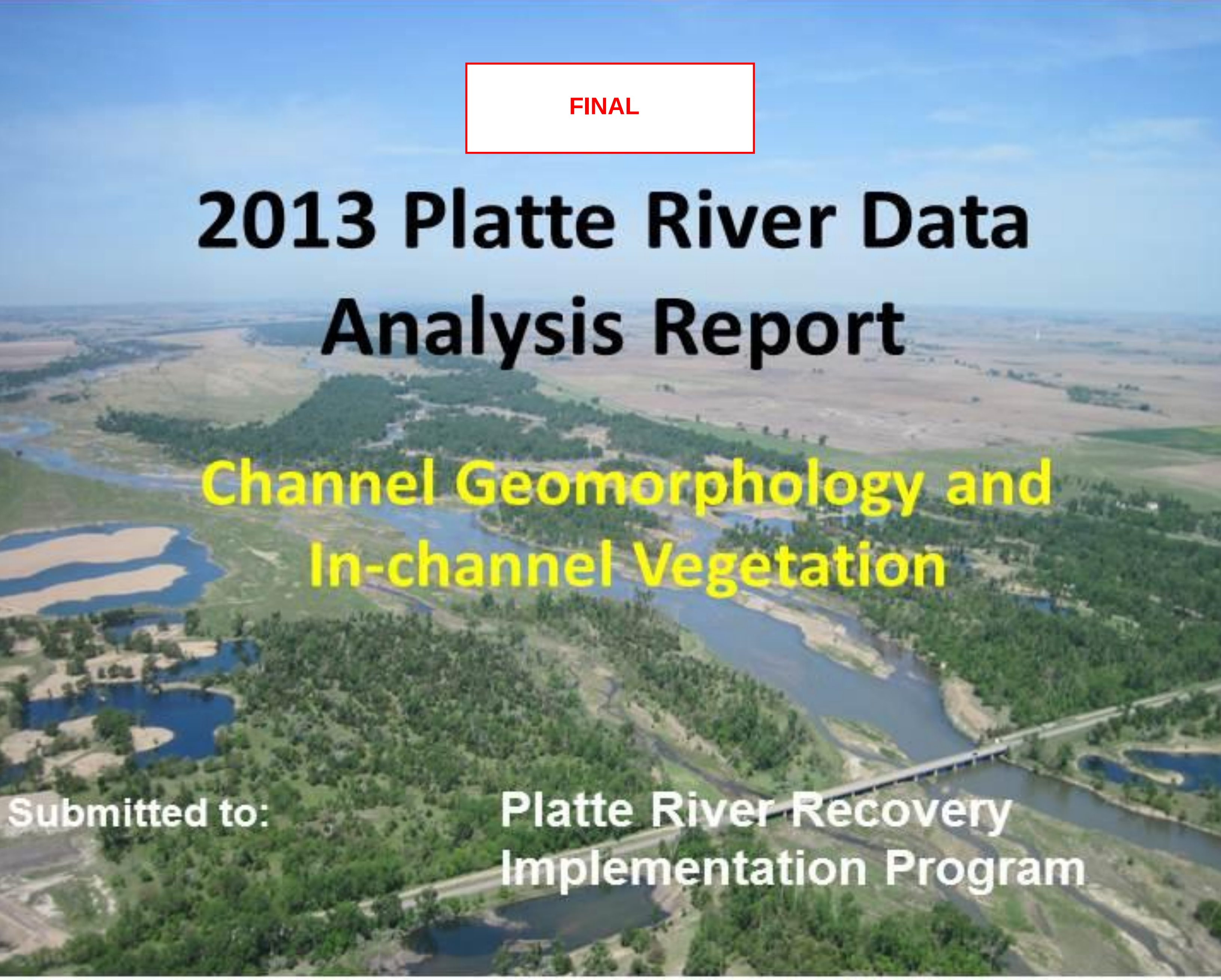

FINAL

2013 Platte River Data Analysis Report

Channel Geomorphology and In-channel Vegetation

Submitted to: Platte River Recovery Implementation Program

TETRA TECH

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August 1, 2014

Channel Geomorphology and In-Channel Vegetation

2013 Final Data Analysis Report

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August 1, 2014

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1 INTRODUCTION

1.1 Background

The Platte River Recovery Implementation Program (Program, aka PRRIP) was initiated on January 1, 2007, between Nebraska, Wyoming, Colorado, and the Department of the Interior to address endangered species concerns in the central and lower Platte River. Four "target" species are of primary concern to the Program: the whooping crane, piping plover, interior least tern, and pallid sturgeon. The intent of the Program is to rehabilitate habitat in the Platte River for these species by restoring a braided channel morphology with sand bars free of vegetation, increased channel widths and unobstructed views.

Because of the uncertainty in how the river will respond to management actions, the Program has developed several *Big Questions* and priority hypotheses related to the linkage between channel geomorphology, in-channel vegetation and habitat for the target species (PRRIP, 2006). To help answer these questions and test the hypotheses, a Channel Geomorphology and Vegetation Monitoring Program has been implemented to collect and analyze a suite of data over a multi-year time-frame with the following specific objectives:

- Document trends in channel geomorphology parameters throughout Central Platte River during the 13-year First Increment (2007-2019) of the Program, including shape, width, planform, aggradation/degradation trends, bed-material grain sizes, and sediment loads.

- Provide system-wide status in areal coverage and elevation range of in-channel seedlings and invasive vegetation to assist in implementing the Program's Adaptive Management Plan (AMP) (PRRIP, 2012b) and use of water in the Environmental Account (EA), evaluate the extent of existing native and non-native invasive species infestations, and serve as a mechanism for identification of new invasive species populations before infestations become widespread.

A previous contractor team consisting of Ayres Associates and Olsson Associates implemented the Program's monitoring protocol (PRRIP, 2010) during the first three years of the monitoring program, with the first year of the data collection occurring in 2009 (Ayres and Olsson, 2010, 2011 and 2012). The Program has also developed a draft Data Analysis Plan (PRRIP, 2012a).

Tetra Tech has continued to carry out the program beginning in 2012, including implementation of the Data Analysis Plan that was not included in the earlier contract. Results from the 2012 data collection and the first year of data analysis were presented in Tetra Tech (2013). This report describes the data and results from Tetra Tech's implementation of the fifth year of the monitoring program (2013) and the second year of implementation of the data analysis plan.

1.2 Scope of the Monitoring Program

1.2.1 Area of Interest

The area of interest for geomorphology and vegetation monitoring consists of channels within approximately 0.5 miles on either side of the centerline of the Platte River, beginning at the junction of U.S. Highway 283 and Interstate 80 near Lexington, Nebraska, and extending eastward to Chapman, Nebraska (approximately 100 miles) (**Figure 1.1**). Certain areas within this portion of the central Platte River have been prioritized for monitoring based on key priority hypotheses, ecological need, and Program actions undertaken during the First Increment.

Figure 1.1. Location map showing the project reach for the Channel Geomorphology and In-channel Vegetation Monitoring. Bed-load and suspended-sediment sampling bridge sites are shown as red circles.

1.2.2 Anchor Points

A systematic sample of locations along the river have been identified to serve as "anchors" for the data collection. These locations, referred to as anchor points (APs), are spaced at approximately 4,000-meter (2.5-mile) intervals along the centerline of the river, and each point has been labeled with a U.S. Army Corps of Engineers (USACE) River Mile (RM) (**Table 1.1**). The specific locations of some of the APs were selected to accommodate previously established cross sections within the historical database and to accommodate some land access issues; thus, the actual spacing can vary by up to 800 meters (0.5 miles) from the typical, 4,000-meter spacing. The basic geomorphic sampling unit consists of three transects spaced at approximately 150-meter intervals. The transects extend laterally across the historic flood plain and incorporate the current main channel, as well as all primary split flow channels (i.e., those channels separated from the main channel by islands). Although the north channel (Reach 1) and south channel (Reach 2) of Jeffreys Island share the same AP number, these two channels are treated as separate reaches because the flows in the north channel are derived from the upstream river, while the flows in the south channel are almost entirely derived from flow releases from the J-2 Return.

1.2.3 Pure and Rotating Panel Points

The APs sampled each year under this protocol are components of a “pure panel” subset and a “rotating panel” subset. A panel is made up of a group of sampling sites that are always visited at the same time. Data collection is conducted at the pure panel sites (even numbered sites in Table 1.1) every year, and the rotating panel sites have been divided into four groups that are visited once every four years on a rotating basis. As a result, 25 sample sites are surveyed each year (20 pure panels and 5 rotating panels). Each of the sites in the rotating panel series are to be surveyed three times in the First Increment. In accordance with the protocol, data were collected at all of the Pure Panel (i.e., even-numbered) APs and at the five rotating APs that are designated as R1 (highlighted points in Table 1.1) during the 2013 field season. With this data set, the pure panel points have been sampled four times, the R1 rotating panel points have been sampled twice, and all other the rotating panel points have been sampled once. Per the Monitoring Protocol, the secondary channels at the Pure Panel points were not re-surveyed during the second through fourth year of the data collection. These channels were re-surveyed during 2013, and will not be re-surveyed again until 2017.

1.2.4 Channel Geomorphology Monitoring

The geomorphology portion of this monitoring program is designed to document trends in channel morphology across the entire study area throughout the First Increment (2007-2019). In addition, the data will document trends at specific sites or groups of sites within the overall study area. The monitoring is focused on measuring and tracking changes in river planform, river cross-section geometry (including bed elevation and channel width), longitudinal bed profile, streamflow, sediment loads, and bed, bar and bank material grain-size distributions. The monitoring data are collected through a combination of aerial photographs, airborne terrestrial LiDAR, topographic ground surveys, bed material sampling, ground photography, flow measurements at gaging stations, and sediment-transport measurements. The overall strategy is focused on a randomized scheme, but there is some sampling stratification (e.g., grain size) to reduce variability and improve future comparisons.

Table 1.1. Anchor point locations.

Anchor Point No.	Systematic Point at 4000 m (2.5 miles) (River Mile)	Closest Existing Cross Section	Recommended Anchor Point (River Mile)	Pure (P) or Rotating (R) Panel	Location
40	254	254.4	254.4	R1	Lexington
39	251.5 Bridge	250.5	250.8	P	Lexington bridge (Hwy 283)
38	249	249.5	249	R2	
37	246.5	246.5 N & 246.0 S	246.5 N & S	P	J2 Return - Jeffrey Island
36	244	244.0 N & S	244.0 N & S	R3	
35	241.5		241.5 N & S	P	
34	239	239.1	239.1	R4	D/S Overton bridge (Rd. 444)
33	236.5	237.3	236.4	P	Cottonwood Ranch transects
32	234	233.9	234.1 Main, N, S	R1	
31	231.5	231.5	231.5	P	U/S Elm Creek bridge (Hwy 183)
30	229	228.6	228.6	R2	D/S Kearney Diversion
29	226.5	226.4	226.4	P	
28	224 Bridge	224.3	224.3	R3	Odessa Rd. Bridge
27	221.5	222	221.9	P	
26	219	219.8	219	R4	
25	216.5		216.5	P	
24	214		214	R1	D/S Kearney bridge (Hwy 44)
23	211.5	210.6	211.5 Main & N1,N2	P	
22	209	208.4	208.4 Main & N1	R2	U/S 32 Rd. bridge (Hwy 10)
21	206.5	206.7 (no N)	206.7 Main & N1	P	
20	204	203.3 N&S	204.0 Main & N1	R3	
19	201.5	201.1 N maybe S	201.1 Main & N1	P	D/S Lowell Rd. bridge (Hwy 10C)
18	199	199.5	199.5	R4	
17	196.5	196.4	196.4	P	U/S Shelton Rd. bridge (Hwy 10D)
16	194	193.9	193.8	R1	
15	191.5	190.9	190.7	P	
14	189	189.3	189.3	R2	
13	186.5	187	186.7 Main & N1	P	D/S S. Nebraska Hwy 11 bridge
12	184	183.1	184.0 Main & N1	R3	
11	181.5	181.8 S	181.8 Main & N1	P	D/S S. Alda Rd. bridge
10	179	178.38 & 178.4 M & N	179.0 Main & N1,N2,N3	R4	
9	176.5	177.1	176.5 Main & N1,N2,N3	P	U/S SR 34/281 bridge (Doniphan)
8	174	174.6	174 Main & N1,N2,N3	R1	Grand Island
7	171.5	172.1 S & SM & N & NM	171.5 Main & N1,N2,N3	P	D/S I-80 bridge
6	169	168.7 N & S	169.1 Main & N1	R2	
5	166.5	166.9	166.9	P	D/S SR 34/Hwy 2 bridge
4	164	164.6	164	R3	
3	161.5	162.1	161.8	P	Phillips
2	159	158.7	158.7	R4	
1	156.5	157.3	156.6	P	D/S Bader Park Rd. br (Chapman)

1.2.5 In-channel Vegetation Monitoring

The vegetation monitoring portion of this program is designed to document the areal extent of species of interest within the Vegetation Survey Zone (VSZ) (as defined in the protocol) between the historic high banks. The APs have been identified to provide data collection locations that are consistent from year to year, and that are representative of the entire study area. The vegetation surveys are conducted in conjunction with the field component of the geomorphology monitoring (and at the same locations) so that the vegetation data points can be readily included in the topographic surveys.

Vegetation sampling is conducted within fixed-width (belt) transects that are centered on each of APs, and extend across the VSZ that is generally defined as the area within the historic high banks. The width of each belt transect is approximately 1,000 feet (300 meters), extending for approximately 500 feet (150 meters) upstream and downstream of the AP. During the first four years of data collection, the overall belt transect consisted of seven, roughly parallel, vegetation transects spaced approximately 165 feet (50 meters) apart. The upstream, downstream and middle vegetation transects correspond to the three primary geomorphology transects.

Subsampling and statistical analyses of the large volume of data collected during the first four field seasons showed no significant difference ($p>0.05$ for all analysis) between vegetation data collected at all seven transects compared to five transects when Transects 2 and 6 are removed. Sampling two fewer transects per AP substantially increases the efficiency of the field component of this work, while retaining full comparability to vegetation data collected in prior years. As a result, the Monitoring Protocol has been modified to eliminate two of the transects (typically Transects 2 and 6, counting from the downstream end of each site).

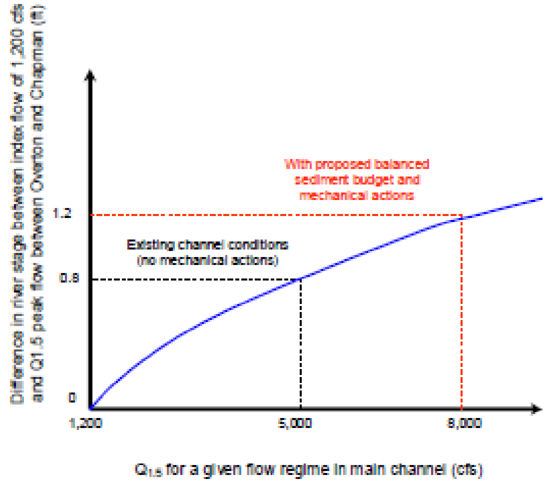
Current vegetation species of interest include six woody species: narrow-leaf willow (*Salix exigua*), peach-leaf willow (*S. amygdaloides*), eastern cottonwood (*Populus deltoides*), false indigo (*Amorpha fruticosa*), saltcedar (*Tamarix ramosissima*), and Russian olive (*Elaeagnus angustifolia*), as well as several herbaceous species, including purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), rice cut grass (*Leersia oryzoides*), and river bulrush (*Bolboschoenus fluviatilis*). In addition, reed canary grass (*Phalaris arundinacea*) was also included because it is a vigorous competitor, is present in high densities in some areas, and it has a tendency to form dense rootmats and monocrop stands. Although the analysis focuses on these species of interest, it is important to note the in-channel monitoring documents all plant species encountered at each sample point.

1.2.6 Airborne Mapping of Topography (LiDAR)

Because of the characteristics of the vegetation on the historic overbanks and islands within the corridor between historic banks, ground surveys outside the active channel and mechanically modified areas would be every laborious and costly. As a result, contour base mapping has been developed from airborne terrestrial LiDAR data. Originally, airborne terrestrial LiDAR flights for mapping were to be flown at the beginning (baseline conditions) and end of the First Increment. Recognizing the high value of the LiDAR data, the Program changed these requirements and LiDAR data are now collected during the fall of each year in conjunction with Color InfraRed (CIR) photography. These data are used to develop topographic surfaces with ±6-inch vertical accuracy, sufficient for one-foot contour interval mapping of the area between the historic outer banks (approximately one mile in width).

1.3 Hypotheses and Performance Metrics

The AMP (PRRIP, 2006) for the 13-year, First Increment of the Program that extends from Program inception in 2007 through 2019, focuses on several critical scientific and technical uncertainties about the target species, physical processes, and the response of the target species to management actions. These uncertainties are captured in statements of broad hypotheses on pages 14-17 of the AMP and, as a means of better linking science learning to Program decision-making, those uncertainties comprise a set of “Big Questions” that provide a template for linking specific hypotheses and performance measures to management objectives and overall Program goals.



1.4 Big Questions

This monitoring program is focused on four specific Big Questions that relate directly to river morphology and in-channel vegetation (**Table 1.2**):

Big Question #1 – Will implementation of SDHF produce suitable tern and plover riverine nesting habitat on an annual or near-annual basis?

Big Question #2 – Will implementation of SDHF produce and/or maintain suitable whooping crane riverine roosting habitat on an annual or near-annual basis?

Big Question #3 – Is sediment augmentation necessary for the creation and/or maintenance of suitable riverine tern, plover, and whooping crane habitat?

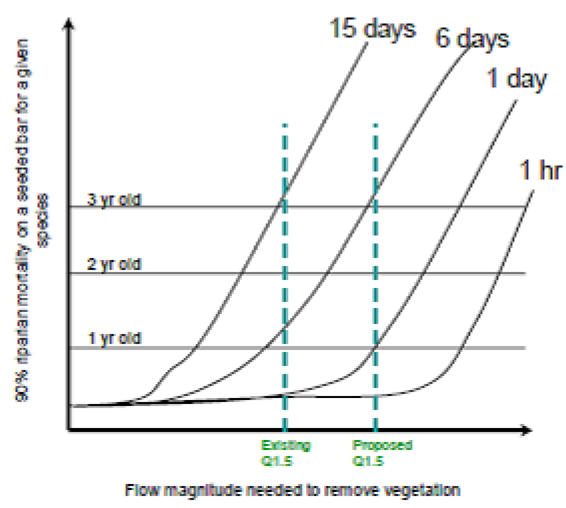
Big Question #4 – Are mechanical channel alterations (channel widening and flow consolidation) necessary for the creation and/or maintenance of suitable riverine tern, plover, and whooping crane habitat?

Table 1.2. PRRIP Big Questions relevant to the Geomorphology and Vegetation Monitoring Program (from PRRIP, 2012a).

PRRIP Big Questions = What we don't know but want to learn	Broad Hypotheses[1]	Priority Hypotheses[2]
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

1.5 System-Scale Hypotheses

The above Big Questions are based on the following broad hypotheses that are directly related to river morphology and the influence of in-channel vegetation:



S-1: A combination of flow management, sediment management, and land management (i.e., Clear/Level/Pulse) will/will not generate detectable changes in the channel morphology of the Platte River on Program lands, and/or habitats for whooping crane, least tern, piping plover, pallid sturgeon, and other species of concern.

S-2: A combination of non-managed flows, sediment management, and land management (i.e., Clear/Level/Mechanical Maintenance) will/will not generate detectable changes in the channel morphology of the Platte River, and/or habitats for whooping crane, least tern, piping plover, pallid sturgeon, and other species of concern.

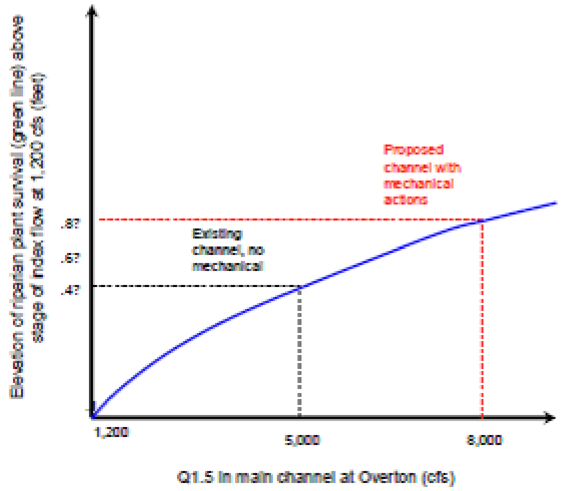
S-4: Program management actions will/will not be of sufficient scale and magnitude to cause detectable system wide changes in channel morphology and/or habitats for the target species.

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

- Flows of 5,000- to 8,000-cfs magnitude in the habitat reach for a duration of three days at Overton on an annual or near-annual basis will build sand bars to an elevation suitable for least tern and piping plover habitat;
- Flows of 5,000- to 8,000-cfs magnitude in the habitat reach for a duration of three days at Overton on an annual or near-annual basis will increase the average width of the vegetation free channel;
- Variations in flows of lesser magnitude will positively or negatively affect the sand bar habitat benefits for least terns and piping plovers.

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

- Reduce net erosion of the river bed;
- Increase the sustainability of a braided river;
- Contribute to channel widening;

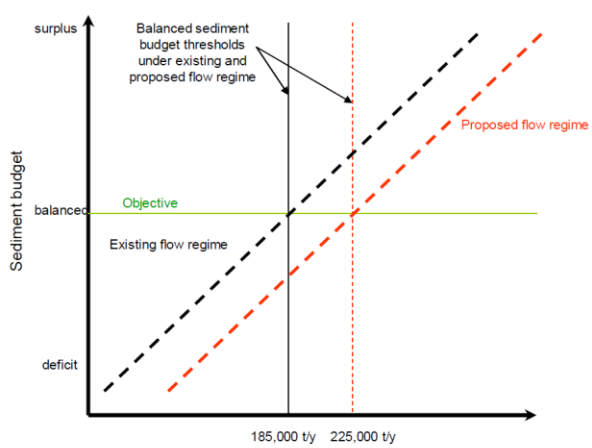


1.6 Priority Hypotheses

The AMP (PRRIP, 2006) formalizes several detailed hypotheses that specifically address uncertainty in the underlying physical process relationships related to potential flow, sediment, and mechanical (FSM) actions. The Tier 1 physical process priority hypotheses related to potential FSM actions include:

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.

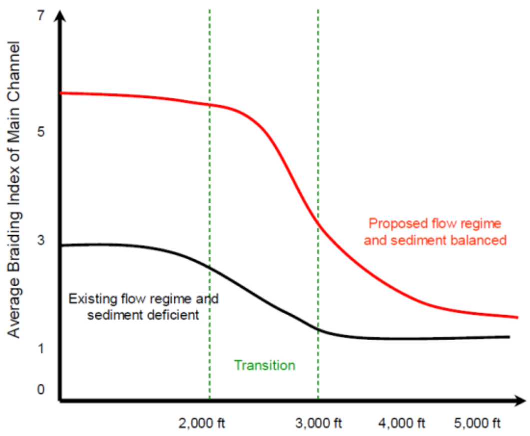
Flow #3: Increasing $Q_{1.5}$ with Program flows will increase local boundary shear stress and frequency of inundation at the existing green line (elevation at which riparian vegetation can establish). These changes will increase riparian plant mortality along margins of the channel, raising the elevation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

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

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



1.7 Performance Metrics

The Program has identified a suite of performance metrics that are quantified using the data from the monitoring program, in conjunction with the available data from the various USGS stream gages and results from the Program's system-wide 1-D hydraulic model. Data and results from other Program activities, including the Elm Creek and Shoemaker Island FSM Experiments, the Pilot-scale Sediment Augmentation Project, and the Cottonwood Ranch Flow Consolidation project will also be considered, where appropriate, to supplement the data collected specifically for this monitoring program. Many of these performance metrics can be directly associated with the above-described priority hypotheses (**Table 1.3**).

Table 1.3. Performance metrics relevant to the Priority Hypotheses.

Hypothesis	Performance Metric(s)
Flow #1	• Stage-discharge relation
Flow #3	• Green line elevation • Vegetation percent cover • Unvegetated channel width • Channel stage-width relationship
Flow #5	• Vegetation species-specific elevation data • Vegetation species-specific areal coverage data • Stage-discharge relation • Green-line elevation
Sediment #1	• Sediment load • Bed and bar material grain-size distribution • Bank material grain-size distribution • Channel volume • Braiding index • Longitudinal profile
Mechanical #2	• Braiding index

2 METHODS

The Program's Monitoring Protocol (PRRIP, 2010) and draft Data Analysis Protocol (PRRIP, 2012a) describe the methods that are to be used to collect and analyze the data from this program. A summary of the key elements of those protocols that were implemented in 2012 and 2013 are described in the following paragraphs. In assessing the following discussion, it is important to note that the Data Analysis Protocol is still in draft form; the specific methods and techniques for analyzing the data and relating the results back to the Big Questions and Priority Hypotheses may evolve as additional data are obtained and the results are reviewed by the various entities involved in the Program.

2.1 Field Data Collection Methods

As discussed in Chapter 1, the field data being collected for this program fit into three general categories:

- Geomorphic data that describe the physical characteristics of the river, including dimension, planform, pattern, and boundary sediments.
- Vegetation data that describe the distribution, frequency, density and other relevant characteristics of the in-channel vegetation.
- Sediment-transport data to quantify the relationship between discharge and sediment transport rates throughout the reach.

In accordance with the monitoring protocol, the 2013 geomorphology and vegetation data were collected during the period between July 9 and August 10. The total flow in the river was generally quite low during the survey period, ranging from less than 10 cfs on July 24 and 25, when AP23 and AP24 were surveyed to about 760 cfs on August 7, when AP9 was surveyed (**Figures 2.1 and 2.2**). The data collection generally proceeded from upstream to downstream through the reach, although there was some variability in this pattern (Figure 2.1). Bed-load sediment transport data were collected on April 12-14 during the SDMF, and from September 23-29 during the fall 2013 flood. Discharges at the sample sites during the April period ranged from 2,250 cfs at Darr to 3,990 cfs at Kearney, and the discharges at the samples sites during the September flood ranged from 3,670 cfs at Darr to 11,960 cfs at Overton.

The following sections describe the specific field methods that were employed in implementing the monitoring protocol during the 2013 field season.

2.1.1 Landowner Contact

A protocol for obtaining landowner permission was established by the Program and the previous contractor before conducting the field survey work in Year 1 (2009). Program staff made the initial contact with the landowners and obtained written permission allowing access to their properties. Program staff also created a geodatabase that included landowner contact information for each AP. This database was updated during each of the subsequent years of the program. The signed permission forms and the updated geodatabase were provided to Tetra Tech prior to the start of the 2012 field work. A binder containing copies of the landowner permission forms was kept with the field crews in case questions or disputes arose while in the field. Tetra Tech contacted the affected landowners by telephone before the start of the overall

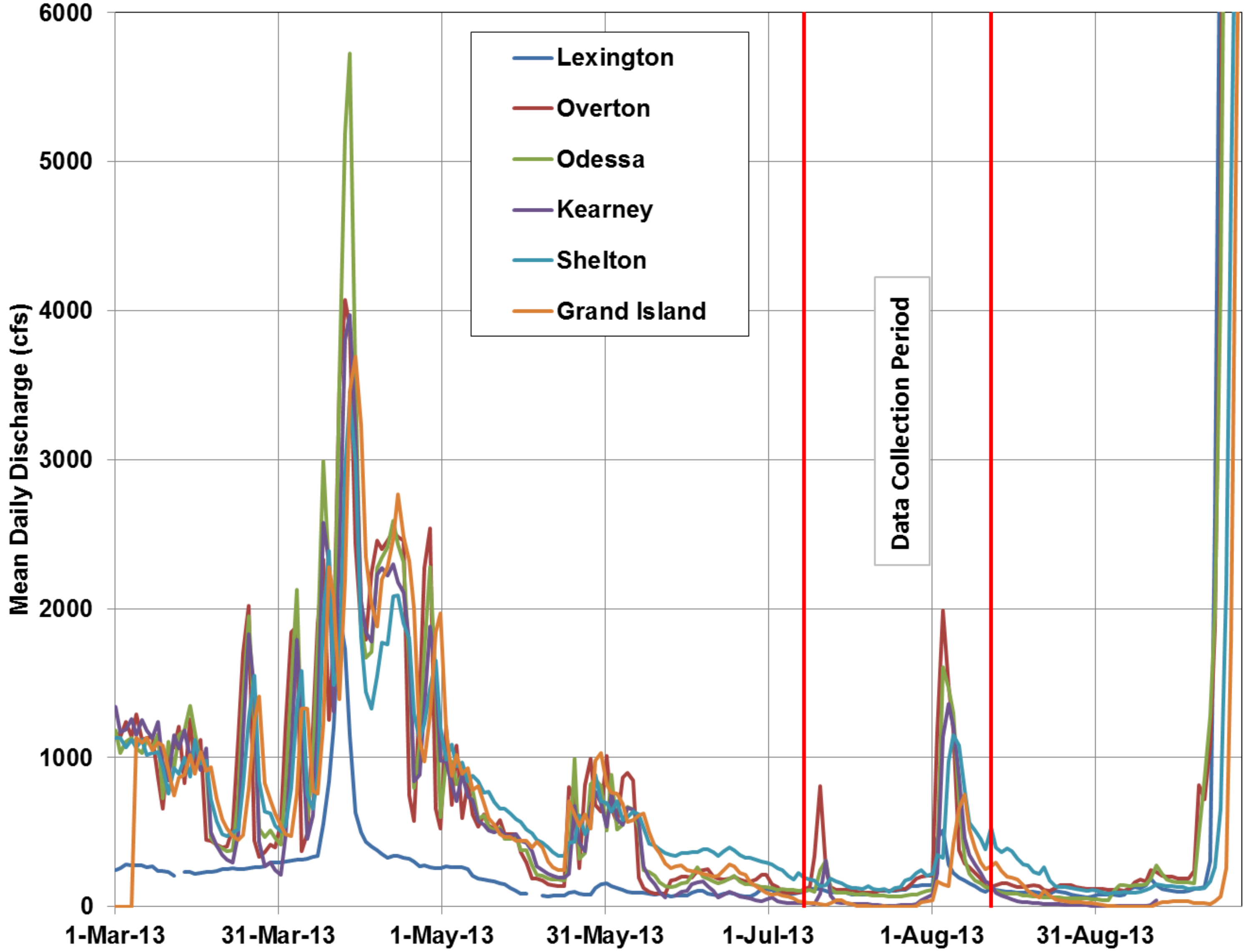


Figure 2.1. Mean daily flows at the USGS and NDNR stream gages between March 1 and September 30, 2013. Also show is the period during which the field surveys were conducted.

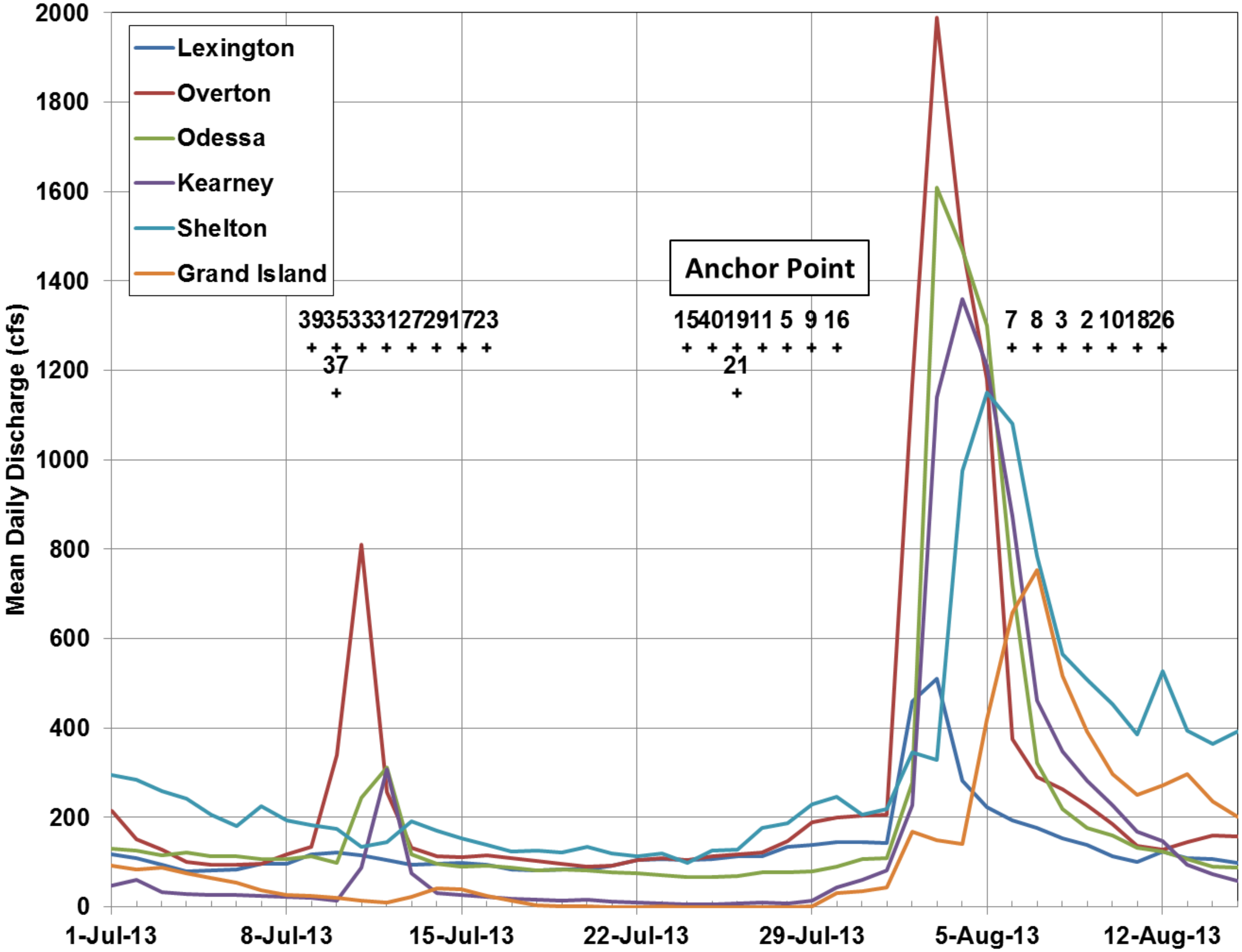


Figure 2.2. Mean daily flows at the USGS and NDNR stream gages between July 1 and August 15, 2013. Also show are the days on which each AP was surveyed.

fieldwork, and followed-up with a courtesy call at least one day before data collection at each property. In cases where the call was not answered, a phone message was left for the landowner/representative with the name and phone number of the field crew leaders and a request to return the call if they had any questions or concerns. In addition, significant coordination was conducted between the field crews and Program staff during the fieldwork to ensure that property access protocols were followed, to obtain updates on new landowner requirements, and to report problems with landowners or access. In this regard, it should be noted that Pure Panel AP37B was not surveyed in 2012 or 2013 because permission to access the property has been revoked by the property owner due to a dispute that arose during the 2011 data collection. Additionally, Pure Panel AP25 was not surveyed in 2013 because the landowner on the south side of the river at this location revoked permission for access.

2.2 Topographic Ground Survey Methods

Ground surveys were conducted to obtain elevation profiles within the active channel (i.e., the accretion zone) at each of the 20 pure-panel and five rotating APs that were sampled during the 2013 field season. The surveys also included the horizontal and vertical location of all vegetation sample quadrats and bed and bar material samples.

2.2.1 Survey Control

The horizontal coordinates of all topographic survey points were referenced to the North American Datum of 1983 (NAD) and the elevations were referenced to the North American Vertical Datum of 1988 (NAVD88). The original primary control for the project was established by the previous contractor at approximately 12-mile intervals along the reach based on static GPS observations over an approximately 4-hour period at each point. Secondary control was subsequently established between the primary control points using RTK GPS. A more detailed description of the procedure for setting the primary and secondary control points can be found in Ayres and Olsson (2010, 2011 and 2012).

2.2.2 Geomorphic Transects

The topographic surveys of the geomorphology transects included only the portion of the cross sections where the ground had been inundated since the previous survey, and also included areas where the ground has been disturbed by discing, mowing, or grading, where natural processes have created significant topographic changes (i.e., channels and islands where sediment could have been deposited or eroded), and locations where new dikes or other river training structures have been placed or removed by landowners. The transect surveys included the channels, banks, and small islands within the accretion zone, but not the upland portions of the cross section beyond the potential bank erosion/deposition zone. As will be described below, data for these portions of the cross sections were obtained from the Program's LiDAR data. Per the monitoring protocol, ground surveys were also conducted on the secondary, split flow channels at the Pure Panel APs and the Year 1 Rotating Panel Points (R1) between Kearney and Grand Island.

The transects were surveyed using a Leica survey-grade global positioning system (GPS) per the requirements defined in the monitoring protocol. When each of the surveyed APs was originally established, the transects were generally oriented perpendicular to the principal flow direction and extended through all channels at the AP. In some instances where a single transect alignment would not remain perpendicular to the primary flow direction across all active channels, the transect was divided into an appropriate number of segments bounded by internal nodes that were also monumented in the field with a marker pin. The end-points of each cross section were monumented on both historic outer banks with a permanent metal marker (pin) set above the flood elevation and far enough from the active channel to avoid all but the most severe erosion effects.

The location of cross-section and transect marker pins, their monumentation, and the extent of the survey beyond the pins depended on accessibility and private property requirements and restrictions. The marker pins consist of approximately 18-inch long, 1/2-inch (#4) rebar, driven flush with the ground surface, and topped with an aluminum cap that is stamped with the AP and transect identification. The geographic coordinates and elevation of each marker pin were established with vertical and horizontal accuracies of 0.1 feet or less using standard survey techniques and criteria. In cases where previously established marker pins were lost, damaged, or displaced, a new marker pin was set at a suitable location prior to conducting the surveys.

In performing the surveys, a code was recorded in the GPS datalogger to identify the feature represented by each point to facilitate reduction and interpretation of the data. Typical features included :

- Top and toe of bank
- Bed or ground elevation
- Left and right edge of water of all channels
- Water surface at exposed bars and islands
- Edge of canopy of permanent woody vegetation >1.5 meters tall
- Edge of vegetation (green line)
- Other significant geomorphic features

To insure that the ground profile across each transect was adequately described, GPS readings were also taken at all significant breaks in slope. Where no obvious breaks in slope were present, GPS survey points were recorded at a maximum spacing of 15 meters (50 feet).

2.2.3 Unobstructed Channel Width

During the first four years of data collection, a key purpose of collecting the vegetation height data (described in the following section) was to facilitate analysis of the unobstructed channel width that is related to maximum sight distance for whooping cranes. In using these data to compute the sight distance metric, it became apparent that a direct measurement of the maximum distance between visual obstructions on each transect would simplify the analysis, improve the accuracy and reduce the uncertainty of the result. For this reason, the data collection protocol for this metric was changed in 2013 to direct measurement. This was accomplished at each of the surveyed transects, as follows:

1. When a substantial opening in vegetation that was higher greater than 1.5 m (4.9 feet) occurred along the transect (e.g., bare sand and open water areas, grassy islands, etc.), the location of the edge of water at 2,400 cfs on one side of the opening was located using the RTK GPS, based on the modeled water-surface elevation for the transect.

2. A Simmons LRF 600 laser rangefinder, with magnification set at 4x and reported accuracy of ±3 feet, was held at approximately 4.9 feet (1.5 m) above the ground and the distance to the next obstruction along the transect at that same height was measured and recorded.

When more than one opening occurred along the transect, a measurement was typically taken at each opening, and the largest of the measurements was used as the unobstructed channel width.

2.3 Vegetation Survey Methods

As discussed above, during the first four years of monitoring, vegetation sampling was conducted at seven transects at each AP. Subsampling and statistical analyses of the large volume of data collected during these field seasons showed no significant difference ($p>0.05$ for all analysis) between vegetation data collected at all seven transects compared to five transects when Transects 2 and 6 are removed. As a result, the Monitoring Protocol was modified in 2013 to eliminate two of the transects (typically Transects 2 and 6, counting from the downstream end of each site) to increase the efficiency of the data collection.

The start and end points of the VSZ along the each transect were determined in the field by assessing local vegetation characteristics and topography. Areas identified as out of the active channel were not surveyed. These areas included any portion of each transect dominated by mature woody vegetation having greater than 25 percent tree canopy cover and/or areas that were located topographically above the active channel and dominated by upland vegetation. The first quadrat on each linear transect was sampled at the start of each VSZ. All subsequent quadrats along each linear transect were sampled at regular 15-meter intervals until the end of the VSZ was reached. Occasionally, more than one VSZ was identified on a single linear transect. In these cases, the start and end points of each VSZ were determined as described above. Areas along a transect identified as not within the VSZ were generally larger than 15 meters (50 feet) in width.

The Daubenmire (1959) canopy coverage method was used to collect the vegetation data within each quadrat. At each 15-meter increment along the VSZ, a 1 m^2 quadrat was randomly positioned on the ground. All plant species within the quadrat frame and present at greater than trace densities (i.e., greater than approximately 2 percent of the quadrat area) were identified, and their cover was documented using Daubenmire (1959) cover classes. Plant species were identified primarily using The Flora of Nebraska (Kaul et al., 2011), although other field guides were also referenced (e.g., Shaw, 2008). Plant taxonomy was based primarily on Kaul et al. (2011), but was standardized using the PLANTS Database (USDA-NRCS, 2013).

Other data collected at each quadrat included height of woody and herbaceous species, and vegetation community type. All quadrats with quantifiable vegetation cover (i.e., with standing vegetation – either living or recently senesced) were photographed and archived. Specific data collected at each quadrat included the following:

- **Spatial data:** Horizontal coordinates and elevation of each quadrat (taken at the center point) were recorded with an RTK GPS on the same coordinate system used for the geomorphic data.
- **Plant species:** All plant species present within a quadrat frame at densities greater than 2 percent of the total quadrat area were recorded. Dead, standing vegetation was recorded during all field seasons (2009-2013) if it retained the same structure characteristics as analogous living vegetation.
- **Daubenmire cover (percent) by species:** Areal cover measures the degree to which above ground portions of plants cover the ground surface. The potential presence of more

than one vegetation layer in a quadrat allows total cover to exceed 100 percent in some cases, due to foliage overlap. Areal cover was quantified using the following Daubenmire cover classes.

- Cover class 1: 2-5%
- 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%

- **Areal cover (acres) by species:** Quantified by multiplying areal cover (percent) by total area sampled for each plant species.

- **Percent bare ground**: The percent of each quadrat which is bare exposed ground (i.e., sand, gravel, rock, or dirt) with no organic matter of any kind, living or dead. Bare ground was only quantified after 2011.

- **Percent dead organic matter**: The percent of each quadrat covered by dead organic matter, standing or downed (as collected after 2013). Percent dead organic matter was quantified from 2012 through 2013 as downed organic matter (i.e., thatch, downed woody debris, etc.), and standing dead vegetation with structure characteristics of living plants was quantified as living specimens. Dead organic matter was only quantified after 2011.

- **Woody vegetation height:** During 2013 data collection, a visual estimate of the actual maximum height of woody vegetation in each quadrat was made. From 2009 through 2012, vegetation height was collected categorically using mean height classes, or directly as a mean height. Values of actual maximum height are more appropriate for testing key hypotheses. The maximum height data are suitable for comparison with data from prior years.

- **Herbaceous vegetation height:** During 2013 data collection, a visual estimate of the actual maximum height of herbaceous vegetation in each quadrat was made. From 2009 through 2012, vegetation height was collected categorically using mean height classes, or directly as a mean height. Values of actual maximum height are more appropriate for testing key hypotheses. The maximum height data are suitable for comparison with data from prior years.

- **Vegetation community:** The predominant vegetation community type was identified as best represented by the quadrat. Community types were based on *Terrestrial Ecological Systems and Natural Communities of Nebraska* (Rolfsmeier and Steinauer, 2010), although several that were quantified in the field were not officially recognized by this resource (due to the predominance of non-native species). Community types and/or habitat types identified during the 2012 and 2013 vegetation surveys are categorized by the following:

  - Eastern cottonwood – (peachleaf willow)/coyote willow woodland (Rolfsmeier and Steinauer, 2010)
  - Riparian dogwood – false indigo shrubland (Rolfsmeier and Steinauer, 2010)
  - Sandbar willow shrubland (Rolfsmeier and Steinauer, 2010)
  - Sandbar/mudflat (Rolfsmeier and Steinauer, 2010)

- Russian olive sandbar
- Perennial sandbar (Rolfsmeier and Steinauer, 2010)
- Freshwater marsh (Rolfsmeier and Steinauer, 2010)
- Fallow agricultural land
- Ruderal upland
- Water
- Upland community

All vegetation data were collected using either a Trimble Geo XT or XH datalogger. A data dictionary was developed specifically for this work and uploaded into the datalogger using Trimble GPS Pathfinder Office (version 5.30) software. During field sampling, each quadrat was uniquely identified by capturing the associated AP number, transect number, and quadrat number. All spatial data were collected using an RTK GPS roving unit at sub-inch accuracy.

Each AP was surveyed using two teams of two biologists. In general, each survey team was responsible for 2 to 3 transects at each AP, allowing the survey for each AP to be completed in one day.

2.3.1 Sediment Sampling Methods

2.3.1.1 Bed and Bar Material

Up to 10 bulk bed-material samples and at least one composite bar material sample were collected at each AP in accordance with the Monitoring Protocol. Typically, each transect was subdivided into three segments, and a representative bed material sample was collected from each segment, insuring that one sample was taken from near the thalweg and the other two taken from the lowest elevation surface in other two segments. The 2012 and 2013 samples were analyzed in Tetra Tech's Fort Collins soils laboratory to determine the particle size gradations. Samples collected by the previous contractor in 2009, 2010 and 2011 analyzed in a similar manner at a local soils laboratory. The samples were collected using a sampler constructed from a 6-inch diameter by 12-inch long PVC pipe, beveled at one end and covered with a 200-micron mesh at the other end (**Figure 2.3**). In collecting the samples, the sampler was pushed 6 to 8 inches deep at an angle into the bed of the channel at the sampling location. The resulting sample sizes for the 2013 data ranged from about 360 to 2,600 g and averaged about 840 g. Sample sizes in the earlier years were similar to the 2013 samples. Since the samples were often collected from below the water, the sampler was oriented with the opening facing upstream so that the water could drain from the sampler with minimal loss of the sample material. All bed samples collected from the main and secondary channels were transferred to individual sample bags that were labeled with the sampled AP, transect ID, sample number, and date, and the sample locations were determined using an RTK GPS roving unit.

Bar material samples were generally collected at the head of a high bar in the area with the coarsest material. Samples were taken at three different locations on the bar within relatively close proximity to each other to insure that the overall sample site was on the same geomorphic feature. The bar samples were collected with a shovel after noting and removing any armor or coarse lag material. An approximately equal volume of materials was collected at each of the three locations, and the material was placed in one or more sample bags that were labeled with the sampled AP, transect ID, sample number, and the date the sample was taken. The total weights of the bar samples in 2013 ranged from 550 to 1,480 g, and averaged about 900 g, and the range of sample sizes in previous years was similar. A single georeferenced survey point was taken at the approximate center of the area encompassed by the three sites using one of the RTK GPS roving units.

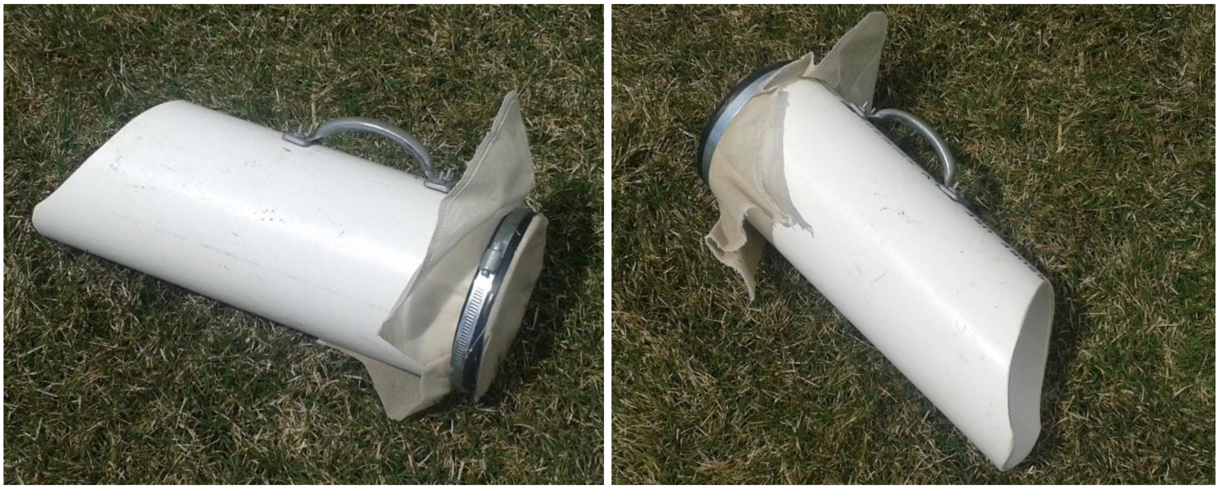


Figure 2.3. Pipe dredge used to collect bed-material samples.

2.3.1.2 Bed-load and Depth-Integrated Suspended Sediment Sampling

The Monitoring Protocol specifies that bed-load and depth-integrated suspended-sediment sampling is to be conducted at the following five bridge locations during pre-defined flow ranges:

- Lexington (SH-L24A/Rd 755),
- Overton (SH-L24B/Rd 444),
- Kearney (SH-44/S. 2nd Ave.),
- Shelton (SH-L10D/Shelton Road), and
- near Grand Island (US-34/Schimmer Drive).

The target flow ranges and corresponding number of samples is as follows:

- 1,000 to 3,000 cfs – 3 samples
- 3,000 to 5,000 cfs – 2 samples
- >5,000 cfs – at least 1 sample, if such flows occur.

In addition, a single depth-integrated suspended sediment sample is to be collected at each location during the bed-load sampling in the >5,000-cfs flow increment.

Bed load samples were collected during two periods during in 2013. The first period occurred between April 12 and 14 during the Spring 2013 SDMF. A total of nine samples were collected, with only one sample at Darr and duplicate samples at each of the other four locations. Discharges during this sampling period ranged from 2,250 cfs at Darr to 3,990 cfs at Kearney. A single suspended sediment sample was also collected at Overton and Grand Island during the April sampling at discharges of 3,830 and 3,650 cfs, respectively. The Fall 2013 sampling was performed between September 23 and 29 when the discharges at the sample sites ranged from 3,670 cfs at Darr to 11,960 cfs at Overton. A total of 11 bed-load samples were collected during this period, with duplicate samples at each of the five primary sample sites and one additional sample collected at the Elm Creek Bridge. Suspended-sediment samples were collected in conjunction with each of the bed load samples.

2.3.2 Data Analysis Methods

The basic data collected during the field program were evaluated in accordance with the draft Data Analysis Plan (PRRIP, 2012a).

2.3.2.1 Spatial and Temporal Scales

The Data Analysis Plan specifies that the data are to be evaluated at a range of spatial and temporal scales. The relevant *spatial* scales include the following:

- Transect—analyses to be summarized (i.e., mean and standard deviation) by transect. The draft Data Analysis Plan specifies that vegetation data are to be collected at seven transects that are spaced approximately 165 feet apart, and the geomorphic data are to be collected at three of these transects. This protocol was followed in 2009, 2010 and 2011. During 2012, geomorphic data were collected at all seven transects. As described elsewhere in this document, statistical analysis indicates that the information obtained from only five transects is essentially the same as is obtained from seven transects; thus, geomorphic and vegetation data were collected at five transects at each AP during 2013, and the protocol will be followed for all future sampling.
- Anchor point—analyses to be summarized (mean and standard deviation) by anchor point: one summary for anchor point transects on the main channel, and a second summary for all side channel transects that occur at the anchor point. There are 40 anchor points spaced approximately 2.5 miles apart from Lexington to Chapman.
- Complex – analyses to be summarized for each of the following Platte River Recovery Implementation Program complexes: Plum Creek (AP35, AP36, AP37), Cottonwood Ranch (AP32, AP33), Elm Creek (AP29, AP30), Fort Kearney (AP22, AP23), and Shoemaker Island (AP12). Average and standard deviation will be reported for complex anchor points, and separately for non-complex anchor points.
- Bridge segment—analyses to be summarized (mean and standard deviation) by bridge segment: Lexington to Overton, Overton to Elm Creek, Elm Creek to Odessa, Odessa to Kearney, Kearney to Newark, Newark to Shelton, Shelton to Wood River, Wood River to Grand Island, and Grand Island to Chapman. The main channel will be summarized separately from the side channels.
- Geomorphic reach—reach-averaged results (mean and standard deviation) to be summarized by reach [based on reaches with consistent planform, as characterized in Fotherby (2008); **Table 2.1**]. The main channel will be summarized separately from the side channels.
- System—analyses to be summarized (mean and standard deviation) for the overall study reach from Lexington to Chapman (i.e., all anchor points). The main channel will be summarized separately from the side channels.

The relevant *temporal* scales include the following:

- Annual—Main channel transect data at the 20 pure-panel anchor points that are monitored annually will be reduced and analyzed every year.

- Four-year (rotating panel and side channels)—Data for side channels at the pure-panel APs were initially collected in 2009, and data will be collected in these channels again every fourth year. The data from the rotating panel points will be reduced and summarized as part of the annual report for the year in which they were collected.
- First Increment—All data collected for this Program will be analyzed after the 2019 monitoring season to assess the change in each of the metrics over the course of the First Increment.

Table 2.1. Geomorphic reaches from Fotherby (2008).

Reach	Description	River Miles	Main Channel Transects	Side Channel Transects
1	Lexington Bridge to Overton Bridge (including north channel of Jeffrey Island)	239.5-254.5	38 to 40; 37a, 36b, 35a	None
2	South channel of Jeffrey Island from J2 Return to Overton Bridge	239.5-247	37a, 36b, 35b	37b, 36a, 35b
3	Overton Bridge to Elm Creek Bridge	231-239.5	31, 32a, 33a, 34	32b-c, 33b-c
4	Elm Creek Bridge to Odessa Bridge	224-231	28-30	None
5	Odessa Bridge to Minden	208-231	22a, 22b, 23a, 24-27	23bS, 23bN
6	Minden to Gibbon Bridge	202-207	20a, 21a	20b, 21bS, 21bN
7	Gibbon Bridge to Wood River	187.5-202	14-18, 19a	19b
8	Wood River to Grand Island	173-187.5	8a, 9a, 10a, 11a, 12a, 13a	8b-c, 9bS, 9bN, 9c, 10b-c, 11b, 12b, 13b
9	Grand Island to Chapman	156.5-173	1-5, 6b, 7a	6a, 7bS, 7bN, 7c

2.3.3 Performance Metrics

A suite of 35 individual performance metrics that can be quantified from the field data from this program and other available data sources have been identified for use in evaluating trends in channel morphology and in-channel vegetation for purposes of answering the Big Questions and testing the priority hypotheses (**Table 2.2**). As shown in the table, these metrics fall into six general categories: Hydrologic, Hydraulic, Geomorphic, Vegetation, Sediment, Whooping Crane. A brief description of the data and methods that were used to quantify each of the metrics is provided in the following sections. Specific definitions and criteria are spelled out in more detail in the draft Data Analysis Protocol (PRRIP, 2012a).

2.3.3.1 Hydrologic Performance Metrics

Data for eight hydrologic (or flow-related) performance metrics were derived primarily from the following gages that are maintained and operated by the U.S. Geological Survey (USGS) or Nebraska Department of Natural Resource (NDNR):

Table 2.2. Performance metrics defined in the Channel Geomorphology and In-channel Vegetation Data Analysis Plan.

Variable/Relationship	Monitoring Plan Section	Definition	Type	Reporting Scale	
				Temporal	Spatial
Hydrologic Performance Measures					
Q_P	5.1.1	Annual instantaneous peak discharge	Value	Annual	By Gage
DUR_{5000}	5.1.1	Duration of Q>5,000 cfs	Value	Annual	By Gage
FDC_{Ger}	5.1.2	Flow duration curve for germination season (6/1-7/15)	Curve	Annual	By Gage
Q_{Ger}	5.1.2	Germination season discharge (Q_{Mean} 6/1-7/15)	Value	Annual	By Gage
Q_{WC_Spring}	5.1.3	Spring Whooping Crane migration discharge (Q_{mean} 3/21-4/29)	Mean Value	Annual	By Gage
Q_{WC_Fall}	5.1.3	Fall Whooping Crane migration discharge (Q_{mean} 10/9-11/10)	Mean Value	Annual	By Gage
FDC_{WC_Spring}	5.1.4	Spring Whooping Crane migration flow duration curve (3/21-4/29)	Curve	Annual	By Gage
FDC_{WC_Fall}	5.1.4	Fall Whooping Crane migration flow duration (10/9-11/10)	Curve	Annual	By Gage
Hydraulic Performance Measures					
Stg-Q	5.2.1	Stage-discharge rating curves for 500 cfs <= Q <= 8,000 cfs	Curve	Annual	AP Transect
Geomorphic Performance Measures					
BI	5.3.1	Braiding index	Value	By Survey[1]	Anchor Point and Subreach
W_T	5.3.2	Total channel width @ 1,200 cfs	Value	By Survey[1]	Transect and Anchor Point
$W_{T\text{-}Wetted}$	5.3.3	Wetted Channel Width (Total channel width (W_T)-Total width above 1,200-cfs WSEL)	Value	By Survey[1]	Transect and Anchor Point
D_H	5.3.4	Average channel depth (Cross sectional area @ 1,200 cfs / $W_{T\text{-}Wetted}$)	Value	By Survey[1]	Transect and Anchor Point
D_{Max}	5.3.5	Maximum channel depth (WSEL @ 1,200 cfs – Thalweg Elevation)	Value	By Survey[1]	Transect and Anchor Point
W/D	5.3.6	Wetted channel width ($W_{T\text{-}Wetted}$)/Maximum Channel Depth	Value	By Survey[1]	Transect and Anchor Point

Variable/Relationship	Monitoring Plan Section	Definition	Type	Reporting Scale	
				Temporal	Spatial
ΔA_i	5.3.7	Change in cross sectional area @ 1,200 cfs from previous survey	Value	By Survey[1]	Transect and Anchor Point
ΔA_t	5.3.7	Change in cross sectional area @ 1,200 cfs from 2009 survey	Value	By Survey[1]	Transect and Anchor Point
LProf	5.3.8	Plot of longitudinal thalweg profile by ACOE River Mile (2009 and 2019, only)	Curve	2009, 2019	Reach
Vegetation Performance Measures					
GLE	5.4.1	Green line elevation (edge of 25% cover)	Value	By Survey[1]	Transect and Anchor Point
W_{Unveg}	5.4.2	Cumulative distance between pairs of GLE points within main channel, by transect	Value	By Survey[1]	Transect and Anchor Point
$f_{species}$	5.4.3	Frequency of occurrence for each species of interest and/or 25 most common species in current year	Value	By Survey[1]	Transect and Anchor Point
%Cover	5.4.4	Percent cover for each species of interest and/or 25 most common species in current year	Value	By Survey[1]	Transect and Anchor Point
$AC_{Species}$	5.4.5	Aerial cover occupied by each species of interest and/or 25 most common species in current year (Surface Area of AP X %Cover)	Value	By Survey[1]	Anchor Point
$\bar{E}_{Species}$	5.4.6	Mean elevation by species of interest and/or 25 most common species in current year	Value	By Survey[1]	Transect and Anchor Point
$H_{species}$	5.4.7	Mean vegetation height (not species specific)	Value	By Survey[1]	Transect and Anchor Point
Sediment Performance Measures					
Q_{s_bed}-Q	5.5.1	Bed-load versus discharge rating curve	Scatter Plot and Fitted Curve	Cumulative by sampling event	Five specified locations
Q_{s_susp}-Q	5.5.2	Suspended-sediment load versus discharge rating curve	Scatter Plot and Fitted Curve	Cumulative by sampling event	Five specified locations

Variable/Relationship	Monitoring Plan Section	Definition	Type	Reporting Scale	
				Temporal	Spatial
GSD_{bed}	5.5.3	Bed material grain-size distribution curve of percent finer by weight	Curve	By Survey[1]	Transect and Anchor Point
GSD_{bar}	5.5.4	Bar material grain-size distribution curve of percent finer by weight	Curve	By Survey[1]	Transect and Anchor Point
GSD_{bank}	5.5.5	Bank material grain-size distribution curve of percent finer by weight	Curve	By Survey[1]	Transect and Anchor Point
$D_{50\_bed, bar, bank}$	5.5.3-.5	Median size of bed, bar and bank distributions	Value	By Survey[1]	Transect and Anchor Point
$D_{16\_bed, bar, bank}$	5.5.3-.5	16th percentile size of bed, bar and bank distributions	Value	By Survey[1]	Transect and Anchor Point
$D_{84\_bed, bar, bank}$	5.5.3-.5	84th percentile size of bed, bar and bank distributions	Value	By Survey[1]	Transect and Anchor Point
$G_{bed, bar, bank}$	5.5.3-.5	Gradation coefficient for bed, bar and bank material samples ($G_i=D_{84}/D_{50}+D_{50}/D_{16}$)	Value	By Survey[1]	Transect and Anchor Point
Whooping Crane Performance Metrics					
W_{c_unobs}	5.6.1	Maximum distance in main channel between obstructions higher than 4.9 feet above 2,400 cfs WSEL	Value	By Survey[1]	Transect and Anchor Point
$W_{c\_unobs\_S}$	5.6.1	Maximum distance in main channel between obstructions higher than 4.9 feet above Q_{WC_Spring}	Value	By Survey[1]	Transect and Anchor Point
$W_{c\_unobs\_F}$	5.6.1	Maximum distance in main channel between obstructions higher than 4.9 feet above Q_{WC_Fall}	Value	By Survey[1]	Transect and Anchor Point
$W_{D<8\_in}$	5.6.2	Maximum width in main channel with flow <8" deep, including exposed sandbars	Value	By Survey[1]	Transect and Anchor Point

[1]Annual for Pure Panel Points/Every 4 years for rotating points

- Platte River at Lexington (NDNR 228400)[1],
- Platte River near Overton (USGS 06768000),
- Spring Creek near Overton (USGS 06768020),
- Buffalo Creek near Overton (USGS 06769000),
- Elm Creek near Elm Creek (USGS 06769525),
- Platte River near Kearney (USGS 06770200),
- Platte River near Shelton (NDNR 229300), and
- Platte River near Grand Island (USGS 06770500)

In the 2012 annual report, the Platte River near Odessa gage (NDNR 6770000) was also used; however, further evaluation of the data from that gage shows inconsistencies that make the data suspect for purposes of this study, particularly at high flows. For this reason, the Odessa gage is no longer being used in the analysis.

Data for the USGS gages were obtained from the National Water Information System (NWIS) website (http://waterdata.usgs.gov/nwis), and data for the Nebraska Department of Natural Resources (NDNR) gages were obtained directly from NDNR since their publically-available website only contains data through Water Year (WY) 2010. The specific values of the seven hydrologic performance metrics were computed by estimating a mean daily flow record for each AP using distance-weighted interpolation between each of the mainstem gages, adjusting gaged tributary inflows and ungaged losses or gains between the mainstem gages. The ungaged rate of gain or loss in each segment of the reach was estimated by taking the difference between the corresponding mean daily flows at the mainstem gages, subtracting the reported tributary inflows or adding the reported diversions (at the Kearney Canal Diversion), as appropriate, and dividing the remainder by the length of the segment.

The following specific clarifications to the DAP were employed in computing the hydrologic performance metrics:

- The annual peak flow event discharge (DAP 5.1.1; Q_P) was defined as the maximum mean daily discharge between January 1 and the date of the respective surveys during each year. The maximum mean daily flow is being used because instantaneous peak flow data are not available at all locations, and from a riverine process perspective, the mean daily discharge is a more meaningful value because it occurs for a sufficient duration to do work within the channel.

- DAP 5.1.2 defines the germination season discharge exceedence as *the frequency of flows within the April 1 to July 31 germination season*. Because a key use of this metric is to assess the effects of flow on cottonwood germination and persistence, the time-frame was modified to June 1 through July 15 to more closely correspond to the timing of cottonwood seed dispersal and germination. Although the duration of discharges is important, a specific, representative discharge during the germination season is also necessary to facilitate the trend analyses. As a result, the representative germination season discharge (Q_{GER}) was defined as the mean discharge during the period.

[1] In some cases, data from the Cozad gage (NDNR 6466500 for 1992 and later; USGS Gage No. 06766498 prior to 1992).

2.3.3.2 Hydraulic Performance Metrics

The hydraulic performance metrics consist of stage versus discharge relationships at the transects that make up each of the APs. These relationships were developed by making multiple-profile runs with the Program's existing 1-D hydraulic model. This model is based primarily on the 2009 LiDAR data and the transect survey data from the initial 2009 survey for this monitoring program, supplemented with other available survey data that had been collected in specific locations for other purposes. As will be discussed in more detail below, certain of the geomorphic performance metrics from the 2012 and 2013 data appear to be unreasonable, suggesting that the channel geometry has changed sufficiently since 2009 so that the relationships are no longer valid. At the time of the report, the model is being updated with the 2012 data. Key metrics that rely on the model results will need to be re-evaluated after completion of the model updates.

2.3.3.3 Geomorphic Performance Metrics

The geomorphic performance metrics include nine specific measures of channel geometry and form. Eight of the nine metrics were quantified for the original three years of data collected by the previous contractor and the 2012 data collected by Tetra Tech for the 2012 annual report. The values of these eight metrics from the 2013 were added to the data sets for this report. Data for the 9th metric (longitudinal thalweg profile) were only collected in 2009 as part of the initial surveys, and these data will be collected again in 2019.

In quantifying the metrics, one relatively minor deviation from the draft Data Analysis Plan was employed. Total channel width is defined in the Plan as total channel width at 1,200 cfs, including non-wetted areas (e.g., exposed sand bars, and vegetated islands), but excluding ineffective flow areas. After evaluating the data in more detail, Tetra Tech recommended that the ineffective flow areas should be included in the width calculations, and Program staff agreed to the change (Jason Farnsworth, personal communication, March 2013).

2.3.3.4 Vegetation Performance Metrics

The vegetation performance metrics are quantified directly from the field data. Although 178 individual species were identified in 2013, the analysis considered only the 25 most frequently observed, based on data collected in the main channel at the Pure Panel APs, and at APs 35b and 37b in Reach 2, due to their relationship with the J-2 Return (**Table 2.3**). In the case where species of interest (see Section 1.2.5) were uncommon and not within the 25 most frequently observed species, they were also included to maintain consistency with analyses from prior years. Data for the species not included in Table 2.3 (i.e., species that were not common or a species of interest) have been retained in the master dataset and are available for additional analysis.

Hypotheses testing and trend analyses were restricted to a select subset of four plant taxa: purple loosestrife, common reed, eastern cottonwood, and willow (*Salix exigua* and *S. amygdaloides* combined). These taxa were chosen because of their rapid growth rate and colonization of bars in the Platte River system and wide distribution. Other taxa were excluded from these analyses to streamline the statistical calculations that support hypothesis testing and trend analysis.

Table 2.3. Species considered in the analyses. Included are the 25 most frequently observed species in 2013 and individual species of interest occurring at lower frequencies.

Scientific Name	Common Name	Growth Form	Wetland Indicator Status[1]	Native (Y/N)[2]
Ambrosia artemisiifolia	Annual ragweed	Forb	FACU	Yes
Ambrosia psilostachya	Perennial ragweed	Forb	FAC	Yes
Amorpha fruticosa	False indigo-bush	Shrub	OBL	Yes
Bidens cernua	Nodding bur-marigold	Forb	OBL	Yes
Bolboschoenus fluviatilis	River bulrush	Reed/Sedge	OBL	Yes
Bromus tectorum	Cheatgrass	Grass	NL	No
Carex emoryi	Emory's sedge	Reed/Sedge	OBL	Yes
Conyza canadensis	Horseweed	Forb	FACU-	Yes
Cyperus odoratus	Rusty flatsedge	Reed/Sedge	FACW	Yes
Cyperus squarrosus	Bearded flatsedge	Reed/Sedge	OBL	Yes
Echinochloa crus-galli	Large barnyard grass	Grass	FACW	No
Elaeagnus angustifolia	Russian olive	Tree	FAC	No
Eragrostis pectinacea	Tufted lovegrass	Grass	FAC	Yes
Helianthus annuus	Common sunflower	Forb	FACU	Yes
Leersia oryzoides	Rice cut grass	Grass	OBL	Yes
Leptochloa fusca	Sprangletop	Grass	FACW	Yes
Lythrum salicaria	Purple loosestrife	Forb	OBL	No
Melilotus albus	White sweetclover	Forb	FACU	No
Panicum capillare	Common panic grass	Grass	FAC	Yes
Panicum virgatum	Wand panic grass	Grass	FAC	Yes
Phalaris arundinacea	Reed canary grass	Grass	FACU+	Yes
Phragmites australis	Common reed	Grass	FACW	Yes
Polygonum lapathifolium	Curlytop knotweed	Forb	OBL	Yes
Polypogon monspeliensis	Annual rabbitfoot grass	Grass	OBL	No
Populus deltoides	Eastern cottonwood	Tree	FAC	Yes
Rumex crispus	Curly dock	Forb	FACW	No
Salix amygdaloides	Peach-leaf willow	Tree	FACW	Yes
Salix exigua	Narrow-leaf willow	Tree	FACW+	Yes
Solidago gigantea	Late goldenrod	Forb	FACW	Yes
Spartina pectinata	Freshwater cord grass	Grass	FACW	Yes
Tamarix ramosissima	Saltcedar	Tree	FACW	Yes
Xanthium strumarium	Rough cockleburr	Forb	FAC	Yes

[1] Source: North American Digital Flora: National Wetland Plant List (Lichvar and Kartesz 2012); Midwest Region
[2] Source: PLANTS Database (USDA-NRCS, 2013)
3 Source: National Wetland Plants List (USACE 2013)

Evaluation of the vegetation performance metrics provides at least three essential insights that facilitate understanding of the ecology of the study area and guide management actions, as follows:

1. Describes baseline conditions,
2. Provides a basis for tracking ecosystem changes through time, and
3. Provides a benchmark to measure response to experimental management actions.

Vegetation performance metrics for each survey year were partially examined in the annual reports from previous years of this monitoring program (Ayres and Olsson, 2010, 2011, 2012; Tetra Tech 2013). The vegetation performance metrics presented in this report include a more comprehensive treatment of the previous data and incorporate data collected during the 2013 field season. The vegetation performance metrics provide insight into the most prevalent species at the sample sites (and by inference, the overall Central Platte River Reach), where they are distributed, and the ecological conditions that they collectively represent.

2.3.3.5 Sediment Performance Metrics

The sediment performance metrics fall into two general categories:

- Sediment-transport rates
- Bed-, bar- and bank-material particle size gradations

The sediment-transport data from the 2009, 2010 and 2011 data collection efforts have been reduced and plotted in the form of sediment discharge rating curves to support a variety of sediment transport analyses, including the modeling that was conducted for the Sediment Augmentation Feasibility Study (Tetra Tech, 2010) and the Elm Creek FSM Experiment (Tetra Tech, 2012).

2.3.3.6 Whooping Crane Performance Metrics

The whooping crane performance metrics are intended to quantify the available sight distances and associated channel widths within the channel corridor. These metrics are based on a combination of direct measurements of unobstructed widths (2013 data, only), vegetation height data (2009 through 2012) and hydraulic model results. The hydraulic model results were used to quantify the widths of the channel that consist of either bare sand or flow depths of less than 8 inches at a discharge of 2,400 cfs and at the whooping crane migration season discharges (i.e., average mean daily discharge during the period from March 21 through April 29 for the spring migration season and October 9 through November 11 for the fall migration season). As discussed in the 2012 annual report (Tetra Tech, 2013), there are at least two significant challenges in quantifying these metrics with 2009-2012 data:

1. Vegetation heights were not collected in a consistent manner across years; thus, interpretation of the data is confounded by differences in the data sets,
2. The data were collected in broad categories of vegetation heights which introduces significant uncertainty into the actual height of the vegetation.

2.3.4 Trend Analysis

For the 2012 annual report, a broad range of statistical comparisons were made across the 2009 through 2012 data sets to identify trends in the geomorphic, vegetation and sediment variables (**Table 2.4**). This resulted in a large number of analyses that are difficult to interpret in the context of Program priorities. To provide a more focused analysis, the Program directed that the trend analysis for this annual report be restricted to the following:

Table 2.4. Summary of trend analysis specified in the Data Analysis Plan.

Analysis Plan Section	Specified Analysis	Performance Metrics		Spatial Analysis Scale	
		Variable	Analysis Plan Section	Geomorphic Reach	System
6.1.	**Analyses for Broad Hypotheses S-1, S-2, and S-4**				
6.1.1.1.	Braiding Index Trend Analysis	BI	5.3.1	X	X
6.1.1.2.	Aggradation/Degradation Trend Analysis	DA_i	5.3.7	X	X
6.1.1.3.	Total Channel Width Trend Analysis	W_T	5.3.2	X	X
6.1.1.4.	Wetted Channel Width Trend Analysis	$W_{T\text{-}Wetted}$	5.3.3	X	X
6.1.1.5.	Unvegetated Channel Width Trend Analysis	W_{Unveg}	5.4.2	X	X
6.1.1.6.	Width-to-Depth Ratio Trend Analysis	W/D	5.3.6	X	X
6.2.	**Analyses for Broad Hypothesis PP-1**				
6.2.1.	Relationship between Annual Peak Flow and Unvegetated Channel Width	W_{unveg}, Q_P	5.4.2, 5.1.1	X	X
6.2.2.	Relationship between Germination Season Discharge and Unvegetated Channel Width	W_{unveg}, Q_{PGer}	5.4.2, 5.1.2	X	X
6.3.	**Analyses for Broad Hypothesis PP-2**				
6.3.1.	Relationship between Sediment Augmentation and Channel Volume Change	DAi, V_{SedAug}	5.3.7, *	N/A	N/A
6.3.2.	Relationship between Sediment Augmentation and Braiding Index	BI, V_{SedAug}	5.3.7, *	N/A	N/A
6.3.3.	Relationship between Sediment Augmentation and Total Channel Width	DAi, V_{SedAug}	5.3.7, *	N/A	N/A
6.3.4.	Relationship between Sediment Augmentation and Channel Width-to-Depth Ratio	DAi, V_{SedAug}	5.3.7, *	N/A	N/A
6.4.	**Analyses for Priority Hypothesis Flow 3**				
6.4.1.	Relationship between Annual Peak Flow and Green Line Elevation (GLE)	GLE, Q_p	5.4.1, 5.1.1	X	X
6.4.2.	Relationship between GLE and 1,200 cfs WSEL	GLE, $WSEL_{1200}$	5.4.1, 5.2.1	X	X
6.4.3.	Relationship between Green Line Elevation and Unvegetated Channel Width	GLE, W_{unveg}	5.4.1, 5.4.2	X	X
6.5.	**Analyses for Priority Hypothesis Flow 5**				
6.5.1.	Relationship between Annual Peak Flow and Mean Vegetation Elevation by Species	$\bar{E}_{species}$, Q_p	5.4.6, 5.1.1	X	X
6.5.2.	Relationship between Discharge during Germination Season and Mean Vegetation Elevation by Species	$\bar{E}_{species}$, Q_{pGer}	5.4.6, 5.1.2	X	X
6.6.	**Analyses for Priority Hypothesis Sediment 1**				
6.6.1.	Relationship between Sediment Augmentation and Trends in Bed and Bar Grain Size Distribution	D_i, V_{SedAug}	5.5.3-.5, *	N/A	N/A
6.7.	**Analyses for Priority Hypothesis WC-X**				
6.7.1.	Analysis of Wetted Widths across a Range of Discharges	$W_{D<8\_in}$	5.6.2	X	X
6.7.2.	Analysis of Portion of Channel with Flow Depth less than 8 inches at a Range of Discharges	$W_{D<8\_in}$	5.6.2	X	X
6.8.	**Analyses for Vegetative Species of Interest**				
6.8.1.	Frequency of Occurrence Trend Analysis	$f_{species}$	5.4.3	X	X
6.8.2.	Percent Cover Trend Analysis	%Cover	5.4.4	X	X
6.8.3.	Aerial Coverage Trend Analysis	ACSpecies	5.4.5	X	X

* Sediment augmentation volume developed from sediment augmentation monitoring records.

1. Flow 1 – Perform a detailed analysis of changes in bed sediment volume within the main channel for each of the 5 years of available data, and evaluate the results in the context of the sediment balance along the study overall study reach. In presenting the analysis, address the amount of variability in sediment loads (and the resulting sediment balance) and the implications of this variability to drawing conclusions about whether each portion of the reach is in aggrading, degrading or in dynamic equilibrium.

2. Flow 3 – Determine the correlation between flow, green line elevation (GLE) and unvegetated width. As specified in the Data Analysis Plan, the edges of unvegetated segments along each transect are identified by the GLE points. In the 2012 annual report, the unvegetated width metric was defined as the length of the longest uninterrupted unsegment between GLE points at each transect. For this analysis, the total unvegetated width, defined as the cumulative length of all unvegetated segments between GLE points within the main channel at each transect, was used. To remove the effects of river slope in the correlations, GLE values were normalized to the 1,200-cfs water surface (i.e., the difference between the GLE and the local 1,200-cfs water surface was used rather than the actual elevation). The following specific correlations will be evaluated using the metrics defined in this manner:

   a. GLE versus annual peak discharge (Q_p, Monitoring Plan Section 5.1.1), defined as the maximum mean daily discharge between January 1 and the date of the survey in each year.
   b. GLE versus germination season discharge (Q_{Ger}, Monitoring Plan Section 5.1.2), defined as the either the mean or median mean daily discharge between June 1 and July 15 (the primary season for establishment of cottonwood seedlings). For this analysis the correlations were performed using the both the mean and median discharges to assess which one provides the best correlation.
   c. Total unvegetated width (W_{unveg}) versus annual peak discharge (Q_{Ger}).
   d. Total unvegetated width (W_{unveg}) versus germination season discharge (Q_{Ger}).
   e. GLE versus total unvegetated width (W_{unveg}).

3. Flow 5 – Assess influence of spraying versus peak flows on phragmites distribution and frequency using vegetation plot data in conjunction with GIS-formatted records of annual spraying.

4. Mechanical 2 – Evaluate correlation between total unvegetated width (W_{unveg}), braiding index (BI) and percent consolidation at bankfull discharge.

Additional evaluations that were considered, but postponed to the 2014 annual report, include assessing the correlation between amount of lateral erosion into the primary banklines and large islands/bars, the braiding index and the annual peak discharge.

3 RESULTS

The performance metrics for the 2009 through 2013 data were quantified using the procedures described in Chapter 2. As noted, the specific definition of the some of the metrics has changed from the earlier definitions to better represent the intent of the analysis. Associated adjustments to the values were made for all of the years of data. The hydrologic, geomorphic and selected vegetation metrics, and remainder of the vegetation metrics are summarized in **Appendices A, B and C**, respectively**.**

3.1 Hydrologic

To facilitate quantification of the suite of hydrologic performance measures, a record of mean daily flows from October 1, 2008, through the date of the last 2013 monitoring survey was compiled for all of the USGS and NDNR mainstem and tributary gages within the reach (Figure 1.1). These flow records were then used to estimate an equivalent record for each of the APs by distance-weighted interpolation between the measured mainstem flows, taking into account measured tributary inflows and diversions, as described in Chapter 2. Flow-duration curves at the mainstem gages for each the flow-duration related metrics are provided in Appendix A.

3.1.1 Annual Peak Flow Event Discharge and Duration (DAP 5.1.1)

The maximum mean daily flows between January 1 and the surveys (Q_P) during 2009, 2012 and 2013 were in the range of 1,500 to 2,000 cfs upstream from Overton and the confluence of the North and South Channels at Jefferys Island, and 3,000 to 4,000 cfs downstream from that point (**Figure 3.1**). The flows were much higher in 2010 and 2011, generally ranging from 7,000 to 8,500 cfs in 2010 and from 7,200 cfs to over 10,000 cfs in 2010. In both years of these high-flow years, the maximum mean daily discharge tended to increase in the downstream direction. Maximum mean daily flows from the J-2 Return into the South Channel at Jefferys Island (Geomorphic Reach 2) were in the range of 1,900 to 2,000 cfs during all five years.

