Sediment and Carp Dynamics in Lake Mendota's Yahara River Estuary

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Prof. Chin Wu (Project Principal Investigator), UW–Madison Dept. Civil Environ. Engineering
Richard Lathrop (Project Co-Investigator), UW–Madison Center for Limnology & Wis. DNR
Kurt Welke (Project Co-Investigator), Wis. DNR, South Central Region

(Field, laboratory and modeling work conducted by graduate students from the Environmental Fluid Mechanics Lab, Dept. Civil Environ. Engineering, UW-Madison under the supervision of C. Wu.; report prepared by R. Lathrop et al. from information provided by UW EFM lab.)

Introduction

Fig. 1. The Yahara River estuary system upstream of Lake Mendota. (Photo: C. Wu, UW-Madison)

The Yahara River–Cherokee Marsh system is an important though rarely studied freshwater estuary to Lake Mendota near Madison, Wisconsin (Figs 1, 2). The open-water area of the river-marsh system (upstream from the STH 113 bridge) is about 3.0 miles long and has a surface area of 515 acres, with water depths being shallow and generally less than 1-2 meters. Currently, the open-water area (henceforth called the "Yahara estuary" in this report) upstream of the STH 113 bridge constriction is characterized by three water basins: the "north basin," the "middle basin" and the "south basin" (in downstream order) that are somewhat distinct due to channel narrowings in between. Downstream of the STH 113 bridge (and two other nearby bridge constrictions), much of the river estuary shoreline is developed (including marinas) prior to the river entering Lake Mendota (Fig. 1). The shoreline of the Yahara estuary upstream of the bridge contrictions is almost entirely natural, being surrounded by the large Cherokee Marsh wetland system dominated by emergent vegetation.

Historically, the open-water surface area of the Yahara estuary was significantly less prior to Lake Mendota's outlet being dammed in 1849 – an action that raised the lake's water level approximately 1.5 m. The higher water level flooded the pre-settlement marsh system and its narrow meandering stream channel, creating the beginnings of a larger river widespread that has steadily grown in surface area throughout the 1900's. Erosion of the surrounding marshland has increased the open water surface area, coupled with the dredging of Cherokee Lake (now part of the Yahara estuary's Middle Basin) in the 1960's. Shoreline erosion continues to this day especially when water levels in the lake are high.

Fig. 2: Yahara River estuary and Cherokee Marsh wetland, and locations of USGS monitoring stations.

The Yahara River and Token Creek, the two principal streams that first join before entering the estuary (Fig. 2), represent almost 50% of Lake Mendota's total direct drainage area. However, the two streams provide more than half of the surface water inflow into Lake Mendota because of the streams' high baseflow (especially Token Creek) when compared to tributaries in the western portion of Mendota's watershed. Because the Yahara River subwatershed is particularly large and comprised mostly of agricultural land uses, water discharge rates through the estuary increase greatly during runoff events when large amounts of sediment and phosphorus also enter the estuary. While sediment deposition in the estuary can occur during small runoff events, major amounts of sediment can leave the estuary and enter Lake Mendota during large events (Fig. 3). This sediment and associated phosphorus comes from upstream nonpoint pollution sources as well as from resuspended sediments previously deposited in the estuary. New material eroded from the estuary's marshland shoreline also adds to the sediment load moving through the system.

Fig. 3. Yahara estuary system with high load of suspended sediment following a major runoff event in July 1993. (Photo: Skot Weidemann Photography for Dane County Land and Water Resources Dept.)

Another important feature of the Yahara estuary is that carp densities in the system are large. Carp through their feeding activities cause the bottom sediments to be unconsolidated and easily resuspended, thus making the overlying water turbid and murky. The poor water clarity in the estuary restricts aquatic plant growth, which in turn allows greater open-water fetch zones for wind-induced water currents to further erode the marsh shoreline. Without aquatic plants, the estuary's ability to trap and retain sediment especially in the system's backwater areas and along shorelines is reduced. Habitat for desirable fish species is also poor due to the lack of aquatic plants throughout the estuary. As a result, fishing in this large water body is limited.

