Elm Creek Flow-Sediment-Mechanical Adaptive Management Experiment Final Report

Submitted to: **Platte River Recovery Implementation Program**

Submitted by: TETRA TECH
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Fort Collins, CO 80525




June 15, 2015

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Table of Contents

Page

List of Figures

List of Tables

TETRA TECH

1 INTRODUCTION

Key management objectives of the Platte River Recovery Implementation Program (Program) 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. Flow-Sediment-Mechanical (FSM) is one of the management strategies being used by the Program to meet at least the first two objectives. The FSM strategy attempts to rehabilitate the Platte River toward a braided channel morphology, a key habitat characteristic for the target species, through a combination of management actions that include short-duration, near-bankfull flow releases, sediment augmentation, and mechanical vegetation clearing and grading.

The Program is conducting the Elm Creek Adaptive Management (AM) Experiment to test a range of hypotheses related the FSM strategy in an effort to reduce uncertainty related to the interaction of physical processes and habitat availability and use in the central Platte River (PRRIP and Tetra Tech, 2011). The Experiment began in Fall 2010 with mechanical clearing and disking of most of the sand bars within the Elm Creek Complex, (ECC) and continued in subsequent years with selective clearing and grading of subsets of the bars, herbicide application to control common reed (*Phragmites australis*) and other noxious weeds, removal of trees on older, high elevation islands and significant portions of the overbanks, and construction of additional islands in portion of the reach downstream. Beginning in April 2011, Tetra Tech, Inc. conducted a detailed, 3-year, field monitoring program on behalf of the Program to collect the necessary data to test key hypotheses related to the FSM strategy.

This report presents the data collected during the three 2013 surveys, and then provides a synthesis of the overall outcome of the experiment relative to the Big Questions and Priority hypotheses using the data from all three years. The synthesis considers the highly variable flow regime during the period of the Experiment, management actions performed by the Program and others within the ECC and other upstream, off-site activities that include the mechanical actions at Cottonwood Ranch and the Pilot Sediment Augmentation study.

1.1 Program Hypotheses Related to Elm Creek AM Experiment

Two general Program hypotheses are being assessed through the Experiment (see Physical Process Hypotheses PP-1 in PRRIP, 2006):

1. The FSM strategy will increase the height of sandbars to a height suitable for tern and plover nesting.

2. The FSM strategy will increase riparian plant mortality and raise the green line, resulting in more exposed sandbar area and a wider, unvegetated main channel.

A series of related FSM-specific Big Questions, Broad Hypotheses and Priority Hypotheses are also being assessed through the Experiment **(Table 1.1**, PRRIP, 2014)

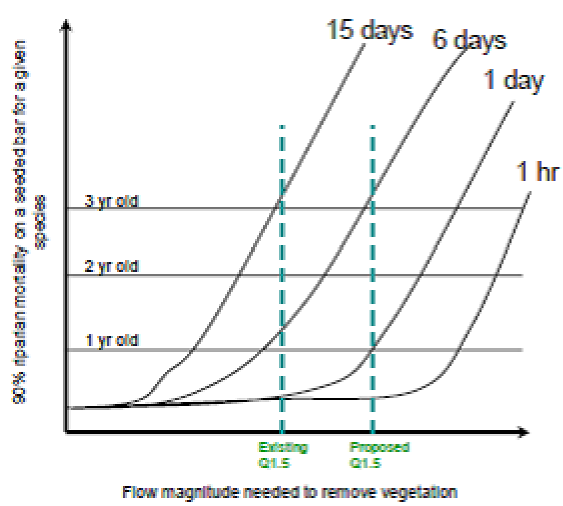
Table 1.1. Big questions, broad hypotheses and related Program Priority Hypotheses being assessed through the Elm Creek AM Experiment (from PRRIP, 2014).

PRRIP Big Questions = What we don't know but want to learn	Broad Hypotheses[1]	Priority Hypotheses[2]	2012 Assessment	2013 Assessment
Implementation – Program Management Actions and Habitat				
1. Will implementation of SDHF[3] produce suitable[4] tern and plover riverine nesting habitat on an annual or near-annual basis?	*PP-1a: Flows of 5,000 to 8,000 cfs magnitude in the habitat reach for a duration of three days at Overton on an annual or near-annual basis will build sandbars to an elevation suitable for least tern and piping plover habitat.*	Flow #1		
2. Will implementation of SDHF produce and/or maintain suitable whooping crane riverine roosting habitat on an annual or near-annual basis?	*PP-1b: Flows of 5,000 to 8,000 cfs magnitude in the habitat reach for a duration of three days at Overton on an annual or near-annual basis will increase the average width of the vegetation-free channel.*	Flow #3, Flow #5		
3. Is sediment augmentation necessary for the creation and/or maintenance of suitable riverine tern, plover, and whooping crane habitat?	*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, and reduce the potential for degradation in the north channel of Jeffrey Island resulting from headcuts.*	Sediment #1		
4. Are mechanical channel alterations (channel widening and flow consolidation) necessary for the creation and/or maintenance of suitable riverine tern, plover, and whooping crane habitat?	*PP-3: Designed mechanical alterations of the channel at select locations can accelerate changes towards braided channel conditions and desired river habitat.*	Mechanical #2		

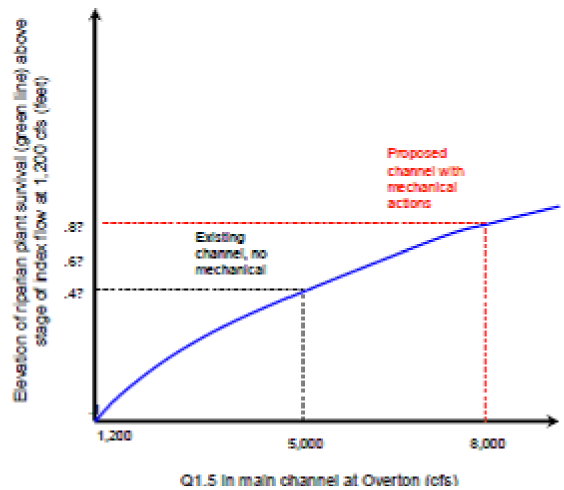
1

[1] From the Final Program Document, Adaptive Management Plan (AMP), Broad Hypotheses, Pages 14-17.
[2] From the Final Program Document, Adaptive Management Plan (AMP), Table 2, Pages 70-78. See **Appendix C** for the specific language of each Priority Hypothesis listed as well as the associated X-Y graph.
[3] Short-Duration High Flows (SDHF) = 5,000-8,000 cfs at Overton for 3 days. This is the only flow-related management action specified in the AMP.
[4] The term "suitable" is defined by the Program either as a function of habitat suitability criteria developed by the Technical Advisory Committee (see **Appendix D**) or Department of Interior (DOI) target habitat criteria in Land Plan Table 1 (see **Appendix E**).

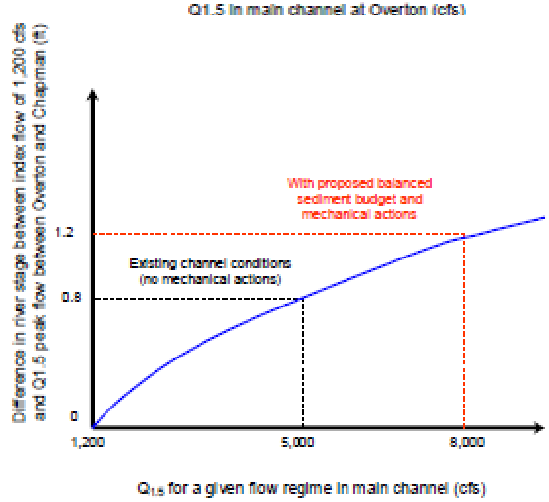
Flow #1: Increasing the variation between river stage at peak (indexed by the $Q_{1.5}$ @ Overton) and average flows (1,200-cfs index flow), by increasing the stage of the $Q_{1.5}$ through Program flows, will increase the height of sandbars between Overton and Chapman by 30 to 50 percent from existing conditions, assuming balanced sediment budget.



Flow #3: Increasing $Q_{1.5}$ with Program flows will increase local boundary shear stress and frequency of inundation at the existing green line (elevation at which riparian vegetation can establish). These changes will increase riparian plant mortality along margins of the channel, raising the elevation of the green line, providing more exposed sandbar area and a wider, unvegetated main channel.



Flow #5: Increasing the magnitude and duration of the $Q_{1.5}$ will increase riparian plant mortality along the margins of the river. There will be different relations for different species.



A series of performance measures and quantitative benchmarks (i.e., criteria) have been established for use in testing these hypotheses (**Table 1.2**). The topographic, bed and bank material, water-surface elevation and vegetation data from the 2011 and 2012 monitoring surveys and an assessment of changes and temporal trends between the sampling periods were reported in Tetra Tech (2012 and 2013).

Table 1.2. Relevant performance measures and benchmarks.

Hypothesis	Performance Measure	Benchmarks	
		Min	Target
Flow #1	Mean and maximum sandbar height relative to peak stage of formative flow event	-0.7’	0.0’
Flow #1	Mean and maximum sandbar height relative to 1,200-cfs stage for flow events of 5,000 to 8,000 cfs	1.5’	N/A
Flow #1	Unvegetated sandbar area exceeding height of 1.5 feet above 1,200-cfs stage per one-fourth mile of river channel	1.5 ac	N/A
Flow #3	Elevation of green line above 1,200-cfs stage for flow event of 5,000 to 8,000 cfs (ILT and PP nesting)	>1.5’	N/A
Flow #3	Unvegetated channel width following flow event of 5,000 to 8,000 cfs (WC roosting)	750’	1,125’
Flow #5	For flows of 5,000 to 8,000 cfs, is 90 percent of vegetation scoured in any inundated sandbar area 1.5 feet above 1,200 cfs?	YES	N/A
Flow #5	For flows of 5,000 to 8,000 cfs, channel width at which 90-percent vegetation scour is achieved.	750’	1,125’
Flow #5	Can sustain releases necessary to inundate 750 foot wide channel >0.25 feet deep for period exceeding inundation mortality threshold?	YES	N/A

Although a short-duration, high-flow release (SDHF) that met the specific range of magnitudes and durations suggested by the hypotheses was not made during the period of the Experiment, flows significantly exceeding the suggested SDHF occurred in 2011, and a short-duration, medium-flow release (SDMF) that resulted in maximum flows in the project of about 4,000 cfs and exceeded 3,000 cfs for about 3 days was made in early-April 2013. As a result, the monitoring data provides information to assess the response of sand bars and vegetation to high flows, as suggested by Priority Hypotheses Flow #1, Flow #3 and Flow #5. Significant mechanical treatment and spraying were also conducted in the project reach during the period of the Experiment; thus, the monitoring data also provide information to assess Priority Hypothesis Mechanical #2. The Program's Pilot Sediment Augmentation Project that was conducted near Overton in 2012 and early 2013 may provide limited ability to assess Priority Hypothesis Sediment #1; however, the effects of the augmentation on conditions in the ECC may not be detectable in the ECC monitoring data due to the limited amount of sediment that was input to the river, the relatively short duration and low magnitude of flows between the augmentation and the surveys, and the distance from the augmentation points. These issues will be discussed in further detail in subsequent sections of this report.

1.2 Physical Description of Elm Creek Complex

The ECC is an approximately four mile reach of the Platte River and adjacent overbanks that extends from the Elm Creek (Highway 183) Bridge at ~RM230.8 downstream to RM 227, about 2.3 miles downstream from the Kearney Diversion Structure (KDS) (**Figures 1.1 and 1.2**). Elm Creek, that has a drainage area of about 31 mi^2 and enters from the north just upstream from the KDS, is the only significant tributary in the Elm Creek Reach.

The KDS, owned and operated by the Nebraska Public Power and Irrigation District (NPPID), bisects the Complex at about RM 229.3 (**Figures 1.3 and 1.4**). This structure consists of an approximately 785-foot long weir with three 20-foot wide radial gates at the left (north) end and a single radial gate at the head of the Kearney Canal. The invert of the radial gates in the river is at Elevation 2,232 feet and the invert of the main, approximately 600-foot section of the weir is at Elevation 2,237.2 feet. The invert of the radial gates in the canal is at about Elevation 2234.4 feet. Based on results from the existing HEC-RAS model (Tetra Tech, 2012), the structure begins to create backwater at flows in the range of 1,500 cfs and the main part of the weir begins to overtop at about 2,100 cfs when all three radial gates in the river are open and no flow is being diverted into the Kearney Canal. Diversions of up to 350 cfs are made into the canal, typically beginning in April and ending in October (**Figure 1.5**). According to records provided by NPPID, the total volume of the diversions was about 89,000 ac-ft in 2009, 110,000 ac-ft in 2010 and about 101,000 ac-ft in 2011. The diversion volumes during 2012 and 2013 were only about half of the previous two years, at about 51,000 and 48,000 ac-ft, respectively.

The Elm Creek reach has a relatively straight planform alignment, with a wide, braided sand bed. Based on the 2011 survey data, the total wetted width of the nine cross sections upstream from the KDS at the 1,200-cfs index flow ranged from 645 feet to 1,120 feet, and averaged 825 feet. The 1,200-cfs width at the 13 cross sections downstream from the KDS ranged from 690 to 930 feet, and averaged 810 feet. Based on the 2011 through 2013 data from the system-wide Platte River Geomorphic and Vegetation Monitoring Program, the average total width at 1,200 cfs upstream from the KDS is about 30 percent greater than the average in Geomorphic Reach 3 (Overton to Elm Creek Bridge), and the average total width downstream from the KDS is about 50 percent narrower than the average width through Geomorphic Reach 4 (Elm Creek Bridge to the Odessa Bridge) (Tetra Tech, 2014; Fotherby, 2008; PRRIP, 2012).

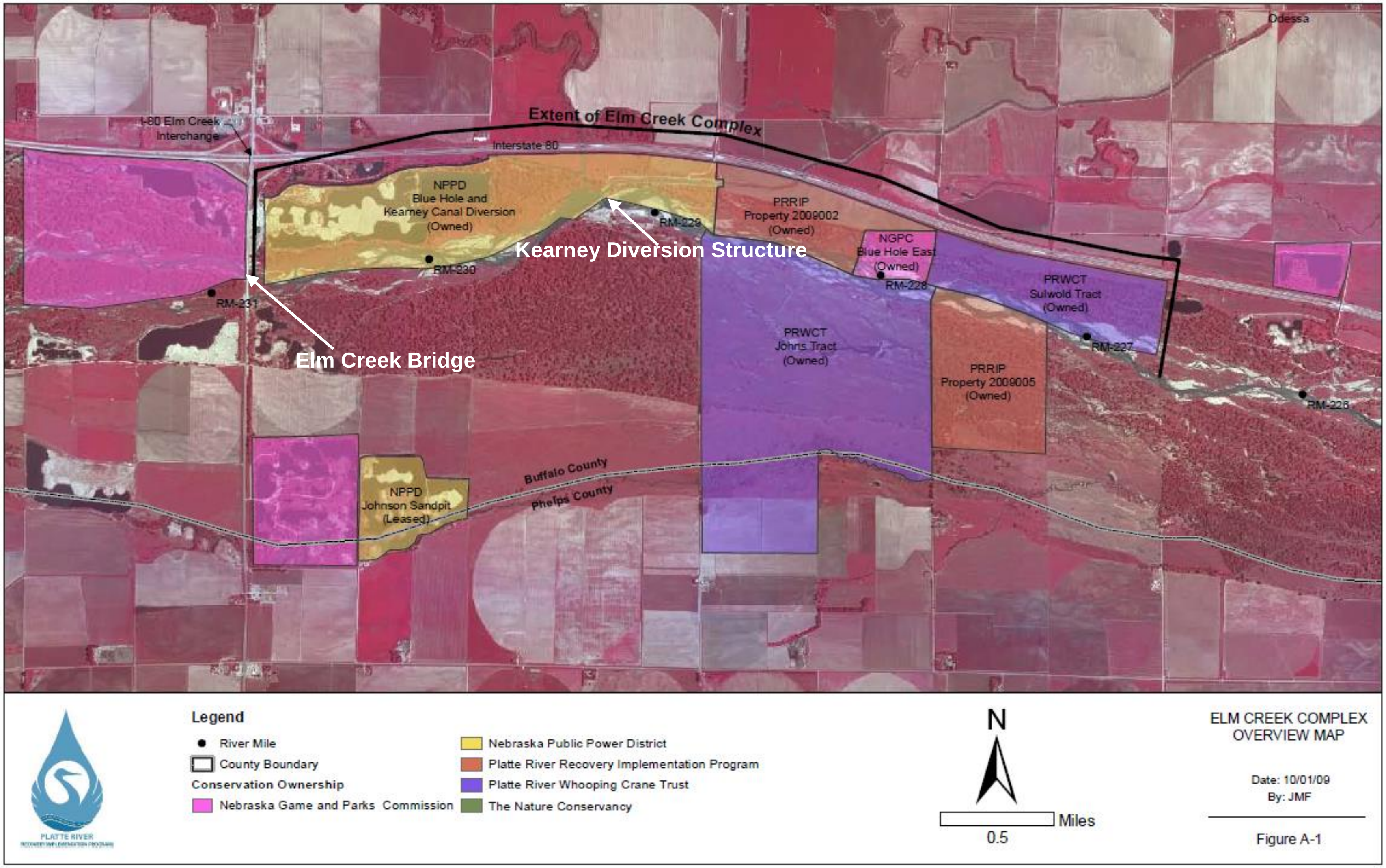


Figure 1.1. Overview map of Elm Creek Complex.

Figure 1.2. Downstream-oriented view of the upstream portion of the Elm Creek Complex. The Elm Creek (Highway 183) Bridge is visible in the foreground (Photo by R.A. Mussetter, May 2, 2012; Discharge ~2,100 cfs @ Overton, 1,800 cfs at Kearney).

Figure 1.3. Kearney Canal Diversion Structure (KDS) (photo by B. Mussetter, May 2, 2012).

Figure 1.4. Upstream-oriented view of the Kearney Canal Diversion Structure (KDS) (photo by B. Mussetter, July 12, 2011); Discharge ~ 5,800 cfs @ Overton and Kearney.

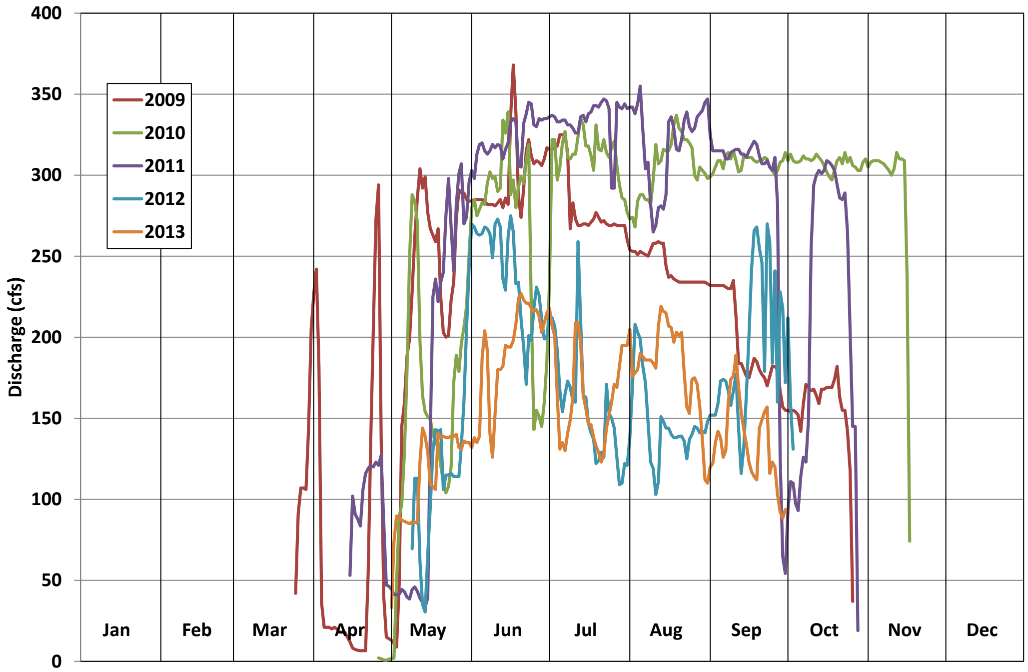


Figure 1.5. Diversions into the Kearney Canal at the KDS during the period from 2009 through 2013 (data provided by NPPID).

The 2011 survey data also indicate that the thalweg of the river drops about 24 feet between the Elm Creek Bridge and Cross Section EC-22 at the downstream end of the site, creating an overall average bed slope, including the drop across the KDS, of about 6.6 feet/mile (**Figure 1.6**). This overall gradient is slightly flatter than, but generally consistent with, the river slope over several miles up- and downstream from the ECC. For example, the gradient between AP33, located about 5.7 miles upstream from the Elm Creek Bridge, and AP 28, located just upstream from the Odessa Bridge, is about 6.5 feet/mile based on the data from Tetra Tech (2013a). The gradient of the portion of the reach upstream from the KDS is somewhat flatter than the downstream portion (~4.5 feet/mile between the Elm Creek Bridge and Cross Section EC-9 versus about 5.6 feet/mile between Cross Sections EC-10 and EC-22), most likely due to deposition in the backwater upstream from the KDS and incision downstream from the KDS. The total elevation drop between Cross Sections EC-9 and EC-10 (~1,900 feet upstream to ~600 feet downstream from the KDS) is about 7.9 feet. Based on a straight-line projection of the bed profile between Cross Sections EC-1 and EC-22, there appears to have been about 2 feet of incision at Cross Section EC-10 and about 3 feet of aggradation at Cross Section EC-9.

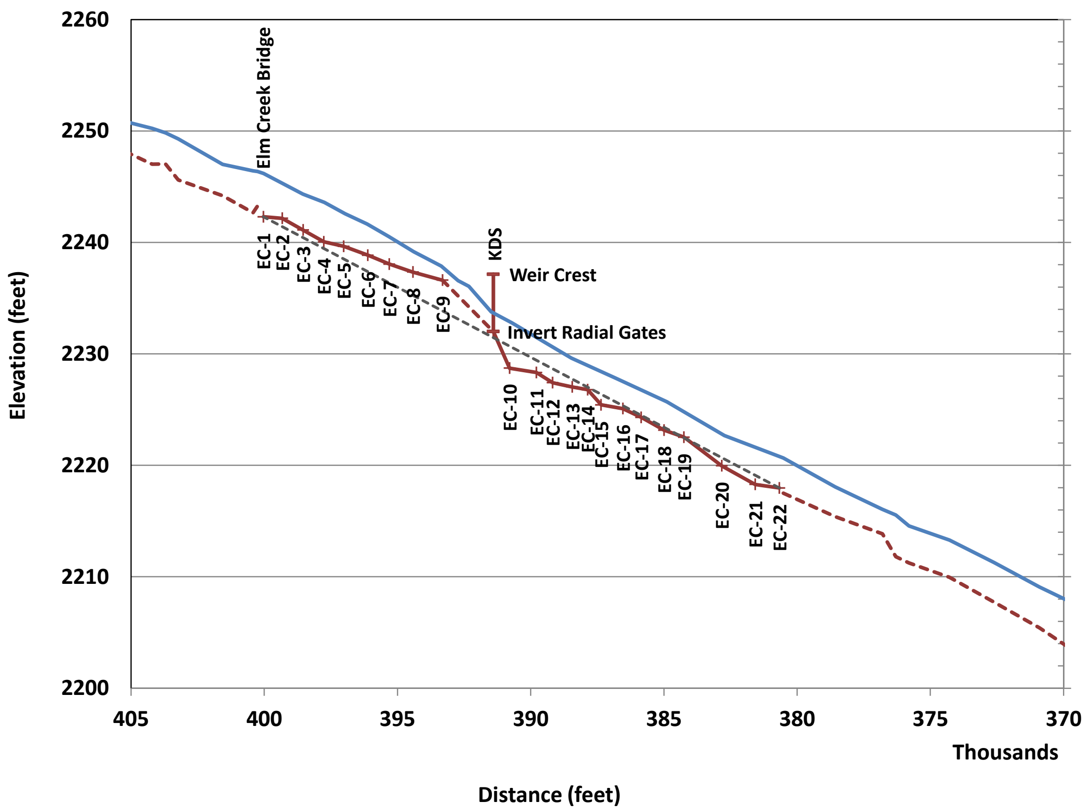


Figure 1.6. Thalweg (based on 2011 survey data) and predicted 1,200-cfs water-surface profiles through the Elm Creek Complex. Also shown is the elevation of the radial gate invert and main wier crest at the KDS.

1.3 Overview of Elm Creek AM Experiment

Prior to the start of the Elm Creek AM Experiment, the Platte River channel through the Complex had a braided planform, but significant herbaceous and woody vegetation had established on many of the islands that effectively narrowed the river and limited the potential for continued reworking of the islands by the flow to create open sandbar habitat (**Figure 1.7**). A variety of recovery-related management actions had been implemented prior to mid-2010, including NPPID's construction of an approximately 2-acre nesting island along the left side of the channel about 0.5 miles upstream from the KDS in the late-1990s and construction of nesting habitat in the left overbank at the Blue Hole site that is located in the left (north) overbank upstream from the KDS. In addition, about 213 acres of sand bars downstream from the KDS and about 84 acres of sand bars upstream from the KDS were disked in 2008 and 2009, respectively, and vegetation mowing and shredding operations were conducted on about 162 acres of sand bars in the downstream part of the reach and 59 acres in the upstream part of the reach (**Appendix A.1**)

In Fall 2010, most of the vegetated sandbars within the complex were cleared and disked (~64 acres upstream and ~44 acres downstream from the KDS), trees were cleared from an approximately 250-foot wide swath of the right (south) overbank from about 0.5 miles downstream from the Elm Creek Bridge to ~0.5 miles downstream from the KDS and from the left overbank in the vicinity of the PRRIP Cabin, and several islands in the downstream portion of the reach were cleared and disked (**Appendix A.2**).Although the experimental plan anticipated clearing and disking of a subset of the islands in 2011, the very high flows limited management actions to herbicide spraying of common reed and grass seeding in some of the overbank areas where the trees had been cleared in 2010 (**Appendix A.3**). The island clearing and disking program continued during Fall 2012 when the flows were substantially lower, with about 18 acres of disking upstream from the KDS and 21 acres of disking downstream from the KDS (**Appendix A.4**) to produce a mosaic of vegetation year classes. In addition, nine new islands with total surface area of about 20 acres were constructed in the portion the reach downstream from the KDS, and herbicide spraying continued throughout the reach in areas infested with common reed[1].

Other FSM-related management actions that occurred during the period of the AM Experiment that have the potential to impact the Complex include the 2012/2013 Pilot Sediment Augmentation Study that introduced approximately 182,000 tons of new sediment into the river (~82,000 tons at the Dyer Property upstream from Overton and ~100,000 tons at Cottonwood Ranch) and the Short-duration Medium Flow (SDMF) release that occurred in mid-April 2013. It should also be noted that direct grading of approximately 50,000 tons/year of sediment into the river occurred at Cottonwood Ranch for several years prior to the start of the Elm Creek AM Experiment.

Field data collection and sampling were conducted in 2011, 2012 and 2013 following procedures spelled out in the Project-scale Geomorphology and Vegetation Monitoring Protocol (PRRIP, 2011) to provide the information to assess the response of the river to the above actions. A total of seven individual surveys were completed during the three-year period that included a broad range of flows from the very dry conditions in 2012 to the very wet, sustained high-flow conditions in 2011 (**Figure 1.8**). Two surveys were conducted during each year, with the first in late-April or early-May, prior to the snowmelt runoff, and the second in late-August or early-September, at the end of the summer. A third survey was added in early-April 2013 to isolate the effects of the mid-April SDMF.

[1]The PRRIP management database shows only 8 islands with total area of 23 acres; however, one additional ~1.4 acre, constructed island appears on the November 2012 aerial photograph about 1.3 miles downstream from the KDS.

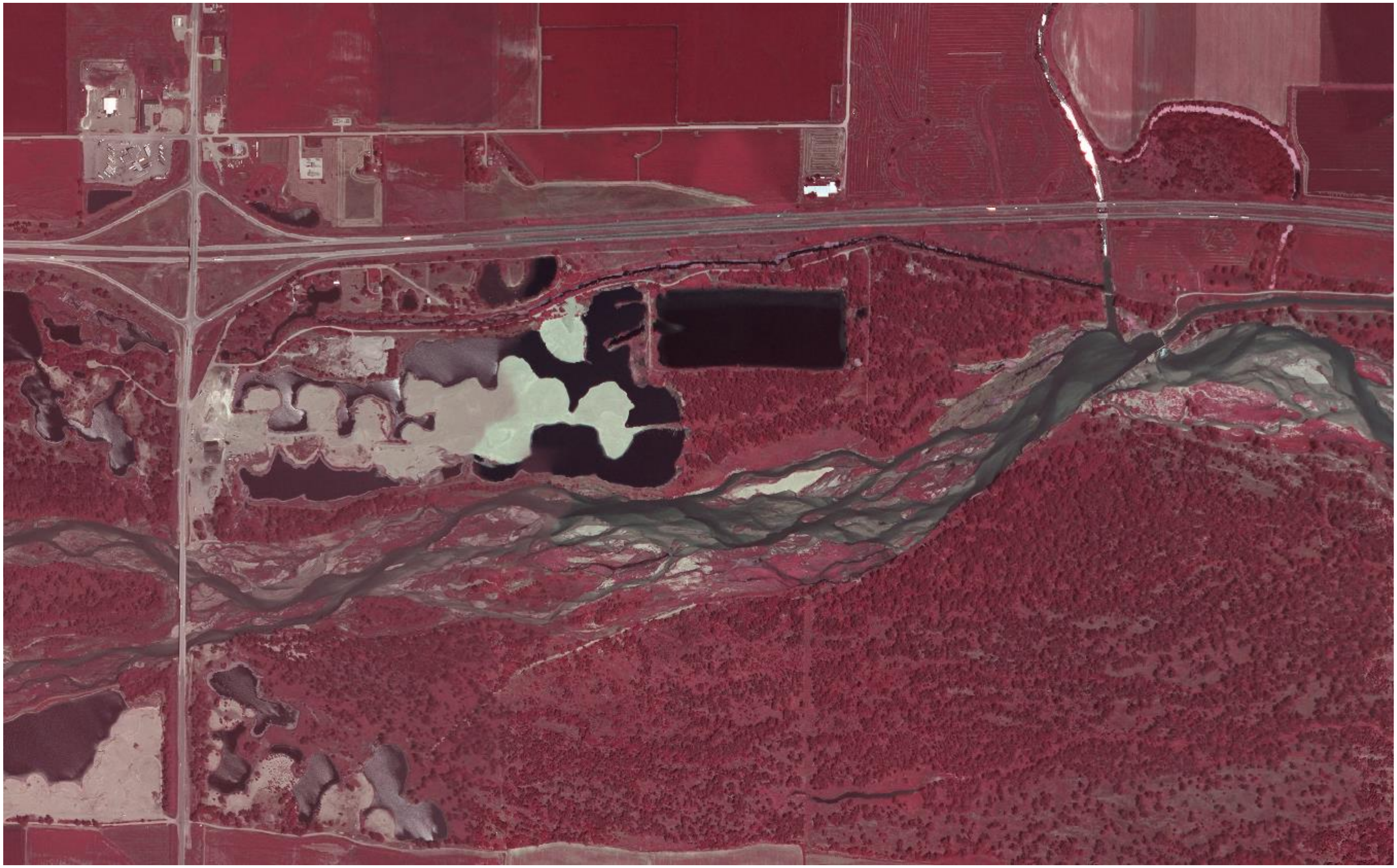


Figure 1.7a. Color Infrared aerial photograph of the upstream portion of the Elm Creek Reach (July 15, 2009; Mean daily discharge: Overton=358 cfs, KDS Diversion=270 cfs).

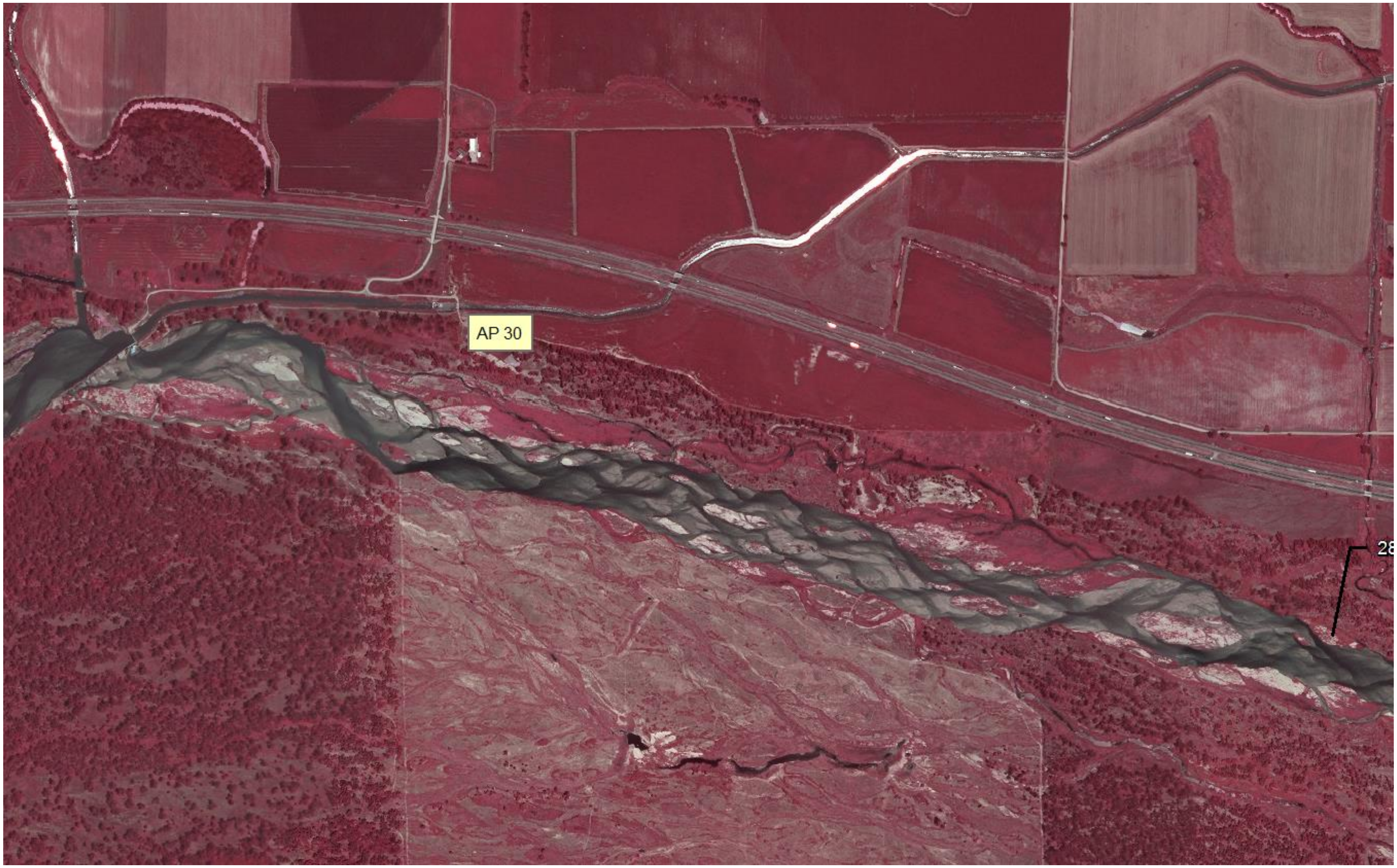


Figure 1.7b. Color Infrared aerial photograph of the downstream portion of the Elm Creek Reach (July 15, 2009; Mean daily discharge: Overton=358 cfs, KDS Diversion=270 cfs, Odessa=309 cfs).

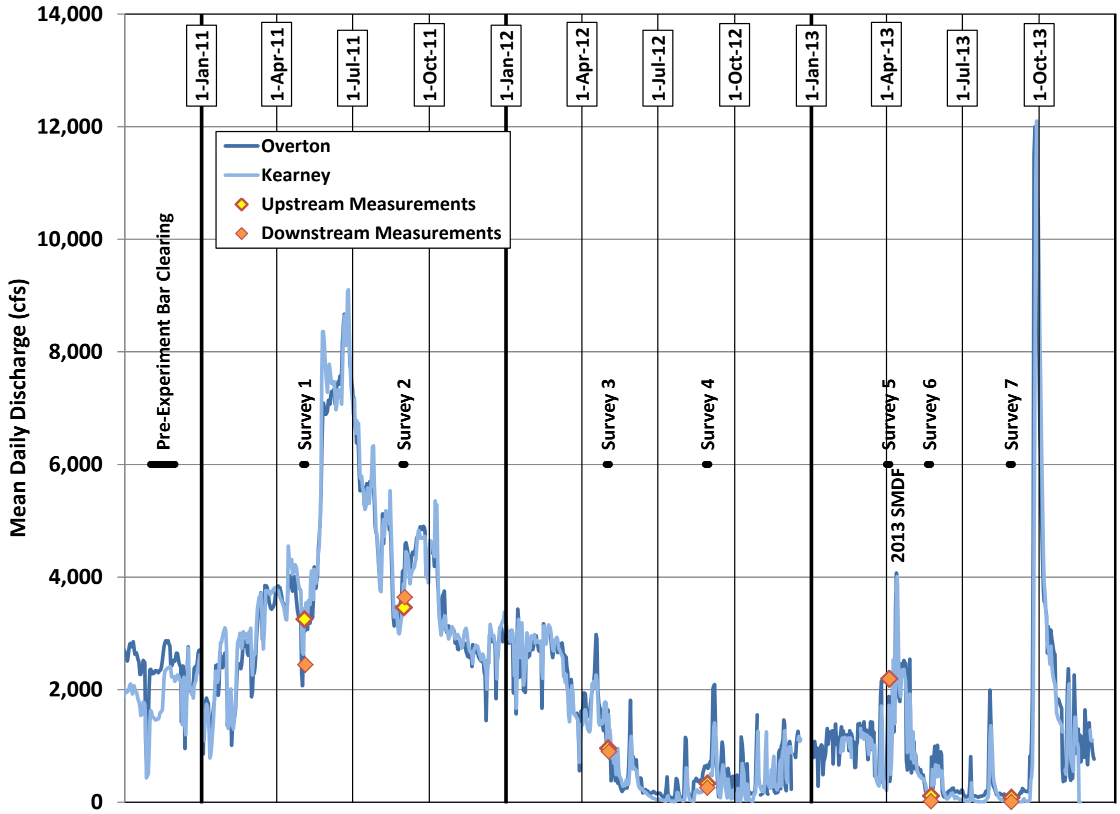


Figure 1.8. Mean daily flows at Overton (USGS Gage No. 6768000), Cottonwood Ranch[2] (USGS Gage Nos. 06768035 and 06768025) and Kearney (USGS Gage No. 6770200) during the Elm Creek Adaptive Management Experiment (provisional flows for WY2013 and WY2014). Also shown are the measured discharges from the Elm Creek monitoring surveys up- and downstream from the KDS.

[2] Includes total river flow up to about 3,000 cfs; ungaged flow in North Channel at higher flows not represented by these two gage.

2 TOPOGRAPHIC AND BATHYMETRIC SURVEYS

The topographic and bathymetric surveys conducted during each of the sampling events included 22 river transects extending from high-bank to high-bank, the perimeter and topography of all exposed sandbars (30 total bars during both sampling periods), the corner coordinates of the vegetation sampling plots, and other relevant topography, including the top-of-bank in limited areas between cross sections where the bankline appears to be migrating. Details of the 2011 and 2012 surveys were provided in Tetra Tech (2012 and 2013b). As noted above, three surveys were conducted in 2013. The first survey was conducted during the week of April 1 through 5, when the discharge at Overton ranged from 300 to 2,190 cfs and averaged about 1,080 cfs (**Figure 2.1**; **Table 2.1**). The discharge at Kearney during this period ranged from 200 to 1,980 cfs, and averaged 870 cfs. The SDMF occurred between April 11 and 16, and had peak discharges at Overton and Kearney of 3,910 and 4,080 cfs, respectively. The second survey was conducted during the week of May 20 through 24, when the discharge was relatively steady at about 150 cfs at Overton and about 210 cfs at Kearney. The final survey was conducted during the week of August 26 through 30. The discharge was also relatively steady during the last survey at about 125 cfs at Overton and only 12 to 15 cfs at Kearney.

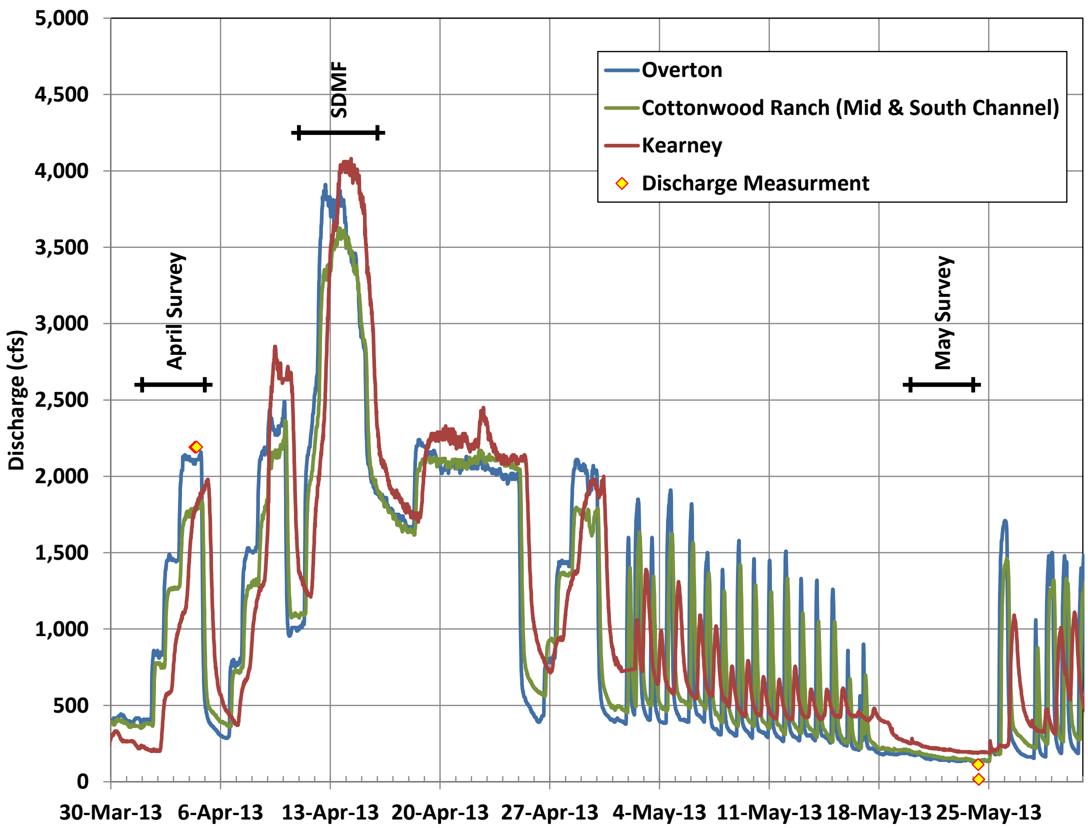


Figure 2.1. Recorded (provisional) discharges at the USGS Overton, Cottonwood Ranch[1] and Kearney gages during the April-May 2013 survey period.

Table 2.1. Summary of monitoring survey dates and mean daily discharges during the surveys (cfs).

Year	Date	Overton			Cottonwood Ranch[1]			Diversion from KDS			Kearney		
		Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
2011	May 2 - May 6	2,870	2,070	3,430	2,448	2,080	2,730	-42	-45	-41	3,100	2,630	3,540
2011	Aug 29 - Sept 2	4,110	3,690	4,580	2,992	2,760	3,240	-334	-347	-315	3,734	3,290	4,060
2012	April 30 - May 4	1,180	900	1,640	1,141	603	1,590	0	0	0	1,492	1,100	1,880
2012	Aug 27 - Aug 31	630	600	660	648	610	706	-143	-148	-141	409	371	445
2013	April 1 - April 5	1,169	371	1,880	981	469	1,590	0	0	0	955	211	1,790
2013	May 20 - May 24	150	140	180	155	132	185	-138	-139	-138	212	192	246
2013	Aug 26 - Aug 30	130	120	140	87	75	101	-150	-175	-112	10	8	13

[1]Sum of Mid and South Channel gages; may be additional ungaged flow in North Channel when total discharge exceeds 3,000 cfs.

2.1 Survey Procedures and Control

Field procedures used to collect the channel topography and bathymetry followed the protocol described in PRRIP (2011) and the Geomorphology and Vegetation Monitoring and Analysis Plan specifically developed for this project (Tetra Tech, 2011; **Appendix B**). The surveys were conducted using a real-time, kinematic survey-grade global position system (RTK-GPS) that consisted of two Leica Viva roving data collectors (**Figure 2.2**) and a Leica Viva base station that was set up on a known control point near the KDS to provide ground-correction to the satellite signal (**Figure 2.3**). As will be discussed in more detail below, flows were too deep and swift to wade in some locations during some of the surveys. When this occurred, the RTK-GPS was dynamically linked to a Sonarmite Echosounder that was mounted onto a boat and paddled across the cross section to obtain the data.

All surveyed points were referenced horizontally to the North American Datum of 1983 (NAD 1983) and vertically to the North American Vertical Datum of 1988 (NAVD 1988). The primary local control that was used to provide ground-correction to the GPS satellite signal, and on which the base station was set, is a permanent survey monument set and maintained by NPPID near the left wingwall of the KDS (CP-1 in **Figure 2.4**). Two other monuments were used as check points to insure that the GPS was properly configured. One of these points is a #4 rebar stake that is located on the west side of the steps at the KDS (CP-2), and the other is a 4-inch diameter disk embedded in the deck on the left end of the Elm Creek (Highway 183) Bridge (CP-3) (Figure 2.3).

2.2 Cross Sections

Twenty-two (22) primary river cross sections that were originally established during the May 2011 baseline survey were re-surveyed during each of the subsequent monitoring surveys (**Figure 2.5**, **Table 2.2**). During the baseline survey, the cross-section end points were monumented with a #4 rebar stake, labeled aluminum cap, and the coordinates recorded to insure that they can be relocated during future surveys. The average spacing of the cross sections (excluding the approximately 1,100-foot reach in the backwater upstream from the KDS), is approximately 880 feet, which is consistent with the average topwidth of the main channel in the project reach.

Most of the project reach during the 2011 surveys, the right end of the most upstream cross section in May and August 2012, and the left channel at Cross Sections 6 and 9 during the April 2013 survey were too deep to wade. For these portions of the cross sections, the bathymetry was measured using a Sonarmite Echosounder dynamically linked to one of the Leica Viva roving units and mounted in a porthole in the floor of a specially fabricated inflatable kayak (**Figure 2.6**). This configuration provides excellent ability to control the location and orientation of the sensor while traversing the river along the measurement transect.

Figure 2.2. RTK-GPS roving unit being operated by the Tetra Tech field crew during the May 2012 baseline survey.

Figure 2.3. View looking upstream of the GPS base station set up on the primary survey control point near the left wingwall of the Kearney Diversion Structure.

Name	Point X	Point Y	Point Z
CP 1	1820496.67	312004.85	2242.67
CP 2	1820508.53	311991.38	2242.89
CP 3	1812243.84	310217.62	2261.93

Figure 2.4. Control points used for the GPS base station (CP-1) and check shots (CP-2 and CP-3) during the May and August surveys.

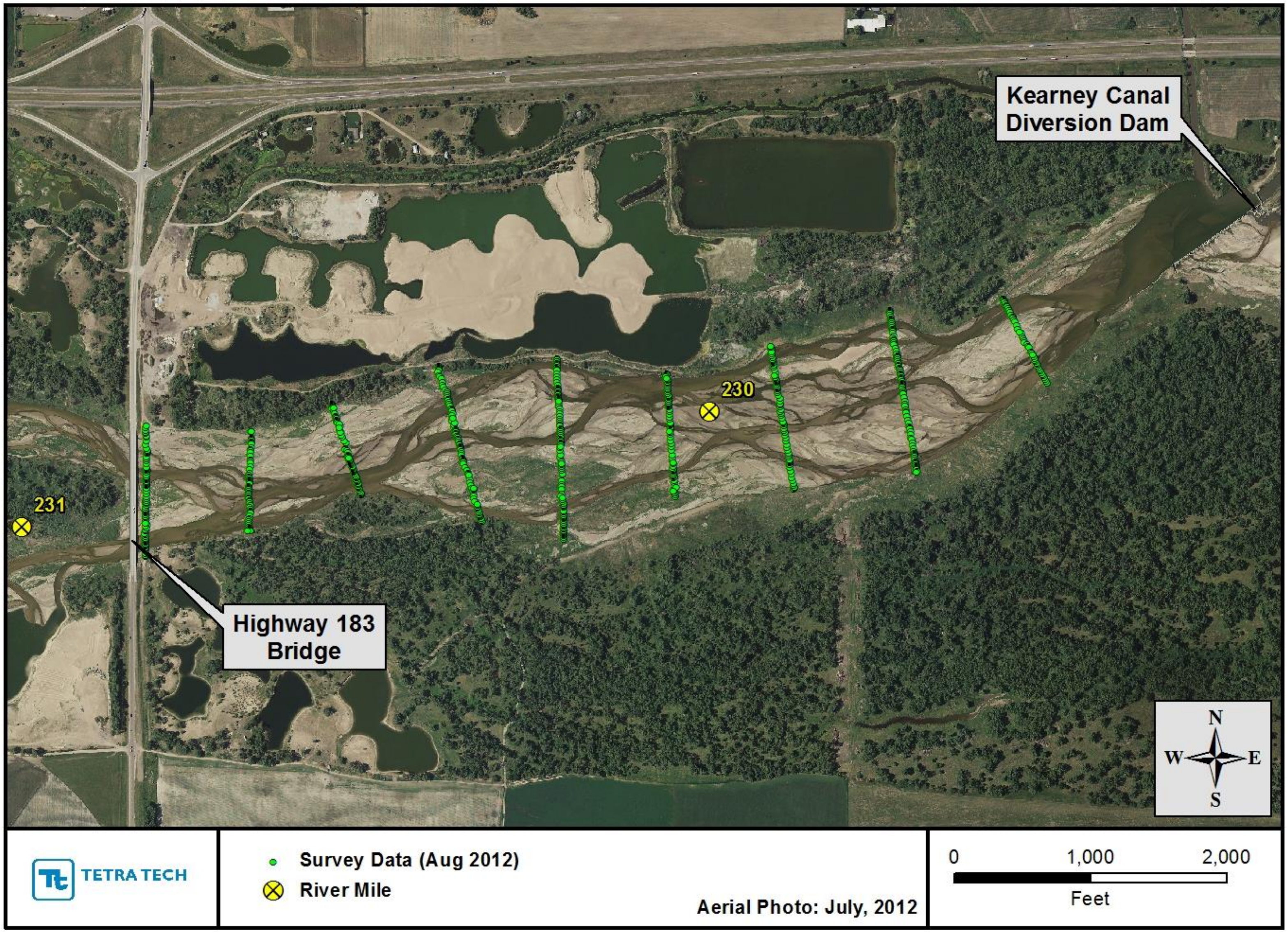


Figure 2.5a. Primary river cross sections upstream from the Kearney Diversion Structure surveyed during each of the sampling periods.

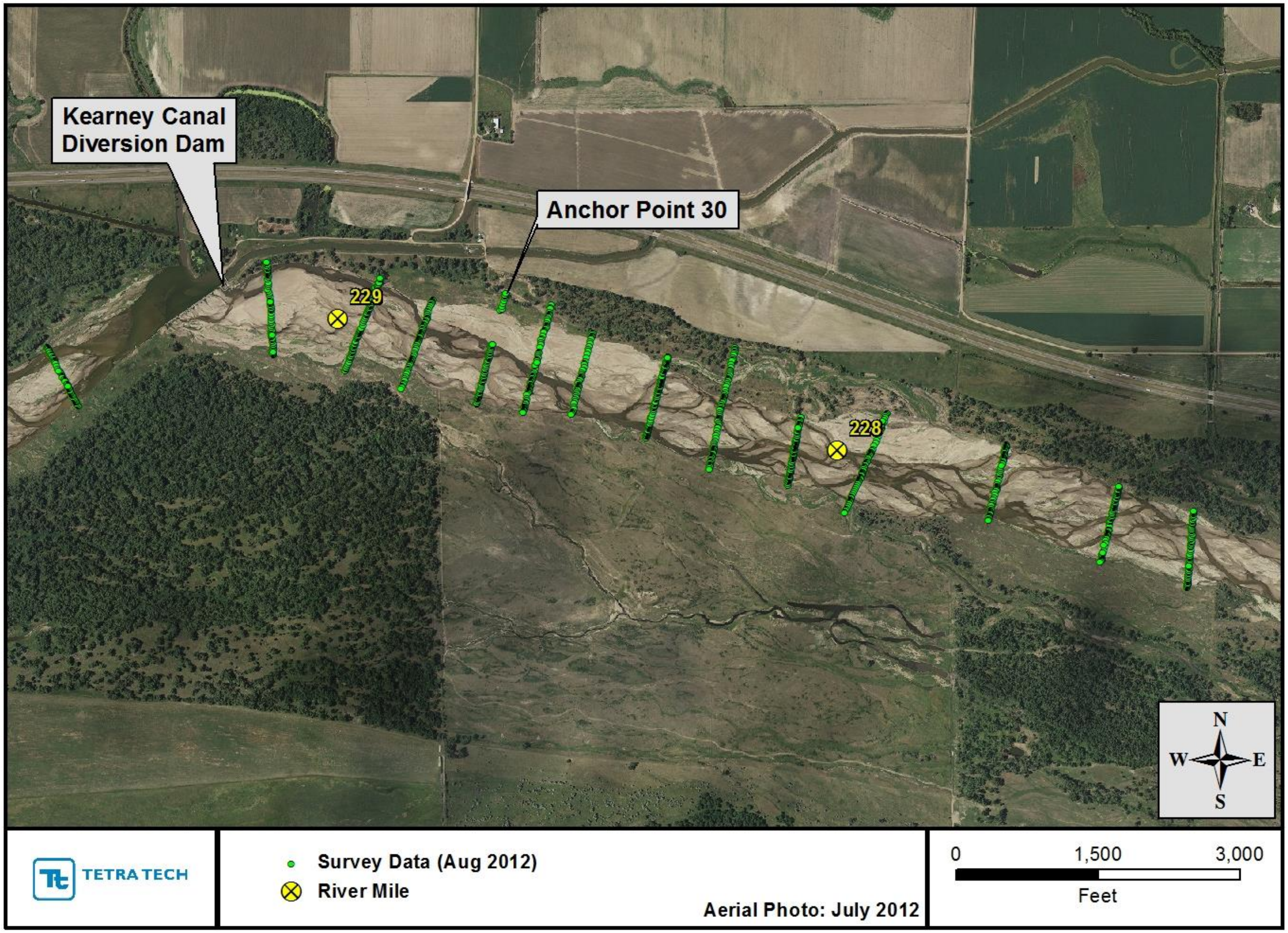


Figure 2.5b. Primary river cross sections upstream from the Kearney Diversion Structure surveyed during each of the sampling periods.

Table 2.2. Summary of cross section end-point coordinates.

Cross Section	River Station (ft)	Left End Pin			Right End Pin		
		North (ft)	East (ft)	Elevation (ft)	North (ft)	East (ft)	Elevation (ft)
XS 1	400,032	310,286.3	1,812,364.1	2,251.5	309,328.7	1,812,363.7	2,251.5
XS 2	399,323	310,250.3	1,813,133.7	2,247.4	309,515.4	1,813,113.0	2,247.9
XS 3	398,541	310,451.2	1,813,727.6	2,247.2	309,781.1	1,813,943.1	2,246.5
XS 4	397,762	310,722.8	1,814,510.1	2,257.9	309,934.2	1,814,728.1	2,246.9
XS 5	397,020	310,779.9	1,815,380.3	2,255.0	309,763.2	1,815,425.2	2,246.5
XS 6	396,112	310,672.3	1,816,187.8	2,252.8	309,766.2	1,816,250.5	2,245.0
XS 7	395,303	310,874.2	1,816,948.9	2,242.8	309,820.8	1,817,119.4	2,242.8
XS 8	394,418	311,134.4	1,817,823.1	2,241.7	309,948.3	1,818,022.8	2,241.7
XS 9	393,309	311,222.3	1,818,655.0	2,240.3	310,643.6	1,818,953.1	2,240.3
XS 10	390,791	312,127.6	1,820,973.9	2,241.2	311,142.3	1,821,037.7	2,236.3
XS 11	389,787	311,956.4	1,822,171.1	2,238.3	310,974.6	1,821,800.3	2,235.5
XS 12	389,175	311,727.6	1,822,727.5	2,234.4	310,785.6	1,822,394.5	2,235.2
XS 13	388,435	311,796.4	1,823,497.0	2,240.1	310,623.7	1,823,187.4	2,234.9
XS 14	387,863	311,671.6	1,823,981.3	2,234.8	310,540.2	1,823,682.4	2,231.7
XS 15	387,358	311,377.5	1,824,418.7	2,232.1	310,514.0	1,824,192.7	2,232.4
XS 16	386,537	311,126.9	1,825,212.2	2,231.5	310,270.9	1,824,982.0	2,231.6
XS 17	385,851	311,231.0	1,825,924.9	2,230.5	309,933.0	1,825,648.9	2,230.3
XS 18	384,993	310,491.7	1,826,618.6	2,233.0	309,763.8	1,826,481.6	2,228.8
XS 19	384,245	310,365.6	1,827,469.1	2,228.2	309,478.0	1,827,080.5	2,228.0
XS 20	382,827	310,191.5	1,828,795.5	2,226.3	309,392.4	1,828,598.5	2,226.6
XS 21	381,573	309,754.7	1,829,980.9	2,225.2	308,958.9	1,829,785.7	2,224.8
XS 22	380,668	309,493.8	1,830,770.4	2,224.5	308,684.3	1,830,702.9	2,223.4

Figure 2.6. Inflatable kayak to which the Echosounder and RTK-GPS were mounted to paddle across a cross section during the May 2012 baseline survey.

The spacing of the individual survey points across the cross sections varied depending on the technique being used in each portion of the cross section. Points that were surveyed directly with the RTK-GPS rover were located at key geomorphic features and at all significant grade breaks between these points, resulting in typical average spacing of 8 to 10 feet. The spacing of the recorded points from the echosounder depends on a variety of factors including the sampling frequency and the speed at which the sampler is moving. For this portion of the surveys, the typical spacing was in the range of 1.5 to 2.0 feet. In general, the resulting spacing provides high resolution for plotting and interpreting the cross-section data.

The cross-section data from the surveys were reduced and compared to assess general aggradation/degradation trends along the reach (**Appendix C.1**). The cross sections are intended to represent the bed profile along a straight line that runs across the channel perpendicular to the flow. Re-surveying of the same lines provides a means of directly comparing changes in the bed topography over the interval between the surveys. Because it is not possible to precisely follow the intended straight line between the cross-section endpoints, the horizontal location of the individual survey points was projected perpendicularly onto a straight line between the cross-section endpoints for purposes of the analysis to insure that the cross-section length is accurately represented (**Figure 2.7**).

The changes in cross-sectional area within the active channel were computed based on the cross-section profiles (**Figure 2.8**[3], Appendix C.1; **Table 2.3**). The net change in sediment volume within the reach encompassed by the cross sections was then computed using the average end-area method (**Figures 2.9 and 2.10**). The largest changes in bed-sediment volume between successive surveys of up to 10 ac-ft occurred at Cross Section (XS) 8 and XS9 in the upstream part of the reach and at XS10 that is located just downstream from the KDS. In the

[3]Similar plots for all of the cross sections, along with the raw and reduced survey data are provided in Appendix C.

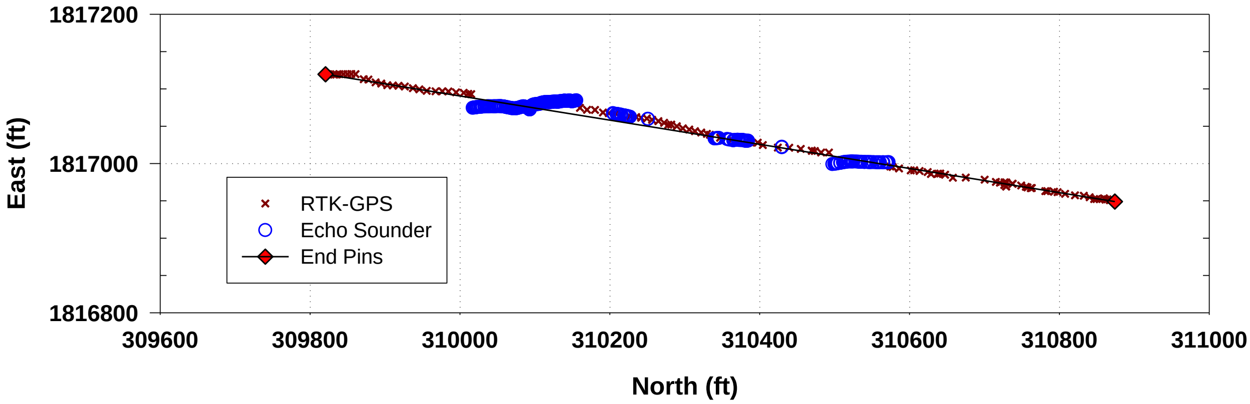


Figure 2.7. Example plan view of survey points taken directly with the RTK-GPS roving unit (red x), and Sonarmite Echosounder (blue circles) during the August, post-runoff survey. Also shown are the cross section endpoints and the connecting straight line onto which the survey points were projected.

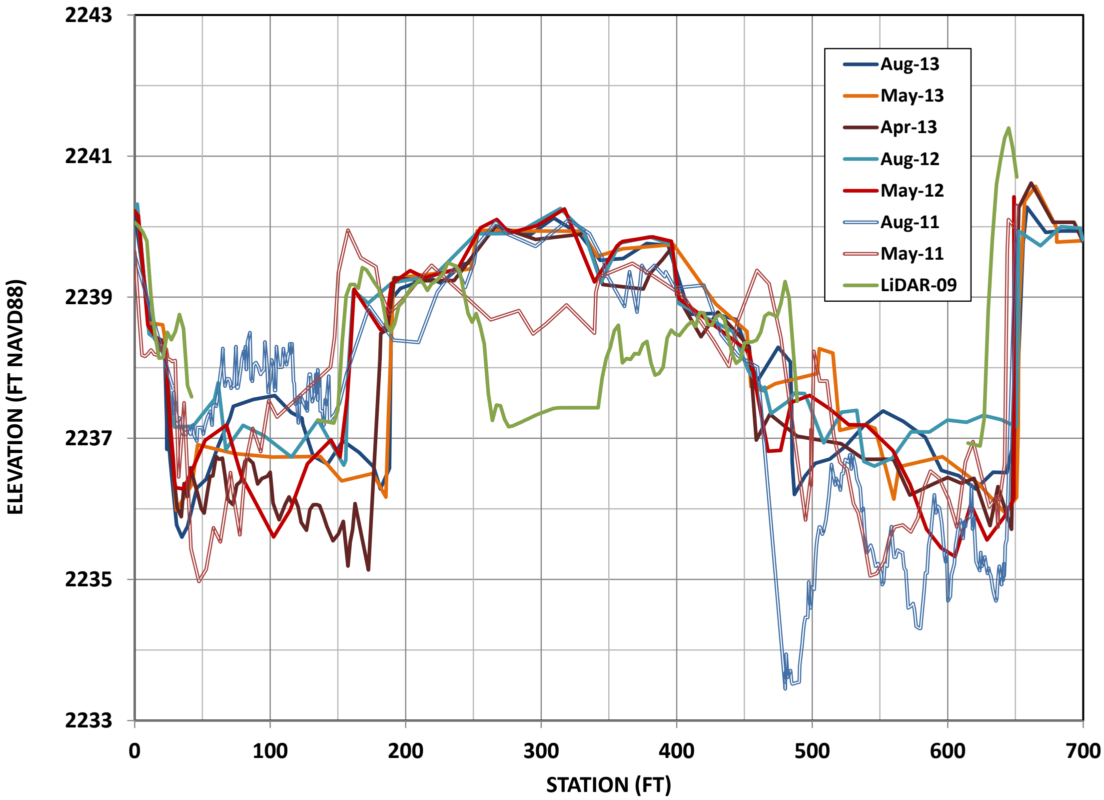


Figure 2.8. Typical profiles at Cross Section 9 from the seven surveys and from the 2009 LiDAR data.

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Table 2.3a. Change in cross-sectional area between surveys at the Elm Creek site.

Cross Section	Station (feet)	Change in Cross Sectional Area (ft^2)											
		from Previous Survey						from May 2011 Baseline Survey					
		Aug-11	May-12	Aug-12	Apr-13	May-13	Aug-13	Aug-11	May-12	Aug-12	Apr-13	May-13	Aug-13
Upstream from KDS													
XS 1	400,032	-383	142	-60	83	79	-53	-383	-240	-301	-217	-139	-192
XS 2	399,323	109	9	3	-16	-2	26	109	118	121	105	103	129
XS 3	398,541	9	43	6	3	15	-23	9	51	57	60	75	52
XS 4	397,762	-65	-17	-18	-23	-4	-2	-65	-82	-100	-123	-127	-129
XS 5	397,020	30	-117	-63	57	18	-61	30	-87	-150	-93	-75	-136
XS 6	396,112	150	28	39	-195	-24	-16	150	178	217	22	-2	-18
XS 7	395,303	-94	-1	-50	-195	108	22	-94	-94	-145	-339	-231	-210
XS 8	394,418	-285	-75	-32	-421	78	82	-285	-360	-392	-813	-735	-653
XS 9	393,309	-104	136	188	-349	207	-202	-104	32	220	-129	78	-124
Downstream from KDS													
XS 10	390,791	207	-213	-13	419	-161	-92	207	-6	-19	400	239	147
XS 11	389,787	-295	6	-33	6	107	-58	-295	-289	-322	-316	-209	-267
XS 12	389,175	-74	-108	40	15	139	-7	-74	-182	-141	-126	13	6
XS 13	388,435	49	-52	50	58	172	-25	49	-4	46	103	275	250
XS 14	387,863	188	-140	259	-434	163	-37	188	48	308	-126	37	0
XS 15	387,358	259	-97	146	-237	114	-27	259	162	308	71	185	158
XS 16	386,537	97	24	1	-93	132	-25	97	121	121	29	161	136
XS 17	385,851	70	35	-11	-237	218	6	70	105	94	-143	75	81
XS 18	384,993	5	-52	-57	-48	108	-2	5	-46	-103	-151	-43	-45
XS 19	384,245	-43	82	6	-36	70	-69	-43	39	45	9	78	10
XS 20	382,827	-172	45	37	-137	148	17	-172	-127	-90	-227	-79	-62
XS 21	381,573	105	-156	-38	13	88	-36	105	-51	-88	-75	12	-23
XS 22	380,668	-155	-129	44	-24	54	11	-155	-284	-239	-264	-210	-198
Average													
Upstream from KDS		**-70**	**17**	**1**	**-117**	**53**	**-25**	**-70**	**-54**	**-52**	**-170**	**-117**	**-142**
Downstream from KDS		**18**	**-58**	**33**	**-57**	**104**	**-26**	**18**	**-40**	**-6**	**-63**	**41**	**15**

Table 2.3b. Estimated change in bed sediment volume based on the changes in cross-sectional area between surveys at the Elm Creek site (-aggradation/+degradation).

Cross Section	Station (feet)	Change in Bed Sediment Volume (ac-ft)											
		from Previous Survey						from May 2011 Baseline Survey					
		Sep-11	May-12	Aug-12	Apr-13	May-13	Aug-13	Sep-11	May-12	Aug-12	Apr-13	May-13	Aug-13
Upstream from KDS													
XS 1	400,032	-3.59	1.33	-0.57	0.78	0.74	-0.50	-3.59	-2.25	-2.82	-2.04	-1.30	-1.80
XS 2	399,323	1.86	0.16	0.05	-0.28	-0.03	0.45	1.86	2.02	2.07	1.79	1.76	2.21
XS 3	398,541	0.15	0.76	0.11	0.05	0.27	-0.40	0.15	0.92	1.02	1.07	1.34	0.94
XS 4	397,762	-1.14	-0.29	-0.31	-0.40	-0.08	-0.04	-1.14	-1.43	-1.74	-2.14	-2.22	-2.26
XS 5	397,020	0.56	-2.22	-1.19	1.08	0.34	-1.15	0.56	-1.66	-2.85	-1.77	-1.43	-2.58
XS 6	396,112	2.96	0.55	0.77	-3.84	-0.47	-0.32	2.96	3.51	4.27	0.43	-0.04	-0.35
XS 7	395,303	-1.82	-0.01	-0.98	-3.78	2.09	0.42	-1.82	-1.83	-2.81	-6.59	-4.50	-4.08
XS 8	394,418	-6.52	-1.71	-0.74	-9.64	1.79	1.88	-6.52	-8.24	-8.97	-18.61	-16.82	-14.94
XS 9	393,309	-2.65	3.45	4.79	-8.89	5.28	-5.14	-2.65	0.81	5.60	-3.29	1.99	-3.15
Downstream from KDS													
XS 10	390,791	5.05	-5.21	-0.32	10.26	-3.93	-2.26	5.05	-0.15	-0.48	9.78	5.85	3.59
XS 11	389,787	-5.48	0.11	-0.60	0.12	1.98	-1.07	-5.48	-5.37	-5.97	-5.85	-3.87	-4.95
XS 12	389,175	-1.15	-1.67	0.63	0.23	2.16	-0.11	-1.15	-2.82	-2.19	-1.96	0.20	0.09
XS 13	388,435	0.73	-0.79	0.75	0.87	2.59	-0.38	0.73	-0.06	0.69	1.56	4.15	3.77
XS 14	387,863	2.33	-1.73	3.21	-5.36	2.01	-0.45	2.33	0.60	3.80	-1.56	0.45	0.00
XS 15	387,358	3.95	-1.48	2.22	-3.60	1.73	-0.41	3.95	2.47	4.69	1.09	2.82	2.41
XS 16	386,537	1.67	0.42	0.01	-1.61	2.29	-0.44	1.67	2.09	2.10	0.49	2.78	2.35
XS 17	385,851	1.23	0.63	-0.19	-4.21	3.87	0.10	1.23	1.86	1.67	-2.54	1.33	1.44
XS 18	384,993	0.10	-0.95	-1.04	-0.89	1.99	-0.03	0.10	-0.85	-1.90	-2.79	-0.80	-0.83
XS 19	384,245	-1.07	2.04	0.14	-0.89	1.73	-1.71	-1.07	0.97	1.11	0.22	1.95	0.24
XS 20	382,827	-5.28	1.38	1.15	-4.21	4.55	0.53	-5.28	-3.90	-2.75	-6.97	-2.42	-1.89
XS 21	381,573	2.61	-3.86	-0.93	0.32	2.18	-0.88	2.61	-1.25	-2.19	-1.87	0.31	-0.57
XS 22	380,668	-3.22	-2.68	0.92	-0.50	1.12	0.24	-3.22	-5.90	-4.98	-5.48	-4.36	-4.12
Average													
Upstream from KDS		**-10.18**	**2.03**	**1.93**	**-24.92**	**9.93**	**-4.79**	**-10.18**	**-8.15**	**-6.22**	**-31.14**	**-21.21**	**-26.00**
Downstream from KDS		**1.48**	**-13.80**	**5.92**	**-9.48**	**24.26**	**-6.88**	**1.48**	**-12.32**	**-6.40**	**-15.88**	**8.39**	**1.51**

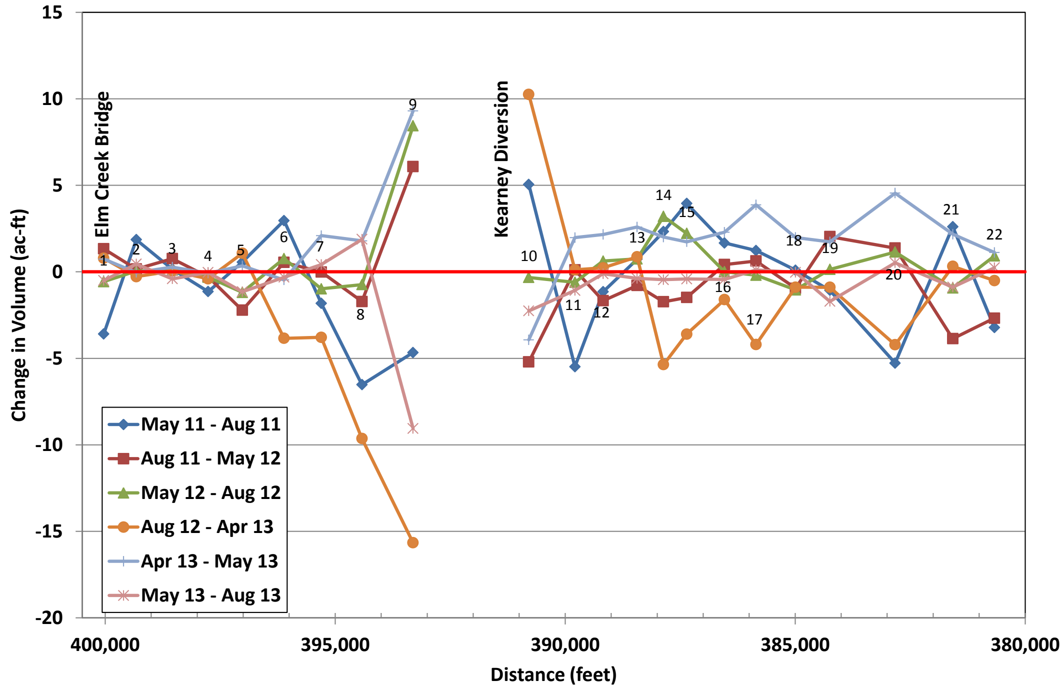


Figure 2.9. Incremental change in bed sediment volume [i.e., aggradation (+) or degradation (-)] between the surveys, based on area change and length between each cross section.

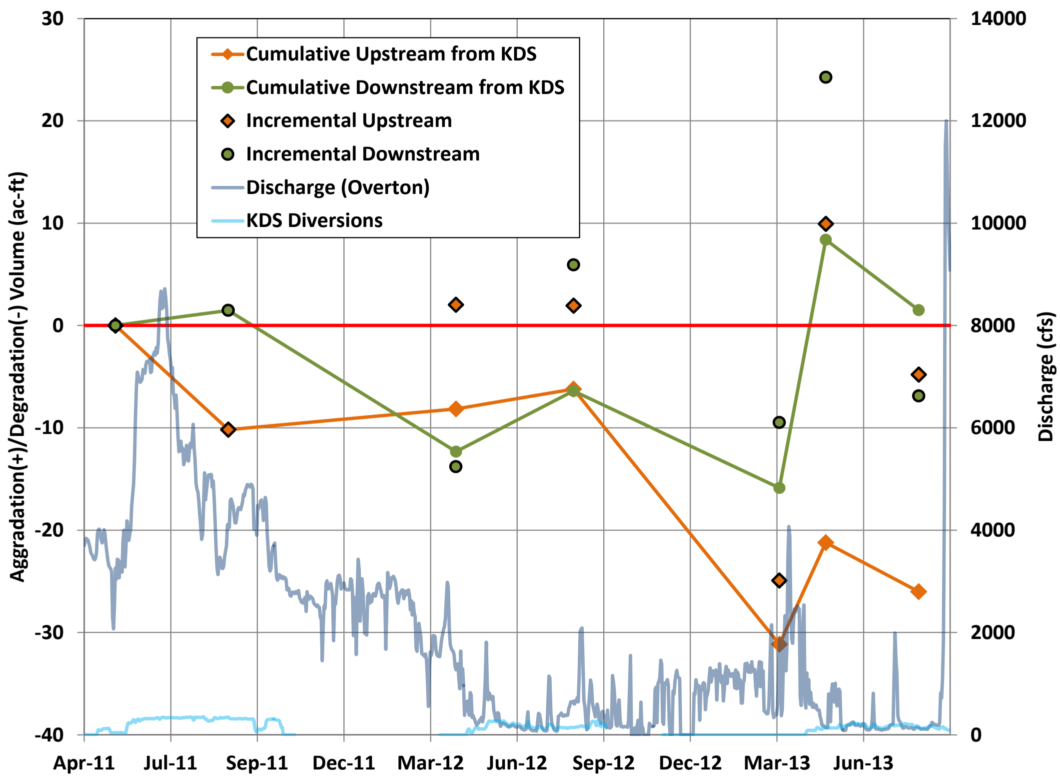


Figure 2.10. Incremental and cumulative change in bed sediment volume at the Elm Creek Complex up- and downstream from the KDS between the May 2011 and August 2013 surveys. Also shown is the recorded mean daily discharge hydrograph at Odessa and the diversion rates at the KDS during the period.

remainder of the reach, the changes between surveys were typically less than 5 ac-ft, with the upstream part of the reach showing the least change.

Based on the volume estimates, the portion of the reach between the Elm Creek Bridge and about 1,400 feet upstream from the KDS experienced about 10.2 ac-ft (~22,170 tons) of degradation between the baseline (May 2011) survey and August 2011, about 2 ac-ft (~4,400 tons) of aggradation between August 2011 and May 2012 and an additional 1.9 ac-ft (4,200 tons) of aggradation between May 2012 and August 2012 (Figure 2.10). During the relatively low-flow period between the August 2012 and pre-SDMF survey conducted in April 2013, the upstream reach degraded by about 24.9 ac-ft (54,200 tons). This part of the reach then backfilled by about 9.9 ac-ft (~21,600 tons) during the SDMF and early part of May. Between the May 2013 and August 2013 surveys, an additional 4.8 ac-ft (~10,400 tons) of sediment were removed from the reach. Over the 27-month period encompassed by the surveys, this portion of the reach degraded by 26 ac-ft (~56,600 tons). About 70 percent of the total degradation volume occurred in the approximately 3,000 foot reach represented by XS8 and XS9.

The downstream portion of the reach aggraded by about 1.5 ac-ft (~3,200 tons) between the May and August 2011 surveys, degraded by 13.8 ac-ft (~30,100 tons) between August 2011 and May 2012, and then aggraded back by about 5.9 ac-ft (~12,900 tons) between May and August 2012. About 9.5 ac-ft (~20,700 tons) of degradation occurred between August 2012 and April 2013, and then the reach aggraded by about 24.3 ac-ft (~52,900 tons) during the SDMF and early part of May. Between May and August 2013, this part of the reach degraded by about 6.9 ac-ft (~15,000 tons). Despite the relatively significant changes between the surveys, the net changes in the reach downstream from the KDS over the 27-month period encompassed by the surveys was only about 1.5 ac-ft (~3,300 tons) of aggradation.

The changes in cross sectional area and total bank-to-bank channel width were used to estimate the change in average bed elevation between each of the surveys and the cumulative change over the survey period (**Figure 2.11**). The largest changes generally occurred at XS1, XS8, XS9, XS10, XS11, and XS15. XS1, located about 75 feet downstream from the Elm Creek Bridge, degraded to its maximum of about 0.45 feet between May and August 2011, and then showed a general aggradation trend back to a final net degradation over the 27-month period of about 0.2 feet by August 2013 (**Figure 2.12**). Cross Section 8, located about 3,000 feet upstream from the KDS, degraded by about 0.25 feet between May and August 2011, continued to degrade at a slower rate until August 2012 to about 0.38 feet, and then degraded more rapidly between August 2012 and April 2013 to about 0.75 feet (**Figure 2.13**). The cross section then aggraded back to a final net degradation over the 27-month period of about 0.6 feet. Cross Section 9 showed a cyclical behavior with relatively little change through the first 12 months of the study period, relatively significant aggradation of nearly 0.4 feet during the low-flow period between the May and August 2012 surveys, followed by about 0.4 feet of degradation between August and April 2012. By the end of the period in August 2013, this cross section had degraded by only about 0.15 feet compared to May 2011. Cross Section 10, just downstream from the KDS, aggraded by an average of about 0.2 feet between May and August 2011; however, the bulk of the aggradation was associated with building of a large bar in the eddy that forms during high- flow releases along the left side of the channel during the high-flow releases (**Figure 2.14**). This eddy then eroded away during the sustained recession period of the 2011 hydrograph and the intermediate flows that occurred through the early part of 2012 and did not return for the rest of the 27-month period. This cross section appears to have aggraded significantly between August 2012 and April 2013; however, the bulk of the increase in volume resulted from construction of a mid-channel island in late-2012. A modest amount of degradation occurred between the April and August 2013 surveys, which a significant portion associated with bank erosion around the margins of the new island.

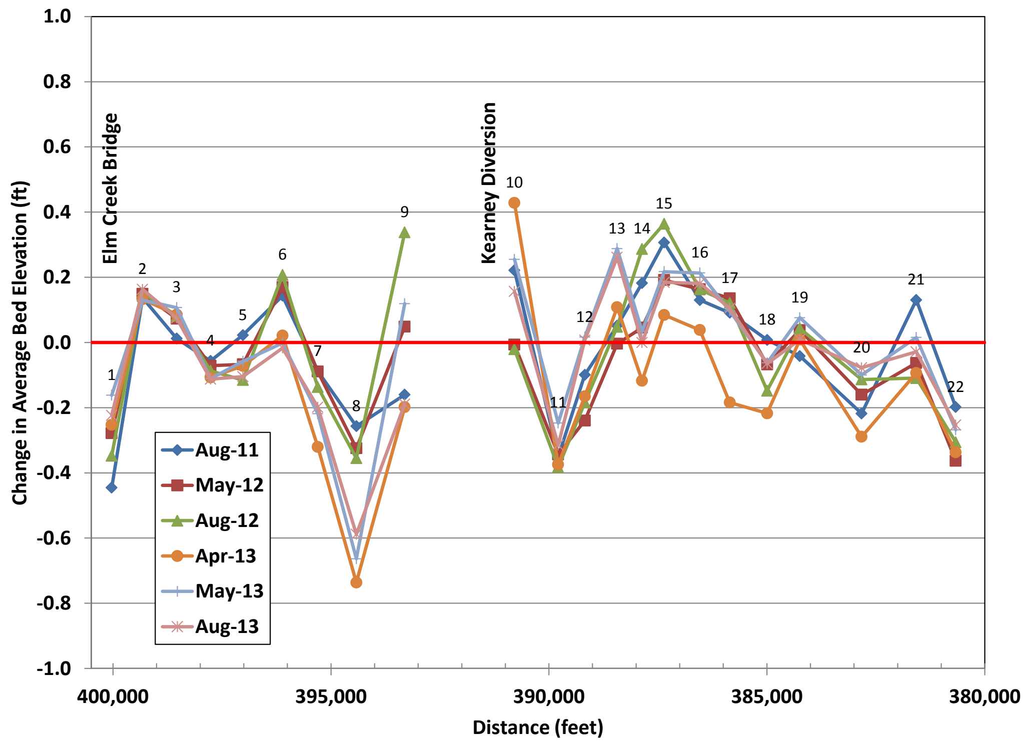


Figure 2.11. Change in average bed elevation from the May 2011 (baseline survey).

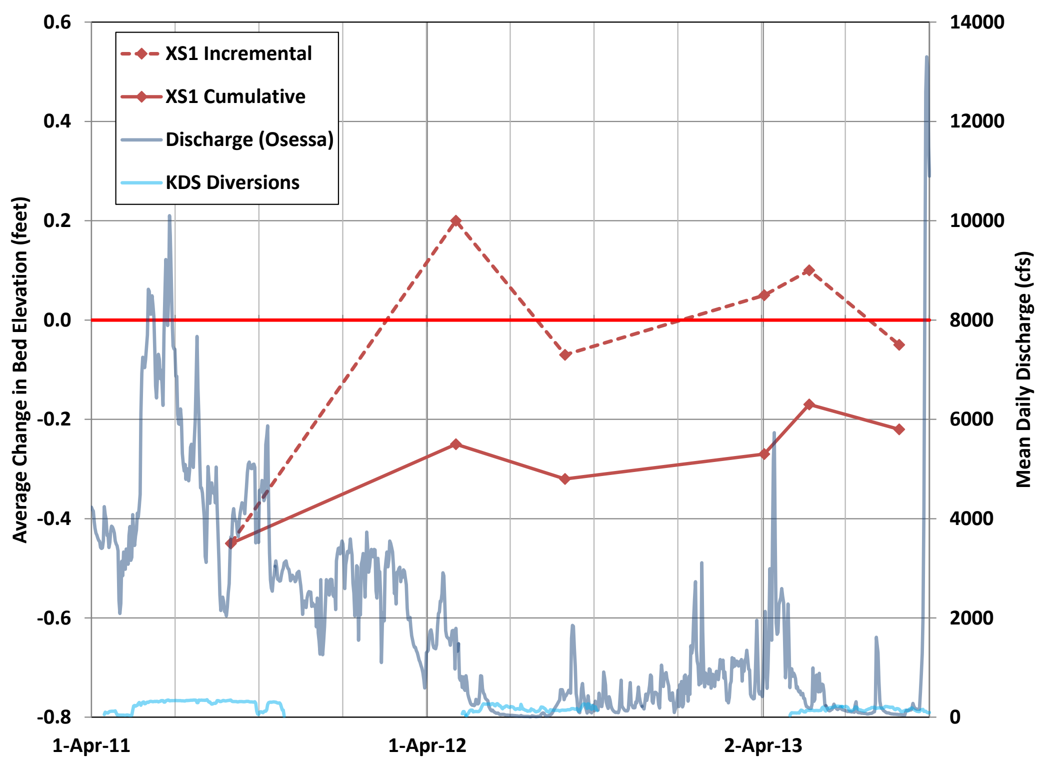


Figure 2.12. Incremental and cumulative change in average bed elevation at Cross Section 1, just downstream from the Elm Creek Bridge.

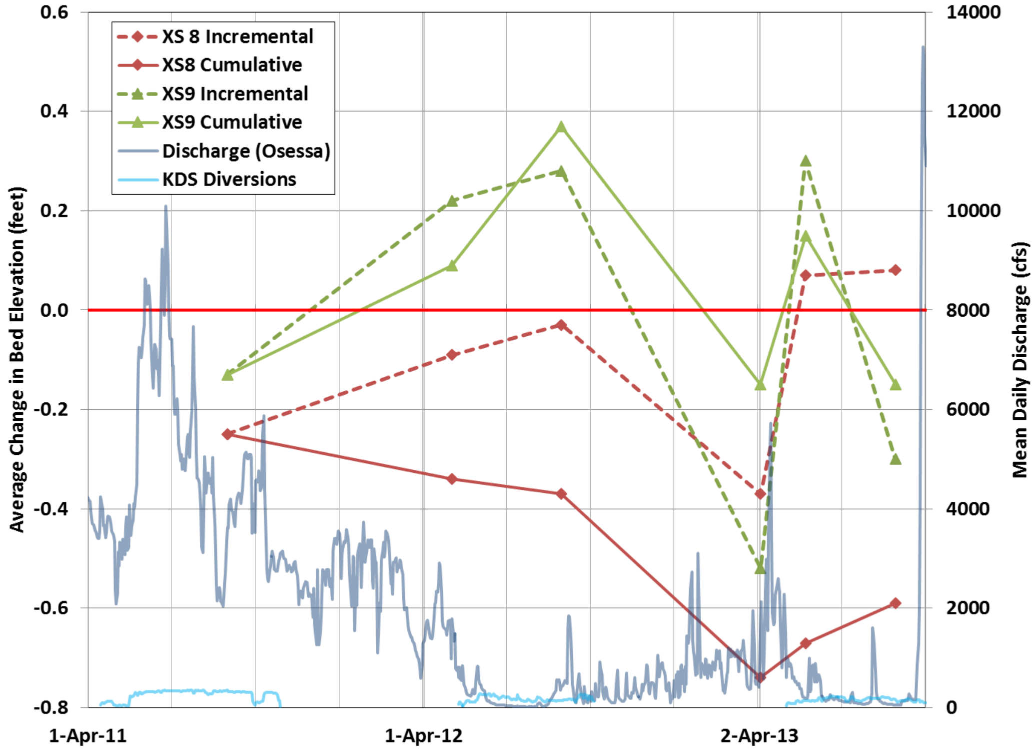


Figure 2.13. Incremental and cumulative change in average bed elevation at Cross Sections 8 and 9, approximately 0.3 and 0.5 miles upstream from the KDS, respectively.

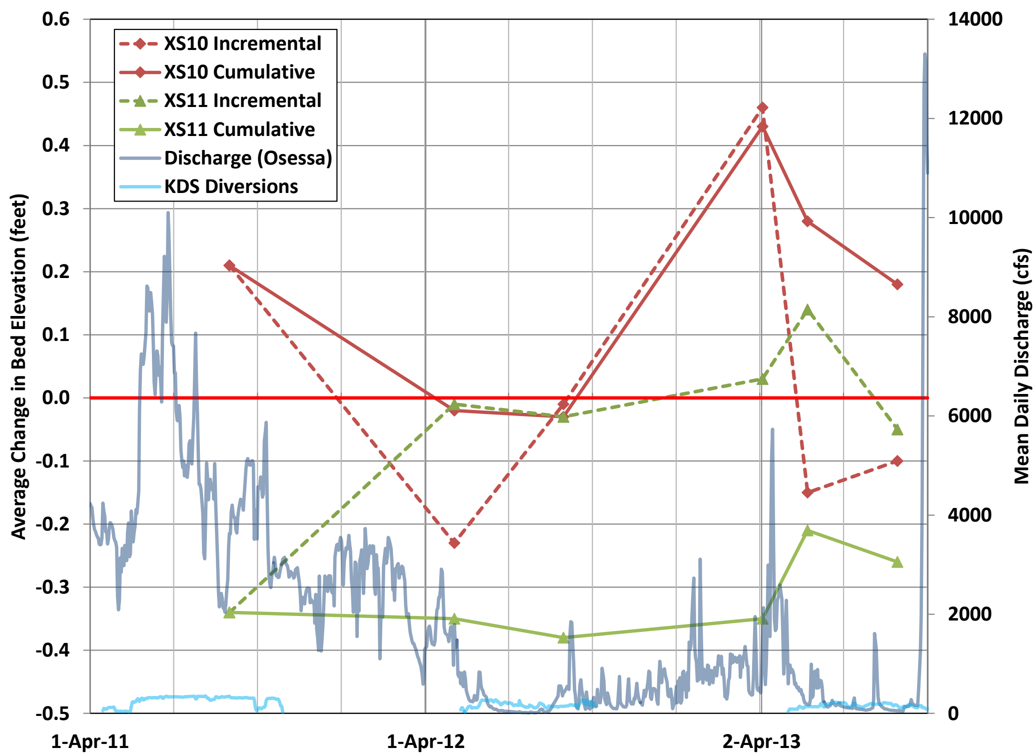


Figure 2.14. Incremental and cumulative change in average bed elevation at Cross Sections 10 and 11, approximately 700 feet and 0.3 miles upstream from the KDS, respectively.

Cross Section 11 degraded by about 0.35 feet during the high flows between the April and August 2011 surveys and then showed little net change over the remainder of the period up to April 2013. This cross section aggraded by about 0.15 feet during the SDMF and early part of May 2013. In August 2013, the average bed elevation was about 0.25 feet lower than during the initial survey in April 2011. XS15 aggraded by about 0.3 feet between the April 2011 and August 2011 surveys, and then fluctuated about this level for the remainder of the period, with a general degradation tendency between the August and April surveys and aggradation during the summer months of 2011 and 2012. About 0.2 feet of aggradation occurred during the April 2013 SDMF, and this was followed by a small amount of degradation over the summer.

In addition to the changes in cross-sectional area, the wetted channel topwidth at 1,200 cfs was also assessed at each of the cross sections (**Figure 2.15**). The widths of the nine cross sections upstream from the KDS during the May 2011 survey was ranged from 320 feet (Cross Section 9) to 900 feet (Cross Section 7) and averaged 555 feet. By August 2011, the average width upstream from the KDS increased to about 570 feet, with XS7 and XS9 remaining about the same, but XS8 widening significantly from about 300 feet to over 600 feet. The 1,200-cfs topwidth continued to increase through May 2012 to an average of about 590 feet, and then remained in the range of 585 to 610 feet throughout the remainder of the survey period. Similar changes occurred downstream from the KDS, with the average width at about 530 feet in May and August 2011, increasing to about 590 feet by May 2012, and remaining at about 590 feet width throughout the rest of the period. In general, the wetted channel tends to widen in the downstream direction from the Elm Creek Bridge to Cross Section 8 (~0.5 miles upstream from the KDS), and then narrows significantly at Cross Section 9. The narrowing is mostly associated with training of the flow through the radial gates at the KDS. During periods when the diversion weir is overtopping, the flow spreads across essentially the entire structure. The wetted channel tends to narrow in the downstream direction below the KDS, from about 600 to 700 feet at Cross Section 10, just downstream from the diversion structure, to about 500 feet at the downstream end of the ECC.

2.3 Bar Topography

The Program has defined sandbars as exposed surfaces above the water surface at 1,200 cfs. The topography of all of the individual sandbars meeting this criterion that could be identified in the reach was surveyed following the procedures described in the Project-scale Monitoring Protocol (PRRIP, 2011). The total number of bars surveyed during each period varied from the lowest number of 22 (11 upstream and 11 downstream from the KDS) in August 2011 to 42 (17 upstream and 25 downstream from the KDS) in April 2013 (**Table 2.4**; **Appendix C.2**).

The discharge during the 2011 surveys was considerably higher than 1,200 cfs (Table 2.1); thus, a significant the portion of the total sand bar area was inundated at the time of the surveys. It is also likely that a number of bars that would have been exposed at 1,200 cfs were inundated and went undetected. In addition, some of the individual bars that were surveyed during May 2011 had consolidated into a single bar during the high-flow period between the May and August 2011 surveys (e.g., May 2011 Bars 2, 3, 4, and 5 along the left bank just downstream from the Elm Creek Bridge consolidated into a single bar by August 2011). During 2012 and 2013, when relatively low flows persisted through the reach, several of the pre-existing bars became dissected and the total number of individual bars increased.

During the 2011 surveys, the survey lines on the bars were extended to a sufficient distance below the water-surface to insure that the topography above the 1,200-cfs water-surface was captured. Since the discharge during the 2012 and 2013 surveys was well below 1,200 cfs, the entire exposed surface of the bars was surveyed. The survey data were used to estimate the perimeter of the 1,200-cfs bars by matching the predicted water surface at 1,200 cfs from the existing 1-D hydraulic model with the survey data points, and the data above this perimeter were then used to create a topographic surface for each bar (**Figures 2.16a and 2.16b**). The distribution of area with elevation above 1,200 cfs was then estimated based on the topographic surfaces, and the median, upper 10 percent (10 percent of the bar area is above this elevation), and maximum elevation were determined from the resulting curves (**Figure 2.16c**). Tables showing the relevant elevations, areas and volumes of the surveyed bars from each of the seven surveys are provided in Appendix C.2.