The maximum mean daily discharge did not exceed 5,000 cfs (DUR_{5000}) at any location in the reach prior to the 2009, 2012, and 2013 surveys, and it occurred for 6 days upstream from Overton and for 15 to 17 days downstream from Overton, with a slight increase in the downstream direction in 2010 (**Figure 3.2**). During the sustained high-flow period in 2011, the discharge exceeded 5,000 cfs for about 50 days upstream from Overton, 70 to 80 days between Overton and the Kearney Diversion Canal (KDC) Return, and about 80 days downstream from that point.

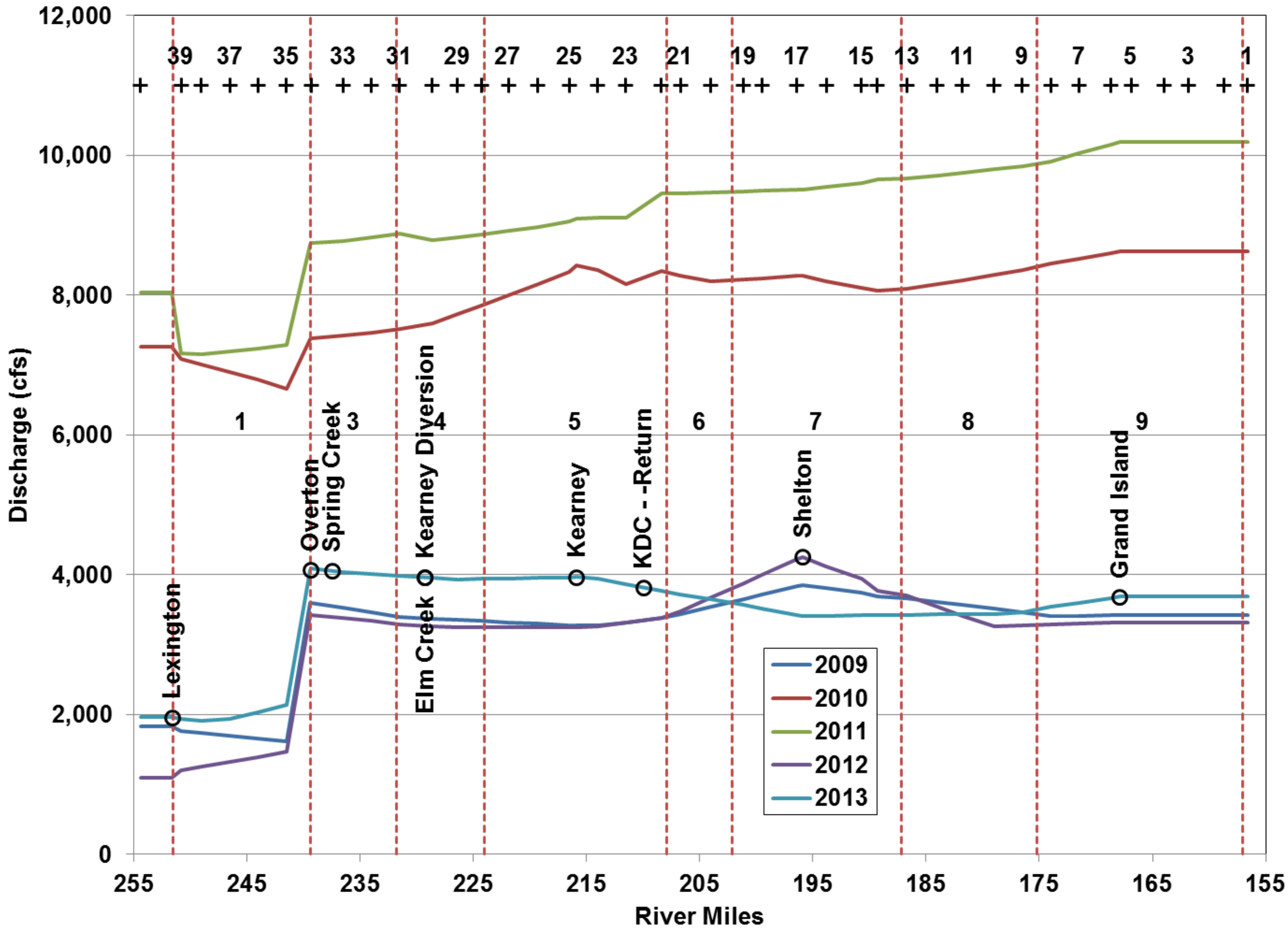


Figure 3.1. Maximum mean daily discharge (Q_P) between January 1 of each year and the dates of the 2009 through 2013 monitoring surveys.

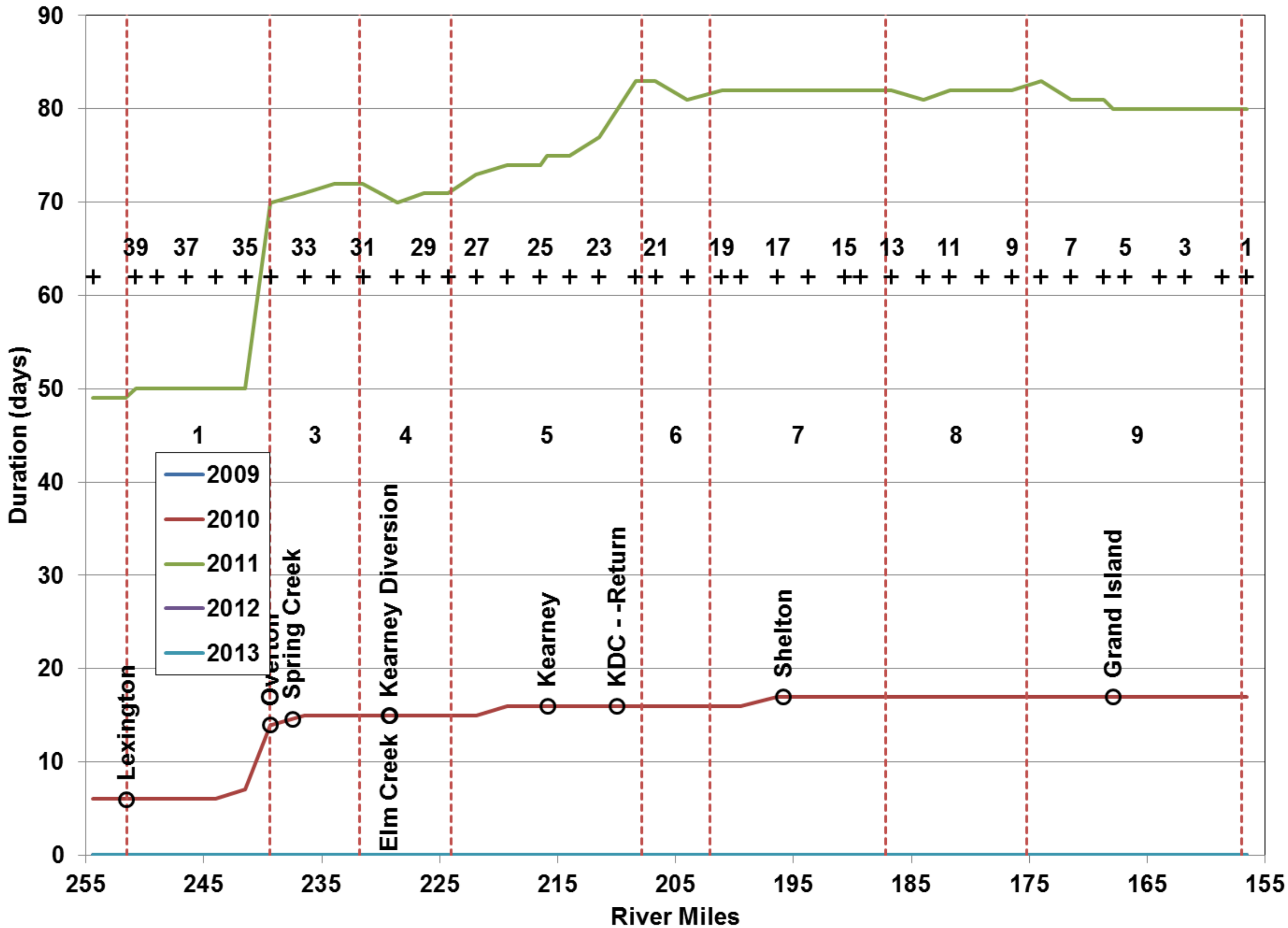


Figure 3.2. Duration of flows exceeding 5,000 cfs between January 1 of each year and the dates of the 2009 through 2013 monitoring surveys (DUR_{5000}).

3.1.1.1 Germination Season Discharge (DAP 5.1.2)

The mean discharge during the germination season (Q_{GER}, defined as June 1 through July 15 for purposes of this study) ranged from 400 to 550 cfs upstream from Overton, and were relatively constant in the range of 1,000 to 1,200 cfs downstream from that Overton (**Figure 3.3**). In 2010, the germination season flows were considerably higher, ranging from 2,300 to 2,400 cfs upstream from Overton, 3,900 to 4,700 cfs between Overton and the KDC Return, and were relatively constant at about 4,700 cfs downstream from that point. The flows more even higher in 2011, ranging from 5,300 to 5,800 cfs upstream from Overton, and from 7,200 to 7,600 cfs downstream from Overton, with a slight increasing trend in the downstream direction in both parts of the reach. The germination season flows in 2012 and 2013 were very similar, and also very low, ranging from 100 to 180 cfs upstream from Overton, relatively constant at about 270 cfs between Overton and the Kearney Diversion, decreasing to 150 to 180 cfs between the Kearney Diversion and the KDC Return, and then increasing back to the 260- to 320-cfs range, with a slight decreasing trend in the downstream direction, downstream from the KDC Return.

3.1.1.2 Spring and Fall Whooping Crane Migration Season Discharge (DAP 5.1.3)

The mean discharge during the spring whooping crane migration season (Q_{WC_Spring}; March 21 to April 29) in the portion of the reach upstream from Overton was approximately 500 cfs in 2009, and slightly higher in 2010, 2012 and 2013 (**Figure 3.4**). A similar pattern occurred downstream from Overton, with 2009 discharges ranging from about 1,200 to 1,300 cfs, 2010 discharges ranging from about 1,300 to 1,600 cfs, 2012 discharges ranging from 1,600 to 2,000 cfs, and 2013 discharges ranging from 1,500 to 1,700 cfs. The discharges were relatively consistent through the Overton to Chapman reach in 2009, 2010 and 2013, but the Shelton data indicate flows during this period were somewhat higher at that location than both up- and downstream. The discharges were much higher in 2011, in the range of 2,000 to 2,100 cfs upstream from Overton, and 3,600 to 4,300 cfs, with a general trend of increasing discharge in the downstream direction downstream from Overton.

The mean discharge during the fall whooping crane migration season (Q_{WC_Fall}; October 9 to November 10) ranged from 500 to 600 cfs upstream from Overton and from 1,600 to 1,900 cfs downstream from Overton in 2009 (**Figure 3.5**). In 2010, the flows were somewhat lower upstream from Overton, 500 to 600 cfs higher between Overton and the KDS, and then similar in the range of 1,500 to 1,900 cfs through the remainder of the reach (about 150 cfs higher downstream from Grand Island). Consistent with the other discharge metrics, the fall whooping crane migration discharge was much higher throughout the reach in 2011, ranging from 1,200 cfs to nearly 1,500 cfs upstream from Overton, and from about 3,200 to 3,700 cfs downstream from Overton, with a general trend of increasing discharge in the downstream direction. Flows during this period were much lower in 2012, ranging from ab0ut 110 to 215 cfs upstream from Overton, and from 500 to 190 cfs downstream from Overton, with a general trend of decreasing discharge in the downstream direction. Due to the effects of the lingering effects of the September 2013 flood, the 2013 flows were much higher than in 2012, ranging from 250 to 800 cfs upstream from Overton, and from 1,750 to 1,800 cfs downstream from Overton.

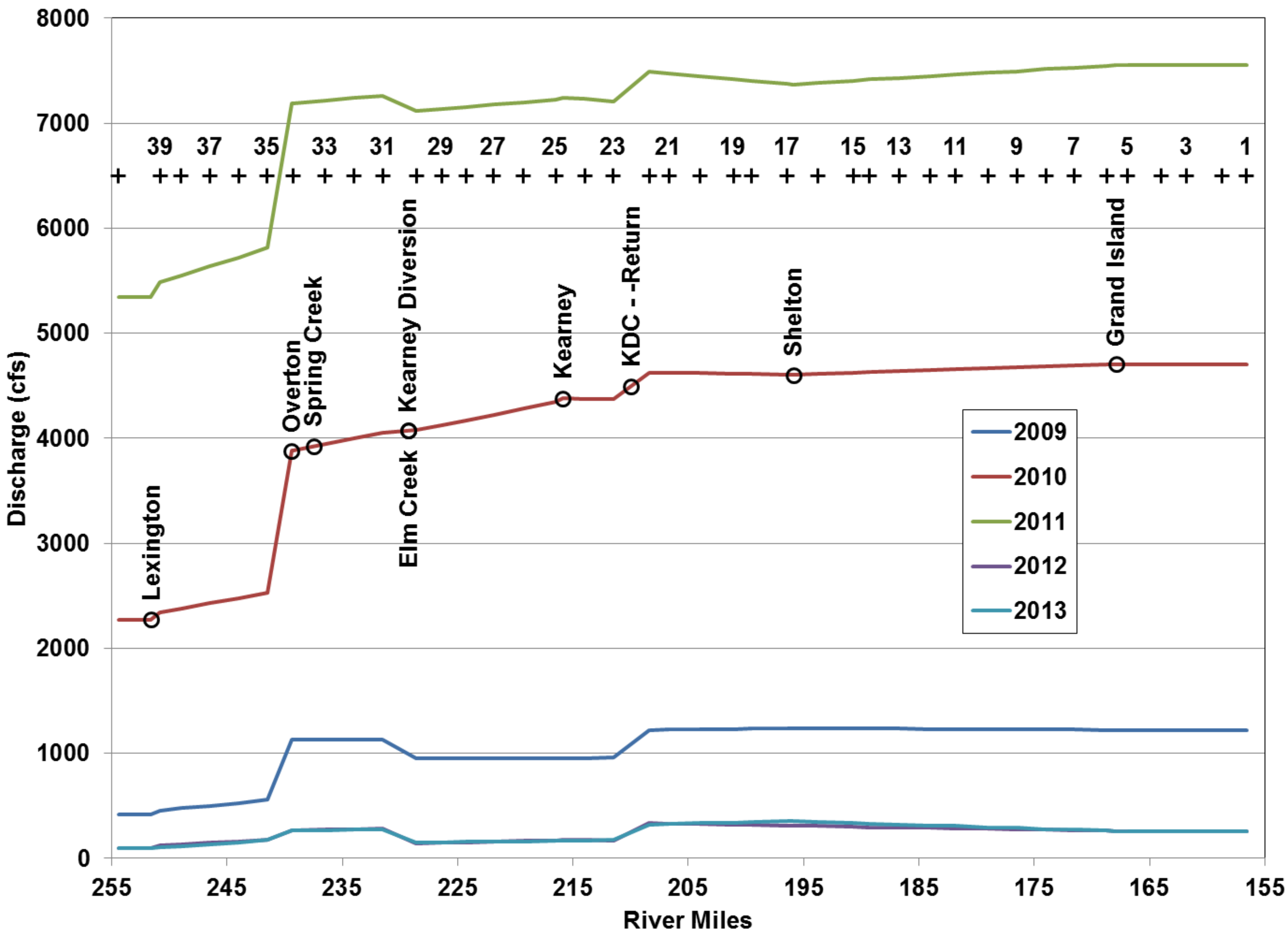


Figure 3.3. Average mean daily discharge during the germination season (Q_{GER}; June 1 – July 15) during 2009 through 2013.

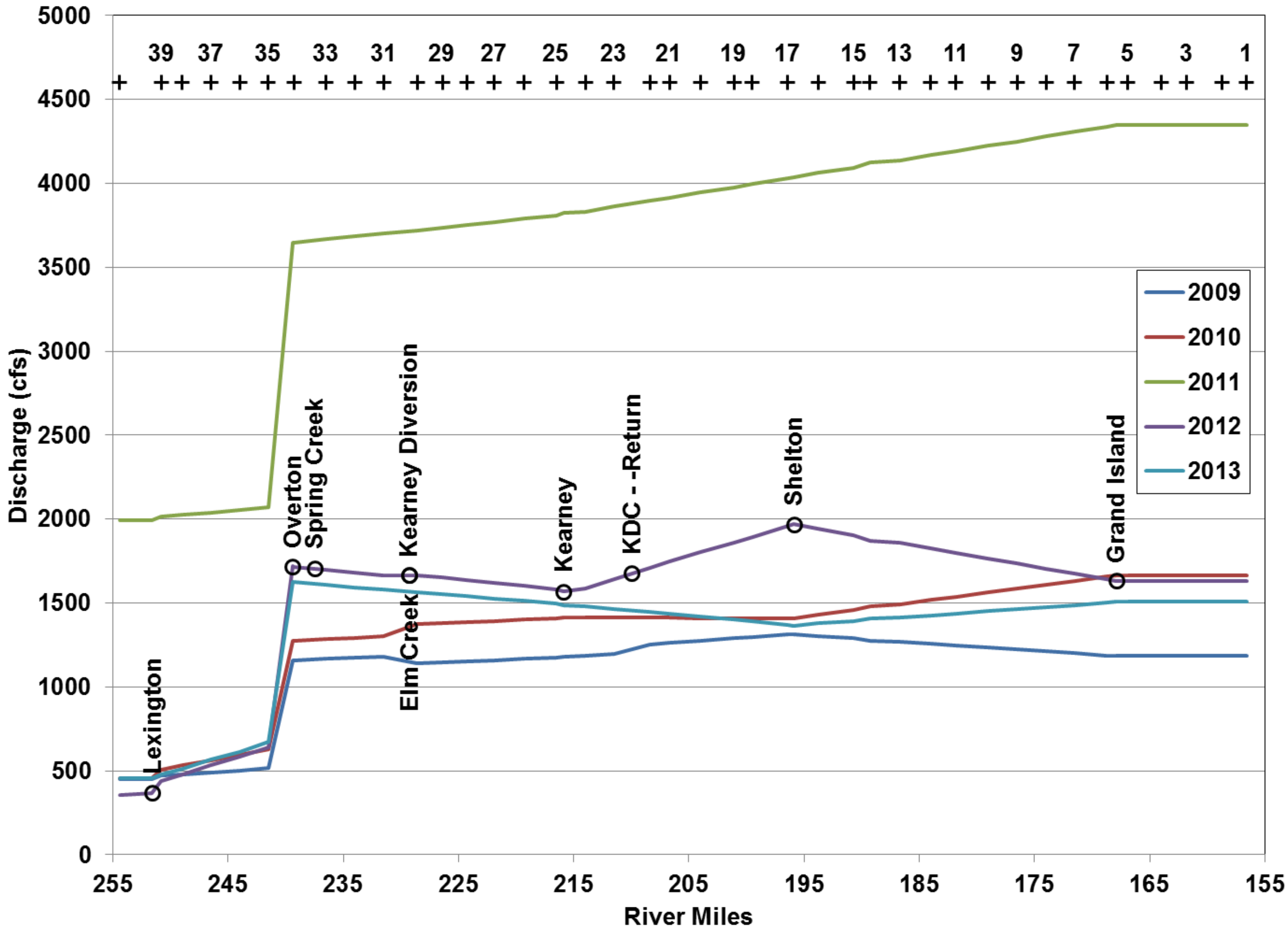


Figure 3.4. Average mean daily discharge during the spring whooping crane migration season (Q_{WC_Spring}; March 21 – April 29) during 2009 through 2013.

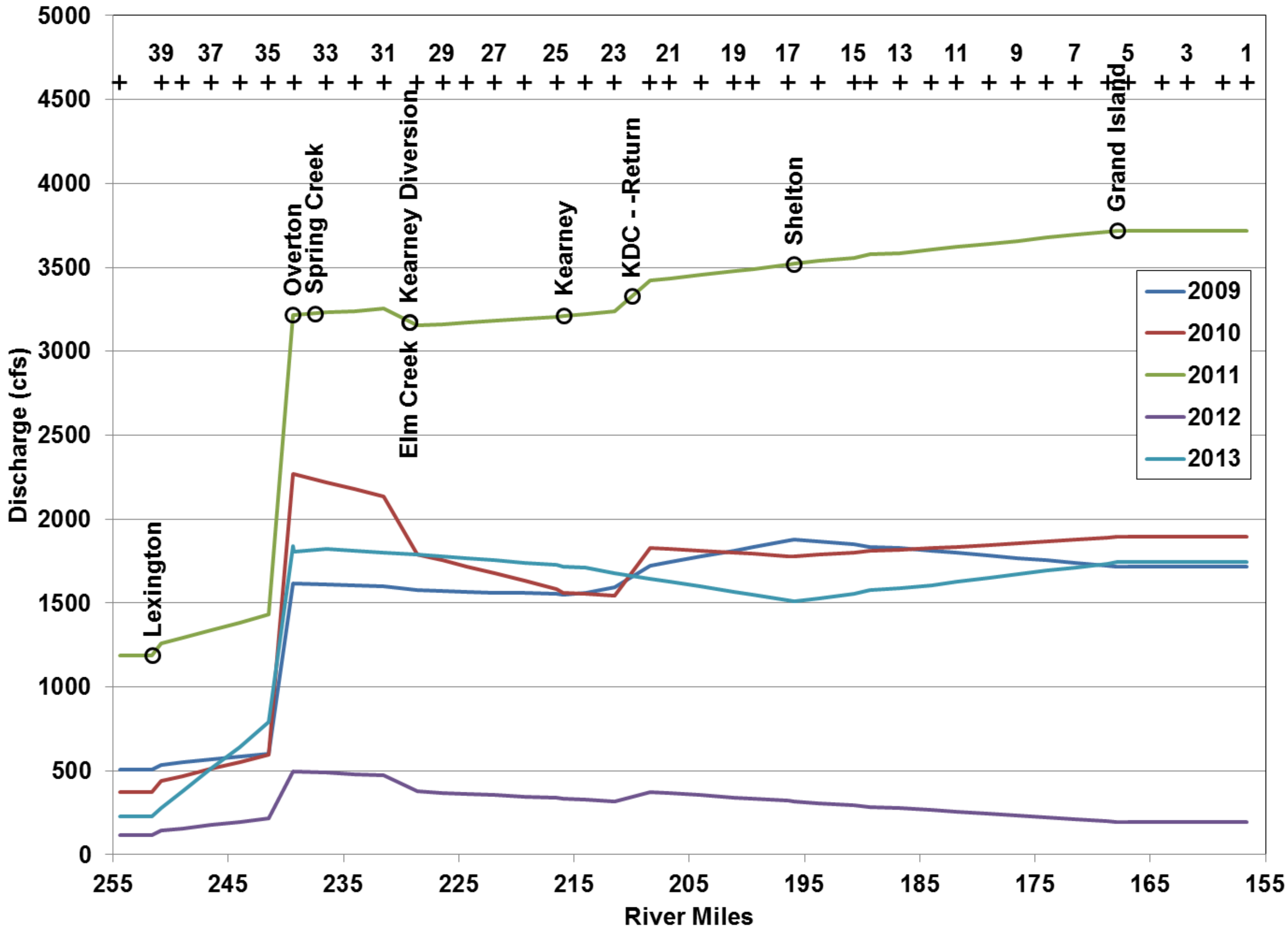


Figure 3.5. Average mean daily discharge during the fall whooping crane migration season (Q_{WC_Spring}; October 9 – November 10) during 2009 through 2013.

3.2 Hydraulic

3.2.1 Stage-Discharge Relationships (DAP 5.2.1)

The PRRIP 1-D hydraulic model that is based primarily on the 2009 LiDAR data was used to define stage-discharge relationships for the transects at each of the APs. These curves can be obtained from the HEC-RAS model output files.

3.3 Geomorphic

A suite of six geomorphic metrics are defined in the DAP to describe various aspects of the channel planform and cross sectional geometry (Table 2.2):

- Braiding Index (DAP 5.3.1) – Number of wetted channels crossed by each transect.
- Total Channel Width (DAP 5.3.2) - Total width, including non-wetted areas (e.g., exposed sand bars)
- Wetted Channel Width (DAP 5.3.3) – Cumulative width of individual wetted.
- Mean Channel Depth (DAP 5.3.4) – Average water depth (aka, hydraulic depth).
- Maximum Channel Depth (DAP 5.3.5) – Maximum depth (i.e., depth at thalweg).
- Channel Width-to-Depth Ratio (DAP 5.3.6) – Ratio of wetted channel width to maximum channel depth.

The values of these metrics were initially quantified at the transect scale using the survey data and the predicted water-surface elevations from the existing HEC-RAS model[2] that is primarily based on the 2009 LiDAR data (Appendix B). As discussed in the 2012 report, the values of several of the metrics showed significantly more year-to-year variability than anticipated. Back-calculated velocities for several of the suspicious results using the target discharge and cross sectional area from the updated cross section profile were unreasonable high, particularly where the cross section aggraded after the initial survey. This was especially true for the 1,200-cfs reference discharge that is used for several of the metrics. To provide a more reasonable, interim result, the affected metrics were re-computed by determining the water-surface elevation that would reproduce the modeled velocity at each of the three surveyed transects at each AP, the average difference between the modeled and back-calculated water-surface was determined at each AP, and the water-surface at each cross section was adjusted by the average shift. The average was determined to be the most reasonable since applying different adjustments to each cross section sometimes resulted in unreasonable (even adverse, in some cases) water-surface elevations within the AP. The 1-D model is currently being updated with the 2012 topography, and the affected metrics for 2012 and 2013 will be re-evaluated when the updated model is available.

Appendix B includes the results for both the Pure Panel and Rotating APs; however, the discussion below focuses on the Pure Panel AP results because the bulk of the Rotating APs have only been sampled once (the R1 APs were actually sampled for the second time in 2013).

[2]As discussed in the 2012 annual report, the stage-discharge rating curves in much of the reach appear to have shifted significantly, mostly as a result of the 2011 high flows. The HEC-RAS model is being updated using the 2012 LiDAR and survey data, and the values for affected metrics will be adjusted based on the updated model results for subsequent annual reports.

Average values for the various scales being considered in the analysis (i.e., AP, geomorphic reach, system-wide) were then developed from the by-transect results.

3.3.1 Braiding Index (DAP 5.3.1)

Based on the initial, 2009 survey data, the average braiding index at the Pure Panel APs ranged from about 1.3 (AP37) to 7.3 (AP1) (**Figure 3.6a**). The overall range was similar in subsequent years, with maximum values exceeding 8 at AP1 and AP17 in 2010, AP 17 in 2012 and at AP21 in 2013. Relatively large changes occurred at several of the APs over the period of the surveys, particularly AP1, AP15, AP17, AP21 and AP35. At AP1, the transects at the upstream and downstream limits of the site had several small channels that were inundated by only a small amount at the estimated 1,200-cfs water-surface in 2009, 2010 and 2011, and these channels either disappeared or the slight year-to-year change in water-surface elevation required to achieve reasonable in-channel velocities inundated the bars that separated several of these channels in 2012 and 2013. Similar year-to-year variability occurred at AP15, AP17 and AP21, although activities at the Rowe Sanctuary likely also affected AP21. Based on these results, it appears that the braiding index is very sensitive to small changes in water-surface elevation, especially when it is referenced to the 1,200-cfs water-surface that barely inundates many of the low-elevation, in-channel bars.

The reach-wide average braiding index remained relatively constant throughout the survey period at 4.5 to 4.6, with a somewhat lower value of 4.3 in 2012 (**Figure 3.6b**)[3]. The difference between 2012 and the other years is not statistically significant. Geomorphic Reach 6 (Minden to Gibbon) consistently had the highest braiding index, followed by Reaches 4 (Elm Creek to Odessa) and 7 (Gibbon to Wood River) (**Figure 3.6c**). Reach 9 (Grand Island to Chapman) also had relatively high braiding indices. The braiding index for Reach 6 is derived from only AP21 that, as noted above, is located at the Rowe Sanctuary and has a very high braiding index. Rotating AP20 that was surveyed only in 2011 had a braiding index of 4.7, similar to Reaches 4, 7 and 9, suggesting that AP21 may not be representative of the remainder of Reach 6. Reaches 1, 2 and 8 (Lexington to Overton, south channel at Jefferys Island, and Wood River to Grand Island, respectively) consistently had the lowest braiding index, followed by Reaches 3 and 5 (Overton to Elm Creek and Odessa to Minden, respectively).

Fotherby (2008) states in the Methods section of here paper that *a reach of river was …labeled as having a fully braided river pattern if the main channel had a braiding index of 3 or more throughout the reach.* In her analysis, however, she categorized reaches with main channel braiding index (defined as the average number of channels) less than 2.5 as wandering or meandering, 2.5 to 3.5 as braided and greater than 3.5 as anastomosed (See Fotherby, 2008, Section 4.1). The currently defined PRRIP subreaches were classified by Fotherby (2008) (Table 2.1) as follows[4]:

- Reach 1 – Wandering
- Reach 2 – Meandering
- Reach 3 (*Reach 3A*) – Anastomosed with some braiding
- Reach 4 (*Reach 3B*) – Braided
- Reach 5 – Anastomosed with some braiding (*Reach 3C*); anastomosed (*Reach 3D*)
- Reach 6 (*Reach 4A*) – Braided

[3]Because APs 25 and 37 were not surveyed in all years, it was assumed that the values of the geomorphic variables during the non-surveyed years remained the same as the last surveyed year for purposes of developing the geomorphic and overall reach averages to avoid bias resulting from simply eliminating these values.
[4]Fotherby (2008) reach designations in *italics*, where different from current definition

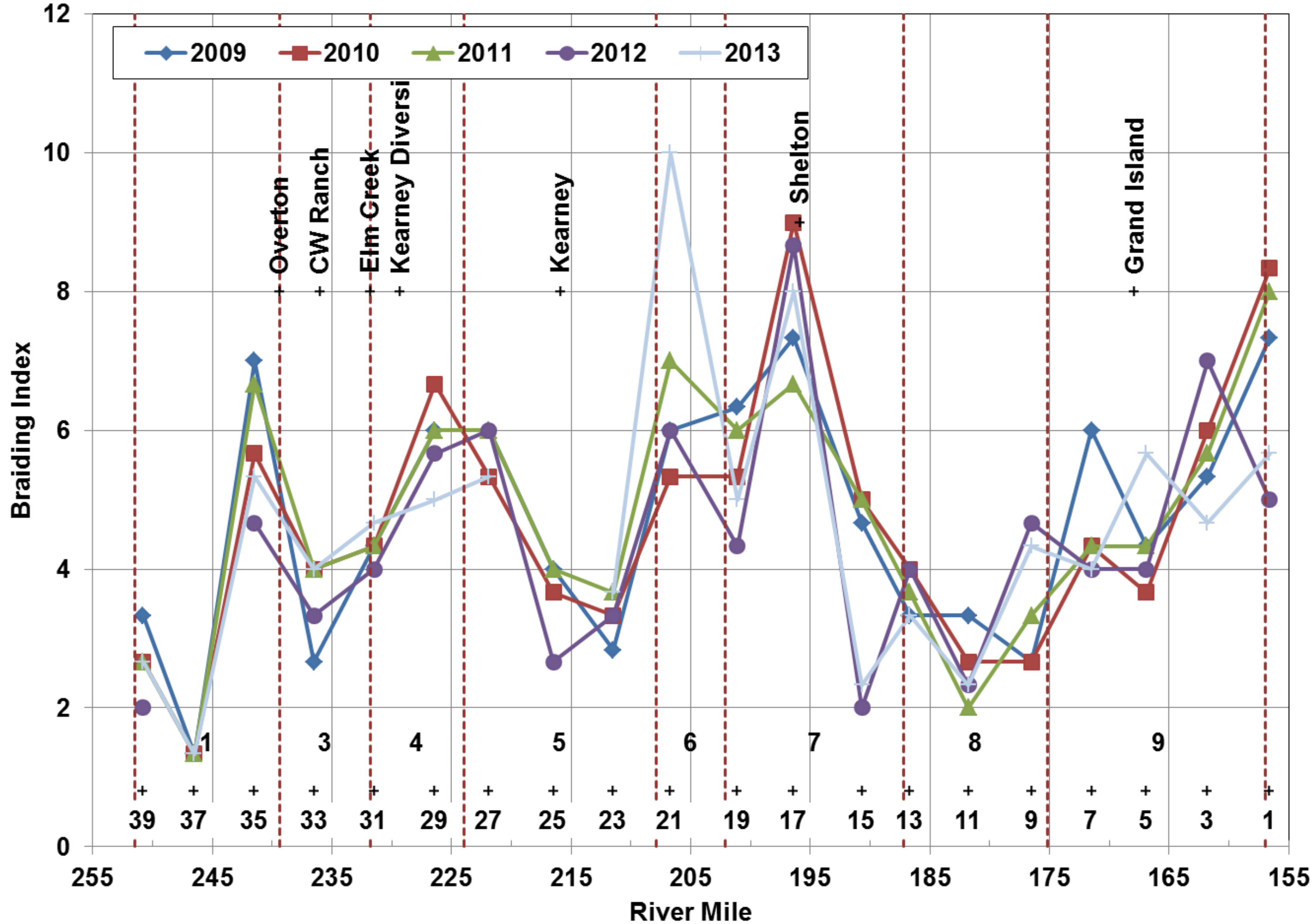


Figure 3.6a. Average braiding index at pure panel APs from the 2009 to 2013 data.

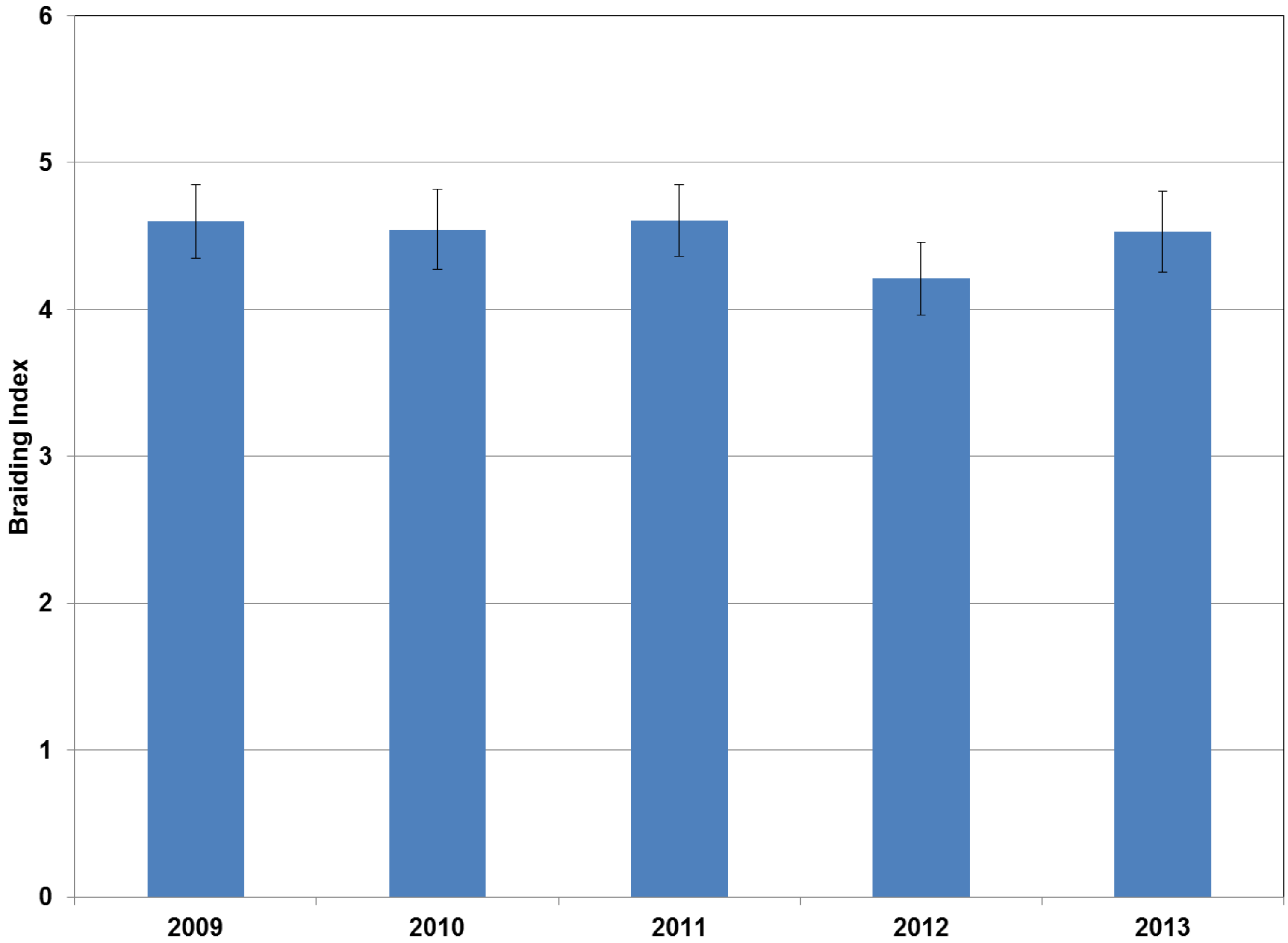


Figure 3.6b. Average braiding index for the overall study reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value.

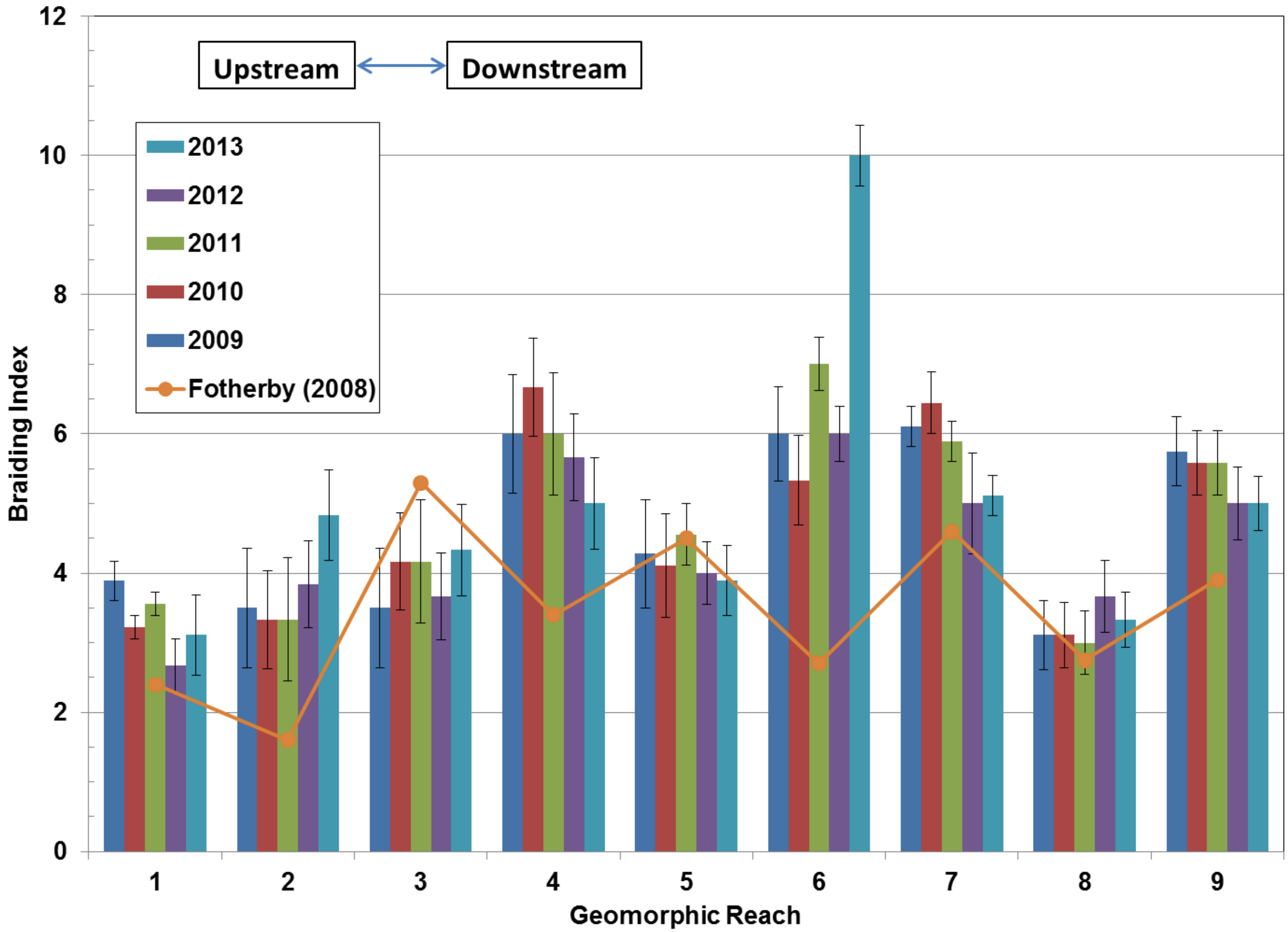


Figure 3.6c. Average braiding index by geomorphic reach, based on the pure panel AP data from the 2009 to 2013. Also shown are Fotherby (2008) braiding indices. Whiskers represent ±1 standard error on mean value.

- Reach 7 (*Reach 4B*) - Anastomosed with some braiding
- Reach 8 - Anastomosed with some braiding (*Reach 4C*); braided (*Reach 4D*)
- Reach 9 (*Reach 5*) – Alternating braided and anastomosed.

Fotherby's (2008) braiding indices were developed by counting the number of individual channels evident in the 1998 color-infrared (CIR) photography that was taken when the discharge along the reach varied from about 450 cfs at Overton to 1,030 cfs at Grand Island (Friesen et al., 2000). The braiding indices for Reaches 1 and 2 developed for this study (reference discharge of 1,200 cfs) are considerably higher than those from Fotherby (2008) [average of 3.3 and 3.8 over the five surveys for this study versus 2.4 and 1.6 from Fotherby (2008), respectively] , while the values for Reach 3, 5 and 8 are reasonably consistent between the two studies (Figure 3.6c). Fotherby's (2008) braiding indices for the remaining reaches were also considerably lower than those obtained for this study, with Reaches 6 having the greatest difference [average of 8.4 over the five surveys for this study versus 2.7 from Fotherby (2008)]. The generally smaller indices from Fotherby (2008) are surprising, considering that the discharge in the 1998 aerial photographs is lower than that used in this study. Differences in methodology, however, likely account for at least some of the differences, and activities associated with Program and partner activities that include channel grading, disking and herbide spraying to eliminate noxious weeds (primarily phragmites), and tree and riparian vegetation clearing to promote channel widening also contribute the differences. As noted above, this is especially true for Reach 6, where the value for this study is based on conditions at AP21 at the Rowe Sanctuary where the channel has been manipulated extensively over the last +/-5 years to improve habitat.

Based on Fotherby's (2008) classification system and the 5-year average values for this study, none of the reach would be classified in the meandering or wandering categories, only Reach 1 would be solidly in the braided category, Reach 8 would be borderline between braided and anastomosed and the remainder would be in the anastomosed category. Although some portions of the reach are certainly anastomosed, as evidenced by the presence of one or more relatively persistent, secondary channels, all of the pure panel AP's, with the possible exception of APs 35, 37 and 39, exhibit at least some degree of braiding.

3.3.2 Total Channel Width (DAP 5.3.2)

The total channel width at 1,200 cfs ranged from slightly more than 200 feet at AP37 (north channel at Jefferys Island, 2011) to 1,700 to 1,800 feet at the most downstream AP1, and this metric changed very little at most APs over the 5-year monitoring period (**Figure 3.7a**). In addition to AP 37, the APs with the narrowest total channel width include AP23, AP25, AP31, and AP39, and the widest (in addition to AP1) include AP17, AP21, AP27, AP29, AP33, and AP37. The total channel width tends to alternate between wide and narrow segments along the reach, with a general trend of increasing width in the downstream direction. The very large total channel width at AP1 is somewhat deceptive because this part of the reach is highly anastomosed, with roughly one-third of the width occupied by large islands with mature woody vegetation. Similar conditions occur at AP17, near Shelton, and AP27, between Kearney and the KDS, although the vegetated islands occupy less of the total width than at AP1. The wide channels at AP21 and AP33 most likely result from restoration activities at the Rowe Sanctuary and Cottonwood Ranch, respectively.

The average total channel width for the overall reach increased by a small, but statistically insignificant, amount from about 830 feet in 2009 to about 850 feet in 2013 (**Figure 3.7b**). There is considerable variability among the geomorphic reaches, with Subreaches 1 and 2, at

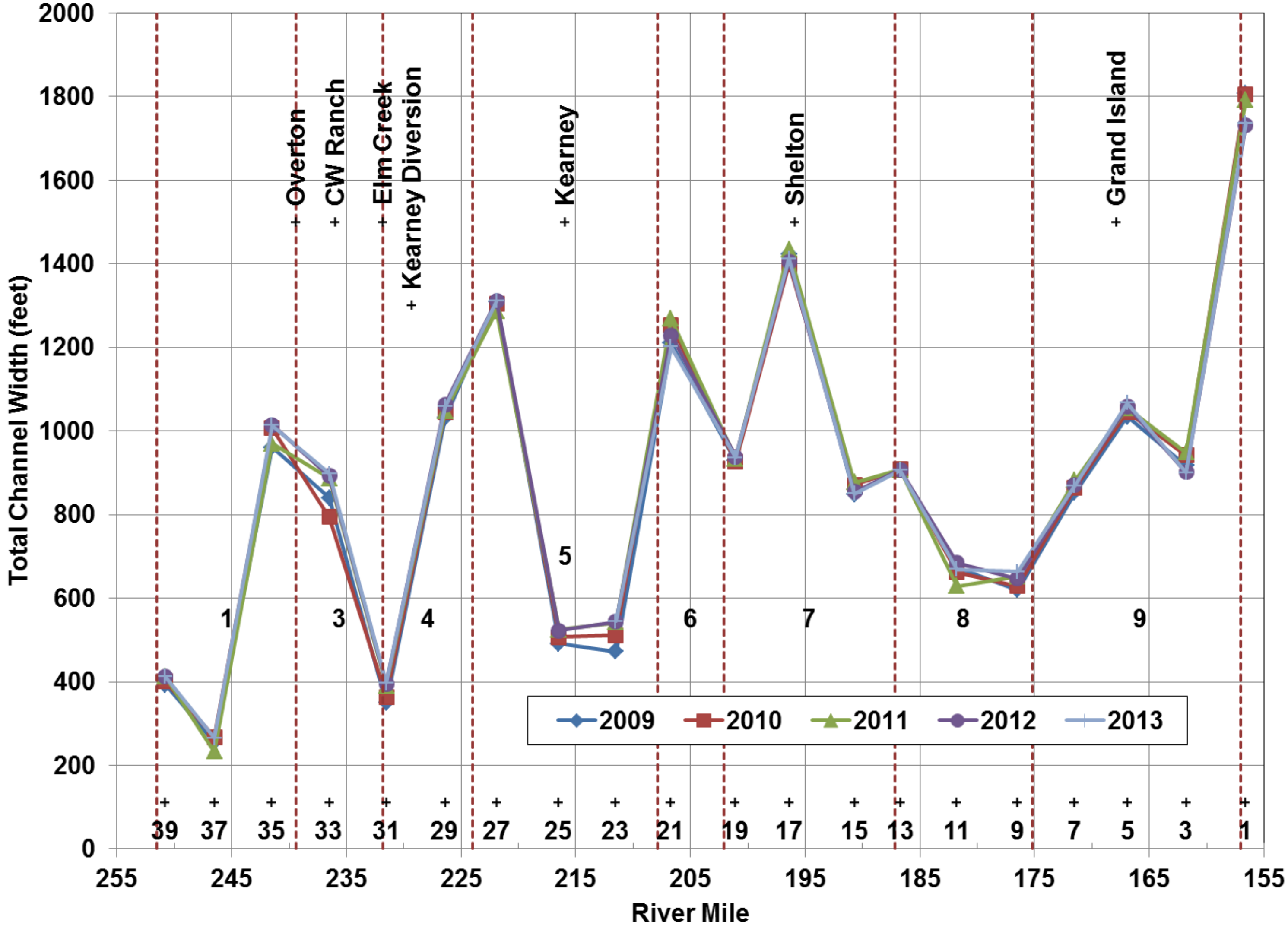


Figure 3.7a. Average total channel width at pure panel APs from the 2009 to 2013 data.

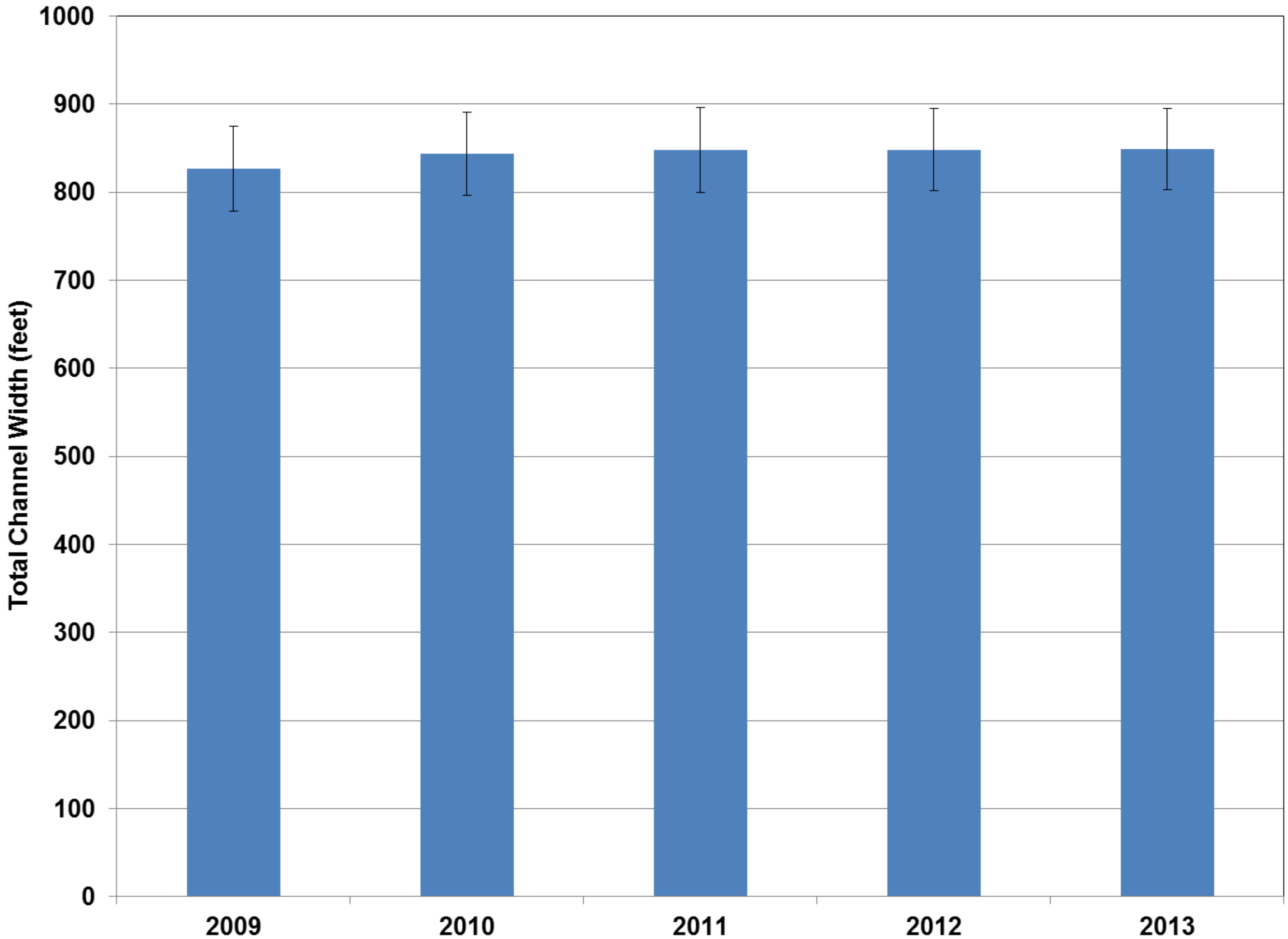


Figure 3.7b. Average total channel width for the overall study reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value.

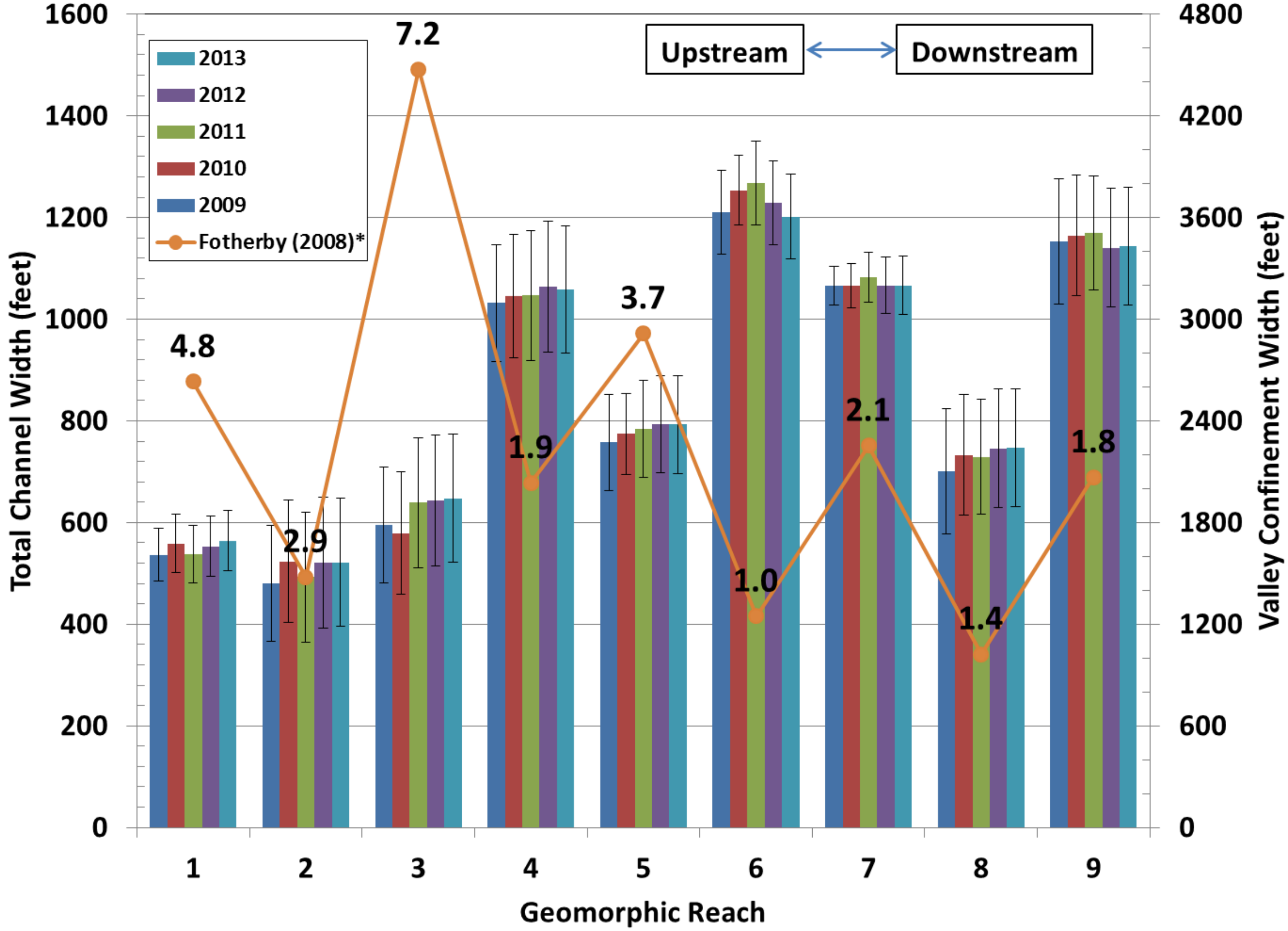


Figure 3.7c. Average total channel width by geomorphic reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value. Also shown are the valley confinement widths from Fotherby (2008); **note right-hand scale for this variable**. Values above Fotherby (2008) line are ratio of valley confinement width to total channel width.

the upstream end of the overall monitoring reach, having the narrowest average width (500 to 550 feet), and Subreach 6 (Minden to Gibbon) the widest (about 1,200 feet) (**Figure 3.7c**). The year-to-year variability within the reaches is also relatively small.

Fotherby (2008) concluded that valley confinement associated with both the natural geology of the reach and human influences is the primary driver of channel form in essentially the entire portion of the study reach downstream from Overton, while sediment size and transport capacity are the primary drivers upstream from Overton. With the exception of Reach 6, where Fotherby's (2008) valley confinement width is about the same as the total channel width and Reach 8, where it is about 40 percent larger, the confinement widths through the reach are significantly larger than the total channel width (Figure 3.7c). The margin between the valley confinement feature and the total channel width in Reach 6 and 8 may be sufficiently small to have a direct influence on the channel pattern, however, this is probably not the case in other portions of the reach. It is particularly interesting to note that AP21, where the Fotherby's (2008) valley confinement width is essentially the same as the total channel width, is one of the most braided of all of the Pure Panel APs.

3.3.3 Wetted Channel Width (DAP 5.3.3)

The wetted channel width at 1,200 cfs ranged from about 200 feet (AP37, 2011) to about 925 feet (AP21, 2011) (**Figure 3.8a**). The wetted widths at AP7, AP19, AP23, AP31, AP37 and AP39 are narrower than the typical widths in other parts of the reach (generally in the 200- to 300-foot range). Unlike the total widths that changed very little, the wetted width changed substantially at many of the APs over the 5-year monitoring period as the channels and macro-scale bedforms and bars changed shape.

The reach-wide average wetted width increased by a modest (but not statistically significant) amount from about 460 in 2009 to about 515 feet in 2012, and then declined back to about 490 feet in 2013 (**Figure 3.8b**). Similar to the total width, there is considerable variability among the geomorphic reaches, with Subreaches 1 and 2, at the upstream end, having the narrowest average wetted width (300 to 350 feet), and Subreach 6 (Minden to Gibbon) the widest [620 feet (2013) to 925 feet (2011)] (**Figure 3.8c**). The year-to-year variability in wetted width is generally greater in most reaches than the total width, again due to changes in shape of the macro-scale bedforms and bars.

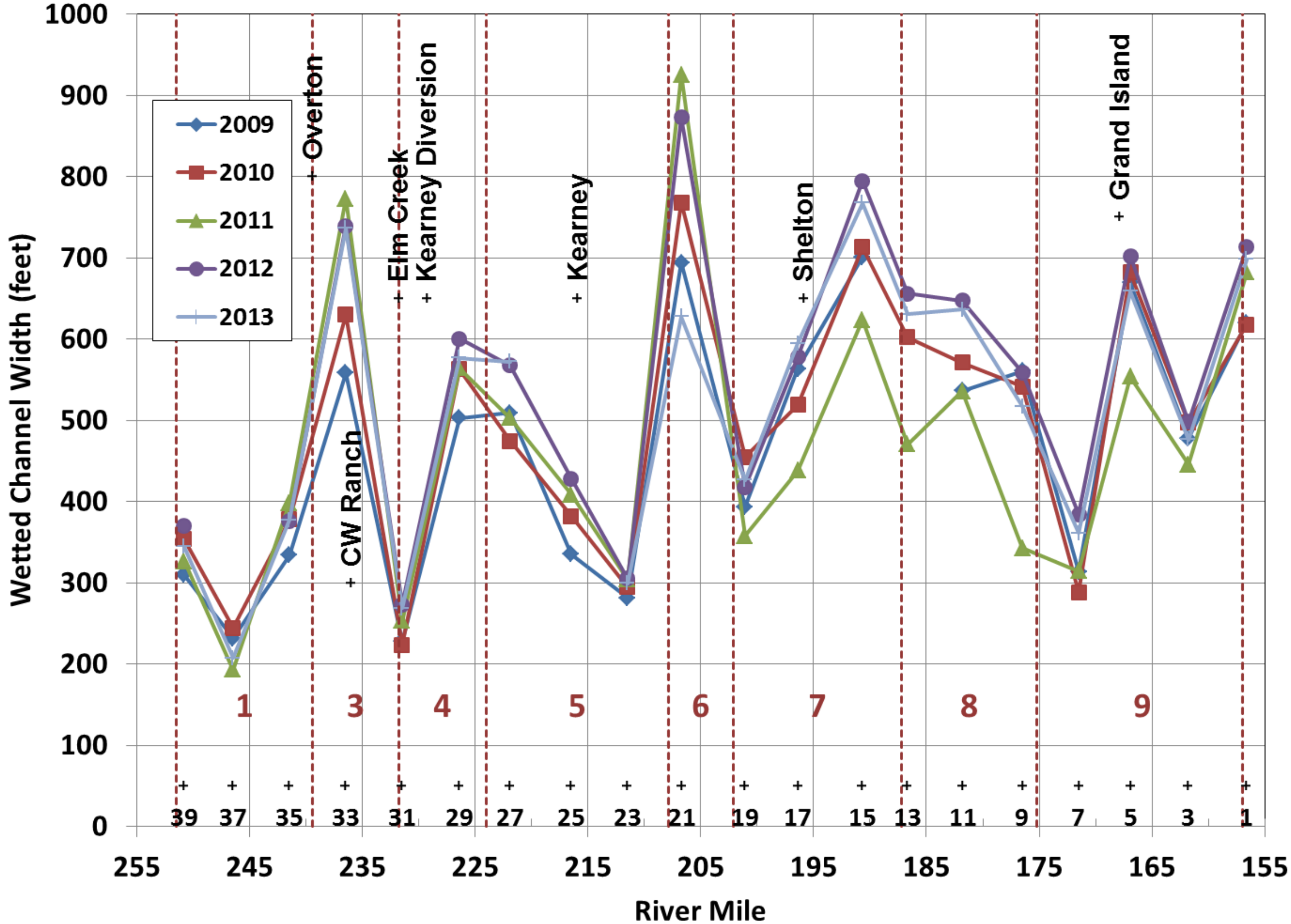


Figure 3.8a. Average wetted width at 1,200 cfs at pure panel APs from the 2009 to 2013 data.

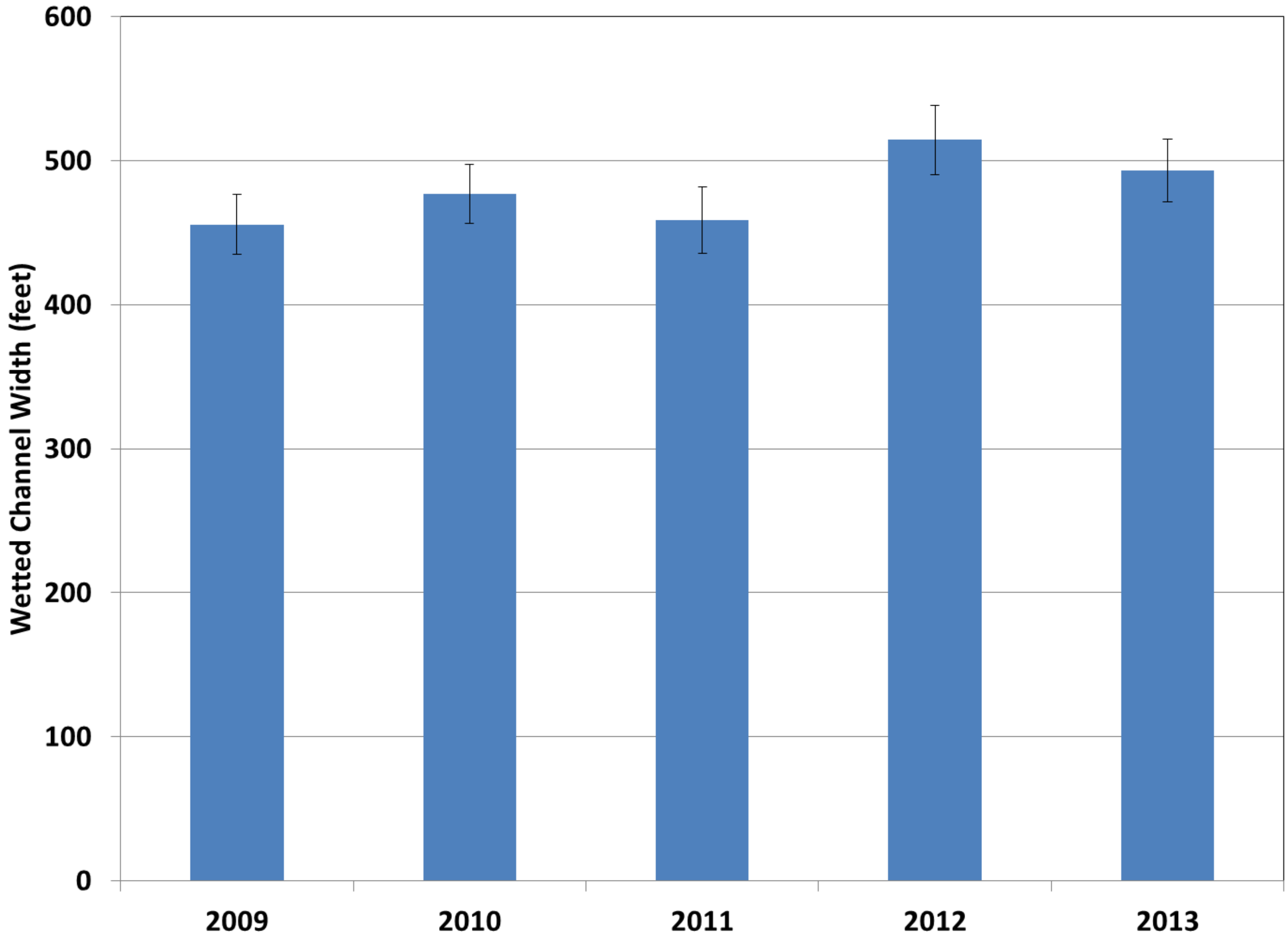


Figure 3.8b. Average wetted width at 1,200 cfs for the overall study reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value.

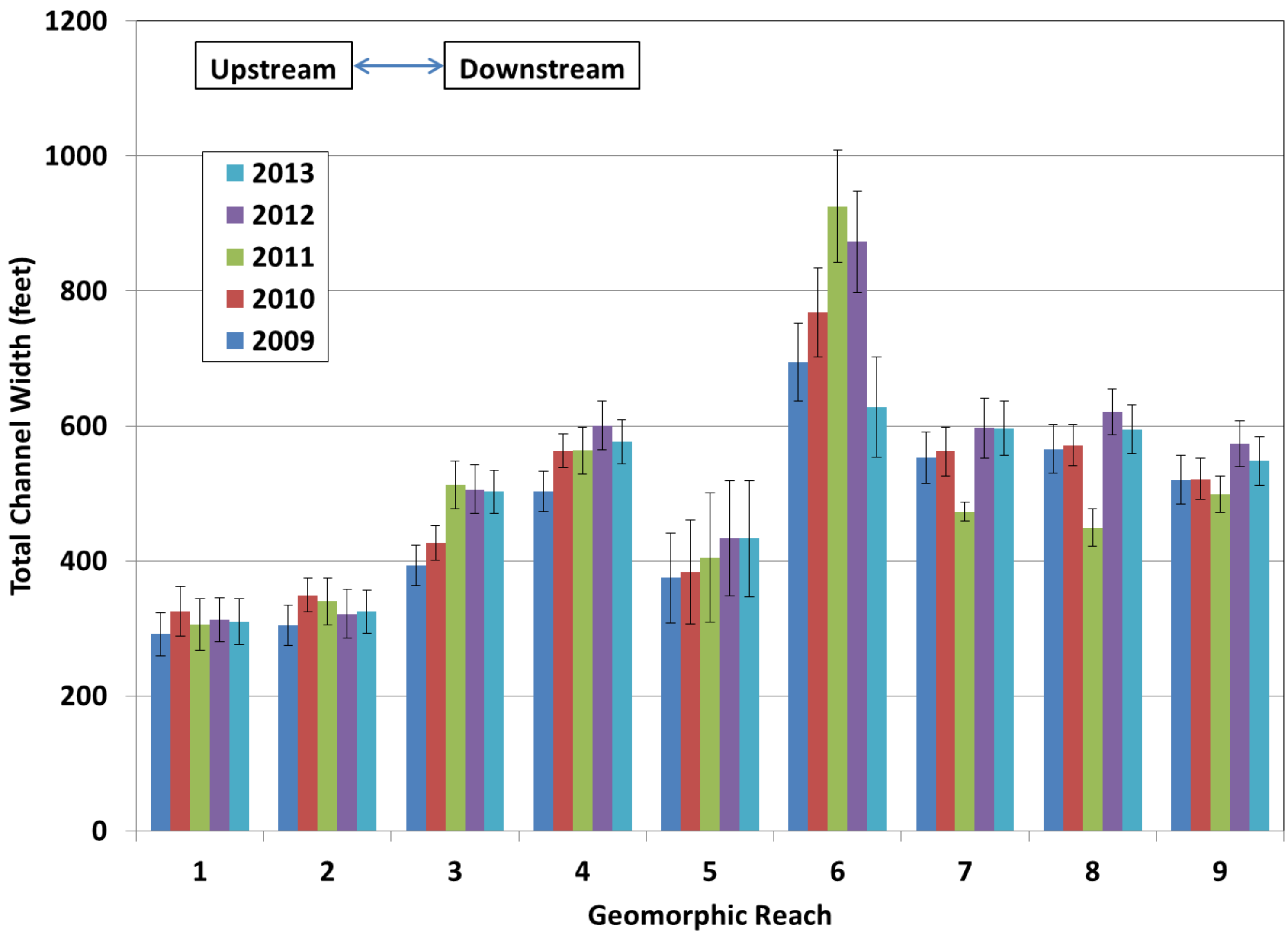


Figure 3.8c. Average wetted width at 1,200 cfs by geomorphic reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value.

3.3.4 Mean Channel Depth (DAP 5.3.4)

In 2009, the mean channel depth at 1,200 cfs ranged from about 0.7 feet (AP9) to 2.3 feet (AP37B), with a general trend of decreasing depth in the downstream direction (**Figure 3.9a**). Mean channel depths in subsequent years followed a similar pattern, with the depths in 2010 and 2011 generally consistent with those in 2009, and the depths in 2012 and 2013 somewhat smaller.

The mean channel depth over the entire study reach averaged about 1.3 feet in 2009, increasing to about 1.5 in 2011, and then decreasing back to about 1.1 feet in 2012 and 2013 (**Figure 3.9b**). The differences between 2009, 2010 and 2011 are not statically significant, nor are the differences between 2012 and 2013; however, the differences between these two groups of years is statistically significant (based on the Kruskal Wallace test, p=0.002 and 0.004, respectively). Geomorphic Reach 2 (south channel at Jefferys Island) consistently had the largest mean depth, followed by Reaches 1 and 3; whereas, Reach 6 typically has the smallest mean depth (**Figure 3.9c**). These width tend to be inversely proportional to the wetted channel width.

Some of the differences in depth between years may be due to changes in the stage-discharge rating curve at the individual transects that were not completely accounted for in the adjustments that were discussed in the introduction to this section. Nevertheless, the same algorithm was used for all years; thus, there appears to have been a systematic shift in channel geometry as a result of the 2011 high flows that tended to reduce the topographic variability of the channel, widening the wetted channel at 1,200 cfs and decreasing the mean depth (see Section 3.3.3). A typical example occurred at AP15, Transect 4, where the wetted width increased from about 500 feet to over 780 feet due to general flattening of the bed across the river (**Figure 3.9d**).

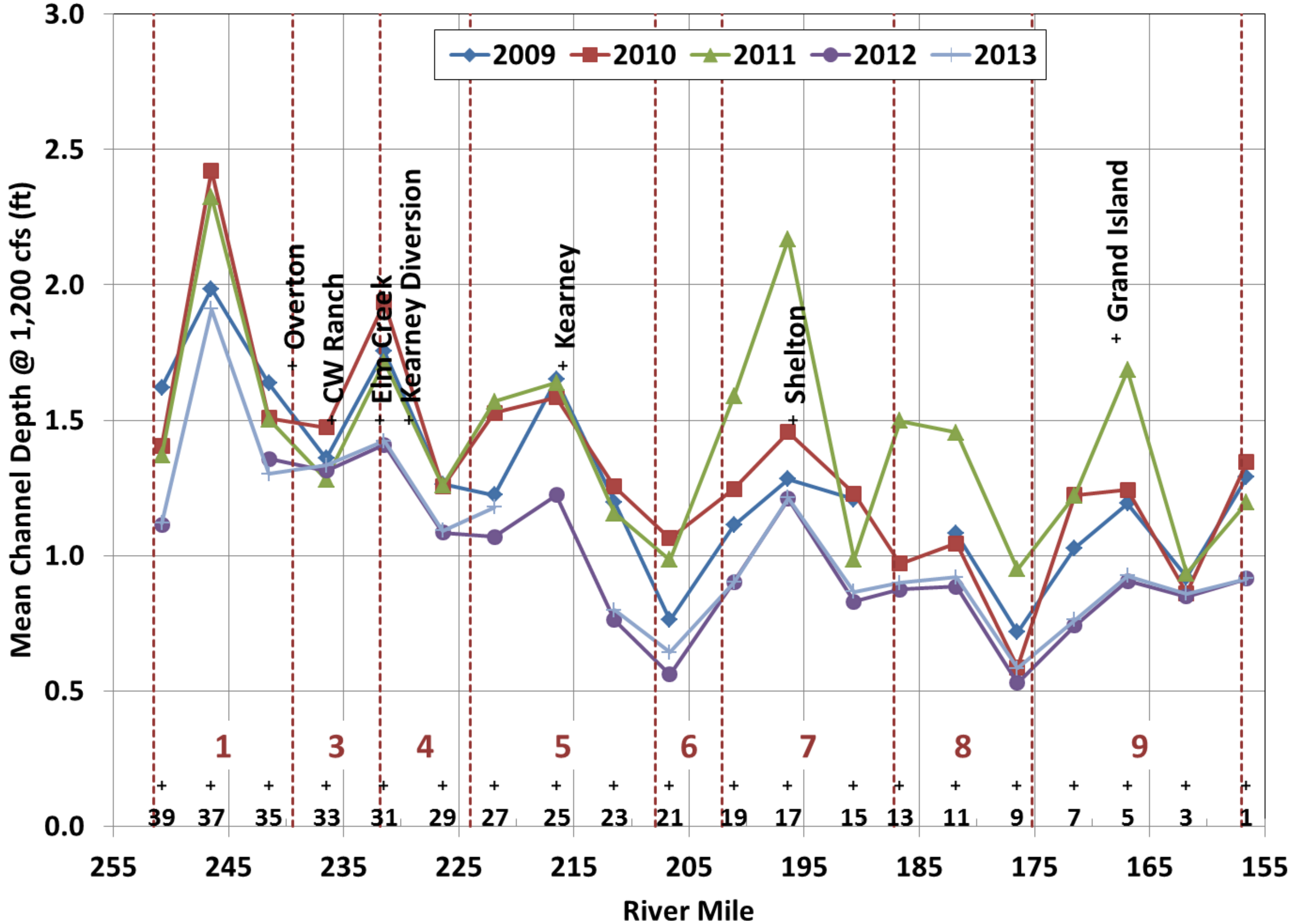


Figure 3.9a. Average mean channel (i.e., hydraulic) depth at 1,200 cfs at pure panel APs from the 2009 to 2013 data.

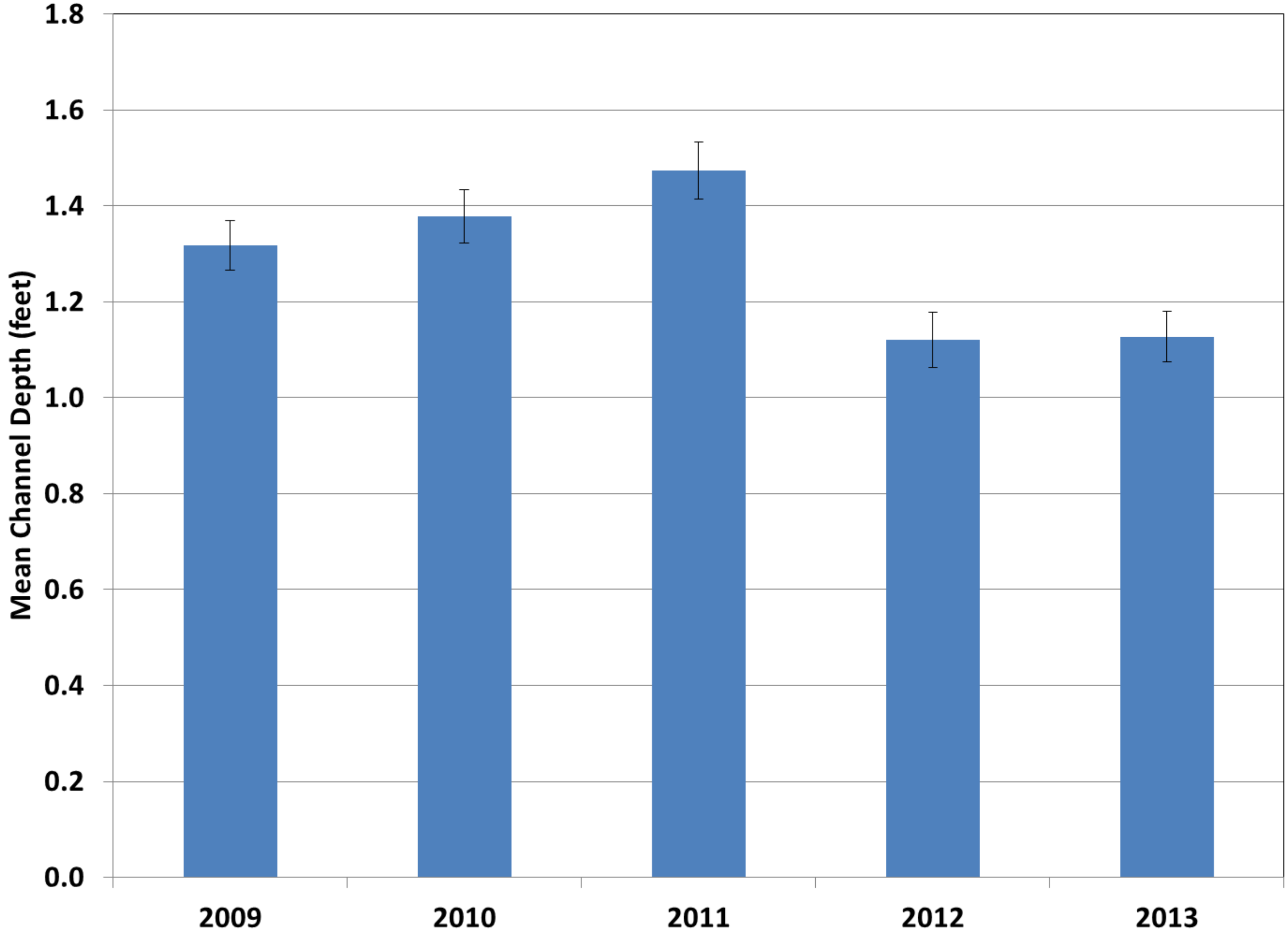


Figure 3.9b. Average mean channel (i.e., hydraulic) depth at 1,200 cfs for the overall study reach, based on the pure panel AP data from the 2009 to 2013 data.