Thus, reducing carp densities in the Yahara estuary may be the first step to restoring the ecological health of the system. If carp densities were reduced, then clearer water would allow more aquatic plants to grow that would dampen water velocities and increase sediment depositon. Trapping and retaining more sediment along the shoreline edges would allow emergent vegetation to become re-established, thus reversing the long trend of marshland loss. Trapping more sediment and associated phosphorus in the Yahara estuary is also consistent with the overall Yahara CLEAN project goal of reducing phosphorus inputs to Lake Mendota.

The study summarized in this report documented sediment and carp dynamics in the Yahara estuary system as a necessary first step to a potential restoration of the whole river-marsh system. The ability to reduce carp densities in the Yahara estuary system was specifically evaluated by tracking carp locations over a two-year period using radio-telemetry of carp implanted with transmitters. The working hypothesis based on the previously successful radio-tracking work on Lake Wingra was that carp would congregate ("school") during the winter months where they would be vulnerable to being removed by commercial netting operations.

Along with the carp tracking work, a sediment dynamics study was initiated to elucidate factors controlling sediment movement in and through the Yahara estuary. While water levels, wind-induced water currents, storm runoff events, and carp resuspension were all hypothesized to effect shoreline erosion and sediment movement dynamics, the first effort evaluated in this study was to determine when, where and how much sediment was being deposited, eroded and moved through the estuary. The results from this study then lay the groundwork for additional studies that will lead to a full-scale restoration of the whole estuary system while also enhancing its sediment retention capabilities to reduce sediment and phosphorus loads to Lake Mendota.

Methods

Carp tracking study

WDNR fisheries biologists captured 20 large carp from the three basins of the Yahara estuary system in mid-September 2010. On shore, WDNR biologists implanted each anesthetized carp with a radio transmitter (Fig. 4) that emitted an unique frequency so that the movement of individual carp could be recorded over the study period. After a short convalescing period the implanted carp were then released back in the estuary; subsequent radio tracking confirmed all 20 fish were active, having successfully recovered the surgical procedure.

Fig. 4. Implantation of radio transmitters in carp from the Yahara estuary system, Sept. 2010. (Photo: R. Lathrop, WDNR)

Movement patterns of the 20 radio-tagged carp were generally recorded each month throughout the two-year tracking study that began in October 2010 and ended in August 2012 when the transmitter batteries began dying (as expected). During the open-water period, a boat was used for the tracking; during the winters of 2010-2011 and

2011-2012 due to unsafe ice, tracking was conducted 1-2 times per winter from an airplane. On some survey trips where a boat traversed the three Yahara estuary basins, not all carp were located as the transmitter signal could not be detected beyond a certain distance (e.g., 200 meters) due to water attenuation of the signal. However, on subsequent trips all "lost" fish were found. Signal attenuation in the water was not a problem for locating the carp by airplane, although recording carp locations was less precise than when the survey was done by boat.

Sediment dynamics study

A sediment budget for the Yahara estuary system during 2002-2010 was developed from mean daily suspended sediment loading data computed by the USGS at the Yahara River @ Windsor and Yahara River @ STH 113 monitoring stations upstream and downstream of the estuary, respectively (Fig. 2). Modeling was used in conjuntion with the monitoring data to estimate suspended sediment loads for the unmonitored Token Creek subwatershed and the lower unmonitored portion of the Yahara River subwatershed.

Sediment dynamics within the Yahara estuary system itself were documented using high-precision bathymetric mapping of the entire system at six different time periods from November 2008 through July 2011. Such successive bathymetry mapping revealed spatial patterns of erosion and deposition of the estuary's bottom topography between two time periods. Tritech SeaKing Parametric Sub Bottom Profiler (SBP), an acoustic, dual frequency, depth recording instrument was coupled with a poking method to map the bathymetry in deep and shallow areas. This technique required water level records to be obtained simultaneously with water depth measurements. Accuracy of changes in bottom topography between two time periods was approximately ±1 cm. Additional sediment studies not funded by this project are ongoing.

