PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Draft Final

Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment

2015 Annual Summary Report and 3-Year Summary

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Submitted to:
Platte River Recovery Implementation Program
4111 4th Avenue, Suite 6
Kearney, NE 68845

Submitted by:

EA Engineering, Science, and Technology, Inc., PBC
221 Sun Valley Blvd, Suite D
Lincoln, NE 68528

Northern Hydrology and Engineering
PO Box 2515
McKinleyville, CA 95519

GMA Hydrology, Inc.
PO Box 1516
Weaverville, CA 96093

Western Ecosystems Technology, Inc.
415 West 17th Street, Suite 200
Cheyenne, WY 82001

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EXECUTIVE SUMMARY

The Platte River Recovery Implementation Program (Program) was initiated on January 1, 2007 between Nebraska, Wyoming, Colorado, and the Department of the Interior to address endangered species issues in the central and lower Platte River Basin. In an effort to improve the survival of whooping cranes during migration, improve least tern and piping plover production, and avoid adverse impacts to pallid sturgeon in the Lower Platte River, the Program is evaluating the ability of a Flow-Sediment-Mechanical (FSM) management strategy to achieve these goals. The management actions include:

1) Flow— Augment Q1.5 through flow releases to create short duration high flows (SDHF) of 5,000 to 8,000 cubic feet per second (cfs) for 3 days in 2 out of 3 years.
2) Sediment— Augmentation of approximately 150,000 tons of medium sand annually to offset sediment deficit upstream of Kearney.
3) Mechanical— Channel widening, clearing, and leveling of in-channel bars and flow consolidation (85-90 percent of 8,000 cfs in a single channel).

The Shoemaker Island Complex, which is assumed to be in sediment balance, was chosen as the location to implement the FSM "Proof of Concept". The Shoemaker Island Complex is located approximately 1.6 miles downstream of Highway 11, and extends 2.6 miles downstream to a point approximately 1.1 miles upstream of South Alda Road, which is in the downstream portion of the Associated Habitat reach. Over a three-year period, the experiment evaluated the performance of the FSM management actions, in creating and/or maintaining channel characteristics that are consistent with the Program's management objectives. Learning objectives for the Shoemaker Island Complex management experiment include:

1) Evaluate the relationship between peak flows (magnitude and duration) and sandbar height and area.
2) Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.
3) Evaluate the ability of the FSM management strategy to create and/or maintain habitat for whooping cranes, least terns, and piping plovers.

Data were collected to monitor changes within the Shoemaker reach relative to high flow events and to other management actions such as disking vegetated bars and constructing nesting bars. Field data are used to parameterize and calibrate the two-dimensional fixed-bed hydrodynamic model and the two-dimensional mobile-bed model. The key data collected during the three year effort (2013, 2014, and 2015) included:

- High resolution aerial photographs
- LiDAR
- Flow rate, depth, velocity, and water-surface elevation
- Sediment transport (suspended load and grain size distribution)
- Scour and fill monitoring via scour chains

- Bed material characteristics (grain size distribution, bulk density, porosity)
- Channel cross-section and longitudinal topography
- Vegetation type, density, stem diameter, height, and green line elevation on bars (established vegetation and where new growth vegetation was apparent) and channel banks
- Channel width
- Bar topography and morphometry
- Land-based photography
- Channel unobstructed view width.

The three-year study examined four distinct high flow events:

- 2013 Short Duration Medium Flow (6 days over 2,000 cfs with a 3-day mean peak of 3,552 cfs)
- Fall 2013 High Flow (28 days over 2,000 cfs with a 3-day mean peak of 9,700 cfs)
- June 2014 High Flow (30 days over 2,000 cfs with a 3-day mean peak of 7,320 cfs)
- June 2015 High Flow (72 days over 2,000 cfs with a 3-day mean peak of 15,700 cfs).

The 2013 SDMF did not meet the target for a SDHF and the 2013 fall flood was not directly monitored, so the conclusions discussed below pertain primarily to the 2014 and 2015 high flow events and are framed in the context of the three Learning Objectives:

1. **Evaluate the relationship between peak flows (magnitude and duration) and sandbar height and area.**

The 2013 SDMF was monitored pre and post the high flow event and the magnitude and duration of the event did not demonstrably affect the height and area of sand and vegetated bars in the Shoemaker study reach.

The Fall 2013 High Flow was not monitored for its effects on the height and area of sand and vegetated bars in the Shoemaker study reach.

The June 2014 High Flow was monitored pre and post the high flow event and the magnitude and duration was sufficient enough to affect height and area of sand and vegetated bars in the Shoemaker study reach.

Sand Bar Height and Area: Sand bar topography data was analyzed to describe the height and area of new sand bars that evolved during the June 2014 high flow event. Fourteen new sand bars greater than 0.25 acres were formed during the June 2014 high flow event with a mean height of 0.36 feet above the 1,200 cfs TRF stage or a mean depth of 1.55 feet below the formative event 3-day mean peak discharge stage of 7,320 cfs. The maximum height of the 3-day mean peak stage above the 1,200 cfs TRF stage was 2.46 feet and the minimum height was 1.49 feet. None of the new sand bars formed to a height to greater than or equal to least tern and piping plover minimum sandbar height criterion of 1.5 feet above the 1,200 cfs TRF stage. Sand bar area decreased from

104 acres pre to 48 acres post high flow event for bars greater 0.25 acres in size. Of the 48 acres of sand bars greater than 0.25 acres surveyed post high flow, 7 acres were new bars that evolved during the high flow event. Overall there was a net reduction in the number of sand bars greater than 0.25 acres, the minimum sandbar area criterion for terns and plovers.

Vegetated Bar Area: Vegetated bar area in the Shoemaker study reach increased from 49 acres pre high flow to 117 acres post the June 2014 high flow event. New vegetation that germinated and grew post high flow was primarily warm season annual plants; barnyard grass, cockle burr, Malabar sprangle top, and common ragweed as opposed to perennials (e.g. eastern cottonwood, willow trees, common reed, curly dock, bulrush sp., purple loosestrife). .

The June 2015 High Flow was monitored post high flow event and the magnitude and duration that was sufficient to affect the height and area of sand bars and area of vegetated bars in the Shoemaker study reach.

Sand Bar Height and Area: Sand bar topography data collected post 2014 high flow and post 2015 high flow were analyzed to describe the height and area of sand bars that were transformed/created by the June 2015 high flow event. All of the surveyed sand bars (59.6 acres) and 97.8 percent of the vegetated bars (62.1 acres out of 63.5 acres) in the study reach were subjected to river flows during the June 2015 high flow. The June 2015 high flow event did not result in the growth of sand bars equal to or greater than 1.5 feet above the 1,200 cfs TRF. Twenty-three sand bars greater than 0.25 acres were surveyed post the June 2014 high flow event with a mean height of 0.52 feet above the 1,200 cfs TRF stage or a mean depth of 2.14 feet below the formative event 3-day mean peak discharge stage of 15,700 cfs. The mean height of the 3-day mean peak stage above the 1,200 cfs TRF stage was 2.59 feet with a maximum and minimum height of 4.05 and 1.38 feet, respectively. The mean height of sand bars above the 1,200 cfs TRF stage surveyed in July 2014 (M=0.36 ft) were found to be significantly higher ($p<0.05$) than sand bars surveyed August 2015 (M=0.52). The number of sand bars in the Shoemaker study reach >0.25 acres decreased from 40 bars surveyed July 2014 to 23 bars surveyed August 2015 and sand bar area increased from 48.5 acres to 59.6 acres, respectively. The formative flow event did increase mean bar height by 0.16 feet, however none of the sand bars met or increased in height to the minimum height of 1.5 feet or higher than the 1,200 cfs TRF stage for tern and plover habitat.

Vegetated Bar Area: Vegetated bar area had a net decrease of 53 acres in the Shoemaker study reach from the post 2014 to the post 2015 bar surveys. Sand bars had a net increase of 8 acres and water/river bed area (elevations less than 1,200 cfs TRF stage) increased by 45 acres. The June 2015 high flow was effective at removing vegetated bars in the study reach with the majority being replaced by open water/river bed.

2. **Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.**

The 2013 SDMF was monitored pre and post the high flow event and the magnitude and duration of the event did not demonstrably affect vegetated bars or the vegetation assessment plots in the Shoemaker study reach.

> **<u>Vegetation Plot Assessment:</u>** Perennial vegetation was present in 24 vegetation plots, nine of which were inundated during the 2013 SDMF. Disturbance of the vegetation did not occur because inundation was shallow and velocity and shear stress were low.

The Fall 2013 High Flow was not specifically monitored for its effects on vegetated bars or on the vegetation assessment plots in the Shoemaker study reach. However, vegetation surveys prior to the high flow (post 2013 SDMF) and following the high flow (pre-2014 high flow) bracket this flow.

> **<u>Vegetation Plot Assessment:</u>** Nineteen of the 24 plots with perennial vegetation were inundated by the Fall 2013 high flow. Nine of these plots were disked prior to the high flow. All perennial vegetation that was present post 2013 SDMF was removed from inundated plots, with the exception of one plot where disturbance was uncertain.

The June 2014 High Flow was monitored pre and post the high flow event and the magnitude and duration was sufficient enough to affect vegetated bars and the vegetation assessment plots in the Shoemaker study reach.

> **<u>Vegetated Bar Mortality:</u>** Vegetated bar area increased post the June 2014 high flow event in the Shoemaker study reach by 68 acres. The increase in vegetation was attributable to low Platte River flows (<500 cfs) that exposed sand bars and permitted the germination and growth of annual plants on bars. Any net plant mortality on bars that may have occurred during the June 2014 high flow was negated by the post event low flows that were conducive to the growth of annual plants.

> **<u>Vegetation Plot Assessment:</u>** Sixteen plots with perennial vegetation were inundated in June 2014. Six plots of these plots were disturbed, six plots were undisturbed, and disturbance was uncertain in four plots. This response of perennial vegetation lands between the end members of 2013 SDMF (no perennial vegetation was disturbed within the plots) and Fall 2013 High Flow (all perennial vegetation was disturbed in the plots).

The June 2015 High Flow was monitored post high flow event and the magnitude and duration was sufficient enough to affect vegetated bars and the vegetation assessment plots in the Shoemaker study reach.

> **<u>Vegetated Bar Mortality</u>**: The June 19, 2015 daily mean flow was 16,000 cfs at Grand Island, NE which is a 15-year recurrence interval peak flow. The magnitude of the June

2015 high flow inundated all of the surveyed sand bars (59.6 acres) and 97.8 percent of the vegetated bars (62.1 acres out of 63.5 acres) in the study reach. Vegetated bar area decreased post the June 2015 high flow event in the shoemaker study reach by 53 acres. Sand bar area in the study reach increased by 7.7 acres and water/riverbed area increased by 45.2 acres. The extended period (72 days) of flow greater than 2,000 cfs eroded vegetated bars and inundated sand bars that would typically support the growth of annual plants.

<u>Vegetation Plot Assessment:</u> Disturbance of perennial vegetation during the 2015 High Flow was similar to the disturbance following the Fall 2013 High Flow. Twenty-two vegetation plots with perennial vegetation were inundated. Eight of these plots were disked in the fall of 2014. All perennial vegetation was removed from the inundated plots.

Hydraulic data was pooled for all vegetation plots with perennial vegetation present for the four high flow events that occurred between 2013 and 2015. The Mann-Whitney-Wilcoxon test was used to compare populations of disturbed and undisturbed plots for depth, velocity, and shear stress. The results of the analysis indicate that there is statistically significant difference ($P<0.05$) between the disturbed and undisturbed populations for all three hydraulic parameters (depth, velocity, and shear stress). Undisturbed plots have a mean depth, velocity, and shear stress of 0.5 ft, 0.7 ft/s, and 0.9 Pa while disturbed plots have values of 1.8 ft, 2.5 ft/s, and 7.3 Pa.

These results of the pooled data for all perennial vegetation indicates velocities that disturb the vegetation are relatively low with a mean velocity of 2.5 ft/s. This velocity falls into the "uprooting initiating" velocity class for 1-year old cottonwood, suggesting that there should be some disturbance, but not uprooting of all plants, as observed, which requires a much higher velocity of >10.8 ft/s. There were no plots with 1 or 2-year old cottonwood during the 3-year period to compare results. Pollen-Bankhead et al. (2012) estimated the initiation of uprooting of reed canarygrass to begin when velocities of reed canarygrass is 4.4 ft/s and all plants uprooted requires >28.8 ft/s. Six of the eight plots with reed canarygrass were disturbed (all vegetation removed), one was disked and one was undisturbed. Disturbed plots of reed canarygrass also has lower velocities than required for initiation of uprooting. Velocities at disturbed reed canarygrass plots ranged from 2-4 ft/s, while initiation of uprooting is estimated at 4.4 ft/s and uprooting of all reed canarygrass requires velocities >28.8 ft/s. There were 4 plots with *Phragmites sp*. Two of the plots with *Phragmites sp* were disturbed by high flows (complete removal of all vegetation in the plot), one plot was disked, and one was undisturbed. Both disturbed plots had velocities < 1.7 ft/s which substantially lower than that required to initiate uprooting (34.8 ft/s), or complete removal >69 ft/s to uproot all plants. There are insufficient data to create new statistical relations for these species; however, the results suggest that the that other forces (such as scour) are likely destabilizing vegetation well below the thresholds required to uproot vegetation by drag forces alone.

One-dimensional bank erosion modeling using the USDA-ARS BSTEM model was applied to evaluate the relationship between lateral erosion and vegetation mortality. Vegetation root structure can reduce lateral erosion by increasing the resistive forces of the bank. Vegetation mortality can occur when bank failure occurs. The results below are based on a small number of bank sites where detailed information collected (e.g. topography, grain size, root structure, rooting depth) and general observations at the vegetation plots. Banks tended to be stable when roots extended to the toe of the channel and eroded when banks were unvegetated or vegetated with shallow root systems. Bank erosion occurred both during high flows and moderate flows. Bank erosion that was observed during short duration flows (2013 SDMF) and predicted for SDHF was insufficient to produce substantial vegetation mortality as observed in the vegetation plots and bank sites. The 2014 High Flow was a similar magnitude to a SDHF and produced substantially more vegetation mortality due to longer flow duration. Further increasing flow magnitude (as occurred in the Fall 2013 High Flow and 2015 High Flow) results in additional vegetation mortality across bars through a combination of vertical and lateral erosion and high drag forces; however, three of the four modeled bank sites that were stable in 2014 remained stable through the 2015 high flow. These results from the bank sites indicate that deeply rooted plants are highly resistant to hydraulic forces. The role of rooting depth at the vegetation plots is unknown because this parameter was not estimated or measured at these sites.

3. **Evaluate the ability of the FSM management strategy to create and/or maintain habitat for whooping cranes, least terns, and piping plovers.**

The FSM management strategy includes:

<u>Flow:</u> Augment Q1.5 through flow releases to create short duration high flows (SDHF) of 5,000 to 8,000 cubic feet per second (cfs) for 3 days in 2 out of 3 years.

- 2013 SDMF – The 3-day mean peak discharge was 3,840 cfs with a flow duration of 6-days with flows greater than 2,000 cfs.
- June 2014 High Flow - The 3-day mean peak discharge was 7,320 cfs and duration of 30-days with flows greater than 2,000 cfs.
- June 2015 High Flow - The 3-day mean peak discharge was 15,700 cfs and duration of 72-days with flows greater than 2,000 cfs.

<u>Sediment:</u> Augmentation of approximately 150,000 tons of medium sand annually to offset sediment deficit upstream of Kearney.

- To our knowledge, no sediment was added above Shoemaker during the 3-year study. Measured sediment loads and volume changes within Shoemaker relate to this learning objective by informing the mechanics of habitat (bar) formation.

<u>Mechanical:</u> Channel widening, clearing, and leveling of in-channel bars and flow consolidation (85-90 percent of 8,000 cfs in a single channel).

- River bed/bars in the Shoemaker study reach were mechanically treated before the first geomorphology survey was completed in March, 2013. Additionally, mechanical treatment of bars/riverbed occurred annually in October and herbicide treatment was early spring.

The 2013 SDMF did not have a measurable effect on lest tern, piping plover and whooping crane habitat. Post the June 2014 and June 2015 high flow 14 and 23 sand bars, respectively were surveyed in the study reach greater than 0.25 acres in size the minimum areal extent for least tern and piping plover habitat. The height of all the surveyed sand bars post 2014 and 2015 high flows were less than least tern and piping plover nesting suitability criterion for sand bar height greater than 1.5 feet above 1,200 cfs TRF stage. The areal extent of sand bars >0.25 acres in size that met minimum nesting suitability criterion of less than 20 percent vegetation coverage (or >80% sand) decreased by 55 acres post the June 2014 high flow and increased by 11 acres post June 2015 high flow.

The sediment data was not evaluated relative to the creation and maintenance of least tern, piping plover and whopping crane habitat. Changes in sediment storage and the measured (or estimated) sediment loads were as follows:

- The 2013 SDMF total sediment load was 27,700 and volume change was a net deficit of 16,000 cubic yards (cy).
- The Fall 2013 High Flow was not directly monitored and the estimated total sediment load was 170,000 and estimated volume change was a net deposition of 82,920 cy.
- The June 2014 High Flow total sediment load was 99,300 tons and volume change was a net deficit of 10,300 cy.
- The June 2015 High Flow total sediment load was 966,000 tons and volume change was a net deposition of 48,000 cy.

Sand bar area greater than 0.25 acres in size the minimum areal extent for least tern and piping plover habitat.in the mechanically treated portion of the study reach decreased by 50 acres post the June 2014 high flow and increased by 5 acres post the June 2015 high flow. Unobstructed channel width that met whooping crane roosting criterion is 750 ft with a target of 1,150 ft. Of the eighteen monitored river cross sections six mechanically treated segments exceeded the minimum criterion post the 2013 SMF. Eight and 9 mechanically treated segments exceeded the minimum criterion post the June 2014 and June 2015 high flow, respectively.

Model Findings

Mobile-bed models are sediment transport models that predict changes in the channel form through erosion and deposition. Two models were applied with a focus on Learning Objective 1:

i). The relationship between sediment transport (surplus/deficit) and the frequency of sandbar occurrence.
ii). The relationship between sediment grain size distribution and sandbar height potential.
iii). The role of hydrograph duration and shape in sandbar height.

These analyses were conducted to determine the role of these parameters within the context of the target volume of water available for a SDHF.

The models were developed and calibrated using measurements collected during the 2013 and 2014 high flows. The mobile bed model was not applied to 2015 High Flow because the data collected in 2014 was sufficient to calibrate the model within the flows of interest (SDHF), and the high flow was clearly outside the range of flows (both in magnitude and duration) that the mobile-bed models were developed to analyze.

The results of the mobile-bed modeling analysis are consistent with field observations in the Shoemaker reach that SDHF events are not likely to create bars with sufficient height or areas to achieve biological objectives. While there were differences in sediment transport (cut/fill) and total number of bars formed, the relative changes in bar area and height during a SDHF were minor. Differences in peak magnitude (5,000 cfs - 8,000 cfs) and duration of peak flow (3 - 6.5 days), grain size (0.5, 1 mm, 2 mm) and sediment supply changes (0.5 – 2x sediment supply) did not produce statistically significant changes in the bar forms created during the SDHF. These results are limited to the effect of one SDHF event. The conclusion from the modeling analysis is consistent with field measurements of barform changes following a short duration medium flow and three distinct high flow events (Fall 2013, June 2014 and June 2015) that met or exceeded the target SDHF.

I. INTRODUCTION

In 2013, the Platte River Recovery Implementation Program (Program) contracted EA Engineering, Science, and Technology, Inc., PBC (EA) to implement a Flow-Sediment-Mechanical (FSM) Proof of Concept Experiment. Team members for the implementation of the Experiment include: GMA Hydrology (GMA) fluvial geomorphology and sediment transport monitoring, Northern Hydrology and Engineering (NHE) hydraulic and sediment transport modeling, and Western Ecosystems Technology, Inc. (WEST) vegetation monitoring, mapping and classification. This report presents results of the third year of “Proof of Concept” monitoring, modeling, data analysis, and a summary of the three-year experiment findings.

Year 3 monitoring and data analysis efforts focus on a natural high flow event. The monitored runoff period during which discharge was greater than 2,000 cubic feet per second (cfs) lasted from May 11, 2015 to July 21, 2015 and produced a peak discharge of 16,100 cfs at the Grand Island gaging station. Year 3 modeling included hydrodynamic predictions for the natural high flow event and the effect of a hypothetical SDHF event with a range of sediment supplies and grain sizes.

Section II and III provide the purpose and experiment design, respectively for the FSM “Proof of Concept” Experiment. Section IV presents the methods used to collect relevant data pre and post a high flow event during Year 3, and Section V presents the results of the Year 3 field data. Section VI provides a summary of the Year 3 model objectives and results; further detail can be found in Attachments I and II. Section VII presents the findings of the FSM action on the geomorphology of the Platte River relative to the “Learning Objectives” for the Shoemaker Island Complex Management Experiment during Year 3. Section VIII presents a discussion of the inter year observations (2013, 2014, and 2015) of the geomorphologic changes of the Platte River relative to the high flow events in the Shoemaker Study Reach.

II. PURPOSE

II.A. Program Management Objectives and Management Strategies

The Program's management objectives are to 1) improve survival of whooping cranes during migration, 2) improve least tern and piping plover production, and 3) avoid adverse impacts to pallid sturgeon in the Lower Platte River. The Program is tasked with evaluating the ability of the FSM management strategy to achieve these management objectives. The FSM strategy includes the following management actions:

1) Flow— Augment Q1.5 through flow releases to create short duration high flows (SDHF) of 5,000 to 8,000 cfs for 3 days in 2 out of 3 years.

2) Sediment— Augmentation of approximately 150,000 tons of medium sand annually to offset sediment deficit upstream of Kearney.

3) Mechanical— Channel widening, clearing, and leveling of in-channel bars and flow consolidation (85-90 percent of 8,000 cfs in a single channel).

II.B. Hypotheses

The Program uses a process of rigorous adaptive management to reduce uncertainty associated with the ability of management actions to create and/or maintain suitable habitat for the Program's target species. This is achieved by explicitly acknowledging uncertainty in the form of alternative hypotheses of management action performance and testing the hypotheses through implementation of management experiments. Uncertainty associated with implementation of the FSM management strategy is formalized in the Program's Adaptive Management Plan (AMP) in the form of physical process broad and priority hypotheses. Broad hypotheses that pertain to the FSM management strategy include:

PP-1: Flows of varying magnitude, duration, frequency, and rate of change affect the morphology and habitat quality of the river, including:

- Flows of 5,000 to 8,000 cfs magnitude in the habitat reach for a duration of 3 days at Overton on an annual or near-annual basis will build bars to an elevation suitable for least tern and piping plover habitat.

- Flows of 5,000 to 8,000 cfs magnitude in the habitat reach for a duration of 3 days at Overton on an annual or near-annual basis will increase the average width of the vegetation-free channel.

- Variations in flows of lesser magnitude will positively or negatively affect the sandbar habitat benefits for least terns and piping plovers.

PP-2: Between Lexington and Chapman, eliminating the sediment imbalance of approximately 400,000 tons annually in eroding reaches will:

- Reduce net erosion of the river bed.

- Increase the sustainability of a braided river.

- Contribute to channel widening.

- Shift the river over time to a relatively stable condition, in contrast to present conditions where reaches vary longitudinally between degrading, aggrading, and stable conditions.

- Reduce the potential for degradation in the north channel of Jeffrey Island resulting from headcuts.

PP-3: Designed mechanical alterations of the channel at select locations can accelerate changes towards braided channel conditions and desired river habitat using techniques including:

- Mechanically cutting the banks and bars to widen the channel to a width sustainable by Program flows at that site, and distributing the material in the channel.

- At specific locations, narrowing the river corridor and increasing stream power by consolidating more than 85 percent of river flow into one channel will accelerate the plan form change from anastomosed to braided, promoting wider channels and more sandbars.

- Clearing vegetation from banks and bars will help to increase the width-to-depth ratio of the river.

These hypotheses provide a broad view of the possible changes in river morphology/channel characteristics that may be produced through implementation of FSM management actions.

The following more detailed hypotheses address uncertainty in underlying physical process relationships and are formalized in the AMP as flow, sediment, and mechanical priority hypotheses. Tier I physical process priority hypotheses include:

Flow #1: Increase the variation between river stage at peak (indexed by Q1.5 flow at Overton) and average flows (1,200 cfs index flow), by increasing the stage of the peak (1.5-year) flow through Program flows, will increase the height of sandbars between Overton and Chapman by 30 percent to 50 percent from existing conditions.

Flow #3: Increase 1.5-year Q with Program flows will increase local boundary shear stress and frequency of inundation at existing green line. These changes will increase riparian plant mortality along margins of channel, raising elevation of green line. Raised green line equals more exposed sandbar area and wider unvegetated main channel.

Flow #5: Increase magnitude and duration of a 1.5-year flow will increase riparian plant mortality along the margins of the river. There will be different relations (graphs) for different species.

Sediment #1: Average sediment augmentation near Overton of 185,000 tons/year under existing flow regime and 225,000 tons/year under Governance Committee (GC) proposed flow regime achieves a sediment balance to Kearney.

Mechanical #2: Increase the Q1.5 in the main channel by consolidating 85 percent of the flow, and aided by Program flow and a sediment balance, flows will exceed stream power thresholds that will convert main channel from meander morphology in anastomosed reaches to braided morphology with an average braiding index greater than 3.

II.C. Experiment Purpose

The Shoemaker Island Complex is located in the downstream portion of the Associated Habitat reach where the channel is assumed to be in sediment balance, which is one of the reasons why this area was chosen for implementation of a replicate "Proof of Concept" management experiment. The experiment will evaluate the performance of the FSM management actions, as discussed above, in creating and/or maintaining channel characteristics that are consistent with the Program's management objectives. Learning objectives provided in the Request for Proposal for the Shoemaker Island Complex management experiment include:

1) **Evaluate the relationship between peak flows (magnitude and duration) and sandbar height and area.** Understanding the relationship between river stage at peak discharge and sandbar height in relation to maximum water surface elevation are fundamental to testing the Program's FSM management strategy. The Environmental Impact Statement (EIS) analysis assumed that sandbars form to the water surface elevation during high flow events but that under the current flow regime, the difference between the 1.5-year return frequency flow elevation and the normal water surface elevation during the summer nesting months is not sufficient to create sandbars that are high enough for nesting. As such, doubling the 1.5-year return frequency flow from approximately 4,000 cfs to approximately 8,000 cfs would increase bar heights by 30 percent to 50 percent as presented in Priority Hypothesis Flow 1. Sandbar formation during the natural flow events of 2010 and 2011, which exceeded SDHF magnitude and duration, indicates that sandbars are not forming to the water surface elevation during high flow events; however, this has raised additional questions about:

    i). The relationship between sediment transport (surplus/deficit) and the frequency of sandbar occurrence.
    ii). The relationship between sediment grain size distribution and sandbar height potential.
    iii). The role of hydrograph duration and shape in sandbar height.

2) **Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.** Understanding the relationship between flow and riparian plant mortality is fundamental to testing the Program's FSM management strategy. Modeling conducted during the EIS development indicated that increasing the 1.5- year return frequency flow from approximately 4,000 cfs to approximately 8,000 cfs through the use of SDHF in 2 years out of 3 years (under sediment balance) would increase riparian plant mortality sufficiently to maintain wide, braided, unvegetated main channels with exposed sandbars. This relationship is presented in Program Priority Hypotheses Flow 3. Analysis of existing system and project-scale vegetation monitoring is ongoing. Preliminary results indicate a need to continue to evaluate the interaction between scour and inundation mortality as well as the role of lateral erosion in vegetation removal from sandbars.

3) **Evaluate ability of FSM management strategy to create and/or maintain habitat for whooping cranes, least terns and piping plovers.** Linking physical process relationships to target species habitat requirements is fundamental to the development of management experiment performance criteria and action adjustments. The overarching Program objectives relate to target species survival and productivity. As such, Program management strategies must be capable of creating and/or maintaining river conditions that are suitable for achieving those objectives. Specifically, the FSM management strategy must be able to scour enough vegetation to maintain unobstructed view widths suitable for whooping crane roosting, and build/maintain bars of sufficient height and lack of vegetation to function as least tern and piping plover nesting habitat.

III. EXPERIMENT DESIGN CONSIDERATIONS

This document describes the field activities that were completed during the 2015 Shoemaker Island FSM "Proof of Concept" Experiment. Many factors and lessons learned from the 2013 and 2014 experiment monitoring and data analysis (PRRIP 2014 and PRRIP 2015a) were considered for the 2015 Shoemaker Island FSM "Proof of Concept" project, including the location, duration, data needs for model input, and refinement of methods and procedures used during the 2013 and 2014 field data collection activities. The Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment Monitoring and Analysis Plan (PRRIP 2015b) presented the plans for the experiment monitoring and analysis.

The 2015 Shoemaker Island FSM "Proof of Concept" experiment monitoring is the third and final year of monitoring for the three-year experiment. This document describes the field activities and subsequent analyses that were completed during 2015.

III.A. Overview of Data Collection

The Shoemaker Island Complex was selected for this FSM "Proof of Concept" due to its location and its suitability to investigate a number of the Program's hypotheses. The primary focus of fieldwork efforts was to monitor changes within the Shoemaker reach relative to high flow events and relate those changes to other management actions such as disking vegetated bars and construction of nesting bars. Monitoring in 2015 describes geomorphic change related to a significant high flow event: the June 2015 high flow at 16,100 cfs Total River Flow (TRF) instantaneous peak discharge at the Grand Island gage on June 19, 2015 (a nearly identical peak occurred on June 5, 2015 at 16,200 cfs, but the June 5 peak was slightly higher at Shoemaker, thus we refer to the June 19, 2015 event as the annual peak). Data collected fell into three primary categories, though many data types fall into multiple categories:

1. Geomorphic monitoring

2. Model development, calibration and verification

3. Vegetation monitoring

The geomorphic and vegetation monitoring of the Shoemaker reach included numerous elements which also supported modeling efforts, notably:

- Sediment loads were computed using 2015 sample data, continuous discharge and checked against estimates based on 2013-2014 datasets.
- Volume change and topographic changes were developed from cross section and longitudinal profile surveys.
- Scour rates, bed and bar grain size distributions, water surface slope and stage at cross sections were measured.

- Continuous discharge monitoring and limited bedload sampling were conducted during the 2015 monitoring effort.

The primary predictive components of the experiment design are the two-dimensional fixed-bed and mobile-bed hydrodynamic models. Field data are used to parameterize and calibrate the models. Many tasks, such as stage observations at cross sections, provide calibration and thereby increase model accuracy. Virtually all monitoring tasks provide intrinsic value to the Program as stand-alone metrics; were the mobile-bed model effort to be inconclusive, most of the other monitoring tasks provide direct evaluation of management actions and channel response.

III.B. Area of Interest

The Shoemaker Island Complex was selected for this FSM "Proof of Concept" due to its location on the river where it is assumed that sediment is in balance (i.e. the sediment loads entering and exiting the reach are approximately equal and the reach is neither aggrading nor degrading) and is not directly impacted by irrigation or transportation infrastructure. The FSM "Proof of Concept" Experiment documented degradation in the study reach of 16,000 cubic yards (cy) in 2013 and 10,300 cy of degradation in 2014 (PRRIP 2014 and PRRIP 2015a). The fall 2013 high flow event which was not monitored produced a net deposition of 82,900 cy in the study reach (PRRIP 2015a).

The Shoemaker Island Complex is located approximately 12 miles southwest of Grand Island, Nebraska (Figure 3-1). Access to Program lands was provided via two gates along Shoemaker Island Road. The study site begins approximately 1.6 miles downstream of Highway 11 (Wood River Road), and extends 2.6 miles downstream to a point approximately 1.1 miles upstream of South Alda Road (Figure 3-1).

III.C. Data Collection

Aerial photographs, taken July 2015, were obtained from the Program to facilitate development of a site study plan in which cross section locations, profile alignments, and sampling sections were determined. The resulting data collection locations within and surrounding the study site are summarized and illustrated on monitoring network site maps provided in Appendix A; Figures A-1 through A-3.

The 2015 spring runoff began unusually early and was of significant magnitude that no "Pre" data were collected. The following summarizes the key data collected during and after the spring runoff period:

- Flow rate, depth, velocity, and water-surface elevation
- Sediment transport (suspended load, and grain size distribution)
- Bed material characteristics (grain size distribution, bulk density, porosity)
- Channel cross-section and longitudinal topography

- Vegetation type, density, stem diameter, height, and green line elevation on bars (established vegetation and were new growth vegetation was apparent) and channel banks
- Channel width
- Bar topography and morphometry
- Land-based photography
- Channel unobstructed view width

IV. MONITORING AND ANALYSIS METHODS

The monitoring and analysis methods conformed to the established Project-Scale Geomorphology and Vegetation Monitoring protocol (PRRIP 2011), the detailed methods are presented in the Experiment and Monitoring and Analysis Plan (PRRIP 2015b). The field activities completed for the 2015 Shoemaker Island FSM "Proof of Concept" experiment did not address all of the tasks specified in the monitoring and analysis protocol and plan. The desired experiment called for the completion of a pre high flow, high flow, and post high flow monitoring. Pre high flow monitoring was not performed in the spring of 2015 due to persistently high flows in the Platte River that prevented safe wading access to the river. Data analysis for the 2015 FSM experiment focuses on geomorphic change between the June 2014 and the August 2015 monitoring efforts relative to the June 2015 natural high flow event.

The June 2015 high flow, peaking at 16,100 cfs, in the Grand Island gaging station hydrograph, occurred from May 11, 2015 to July 20, 2015. Post high flow monitoring data were collected from August 24, 2015 to August 28, 2015 and September 1, 2015 to September 2, 2015. The following summarizes the data that were collected during and following the June 2015 high flow.

Sampling activities during the June 2015 high flow:

- Maintained and downloaded automated stage and turbidity recorders
- Conducted stage monitoring at 18 cross sections
- Conducted depth and velocity (discharge) measurements between cross sections 2 and 3
- Conducted suspended sediment depth integrated sampling between cross sections 2 and 3
- Conducted box suspended sediment depth integrated sampling between cross sections 2 and 3
- Collected bedload samples to compare with Modified Einstein predictions of total sediment load

Sampling activities following the June 2015 high flow:

- Surveyed 18 monumented cross sections
- Surveyed 19 supplemental cross sections
- Surveyed exposed bars
- Maintained and downloaded automated stage recorders
- Conducted suspended sediment depth integrated sampling between cross sections 2 and 3
- Completed ground photography
- Collected bed and bar material samples
- Conducted vegetation sampling at assessment plots
- Field verified vegetation cover polygons for models
- Conducted depth and velocity (discharge) measurements between cross sections 2 and 3
- Monitored scour chains (none were found)

IV.A. Topography and Bathymetry

Topography and bathymetry data were obtained using several approaches, including LiDAR survey, ground surveys at primary and supplemental river cross sections, and bar topography.

Topographic, bathymetric, and ground surveys were completed using survey-grade Real Time Kinematic (RTK) / Global Positioning System (GPS) survey equipment. Primary Survey control points established on March 22, 2013 by a licensed Nebraska Surveyor were used to facilitate the 2015 base station deployments. The horizontal reference datum for all surveys was in North American Datum of 1983 (NAD 1983) and the vertical reference datum was the North American Vertical Datum of 1988 (NAVD 1988). The Nebraska State Plane Coordinate System in US survey feet was utilized.

IV.A.1. Primary River Cross Sections

The primary river cross sections were oriented perpendicular to the river center-line, and cross-sections were spaced approximately 800 feet apart. Eighteen cross sections were established throughout the 2.6 mile long reach of the Platte River as shown in Figure 3-2 and in Appendix A-1 to A-3. Nineteen supplemental cross sections were established between the primary cross sections to provide improved spatial resolution for volume change calculations. The primary and supplemental river cross sections were surveyed September 1 and 2, 2015.

Existing monuments established by the Program for the Channel Geomorphology and In-channel Vegetation Monitoring (PRRIP 2011) were utilized as control points by the licensed surveyor. Temporary benchmarks were established for local base station deployment for the post high flow survey. Capped rebar monuments were established on the north and south banks of the Platte River at the 18 cross sections (Figure 3-2), with a few exceptions. Top-of-bank access was not granted to the south bank of the Platte River from cross section 1 to cross section 9. Pins successfully placed at the top of bank are designated with “Set.” Pins that could not be placed due to restricted access are designated with an “R” for the south bank of the river. The coordinates and elevations for the cross section pins, and benchmarks are included in Table 4-1.

For each cross section easting, northing, and elevation data points were taken for defined features across the cross section. Features were identified and logged in the data recorder when a point was taken. At a minimum, the following features were noted:

- Left and right bank pins
- Top and toe of bank
- Left and right edge of water at main banks
- All edges of water across the cross section
- Top and toe of bank for each bar
- Bed or ground elevation along the cross section green line (where vegetation cover exceeds 25 percent)
- Edge of canopy of permanent woody vegetation greater than 1.5 meters tall

- Any other significant geomorphic feature in the cross section, including whether the flow is consolidated at the cross section or if flow is split between multiple channels
- Other points of interest identified by the investigators

A standard set of survey codes was developed to describe significant features that were surveyed (Table 4-2). To adequately define the channel bed, GPS readings were taken at significant breaks in slope. The Stakeout Line function on the survey data logger was used to ensure repeatable straight line surveys defined by paired cross section monument pins. All cross section data collected during the survey were downloaded and compiled electronically into spreadsheets for analysis, and used in identifying volumetric changes of the channel over time.

The survey of a bar's perimeter and transects was completed as part of the bar topography—described in later sections. The edge of mature vegetation and new annual vegetative growth on bars was noted during the survey. The study area was limited to the main Platte River channel on the south side of Shoemaker Island, and did not include survey of the smaller channel approximately 2 miles north of the study area.

Cross section data were edited during post processing to minimize implied topographic change resulting from variation in point density, point location or survey alignment as follows:

- Alignments for anomalous points were checked in ArcGIS
- Cross sections were checked against bar surveys
- Cross sections were checked against the approximate peak water surface elevation to determine locations which were not inundated

For volume change computation, the average end area method was used to compute change between the 2014 post monitoring event and September 2015 post monitoring event. The primary drivers of geomorphic change during this period are the February 2015 ice floe (Figure 4-1) and the June 2015 high flow. Volume change was calculated using the 18 monumented cross sections and the 19 supplemental cross sections (n=37). The cross section data were examined in ArcGIS. Areas showing anomalous results (e.g. deposition or erosion in areas that were not inundated or areas in which nesting bars had been constructed near the western project boundary) were omitted from area change calculations. Areas of lateral erosion were identified and summed as a separate category. Changes above the peak flow elevation were included if they were associated with vertical bank failure resulting from lateral erosion. Vertical incision at the toes of banks was included in "lateral erosion" when it occurred inland of the former toe. The distance between cross-sections was measured along the channel centerline. The changes in cross section area were averaged from one section to the next, and then multiplied by the distance between sections. The resulting volume of cut and fill between each section was summed over the reach.

Supplemental ground cross sections were surveyed to provide additional topographic/bathymetric data (and primarily, to add resolution/accuracy for volume change calculations) above, below, and within the study area. Within the study area 17 supplemental cross sections located equidistant between the 18 primary cross sections were surveyed and a cross section was completed approximately 400-feet upstream and downstream of primary cross section 1 and 18 (Figure 3-2). This effort resulted in a total of 19 additional cross sections within and adjacent to the study reach. Supplemental cross sections were surveyed using RTK/GPS post June 2015 high flow. The supplemental cross sections were also used to facilitate surface development for the fixed-bed and mobile-bed hydrodynamic models (Attachments I and II).

Supplemental ground survey cross sections were surveyed across the channel using similar methods to the primary river cross sections. The Stakeout Line function on the survey data logger utilized established coordinates to delineate cross sections and ensured repeatable straight line surveys (Table 4-1). Each cross section extended across all active channels and bars of the Platte River and extended from the confining bank to confining bank, but did not include the upland portions of the cross section beyond the potential bank erosion/deposition zone, or areas where access was not permitted.

IV.A.2. Bar Topography

Survey data were collected to define the shape and topography of all natural and constructed bars. A bar is defined as the portion of the ground surface that is dry at 1,200 cfs TRF. The water surface elevation at 1,200 cfs TRF was estimated throughout the study reach with a 2D model (see Attachment 1). The model result (a .TIN file) was imported into the Carlson SurvCE data logger software. The predicted water surface elevation was used as a guide by the survey crew to ensure that "toe" survey points extended to the edges of the bars at 1,200 cfs TRF. This approach was particularly helpful when flows were higher than 1,200 cfs TRF and the edge of the bar was submerged.

Data collected included: cross-stream and longitudinal (i.e., parallel to flow) transects, the top-of-bank and toe-of-bank perimeter of each bar, and any supplementary survey points deemed necessary by the survey crews to adequately define the topography of the bar surface. The surveys included a minimum of three cross-stream transects, with maximum spacing of 200 feet. For bars less than 1 acre in size, a single longitudinal transect was surveyed from the midpoint of the upstream end of the bar to the midpoint of the downstream end of the bar, with doglegs as needed to run through the highest "crest" of the bar. For bars larger than 1 acre in size, at least two additional transects were surveyed approximately midway between the primary longitudinal transect and the water's edge on either side of the bar. Ground photography was also completed for each bar above the water-surface elevation at the time of the survey.

One-hundred and forty-one bars were individually surveyed post high flow from August 24, 2015 to August 28, 2015 in the Shoemaker study reach by the survey crew. Five bars were located on property that was not accessible because permission was not granted by the landowner. Generally, the bars were numbered from upstream to downstream with a few exceptions.

To assess the ability of a high flow event to create and/or modify bars in the Shoemaker study reach area the vegetation coverage of surveyed bars was assessed pre (July 2014) and post

(August 2015) the monitored high flow (June 2015). Bars were grouped to evaluate the effect of Program activities on the bars, suitability of bars for tern and plover habitat and the ability of a high flow event to create new bars.

- Natural bars and treated bars. A natural bar is a bar or area of the river bed that has not been treated by Program activities. A treated bar is a bar or area of the river bed that was mechanically treated by Program disking in September 2014. The treated area surveyed in the Shoemaker study reach is presented in Figure 5-5.
- Sand bars and vegetated bars. A sand bar is a bar whose area above 1,200 cfs TRF stage is 80 percent or greater sand. A vegetated bar is a bar whose area above 1,200 cfs TRF stage is 20 percent or greater vegetated.
- Bars less than 0.25 acres and bars greater than 0.25 acre. A bar area in acres is determined at the 1,200 cfs TRF stage.

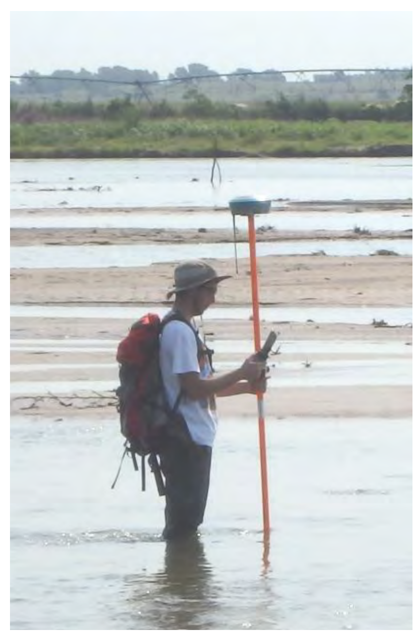
Bar survey data were loaded into ArcGIS with Spatial Analyst extension for analysis. A topographic surface (raster) of the study reach after the June 2015 high flow was developed using survey data and supplemental LiDAR data. LiDAR was used to develop the topography of bars, or portion of bars, that were not surveyed and for the floodplains.

Bars were delineated by computing the difference between the bed elevation and the predicted water surface elevation at 1,200 cfs TRF (see Attachment 1). Negative values are areas where the bed is below water (no bar) and positive values are bars. This calculation resulted in all surveyed bars set to a zero elevation at the edge of the bar and height is the bar height above the 1,200 cfs TRF water surface elevation. Bar features were entered into a GIS attribute table for each bar surveyed for data analysis. Bar attributes included: July 2014 and August 2015 survey, treated or natural, sand or vegetated, and bar area at the 1,200 cfs TRF elevation.

Mean bar height is computed by averaging the height of all cells in each polygon. Mean bar height can change by changes to the bar such as: (1) direct erosion of an existing bar (e.g. vertical erosion), (2) deposition on top of an existing bar, and/or (3) deposition adjacent to the existing bar. Mean bar height may increase without deposition on the bar if lower areas of the bar are eroded. Mean bar height may decrease without erosion of the bar if deposition occurs that has a lower elevation than the rest of the bar.

IV.A.3. Longitudinal Profile

Longitudinal profiles were surveyed through the reach to provide a post June 2015 high flow ground surface. Surveys were conducted by wading and using the same GPS/RTK system described earlier (see adjacent photo). Longitudinal



GPS/RTK longitudinal profile surveying.

profiles typically followed the dominant flow paths of deepest water and where possible, followed the 2014 alignment.

IV.B. Documentation of Bank and Channel Features Using Ground Photography

Ground photography was captured at each primary river cross section to document and describe bank condition, vegetation type, structure, and bar features. Four photographs were taken on each bank of the main channel from the monument point, with the photographs oriented across the channel, looking up and downstream, through the cross section, and back towards the bank. The up and downstream oriented photo points were located at least 25 feet from the cross section line and a survey flag was placed on the cross-section line for visual identification.

Three photographs were also taken on the perimeter of each bar; one at the upstream midpoint of the bar looking downstream across the bar, and one at the downstream midpoint of the bar looking upstream. When the entire bar was not visible in the photographs, additional photos were taken with similar up and downstream oriented views from appropriate location(s) in the middle of the bar so that the collection of photos covers essentially the entire bar.

Additional photographs and survey points document scour chain locations, stage monitors, and bulk sample and bulk density sample locations. The location of the photo points were documented with a GPS camera and cross section/bar identification, point identification included; date, time, lens, azimuth, and waypoint number for each photograph.

IV.C. Bed and Bar Material Sampling

Bed and bar material samples were collected post June 2015 high flow, concurrent with topography survey of the river bars. Due to natural variation in grain size in river channels, multiple samples were collected in the channel and on the bars to provide a well-distributed sample set and reduce uncertainty in bed and bar material data. When possible, 2014 sample locations were reoccupied.

- Main Channel Bed Samples— A minimum of two bed material samples were collected in the main channel at every other surveyed cross section, at or near the cross section primary flow line.

- Bar Samples— Collected from emergent natural and constructed bars larger than 0.4 acres at some cross sections. If a surface armor layer or coarse surface layer was present, it was noted and the surface was sampled separately prior to sampling the subsurface material.

Bed samples were collected with a rigid ABS tube that contained slightly less volume than the sample bags. The tube had a beveled end to allow for easy dredging; the other end was open and covered with a very fine mesh screen that trapped the sediment, while allowing water to pass through. Using a sampler that has slightly less volume than the sample bags allowed the entire sample to be placed directly into the bag without the potential for sorting or loss of fines. This also allowed for a similar volume of material to be sampled each time at each sample point.

Bulk density samples were collected on bars by driving a 3-inch diameter by 6-inch-long cylinder into a bar surface to its full depth, then excavating down to the aperture and carefully incising a flat blade across the aperture to trap the sample in the cylinder.

All bed/bar samples were transferred to individual sample bags, labeled with the cross section ID, sample number, and date the sample was taken. The location of the sample was recorded with the RTK rover. Samples were shipped to the GMA Coarse Sediment Laboratory in Placerville, California. Samples were sieve-analyzed for grain size distribution and—in the case of bulk density samples—for total mass and density. The samples were processed in accordance with ASTM Standard D422. The results reported for each sample were compiled in Microsoft Excel and include the sample description, total sample weight, and the weight and percent passing for each of the sieve sizes. The D5, D16, D50, D84, D95 grain size of each sample was also reported.

IV.D. Vegetation Type, Density, and Green Line

Vegetation monitoring methods for Shoemaker Island are described in the following sections.

IV.D.1. Vegetation Survey

The vegetation plots assessed for the 2015 experiment were established during the 2013 "Proof of Concept" Experiment. A hand held sub-foot GPS unit was used to relocate the center of the 2013 plot and the vegetation was surveyed for the 2015 experiment. A total of seven vegetative assessment plots were located along each of the 18 primary river cross sections for a total of 126 plots within the study reach. These plots were measured post the June 2015 high flow, to provide an assessment of the vegetation present. Each vegetation assessment plot was a 3.3 feet x 3.3 feet (1 meter x 1 meter) quadrat and were evenly spaced along the cross section starting randomly from the north side. The plots were offset upstream from the cross section by 5 feet or more to avoid disturbing vegetation underneath the cross section line during other work. Oblique and vertical photos of all plots were taken using a GPS camera. The following data were collected at each plot:

- Density of live and dead stems of eastern cottonwood, willows, and common reed (*Phragmites sp.*).
- Presence of other species (presence/absence).
- Photos showing total percent vegetation and percent sand.

IV.D.2. Vegetation Roughness

Polygons delineating aerial extent of uniform vegetation on the bars were mapped using ArcGIS to identify areas of uniform hydraulic roughness for modeling. When warranted, bars were subdivided to account for variation in bar vegetation and sand areas with no vegetation. Stem counts (all stems), stem diameter, and stem heights were determined by vegetation types for several 3.3 feet x 3.3 feet (1-meter x 1-meter) sub-plots across the polygon of a bar. Vegetative counts for several plots were averaged and extrapolated to obtain stem density, average stem diameter and height for the uniform vegetative polygons. The number of plots taken per polygon was determined in the field by the plant biologist to adequately describe the vegetation based on density, type of vegetation, and aereal extent of the polygon.

IV.D.3. Vegetation Green Line

A vegetation green line is the edge of vegetation on a bar or wetted channel, defined by at least 25-percent vegetative cover. Green line edges were surveyed during the primary and supplemental cross section surveys and the bar topography surveys. Surveyed green line edge data was used to define vegetative bar area and elevation.

IV.E. Stage Recorders

In-Situ Inc. Level TROLL® 500 pressure transducers were installed between cross sections 2 and 3 and at cross section 18 to record river stage during the 2015 “Proof of Concept” Experiment. Transducer elevations were surveyed during the primary cross section topography surveys. The vented transducers were installed April 18, 2015 at cross section 18 and May 24, 2015 between cross section 2 and 3, set to record river stage in feet at 15-minute intervals and monthly maintenance and downloading of data collected by the pressure transducers was scheduled for the duration of the study.

Water surface elevation is a model input and is the primary calibration parameter for the two-dimensional hydrodynamic model. Stage references (t-posts) were established along the north bank of some cross sections. Posts were surveyed using 3 minute occupations to a vertical accuracy of approximately 0.03 feet. Water surface elevations (stage) were manually measured from the posts down to the water surface during the peak of runoff, providing field verification of stage and a water surface slope through the reach.

IV.F. Discharge

Continuous discharge data were required for modeling and sediment load computation for the period of interest: the June 2015 high flow. Direct discharge measurements were collected during and after the June 2015 high flow. Computed continuous discharge data were compared with from one or more the following sources:

- USGS 15-minute gage data for Kearney (USGS 06770200),
- Nebraska Department of Natural Resources (NDNR) 30-minute gage at Shelton; and
- USGS 15-minute gage data at Grand Island (USGS 06770375).

The project site is located:

- 32 miles downstream of the United States Geological Survey (USGS) gage near Kearney;
- 10.3 miles downstream of the NDNR Shelton Road gage; and
- 13.5 miles upstream of the Highway 34 USGS gage east of Grand Island.

The gages listed above measure total river discharge. Fifteen-minute discharge records were obtained for (1) the basis of any scaled discharge relations for Shoemaker (using the TRF ratio developed from the Shoemaker HEC-RAS model, generally 82 percent), and (2) for hydrographic comparison with hydrographs developed for Shoemaker.
Some low flow discharge measurements were collected within the project area after the June 2015 high flow. Low flow measurements were collected using conventional wading techniques and a Price AA current meter, a 4 foot topset rod, a JBS Systems Aquacalc pro data collector, and a rangefinder. High flow measurements were collected at the upstream end of the project site using a Price AA meter, 50 lb sounding weight and a B-reel deployed from a boat. Bank observers directed the boat operator to remain on the cross section.

Discharge data were used to compute sediment loads and provide the hydrograph for fixed-bed and mobile-bed hydrodynamic models. Techniques, data sources and assumptions are detailed in Section V.A.

IV.G. Sediment Transport Measurements

Suspended sediment monitoring was completed to facilitate sediment load computations. The Modified Einstein Procedure (MEP) was employed as in 2013 (EA 2013) and some bedload samples were collected for comparison.

IV.G.1. Turbidity

The purpose of recording continuous turbidity is to provide a surrogate for suspended sediment concentration, namely to detect temporal changes in concentration that are not necessarily correlated with changes in discharge (as when banks collapse on the falling limb of a hydrograph). Suspended sediment samples are collected along with turbidity to develop turbidity versus suspended sediment concentration (SSC) relation.

A Eureka Manta 2 water quality data sonde was installed between cross sections 2 and 3 on May 24, 2015. The data sonde was positioned on the left bank where a relatively deeper river channel had been observed during field efforts to ensure adequate depth for the duration of the sonde deployment. The data sonde was set to record turbidity and temperature at 15 minute intervals and scheduled for maintenance and the downloading of data at 1 week intervals for the duration of the study. The turbidity probe on the Eureka Manta 2 was equipped with a wiper to minimize the effects of bio-fouling.

The turbidity data sonde was lost in early May due to the erosion of the river bottom around the stakes used to anchor the sonde. The sonde was subsequently retrieved in late August after the river stage had dropped and was located by a redundant safety cable attached to the sonde. Usable turbidity data were retrieved from the data sonde from May 24, 2015 to May 30, 2015.

IV.G.2. Suspended-Sediment-Depth Integrated Sampling

Suspended sediment transport sampling was performed by depth integrated sampling at the turbidity sonde located between cross sections 2 and 3. Suspended sediment monitoring was performed using a DH-59 suspended sediment sampler with a 3/16-inch nozzle from a 16 foot cataraft and, during lower flows, by wading between cross sections 2 and 3 using a DH-48 suspended sediment sampler with ¼ inch nozzle.

Samples were collected using techniques according to USGS protocols as described by Edwards and Glysson (1998), using the Single Equal-Width Increment method. Depth integrated samples were composed of two passes (of approximately 8 equally spaced verticals) using the same stationing and the same transit rate. The transit rate was manually determined at the thalweg as the rate which fills the bottle 70-90 percent full. Suspended sediment samples were analyzed for concentration and grain size distribution at the GMA fine Sediment Laboratory in Placerville, California. The samples were processed in accordance with ASTM Standard D422. The results reported for each sample were compiled in Microsoft Excel and include the sample description, total sample weight, and the weight and percent passing 0.063, 0.125, 0.25, 0.5, 1, and 2 mm sized sieves.

IV.G.3. Experimental ‘Box’ Sampling

If very large sample sets are desirable to reduce uncertainty in suspended sediment load computations, correlation samples (single vertical samples paired with full cross section samples) can provide high resolution at a low cost. Correlation sampling (also known as box sampling) is a well-established protocol employed by the USGS and others where a strong relation exists between single vertical concentrations and cross sectional concentrations. This technique was evaluated for the Platte River during the 2013 Short Duration Medium Flow (SDMF) and the 2014 “Proof of Concept” experiment showed a high correlation between box and full-cross-section concentrations. The relationship of the “at-a-point” single vertical samples to cross sectional values is of interest between Cross Sections 2 and 3, when personnel could not always wade across the channel. Such a correlation, or “box coefficient,” can be used to transform single vertical samples to the cross sectional value. This method is highly practical in areas with strong point-to-cross section relations: a single operator can collect many times more samples over a broader range of conditions than technicians employing the full cross section method. “Box” suspended sediment samples were collected using the depth integrated technique (at a single vertical generally adjacent to a “thalweg”) as previously described.

Box samples were collected in 2015 but since no samples were collected outside periods when full DIS sampling was occurring, development of a box-DIS sample relation was un-necessary and these data were not used.

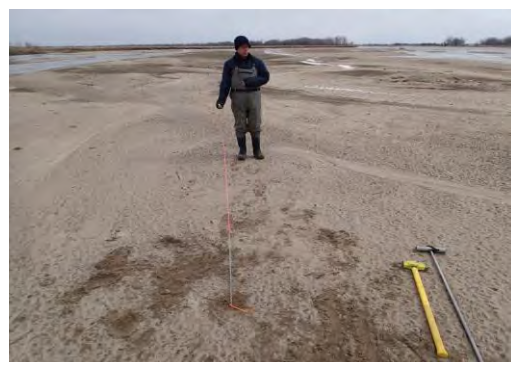
IV.G.4. Bedload Monitoring

Bedload monitoring was not included in the 2015 scope of work. However, two bedload samples were collected during suspended sediment monitoring for the purpose of comparison with Modified Einstein-predictions of total sediment load.

IV.G.5. Scour and Fill Monitoring

Scour chains are a new monitoring approach for the Program and data from the first year (2013) implementation was considered a pilot study. Aerial photo analysis and two-dimensional fixed bed modeling (PRRIP, 2014, Attachment 2?) guided development of strata (e.g. active bars, vegetated bars) in which to sample. In order to maximize the utility of monitoring observations, sampling areas were located along cross sections to the degree possible. Monitoring areas focused on mechanically treated bars, untreated vegetated surfaces, untreated unvegetated active bars, vegetated high flow channel, and unvegetated active channel.

In 2014, scour chains were driven vertically into selected features to provide estimates of scour and fill values (Pittman 2002) relative to the peak flow magnitude. The chains were attached to steel anchors buried as deep as possible (~ 2 feet) into the feature of interest (Figure 4-2). A wire tie was used to mark the ground surface. Subsequent deflection (measured from the tie upstream to the 90-degree bend) following scour events indicates the magnitude of scour. The distance from the 90-degree bend to the new bar surface indicates fill.



Scour chain deployed pre runoff event, 2014.

Each chain location was surveyed with GPS/RTK during the post June 2014 high flow monitoring. Since there was no pre monitoring event in 2015, scour chain monitoring relates to the 2014 post monitoring thus bracketing the February 2015 ice floe and the June 2015 high flow event. No scour chains were recovered in 2015.

IV.H. Modeling

Fixed-bed and mobile-bed hydrodynamic models and one-dimensional bank erosion models were used to estimate responses of channel morphology and vegetation to the implementation of FSM Program Management Action in the Platte River during the 3-year study period. Models were developed in Year 1 of the study (2013) with a focus on informing the learning objectives and included a lateral erosion model (BSTEM), a 2-D fixed bed models (FaSTMECH and EFDC) and 2-D mobile bed models (FaSTMECH and EFDC). In Year 1 (2013), the models were calibrated using data collected during the 2013 SDMF and run for higher flows and durations that would be typical of target SDHF using input parameters extrapolated from data collected in 2013. The primary limitation of the Year 1 (2013) 2-D modeling analysis was a lack of high flow calibration data to confirm model results for the high flow simulations. Calibration and verification of the lateral erosion model was limited by little to no observed erosion of vegetated bars.

Two high flows occurred following the 2013 SDMF. One high flow occurred in the fall of 2013 (fall 2013 high flow) and a second in June 2014 (June 2014 high flow). Water surface elevation data were collected by Program staff for model calibration during the fall 2013 high flow and by the EA project team during the June 2014 high flow. High flow simulations in Year 2 (2014) confirmed that model parameters selected in Year 1 were suitable for high flow fixed-bed simulations. Additional data was collected to calibrate the lateral erosion model on vegetated bars.

The highest peak flow with the longest duration of the study period occurred in 2015 (Year 3). However, this high flow was clearly outside the range of flows (both in magnitude and duration) that the 2-D mobile-bed models were developed to analyze. Similarly, the lateral erosion analysis and monitoring data in Year 2 clearly demonstrated that substantial lateral erosion of bars would occur across both vegetated and non-vegetated bars if the rooting depth did not extend to the toe of the channel. Although the rooting depth is clearly an important parameter for predicting lateral erosion, this parameter was not part of the data collection effort, except for cross-sections specifically targeted for BSTEM analysis during the 2014 high flow. No data was collected prior to the 2015 high flow to support additional analyses of lateral erosion during the 2015 high flow.

The specific objectives of the two-dimensional fixed-bed model for Year 3 (2015 high flow) include:

1. Predict water surface elevations at 1,200 cfs TRF with updated topography (collected following the June 2015 High Flow event) and 3-day average peak flow for the June 2015 High Flow for bar area and height computations (see PRRIP 2016) (Learning Objective 1). The results of this analysis are provided in Attachment 1, Figure 3.

2. Predict the velocity during the peak and 3-day average peak flow for the June 2015 High Flow event to compare the measured and predicted vegetation patch response resulting from drag forces alone (Learning Objective 2). These model predictions do not account for riparian plant mortality from lateral erosion or vertical scour and is limited to responses of the target species (*Phragmites sp.*, reed canarygrass, and 1-2-year-old cottonwood).

A technical memorandum with detailed information on the methods, model development and results can be found in Attachment I Fixed Bed Model.

V. RESULTS: JUNE 2015 HIGH FLOW EVENT

A natural high flow peaked through the Shoemaker study reach on June 19, 2015. Persistently high river flows prevented safe river access for the collection of pre high flow data. Post high flow data were collected from August 24, 2015 to August 28, 2015 and September 1, 2015 to September 2, 2015. High flow data were collected from May 26, 2015 to July 17, 2015. The results from the 2015 field activities are presented in the following sections and a summary of field data and analysis is provided in Table 5-1.

V.A. Hydrologic Setting

V.A.1. Discharge: June 2015 High Flow

The Shoemaker Island Study reach was monitored during and after the June 2015 high flow resulting from snowpack melt and heavy rainfalls in the South Platte River basin. Snowpack in the headwaters of the South Platte River in Colorado was near normal at 93 percent of the median snowpack on May 2, 2015 (Denver Post 2015). Heavy rainfall of up to 9.0 inches in northeast Colorado from May 1, 2015 to May 10, 2015 (NWS 2016) produced a peak discharge of 14,900 cfs at the Roscoe, Nebraska USGS gage on May 26, 2015 (USGS 2015). The June 2015 high flow hydrograph (May 11, 2015 at 02:45 to July 20, 2015 at 18:30) recorded at the Grand Island Platte River gage (USGS 06770500), located 13.5 miles downstream of the study reach is presented in Figure 5-1. The total river flow (TRF) instantaneous peak reported for the Grand Island gage was 16,100 cfs, on June 19, 2015 with a 3-day mean peak discharge of 15,700 cfs TRF and a volume of 1.231 million acre feet (for flows over 2,000 cfs). The June 2015 three-day mean peak discharge exceeded the Program-defined SDHF event of 5,000 to 8,000 cfs by 196 percent and exceeded the SDHF defined volume (50,000 to 75,000 acre-feet) by 1,641 percent. Table 5-2 present the Program's FSM management strategy flow "Benchmark" magnitude and duration compared to the June 2105 high flow. However, the June 2015 high flow event does not meet the Program's definition for a SDHF event. As defined above, the June 2015 high flow was not augmented (through flow releases) with Environmental Account water to produce a SDHF event. The Platte River high flow that was monitored for this report will be referenced as the June 2015 high flow.

The Platte River stream gage at Grand Island provided the historical streamflow data to calculate descriptive statistics and streamflow exceedance probabilities. The Grand Island gage record spans from April 1, 1934 to June 6, 2016. The record contains 30,018 observations, of which 29,993 are mean daily discharges and 25 days of no record (ice). The Grand Island June 19, 2015 daily mean discharge was 16,000 cfs, which is exceeded by only 0.15 percent of the mean daily streamflows at that location (1 in 667 year event). Of the 29,993 records, only 45 days recorded mean daily values greater than 16,000 cfs (USGS 2016). The magnitude of the June 2015 high flow inundated all of the surveyed sand bars (59.6 acres) and 97.8 percent of the vegetated bars (62.1 acres out of 63.5 acres) in the study reach.

The Kearney, Shelton and Grand Island gages estimate TRF in the Platte River. Shoemaker Island splits the Platte River flow upstream of the project site into a north channel and a south channel. Approximately 18 percent (USGS 2014, EA 2013) of Platte River discharge passes through the river channel north of Shoemaker Island and approximately 82 percent flows through the south channel (through the Shoemaker study reach). This ratio is predicted by averaging relations between total river and Shoemaker discharge (from 100 to 15,000 cfs TRF), generated from the HEC-RAS model provided by the Program (PRRIP 2013). The ratio ranges from 77 to 95 percent.

The target discharge rates for flow releases and biological objectives are referenced to the TRF, not the portion of the flow that passes through the study reach. Therefore, references in our study may be made to the TRF or the flow in the Shoemaker study reach, referred to as split flow (SF). The target ecological flow (1,200 cfs TRF) provided by the Program, equates to a split flow of approximately 954 cfs through the Shoemaker study reach.

In order to develop the 2015 hydrograph for Shoemaker SF, we collected 12 discharge measurements ranging from 1,020 to 10,800 cfs (Table 5-3) and used these to develop the stage discharge relation described in Figure 5-2. The pressure transducers installed between cross sections 2 and 3 provided poor records so we used the data from cross section 18 (lagged by one hour) to develop the rating and compute the 15-minute discharge record (Rantz 1982) for the upstream end of Shoemaker from April 14, 2015 at 11:15 to September 16 at 11:15 (Figure 5-3) The peaks occurring on June 4 and June 18 are nearly identical in magnitude (11,400 and 11,600 cfs SF). Comparing Shoemaker split flow discharge to the USGS discharge at Grand Island shows that the hydrograph shapes agree fairly well while the discharge magnitudes expectedly differ (11,600 cfs SF vs 16,100 cfs TRF for the peak on June 4) (Figure 5-4). These gaging records suggest 28 percent of the total flow bypasses Shoemaker during this high flow, while the HEC-RAS model described earlier predicts 23 percent flows through the north channel (at 16,000 cfs TRF). These differences may be attributed to: assumptions built into the HEC-RAS model, changing bed conditions which may alter the proportion of water that each channel carries from year to year, potential stream gaging error and to the fact that a small amount of Shoemaker discharge bypasses the upstream end of the project (3 percent of the SF at 11,000 cfs).

V.B. Field Observations

V.B.1. Field Classification of Nested Alluvial Features

Within and adjacent to the main channel in the at Shoemaker study reach different scales of nested alluvial features were identified:

1. High, densely vegetated bars which appear relatively stable, confine and direct primary high flow paths.

2. Large macroforms, often colonized by herbaceous species, direct the primary low flow pathways into a characteristic braided pattern. *Phragmites sp* occurred in a few areas in the project site.

3. Meso-scale bars and dunes remain unvegetated and highly active, even at low flows. Dunes on the order of 1–2 feet tall were observed migrating through the primary low flow channels during all phases of fieldwork.

4. Microforms of highly mobile and sometimes much coarser material appear as ripples in the low gradient cross-over riffles which form between the meso-scale sandbars. Flow and sediment transport rates associated with the microforms is highly variable, often building, winnowing, or scouring in response to a beached canoe and then disappearing when the obstruction is removed.

5. During the high flows, it was observed that sand bars were forming to high elevations, and in some cases, up to the water surface; however, the sand bars did not appear to persist at that elevation, deflating on the falling limb of the hydrograph. The two-dimensional mobile-bed model did not predict this phenomenon.

V.B.2. Pools and Thalweg Maintenance

While a contiguous thalweg was seldom observed through any given channel, lateral scour pools associated with vertical banks along the outsides of bends, as well as multiple deep thread channels with pools present at channel confluences, seemed to persist throughout the 2015 monitoring season. The combined effect of the February ice floe and the June 2015 high flow event was more effective at modifying flow patterns than the previous monitored events; the primary flow paths generally remained the same within monitoring seasons (2013, 2014), but varied greatly between 2014 and 2015 (Appendix A, Figures A-4 through A-6).

V.B.3. Documentation of Bank and Channel Features

Post June 2015 high flow photographs were taken to document bank condition, vegetation type, structure, and bar features. The left and right bank condition were photographed at the 18 primary cross sections, 129 bars post high flow were photographed. Photos were taken with GPS enabled Nikon CoolPix AW100 camera with a 5-25 millimeter (mm) zoom lens. All photographs were cataloged and saved with photo specific GPS data using Nikon ViewNX 2 geo-referencing program. The geo-referenced photos were provided to the Program for archiving.

A photographic log is included in Appendix B which provides representative photos from the field monitoring activities and bank and channel features.

V.C. Channel Geometry

V.C.1. Bar Topography

Bar Numbers and Area

A topographic survey of accessible bars in the study reach was completed following the June 2015 high flow from August 24, 2015 to August 28, 2015. One-hundred and forty-one bars were surveyed and five bars were located on property where access was denied by the landowner.

Figure 5-6 presents the bars surveyed in the Shoemaker study reach July 2014 and August 2015. The number of bars surveyed decreased from 187 bars in July 2014 to 141 bars in August 2015, a 24 percent decrease and bar area decreased from 174.7 acres to 127.4 acres, a 26 percent decrease (Table 5-4). The net decrease in the number of vegetated bars surveyed was 13 and bar area decreased from 117.4 acres to 64.4 acres. The percent decrease in bar area for natural and treated vegetated bar area was similar at 46 percent and 45 percent, respectively.

The overall number of sand bars decreased from 143 bars surveyed in July 2014 to 110 sand bars August 2015, a 23 percent decrease. Conversely, total area of sand bars in the study reach increased from 57.3 acres to 65.0 acres, a 12 percent increase. Sand bar numbers in treated portions of the study reach decreased from 113 to 79 and sand bar area increased from 57.3 acres to 65.03 acres. Natural areas of the study reach saw an increase in sand bar numbers from 30 to 31 and in area from 6.1 acres to 11.5 acres (Table 5-4).

The number of natural sand bars increased from 30 to 31 and sand bar area increased from 6.1 acres to 11.5 acres. The number of sand bars in the treated areas less than 0.25 acres in size decreased from 81 to 59 bars and bar area decreased from 7.2 acres to 3.4 acres from the July 2014 to August 2015. The number of sand bars in the treated area greater than 0.25 acres decreased from 32 to 20 bars, however, area increased from 44.1 acres to 50.1 acres (Table 5-5).

Bar Habitat Suitability

The August 2015 survey documented 110 unique sand bars covering 65.0 acres (Figure 5-6). Additional minimum suitability criteria for tern and plover nesting habitat is for bare sand bars greater than 0.25 acres in size and a height of 1.5 feet above the 1,200 cfs TRF stage. The mean height of the 20 treated sand bars that were surveyed post formative event >0.25 acres in area was 0.52 feet above the 1,200 cfs TRF stage (Figure 5-8). The mean height for the three natural sand bars >0.25 acres was 0.44 feet above the 1,200 TRF stage. None of the post formative flow natural or treated sand bars met the minimum bar height criterion for tern and plover nesting habitat. Sand bars >0.25 acres formed to a mean height at an average depth of 2.27 feet below the maximum formative event height. Sand bars <0.25 acres in size formed to a height that was at an average depth of 2.63 feet less than the maximum formative flow event height.

Figure 5-7 and Table 5-5 presents surveyed bars in the Shoemaker study reach that meet minimum suitability criteria for tern and plover habitat. A bar that presents suitable habitat is 80 percent or greater bare sand (sand bar), vegetation is less than 20 percent, woody or perennial vegetation is not established and mature annual plants are absent. Additional suitable habitat for a sand bar includes a surface area >0.25 acres at the 1,200 cfs TRF stage. Sand bars are further grouped as natural or treated to assess the impacts of Program activities on bars in the study reach. The overall number of sand bars >0.25 acres decreased from 40 bars surveyed July 2014 to 23 bars surveyed August 2015. Sand bar area for bars >0.25 acres in size increased by 19 percent from 48.5 acres to 59.6 acres.

V.C.2. Primary and Supplemental River Cross Sections

The 18 primary river cross sections were closely examined for topographic change (Appendix A Figure A-7 through A-24). All 37 sections (primary + supplemental) were used in volume change calculations for the June 2015 high flow and this was compared to a volume change calculation performed using only the 18 primary sections (in order to assess the effect of increasing spatial resolution).

A typical cross section is presented in Figure 5-9 showing the bottom profile and areas of aggradation and degradation. The 18 primary cross sections figures are presented in Appendix A, Figures A-7 through A-24. The 19 supplemental cross sections figures are presented in Appendix A, Figures A-25 through A-43. The volume change calculations are provided in Tables 5-6 and 5-7, and a cumulative graph of sediment volume changes for each cross section is provided in Figure 5-10.

Most of the stage observation posts were scoured during the June 2015 high flow. In order to estimate water surface at each cross section we used the water surface slope equation developed in previous years and adjusted it with 2015 peak stage observations from between cross sections 2 and a 3 and at cross section 10 (Figure 5-11). The water surface plotted on the cross sections corresponds to approximately 11,600 cfs, the 2015 SF peak discharge.

With the exaggerated y axis, small amounts of lateral erosion do not show up in the Excel cross section plots in Appendix A, Figures A-7 through A-24. The 1:1 scale was used in ArcGIS to assess change. In discussing cross section change, we attempt to ignore the “noise” of the small scale bedforms commonly observed migrating through the reach—though these are included in the area-change calculations—and focus instead on detecting the processes which influence management objectives:

- Lateral erosion of any scale
- Scour or deposition to a depth greater than the amplitude of commonly occurring bedforms in active channels (typically >1.5 feet); and
- Any change believed to be attributed to ice or other disturbance rather than the June high flow.

Lateral erosion is a subset of “total cut” and is presented separately in Tables 5-6 and 5-7 for comparative purposes. Cut and fill are discussed in the two-dimensional field, hence units are in square feet. 2014-2015 change is attributed to: August 2014 bar building at the downstream end, the February 2015 ice floe and the June 2015 high flow event. Notable changes in area for each of the primary river cross sections for the July 2014 to September 2015 period are as follows:

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Cross Section	Notable Changes
1	This section was one of the few to show net cut, primarily as a result for bar erosion in the north channel. The vegetated bar exhibited over 3 feet of lateral erosion along the northern aspect. The aggradation above the high water line may have been due to the ice floe, which clearly impacted this area (Figure 4-1). Overall change = 234 ft^2 cut.
2	The northern bank retreated approximately 5 feet in this area (also observed during high flow monitoring: the stage recorder was scoured and relocated five times). While the south channel scoured two feet, most of the change is in the form of aggradation in the main channel. Overall change = 270 ft^2 fill.
3	Scour and fill are fairly balanced here, with a bar and a channel of very similar dimensions forming along the north half of the channel. Overall change = 43.7 ft^2 fill.
4	This section exhibits the noise common along wider sections (>900 ft) observed in previous years' monitoring. Again, scour and fill are fairly balanced. Overall change = 52.5 ft^2 cut.
5	Significant bank retreat (80 ft) and thalweg scour (2 feet) along the south bank is offset by bar building in mid channel for a net positive change Overall change = 145 ft^2 fill.
6	This section is the first to intersect the nesting bars (Bar 18 in 2014) constructed in fall 2013 (after the high flows). Most of this constructed bar is now eroded. Overall change = 126 ft^2 fill.
7	This section shows the largest cut of any of the 18 monumented sections. The constructed nesting bar scoured 1-2 feet and was essentially removed. Overall change = 242 ft^2 cut.
8	The complete removal of the 2014 remaining nesting bar was offset by the development of a new bar which developed at approximately 1.5 feet lower in elevation. Overall change = 314 ft^2 fill. *The next section downstream (supplemental I) shows the same response*.
9	This very wide section (>1,400 ft) shows nearly channel-wide aggradation and the filling of at least 7 flow threads. Overall change = 371 ft^2 fill.
10	This section reveals significant expansion of a previously existing bar along the north side of the channel resulting in an overall volume change very similar to that observed at the previous section. Overall change = 340 ft^2 fill.
11	While the difference between 2014 and 2015 appears quite noisy (redistribution of bars and channels), the overall cross sectional area change is essentially zero. Overall change = 4.3 ft^2 fill.
12	The north bank retreated nearly 40 feet, but this erosion was offset by filling in the north channel and the development of two taller bars along the south side. Overall change = 273 ft^2 fill.
13	The primary northern flow threads both show fill (up to 3 feet) and although the mid channel bar and one south side bar scoured, the net change remained positive. Overall change = 198 ft^2 fill.
14	A new 3 foot deep primary flow thread developed along the north half of the channel and the tall bar in the south channel eroded; however, bar building in the middle of the channel resulted in net positive change. Overall change = 357 ft^2 fill.
15	Channel filling and bar building offset the scour of the south side bar for the largest positive change in the study reach. Overall change = 390 ft^2 fill.

Cross Section	Notable Changes
16	Similar to the last section, channel filling and bar building offset bar erosion for a net positive change. The constructed nesting island areas were excluded from the calculation (Appendix A, Figures A-1 through A-3). Overall change = 267 ft^2 fill.
17	The thalweg along the north bank scoured considerably, deepening by over two feet. The constructed nesting island areas were excluded from the calculation (Appendix A, Figures A-1 through A-3). The large mid-channel bar development results in net positive change. Overall change = 101 ft^2 fill.
18	The large constructed bar is omitted from the calculated area resulting on a net negative change. Overall change = 53.3 ft^2 cut.

In order to assess the effect of increasing the number of cross sections, we first computed volume change using only the primary 18 sections. The changes in pre and post cross section area were averaged from one section to the next, and then multiplied by the distance between. Thus, the last row in Table 5-6 shows no values as the computation ends at the row for cross section 17; which is the change for the section between cross sections 17 and 18.

Only four computational sections (below cross sections1, 4, 7 and 18) showed net cut (53.3 to 242 cy). Of the total cut (202,400 cy), 16 percent was due to lateral erosion (32,600 cy). Every other section shows fill, generally in the form of bar building and channel filling. The net change for the reach, using only the primary 18 cross sections, was (rounded) 73,500 cy fill (Table 5-6).

In order to test the impact of increasing spatial resolution in volume change calculations, we repeated the calculations adding the 19 additional supplemental cross sections. This additional data collection step increased cross section survey time from 1 to 2 days. The volume change calculations are provided in Table 5-7, and a cumulative graph of sediment volume changes for each cross section is provided in Figure 5-10. By adding the 19 additional cross sections, the total volume change decreased by approximately 35 percent; from 73,500 cy to 48,000 cy fill (Table 5-7). We assume the most accurate volume change assessment to be using all 37 sections and hold 48,000 cy as our best estimate of change for the June 2015 high flow event. The volume attributed to lateral erosion was 32,600 cy using the 18 sections and as 24,600 cy using all 37 sections, a 33 percent reduction.

The 2014 to 2015 braiding index was examined for the modeled 1,200 cfs TRF index flow. The number of channels was determined by breaking the discrete channels wherever the ground surface intersected the predicted water surface elevation at 1200 cfs TRF. The mean 2015 braiding index for the 18 monumented cross sections increased from 3.5 in 2014 to 3.8 in 2015 (Appendix A, Table A-1). The braiding indexes measured in the Shoemaker study reach have met the Program's goal for an average braiding index greater than 3.

V.C.3. Longitudinal Profile

The post 2014 and post 2015 longitudinal profiles are discussed here, with the reach broken into three areas: cross section 1-6 (Upper); cross section 7-12 (middle; cross section 13-18 (lower) (Appendix A: Figures A-44 to A-49). The meso and micro features described in Section V.B.1 appear clearly in the profile plots: small ripples migrating over larger dunes and other bedforms. Data were collected along the two main flow paths identified through the project: the northern route, which includes the channel along the north side of the treated bars near cross section 6; and the southern route, which includes the portion of private property between cross sections 7 and 10, for which field crews had no wading access. Only points that were collected in reasonable proximity between surveys (e.g. in the same flow thread) are considered comparable for detailed comparison and are indicated as such in Appendix A: Figure A-44 to Figure A-46. The combined effect of the February 2015 ice floe and the June 2015 high flow resulted in very different flow distribution (north and south thread alignments) and little of the profile is directly comparable. Planform alignments of the profile surveys are provided in Appendix A, Figure A-4 to Figure A-6.

North Alignment: Although the profiles were hand surveyed and we followed the previous (post 2014) alignment as closely as possible, some flow threads were widely re-routed by the June 2015 high flow (Appendix A: Figure A-44 to A-46). The trendlines indicate relative fill, though since they depart in the downstream direction, and since the 2015 data plot increasingly higher than the 2014 data, they may indicate relatively more aggradation in the downstream direction (Figure 5-10). The trendline slopes indicate a very slight bed slope reduction, from 0.001209 to 0.001184. The trendline analysis is only a very coarse indicator of the direction of change and because it includes sections that are not directly comparable, it should be regarded as only an indicator. The scour and fill between cross sections 1 and 3 appear fairly balanced. The upper half of the section between cross section 10 and 13 appears unchanged though the lower half shows fill of up to 3 feet. Below cross section 16, the thalweg along the north bank scoured up to 3 feet.

South Alignment: Only the uppermost section from cross section 1 to 3 was directly comparable on a feature-by-feature basis (Appendix A: Figure A-47 to A-49). The pools and bar riffle crests generally prograded downstream. While the first two pools scoured 1.5 to 2 feet, the last riffle crest aggraded by about a foot. Below here, channel change precludes detailed comparison, though below supplemental cross section N (station 9,560), the surveys do describe the same dominant geomorphic feature: the primary flow thread along the south side, paralleling the south bank. In this reach, the profiles illustrate a clear trend toward aggradation, with most of the pools filled and the bars growing in height. The trendline comparison (again, a very general indicator) suggests incision in the upstream reach and aggradation in the lowermost. As was the case with the north alignment, the departure results in a very small bed slope reduction, from 0.001217 to 0.001116.

V.C.4. Vegetation

The response of vegetation to high flows was measured with vegetation assessment plots. The predicted response for 2015 high flow is limited to the effects of drag forces on uprooting vegetation and does not include the effects of lateral erosion, vertical scour, or duration of inundation.

V.C.4.1 Vegetative Assessment Plots

The July 2014 and August 2015 evaluation of the vegetation assessment plots showed a net decrease of vegetation in the assessed quadrants. The timing of the surveys July and August permitted the identification and percent cover estimation of perennial and annual plant growth in the assessed quadrants.

A total of seven vegetative assessment plots were located along each of the 18 primary river cross sections (Figure 5-12) for a total of 126 plots within the reach. However, one plot was located within the no access area on cross section 7 for a final assessed plot number of 125. Photo documentation of the 125 assessed plots is provided in Appendix C. The plots were measured July 2014 and August 2015 for:

- Density of live and dead stems of cottonwood trees, willows, and *Phragmites* sp.
- Presence of other species (presence/absence).
- Photos showing total percent vegetation and percent sand.

The July 2014 vegetation survey found 40 of the 125 plots contained vegetation for a 32 percent occurrence rate or 68 percent of the assessed plots contained no vegetation (Appendix C Figure C-1 to Figure C-3). The August 2015 vegetation survey found 36 of the 125 plots contained vegetation for a 29 percent occurrence rate or 71 percent of the assessed plots contained no vegetation being comprised of 100 percent sand and/or water. The number of plots documented to contain vegetation numerically decreased by 4 plots between the July 2014 and August 2015 surveys a 10 percent decrease. The total aerial coverage of vegetation in the 125 assessed plots was 15.1 percent July 2014 and 6.3 percent August 2015. No vegetation was documented during the July 2014 survey in the seven plots assessed for primary cross sections 2 and 8, and August 2015 vegetation survey documented no vegetation for primary cross section 3.

July 2014 coverage for vegetation in the 40 plots with vegetation ranged from 0.3 m^2 to 0.98 m^2 per quadrant (1 meter x 1 meter) or a total of 18.90 m^2 out of 125 m^2 assessed. August 2015 coverage for vegetation in the 36 plots with vegetation ranged from 0.1 m^2 to 1.0 m^2 per quadrant (1 meter x 1 meter) or a total of 7.82 m^2 out of 125 m^2 assessed. Vegetation in quadrants documented July 2014 decreased from 18.90 m^2 to 7.82 m^2 in August 2015. Twenty quadrants that contained 7.92 m^2 of vegetation July 2014 were 100 percent sand/water for the August 2015 survey. Seventeen quadrants that were documented as 100 percent sand/water July 2014 flow contained 1.63 m^2 of vegetation during the August 2015 assessment (Appendix C, Table C-1). No vegetation or all sand/water was documented in 85 of the July 2014 and 89 of the August 2015 quadrants.

V.C.4.2 Vegetation of Interest: Observed and Predicted Response

Pollen-Bankhead et al. (2012) developed relations between velocity and vegetation patch resistance were developed by for one-year old cottonwoods, two-year old cottonwoods, reed canarygrass and phragmites. These relations do not account for lateral erosion or vertical scour of vegetation. The classes include no uprooting, uprooting initiated, three classes of increasing velocity, and finally, a velocity class where all plants are expected to uproot. Spatial patterns of velocity consistent with these class are shown within the computational boundary for the June 2015 High Flow (Attachment I: Fixed Bed Modeling).

Results of the analysis indicate that there are no areas within the Shoemaker Reach where all plants in a patch are expected to be uprooted by drag forces alone, even during a very large magnitude high flow. Results for individual species of interest are provided below.

V.C.4.2.1 *Phragmites sp.*

Live or dead *Phragmites sp.* was not documented in any of the vegetative assessment plots in 2014 or 2015 (Appendix C Figure C-4 to C-7 and Table C-1).

Vegetated Bar 46 (Figure 5-13) is an established bar with areas of bare sand, woody vegetation, annual and perennial plants including: Carolina lovegrass, common ragweed, purple loosestrife, Malabar sprangletop, river bulrush, barnyard grass, bur marigold, cocklebur, narrowleaf dock, false indigo, common reed, and lady's thumb. The ground photo from July 2014 (Figure 5-14) shows *Phragmites* sp. was limited to a strip of vegetation along the far edge of the bar, away from the initial area of active bank erosion. Substantial bank erosion occurred during the study period with 33 feet of erosion between November 2013 and May 2014 survey, and another 76 feet of erosion during the 2014 high flow. Figure 5-15 shows the bar has completely eroded in August 2015 as a result of the June 2015 high flow, but at least some of the *Phragmites* sp. persisted along the channel margin. The rooting depth of vegetation on the bank in 2014 was documented to be 0.7 feet, and thus, did not limit the erosion of the bar. The rooting depth of the *Phragmites* sp. on this bar is unknown. Model results of the peak flood using topography following the high flow (bar is eroded) do not generate velocities high enough to remove *Phragmites* sp. by drag forces alone. These model predictions and field observations are not conclusive, but support evidence from other studies that this species persists even during flows that produce substantial channel change.

Sandbar Willow

For the July 2014 survey eight live sandbar willow stems were documented in quadrant 13f and three dead stems were documented in quadrant 16g. Sandbar willows, live or dead were not noted in any of the August 2015 vegetation assessment plots. Model predictions were not made for sandbar willow.

V.C.4.2.2 *Cottonwood Trees*

No live or dead cottonwood stems were noted in the vegetation assessment quadrants surveyed in July 2014. No dead cottonwood stems were noted and 111 live cottonwood stems were documented in 14 of the vegetation assessment quadrants surveyed in August 2015. Live stems averaged 8 stems per quadrant ranging from a minimum of 1 to a maximum of 34 stems per quadrant. Average stem diameter for the 53 measured live cottonwoods was 0.96 mm and average height was 120 mm (~5 inches) maximum stem height was 385 mm (~15 inches). The 14 quadrants with cottonwood stems were 35.7 percent vegetation, 57.2 percent sand and 7.1 percent water in July 2014 and in August 2015 the same quadrants were 34.1 percent vegetation, 65.9 percent sand, and zero percent water. The proportion of vegetation and sand in the quadrants was essentially unchanged from July 2014 to August 2015 in the 14 quadrants were new cottonwood growth was documented.

An independent-samples t-test was conducted to compare the mean height of vegetated quadrants with cottonwood trees to those without cottonwood trees above the 1,200 cfs TRF stage. At the 95 percent confidence coefficient there was no significant difference in the mean height for quadrants with cottonwood trees (M=1.00, SD 0.53) and quadrants with no cottonwood trees (M=0.86, SD=0.99) above the 1,200 cfs TRF stage $t(33)=0.510$, $p=0.614$.

The velocities required for initiating uprooting of one-year old cottonwoods are generally predicted within the low flow channels and across all vegetated bars (Attachment I: Fixed Bed Modeling) during the June 2015 High Flow. Velocities across all bars are predicted to be within the two lowest uprooting classes (54 percent in the lowest class and 45 percent in the next higher class). Only 1 percent of the bar area did not meet the velocity criteria to initiate uprooting.

Two-year old cottonwoods require higher velocities to initiate uprooting. Similar to 1-year cottonwoods, only 1 percent of the bar area does not meet the criteria to initiate uprooting. However, 94 percent of the bar area is in the lowest velocity class for initiation of uprooting and 5 percent is in the next higher velocity class during the June 2015 High Flow.

These results suggest that an event similar in magnitude to the 2015 high flow would uproot some of the established one-year old cottonwoods; however, uprooting of all plants is not predicted to occur by drag forces alone. Thus, some percentage of the cottonwoods that established in 2015 are likely to persist across these bars in the absence of removal through other means such as lateral erosion or disking.

V.C.4.2.3 *Reed Canarygrass*

Reed canarygrass occurred in four plots (3g, 10a, 12a, 12e) in July 2014. High flows removed vegetation from three of the plots (3g, 10a, 12e), and a combination of disking and/or high flows removed reed canarygrass from Plots 12a.

Velocities are predicted to be too low throughout the reach to initiate uprooting of reed canary grass by drag forces with the exception of a few small patches identified in higher velocity zones within the main channel during the June 2015 High Flow (Attachment I: Fixed Bed Modeling).

None of the observed plots provide a reasonable test of the Pollen-Bankhead (2012) estimates of when uprooting will occur by drag forces. The removal of reed canarygrass at plots 10a, 12a and

3g appears to be due to substantial cut which likely occurred through lateral erosion. In these three cases, the plot started at the top of the vegetated bar and eroded to the wetted channel elevation. The adjacent bank remained vegetated and near vertical. Plot 12e was an exception. This plot remained on the top of the bar and aggraded 1.8 feet. This plot is adjacent to a very active channel and may have scoured before filling, contributing to the remove of the reed canarygrass. Assuming the Pollen-Bankhead (2012) results are reasonable for the role of drag forces alone, these results demonstrate the combined effects of lateral erosion, drag forces and vertical scour can remove this species. The integration of these three parameters is not possible with the existing set of models and requires a mobile-bed model that integrates lateral erosion.

V.C.5. Treated and Natural River Areas

The Shoemaker study reach from cross section 1 to cross section 18 of the active Platte River channel encompasses 380 acres of which 18 acres were inaccessible resulting in 362 surveyed acres. Of the 362 surveyed acres, 246 acres in July 2014 and 266 acres in August 2015 and have been subjected to mechanical disking by the Program to control vegetation, and 96 acres in August 2015 and 116 acres in July 2014 and have not been treated by the Program for vegetation control. Table 5-8 and Figure 5-5 present the surveyed areas for vegetated bars (>20 percent vegetated), sand bars (>80 percent sand), and water/river bed in the surveyed treated and natural areas of the Shoemaker study reach in July 2014 and August 2015.

In the treated portion of the study reach vegetative bar area decreased by 36 acres from 32 percent to 17 percent of the treated area in the study reach from July 2014 to August 2015. Sand bar area in the treated portion remained proportionally the same at 21 percent to 20 percent but gained in area by 3 acres. Water/river bed area increased by 53 acres from 47 to 63 percent of the treated study reach. In the natural areas of the study reach not subjected to mechanical treatment the portion that was vegetated decreased by 18 acres from 33 percent to 20 percent. Sand bar area increased by 5 acres from 5 percent to 11 percent and the water/river bed area decreased by 8 acres from 62 percent to 67 percent of the natural area in the study reach July 2014 to August 2015 (Appendix C, Table C-1). The high flow limited the growth of new vegetation on sand bars or eroded vegetated bars in the study reach.

Vegetated areas in the natural and treated areas in the study reach decreased between the July 2014 and August 2015 surveys by 15 percent and 12 percent, respectively. The response of the study reach to the loss of the vegetated areas was not the same for the treated and natural areas. The proportion of sand bars in the treated area remained the same at 21 percent in July 2014 and 20 percent in 2015 and in the natural area from 5 percent to 12 percent. The proportion of water/riverbed in the treated areas increased from 47 percent in July 2014 to 63 percent in August 2015 and in the natural areas increased from 62 percent to 67 percent. Water/river bed areas of the study reach are characterized as having an elevation less than the 1,200 cfs TRF stage and a bar is at an elevation greater than the 1,200 cfs TRF stage.

Vegetated bar area had a proportionally similar 45 percent decrease in both the treated and natural areas of the study reach. This decrease in vegetated bar area will result in a net increase of sand bar or water/river bed area of the study reach. Increases to sand bar area and water/river bed area was not the same between the treated and natural areas in the study reach. For the treated areas sand bar area did not change (51.2 to 53.6 acres) and water/river bed area increased (115.1 to 168.4 acres). The natural areas in the study reach had an increase in sand bar area (6.1 to 11.5 acres) and a decrease in water/river bed area (72.2 to 64.1 acres). The erosion of vegetative bars in the study reach by the high flow event did not result in a proportional increase in sand bar area.

V.C.6. Unvegetated Channel Widths

The occurrence of vegetation in the river channel at the 18 primary cross sections surveyed through the Shoemaker study reach is presented in Figure 5-16. The surveyed widths for water, mature vegetated bars, natural bars, and mechanically treated bars are presented from the south to the north bank of the river channel. In July 2104 and August 2015 Eleven of the 18 primary cross sections surveyed had unvegetated channel widths greater than 750. Average unvegetated cross section width in July 2104 was 1,286, ranging from 786 feet to 1,633 feet and in August 2105 average unvegetated width was 1,069 feet, ranging from a minimum of 769 feet at transect 4 to a maximum of 1,459 feet at transect 18.

V.C.7. Vegetation Roughness

Polygons of similar land cover were created for the bars and riparian areas in the study reach to estimate vegetation roughness. Polygons of uniform land cover were then used as a data input parameter for hydraulic modeling. One-hundred forty-six polygons were created for the 141 bars that were surveyed by plant biologists (Figure 5-17). A polygon was also created for each of the five bars located where access was denied by the landowner. Nine vegetation roughness polygons were created for riparian areas for hydraulic modeling of 8,000 cfs TRF Platte River flows. Vegetation roughness for the inaccessible bars and riparian areas was estimated from aerial photos, distant photos taken during field activities, and adjacent bar vegetation surveyed by the plant biologist

V.D. Sediment

V.D.1. Turbidity

Turbidity data were collected from May 24, 2015 to May 30, 2015 between cross sections 2 and 3 in the Shoemaker study reach. The turbidity data sonde was lost in early May due to the erosion of the river bottom around the stakes used to anchor the sonde. The sonde was retrieved in late August after the river staged had dropped. No turbidity data were usable for load computations. The continuous turbidity data were to be used as a surrogate for continuous suspended sediment concentration into the project area. The sensitivity of turbidity to short term variations in concentration (versus a discharge relation with concentration) facilitates more accurate load computation and an examination of temporal changes in the load, potentially related to geomorphic processes occurring in Shoemaker.

V.D.2. Suspended Sediment

Box samples were collected but were not analyzed; as all were collected during depth integrated sampling efforts and box samples were not required.

Depth Integrated Sampling

For the June 2015 high flow event 18 DIS samples were collected between cross sections 2 and 3. All but one sample were two-pass samples, for a total of 35 passes. Six passes were excluded from transport curve development due to the inclusion of coarse grains (assumed to be bedload collected by sampling error). Samples were collected between 994 and 11,000 cfs SF and concentrations ranged from 49 to 548 mg/l. Concentration and grain size data for all suspended sediment samples are provided in Table 5-9. Suspended sediment loads were computed directly from the concentration data as follows:

- All loads were computed as a function of discharge as no turbidity record was available. For the <0.063mm class, there was no relation with discharge and since no turbidity record was available, we proportionally fit hydrograph through sample values to produce sedigraph and load. One of the applied sediment transport models requires suspended sediment transport computed by size classes (see Attachment 2). The following size classes were developed from the grain size analyses performed on the sample data:
  - <0.063mm (no relation with discharge)
  - 0.063-0.25mm
  - 0.25-0.5mm
  - 0.5-1mm
  - 1-2mm
  - >2mm (zero transport)
- The transport relations and their respective equations are provided in Appendix A: Figure 53 to Figure 56. The transport equations are provided in Table 5-10
- Equations were applied to the 15-minute discharge hydrograph over the June 2015 high flow computational period: April 14, 2015 at 11:15 to September 6, 2015 at 11:15.
- The sedigraph method was applied to the continuous concentration curves by shifting to samples by fitting or proportional fitting between sample values.
- Continuous (15 minute) concentration was transformed into continuous suspended sediment load (SSL) by the standard equation:
  - SSL (tons/day) = 0.002697*Q(cfs)*SSC(mg/l)
- Continuous SSL was summed over the computational period and divided by 96 (the number of 15 minute intervals in a day) to provide the load in tons (Table 5-11).
- Total suspended load for the computational period was 505,000 tons, with the largest component being the 0.063-0.25mm size class (47 percent).

V.D.3. Total Load and Bedload

Total load was computed (from the suspended sediment data, hydraulic parameters measured during sampling efforts, and the 2015 bed material data) using the Modified Einstein (MEP) method as we did for 2013 monitoring (PRRIP 2014). The models required 15 minute continuous bedload (broken into the same six size classes as for suspended sediment) which we calculated by subtracting suspended load from total load (Table 5-12). These MEP-derived bedload values were plotted with previous years MEP-derived and 2013-2015 measured bedload values. A single regression fitted through the 2015 MEP-derived bedload data were used to compute continuous bedload as a function of discharge (Figure 5-18).

Using grain size distributions for bedload samples collected in 2015, we developed percentages for each size class and deconstructed the total load into the six size classes. Total load was then computed as the sum of suspended load and bedload: the June 2015 high flow event transported a total of 966,000 tons with 461,000 tons (48 percent) as bedload (Table 5-11). Seventy two percent of the bedload (332,600 tons) was >1mm and 25 percent of the total load was composed of the 0.063-0.25mm size class (Table 5-11).

V.D.4. Scour Monitoring

No scour chains were recovered in 2015 and we assume rates of scour or fill were simply too great to facilitate recovery of the post 2014 chains. The post 2014 chains were typically one to three feet deep. Staking to the 2014 locations revealed zero to 1.9 feet of fill at the downstream locations (with one exception where a 2 foot deep channel had developed). Above cross section 7, channel change was significant enough to prevent staking to the 2014 locations; deep threads of flowing water had developed in former bar areas.

V.D.5. Bed and Bar Sampling

A total of 28 bed samples and 6 bar samples were collected following the June 2015 high flow and were analyzed by the GMA Coarse Sediment Laboratory in Placerville, California for grain size. Dry bulk density was computed for the 6 bar samples. Grain size analysis results for all bed and bar samples are provided in Appendix A: Table A-2 and Table A-3. Bed and bar sample data were utilized in model development. Due to extensive channel change, none of the individual 2014 samples were directly comparable (spatially) for examining the potential effect of the June 2015 high flow on grain size; areas which had been bars became flowing channels and vice versa.

The bulk density samples provide input data for mobile-bed models and facilitate volumetric conversions between sediment loads and volumes. The 28 bed and bar bulk samples are presented in Table 5-13. Sites labeled “bar” are very low lying bars generally at or less than the 1,200 cfs TRF index flow. Comparing the overall bed and bar mean D50 between 2014 and 2015 reveals virtually no change in the median grain size. The overall mean D50 decreased very slightly from 1.00mm to 0.97mm. The bar D50 remained virtually the same at 1.08mm in 2014 and 1.07mm in 2015. Likewise, the mean bed D50 was 0.96mm in 2014 and 0.94mm in 2015.

The mean bulk density of post 2013 SDMF samples was 1.74 g/cm^3 and this value was utilized to estimate volumes from computed sediment loads in 2013. The mean bulk density of the 2014 samples was 1.67 g/cm^3, representing a four percent difference from the 2013 accepted value.

The difference is likely measurement error inherent in a small dataset (n=4 to 8). The mean bulk density measured in 2015 was again 1.74 g/cm^3 (Table 5-13).

VI. CONCLUSIONS FOR 2015 HIGH FLOW EVENT

Based on the results and evaluation of the data presented in this report, this section summarizes the conclusions that can be reached as directly related to the three Learning Objectives of the Shoemaker Island FSM Experiment. The FSM priority hypothesis provides a broad view of the possible changes in river morphology/channel characteristics that may be produced through implementation of FSM management action.

