



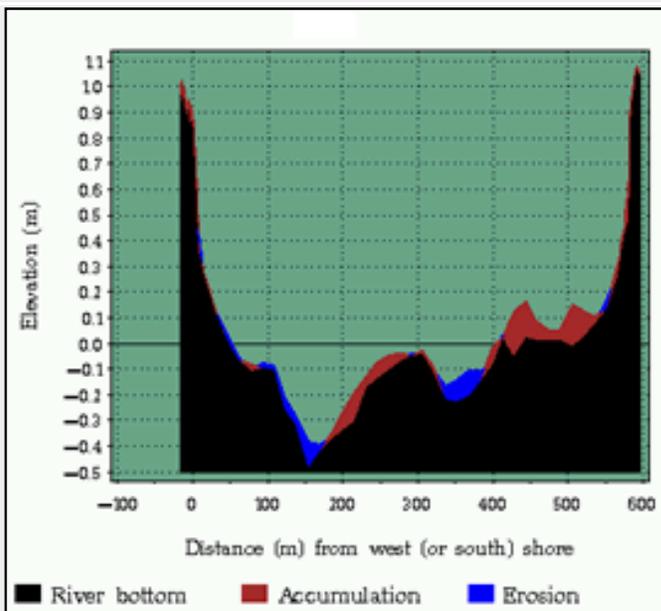
Rates and Patterns of Net Sedimentation in Backwaters of Pools 4, 8, and 13 of the Upper Mississippi River

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Contents

- [Preface](#)
- [Abstract](#)
- [Introduction](#)
- [Methods](#)
- [Results and Discussion](#)
- [Conclusions](#)
- [Acknowledgments](#)
- [References](#)
- [Tables](#)
- [Figures](#)
- [Appendixes](#)



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 [Backwater sedimentation rates](#)

[Rates and Patterns of Net Sedimentation in Backwaters](#)

Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U. S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

This report was prepared under Task 2.2.1.4, *Conduct Monitoring* of the Operating Plan (U.S. Fish and Wildlife Service 1993). This report was developed with funding provided by the LTRMP.

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Abstract

Net sedimentation rates were obtained for backwaters of the Upper Mississippi River in Pools 4, 8, and 13 by measuring annual bed elevation changes along transects between 1997 and 2001. Average sedimentation rates ($\text{cm}\cdot\text{yr}^{-1}$) during the 5-yr period were lower than most previously reported rates in backwaters of the River, with means of -0.08 (standard error [SE] = 0.18) in Pool 4, 0.21 (SE = 0.10) in Pool 8, and 0.47 (SE = 0.26) in Pool 13. Poolwide estimated mean sedimentation rates in the terrestrial areas adjacent to backwaters appeared higher, ranging from 0.32 (SE = 0.14) to 0.78 (SE = 0.25) $\text{cm}\cdot\text{yr}^{-1}$, but were not significantly different than rates in aquatic areas. When averaged over the study period, sedimentation rates were correlated with bed elevation, but the relations differed in aquatic and terrestrial areas. On an annual basis, the correlation between annual sedimentation rates and bed elevation was similar across aquatic and terrestrial areas, with annual river discharge explaining some of the variability. During the high discharge year of 2001, a positive correlation between sedimentation and bed elevation was observed, whereas in low discharge years, such as 2000, there was a negative correlation. This correlation is reflected in poolwide mean rates for backwaters, that in some pools were significantly higher during low discharge years than in high discharge years. The above inferences suggest there is an opportunity to predict future conditions in a reasonable manner. These predictions would be of value when planning management actions to maintain the viability of the diverse ecosystem of the Upper Mississippi River.

Key words: Backwaters; erosion; Mississippi River; sediment transport; sedimentation

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Introduction

Sedimentation is a major concern of resource managers of the Upper Mississippi River (UMR). Land use changes (i.e., agricultural practices and urban development) in the basin have contributed to high sediment delivery rates. The problem has been exacerbated by river projects for navigation and flood control (i.e., dams, training structures, and levees) that have altered the natural sediment transport process within the river. Even in a natural state, the river's complex floodplain was conducive to deposition of sediments in transport. Accumulation of sediment may result in loss of backwater volume and encroachment of terrestrial vegetation into formerly aquatic areas. Such accumulation will largely determine the fate of off-channel areas in the UMR (Fremling and Claflin 1984; Nielsen et al. 1984), and the fate of the biota that rely on those habitat conditions. Studies to determine sedimentation rates and processes were among the recommendations developed by the Sediment Transport and Geomorphology Work Group convened to define informational needs for the UMR ([Gaugush and Wilcox 2002](#)).

The UMR extends over 1,365 km from Minneapolis-St. Paul, Minnesota, to Cairo, Illinois, with floodplain complexity that differs greatly longitudinally. The 523-km reach of the UMR from Pool 2 to Pool 13 is particularly complex, having a mosaic of channel and off-channel environments that are still in the active floodplain. Off-channel areas, generally grouped into impounded areas and backwater lakes, are plentiful in this reach. Impounded areas are large expanses of open water formed just upstream of the dam and typically have flow even at low river discharge. In contrast, backwater lakes have little or no flow during low river discharge periods, thus, periodically providing a lentic environment in a lotic system. Most backwater lakes are typically shallow (<1 m) during low discharge conditions. The degradation of these highly productive backwater lakes because of sedimentation has been a long-standing issue for river managers (GREAT 1980).

Using a variety of methods, several researchers have estimated sedimentation rates in off-channel areas of the UMR. Using Cesium-137 sediment dating techniques to estimate net sedimentation in mostly impounded areas, McHenry et al. (1984) found rates between 1954 and 1975 ranging from 1 to 4 cm•yr⁻¹ in Pools 4 through

10. Korschgen et al. (1987) reported lower rates ($0.2 \text{ cm}\cdot\text{yr}^{-1}$) for a period of 50 years in an impounded backwater area in Pool 7 using bathymetric maps. In a large backwater lake in Pool 9, an annual sedimentation rate of $1.69 \text{ cm}\cdot\text{yr}^{-1}$ was reported between 1964 and 1974 by Eckblad et al. (1977) using the Cesium-137 dating technique. Using deep coring to parent material, Rogala et al. (1997) observed sedimentation rates for the 58-yr period since impoundment ranged from 0 to $1.5 \text{ cm}\cdot\text{yr}^{-1}$ in backwater lakes of Pool 8. For a 6-yr period ending in 1996, Rogala and Boma (1996) reported average rates of 0.29, 0.12, and $0.80 \text{ cm}\cdot\text{yr}^{-1}$ in Pools 4, 8, and 13, respectively, from bed elevation surveys conducted along a nonrandom set of transects.

There are several shortcomings regarding these past studies, particularly for predicting future conditions of backwater lakes in the UMR. First, many of the studies were conducted in impounded areas, where sedimentation rates may differ greatly from rates in backwater lakes. Second, most of these studies probably overestimated sedimentation rates by sampling only in areas known to have accumulated sediments, or provided an opportunity for bias by selecting sample sites nonrandomly. Third, most of these studies did not provide estimates of sedimentation for a recent period. The historical sedimentation rates may be inappropriate for predicting future conditions of the river because impounded systems are expected to trap less sediment as the system ages (McHenry et al. 1984; Church 1995). Finally, past studies provided little information on spatial variability in sedimentation among and within pools, which is critical for predicting future conditions.

To address the shortcomings of these earlier studies, we redesigned the short-term monitoring study conducted by Rogala and Boma (1996). One objective of our study was to compare sedimentation rates we obtained for a present 5-yr period with past estimates. A second objective was to determine variability in rates along transects and among years. Finally, we examined spatial and temporal variability to identify variables of interest for future predictive modeling efforts. Overall, we addressed spatial and temporal variability in sedimentation rates at finer scales than has previously been investigated.

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Methods

Sedimentation monitoring was conducted in backwater lakes, as defined by Wilcox (1993), in Navigation Pools 4, 8, and 13 of the UMR (Figure 1). Backwaters are much less prevalent downstream of Pool 13; therefore, pools below Pool 13 were excluded from this study. Impounded areas within the study pools were excluded from the study area because, while these areas are considered backwaters, these areas are typically more lotic environments and not the focus of this study. Lake Pepin in Pool 4, a large tributary delta lake, was also excluded from the study area because it is atypical of backwater lakes of the UMR. The spatial extent and stratification of the study area were delineated using a Geographic Information System (GIS) database of aquatic areas in the UMR (Owens and Ruhser 1996).

