale measurements of erosion. We recognize the fundamental importance of the empirical plot-scale studies that have quantified the effects of erodibility, slope, flow length, land cover, and other factors on erosion and nutrient transport. Yet, the complexities of transport paths between field and receiving waters make watershed-scale erosion highly variable and difficult to predict. Use of plot-scale parameters without modification to predict watershed-scale sediment yields is inappropriate. We need better understanding to re-scale such parameters appropriately, which can only be achieved by intensive studies that bridge the intermediate scales between fields and watersheds. New data sets, especially improved topographic data from LiDAR, will help with this effort. However, nothing can replace the actual measurement of sediment yield at different scales, which will provide the necessary constraints for theoretical equations to give realistic results.

Project Results Use and Dissemination

- An interpretive summary report will be downloadable from the Museum web site.
- A short (2-4 pp.) fact sheet likewise will be downloadable from the Museum web site, with hardcopies made available as requested.
- Results will be published in the academic peer-reviewed literature.

Trust Fund 2007 Work Program Final Report

Date of Report: 16 August 2010
Final Report
Date of Work program Approval: 5 June 2007
Project Completion Date: 30 June 2010

I. PROJECT TITLE:

Demonstrating Benefits of Conservation Grasslands on Water Quality

Project Manager: James E. Almendinger
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Web Page address: www.smm.org/scwrs/

Location: central southern Minnesota; see attached map for potential study counties

Total Trust Fund Project Budget:			
	Trust Fund Appropriation:	**$**	**374,000**
	Minus Amount Spent:	**$**	**374,000**
	Equal Balance:	**$**	**0**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 5(d).

Appropriation Language:
(d) Demonstrating Benefits of Conservation Grasslands on Water Quality
$374,000 is from the trust fund to the Science Museum of Minnesota to assess the long-term benefits of conservation grasslands in reducing sediment and nutrient loads through quantitative lake sediment analysis in small watersheds with different grassland acreages. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. and III. FINAL PROJECT SUMMARY:

This study used sediment accumulation rates in 26 lakes in southern and western Minnesota as a measure of the delivery of eroded soil and phosphorus from watershed uplands to the lakes. Accumulation rates were calculated for the periods 1963-1986 and 1986-2007 to characterize sediment and phosphorus delivery before and after 1986, when many agricultural lands were converted to grasslands as part of the Conservation Reserve Program (CRP). Inorganic sediment accumulation rates decreased with increasing area of conservation grassland in the watershed.

This linear relation explained only about 20% of the variance, leaving substantial unexplained scatter. The relation predicted that sediment accumulation would decrease by 3-4% for every 10% of cropland converted to grassland. Consideration of wetland sediment traps within the watershed did not measurably improve the relationship, nor did consideration of soil erodibility, slope, or flow accumulation factors. The decrease in sediment phosphorus accumulation rates as a function of increasing grassland area was not statistically significant at the $p = 0.05$ level. Diatom analyses demonstrated biotic change in selected lakes over time. In two of these lakes the change appeared to be driven by lake-water phosphorus concentrations, which declined in the post-1986 period perhaps in response to increased grassland area. In the absence of substantial land-cover change, inorganic sediment accumulation increased by about 20% and sediment phosphorus increased by about 35%, indicating that other factors were influential. These factors could include changes in annual rainfall, artificial drainage, in-lake sediment transport processes, and lag effects in transport from uplands to lowlands.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Water-quality benefits of conservation grasslands

Description:

To measure how water quality may have been improved by the replacement of cropland by grassland, we compared watershed-scale erosion before and after 1986, the first year of the Conservation Reserve Program. Because lakes trap most of the sediment that erodes in their watersheds, we used lake-sediment accumulation as a measure of watershed-scale erosion. We also explored how phosphorus in lake sediment might provide a similar measure of watershed-scale transport from fields to receiving waters.

In using lake sediment accumulation as a measure of watershed scale erosion, we put forth the following three hypotheses:

- Hypothesis (1): Lake sediment and phosphorus accumulation rates (and therefore landscape erosion rates) were lowest under natural prairie conditions, increased dramatically from 20th century agriculture practices, and decreased somewhat after the establishment of conservation grasslands.
- Hypothesis (2): Reductions in lake sediment and phosphorus accumulation rates accrued by establishment of conservation grasslands can be related primarily (a) to areal extent of these grasslands and other perennial vegetation, and (b) to the location of these vegetation units relative to overland flow paths from the uplands to the lake.
- Hypothesis (3): The algal community in the lakes has responded over time to phosphorus loading and will therefore be related to phosphorus accumulation rates in the sediment.

To test these hypotheses, we selected 26 lakes in small watersheds with different acreages of conservation grasslands. Sediment and phosphorus accumulation rates were measured in each lake via the analysis of lake sediment cores, thereby addressing Hypotheses (1) and (2). Five lakes were selected for analysis of sedimentary diatoms, a type of algae sensitive to phosphorus and well-preserved in lake sediments, thereby addressing Hypothesis (3). Results helped determine the degree to which agriculture has impacted landscape erosion and lake eutrophication, and how much the establishment of conservation grasslands may have improved the situation.

The project consisted of five tasks plus report preparation:

Task 1, Site Selection and Fieldwork: Site selection required significant review of available digital data to choose appropriate study lakes. Out of more than 40,000 open-water bodies in the 44-county study area in the southwestern half of Minnesota, we chose 20 lakes that had significant areas of CRP grassland in their watersheds. Six other lake watersheds with virtually no grassland were included as a contrast. One sediment core was collected from near the center of each lake, with the goal of collecting sediment dating back to the 1800s if possible.

Task 2, Sediment Analyses: Sediments were analyzed to separate the components that originated within the lake (organic matter and calcium carbonate) from those that eroded from the watershed. Radiometric methods were used to date the cores, which allowed us to calculate the rate of lake-sediment accumulation for eroded material for selected periods of time. Analysis of sediment phosphorus allowed a parallel calculation of phosphorus accumulation rates as well.

Task 3, Diatom Analyses: Five lakes were analyzed for sedimentary diatom remains to estimate past lake-water phosphorus concentrations. The time-consuming and specialized nature of diatom analysis precluded analysis of more lakes.

Task 4, Spatial Data Analyses: Lake watersheds were analyzed with geographic information system (GIS) software for two principal purposes. First, the landscape was topographically analyzed to determine the contributing areas for water and sediment, taking into account that some landscape depressions (identified with open water or wetland vegetation in aerial photographs) may trap some runoff-borne sediment that was otherwise bound for the lake. Second, land uses in the so-identified contributing areas were analyzed to determine their area and location for selected time periods. In particular, how much of the cropland in the watershed was replaced with grassland after 1986, and were those grasslands located in places where erosion would be stanched?

Task 5, Data Synthesis: Here, we related the changes in the rates of lake-sediment accumulation to the changes in land use (as cropland was converted to grassland), from before to after 1986, when the Conservation Reserve Program was effective. That is, how much did sediment accumulation change from before to after 1986? How much did land use (conversion of cropland to grassland) change from before to after 1986? How did the change in sediment accumulation rate relate to the change in land use?

We summarize the results of our findings below in the Final Report Summary section and have produced an interpretive report that discusses the methods, results, and conclusions in greater detail.