VI.A. Learning Objectives

The learning objectives for the "Shoemaker Island FSM "Proof of Concept" Experiment are:

1. Evaluate the relationship between peak flows (magnitude and duration) and sandbar height and area.
   i). The relationship between sediment transport (surplus/deficit) and the frequency of sandbar occurrence.
   ii). The relationship between sediment grain size distribution and sandbar height potential.
   iii). The role of hydrograph duration and shape in sandbar height.

2. Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.

3. Evaluate the ability of FSM management strategy to create and/or maintain habitat for whooping cranes, least terns, and piping plovers.

VI.A.1. Evaluate the relationship between peak flows (magnitude and duration) and bar height and area.

- The June 2015 high flow event at the Grand Island gage had a 3-day mean peak discharge of 15,700 cfs TRF that was 196 percent of the benchmark 3-day peak mean discharge of 8,000 cfs TRF. An estimated volume of 1.231 million acre-feet (cumulative volume of flows greater than 2,000 cfs) that was 1,641 percent of the benchmark event volume of 50,000 to 75,000 acre-feet passed the Grand Island gage from May 11 to July 20, 2015.

    - Bar frequency decreased from 187 to 141 bars.
    - Total bar area (sand and vegetated) decreased from 174 to 129 acres.
        - Sand bar area increased by 7.7 acres
        - Vegetated bars decreased by 53 acres.
    - The mean height of the 3-day high flow stage above the 1,200 cfs TRF stage was 2.59 feet with a maximum and minimum height of 4.05 and 1.38 feet, respectively.
    - Mean depth below the formative event 3-day mean peak discharge stage for the 23 sand bars >0.25 acres was 2.14 ft and mean bar height above the 1,200 cfs TRF stage was 0.52 feet.

- Mean depth below the formative event 3-day mean peak discharge stage for the 87 sand bars <0.25 acres 2.54 ft and mean bar height above the 1,200 cfs TRF stage was 0.16 feet.

None of the surveyed bars bars >0.25 acres in size meet the minimum tern and plover habitat for a bar height >1.5 feet or higher than 1,200 cfs TRF stage.

VI.A.2. Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.

- The July 2014 aerial coverage for the vegetation plots per 125 m2 was 15.1 percent and decreased to 6.3 percent for the August 2015 survey. Bar vegetation decreased between the survey events from 18.90 m2 in July 2014 to 7.82 m2 in August 2015.

- Live or dead Phragmites sp. was not documented in any of the vegetation plots. Eight live and three dead sandbar willows (established growth) were documented in July 2014 and none were present during the August 2015 survey. One-hundred and eleven live cottonwood stems were documented in the August 2015 vegetation plots. Cottonwood stems averaged 8 per quadrant with an average height of ~5 inches.

- Mean height of plots above the 1,200 cfs TRF stage with cottonwood tree growth was equal to plots with vegetation and no cottonwood trees. At the 95 percent confidence coefficient there was no significant difference in the mean height for quadrants with cottonwood.

- Removal of reed canarygrass was observed at four plots, primarily associated with large channel changes that had more than 1 foot of scour or fill. Comparison of the observed and model predictions based on Pollen-Bankhead (2012) demonstrates the combined effects of lateral erosion, drag forces and vertical scour can remove this species at substantially lower velocities than necessary to remove the plants by drag forces alone. The integration of the effect of drag forces, lateral and vertical erosion is not possible with the existing set of models and requires a mobile-bed model that integrates lateral erosion.

VI.A.3. Evaluate ability of FSM management strategy to create and/or maintain habitat for whooping cranes, least terns and piping plovers

Figure 5-5 provides a visual summary of bar attributes July 2015 and August 2015; before and after the June high flow event through the Shoemaker study reach. A decrease in the aerial extent of vegetated bars from July 2014 to August 2015 is evident in the figure. Vegetated bar area decreased for the mechanical treated and untreated (natural vegetation) bars in the study reach suggesting that the June 2015 high flow had a larger impact on vegetation than mechanical treatment by the Program. Additional conclusion relative to the FSM management actions are presented below.

- Flow

The June 2015 high flow event 3-day mean peak discharge of 15,700 cfs TRF increased the depth of water above the 1,200 cfs TRF stage by 2.59 feet to 4.05 feet. The post high flow survey documented 110 sand bars in the study reach. Of the 110 sand bars, the 23 that were greater than 0.25 acres in size had a mean height of 0.52 feet above the 1,200 cfs TRF stage or a mean depth of 2.14 feet below the formative event 3-day mean peak discharge stage. None of the surveyed sand bars >0.25 acres in size met the minimum tern and plover nesting suitability for sand bar height of >1.5 feet above 1,200 cfs TRF stage. No suitable sand bar habitat was documented post the June 2015 high flow event which exceeded a SDHF target flow duration and magnitude.

Bars that exceeded the minimum vegetation criteria (>20 percent vegetation) decreased from 44 bars July 2014 to 31 vegetated August 2015 post the June 2015 high flow event. A 45 percent and 46 percent decrease in vegetated bar area was documented in the mechanically treated and natural areas in the study reach, respectively. Vegetated bars in the study reach decreased from 117.4 acres in July 2014 to 64.4 acres in August 2015 a 45 percent study area decrease. Conversely, sand bar area in the study reach increased by 7.7 acres (13.4 percent), vegetated bar area decreased by 45.3 acres resulting in a 45.2-acre net increase in study reach area less than the 1,200 cfs TRF stage (Table 5-4).

The cumulative area of bar depth relative to the 3-day mean peak discharge of 15,700 cfs TRF is presented on Figure 6-1. The graph shows that the mean depth below the 3-day mean peak discharge height for sand bars is greater than that for vegetated bars. All of the surveyed sand bars (59.6 acres) and 97.8 percent of the vegetated bars (62.1 acres out of 63.5 acres) in the study reach were inundated by the June 2015 high flow. An independent-samples t-test was conducted to compare the mean depth relative to the formative event 3-day peak mean discharge stage of sand bars and vegetated bars >0.25 acres in size. At a 95 percent confidence coefficient there was a significant difference in the mean depth for sand bars ($M=2.14$, $SD=0.51$) and vegetated bars ($M=1.41$, SD 0.43) below the formative discharge stage $t(40)=4.93$, $p=0.00$. The near complete inundation of sand and vegetated bars by the June 2015 high flow event did not result in the growth of sand bars equal to the height of vegetative bars in the study reach. The mean height of sand bars surveyed July 2014 ($M=0.46$, $SD=0.29$) were found to not be significantly different at the 95 percent confidence coefficient from the post formative high flow August 2015 sand bar mean height ($M=0.52$, $SD=0.28$) $t(61)=-0.77$, $p=0.44$. The June 2015 formative high flow event which exceeded Program target flows did not increase the height of sand bars in the Shoemaker study reach.

- Sediment

Sediment supply into the Shoemaker Project was not augmented for the June 2015 high flow event, thus we cannot evaluate the effectiveness of geomorphic changes resulting from sediment augmentation for the June 2015 high flow. However, the results of the study indicate volume change from Fall 2014 to Fall 2015 was 48,000 cy fill. The total sediment load was 966,000 tons.

Thus the implication is that given the 2015 hydrograph shape, with a total load of 966,000 tons, the reach is in sediment surplus.

- Mechanical

The erosion of vegetated bars in the mechanically treated and natural areas suggests that the high flow event had a greater impact on vegetated bars in the study reach then the mechanical treatment did. Vegetated bar area decreased by 45 percent and 46 percent in the mechanical treated and natural areas, respectively. Sand bar area in the mechanically treated areas increased by 5 percent (51.2 acres to 53.6 acres) and in the natural areas by 88 percent (6.1 acres to 11.5 acres). Water/river bed area in the study reach less than the 1,200 cfs TRF stage increased in the mechanically treated area by 46 percent (115.1 acres to 168.4 acres) and in the natural areas decreased by 11 percent (72.2 acres to 64.1 acres). For the mechanically treated areas vegetated bar area decreased, sand bar area did not change and water/river bed area increased. For the natural areas in the study reach vegetated bar area decreased, sand bar area increased, water/river bed decreased. The erosion of vegetative bars in the study reach by the high flow event did not result in a proportional increase in sand bar area.

The occurrence of vegetation in the river channel at the 18 primary cross sections surveyed through the Shoemaker study reach is presented in Figure 5-16. The surveyed widths for water, mature vegetated bars, natural bars, and mechanically treated bars are presented from the south to the north bank of the river channel. Eleven of the 18 primary cross sections surveyed had unvegetated channel widths greater than 750 feet. Average unvegetated cross section width was 1,069 feet, ranging from a minimum of 769 feet at transect 4 to a maximum of 1,459 feet at transect 18.

Two of the eighteen primary cross sections in the Shoemaker study reach had natural unvegetated cross sections lengths greater than 750 feet at 769 feet and 844 feet. Mechanical treatment increased unvegetated width to greater than 750 ft in nine additional primary cross sections. Average mechanically treated unvegetated cross section width was 1,127 feet, ranging from a minimum 827 feet at cross section 17 to a maximum of 1,459 feet at cross section 18. Seven of the 18 cross sections did not contain unvegetated lengths greater than 750 feet (Figure 5-16).

The Shoemaker study reach covers 362 acres of Platte River main channel area. The study reach consists of 266 mechanically treated acres and 96 natural or untreated acres. If the untreated areas of the Study reach are considered typical then the treatment of the river bed and sand bars has altered the natural ratio of vegetated/sand bars and water/river bed in the study reach. For the August 2015 survey, untreated areas have a water/river bed to sand bar to vegetated bar ratio of 0.79:0.08:0.13 and mechanically treated areas are 0.63:0.20:17. Mechanical treatment has increased the aerial proportion of sand bars in the study reach, decreased the proportion water/river bed areas <1,200 cfs TRF stage in the study reach, and increased vegetation (pioneer taxa such as annual grasses on freshly disturbed soils) on bars compared to the untreated portion of the reach. Mechanical treatment appears to produce more sand bar area in the Shoemaker Reach.

VII. MODELING OF THE SHORT DURATION HIGH FLOW

Model runs in 2015 focused on Learning Objective 1: estimating the channel response to SDHF and sensitivity to changes in (a) sediment supply, (b) grain size, and (c) hydrograph shape (magnitude and duration). These runs were conducted to determine whether altering these parameters within the context of the target volume of water available for a SDHF could generate higher sand bars or more sand bar area. The model used in the analysis is FaSTMECH and EFDC. A detailed description of the models are provided in Attachment II.

Sediment supply within the Platte River can be managed by direct sediment augmentation; however, the field results suggest that the Shoemaker Reach is not deficient in sediment. The effect of sediment supply is estimated with the FaSTMECH model using twice the predicted equilibrium sediment supply (2x), equilibrium sediment supply (1x), and half the equilibrium sediment supply (0.5x). The effect of sediment supply is also estimated with EFDC using grain-size specific sediment rating curves derived from direct measurements at the project site using EFDC.

Bed material grain size in the Platte River varies longitudinally and may be affected by sediment augmentation of particular grain sizes. The effect of grain size is estimated using grain sizes of 0.75 mm, 1 mm, and 2 mm using FaSTMECH.

SDHF are controlled releases that piggy back on natural river flows. The releases can theoretically be managed to produce a higher peak discharge of long flow duration. The effect of hydrograph shape is analyzed using hydrographs that have the same volume of water (60,000 acre-feet), but have different peak magnitude and flow duration. A peak flow of 8,000 cfs, for 3-days is compared to a peak flow of 5,000 cfs for ~6.5 days using FaSTMECH.

A preliminary analysis of the effects of these parameters (sediment supply, grain size and hydrograph shape) were reported in PRRIP (2014). The mobile-bed model runs conducted in 2015 are improved estimates of channel response. These runs utilize the model parameters calibrated to the 2014 high flow, post-processing methods requested by PRRIP, a modified duration of the peak flow to maintain a similar volume of water between the two hydrographs. Thus, these results supersede those reported in the PRRIP (2014). The results and conclusions of the fixed-bed analyses and bank erosion analyses reported in PRRIP (2014) remain unchanged.

Effects of these variables (sediment supply, grain size and hydrograph shape) are evaluated for:

- Populations of all bars (sand and vegetated) following the SDHF. This analysis is intended to demonstrate reach wide effects on all bars (Attachment II: Figure 10).
- Populations of sand bars only following the SDHF. This analysis removes the influence of vegetated bars which may be less sensitive to the variables due to higher stability. The analysis is focused on the response of sand bars, which is the target bar type to meet biological objectives.

- Populations of new sand bars only. This analysis focuses on new sand bars created during the high flow, which are expected to be most responsive to changes in variables.

A hydrograph with a 3-day peak of 8,000 cfs that contains ~60,000 acre-feet of water, a bed material grain size of 1 mm, and a sediment supply that is equivalent to an "equilibrium" supply is used as the basis for comparison ("base case") of FaSTMECH runs. The same "base case" is applied in EFDC except for grain size and sediment supply. In EFDC, grain size is defined by multiple grain size classes, which more closely matches the measured bed material. Grain size specific sediment rating curves developed from paired measurements of sediment concentrations and flow is used to define the sediment supply, rather than an equilibrium supply. EFDC is only used to verify the effect of altering sediment supply.

VII.A. Effect of a SDHF

A hypothetical SDHF with a peak flow of 8,000 cfs for 3 days with a total volume of water of ~60,000 acre-feet, a bed material grain size of 1 mm and a sediment supply equivalent to an "equilibrium" sediment supply is used as a basis for comparison for effects of hydrograph shape, grain size and sediment supply. This run is referred to as the "base case".

FaSTMECH predicted a total cut of 90,000 CY and fill of 94,000 CY with a net fill of 4,000 CY during the SDHF, indicating the reach is roughly at equilibrium (Attachment II: Table 6). The predicted net fill is likely an artifact of the initial conditions. The initial channel is plane bed and low relief bar formation develop over this plane bed over the course of the model run (Attachment II: Figure 8).

The overall acreage of bars declined slightly from 175 acres before the SDHF to 169 acres after the SDHF. The total number of bars decreased substantially from 303 bars before the SDHF to 177 bars following the SDHF (Attachment II: Figure 11). Bar frequency declined primarily due to direct erosion of very small bars or translation of these small bars far enough downstream that they did not intersect with the original bar location (126 bars), accounting for a total of 2.5 acres of change. Many bars merge with adjacent bars which accounts for the decline of an additional 35 bars. A statistically significant (p-value =0.04) increase in individual bar areas occurred due to erosion of the smaller bars and merging of adjacent bars (Attachment II: Table 7). Total new bar area was 0.9 acres following the 8,000 cfs SDHF. New bars were generally small. Only one bar was close to reaching the biological target of 0.25 acres.

A very small (<0.1 feet), but statistically significant (p-value=0.03), increase in mean bar height occurred following the SDHF. The maximum mean bar height of new bars was less than 0.6 feet (Attachment II: Figure 12 and Figure 13) which does not meet the biological objective of 1.5 feet. A SDHF did not occur within the monitoring period. A smaller flow occurred (2013 SDMF) as well as three larger flows (fall 2013 high flow, 2014 high flow and 2015 high flow). These high flows were higher in magnitude and longer in duration that the target SDHF. The field data at Shoemaker is consistent with the model results that a SDHF is insufficient for producing bar heights that meet the biological objective.

During high flow field efforts, bars were observed to grow in height on the rising limb of the hydrograph, reaching close to the water surface at the peak of the flow, then decline in elevation on the falling limb of the hydrograph. The model did not predict this phenomenon. Bars at the peak flow were not predicted to be higher than those at the end of the hydrograph. Capturing this phenomenon likely requires the application of a fully three-dimensional model.

VII.B. Effect of Sediment Supply

Objective 1a: Evaluate relationships between sediment supply and frequency of sand bar occurrence. The effect of sediment supply on bar frequency was evaluated with FaSTMECH and EFDC during a SDHF with a peak flow of 8,000 cfs TRF for 3 days. Sediment supply was doubled and reduced by half compared to the base case. Sediment supply was adjusted in FaSTMECH by modifying the equilibrium sediment supply and in EFDC by modifying the measured sediment concentrations.

Both models predicted negligible changes to bar frequency, height, and area in response to a change in the upstream sediment supply during one SDHF. FaSTMECH predicted a difference of 1 bar between the cases of half and double the equilibrium supply during a SDHF (Attachment II: Figure 16) and a difference of 4 bars across all cases for sand bars and new sand bars (Attachment II: Figure 17 and Figure 18). Some small differences occur in the total area of bars (lower sediment supply resulting in slightly more new bar area and higher bars (Attachment II: Figure 19), but these differences are not statistically significant (Attachment II: Table 9).

The most significant changes occurred at the project boundary in EFDC, which resulted in accumulations of sediment in the form of a delta as observed in previous years (PRRIP, 2014, 2015). These sediment accumulations were localized and did not translate through the project reach during the SDHF. A significantly longer duration simulation is likely necessary to observe the long-term impacts of changes in sediment supply. It is also important to note that the channel response is inherently linked to the initial conditions of the channel bed. The channel geometry may be significantly different in reaches that have a chronic sediment deficit resulting in a different response to a change in sediment supply than the Shoemaker reach.

VII.C. Effect of Grain Size

Objective 1b: Evaluate the Relationship between grain size and sand bar height. The effect of bed material grain size on bar height and area was evaluated with FaSTMECH during a SDHF with a peak flow of 8,000 cfs TRF for 3 days. Bed material grain sizes of 0.75 mm, 1 mm (base case) and 2 mm were evaluated.

Bed material grain size affects the predicted amount of scour and fill, total number of bars, number of new bars and bar area. Reducing the bed material size from 1 mm to 0.75 mm increases cut by 22 percent and fill by 21 percent. Coarsening the bed material from 1 mm to 2 mm decreases cut by 42 percent and fill by 40 percent (Attachment II: Table 6).

The total number of bars decreases substantially from the initial condition of 303 bars to 177 bars following an 8,000 cfs TRF SDHF for the base case (grain size = 1 mm). As discussed in the previous section, bar frequency declines due to merging of bars, erosion of smaller bars or downstream translation of bars. The decline in bar frequency for finer bed material (0.75 mm) is less pronounced (a reduction from 303 bars to 215 bars), but there is not a clear trend associated with increasing grain size (Attachment II: Figure 21). In the case of the finer grain size (0.75 mm), the erosion of smaller bars appears to be somewhat offset by new bar development and a more active bed. As grain size is increased, the bed is less active and the higher bar frequency of bars in the coarser bed (188 versus 177) may be a result of a less active bed that resulted in less erosion of the smaller bars.

Total bar area decreases from 175 acres to 169 acres with a bed material grain size of 1 mm (base case). Decreasing the grain size to 0.75 mm results in a bar area of 173 acres, and increasing the grain size to 2 mm results in a decline in bar area to 166 acres. Thus, less total bar area is lost when grain sizes are smaller, with a total difference in bar area of about 4 percent.

The populations of average bar height and bar area for all bars (sand bars and vegetated bars), sand bars with grain sizes ranging between 0.75 and 2mm, are not statistically different (Attachment II: Figure 21, Figure 22, and Table 8)

The number of new bars formed during the SDHF is substantially larger with a finer grain size (74 new bars with a 0.75 mm grain size versus only 9 new bars with a 2 mm grain size) (Attachment II: Figure 23). Total new bar area also increases with finer grain size (1.7 acres for 0.75 mm, 0.89 acres for 1 mm, 0.12 acres for 2 mm grain size) (Attachment II: Figure 25). However, these differences in total area are quite small relative to the total bar area in the project site, representing a change of less than 1 percent of the total bar area. There appears to be a trend of higher and larger bars with decreasing grain size (Attachment II: Figure 23, Figure 24, and Figure 25); however, the differences between the populations are not statistically significant (Attachment II: Table 8).

In all grain size cases, none of the bars met the biological target of 0.25 acres; however, one bar nearly met the target at 0.23 acres (0.75-mm grain size). Similarly, none of the bars met the height target of 1.5 feet above the 1,200 cfs water level for 1 mm and 2 mm grain size, and only one bar exceeded an average height of 1.5 feet when the bed material was 0.75 mm (Attachment II: Figure 24). Generally, average heights of bars were substantially lower than the target heights, with median heights of 0.1 feet or less.

While grain size appears to have an important effect on sediment transport, reflected in the total cut and fill that occurred throughout the project site, it does not appear to have a significant impact on bar height or area during one SDHF. Given the strong effect that grain size has on sediment transport cut and fill volumes, it is possible that over longer time scales, grain size could emerge as a statistically significant parameter.

VII.D. Effect of Hydrograph Shape and Duration

Objective 1c: Evaluate relationship between hydrograph (shape and duration) and sand bar height. The effect of hydrograph shape is evaluated using hydrographs that have the same volume of water (~60,000 acre-feet), but have different peak magnitude and flow duration. A peak flow of 8,000 cfs for 3 days (base case) is compared to a peak flow of 5,000 cfs for ~6.5 days using FaSTMECH.

The SDHF hydrographs both produce a significant amount of cut and fill throughout the study reach (Attachment II: Table 6). The 8,000 cfs hydrograph produces roughly 17 percent more cut and 19 percent more fill than the 5,000 cfs hydrograph. Both hydrographs result in a small net fill, which was likely due to low relief bar formation on the otherwise plane bed channel present in the initial topography as stated earlier.

The total number of bars increased by 3 following a 5,000 cfs SDHF compared to the 8,000 cfs SDHF (Attachment II: Figure 11). Total bar area decreases from 175 acres, to 166 acres and 169 acres, respectively, following a 5,000 cfs and 8,000 cfs TRF SDHF. The results of the statistical tests indicate there is not a statistically significant difference between populations of bar heights or bar areas due to the hydrograph shape of the SDHF (Attachment II: Table 7).

The difference in sand bar frequency following a 5,000 cfs and 8,000 cfs is small (140 bars following a 5,000 cfs peak flow versus 134 bars following an 8,000 cfs peak flow). While the median bar height appears slightly higher following an 8,000 cfs peak flow, the populations are not statistically different between the two flows (Attachment II: Figure 12 and Table 7)

The difference in number of new bars formed is minor, with 32 new bars formed following the 5,000 cfs SDHF and 30 bars formed following the 8,000 cfs SDHF. Total new bar area is 0.5 acres following the 5,000 cfs SDHF and 0.9 acres following the 8,000 cfs SDHF. New sand bars are less than 0.07 acres following the 5,000 cfs SDHF, and less than 0.23 acres following the 8,000 cfs SDHF (Attachement II: Figure 13 and Figure 14). In both cases, no bars met the biological target of 0.25 acres. Mean new sand bar heights are less than 0.5 foot above the 1,200 cfs water surface elevation for both hydrographs. These heights are substantially less than the biological target of 1.5 feet. Although there appears to be a tendency for higher bar heights and larger bar areas associated with a higher peak discharge, the populations following one SDHF are not statistically different (Attachment II: Table 7).

New bars are formed 0.4 to 1.7 feet below the peak stage with a median depth of 1.2 feet at 5,000 cfs, while bars that formed during the 8,000 cfs SDHF formed 0.6 to 2.3 feet below the peak stage with a median value of 1.7 feet.

New bars formed during the 5,000 cfs and 8,000 cfs TRF SDHF were all lower and smaller than needed to achieve biological objectives of 0.25 acres and 1.5 feet above the 1,200 cfs TRF water level. Overall, bars on the reach scale did not change substantially with a single SDHF. It is possible that multiple events could produce a statistically significant difference in bar height and area, however; the results of the field study indicate the potential differences are relatively small.

Hydrographs within the range of the target SDHF do not appear to be sufficient to achieve biological objectives.

VII.E. SDHF Conclusions

The results of the mobile-bed modeling analysis are consistent with field observations in the Shoemaker reach that SDHF events are not likely to create bars with sufficient height or areas to achieve biological objectives. While there were differences in sediment transport (cut/fill) and total number of bars formed, the relative changes in bar area and height during a SDHF were minor. Differences in peak magnitude (5,000 cfs -8,000 cfs) and duration of peak flow (3- 6.5 days), grain size (0.5, 1 mm, 2 mm) and sediment supply changes (0.5 – 2x sediment supply) did not produce statistically significant changes in the bar forms created during the SDHF. These results are limited to the effect of one SDHF event. It is possible that some of these parameters may have a long-term effect that was not captured during this study. The conclusion from the modeling exercise is consistent with field measurements of barform changes following a short duration medium flow and three distinct high flow events (Fall 2013, June 2014 and June 2015) that met or exceeded the target SDHF.

VIII. THREE YEAR SUMMARY

The FSM "Proof of Concept" experiment was implemented by the Program to evaluate the ability of a Flow-Sediment-Mechanical (FSM) management strategy to achieve Program goals. The goals include: improve the survival of whooping cranes during migration, improve least tern and piping plover production, and avoid adverse impacts to pallid sturgeon in the Lower Platte River. General management actions include:

1. Flow— Augment Q1.5 through flow releases to create short duration high flows (SDHF) of 5,000 to 8,000 cubic feet per second (cfs) for 3 days in 2 out of 3 years.
2. Sediment— Augmentation of approximately 150,000 tons of medium sand annually to offset sediment deficit upstream of Kearney.
3. Mechanical— Channel widening, clearing, and leveling of in-channel bars and flow consolidation (85-90 percent of 8,000 cfs in a single channel).

The Shoemaker Island Complex, which is assumed to be in sediment balance, was chosen as the location to implement the FSM "Proof of Concept". Over a three-year period, the experiment evaluated the performance of the FSM management actions, in creating and/or maintaining channel characteristics that are consistent with the Program's management objectives. Learning objectives included:

1. Evaluate the relationship between peak flows (magnitude and duration) and sandbar height and area.
2. Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.
3. Evaluate the ability of the FSM management strategy to create and/or maintain habitat for whooping cranes, least terns, and piping plovers.

VIII.A. Timeline of Events

The findings from the 2013 and 2014 monitored high flow events were presented in their respective annual Shoemaker Island FSM "Proof of Concept" reports (PRRIP 2014a and PRRIP 2015b). Findings from the 2015 monitoring effort were presented in this report. Following is a discussion of the inter year observations (2013, 2014, and 2015) of the geomorphologic changes of the Platte River to high flow events in the Shoemaker Study Reach.

Eight field efforts were expended to quantify the effects of four unique high flow events on the geomorphology of the Platte River in the Shoemaker study reach. "Proof of Concept" Experiment Milestones:

March 25 to April 3 2013 - Field Effort
Geomorphology and vegetation surveys in the Shoemaker Study reach completed.

April 13, 2013 to April 18, 2013 - Short Duration Medium Flow

The April SDMF (April 13, 2013 at 00:00 to April 18, 2013 at 23:45) recorded at the Grand Island Platte River gage (USGS 06770500), located 13.5 miles downstream of the study reach recorded a TRF instantaneous peak discharge of 3,840 cfs. The 3-day mean peak discharge was 3,552 cfs TRF at a volume of 33,743 acre-feet. The April 2013 SDMF three-day mean peak discharge was 44 percent of the Program-defined SDHF event of 5,000 to 8,000 cfs and was 45 percent of the SDHF defined volume of 50,000 to 75,000 acre-feet (Table 8-1). The April 2013 high flow event was augmented (through flow releases) with Environmental Account water to produce a flow event. However, the 3-day mean peak discharge was 44 percent of the Program-defined SDHF and for this reason is referenced as a Short Duration Medium Flow (SDMF).

April 13, 2013 to April 18, 2013 - Field Effort

River stage monitoring and sediment sampling completed during 2013 SDMF.

April 26, 2013 to April 29, 2013 - Field Effort

Geomorphology and vegetation surveys in the Shoemaker Study reach completed post 2013 SDMF.

September 24, 2013 to November 1, 2013 – Fall 2013 High Flow

The fall 2013 high flow in the Platte River resulted from approximately 15 inches of rain that fell over the headwaters of the South Platte River Basin near Boulder, Colorado over a 7-day period starting on September 9, 2013 (Erdman 2013). The high flow hydrograph (September 24, 2013 to November 1, 2013) at the Grand Island Platte River gage (USGS 06770500) recorded a TRF instantaneous peak discharge of 10,600, on October 3, 2013 with a 3-day mean peak discharge of 9,700 cfs TRF and a TRF volume of 248,273 acre feet. The fall 2013 high flow three-day mean peak discharge was 121 percent of the Program-defined SDHF event of 5,000 to 8,000 cfs and was 331 percent of the SDHF defined volume of 50,000 to 75,000 acre-feet (Table 8-1). The fall 2013 high flow event was not augmented (through flow releases) with Environmental Account water to produce a SDHF event.

May 5, 2014 to May 9, 2014 – Field Effort

Geomorphology and vegetation surveys in the Shoemaker Study reach completed pre June 2014 High Flow.

June 6, 2014 to July 5, 2014 - June 2014 High Flow

The June 2014 high flow in the Platte River Resulted from snowpack melt in South Platte River basin. Snowpack in the headwaters of the South Platte River basin in Colorado was at 133 percent of the median snowpack on May 1, 2014 (NRCS 2014). The June 2014 high flow hydrograph (June 6, 2014 at 00:00 to July 5, 2014 at 23:45) at the Grand Island Platte River gage (USGS 06770500) recorded a TRF instantaneous peak discharge of 8,800 cfs, on June 15, 2014 with a 3-day mean peak discharge of 7,320 cfs TRF and a TRF volume of 181,270 acre feet. The June 2014 three-day mean peak discharge was 92 percent of the Program-defined SDHF event of 5,000 to 8,000 cfs and exceeded the SDHF defined volume of 50,000 to 75,000 acre-feet by 241 percent (Table 8-1). The June 2014 high flow event was not augmented (through flow releases) with Environmental Account water to produce a SDHF event.

June 6, 2014 to June 26, 2014 - Field Effort
River stage monitoring and sediment sampling completed during June 2014 high flow.

July 21, 2014 to July 26, 2014 - Field Effort
Geomorphology and vegetation surveys in the Shoemaker Study reach completed post June 2014 high flow.

May 11, 2015 to July 20, 2015 - June 2015 High Flow
The June 2015 high flow in the Platte River resulted from snow-pack melt and heavy rainfall in the South Platte River basin. Snowpack in the headwaters of the South Platte River in Colorado was near normal at 93 percent of the median snowpack on May 2, 2015 (Denver Post 2015). Heavy rainfall of up to 9.0 inches in northeast Colorado from May 1, 2015 to May 10, 2015 (NWS 2016) produced a peak discharge of 14,900 cfs at the Roscoe, Nebraska USGS gage on May 26, 2015 (USGS 2015). The June 2015 high flow (May 11, 2015 at 02:45 to July 20, 2015 at 18:30) at the Grand Island Platte River gage (USGS 06770500) recorded a total river flow (TRF) instantaneous peak discharge of 16,100 cfs, on June 19, 2015 with a 3-day mean peak discharge of 15,700 cfs TRF and a TRF volume of 1.231 million acre feet (for flows over 2,000 cfs). The June 2015 three-day mean peak discharge exceeded the Program-defined SDHF event of 5,000 to 8,000 cfs by 196 percent and exceeded the SDHF defined volume (50,000 to 75,000 acre-feet) by 1,641 percent (Table 8-1). The June 2015 high flow event was not augmented (through flow releases) with Environmental Account water to produce a SDHF event.

May 26, 2015 to July 17, 2015 – Field Effort
River stage monitoring and sediment sampling completed during June 2015 high flow.

August 24, 2015 to September 2, 2015 - Field Effort
Geomorphology and vegetation surveys in the Shoemaker Study reach completed post June 2015 high flow.

VIII.B. Inter Year Summary

The conclusions and data that were presented for the four high flow events were re-examined to evaluate inter year changes. Inter year data were evaluated as they directly relate to the three Learning Objectives of the Shoemaker Island FSM Experiment. The FSM priority hypothesis provides a broad view of the possible changes in river morphology/channel characteristics that may be produced through implementation of FSM management action.

VIII.B.1. Evaluate the relationship between peak flows (magnitude and duration) and bar height and area.

The magnitude and duration of the monitored peak flows in the Shoemaker study reach did not increase bar height and area commensurate with flow.

- 2013 SDMF – The 3-day mean peak discharge was 3,840 cfs with a flow duration of 6-days with flows greater than 2,000 cfs.
- June 2014 High Flow - The 3-day mean peak discharge was 7,320 cfs and duration of 30-days with flows greater than 2,000 cfs.
- June 2015 High Flow - The 3-day mean peak discharge was 15,700 cfs and duration of 72-days with flows greater than 2,000 cfs.

Bar height and area relative to the June 2014 high flow and the June 2015 high flow are presented in Figure 5-8 and Figure 8-1, respectively. None of the sand bars greater than 0.25 acres in size surveyed post high flow events in 2014 and 2015 met the least tern and piping plover nesting suitability criterion for sand bar height greater than 1.5 feet above 1,200 cfs TRF stage.

VIII.B.2. Evaluate the relationship between sediment supply and bar height and area.

Sediment supply within the Platte River can be managed by direct sediment augmentation; however, the field measurements of changes in sediment storage suggest that the Shoemaker Reach is not deficient in sediment.

- 2013 SDMF – Net sediment -16,000 cubic yards (cy)
- Fall 2013 High Flow – Net sediment +82,920 cy
- June 2014 High Flow – Net sediment -10,300 cy
- June 2015 High Flow – Net sediment +73,500 cy

The effect of sediment supply is estimated with the FaSTMECH model using twice the predicted equilibrium sediment supply (2x), equilibrium sediment supply (1x), and half the equilibrium sediment supply (0.5x). The effect of sediment supply is also estimated with EFDC using grain-size specific sediment rating curves derived from direct measurements at the project site using EFDC.

VIII.B.3. Evaluate the relationship between grain size and bar height and area.

Bed material grain size of the Platte River varies longitudinally and may be affected by sediment augmentation of particular grain sizes. There was not a statistically significant change in the grain size within the Shoemaker Reach during the study period. The effect on bar height and area is estimated using grain sizes of 0.75 mm, 1 mm, and 2 mm using FaSTMECH. Grain size has an important effect on sediment transport, reflected in the total cut and fill that occurred throughout the project site, it does not appear to have a significant impact on bar height or area during one SDHF. Given the strong effect that grain size has on sediment transport cut and fill volumes, it is possible that over longer time scales, grain size could emerge as a statistically significant parameter.

VIII.B.4. Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.

The magnitude and duration of the monitored peak flows in the Shoemaker study reach impact on riparian plant mortality was inconclusive. The impacts of the monitored peak flows (magnitude and duration) could not be separated from the impacts of the Program's mechanical disking activities, nesting island construction and herbicide treatment on riparian plants in the study reach.

- 2013 SDMF – Vegetated area in the study reach decreased from 125.9 acres pre to 124.1 acres post the monitored SDMF flow event.
- June 2014 High Flow – Vegetated area in the study reach increased from 49.2 acres pre to 117.4 acres post the monitored high flow event.
- June 2015 High Flow – Vegetated area in the study reach decreased from 117.4 acres in July 2014 to 64.4 acres post the monitored high flow event.

Areal extend of sand bars, vegetated bars, and water/river bed area in mechanically treated areas and the untreated areas of the Shoemaker study reach for the three monitored flows are presented in Table 5-8.

VIII.B.4.1 Summary of Lateral Erosion Predictions

Lateral/bank erosion contributes to riparian plant mortality by direct erosion of the banks, or undermining the banks below the root zone and producing geotechnical failures. Drag forces can pull vegetation from bars and vertical scour can expose root systems making them more susceptible to uprooting by drag forces. One-dimensional bank erosion modeling using the USDA-ARS BSTEM model was one component of the analysis conducted for the Shoemaker Reach of the Platte River over the past three years (WY 2013 – WY 2015). The analyses conducted with BSTEM supports previous research suggesting that lateral erosion is a primary fluvial process contributing to riparian plant mortality (Pollen-Bankhead et al., 2012).

The USDA Bank Stability and Toe Erosion Model (BSTEM) is a one-dimensional bank erosion model developed at the USDA Agricultural Research Services (Simon et al. 2011; USDA 2010). BSTEM estimates hydraulic erosion of the bank and bank toe based on hydraulic boundary shear stresses calculated from channel geometry and flow parameters. Hydraulic erosion occurs when the tractive force of the water column [shear stress] exceeds the resisting force of bank materials. Additional lateral erosion through geotechnical bank failure, (gravitational forces exceed cohesive forces), is based on equilibrium factor of safety calculations that include horizontal erosion, vertical tension cracks and cantilever failure (USDA 2010). Input requirements include bank geometry, soil type for bank material, vegetation coverage, channel slope, and water depth at the channel boundary for a given duration of time. Sediment transport is not incorporated into this model and the channel bed elevation is assumed to be fixed. This model does not incorporate incision of the channel bed and the bottom elevation of the bank toe can't erode below the elevation of the channel bed.

The BSTEM model is a fixed-bed model, and thus, performed well when the bed and banks maintained a relatively stable configuration as occurred during the 2013 SDMF and in many areas during the 2014 high flow. The model performed poorly at locations where there were widespread channel changes that resulted in new bar growth or substantial bank erosion that substantially changed the flow hydraulics at the bank.

The 2013 SDMF did not change the overall configuration of the bars and channels, but lateral erosion was observed at 2 of the 5 bank sites analyzed with BSTEM. One site (BSTEM Site C: cross-section 6, Bar 7) has 10 feet of erosion and the second site (BSTEM Site E: cross-section 10 bar 18) had 14 feet of lateral erosion. The model demonstrated that the erosion occurred both during the SDMF, and continued during moderate natural flows following the release. Roughly 82% of the erosion occurred after the SDMF at BSTEM Site C and 45% occurred after the SDMF at BSTEM Site E.

BSTEM Site C was selected as a test case to determine how much erosion would occur during a hypothetical SDHF with a peak magnitude of 8,000 cfs. These results indicated that the amount of erosion over the SDHF was higher than over the same equivalent time as the SDMF, but that the total amount of erosion predicted during a SDHF was only 30% of the measured erosion that was observed over the 28-day period of more moderate flows.

These results indicate that after flows rise high enough to initiate erosion, sustained flows may be more effective at eroding banks than higher magnitude, shorter duration flows. Additional detail can be found in PRRIP (2014).

Vegetation on banks may reduce bank erosion by providing root strength to soil. Vegetated banks with roots that did not extend to the toe of the channel were modeled using the methodology as unvegetated banks with similar success (generally within 5% of the measured data, see PRRIP (2015)). The Manning's n value was adjusted such that the shear stress applied at the toe of the bank was equal to the shear stress predicted by the two-dimensional model. This methodology does not provide good predictive results when the rooting depth of the vegetation extends to the bottom, or toe, of the bank. Banks with deeply rooted vegetation (to or below the bottom of the bank) did not erode during both the 2013 SDMF or 2014 high flow. A review of the air photos indicates that three of the four sites that were stable in 2014 remained stable through the 2015 high flow.

BSTEM analyses were not conducted for the 2015 high flow due to a lack of pre-high flow data and substantial reorganization of the channel bed. BSTEM does not provide adequate results when large morphological changes occur in the channel that substantially alters the shear stress applied at the toe of the bank. Analysis of this type of high flow requires coupling of the mobile-bed and bank erosion model to adequately capture the changing hydraulic forces applied at the bank during the high flow.

VIII.B.5. Evaluate ability of FSM management strategy to create and/or maintain habitat for whooping cranes, least terns and piping plovers

Figure 8-2 provides a visual summary of bar attributes April 2013, July 2014, and August 2015. The images show that the aerial distribution of bar attributes have changed in the Shoemaker study reach through mechanical treatment and/or high flows. Tern and plover preferred bar attributes includes: ≥0.25 contiguous acre of bare sand (less than 20 percent vegetative cover) and ≥1.5 feet above the 1,200 cfs TRF stage. Unobstructed minimum channel widths for whooping crane roosting is 750 ft with a target of 1,150 ft to increase probability of roosting. Inter year conclusions relative to the FSM management actions are presented below.

VIII.B.5.1 Flow

The magnitude and duration of the monitored high flow events in the Shoemaker study reach were estimated using event specific stage/discharge data and data from USGS gaging station near Grand Island, NE. Three distinct flows were monitored for their effects on least tern, piping plover and whooping crane habitat in the Shoemaker study reach.

The 3-day mean peak discharge above the 1,200 cfs TRF stage at cross section 18 was 0.94-feet for the April 2013 SDMF, 1.60-feet for the 2014 high flow, and 2.69-feet for the 2015 high flow event. The April 2013 SDMF 3-day peak mean discharge stage increased the mean depth of water above the 1,200 cfs TRF stage by 1.04 feet. The June 2014 high flow 3-day mean peak discharge stage increased the depth of water above the 1,200 cfs TRF stage by 1.49 feet to 2.46 feet. The June 2015 high flow event 3-day mean peak discharge stage increased the depth of water above the 1,200 cfs TRF stage by 2.59 feet to 4.05 feet. The duration of flows over 2,000 cfs for the June 2014 high flow was 30 days and for the June 2015 high flow it was 71 days.

The 2013 SDMF was monitored pre and post the high flow event and the magnitude and duration of the event did not demonstrably affect the height and area of sand and vegetated bars in the Shoemaker study reach. The post June 2014 high flow survey documented 40 sand bars, encompassing 48.5 acres that were greater than 0.25 acres in size. The post June 2015 high flow survey documented 23 sand bars encompassing spanning 59.6 acres that were greater than 0.25 acres in size.

None of the monitored flow events formed sand bars to a height that was equal to or greater than 1.5 feet above the 1,200 cfs TRF stage. Sand bars >0.25 acres in size surveyed post June 2014 high flow had a mean height of 0.39 feet above the 1,200 cfs TRF stage. Sand bars >0.25 acres in size surveyed post June 2015 high flow had a mean height of 0.52 feet above the 1,200 cfs TRF stage.

The monitored peak flows impact on unobstructed channel width could not be segregated from the impacts of the Program's mechanical disking activities, nesting island construction and herbicide treatment on riparian plants in the study reach.

VIII.B.5.2 Sediment

Sediment volume changes in the Shoemaker study reach was estimated for three monitored flow events and the fall 2013 high flow event. Volume change was estimated using the average end method and the 18 monumented cross sections for the 2013 SDMF and the fall 2013 high flow. The June 2014 and June 2015 high flow volume change estimate used the primary and supplemental cross sections (n=37). The 2013 SDMF had a net erosion of 16,000 cubic yards, fall 2013 high flow had a net deposition of 82,920 cy, June 2014 high flow had a net erosion of 10,300 cy, and the June 2015 high flow had a net deposition of 48,000 cy. A summation of erosion/deposition in the Shoemaker study reach during the three-year study results in a net deposition of 104,620 cy of sediment. This result indicates that Shoemaker was not in a sediment deficit during the 3-year monitoring period. The net deposition of sediment in the Shoemaker study reach did not increase bar area or height during the three year “Proof of Concept” experiment.

Sediment supply into the Shoemaker Project was not augmented during the study, thus we cannot evaluate the effectiveness of geomorphic changes resulting from sediment augmentation. We can however examine channel response related to sediment load on an event-by-event basis and evaluate changes in grain size over the study period

The 2013 SDMF transported 15,200 tons of suspended load and 12,500 tons of bedload at the upstream boundary for a total load of 27,700 tons. Volume change calculations resulted in a deficit of 16,000 cy. The implication for this event is that given the hydrograoh shape and sediment load, the reach was in sediment deficit.

The fall 2013 high flow transported 93,300 tons of bedload, which summed with suspended load results in 170,000 tons transported into Shoemaker. Using the rounded mean of the 2013 and 2014 bulk density calculated from bar samples (1.7 g/cm^3), we convert mass to volume which yields 119,000 cy for the total load. The calculated volume change was 83,000 cy of deposition. The implication is that with this (estimated) sediment supply, the reach is in a sediment-surplus condition, aggrading in response to the fall 2013 hydrograph and sediment load.

The June 2014 high flow transported 49,500 tons of bedload, which summed with suspended load results in 99,300 tons transported into Shoemaker. The calculated total sediment load volume is 69,000 cy. The percent difference in the total cut and total fill volumes is only 8 percent. The calculated volume change resulted in a deficit of 10,300 overall cy. The implication is that with this (estimated) sediment supply, the reach is near sediment balance with the potential for a slight sediment-deficit condition, in response to the June 2014 hydrograph and sediment load. The 8 percent difference is quite small, given the uncertainty in our calculations (we saw a 10,000 cy difference just by adding the supplemental cross sections), therefore, the reach may likely be in sediment balance for this event.

The 2015 high flow event transported 505,000 tons of suspended sediment and 461,000 tons of bedload for a total load of 966,000 tons. The calculated volume change indicated a net deposition of 73,500 cy. The implication is that with the measured sediment supply, the reach is in a sediment-surplus condition, aggrading in response to the 2015 hydrograph and sediment load. As stated previously, over the three year study and over four distinct high flow periods, the Shoemaker Study reach is not in sediment deficit.

Grain size distributions from bed and bar samples showed little change in the D50 over the three year monitoring period. Of the 150 samples collected, we removed three that were collected in very unusual, very coarse riffles (Figure 8-3). The D50 ranged from 0.64 to 1.0mm and averaged 0.82mm. the final two sampling events (post 2014 and post 2015) show a very slight coarsening to approximately 1mm. However, there was no significant difference between the populations.

VIII.B.5.3 Mechanical

Concurrent with the three year "Proof of Concept" experiment to monitor the geomorphology of the Shoemaker study reach the Program annually performed mechanical disking of vegetation and constructed nesting bars. Nesting bars were constructed in early fall after the post high flow geomorphology surveys. Geomorphology data were not collected for the constructed bars and the mechanical impact of bar construction on vegetation was not evaluated. Mechanical disking of the river bed/bars in the Shoemaker study reach was performed prior to the first geomorphology survey in March 2013 and in early fall of 2013, 2014, 2015 during the experiment. No geomorphology surveys were completed in the Shoemaker study reach that predated mechanical disking of the river bed/bars for the "Proof of Concept" experiment.

The braiding index was examined for the five geomorphological surveys completed at the modeled 1,200 cfs TRF index flow. The mean braiding index for the five surveys at the 18 monumented cross exceeded the Program's goal for an average braiding index greater than 3. The five year mean braiding index was 4.1 ranging from a maximum of 5.1 in March, 2013 to a minimum of 3.5 in May and July, 2014.

The eighteen primary transects that were surveyed in the Shoemaker study reach were assessed to identify segments greater than750 feet with no vegetation and evaluate the role of mechanical treatment in the "creation" of the segments. The Department of the Interior hypothesizes that an unobstructed minimum channel width of 750 feet and a target of 1,150 feet is needed to increase the probability of whooping crane roosting.

2013 - Four of the 18 primary cross sections in the Shoemaker study reach had natural unvegetated transect widths greater than 750 feet ranging from 750 feet to 1,125 feet. With mechanical treatment, five additional primary cross sections were "created" that had widths greater than 750 feet— with two unvegetated widths greater than 1,150 feet. Average mechanical aided unvegetated cross section width 1,039 feet, ranging from a minimum 771 feet to a maximum of 1,604 feet. Nine of the 18 cross section did not contain unvegetated lengths greater than 750 feet.

2014 - Three of the eighteen primary cross sections in the Shoemaker study reach had natural unvegetated cross sections lengths greater than 750 feet ranging from 803 feet to 933 feet. With mechanical treatment, eight additional primary cross sections were "created" that had widths greater than 750 feet— with eight unvegetated widths greater than 1,150 feet. Average mechanical aided unvegetated transect width was 1,286 feet, ranging from a minimum 786 feet to a maximum of 1,633 feet. Seven of the 18 cross sections did not contain unvegetated lengths greater than 750 feet.

2015 - Two of the eighteen primary cross sections in the Shoemaker study reach had natural unvegetated cross sections lengths greater than 750 feet at 769 feet and 844 feet. With mechanical treatment, nine additional primary cross sections were "created" that had unvegetated widths greater than 750 feet— with three unvegetated widths greater than 1,150 feet. Average mechanically aided unvegetated cross section width was 1,127 feet, ranging from a minimum 827 feet to a maximum of 1,459 feet. Seven of the 18 cross sections did not contain unvegetated lengths greater than 750 feet.

River bed/bars in the Shoemaker study reach were mechanically treated before the first geomorphology survey was completed the week of March 23, 2013. Data were not available for vegetation occurrence at the eighteen primary cross sections prior to mechanical treatment. The "Proof of Concept" experiment monitored unvegetated cross section widths resulting from an in place, mechanical treatment of vegetation. Based on our results and observations, mechanical treatment contributes to maintaining and/or decreasing vegetation in the study reach with: 9,353, feet of unvegetated width in April 2013, 14,155 feet in May, 2014, and 11,764 feet in September 2015.

The Shoemaker study reach covers 362 acres of Platte River main channel area. At the time of the geomorphology surveys the study reach consisted of 252 mechanically treated acres in 2013, 246 acres in 2014, and 266 acres in 2015. Natural area not subjected to mechanical treatment in the study reach was 110 acres in 2013, 116 acres in 2014, and 96 acres in 2015 (Table 8-2). River stage (depth) during mechanical treatment in the fall of the year limits/permits access to bars for treatment.

Figure 8-4 presents the acres and attributes for the bars in the study reach above the 1,200 cfs TRF stage. The increase of vegetated acres for the July 2014 survey resulted from the short high flow duration (flows greater than 2,000 cfs) of 30 days, which permitted the germination of annual plants on bars before the July 21 to July 31, 2014 survey. The amount of treated sand bars was consistent for the three annual surveys. Total area of natural sand bars in April 2013 is low because the river stage was greater than 1,200 cfs TRF and the sand bars were not surveyed. Total bar area increased during the late July 2014 survey as vegetated bars and river bed area decreased. The causative factor for the increase in vegetative bar area was not evident in the data. The August 2015 bar area proportions are comparable to what was documented in 2013, a stable condition for bar area in the study reach.

IX. REFERENCES

Abraham, D. and Pratt, T. June 2002. Quantification of Bedload Transport on the Upper Mississippi River Using Multibeam Survey Data and Traditional Methods. US Army Corps of Engineers – ERDC/CHL-VII-4.

Abraham, D., Kuhnle, R., and Odgaard, A. 2011. Validation of Bed-Load Transport Measurements with Time-Sequenced Bathymetric Data. Journal of Hydraulic Engineering (137)7, 723-728.

Denver Post. 2015. Colorado Experts to Update Snowpack, Flood Outlook. http://www.denverpost.com/2015/03/16/colorado-experts-to-update-snowpack-flood-outlook/

Dinehart, R.L. 2002. Bedform Movement Recorded by Sequential Single-Beam Surveys in Tidal Rivers. Journal of Hydrology 258 (2002) 25-39.

Edwards, T.K., and Glysson, G.D., 1998. Field Methods for Measurement of Fluvial Sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Applications of Hydraulics, Chapter C2.

Erdman, Jon. 2013. Colorado Flash Flooding: How It Happened, How Unusual. The Weather Channel. http://www.weather.com/storms/severe/news/colorado-flash-flood-how-it-happened-unusual-20130912.

Holmquist-Johnson, C.L., and Raff, D.A. Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) Program for Computing Total Sediment Load. Federal Interagency Sedimentation Conference in Reno, NV., April 2-6, 2006. (PDF 145 KB)

National Weather Service (NWS). 2015. Northeast Colorado may Rainfall 2015: Total Rainfall over Northeast Colorado from 5/1/15 to 5/10/15. http://www.weather.gov/bou/2015mayrainfall

Pittman, S.A. 2002. A Geomorphic Investigation of Mainstem Spawning by Chinook Salmon (Oncorhynchus tshawystcha) in the Smith River, California. Masters thesis at California State University at Humboldt, Arcata, California.

Platte River Recovery Implementation Program (PRRIP), 2011. DRAFT Project-scale Geomorphology and Vegetation Monitoring, April 22, 2011.

PRRIP, 2013. HEC-RAS model of the Platte River, personal communication with Jason Farnsworth. August 2013.

PRRIP, 2014. Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment 2013Annual Summary Report. April 2014.

PRRIP, 2015a. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment 2014 Annual Summary Report. December 2015.

PRRIP, 2015b. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment Monitoring and Analysis Plan. March 2015.

Podolak, C. and Pittman, S., 2011. Marmot Dam Removal Geomorphic Monitoring and Modeling Project—Final Report June 2007 – October 2011. Report prepared for Sandy River Basin Watershed Council, 111 p. Available at http://digital.library.ucr.edu/cdri/?record=1191.

Pollen-Bankhead, N, R. Thomas and A. Simon. 2012. Can Short Duration High Flows be Used to Remove Vegetation from Bars in the Central Platte River? Final report to the Platte River Recovery Implementation Program. Directed Vegetation Research Study.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 2 v., 631 p.

Simon, A., N. Pollen-Bankhead, and R. Thomas. 2011. Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools, Geophysical Monograph Series 194, American Geophysical Union. 10.1029/2010GM001006.

USDA. 2010. Bank Stabilty and Toe Erosion Model: Static Version 5.2, http://ars.usda.gov/Research/docs.htm?docid=5045, viewed on October 21, 2013.

USGS. 2013. National Water Information System: Web Interface, Platte River near Grand Island.

USGS 2014. pers. Comm. with J. Farnsworth, January 16, 2014. http://waterdata.usgs.gov/ne/nwis/measurements?site_no=06770375&agency_cd=USGS&format=html_table_expanded.

Water Year 2005 Technical Memo #1, TOUTLE RIVER-2 Bedload Sampler. Report for US Department of the Interior, Bureau of Reclamation, Trinity River Restoration Program, Shasta Lake, CA.

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Table 4-1 Coordinates and Elevation for Cross Section Pins and Benchmarks

Description	Northing	Easting	Elevation
Benchmarks			
12A-T1-L	2046980.74	340291.98	1,940.37
12A-T4-L	2047439.48	340490.18	1,941.30
12A-T7-L	2047882.54	340712.10	1,939.69
Primary Cross Sections			
1 R	2040775.00	337870.08	-
1LSET	2040753.55	338731.37	1,948.70
2 R	2041479.53	337940.10	-
2LSET	2041598.23	338659.28	1,947.13
3 R	2042288.34	337847.56	-
3LSET	2042382.74	338417.12	1,946.61
4 R	2043032.00	337442.10	-
4LSET	2043188.14	338373.92	1,946.69
5 R	2043827.94	337352.07	-
5LSET	2043971.93	338526.85	1,944.51
6 R	2044604.65	337126.32	-
6LSET	2044835.66	338545.96	1,942.62
7 R	2045513.15	337686.93	-
7LSET	2045366.49	338600.09	1,942.98
8 R	2046376.53	337852.15	-
8LSET	2045707.51	338834.39	1,942.14
9 R	2047145.68	338188.11	-
9LSET	2046230.78	339383.72	1,940.07
10RSET	2047892.86	338475.99	1,941.60
10LSET	2047142.72	339511.21	1,939.92
11RSET	2048555.07	338937.41	1,940.52
11LSET	2047788.14	339974.97	1,938.76
12RSET	2049184.35	339441.89	1,939.63
12LSET	2048509.37	340352.44	1,937.19
13RSET	2049914.29	339833.83	1,938.64
13LSET	2049113.66	340884.84	1,935.98
14RSET	2050447.30	340425.67	1,935.36
14LSET	2049629.27	341642.71	1,936.51

15RSET	2051139.03	340857.55	1,933.88
15LSET	2050216.65	342100.80	1,936.91
16RSET	2051874.58	341212.56	1,935.94
16LSET	2050921.97	342540.41	1,935.45
17RSET	2052463.62	341628.06	1,934.73
17LSET	2051614.11	342876.22	1,934.94
18RSET	2053214.06	342083.87	1,933.19
18LSET	2052327.76	343280.25	1,933.51
Supplemental Cross Sections			
A R	2040411.49	337854.83	-
A L	2040317.27	338643.21	-
B R	2041303.67	337915.49	-
B L	2041223.39	338758.56	-
C R	2041878.26	338011.93	-
C L	2041894.58	338536.54	-
D R	2042618.24	337706.52	-
D L	2042729.87	338377.12	-
E R	2043473.36	337380.12	-
E L	2043602.58	338399.60	-
F R	2044163.83	337370.07	-
F L	2044307.21	338439.95	-
G R	2045036.85	337616.91	-
G L	2045080.66	338537.36	-
H R	2045853.93	337737.36	-
H L	2045589.37	338655.16	-
I R	2046774.83	338024.18	-
I L	2045986.33	339127.69	-
J R	2047590.33	338341.02	-
J L	2046690.82	339536.37	-
K R	2048297.53	338772.69	-
K L	2047511.73	339841.80	-
L R	2048860.03	339168.52	-
L L	2048207.26	340052.33	-
M R	2049529.52	339648.65	-
M L	2048805.20	340625.76	-
N R	2050157.84	340178.59	-

N L	2049385.93	341185.33	-
O R	2050773.88	340745.25	-
O L	2049936.66	341868.66	-
P R	2051564.95	341007.90	-
P L	2050625.49	342317.34	-
Q R	2052186.29	341431.91	-
Q L	2051269.03	342750.29	-
R R	2052828.02	341867.30	-
R L	2051952.31	343047.54	-
S R	2053552.54	342302.75	-
S L	2052699.21	343448.73	-

The coordinate system for all of the anchor points:
Horizontal: NAD83 Nebraska State Plane, FIPS 2600. Units: US Survey Feet
Vertical: NAVD88, Geoid 03, Units: Feet

Table 4-2 Survey Codes

Cross Section Point Labels	Description
OB	Overbank topo
LTP	Left Top of Pin
RTP	Right Top of Pin
LTB	Left Top of Bank
RTB	Right Top of Bank
LEW	Left Edge of Water
REW	Right Edge of Water
LBB	Left Bottom of Bank
RBB	Right Bottom of Bank
TBR	Top of Bar
GTBR	Green Top of Bar
CB	Channel Bottom
CBG	Channel Bottom-Gravel
Bar Point Labels	**Description**
Top	Perimeter of the top of the Bar
Toe	Perimeter of the toe of the Bar
Tran	Cross Section
Bank	Top of the bank of the river
Supplemental Data Labels	**Description**
Wat ele	Water Elevation
Pst	Pressure Transducer Post
Wse	Water surface elevation at pressure transducer post
Bs	Bulk Sample
Bd	Bulk Density Sample
Sc	Scour Chain
Dck blnd	Duck Blind
Pnd water ele	Pond Water Elevation

Table 5-1 Geomorphic Monitoring and Modeling Support Summary – June 2015 High Flow and August 2015 Effort

Data Collection	During June 2015 High Flow	August 2015
Survey		
Control Survey		1
LiDAR Data QA/scaling		1
Monumented Cross Sections		18
Supplemental Cross Sections		19
Long Profile		2
Bar Surveys		141
Stage and Turbidty		
Stage Reference Observations	25	2
Continuous Stage Recorders	3	1
Continuous Turbidimeters	1	
Discharge		
Meter Measurements	11	1
Sediment Sampling		
Suspended Sediment	18	1
Bed & Bar Bulk Samples		35
Bedload	2	
Bedload Variability	7	
Scour Monitoring		
Scour Chains		11
Photography		
Aerial photo acquisition		1
Repeat ground photos		2,239
Lab Analyses		
Suspended Sediment Concentration, GSA	34	2
Bed and Bar GSA		29
Bulk Density Calculations		6
Bedload Grain Size Analyses		9
Data Analysis		
GeoSpatial		
Cross Section Data Reduction		18
Supplemental Cross Section Data Reduction		19
Long Profile Data Reduction		2
Bar Survey Spatial Analyses		141
Volume Change Calculations		1
Stage		
Water Surface Slope	1	
Continuous Stage Records	1	
Discharge		
Stage Discharge Ratings	1	
Continuous Discharge Record Computation	1	
Sediment Discharge		
Suspended Sediment Load Computation	7	
Bed & Bar Grain Size Comparisons	22	
Bedload or Total Load Calculations	7	

Table 5-2 FSM Management Strategy Flow Benchmarks and June 2015 High Flow Event Magnitude and Durations

		June 2015 High Flow Event	
	Program Flow Benchmarks (TRF)	Grand Island Gage (TRF)	Shoemaker Study Reach* (SF)
Peak Instantaneous Discharge, cfs	NA	16,100	11,270
3-day Peak Mean Discharge, cfs	5,000 – 8,000	15,700	11,200
Volume, acre-feet (un-rounded, for flows above 2,000 cfs)	50,000 – 75,000	1.231 million	861,723
Duration, Days (for flows above 2,000 cfs)	3 - Days	72 – Days	72 - Days

*The 2015 hydrograph for the Shoemaker total river flow was developed using 15-minute pressure transducer stage data collected at cross section 18.

Table 5-3 June 2015 High Flow Discharge Summary – Collected Between Cross Sections 2 and 3

Measurement Number	WY Msmt #	Date	Made By	Width (feet)	Mean Depth (feet)	Area (ft2)	Mean Velocity (ft/sec)	Staff Height (feet)	Gage Height * (feet)	Discharge (cfs)	Rating 1.1			Method	Begin Time (hours)	End Time (hours)	Msmt Rating
											Comp. Shift (feet)	Used Shift (feet)	% Diff.				
1	**2015-01**	5/25/2015	GMA	480	4.74	2273	3.72	7.21	1932.17	8450	-0.08	0.00	-6	Boat	15:37	16:37	Poor
2	**2015-02**	5/28/2015	GMA	486	4.23	2055	4.31	7.09	1931.99	8860	0.16	0.00	10	Boat	13:10	13:50	Fair
3	**2015-03**	6/4/2015	GMA	516	4.59	2366	4.56	7.50	1932.48	10800	-0.01	0.00	-1	Boat	13:40	14:18	Poor
4	**2015-04**	6/5/2015	GMA	498	4.80	2392	4.43	7.47	1932.48	10600	-0.04	0.00	-2	Boat	13:03	13:35	Fair
5	**2015-05**	6/6/2015	GMA	483	4.80	2318	4.62	7.46	1932.48	10700	-0.02	0.00	-1	Boat	10:23	10:55	Fair
6	**2015-06**	6/15/2015	EA Engineering	491	4.12	2021	4.29	7.25	1932.21	8680	-0.08	0.00	-6	Boat	12:00	12:50	Poor
7	**2015-07**	7/2/2015	EA Engineering	477	3.82	1821	3.59	6.62	1931.69	6540	0.03	0.00	2	Boat	12:47	13:20	Poor
8	**2015-08**	7/3/2015	EA Engineering	486	3.53	1717	3.59	6.47	1931.57	6170	0.07	0.00	5	Boat	9:26	10:04	Fair
9	**2015-09**	7/6/2015	EA Engineering	486	2.93	1426	3.45	6.06	1931.25	4920	0.10	0.00	9	Boat	12:35	13:54	Fair
10	**2015-10**	7/9/2015	EA Engineering	483	2.33	1128	3.02	5.73	1931.03	3410	-0.09	0.00	-9	Boat	12:38	13:45	Fair
11	**2015-11**	7/14/2015	EA Engineering	444	2.08	921	2.50	5.09	1930.63	2300	-0.06	0.00	-8	Boat	12:25	13:08	Fair
12	**2015-12**	8/27/2015	GMA	488	1.01	491	2.08	4.28	1929.94	1020	0.02	0.00	2	Wading	12:15	13:06	Good

Table 5-4 Bar Data Summary – July 2014 and August 2015

	All Bars													
	Sand						Vegetated						All Bars	
	Natural		Treated		Total Sand		Natural		Treated		Total Vegetated			
	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015
Number	30	31	113	79	143	110	18	15	26	16	44	31	187	141
Total Area (acres)	6.05	11.47	51.25	53.56	57.30	65.03	37.71	20.39	79.67	43.99	117.38	64.37	174.68	129.41
Minimum (acres)	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.007	<0.001	0.002	0.007	0.002	<0.001	<0.001	<0.001
Maximum (acres)	1.53	8.81	18.31	8.95	18.31	8.95	19.67	6.53	19.95	18.21	19.95	18.21	19.95	18.21

Table 5-5 Sand Bar Data Summary – July 2014 and August 2015

	Sand Bars Only													
	<0.25 Acres						>0.25 Acres						All Sand Bars	
	Natural		Treated		Total <0.25		Natural		Treated		Total >0.25			
	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015	July 2014	August 2015
Number	22	28	81	59	103	87	8	3	32	20	40	23	143	110
Total Area (acres)	1.62	2.02	7.19	3.43	8.81	5.46	4.44	9.45	44.05	50.13	48.49	59.58	57.30	65.03
Minimum (acres)	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.283	0.312	0.260	0.273	0.251	0.273	<0.001	<0.001
Maximum (acres)	0.22	0.24	0.23	0.25	0.23	0.25	1.53	8.81	18.31	8.95	21.72	8.95	18.31	8.95

Table 5-6 Primary Cross Section Area and Volume Change by Average End Area Method – July 2014 to August 2015

Cross Section	Cut Area	Fill Area	Net Area Cut/Fill	Station	Distance to Next	Volume Cut	Volume Fill	Net Volume	Volume Cut	Volume Fill	Net Volume	Lateral Erosion Area	Lateral Erosion Volume	
	(ft^2)	(ft^2)	(ft^2)	(ft)	(ft)	(ft^3)	(ft^3)	(ft^3)	(yd^3)	(yd^3)	(yd^3)	(ft^2)	(ft^3)	(yd^3)
1	346.4	112.8	**-233.6**	19,386	777	231,083	245,381	14,298	8,559	9,088	**530**	**35.93**	27,916	1,034
2	248.5	518.9	**270.4**	18,609	815	174,332	302,347	128,015	6,457	11,198	**4,741**	**35**	28,835	1,068
3	179.2	222.8	**43.7**	17,794	802	253,154	249,632	-3,522	9,376	9,246	**-130**	**20.41**	16,362	606
4	452.5	400.1	**-52.5**	16,992	777	377,952	414,031	36,080	13,998	15,334	**1,336**	**146.35**	113,696	4,211
5	520.5	665.8	**145.3**	16,215	824	390,065	501,865	111,799	14,447	18,588	**4,141**	**307.25**	253,160	9,376
6	426.3	552.4	**126.0**	15,391	801	399,297	352,885	-46,412	14,789	13,070	**-1,719**	**113.54**	90,997	3,370
7	570.1	328.2	**-241.9**	14,590	688	446,839	368,510	-78,329	16,550	13,649	**-2,901**	**12.95**	8,912	330
8	728.3	742.5	**14.3**	13,902	794	375,739	528,681	152,942	13,916	19,581	**5,665**		0	0
9	218.2	589.2	**371.0**	13,108	796	231,928	515,158	283,230	8,590	19,080	**10,490**		0	0
10	364.3	704.6	**340.3**	12,311	807	379,567	518,667	139,101	14,058	19,210	**5,152**	**59.62**	48,126	1,782
11	576.1	580.4	**4.3**	11,504	805	355,093	466,517	111,424	13,152	17,278	**4,127**		0	0
12	306.6	579.3	**272.7**	10,699	811	273,121	464,024	190,902	10,116	17,186	**7,070**	**133.12**	107,965	3,999
13	366.9	565.0	**198.1**	9,888	816	341,516	567,956	226,440	12,649	21,035	**8,387**	**66.47**	54,210	2,008
14	470.5	827.7	**357.2**	9,073	787	349,474	643,518	294,045	12,943	23,834	**10,891**	**138.43**	108,936	4,035
15	417.7	807.8	**390.1**	8,286	815	298,758	566,599	267,840	11,065	20,985	**9,920**	**23.70**	19,311	715
16	315.5	582.8	**267.2**	7,471	741	243,982	380,433	136,451	9,036	14,090	**5,054**	**3**	2,128	79
17	342.7	443.6	**100.9**	6,730	848	343,090	363,269	20,179	12,707	13,454	**747**	**0.31**	266	10
18	466.5	413.1	**-53.3**	5,882	0								0	0
*final row is rounded to nearest 100				13,500	13,500	5,465,000	7,449,500	1,984,500	**202,400**	275,900	**73,500**	**1,100**	880,800	**32,600**

Table 5-7 Supplemental and Primary Cross Section Area and Volume Change by Average End Area Method – July 2014 to August 2015

Cross Section	Cut Area	Fill Area	Net Area Cut/Fill	Station	Distance to Next	Volume Cut	Volume Fill	Net Volume	Volume Cut	Volume Fill	Net Volume	Lateral Erosion Area	Lateral Erosion Volume	
	(ft^2)	(ft^2)	(ft^2)	(ft)	(ft)	(ft^3)	(ft^3)	(ft^3)	(yd^3)	(yd^3)	(yd^3)	(ft^2)	(ft^3)	(yd^3)
A	248.0	450.8	**202.8**	19,793	407	121,078	114,806	-6,272	4,484	4,252	**-232**	**29.1**	13,240	490
1	346.4	112.8	**-233.6**	19,386	505	150,956	83,931	-67,025	5,591	3,109	**-2,482**	**35.9**	26,279	973
B	252.0	219.9	**-32.1**	18,881	272	68,150	100,593	32,443	2,524	3,726	**1,202**	**68.2**	14,107	522
2	248.5	518.9	**270.4**	18,609	353	118,253	93,378	-24,875	4,380	3,458	**-921**	**35.4**	13,116	486
C	421.6	10.3	**-411.3**	18,256	462	138,876	53,882	-84,994	5,144	1,996	**-3,148**	**39.0**	13,725	508
3	179.2	222.8	**43.7**	17,794	348	114,872	82,142	-32,730	4,255	3,042	**-1,212**	**20.4**	6,365	236
D	481.8	249.8	**-232.0**	17,446	454	212,086	147,520	-64,566	7,855	5,464	**-2,391**	**16.2**	36,899	1,367
4	452.5	400.1	**-52.5**	16,992	425	194,692	209,317	14,625	7,211	7,752	**542**	**146.3**	38,122	1,412
E	464.3	585.7	**121.3**	16,567	352	173,417	220,372	46,956	6,423	8,162	**1,739**	**33.2**	59,945	2,220
5	520.5	665.8	**145.3**	16,215	336	171,604	191,236	19,633	6,356	7,083	**727**	**307.2**	54,251	2,009
F	501.9	473.5	**-28.4**	15,880	488	226,613	250,458	23,845	8,393	9,276	**883**	**16.0**	31,618	1,171
6	426.3	552.4	**126.0**	15,391	350	131,807	146,013	14,206	4,882	5,408	**526**	**113.5**	21,421	793
G	326.5	281.6	**-44.9**	15,041	451	202,299	137,593	-64,706	7,493	5,096	**-2,397**	**8.8**	4,908	182
7	570.1	328.2	**-241.9**	14,590	315	200,769	100,679	-100,090	7,436	3,729	**-3,707**	**12.9**	2,042	76
H	703.1	310.2	**-392.9**	14,274	373	266,894	196,299	-70,594	9,885	7,270	**-2,615**	**0.0**	0	0
8	728.3	742.5	**14.3**	13,902	414	284,201	267,457	-16,743	10,526	9,906	**-620**	**0.0**	0	0
I	643.6	548.5	**-95.1**	13,487	380	163,593	215,971	52,378	6,059	7,999	**1,940**	**0.0**	0	0
9	218.2	589.2	**371.0**	13,108	457	147,339	281,495	134,156	5,457	10,426	**4,969**	**0.0**	1,491	55
J	426.5	642.5	**216.0**	12,650	339	134,148	228,524	94,376	4,968	8,464	**3,495**	**6.5**	11,220	416
10	364.3	704.6	**340.3**	12,311	501	234,324	455,368	221,044	8,679	16,865	**8,187**	**59.6**	14,946	554
K	570.4	1111.8	**541.4**	11,810	306	175,335	258,788	83,452	6,494	9,585	**3,091**	**0.0**	0	0
11	576.1	580.4	**4.3**	11,504	383	225,886	224,378	-1,508	8,366	8,310	**-56**	**0.0**	11,156	413
L	604.4	592.3	**-12.2**	11,121	422	192,182	247,136	54,955	7,118	9,153	**2,035**	**58.3**	40,381	1,496
12	306.6	579.3	**272.7**	10,699	400	156,643	216,087	59,443	5,802	8,003	**2,202**	**133.1**	39,839	1,476

Cross Section	Cut Area	Fill Area	Net Area Cut/Fill	Station	Distance to Next	Volume Cut	Volume Fill	Net Volume	Volume Cut	Volume Fill	Net Volume	Lateral Erosion Area	Lateral Erosion Volume	
	(ft^2)	(ft^2)	(ft^2)	(ft)	(ft)	(ft^3)	(ft^3)	(ft^3)	(yd^3)	(yd^3)	(yd^3)	(ft^2)	(ft^3)	(yd^3)
M	476.0	500.2	**24.3**	10,299	411	173,076	218,735	45,659	6,410	8,101	**1,691**	**65.9**	27,180	1,007
13	366.9	565.0	**198.1**	9,888	401	199,570	282,024	82,454	7,391	10,445	**3,054**	**66.5**	37,995	1,407
N	629.1	842.5	**213.4**	9,488	415	228,089	346,451	118,362	8,448	12,832	**4,384**	**123.2**	54,262	2,010
14	470.5	827.7	**357.2**	9,073	425	183,686	291,334	107,647	6,803	10,790	**3,987**	**138.4**	29,398	1,089
O	394.4	544.1	**149.7**	8,648	362	147,075	244,842	97,767	5,447	9,068	**3,621**	**0.0**	4,292	159
15	417.7	807.8	**390.1**	8,286	443	244,766	416,959	172,193	9,065	15,443	**6,378**	**23.7**	23,911	886
P	686.8	1073.7	**386.9**	7,843	372	186,305	307,877	121,573	6,900	11,403	**4,503**	**84.2**	16,183	599
16	315.5	582.8	**267.2**	7,471	394	155,986	231,749	75,762	5,777	8,583	**2,806**	**2.9**	648	24
Q	477.2	595.0	**117.8**	7,077	348	142,575	180,614	38,040	5,281	6,689	**1,409**	**0.4**	128	5
17	342.7	443.6	**100.9**	6,730	406	152,520	194,762	42,242	5,649	7,213	**1,565**	**0.3**	5,963	221
R	408.8	516.0	**107.2**	6,324	442	193,473	205,382	11,908	7,166	7,607	**441**	**29.1**	6,425	238
18	466.5	413.1	**-53.3**	5,882	404	129,398	194,764	65,366	4,793	7,213	**2,421**	**0.0**	2,080	77
S	174.3	551.4	**377.0**	5,478	0	0	0	0	0	0	**0**	**10.3**	0	0
*final values rounded to nearest hundred				468,200	14,300	6,342,500	7,638,900	1,296,400	234,900	282,900	**48,000**	**1,700**	663,500	**24,600**

Table 5-8 Shoemaker Study Reach Vegetated Bars, Sand Bars, and Water/River Bed Area – July 2014 and August 2015

	July 2014		**August 2015**	
	Acres	**Percent**	**Acres**	**Percent**
	Mechanically Treated Study Reach – 246 Acres		**Mechanically Treated Study Reach – 266 Acres**	
Vegetated Bars	79.7	32%	44.0	17%
Sand Bars	51.2	21%	53.6	20%
Water/River Bed	115.1	47%	168.4	63%
Total	**246**	**100%**	**266**	**100%**
	Natural Study Reach – 116 Acres		**Natural Study Reach – 96 Acres**	
Vegetated Bars	37.7	33%	20.4	21%
Sand Bars	6.1	5%	11.5	12%
Water/River Bed	72.2	62%	64.1	67%
Total	**116**	**100%**	**96**	**100%**

Table 5-9 June 2015 High Flow Suspended Sediment Sample Data

Site	Date/Time	Type	Discharge (cfs)	Measured Concentration (mg/l)	% Finer Than 0.062 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm
XS 2-3	5/24/15 14:34	DIS	9070	488	9	17	65	94	99	100
	5/24/15 16:57	DIS	9150	548	11	19	67	93	99	100
	5/25/15 14:26	DIS	8980	436	8	15	63	94	99	100
	5/25/15 17:27	DIS	8930	498	8	15	61	91	98	100
	5/26/15 15:10	DIS	8590	526	10	16	56	85	93	100
	5/27/15 14:12	DIS	8360	536	8	14	45	73	93	100
	5/28/15 11:14	DIS	7930	332	13	21	61	93	99	100
	6/3/15 18:00	DIS	10700	394	13	22	62	94	99	100
	6/4/15 14:56	DIS	11000	343	9	20	66	96	99	100
	6/5/15 9:49	DIS	11100	445	6	15	54	84	97	100
	6/6/15 9:12	DIS	10800	512	5	12	45	89	99	100
	6/15/15 11:16	DIS	9230	371	15	25	72	96	99	99
	7/2/15 11:37	DIS	6400	211	41	52	77	95	99	100
	7/3/15 8:53	DIS	5870	194	35	46	74	95	99	100
	7/6/15 11:37	DIS	4490	160	35	48	71	90	98	100
	7/9/15 10:58	DIS	3750	103	29	42	73	93	99	100
	7/14/15 11:17	DIS	2210	84	79	92	98	99	100	100
	8/27/15 13:21	DIS	994	49	50	61	79	95	100	100

[1]values are not rounded (Porterfield, 1972)

Table 5-10 June 2015 High Flow Suspended Sediment Transport Equations by Size Class

Size Class	Equation y = SSC	X-Variable
<0.063mm	No Relation	
0.063 - 0.25mm	0.000313228*Q^1.46324	Water Discharge
0.25 - 0.5mm	5.49746e-006*Q^1.840692	Water Discharge
0.5 - 1mm	3.66218e-005*Q^1.47645	Water Discharge
0.5 - 1mm	2.49043e-005*Q^1.34534	Water Discharge
1 - 2mm	Zero Transport	
>2mm	No Relation	

Table 5-11 June 2015 High Flow Sediment Load Totals by Size Class

	SS Loads (tons)	Bedload (tons)	Total (tons)
<0.063mm	99,923	92	100,016
0.063-0.25mm	236,316	4,795	241,110
0.25-0.5mm	135,106	32,502	167,607
0.5-1mm	28,587	91,050	119,637
1-2mm	5,593	168,224	173,817
>2mm	-	164,398	164,398
Total*	**505,000**	**461,000**	**966,000**

*only the Total is rounded as per Porterfield (1972)
Summing then rounding only the totals yields 967,000 tons

Table 5-12 June 2015 High Flow Sediment Sample Summary

Site	Date/Time	Discharge (cfs)	Measured Concentration (mg/l)	Measured SS Discharge (t/d)	Measured Bedload Discharge (t/d)	Bedload as Residual (t/d)	Measured Bedload + SS Discharge (t/d)	MEP Total Load (t/d)	MEP Total Sand Load >0.625mm (t/d)	Ratio of SS to Total
XS 2-3	5/24/15 14:34	9,070	488	11,940	NA	6,695	NA	**18,635**	17,586	64%
XS 2-3	5/24/15 16:57	9,150	548	13,539	NA	6,846	NA	**20,385**	18,898	66%
XS 2-3	5/25/15 14:26	8,980	436	10,578	NA	5,805	NA	**16,383**	15,576	65%
XS 2-3	5/25/15 17:27	8,930	498	12,012	NA	6,155	NA	**18,167**	17,217	66%
XS 2-3	5/26/15 15:10	8,590	526	12,193	NA	6,038	NA	**18,231**	17,020	67%
XS 2-3	5/27/15 14:12	8,360	536	12,090	NA	7,721	NA	**19,811**	18,801	61%
XS 2-3	5/28/15 11:14	7,930	332	7,102	NA	5,301	NA	**12,403**	11,470	57%
XS 2-3	6/3/15 18:00	10,700	394	11,383	NA	8,479	NA	**19,862**	18,346	57%
XS 2-3	6/4/15 14:56	11,000	343	10,196	NA	13,622	NA	**23,818**	22,893	43%
XS 2-3	6/5/15 9:49	11,100	445	13,322	NA	12,461	NA	**25,784**	24,947	52%
XS 2-3	6/6/15 9:12	10,800	512	14,937	NA	16,045	NA	**30,982**	30,295	48%
XS 2-3	6/15/15 11:16	9,230	371	9,255	NA	9,590	NA	**18,845**	17,440	49%
XS 2-3	7/2/15 11:37	6,400	211	3,653	NA	4,467	NA	**8,120**	6,589	45%
XS 2-3	7/3/15 8:53	5,870	194	3,077	NA	4,737	NA	**7,814**	6,723	39%
XS 2-3	7/6/15 11:37	4,490	160	1,937	NA	3,692	NA	**5,629**	4,922	34%
XS 2-3	7/9/15 10:58	3,750	103	1,041	NA	2,061	NA	**3,102**	2,797	34%
XS 2-3	7/14/15 11:17	2,210	84	502	NA	*	NA	NA	NA	NA
XS 2-3	8/27/15 13:21	994	49	131	NA	416	NA	**546**	474	24%

* MEP grain size error code

Table 5-13 2015 Bed and Bar Sample Summary

Field ID	Type	Date	Description	Feature	5-									Mass (g)	Dry Bulk Density (g/cm3)
					D5	D16	D25	D35	D50	D65	D75	D84	D90		
1	Bulk	8/26/15	lateral bar lightly vegetated	Bar	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.5 mm	0.7 mm	0.8 mm	1,206	*na*
3	Bulk	8/26/15	unvegetated active bar coarse lens	Bar	0.2 mm	0.3 mm	0.4 mm	0.5 mm	1.0 mm	1.8 mm	2.6 mm	3.7 mm	4.7 mm	1,012	*na*
4	Bulk	8/26/15	unvegetated active bar fine lens	Bar	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.2 mm	1.8 mm	995	*na*
7	Bulk	8/26/15	emergent bar - unvegetated	Bar	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.7 mm	1.2 mm	1.9 mm	3.0 mm	4.1 mm	1,872	*na*
8	Bulk	8/26/15	US end of large lightly vegetated bar	Bar	0.1 mm	0.2 mm	0.4 mm	0.6 mm	2.0 mm	3.8 mm	5.3 mm	7.2 mm	8.8 mm	1,328	*na*
12	Bulk	8/26/15	lateral bar lightly vegetated below XS13	Bar	0.1 mm	0.3 mm	0.4 mm	0.7 mm	1.6 mm	2.8 mm	3.8 mm	4.9 mm	5.9 mm	888	*na*
13	Bulk	8/26/15	Fine component of large 1.5' high lateral bar near XS16	Bar	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.7 mm	1.6 mm	2.7 mm	4.1 mm	5.8 mm	1,090	*na*
14	Bulk	8/26/15	Coarse component of large 1.5' high lateral bar near XS16	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.6 mm	2.3 mm	3.3 mm	4.6 mm	1,434	*na*
19	Bulk	8/26/15	Fresh lateral bar above XS1	Bar	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.8 mm	1.0 mm	1.4 mm	1.8 mm	1,168	*na*
21	Bulk	8/26/15	High new bar	Bar	0.1 mm	0.2 mm	0.3 mm	0.5 mm	0.9 mm	1.7 mm	2.4 mm	3.4 mm	4.5 mm	1,126	*na*
33	Bulk	8/27/15	Bar near XS6	Bar	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm	1.4 mm	1.8 mm	976	na
2	Bulk	8/26/15	active dune field in north channel	Bed	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm	1.5 mm	2,438	*na*
5	Bulk	8/26/15	Active dune 2° flow channel	Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	1.0 mm	1,690	*na*
6	Bulk	8/26/15	Dune 1° flow channel	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.4 mm	2.0 mm	2.7 mm	1,130	*na*
9	Bulk	8/26/15	Dune 2° flow channel	Bed	0.2 mm	0.4 mm	0.5 mm	0.6 mm	0.8 mm	1.1 mm	1.5 mm	1.9 mm	2.3 mm	992	*na*
11	Bulk	8/26/15	Same-all size classes seem mixed even with fine dune surfaces	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.5 mm	2.4 mm	3.9 mm	1,724	*na*
15	Bulk	8/26/15	Very fine flat dune	Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.8 mm	1.0 mm	1.4 mm	1.9 mm	1,330	*na*
16	Bulk	8/26/15	Coarser bedform 0.1' above water surface	Bed	0.2 mm	0.3 mm	0.3 mm	0.5 mm	0.8 mm	1.3 mm	1.9 mm	2.7 mm	3.7 mm	1,016	*na*
17	Bulk	8/26/15	Submerged bar @ XS17	Bed	0.2 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.1 mm	1.7 mm	1,202	*na*
18	Bulk	8/26/15	XS1	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.5 mm	2.2 mm	3.0 mm	2,208	*na*
20	Bulk	8/26/15	Main thread (N) dune	Bed	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.2 mm	1.8 mm	2.5 mm	3.7 mm	5.1 mm	2,026	*na*
24	Bulk	8/27/15	tertiary channel near NB XS3	Bed	0.3 mm	0.6 mm	0.9 mm	1.2 mm	1.9 mm	2.6 mm	3.3 mm	4.2 mm	5.1 mm	2,322	*na*
27	Bulk	8/27/15	Main channel	Bed	0.2 mm	0.4 mm	0.6 mm	1.1 mm	2.6 mm	4.6 mm	6.8 mm	9.4 mm	11.7 mm	1,502	*na*
28	Bulk	8/27/15	N. channel around Tx Bar complex @XS5	Bed	0.3 mm	0.5 mm	0.7 mm	1.0 mm	1.6 mm	2.5 mm	3.3 mm	4.5 mm	5.5 mm	1,161	na
29	Bulk	8/27/15	Same channel S side	Bed	0.3 mm	0.3 mm	0.5 mm	0.6 mm	1.0 mm	1.5 mm	2.1 mm	3.0 mm	3.8 mm	2,142	na
31	Bulk	8/27/15	1° flow channel along south bank near BSTEM XS5	Bed	0.3 mm	0.4 mm	0.7 mm	1.2 mm	2.1 mm	3.1 mm	4.0 mm	5.0 mm	5.8 mm	2,126	na
32	Bulk	8/27/15	South channel below XS5 near property boundary	Bed	0.1 mm	0.2 mm	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.4 mm	2.0 mm	1,784	na
35	Bulk	8/27/15		Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.4 mm	0.6 mm	0.7 mm	1.0 mm	1.5 mm	1,806	na
22	BD	8/27/15	DS end of XS2 bar-unvegetated	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.3 mm	1.7 mm	2.5 mm	3.3 mm	552	1.79

Field ID	Type	Date	Description	Feature	5-									Mass (g)	Dry Bulk Density (g/cm3)
					D5	D16	D25	D35	D50	D65	D75	D84	D90		
23	BD	8/27/15	DS end of XS2 bar-lightly vegetated	Bar	0.2 mm	0.4 mm	0.5 mm	0.6 mm	0.8 mm	1.3 mm	1.7 mm	2.4 mm	3.3 mm	550	1.78
25	BD	8/27/15	fine lobe	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	1.0 mm	1.8 mm	2.6 mm	3.8 mm	5.0 mm	523	1.69
26	BD	8/27/15	coarser lobe	Bar	0.2 mm	0.4 mm	0.5 mm	0.8 mm	2.0 mm	3.4 mm	4.9 mm	6.7 mm	8.1 mm	470	1.52
30	BD	8/27/15	Mid channel new bar on XS5	Bar	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.9 mm	1.6 mm	2.3 mm	3.5 mm	4.8 mm	589	1.91
34	BD	8/27/15	Near XS8-highly braided 1.5' above WSE	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.6 mm	2.3 mm	3.2 mm	4.0 mm	539	1.74
			For the 6 bulk density samples:	**mean**	0.19	0.33	0.45	0.62	1.07	1.81	2.60	3.67	4.73		1.74
				min	0.16	0.28	0.39	0.55	0.81	1.25	1.74	2.43	3.26		1.52
				max	0.24	0.37	0.50	0.81	1.98	3.41	4.92	6.68	8.06		1.91

Table 8-1 Shoemaker Island FSM Experiment Monitored Flow Events, Field Efforts, Total River Flow at the Grand Island Gaging Station

	Program Benchmarks	Post SDMF Field Effort: 25 March 2013 to 3 April 2013	April 2013 SDMF (12 April 2013 to 18 April 2013)		Post SDMF Field Effort: 26 April 2013 to 29 April 2013	Fall 2013 High Flow (24 September 2013 to 1 November 2013)		Pre June 2014 High Flow Field Effort: 5 May 2014 to 9 May 2014	June 2014 High Flow (6 June 2014 to 5 July 2014)		Post June 2014 High Flow Field Effort: 21 July 2014 to 31 July 2014	June 2015 High Flow (11 May 2015 to 20 July 2015)		August 2015 Field Effort: 24 August 2015 to 2 September 2015
			Volume	% of Benchmark		Volume	% of Benchmark		Volume	% of Benchmark		Volume	% of Benchmark	
Peak Instantaneous Discharge, cfs	NA		3,840	NA		10,600	NA		8,800	NA		16,100	NA	
3-day Peak Mean Discharge, cfs	5,000 – 8,000		3,552	44%		9,700	121%		7,320	92%		15,700	196%	
Volume, acre-feet (un-rounded, for flows above 2,000 cfs)	50,000 – 75,0000		33,743	45%		248,270	331%		181,270	242%		1.231 million	1641%	
Duration, Days (for flows above 2,000 cfs)	3		6			28			30			72		

Table 8-2 Shoemaker Study Reach – 3 Year Breakdown

	April 2013		July 2014		August 2015	
	Acres	Percent	Acres	Percent	Acres	Percent
	Mechanically Treated Study Reach - 252 Acres		Mechanically Treated Study Reach – 246 Acres		Mechanically Treated Study Reach – 266 Acres	
Vegetated Bars	46.1	18%	79.7	32%	44.0	17%
Sand Bars	54.3	22%	51.2	21%	53.6	20%
Water/River Bed	151.6	60%	115.1	47%	168.4	63%
Total	252.0	100%	246	100%	266.0	100%
	Natural Study Reach - 110 Acres		Natural Study Reach – 116 Acres		Natural Study Reach – 96 Acres	
Vegetated Bars	27.9	25%	37.7	33%	20.4	21%
Sand Bars	0.7	1%	6.1	5%	11.5	12%
Water/River Bed	81.4	74%	72.2	62%	64.1	67%
Total	110.0	100%	116	100%	96.0	100%

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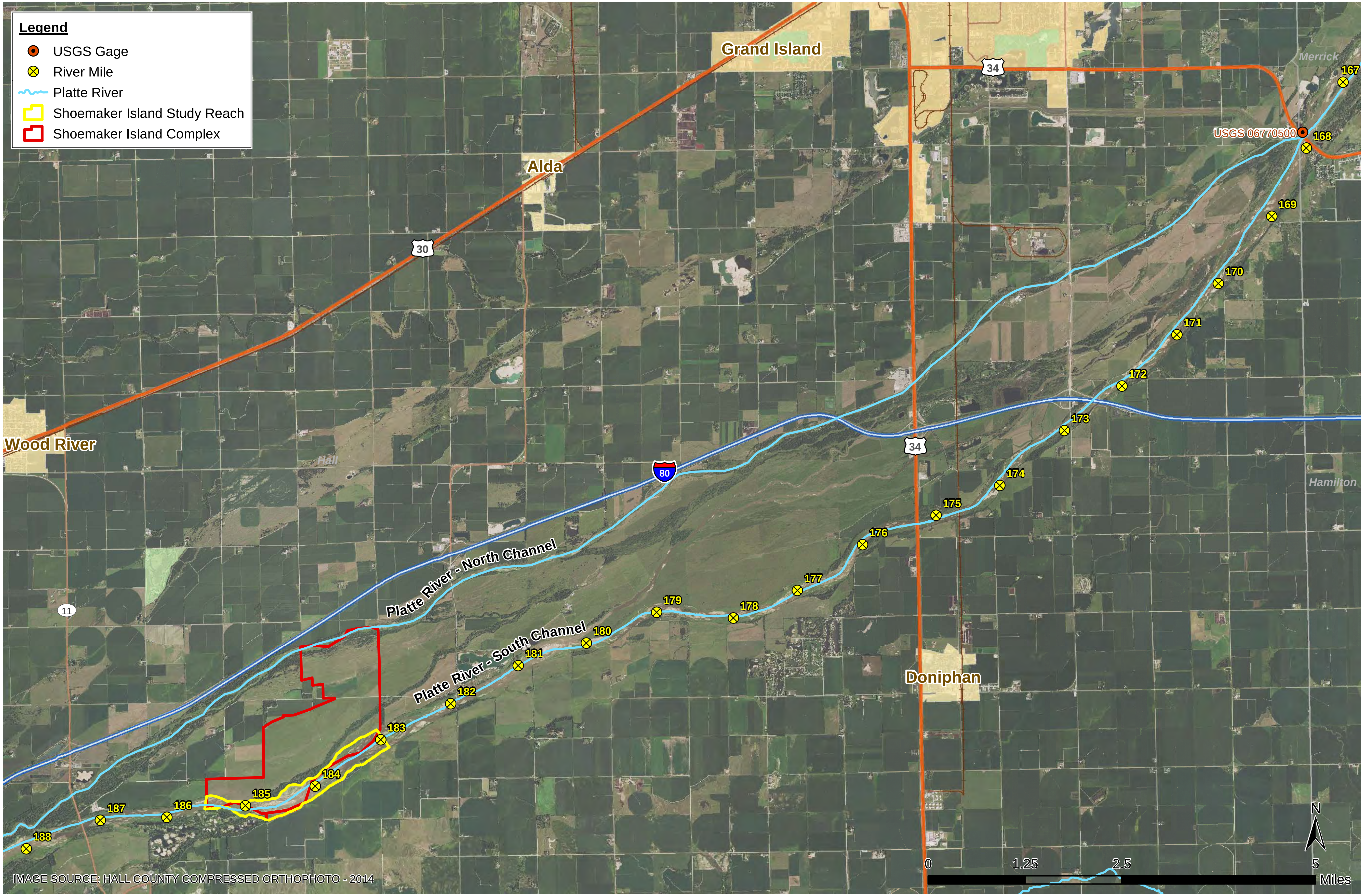
Figures

FIGURES



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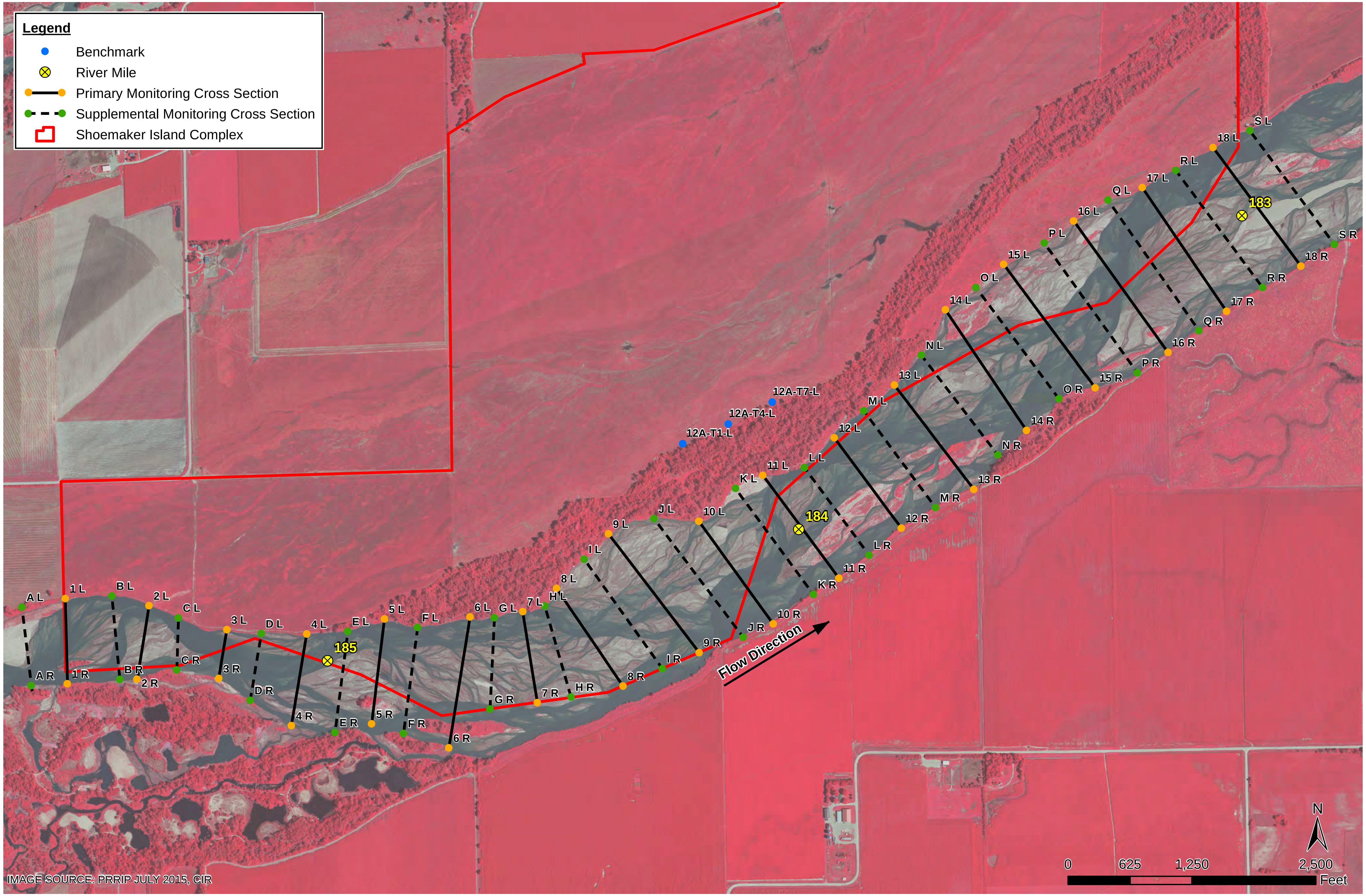
SITE MAP

SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

FIGURE	3-1
DRAWING NO.	-
FILE NAME	-
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	MAY 2016
CHECKED BY	KMD
DRAWN BY	JKP
DESIGNED BY	-
PROJECT MGR.	DLB



MONITORING CROSS SECTION LOCATIONS

SHOEMAKER ISLAND FSM PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

FIGURE	3-2
DRAWING NO.	–
FILE NAME	–
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	MAY 2016
CHECKED BY	KMD
DRAWN BY	JKP
DESIGNED BY	–
PROJECT MGR.	DLB

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Figure 4-1 February 2015 Ice Floe Through the Shoemaker Study Reach

Figure 4-2 Schematic Figure Showing Scour Chain

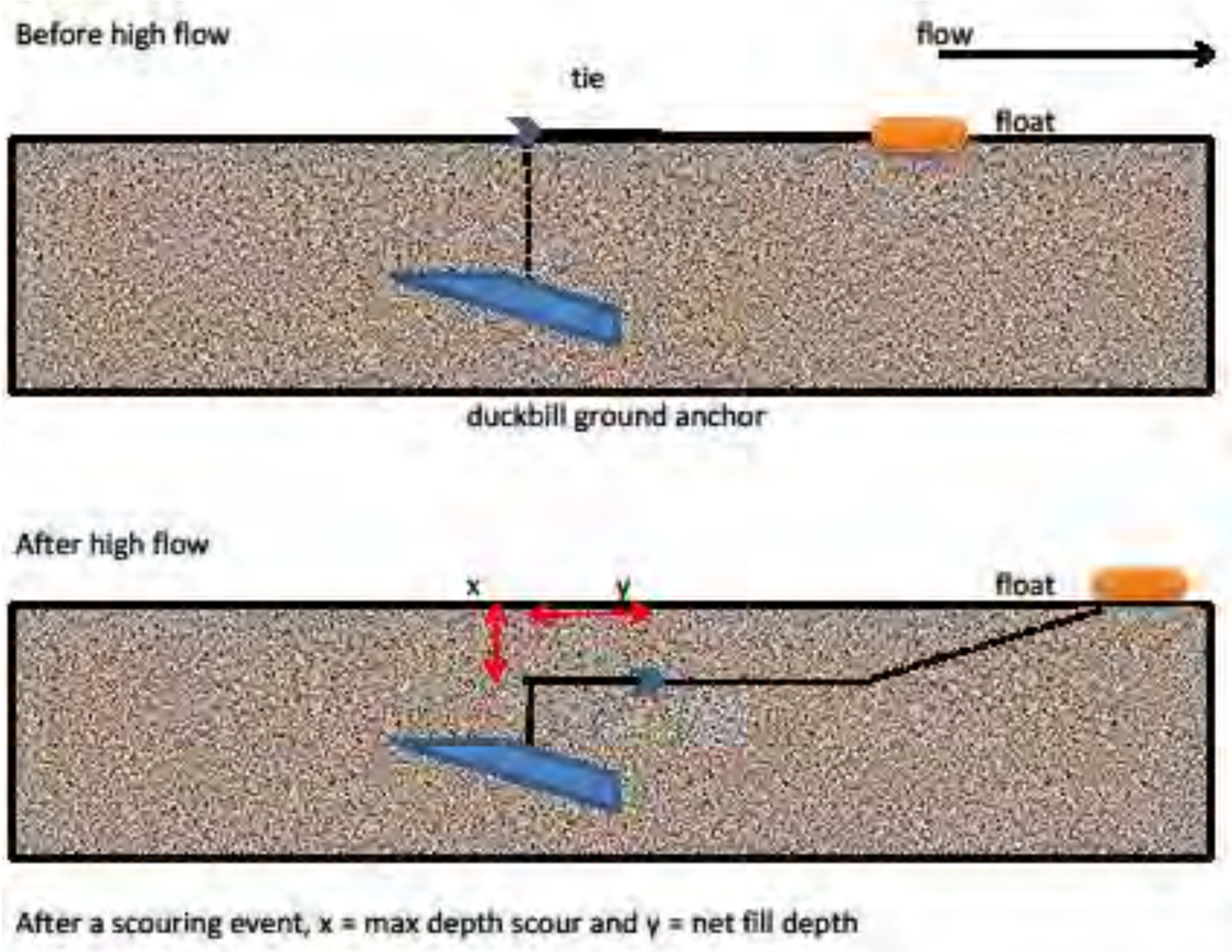


Figure 5-1 Hydrograph Grand Island Gage (USGS 06770500) Total River Flow (TRF) with July 2014 and August 2015 Field Efforts