Transects for sampling were aligned perpendicular to flow and allocated across three strata. The large backwater lake stratum included lakes greater than 40 ha. Each pool had six large backwater lakes from which we randomly selected two transect locations in each lake, for a total of 12 transects. The remaining smaller backwater lakes were divided into two additional strata (low and high connectivity) based on connectivity metrics, such as the percent of their perimeter connected to a channel. We randomly selected 13 transects within these two strata based on the size of the strata in the pool. Of the 75 transects selected for survey, 63 transects were surveyed sufficiently to be included in the analysis presented here (Table I). The size of the study area represented by transects was 2,199 ha in Pool 4, 1,976 ha in Pool 8, and 2,780 ha in Pool 13.

We obtained net sedimentation rates annually between 1997 and 2001 by repeated annual measurement of the bed elevation at fixed sites along each transect. Vertical and horizontal benchmarks were established at each transect to allow replication of surveys. To ensure that we did not undersample short transects or oversample long transects, we selected the distance between sample locations along each transect based on the length of each transect. Transects longer than 600 m were sampled at 30.4-m intervals; transects between 150 and 600 m in length had 15.2-m intervals; and transects shorter than 150 m had 7.6-m intervals. Sampling intervals along terrestrial portions of transects were 1.52 m. The terrestrial portion of transects extended 15.2 m shoreward of the posts set near each shore, or ending sooner if a physical obstruction

was present (e.g., rock embankment). The terrestrial portions were surveyed using differential leveling (Brinker and Wolf 1984) to determine bed elevation relative to the benchmark.

Most aquatic surveys were conducted over the ice to increase the accuracy of the measurements. Sampling sites along transects were located by tape measure using the established benchmarks and realigning every 90 m with an electronic distance measuring device. Water depths were measured with a surveyor's tape attached to a somewhat buoyant pole with a 20-cm diameter plate at the end to retard sinking in soft sediments. Given that soft sediments are uncommon in backwaters of these pools (<2% of the area has sediments with moisture content >80%; [Rogala 1996](#)), we assumed only minor problems associated with sinking of the pole. These problems could result in underestimating sedimentation rates of unconsolidated sediments at some locations, but given the transient nature of unconsolidated sediments in a river system, we further assume minor impacts to our estimates of sedimentation. The water elevation relative to the benchmark was determined each year of survey by differential leveling. The aquatic portions of some transects were sampled during ice-free conditions using the differential leveling method for shallow or short transects. Maps illustrating the location of transects are included in [Appendix A](#).

Bed elevation relative to a reference water surface elevation was calculated for each sampling of selected locations to allow comparisons among transects. Using U.S. Army Corps of Engineers daily discharge records (U.S. Army Corps of Engineers 2002a,b), a low water condition that is exceeded 90% of the time was used as the reference elevation for each pool. Sedimentation rates at each sampling location were calculated as the difference in bed elevation over two surveys, divided by the period between the two surveys. These periods could be individual years or multiple years. When comparing changes over selected periods, rates were determined using only sampling locations where data were present for all periods of comparison. We excluded data from recently dredged areas in Brown's Lake, Pool 13, when estimating poolwide mean rates because of abnormal sedimentation processes in these areas. The data from dredged areas were only used to estimate rates in the dredged areas themselves.

The rates over an entire transect are of little interest because the ecological significance of sedimentation would generally be dependent on whether the sedimentation was in terrestrial or aquatic areas. Therefore, we also determined mean sedimentation rates for aquatic and terrestrial portions of transects by post-stratifying on the basis of positive or negative bed elevation (relative to the reference condition) in the first year of the period of comparison. As a result, for annual change detection, a given site might be classified as terrestrial one year and aquatic the next. Additional post-stratification was used in a similar manner to investigate rates of sedimentation along shorter segments of transects

(e.g., shallow near-shore segments based on bed elevation).

Data were analyzed to determine mean sedimentation rates, standard errors, and significant differences between means rates using analyses that addressed both the stratification and clustering within the study design. We used survey software (SAS® PROC SURVEYMEANS; SAS 2000) to adjust for potential correlation within transects. This software assumed equal (rather than spatial) correlation within transects. This correlation assumption is an approximation for these potentially spatially correlated data, but we assumed this approach to have only minor effects on standard error estimates. Weighting was used to account for the disparities in sampling location intervals along and among transects and surface areas among sampling strata. Differences in means were tested using contrast statements provided by the SAS® macro, smsub (available at <http://ftp.sas.com/techsup/download/stat/smsub.html>), an extension of SURVEYMEANS. We used a Bonferroni correction ($\alpha = 0.05 \div \text{number of comparisons}$) to adjust for multiple comparisons. Data were not summarized for strata used in the allocation of sampling, as sample size precluded such analyses.

We used a model-based approach to investigate correlations between sedimentation rates and predictor variables, such as bed elevation and discharge. Using linear mixed modeling software (SAS® PROC MIXED; SAS 2000), we modeled relations between predictor variables and mean sedimentation rates of levels (e.g., pool, year, elevation class) produced by SURVEYMEANS. Bed elevation class means for sedimentation were graphically depicted by the center of the category range, but the mean bed elevations within the depth category were used in models to assess bed elevation effects. We assumed independence across depth category means within pools. (The range of spatial correlation for these sedimentation data appeared to be approximately 25 m [J. Rogala, unpublished data]. Because aquatic section means typically derive from groups of observations with combined length of >25 m along a transect, this assumption seems reasonable for means from that section, but may be liberal for means from the terrestrial section groups that typically have a combined length of <5 m.) Discharge effects on annual sedimentation were investigated using a high discharge condition that was represented by the discharge value exceeded 5% of the time within each study year; daily discharge data were obtained using U.S. Army Corps of Engineers discharge records (U.S. Army Corps of Engineers 2002a,b).