Summary Budget Information for Result 1:			
	Trust Fund Budget:	**$**	**374,000**
	Amount Spent:	**$**	**374,000**
	Balance:	**$**	**0**

In the table below, deliverable products are categorized according to the tasks listed above. Completion date given below was the target for full achievement of each task. Fieldwork and lab work were completed mostly during years 1 and 2. Diatom analyses, GIS analyses, and data synthesis were done mostly during Years 2 and 3. Note that we actually sampled 26 lakes, rather than just the 10 planned for below; we did this by analyzing only one core per lake, rather than two or three.

Deliverable	**Completion Date**	**Budget**	**Status**
1. Site Selection & Fieldwork (10 sites, $5000/site)	31 Dec 2008	$50,000	100%
2. Sediment Analyses			
(a) LOI & magnetics (10 lakes, $1425/lake)	30 Jun 2009	$14,250	100%
(b) Core dating (10 lakes, $7675/lake)	30 Jun 2009	$76,750	100%
(c) Phosphorus & biogenic silica (10 lakes, $3400/lake)	31 Dec 2010	$34,000	100%
3. Diatom Analyses			
(a) Sample prep & counting (5 lakes, $8400/lake)	31 Dec 2009	$42,000	100%
(b) Inferred lake total phosphorus (5 lakes, $2100/lake)	31 Mar 2010	$10,500	100%
4. Spatial Data Analysis			
(a) Watershed current land use (10 lakes, $1575/lake)	30 Jun 2009	$15,750	100%
(b) Past land use (10 lakes, $2100/lake)	31 Dec 2009	$21,000	100%
(c) Grassland location analysis (10 lakes, $1575/lake)	31 Dec 2009	$15,750	100%
5. Data Synthesis			
(a) Temporal trend analysis	30 Sep 2009	$25,000	100%
(b) Relation to grass area & location	31 Mar 2010	$35,000	100%
6. Report Preparation	30 Jun 2010	$34,000	100%

Final Report Summary:

Task 1, Site Selection and Fieldwork:

Geographic information software (ArcGIS) was used to systematically search for study lakes across the 44-county study area (Figure 1). The ideal study lake would have a clearly delineated area of conservation grassland in its watershed; it would be deep enough to have a continuous sediment record; and it would have no perennial unvegetated channelized inlet that could contribute non-field (near-channel) erosion, as opposed to only field erosion, to the lake. Out of a total of 40,276 lakes in the study area identified in the 24K open-water data set available from the Minnesota Department of Natural Resources (MDNR), 1,155 were selected as being potentially deep (>6 m, or 20 ft) and without an inlet stream. For each of these lakes, a 1-km buffer was created (as a screening proxy for the lake watershed) and the percentage areas of grassland and Conservation Reserve Program (CRP) lands in this buffer were calculated. Grassland was identified from the Minnesota 2000 Level 1 Landsat Landcover Classification data set, produced by the University of Minnesota and available from the MDNR. CRP polygons as of 1993 and 2007 were obtained from the Farm Services Agency, and lakes were ranked according to the percentages of grassland and CRP in their 1-km buffers. About 150 lakes were examined in aerial photographs and screened for accessibility, with about 40 being chosen as possible sites. About half were rejected in the field, resulting in 20 lakes with different areas of CRP and other grassland in their watersheds being selected for study. Six other lakes with virtually no grassland in their watersheds were selected as control sites where land use did not change appreciably during the 1963-2007 study period, at least not with regards to the amount of CRP and grassland.

Sediment cores from the lakes were collected during the 2007-08 field seasons. Despite our screening process to target deep lakes, most lakes were in fact shallow (median depth of 2.78 m) and most appeared to have dried out (or nearly so) during the 1930s dust-bowl era. One core was collected from near the deepest part of each lake with a hand-operated piston sampler fit with a 7-cm diameter, 2-m long polycarbonate tube. The median core length was 83 cm. Commonly, the coring was stopped short by a layer of dense sediment, often with soil-like texture likely representing times in the past when the lake had dried out. Generally the top 10 cm of sediment was subsampled in 1-cm increments and deeper portions in 2-cm increments. Subsamples were stored in polycarbonate specimen cups in the cold room until further analysis.

Task 2, Sediment Analyses:

Basic sediment content was determined by loss-on-ignitions (LOI) analysis, which involves heating a sediment sample to increasingly higher temperatures and weighing the sample after each step to determine the weight loss. Three fractions are determined: organic matter, calcium carbonate, and residual inorganic matter. Our focus here was on the residual inorganic matter because it is derived mostly from soil erosion, which is what this project is trying to measure. We also determined the amount of biogenic silica (glass cell walls from diatoms, a type of algae) on several cores, to make sure that it was not a large part of the residual inorganic matter. Total phosphorus was also measured on the lake sediment with a chemical digestion procedure that dissolves all forms of phosphorus in the sediment.

The lake cores were dated principally with ^{210}Pb (lead-210), a naturally occurring radioisotope that is deposited in the sediment. This method can be used to date sediments back to about 1800 A.D. in many cases. The ^{210}Pb dating was confirmed or improved by analyzing for ^{137}Cs (cesium-137), a bomb product that peaked in 1963, which can generally be identified in sediment cores. We note here that developing sediment chronologies for these shallow lakes was challenging, partially because of processes that can slightly disturb sediment accumulation in shallow lakes, especially if these lakes dried in the past. Nonetheless, because ^{137}Cs can anchor the 1963 date, and because we know the core-top date is 2007-08 (when we cored the lakes), the period from 1963-2007 is the best-dated segment of each core. This segment is a convenient interval for testing the effect of conservation grasslands on erosion, because the 1986 initiation of such grasslands is about at the midpoint of the interval. In lakes that never went dry, such as Solem Lake, the sediment record is well-dated back to about the time of European settlement.

In combination, the ^{210}Pb and LOI analyses resulted in an estimated rate of dry matter accumulation rate (g cm^{-2} yr^{-1}) for selected points (time slices) in each core. Multiplying these dry-matter accumulation rates by the percentage of residual inorganic matter and sediment phosphorus concentrations gave the accumulation rates of eroded sediment and total phosphorus. The average accumulation rates from 1963-1986 and from 1986-2007 were calculated for each lake to quantify the percentage change in accumulation rate that could be related to the period before (pre-1986) and after (post-1986) the establishment of conservation grasslands.

Here we give an example of data from one lake, Solem Lake in Douglas County, which was well-dated back to at least 1850. Figure 2a shows that as agriculture became established in the late 1800s, the sediment became more inorganic, and its density increased. Beginning in 1986, about of the cropland (92%) was converted to grassland, and the sediment became slightly less inorganic. Sediment phosphorus concentrations increased gradually over the entire record. Note that biogenic silica (glass cell-walls from diatoms) was never a large component. The rates of sediment accumulation show a similar story. The accumulation rate of inorganic sediment (which we believe is a measure of watershed-scale erosion) peaked in the 1963-1986 period, and then declined about 28% after grassland was established (Figure 2b). In contrast, the accumulation rate of sediment phosphorus shows no such decline (Figure 2c).

