SANDBAR GROWTH AND DECAY ON THE MISSOURI RIVER DURING THE HIGH FLOWS OF 2010 AND THE HISTORIC 2011 FLOOD

Jake Gusman, P.E., Project Manager, WEST Consultants, San Diego, CA, jgusman@westconsultants.com; Vicki Tripolitis, EIT, Hydraulic Engineer, WEST Consultants, San Diego, CA, vtripolitis@westconsultants.com; Cameron Jenkins, P.E., Hydraulic Engineer, WEST Consultants, San Diego, CA, cameronj@westconsultants.com; Christopher Svendsen, P.E., Hydraulic Engineer, U.S. Army Corps of Engineers, Omaha District, Omaha, NE, christopher.j.svendsen@usace.army.mil; Daniel Pridal, P.E., Chief, Sedimentation and Channel Stabilization Section, U.S. Army Corps of Engineers, Omaha District, Omaha, NE, daniel.b.pridal@usace.army.mil

The views expressed in this paper are those of the author(s) and do not necessarily reflect the official policy or position of the United States Army Corps of Engineers, the Department of the Army, Department of Defense, or the United States Government.

Abstract: The U.S. Army Corps of Engineers, Omaha District implements an Emergent Sandbar Habitat (ESH) construction program on the Missouri River to create nesting habitat for the interior least tern and piping plover bird populations. Beginning in August 2010, high flows prompted the Corps to initiate physical monitoring of six sites to document whether the flow level and duration were sufficient to create sandbars suitable for nesting. In 2011, a historic flood resulted in dam releases reaching 160,000 cfs, approximately a 0.2% annual chance exceedance (500-year) event. The monitoring period was extended to capture sandbar formation during this event and to document the subsequent degradation once the high water had receded.

Analysis of the data for the high flows of 2010 and 2011 yielded important insights regarding the sediment volume change at each site, total sandbar area, individual sandbar characteristics (wetted perimeter to area ratio, average side slope, average sandbar height, etc.), and the mechanisms for sandbar growth and decay. A two-dimensional, fixed-bed hydrodynamic model was constructed for one of the survey sites using the ADH (ADaptive Hydraulics Modeling System) program. Computed flow depth, velocity, and shear stress were analyzed during periods of sandbar growth and decay. For the highest flows, there was a zone with highly transient sandbars—a zone in which bed material was continuously moving, depositing, and eroding. These highly transient sandbars did not persist after the floodwaters receded. As expected, sandbars were more likely to persist in areas of reduced shear stress, velocity, and depth.

The location of the thalweg versus the location of major sandbars has a strong correlation to the sandbar decay rate. In periods when the thalweg was close to the major sandbars, the decay rate was significantly higher. As the thalweg moved away from the sandbars (e.g., toward one of the banklines), the decay rate was lower. Based on the survey data, wind erosion was not a significant factor in sandbar decay following the 2011 flood. The rate of sandbar erosion was directly related to sandbar area. Sites with the largest sandbars generally eroded at the highest rate. Finally, the sandbar area at each site was projected 10 years into the future based on observed sandbar growth/decay, thalweg location, and site characteristics.

INTRODUCTION

Emergent Sandbar Program: The U.S. Army Corps of Engineers, Omaha District implements an Emergent Sandbar Habitat (ESH) construction program to create nesting habitat (see Figure 1) for the interior least tern (*Sternula antillarum)* and piping plover (*Charadius melodus*) bird populations. In contrast to islands, sandbars are temporary formations and comparatively dynamic in nature that change dramatically in form and extent both within and among seasons. The ESH program was implemented based on the Amended Missouri River Biological Opinion (BiOp) issued in 2003 by the U.S. Fish and Wildlife Service. The BiOp provides the Corps with reasonable and prudent alternatives with respect to providing sufficient ESH acreage in order to support least tern and piping plover populations on the Missouri River. The BiOp also suggests that the flows from Gavins Point be used to create ESH. The Corps has not attempted to utilize flows for the creation of ESH. Instead, the Corps has relied on mechanical construction to augment ESH acres, but high water events occurring in 2010 and 2011 resulted in the natural formation of ESH.

Figure 1 Missouri River Sandbar Habitat

Recent High Flows and Sandbar Monitoring: Discharge from Gavins Point Dam exceeded 45,000 cubic feet per second (cfs) from late August through mid-December 2010 (see Figure 2)—the first instance of extended flows of this size since the ESH program began. Flow contributed by the James River (1960 RM 800) and Vermillion River (RM 772) increased this flow to greater than 50,000 cfs during this period, peaking at over 63,000 cfs on 4 August 2010. The Corps initiated physical monitoring of six sites to capture sandbar response to the large flows. The goal was to document whether the flow level and duration were sufficient to create sandbars suitable for nesting. In 2011, the historic flood resulted in dam releases reaching 160,000 cfs, approximately a 0.2% annual chance exceedance (500-year) event. The ESH

monitoring period was extended to capture the formation of sandbars during this event and to document the subsequent degradation once the high water had receded.