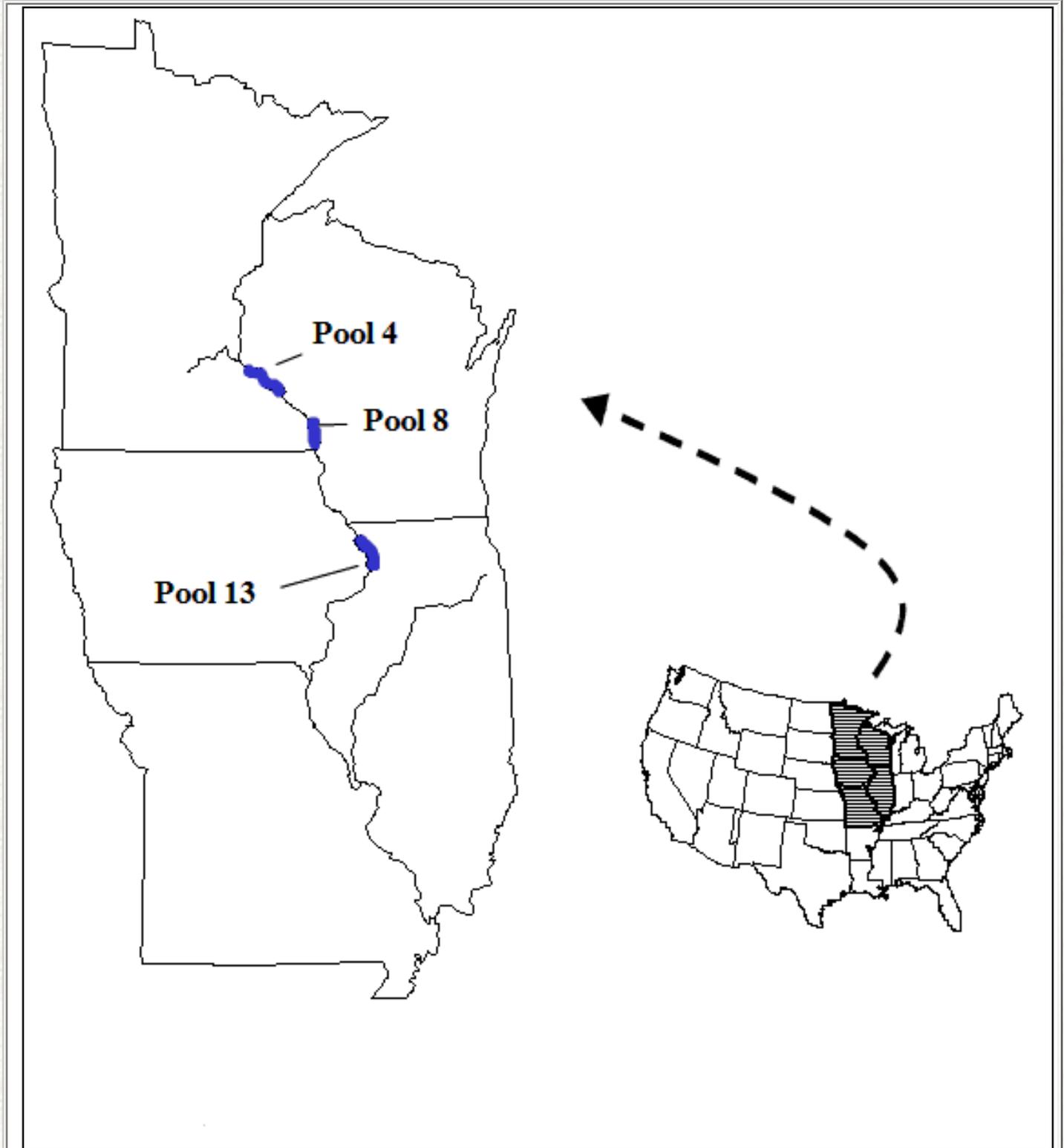


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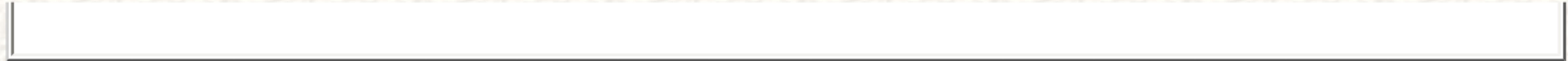
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Figure 1. Location of study Pools 4, 8, and 13 in the Upper Mississippi River, USA.



Recent rates of sedimentation rates in backwaters of the Upper Mississippi River - Figure 1. Location of study Pools 4, 8, and 13




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 [Rates and Patterns of Net Sedimentation in Backwaters](#)

Table 1. Number of transects sampled out of the number selected (in parentheses) in the three strata in Pools 4, 8, and 13.

	Pool 4	Pool 8	Pool 13
Large backwater lakes	8 (12)	12 (12)	10 (12)
Small, low-connectivity backwater lakes	8 (9)	7 (7)	7 (9)
Small, high-connectivity backwater lakes	4 (4)	6 (6)	0 (4)

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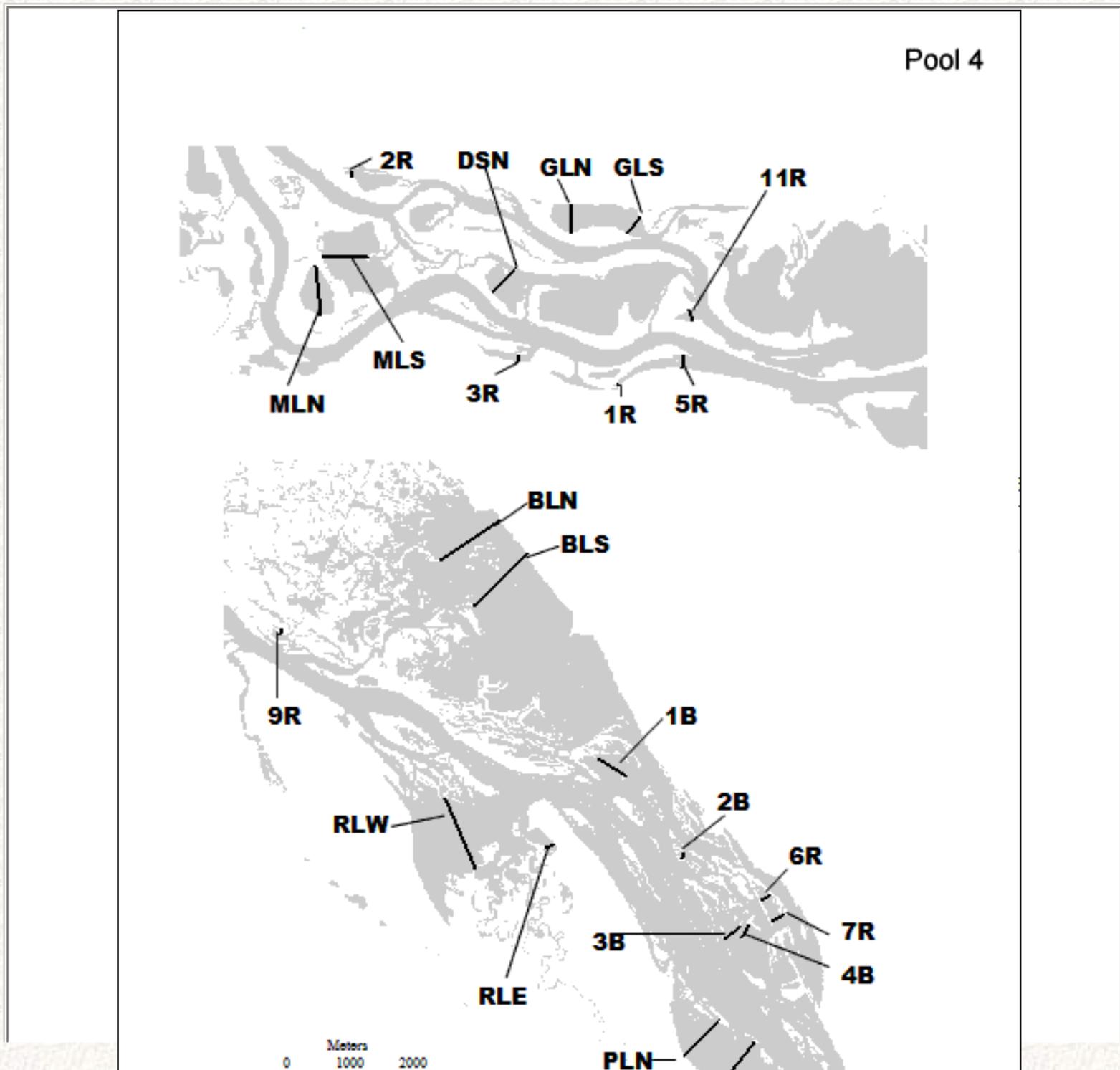
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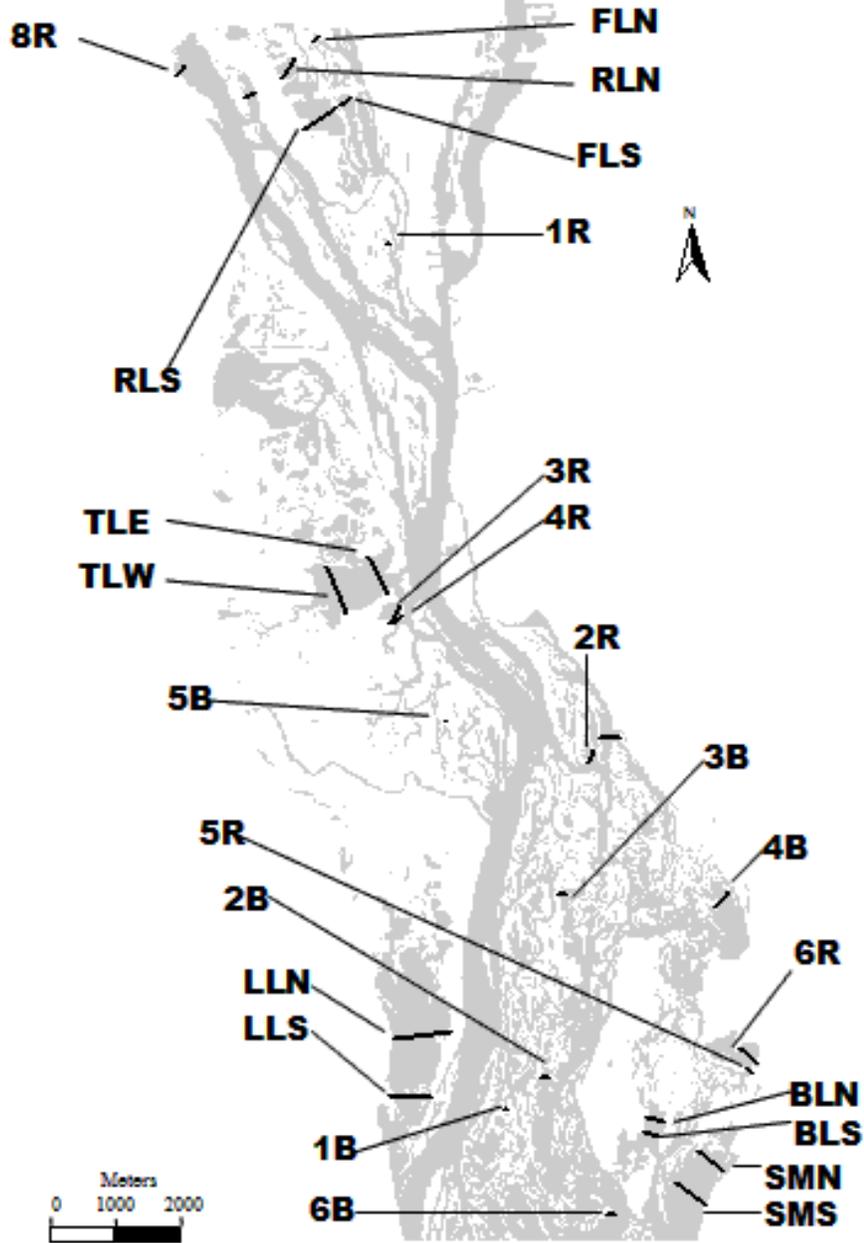
Appendix A