Task 3, Diatom Analyses:

Diatoms are a type of microscopic algae that are responsive to lake-water chemistry and that have glass (biogenic silica) cell walls called “valves,” unique to each species, that tend to be preserved in lake sediments. Consequently, the analysis of diatom valves in lake sediments can show how the diatom community (the array of species present at any one time) changed over time, which in some lakes can be related to past lake-water total phosphorus (TP) concentrations. Because of the time-consuming and specialized nature of sedimentary diatom analysis, only six lakes were selected for diatom analysis. For each of these lakes, 10 down-core subsamples were processed to extract the diatom valves, which were mounted on microscope slides and examined under 1250X magnification. About

400 valves were identified to species on each slide and tallied to assess relative (percent) abundance.

Of six lakes examined, one was unsuitable because of poor preservation (dissolution) of diatom valves. Three showed diatom community change over time, but the changes were not clearly related to TP concentrations. Two lakes did show a relation to TP, however, and here we show the example from Little Lower Elk Lake, in Grant County (Figure 3). The species names mean little to anyone who is not a trained diatom specialist, but each of these species has a preferred, optimum TP concentration. For each level in the core, an aggregate TP concentration can be calculated by weighting these optimum concentrations by the relative abundance of each species in a sample. The result for Little Lower Elk Lake was that the TP concentrations in the lake water apparently peaked in about 1986 and declined thereafter, coincident with the increase in grassland in the watershed. However, because of the few lakes analyzed, this result may not be representative of other sites.

Task 4, Spatial Data Analyses:

We used the commercial ArcGIS package of geographic information system (GIS) software to analyze spatial data, both topographical and land-use data. Topographic analysis was critical to this project to identify the landscape areas contributing water, sediment, and nutrients to each lake. The principal data sets used were the digital elevation models (DEMs) surrounding each study lake. DEMs were obtained from the National Elevation Dataset (NED) website administered by the U.S. Geological Survey. A DEM is essentially an electronic map of an area comprising contiguous squares (grid cells), about 9x9 m in size, each of which is given the value of the land elevation at the center of that square. ArcHydro is a module within ArcGIS that analyzes the elevations of nearby grid cells to infer landscape slope, landscape depressions, flow directions, drainage networks, and watershed boundaries. We used ArcHydro to identify the hydrologic watershed for each lake, and we checked the result against recent aerial photographs and topographic maps for consistency, in case there were large errors in the digital data set.

Besides the hydrologic watershed, we also identified alternative contributing areas that may better represent the “sediment-shed” of each lake, that is, the area of landscape that may contribute sediment to each lake. To this end we excluded areas of the watershed that drain internally to wetlands depressions, which presumably trap incoming sediment. We used ArcHydro to identify depressions and examined aerial photos to estimate whether each depression was major or minor, based on the presence of standing water and wetland vegetation cover. We labeled the full hydrologic watershed of each lake WS1. Then, the secondary watershed (WS2) started with the WS1 polygon and then excluded the drainage areas of major depressions. In turn, the tertiary watershed (WS3) started with the WS2 polygon and then excluded the drainage areas of minor depressions. Figure 4 shows the resulting contributing areas for Solem Lake, which had a very simple watershed. Most lakes had larger watersheds with a more complex array of wetland depressions.

Digital land-use data were obtained for all study sites. Maps of set-aside lands enrolled in the CRP were obtained for about 1993 and 2007 from the Farm Services Agency (FSA) in Minnesota. Land use over time was acquired from several different data sets. Aerial photographs from 2006 were obtained from the Farm Services Administration National Aerial Image Program. Photographs from the 1980s and 1990s were obtained principally from the National Aerial Photography Program (NAPP), and the National High Altitude Photography Program (NHAP). In addition, we also used the National Land Cover Datasets (NLCD) for 1992 and 2001, which are based on interpretations of satellite imagery at a resolution of 30-m grid cells. Figure 5 shows example land uses for (again) Solem Lake in Douglas County. Note that this lake had most (92%) of the cropland in its pre-1986 watershed (WS1) converted to grassland in the 1990s and 2000s.

The above data sets allowed quantification of the areas of CRP lands and other perennial vegetation land-cover types, and how these areas changed over time, in particular from the pre- to post-1986 periods (before and after establishment of CRP). The locations of these vegetation patches must also be important in modifying watershed-scale erosion processes and rates. To address this concern, we quantified two factors known to influence erosion as determined by their inclusion in the Universal Soil Loss Equation (USLE). The K factor is soil erodibility, which was available from the digital Soil Survey Geographic Database (SSURGO). The LS factor in the USLE combines the effect of land slope length and steepness, which was calculated from the DEM for each watershed. The larger the K and LS factors, the greater the potential for erosion at that point in the watershed. We used these factors to weight the areas of grassland in each watershed, to see if grassland located where K and LS were large had an identifiable effect in reducing erosion.

Task 5, Data Synthesis:

Our goal in data synthesis was to search for a simple relationship between watershed-scale erosion (our y, or dependent, variable) and area of grassland in the contributing watershed (our x, or independent, variable). Watershed-scale erosion can also be called the sediment yield. Comparing the sediment yield in one watershed to that of another with different grassland area is imprecise, because all watersheds are different in more ways than just land cover. Instead, we normalized for all between-watershed differences by comparing each watershed with itself. That is, we compared sediment yields in the same watershed before (pre-1986), and after (post-1986), conservation grasslands were established.

Our principal method here was to construct our dependent (y) variable as the change in accumulation rate of residual inorganic sediment from pre- to post-1986, as a percentage relative to the pre-1986 rate: 100 * (rate 2 – rate 1) / rate 1. This y variable was then regressed against various selected possible independent (x) variables quantifying in different ways the conversion of cropland to grassland. We likewise constructed a dependent (y) variable as the relative change in sediment phosphorus accumulation, and regressed that y variable against the same set of x variables.

The first independent (x) variable was simply the relative change in grassland area from pre-1986 to post-1986, calculated here as a percent of the pre-1986 cropland area it replaced. For the WS1 level of watershed delineation, the percent change in residual inorganic sediment accumulation was negatively related to the percent change of cropland replaced by grassland from the pre- to post-1986 period (Figure 6a). In seeking a tighter relation with less scatter, we recalculated the regression for the same variables, except this time for the WS2 and WS3 watershed delineations, reasoning that the relation between land cover and sediment accumulation should be improved by excluding those areas of landscape that do not appear to contribute sediment (Figure 6b and c). These efforts in fact worsened the relationship, which became progressively less significant (p values increased) and explained even less variance (R^2 values decreased). The scatter about the lines, and the difference between the three watershed delineations, indicate that the regression parameters should be viewed as only approximate.

The same set of regressions were run for the percent change in accumulation rate of sediment total phosphorus as a function of percent cropland converted to grassland within WS1, WS2, and WS3 delineations (Figure 6 d, e, and f). All regressions had negative slopes, qualitatively suggesting that replacing cropland with grassland results in lower accumulation of sediment phosphorus. However, none of these relations was significant at the $p = 0.05$ level and the variance explained was small ($R^2 = 0.12$ at most, for the WS1 delineation). As for the sediment accumulation rates, recalculating the regressions for the WS2 and WS3 delineations worsened the relationship (smaller R^2 values and larger p values).