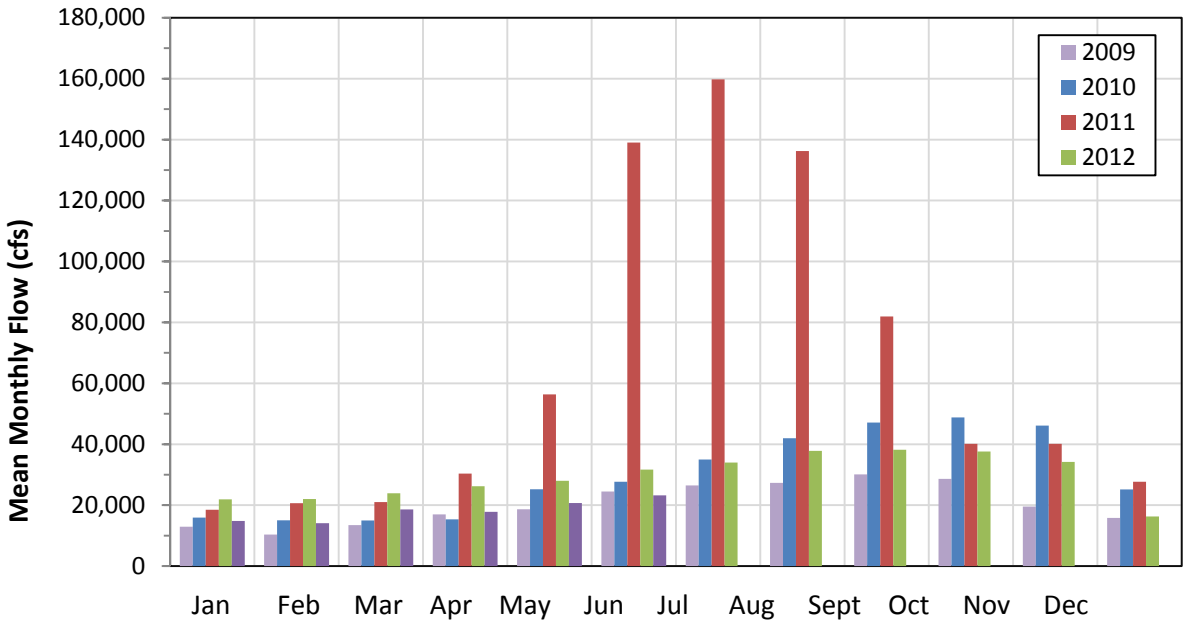

Figure 2 Gavins Point Dam Mean Monthly Flows

SEDIMENT VOLUME CHANGE

High-density hydrographic surveys, with an average of 10 cross sections per mile, were completed in 1995 and 2013. The high-density data sets were merged with LiDAR survey data of islands and overbanks to create elevation surfaces (see Figure 3 for an example). The difference between the two surfaces was then used to identify major changes in sediment volume. An elevation change over 15 feet was considered a major change. There are 45 locations with elevation differences over 15 feet with 33 of them based on erosion and 12 based on deposition (see Figure 4 for example). Most of the major erosive areas are locations where the river has encroached on its banks. However, some of these erosion areas are located further away from the banks.

Between 1995 and 2013, net erosion exceeded 55 million cubic yards within the study reach (approximate 1960 River Mile 753 to 810). The study reach was divided into six segments and only one (RM 790.3 to 800) showed net deposition (3.4 million cubic yards). The highest net erosion occurred in the most downstream segment (RM 753 to 763), totaling over 22.3 million cubic yards. Table 1 shows the volume change for all six segments.