Results

Carp tracking study

The two-year tracking study found that in both winters carp congregated in the Yahara estuary's middle basin in the general location of Cherokee Lake (Fig. 5) although the congregation was much tighter in the winter of 2010-2011 than in the relatively warm winter of 2011-2012 (survey data not shown). Reasons for the carp overwintering in this area were not determined other than the area is slightly deeper than most other areas in the estuary system. Deeper water is somewhat warmer than water just below the ice surface so the warm-water-loving carp were likely located near the bottom sediments in Cherokee Lake. Possible springs bringing in warmer groundwater to the bottom of Cherokee Lake would be another possible reason for carp over-wintering in this area, but no evidence of the springs was noted. Surprisingly, the radio-tagged carp were not found closer to the upper end of the estuary where the Yahara River enters (after merging with Token Creek), as this location would be influenced by warmer winter water temperatures in the stream's baseflow maintained by groundwater springs farther upstream. This finding indicated that carp during the cold winter months seemed to stay away from relatively strong water currents even though the water might be slightly warmer.

Once the ice began to break up in early spring, the radio-tagged carp began to disperse throughout the Yahara estuary (Fig. 5). The carp remained widely dispersed in the estuary during the two summer survey periods although the tagged carp were rarely found in the very upper and lower ends of the estuary system. Carp have been observed to be dense in the eastern side of the upper basin of the estuary during the summer months, but this was not a location frequented by the tagged carp. During fall, the tagged carp began to converge in the middle basin. During mid-November just before freeze up, the schooling was much tighter in 2010 than in 2011 (survey data not shown). These same patterns just before freeze up carried over into the respective winter periods.