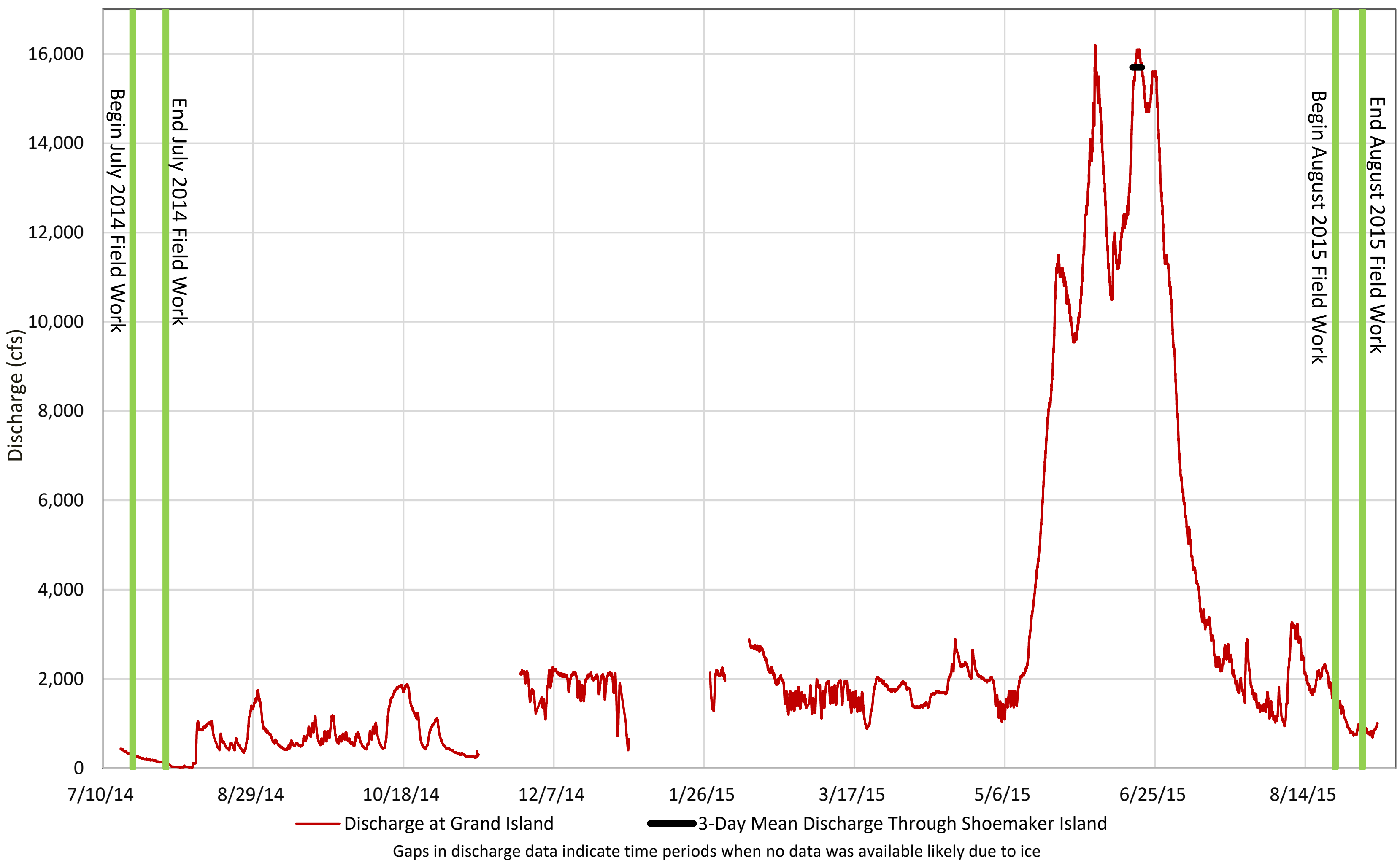


Figure 5-2 Stage Discharge Relation for Shoemaker Study Reach – June 2015 High Flow

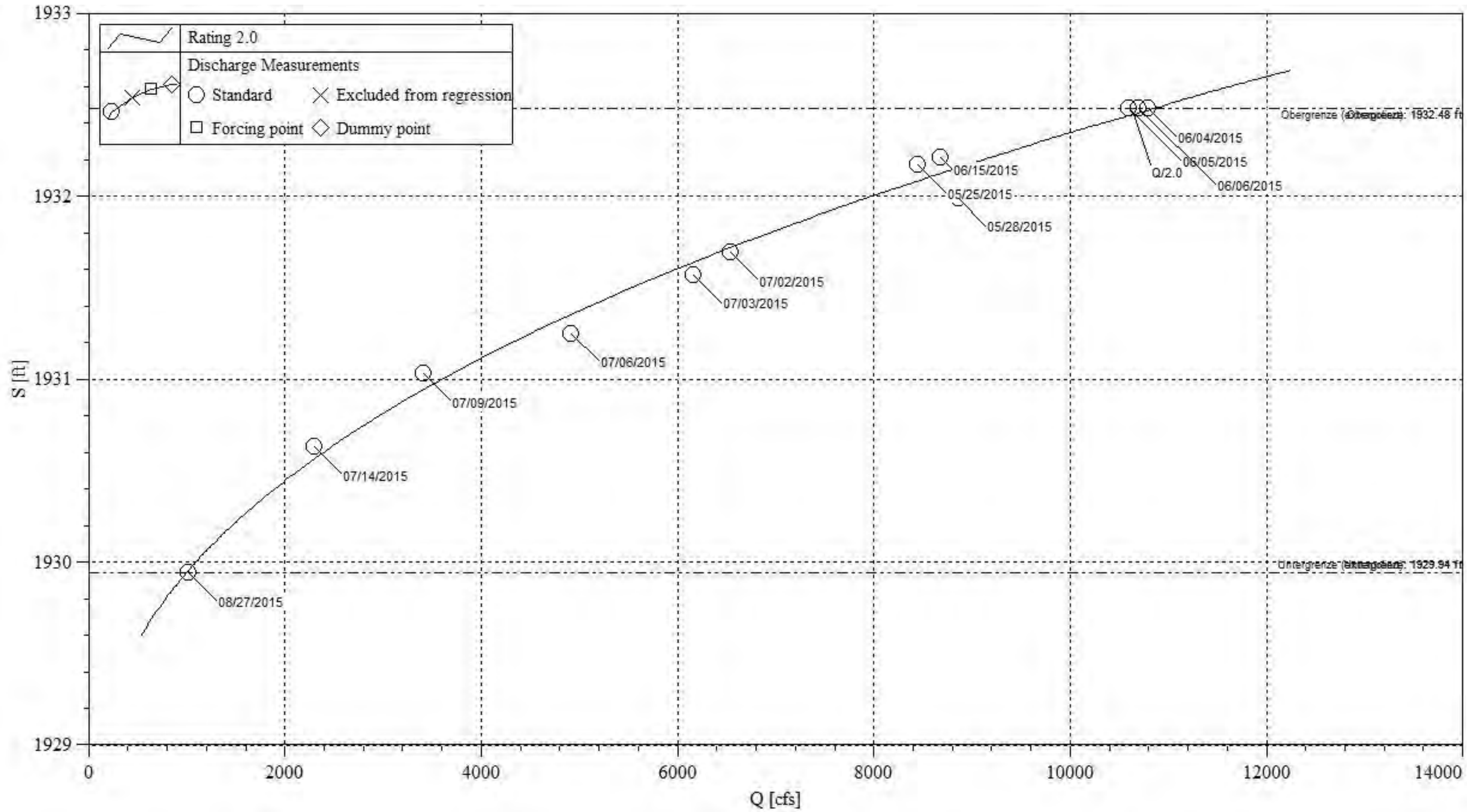


Figure 5-3 Shoemaker Reach Split Flow Discharge and Sampling Events During June 2015 High Flow

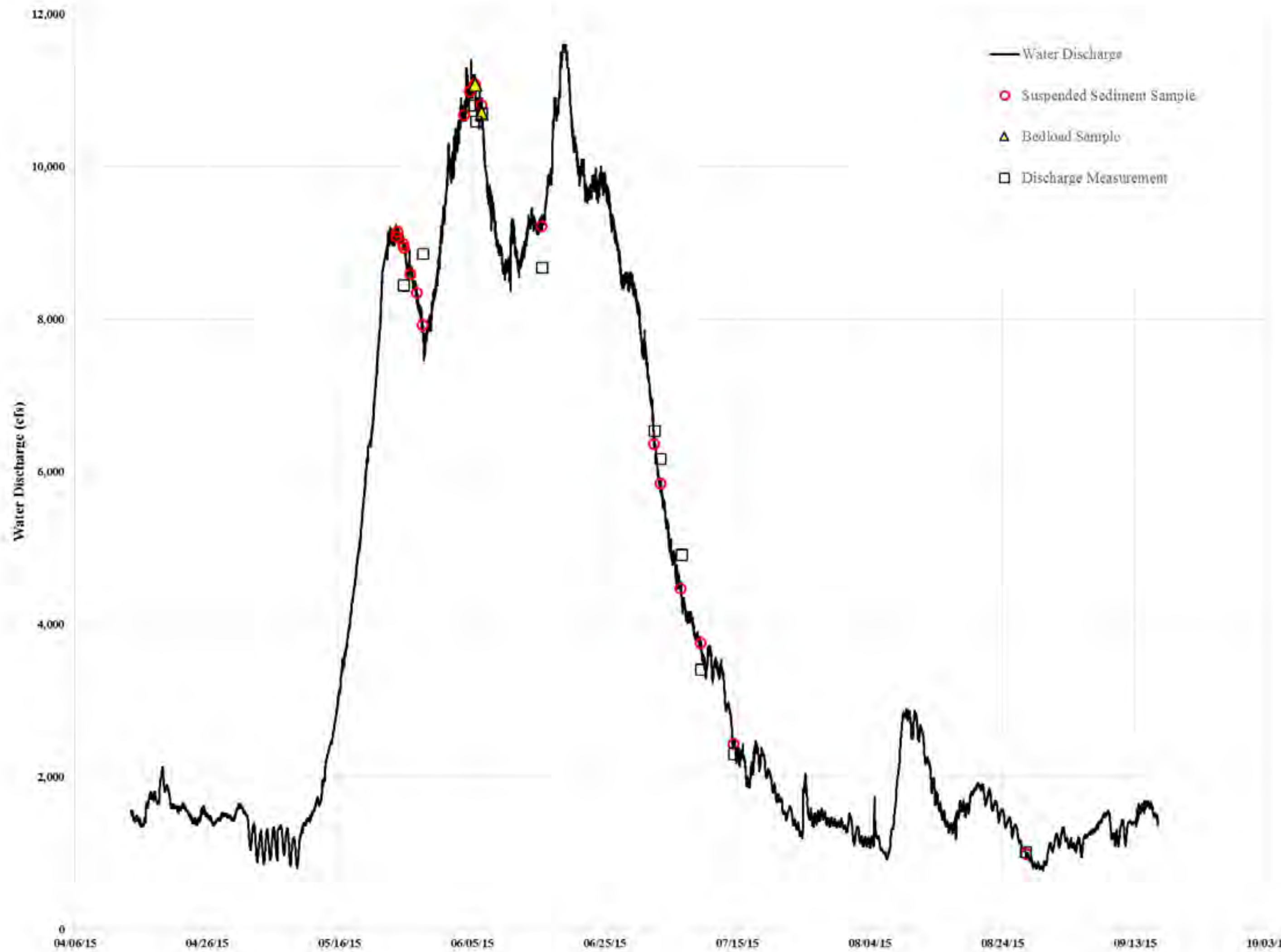
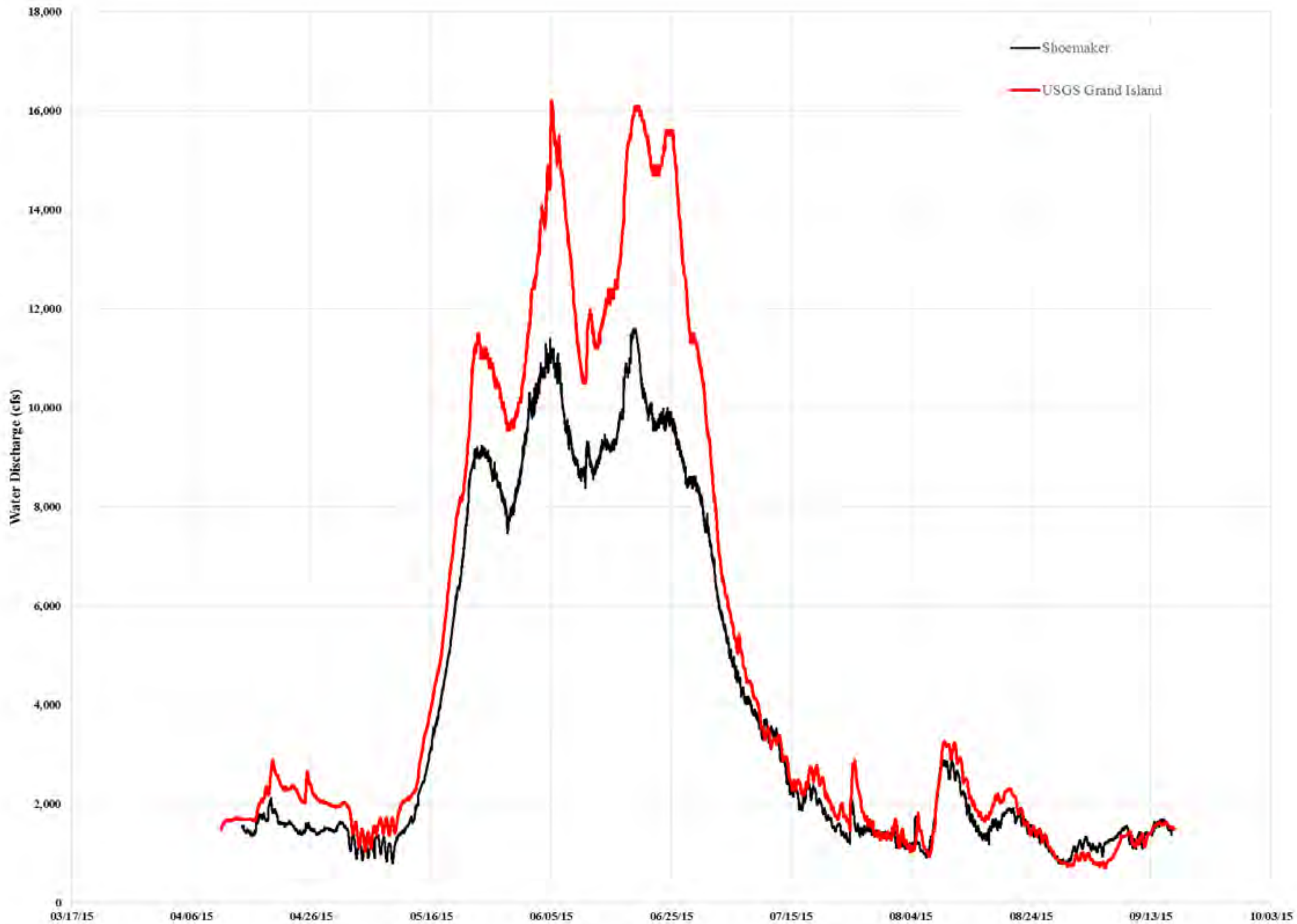
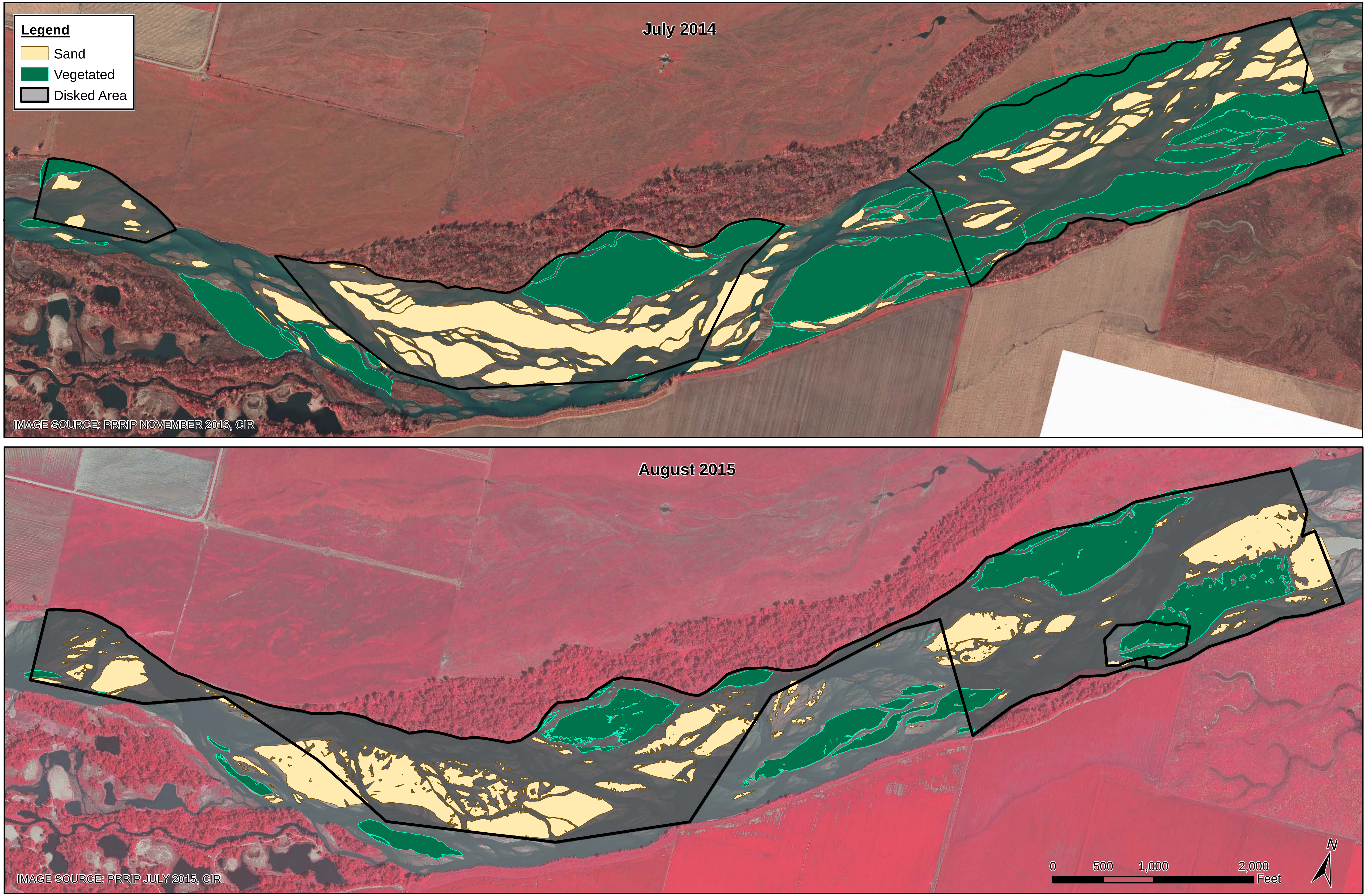


Figure 5-4 Shoemaker Reach Split Flow Discharge and USGS Total River Flow Discharge at Grand Island – June 2015 High Flow





BAR ATTRIBUTES
JULY 2014 TO AUGUST 2015

SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

FIGURE	5-5
DRAWING NO.	--
FILE NAME	--
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	AUG 2016
CHECKED BY	KMD
DRAWN BY	JKP
DESIGNED BY	--
PROJECT MGR.	DLB

Figure 5-6 Area of All Bars Surveyed – July 2014 and August 2015

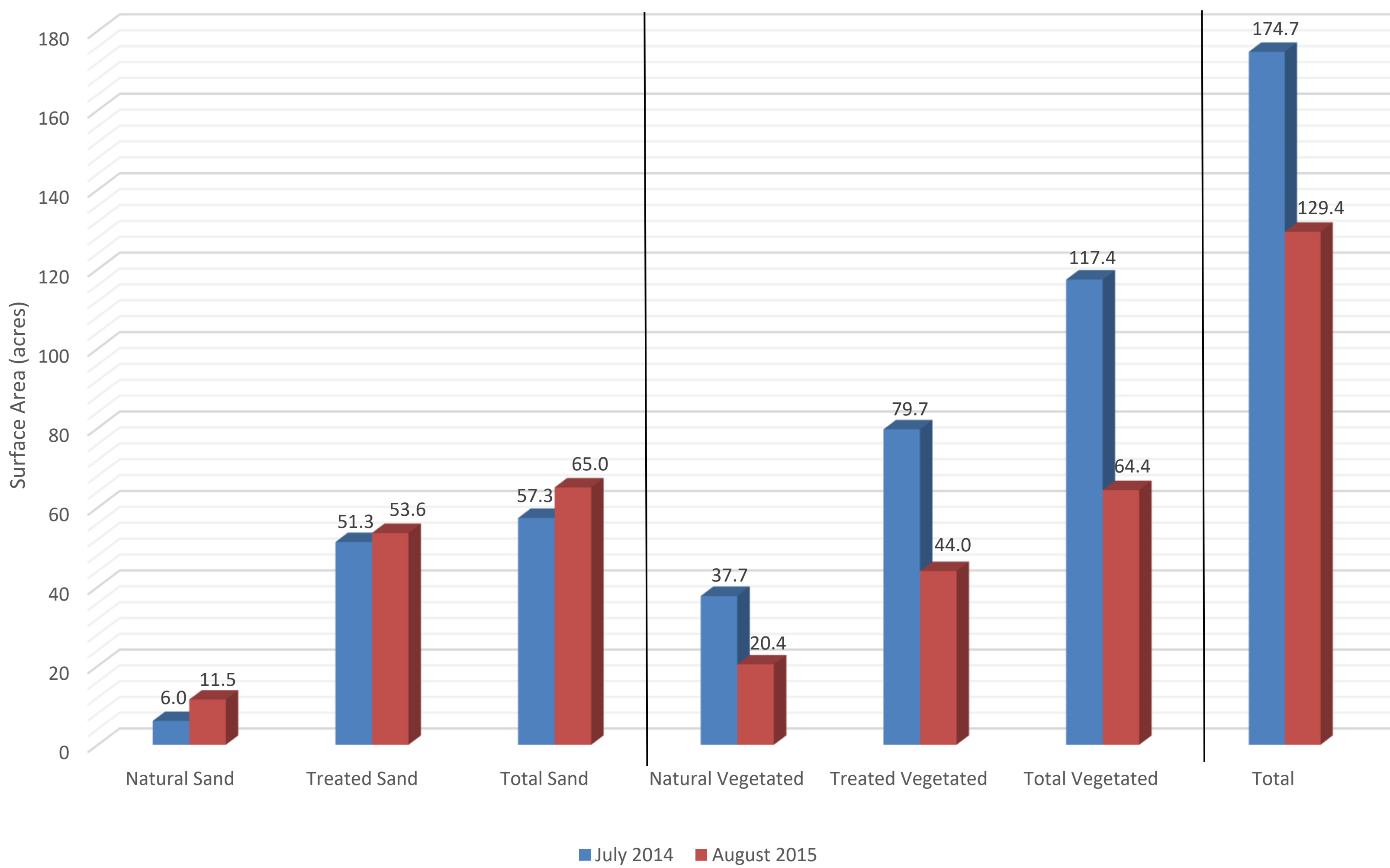


Figure 5-7 Sand Bars Surveyed – July 2014 and August 2015

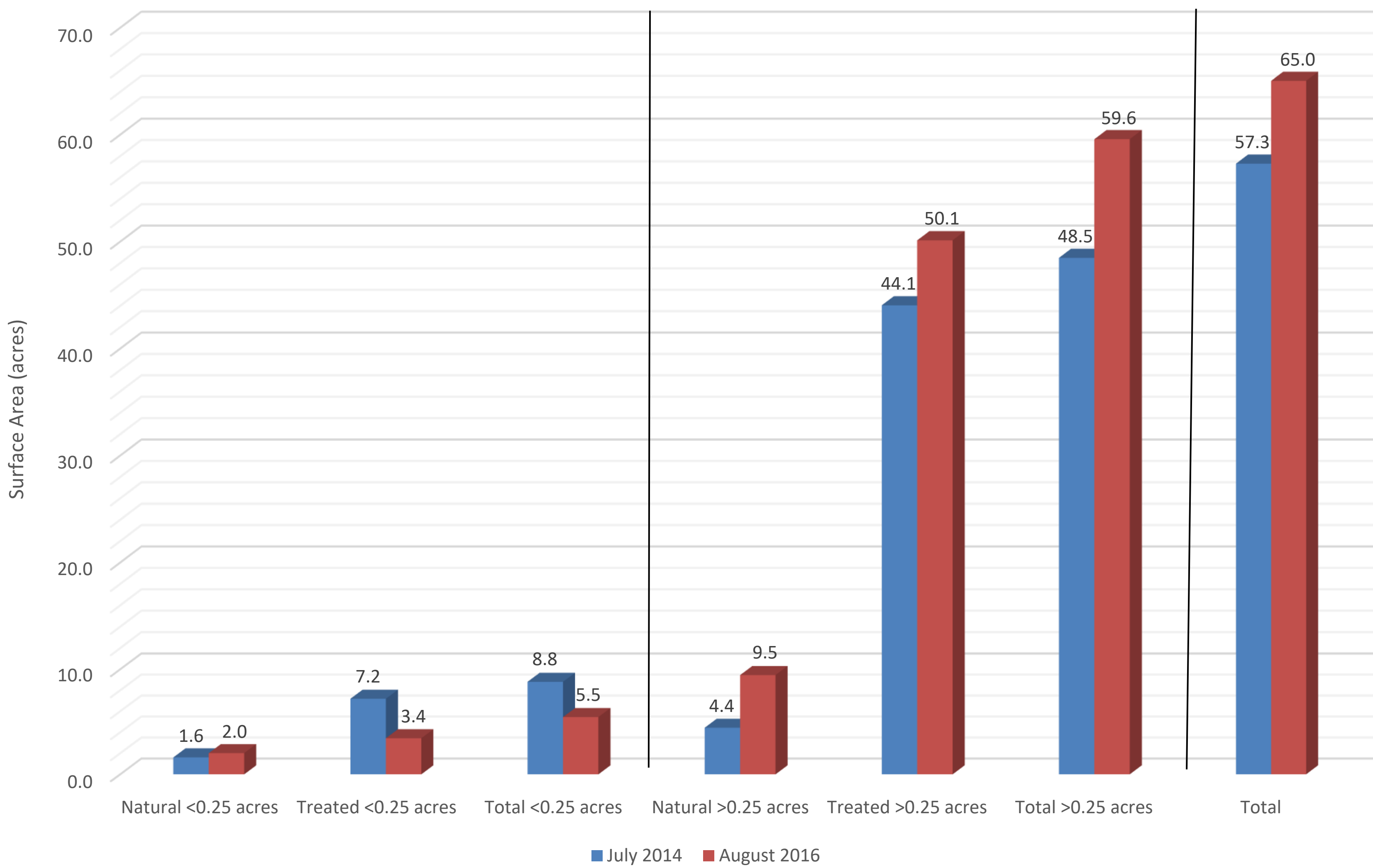


Figure 5-8 Mean Sand Bar Height Above 1,200 cfs TRF Stage - August 2015

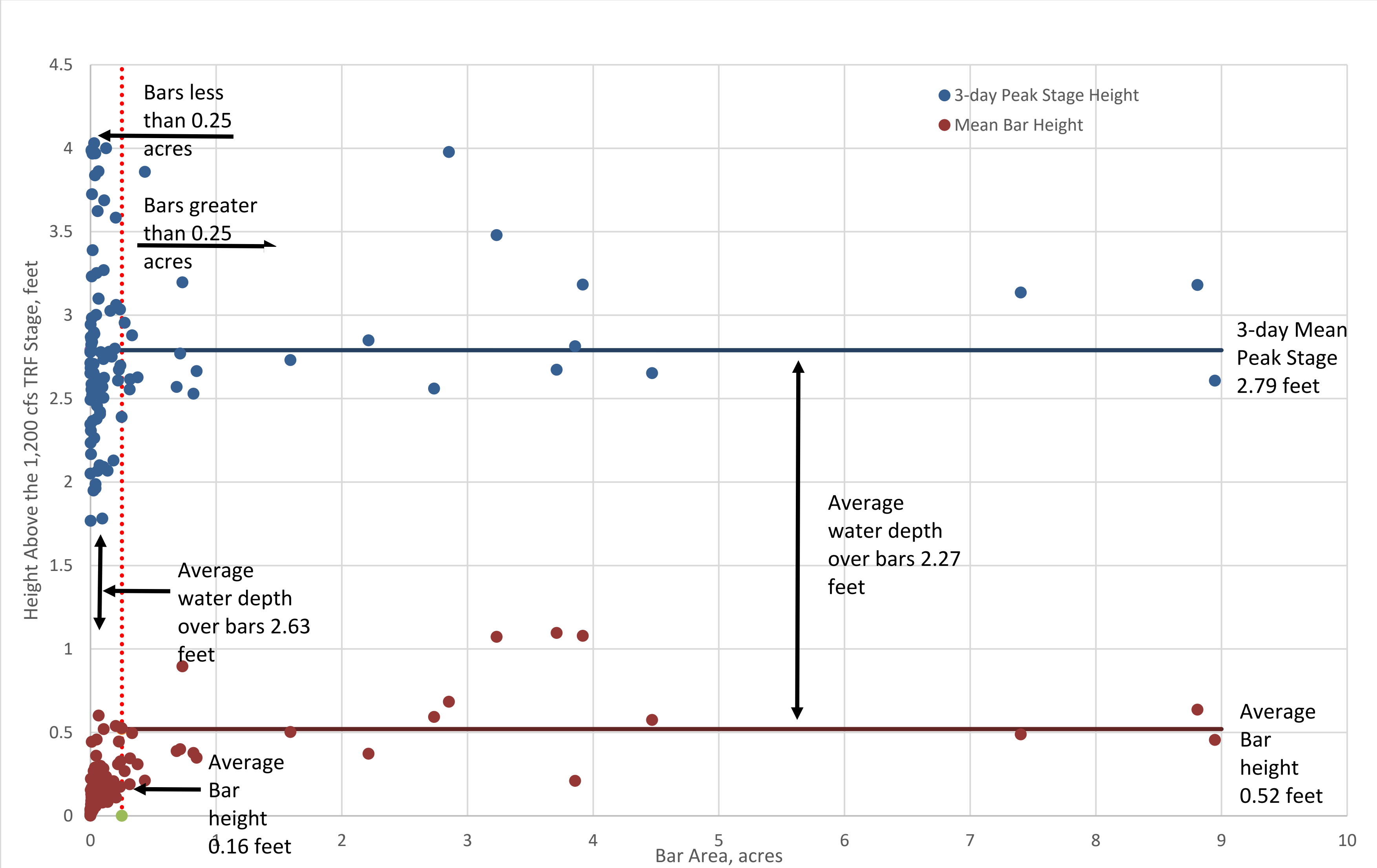


Figure 5-9 Typical Primary Cross Section – Bottom Profile – July 2014 and August 2015

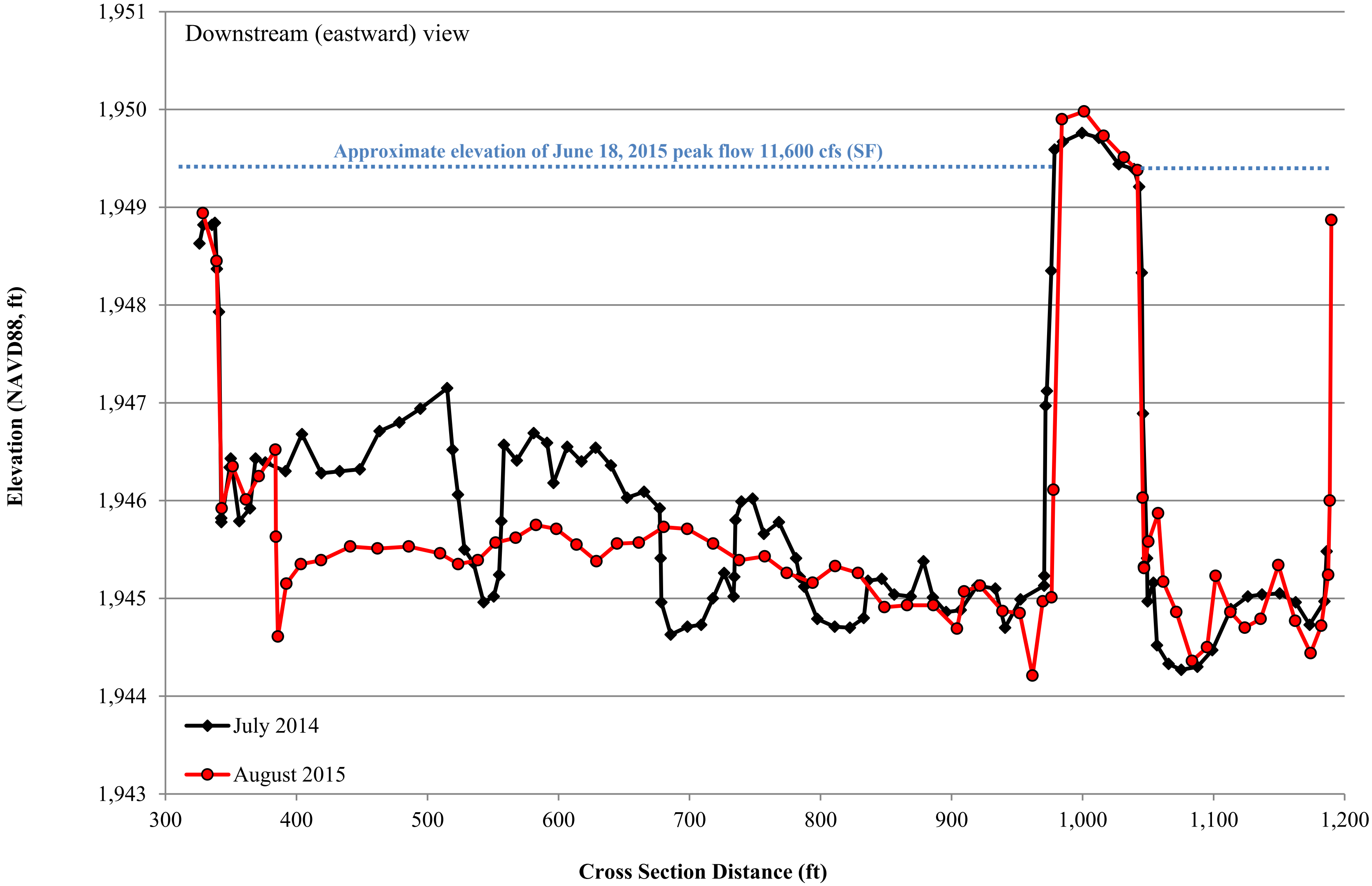


Figure 5-10 Cumulative and Net Volume Change at the 37 Primary and Supplemental Cross Sections – August 2015

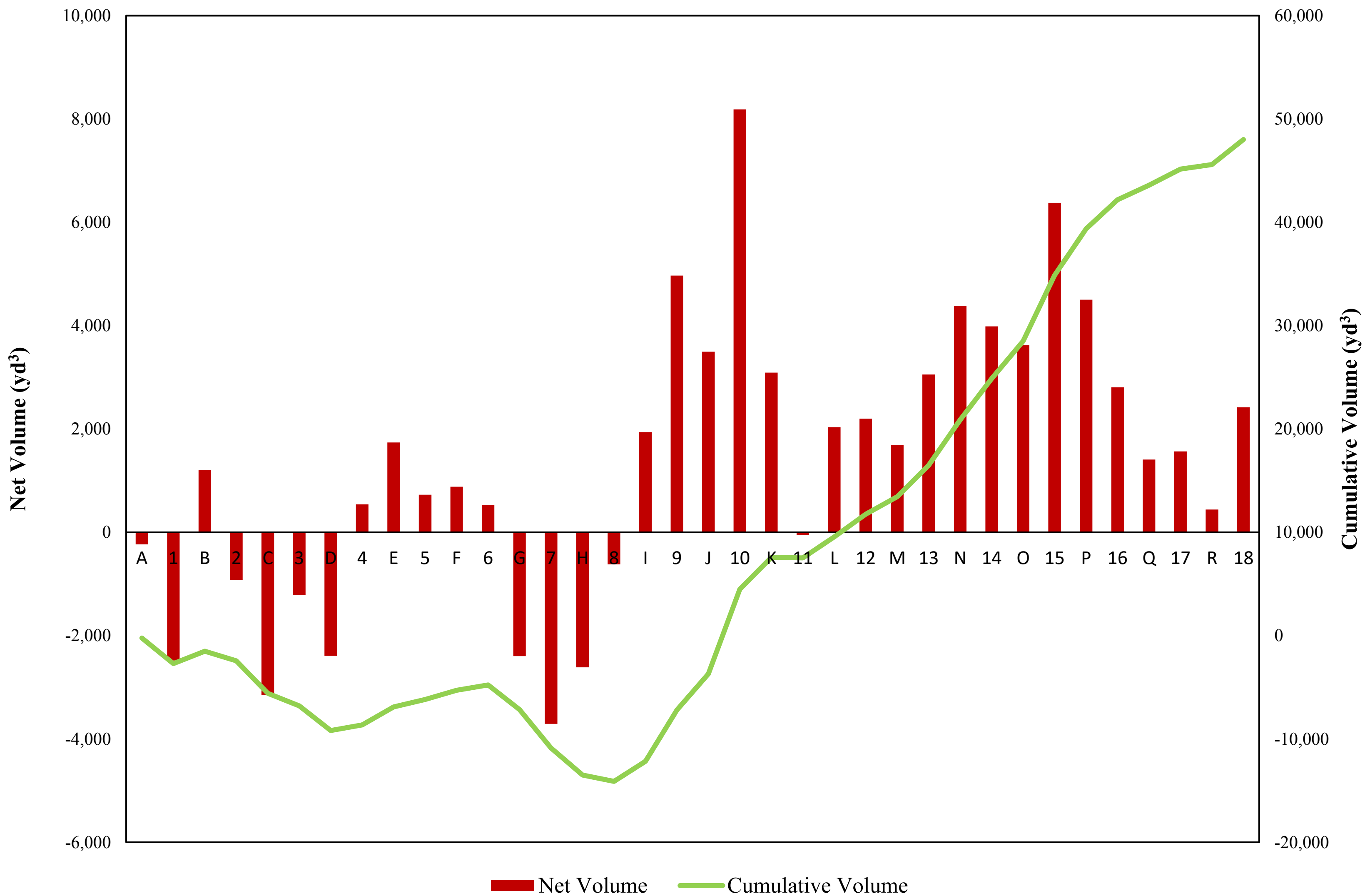
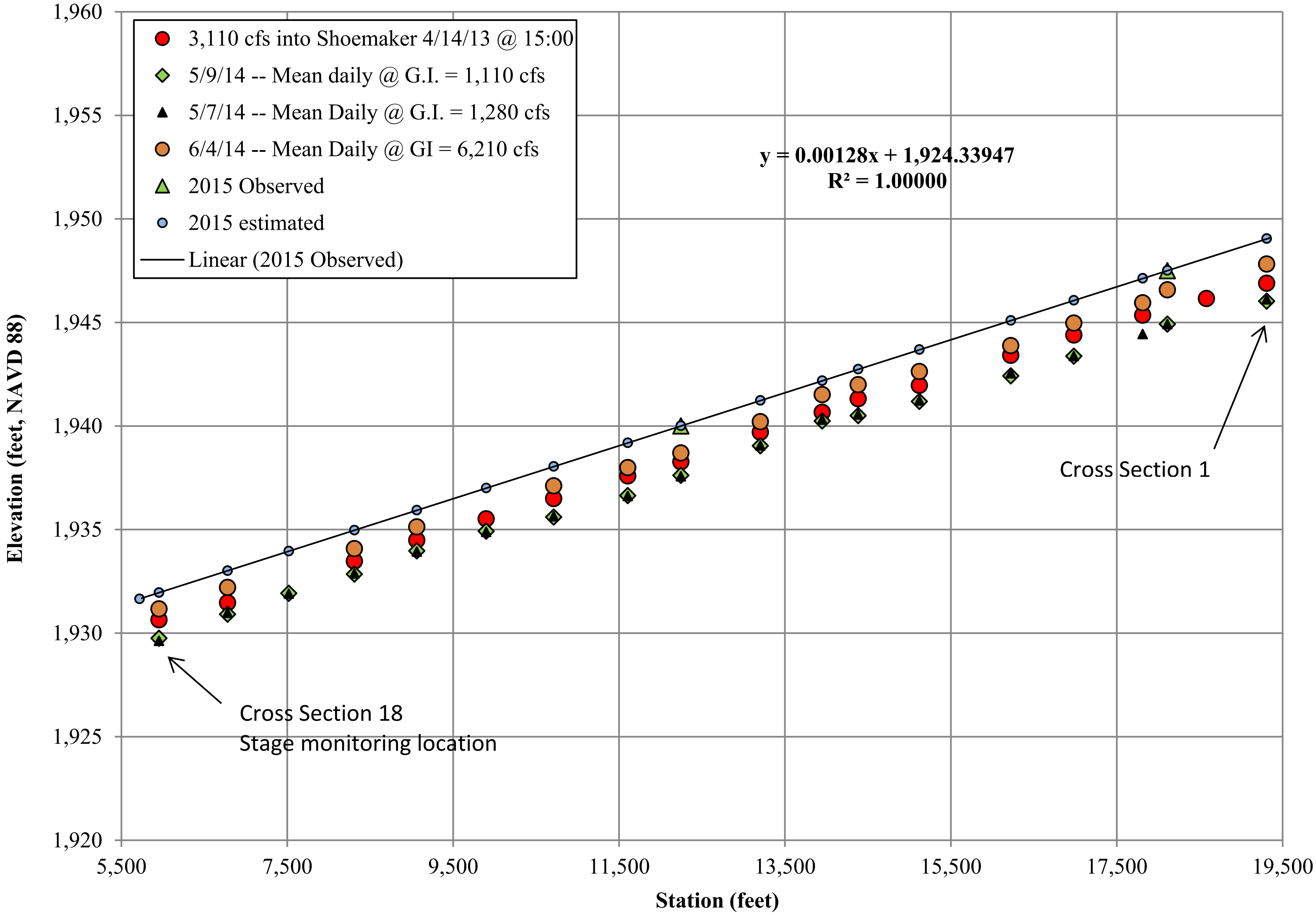


Figure 5-11 Platte River Water Surface Slope Profile Through the Shoemaker Study Reach



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VEGETATION PLOTS

SHOEMAKER ISLAND FSM
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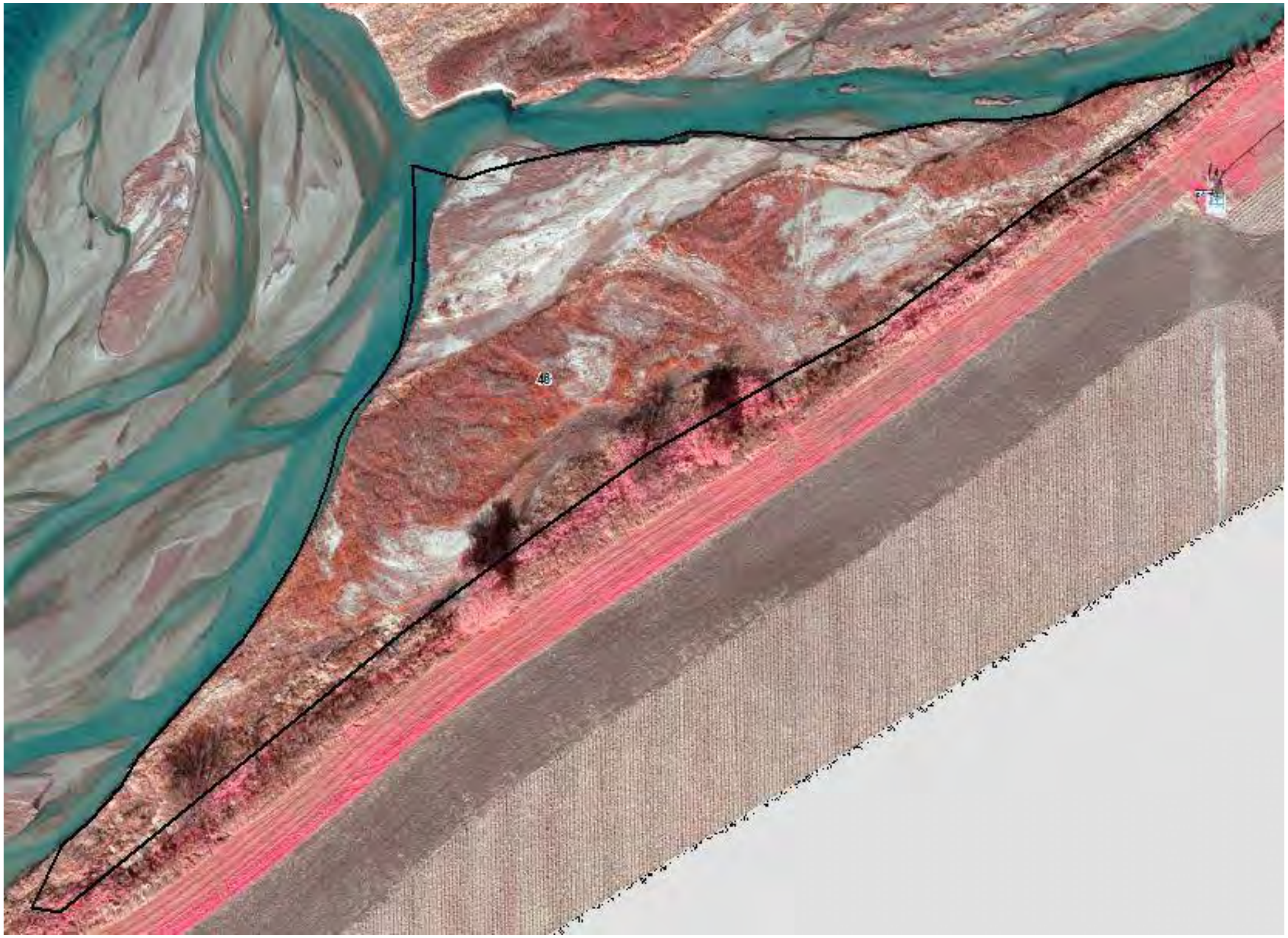
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

FIGURE	5-12
DRAWING NO.	--
FILE NAME	--
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	JULY 2016
CHECKED BY	KMD
DRAWN BY	MAW
DESIGNED BY	MAW
PROJECT MGR.	DLB

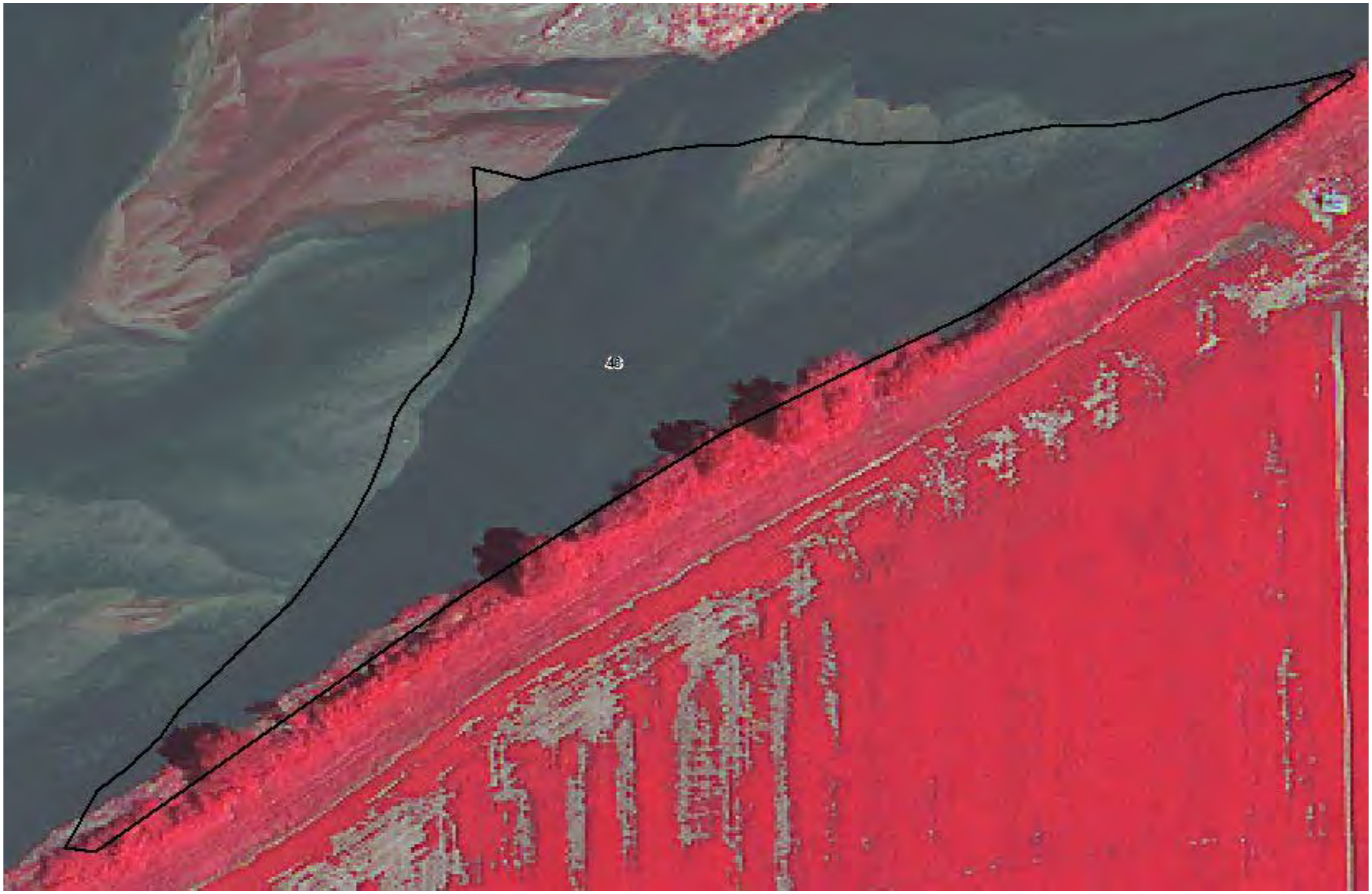
Figure 5-13 Bar 46 in July 2014 (November 2014 Aerial)



The boundary of the bar in July 2014 is outlined in black.

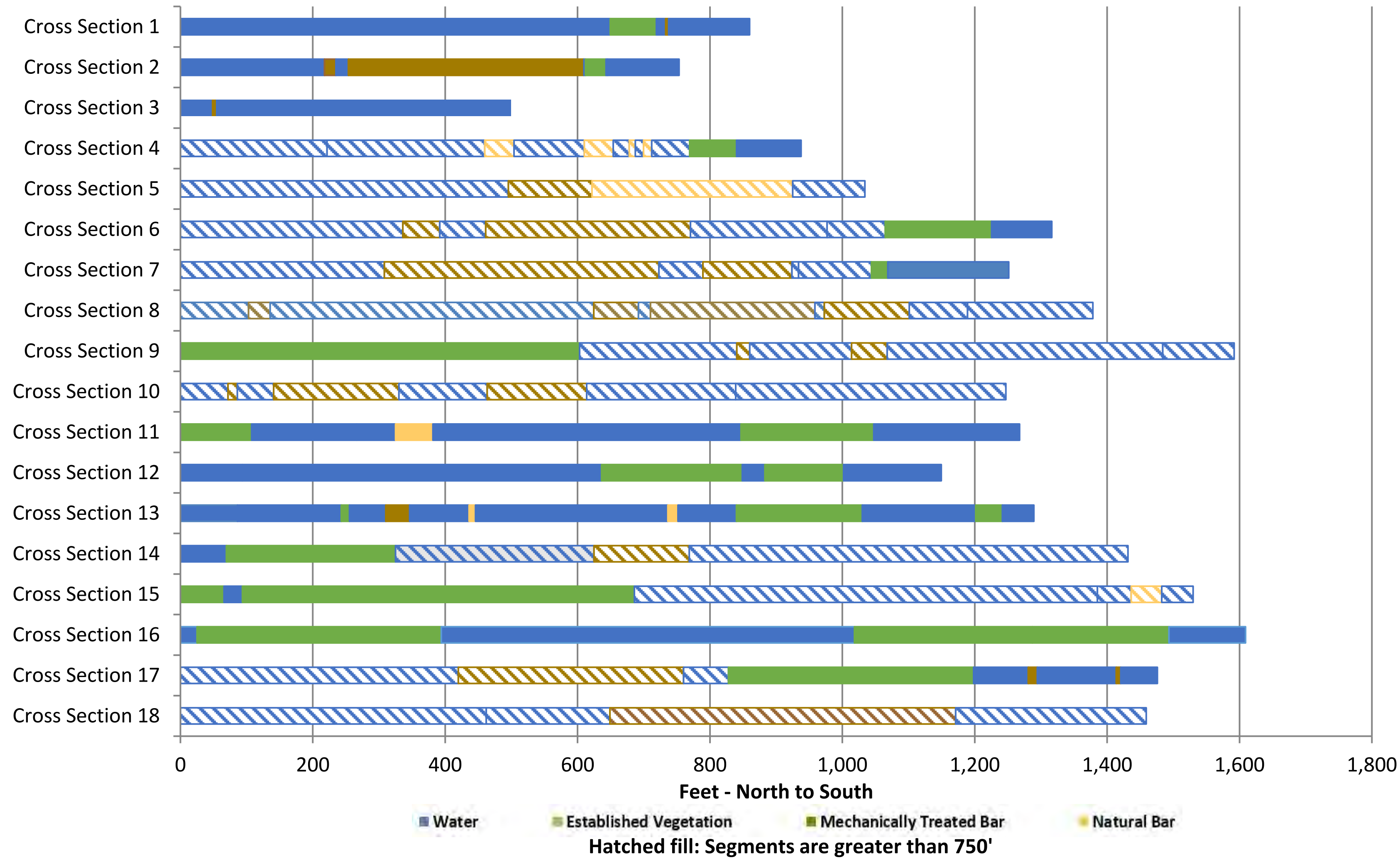
Figure 5-14 Bar 46 in July 2014 – Ground Photo

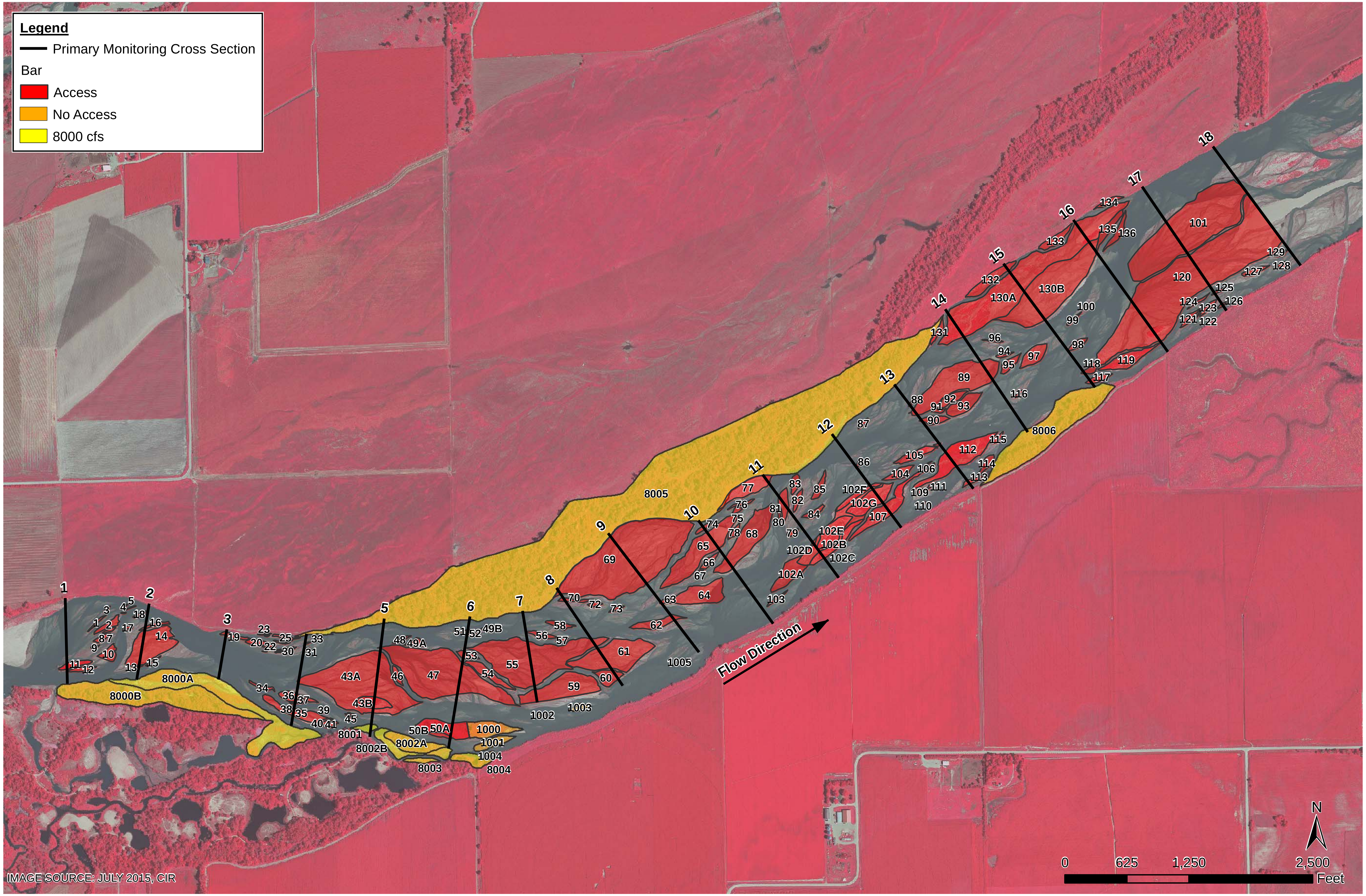
Figure 5-15 Bar 46 in August 2015 (July 2015 Aerial)



The boundary of the bar in July 2014 is outlined in black.

Figure 5-16 Maximum Un-Vegetated Channel Widths at the 18 Primary Cross Sections – August 2015





VEGETATION ROUGHNESS POLYGONS

SHOEMAKER ISLAND FSM PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

FIGURE	5-17
DRAWING NO.	–
FILE NAME	–
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	JULY 2016
CHECKED BY	KMD
DRAWN BY	MAW
DESIGNED BY	MAW
PROJECT MGR.	DLB

Figure 5-18 Platte River Bedload Discharge – June 2015 High Flow

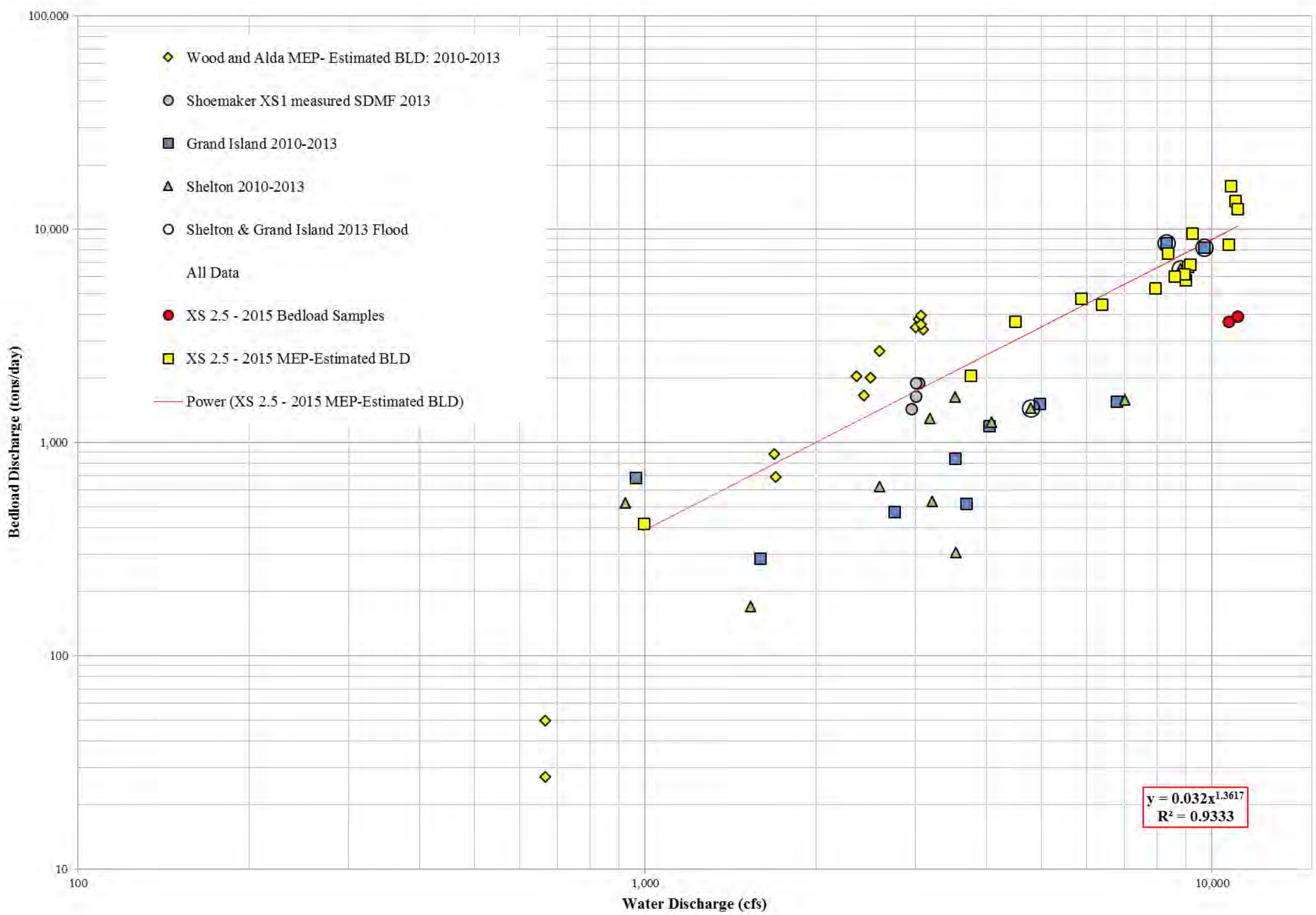


Figure 6-1 Cumulative Distributions of Sand Bar and Vegetated Bar Area Relative to the June 2015 High Flow 3-Day Mean Peak Discharge Stage

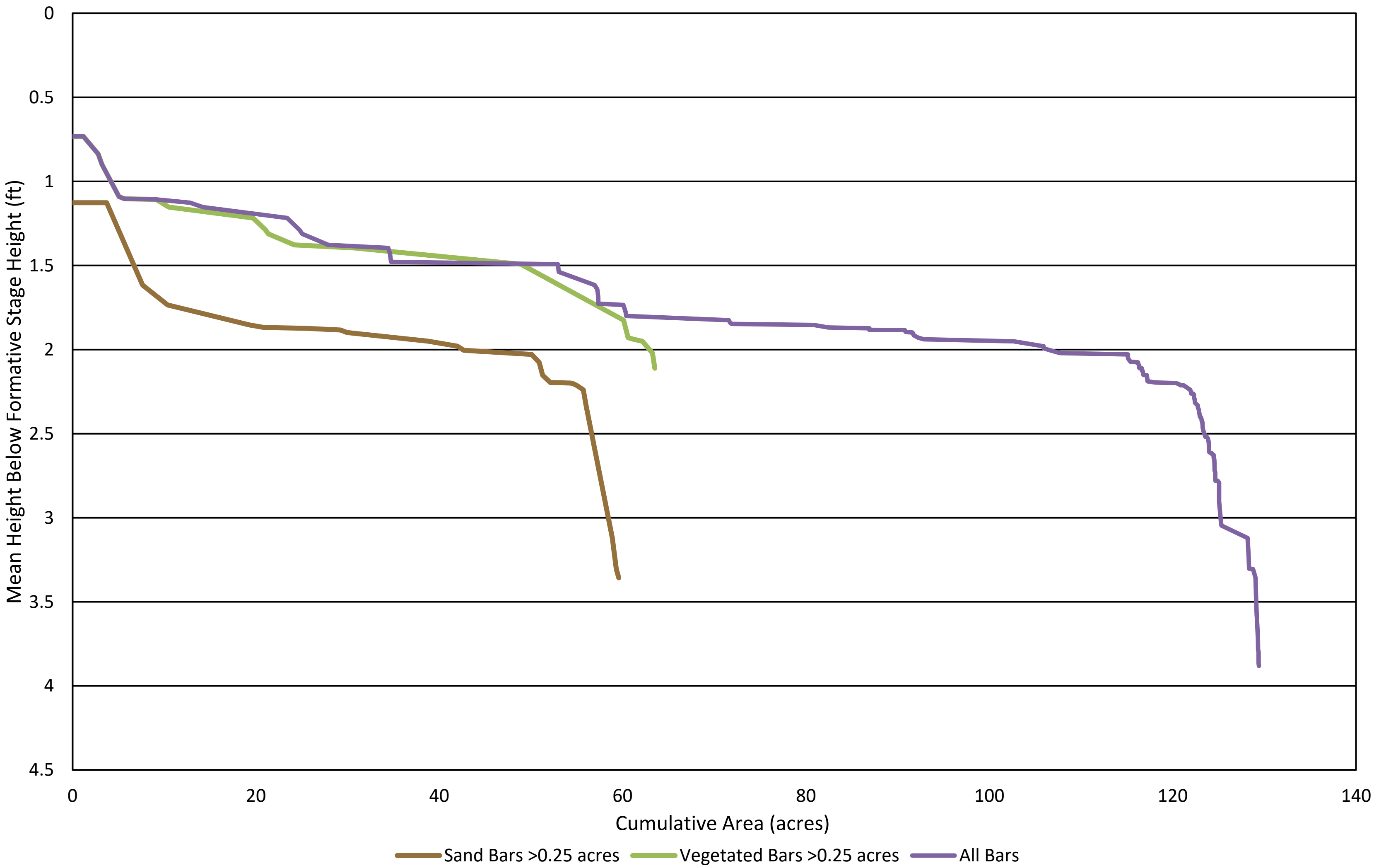
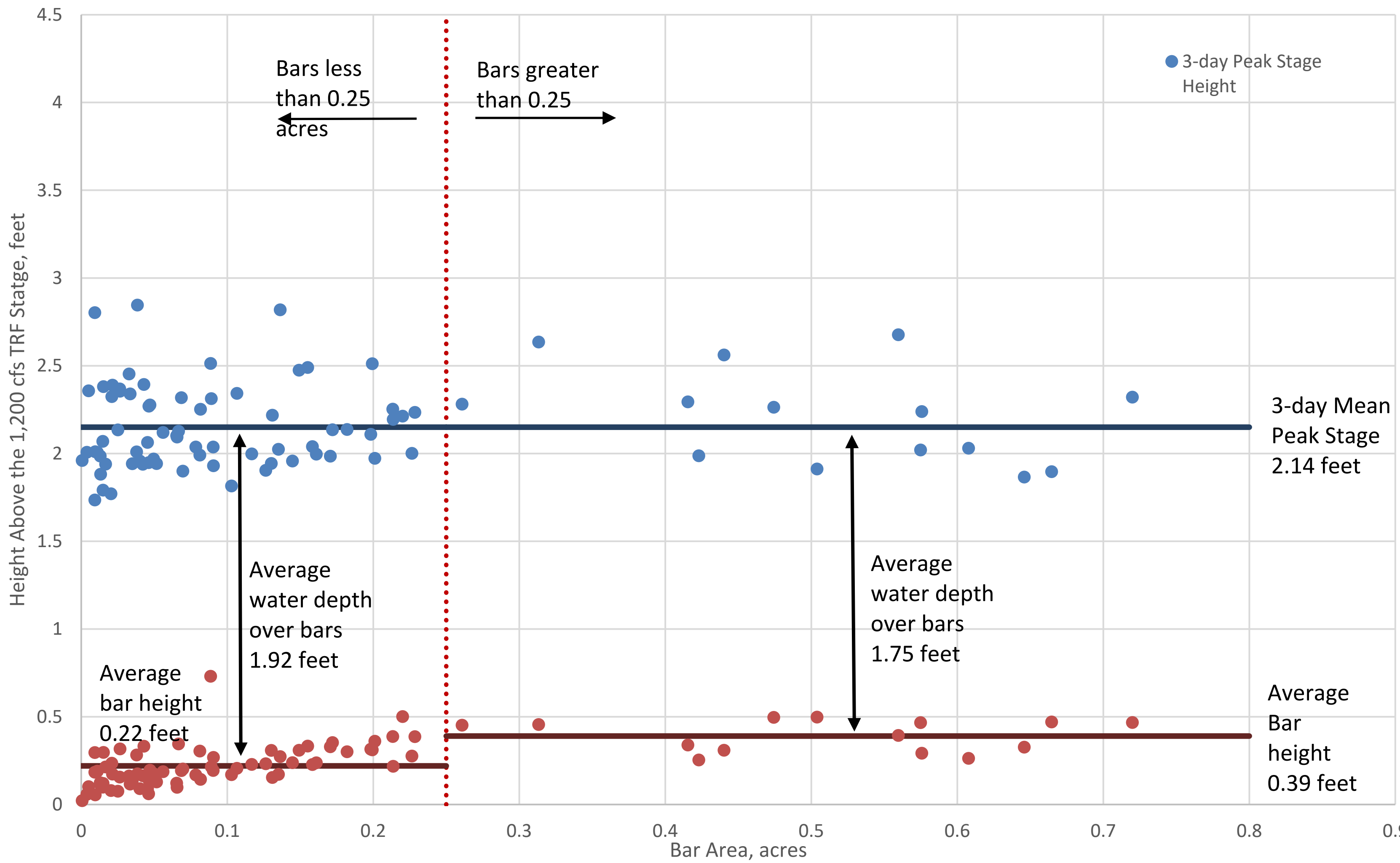
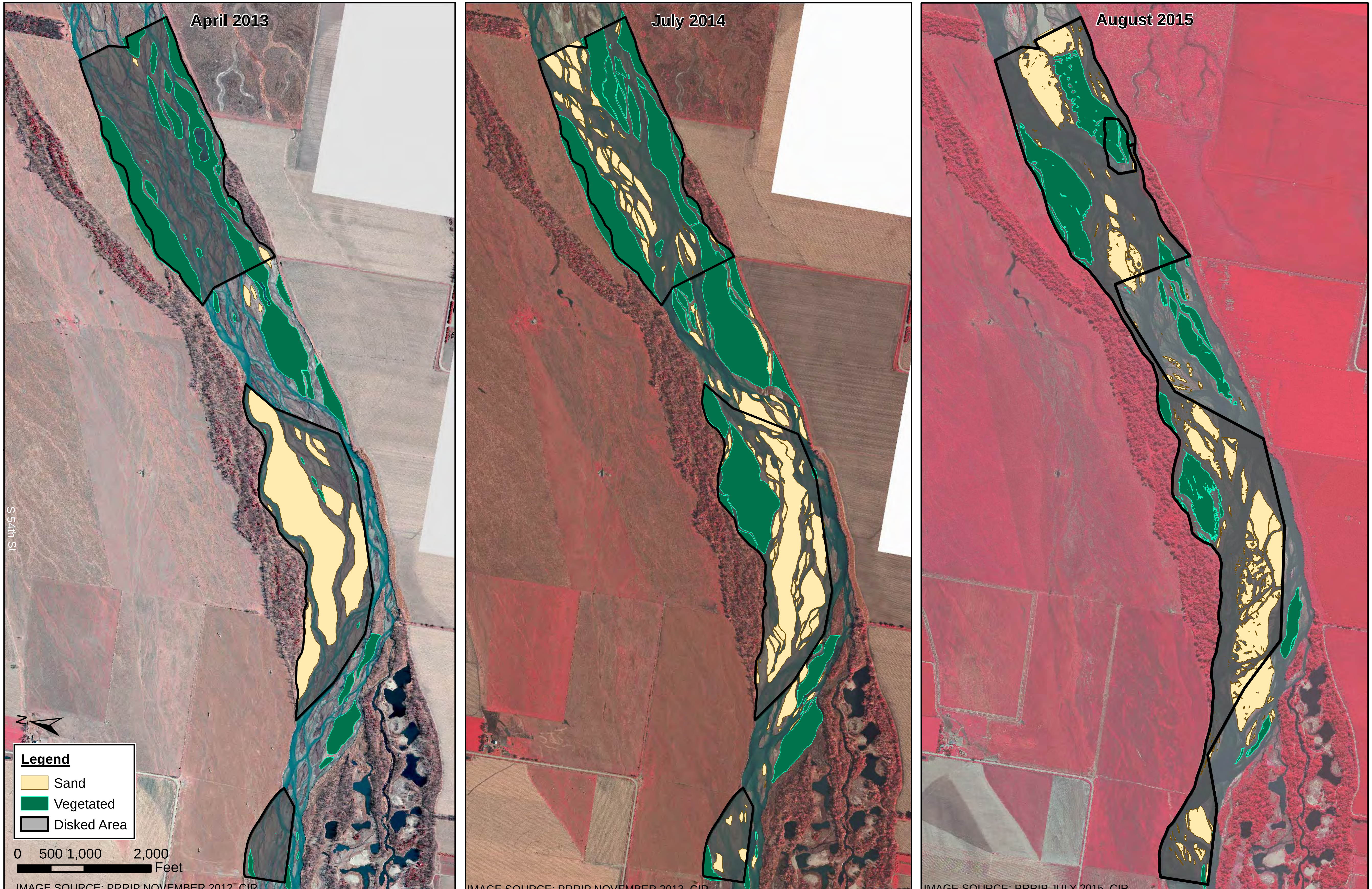


Figure 8-1 Mean Sand Bar Height Above 1,200 cfs TRF Stage – July 2014





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BAR ATTRIBUTES APRIL 2013, JULY 2014, AND AUGUST 2015

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HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

PROJECT MGR.	DESIGNED BY	DRAWN BY	CHECKED BY	DATE	SCALE	PROJECT NO.	FILE NAME	DRAWING NO.	FIGURE
DLB	--	JKP	KMD	AUG 2016	AS SHOWN	1499201	--	--	8-2

Figure 8-3 D50 Ranges for 2013 Pre and Post, 2014 Pre and Post, and 2015 Post

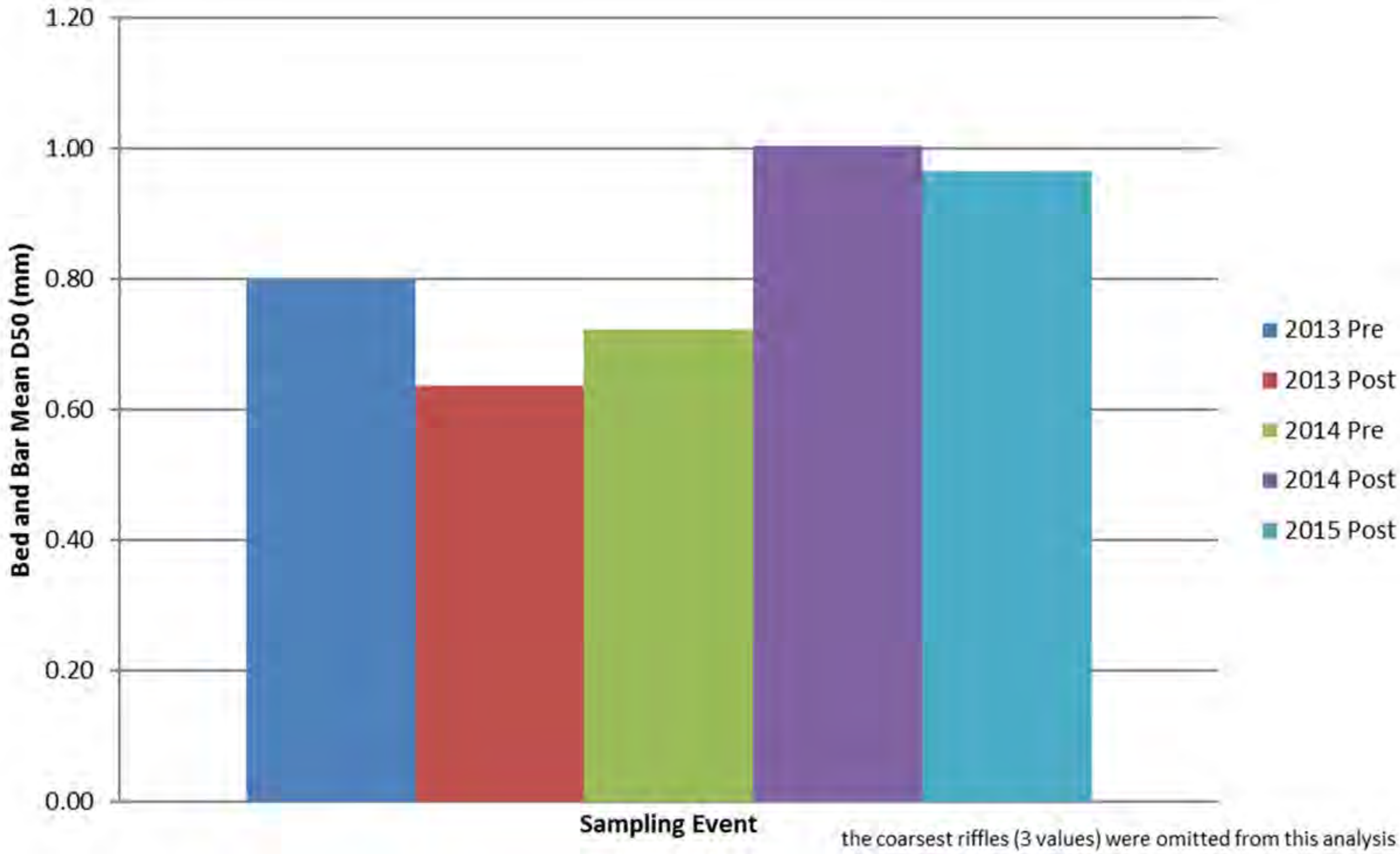
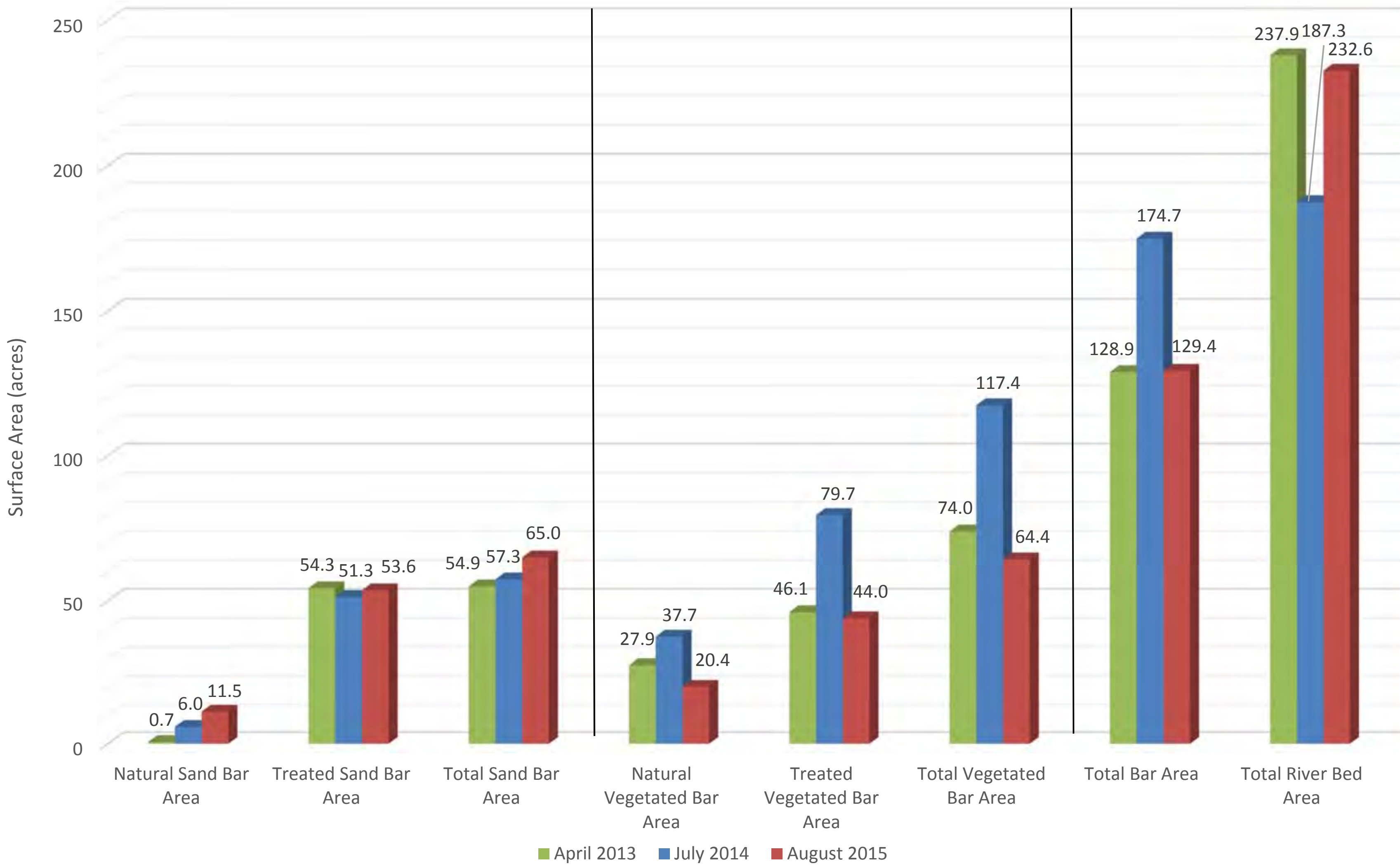


Figure 8-4 Area of All Bars Surveyed – April 2013, July 2014, and August 2015



APPENDIX A
GEOMORPHOLOGY

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Tables

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TABLES

Table A-1. July 2014 and August 2015 Braiding Index

XS	Number of Channels	
	July 2014	August 2015
1	2	2
2	4	2
3	1	2
4	3	4
5	2	3
6	4	6
7	1	5
8	3	2
9	3	3
10	5	3
11	2	4
12	4	4
13	5	5
14	4	4
15	5	6
16	5	4
17	5	4
18	5	5
Mean:	**3.5**	**3.8**

Table A-2. Bed and Bar Sample Particle Size Analysis – Sieve Data – August 2015

Field ID	Type	Date	Description	Feature	Sieve Data -- Finer Than (mm)															
					45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1	0.85	0.5	0.25	0.125	0.063
1	Bulk	8/26/2015	lateral bar lightly vegetated	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	95.2%	92.5%	71.8%	25.0%	0.9%	0.1%
3	Bulk	8/26/2015	unvegetated active bar coarse lens	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	94.6%	85.8%	76.8%	68.3%	50.4%	46.6%	34.7%	14.5%	1.2%	0.2%
4	Bulk	8/26/2015	unvegetated active bar fine lens	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.1%	96.9%	94.4%	91.2%	81.1%	77.7%	61.2%	23.9%	3.6%	1.2%
7	Bulk	8/26/2015	emergent bar - unvegetated	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	99.7%	96.6%	89.5%	82.3%	75.6%	61.2%	57.2%	42.3%	19.4%	1.0%	0.2%
8	Bulk	8/26/2015	US end of large lightly vegetated bar	Bar	100.0%	100.0%	100.0%	100.0%	96.9%	87.1%	76.4%	66.3%	57.2%	49.6%	40.0%	38.3%	32.0%	16.4%	3.1%	1.1%
12	Bulk	8/26/2015	lateral bar lightly vegetated below XS13	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	97.6%	88.5%	76.4%	64.6%	54.2%	39.4%	36.9%	29.5%	15.2%	1.8%	0.4%
13	Bulk	8/26/2015	Fine component of large 1.5' high lateral bar near XS16	Bar	100.0%	100.0%	100.0%	100.0%	99.4%	94.9%	89.4%	83.4%	76.1%	69.0%	56.8%	54.4%	45.2%	22.3%	5.7%	1.7%
14	Bulk	8/26/2015	Coarse component of large 1.5' high lateral bar near XS16	Bar	100.0%	100.0%	100.0%	100.0%	99.8%	98.8%	93.6%	87.6%	80.6%	71.9%	52.4%	47.6%	32.0%	12.9%	1.3%	0.2%
19	Bulk	8/26/2015	Fresh lateral bar above XS1	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.2%	96.5%	92.0%	74.7%	69.0%	46.0%	13.0%	1.9%	0.3%
21	Bulk	8/26/2015	High new bar	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	98.8%	94.8%	87.8%	79.0%	69.7%	52.1%	48.1%	35.1%	16.8%	2.3%	0.2%
33	Bulk	8/27/2015	Bar near XS6	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.1%	98.0%	95.8%	92.4%	76.1%	69.5%	43.0%	11.5%	1.0%	0.2%
2	Bulk	8/26/2015	active dune field in north channel	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.3%	98.2%	96.6%	93.9%	83.6%	79.2%	58.6%	19.8%	0.4%	0.0%
5	Bulk	8/26/2015	Active dune 2° flow channel	Bed	100.0%	100.0%	100.0%	100.0%	99.6%	99.1%	98.6%	98.2%	97.5%	96.6%	90.9%	87.2%	54.3%	6.2%	0.1%	0.0%
6	Bulk	8/26/2015	Dune 1° flow channel	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.3%	97.9%	94.9%	90.4%	84.0%	65.6%	59.8%	37.7%	6.1%	0.1%	0.0%
9	Bulk	8/26/2015	Dune 2° flow channel	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	97.8%	94.0%	86.9%	61.0%	52.8%	26.1%	5.0%	0.1%	0.0%
11	Bulk	8/26/2015	Same-all size classes seem mixed even with fine dune surfaces	Bed	100.0%	100.0%	100.0%	100.0%	98.0%	96.4%	93.6%	90.3%	86.1%	81.1%	64.8%	58.6%	31.8%	5.3%	0.1%	0.0%
15	Bulk	8/26/2015	Very fine flat dune	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	96.0%	91.7%	76.1%	70.5%	46.7%	11.9%	0.3%	0.1%
16	Bulk	8/26/2015	Coarser bedform 0.1' above water surface	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.2%	97.0%	91.8%	84.6%	76.5%	57.5%	52.8%	37.5%	15.2%	0.5%	0.1%
17	Bulk	8/26/2015	Submerged bar @ XS17	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	99.2%	97.8%	95.5%	92.3%	82.4%	78.9%	61.0%	17.7%	0.3%	0.0%
18	Bulk	8/26/2015	XS1	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	97.8%	94.1%	88.9%	82.1%	63.8%	58.2%	36.9%	8.0%	0.3%	0.0%
20	Bulk	8/26/2015	Main thread (N) dune	Bed	100.0%	100.0%	100.0%	100.0%	99.4%	96.7%	91.5%	85.7%	77.9%	68.1%	44.6%	38.9%	20.5%	3.8%	0.0%	0.0%
24	Bulk	8/27/2015	tertiary channel near NB XS3	Bed	100.0%	100.0%	100.0%	100.0%	99.7%	98.4%	92.7%	82.8%	68.3%	51.5%	27.9%	23.5%	14.2%	4.8%	0.6%	0.1%
27	Bulk	8/27/2015	Main channel	Bed	100.0%	100.0%	100.0%	96.8%	89.0%	79.2%	70.3%	61.4%	52.2%	44.1%	32.8%	30.2%	20.3%	7.0%	0.2%	0.0%
28	Bulk	8/27/2015	N. channel around Tx Bar complex @XS5	Bed	100.0%	100.0%	100.0%	100.0%	99.8%	98.1%	90.6%	80.8%	69.5%	58.1%	34.8%	29.9%	15.4%	2.4%	0.2%	0.0%
29	Bulk	8/27/2015	Same channel S side	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.5%	97.3%	91.6%	82.5%	73.4%	50.8%	45.4%	28.2%	4.9%	0.1%	0.0%
31	Bulk	8/27/2015	1° flow channel along south bank near BSTEM XS5	Bed	100.0%	100.0%	100.0%	100.0%	99.9%	97.0%	89.1%	75.0%	60.6%	47.7%	31.1%	28.2%	19.3%	3.1%	0.0%	0.0%
32	Bulk	8/27/2015	South channel below XS5 near property boundary	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	98.9%	96.9%	94.1%	90.2%	78.5%	74.6%	58.4%	26.8%	0.5%	0.0%
35	Bulk	8/27/2015		Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.0%	97.4%	94.6%	84.6%	81.0%	59.2%	11.1%	0.1%	0.0%
22	BD	8/27/2015	DS end of XS2 bar-unvegetated	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	99.4%	97.2%	93.5%	87.2%	79.1%	58.2%	52.0%	31.0%	8.4%	0.8%	0.1%
23	BD	8/27/2015	DS end of XS2 bar-lightly vegetated	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	99.5%	96.9%	93.5%	87.4%	79.4%	57.3%	50.4%	24.9%	5.2%	0.4%	0.1%
25	BD	8/27/2015	fine lobe	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	97.3%	92.5%	85.2%	77.4%	68.2%	49.9%	45.4%	28.5%	9.2%	2.3%	0.5%
26	BD	8/27/2015	coarser lobe	Bar	100.0%	100.0%	100.0%	100.0%	97.5%	89.8%	78.3%	69.7%	59.1%	50.1%	38.3%	35.8%	25.3%	6.3%	0.8%	0.1%
30	BD	8/27/2015	Mid channel new bar on XS5	Bar	100.0%	100.0%	100.0%	100.0%	100.0%	97.8%	92.5%	87.0%	79.5%	71.4%	52.6%	47.8%	32.2%	12.6%	0.9%	0.1%
34	BD	8/27/2015	Near XS8-highly braided 1.5' above WSE	Bar	100.0%	100.0%	100.0%	100.0%	99.3%	99.0%	96.4%	90.0%	80.8%	71.1%	52.7%	49.0%	29.2%	8.4%	1.1%	0.1%
	Total:	34		mean	100.0%	100.0%	100.0%	99.9%	99.4%	97.7%	94.1%	89.0%	82.6%	75.5%	59.4%	54.9%	37.4%	11.8%	1.0%	0.2%
				min	100.0%	100.0%	100.0%	96.8%	89.0%	79.2%	70.3%	61.4%	52.2%	44.1%	27.9%	23.5%	14.2%	2.4%	0.0%	0.0%
				max	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	95.2%	92.5%	71.8%	26.8%	5.7%	1.7%

Table A-3. Bed and Bar Density Sample Particle Size Analysis – Grain Size Percentiles – August 2015

					Grain Size Percentiles									Mass	Dry Bulk
Field ID	Type	Date	Description	Feature	D5	D16	D25	D35	D50	D65	D75	D84	D90	(g)	Density (g/cm3)
1	Bulk	8/26/2015	lateral bar lightly vegetated	Bar	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.5 mm	0.7 mm	0.8 mm	1,206	*na*
3	Bulk	8/26/2015	unvegetated active bar coarse lens	Bar	0.2 mm	0.3 mm	0.4 mm	0.5 mm	1.0 mm	1.8 mm	2.6 mm	3.7 mm	4.7 mm	1,012	*na*
4	Bulk	8/26/2015	unvegetated active bar fine lens	Bar	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.2 mm	1.8 mm	995	*na*
7	Bulk	8/26/2015	emergent bar - unvegetated	Bar	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.7 mm	1.2 mm	1.9 mm	3.0 mm	4.1 mm	1,872	*na*
8	Bulk	8/26/2015	US end of large lightly vegetated bar	Bar	0.1 mm	0.2 mm	0.4 mm	0.6 mm	2.0 mm	3.8 mm	5.3 mm	7.2 mm	8.8 mm	1,328	*na*
12	Bulk	8/26/2015	lateral bar lightly vegetated below XS13	Bar	0.1 mm	0.3 mm	0.4 mm	0.7 mm	1.6 mm	2.8 mm	3.8 mm	4.9 mm	5.9 mm	888	*na*
13	Bulk	8/26/2015	Fine component of large 1.5' high lateral bar near XS16	Bar	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.7 mm	1.6 mm	2.7 mm	4.1 mm	5.8 mm	1,090	*na*
14	Bulk	8/26/2015	Coarse component of large 1.5' high lateral bar near XS16	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.6 mm	2.3 mm	3.3 mm	4.6 mm	1,434	*na*
19	Bulk	8/26/2015	Fresh lateral bar above XS1	Bar	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.8 mm	1.0 mm	1.4 mm	1.8 mm	1,168	*na*
21	Bulk	8/26/2015	High new bar	Bar	0.1 mm	0.2 mm	0.3 mm	0.5 mm	0.9 mm	1.7 mm	2.4 mm	3.4 mm	4.5 mm	1,126	*na*
33	Bulk	8/27/2015	Bar near XS6	Bar	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm	1.4 mm	1.8 mm	976	na
2	Bulk	8/26/2015	active dune field in north channel	Bed	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm	1.5 mm	2,438	*na*
5	Bulk	8/26/2015	Active dune 2° flow channel	Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	1.0 mm	1,690	*na*
6	Bulk	8/26/2015	Dune 1° flow channel	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.4 mm	2.0 mm	2.7 mm	1,130	*na*
9	Bulk	8/26/2015	Dune 2° flow channel	Bed	0.2 mm	0.4 mm	0.5 mm	0.6 mm	0.8 mm	1.1 mm	1.5 mm	1.9 mm	2.3 mm	992	*na*
11	Bulk	8/26/2015	Same-all size classes seem mixed even with fine dune surfaces	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.5 mm	2.4 mm	3.9 mm	1,724	*na*
15	Bulk	8/26/2015	Very fine flat dune	Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.8 mm	1.0 mm	1.4 mm	1.9 mm	1,330	*na*
16	Bulk	8/26/2015	Coarser bedform 0.1' above water surface	Bed	0.2 mm	0.3 mm	0.3 mm	0.5 mm	0.8 mm	1.3 mm	1.9 mm	2.7 mm	3.7 mm	1,016	*na*
17	Bulk	8/26/2015	Submerged bar @ XS17	Bed	0.2 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.1 mm	1.7 mm	1,202	*na*
18	Bulk	8/26/2015	XS1	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.5 mm	2.2 mm	3.0 mm	2,208	*na*
20	Bulk	8/26/2015	Main thread (N) dune	Bed	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.2 mm	1.8 mm	2.5 mm	3.7 mm	5.1 mm	2,026	*na*
24	Bulk	8/27/2015	tertiary channel near NB XS3	Bed	0.3 mm	0.6 mm	0.9 mm	1.2 mm	1.9 mm	2.6 mm	3.3 mm	4.2 mm	5.1 mm	2,322	*na*
27	Bulk	8/27/2015	Main channel	Bed	0.2 mm	0.4 mm	0.6 mm	1.1 mm	2.6 mm	4.6 mm	6.8 mm	9.4 mm	11.7 mm	1,502	*na*
28	Bulk	8/27/2015	N. channel around Tx Bar complex @XS5	Bed	0.3 mm	0.5 mm	0.7 mm	1.0 mm	1.6 mm	2.5 mm	3.3 mm	4.5 mm	5.5 mm	1,161	na
29	Bulk	8/27/2015	Same channel S side	Bed	0.3 mm	0.3 mm	0.5 mm	0.6 mm	1.0 mm	1.5 mm	2.1 mm	3.0 mm	3.8 mm	2,142	na
31	Bulk	8/27/2015	1° flow channel along south bank near BSTEM XS5	Bed	0.3 mm	0.4 mm	0.7 mm	1.2 mm	2.1 mm	3.1 mm	4.0 mm	5.0 mm	5.8 mm	2,126	na
32	Bulk	8/27/2015	South channel below XS5 near property boundary	Bed	0.1 mm	0.2 mm	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.4 mm	2.0 mm	1,784	na
35	Bulk	8/27/2015		Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.4 mm	0.6 mm	0.7 mm	1.0 mm	1.5 mm	1,806	na
22	BD	8/27/2015	DS end of XS2 bar-unvegetated	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.3 mm	1.7 mm	2.5 mm	3.3 mm	552	1.79
23	BD	8/27/2015	DS end of XS2 bar-lightly vegetated	Bar	0.2 mm	0.4 mm	0.5 mm	0.6 mm	0.8 mm	1.3 mm	1.7 mm	2.4 mm	3.3 mm	550	1.78
25	BD	8/27/2015	fine lobe	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	1.0 mm	1.8 mm	2.6 mm	3.8 mm	5.0 mm	523	1.69
26	BD	8/27/2015	coarser lobe	Bar	0.2 mm	0.4 mm	0.5 mm	0.8 mm	2.0 mm	3.4 mm	4.9 mm	6.7 mm	8.1 mm	470	1.52
30	BD	8/27/2015	Mid channel new bar on XS5	Bar	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.9 mm	1.6 mm	2.3 mm	3.5 mm	4.8 mm	589	1.91
34	BD	8/27/2015	Near XS8-highly braided 1.5' above WSE	Bar	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.6 mm	2.3 mm	3.2 mm	4.0 mm	539	1.74
				mean	0.19	0.33	0.45	0.62	1.07	1.81	2.60	3.67	4.73		1.74
				min	0.16	0.28	0.39	0.55	0.81	1.25	1.74	2.43	3.26		1.52
				max	0.24	0.37	0.50	0.81	1.98	3.41	4.92	6.68	8.06		1.91

Table A-4. Bed Sample Particle Size Analysis – Sieve Data – August 2015

Field ID	Type	Date	Description	Feature	Sieve Data -- Finer Than (mm) 45	31.5	22.4	16	11.2	8	5.6	4	2.8	2	1	0.85	0.5	0.25	0.125	0.063
2	Bulk	8/26/2015	active dune field in north channel	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.3%	98.2%	96.6%	93.9%	83.6%	79.2%	58.6%	19.8%	0.4%	0.0%
5	Bulk	8/26/2015	Active dune 2° flow channel	Bed	100.0%	100.0%	100.0%	100.0%	99.6%	99.1%	98.6%	98.2%	97.5%	96.6%	90.9%	87.2%	54.3%	6.2%	0.1%	0.0%
6	Bulk	8/26/2015	Dune 1° flow channel	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.3%	97.9%	94.9%	90.4%	84.0%	65.6%	59.8%	37.7%	6.1%	0.1%	0.0%
9	Bulk	8/26/2015	Dune 2° flow channel	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	97.8%	94.0%	86.9%	61.0%	52.8%	26.1%	5.0%	0.1%	0.0%
11	Bulk	8/26/2015	Same-all size classes seem mixed even with fine dune surfaces	Bed	100.0%	100.0%	100.0%	100.0%	98.0%	96.4%	93.6%	90.3%	86.1%	81.1%	64.8%	58.6%	31.8%	5.3%	0.1%	0.0%
15	Bulk	8/26/2015	Very fine flat dune	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	96.0%	91.7%	76.1%	70.5%	46.7%	11.9%	0.3%	0.1%
16	Bulk	8/26/2015	Coarser bedform 0.1' above water surface	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.2%	97.0%	91.8%	84.6%	76.5%	57.5%	52.8%	37.5%	15.2%	0.5%	0.1%
17	Bulk	8/26/2015	Submerged bar @ XS17	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	99.2%	97.8%	95.5%	92.3%	82.4%	78.9%	61.0%	17.7%	0.3%	0.0%
18	Bulk	8/26/2015	XS1	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	97.8%	94.1%	88.9%	82.1%	63.8%	58.2%	36.9%	8.0%	0.3%	0.0%
20	Bulk	8/26/2015	Main thread (N) dune	Bed	100.0%	100.0%	100.0%	100.0%	99.4%	96.7%	91.5%	85.7%	77.9%	68.1%	44.6%	38.9%	20.5%	3.8%	0.0%	0.0%
24	Bulk	8/27/2015	tertiary channel near NB XS3	Bed	100.0%	100.0%	100.0%	100.0%	99.7%	98.4%	92.7%	82.8%	68.3%	51.5%	27.9%	23.5%	14.2%	4.8%	0.6%	0.1%
27	Bulk	8/27/2015	Main channel	Bed	100.0%	100.0%	100.0%	96.8%	89.0%	79.2%	70.3%	61.4%	52.2%	44.1%	32.8%	30.2%	20.3%	7.0%	0.2%	0.0%
28	Bulk	8/27/2015	N. channel around Tx Bar complex @XS5	Bed	100.0%	100.0%	100.0%	100.0%	99.8%	98.1%	90.6%	80.8%	69.5%	58.1%	34.8%	29.9%	15.4%	2.4%	0.2%	0.0%
29	Bulk	8/27/2015	Same channel S side	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.5%	97.3%	91.6%	82.5%	73.4%	50.8%	45.4%	28.2%	4.9%	0.1%	0.0%
31	Bulk	8/27/2015	1° flow channel along south bank near BSTEM XS5	Bed	100.0%	100.0%	100.0%	100.0%	99.9%	97.0%	89.1%	75.0%	60.6%	47.7%	31.1%	28.2%	19.3%	3.1%	0.0%	0.0%
32	Bulk	8/27/2015	South channel below XS5 near property boundary	Bed	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	98.9%	96.9%	94.1%	90.2%	78.5%	74.6%	58.4%	26.8%	0.5%	0.0%
35	Bulk	8/27/2015		Bed	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.0%	97.4%	94.6%	84.6%	81.0%	59.2%	11.1%	0.1%	0.0%
				mean	100.0%	100.0%	100.0%	99.8%	99.1%	97.8%	94.9%	90.3%	84.2%	77.2%	60.6%	55.9%	36.8%	9.4%	0.2%	0.0%
				min	100.0%	100.0%	100.0%	96.8%	89.0%	79.2%	70.3%	61.4%	52.2%	44.1%	27.9%	23.5%	14.2%	2.4%	0.0%	0.0%
				max	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.0%	97.5%	96.6%	90.9%	87.2%	61.0%	26.8%	0.6%	0.1%