Placing the grassland in areas where it could armor the watershed against potential erosion as measured by K and LS factors produced similar, but not strikingly better, results (Figure 7). Our dependent variable here was again the percent change in inorganic sediment accumulation rate from the pre- to post-1986 period. The relation shown in Figure 7a is entirely parallel to that shown in Figure 6a, except here the change in grassland area is given as a percent of total upland area, rather than cropland area, without taking into consideration where that grassland was located. Figures 7b and c show that incorporating the effects of K and LS factors did not substantially improve our understanding of the relation between sediment accumulation and conversion of cropland to grassland. This analysis does not mean that the K and LS factors are not important, only that their effects were not demonstrated in our data configuration at the watershed scale.

The principal results above are epitomized in Figures 6a and 7a, which indicate that watershed-scale erosion decreased as area of conservation grassland (either as percent of cropland or as percent of upland) increased. Two characteristics of this relationship beg explanation. Why was the intercept so much greater than zero? Why was there so much scatter about the regression line?

The positive intercept indicated that something systematically changed across the study area such that rates of sediment accumulation increased about 20% from the pre- to post-1986 period. Annual normal precipitation has increased by as much as two inches in parts of the study area over this time, which could contribute to increased erosion and transport to receiving waters. Increased artificial drainage practices that concentrate flow to erosive gullies could also contribute. This increase in sediment transport is contrary to what would be expected from increased use of conservation tillage, which we presume has increased during the post-1986 period. Perhaps the increase would have been greater than 20% without such practices.

Scatter about the regression line is expected in all such studies based on field data and points to the value of studying as many lakes as possible. The scatter could have been caused by errors in the sediment data, errors in the land-use data, or the influence of unaccounted factors. Errors in sediment data analysis were no larger for this project than others, where sediment content (LOI and phosphorus) analyses and ^{210}Pb dating methods have been substantiated many times. Probably the largest sediment-related errors are related to whether the one core we collected from each lake was representative for that lake, though comparison of rates within the same core should minimize the effects of differences among cores. Errors in land use also do not seem to be overly problematic. Interpretation of satellite imagery can fairly reliably distinguish between cropland and grassland, and CRP polygons were reliably grassland when we field-checked each watershed.

Many unaccounted factors could have contributed to the scatter in Figures 6 and 7. Foremost among these is that lands other than cropland may have been major sediment sources; replacement of cropland with conservation grassland would have had little or no effect on erosion from these sources. Even though we chose lakes without perennial inlet streams that could contribute sediment from channel erosion, erosion from intermittent channels, ravines, or gullies could have continued unabated. Wind-blown sediment is another potential source unaffected by conversion of local cropland to grassland, though we doubt regional dustfall can account for drastic differences between lakes. Finally we speculate that there may be time lags in operation, wherein eroded sediment is temporarily stored in intermediate locations and later mobilized by runoff to points farther downgradient. The toes of slopes along the valley walls of intermediate streams and floodplains of perennial streams may provide such temporary storage locations. Likewise, macrophyte beds in shallow lakes may provide temporary holding locations for fine-grained sediment before being resuspended and moved toward the middle of lake, where our sediment cores are typically collected. These temporary storage locations may be envisioned as an intermittent conveyor belt, effecting a time lag between the initial erosion in the upland and the eventual deposition at the coring site.

We conclude that this study demonstrated a fundamental incoherence between field-scale parameters influencing erosion and watershed-scale measurements of erosion. We recognize the fundamental importance of the empirical plot-scale studies that have quantified the effects of erodibility, slope, flow length, land cover, and other factors on erosion and nutrient transport. Yet, the complexities of transport paths between field and receiving waters make watershed-scale erosion highly variable and difficult to predict. Use of plot-scale parameters without modification to predict watershed-scale sediment yields is inappropriate. We need better understanding to re-scale such parameters appropriately, which can only be achieved by intensive studies that bridge the intermediate scales between fields and watersheds. New data sets, especially improved topographic data from LiDAR, will help with this effort. However, nothing can replace the actual measurement of sediment yield at different scales, which will provide the necessary constraints for theoretical equations to give realistic results.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $360,150

- Staff: $206,150
  - Almendinger (~50%) & Schottler (~17%) (PIs)
  - Edlund &/or Ramstack (~15%) (Diatom analyses)
- Analytical expenses: $154,000
  - Sediment analyses ($104,000)
  - GIS analysis ($50,000)

Equipment/Other: $13,850

- Supplies (5% analytical): $10,200
- Travel: $3,650

Development: $0

Restoration: $0

Acquisition, including easements: $0

TOTAL TRUST FUND PROJECT BUDGET: $374,000

Explanation of Capital Expenditures Greater Than $3,500:

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Local partnerships will be developed upon site selection

B. Other Funds Proposed to be Spent during the Project Period:

None.

C. Past Spending:

Several LCMR-recommended projects totaling about $400,000 allowed us to develop novel sediment fingerprinting methods and gain watershed modeling expertise which is relevant to this project.

D. Time:

Years 1 and 2 were occupied largely by fieldwork and laboratory analyses of the lake sediment. Year 3 was devoted to final laboratory analyses, GIS analyses, statistical analyses, and data synthesis.

VII. DISSEMINATION:

- The academic community will be informed via the technical interpretive report, conference presentations, and peer-reviewed journal articles. The interpretive report will be downloadable from the Museum web site.
- Local resource managers in the counties where lake sites are located will be given hard copies of the report.
- LCCMR members and other selected legislators at the state and federal level will be informed via a fact sheet that summarizes the principal findings of this project. The fact sheet will also be available via the Museum web site.
- **Dissemination activities:**

None to date.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports were submitted in January 2008, July 2008, January 2009, July 2009, and January 2010. This final work program report was submitted August 16, 2010 as requested by the LCCMR

IX. RESEARCH PROJECTS:

The associated research report for this project provides greater detail on the methods, results, and discussion.