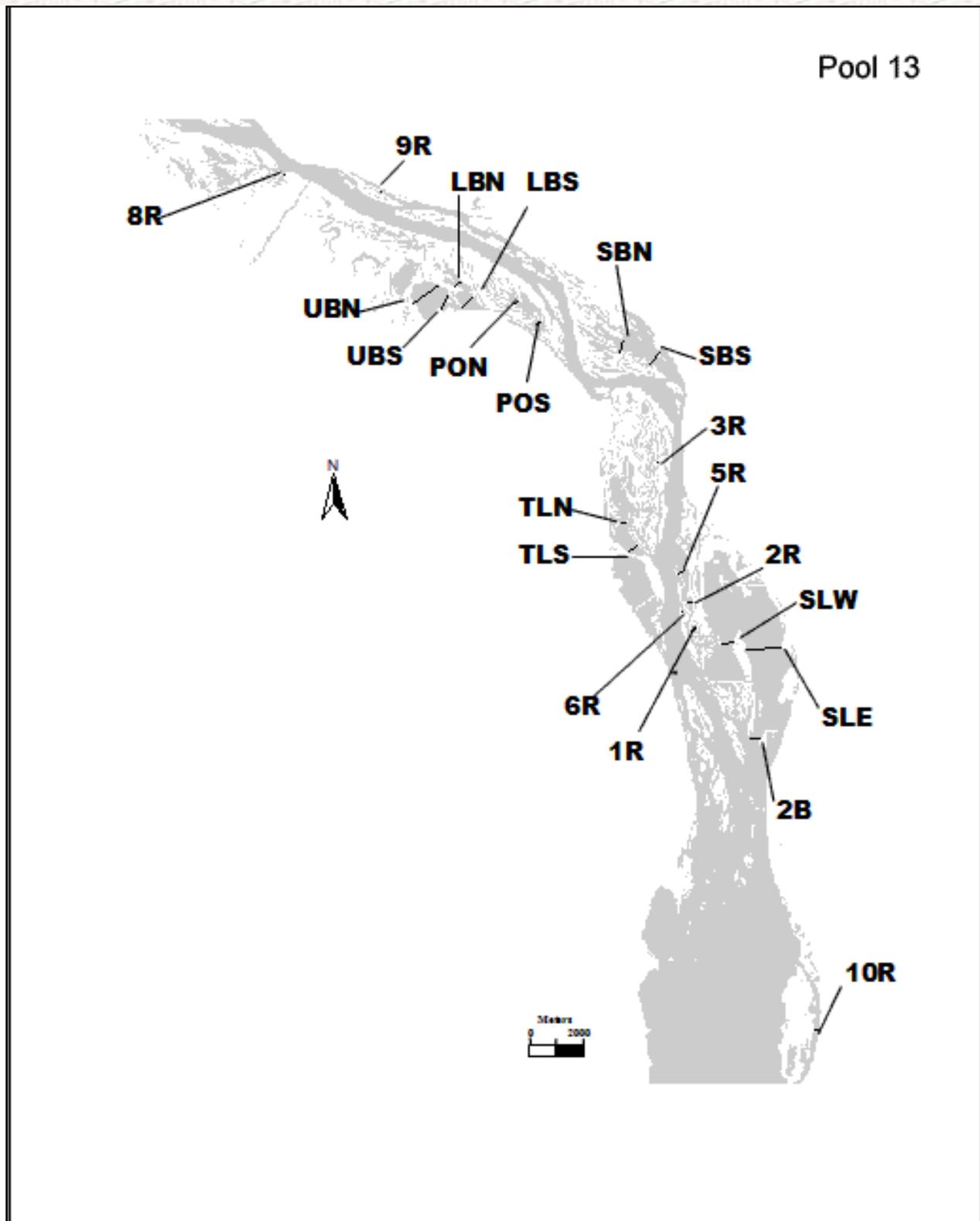
Maps of transect locations (designated by identification codes) in Pools 4, 8, and 13





Pool 8







Results and Discussion

Average Sedimentation Rates During the Study Period

Poolwide mean rates (in $\text{cm}\cdot\text{yr}^{-1}$) of backwater sedimentation over the entire length of the sampling transects during the 5-yr period were 0.04 (SE = 0.13) in Pool 4, 0.27 (SE = 0.11) in Pool 8, and 0.52 (SE = 0.20) for Pool 13. These rates often differed between aquatic and terrestrial portions, both within and among pools ([Table 2](#)). However, because of relatively large variances, we found no significant differences in mean rates among pools within aquatic or terrestrial portions ($t < 1.8$, $df = 54$, $p > 0.08$). We also found no significant differences between aquatic and terrestrial areas within pools ($t < 1.5$, $df = 54$, $p > 0.15$).

The maximum poolwide estimate of $0.47 \text{ cm}\cdot\text{yr}^{-1}$ (Pool 13) for aquatic portions of transects was lower than most rates presently used to evaluate effects of sedimentation in UMR backwaters (e.g., backwater life-expectancy). Considering that one of the objectives of this study was to determine if rates obtained from previous studies reasonably depict present day rates, this comparison is noteworthy. To better assess the differences between our rates and previous estimates, we compared mean rates of the past studies to the upper 95% confidence limits for our mean rates. We are limited to this method of comparison because past rates are often presented without estimates of variance, or past estimates were obtained from a biased sampling of backwater areas (e.g., sampled only in deep areas). The treatment of past estimates as true means in our comparison seems appropriate, given that the past rates have often been used without regard to the confidence in the estimate. Upper confidence limits for our poolwide estimate of rates ($\text{cm}\cdot\text{yr}^{-1}$) in aquatic portions of transects for Pools 4, 8, and 13 ranged from 0.27 to 0.84, which are much lower than rates of between 1 and $4 \text{ cm}\cdot\text{yr}^{-1}$ reported by McHenry et al. (1984). Whether or not these differences are a result of the biased sampling designs of past studies, changes in sedimentation rates over time, or atypical rates during our study period is unknown. We will address the potential for atypical rates in our study later in this report.

The high variability we observed in rates within pools and within the aquatic and terrestrial portions of transects is undesirable for estimating a mean, but is interesting

from a modeling standpoint. Explaining the variability among transects or within transects may be of greater importance to resource managers than obtaining mean rates at large scales (e.g., pool). One potential explanatory variable that may be useful is bed elevation. In some lentic systems, relations between sedimentation and bed elevation can be strong, as sediments tend to accumulate at greater rates in deeper areas (i.e., sediment focusing; Hakanson 1977; Hilton et al. 1986). To examine this potential relation, we developed simple correlations between bed elevation and sedimentation rates at both transect and sample location levels.

Although we expected relations between sedimentation rates and elevation to be stronger at the location level, we began by looking for relations at the transect level because it would generate a simpler predictive model. Mean sedimentation rates were highly variable among transects ([Appendix B](#)). However, little of the variability in mean sedimentation rates among transects within pools could be explained by correlations with measures of mean, maximum, or selected quantiles of bed elevation at the transect level. The lack of a correlation may be because of differences in dominant sediment transport processes among backwaters, as water velocities can vary greatly among backwater areas. In addition, great differences in the relations between bed elevation and sedimentation rate may be present at the location level, thus making relations at the transect level difficult to detect.