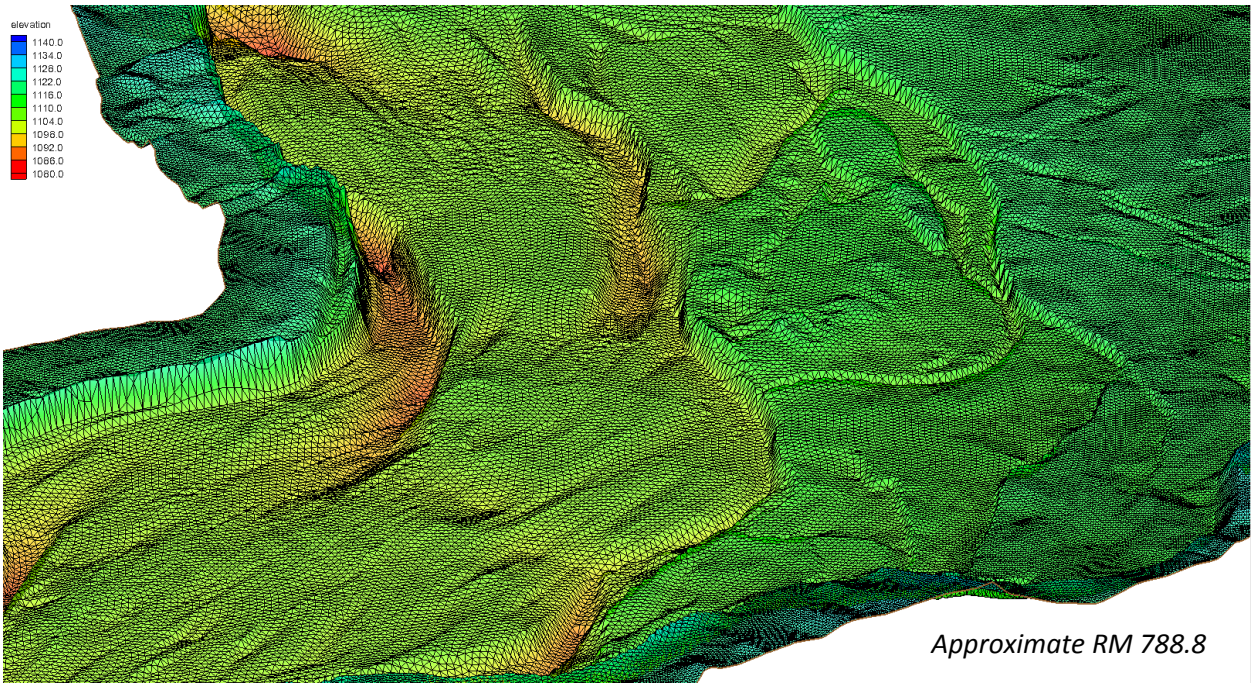

Figure 3 Example of a Finished Surface

Table 1 Volume Change (1995 to 2013) based on High-density Survey and LiDAR Data

Segment	Segment Boundary		Change in Volume (cubic yards)		
	Sediment Range	1960 RM[1]	Erosion[2]	Deposition	Total
1	783.6 – 793.9	753 – 763	(28,766,000)	6,397,000	(22,369,000)
2	793.9 – 804.2	763 – 771	(17,394,000)	10,206,000	(7,188,000)
3	804.2 – 814.7	771 – 780.5	(25,823,000)	11,867,000	(13,956,000)
4	814.7 – 824.1	780.5 – 790.3	(17,449,000)	7,661,000	(9,788,000)
5	824.1 – 834.5	790.3 – 800	(10,167,000)	13,539,000	3,372,000
6	834.5 – 845.1	800 – 810	(11,175,000)	5,950,000	(5,225,000)
Total	783.6 – 845.1	753 – 810	(110,774,000)	55,621,000	(55,153,000)

1. Approximate 1960 river mile location.
2. Values in parentheses represent negative numbers, i.e., areas of erosion; positive values are shown without parentheses and represent deposition.

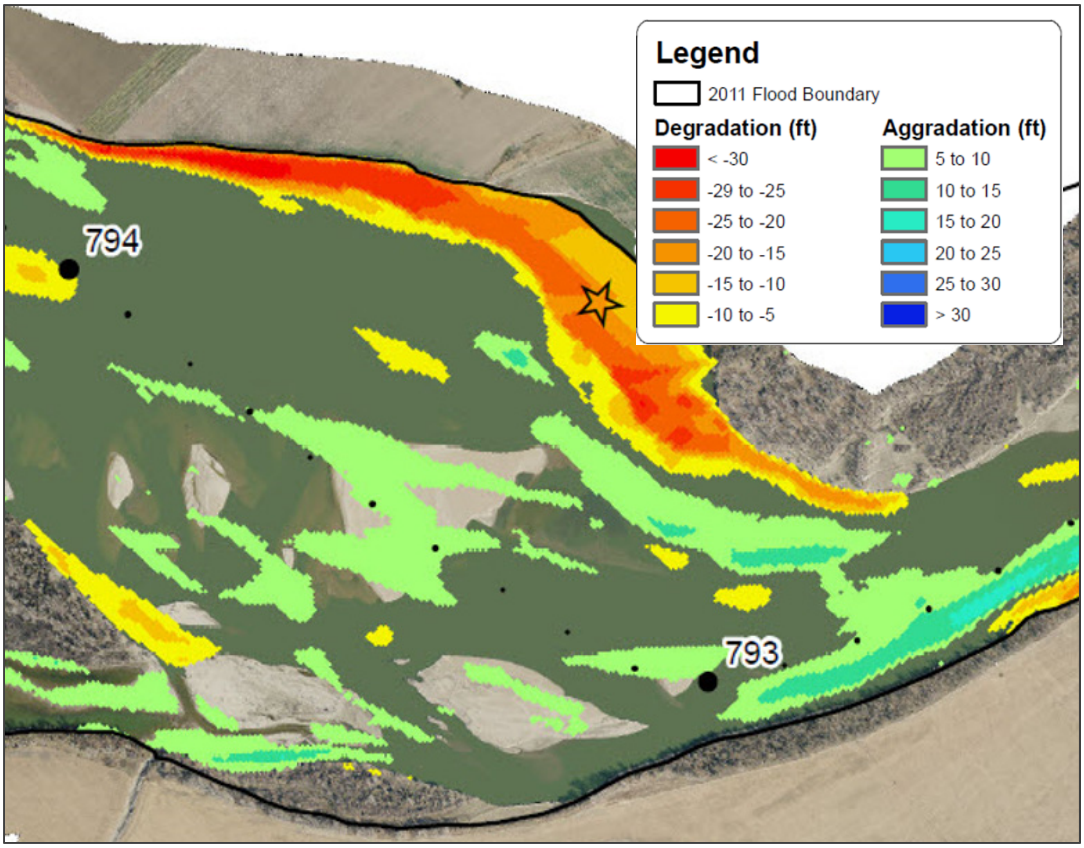

Figure 4 Example of Major Elevation Change (River Mile 793 to 794)

ESH SURVEY SANDBAR AREA ANALYSIS

Sandbar Survey Sites: The ESH surveys were conducted at approximate 1960 river miles 761, 770, 776, 782, 793, and 795, for sites ranging from a half mile to a mile in length (see Figure 5). The average width of the sandbar sites ranged from 2,759 feet (Site 761) to 4,100 feet (Site 770). The average site width was approximately 30 percent larger than the average width of the corresponding river segment. Most sites lie within fairly straight stretches or with slight bends in the channel. However, Site 776 is located near the apex of a sharp bend. Although Site 782 is located within a fairly straight section of the river, it differs from the other straight section sites because it is located just downstream of a large vegetated island that splits the channel flow. Sites 795 and 793 are within the same segment, and located only two miles apart.

In general, two surveys were performed per year in 2010, 2011, and 2012, with one survey in 2013. To evaluate the survey results, sandbar elevations and areas were analyzed at the 10-, 50-, and 90-percent exceedance flow levels (i.e., the flow level exceeded 90 percent of the time). To be considered a sandbar, a minimum area of one acre was required at the 90-percent flow level.