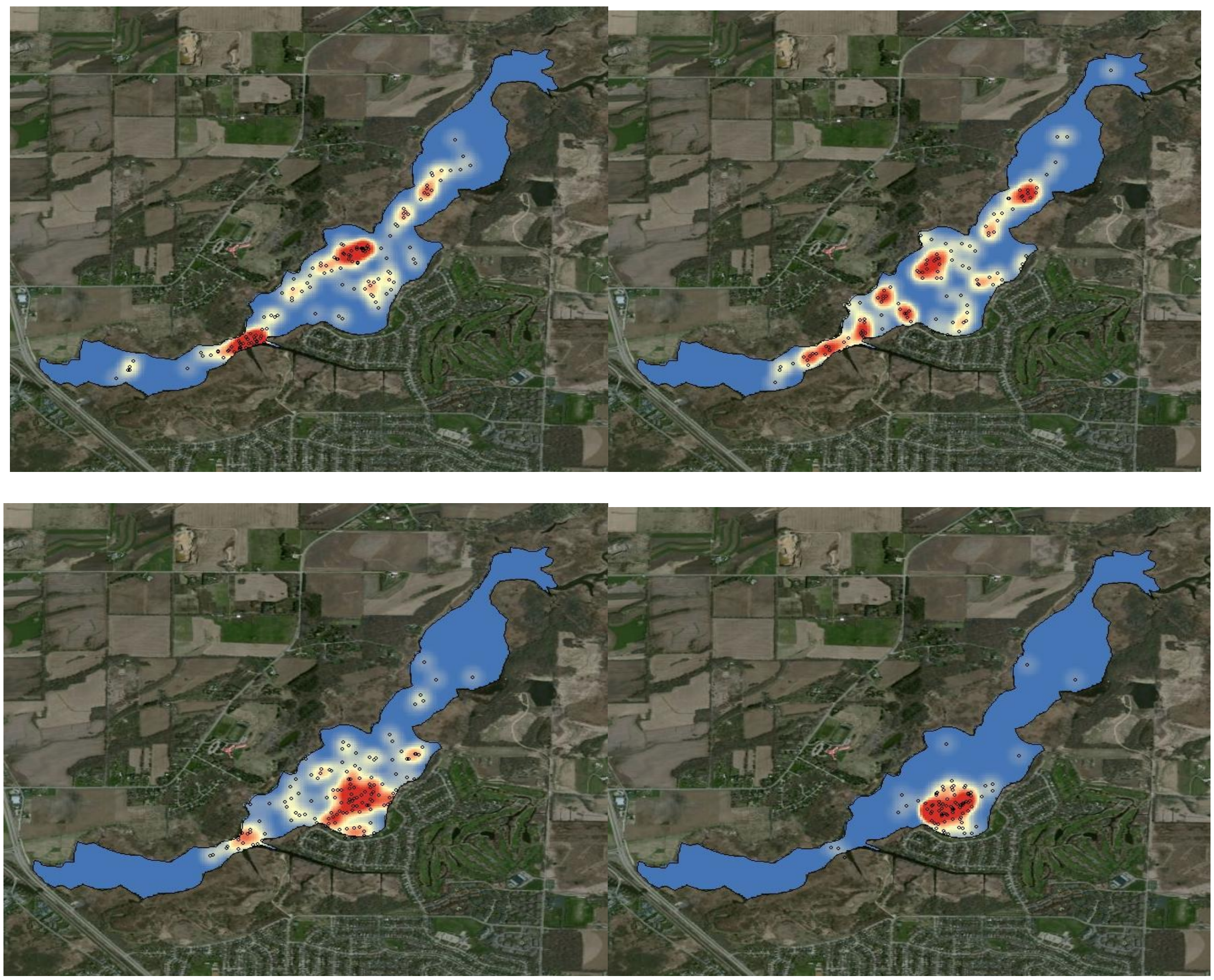

Fig. 5. Density probabilities of radio-tagged carp in the Yahara estuary system found during spring (upper left), summer (upper right), fall (lower left), and winter (lower right) as indicated by red areas (very dense), light yellow (moderately dense) and blue (sparse) colors. The density maps are summaries of surveys conducted approximately monthly from October 2010 through August 2012 during the open water period and 1-2 times per winter when the estuary was ice-covered.

General conclusions from this carp radio-tracking study indicated that late fall just before ice forming in the Yahara estuary may be the most opportune time to reduce carp densities in the estuary system. This would most logically be accomplished by a commercial contractor using a large seine that would fish the estuary's entire middle basin with the seine possibly being pulled up along the Cherokee Lake shoreline for relatively easy access. This same seining might also be done under the ice in winter if air temperatures were cold enough for safe ice to form throughout the middle basin in this riverine system with flowing water making ice conditions variable. Based on ice forming dates and carp survey findings from our two study years, removing carp during the week immediately prior to Thanksgiving when the estuary is still ice free might be ideal.

Sediment dynamics study

The sediment budget for the Yahara estuary system expressed as a time series of daily suspended sediment loads in and out of the system indicated highly variable conditions during 2002-2010 (Fig. 6). Periods of low loads were evident during the years of little runoff in 2002-2003, and 2005. Major loading events in May 2004, August 2007, and June 2008 (preceeded by high sustained river flows that spring) indicated major amounts of sediment were being transported. Only a few moderate runoff events with substantial sediment loadings (e.g., March 2009) occurred during the bathymetric mapping study period (Nov. 2008 – July 2011). For the 2004 and 2009 event years, the estuary gained sediment, whereas for the 2007 and 2008 event years, the estuary experienced a net loss of sediment. While estimating the total input of suspended sediment to the estuary can only be considered approximate because much of the subwatershed contributing area was unmonitored, the budget data indicated how dynamic the system is and that deposited sediment is not being permanently retained in the system.

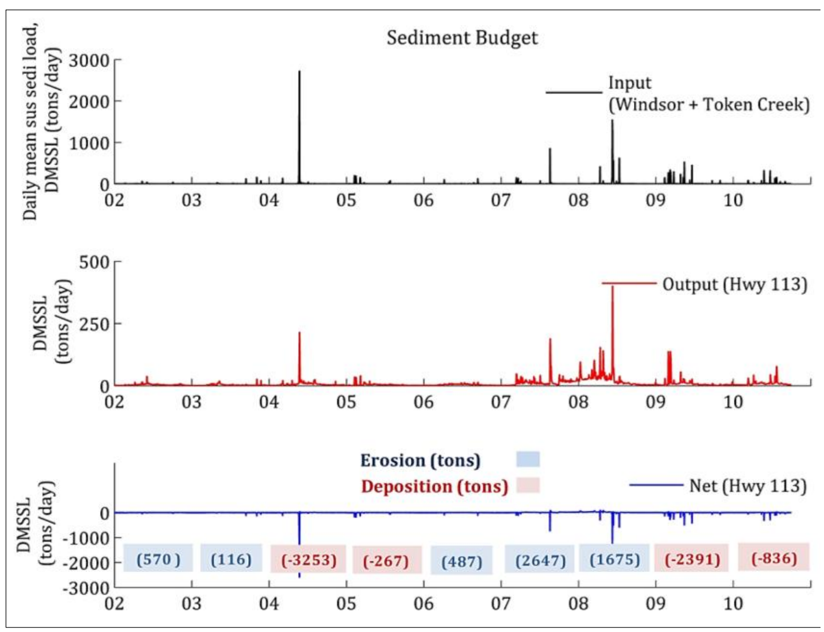

Fig. 6. Sediment budget for the Yahara estuary system with daily inputs and outputs of suspended sediment loads plotted for 2002–2010. The difference in input and output loads for each year is indicated in the lower graph where positive blue values indicate more sediment left the estuary than entered (i.e., net erosion) and negative red values indicate more sediment entered than left (i.e., net deposition).