To investigate the relation between sedimentation rate and bed elevation within transects, we determined mean poolwide sedimentation rates for eight bed elevation ranges for the period 1997 to 2001. The relation between sedimentation rate and bed elevation within transects differed between aquatic (negative) and terrestrial (positive) portions of transects ([Figure 2](#)). Bed elevation, as an interaction term with the aquatic or terrestrial portion of transect, had a significant effect on sedimentation rates when using mean rates from all three pools ($F = 8.8$, $df = 1,20$, $p = 0.008$).

The loss of water surface area (i.e., terrestrial encroachment) and the filling of the deepest areas of backwaters are two concerns of managers. Encroachment of terrestrial areas into aquatic areas was not apparent in Pools 4 and 8, as erosion occurred in the near-shore bed elevation range of -0.2 to 0 m. ([Figure 2](#)). High rates of sedimentation in the deepest areas (bed elevation < -0.6 m) were not found in these data. The deepest areas in all pools tended to have low sedimentation rates (< 0.5 $\text{cm}\cdot\text{yr}^{-1}$), with rates lower than 0.15 $\text{cm}\cdot\text{yr}^{-1}$ in Pools 4 and 8. However, an exception to this occurred in the recent dredge cuts (bed elevation < -1.0 m) in Brown's Lake, Pool 13 where sediments accumulated at over 7.5 $\text{cm}\cdot\text{yr}^{-1}$.

As indicated, we observed slight associations between bed elevation and average sedimentation rates within transects. This association may be confounded by effects of

variables not included in our simple model, such as velocity and vegetation. Any effects of bed elevation may become clearer after adjusting for such effects, but we were unable to examine these effects because suitable data for these other variables do not exist.

Annual Sedimentation Rates During the Study Period

We considered annual discharge the most likely factor driving annual variability in sedimentation. Annual discharge varied greatly during our study ([Table 3](#)), allowing us to investigate this relation by comparing poolwide mean sedimentation rates for terrestrial to aquatic portions of transects during the highest (2001) and lowest (2000) discharge years. Accumulation occurred in terrestrial areas and erosion in aquatic areas during the high discharge year of 2001, with the inverse occurring in 2000 ([Figure 3](#)). Differences between 2000 and 2001 are significant for terrestrial areas in all three pools ($t > 3.1$, $df = 55$, $p < 0.005$) and for aquatic areas in Pool 8 ($t = 4.72$, $df = 52$, $p < 0.0001$), assuming year effects are independent of pool effects. Differences between aquatic and terrestrial portions of transects were significant in 2000 and 2001 ($t > 2.5$, $df = 55$, $p < 0.02$), except for Pool 13 in 2000 ($t = 1.5$, $df = 55$, $p = 0.13$).

The observed difference in sedimentation rates for the lowest and highest discharge years suggests annual poolwide sedimentation rates are correlated with discharge. To see if a correlation existed across all discharge levels during our study period, we examined the association between discharge and poolwide annual sedimentation rates in aquatic and terrestrial areas for all years with sufficient data in each pool ($n = 24$ out of a possible $n = 30$). The effect of discharge was significantly associated with aquatic or terrestrial portion of transect in this model ($F = 22.1$, $df = 1,20$, $p = 0.0001$). Discharge (in thousands of $m^3 \cdot sec^{-1}$) effects on sedimentation rate ($cm \cdot yr^{-1}$) were positive for the terrestrial portion of transects (slope = 0.57, SE = 0.15) and negative for the aquatic portion of transects (slope = -0.21, SE = 0.10). Based on the model, sedimentation rates are similar in both terrestrial and aquatic portions of transects at discharges near 3,000 $m^3 \cdot sec^{-1}$ ([Figure 4](#)). This model excluded pool effects and assumed no temporal correlation for annual means.

Using the associations we observed between annual sedimentation rates and annual discharge, we assessed whether our study period was a typical period of sedimentation, at least for discharge effects. Of concern was the occurrence of a high discharge year within our study period. For example in Pool 8, the year 2001 was the highest discharge year during the period 1959-2001, as measured by the discharge value exceeded 5% of the time within each year ([Figure 5](#)). Therefore, the mean sedimentation rates obtained for aquatic areas over our study period may be lower than long-term rates, considering our finding of net erosion in 2001. Furthermore, our study did not include a low

discharge year; our lowest year (2000) was only in the lower 25% of occurrence. As a result, this may have also contributed to our rates potentially being lower than long-term rates, given our finding of high accumulation in lower discharge years. However, the effect of a low discharge year on sedimentation is unknown, as we did not have a drought year during our period of sampling.

The observed differences in annual mean rates of sedimentation in aquatic and terrestrial portions of transects may be a simplification of relations along a bed elevation gradient. To further assess these relations, we compared mean sedimentation rates for eight bed elevation ranges for each year by pool. Patterns for the lowest and highest discharge years were quite different, with negative correlation between bed elevation and sedimentation rate in the low discharge year of 2000, and positive correlation in the high discharge year of 2001 ([Figure 6](#)). Using annual rates for all years in study period, bed elevation was significant ($F = 4.3$, $df = 24,60$, $p < 0.0001$) as an interaction term (bed elevation*year). The significant effect was not present simply because of differences between 2000 and 2001, as bed elevation effects were still highly significant when 2001 data was excluded ($F = 2.7$, $df = 17,44$, $p = 0.0041$). These findings differ from the bed elevation effects observed in the average sedimentation rate over the study period, where bed elevation effects were only present when the portion of the transect (aquatic versus terrestrial) effect was included in the model.

Several patterns in the relations between sedimentation and bed elevation classes were similar across years. For example, we found low sedimentation rates ($<0.2 \text{ cm}\cdot\text{yr}^{-1}$) in near-shore areas over the study period during most of the study years. This suggests that discharge does not play a large role in determining sedimentation in these areas. Similarly, rates of sedimentation in the dredge cuts in Brown's Lake, Pool 13 were high ($>6 \text{ cm}\cdot\text{yr}^{-1}$) in all years, suggesting these areas are not susceptible to scour in high discharge years. Although discharge affected the relations between sedimentation and bed elevation as a whole, the effects may be limited to only some bed elevation classes along transects and can differ among transects.

The annual sedimentation patterns we observed can be attributed to several processes that drive sedimentation. Our findings of erosion in aquatic portions of transects in high discharge years (2001) suggests that, while the suspended sediment delivery may be high in the backwaters during high discharge, sediments are kept in suspension and transported out of the backwaters. Furthermore, previously accumulated sediments that formed the existing bed are probably resuspended because of high shear stress associated with high discharge periods. Accumulation of sediments in normally terrestrial areas during high discharge events can be attributed to the delivery of sediments during high water and the ability of terrestrial vegetation to reduce flows and allow deposition of suspended sediments.

In contrast, suspended sediments delivered to the backwaters in a low discharge year, albeit a lesser mass of sediments, are potentially accumulated because lower velocity conditions are present in backwaters. For the same reason, existing bed sediments are not eroded in low discharge years. In the normally terrestrial portions of transects, there is net erosion in low discharge years because accumulation during the maximum discharge period within low discharge years is not great enough to offset erosion occurring the rest of the year. Wind-generated wave action is a likely mechanism for erosion of near-shore areas.

More complex models, developed using our observed correlations as a foundation, show promise in strengthening our capability to predict sedimentation spatially and temporally. Inclusion of other explanatory variables (e.g., water velocity) would further strengthen future modeling efforts. In particular, an approach that analyzes effects from different levels (e.g., pool, transect, and year) simultaneously seems appropriate. Such “mixed” statistical models will allow us to model sedimentation in UMR backwaters more explicitly.

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 [Rates and Patterns of Net Sedimentation in Backwaters](#)

Table 2. Poolwide mean sedimentation rates ($\text{cm}\cdot\text{yr}^{-1}$) for the entire transect, terrestrial portions of transects, and aquatic portions of transects for the period 1997 to 2001 in Pools 4, 8, and 13. Standard errors of the means are in parentheses.

	Pool 4	Pool 8	Pool 13
Entire transect	0.04 (0.13)	0.27 (0.11)	0.52 (0.20)
Terrestrial portion	0.43 (0.25)	0.32 (0.14)	0.78 (0.25)
Aquatic portion	-0.08 (0.18)	0.24 (0.10)	0.47 (0.26)

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Appendix B

Rates of net sedimentation ($\text{cm}\cdot\text{yr}^{-1}$) for transects (designed by identification codes) in Pools 4, 8, and 13 between 1997 and 2001. Asterisk indicates mean rate of sedimentation not estimated because of small sample size.