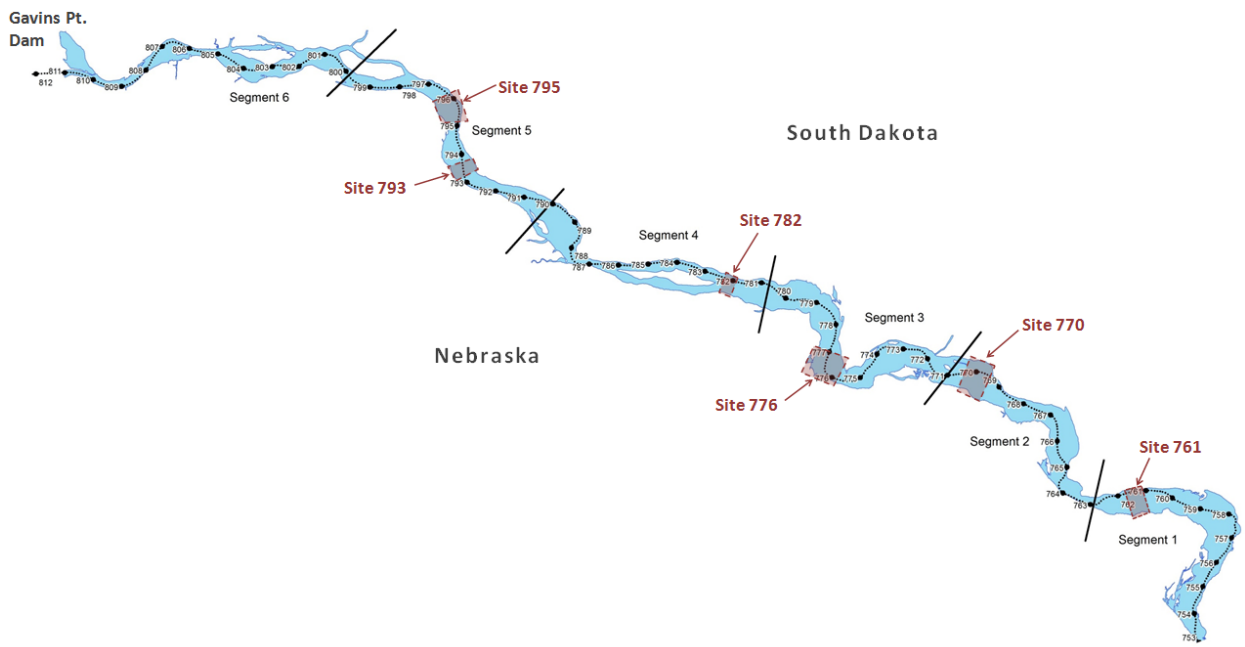

Figure 5 Missouri River ESH Sites and Study Extents

Total Sandbar Area: The total sandbar area was estimated at each study site for each season surveyed. These areas were then used to estimate the rates of growth and decay of the sandbars during the study period, and for use in projecting the rates of decay 10 years into the future.

Emergent sandbar habitat acreage is defined by USACE (2011) as all bare or sparsely vegetated sandbars available to terns and plovers. By definition, this encompasses new ESH (non-vegetated sandbars) as well as old ESH (sandbars that have aged and been subject to limited vegetation encroachment and erosion). Aged sandbars, however, should not be confused with islands that have woody riparian vegetation. Sandbars have only sparse plant cover and little or no woody vegetation. In the current study, islands were not considered ESH, and were not included in total sandbar area computations. In addition, point bars (formed on the inside of river bends) and shoreline deposition were not included in the total area. Figure 6 shows an example of what was included when determining total sandbar area.

All but two of the sites had the largest ESH area occur during summer 2011—Sites 761 and 776 had the largest ESH during fall 2011. Overall, the results show significant increases in ESH area (90-percent flow level) during the historic 2011 flood—from an average of 60.6 acres per mile in winter 2010 to 136.5 acres per mile in summer 2011 (see Table 2). ESH area ranged from 55.8 acres per mile (Site 776) to 223.5 acres per mile (Site 770) in summer 2011. At the 10- and 50-percent flow levels, average ESH went from 0.5 and 25.5 acres per mile in winter 2010 to 52.2 and 94.0 acres per mile, respectively, in summer 2011. After the historic flood, the average total sandbar area (90-percent flow level) decreased to 51.4 acres per mile by fall 2013 (20.0 and 44.4 acres per mile for the 10- and 50-percent flow levels).

Table 2 Average Total Sandbar Area per Mile

Season/ESH Level	Site Average (acres/mile)		
	10%	50%	90%
Fall 2010	0.5	15.6	63.5
Winter 2010	0.5	25.5	60.6
Summer 2011	52.2	94.0	136.5
Fall 2011	48.3	86.8	117.2
Spring 2012	35.5	66.6	85.7
Fall 2012	23.1	48.7	58.1
Fall 2013	20.0	44.4	51.4

