SCOUR AND SUBSEQUENT REPAIR AT LOCK & DAM 25

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INTRODUCTION

Lock and Dam 25 is a U.S. Army Corps of Engineers navigation structure located at Upper Mississippi River mile 241.4 on the Mississippi River near Winfield, MO. Events in early 2011 led to a sustained necessary deviation from the normal operations practices for the roller and tainter gates, forcing the majority of the flow of the Mississippi River through gates 12 through 17 (the gates closest to the Illinois bank) for almost five months. This sustained deviation led to significant scour in the river bed downstream of the dam and adjacent to the lock, requiring repairs underneath the intermediate wall and downstream slab, removal and replacement of a portion of the downstream slab, and placement of rock for downstream slope protection and global stability of the structure. The following will outline the change in conditions at the structure and the subsequent necessary repairs.

DEVIATION, RESULTS, AND REPAIRS

The Operations Deviation: On March 6, 2011, at approximately 3 PM, operations of Lock and Dam 25 (L&D25) underwent a change that would lead to a necessary deviation from normal dam operation practices for nearly five months. The initiating change is outside of the scope of this paper; this paper is intended to focus on the deviation and its effects. The deviation consisted of routing the majority of the flow that would normally flow through a combination of all of the gates primarily thru Gates 12 to 17 (a plan view is presented in figure 1). From March 6 to July 26, the flow rate varied from approximately 107,000 cfs to 317,000 cfs for an average of approximately 216,000 cfs. Normal operations resumed at the lock and dam on July 26, 2011. As necessary for repairs, gates were closed by compensating with corresponding openings of other gates.