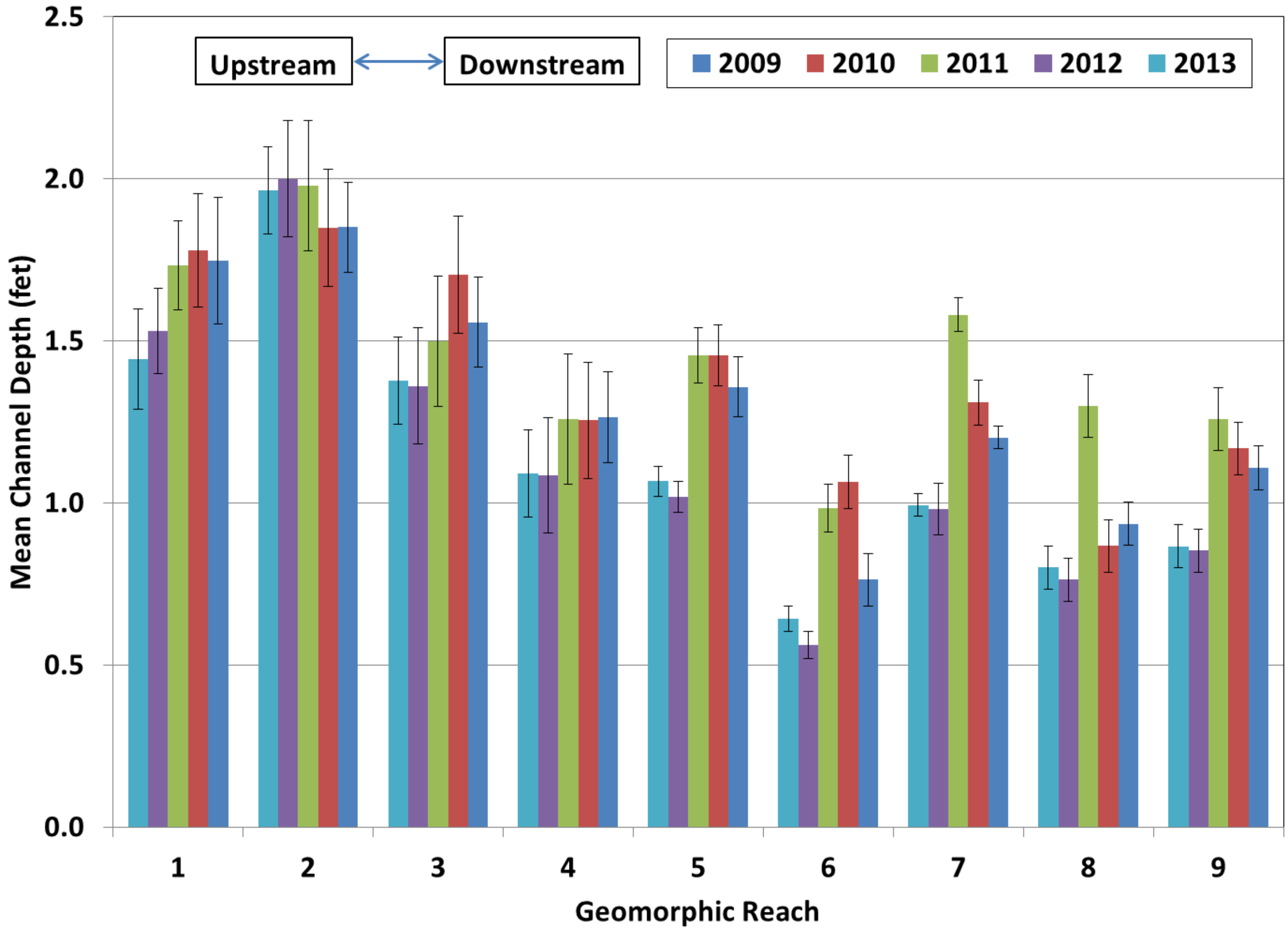


Figure 3.9c. Average mean channel (i.e., hydraulic) depth at 1,200 cfs by geomorphic reach, based on the pure panel AP data from the 2009 to 2013 data.

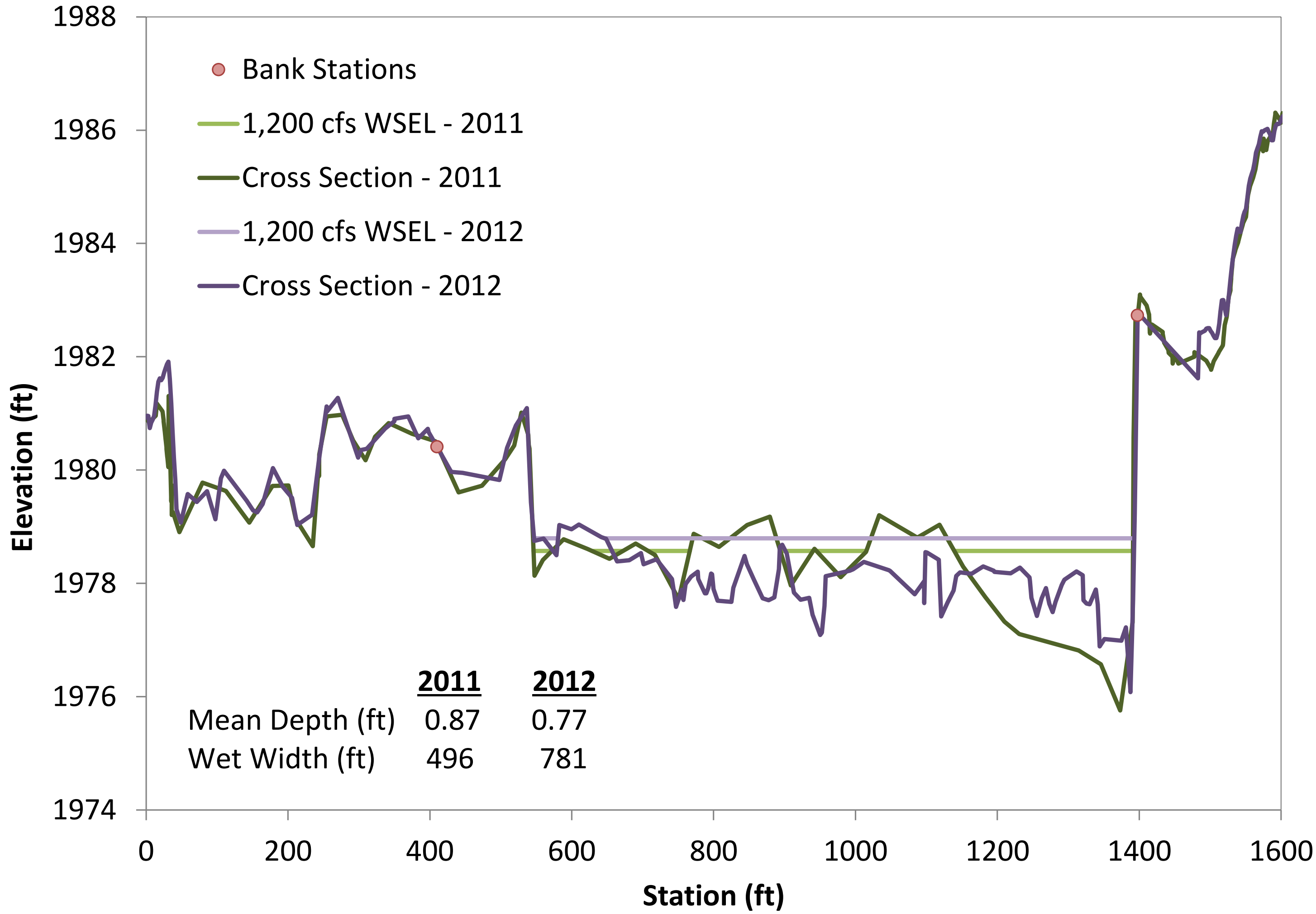


Figure 3.9d. Surveyed cross-section profiles at AP15, Transect for in 2011 and 2012.

3.3.5 Maximum Channel Depth (DAP 5.3.5)

The relative magnitudes and trends in the maximum channel depth (i.e., the thalweg depth) at 1,200 cfs are very similar to those for the mean channel depth, but as expected, the individual magnitudes are 2.5 to 3 times the average depth (**Figure 3.10a**). The reach-wide average maximum depth increased from about 3 feet in 2009 to about 3.9 feet in 2011, and then declined back to about 2.5 feet in 2012 and 2013. (**Figure 3.10b**). Consistent with the average depth, the average maximum depth in the geomorphic subreaches generally declines in the downstream direction, with the highest values occurring in Subreach 2 (4 to 5 feet) and the lowest values occurring in Subreach 6 (actually AP21) (**Figure 3.10c**).

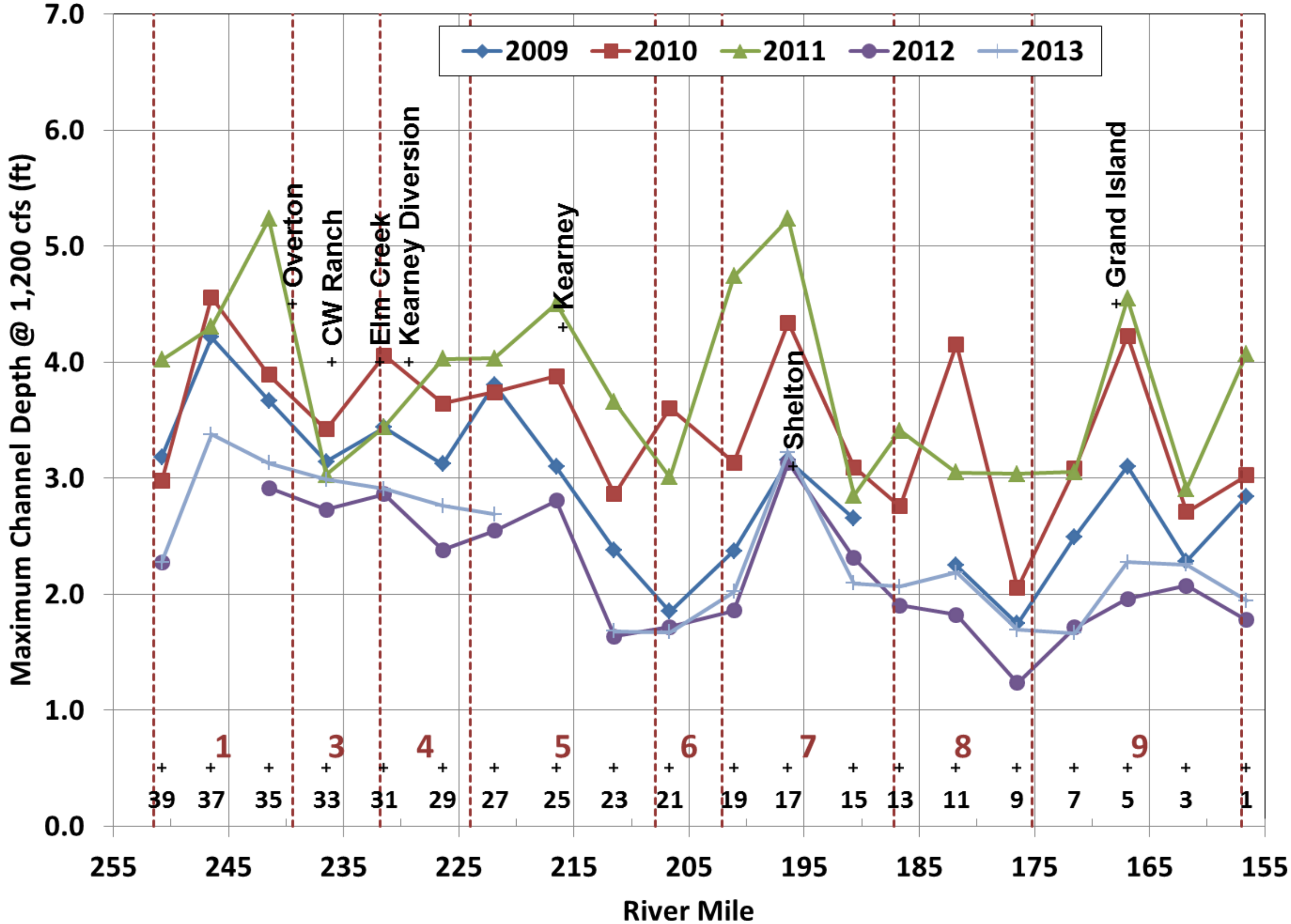


Figure 3.10a. Average maximum channel depth at 1,200 cfs at pure panel APs from the 2009 to 2013 data.

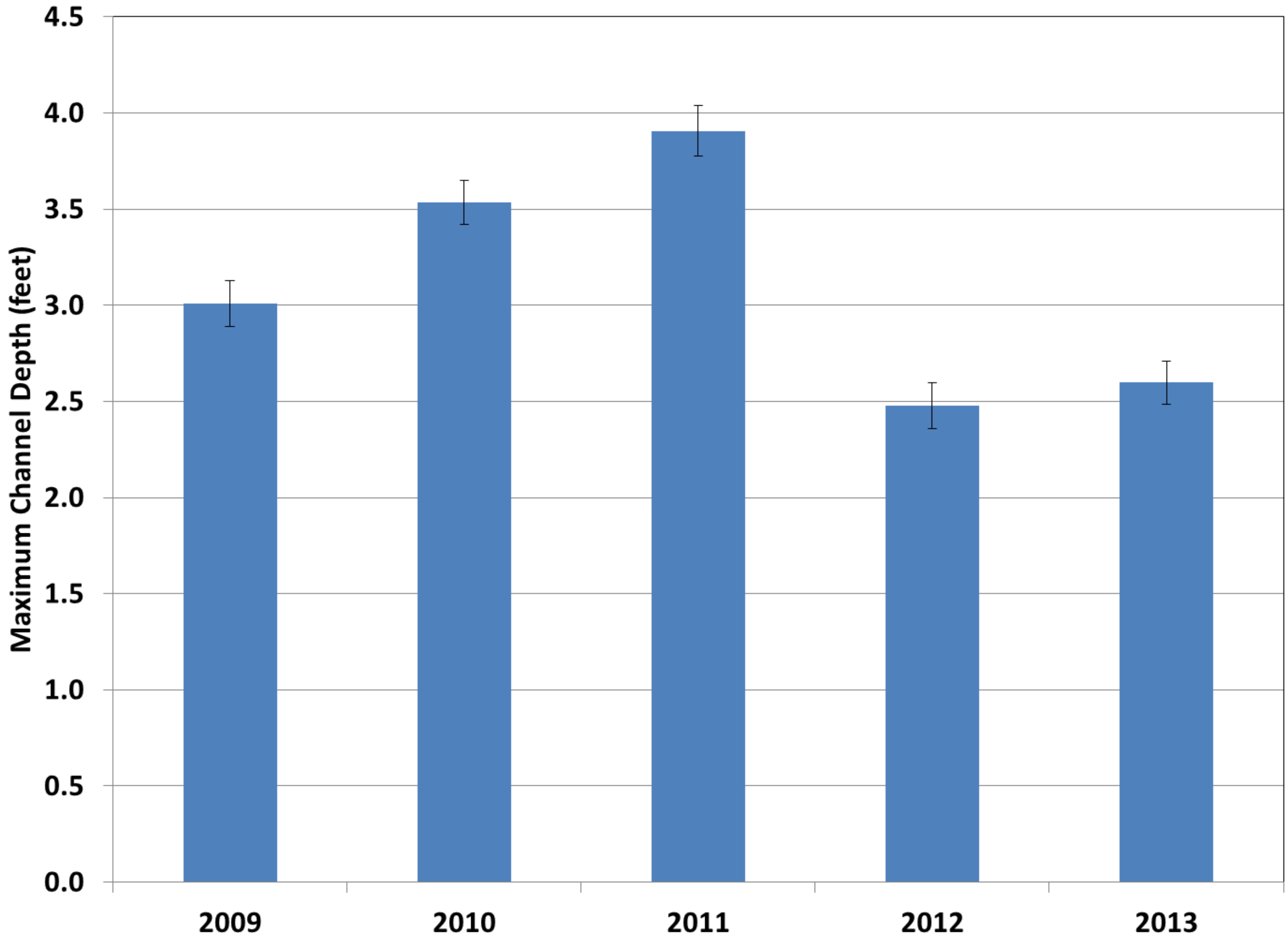


Figure 3.10b. Average maximum channel depth at 1,200 cfs for the overall study reach, based on the pure panel AP data from the 2009 to 2013 data.

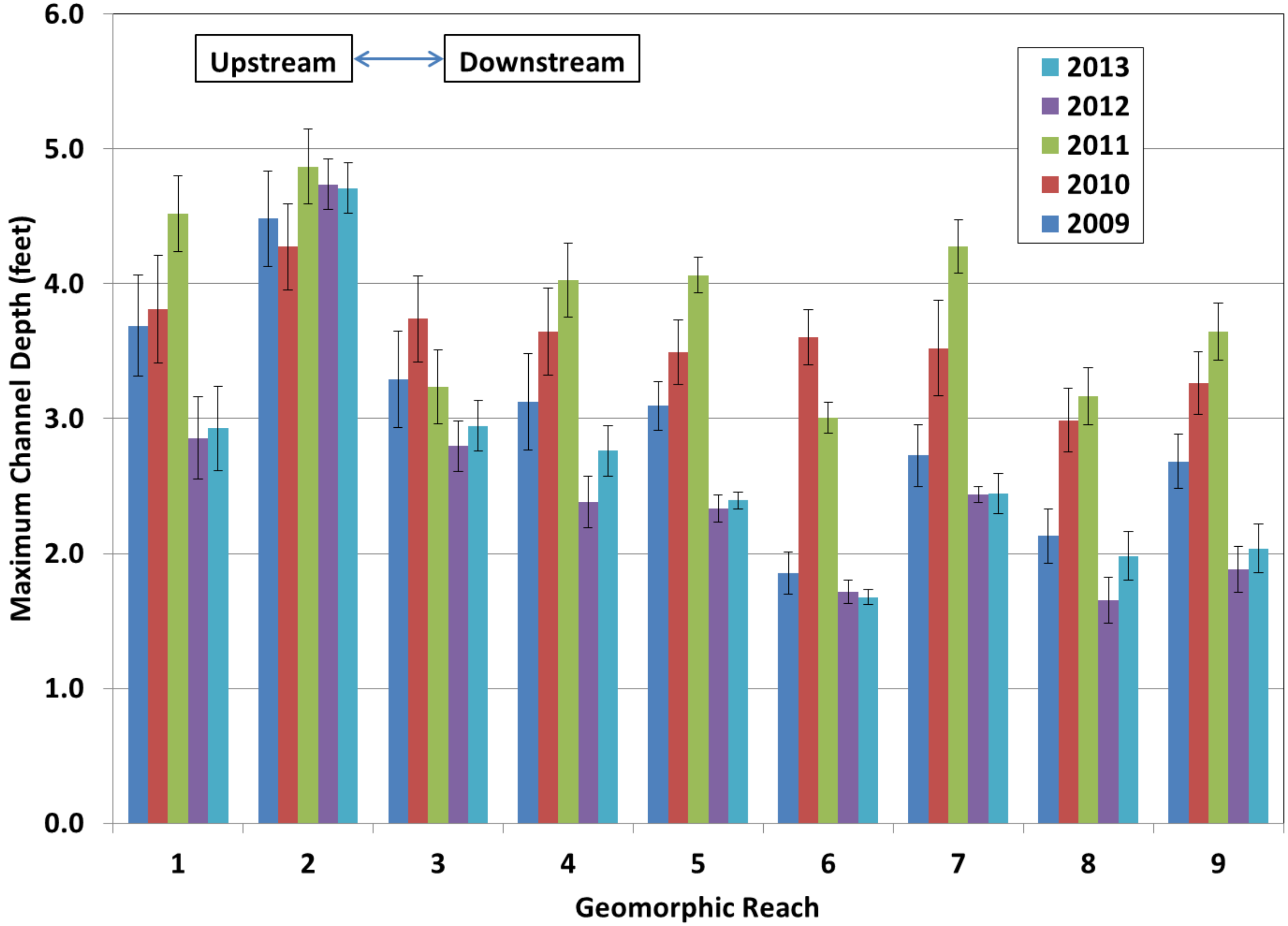


Figure 3.10c. Average maximum channel depth at 1,200 cfs by geomorphic reach, based on the pure panel AP data from the 2009 to 2013 data.

3.3.6 Channel Width-to-Depth Ratio (DAP 5.3.6)

The average width-to-depth ratio at 1,200 cfs at the pure panel APs range from about 50 (AP39, 2011) to over 500 (AP21, 2012), with a general trend of increasing values in the downstream direction (**Figure 3.11a**). AP21, however, had the highest width-to-depth ratio in both 2012 and 2013. AP9 also had a very high ratio in 2012, but this declined substantially in 2013.

For the overall reach, the width-to-depth ratio declined from about 175 in 2009 to 130 in 2011, and then increased substantially to over 240 in 2012. The average width-to-depth ratio in 2013 decreased to 214 (**Figure 3.11b**). This trend is consistent with the trends in mean channel discussed above, in which the topographic variability across many of the cross sections tended to decrease as the individual braid channels filled in and the sand bars flattened (see Figure 3.7d). The average width-to-depth ratios for the geomorphic reaches follow the same general trend as the individual AP averages, with Reaches 1 and 2 having the smallest values, Reach 6 (again, as represented by AP21) having the largest values (**Figure 3.11c**). The ratios for the three downstream reaches (Reaches 7, 8 and 9) are generally larger than Reaches 3, 4 and 5.

Fotherby (2008) computed width-to-depth ratios using results from the hydraulic model discussed by Murphy et al. (2006) at a discharge of 2,000 cfs. Her calculations differ from those specified in the DAP, and reported above, in that she used the mean depth rather than the maximum (thalweg) depth, which tends to make the ratios considerably larger. The width-to-depth ratios obtained from the data from this monitoring program using the mean depth (and a discharge of 1,200 cfs) are very consistent with Fotherby's (2008) values, except in Reach 6, where they current data indicated much larger ratios (**Figure 3.11d**). This difference is most likely due to mechanical activities in the channel at the Rose Sanctuary.

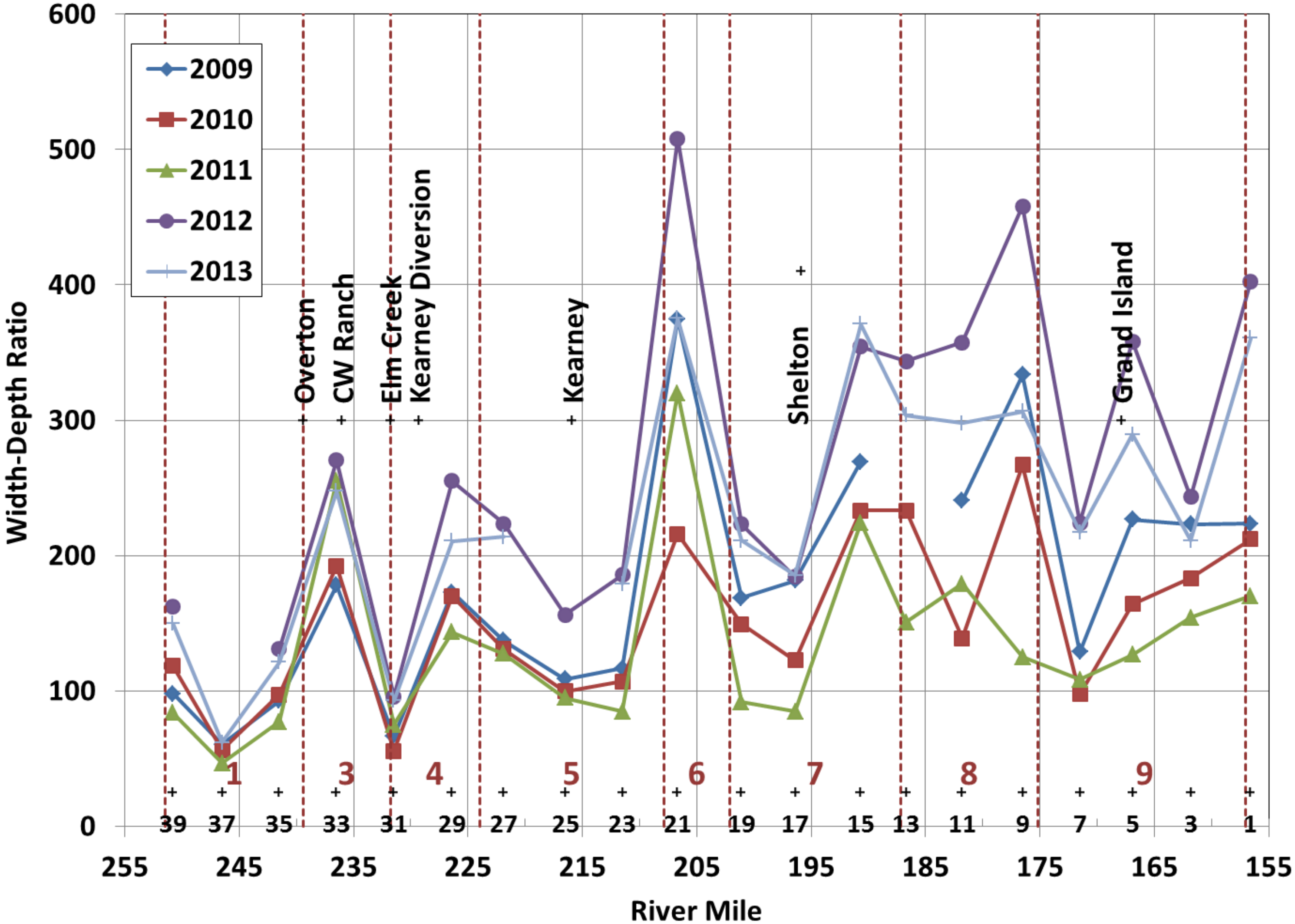


Figure 3.11a. Average width-to-depth (maximum depth) ratio at 1,200 cfs at pure panel APs from the 2009 to 2013 data.

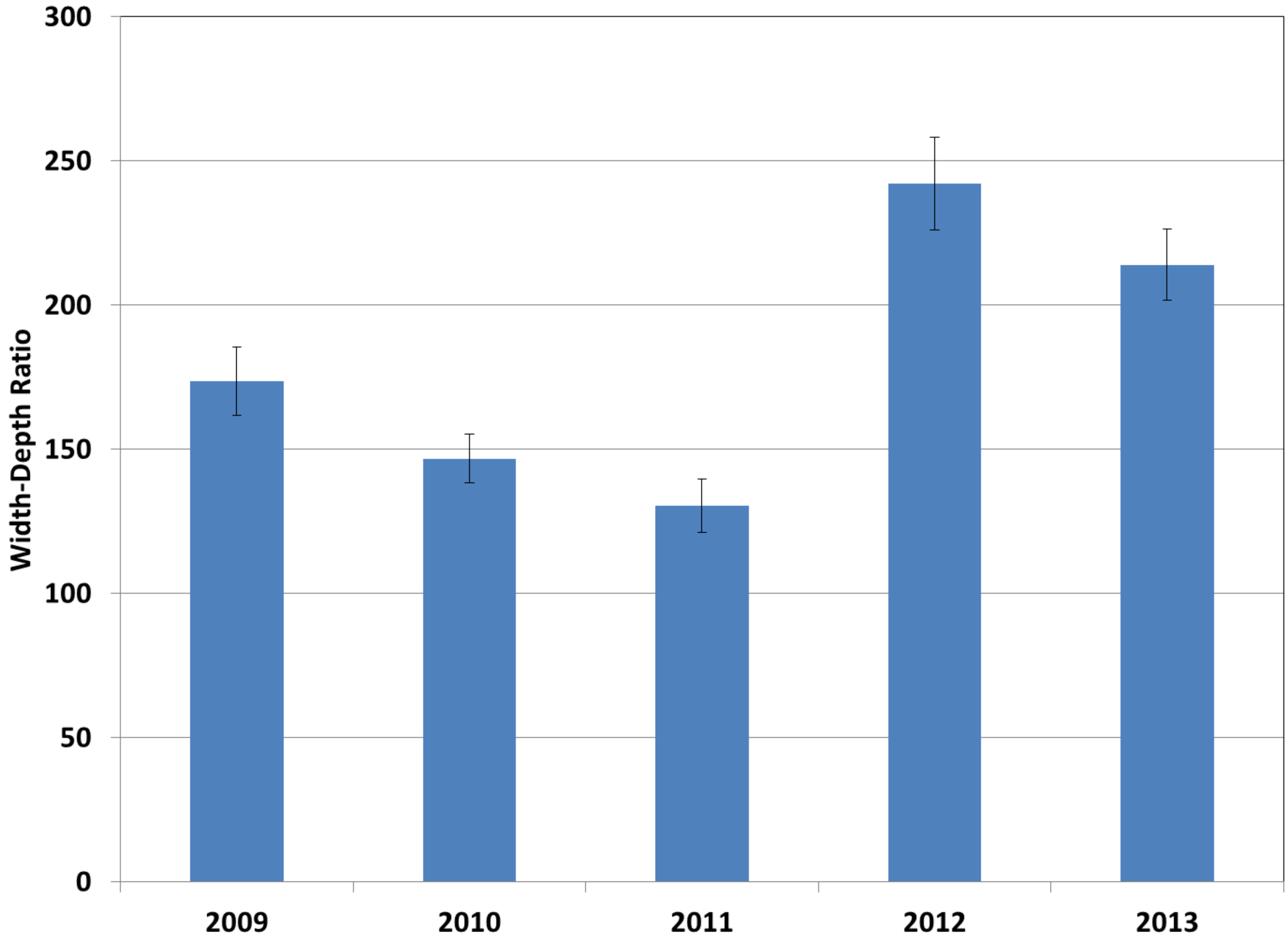


Figure 3.11b. Average width-to-depth (maximum depth) ratio at 1,200 cfs for the overall study reach, based on the pure panel AP data from the 2009 to 2013 data.

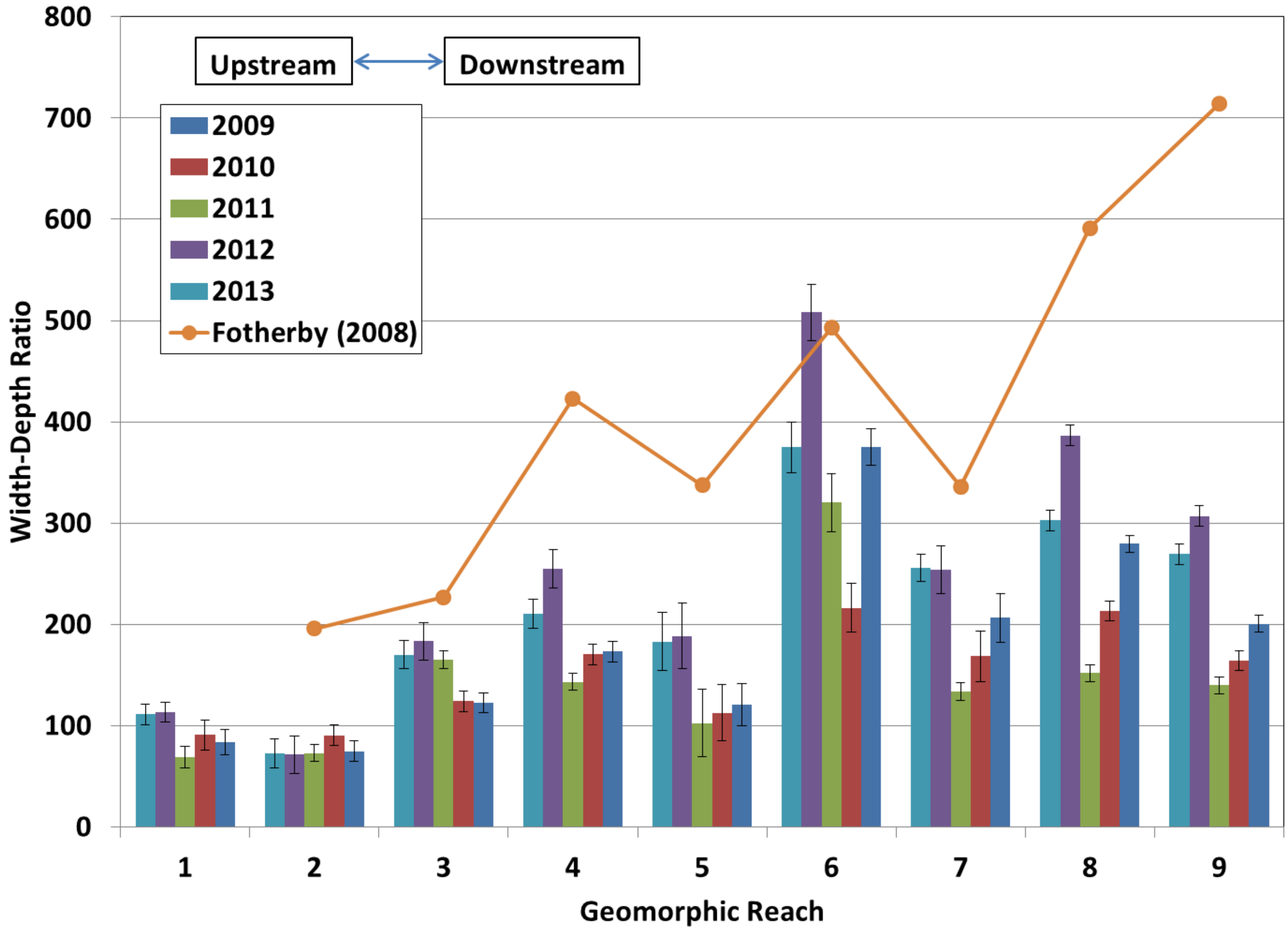


Figure 3.11c. Average width-to-depth (maximum depth) ratio at 1,200 cfs by geomorphic reach, based on the pure panel AP data from the 2009 to 2013 data.

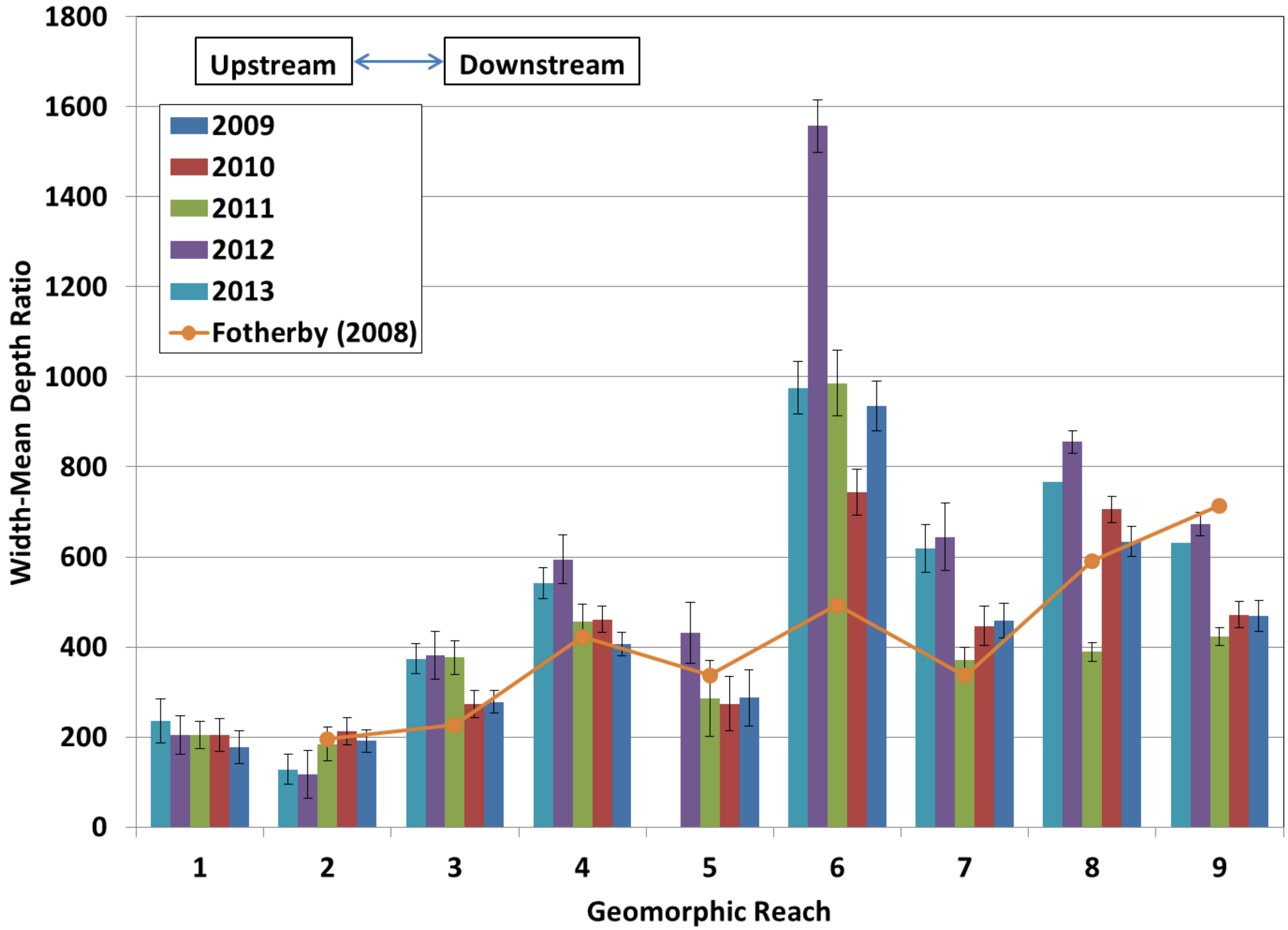


Figure 3.11d. Average width-to-**mean** depth ratio at 1,200 cfs by geomorphic reach, based on the pure panel AP data from the 2009 to 2013 data. Also shown are the width-to-depth ratios from Fotherby (2008).

3.3.7 Channel Cross-sectional Area (DAP 5.3.6)

The cross-sectional area data indicate that the overall reach was generally degradational from AP19 upstream and slightly aggradational, to in-balance, downstream from AP19 between the 2009 and 2010 surveys, degradational to in-balance throughout most of the reach downstream from AP37 between the 2010 and 2011 surveys, and aggradational throughout most of the reach between the 2011 and 2012 surveys (**Figure 3.12a**). Between the 2012 and 2013 surveys, the portion of the reach from AP15 upstream was approximately in balance, with AP15, AP19, AP21, and AP27degrading and the other APs aggrading by a small amount. (Note that the indicated degradation at AP33 between the 2009 and 2011 surveys resulted from mechanical removal of a large, mid-channel bar; the indicated loss of sediment volume does not reflect a general sediment imbalance in the reach. The most upstream cross section at AP33 also widened by about 135 feet during this period, due primarily to deflection of the flow around the graded material and into the banks. The material from the bar was graded directly into the channel where most, if not all, was entrained and carried downstream. The material from the channel widening was also entrained and carried downstream.) All APs downstream from AP 15, except AP1 that was approximately in-balance, aggraded during this period. AP35B, located about 2 miles upstream from the Overton Bridge in the South Channel at Jeffreys Island, degraded between 2009 and 2010, and also degraded by a relatively small amount between 2010 and 2011 and between 2012 and 2013, and aggraded between 2011 and 2012. The changes in cross sectional area represent changes in average bed elevation across the cross sections in the range of ±0.5 feet (**Figure 3.12b**).

The overall aggradation/degradation quantities over the four-year monitoring period were estimated based on the assumption that the changes at the APs, except for the 2009 to 2010 changes at AP33, are representative of the changes in the intervening reaches of the river. The 2009 to 2010 changes at AP33 was excluded from the analysis because this calculation is intended to provide information about the overall sediment transport balance in the reach. Not considering the changes at AP33, the overall study reach degraded by about 2.4M tons between 2009 and 2010, an additional 1.2M tons between 2010 and 2011, and then aggraded by about 5.8M tons between 2011 and 2012 (**Figure 3.12c**). An additional approximately 1.6M tons of aggradation occurred between 2012 and 2013; thus, the overall reach experienced net aggradation of about 3.8M tons over the four years encompassed by the surveys. On a geomorphic reach-by-reach basis, the bulk of the degradation volume between 2009 and 2010 occurred in Reaches 3, 5 and 6 (Overton to Elm Creek and Odessa to Gibbon), with substantial degradation also occurring in Reaches 1, 2 and 4 (Lexington to Overton, including the South Channel at Jeffreys Island and Elm Creek to Odessa (**Figure 3.12d**). Aggradation occurred during this period in the downstream Reaches 7, 8 and 9 (downstream from Gibbon). Reach 1 aggraded during all three years from 2010 through 2013, creating net aggradation over the four year period of about 42,000 tons. AP35, in the South Channel at Jefferys Island (Reach 2), appears to have been approximately in balance between 2010 and 2013, resulting in net degradation of about 9,000 tons for the overall survey period. A similar pattern occurred in Reach 3 that includes Cottonwood Ranch, although the volumes during each of the years were somewhat greater. Reach 3 experienced net degradation of about 53,000 tons over the period. After degrading by about 20,000 tons during the first year, Reach 4 was aggradational in the subsequent three years, resulting in net aggradation over the four year period encompassed by the surveys of 32,000 tons. Reach 5 degraded by about 57,000 tons between 2009 and 2010 and an additional 14,000 tons between 2010 and 2011. The reach then aggraded by about 44,000 tons between 2011 and 2012, with little change between 2012 and 2013, resulting in net degradation of about 57,000 tons over the period. Reach 6 degraded by about 37,000 tons

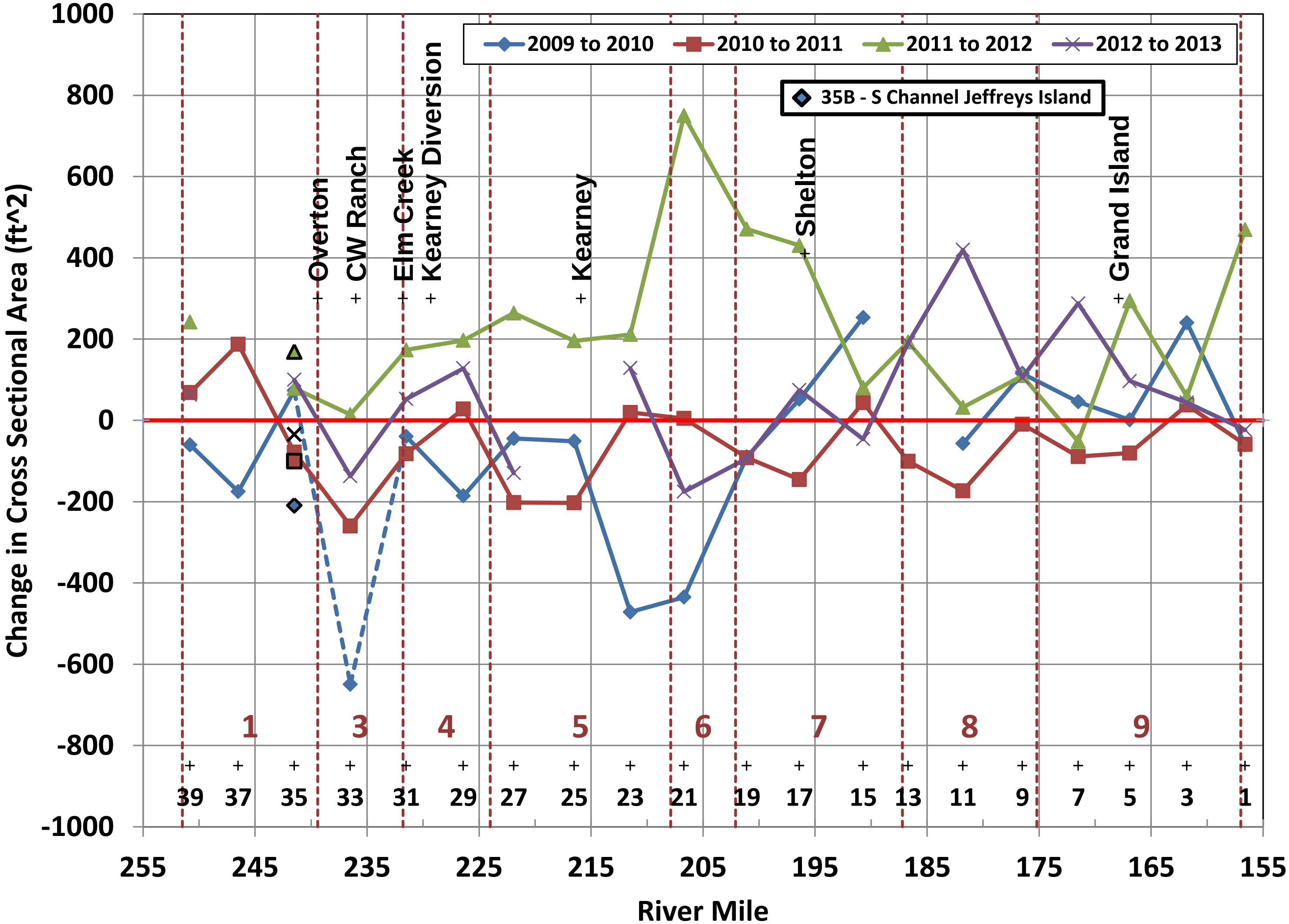


Figure 3.12a. Year-to-year change in average cross-sectional area at pure panel APs from 2009 through 2013. Line connecting AP33, 2009 to 2010, dashed to reflect effect of mechanical bar removal.

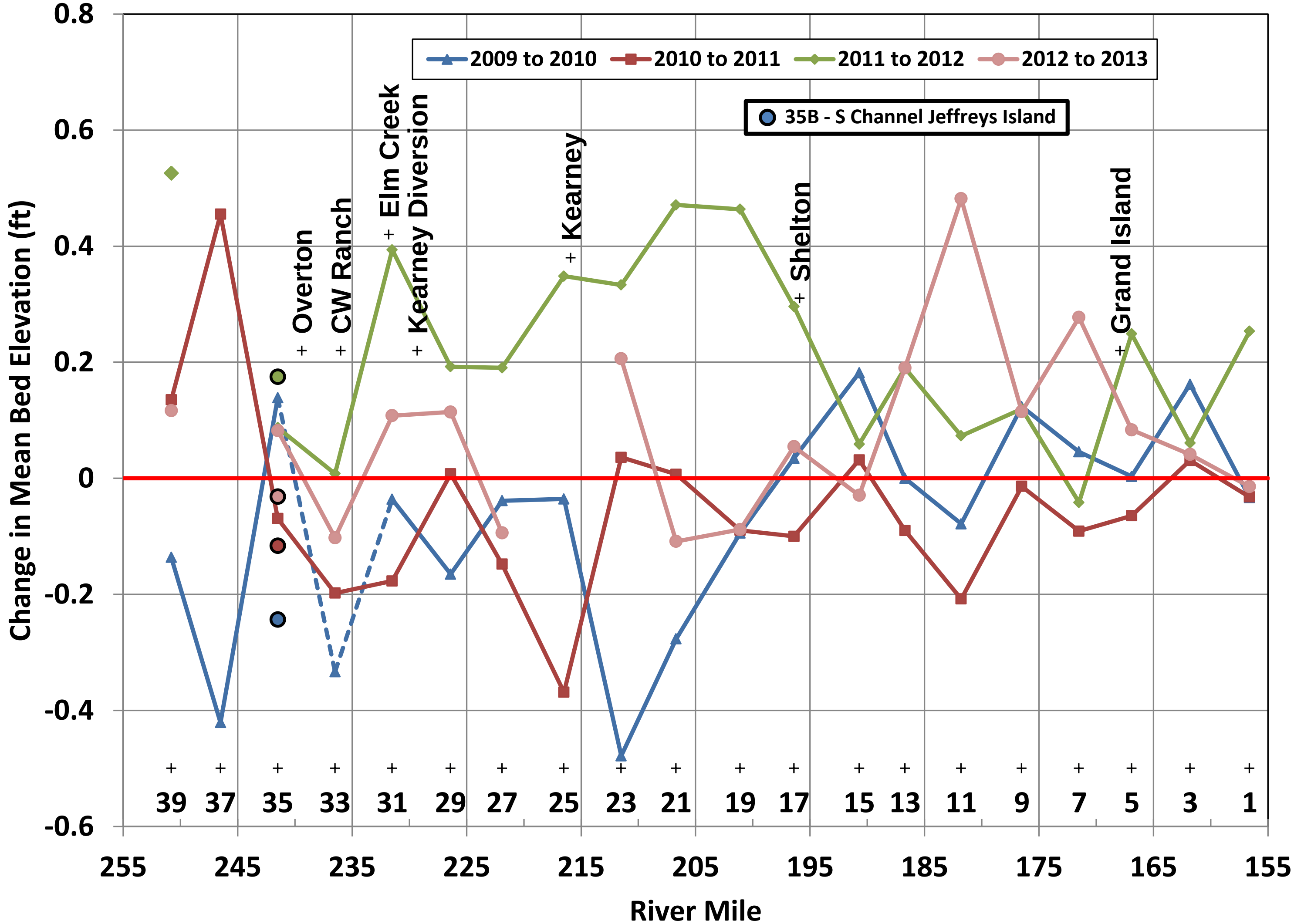


Figure 3.12b. Year-to-year change in mean bed elevation at the pure panel APs from 2009 through 2013. Line connecting AP33, 2009 to 2010, dashed to reflect effect of mechanical bar removal.

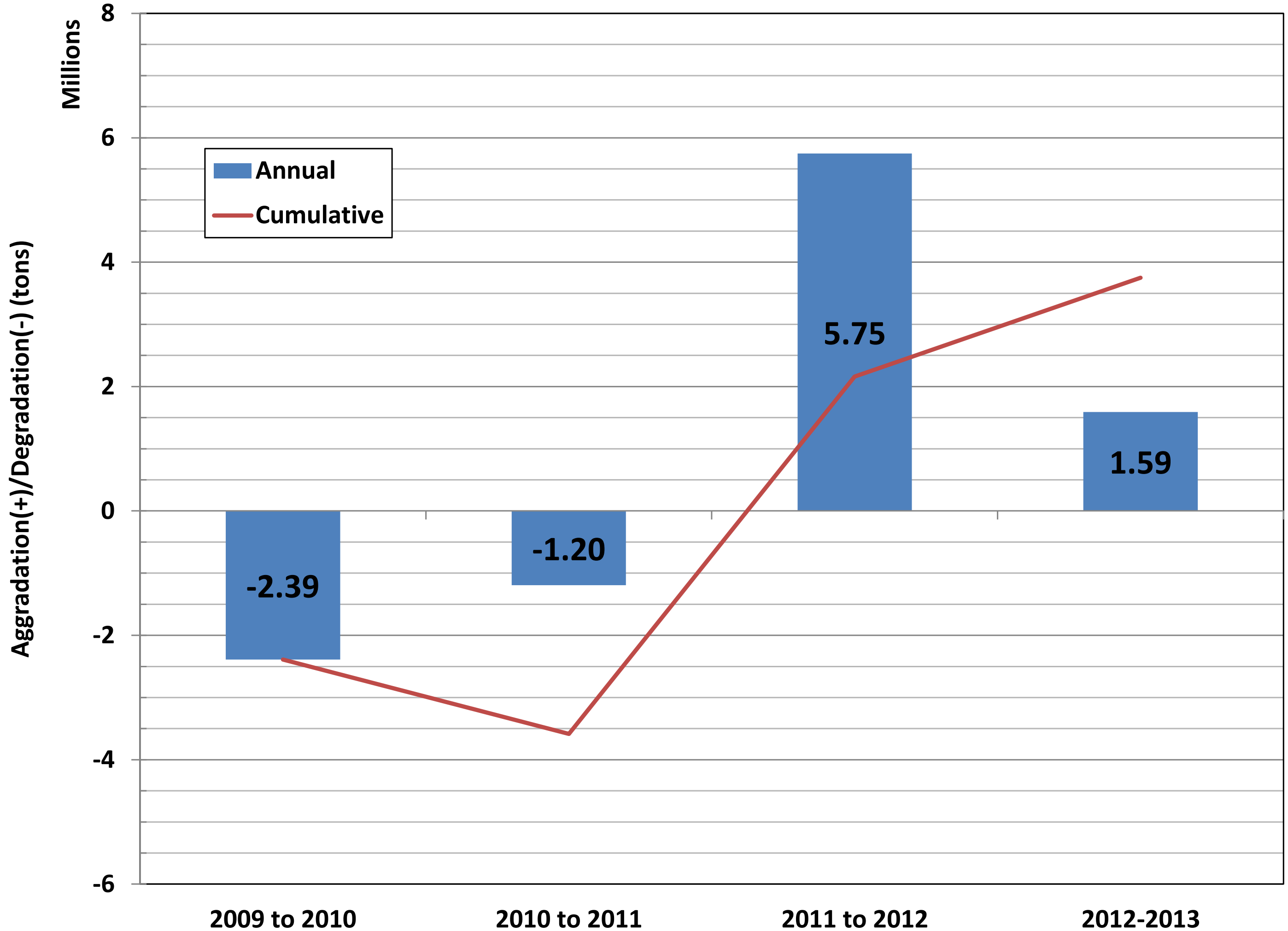


Figure 3.12c. Year-to-year aggradation/degradation volumes in the overall study reach from 2009 through 2013. Quantity for 2009 to 2010 does not include changes at AP33 due to mechanical removal of a large mid-channel bar.

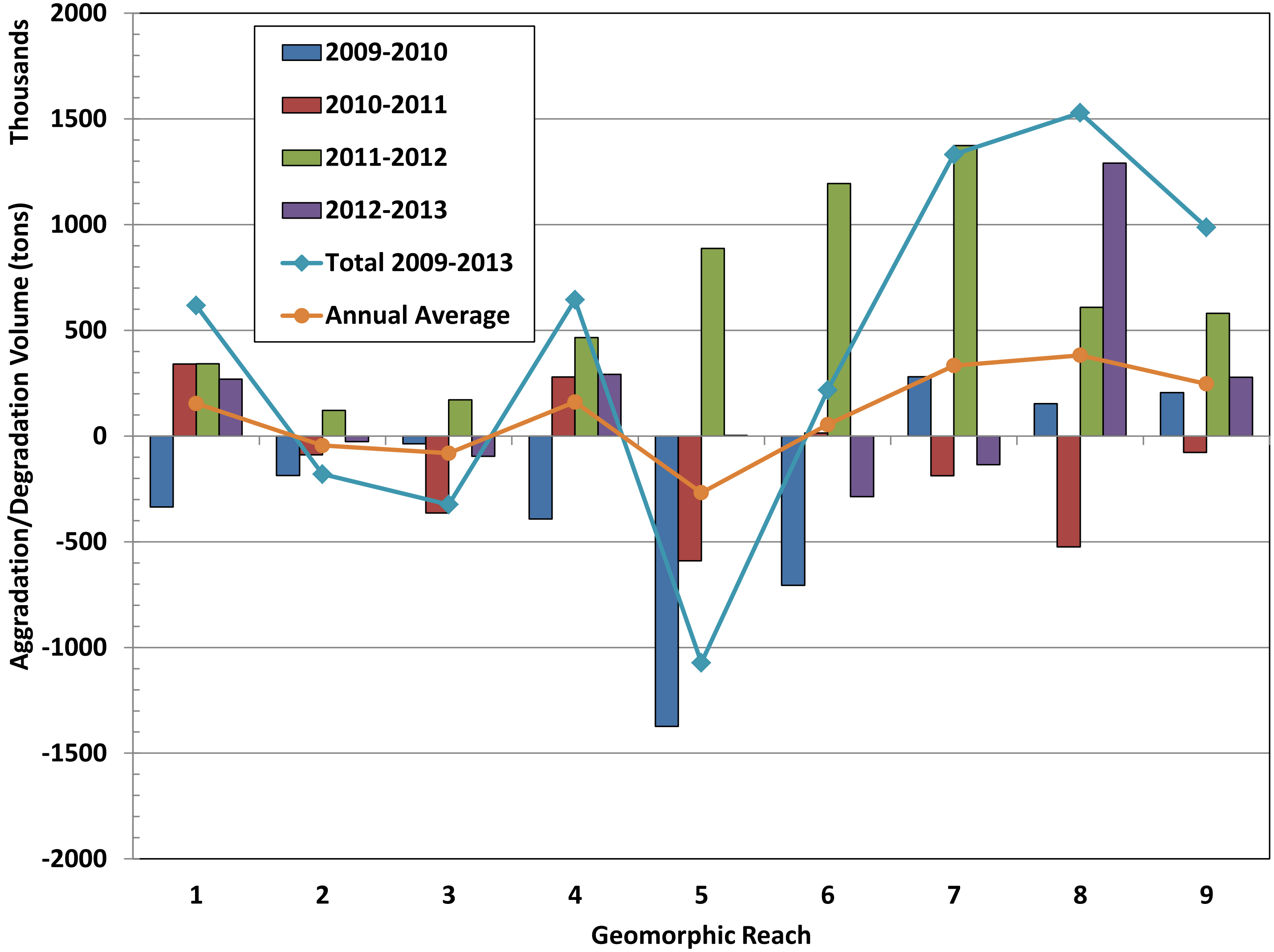


Figure 3.12d. Year-to-year aggradation/degradation volumes in the overall study reach from 2009 through 2013. Quantity for Reach 3, 2009 to 2010, does not include changes at AP33 due to mechanical removal of a large mid-channel bar.

during the first year, was approximately in balance during the second year, and then aggraded by nearly 65,000 tons during the third year. With about 18,000 tons of degradation during the fourth year, this reach experience net aggradation over the period of about 10,000 tons. Reach 7 aggraded by about 16,000 tons during the first year, degraded by about 7,500 tons during the second year, and then aggraded by nearly 74,000 tons during the third year. With net degradation of about 11,000 tons during the fourth year, the reach experienced net aggradation of about 79,000 tons over the entire period. Reach 8 aggraded by a modest amount (9,000 and 10,000 tons, respectively) during the first year, then degraded (27,000 and 4,000 tons, respectively) during the second year, and then aggraded during the last two years. Over the entire period, Reach 8 experienced net aggradation of about 76,000 tons and Reach 9 had net aggradation of about 49,000 tons.

3.4 Vegetation

The vegetation monitoring surveys have produced large data sets that provide the basis for a broad range of analyses (**Table 3.1**). In 2009, a total of 4,496 quadrats were sampled at 308 individual transects at the 27[5] APs (41 independent survey sites including both primary and secondary channels). A total of 3,119 quadrats and 154 transects were at pure panel APs. Twenty six (26) individual species were documented during the surveys. About 1,000 more quadrats (5,469) were sampled in 2010 at 26 APs/29 independent sites and 210 transects, and all species present in the quadrats were documented, resulting in a total of 125 species. This same protocol was followed in subsequent years, with 5,447 total quadrats (4,342 at pure panel APs) and total of 102 different species documented in 2011 because of the very high flows during the sampling period. The 2012 surveys included 4,401 quadrats (2,987 at pure panel APs) and 125 species at 25 AP/27 total survey sites. In 2013, the monitoring protocol was modified to include only 5 transects per site, reducing the survey effort. Because all secondary channels were surveyed for the second time in 2013; however, a total of 3,174 quadrats at 41 independent sites and 220 transects were sampled with 179 species documented. Of the 179 species, 42 were only encountered once and an additional 22 were only encountered twice.

During the 2012 and 2013 surveys, many individual plants appeared to be prematurely dead or dying, a condition likely due to the drought conditions that caused the Platte River to be completely dry across much of the survey reach. The generally hot, dry weather pattern that dominated the survey season exacerbated these conditions.

Table 3.1. Summary of vegetation survey sites.

Year	Anchor Points	Sites*	Transects		Quadrats		Number Individual Species
			Pure Panel	Total	Pure Panel	Total	
2009	27	41	154	308	3119	4496	26
2010	26	29	154	210	4210	5469	125
2011	27	29	147	189	4342	5447	102
2012	25	27	140	189	2987	4401	125
2013	25	41	105	220	2157	3174	179

*Includes secondary channels surveyed once every four years.

[5] APs 35A, 36B and 37A are in the North Channel at Jeffreys Island and 35B, 36A and 37B are in the South Channel. All 6 of these sites are considered to be primary APs for purposes of the analysis because the flows are derived from different sources (upstream main channel for the former; J-2 Return for the latter) and because they represent different geomorphic reaches.

3.4.1 Green Line Elevation (GLE) (DAP 5.4.1)

The green line elevations (GLEs) varied by an average of about 2 feet throughout the 5-year survey period, with the highest elevations recorded during 2011, when long-duration, high flows were present in the reach and the lowest elevations occurring during the very low-flow conditions in 2013 (**Table 3.2, Figure 3.13a**). In 2010, the GLEs averaged about 1.0 feet higher than in 2009, increasing to 1.8 feet in 2011, and then decreasing back to only 0.2 feet higher in 2012 (**Figure 3.13b**). In 2013, the GLE averaged about 0.2 lower than in 2009. As expected from the by-AP averages and the overall reach averages, the averages for the geomorphic reaches were also relatively consistent within each of the years, and particularly, in 2010 and 2011 when the flows were relatively high (**Figure 3.13c**). (Note that Reach 2 is the south channel at Jefferys Island, where the flows are derived from the J-2 Return and maximums are in the range of 2,000 cfs in all years.)

During 2009, 2010 and 2011, the GLEs were consistently in the range of 1 to 2 feet below the water surface associated with the maximum preceding discharge (Q_p; DAP 5.1.1) (**Figure 3.14**), with generally greater differences upstream from the Kearney Diversion and downstream from Grand Island. During the low-flow years in 2012 and 2013, the GLE tended to be above the preceding maximum water-surface elevation.

With a few notable exceptions, differences in GLE from the initial survey in 2009 during each of the subsequent years were relatively consistent throughout the reach (Figure 3.13a), suggesting that the GLE is responsive to the hydrologic conditions in any particular year. The data also suggests that the GLE is responsive to the relative change in stage associated with the preceding flows that is a function of both the discharge and the hydraulic geometry relationship at the cross sections, especially during high-flow years. Three different measures of the preceding discharge were considered in quantifying these observations: (1) preceding maximum discharge (Q_p; DAP 5.1.1), (2) germination season discharge (Q_{GER}; DAP 5.1.2), and (3) maximum discharge during the germination season. Correlation between the change in GLE from 2009 and the difference in stage from 2009 is significant for each of these metrics for the two high-flow years (2010 and 2011), but not significant for the two low-flow years, and the correlation is marginally stronger when the peak discharge during the germination season is used rather than the mean discharge during the germination season (Q_{GER}) that is defined in the DAP (**Figure 3.15a, b, c**). When only the difference in discharge is used rather than the difference in stage, the correlations are considerably lower, verifying the importance of the hydraulic geometry relationships (i.e., narrower cross sections at which the stage changes more rapidly with discharge tend to have larger differences in GLE during the high-flow years than those with relatively flat stage-discharge rating curves.)

Table 3.2. Average green line elevations at all pure panel APs.

Anchor Point	River Mile	Green line Elevation (ft)				
		2009	2010	2011	2012	2013
39	250.8	2372.6	2374.5	2375.1	2373.6	2373.5
37	246.5	2347.5	2348.5	2349.2		2347.2
35	241.5	2315.1	2316.6	2317.7	2315.5	2314.4
33	236.5	2281.8	2282.8	2283.2	2282.4	2281.1
31	231.5	2249.5	2250.6	2251.4	2249.6	2249.3
29	226.4	2215.2	2216.2	2217.1	2215.9	2214.8
27	221.9	2184.3	2185.8	2186.5	2184.5	2184.1
25	216.5	2148.4	2149.7	2150.3	2148.3	
23	211.5	2114.0	2115.0	2115.9	2114.1	2114.2
21	206.7	2083.7	2085.6	2084.2	2083.9	2083.6
19	201.1	2047.3	2048.2	2048.9	2047.5	2047.3
17	196.4	2016.0	2017.1	2018.2	2016.1	2015.8
15	190.7	1978.1	1979.2	1980.2	1978.1	1978.2
13	186.7	1952.8	1953.8	1954.5	1952.4	1952.7
11	181.8	1921.8	1922.8	1923.3	1921.6	1921.9
9	176.5	1888.9	1889.7	1890.0	1889.5	1888.6
7	171.5	1856.6	1857.5	1858.3	1856.6	1855.8
5	166.9	1828.3	1829.0	1829.8	1827.9	1827.8
3	161.8	1792.1	1793.1	1793.6	1792.0	1791.1
1	156.6	1762.0	1762.7	1763.5	1761.7	1761.3

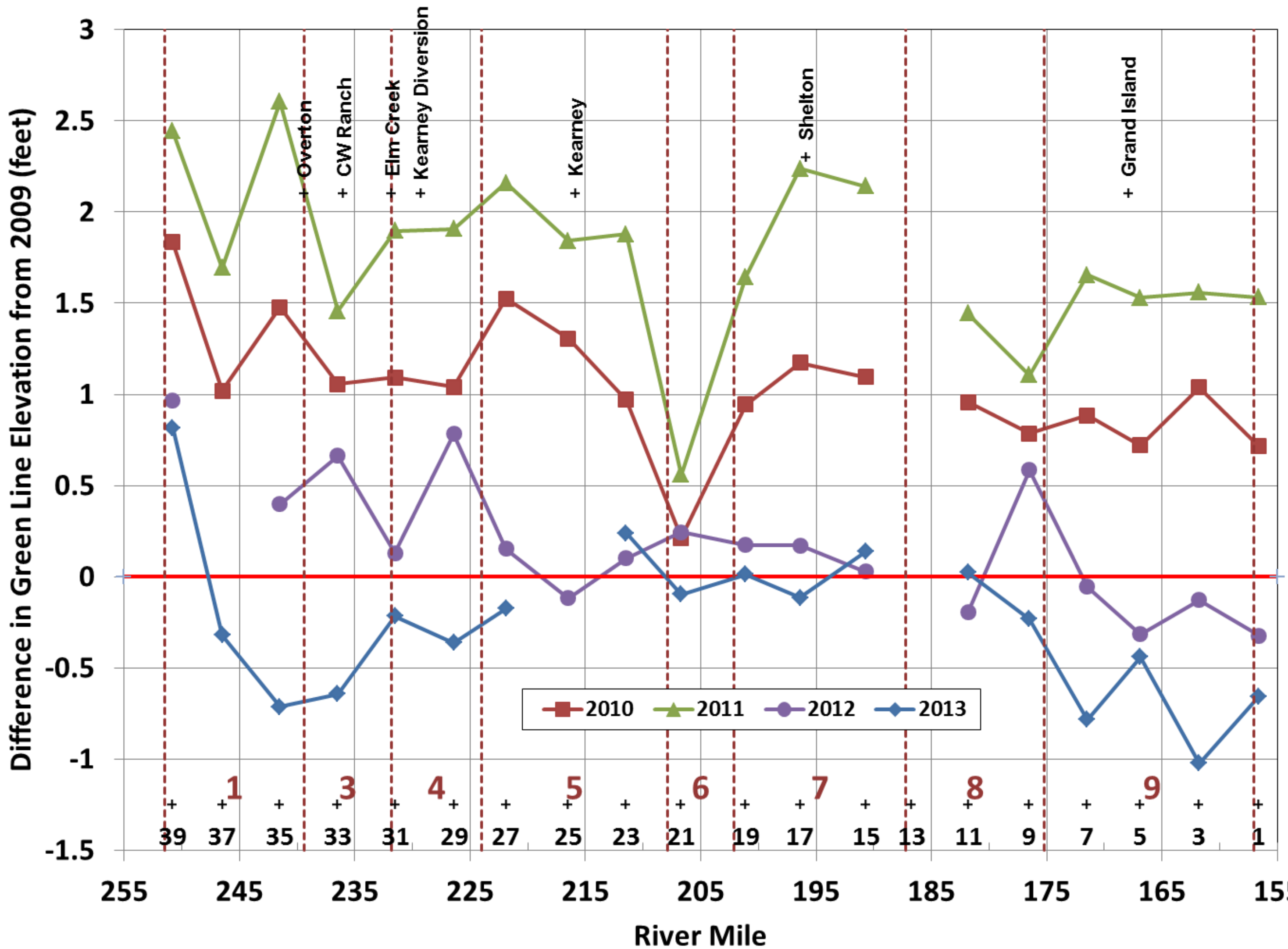


Figure 3.13a. Difference between average GLE at pure panel APs from 2009 to 2010 through 2013.

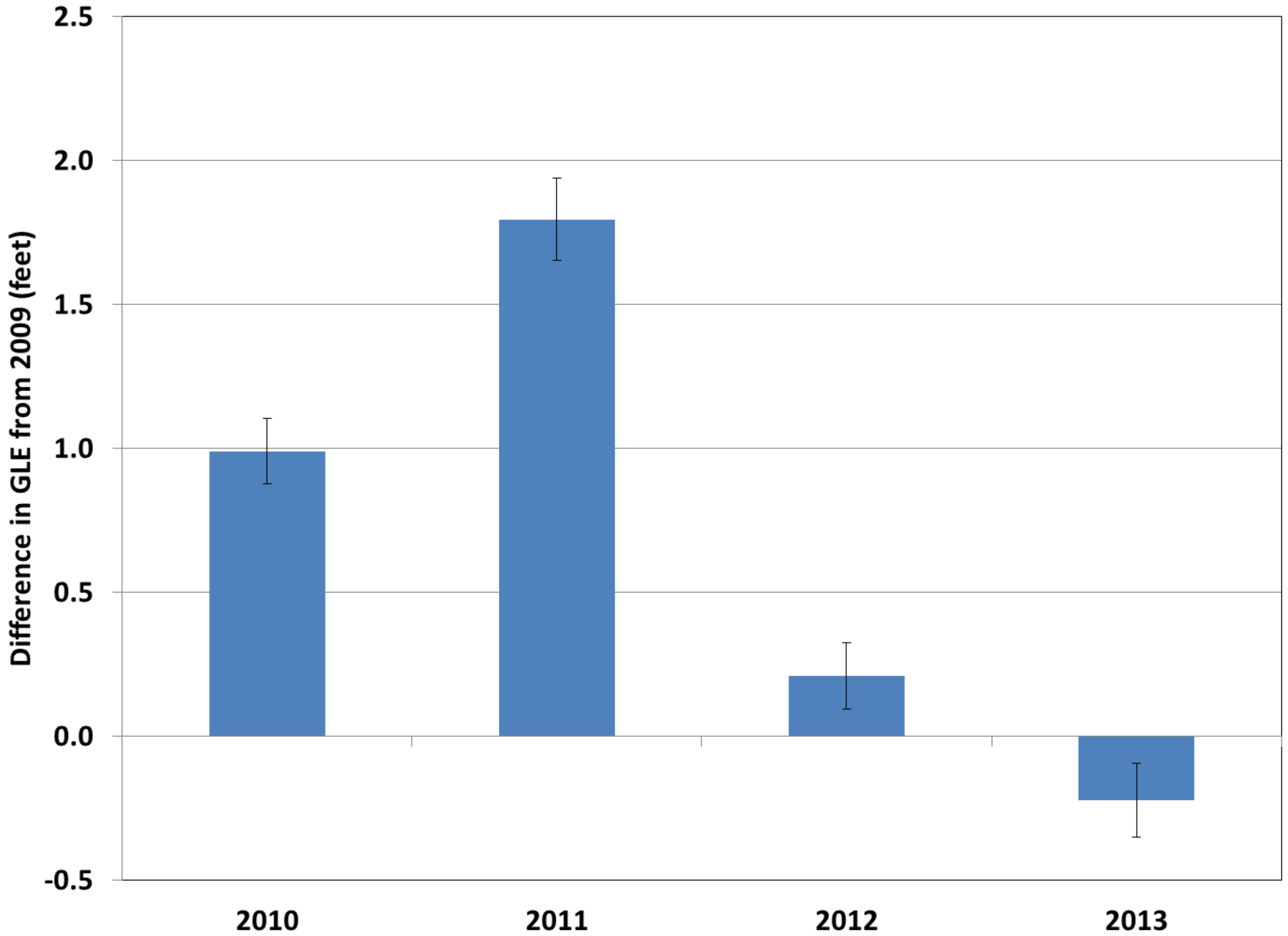


Figure 3.13b. Reach-wide average difference in GLE at pure panel APs from 2009 to 2010 through 2013.

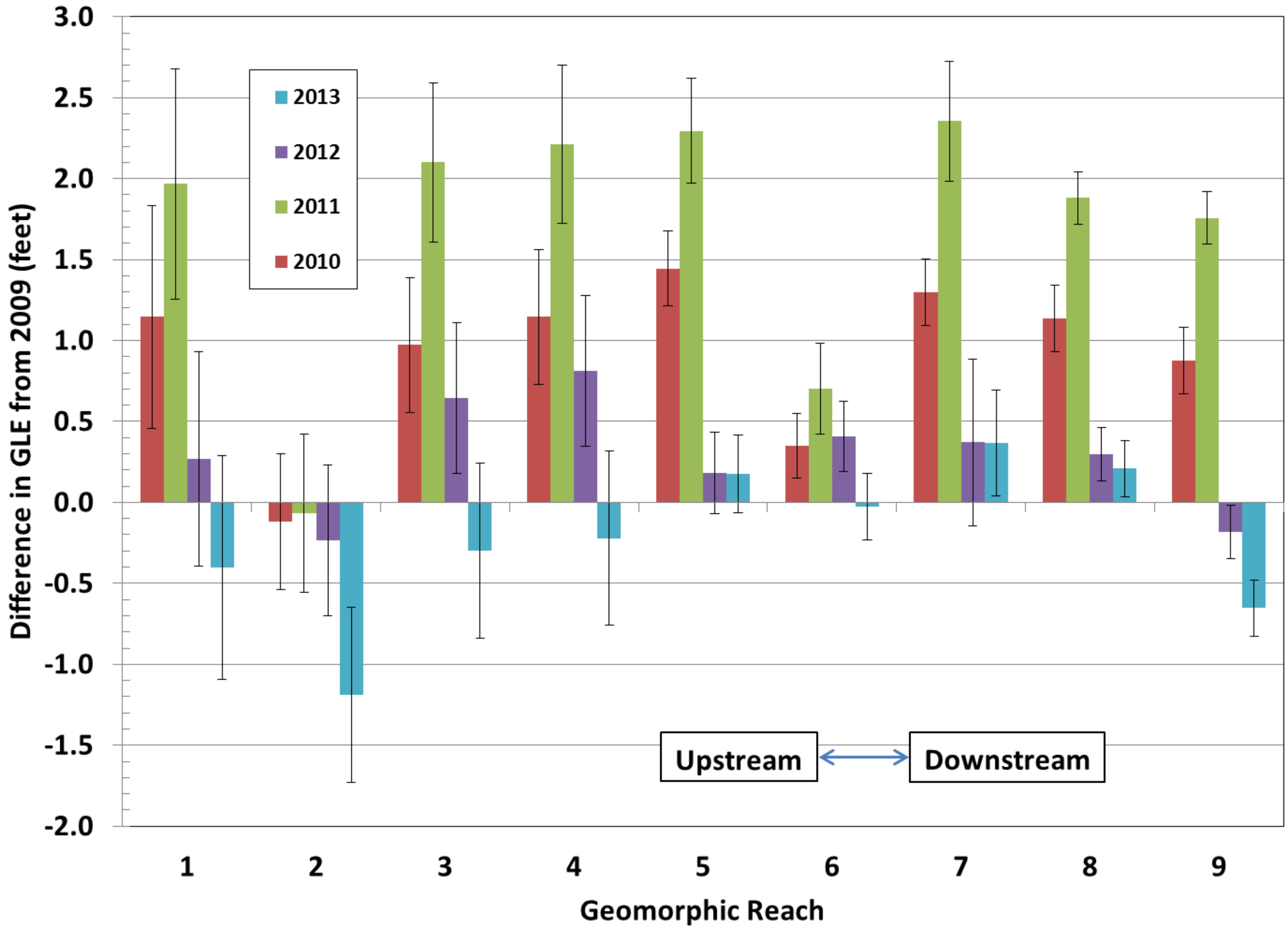


Figure 3.13c. Average change in GLE from 2009 survey, by geomorphic reach.

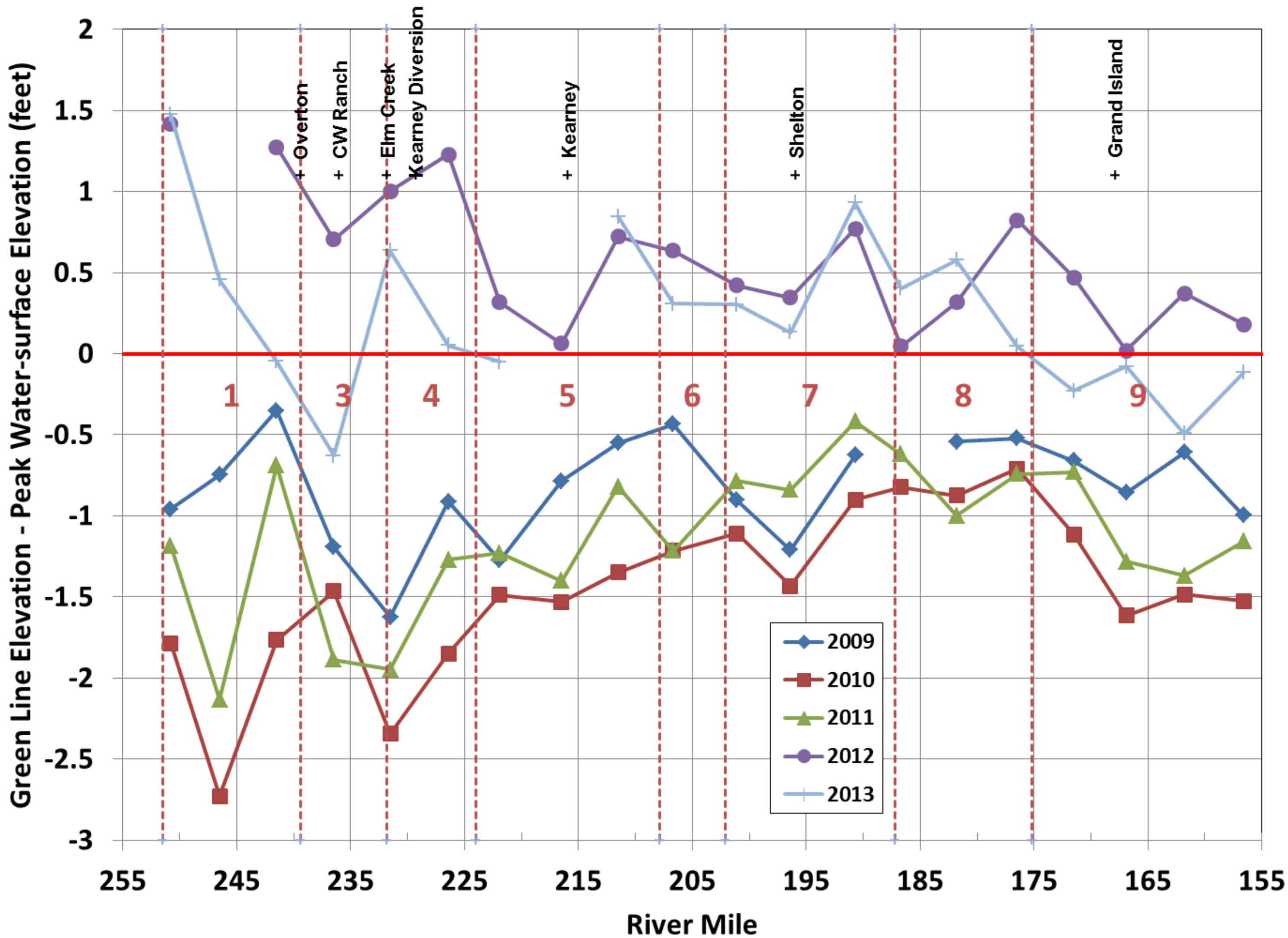


Figure 3.14. Average difference between GLE and water-surface elevation associated with the maximum preceding discharge (Q_P) at pure panel APs from 2009 to 2013.