Table A-5. Bed Sample Particle Size Analysis – Grain Size Percentiles – August 2015

Field ID	Type	Date	Description	Feature	Grain Size Percentiles D5	D16	D25	D35	D50	D65	D75	D84	D90	Mass (g)	Dry Bulk Density (g/cm3)
2	Bulk	8/26/2015	active dune field in north channel	Bed	0.1 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm	1.5 mm	2,438	*na*
5	Bulk	8/26/2015	Active dune 2° flow channel	Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	1.0 mm	1,690	*na*
6	Bulk	8/26/2015	Dune 1° flow channel	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.4 mm	2.0 mm	2.7 mm	1,130	*na*
9	Bulk	8/26/2015	Dune 2° flow channel	Bed	0.2 mm	0.4 mm	0.5 mm	0.6 mm	0.8 mm	1.1 mm	1.5 mm	1.9 mm	2.3 mm	992	*na*
11	Bulk	8/26/2015	Same-all size classes seem mixed even with fine dune surfaces	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.5 mm	2.4 mm	3.9 mm	1,724	*na*
15	Bulk	8/26/2015	Very fine flat dune	Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.5 mm	0.8 mm	1.0 mm	1.4 mm	1.9 mm	1,330	*na*
16	Bulk	8/26/2015	Coarser bedform 0.1' above water surface	Bed	0.2 mm	0.3 mm	0.3 mm	0.5 mm	0.8 mm	1.3 mm	1.9 mm	2.7 mm	3.7 mm	1,016	*na*
17	Bulk	8/26/2015	Submerged bar @ XS17	Bed	0.2 mm	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.1 mm	1.7 mm	1,202	*na*
18	Bulk	8/26/2015	XS1	Bed	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.7 mm	1.0 mm	1.5 mm	2.2 mm	3.0 mm	2,208	*na*
20	Bulk	8/26/2015	Main thread (N) dune	Bed	0.3 mm	0.4 mm	0.6 mm	0.8 mm	1.2 mm	1.8 mm	2.5 mm	3.7 mm	5.1 mm	2,026	*na*
24	Bulk	8/27/2015	tertiary channel near NB XS3	Bed	0.3 mm	0.6 mm	0.9 mm	1.2 mm	1.9 mm	2.6 mm	3.3 mm	4.2 mm	5.1 mm	2,322	*na*
27	Bulk	8/27/2015	Main channel	Bed	0.2 mm	0.4 mm	0.6 mm	1.1 mm	2.6 mm	4.6 mm	6.8 mm	9.4 mm	11.7 mm	1,502	*na*
28	Bulk	8/27/2015	N. channel around Tx Bar complex @XS5	Bed	0.3 mm	0.5 mm	0.7 mm	1.0 mm	1.6 mm	2.5 mm	3.3 mm	4.5 mm	5.5 mm	1,161	na
29	Bulk	8/27/2015	Same channel S side	Bed	0.3 mm	0.3 mm	0.5 mm	0.6 mm	1.0 mm	1.5 mm	2.1 mm	3.0 mm	3.8 mm	2,142	na
31	Bulk	8/27/2015	1° flow channel along south bank near BSTEM XS5	Bed	0.3 mm	0.4 mm	0.7 mm	1.2 mm	2.1 mm	3.1 mm	4.0 mm	5.0 mm	5.8 mm	2,126	na
32	Bulk	8/27/2015	South channel below XS5 near property boundary	Bed	0.1 mm	0.2 mm	0.2 mm	0.3 mm	0.4 mm	0.6 mm	0.9 mm	1.4 mm	2.0 mm	1,784	na
35	Bulk	8/27/2015		Bed	0.2 mm	0.3 mm	0.3 mm	0.4 mm	0.4 mm	0.6 mm	0.7 mm	1.0 mm	1.5 mm	1,806	na
				mean	0.21	0.33	0.45	0.62	0.98	1.49	2.04	2.80	3.66		
				min	0.14	0.19	0.24	0.30	0.42	0.56	0.70	0.81	0.96		
				max	0.29	0.55	0.90	1.23	2.55	4.58	6.76	9.43	11.71		