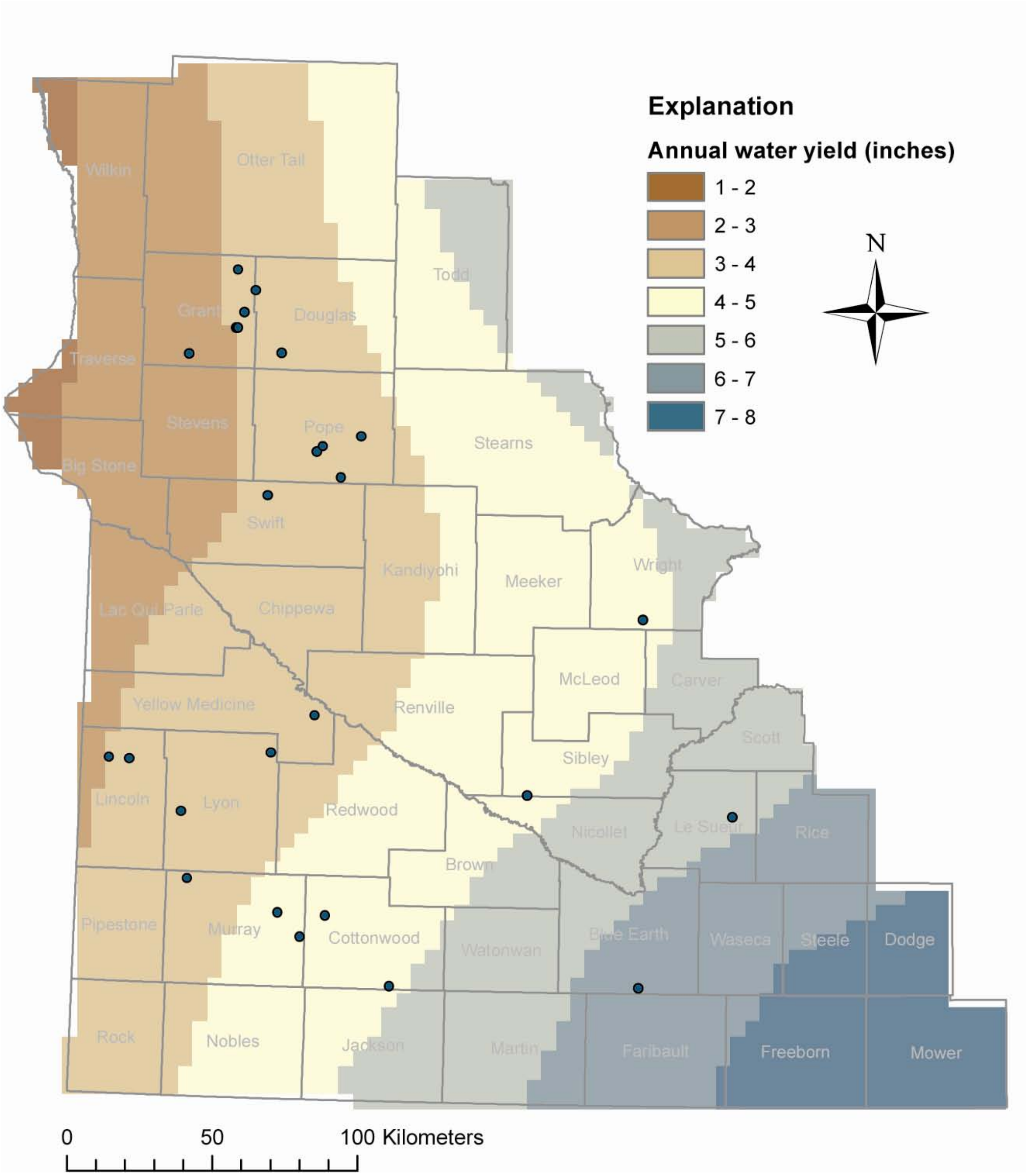
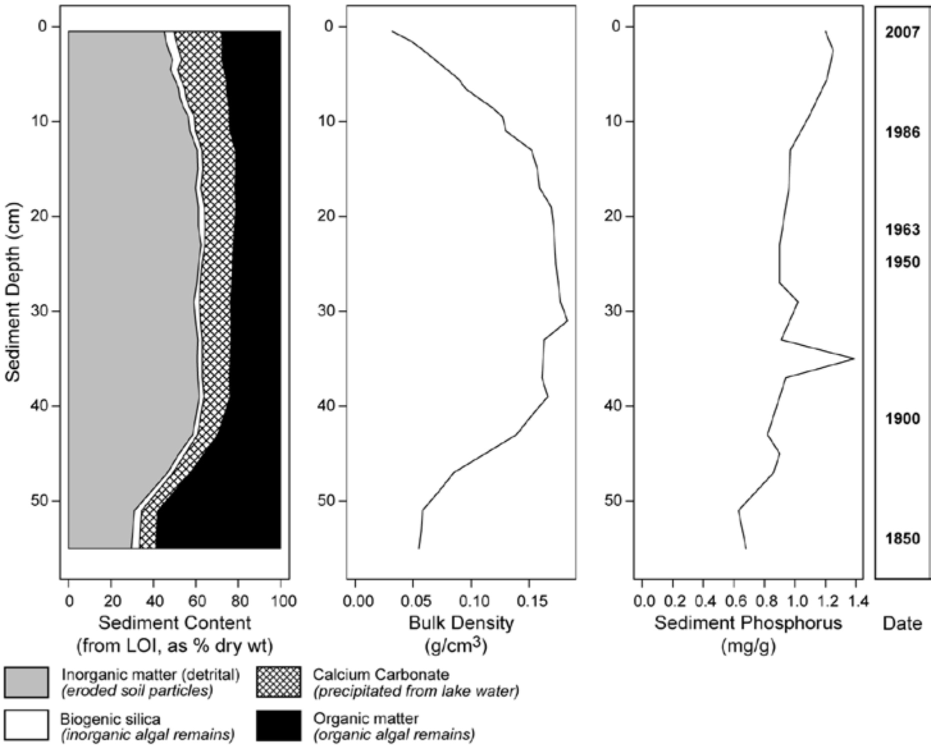


Figure 1. Study lake locations in 44-county area of southwestern Minnesota in relation to mean annual water yield
(Water yield, also called generalized runoff, was based on 1940-2005 flow data; gridded map shown here courtesy of D.L. Lorenz, U.S. Geological Survey, personal communication, 2010)

(a) Sediment Content



(b) Residual inorganic sediment accumulation

(c) Sediment phosphorus accumulation

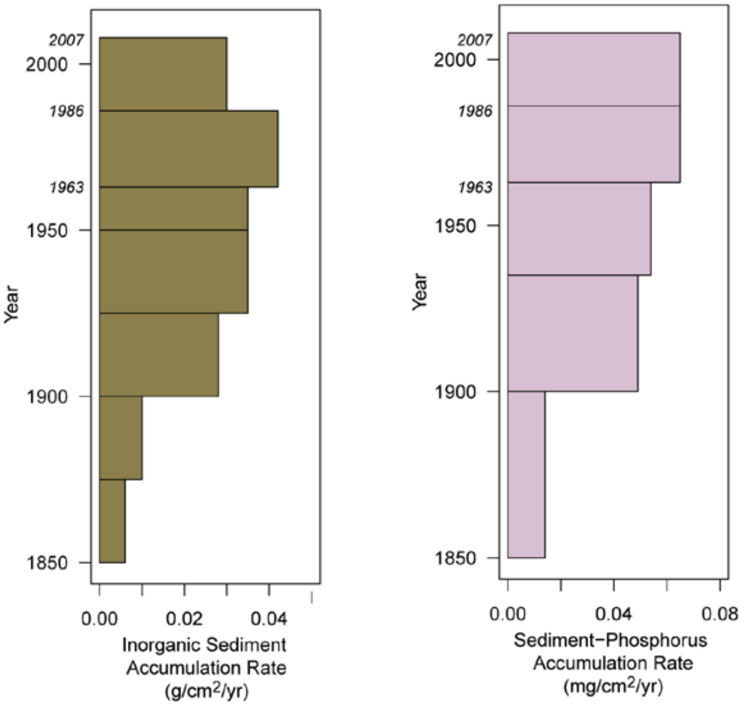


Figure 2. Sediment data for Solem Lake, Douglas County.