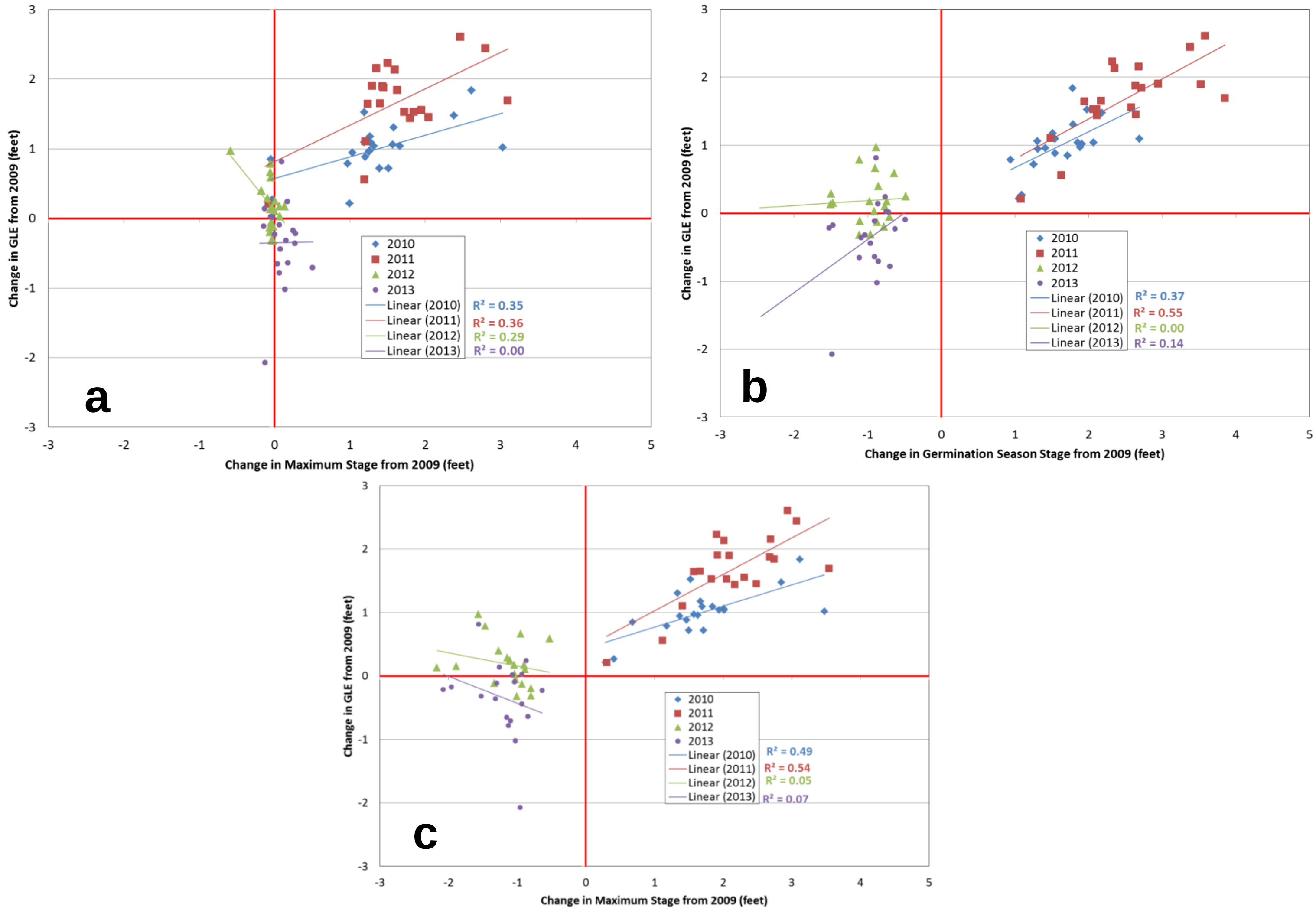


Figure 3.15. Change in water-surface elevation from 2009 versus change in GLE from 2009: (a) preceding maximum discharge (Q_p; DAP 5.1.1), (b) germination season discharge (Q_{GER}; DAP 5.1.2), (c) maximum discharge during germination season.

3.4.2 Total Unvegetated Channel Width (DAP 5.4.2)

The draft DAP defines unvegetated channel width (W_{Unveg}) as the *maximum width between vegetation within the channel and/or the channel banks*, and specifies that it is to be quantified by calculating *the distance between each pair of GLE points that bound the unvegetated channel segment*. After evaluating the first four years of data, it was determined that the total unvegetated width (sum of all unvegetated lengths across the transect) would better represent the original intent of this metric. The widths were determined by overlaying the surveyed GLE points over the applicable aerial photography and physically measuring the unvegetated distance between pairs of points in ArcGIS. This resulted in a shapefile and summary table with georeferenced points that define the ends of each unvegetated sediment and the associated widths. For a variety of reasons, a suitable GLE point was not measured on one side of the unvegetated zone in every locations. These reasons included the presence of rock or other bank protection or a raw vertical bank where vegetation could not establish at an elevation comparable to the other GLE points at the site. In these cases, the aerial photograph, adjacent survey data, and in some cases, ground photographs were used to identify an appropriate location for the missing GLE points. The measurements for the 2009, 2010 and 2011 data were initially made by Program staff, and Tetra Tech staff made the measurements for the 2012 and 2013 data. Tetra Tech also checked the 2009, 2010, and 2011 measurements to insure consistency with the approach used for the 2012 and 2013 data.

The resulting measurements indicate that the unvegetated width varied considerably throughout the reach and from year-to-year at the individual narrowest unvegetated widths typically occurred at AP7, AP23, AP31 and AP35 through AP39, and the widest occurred at AP15, AP21 (Rowe Sanctuary), AP29 and AP33 (Cottonwood Ranch) (**Figure 3.16a**). The reach-wide average unvegetated width for the pure panel APs increased from about 410 feet in 2009 to 630 feet in 2011 and then decreased back to about 310 feet in 2013 (**Figure 3.16b**). Geomorphic Reach 6 had the widest average width during all five years, followed by Reaches 4 and 7 (**Figure 3.16c**). The year-to-year variability within the geomorphic reaches is similar to the reach-wide average.

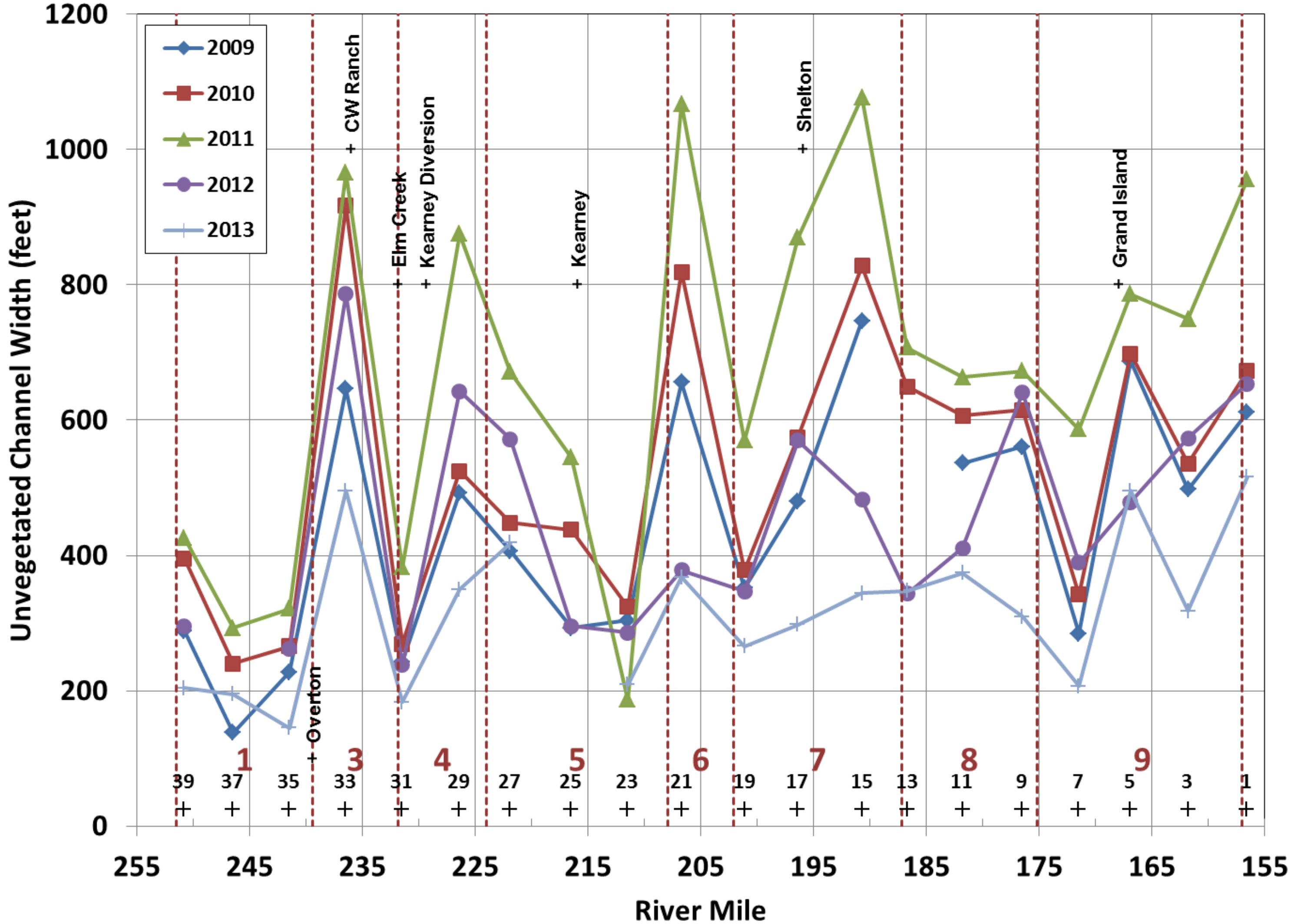


Figure 3.16a. Average unvegetated channel width at pure panel APs from 2009 to 2013.

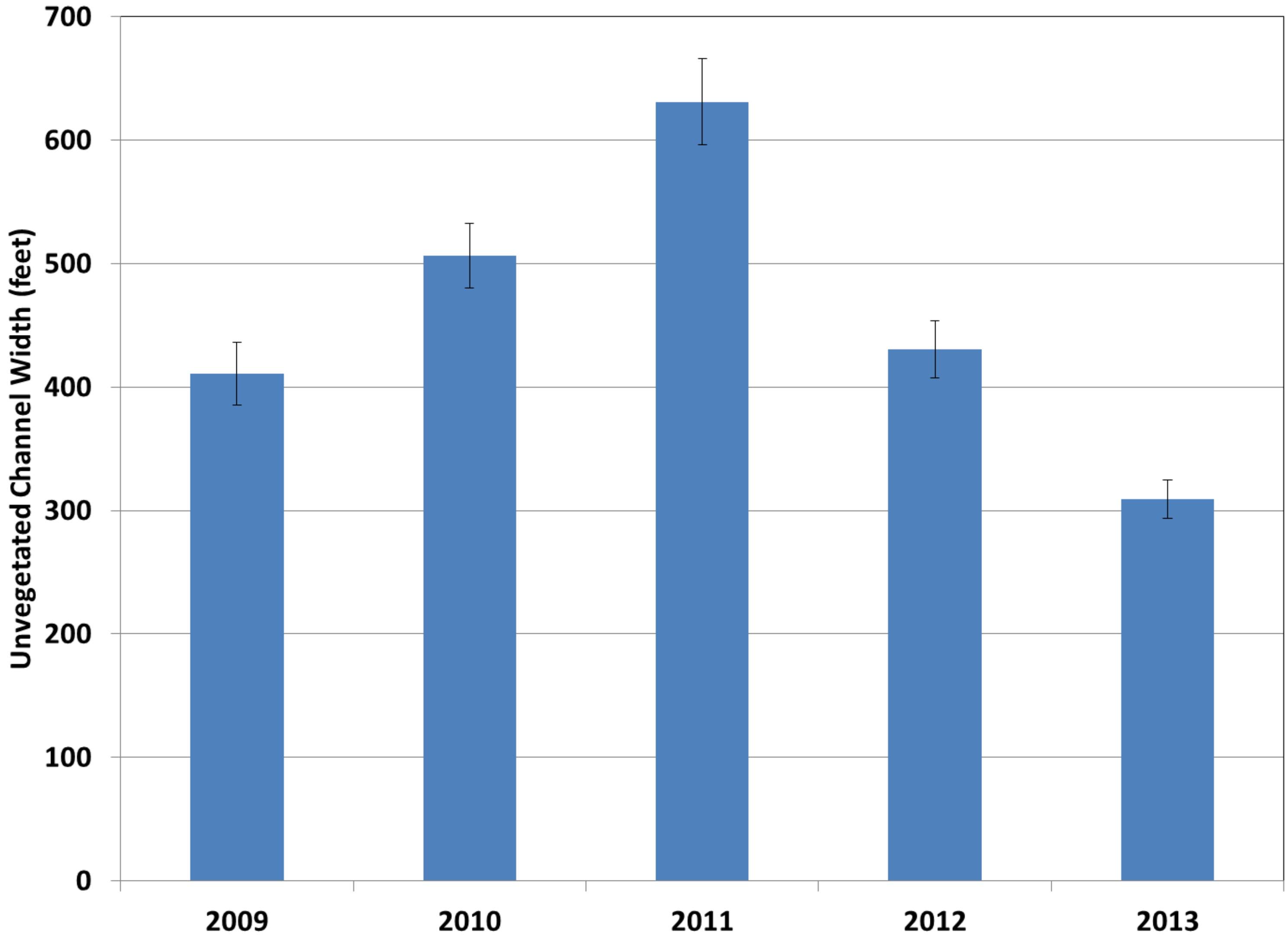


Figure 3.16b. Reach-wide average unvegetated channel width at pure panel APs from 2009 to 2010 through 2013.

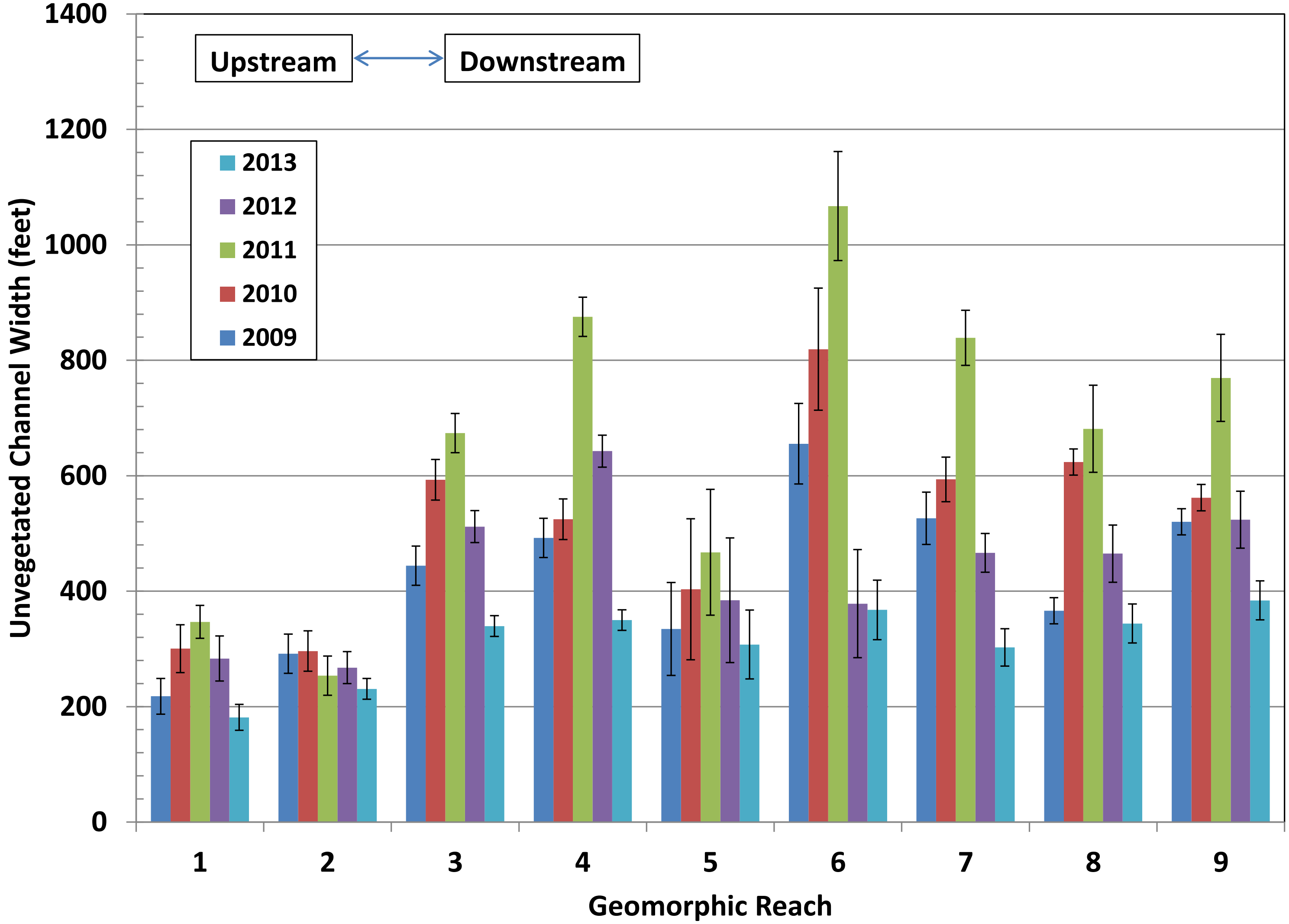


Figure 3.16c. Average unvegetated channel width by geomorphic reach from 2009 through 2013.

3.4.3 Frequency of Occurrence by Species (DAP 5.4.3)

Based on the frequency of occurrence, perennial ragweed (17.9 percent) was the most common species encountered in the reach during the initial survey in 2009, followed by rough cocklebur (13.2 percent), purple loosestrife (12.6 percent), common reed (12.5 percent), and reed canary grass (9.8 percent) (**Figure 3.17**). During the high-flow years in 2010 and 2011, the most frequently occurring species were common reed (12 percent in 2010) and reed canary grass (8.5 percent in 2011), and perennial ragweed was encountered relatively infrequently. Other commonly occurring species during 2010 and 2011 included rusty flatsedge (10.8 percent 2010, but very little in 2011), rice cut grass (9.9 percent in 2010; 3.9 percent in 2011), and flatsedge (9.3 percent in 2010; 5.3 percent in 2011). During the dry year in 2012, the two most common species were rusty flatsedge (23.1 percent) and bearded flatsedge (19 percent), followed by sprangletop (14.4 percent), eastern cottonwood (14.2 percent) and rough cocklebur (10.1 percent). In 2013, when the flows were also very low, annual ragweed (19.6 percent) and sprangletop (17.9 percent) were the most frequently occurring species, followed by bearded flatsedge (15.1 percent), rough cocklebur (13.6 percent) and reed canary grass (12.2 percent).

In previous annual reports, five species of primary interest (purple loosestrife, common reed, eastern cottonwood, willow and cattail) were assessed in greater detail than the other species. Because it was encountered relatively infrequently and is generally not a species of particular concern to the Program, cattail was not evaluated in detail for this report. (Cattail continues to be included in the data collection, but is rarely encountered.) The frequency of purple loosestrife in the overall study reach declined by over 40 percent from about 12.6 percent in 2009 to about 7.2 percent in 2010, and declined further to 4.4 percent in 2011 (**Figure 3.18**). The frequency then increased progressively to about half the 2009 value (6.6 percent) in 2012 and even further to 8 percent, or about 63 percent of the 2009 value in 2013. The frequency of common reed was relatively consistent at about 12.5 and 12.0 percent in 2009 and 2010, respectively, and then declined by about half to 6 percent in 2011. The decline continued in 2012 to about 3.7 percent, followed by a modest increase to about 4.7 percent in 2013. Eastern cottonwood were relatively uncommon (frequency of occurrence ~3.6 percent) in 2009, and even less common in 2010 and 2011 (1.4 percent and 1 percent, respectively. A significant increase occurred in 2012 to over 14 percent, followed by a modest decline to about 11 percent in 2013. The frequency of willow (all species combined) showed a similar pattern to purple loosestrife and common reed, decreasing from 9.6 percent in 2009 to 7.3 percent in 2010, and decreasing further to 3.4 percent in 2011. Modest increases occurred in 2012 and 2013 to 4 and 5.1 percent, respectively.

The distribution of the four species of interest along the study reach was assessed based on the average frequency of occurrence within each of the nine geomorphic reaches. Purple loosestrife (*Lythrum salicaria*) is most prevalent in the downstream half of the reach (Geomorphic Reaches 6 through 9), although it was also present at a significant frequency (>7.5 percent) in Reaches 1 and 5 in 2009 (**Figure 3.19**). With the exception of Reach 6 in 2010, the frequency of purple loosestrife generally declined in all of these reaches after 2009, but it remains relatively abundant in Reaches 6 through 9 in 2013.

Common reed (*Phragmites australis*) was most prevalent in the middle reaches (Reaches 4 and 5) and at the downstream end of the study reach (Reaches 7 and 9), in 2009 (**Figure 3.20**). A considerable amount of common reed was also present in Reach 1 at the upstream end of the study reach. The frequency remained relatively high in these reaches in 2010 and then decreased substantially in 2011 and 2012. Reaches 1 and 7 saw substantial increases in common reed in 2013, although the frequency was still well below the levels in 2009 and 2010.

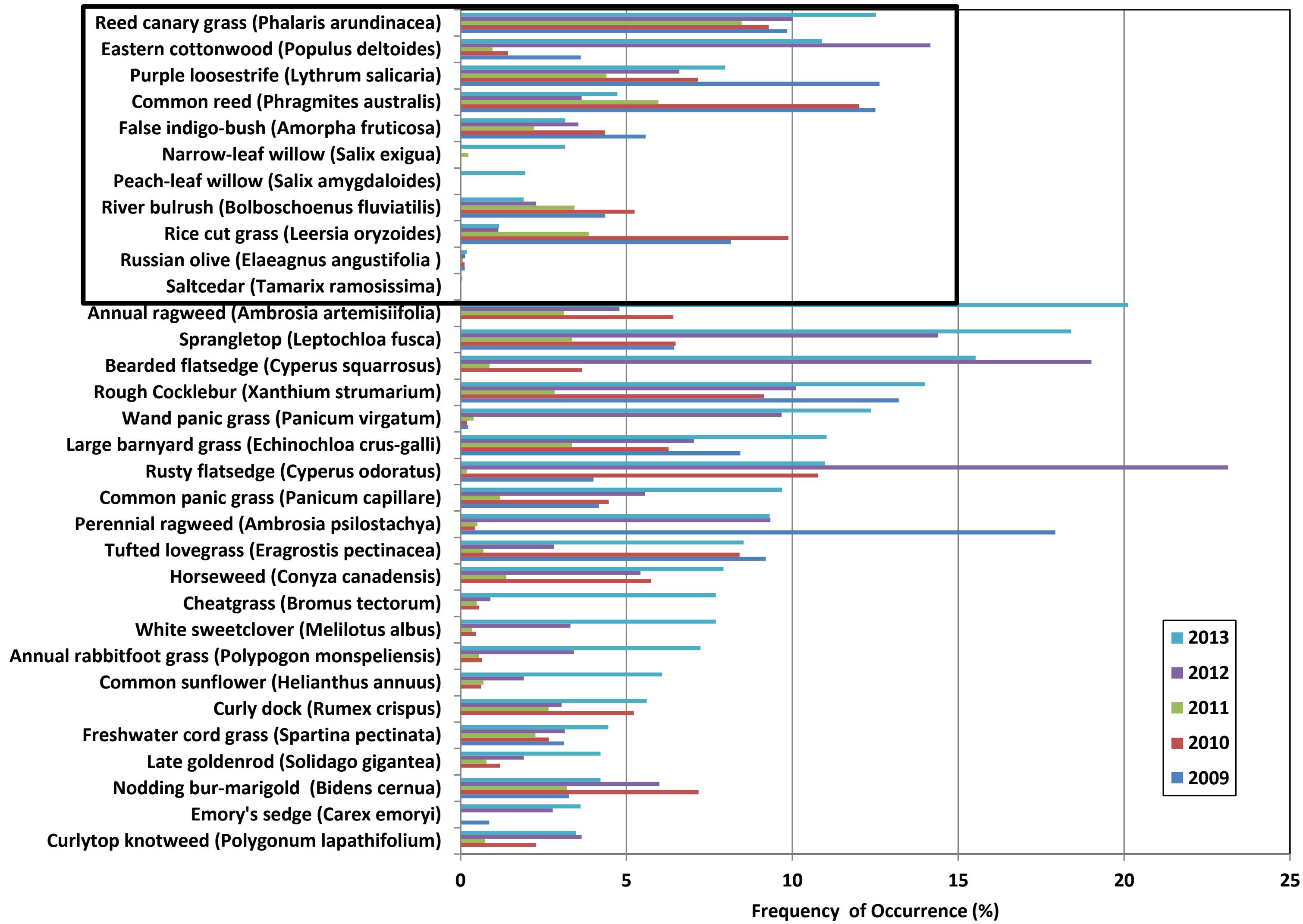


Figure 3.17. Frequency of occurrence of the species of interest (inside black box) and other common species encountered during the 2009 through 2013 surveys. Species of interest and other common species are sorted in decreasing frequency from 2013 data.

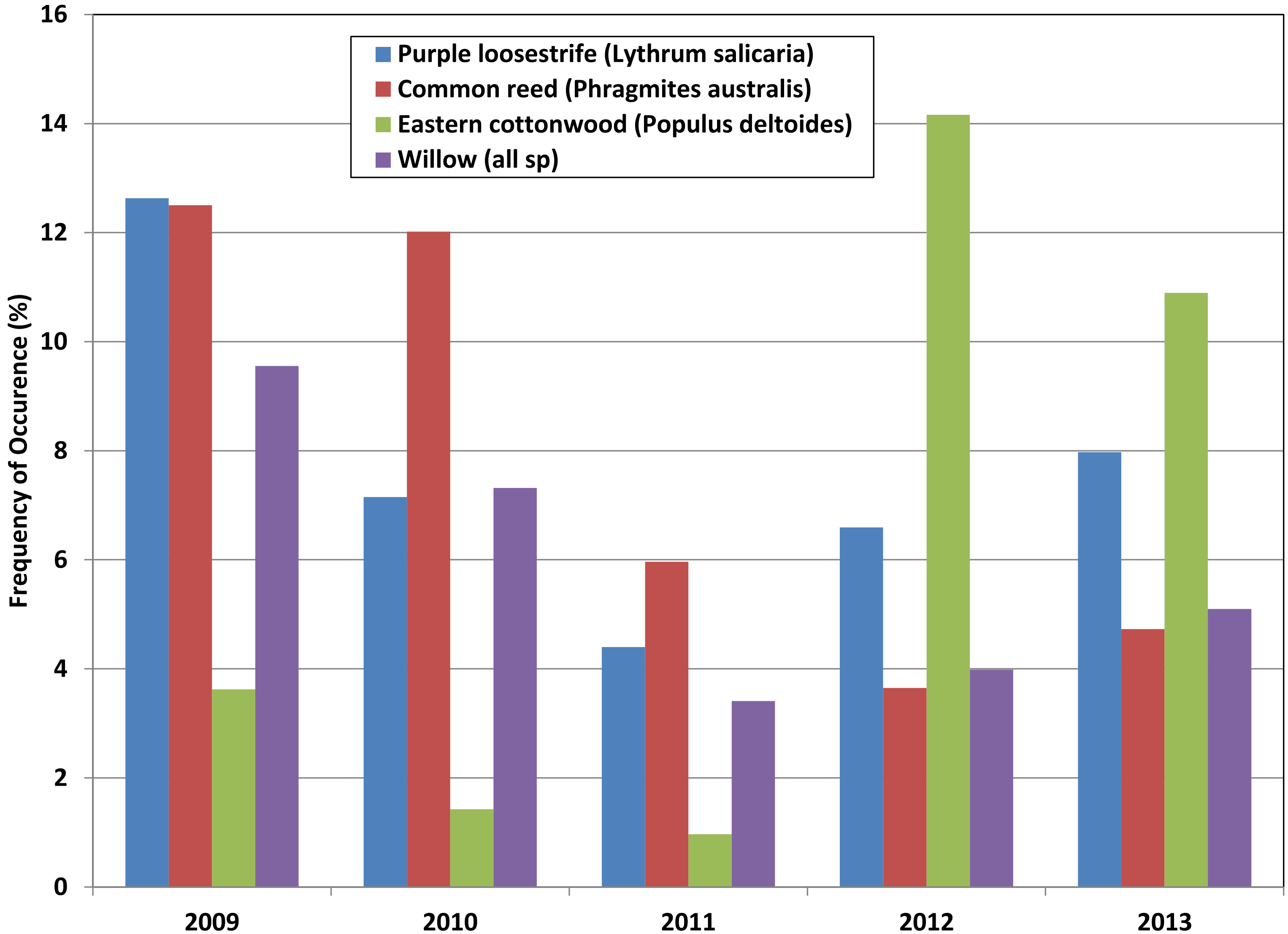


Figure 3.18. Frequency of occurrence of the four species of primary interest during the 2009 through 2013 surveys.

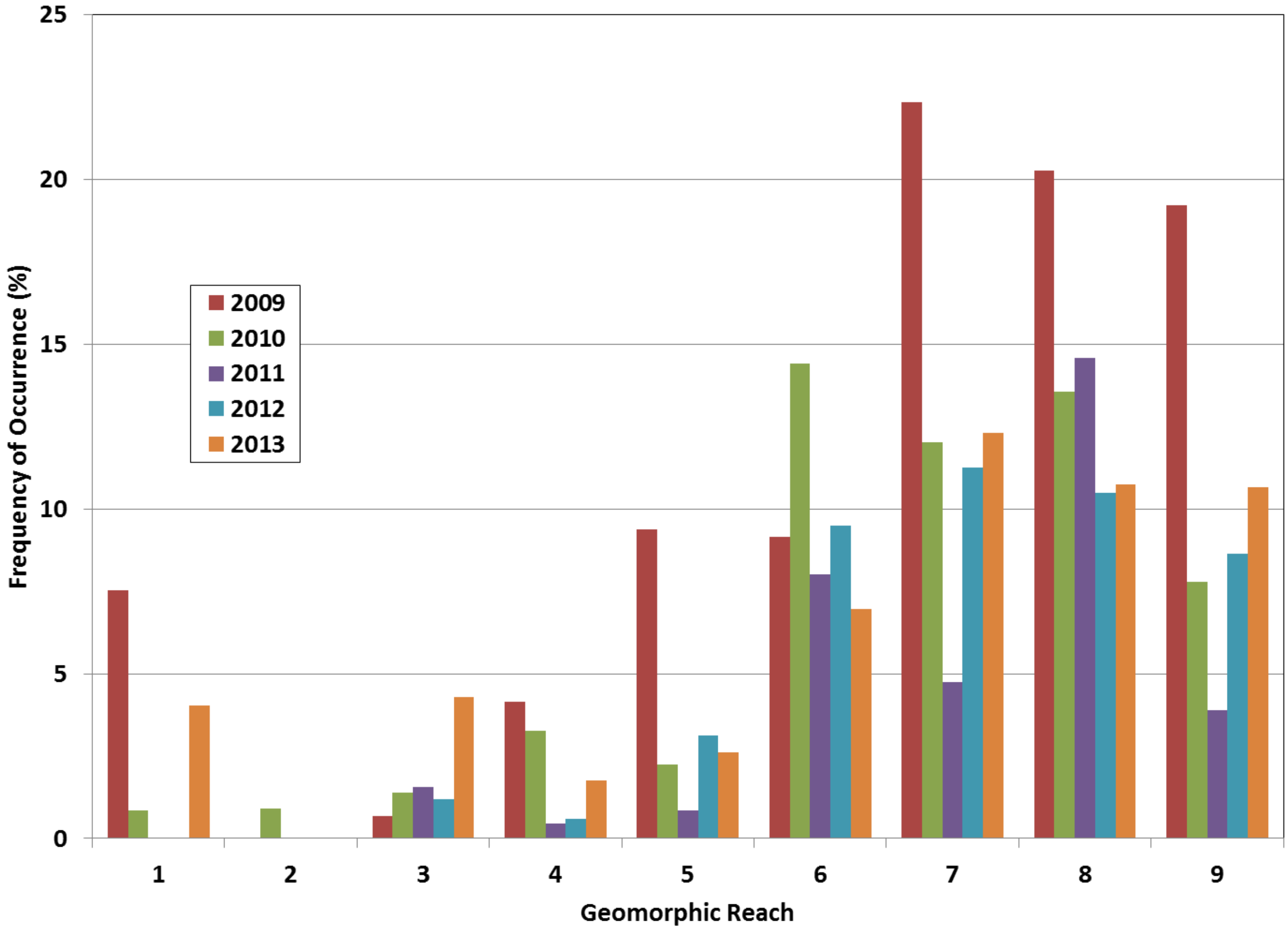


Figure 3.19. Mean frequency occurrence of purple loosestrife (*Lythrum salicaria*) by geomorphic reach and year.

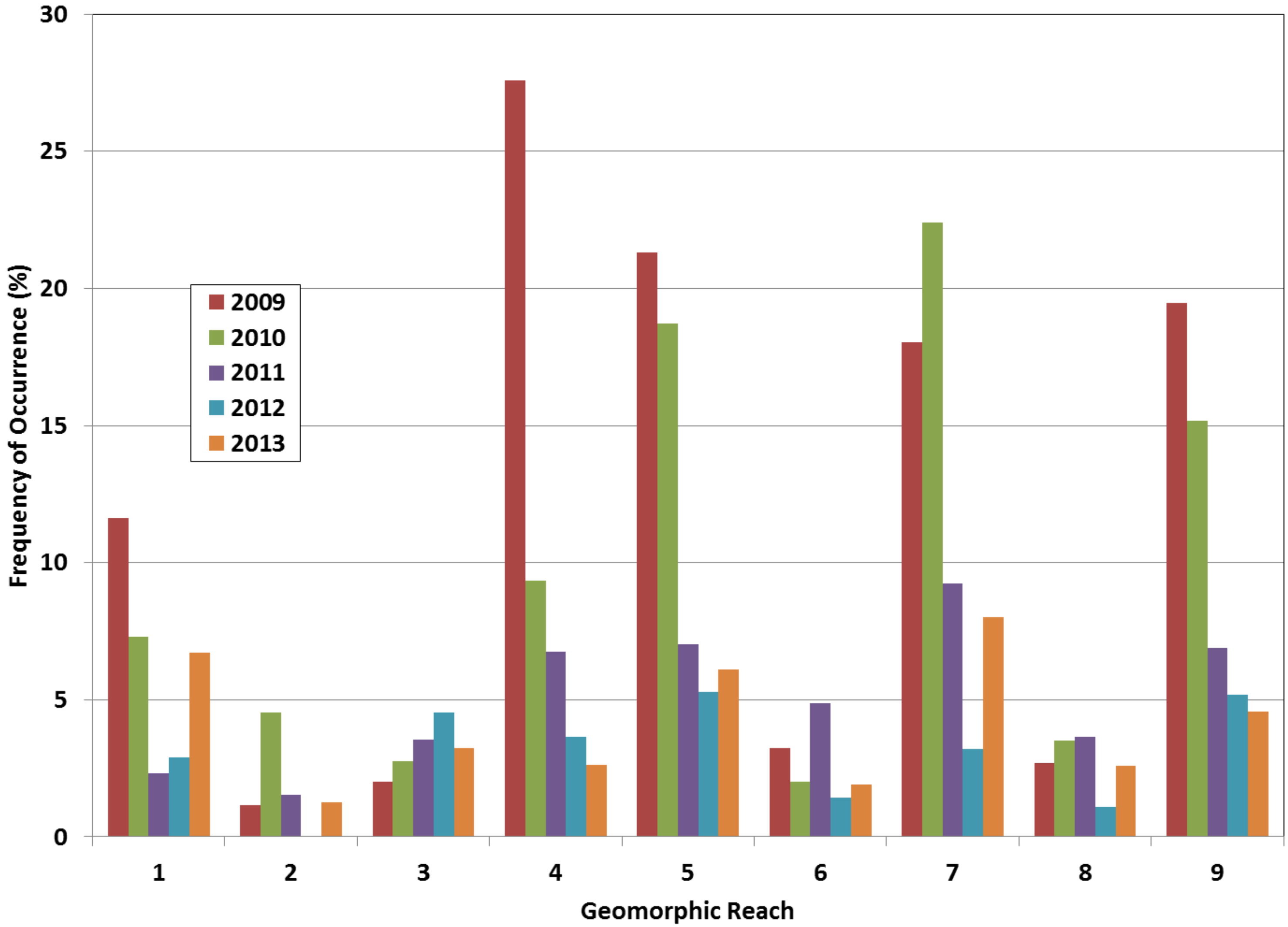


Figure 3.20. Mean frequency occurrence of common reed (*Phragmites australis*) by geomorphic reach and year.

Eastern cottonwood (*Populus deltoides*) was present at relatively low frequencies throughout the entire study reach in 2009, with a mild trend of increasing frequency in the downstream part of the reach (5.7 and 6.7 percent in Reaches 8 and 9, respectively) (**Figure 3.21**). The frequency of this species generally declined throughout the reach in 2010, with the exception of Reaches 2 and 3, where it increased from very low levels in 2009 to 3.2 percent in both reaches. Cottonwood continued to show a general decline in 2011 in most reaches, except for Reach 2 where the frequency increased to about 5.4 percent. A significant increase occurred in most reaches in 2012 to over 20 percent in Reach 1, 19 percent in Reaches 3 and 7, and 12 percent to 13 percent in Reaches 4, 8 and 9. Interestingly, no cottonwood were documented in Reach 2 in either 2012 or 2013. The frequency of cottonwood declined in Reaches 1, 3 and 5 and remained relatively consistent in the remaining reaches in 2013.

Willow (all species combined) was present throughout the study reach in 2009, with the highest frequency occurring in Reach 4 (38 percent), followed by Reach 5 (17 percent) and Reach 7 (13.7 percent) (**Figure 3.22**). Other reaches where willow was present at frequencies greater than 5 percent include Reaches 1, 2, 8 and 9. A substantial reduction in the frequency of willow occurred in Reaches 4 and 9 between 2009 and 2010, and it also declined by modest amounts in Reach 5 and 7. The frequency nearly doubled in Reach 2 between 2009 and 2010, and increases also occurred in Reaches 3 and 8. In 2011, the frequency of willow generally declined throughout the reach, and it continued to decline in most of the reach in 2012 and 2013. Exceptions to this general trend occurred in Reach 1, where the frequency of willow increased to about 6.5 percent in 2012 and even further to 13.4 percent in 2013, and in Reach 6, where the frequency increased to about 7.1 percent in 2012 and 7.6 percent in 2013.

3.4.4 Percent Cover by Species (DAP 5.4.4)

Using the Daubenmire Method, the percent cover of individual species ranged from 0 to about 5.5 percent across all sampled main channel quadrats at the pure panel APs in 2009, and the ranges were similar but somewhat lower in the subsequent years (4.2 percent in 2010, 4.8 percent in 2011, 3.2 percent in 2012 and 5.1 percent in 2013) (**Figure 3.23**). Common reed was the species with the greatest percent cover in 2009 (5.6 percent), followed by reed canary grass (4.9 percent), perennial ragweed (3.6 percent), willow (all species combined) (2.8 percent) and purple loosestrife (2.8 percent). The percent cover of common reed declined substantially after 2009, but it remained in the top two in terms of percent cover in 2010 and 2011 (3.8 percent and 1.8 percent, respectively), and continued to decline to relatively low levels in 2012 and 2013 (0.8 and 0.9 percent, respectively. Reed canary grass was in the top two in percent cover in all years, and was the highest in 2010, 2011, and 2012 (4.2 percent, 4.8 percent and 3.2 percent, respectively). The percent cover of reed canary grass actually increased to about 4.8 percent in 2013, although annual ragweed was more prevalent (5.1 percent cover). Other species that had substantial percent cover in 2010 included rusty flatsedge (3.5 percent), rice cut grass (2.9 percent) and rough cocklebur (2.4 percent). Rice cutgrass (1.5 percent) and purple loosestrife (1.3 percent) also had substantial cover in 2011, as did river bulrush (1.1 percent). In 2012, rough cocklebur (1.7 percent), bearded flatsedge (1.3 percent) and purple loosestrife (1 percent) were present with substantial cover, and in 2013, other species with substantial cover included rough cocklebur (2.6 percent), wand panic grass (2.5 percent) and bearded flatsedge (2.1 percent).

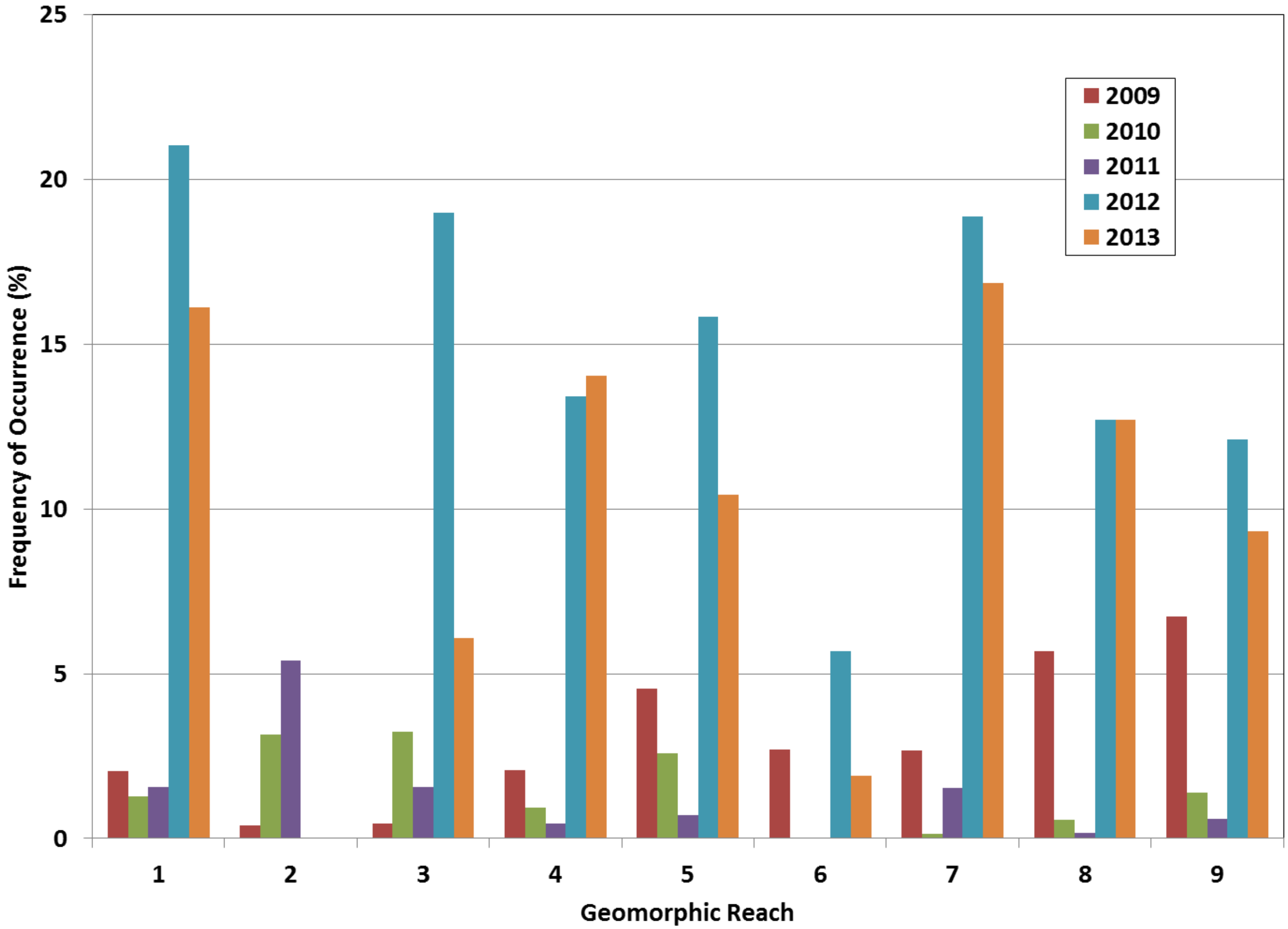


Figure 3.21. Mean frequency occurrence of eastern cottonwood (*Populus deltoids*) by geomorphic reach and year.

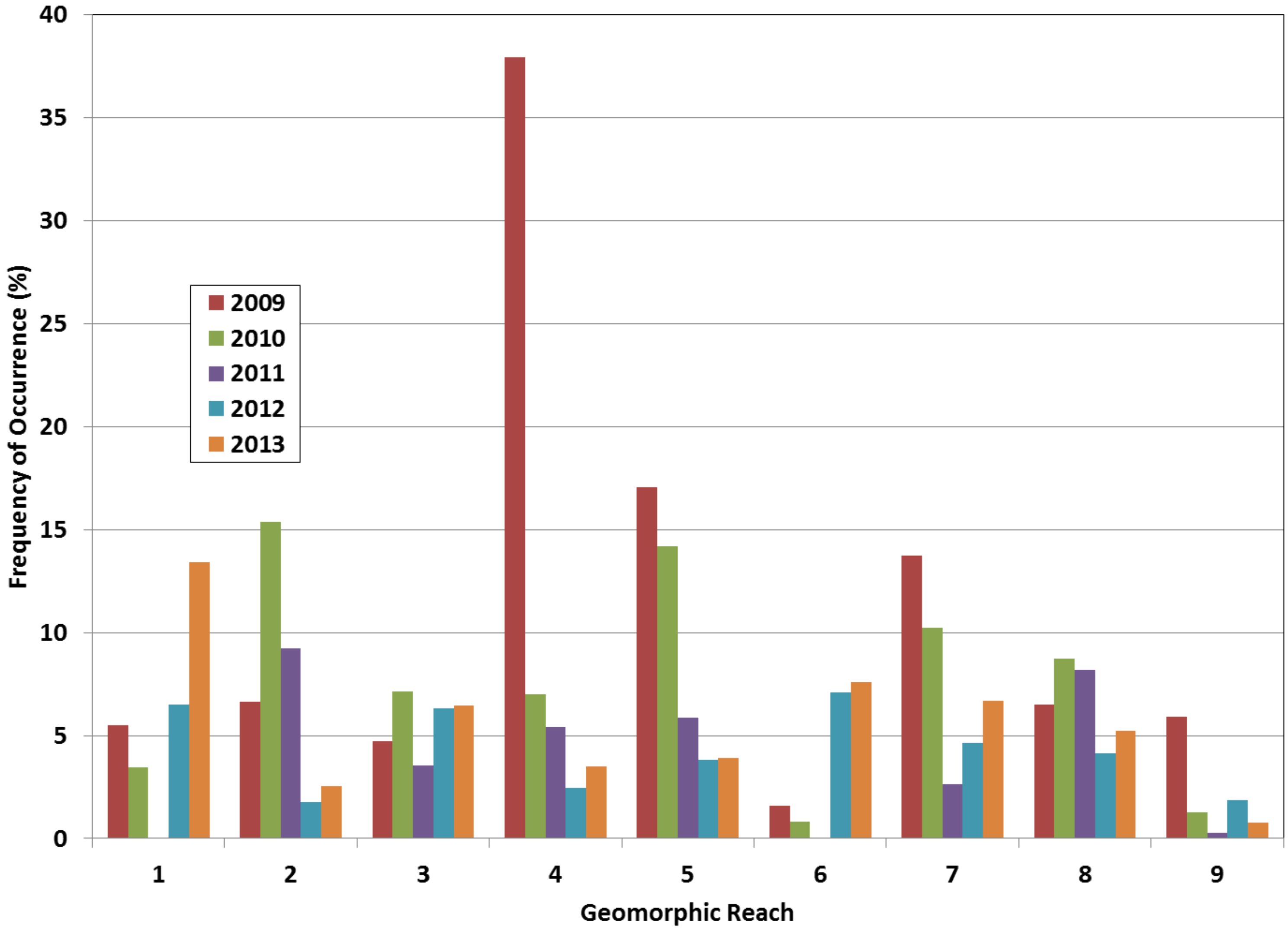


Figure 3.22. Mean frequency occurrence of willow (all species) by geomorphic reach and year.

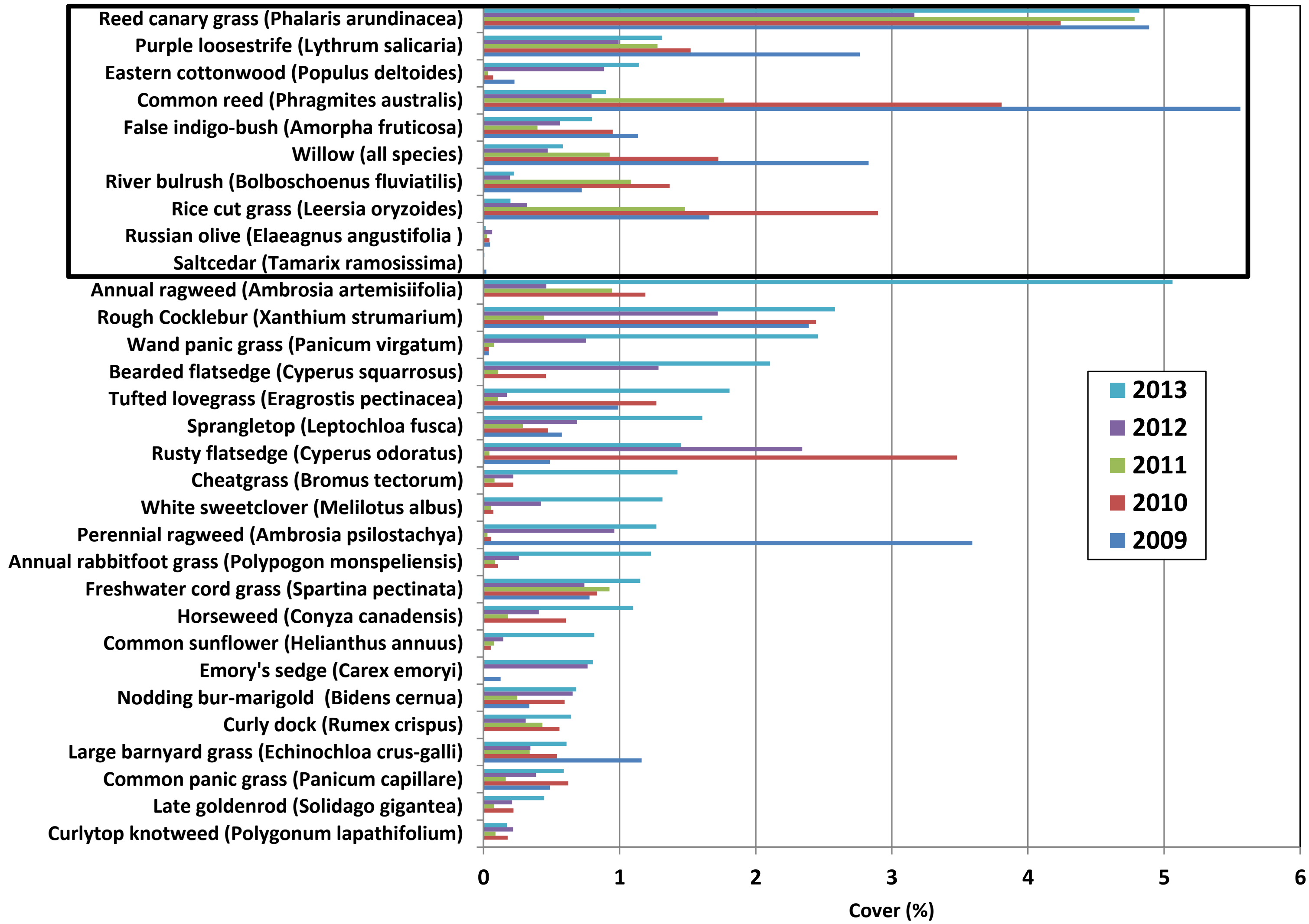


Figure 3.23. Percent cover of the species of interest (inside black box) and other common species encountered during the 2009 through 2013 surveys. Species of interest and other common species are sorted in decreasing percent cover from 2013 data.

In assessing these results, it is important to note that cover was estimated as the percentage cover over the quadrat, which quantifies each species separately. As a result, different vegetation strata and individual plants within each quadrat can and do overlap, which sometimes results in the total cover within a quadrat exceeding 100 percent.

The temporal patterns in percent cover for purple loosestrive and common reed (two of the four species of primary interest) are similar to the frequency of occurrence in that they generally declined throughout the five year survey period (**Figure 3.24**). Eastern cottonwood showed a temporal pattern of declining during the first three years and then increasing substantially during 2012 and 2013. The percent cover of willow declined throughout the period, in spite of the modest increases in frequency of occurrence in 2012 and 2013. The spatial patterns of the percent cover for the four species of primary interest are very similar to those discussed above with respect to the frequency of occurrence (**Figures 3.25 through 3.28**).

3.4.5 Aerial Cover by Species (DAP 5.4.5)

Since aerial cover is the product of the percent cover and the sample area, the trends and relative magnitudes are essentially the same as percent cover. The total area encompassed by the vegetation surveys (i.e., basically, the total main channel area within the primary flow path at the pure panel APs) ranged from about 490 acres (2013) to 590 acres (2010) (**Figure 3.29**). The Dabenmire data indicate that about 29 percent of the surveyed area had measurable vegetation in 2009 and 2010 (164 acres and 170 acres, respectively), declining substantially to only about 10 percent (60 acres) in 2011, and then increasing back to about 20 percent (112 acres) in 2012 and 17 percent (81 acres[6]) in 2013. All other areas were bare ground, dead organic matter, or open water.

As with percent cover, common reed and reed canary grass had the greatest aerial cover of the sampled species in 2009, 2010 and 2011 (**Figure 3.30**). Reed canary grass remained in the top two species for aerial cover in 2012 and 2013, common reed was replaced in the top two by rusty flatsedge and annual ragweed, respectively. Other species with substantial aerial cover included perennial ragweed, willow, and purple loosestrife in 2009, rusty flatsedge, rice cut grass and rough cocklebur in 2010, rice cut grass, purple loosestrife and river bulrush in 2011, rough cocklebur, bearded flatsedge and purple loosestrife in 2012 and rough cocklebur, wand panic grass, and bearded flatsedge in 2013.

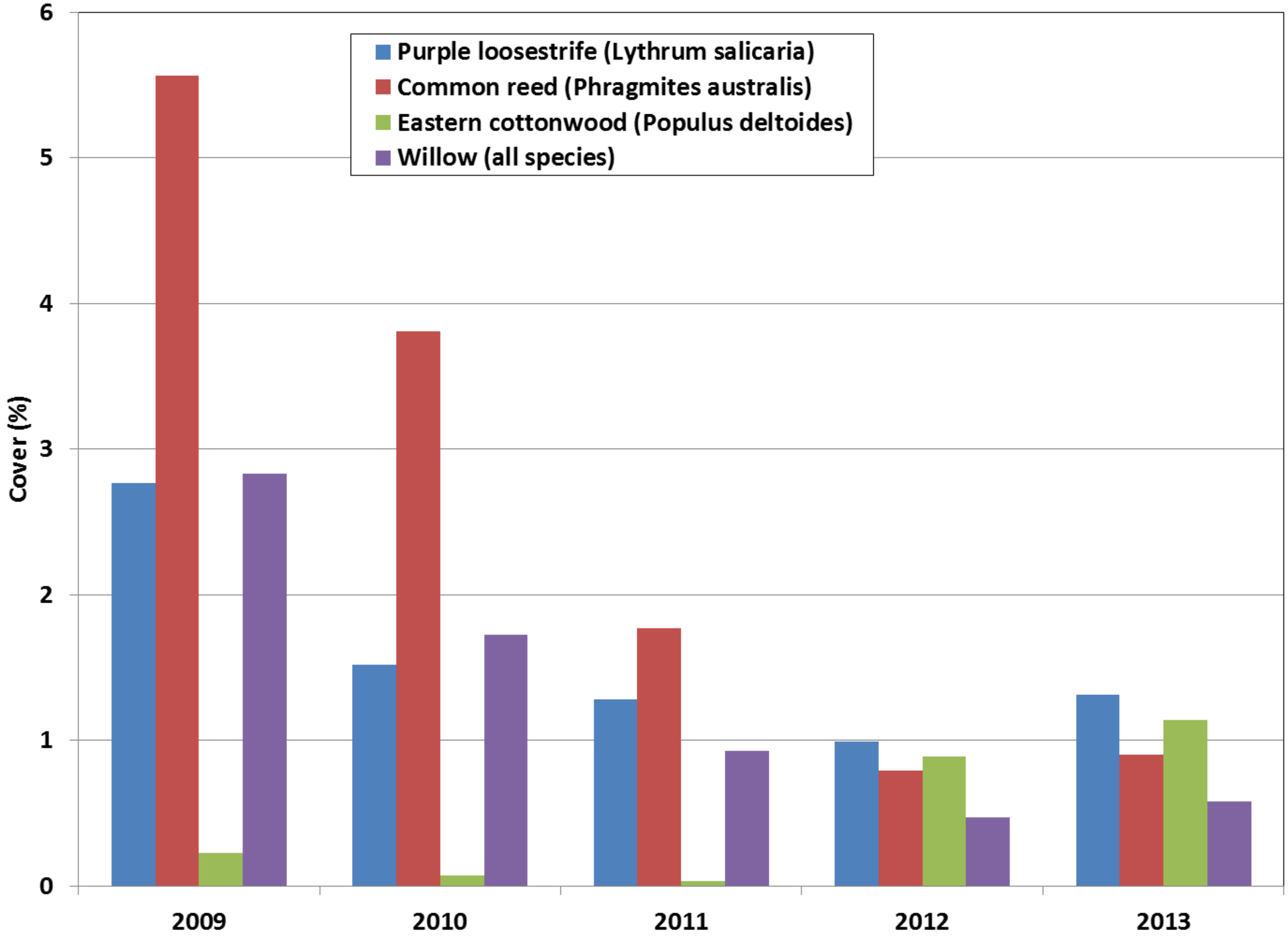


Figure 3.24. Percent cover of the species of primary interest during the 2009 through 2013 surveys. (Same data as Figure 3.21.)

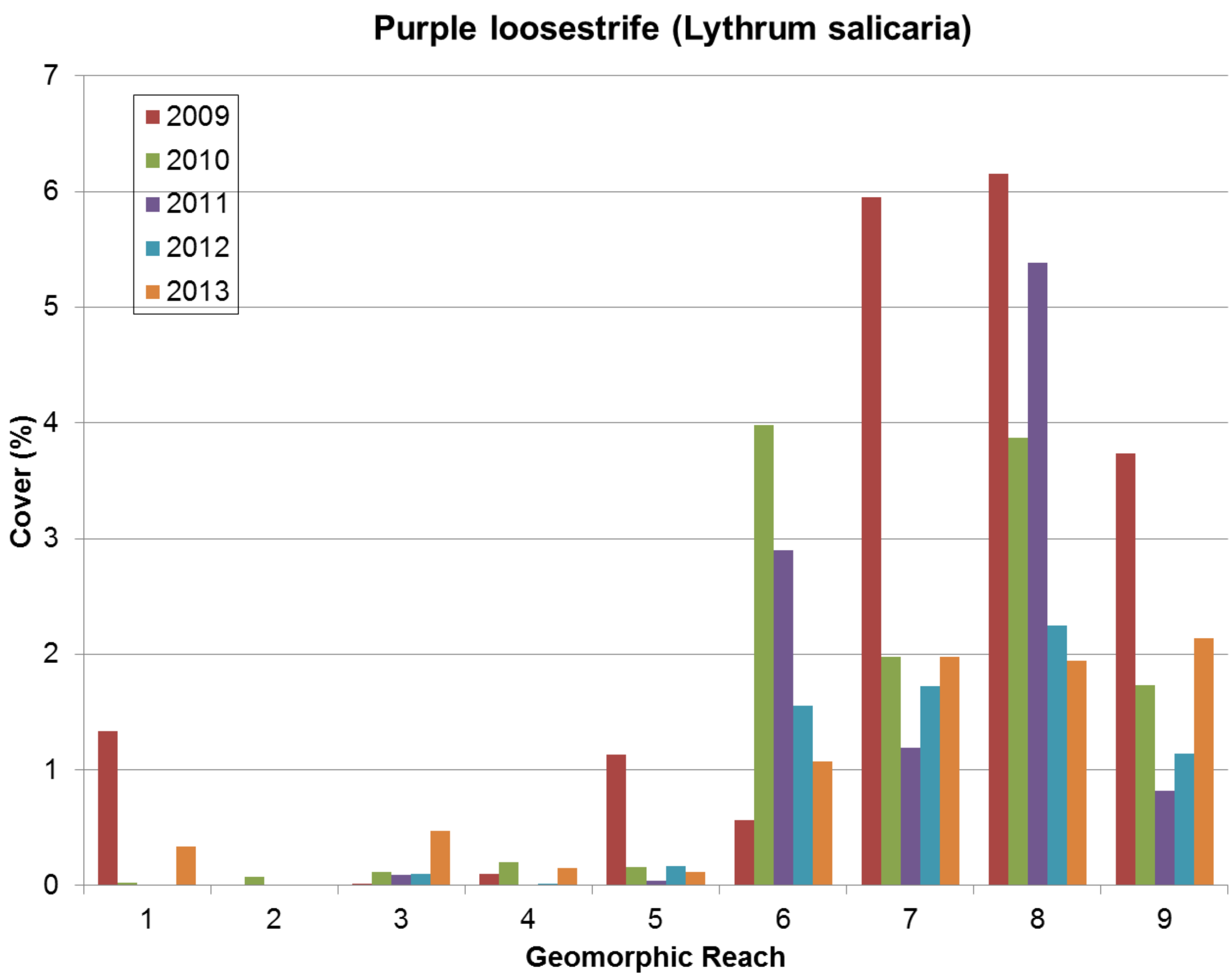


Figure 3.25. Percent cover of purple loosestrife (*Lythrum salicaria*) by geomorphic reach and year.

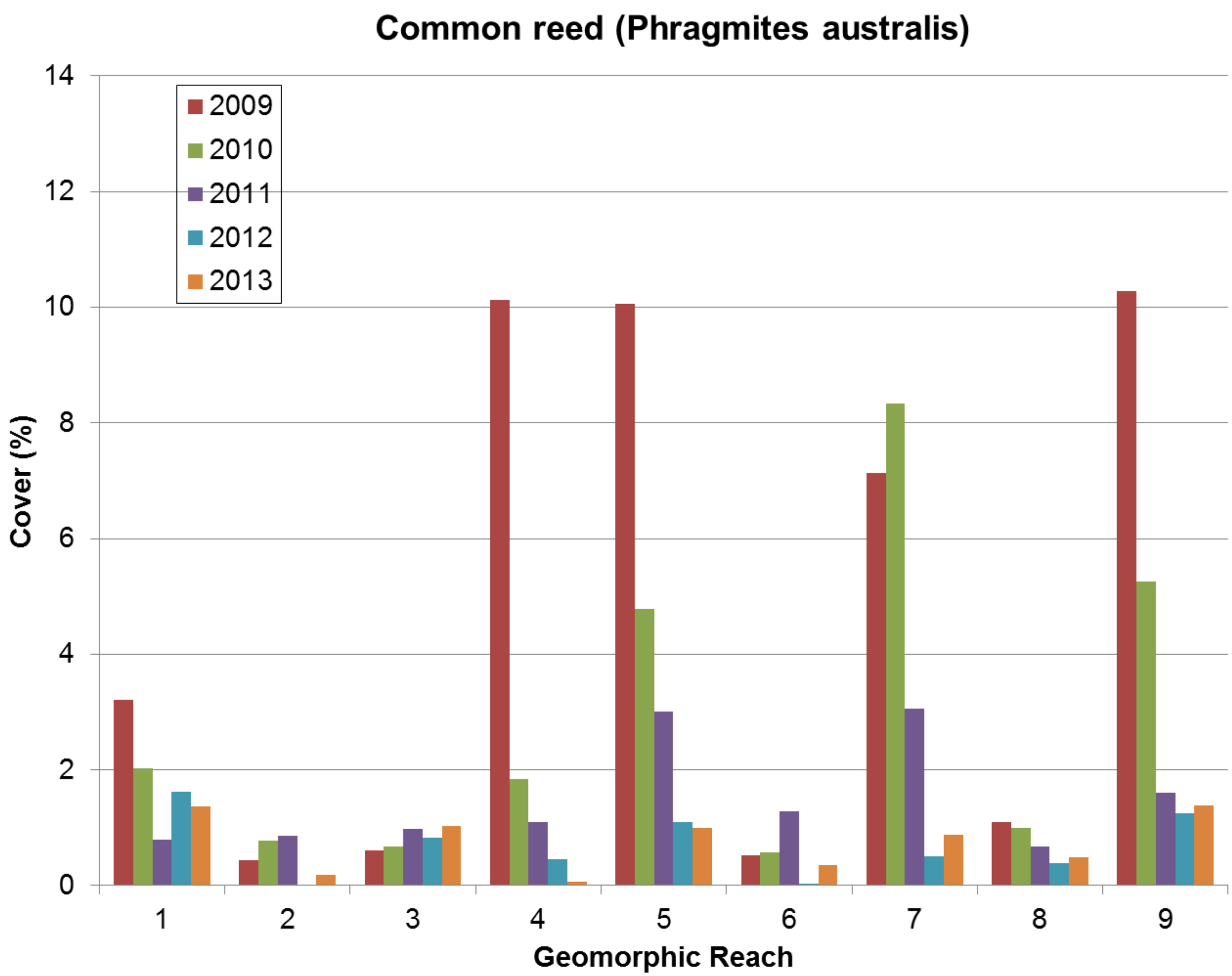


Figure 3.26. Percent cover of common reed (*Phragmites australis*) by geomorphic reach and year.

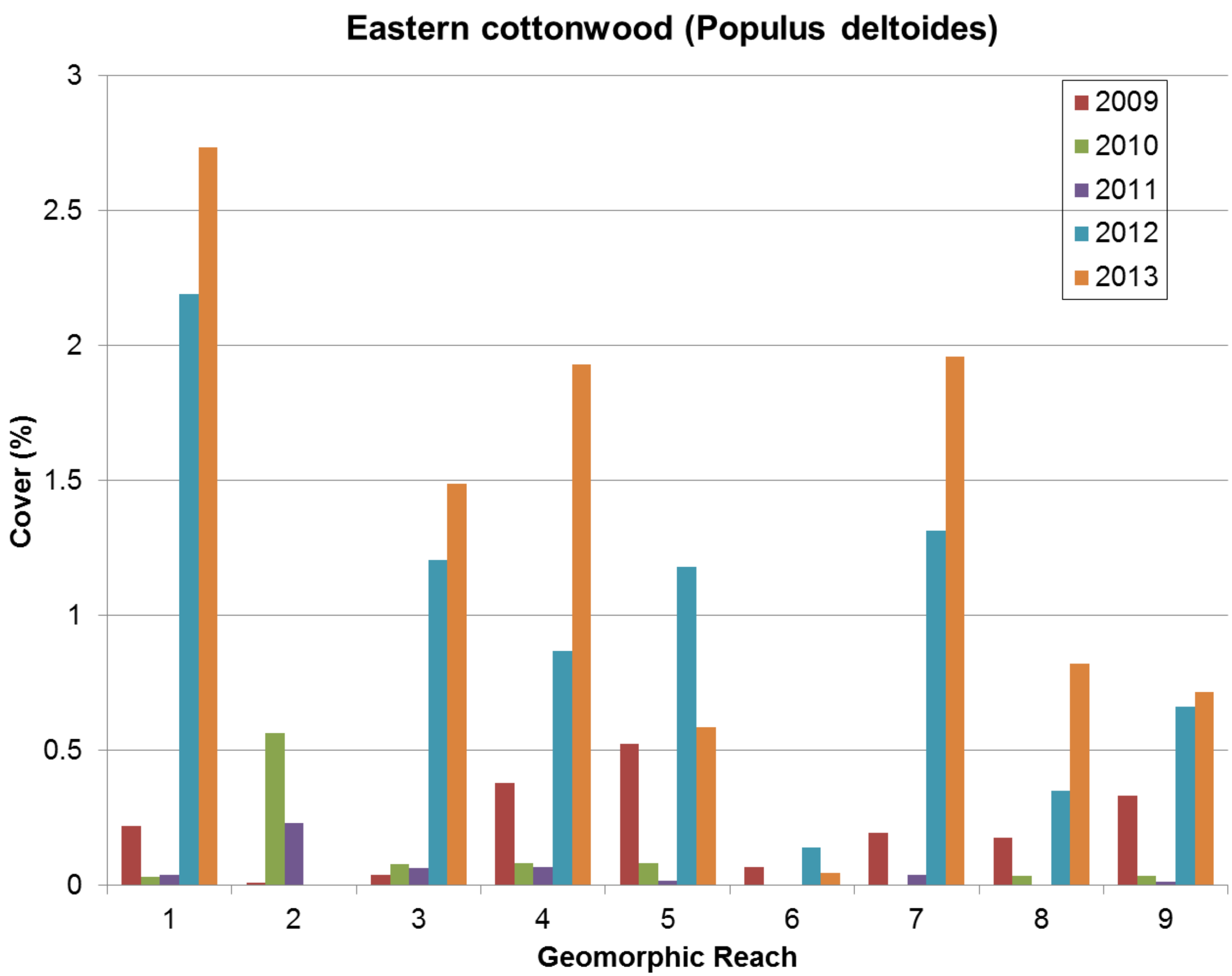


Figure 3.27. Percent cover of eastern cottonwood (*Populus deltoids*) by geomorphic reach and year.

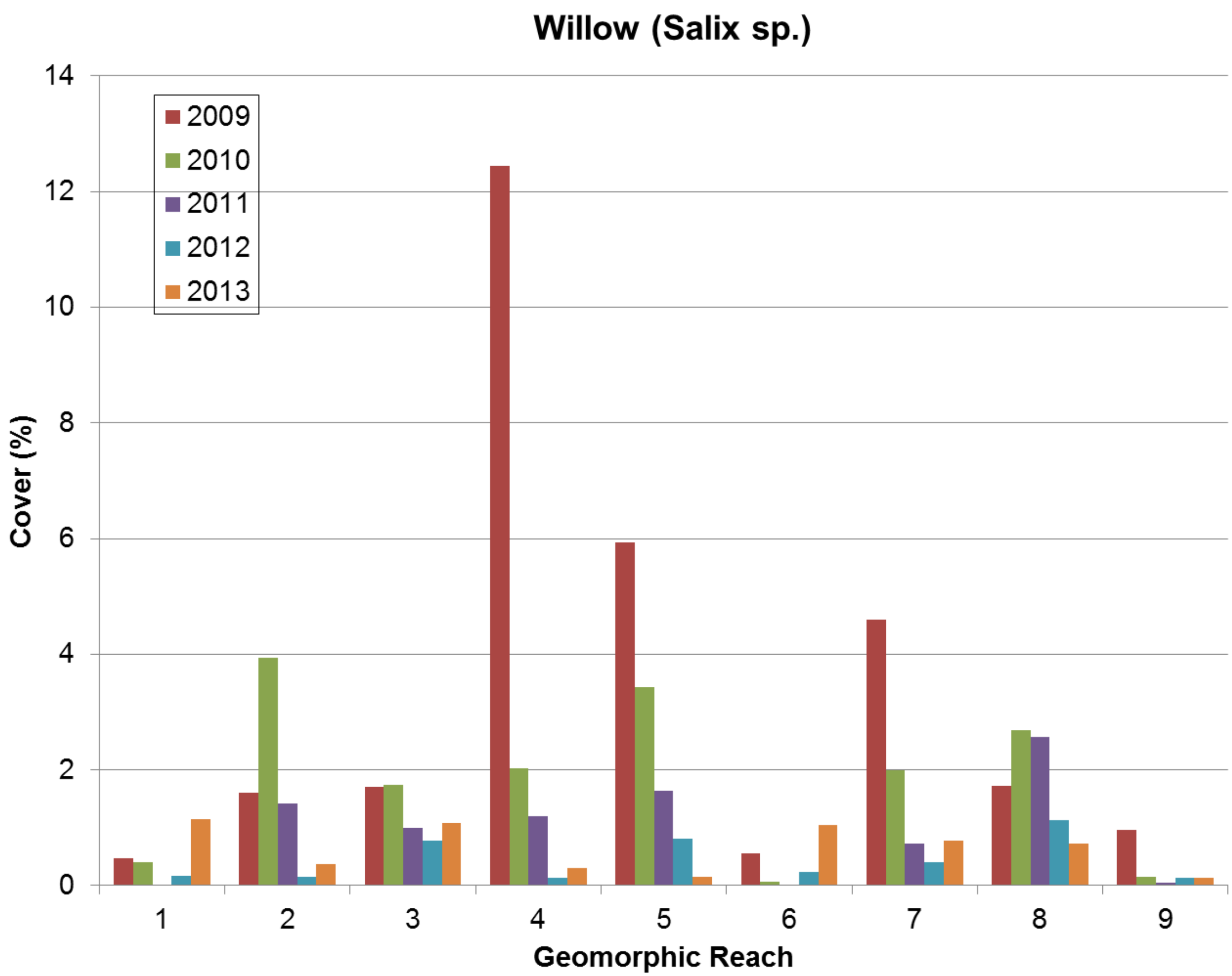


Figure 3.28. Percent cover of willow (all species) by geomorphic reach and year.

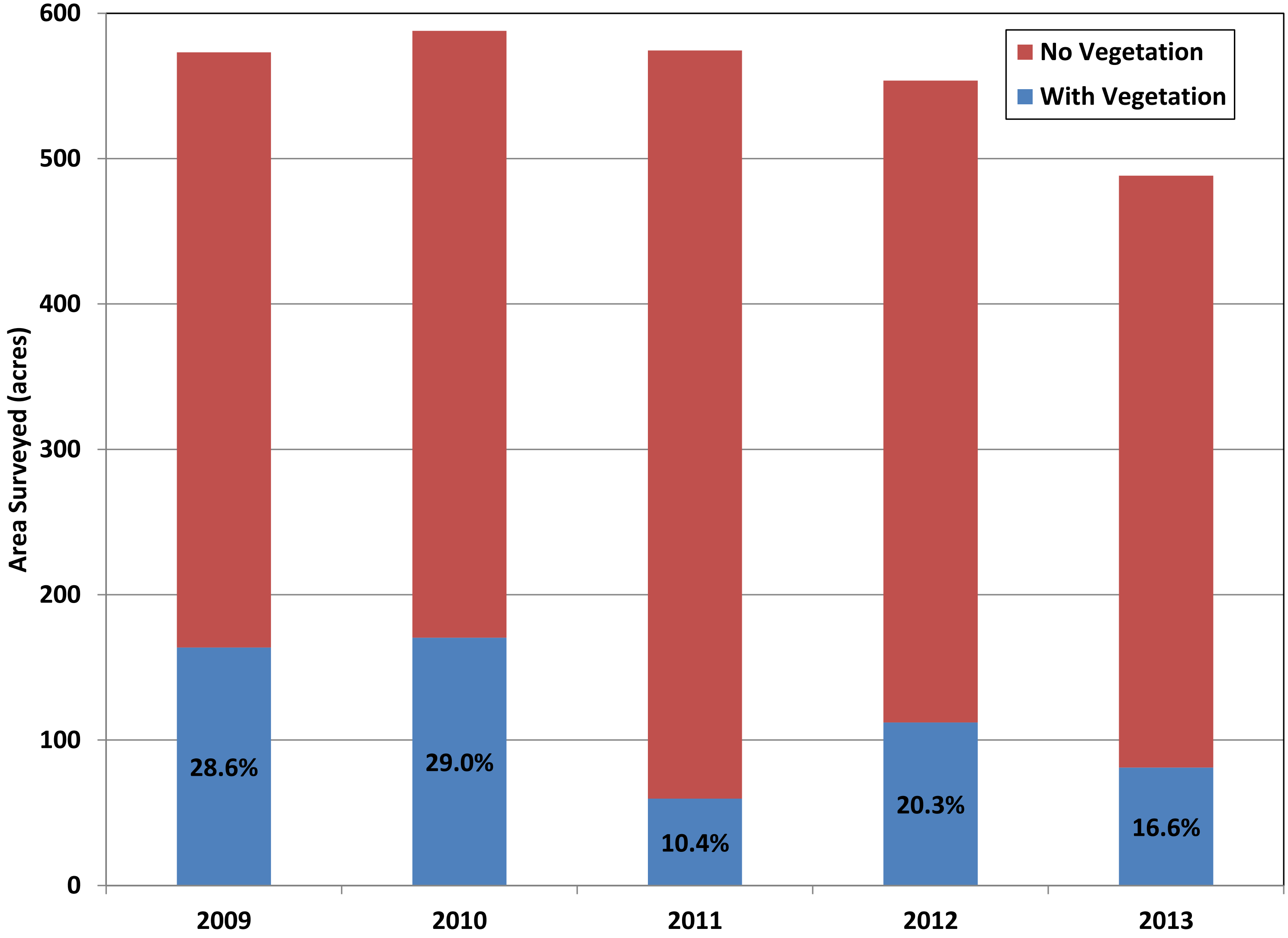


Figure 3.29. Total surveyed area and area with measurable vegetation based on Daubenmire cover-class data. Percentage of total area with measurable vegetation indicated by labels inside with-vegetation bars.

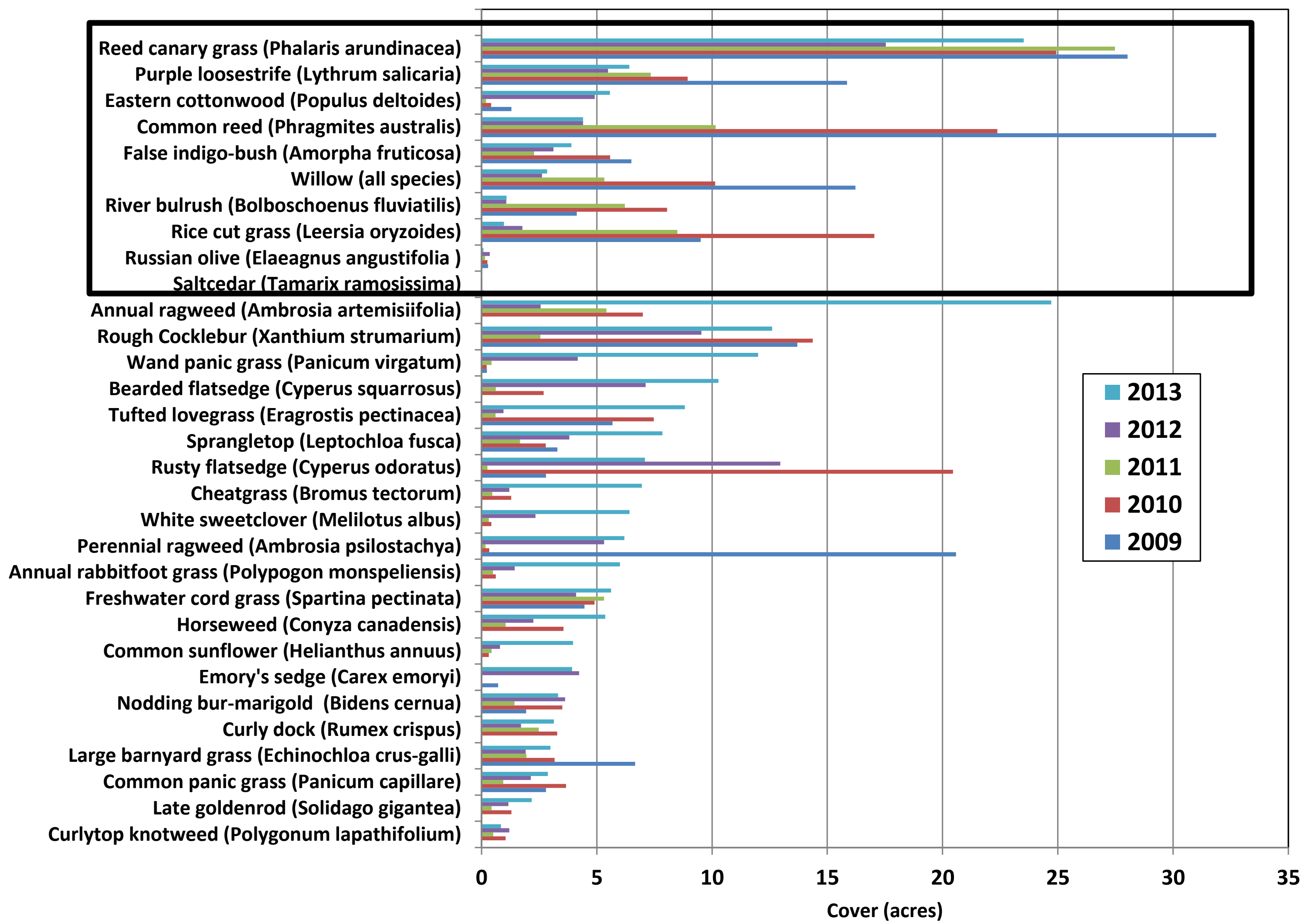


Figure 3.30. Aerial cover of the species of interest (inside black box) and other common species encountered during the 2009 through 2013 surveys. Species of interest and other common species are sorted in decreasing aerial cover from 2013 data.

Of the four species of primary interest, purple loosestrife declined from about 15.9 acres in 2009 to 8.9 acres in 2010, 7.3 acres in 2011, and 5.5 acres in 2012, and then increased back to about 6.4 acres in 2013 (**Figure 3.31**). The total cover of common reed declined from 31.9 acres in 2009 to 22.4 acres in 2010, 10.2 acres in 2011, and only about 4.4 acres in 2012 and 2013. Eastern cottonwood was present in very small quantities in the first three years (1.3 acres in 2009, 0.4 acres in 2010 and 0.2 acres in 2011), but increased to about 4.9 acres in 2012 and 5.6 acres in 2013. The aerial cover of willow declined through the period from about 16.2 acres in 2009 to 10.1 acres in 2010, 5.3 acres in 2011, and 2.6 areas in 2012, and then increased back to about 2.9 acres in 2013.