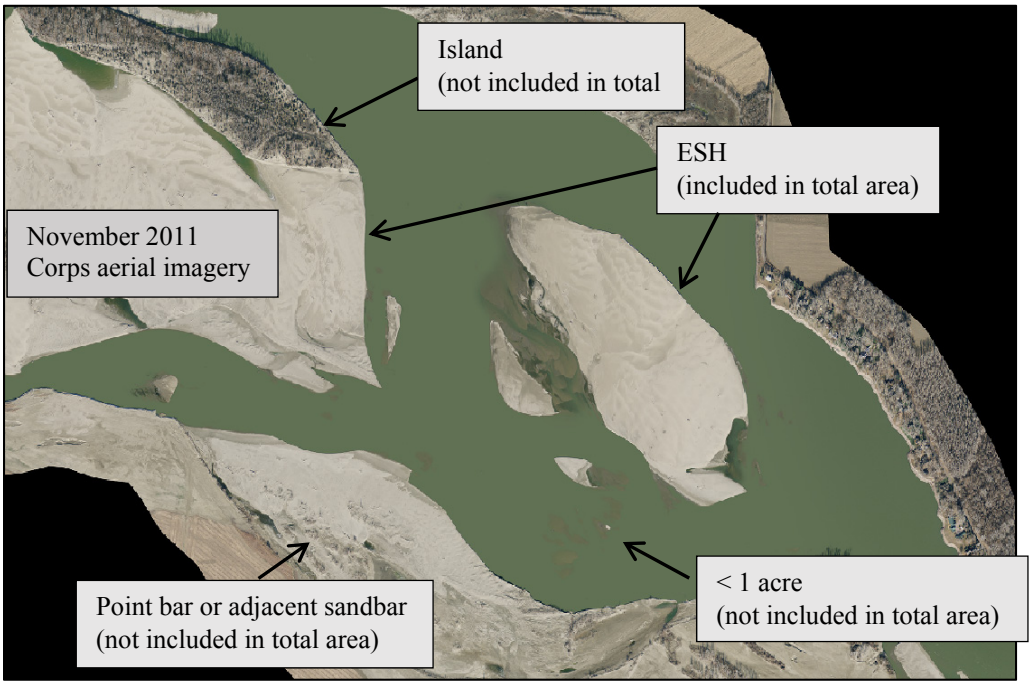

Figure 6 Example of Areas Included and Not Included in Total ESH Area

Sandbar Characteristics: In winter 2010, the average size of an individual sandbar (90% flow level) ranged from 2.2 acres at Site 782 to 31.9 acres at Site 795. The average sandbar size was 14.1 acres across all sites. In fall 2011, the average size of an individual sandbar (90% flow level) ranged from 14.6 acres at Site 782 to 78.6 acres at Site 776. The average sandbar size was 37.2 acres across all sites. Overall, the habitat formed during the 2011 flood was much larger in total area compared to the ESH formed in winter 2010. Although the total area at each site was greater in fall 2011, there were more sandbars in winter 2010 (25 versus 17 across all sites).

Wetted perimeter to area ratios (90% flow level) ranged from 369 feet per acre (Site 793) to 1,119 feet per acre (Site 782) in winter 2010. In fall 2011, sandbars were much larger. As a result, the wetted perimeter-to-area ratios were much lower overall, ranging from 146 feet per acre (Site 776) to 298 feet per acre (Site 793). The average sandbar height above the 90% flow

level was 1.1 feet in winter 2010 (ranging from 0.7 to 1.4 feet). The average height increased to 3.3 feet by fall 2011 (ranging from 2.1 to 4.3 feet). In winter 2010, the average sandbar slope was 1.4 percent. By fall 2011, it had increased to 2.0 percent.

Geomorphic and Bed Material Impacts: Thalweg depths and movement were analyzed at the 50-percent flow level (see Figure 7 for an example). The average thalweg generally deepened due to the high flows of 2010, as well as between summer and fall 2011. Thalweg movement varied between sites. For some sites, there was only minor change between seasons, while other sites experienced significant movement from season to season. The average bed material size (D_{50}) did not change significantly during the 2011 flood, indicating that the riverbed is largely homogeneous and the sandbar sites are not bed material limited.