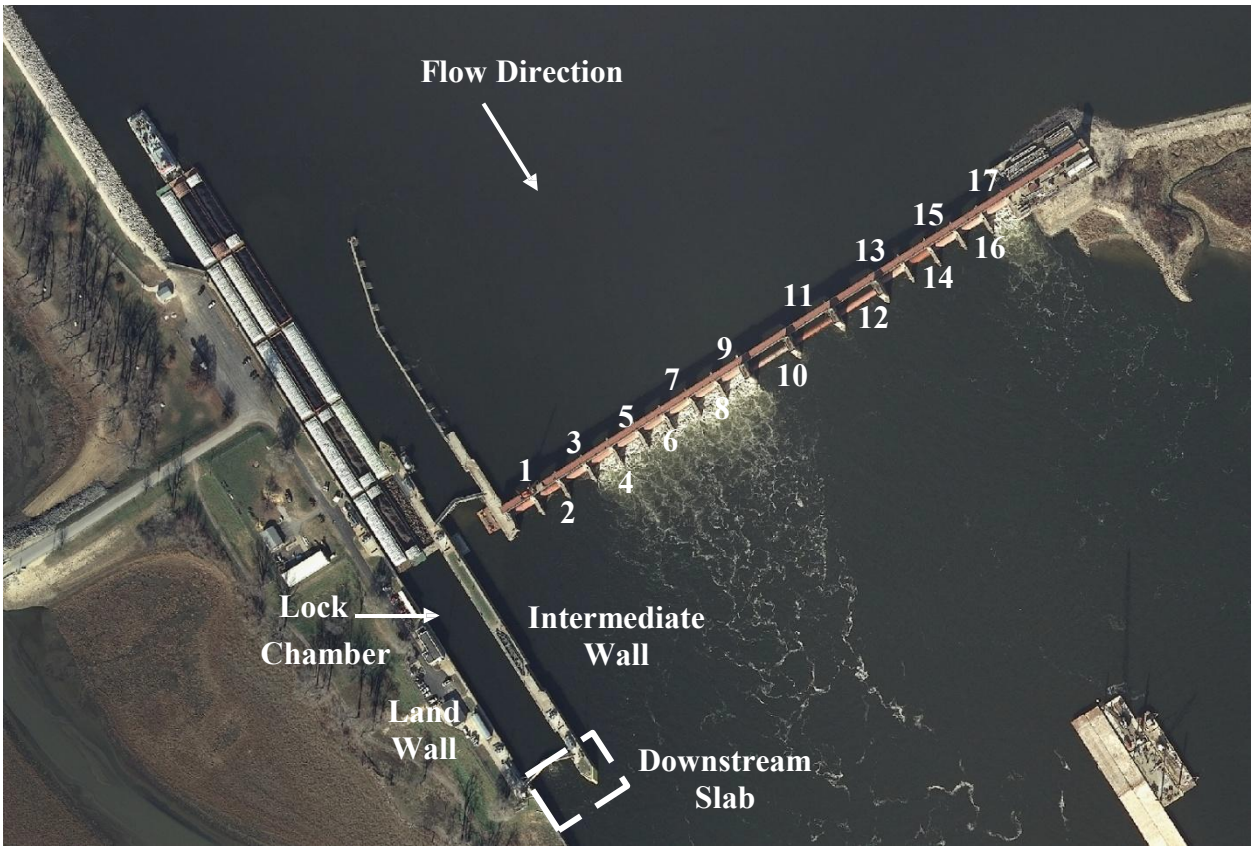

Figure 1 Plan view of L&D25 during late fall 2012, releasing approximately 48,000 cfs during normal operations.

Video taken March 17, 2011 (flow of approx. 127,000 cfs, figure 2) showed standing waves downstream of the open gates suggesting that supercritical flow was present outside of the stilling basin. This contrasts with normal flow conditions at the same approximate flow rate (figure 3), where energy dissipation is more three-dimensional and contained within the stilling basin. Additionally, anecdotal evidence from the surveying crew and other boats involved with the repair noted strong surface currents to the point that many areas downstream were deemed unsafe to survey until normal operations resumed. The hypothesis that energy dissipation was no longer contained in the stilling basin is further supported by looking at the head before and after the deviation (figure 4). The data shows that from approximately 120,000 cfs to 220,000 cfs, a head of up to 2.5 feet higher than normal was otherwise measured. For typical open river conditions (gates out of the water), flow is not forced under a gate, leading to a head of approximately 1 ft or less. When the flow is greater than 1foot, it is typically due to a regulated pool condition forcing the flow underneath the Tainter and roller gates, downward towards the stilling basin. In this case, a head representative of a regulated pool condition existed during what would normally be an open river condition. The higher head suggests flow was not passing through the structure as intended, with the possible result that energy dissipation that would normally occur in the stilling basin as designed was potentially happening downstream through the scour of downstream sediments.

Figure 2 Downstream view of L&D25 on March 17, 2011 showing large standing waves

Figure 3 Downstream view of L&D25 on May 23, 2012 showing similar flow conditions