As with the percent cover, the spatial patterns of aerial cover of the four species of primary interest are very similar to the frequency of occurrence (**Figures 3.32 through 3.34**). Based on the 2013 data, most of the purple loosestrife in is located in Reaches 7, 8, and 9 at the downstream end of the overall study reach; common reed is more or less evenly distributed through the study reach, with the largest aerial cover occurring in the downstream Reach 9; eastern cottonwood is also distributed throughout the study reach with the greatest aerial cover occurring in Reaches 7, 3, 1, and 9 (in order of decreasing cover); willow is also distributed throughout the study reach with the greatest cover occurring in Reaches 3 and 7.

During 2011, the survey area was inundated with a long-duration, high-flow flow event, which likely reduced vegetation cover and increased the extent of bare ground (Figure 3.27). In 2012, the vegetated area doubled, suggesting the newly established bare ground was available for plant establishment during the relatively low spring and summer flows, and these areas quickly became colonized. In this regard, the frequency of occurrence of both eastern cottonwood and willow increased much more significantly in 2012 and 2013 than the amount of cover, suggesting that new stands of young plants were established following the high-flow years in 2010 and 2011.

3.4.6 Mean Elevation by Species (DAP 5.4.6)

The mean elevation of each of the species of interest and other commonly occurring species was evaluated by averaging the elevations of all quadrats that contained the species. Interpretation of this metric is challenging because the raw elevations are controlled by both the elevation profile of the river and the local effects of flows and other factors. In fact, the differences in elevation among the APs is generally greater than the elevation range within the individual APs. As a result, the average elevations are more a reflection of how each species is distributed within the overall reach than the influence of local factors such as flow, substrate, and management actions. The data generally indicate that Russian olive tends to grow at the highest elevation, although this species was only encountered in Reaches 3, 5 and 7, and in relatively low quantities in those reaches (**Figure 3.35**). Although salt cedar appears to be at a relatively high elevation, the data represent only one encounter; thus, this point is probably not meaningful. Other commonly occurring species in which the average elevation was high relative to the others included rice cut grass (2009 and 2010), perennial and annual ragweed (2010, 2012 and 2013) common sunflower (2010 and 2012), cheatgrass (2010 and 2013), and tufted lovegrass (2009 and 2011).

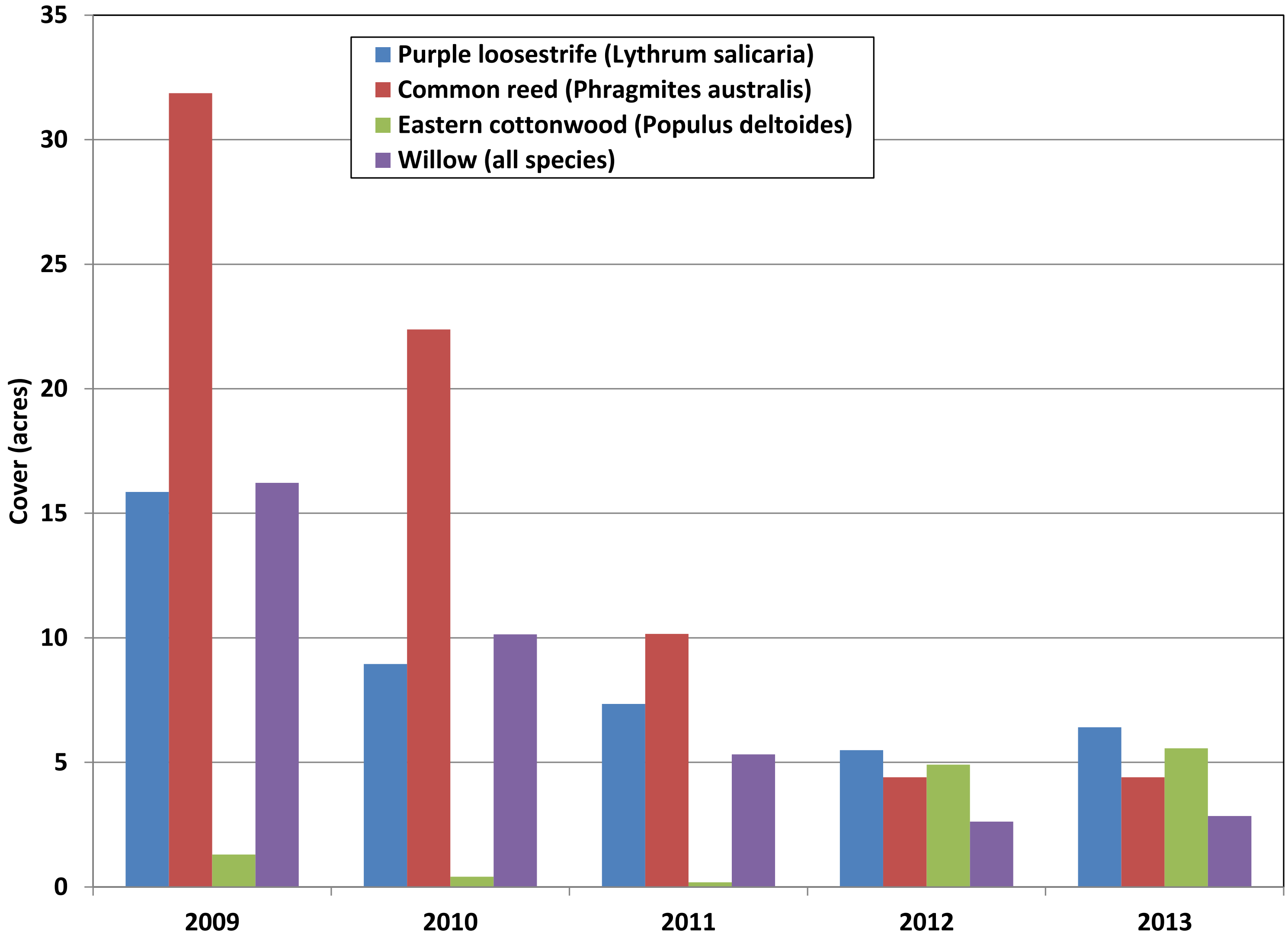


Figure 3.31. Aerial cover of the four primary species of interest Percent cover of the species of primary interest during the 2009 through 2013 surveys. (Same data as Figure 3.30.)

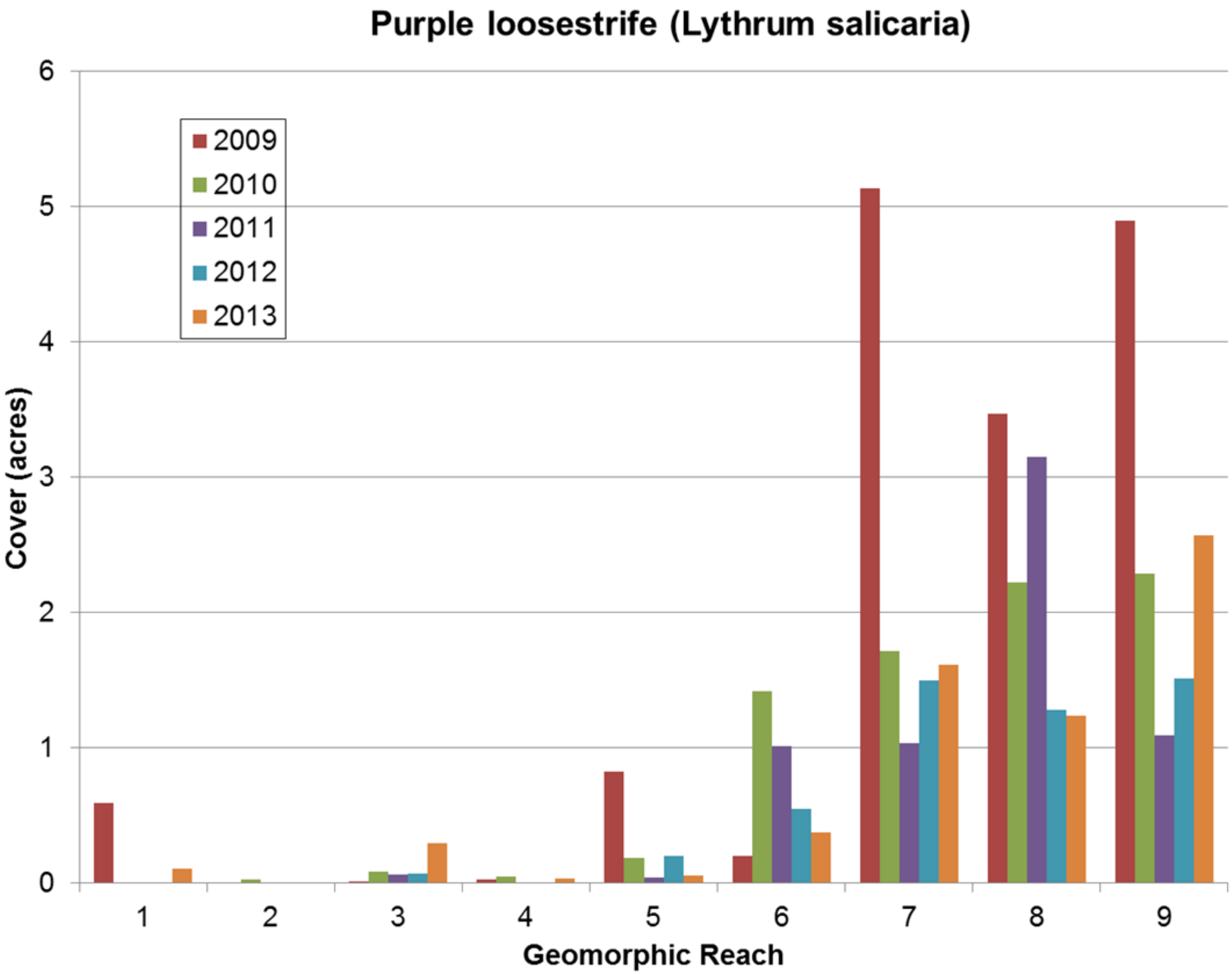


Figure 3.32. Aerial cover of purple loosestrife (*Lythrum salicaria*) by geomorphic reach and year.

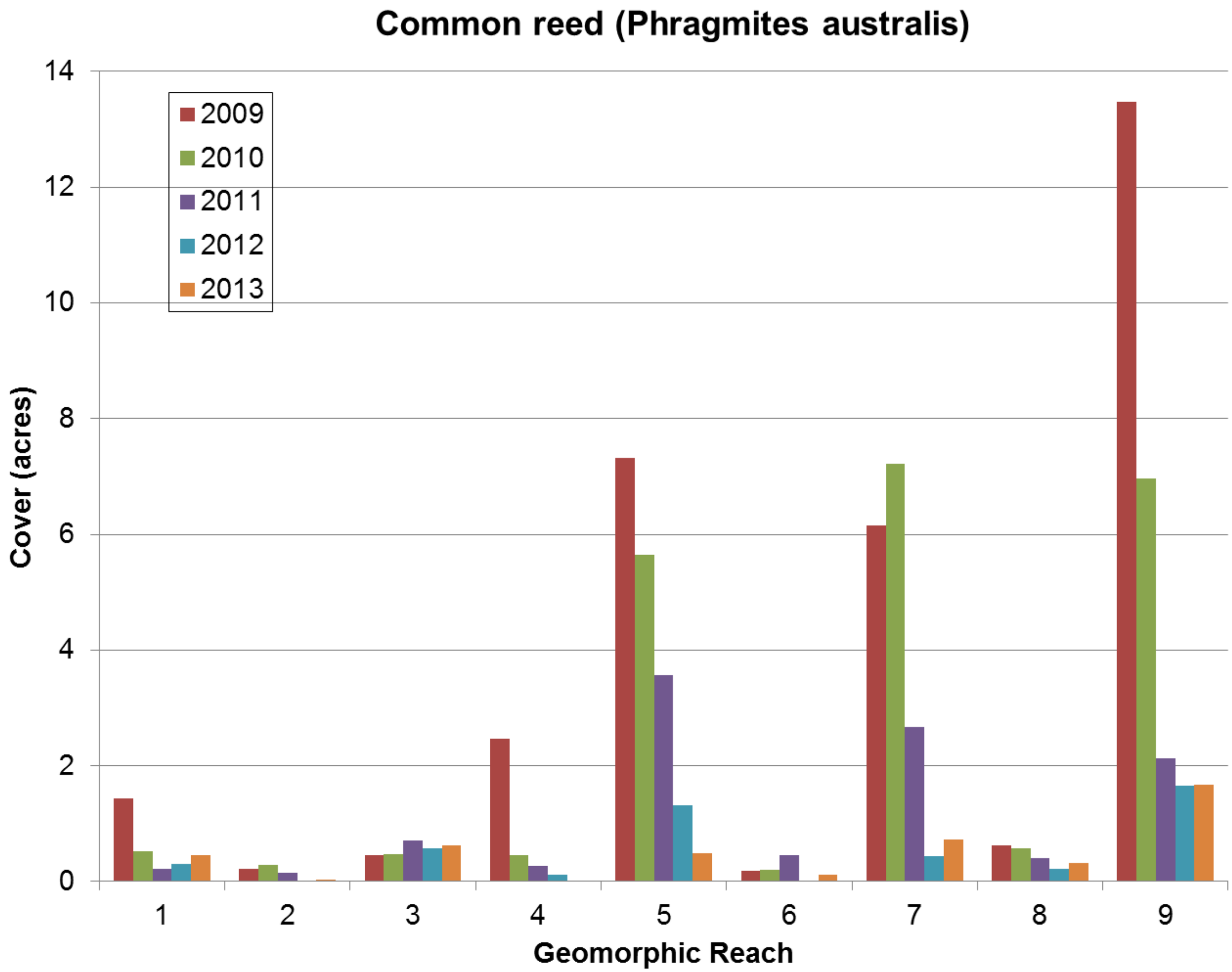


Figure 3.33. Aerial cover of common reed (*Phragmites australis*) by geomorphic reach and year.

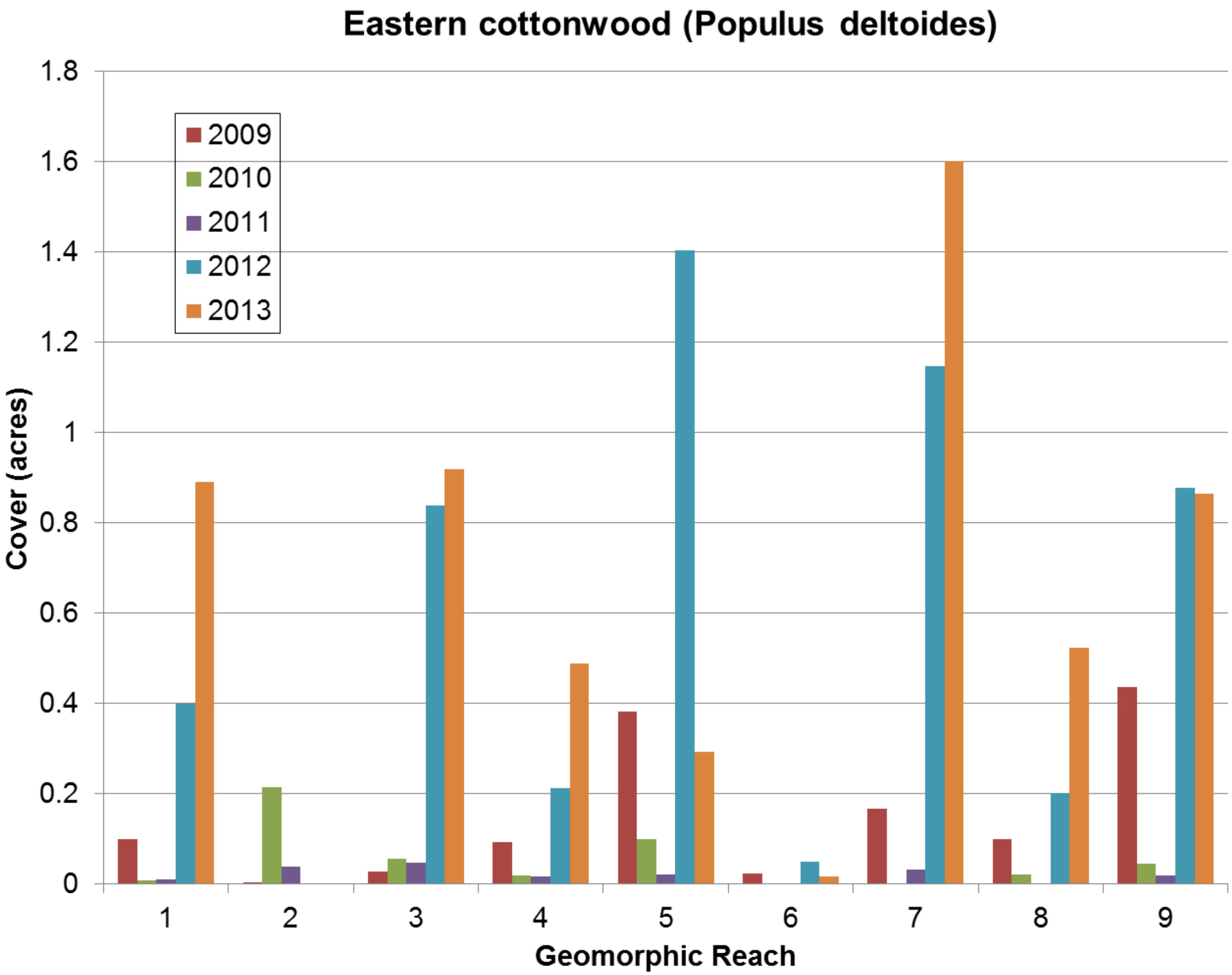


Figure 3.34. Aerial cover of eastern cottonwood (*Populus deltoids*) by geomorphic reach and year.

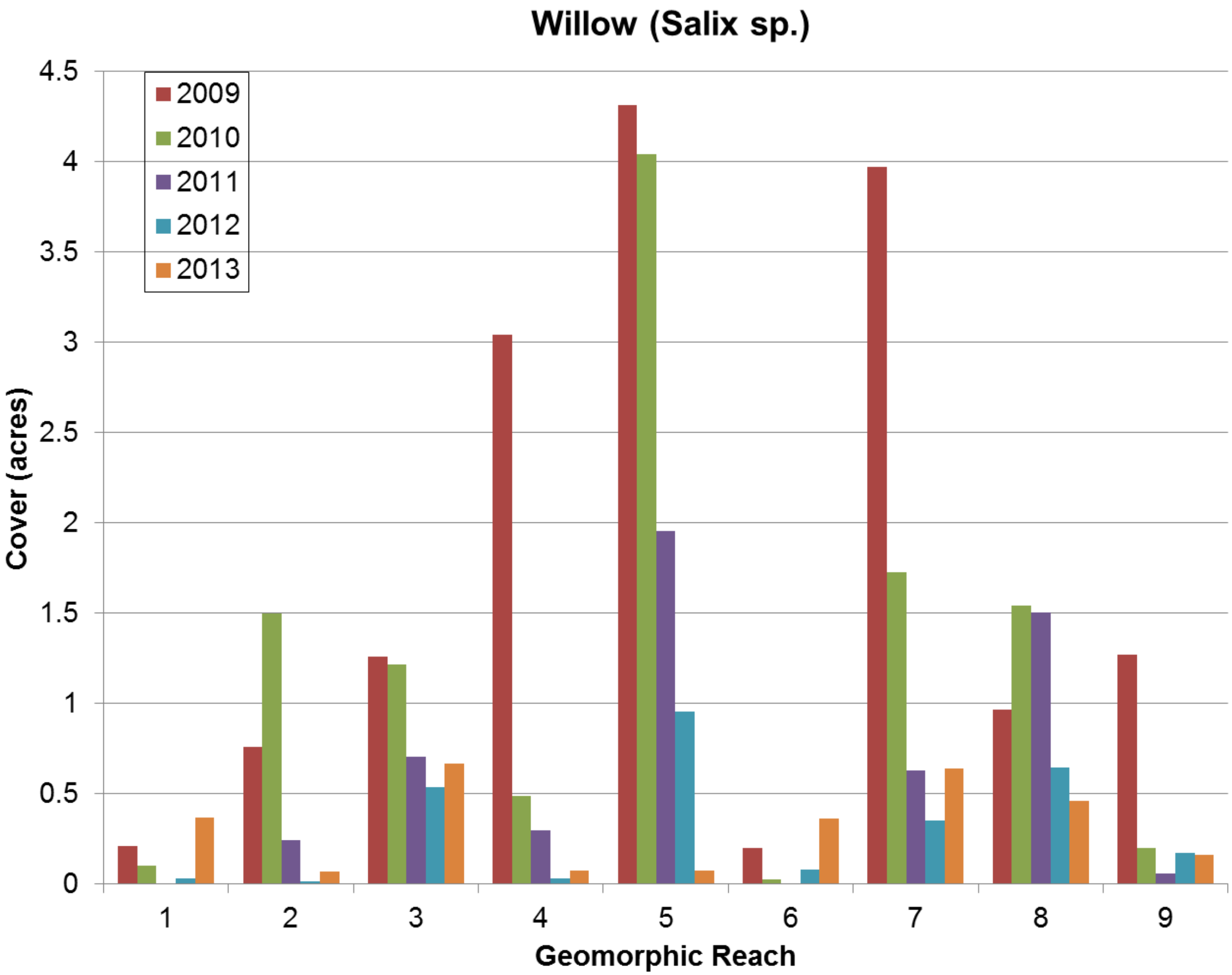


Figure 3.35. Aerial cover of willow (all species) by geomorphic reach and year.

The influence of the river profile on the elevations was eliminated from the analysis by averaging the differences between the elevation of each sample point and the local 1,200-cfs water-surface elevation.

None of the species of interest were in the top five highest elevation zones relative to the local 1,200-cfs water surface. The species that grew at the lowest relative elevation were annual rabbitfoot grass and bearded flatsedge (**Figure 3.36**). The four species of primary interest tended to grow at among the lowest elevations of the sampled species, and thus, likely have more influence on the green line elevation and sandbar habitats. The average relative elevation of all four of these species increased from 2009 through the high-flow year in 2011, and then declined substantially in the dry years of 2012 and 2013 (**Figure 3.37**).

3.4.7 Mean Vegetation Height (DAP 5.4.7)

Mean vegetation height was included among the metrics to facilitate estimates of the unobstructed sight distance. Methods for sampling vegetation height varied across years In 2009, 2010 and 2012, the data were collected categorically as a mean value, whereas 2011 data were collected as a combination of actual mean heights and categorical mean heights. In 2013, the method was modified to document actual maximum heights. As noted elsewhere in this report, unobstructed sight distances were measured directly in the field using a laser rangefinder; thus, the vegetation height data are not necessary for any of the metrics that are being reported at this time. The data are, however, being provided with this report to allow future analysis, if such analysis becomes necessary.

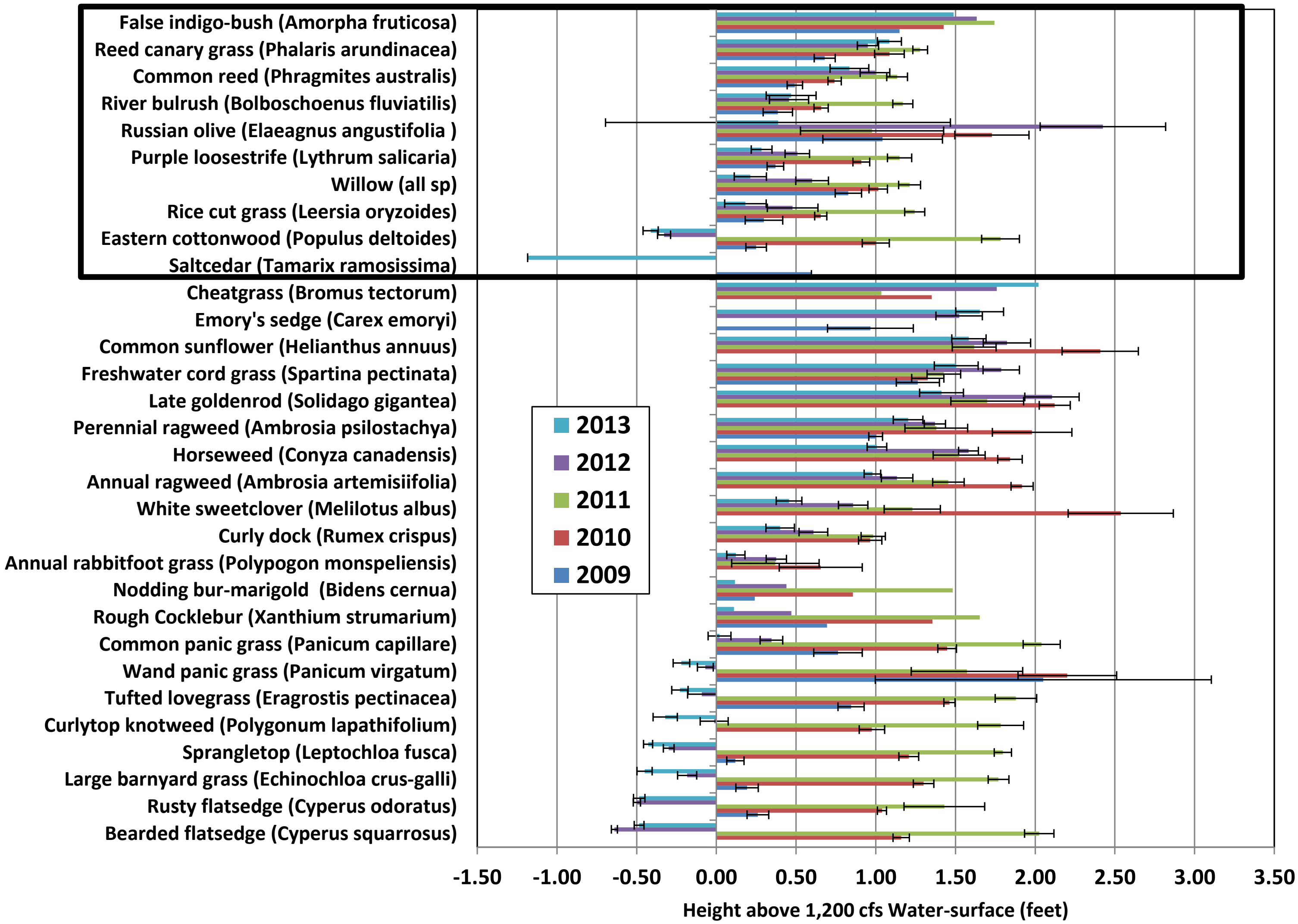


Figure 3.36. Mean height above the 1,200-cfs water surface of the species of interest (inside black box) and other common species encountered during the 2009 through 2013 surveys. Species of interest and other common species are sorted in order of decreasing elevation from 2013 data. Whiskers represent ±1 standard error.

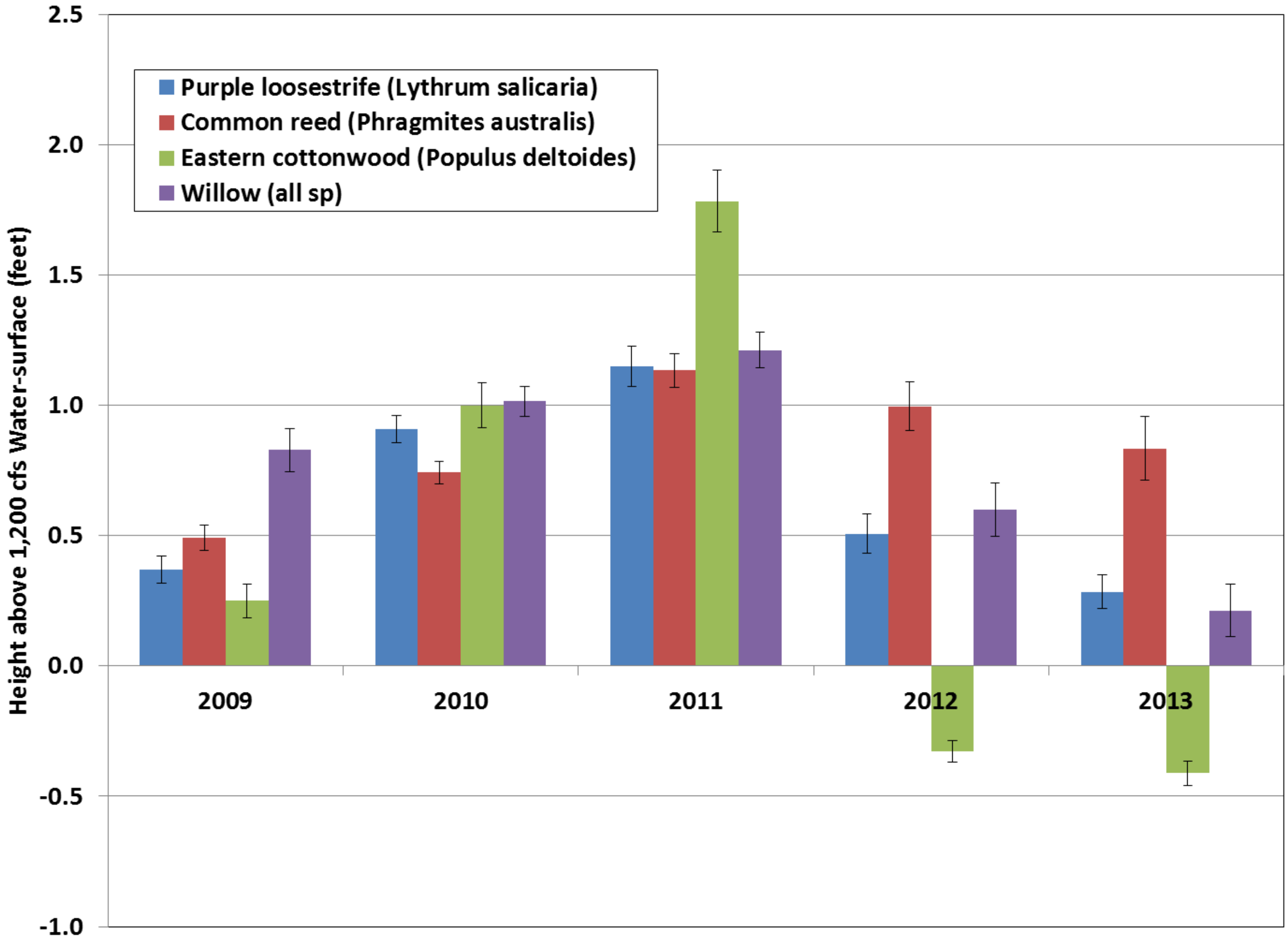


Figure 3.37. Mean height of the four species of primary interest above the 1,200-cfs water surface from the 2009 through 2013 survey data. Error bars represent ±1 standard error.

3.5 Sediment

3.5.1 Bed-load versus Discharge Rating Curves (DAP 5.5.1)

To-date, a total of 51 bed-load sediment samples have been collected for this monitoring program at the five designated bridge sites at flows ranging up to nearly 12,000 cfs that occurred during the September 2013 flood (**Table 3.3**) (An additional sample was collected at the Elm Creek Bridge during the September 2013 flood). The number of samples at each of the primary measuring sites ranges from 8 (Darr) to 11 (Overton, Kearney, and Shelton). While the data from these samples has relatively high variability that is typical of bed-load samples, they show sufficiently strong trends to allow development of reasonable bed-load transport rating curves (**Figures 3.38 through 3.42**). The best-fit, power-function curves were developed using least-squares, linear regression on the logarithms of the measured bed loads and corresponding discharges, a well-accepted procedure in sediment transport analysis (Runkel, et al, 2004; Shen and Julien, 1993). Correlation coefficients (R^2) for the best-fit relationships range from 0.49 (Overton) to 0.80 (Darr). The curves indicate that the bed-load transport rates are relatively consistent through the reach, with Overton generally having the lowest rates, and Darr having the highest rates at discharges exceeding about 1,000 cfs (**Figure 3.43**). The samples contained 70- to 84-percent sand and 16- to 30-percent gravel, on average, with the Grand Island samples having the least gravel (16 percent) and the Overton samples having the least sand (~70 percent) (**Figure 3.44**). In general, the percentage of sand in the samples tends to increase in the downstream direction. Most of the coarser fraction of the samples was in the very fine to fine gravel size range (i.e., 2 to 8 mm), with a few of the samples containing small amounts of medium gravel (8 to 16 mm). The median (D_{50}) size of the samples at Darr, Overton and Shelton tended to increase with increasing discharge, while the Kearney and Grand Island samples showed no significant size trend with discharge, while the D_{84} size tended to increase with discharge at all of the measurement sites (**Figure 3.45a and b**).

As will be discussed in a later section of this report, the rating curves were developed to provide a means of estimating the quantity of sediment carried past each of the measurement locations over specific periods of time. Because the regressions are performed in logarithmic space, simply transforming the results back to linear space provide an unbiased estimate of the median value of the loads, but not the mean value that is most important to the analysis (Hirsch et al., 1993; Ferguson 1986; Thomas 1985; Walling 1977). Several methods for correcting for this bias have been proposed in the literature, including the *smearing estimate* (Duan, 1983) and the Maintenance of Variance Unbiased Estimator (*MVUE*) method (Cohn and Gilroy, 1991). The *smearing* estimate results in a constant percentage adjustment to all of the estimated loads, regardless of the distribution of the underlying data, while the *MVUE* method provides an adjustment for each load based on the statistical distribution of the data. USGS (1992) recommends the MVUE method, and this method was, therefore, selected for use in this study. The rating curves that reflect the MVUE adjustments are shown by the blue lines in Figures 3.38 through 3.42.

Table 3.3. Summary of bed-load sediment discharge measurements taken since the start of the monitoring program in 2009. Also shown are the correlation coefficients (R^2) for best-fit, power-function regression lines through each of the data sets.

Sample Location	Discharge Range (cfs)			Total Samples	R^2
	1,000-3,000	3,000-5,000	>5,0000		
Darr	5	1	2	8	0.80
Overton	3	6	2	11	0.49
Elm Creek	0	0	1	1	N/A
Kearney	3	5	3	11	0.53
Shelton	3	6	2	11	0.56
Grand Island	3	4	3	10	0.64
Total Samples	17	22	13	52	

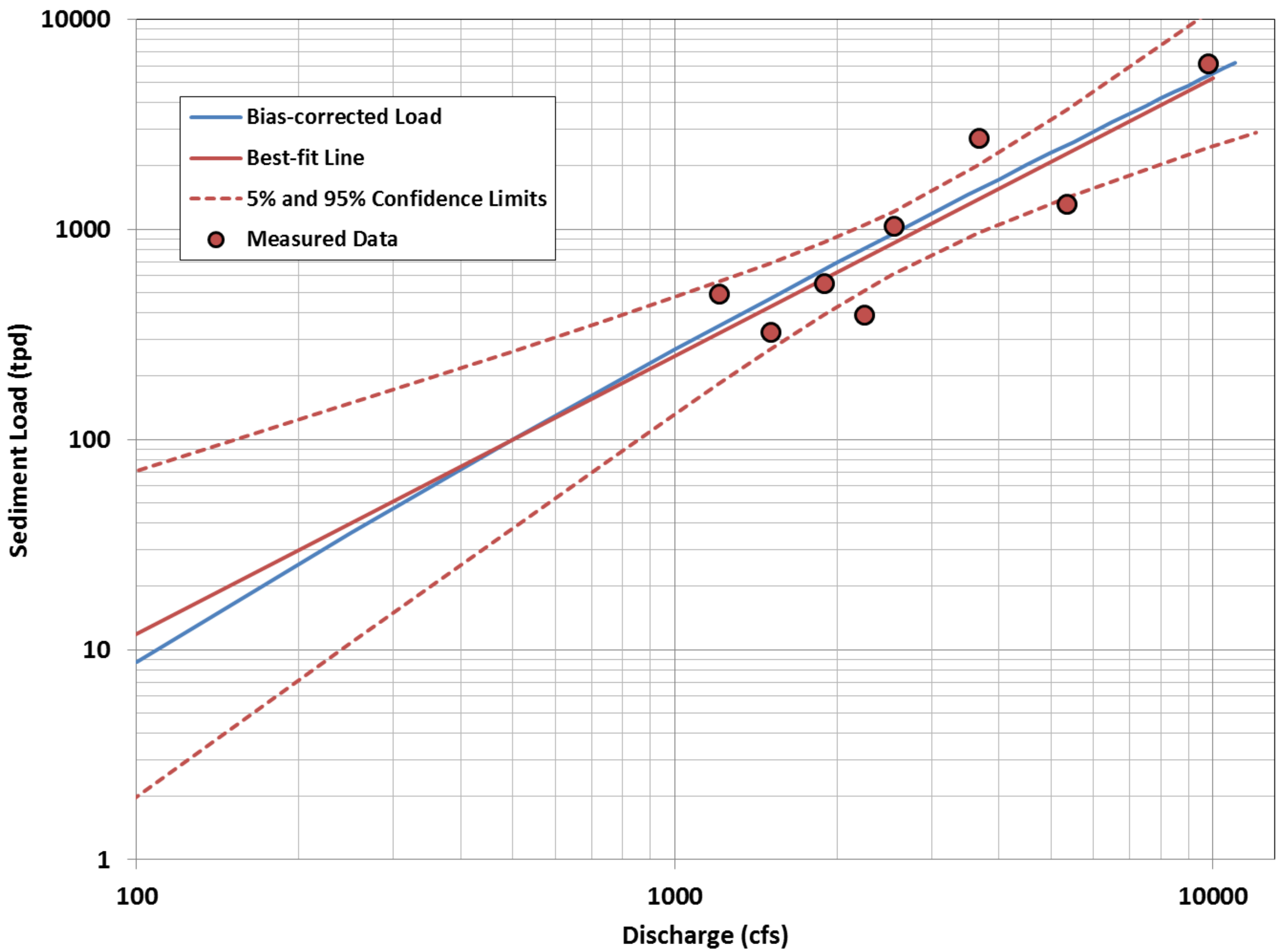


Figure 3.38. Bed-load transport rates measured at the Darr Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

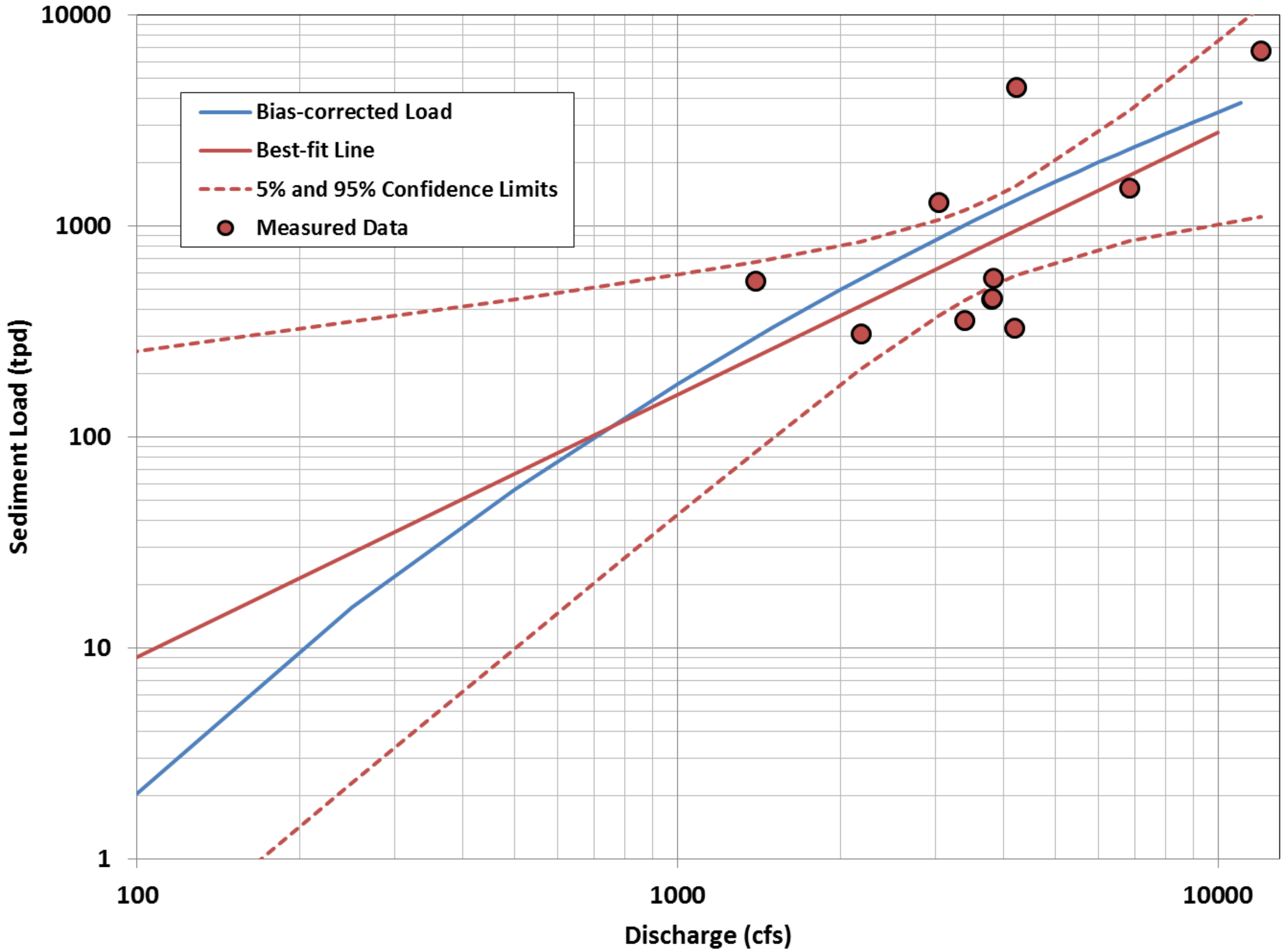


Figure 3.39. Bed-load transport rates measured at the Overton Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

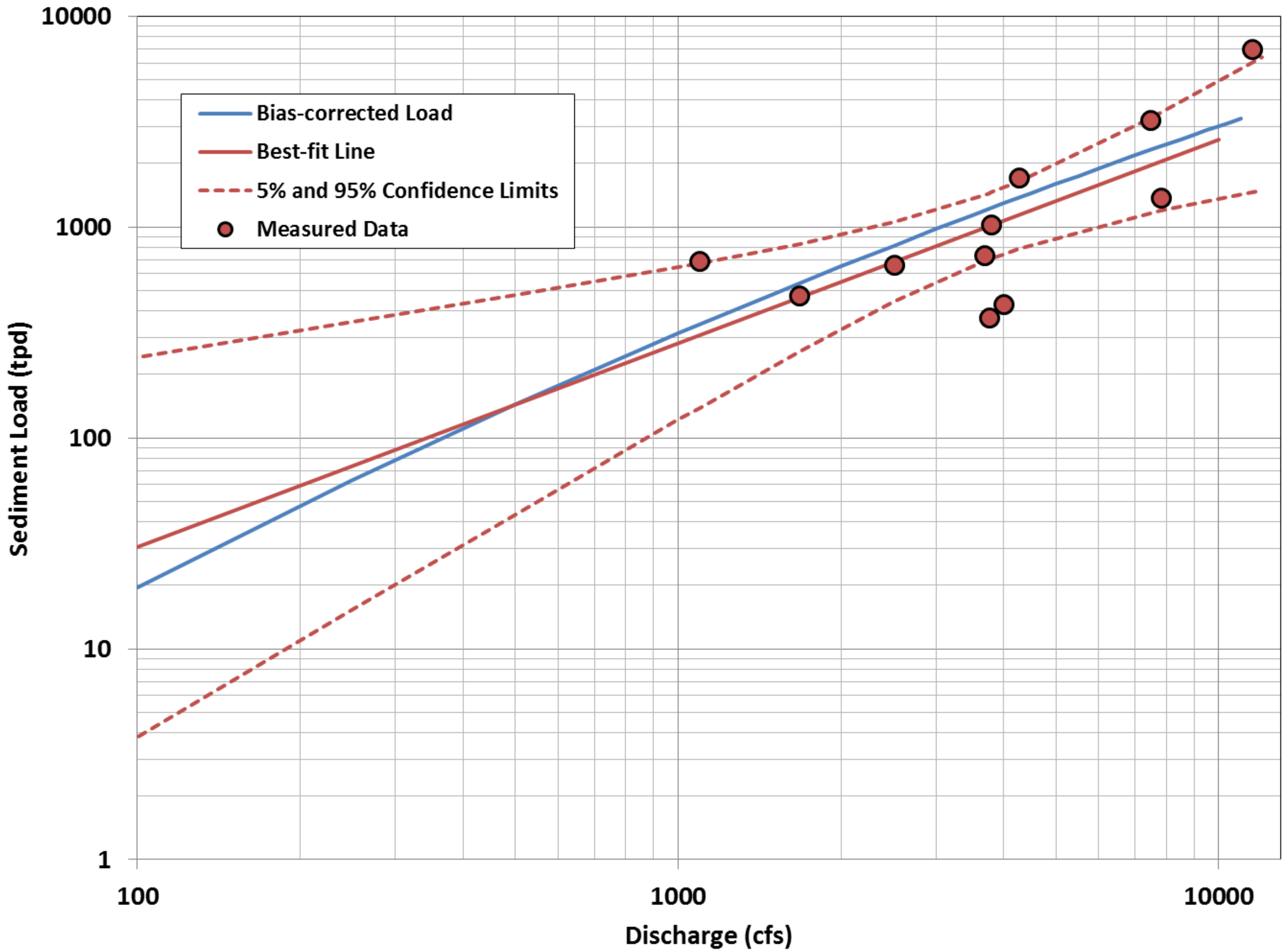


Figure 3.40. Bed-load transport rates measured at the Kearney Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

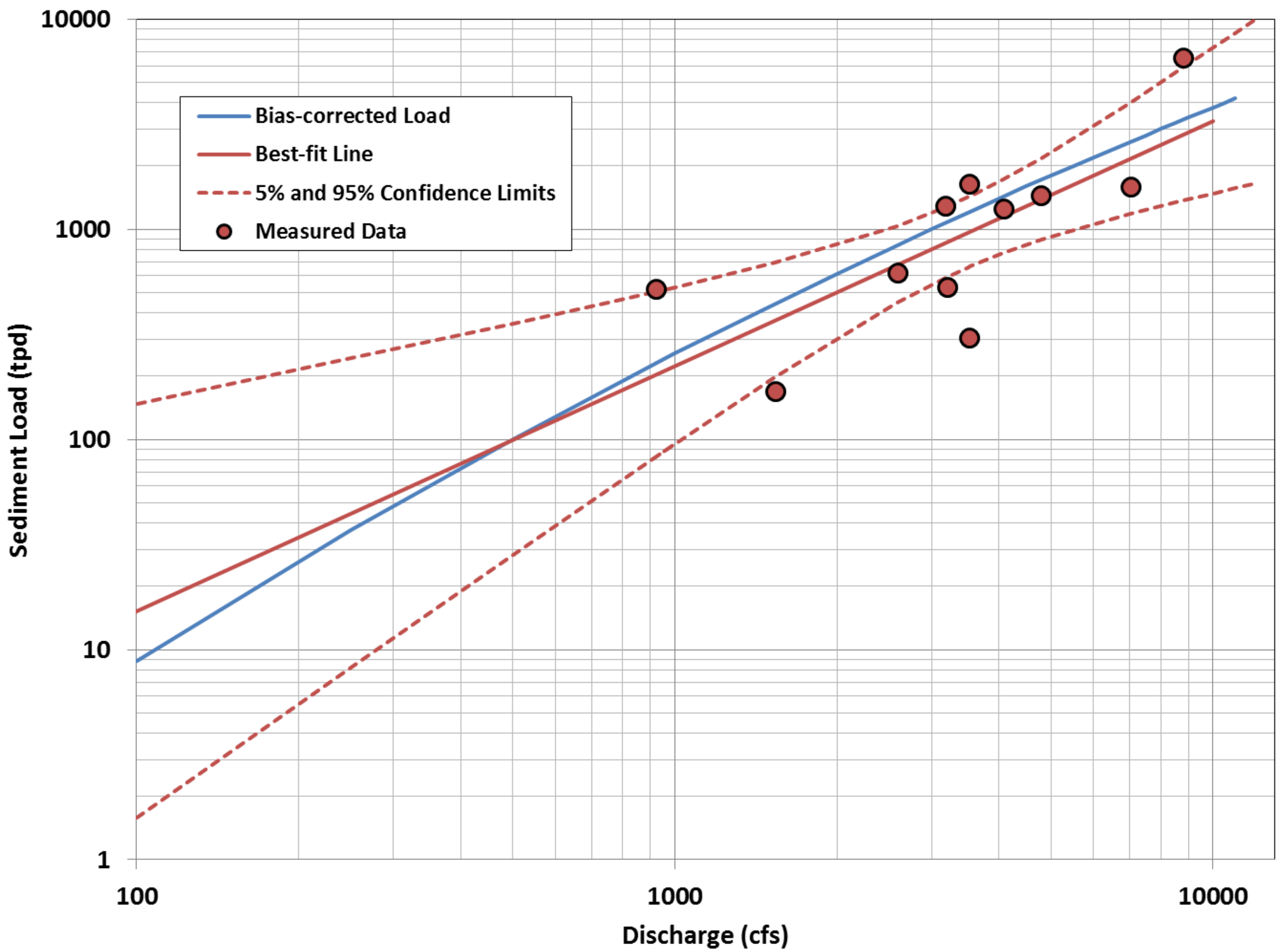


Figure 3.41. Bed-load transport rates measured at the Shelton Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

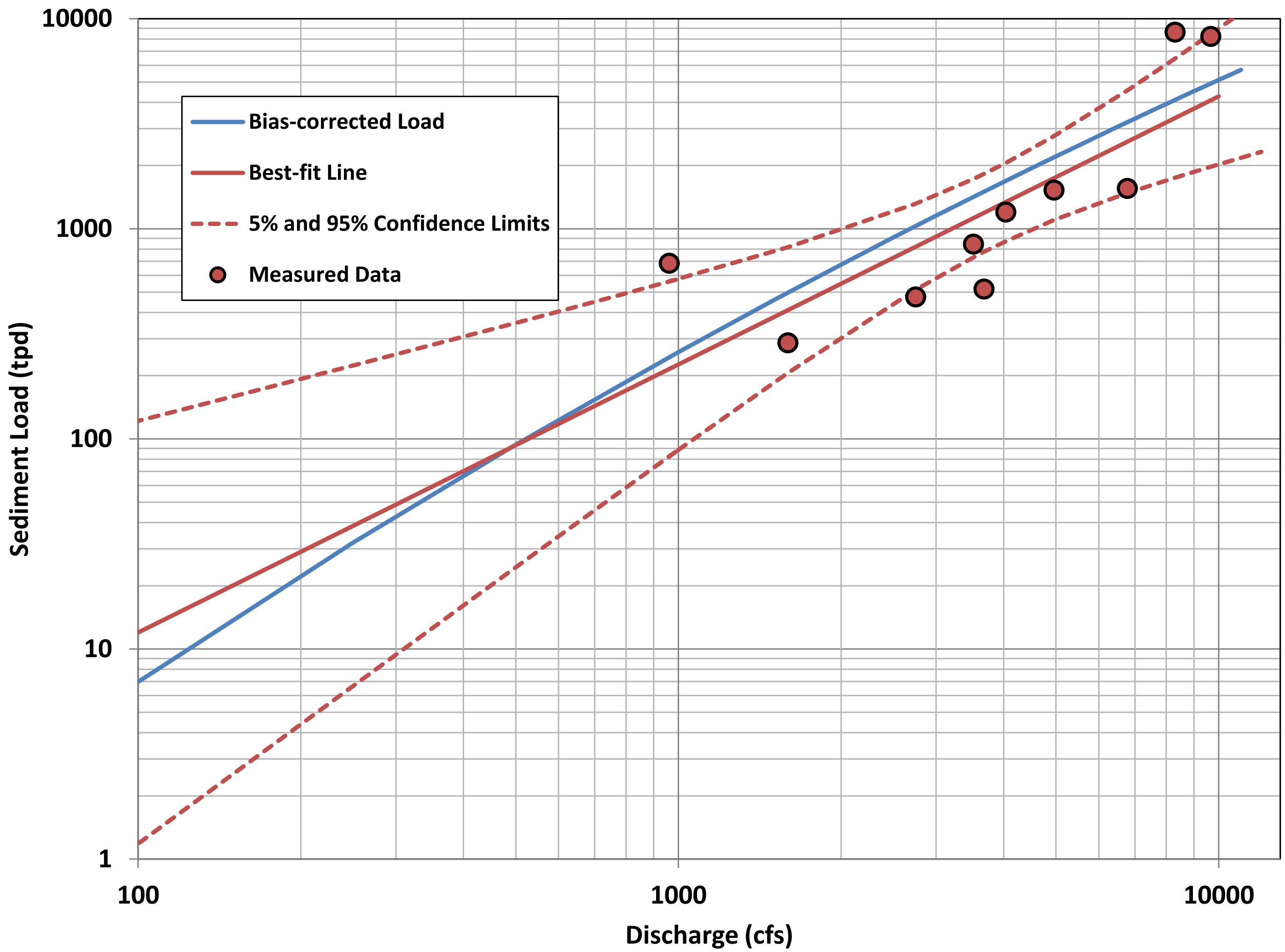


Figure 3.42. Bed-load transport rates measured at the Grand Island (Highway 34/Highway2) Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

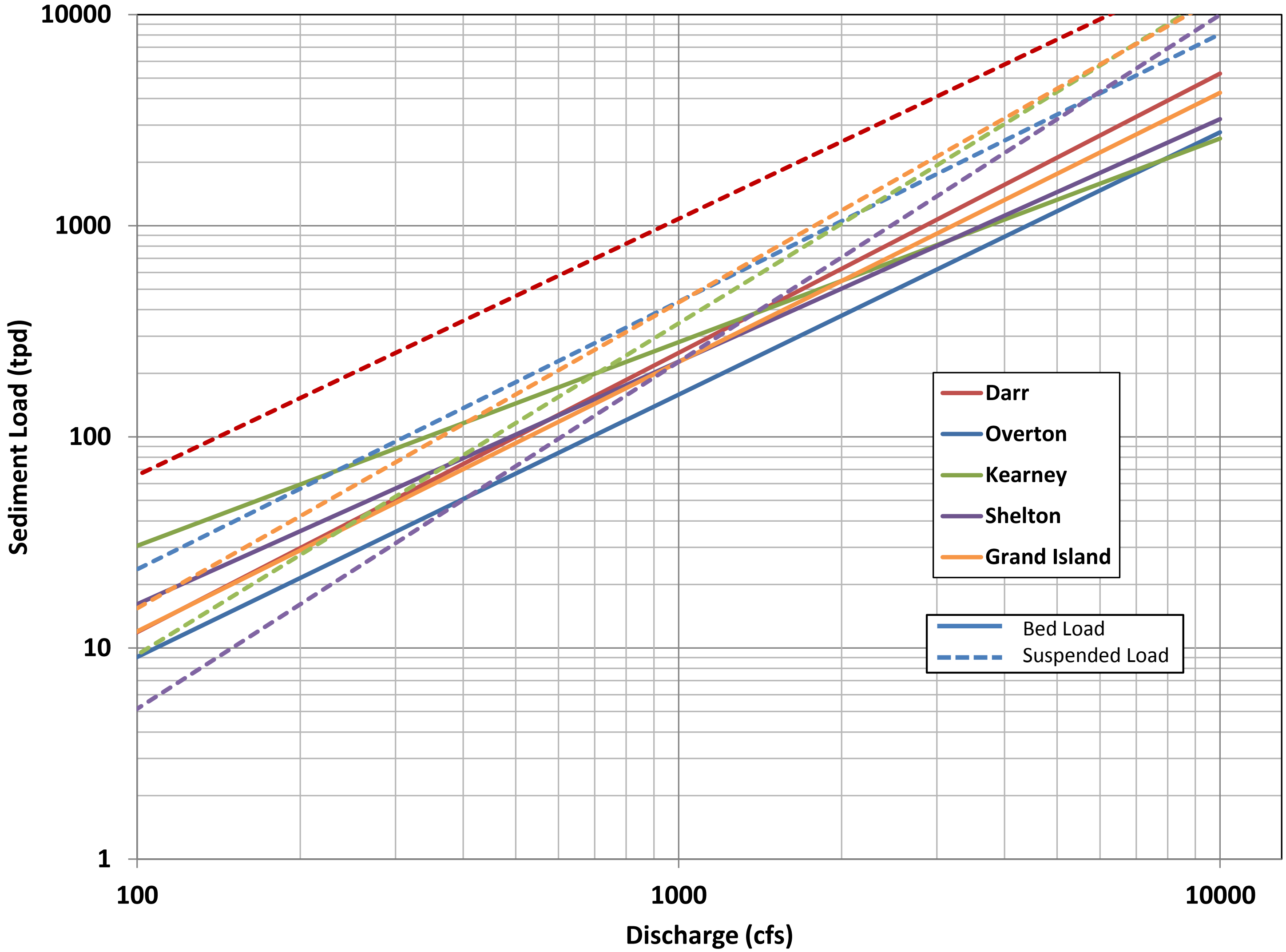


Figure 3.43. Power-function, best-fit lines for the measured bed- and suspended-sediment transport rates at the five measurement sites.

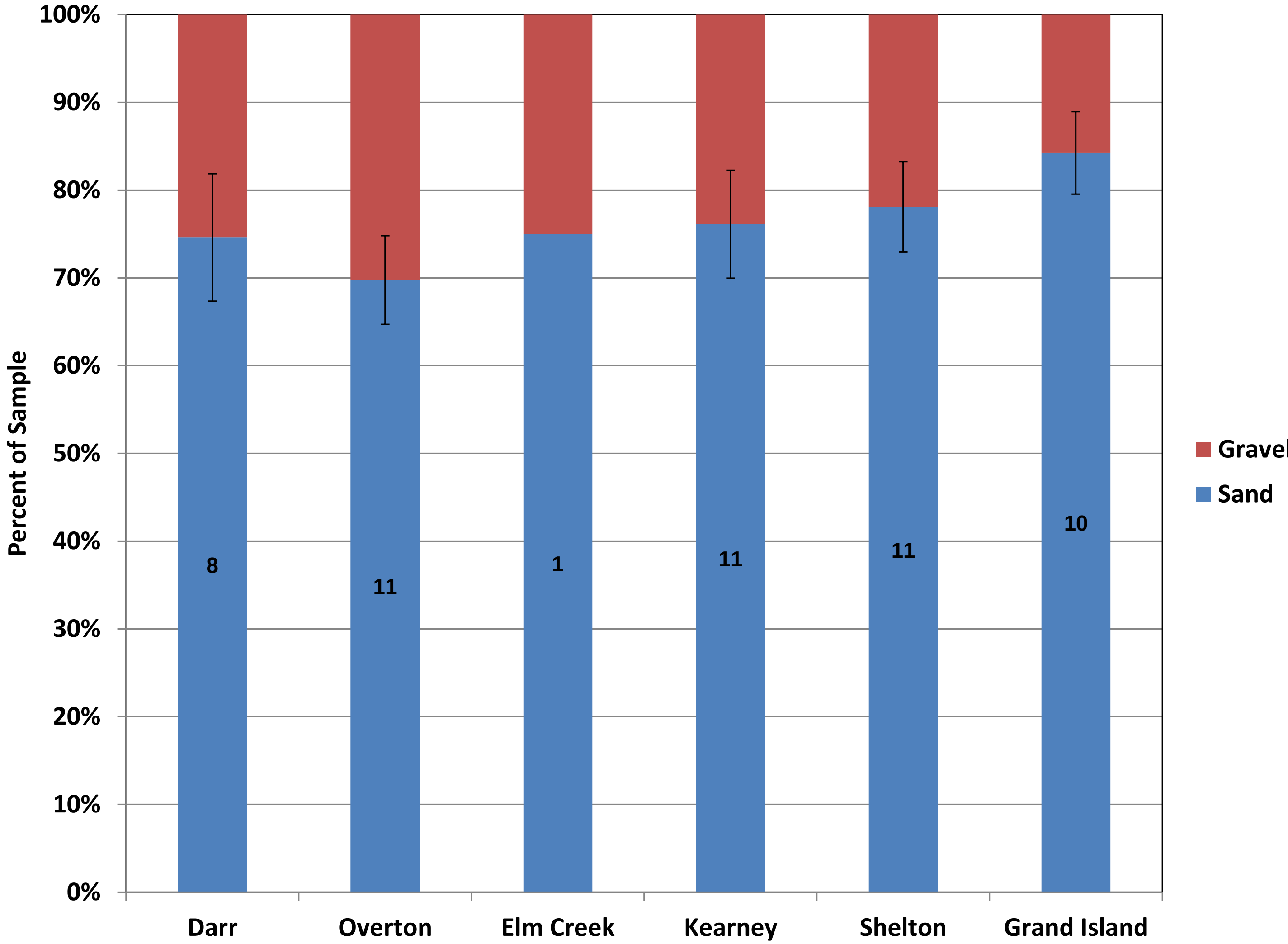


Figure 3.44. Average percentage of sand and gravel in the bed-load samples from the five primary measurement sites and the single sample collected at the Elm Creek Bridge. Embedded values represent number of samples at each site; whiskers represent ±1 standard deviation about the mean.

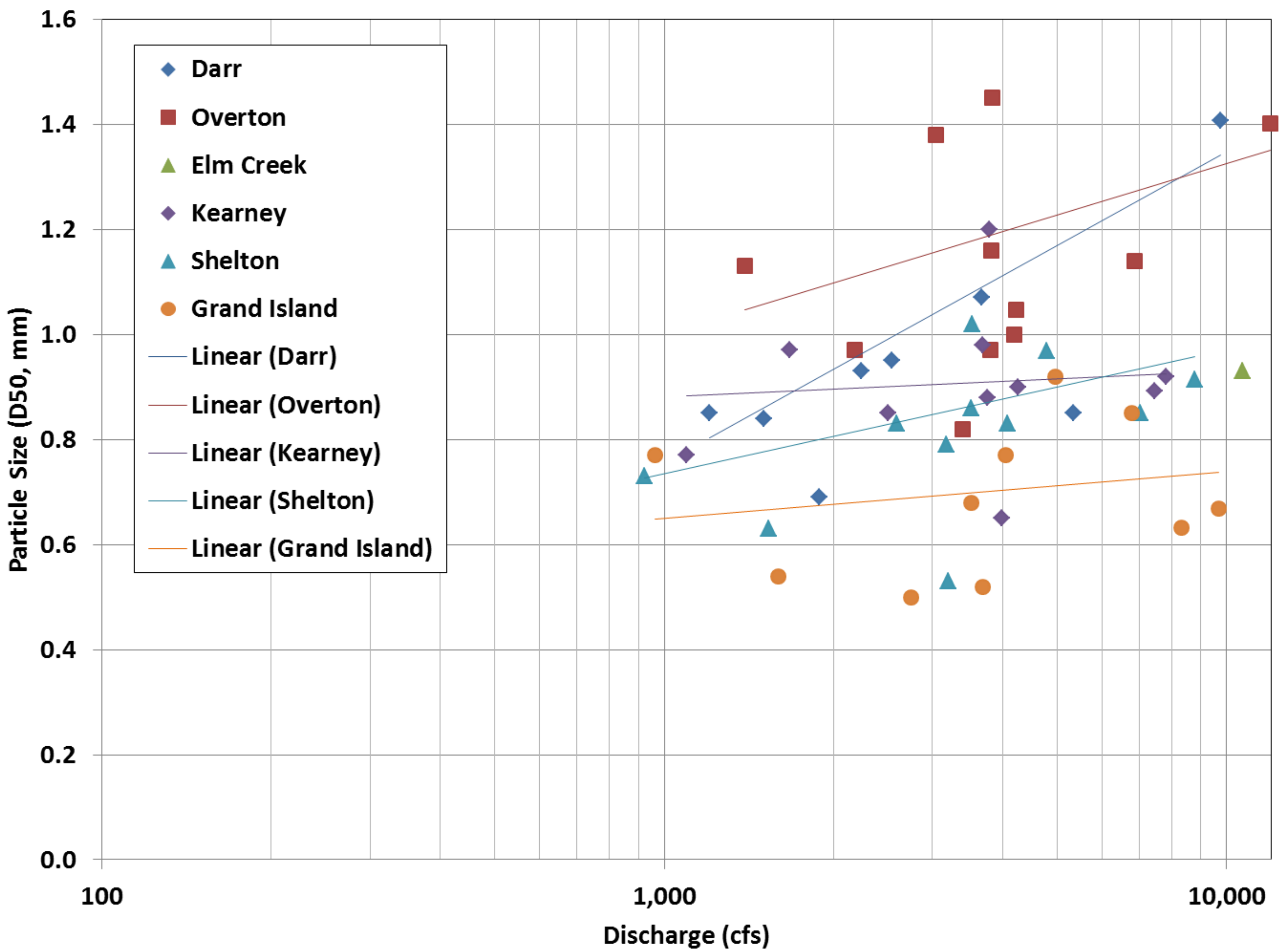


Figure 3.45a. Particle size of bed-load samples from the five measurement sites: Median (D_{50}).

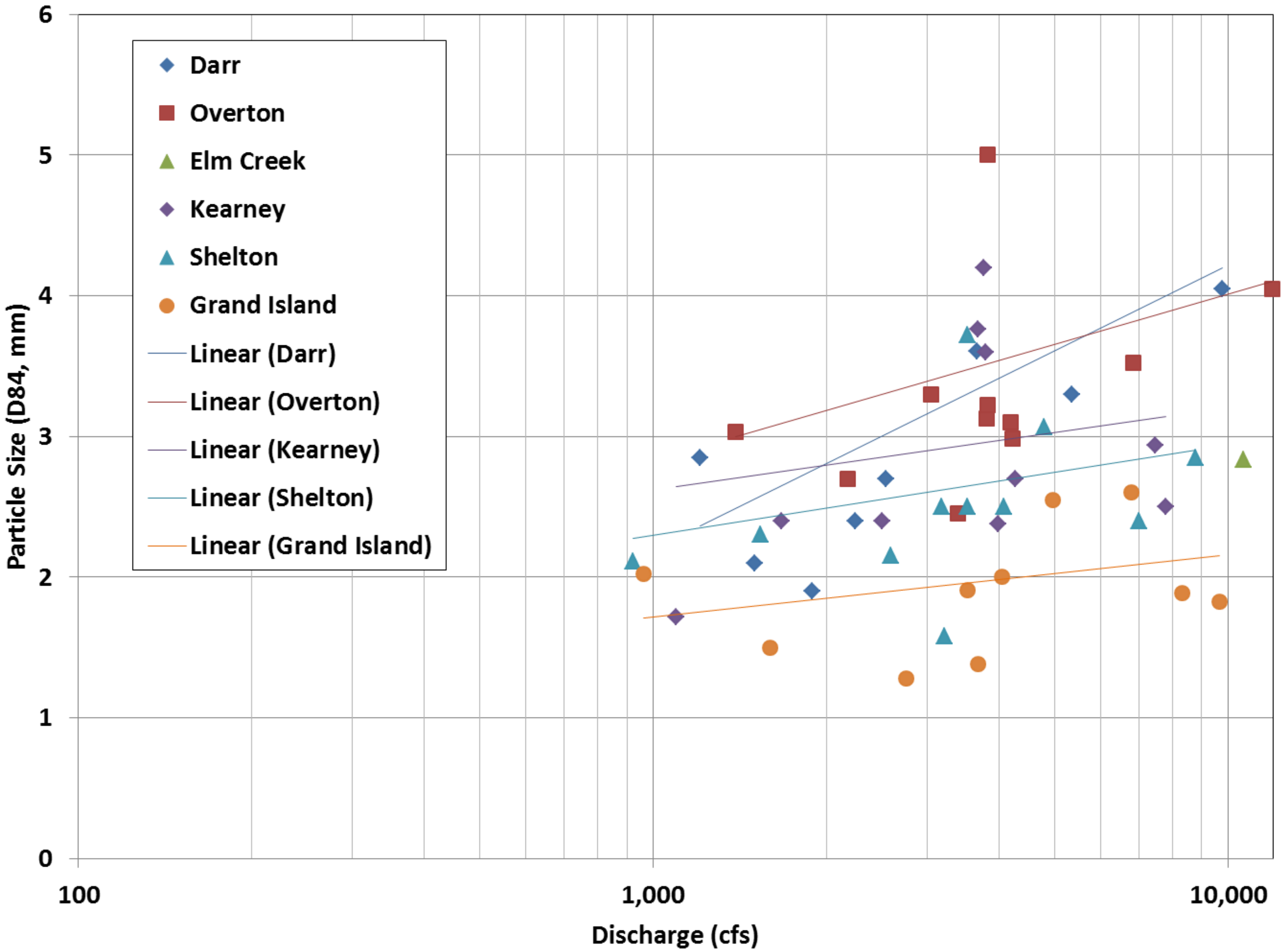


Figure 3.45b. Particle size of bed-load samples from the five measurement sites: D_{84}.

3.5.2 Suspended Sediment Load versus Discharge Rating Curves (DAP 5.5.2)

A total of 48 suspended sediment samples have been collected at the five designated bridge sites at flows ranging up to nearly 12,000 cfs that occurred during the September 2013 flood (**Table 3.4**) (An additional sample was collected at the Elm Creek Bridge during the September 2013 flood, and single samples were collected at Lexington in 2009 and at Gibbon in 2011. For purposes of the analysis, the Lexington sample was included in the Darr data set). The number of samples at each of the primary measuring sites ranges from 7 (Darr/Lexington) to 12 (Overton). The total suspended sediment concentrations (i.e., silt/clay and sand) ranged from about 125 to 1,700 ppm (**Figure 3.46**). Due to the significant scatter in the data, the correlation with discharge is not statistically significant at any of the sites.

The samples contained 55- to 80-percent sand and 20- to 45-percent silt and clay, on average, with the Shelton samples having the least amount of sand (55 percent) and the Darr and Overton samples having the most sand (~22 percent) (**Figure 3.47**). There is essentially no correlation between the median size of material in these samples and discharge. In general, the percentage of silt and clay in the samples tended to increase in the downstream direction, although the Grand Island samples contained amounts of sand similar to Kearney.

To facilitate analysis of the sediment-transport balance that will be described in a later section of this report, the sand fraction of the samples was separated from the silt/clay fraction and suspended sand load rating curves were developed from the resulting sand-load data sets (**Figures 3.48 through 3.50**). With the exception of the Shelton site, all of the suspended sediment loads were considered in the regression analysis. At Shelton, the sand load for the sample that was collected on September 26, 2013 on the rising limb of the flood hydrograph appears to unreasonably low. The residual for this sample when it is included in the regression has a Z-score of -1.99, confirming that it is, in fact, an outlier. Review of the field notes and discussions with the field crew revealed nothing that would suggest that conditions during the sampling were different from previous sampling efforts. As will be discussed in a later section of this report, inclusion of this data point results in a rating curve that appears to predict unreasonably low total sand transport volumes at the Shelton site compared to the up- and downstream sites. As a result, the data point was not considered in the analysis.

Correlation coefficients (R^2) for the above relationships range from 0.70 (Overton) to 0.81 (Kearney), generally somewhat higher than for the bed-load rating curves. For purposes of estimating annual sediment loads, bias-correct lines were also developed using the MVUE method described in the previous section. The curves indicate that the suspended sand loads vary considerably through the reach, with Darr being 3 to 5 times higher than at the other sites at flows in the range of 500 cfs, decreasing to 2 to 3 times higher in the range of 5,000 cfs (Figure 3.43). A substantial amount of the sand in these samples is less than 1 mm (i.e., fine, medium and coarse sand), with relatively minor amounts of very coarse sand (1 – 2 mm).

Table 3.4. Summary of suspended sediment load measurements taken since the start of the monitoring program in 2009. Also shown are the correlation coefficients (R^2) for best-fit, power-function regression lines through each of the data sets.