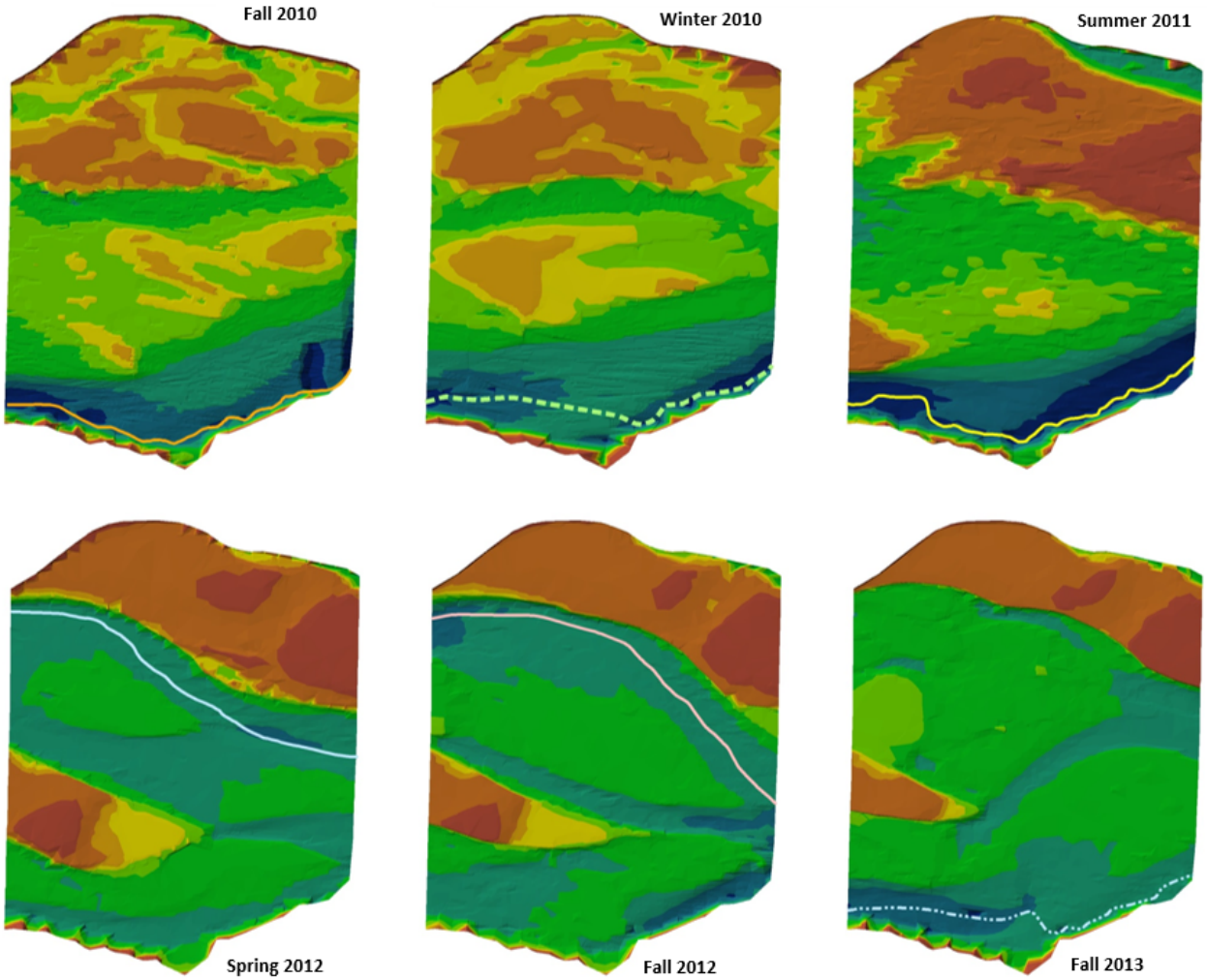

Figure 7 Thalweg Locations for Each Season Surveyed – Site 761

Sandbar Growth and Decay: A major question in the 2003 BiOp Amendment is whether a flow of 60,000 cfs for 60 days will produce sandbars within the study reach. Although the study data do not provide a definitive answer to this question, some observations can be made. The high releases from Gavins Point Dam in 2010 were on the order of 45,000 cfs. Tributary flows, particularly from the James River (RM 800), helped to increase the total flow through the project reach during the fall 2010 survey period. Flows peaked above 63,000 cfs on 4 August 2010, exceeding 50,000 cfs through mid-August and from the beginning of September through mid-November. Although these flows were much higher than normal flows, they were too small to create significant ESH area. In contrast, the 2011 flows were much higher than 60,000 cfs, and greatly increased ESH area.

Every significant sandbar-building flood event affects future building events. If the 60,000 cfs flow would have occurred in 2010 for a longer duration, it may have created more significant sandbar habitat. The current remaining sandbars were formed by large flows and many remain above the 10-percent flow level. If the 60,000 cfs flow occurred today, it may not act as a building event because it could erode the existing high-elevation sandbars rather than form new sandbars.

Relative shear stress over a sandbar and/or adjacent to a sandbar is a good indicator of whether the sandbar would be eroded away by the time of the next survey. Typically, initiation of particle movement is modeled with the Shields method. Inversely, low shear stresses indicate depositional areas. Using this approach and assuming a 0.4 mm median particle size, deposition is assumed to occur for shear stresses of approximately 0.005 lb/ft^2 or lower, under normal flow conditions. This appears to be appropriate for determining sandbar persistence for the lower flow periods, but not necessarily for the higher flows.

The location of the thalweg versus the location of major sandbars has a strong correlation to the sandbar decay rate. In periods when the thalweg was close to the major sandbar(s), the decay rate was significantly higher. As the thalweg moved away from the sandbars (e.g., toward one of the banklines), the decay rate was lower. Based on the survey data, wind erosion was not a significant factor in sandbar decay following the 2011 flood.

The study also examined correlations between sandbar growth and two-dimensional hydraulic model results at Site 795 (see Figure 8 for an example of the results). For the highest flows, there was a zone with highly transient sandbars. Surveyed sandbars within this zone represent snapshots in time, with bed material that is continuously moving, depositing, and eroding. The highly transient sandbars did not persist after the floodwaters receded. As expected, sandbars were more likely to persist in areas of reduced shear stress, velocity, and depth.

There was an average flow depth of 3.0 feet above the sandbars created between fall and winter 2010. This depth increased to 12.5 feet for sandbar area formed between summer and fall 2011. The rate of sandbar erosion following the 2011 flood was directly related to sandbar area. Sites with the largest sandbars generally eroded the quickest (based on the percent decrease in area between fall 2011 and spring 2012).