Results from bathymetry mapping of the north, middle, and south basins of the Yahara estuary system for two annual periods (June 2009 – June 2010; June 2010 – July 2011) indicated that the deposition and erosion patterns of the estuary's sediments were highly dynamic both temporally and spatially (Figs. 7a,b). During the first yearly period, the middle and south basins displayed significant areas of sediment deposition whereas moderate sediment erosion was observed throughout most of the north basin (Fig. 7a). In many areas of the middle and south basins, as much as 0.5 m of sediment was deposited although not uniformly even as some areas (especially in the middle basin) experienced sediment erosion up to 0.5 m. Overall the Yahara estuary exhibited deposition, consistent with the sediment budget results (Fig. 6).

During the second annual period, the sediment bed of each basin was eroded (Fig. 7b) with the largest sediment depth of erosion occurring in the middle and south basins, thus yielding overall erosion for the whole estuary system. The reasons for this erosion behavior during the second annual period cannot be entirely explained from the available data, but the loss of sediment (and associated phosphorus) from all three basins can only be construed as a serious problem for downstream Lake Mendota and the lake's river inlet navigational area.

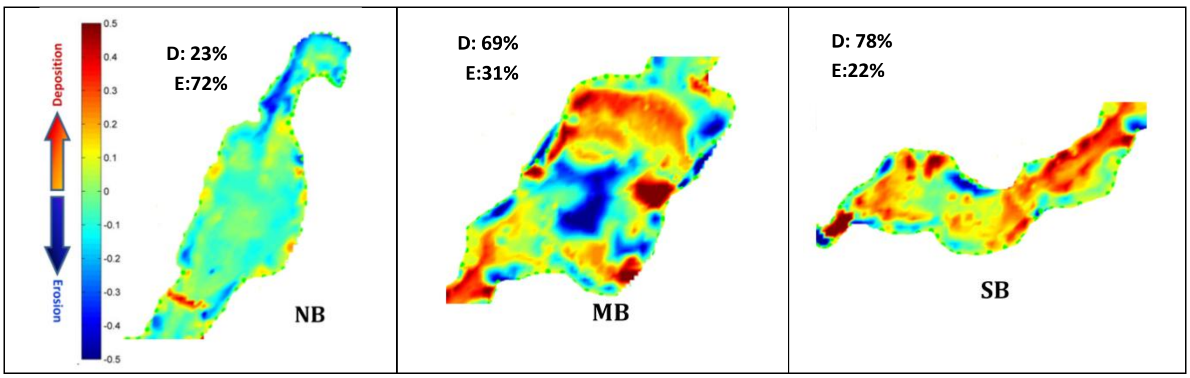

Fig. 7a. Bathymetry mapping during the first annual study period (June 2009 – June 2010) where yellow/red colors indicate areas of net deposition and blue colors indicate areas of net erosion that occurred in each of the three Yahara estuary basins between the two mapping exercises (NB = north basin, MB = middle basin, SB = south basin; color scale in meters). Overall, the north basin reflected more areas of moderate erosion while the middle and south basins displayed significant areas of both deposition and erosion during the period (D = deposition, E = erosion, expressed as a percent of total basin area).