Pool 4			Pool 8			Pool 13		
	Terrestrial	Aquatic		Terrestrial	Aquatic		Terrestrial	Aquatic
1R	0.35	-0.71	1R	0.01	-0.77	1R	1.42	0.91
2R	0.39	*	2R	0.20	0.58	2R	0.01	0.01
3R	-0.30	-1.02	3R	0.22	0.32	3R	0.82	0.71
5R	1.12	0.76	4R	-0.55	0.38	5R	0.83	1.45
6R	-0.01	1.13	5R	0.81	-1.06	6R	6.11	-2.78
7R	-0.31	0.49	6R	0.59	0.71	8R	0.13	0.91
9R	-0.01	-0.46	8R	0.41	0.84	9R	0.65	-1.44
11R	0.69	0.31	1B	1.02	-0.01	TLN	1.28	0.35
1B	0.90	0.26	2B	0.51	0.27	TLS	1.15	0.16
2B	1.28	-0.79	3B	0.86	0.47	SBN	0.22	0.14
3B	-0.03	-2.23	4B	0.73	0.49	SBS	1.01	-0.45

4B	2.66	-1.50	5B	0.50	0.03	PON	-0.36	0.73
BLN	-0.29	0.12	6B	-1.88	-0.15	POS	1.22	1.66
BLS	0.69	-0.13	LLN	0.79	-0.18	LBN	-0.14	1.93
PLN	1.12	0.46	LLS	1.49	-1.08	LBS	0.063	0.24
PLS	1.11	0.59	SMN	0.02	-0.04	UBN	0.90	0.49
GLN	-0.20	0.92	SMS	0.15	0.72	UBS	0.61	0.91
GLS	-0.59	0.71	BYN	0.76	0.39			
MLN	1.52	1.23	BYS	0.18	0.48			
MLS	-0.89	0.21	TLE	-0.41	-0.17			
			TLW	-0.02	0.80			
			FLN	0.05	*			
			FLS	0.19	1.13			
			RLN	0.33	0.43			
			RLS	0.58	0.50			

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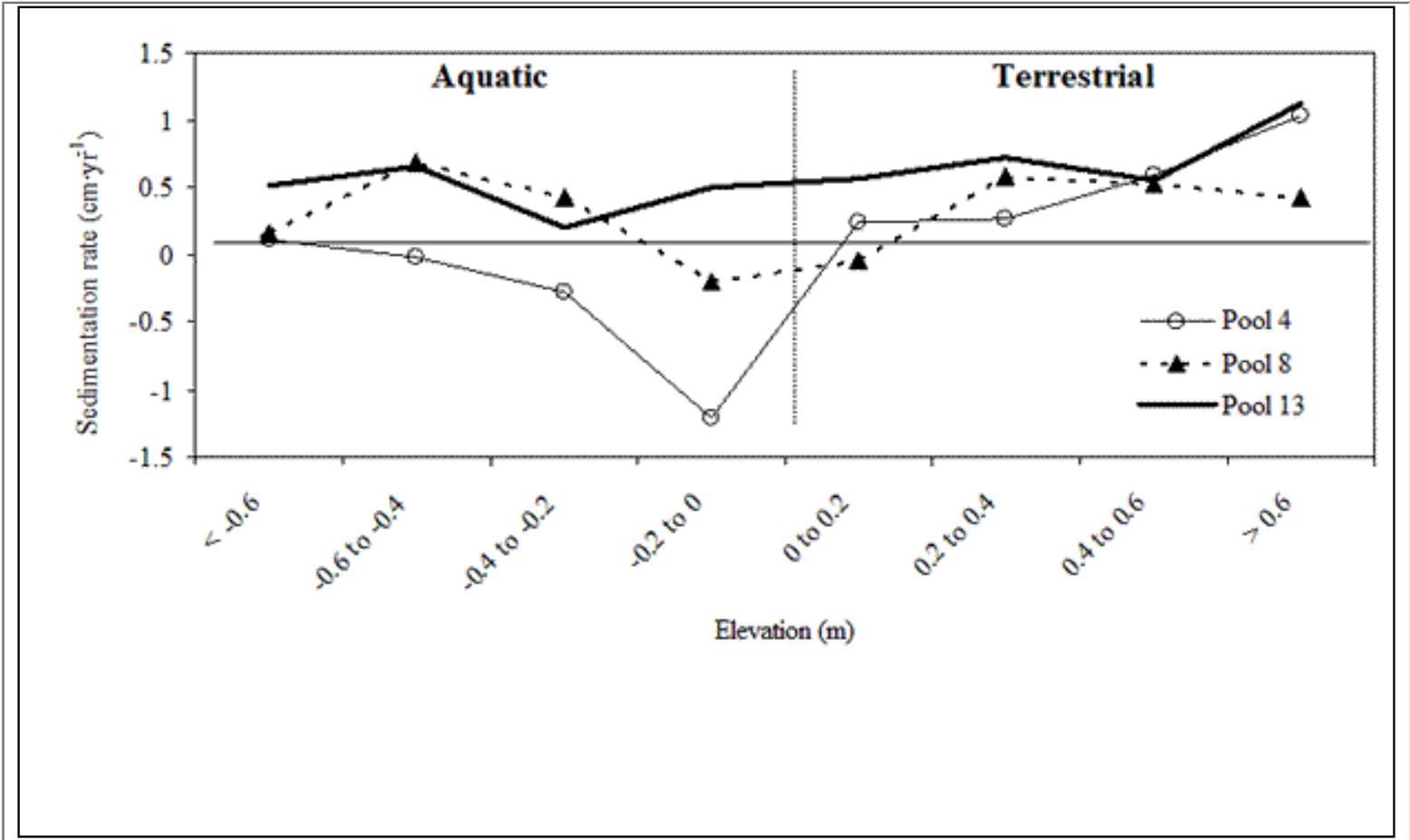


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Backwater sedimentation rates

Rates and Patterns of Net Sedimentation in Backwaters

Figure 2. Mean poolwide sedimentation rates for selected elevation classes for the period 1997 to 2001 in Pools 4, 8, and 13.



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[Rates and Patterns of Net Sedimentation in Backwaters](#)

Table 3. Annual discharge ($\text{m}^3 \cdot \text{sec}^{-1}$) as measured by the condition exceeded 5% of the time within each year during our study period.

	1997	1998	1999	2000	2001
Pool 4	3,444	2,040	2,049	1,316	5,646
Pool 8	3,532	2,609	2,295	1,871	5,603
Pool 13	4,701	3,707	3,453	2,765	6,679

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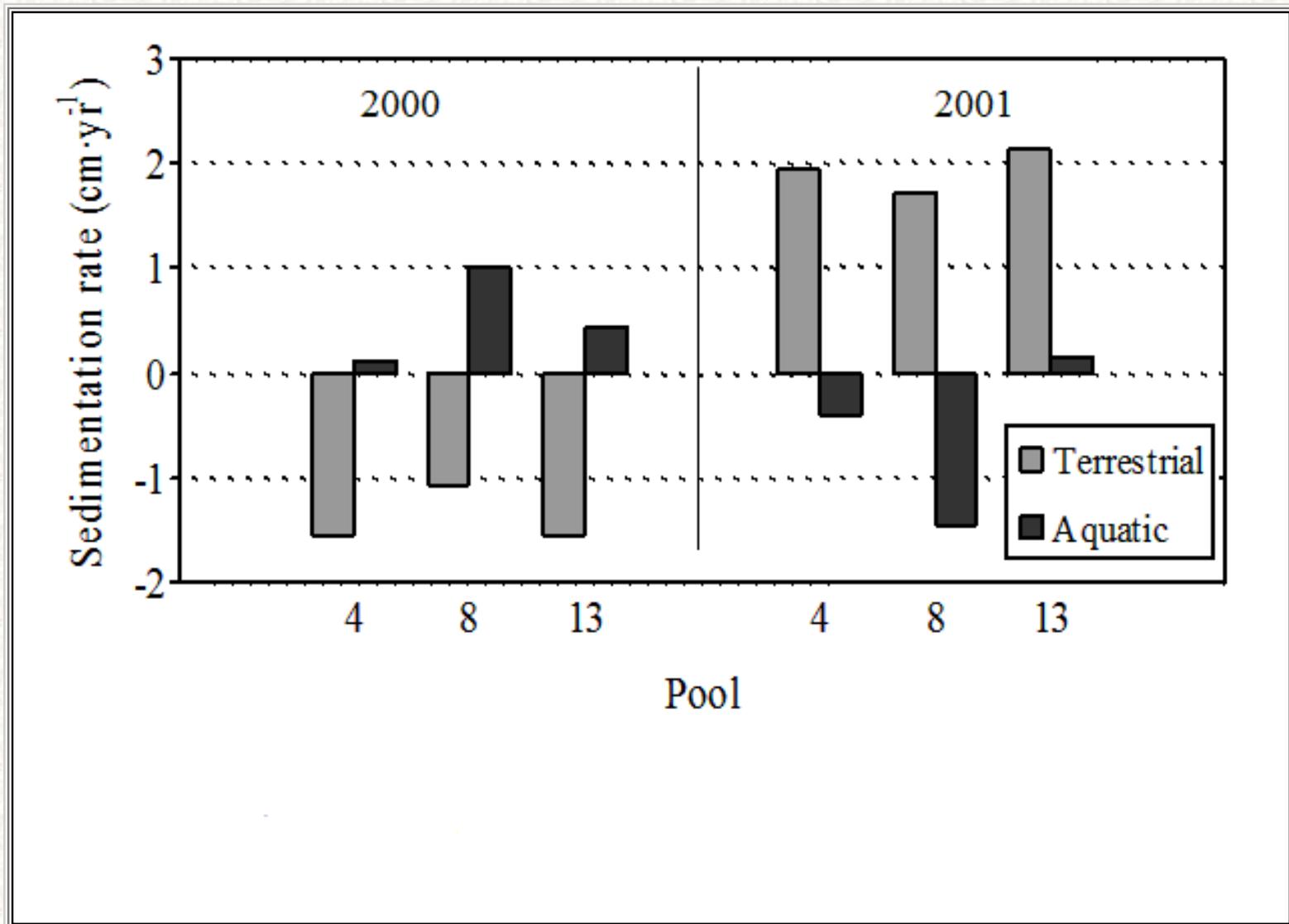
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Figure 3. Mean poolwide sedimentation rates during 2000 (low discharge year) and 2001 (high discharge year) for Pools 4, 8, and 13.