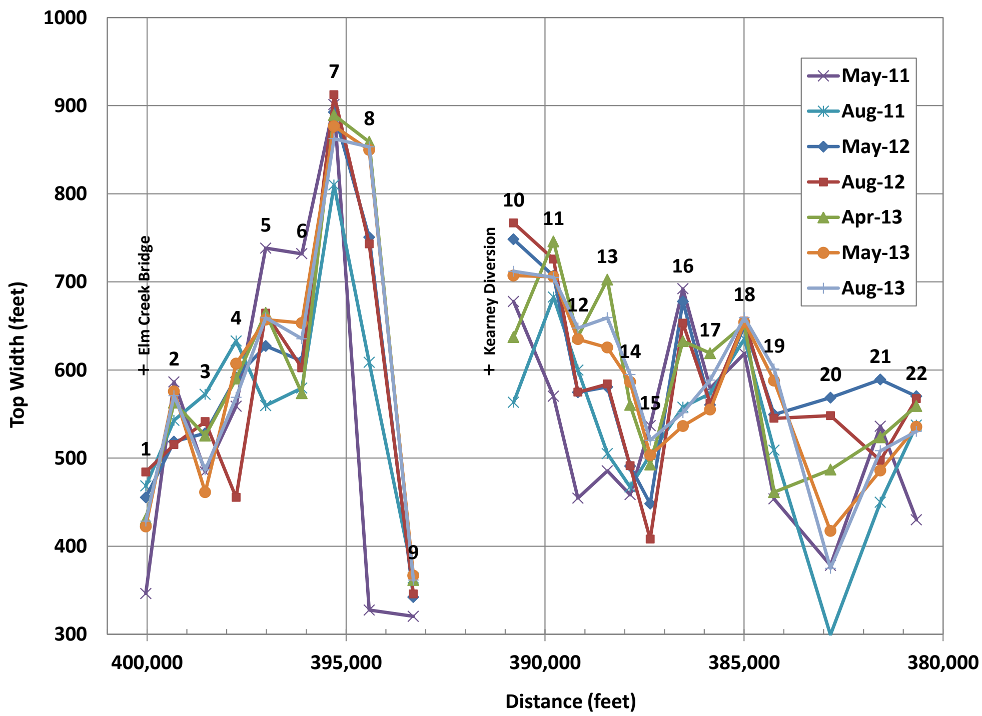


Figure 2.15a. Channel topwidth at 1,200 cfs at the monitoring cross sections during the seven surveys.

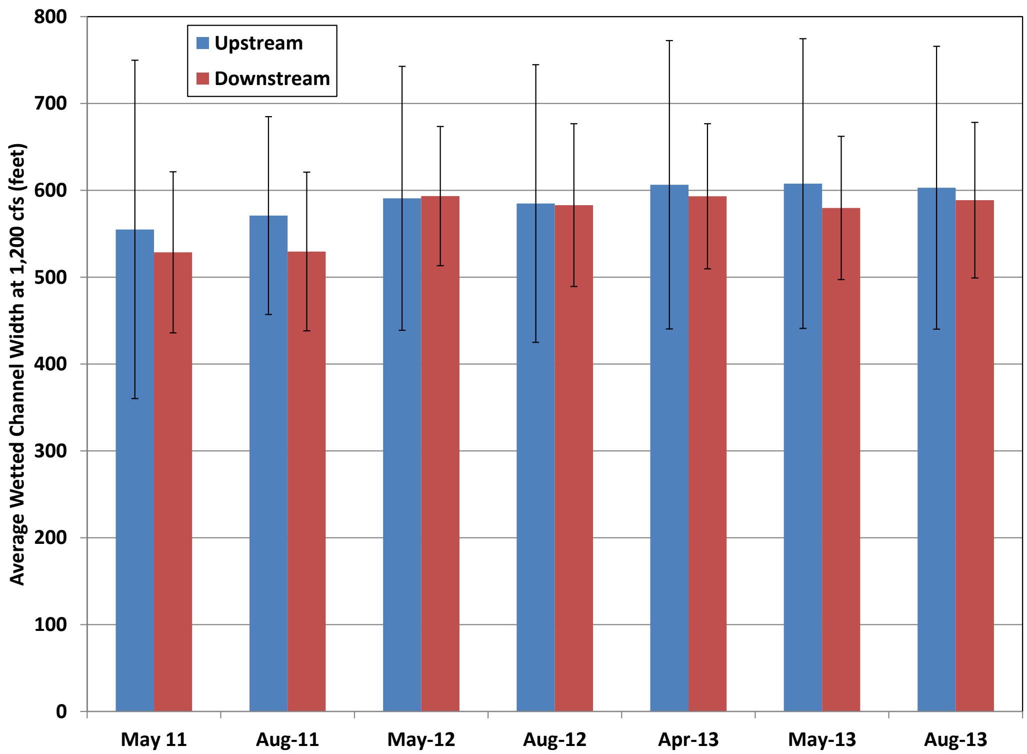


Figure 2.15b. Average wetted channel width at 1,200 cfs upstream and downstream from the KDS. Error bars represent ±1 standard deviation based on the variability among the individual cross sections.

Table 2.4. Number of surveyed bars at the Elm Creek Complex during each of the monitoring surveys.

Survey Date	Upstream[1]	Downstream[2]	Total
May-11	14	20	34
Aug-11	11	11	22
May-12	15	13	28
Aug-12	17	16	33
Apr-13	17	25	42
May-13	17	23	40
Aug-13	15	24	39

[1] Includes NPPID nesting island.

[2] 2013 surveys include 8 islands constructed in late-2012.

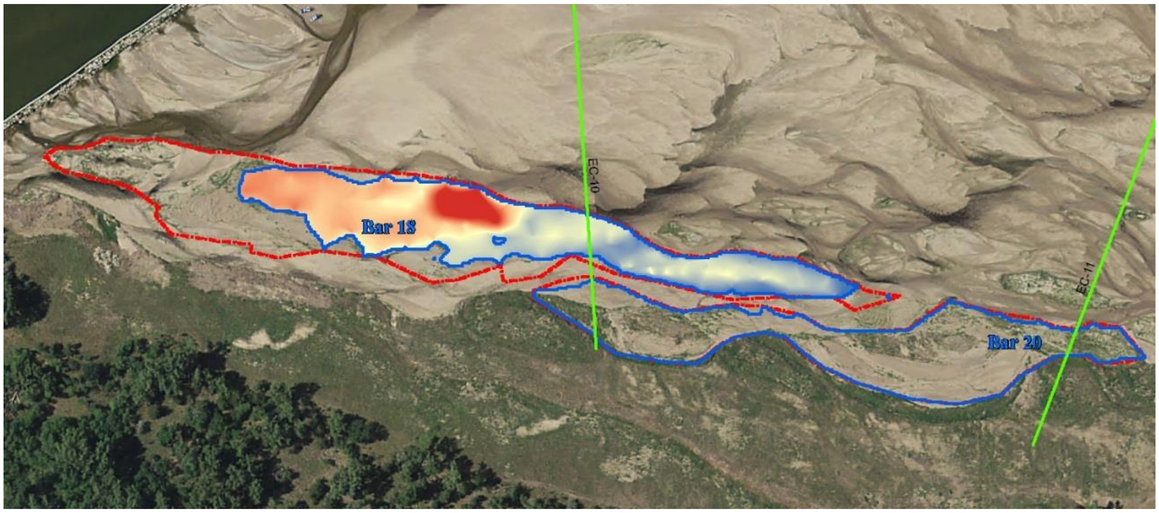


Figure 2.16a. Survey points at a typical bar (Bar 18 from the May 2012 survey). (Red line = edge of exposed bar (i.e., edge of water) at time of the survey; blue lines = estimated 1,200-cfs boundary; yellow dots = individual survey points, green lines = surveyed cross sections discussed in previous section.)

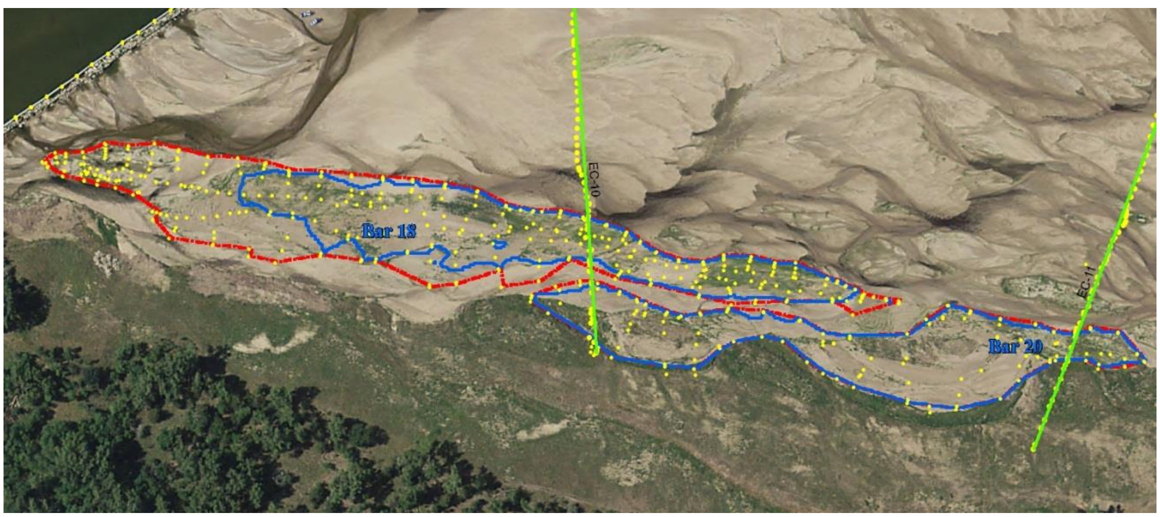


Figure 2.16b. Topographic surface of 2012 Bar 18, shown in Figure 2.16a.

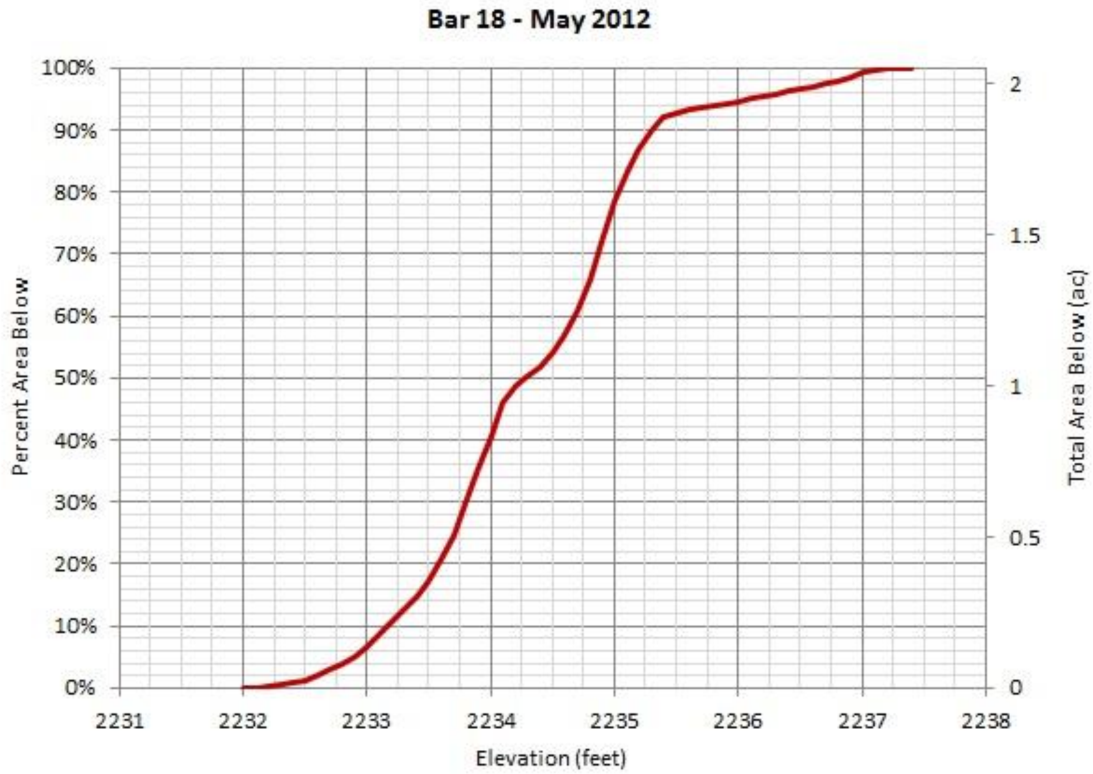


Figure 2.16c. Distribution of surface area by elevation for Bar 18, shown in Figure 2.16a.

Bars 27 and 29 were re-graded by the Program just before the August 2012 survey; thus, the surveyed topography reflects the mechanical changes associated with the re-grading. The upstream approximately half of August 2012 Bar 21 was also not surveyed for safety reasons due to the presence and operation of heavy equipment. In addition, eight new bars were constructed by the Program in the downstream portion of the reach between the May 2012 and April 2013 surveys; the constructed topography is reflected in the 2013 surveys for all eight of these bars.

The surface area of all of the bars (i.e., vegetated and unvegetated, excluding the NPPID nesting island) above the 1,200-cfs water-surface elevation upstream from the KDS decreased from 42.4 acres in May 2011 to only 30.5 acres in August 2011 (**Figure 2.17**). The total unconstructed bar area in this part of the reach then increased slightly to 31.7 acres during both of the 2012 surveys, and then continued to increase to 33.2 acres in April 2013 and 34.6 acres in May 2013. The then decreased back to 29.6 acres during the by August 2013.

Downstream from the KDS, the largest acreage of bars also occurred during the May 2011 survey (45.4 acres), decreasing slightly to 44.6 acres by August 2011, and to 32.9 acres in May 2012 (excluding about 6.4 acres of constructed/stockpile area in the upstream portion of Bar 22, near the PRRIP Cabin). By August 2012, there were only 18.3 acres of unconstructed bars in this part of the reach, but an additional 19.0 acres had either been constructed or were under construction from material in the channel bed, including pre-existing bars. The total area of unconstructed bars remained about the same through the remainder of the monitoring period (18.2 acres in April 2013, 17.7 acres in May 2013 and 18.4 acres in August 2013). A small increase constructed bar area occurred between August 2012 and the April 2013 survey (about

1.6 acre increase to 20.6 acres). The April 2013 SDMF eroded the perimeter of many of these bars, resulting in total constructed bar area of 18.7 acres during the May 2013 survey. Erosion around the perimeter caused an additional loss of about 0.7 acres by the August 2013 survey.

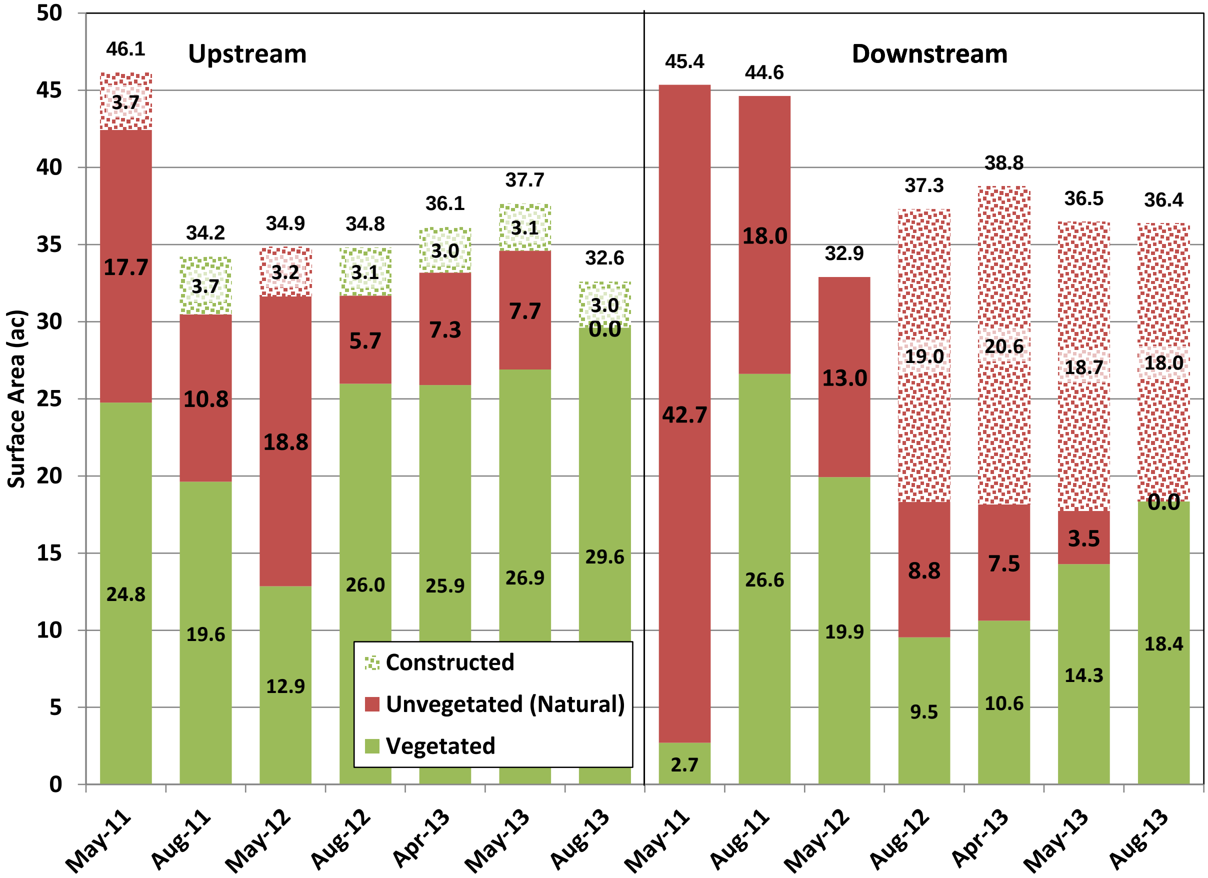


Figure 2.17. Total surface area of bars extending above the 1,200-cfs water surface in the portions of the Elm Creek Reach up- and downstream from the Kearney Diversion Structure during the 2011, 2012 and 2013 surveys. Note that an SDMF release with maximum discharges at Overton and Kearney of 3,910 and 4,080 cfs, respectively, and lasting about 3 days, occurred between the April and May 2013 surveys.

In performing the analysis, the vegetation sample plot data (discussed in Chapter 5) were used to estimate the area-weighted percent vegetative cover on the individual bars. Bars with less than 10 percent cover were classified as unvegetated and bars with greater than 10 percent cover were classified as vegetated. The total area of unvegetated bars upstream from the KDS decreased from 17.7 acres in May 2011 to 10.8 acres in August 2011, primarily due to the reduction in bar area during the high flows that persisted through the summer. By May 2012, the area of unvegetated bars had increased back to 18.8 acres, due to a combination of expansion of the bars and loss of vegetation during the winter months. The generally low flows during Summer 2012 resulted in a significant decrease in unvegetated bar area to 5.7 acres by August, and this area increased by a small amount to 7.3 acres and 7.7 acres at the time of the April and May 2013. The very low flows during Summer 2013 allowed vegetation to establish on essentially the entire bar area upstream from the KDS by August 2013. Downstream from the KDS, the majority of the sand bar area was unvegetated (42.7 acres) in May 2011, and this declined to about 18 acres by August 2011 and to 13.0 acres by May 2012. The amount of unvegetated bar area increased significantly through Summer 2012, primarily due to the bar construction activities. The unvegetated area on unconstructed bars actually declined to 8.8 acres by August 2012 and 7.5 acres April 2013, followed by an additional decline to about 3.5 acres in May 2013. By August 2013, all of the unconstructed bars had become vegetated.

In the portion of the reach upstream from the KDS, the total (vegetated and unvegetated) surface area of the portion of the bars at least 1.5 feet above the 1,200-cfs water surface decreased from 7.6 acres (excluding the NPPID Nesting Island) to 4.2 acres between May and August 2011, increased to 8.6 acres in May 2012 and then decreased back to 7.6 acres in August 2012 (**Figure 2.18**). By April 2013, there were about 8.3 acres of unconstructed bars in this part of the reach, and this remained about the same at 8.1 acres by the May survey, and then decreased to 6.4 acres by August. The unvegetated portion of these bars increased from 0.1 acres in May 2011 to 3.4 acres in May 2012, and then declined to 1.4 acres in April 2013, prior to the SDMF release. During the post-SDMF survey, the unvegetated area of the bars had declined to 0.9 acres. The August unvegetated areas were typically smaller than the April/May values due to vegetation growth during the summer months.

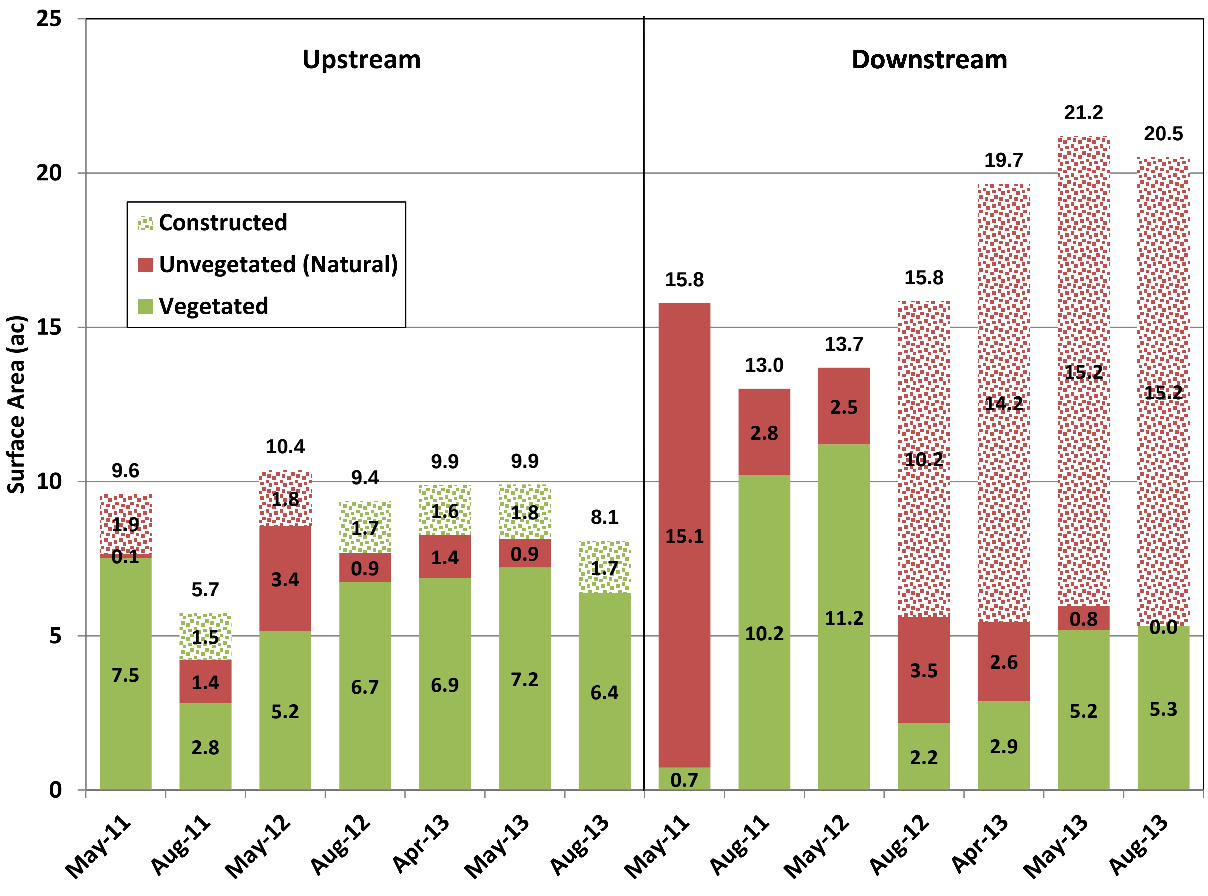


Figure 2.18. Total surface area of bars 1.5 feet or more above the 1,200-cfs water surface in the portions of the Elm Creek Reach up- and downstream from the Kearney Diversion Structure during the 2011, 2012 and 2013 surveys.

Downstream from the KDS, the total sand bar more than 1.5 feet above the 1,200-cfs water-surface area decreased from 15.8 acres in May 2011 to 13 acres in August, and then increased back to 13.7 acres in May 2012. The bulk of these bars were unvegetated in May 2012 (15.1 acres), and this declined to only 2.5 acres by May 2012. The unvegetated area of unconstructed bars was about 2.6 acres in April 2013. Constructed bars accounted for 10.2 acres of unvegetated sandbar area more than 1.5 feet above the 1,200-cfs water surface during the August 2012 survey, and this increased to about 14.2 acres by April 2013. The area of the constructed bars increased by about 1 acre to 15.2 acres during the April 2013 SDMF, and remained the same during the August 2013 survey.

The Program's Priority Hypothesis Flow #1 (PRRIP, 2006)[4] suggests that increasing the frequently occurring (1.5-year) peak flows through Program activities will increase the height of the sandbars by 30 to 50 percent. Program activities in this context specifically refer to short-duration, high-flow (SDHF) releases of 5,000 to 8,000 cfs for 3 days. A key assumption underlying this hypothesis is that unvegetated sandbars will build to near the water surface. This assumption is supported by Crowley (1981), who found that macroforms in the Platte River downstream from Grand Island migrated downstream at a rate of 1.0 to 1.5 m/hr during high flows, with the migration rate decreasing rapidly as the inundation levels decreased. In most instances, the migration was undetectable when the flow depth over the macroform was less than 20 cm (~0.7 feet). These findings are the primary basis for the benchmark sand bar heights of 0.7 feet below to near the 1,200-cfs water-surface (Table 1.2). Crowley (1981) further suggested that, once the bars become vegetated, they stop migrating and become stable islands.

The magnitude of the 2011 high flows was on the same order as the planned SDHF releases; however, the duration was much longer. For example, the measured mean daily discharge at the Overton gage exceeded 5,000 cfs for 70 days and 8,000 cfs for 9 days between May 15 and August 15, 2011, and the estimated mean daily flows in the ECC upstream from the KDS exceeded these magnitudes for 67 and 11 days, respectively. Diversions into the Kearney Canal at the KDS and other flow losses reduced the durations downstream from the KDS to 60 days and 7 days, respectively. To assess of the maximum height assumption, the elevations of the tops of the sand bars in August 2011 and May 2013, the only two of the seven surveys that were performed after high flows occurred in the reach, were compared to the stage associated with the maximum mean daily flow during the preceding high flow period (8,720 cfs on June 26, 2011 for the August 2011 survey; 4,640 cfs on April 13, 2013 for the May 2013 survey)[5].

The maximum elevation of a significant number of both the vegetated and unvegetated bars in August 2011 was within 1 foot below the maximum water-surface elevation (15 of 22) (**Figure 2.19a**). The top of one of the unvegetated bars and two of the vegetated bars in the upstream part of the reach was above the maximum water surface that occurred in June 2011, and two of the vegetated bars downstream from the KDS was above the maximum water surface. The median elevation of the unvegetated bars in the upstream part of the reach increased by an average of about 0.4 feet between the two surveys, and the maximum height of the three bars that were completely overtopped increased by an average of about 0.2 feet, although the maximum elevation of one of the three (Bar 11) actually decreased by about 0.3 feet (**Figure 2.19b**). Because the maximum elevation represents a single surveyed point, the relatively small changes are likely within the uncertainty of the surveys. The 90-percentile height (height below which 90 of the surface area of the bar occurs) increased by about 0.4 feet, similar to the

[4]Program Hypotheses and Big Questions are summarized, and the implications of the Elm Creek Complex monitoring data to these Hypotheses and Big Questions are discussed in more detail in Chapter 6, below.
[5]Maximum flows between all of the other surveys were well below the tops of essentially all bars in the ECC.

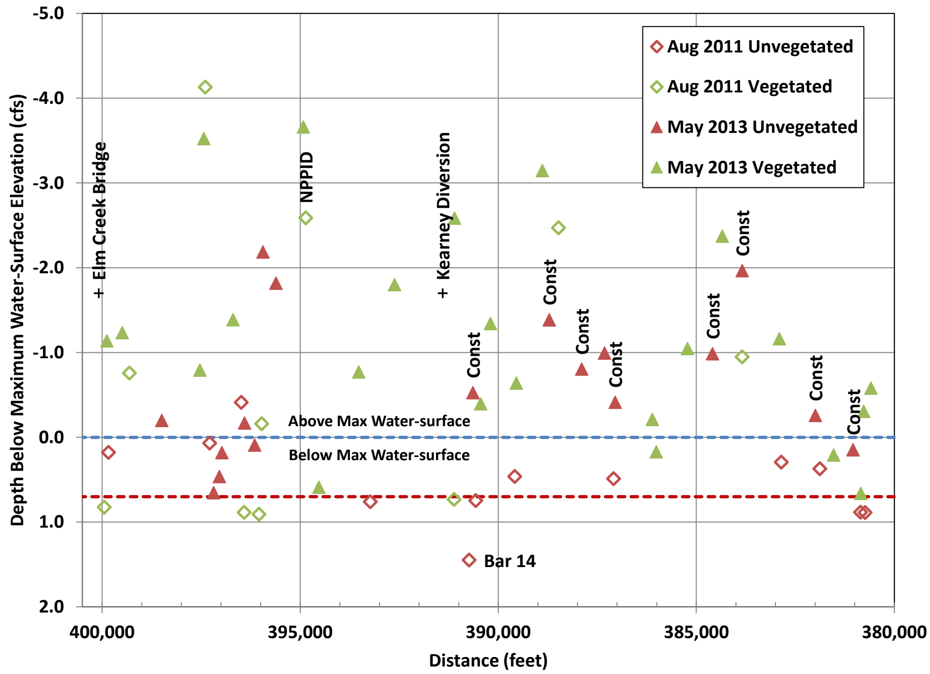


Figure 2.19a. Depth of highest elevation on each of the August 2011 bars below the June 2011 maximum water-surface elevation. Positive (+) values indicate bar elevation below maximum water surface, negative (-) above maximum water surface. Dashed red line is the benchmark target minimum depth below the maximum water-surface elevation.

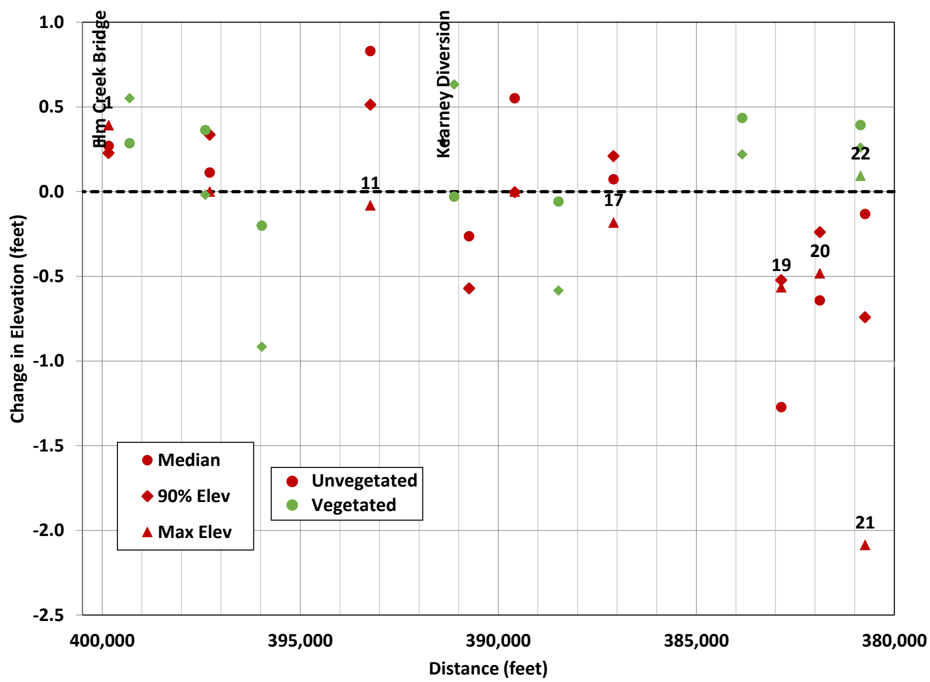


Figure 2.19b. Change in height (from May 2011 survey to August 2011 survey) of the median, 90-percentile and highest elevations of the bars present in the reach August 2011 that were inundated to at least the indicated level during the June 2011 high flows.

TETRA TECH

median height; thus, it is reasonable to conclude that the height of these bars actually did increase between the two surveys. Two of the vegetated bars in the upstream part of the reach actually increased in height between the two surveys, as well.

Between the May and August 2011 surveys, the 90-percentile height of vegetated Bar 12 that is located along the right side of the channel just downstream from the KDS increased in height by about 0.7 feet, although the median height actually changed very little, indicating that deposition occurred on the intermediate to higher portions of the bar, in spite of the fact that the very top of the bar was not completely overtopped. Bar 14, a very small bar in the lee of this larger bar eroded significantly during the June 2011 high flows. The median height of Bar 15, a small bar along the left side of the channel about ¼ mile downstream from the KDS increased by about 0.5 feet, although the 90-percentile and maximum heights did not change significantly. The heights of the other unvegetated bars downstream from the KDS actually decreased by 0.5 feet to 1 foot during the period.

Only a few of the bars in both parts of the reach were completely inundated during the May 2013 SDMF (5 of the 17 in the upstream from the KDS and 4 of the 23 downstream from the KDS) (**Figure 2.20a**). The median elevation of most of the bars was, however, inundated. The only one of these bars in which the higher elevation portions increased significantly in height during the SDMF was Bar 7, a relatively small unvegetated bar on the left side of the channel about 0.6 miles downstream from the KDS (**Figure 2.20b**). The small changes indicated for the other bars are likely within the uncertainty of the surveys.

The changes that occurred in the part of the reach upstream from the KDS during the sustained high flows in June 2011 are generally consistent with the findings of Crowley (1981) in that the bars built in height and most were within 1 foot of the maximum water surface. The tops of most of the bars that were completely overtopped in the portion of the reach well downstream from the direct effects of the KDS were also within 1 foot of the maximum water-surface, but the height of these bars generally decreased in response to the flows. The reason for the decrease is not apparent from the available information, but it could be related to loosening and increased erodibility of the surface layer by the vegetation disking that occurred the previous fall. Why this process did not occur in the reach upstream from the KDS is also not apparent.

The majority of the bars that were present in April and May 2013 were above the maximum water-surface during the April 2013 SDMF; thus, these data provide limited information about the response of the top-of-bar elevations to high flows. In spite of this limitation, the change in the median, 90th percentile (i.e., 90 percent of the bar area is below this elevation), and elevations on the bars that were completely inundated were evaluated to assess whether detectable changes in bar elevations occurred. The median elevation of most of the bars was inundated during the April 2013 SDMF, and the data indicate that these elevations increased by amounts that were generally in the range of a few tenths of feet at most locations (**Figure 2.20**). Similarly small changes also occurred in the 90th percentile and maximum elevations. The bars in the vicinity of Sta 397,000, upstream from the KDS, that appear to have increased in height by more than a few tenths of feet (Bars 6 and 8) are small, mid-channel bars with relatively low elevations, and located in the lee of larger bars where flow separation during the SDMF likely created a depositional environment. The bar near Sta 386,000, downstream from the KDS, that showed a substantial increase in height during the SDMF (Bar 28), is also a small mid-channel bar that decreased significantly in area, with the small remaining portion building in height compared to the April survey. The uncertainty in the estimated median, 90th percentile and

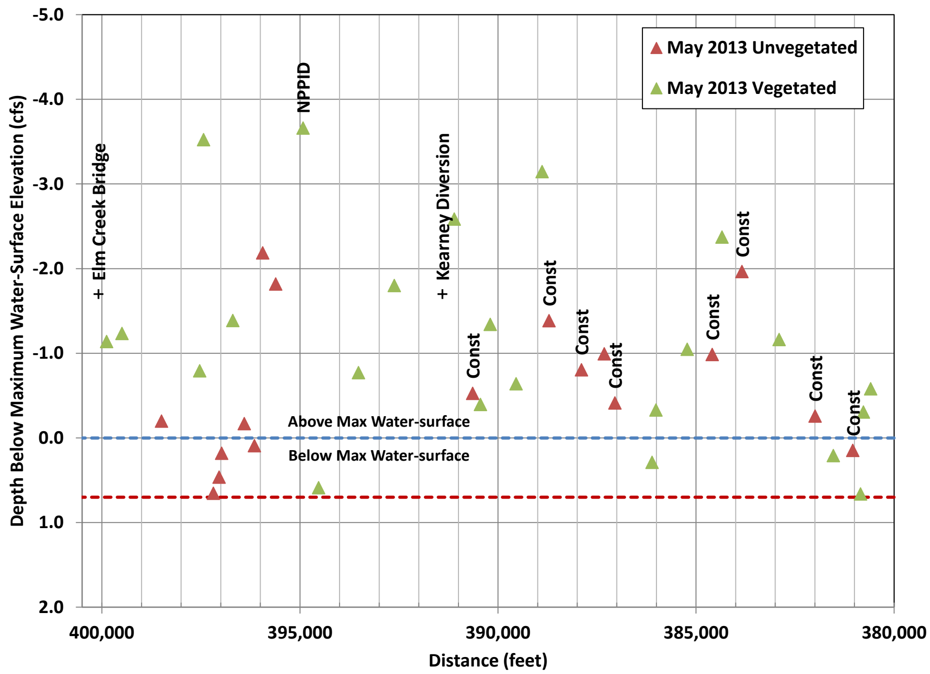


Figure 2.20a. Depth of highest elevation on each of the May 2013 bars below the maximum water surface during the April 2013 SDMF. Positive (+) values indicate bar elevation below maximum water surface, negative (-) above maximum water surface. Dashed red line is the benchmark target minimum depth below the maximum water-surface elevation.

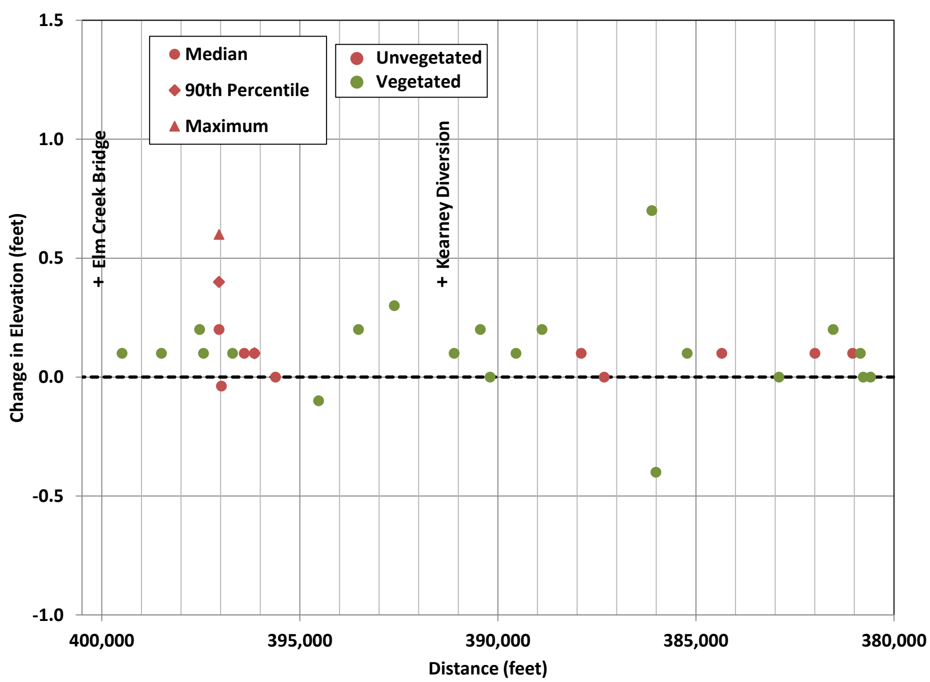


Figure 2.20b. Change in height of the median, 90-percentile and highest elevations of the bars present in the reach in May 2013 that were inundated to at least the indicated level during the April 2013 SDMF.

maximum elevations at any particular bar is probably in the range of a few tenths of feet[6]; thus, the small changes indicated by the data are likely within the uncertainty bands. Nevertheless, the majority of the data points indicate an increase in both the median and 90th-percentile elevations, producing an area-weighted average increase of about 0.1 feet in both measures, suggesting that a modest increase in bar elevations probably did occur as a result of the SDMF.

[6]The elevations measured RTK GPS are generally accurate to within ±0.1 foot. Coupled with the uncertainty in transforming the bar transect data into complete topographic surfaces on the bars, the uncertainty in the estimated median, 90th percentile and maximum elevations is probably no smaller than ±0.2 feet.

3 SEDIMENT SAMPLING

A series of bed-and-bar material samples were collected at every other cross section along the reach to quantify changes in the caliber and size-distribution of the material. The bed-material samples were collected from near the channel thalweg at each of the sampled cross sections, and the bar samples were collected from a representative area near the head of the exposed portion of each bar. The number of samples during each survey varied from 10 to 14 bed material samples and 10 to 12 bar samples. In addition to the bed and bar samples, two bank material samples were collected from the right end of Cross Sections 7 and 9 during the May 2011 survey, and two samples of the coarse surface layer that was present along the left side of XS1 were also collected during the May 2012 survey. The samples were collected using a scoop sampler fabricated from a 6-inch PVC pipe beveled on one end and covered on the opposite end with a 200 µ mesh to allow water to drain from the subaqueous samples while insuring that all of the sand and coarser material is retained (**Figure 3.1**). Typical sample sizes were in the range of 2 to 4 pounds (1 to 2 kg), which significantly exceeds the minimum sample size required to obtain a representative particle-size gradation. The samples were analyzed in Tetra Tech's Fort Collins Soils Laboratory following ASTM Standard D422. The gradation curves for these samples are provided in **Appendix D**, and the laboratory data are provided with the electronic files that accompany this report.

The median (D_{50}) size of the bed material varied considerably from survey to survey at most locations (generally in the range of 0.5 mm to 2 mm), with a general trend of decreasing size in the downstream direction in the upstream part of the reach and no obvious trend in the downstream part of the reach, although the coarsest samples tended to occur just downstream from the KDS (**Figure 3.2**). The bar samples were typically somewhat finer than the bed material, but showed the same general trends (**Figure 3.3**). The coarseness of the samples at XS1 is likely due to hydraulic sorting due to the accelerated flows through the bridge opening and deposition of coarser material from the pier scour holes. The average median (D_{50}) size of the bed material samples varied from about 0.9 mm in August 2012 to 1.4 mm in August 2011 in the part of the reach upstream from the KDS, and from 0.6 mm in May 2012 to 1.8 mm in May 2013 downstream from the KDS (**Figure 3.4**). The overall average D_{50} for all of the sampling periods was about 1.2 mm in the upstream part of the reach and about 1.1 mm in the downstream part of the reach. The bar material was generally finer than the bed material, with the average D_{50} size ranging from 0.7 mm in August 2013 to 1.4 mm in August 2012 in the upstream part of the reach, and from 0.4 mm (May 2012) to 1.1 mm (August 2013) (**Figure 3.5**). The overall average D_{50} of the bar material samples throughout the sampling period was about 1.0 mm in the upstream part of the reach and 0.8 mm in the downstream part of the reach. No particular temporal trend is evident from the data.

Figure 3.1. Scoop-type sampler used to collect bed- and bar-material samples.

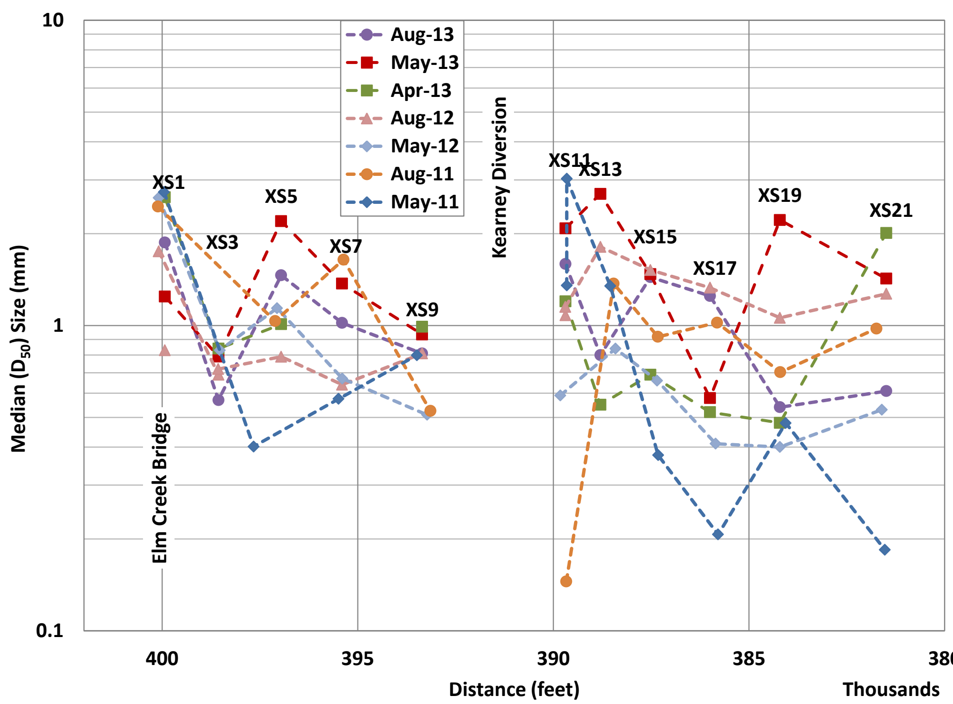


Figure 3.2. Median (D_{50}) size of **bed**-material samples collected in the Elm Creek Reach during each of the seven monitoring surveys. Samples with D_{50} less than 0.3 mm likely collected in low velocity areas where fine sand and silt has settled out; probably not be representative of the bed material in that location.

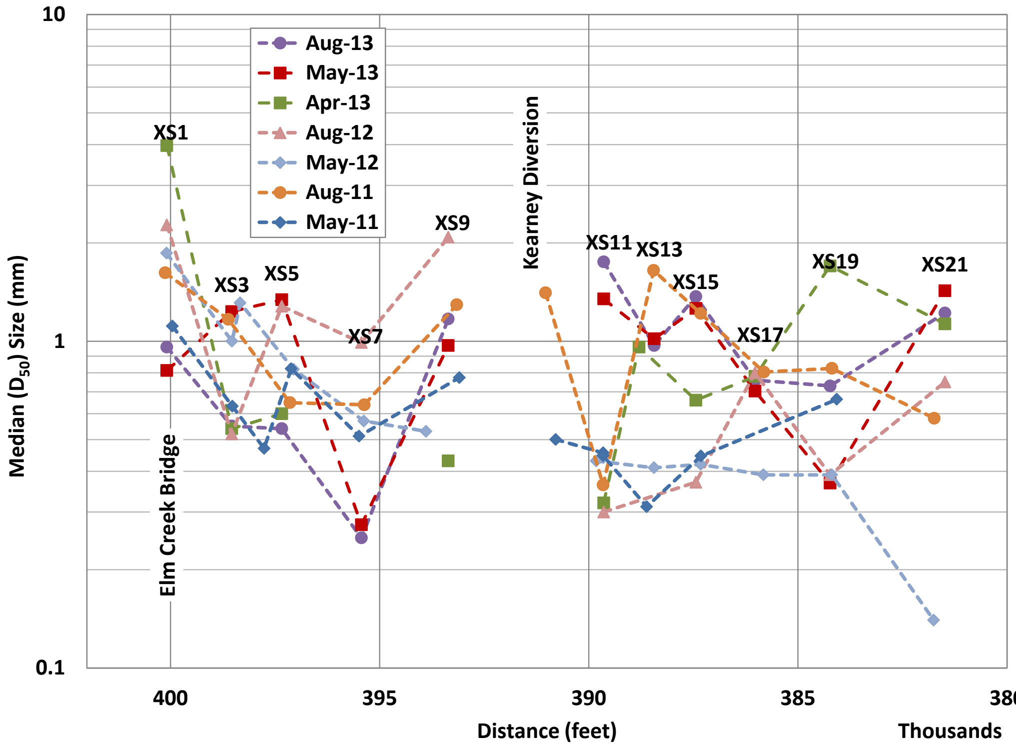


Figure 3.3. Median (D_{50}) size of **bar**-material samples collected in the Elm Creek Reach during each of the seven monitoring surveys.

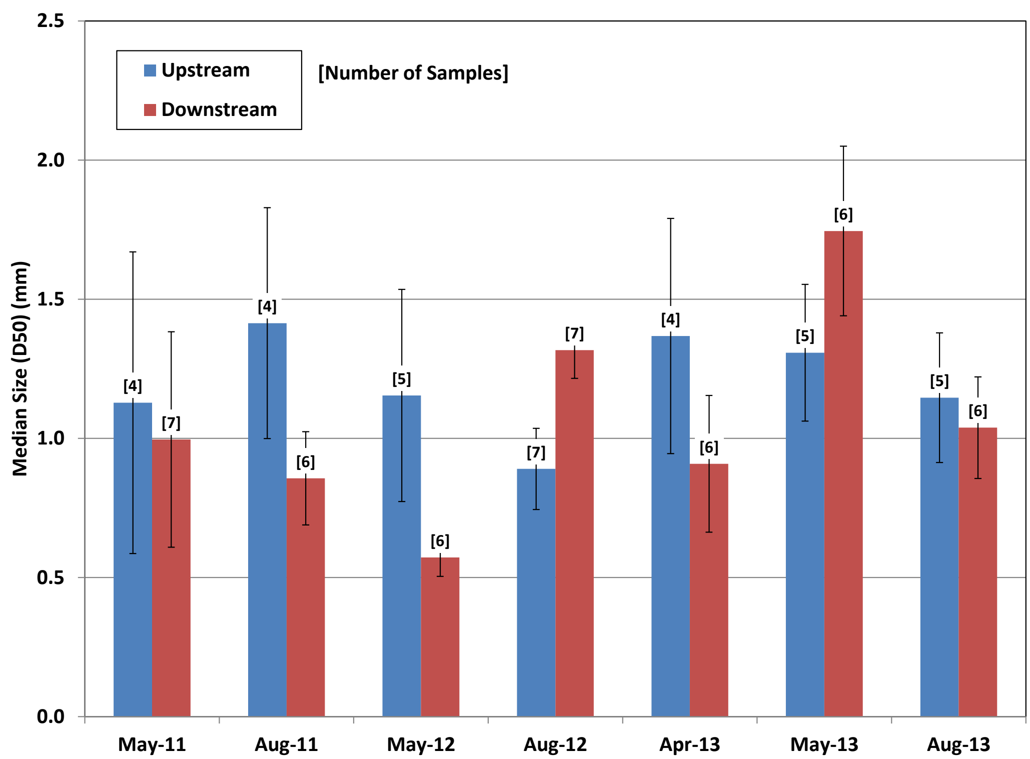


Figure 3.4. Average median (D_{50}) sizes of **bed**-material samples collected during the seven monitoring surveys. Whiskers represent ±1 standard error on mean.

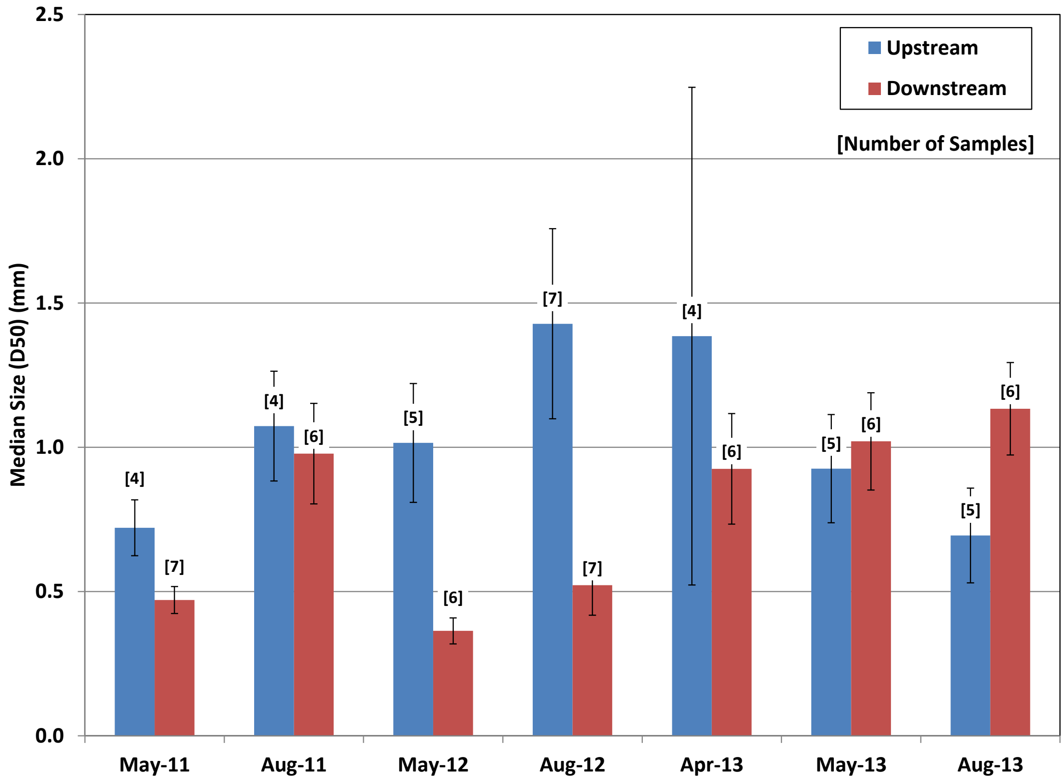


Figure 3.5. Average median (D_{50}) sizes of **bar**-material samples collected during the seven monitoring surveys. Whiskers represent ±1 standard error on mean.

4 DISCHARGE AND STAGE MEASUREMENTS

Discharges in the project reach are being monitored based on the real-time data collected at the Overton and Kearney Gages (USGS Gage Nos. 6768000 and 6770200) that are located approximately 9 miles upstream from the Elm Creek Bridge and 12 miles downstream from the downstream end of the project reach, respectively. Mean daily flow data are also available from the NDNR Odessa Gage (NDNR Gage No. 06770000) that is located 4.5 miles downstream from the KDS. Pressure transducer gages were installed and operated near the middle of each portion of the reach in April 2011 to maintain a continuous record of stages from April through October of each monitoring year (**Figures 4.1 and 4.2**). In addition, a discharge measurement was made in each part of the reach during the monitoring surveys.

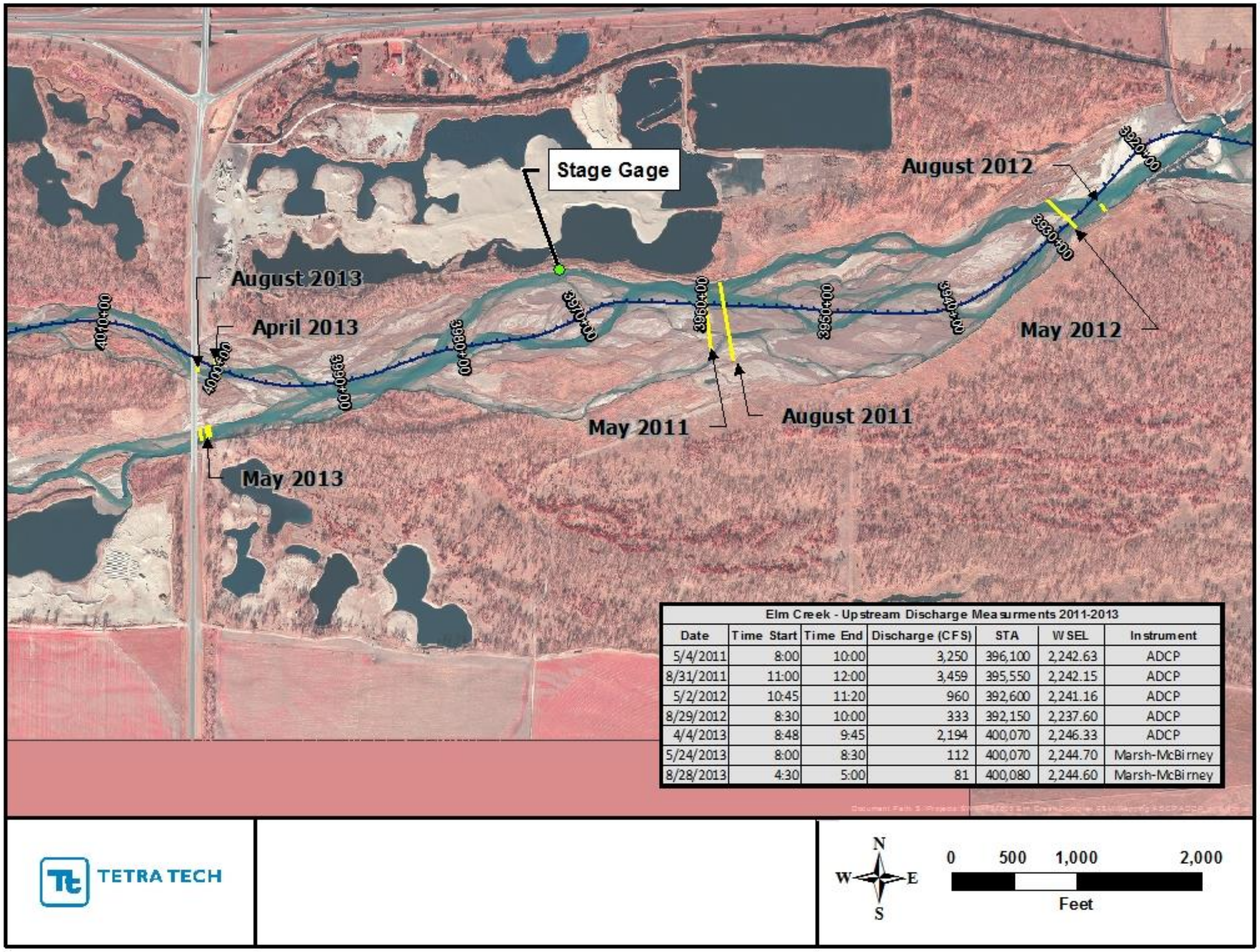
4.1 Installation and Operation of Stage Recorders

The pressure transducer gages consist of a Level Troll 500 Sonde and standard staff gage attached to a metal pipe that was driven into the bed of the river in a suitable location where the possibility of damage due to debris or erosion is limited (**Figures 4.3 and 4.4**). The Sonde was connected to a data recorder placed inside of a capped PVC pipe that was mounted on a large tree near the top of the bank. A reference point on the staff gage was then surveyed with the RTK GPS to provide an accurate horizontal and vertical location that can be tied to the project mapping. The gage in the portion of the reach upstream from the KDS was placed along the left bank near the east end of the NPPID Blue Hole ponds about half way between the KDS and the Elm Creek Bridge (Figure 4.1). This location is about 150 feet upstream from XS5. The downstream gage was placed at the edge of the channel approximately 1 mile downstream from the KDS and about 400 feet downstream from XS 16 (Figure 4.4).

Data from the upstream stage gage were downloaded at the end of the August monitoring period during each year (**Figure 4.5**; **Appendix E**). The data are consistent with the pattern of recorded stages at the USGS Overton and Kearney gages and provide a reliable measure of the variability in stage during the monitoring period. The stage loggers were repositioned at the beginning of each monitoring season, and they were also repositioned on June 6 in the middle of the 2012 season, to accommodate the lower flows, as the previous positions left the instruments dry. The gage reference elevations were re-established during each of the surveys. Water-surface elevations during the overall monitoring period ranged from a low of about 2240.4 feet during Summer 2012 to maximum of 2244.6 feet in June 2011 (total range of about 4.2 feet) at the upstream transducer, and from about 2225.6 feet during Summer 2012 to 2228.7 feet during the April 2013 SDMF (total range of about 3.1 feet) at the downstream transducer. For comparison, the peak water-surface elevations during the September 2013 flood that occurred after the last monitoring survey was about 2246 feet at the upstream transducer and about 2230.3 feet at the downstream transducer, 5.6 and 4.8 feet above the minimum water-surface elevations, respectively.

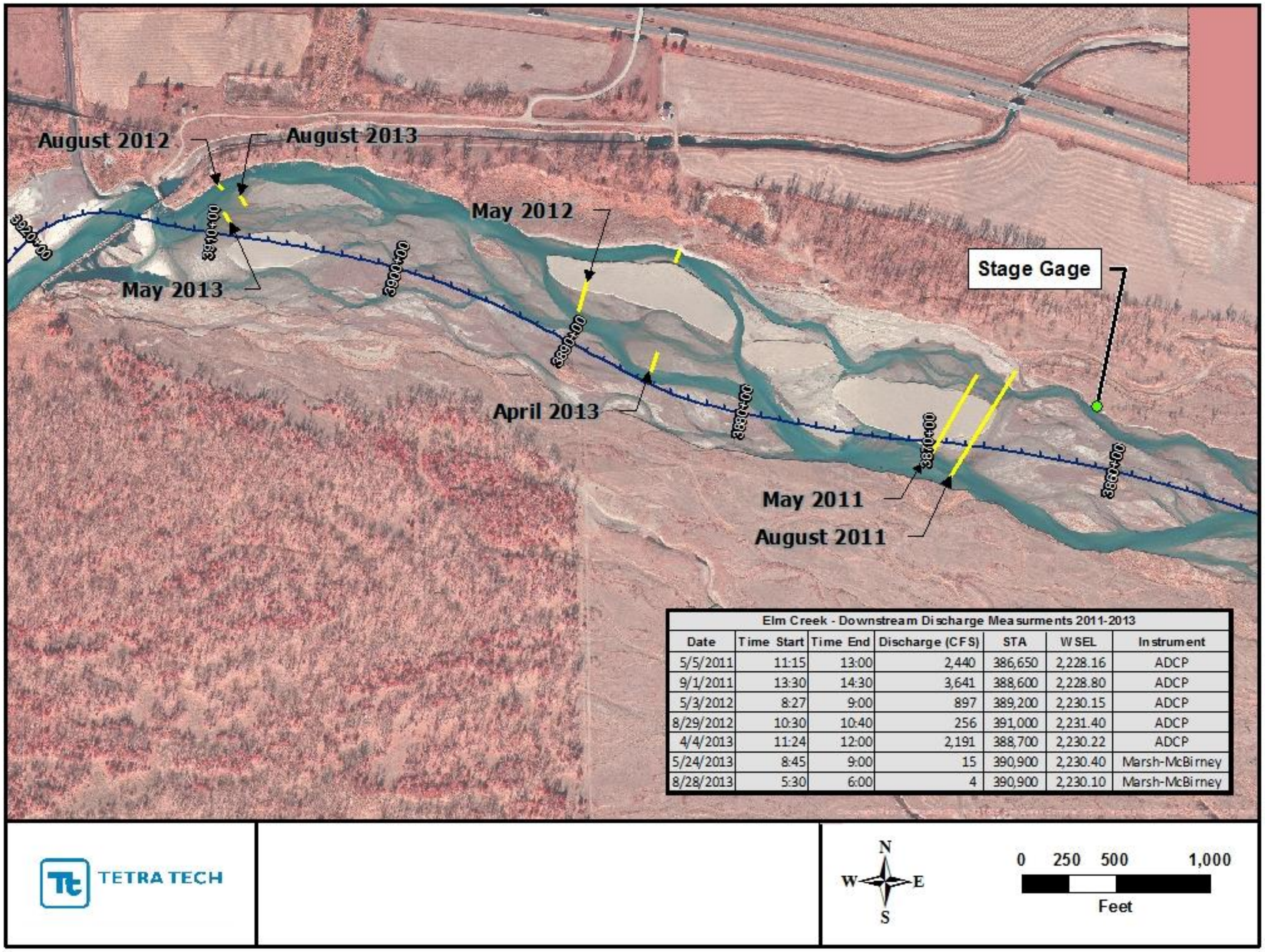
4.2 Discharge Measurements

The discharge measurements were made using a RiverRay^{TM} Acoustic Doppler Current Profiler (ADCP) following procedures in Oberg et al. (2005) when flow depths across most the cross section exceeded one foot (**Figure 4.6; Table 4.1**). When the flows were too low and shallow for the ADCP, the measurements were made using a Marsh-McBirney 2000 flow meter with wading



Elm Creek - Upstream Discharge Measurments 2011-2013						
Date	Time Start	Time End	Discharge (CFS)	STA	WSEL	Instrument
5/4/2011	8:00	10:00	3,250	396,100	2,242.63	ADCP
8/31/2011	11:00	12:00	3,459	395,550	2,242.15	ADCP
5/2/2012	10:45	11:20	960	392,600	2,241.16	ADCP
8/29/2012	8:30	10:00	333	392,150	2,237.60	ADCP
4/4/2013	8:48	9:45	2,194	400,070	2,246.33	ADCP
5/24/2013	8:00	8:30	112	400,070	2,244.70	Marsh-McBirney
8/28/2013	4:30	5:00	81	400,080	2,244.60	Marsh-McBirney

Figure 4.1. Stage gage location and discharge measurement transects upstream from the KDS.



Elm Creek - Downstream Discharge Measurments 2011-2013						
Date	Time Start	Time End	Discharge (CFS)	STA	WSEL	Instrument
5/5/2011	11:15	13:00	2,440	386,650	2,228.16	ADCP
9/1/2011	13:30	14:30	3,641	388,600	2,228.80	ADCP
5/3/2012	8:27	9:00	897	389,200	2,230.15	ADCP
8/29/2012	10:30	10:40	256	391,000	2,231.40	ADCP
4/4/2013	11:24	12:00	2,191	388,700	2,230.22	ADCP
5/24/2013	8:45	9:00	15	390,900	2,230.40	Marsh-McBirney
8/28/2013	5:30	6:00	4	390,900	2,230.10	Marsh-McBirney

Figure 4.2. Stage gage location and discharge measurement transects downstream from the KDS.

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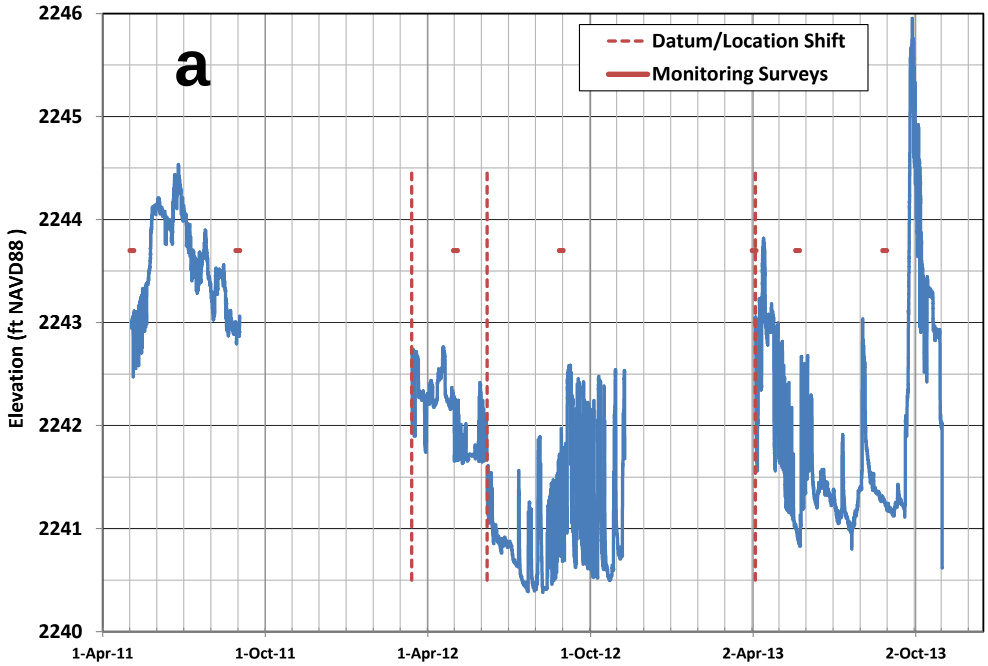
Figure 4.3. Pressure transducer stage gage at the measurement point between the KDS and Elm Creek Bridge.

Figure 4.4. Level TROLL 500 Sonde being used to monitor stages at the Elm Creek Complex.



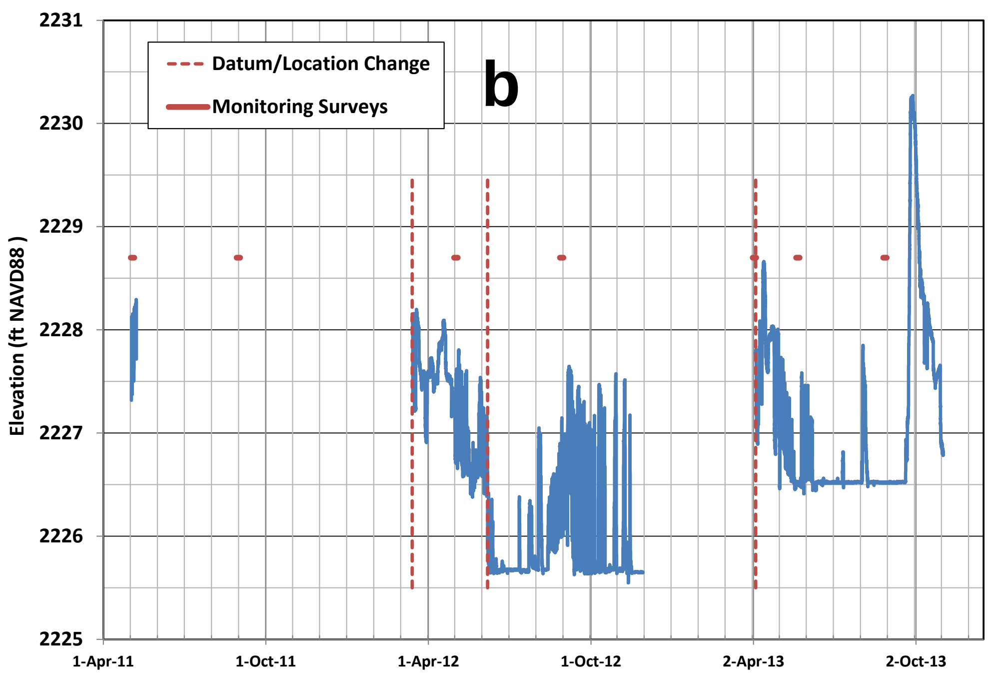


Figure 4.5. Water-surface elevations at the pressure transducers during the period of experiment: (a) upstream transducer, (b) downstream transducer.

Figure 4.6. ADCP discharge measurement being made at the upstream measurement transect on May 2, 2012.

Table 4.1. Summary of discharge measurements during monitoring surveys.

Date	Start Time	End Time	Discharge (cfs)	Station	Water-surface Elevation (ft)		Instrument
					Measurement Site	Stage Logger[1]	
Upstream							
5/4/2011	8:00	10:00	3,250	396,100	2,242.63	2,242.48	ADCP
8/31/2011	11:00	12:00	3,459	395,550	2,242.15	2,242.36	ADCP
5/2/2012	10:45	11:20	960	392,600	2,241.16	2,241.19	ADCP
8/29/2012	8:30	10:00	333	392,150	2,237.60	2,240.55	ADCP
4/4/2013	8:48	9:45	2,194	400,070	2,246.33	2,241.64	ADCP
5/24/2013	8:00	8:30	112	400,070	2,244.70	2,240.70	M-McB[3]
8/28/2013	16:30	17:00	81	400,080	2,244.60	2,240.87	M-McB[3]
Downstream							
5/5/2011	11:15	13:00	2,440	386,650	2,228.16	2,227.80	ADCP
9/1/2011	13:30	14:30	3,641	388,600	2,228.80	[2]	ADCP
5/3/2012	8:27	9:00	897	389,200	2,230.15	2,227.02	ADCP
8/29/2012	10:30	10:40	256	391,000	2,231.40	2,226.26	ADCP
4/4/2013	11:24	12:00	2,191	388,700	2,230.22	2,227.05	ADCP
5/24/2013	8:45	9:00	15	390,900	2,230.40	2,226.50	M-McB[3]
8/28/2013	17:30	18:00	4	390,900	2,230.10	2,226.51	M-McB[3]

[1] Dataloggers shifted slightly from year to year. Elevations adjusted to represent 2013 location based on the local water-surface slope from HEC-RAS model.
[2] No reading because datalogger washed out during June high flows.
[3] March-McBirney 2000 with wading rod.

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rod using the standard USGS flow measurement protocol. All of the 2011 and 2012 measurements and the April 2013 measurements were taken with the ADCP, and the May and August 2013 measurements were taken with the Marsh-McBirney 2000.

A key element of the ADCP measurement procedures is the “5-percent” rule that specifies that a minimum of four transects are to be measured. If the discharge from each of the individual measurements is within 5 percent of the average of the four measurements, the measured discharge is then taken to be the average value of the four individual measurements. If any of the individual measurements differs from the average by more than 5 percent and no critical data-quality issues can be identified, a minimum of four additional transect measurements are made, and the measured discharge is taken as the average of all eight measurements. The procedure allows for one of the transect measurements to be discarded and replaced by a single additional measurement if a data-quality issue can be clearly identified that caused that specific measurement to be in error. The primary factor that causes variability in the measurements in rivers such as the Platte, particularly at low flows, is shallow flow depth across substantial portions of the cross section. The ADCP is typically not able to take valid velocity measurements at depths less than about 1 foot, and substantial portions of the transects had depths at or below this range. A summary of the individual measurements that were used to derive the reported discharges for the April 2013 ADCP measurements is provided in **Table 4.2**. Similar summaries for the 2011 and 2012 ADCP measurements were provided in the respective annual reports.

The individual measurements are shown in Figures 1.8 and 2.1 to put all of these measurements into the context of the mean daily and real-time data at the Overton and Kearney gages. In general, the measurements are consistent with the USGS-reported data, considering the time-lag between the gages and the measurement sites. In considering these data, it is important to recognize that the USGS data are provisional; thus, some adjustments may occur as the data are subjected to the quality assurance review process. These data are useful in providing at least a few points on the local stage-discharge rating curves, they provide a means of quantifying the lag-time and at least some portion of the flow profile changes between Overton and Kearney, and the ADCP data also provide measurements of the velocity distribution across the channel that can be used to assess sediment movement and validate model results.

Table 4.2. Summary of individual measurement passes for April 4, 2013, ADCP measurements.

Transect	Upstream from KDS				Downstream from KDS			
	North Channel		South Channel		North Channel		South Channel	
	Discharge (cfs)	% Difference from Average	Discharge (cfs)	% Difference from Average	Discharge (cfs)	% Difference from Average	Discharge (cfs)	% Difference from Average
1	798	-8.8%	1,252	-4.9%	462	-2.7%	1,783	3.7%
2	855	-2.3%	1,364	3.7%	497	4.7%	1,787	3.9%
3	1,029	17.6%	1,296	-1.5%	472	-0.7%	2,027	17.9%
4	753	-14.0%	1,344	2.1%	486	2.4%	1,707	-0.7%
5	959	9.6%	1,205	-8.4%	473	-0.5%	1,735	0.9%
6	782	-10.7%	1,370	4.1%	493	3.7%	1,855	7.9%
7	982	12.2%	1,321	0.3%	434	-8.7%	1,728	0.5%
8	843	-3.7%	1,376	4.6%	483	1.7%	1,132	-34.1%
Average*	**875**		**1,316**		**475**		**1,719**	
Total	**2,191**				**2,194**			

*Per procedures from Oberg et al. (2005).

5 VEGETATION MONITORING

5.1 2013 Monitoring Activities

Vegetation sampling was systematically performed to identify the range of plant species and to quantify the frequency and aerial cover and other key characteristics of the key species on the sand bars over the range of bar heights within the Elm Creek Complex. Sample plots were initially identified in 2011 based on a series of elevations that correspond to the water surface at four increments of flow between 1,200 and 8,000 cfs using the PRRIP LiDAR data and hydraulic model results. It was initially assumed that these elevation/flow zones would produce distinct vegetation growth patterns that can be correlated with flow depths, velocities, and other factors; however, the data did not support this assumption. In addition, the green line (lower boundary at which vegetation cover equals or exceeds 25 percent) was surveyed around the perimeter of all bars and on the cross sections where it could be identified.

The vegetation sampling was conducted using a series of Modified Whittaker assessment plots (Stohlgren et al., 1995) of approximately 1,000 m^2 each located on individual bars that represent the range of elevations (**Figure 5.1**). On small bars where the 1,000-m^2 plot extends beyond the perimeter of the island, the sample plot shape was modified to the bar perimeter. A total of 21 bars were samples in 2011 and 28 bars were sampled in both 2012 and 2013. Additional sample plots/bars were included after the 2011 field season to ensure a sufficient number of bars in each elevation range to allow for both cleared and uncleared bars to be evaluated in all three years (**Table 5.1**). Seventeen of the 21 bars sampled in 2011 had been disked prior to sampling to remove all perennial or persistent vegetation, and none of the bars were cleared between the 2011 and 2012 sampling events. Eight of the 28 bars sampled in 2013 had been cleared and sprayed in 2012 to create nesting islands; all other bars were not cleared.

The plots were selected to represent a reasonable distribution of elevations with respect to the range of flow levels that would be affected by an SDHF release. For purposes of the analysis, the bars were grouped into the following four water-surface elevation ranges:

1. Q<1,200 cfs
2. 1,200 cfs<=Q<3,000 cfs
3. 3,000 cfs<=Q<5,000 cfs
4. Q>=5,000 cfs

In the Modified Whittaker design, one 100-m^2 subplot, two 10-m^2 subplots, and 10 1-m^2 subplots are nested within the overall 1,000 m^2 sample plot (Stohlgren et al., 1995; Comiskey et al., 2000) (inset in Figure 5.1). The 100 m^2 subplot is located in the center of the plot, with the two 10-m^2 subplots in two opposite corners and the 10 1-m^2 subplots distributed evenly around the edges. Vegetation sampling within each subplot included identification of all species present, percent cover of each species using Daubenmire cover classes[7] and height classes for woody[8]

[7] Daubenmire cover classes are:

- Cover class 1: 1-5%
- Cover class 2: 6-25%
- Cover class 3: 26-50%
- Cover class 4: 51-75%
- Cover class 5: 76-95%
- Cover class 6: 96-100%

and herbaceous species[9] using the categories identified in the system-wide monitoring protocol (Ayres and Olsson, 2010).

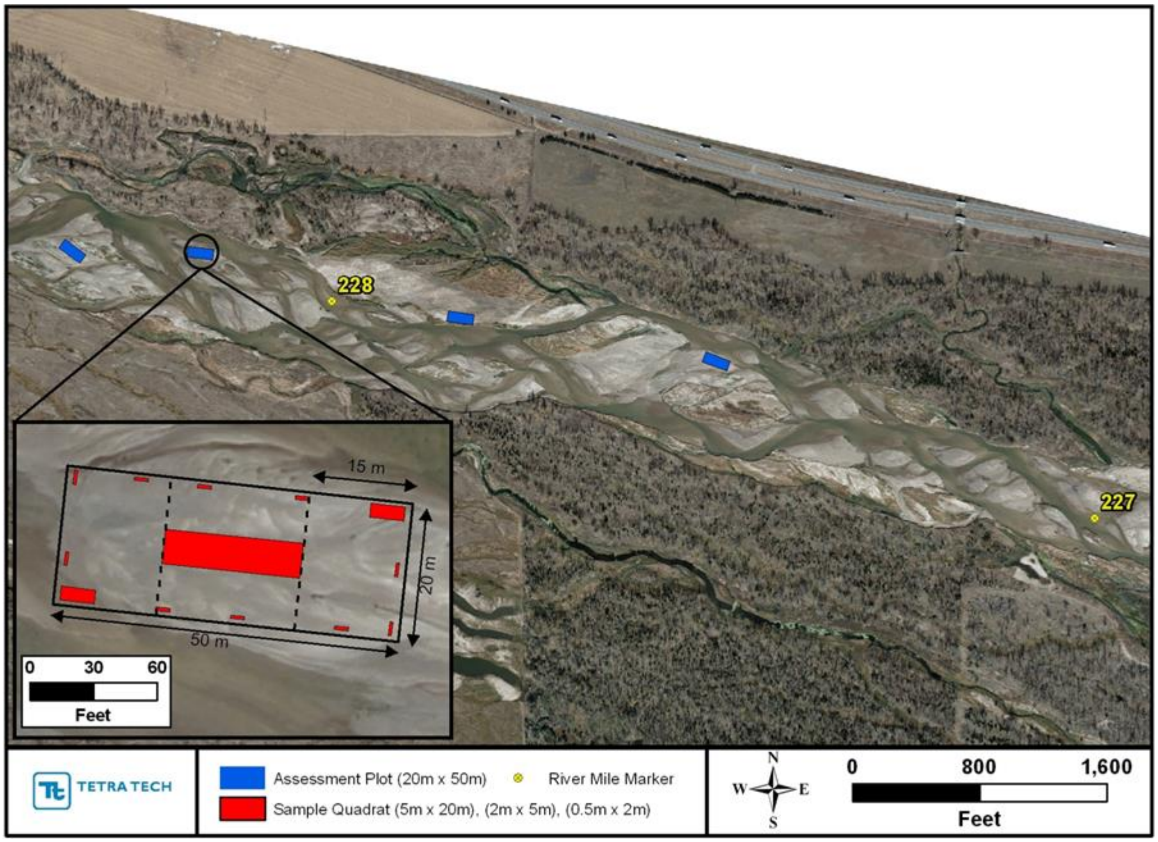

Figure 5.1. Example layout of modified Whittaker plots used for the vegetation sampling.

[8] Woody vegetation was categorized into two classes: 1) less than 59 inches (1.5 meters), and 2) greater than 59 inches (1.5 meters).
[9] Herbaceous vegetation was categorized into three classes: (1) less than 12 inches (0.3 m); (2) 12- 59 inches (0.3 to 1.5 m); and (3) greater than 59 inches (1.5 m).

Table 5.1. Vegetation clearing prior to applicable annual survey.

Veg Sample Plot ID	Bar Grouping	Year 1 (2011)	Year 2 (2012)	Year 3 (2013)
3	1	Cleared	Not Cleared	Not Cleared
6	1	Cleared	~~Cleared~~*	Not Cleared
10	1	Cleared	Not Cleared	Not Cleared
12	1	Cleared	~~Cleared~~*	Not Cleared
13	1	Cleared	Not Cleared	Not Cleared
16	1	Cleared	~~Cleared~~*	Cleared
17	1	Not Cleared	Not Cleared	Not Cleared
18	1	Not Cleared	Not Cleared	Not Cleared
19	1	Cleared	~~Cleared~~*	Cleared
22	1	N/A	Not Cleared	Not Cleared
26	1	N/A	~~Cleared~~*	Cleared
5	2	Cleared	~~Cleared~~*	Not Cleared
11	2	Cleared	~~Cleared~~*	Not Cleared
14	2	Cleared	~~Cleared~~*	Not Cleared
20	2	Not Cleared	Not Cleared	Not Cleared
28	2	N/A	~~Cleared~~*	Not Cleared
1	3	Cleared	Not Cleared	Not Cleared
2	3	Cleared	~~Cleared~~*	Cleared
4	3	Cleared	~~Cleared~~*	Not Cleared
7	3	Cleared	Not Cleared	Not Cleared
23	3	N/A	~~Cleared~~*	Cleared
24	3	N/A	~~Cleared~~*	Not Cleared
8	4	Cleared	Not Cleared	Not Cleared
9	4	Cleared	~~Cleared~~*	Cleared
15	4	Cleared	~~Cleared~~*	Not Cleared
21	4	Not Cleared	Not Cleared	Not Cleared
27	4	N/A	~~Cleared~~*	Cleared
25		N/A	~~Cleared~~*	Cleared

*The experimental plan called for clearing of these bars; however, because of the high-flow disturbance in 2011 and unusually low flows in 2012, no bar clearing was done prior to the 2012 surveys. New nesting islands were created in 2012 and are shown as cleared bars for 2013. No other clearing occurred prior to the 2013 sampling.

5.2 Analysis Approach

The following statistical analysis approach will be used for analyzing the individual and combined effects of flow, mechanical actions and sediment augmentation on vegetation. Changes in vegetation areal coverage and distribution between years are determined by estimating total area of vegetation coverage from LiDAR imagery and green-line data collected with the geomorphic surveys. During each year, vegetation frequency, percent cover, areal coverage and distribution were calculated for each sampling event.

To determine differences in vegetation response due to different sequences of flow, changes in sediment load and mechanical activities, and to assess year-to-year variability, the data were analyzed using a single factor analysis-of-variance (ANOVA) model or the equivalent non-parametric Kruskal-Wallis test. The purpose of the analysis is to identify the statistical significance of variability between vegetation species and cover and each of the response variables.

5.3 Summary of Vegetation Monitoring Results

5.3.1 Green-line Elevations

Green-line points (i.e., edge of vegetation around sand bars and along banks, defined by minimum 25-percent vegetative cover) were surveyed during six of the seven monitoring surveys[10]. The primary purpose of the collecting these points is to define the unvegetated channel width for purposes of assessing Priority Hypotheses #3 and #5. The number of individual green-line points that were collected during each survey varied from 270 (August 2013) to 819 (May 2012) (**Appendix E**). Because a variety of factors other than flow levels can influence the location of the green line and because the line can be difficult to identify on sparsely vegetated bars and banks, the elevations among the surveyed green-line points tend to have a relatively large amount of scatter (**Figure 5.2**).

The 2-D model results (described in a later section of this report) were used to assess the height of the greenline points relative to the 1,200-cfs water surface. Points surveyed in May and August 2011 were assess using the model developed from the 2011 survey data, and the points from the later surveys (i.e., May 2012, August 2012, May 2013 and August 2013) were assessed using the model developed from the 2012 survey data. The 1,200-cfs water surface was used for this comparison because it is the reference elevation for identifying the perimeter of the individual bars, and it serves as a useful reference plan for comparing the relative heights of the greenline points along the reach. Because of the shifting nature of the sand bed and the tendency for erosion and deposition around the margins of the bars, the ground elevation at the surveyed greenline points tends to vary from the corresponding point in the model topography, except for the two surveys on which the model is based. Fortunately, the variation in water surface associated with this process is much smaller. For this reason, the modeled water-surface elevations were compared with the surveyed elevations at the greenline points, rather than the depth reported by the model.

In general, the greenline tended to be highest during the initial three surveys (i.e., May 2011, August 2011 and May 2012) when flows in the reach were relatively high, and they showed a mild trend of increasing height with time during the period (**Figure 5.3, Table 5.2**). In May 2011, the average height was about 1.2 feet above the 1,200 cfs water-surface, increasing to 1.3 feet in August and increasing further to about 1.4 feet in May 2012. The points in the downstream part of the reach showed a similar trend, increasing from about 1.4 feet above the 1,200 cfs water-surface in May 2011 to about 1.6 feet in both August 2011 and May 2012. The height of the points then declined during the subsequent surveys when the flows through the reach were generally quite low. In August 2012, the average height in the upstream part of the reach was only about 0.2 feet above the 1,200 cfs water-surface, they declined to about 0.2 feet below by May 2013, then declined even further to about 1.1 below by August 2013. In the downstream part of the reach, the August 2012 points were about 0.5 feet below the 1,200 cfs water-surface, and this increased to about 0.2 feet above by May 2013 and then declined back to about 0.8 feet below by August 2013.

The depths of inundation of the greenline points at the maximum water-surface elevation during portion of the growing season leading up to each of the monitoring surveys and the maximum

[10]No green-line points were surveyed during April 2013 because annual vegetation growth had not started sufficiently to allow identification of the points.

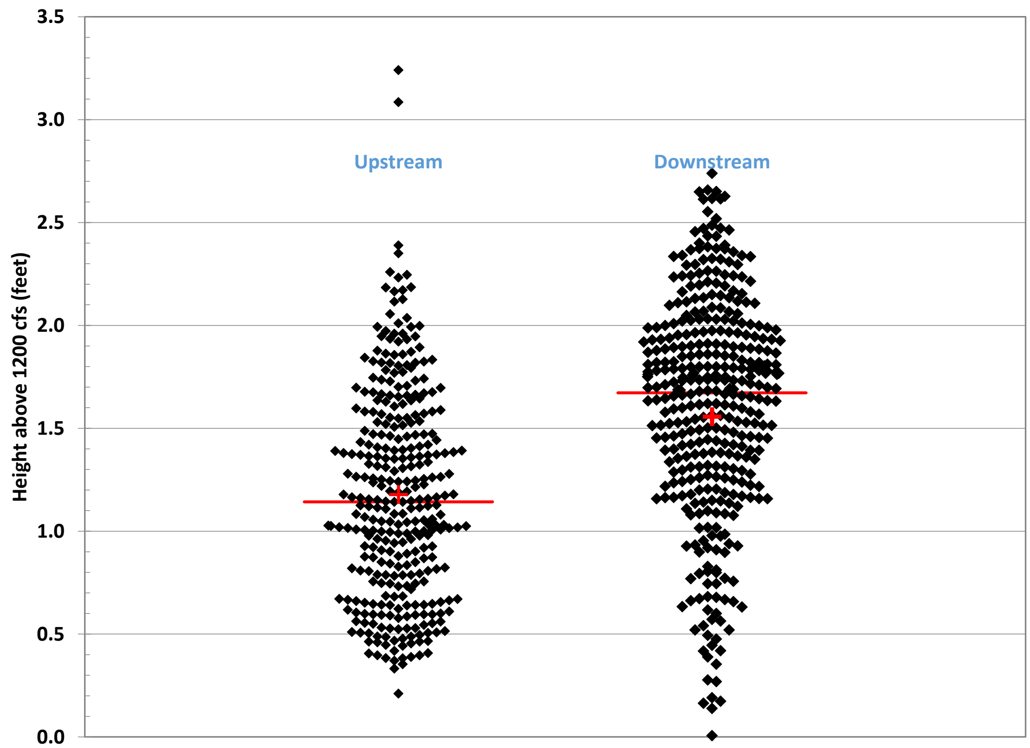

Figure 5.2. Scatter plot of surveyed greenline points up- and downstream from the KDS during the May 2011 survey. Red line is median value; red "+" is mean value. Scatter for other surveys is similar.

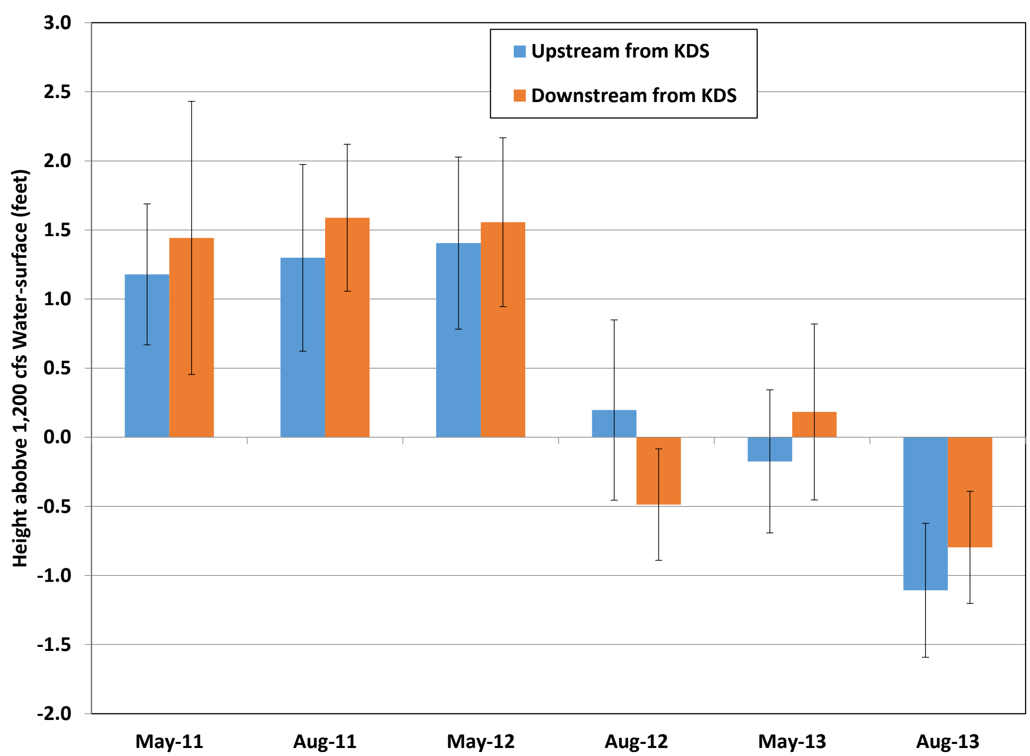

Figure 5.3. Height of surveyed greenline points above the 1,200-cfs water-surface elevation during the May and August monitoring surveys. Bars represent average height, whisker represent ±1 standard deviation on the scatter of individual points.

Table 5.2. Maximum discharge between the start of the growing season (April 1) and the date of the surveys during each of the three monitoring years.

Survey Dates		Maximum Mean Daily Discharge[1]				
Start	End	Date	Overton	Upstream[2]	KDS[2]	Downstream[2]
5/2/2011	5/6/2011	4/17/2011	4,020	4,027	91	3,936
8/29/2011	9/2/2011	6/25/2011	8,720	9,503	331	9,172
4/30/2012	5/4/2012	4/18/2012	2,980	2,928	0	2,928
8/27/2012	8/31/2012	4/18/2012	2,980	2,928	0	2,928
4/1/2013	4/5/2013	4/3/2013	1,840	1,655	0	1,655
5/20/2013	5/24/2013	4/13/2013	4,070	4,641	0	4,641
8/26/2013	8/30/2013	4/13/2013	4,070	4,641	0	4,641

[1]Maximum from start of growing season (April 1) to date of survey.

[2]Maximum flow from USGS Overton gage record; recorded mean daily diversion at KDS and estimated mean daily flow up- and downstream from KDS on day of maximum at Overton.