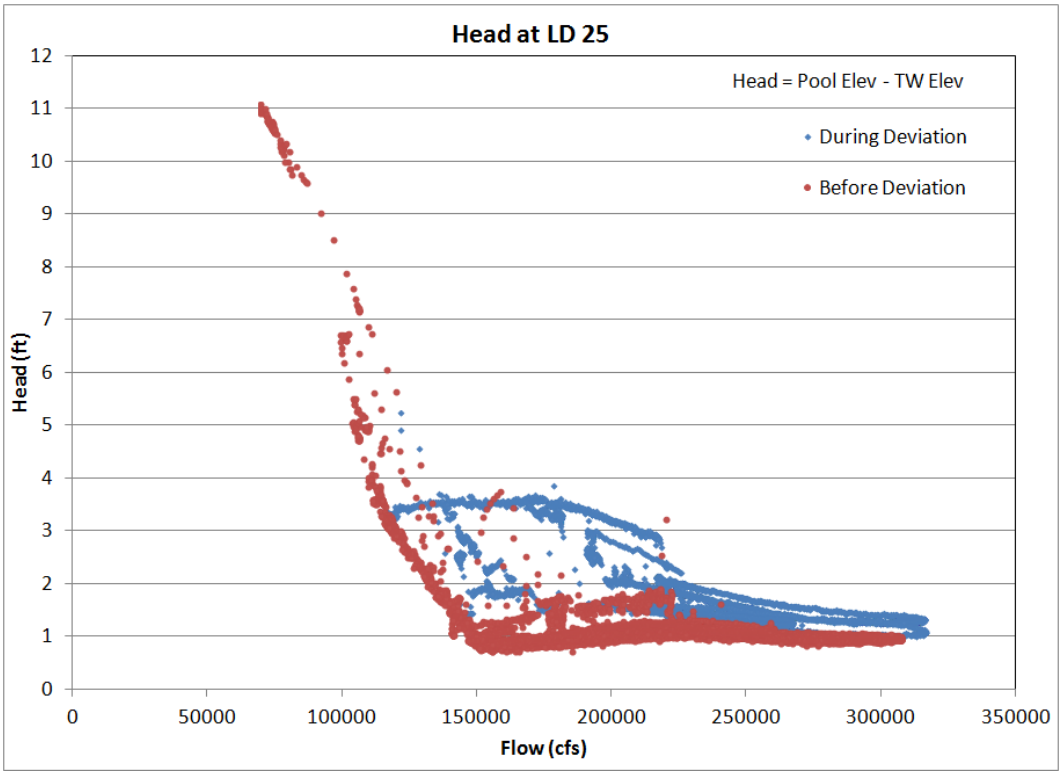

Figure 4 Head for different flows before and during deviation

<u>The Results of the Deviation:</u> The St. Louis District took a number of multibeam hydrographic surveys upstream and downstream of the dam for monitoring purposes. These surveys showed fluctuating deposition and erosion upstream and downstream of the dam as sediment waves moved through the system. The first comprehensive hydrographic survey following the deviation was taken on August 2,2011. The survey revealed significant downstream scour, well outside of the normal fluctuations. The four scour holes downstream of the lock and dam before the deviation had transformed into two deeper holes. The two primary interest areas for scour were downstream of Gates 12 to 16 and along the Intermediate Wall (I-Wall). The scour downstream of Gates 12 to 16 scoured over 55 ft of material in the worst scour locations, and over 30 ft at the deepest location (figure 5). Reports of shallow areas downstream of the lock and dam from the navigation industry prompted the collection of a pre-dredge hydrographic survey. The survey revealed excess material downstream of the lock and further downstream in the navigation channel that was not present the year before; assumedly, this was partially the material that had scoured out downstream of the dam and rock used as protection near the slab. The material further downstream in the navigation channel was removed with St. Louis District's Dredge Potter; the material immediately downstream of the lock could not be dredged due to the large rock mixed with the sand.

In the immediate vicinity of the I-Wall, loss of material along and downstream of the I-Wall (over 45 ft at the worst location) led to a partial failure of the downstream slab (figure 6). This slab serves to prevent undermining of the I-Wall due to the lock's discharge ports and tows entering and leaving the lock. Due to the slab failure, the lock was instructed to halt usage of the I-Wall's discharge ports, increasing the time required for lockages and leaving the lock with no redundancy for emptying the lock chamber.