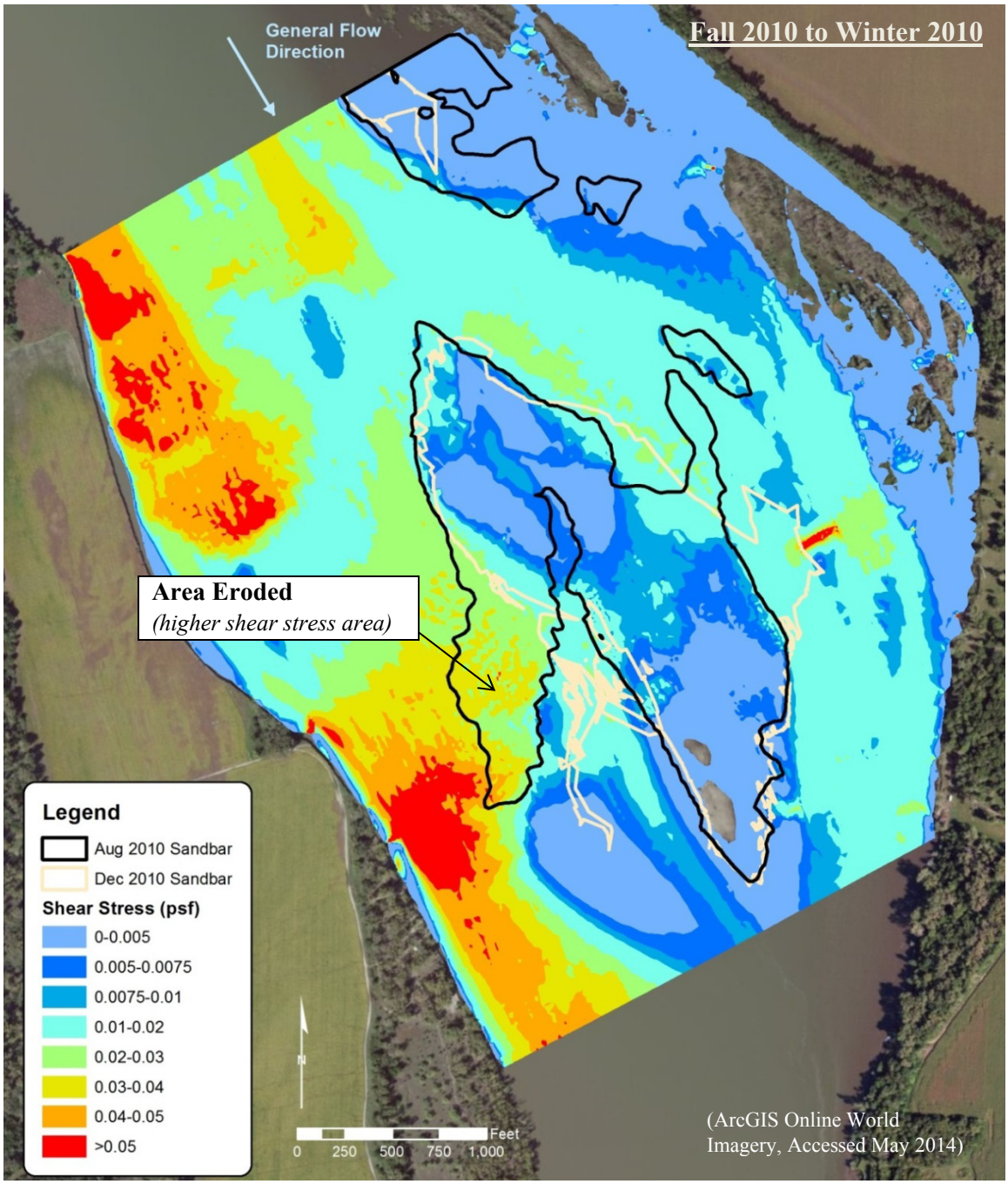

Figure 8 Computed Shear Stress (Fall 2010 at 52,000 cfs) – Sandbar Decay

Sandbar formation is a dynamic sediment transport process. Figure 9 compares the 90-percent sandbars at Site 795 for all survey periods. This figure shows where the sandbars are highly transient versus areas where the sandbars are relatively persistent. The surveyed sandbars, especially within the highly transient zone, represent snapshots in time of bed material that is continuously moving, depositing, and eroding. Moreover, these highly transient sandbars did not persist after the floodwaters receded. As expected, sandbars are more likely to persist in areas of reduced shear stress, velocity, and depth.