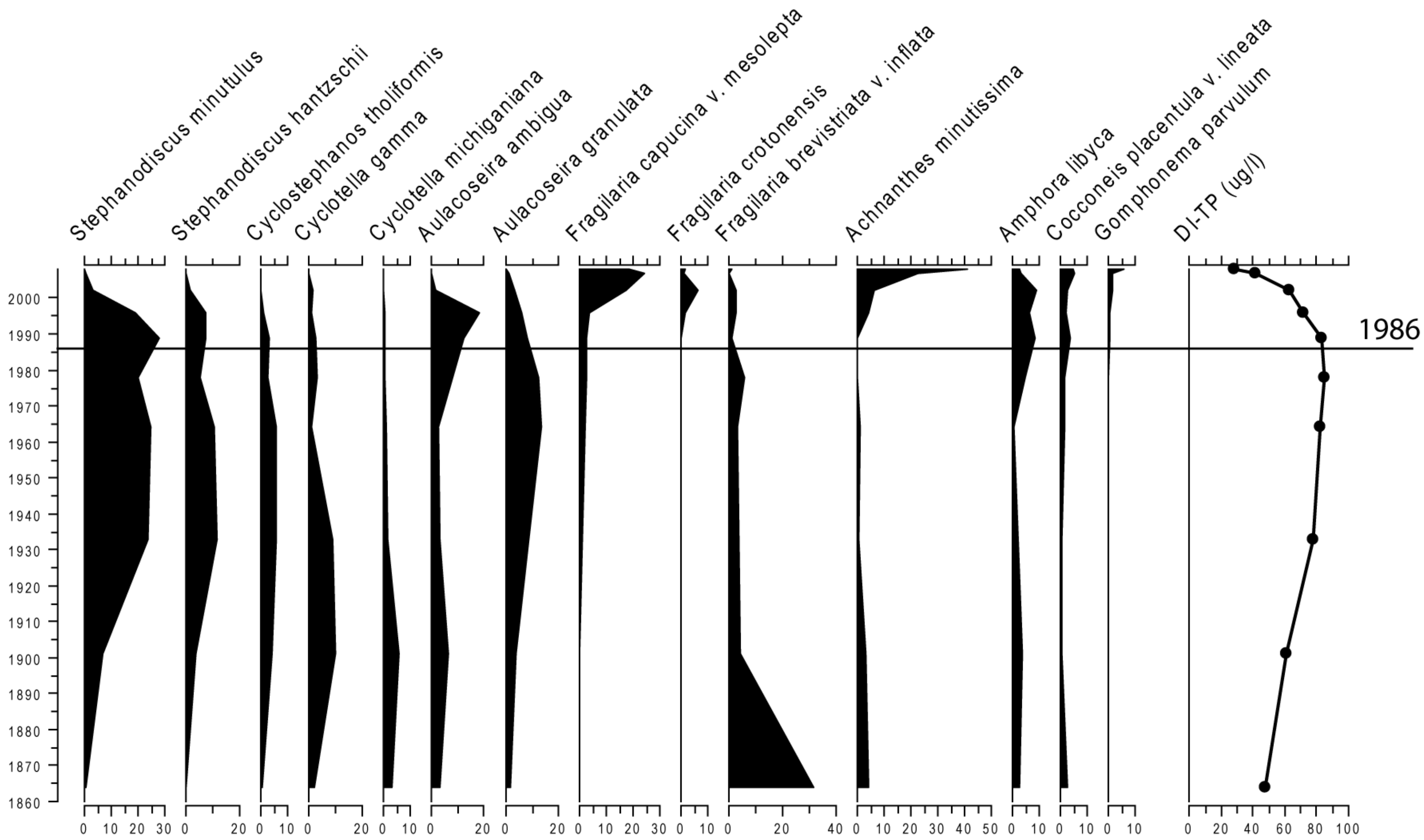


Figure 3. Diatom stratigraphy and diatom-inferred total phosphorus (DI-TP) for Little Lower Elk Lake, Grant County