Parameter	Upstream						Downstream					
	May-11	Aug-11	May-12	Aug-12	May-13	Aug-13	May-11	Aug-11	May-12	Aug-12	May-13	Aug-13
Number of Points	325	543	391	379	318	165	114	242	380	121	129	105
Mean	1.13	1.66	-0.33	1.09	1.55	1.54	1.32	1.75	-0.30	1.07	1.44	1.27
Minimum	0.00	0.00	-1.85	-1.80	-0.23	-2.88	0.00	0.23	-1.91	-0.38	-0.23	0.46
Maximum	3.48	4.27	1.96	2.65	3.32	2.59	3.91	4.15	1.94	2.26	2.94	2.16
Standard deviation	0.60	0.82	0.61	0.70	0.63	0.55	0.89	0.76	0.60	0.50	0.69	0.37
Confidence Limits on Mean (95%)	0.07	0.07	0.06	0.07	0.06	0.07	0.16	0.10	0.06	0.09	0.10	0.06

Water surface between the May and August surveys in 2012 and 2013 were assessed using the same approach that was used for the 1,200 cfs comparison. (Only one comparison was made for the August 2011 survey because the highest discharge (8,720 cfs) occurred between the May and August surveys.) In both parts of the reach, a significant percentage of the points that were surveyed in May 2011 had not been inundated by the preceding high flow during the growing season, but all were inundated by the high flow that occurred between the May and August surveys (average depth of about 0.9 feet) (**Figure 5.4**). The vast majority of the surveyed points in May 2012 were also well below preceding high flow during the growing season (average of about 0.6 feet below in the upstream part of the reach and about 1.6 feet below in the downstream part of the reach.) By August 2012, the greenline elevations in the upstream part of the reach had declined to an average of about 1.5 feet below the Spring 2012 maximum water-surface and about 0.7 feet below the highest water-surface between the May and August 2012 surveys. Because of the generally flatter stage-discharge rating curve in the downstream part of the reach, the inundation depths at the August 2012 survey points was somewhat less at about 0.8 feet below the spring high water elevation and about 0.5 feet below the summer high water. The May 2013 points were inundated to an average depth of about 1.7 feet by April 2013 SDMF in the upstream part of the reach and about 0.4 feet in the downstream part of the reach. The elevations then decreased to about 2.6 feet below the spring high water elevation and 1.5 feet below the maximum water-surface during the summer in the upstream part of the reach by August 2013. In the downstream part of the reach, the average inundation

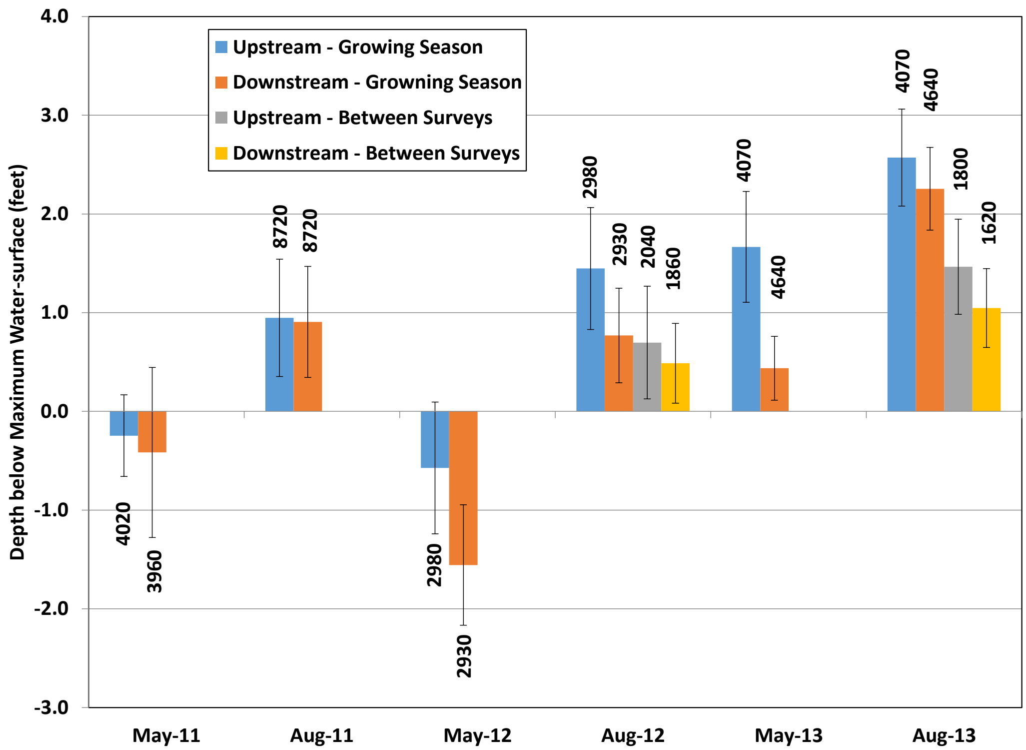

Figure 5.4. Depth of inundation of the greenline points by the maximum water-surface elevation during the portion of the growing season prior to each survey (assumed to begin on April 1) and during the period between the May and August surveys in 2012 and 2013. Bars represent average height, whiskers represent ±1 standard deviation on the scatter of individual points. Values adjacent to the bars are the discharge corresponding to the maximum water surface.

depths in the downstream part of the reach were about 2.3 feet below the spring high water and about 1.1 feet below the summer high water.

5.3.2 Total Unvegetated Channel Widths

The total unvegetated channel width was also assessed by identifying the cumulative distance between green-line points across each of the surveyed cross sections (**Figure 5.5**). Similar plots for 2011 and 2012 were provided in the respective annual reports. As noted above, no green-line points were surveyed in April 2013 because very little vegetation was present. As a result, unvegetated widths shown in **Figure 5.6** for this survey represent the total channel width that averaged about 830 feet in the upstream part of the reach and about 760 feet in the downstream part of the reach. At the time of the May 2013 survey, the unvegetated widths were about 680 feet upstream from the KDS and about 745 feet downstream from the KDS, and the average width decreased substantially to 380 feet upstream and 450 feet and downstream from the KDS by August 2013.

The unvegetated widths during the April and May surveys in each year were essentially the same as the total channel width, primarily because the surveys were conducted early in the growing season (**Figure 5.7**). During 2011, when the flows were very high, the unvegetated width decreased by only a small amount by the end of August, while a significant reduction occurred in both 2012 and 2013. During 2011, the average width was slightly less than 800 feet

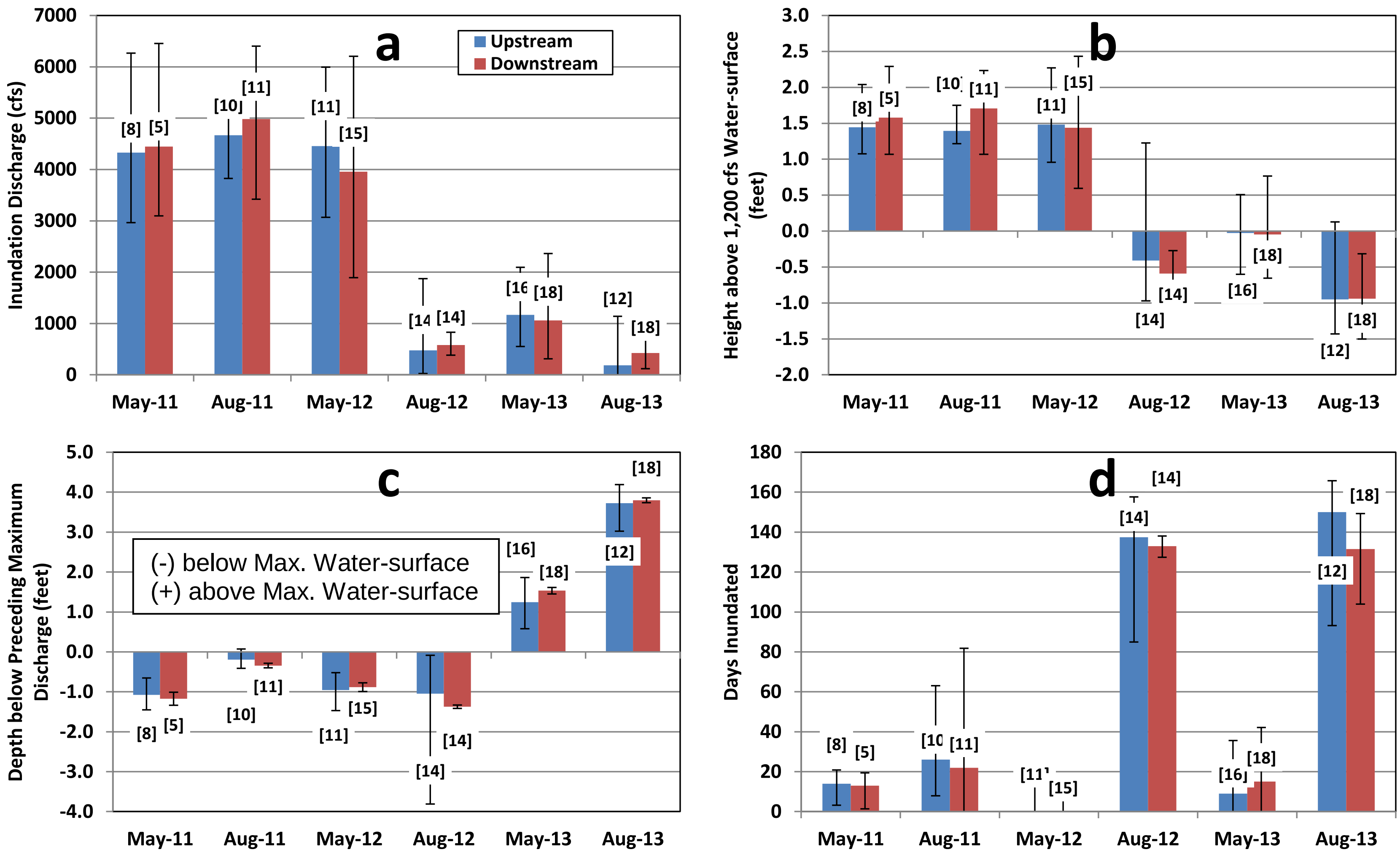

Figure 5.5. Summary of greenline elevation data: (a) inundation discharge, (b) height above 1,200-cfs water surface, (c) depth below preceding maximum water surface, (d) days inundated. Whiskers present upper and lower bounds that encompass 75 percent of the data points for each parameter.

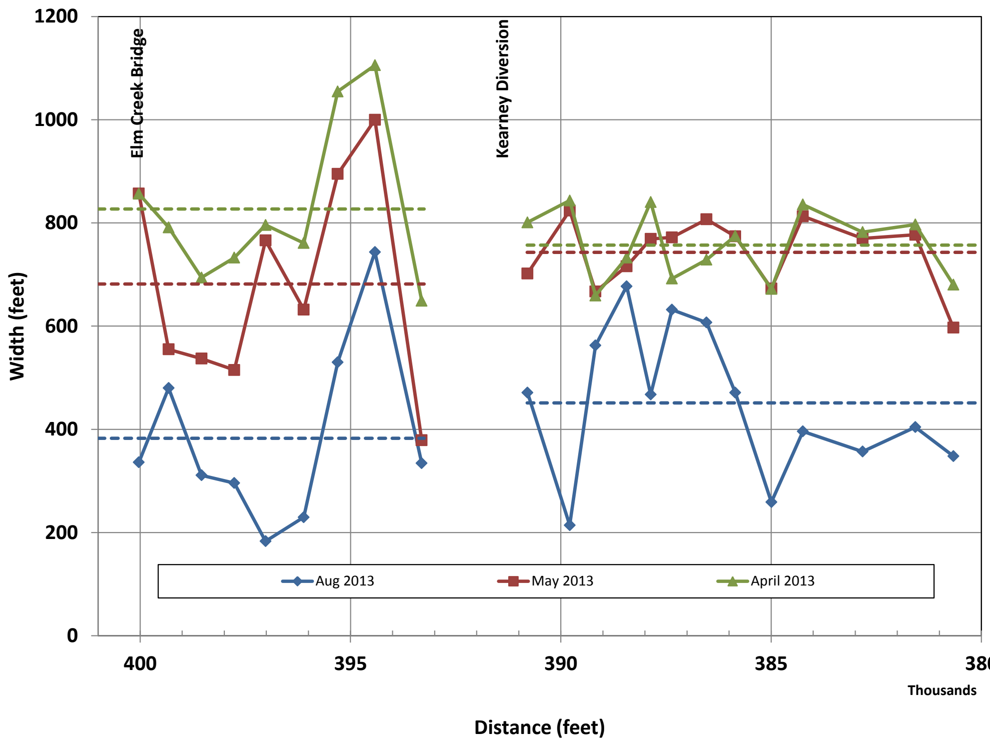

Figure 5.6. Total unvegetated channel widths at the surveyed transects during the 2013 surveys, based on the greenline data.

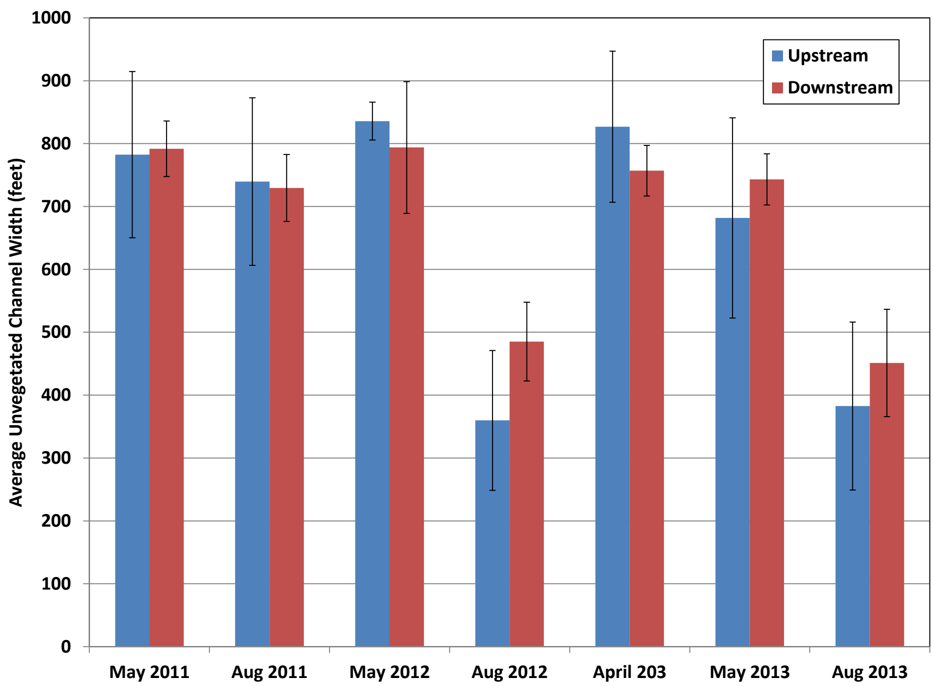

Figure 5.7. Average unvegetated width in the up- and downstream portions of the reach during each of the seven monitoring surveys that were conducted in 2011, 2012 and 2013. Whiskers represent ±1 standard deviation about the mean.

in both parts of the reach during the May survey, and only declined to 730 to 740 feet by August. The unvegetated width in May 2012 was about 840 feet in the upstream part of the reach and 790 feet in the downstream part of the reach, both somewhat greater than May 2011. These values then declined to about 360 feet upstream and 485 feet downstream from the KDS by August, due primarily to the very low flows that occurred during the intervening period. Based on the non-parametric Kruskal-Wallace test, the differences between all of the May widths and the August 2011 widths are not statistically significant in either part of the reach at the 95-percent confidence level (**Table 5.3**). Similarly, the differences between the August 2012 and August 2013 data are not statistically significant. The August 2012 and August 2013 data are, however, statistically different from the other four samples periods.

Table 5.3a. Pairwise comparison of total unvegetated channel widths in the portion of the Elm Creek reach upstream from the KDS (Kruskal-Wallace, p-values).

	May 2011	Aug 2011	May 2012	Aug 2012	April 2013	May 2013	Aug 2013
May 2011	1						
Aug 2011	0.653	1					
May 2012	0.550	0.295	1				
Aug 2012	**0.000**	**0.002**	**< 0.0001**	1			
April 2013	0.653	0.368	0.882	**< 0.0001**	1		
May 2013	0.437	0.743	0.169	**0.006**	0.219	1	
Aug 2013	**0.001**	**0.003**	**< 0.0001**	0.898	**0.000**	**0.009**	1

Table 5.3b. Pairwise comparison of total unvegetated channel widths in the portion of the Elm Creek reach downstream from the KDS (Kruskal-Wallace, p-values).

	May 2011	Aug 2011	May 2012	Aug 2012	April 2013	May 2013	Aug 2013
May 2011	1						
Aug 2011	0.063	1					
May 2012	0.815	0.105	1				
Aug 2012	**< 0.0001**	**0.009**	**< 0.0001**	1			
April 2013	0.453	0.269	0.606	**0.000**	1		
May 2013	0.259	0.467	0.371	**0.001**	0.705	1	
Aug 2013	**< 0.0001**	**0.002**	**< 0.0001**	0.593	**< 0.0001**	**0.000**	1

5.3.3 Channel Widths Inundated to Greater than 0.25 Feet

The performance measures and benchmarks for Priority Hypothesis Flow #5 include a minimum 750-foot wide channel within which 90 percent of the vegetation is scoured. A related benchmark calls for flow releases of sufficient duration to inundate a 750-foot channel to depths greater than 0.25 feet for periods exceeding the inundation mortality threshold for in-channel vegetation (Table 1.1). The green-line analysis presented in the previous section provides an initial assessment of the variability in unvegetated channel width during the monitoring period (although the green-line is based on a 25-percent cover threshold versus a 10-percent cover required by this hypothesis). To help evaluate the duration-related portion of this performance measure, the total channel width[11] having flow depth greater than 0.25 feet for 30, 60 and 90 days between the start of the growing season (assumed to be April 1 for purposes of this analysis) and the start of the August survey in each year was estimated for each of the surveyed transects using the surveyed cross section data, the hydraulic model results, and the estimated mean daily flows during the period. The total width with depth greater than 0.25 feet for the entire period (i.e., the width corresponding to the lowest mean daily flow) was also estimated.

Flow records used in the analysis were taken from mean daily flow records that were developed for each of the anchor points (APs) in the system-wide monitoring program (Tetra Tech, 2014) by interpolating between the active gages and measured tributary inflows and diversions along the reach[12]. The estimated flow record for AP31, that is located about 0.7 miles upstream from the Elm Creek Bridge, was assumed to be representative of flows in the upstream portion of the reach, and the estimated flows immediately downstream from the KDS were used for the downstream part of the reach. The flows at these two locations were estimated by linearly interpolating (based on distance) between the measured flows at the Overton and Odessa gages, with adjustments for the measured inflows from Spring Creek, Elm and Buffalo Creeks and the diversions into the Kearney Canal. As previously noted, the flows during the 2011 growing season were much higher than normal, and the flows during the 2012 and 2013 growing seasons were very low (**Table 5.4**).

As expected, the inundated widths varied by cross section, based on the channel width and presence of sand bars, but were significantly greater in 2011 than in 2012 and 2013 for all of the durations analyzed, due to the much higher flows (**Figure 5.8**). In 2011, the average widths with depths greater than 0.25 feet all cross sections in 2011 were in the range of 800 feet in both parts of the reach for durations less than 60 days, decreasing to 740 feet to 750 feet for the 90 day duration. The minimum inundated width for the entire approximately 150-day period of the growing season leading up to the August 2011 survey was about 570 feet in the upstream part of the reach and 590 feet in the downstream part of the reach. The average inundated width for the 30-day duration was only about 510 feet in the upstream part of the reach and about 575 feet in the downstream part of the reach in 2012, and 370 and 470 feet, respectively, in 2013. The average width decreased to about 300 feet in the upstream part of the reach during both years for the 60-day duration. In the downstream part of the reach, the average width for the 60-day duration was 260 feet to 270 feet in both parts of the reach. For the 90-day duration, the average widths were in the range of 230 to 260 feet in the upstream part of the reach during both years, and this decreased to about 120 feet in 2012 and only about 80 feet in 2013 in the

[11]The **widest contiguous width of channel** with depth greater than 0.25 feet was reported in the 2011 and 2012 annual reports.

[12]Flows used for the wetted-width analysis included in the 2011 and 2012 annual reports were taken directly from the Overton gage record. Although the differences are not large, the refined estimates used here are believed to better represent the flows that actually occurred in the Elm Creek reach.

downstream part of reach. The minimum width was about 180 feet in the upstream part of the reach in 2012, increasing to about 230 feet in 2012. In the downstream part of the reach, the minimum width was only about 90 feet in 2012, decreasing to about 80 feet in 2013.With the exception of 2011 when high sustained flows occurred, the inundated widths throughout the reach were significantly less than the 750-foot threshold throughout the monitoring period.

Table 5.4. Mean daily flows of various durations between the start of the growing season (April 1) and the start of each survey.

Duration (days)	Overton	Upstream[1]	Downstream[2]
	August 29 - September 2, 2011 [3]		
30	7,082	7,191	6,878
60	5,422	5,318	4,978
90	4,016	4,017	3,951
Entire Period	2,070	2,079	2,038
	August 27 - 31, 2012[3]		
30	1,300	1,385	1,386
60	450	494	357
90	277	262	94
Entire Period	68	72	0
	August 26 - 30, 2013[3]		
30	872	888	790
60	350	421	278
90	182	228	27
Entire Period	85	115	0

[1] Elm Creek Bridge to Kearney Diversion Structure.

[2] Kearney Diversion to downstream end of Elm Creek Complex.

[3] Monitoring survey period.

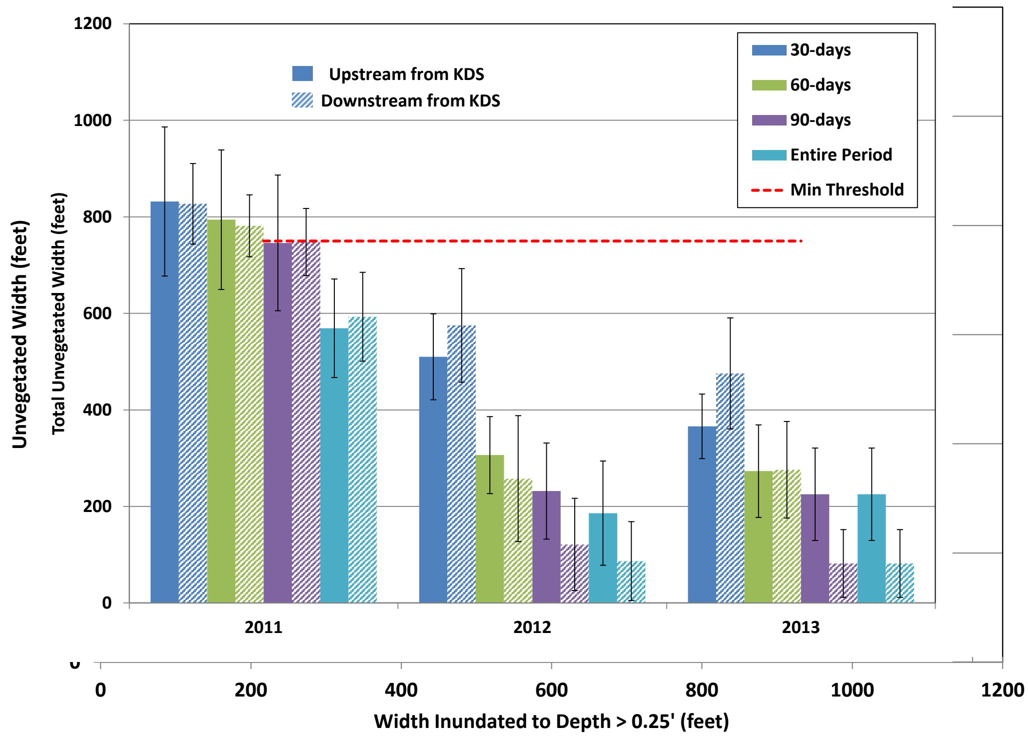

Figure 5.8. Average widths up- and downstream from the KDS inundated to greater than 0.25 feet for periods of 30, 60 and 90 days between April 1 (assumed start of growing season) to the August during each of the three monitoring years. Also shown are the average widths inundated to greater than 0.25 days for the entire period between April 1 and the start of the August survey. Whiskers represent ±1 standard deviation from mean.

The relationship between inundation durations and unvegetated width was evaluated by correlating the corresponding data described in the previous sections. The results indicate that the unvegetated width is highly correlated with the widths inundated to more than 0.25 feet for all three durations that were analyzed. The strongest correlation in the upstream part of the reach occurs with the 30-day duration R^2=0.63 (**Figure 5.9a**), while the strongest correlation in the downstream part of the reach occurs with at the 90-day duration (R^2=0.44) (**Figure 5.9b**). The low correlation in the downstream part of the reach is due, in large part, to the bar building and grading activity that occurred prior to the August 2012 and 2013 surveys.

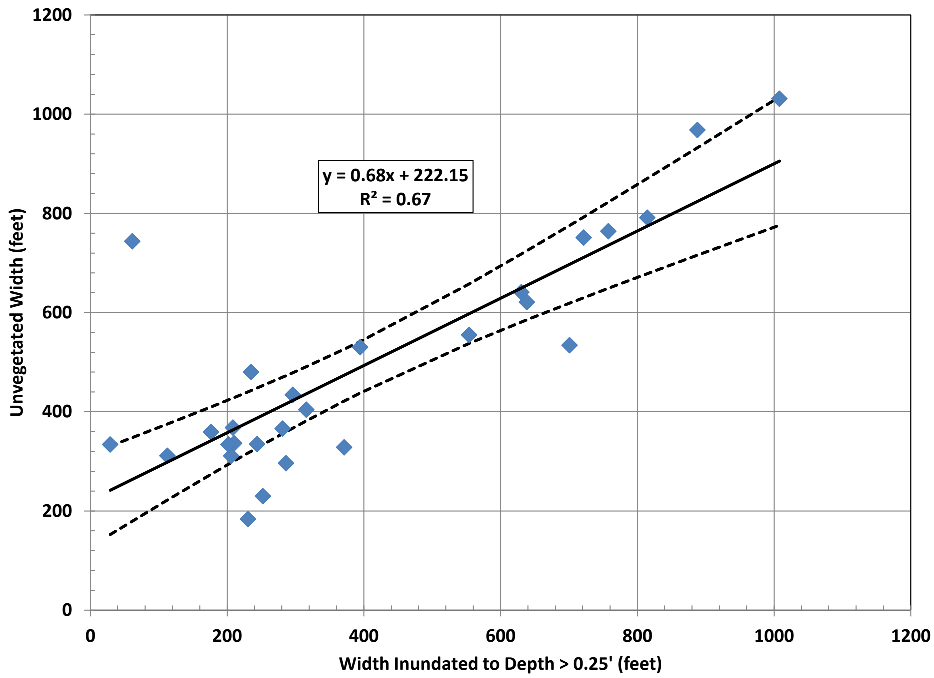

Figure 5.9a. Total unvegetated width as a function of the width inundated to depth of greater than 0.25 feet for 90 days between April 1 (start of growing season) and start of August survey upstream from KDS.

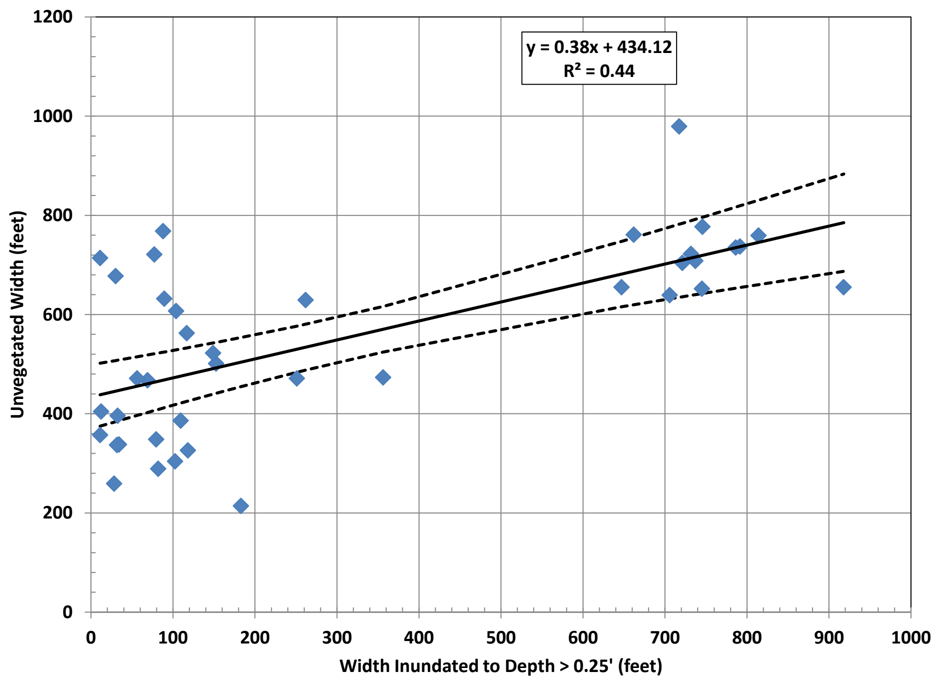

Figure 5.9b. Total unvegetated width as a function of the width inundated to depth of greater than 0.25 feet for 90 days between April 1 (start of growing season) and start of August survey downstream from KDS.

5.3.4 Vegetation Plot Elevations and Changes (April, May, and August 2013)

A total of 28 vegetation plots were sampled in April 2013, May 2013 after the Short Duration Medium Flow (SDMF), and then again in August 2013[13]. During all sampling events, the four corners of each plot and the maximum and minimum elevation within the plot were surveyed using an RTK-GPS roving unit.

The mean elevation of 3 of the sample plots that were overtopped by the April 2013 SDMF increased by more than 0.1 feet[14] between the April and May 2013 (Bar 2 – 0.2 feet, Bar 10 – 0.5 feet and Bar 13 – 1.1 feet) (**Figure 5.10a**). Eight (8) of the overtopped plots decreased in elevation by more than 0.1 feet, with magnitudes ranging up to 0.7 feet (Bar 24). Between May and August 2013 surveys, five (5) of the bars that were overtopped by the highest flows during the summer period increased by more than 0.1 feet, and only one of these increased by more than 0.2 feet (Bar 22, 0.5 feet), and 11 of the overtopped bars decreased in elevation by more than 0.1 feet, with the largest decreases occurring at Bar 20 (0.5 feet), Bar 26 (0.5 feet) and Bar 28 (1.0 feet) (**Figure 5.10b**).

5.3.5 Vegetation Species Occurrence and Distribution

There was relatively little vegetation cover on most sampled bars in both April and May 2013, and the vegetation that was present was dominated by seedlings of both annual and perennial species. Dieback of annual vegetation and winter ice scour are likely the two major causes of the typical lack of vegetation early in the growing season. The surface sediments on the bars were loose at most sample locations.

In the August 2013, all bars were above the average summer flow elevation, and most locations had a dense growth of annual and/or perennial vegetation. A large number of plant species were identified in the sample plots in all 2013 sampling efforts. A total of 29 species were identified in the overall Elm Creek Complex during the April 2013 sampling effort, with 73 species identified in May 2013 and 101 species identified in August 2013. Nineteen (9) key species that include the original species of interest from the system-wide monitoring protocol[15] (PRRIP, 2010), plus other commonly observed species, were selected for this analysis to provide a more comprehensive understanding of typical conditions on the bars (**Table 5.5**). Complete lists of species observed and all field data are provided in **Appendix G**. Photographs of representative plots in each of the flow inundation ranges are shown in **Figures 5.11 through 5.14**.

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[13]All of these plots were also sampled in May and August 2012, 20 of the plots were sampled in May 2011 and 21 were sampled in August 2011. The plot not sampled in 2011 were completely inundated, preventing sampling.

[14] For purposes of this analysis, it was assumed that changes less than 0.1 feet are within the uncertainty of the survey.

[15] The species of interest include woody species less than 1.5 m high, including willows, cottonwood, false indigo, saltcedar (all heights), and Russian olive, as well as four herbaceous species: purple loosestrife, phragmites, cattails, and river bulrush.

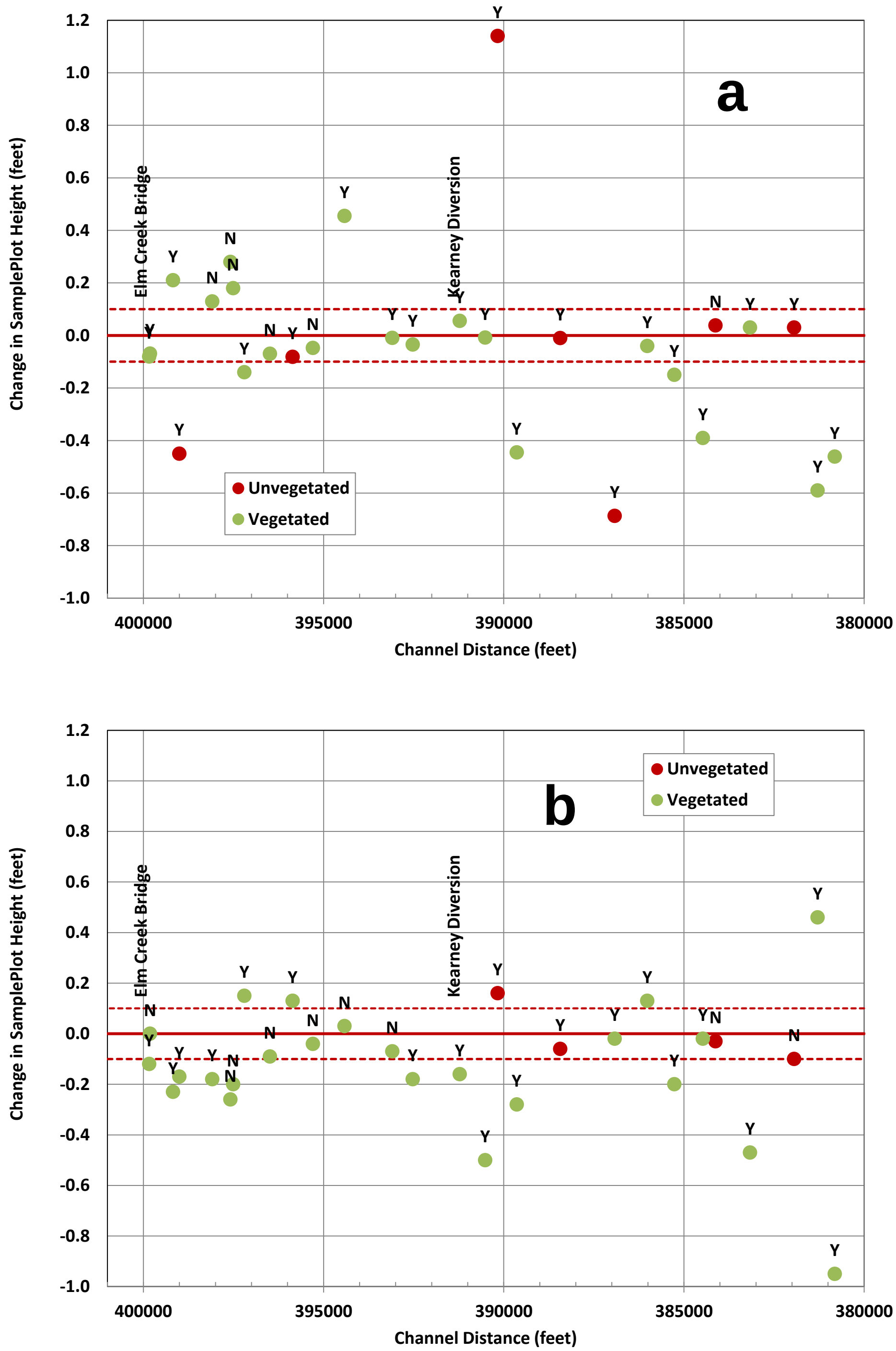

Figure 5.10. Change in mean height of the vegetation sample plots above the 1,200-cfs water-surface elevation between the May and August 2012 surveys.

Table 5.5. Key species from 2013 Elm Creek sampling. (Shaded = species of interest).

Scientific Name	Common Name	Veg Type	Wetland Indicator	Native?
Ambrosia artemisifolia	Annual ragweed	Forb	FACU	Y
Amorpha fruticosa	False indigo	Shrub	OBL	Y
Bidens cernua	Nodding beggar's tick	Forb	OBL	Y
Carex sp.	Sedge	Sedge	N/A	Y
Cyperus oderatus	Fragrant flat sedge	Sedge	FACW	Y
Echinochloa muricata	Rough barnyard grass	Grass	FACW	N
Elaeagnus angustifolia	Russian olive	Tree	FAC	N
Eragrostis pectinacea	Purple love grass	Grass	FAC	Y
Leersia oryzoides	Rice cut grass	Grass	OBL	Y
Leptochloa fusca	Bearded sprangletop	Grass	OBL	Y
Lythrum salicaria	Purple loosestrife	Subshrub	OBL	N
Panicum capillare	Witch grass	Grass	FAC	Y
Persicaria lapathifolia	Dock-leaf smartweed	Forb	OBL	Y
Phalaris arundinacea	Reed canary grass	Grass	FACW	N
Phragmites australis	Common reed	Grass	FACW	N
Populus deltoides	Eastern cottonwood	Tree	FAC	Y
Salix sp.	Willow (combined narrow-leaf willow and peach-leaf willow)	Shrub	FACW/OBL	Y
Tamarix chinensis	Salt cedar	Shrub	FACW	N
Xanthium strumarium	Cocklebur	Forb	FAC	Y

Looking Upstream		
(a) Plot 6		
April	May	August
		
(b) Plot 12		
		

Figure 5.11. Field photos of typical bars in Elevation/Flow Class 1 (overtops at less than 1,200 cfs): (a) Vegetation Plot 6; (b) Vegetation Plot 12.

Looking Upstream		
(a) Plot 5		
April	May	August
		
(b) Plot 20		
		

Figure 5.12. Field photos of typical bars in Elevation/Flow Class 2 (overtops at 1,200 to 3,000 cfs): (a) Vegetation Plot 5; (b) Vegetation Plot 20.

TETRA TECH

Looking Upstream		
(a) Plot 2		
April	May	August
		
(b) Plot 14		
		

Figure 5.13. Field photos of typical bars in Elevation/Flow Class 3 (overtops at 3,000 to 5,000 cfs): (a) Vegetation Plot 2; (b) Vegetation Plot 14.

Looking Upstream		
(a) Plot 8		
April	May	August
		
(b) Plot 15		
		

Figure 5.14. Field photos of typical bars in Elevation/Flow Class 4 (overtops at greater than 5,000 cfs): (a) Vegetation Plot 8; (b) Vegetation Plot 15. Vegetation Plot 15 is managed for tern and plover nesting to be free of vegetation.

5.4 Percent Cover

The species with the highest percent cover in April 2013 were reed canary grass, eastern cottonwood *(Populus deltoides), and* common mullein (*Verbascum thapsus*) (**Figure 5.15**). The next most significant group were seedlings of horseweed (*Conyza canadensis*), curly doc (*Rumex crispus*), cinquefoil (*Potentilla paradoxa*), and wild mint (*Mentha arvense*).

The species with the highest percent cover in May 2013 were reed canary grass, cocklebur (*Xanthium strumarium*), annual ragweed (*Ambrosia artemisifolia*), and eastern cottonwood seedlings (**Figure 5.16**). Cocklebur and ragweed are annuals that readily colonize disturbed surfaces. The next most significant group was horseweed, common reed (*Phragmites australis*), common mullein, and cinquefoil.

The species with the most percent cover in August 2013 were annual ragweed, Carolina love grass (*Eragrostis pectinacea*), cocklebur, common sunflower, and eastern cottonwood (**Figure 5.17**). The next most significant group were common panic grass (*Panicum capilare*), horseweed, pigweed (*Amaranthus* sp.), white sweet clover (*Melilotus albus*), reed canary grass, rusty flatsedge (*Cyperus oderatus*) and bearded sprangletop (*Leptochloa fascicularis*).

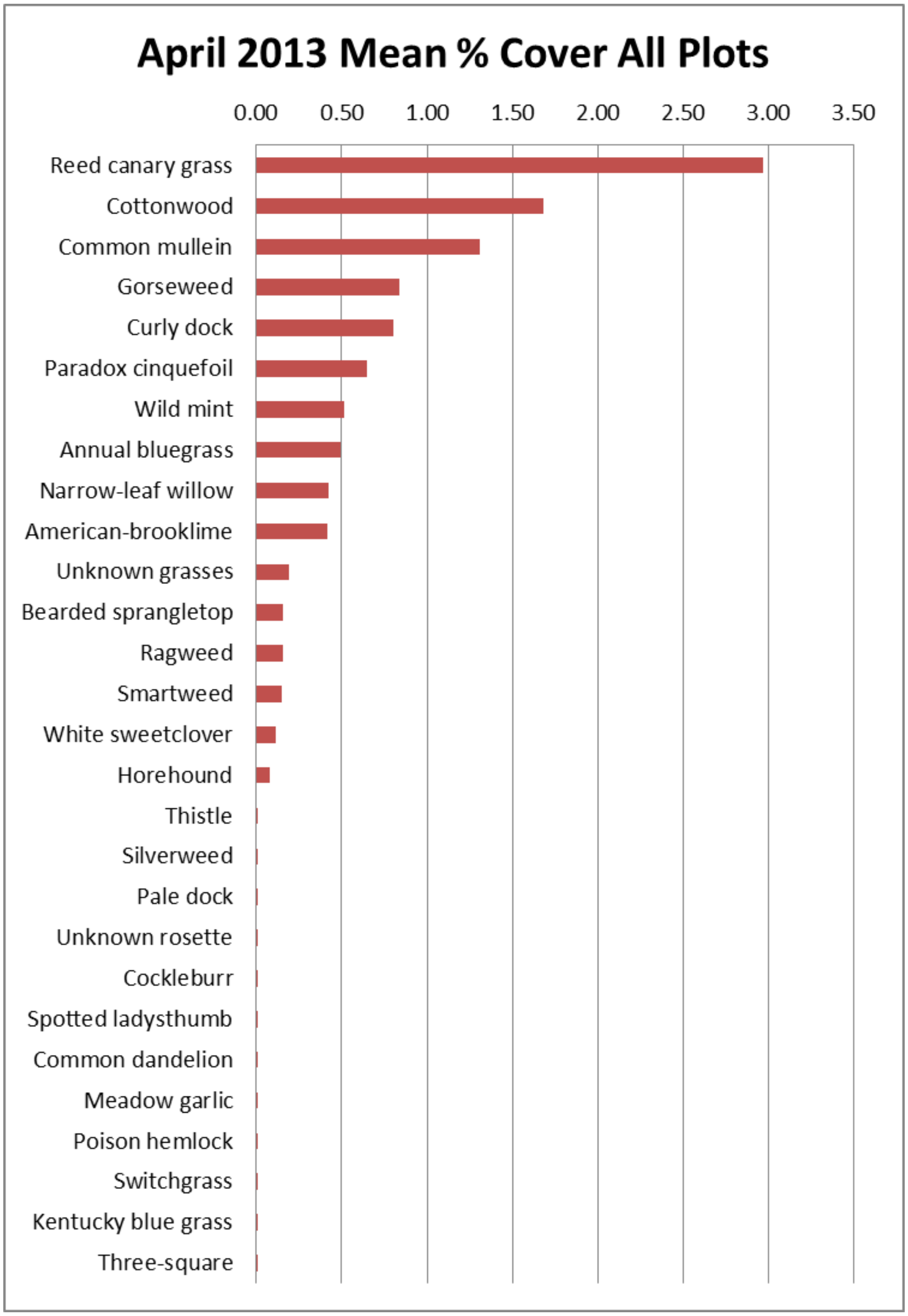

Figure 5.15. Percent cover for all species identified during the April 2013 survey.

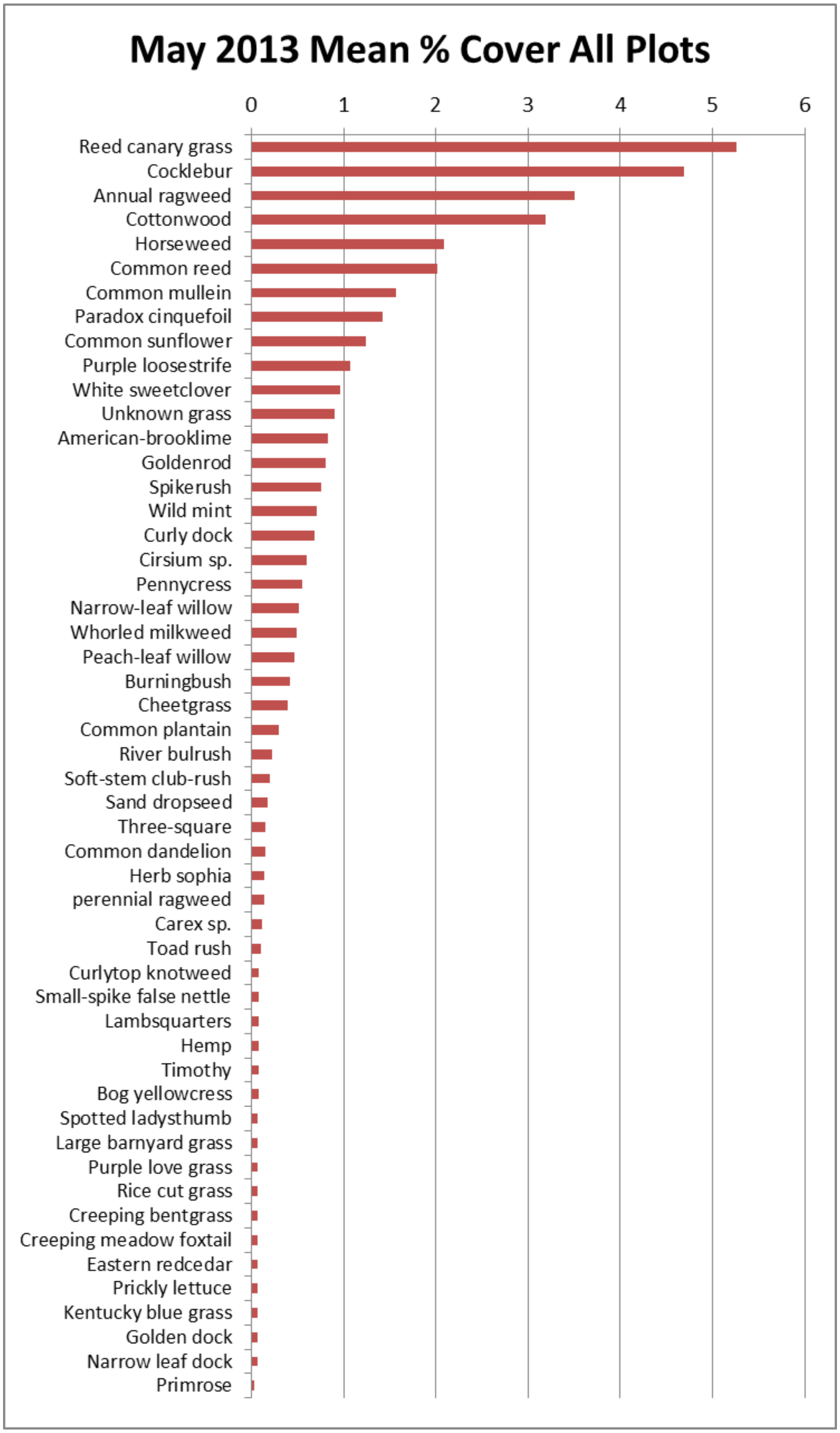

Figure 5.16. Percent cover for all species identified during the May 2013 survey.

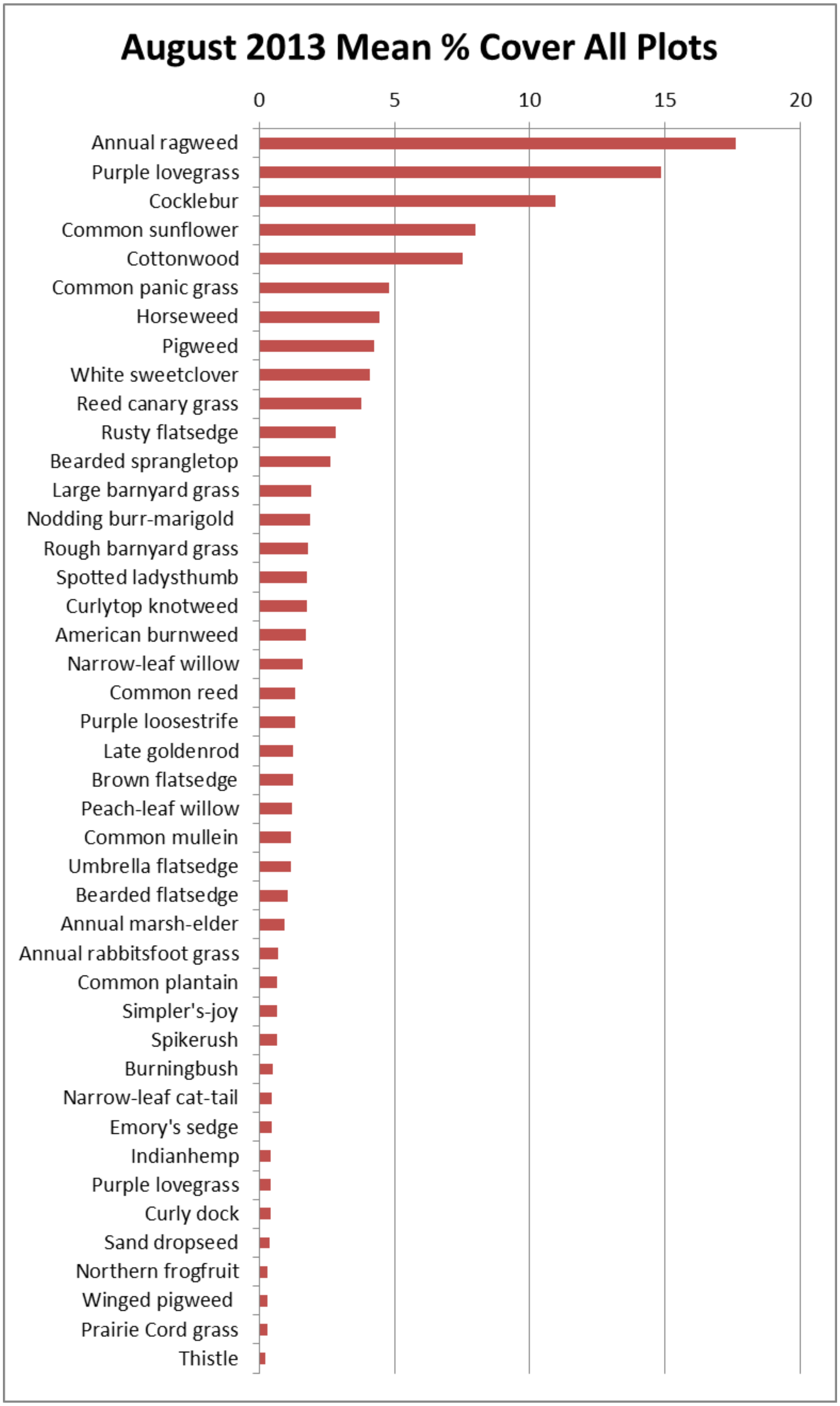

Figure 5.17. Percent cover for all species identified during the August 2013 survey.

Common reed is an invasive perennial grass species of high concern to the Program, and it was present in many locations during all surveys, although with lower percent cover over less area than in either 2011 or 2012 (**Figure 5.18**). This species was present, though not dense, on 13 bars (46 percent) in May 2013 and 13 bars (75 percent) in August 2013. Percent cover was slightly less in 2013 than in 2012 and more substantially less than 2011, with mean percent cover across all bars of 1.3 percent in August of 2013, compared to 1.4 percent in August 2012 and 4.26 percent in August 201.

Reed canary grass is another invasive perennial grass species with a very dense and persistent rootmat that was present in many locations. This species increased in percent cover to 3.8 percent in August 2013, compared to 1.7 percent in August 2012 and 1.6 percent in August 2011.

Russian olive was not encountered during either the 2011 and 2012 sampling, but was sampled once during 2013 (plot 6). Salt cedar (*Tamarix chinensis*) occurred only once, as well (Plots 6), in August 2013. False indigo (*Amorpha fruticosa*) was present with very low percent cover in August 2011, not encountered in 2012, and encountered again at very low percent cover in both May and August 2013 (0.01 percent).

Bare ground increased about 43 percent of the plot areas in April 2013 to 56.4 percent in May 2013 (post SDHF), then decreased to 34 percent in August (compared to 40 percent in August 2012 and 60 percent in August 2011).

During the April 2013 survey, reed canary grass was the most dominant species on Bar Class 1 (<1,200 cfs), Class 3 (3,000-5,000 cfs) and Class 4 (>5000 cfs) bars, with cottonwood being the most dominant species on the Class 2 bars (1,200-3,000 cfs) (**Figure 5.19a**). During the May 2013 survey, cocklebur was the most dominant species on the low bars, with reed canary grass the most dominant species on Bar Classes 2, 3, and 4 (**Figure 5.19b**). During the August 2013 survey, Carolina lovegrass was the most dominant species on Class 1 bars, cocklebur was the most dominant species on Class 2 bars, annual ragweed was the most dominant species on Class 3 bars, and reed canary grass was the most dominant on Class 4 bars (**Figure 5.19c**). In general, all species increased in percent cover from April to May to August, except for reed canary grass and common reed which declined slightly from May to August.

5.4.1 Acreages

The estimated acreage of the key vegetation species within the Elm Creek Complex was estimated by multiplying the mean percent cover from the field plots for each survey by the estimated vegetated bar areas above 1,200 cfs (**Table 5.6**). Bare ground averaged 43 percent (3.0 acres) in April 2013, 56 percent (3.9 acres) in May 2013 and 34 percent (2.3 acres) in August. (It is important to note that the acreages are not additive in Table 5.6, as multiple overlapping species can occur within a single bar or sample plot.)

5.5 Frequency of Occurrence

The relative frequency of occurrence of cottonwood, smartweed (*Persicaria lapathifolia*), and ragweed increased from April to May to August 2013, and the frequency of sedges, reed canary grass, and common reed decreased between May and August 2013 (**Table 5.7, Figure 5.20**). During the April 2013 survey, reed canary grass had the highest frequency in all bar classes (**Figure 5.21a**). During the May survey, cocklebur was the most frequent species on the low bar elevations; whereas, annual ragweed was the most frequent on Bar Class 2 (1,200 to 3,000 cfs and Class 3 (3,000 to 5,000 cfs), and cocklebur and ragweed occurred at the highest frequency

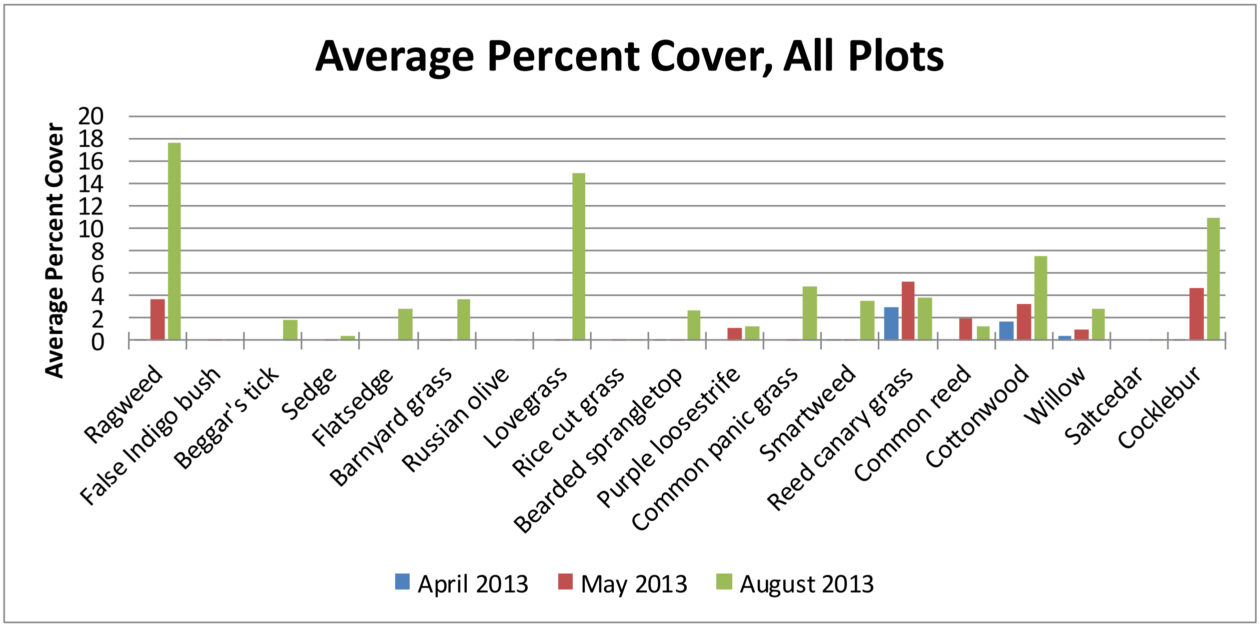

Figure 5.18. Mean percent cover for 19 key species, all plots, April, May, and August 2013.

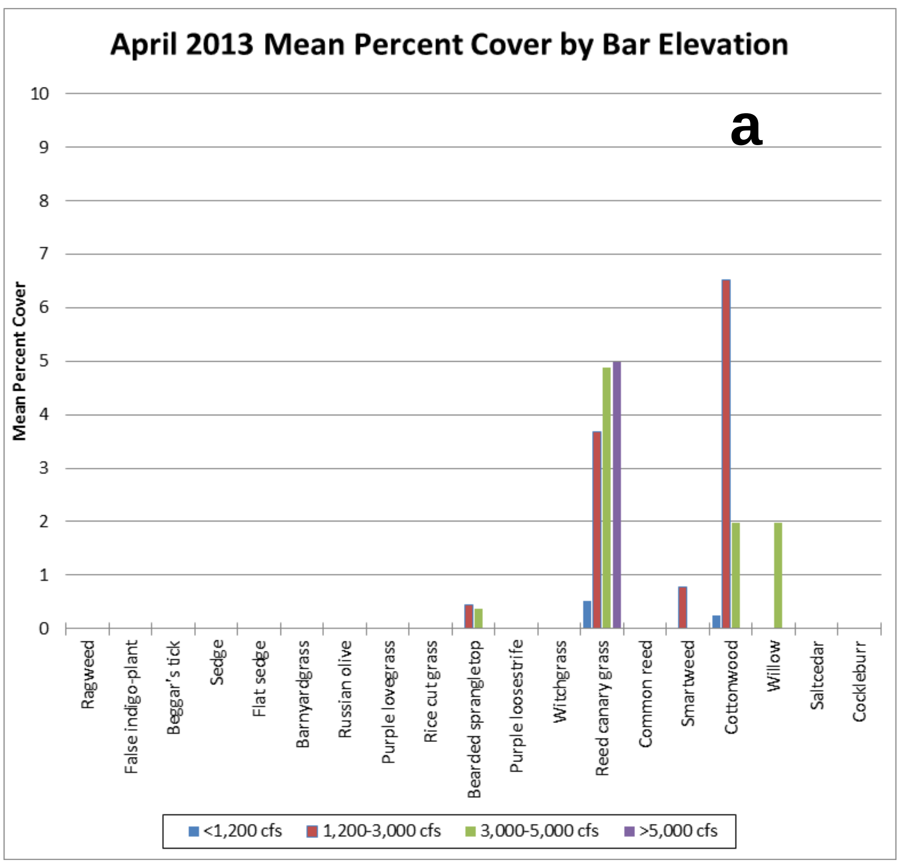

Figure 5.19a. Mean percent cover of the 19 key species by bar elevation during the (a) April 2013 surveys. NOTE: Vertical scale is the same in both plots to illustrate change between the surveys.

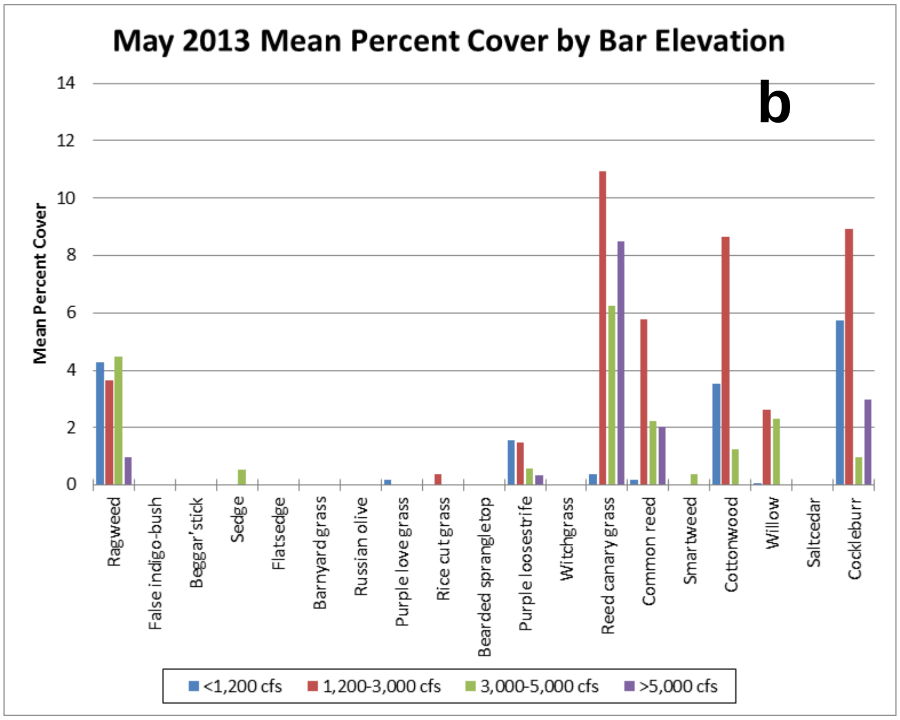

Figure 5.19b. Mean percent cover of the 19 key species by bar elevation during the (b) May 2013 surveys. NOTE: Vertical scale is the same in both plots to illustrate change between the surveys.

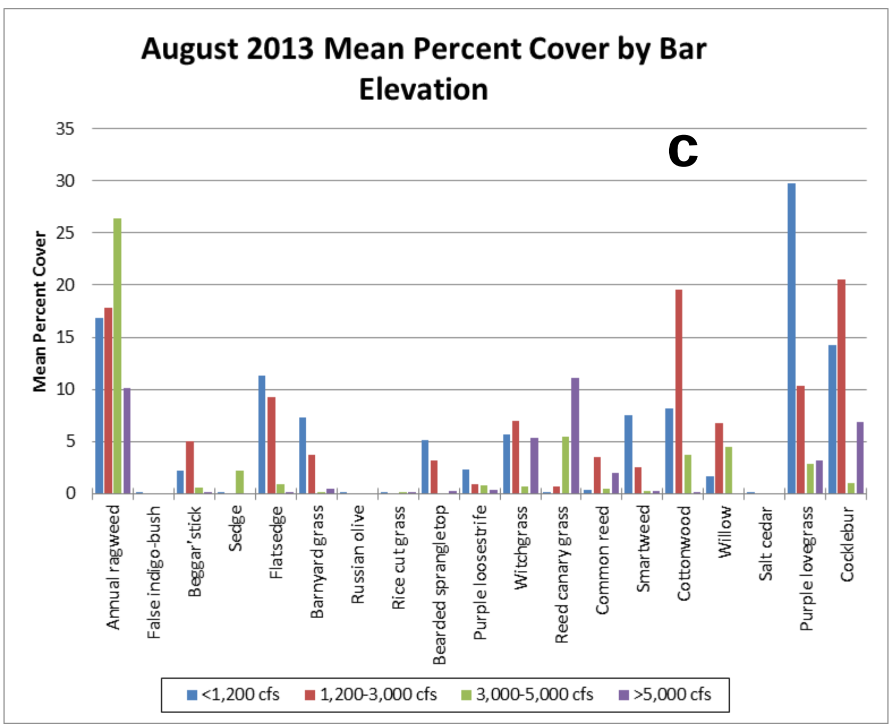

Figure 5.19c. Mean percent cover of the 19 key species by bar elevation during the (c) August 2013 surveys. NOTE: Vertical scale is the same in both plots to illustrate change between the surveys.

Table 5.6. Acreage of 19 key species during 2013 surveys (shaded = species of interest).

Scientific Name	Common Name	April 2013 Acres	May 2013 Acres	August 2013 Acres
Ambrosia artemisifolia	Annual ragweed	0.0	0.2	1.2
Amorpha fruticosa	False indigo	0.0	0.0	0.01
Bidens cernua	Nodding beggar's tick	0.0	0.0	0.1
Carex sp.	Sedge	0.0	0.01	0.0
Cyperus oderatus	Fragrant flat sedge	0.0	0.0	0.2
Echinochloa muricata	Rough barnyard grass	0.0	0.0	0.1
Elaeagnus angustifolia	Russian olive	0.0	0.0	0.0
Eragrostis pectinacea	Purple love grass	0.0	0.0	1.0
Leersia oryzoides	Rice cut grass	0.0	0.0	0.0
Leptochloa fusca	Bearded sprangletop	0.01	0.0	0.2
Lythrum salicaria	Purple loosestrife	0.0	0.1	0.1
Panicum capillare	Witch grass	0.0	0.0	0.3
Persicaria lapathifolia	Dock-leaf smartweed	0.0	0.0	0.1
Phalaris arundinacea	Reed canary grass	0.2	0.4	0.3
Phragmites australis	Common reed	0.0	0.1	0.1
Populus deltoides	Plains cottonwood	0.1	0.2	0.5
Salix sp.	Peach leaf willow	0.0	0.1	0.2
Tamarix chinensis	Salt cedar	0.0	0.0	0.0
Xanthium strumarium	Cocklebur	0.0	0.3	0.8
	Bare Ground	3.0	3.9	2.3

Table 5.7. Frequency of occurrence (percent) for key species among all plots in the Elm Creek Complex project area 2013 (shaded = species of interest).

Scientific Name	Common Name	April Frequency	May Frequency	August Frequency
Ambrosia sp.	Ragweed	2.2	34.6	49.2
Amorpha fruticosa	False indigo	0.0	0.3	0.3
Bidens cernua	Nodding beggar's tick	0.0	0.0	14.8
Carex sp.	Sedge	0.0	2.2	0.8
Cyperus oderatus	Fragrant flat sedge	0.0	0.00	17.0
Echinochloa sp.	Barnyard grass	0.0	0.5	17.6
Elaeagnus angustifolia	Russian olive	0.0	0.0	0.3
Eragrostis pectinacea	Purple love grass	0.0	0.5	40.7
Leersia oryzoides	Rice cut grass	0.0	0.5	1.1
Leptochloa fusca	Bearded sprangletop	2.7	0.3	22.3
Lythrum salicaria	Purple loosestrife	0.0	8.0	11.5
Panicum capillare	Witch grass	0.0	0.8	26.4
Persicaria lapathifolia	Smartweed	2.5	1.1	15.1
Phalaris arundinacea	Reed canary grass	14.8	14.3	9.3
Phragmites australis	Common reed	0.0	9.6	8.0
Populus deltoides	Plains cotttonwood	5.5	14.3	24.7
Salix sp	Willow	1.4	5.7	12.9
Tamarix chinensis	Salt cedar	0.0	0.0	0.3
Xanthium strumarium	Cocklebur	0.5	29.9	33.8

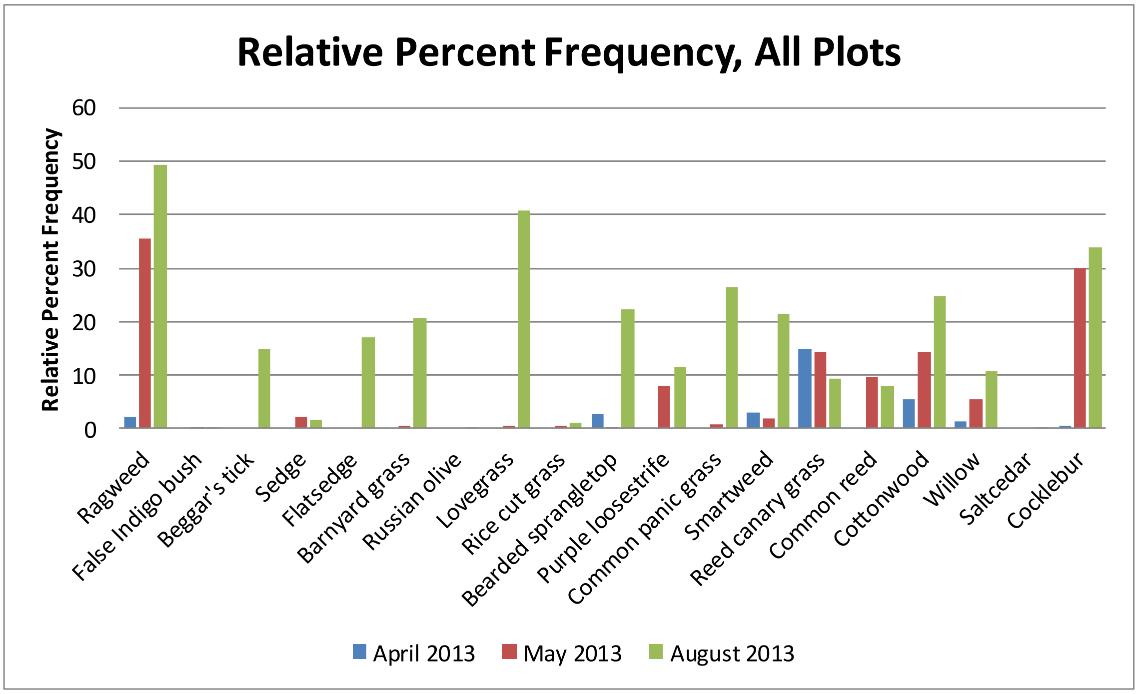

Figure 5.20. Relative percent frequency of occurrence of the 19 key species across all plots during the April, May and August 2013 surveys.

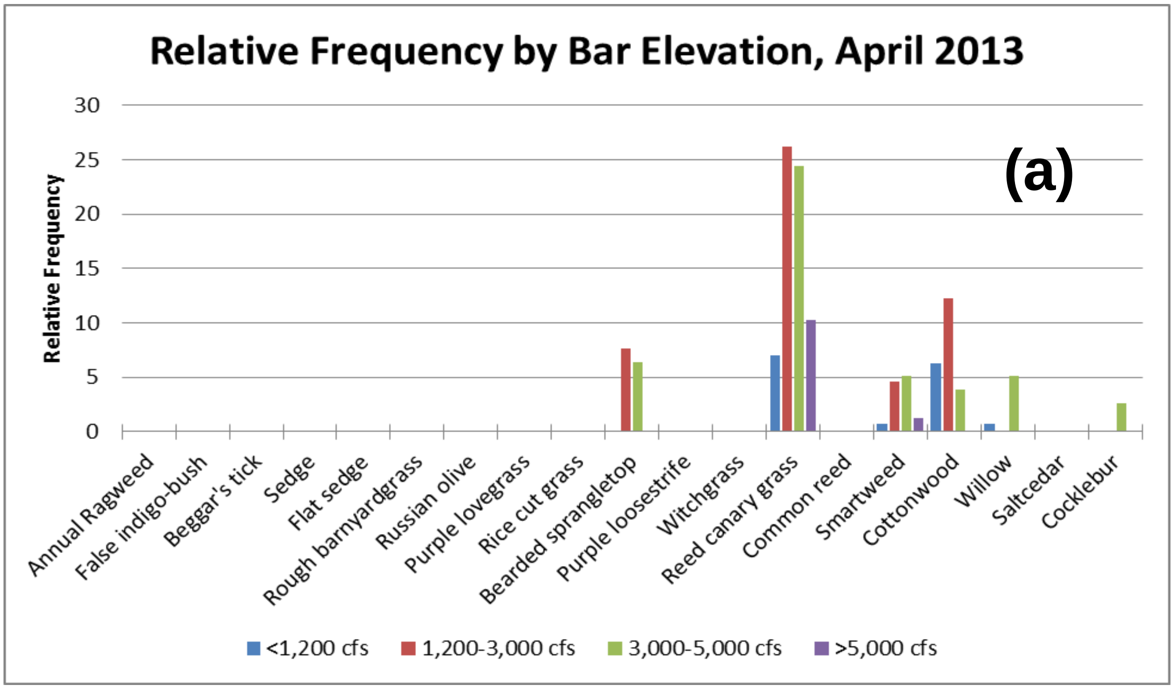

Figure 5.21a. Relative percent frequency of occurrence of the key species by bar elevation during the April 2013 surveys.

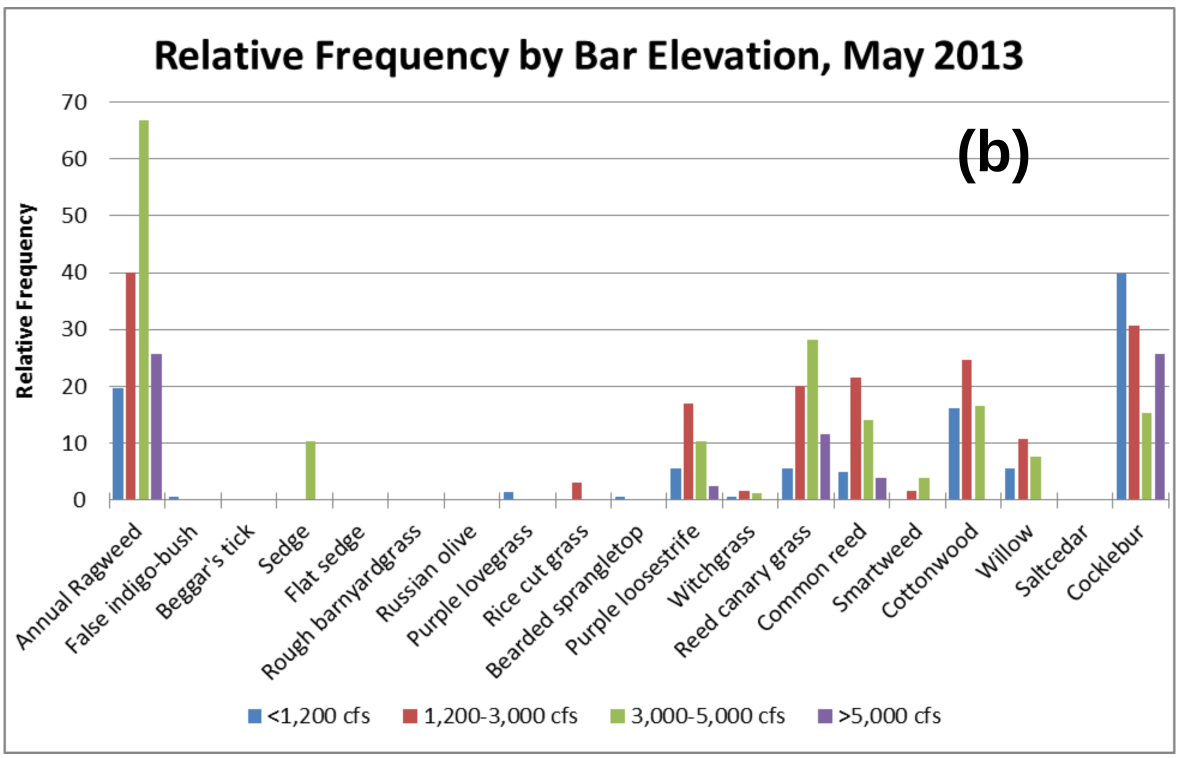

Figure 5.21b. Relative percent frequency of occurrence of the key species by bar elevation during the May 2013 surveys.

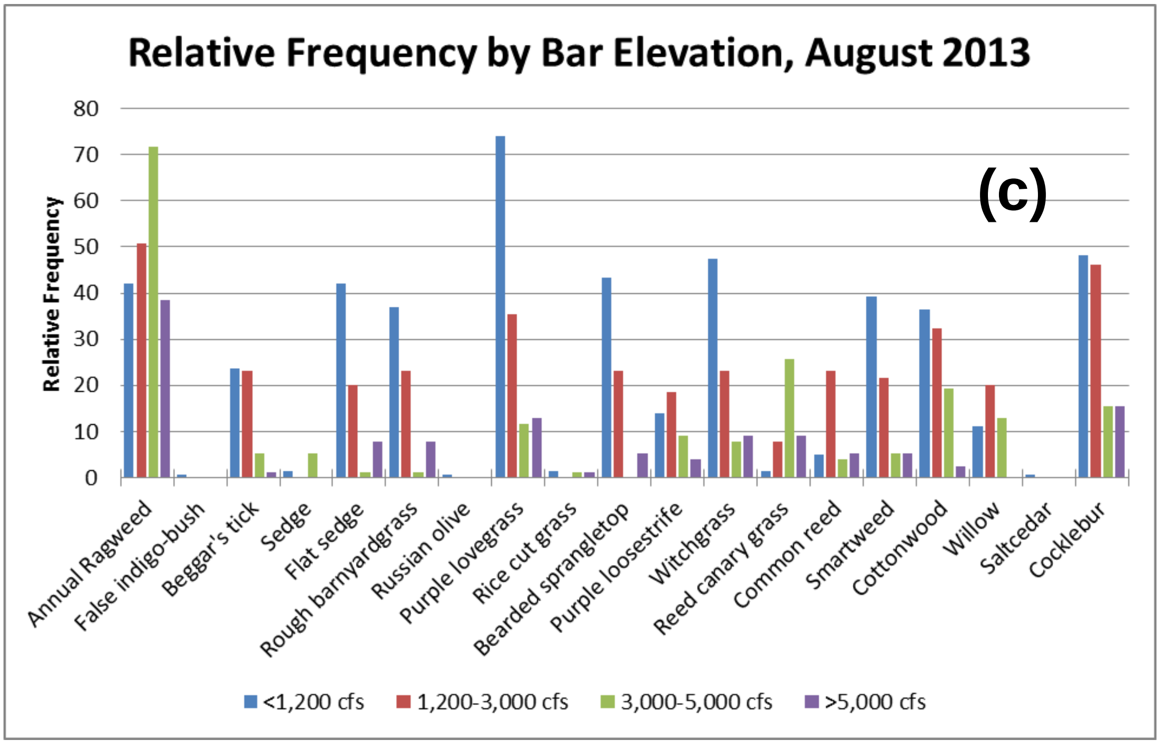

Figure 5.21c. Relative percent frequency of occurrence of the key species by bar elevation during the August 2013 surveys.

Class 4 bars (>5,000 cfs) (**Figure 5.21b**). During the August survey, purple love grass was the most frequent species on Bar Classes 1 (<1,200) and annual ragweed was the most frequent on Bar Class 2, 3 and 4 (1,200 to 3,000 cfs, 3,000 to 5,000 cfs, and >5,000 cfs); however, numerous species were present on all bars (**Figure 5.21c**). During the August survey, purple loosestrife, common reed, and peach leaf willow were most frequently on Bar Class 2; whereas, reed canary grass was most frequent on Bar Classes 3, and cottonwood was most frequent on Bar Classes 1, 2, and 3.

5.6 Vegetation Trend Analysis

The vegetation data from all seven sampling events were analyzed to identify temporal trends over the three-year monitoring period, and spatial trends within the overall Elm Creek Complex based on location, elevation, or mechanical actions (**Table 5.8**). The analysis was performed based on the following comparisons:

- May to August within individual years
- Year-to-year
- Individual sample plots by clearing regime
- Individual plots by bar elevation class, and
- Location upstream versus downstream of the Kearney Diversion Structure

Table 5.8. Summary of mechanical treatments affecting vegetation sample plots prior to the monitoring surveys for each year.

Plot No.	Station (ft)	Sand-bar Class	Mechanical Treatment*							
			Tree Clearing	Disking			Spraying			Island Construction
			2011	2011	2012	2013	2011	2012	2013	2013
Upstream from KDS										
1	399,839	3		X				X		
23	399,814	3		X		X				
2	399,174	3		X		X		X	Part	
3	399,002	1		X						
24	398,087	3		X		X			Part	
4	397,586	3	X			X				
5	397,509	2		X		X				
6	397,196	1		X		X		X		
7	396,486	3		X				Part		
8	395,857	4						X		
9	395,296	4				X		Part		
10	394,416	1		X						
11	393,093	2		X		X				
25	392,525	4				X		X		
Downstream from KDS										
12	391,220	1		X		X			Part	
26	390,513	1		Part		X	X	Part		
13	390,169	1							Part	
14	389,639	2		X		X	X	Part		
15	388,431	4				X				X
16	386,921	1		X						
17	386,015	1		X						
18	385,263	1								
27	384,473	4		X		X	X			
19	384,121	1		X		X	X			X
20	383,162	2		X				X		
21	381,939	4		X				X		X
22	381,289	1		X						
28	380,811	2		X				Part		

* Action just taken prior to the indicated year.

5.6.1 Vegetation Cover - May vs. August

The changes in vegetation cover from the May to August surveys were evaluated for six species, four of which are key species of interest that commonly in the study reach [willow (*Salix* sp.), cottonwood (*Populus deltoides*), common reed (*Phragmites australis*), and purple loosestrife (*Lythrum salicaria*)], and two are the most abundant species in the reach [reed canary grass (*Phalaris arundinaceae*), ragweed (*Ambrosia* sp.)]. In performing the analysis, vegetation plots that are located on reconstructed (or newly-constructed) sandbars were removed from analysis for years after the construction occurred. As the data were not normally distributed, the Kruskal-Wallis test was used to assess the between sampling events for each species. The mean percent cover of each species per sampling event is shown in the graphs for comparison; however, Kruskal-Wallis is not a test of the difference in means or medians, rather it is a ranked test to detect whether two or more samples come from the same distribution.

5.6.1.1 Willow

The highest percent coverage for willow occurred in August of 2013 and the lowest occurred in August 2011; the mean percent cover of willow was actually lower in August than in May in both 2011 and 2012 (**Figure 5.22**). Based on the Kruskal-Wallace test, the only difference among these sample sets is between August 2011 and August 2013 (**Table 5.9**).

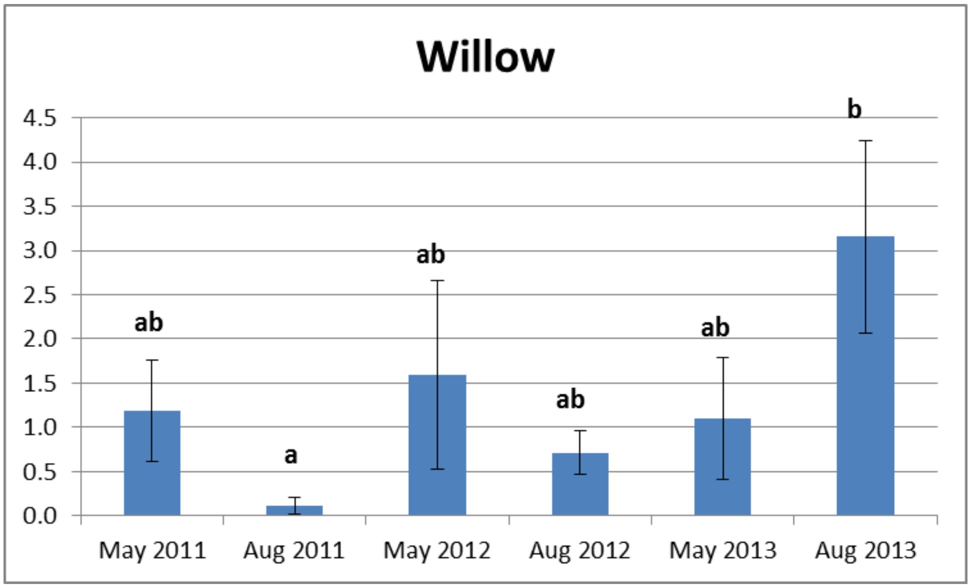

Figure 5.22. Mean percent cover for willow based on sample events (May and August for three years) compared using Kruskal-Wallis nonparametric test. Error bars show standard error with different letters indicating significantly different groups.

Table 5.9. Dunn's multiple pairwise comparison p-values for willow. The Bonferroni corrected significance level is p= 0.0033. Significant p-values are shown in bold.

	May 2011	Aug 2011	May 2012	Aug 2012	May 2013	Aug 2013
May 2011	1					
Aug 2011	0.025	1				
May 2012	0.343	0.146	1			
Aug 2012	0.775	0.038	0.486	1		
May 2013	0.195	0.296	0.688	0.284	1	
Aug 2013	0.551	**0.003**	0.102	0.353	0.048	1

5.6.1.2 Cottonwood

Cottonwood generally had higher mean percent cover in August than in May for all years (**Figure 5.23**). Pairwise comparisons indicate statistical significance only between May 2011 and August 2013 samples (**Table 5.10**).

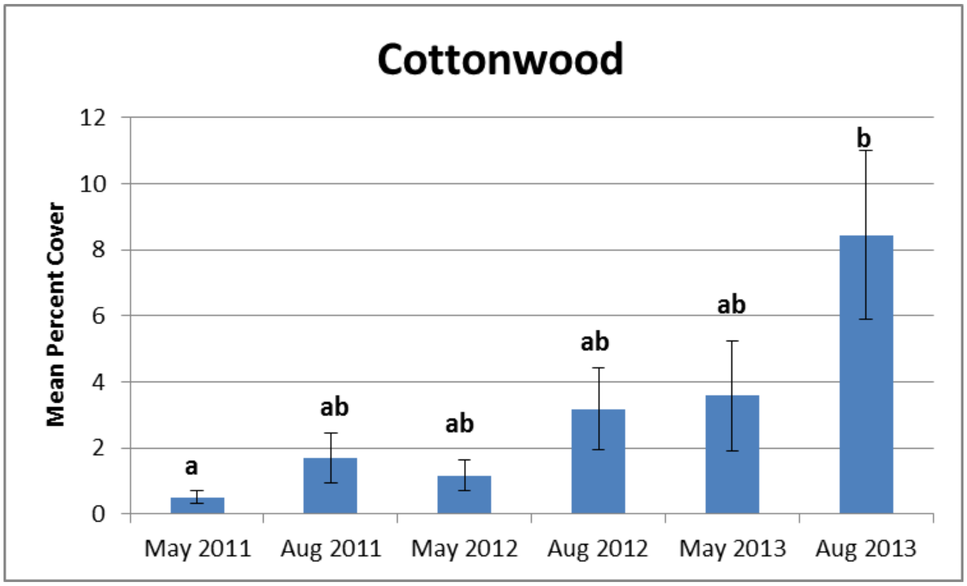

Figure 5.23. Mean percent cover for cottonwood based on sample events (May and August for three years) using Kruskal Wallis nonparametric test. Error bars show standard error with different letters indicating significantly different groups.

Table 5.10. Dunn's multiple pairwise comparison p-values for cottonwood. The Bonferroni corrected significance level is p= 0.0033. Significant p-values are in bold.

	May 2011	Aug 2011	May 2012	Aug 2012	May 2013	Aug 2013
May 2011	1	0.327	0.268	0.012	0.103	**0.001**
Aug 2011	0.327	1	0.952	0.135	0.542	0.020
May 2012	0.268	0.952	1	0.122	0.553	0.015
Aug 2012	0.012	0.135	0.122	1	0.356	0.376
May 2013	0.103	0.542	0.553	0.356	1	0.074
Aug 2013	**0.001**	0.020	0.015	0.376	0.074	1

5.6.1.3 Common Reed

Percent cover of common reed was not statistically different between May and August samples in any year (KW: 6.917, p= 0.227); thus, no table of p-values is shown. However, August 2011 had the highest percent cover (**Figure 5.24**).

5.6.1.4 Reed Canary Grass

Reed canary grass showed highest mean percent coverage in May 2013 (KW= 14.507, p= 0.013). Pairwise comparisons indicate statistical significance between Aug 2011 and May 2013 (**Figure 5.25** and **Table 5.11**).

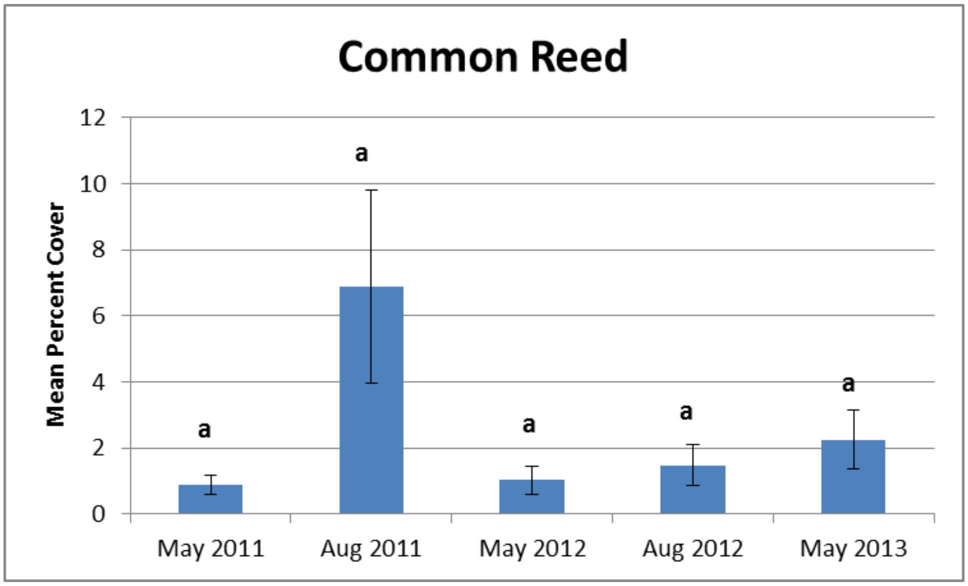

Figure 5.24. Mean percent cover for common reed based on sample events (May and August for three years) using Kruskal-Wallis nonparametric test. Error bars show standard error with different letters indicating significantly different groups.

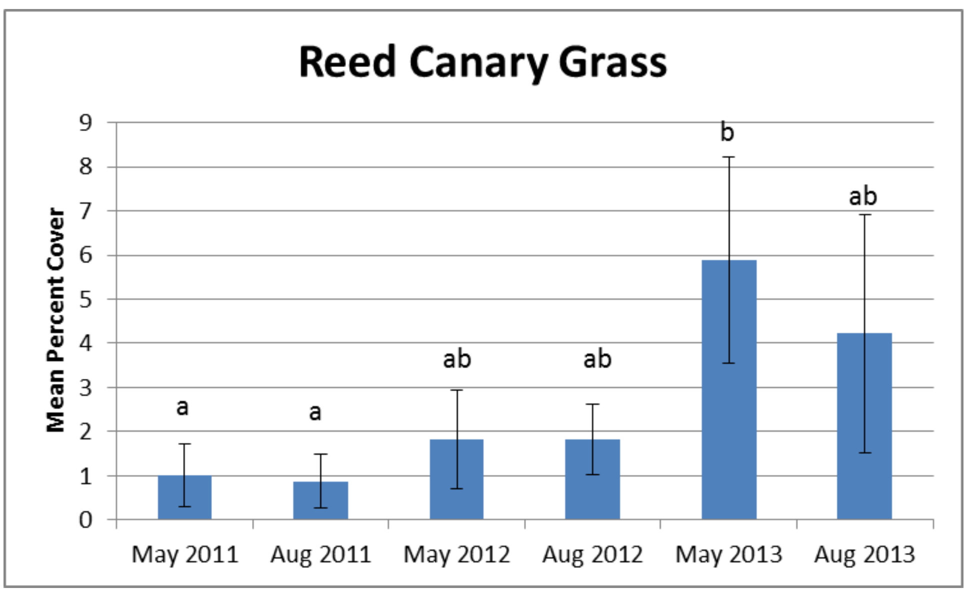

Figure 5.25. Mean percent cover for reed canary grass based on sample times (May and August for three years) using Kruskal -Wallis nonparametric test. Error bars show standard error with different letters indicating significantly different groups.

Table 5.11. Dunn's multiple pairwise comparison p-values for May and August comparisons for reed canary grass. The Bonferroni corrected significance level is p= 0.0033. Significant p-values are in bold.

	May 2011	Aug 2011	Aug 2012	May 2013	May 2012	Aug 2013
May 2011	1	0.736	0.312	**0.003**	0.594	0.159
Aug 2011	0.736	1	0.173	**0.001**	0.372	0.078
Aug 2012	0.312	0.173	1	0.039	0.601	0.666
May 2013	**0.003**	**0.001**	0.039	1	0.009	0.105
May 2012	0.594	0.372	0.601	0.009	1	0.339
Aug 2013	0.159	0.078	0.666	0.105	0.339	1

5.6.1.5 Ragweed

Ragweed had significantly more coverage in August (KW=29.614, p= 0.000) with means over 15 percent in both August 2012 and 2013 (**Figure 5.26**). Pairwise comparisons indicate statistical significance as shown in **Table 5.12**.

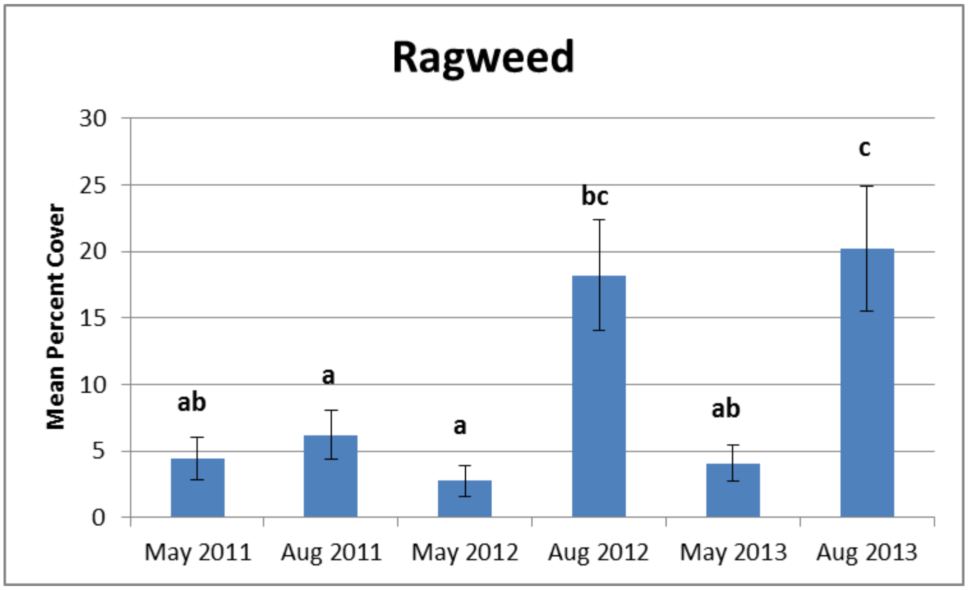

Figure 5.26. Mean percent cover for ragweed based on sample times (May and August for three years) using Kruskal -Wallis nonparametric test. Error bars show standard error with different letters indicating significantly different groups.

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Table 5.12. Dunn's multiple pairwise comparison p-values for May and August comparisons for ragweed. The Bonferroni corrected significance level is p=0.0033. Significant p-values are in bold.

	May 2011	Aug 2011	May 2012	Aug 2012	May 2013	Aug 2013
May 2011	1	0.721	0.462	0.006	0.912	**0.002**
Aug 2011	0.721	1	0.683	**0.001**	0.622	**0.000**
May 2012	0.462	0.683	1	**0.000**	0.373	**< 0.0001**
Aug 2012	0.006	**0.001**	**0.000**	1	0.006	0.518
May 2013	0.912	0.622	0.373	0.006	1	**0.002**
Aug 2013	**0.002**	**0.000**	**< 0.0001**	0.518	**0.002**	1

5.6.1.6 Purple Loosestrife

Purple loosestrife increased each sampling period with the highest percent cover in August 2013 with a mean percent cover of 1.5 percent (**Figure 5.27**; KW=21.55, p= 0.000). Pairwise comparisons indicate statistical significance as shown in **Table 5.13**. Purple loosestrife was not present in May 2012.

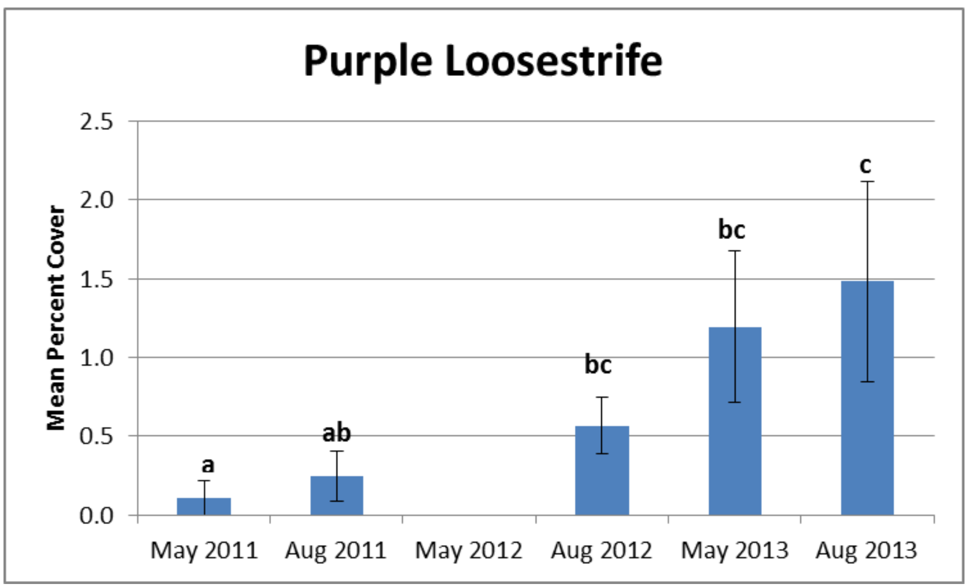

Figure 5.27. Mean percent cover for purple loosestrife based on sample times (May and August for three years) using Kruskal-Wallis nonparametric test w/Dunn's multiple pairwise comparisons. Error bars show standard error with different letters indicating significantly different groups.