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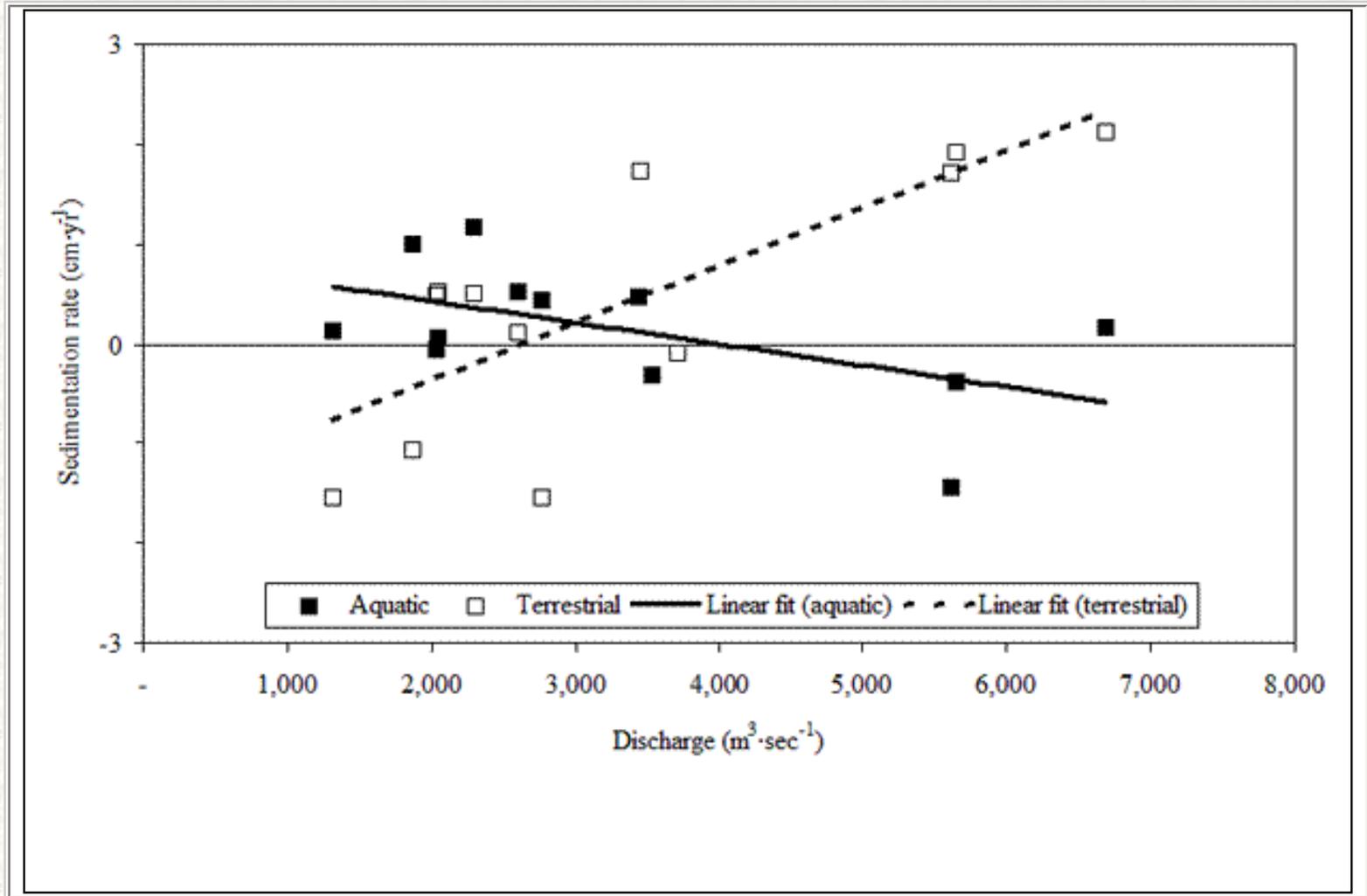


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Backwater sedimentation rates

Rates and Patterns of Net Sedimentation in Backwaters

Figure 4. Correlation between poolwide annual sedimentation rates for terrestrial and aquatic portions of transects and annual discharge (as measured by the discharge condition exceeded 5% of the time within each year). Data derived from Pools 4, 8, and 13.



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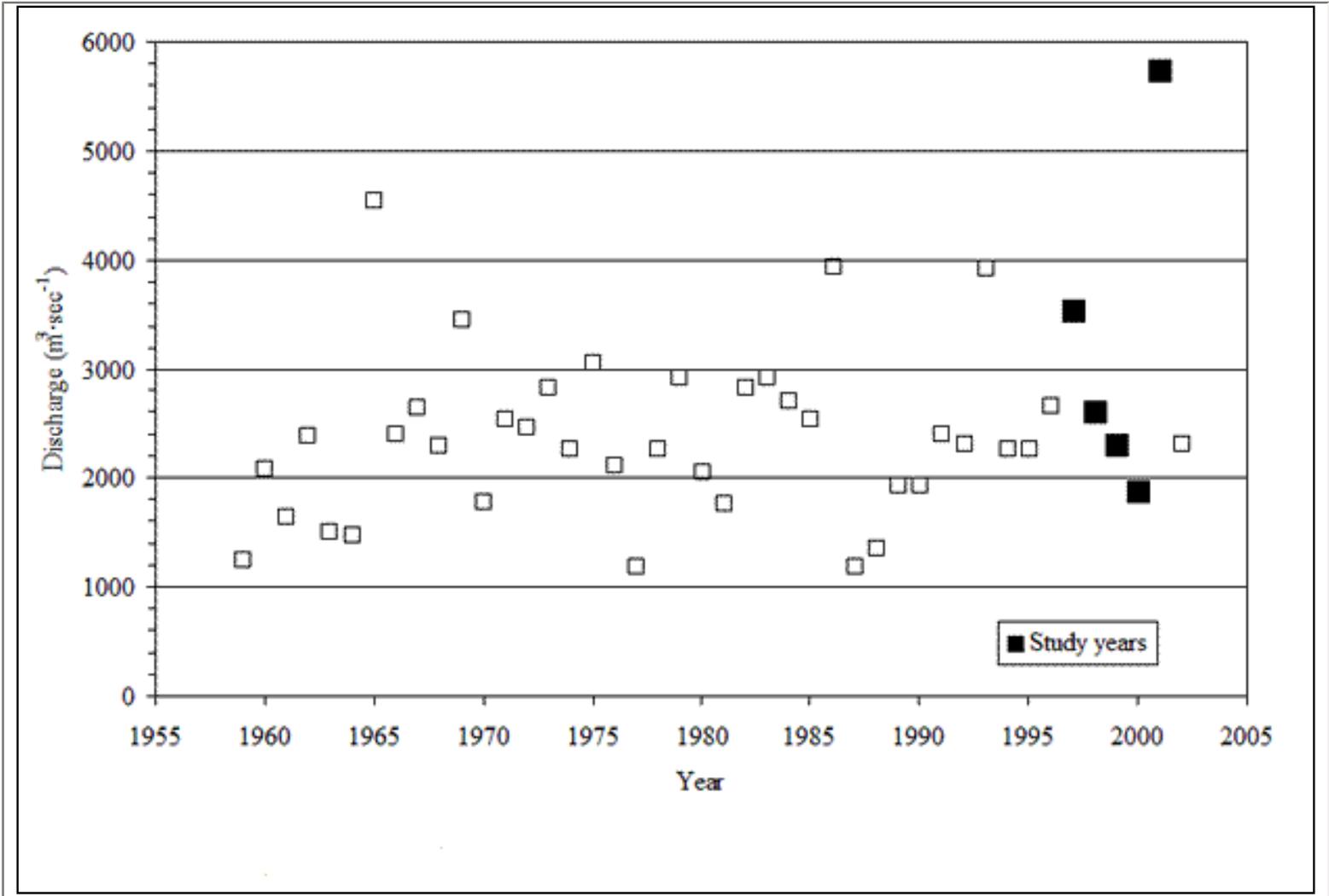