FIGURES

Figure A-1. Geomorphic Monitoring Network – Cross Sections 1-9

Figure A-2. Geomorphic Monitoring Network – Cross Sections 7-15

Figure A-3. Geomorphic Monitoring Network – Cross Sections 13-18

Figure A-4. Planform of Longitudinal Profile Alignment Cross Sections 1-9

Figure A-5. Planform of Longitudinal Profile Alignment Cross Sections 7-15

Figure A-6. Planform of Longitudinal Profile Alignment Cross Sections 13-18

Figure A-7. Primary Cross Section #1 – June 2014 and August 2015

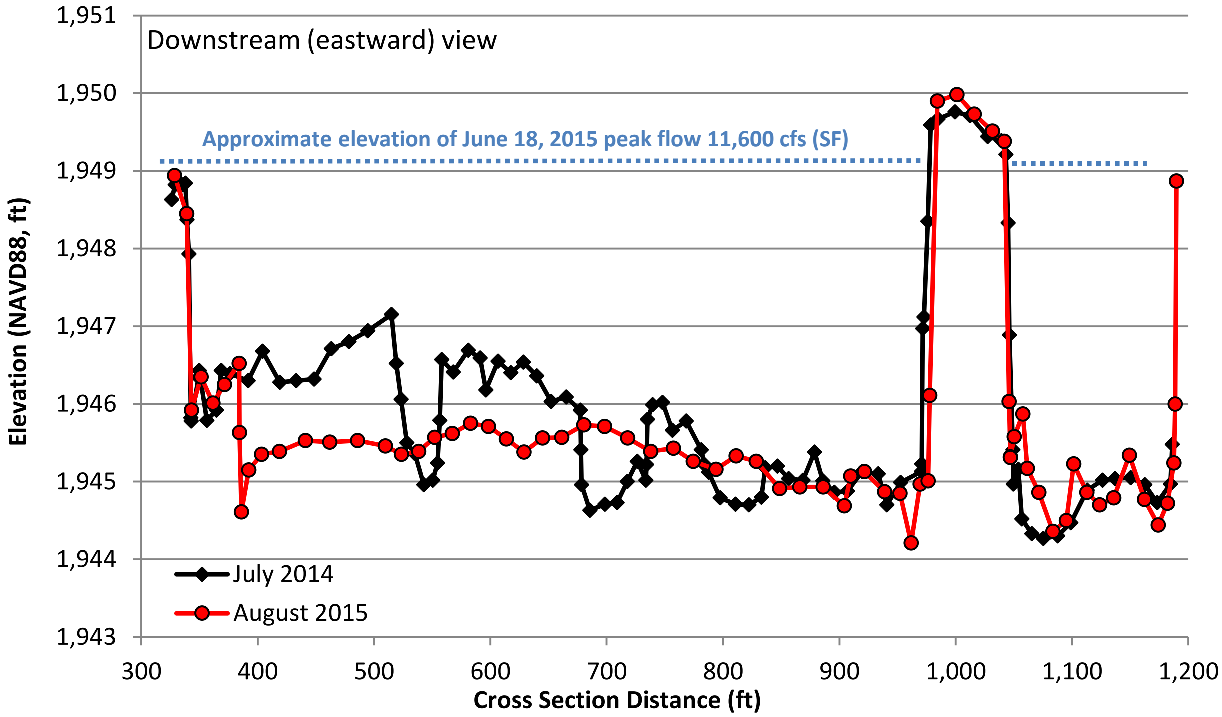


Figure A-8. Primary Cross Section #2 – June 2014 and August 2015

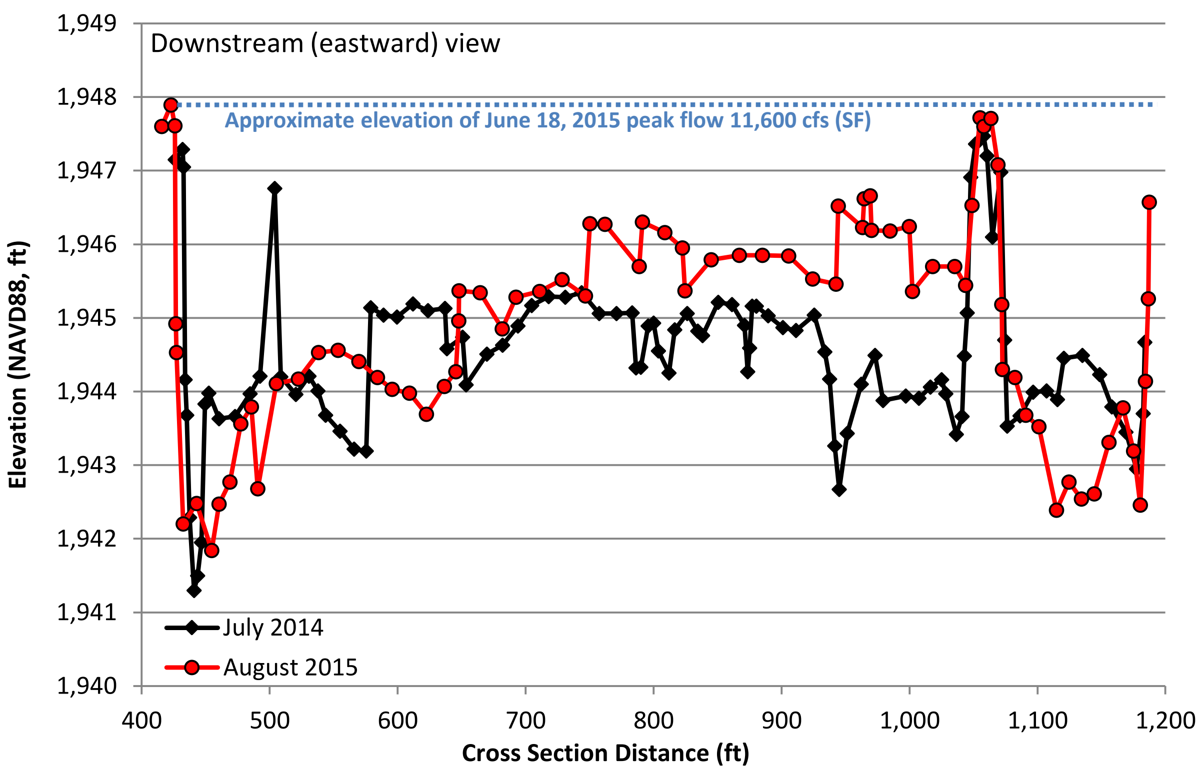


Figure A-9. Primary Cross Section #3 – June 2014 and August 2015

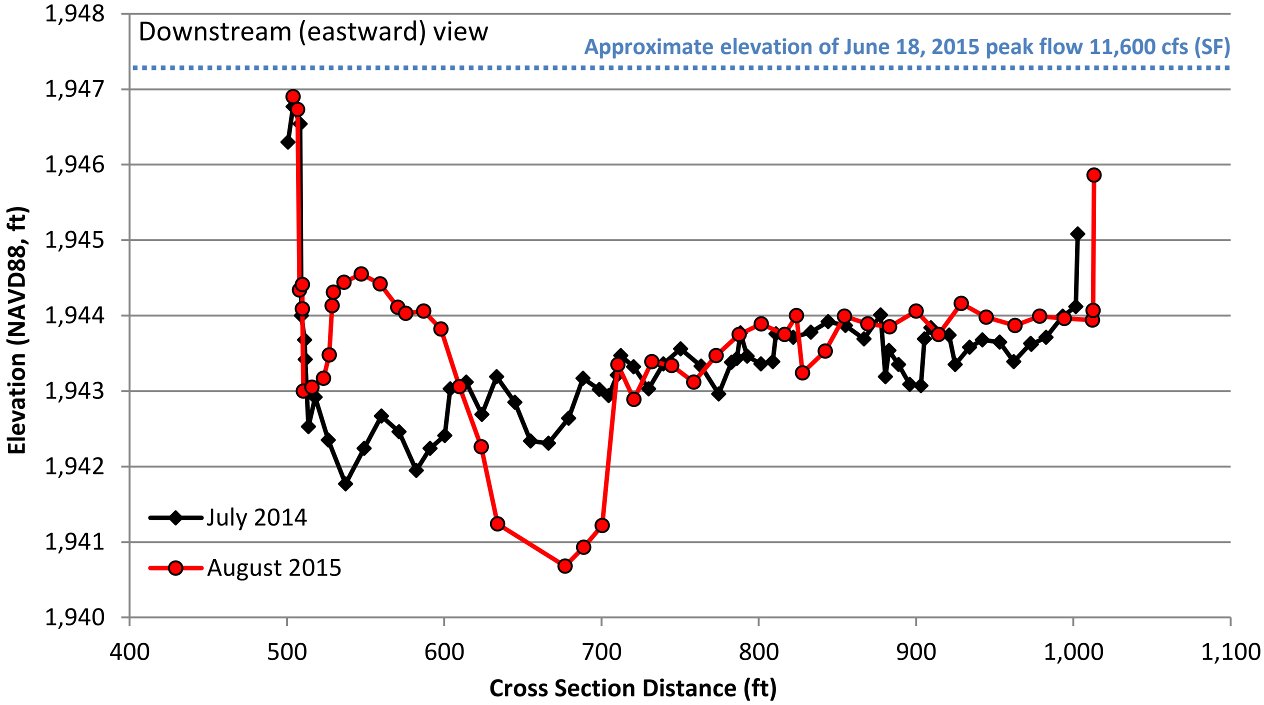


Figure A-10. Primary Cross Section #4 – June 2014 and August 2015

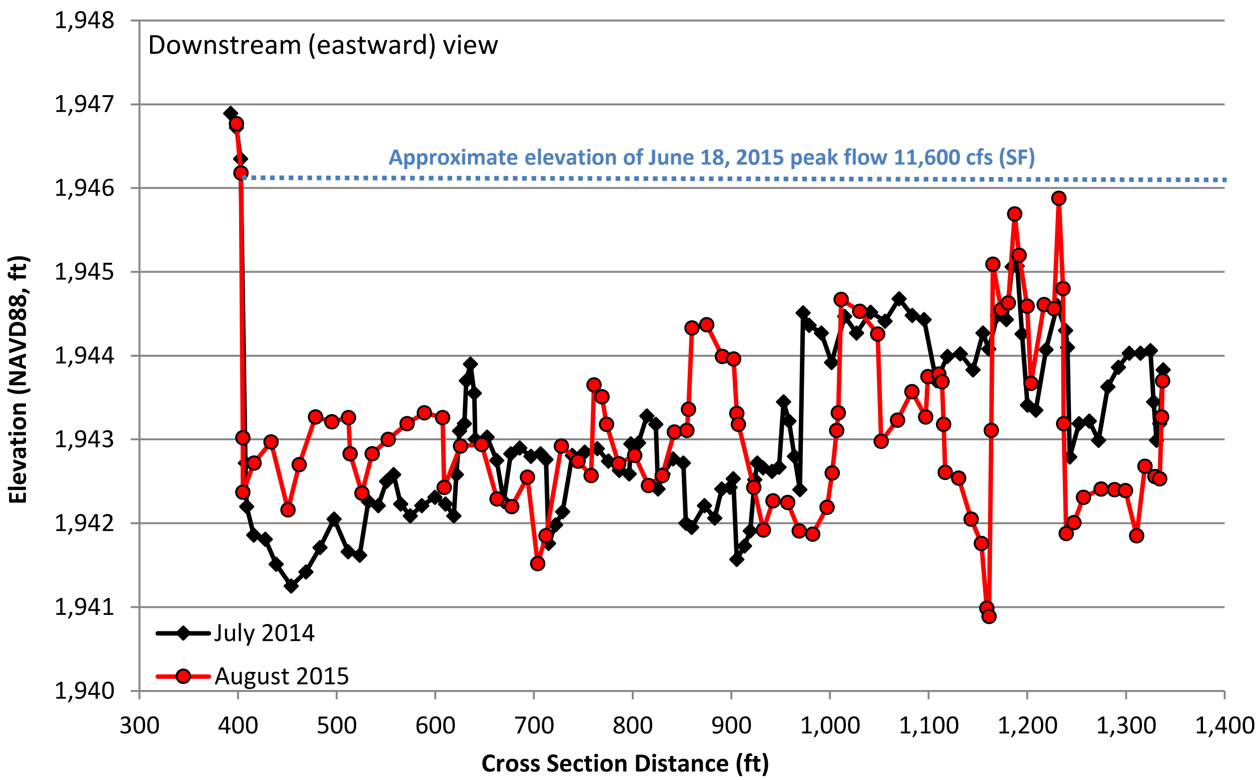


Figure A-11. Primary Cross Section #5 – June 2014 and August 2015

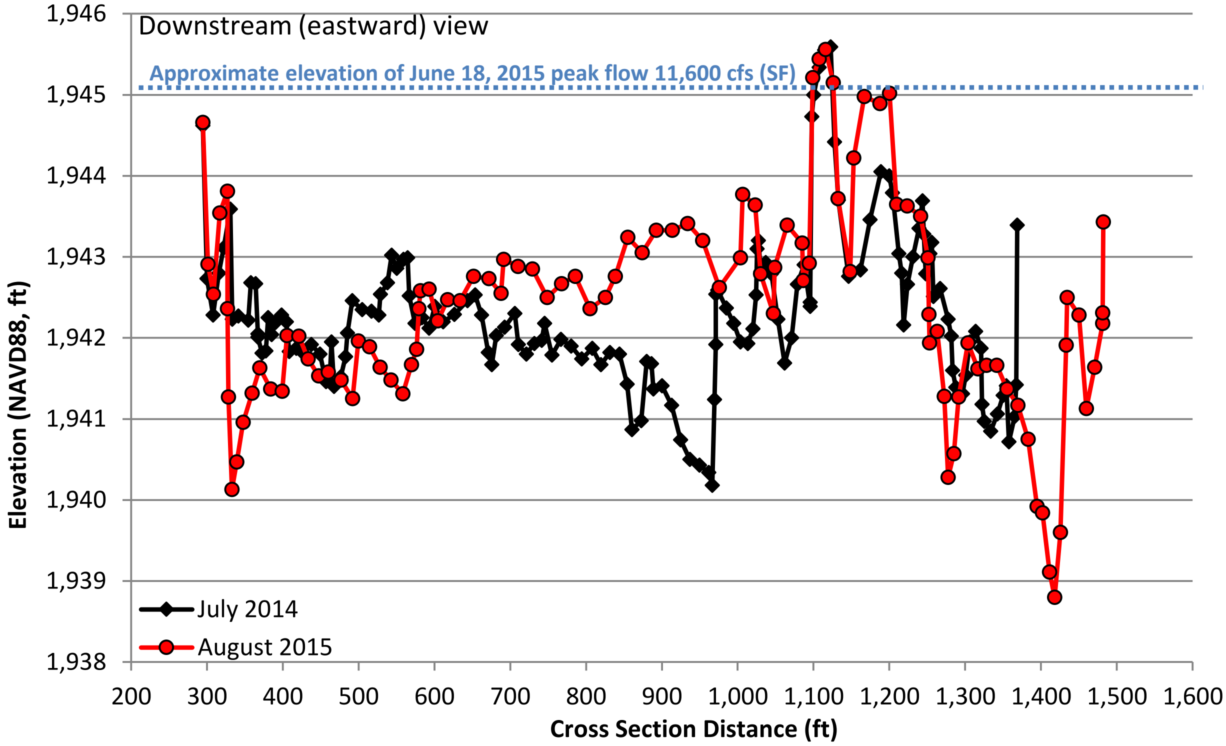


Figure A-12. Primary Cross Section #6 – June 2014 and August 2015

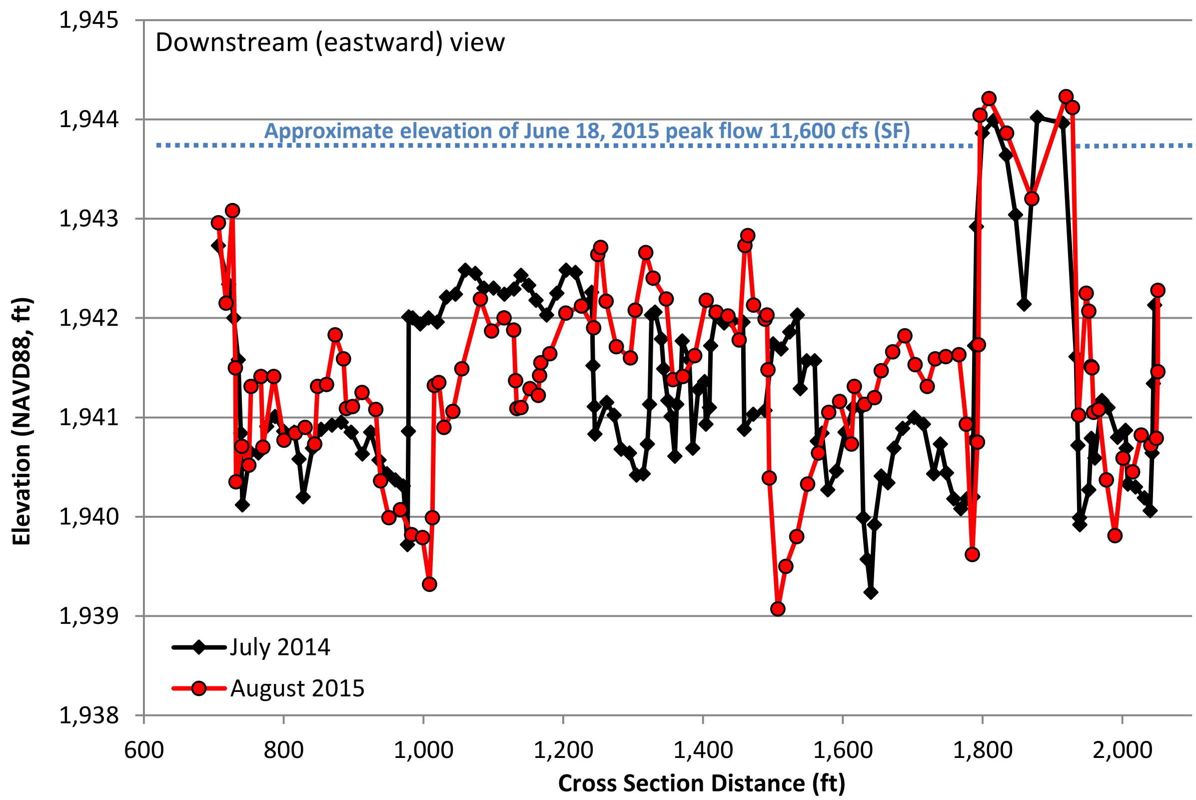


Figure A-13. Primary Cross Section #7 – June 2014 and August 2015

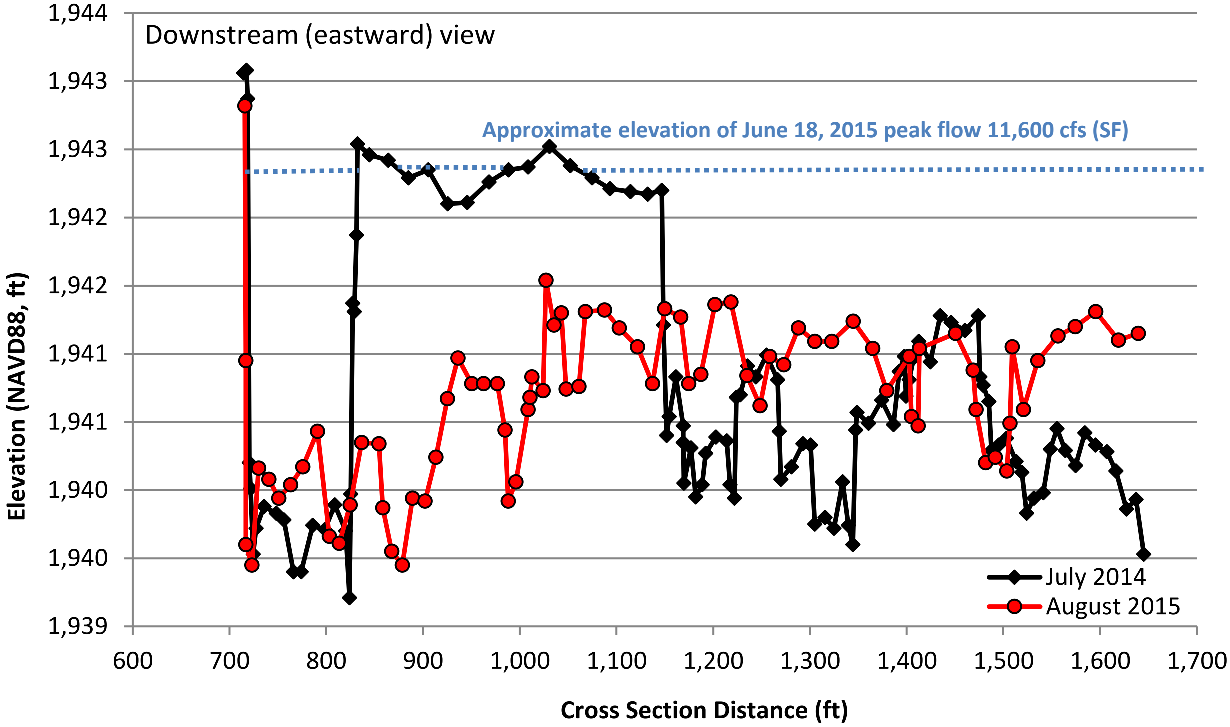


Figure A-14. Primary Cross Section #8 – June 2014 and August 2015

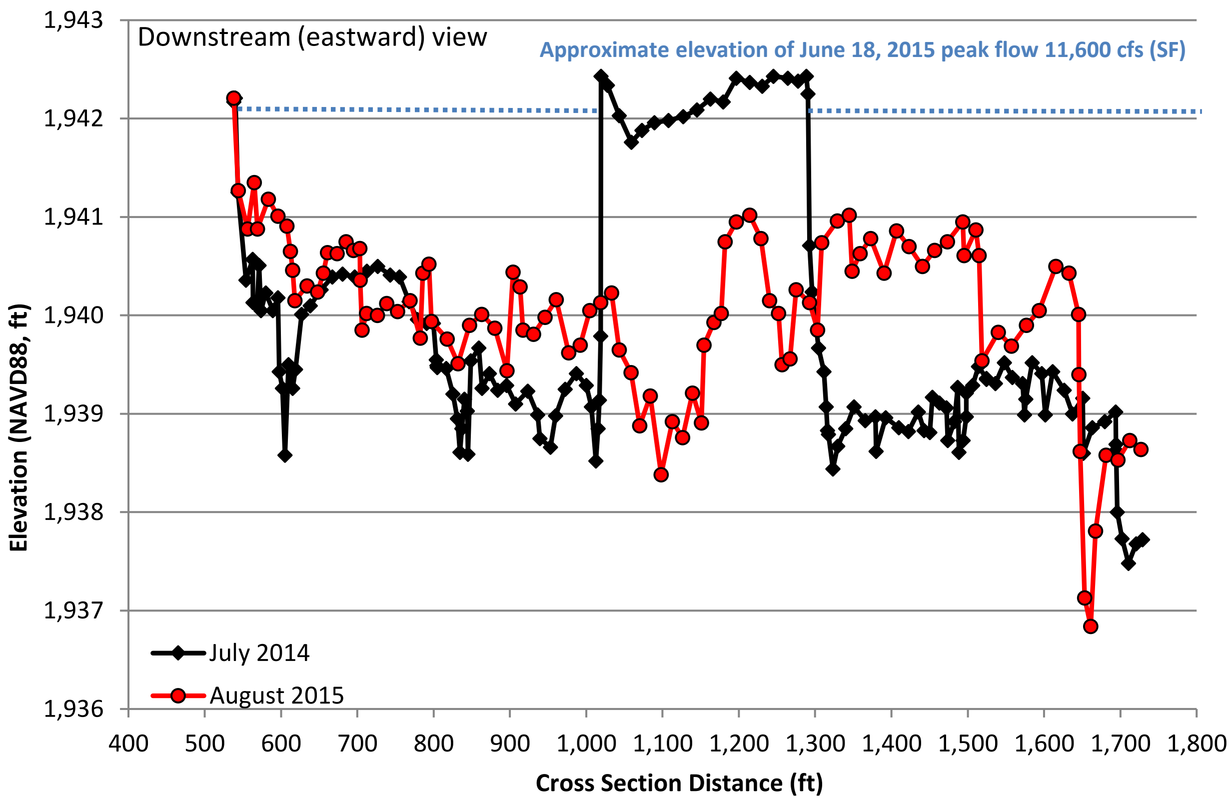


Figure A-15. Primary Cross Section #9 – June 2014 and August 2015

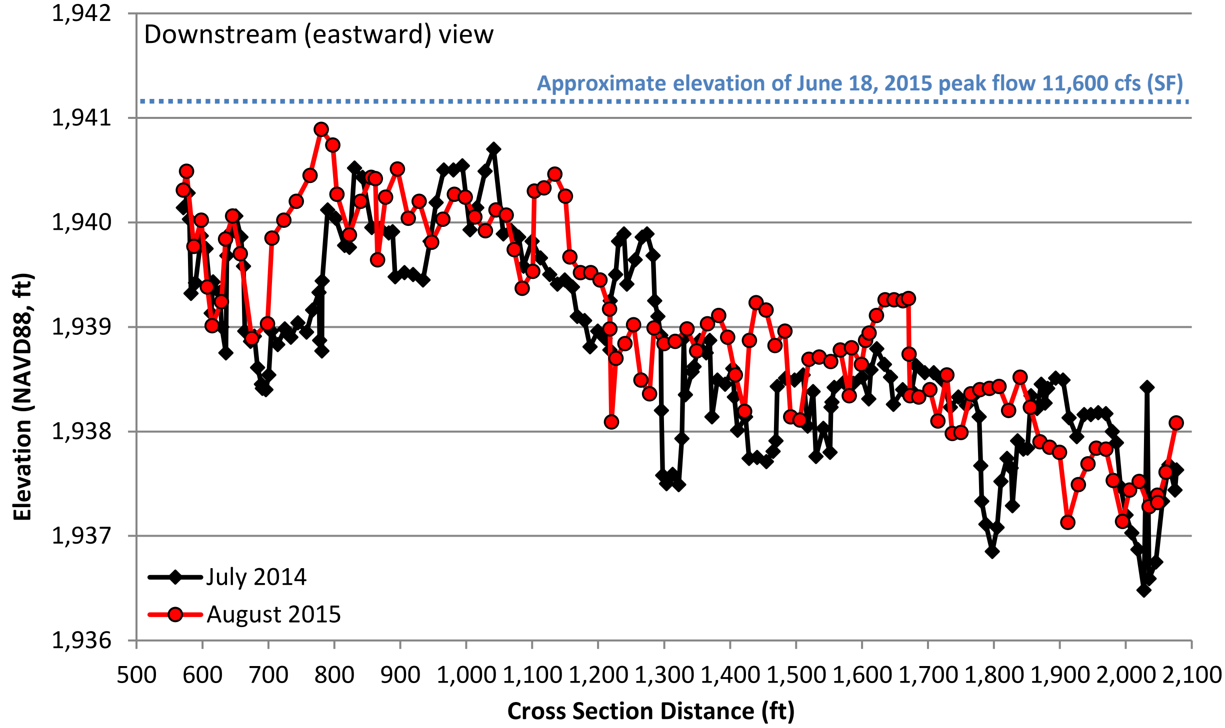


Figure A-16. Primary Cross Section #10 – June 2014 and August 2015

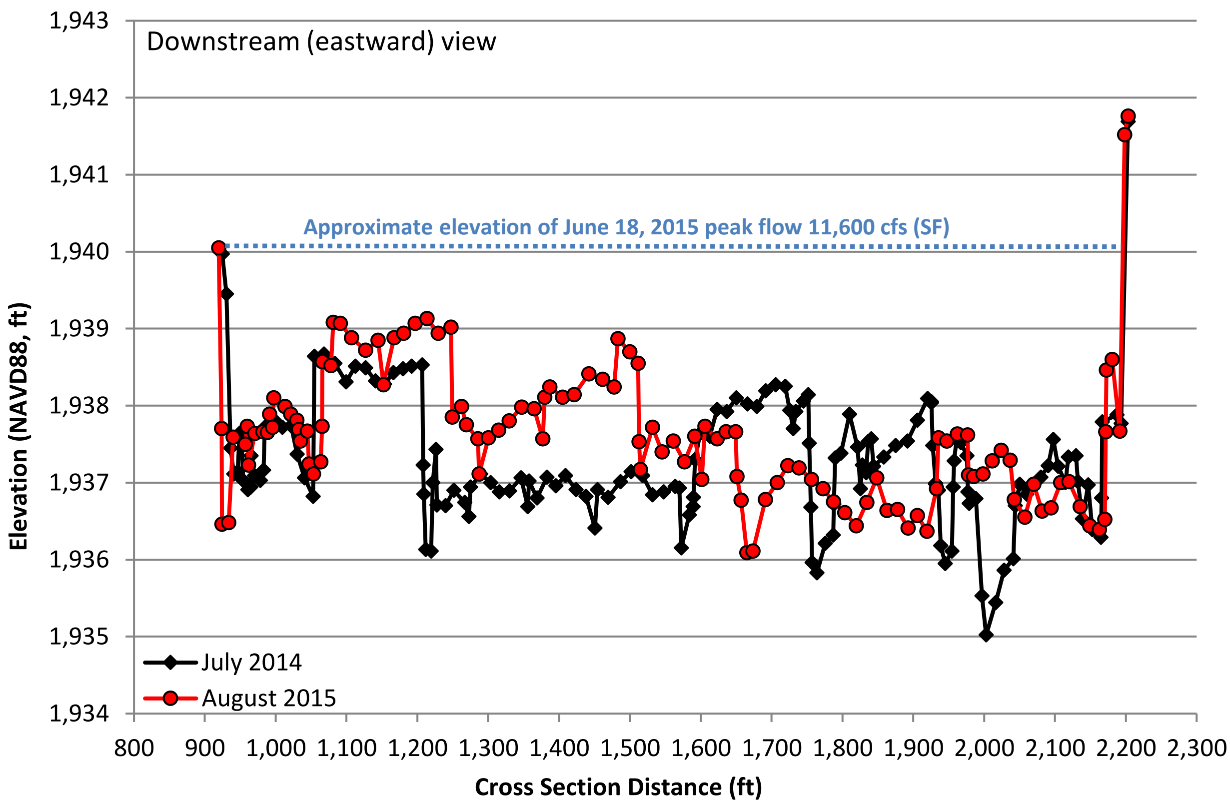


Figure A-17. Primary Cross Section #11 – June 2014 and August 2015

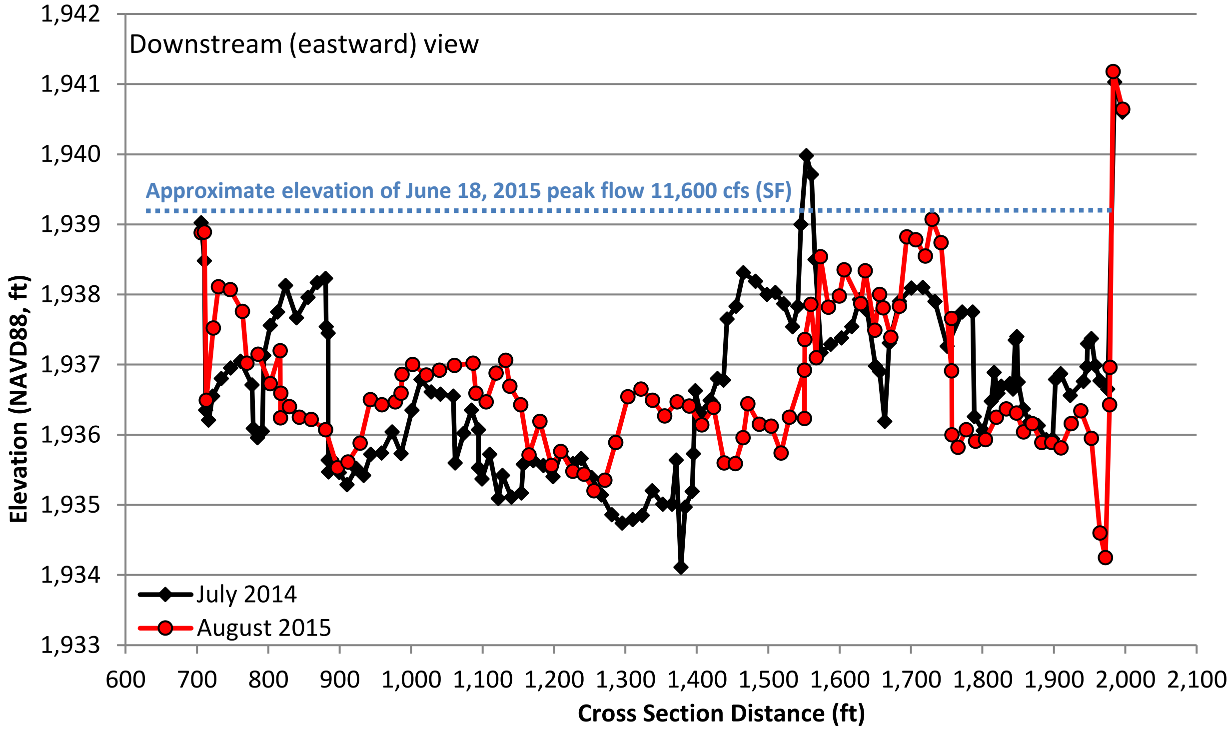


Figure A-18. Primary Cross Section #12 – June 2014 and August 2015

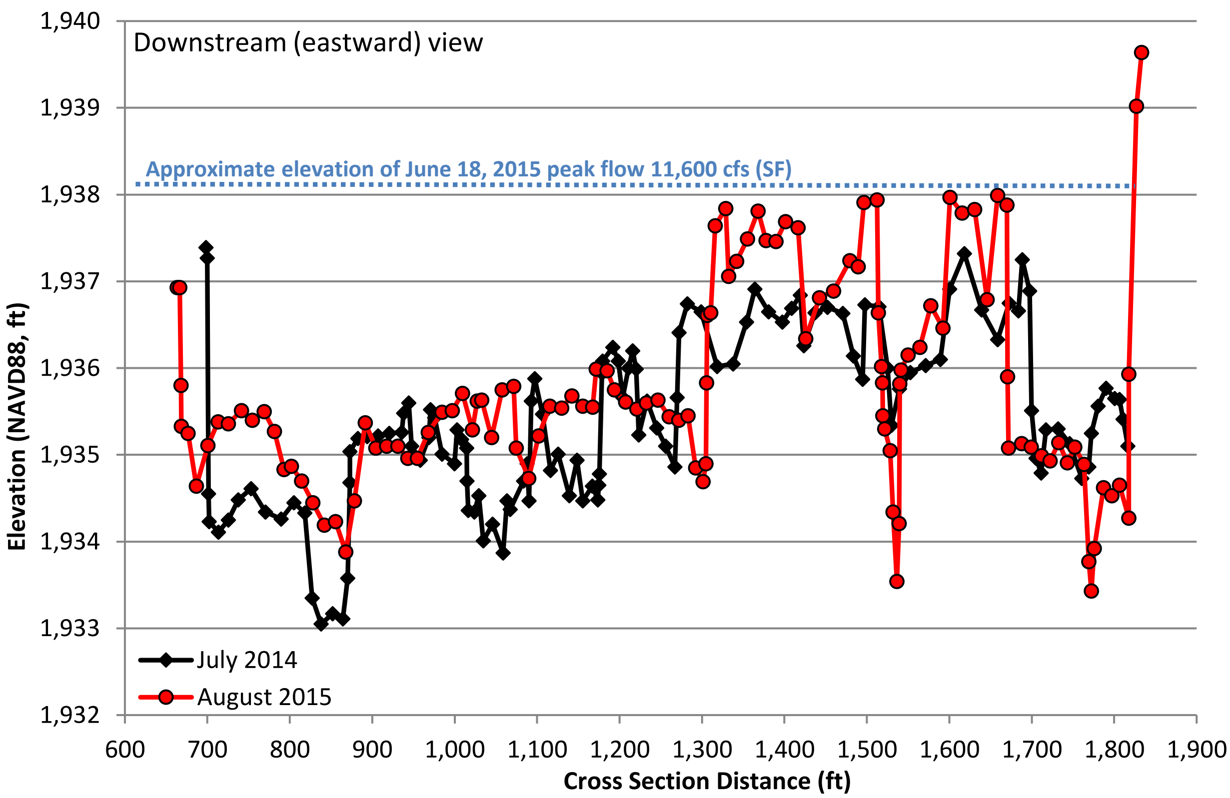


Figure A-19. Primary Cross Section #13 – June 2014 and August 2015

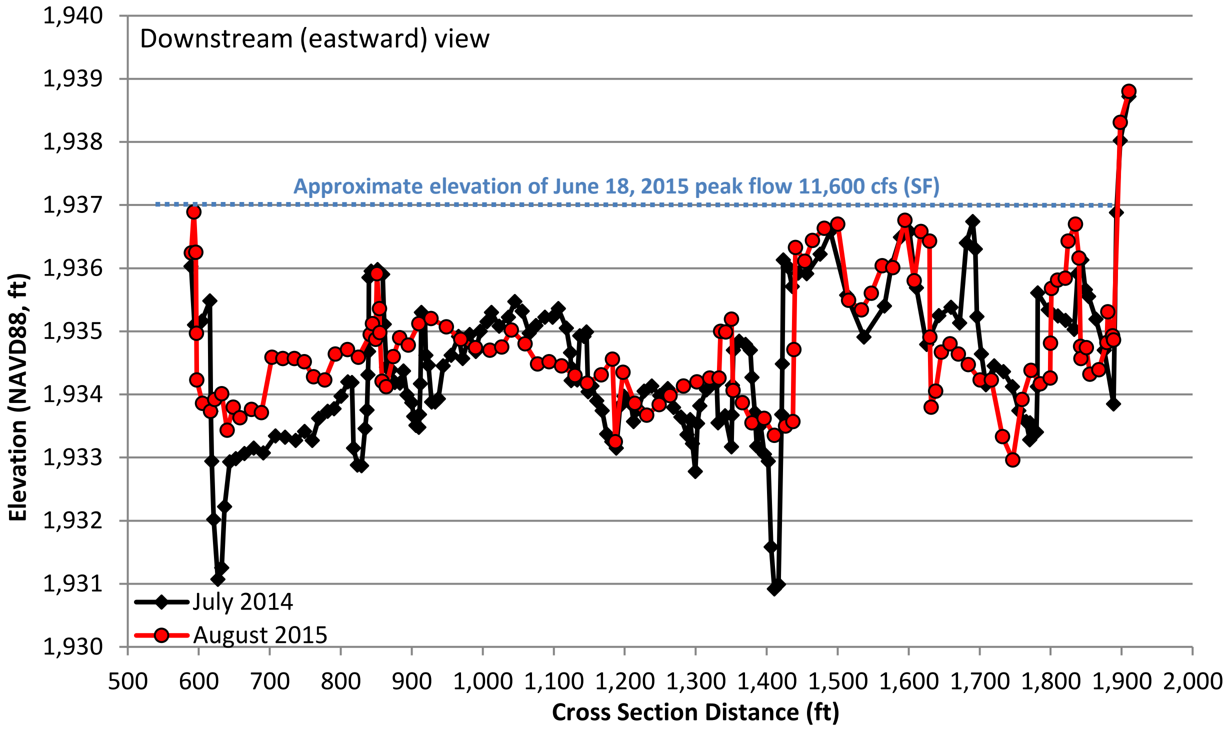


Figure A-20. Primary Cross Section #14 – June 2014 and August 2015

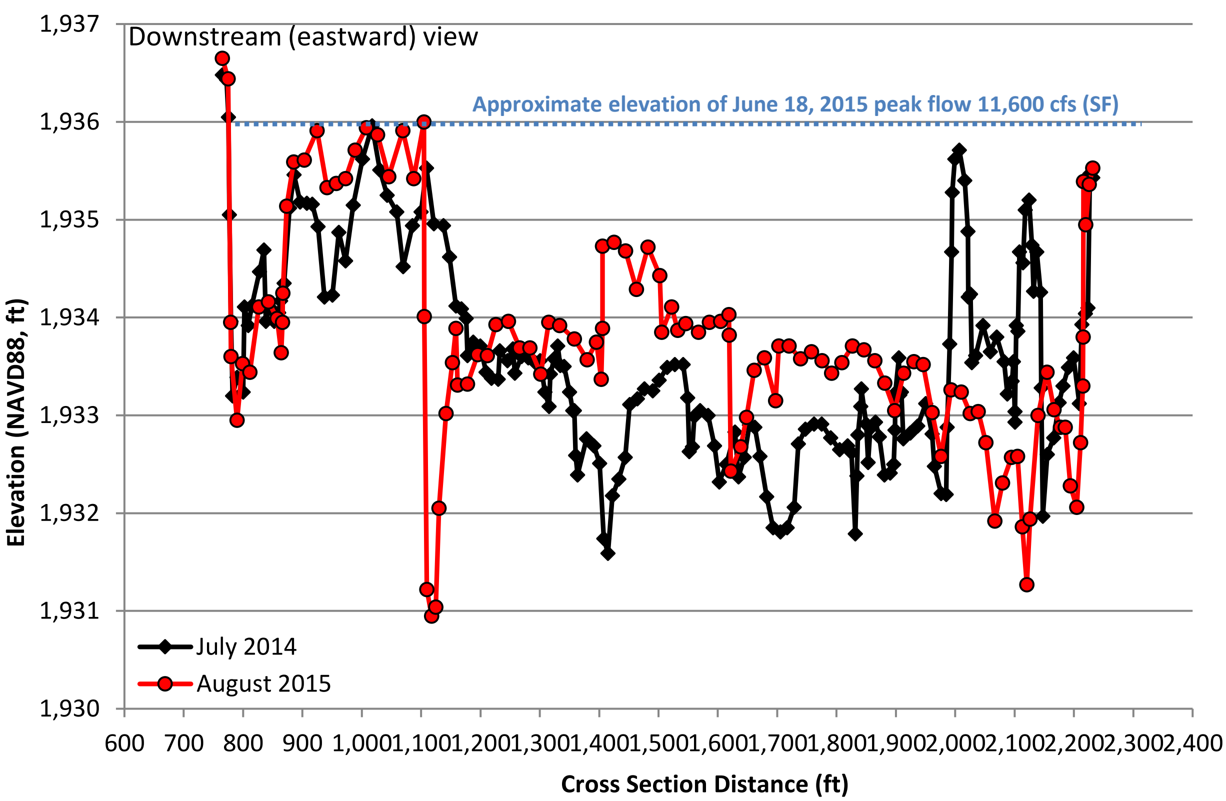


Figure A-21. Primary Cross Section #15 – June 2014 and August 2015

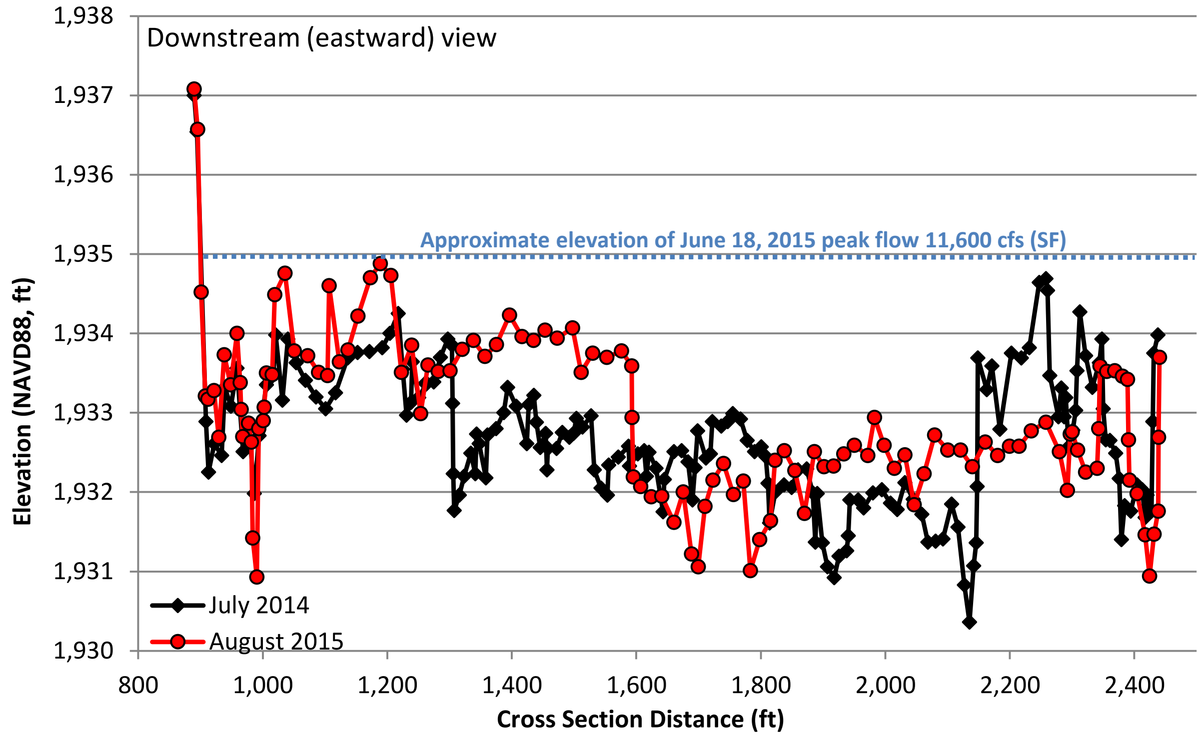


Figure A-22. Primary Cross Section #16 – June 2014 and August 2015

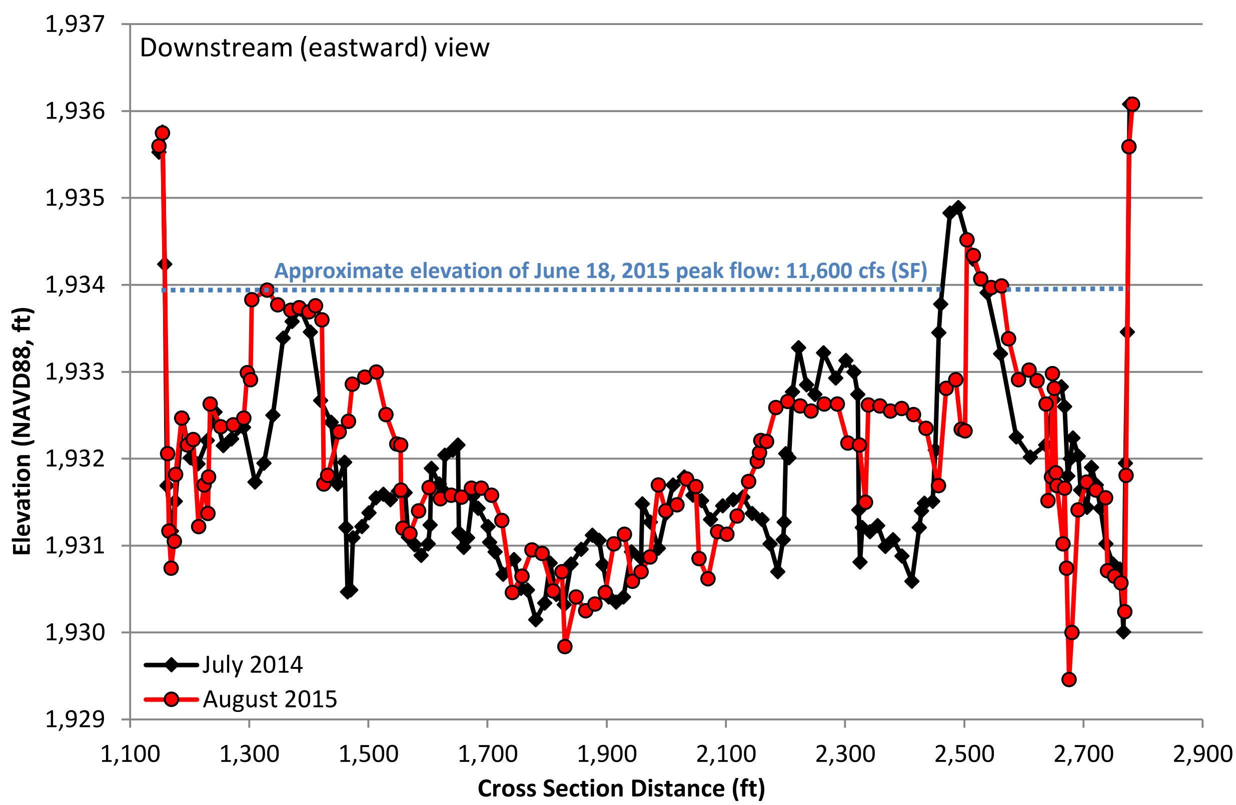


Figure A-23. Primary Cross Section #17 – June 2014 and August 2015

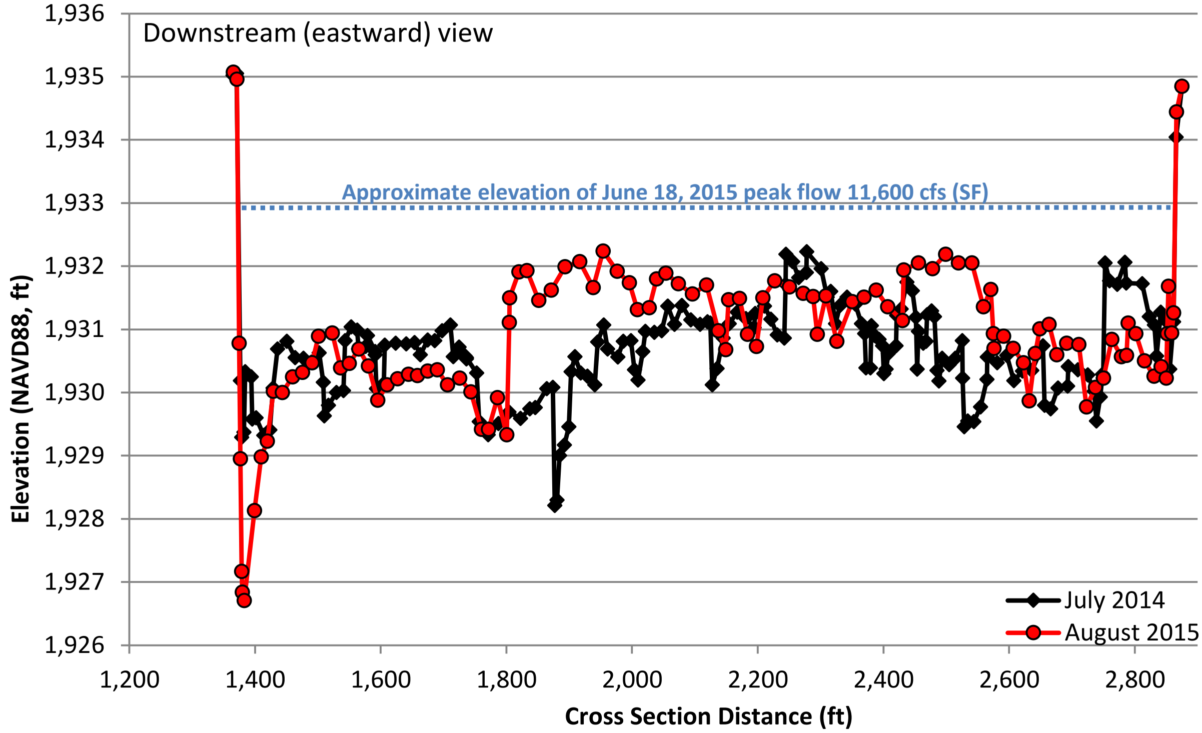


Figure A-24. Primary Cross Section #18 – June 2014 and August 2015

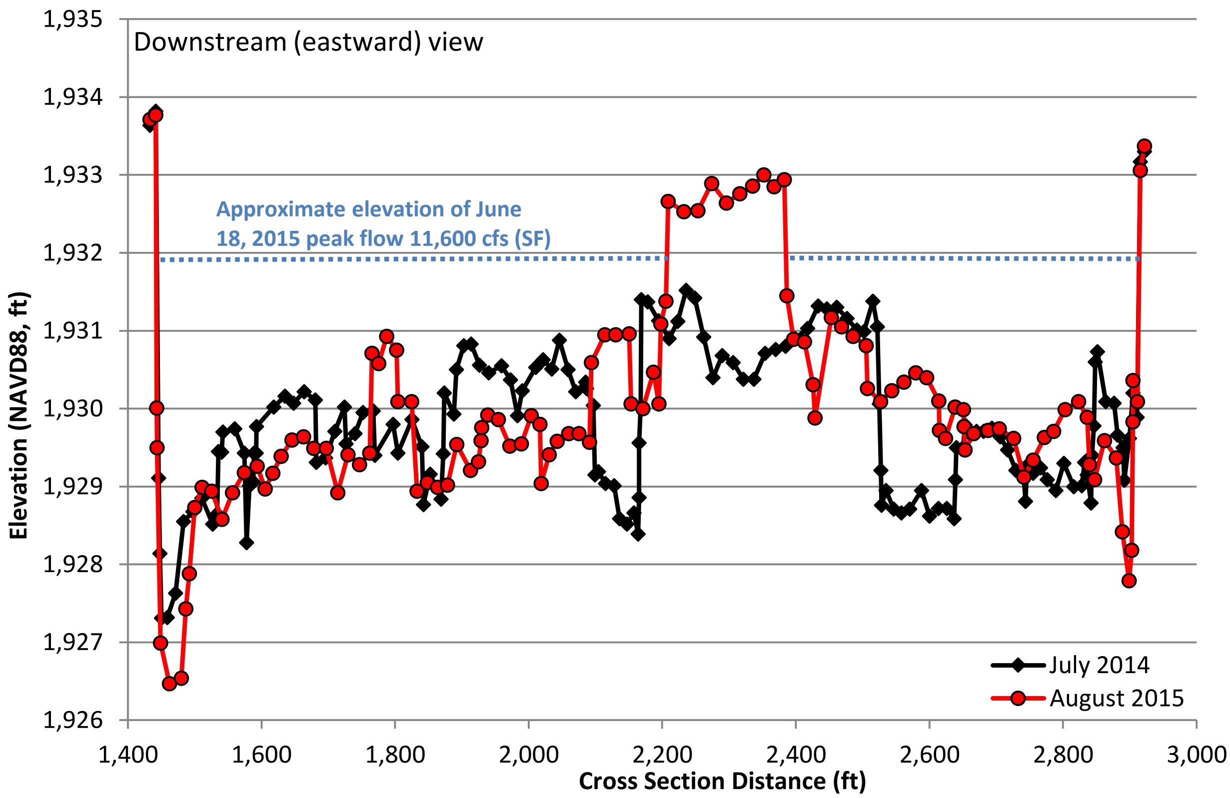


Figure A-25. Supplemental Cross Section A – June 2014 and August 2015

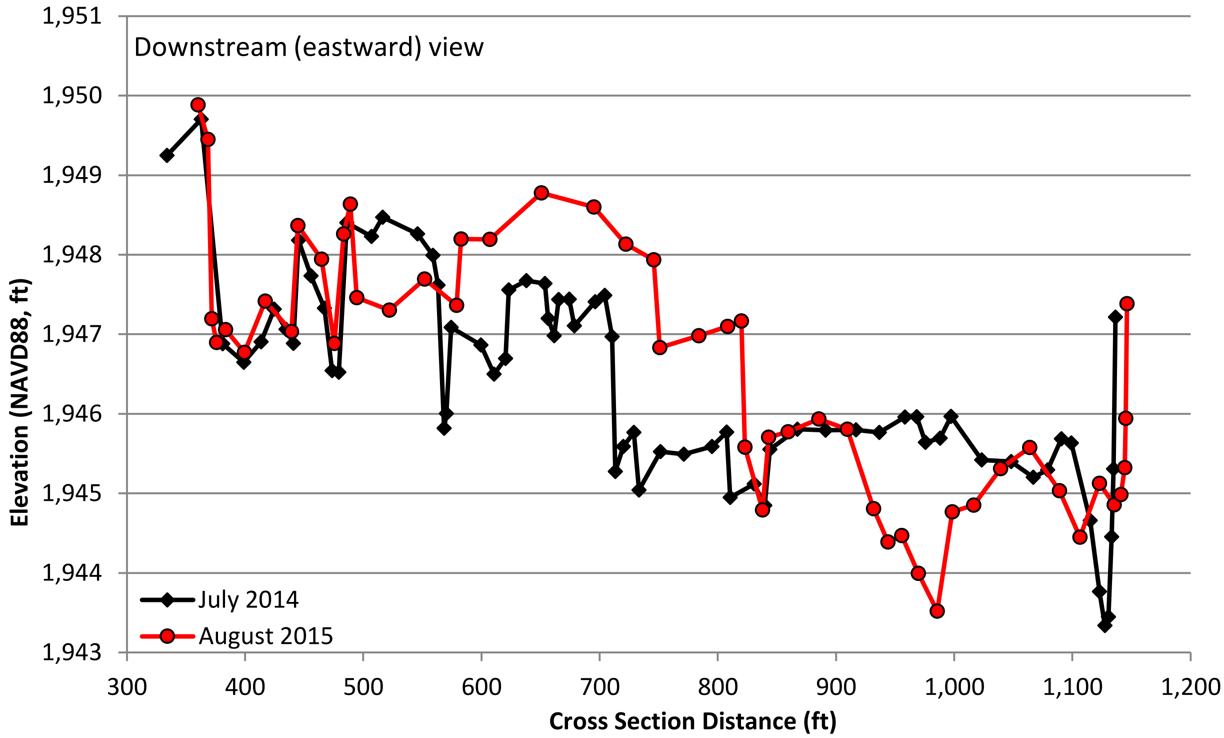


Figure A-26. Supplemental Cross Section B – June 2014 and August 2015

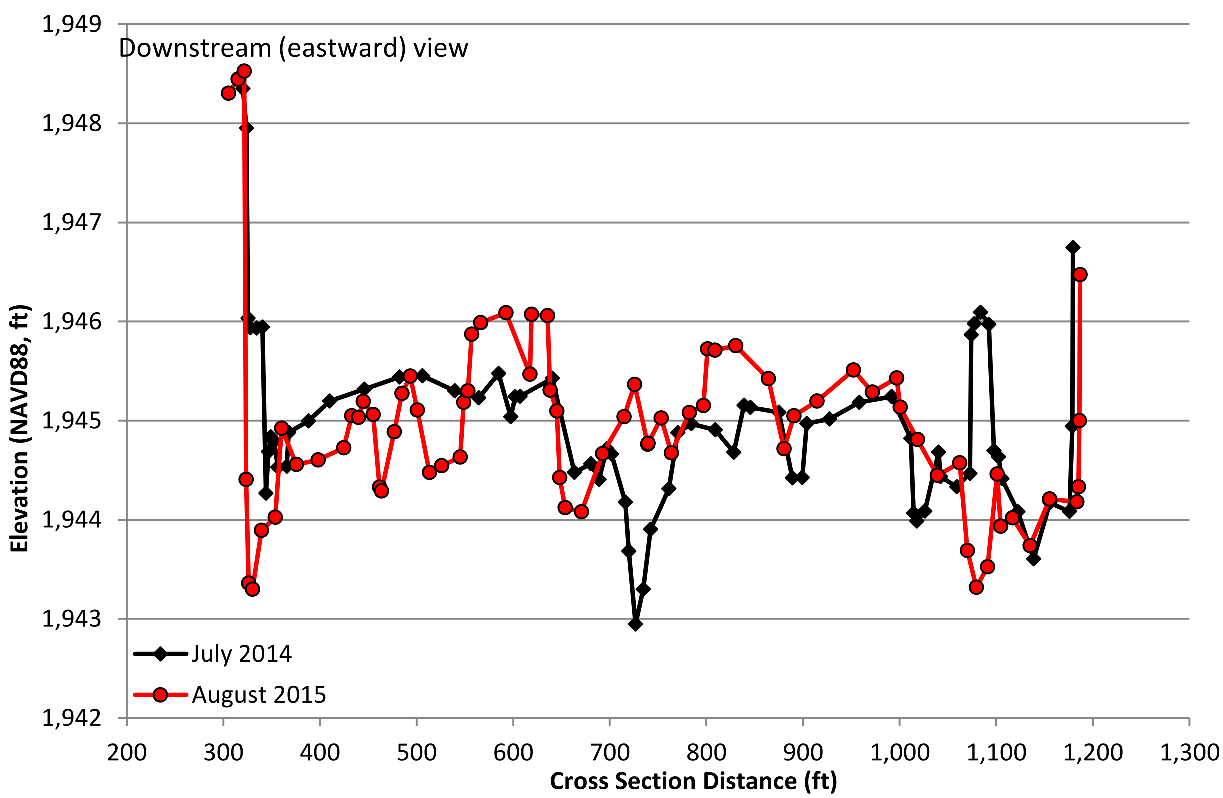


Figure A-27. Supplemental Cross Section C – June 2014 and August 2015

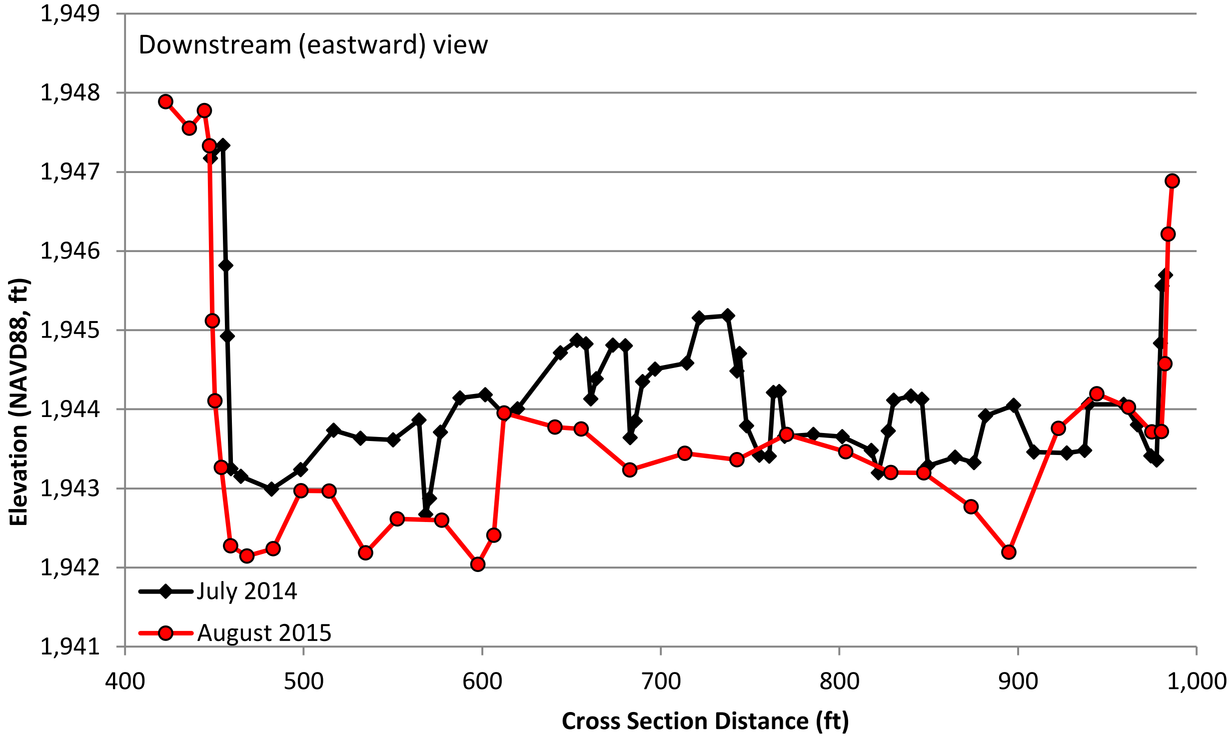


Figure A-28. Supplemental Cross Section D – June 2014 and August 2015

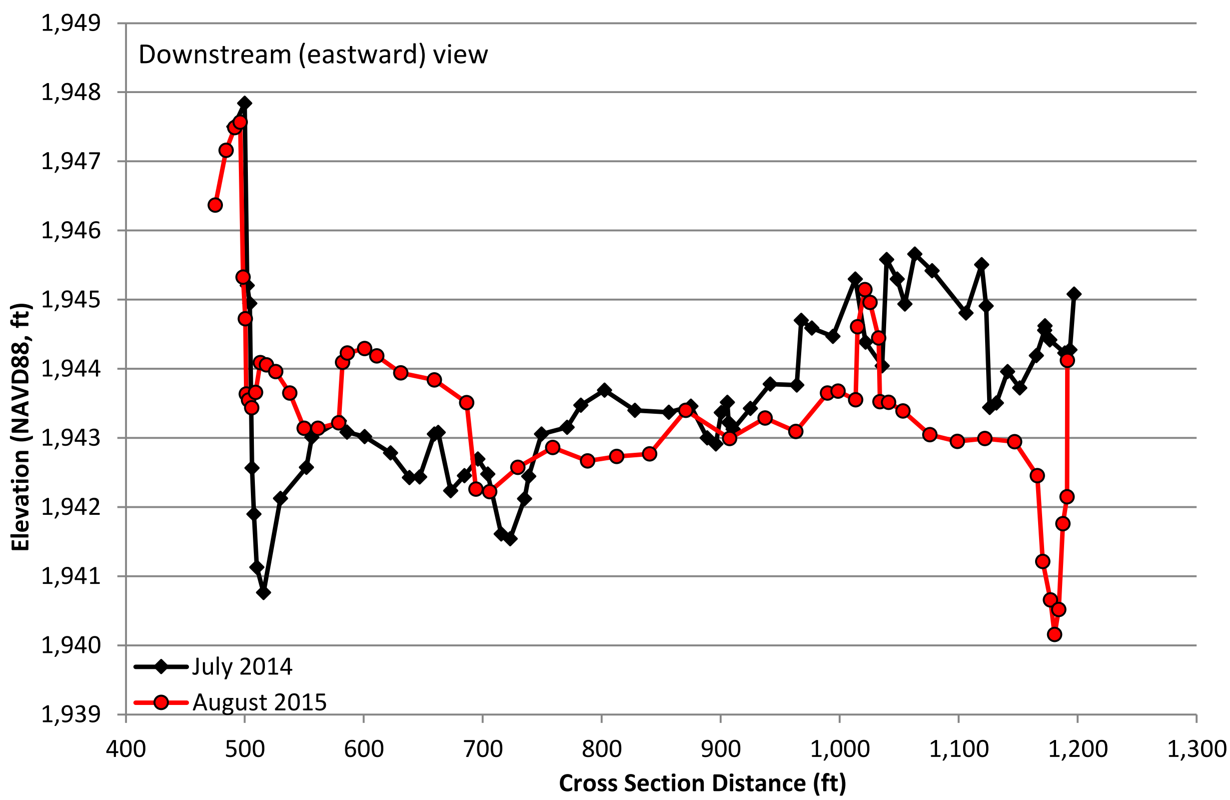


Figure A-29. Supplemental Cross Section E – June 2014 and August 2015

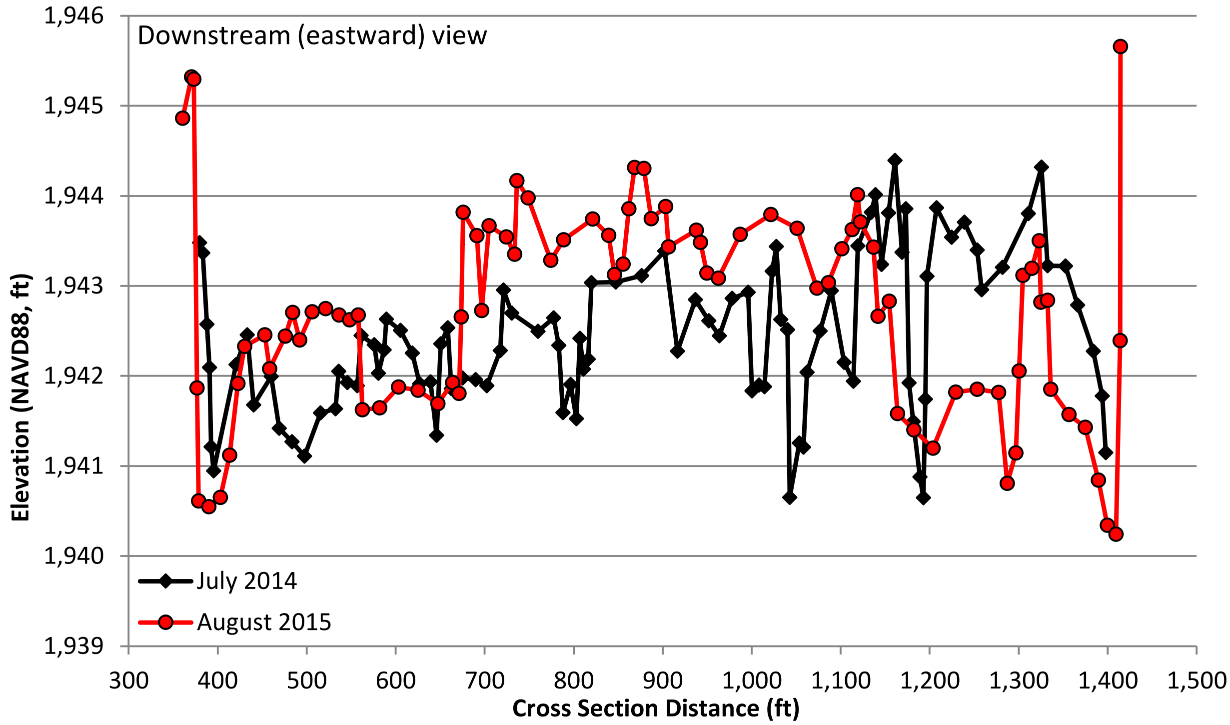


Figure A-30. Supplemental Cross Section F – June 2014 and August 2015

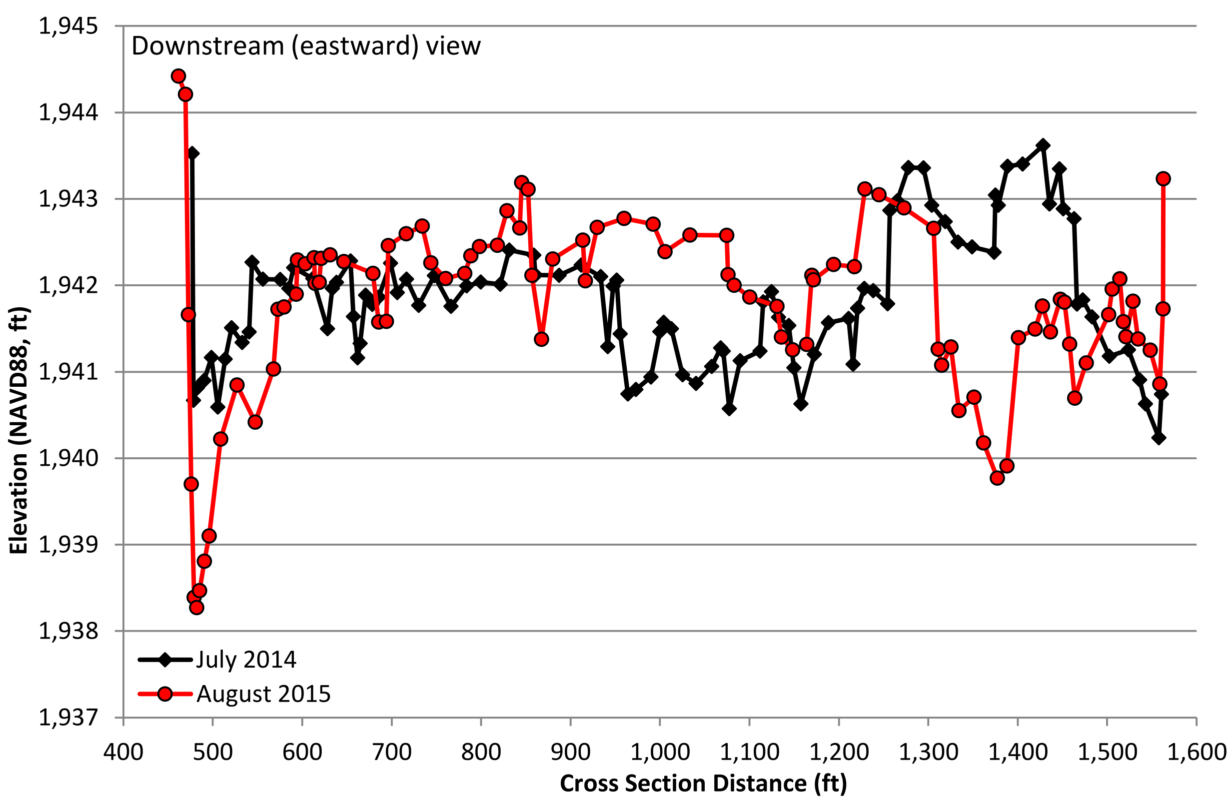


Figure A-31. Supplemental Cross Section G – June 2014 and August 2015

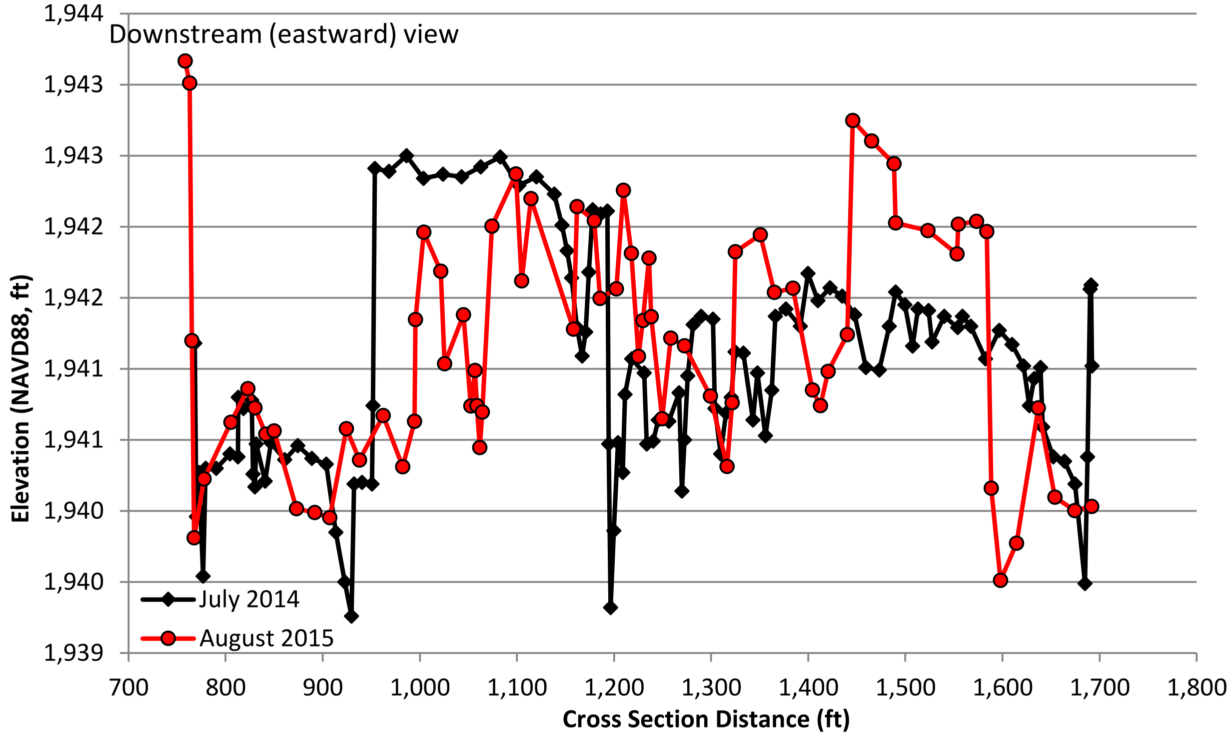


Figure A-32. Supplemental Cross Section H – June 2014 and August 2015

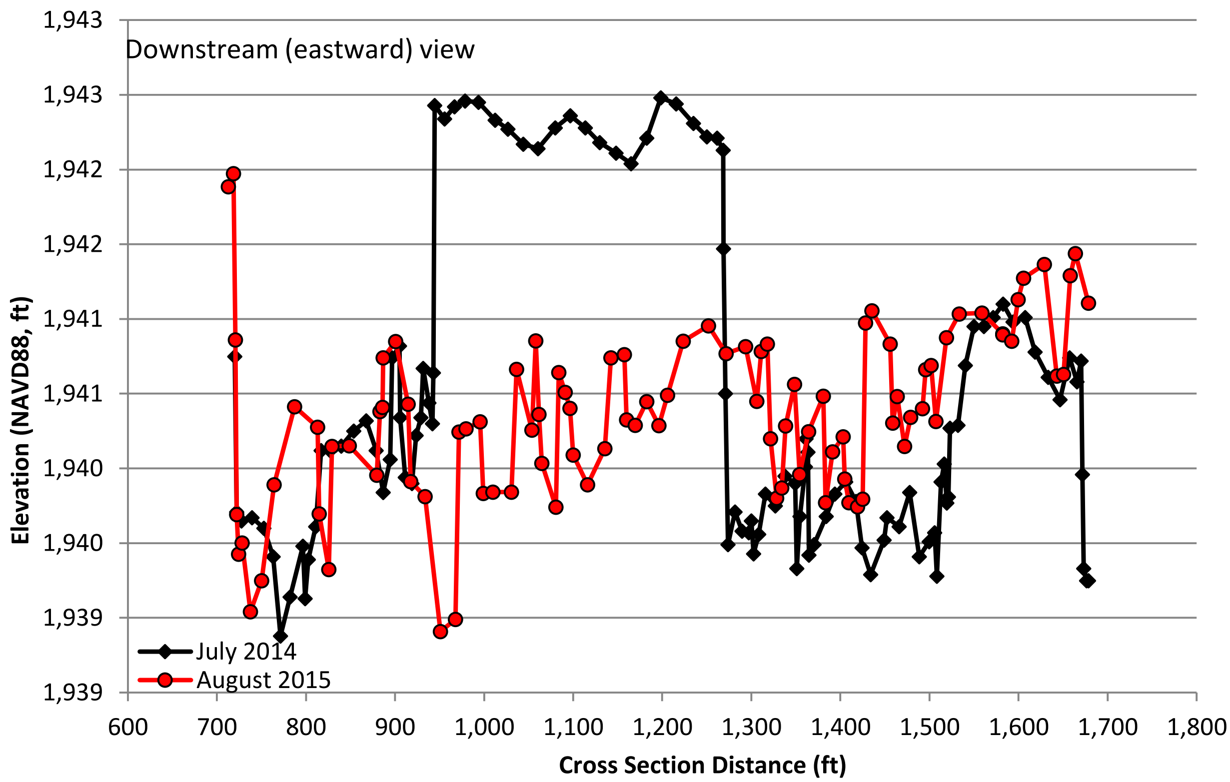


Figure A-33. Supplemental Cross Section I – June 2014 and August 2015

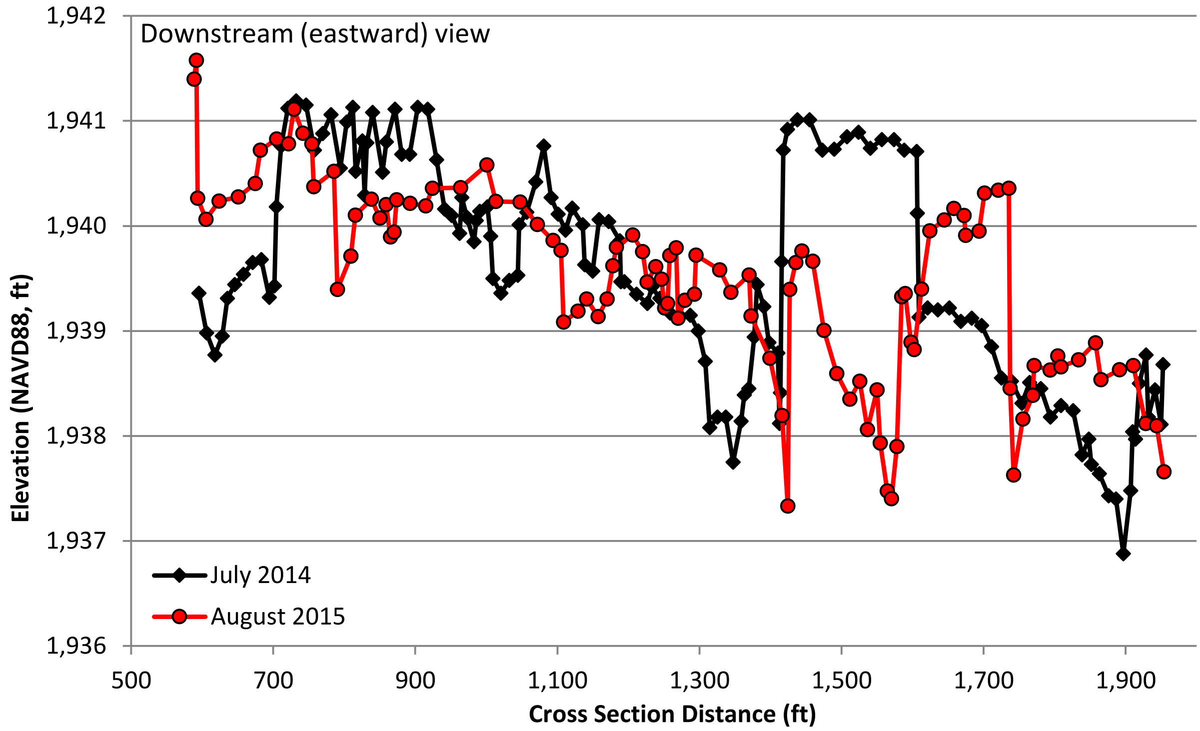


Figure A-34. Supplemental Cross Section J – June 2014 and August 2015

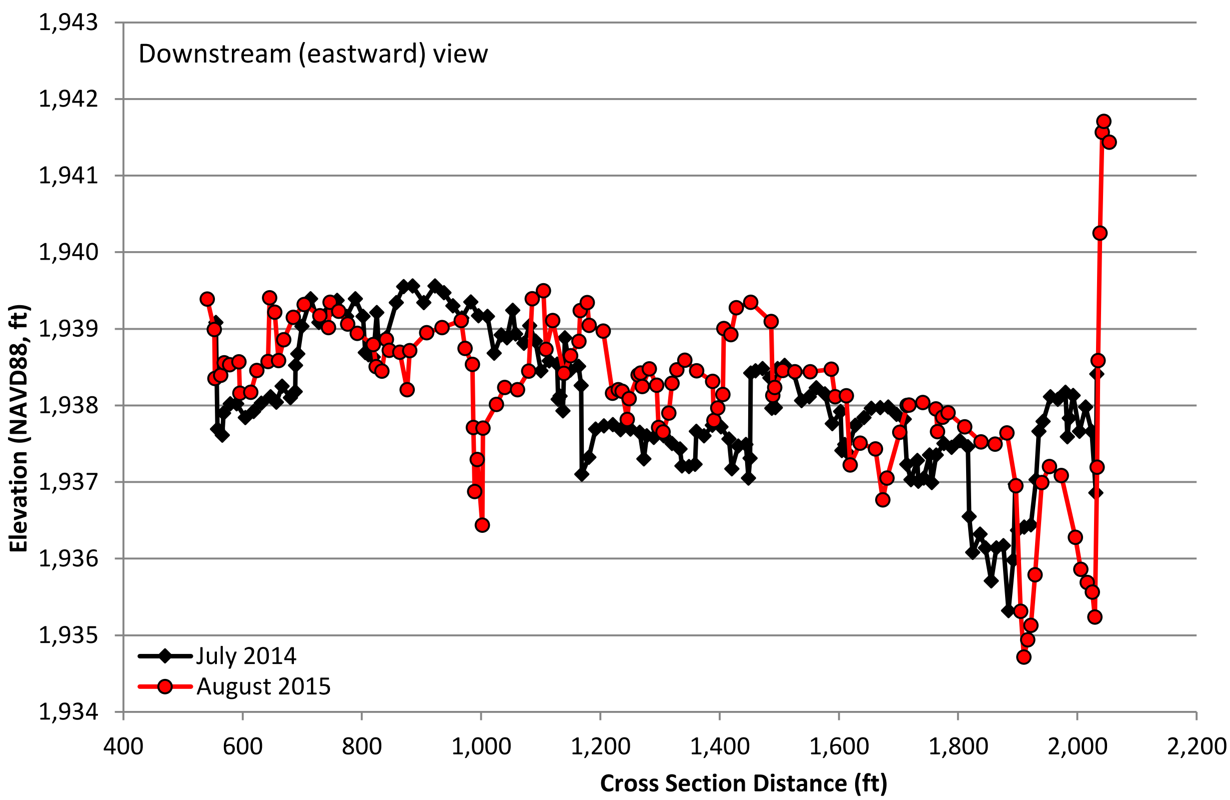


Figure A-35. Supplemental Cross Section K – June 2014 and August 2015

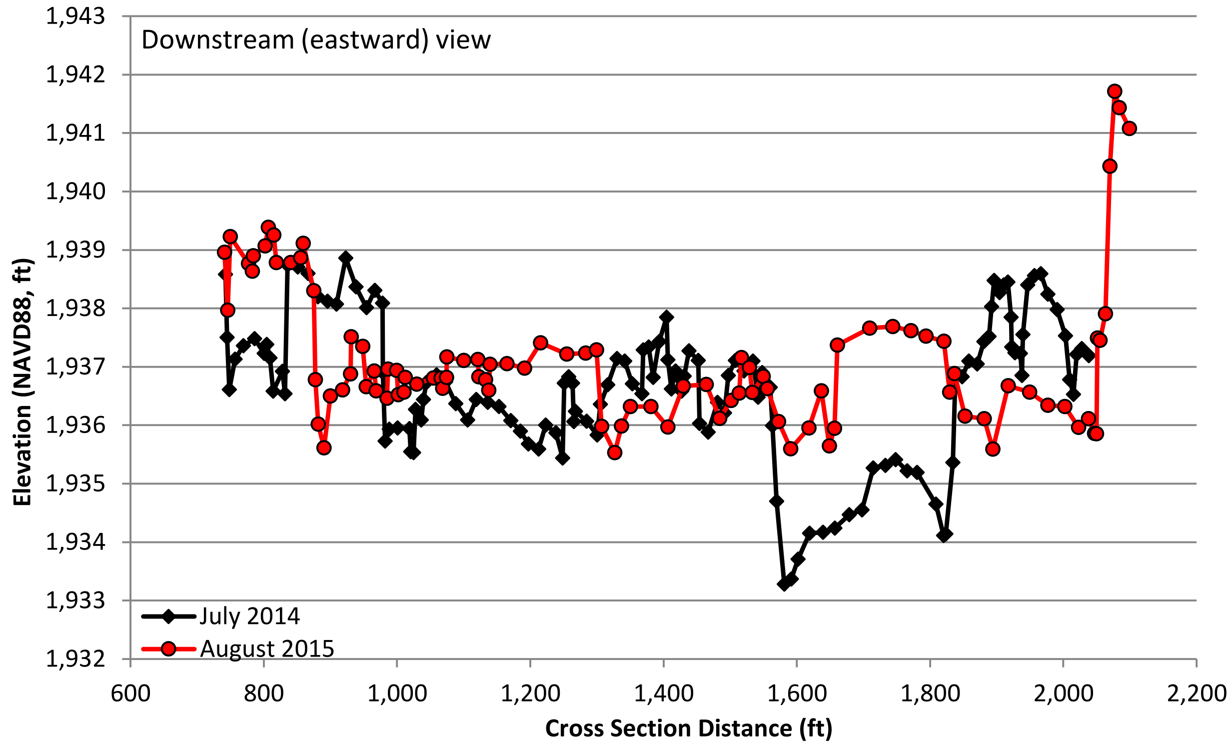


Figure A-36. Supplemental Cross Section L – June 2014 and August 2015

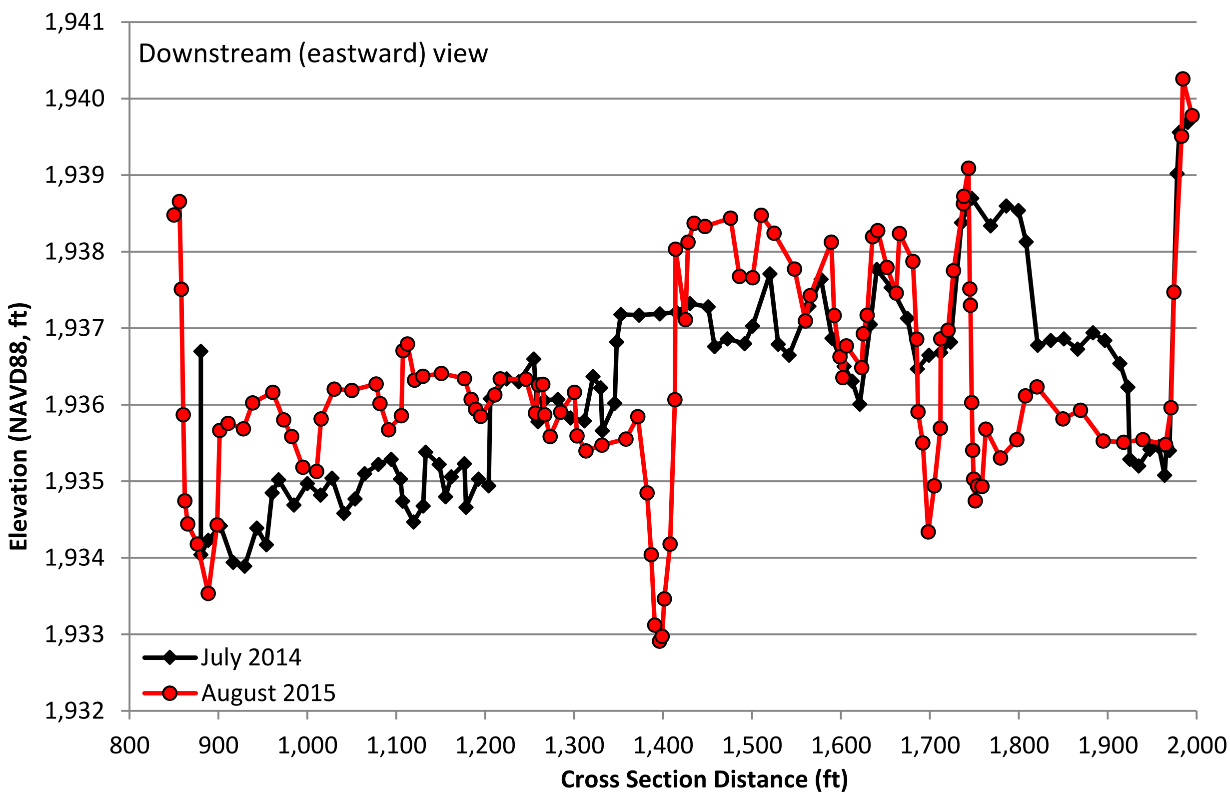


Figure A-37. Supplemental Cross Section M – June 2014 and August 2015

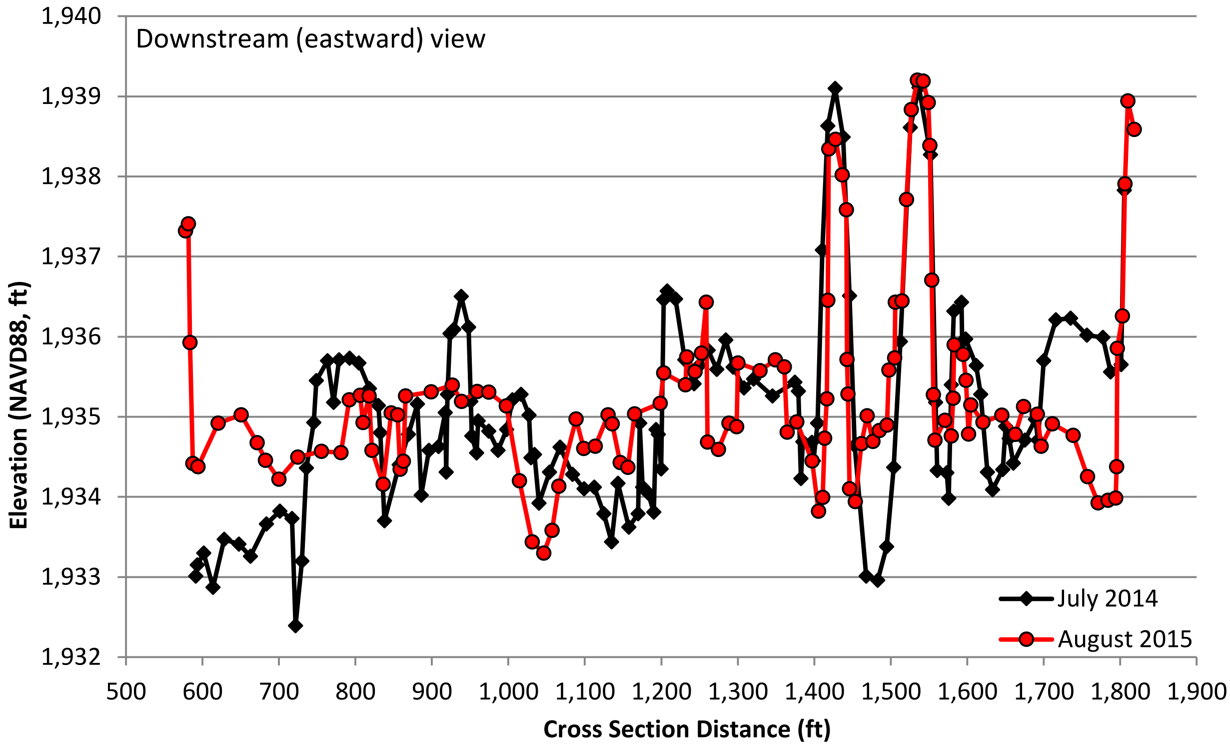


Figure A-38. Supplemental Cross Section N – June 2014 and August 2015

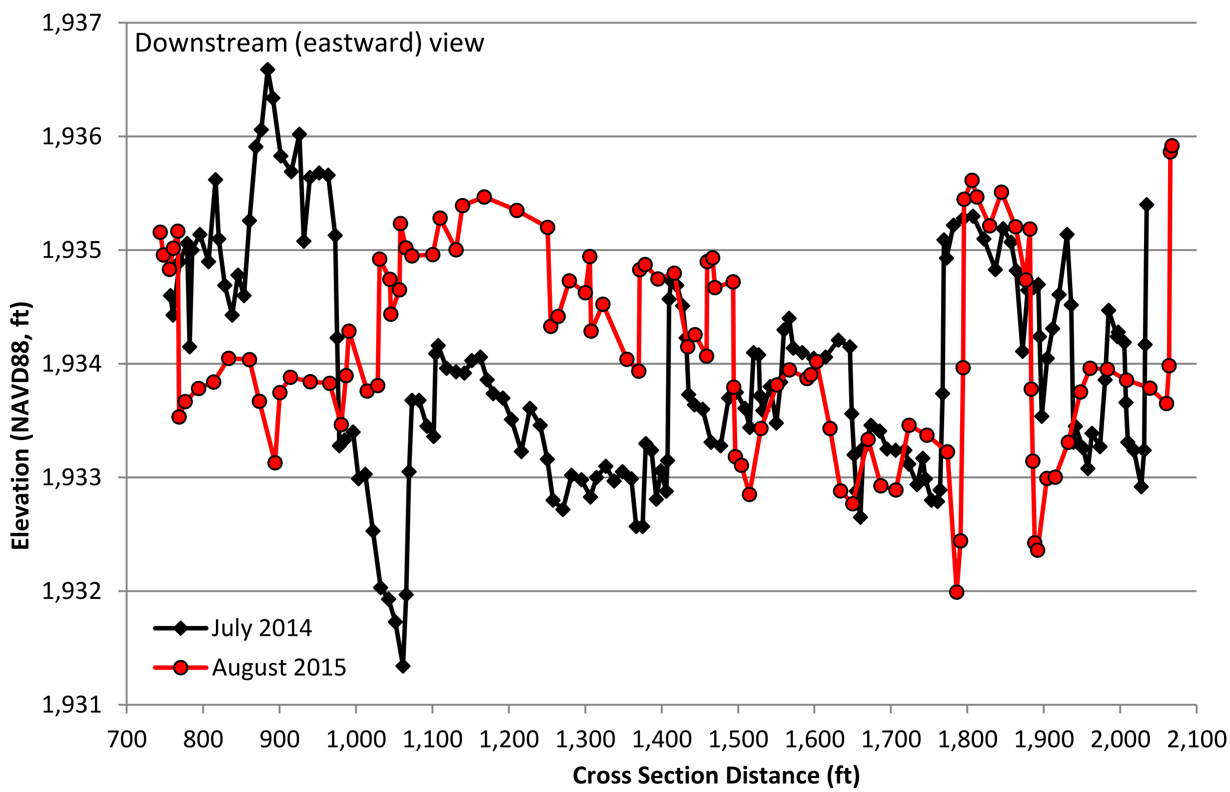


Figure A-39. Supplemental Cross Section O – June 2014 and August 2015

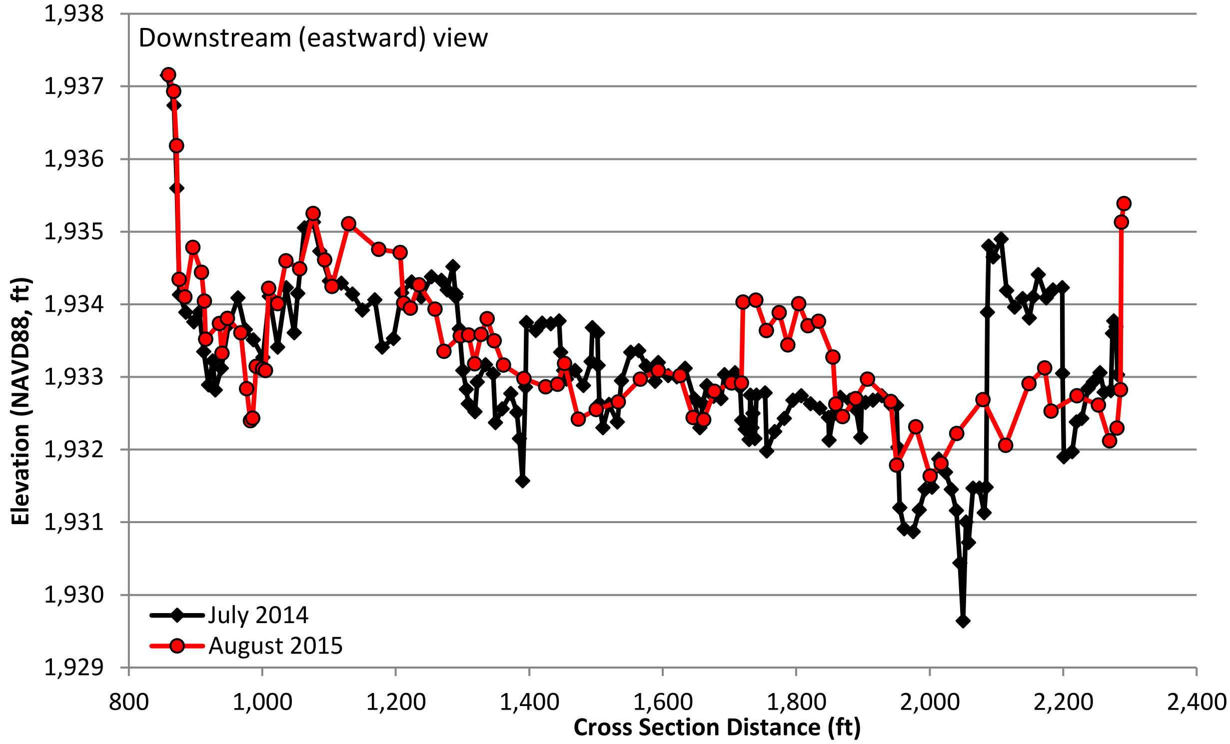


Figure A-40. Supplemental Cross Section P – June 2014 and August 2015

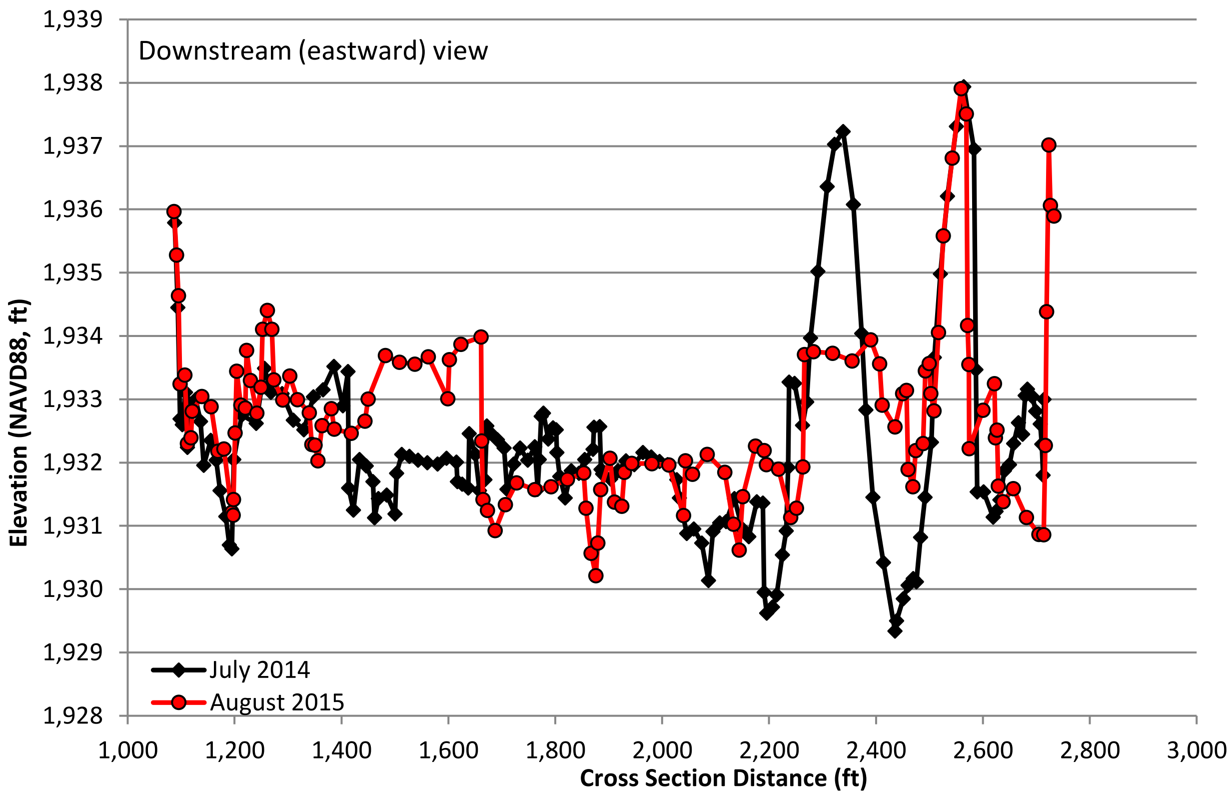


Figure A-41. Supplemental Cross Section Q – June 2014 and August 2015

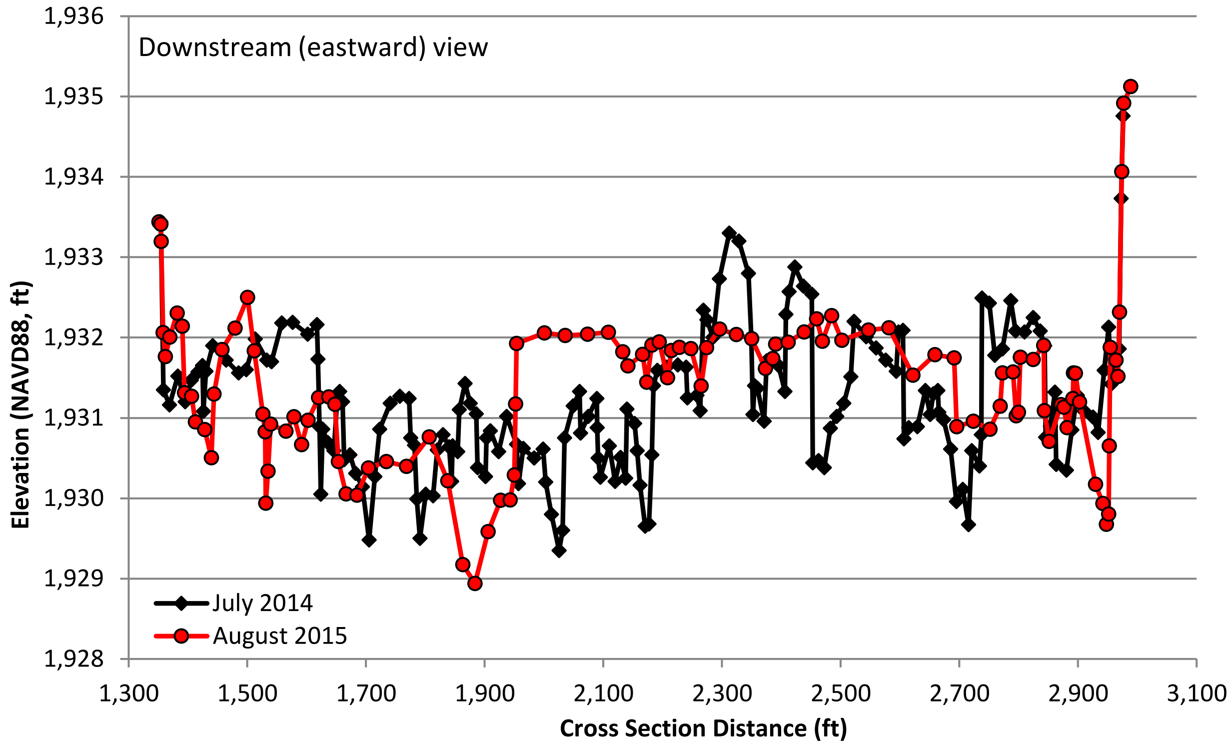


Figure A-42. Supplemental Cross Section R – June 2014 and August 2015

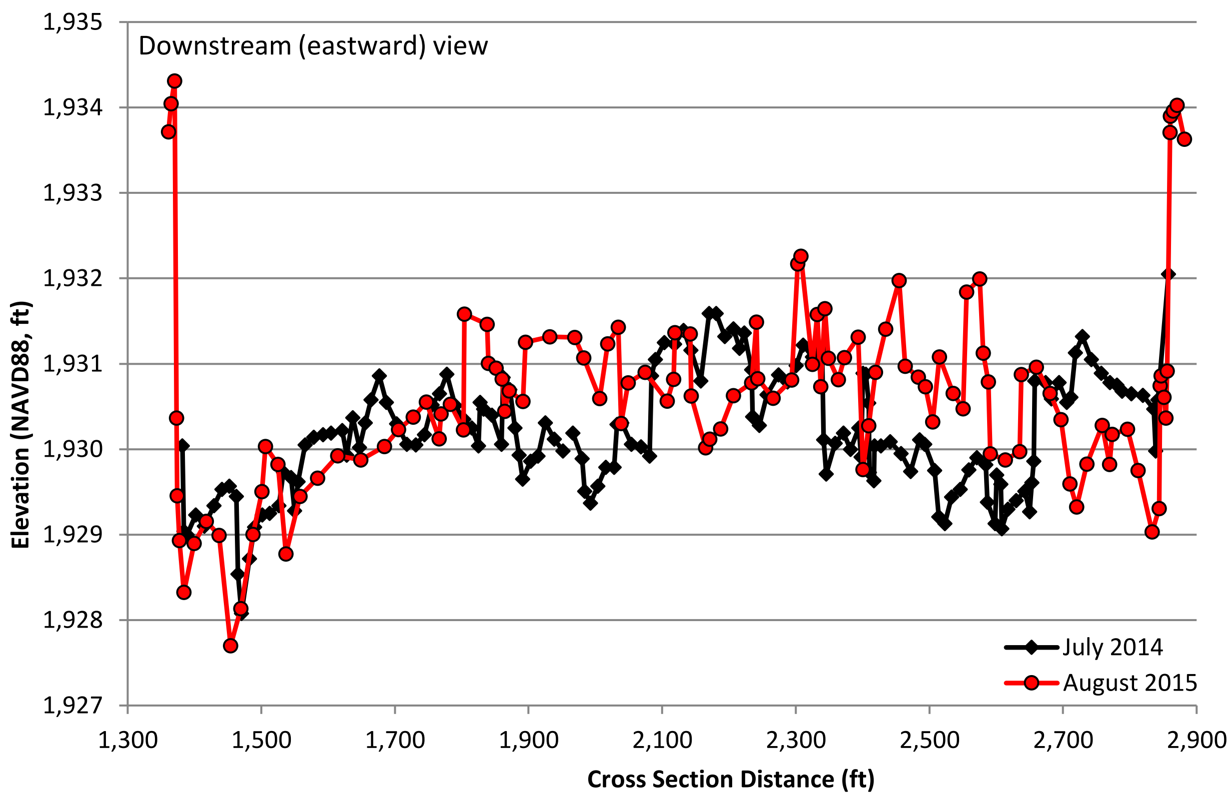


Figure A-43. Supplemental Cross Section S – June 2014 and August 2015

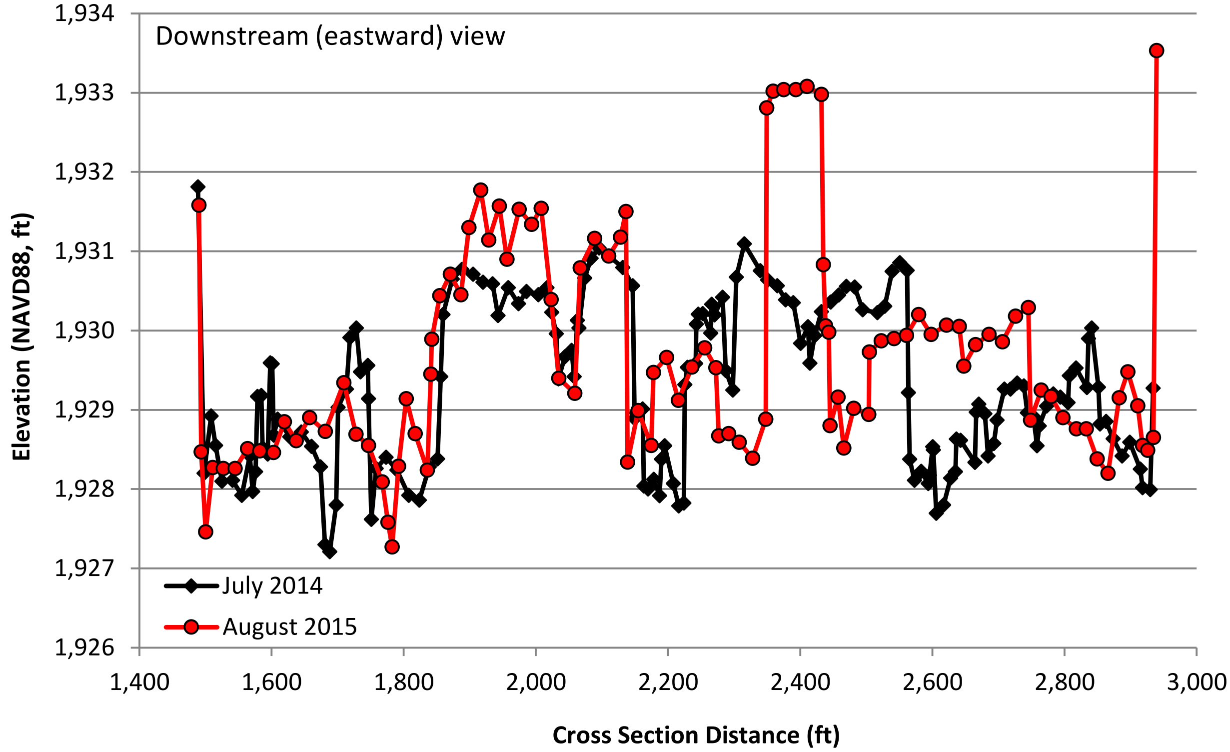


Figure A-44. Longitudinal Profile – Northern Route July 2014 and August 2015 – Cross Sections 1-6

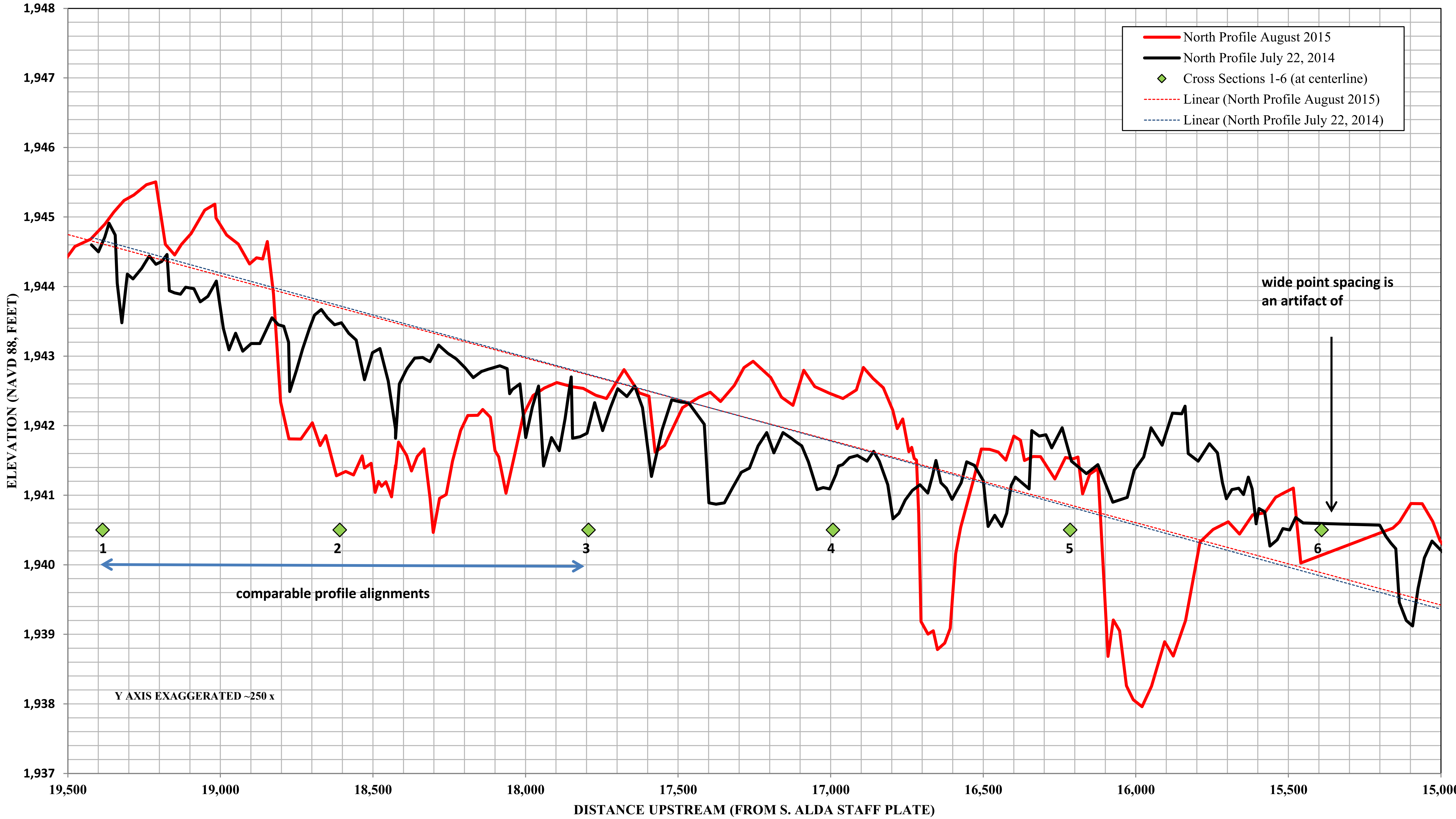


Figure A-45. Longitudinal Profile – Northern Route July 2014 and August 2015 – Cross Sections 7-12

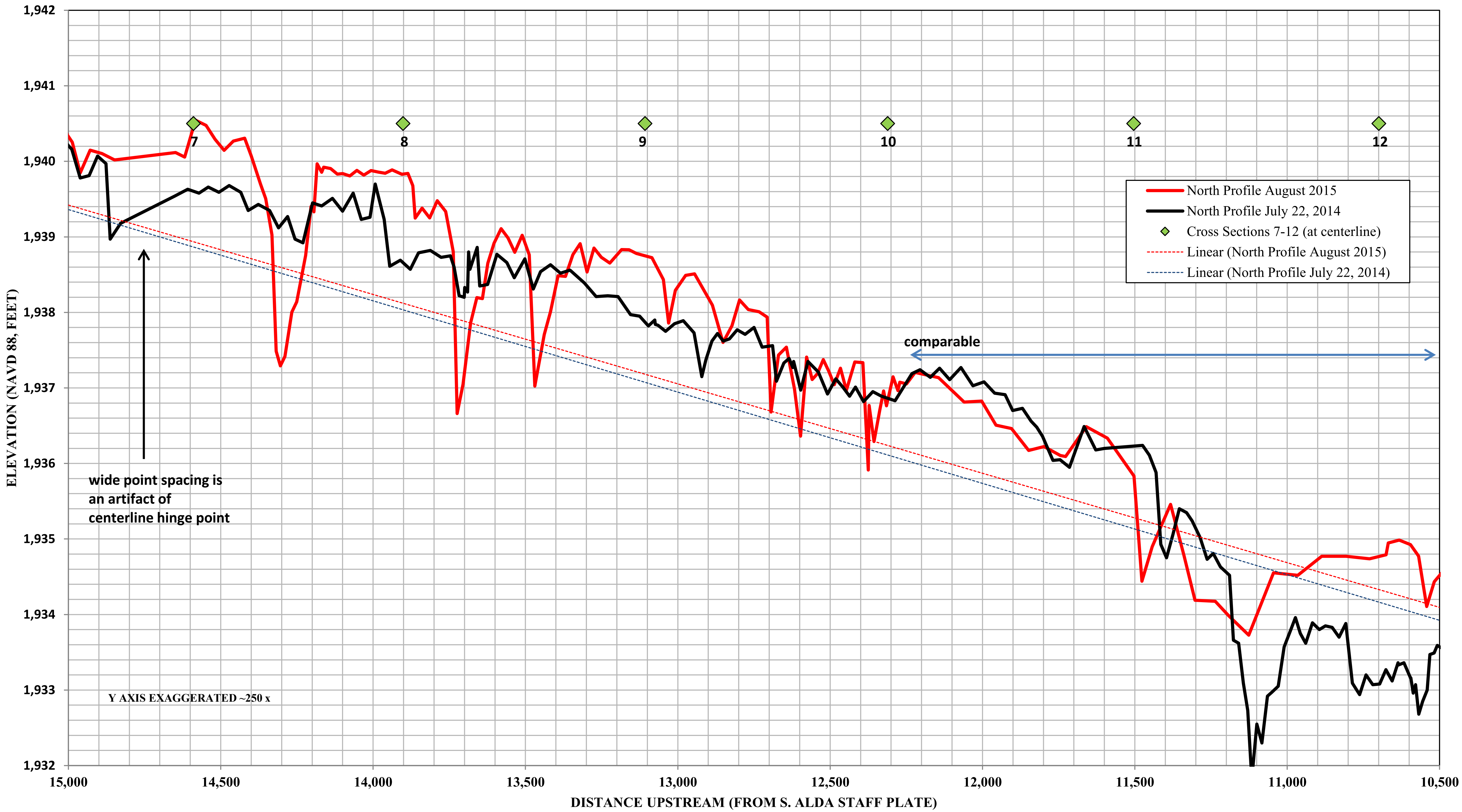


Figure A-46. Longitudinal Profile – Northern Route July 2014 and August 2015 – Cross Sections 13-18

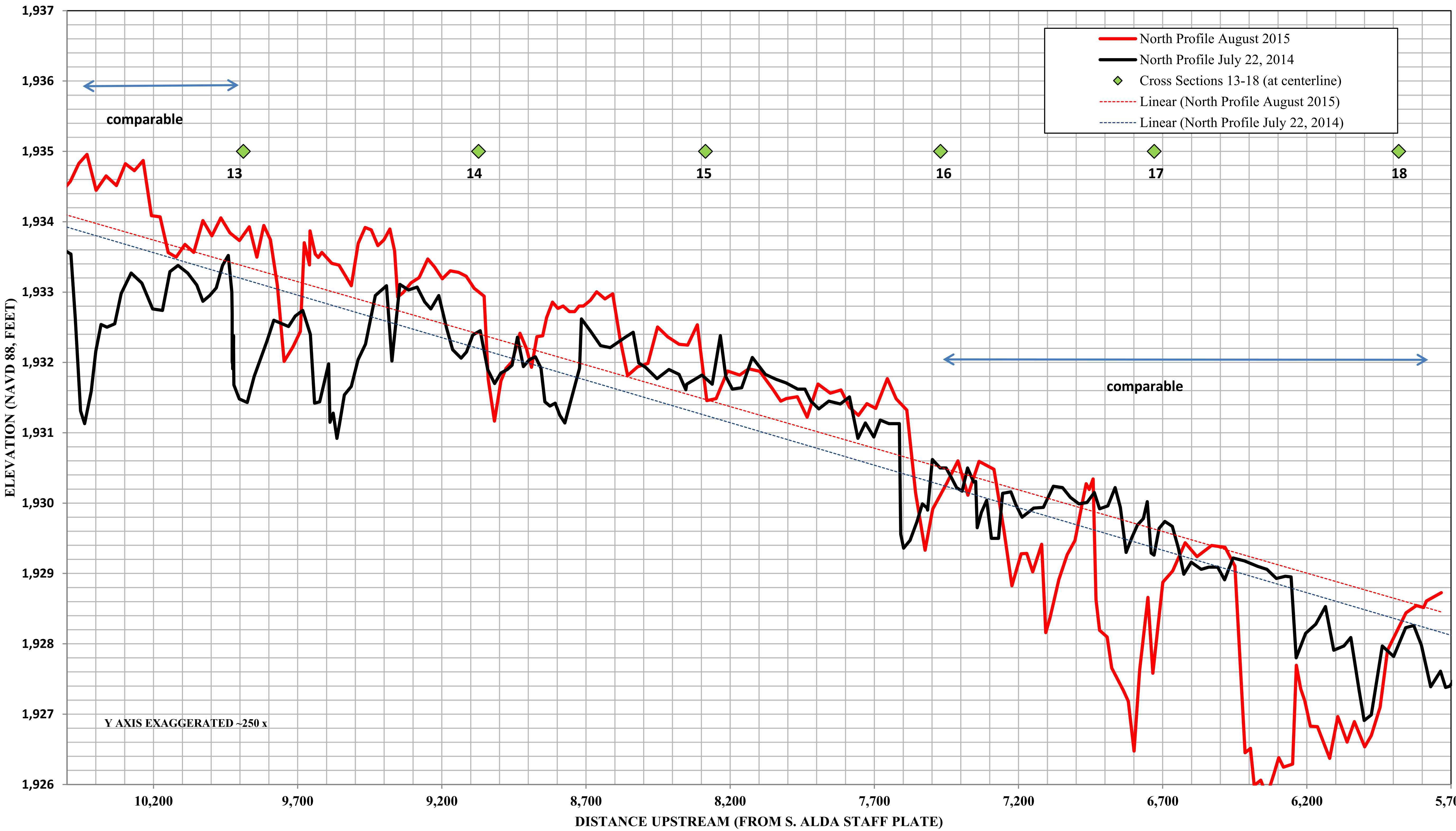


Figure A-47. Longitudinal Profile – Southern Route July 2014 and August 2015 – Cross Sections 1-6

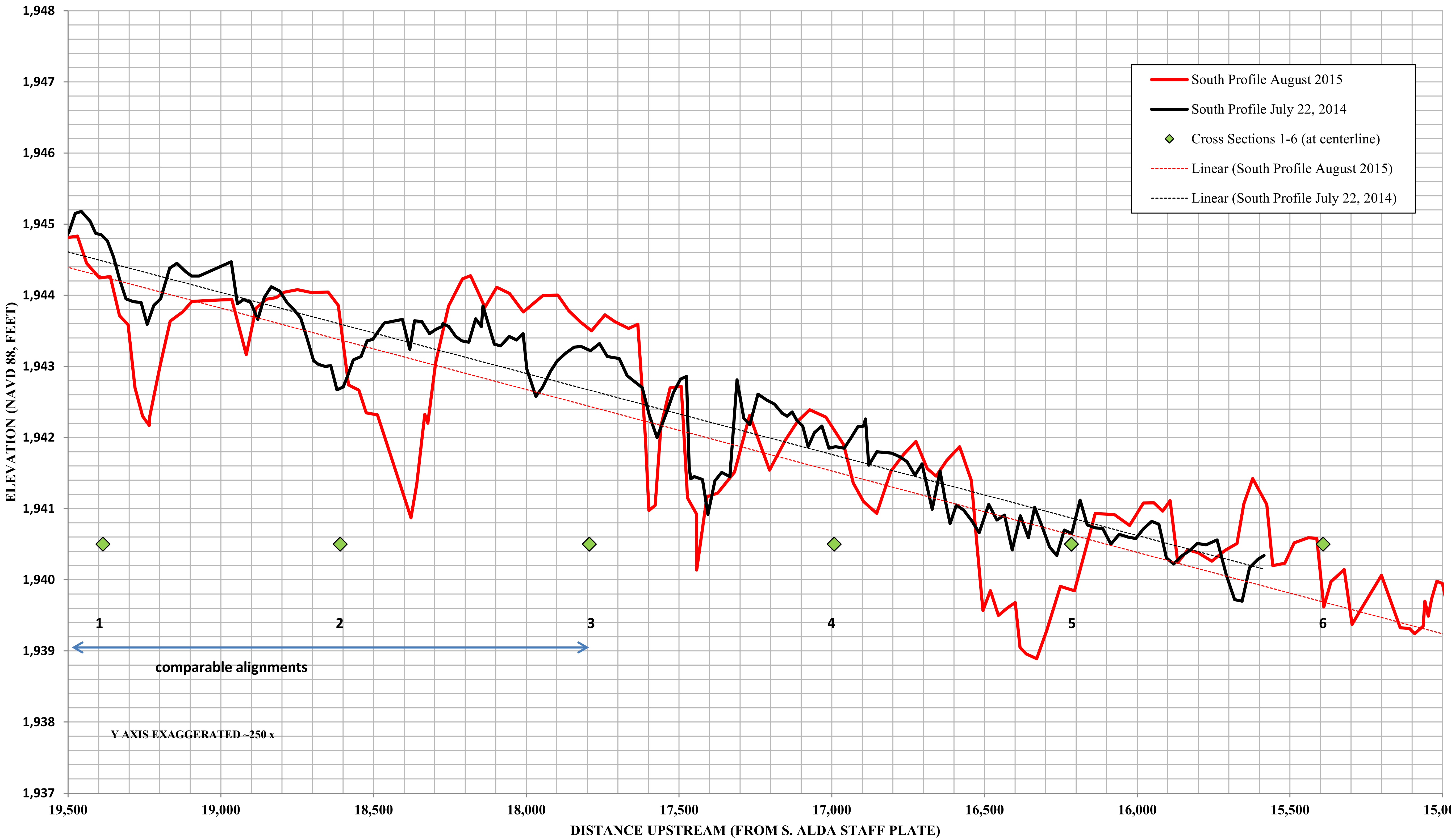


Figure A-48. Longitudinal Profile – Southern Route July 2014 and August 2015 – Cross Sections 7-12

Figure A-49. Longitudinal Profile – Southern Route July 2014 and August 2015 – Cross Sections 13-18

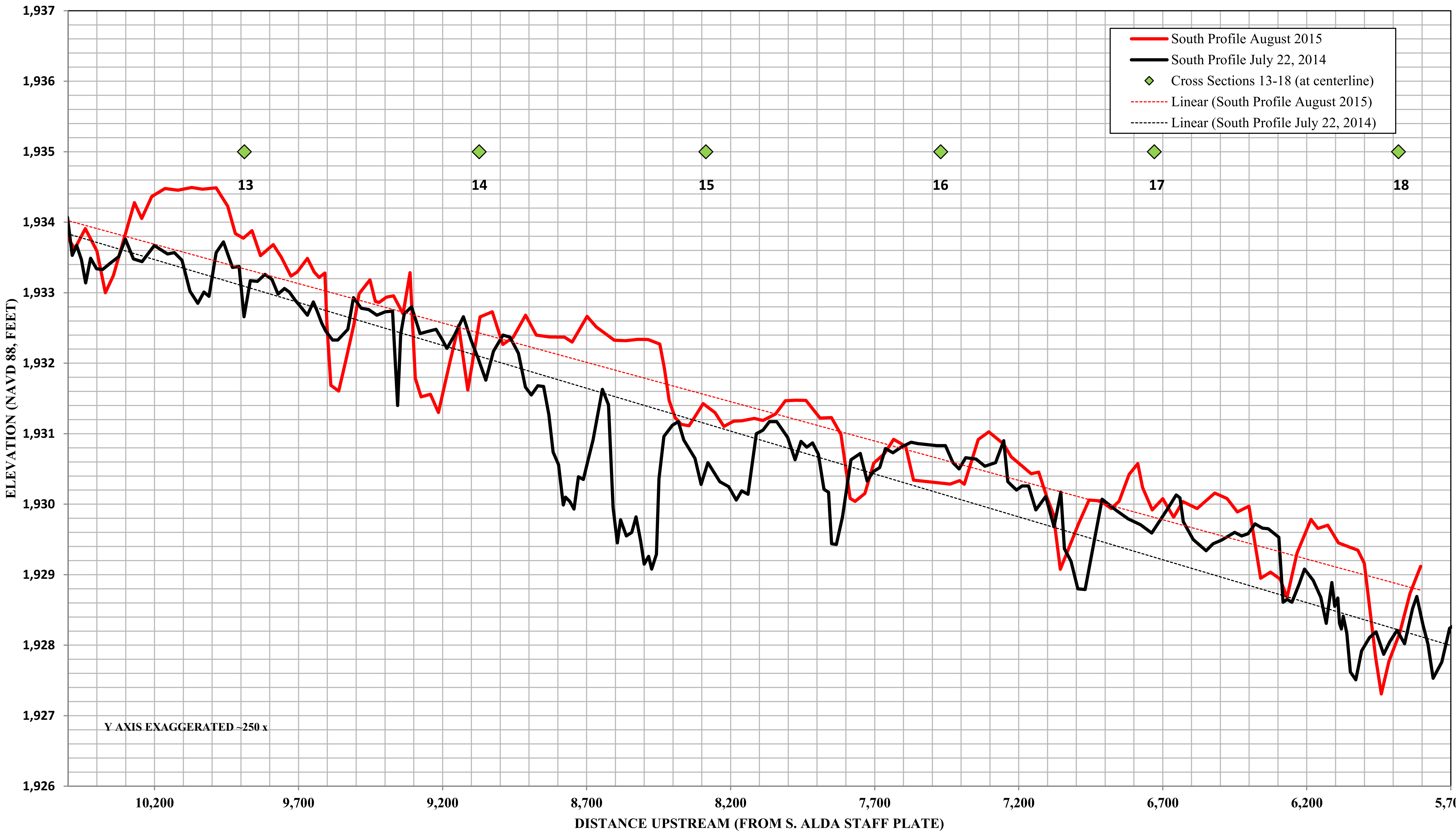


Figure A-50. 0.063mm to 0.25mm Suspended Sediment Transport Curve

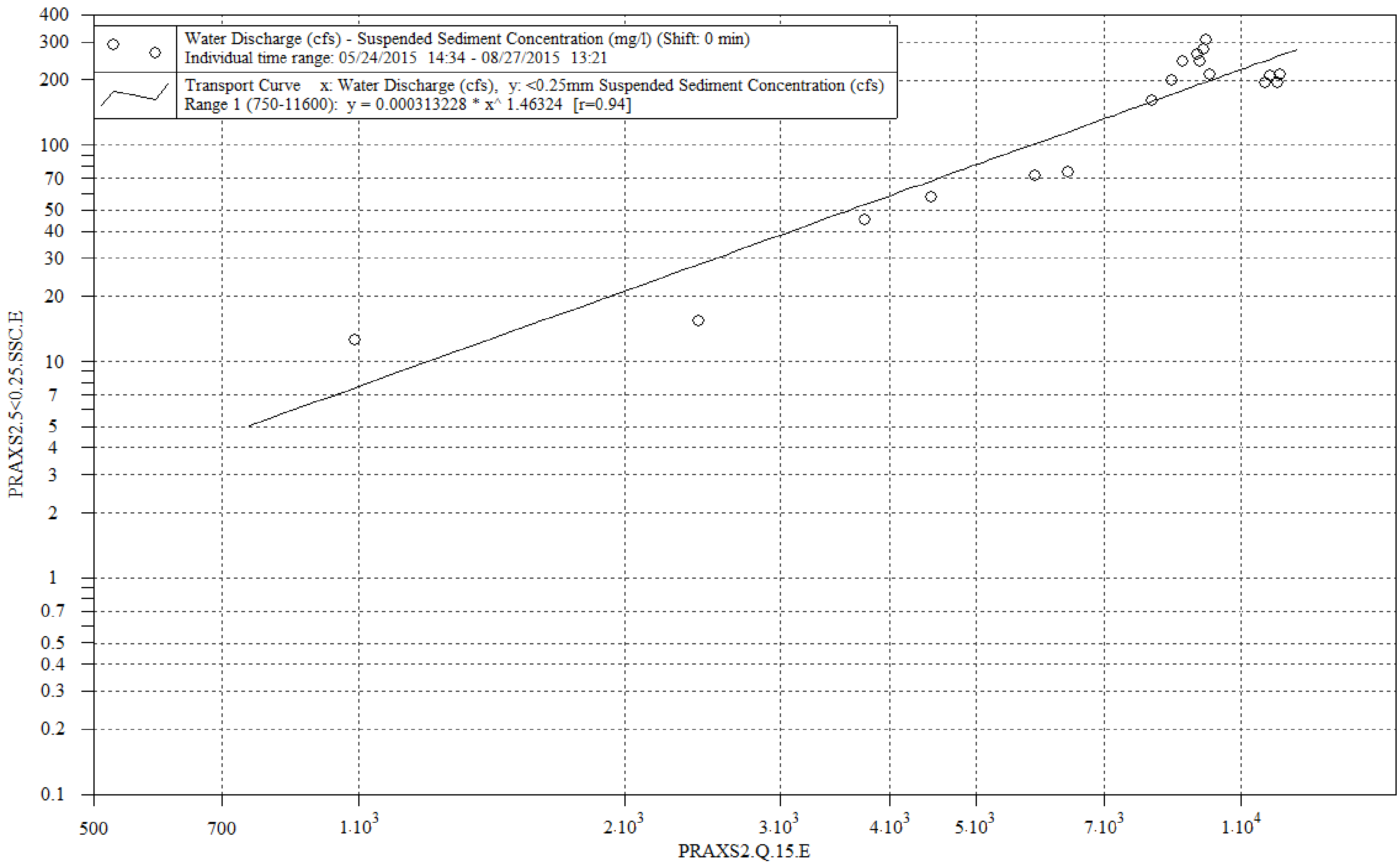


Figure A-51. 0.25mm – 0.5mm Suspended Sediment Transport Curve

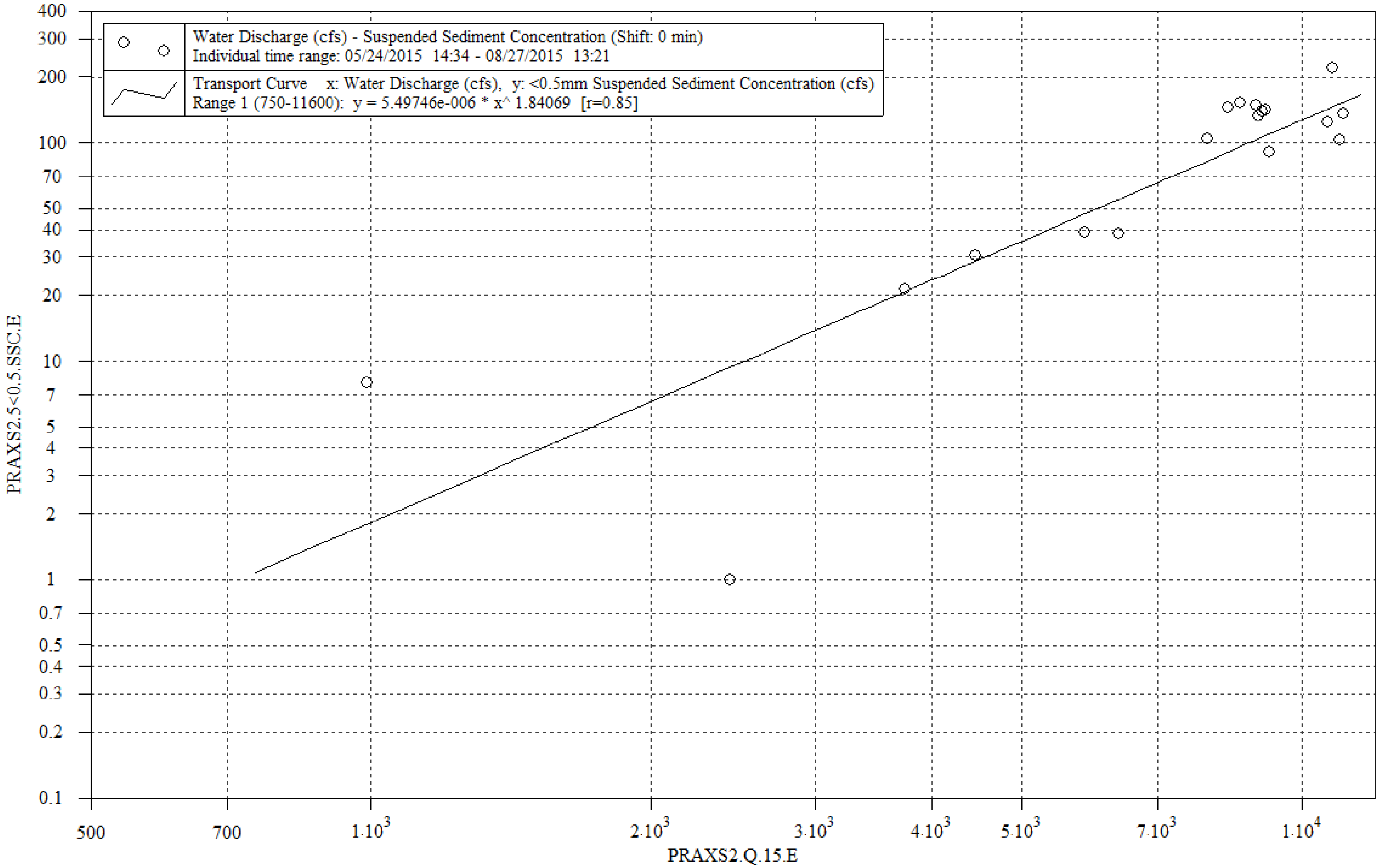


Figure A-52. 0.5mm – 1mm Suspended Sediment Transport Curve

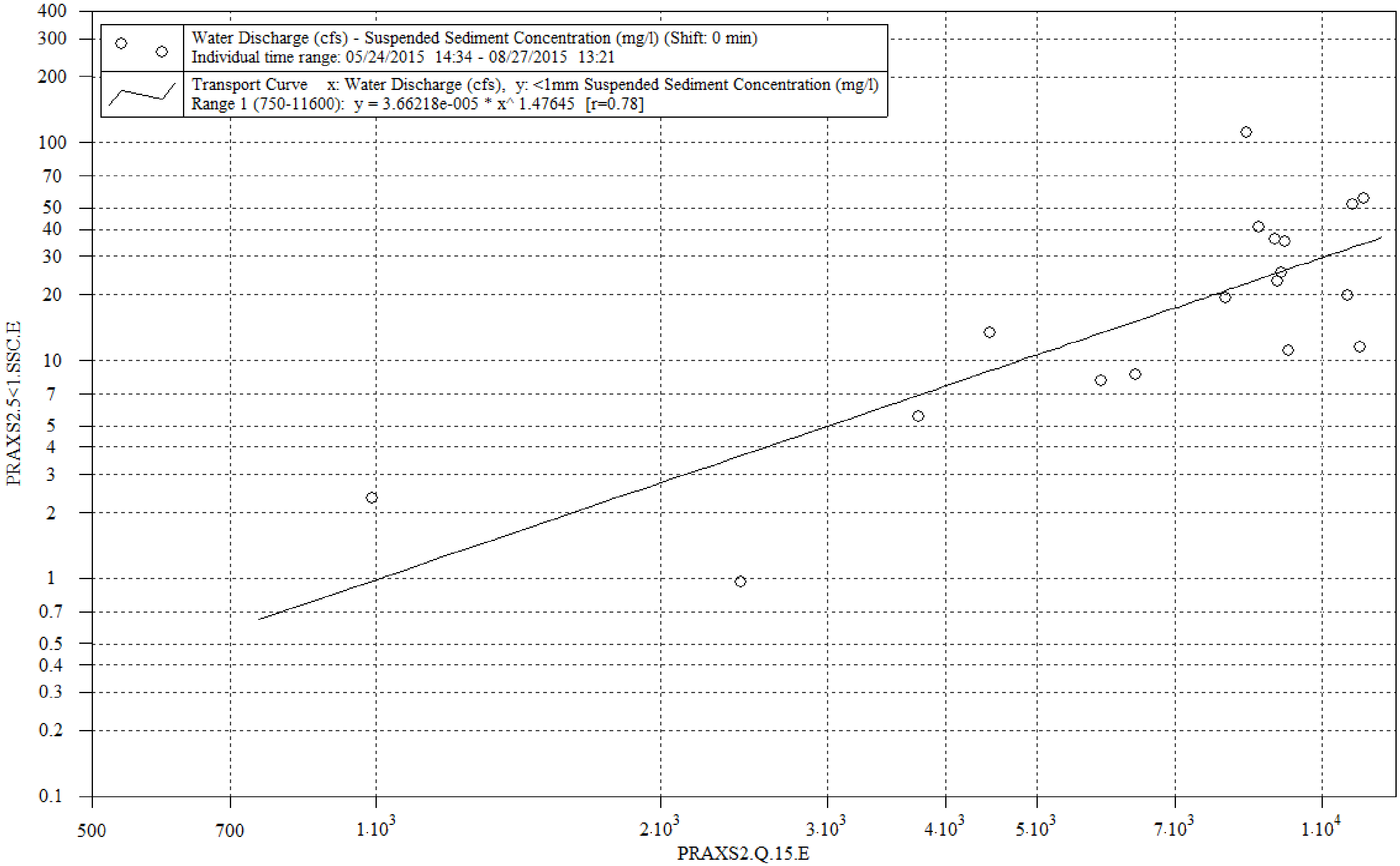
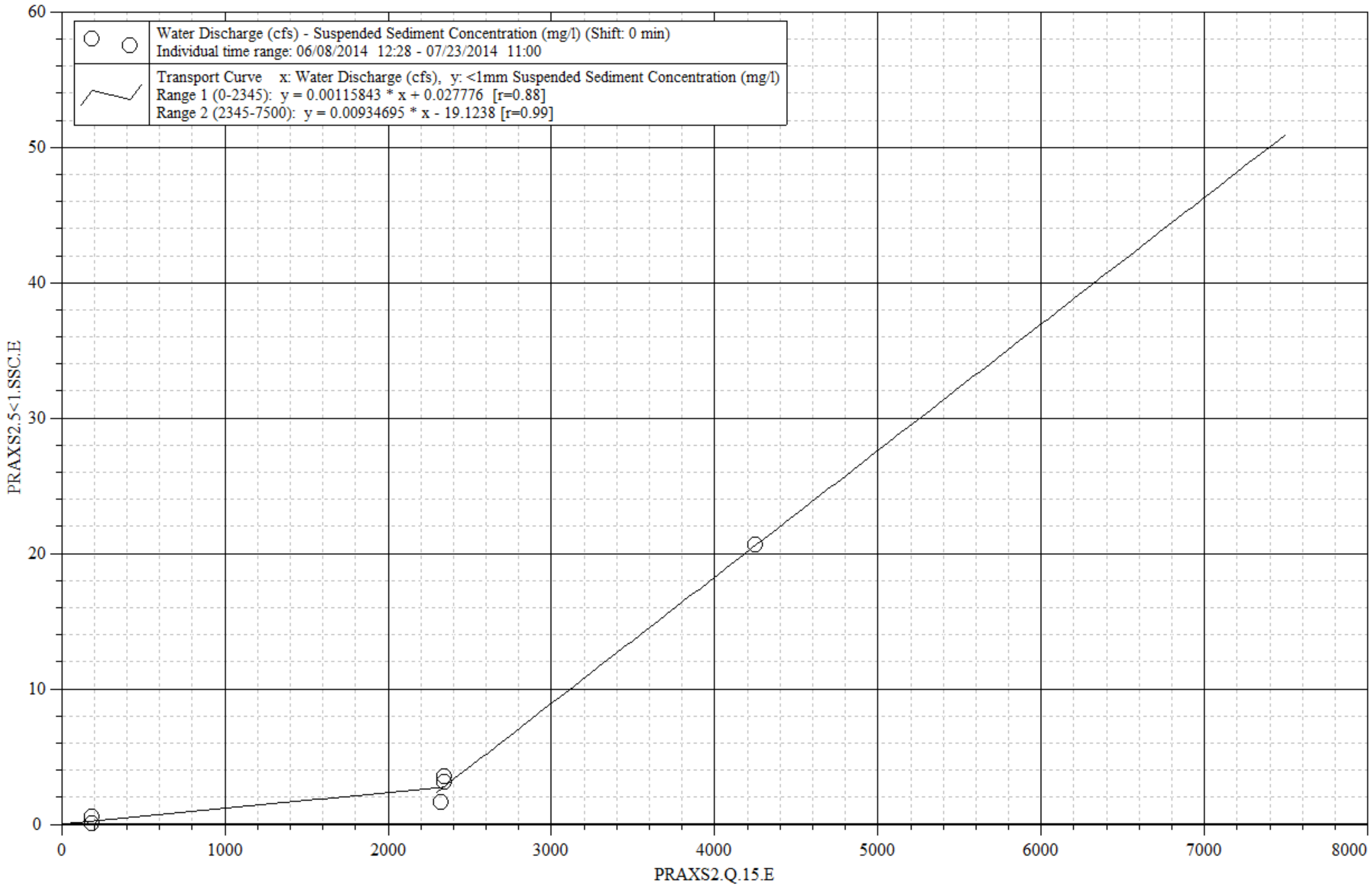


Figure A-53. 1mm – 2mm Suspended Sediment Transport Curve



APPENDIX B
PHOTOS

1. **Bar Topography -** Natural sand bar (108) with less than 20% vegetative cover post June 2015 high flow event.

2. **Bar Topography -** Treated sand bar (64) post June 2015 high flow event.

3. **Bar Topography -** Vegetated natural bar (11) with greater than 20% vegetative cover post June 2015 high flow event.

4. **Bar Topography -** Treated bar with new vegetation (120) with greater than 20% vegetative cover post June 2015 high flow event.

5. **Primary River Cross Sections** – View looking south along the cross section located on the north bank of the Platte River post June 2015 high flow event.

6. **Primary River Cross Sections** – View looking upstream from the cross section located on the north bank of the Platte River post June 2015 high flow event.

7. **Primary River Cross Sections** – View looking downstream from the cross section located on the north bank of the Platte River post June 2015 high flow event.

8. **Primary River Cross Sections** – View looking north along the cross section from the main channel of the Platte River post June 2015 high flow event.

9. **Depth Integrated Sampling** – DIS samples collected from a cataraft between cross sections 2 and 3.

10. **River Stage** – Collection of river stage measurements at the pressure transducer located near cross section 18 during the June 2015 high flow event.

11. **Vegetation Survey** – Collection of vegetation assessment data from a plot pre June 2015 high flow event.

12. **Bar Topography** – Natural bar surveyed prior to the June 2015 high flow event.

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VEGETATION SURVEY

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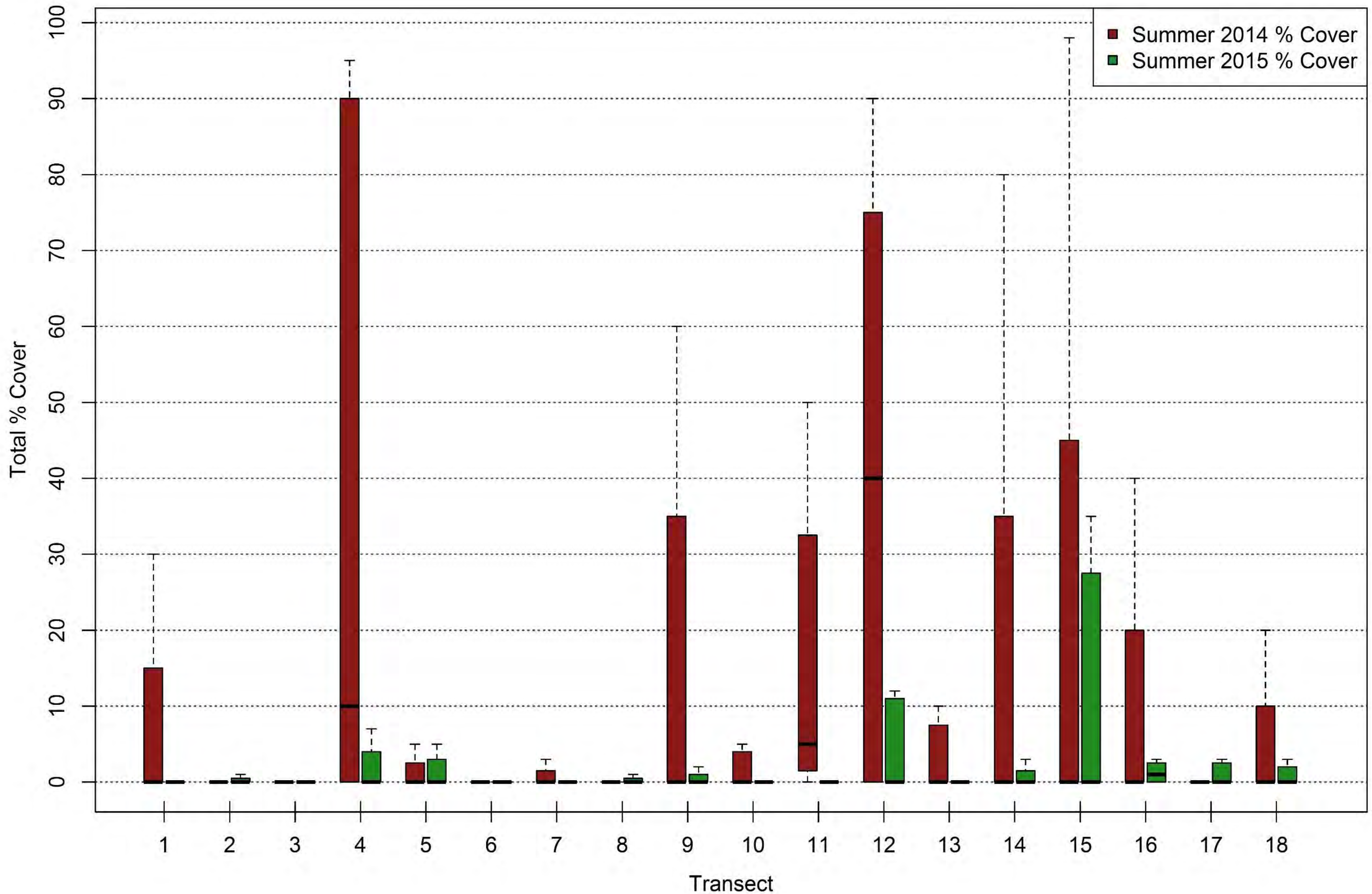


Figure C-2. **July 2014 and August 2015 % Vegetation Cover – First Half of the Data**

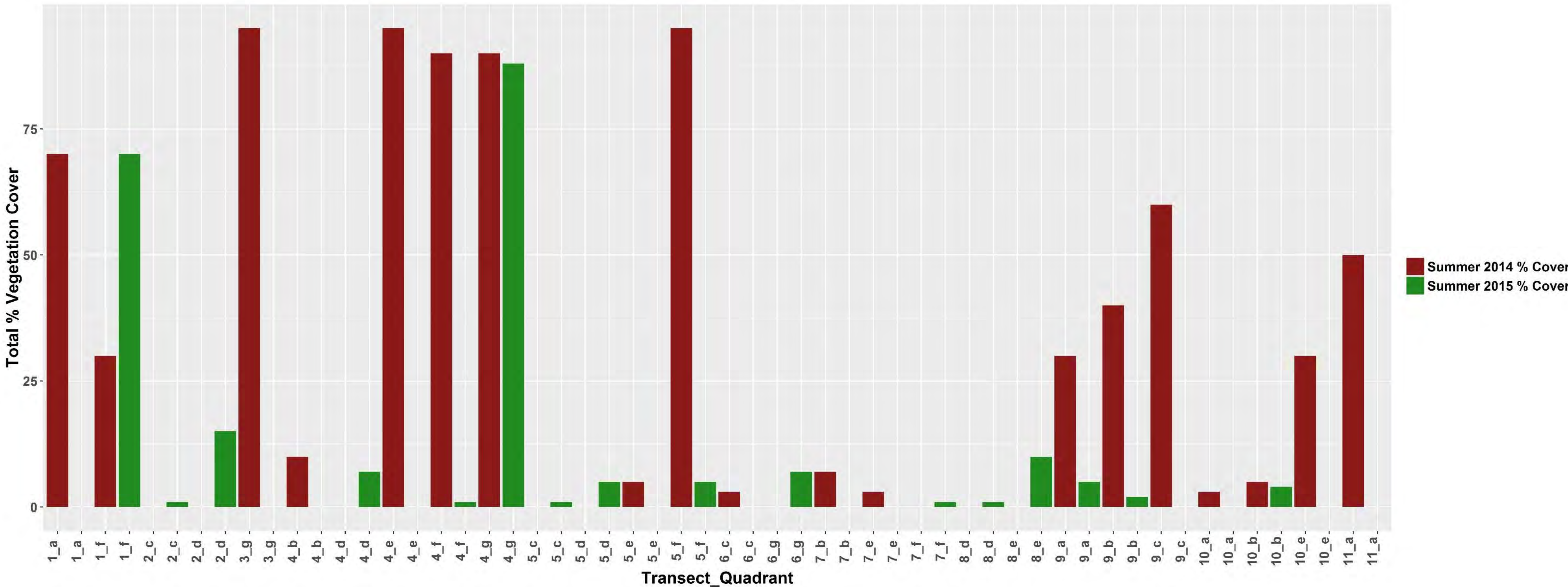


Figure C-3. July 2014 and August 2015 % Vegetation Cover – Second Half of the Data

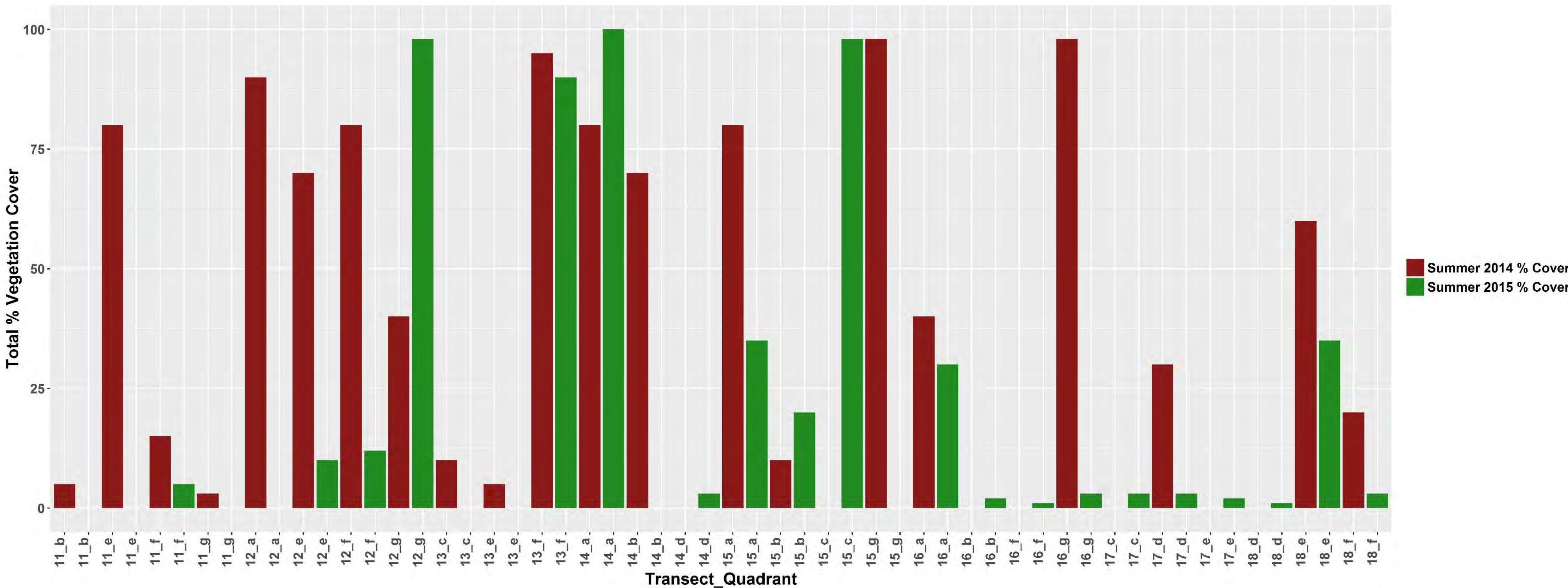


Figure C-4. **July 2014 Live Frequency Counts**

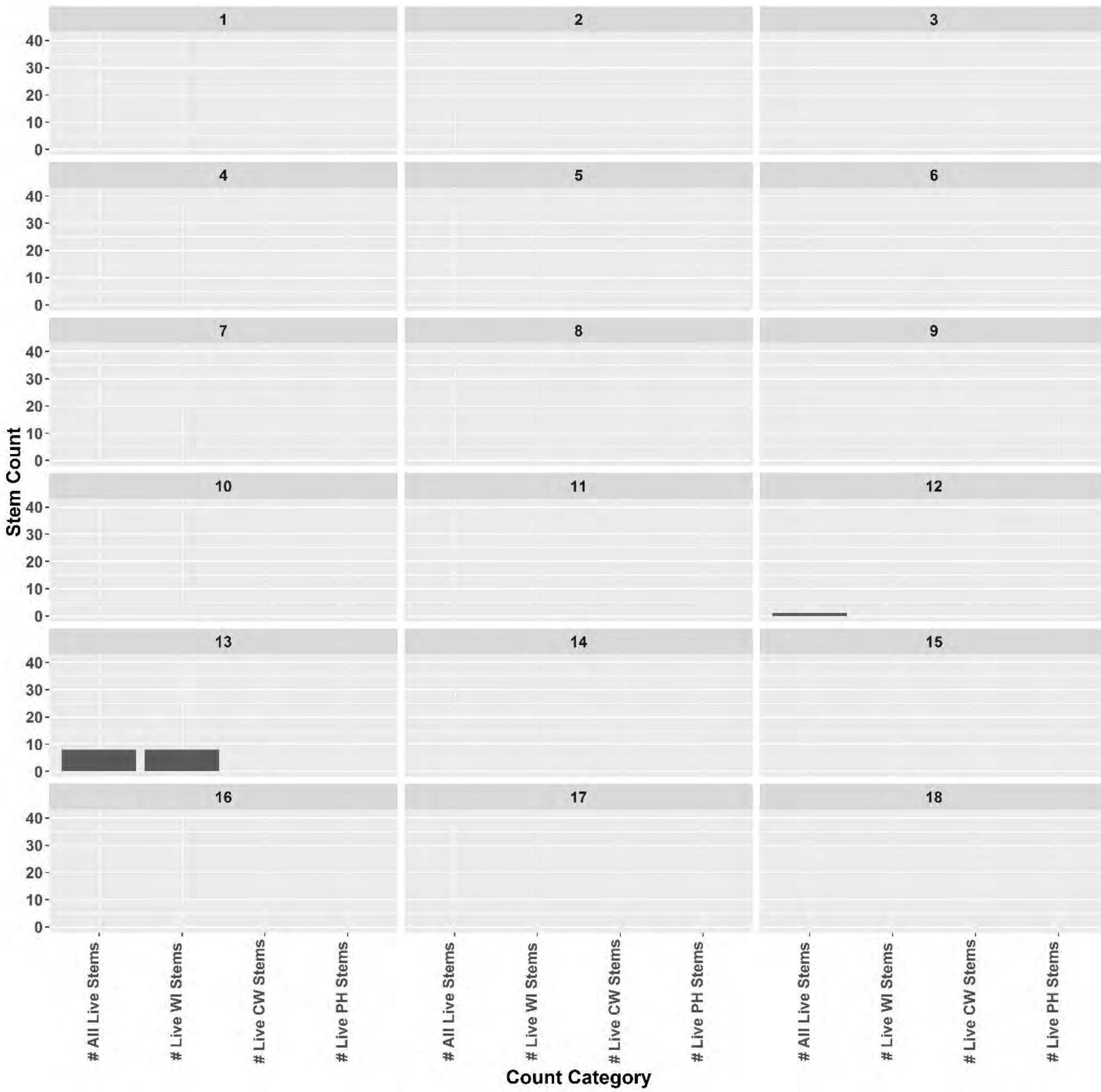


Figure C-5. August 2015 Live Frequency Counts

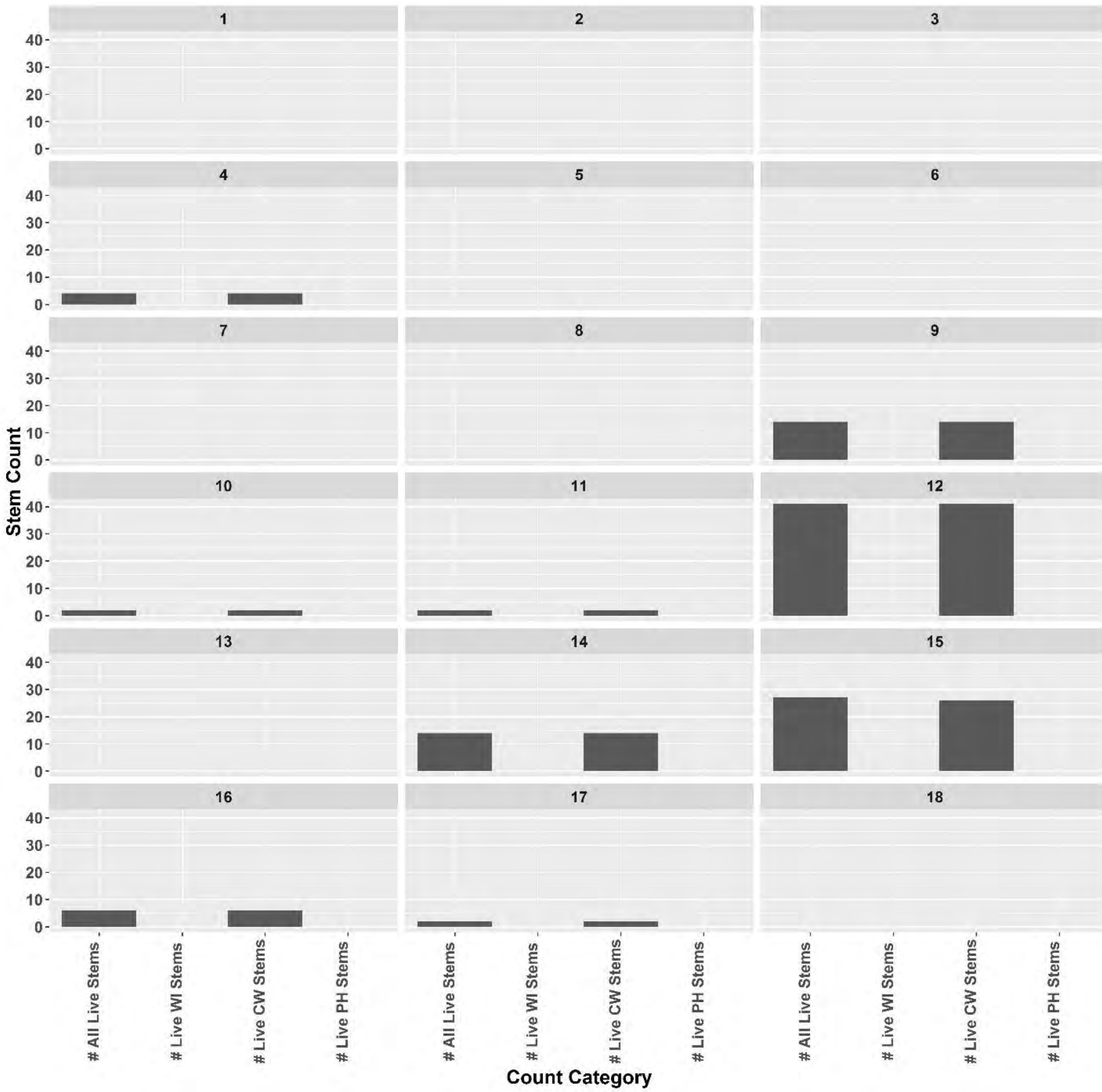


Figure C-6. July 2014 Dead Frequency Counts

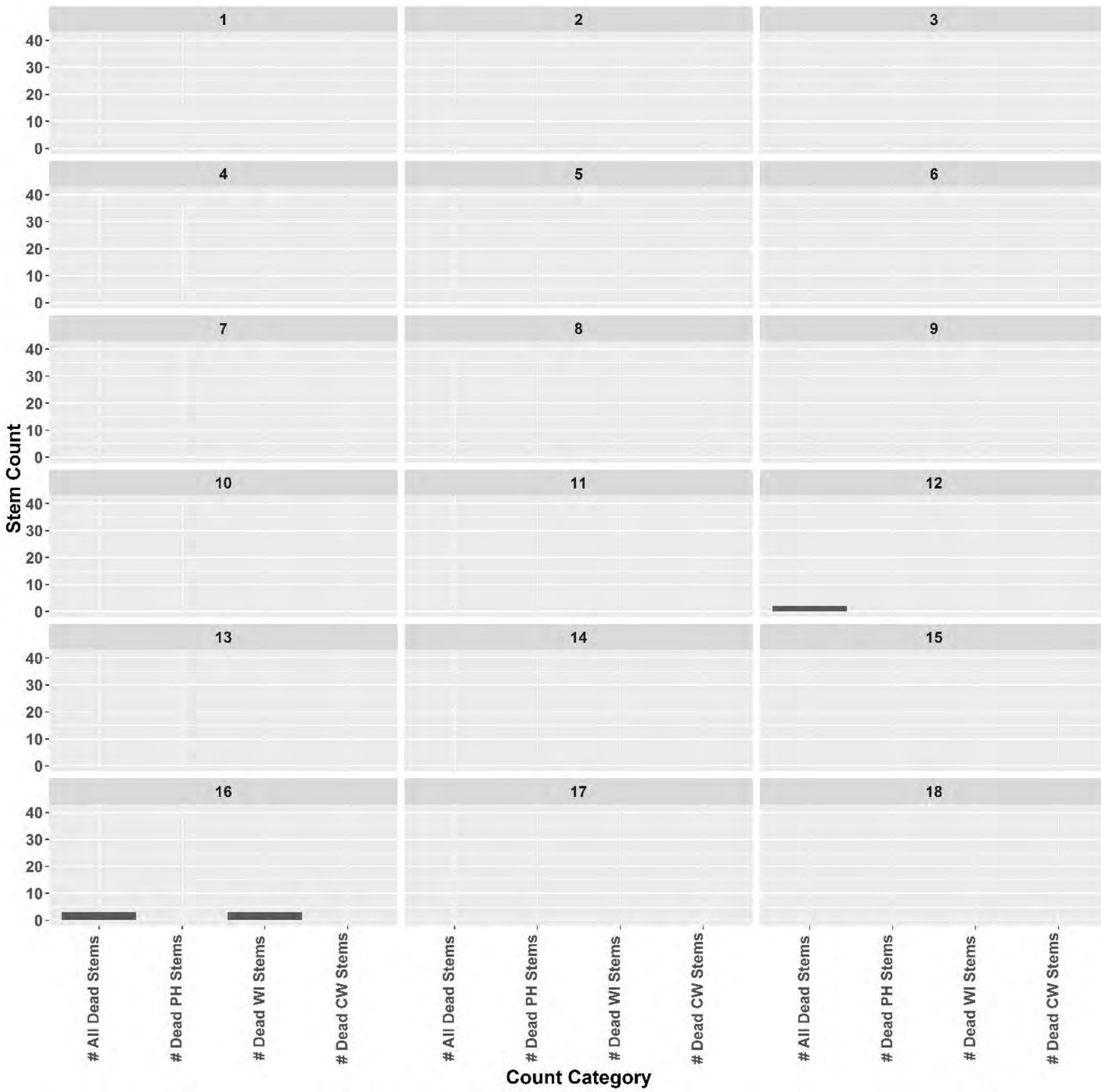
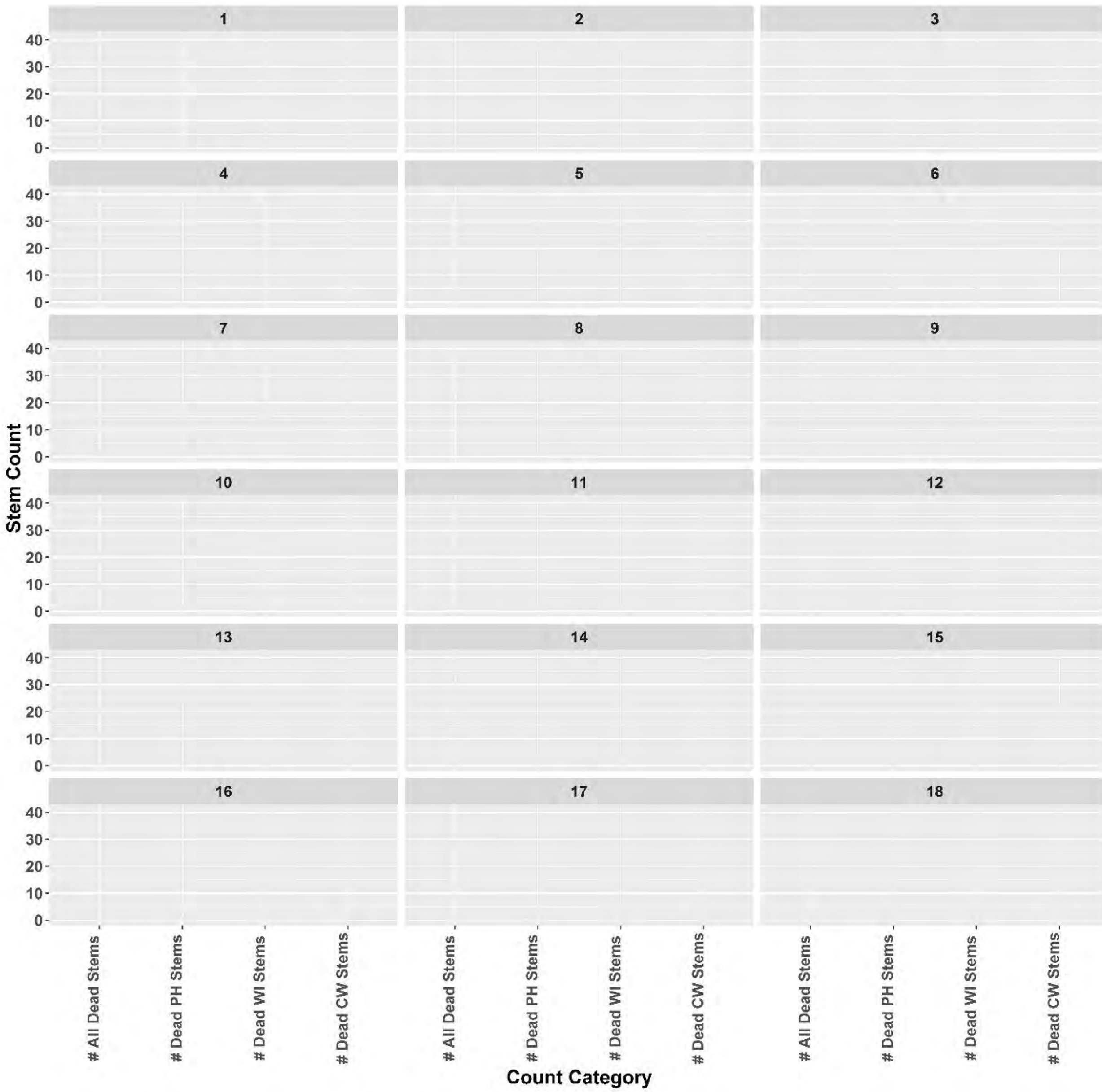


Figure C-7. August 2015 Dead Frequency Counts



TABLES

Table C-1. Vegetation Plot Results

Cross Section	Quadrant	Vegetated Cover		Stem Count July 2014 (PHAU, PODE, SAEX)		Stem Count August 2015 (PHAU, PODE, SAEX)		All Species	Sand/Water Cover	Sand/Water Cover
		July 2014	August 2015	Live Stems	Dead Stems	Live Stems	Dead Stems		July 2014	August 2015
1	a	70%	--	0	0	0	0	RUCR	Sand-30%	Water-100%
1	b	--	--	0	0	0	0	--	Water-100%	Water-100%
1	c	--	--	0	0	0	0	--	Sand-100%	Water-100%
1	d	--	--	0	0	0	0	--	Sand-100%	Water-100%
1	e	--	--	0	0	0	0	--	Water-100%	Water-100%
1	f	30%	70%	0	0	0	0	AMAR, BRJA, ERPE, HESU, LEDE, LEFU, SPCR, VEsp	Sand-70%	Sand-30%
1	g	--	--	0	0	0	0	--	Water-100%	Water-100%
2	a	--	--	0	0	0	0	--	Sand-100%	Water-100%
2	b	--	--	0	0	0	0	--	Sand-100%	Water-100%
2	c	--	1%	0	0	0	0	CYOD, UNK FORB	Sand-100%	Water-99%
2	d	--	25%	0	0	0	0	CYOD, ERPE	Sand-100%	Sand-75%
2	e	--	--	0	0	0	0	--	Sand-100%	Sand-100%
2	f	--	--	0	0	0	0	--	Water-100%	Sand-100%
2	g	--	--	0	0	0	0	--	Water-100%	Water-100%
3	a	--	--	0	0	0	0	--	Water-100%	Water-100%
3	b	--	--	0	0	0	0	--	Water-100%	Water-100%
3	c	--	--	0	0	0	0	--	Sand-90%/Water-10%	Water-100%
3	d	--	--	0	0	0	0	--	Sand-70%/Water-30%	Water-100%
3	e	--	--	0	0	0	0	--	Sand-100%	Water-100%
3	f	--	--	0	0	0	0	--	Sand-100%	Water-100%
3	g	95%	--	0	0	0	0	PHAR, UNK FORB	Sand-5%	Water-100%
4	a	--	--	0	0	0	0	--	Water-100%	Water-100%
4	b	10%	--	0	0	0	0	ECCR, LEFU, POPE, RUCR, XAST	Sand-90%	Water-100%
4	c	--	--	0	0	0	0	--	Sand-100%	Water-100%
4	d	--	7%	0	0	0	0	CYOD, ELPA, POPE, UNK FORB	Water-100%	Sand-93%
4	e	95%	--	0	0	0	0	AMAR, BICE, LEFU, LYSA, POPE, RUCR, UNK FORB	Sand-5%	Water-100%
4	f	90%	1%	0	0	0	0	AMAR, BICE, CYOD, LYSA, POPE, RUCR, XAST, UNK FORB	Sand-10%	Sand-99%
4	g	90%	88%	0	0	4	0	AMAR, AMTU, BICE, CYOD, ECCR, ERPE, PODE, POPE, RUCR, SCFL, THAR, XAST	Sand-10%	Sand-12%
5	a	--	--	0	0	0	0	--	Water-100%	Water-100%
5	b	--	--	0	0	0	0	--	Sand-100%	Water-100%
5	c	--	1%	0	0	0	0	ECCR	Sand-100%	Sand-99%
5	d	--	5%	0	0	0	0	AMAR, CYOD, ECCR, LEFU, VEsp, UNK FORB	Water-100%	Sand-95%
5	e	5%	--	0	0	0	0	ECCR, POPE, UNK FORB	Sand-95%	Water-100%
5	f	95%	5%	0	0	0	0	AMAR, AMTU, BICE, CYOD, ERPE, RUCR, THAR, XAST	Sand-5%	Sand-95%
5	g	--	--	0	0	0	0	--	Water-100%	Water-100%
6	a	--	--	0	0	0	0	--	Water-100%	Water-100%
6	b	--	--	0	0	0	0	--	Water-100%	Water-100%
6	c	3%	--	0	0	0	0	ECCR, LEFU, XAST	Sand-97%	Water-100%
6	d	--	--	0	0	0	0	--	Water-100%	Sand-10%/Water-

Cross Section	Quadrant	Vegetated Cover		Stem Count July 2014 (PHAU, PODE, SAEX)		Stem Count August 2015 (PHAU, PODE, SAEX)		All Species	Sand/Water Cover	Sand/Water Cover
		July 2014	August 2015	Live Stems	Dead Stems	Live Stems	Dead Stems		July 2014	August 2015
										90%
6	e	--	--	0	0	0	0	--	Sand-100%	Water-100%
6	f	--	--	0	0	0	0	--	Water-100%	Sand-20%/Water-80%
6	g	--	7%	0	0	0	0	CYOD, ECCR, LEFU	Water-100%	Water-93%
7	a	--	--	0	0	0	0	--	Water-100%	Water-100%
7	b	7%	--	0	0	0	0	LEFU	Sand-93%	Water-100%
7	c	--	--	0	0	0	0	--	Sand-100%	Sand-5%/Water-95%
7	d	--	--	0	0	0	0	--	Water-100%	Sand-100%
7	e	3%	--	0	0	0	0	ECCR, LEFU, UNK FORB	Sand-97%	Sand-2%/Water-98%
7	f	--	1%	0	0	0	0	CYOD, ECCR, LEFU	Sand-97%/Water-3%	Sand-99%
7	g	--	--	0	0	0	0	--	**No Access**	**No Access**
8	a	--	--	0	0	0	0	--	Sand-100%	Water-100%
8	b	--	--	0	0	0	0	--	Water-100%	Water-100%
8	c	--	--	0	0	0	0	--	Sand-25%/Water-75%	Water-100%
8	d	--	1%	0	0	0	0	CYOD, ECCR, LEFU	Sand-100%	Sand-99%
8	e	--	10%	0	0	0	0	CYOD, LEFU	Water-100%	Sand-90%
8	f	--	--	0	0	0	0	--	Sand-100%	Sand-10%/Water-90%
8	g	--	--	0	0	0	0	--	Water-100%	Water-100%
9	a	30%	5%	0	0	10	0	CYOD, ERPE, LEFU, PODE, XAST	Sand-70%	Sand-95%
9	b	40%	2%	0	0	4	0	AMAR, CYOD, ECCR, ERPE, LEFU, PODE	Sand-60%	Sand-98%
9	c	60%	--	0	0	0	0	ECCR, LEFU, XAST, UNK FORB/GRASS	Sand-40%	Water-100%
9	d	--	--	0	0	0	0	--	Sand-60%/Water-40%	Water-100%
9	e	--	--	0	0	0	0	--	Sand-100%	Water-100%
9	f	--	--	0	0	0	0	--	Water-100%	Water-100%
9	g	--	--	0	0	0	0	--	Water-100%	Water-100%
10	a	3%	--	0	0	0	0	PHAR	Sand-97%	Water-100%
10	b	5%	4%	0	0	2	0	CYOD, ECCR, ERPE, LEFU, PODE, RUCR, UNK FORB/GRASS	Sand-95%	Sand-96%
10	c	--	--	0	0	0	0	--	Sand-100%	Water-100%
10	d	--	--	0	0	0	0	--	Water-100%	Sand-50%/Water-50%
10	e	30%	--	0	0	0	0	ECCR, XAST, UNK FORB/GRASS	Sand-70%	Water-100%
10	f	--	--	0	0	0	0	--	Sand-100%	Water-100%
10	g	--	--	0	0	0	0	--	Water-100%	Water-100%
11	a	50%	--	0	0	0	0	AMAR, ECCR, LEFU	Sand-50%	Water-100%
11	b	5%	--	0	0	0	0	ECCR, POPE, XAST, UNK FORB/GRASS	Sand-95%	Sand-10%/Water-90%
11	c	--	--	0	0	0	0	--	Water-100%	Water-100%
11	d	--	--	0	0	0	0	--	Water-100%	Water-100%

Cross Section	Quadrant	Vegetated Cover		Stem Count July 2014 (PHAU, PODE, SAEX)		Stem Count August 2015 (PHAU, PODE, SAEX)		All Species	Sand/Water Cover	Sand/Water Cover
		July 2014	August 2015	Live Stems	Dead Stems	Live Stems	Dead Stems		July 2014	August 2015
11	e	80%	--	0	0	0	0	AMAR, BICE, RUCR	Sand-20%	Water-100%
11	f	15%	5%	0	0	2	0	AMAR, BICE, CYOD, ERPE, LEFU, PODE, RUCR, SCPU, XAST	Sand-85%	Sand-95%
11	g	3%	--	0	0	0	0	ELPA, SCFL	Sand-97%	Water-100%
12	a	90%	--	1	2	0	0	AMAR, CIAR, COCA, CODR, PHAR, SOCA	Sand-10%	Water-100%
12	b	--	--	0	0	0	0	--	Water-100%	Water-100%
12	c	--	--	0	0	0	0	--	Sand-100%	Water-100%
12	d	--	--	0	0	0	0	--	Water-100%	Water-100%
12	e	70%	10%	0	0	34	0	AMRU, BICE, CYOD, ELPA, ERPE, MUVE, PHAR, PODE, RUCR, UNK FORB/GRASS	Sand-30%	Sand-90%
12	f	80%	12%	0	0	1	0	BICE, CYOD, ELPA, ERPE, LEFU, PODE, RUCR, SCPU, XAST, UNK FORB/GRASS	Sand-20%	Sand-88%
12	g	40%	98%	0	0	6	0	AMAR, AMTU, BICE, CYOD, ECCR, ELPA, ERPE, POPE, PODE, RUCR, SCFL, XAST, UNK FORB/GRASS	Sand-60%	Sand-2%
13	a	--	--	0	0	0	0	--	Water -100%	Water-100%
13	b	--	--	0	0	0	0	--	Water-100%	Water-100%
13	c	10%	--	0	0	0	0	ECCR, LEFU, POPE	Sand-90%	Water-100%
13	d	--	--	0	0	0	0	--	Water- 100%	Water-100%
13	e	5%	--	0	0	0	0	SCPU, XAST	Sand-95%	Water-100%
13	f	95%	90%	8	0	0	0	AMAR, BICE, LYSA, SAEX, SCFL	Sand-5%	Sand-10%
13	g	--	--	0	0	0	0	--	Sand-100%	Water-100%
14	a	80%	100%	0	0	13	0	AMAR, AMTR, AMRU, BICE, BRJA, CYOD, ECCR, ERPE, LEFU, PODE, POMO, RUCR, SCFL, XAST	Sand- 20%	None
14	b	70%	--	0	0	0	0	AMRU, BICE, ECCR, JUBU, RUCR	Sand-30%	Water-100%
14	c	--	--	0	0	0	0	--	Sand-100%	Water-100%
14	d	--	3%	0	0	1	0	CYOD, ECCR, ERPE, PODE	Sand-100%	Sand-97%
14	e	--	--	0	0	0	0	--	Water-100%	Water-100%
14	f	--	--	0	0	0	0	--	Sand-80%/Water-20%	Water-100%
14	g	--	--	0	0	0	0	--	Sand-100%	Water-100%
15	a	80%	35%	0	0	0	0	BICE, ECCR, LEFU, POPE, RUCR, SCFL, SCPU, UNK FORB/GRASS	Sand-20%	Sand-65%
15	b	10%	20%	0	0	25	0	AMAR, CYOD, ECCR, ERPE, HEPE, LEFU, PODE, SCPU, RUCR, UNK FORB	Sand- 90%	Sand-80%
15	c	--	98%	0	0	2	0	AMFR, CYOD, ERPE, LEFU, PODE	Sand-100%	Sand-2%
15	d	--	--	0	0	0	0	--	Sand-100%	Water-100%
15	e	--	--	0	0	0	0	--	Water- 100%	Water-100%
15	f	--	--	0	0	0	0	--	Water-100%	Water-100%
15	g	98%	--	0	0	0	0	AMAR	Sand-2%	Water-100%
16	a	40%	30%	0	0	6	0	BICE, ECCR, ELPA, JUBU, LEFU, POMO, RUCR, SCFL, SCPU, SCTA	Sand-60%	Sand-70%
16	b	--	2%	0	0	0	0	CYOD, LEFU	Sand-100%	Sand-98%
16	c	--	--	0	0	0	0	--	Sand-100%	Water-100%
16	d	--	--	0	0	0	0	--	Water -100%	Water-100%
16	e	--	--	0	0	0	0	--	Water- 100%	Water-100%
16	f	--	1%	0	0	0	0	CYOD, ERPE, LEFU	Water- 100%	Sand-99%

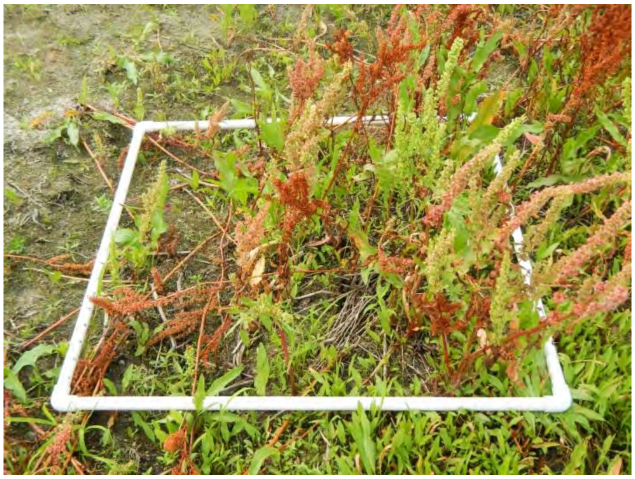
Cross Section	Quadrant	Vegetated Cover		Stem Count July 2014 (PHAU, PODE, SAEX)		Stem Count August 2015 (PHAU, PODE, SAEX)		All Species	Sand/Water Cover	Sand/Water Cover
		July 2014	August 2015	Live Stems	Dead Stems	Live Stems	Dead Stems		July 2014	August 2015
16	g	98%	3%	0	3	0	0	AMAR, BICE, COCA, CYOD, ECCR, ERPE, LYSA, MESA, POPE, SAEX, THAR, XAST	Sand-2%	Sand-97%
17	a	--	--	0	0	0	0	--	Sand-100%	Water-100%
17	b	--	--	0	0	0	0	--	Sand-100%	Water-100%
17	c	--	3%	0	0	2	0	CYOD, ERPE, LEFU, PODE, UNK FORB	Water -100%	Sand-97%
17	d	30%	3%	0	0	0	0	CYOD, ECCR, ERPE, LYSA, RUCR, UNK FORB/GRASS	Sand-70%	Sand-97%
17	e	--	2%	0	0	0	0	CYOD, LEFU	Sand-100%	Sand-98%
17	f	--	--	0	0	0	0	--	Sand-100%	Sand-100%
17	g	--	--	0	0	0	0	--	Sand-10%/Water-90%	Water-100%
18	a	--	--	0	0	0	0	--	Sand-100%	Water-100%
18	b	--	--	0	0	0	0	--	Sand-100%	Water-100%
18	c	--	--	0	0	0	0	--	Sand-100%	Sand-10%/Water-90%
18	d	--	1%	0	0	0	0	ERPE, LEFU	Water -100%	Sand-99%
18	e	60%	35%	0	0	0	0	AMAR, ERPE, LEFU, MESA, PACA, POMO, RUCR, XAST	Sand- 40%	Sand-65%
18	f	20%	3%	0	0	0	0	AMAR, AMRU, CYOD, ECCR, ERPE, JUBU, LEFU, MESA, UNK FORB/GRASS	Sand-80%	Sand-97%
18	g	--	--	0	0	0	0	--	Sand-100%	Water- 100%

Table C-2. Plant Identification Codes

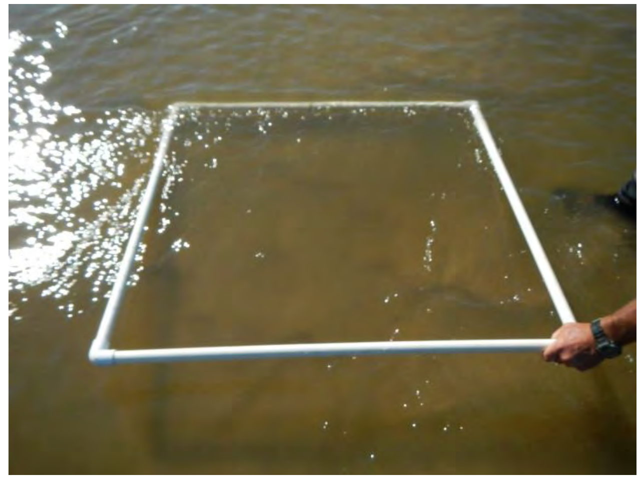
Abbreviation	Scientific	Common
ACNE	*Acer negundo*	box elder
AMAR	*Ambrosia artemisiifolia*	common ragweed
AMFR	*Amorpha fruticosa*	false indigo
AMPS	*Ambrosia psilostachya*	western ragweed
AMTU	*Amaranthus tuberculatus*	common waterhemp
AMTR	*Ambrosia trifida*	giant ragweed
APCA	*Apocynum cannabinum*	Indianhemp
ASSY	*Asclepias syriaca*	common milkweed
BICE	*Bidens cernua*	bur marigold
BRIN	*Bromus inermis*	smooth brome
BRJA	*Bromus japonicus*	japanese brome
CASA	*Cannabis sativa*	Marijuana
CASP	*Catalpa speciosa*	northern catalpa
CELO	*Cenchrus longispirus*	field sandbur
CIAR	*Cirsium arvense*	canada thistle
CIVU	*Cirsium vulgare*	bull thistle
COCA	*Conyza canadensis*	horseweed
CODR	*Cornus drummondii*	rough-leaved dogwood
CYOD	*Cyperus odoratus*	fragrant sedge
CYsp	*Cyperus sp.*	sedge
ECCR	*Echinochloa crus-galli*	barnyard grass
ELPA	*Eleocharis palustris*	common spikerush
ERPE	*Eragrostis pectinacea*	Carolina lovegrass
FRPE	*Fraxinus pennsylvanica*	green ash
GAAP	*Galium aparine*	sticky willy
HEAN	*Helianthus annuus*	common sunflower
HEGR	*Helianthus grosseserratus*	sawtooth sunflower
HEPE	*Helianthus petiolaris*	prairie sunflower
HESU	*Heterotheca subaxillaris*	camphor weed
HILA	*Hibiscus laevis*	marsh mallow
JUBU	*Juncus bufonius*	toad rush
JUTO	*Juncus torreyi*	Torrey's rush
KOSC	*Kochia scoparia*	kochia
LEDE	*Lepidium densiflorum*	common pepperweed
LEFU	*Leptochloa fusca*	malabar sprangletop
LYSA	*Lythrum salicaria*	purple loosestrife
MESA	*Medicago sativa*	alfalfa
MOAL	*Morus alba*	white mulberry
MUVE	*Mullogo verticillata*	carpetweed
PACA	*Panicum capillare*	witchgrass
PHAR	*Phalaris arundinacea*	reed canary grass
PHAU	*Phragmites australis*	common reed
PODE	*Populus deltoides*	eastern cottonwood
POLA	*Polypogon lapathifolium*	pale smartweed
POMO	*Polypogon monspeliensis*	rabbit's foot grass
POPE	*Polygonum persicaria*	lady's thumb
POsp	*Polygonum sp.*	smartweed
RUCR	*Rumex crispus*	curly dock

Abbreviation	Scientific	Common
RUST	*Rumex stenophyllus*	narrowleaf dock
SAAM	*Salix amygdalodes*	peachleaf willow
SAEX	*Salix exigua*	sandbar willow
SALA	*Sagittaria latifolia*	arrowhead
SCFL	*Schoenoplectus fluviatilis*	river bulrush
SPCR	*Sporobolus cyptandrus*	sand dropseed
SCPU	*Schoenoplectus pungens*	threesquare bulrush
SCTA	*Schoenoplectus tabernaemontani*	softstem bulrush
SEsp	*Setaria sp.*	foxtail/bristlegrass
SOCA	*Solidago canadensis*	Canada goldenrod
SPPE	*Spartina pectinata*	prairie cordgrass
SYLA	*Symphyotrichum lanceolatum*	panicled aster
THAR	*Thlaspi arvense*	field pennycress
TORA	*Toxicodendron radicans*	poison ivy
TYAN	*Typha angustifolia*	narrowleaf cattail
TYLA	*Typha latifolia*	broadleaf cattail
ULAM	*Ulmus americana*	American elm
unk forb	NA	unkown forb
unk grass	NA	unkown grass
VEsp	*Veronica sp.*	Speedwell
VEHA	*Verbena hastata*	blue vervain
VETH	*Verbascum thapsus*	common mullein
VIRI	*Vitis riparia*	river bank grape
XAST	*Xanthium strumarium*	cocklebur

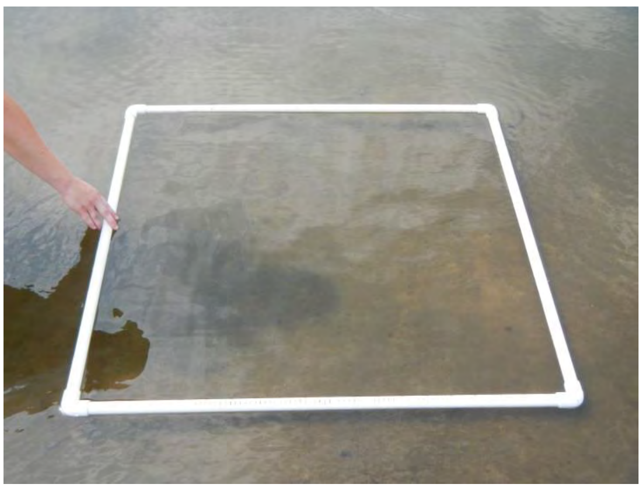
PHOTOS



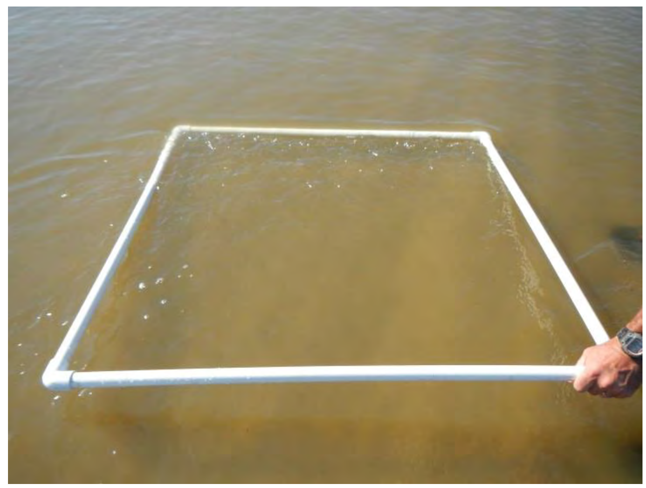
1 - Plot 1A – July 2014.