Table 5.13. Dunn's multiple pairwise comparison p-values for May and August comparisons for purple loosestrife. The Bonferroni corrected significance level is p= 0.005. Significant p-values are in bold.

	May 2011	Aug 2011	Aug 2012	May 2013	Aug 2013
May 2011	1	0.221	**0.003**	**0.001**	**< 0.0001**
Aug 2011	0.221	1	0.093	0.051	**0.004**
Aug 2012	**0.003**	0.093	1	0.761	0.212
May 2013	**0.001**	0.051	0.761	1	0.351
Aug 2013	**< 0.0001**	**0.004**	0.212	0.351	1

5.6.2 Bare Ground

Mean percent bare ground had a normal distribution so a one way ANOVA test was used instead of Kruskal-Wallis. Percent bare ground was analyzed between all sampling events (n=145). The ANOVA test showed significant differences between samples years (**Figure 5.28**; F=16.208, p<0.001). Pairwise comparisons were completed with Dunnets T3 test using separate variances error terms due to unequal variances (**Table 5.14**). In general, August samples typically had a lower mean percent cover of bare ground as would be expected at the peak of the growing season. Mean percent cover of bare ground also generally decreased over the 2011 to 2013 period, primarily due to the low flows in 2012 and 2013.

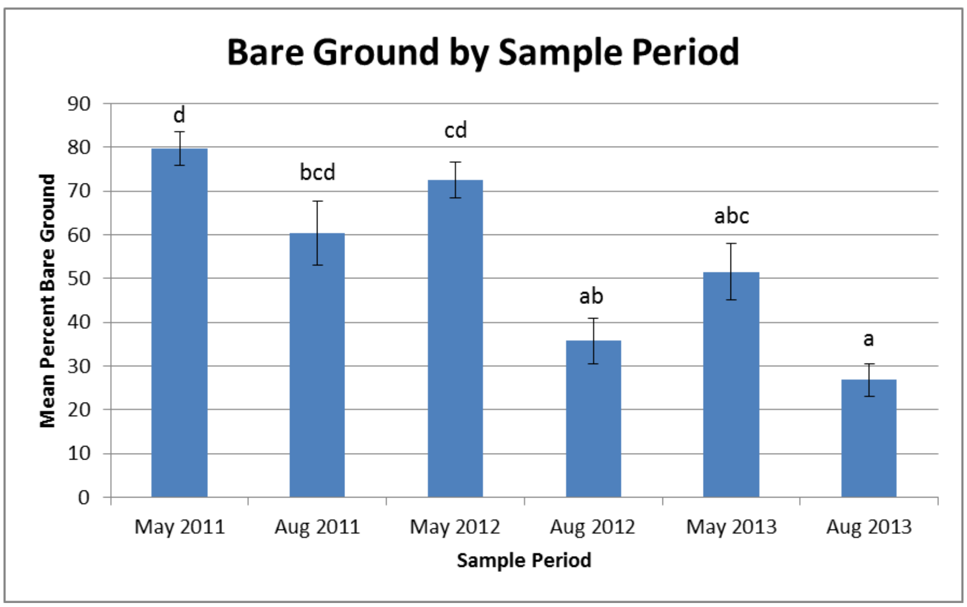

Figure 5.28. Mean percent bare ground based on sample times (May and August for three years).

Table 5.14. P-values for pairwise comparisons for bare ground ANOVA test. Significance level is p=0.05.

	May 2011	Aug 2011	May 2012	Aug 2012	May 2013	Aug 2013
May 2011	1	0.190	0.819	**0.000**	**0.004**	**0.000**
Aug 2011	0.190	1	0.884	0.118	0.998	**0.004**
May 2012	0.819	0.884	1	**0.000**	0.118	**0.000**
Aug 2012	**0.000**	0.118	**0.000**	1	0.598	0.914
May 2013	**0.004**	0.998	0.118	0.598	1	**0.029**
Aug 2013	**0.000**	**0.004**	**0.000**	0.914	**0.029**	1

5.7 Comparisons Based on Clearing

5.7.1 Species Percent Cover

The clearing regime was analyzed to identify potential effects on the percent cover for the six species of interest. The Kruskal-Wallis test was used as the data was not normally distributed. The analysis was only done for the 2013 data as the clearing categories only apply to the third year. The only statistically significant difference in percent cover with differing clearing regimes was in common reed in the May 2013 sample (K-W test statistic=6.861, p=0.032) (**Figure 5.29** and **Table 5.15**). No significant differences were identified for the August samples (**Figure 5.30** and **Table 5.16**). Sample size for the clearing analysis was: never cleared=4, cleared once=12, cleared twice=9. May was found to be statistically different from August, so the two time periods were analyzed separately.

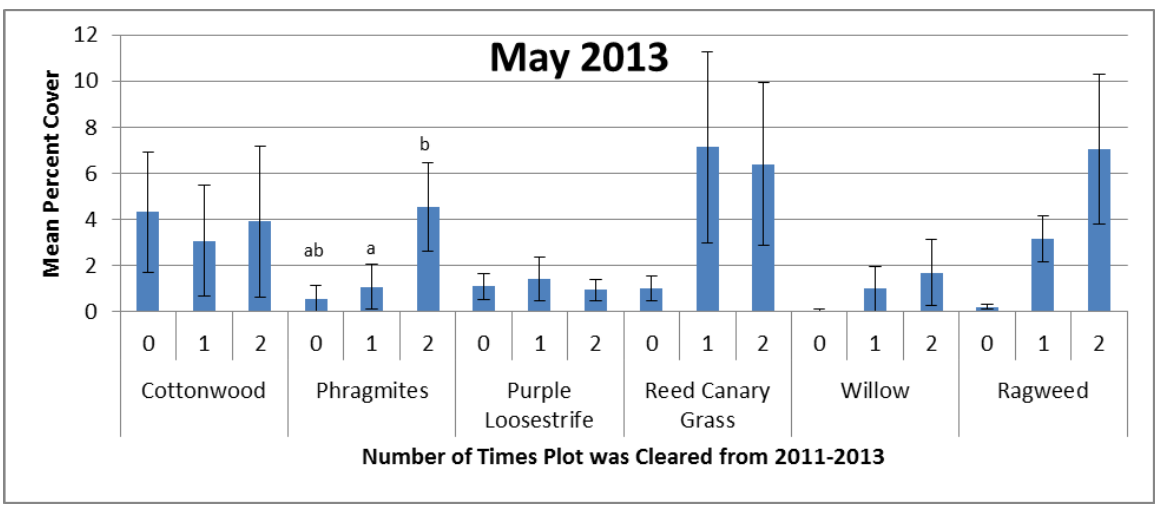

Figure 5.29. May 2013 data comparing mean percent cover of species by clearing regime. 0 = never cleared; 1 = cleared once; 2 = cleared twice.

Table 5.15. Test statistics and p-values for Kruskal-Wallis test comparing clearing regimes for May 2013 (significance level is p=0.05).

May 2013	K-W Test Statistic	p-value
Cottonwood	1.853	0.396
Common reed	6.861	**0.032**
Ragweed	4.280	0.118
Purple loosestrife	1.528	0.466
Willow	4.856	0.088
Reed canary grass	0.204	0.903

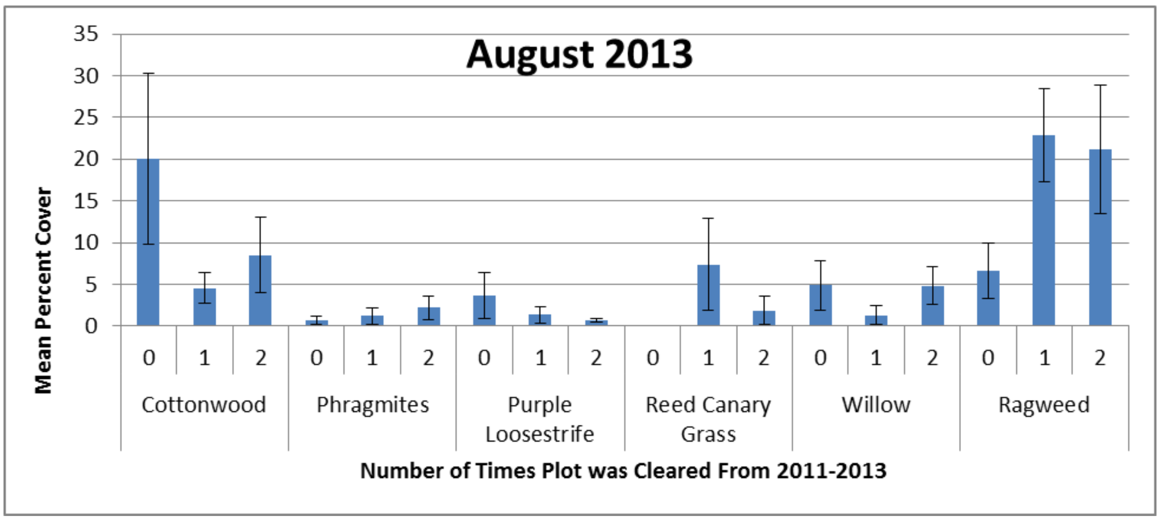

Figure 5.30. August 2013 data comparing mean percent cover of species by clearing regime.

Table 5.16. Test statistics and p-values for Kruskal-Wallis test comparing clearing regimes for August 2013 (significance level is p=0.05).

August 2013	K-W Test Statistic	p-value
Cottonwood	4.229	0.121
Common reed	2.659	0.265
Ragweed	3.484	0.175
Purple loosestrife	2.454	0.293
Willow	4.385	0.112
Reed canary grass	4.297	0.117

5.8 Cover Comparisons between Upstream vs. Downstream of KDS

5.8.1 Bare Ground

ANOVA was used to examine potential differences in percent cover of bare ground between plots up- and downstream of the Kearney Diversion Structure (**Table 5.17**). Comparisons were made for each individual sampling event; no statistical difference was observed between up- and downstream plots (**Figure 5.31**).

Table 5.17. Summary for all ANOVA tests on mean percent bare ground comparing plots up- and downstream of Kearney Diversion Structure.

	May 2011	Aug 2011	May 2012	Aug 2012	May 2013	Aug 2013
F	0.081	0.005	0.065	0.003	0.822	0.589
p-value	0.779	0.943	0.801	0.956	0.374	0.451

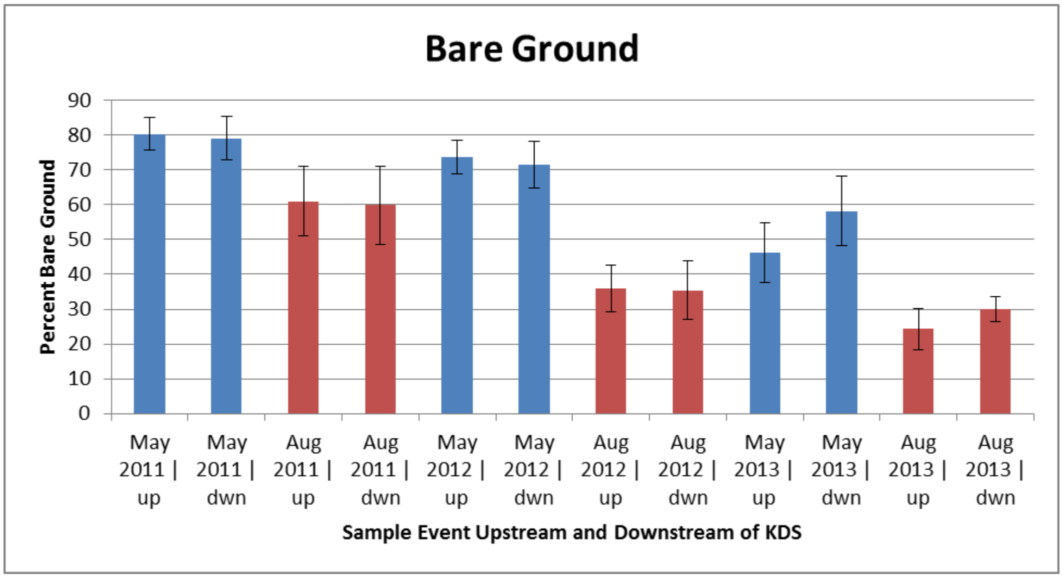

Figure 5.31. Mean percent bare ground for each sampling event comparing up- to downstream plots separated by the Kearney diversion structure.

When all sampling events were grouped together, downstream plots showed slightly higher mean percent bare ground than upstream; however, the difference is not statistically significant (F=0.428, DF=1, p=0.514) (**Figure 5.32**).

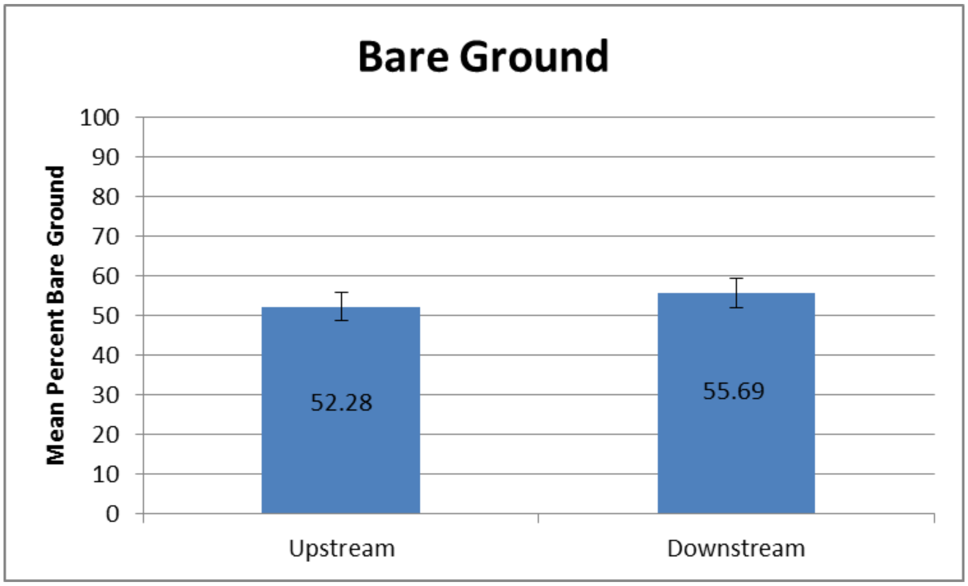

Figure 5.32. Percent bare ground for all years grouped then compared by up- and downstream.

5.8.2 Species

Each of the six species of interest was analyzed as to whether they differed by year in upstream and downstream mean percent cover. If there were no statistically significant differences, then the years were grouped together. Of all the analyses, only ragweed (**Figure 5.33**) in May (KW=7.298, p=0.007) and reed canary grass (**Figure 5.34**) in August (KW=4.771, p=0.029) showed a significant difference between upstream and downstream cover percentages.

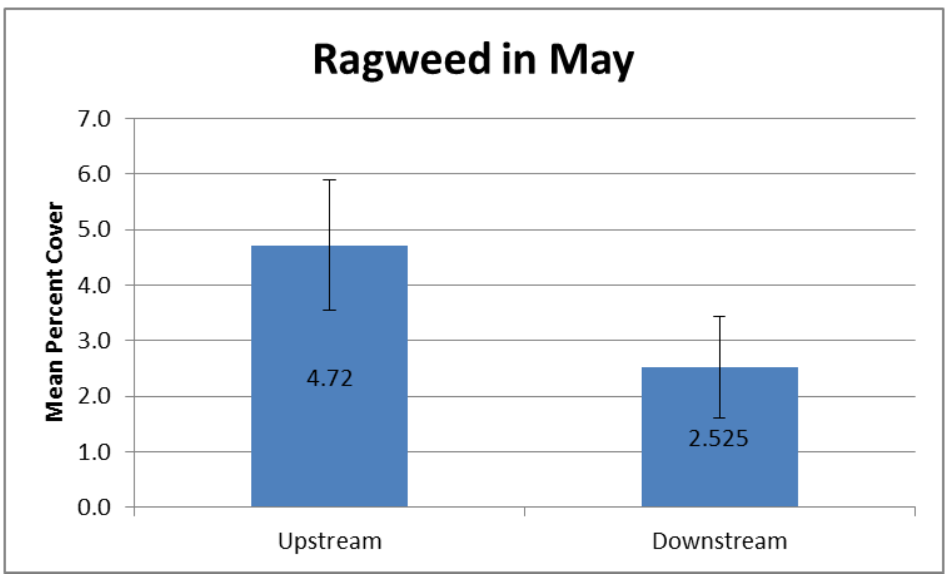

Figure 5.33. Upstream vs. downstream mean percent cover for ragweed in May sample events (all years).

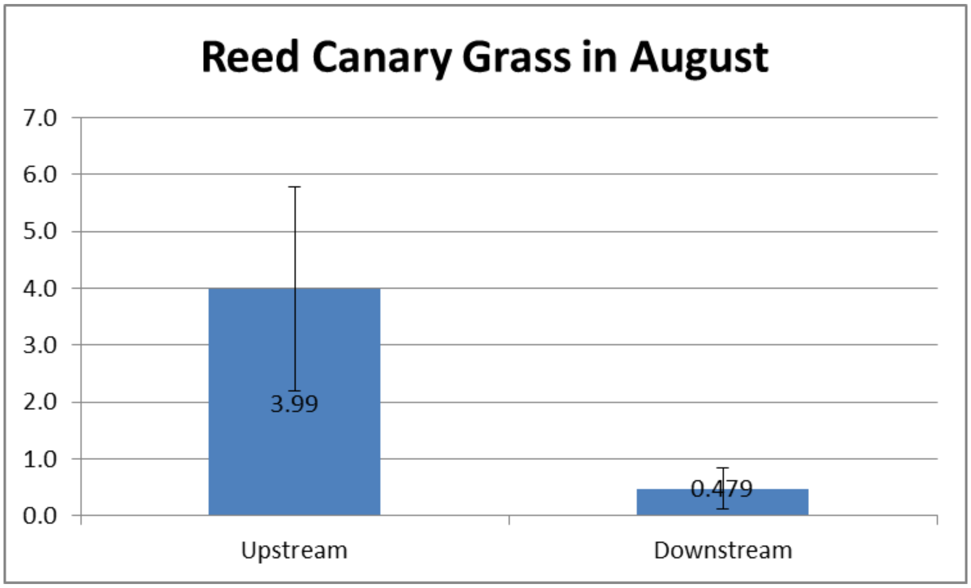

Figure 5.34. Upstream vs. downstream mean percent cover for reed canary grass in August sample events (all years).

5.9 Cover Comparisons by Bar Elevation Class

Sand-bar elevation class was analyzed by separating all the data into May and August categories (n=153), as the two were statistically different. The mean percent cover of each species of interest was tested across the four different bar classes: Class 1 (<1,200 cfs), Class 2 (1,200-3,000 cfs), Class 3 (3000-5000 cfs) and Class 4 (>5,000 cfs). The Kruskal-Wallis one way analysis of variance test was used with a significance level of 0.05.

5.9.1 Willow

Willow was significantly different by year so was analyzed individually for bar elevation class. In May sampling events, the only year to show significant difference was 2012, where Class 1 and 3 were significantly different (p=0.005 with Bonferroni corrected significance level of p=0.0083). The highest mean percent cover was not the same by bar class in each year (**Figure 5.35**). For 2011 the most willow coverage was on low bars (Classes 1 and 2); in 2012 the most coverage was on high bars (Classes 3 and 4); and, for 2013 the most willow coverage was on middle bars (Classes 2 and 3). For August sampling, in 2011 willows were only found on the Class 3 bars (**Figure 5.36**). The Class 2 sand bars had the highest mean percent cover of willows in both 2012 and in 2013.

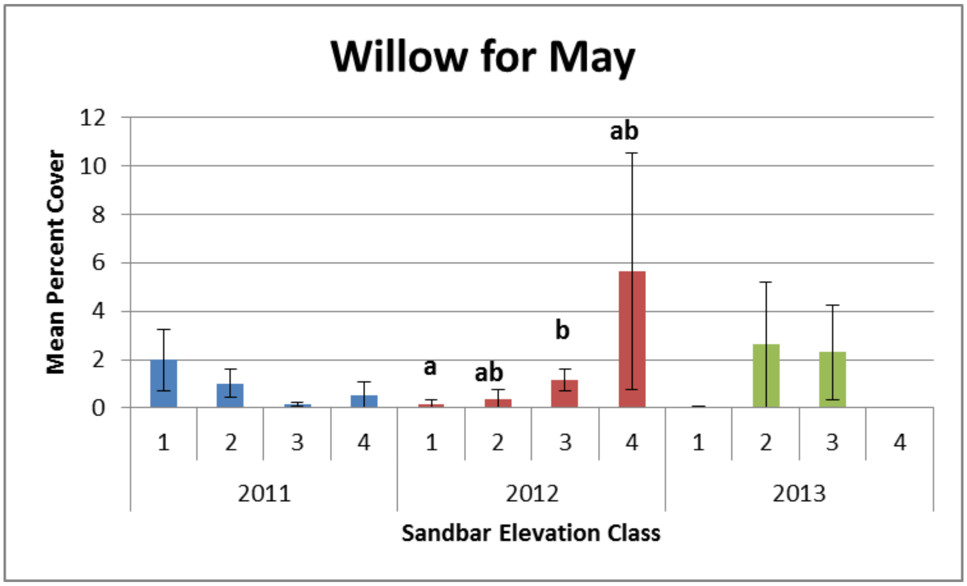

Figure 5.35. Mean percent cover for willow comparing bar elevation class for May.

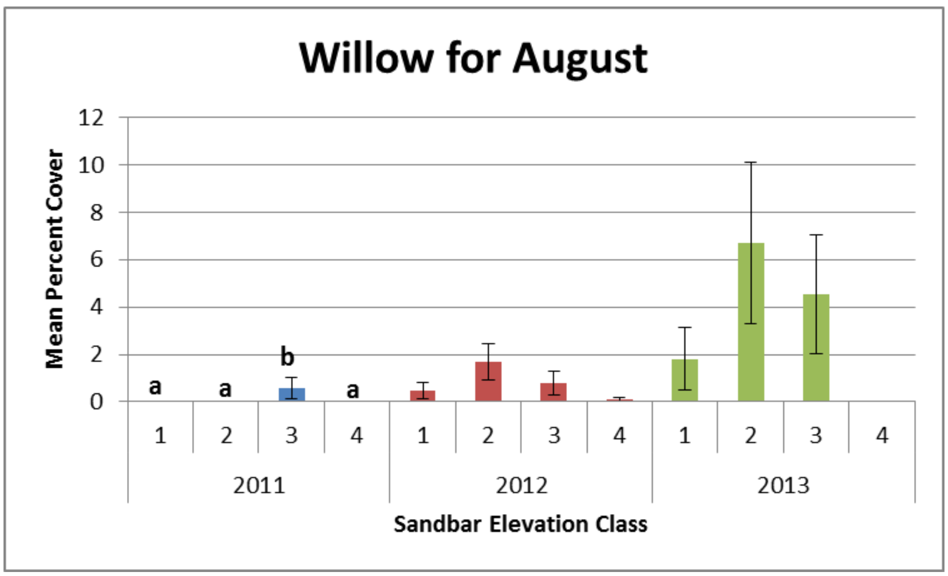

Figure 5.36. Mean percent cover for willow comparing bar elevation class for August.

5.9.2 Cottonwood

Cottonwood was not significantly different between the three years for May samples, so they were pooled and analyzed together (**Figure 5.37**). The highest mean percent cover for cottonwood in May was 3.7 percent on the Class 2 sand bars (1,200-3,000 cfs) but the only significantly different classes were between Classes 3 and 4 (KW=8.874, p=0.031). For August, the mean percent cover differed significantly between years so they were analyzed individually (**Figure 5.38**). In 2011, Class 3 had the highest mean percent cover (p=0.001) and in 2012, Class 2 had the highest mean percent cover (p=0.008). In 2013, cottonwoods were also predominantly found on the Class 2 sandbars, but were not statistically different between classes.

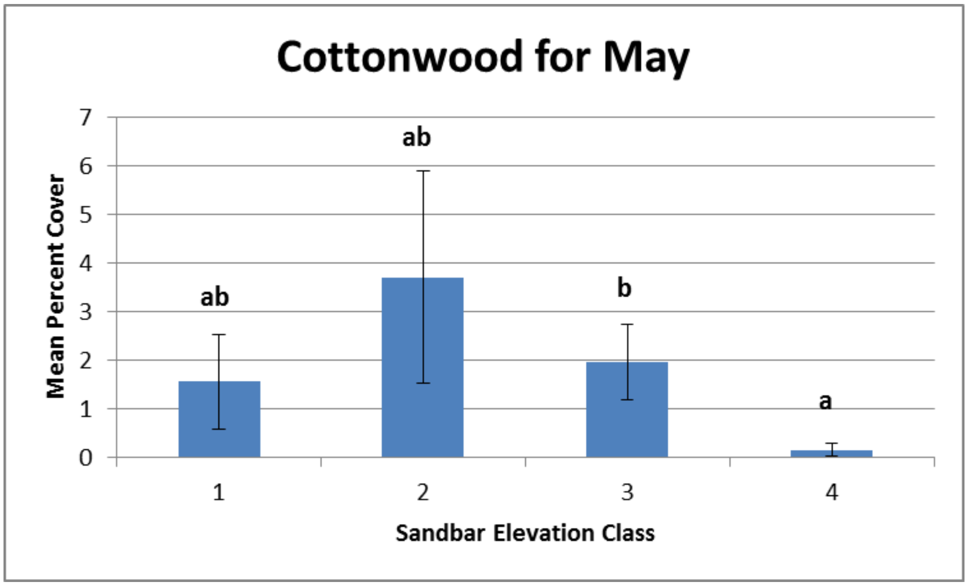

Figure 5.37. Mean percent cover of cottonwood based on bar elevation class for May samples, all years.

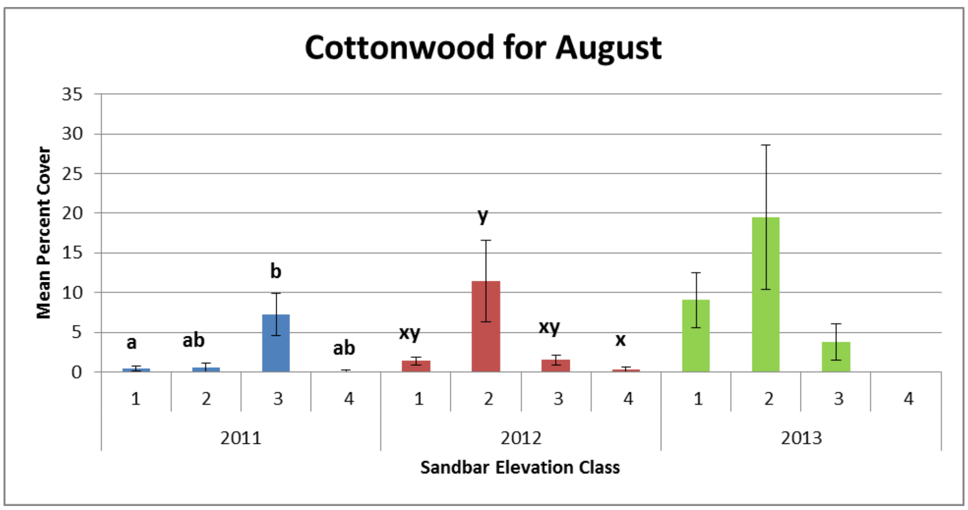

Figure 5.38. Mean percent cover of cottonwood based on bar elevation class for August samples for individual years.

5.9.3 Common Reed

Common reed did not differ significantly by year for either sampling month, and so all years were pooled and analyzed together for bar elevation class (**Figure 5.39**). Common reed showed the highest mean percent cover in May on the Class 2 sand bars, although this was not statistically significant (KW= 4.789, p-value = 0.188). In August, the highest sand bars had the greatest mean percent cover; however, the difference was still not statistically significant (KW= 7.468, p = 0.058).

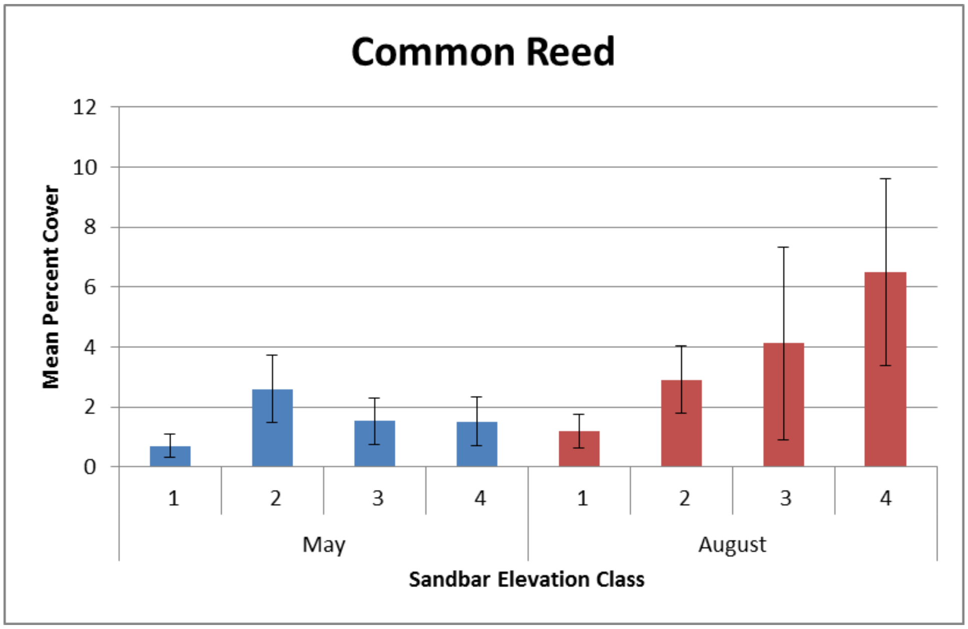

Figure 5.39. Mean percent cover for common reed by bar elevation class for both May and August, all years.

5.9.4 Reed Canary Grass

Reed canary grass was significantly different between years for May samples (**Figure 5.40**). It showed the highest mean percent cover for the Class 4 sandbars for all three years but was only statistically significant for 2012, due to no reed canary grass presence on Class 1 and 3 bars (p=0.005 and 0.004 respectively). Reed canary grass also had the highest mean percent coverage on Class 4 sand bars in August, with all years pooled (KW= 11.505, p = 0.009) (**Figure 5.41**).

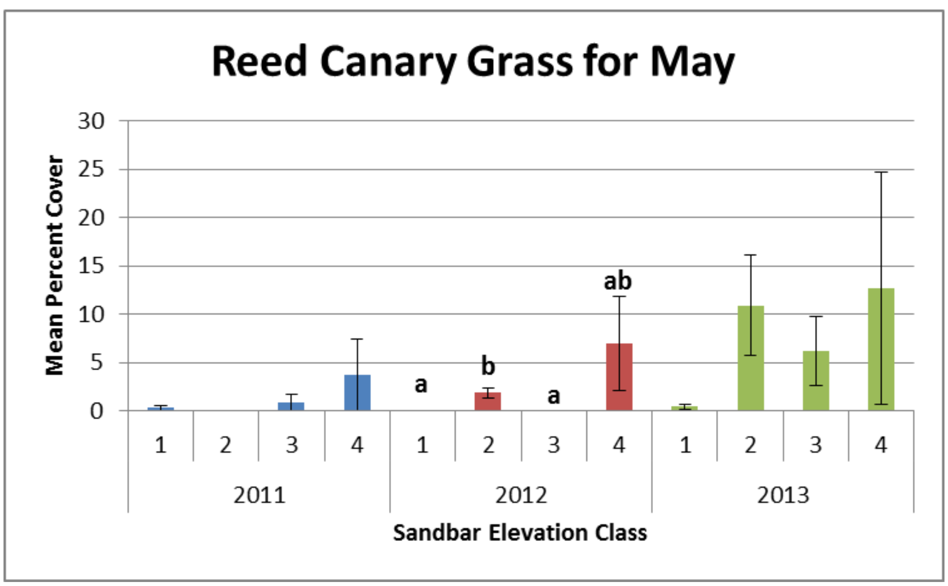

Figure 5.40. Mean percent cover of reed canary grass by bar elevation classes for May by individual years.

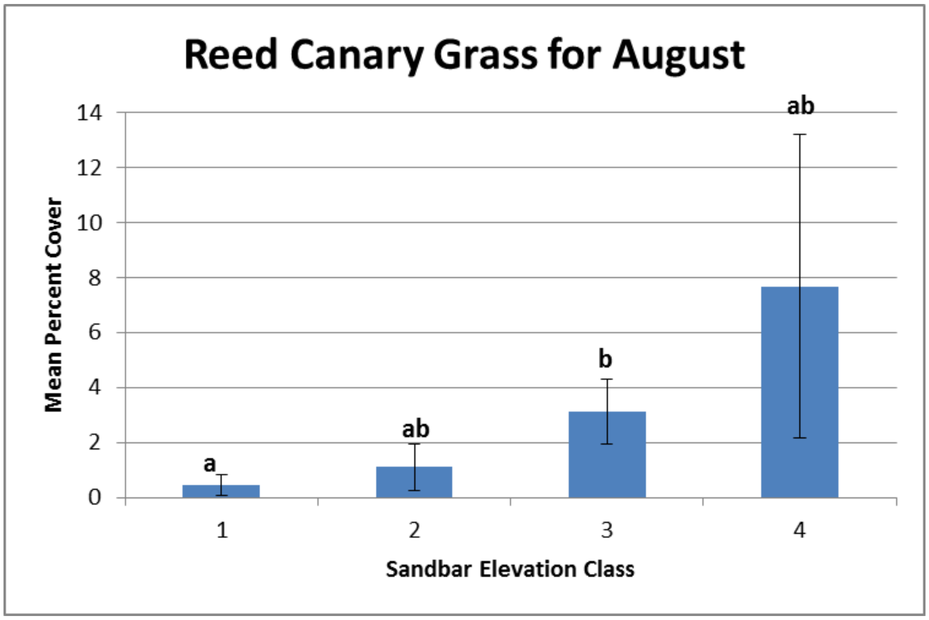

Figure 5.41. Mean percent cover of reed canary grass by bar elevation class in August, all years.

5.9.5 Ragweed

Ragweed mean percent cover was not significantly different between years during either May or August. For May, after all years were pooled the highest mean percent cover of ragweed was on Class 3 bars (**Figure 5.42**; p=0.001 with Bonferroni corrected significance level at p= 0.0083). For August, Class 3 bars had the highest mean percent cover (**Figure 5.43**; p = 0.001, with Bonferroni corrected significance level at p= 0.0083).

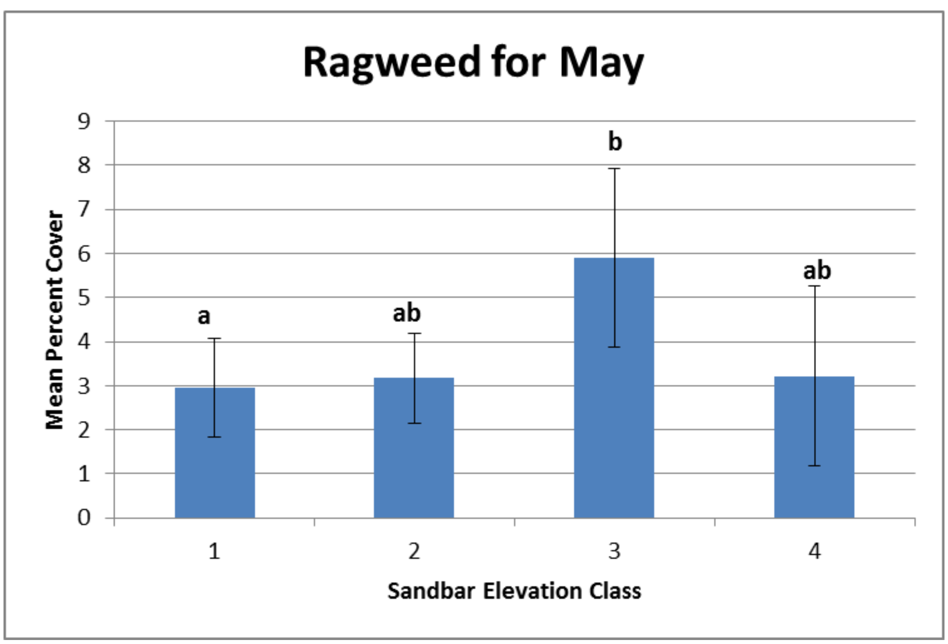

Figure 5.42. Mean percent cover for ragweed in May with years pooled.

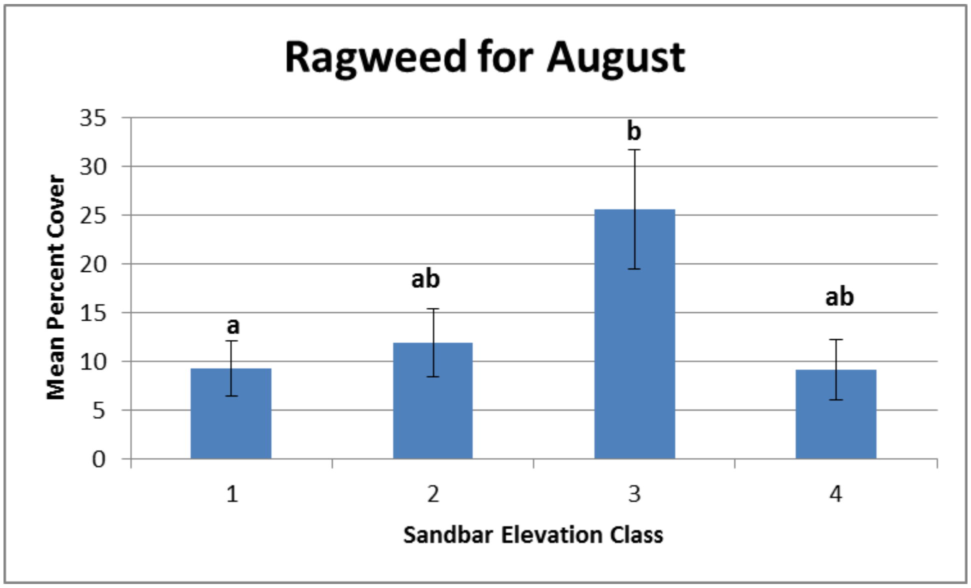

Figure 5.43. Mean percent cover for ragweed in August with years pooled.

5.9.6 Purple Loosestrife

Purple loosestrife in the May sampling events was only present in the 2011 and 2013 sampling. The means did not differ by year for either month (KW=4.250, p=0.236), so they were pooled. In May, the highest mean percent cover of purple loosestrife was on the lowest bars, but was not statistically different from the other classes (**Figure 5.44**). In August, purple loosestrife showed only marginally more cover on the lower bars and was not statistically significant between any of the four classes (**Figure 5.45**).

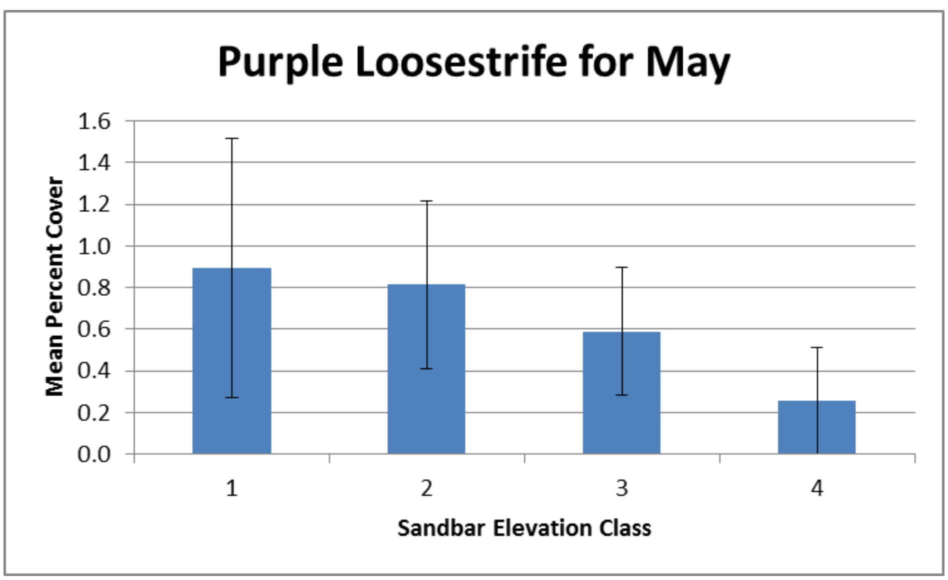

Figure 5.44. Mean percent cover for purple loosestrife in May, all years.

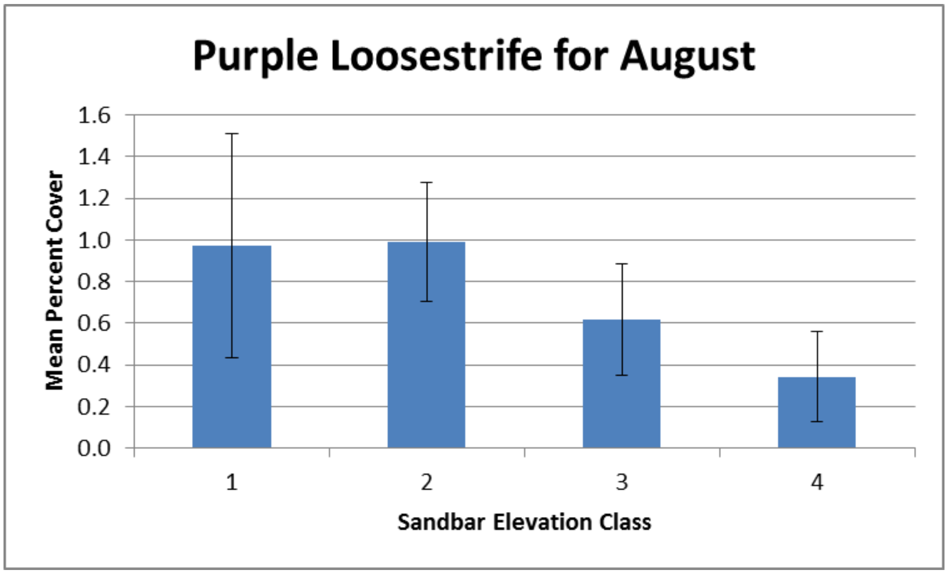

Figure 5.45. Mean percent cover for purple loosestrife in August, all years.

5.9.7 Bare Ground

The percent cover of bare ground, when separated into bar elevation classes then compared between sample years and sample period (May or August) (**Figures 5.46** and **5.47**), was significantly different. Sandbar classes within each sample month were therefore analyzed separately. Bare ground data were normally distributed with homogenous variances, so the ANOVA test was used. None of the bar elevation classes were statistically different within a sample year for either May or August (**Table 5.18**).

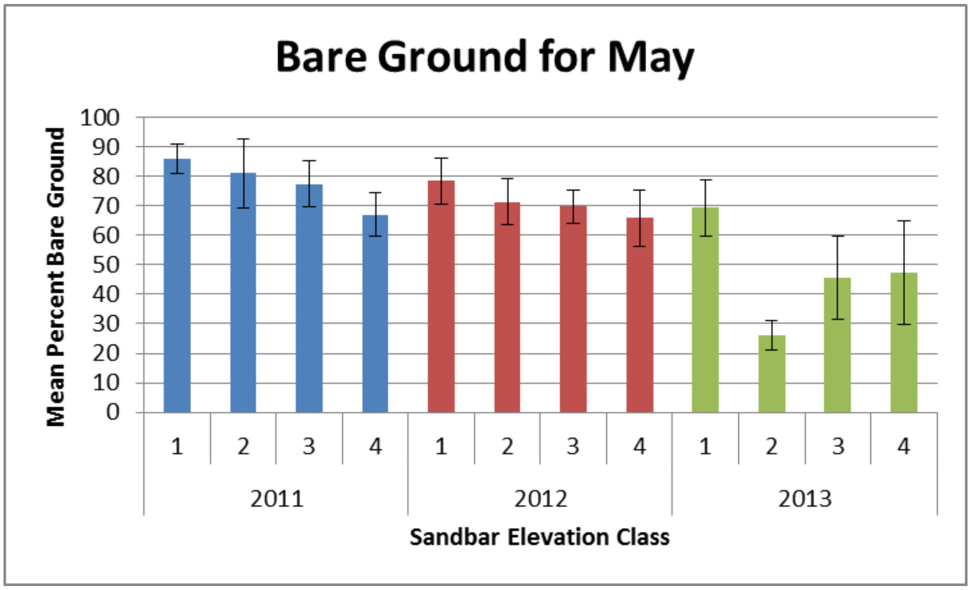

Figure 5.46. Mean percent bare ground in May by years.

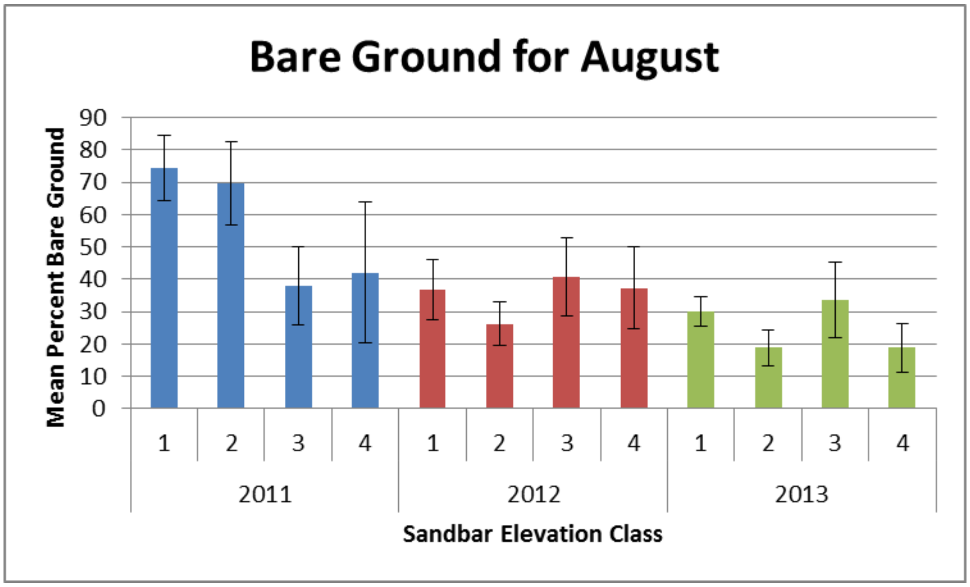

Figure 5.47. Mean percent bare ground in August by years.

Table 5.18. Test statistic and p-value for ANOVA test for bare ground by year.

Bare ground by sandbar class ANOVA tests		
Month/Year	F	p
May 2011	0.567	0.645
August 2011	1.841	0.178
May 2012	0.475	0.702
August 2012	0.271	0.846
May 2013	2.516	0.086
August 2013	0.941	0.439

5.10 Effect of Spraying on Common Reed

Selected plots were sprayed for common reed in 2010 (4 plots), 2011 (14 plots) and 2012 (4 plots), prior to sampling in the 2011, 2012 and 2013 seasons, respectively. **Figure 5.48** shows the mean percent cover of common reed in the sprayed and unsprayed plots. None of the differences between sprayed and unsprayed plots for May and August were significant for any year. **Figure 5.49** indicates an increase in mean common reed percent cover, the more a plot is sprayed; but this is most likely to the targeting of areas that have common reed.

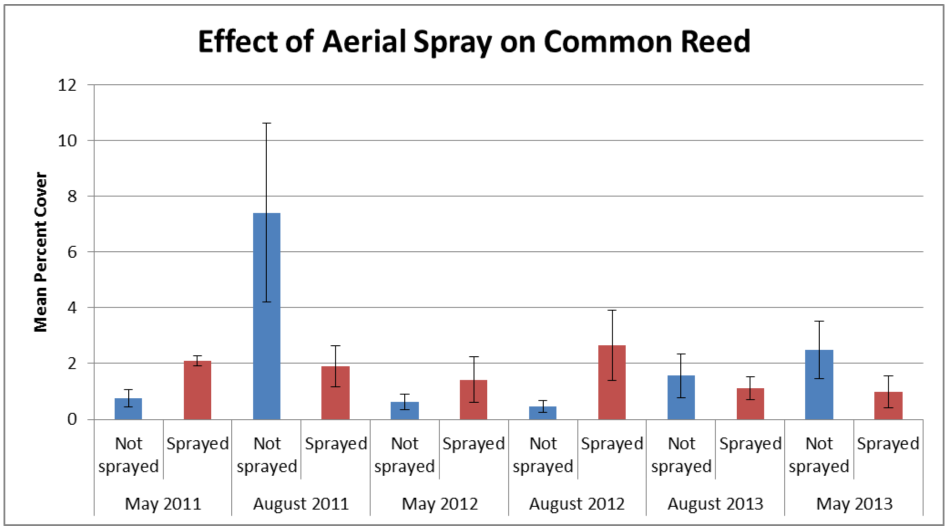

Figure 5.48. Mean percent cover of common reed of those plots receiving aerial spray and those left unsprayed throughout the three year study.

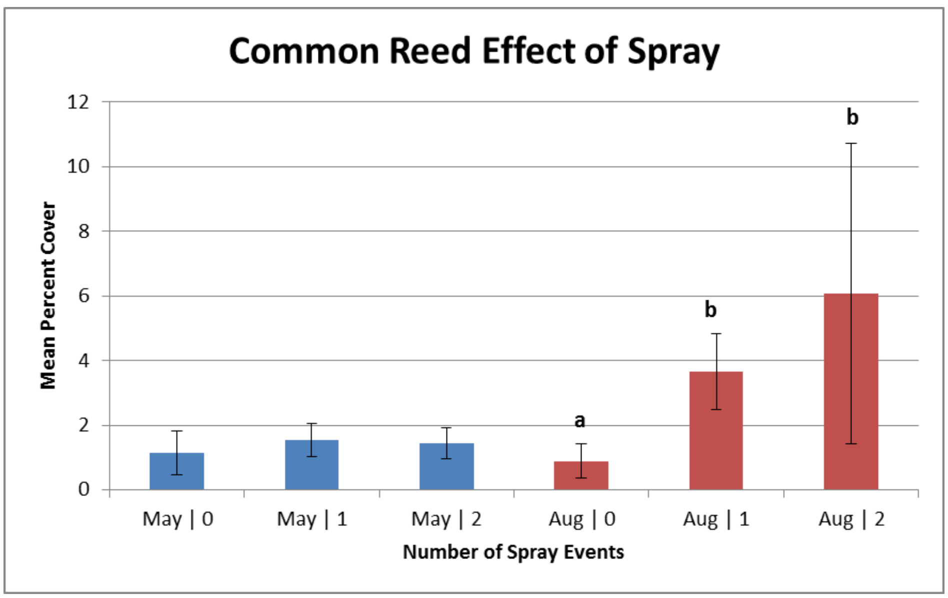

Figure 5.49. Mean percent cover of common reed in plots having alternate spray regimes.

5.11 Frequency

The mean frequency for each of the six species of interest was calculated and then compared by sample month/year and sandbar elevation class.

5.11.1 Frequency by Year

5.11.1.1 Willow

The frequency of willow did not differ significantly within the May (KW=2.224, p=0.329) and August (KW=4.831, p=0.089) sample periods. Willow frequency in May was variable over the three years, whereas the frequency of willow in August slightly increased each year (**Figure 5.50**).

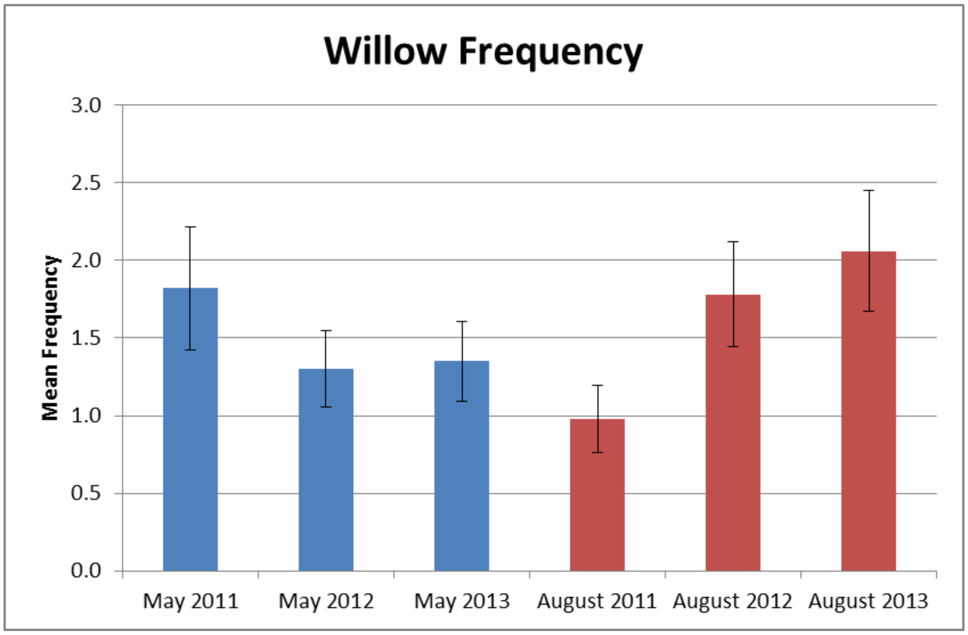

Figure 5.50. Willow mean frequency for each sample period, May and August analyzed separately.

5.11.1.2 Cottonwood

Mean cottonwood frequency (**Figure 5.51**), although increasing each year for both May and August sample periods, did not have statistically significant differences for either May (KW=2.758, p=0.252) or August (KW=2.708, p=0.258).

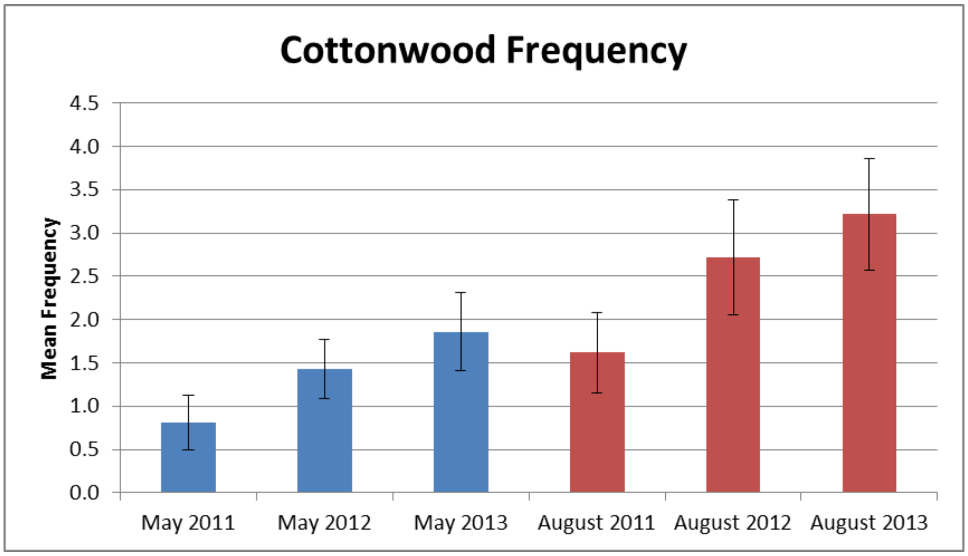

Figure 5.51. Cottonwood mean frequency for each sample period, May and August analyzed separately.

5.11.1.3 Common Reed

Mean frequency of common reed for the May sampling periods declined between 2011 and 2012, then increased slightly for 2013 (**Figure 5.52**). None of the three periods were statistically different from the other (KW=1.093, p=0.579). Common reed mean frequency in August decreased each year between 2011 and 2013, however the difference was also not statistically significant (KW=5.063, p=0.079).

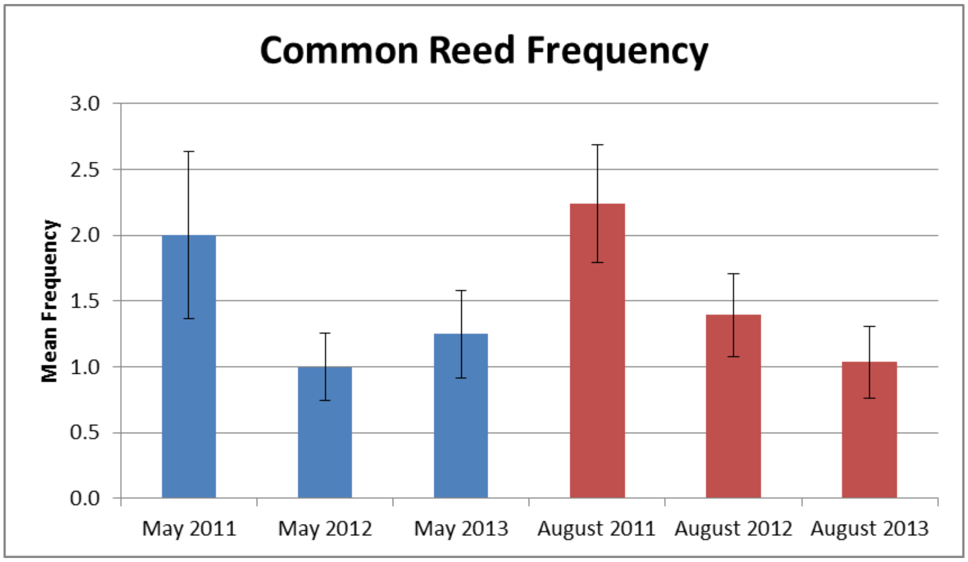

Figure 5.52. Common reed mean frequency for each sample period with May and August analyzed separately.

5.11.1.4 Reed Canary Grass

Reed canary grass for May showed a decrease in mean frequency between 2011 and 2012, but then increased again in 2013 (**Figure 5.53**). Mean frequency for the August sample period increased between 2011 and 2012, then remained steady for 2013. However, the means from neither May (KW=5.380, p=0.068) nor August (KW=3.265, p=0.195) were significantly different.

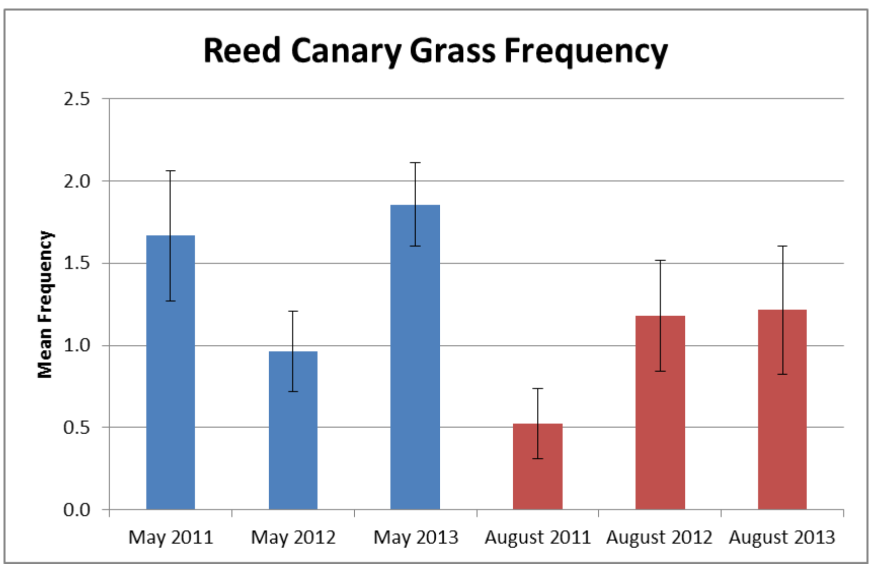

Figure 5.53. Mean frequency for reed canary grass with May and August analyzed separately.

5.11.1.5 Ragweed

Ragweed mean frequency for May decreased in 2012 only to increase again in 2013 (**Figure 5.54**), although this was not a significant difference (KW=2.894, p=0.235). For the August sampling period, mean frequency increased each year, with the difference between 2011 and 2012 statistically significant (KW=16.614, p=0.000).

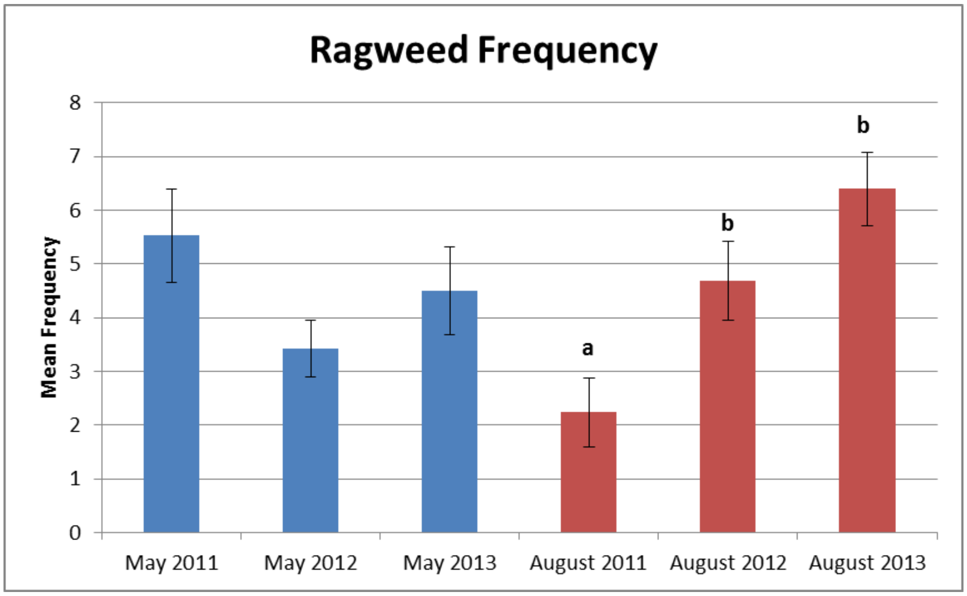

Figure 5.54. Mean frequency of ragweed with May and August analyzed separately.

5.11.1.6 Purple Loosestrife

The increase in mean frequency of purple loosestrife in May from 2011/2012 to 2013 was significant (KW=22.349, p<0.0001). In the August samples, frequency of purple loosestrife increased between 2011 and 2012, then only marginally increased for 2013, although the three years were not significantly different (KW=5.317, p=0.070) (**Figure 5.55**).

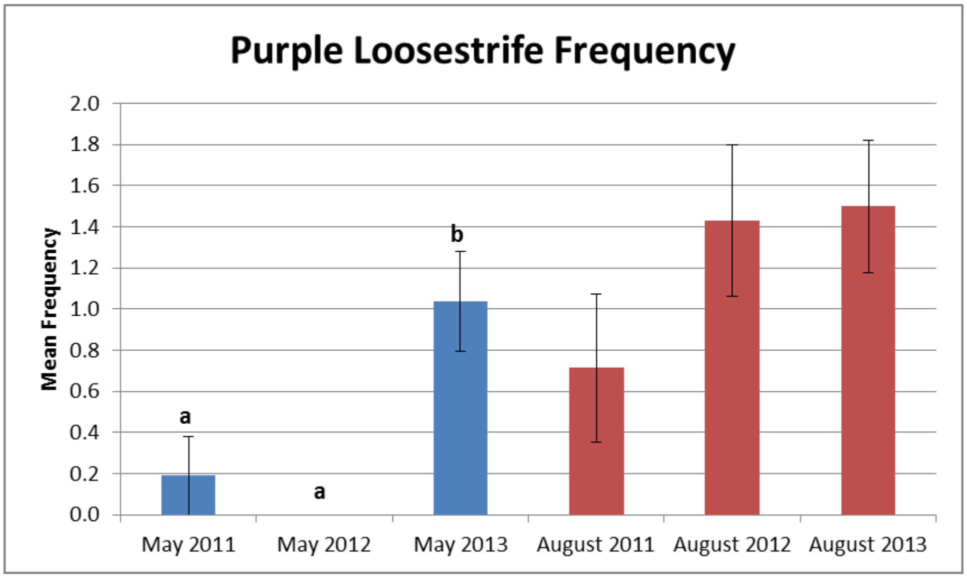

Figure 5.55. Mean frequency of purple loosestrife with May and August analyzed separately.

5.11.2 Frequency by Sandbar Elevation Class

Mean frequency of each species of interest was analyzed by sandbar elevation class for each sampling month. Years were pooled which led to larger sample sizes for each class: Class 1 (n=31), Class 2 (n=14), Class 3 (n=16), and Class 4 (n=16). **Tables 5.19 and 5.20** show the levels of significance for pairwise comparisons between classes for each species in May and August, respectively.

5.11.2.1 May

For the May sample periods, ragweed was most frequent on Class 3 bars ($p<0.0001$) and cottonwoods were most frequent on the middle bars ($p=0.005$) (**Figure 5.56**).

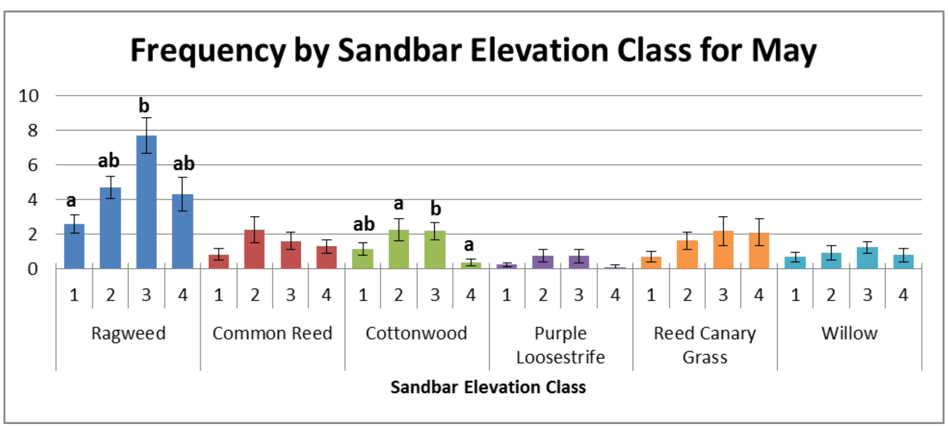

Figure 5.56. Mean frequency per species analyzed by sandbar elevation class for May sample events.

5.11.2.2 August

Mean frequency of species for the August sample periods was analyzed by sandbar elevation class (**Figure 5.57**). Ragweed was found to be significantly more frequent on Class 3 bars than Class 1 bars (p=0.000), reed canary grass was significantly more frequent on Class 3 bars than Class 1 bars (p=0.000), and willow was significantly more frequent on class 2 bars than Class 4 bars (p=0.002).

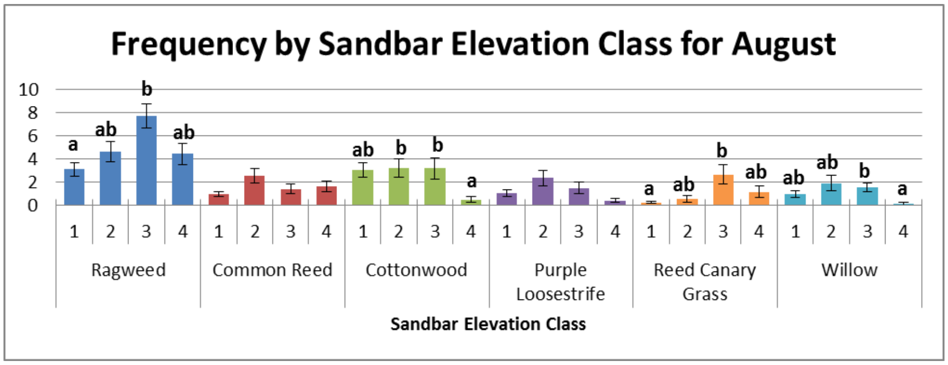

Figure 5.57. Mean frequency per species analyzed by sandbar elevation class for August sample events.

Table 5.19. P-values for frequency using the Kruskal-Wallis test for sandbar elevation class in May. Bonferroni corrected significance level is p= 0.0083.

Ragweed				
Class	*1*	*2*	*3*	*4*
1	1	0.029	**< 0.0001**	0.134
2	0.029	1	0.128	0.510
3	**< 0.0001**	0.128	1	0.024
4	0.134	0.510	0.024	1
Common Reed				
Class	*1*	*2*	*3*	*4*
1	1	0.030	0.117	0.242
2	0.03	1	0.557	0.358
3	0.117	0.557	1	0.731
4	0.242	0.358	0.731	1
Cottonwood				
Class	*1*	*2*	*3*	*4*
1	1	0.116	0.05	0.206
2	0.116	1	0.792	0.014
3	0.05	0.792	1	**0.005**
4	0.206	0.014	**0.005**	1
Purple Loosestrife				
Class	*1*	*2*	*3*	*4*
1	1	0.229	0.33	0.463
2	0.229	1	0.811	0.094
3	0.33	0.811	1	0.137
4	0.463	0.094	0.137	1
Reed Canary Grass				
Class	*1*	*2*	*3*	*4*
1	1	0.031	0.112	0.13
2	0.031	1	0.575	0.534
3	0.112	0.575	1	0.95
4	0.13	0.534	0.95	1
Willow				
Class	***1***	***2***	***3***	***4***
1	1	0.616	0.023	0.831
2	0.616	1	0.14	0.794
3	0.023	0.14	1	0.072
4	0.831	0.794	0.072	1

Table 5.20. P-values for frequency using the Kruskal-Wallis test for sandbar elevation class in August. Bonferroni corrected significance level is p= 0.0083.

Ragweed				
Class	***1***	***2***	***3***	***4***
1	1	0.133	**0.000**	0.215
2	0.133	1	0.068	0.78
3	**0.000**	0.068	1	0.029
4	0.215	0.78	0.029	1
Common Reed				
Class	***1***	***2***	***3***	***4***
1	1	0.014	0.464	0.303
2	0.014	1	0.124	0.198
3	0.464	0.124	1	0.795
4	0.303	0.198	0.795	1
Cottonwood				
Class	***1***	***2***	***3***	***4***
1	1	0.437	0.478	0.011
2	0.437	1	0.932	0.005
3	0.478	0.932	1	0.005
4	0.011	0.005	0.005	1
Purple Loosestrife				
Class	***1***	***2***	***3***	***4***
1	1	0.078	0.339	0.242
2	0.078	1	0.457	0.011
3	0.339	0.457	1	0.064
4	0.242	0.011	0.064	1
Reed Canary Grass				
Class	***1***	***2***	***3***	***4***
1	1	0.551	**0.000**	0.302
2	0.551	1	0.014	0.732
3	**0.000**	0.014	1	0.029
4	0.302	0.732	0.029	1
Willow				
Class	***3***	***1***	***2***	***4***
3	1	0.442	0.156	0.034
1	0.442	1	0.606	0.014
2	0.156	0.606	1	**0.002**
4	0.034	0.014	**0.002**	1

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6 EFFECTIVENESS MONITORING AND IMPLICATIONS TO BIG QUESTIONS AND HYPOTHESES

As discussed in the introduction, specific benchmarks have been established by the Program to test each of the relevant hypotheses (Table 1.1). The monitoring data and modeling results were used to assess whether or not these benchmarks were met during each of the three monitoring years. This information was also used to assess the effectiveness of the various FSM treatments that occurred at the site in shifting the reach toward the desired condition.

6.1 Flows Regime during AM Experiment

Flows in the Central Platte River and the Elm Creek Reach were unusually high during 2011, and unusually low during the latter half of 2012 and 2013 (Figure 1.8). The total runoff volume at Overton was about 2.69M ac-ft in Water Year (WY) 2011, about 1.25M ac-ft in WY2012 and only about 592,000 ac-ft in WY2013, compared to the long-term average (WY1942 through WY2013) of about 1.13M ac-ft. The slightly higher-than-average volume for WY2012 is deceiving, however, because over 80 percent of the volume occurred before the start of the 2012 growing season (April 1). The period from April 1, 2012 through September 30, 2012 actually had a lower total flow volume than the same period in 2013 (244,000 ac-ft versus 345,000 ac-ft, compared to the long-term average for this portion of the year of about 550,000 ac-ft). About 30,000 ac-ft of the difference occurred during the April 2013 SDMF; thus, even in the absence of the SDMF, April through September, 2012 would still have had a lower total flow volume.

The maximum mean daily flow at Overton between November 2010, when the initial bar clearing was conducted, and the May 2011, baseline survey was 4,020 cfs, and the maximum flow between the May and August 2011 surveys was 8,720 cfs (**Table 6.1**). For comparison, the maximum flow between January 1 and the May 2012 survey was about 3,430 cfs (January 15), and the maximum flow between the May and August 2012 surveys was only about 1,810 cfs. In 2013, the maximum flow between January 1 and the April, pre-SDMF survey was about 2,020 cfs, the maximum mean daily flow during the SDMF was 4,070 cfs and the maximum summer flow was 1,990 cfs.

The low flows during 2012 and 2013 caused relatively little change in the sandbar area and volumes, and the overall topography in the Elm Creek reach (Table 2.2). The vegetation, however, responded by colonizing to a much lower elevation and to generally higher percent cover than in 2011 when the flows were much higher, primarily due to three specific species: cocklebur, annual ragweed, and purple lovegrass.

6.2 Flow-related Hypotheses

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

Table 6.1. Maximum mean daily discharge between surveys.

Survey Dates		Maximum Mean Daily Discharge Between Surveys[1]				
Start	End	Date	Overton	Upstream	KDS	Downstream
5/2/2011	5/6/2011	6/26/2010	7,370	7,890	155	7,730
8/29/2011	9/2/2011	6/25/2011	8,720	9,500	331	9,170
4/30/2012	5/4/2012	1/15/2012	4,900	5,120	305	4,820
8/27/2012	8/31/2012	5/29/2012	1,810	1,380	160	1,220
4/1/2013	4/5/2013	3/26/2013	2,090	2,040	173	1,860
5/20/2013	5/24/2013	4/13/2013	4,070	4,640	0	4,640
8/26/2013	8/30/2013	8/3/2013	1,990	1,800	178	1,620

[1]Maximum measured flow at Overton; mean daily diversion at KDS and estimated mean daily flow up- and downstream from KDS on day of maximum at Overton.

6.2.1 *S*tage-discharge Relationship

Tetra Tech developed two SRH-2D models of the Elm Creek Complex to support this study. The topography for the initial model was developed from the May 2011 field survey data and the Program's 2010 LiDAR (Tetra Tech 2012a). An updated model was subsequently developed using the November 2012 LiDAR data for most of the area, with adjustments to the below-water areas based on the April 2013 field survey data. These models are the primary tool for evaluating the stage-discharge relationships at the various points of interest. As described in Tetra Tech (2012a), the initial model calibrates very well to the water-surface elevations surveyed along the reach in May 2011 (**Figures 6.1a and 6.1b**). In the portion of the reach upstream from the KDS, the average error between the measured and computed water-surface elevations at 3,420 cfs was 0.0 feet and the maximum absolute difference that occurs at the upstream end of the pool above the diversion structure (Sta 392,600) is 0.4 feet. In the portion of the reach downstream from the KDS, the average error between the measured and computed values at 3,370 cfs is 0.0 feet and the maximum absolute difference is also 0.4 feet, occurring in the vicinity of Sta 383,800. A significant portion of the variability between modeled and measured water-surface elevations is likely due to variability in the discharge during the survey period.

As noted above, the model update was performed using the non-wetted are in the November 2012 LiDAR data and in-channel geometry surveyed by Tetra Tech in April 2013. The 2012 data were used because the November 2013 LiDAR data were not yet available at the time of the update. In addition, significant changes in topography occurred in the reach during the late-September 2013 flooding; thus, these data would not be relevant for analysis of pre-flood conditions when the monitoring surveys were conducted. Very little of the channel was inundated during the 2012 LiDAR survey that was flown when the mean daily discharge was about 225 cfs through the Elm Creek reach (all three river gates at the KDS were open with no flow being diverted into the Kearney Canal). As a result, minimal adjustments were necessary to create a complete picture of the channel bed. In updating the model, **t**he original mesh was adjusted to reflect the 2012/early-2013 flow paths and roughness elements. Roughness values for the different zones defined in the original model were retained in the update model, but the zone boundaries were adjusted to correspond with changes in vegetation distribution and channel geometry (i.e., bank erosion, bed changes and constructed sandbars).

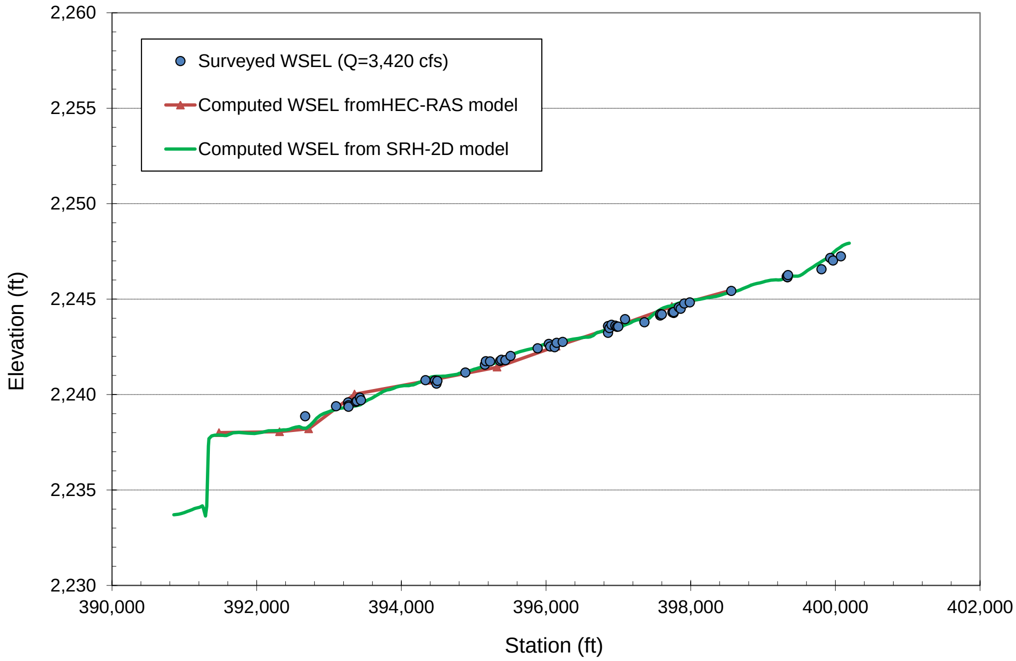


Figure 6.1a. Comparison of the predicted water-surface profiles from the original SRH-2D and 1-D HEC-RAS upstream models with the measured water-surface elevations from the May 2011 survey when the discharge was 3,420 cfs.

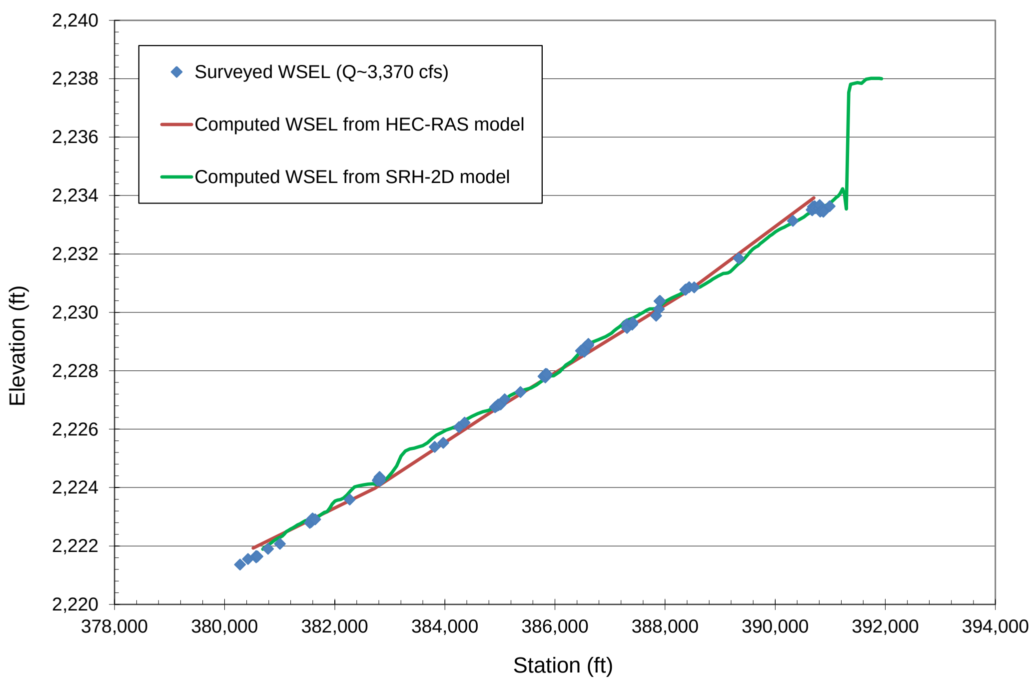


Figure 6.1b. Comparison of the predicted water-surface profiles from the original SRH-2D and 1-D HEC-RAS downstream models with the measured water-surface elevations from the May 2011 survey when the discharge was 3,370 cfs.

The updated model calibrates well to measured water-surface elevations collected during this survey, when the mean daily discharge was approximately 1,200 cfs (1,141-1,286 cfs upstream and 1,033-1,278 cfs downstream) (**Figure 6.2a and 6.2b**). The scatter that occurs in the data is mostly due to high variability in discharge resulting from hydro-cycling and migratory bird flows from the J-2 Return that occurred during the survey periods. The discharge ranged from 240 to 2,020 cfs at the Overton gage; however, the stage in the Elm Creek Reach remained relatively constant during daylight hours for a substantial portion of the May 2012 survey.

6.2.2 Unvegetated Sandbar Heights and Areas above 1,200-cfs Water Surface

As discussed in Section 2.3, the median and maximum heights of the unvegetated and vegetated sandbars above the 1,200-cfs water-surface elevation were evaluated to assess their distribution in each part of the reach and the extent to which the minimum 1.5-foot benchmark height associated with Hypothesis Flow #1 is being met for the unvegetated islands. The following discussion focuses on the changes that occurred between the spring surveys in each of the years to avoid confounding of the comparisons due to vegetation growth that occurred between the spring and late-summer surveys, shifting unvegetated bars into the vegetated category[16]. The consolidated data indicate that the vegetated bars upstream from the KDS tended to be a few tenths of feet higher than the unvegetated bars, and the median height of both bar types generally increased from May 2011 through May 2012, and then decreased back to about midway between the two earlier values by April 2013 (**Table 6.2, Figure 6.3a**). The average maximum height of unvegetated sandbars upstream from the KDS remained relatively consistent at 1.6 to 1.7 feet from May 2011 to May 2012, and this decreased to about 1.3 feet by April 2013 and remained essentially the same in May 2013 after the SDMF release (**Figure 6.3b**). Based on the non-parametric Kruskal-Wallace test, the only one of the changes that is statistically significant at the 90-percent confidence level is the increase in the median sand bar height from 0.4 feet above the 1,200-cfs water surface in May 2011 to 1.1 feet above in May 2012.

Downstream from the KDS, the average median height of the unvegetated bars decreased from about 2.6 feet in May 2011 to about 1.2 foot in May 2012. Significant bar construction activity occurred in the reach downstream from the KDS beginning at about the time of the August 2012 survey, and the majority of the unvegetated bars during the 2013 surveys had been constructed. The constructed bars had average median height of about 1.9 feet in April 2013, increasing slightly increase about 2.0 feet in May 2013, only slightly higher than the median height due to the relatively flat topography on the tops of the bars. The four remaining natural unvegetated bars had an average median height of 0.8 feet in April 2013. Only one of these bars was unvegetated by the May 2013 survey (Bar 26). This bar was not overtopped during the SDMF; thus, the median and maximum height of 1.1 feet and 1.9 feet, respectively, was the same during both surveys. Based on the Kruskal-Wallace test, the decreases in average height of the median bar elevations in August 2011 (1.0 feet) and April 2013 (0.8 feet) from the May 2011 average height (2.3 feet) are statistically significant at the 90-percent confidence level. Similar to the upstream part of the reach, none of the differences in maximum height are statistically significant. The test also indicates that the decreases in average maximum height from 3.7 feet in May 2011 to 2.1 feet in May 2012 and 2.3 feet in April 2013 are statistically significant.

[16]Comparison of the May heights with the August heights does not necessarily represent actual changes because many of the bars in the May data sets became vegetated over the summer; thus, differences in the average heights are associated more with differences among the bars than actual changes in height of individual bars.

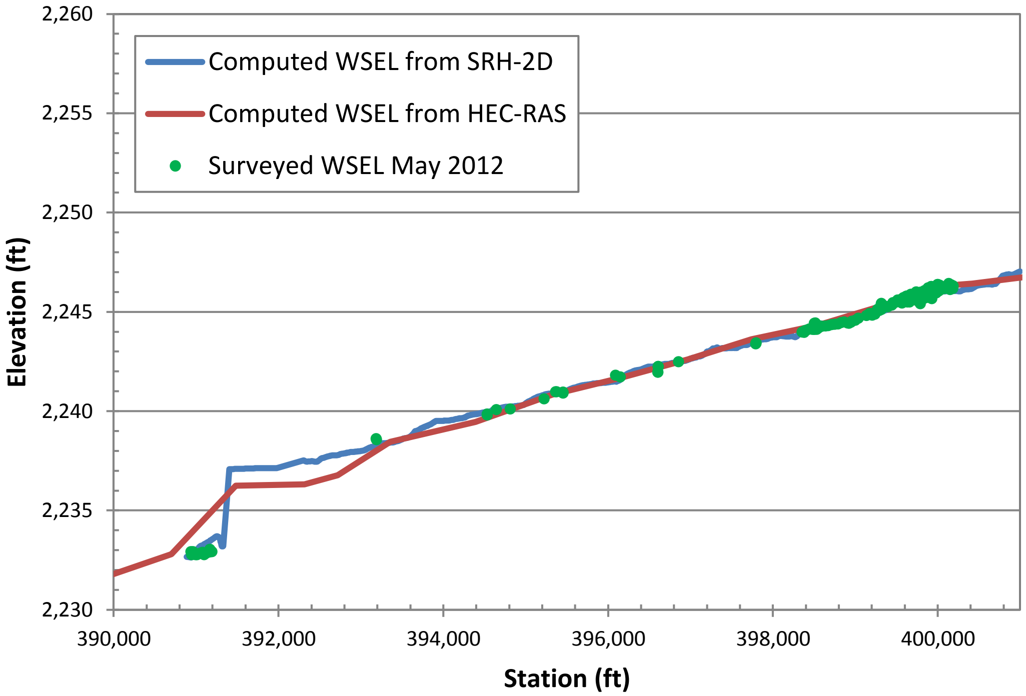


Figure 6.2a. Comparison of the predicted water-surface profiles from the updated SRH-2D and 1-D HEC-RAS upstream models with the measured water-surface elevations from the May 2013 survey when the discharge was approximately 1,200 cfs.

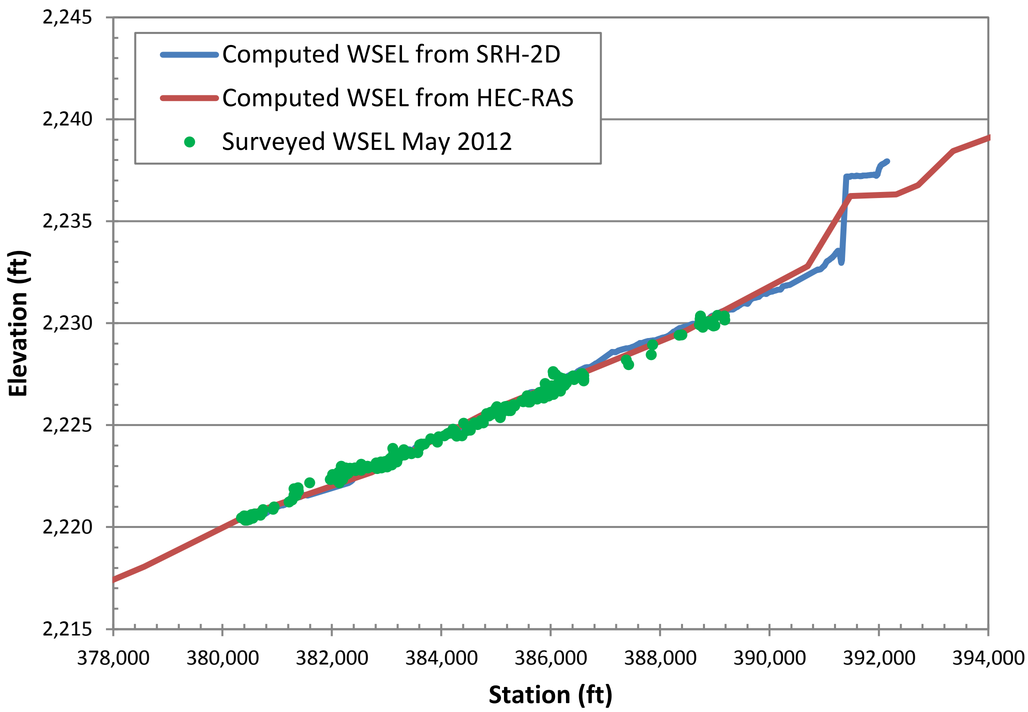


Figure 6.2b. Comparison of the predicted water-surface profiles from the updated SRH-2D and 1-D HEC-RAS downstream models with the measured water-surface elevations from the May 2013 survey when the discharge was approximately 1,200 cfs.

Table 6.2. Summary of sandbar heights and areas above 1,200-cfs water-surface elevation.

Reach	Vegatation	# Bars	Minimum Depth Criterion (ft)	Height above 1,200 cfs Water-surface (feet)					
				Median Bar Elevation			Maximum Bar Elevation		
				Mean	Standard Deviation on Mean	95% Confidence Limit on Mean (+/-)	Mean	Standard Deviation on Mean	95% Confidence Limit on Mean
May 2011 Survey									
Upstream	Unvegetated	9	-0.7	0.44	0.39	0.87	1.63	1.10	2.49
Upstream	Vegetated	5	-0.7	1.00	0.54	1.38	3.46	2.58	6.64
Downstream	Unvegetated	17	-0.7	2.26	0.79	1.66	3.66	1.20	2.52
Downstream	Vegetated	3	-0.7	1.00	0.54	1.71	3.05	1.51	4.80
August/September 2011 Survey									
Upstream	Unvegetated	4	-0.7	0.83	0.35	0.98	1.72	0.23	0.64
Upstream	Vegetated	6	-0.7	0.93	0.27	0.66	1.77	0.51	1.25
Downstream	Unvegetated	8	-0.7	1.02	0.29	0.66	1.80	0.35	0.82
Downstream	Vegetated	3	-0.7	0.97	0.71	2.26	2.11	0.74	2.35
April/May 2012 Survey									
Upstream	Unvegetated	13	-0.7	1.12	0.50	1.09	1.63	0.64	1.37
Upstream	Vegetated	3	-0.7	1.60	0.33	1.05	2.60	0.52	1.65
Downstream	Unvegetated	7	-0.7	1.18	0.67	1.58	2.08	0.73	1.72
Downstream	Vegetated	8	-0.7	1.45	0.69	1.59	2.25	1.00	2.32
August 2012 Survey									
Upstream	Unvegetated	13	-0.7	0.69	0.37	0.80	1.48	0.46	1.00
Upstream	Vegetated	3	-0.7	1.22	0.70	2.23	1.93	0.83	2.63
Downstream	Unvegetated	7	-0.7	1.54	0.69	1.64	2.20	0.89	2.11
Downstream	Vegetated	8	-0.7	0.99	0.43	0.99	1.91	0.88	2.02
April 2013 Survey									
Upstream	Unvegetated	8	-0.7	0.74	0.38	0.88	1.28	0.71	1.63
Upstream	Vegetated	9	-0.7	1.07	0.38	0.87	2.17	0.99	2.24
Downstream	Unvegetated	4	-0.7	0.76	0.70	1.94	1.29	1.07	2.96
Downstream	Vegetated	14	-0.7	0.87	0.48	1.03	1.69	0.88	1.88
Downstream	Constructed	8	-0.7	1.90	0.60	1.38	2.12	0.54	1.23
May 2013 Survey									
Upstream	Unvegetated	8	-0.7	0.77	0.40	0.92	1.32	0.64	1.48
Upstream	Vegetated	9	-0.7	1.24	0.46	1.03	2.22	1.00	2.26
Downstream	Unvegetated	1	-0.7	1.08			1.92		
Downstream	Vegetated	13	-0.7	1.10	0.45	0.97	2.01	0.86	1.87
Downstream	Constructed	8	-0.7	2.02	0.53	1.22	2.23	0.53	1.22
August 2013 Survey									
Upstream	Unvegetated	0	-0.7						
Upstream	Vegetated	15	-0.7	0.92	0.53	1.14	1.70	1.04	2.21
Downstream	Unvegetated	0	-0.7						
Downstream	Vegetated	16	-0.7	0.75	0.47	0.99	1.62	0.87	1.85
Downstream	Constructed	8	-0.7	1.93	0.54	1.24	2.08	0.53	1.22

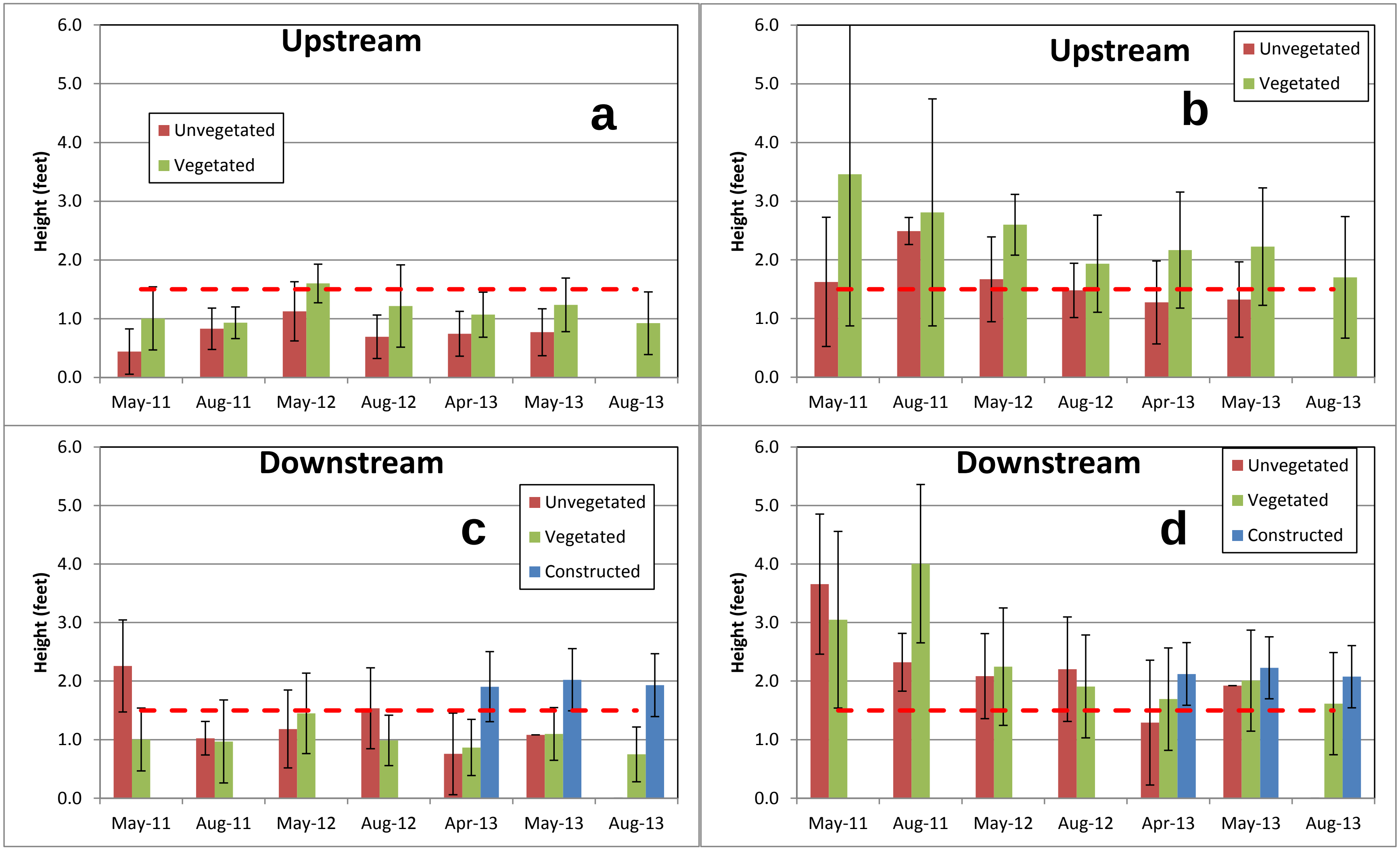


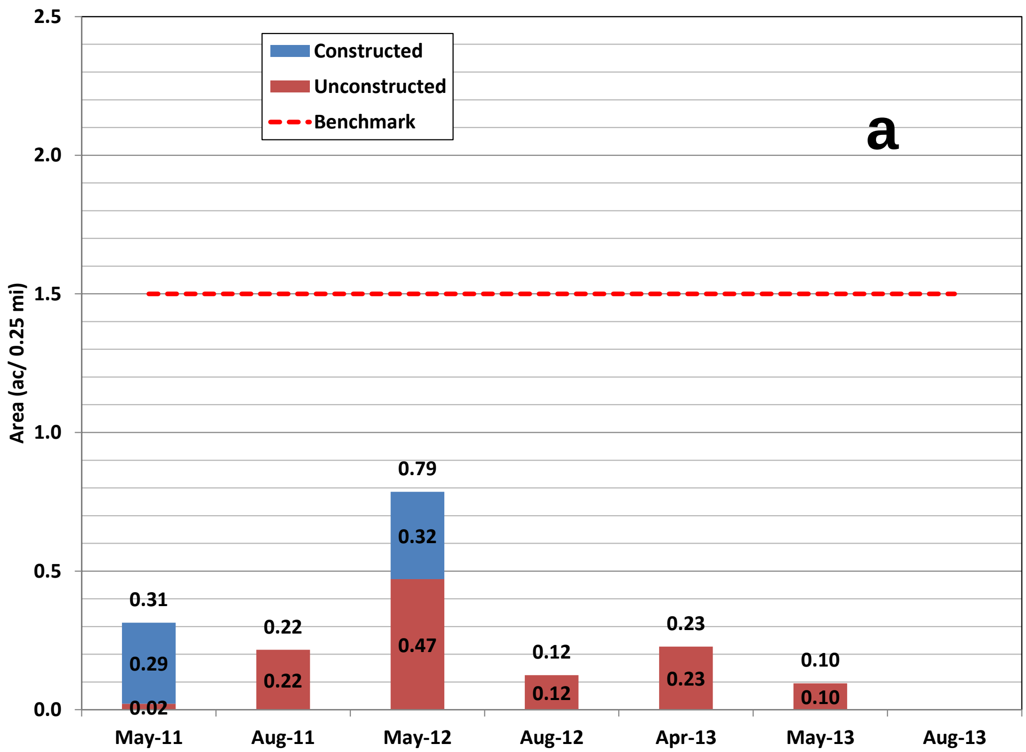
Figure 6.3. Average height of sand bars above the 1,200-cfs water surface: (a) upstream, median bar elevation, (b) upstream, maximum bar elevation, (c) downstream, median bar elevation, (d) downstream, maximum bar elevation. Whiskers represent ±1 standard deviation about the mean.