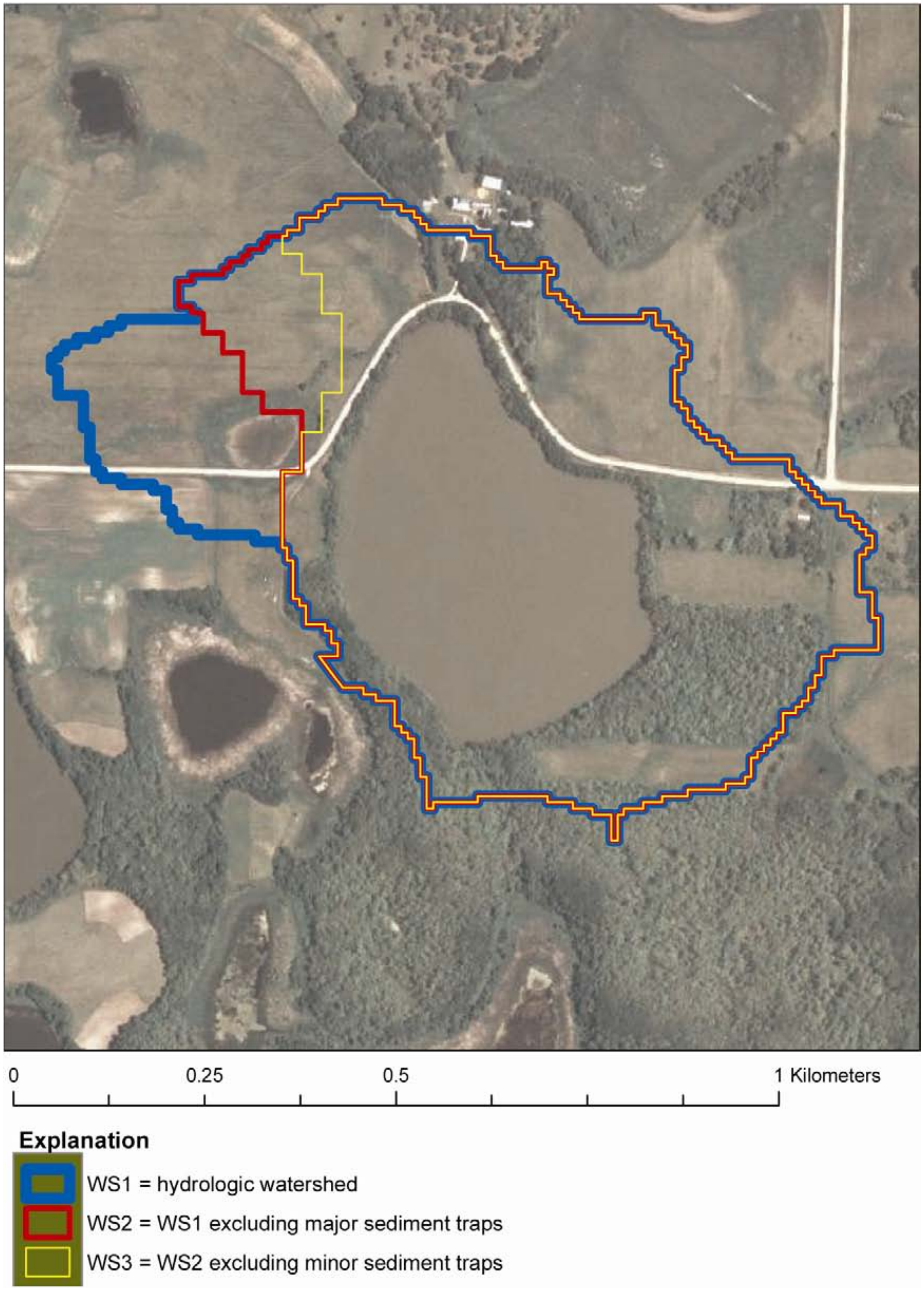
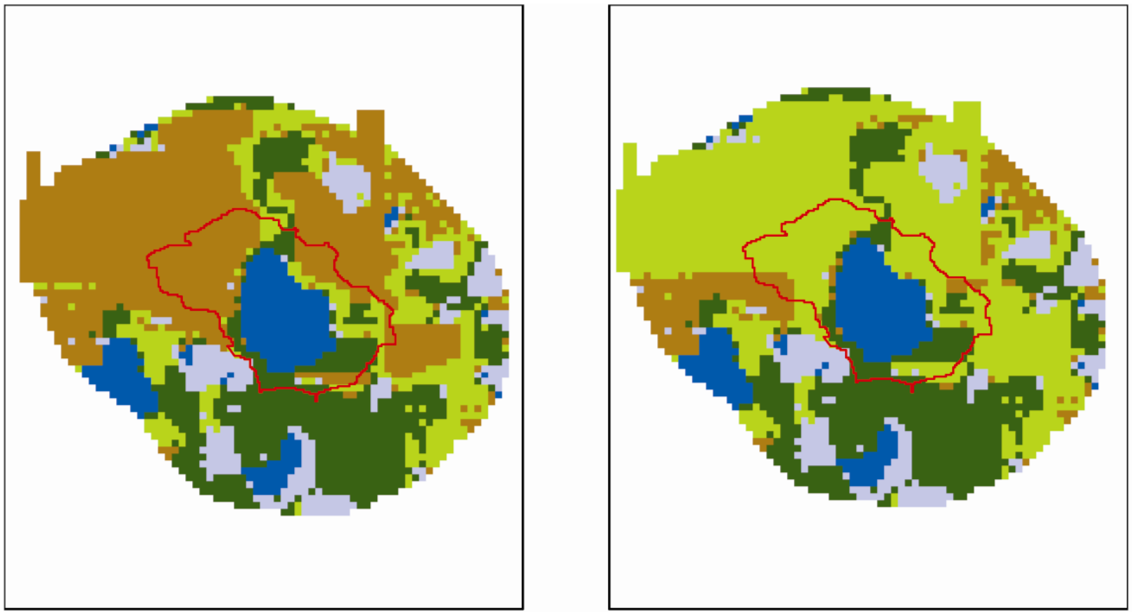
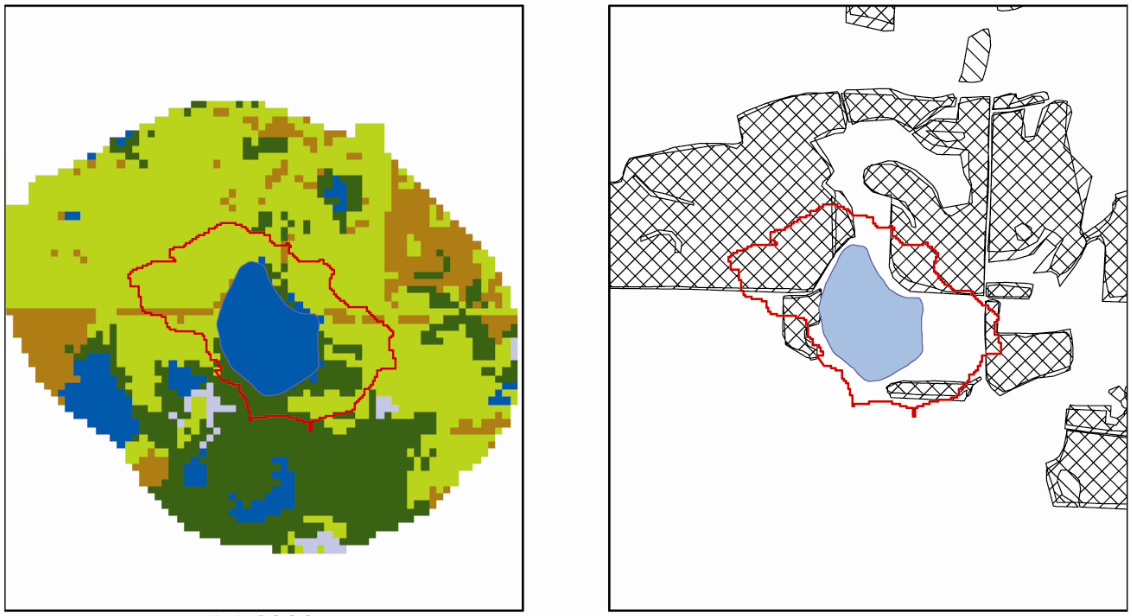


Figure 4. Watershed delineations for Solem Lake, Douglas County.



(a) Pre-1986

(b) 1990s



(c) 2000s

(d) CRP 1993 & 2007

Explanation

🟫 Cropland
🟩 Forest
🟩 Grassland
🟧 Developed
🟦 Water
🟪 Wetland
▧ CRP ~1993
▨ CRP ~2007

Figure 5. Land use surrounding Solem Lake, Douglas County.
Red line delineates the WS1 watershed boundary.