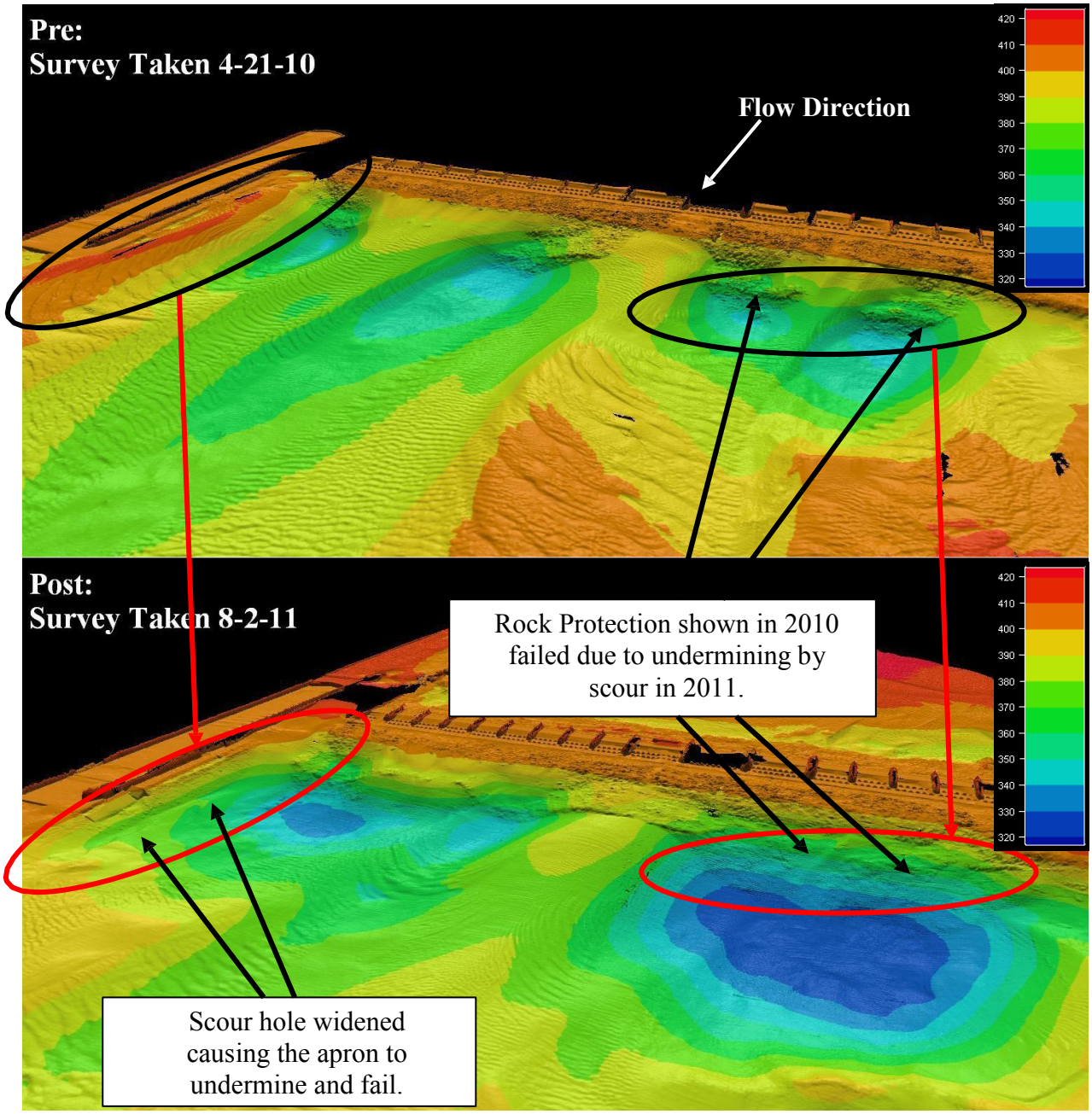

Figure 5 Before and after hydrographic surveys downstream of L&D25

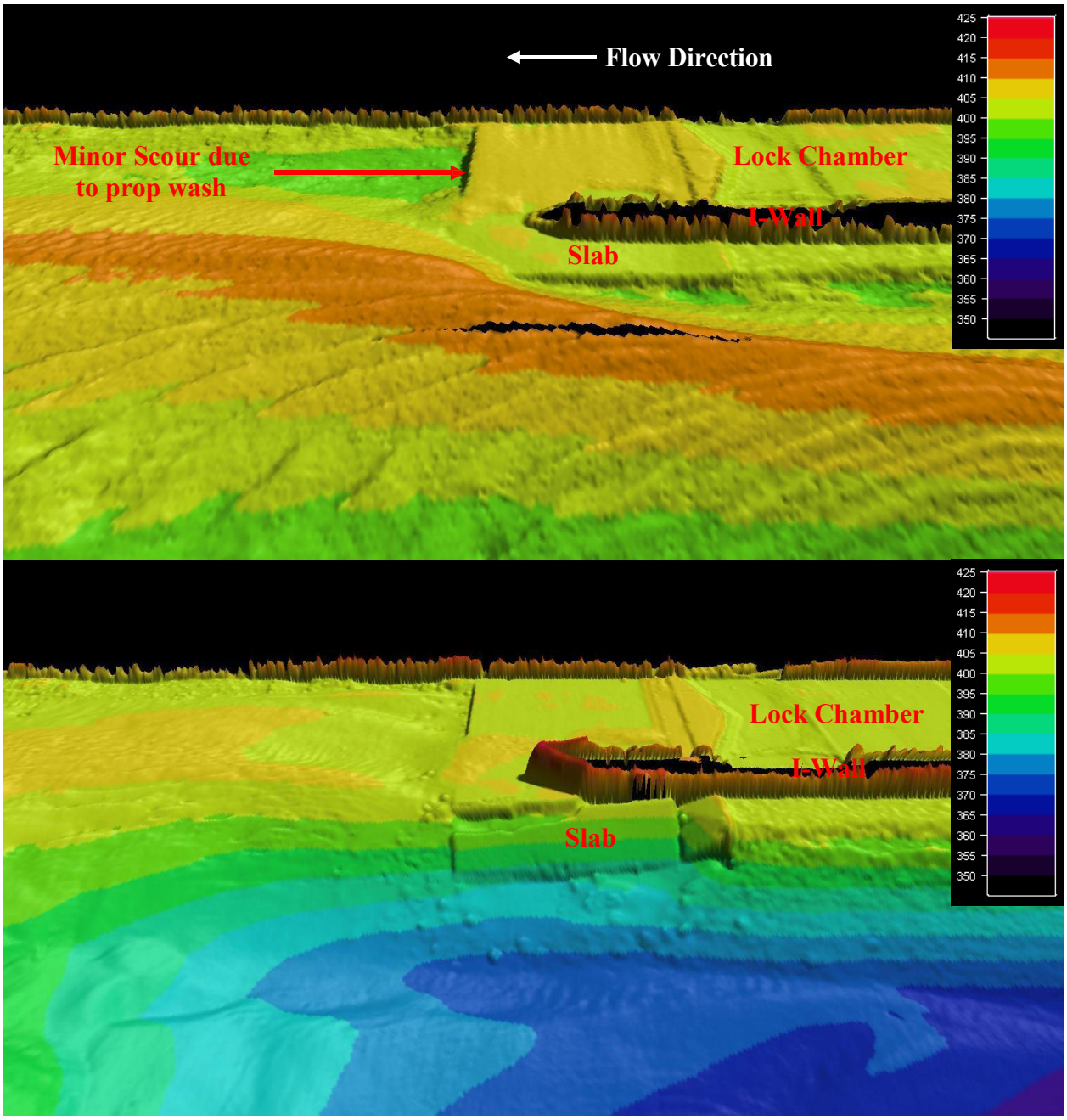

Figure 6 Before and after hydrographic surveys of downstream slab

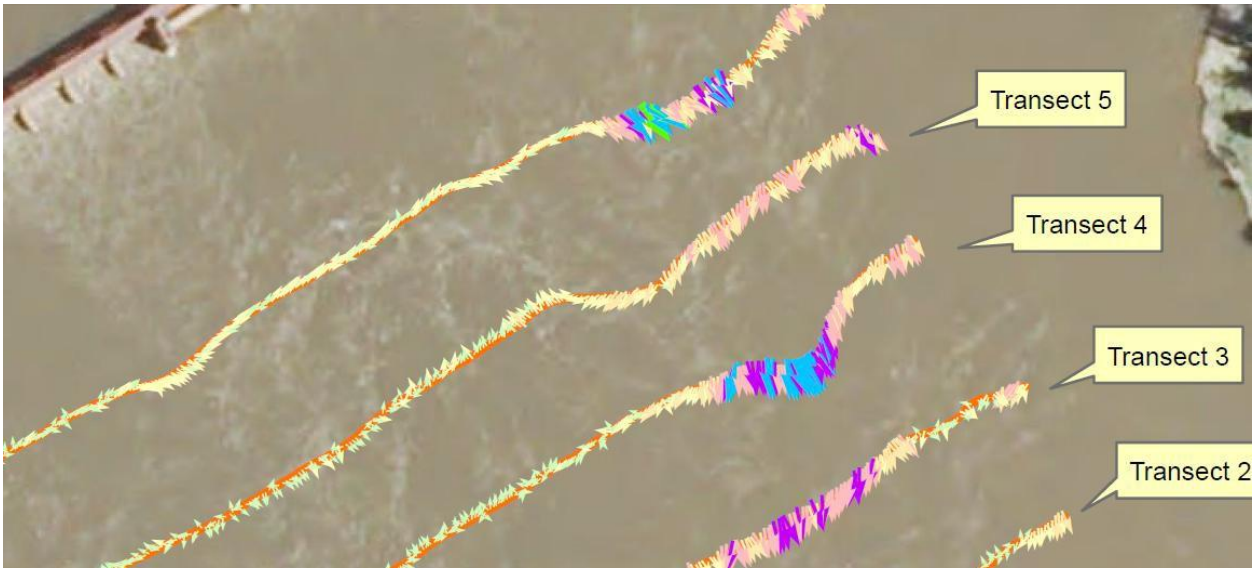

Figure 7 Velocity magnitudes and directions processed from ADCP data collected

It was suggested that scour adjacent to the I-Wall was partially caused by a significant eddy back towards the I-Wall that developed downstream of the dam due to the reliance on Gates 12 to 17 to pass flow. Anecdotally, the eddy was mentioned by pilots of survey and contractor repair boats. To test to see if an eddy back towards the I-Wall did in fact occur during releases through principally Gates 12-17, this condition was simulated. Unfortunately, the same flows passing through the dam during the deviation could not be simulated due to the time of year (measurements were taken around approximately 53,000 cfs, figure 