One of the benchmarks for Hypothesis Flow #1 is a need for at least 1.5 acres of unvegetated sandbar area at least 1.5 feet above the 1,200-cfs water surface per one-quarter mile of channel. At the time of the May 2012 survey, there were approximately 0.6 acres/one-quarter mile of unvegetated sandbar area between the Elm Creek Bridge and the KDS, about half of which was the constructed NPPID nesting island (**Figure 6.4a**). This increased to about 1.1 acres by May 2012, and then declined to about 0.2 acres by April 2013, and declined even further to only about 0.1 acres in May 2013. The unvegetated area in August of all years was very low due to vegetation growth on this relatively high portion of the bars during the summer months. The large increase from August 2011 to May 2012 occurred because flows were high during Fall 2011 and the early part of 2012, coupled with winter die-back of the vegetation, resulting in a relatively large unvegetated area in May 2012.

Downstream from the KDS, there were about 1.9 acres of unvegetated sand bars per one-quarter mile of channel in May 2011, and this declined significantly to only about 0.4 acres by May 2012 (**Figure 6.4b**). The bar construction that began in Summer 2012 represented about 1.9 acres of unvegetated bar area per one-quarter mile and there were about 0.3 acres per quarter mile of unconstructed, unvegetated bars in April 2013, totaling 2.2 acres. The total unvegetated bar area declined to about 1.8 acres in May 2013 and about 1.7 acres by August 2013.

6.2.3 Unvegetated Sandbar Heights below Maximum Water-surface Elevation

As discussed in Section 2.3, Priority Hypothesis Flow #1 is based, in part, on observations by Crowley (1981) that macroforms in the Platte River downstream from Grand Island essentially stopped downstream migration and vertical building when the depth over the top of the bar declined to less than 20 cm (~0.7 feet). The validity of this assumption for bars in the ECC was assessed by comparing the median and maximum bar elevations with the water-surface elevation associated with the maximum mean daily flow that occurred between each successive survey (**Table 6.3**). The median elevation of most of the bars was inundated during the period before each of the surveys in both parts of the reach except August 2012, April 2013 and August 2013 (**Figures 6.5a and 6.5c**). The maximum elevation of most of the bars was, however, only inundated between the May and August 2011 surveys (Figure 2.19a), and only a few of the low elevation bars were inundated by the April 2013 SDMF (Figure 2.20b). The tops of the unvegetated bars in the upstream part of the reach (excluding the NPPID nesting island) averaged about 0.2 feet below the June 2011 high flow water surface, and the tops of the downstream unvegetated, bars averaged about 0.7 feet below the June 2011 water surface (**Figures 6.5b and 6.5d**). As shown in Figure 2.19a, the tops of all of the bars that were completely inundated by the June 2011 high flows in both parts of the reach were within 1 foot of the maximum water-surface, with one exception (Bar 14, a very small unvegetated bar along the right bank just downstream from the KDS near Station 390,700; Appendix C.1). In addition, the tops of the bars (5 upstream from the KDS and 4 downstream from the KDS) that were overtopped by the April 2013 SDMF were within 1 foot of the maximum water surface.



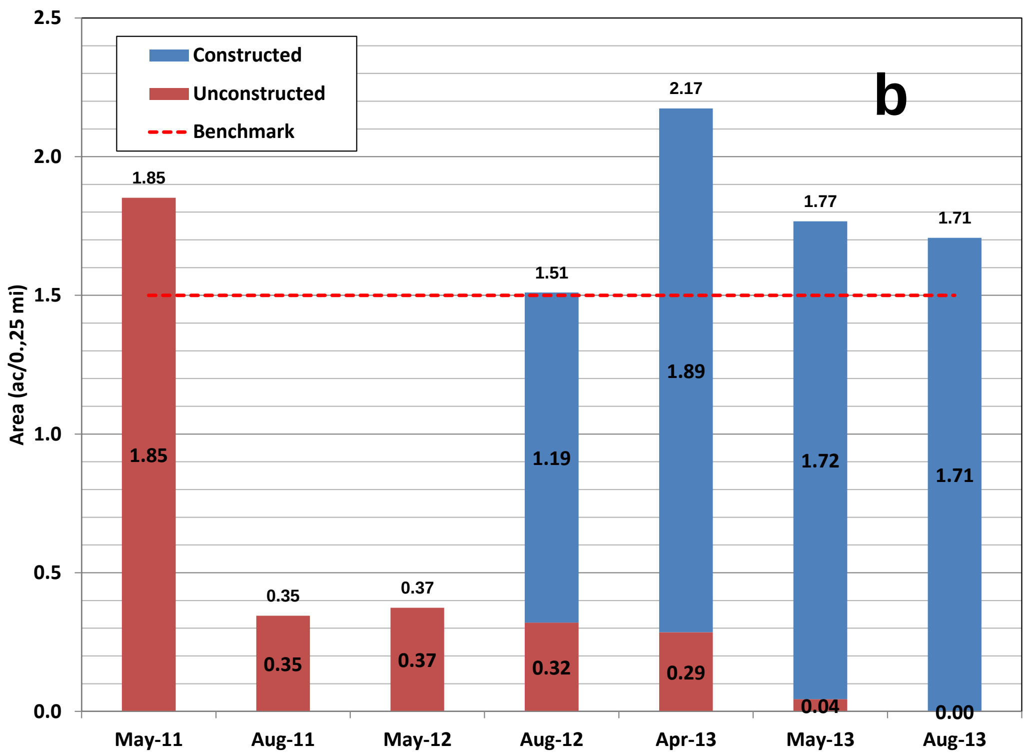


Figure 6.4. Area of unvegetated sand bars more than 1.5 feet above 1,200-cfs water surface per one-fourth mile of channel: (a) upstream from KDS, (b) downstream from KDS.

Table 6.3. Summary of sandbar depths below preceding maximum water-surface elevation.

Reach	Vegatation	# Bars	Minimum Depth Criterion (ft)	Depth Below Preceding Maximum Water-surface Elevation (ft)*					
				Median Bar Elevation			Maximum Bar Elevation		
				Mean	Standard Deviation on Mean	95% Confidence Limit on Mean (+/-)	Mean	Standard Deviation on Mean	95% Confidence Limit on Mean
May 2011 Survey									
Upstream	Unvegetated	9	-0.7	1.81	0.28	0.64	0.41	0.78	1.76
Upstream	Vegetated	5	-0.7	1.18	0.53	1.36	-1.27	2.54	6.53
Downstream	Unvegetated	17	-0.7	0.46	0.74	1.56	-0.94	1.15	2.42
Downstream	Vegetated	3	-0.7	1.26	1.15	3.65	-0.31	1.83	5.84
August/September 2011 Survey									
Upstream	Unvegetated	4	-0.7	1.81	0.12	0.33	0.15	0.48	1.34
Upstream	Vegetated	6	-0.7	1.47	0.40	0.99	-0.41	1.95	4.76
Downstream	Unvegetated	8	-0.7	2.00	0.33	0.76	0.70	0.38	0.87
Downstream	Vegetated	3	-0.7	2.14	0.98	3.12	-0.90	1.60	5.10
April/May 2012 Survey									
Upstream	Unvegetated	13	-0.7	0.81	0.58	1.25	-0.34	0.70	1.51
Upstream	Vegetated	3	-0.7	0.27	0.17	0.55	-2.49	1.15	3.66
Downstream	Unvegetated	7	-0.7	1.13	0.97	2.30	-0.85	1.42	3.36
Downstream	Vegetated	8	-0.7	0.85	0.84	1.93	-0.78	1.32	3.04
August/September 2012 Survey									
Upstream	Unvegetated	3	-0.7	-0.51	0.36	1.14	-2.02	0.54	1.72
Upstream	Vegetated	11	-0.7	-1.13	0.74	1.63	-2.98	1.56	3.42
Downstream	Unvegetated	4	-0.7	-1.51	0.17	0.47	-2.96	1.15	3.19
Downstream	Vegetated	12	-0.7	-0.94	0.46	1.00	-2.58	0.93	2.04
April 2013 Survey									
Upstream	Unvegetated	8	-0.7	-0.18	0.40	0.93	-1.23	1.04	2.40
Upstream	Vegetated	9	-0.7	-0.33	0.42	0.95	-2.37	1.23	2.79
Downstream	Unvegetated	4	-0.7	-1.02	0.72	1.99	-2.55	1.50	4.17
Downstream	Vegetated	14	-0.7	-1.11	0.84	1.81	-2.70	1.19	2.55
Downstream	Constructed	8	-0.7	-2.20	0.99	2.28	-2.69	0.88	2.03
May 2013 Survey									
Upstream	Unvegetated	8	-0.7	0.66	0.51	1.17	-0.37	1.05	2.42
Upstream	Vegetated	9	-0.7	0.54	0.46	1.03	-1.52	1.34	3.04
Downstream	Unvegetated	1	-0.7	0.69			-0.99		
Downstream	Vegetated	13	-0.7	0.83	0.60	1.29	-0.85	1.04	2.25
Downstream	Constructed	8	-0.7	-0.29	0.62	1.43	-0.77	0.67	1.54
August/September 2013 Survey									
Upstream	Unvegetated	0	-0.7	0.00	0.00		0.00	0.00	
Upstream	Vegetated	15	-0.7	-0.48	0.47	1.00	-2.05	1.46	3.12
Downstream	Unvegetated	0	-0.7						
Downstream	Vegetated	16	-0.7	-2.36	1.22	2.58	-2.36	1.22	2.58
Downstream	Constructed	8	-0.7	-1.66	0.55	1.28	-2.12	0.68	1.56

*See Table 6.2.

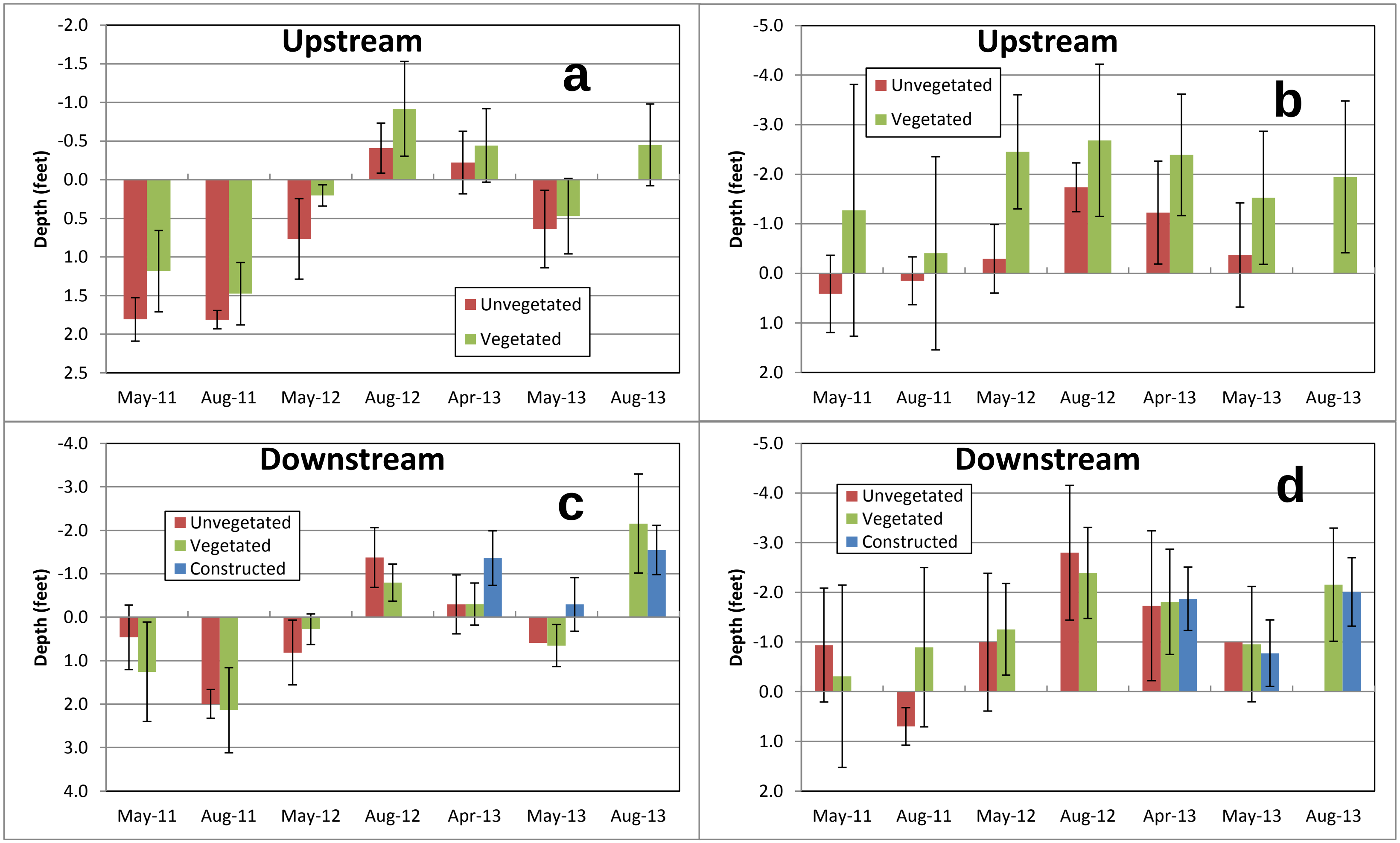


Figure 6.5. Average depth of the median and maximum sand bars elevations below the preceding maximum water-surface: (a) upstream, median bar elevation, (b) upstream, maximum bar elevation, (c) downstream, median bar elevation, (d) downstream, maximum bar elevation. (Negative values mean the indicated elevation is above the maximum waster surface.)

As discussed above, the changes that occurred between the Elm Creek Bridge and the KDS during the sustained high flows in June 2011 are generally consistent with the findings of Crowley (1981) in that all but one of the unvegetated bars (Bar 11) increased in height (Figure 2.19b), and as noted above, most were within 1 foot of the maximum water surface. The tops of all of the unvegetated bars that were completely overtopped in the downstream portion of the reach away from the direct effects of the KDS were also within 1 foot of the maximum water-surface, but the heights of the three bars in the downstream 0.6 miles of the reach decreased in response to the flows. The reason for the decrease is not clear, but it could be related to loosening and increased erodibility of the surface layer by the vegetation disking that occurred the previous fall. Why this process did not occur in the reach upstream from the KDS is also unclear.

The tops of majority of the bars that were present in April and May 2013 were above the maximum water-surface during the April 2013 SDMF. The maximum elevation of the only bar that was present during both surveys that was completely overtopped (April Bar 6/May Bar 7, **Figure 6.6a**) increased in elevation by about 0.6 feet. This particular bar is the remnant of a much larger bar that formed during the Summer 2011 high flow, and then dissected during the high, recessional flows that occurred during Winter 2011/2012 (**Figure 6.6b**). The upstream end of the bar was relatively low prior to the April 2013 SDMF, and this area appears to have built up during the SDMF due to deposition from local scour in the higher velocity area just upstream (**Figure 6.6c**). The building that occurred during the SDMF at this location is a distinctly different process from that described by Crowley (1981), in which the top surface of migrating bars build to near the water-surface as they evolve. In short, the limited magnitude and duration of the April 2013 SDMF provides very limited, if any, information about the response of the top-of-bar elevations to high flows.

6.2.4 Effect of Sediment Balance on Sandbar Height and Size

Based on average end-area calculations from the repeat surveys of the 22 monumented cross sections, the portion of the study reach upstream from the KDS degraded by about 57,000 tons and the downstream part of the reach aggraded by about 3,200 tons over the 27-month period encompassed by the surveys (**Figure 6.7**[17]). The most significant degradation in the upstream part of the reach occurred during Summer 2011 (~22,000 tons) and Winter 2012-2013 (~54,000 tons). The majority of the degradation during Summer 2011 occurred at XS1, just downstream from the Elm Creek Bridge and at XS8, about 3,000 feet upstream from the KDS (Figures 2.9 and 2.11). Most of the degradation during Winter 2012-2013 occurred at XS8 and XS9, 2,000 to 3,000 feet upstream from the KDS, respectively. The river narrows significantly between XS8 and the KDS; thus, the degradation in this area during the very high-flow period in Summer 2011 probably results from contraction scour through the constricted area. During Winter 2012-2013, flows in the range of 1,500 cfs associated with hydropower releases from the J-2 Return regularly passed through the reach. Since diversions into the Kearney Canal were not being made during this period, it is assumed that the majority of the flows passed through the radial gates at the KDS, which would tend to draw the water surface down due to the lower invert elevation, at least at low to moderate flows, inducing upstream incision and transfer of sediment through the KDS into the downstream reach. Although the portion of the reach downstream from the KDS experienced overall net degradation during Winter 2012-2013, about 10.3 ac-ft (~22,000 tons) of aggradation occurred in the vicinity of XS10 that is located just downstream from the KDS (Figure 2.9), more than half the volume of material eroded from the vicinity of XS8 and XS9. About 53,000 tons of sediment was deposited in the portion of the study reach downstream from the KDS during the April 2013 SDMF. During this period, about 9,000 tons of sediment was removed from the vicinity of XS10.

[17]To convert from ac-ft (Figure 2.10) to tons (Figure 6.7), multiply by 2,178.

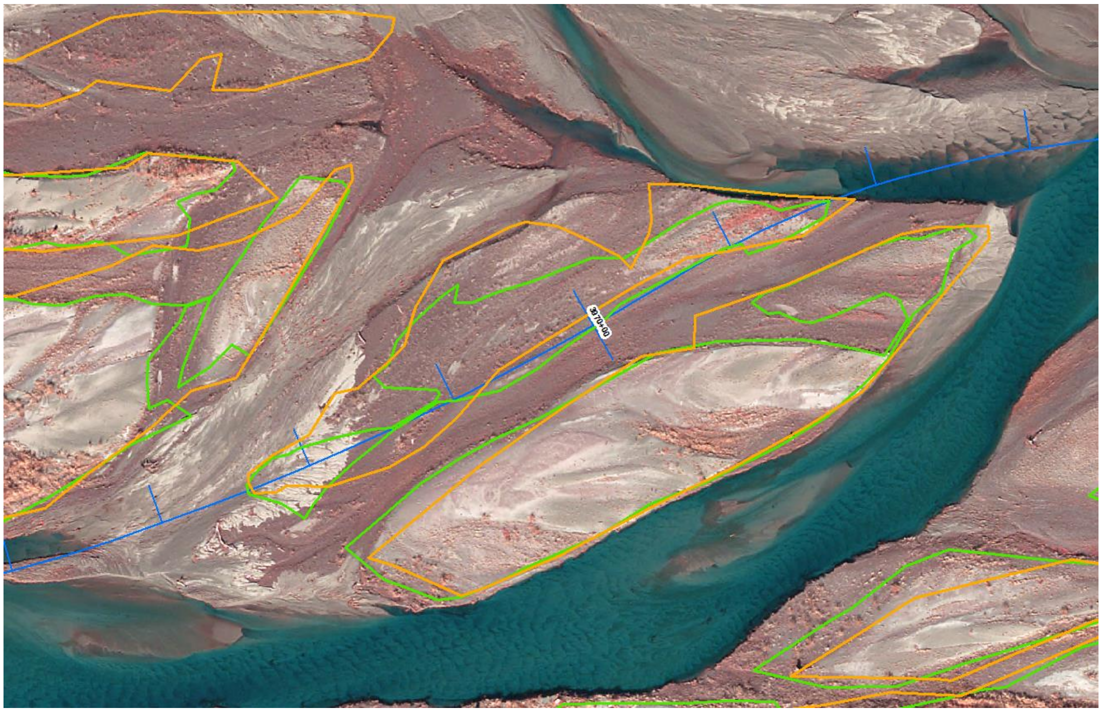


Figure 6.6a. 1,200-cfs perimeters of April 2013 Bar 6 (green line) and May 2013 Bar 7 (orange line). The head of the bar between ~Sta 3971+00 and Sta 3972+30 built up during the April 2013 SDMR. Note deposition along the edge at the head of the bar in the November 2012 aerial photo.

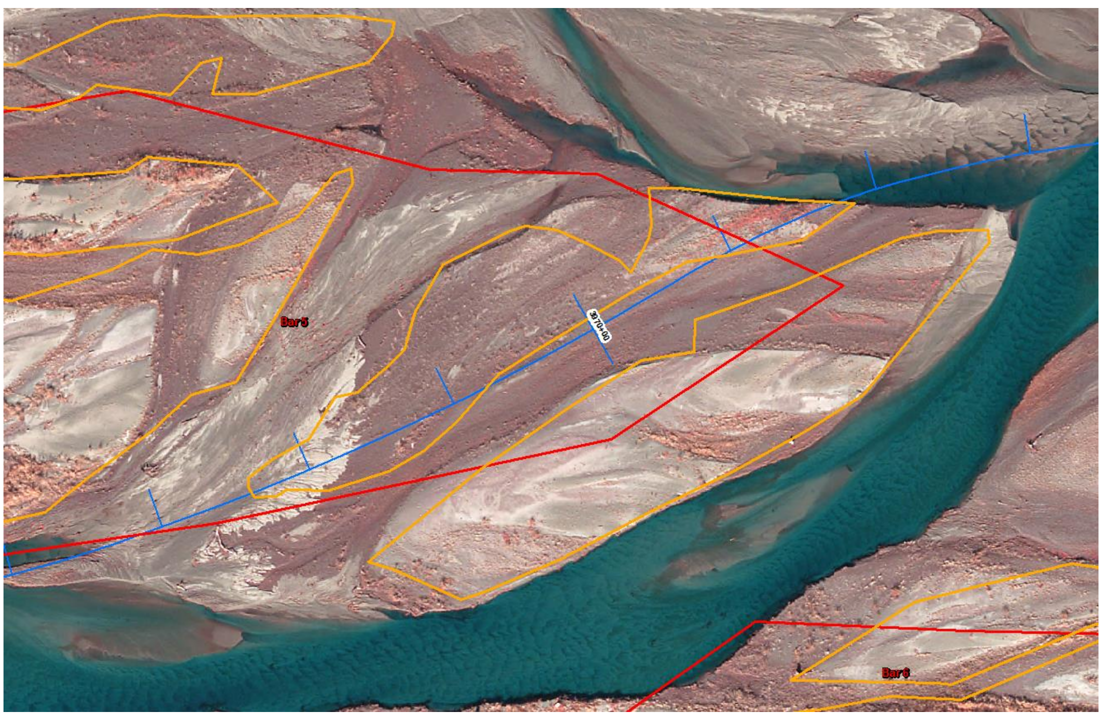


Figure 6.6b. 1,200 cfs perimeter of August 2011 Bar 5 (red line) and May 2013 Bar 7 (orange line). This bar was not present during the May 2011 survey.

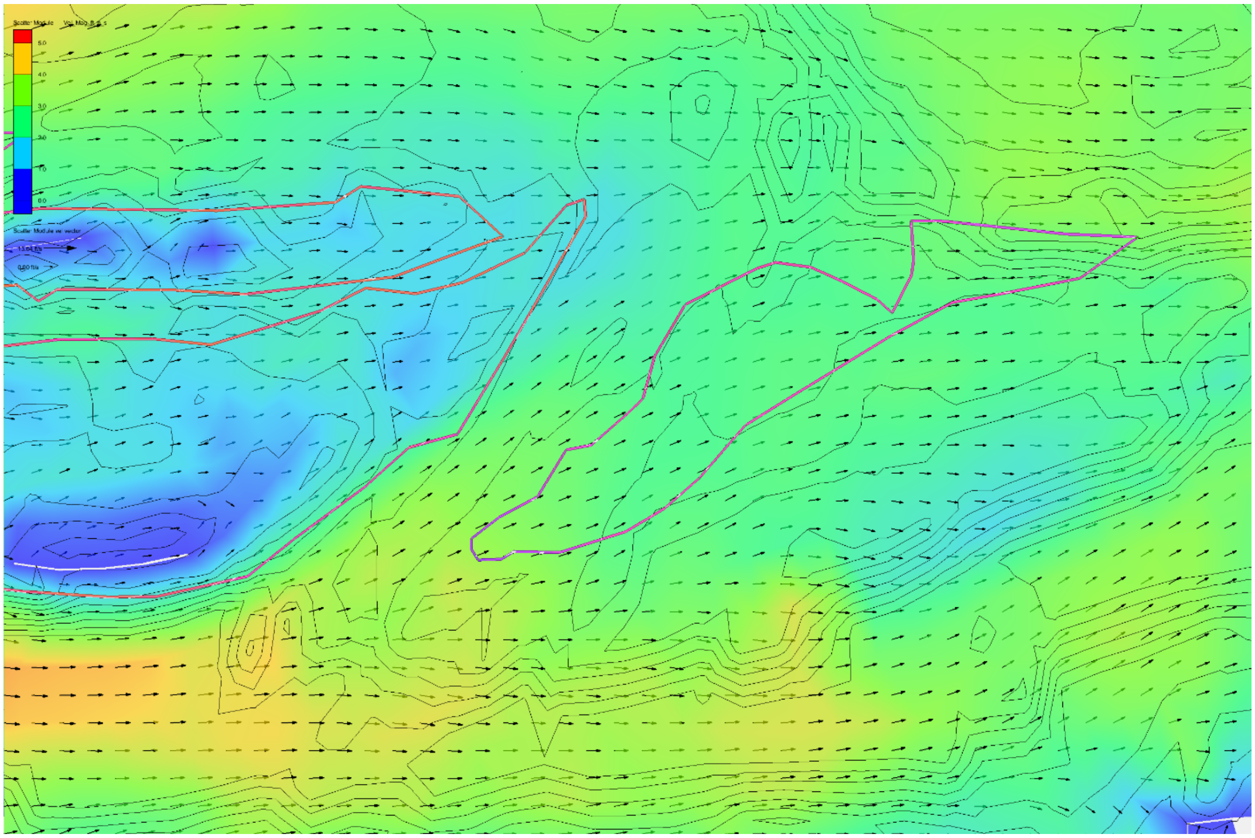


Figure 6.6c. Velocity patterns in the vicinity of May 2013 Bar 7 at 4,640 cfs (the estimated maximum flow in the reach during the April 2013 SDMF) showing the high velocity scour area (yellow to red shading) just upstream from the head of May Bar 7.

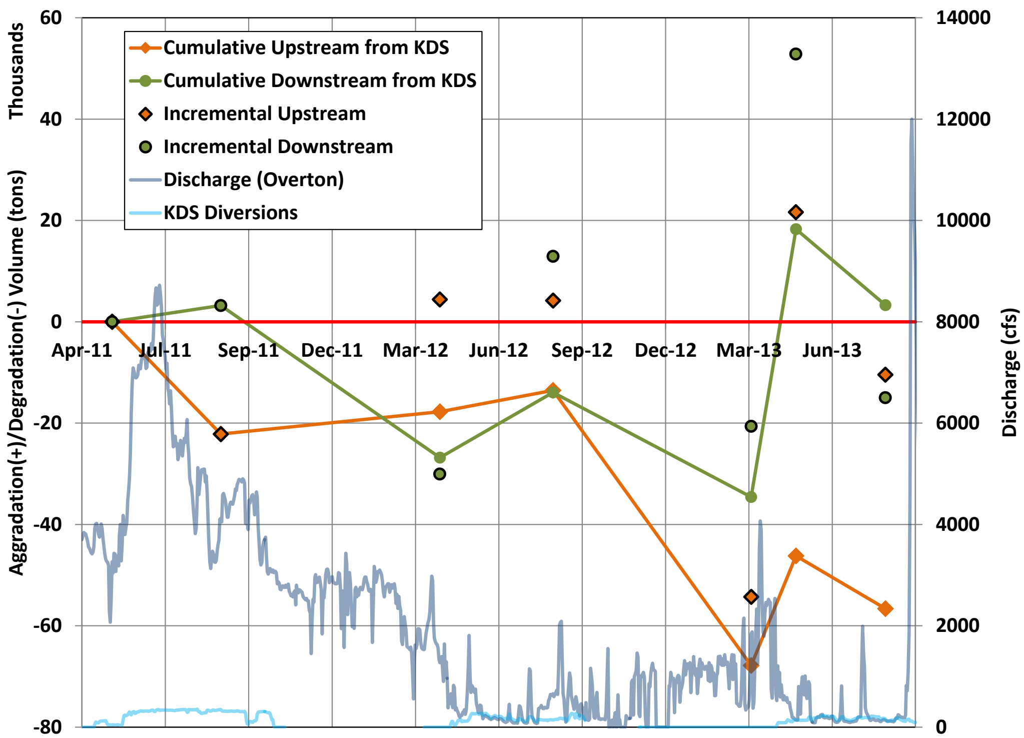


Figure 6.7. Change in bed sediment volume at the Elm Creek Complex from the May 2011 baseline survey based on average end-area calculations for each of the six subsequent surveys (- indicates degradation, + indicates aggradation).

As noted in Section 6.2.2, the only statistically significant change in median or maximum bar height in the upstream part of the reach was the increase in median height from 0.4 feet in May 2011 to about 1.1 feet in May 2012. The reach was net degradational during this period; thus, it appears that the changes in height primarily resulted from the effects of the high flows depositing material on the bar tops while eroding material from the higher-velocity chute channels between the bars. Examination of the individual bars indicates that the increases in height primarily occurred along the left bank just downstream from the Elm Creek Bridge and the small, relatively low-elevation mid-channel bar between Cross Sections 6 and 7. Building of the bars along the left bank below the Elm Creek Bridge is probably related to flow expansion through the bridge.

As also noted in Section 6.2.2, the decrease in median bar height downstream from the KDS from 2.3 feet in May 2011 to 1 foot in August 2011 and 0.8 feet in April 2013 was statistically significant, as was the decrease in maximum bar height from 3.7 feet in May 2011 to 2.1 feet in May 2012 and 2.3 feet in April 2013. The May to August 2011 change occurred when the reach was slightly aggradational. Examination of the individual bars indicates that both the median and 90th percentile heights decreased in this part of the reach during the period, while the average bed elevation in the middle portion of the reach (Cross Sections 12 to 18) actually increased (Figure 2.11). Field observations and the comparative cross sections indicate that the topographic variability across the channel decreased during the high flows that occurred in Summer 2011, with the bars and macro-forms becoming generally flatter and the braid channels somewhat shallower. During the intervening lower flow periods, the braid channels tended to consolidate and deepen. This can be clearly seen by contrasting the photo in **Figure 6.8a** that was taken on September 25, 2011, when the discharge in the river was about 3,000 cfs after a

Figure 6.8a. Aerial photo of downstream part of the ECC study reach taken on September 25, 2011 when the discharge was about 3,000 cfs.

Figure 6.8b. Aerial photo of downstream part of the ECC study reach taken on July 23, 2013, when the discharge was about 100 cfs.

long period of substantially higher flows with **Figure 6.8b**, taken on July 23, 2013, when the discharge in the reach was about 100 cfs.

In general, the data from the portion of the reach downstream from the KDS suggest that the bars may diminish in height and consolidate, with an overall tendency for smoothing of the bed topography, during high flows under certain conditions that include approximate sediment balance (i.e., Summer 2011 downstream from KDS), while the bar heights may actually increase when there is an overall sediment deficit because sediment deposits on the tops of the bars while the intervening lower flow chutes tend to deepen and consolidate.

Although both obviously involve entrainment and deposition of sediment, the conditions for sand bar evolution in the Elm Creek Reach are somewhat different from those described by Crowley (1981) for the Platte River below Grand Island. The majority of the sand bars in the Elm Creek reach can be directly associated with local hydraulic conditions and hydraulic controls (i.e., the Elm Creek Bridge, the KDS, local contractions and expansions in the erosion-resistant banklines. As a result, these features tend to build and erode in essentially the same location. Comparison of the bar locations between surveys shows little or no evidence of progressive downstream migration. In contrast, Crowley (1981) focused primarily on migrating macroforms associated with riverine bedform processes that were not tied directly to external hydraulic or erosion controls. As a result, it is not surprising that the behavior of the bars in the Elm Creek reach is somewhat different.

Hypothesis Flow #3: *Increasing $Q_{1.5}$ with Program flows will increase local boundary shear stress and frequency of inundation at the existing green line (elevation at which riparian vegetation can establish). These changes will increase riparian plant mortality along margins of the channel, raising the elevation of the green line, providing more exposed sandbar area and a wider, unvegetated main channel.*

6.2.5 Green-line Elevation Relative to Stage at Maximum Flow Event, Depth Scour Thresholds, and Inundation Effects on Unvegatated Channel Widths

As discussed in Section 5.3.1, the relative heights of the greenline points was relatively consistent during the first three surveys when high flows persisted through the reach, and they then declined by 2 feet to 2.5 feet during the subsequent low-flow periods (Figure 5.3). The maximum inundation depths during the preceding growing-season high-flows varied from survey to survey in both parts of the reach, with the greatest depths occurring during the April 2013 SDMF (Figure 5.4, **Table 6.4**). Based on these results, it is apparent that long-duration high-flows have a significant impact on the location of the greenline. Based on both the quantitative field data and observations by the field crews, the greenline tends to be defined by annual species for which continuous inundation prevents establishment rather than the perennial species that persist from growing season to growing season.

6.2.6 Channel Stage—Width Relationship

As discussed in Section 5.3, the total unvegetated channel width (i.e., width between the left- and right-most green-line points) at the surveyed cross sections was typically highest during the spring surveys, averaging the range of 800 feet during the May 2011, May 2012 and April 2013 surveys (**Table 6.5**; **Figure 6.9**). The average width declined to about 680 feet upstream from the KDS and 740 feet downstream from the KDS during the late-May 2013 survey. Due to inundation associated with the high flows that occurred between the May and August 2011

Table 6.4. Summary statistics for depths at the individual green-line points based on the difference between the water-surface elevations from the 2-D model for the preceding flow during the growing season and the surveyed elevation of each point.

Parameter	Upstream						Downstream					
	May-11	Aug-11	May-12	Aug-12	May-13	Aug-13	May-11	Aug-11	May-12	Aug-12	May-13	Aug-13
Number of Points	325	557	439	386	189	165	114	241	380	275	122	105
Mean	-0.25	0.95	-0.57	1.45	1.67	2.57	-0.42	0.91	-1.56	0.77	0.44	2.25
Minimum	-2.01	-2.10	-2.61	-1.60	0.12	-1.73	-3.05	-1.51	-2.74	0.04	0.01	1.30
Maximum	0.47	2.52	1.67	2.54	3.33	3.47	1.13	2.50	0.66	2.32	1.55	3.54
Standard deviation	0.41	0.59	0.67	0.62	0.56	0.49	0.86	0.56	0.61	0.48	0.32	0.42
Confidence Limits on Mean (95%)	0.05	0.05	0.06	0.06	0.08	0.08	0.16	0.07	0.06	0.06	0.06	0.08

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Table 6.5. Summary statistics for total unvegetated channel width up- and downstream from the Kearney Diversion Structure during the four surveys conducted in 2011 and 2012.

Parameter	Upstream							Downstream						
	May-11	Aug-11	May-12	Aug-12	Apr-13	May-13	Aug-13	May-11	Aug-11	Mar-12	Aug-12	Apr-13	May-13	Aug-13
Number of Points	9	9	9	9	9	9	9	13	13	13	13	13	13	13
Mean	782	740	836	360	827	682	383	792	729	794	485	757	743	451
Minimum	595	534	646	311	649	379	183	655	639	649	289	659	597	214
Maximum	1,111	1,031	1,047	434	1,106	1,000	743	921	979	978	768	843	824	677
Standard deviation	162	163	136	37	147	195	164	70	85	100	167	64	65	136
Confidence Limits on Mean (95%)	132	133	30	111	120	159	134	44	53	105	63	40	41	85

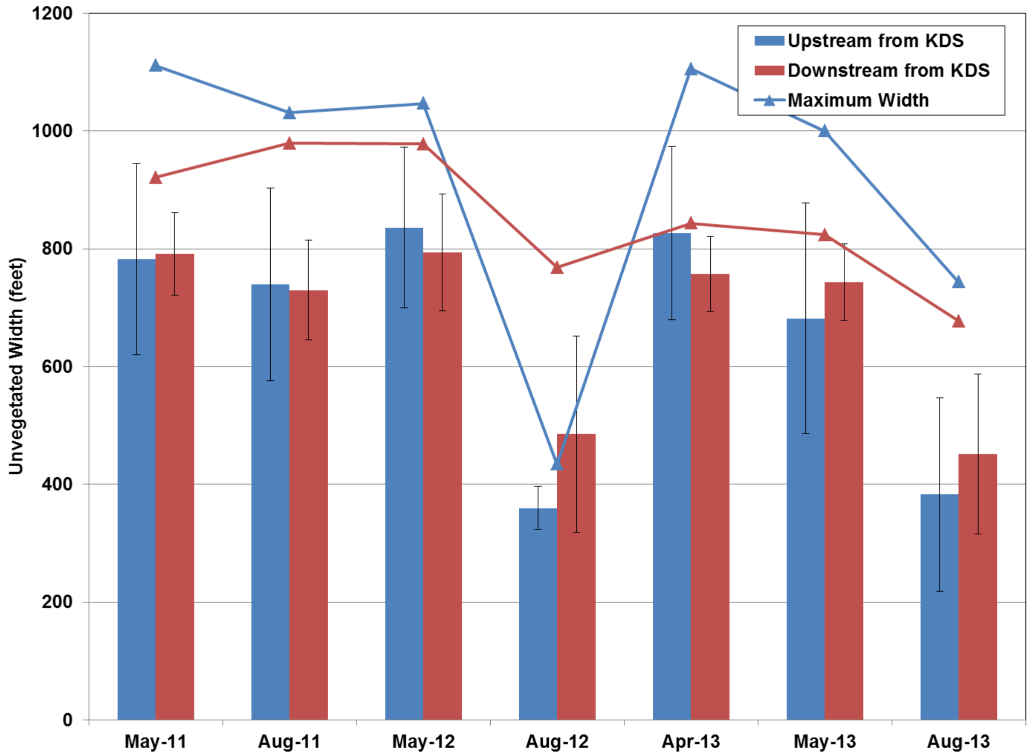

Figure 6.9. Average unvegetated channel width during each of the seven surveys. Bars are average width; whiskers are ±1 standard deviation.

surveys, the unvegetated width remained at 730 to 740 feet. The very low flows that occurred during Summer 2012 and 2013 allowed vegetation to encroach significantly into the channel, narrowing the unvegetated width to less than 400 feet in the upstream part of the reach and 450 (August 2013) to 480 feet (August 2012) in the downstream part of the reach. These results clearly indicate that inundation is effective in preventing vegetation from establishing on the lower elevation surfaces along the banks and sand bars.

Flow #5: *Increasing the magnitude and duration of the $Q_{1.5}$ will increase riparian plant mortality along the margins of the river. There will be different relations for different species.*

6.2.7 Velocity Scour Thresholds

Studies by the USDA-ARS (Pollen-Bankhead et al., 2011) showed that the average flow velocity required to remove 1- and 2-year-old cottonwood seedlings by direct drag on the individual plants is in the range of 6 to 7 fps, although their data showed this threshold to be quite variable (**Table 6.6**; **Figure 6.10**). Their studies also showed that the mean velocities required to remove phragmites and reed canary grass (46 and 17 fps, respectively) are much higher than the highest modeled velocities in the reach for flows up to 8,000 cfs.

As noted above, the majority of the plants at the surveyed greenline points were annual species that most likely have different scour thresholds than the species considered by Pollen-Bankhead et al. (2011). The data strongly suggests that inundation during the growing season is the driving factor that controls the level to which these plants establish. Inundation also likely controls the extent to which the perennial species considered by Pollen-Bankhead et al. (2011). A relevant question is whether the hydraulic energy around the margins of the bars is sufficient

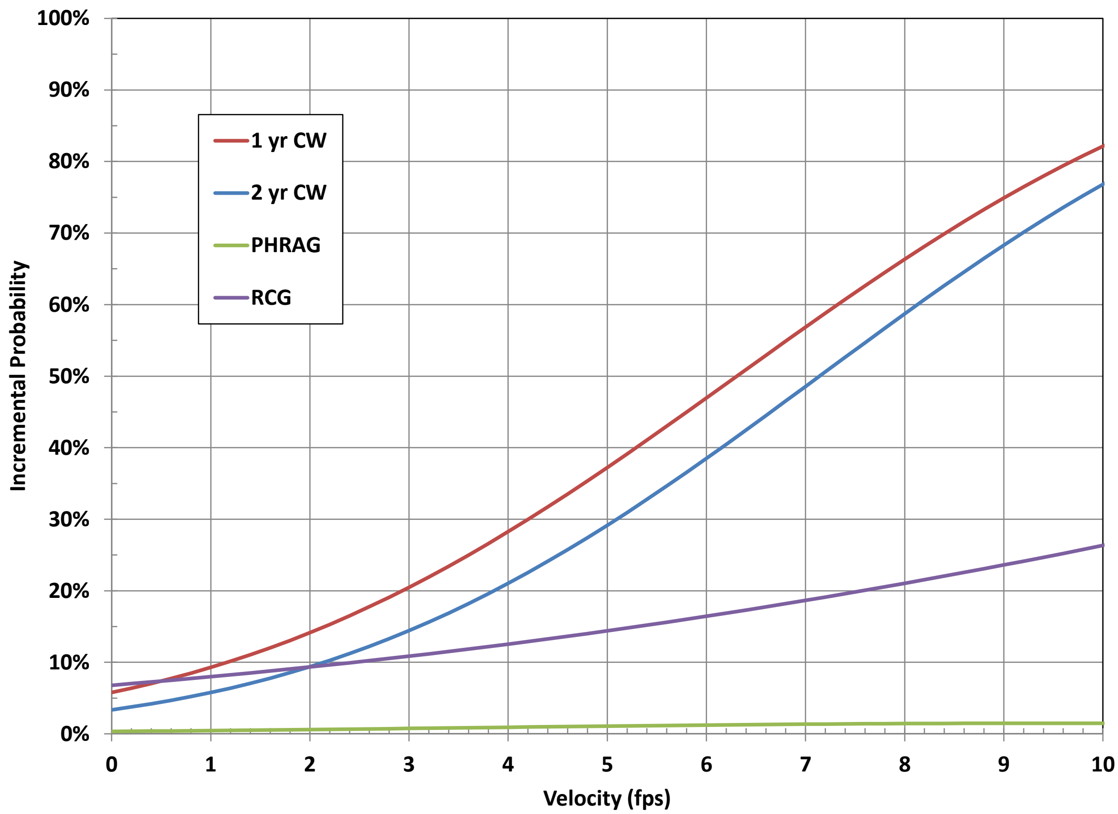

Figure 6.10. Incremental probability of plant removal for 1- and 2-year-old cottonwood (1-year CW and 2-year CW), phragmites (PHRAG) and reed canary grass (RCG) based on results from Pollen-Bankhead et al. (2011).

to scour plants of these species that establish during prior low-flow periods, and therefore, to control the elevation to which they will persist. The 2D hydraulic model results were used to assess whether there would be sufficient energy to scour pre-established plants among the species that were considered by Pollen-Bankead et al. (2011) in an effort to understand whether scour can be relied on to prevent these plants from encroaching into the channel once they become established. This question was assessed by comparing the modeled velocities in regions with depths in the range of the maximum inundation depths at the greeline points with the thresholds from Pollen-Bankhead at al. (2011). Because of the changes in topography around the margins of the sandbars between collection of the data on which the each of the 2-D models and the subsequent surveys, the predicted velocities at the individual points will not correctly represent conditions that actually occurred at that location. To overcome this limitation, depth-velocity relationships were developed from the 2-D model output for each of the maximum discharges that occurred between the surveys, and these relationships were applied to the depths below the maximum preceding water-surface elevation discussed in Section 6.2.5 to estimate the range of velocities. While this does not provide a precise estimate of the velocity at any given location, the overall distribution should represent the actual distribution that occurred in the field. Based on these estimates, the velocities at most of the greenline points were well below the lowest scour threshold of about 3.6 fps for 1-year-old cottonwood throughout the monitoring period, including the high flows in August 2011 (**Figure 6.11, Table 6.7**). The results also indicate that the maximum velocities at a small number of locations exceeded the 25 percent probability threshold for scour of 1- and 2-year-old cottonwood in both parts of the reach during the high flows in 2011 and in the downstream part of the reach during the April 2013 SDMF. It should be noted, however, that most of the vegetation at the green line points were not cottonwood; thus, the effectiveness of these flows in removing the species that were actually present is not known.

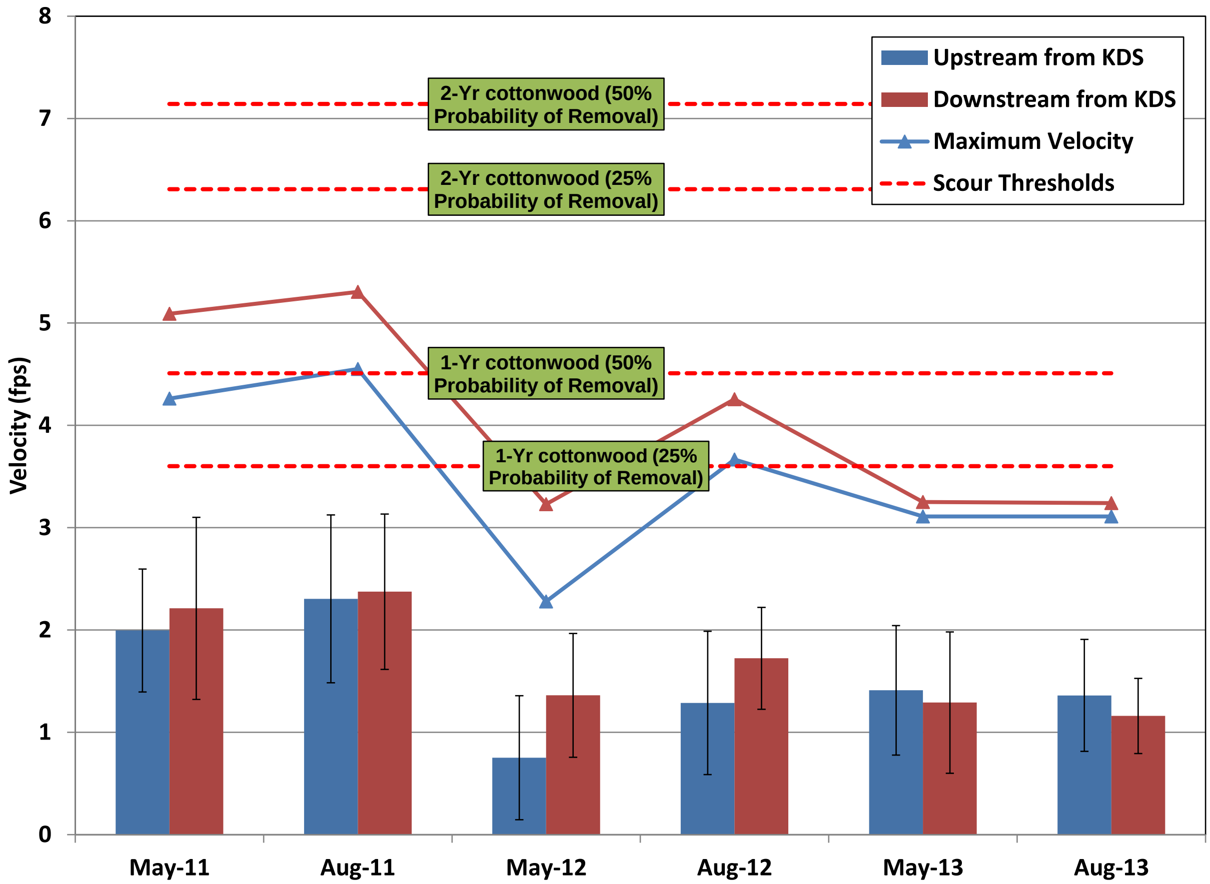

Figure 6.11. Modeled velocity at the green line points up- and downstream from the KDS during each of the monitoring surveys. Bars are average; whiskers are ±1 standard deviation of the sample population and the solid lines represent the maximum velocities. Velocity scour thresholds for 25- and 50-percent probability of scour of 1- and 2-year-old cottonwoods from Pollen-Bankhead et al. (2011) are also shown.

Table 6.7. Summary statistics for estimated velocities from 2-D model output for the preceding maximum flow*

Parameter	Upstream						Downstream					
	May-11	Aug-11	May-12	Aug-12	May-13	Aug-13	May-11	Aug-11	May-12	Aug-12	May-13	Aug-13
Number of Points	325	543	439	368	189	165	114	242	380	275	118	103
Mean	1.99	2.30	0.75	1.29	1.41	1.36	2.21	2.37	1.36	1.72	1.29	1.16
Minimum	0.00	0.00	-1.17	-0.90	0.00	0.00	0.00	0.31	0.22	0.14	0.00	0.00
Maximum	4.26	4.55	2.28	3.67	3.11	3.11	5.09	5.30	3.23	4.26	3.25	3.24
Standard deviation	0.92	0.96	0.75	0.70	0.66	0.66	1.46	0.95	0.60	0.76	0.80	0.89
Confidence Limits on Mean (95%)	0.10	0.08	0.06	0.05	0.09	0.10	0.27	0.12	0.05	0.05	0.14	0.17

*See Table 5.4

6.3 Summary and Synthesis of Experimental Results

Of the eight performance measures related to the Elm Creek FSM Adaptive Management Experiment, three were partially met based on the 2011 through 2013 monitoring data and four were not met (**Table 6.8**). The eighth could not be specifically evaluated because information on the duration of inundation necessary to exceed plant mortality thresholds is not available. In fact, the species that colonize the sand bars and riparian zone along the banklines are generally tolerant of extended inundation. While inundation prevents colonization of bare sand areas, once the plants germinate, inundation is unlikely to have a substantive effect on whether they persist. The following paragraphs describe the basis for the conclusions as to whether the benchmarks were met for each of the hypotheses listed in Table 6.1 (superscripts refer to the3 applicable paragraph).

1. The tops of many of the bars was within one foot of maximum water-surface during the long-duration, high flows in Summer 2011. However, the top of only one of the unvegetated bars in the upstream part of the reach increased in elevation during this period, and the tops of most of the bars in the downstream part of the reach actually decreased by an average of about 1.1 feet. The median and 90th percentile heights in the upstream part of the reach increased at by an average of about 0.4 feet, while both measures decreased at most of the bars in the downstream part of the reach. Except for the April 2013 SDMF, flows were very low from Summer 2012 through the end of the monitoring period in August 2013. Very few of the bars were completely overtopped during the April 2013 SDMF.

2. Average median height of unvegetated bars upstream from KDS increased from 0.4 feet to 0.8 from May 2011 to May 2012 (statistically significant) and then decreased back to ~0.6 feet by April 2013 (change not statistically significant). Mean height of upstream bar tops increased from 1.6 feet in May 2011 to ~2.4 feet in May 2012 and then decreased back to ~1.5 feet by April 2012 (change not statistically significant). Downstream from the KDS,

median bar height actually decreased from about 2.3 feet in May 2011 to 1.2 feet in May 2012. Neither median nor maximum height changed significantly in response to April 2013 SDMF in either part of the reach (Section 6.2.2).

Table 6.8. Summary of performance measure evaluation results.

Hypothesis	Performance Measure	Benchmarks		Benchmark Met?	
		Min	Target	Upstream	Downstream
Flow #1	Mean and maximum sandbar height relative to peak stage of formative flow event	-0.7’	0.0’	Partially[1]	Partially[1]
Flow #1	Mean and maximum sandbar height relative to 1,200-cfs stage for flow events of 5,000 to 8,000 cfs	1.5’	N/A	No[2]	No[2]
Flow #1	Unvegetated sandbar area exceeding height of 1.5 feet above 1,200-cfs stage per one-fourth mile of river channel	1.5 ac	N/A	No[3]	No[3]
Flow #3	Elevation of green line above 1,200-cfs stage for flow event of 5,000 to 8,000 cfs (ILT and PP nesting)	>1.5’	N/A	Partially[4]	Partially[4]
Flow #3	Unvegetated channel width following flow event of 5,000 to 8,000 cfs (WC roosting)	750’	1,125’	Partially[5]	Partially[5]
Flow #5	For flows of 5,000 to 8,000 cfs, is 90 percent of vegetation scoured in any inundated sand-bar area 1.5 feet above 1,200 cfs?	YES	N/A	No[3,4]	No[3,4]
Flow #5	For flows of 5,000 to 8,000 cfs, channel width at which 90-percent vegetation scour is achieved	750’	1,125’	Partially[5]	No[5]
Flow #5	Can sustain releases necessary to inundate 750-foot wide channel >0.25 feet deep for period exceeding inundation mortality threshold?	YES	N/A	No[6]	No[6]

The reason(s) for the different behavior between the two reaches is not clear from the available information, but it suggests that the tops of the bars in the downstream part of the reach were more erodible than those in the upstream part of the reach. Although the above discussion focuses on the unvegetated bars, the sampling data indicate that there tended to be substantially more vegetation in the upstream part of the reach than downstream during all surveys, including May and August 2011, which may have inhibited erosion in the upstream part of the reach (**Figure 6.12**). The cross section data indicate that the upstream part of the reach degraded by about 10 ac-ft during the Summer 2011 high flows, while the downstream part of the reach was approximately in sediment transport balance. The data also indicate that the variability in cross-channel topography in the upstream part of the reach did not change significantly during the high flows, but downstream part of the reach tended to become less variable. In spite of the aggradation, net sediment accumulation material occurred on the upstream bars with little filling of the chute channels between them, while a portion of the material from the bars in the downstream part of the reach eroded and re-deposited in the chute channels.

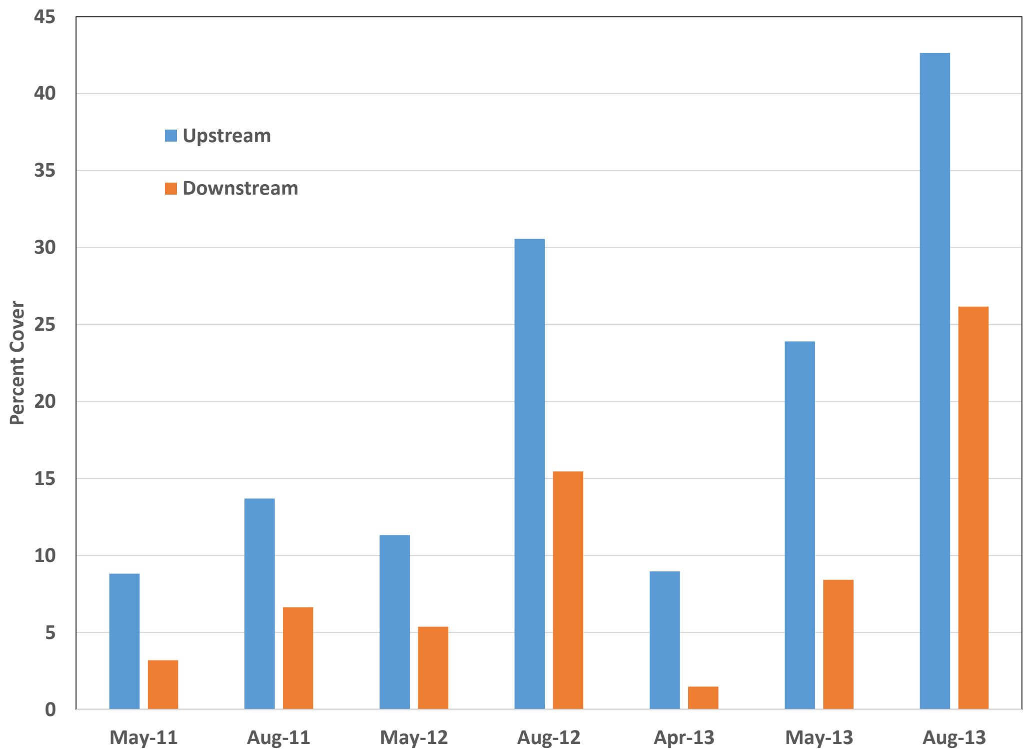

Figure 6.12. Total percent cover of the 6 key species discussed in Chapter 5.

3. The area of unconstructed bars more than 1.5 feet above the 1,200-cfs water surface upstream from KDS increased from 0.3 ac/¼-mi in May 2011 to 0.8 ac/¼-mi in May 2012, then declined back to about 0.2 ac/¼-mi by April 2013, declining even further to 0.1 in May 2013, despite the SDMF release. Downstream from KDS, unvegetated bar area decreased from 1.9 ac/¼-mi in May 2011 (due primarily to significant disking and clearing in November 2010) to ~0.4 ac/¼-mi in May 2012, despite the very high, long-duration flows in 2011, reflecting the general lowering and flattening of the bars during the sustained 2011 sustained high-flow period discussed above. Bar construction downstream from KDS beginning in Summer 2012 increased unvegetated bar area to maximum of 2.2 ac/¼-mi in April 2012, declining back to about 1.7 ac/¼-mi by August 2013 (Section 6.2.2).

4. During the 2011 surveys when flows were very high and during the May 2012 survey, the average elevation of the green line points was between 1 foot and 2 feet above the 1,200 cfs water-surface. During the dry periods from Summer 2012 through August 2013, the green-line points were mostly below the 1,200-cfs water surface. The May 2013 green line elevations were about 0.3 feet below the 1,200 cfs water-surface upstream from the KDS and at about the 1,200-cfs water surface downstream from the KDS.

5. During May 2011 and May 2012 that were preceded by long-duration, high flows, unvegetated channel widths averaged about 800 feet in both parts of the reach, and they were in the range of 730 to 740 feet even during August 2011. Maximum unvegetated channel widths during this period were in the range of 1,000 to 1,100 feet upstream from the KDS and 900 to 1,000 feet downstream from the KDS. Average unvegetated channel widths in April 2013 were also in the range of 750 to 800 feet, with maximum widths of about 1,100

feet upstream and 840 feet downstream. In spite of the April 2013 SDMF, unvegetated widths decreased by the May 2013 survey to 680 feet upstream and 740 feet downstream, with maximum widths of 1,000 feet and 800 feet, respectively. Unvegetated widths in August 2012 and 2013, after very low-flow summer periods, were only about 400 feet in both parts of the reach.

6. During the sustained high flows in 2011, flows were in the range of 7,000 cfs for over 30 days, 5,000 cfs to 5,300 cfs for over 60 days, and in the range of 4,000 cfs for over 90 days (Table 5.4). As a result, the average widths with depths greater than 0.25 were about 800 feet in both parts of the reach for durations less than 60 days, decreasing by a relatively small amount to about 750 feet for the 90-day (Figure 5.8). As a result, the greenline elevation (Figure 5.5) and unvegetated channel widths (Figure 5.7) remained about the same between the May 2011 baseline survey and the May 2012 survey. Since the bars had been cleared prior to start of the 2011 growing season, this result primarily demonstrates that inundation prevents vegetation from establishing, but it does not provide direct evidence that inundation will cause mortality for already-established plants.

   From May 2012 through the April 2013 SDMF, flows in the reach were very low. During this part of the experimental period, the greenline moved well down into the channel, causing a significant reduction in unvegetated channel width, and there were statistically significant increases in percent cover of several of the key vegetation species (Table 6.8). The average inundated width for the 30-day duration was only about 510 feet in the upstream part of the reach and about 575 feet in the downstream part of the reach in 2012, and 370 feet and 470 feet, respectively, in 2013. The average width decreased to about 300 feet in the upstream part of the reach during both years for the 60-day duration. For the 90-day duration, the average widths were in the range of 230 feet to 260 feet in the upstream part of the reach during both years, and this decreased to about 120 feet in 2012 and only about 80 feet in 2013 in the downstream part of reach. With the exception of 2011 when high sustained flows occurred, the inundated widths throughout the reach were significantly less than the 750-foot threshold throughout the monitoring period. The April 2013 SDMF occurred prior to the start of the growing season. As a result, it was not possible to clearly identify the greenline elevations during this survey. The May 2013 greeline was at about the 1,200 cfs water-surface, on average, about 0.5 feet higher than in August 2012; however, the average elevation dropped by nearly 1 foot over the summer of 2013. Based on the vegetation sampling data, there was a statistically significant increase in amount of ragweed and the amount of bare ground decreased during this part of the monitoring period. The data provide no direct evidence that the relatively short 2013 SDMF was sufficient to cause plant mortality.

The most of the bars throughout reach had been disked in Fall 2011, and very little pre-established, undisked vegetation was present during the May 2011 baseline survey. As a result, the 2011 high flows do not provide a test of whether other species can be removed by direct scour. Similarly, annual species had not germinated at the time of the April 2013 SDMF; thus, this flow also does not provide a test of the effectiveness of moderate-magnitude flows in removing other species. With the exception of a decrease in reed canary grass from August 2011 to May 2013, all of the statistically significant changes in vegetative cover during the monitoring period resulted in an increase in vegetation, and the majority of these occurred during prolonged low-flow periods (**Table 6.9**).

As discussed above, evaluation of the inundation depths and velocities from the applicable 2D model at the greenline points show that there is insufficient energy to directly scour 1- and 2-year-old cottonwood, and already-established common reed or reed canary grass. The 2D model results at the individual vegetation sampling plots were also analyzed to determine if the amount of vegetation (based on percent cover) for the six key species is correlated with the hydraulic conditions that occurred between the surveys. The parameters that were considered included the duration of inundation, the maximum depth, velocity, shear stress and unit stream power, and the total flow energy expended on the sample plot. In general, the correlation was very low, except for common reed and reed canary grass, where a substantial amount was present in August 2011 after the sustained high flows in Summer 2011 for which both the duration and hydraulic energy of the flows was relatively high (**Table 6.10**; **Figures 6.13 and 6.14**). The example for common reed in Figure 6.14 suggests positive correlation between duration the amount of vegetation present, a result that is contrary to the hypothesis. The example result in Figure 6.15 for purple loosestrife suggest essentially no correlation with maximum unit stream power.

Table 6.9. Statistically significant changes in percent cover (or bare ground). (xxx=increase, **yyy=decrease**).

	May-11	Aug-11	May-12	Aug-12	Apr-13	May-13	Aug-13
May-11				PLS, **BG**		RCG, PLS, **BG**	CW,RW, PLS, **BG**
Aug-11				RW	W	**RCG**	RW, PLS, **BG**
May-12				RW, **BG**			RW, **BG**
Aug-12							
Apr-13							
May-13							RW, **BG**
Aug-13							

CW=Cottonwood

RCG=Reed Canary Grass

RW=Ragweed

PLS=Purple Loosestrife

BG=Bare Ground

Based on the greenline results, it appears that inundation during the early part of the growing season that prevents the plants from establishing appears to be the primary factor in maintaining the elevation of the greenline, or pushing it to a higher elevation. The results further suggest that even the sustained high flows that occurred in 2011 are likely not sufficient to remove vegetation of the key species that is already established. These results further suggest that direct mechanical treatment is probably the only effective method of maintaining the desired physical attributes of the reach.

Table 6.10. Correlation coefficients (R^2) for percent cover versus duration and stream power for the six key species and the total of all six species.

Status	Willow	Cottonwood	Common Reed	Purple Loosestrife	Reed Canary Grass	Ragweed	Total All 6
	Duration (days)						
Cleared and/or Sprayed	0.24	0.08	0.73	0.02	0.19	0.06	0.02
Not Cleared or Sprayed	0.02	0.02	0.91	0.00	0.34	0.01	0.02
	Stream Power (ft-lb/s/ft^2)						
Cleared and/or Sprayed	0.24	0.07	0.74	0.02	0.21	0.07	0.03
Not Cleared or Sprayed	0.05	0.09	0.96	0.00	0.41	0.00	0.00

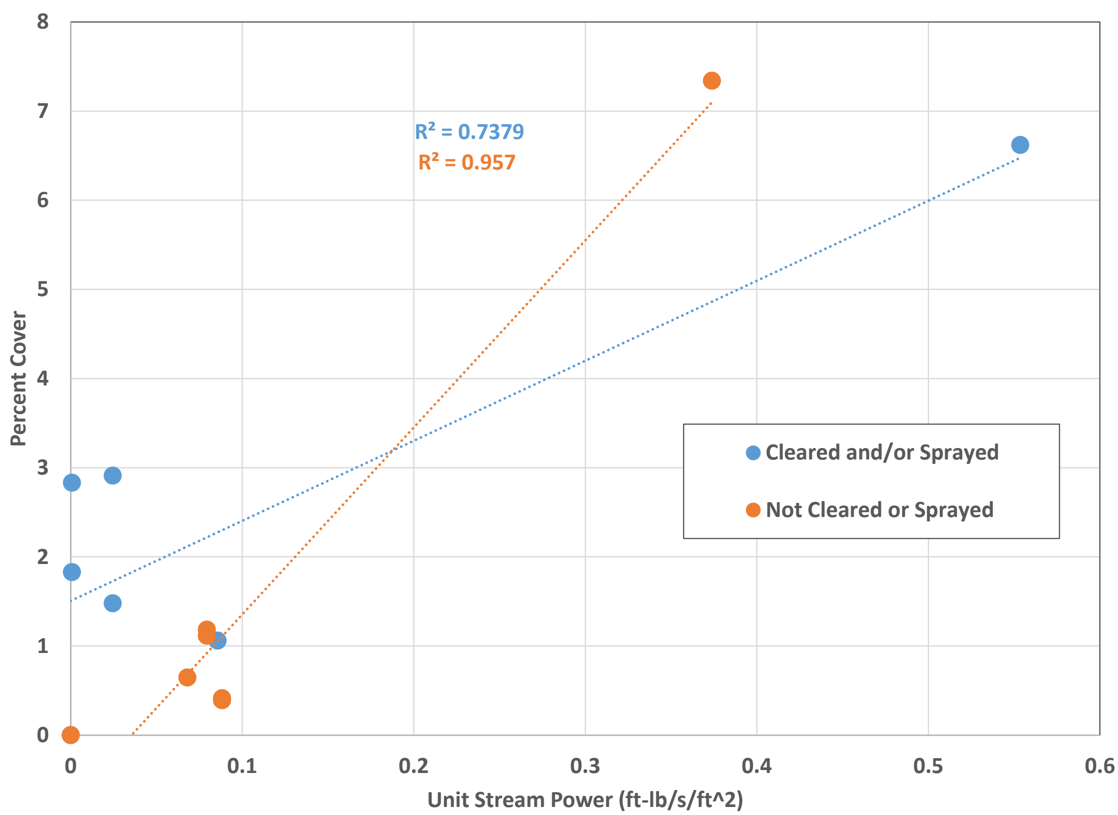

Figure 6.13. Average percent cover of common reed versus maximum unit stream power expended on the sample plots during period between surveys. Upper right points are for August 2011 after the sustained high-flow period.

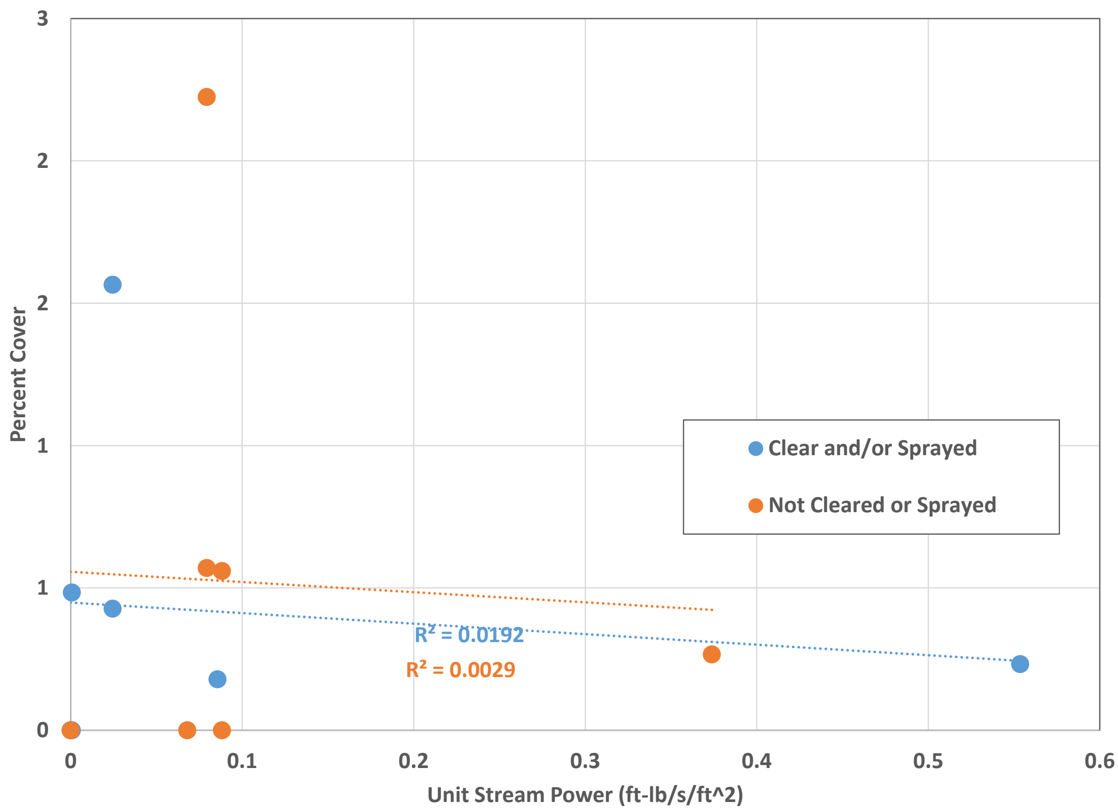

Figure 6.14. Average percent cover of purple loosestrife versus maximum unit stream power expended on the sample plots during period between surveys. Upper right points are for August 2011 after the sustained high-flow period.

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APPENDIX A

Maps Showing Location and Extent of Program-Related Management Activities that Directly Affect the Platte River in the Elm Creek Reach

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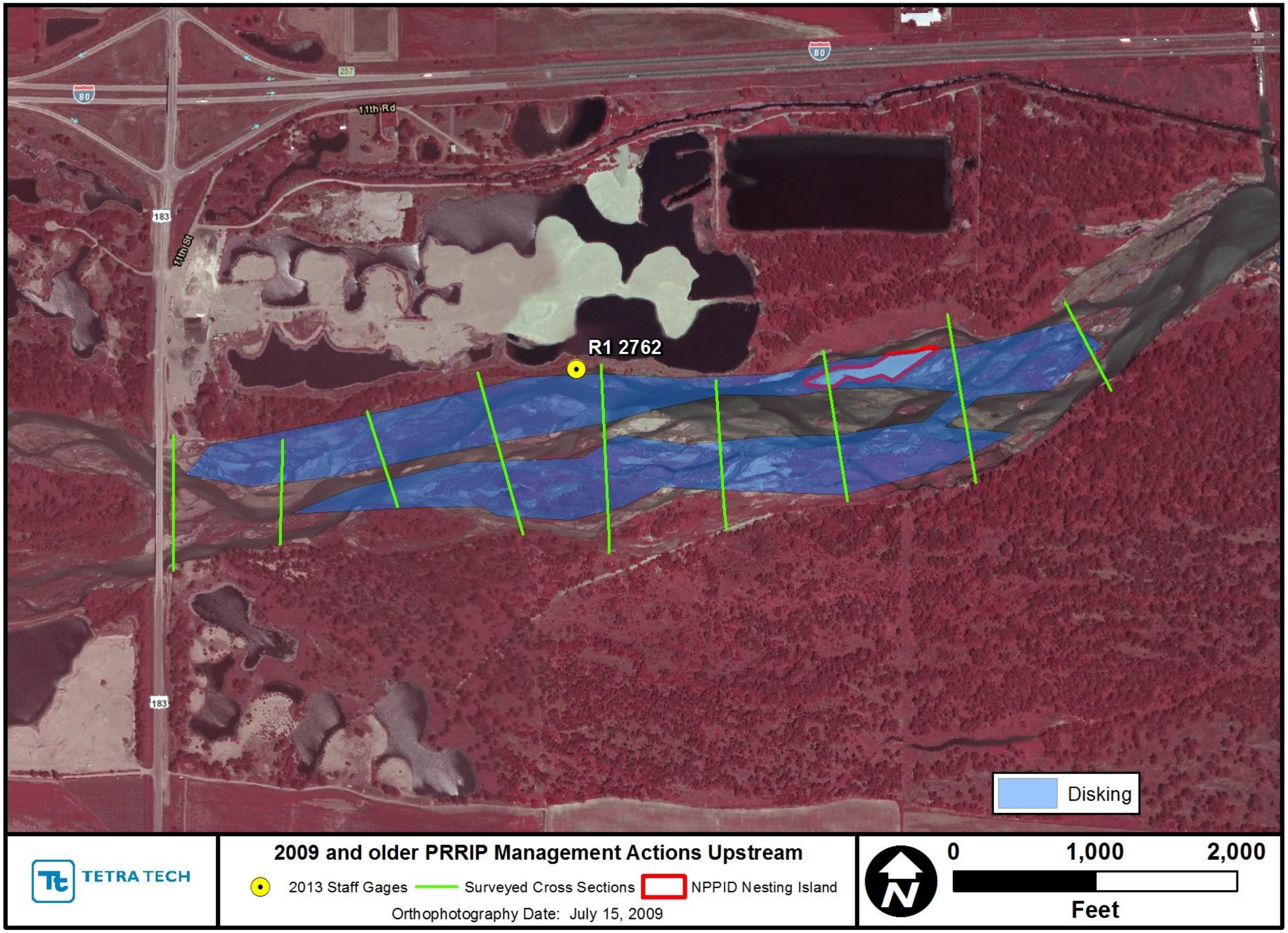
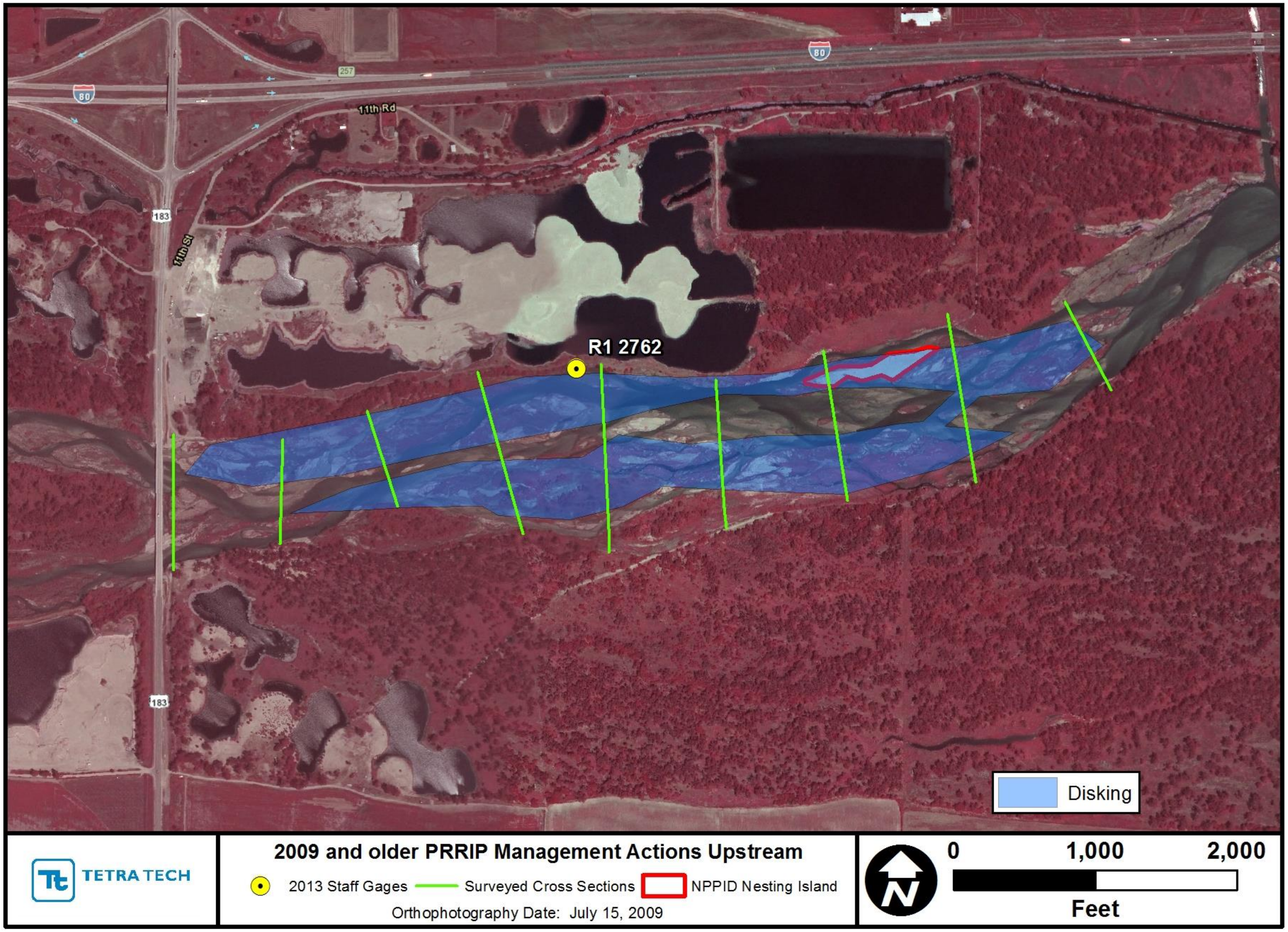
Appendix A. Maps showing location and extent of Program-related management activities that directly affect the Platte River in the Elm Creek reach.

Table A.1. Mean daily discharge at Platte River gages on the day of the aerial photographs.					
Photo Date	**Mean Daily Discharge (cfs)**				
	Overton	**Cottonwood Ranch**	**Diversion to Kearney Canal**	**Odessa**	**Kearney**
15-Jul-09	358	N/A	270	309	275
3-Sep-10	1,810	1,470	305	1,196	1,340
28-Oct-10	717	675	303	413	472
29-Nov-11	2,580	2,130	0	2,250	2,700
20-Nov-12	166	239	0	247	251

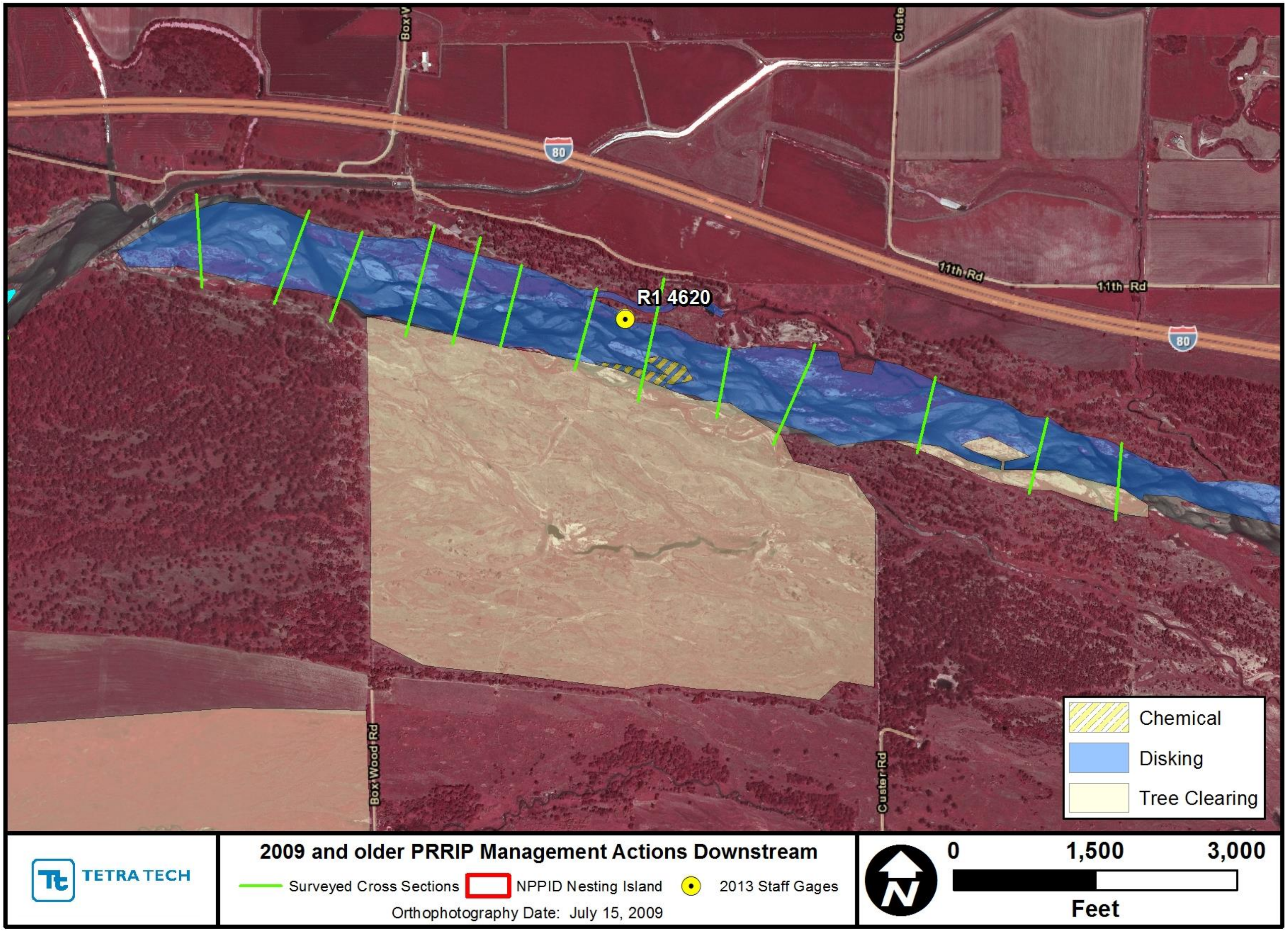
Appendix A.1a.1. Shredding and mowing upstream from KDS in 2008.
Appendix A.1a.2. Disking upstream from KDS in 2009.
Appendix A.1b. Disking downstream from KDS in 2008.
Appendix A.2a. Double disking and tree clearing upstream from KDS in 2010.
Appendix A.2b. Double disking, tree clearing, island clearing and smoothing, and herbicide spraying downstream from KDS in 2010.
Appendix A.3a. Herbicide spraying upstream from KDS in 2011.
Appendix A.3b. Herbicide spraying and grass seeding downstream from KDS in 2011.
Appendix A.4a. Disking and herbicide spraying upstream from KDS in 2012.
Appendix A.4b. Island construction, disking, prescribed fire and herbicide spraying downstream from KDS in 2012.



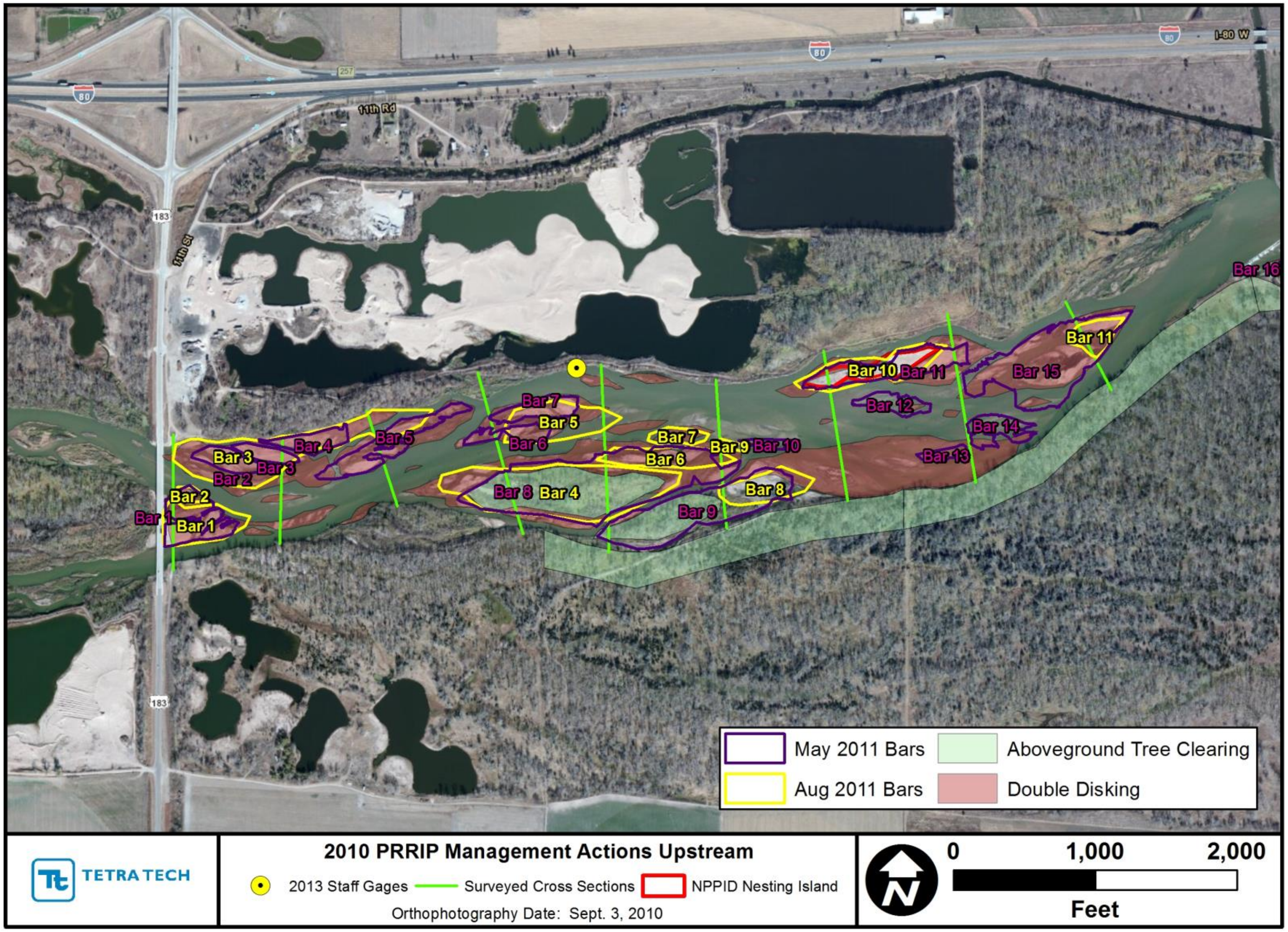
Appendix A.1a.1. Shredding and mowing upstream from KDS in 2008.



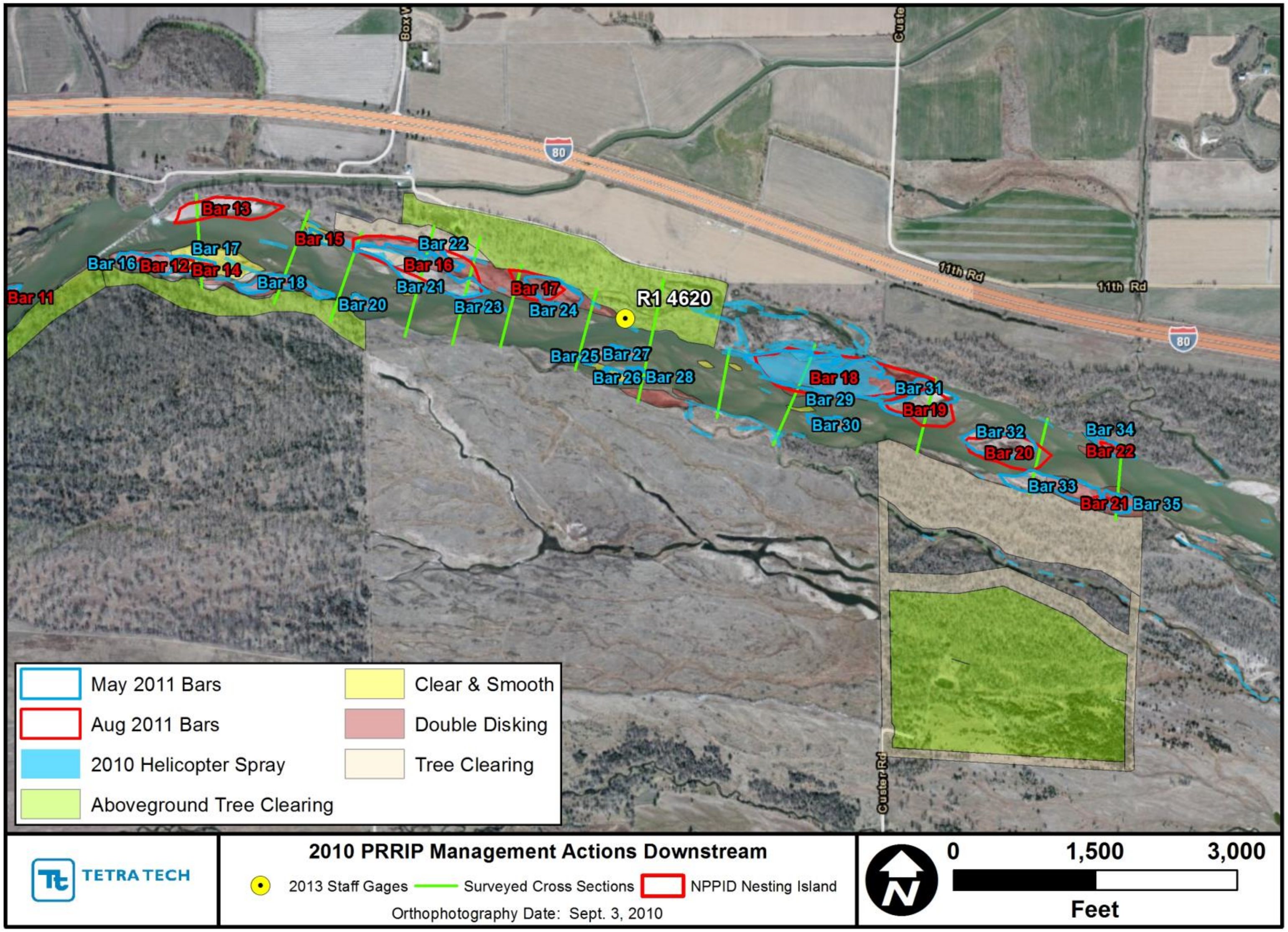
Appendix A.1a.2. Disking upstream from KDS in 2009.



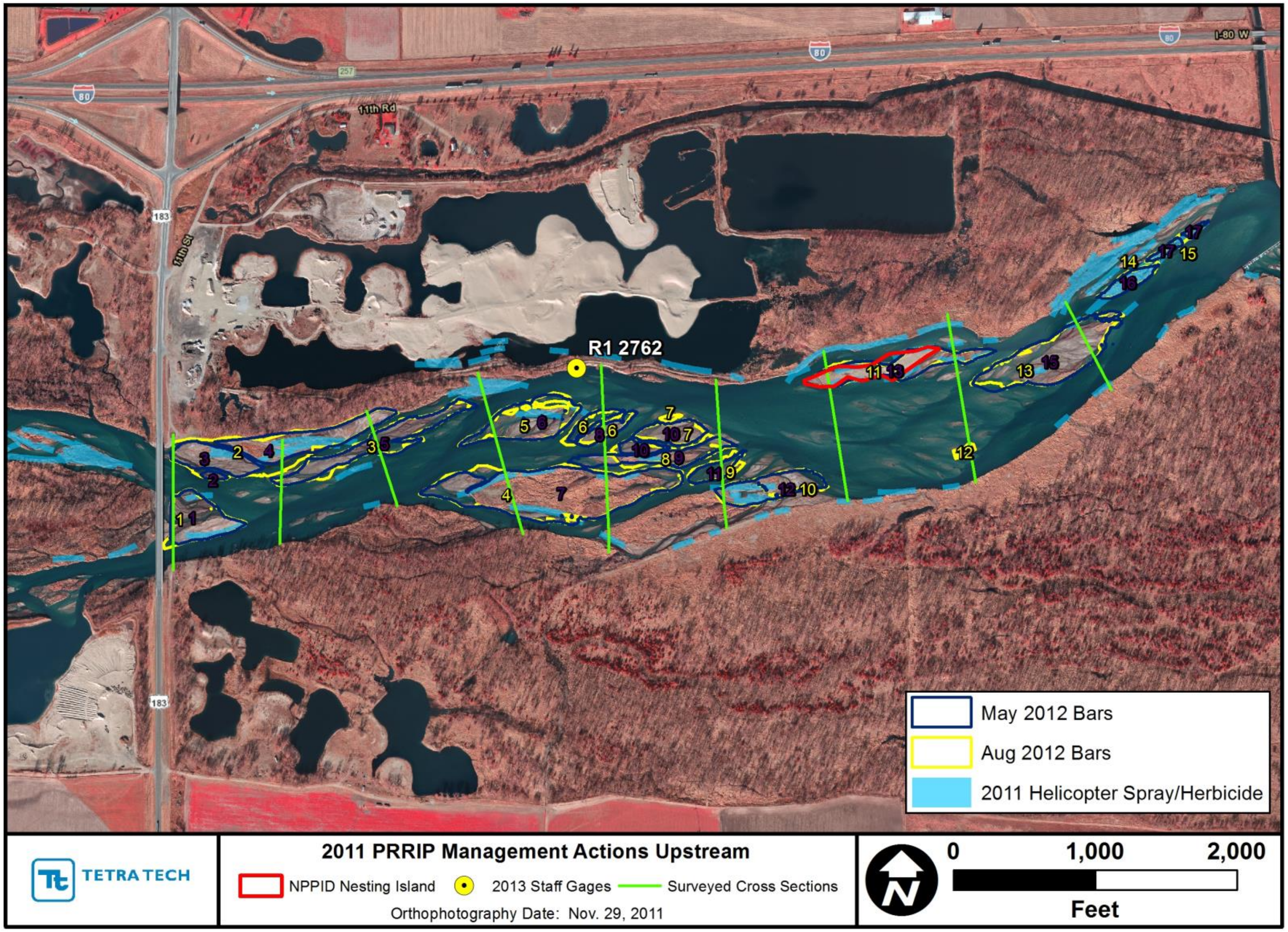
Appendix A.1b. Disking downstream from KDS in 2008.