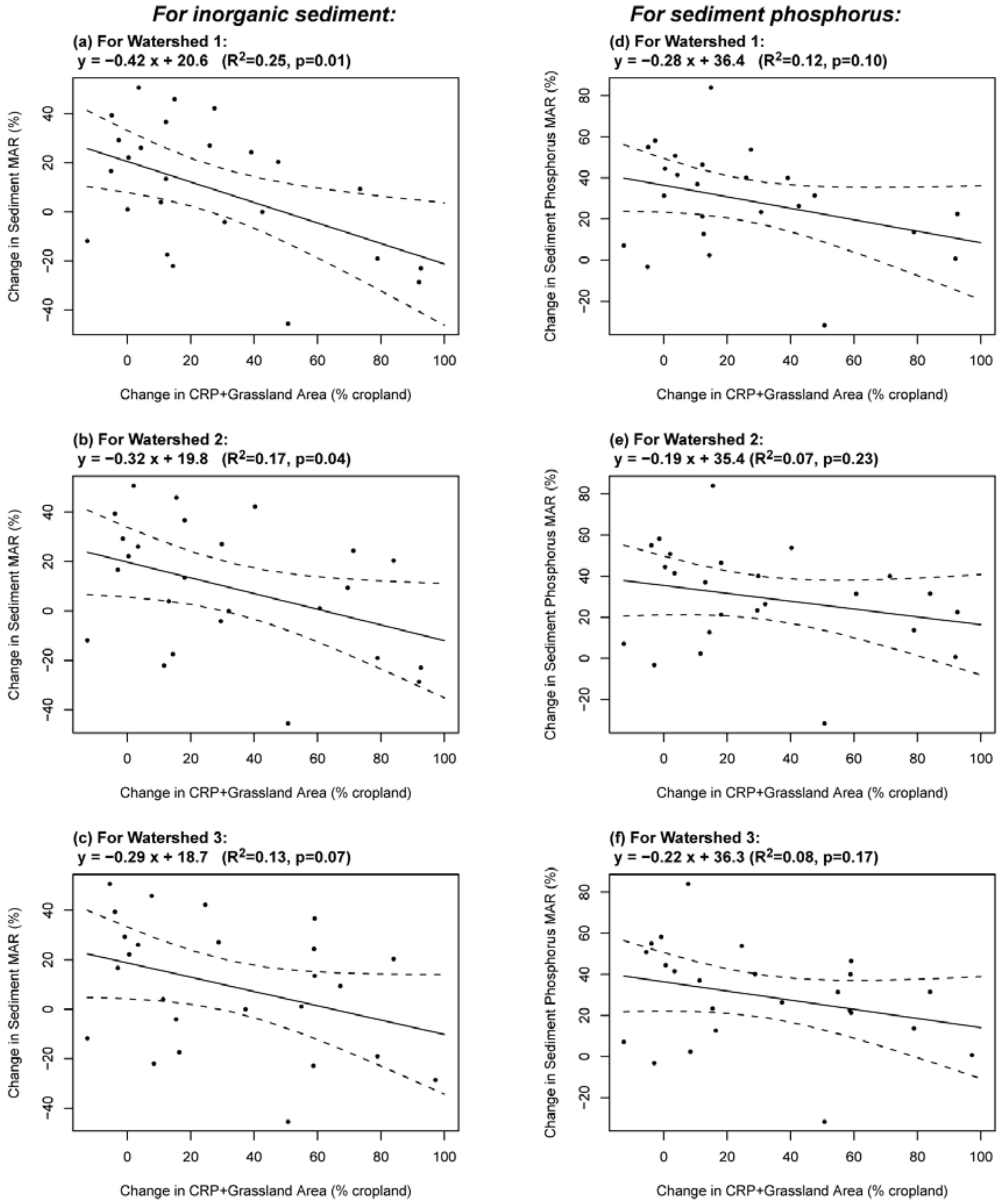
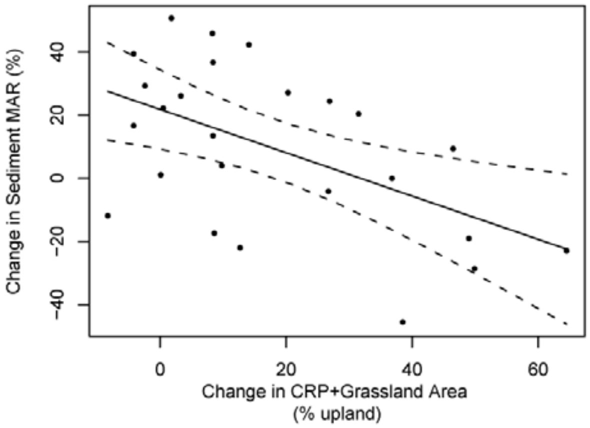
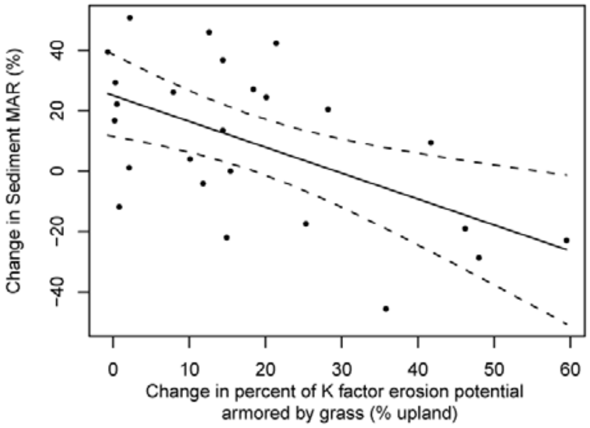


Figure 6. Relations between change in grassland cover, change in inorganic sediment mass accumulation rate (MAR), and change in sediment-phosphorus MAR, for three levels of watershed delineation.
CRP = Conservation Reserve Program

(a) For change in area alone:
$y = -0.69 x + 21.8$ (R^2=0.29, p=0.01)



(b) For change in area weighted by K factor (erodibility):
$y = -0.86 x + 25.0$ (R^2=0.31, p<0.01)



(c) For change in area weighted by LS factor:
$y = -0.87 x + 21.8$ (R^2=0.21, p=0.02)

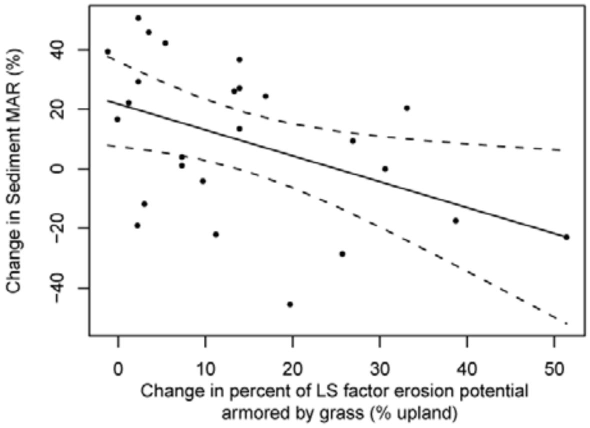


Figure 7. Relations between change in inorganic sediment mass accumulation rate (MAR) and (a) change in grassland area, (b) grassland area weighted by K factor, and (c) grassland area weighted by LS factor.

Attachment A: Budget Detail for 2007 Projects

Project Title: 5(d) Demonstrating Benefits of Conservation Grasslands on Water Quality

Project Manager Name: James E. Almendinger

Trust Fund Appropriation: $374,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent as of 30 Jun 2010**	**Balance as of 30 Jun 2010**	**TOTAL BUDGET**	**TOTAL BALANCE**
BUDGET ITEM	Water-quality benefits of conservation grasslands				
Personnel: wages and benefits Subtotal -->	**$206,150**	**$206,150**	**$0**	**$206,150**	**$0**
Almendinger *(project manager) -- 50% time* ***Schottler*** *-- 17% time* ***Ramstack*** *&/or* ***Edlund*** *(diatom analyses) -- 15% time*	*$161,687*	*$161,687*			
Benefits *(FTE's only) -- Approx. 27.5% FTE salaries*	*$44,463*	*$44,463*			
Medical: Single $200/mon; Family $720/mon *Dental: Single, $25/mon; Family $55/mon* *Life Insurance: 0.16*2*annual salary/1000* *Retirement: 8% annual salary/year*					
Other direct operating costs Subtotal -->	**$154,000**	**$154,000**	**$0**	**$154,000**	**$0**
Sediment analyses	*$104,000*	*$104,000*			
LOI, magnetics, radiometric dating, phosphorus, and biogenic silica					
Diatom analyses	*$0*	*$0*			
Sample preparation and counting; statistical inference of lake-water total phosphorus concentration ($50,000 expense moved to Personnel category -- see Ramstack & Edlund above)					
GIS analyses	*$50,000*	*$50,000*			
Watershed delineation, present and past land use, and grassland location analysis					
Other Supplies Subtotal -->	**$10,200**	**$10,200**	**$0**	**$10,200**	**$0**
Lab supplies (reagents, glassware, etc.) and field supplies (core tubes, tape, hardware, etc.)					
Travel expenses in Minnesota Subtotal -->	**$3,650**	**$3,650**	**$0**	**$3,650**	**$0**
COLUMN TOTAL	**$374,000**	**$374,000**	**$0**	**$374,000**	**$0**

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COLUMN TOTAL	**$374,000**	**$374,000**	**$0**	**$374,000**	**$0**