2 - Plot 1A – August 2015.

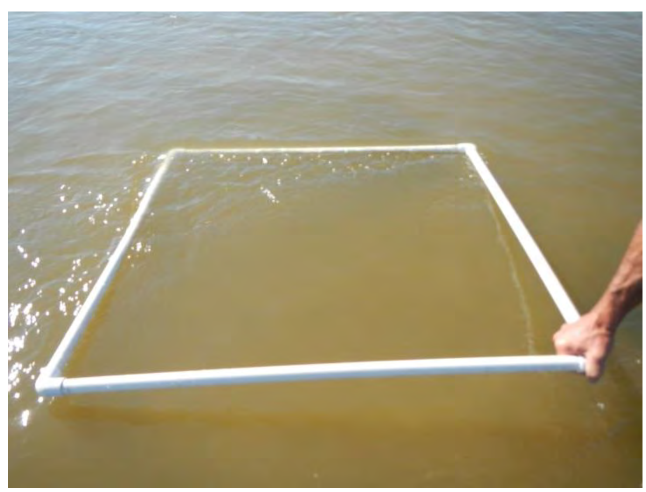


3 - Plot 1B – July 2014.



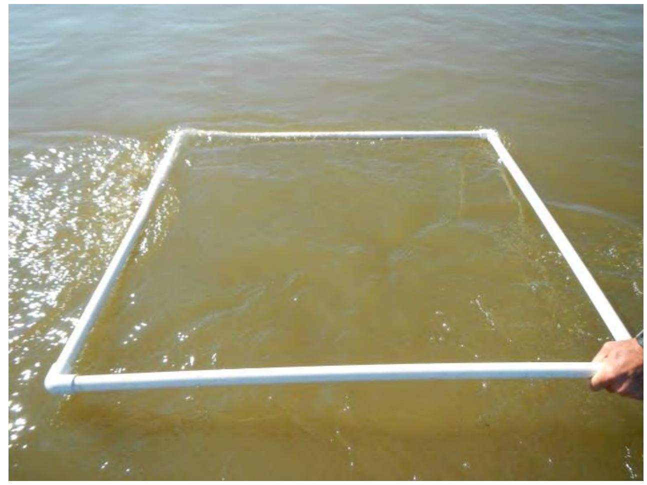
4 - Plot 1B – August 2015.

5 - Plot 1C – July 2014.

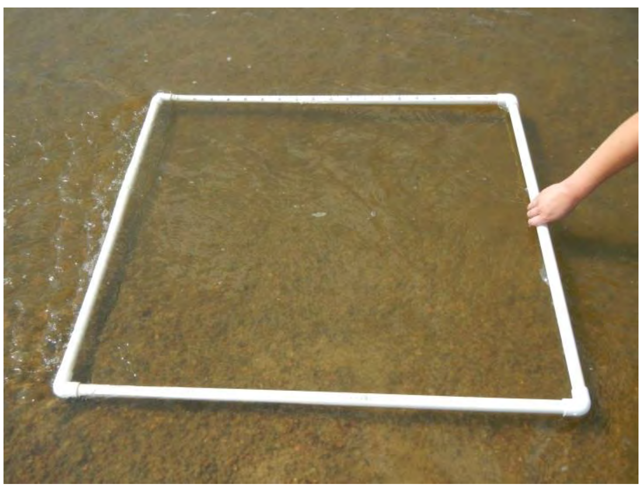


6 - Plot 1C – August 2015.

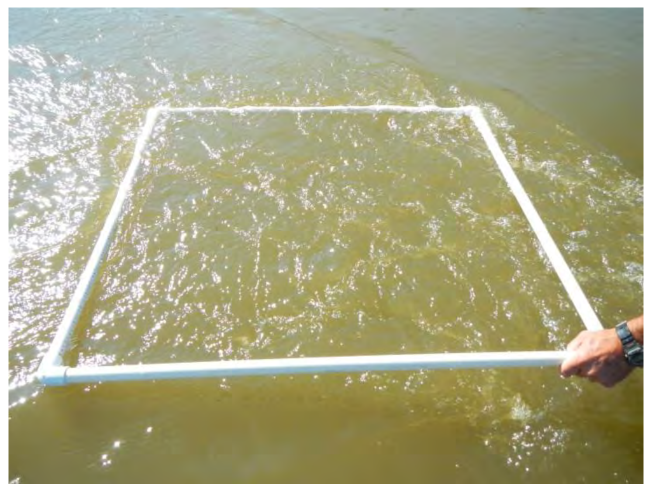
7 - Plot 1D – July 2014.



8 - Plot 1D – August 2015.



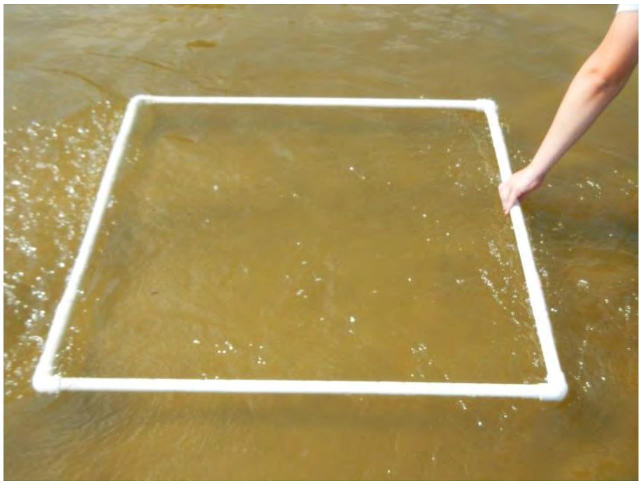
9 - Plot 1E – July 2014.



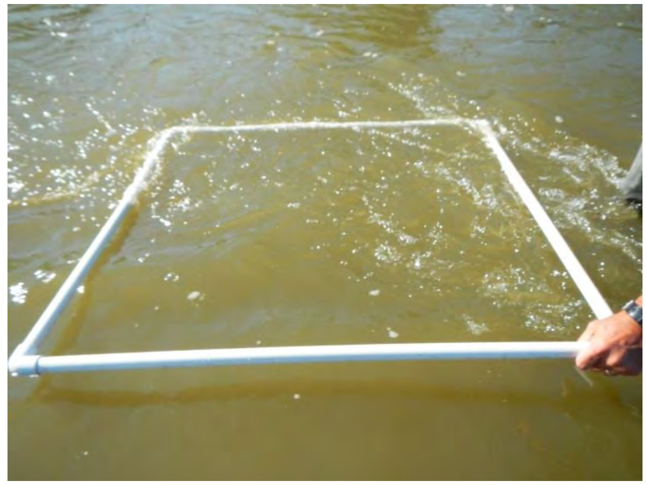
10 - Plot 1E – August 2015.

11 - Plot 1F – July 2014.

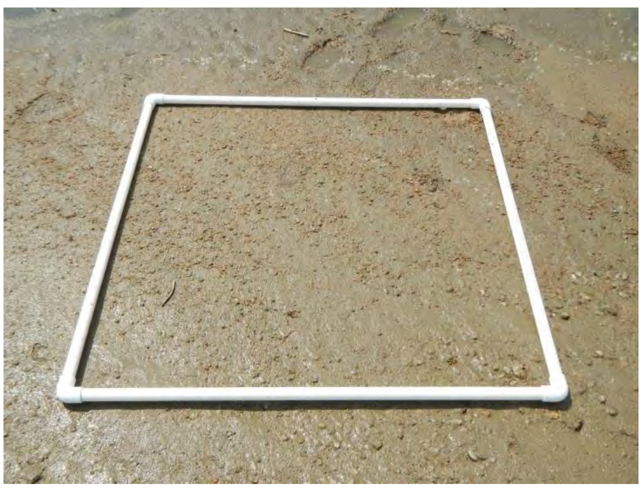
12 - Plot 1F – August 2015.



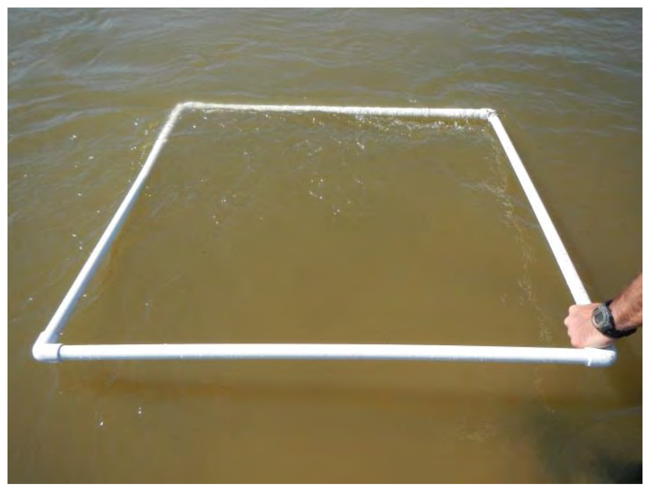
13 - Plot 1G – July 2014.



14 - Plot 1G – August 2015.



15 - Plot 2A – July 2014.



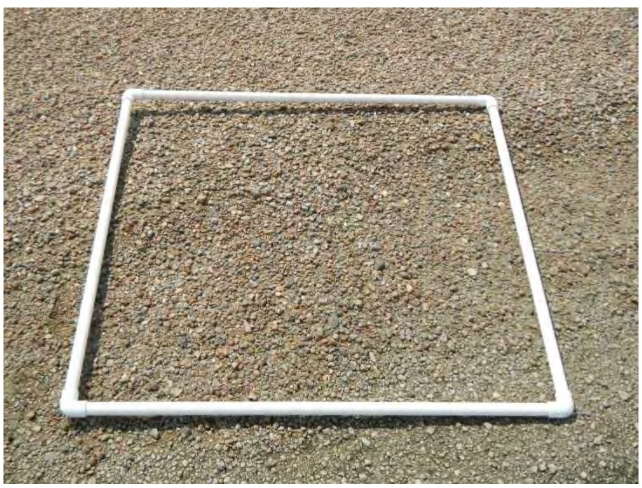
16 - Plot 2A – August 2015.

17 - Plot 2B – July 2014.

18 - Plot 2B – August 2015.


19 - Plot 2C – July 2014.


20 - Plot 2C – August 2015.


21 - Plot 2D – July 2014.

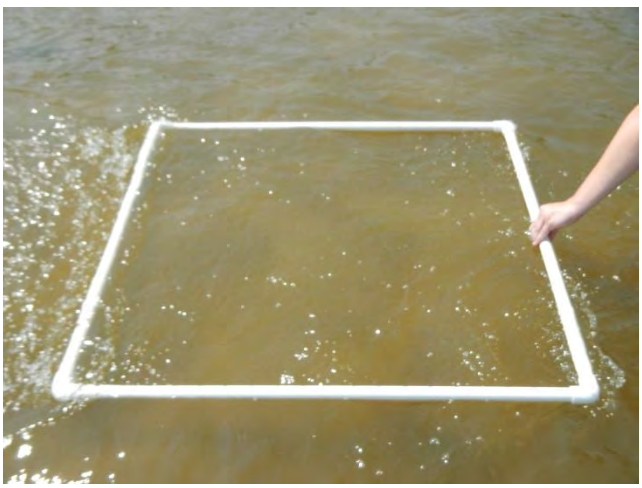

22 - Plot 2D – August 2015.


23 - Plot 2E – July 2014.

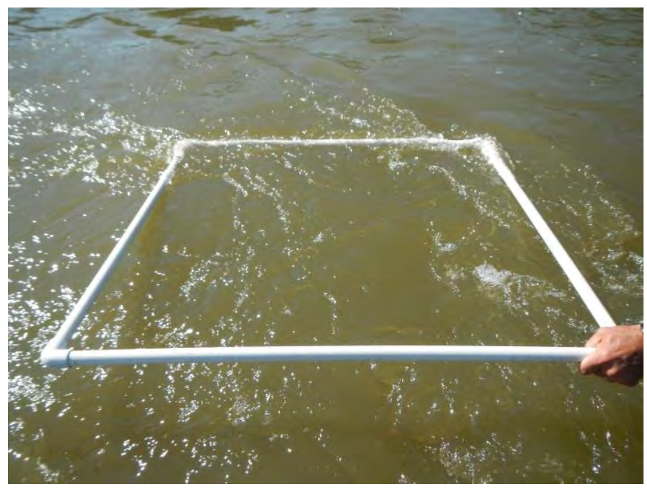

24 - Plot 2E – August 2015.

25 - Plot 2F – July 2014.

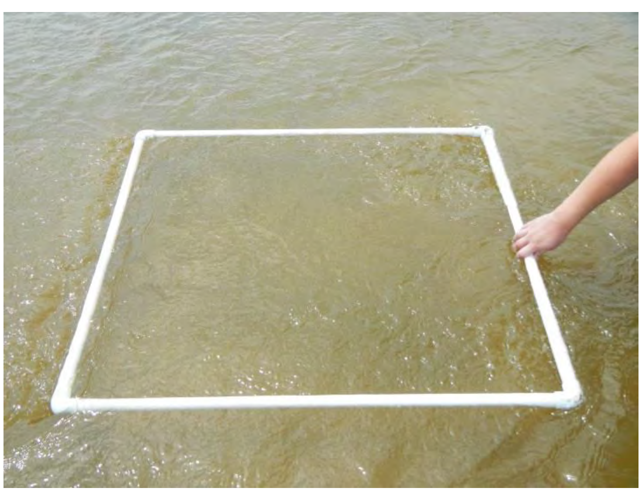
26 - Plot 2F – August 2015.



27 - Plot 2G – July 2014.



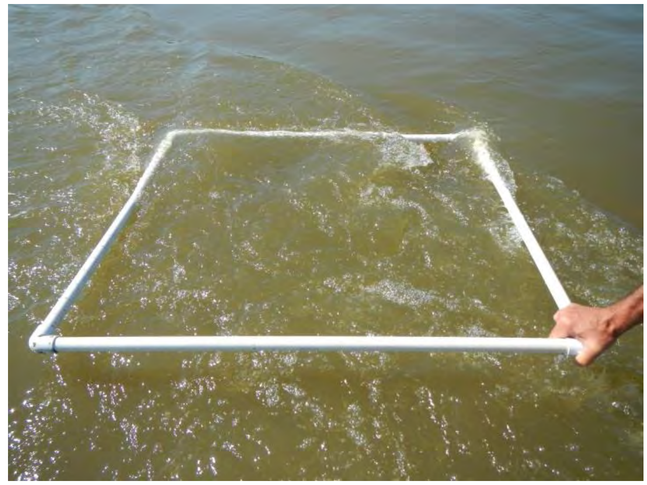
28 - Plot 2G – August 2015.



29 - Plot 3A – July 2014.

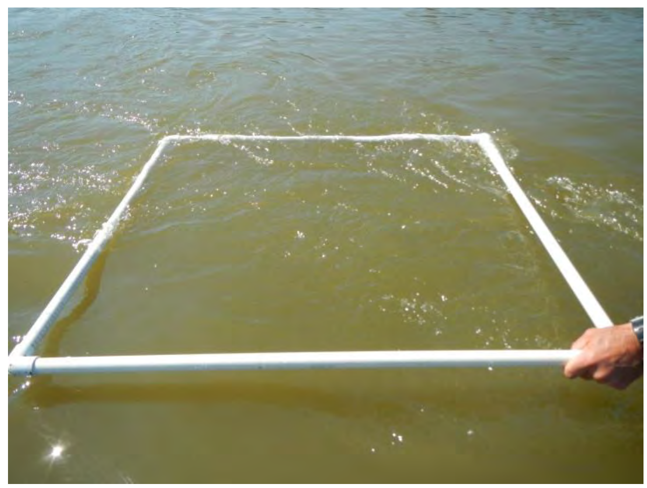
30 - Plot 3A – August 2015.

31 - Plot 3B – July 2014.



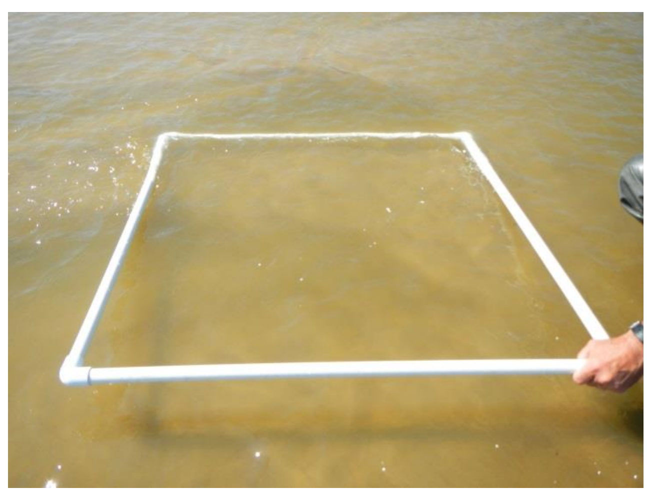
32 - Plot 3B – August 2015.

33 - Plot 3C – July 2014.



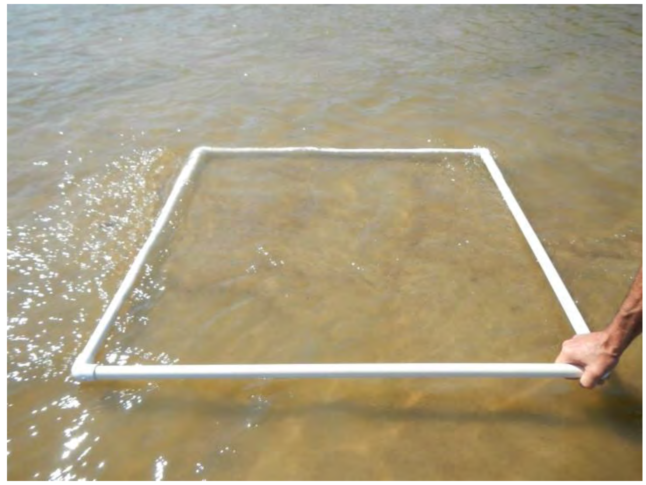
34 - Plot 3C – August 2015.

35 - Plot 3D – July 2014.

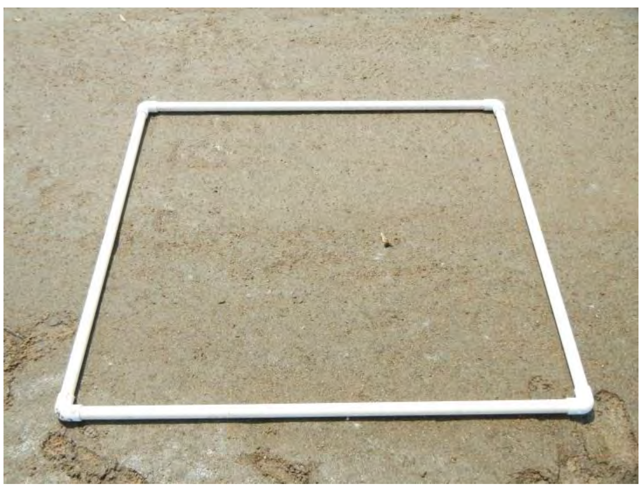


36 - Plot 3D – August 2015.

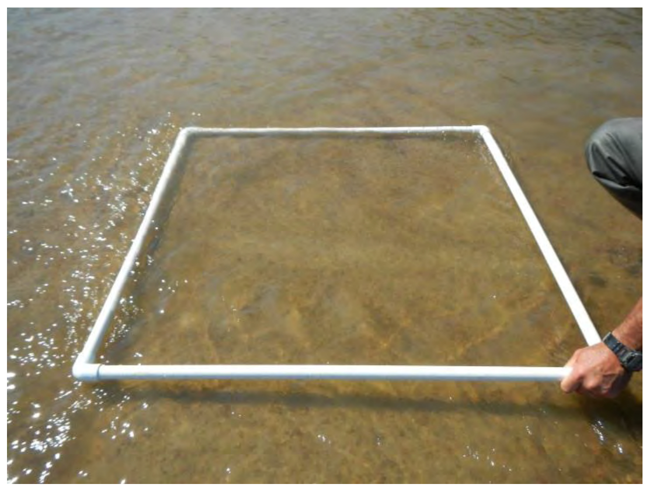
37 - Plot 3E – July 2014.



38 - Plot 3E – August 2015.



39 - Plot 3F – July 2014.

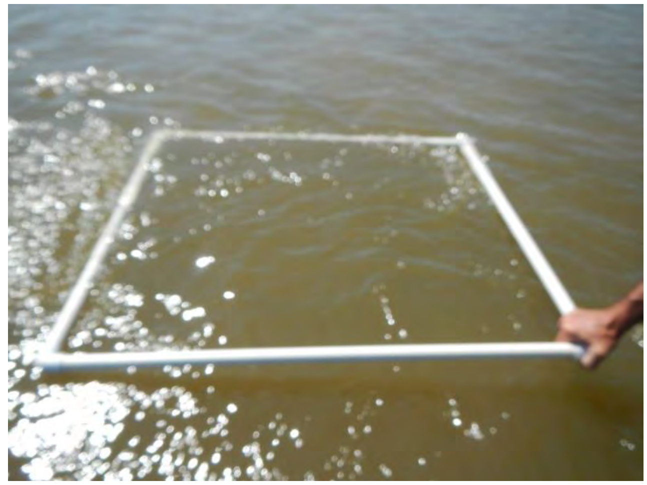


40 - Plot 3F – August 2015.

41 - Plot 3G – July 2014.

42 - Plot 3G – August 2015.

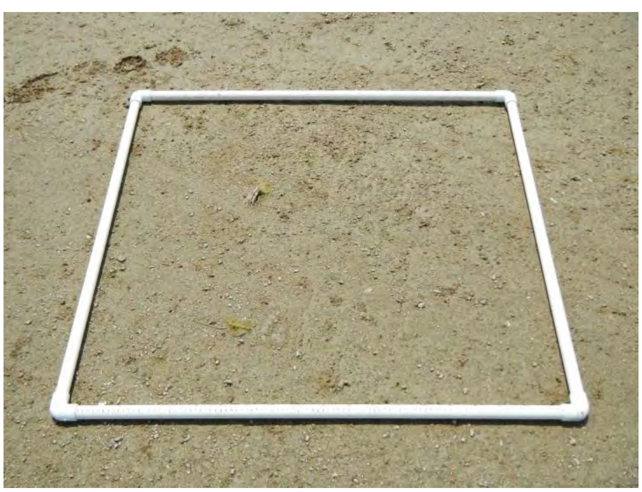
43 - Plot 4A – July 2014.



44 - Plot 4A – August 2015.

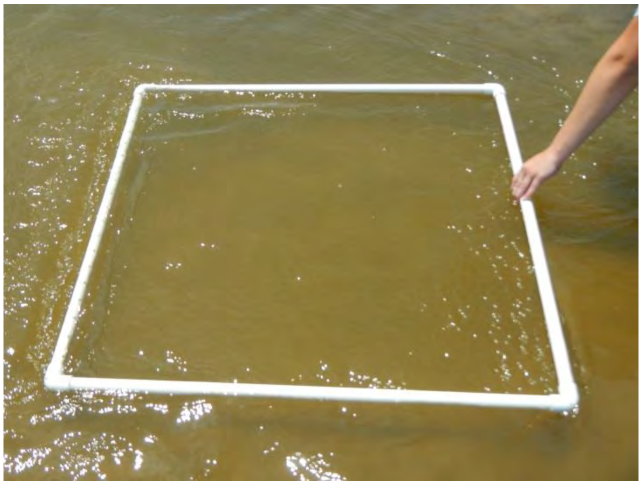
45 - Plot 4B – July 2014.

46 - Plot 4B – August 2015.



47 - Plot 4C – July 2014.

48 - Plot 4C – August 2015.



49 - Plot 4D – July 2014.

50 - Plot 4D – August 2015.

51 - Plot 4E – July 2014.

52 - Plot 4E – August 2015.

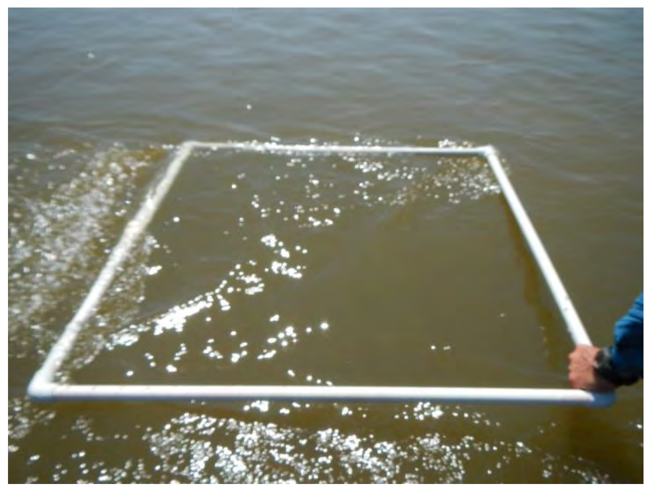
53 - Plot 4F – July 2014.

54 - Plot 4F – August 2015.

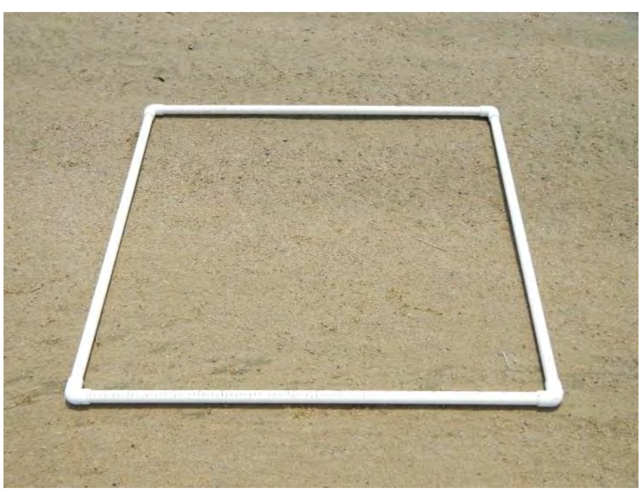
55 - Plot 4G – July 2014.

56 - Plot 4G – August 2015.

57 - Plot 5A – July 2014.



58 - Plot 5A – August 2015.

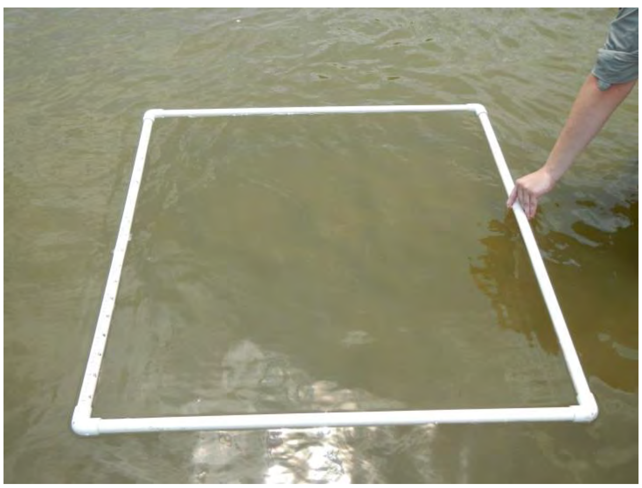


59 - Plot 5B – July 2014.

60 - Plot 5B – August 2015.

61 - Plot 5C – July 2014.

62 - Plot 5C – August 2015.



63 - Plot 5D – July 2014.

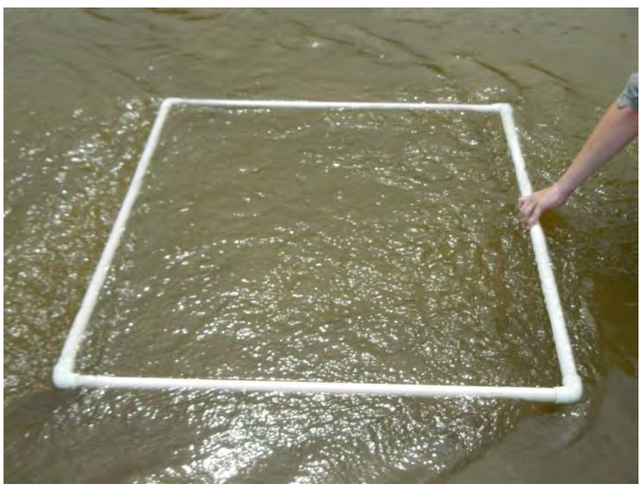
64 - Plot 5D – August 2015.

65 - Plot 5E – July 2014.

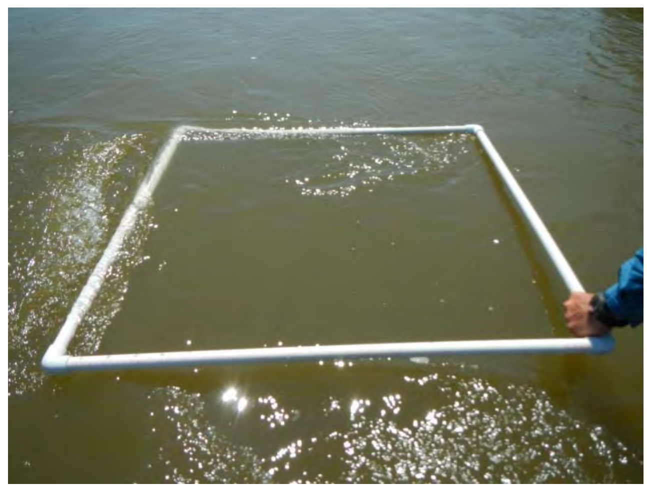
66 - Plot 5E – August 2015.

67 - Plot 5F – July 2014.

68 - Plot 5F – August 2015.



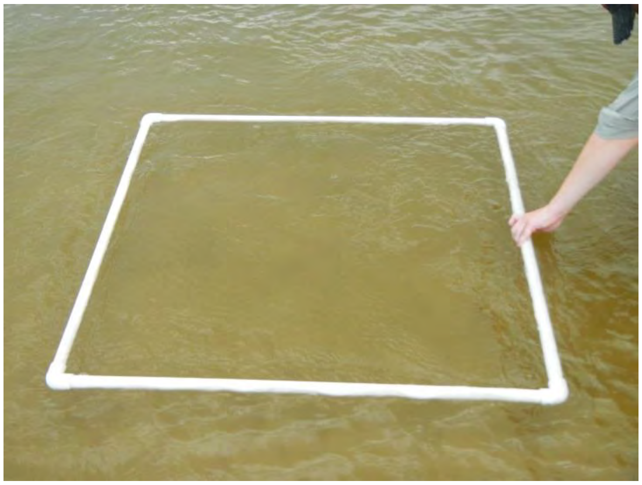
69 - Plot 5G – July 2014.



70 - Plot 5G – August 2015.

71 - Plot 6A – July 2014.

72 - Plot 6A – August 2015.



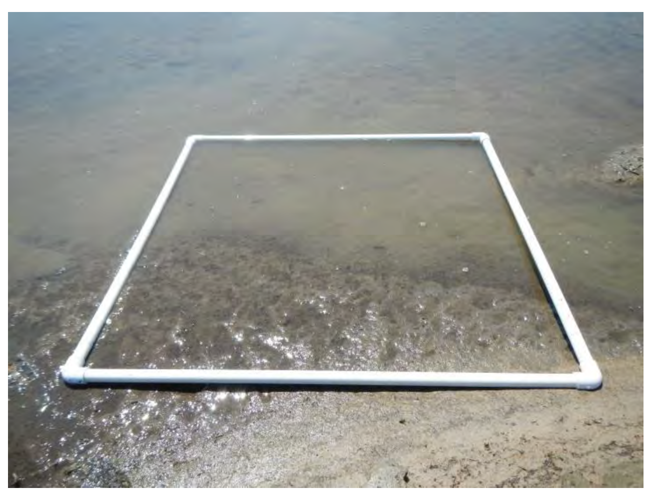
73 - Plot 6B – July 2014.

74 - Plot 6B – August 2015.

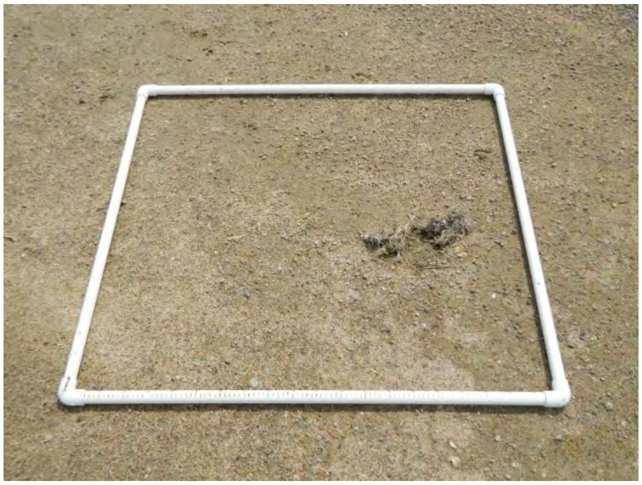
75 - Plot 6C – July 2014.

76 - Plot 6C – August 2015.

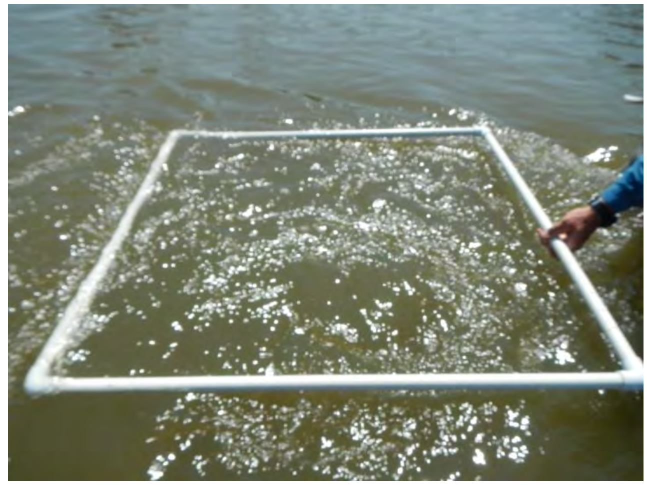
77 - Plot 6D – July 2014.



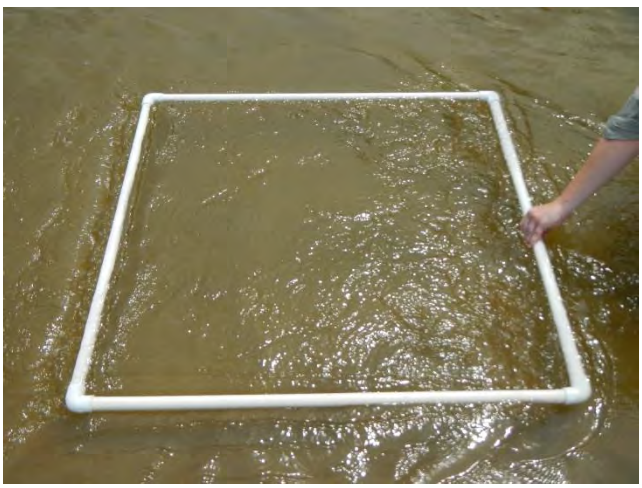
78 - Plot 6D – August 2015.



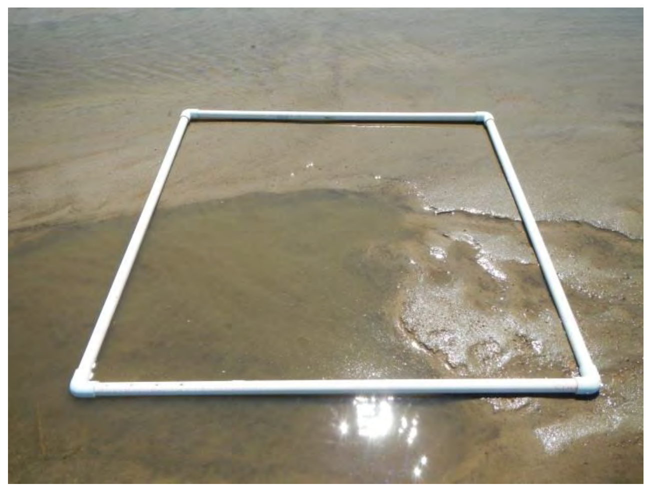
79 - Plot 6E – July 2014.



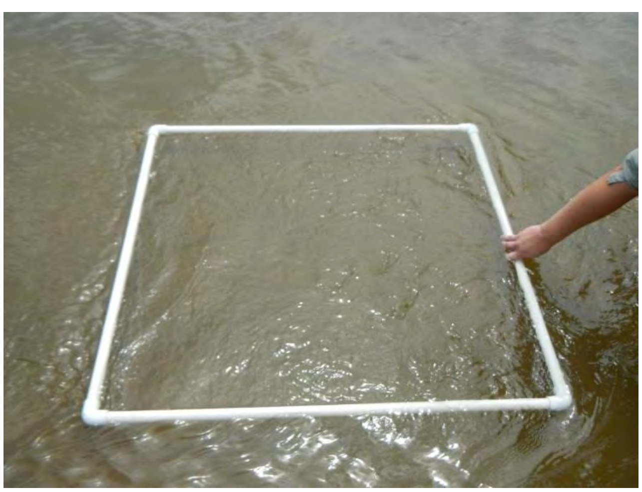
80 - Plot 6E – August 2015.



81 - Plot 6F – July 2014.



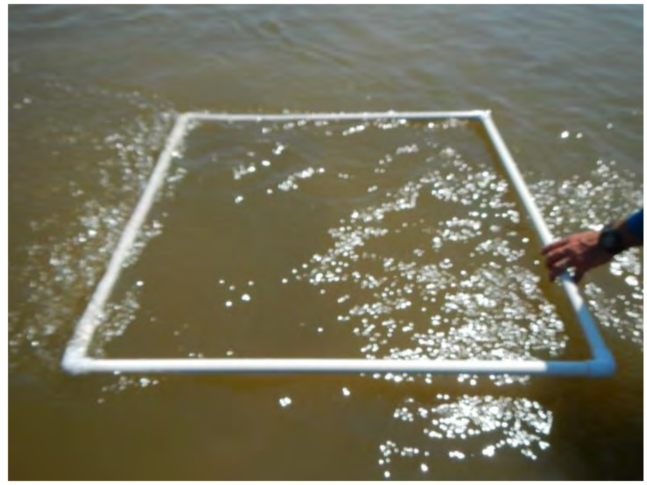
82 - Plot 6F – August 2015.



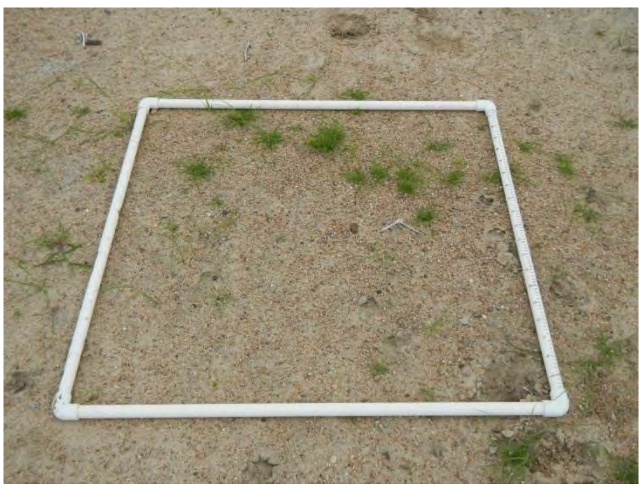
83 - Plot 6G – July 2014.

84 - Plot 6G – August 2015.

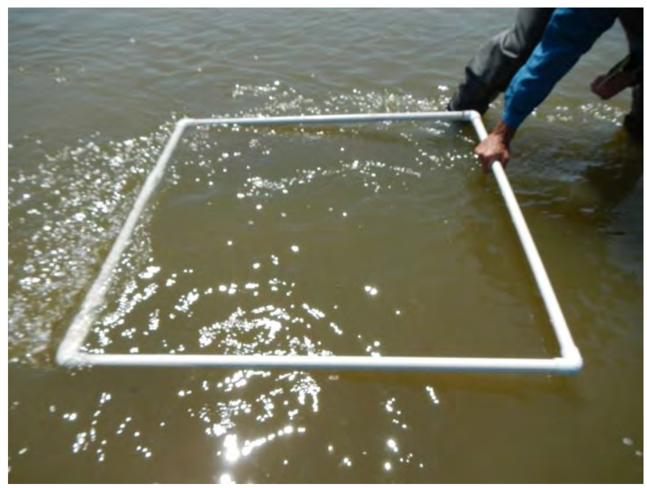
85 - Plot 7A – July 2014.



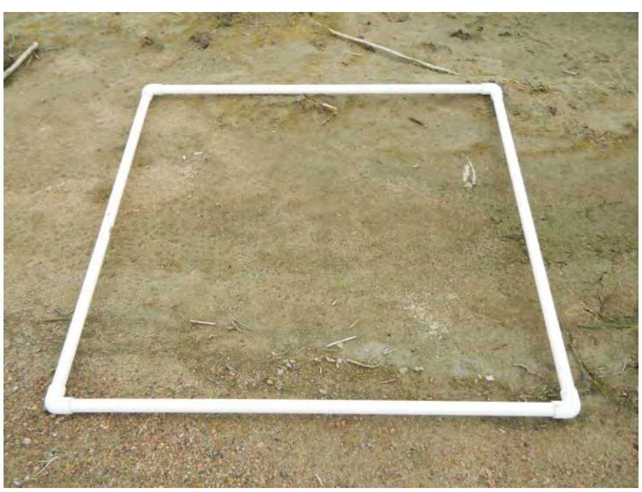
86 - Plot 7A – August 2015.



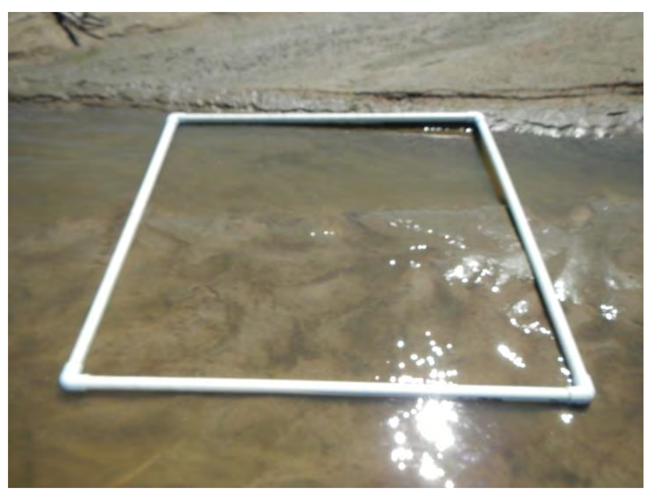
87 - Plot 7B – July 2014.



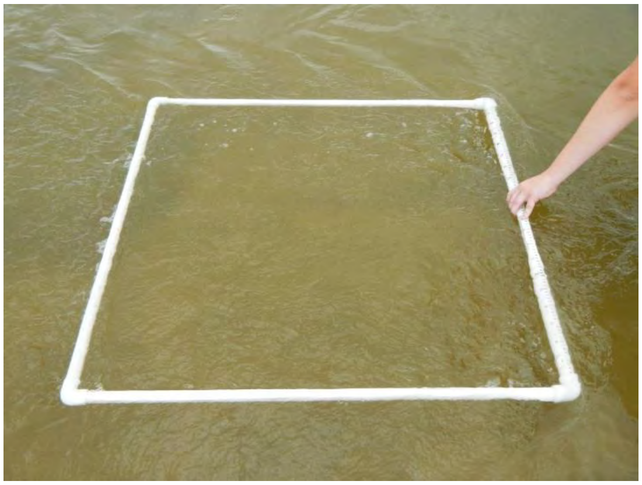
88 - Plot 7B – August 2015.



89 - Plot 7C – July 2014.



90 - Plot 7C – August 2015.

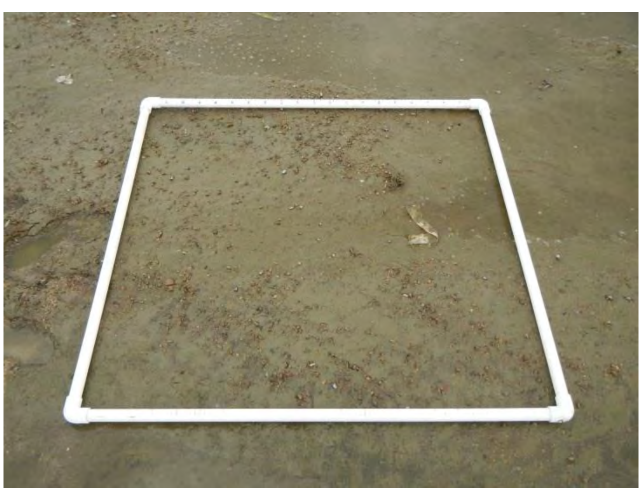


91 - Plot 7D – July 2014.

92 - Plot 7D – August 2015.

93 - Plot 7E – July 2014.

94 - Plot 7E – August 2015.



95 - Plot 7F – July 2014.

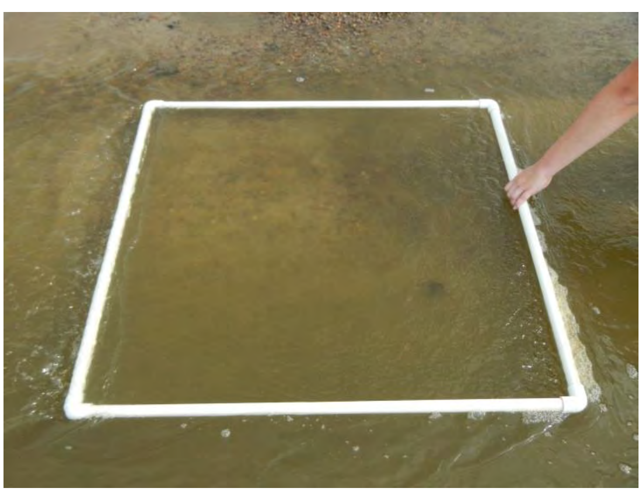
96 - Plot 7F – August 2015.

97 - Plot 7G – July 2014.

98 - Plot 7G – August 2015.

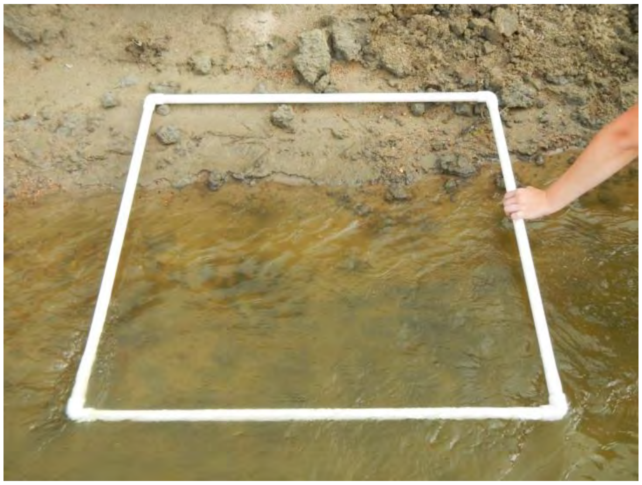
99 - Plot 8A – July 2014.

100 - Plot 8A – August 2015.



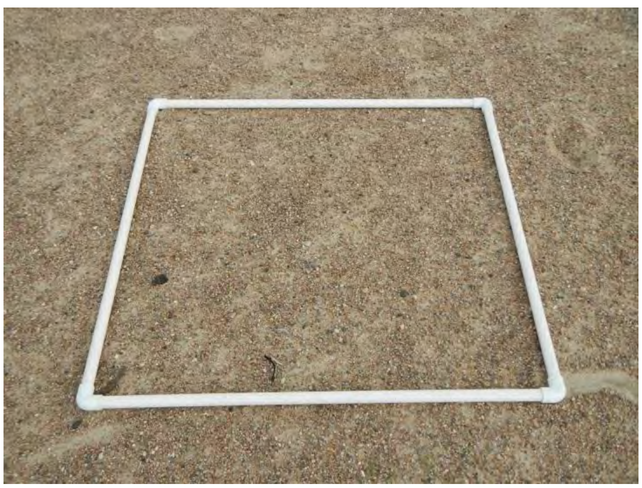
101 - Plot 8B – July 2014.

102 - Plot 8B – August 2015.



103 - Plot 8C – July 2014.

104 - Plot 8C – August 2015.



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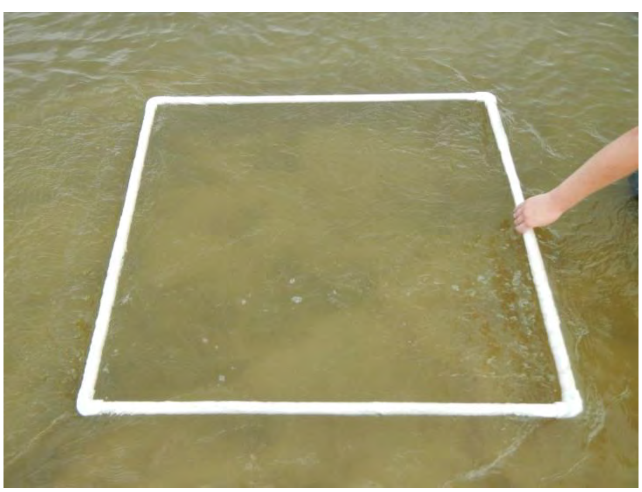
106 - Plot 8D – August 2015.



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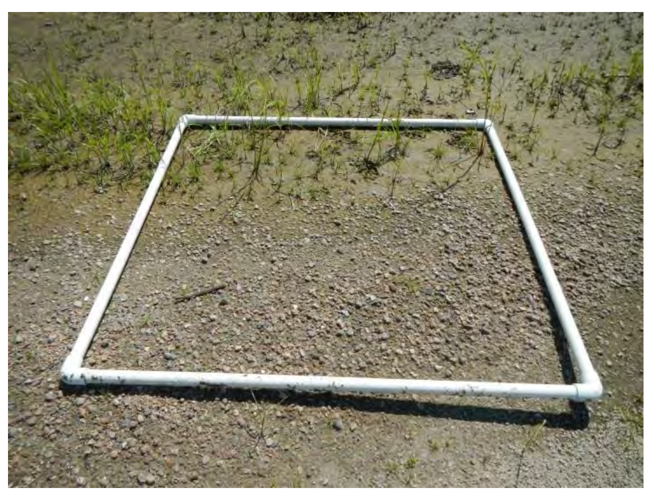
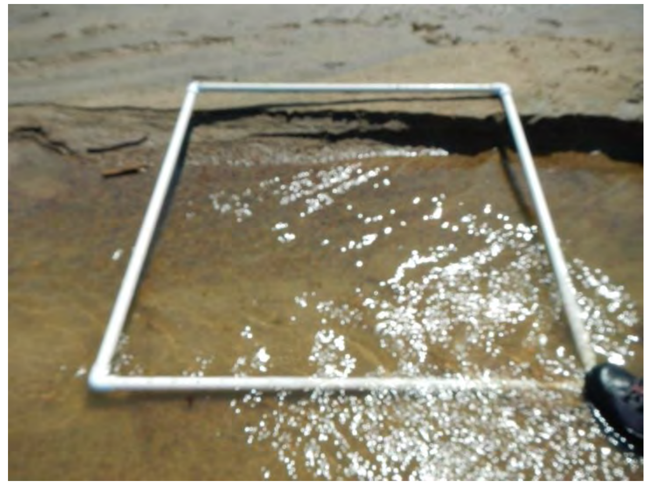


108 - Plot 8E – August 2015.

109 - Plot 8F – July 2014.

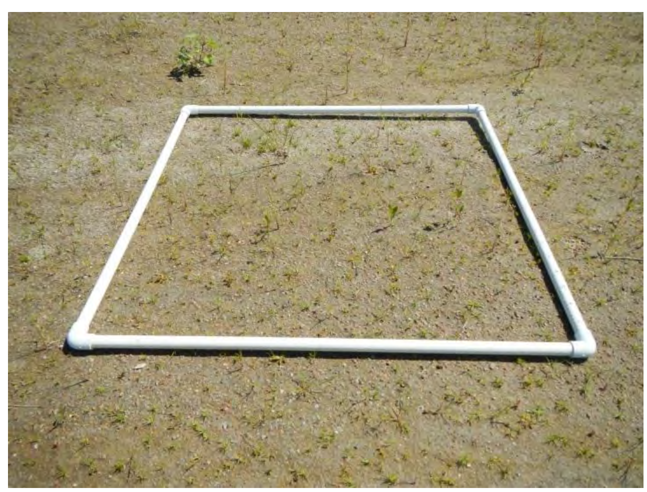


110 - Plot 8F – August 2015.

111 - Plot 8G – July 2014.

112 - Plot 8G – August 2015.

113 - Plot 9A – July 2014.

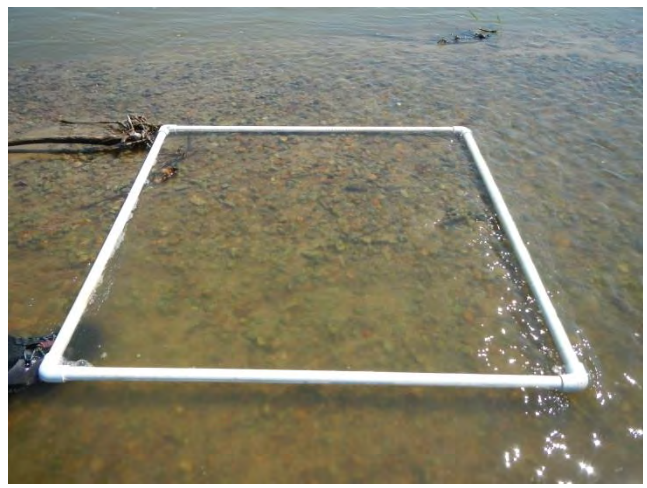


114 - Plot 9A – August 2015.

115 - Plot 9B – July 2014.

116 - Plot 9B – August 2015.

117 - Plot 9C – July 2014.



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119 - Plot 9D – July 2014.

120 - Plot 9D – August 2015.

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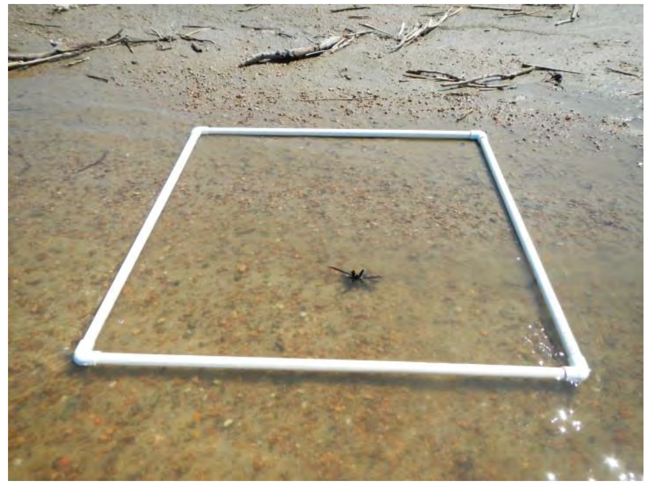

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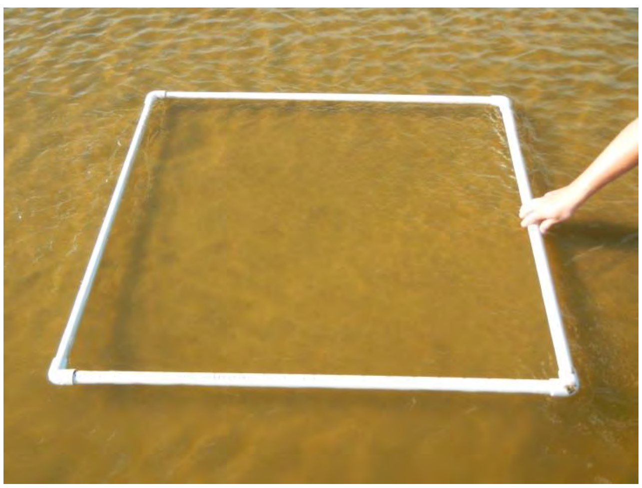

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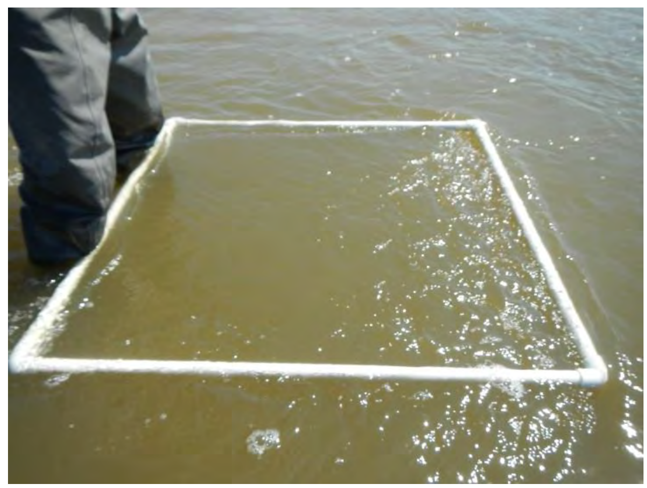

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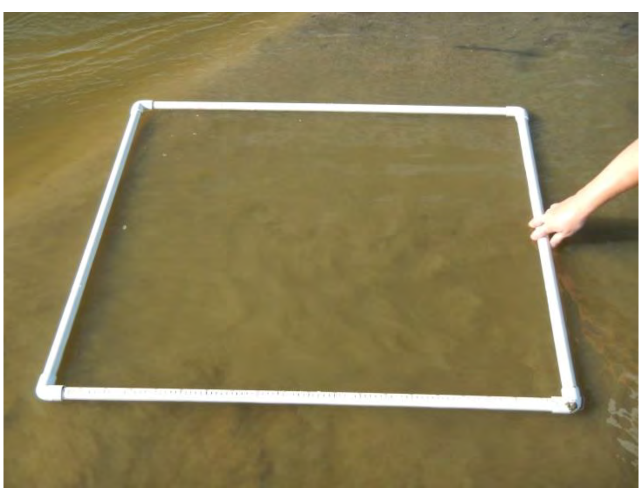

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126 - Plot 9G – August 2015.

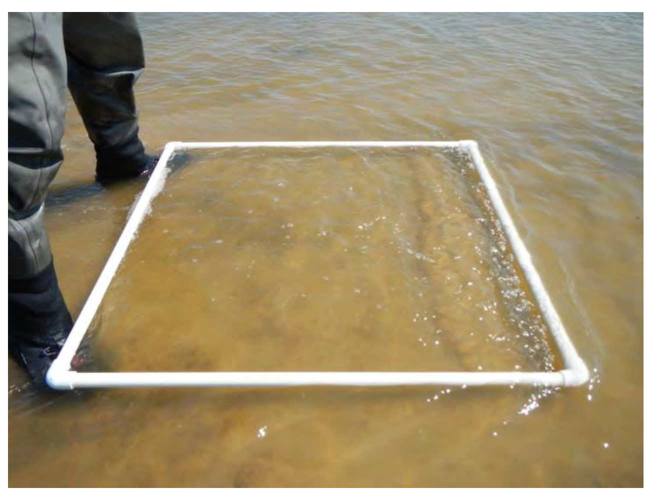
127 - Plot 10A – July 2014.

128 - Plot 10A – August 2015.

129 - Plot 10B – July 2014.

130 - Plot 10B – August 2015.

131 - Plot 10C – July 2014.



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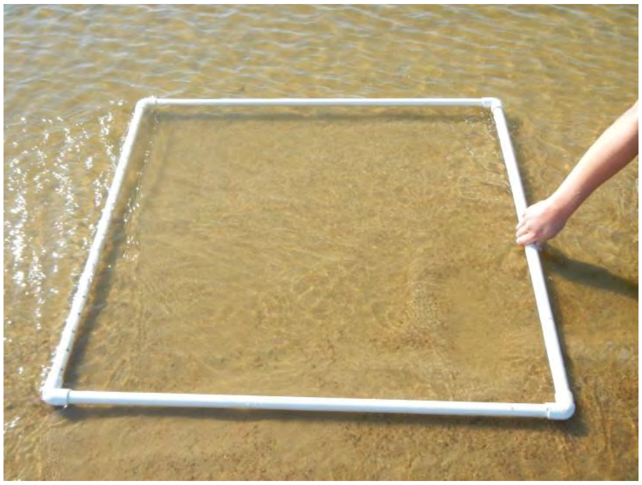

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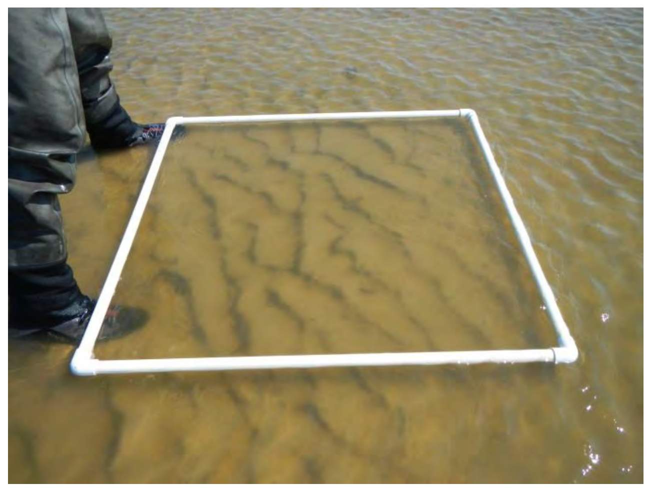
135 - Plot 10E – July 2014.



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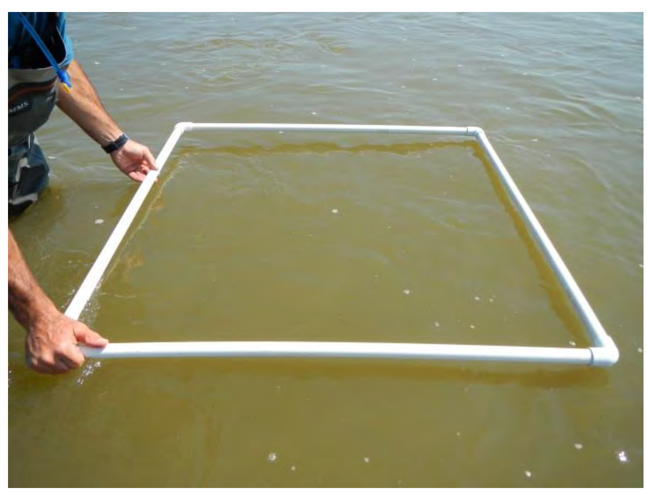

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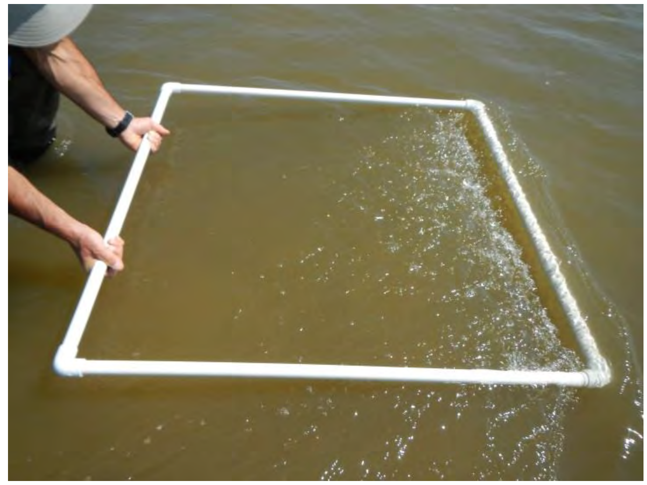
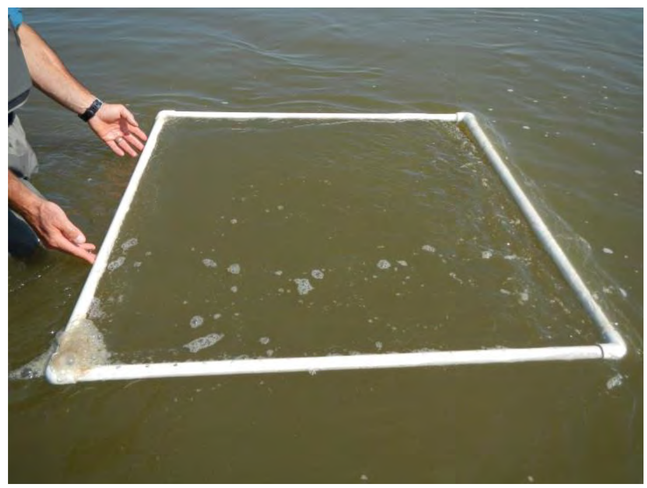
139 - Plot 10G – July 2014.


140 - Plot 10G – August 2015.


141 - Plot 11A – July 2014.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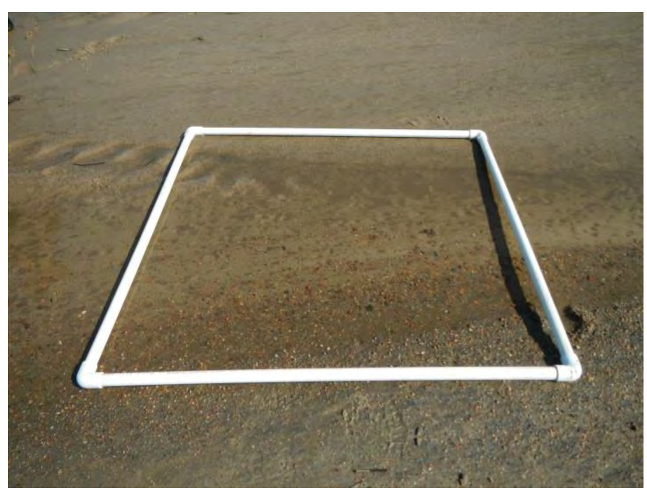
143 - Plot 11B – July 2014.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145 - Plot 11C – July 2014.

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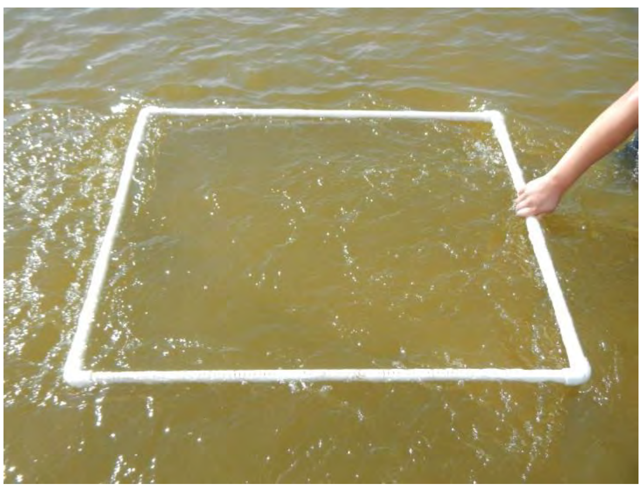

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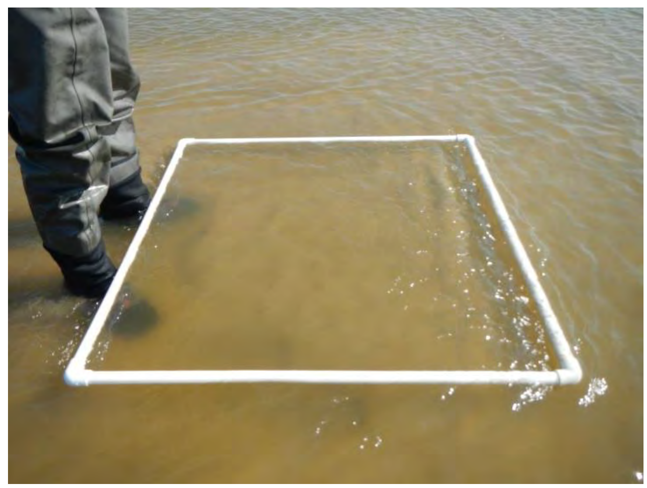

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149 - Plot 11E – July 2014.

150 - Plot 11E – August 2015.

151 - Plot 11F – July 2014.

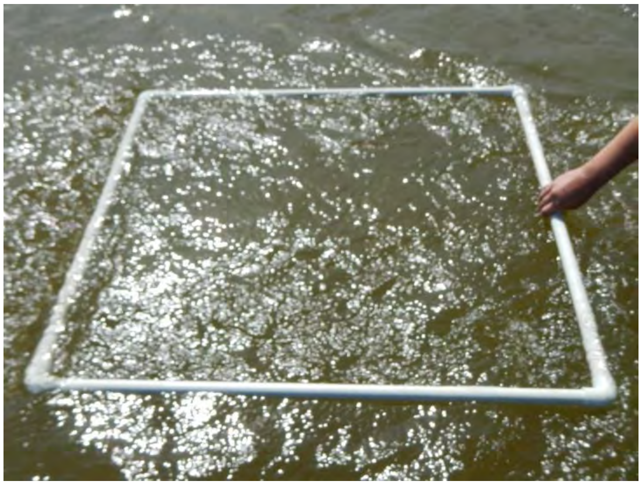
152 - Plot 11F – August 2015.

153 - Plot 11G – July 2014.

154 - Plot 11G – August 2015.

155 - Plot 12A – July 2014.

156 - Plot 12A – August 2015.



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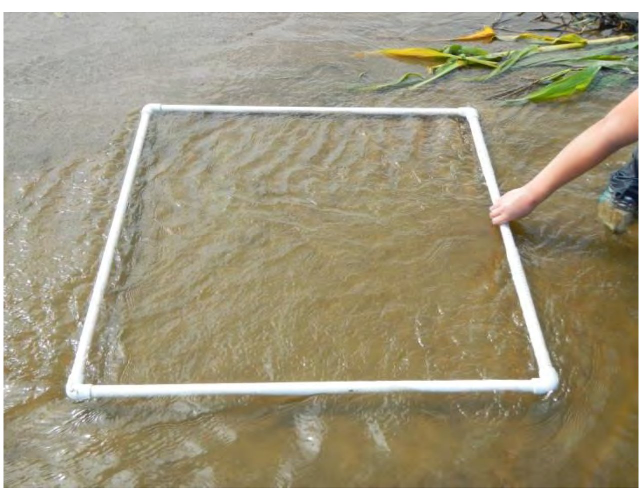

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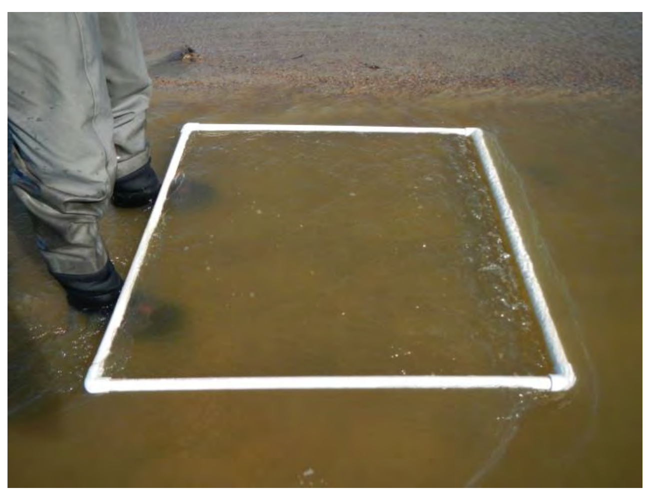

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163 - Plot 12E – July 2014.

164 - Plot 12E – August 2015.

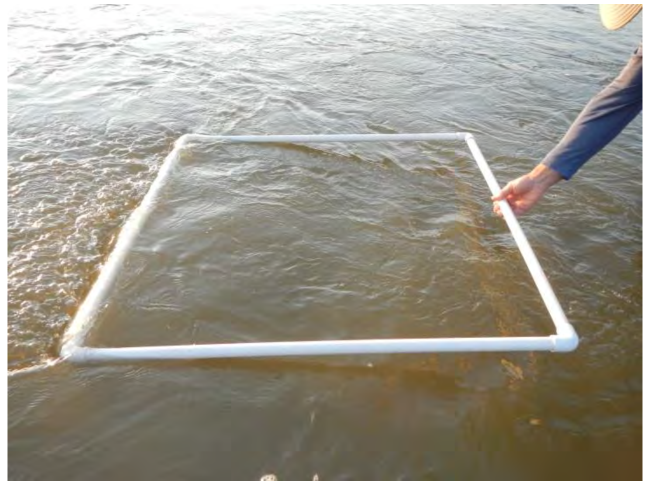
165 - Plot 12F – July 2014.

166 - Plot 12F – August 2015.

167 - Plot 12G – July 2014.

168 - Plot 12G – August 2015.

169 - Plot 13A – July 2014.



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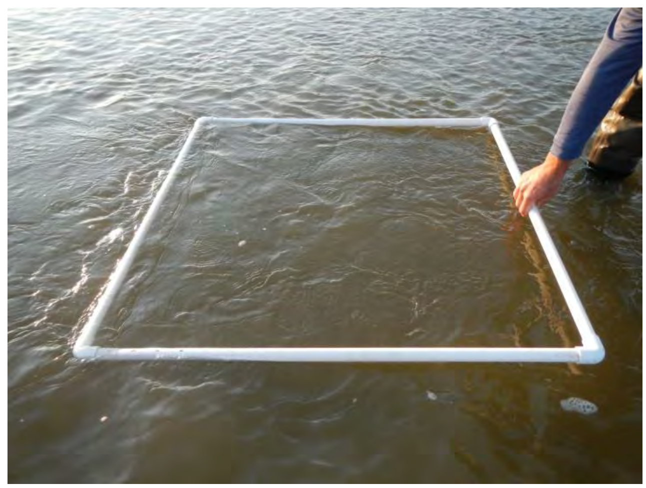

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173 - Plot 13C – July 2014.

174 - Plot 13C – August 2015.

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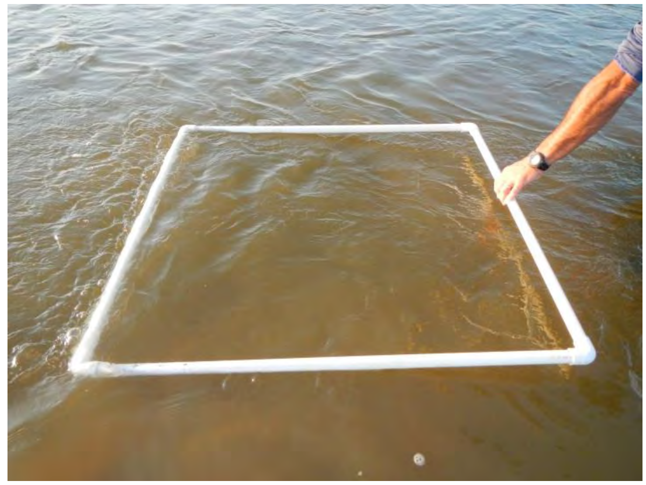

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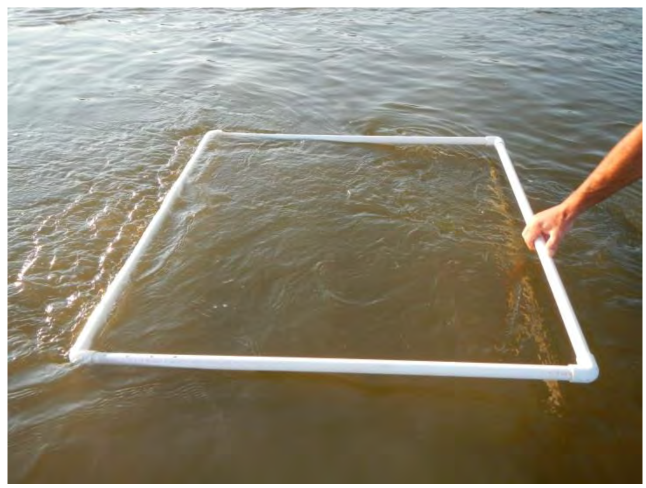

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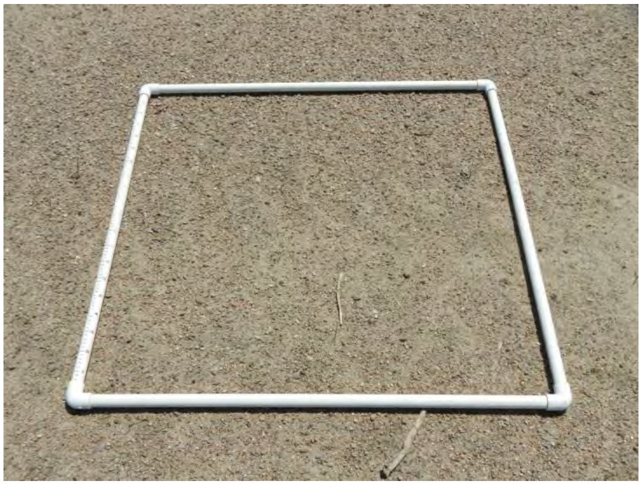

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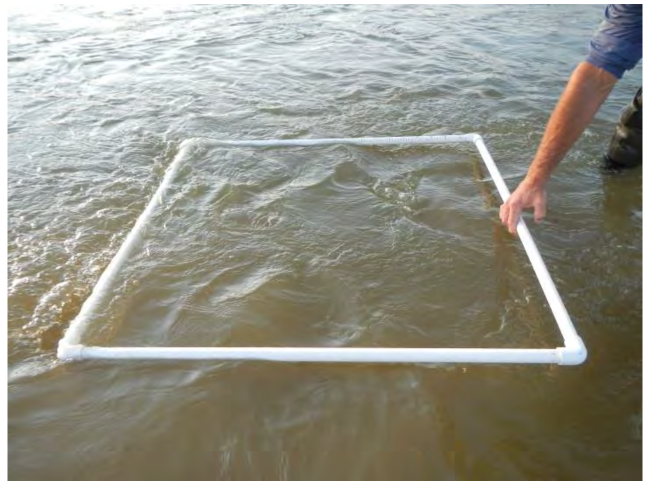

182 - Plot 13G – August 2015.

183 - Plot 14A – July 2014.

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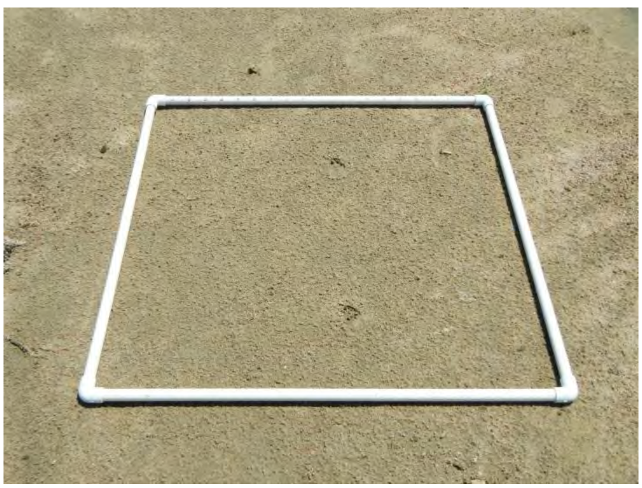
186 - Plot 14B – August 2015.

187 - Plot 14C – July 2014.

188 - Plot 14C – August 2015.



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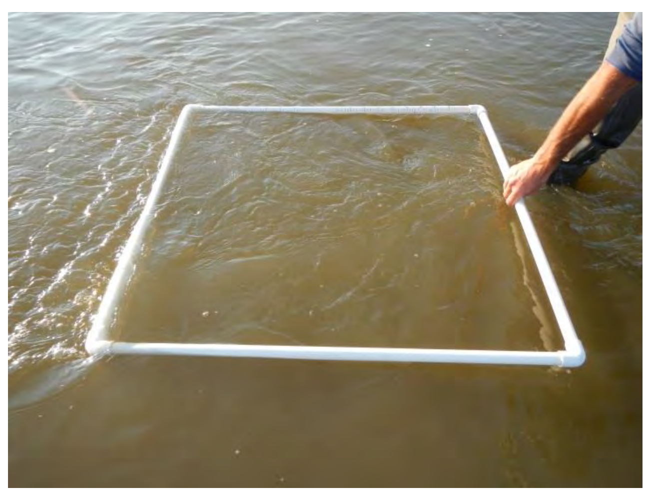

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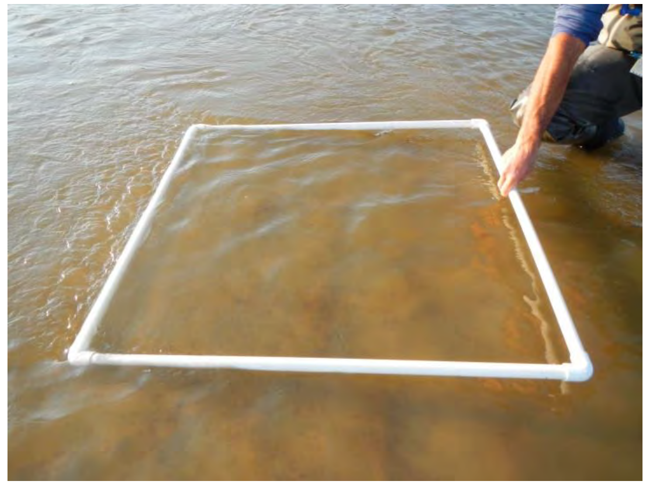
193 - Plot 14F – July 2014.



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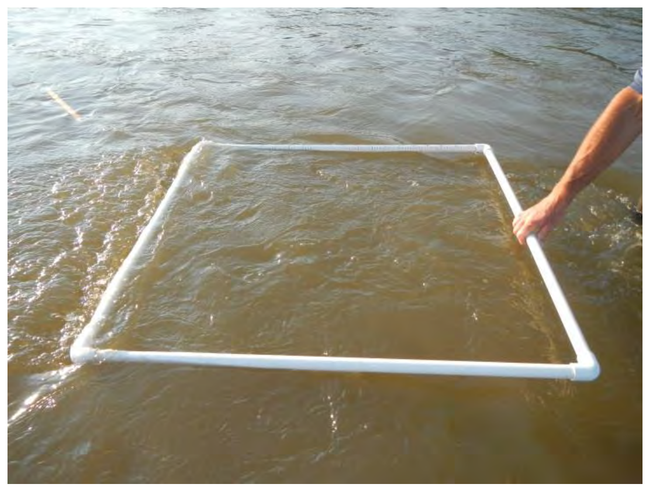

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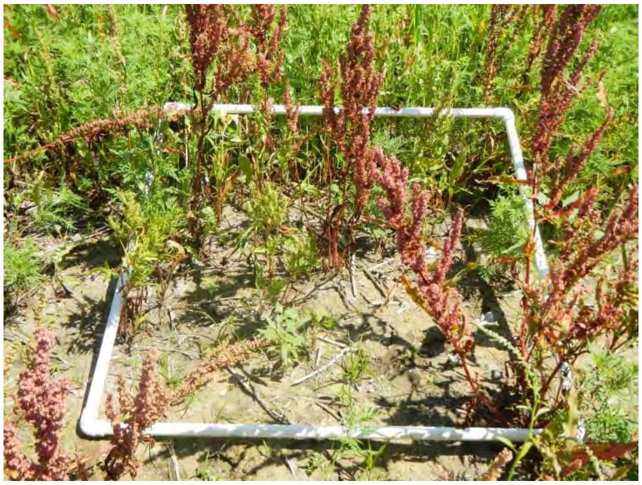
197 - Plot 15A – July 2014.

198 - Plot 15A – August 2015.



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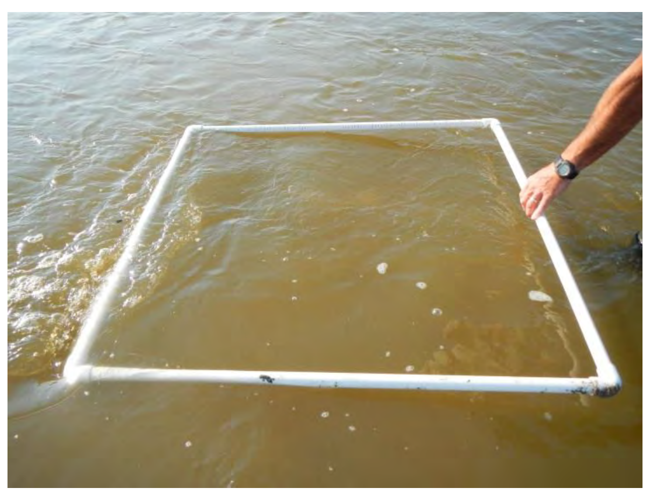
201 - Plot 15C – July 2014.

202 - Plot 15C – August 2015.

203 - Plot 15D – July 2014.



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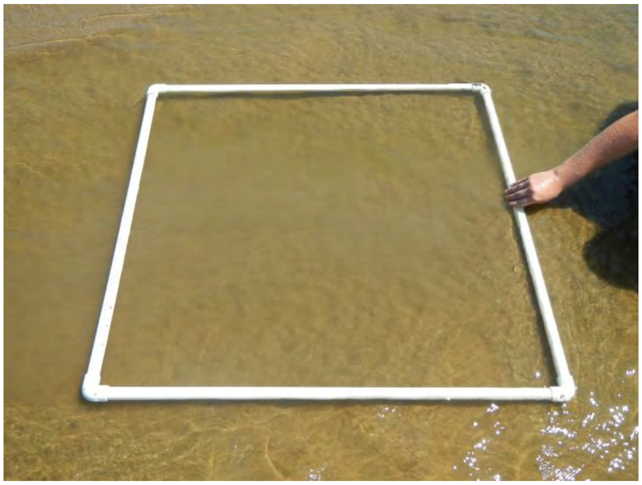

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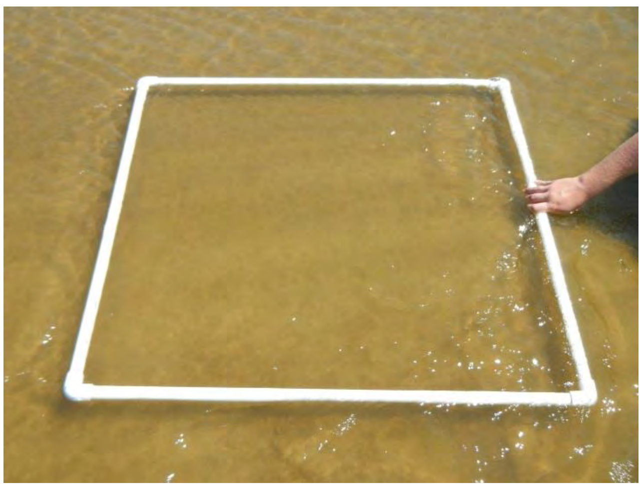

207 - Plot 15F – July 2014.

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209 - Plot 15G – July 2014.

210 - Plot 15G – August 2015.

211 - Plot 16A – July 2014.

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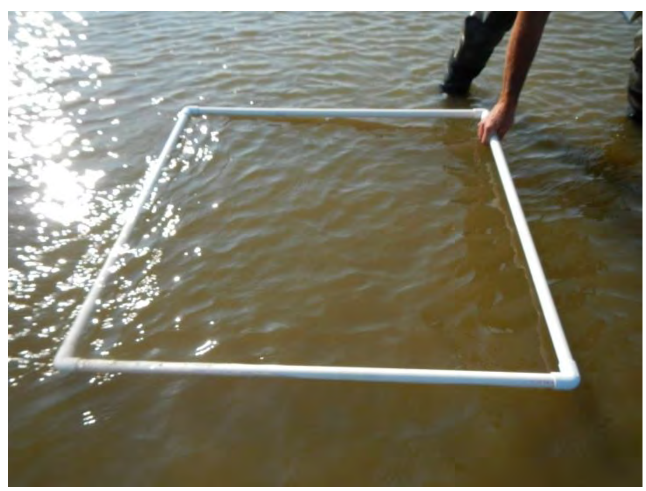
213 - Plot 16B – July 2014.

214 - Plot 16B – August 2015.

215 - Plot 16C – July 2014.



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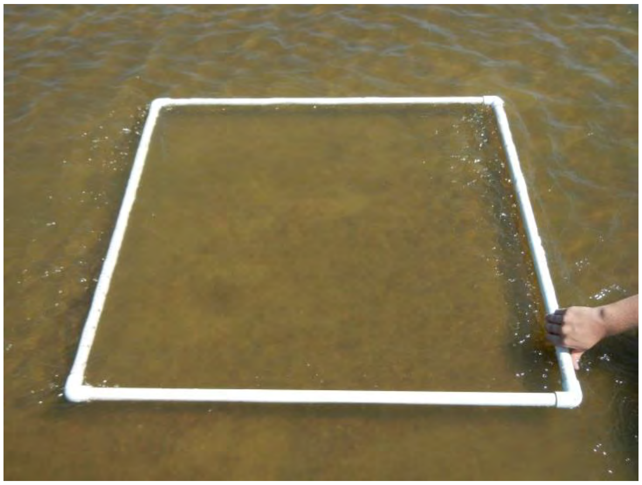

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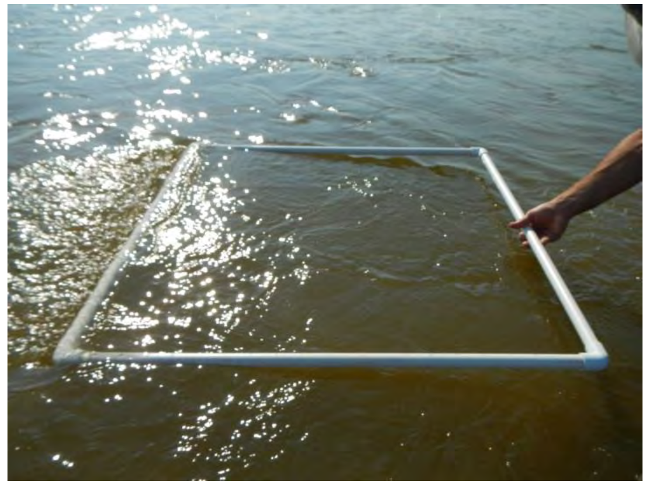

218 - Plot 16D – August 2015.

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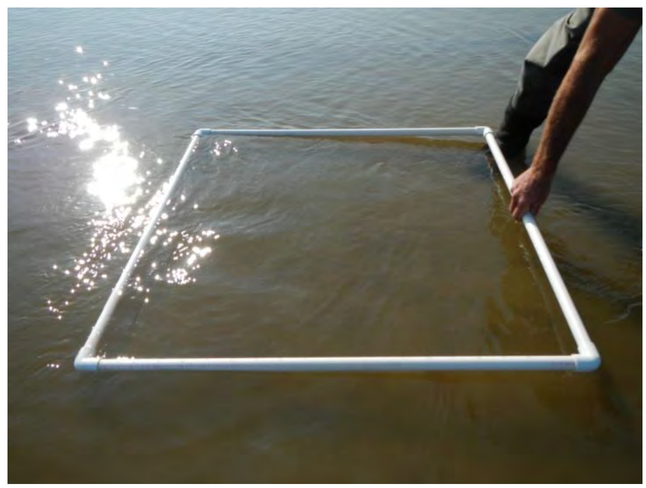

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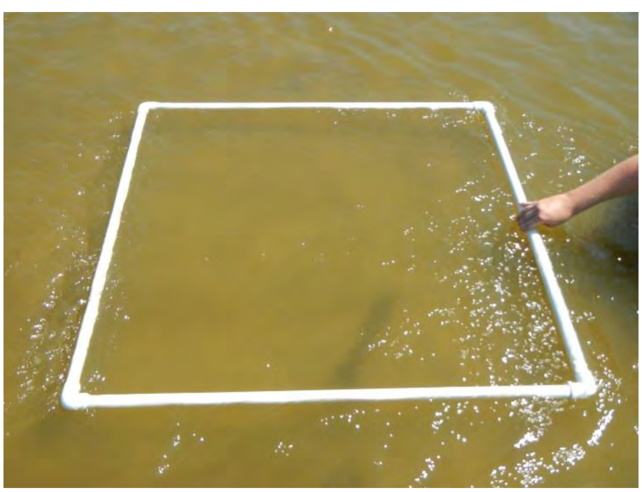

221 - Plot 16F – July 2014.

222 - Plot 16F – August 2015.

223 - Plot 16G – July 2014.

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225 - Plot 17A – July 2014.

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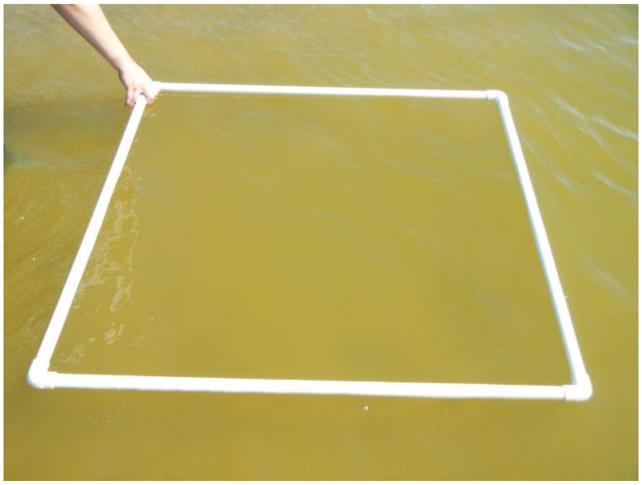
228 - Plot 17B – August 2015.



229 - Plot 17C – July 2014.

230 - Plot 17C – August 2015.

231 - Plot 17D – July 2014.

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233 - Plot 17E – July 2014.

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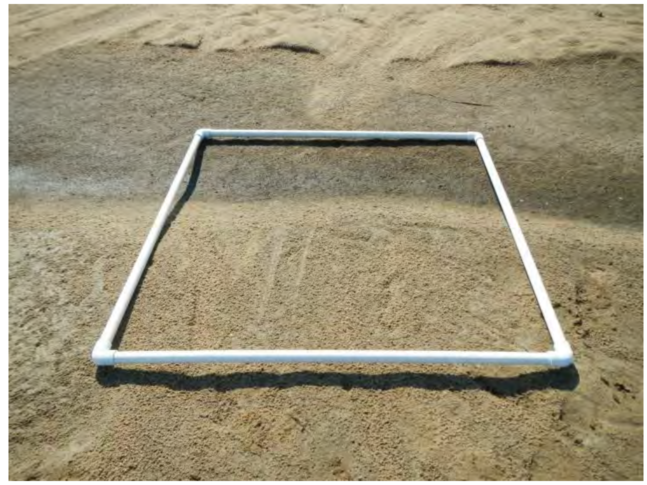

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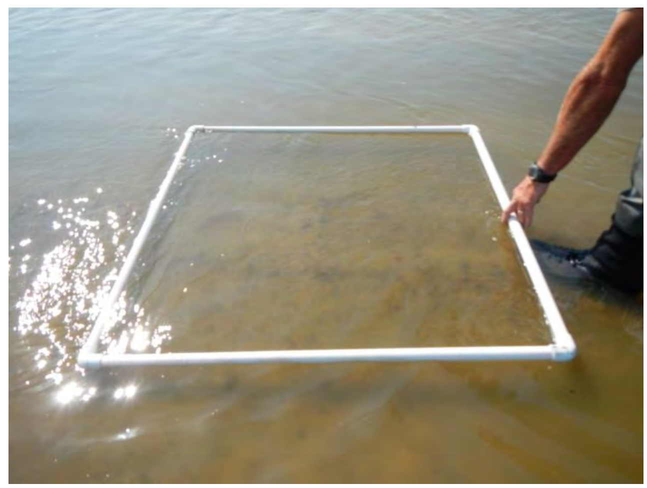
237 - Plot 17G – July 2014.



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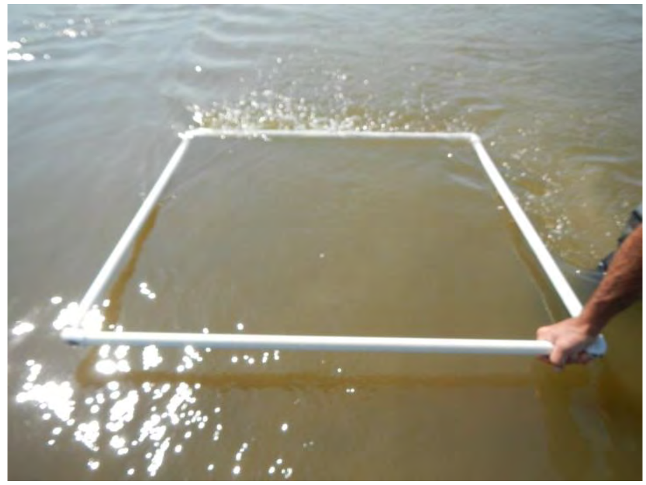
239 - Plot 18A – July 2014.

240 - Plot 18A – August 2015.

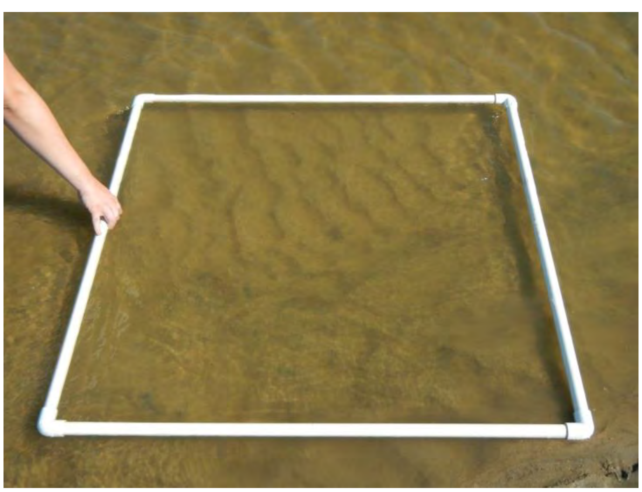
241 - Plot 18B – July 2014.



242 - Plot 18B – August 2015.

243 - Plot 18C – July 2014.

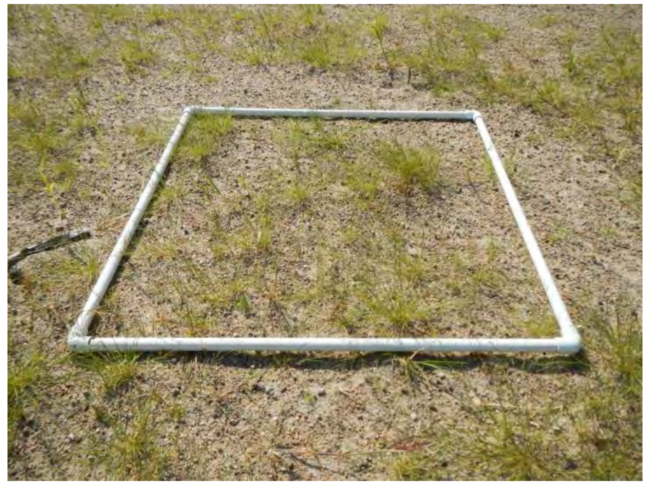
244 - Plot 18C – August 2015.



245 - Plot 18D – July 2014.

246 -   Plot 18D – August 2015.

247 - Plot 18E – July 2014.

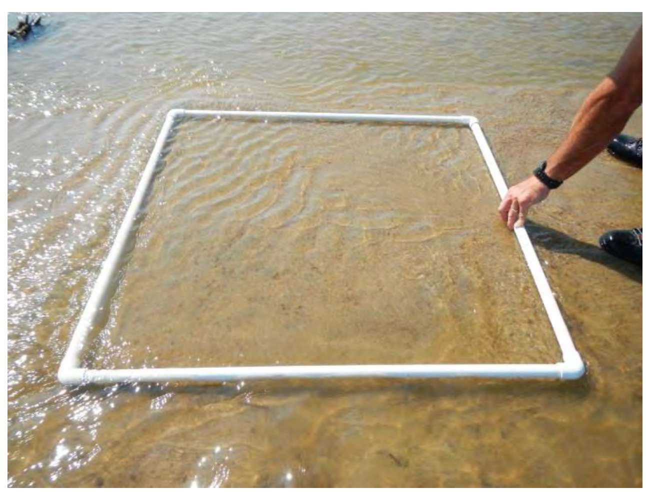


248 - Plot 18E – August 2015.

249 - Plot 18F – July 2014.

250 - Plot 18F – August 2015.

251 - Plot 18G – July 2014.



252 - Plot 18G – August 2015.