Sample Location	Discharge Range (cfs)			Total Samples	R^2
	1,000-3,000	3,000-5,000	>5,000		
Darr/Lexington	4	0	3	7	0.71
Overton	4	5	3	12	0.70
Elm Creek	0	0	1	1	N/A
Kearney	4	2	4	10	0.81
Gibbon	0	0	1	1	N/A
Shelton	3	4	2	9	0.76
Grand Island	3	3	4	10	0.80
Total Samples	18	14	17	49	

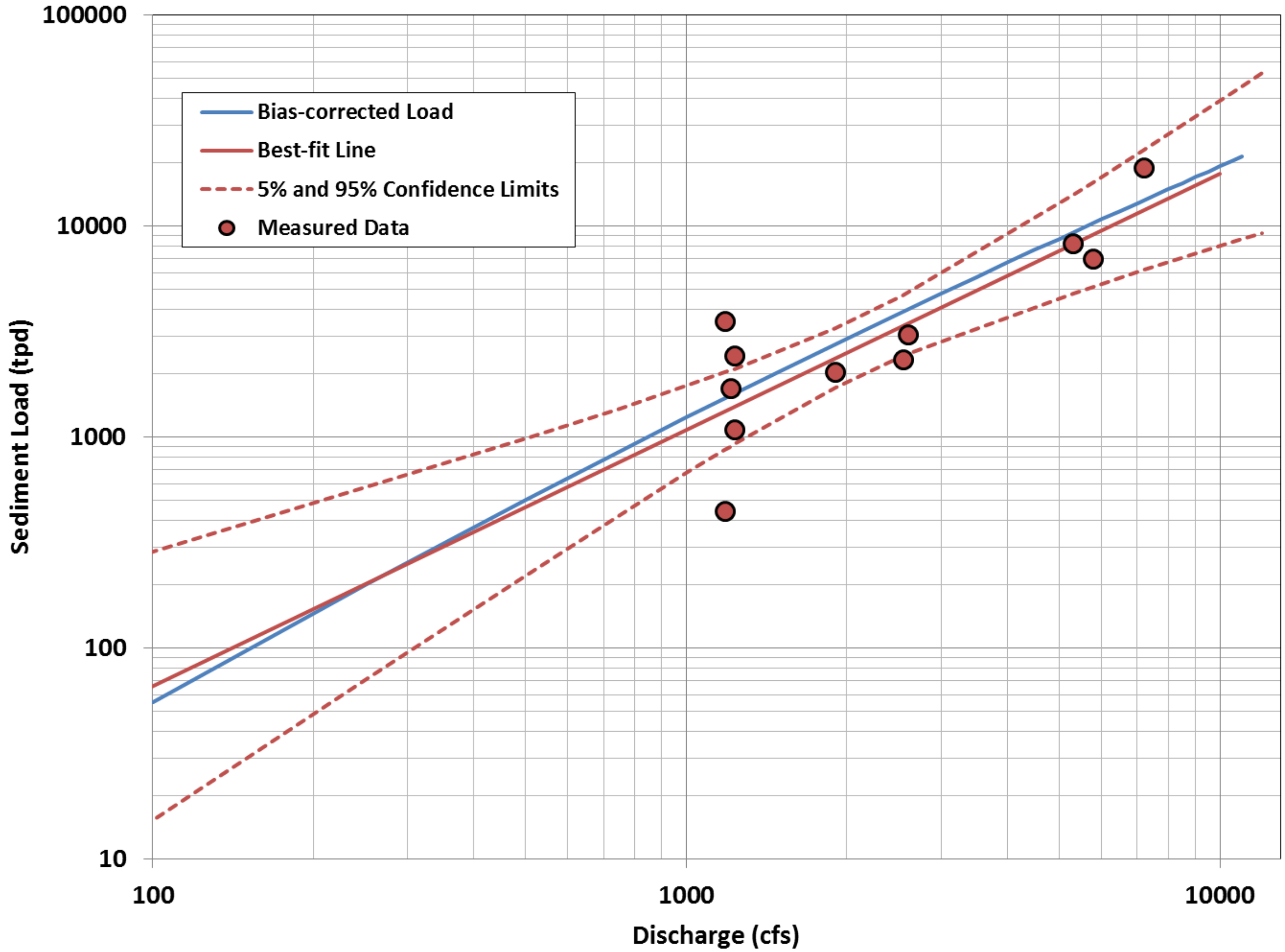


Figure 3.46. Suspended sand transport rates measured at the Darr Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

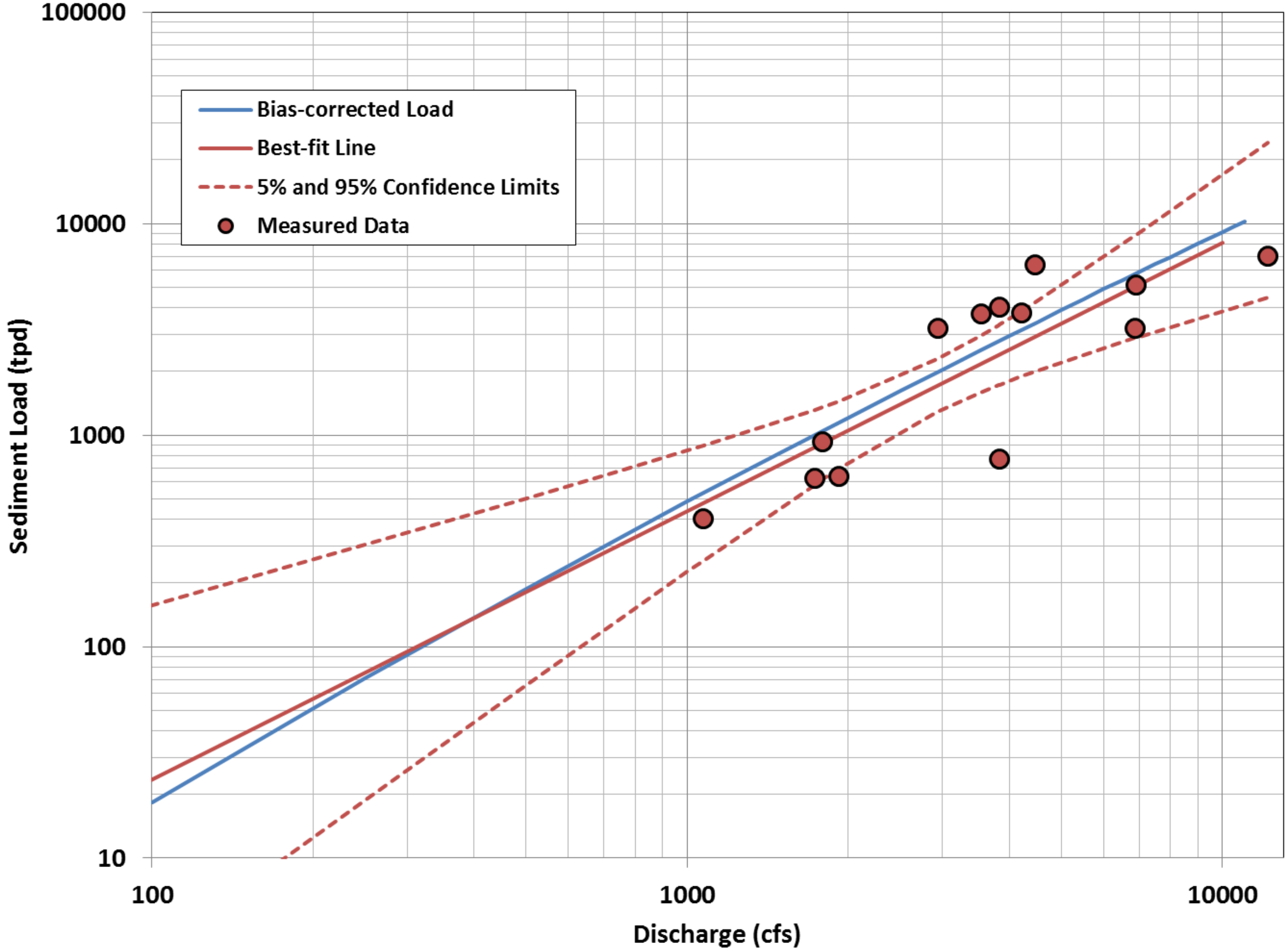


Figure 3.47. Suspended sand transport rates measured at the Overton Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

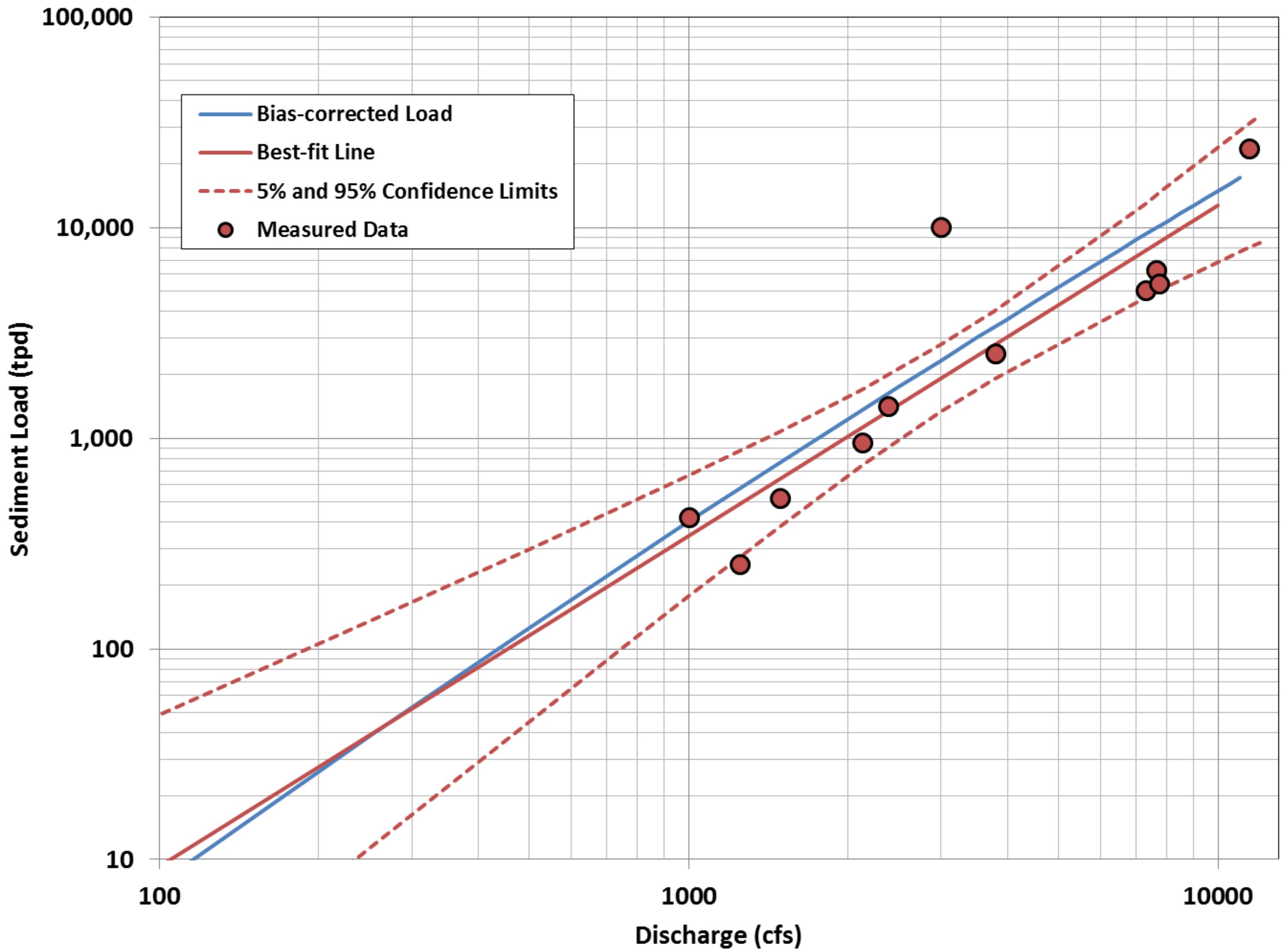


Figure 3.48. Suspended sand transport rates measured at the Kearney Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

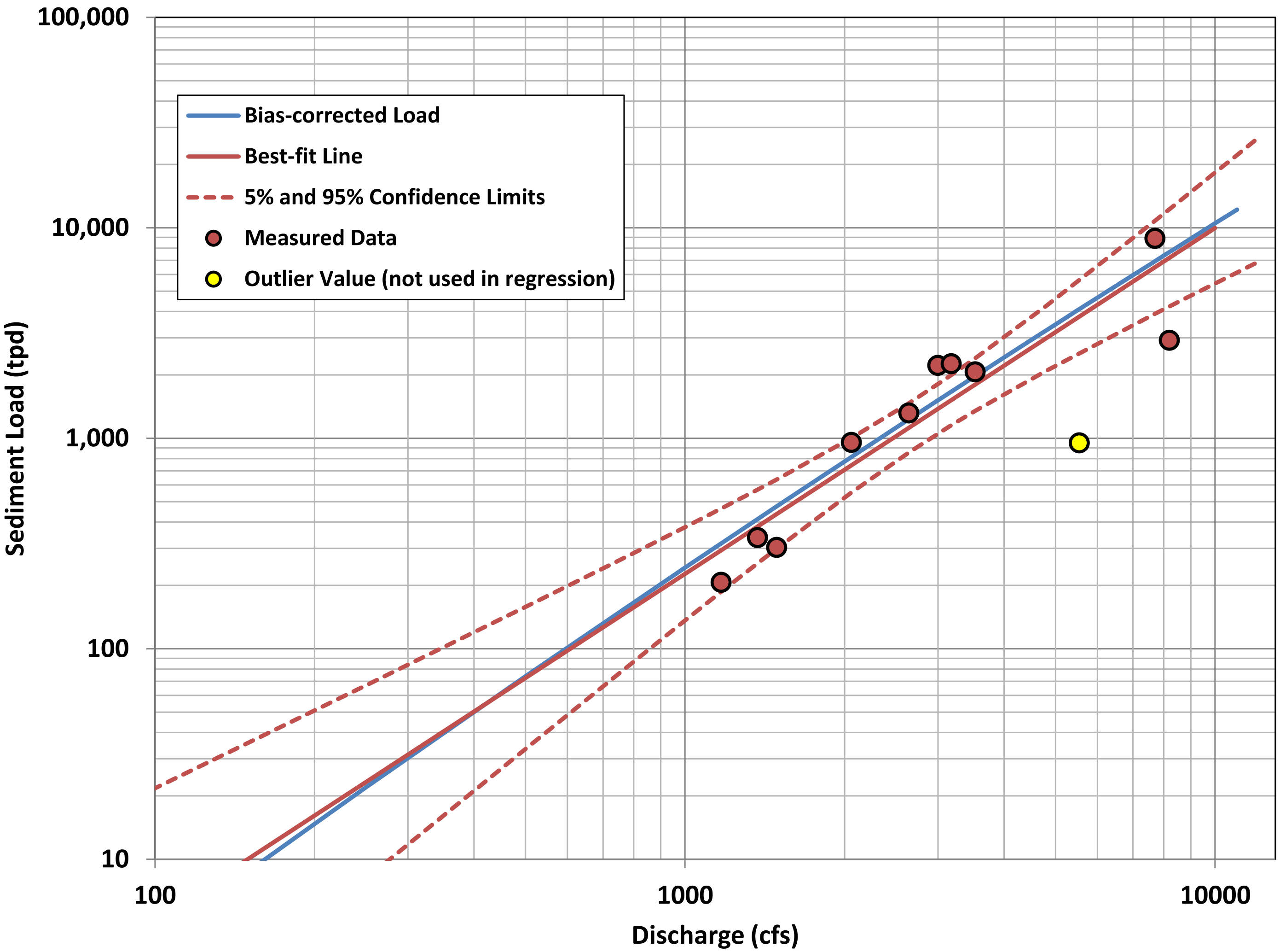


Figure 3.49. Suspended sand transport rates measured at the Shelton Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

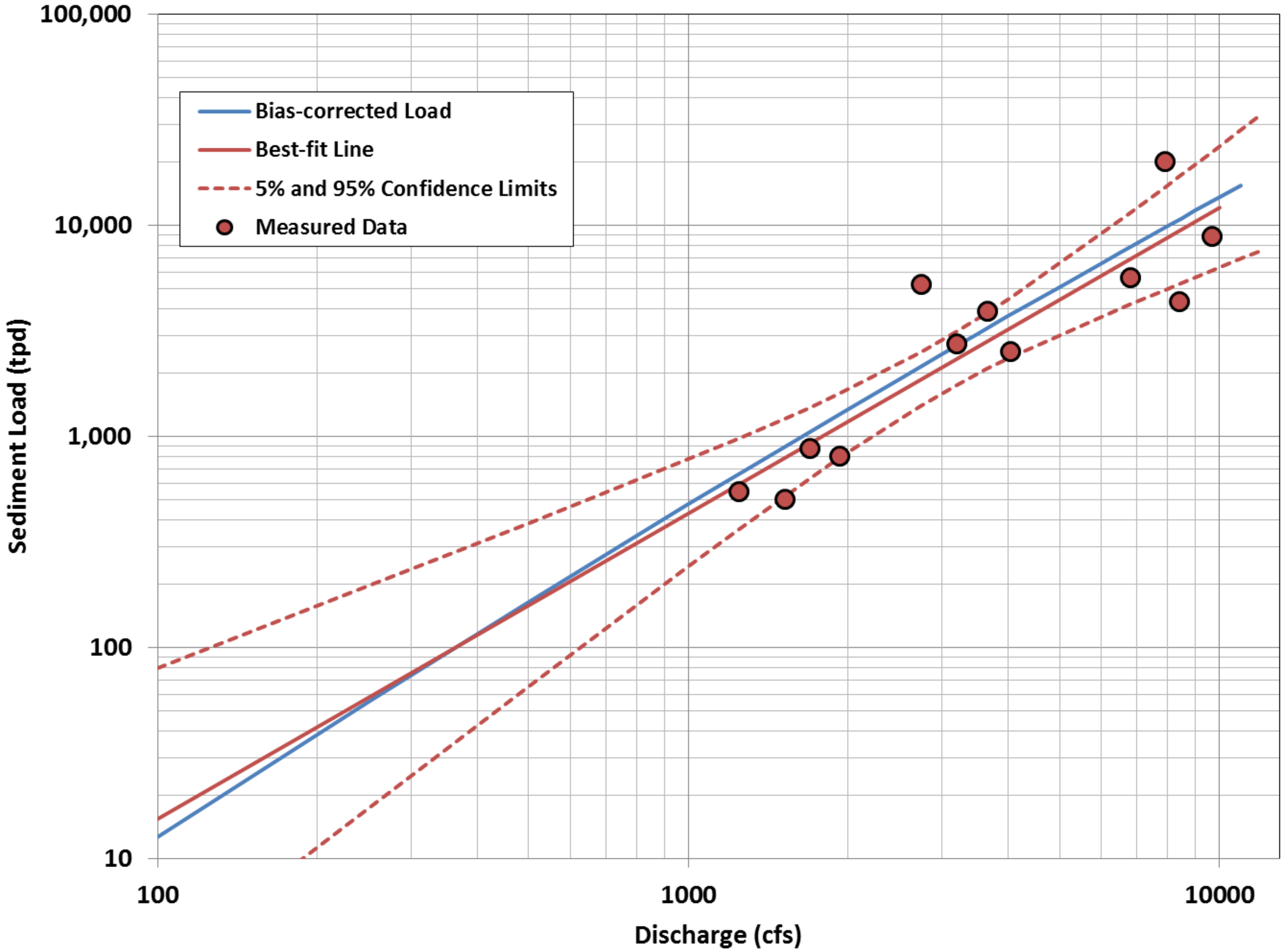


Figure 3.50. Suspended sand transport rates measured at the Grand Island (Highway 34/Highway2) Bridge between 2009 and 2013. Also shown is the best-fit, power-function line through the data, the upper and lower 95-percent confidence bands on the best-fit line, and the MVUE-based, biase corrected line.

3.5.3 Bed-material Grain-size Distribution and Distribution Parameters (DAP 5.5.3)

The total number of bed material samples collected during each of the 5 years of monitoring that have been completed, to-date, ranged from 230 (2012) to 260 (2009). These sample sets included 9 to 10 samples at the surveyed APs and a single sample at each of the five bridges at which bed load measurements are being made (except for 2012, when no sample was collected at the Darr Bridge). For purposes of evaluating trends in the typical bed material sizes along the reach, the samples at each of the APs were averaged to provide a representative bed-material gradation (**Figure 3.51**). The resulting median (D_{50}) bed-material size generally ranged from 1 to 2 mm in the upstream part of the reach, decreasing to 0.5 mm to 1 m in the downstream part of the reach. Linear regression of the D_{50} versus distance along the reach (excluding Reach 2, J-2 Return Channel) indicates that the trend of decreasing grain size in the downstream direction is statistically significant in all years except 2012. The 2012 trend is not statistically significant primarily because of the relatively fine gradation of the samples at AP35 and AP39. A sample set collected by the Bureau of Reclamation in 1989 showed similar trends, although the median grain size was typically finer that those collected as part of this monitoring program.

The reach-averaged D_{50} of the 1989 Reclamation samples was 0.72 mm, and the average D_{84} and D_{16} was 0.34 and 2.35 mm, respectively (**Figure 3.52**). The 2009 bed-material samples were considerably coarser, with average D_{50} of about 1.2 mm and D_{84} and D_{16} of 0.77 and 4.3 mm, respectively. The data showed a general finer trend from 2010 to 2012, when reach-averaged D_{50} was 0.72 mm and the D_{84} and D_{16} were 2.44 and 0.39 mm, respectively, very similar to the 1989 samples. The material then coarsened somewhat in 2013 to D_{50} of 0.88 mm, and D_{84} and D_{16} of 3.0 and 0.55 mm, respectively. Based on the non-parametric Kruskal-Wallace test, the 2012 averages are significantly different from the other years at the 90-percent confidence level, but the differences between the 2009, 2010, 2011 and 2013 samples are not statistically significant.

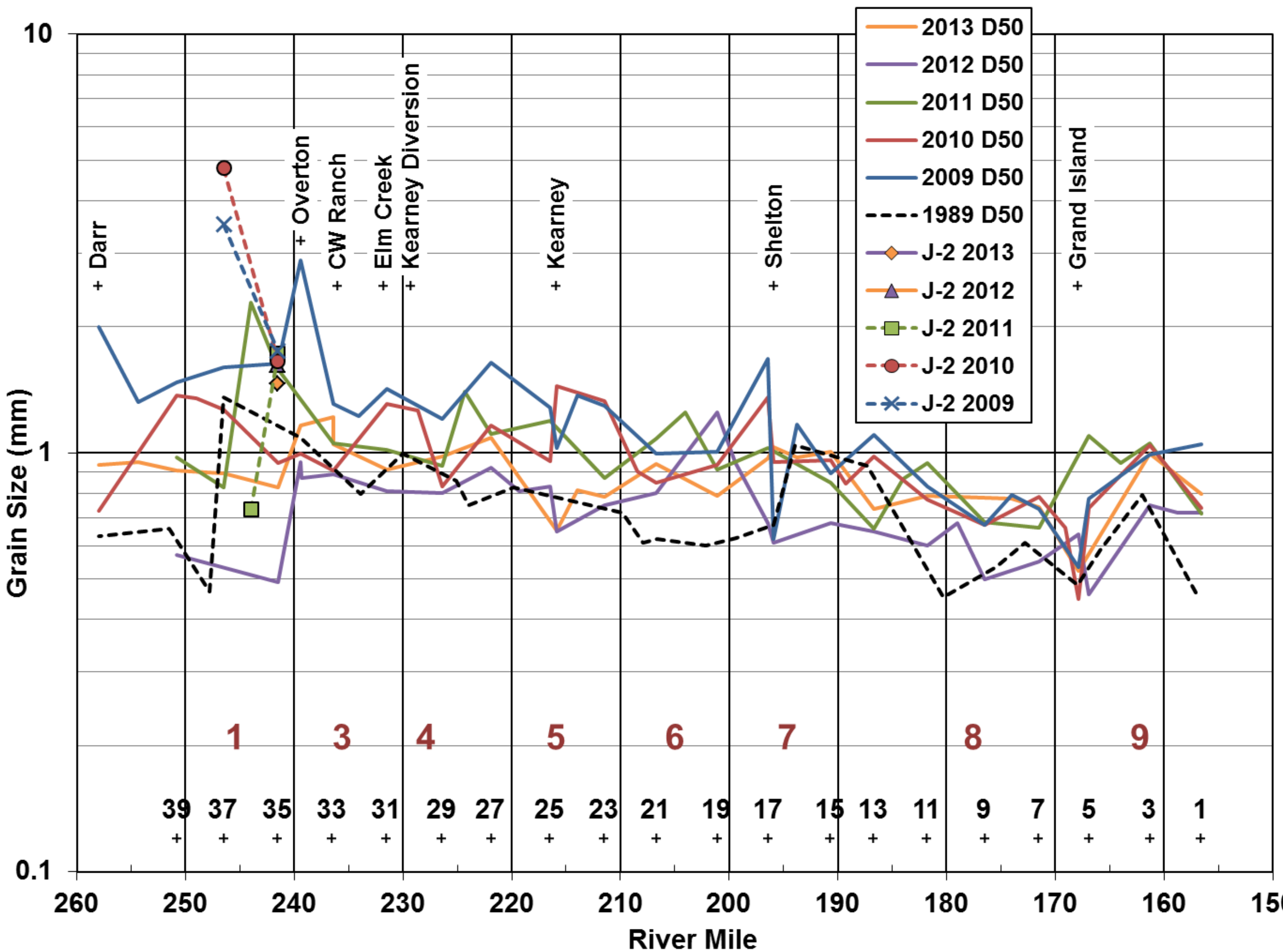


Figure 3.51. Average median (D_{50}) size of bed material samples collected at the APs during 2009 through 2013 monitoring surveys. Also shown are the D_{50} sizes of the samples collected by Reclamation in 1989.

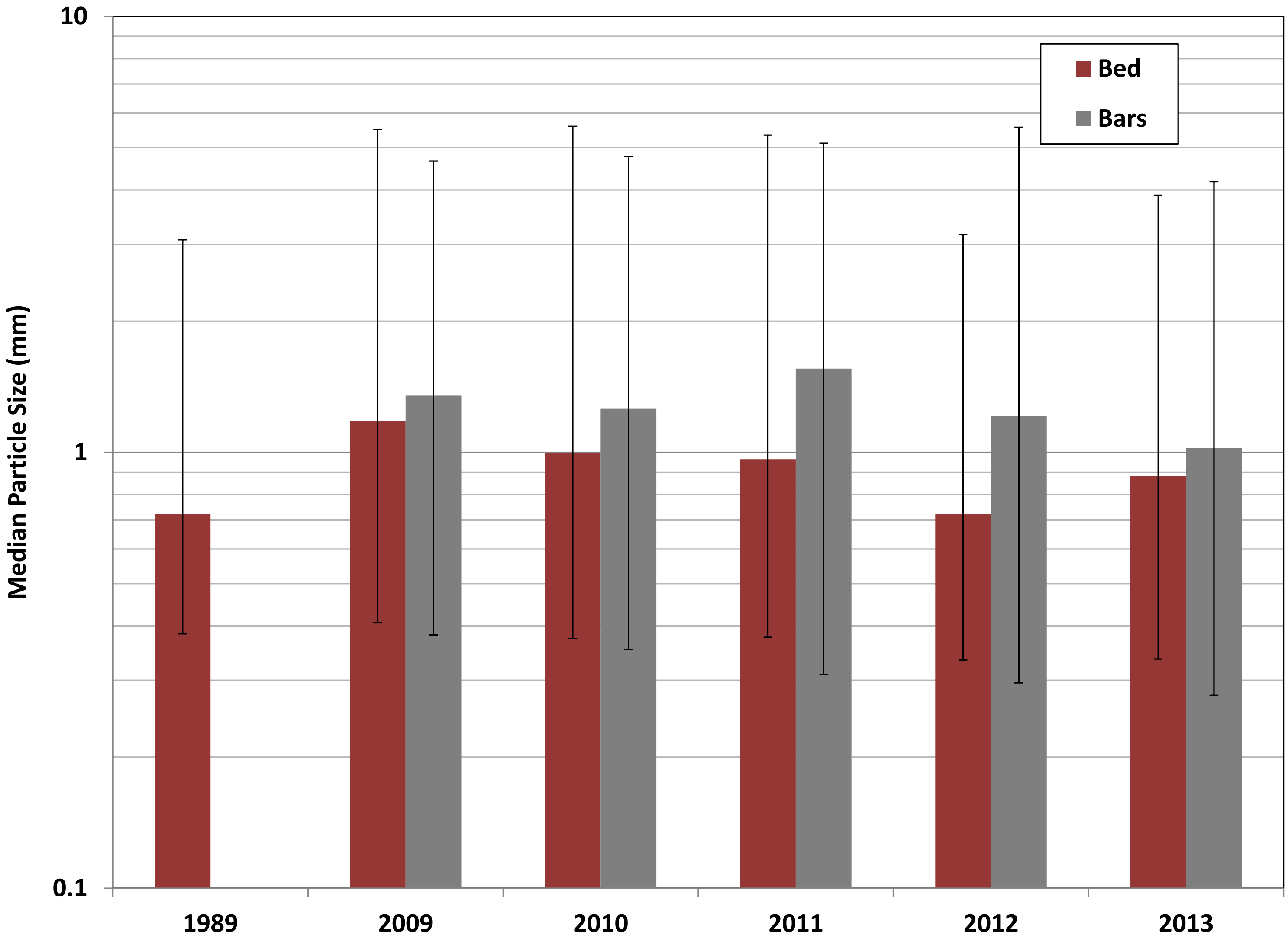


Figure 3.52. Reached averaged median (D_{50}) particle size of samples collected by Reclamation in 1989 and for this monitoring program in 2009 through 2013. Whiskers represent reach-averaged D_{16} and D_{84}.

3.5.4 Bar Material Grain-size Distribution (DAP 5.5.4)

The gradations of the bar material samples were generally coarser and more highly variable than the bed material samples (**Figure 3.53**). The D_{50} of these samples varied from 0.4 to about 5 mm. Visual inspection of the spatial trend plot indicates a general fining trend in the downstream direction, however, the variability along the reach is sufficiently high that this trend is not statistically significant. The reach-averaged D_{50} increased from 1.35 mm in 2009 to 1.56 mm in 2011, and then declined to about 1.0 mm in 2013 (Figure 3.53). The reach-averaged D_{16} and D_{84} were similar to the bed material samples, with the D_{16} ranging from 0.75 mm (2013) to 1.25 (2011) and the D_{84} ranging from 3.2 mm (2013) to 4.35 mm (2011). Again, due to the relatively high variability in the sample gradation, the differences in D_{50} from year to year are not statistically significant.

3.5.5 Bank Material Grain Size Distribution (DAP 5.5.5)

Note: No bank-material samples have been taken since 2009. Results from the 2009 samples are summarized in Ayres and Olsson (2010).

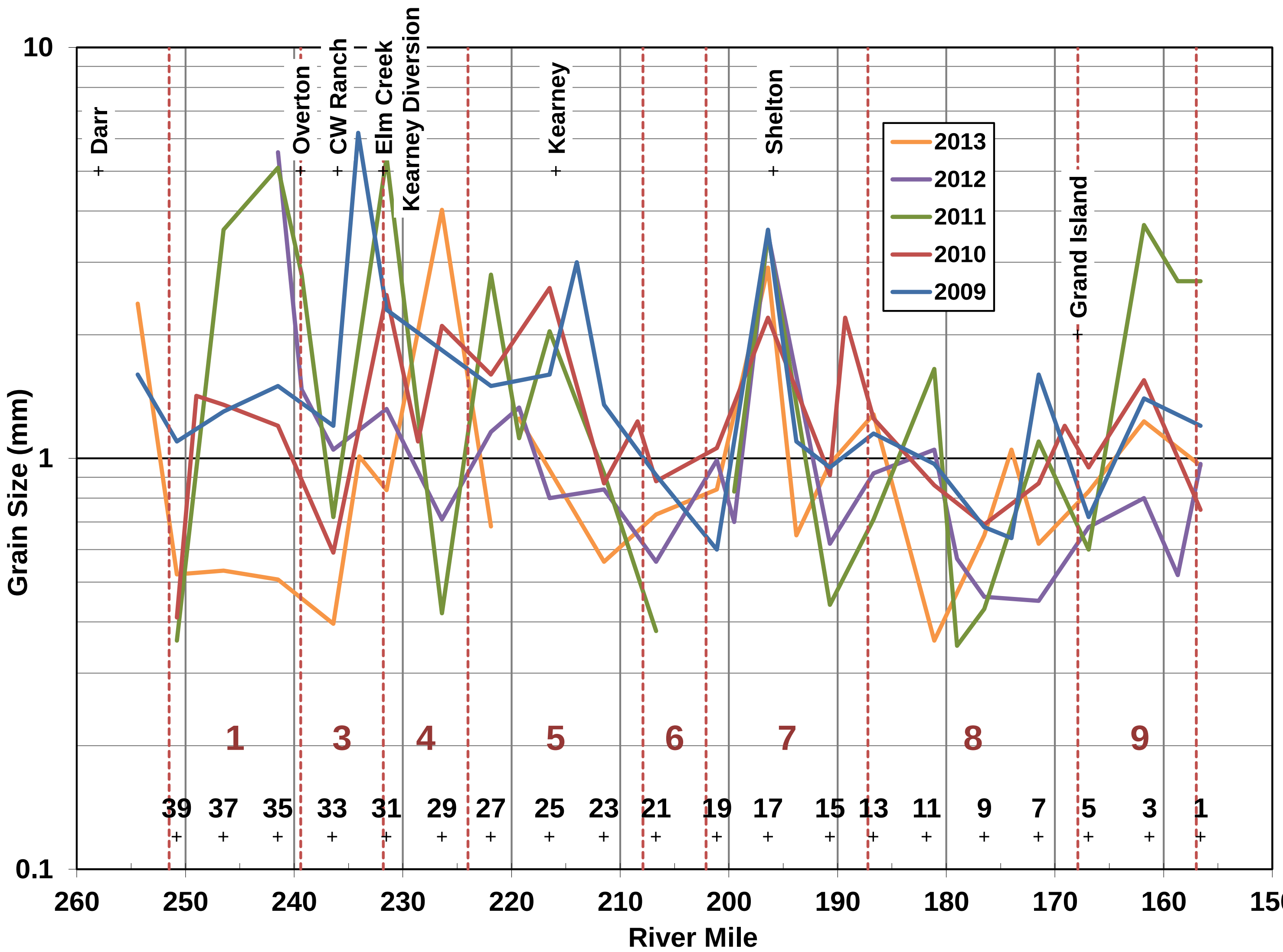


Figure 3.53. Reach-averaged median (D_{50}) size of bed and bar-material samples collected during 2009 through 2013 monitoring surveys. Whiskers represent D_{16} and D_{84} sizes. Also shown are the D_{50}, D_{16} and D_{84} sizes of the Reclamation 1989 samples.

3.6 Whooping Crane Performance Metrics

3.6.1 Unobstructed Channel Width (DAP 5.6.1)

Unobstructed channel widths were determined based on the assumption that vegetation higher than 4.9 feet above a reference elevation would obstruct the line-of-sight for migrating whooping cranes. During the 2009 through 2012 surveys, vegetation heights were recorded in the field data in the following height classes:

- **Woody species:**
  - W1: 0-59 inches (<1.5 meters)
  - W2: 60-120 inches (1.5-3 meters)
- **Herbaceous species:**
  - H1: 0-12 inches (<0.3 meters)
  - H2: 13-59 inches (0.3 to 1.5 meters)
  - H3: 60-84 inches (1.5-2.1 meters)

For purposes of estimating unobstructed channel widths, the vegetation height for each quadrat was assumed to be the mid-point of the height class of the highest woody or herbaceous species that occurred in the quadrat. The elevation of the top of the vegetation was then estimated by adding the estimated height to the surveyed elevation in the center of the quadrat. The unobstructed width at each transect was then determined to be the longest distance between quadrats with top-of-vegetation elevation more than 4.9 feet above the reference elevation. Per the DAP, these distances were determined for three different reference elevations: (1) the water-surface elevation at 2,400 cfs, (2) the water-surface elevation corresponding to the median discharge during the spring migration season, and (3) the water-surface elevation for the median discharge during the fall migration season. **As discussed in the methods Section 2.1.3.2, because of the uncertainty introduced by the height-class data, the data collection procedure was modified in 2013 to directly measure the unobstructed channel width using a laser range finder.**

The average unobstructed channel widths at the pure panel APs ranged from about 140 feet (AP37A, 2012) to about 1,350 feet (AP33, 2010) (**Figure 3.54a**). With the exception of AP21 and AP33 that are relatively wide compared to the other APs, visual inspection of the data indicates a general trend of increasing width in the downstream direction. Because of the variability in the data, however, this trend is not statistically significant. Except for 2012, when the unobstructed width was only about 230 feet based on the height class data, AP33 typically had among the largest widths, ranging from about 1,350 feet in both 2009 and 2010 to about 900 feet in 2013. AP21 was also relatively wide compared to the other APs, with widths ranging from 690 feet (2013) to 1,300 feet (2011). The direct measurement for the 2013 data produced unobstructed widths that are generally similar to those from the previous years.

The reach-wide average unobstructed channel widths were relatively consistent during the first 3 years of the monitoring surveys, ranging from 617 feet in 2009 to 660 feet in 2010 and 653 feet in 2011 (**Figure 3.54b**). The 2012 data indicate a significant reduction in average unobstructed width to only 424 feet. The direct measurements in 2013 indicate an increase in width back to about 523 feet. Since climatic and hydrologic conditions during 2012 and 2013 were similar, the difference in average width between these two years may result more from differences in measurement technique than actual, on-the-ground changes. The data indicate that Geomorphic Reaches 2, 3 and 6 typically had the largest unobstructed widths during the first two years of the monitoring activities; however, the widths in Reach 2 (south channel at Jeffreys Island) declined significantly from 725 to 750 feet in 2009 and 2010 to about 375 feet in 2011, and then to only about 65 feet in 2012 (**Figure 3.54c**). The width in 2013, again based on direct measurement, increased back to about 213 feet. The 2009 and 2010 widths shown in the figure include both AP35B and AP37B, while those for 2011, 2012 and 2013 include only AP35B, because access to AP37B was revoked by the landowner. Since AP37B is wider than AP35B, removing those data points from the averages reduces the 2009 and 2010 averages for Reach 2 to 540 and 420 feet, respectively. The general decrease in unobstructed width during 2012 and 2013 are most likely due to the reduced flows that allow more in-channel vegetation.

3.6.2 Proportion of Channel Less Than Eight Inches Deep or Sand (DAP 5.6.2)

The channel width inundated to a depth of 8 inches or less, including both vegetated and unvegetated, exposed sand bars[6], was evaluated for three different target discharges: (1) 2,400 cfs (2) the median discharge during the spring whooping crane migration season and (3) the median discharge during the fall whooping crane migration season. As discussed in Section 3.1.3, the spring discharge in the portion of the reach downstream from Overton was in the range of 1,000 cfs to 2,000 cfs during 2009, 2010, 2012 and 2013, and varied from about 3,600 cfs to 4,400 cfs in 2011 (Figure 3.4). The fall discharge in this part of the reach generally ranged between about 1,500 cfs and 2,000 cfs during 2009, 2010 and 2013, was much lower (less than 500 cfs) in 2012 and ranged from about 3,200 cfs to 3,700 cfs in 2011 (Figure 3.5)**.**

The widths less than 8 inches deep at 2,400 cfs were less than 200 feet at AP31, 37A (north channel at Jeffreys Island) and AP39 during all five years, and they ranged from 200 feet to 250 feet during all years at AP11 and AP25 (**Figure 3.55a**). Other pure panel APs with relatively small widths less than 8 inches deep include AP13, AP15, AP23 and AP33. Pure panel APs with relatively large widths less than 8 inches deep at 2,400 cfs (i.e., typically greater than 600 feet) include AP1, AP3, AP5, AP7, AP17, AP19, AP21, AP27, and AP35. AP1 had the largest width, generally in the range of 1,200 feet.

The reach-wide average width less than 8 inches deep at 2,400 cfs ranged from about 510 feet in 2009 and 2010 to 530 feet in 2011, and then decreased to about 475 feet in 2012 (**Figure 3.55b**). The width increased to about 510 feet in 2013. Because of the relatively high variability of the basic data, none of these differences are statically significant at the 90-percent confidence level based on the Kruskall-Wallace test. Geomorphic Reach 3 generally had the smallest average width less than 8 inches deep (about 280 feet in 2009, decreasing to 180 feet to 190 feet in 2011, 2012 and 2013) (**Figure 3.55c**). Other geomorphic reaches with relatively small widths include Reach 1 (~310 feet) and Reach 8 (250 feet in 2009 to 400 feet in 2011). Reach 6 (AP21) had the largest width, ranging from 700 feet in 2010 to 890 feet in 2013). Reach 1 also had relatively large widths (720 feet in 2012 to 820 feet in 2011).

The spatial distribution of widths with depth less than 8 inches for the spring and fall whooping crane migration season discharges are similar to the patterns for 2,400 cfs; however, the year-to-year differences are greater because of the year-to-year differences in the target discharge (**Figures 3.56a and 3.57a**). The reach-wide average for the spring whooping crane migration season discharge was 700 feet in both 2009 and 2010, decreasing to about 420 feet during the very high-flow year of 2011, and then increasing back to about 620 and 690 feet in 2012 and

[6]The draft DAP indicates that this is the maximum **contiguous** width. Based on discussions with Jason Farnsworth, it was determined that this metric should be the total width less with depth less than 8 inches within the active channel to meet the intent of the metric. The widths from this analysis represent the total width of all areas within the active channel with depth less than 8 inches, including vegetated and unvegetated sand bars.

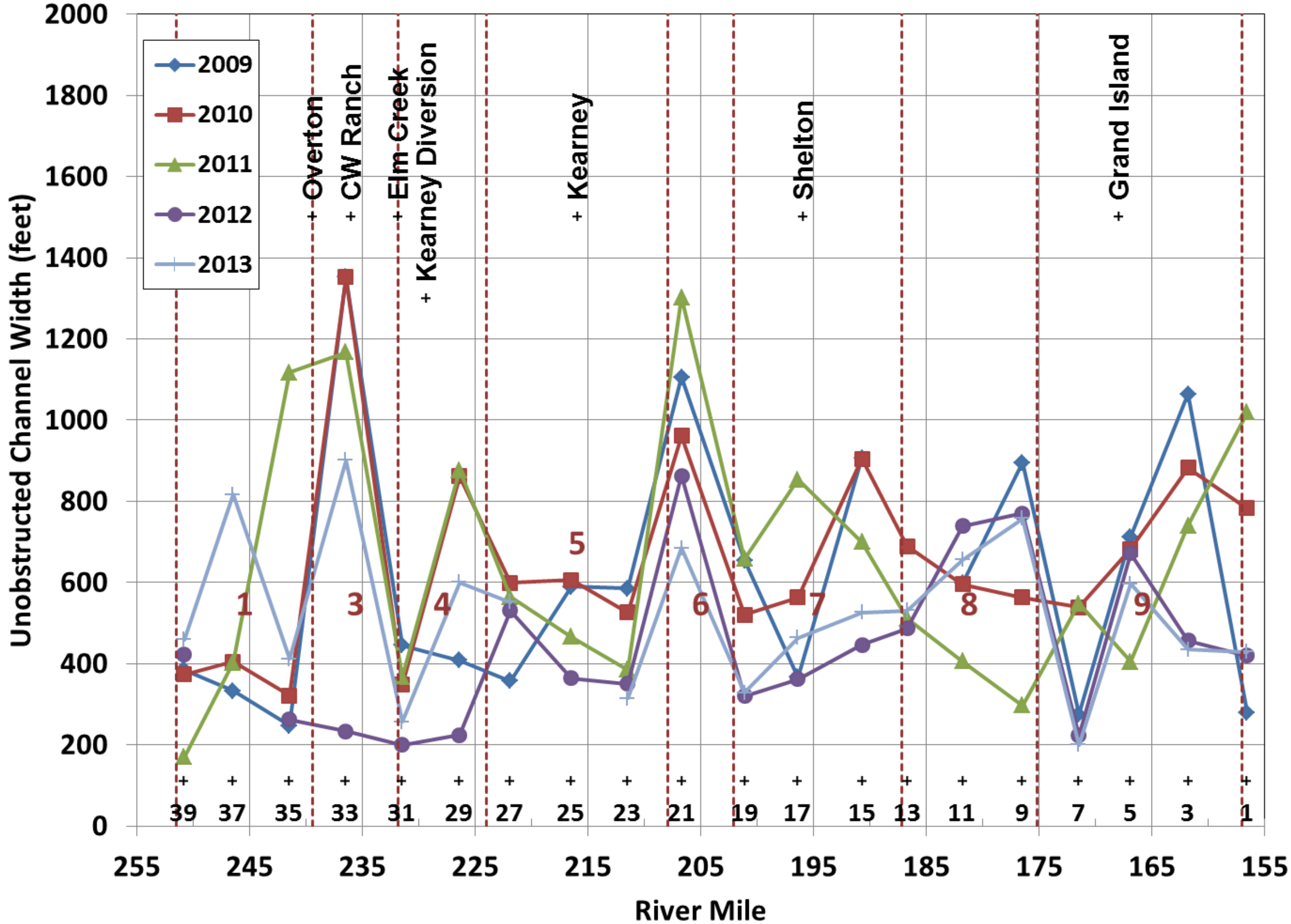


Figure 3.54a**.** Average unobstructed channel width at pure panel APs from 2009 to 2013.

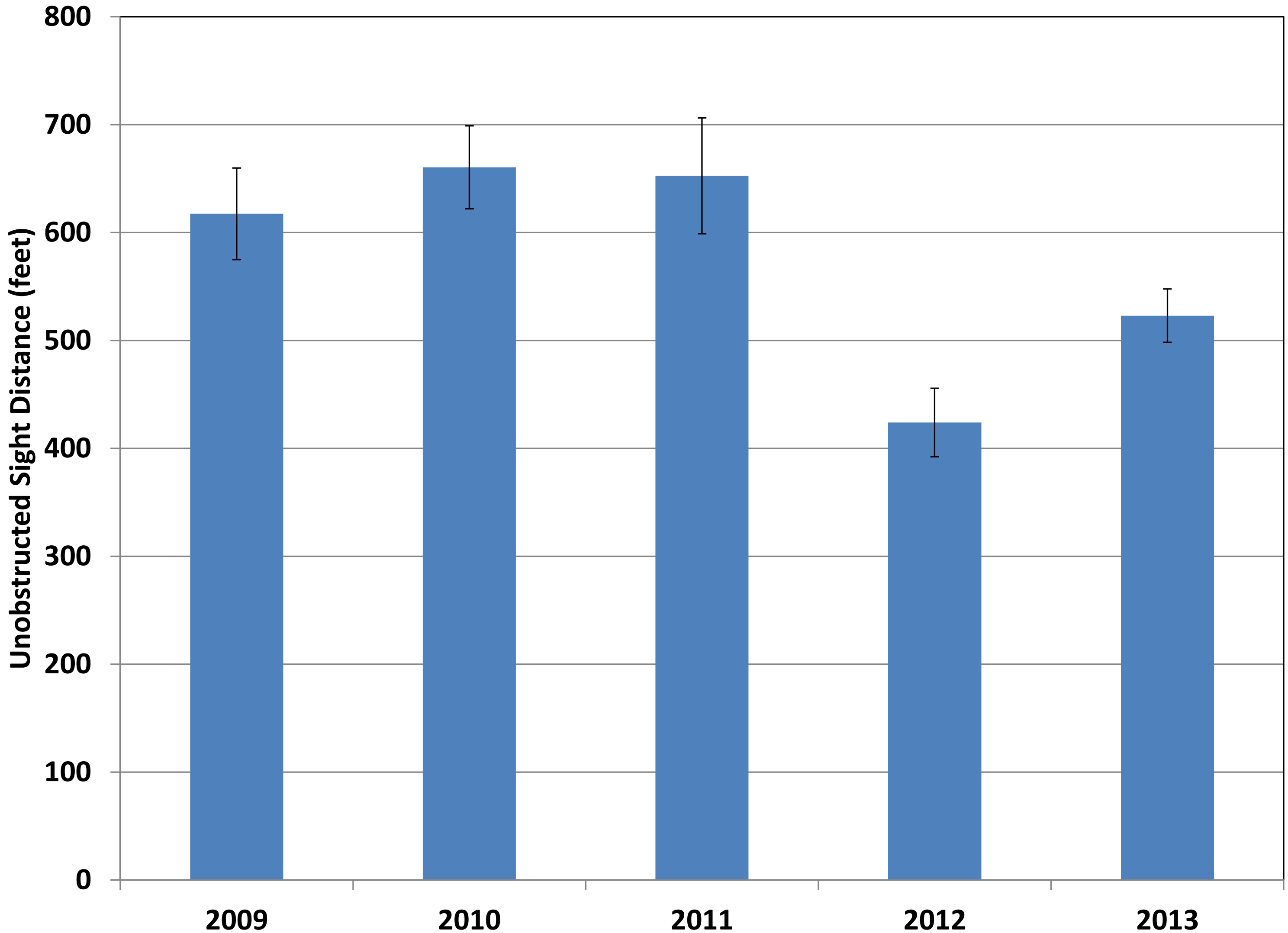


Figure 3.54b. Average unobstructed channel width for the overall study reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value.

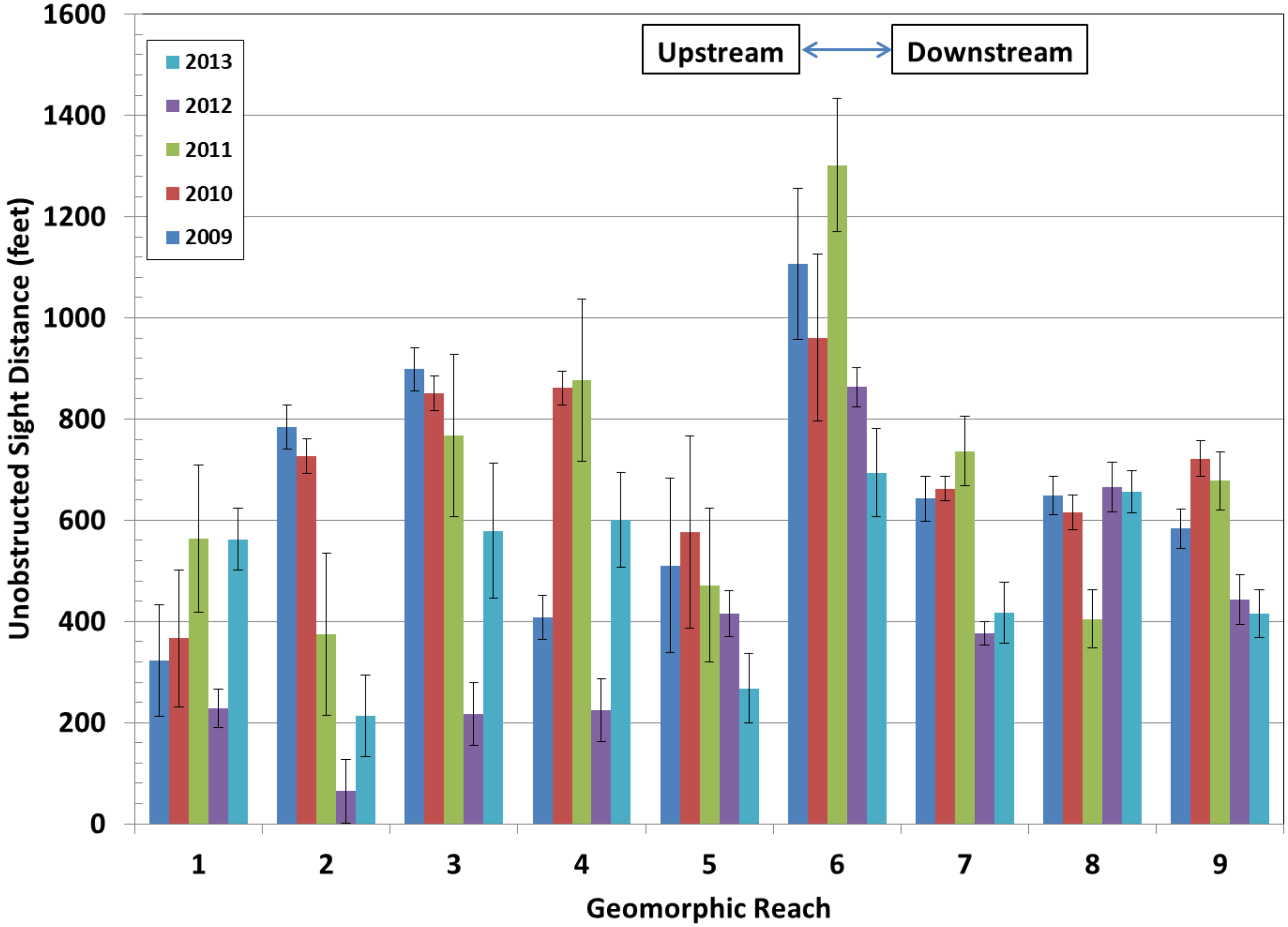


Figure 3.54c. Average unobstructed channel width by geomorphic reach, based on the pure panel AP data from the 2009 to 2013. Whiskers represent ±1 standard error on mean value. Note that the 2009 and 2010 values for Reach 2 include both AP35B and AP37B, while 2011-2013 include only AP35B. Average values for AP35B in 2009 and 2010 were 540 and 420 feet, respectively.

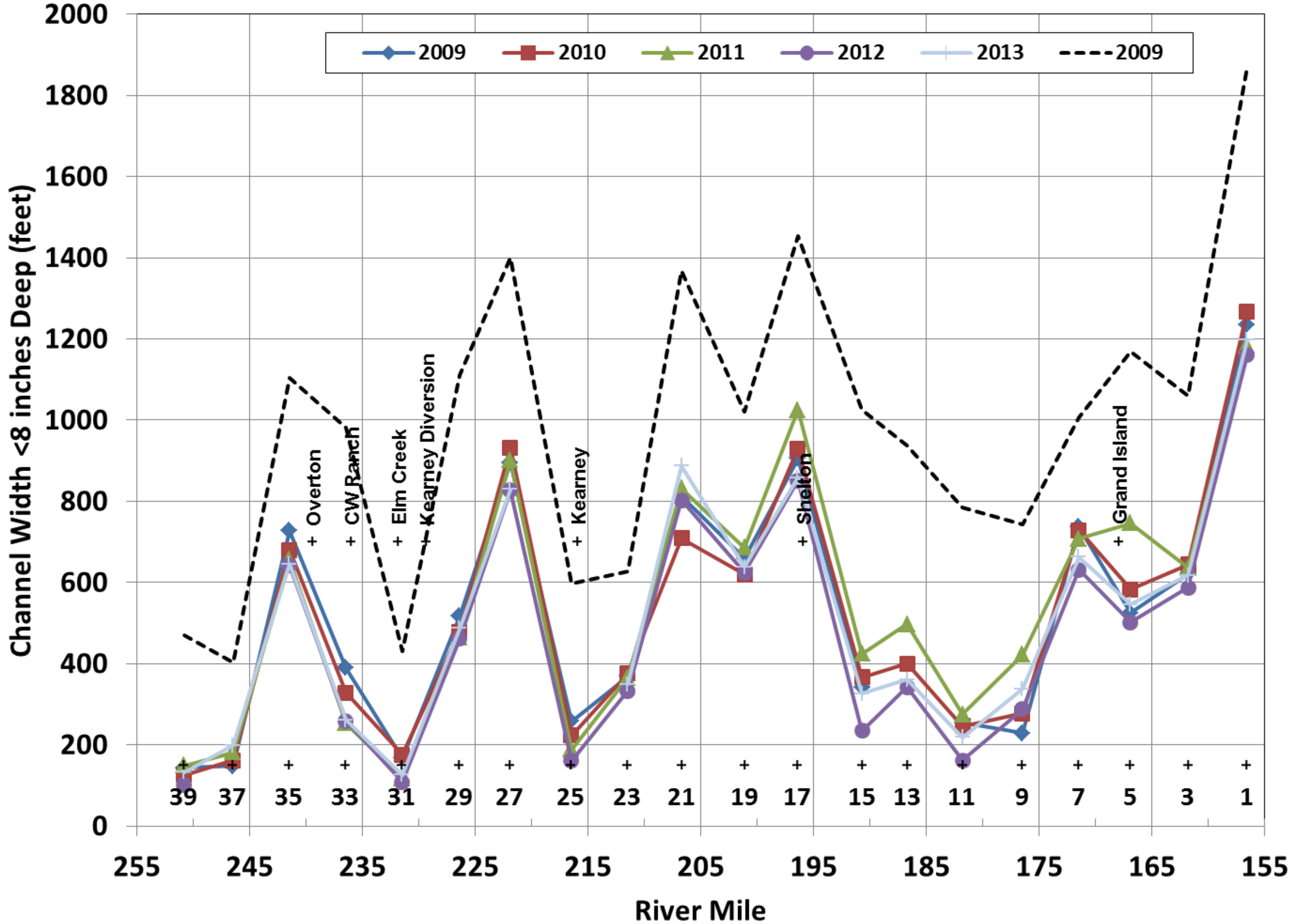


Figure 3.55a. Width of channel less than 8 inches deep (including exposed sandbars) at 2,400 cfs at the pure panes APs for each of the five monitoring years. Dashed black line is total channel width between bank stations.

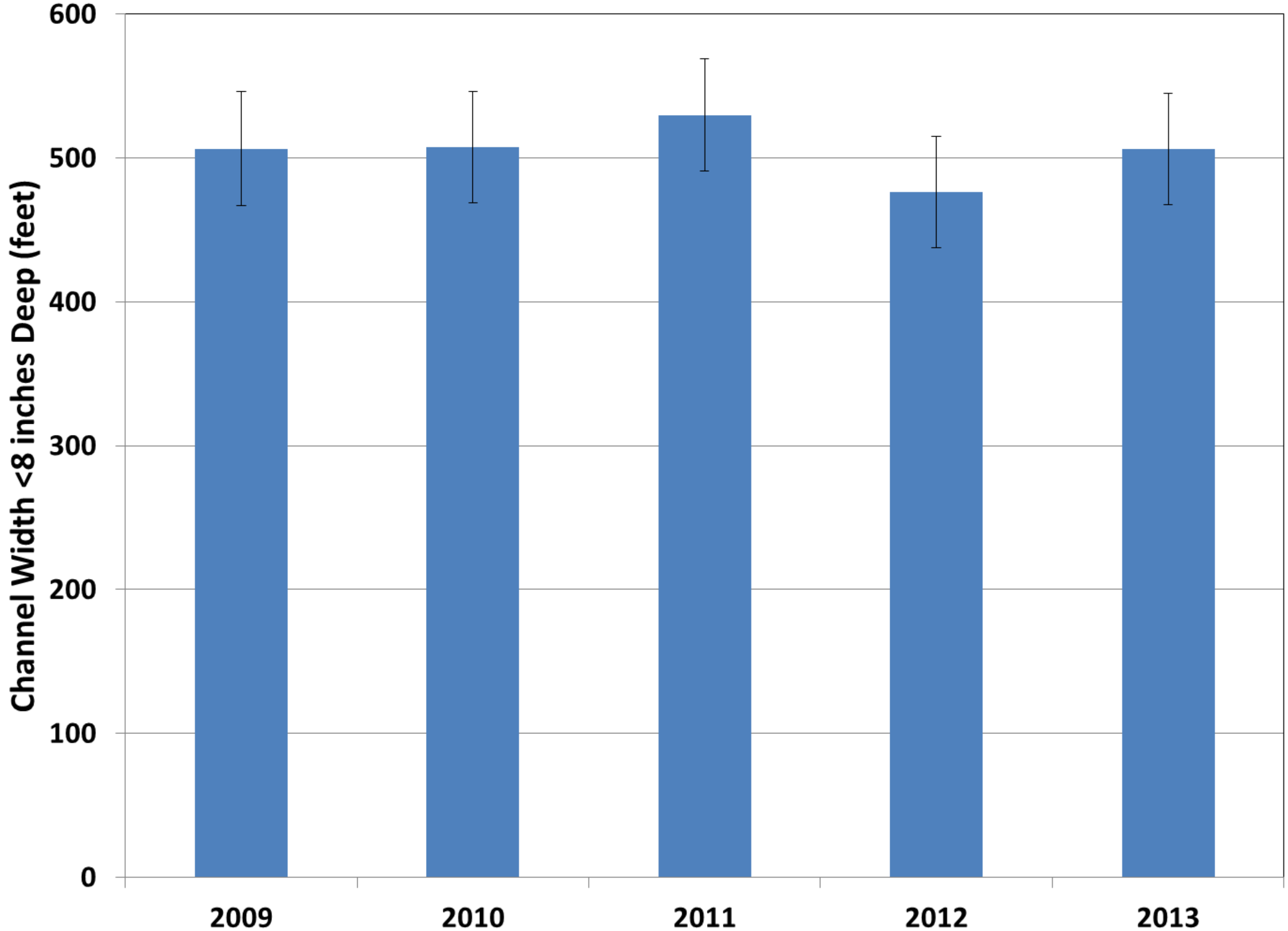


Figure 3.55b. Overall reach-averaged width less than 8 inches deep (including exposed sandbars) at 2,400 cfs. Whiskers represent ±1 standard error. (AP37B was excluded from the average because data are available only for 2009 through 2011.)

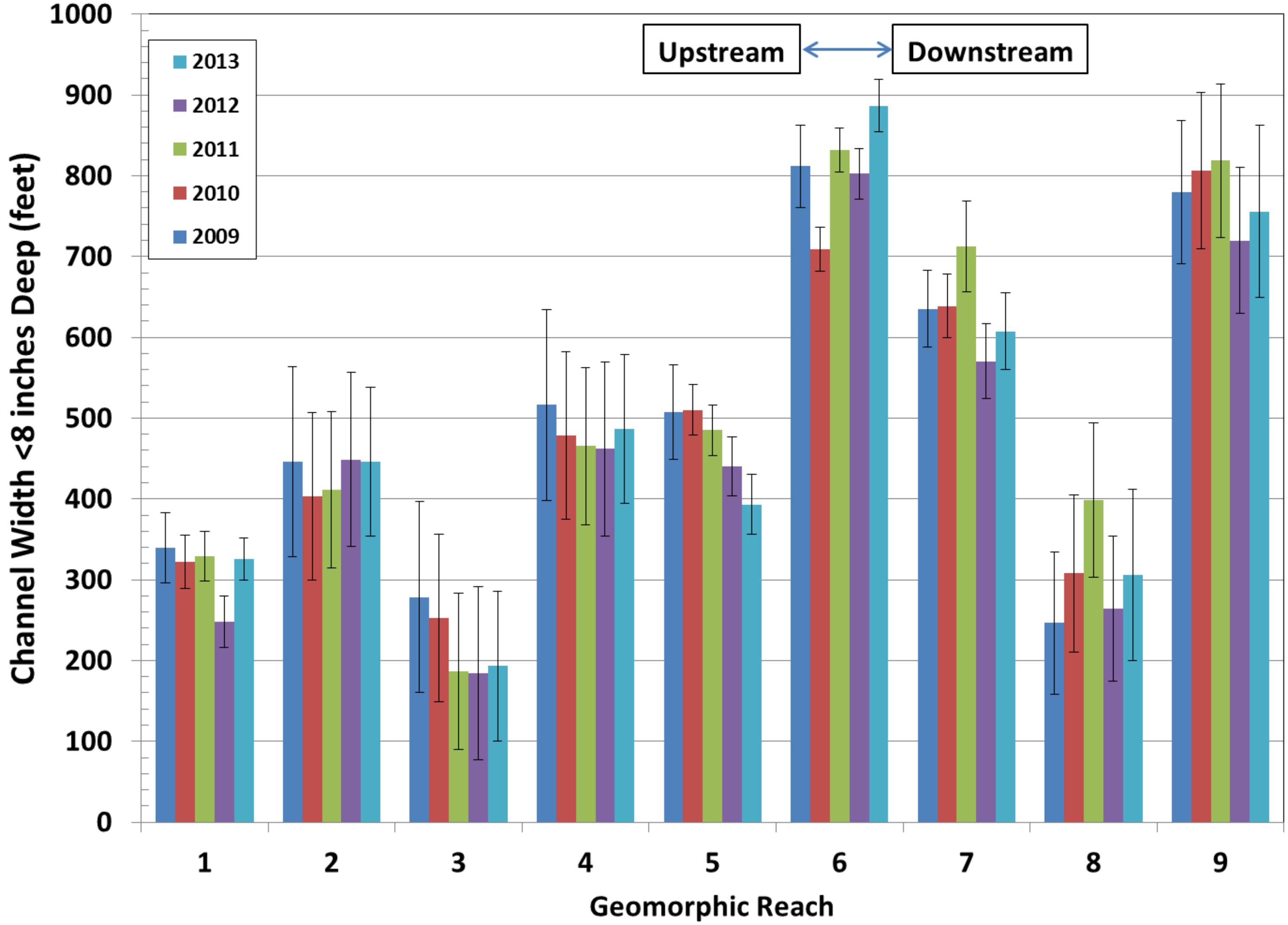


Figure 3.55c. Average width less than 8 inches deep (including exposed sandbars) at 2,400 cfs by geomorphic reach. Whiskers represent ±1 standard error. (AP37B was excluded from the average in Reach 2 because data are available only for 2009 through 2011.)

2013, respectively (**Figure 3.56b**). For the fall whooping crane migration season discharge, the average width was about 620 feet in 2009, increasing to about 650 feet in 2010, and then decreasing to about 470 feet in 2011 (**Figure 3.57b**). The 2012 width was about 943 feet, and this decreased to about 660 feet in 2013, due to the large flows that occurred during the September 2013 flood. The spatial pattern of average width among the geomorphic reaches for the spring and fall discharges is essentially the same as the width at 2,400 cfs, and the year-to-year variability follows the same temporal pattern and the reach-wide averages (**Figures 3.56c and 3.57c**).

As expected, the monitoring data indicate that both the actual width and the portion of the active channel with flow depth less than 8 inches tend to decrease with increasing discharge (**Figure 3.58**). The average widths at 2,400 cfs at the pure panel APs represent 20 percent to 75 percent of the bank-to-bank channel width, with an overall average of about 50 percent for all five years. The average widths at the pure panel APs using the spring migration season discharge represent 15 percent to over 90 percent of the bank-to-bank width, with the reach-wide average ranging from 41 percent (2011) to 74 percent (2009). For the fall migration season discharge, the average widths at the APs represent about 20 percent (2011) to essentially 100 percent of the bank-to-bank channel width, with the reach-wide average ranging from 47 percent (2011) to 93 percent (2012). The 2012 values are very high because of the relatively low migration season discharge.

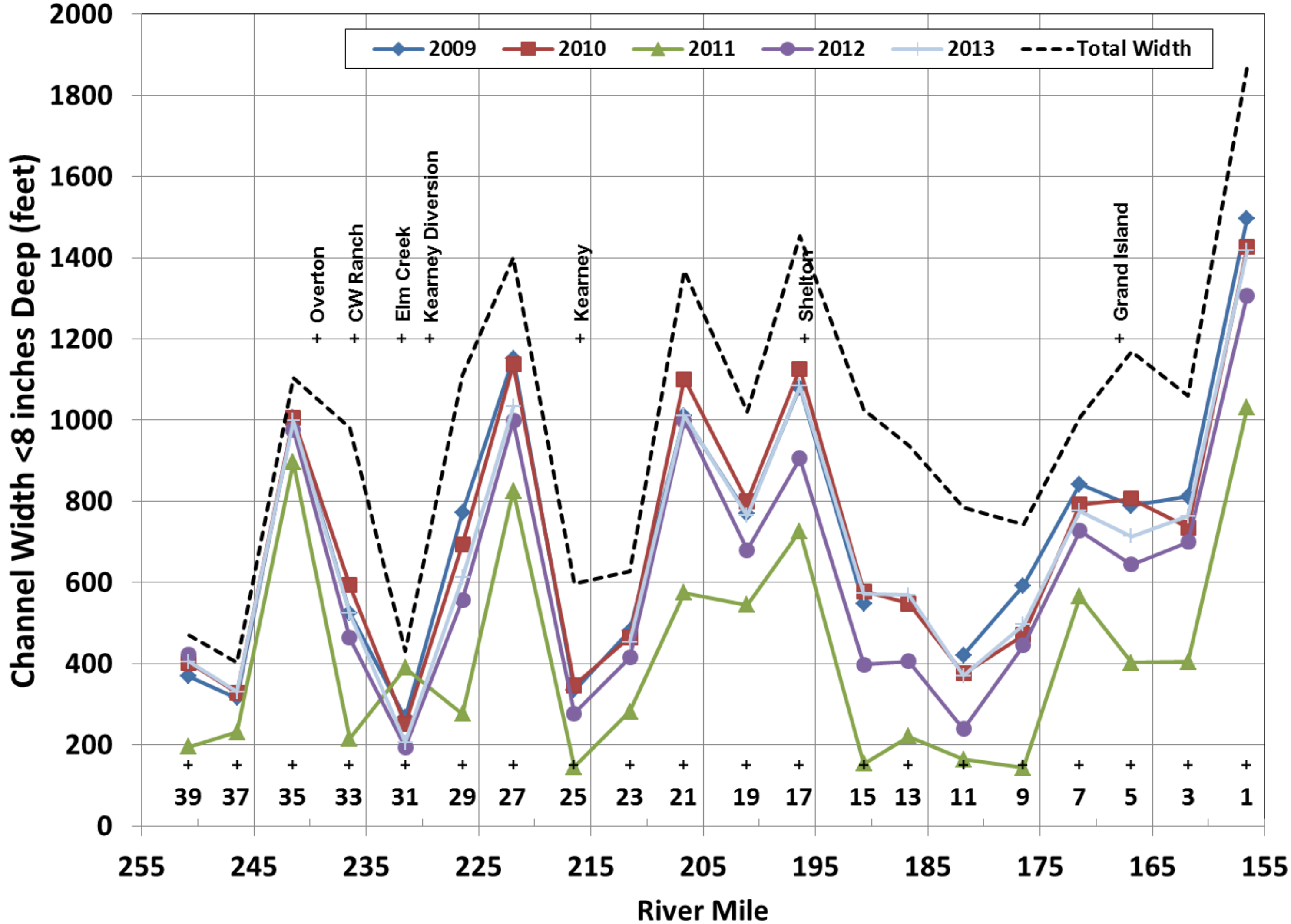


Figure 3.56a. Width of channel less than 8 inches deep (including exposed sandbars) at the spring migration season at the pure panes APs for each of the five monitoring years. Dashed black line is total channel width between bank stations.

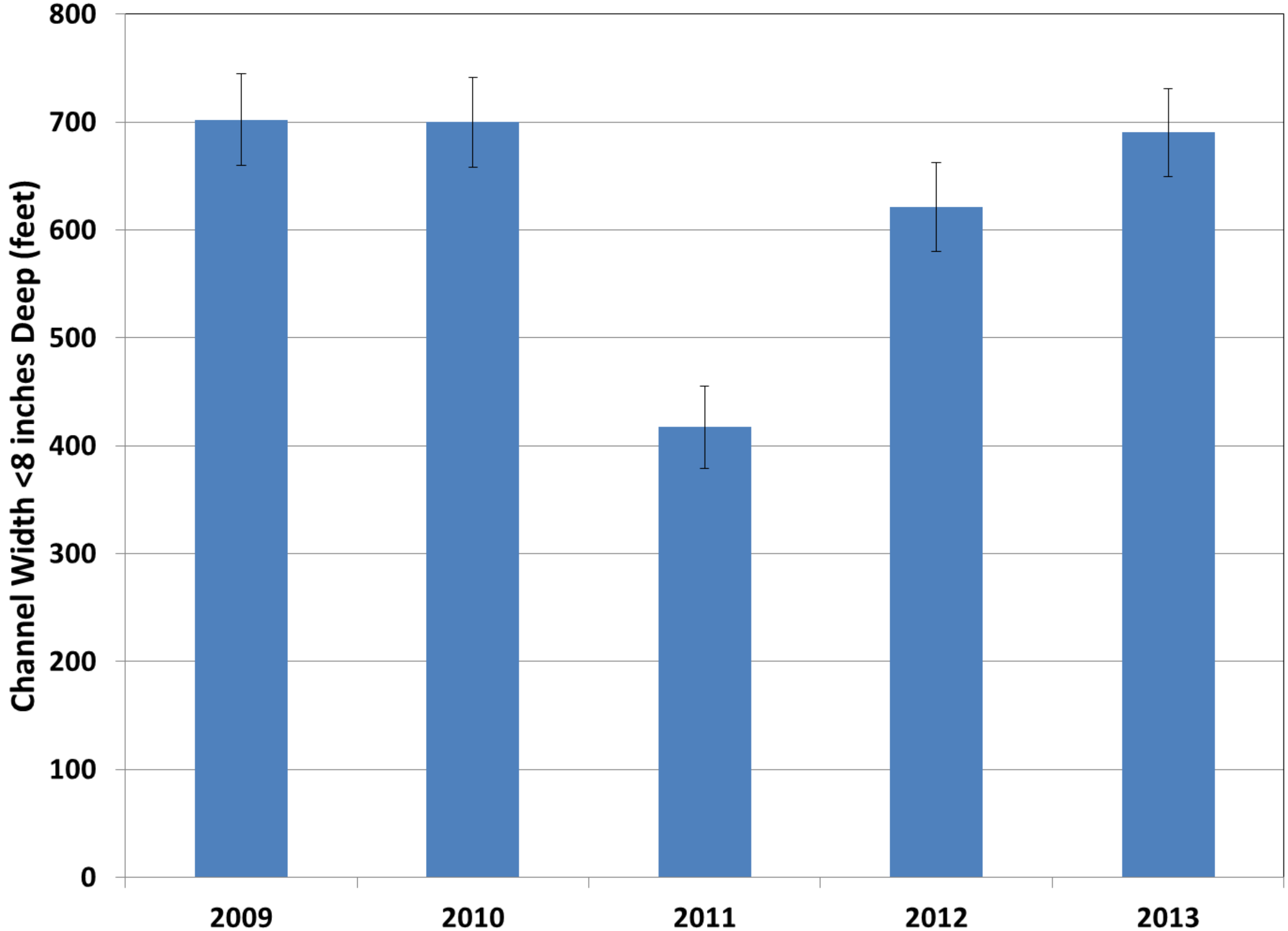


Figure 3.56b. Overall reach-averaged width less than 8 inches deep (including exposed sandbars) at the spring migration season. Whiskers represent ±1 standard error. (AP37B was excluded from the average because data are available only for 2009 through 2011.)

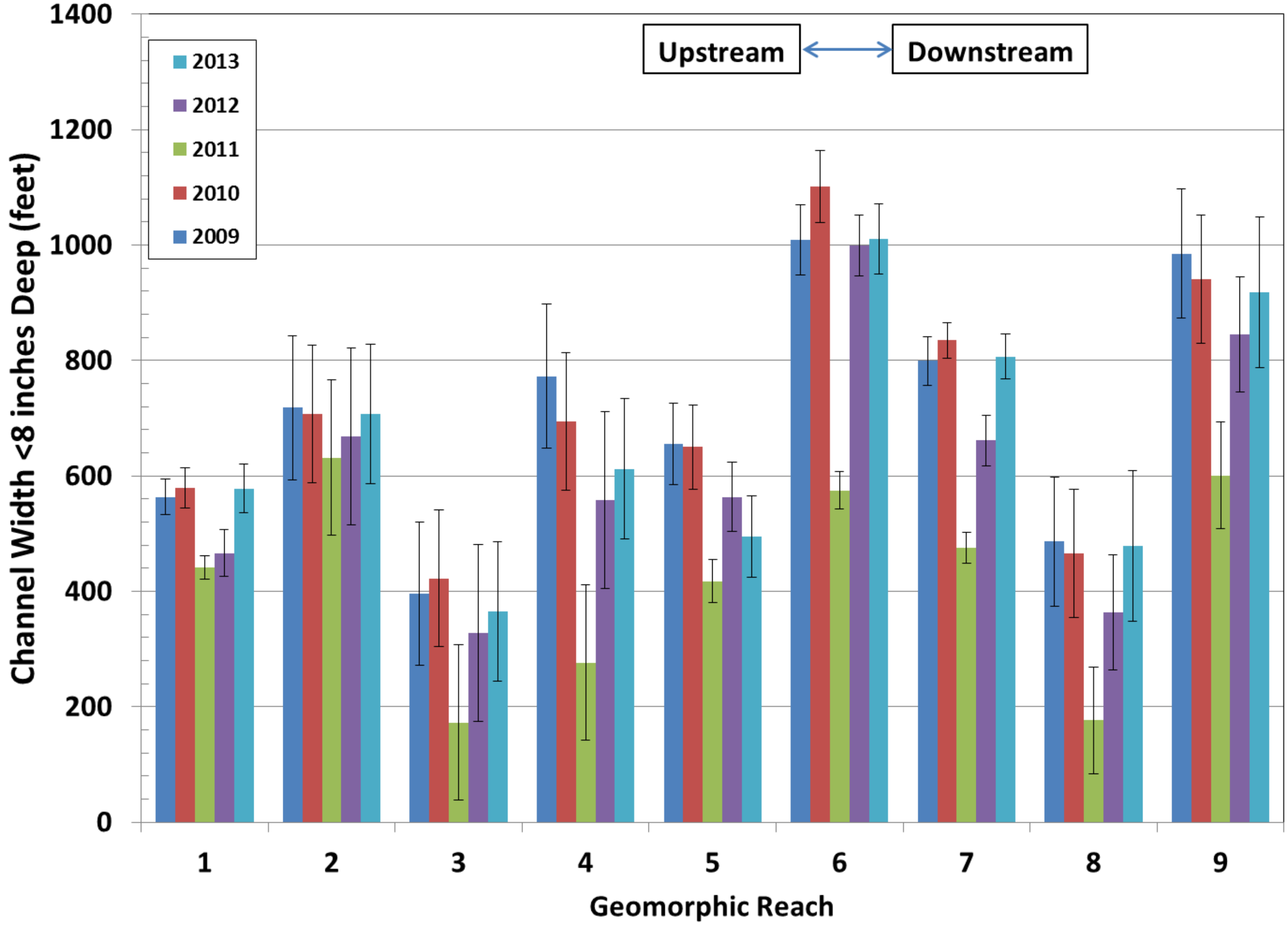


Figure 3.56c. Average width less than 8 inches deep (including exposed sandbars) at the spring migration season by geomorphic reach. Whiskers represent ±1 standard error. (AP37B was excluded from the average in Reach 2 because data are available only for 2009 through 2011.)

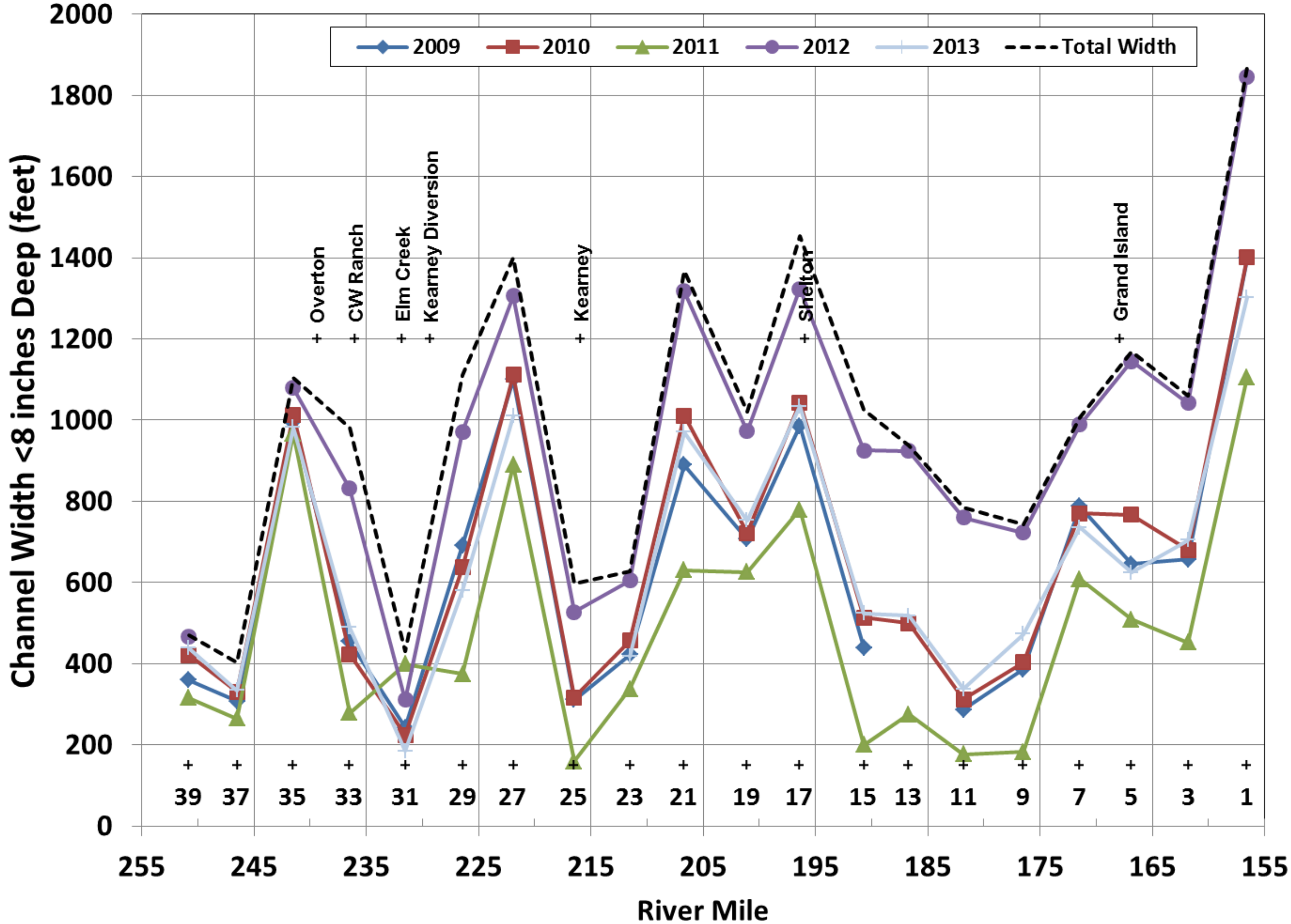


Figure 3.57a. Width of channel less than 8 inches deep (including exposed sandbars) at the fall migration season at the pure panes APs for each of the five monitoring years. Dashed black line is total channel width between bank stations.

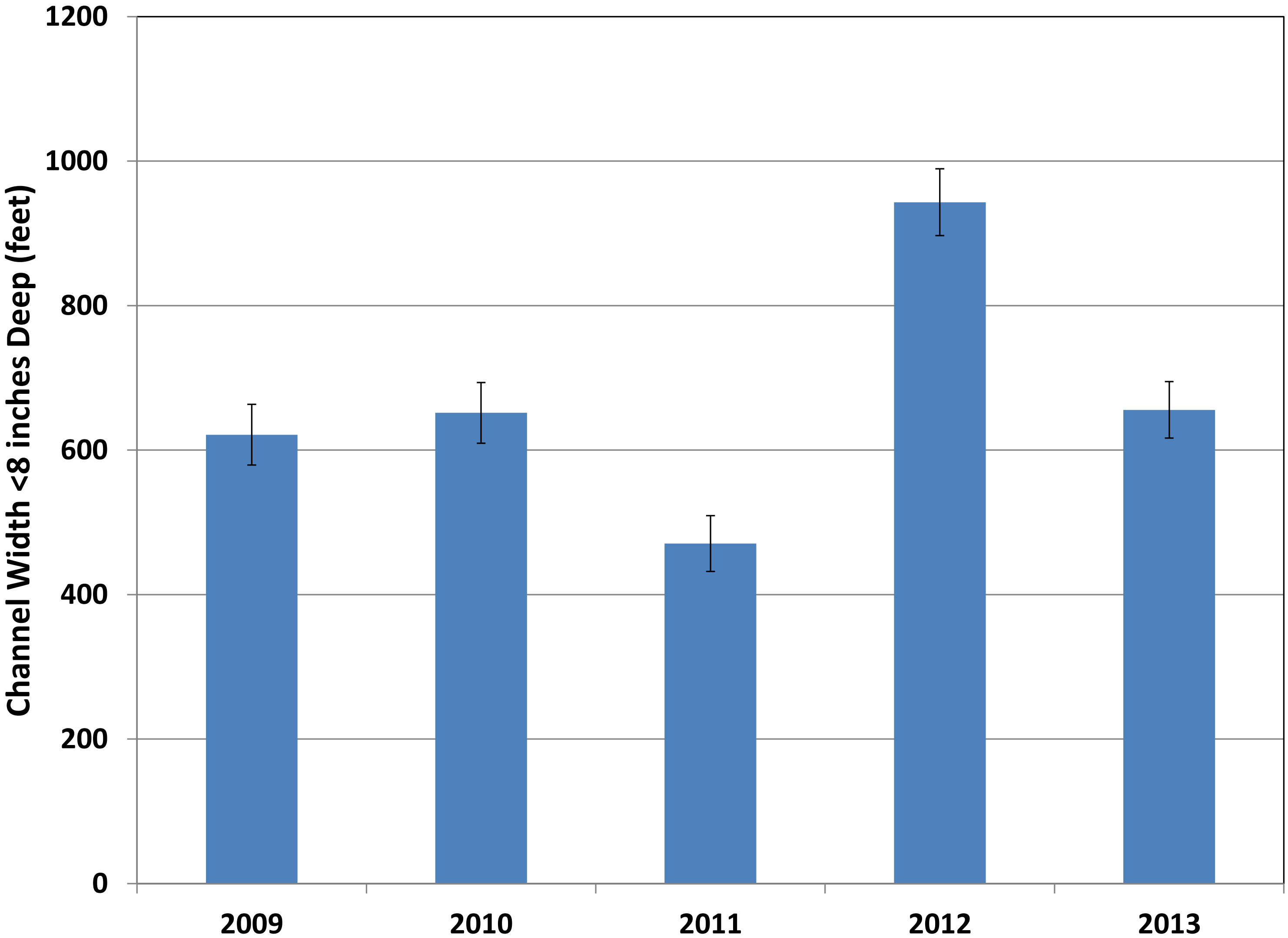


Figure 3.57b. Overall reach-averaged width less than 8 inches deep (including exposed sandbars) at the fall migration season. Whiskers represent ±1 standard error. (AP37B was excluded from the average because data are available only for 2009 through 2011.)