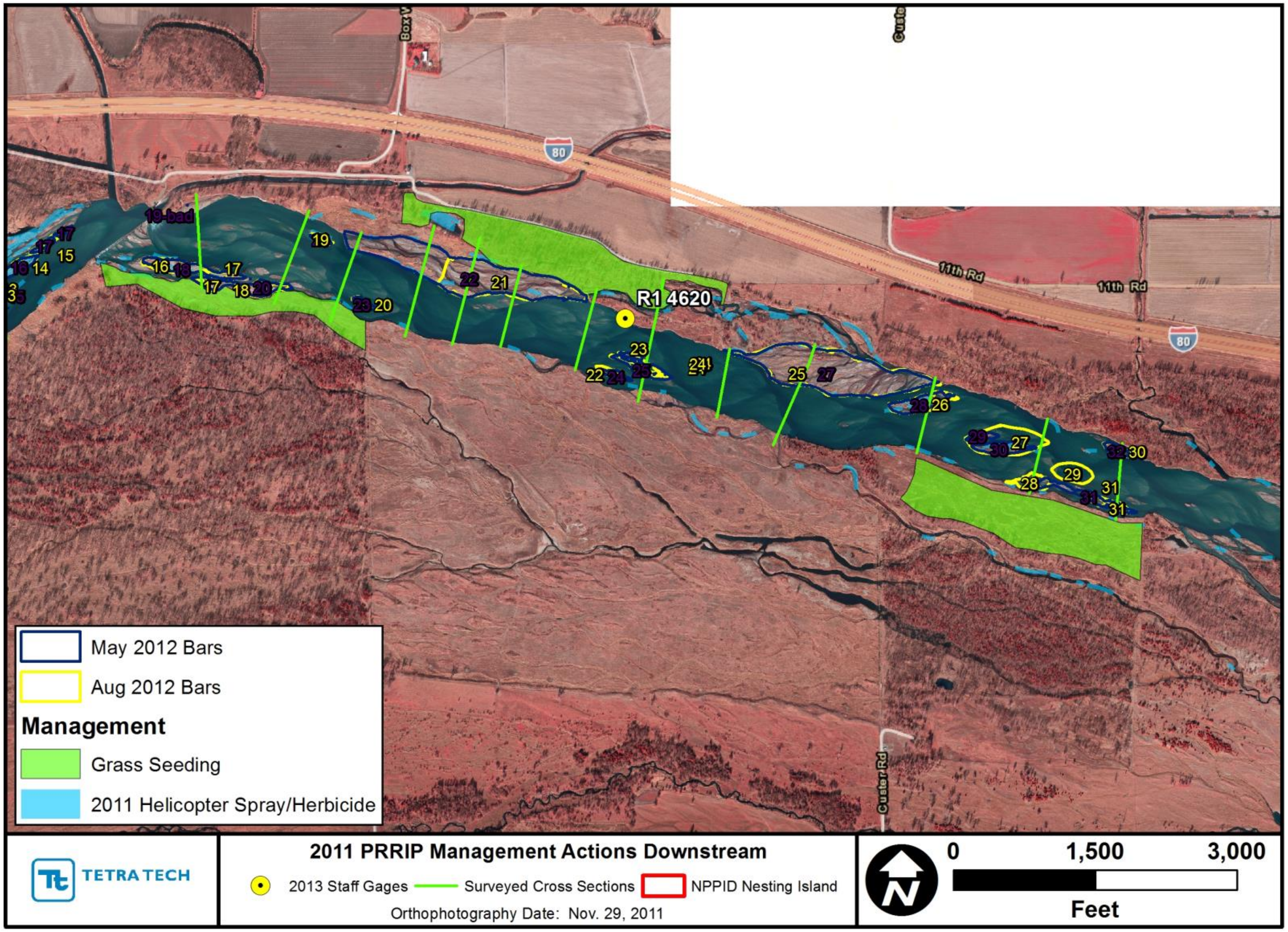
Appendix A.2a. Double disking and tree clearing upstream from KDS in 2010.



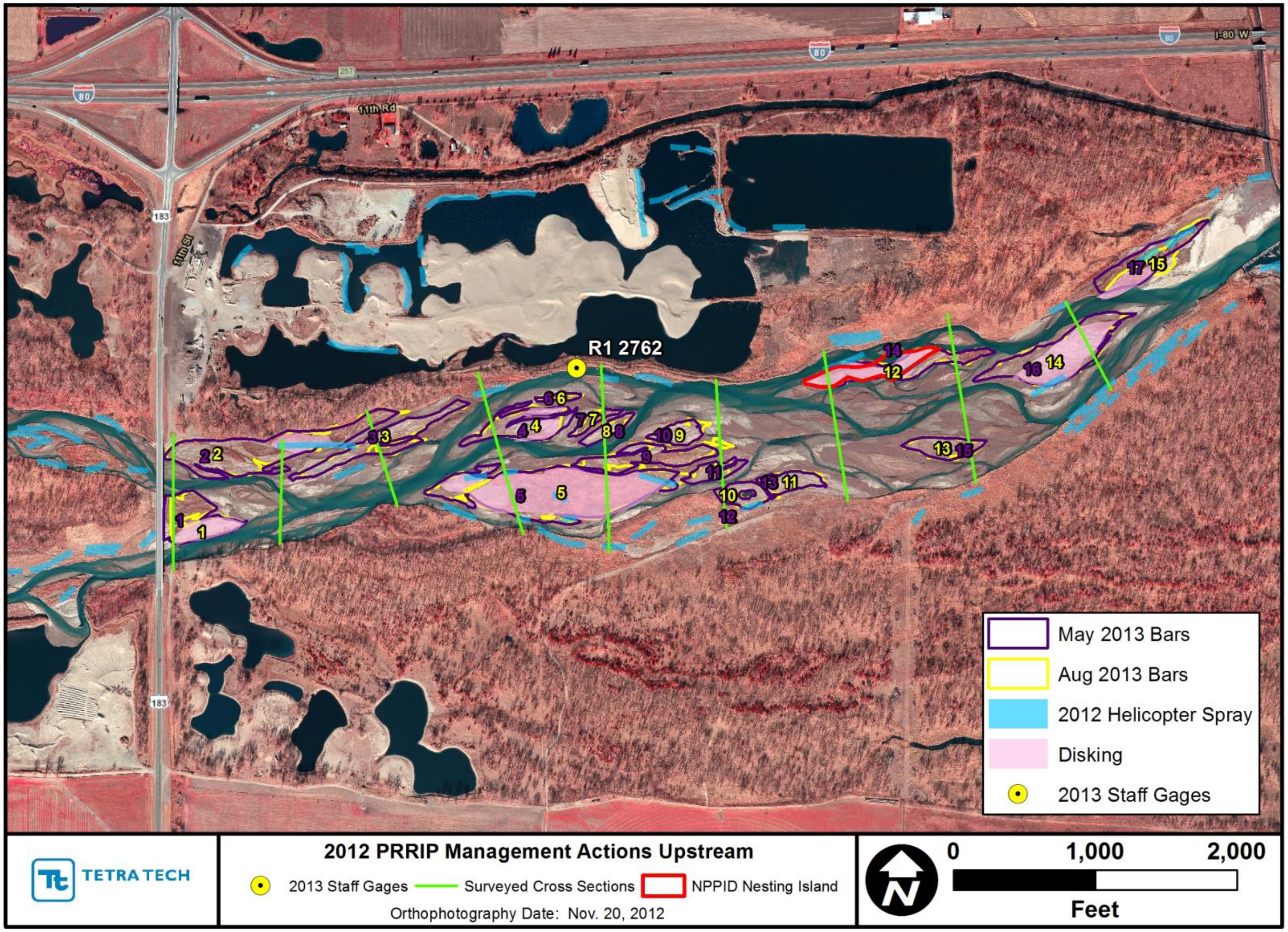
Appendix A.2b. Double disking, tree clearing, island clearing and smoothing, and herbicide spraying downstream from KDS in 2010.



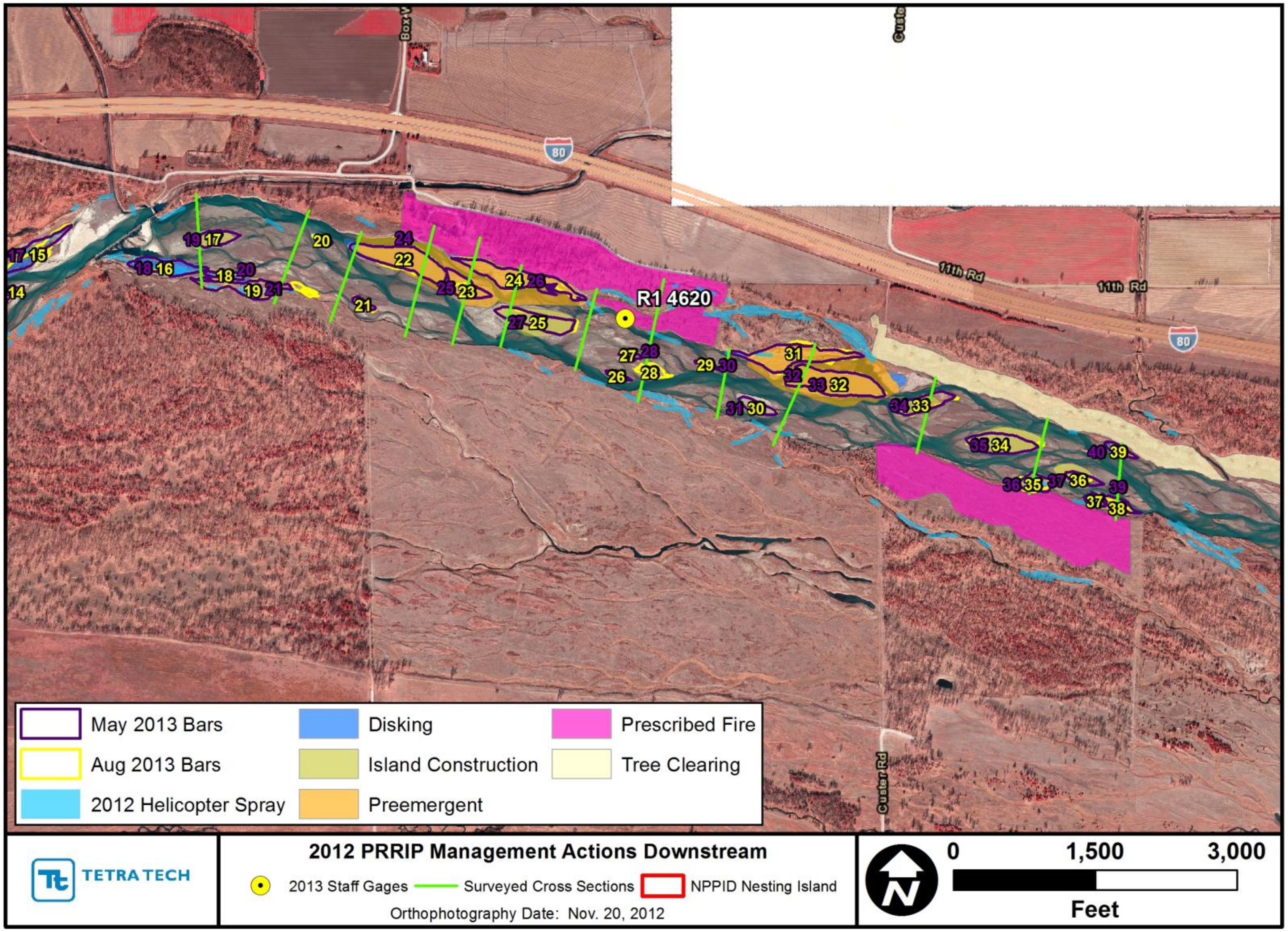
Appendix A.3a. Herbicide spraying upstream from KDS in 2011.



Appendix A.3b. Herbicide spraying and grass seeding downstream from KDS in 2011.



Appendix A.4a. Disking and herbicide spraying upstream from KDS in 2012.



Appendix A.4b. Island construction, disking, prescribed fire and herbicide spraying downstream from KDS in 2012.

APPENDIX B
Sampling and Analysis Plan

APPENDIX_B_ Project Scale Monitoring Protocol_4-22-11.pdf

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APPENDIX C
Cross-section Plots and Data

Appendix_C_Cross Section Data_All.xlsx

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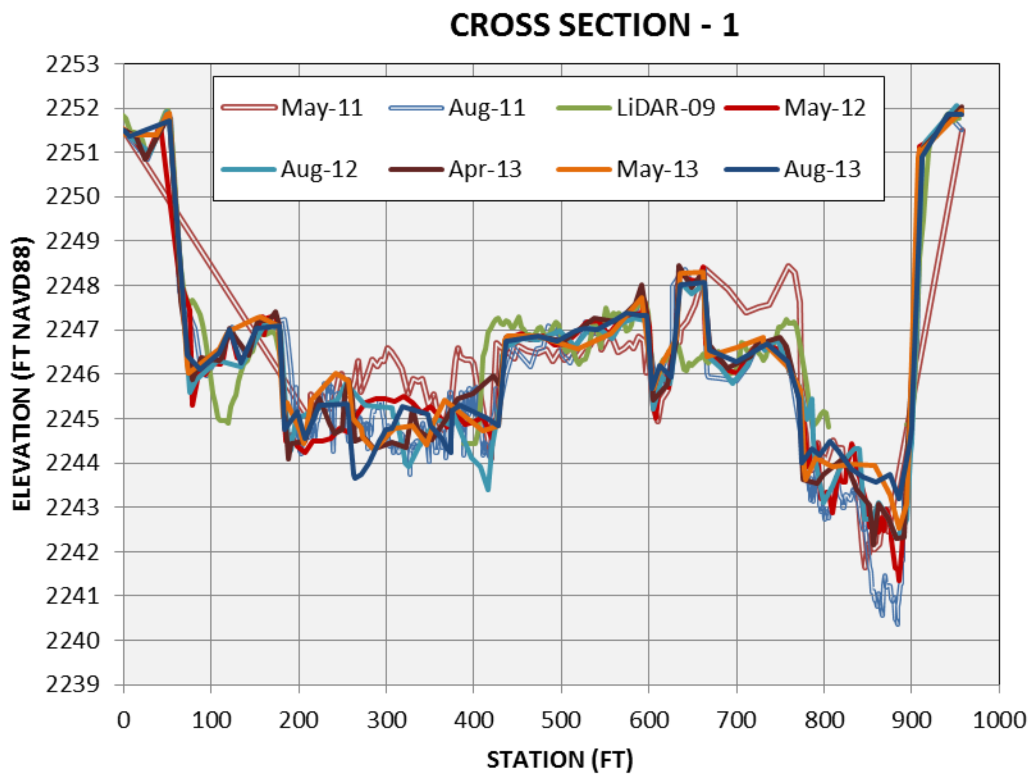
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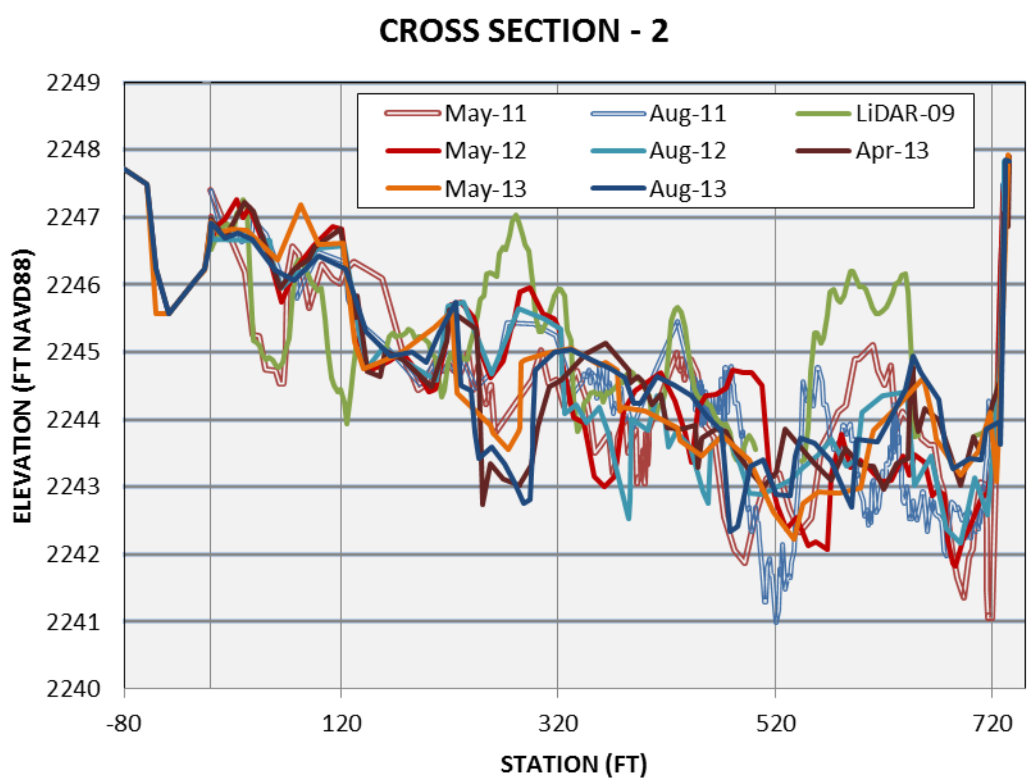
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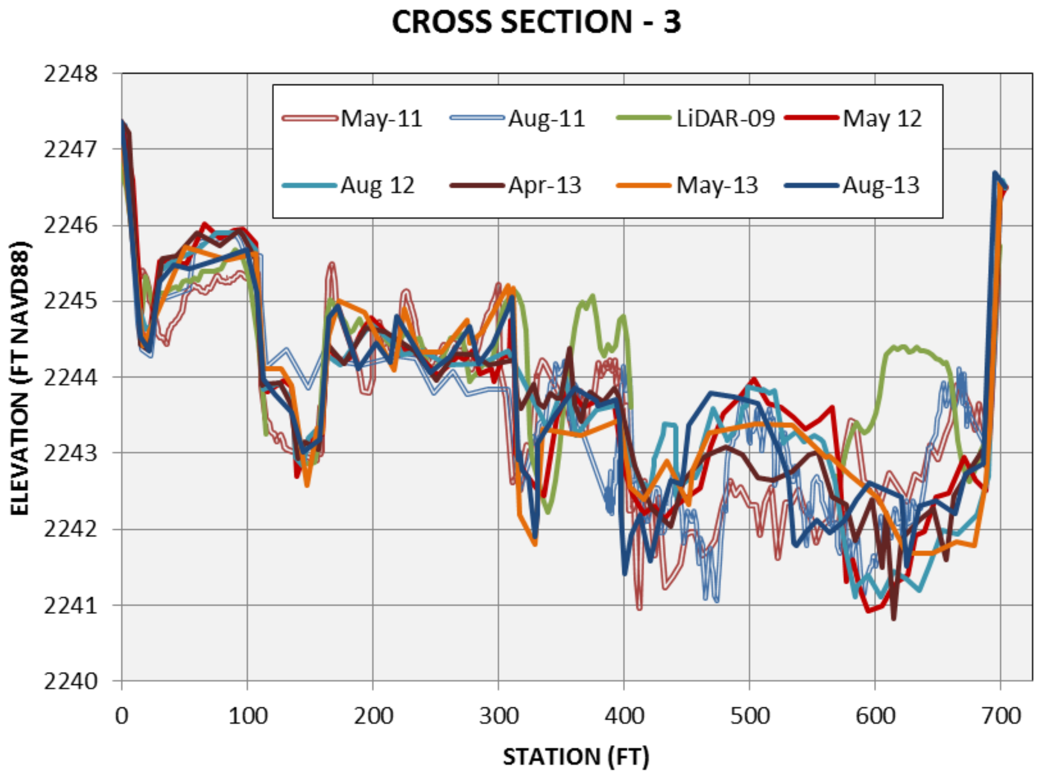
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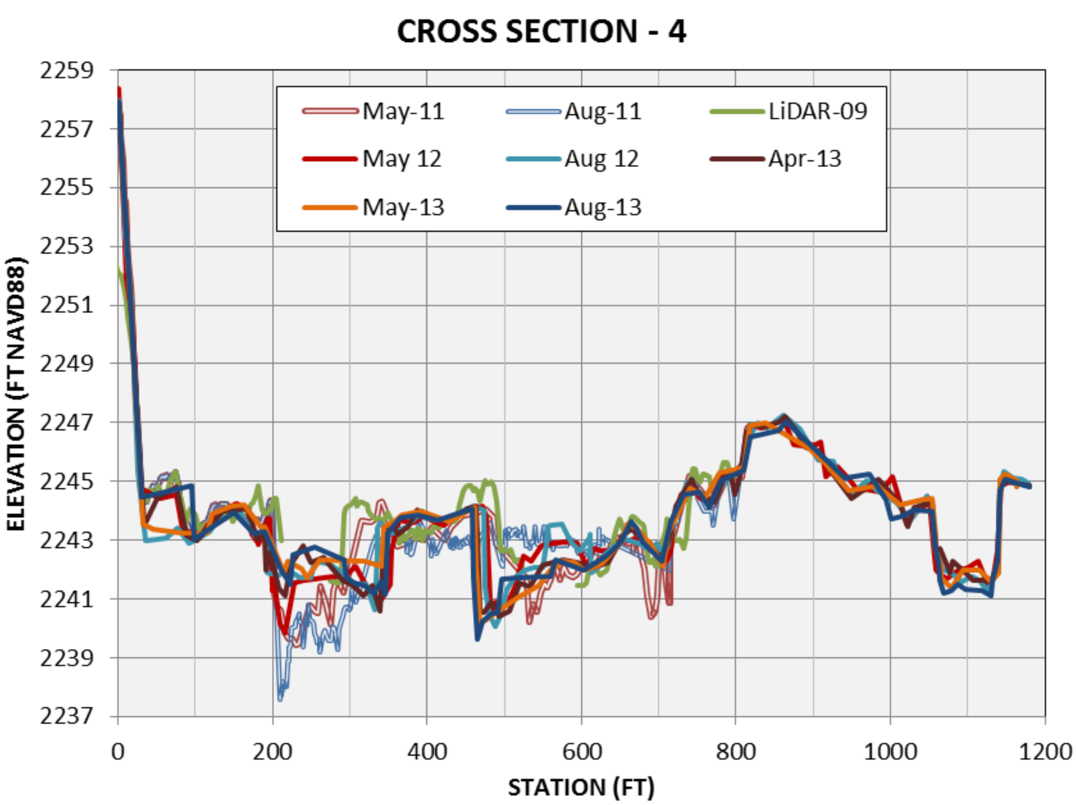
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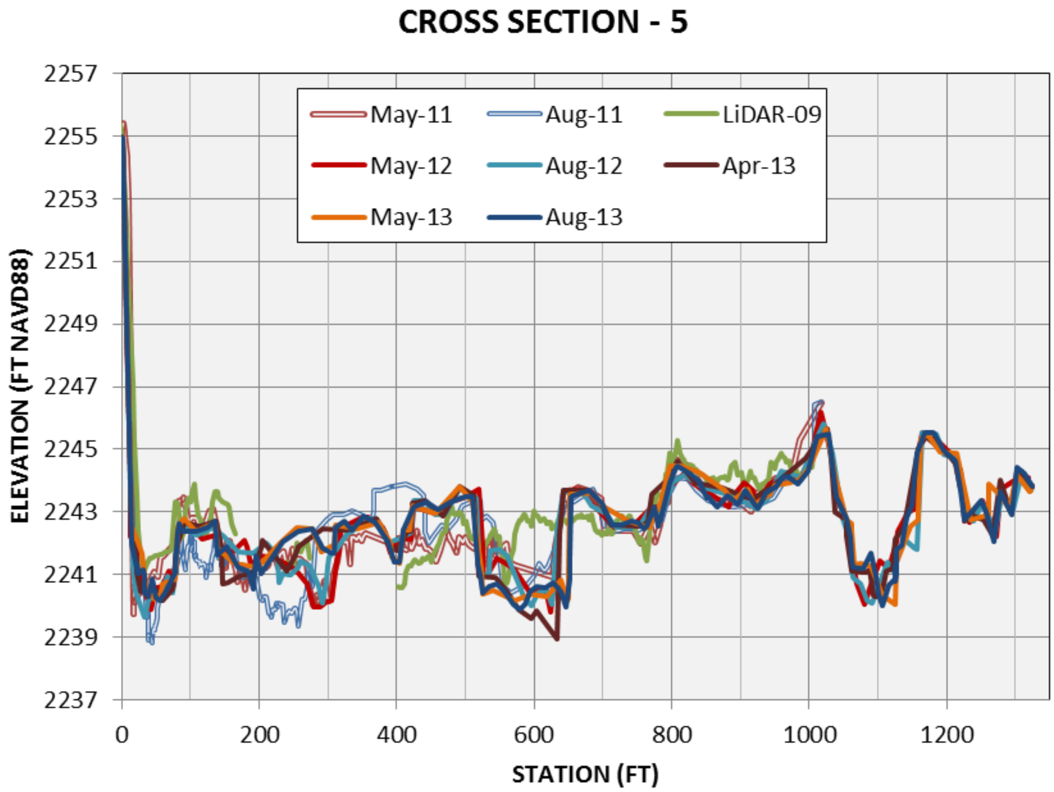
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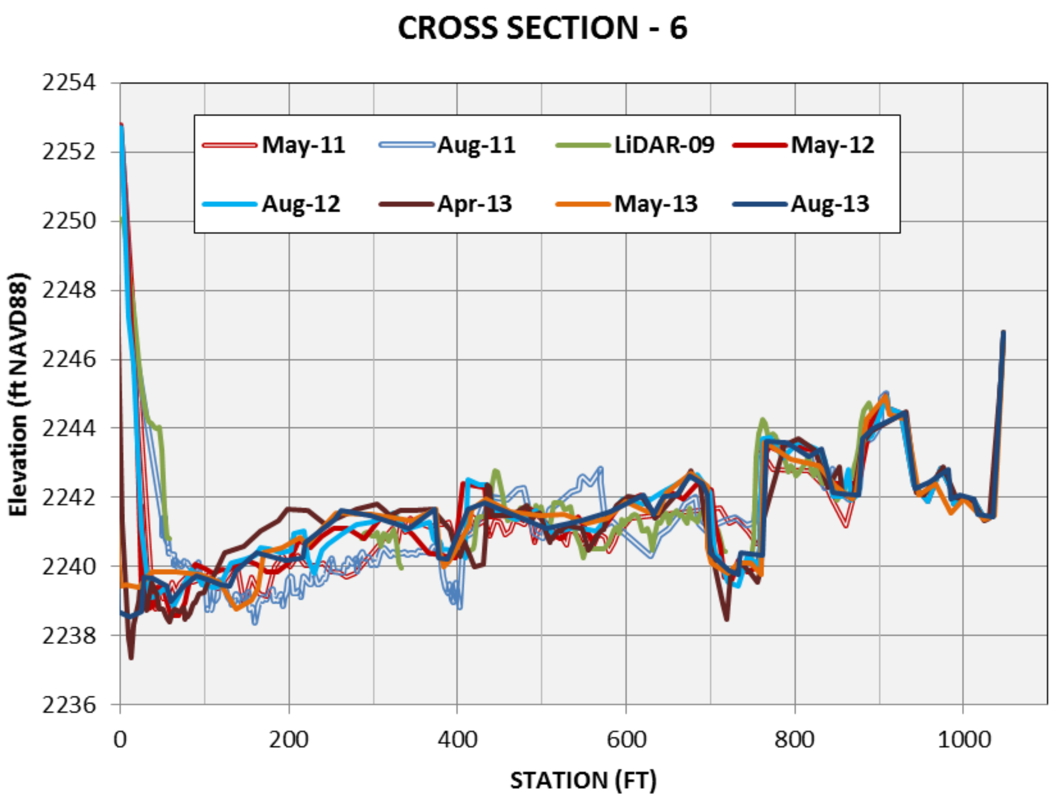
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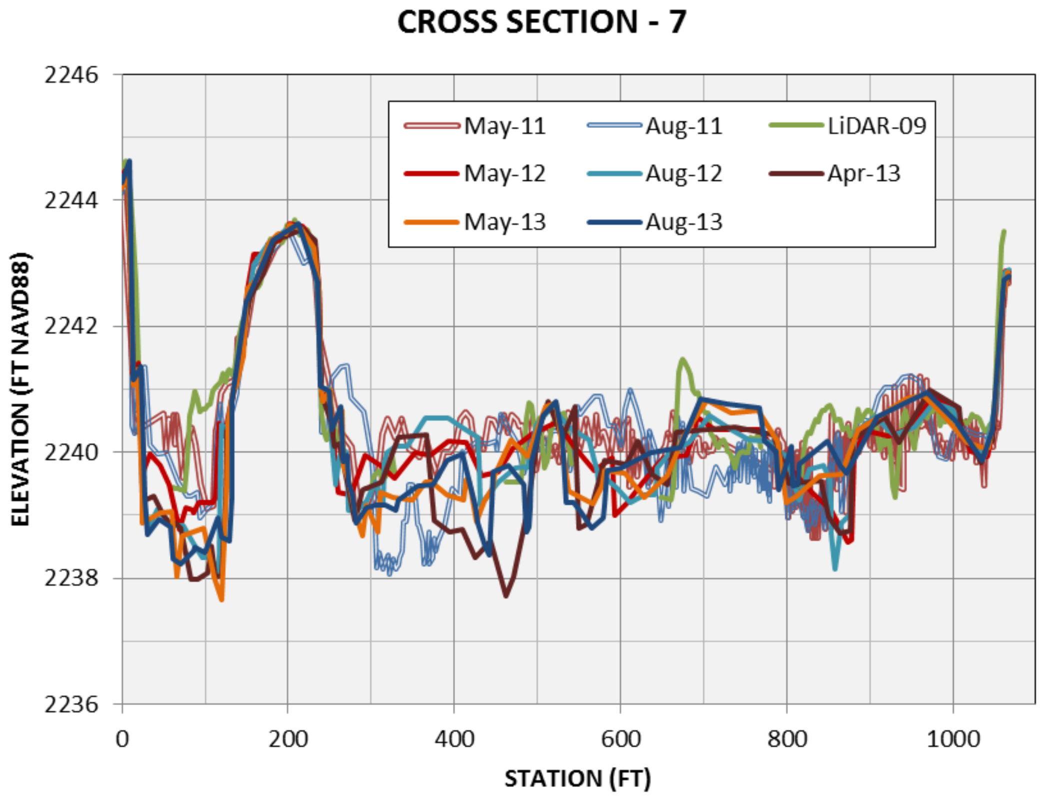
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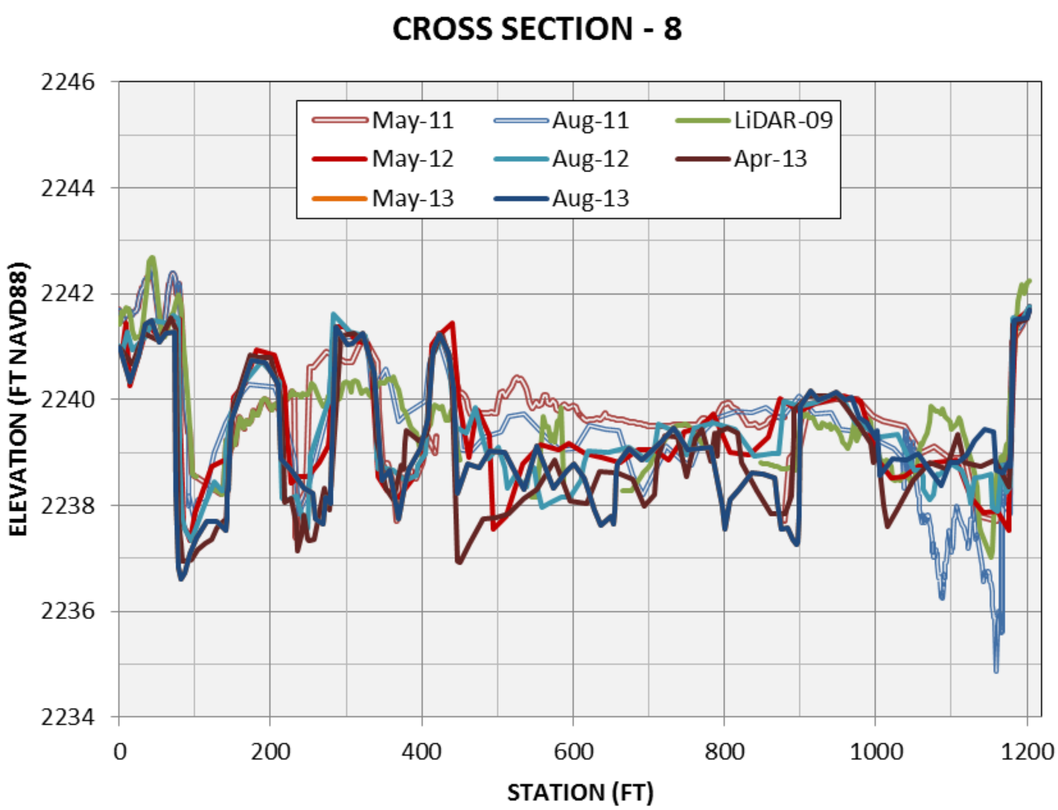
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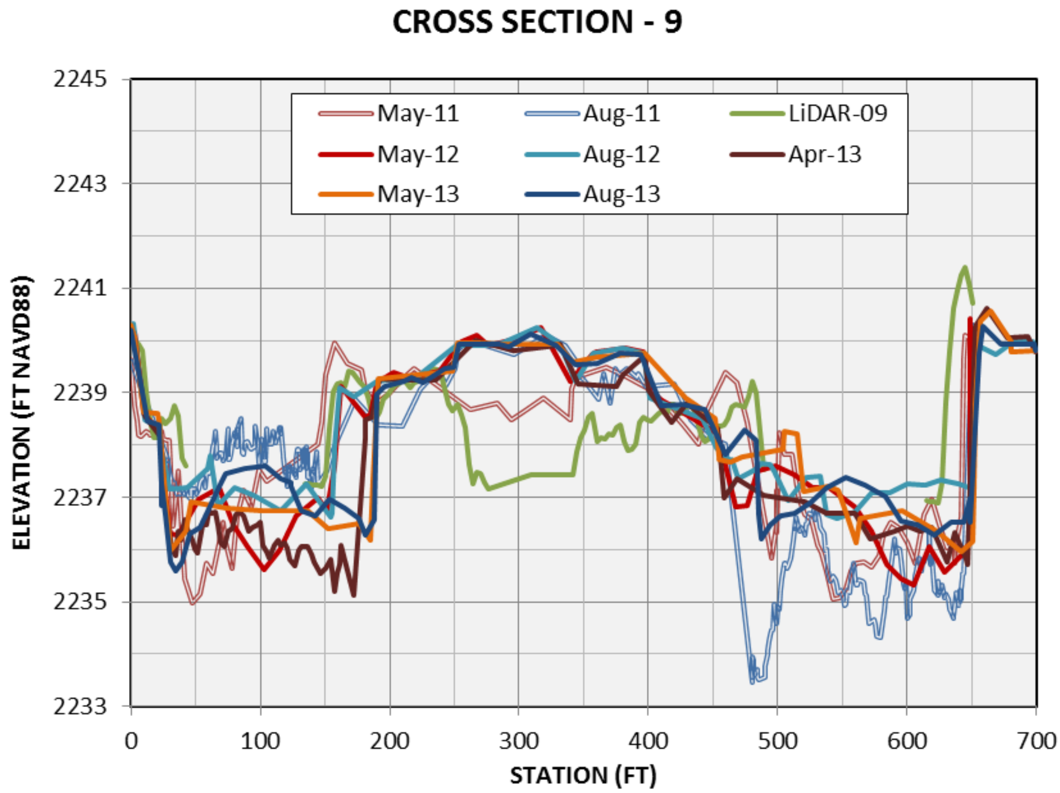
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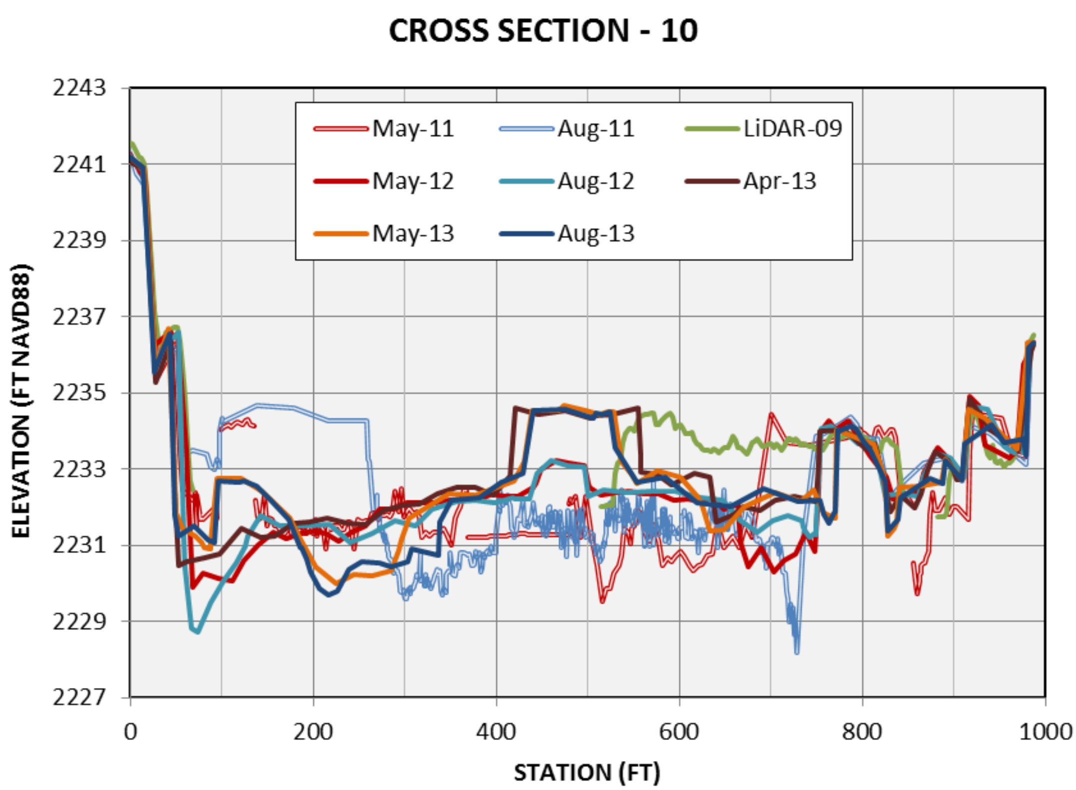
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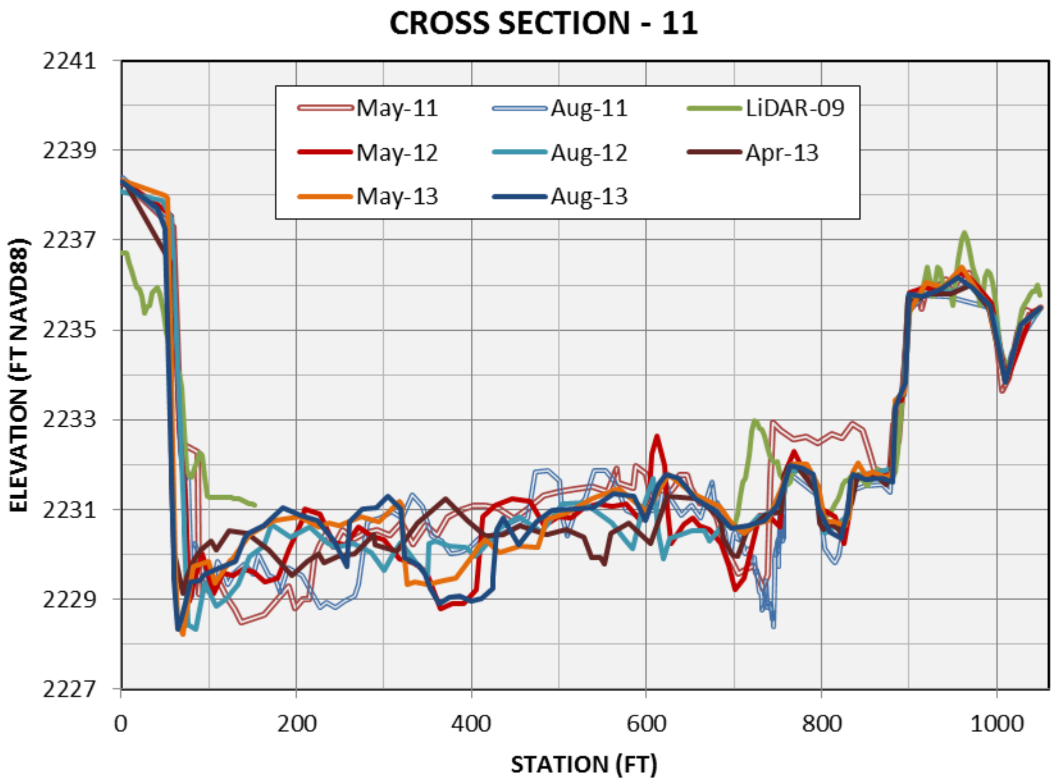
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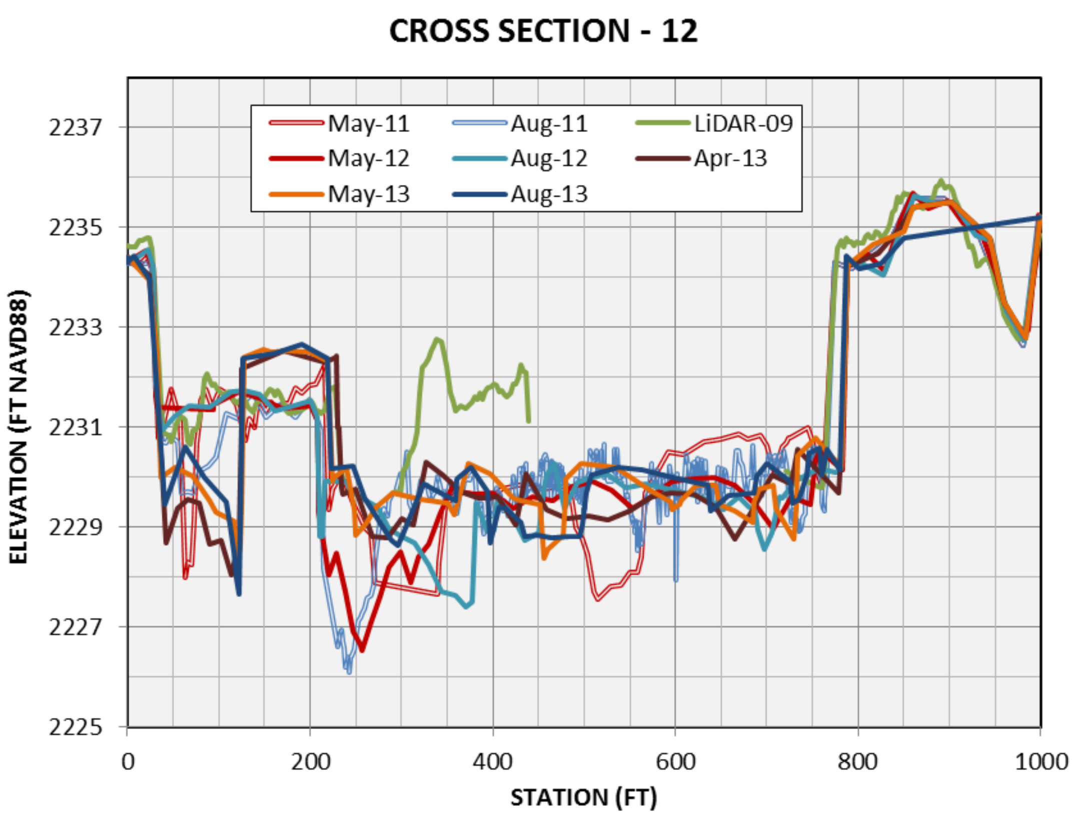
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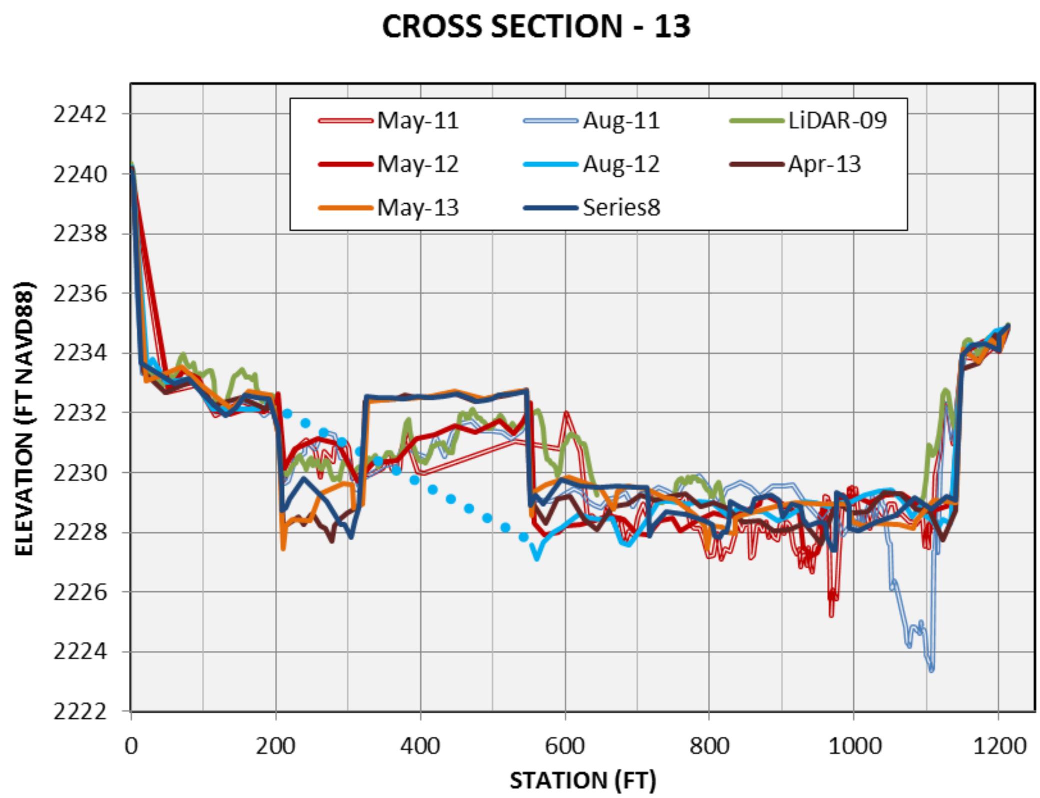
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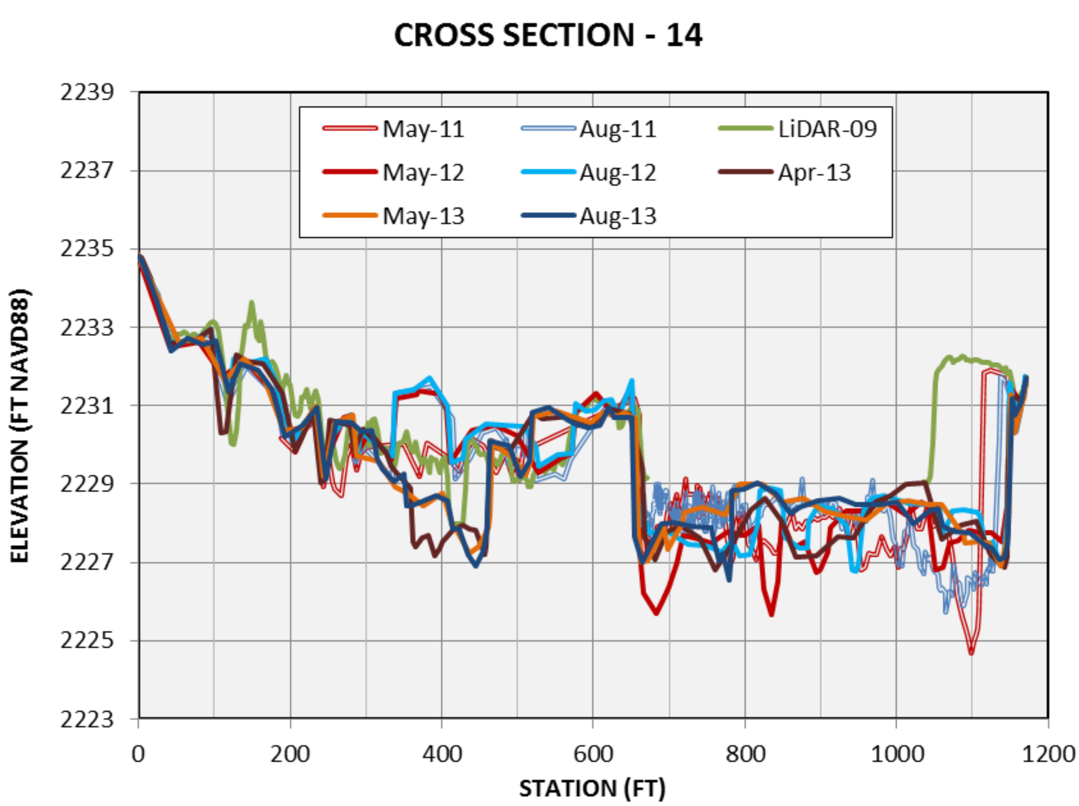
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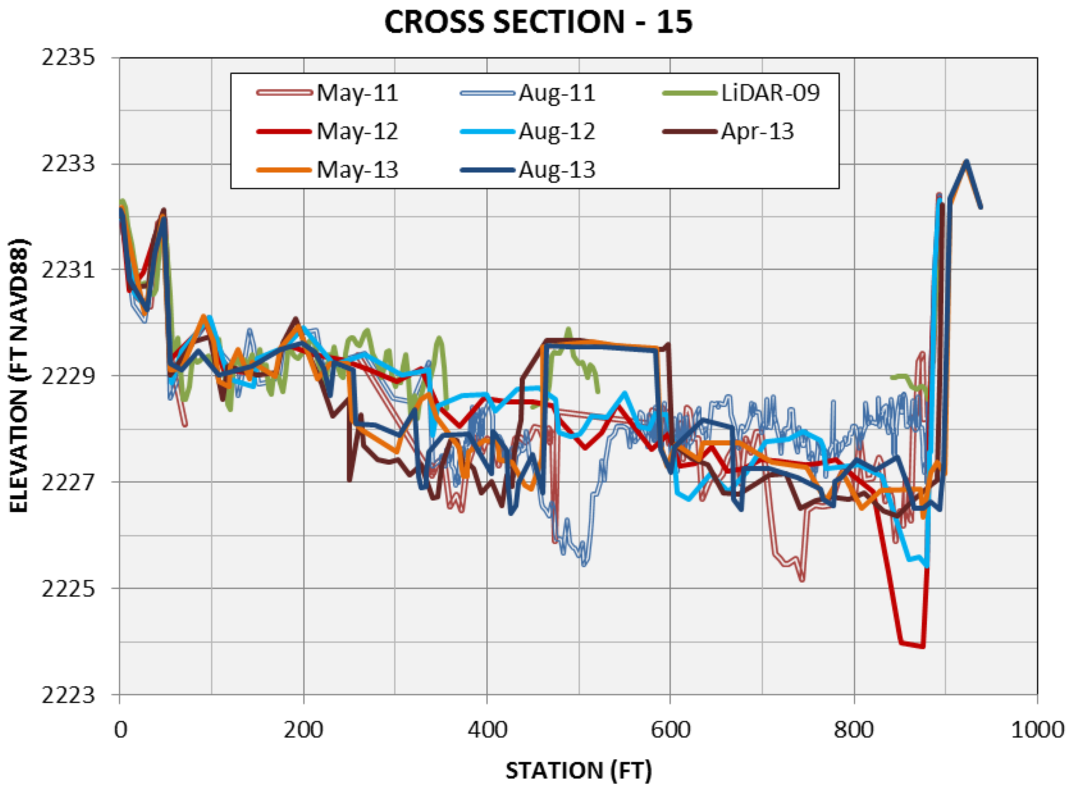
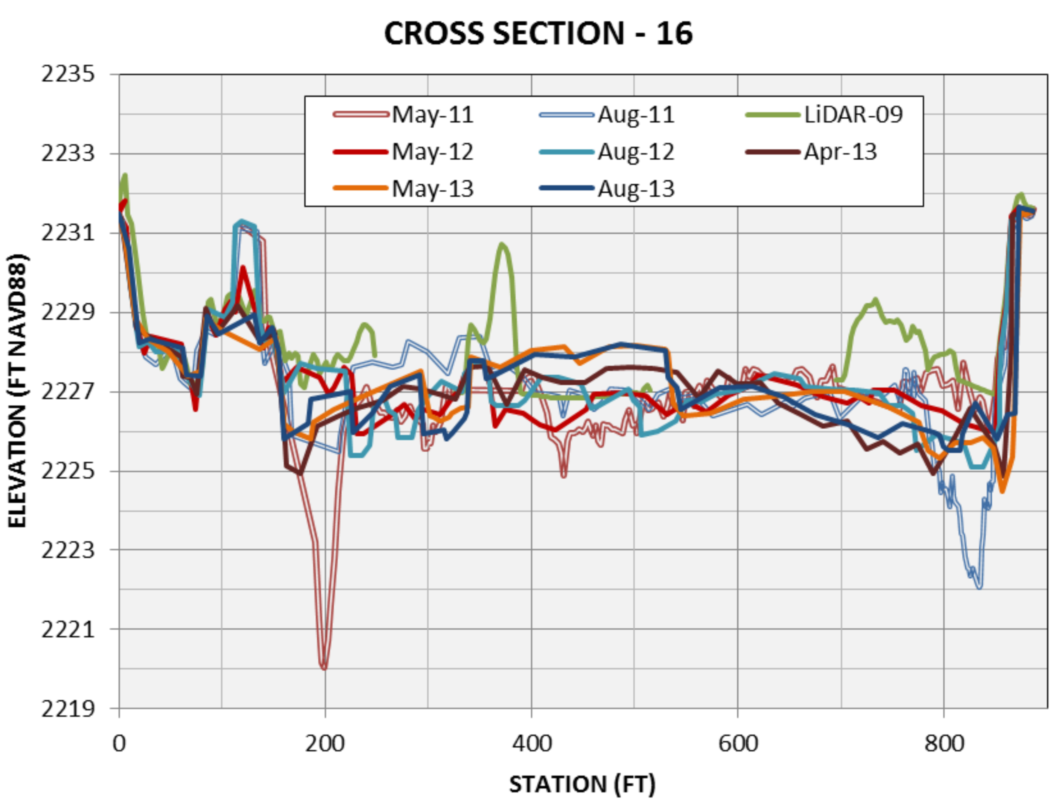
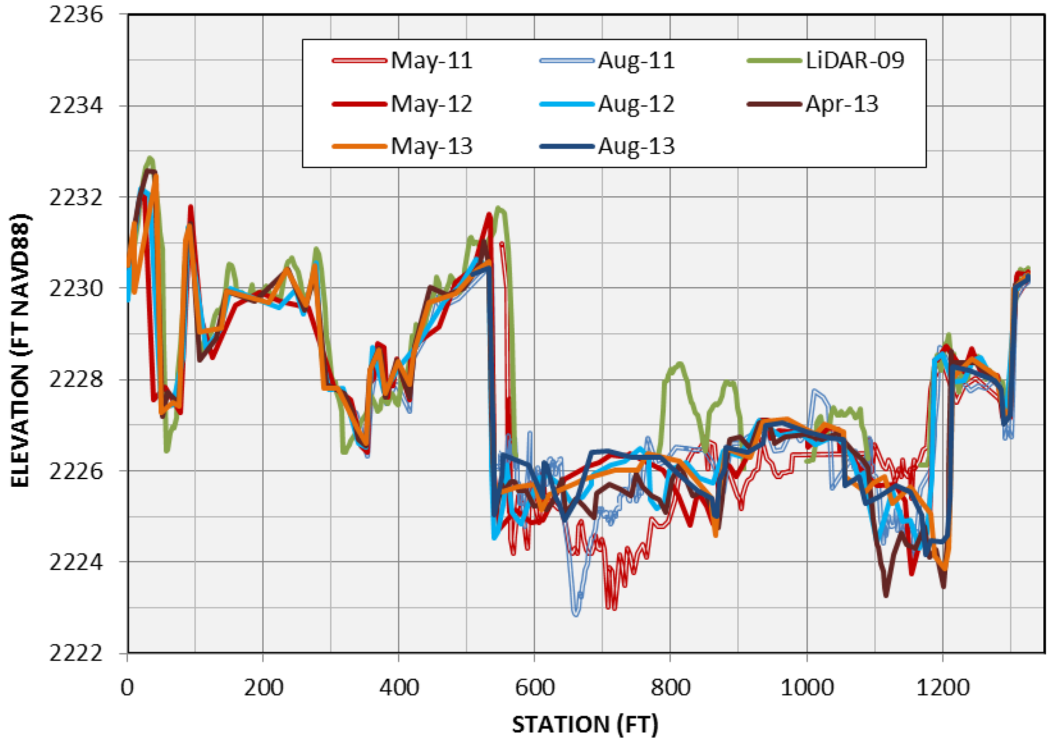
600
800
1000
1200
STATION (FT)

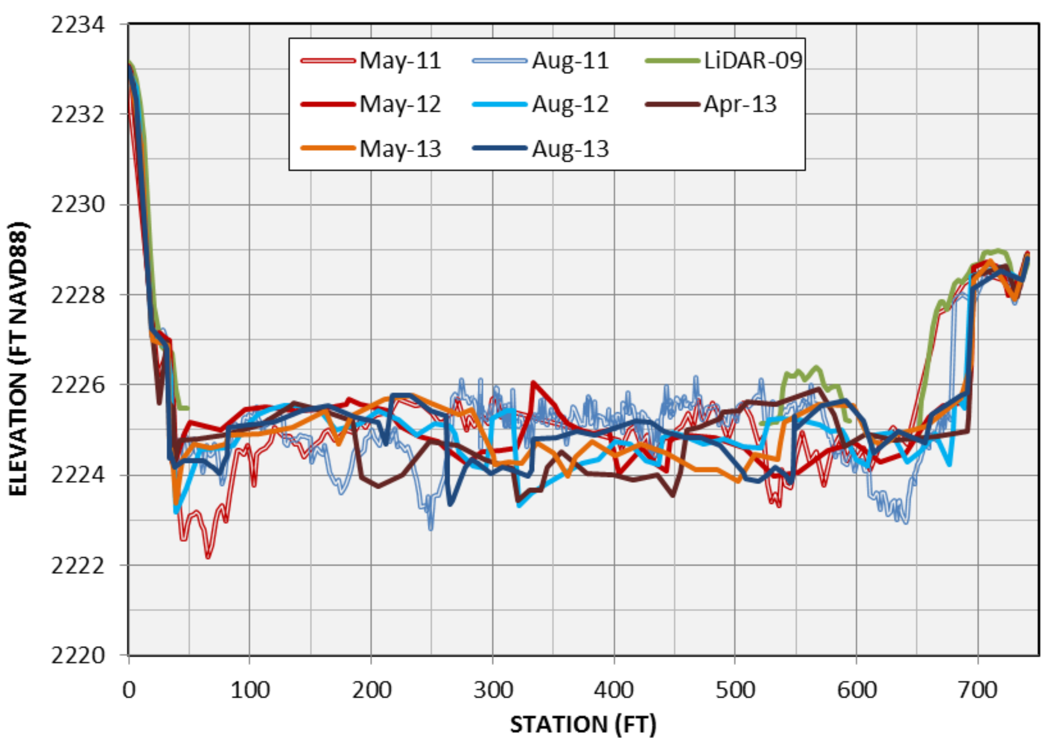

CROSS SECTION - 15
ELEVATION (FT NAVD88)
STATION (FT)
May-11
Aug-11
LiDAR-09
May-12
Aug-12
Apr-13
May-13
Aug-13
2235
2233
2231
2229
2227
2225
2223
0
200
400
600
800
1000


CROSS SECTION - 16
ELEVATION (FT NAVD88)
STATION (FT)
May-11
Aug-11
LiDAR-09
May-12
Aug-12
Apr-13
May-13
Aug-13
2235
2233
2231
2229
2227
2225
2223
2221
2219
0
200
400
600
800

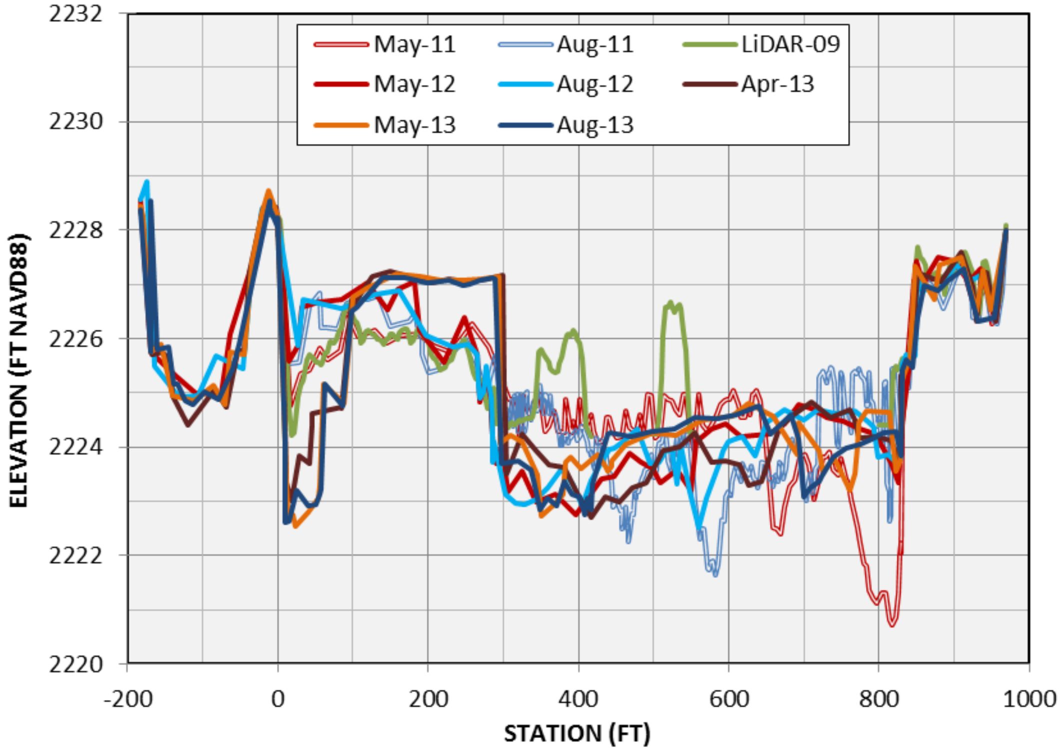
CROSS SECTION - 17



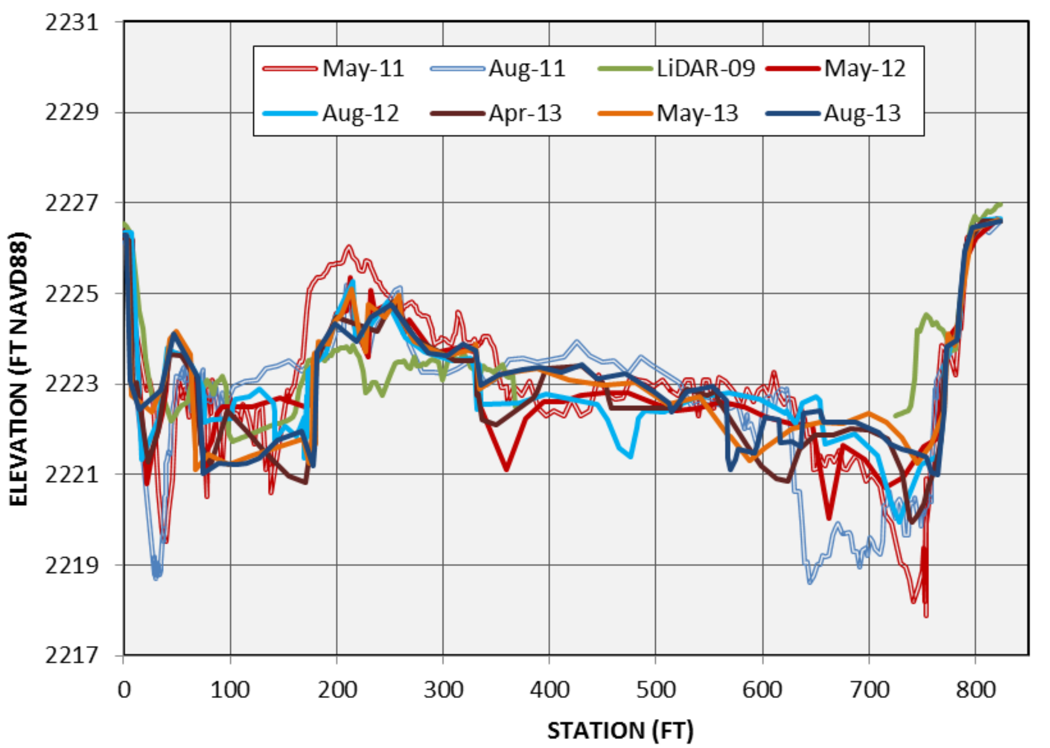
CROSS SECTION - 18

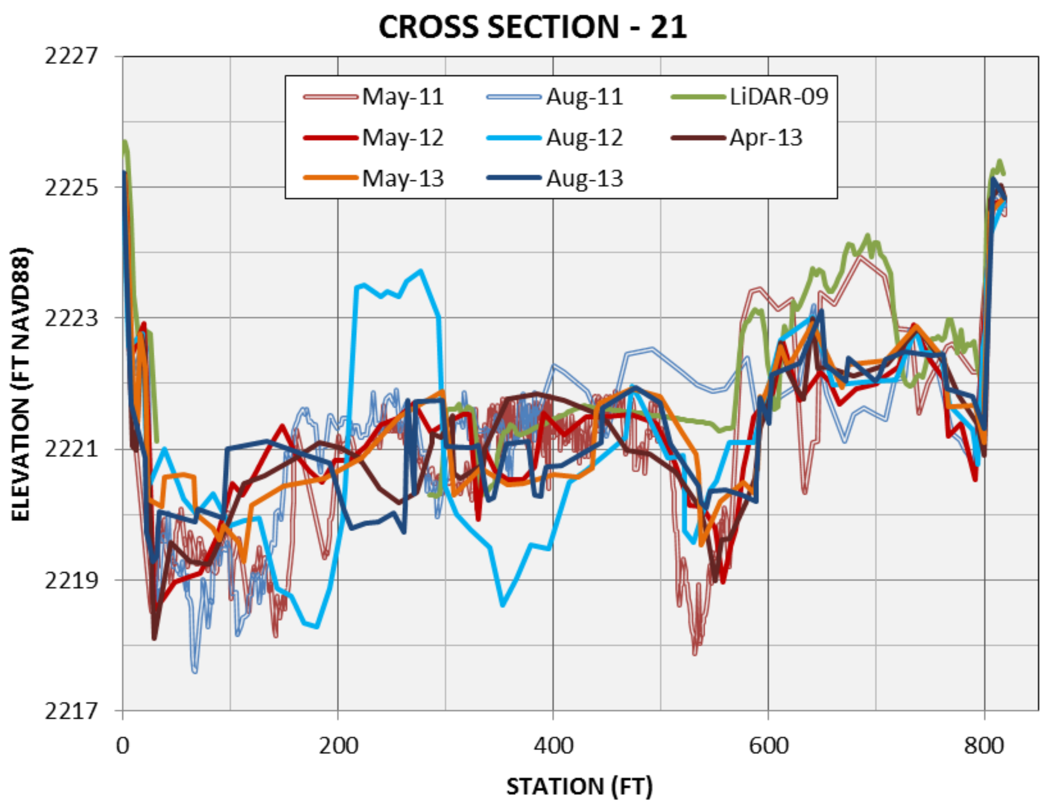


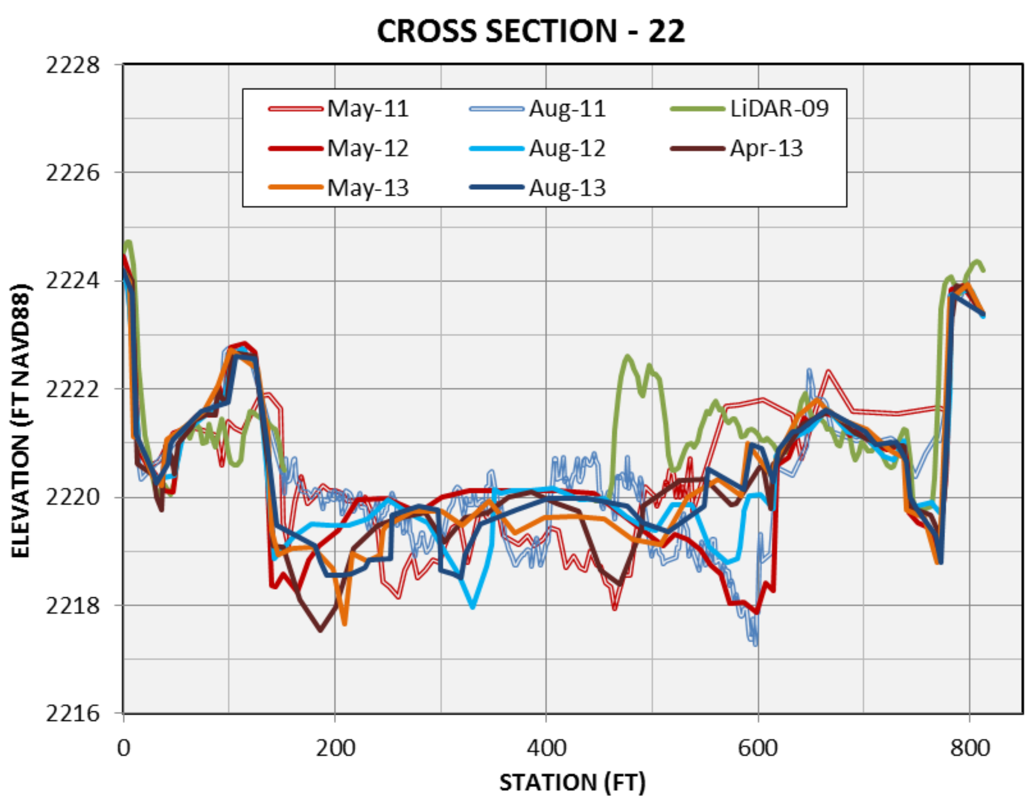
CROSS SECTION - 19



CROSS SECTION - 20




CROSS SECTION - 21
May-11
Aug-11
LiDAR-09
May-12
Aug-12
Apr-13
May-13
Aug-13
2227
2225
2223
2221
2219
2217
ELEVATION (FT NAVD88)
0
200
400
600
800
STATION (FT)


CROSS SECTION - 22
May-11
Aug-11
LiDAR-09
May-12
Aug-12
Apr-13
May-13
Aug-13
2228
2226
2224
2222
2220
2218
2216
ELEVATION (FT NAVD88)
0
200
400
600
800
STATION (FT)

TETRA TECH

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APPENDIX D
Bed and Bank Material Plots and Data

APPENDIX_D_Bed and Bank Material Data_2012_2013.xlsx

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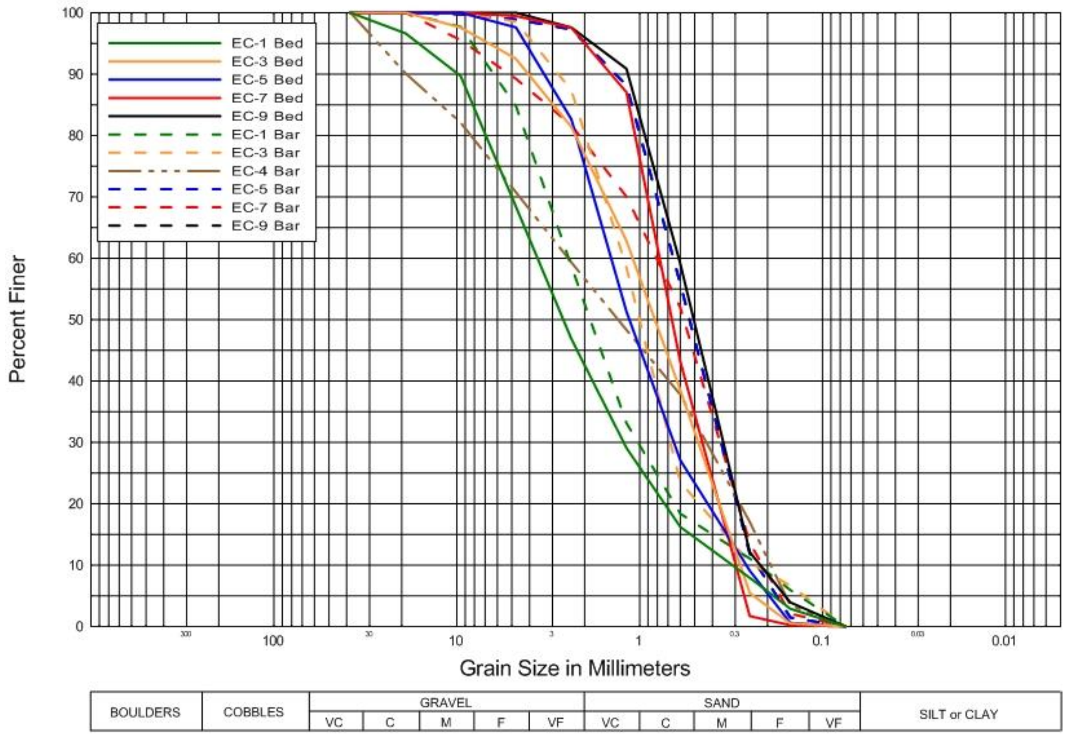
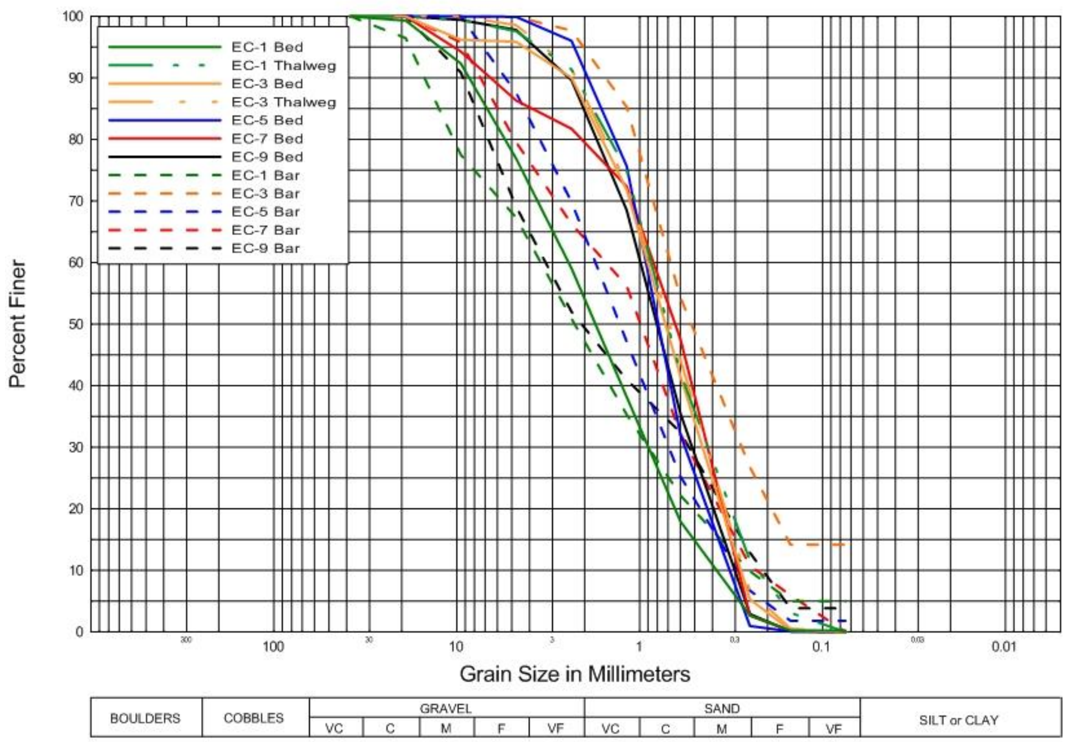
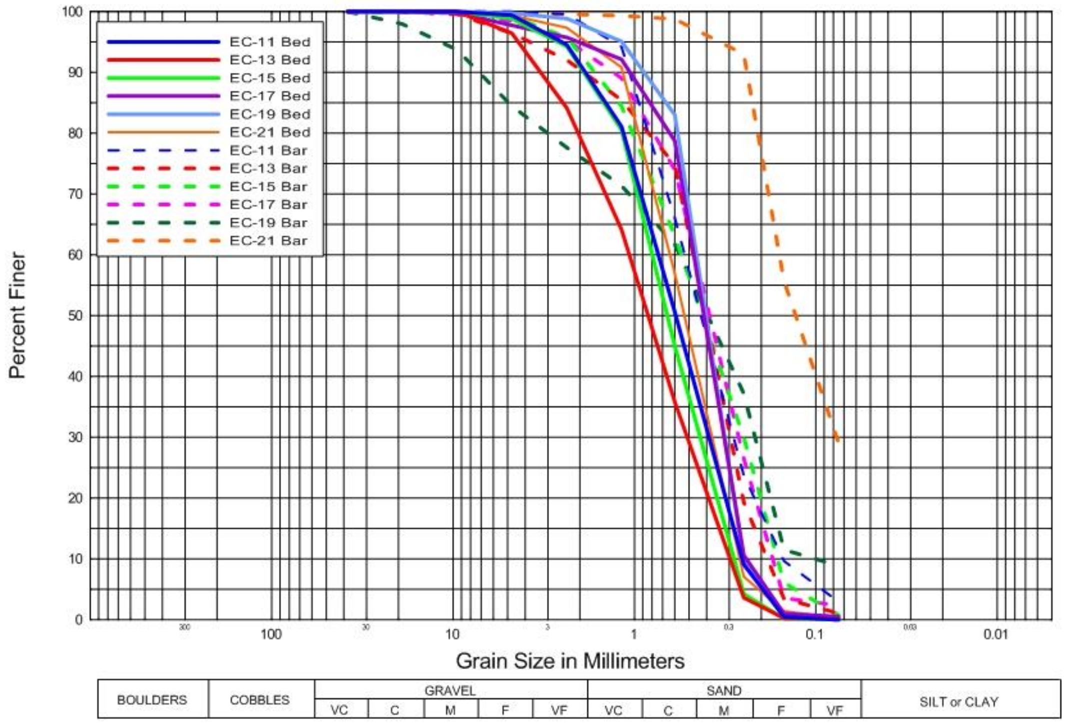
Upstream Sediment Gradations
May-2012



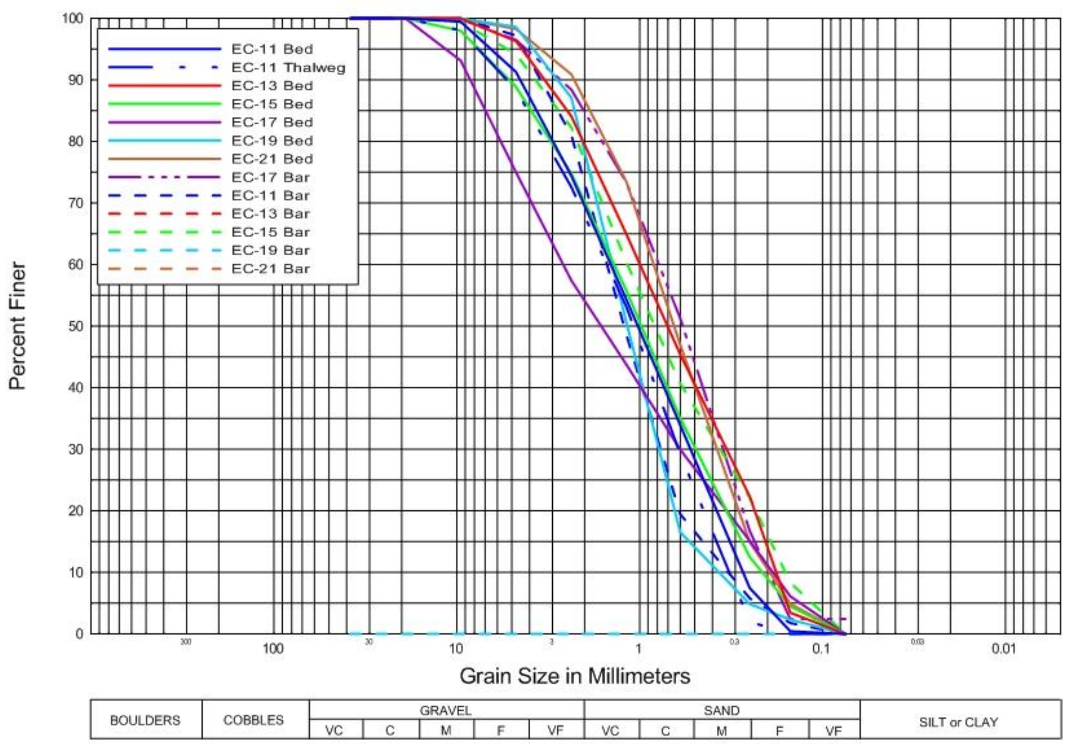
Upstream Sediment Gradations
August-2012



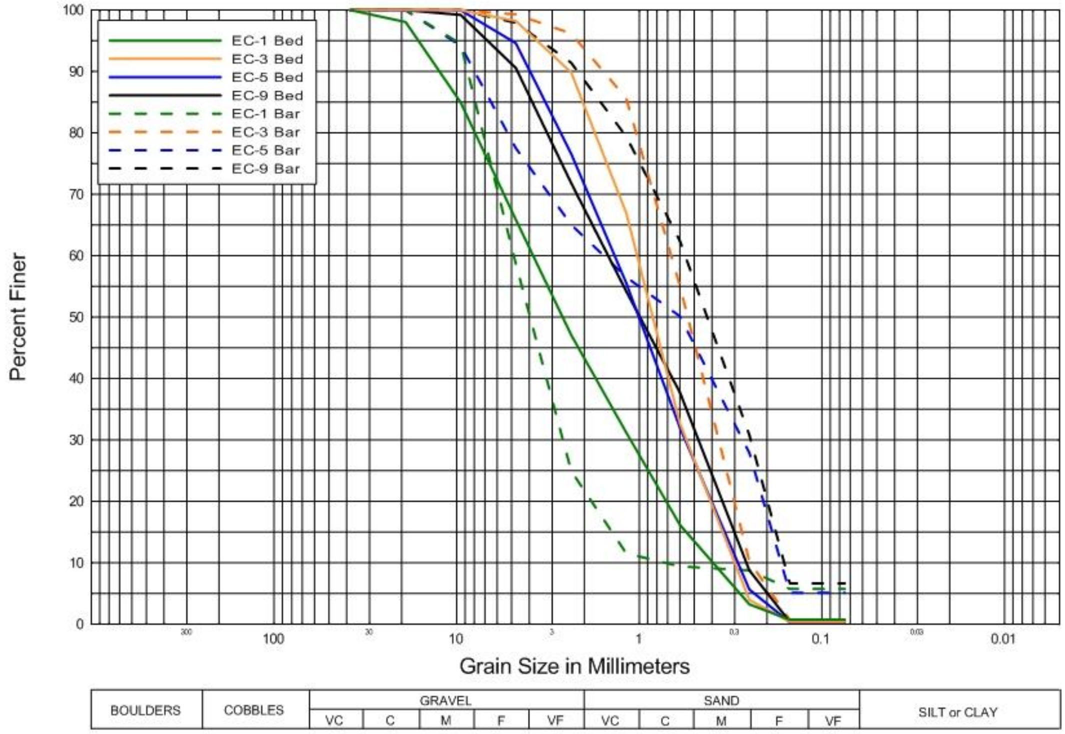
Downstream Sediment Gradations
May-2012



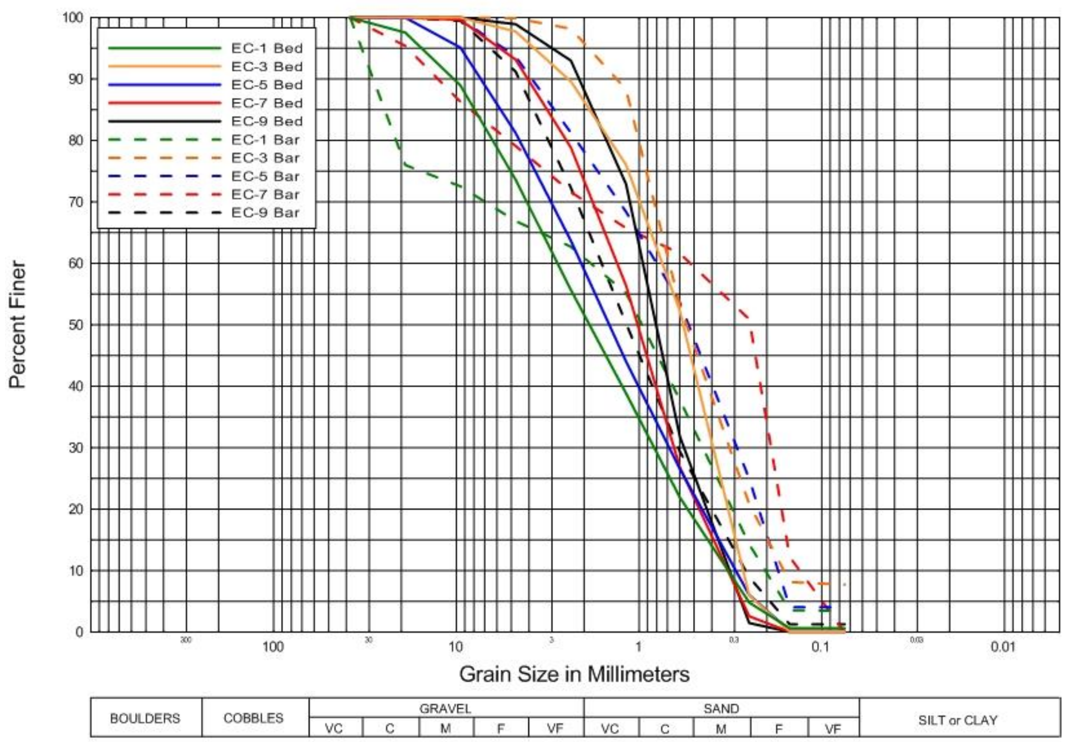
Downstream Sediment Gradations
August-2012



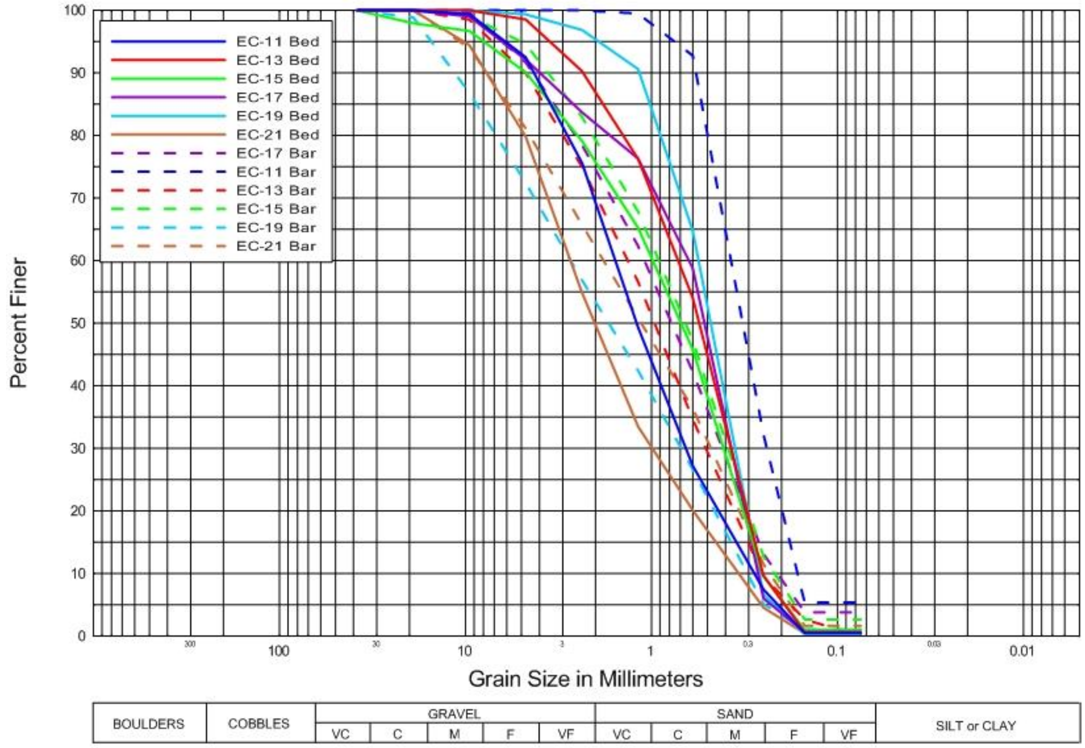
Upstream Sediment Gradations
April-2013



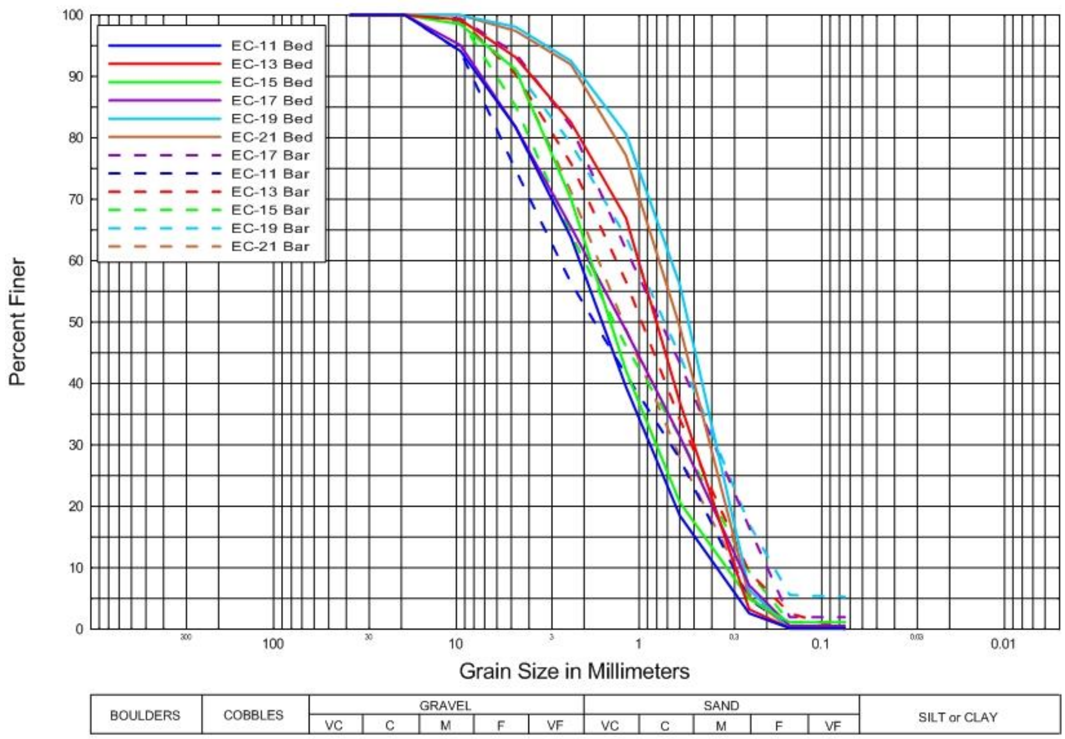
Upstream Sediment Gradations
August-2013



Downstream Sediment Gradations
April-2013



Downstream Sediment Gradations
August-2013



APPENDIX E
Pressure Transducer Data

Appendix_E_ Pressure Transducer Data_2012_2013.xlsx

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APPENDIX F
Greenline Data

APPENDIX_F_Green Line Data Points_2013.xlsx

TETRA TECH

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APPENDIX G

Vegetation Data Spreadsheets

Appendix G_Elm_Creek_Vegetation_Data_May 2011-Aug2013_withStats.xlsx

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APPENDIX H
Combined Bar Histogram Plots