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment

Fixed Bed Modeling

Attachment I

DRAFT

August 2016

Submitted to:
Platte River Recovery Implementation Program
4111 4th Avenue, Suite 6
Kearney, NE 68845

Submitted by:
Northern Hydrology and Engineering
PO Box 2515
McKinleyville, CA 95519

Table of Contents

I. INTRODUCTION

Several types of models were used to estimate responses of channel morphology and vegetation to potential management actions in the Platte River for SDHF (Short Duration High Flow) releases. These models include two-dimensional fixed-bed hydrodynamic models, a one-dimensional bank erosion model, and two-dimensional mobile-bed sediment transport models.

These models were developed in Year 1 of the study (2013) with a focus on informing the following learning objectives:

1. Evaluate relationships between:
   a. Sediment supply and frequency of sandbar occurrence
   b. Grain size and sand bar height
   c. Hydrograph (shape and duration) and sand bar height

2. Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality

3. Evaluate ability of FSM management strategy to create/maintain habitat for whooping cranes, least terns and piping plovers

In Year 1 (2013), the models were calibrated using data collected during the 2013 SDMF (Short Duration Medium Flow) and run for higher flows and durations that would be typical of target SDHF (Short Duration High Flow). The primary limitation of the Year 1 (2013) modeling analysis was a lack of high flow calibration data to confirm model results for the high flow simulations. Two high flows occurred following the 2013 SDMF. One occurred in the fall of 2013 (Fall 2013 High Flow) and a second in June 2014 (June 2014 High Flow). Water surface elevation data was collected by PRRIP (Platte River Recovery Implementation Program) staff for model calibration during the Fall 2013 High Flow and by the EA project team during the June 2014 High Flow. High flow simulations in Year 2 (2014) confirmed that model parameters selected in Year 1 were suitable for high flow fixed-bed simulations. The highest peak flow with the longest duration of the study period occurred in 2015 (Year 3).

The specific objectives of the fixed-bed two-dimensional model for Year 3 included:

1. Predict water surface elevations at 1,200 cfs TRF with updated topography (collected following the June 2015 high flow event) and 3-day average peak flow for the June 2015 high flow for bar area and height computations (see PRRIP 2016) (Learning Objective 1).

2. Predict the velocity during the 3-day average peak flow for the June 2015 high flow event to compare the measured and predicted vegetation patch response (Learning Objective 2).

II. MODEL DESCRIPTION

FaSTMECH (Flow and Sediment Transport with Morphological Evolution of Channels) was selected as the base model to accomplish all fixed-bed modeling objectives. FaSTMECH was selected because the model is computationally efficient and a high grid resolution can be applied to the model domain. The model produced accurate results for the 2013 SDMF and 2014 high flows within the project area. FASTMECH was developed by Dr. Jonathan Nelson of the U.S. Geological Survey (USGS) and is included within the free software package, IRIC (International River Interface Cooperative) available at http://i-ric.org/en/introduction. IRIC is a river flow and riverbed variation analysis software package which combines the functionality of MD_SWMS (Multi-Dimensional Surface Water Modeling System), developed by the USGS (U.S. Geological Survey), and RIC-NAYS2D, developed by the Foundation of Hokkaido River Disaster Prevention Research Center. FaSTMECH is a two-dimensional, vertically averaged model. FASTMECH contains a sub-model that calculates vertical distribution of the primary velocity as well as the secondary flow about the vertically averaged flow. The vertically averaged equations used in the computational solution are cast in a channel-fitted curvilinear coordinate system. The approach uses the assumptions that (1) the flow is steady (or at least does not vary appreciably over short time scales), (2) the flow is hydrostatic (vertical accelerations are neglected), and (3) the turbulence can be treated adequately by relating Reynolds stresses to shear stresses using an isotropic eddy viscosity. Development of the model equations is described in Nelson and Smith (1989), while the numerical techniques and the streamline-based vertical structure sub-model are discussed by Nelson and McDonald (1996). FaSTMECH has a long track record of accurately predicting local flow conditions and morphological change in a variety of rivers (Andrews and Nelson, 1989; Lisle et al., 2000; Conaway and Moran, 2004; Barton et al., 2005). In addition, FaSTMECH differs from many other mobile-bed models by employing a quasi-steady approximation which enables predictions over longer time frames, finer grid resolutions and longer reaches.

II.A. Model Inputs

Fixed-bed model inputs include flow at the upstream boundary, water surface elevation at the downstream boundary for each flow of interest, topography and roughness.

II.A.1. Flow and Stage Boundary Conditions

The project site is located downstream of a major flow split. The portion of the river that flows through the project site is roughly 80% of the total river flow (TRF). Flows reported at the gaging stations, as well as flow targets developed by PRRIP, reference the total river flow. Thus, when referring to the total river flow, “TRF” is attached to the reported value for clarity.

Continuous stage was measured at the project site at cross-section 18 (near the downstream model boundary). A rating curve was developed from the stage measurements and twelve discharge measurements that ranged from 1,020 to 10,800 cfs (See Figure 5-2 main report). A continuous 15-minute discharge record was estimated from a rating curve developed from the discharge and stage measurements collected during the June 2015 high flow (See Figure 5-3 main report). Model flows are 1,200 cfs TRF (956 cfs in Shoemaker Reach) and the 3-day average peak discharge (15,700 cfs TRF; 11,200 cfs in Shoemaker Reach).

II.A.2. Model Domain and Topography

The model domain covers 2.6 miles of the Platte River (Figure 1). The FaSTMECH model grid is curvilinear with an individual grid cell size of 9.8 feet (3 meters) and a total of 326,433 grid cells. The model domain was not extended laterally to include the adjacent fields and channels that route flow away from the main channel at very high flows. These areas are outside of the focus area of this study.

Model topography for previous years (2013 and 2014) were developed from a combination of LiDAR data to define bar surfaces above the wetted channel and terrestrial data to define the channel geometry (Figure 1). In 2015, both data sets could not be combined, with the exception of limited areas, due to substantial topographic changes that occurred between the LiDAR flight (prior to the June 2015 high flow) and the terrestrial ground surveys (following the June 2015 high flow). Thus, terrestrial data collected following the June 2015 high flow were used as the primary data source to create the model topography. LiDAR data collected during fall 2014 were used on selected bars and to define floodplains adjacent to the channel. The overall topographic data set is highly simplified compared to previous years.

II.A.3. Bed Roughness and Vegetation Drag

The formulation of channel and floodplain roughness varies between models. Roughness was used as a calibration parameter in the fixed-bed runs to match measured water surface elevations.

FaSTMECH utilizes a drag coefficient which was estimated using Manning's roughness coefficient (n), mean flow depth (h) and gravity (g) related by the following equation:

$$C_d = \frac{n^2 g}{h^{1/3}}$$

II.A.4. Horizontal Eddy Viscosity and Diffusivity Coefficient

FaSTMECH requires an input of a lateral eddy viscosity. The lateral eddy viscosity (LEV) is a correction to the eddy viscosity used in the vertically averaged equations to treat lateral separation eddies. LEV can be estimated using the following equation:

LEV = 0.1 x average depth (meters) x average velocity (meters/second).

Using reach average values, an LEV of 0.05 was estimated. This value was increased to 0.08 to improve model stability.

III. MODEL CALIBRATION/VERIFICATION

Two data points were collected to calibrate the high flow model run. The model over predicted one point by 0.5 feet near cross-section 2.5 and another point by 0.1 feet near cross-section 10. The over-prediction of the water surface elevation may be a result of a combination of containment of flows within the model domain. Complex out of bank flows occurred upstream of the study area (above the upstream model boundary) and beyond the lateral extent of the model domain and were not captured in the model. The over prediction may also be due to inaccurate representation of model topography due to substantial channel geometry changes that occurred during the high flow and/or poor characterization of channel geometry due to widely spaced cross-sections representing the channel.

Low flow calibration was conducted using 96 measurements collected at 18 cross-sections over a period of 2 days (August 31 and September 1, 2015). Discharge during data collection is estimated from the discharge record at the Grand Island Gage. Discharge at Grand Island ranged from 746 to 1,020 cfs with an average value of 915 cfs over the period of 2 days when water surface elevation measurements were collected. Using an assumed value of 82% of the total river flow at Shoemaker, flow at the project site is estimated to be roughly 750 cfs during the data collection. The root mean square error is 0.22 feet (Figure 2)

IV. FIXED-BED MODEL RESULTS

IV.A. Objective 1: Water Surface Elevation for Measured Bar Changes and Cut/Fill Analyses

Fixed-bed model runs were conducted to predict water surface elevations at 1,200 cfs (TRF) and at the 3-day average peak flow (June 2015 high flow) for bar height computations (Figure 3). Only water levels within the bar computational area are provided. Within this area, the average depth increased from 0.9 feet to 2.6 feet between the low flow and high flow; average velocity increased from 1.3 to 2.7 feet/sec and average shear stress increased from 2 Pa to 9.0 Pascals.

IV.B. Objective 2: Predict Changes in Vegetation Patches Due to Uprooting of Vegetation

Relations between velocity and vegetation patch resistance were developed by Pollen-Bankhead et al. (2012) for one-year old cottonwoods, two-year old cottonwoods, reed canarygrass and phragmites. Spatial patterns of velocity within the computational area are shown for the June 2015 high flow (Figure 4).

The 3-day average peak flow velocity results were further processed to match those presented by Pollen-Bankhead et al. (2012) with the exception that the velocity breaks are provided in units of feet/sec rather than meters/sec. The Pollen-Bankhead et al. (2012) color scheme was also adopted for ease in comparison of results to earlier studies. The velocity range in each class is specific to each vegetation type. The classes include no uprooting, uprooting initiated, three classes of increasing velocity, and finally, a velocity class where all plants are expected to uproot.

The velocities required for initiating uprooting of one-year old cottonwoods are generally predicted within the low flow channels and across all vegetated bars (Figure 5) during the June 2015 high flow. Velocities across all bars are predicted to be within the two lowest uprooting classes (54% in the lowest class and 45% in the next higher class). Only 1% of the bar area did not meet the velocity criteria to initiate uprooting.

Two-year old cottonwoods require higher velocities to initiate uprooting. Similar to 1-year cottonwoods, only 1% of the bar area does not meet the criteria to initiate uprooting. However, 94% of the bar area is in the lowest velocity class for initiation of uprooting and 5% is in the next higher velocity class during the June 2015 high flow.

Velocities are predicted to be too low throughout the reach to initiate uprooting of reed canary grass with the exception of a few small patches identified in higher velocity zones within the main channel during the June 2015 high flow (Figure 5). All predicted velocities are well below that required to initiate uprooting of phragmites (Figure 5).

V. CONCLUSIONS

Velocity predictions at 15,700 cfs (TRF) were used to predict areas where vegetation patches would be uprooted as a result of drag force. Results of the analysis indicate that there are no areas within the Shoemaker Reach where all plants in a patch are expected to be uprooted. Some uprooting is predicted to be initiated for one-year and two-year old cottonwoods across most bars. Initiation of uprooting is not expected for reed canary grass or phragmites on bar surfaces.

Velocity magnitudes were determined to be insufficient for the generation of drag forces capable of uprooting reed canarygrass and phragmites. Thus, hydraulic forces occurring during high flows which exceed the target SDHF are insufficient for managing these vegetation types in the Shoemaker Island Reach (Learning Objective 2).

These results are consistent with Year 1 and 2 results.

VI. REFERENCES

Andrews, E. D., and J. M. Nelson, 1989. Topographic response of a bar in the Green River, Utah to variation in discharge, in River Meandering, Water Resour. Monogr. Ser., vol. 12, edited by S. Ikeda and G. Parker, pp. 463 – 485, AGU, Washington, D. C.

Barton, G. J., R. R. McDonald, J. M. Nelson, and R. L. Dinehart, 2005. Simulation of flow and sediment mobility using a multidimensional flow model for the white sturgeon critical-habitat reach, Kootenai River near Bonners Ferry, Idaho, U.S. Geol. Surv. Sci. Invest. Rep., 2005-5230, 64 pp.

Conaway, J. S., and E. H. Moran, 2004. Development and calibration of a two-dimensional hydrodynamic model of the Tanana River near Tok, Alaska, U.S. Geol. Surv. Open File Rep., 1225, 22 pp.

Lisle, T. E., J. M. Nelson, J. Pitlick, M. A. Madej, and B. L. Barkett, 2000. Variability of bed mobility in natural, gravel-bed channels and adjustments to sediment load at local and reach scales, Water Resour. Res., 36, 3743– 3755, doi:10.1029/2000WR900238.

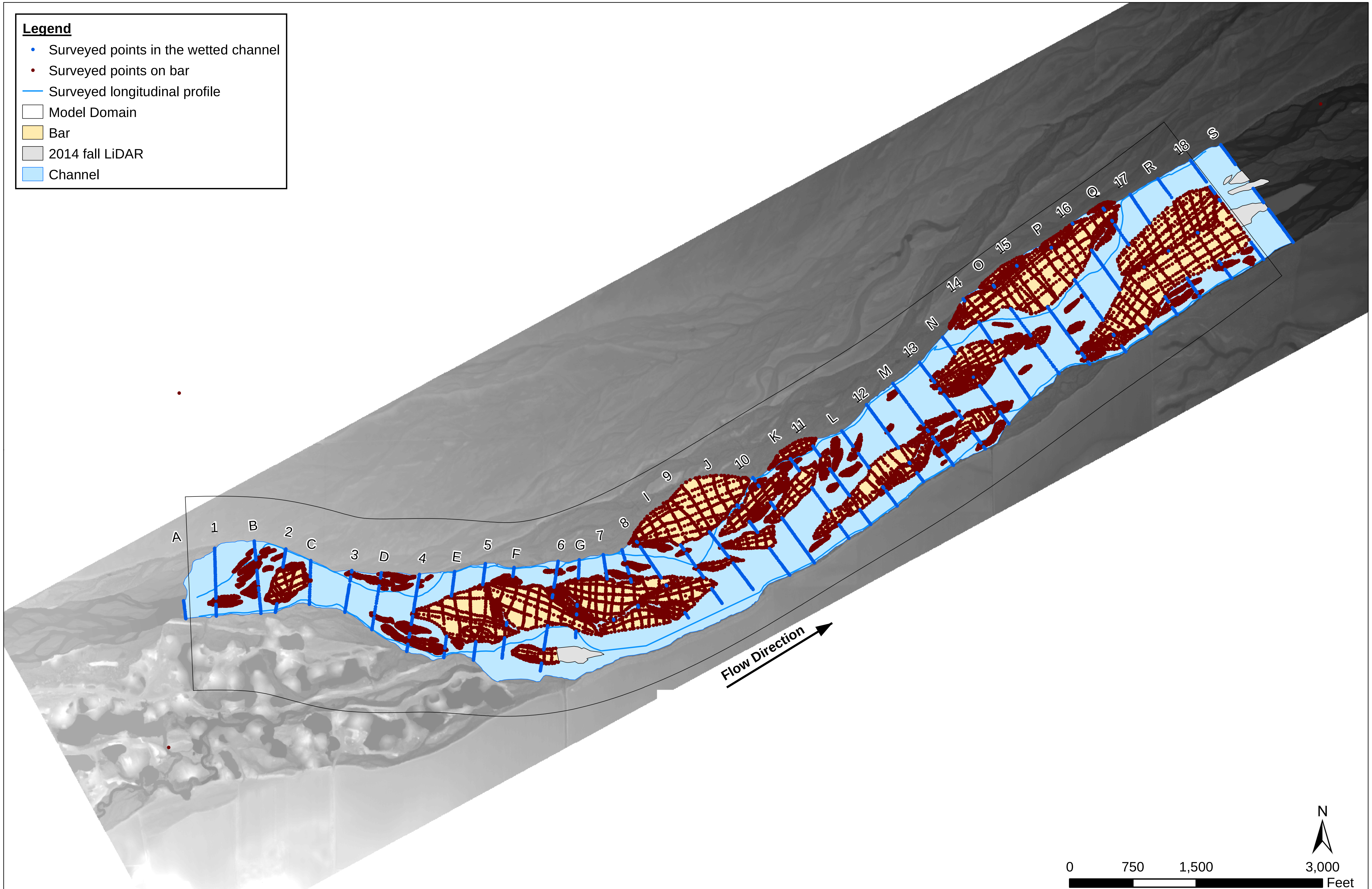
Nelson, J. M., and J. D. Smith, 1989. Flow in meandering channels with natural topography, in River Meandering, Water Resour. Monogr. Ser., vol. 12, edited by S. Ikeda and G. Parker, pp. 69– 102, AGU, Washington, D. C.

Nelson, J. M., and R. M. McDonald, 1996. Mechanics and modeling of flow and bed evolution in lateral separation eddies, report, Grand Canyon Environ. Stud., Flagstaff, Ariz.

Pollen-Bankhead, N., Thomas, R. and A. Simon, 2012. Can short duration high flows be used to remove vegetation from bars on the central Platte River? Platte River Recovery Implementation Program, Directed Vegetation Research Study 127pp.

Platte River Recovery Implementation Program (PRRIP), 2015. Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment Annual Report for 2014. May 2015.

FIGURES



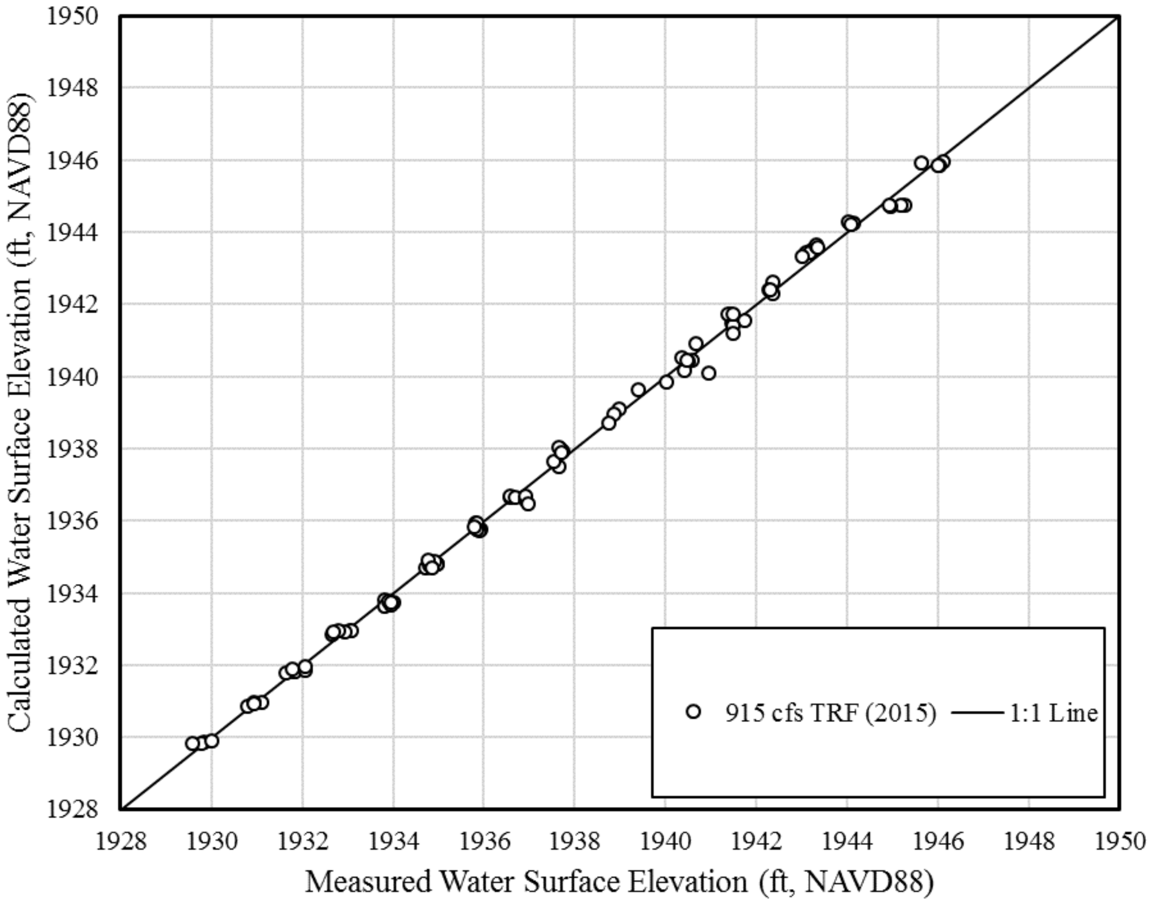
JUNE 2015 HIGH FLOW MODEL TOPOGRAPHY

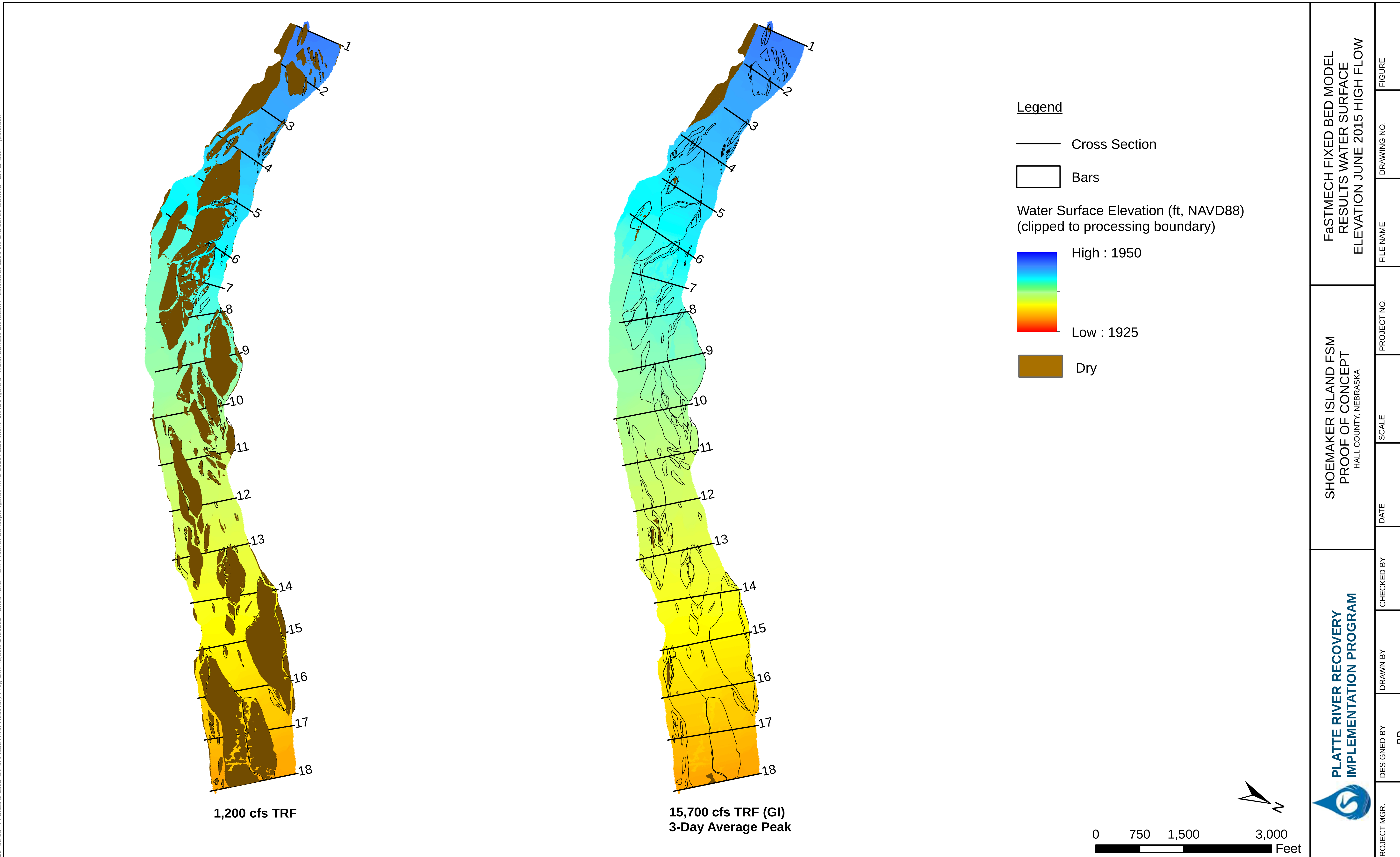
SHOEMAKER ISLAND FSM PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

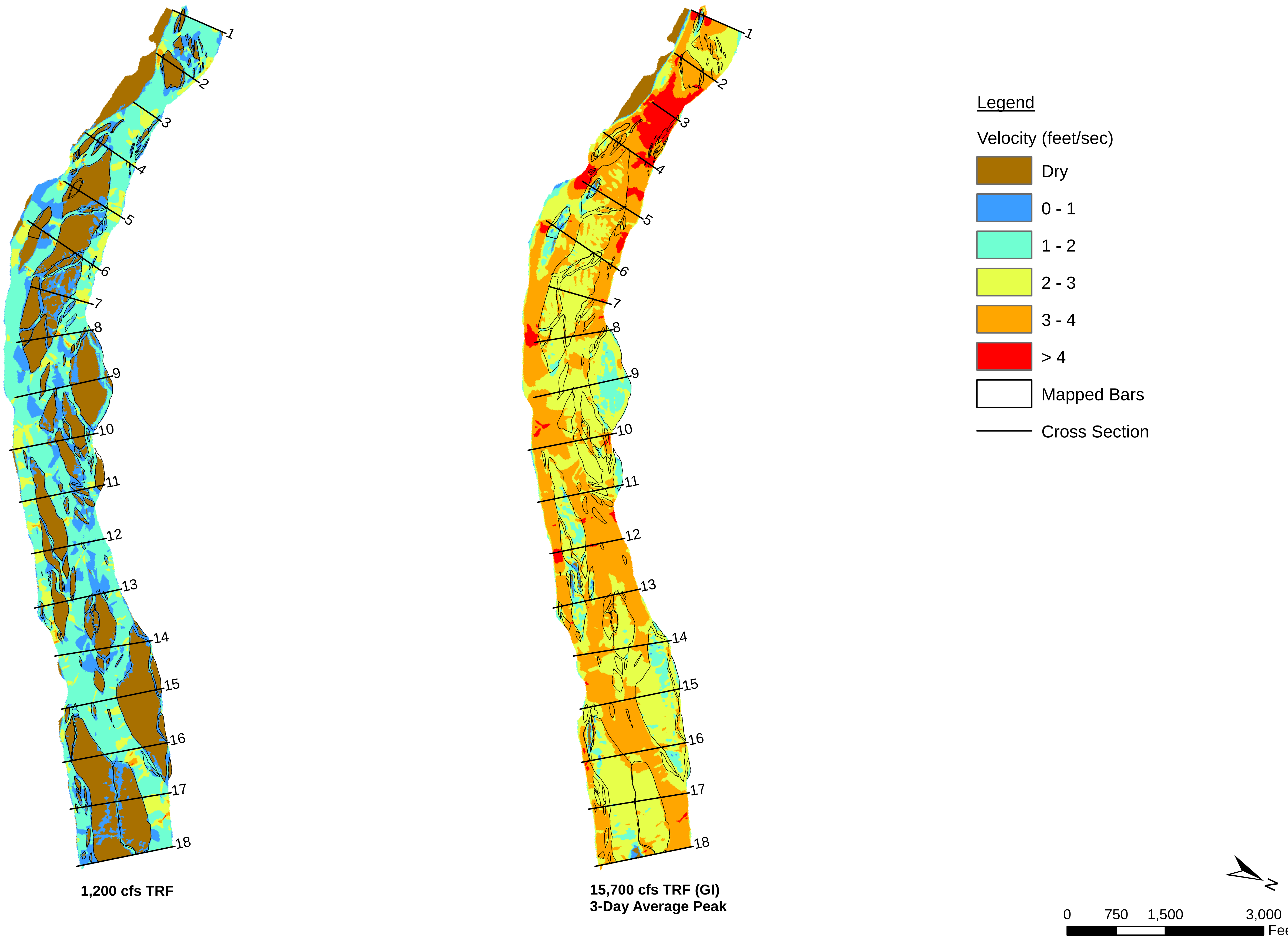
PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

FIGURE	1
DRAWING NO.	–
FILE NAME	–
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	AUG 2016
CHECKED BY	KMD
DRAWN BY	BP
DESIGNED BY	BP
PROJECT MGR.	DLB

Figure 2. Measured and Predicted Water Surface Elevation at 915 cfs TRF (750 cfs in Shoemaker Reach).




1,200 cfs TRF
15,700 cfs TRF (GI)
3-Day Average Peak
Legend
Cross Section
Bars
Water Surface Elevation (ft, NAVD88)
(clipped to processing boundary)
High : 1950
Low : 1925
Dry
0
750
1,500
3,000
Feet
N
FaSTMECH FIXED BED MODEL
RESULTS WATER SURFACE
ELEVATION JUNE 2015 HIGH FLOW
SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA
PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM
FIGURE 3
DRAWING NO. –
FILE NAME –
PROJECT NO. 1499201
SCALE AS SHOWN
DATE AUG 2016
CHECKED BY KMD
DRAWN BY BP
DESIGNED BY BP
PROJECT MGR. DLB



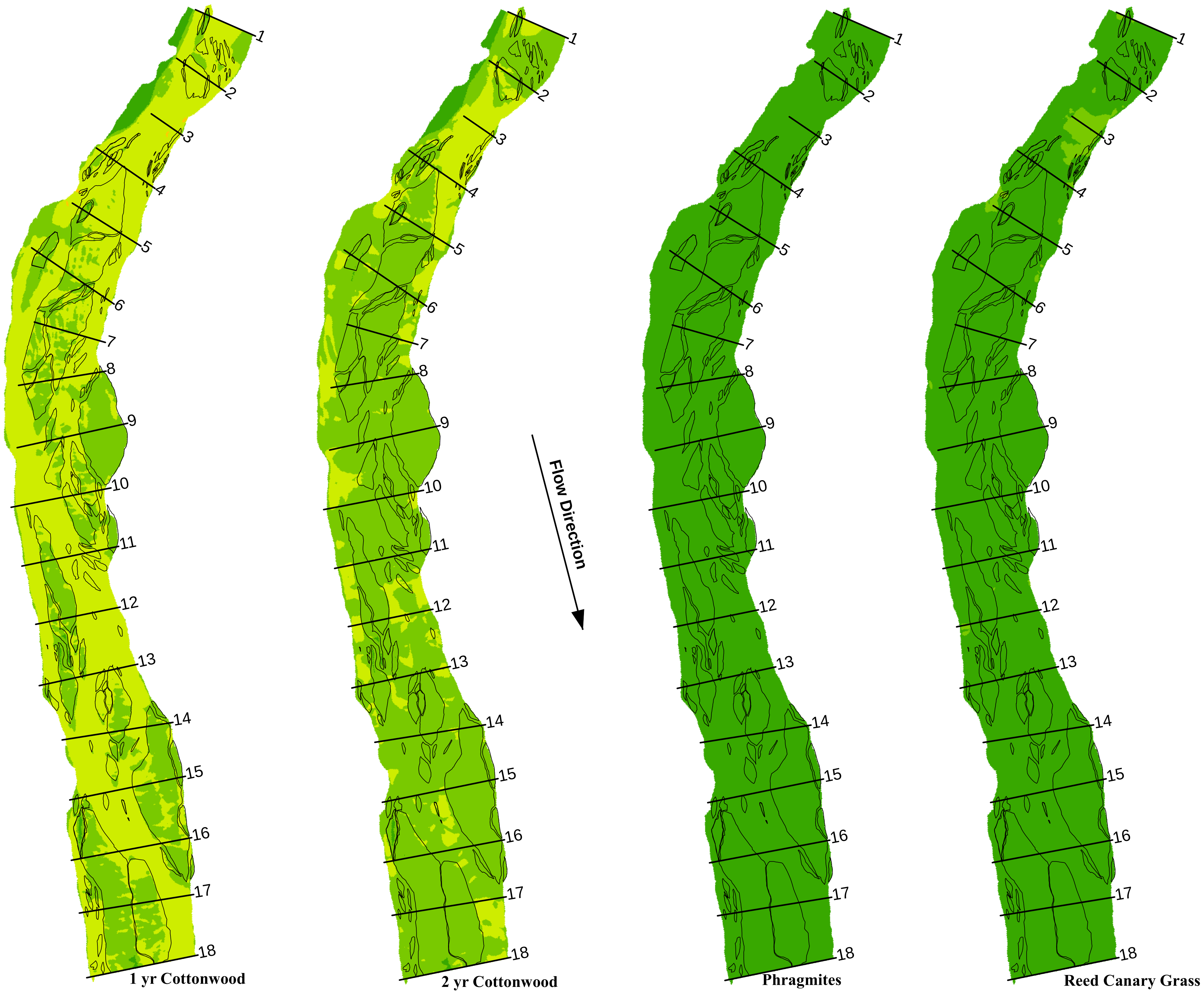
FaSTMECH FIXED BED MODEL RESULTS
VELOCITY JUNE 2015 HIGH FLOW

SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

FIGURE	4
DRAWING NO.	–
FILE NAME	–
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	AUG 2016
CHECKED BY	KMD
DRAWN BY	BP
DESIGNED BY	BP
PROJECT MGR.	DLB

2016-08-18 F:\State & Local\Other\Platte River Recovery Program\Projects\1499201 - Shoemaker FSM Proof of Concept\Figures\MXD\2015\Attachment I\MXD\Figure 4 - Velocity Predicted at 1,200 cfs TRF and 15,700 cfs TRF.mxd EA-Lincoln jpetersen



Legend

- Mapped Bars
- Cross-section

Velocity (feet/sec)

1-yr Cottonwood
- < 0.007 (no uprooting)
- 0.007 - 2.694 (uprooting initiated)
- 2.694 - 5.384
- 5.384 - 8.071
- 8.071 - 10.761
- > 10.761 (all plants uprooted)

2-yr Cottonwood
- < 0.023 (no uprooting)
- 0.023 - 3.507 (uprooting initiated)
- 3.507 - 8.15
- 8.15 - 15.262
- 15.262 - 20.341
- > 20.341 (all plants uprooted)

Phragmites
- < 34.777 (no uprooting)
- 34.777 - 43.389 (uprooting initiated)
- 43.389 - 52.001
- 52.001 - 60.614
- 60.614 - 69.226
- > 69.226 (all plants uprooted)

Reed Canarygrass
- < 4.396 (no uprooting)
- 4.396 - 10.509 (uprooting initiated)
- 10.509 - 16.617
- 16.617 - 22.73
- 22.730 - 28.839
- > 28.839 (all plants uprooted)

Velocities relating to the ability of drag forces to uproot patches of one-year old cottonwoods, two-year old cottonwoods, reed canarygrass, and phragmites. Velocity breaks are identical to research completed in the Elm Creek reach (Pollen-Bankhead et al., 2012), but are converted from meters/second to feet/second. Color scheme is consistent with Pollen-Bankhead et al, 2012 to facilitate direct visual comparisons. Velocities are from the June 2015 High Flow 3-day average peak flow (15,700 cfs TRF at Grand Island) FaSTMECH model.

0 750 1,500 3,000 Feet

N

FaSTMECH FIXED BED MODEL RESULTS
VELOCITY JUNE 2015 HIGH FLOW

SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

FIGURE	5
DRAWING NO.	–
FILE NAME	–
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	AUG 2016
CHECKED BY	KMD
DRAWN BY	BP
DESIGNED BY	BP
PROJECT MGR.	DLB

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment

Mobile Bed Modeling: Year 3

Attachment II

FINAL

March 2017

Submitted to:
Platte River Recovery Implementation Program
4111 4th Avenue, Suite 6
Kearney, NE 68845

Submitted by:
Northern Hydrology and Engineering
PO Box 2515
McKinleyville, CA 95519

Table of Contents

I. INTRODUCTION

Two mobile-bed models were developed for the Shoemaker Island reach of the Platte River to evaluate the response of channel morphology and vegetation patterns to a Short Duration High Flow (SDHF) release. The models were developed and calibrated to measured field data in Year 1 and 2 of the study (PRRIP, 2014 and PRRIP, 2015). The calibrated models are applied in Year 3 with a focused on informing following learning objectives:

1. Evaluate relationships between:
    a. Sediment supply and frequency of sandbar occurrence
    b. Grain size and sand bar height
    c. Hydrograph (magnitude and duration) and sand bar height

2. Evaluate the relationship between peak flows (magnitude and duration) and riparian plant mortality.

II. MODEL DEVELOPMENT

The two models applied in the first two years of the study (PRRIP 2013, 2014), were; FaSTMECH (Flow and Sediment Transport with Morphological Evolution of Channels) and EFDC (Environmental Fluid Dynamics Code). The same models were applied in the final year of the study.

FaSTMECH was developed by Dr. Jonathan Nelson of the U.S. Geological Survey (USGS) and is included within the free software package, IRIC (International River Interface Cooperative) available at http://i-ric.org/en/introduction. IRIC is a river flow and riverbed variation analysis software package which combines the functionality of MD_SWMS (Multi-Dimensional Surface Water Modeling System), developed by the USGS (U.S. Geological Survey), and RIC-NAYS2D, developed by the Foundation of Hokkaido River Disaster Prevention Research Center. FaSTMECH is a two-dimensional, vertically averaged model. FaSTMECH contains a sub-model that calculates the vertical distribution of the primary velocity as well as the secondary flow about the vertically averaged flow. The vertically averaged equations used in the computational solution are cast in a channel-fitted curvilinear coordinate system. The approach uses the assumptions that: (1) the flow is steady (or at least does not vary appreciably over short time scales), (2) the flow is hydrostatic (vertical accelerations are neglected), and (3) the turbulence can be treated adequately by relating Reynolds stresses to shear stresses using an isotropic eddy viscosity. Several sediment transport equations are included within the model interface. Development of the model equations is described in Nelson and Smith (1989), while the numerical techniques and the streamline-based vertical structure sub-model are discussed by Nelson and McDonald (1996). FaSTMECH has a long record of accurately predicting local flow conditions and morphological change in a variety of rivers (Andrews and Nelson, 1989; Lisle et al., 2000; Conaway and Moran, 2004; Barton et al., 2005). In addition, FaSTMECH differs from many other mobile-bed models by employing a quasi-steady approximation which enables predictions over longer time frames, finer grid resolutions and longer reaches.

Primary strengths of FaSTMECH based on PPRIP (2014):

- FaSTMECH utilizes a computation algorithm that significantly reduces computational time.
- Bed change over a hydrograph is simulated as a series of quasi-steady approximations which significantly reduces computational time.
- Sediment supply is computed at the model boundary with a transport equation, removing the requirement for sediment transport measurements. This feature is particularly useful in areas that do not have a sediment rating curve developed over the range of flows of interest, such as the Shoemaker Reach at the start of the study.
- Sediment supply can be increased or decreased at the model boundary by applying a multiplication factor. This feature allows efficient evaluation of the effects of increasing or decreasing sediment load into the reach (Learning Objective 1).
- Bed changes predicted by FaSTMECH appeared reasonable for the 2013 SDMF.

Primary limitations of FaSTMECH:

- Changes in the grain size distribution of the sediment supply cannot be specifically modeled because the grain size distribution is not specified, however, increases or decreases in the typical grain size can be modeled (Learning Objective 1).
- The grain size distribution of the bed is simplified into a single value. Processes related to variable grain size distributions (e.g. armoring) are not modeled.
- Grain size of the bed and sediment supply cannot be set to different values (e.g. a finer sediment supply cannot be modeled with a coarser initial bed).
- Sediment transport calculations are limited to total load (suspended load + bedload). Thus, direct comparisons with measured data, such as suspended sediment concentrations, cannot be made.
- Lateral erosion and bank collapse are not supported.

EFDC is an Environmental Protection Agency (EPA) supported modeling system for simulating three-dimensional, two-dimensional, or one-dimensional flow, transport and biogeochemical processes in surface waters including rivers, lakes, wetlands, estuaries, and coastal regions. The EFDC model internally links to cohesive and non-cohesive sediment transport sub-models. EFDC solves the three-dimensional (or two-dimensional), vertically hydrostatic, free surface, Reynolds averaged equations of motion for a variable-density fluid. EFDC uses a curvilinear-orthogonal grid in the horizontal domain and a sigma grid in the vertical. EFDC was originally developed at the Virginia Institute of Marine Science by Dr. John Hamrick (Hamrick, 1992), and full documentation of the EFDC model can be found in Tetra Tech (2007a, 2007b and 2007c). Proprietary pre- and post-processing software was used for EFDC model runs (EFDC_Explorer7.1, Craig, 2013).

Primary strengths of EFDC based on PPRIP (2014):

- Specification of sediment supply is user defined, thus, the grain size distribution of the sediment supply can be different than the grain size distribution of the bed material.
- Field measurements of stem diameter, density and height are used to calculate vegetated drag.

- Vegetation resistance is integrated into the momentum equations resulting in reductions to velocity, bed shear stress and diffusion in vegetated areas. Thus, shear stress is correctly partitioned when applying variable roughness due to vegetation.

Primary limitations of EFDC:

- Number of computation grid cells appears to be limited to roughly 100,000 for mobile bed modeling, limiting grid size to about 5-meters. This limitation may be related to our specific version and hardware combination.
- Computational time is limiting even for a relatively coarse model grid (~10-meters). Small time steps (0.2 to 0.4 seconds) are required for mobile-bed model runs. Using a multi-threaded version of EFDC, run times range from approximately 28 to 70 hours to complete depending on the simulation. Run times are likely two to three times longer using the public domain single-threaded version of EFDC.
- Lateral erosion and bank collapse are not supported.

II.A. Model Domain and Grid

EFDC was configured with a two-dimensional curvilinear orthogonal grid consisting of 27,128 grid cells, with an average grid cell measuring 30.05 x 31.48 feet (9.158 x 9.596 meters) in the x and y direction, respectively. The FaSTMECH model grid is curvilinear and grid cell widths are 9.8 feet (3 meters) with 378,873 grid cells. A finer grid resolution can be modeled with FaSTMECH due to the computation efficiency of the program. Differences in grid resolution between the 9.8 feet (3m) and 32.8 feet (10 meters) are shown in Figure 1. The coarser grid applied in EFDC retains the definition of the larger channels, but loses definition of the smaller bars that are defined at the 9.8 feet (3m) grid resolution applied in FaSTMECH.

II.B. Model Inputs

Mobile-bed models require the following inputs: flow at the upstream boundary, water surface elevation at the downstream boundary, topography, roughness, and grain size of the bed material. The level of detail required for specification of the bed material varies between models. Mobile-bed models vary in their requirements for specification of sediment supply. Some models do not require any specification of sediment supply (e.g. FaSTMECH), while others require detailed specifications of quantity and caliber of sediment delivered to the reach (e.g. EFDC). Models that do not require detailed specification rely on transport equations to estimate the incoming sediment supply. Mobile-bed models have more user-specified computational parameters, which slow the speed of the computations. Mobile-bed models employ different smoothing algorithms to predicted bed changes. Representation of the three-dimensional effects of secondary flows are critical for mobile-bed modeling. Input parameters related to the estimation of secondary flows vary between models. Some of these input parameters were adjusted during model calibration. Only the final calibrated or assumed model parameters and boundary condition adjustments are described herein.

II.B.1. Flow and Stage Boundary Conditions

Discharge magnitude is reported as “Total River Flow (TRF)” but the actual flow through the Shoemaker study site is typically around 80 percent of the TRF due to a flow split upstream (Table 1). A rating curve was applied for SDHF runs using paired measurements of stage and discharge during the 2015 high flow. Hydrographs for (1) SDMF 2013, (2) natural high flows in 2014 and (3) 2015, and (4) a hypothetical SDHF are provided in Figure 2.

II.B.2. Model Topography

The model topography is based on the pre-2014 High Flow topography. This data set was developed by combining November 2013 LiDAR, May 2014 ground surveys and estimates of bars that were constructed at the project site (Figure 3). Due to the more complete coverage, the LiDAR data set is used as the base topography, and the ground surveys are used to supplement LiDAR data where no data was captured (within the wetted channel).

LiDAR was flown on November 10, 2013. The average daily flow through the study reach was estimated to be 500 cfs (80% of daily mean discharge at USGS 06770200 Platte River near Kearney, Nebr.). LiDAR derived elevations matched surveyed elevations with sufficient accuracy and no adjustment to the LiDAR elevations was performed. LiDAR data was used in all areas that were dry during the LiDAR flight, except where bars were constructed by PRRIP. The LiDAR contractor provided hydro-breaklines which delineate the interface between water and dry land. Wet areas between these hydro-breaklines consisted of a hydro-flattened surface which approximates the water surface during the LiDAR flight.

Aerial imagery collected during the LiDAR flight indicated that the topography of wetted areas is complex and consist of various sized dunes of different wavelengths, deep areas near channel confluences, and bars of varying sizes and shapes. Ground surveys were used to estimate a simplified channel geometry in the inundated areas. The density of ground survey points varied spatially. Ground survey data consisted of longitudinal profiles through numerous major channels, cross section surveys, and bar topographic surveys, which included the top and toe of the bars. Numerous smaller channels had little to no survey data, while some larger channels were better defined.

In summary, the final model topography consisted primarily of a LiDAR derived digital elevation model (DEM). Within the wetted channel regions of the DEM, ground survey data was used to develop an approximation of the channel bed. The channel topography and constructed bars were added to the LiDAR DEM. This hybrid surface is referred to as “model topography”.

II.B.3. Bed Roughness and Vegetation Drag

The formulation of channel and floodplain roughness varies between models. Roughness was used as a calibration parameter in the fixed bed runs to match measured water surface elevations. Variable roughness due to grain size was not considered because there were not sufficient data to justify stratification. Roughness variation due to vegetation was not included in FaSTMECH model runs.

FaSTMECH utilizes a drag coefficient which was estimated using Manning's roughness coefficient (n), mean flow depth (h) and gravity (g) using the following relation (FaSTMECH Solver Manual):

$$C_d = \frac{n^2 g}{h^{1/3}}$$

The adjusted parameter for bottom friction in EFDC is the effective bed roughness height (Z_0). This value represents the total roughness due to skin friction and form drag, and is generally represented by bed physical properties. Based on the bed physical data described previously and literature values (Ji, 2008; Tetra Tech, 2007a and 2007b), a constant Z_0 value of 0.016 feet (0.005 meters) was used within the model domain.

Vegetation resistance formulation in EFDC was used (Moustafa and Hamrick, 2000) to account for frictional resistance effects on the flow field from the vegetated islands and floodplain. Data required to incorporate the EFDC vegetation resistance formulation includes plant density, stem diameter and stem height. Required input data for the vegetated islands were measured and consolidated into 11 vegetation community types by similar plant characteristics. The plant density, stem diameter and stem height of the 11 vegetation community types (Table 2) were then assigned to the model grid via vegetation polygons (Figure 4).

Following completion of the June 2014 model runs, an error was identified in the roughness parameters for bars that were inundated at high flows. The inundation of these surfaces is relatively shallow and the errors in the vegetation drag are not expected to substantially change the outcome of the larger scale sedimentation patterns.

II.B.4. Horizontal Eddy Viscosity and Diffusivity Coefficient

Horizontal eddy viscosity and diffusivity were set to zero for the EFDC simulations. It was assumed that the numerical diffusion associated with the EFDC model is likely similar in magnitude to realistic viscosity and diffusivity coefficients due to the fine grid resolution.

FaSTMECH requires an input of a lateral eddy viscosity. The lateral eddy viscosity (LEV) is a correction to the eddy viscosity used in the vertically averaged equations to treat lateral separation eddies. LEV can be estimated using the following equation:

LEV = 0.1 x average depth (meters) x average velocity (meters/second).

A reach-average value of 0.05 was estimated and applied.

II.B.5. Bed Material

Bed material samples collected throughout the study reach in May 2014 (n=22) were used to parametrize EFDC for the SDHF high flow model runs. A wide range of grain size distributions were measured throughout the reach; however, no systematic variations between bed material samples collected within the low flow channels and on higher bars were detected in the grain size analysis. Thus, the samples were composited into a single grain size distribution that was applied throughout the model domain (Figure 5).

Specification of variable grain size requires the gradation to be divided into size classes and the effective grain size in each class to be specified. Six sediment classes were defined for the EFDC model (Table 3): one cohesive class, and five non-cohesive classes. The effective diameters (d_{eff}) for each class were determined using the average of the weighted median, weighted geometric mean and weighted critical shear velocity methods based on the sediment grain size distributions, as described by Hayter (2006).

The EFDC bed was initially divided into 6 layers. Each layer has the same material properties (grain size distribution, porosity or void ratio and bulk density), but layer thickness varies (Table 4). The layer thickness can affect the tracking of the grain size changes at the surface and within the subsurface as sediment is removed or deposited within a layer. The top (parent) layer thickness (Layer 6) was defined by the thickness of the armor layer (when present) in field samples. Layers 5, 4, 3 and 2 are approximately the size of the bedforms that were observed to be in transport during the SDMF. The final layer (Layer 1) is substantially thicker to ensure that the scour depth did not exceed the bed thickness.

The applied porosity was 0.37, and the wet bulk density of the bed material was 127.3 lb/ft^3 (2039 kg/m^3) for all model runs.

II.B.6. Sediment Supply

FaSTMECH does not require users to specify the sediment supply. This model internally computes the sediment transport rate at the upstream boundary from the applied transport equation. The sediment transport rate at the boundary, thus sediment supply, can be adjusted within the model interface by multiplying the predicted rate by a factor. The model cannot accept user-specified sediment concentrations and gradations (e.g. field measurements). FaSTMECH uses a single grain size for sediment transport calculations.

EFDC requires a user-specified sediment supply at the upstream boundary. All sediment supplied (bedload and suspended load) is assigned as a suspended sediment concentration (SSC) for each of the user defined sediment classes (Figure 6). Grains that are too coarse to be carried in suspension at the model discharge fall to the bed and are deposited or transported as bedload. Data collection and computational methods to develop the sediment supply (concentrations) for 2015 are provided in the main report (PRRIP, 2017).

II.B.7. Sediment Transport

FaSTMECH has three sediment transport equations: Yalin (bedload equation), Engelund-Hansen (total load) and Wilcock-Kenworthy (two-fraction model). The Engelund-Hansen total load transport equation was selected as it is generally suitable for sand bed rivers. The total boundary shear stress applied in the sediment transport equation is calculated as a combination of skin friction and form drag. The form drag component can be defined using the physical characteristics of the dunes (sand dune height and wavelength). This option essentially reduces the applied shear stress to the bed that is used in the sediment transport calculation. A dune height of 3 feet was applied. A gravitational correction was applied using the pseudo-stress method with a submerged angle of repose set to 12 degrees.

EFDC has numerous sediment transport equations, parameters, and options that can be specified. Key sediment transport model parameters, applied values, and literature sources are provided in Table 5. Bed shear stress was separated into cohesive and non-cohesive fractions within the EFDC model. The Krone (1963) probability of deposition approach using the cohesive grain stress was used for cohesive suspended sediment transport within the EFDC model. The Van Rijn (1984) near-bed equilibrium concentration formulation was used for non-cohesive suspended sediment transport. Non-cohesive settling velocity, critical shear stress and critical Shields stress were determined internal to the EFDC model using the approach of Van Rijn (1984). The modified Engelund-Hansen bedload function (Wu, 2008) was used for non-cohesive bedload transport using default parameters. To reduce computation time, the bed morphology was updated every four time steps.

II.C. Model Calibration and Evaluation

Both mobile-bed models were compared to the measured water surface elevations and channel changes that occurred during the 2013 Short Duration Medium Flow (SDMF) and the June 2014 high flow. The results of the calibration and evaluations were initially reported in PRRIP (2014) and PRRIP (2015) and are summarized below.

FaSTMECH and EFDC were calibrated to the measured water surface elevations. FaSTMECH predicted water surface elevations a root mean square error (RMSE) of 0.18 feet when compared to measured values for higher flows (4366 -7200 cfs) (Figure 7). RMSE is higher for low flow with a value of 0.36 feet. There is a localized area of poor predictions which are likely due to poor representation of topography in the low flow channel. EFDC predictions have a mean bias of 0.30 feet for high flow (7200 cfs).

EFDC provided reasonable estimates of cut and fill for the fall 2013 high flow and excellent results for the June 2014 high flow (PRRIP, 2015). However, EFDC tended to predict the development of longer, deeper pools and a tendency toward incision over much of the reach for both the fall 2013 and June 2014 high flows. The tendency toward incision may be a result of a poor sediment supply boundary condition, inability to predict lateral erosion, or other physical processes governing sediment transport and barform evolution. Recognizable barforms that coalesced and migrated downstream were not predicted by the model. The lack of this type of barform development is likely due at least in part, to the size of the model grid (10 meters) and/or lack of other physical processes governing sediment transport and barform evolution.

FaSTMECH provided reasonable estimates of cut and fill during the June 2014 high flow, but predicted a net fill, rather than a minor net cut as measured. FaSTMECH predicted a bed profile that closely matched the scale of the measured bar forms and maintained the overall grade of the channel. Barforms within the wetted channel were formed over the course of the model run in a similar spatial scale and vertical amplitude to those observed from aerial photography (Figure 8), measured during the 2013 SDMF (PRRIP, 2014), and measured prior to the June 2014 high flow (PPRIP, 2015).

FaSTMECH also provided a reasonable estimate of the total bar area compared to measured values following the June 2014 high flow; however, the frequency of new bars and new bar area was under-predicted by FaSTMECH (PRRIP, 2015). This result is contrary to the initial hypothesis in 2013 that FaSTMECH may be over predicting bar formation. This change may be due to differences in post-processing model results of the 2013 SDMF and the June 2014 high flow or due to modifications to the June 2014 high flow model parameters. A gravitational correction factor was applied in the June 2014 high flow model run which resulted in the widespread formation of bar forms that migrated downstream. In the 2013 SDMF model run, recognizable barforms did not occur. In addition to the potential effects of changes to model parameters, the inability of FaSTMECH to laterally erode limits channel widening and new bar development within the widened channel. Examples of channel widening and new bar development (Figure 9) occurred in the middle treatment reach during the June 2014 high flow (PPRIP, 2015). Predicted bar height was generally within 0.5 feet of the measured values which is within the reported error of the LiDAR data.

Lateral erosion predictions conducted with BSTEM in PRRIP (2014) indicated that flow duration has a particularly strong effect on lateral erosion which is a known limitation of the mobile-bed models. Thus, the mobile-bed models used in this study (EFDC and FaSTMECH) are expected to perform better over shorter durations when lateral erosion has less of an effect on channel change.

III. ANALYSIS METHODOLOGY

Model runs in 2015 focused on estimating the channel response to SDHF and sensitivity to changes in hydrograph shape (magnitude and duration), grain size and sediment supply. The effect of hydrograph shape is analyzed using hydrographs that have the same volume of water (60,000 acre-feet), but have different peak magnitude and flow duration. A peak flow of 8,000 cfs, for 3-days is compared to a peak flow of 5,000 cfs for ~6.5 days using FaSTMECH. The effect of grain size is estimated using grain sizes of 0.75 mm, 1 mm, and 2 mm using FaSTMECH. The effect of sediment supply is estimated using twice the equilibrium sediment supply (2x), equilibrium sediment supply (1x), and half the equilibrium sediment supply (0.5x) using FaSTMECH. The effect of sediment supply is also estimated with EFDC using grain-size specific sediment rating curves derived from direct measurements at the project site using EFDC. Effects of these variables (sediment supply, grain size and hydrograph shape) are evaluated for:

1. Populations of all bars (sand and vegetated) following the SDHF. This analysis is intended to demonstrate reach wide effects on all bars (Figure 10).
2. Populations of sand bars following the SDHF. This analysis removes the influence of vegetated bars which may be less sensitive to the variables due to higher stability. The analysis is focused on the response of sand bars, which is the target bar type to meet biological objectives.
3. Populations of new sand bars. This analysis focuses on new sand bars created during the high flow, which are expected to be most responsive to changes in variables.

Bars are portions of the river channel that are higher than the 1,200 cfs TRF water level. Bar area is computed as the two-dimensional area of the bar surface. New bars are defined as bars that are present at the end of the event that were not present at the beginning of the event. No portion of a new bar may intersect any portion of a pre-existing (old) bar. New depositional areas that are adjacent to an existing bar are simply added to the pre-existing bar even if they do not share the same cover type. For example, if a sand bar is deposited at the toe of an existing vegetated bar, the new deposition will be reported as an increase in area of the vegetated bar. This methodology is equivalent to analyses conducted in the Year 2 (PRRIP, 2015), but differs from the Year 1 (PRRIP, 2014) report.

In FaSTMECH, bars are composed of 3-meter grid cells, while in EFDC bars are composed of 10-meter grid cells, thus the number of bars, particularly small bars, will vary due to model grid resolution.

Bar statistics are computed on a cell by cell basis, then averaged for each bar. Height at each grid cell is computed by subtracting the elevation of the cell from the predicted water surface elevation at 1,200 cfs TRF at the same location. Height is a positive value. Mean bar height is computed by averaging the height of all cells in each polygon. Mean bar height can change by changes to the bar such as: (1) direct erosion of an existing bar (e.g. vertical erosion), (2) deposition on top of an existing bar, and/or (3) deposition adjacent to the existing bar. Mean bar height may increase without deposition on the bar if lower areas of the bar are eroded. Mean bar height may decrease without erosion of the bar if deposition occurs that has a lower elevation than the rest of the bar.

The depth of each cell is computed by subtracting the predicted water level at the peak stage at each cell from the elevation of each cell. If the elevation of a cell is lower than the peak stage height the depth is recorded as a negative value, if the height is above the peak stage, depth is recorded as a positive number. Mean bar depth is computing by averaging the depth of all the cells within each polygon.

Each of the data sets (bar height and area) were tested for normality with the Shapiro–Wilk test. None of the data sets are normally distributed. Thus, a non-parametric test was applied to determine whether there was a statistical difference between bar height and bar area following the SDHF. Statistical tests were applied to "all bars" which include sand and vegetated bars, "sand bars" which excludes vegetated bars and "new bars" which were formed during the SDHF.

When two data sets were compared, Mann-Whitney-Wilcoxon test was applied and when three or more data sets were tested, Kruskal–Wallis test was applied. Both methods test whether samples originate from populations with the same distribution. The null hypothesis is that it is equally likely that a randomly selected value from one sample will be less than or greater than a randomly selected value from a second sample. The significance level is set at a p-value of 0.05.

All boxplots presented in this study were generated using R's default boxplot code, in which upper whisker lengths are extended to the maximum data value when no outliers present, or to the 75th percentile value plus 1.5 times the interquartile range when outliers present. Likewise, lower whisker lengths are extended the minimum data value when no outliers present, or to the 25th percentile value minus 1.5 times the interquartile range (when outliers present). The bottom of the box is the 25th percentile, the top of the box is the 75th percentile and the line through the box is the median (50th percentile).

IV. RESULTS AND DISCUSSION

The effects of hydrograph shape, bed material grain size and sediment supply on the bar frequency, height and area were evaluated for the hypothetical SDHF. A hydrograph with a 3-day peak of 8,000 cfs that contains ~60,000 acre-feet of water, a bed material grain size of 1 mm, and a sediment supply that is equivalent to an "equilibrium" supply is used as the basis for comparison of FaSTMECH runs. FaSTMECH is used to evaluate effects of hydrograph shape, bed material grain size and sediment supply.

The same hydrograph applied to the FaSTMECH runs is also used in the EFDC runs. Bed material grain size differs within the EFDC model because it is defined by multiple grain size classes which more closely matches the measured bed material. Grain size specific sediment rating curves developed from paired measurements of sediment concentrations and flow is used to define the sediment supply, rather than an equilibrium supply in EFDC. EFDC is only used to verify effect of sediment supply.

IV.A. Effect of a SDHF

A hypothetical SDHF with a peak flow of 8,000 cfs for 3 days with a total volume of water of ~60,000 acre-feet, a bed material grain size of 1 mm and a sediment supply equivalent to an "equilibrium" sediment supply is used as a basis for comparison for effects of hydrograph shape, grain size and sediment supply. This run is referred to as the "base case".

FaSTMECH predicted a total cut of 90,000 CY and fill of 94,000 CY with a net fill of 4,000 CY during the SDHF, indicating the reach is roughly at equilibrium (Table 6). The net fill is likely due to low relief bar formation on the otherwise plane bed channel present in the initial topography (Figure 8). The overall acreage of bars declined slightly from 175 acres before the SDHF to 169 acres after the SDHF.

The total number of bars decreased substantially from 303 bars before the SDHF to 177 bars following the SDHF (Figure 11). Bar frequency declined primarily due to direct erosion of very small bars or translation of these small bars far enough downstream that they did not intersect with the original bar location (126 bars), accounting for a total of 2.5 acres of change. Many bars merge with adjacent bars which accounts for the decline of an additional 35 bars. A statistically significant (p-value =0.04) increase in individual bar areas occurred due to erosion of the smaller bars and merging of adjacent bars (Table 7). Total new bar area was 0.9 acres following the 8,000 cfs SDHF. New bars were generally small. Only one bar was close to reaching the biological target of 0.25 acres.

A very small (<0.1 feet), but statistically significant (p-value=0.03), increase in mean bar height occurred following the SDHF. The maximum mean bar height of new bars was less than 0.6 feet (Figure 12 and Figure 13) which does not meet the biological objective of 1.5 feet.

IV.B. Effect of Hydrograph Shape on Bar Height and Area

The effect of hydrograph shape is evaluated using hydrographs that have the same volume of water (~60,000 acre-feet), but have different peak magnitude and flow duration. A peak flow of 8,000 cfs for 3days (base case) is compared to a peak flow of 5,000 cfs for ~6.5 days using FaSTMECH.

The SDHF hydrographs both produce a large amount of cut and fill throughout the study reach (Table 6). The 8,000 cfs hydrograph produces roughly 17% more cut and 19% more fill than the 5,000 cfs hydrograph. Both hydrographs result in a small net fill, which was likely due to low relief bar formation on the otherwise plane bed channel present in the initial topography as stated earlier.

The total number of bars increased by 3 following a 5,000 cfs SDHF compared to the 8,000 cfs SDHF (Figure 11). Total bar area decreases from 175 acres, to 166 acres and 169 acres, respectively, following a 5,000 cfs and 8,000 cfs TRF SDHF. The results of the statistical tests indicate there is not a statistically significant difference between populations of bar heights or bar areas due to the hydrograph shape of the SDHF (Table 7).

The difference in sand bar frequency following a 5,000 cfs and 8,000 cfs is small (140 bars following a 5,000 cfs peak flow versus 134 bars following an 8,000 cfs peak flow). While the median bar height appears slightly higher following an 8,000 cfs peak flow, the populations are not statistically different between the two flows (Figure 14 and Table 7)

The difference in number of new bars formed is minor, with 32 new bars formed following the 5,000 cfs SDHF and 30 bars formed following the 8,000 cfs SDHF. Total new bar area is 0.5 acres following the 5,000 cfs SDHF and 0.9 acres following the 8,000 cfs SDHF. New sand bars are less than 0.07 acres following the 5,000 cfs SDHF, and less than 0.23 acres following the 8,000 cfs SDHF (Figure 13 and Figure 14). In both cases, no bars met the biological target of 0.25 acres. Mean new sand bar heights are less than 0.5 foot above the 1,200 cfs water surface elevation for both hydrographs. These heights are substantially less than the biological target of 1.5 feet. Although there appears to be a tendency for higher bar heights and larger bar areas associated with a higher peak discharge, the populations are not statistically different (Table 7).

New bars are formed 0.4 to 1.7 feet below the peak stage with a median depth of 1.2 feet at 5,000 cfs, while bars that formed during the 8,000 cfs SDHF formed 0.6 to 2.3 feet below the peak stage with a median value of 1.7 feet (Figure 15).

New bars formed during the 5,000 cfs and 8,000 cfs TRF SDHF were all lower and smaller than needed to achieve biological objectives of 0.25 acres and 1.5 feet above the 1,200 cfs TRF water level. Overall, bars on the reach scale did not change substantially with a single SDHF. It is possible that multiple events could produce a statistically significant difference in bar height and area, however; the results of the field study indicate the potential differences are relatively small. Hydrographs within the range of the target SDHF do not appear to be sufficient to achieve biological objectives.

IV.C. Effect of Sediment Supply on Bar Frequency

The effect of sediment supply on bar frequency was evaluated with FaSTMECH and EFDC during a SDHF with a peak flow of 8,000 cfs TRF for 3 days. Sediment supply was doubled and reduced by half compared to the base case. Sediment supply was adjusted in FaSTMECH by modifying the equilibrium sediment supply and in EFDC by modifying the measured sediment concentrations.

Both models predicted negligible changes to bar frequency, height, and area in response to a change in the upstream sediment supply during one SDHF. FaSTMECH predicted a difference of 1 bar between the cases of half and double the equilibrium supply during a SDHF (Figure 16) and a difference of 4 bars across all cases for sand bars and new sand bars (Figure 17 and Figure 18). Some small differences occur in the total area of bars, lower sediment supply resulting in slightly more new bar area and higher bars (Figure 19 and Figure 20), but these difference are not statistically significant (Table 8).

The most significant changes occurred at the project boundary in EFDC, which resulted in accumulations of sediment in the form of a delta as observed in previous years' model predictions (PRRIP, 2014, 2015). These sediment accumulations were localized and did not translate through the project reach during the SDHF. A significantly longer duration simulation is likely necessary to observe the long-term impacts of changes in sediment supply.

IV.D. Effect of Grain Size on Bar Height and Area

The effect of bed material grain size on bar height and area was evaluated with FaSTMECH during a SDHF with a peak flow of 8,000 cfs TRF for 3 days. Bed material grain sizes of 0.75 mm, 1 mm (base case) and 2 mm were evaluated.

Bed material grain size affects the predicted amount of scour and fill, total number of bars, number of new bars and bar area. Reducing the bed material size from 1 mm to 0.75 mm increases cut by 22% and fill by 21%. Coarsening the bed material from 1 mm to 2 mm decreases cut by 42% and fill by 40% (Table 6).

The total number of bars decreases substantially from the initial condition of 303 bars to 177 bars following an 8,000 cfs TRF SDHF for the base case (grain size = 1 mm). As discussed in the previous section, bar frequency declines due to merging of bars, erosion of smaller bars or downstream translation of bars. The decline in bar frequency for finer bed material (0.75 mm) is less pronounced (a reduction from 303 bars to 215 bars), but there is not a clear trend associated with increasing grain size (Figure 21). In the case of the finer grain size (0.75 mm), the erosion of smaller bars appears to be somewhat offset by new bar development and a more active bed. As grain size is increased, the bed is less active and the higher bar frequency of bars in the coarser bed (188 versus 177) may be a result of a less active bed that resulted in less erosion of the smaller bars.

Total bar area decreases from 175 acres to 169 acres with a bed material grain size of 1 mm. Decreasing the grain size to 0.75 mm results in a bar area of 173 acres, and increasing the grain size to 2 mm results in a decline in bar area to 166 acres. Thus, greater total bar areas result with finer grain sizes, with a total difference in bar area of about 4%.

The populations of average bar height and bar area for all bars (sand bars and vegetated bars), for sand bars with grain sizes ranging between 0.75 and 2mm, are not statistically different (Figure 21, Figure 22, and Table 9)

The number of new bars formed during the SDHF is substantially larger with a finer grain size (74 new bars with a 0.75 mm grain size versus only 9 new bars with a 2 mm grain size) (Figure 23). Total new bar area also increases with finer grain size (1.7 acres for 0.75 mm, 0.89 acres for 1 mm, 0.12 acres for 2 mm grain size) (Figure 24). However, these differences in total area are quite small relative to the total bar area in the project site, representing a change of less than 1% of the total bar area. There appears to be a trend of higher and larger bars with decreasing grain size (Figure 23, Figure 24, and Figure 25); however, the differences between the populations are not statistically significant (Table 8).

In all grain size cases, none of the bars met the biological target of 0.25 acres; however, one bar nearly met the target at 0.23 acres (0.75-mm grain size). Similarly, none of the bars met the height target of 1.5 feet above the 1,200 cfs water level for 1 mm and 2 mm grain size, and only one bar exceeded an average height of 1.5 feet when the bed material was 0.75 mm (Figure 24). Generally, average heights of bars were substantially lower than the target heights, with median heights of 0.1 feet or less.

While grain size appears to have an important effect on sediment transport, reflected in the total cut and fill that occurred throughout the project site and bar frequency, it does not appear to have a significant impact on bar height area during one SDHF.

IV.E. Potential for Vertical Erosion of Vegetated Bars

The potential for riparian plant mortality by drag forces and vertical scour across bars was evaluated in Attachment I. The mobile-bed predictions are generally lower than the empirical relation (fixed-bed model) because the fixed-bed results represent “scour potential” or the maximum scour observed for a given shear stress during the study period. Mobile-bed predictions are generally lower than the “maximum” scour potential because shear stress is only one factor that contributes to scour in the mobile bed model. Transport from each cell is computed based on an empirical equation (Engelund-Hansen) that is a function of shear stress and a friction factor. The mobile-bed model performs a mass balance calculation between the amount of sediment entering a cell (from upstream cells) and the amount of sediment exiting the cell. If the amount of incoming sediment is less than the amount of sediment transported out of the cell, scour occurs. If the amount of incoming sediment is more than the amount of sediment transported out of the cell, fill occurs. Thus, for any given shear stress the mobile-bed model may predict scour, fill or no change, depending on the amount of sediment delivered from an upstream cell(s).

The results of both analyses (fixed-bed and mobile-bed) indicated that the potential for vertical scour of deeply rooted vegetation is low. Most of the bar area has predicted scour depths of less than 1 foot (Figure 26) and median values are well below 0.5 feet.

V. CONCLUSIONS/SUMMARY

The results of the mobile-bed modeling analysis indicate that SDHF events are not likely to create bars with sufficient height or areas to achieve biological objectives. While there were differences in sediment transport (cut/fill) and total number of bars formed, the relative changes in bar area and height during a SDHF were minor. Differences in peak magnitude (5,000 cfs - 8,000 cfs) and duration of peak flow (3 - 6.5 days), grain size (0.5, 1 mm, 2 mm) and sediment supply changes (0.5 – 2x sediment supply) did not produce statistically significant changes in the bar forms created during the SDHF. These results are limited to the effect of one SDHF event. It is possible that some of these parameters may have a long-term effect that was not captured during this study. The conclusion from the modeling exercise is consistent with field measurements of barform changes following a short duration medium flow and three distinct high flow events (Fall 2013, June 2014 and June 2015) that met or exceeded the target volume, peak flow magnitude and duration for a SDHF.

The mobile-bed analysis also supports conclusions from the fixed-bed analysis (Attachment I) that the potential for widespread scour of deeply rooted riparian plants during a SDHF is low.

VI. RECOMMENDATIONS FOR FUTURE WORK

- The results in this study are focused on the effects of a single SDHF. The variables (grain size, hydrograph shape and sediment supply) did not have a statistically significant effect on barform height and area. However, longer duration flows and/or multiple events may produce measurable differences, particularly with respect to sediment supply. Increasing sediment supply at the model boundary produced localized effects that were not translated through the model domain over the course of a single SDHF.
- The integration of a coupled bed mobility and lateral erosion model is essential for predicting channel response during longer duration runs when lateral erosion is expected

to create significant changes to bar forms. While a suitable model has not been identified to date, new models that integrate these capabilities should be explored as the field of bed evolution modeling advances.

- Barforms in the low flow channels were excluded from the initial model topography due to the limitations of the LiDAR data in wet areas, as discussed in the Model Topography Section. Improved topography within the wetted channel would likely improve model results and should be explored as LiDAR or other similar technologies advance.

VII. REFERENCES

Andrews, E. D., and J. M. Nelson, 1989. Topographic response of a bar in the Green River, Utah to variation in discharge, in River Meandering, Water Resour. Monogr. Ser., vol. 12, edited by S. Ikeda and G. Parker, pp. 463 – 485, AGU, Washington, D. C.

Barton, G. J., R. R. McDonald, J. M. Nelson, and R. L. Dinehart, 2005. Simulation of flow and sediment mobility using a multidimensional flow model for the white sturgeon critical-habitat reach, Kootenai River near Bonners Ferry, Idaho, U.S. Geol. Surv. Sci. Invest. Rep., 2005-5230, 64 pp.

Conaway, J. S., and E. H. Moran, 2004. Development and calibration of a two-dimensional hydrodynamic model of the Tanana River near Tok, Alaska, U.S. Geol. Surv. Open File Rep., 1225, 22 pp.

Craig, Paul M. 2013. User's Manual for EFDC_Explorer7.1: A Pre/Post Processor for the Environmental Fluid Dynamics Code (Rev 00). Dynamic Solutions-International, LLC, Knoxville, TN. June, 2013.

Engelund, F. and Hansen, E., 1967. A Monograph on Sediment Transport in Alluvial Streams. Danish Technical (Teknisk Forlag).

Hamrick, J.M. 1992. A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects. The College of William and Mary, Virginia Institute of Marine Science, Special Report 317.

Hayter, E.J. 2006. Evaluation of the State-of-the-Art Contaminated Sediment Transport and Fate Modeling System. U.S. Environmental Protection Agency, Ecosystems Research Division, Athens, GA. EPA/600/R-06/108.

Ji, Z. G. 2008. Hydrodynamics and Water Quality, Modeling Rivers, Lakes, and Estuaries. John Wiley & Sons, Inc., Hoboken, New Jersey.

Krone, R.B. 1963. A Study of the Rheologic Properties of Estuarial Sediments. SERL Report No. 63-8, Hydraulic Engineering Laboratory and Sanitary Engineering Research Laboratory, University of California, Berkeley.

Lisle, T. E., J. M. Nelson, J. Pitlick, M. A. Madej, and B. L. Barkett, 2000. Variability of bed mobility in natural, gravel-bed channels and adjustments to sediment load at local and reach scales, Water Resour. Res., 36, 3743– 3755, doi:10.1029/2000WR900238.

Moustafa, M.Z. and J.M. Hamrick. 2000. Calibration of the wetland hydrodynamic model to the Everglades nutrient removal project. Water Quality and Ecosystem Modeling, 1, 141-167.

Nelson, J. M., and J. D. Smith, 1989. Flow in meandering channels with natural topography, in River Meandering, Water Resour. Monogr. Ser., vol. 12, edited by S. Ikeda and G. Parker, pp. 69– 102, AGU, Washington, D. C.

Nelson, J. M., and R. M. McDonald, 1996. Mechanics and modeling of flow and bed evolution in lateral separation eddies, report, Grand Canyon Environ. Stud., Flagstaff, Ariz.

NHE, 2014b. Attachment III: One-Dimensional Bank Erosion Analysis. Technical Memorandum. Shoemaker Island Flow-Sediment-Mechanical “Proof-of-Concept” Experiment. March 2014.

Northern Hydrology and Engineering (NHE), 2014a. Attachment II: Fixed Bed Modeling. Technical Memorandum. Shoemaker Island Flow-Sediment-Mechanical “Proof-of-Concept” Experiment. March 2014.

Platte River Recovery Implementation Program (PRRIP), 2014. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment Annual Summary Report for 2013. April 2014.

PRRIP, 2015. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment Annual Summary Report for 2014. December 2015.

PRRIP, 2017. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment Annual Report for 2015. March 2017.

Tetra Tech. 2007a. The Environmental Fluid Dynamics Code, User Manual, USEPA Version 1.01. Tetra Tech, Inc., Fairfax, VA.

Tetra Tech. 2007b. The Environmental Fluid Dynamics Code, Theory and Computation, Volume 2: Sediment and Contaminant Transport and Fate. Tetra Tech, Inc., Fairfax, VA.

Tetra Tech. 2007c. The Environmental Fluid Dynamics Code, Theory and Computation, Volume 3: Water Quality Module. Tetra Tech, Inc., Fairfax, VA.

van Rijn, L.C., 1984. Sediment transport, part II: suspended sediment load transport, J. Hydr. Engr., ASCE, 110(11): 1613-1638.

Wilcock P.R., and S. T. Kenworthy, 2002. A two-fraction model for the transport of sand/gravel mixtures, Water Resour. Res., 38(10), 1194, doi:10.1029/2001WR00684.

Wu, W. 2008. Computational River Dynamics. Taylor & Francis 494p.

Yalin, M. S. 1963: An expression for bed-load transportation. J. Hydraul. Eng., ASCE, 89, 3, 221-250.

TABLES AND FIGURES

Table 1. Flow characteristic of high flow events relative to target Short Duration High Flow (SDHF)

Model Run	Total Platte River Flow (cfs)		Estimate of Shoemaker Reach Flow (cfs)
	Grand Island USGS Gage	Kearney USGS Gage	
Fall 2013			
3-day Average Peak Flow	9,700	12,100	8,950
Peak Flow	10,600	13,100	10,700
June 2014			
3-day Average Peak Flow	7,320	6,420	5,580
Peak Flow	8,800	6,730	6,280
Target SDHF			
3-day Average Peak Flow	5000-8000	5000-8000	~4000-6400

Table 2. Vegetation community type and physical characteristics used in the EFDC model for the Platte River Shoemaker Reach for the SDHF high flow event

Vegetation Type	Number of Bars	Average Density (stems/sq m)	Average Diameter (mm)	Average Height (cm)
1	Open Water	-	-	-
2	1	0.7	7.1	86.0
3	0	-	-	-
4	2	7.1	8.1	92.0
5	2	13.1	8.7	175.5
6	12	21.7	8.0	56.8
7	3	20.4	8.6	146.0
8	0	-	-	-
9	4	30.7	11.6	164.0
10	16	40.3	8.3	103.1
11	1	62.3	9.4	159.0
12	13	66.3	7.2	100.2
13	4	67.1	5.4	94.3
14	0	-	-	-

Table 3. Sediment particle size classes used in the June 2014 high flow EFDC sediment transport model for the Platte River Shoemaker reach

Sediment Classes	Particle Size Range (mm)	Effective Diameter (mm)			
		Weighted Median	Weighted Geometric Mean	Weighted Critical Shear Velocity	Value used in EFDC Model
Cohesive 1 (coarse silt to very fine clay)	$0.004 < d_{eff} \leq 0.0625$	-	-	-	0.016
Non-Cohesive 1 (fine to very fine sand)	$0.0625 < d_{eff} \leq 0.25$	0.175	0.175	0.176	0.175
Non-Cohesive 2 (medium sand)	$0.25 < d_{eff} \leq 0.5$	0.354	0.354	0.353	0.353
Non-Cohesive 3 (coarse sand)	$0.5 < d_{eff} \leq 1$	0.713	0.705	0.715	0.711
Non-Cohesive 4 (very coarse sand)	$1 < d_{eff} \leq 2$	1.414	1.414	1.414	1.414
Non-Cohesive 5 (medium to very fine gravel)	$2 < d_{eff} \leq 16$	3.852	3.502	3.762	3.705

Table 4. Sediment bed initial conditions used in SDHF EFDC sediment transport model for the Platte River Shoemaker Island Reach

Sediment Bed Parameter	Sediment Bed Layers					
	Layer 6 (a)	Layer 5 (b)	Layer 4 (b)	Layer 3 (b)	Layer 2 (b)	Layer 1 (c)
Thickness (ft)	0.066	1.58	1.64	1.64	1.64	6.56
Cohesive 1 (%)	0	0	0	0	0	0
Non-Cohesive 1 (%)	9	9	9	9	9	9
Non-Cohesive 2 (%)	32.3	32.3	32.3	32.3	32.3	32.3
Non-Cohesive 3 (%)	29.5	29.5	29.5	29.5	29.5	29.5
Non-Cohesive 4 (%)	16.4	16.4	16.4	16.4	16.4	16.4
Non-Cohesive 5 (%)	12.8	12.8	12.8	12.8	12.8	12.8
Wet Bulk Density (lb/ft^3)	127.3	127.3	127.3	127.3	127.3	127.3
Porosity (%)	37	37	37	37	37	37

(a) top layer
(b) subsurface layer
(c) bottom layer

Table 5. Key parameters and EFDC model options used in the SDHF sediment transport model for the Platte River Shoemaker Island reach

Model Parameter/Option	Value/Description	Source
Suspended sediment anti-diffusion correction	On	EFDC option
Suspended sediment flux limitation correction	Off	EFDC option
Maximum sediment bed layer thickness before new layer added to sediment bed model	1.64 ft (0.5 m)	EFDC option, estimate
Non-cohesive roughness grain size for stress separation	d_{90}	EFDC option, estimate
Cohesive 1 settling velocity	3.3E-05 ft/s (0.00001 m/s)	Estimated from range of literature values (Ji 2008, Tetra Tech 2007b)
Cohesive 1 critical shear stress for deposition	0.01 N/m^2	Estimated from range of literature values (Ji 2008, Tetra Tech 2007b)
Cohesive 1 critical shear stress for erosion	0.012 N/m^2	Estimated from range of literature values (Ji 2008, Tetra Tech 2007b)
Reference surface erosion rate	2.04E-05 $lb/ft^2/s$ (0.1 $g/m^2/s$)	Calibrated within range of literature values (Ji 2008, Tetra Tech 2007b)
Constant bed porosity (θ) for depositing non-cohesive sediment (%)	37	Estimated from sediment bed samples
Void ratio (ε) of depositing cohesive sediment	0.587	Estimated based on bed porosity by equation: $\varepsilon = \theta/(1-\theta)$
Non-cohesive bed armoring with active-parent layer (top layer) constant thickness	0.066 ft (0.02 m)	EFDC option, thickness based on sediment bed field observations
Maximum adverse slope for bedload transport	0.1	EFDC option, estimated
Number of time steps to allow bed elevation change	4	EFDC option, estimated

Table 6. Cut and fill volumes for SDHF simulations

Flow	Grain Size	Sediment Supply	Cut (CY)	Fill (CY)	Net (CY)	
Hydrograph Shape						
8,000 cfs (TRF)	1 mm	Equilibrium	-90,000	94,000	4,000	Fill
5,000 cfs (TRF)	1 mm	Equilibrium	-77,000	79,000	2,000	Fill
Grain Size						
8,000 cfs (TRF)	0.75 mm	Equilibrium	-110,000	114,000	4,000	Fill
8,000 cfs (TRF)	1 mm	Equilibrium	-90,000	94,000	4,000	Fill
8,000 cfs (TRF)	2 mm	Equilibrium	-52,000	56,000	4,000	Fill
Sediment Supply						
8,000 cfs (TRF)	1 mm	0.5x Equilibrium	-89,000	93,000	4,000	Fill
8,000 cfs (TRF)	1 mm	Equilibrium	-90,000	94,000	4,000	Fill
8,000 cfs (TRF)	1 mm	2x Equilibrium	-90,000	94,000	4,000	Fill

Table 7. Results of statistical tests that test differences in populations of sand bar heights and areas resulting from a change in hydrograph shape of a SDHF

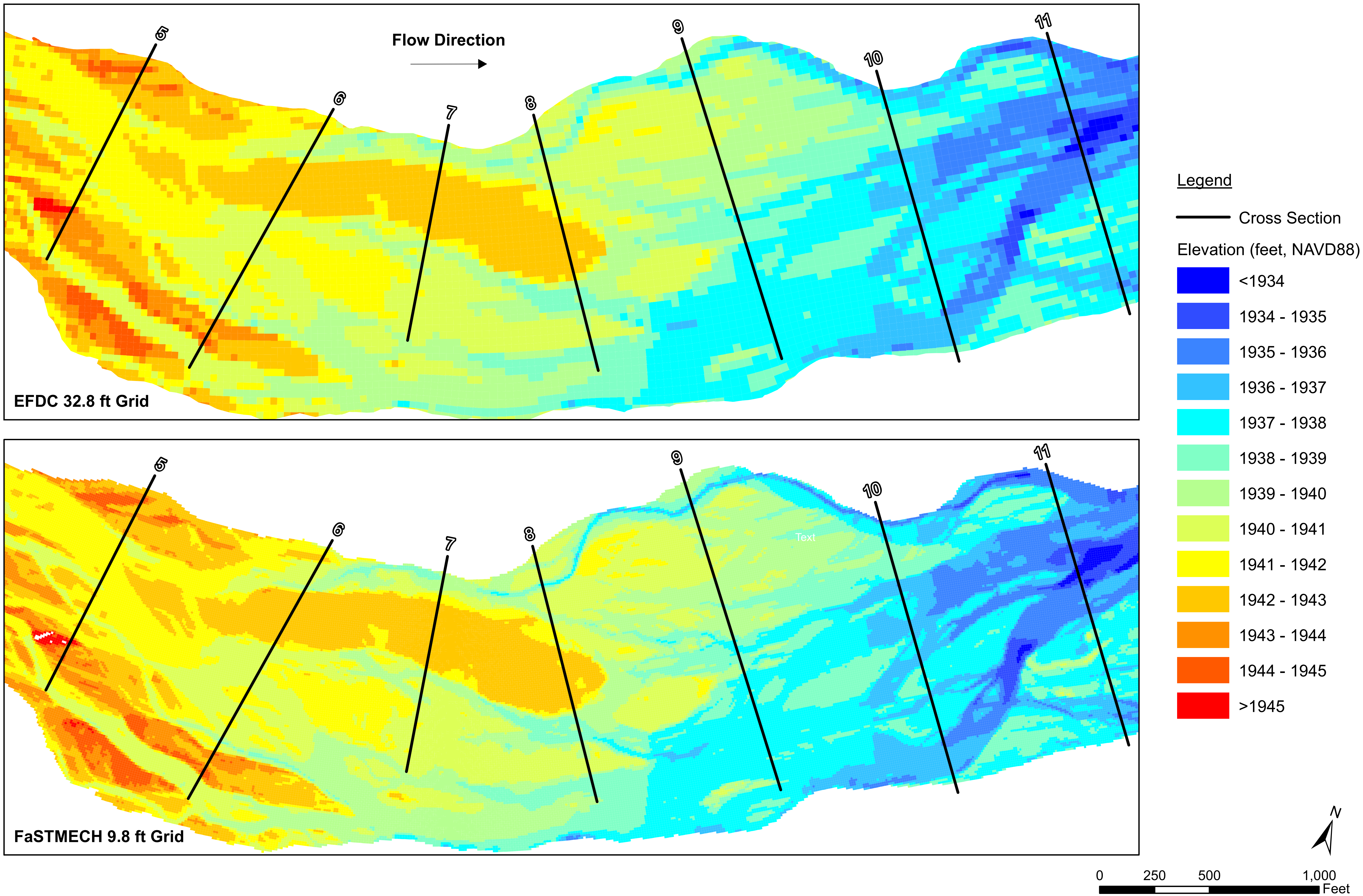
Data Sets	Null Hypothesis	Test Used	p-value	Interpretation
All bars (sand and veg) present at the end of the 8,000 cfs and 5,000 cfs SDHF	All bar heights (sand and veg) are equal	Wilcoxon	0.33	No significant difference
	All bar areas (sand and veg) are equal	Wilcoxon	0.42	No significant difference
Sand bars present at the end of the 8,000 cfs and 5,000 cfs SDHF	New sand bar heights are equal	Wilcoxon	0.37	No significant difference
	New sand bar areas are equal	Wilcoxon	0.33	No significant difference
New sand bars present at the end of the 8,000 cfs and 5,000 cfs SDHF	New sand bar heights are equal	Wilcoxon	0.20	No significant difference
	New sand bar areas are equal	Wilcoxon	0.68	No significant difference

Table 8. Results of statistical tests that test differences in populations of sand bar heights and areas resulting from a change in sediment supply

Data Sets	Null Hypothesis	Test Used	p-value	Interpretation
All bars (sand and veg) present at the end of the SDHF with sediment supply equal to 2x equilibrium, equilibrium and ½ equilibrium.	All bar heights (sand and veg) are equal	Kruskal-Wallis	0.68	No significant difference
	All bar areas (sand and veg) are equal	Kruskal-Wallis	0.99	No significant difference
Sand bars present at the end of the SDHF with sediment supply equal to 2x equilibrium, equilibrium and ½ equilibrium.	All sand bar heights are equal	Kruskal-Wallis	0.66	No significant difference
	All sand bar areas are equal	Kruskal-Wallis	0.92	No significant difference
New sand bars present at the end of the SDHF with sediment supply equal to 2x equilibrium, equilibrium and ½ equilibrium.	New sand bar heights are equal	Kruskal-Wallis	0.65	No significant difference
	New sand bar areas are equal	Kruskal-Wallis	0.97	No significant difference

Table 9. Results of statistical tests that test differences in populations of sand bar heights and areas resulting from a change in the grain size of the bed material

Data Sets	Null Hypothesis	Test Used	p-value	Interpretation
All bars (sand and veg) present at the end of the SDHF with bed material grain sizes of: 0.75 mm, 1mm and 2mm	All bar heights (sand and veg) are equal	Kruskal-Wallis	0.23	No significant difference
	All bar areas (sand and veg) are equal	Kruskal-Wallis	0.51	No significant difference
Sand bars present at the end of the SDHF with bed material grain sizes of: 0.75mm, 1mm and 2mm	All sand bar heights are equal	Kruskal-Wallis	0.20	No significant difference
	All sand bar areas are equal	Kruskal-Wallis	0.36	No significant difference
New sand bars present at the end of the SDHF with bed material grain sizes of: 0.75mm, 1mm and 2mm	New sand bar heights are equal	Kruskal-Wallis	0.31	No significant difference
	New sand bar areas are equal	Kruskal-Wallis	0.19	No significant difference



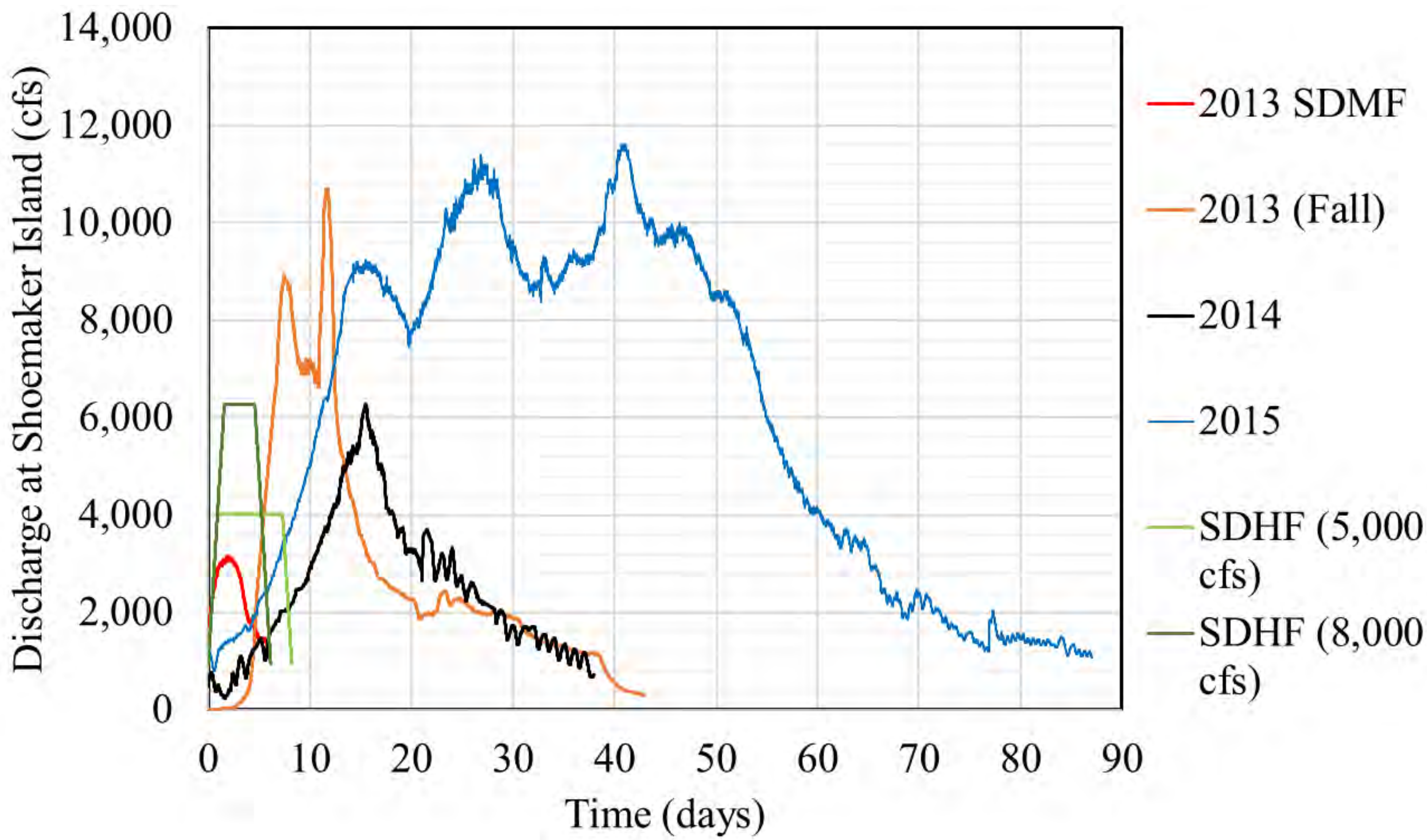
COMPARISON OF MODEL TOPOGRAPHY FOR VARIOUS GRID CELL SIZES

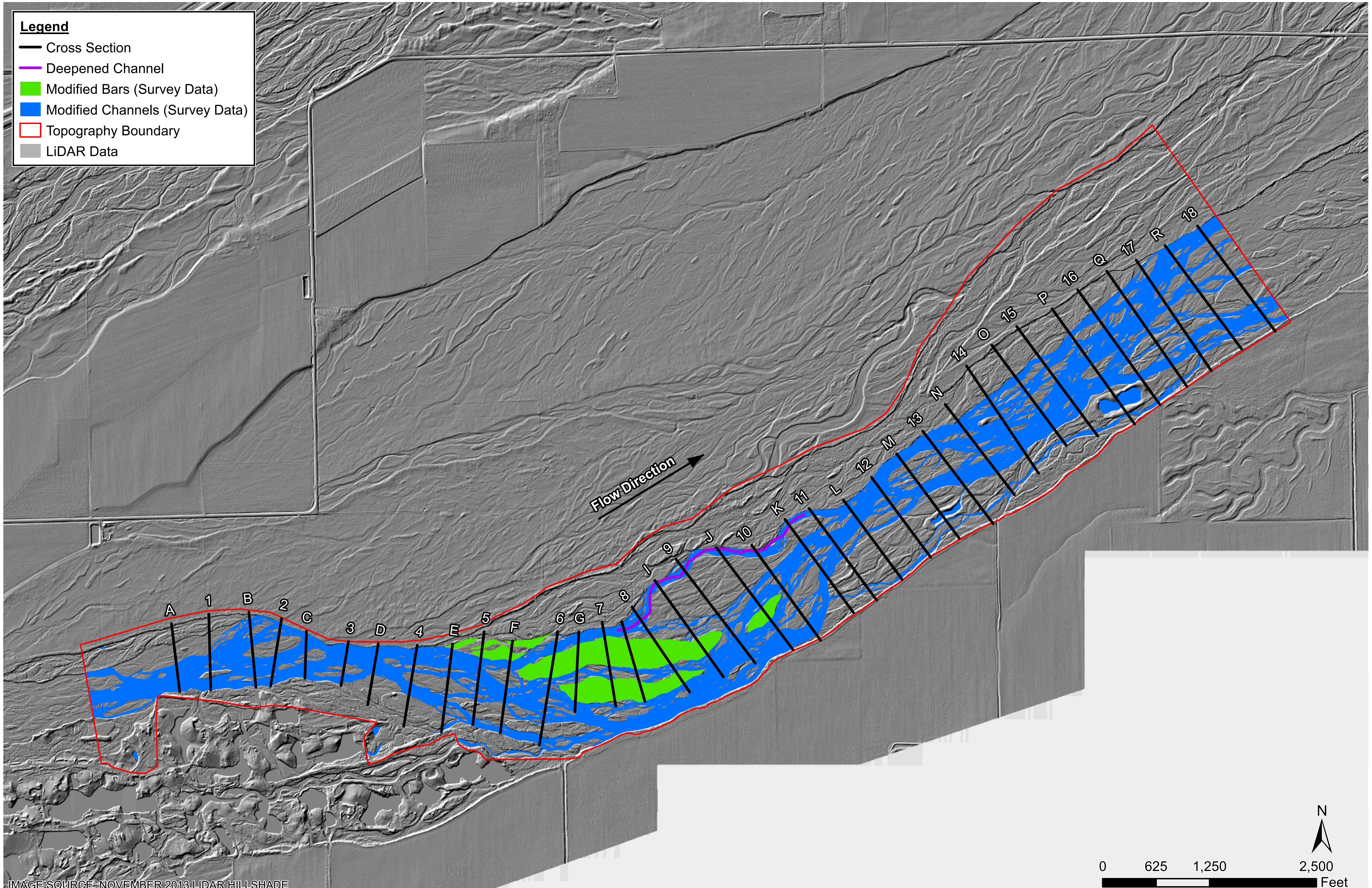
SHOEMAKER ISLAND FSM PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

FIGURE	1
DRAWING NO.	-
FILE NAME	-
PROJECT NO.	1499201
SCALE	AS SHOWN
DATE	JAN 2017
CHECKED BY	KMD
DRAWN BY	BP
DESIGNED BY	BP
PROJECT MGR.	DLB

Figure 2. **Observed and simulated hydrographs (2013-2015)**



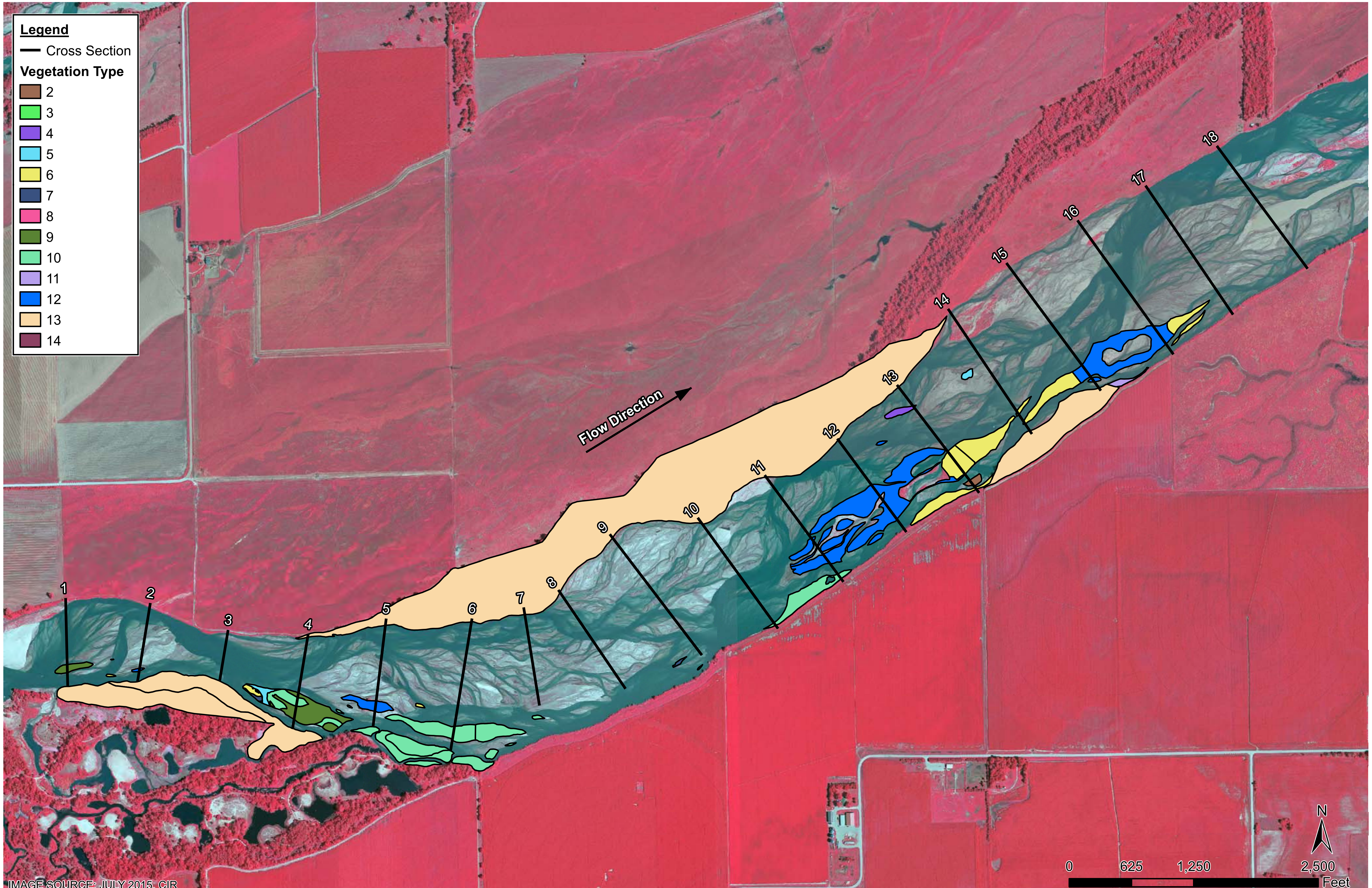


JUNE 2014 HIGH FLOW
MODEL TOPOGRAPHY

SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

FIGURE	DRAWING NO.	FILE NAME	PROJECT NO.	SCALE	DATE	CHECKED BY	DRAWN BY	DESIGNED BY	PROJECT MGR.
3	-	-	1499201	AS SHOWN	JAN 2017	KMD	BP	BP	DLB