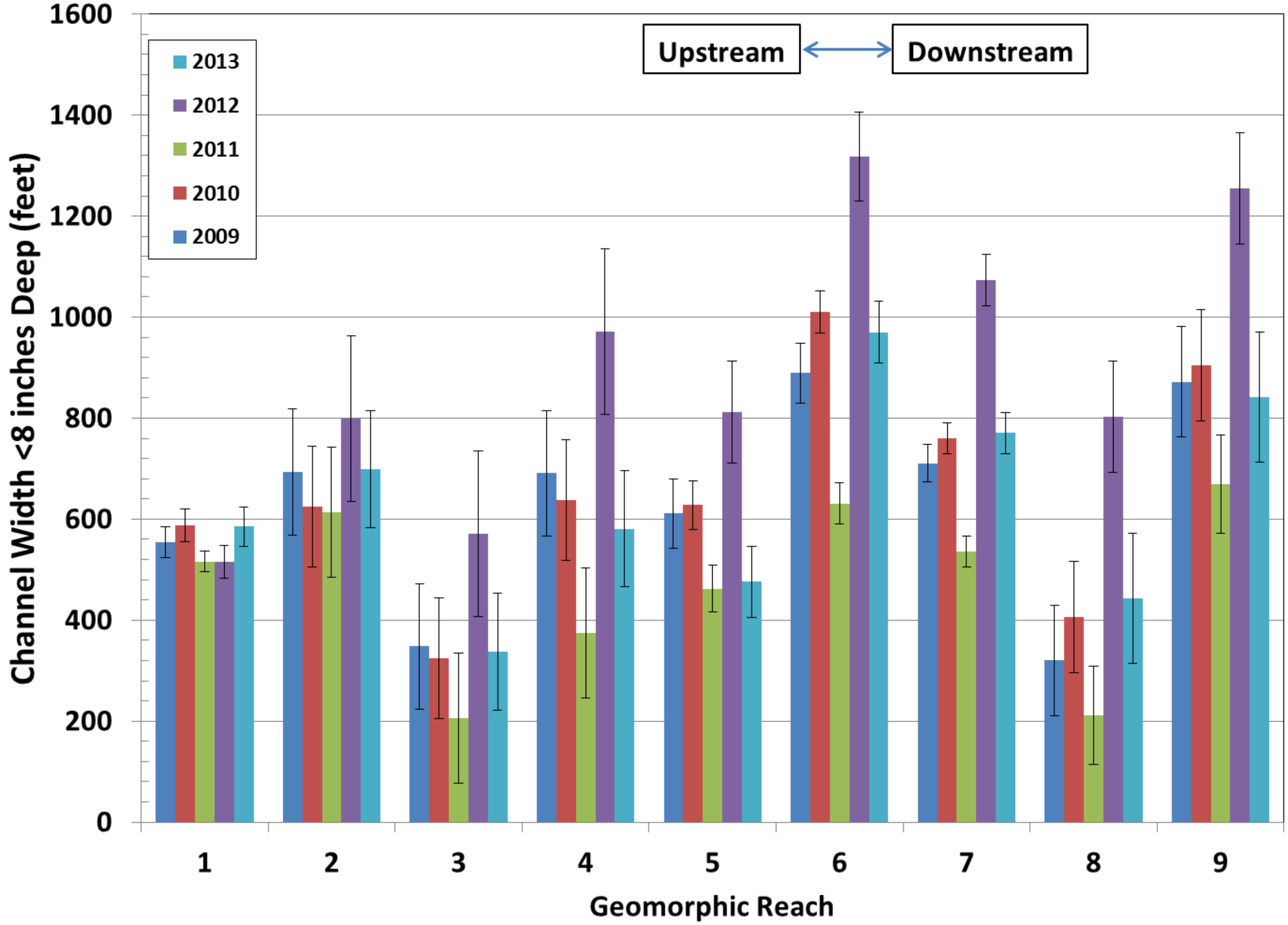
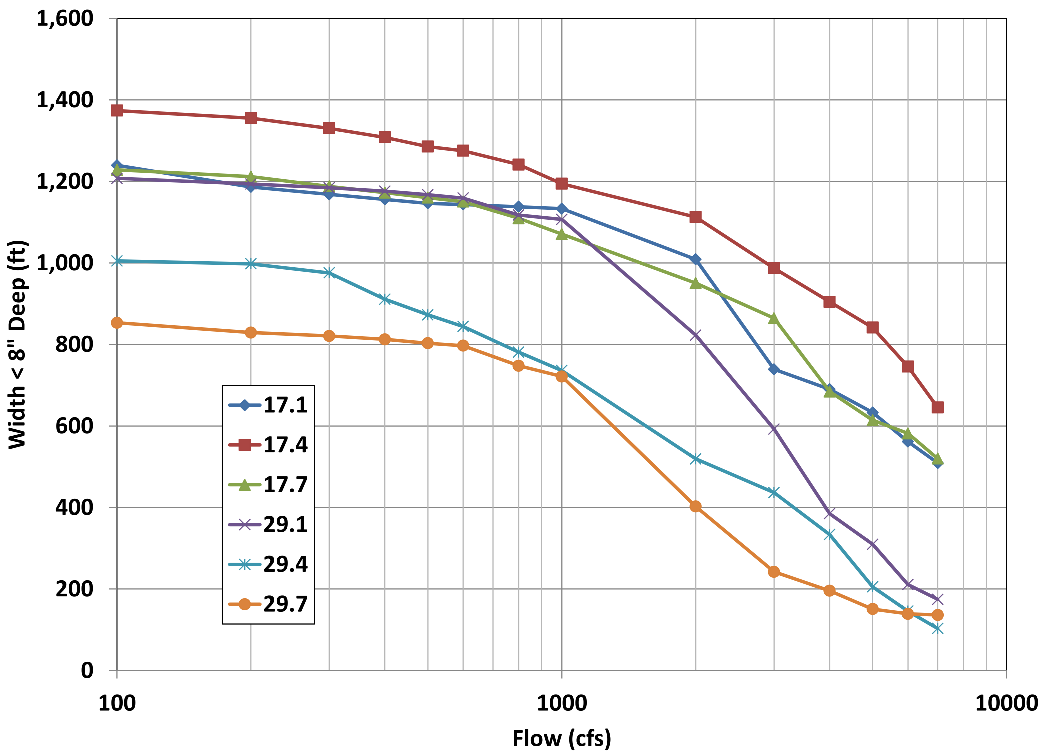


Figure 3.57c. Average width less than 8 inches deep (including exposed sandbars) at the fall migration season by geomorphic reach. Whiskers represent ±1 standard error. (AP37B was excluded from the average in Reach 2 because data are available only for 2009 through 2011.)



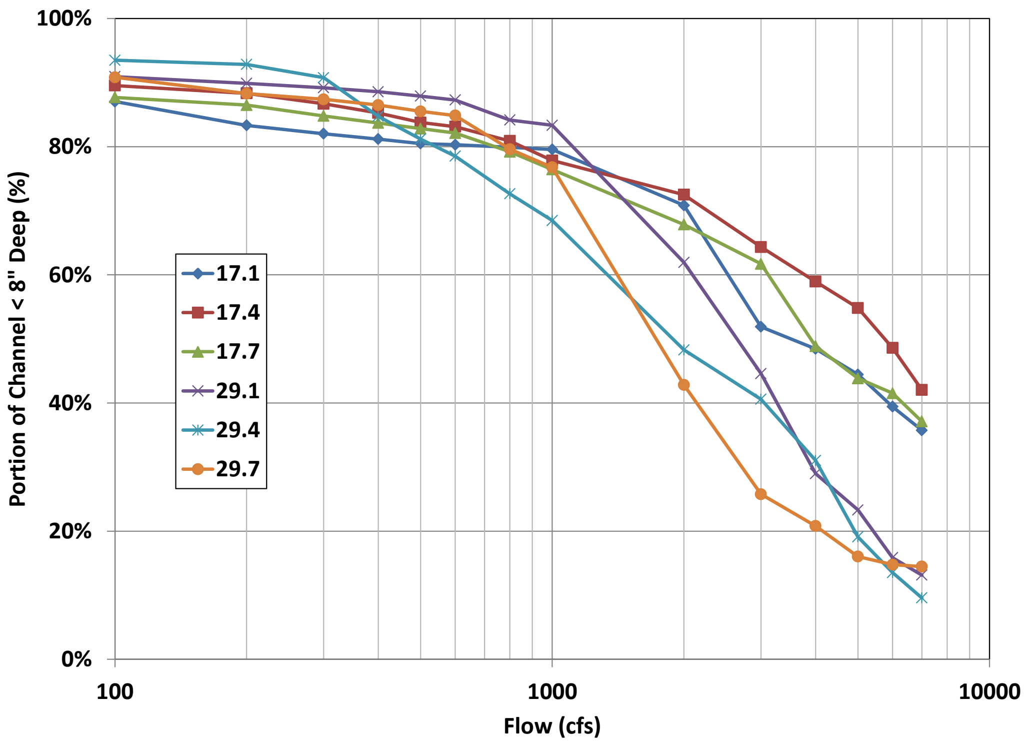


Figure 3.58. Typical relationship between (a) width of the channel and (b) percentage of total active channel width with depth less than 8 inches” deep and discharge, based on the three primary monitoring cross sections at AP 17 and AP 29.

4 HYPOTHESIS TESTING AND TREND ANALYSIS

As noted in Section 2.3, a broad range of statistical comparisons were made across the 2009 through 2012 data sets for the 2012 annual report to identify trends in the geomorphic, vegetation and sediment variables (Table 2.4). This resulted in a large number of analyses that are difficult to interpret in the context of Program priorities. To provide a more focused analysis, the Program directed that the analysis for the 2013 annual report be restricted to specific aspects of the following four hypotheses:

1. Flow #1
2. Flow #3
3. Flow #5
4. Mechanical #2

4.1 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.*

Evaluation of the validity of this hypothesis hinges on an understanding of the relative sediment balance along the reach. Two primary sources of data are available to assess the sediment balance: (1) year-to-year changes in bed sediment volume, based on repeat surveys of the three geomorphic transects at the pure panel APs (Section 3.3.7), and eventually, changes over the 4-year periods at the rotating panel APs, and (2) comparison of the annual sediment loads passing each of the five measurement sites, obtained by integrating the sediment load rating curves over the applicable flow records (Sections 3.5.1 and 3.5.2).

4.1.1 Sediment Balance Based on Transect Surveys

As discussed in Section 3.3.7, extrapolation of the volume changes from the transect surveys at the Pure Panel APs over the intervening, unsurveyed reaches indicates that the overall reach between Lexington and Chapman degraded by about 2.4M tons during Survey Year (SY)[7] 2010, about 1.2M tons during SY2011, and then aggraded by about 5.8M tons during SY2012 and an additional 1.6M tons during SY2013 (Figure 3.12c). This resulted in estimated net aggradation in the overall reach of about 3.8M tons over the four-year period encompassed by the surveys, or about 938,000 tons per year.

Geomorphic Reach 1 (Lexington to Overton Bridge, including the north channel at Jeffreys Island) degraded by about 336,000 tons during SY2010, and then aggraded by 341,000 tons in each of the two succeeding years, followed by additional aggradation of about 270,000 tons in the last year, resulting in net **aggradation** over the 4-year period of about 617,000 tons, or an average of about 154,000 tons/year (Figure 3.12d).

[7]The transect surveys and other detailed field data during all five years were generally collected between mid-July and late-August. To simplify the discussion and to facilitate comparison of the aggradation/ degradation trends based on the surveys with those based on the sediment load rating curves, Survey Years are defined as the period between August 1 of the previous year and July 31 of the current year [e.g., Survey Year (SY) 2010 refers to the period from Augusut 1, 2009 through July 31, 2010).

Based on the repeat surveys at AP35B, Reach 2 (south channel at Jeffreys Island, where essentially all of the flow is derived from the J-2 Return) degraded by about 187,000 tons during SY2010, and it also degraded during SY2011 and SY2013 (~89,000 tons and ~26,000 tons, respectively). With approximately 121,000 tons of aggradation during SY2012, the reach experienced net **degradation** over the 4-year period of approximately 180,000 tons, or about 45,000 tons/year.

Two pure panel APs (AP35B and AP37B) are located in Reach 2. Because permission to access AP37B was revoked by the landowner prior to the 2011 surveys, the aggradation/degradation quantities are based only on the repeat surveys at AP35B to insure consistency in the estimates across all years. (The 2009 and 2010 data indicate that AP37B degraded by about 16,000 tons during the first year of the monitoring program, while AP35B degraded by only about 10,000 tons; thus, the estimates based on only AP35B may be on the low side for this reach.) AP35B is located about 2 miles upstream from the Overton Bridge and about 1 mile upstream from the outfall at the Dyer Property where 82,000 tons of sand was pumped and mechanically graded into the river between September 2012 and June 2013 as part of the Program's Pilot Sediment Augmentation Project (The Flatwater Group et al., 2014). A monitoring cross section about 1,200 feet upstream from the Dyer outfall (XS-1, **Figure 4.1**) showed little net change between the pre- and post-augmentation surveys in August 2012 and August 2013; thus, the augmentation does not appear to have affected aggradation/degradation patterns in the majority of Reach 2 upstream from the outfall. Surveys at the other Pilot Study monitoring sections indicate that about 26,000 tons of sediment accumulated between the outfall and XS-5 between August 2012 and August 2013. Since the pumped sediment was mechanically graded into the river, it is assumed that the remaining 56,000 tons of augmented sediment were transported downstream past the pilot-augmentation monitoring area.

Based on the surveys at AP31, Reach 3 (Overton Bridge to Elm Creek Bridge) degraded by about 36,000 tons during SY2010. As noted above, AP33 was excluded from the SY2010 calculation because a large mid-channel bar was mechanically graded into the channel in Fall 2009; thus, the changes do not reflect trends in the overall sediment transport balance in the reach. Based on both AP31 and AP33, Reach 3 degraded by an additional 313,000 tons during SY2011 and 95,000 tons during SY2013. Considering the approximately 171,000 tons of aggradation during SY2012, this reach appears to have experienced net **degradation** of about 324,000 tons over the four-year monitoring period, or an average of about 81,000 tons/year. Other mechanical grading activities added about 200,000 tons of sediment into the main river channel during the 4-year monitoring period [50,000 tons each in 2010 and 2011, and 100,000 tons during SY2013 (Jason Farnsworth, personal communication, 2014; The Flatwater Group et al., 2014)]. About 130,000 tons of sediment were also graded into the channel during the 5-year period prior to the start of this monitoring program.

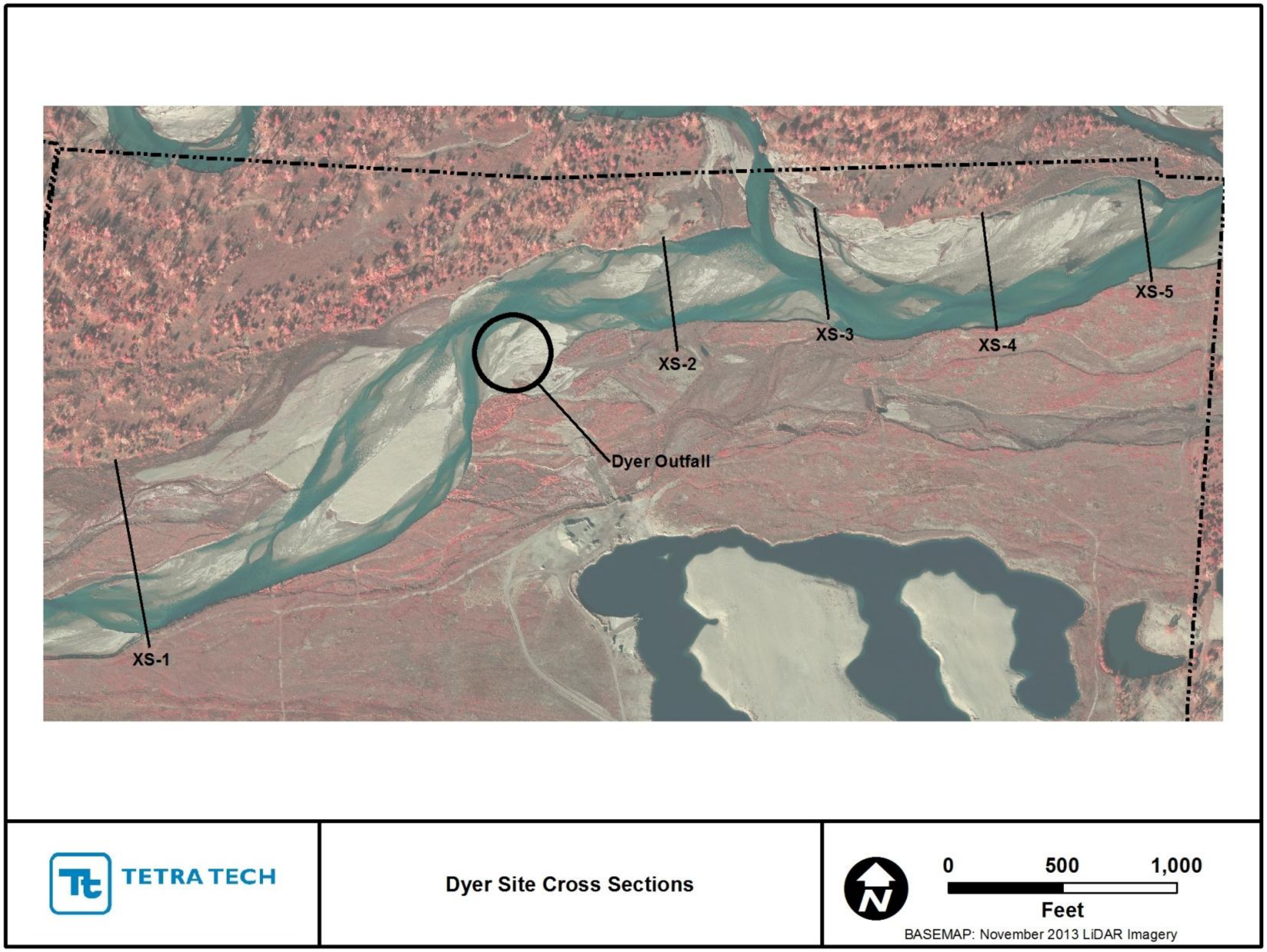


Figure 4.1. Vicinity map of the pilot sediment augmentation area showing the location of the Dyer Outfall and the five monitoring cross sections.

Long-term measurements by the USGS at the Overton gage that is located at the boundary between Reaches 1, 2 and 3 indicate that the channel steadily degraded by a total of about 3.5 feet between 1987 and 2011; however, the more recent data indicate a slight aggradational trend since early 2011 (**Figures 4.2a and b**). Comparison of the data collected at rotating panel AP34 that is located just downstream from the Overton Bridge (and gage), for this monitoring program in July 2012 with surveys conducted at the same transects for the Pilot Sediment Augmentation Study in December 2012 showed a modest degradational tendency over this relatively short period. Similar measurements at the USGS Cottonwood Ranch Mid-Channel Gage, that is located about 3 miles upstream from the Elm Creek Bridge, indicate that this location degraded by about 1 foot between WY2001 and WY2007 and then aggraded back by about 2 feet between WY2007 and early-WY2012 (**Figure 4.3**). Although there is significant scatter in the data, there appears to have been a modest aggradational trend during the first three years of this monitoring program, but a degradational trend may have occurred in WY2012 and WY2013.

Based on the surveys at AP29, Reach 4 (Elm Creek to Odessa) degraded by about 392,000 tons during SY2010 surveys, and then aggraded in all of the subsequent monitoring years (279,000 tons in SY2011, 466,000 tons in SY2012 and 291,000 tons in SY2013), resulting in net aggradation over the 4-year period of about 644,000 tons or about 161,000 tons/year. AP29 is located about midway between the Kearney Canal Diversion Structure (KDS) and the Odessa Bridge. Repeat surveys at 13 cross sections between the KDS and AP29 for the Elm Creek Adaptive Management Experiment indicate that this part of the reach aggraded by about 3,300 tons between April 2011 and August 2013, a rate considerably lower than is indicated by the monitoring data at AP29 (Tetra Tech, 2014). The Elm Creek AM data also indicate that the portion of the reach between the Elm Creek Bridge and the KDS degraded by about 57,000 tons during the 27-month period encompassed by the surveys, with about 22,000 tons of degradation between April 2011 and August 2011, about 9,000 tons of aggradation between August 2011 and August 2012, and the remaining 43,000 tons of degradation between August 2012 and August 2013. The downstream portion of the Elm Creek Reach degraded by about 17,000 tons between August 2011 and August 2012, and then aggraded back by about the same amount between August 2012 and August 2013. The modest amount of aggradation in the downstream portion of the reach occurred during Summer 2011. These results suggest that basing the aggradation/degradation trends for Reach 4 solely on the surveys at AP29 may not accurately represent the amount of change that is actually occurring in the overall reach.

Reach 5 (Odessa to Minden), that includes pure panel AP23, AP25 and AP27, degraded by about 1.4M tons during SY2010 surveys and an additional 590,000 tons during SY2011. The reach then aggraded by about 890,000 tons during SY2012, with very little change (~3,000 tons of aggradation) during SY013, resulting in net degradation over the 4-year period of about 1M tons, or about 268,000 tons/year. For comparison, the USGS gage measurement data indicate that the cross section at the Kearney gage, which is located in the middle of the reach, was slightly aggradational to stable from the mid-1980s through the early-2000s, and it then degraded by about one foot between 2002 and 2005 (**Figure 4.4**). Since 2005, the mean bed elevation has fluctuated in a range of about +/-0.5 feet with no strong trend of aggradation or degradation.

Based on the surveys at AP21, near the Rowe Sanctuary, Reach 6 aggraded by a relatively modest 217,000 tons over the 4-year period, or an average of about 50,000 tons/year. The year-to-year changes were, however, significant, ranging from 706,000 tons of degradation during SY2010 to 1.4M tons of aggradation during SY2012. The temporal patterns of aggradation and degradation were similar in Reaches 7, 8 and 9, with cumulative aggradation

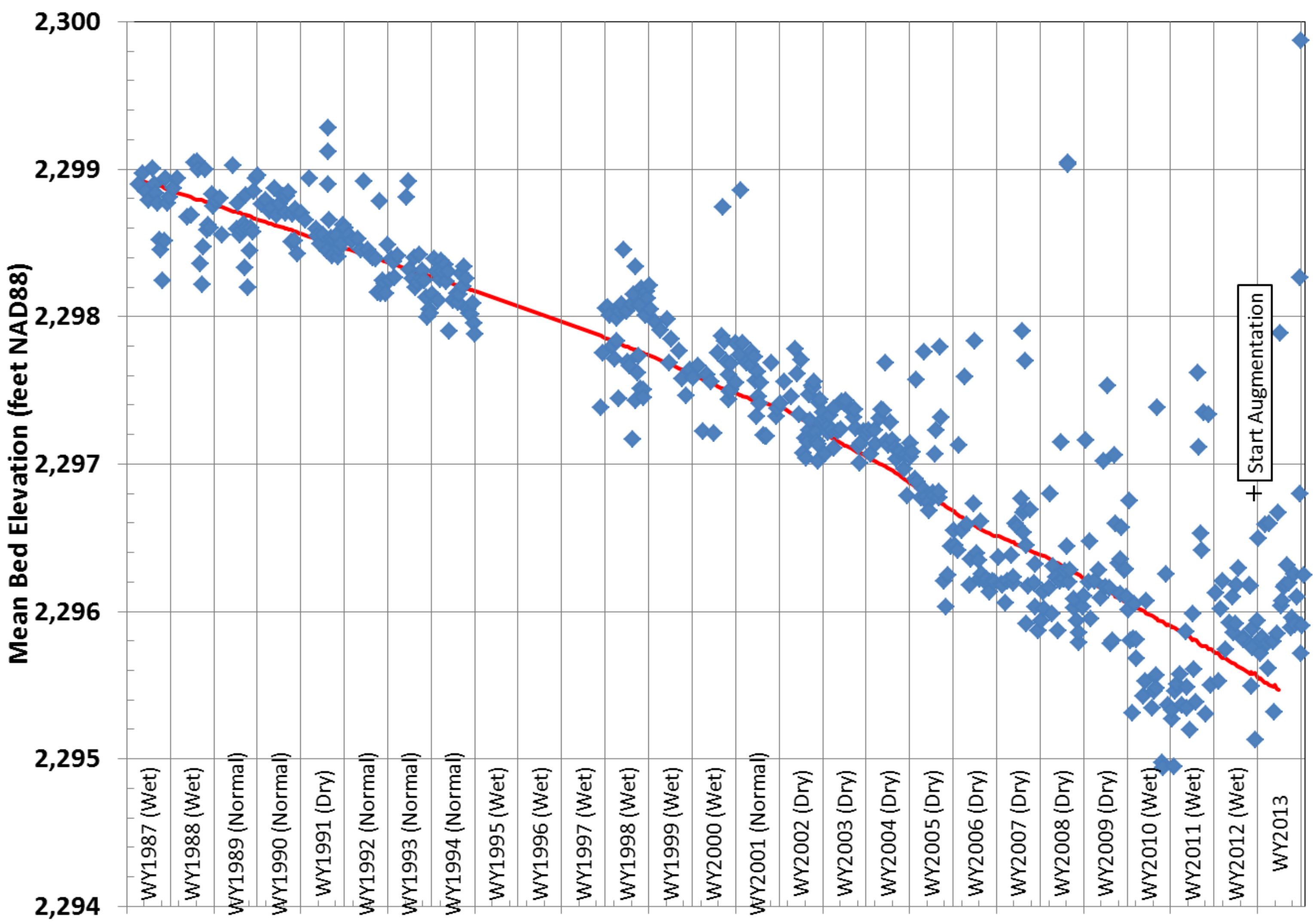


Figure 4.2a. Mean bed elevations at the Overton, based on USGS field measurement data collected during WY1987 through WY2013.

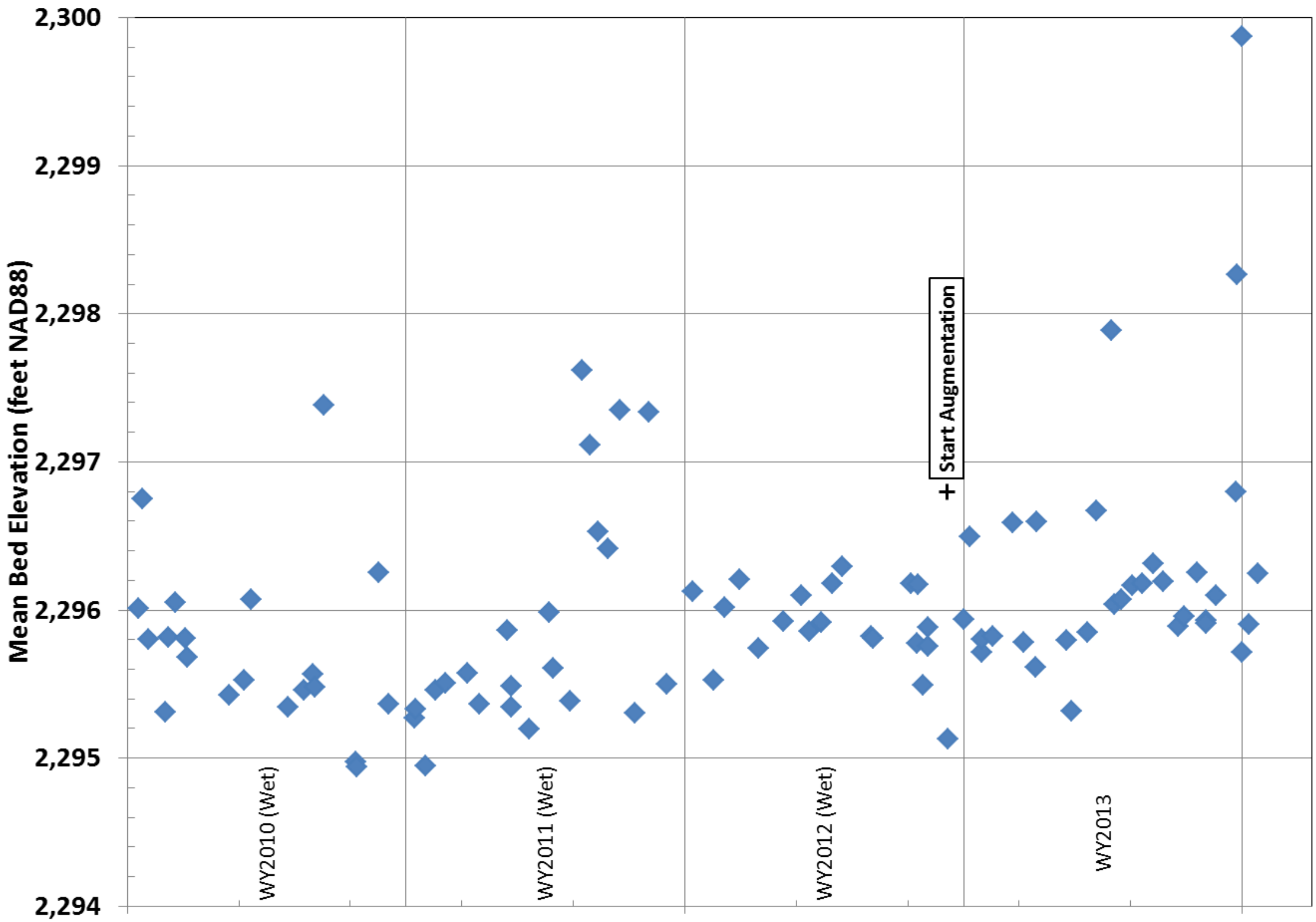


Figure 4.2b. Mean bed elevations at the Overton, based on USGS field measurement data collected during WY2010 through WY2013 (same data as Figure 4.3a).

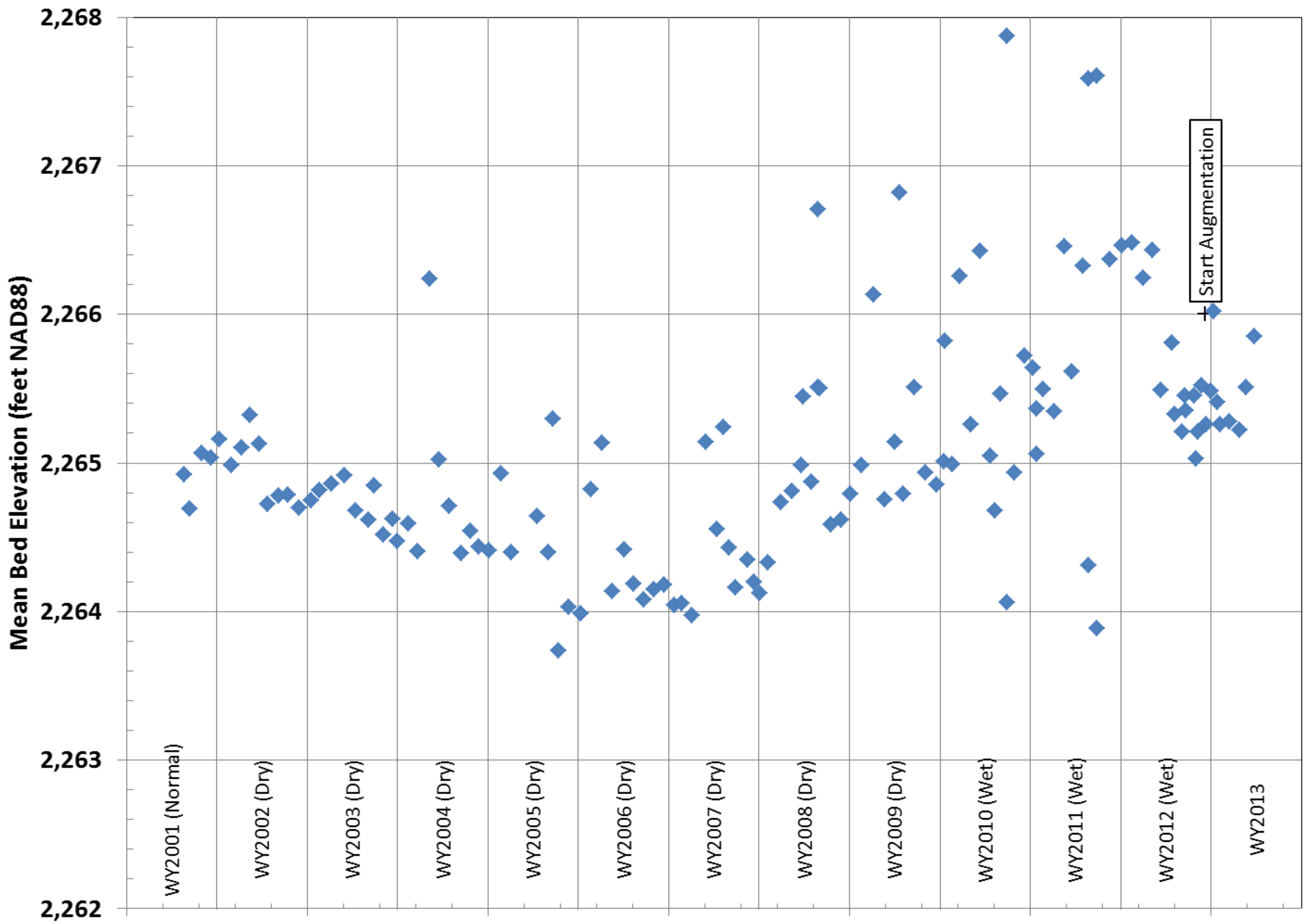


Figure 4.3. Mean bed elevations at the Cottonwood Ranch Mid-Channel gage, based on USGS field measurement data collected during WY2001 through WY2013.

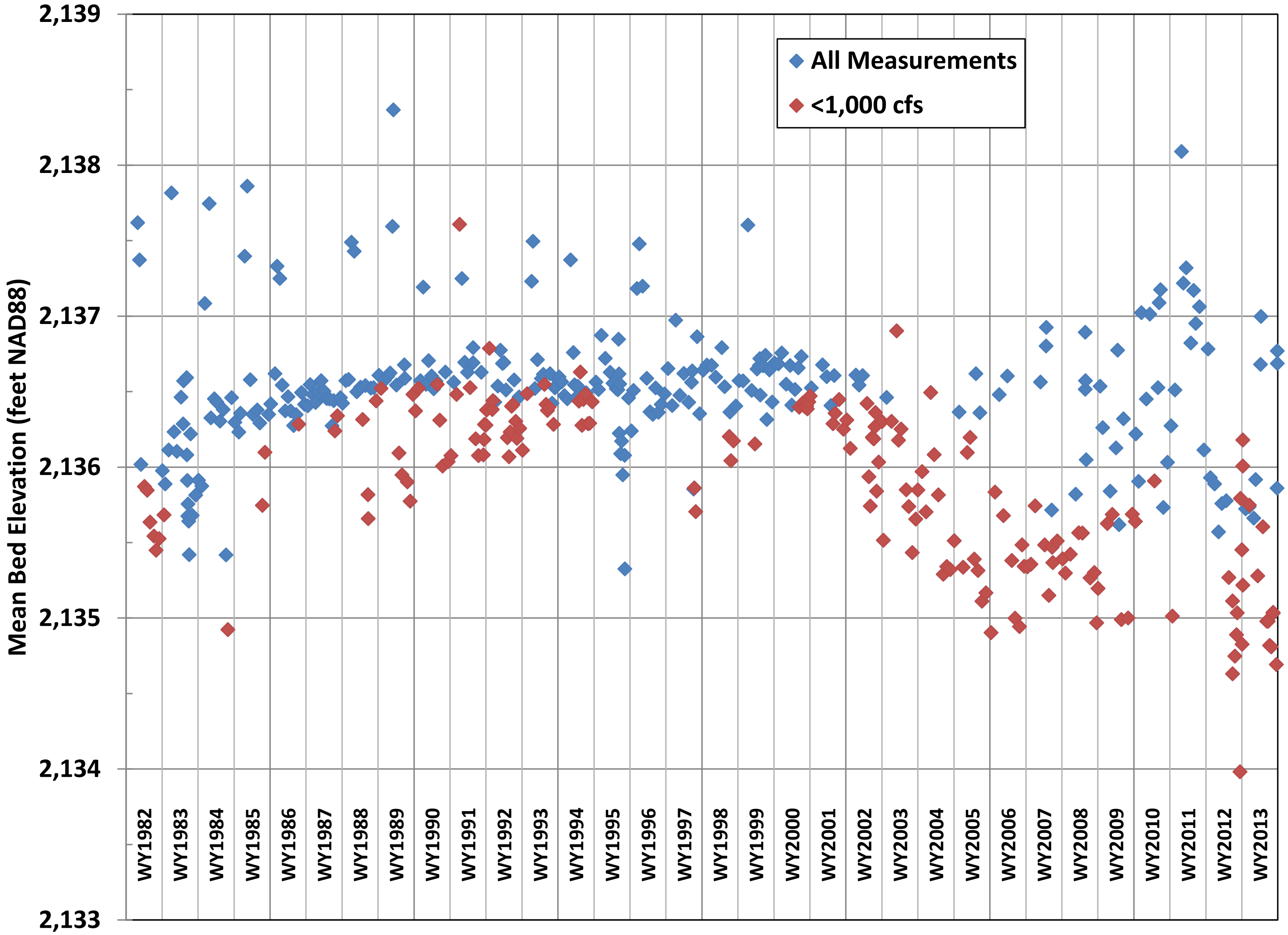


Figure 4.4. Mean bed elevations at the Kearney gage, based on USGS field measurement data collected during WY1982 through WY2013.

among the three reaches of about 640,000 tons during SY2010, 790,000 tons of degradation during SY2011, 2.6M tons of aggradation during SY2012 and an additional 1.4M tons of aggradation during SY2013. (Note that Reach 7 actually degraded by about 135,000 tons during SY2013.) Based on these results, this part of the overall study reach accumulated sediment at a rate of about 960,000 tons/year over the 4-year period. For comparison, the USGS measurement data indicate that the cross section at the Grand Island gage, which is located at the boundary between Reaches 8 and 9, steadily degraded by about 2 feet between the early-1980s and about 2006, but has not shown a systematic trend since that time (**Figure 4.5**).

4.1.2 Sediment Balance Based on Sediment Load Rating Curves

The sediment balance during the four years encompassed by the surveys was estimated from the sand load rating curves discussed in Sections 3.5.1 and 3.5.2 by integrating the MVUE bias-corrected curves over the respective mean daily flow records and comparing the resulting loads between stations. The integrations were performed using flow data for the Survey Years[7] that extend from August 1 of the previous year to July 31 of the current year to facilitate comparison of the sediment balance based on the rating curves with the aggradation/degradation estimates from the transect surveys.

Because the rating curves for the bed and suspended loads were developed separately using data points that do not necessarily represent the same time and discharge, the total load cannot be calculated by simply adding corresponding data points. In addition, the scatter in the data and resulting confidence bands on the two sets of curves are quite different; thus, quantification of the uncertainty associated with each part of the load, as discussed in the next section, requires separate treatment of the data sets. The bed- and suspended sand-load curves were, therefore, integrated separately and the resulting volumes were combined to estimate the total load of sand and coarser material. These volumes represent the “best-estimate” of the bed, suspended sand, and total sand/gravel load at each site (**Figures 4.6a-c**). The results indicate that the total sand load generally increased in the downstream direction during all four years, although Overton had the highest load of the five stations during SY2013, when the flows were generally very low. (A short-duration medium flow (SDMF) release with peak discharge of 4,090 cfs and discharge exceeding 3,800 cfs for about 54 hours at the Overton gage, was, however, made in early April, 2013.) The results also indicate that the total loads at Shelton tend to be lower than at either Kearney or Grand Island.

Based on these results, the total sand load passing Overton exceeded the load passing Darr by a total of about 441,000 tons over the four year period (~110,000 tons/year, on average) (**Figure 4.7**). Considering the 82,000 tons of sediment that was pumped and graded into the south channel at Jefferys Island about one mile upstream from the Overton Bridge between September 2012 and June 2013 for the Pilot Sediment Augmentation Project and assuming that the sediment input from J-2 Return flows is negligible, this indicates that the segment of the study reach between the Darr Bridge and Overton (including the south channel at Jefferys Island) degraded by about 359,000 tons over the four year period, or an average of about 90,000 tons/year. The bulk of the deficit (~269,000 tons) occurred during SY2012.

The total sand load passing Kearney exceeded the load at Overton by about 344,000 tons over the 4-year period (~86,000 tons/year, on average). As noted above, approximately 50,000 tons of sediment were graded into the river at Cottonwood Ranch, just downstream from AP31 during SY 2010 and SY2011, and 100,000 tons of sediment were graded into the channel at this location between September 2012 and April 2013 as part of the Pilot Sediment Augmentation project. Assuming that none of the graded material would have been available for transport in

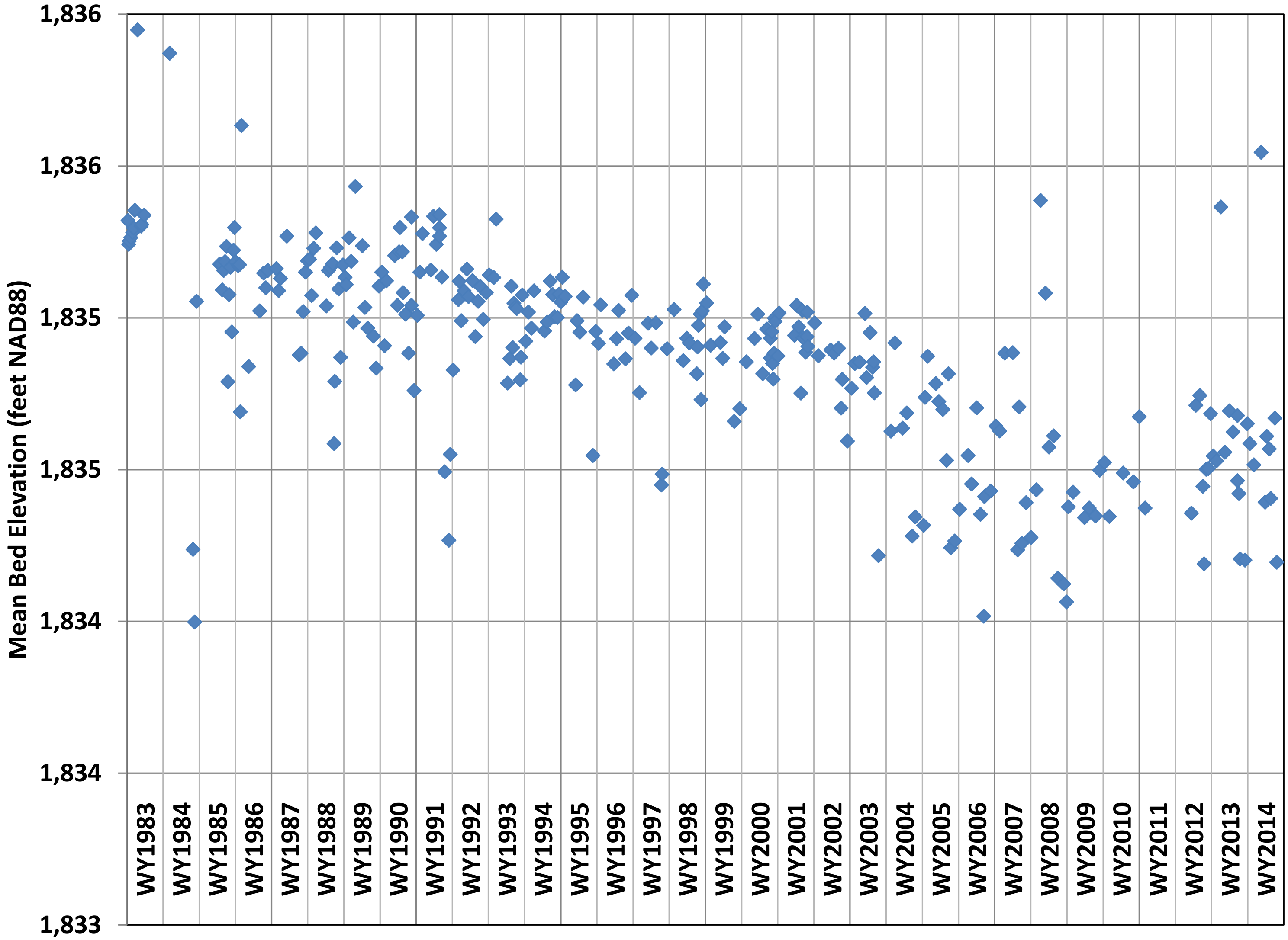


Figure 4.5. Mean bed elevations at the Grand Island gage, based on USGS field measurement data collected during WY1982 through WY2013.

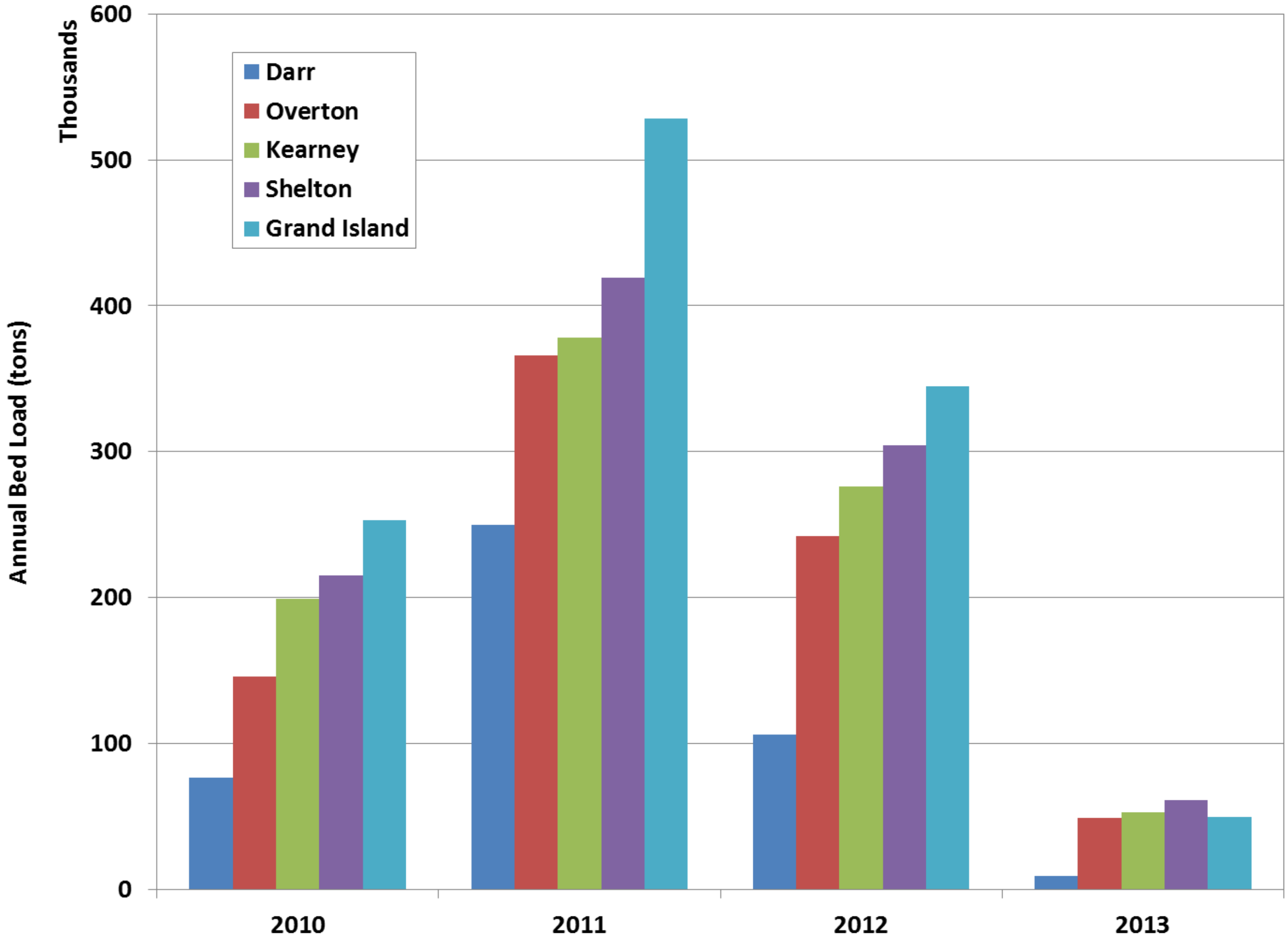


Figure 4.6a. Best-estimate of annual bed load passing the Darr, Overton, Kearney, Shelton and Grand Island measurement point during Survey Years (SY) 2010, 2011, 2012 and 2013, based on integration of the bias-corrected bed load rating curves.

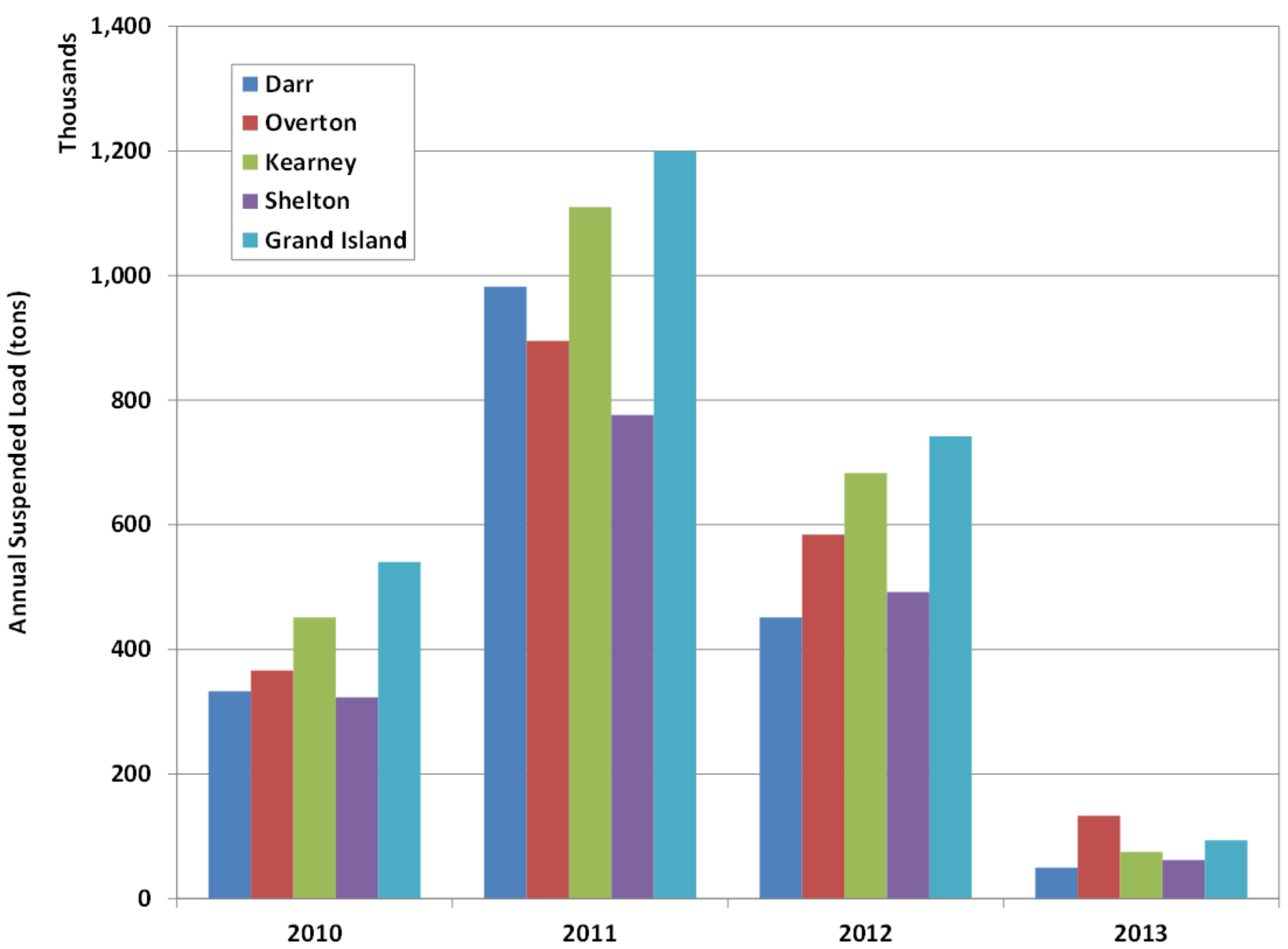


Figure 4.6b. Best-estimate of annual suspended sand load passing the Darr, Overton, Kearney, Shelton and Grand Island measurement point during Survey Years (SY) 2010, 2011, 2012 and 2013, based on integration of the bias-corrected sand load rating curves.

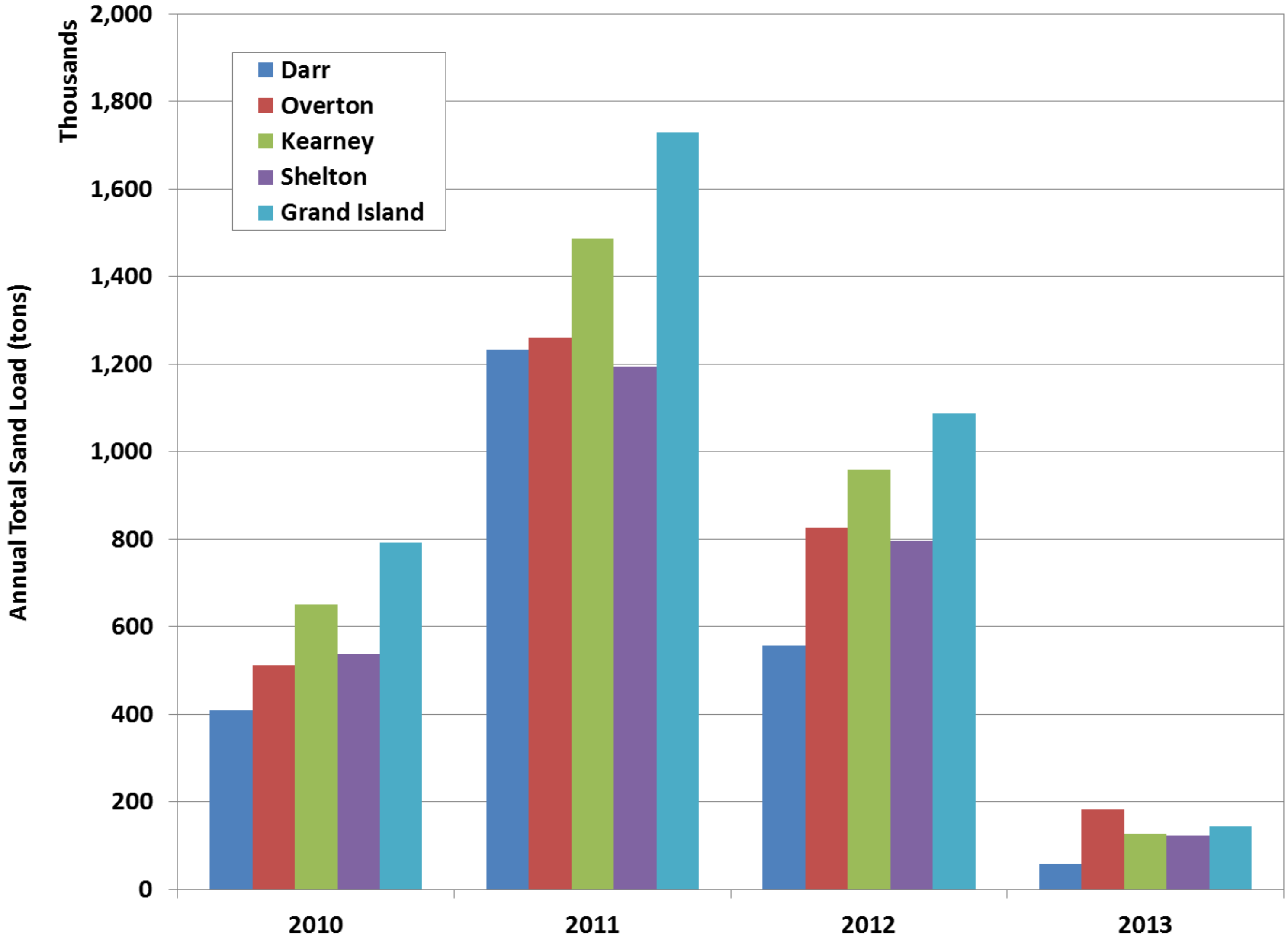


Figure 4.6c. Best-estimate of annual total sand/gravel load passing the Darr, Overton, Kearney, Shelton and Grand Island measurement point during Survey Years (SY) 2010, 2011, 2012 and 2013.

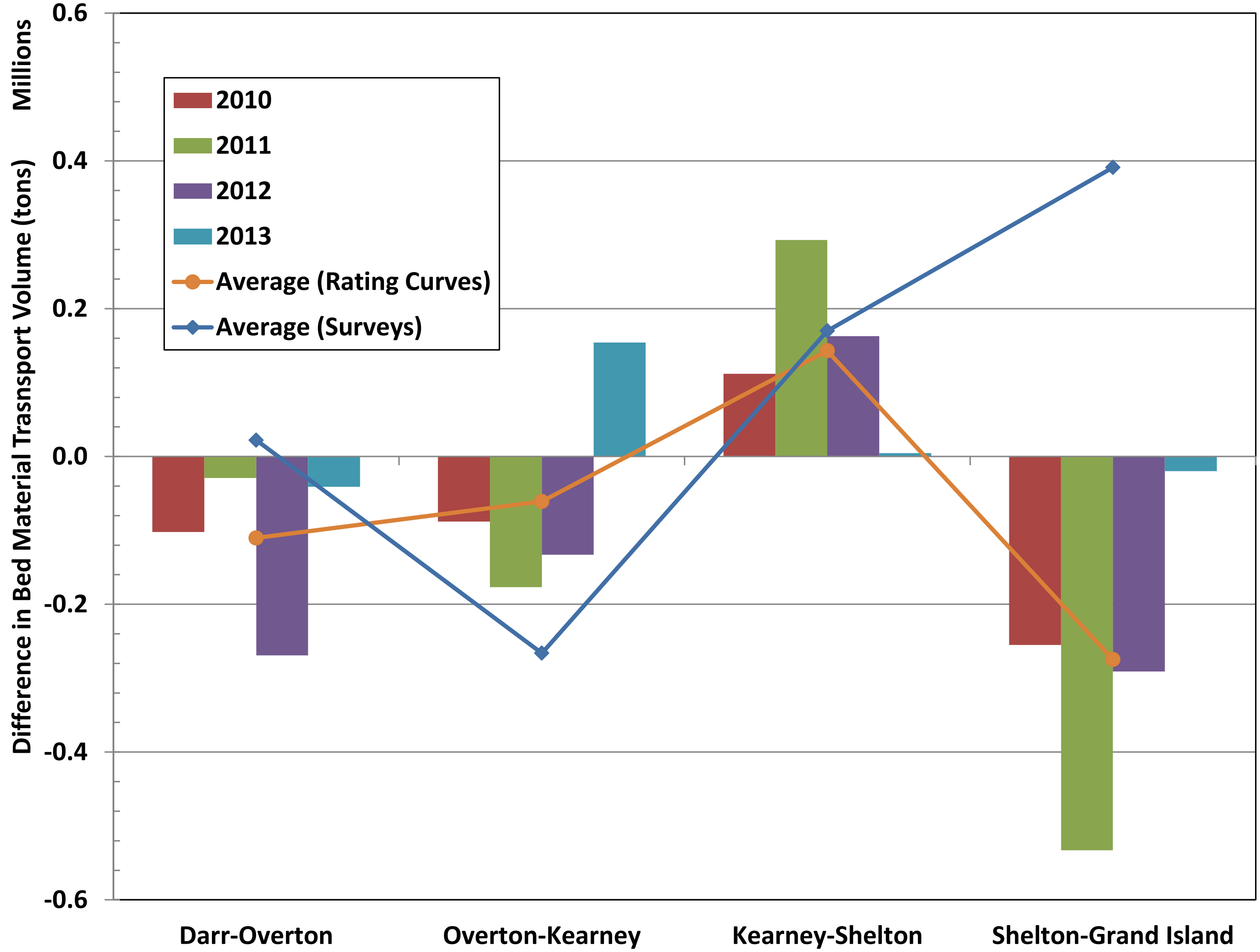


Figure 4.7. Best-estimate of the annual sand transport balance between the five measurement locations during SY2010, 2011, 2012, and 2013. Also shown are the 4-year averages from the rating curves and from the survey-based estimates.

the river in the absence of the grading, this additional input indicates that the reach between Overton and Kearney degraded by about 144,000 tons over the 4-year period, or about 36,000 tons/year.

Based on the bias corrected rating curves, the total sand load passing Kearney exceeded the load passing Shelton by about 632,000 tons over the 4-year period, or an average of about 158,000 tons/year. Over half of the sediment excess occurred during SY2012 (~320,000 tons). Integration of the rating curves also indicates that the sand load passing Grand Island exceeded the load at Shelton by about 1.5M tons over the 4-year period, or about 286,000 tons/year.

Some of the apparent sediment imbalance in the reach that is indicated by these results may be compensated for by unaccounted-for tributary input, although it is unlikely that this input is sufficient to substantively change the overall result. The total tributary input between Overton and Wood River (~8 river miles downstream from Shelton) was estimated by DOI et al. (2006) to be about 105,000 tons/year over the 48-year period from 1947 through 1990, or 11 percent to 18 percent of the estimated loads in the river. It is not clear from the DOI et al. (2006) report whether these loads include silts and clays, as well as the sand load, but the context in which it was presented implies that it does not include the silts and clays. The incremental contributing drainage area between Overton and Grand Island is only about 1,320 mi^2, about 2.5 percent of the approximately 52,000 mi^2 total drainage area. Based on the relatively small incremental drainage area and the conditions at the mouths of the significant tributaries that include Plum Creek (south bank tributary to south channel at Jefferys Island), Spring Creek (north bank tributary just downstream from Overton Bridge), Buffalo and Elm Creek (north bank tributary just upstream from the KDS), and North Dry Creek [south bank tributary just upstream from Kearney (Highway 44) Bridge], sand loading from the tributaries to the Platte River mainstem is likely much smaller than the DOI et al. (2006) estimate and negligible compared to the typical loads in the river.

The sediment balance based on the bias-corrected rating curves is significantly different from the balance based on the aggradation/degradation estimates from the transect surveys. The surveys indicate that the reach between Darr and Overton was roughly in balance to slightly aggradational over the period (net aggradation of ~22,000 tons/year), with degradation during SY2010 and SY2011 and aggradation in SY2012 and SY2013, while the rating curves indicate that the reach should have degraded by an average of about 110,000 tons/year (**Figure 4.8** and Figure 4.7). Both data sets indicate that the reach between Overton and Kearney was degradational, although the magnitude from the surveys is about 4 times higher than the rating curve-based value (~266,000 tons/year versus ~61,000 tons/year). The surveys indicate significant degradation during SY2010 and SY2011, aggradation during SY2012, and modest degradation during SY2013, while the rating curves indicate degradation during the first three years and aggradation during SY2013. Both data sets also indicate net aggradation between Kearney and Shelton, with four-year averages of about 143,000 tons/year based on the rating curves and 170,000 tons/year based on the surveys. Although the 4-year averages are reasonably close, the year-to-year behavior is quite different between the two data set. The surveys showed degradation during SY2010, SY2011 and SY2013, but aggradation during SY2012 that was sufficient to more than overcome the deficits in the other three years. In contrast, the rating curves indicate aggradation during the first three years and approximate balance during SY2013. The results from the two data sets are also very different in the reach between Shelton and Grand Island, with average net aggradation of about 390,000 tons/year based on the surveys and net degradation of about 286,000 tons/year based on the rating curves. Based on the surveys, degradation occurred only in SY2011, while degradation

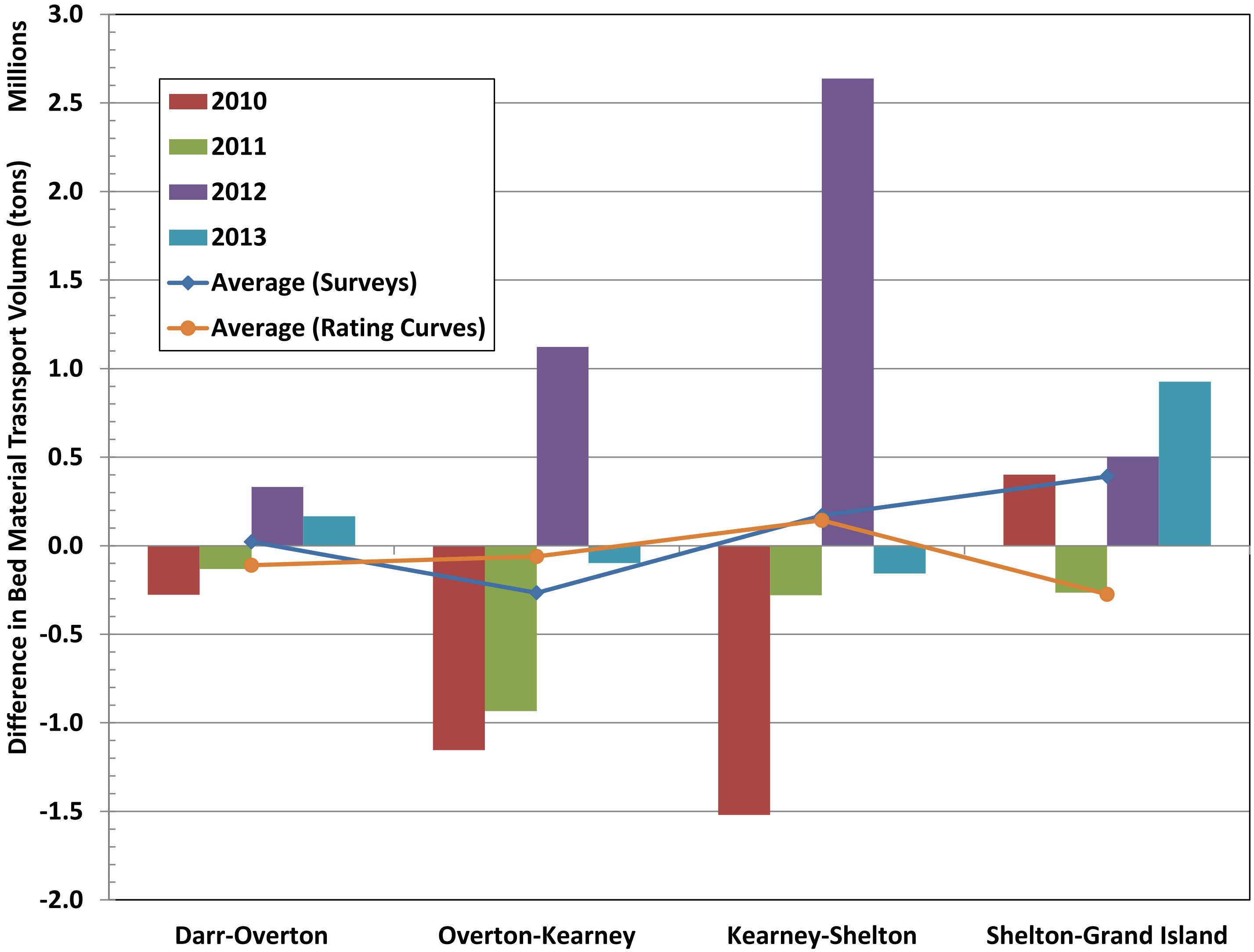


Figure 4.8. Estimated annual aggradation/degradation quantities from the pure panel AP survey data in the reaches encompassed by the five sediment-transport measurement sites. Also shown are the average annual aggradation/degradation quantities from both the surveys and the rating curves.

occurred in all four years based on the rating curves (although the amount of degradation in SY2013 was relatively small).

4.1.3 Uncertainty in Sediment Balance Estimate

There is considerable uncertainty in the sediment balance estimates for both of the above sets of data. The survey-based estimates rely on data at only three transects that are spaced about 500 feet apart in each approximately 5-mile length of the river. Because each transect represents the cross-section profile along only a single line across the river, uncertainty is introduced into the result because the surveyed lines may not accurately reflect the changes that occur in the intervening approximately 500 feet of the river. In addition, the cumulative length encompassed by the three cross sections at each AP represents only about 4 percent of the total length that is being characterized by the AP, and there is uncertainty as to how well the aggradation/degradation response at the AP represents the response in the longer, unsurveyed portions of the reach. Uncertainty in the elevations of the individual survey points also contributes to uncertainty, although this is appears to be a very minor factor compared to the other sources of uncertainty. The rating curve-based sediment balance is also subject to relatively large uncertainty because of the inherently high variability in the data used to develop the rating curves. These sources of uncertainty were quantified, to the extent possible with the available data, to help understand the implications to the Program's ability to draw valid conclusions about whether each portion of the reach is aggrading, degrading or in dynamic equilibrium.

The uncertainty in the rating curve-based estimates was estimated by performing Monte Carlo simulations of annual sediment loads based on the uncertainty bands on each rating curve. The simulations were performed by generating 1,000 estimates of the annual loads for each site assuming that the variability in the logarithm of the individual, estimated loads at the mean of the logarithms of the discharges in each data set follows a normal distribution with mean equal to the load estimated from the rating curve and upper and lower 95-percent confidence limits equal to the corresponding confidence limits on the regression equation at the mean discharge (**Table 4.1**). The difference in annual sediment load between the sites was then calculated for each of the 1,000 sets of annual loads, and the resulting data set was used to assess the variability in the estimated aggradation/degradation volumes.

The above assumptions are illustrated using the suspended sand curves at the Overton site in **Figures 4.9a-c**. The best-estimate sediment load at the back-transformed log mean discharge of the data set (3,465 cfs) is 2,113 tons per day (tpd), and the upper and lower 95-percent confidence limits on the regression line at this discharge are 1,555 tpd and 2,869 tpd, respectively (green vertical line in Figure 4.9a). The resulting standard deviation of the predicted sediment loads in the log domain at this discharge is 0.081. The distribution of the predicted sediment loads at the mean from the Monte Carlo simulation ranged from about 1,150 to 3,650 cfs (Figure 4.9b). The best-estimate of the exponent on the rating curve is 1.268, and the standard deviation of this estimate is 0.251. The resulting exponents from the Monte Carlo simulation ranged from 0.27 to 2.06 (Figure 4.9c). The coefficient (*a*) on the rating curve for each of the 1,000 estimates was back-calculated using on the predicted sediment load (log) at the mean discharge and the exponent (*b*) for each step in the simulation. The annual sediment loads at this site from the Monte Carlo simulation had central tendency very close to the best-estimate values for each year discussed above, but ranged from about 189,000 to 675,000 tons in 2010, 489,000 to 1.525M tons in 2011, 319,000 to 1.019M tons in 2012 and from 50,000 to 455,000 tons in 2013 (**Figure 4.10**).

Table 4.1. Summary of bed and suspended sand load regression equations and associated statistics.									
Measurement Site	Mean Discharge[1]	a[2]	b[2]		Average Bias Correction Factor[3]	Best-estimate Sand Load at log Mean Discharge (tons)[4]			
			Mean	Standard Deviation		Mean	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Standard Deviation (log)
Bed Load									
Darr	2,798	-1.570	1.323	0.271	1.08	975	686	1,385	0.093
Overton	3,818	-1.527	1.242	0.495	1.33	837	519	1,351	0.126
Kearney	3,849	-0.445	0.964	0.305	1.19	1,030	717	1,480	0.096
Shelton	3,354	-1.090	1.149	0.354	1.21	912	625	1,350	0.099
Grand Island	3,781	-1.472	1.276	0.337	1.24	1,233	804	1,893	0.113
Suspended Sand Load									
Darr	2,239	-0.611	1.215	0.261	1.14	2,876	2,068	3,999	0.087
Overton	3,465	-1.163	1.268	0.251	1.15	2,113	1,555	2,869	0.081
Kearney	3,315	-2.169	1.569	0.251	1.20	2,260	1,562	3,268	0.097
Shelton	2,781	-2.574	1.643	0.284	1.09	1,217	929	1,596	0.071
Grand Island	3,504	-1.708	1.448	0.231	1.14	2,664	1,968	3,605	0.080

[1] Mean discharge of measured data set

[2] Coefficient and exponent of power function rating curve (Sediment Load=a*Discharge^{b})

[3] Average bias correction factor for mean daily discharges in the four-year data set

[4] Best-estimate sediment load, confidence limits and standard deviation (log domain) of regression confidence bands at mean discharge of measured data set

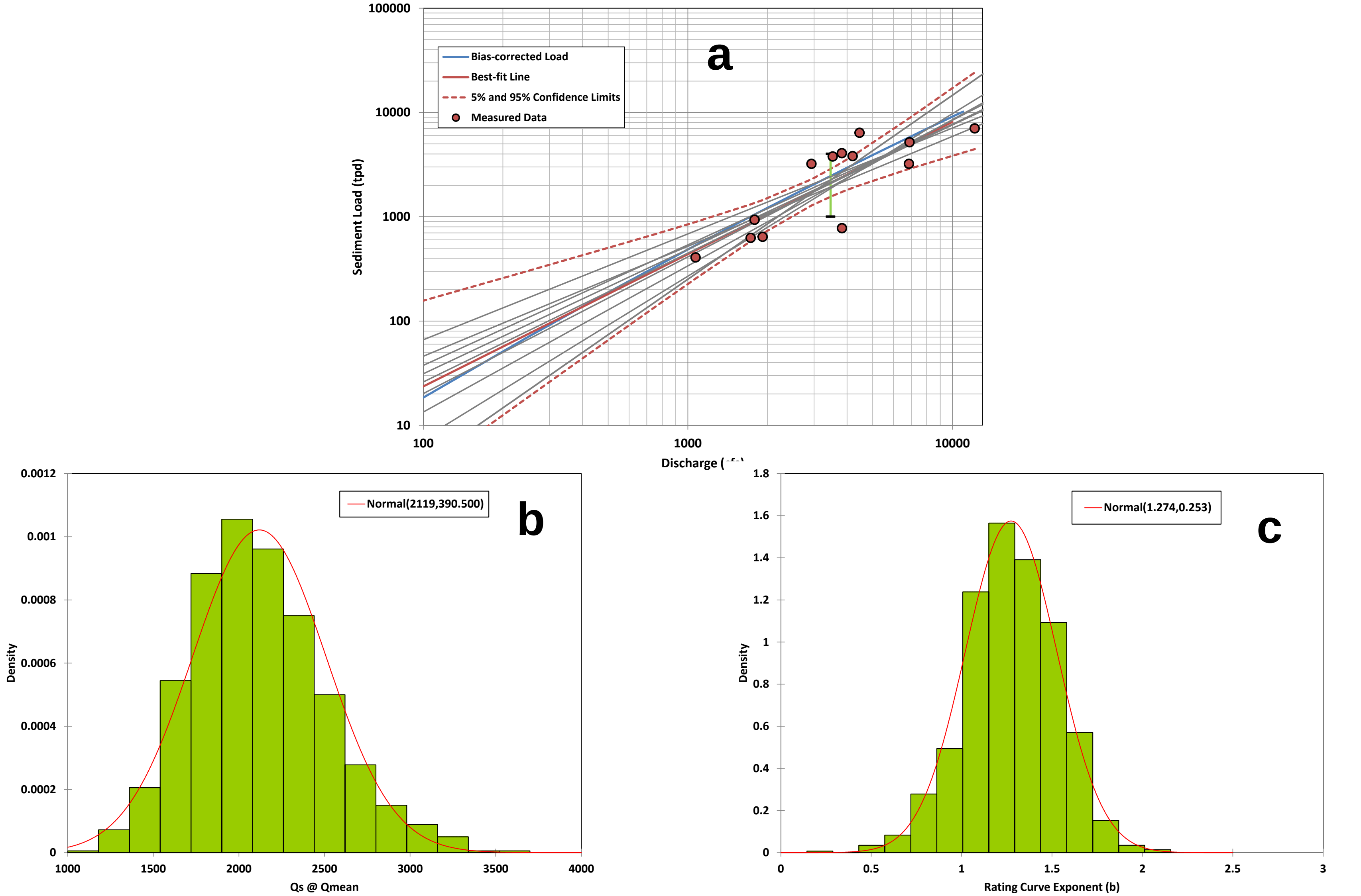


Figure 4.9. (a) Suspended sand rating curves for Overton data set. Light grey lines are sample of rating curves resulting from the Monte Carlo simulation; (b) Distribution of estimated sediment loads at the mean (log) discharge of the measured data set from Monte Carlo simulation; (c) Distribution of the exponents (*b*) on the Overton suspended sand load rating curve from the Monte Carlo simulation.

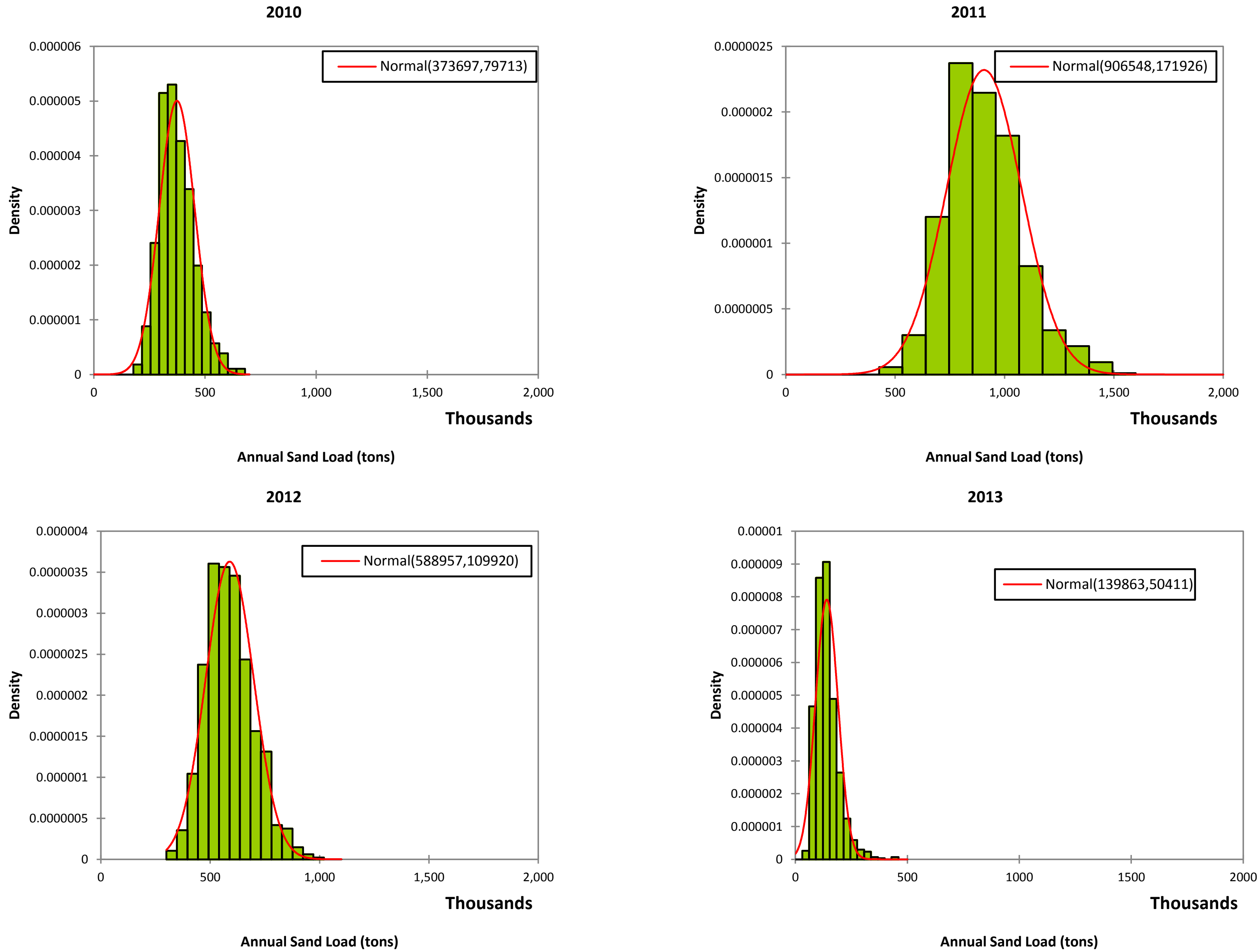


Figure 4.10. Distribution of annual suspended sand loads at Overton during the indicated Survey Years from the Monte Carlo simulation. Horizontal scale same in all figures to illustrate differences in annual loads among years. Red line is normal distribution with mean and standard deviation equal to that of the estimated sediment loads.

Independent Monte Carlo simulations were performed for the bed and suspended sand loads at each site, and the total sediment loads during each year were estimated by adding the corresponding bed and suspended loads for each step in the simulation. The resulting distribution of total sand transport balances, computed from the difference between the upstream inflow and downstream outflow in each segment of the reach for each step in the simulation (**Figure 4.11**) suggest the following with respect to the statistical significance (α=.05, two-tailed) of the aggradation/degradation trends:

1. The degradational trend in the Darr to Overton reach is statistically significant only during SY2012,
2. The degradation during SY2010, SY2011 and SY2012 in the Overton to Kearney reach is not statistically significant, but the aggradation during SY2013 is statistically significant,
3. The aggradational trends in the Kearney to Shelton reach are not statistically significant, and
4. The degradation trends in the Shelton to Grand Island reach are not statistically significant.

Unfortunately, it is not possible to quantify the uncertainty in the survey-based estimates in the same manner as the rating curve-based estimates. The uncertainty associated with the elevations of the individual survey points is actually quite small. For example, the standard deviation of the 695 survey points at AP29 in 2013 reported by the RTK-GPS datalogger averaged 0.059 feet (~0.7 inches). Based on a Monte Carlo simulation that allowed each point to vary about a mean error of 0.0 and standard deviation of 0.059 feet, the 90-percent confidence limits on the area change between the 2012 and 2013 surveys at the middle Transect 4 at AP29 is within about ±0.13 percent of the value based on the raw data, much smaller than the potential uncertainty associated with the other factors. The amount of uncertainty associated with how well the transects represent the area changes within each AP and the overall, approximately 5-mile reach represented by the AP cannot be quantified with the available data. A simple test using the 2012 and 2013 LiDAR surfaces for a bar in the south channel at Jeffreys Island that was regularly inundated by J-2 Return hydropower releases but was dry during both LiDAR surveys showed that the volume change estimated from three transects in the middle of the bar was within about 2 percent of the volume change estimated by overlaying the two LiDAR surfaces (**Figure 4.12**). The excellent agreement for this test results from the relatively uniform distribution of aggradation/degradation zones through the sample area. Attempts to perform a similar test on a larger reach of the river channel were not successful because of the confounding effects of the water-surface at the time of the surveys and the fact that a significant part of the bed elevation changes occur in the inundated part of the channel.