Appendix_H_Combined Bar HIstograms_2013.xlsx

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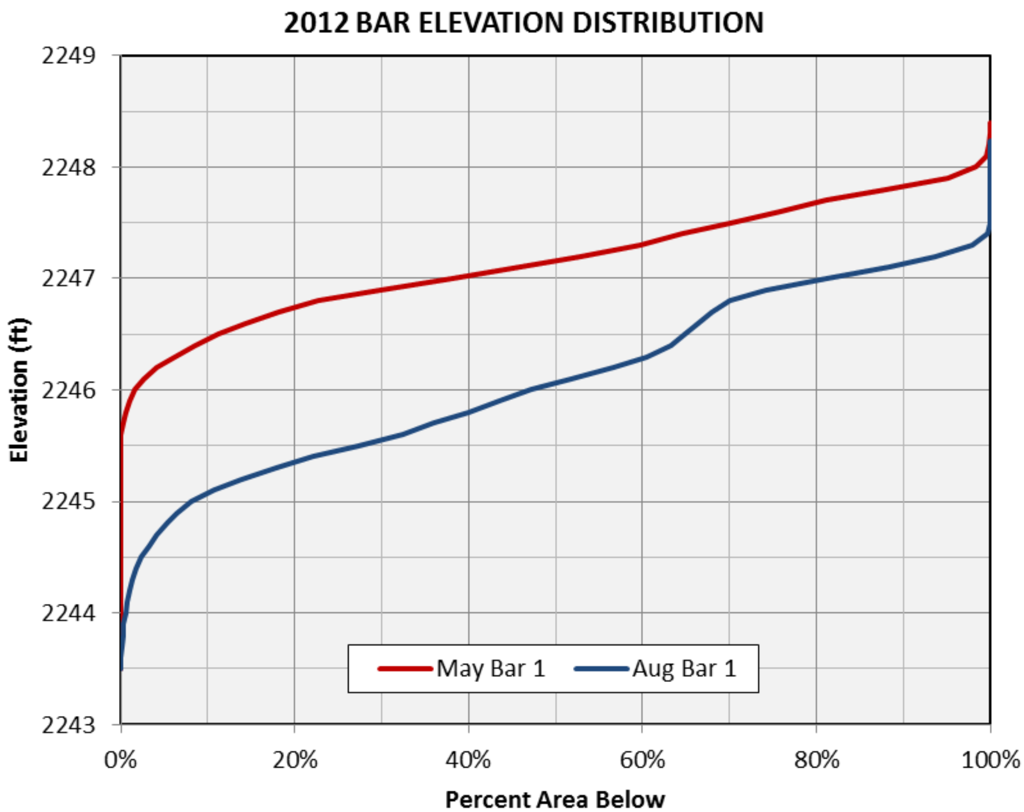
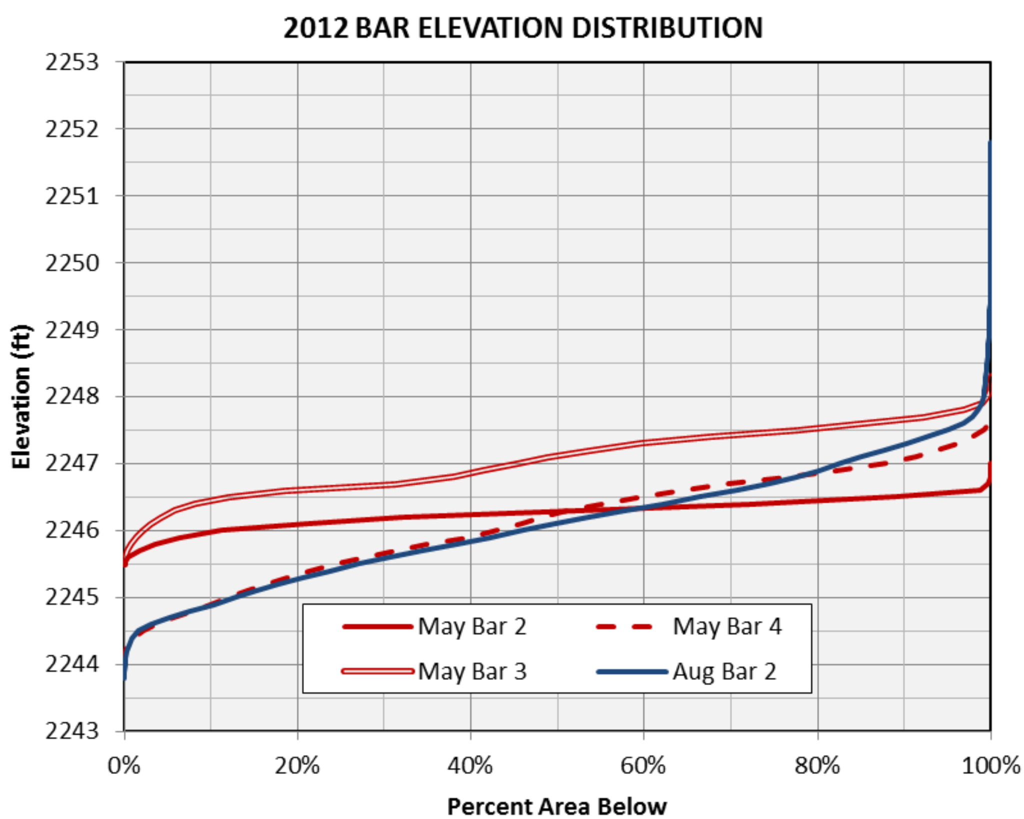
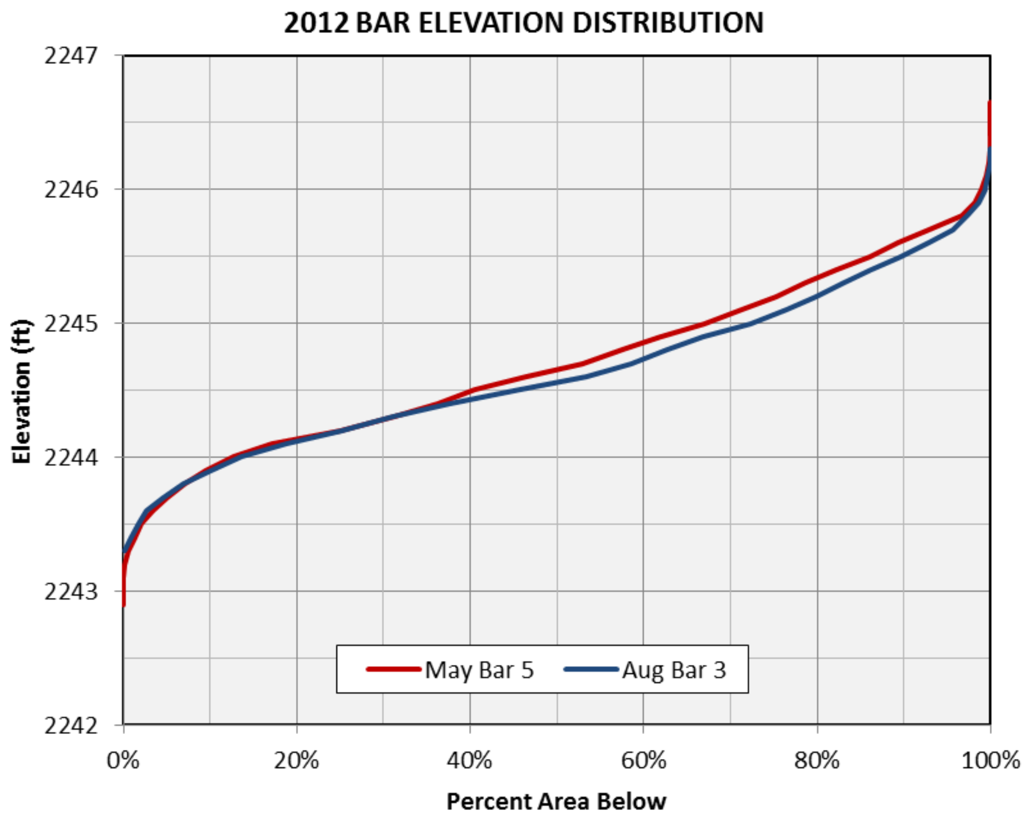
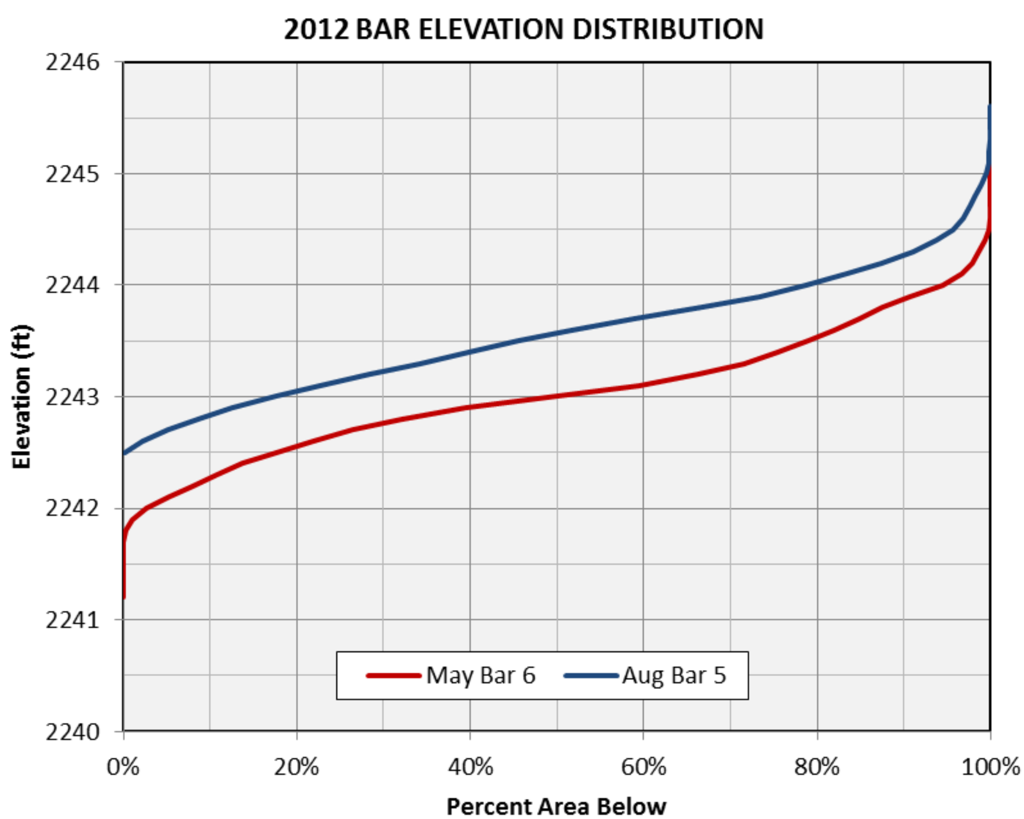


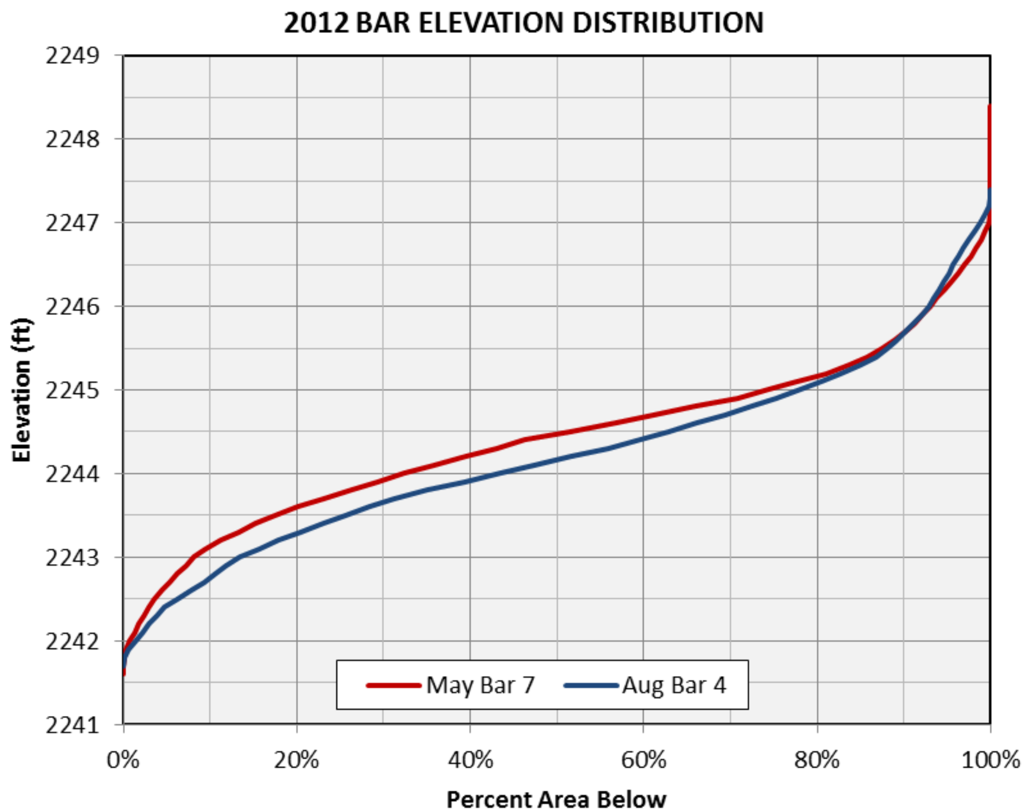
2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2249
2248
2247
2246
2245
2244
2243
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 1
Aug Bar 1

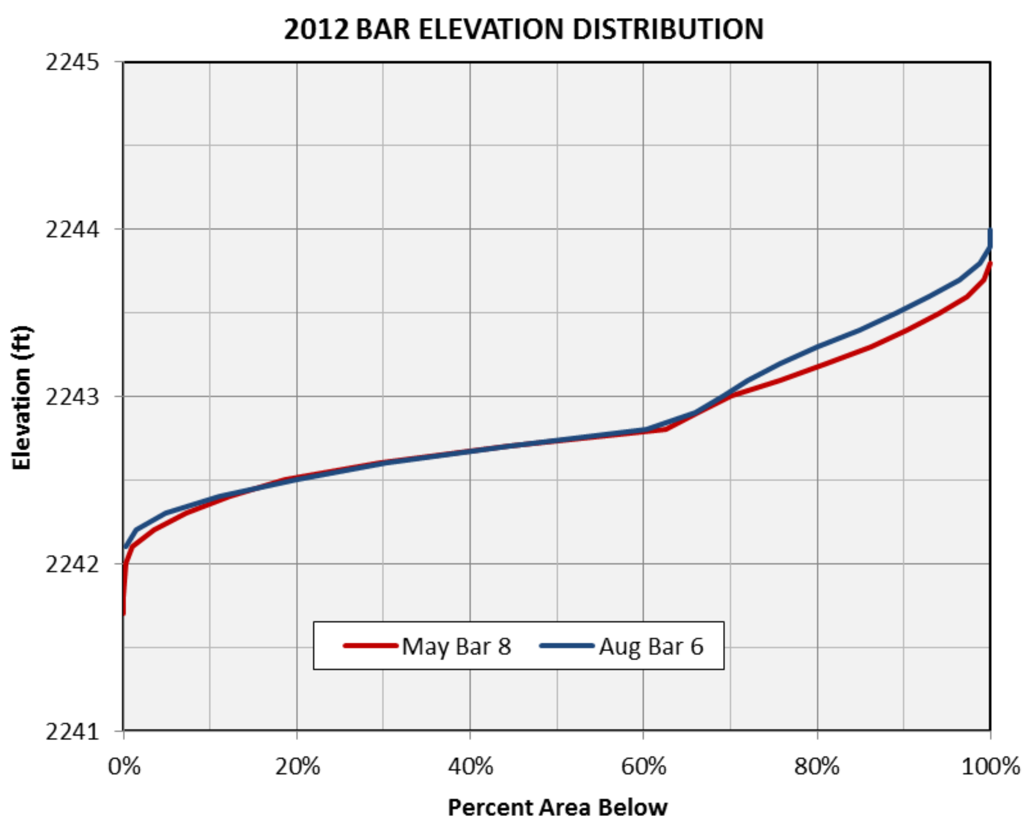


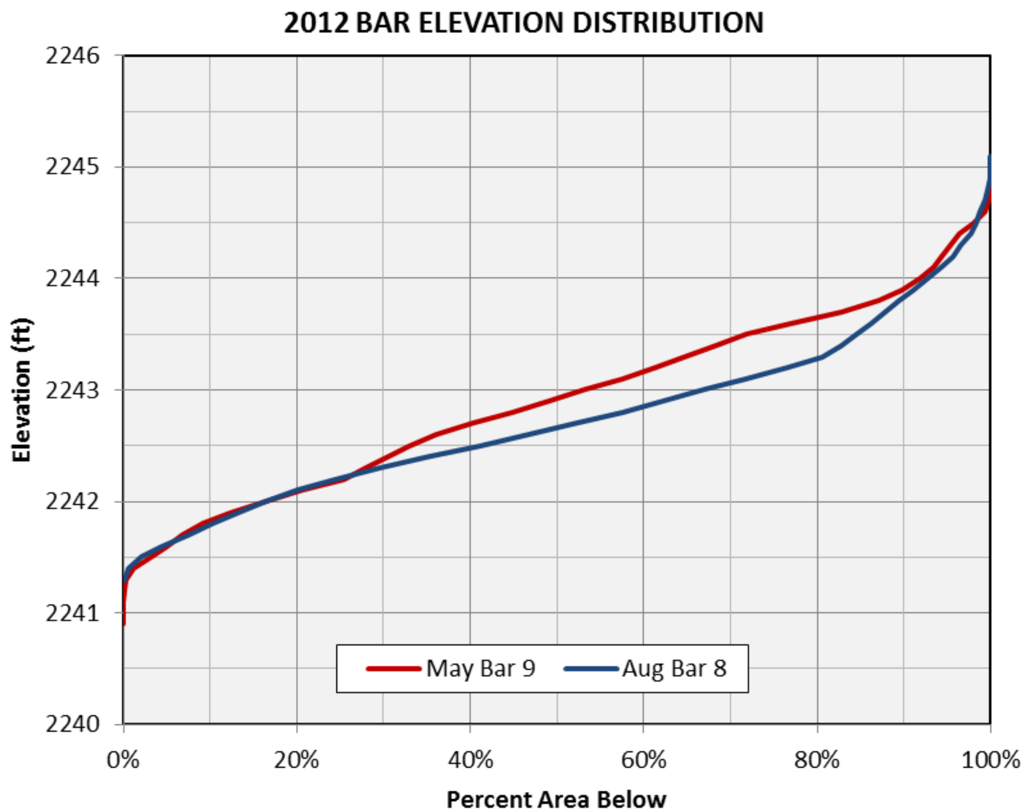
2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2253
2252
2251
2250
2249
2248
2247
2246
2245
2244
2243
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 2
May Bar 4
May Bar 3
Aug Bar 2


2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2247
2246
2245
2244
2243
2242
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 5
Aug Bar 3

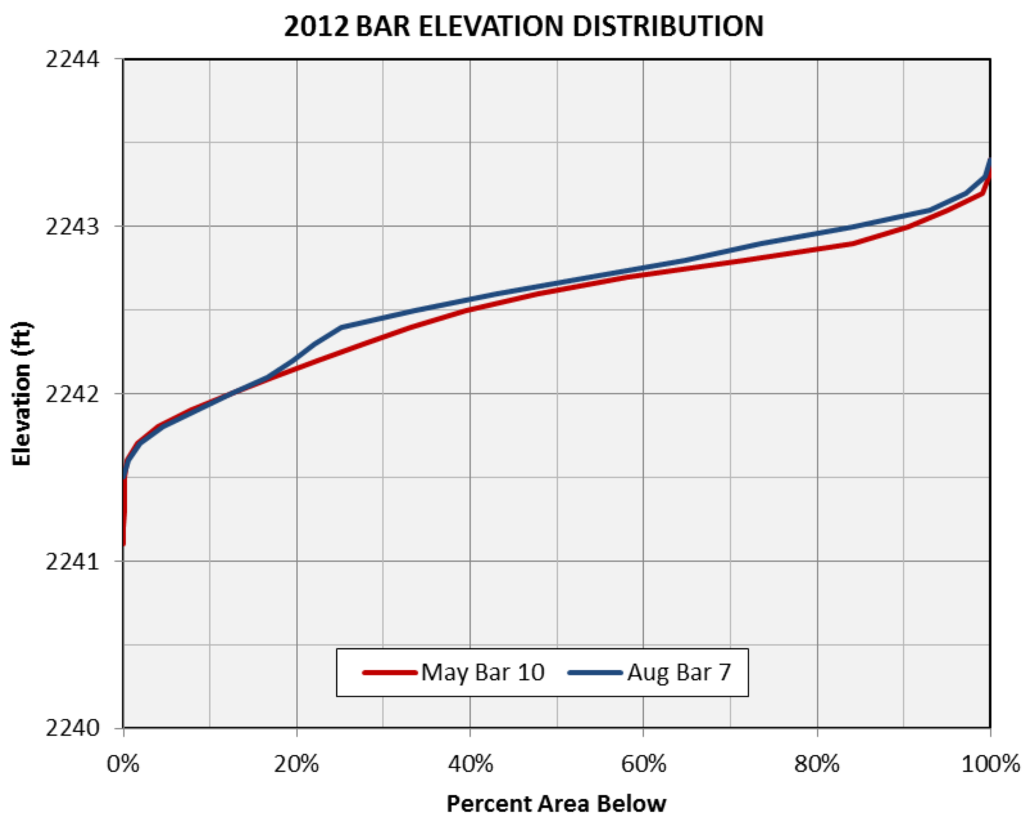

2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2246
2245
2244
2243
2242
2241
2240
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 6
Aug Bar 5


2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2249
2248
2247
2246
2245
2244
2243
2242
2241
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 7
Aug Bar 4


2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2245
2244
2243
2242
2241
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 8
Aug Bar 6

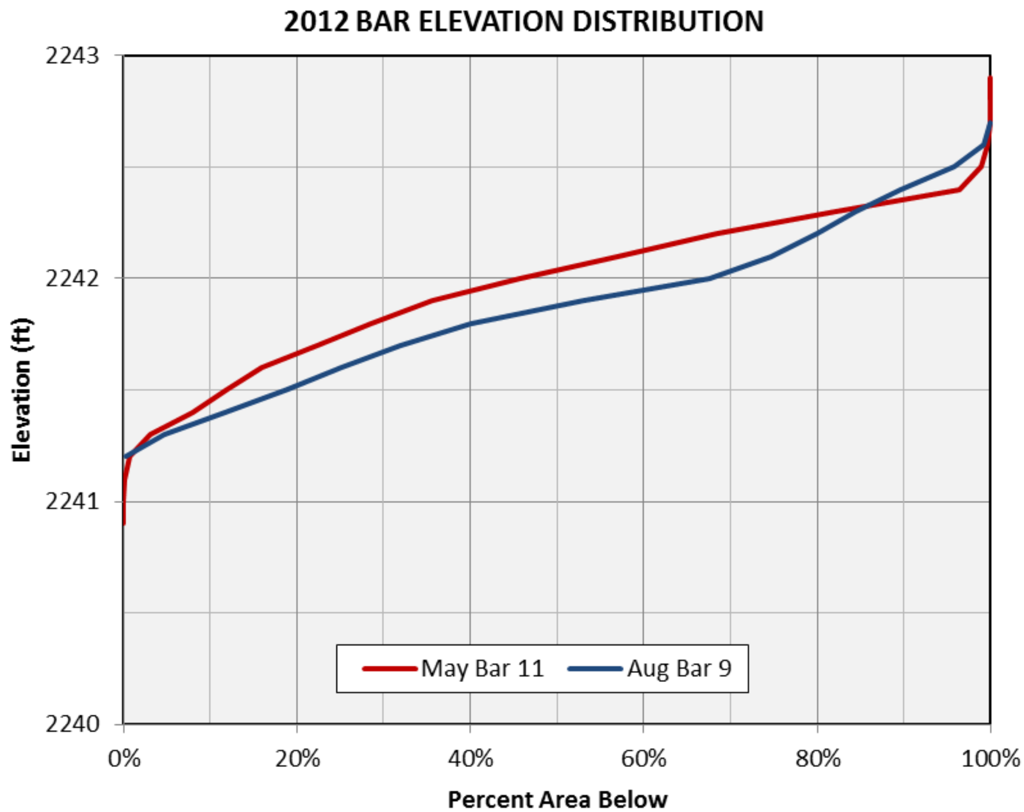


2012 BAR ELEVATION DISTRIBUTION
2246
2245
2244
2243
2242
2241
2240
Elevation (ft)
May Bar 9
Aug Bar 8
0%
20%
40%
60%
80%
100%
Percent Area Below

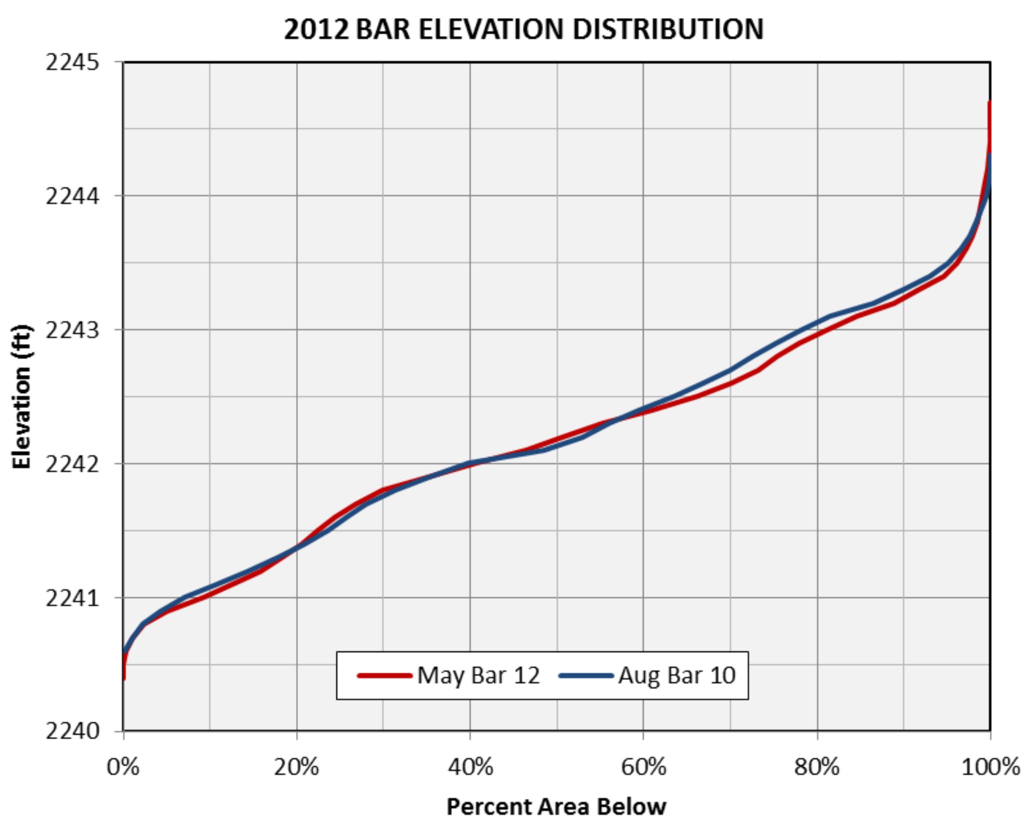


2012 BAR ELEVATION DISTRIBUTION
2244
2243
2242
2241
2240
Elevation (ft)
May Bar 10
Aug Bar 7
0%
20%
40%
60%
80%
100%
Percent Area Below

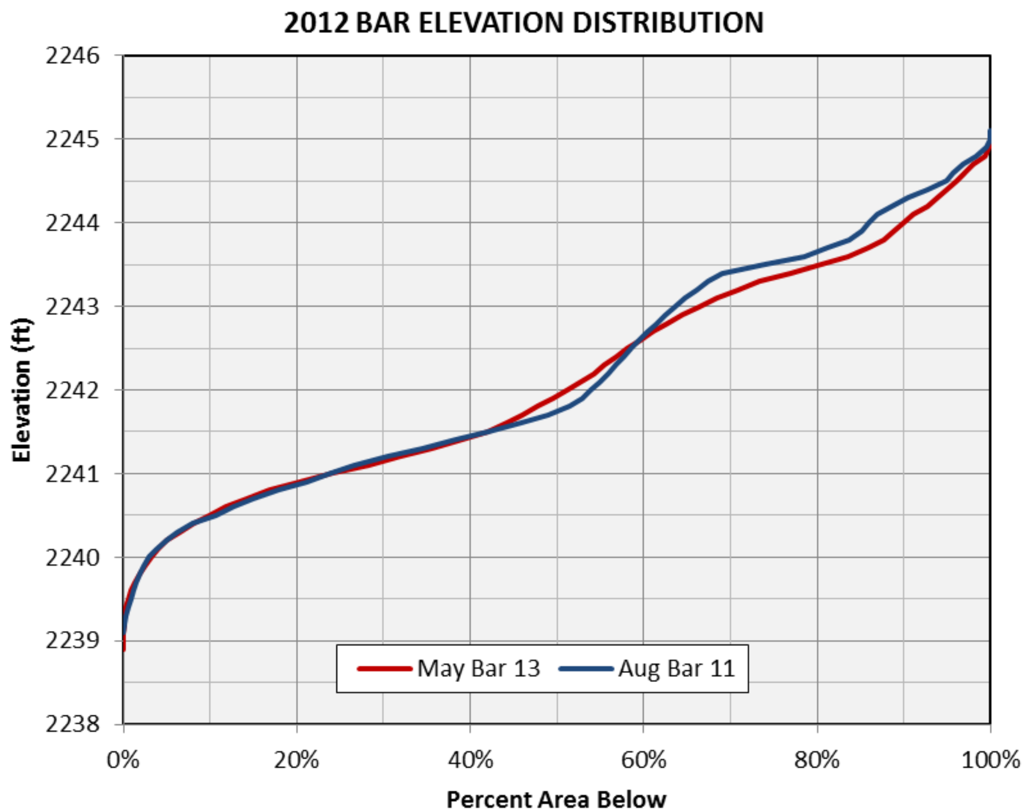
TETRA TECH

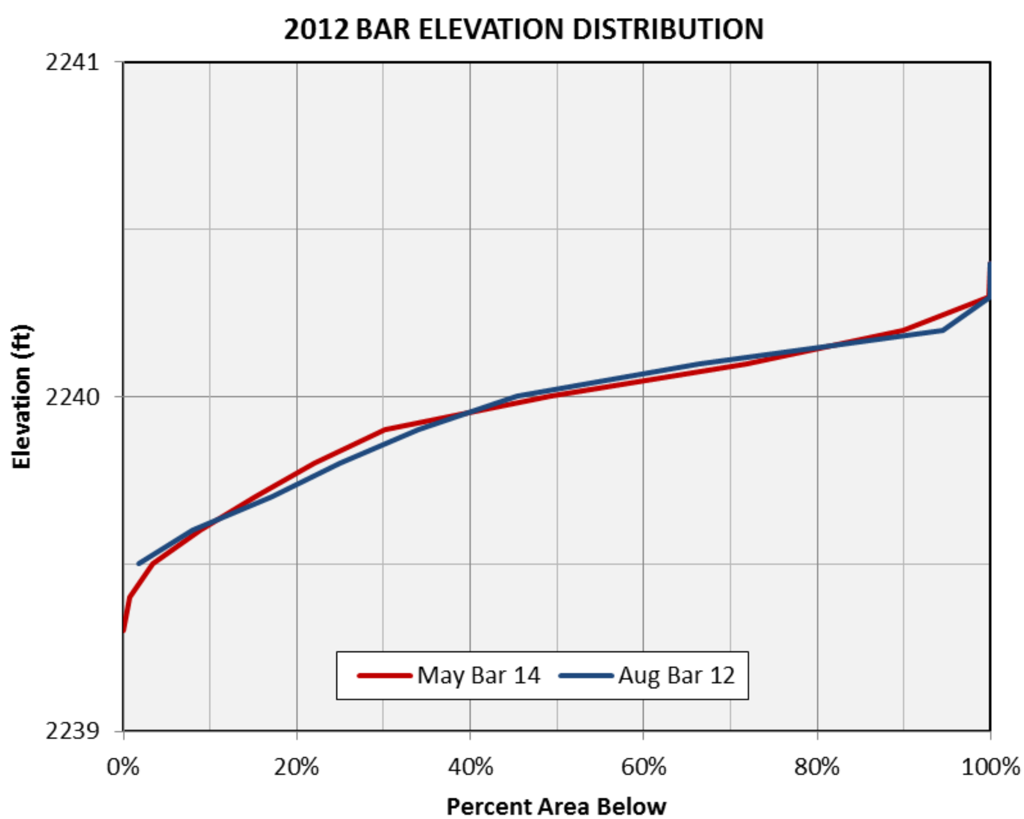


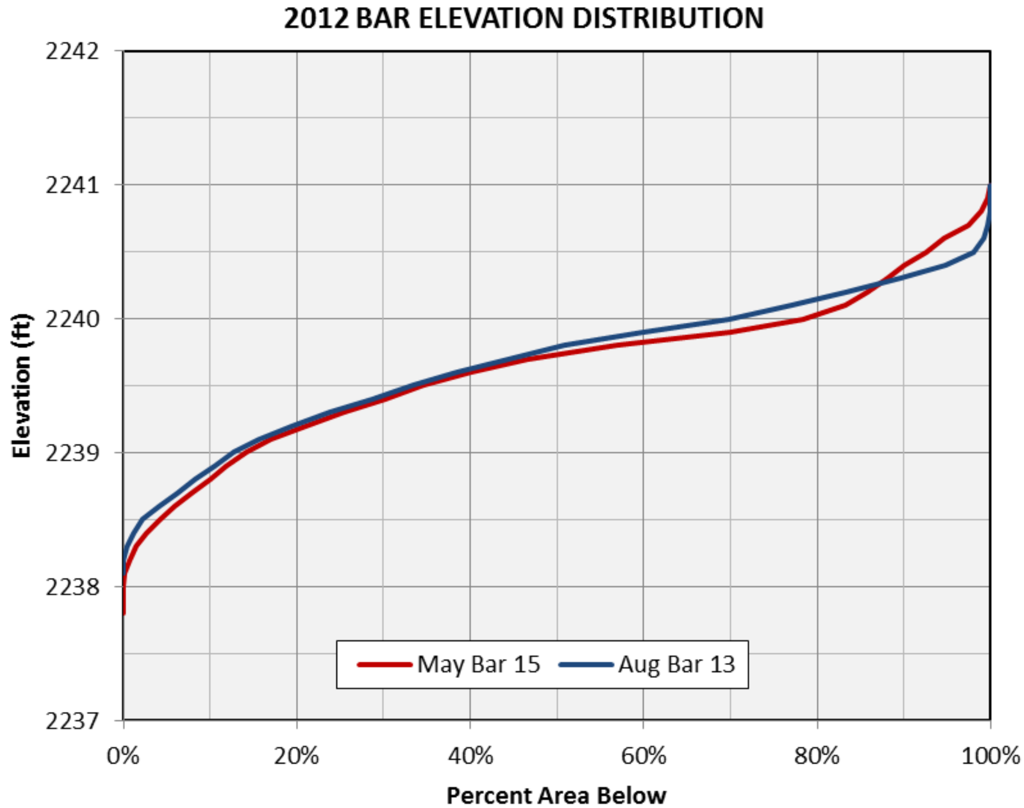
2012 BAR ELEVATION DISTRIBUTION
2243
2242
2241
2240
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 11
Aug Bar 9

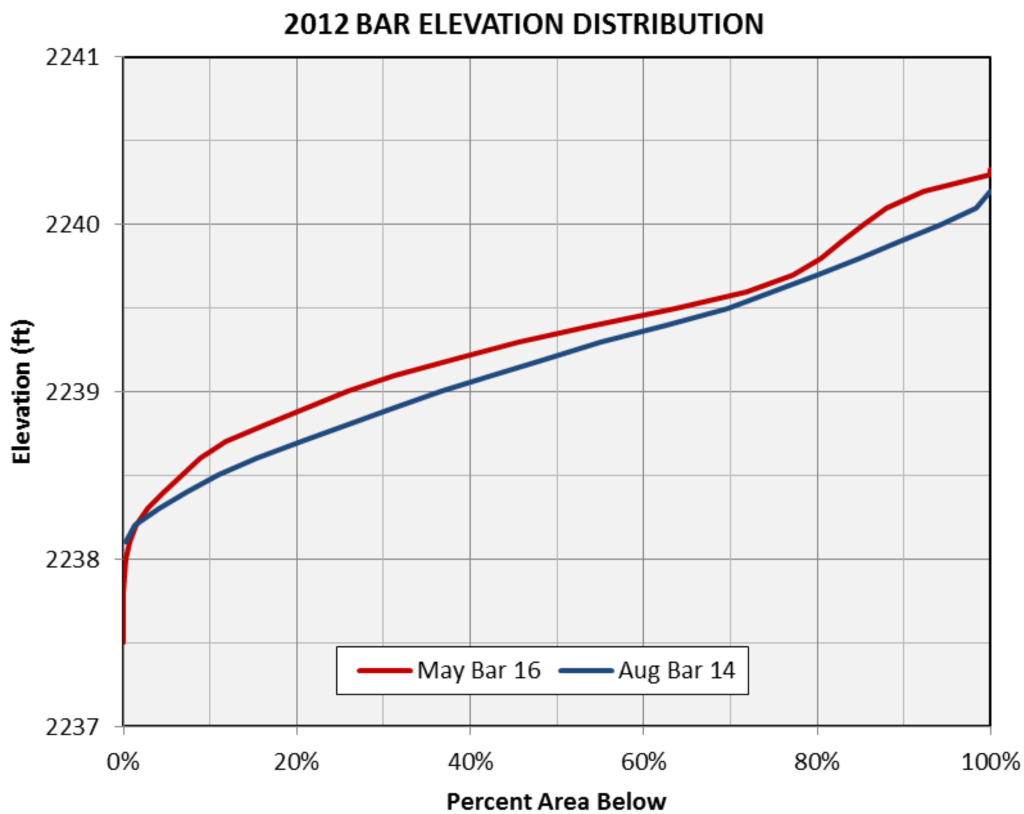


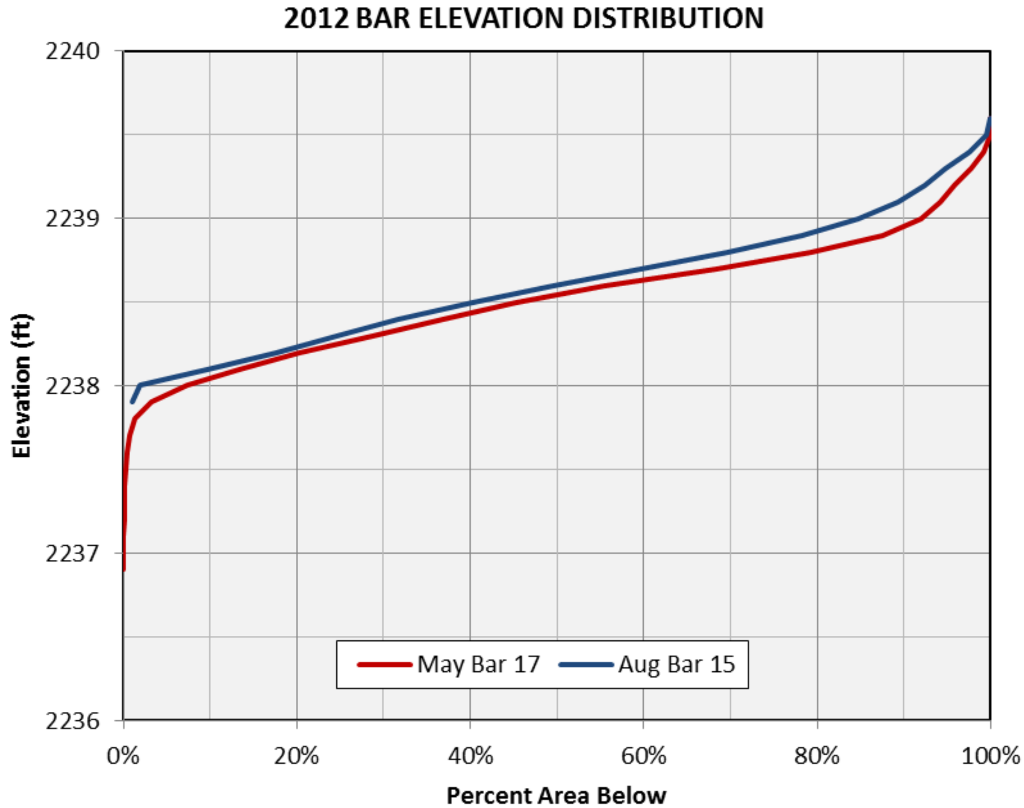
2012 BAR ELEVATION DISTRIBUTION
2245
2244
2243
2242
2241
2240
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 12
Aug Bar 10

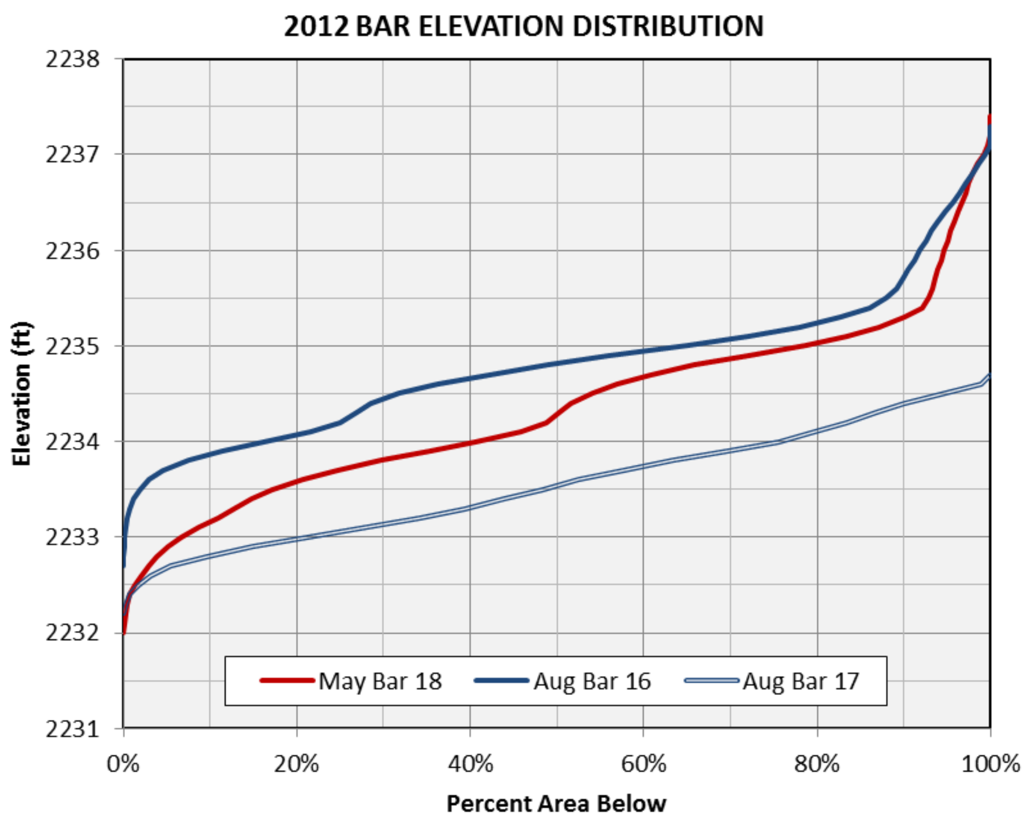

2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2238
2239
2240
2241
2242
2243
2244
2245
2246
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 13
Aug Bar 11


2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2239
2240
2241
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 14
Aug Bar 12


2012 BAR ELEVATION DISTRIBUTION
2242
2241
2240
2239
2238
2237
Elevation (ft)
May Bar 15
Aug Bar 13
0%
20%
40%
60%
80%
100%
Percent Area Below


2012 BAR ELEVATION DISTRIBUTION
2241
2240
2239
2238
2237
Elevation (ft)
May Bar 16
Aug Bar 14
0%
20%
40%
60%
80%
100%
Percent Area Below


2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2240
2239
2238
2237
2236
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 17
Aug Bar 15


2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2238
2237
2236
2235
2234
2233
2232
2231
0%
20%
40%
60%
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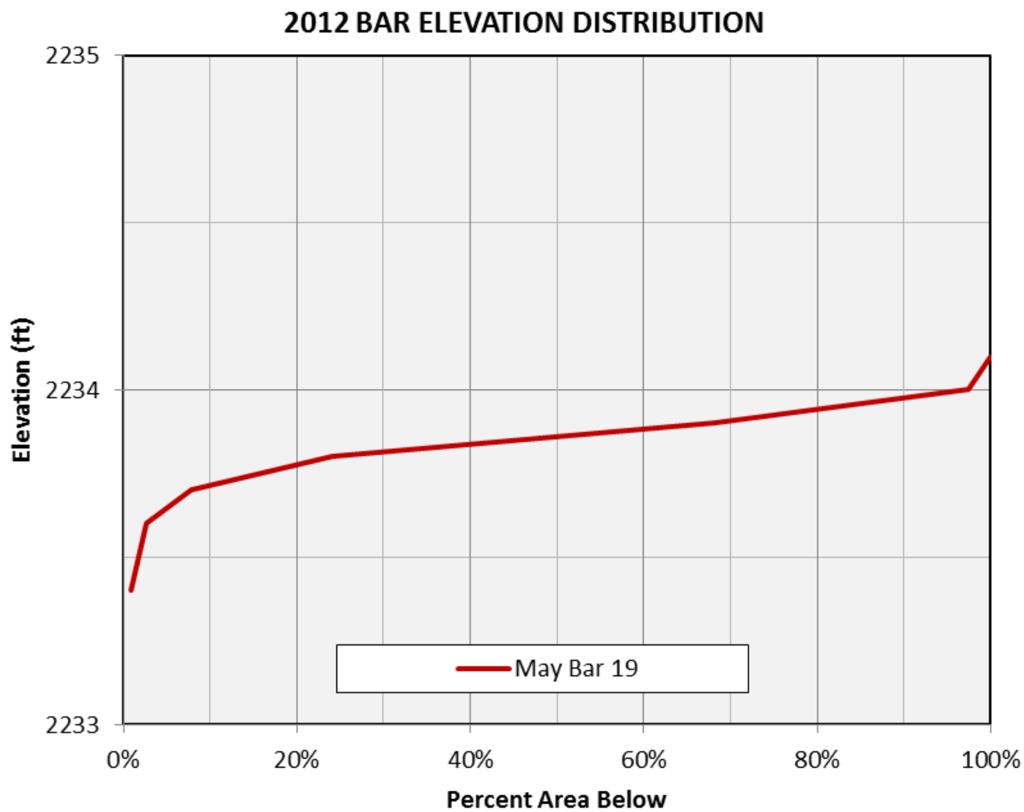
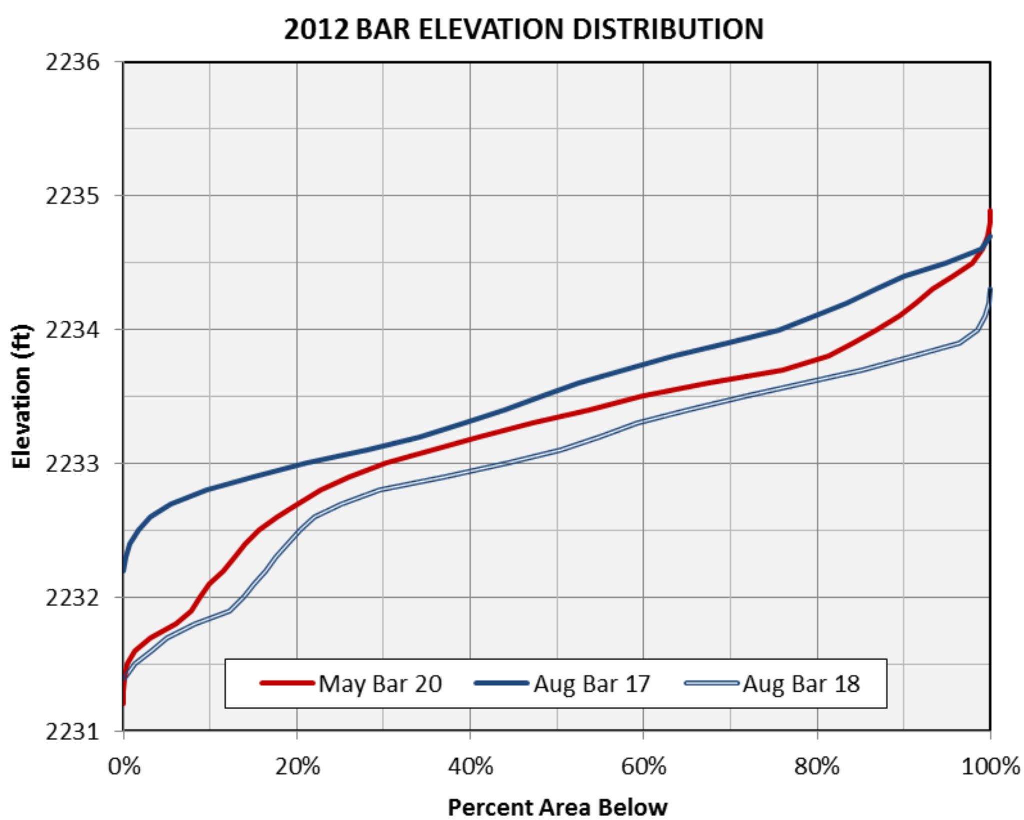
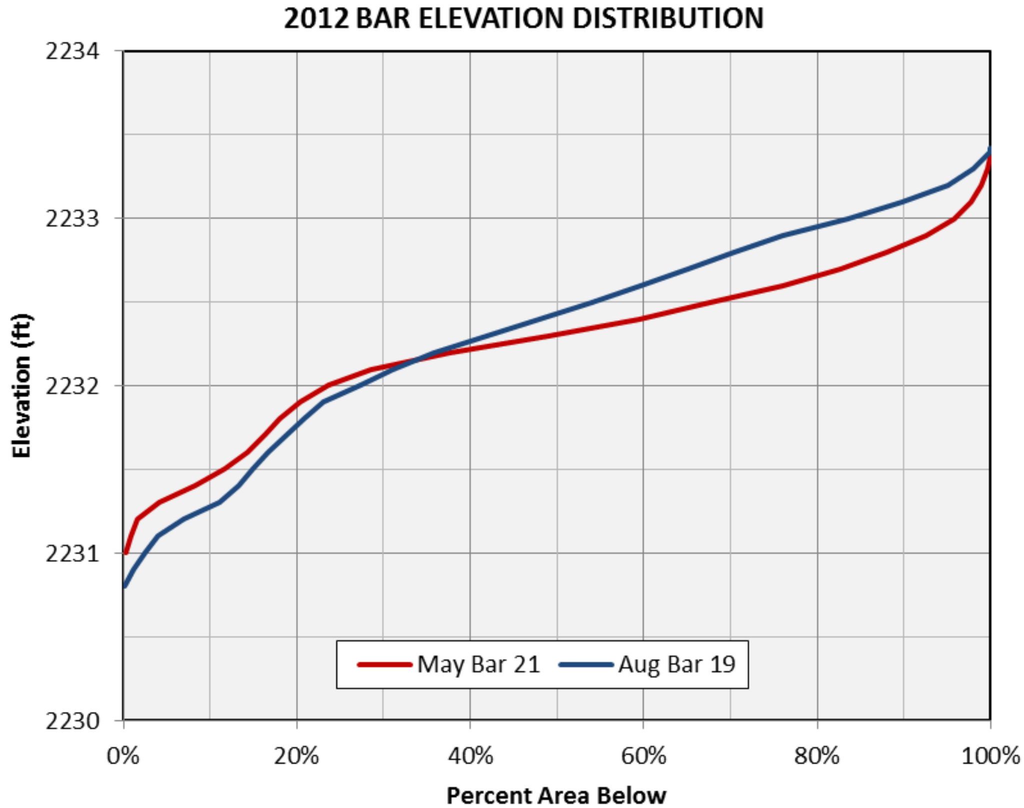
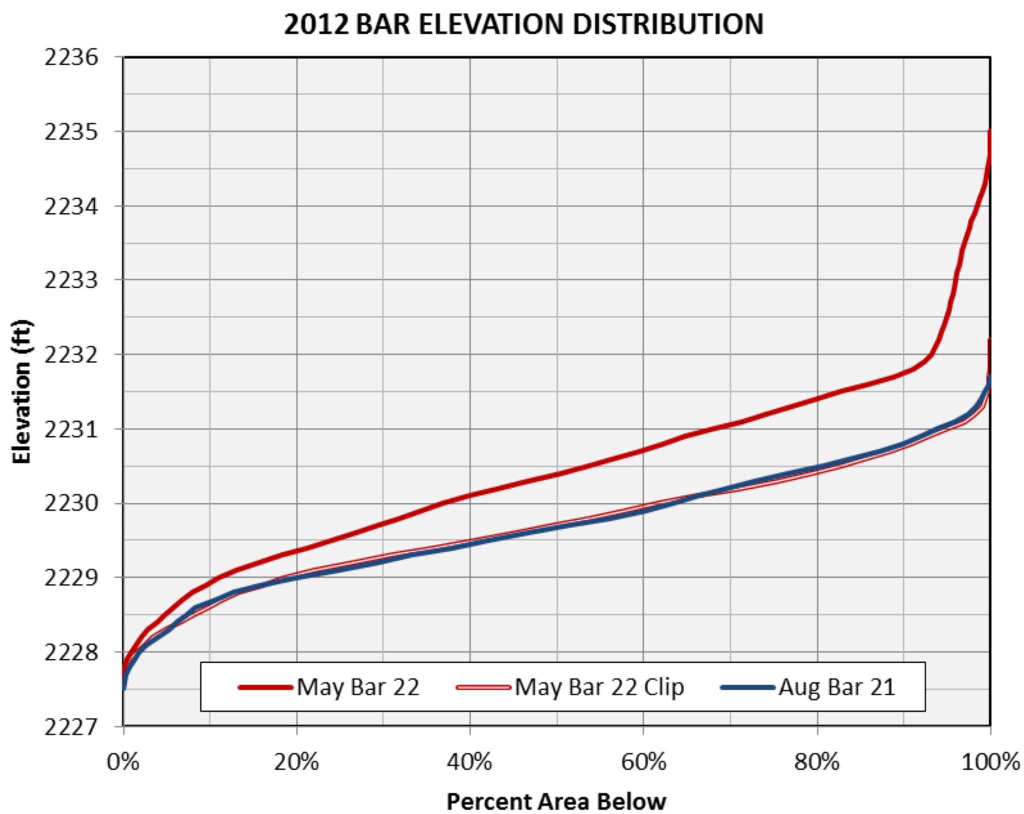
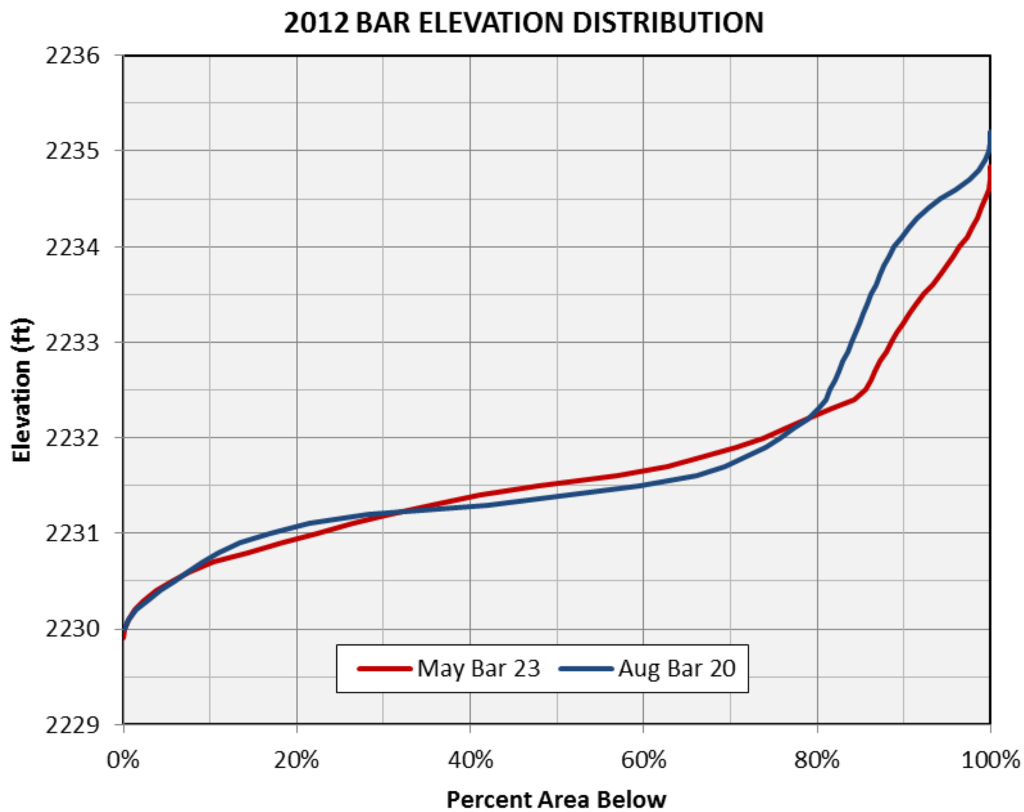
100%
Percent Area Below
May Bar 18
Aug Bar 16
Aug Bar 17

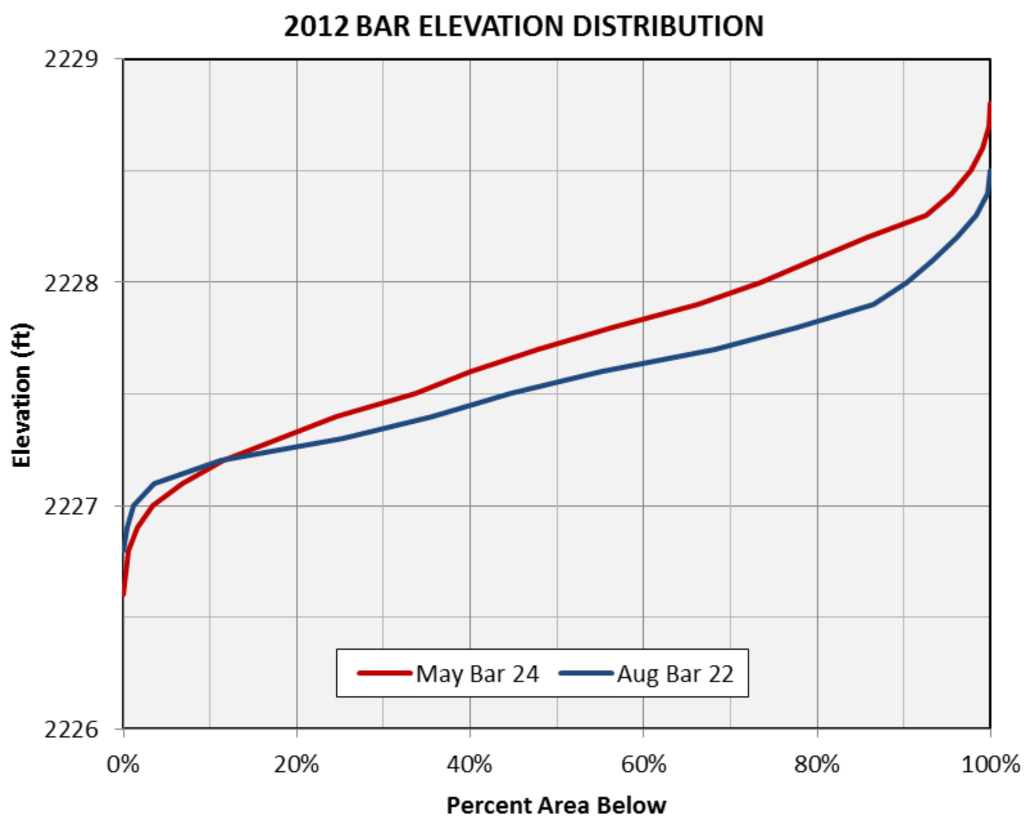

2012 BAR ELEVATION DISTRIBUTION
2235
2234
2233
Elevation (ft)
May Bar 19
0%
20%
40%
60%
80%
100%
Percent Area Below

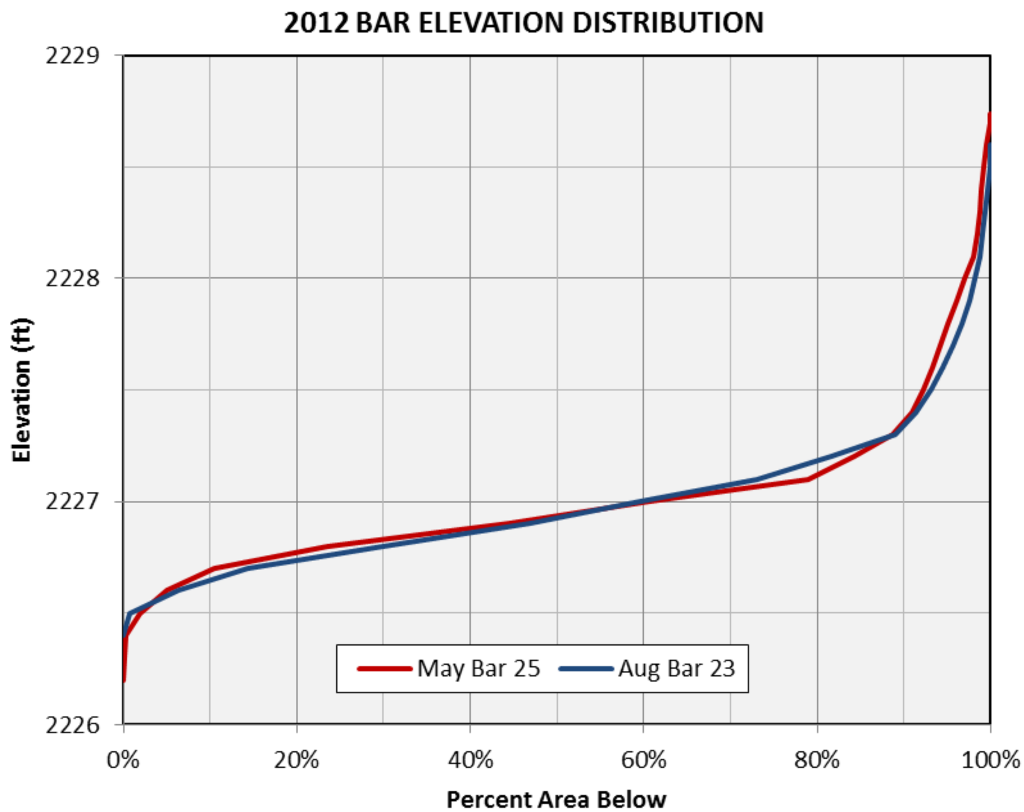

2012 BAR ELEVATION DISTRIBUTION
2236
2235
2234
2233
2232
2231
Elevation (ft)
May Bar 20
Aug Bar 17
Aug Bar 18
0%
20%
40%
60%
80%
100%
Percent Area Below

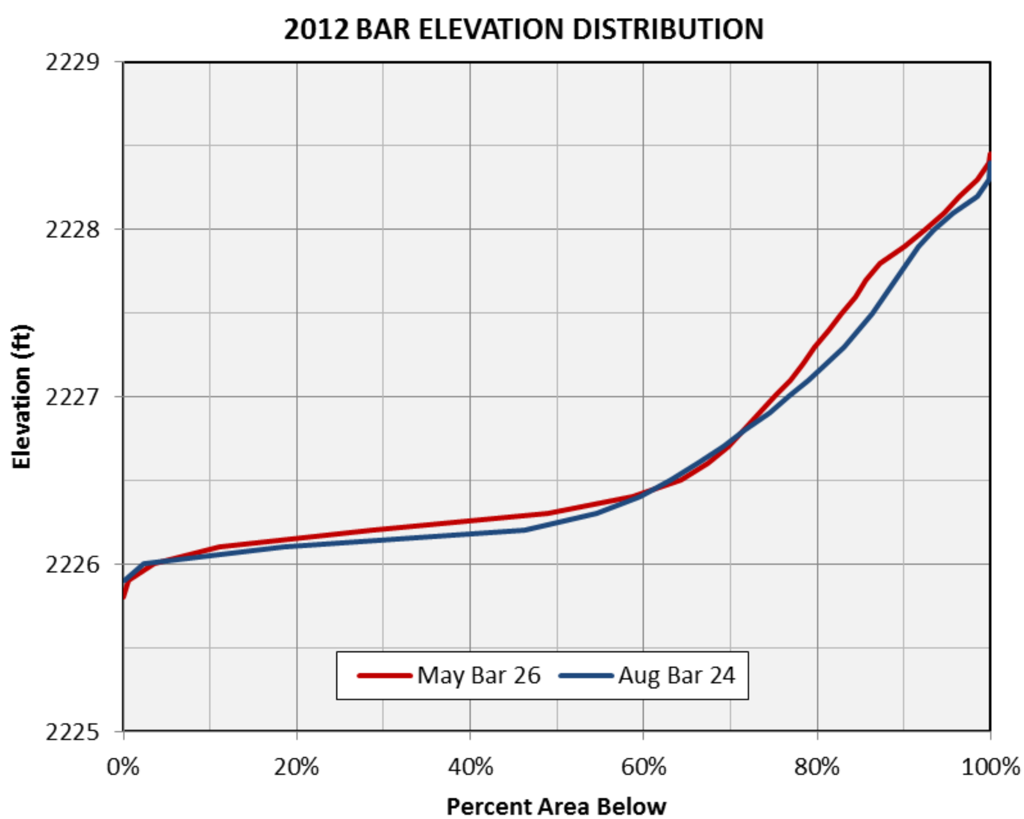

2012 BAR ELEVATION DISTRIBUTION
2234
2233
2232
2231
2230
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 21
Aug Bar 19

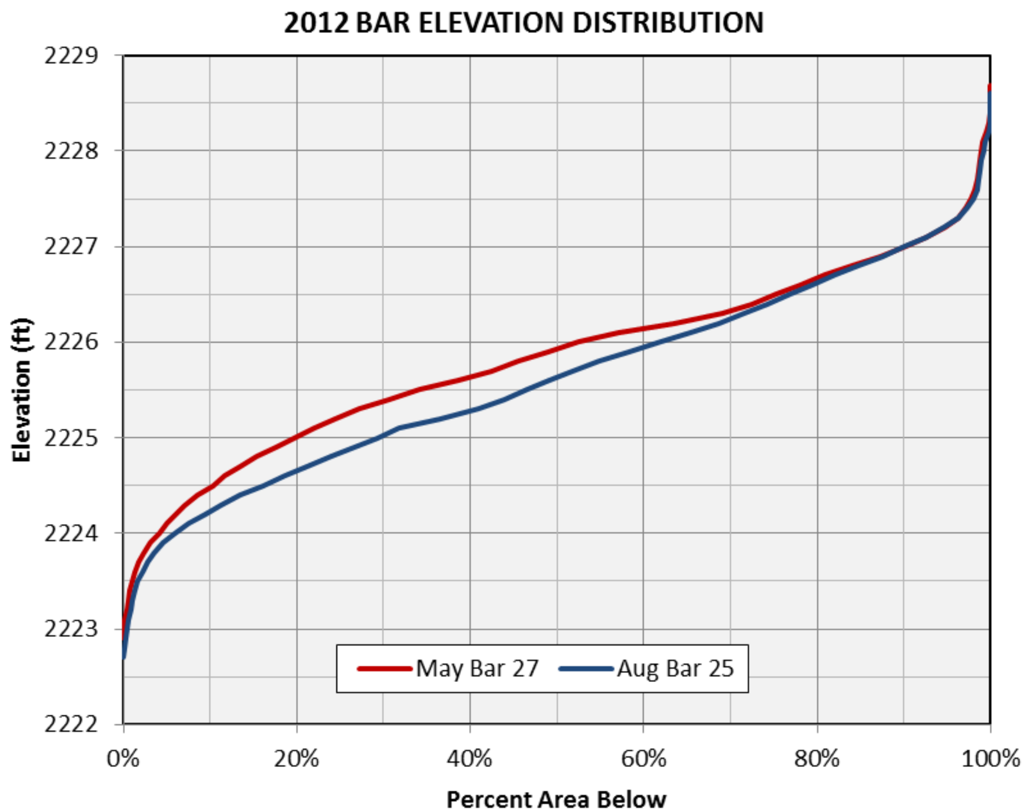

2012 BAR ELEVATION DISTRIBUTION
2236
2235
2234
2233
2232
2231
2230
2229
2228
2227
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 22
May Bar 22 Clip
Aug Bar 21

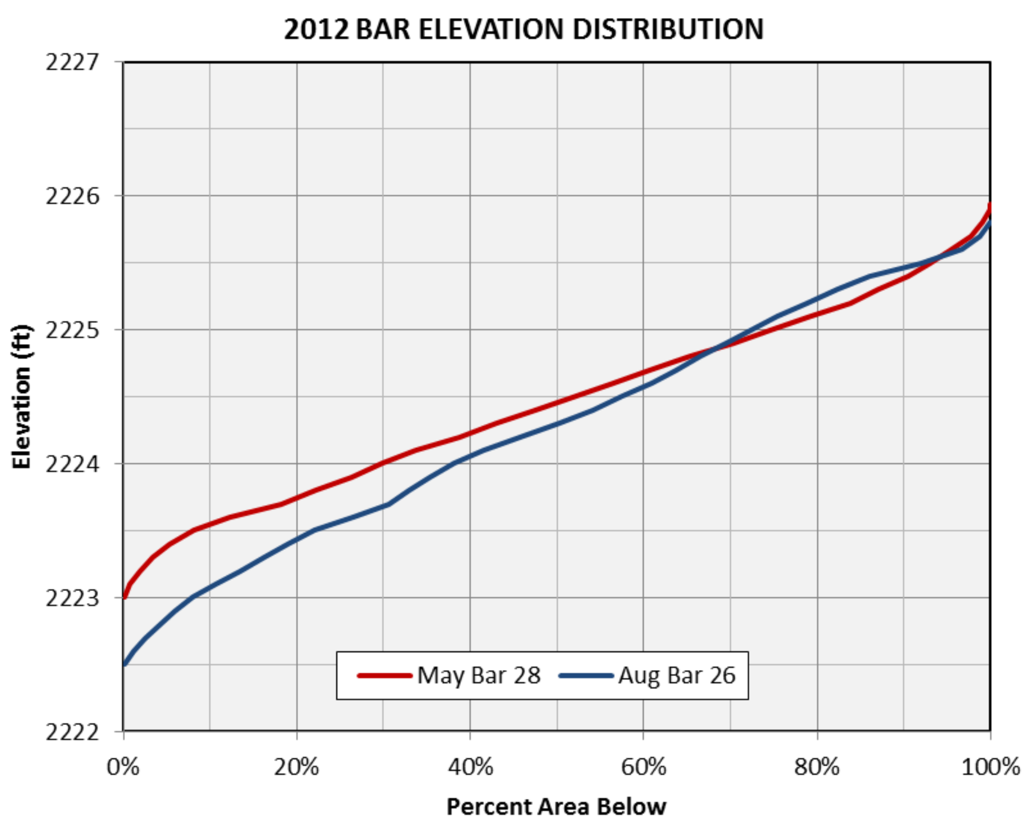

2012 BAR ELEVATION DISTRIBUTION
2236
2235
2234
2233
2232
2231
2230
2229
Elevation (ft)
May Bar 23
Aug Bar 20
0%
20%
40%
60%
80%
100%
Percent Area Below

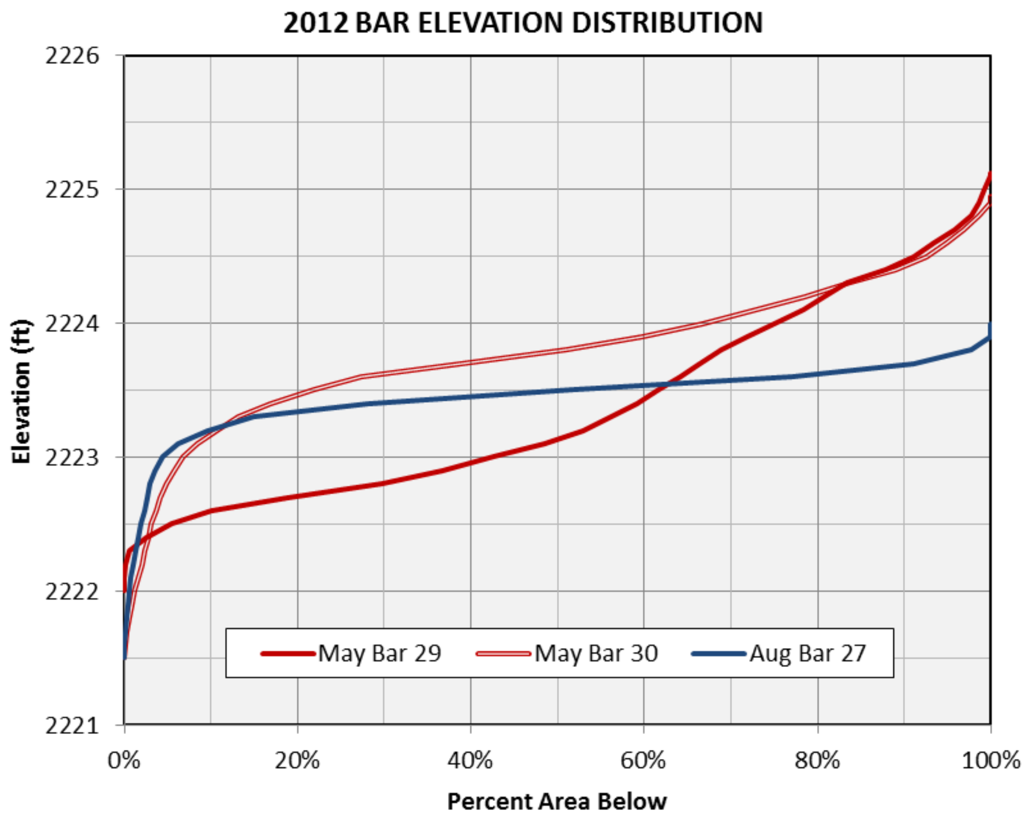

2012 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
Elevation (ft)
May Bar 24
Aug Bar 22
0%
20%
40%
60%
80%
100%
Percent Area Below

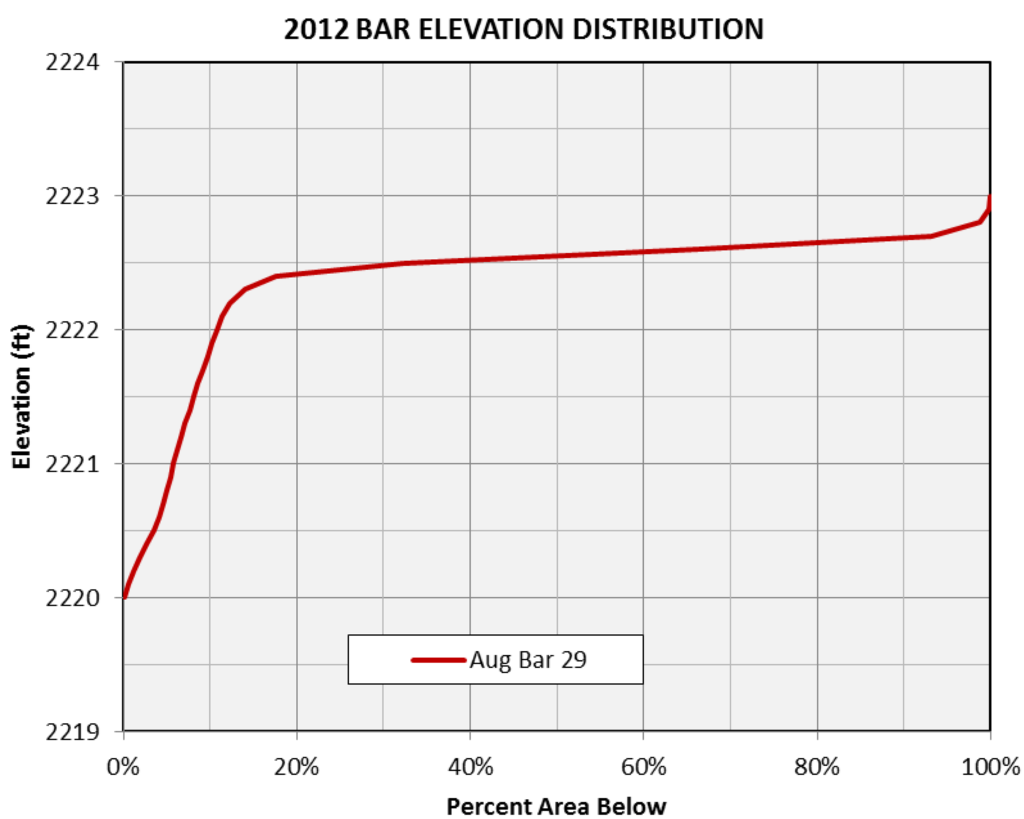

2012 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 25
Aug Bar 23

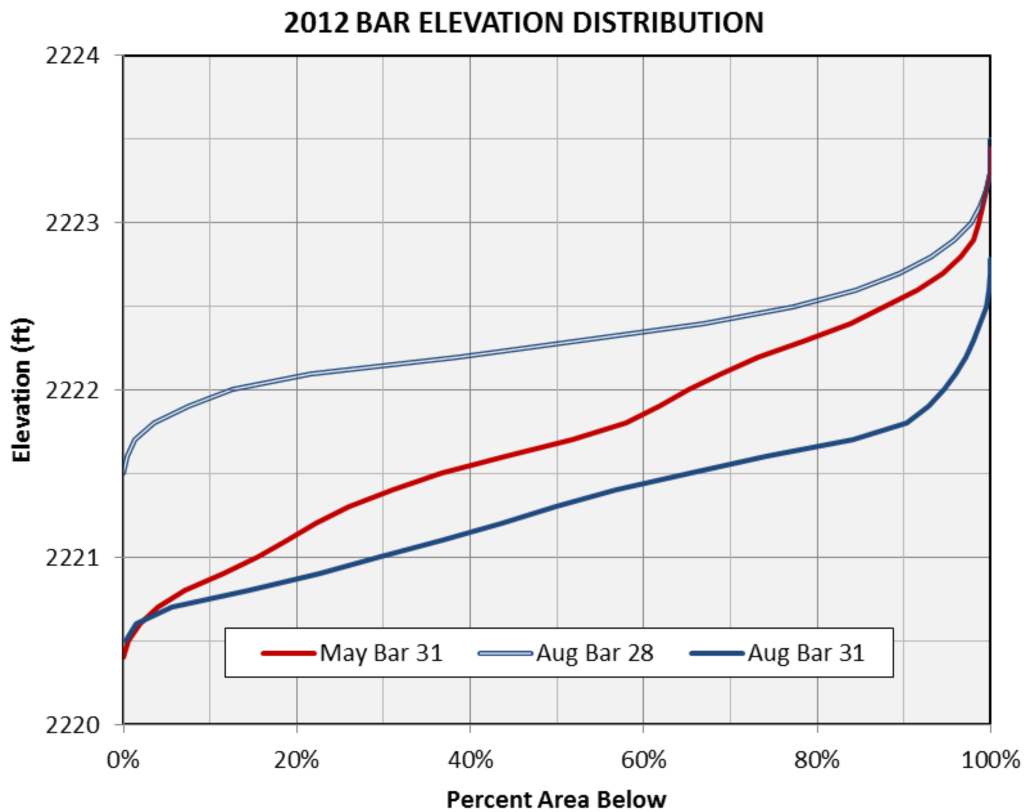

2012 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
2225
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 26
Aug Bar 24

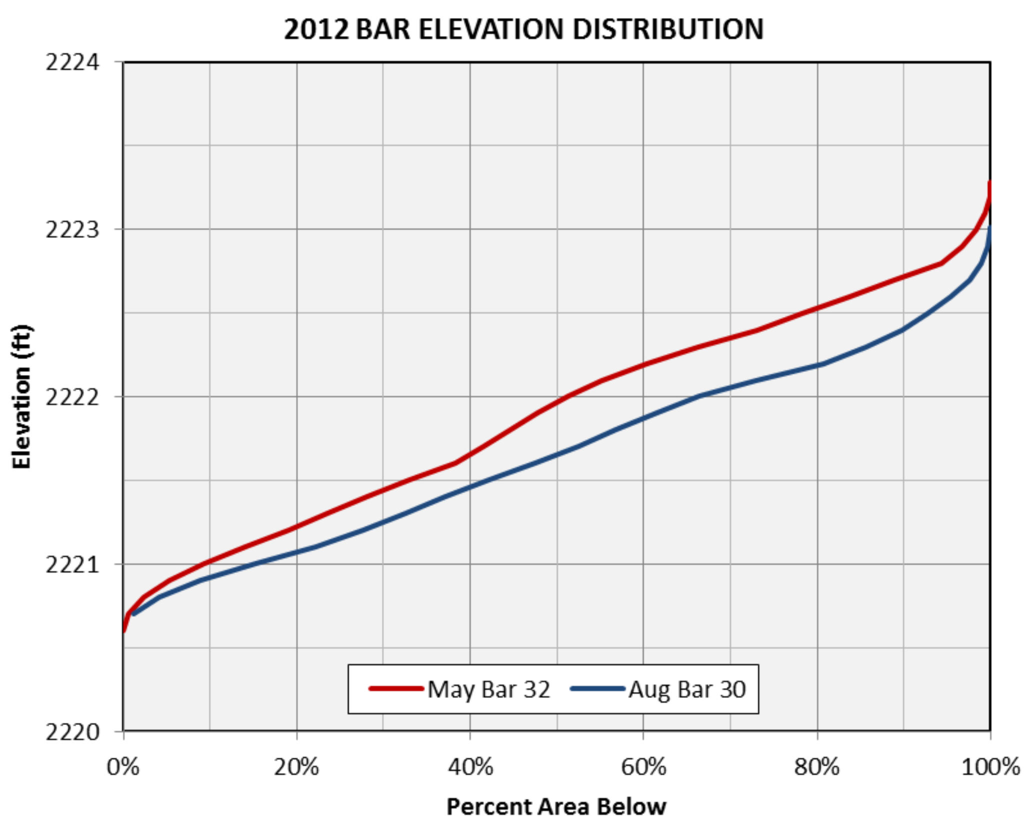

2012 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
2225
2224
2223
2222
Elevation (ft)
May Bar 27
Aug Bar 25
0%
20%
40%
60%
80%
100%
Percent Area Below

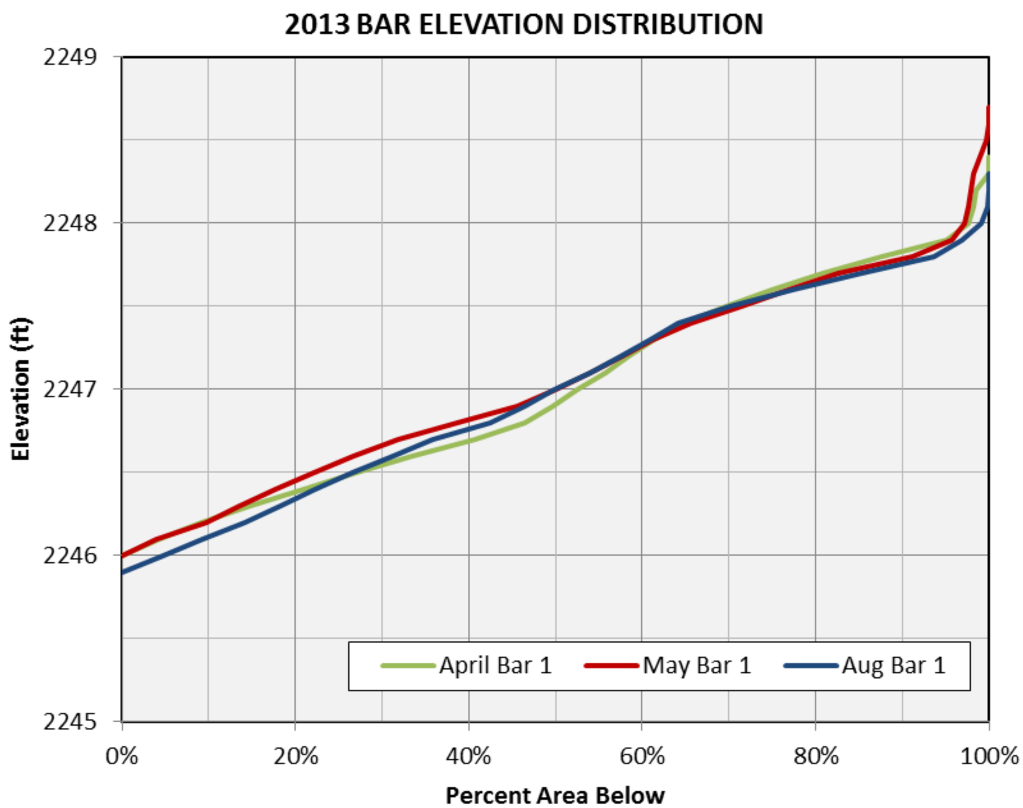

2012 BAR ELEVATION DISTRIBUTION
2227
2226
2225
2224
2223
2222
Elevation (ft)
May Bar 28
Aug Bar 26
0%
20%
40%
60%
80%
100%
Percent Area Below

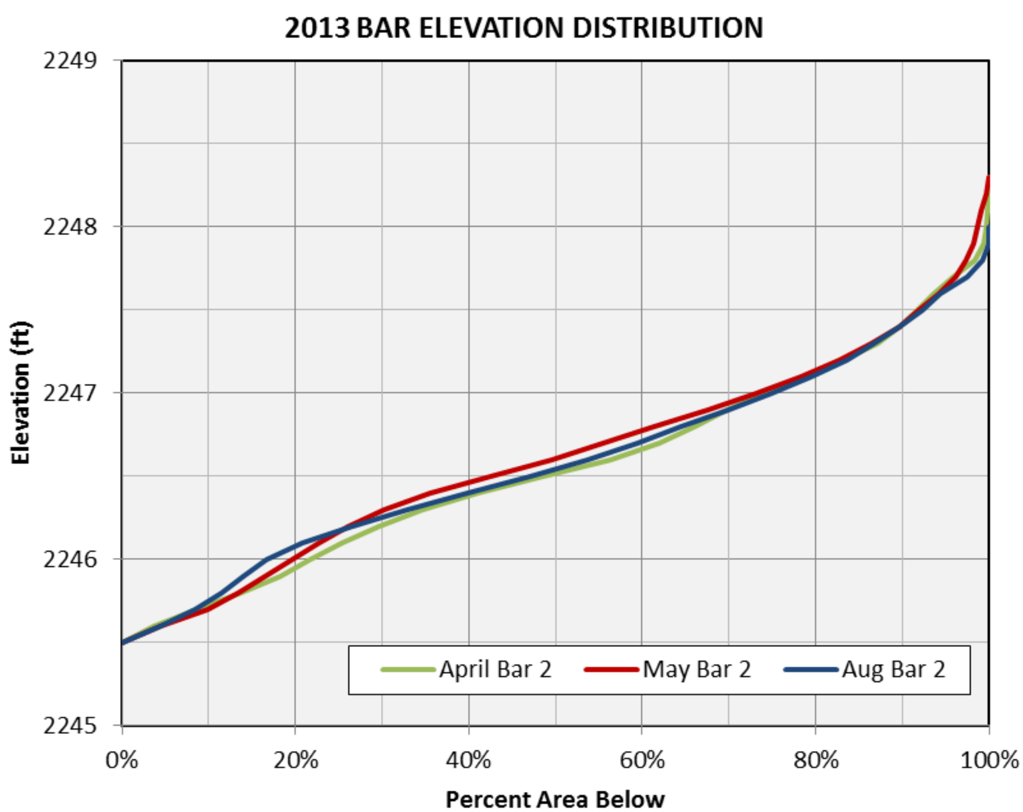

2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2226
2225
2224
2223
2222
2221
May Bar 29
May Bar 30
Aug Bar 27
0%
20%
40%
60%
80%
100%
Percent Area Below

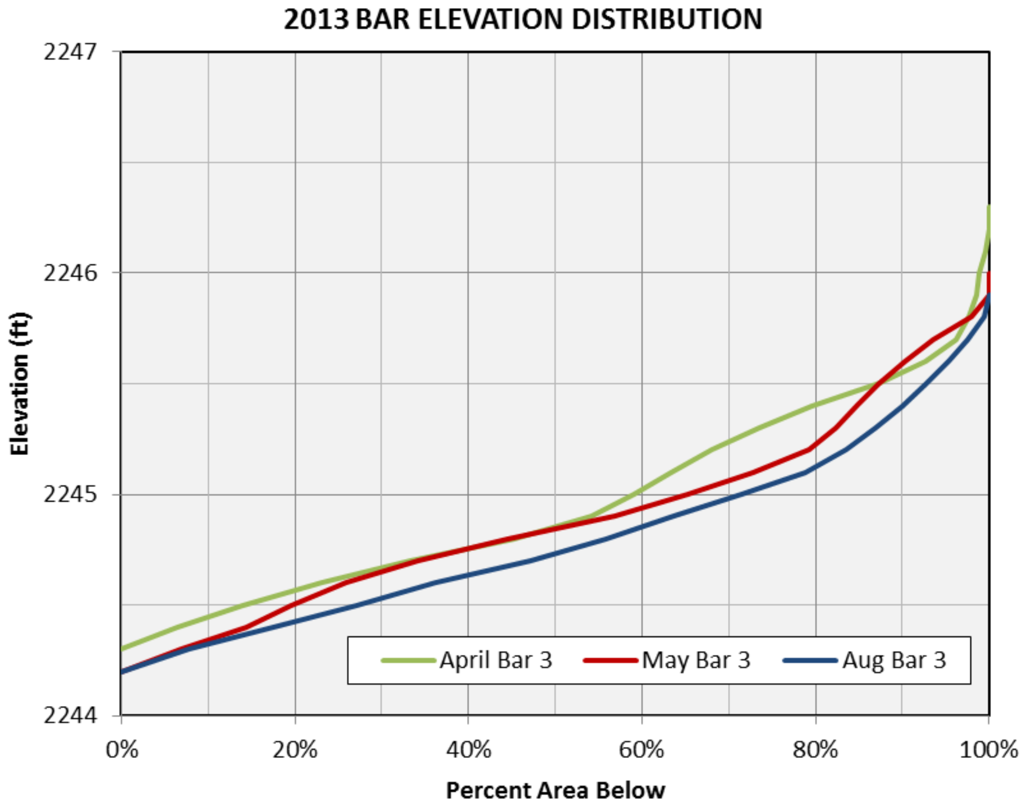

2012 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2224
2223
2222
2221
2220
2219
Aug Bar 29
0%
20%
40%
60%
80%
100%
Percent Area Below

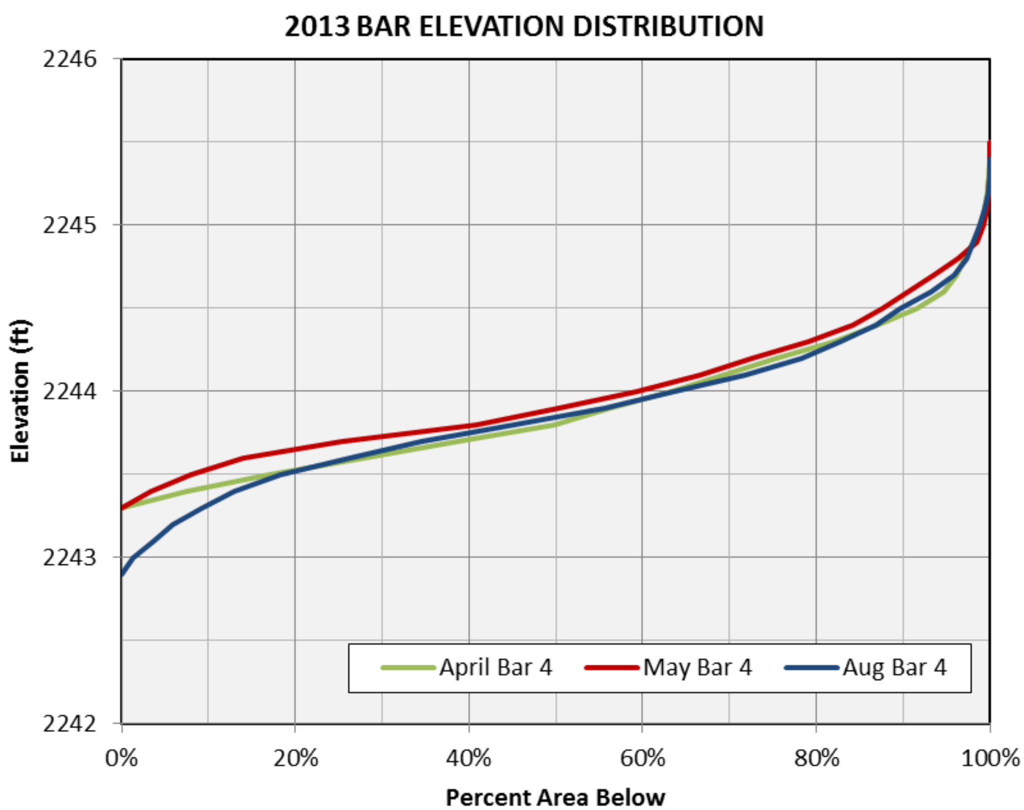

2012 BAR ELEVATION DISTRIBUTION
2224
2223
2222
2221
2220
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 31
Aug Bar 28
Aug Bar 31

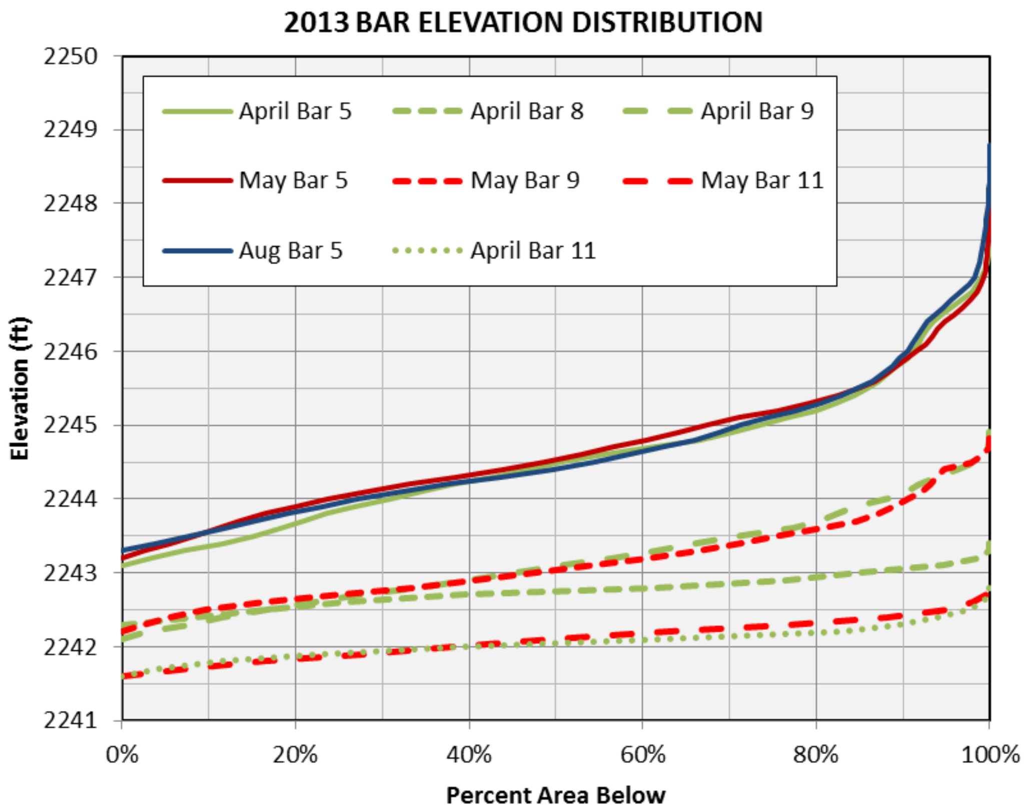

2012 BAR ELEVATION DISTRIBUTION
2224
2223
2222
2221
2220
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
May Bar 32
Aug Bar 30