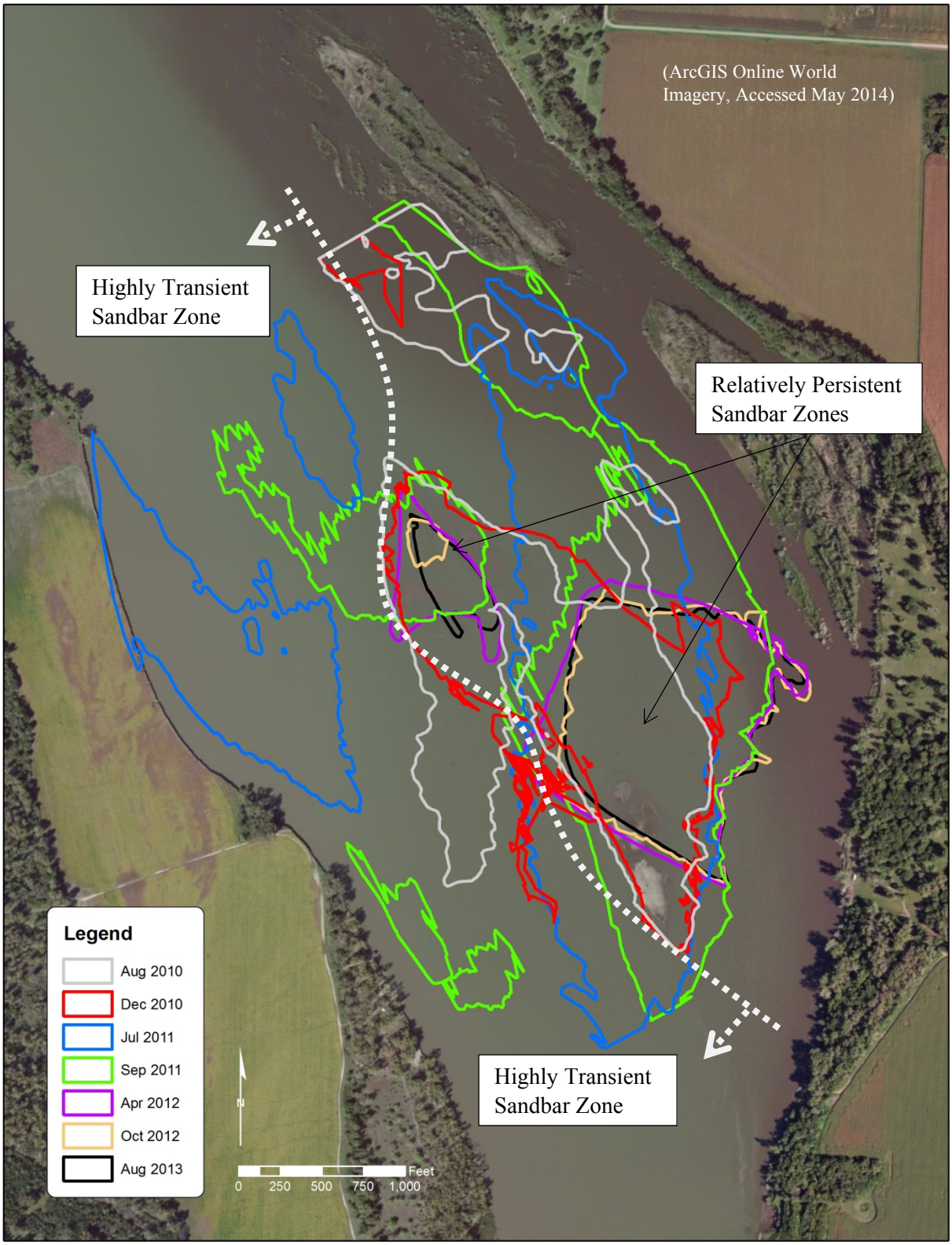

Figure 9 Sandbars (90% flow level) at Site 795 – All Survey Periods

Sandbar Area Projections: The total sandbar area at each site was projected 10 years into the future (see Figure 10 for an example) based on the observed sandbar growth/decay, thalweg location, site characteristics, and engineering judgment. In particular, the variability of the thalweg and its most recent surveyed location were strongly correlated to the sandbar projections. Projected decay of the 90-percent flow level sandbar area was the greatest at Site 770 and the least at sites 793 and 795. The location of the thalweg during the study period, as well as the overall site width, had a direct impact on the sandbar projections. For comparison, USACE (2011) indicates that the projected life expectancy of a constructed sandbar is 5 to 10 years. This is dependent on rates of erosion and vegetation encroachment, as well as flows and potential ice jams or thalweg shifts. The lifespan of a sandbar may be extended through maintenance activities such as vegetation removal and reshaping.

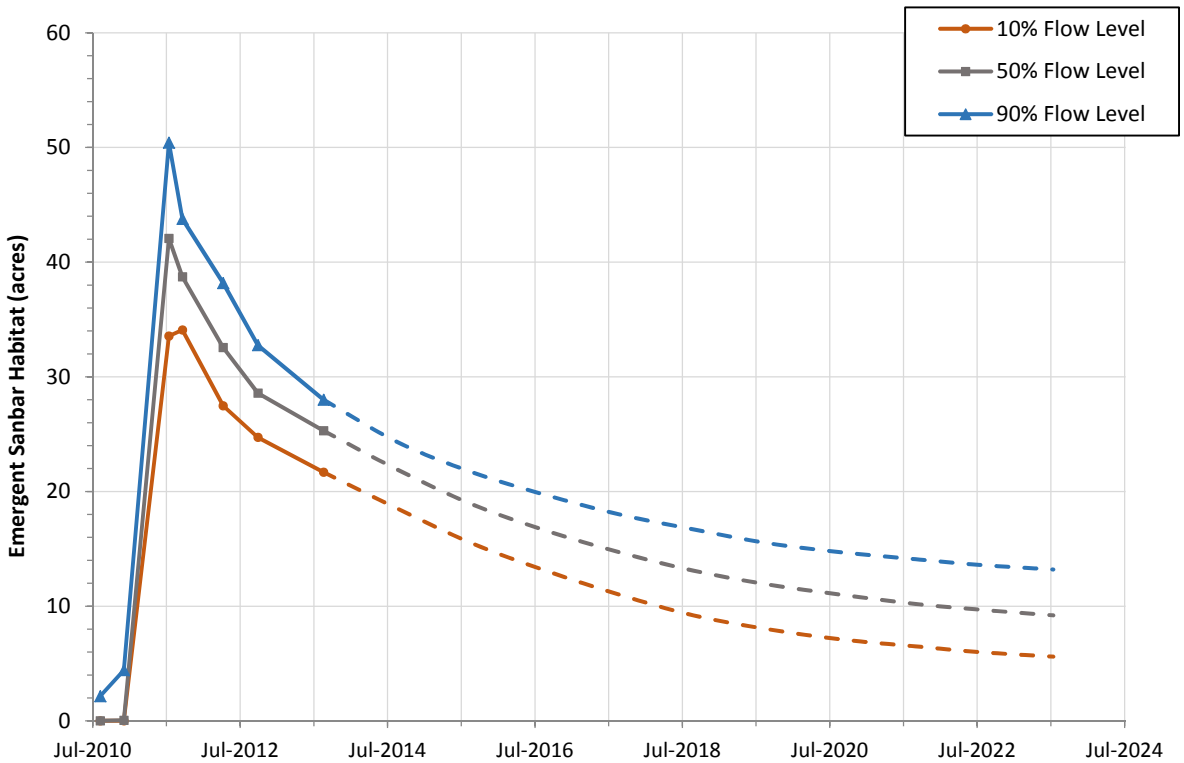

Figure 10 Projected Rates of ESH Growth/Decay – Site 782

REFERENCES

USACE (2011). *Final Programmatic Environmental Impact Statement for the Mechanical and Artificial Creation and Maintenance of Emergent Sandbar Habitat in the Riverine Segments of the Upper Missouri River*. Volume 1: Final Programmatic Environmental Impact Statement.

WEST Consultants (2014). *Geomorphic Change Evaluation in Support of ESH, Final Report*, prepared for the U.S. Army Corps of Engineers, Omaha District, July 2014.