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[Rates and Patterns of Net Sedimentation in Backwaters](#)

Figure 5. Annual discharge (as measured by the discharge condition exceeded 5% of the time within each year) for Pool 8 from 1959 to 2001.



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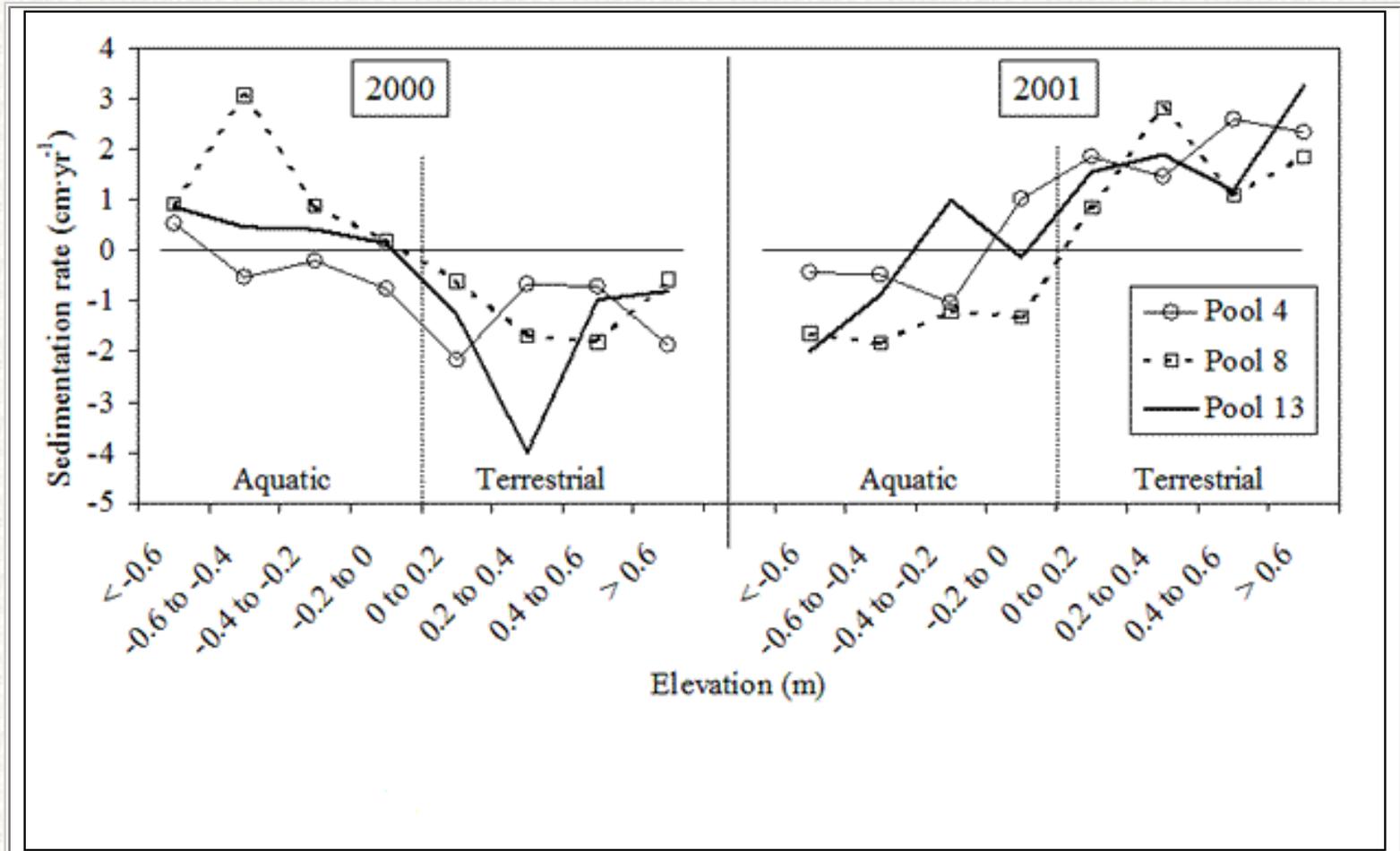


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Figure 6. Mean poolwide sedimentation rates for selected elevation classes during the years 2000 and 2001 for Pools 4, 8, and 13.



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Conclusions

Net sedimentation rates over this 5-yr study were lower than rates presently used to estimate effects of sedimentation on UMR backwaters. Differences in annual sedimentation rates were associated with annual discharge, whereas differences along transects at the annual time scale were associated with bed elevation. These associations are important information for evaluating effects of sedimentation on habitat change. Such an evaluation would be incomplete without explaining spatial and temporal variation in sedimentation. The predictions of cumulative effects of net sedimentation can be used to help manage fish and wildlife resources that may be affected by habitat changes. In addition, the information on spatial and temporal variability derived from the model could be useful for investigating direct annual effects of sedimentation on biotic and abiotic components of the river. To date, these direct effects have largely been ignored in the ecology of floodplain rivers.

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 [Backwater sedimentation rates](#)

 [Rates and Patterns of Net Sedimentation in Backwaters](#)

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Tables

[Table 1](#). Number of transects sampled out of the number selected (in parentheses) in the three strata in Pools 4, 8, and 13.

[Table 2](#). Poolwide mean sedimentation rates ($\text{cm}\cdot\text{yr}^{-1}$) for the entire transect, terrestrial portions of transects, and aquatic portions of transects for the period 1997 to 2001 in Pools 4, 8, and 13. Standard errors of the means are in parentheses.

[Table 3](#). Annual discharge ($\text{m}^3\cdot\text{sec}^{-1}$) as measured by the condition exceeded 5% of the time within each year during our study period.

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Figures

[Figure 1](#). Location of study Pools 4, 8, and 13 in the Upper Mississippi River, USA.

[Figure 2](#). Mean poolwide sedimentation rates for selected elevation classes for the period 1997 to 2001 in Pools 4, 8, and 13.

[Figure 3](#). Mean poolwide sedimentation rates during 2000 (low discharge year) and 2001 (high discharge year) for Pools 4, 8, and 13.

[Figure 4](#). Correlation between poolwide annual sedimentation rates for terrestrial and aquatic portions of transects and annual discharge (as measured by the discharge condition exceeded 5% of the time within each year). Data derived from Pools 4, 8, and 13.

[Figure 5](#). Annual discharge (as measured by the discharge condition exceeded 5% of the time within each year) for Pool 8 from 1959 to 2001.

[Figure 6](#). Mean poolwide sedimentation rates for selected elevation classes during the years 2000 and 2001 for Pools 4, 8, and 13.

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 [Rates and Patterns of Net Sedimentation in Backwaters](#)

Appendixes

[Appendix A](#). Maps of transect locations (designated by identification codes) in Pools 4, 8, and 13

[Appendix B](#). Rates of net sedimentation ($\text{cm}\cdot\text{yr}^{-1}$) for transects (designated by identification codes) in Pools 4, 8, and 13 between 1997 and 2001. Asterisk indicates mean rate of sedimentation not estimated because of small sample size.

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