7). The results of the ADCP collection showed some transects, particularly Transect 5, demonstrated flow vectors back towards the dam, supporting the eddy hypothesis.

Initial analysis after identifying the scour determined that there were two significant problems: 1) the potential of a global stability failure of the I-Wall due to loss of adjacent material, and 2) the potential for undermining of I-Wall and additional undermining of the slab surrounding the intermediate wall beyond what had already failed. Calculations were run to determine the stability of the lock and dam, particularly the I-Wall. The global stability of the I-Wall was found to be an issue, and plans were made to support the slope adjacent to the I-Wall with material in the repairs. Multiple boat-based multibeam surveys were used to monitor the location of the broken slab pieces, as the slab began to slide into the adjacent scour hole.

Multiple dive inspections were undertaken in the vicinity of the I-Wall, slab, downstream of the lock chamber, and land wall. The dive inspections revealed scour underneath the slab adjacent to the broken off section of the slab, downstream of the lock, and underneath the I-Wall. Verbal descriptions were used to characterize the scour occurring in each location. To better improve the knowledge of the undermining of the intact slab and position of the failed slab portion, an in-situ multibeam sonar device was used. A company was contacted and a demonstration was scheduled with a corresponding dive. The multibeam device was mounted on both a tripod and metal plate on the bottom of the river for different scans, and scans were taken from multiple placements around the area of interest (figure 8). From the scans, a better picture of the broken slab was

developed and the extent of intact slab undermining was better determined, allowing for better quantities estimates for the repair design.