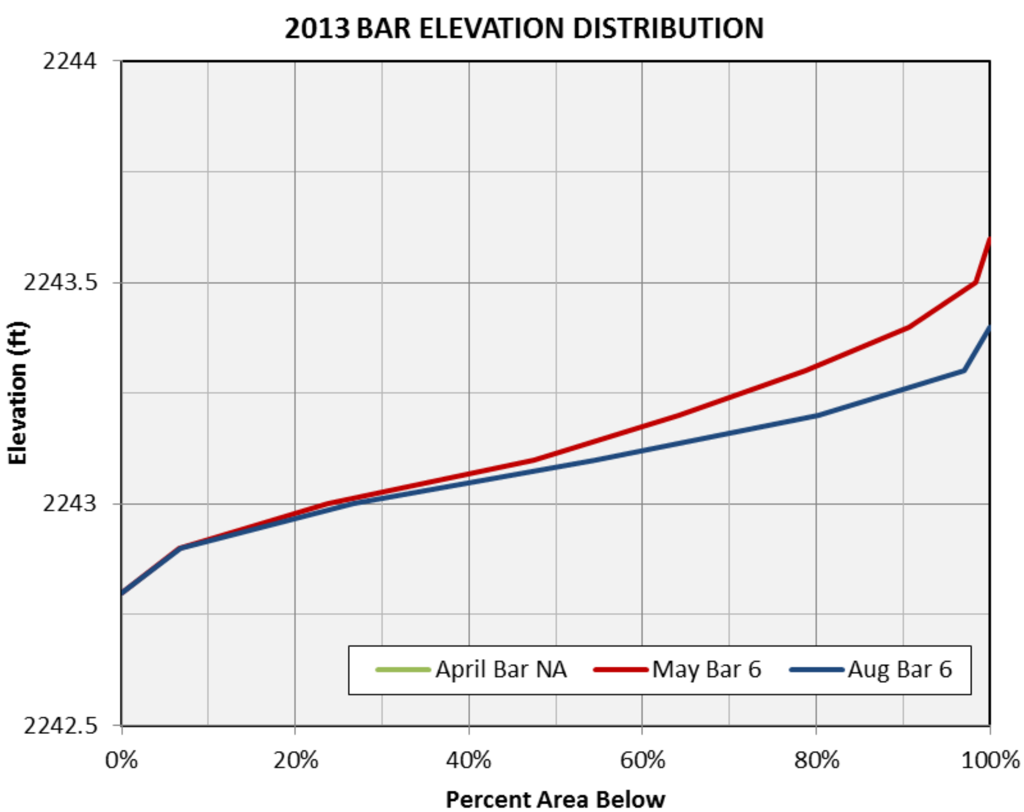

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2249
2248
2247
2246
2245
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 1
May Bar 1
Aug Bar 1

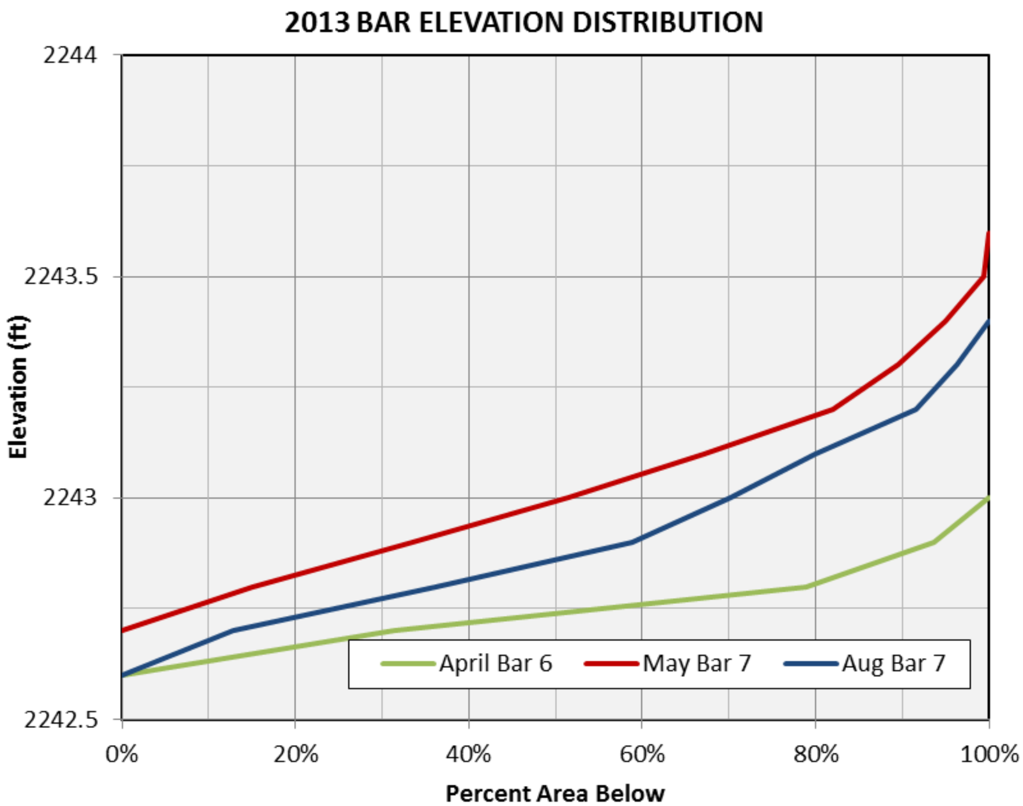

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2249
2248
2247
2246
2245
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 2
May Bar 2
Aug Bar 2

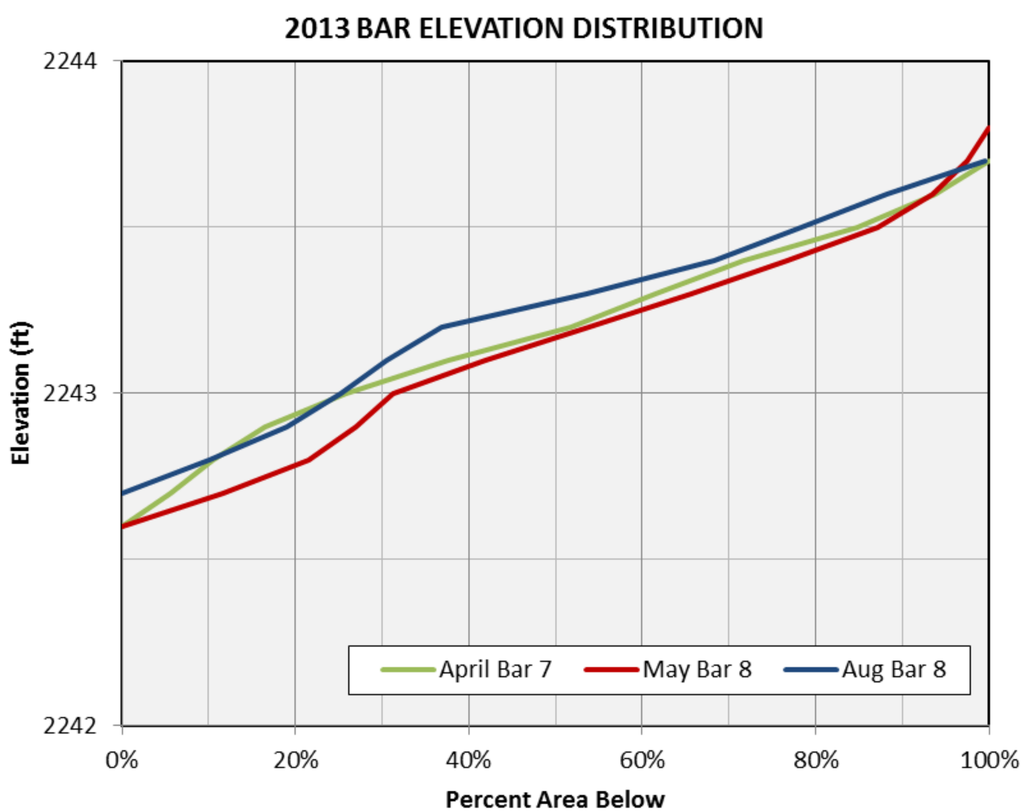

2013 BAR ELEVATION DISTRIBUTION
2247
2246
2245
2244
Elevation (ft)
April Bar 3
May Bar 3
Aug Bar 3
0%
20%
40%
60%
80%
100%
Percent Area Below

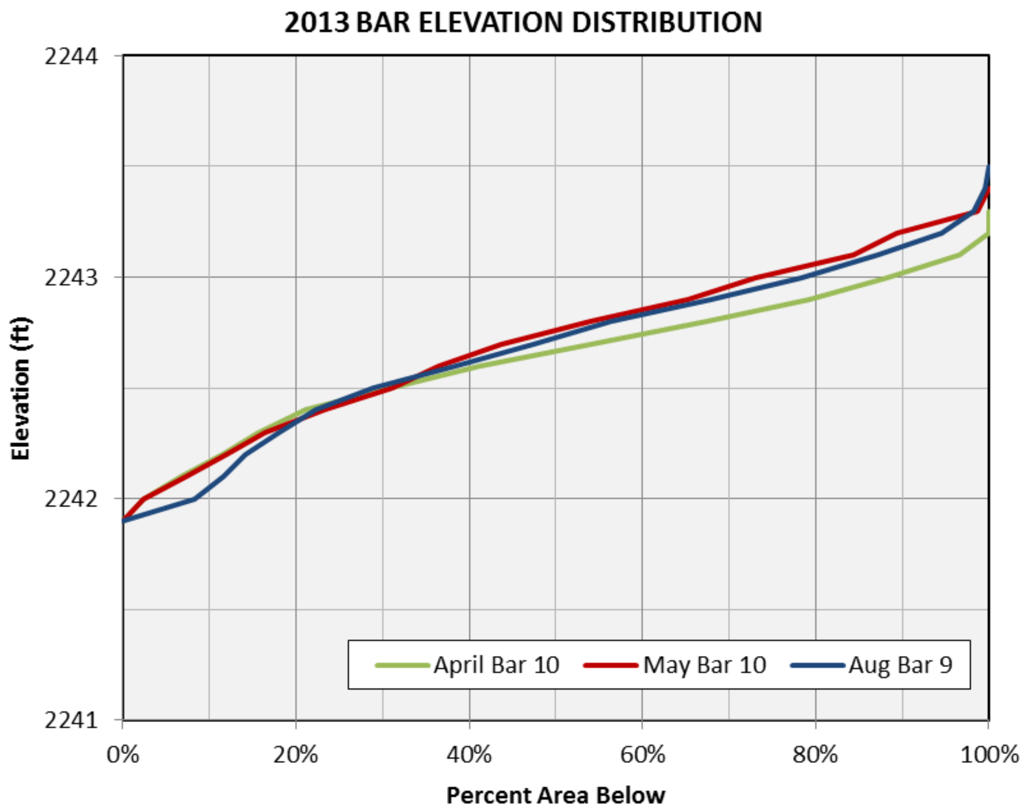

2013 BAR ELEVATION DISTRIBUTION
2246
2245
2244
2243
2242
Elevation (ft)
April Bar 4
May Bar 4
Aug Bar 4
0%
20%
40%
60%
80%
100%
Percent Area Below

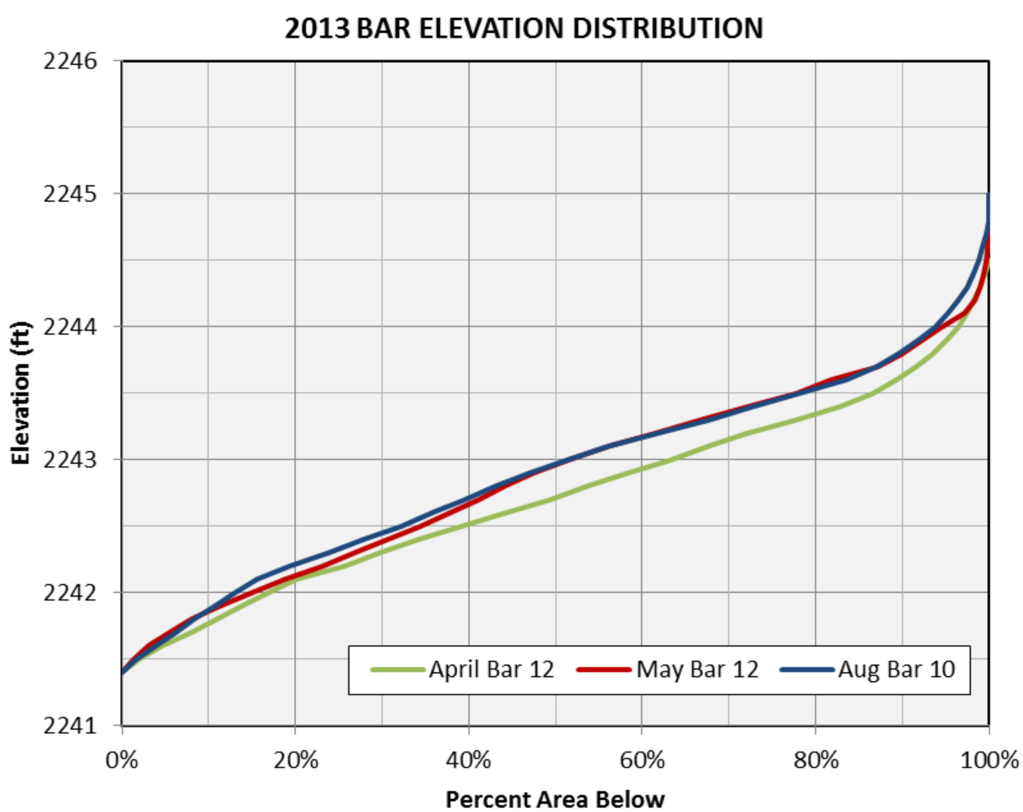

2013 BAR ELEVATION DISTRIBUTION
April Bar 5
April Bar 8
April Bar 9
May Bar 5
May Bar 9
May Bar 11
Aug Bar 5
April Bar 11
Elevation (ft)
2250
2249
2248
2247
2246
2245
2244
2243
2242
2241
0%
20%
40%
60%
80%
100%
Percent Area Below

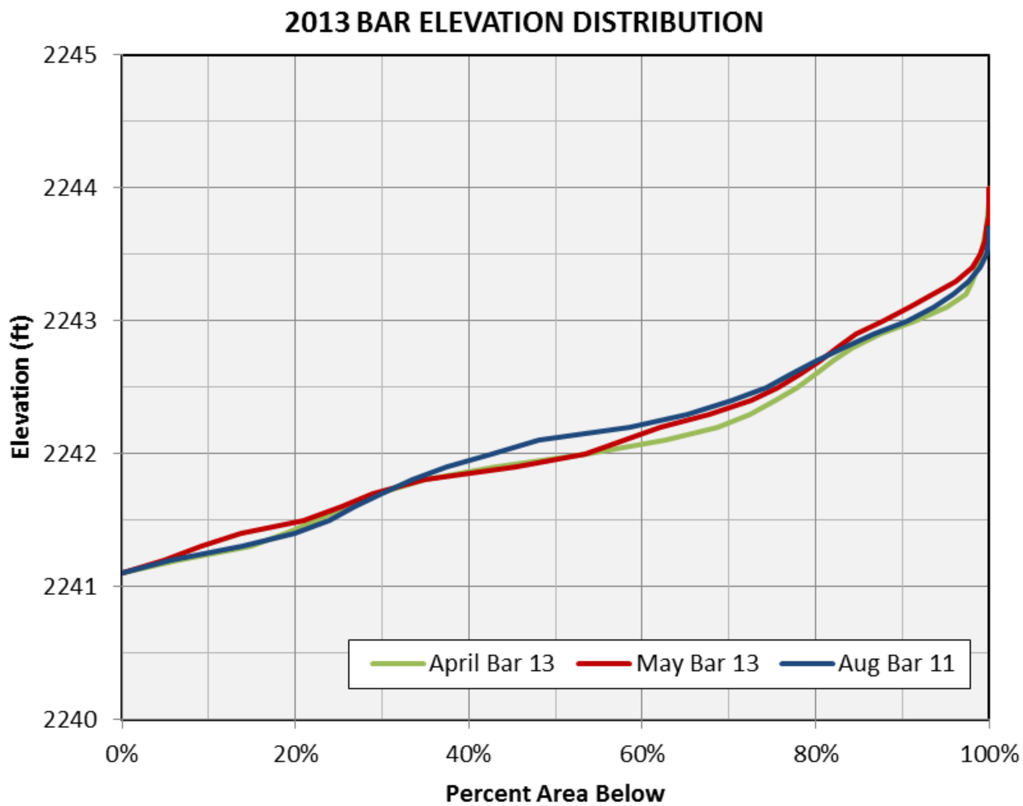

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2244
2243.5
2243
2242.5
April Bar NA
May Bar 6
Aug Bar 6
0%
20%
40%
60%
80%
100%
Percent Area Below


2013 BAR ELEVATION DISTRIBUTION
2244
2243.5
2243
2242.5
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 6
May Bar 7
Aug Bar 7

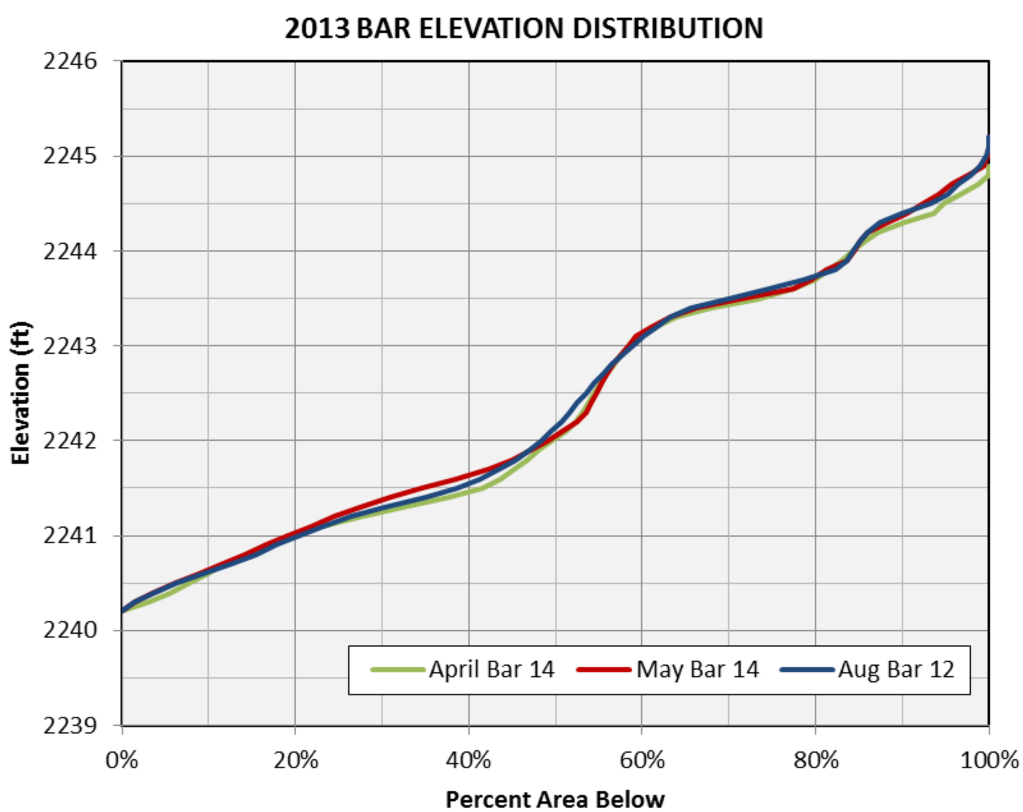

2013 BAR ELEVATION DISTRIBUTION
2244
2243
2242
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 7
May Bar 8
Aug Bar 8


2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2244
2243
2242
2241
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 10
May Bar 10
Aug Bar 9

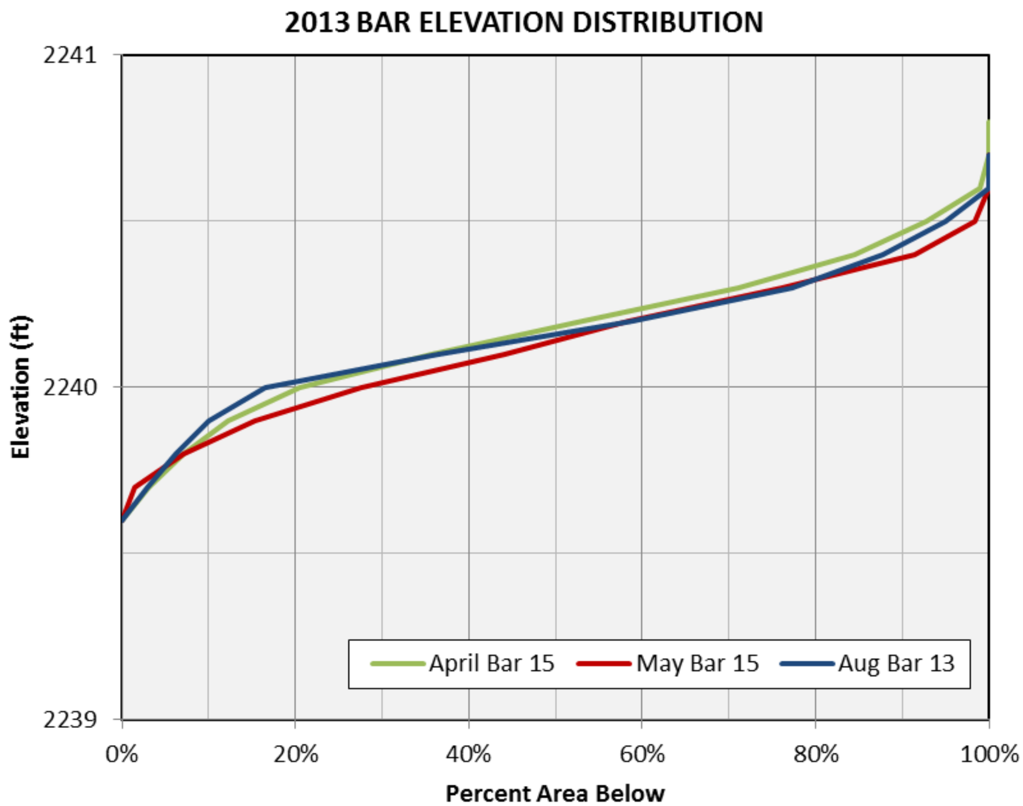

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2246
2245
2244
2243
2242
2241
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 12
May Bar 12
Aug Bar 10



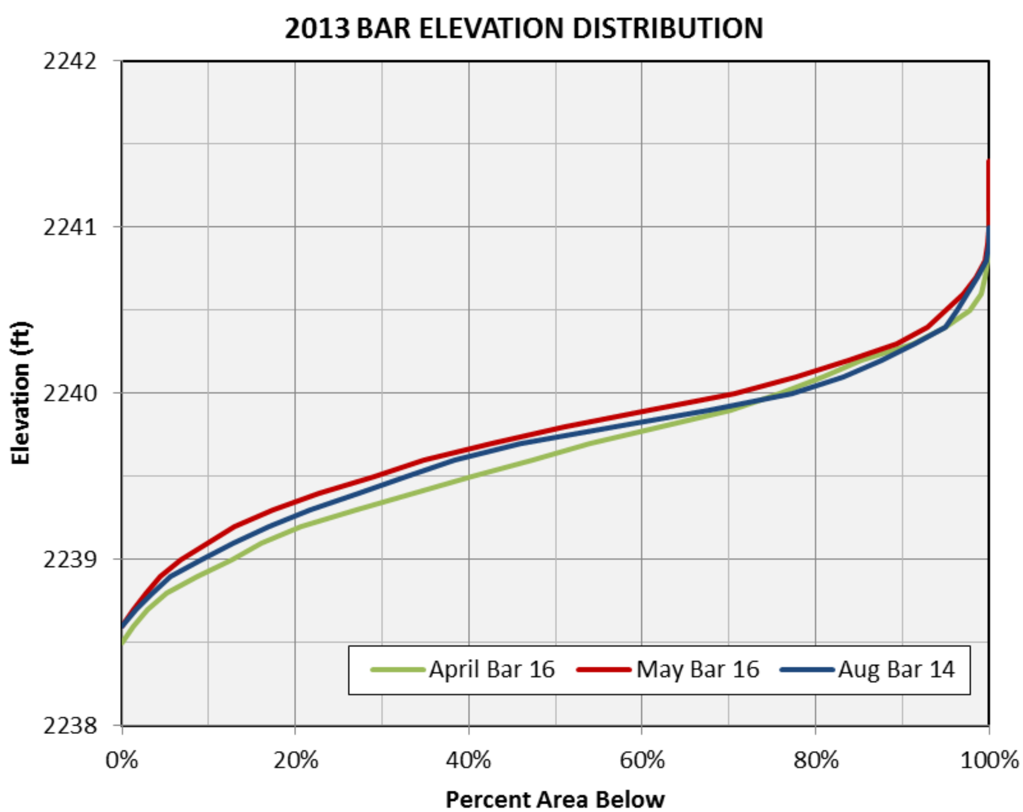
2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2245
2244
2243
2242
2241
2240
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 13
May Bar 13
Aug Bar 11



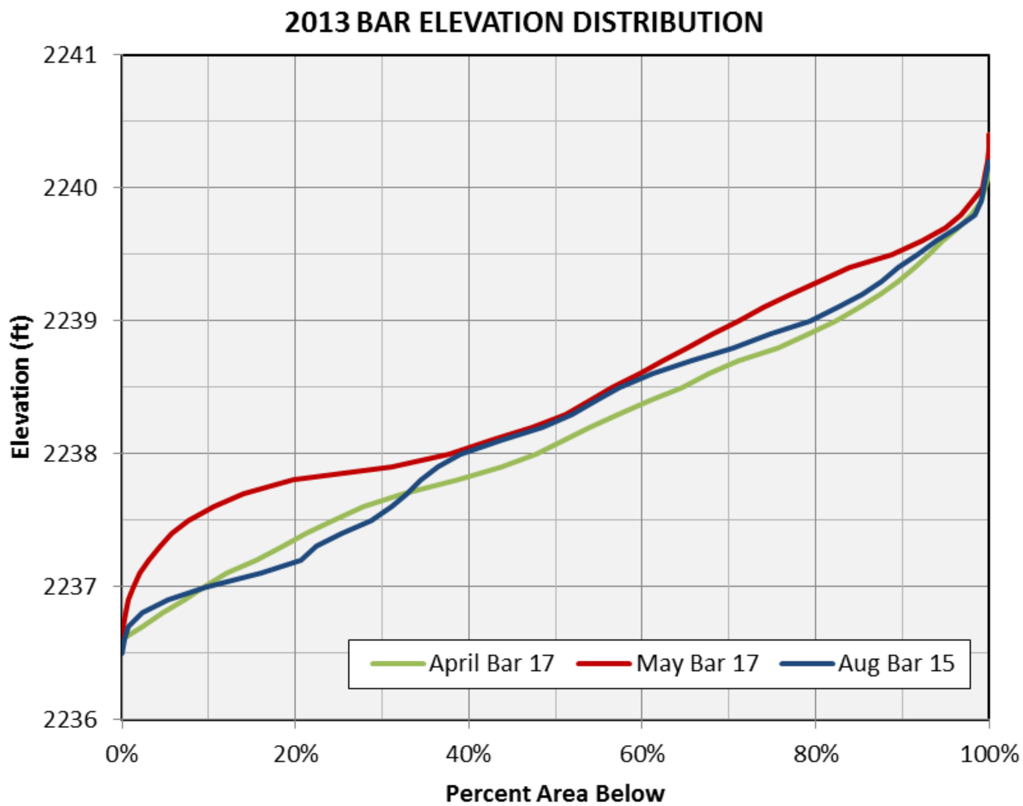
2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2246
2245
2244
2243
2242
2241
2240
2239
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 14
May Bar 14
Aug Bar 12

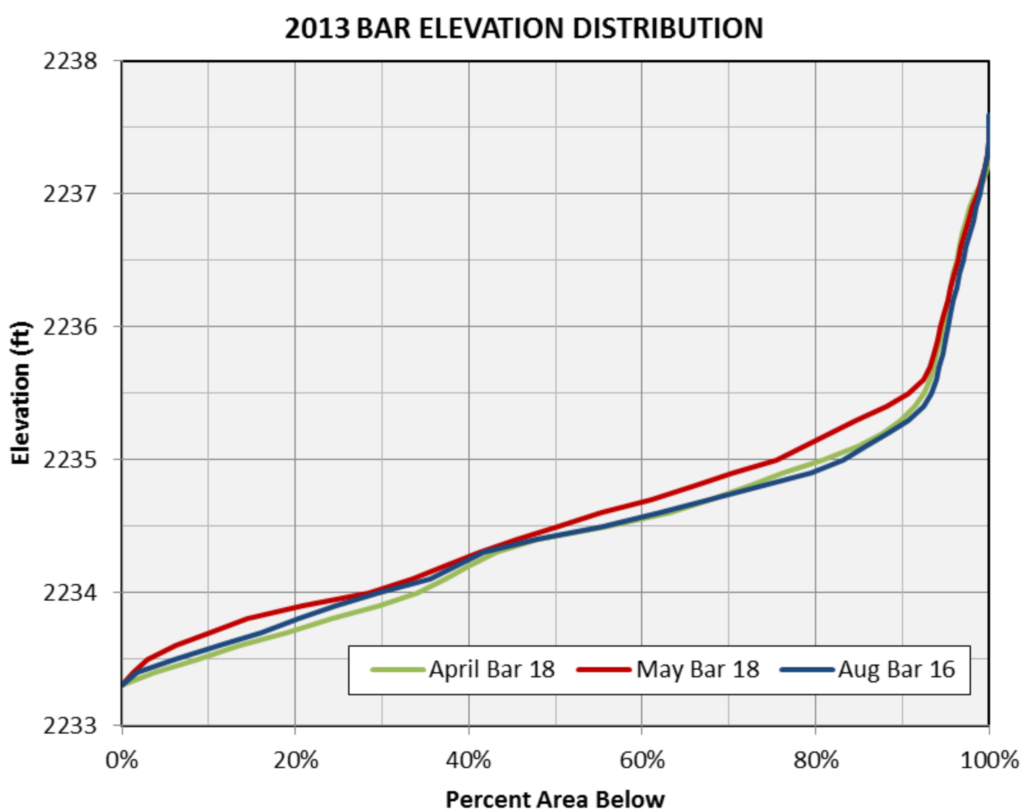


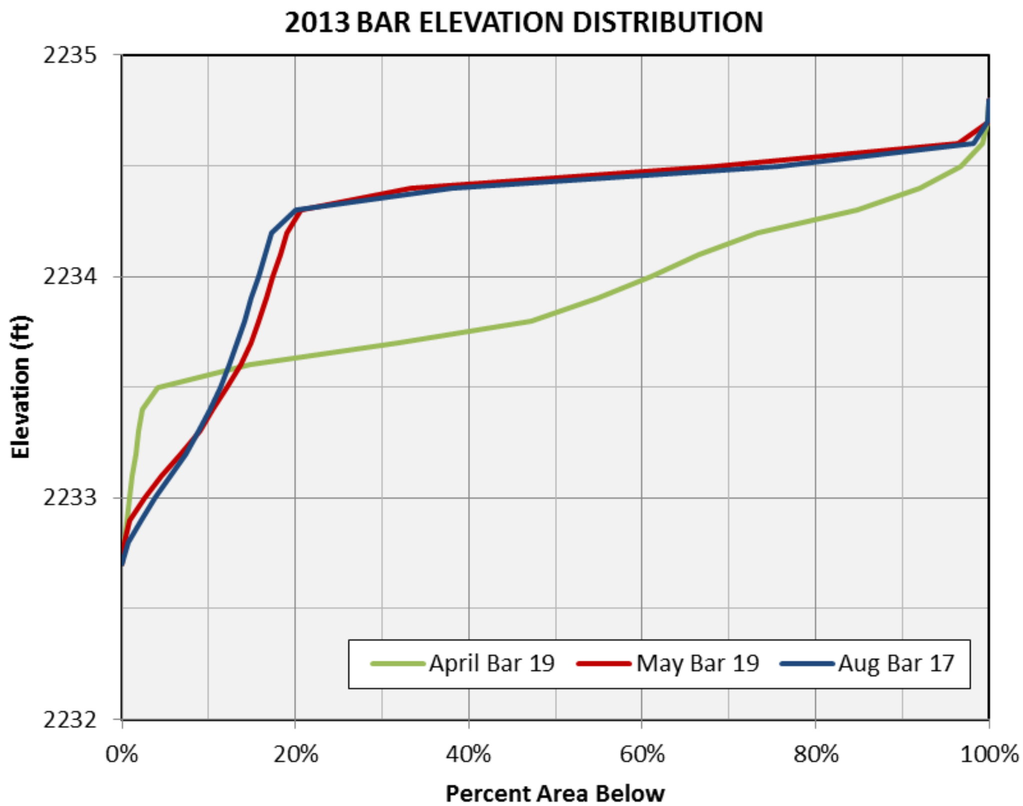
2013 BAR ELEVATION DISTRIBUTION
2241
2240
2239
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 15
May Bar 15
Aug Bar 13

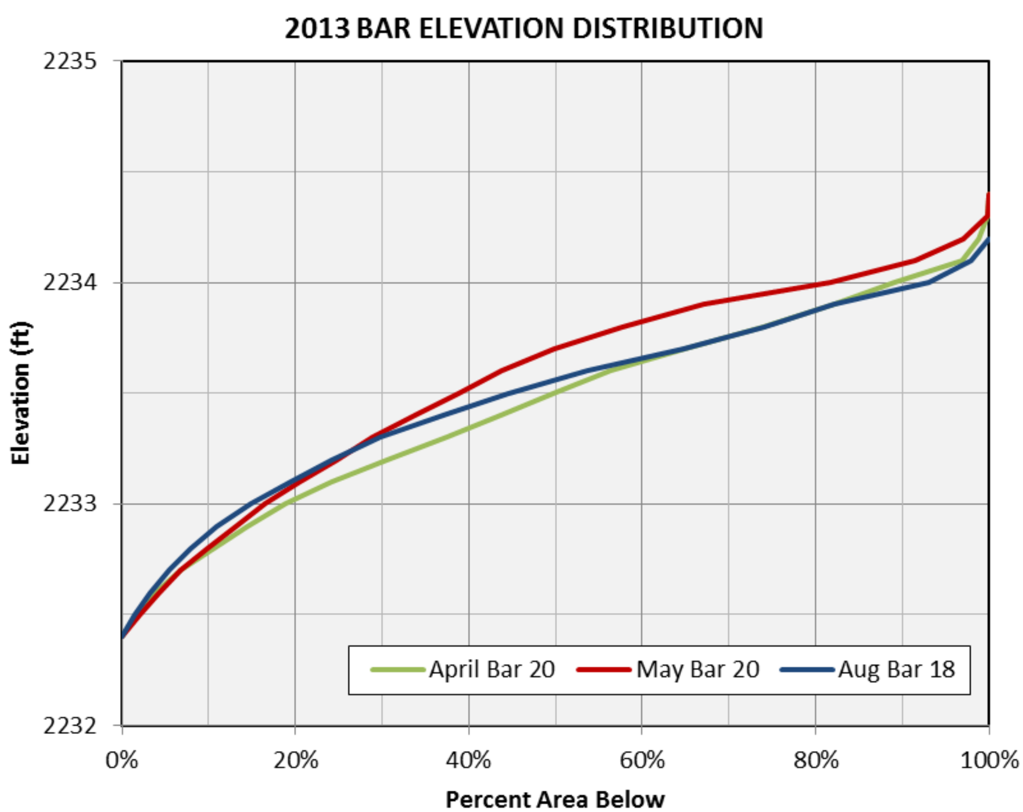


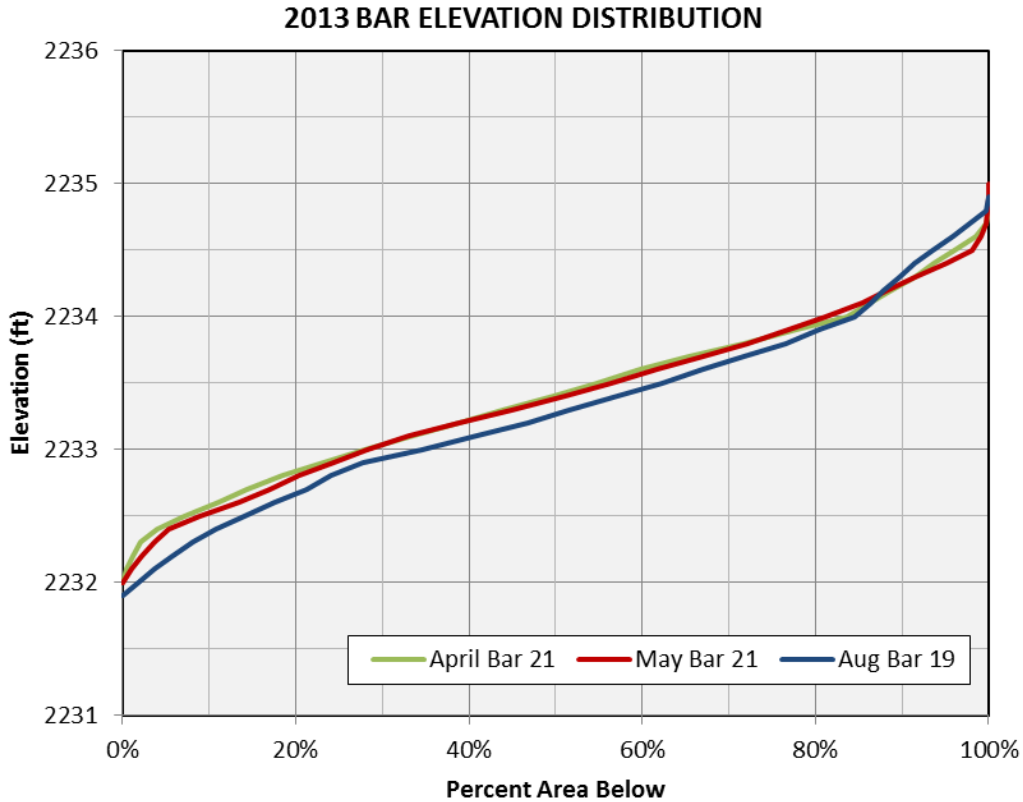
2013 BAR ELEVATION DISTRIBUTION
2242
2241
2240
2239
2238
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 16
May Bar 16
Aug Bar 14

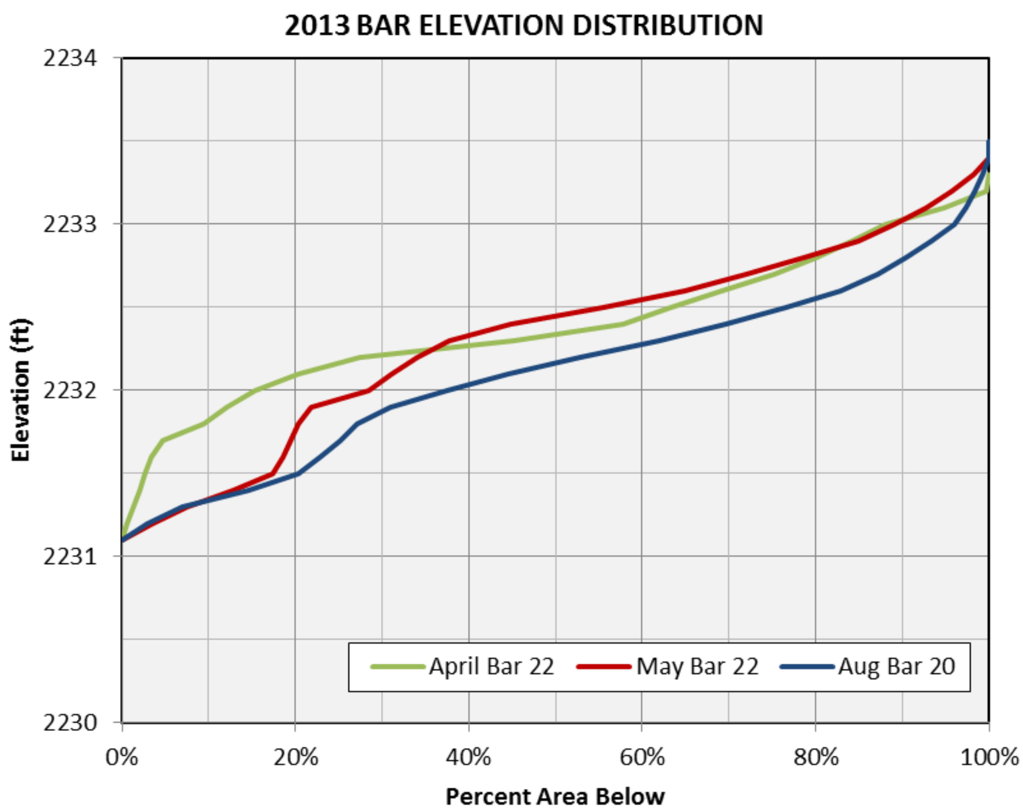

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2241
2240
2239
2238
2237
2236
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 17
May Bar 17
Aug Bar 15

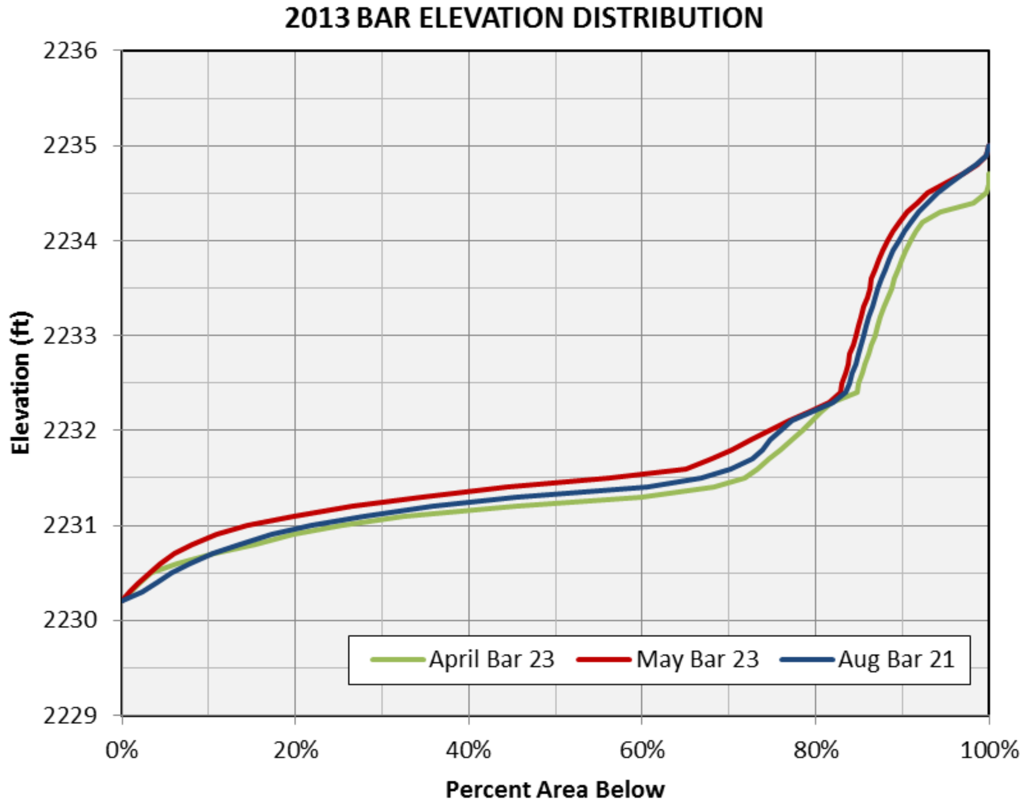

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2238
2237
2236
2235
2234
2233
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 18
May Bar 18
Aug Bar 16


2013 BAR ELEVATION DISTRIBUTION
2235
2234
2233
2232
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 19
May Bar 19
Aug Bar 17

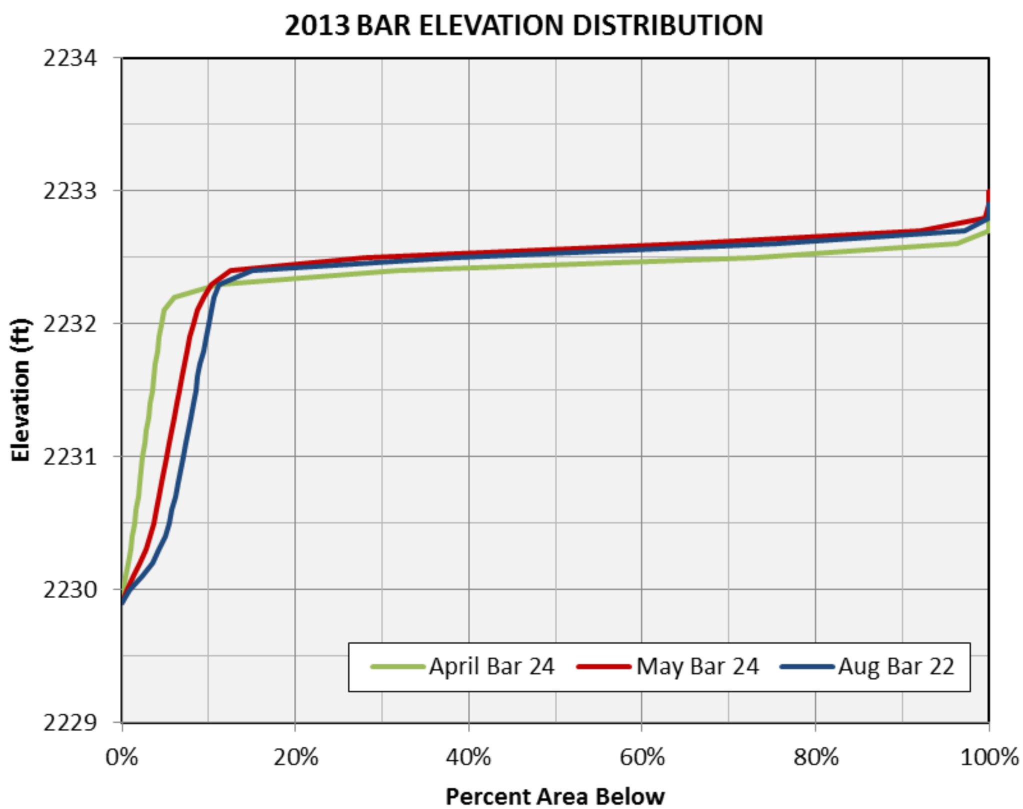

2013 BAR ELEVATION DISTRIBUTION
2235
2234
2233
2232
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 20
May Bar 20
Aug Bar 18


2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2236
2235
2234
2233
2232
2231
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 21
May Bar 21
Aug Bar 19


2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2234
2233
2232
2231
2230
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 22
May Bar 22
Aug Bar 20

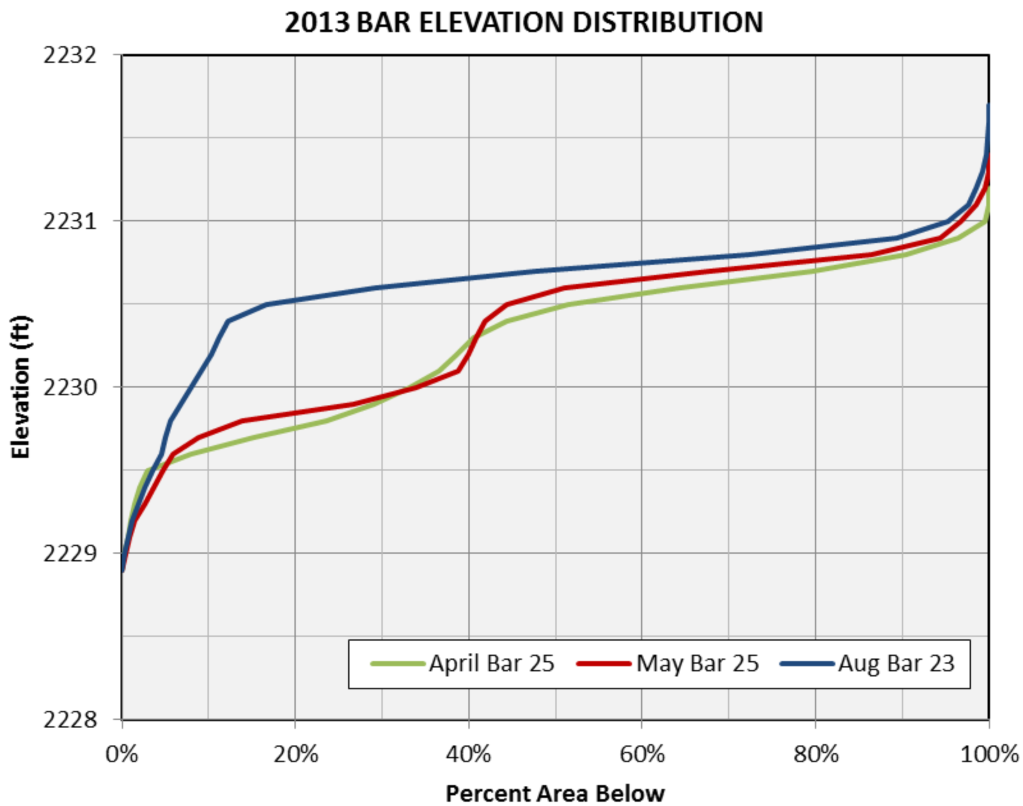


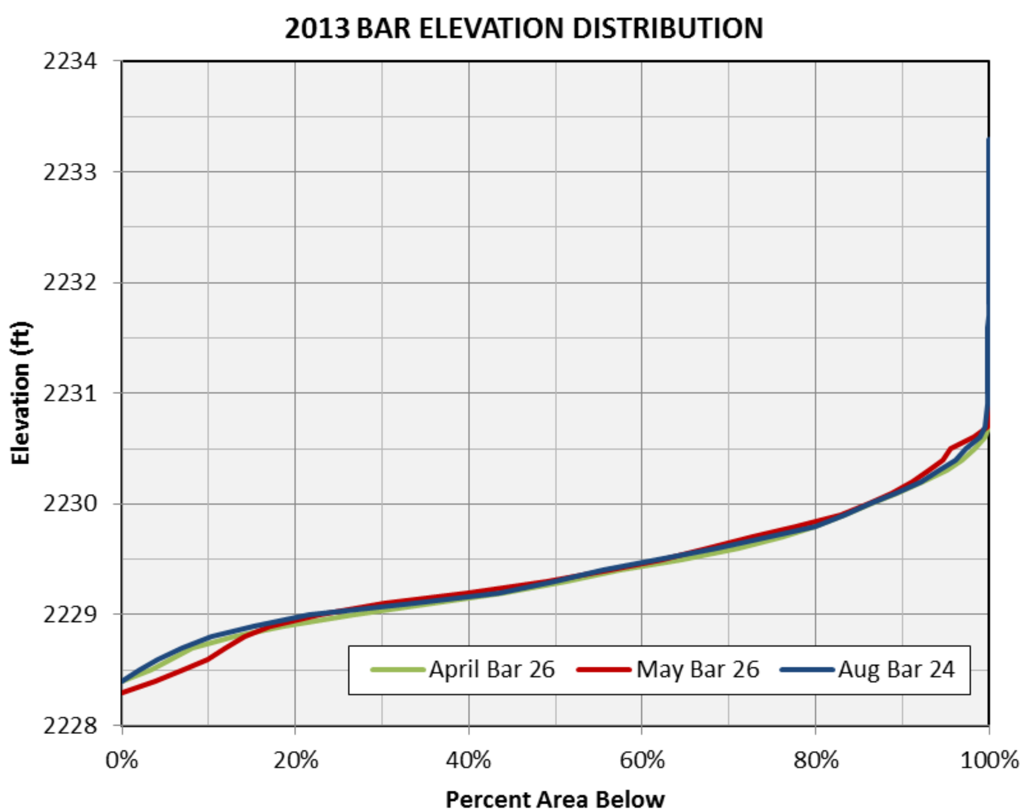
2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2236
2235
2234
2233
2232
2231
2230
2229
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 23
May Bar 23
Aug Bar 21

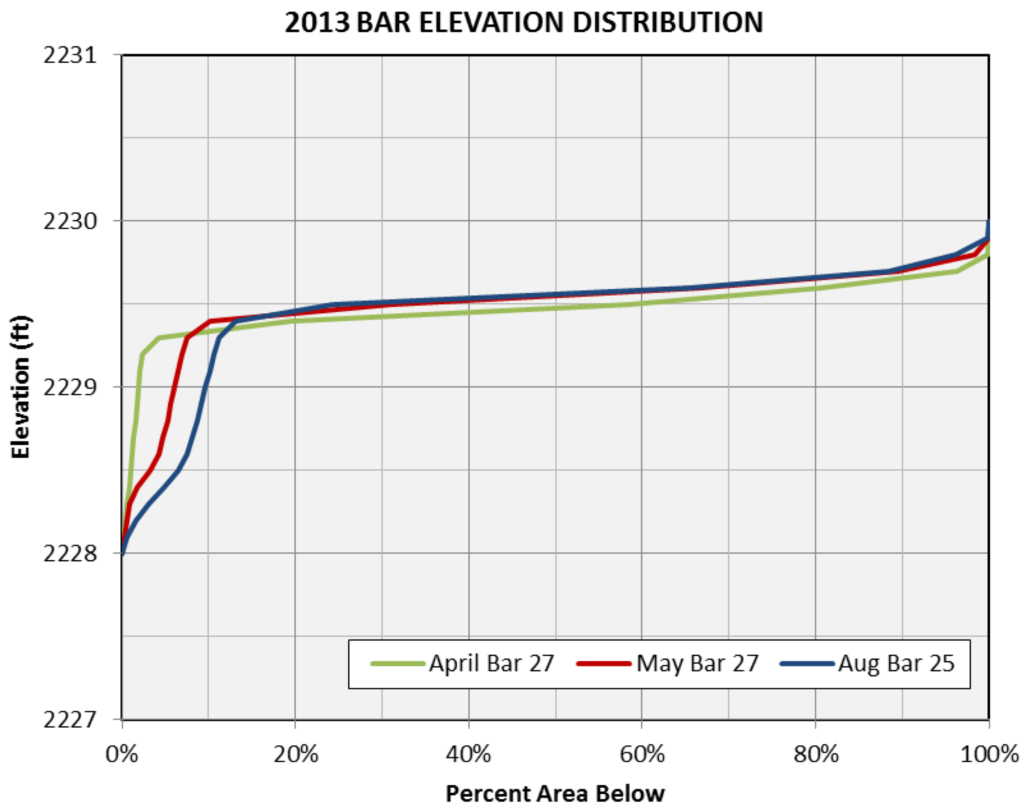


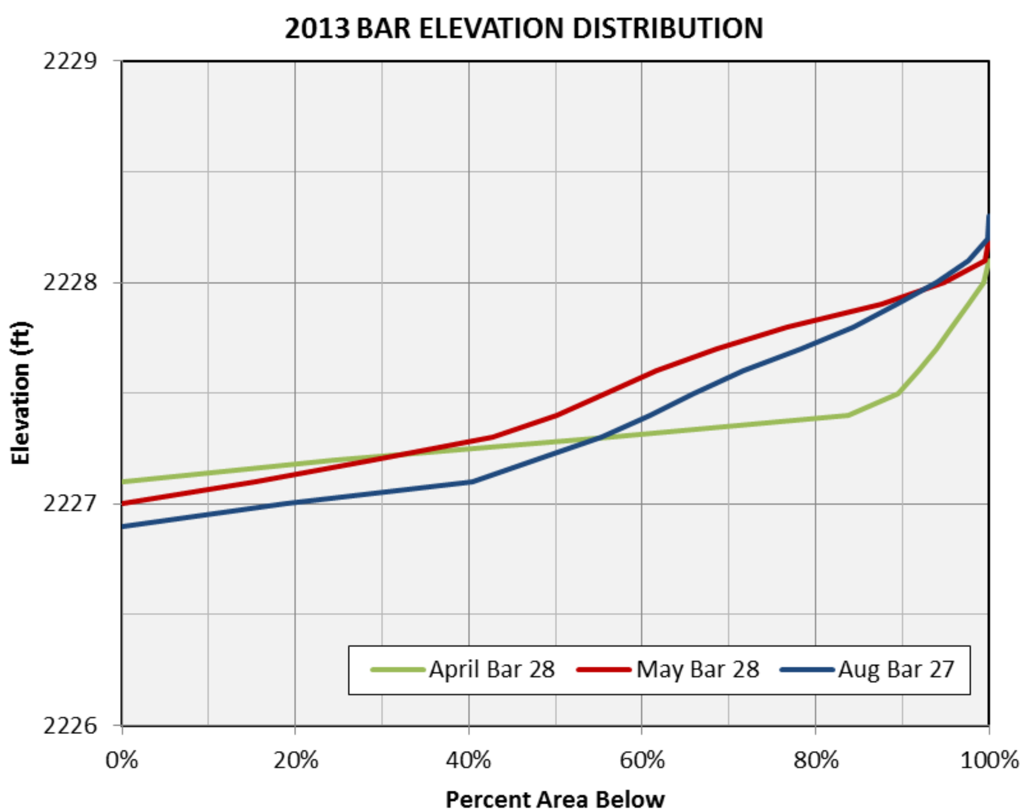
2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2234
2233
2232
2231
2230
2229
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 24
May Bar 24
Aug Bar 22

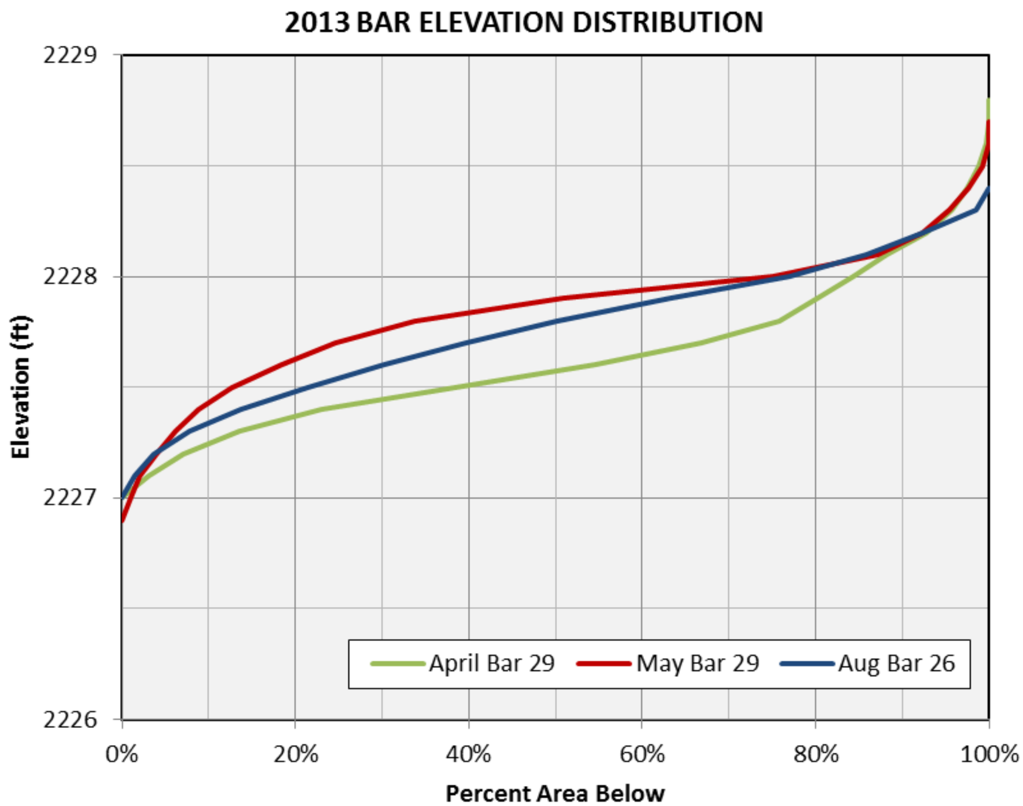
TETRA TECH

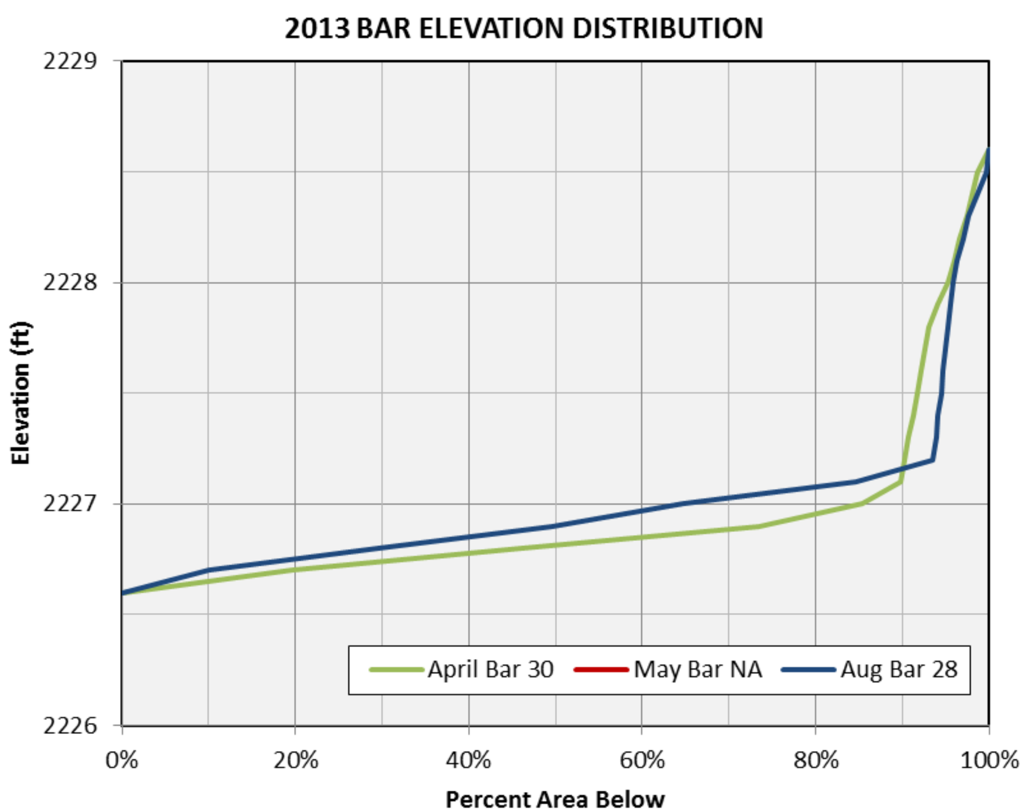

2013 BAR ELEVATION DISTRIBUTION
2232
2231
2230
2229
2228
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 25
May Bar 25
Aug Bar 23

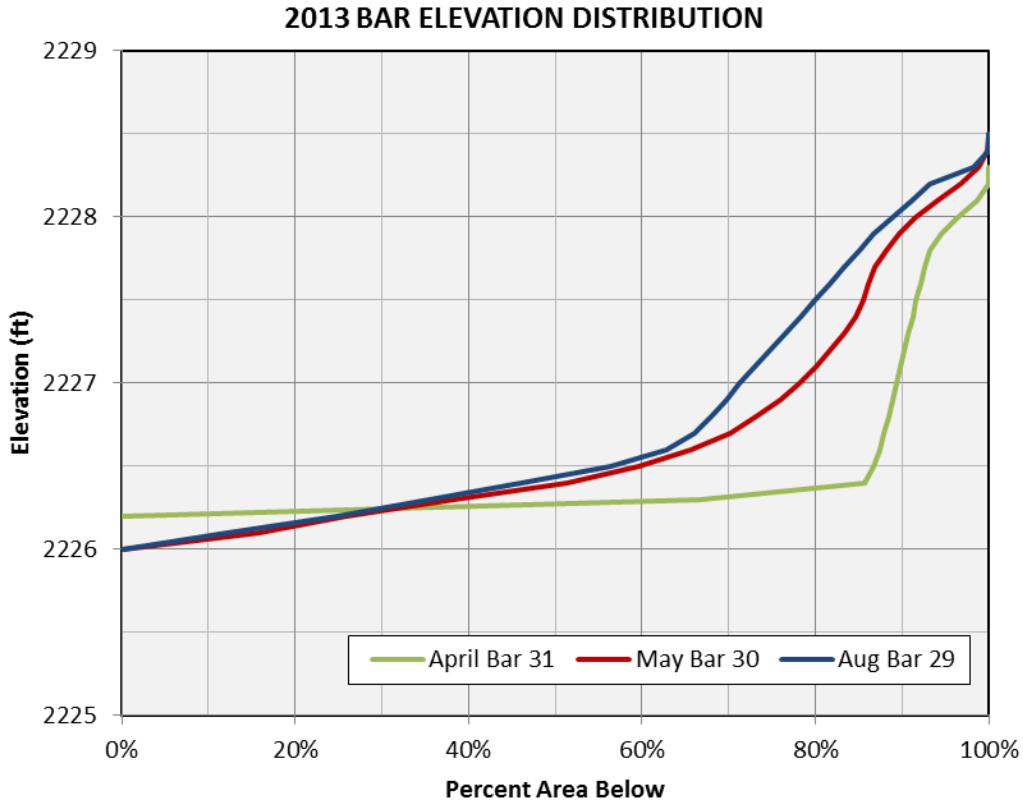

2013 BAR ELEVATION DISTRIBUTION
2234
2233
2232
2231
2230
2229
2228
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 26
May Bar 26
Aug Bar 24

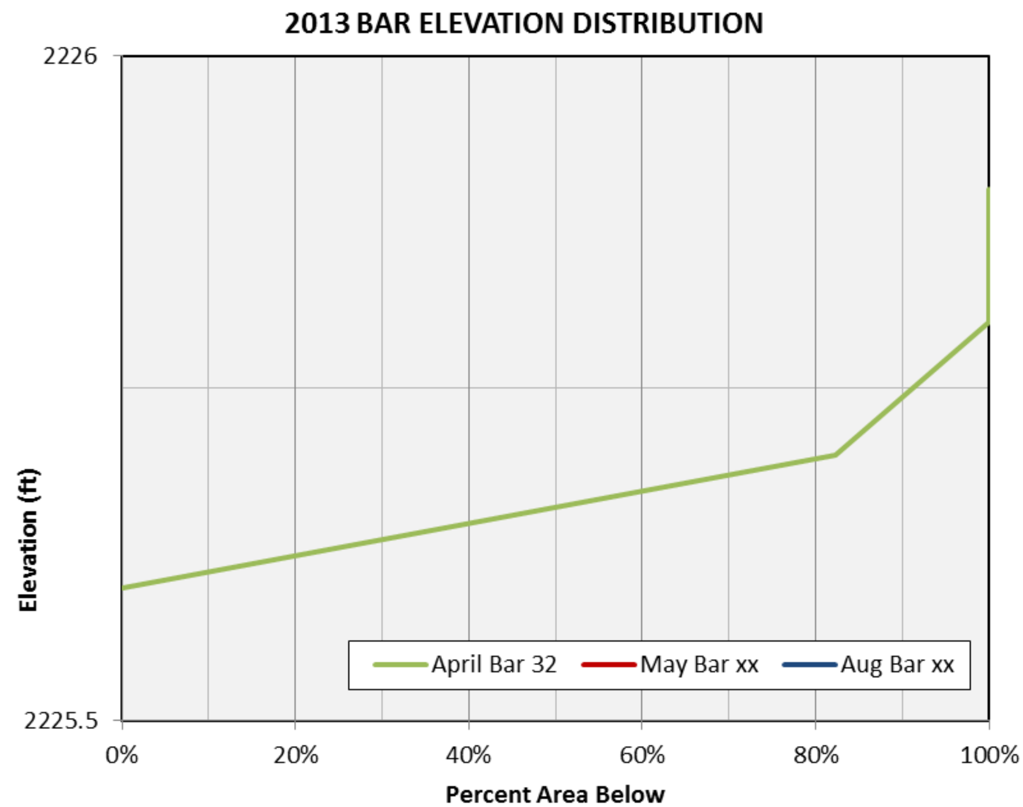

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2231
2230
2229
2228
2227
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 27
May Bar 27
Aug Bar 25

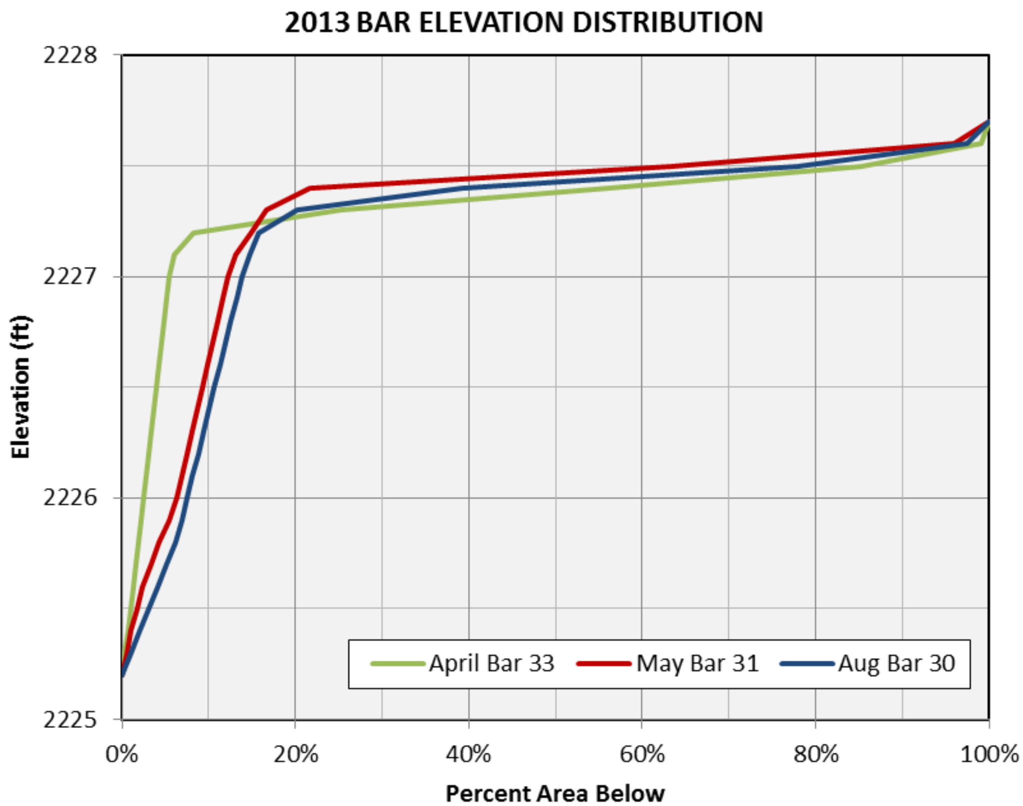

2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2229
2228
2227
2226
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 28
May Bar 28
Aug Bar 27

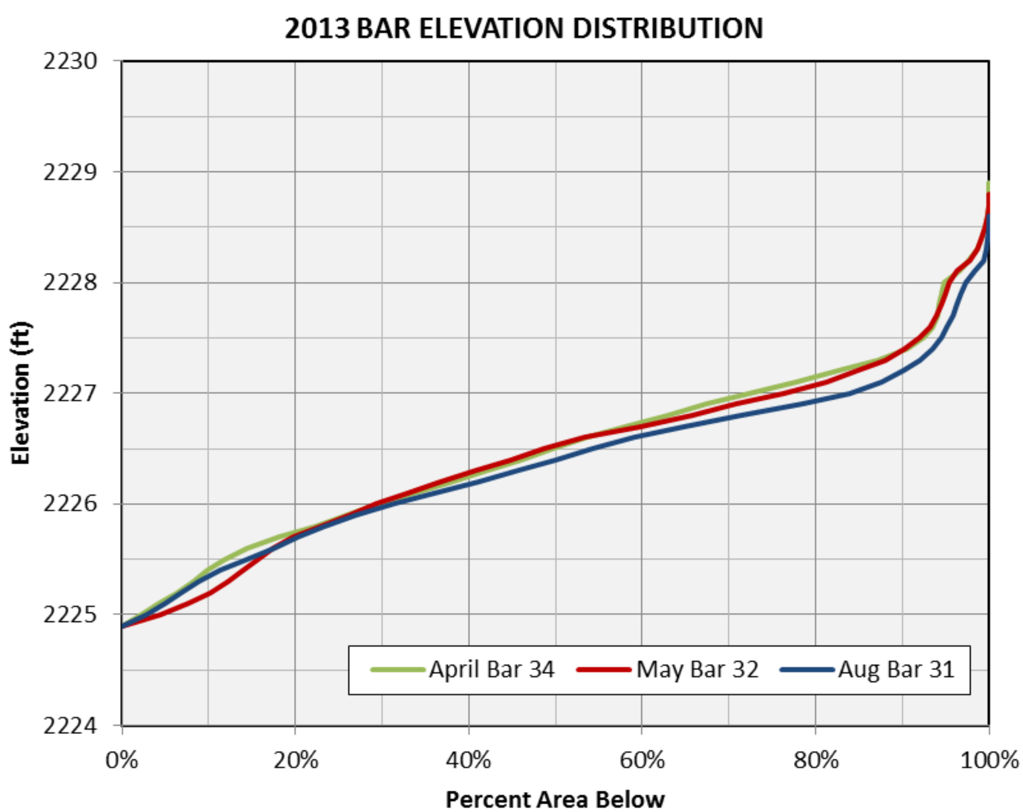

2013 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 29
May Bar 29
Aug Bar 26


2013 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 30
May Bar NA
Aug Bar 28

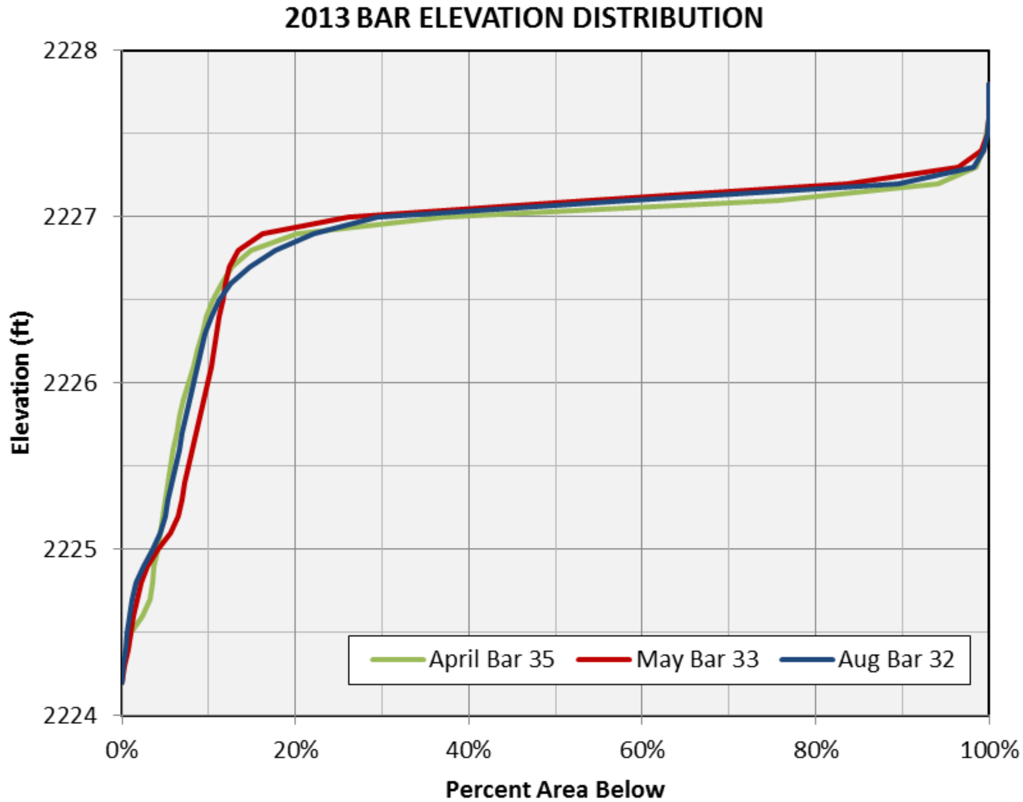

2013 BAR ELEVATION DISTRIBUTION
2229
2228
2227
2226
2225
Elevation (ft)
April Bar 31
May Bar 30
Aug Bar 29
0%
20%
40%
60%
80%
100%
Percent Area Below

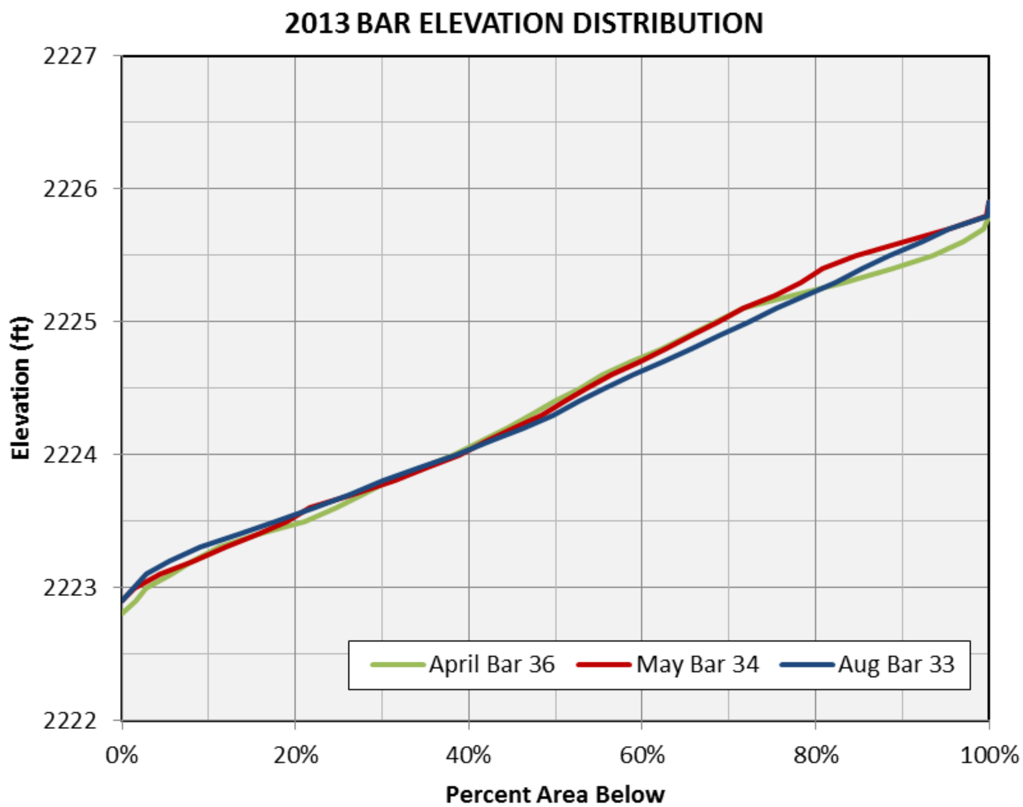

2013 BAR ELEVATION DISTRIBUTION
2226
2225.5
Elevation (ft)
April Bar 32
May Bar xx
Aug Bar xx
0%
20%
40%
60%
80%
100%
Percent Area Below

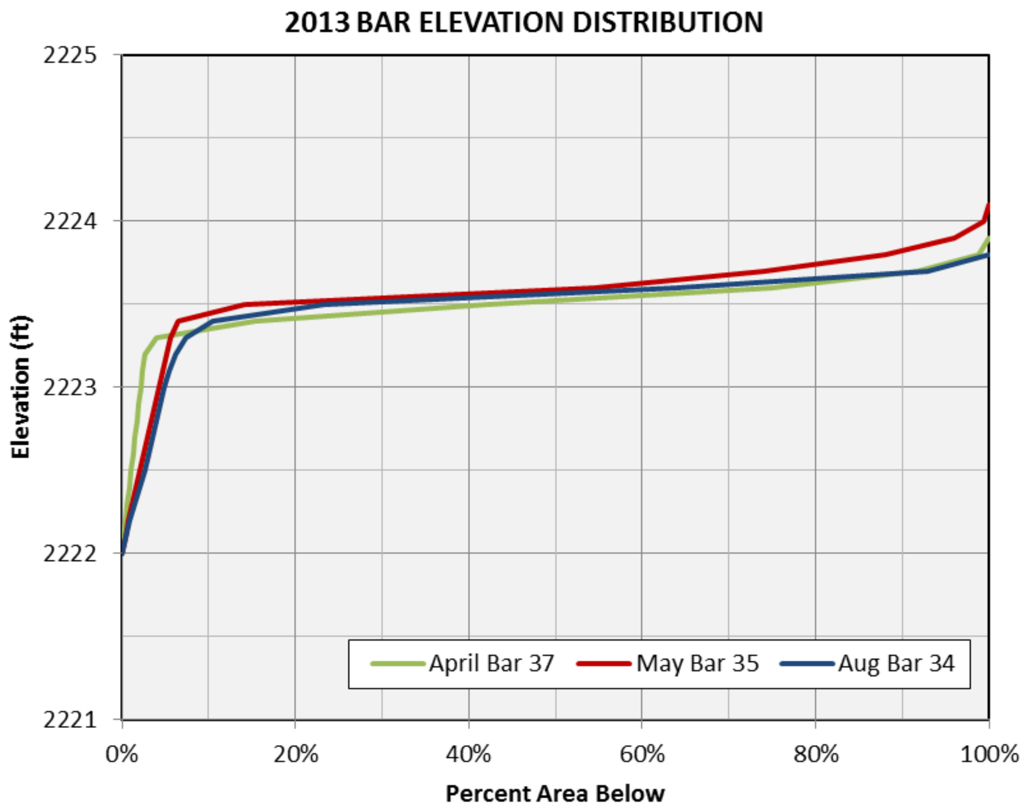

2013 BAR ELEVATION DISTRIBUTION
2228
2227
2226
2225
Elevation (ft)
April Bar 33
May Bar 31
Aug Bar 30
0%
20%
40%
60%
80%
100%
Percent Area Below

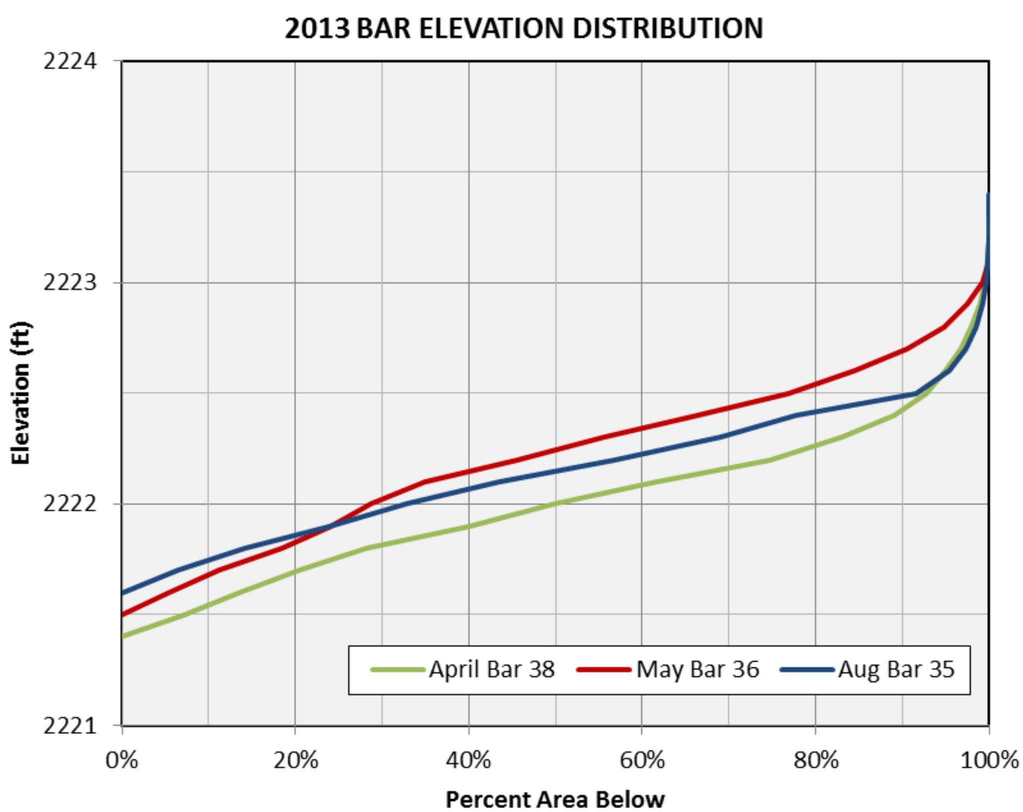

2013 BAR ELEVATION DISTRIBUTION
2230
2229
2228
2227
2226
2225
2224
Elevation (ft)
April Bar 34
May Bar 32
Aug Bar 31
0%
20%
40%
60%
80%
100%
Percent Area Below

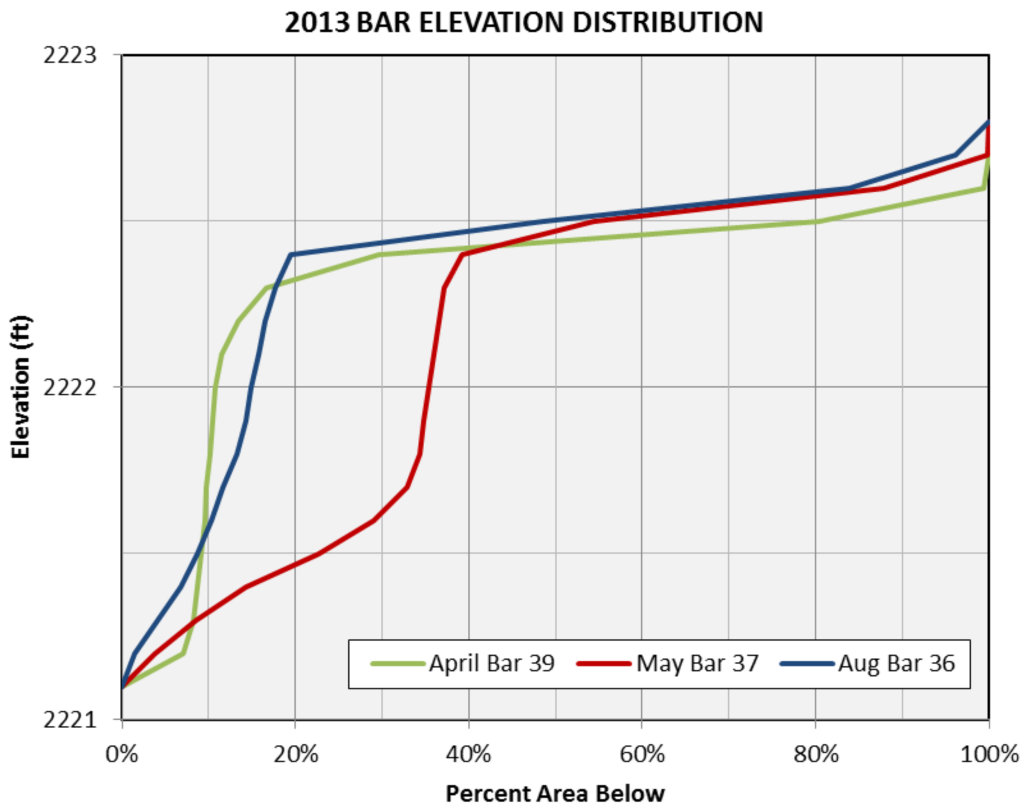
TETRA TECH

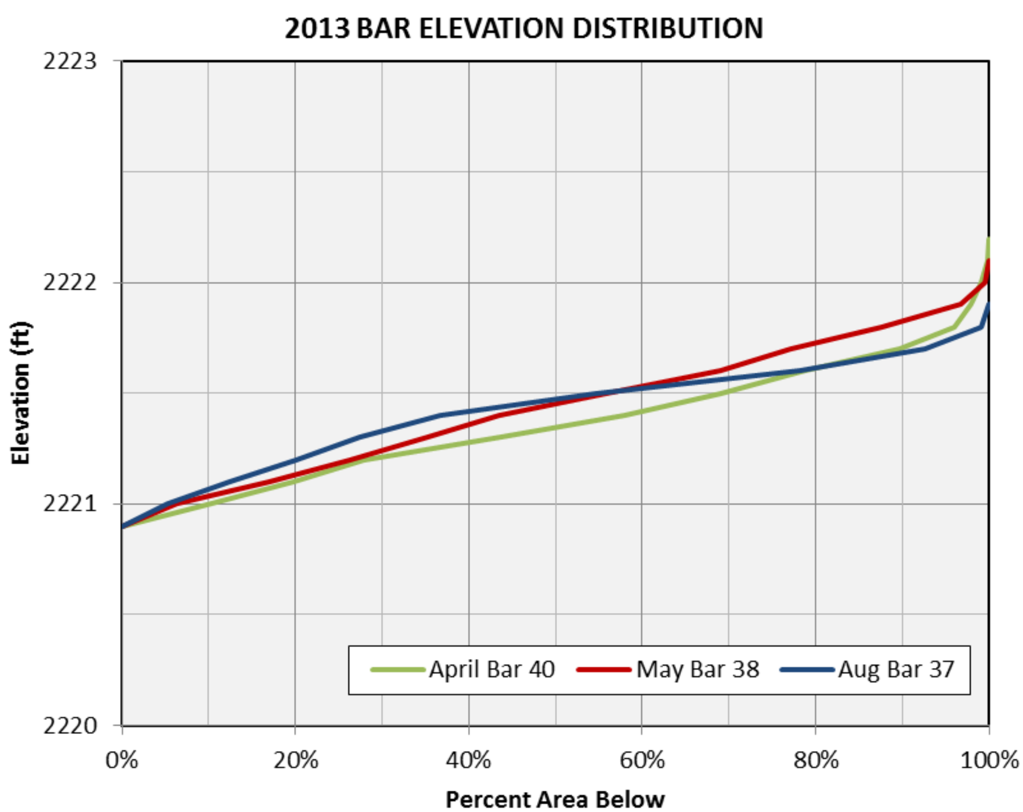

2013 BAR ELEVATION DISTRIBUTION
2228
2227
2226
2225
2224
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 35
May Bar 33
Aug Bar 32

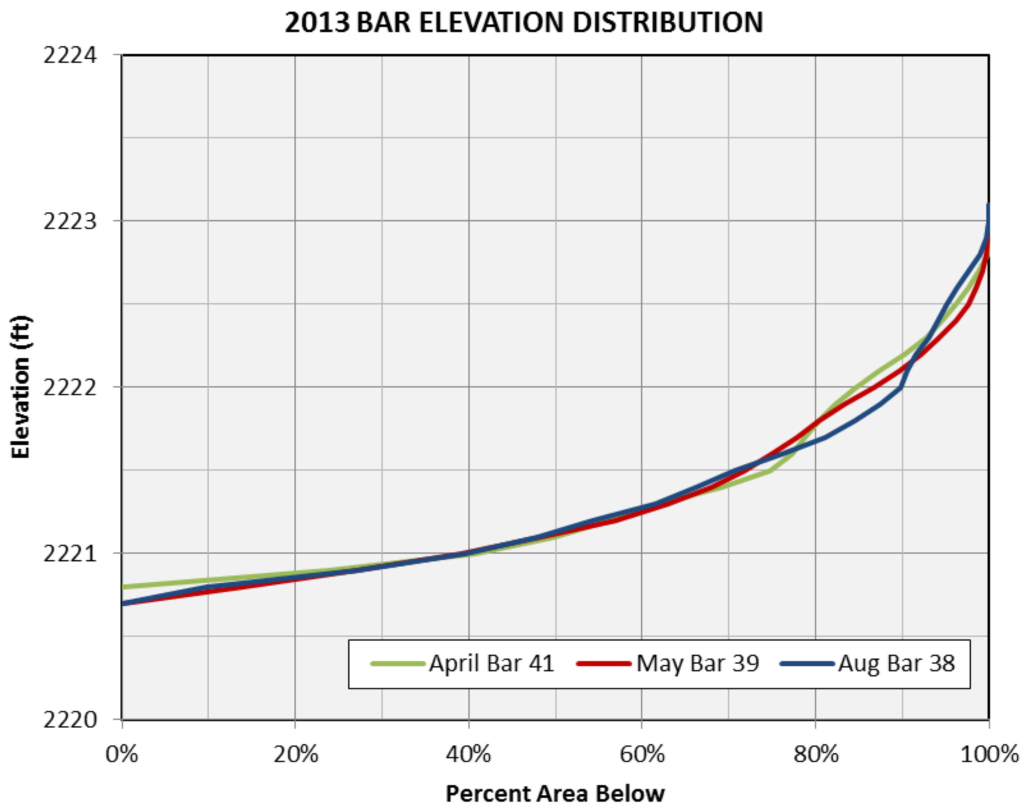

2013 BAR ELEVATION DISTRIBUTION
2227
2226
2225
2224
2223
2222
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 36
May Bar 34
Aug Bar 33

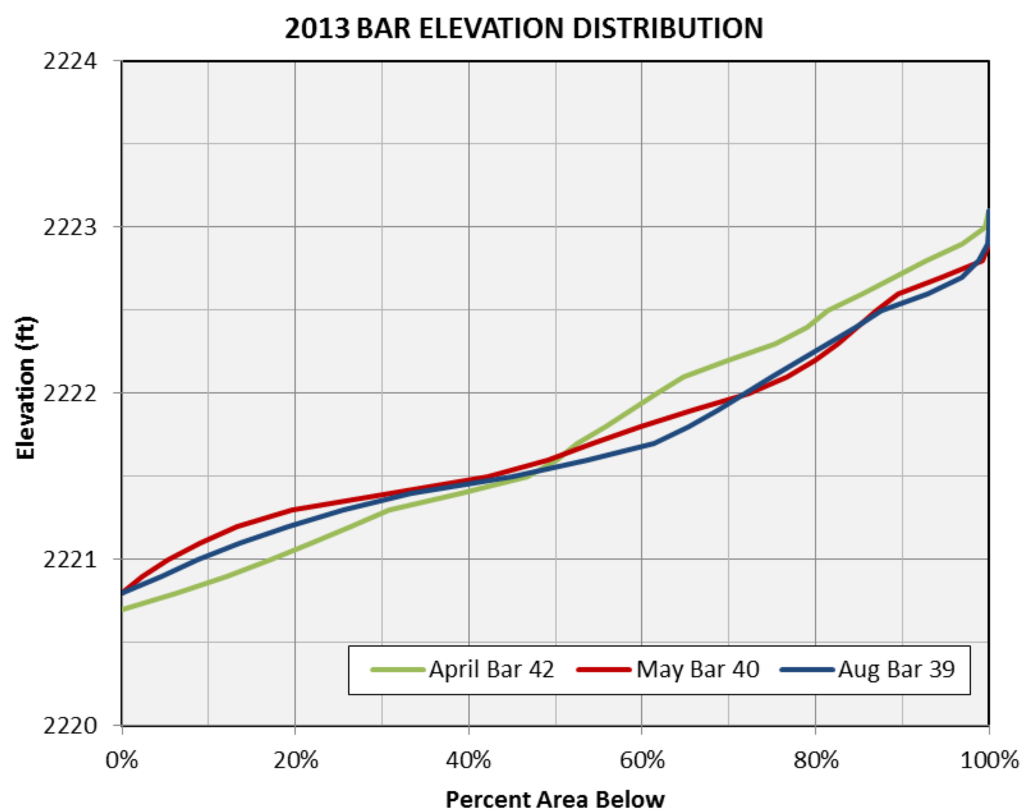

2013 BAR ELEVATION DISTRIBUTION
2225
2224
2223
2222
2221
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 37
May Bar 35
Aug Bar 34


2013 BAR ELEVATION DISTRIBUTION
2224
2223
2222
2221
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 38
May Bar 36
Aug Bar 35


2013 BAR ELEVATION DISTRIBUTION
2223
2222
2221
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 39
May Bar 37
Aug Bar 36


2013 BAR ELEVATION DISTRIBUTION
2223
2222
2221
2220
Elevation (ft)
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 40
May Bar 38
Aug Bar 37


2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2220
2221
2222
2223
2224
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 41
May Bar 39
Aug Bar 38


2013 BAR ELEVATION DISTRIBUTION
Elevation (ft)
2220
2221
2222
2223
2224
0%
20%
40%
60%
80%
100%
Percent Area Below
April Bar 42
May Bar 40
Aug Bar 39

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APPENDIX I
Combined Survey Data 2013

Appendix_I_Combined Survey Data_2013.xlsx

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