EFDC MOBILE BED VEGETATION TYPES

SHOEMAKER ISLAND FSM
PROOF OF CONCEPT
HALL COUNTY, NEBRASKA

PLATTE RIVER RECOVERY
IMPLEMENTATION PROGRAM

PROJECT MGR.	DESIGNED BY	DRAWN BY	CHECKED BY	DATE	SCALE	PROJECT NO.	FILE NAME	DRAWING NO.	FIGURE
DLB	BP	BP	KMD	JAN 2017	AS SHOWN	1499201	-	-	4

Figure 5. **Cumulative grain size distribution of measured data (gray) and grain size distribution used in model (red) for the EFDC SDHF simulations (measured June 2014)**

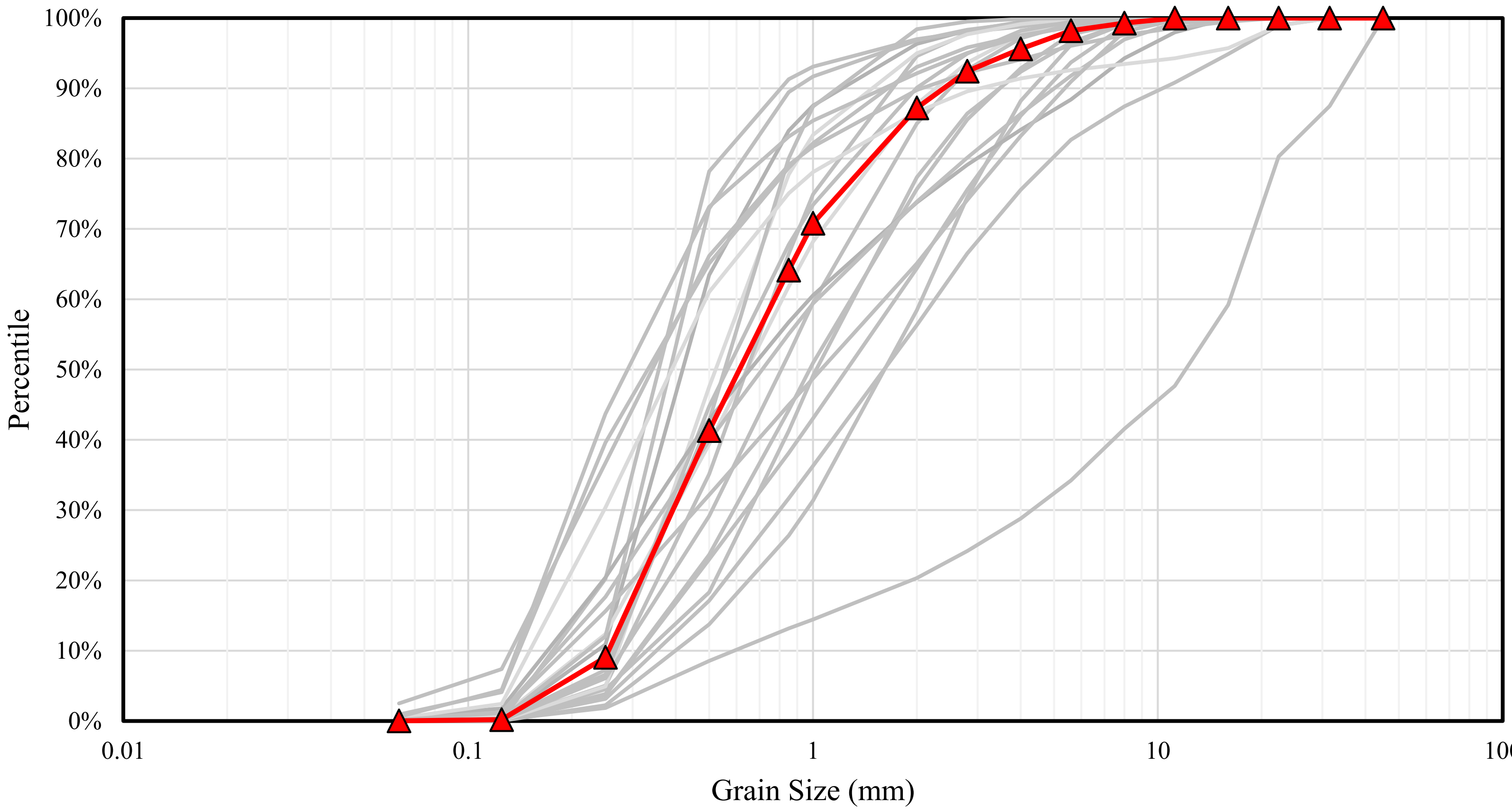


Figure 6. Sediment supply boundary condition applied in EFDC for the SDHF simulations

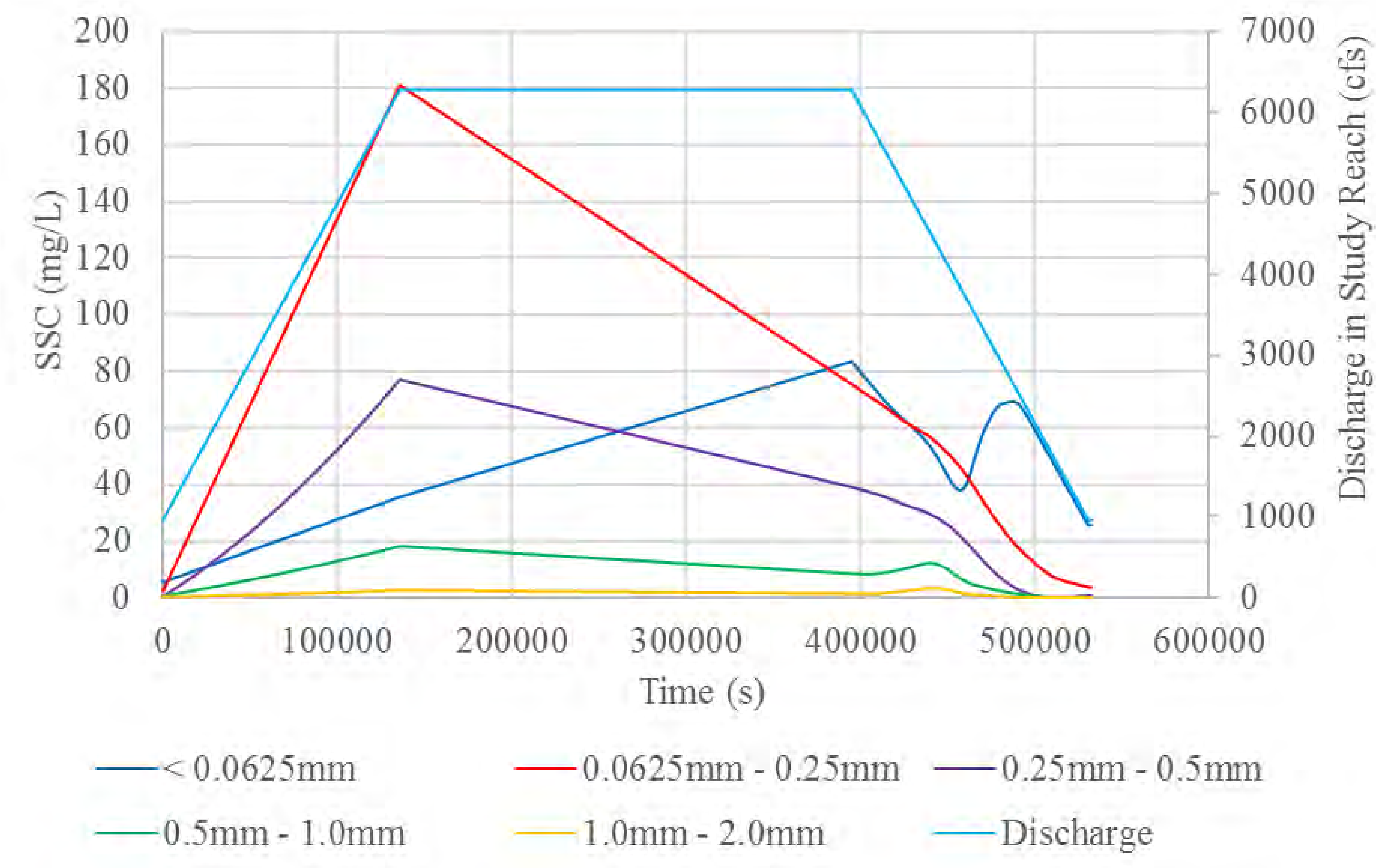


Figure 7. Comparison of measured and predicted water levels for various flows during the fall 2013 (EFDC and FaSTMECH) and June 2014 high flow (FaSTMECH)

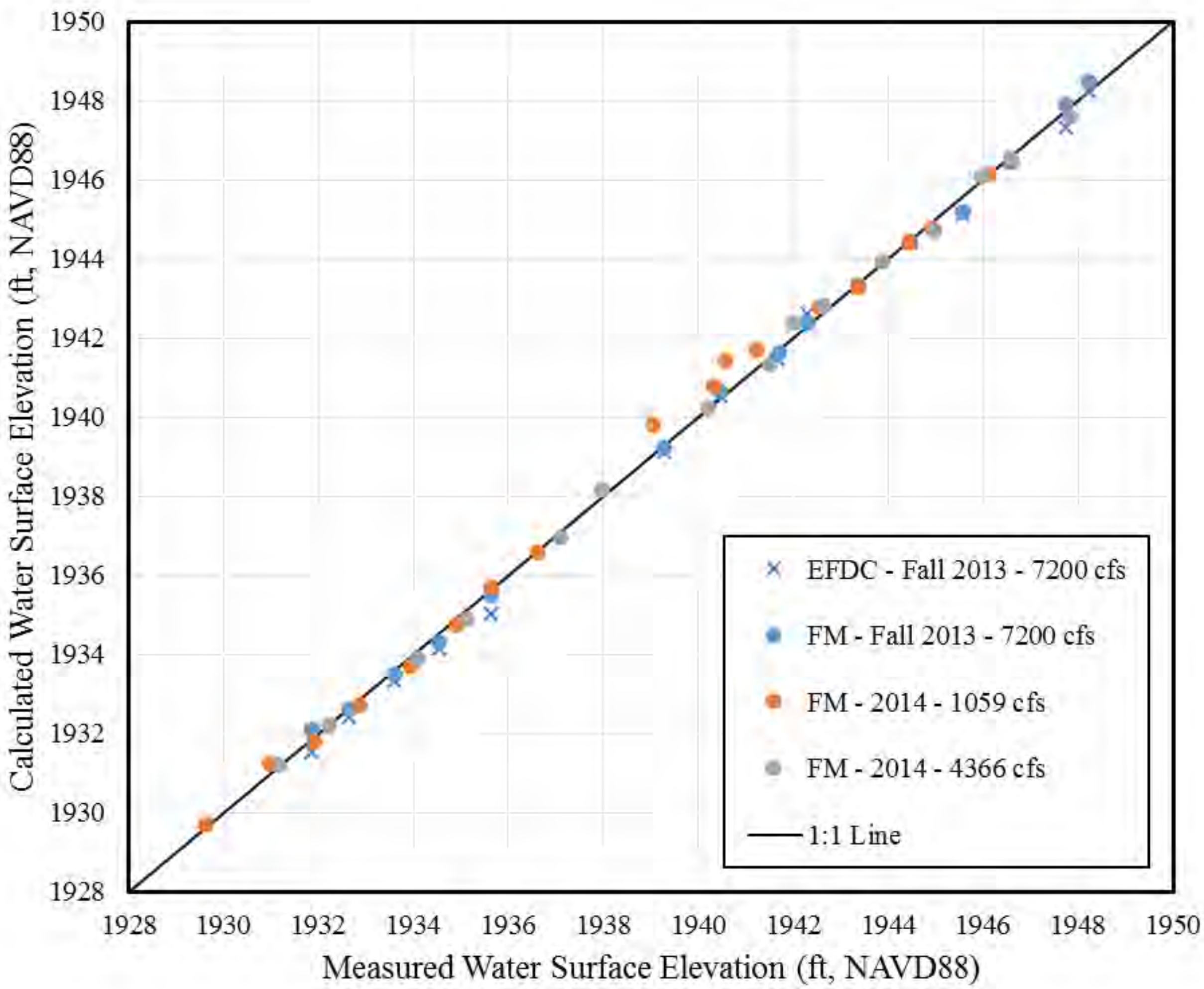


Figure 8. LiDAR data results in a plane bed low flow channel due to lack of data in wetted channels (left). FaSTMECH produces barforms (middle) in the channel that are similar in amplitude and wavelength to those observed in aerial photography (right)

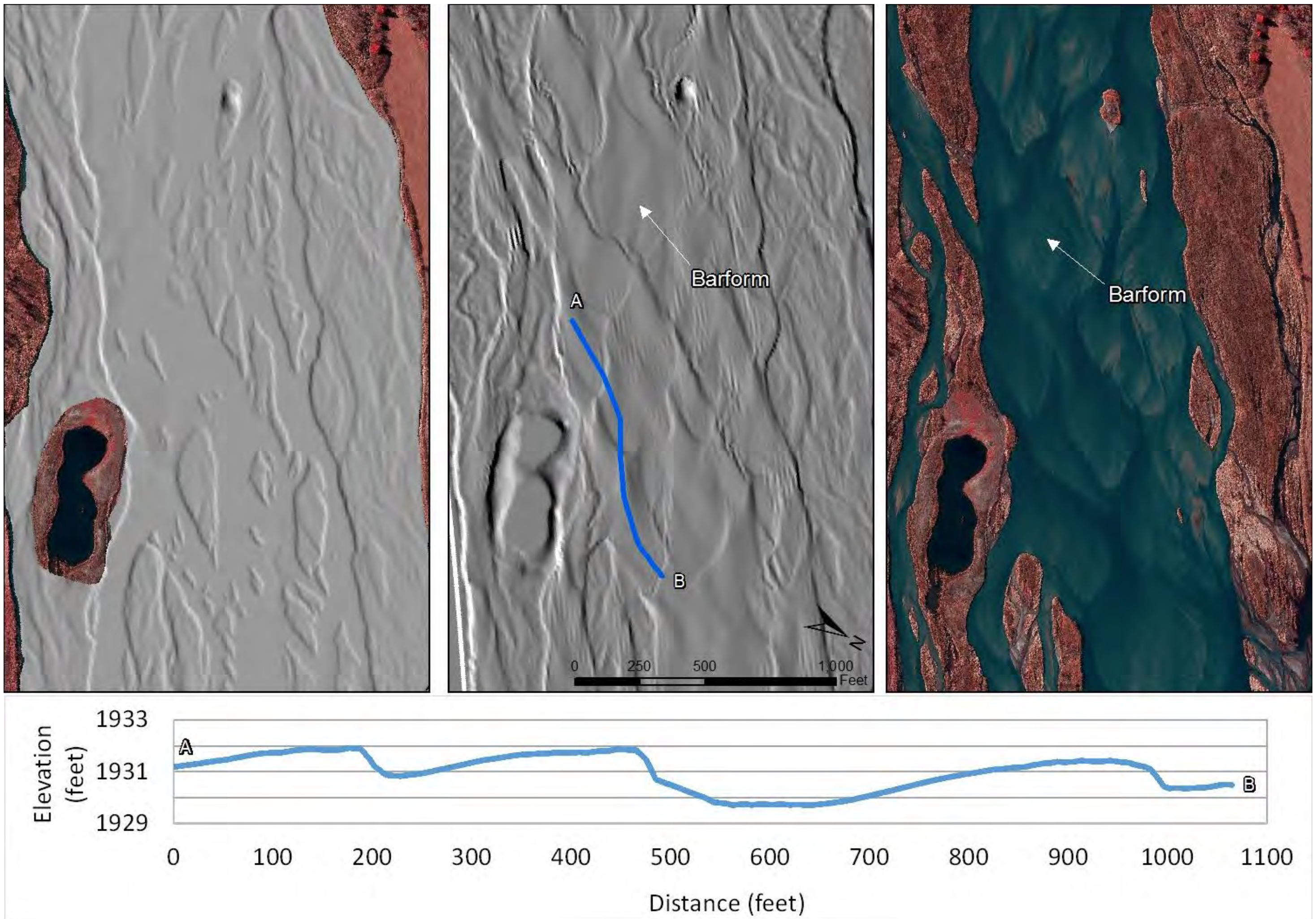


Figure 9. Example of barform changes following a SDHF (8,000 cfs TRF, 3 days)

Figure 10. Predicted (FaSTMECH) vegetated bars, established sand bars and new sand bars prior to, and following, a SDHF

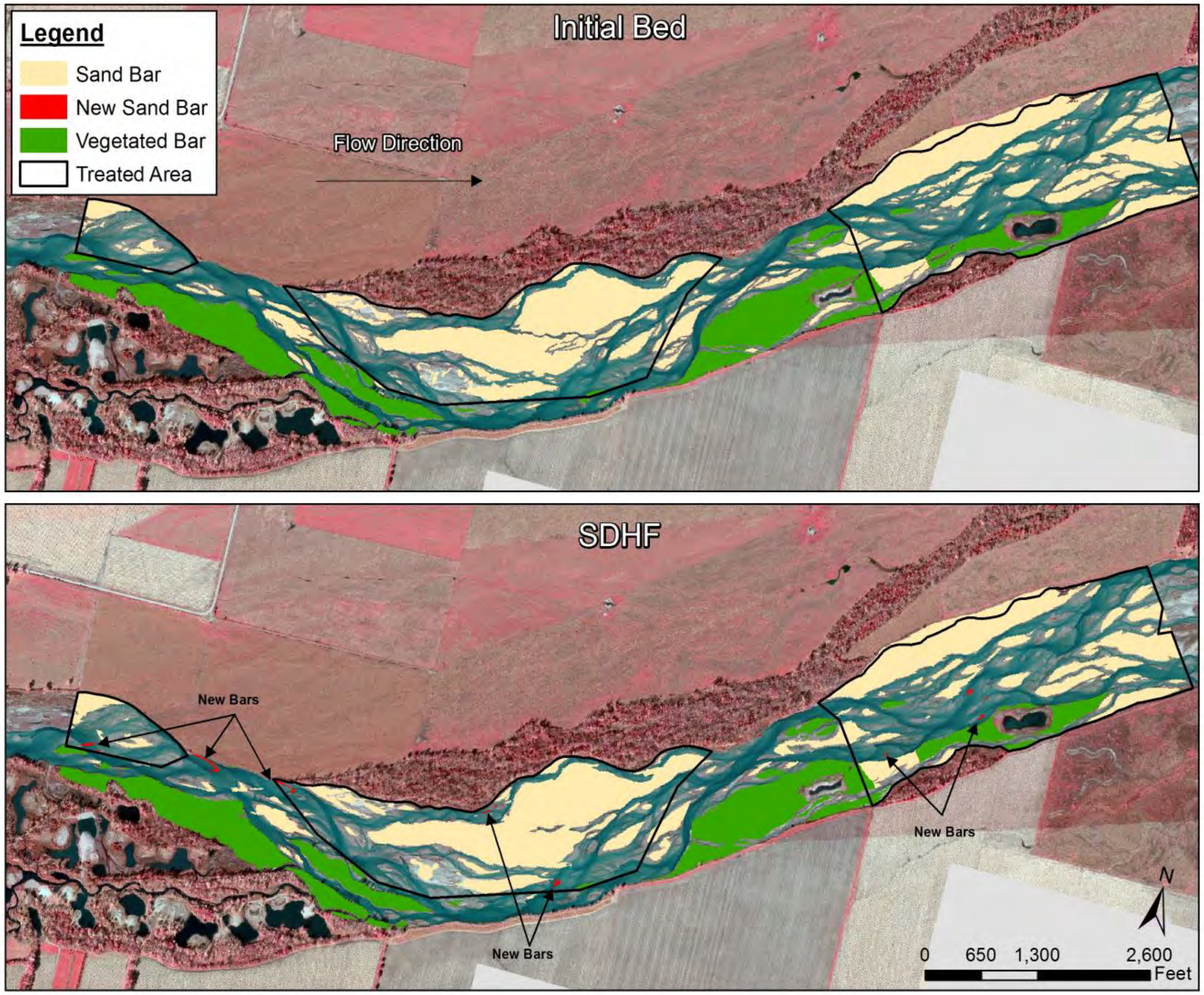


Figure 11. Box plots of mean bar heights and areas of all bars (sand and vegetated) before (IC) and after SDHF with 5,000 cfs and 8,000 cfs peak flow

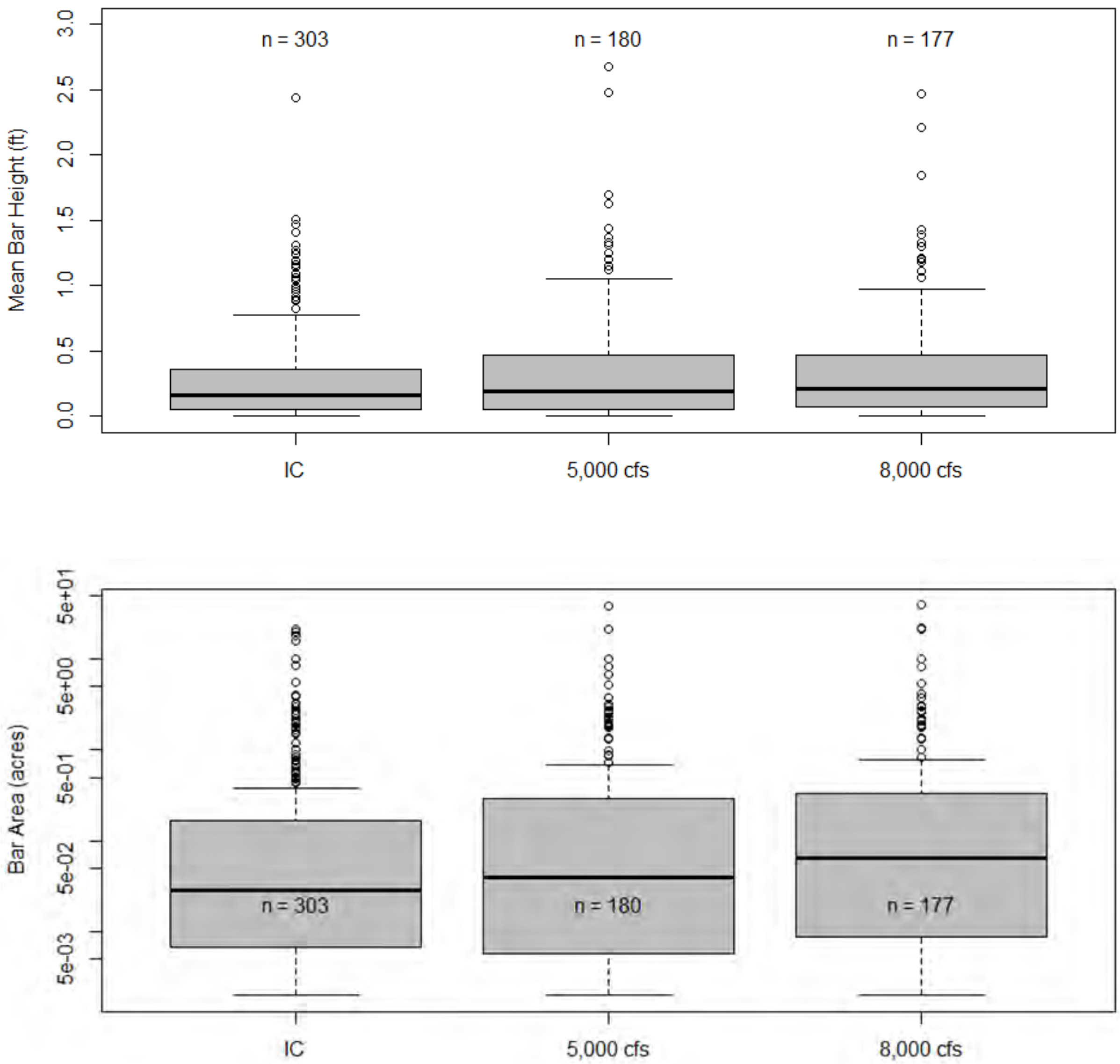
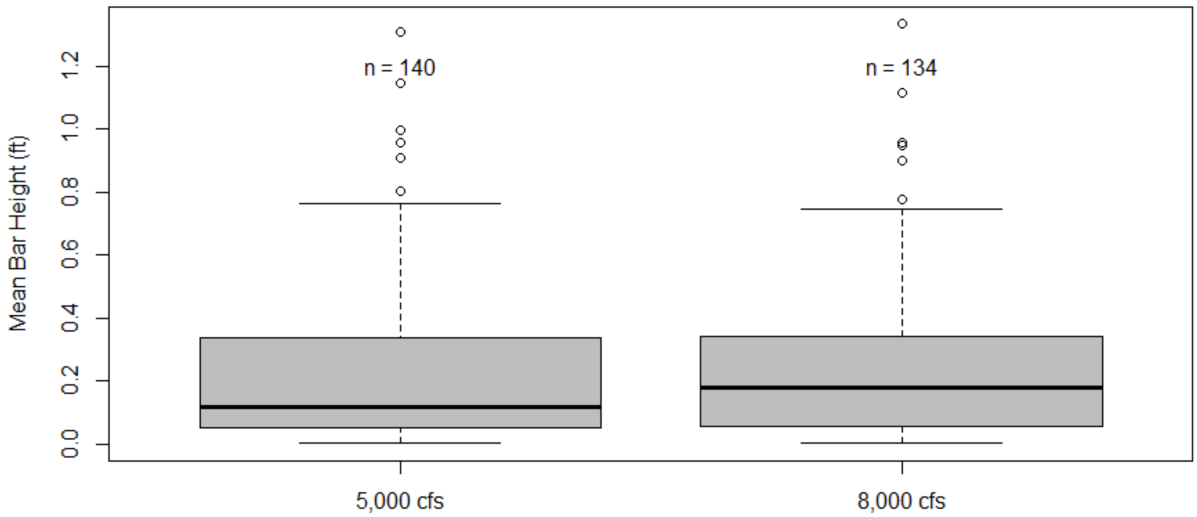


Figure 12. **Box plots of mean bar height and area of sand bars following a 5,000 cfs and 8,000 cfs SDHF**



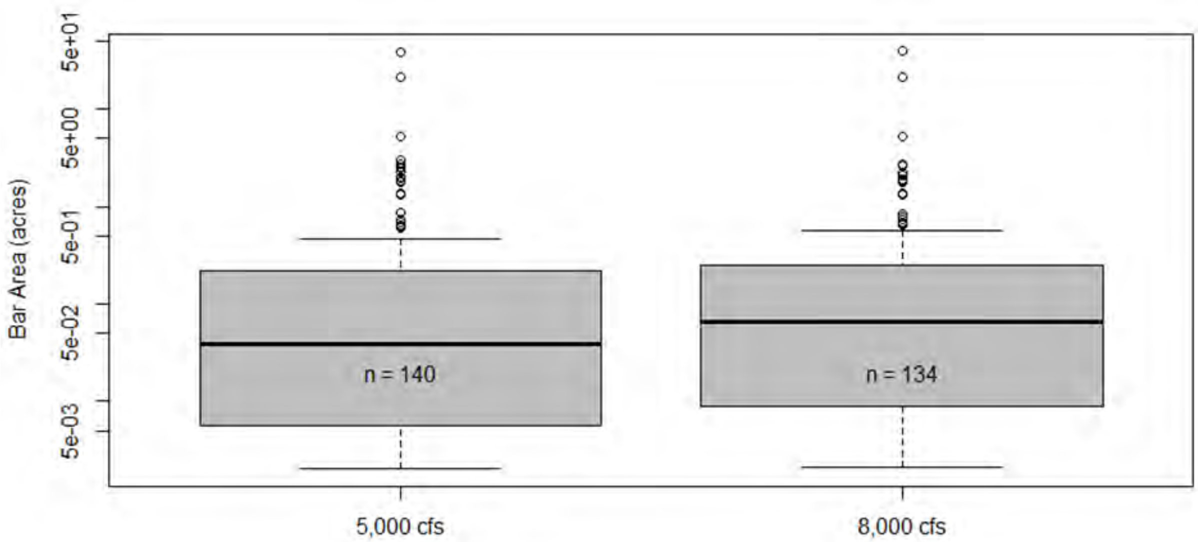


Figure 13. Comparison of mean new sand bar heights above 1,200 cfs formed during a SDHF with a magnitude of 5,000 cfs TRF and 8,000 cfs TRF

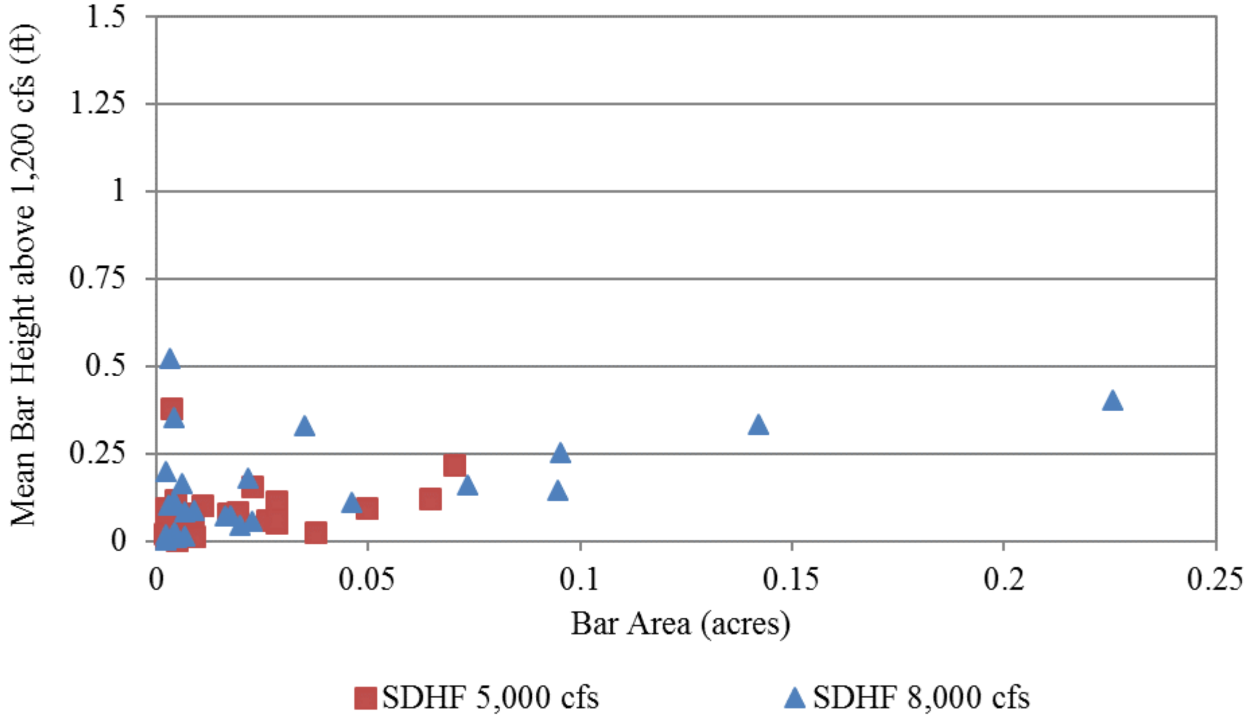
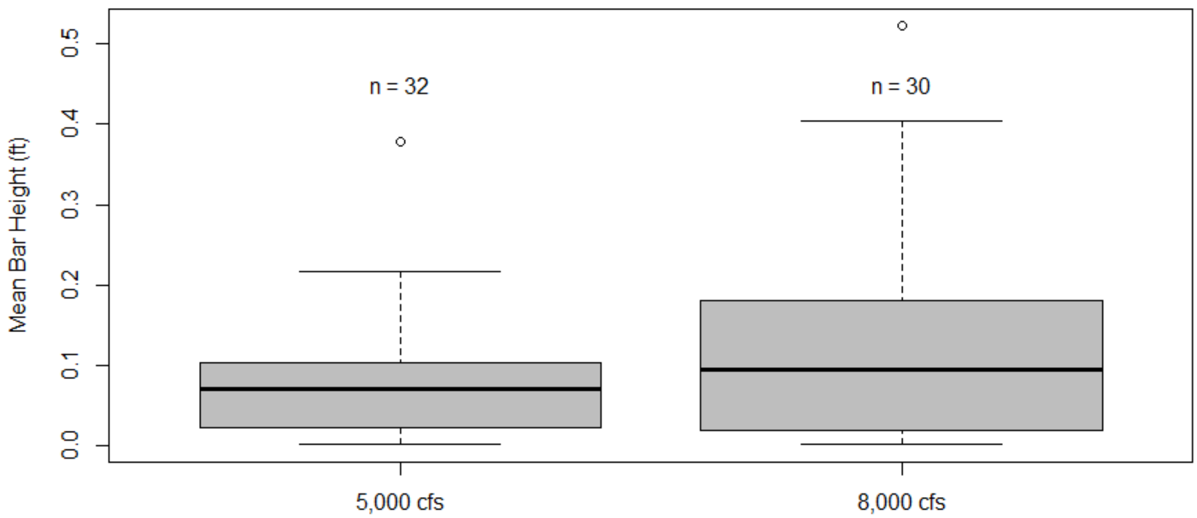


Figure 14. Box plots of mean bar height and area of new bars for 5,000 cfs and 8,000 cfs SDHF



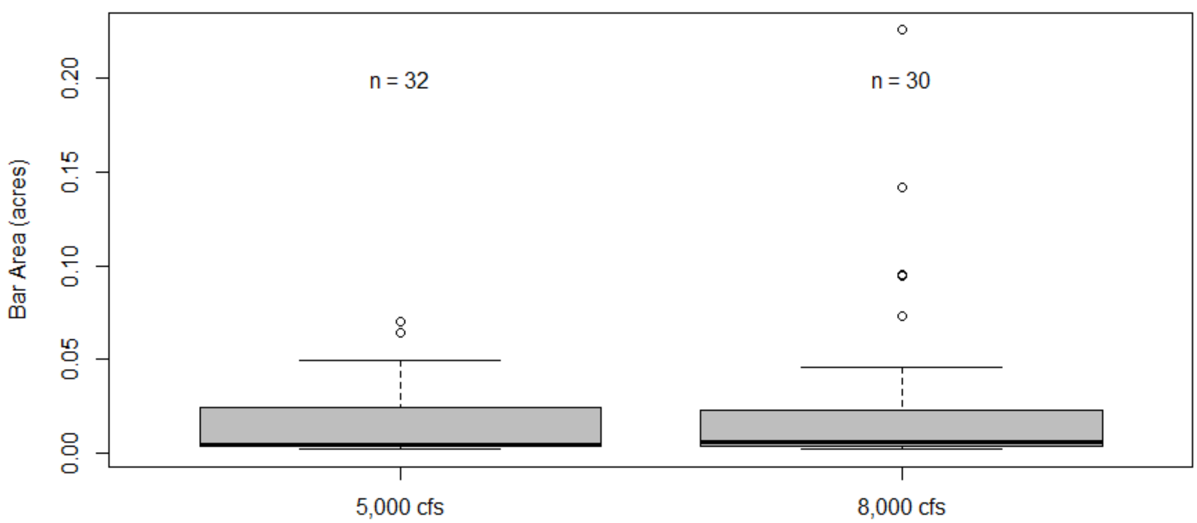
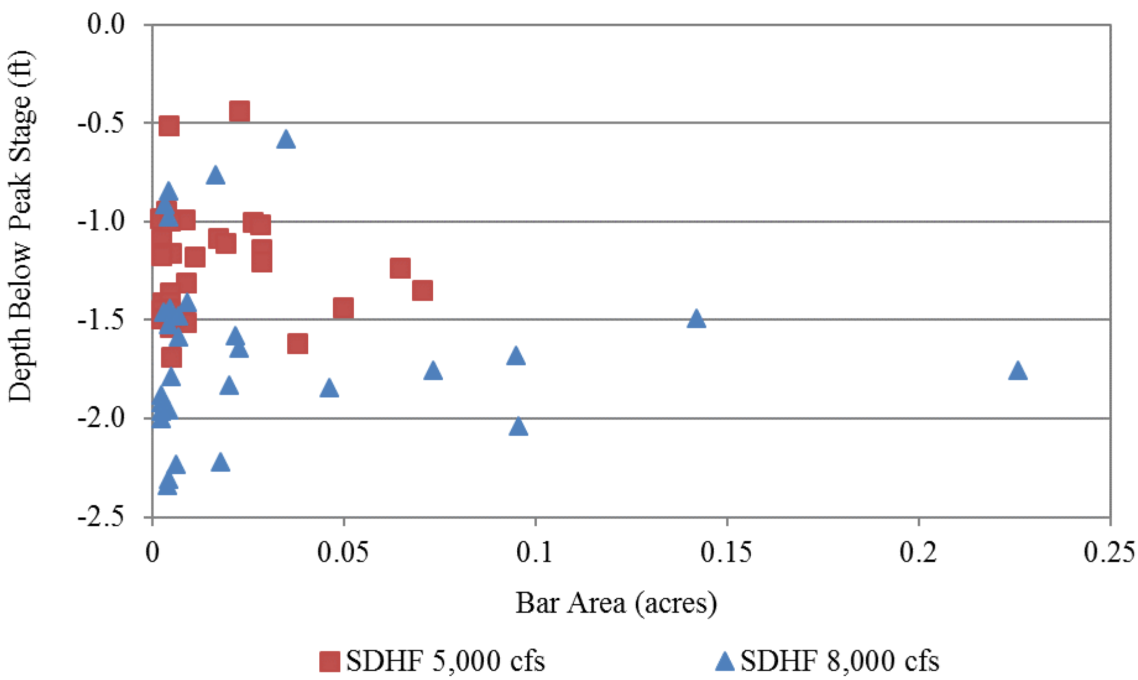


Figure 15. Comparison of depth of new sand bars below peak stage formed during a SDHF of 5,000 cfs and 8,000 cfs TRF. Area reported as individual bar area (top) and cumulative bar area (bottom)



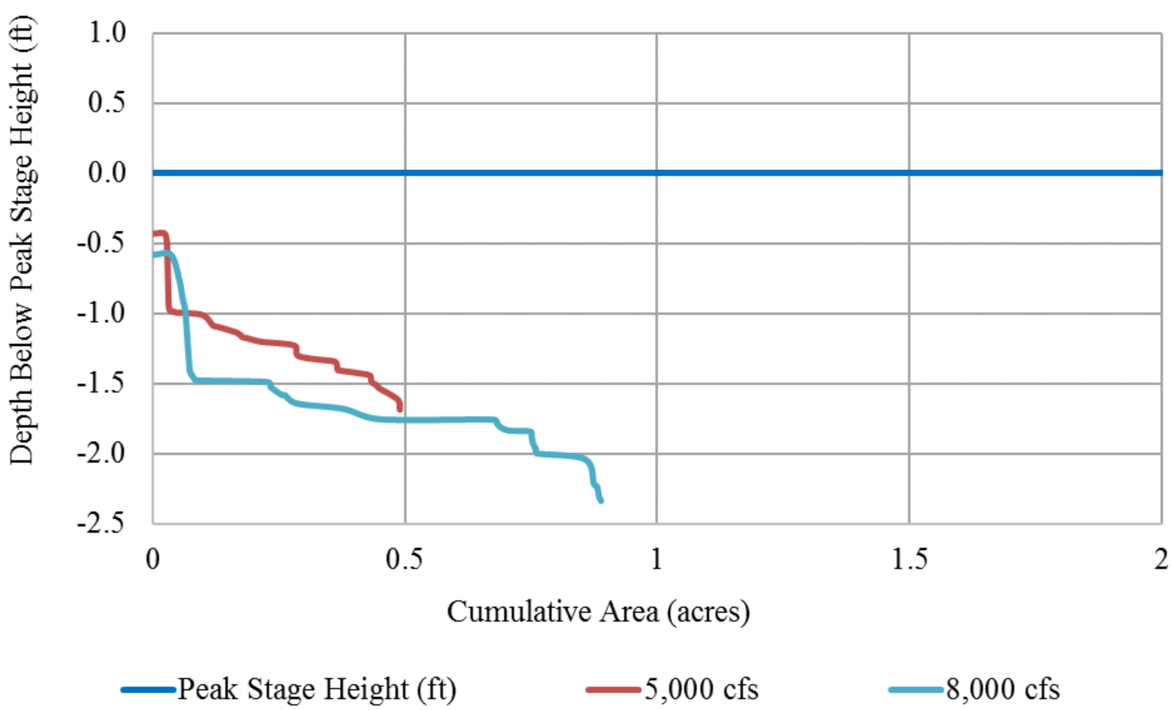
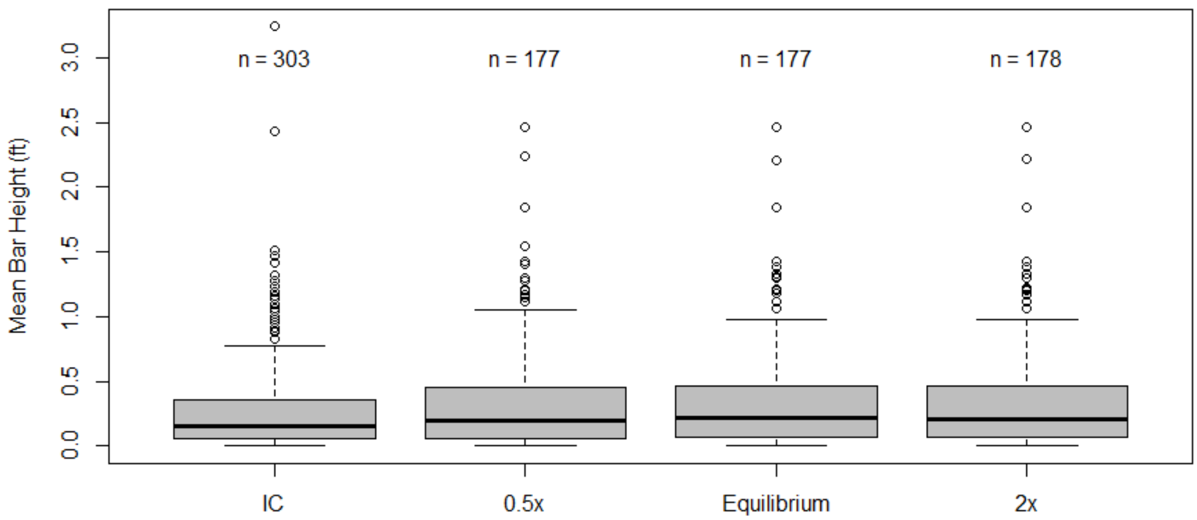


Figure 16. Box plots of mean bar height and bar area of all bars (sand and vegetated) for half (0.5x), equilibrium sediment supply and twice (2x) equilibrium sediment supply



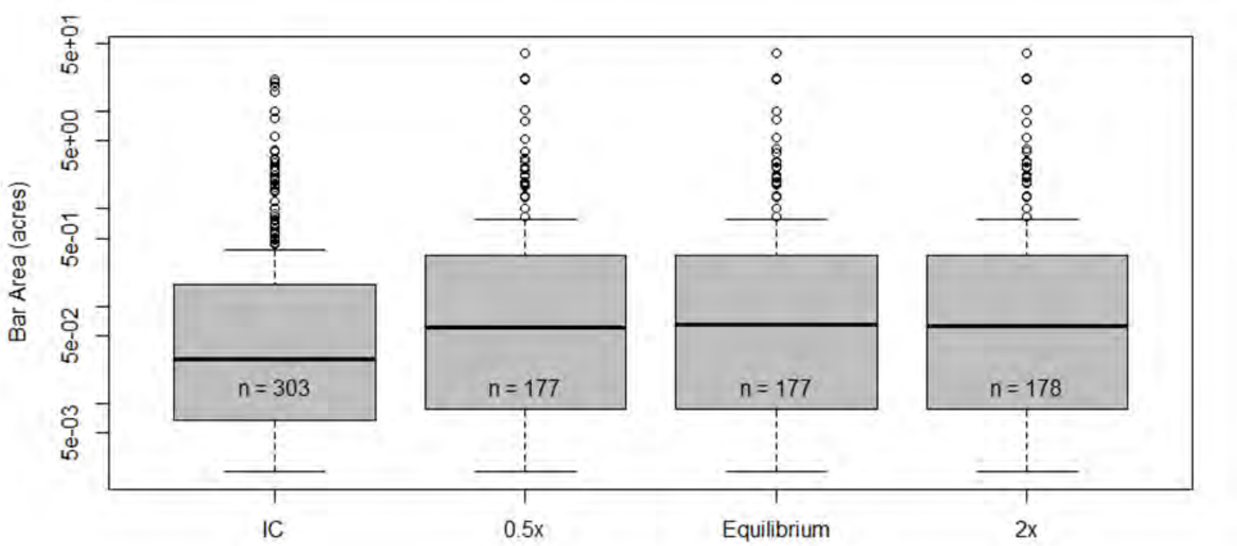


Figure 17. Box plots of mean bar height and bar area of all sand bars for half (0.5x), equilibrium sediment supply and twice (2x) equilibrium sediment supply

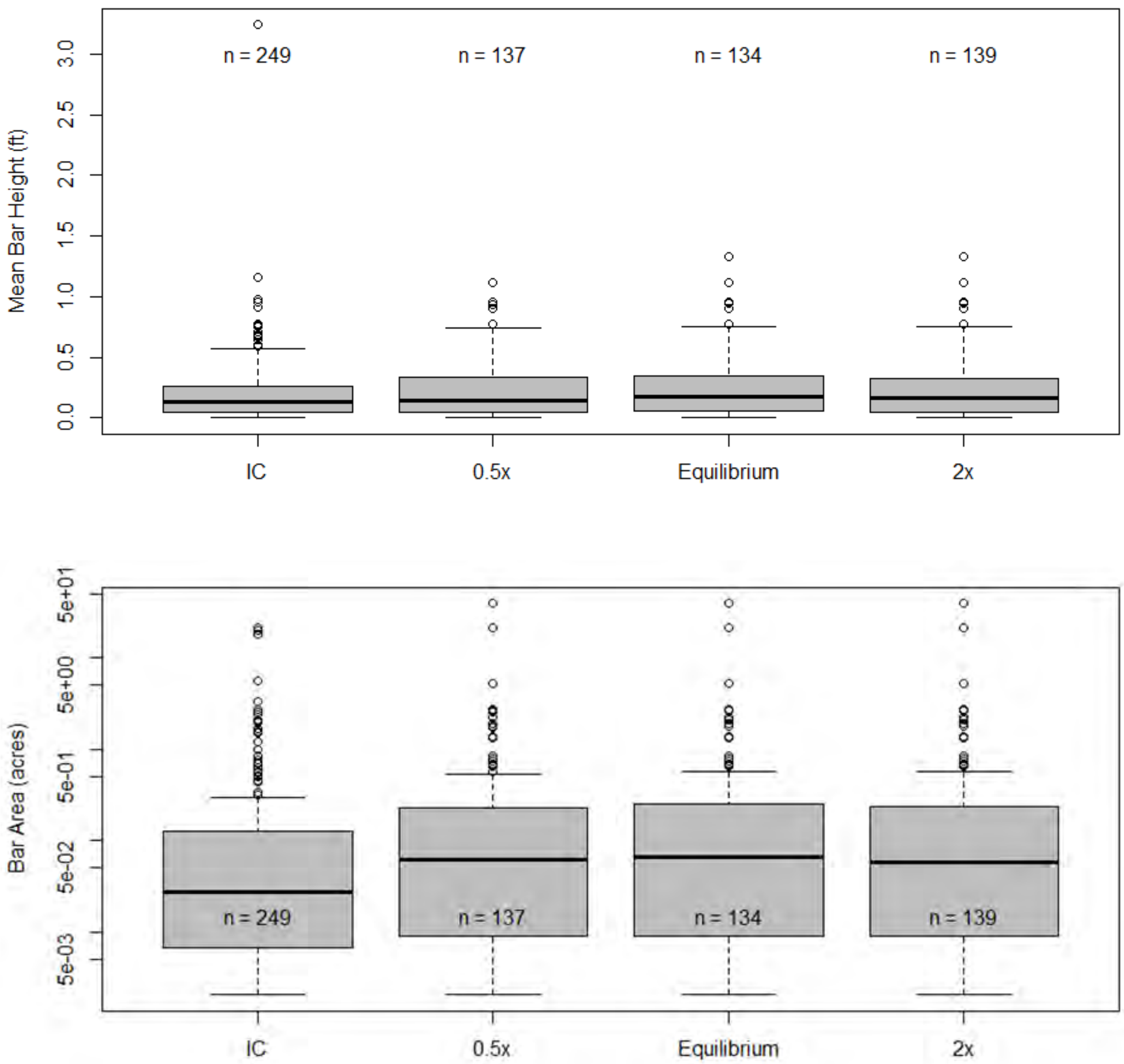
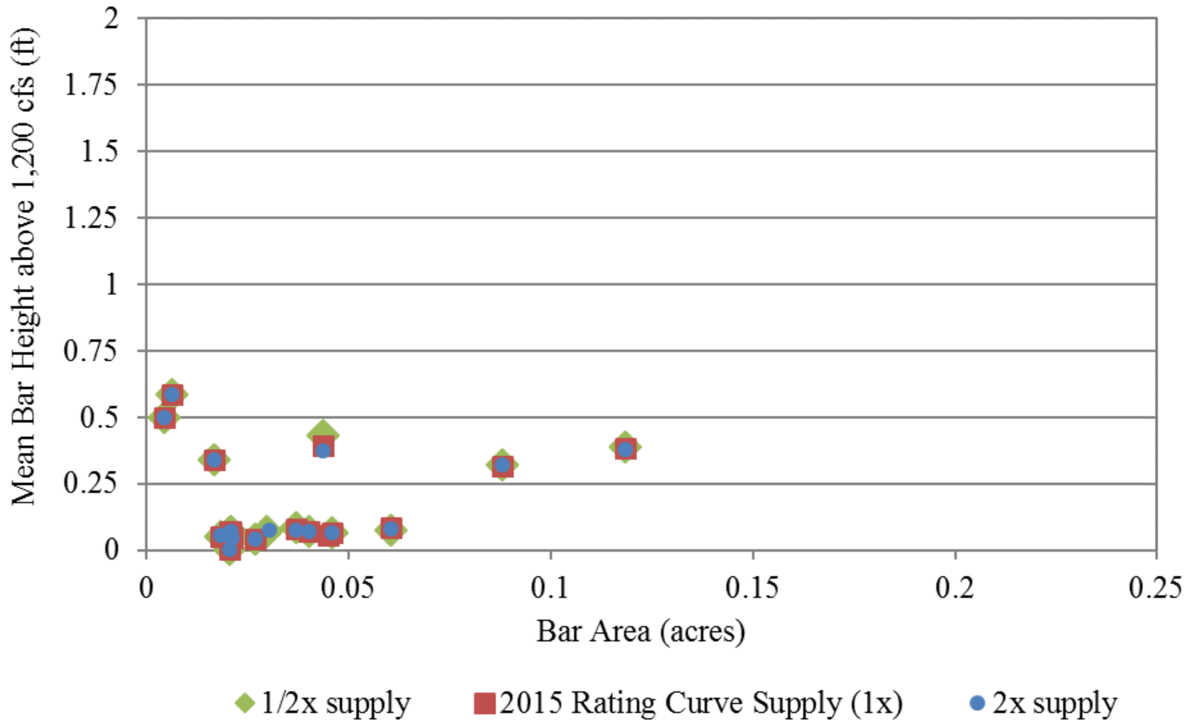


Figure 18. Effect of sediment supply on mean bar height and bar area of new bars predicted by EFDC (top) and FaSTMECH (bottom).



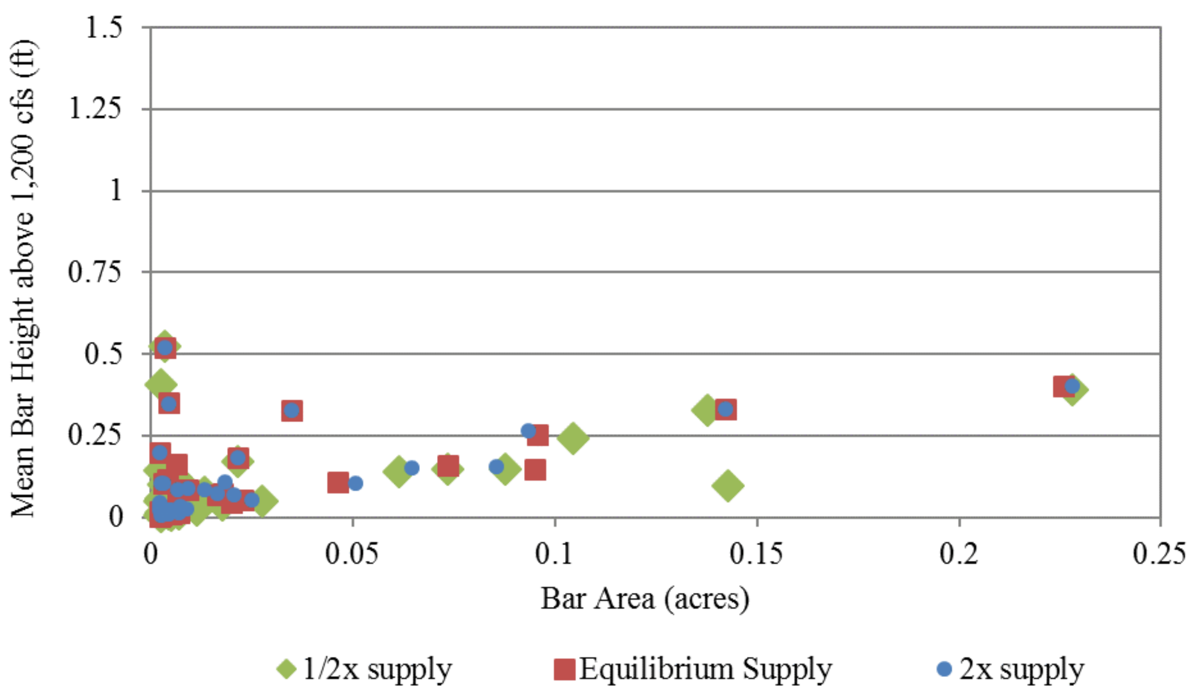


Figure 19. Comparison of depth of new sand bars below peak stage formed during a SDHF with variable sediment supply. Area reported as cumulative bar area

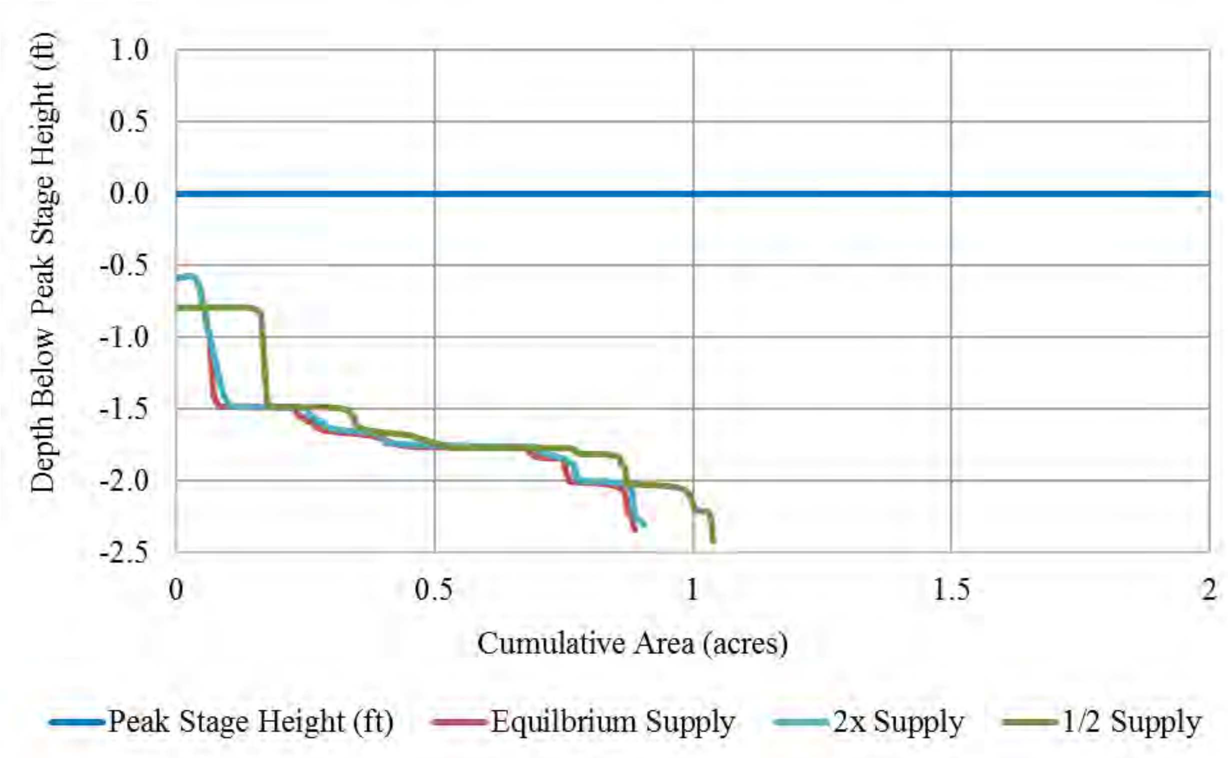


Figure 20. Box plots of mean bar height and bar area of new sand bars for half (0.5x), equilibrium sediment supply and twice (2x) equilibrium sediment supply

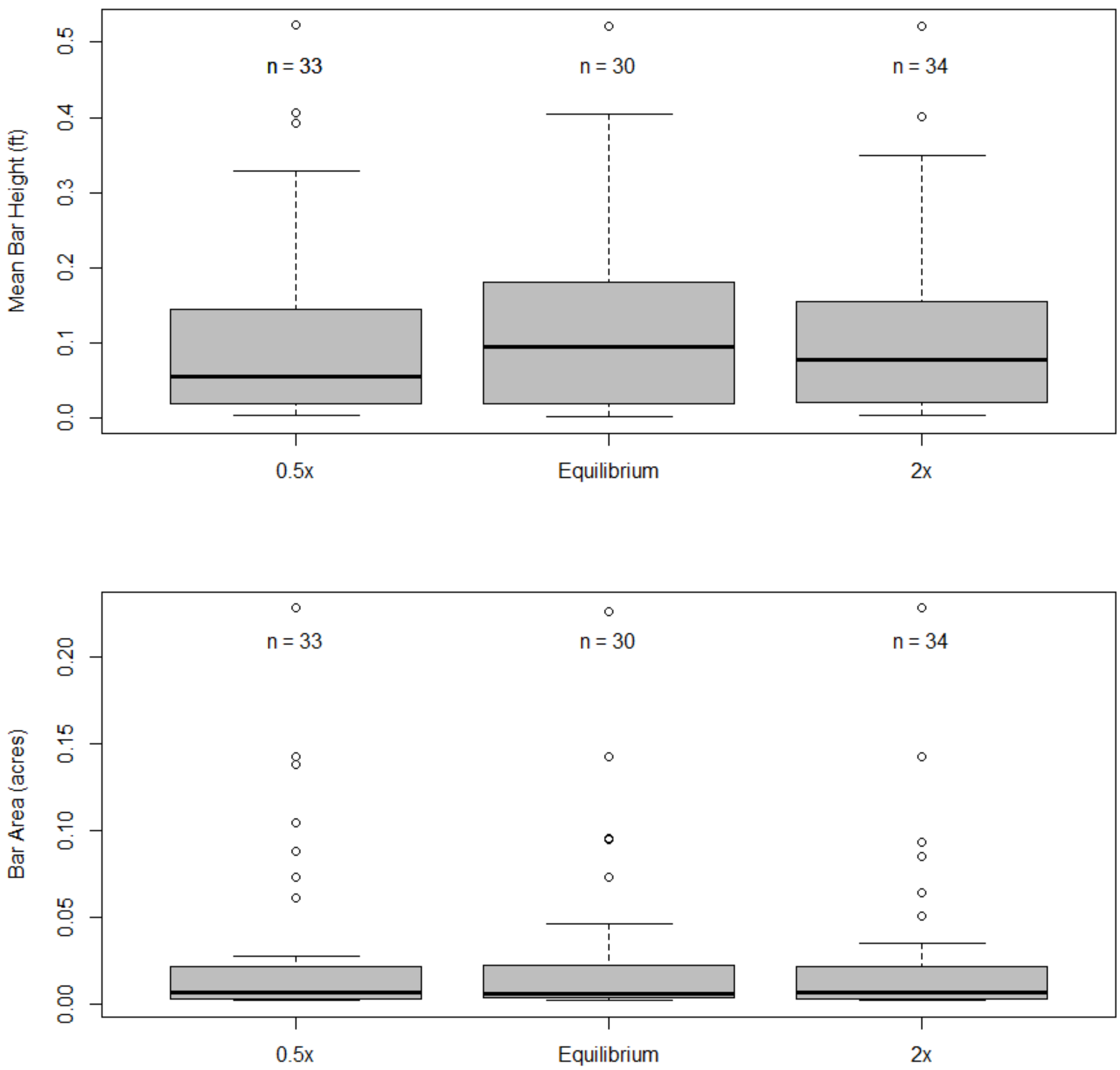
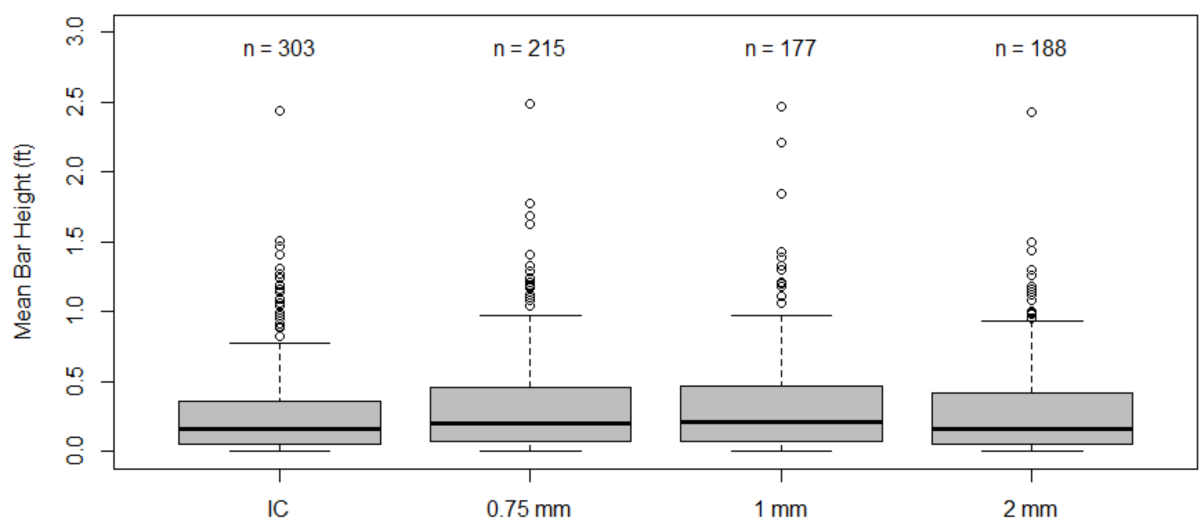


Figure 21. Box plot of bar height and area of all bars (sand and vegetated) before and after a SDHF with bed material grain sizes of 0.75 mm, 1 mm, and 2 mm



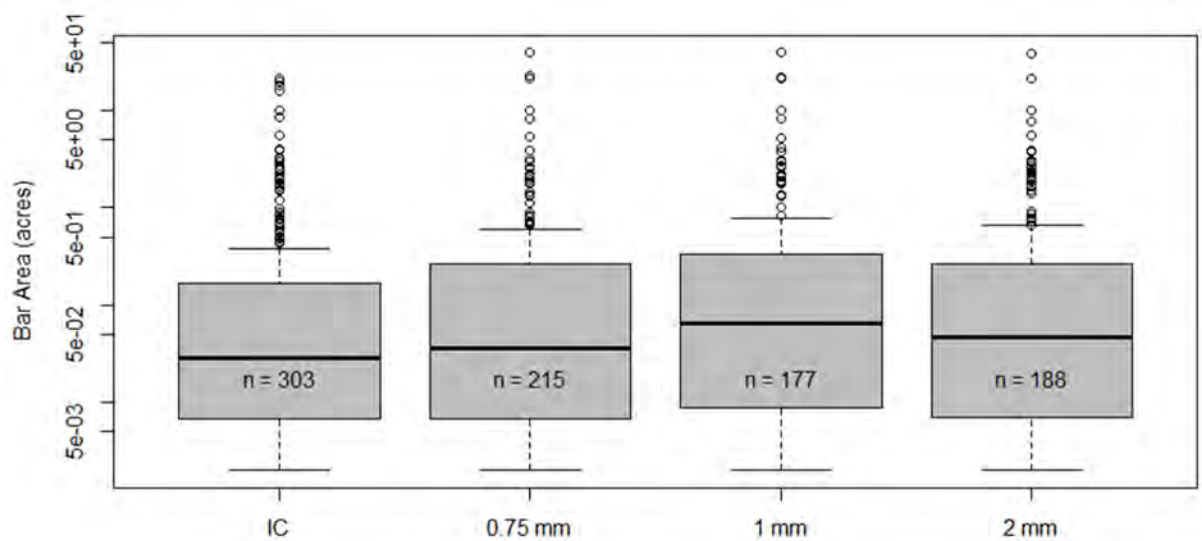


Figure 22. Box plot of bar height and area of sand bars after a SDHF with bed material grain sizes of 0.75 mm, 1 mm and 2 mm

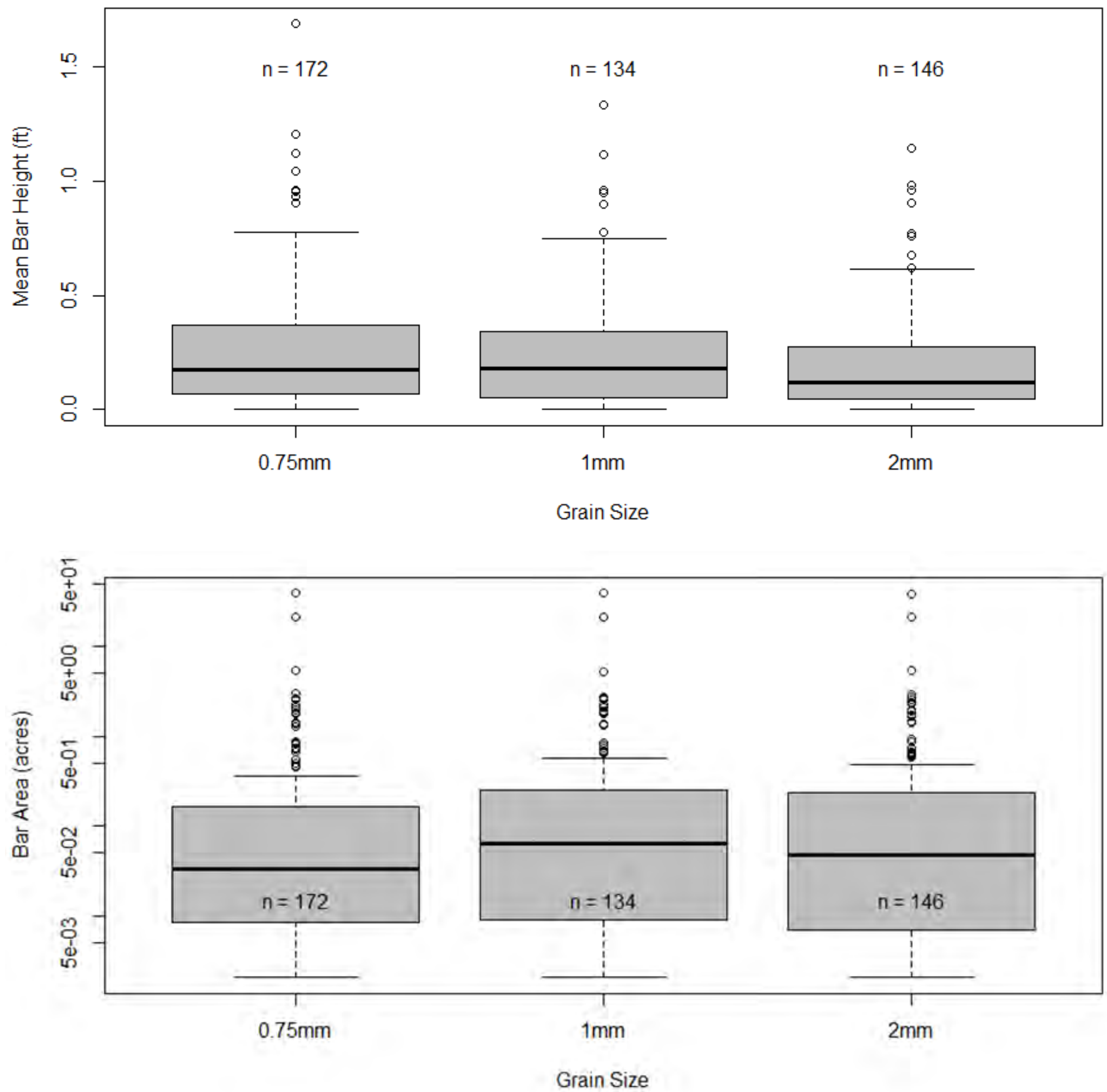
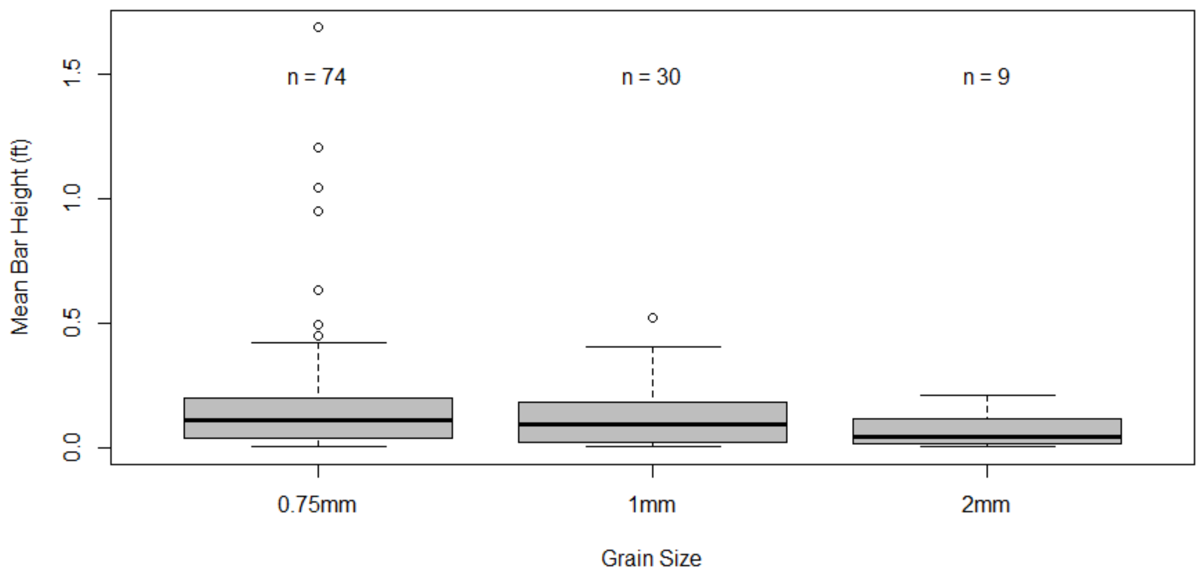


Figure 23. Box plots of mean bar height and area of new sand bars formed during a SDHF with a bed material size of 0.75, 1, and 2mm



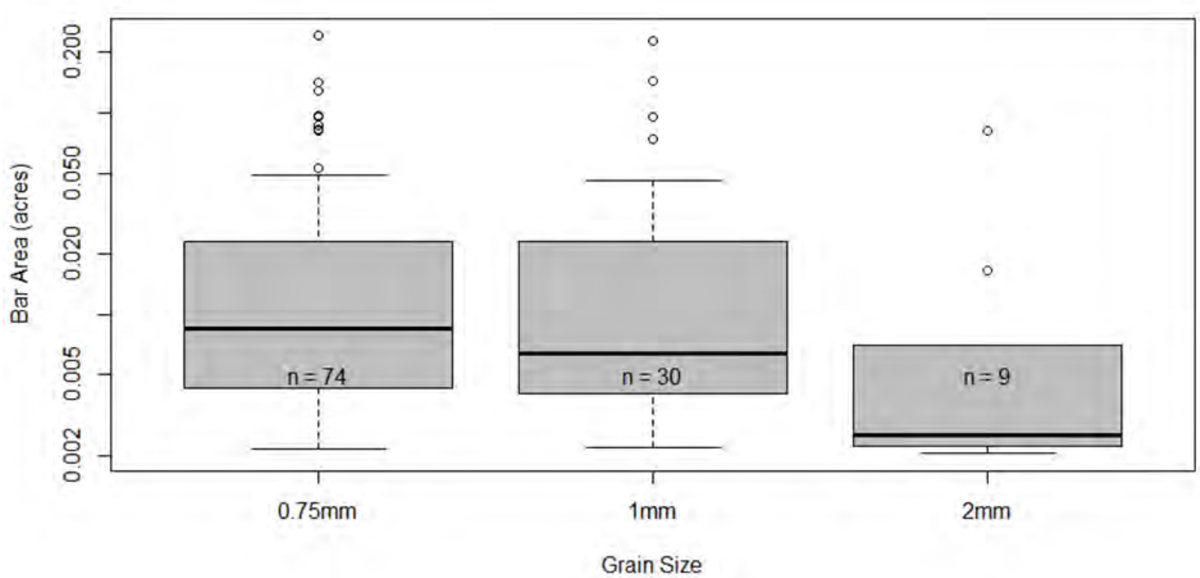


Figure 24. Comparison of mean new sand bar heights above 1,200 cfs and bar area formed with a bed material grain size of 0.75, 1, and 2mm following a SDHF (8,000 cfs TRF)

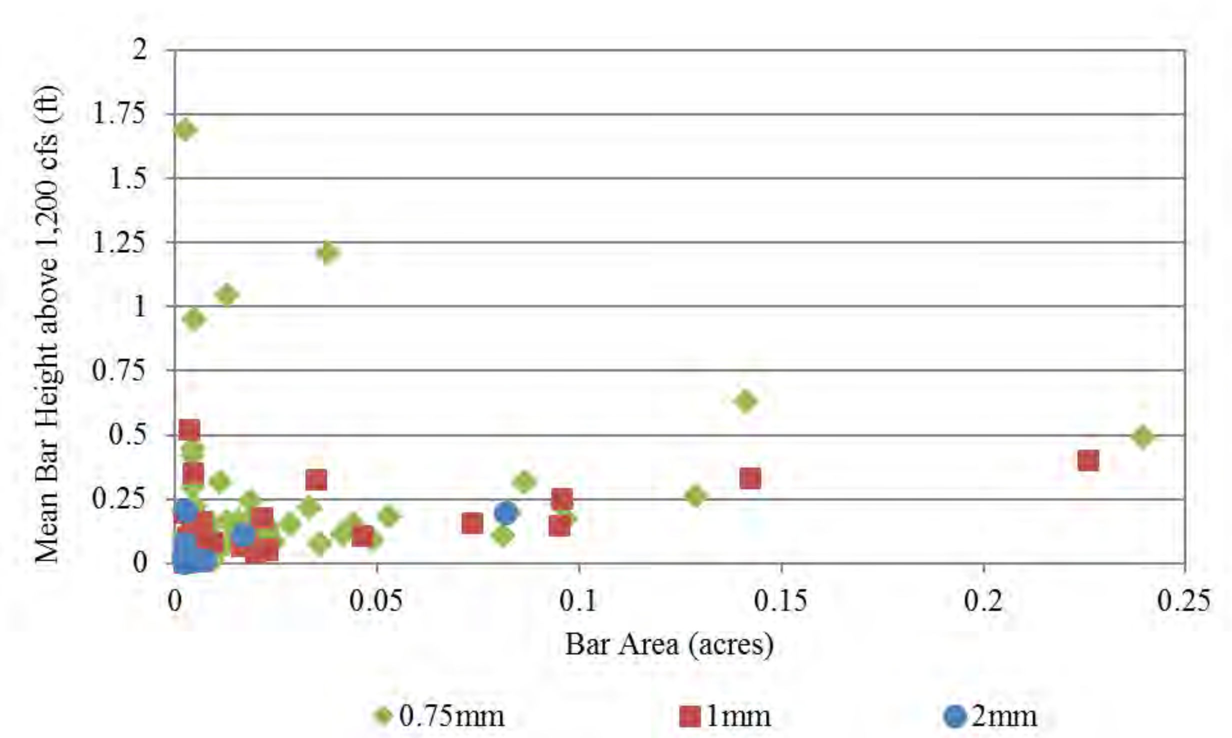
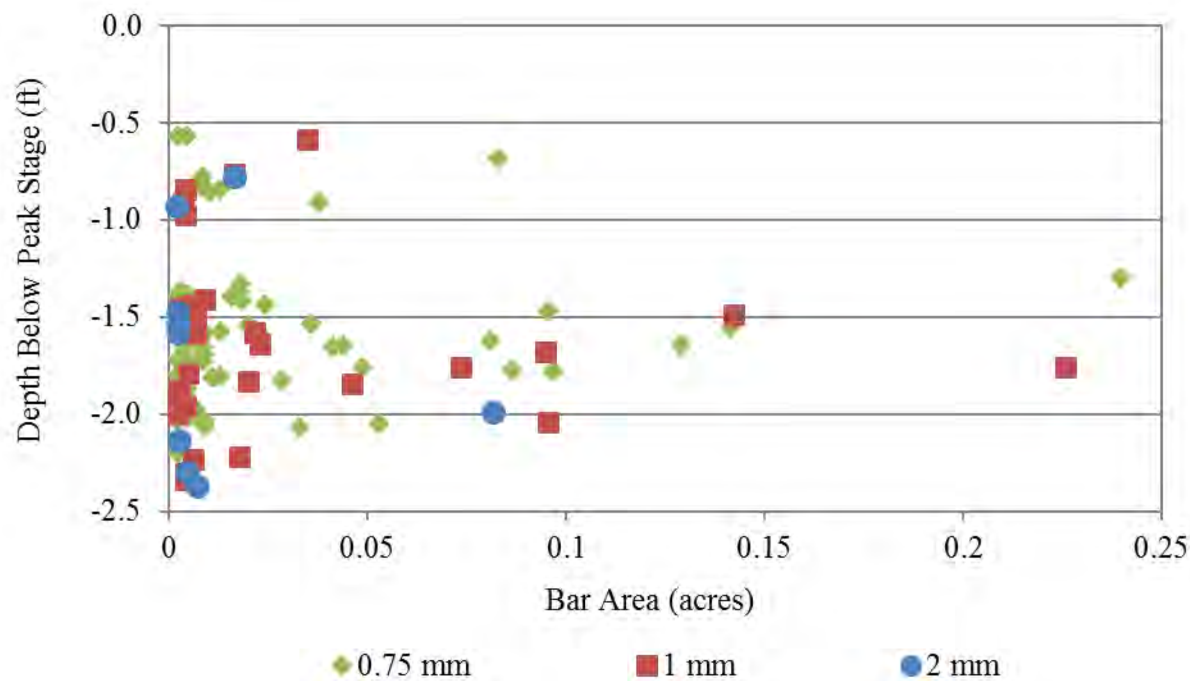


Figure 25. Depth of new sand bars below the peak stage and bar area following a SDHF (peak flow 8,000 cfs TRF) for bed material grain sizes of 1 mm, 2 mm and 0.75 mm. Area is expressed as individual bar area (top) and cumulative bar area (bottom)



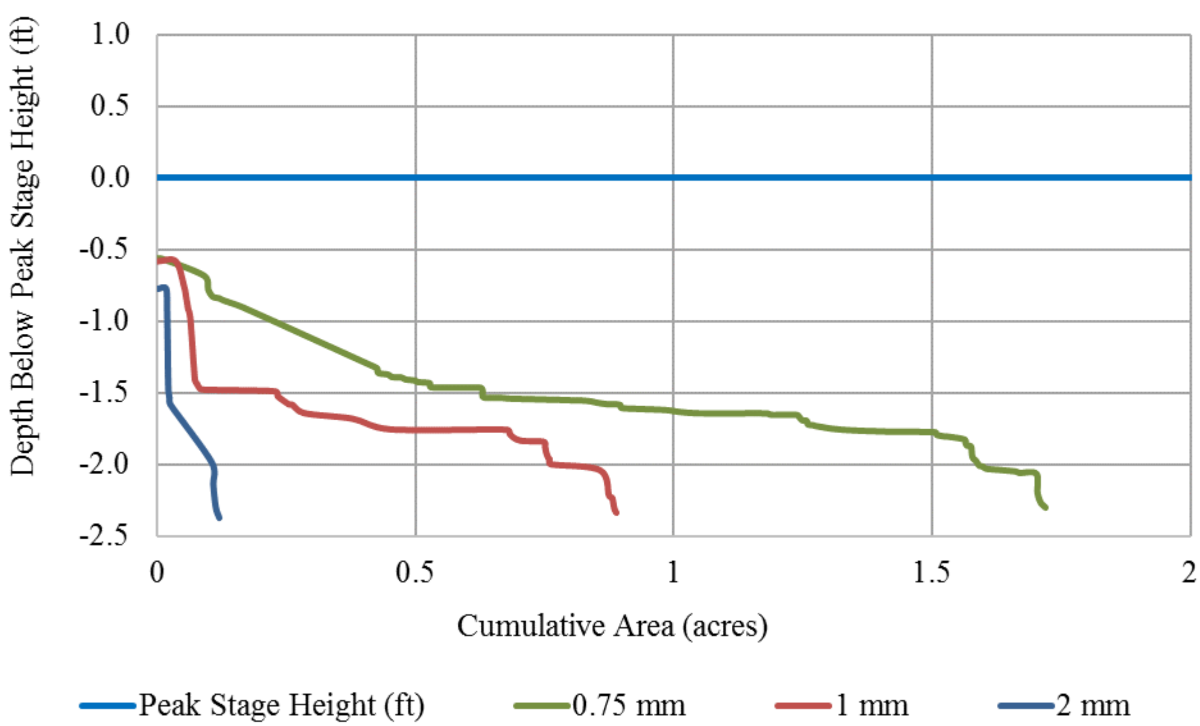
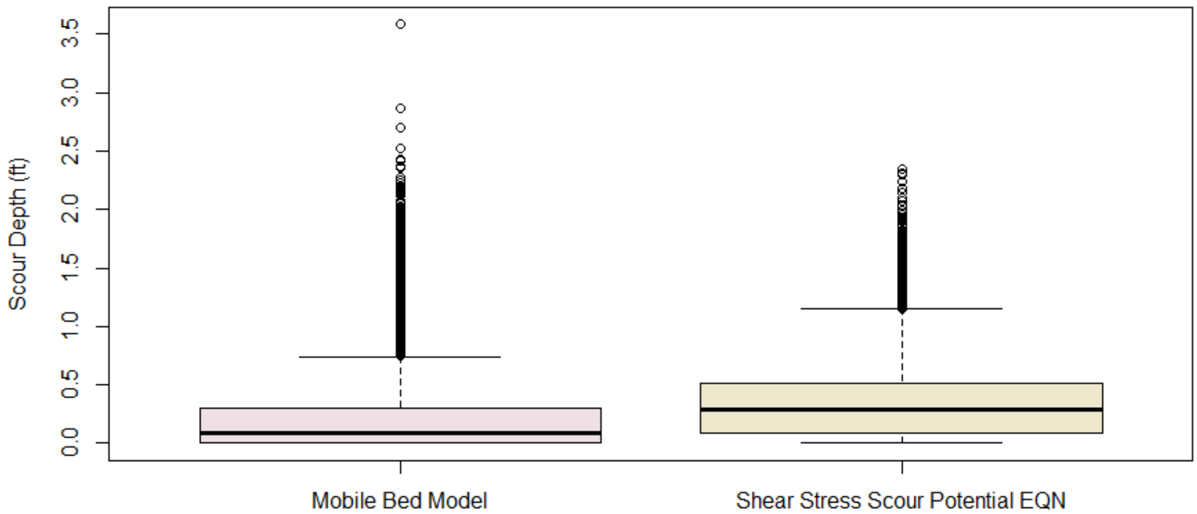
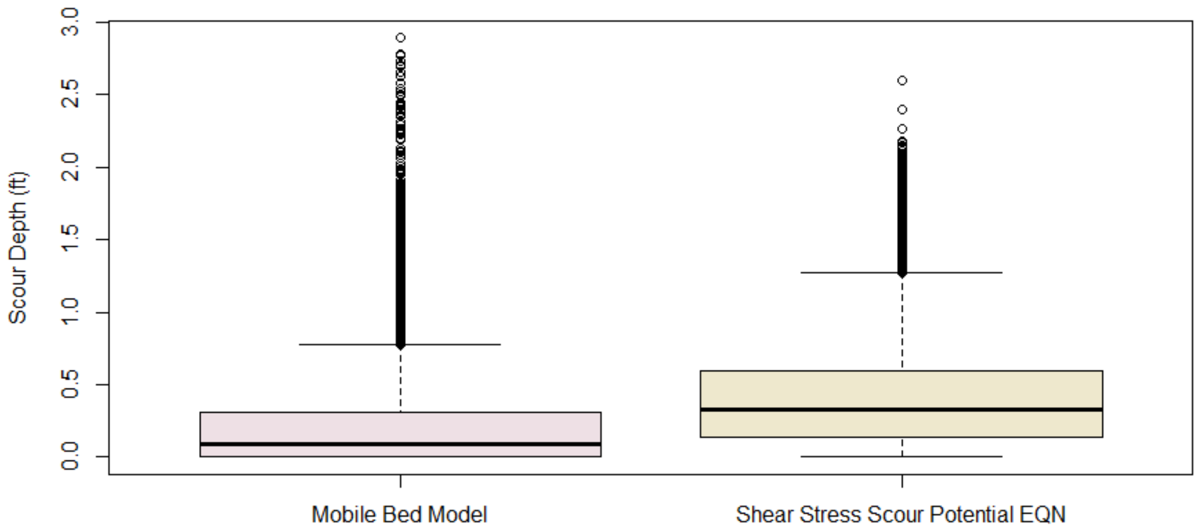


Figure 26. **Box plots of scour depth predicted by mobile-bed model (FaSTMECH) and scour potential predicted by an empirical relation between measured scour depth and predicted shear stress. Scour depth on vegetated bars (top) and sand bars (bottom)**





PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Shoemaker Island Flow-Sediment-Mechanical "Proof of Concept" Experiment

One-Dimensional Bank Erosion Analysis: Final Summary

Attachment III

FINAL

September 2016

Submitted to:
Platte River Recovery Implementation Program
4111 4th Avenue, Suite 6
Kearney, NE 68845

Submitted by:
Northern Hydrology and Engineering
PO Box 2515
McKinleyville, CA 95519

Table of Contents

I. INTRODUCTION

One-dimensional bank erosion modeling using the USDA-ARS BSTEM model was one component of a multi-faceted analysis conducted for the Shoemaker Reach of the Platte River over the past three years (FY 2013 – FY 2015). The analyses conducted with BSTEM supports previous research suggesting that lateral erosion is a primary fluvial process contributing to riparian plant mortality (Bankhead et al., 2012). A summary of the analyses conducted over the three-year period is synthesized in this report.

II. MODEL DESCRIPTION

The USDA Bank Stability and Toe Erosion Model (BSTEM) is a one-dimensional bank erosion model developed at the USDA Agricultural Research Services (Simon et al. 2011; USDA 2010). BSTEM estimates hydraulic erosion of the bank and bank toe based on hydraulic boundary shear stresses calculated from channel geometry and flow parameters. Hydraulic erosion occurs when the tractive force of the water column [shear stress] exceeds the resisting force of bank materials. Additional lateral erosion through geotechnical bank failure, (gravitational forces exceed cohesive forces), is based on equilibrium factor of safety calculations that include horizontal erosion, vertical tension cracks and cantilever failure (USDA 2010). Input requirements include bank geometry, soil type for bank material, vegetation coverage, channel slope, and water depth at the channel boundary for a given duration of time. Sediment transport is not incorporated into this model and the channel bed elevation is assumed to be fixed. This model does not incorporate incision of the channel bed and the bottom elevation of the bank toe can't erode below the elevation of the channel bed.

III. SUMMARY OF YEAR 1

In FY 2013, BSTEM was used to estimate lateral erosion for five sites that exhibited differing erosion responses to the monitored flow conditions during the time period of March 26 to April 28, 2013. Pre and post-bank profiles were surveyed throughout the reach as part of the standard monitoring protocol. The bank profiles modeled represented profiles that were vegetated (untreated) and unvegetated (treated). They also represented bank profiles where varying amounts of lateral erosion occurred over the monitored flow period ranging from no erosion to fairly significant lateral erosion of nearly 15 feet. BSTEM model inputs were derived from topographical survey data collected before and after the 2013 SDMF (April 13-18, 2013) and from continuous river stage measurements. Details of each profile are provided in PRRIP (2014).

The best method for model calibration was evaluated using four different "calibration" methods. The resulting lateral erosion rates for each calibration method were then compared. The primary calibration parameter used in this analysis is a Manning's n value which effectively modifies the shear stress acting on the bank profile.

In all simulations, the model was more successful at replicating lateral erosion at the bank toes when Manning's n was used as a calibration parameter (as opposed to not using the calibration option). Additionally, in all simulations, the model predictions were better at replicating post-survey profiles when the calibration value for Manning's n was varied at each profile rather than set to a constant value of 0.028, corresponding to the 1D HEC RAS analyses.

Calibrated values of Manning's n ranged from a high of 0.045 at profiles where no erosion occurred to a low of 0.016 at profiles where significant erosion occurred. The model was able to predict no lateral erosion on the vegetated bank profiles with the combined input of vegetation parameters that increased bank resistance to erosion and a Manning's n.

The results of the analysis demonstrated that the preferred approach for using BSTEM for management scenarios was to calibrate the model on a profile by profile basis by adjusting Manning's' n to match the shear stress estimated by a 2D model. The shear stresses were matched between BSTEM and the 2D model at the peak of the high flow and the resulting Manning's n was applied over the entire model period. This approach worked very well for unvegetated banks and not as well for vegetated banks. It was difficult to simulate any erosion for vegetated banks

The following conclusions can be drawn from this analysis:

- In four of the five bank profiles modeled, BSTEM was calibrated based on pre and post surveys to within 3% using Manning's n as a calibration parameter. In the fifth bank profile, significant lateral erosion occurred and BSTEM underestimated the erosion by 30%.

- Significant lateral erosion occurred at 2 of the 5 sites. In both cases, only about 12-13% of the predicted erosion occurred during the SDMF. These results can be explained by relatively minor increases in the applied shear stress over a short period of time during the SDMF and the long durations of moderate flow preceding and following the SDMF.

- Lateral erosion of bank profiles was caused by both hydraulic erosion and geotechnical failures. In the 2 sites where significant lateral erosion occurred, the bulk of the geotechnical failures occurred in period after the SDMF. The hydraulic erosion that occurred during the SDMF resulted in steepened bank profiles and bank toe erosion that primed the banks for geotechnical failure.

These results highlight the importance of the timing of pre and post surveys relative to flow release to ensure that the interpretation of channel change is correctly correlated with the flow of interest. These results also have important implications for interpreting the 2D bed mobility modeling results which are conducted over the 6-day SDMF and are compared to cross sections surveyed approximately 28+ days apart.

The results of this analysis indicate the best approach to apply BSTEM for management scenarios are a combination of Approach 3 and 4. Approach 3, calibration of Manning's n to pre and post profiles is required for vegetated banks. Vegetated banks were consistently estimated to be very stable and did not erode under the SDMF event, even when using the lowest recommended values for additional cohesion strength and increased critical shear stress. The model predicted erosion at the bank toes on both vegetated banks unless the Manning's n value was increased sufficiently to reduce shear stresses below the critical shear stress. This value is only appropriate for flows in the range of the 2013 SDMF and may not translate to higher flows. Additional field data (e.g. water surface slope, stage, discharge) to define an appropriate Manning's n value at higher flows is required. Approach 4, calibrating the applied shear stress at the toe in BSTEM to 2D model shear stresses, is the best approach for predicting erosion of un-vegetated banks. This approach is easily translatable to higher and lower flows. Increases of the magnitude and duration of flow increases bank erosion. However, the magnitude of increase varies depending on the shape of the bank profile. Short duration high flow events will initiate lateral erosion of un-vegetated bars (treated, designed, or natural). However, the amount of lateral erosion that occurs during a short duration high flow event is predicted to be a smaller percentage of the total lateral erosion that occurs over longer duration, more moderate flows that occur in the Platte River.

IV. SUMARY OF YEAR 2

The analysis conducted in year two addressed a major limitation of the calibration for the 2013 SDMF in that no erosion occurred on the vegetated banks, thus, the calibration to the minimum Manning's n values were required to reproduce zero erosion and may not be translatable to higher flows. Following the 2013 SDMF, two high flows occurred, the fall 2013 high flow and the June 2014 high flow. Both events were natural high flows and have significantly longer durations than the target SDHF duration used in the 2013 analysis. This analysis focuses on lateral erosion of vegetated bars that occurred during the June 2014 high flow.

Seven vegetated banks that exhibited differing erosion responses to the June 2014 high flow during the time period of May 5, 2014 to July 31, 2014 were selected for evaluation. BSTEM model inputs were derived from vegetation, topographic and stage data collected before and after the June 2014 high flow. All banks are vegetated and degree of lateral erosion varies from 0 to 76 feet. Vegetation varies across sites with a mix of herbaceous, woody, emergent forbs and phragmites. No profile had more than 5% bare soil. Sites were surveyed prior to the June 2014 high flow in May, and following the high flow in July. Details of each profile are provided in PRRIP (2015).

The primary finding that differed from PRRIP (2014) was that vegetated bars do not consistently have roots that extend to toe of the bank in the Shoemaker Reach. Undercutting of the bank, just below the root zone was noted on several cross-sections. The rooting depth is critical for prediction of lateral erosion. Banks that have roots that extend to the toe of the bank, tend not to erode, whereas banks that have shallower roots, have undercutting below the root zone that results in bank failures and lateral erosion.

The lateral erosion modeling focused on prediction of erosion of vegetated banks. Measured erosion at the selected profiles ranged from 0 to 76 feet.

The following conclusions can be drawn from this analysis:

- In six of the seven bank profiles modeled, BSTEM was calibrated based on pre and post surveys to within 5% using Manning's n as a calibration parameter. Calibrated values of Manning's n that were based on matching the pre and post surveyed profile ranged from 0.011 to 0.045. In the seventh bank profile, significant lateral erosion occurred and it was not possible to calibrate BSTEM using a Mannings n of a reasonable value.
- For all vegetated banks where no lateral erosion was observed, a calibrated value of Manning's N of 0.045 was found to best match field data, consistent with the findings from PRRIP (2014). The model was able to predict no lateral erosion on the vegetated bank profiles with the combined input of vegetation parameters that increased bank resistance to erosion and a Manning's n.

Based on these results, the recommend approach for prediction of lateral erosion of vegetated banks with shallow root zones (rooting depth is above the toe) is to calibrate the model on a profile by profile basis by adjusting Manning's n to match the shear stress estimated by a 2D model. The shear stresses were matched between BSTEM and the 2D model at the peak of the high flow and the resulting Manning's n was applied over the entire model period. This method produced the best estimates of lateral erosion of vegetated bars where moderate erosion occurred.

This approach over-estimates the amount of toe erosion that occurs at vegetated bars where the root zone extends to, or below, the toe of the bank. In the case of a deep rooting zone below the toe, the Manning's n value is raised to a high enough value such that the critical shear stress is higher than the applied shear stress (0.045).

BSTEM does not provide adequate results when large morphological changes occur in the channel that substantially shift shear stress applied at the toe of the bank.

V. SUMMARY OF YEAR 3

BSTEM is not sufficient at multiple sites over large areas primarily due to two significant limitations. The first limitation is the static nature of the BSTEM model when conducting analysis over a flow hydrograph. The model must be run multiple times as a series of steady flows that represent the hydrograph. The bank profile is updated at the end of each run to reflect the effects of hydraulic erosion. The geotechnical stability of the bank is evaluated at the end of each run as well and if bank failure is indicated the profile is further modified. A dynamic model where a hydrograph could be easily evaluated at a user specified time step would increase the ability to test the sensitivity of lateral erosion to flow depth and duration.

A second limitation of BSTEM is that changes in shear stress that result from erosion and deposition within the channel are not incorporated into the modeling analysis. BSTEM only analyzes the bank profile and interactions that occur between the channel bed and the bank profile are neglected. This limitation would best be overcome by linking BSTEM to a mobile- bed model that can adequately predict the formation of mid-channel/lateral bars. This coupling has been attempted in the past with varying success and is still in the research/development phase (Lai et al., 2012).

In the third year of the project, the potential to address these identified limitations was investigated with the use of a newly integrated Hydrologic Engineering Center's River Analysis System (HEC RAS version 5.0.1 http://www.hec.usace.army.mil/software/hec-ras/) model that combines the USDA-ARS Bank Stability and Toe Erosion Model (BSTEM) with HEC-RAS 5.0. The advantage of using this upgraded model is that the toe scour and bank failure processes modeled in the BSTEM model and the channel deposition and incision processes modeled in the sediment transport module of HEC RAS are coupled allowing for an evaluation that includes the interactions between the erosional processes. The combined model has been successfully validated on Goodwin Creek in northern Mississippi (Gibson et al. 2015).

The integrated HEC RAS BSTEM model requires a calibrated HEC RAS model for unsteady flow and sediment transport. The development of a new sediment transport model would require the largest amount effort, while populating the BSTEM lateral erosion components could be adapted from the existing BSTEM model directly.

The calibration approach used for the BSTEM analysis in Year and 2 that produced the best estimates of later erosion required modification of Mannings N to adjust the shear stress at the bank toe within BSTEM to match the shear stress predicted by the 2D model. This calibration approach would not be appropriate for the coupled HEC RAS BSTEM model because the modification of Mannings N to match shear stresses would also impact the water surface elevations predicted by HEC RAS and result in inconsistent hydraulics. After consultation with the model developers, it was determined that an alternative calibration approach that may work in the integrated model would be to modify the threshold (critical) shear stress, rather than Mannning's n. For example, if the 2D shear stress is twice the shear predicted in the 1D HEC RAS model, the critical shear stress at the bank would be reduced by half to achieve the same level of lateral erosion. This approach would be reasonable (and relatively quantitative) given the output available from the 2D model.

After consultation with the project team and model developers, it was concluded that the significant effort required for calibration of the unsteady sediment transport HEC RAS model in addition to testing a new BSTEM calibration approach was not justified.

VI. REFERENCES

Bankhead, N. R., 2013. “Lateral Erosion Research”, presentation to the AMP reporting session, April 22-23, 2013, Omaha, Nebraska.

Lai, Y.G., R.E. Thomas, Y. Ozeren, A. Simon, B. Greimann, and K. Wu. Coupling a two-dimensional model with a deterministic bank stability model. ASCE World Environment and Water Resources Congress, Albuquerque, New Mexico, May 20-24, 2012.

Gibson, S., Simon, A., Langendoen, E., Bankhead, N., Shelley, J. (2015) “A Physically-based Channel-modeling Framework Integrating HEC-RAS Sediment Transport Capabilities and the USDA-ARS Bank-Stability and Toe Erosion Model (BSTEM).

Platte River Recovery Implementation Program (PRRIP), 2014. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment Annual Report 2013. September 2014.

Platte River Recovery Implementation Program (PRRIP), 2015. Shoemaker Island Flow-Sediment-Mechanical “Proof of Concept” Experiment Annual Report 2014. May 2015.

Pollen-Bankhead, N, R. Thomas and A. Simon. 2012. Can Short Duration High Flows be Used to Remove Vegetation from Bars in the Central Platte River? Final report to the Platte River Recovery Implementation Program. Directed Vegetation Research Study.

Simon, A., N. Pollen-Bankhead, and R. Thomas. 2011. *Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools*, Geophysical Monograph Series 194, American Geophysical Union. 10.1029/2010GM001006.

USDA. 2010. Bank Stabilty and Toe Erosion Model: Static Version 5.2, http://ars.usda.gov/Research/docs.htm?docid=5045, viewed on October 21, 2013.

USGS. 2013. National Water Information System: Web Interface, Platte River near Grand Island. http://nwis.waterdata.usgs.gov/nwis/dv?cb_00060=on&format=gif_default&period=&begin_date=2013-04-18&end_date=2013-05-01&site_no=06770500&referred_module=sw, viewed on October 22, 2013.