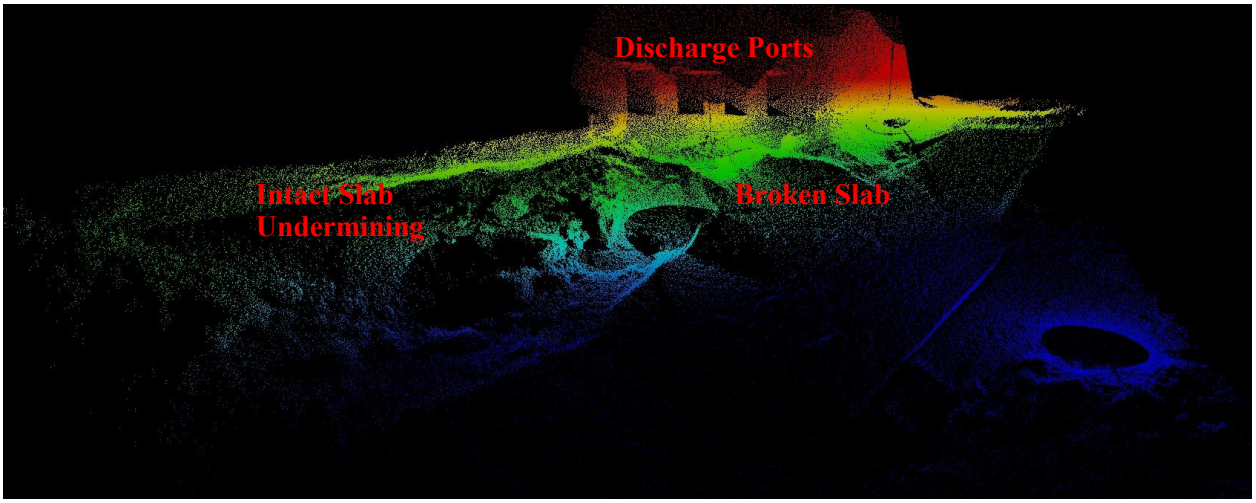

Figure 8 In-situ multibeam survey results

The Repairs: Phase I of the repair contract was awarded on February 8, 2012. Phase I consisted of filling in voids beneath the downstream edge of the slab. Holes were cored through the slab to fill the void. To contain the grout, a sheet pile wall was constructed along the edge of the slab from the landside wall to the eastern edge of the I-Wall. To prevent further downstream scour due to tows entering and exiting the lock chamber, the bed downstream of the slab and sheet pile wall was protected with 40 ft of 2,200 lb riprap.

An emergency repair was required to address undermining of the I-Wall itself. An initial dive inspection on September 24, 2011 identified an undermined area of approximately 6 ft long 1 ft below the base of the lock wall concrete extending at least 3 ft under the lock wall. At the time, the diver could feel that the timber piles that support the wall were exposed. Subsequent dive inspections identified the scour as both lengthening the width of the scour hole and its extents under the I-Wall. To repair this undermining, a 35 ft long, leave-in-place form was designed to cover the mouth of the scour hole. This form was designed with two holes, one at the bottom and top, so that grout could be pumped in the bottom hole until it filled the hole enough to run out the top, so that excess grout was not pumped under the I-Wall leading to a stability issue.

Phase II of the repair contract was awarded on May 25, 2012 for approximately $5.1 million dollars. The Phase II repair consisted of: 1) removing the failed slab, 2) construction of the remainder of the sheet pile wall along the slab edge including the dimensions desired to rebuild the slab, 2) grouting to re-establish the slab and fill voids underneath the intact slab section, 4) placement of rock to support the slope adjacent to the I-Wall, and 5) placement of stone downstream of Gates 11-16 to maintain the slope to the toe of the scour hole. The stone placed on the slope adjacent the I-Wall was constructed in two phases, the first to support the slope before the driving of the sheet pile and slab repair, and the second filling out the slope adjacent to the slab repair. During the design phase for the second phase of the repair, there had been discussion about the potential need for a thicker layer of additional rock downstream of Gates

11-16 to more completely rebuild the slope, including a supporting berm. This idea was rejected as it was thought normal operations would re-establish an approximation of the prior sediment deposition patterns downstream; this has since proven to be the case.

The project was completed in January 2013. Since the project was completed, as mentioned above briefly, the bed has begun to re-establish its pre-deviation form – a sediment deposition has developed adjacent to the I-Wall, two scour holes of less depth have formed downstream of Gates 1-9, and deposition has occurred in the scour hole downstream of gates 11-16 (figure 9). Monitoring of the I-Wall instrumentation has revealed no significant movement. Since project completion, the St. Louis District has returned to taking yearly hydrographic surveys upstream and downstream of the lock for monitoring purposes.