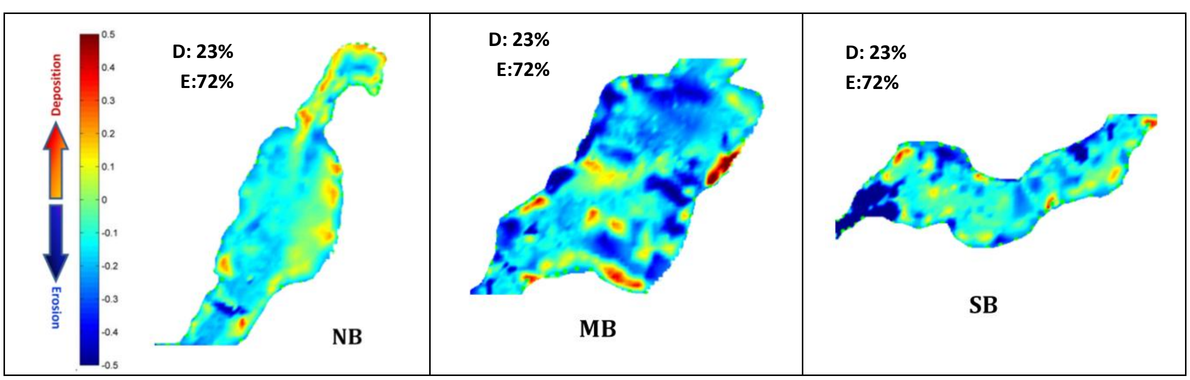

Fig. 7b. Bathymetry mapping during the second annual study period (June 2010 – July 2011); see Fig. 7a for more details. Overall, erosion predominated in all three basins during the study period.

The significant amount of sediment movement within and through the Yahara estuary system is not only linked to highly variable flow conditions (i.e., periods of dry weather baseflow versus major runoff events), but two other factors. During major wind events from southern to western directions, water is pushed to Mendota's northeast end causing significant reverse flow conditions of water moving "upstream" into the estuary system. When winds subside, this excess water then flows back out of the system carrying sediment with the flow. During the intensive study period, reverse flow conditions were observed to last many hours at a time. The other reason relates to fetch within the estuary itself, where major southwesterly or northeasterly winds line up with the major axis of the long estuary causing significant wave and water current effects. The combined result of these three highly variable factors produces highly dynamic flow velocities with erosive energy throughout the entire estuary system in its current state with sparse aquatic plant growth and minimal barriers to dampen those energies.

Summary and Future Directions

The Yahara River estuary upstream of Lake Mendota is a highly degraded system subject to severe bottom and shoreline erosion as a significant amount of sediment dynamically enters and moves through the system. Because of the dense population of carp in the estuary, bottom sediments remained unconsolidated and easily resuspended. This results in poor water clarity that restricts the growth of aquatic plants important not only as fish habitat, but needed to dampen the erosive water currents from major runoff events as well as from reverse flow events and wind-induced waves along the estuary's major fetch axis. When water currents and wave action are strong, then shoreline erosion of the marsh shoreline occurs especially when water levels are high in the system.

To restore the ecological health of the Yahara estuary and prevent further shoreline erosion, a number of actions are needed. First, the carp population must be reduced so that bottom sediments can stabilize and consolidate. This should produce clearer water promoting more aquatic plant growth. The plants in turn will dampen water velocities and allow sediment deposition to increase especially in backwater areas protected by the plants. As sediment accretes in these areas then emergent vegetation can root, which has a longer lasting effect given the submersed aquatic plants die back each year. To this end, a carp removal is being planned for the fall of 2013 in conjunction with a mark-recapture study that will provide an estimate of the total carp population in the estuary. In addition, a study of carp movement from Lake Mendota into the estuary especially during the late spring spawning season is currently being conducted with sonar equipment placed at the railroad bridge constriction on the downstream end of the estuary. This study, which should be completed in the summer of 2013, will hopefully determine if a seasonal carp barrier is needed to help maintain low carp densities in the estuary after carp have been removed.

However, in conjunction with the aforementioned carp removal, structures or barriers may need to be strategically placed both temporarily and permanently in the estuary to absorb the erosive energy of elevated water velocities. Barriers designed as floating bogs recently were tested in the estuary system and have proved to be very successful at stabilizing and trapping sediment in areas sheltered by the barriers. Other structures such as floating islands could also be deployed to add structure to the large open-water area of the estuary system while potentially helping promote a deeper river channel for water flowing through the system. The use of such barriers is currently being evaluated as part of a study employing both experimental pilot testing of different kinds of barriers as well as modeling studies of how such water velocity dampening devices would alter flow patterns in the system. Once this study is completed, then a full-scale restoration of the estuary could proceed once stakeholders agree on the restoration design. This restoration effort would also have important phosphorus loading reduction benefits for Lake Mendota as more sediment-bound phosphorus could be permanently trapped in the estuary system as it accretes sediment while rebuilding marshland.