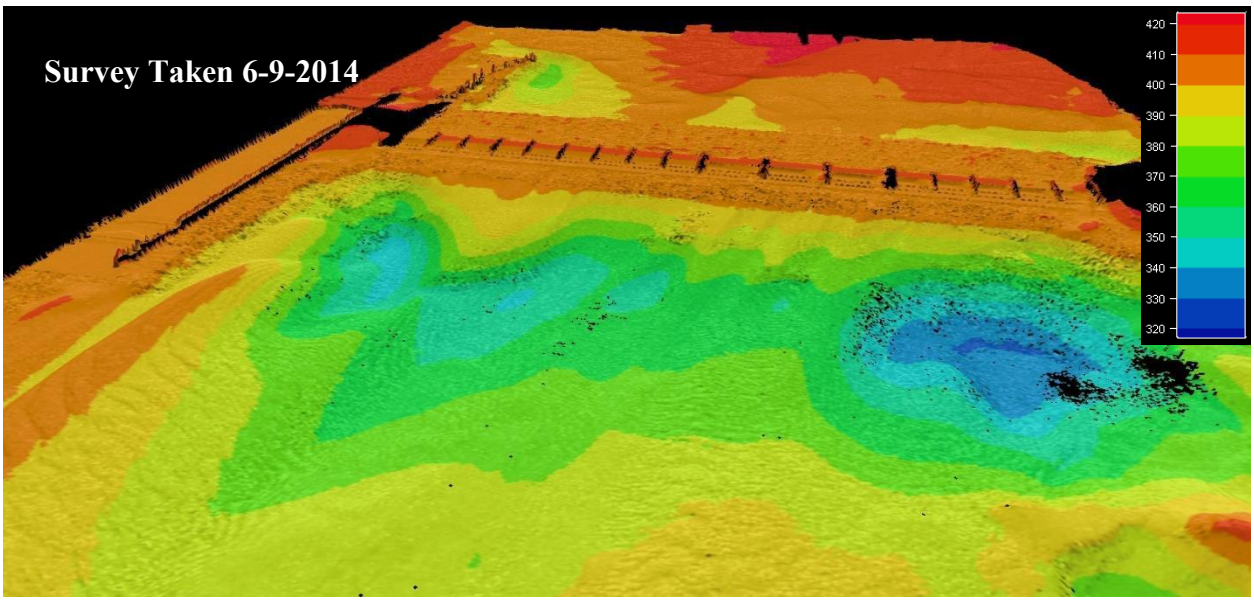

Figure 9 Most recent hydrographic survey

CONCLUSIONS

In March 2011, circumstances necessitated a deviation from normal operations at Lock and Dam 25 for nearly five months, with the large majority of flow being passed through Gates 12-17. Surveys and dive inspections after normal operations resumed revealed significant scour downstream of Gates 12-16 and adjacent to the Intermediate Wall. The scour adjacent to the I-Wall had led to the failure of a portion of the slab downstream of the lock, undermining of a portion of the I-Wall, and a global stability issue. Over the next roughly 1.5 years, repairs were done to return the lock to normal operations.

There were multiple lessons from the scour and subsequent repair from a hydraulics/sedimentation standpoint. The initial interest at the onset of the deviation from a hydraulics standpoint put a smaller emphasis on downstream scour, although this would later be the primary concern. Coupled with this, the potential that the hydraulics should change so drastically that energy dissipation may not have been largely confined to the stilling basin was

not the primary consideration during the deviation itself. Once the scour was identified after the deviation ended, the availability of multibeam surveys, both boat-based and for the first time in the St. Louis District in-situ, allowed for detailed monitoring of the site conditions, alternative development, and later, construction progress. The need for detailed monitoring extended to dive inspections, which revealed the critical I-Wall undermining. Lastly, the bed downstream of the dam has shown that, without any outside drivers, a riverbed will work to re-establish its equilibrium condition.