The aggradation/degradation estimates based on the transect surveys at the pure panel APs fall outside the 90-percent confidence limits on the rating curve-based estimates in the Darr to Overton and Shelton to Grand Island reaches in SY2010, all but the Shelton to Grand Island reach in SY2011, the Darr to Overton and Kearney to Shelton reaches in 2012, and all reaches during 2013 (**Figures 4.13a-d**). For purposes of assessing the effect of uncertainty in the survey-based estimates, it was tentatively assumed that the standard deviation of estimates at each AP is 25 percent of the average aggradation/degradation volume over the four survey years, which implies that the difference between the mean value and the upper and lower 95 percent confidence bands is about 41 percent of the mean value. The resulting confidence bands for each year were plotted over the rating curve-based estimates for comparison. With this assumption, the only case in which the best-estimate value fell outside the confidence bands on the rating curve-based estimates but the confidence bands overlap (i.e., there is reasonable likelihood that the predicted value using both methods is the same) occurs with the 2011 data in the Overton to Kearney reach. With the exception of this case, consideration of the

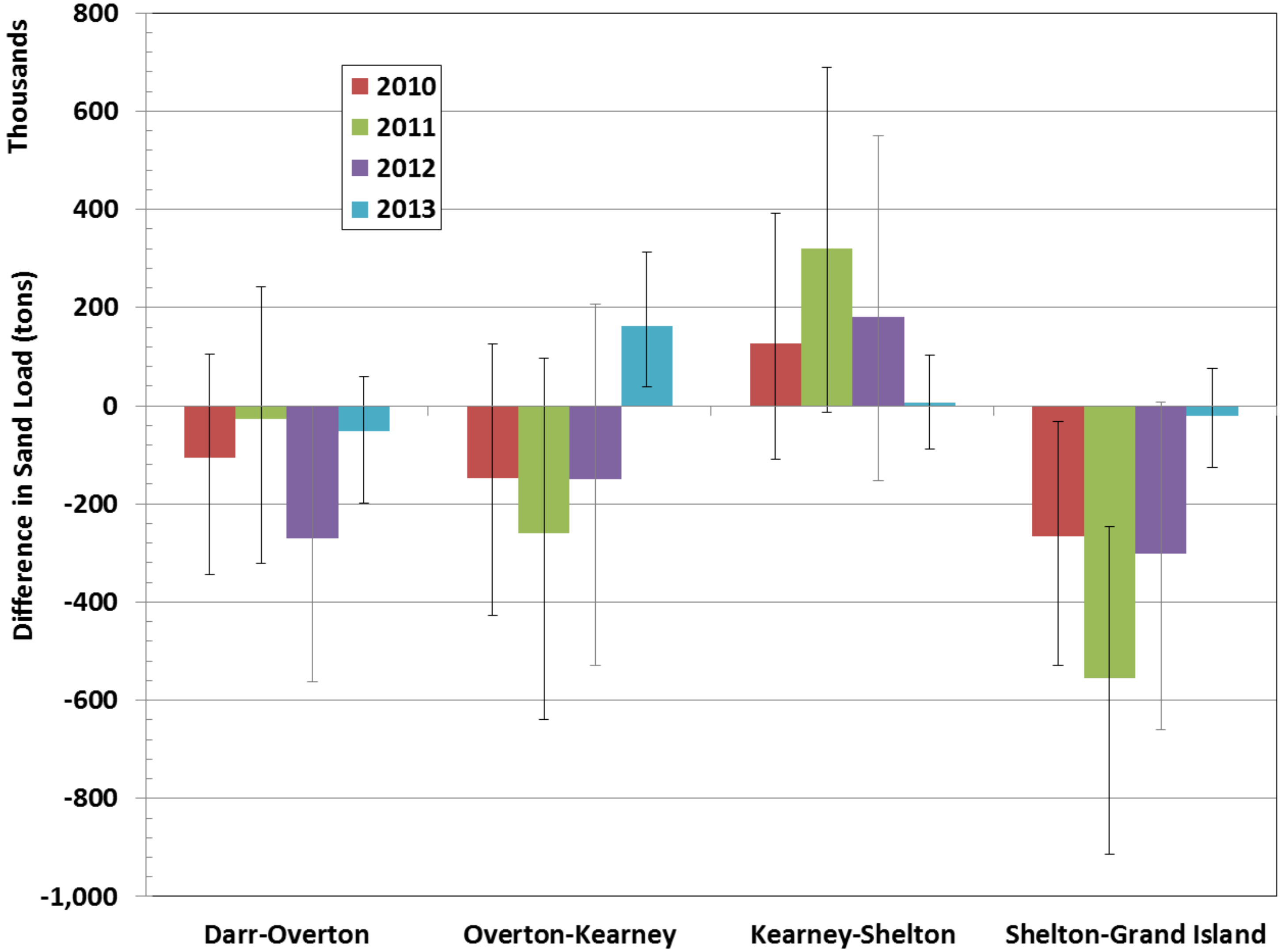


Figure 4.11. Bias-correct, best-estimate aggradation/degradation volumes between measurement locations during each of the four survey years. Whiskers represent upper and lower 95 percent confidence limits on the estimates from the Monte Carlo simulations.

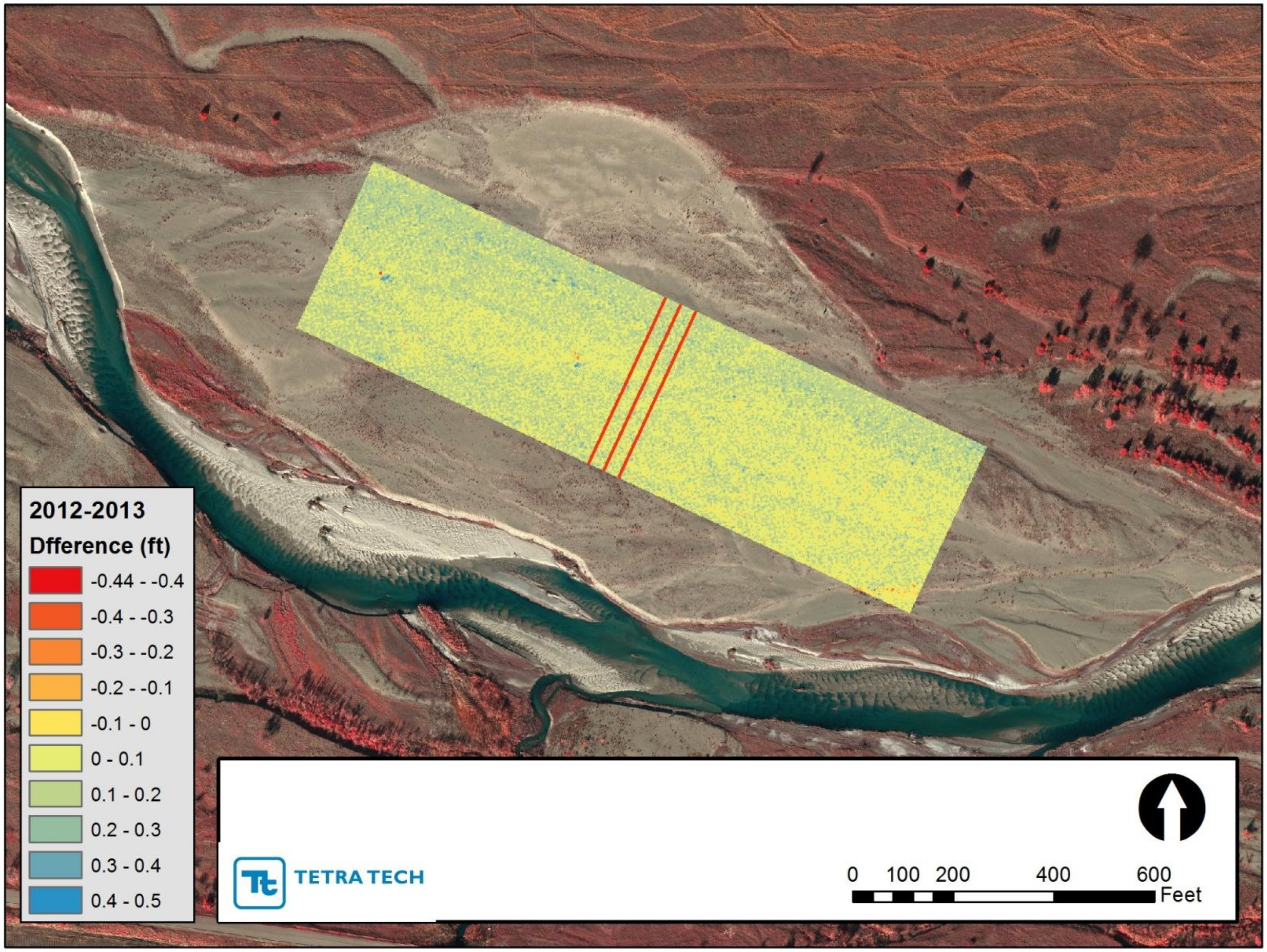


Figure 4.12. Area used to test agreement between cross section-based volume estimates and estimates based on the complete LiDAR surface (~RM245.5, south channel at Jeffreys Island approximately midway between AP36 and 37).

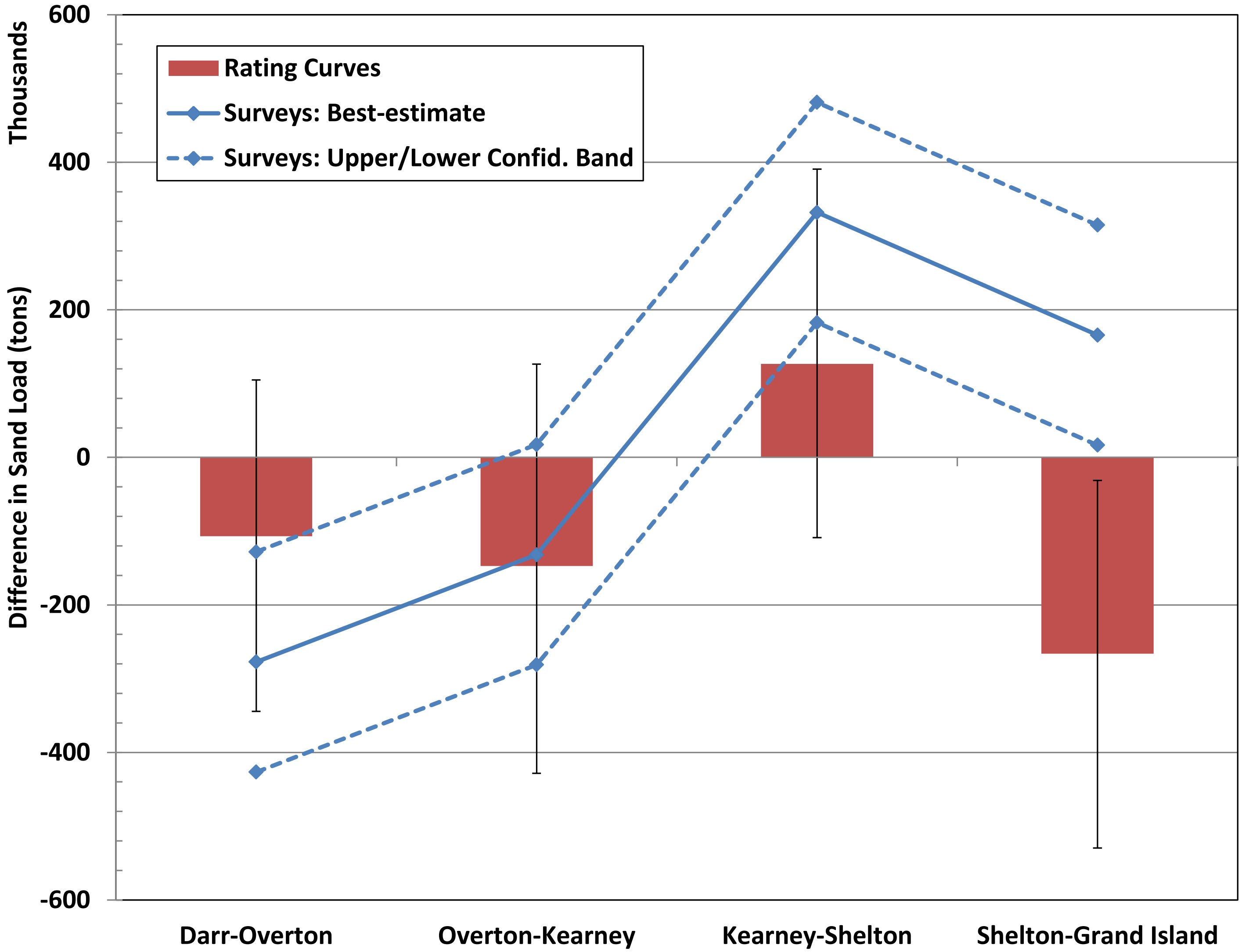


Figure 4.13a. Rating curve-based estimates of aggradation/degradation volume with upper and lower 95-percent confidence limits and the corresponding estimates from the surveys for 2010.

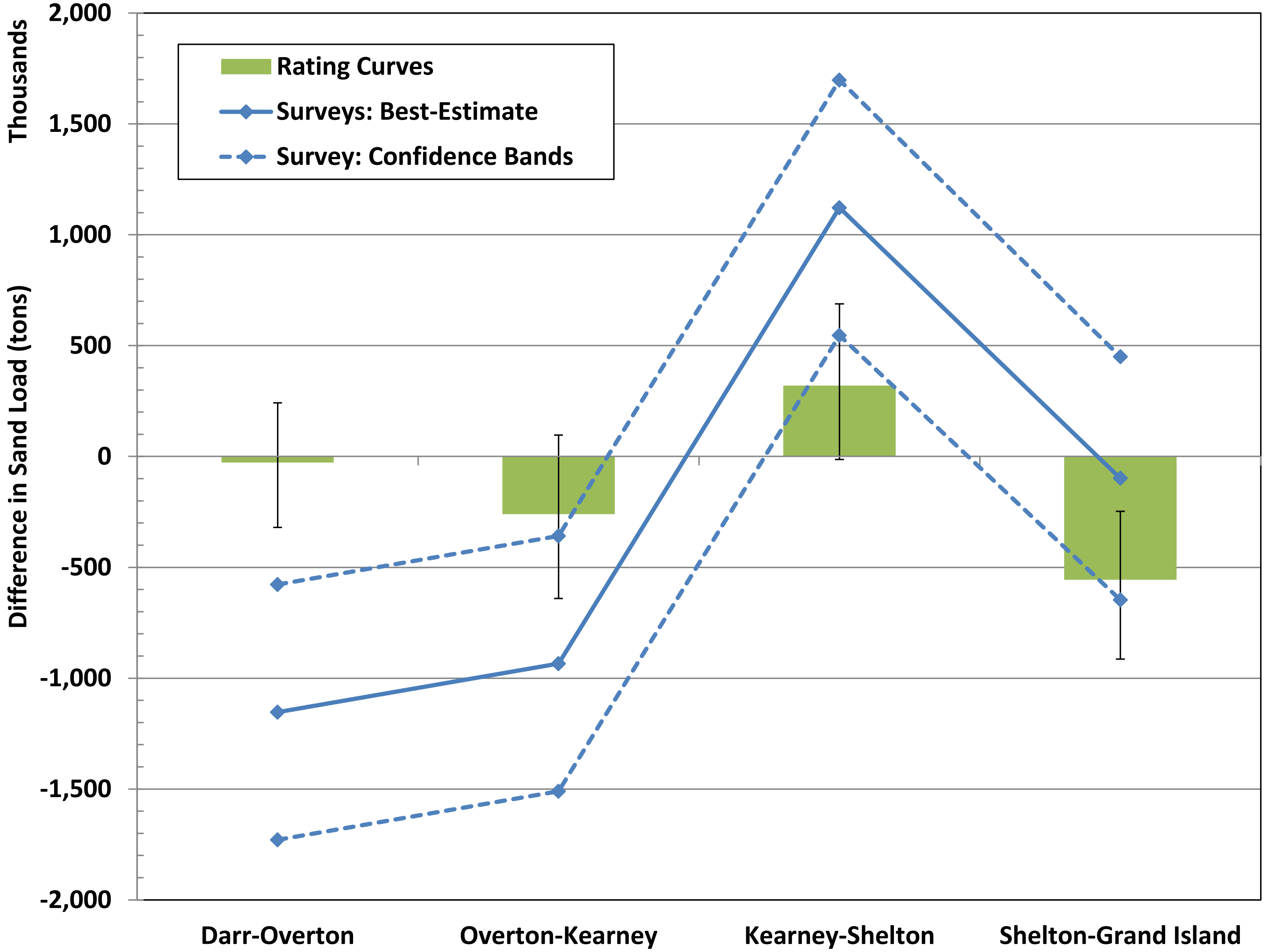


Figure 4.13b. Rating curve-based estimates of aggradation/degradation volume with upper and lower 95-percent confidence limits and the corresponding estimates from the surveys for 2011.

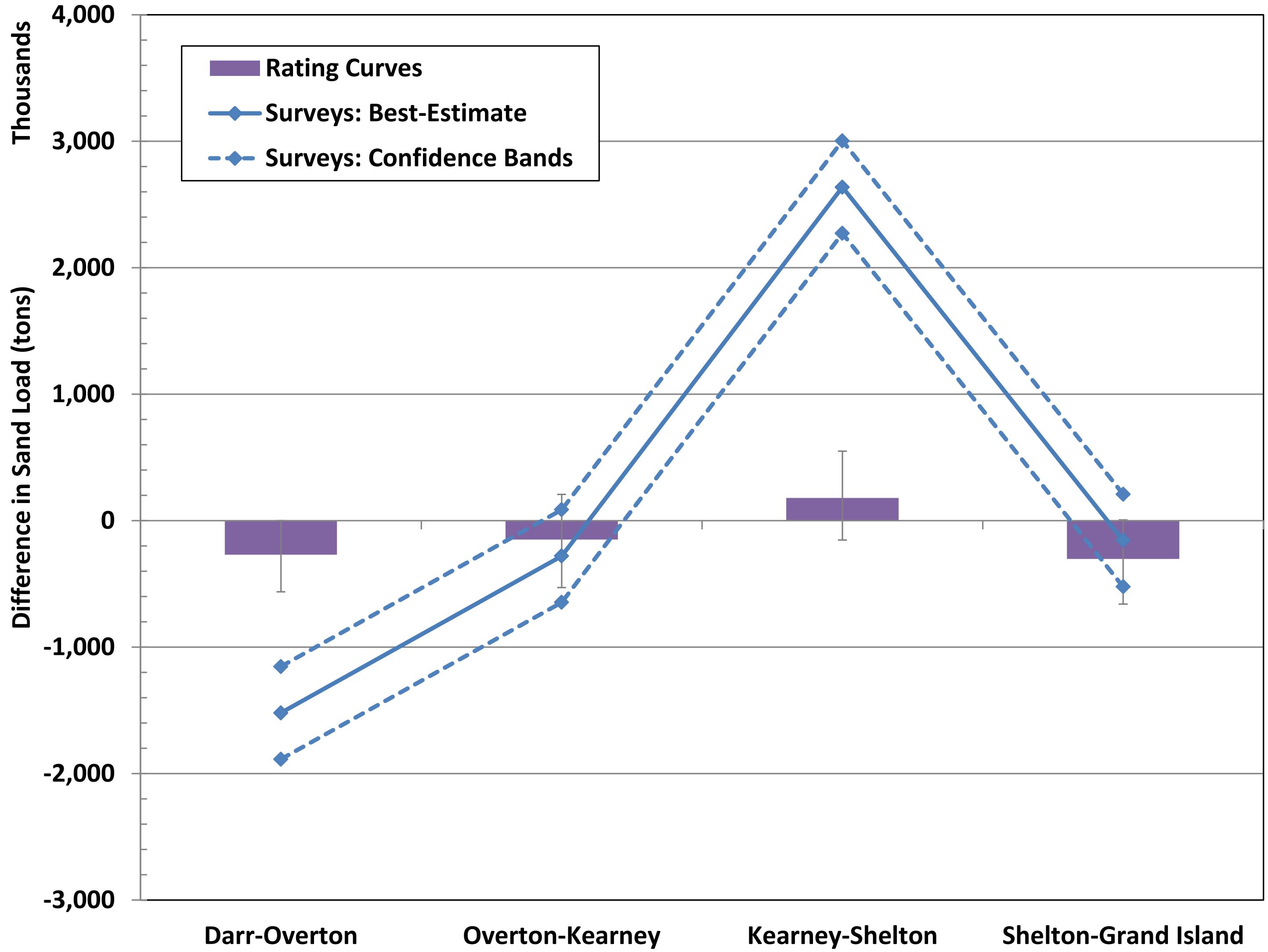


Figure 4.13c. Rating curve-based estimates of aggradation/degradation volume with upper and lower 95-percent confidence limits and the corresponding estimates from the surveys for 2012.

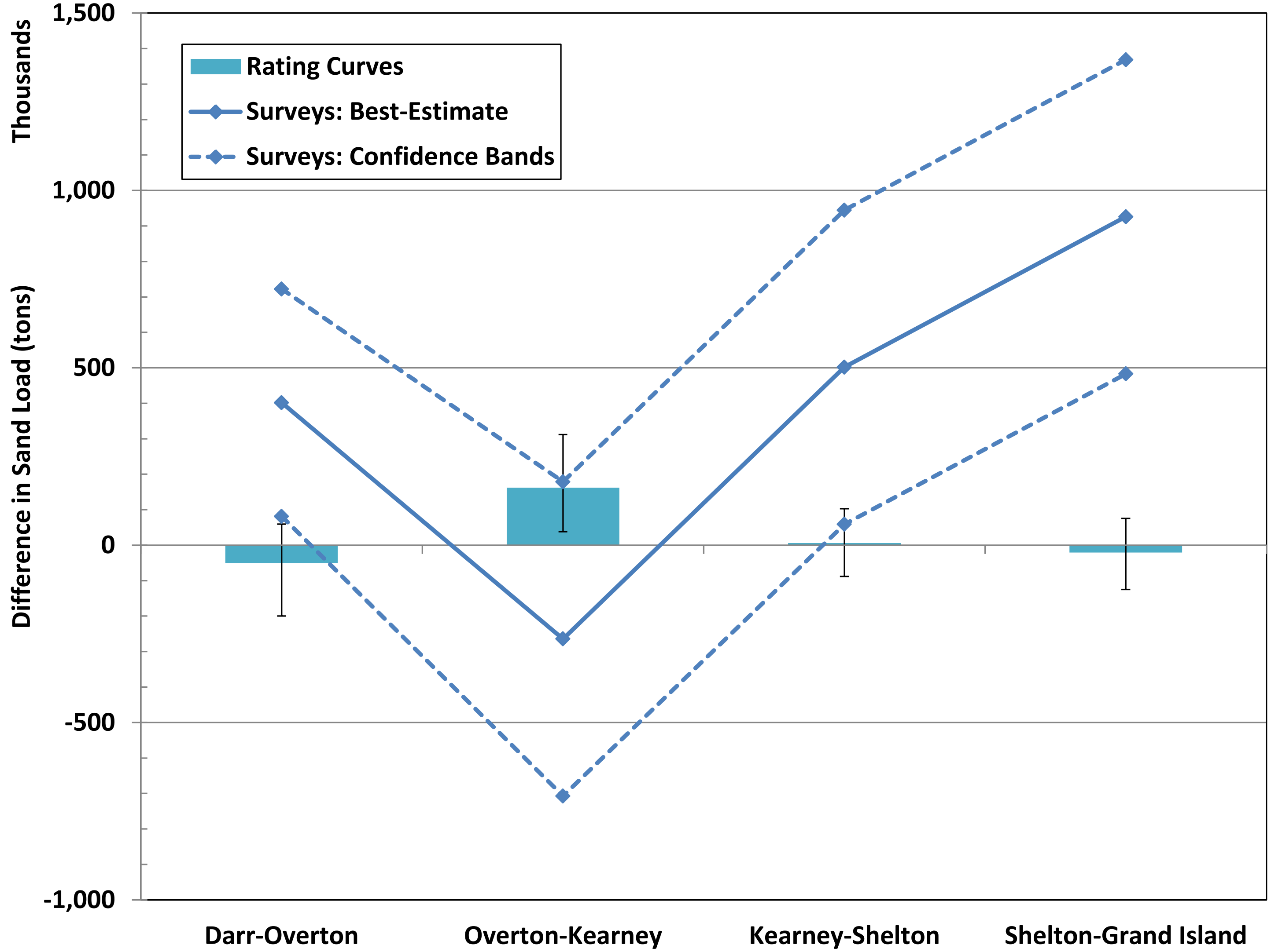


Figure 4.13d. Rating curve-based estimates of aggradation/degradation volume with upper and lower 95-percent confidence limits and the corresponding estimates from the surveys for 2013.

assumed confidence bands does not change the conclusions regarding the correspondence or discrepancy between the survey and rating curve-based results. Increasing the assumed standard deviation to 50 percent of the estimated values (or 90-percent confidence limits of ~82 percent) would cause the confidence bands to overlap in only two additional cases (2011 Kearney to Shelton and 2013 Overton to Kearney).

Using the SEDVEG Gen3 Model with a 48-year flow record (1947-1990) that was adjusted to represent current operations of the system, Reclamation estimated that the reach between the Overton and Elm Creek Bridges has a net sediment deficit of about 185,000 tons/year under the existing flow regime (DOI Reclamation and USFWS, 2006). They also estimated that the reach between Elm Creek and Chapman had net sediment excess of about 62,000 tons/year, with most of the excess occurring downstream from Chapman. HEC-6T modeling by Tetra Tech (2010) using observed hydrology for the 12.5-year period October 1989 through April 2002 estimated that the sediment deficit between Overton and Elm Creek was about 150,000 tons. Although the results were not presented in terms of volumes, HEC-6T modeling of the overall monitoring reach by Tetra Tech (see HDR and Tetra Tech, 2011) was consistent with the Tetra Tech (2010) findings in the Overton to Elm Creek Reach and showed that the reach between Kearney and Shelton was slightly aggradational, the reach between Shelton and Grand Island was degradational, and the remainder of the reach was approximately in balance, with localized zones of both aggradation and degradation. With the exception of WY2012, the flows during the monitoring period were much higher than the typical flows in the records used for both the DOI (2006) and Tetra Tech (2010) modeling (**Figure 4.14**).

The rating curves for Overton, Kearney and Grand Island were also integrated over the published mean daily flows from the USGS records for the longest available overlapping record (WY1984 through WY2013) to provide longer-term estimates of the annual sediment loads and sediment balance. (Longer-term records are not available for the Lexington, used with the Darr rating curves, and Shelton gages.) The best-estimate, annual sand load at Overton averaged about 496,000 tons over the 30-year period, and ranged from about 80,000 tons (WY2004) to 2.1M tons (WY1984) (**Figures 4.15 and 4.16**). The sand loads at Kearney during this period averaged about 571,000 tons, and ranged from 67,000 to 2.69M tons, and the loads at Grand Island averaged 683,000 tons and ranged from 64,000 tons to 3.02M tons. Based on these loads, the best-estimate of the sediment deficit between Overton and Kearney and between Kearney and Grand Island averaged about 75,000 and 112,000 tons, respectively (**Figures 4.17 and 4.18**). The 90-percent confidence bands on these estimates are, however, quite large, with the upper and lower bounds in the Overton to Kearney reach ranging from an average annual deficit of 351,000 tons to an average annual access of 220,000 tons, and the limits for the Kearney to Grand Island reach ranging from a 388,000-ton deficit to a 187,000-ton excess. To help put the confidence bands on these estimates into perspective, the mean value of the sediment balance from the Monte Carlo simulations for the Overton to Kearney reach was negative (i.e., degradational) in 22 of the 30 years, and the distributions for the individual years suggest a 68-percent chance, on average, that the reach was, in fact, degradational. Similarly, the mean value of the sediment balance from the simulations for the Kearney to Grand Island Reach was negative in 28 of the 30 years, with a 73-percent chance, on average, that the reach was degradational. The mean values from this analysis also indicate that both reaches are more strongly degradational during high-water years than during low water years (**Figure 4.19**).

All of the above evidence points to a general degradational tendency upstream from Kearney, with the best-estimate of the long-term average between Overton and Kearney in the range of about 100,000 tons. The available evidence for the reach between Kearney and Grand Island is less clear, with the surveys and gage measurements indicating aggradation and the sand load

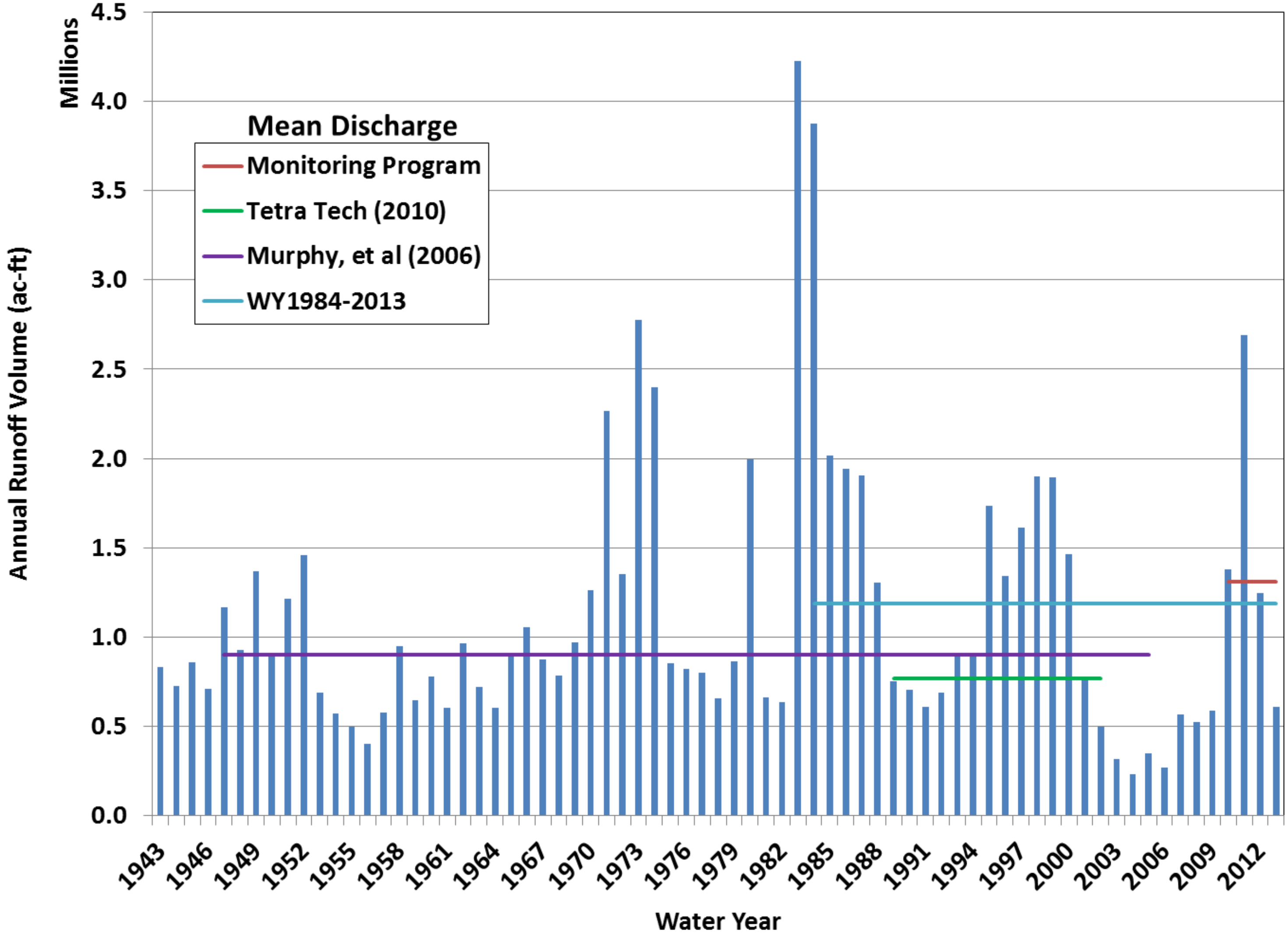


Figure 4.14. Annual total runoff volume at the USGS Overton gage between WY1943 and WY2013. Also shown are the mean flows for the 48-year record used for the DOI (2006) model, the Tetra Tech (2010) model and the 4-year monitoring period.

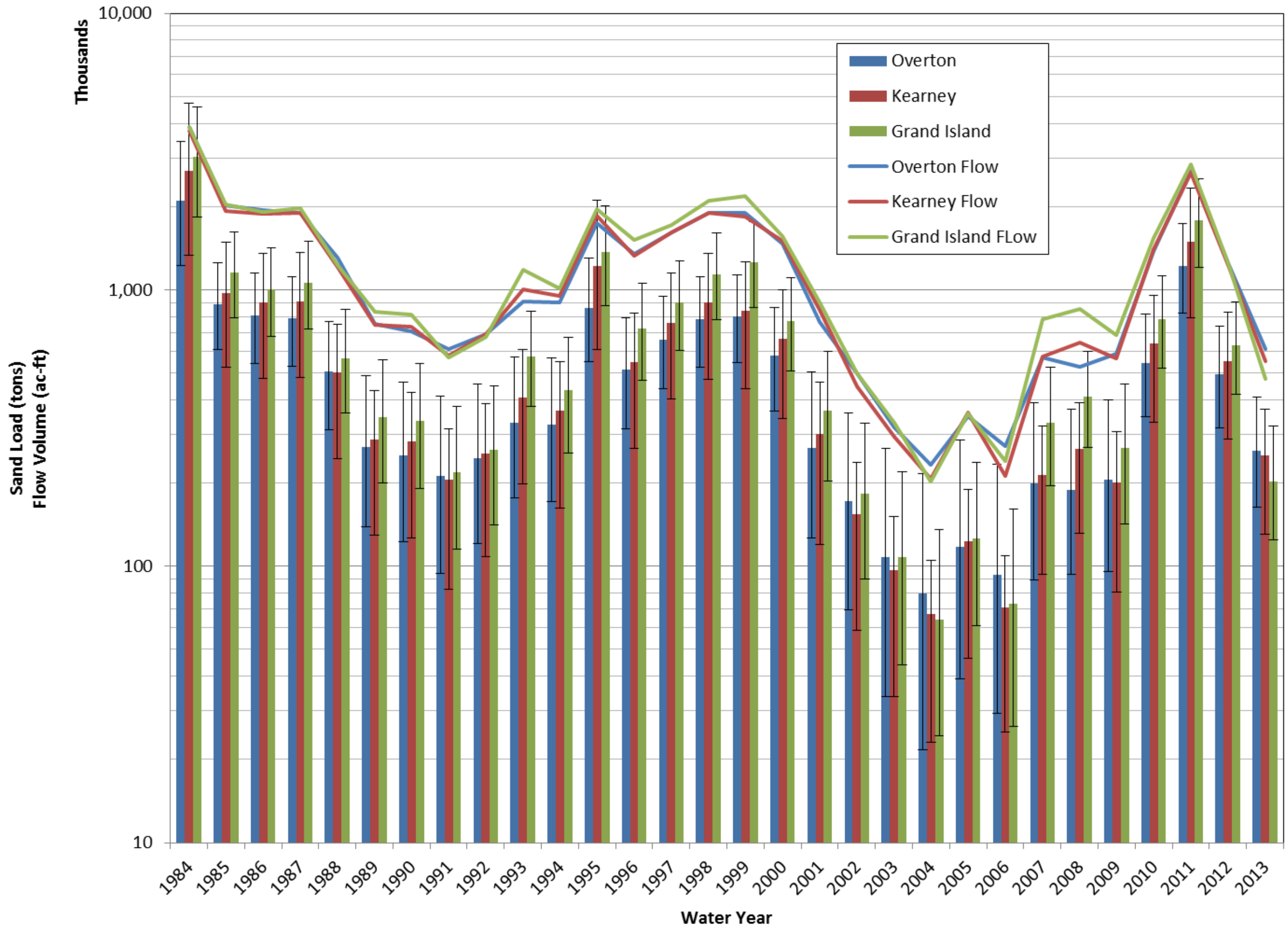


Figure 4.15. Estimated average annual total sand load passing the Overton, Kearney, and Grand Island gages during individual years from WY1984 through WY2013, based on integration of the respective rating curves over the USGS published mean daily. Also shown are the median values and upper and lower 95 percent confidence limits from the Monte Carlo simulations.

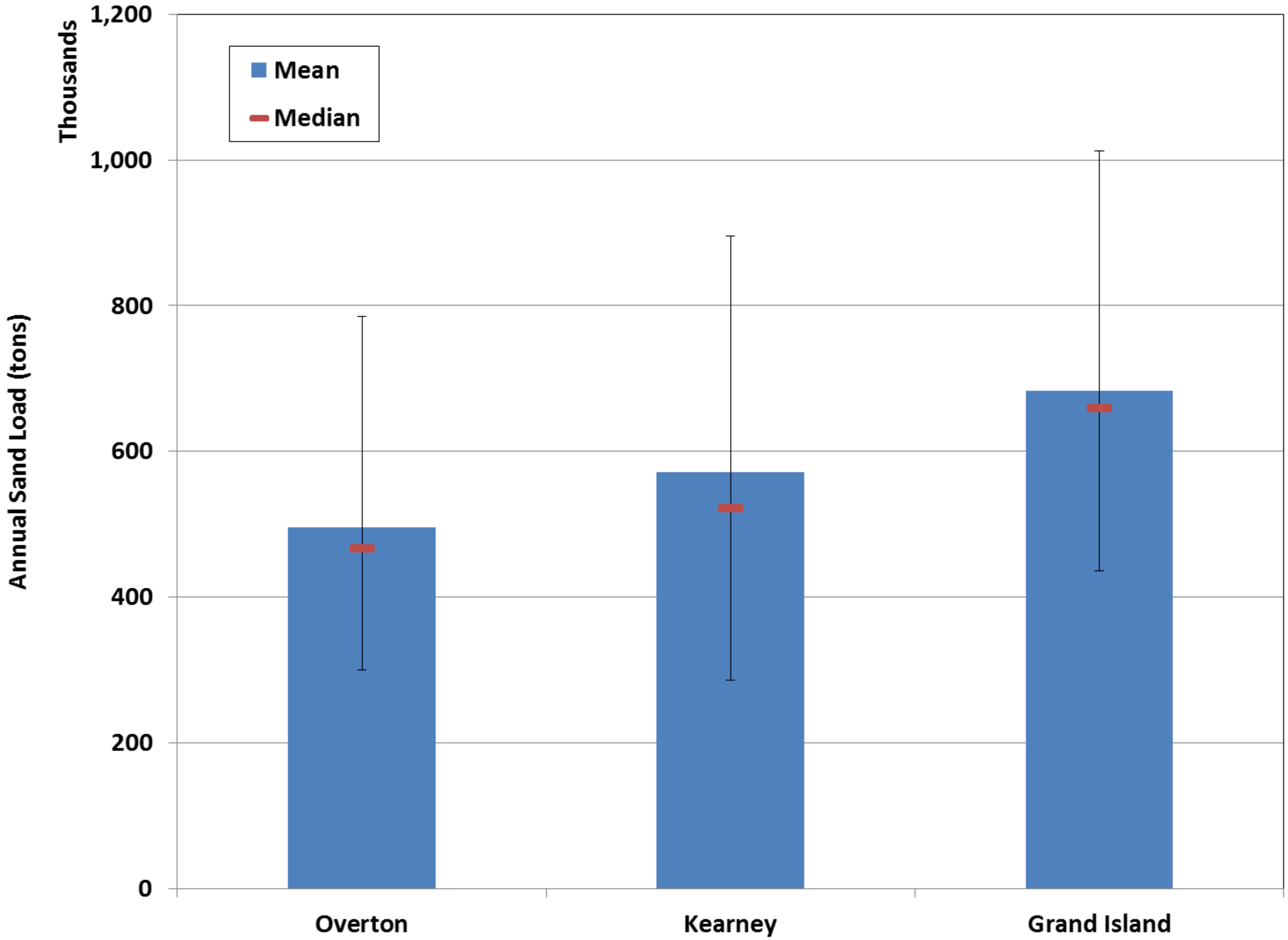


Figure 4.16. Average annual total sand load passing the Overton, Kearney, and Grand Island gages based on integration of the respective rating curves over the USGS published mean daily flows for the period from WY1984 through WY2013. Also shown are the median values and upper and lower 95 percent confidence limits from the Monte Carlo simulations.

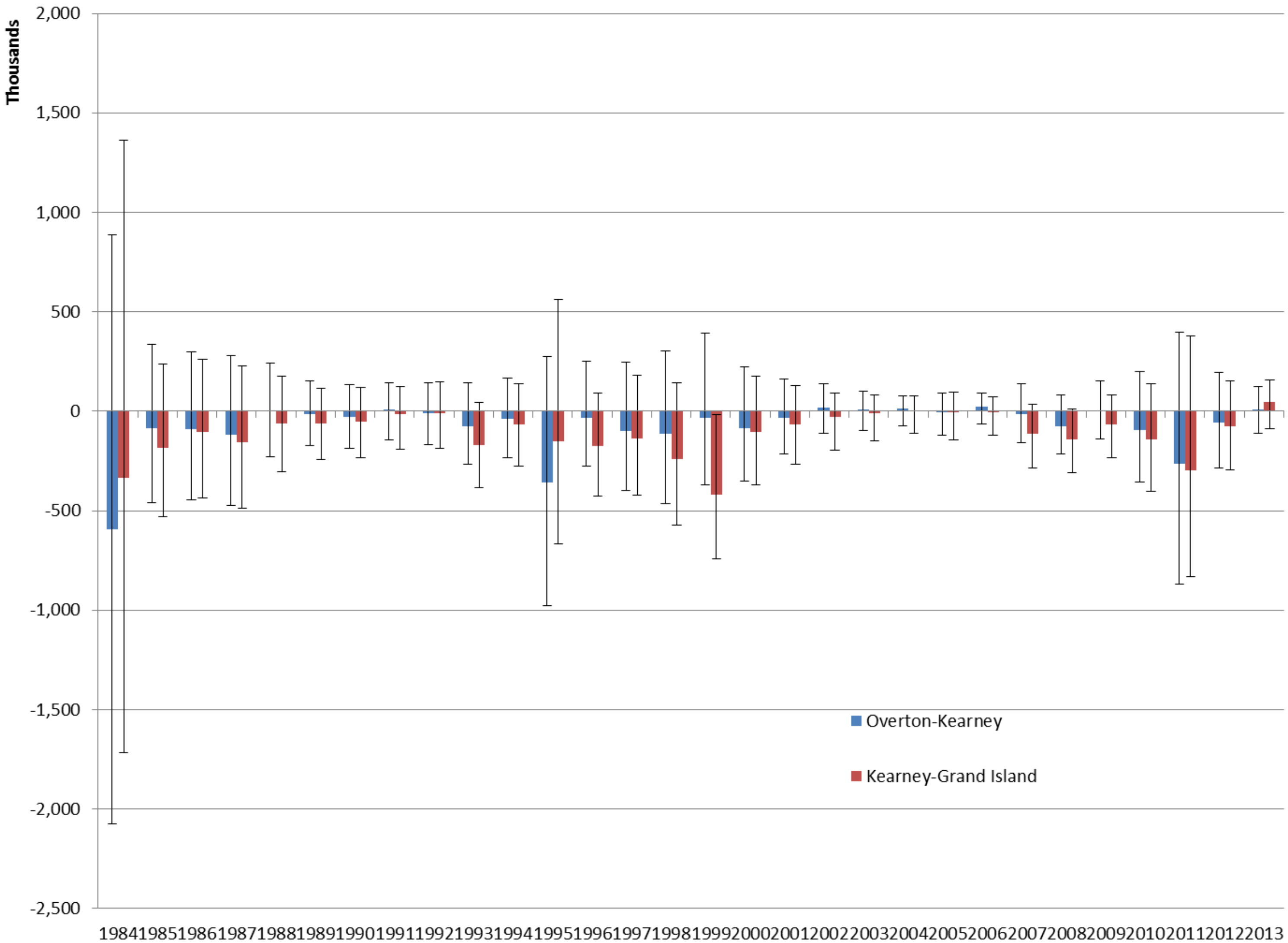


Figure 4.17a. Estimated sand transport balance between Overton, Kearney and Grand Island from WY984 through WY2013. Also shown are the upper and lower confidence bands on the results from the Monte Carlo Simulations.

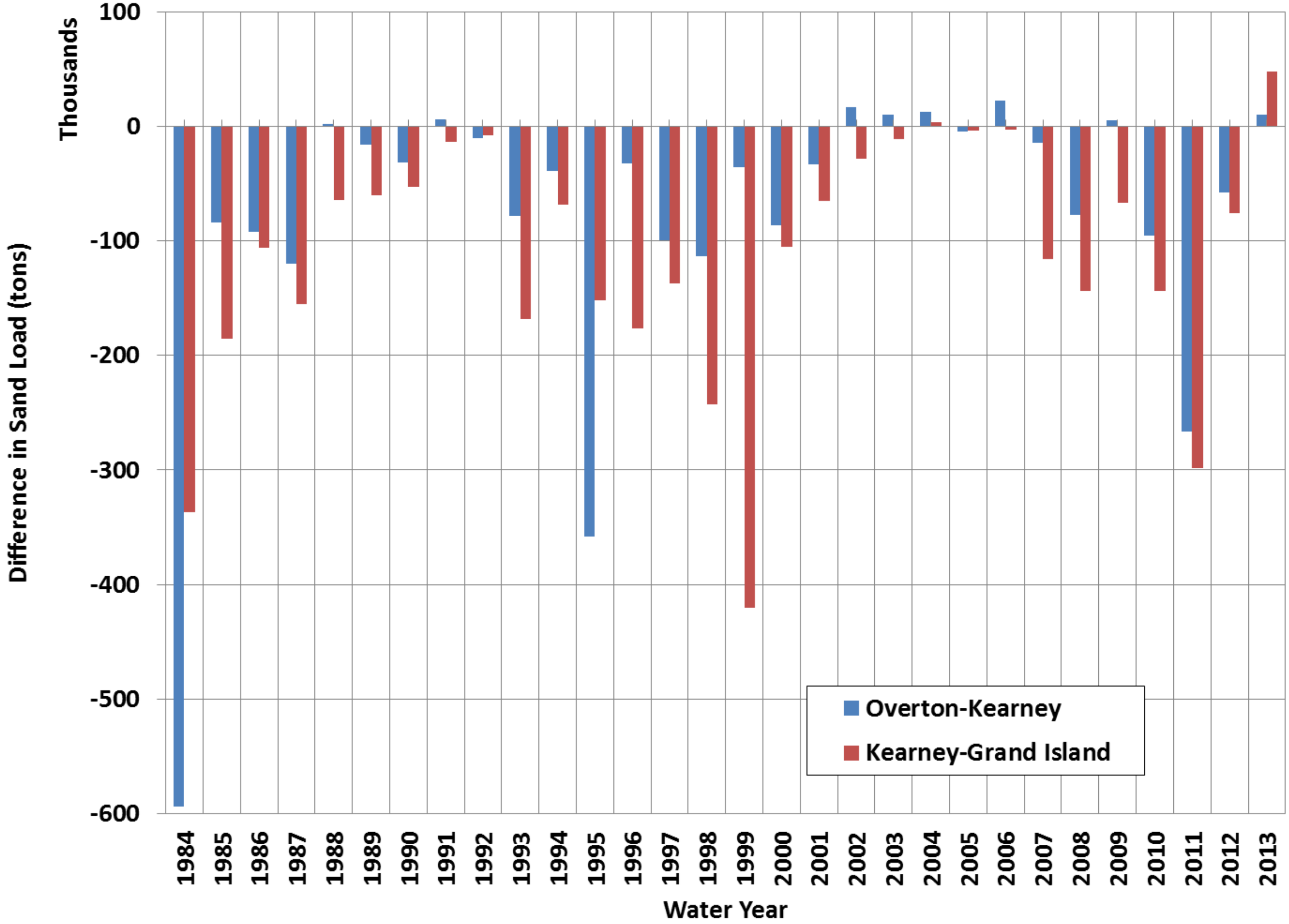


Figure 4.17b. Estimated sand transport balance between Overton, Kearney and Grand Island from WY984 through WY2013. Same as Figure 4.17a with confidence limits removed and scale adjusted to emphasis mean estimates.

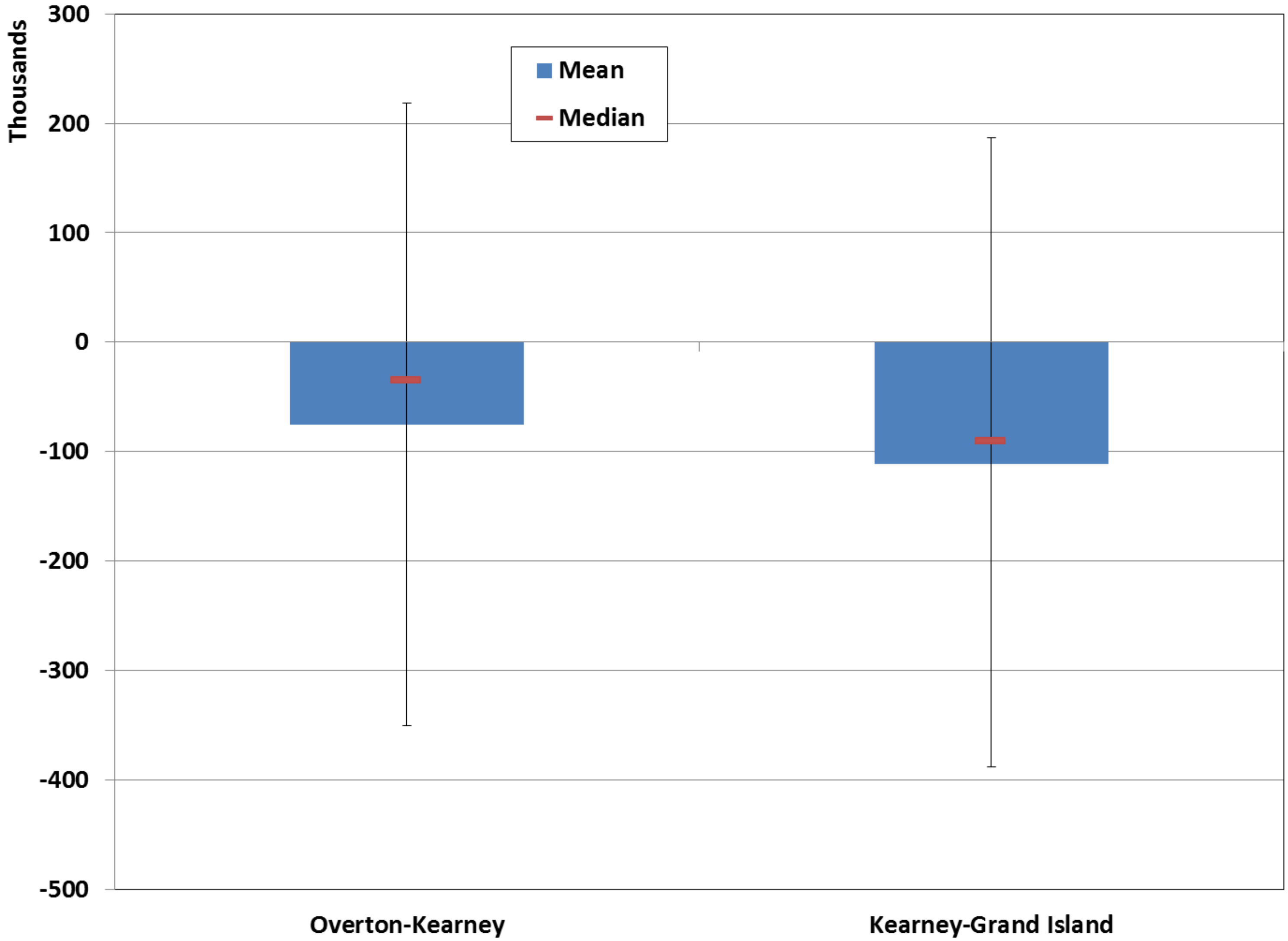


Figure 4.18. Average annual sand transport balance between Overton, Kearney and Grand Island from WY984 through WY2013. Also shown are the upper and lower confidence bands on the results from the Monte Carlo Simulations.

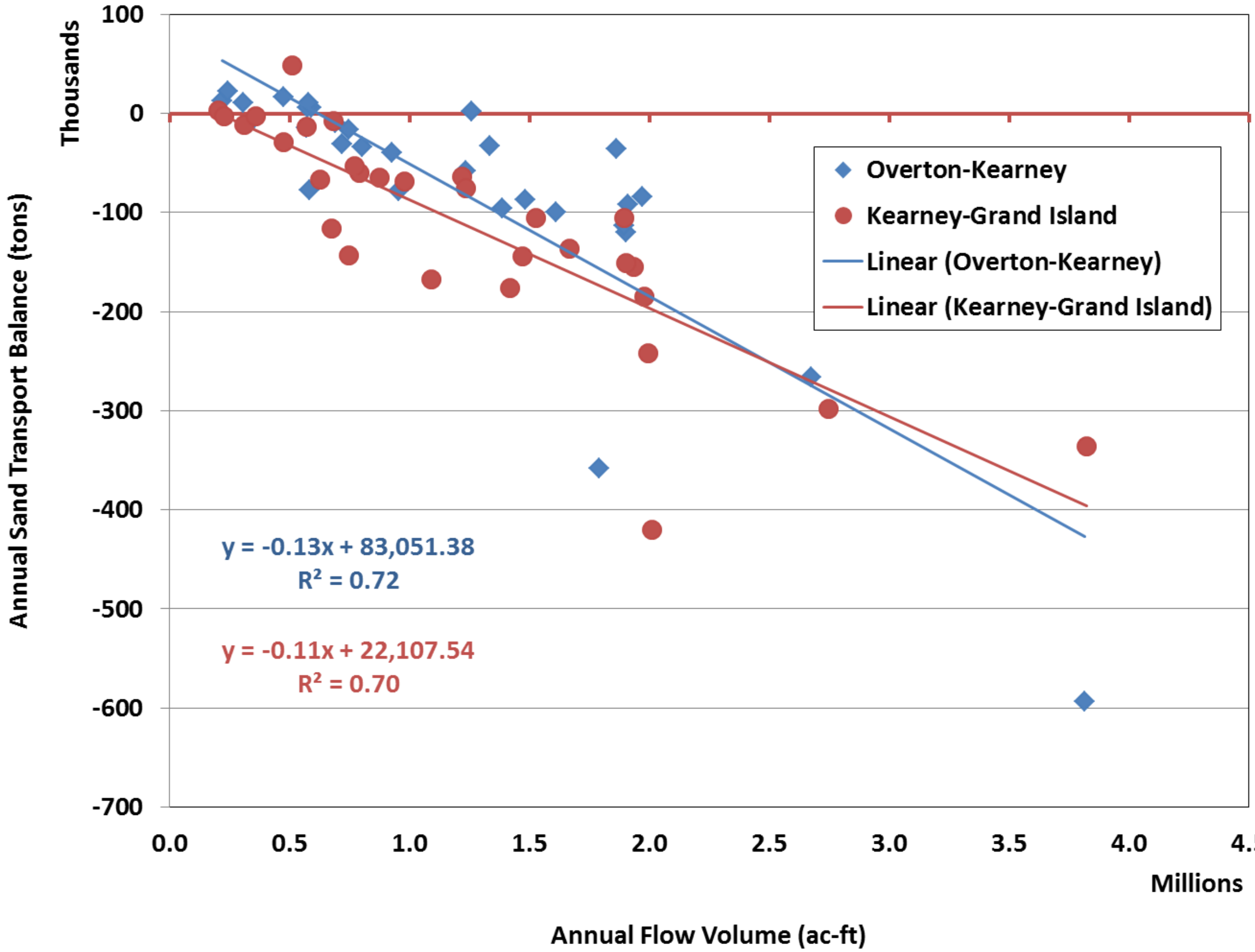


Figure 4.19. Relationship between estimated mean sand balance and total flow volume in the Overton to Kearney and Kearney to Grand Island reaches.

rating curves indicating degradation. Because the various lines of evidence are not consistent, and because conditions in the portion of the reach downstream from Kearney are highly variable, it cannot be concluded with a reasonable degree of certainty that this reach is either aggradational or degradational.

4.2 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.*

The extent to which the GLE and resulting total unvegetated widths measured at the pure panel APs during the monitoring period are responsive to flow was assessed by correlating these metrics with various discharge metrics. (As specified in the DAP, the edges of unvegetated segments along each transect are identified by the GLE points.) To remove the effects of river slope in the correlations, the GLE values were normalized to the 1,200-cfs water surface (i.e., the difference between the GLE and the local 1,200-cfs water surface was used rather than the actual elevation). In addition, the differences in the modeled water-surface elevations (i.e., referred to as stage for brevity) for the applicable discharge metrics were used in the analysis, rather than the actual discharge. The following specific correlations were evaluated:

1. GLE versus stage at annual peak discharge (Q_p, Monitoring Plan Section 5.1.1), defined as the maximum mean daily discharge between January 1 and the date of the survey in each year.
2. GLE versus stage at germination season discharge (Q_{Ger}, Monitoring Plan Section 5.1.2), defined as the either the mean or median mean daily discharge between June 1 and July 15 (the primary season for establishment of cottonwood seedlings). For this analysis the correlations were performed using the both the mean and median discharges to assess which one provides the best correlation.
3. Total unvegetated width (W_{unveg}) versus stage at annual peak discharge (Q_{Ger}).
4. Total unvegetated width (W_{unveg}) versus stage at germination season discharge (Q_{Ger}).
5. Total unvegetated width (W_{unveg}) versus GLE.

4.2.1. Height of Green Line above 1,200-cfs Water Surface

One of the benchmarks established by the Program is to maintain GLEs at least 1.5 feet above the 1,200-cfs water surface. As noted in Section 3.4.1, the GLE tends to be responsive the magnitude of flows in the reach; however, even during 2011, when long-duration, high flows persisted through the reach, the average GLE was still less than the 1.5-foot benchmark, although it was above the benchmark at several of the APs (**Figures 4.20 and 4.21**). With the exception of AP21 and AP31 in 2010, the average GLE at the pure panel APs were all well below the benchmark throughout the period, and below even the 1,200-cfs water surface during 2009, 2012 and 2013.

4.2.2 Total Unvegetated Channel Width versus Stage at Annual Peak Discharge

The Program has also established a benchmark to maintain target unvegetated channel width of 1,125 feet, with minimum width of at least 750 feet. As discussed in Section 3.4.2, the reach-wide

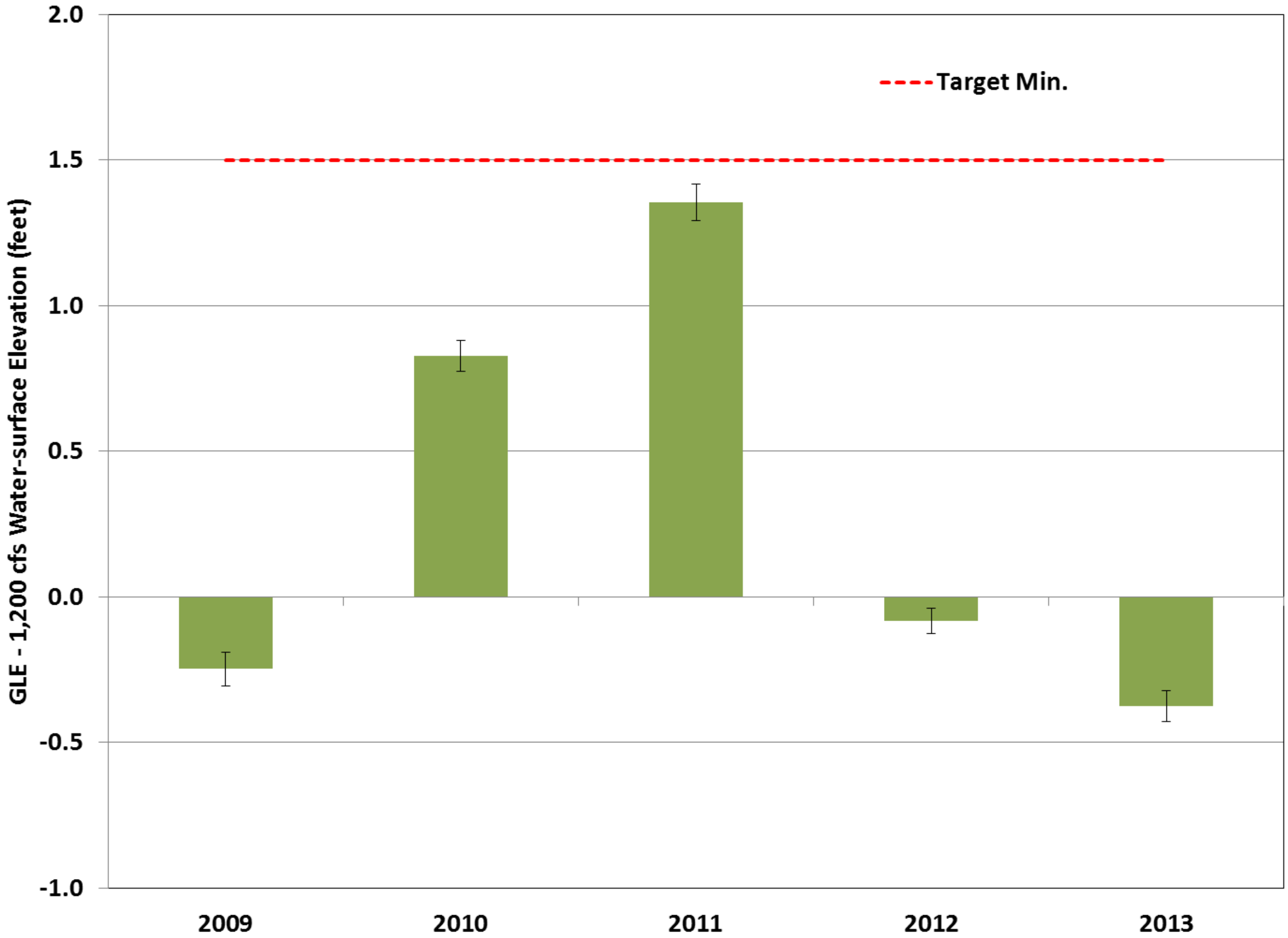


Figure 4.20. Reach-wide average height of the GLE points above the 1,200-cfs water surface at the pure panel APs during 2009 through 2013.

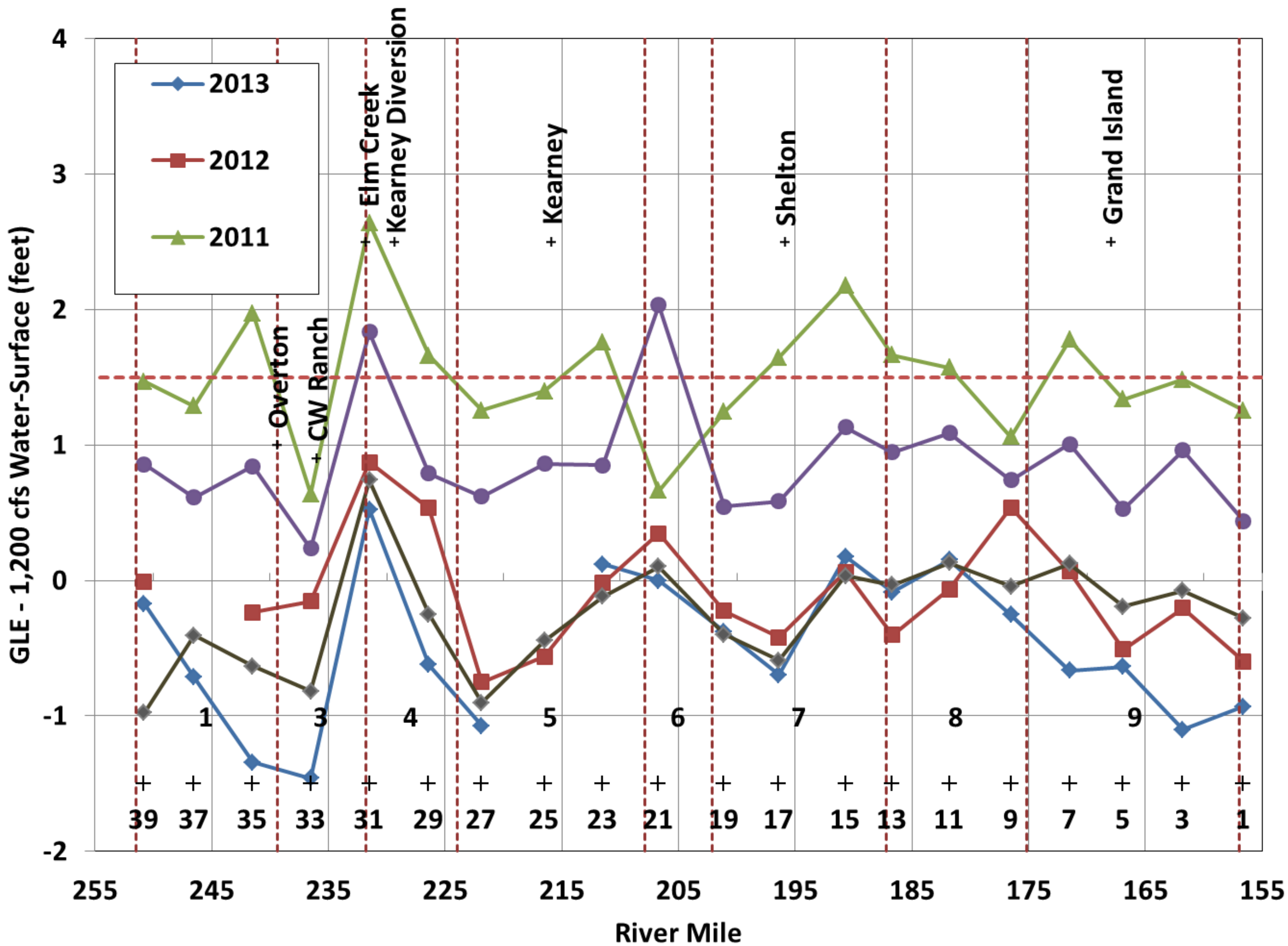


Figure 4.21. Average height of the GLE points at the each of the pure panel APs during 2009 through 2013.

average unvegetated channel width was substantially less than the minimum value in all years, including 2011 (Figure 3.18b). With the exception of in Reach 6 in 2010 and Reaches 4, 6, 7, and 9 in 2011, none of the geomorphic reaches had average unvegetated width exceeding the minimum threshold (Figure 3.19b).

4.2.3 Green Line Elevation versus Stage at Annual Peak Discharge

The year-to-year change in GLE is well-correlated to the difference in stage associated with the annual maximum discharge (**Figure 4.22**). Correlation using the Kendall test on the complete data set results in a Kendall's τ of 0.54, and p-value of less than 0.0001, indicating that the correlation is statistically significant.

4.2.4 Green Line Elevation versus Stage at Germination Season Discharge

The year-to-year change in GLE is even more highly correlated with the stage at the mean discharge during the germination season (**Figure 4.23**; Kendall's $\tau = 0.68$, $p<0.0001$). The germination season discharges were quite low and very similar in magnitude in 2012 and 2013, and the GLE had generally receded well into the low flow channel; thus, eliminating the potential for contrast between the two data sets. As a result, the data points for the year-to-year changes cluster around the line of zero change in stage. Use of the median discharge during the germination season rather than the mean resulted in essentially the same correlation results.

The correlation between the year-to-year change in GLE and the maximum discharge during the germination seasons was also tested (**Figure 4.24**). This also resulted in statistically-significant correlation (Kendall's $t = 0.61$, $p<0.0001$), only slightly weaker than with the mean discharge.

4.2.5 Total Unvegetated Channel Width versus Stage at Annual Peak Discharge

Correlation between the year-to-year change in total unvegetated channel width and the difference in stage associated with the annual maximum discharge is statistically significant (**Figure 4.25**; Kendall's $t = 0.39$, $p<0.0001$). The maximum discharges in 2010 and 2011 were both quite high; thus, the difference is relatively small, yet the total unvegetated width appears to have increased substantially at most locations between the two surveys, most likely due to the long duration of high flows in 2011 that prevented especially the annual species from growing on the sand bars and the low elevation areas along the channel banks

4.2.6 Total Unvegetated Channel Width versus Stage at Mean Germination Season Discharge

Correlation between the year-to-year change in total unvegetated channel width and the difference in stage associated with the mean germination season discharge is also statistically significant (**Figures 4.26**; Kendall's $t = 0.40$, $p<0.0001$). Similar to the GLE correlation analysis, the germination season discharges in 2012 and 2013 were very similar; thus, the changes in total unvegetated width tend to cluster along the line of zero change in stage.

4.2.7 Total Unvegetated Channel Width versus Green Line Elevation

The year-to-year change in total unvegetated channel width is relatively strongly correlated with the corresponding change in GLE (**Figure 4.27**; Kendall's $\tau = 0.51$, $p<0.0001$).

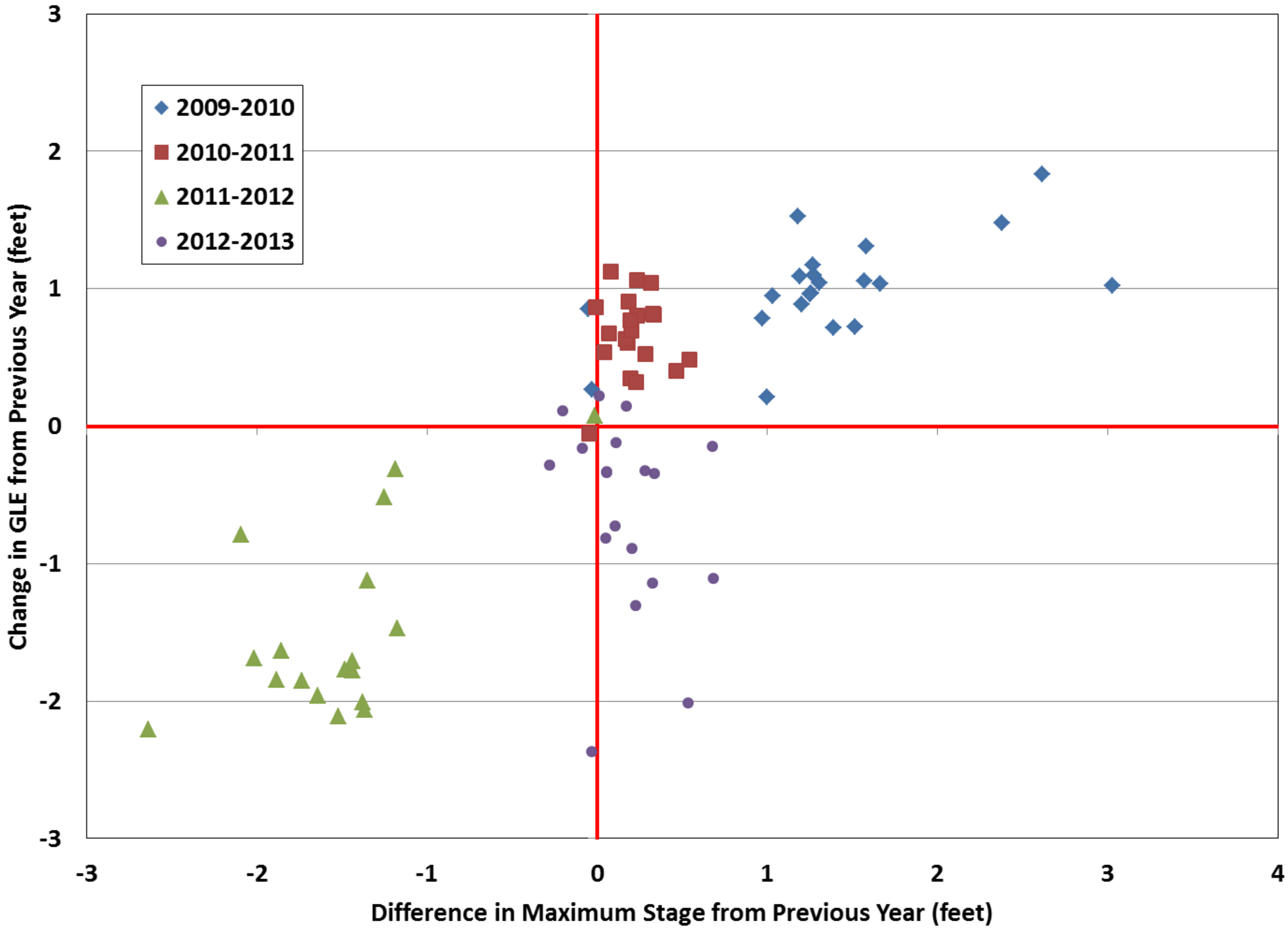


Figure 4.22. Change in GLE versus difference in stage at maximum mean daily flow preceding each survey at the pure panel APs (Kendall's τ = 0.54, p=<0.0001).

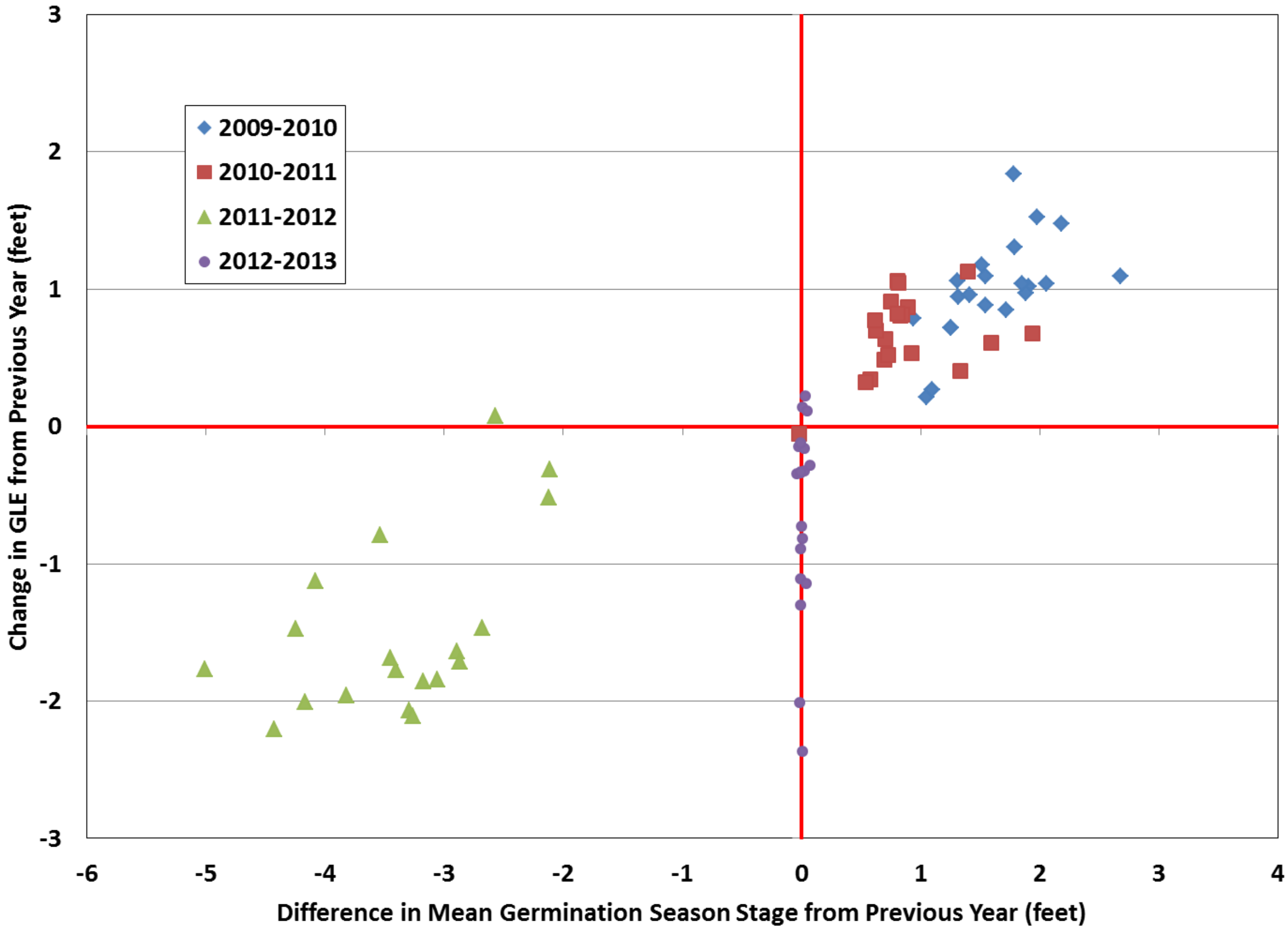


Figure 4.23. Change in GLE versus difference in stage at mean germination season discharge preceding each survey at the pure panel APs (Kendall's τ = 0.68, p=<0.0001).

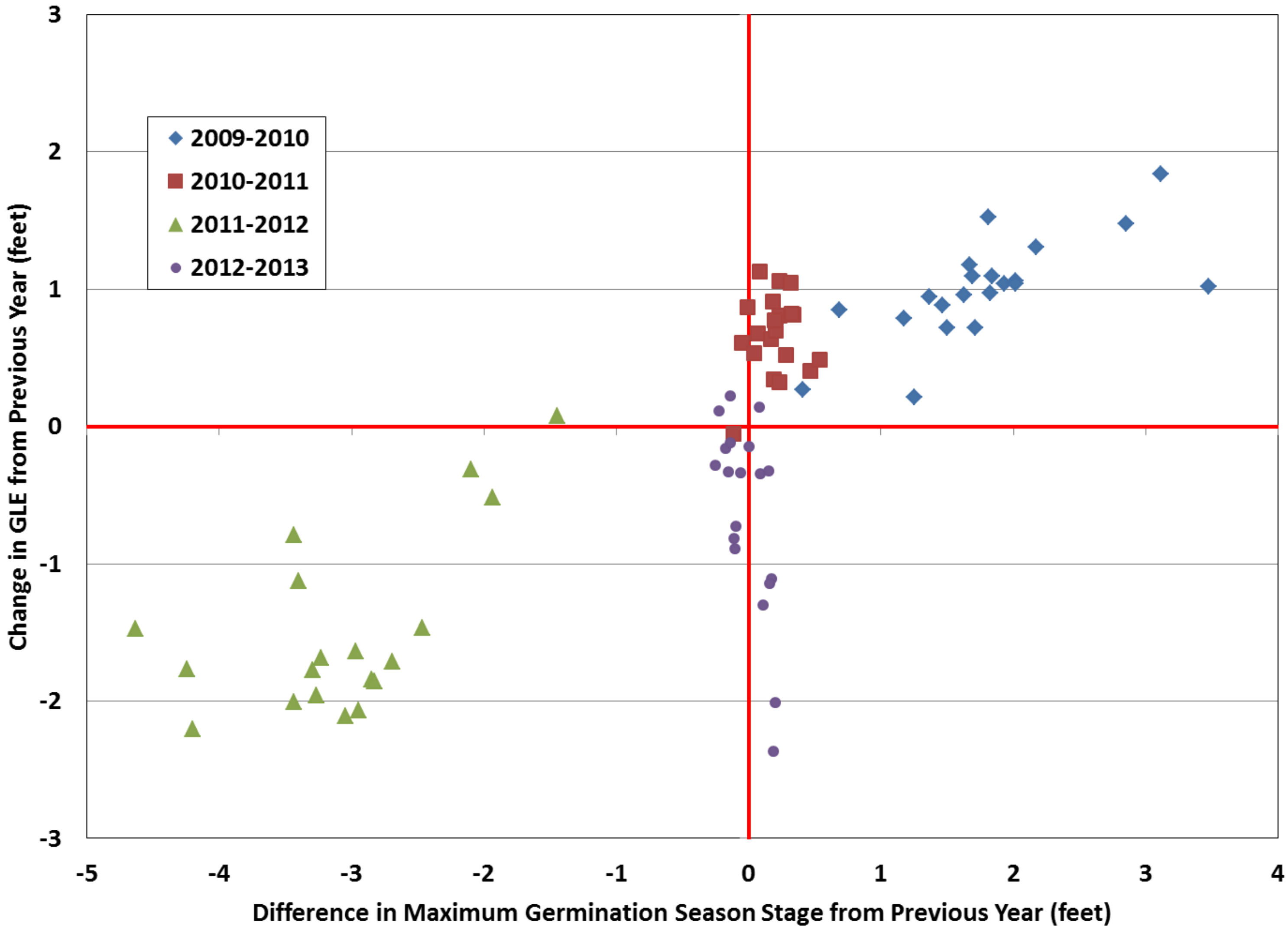


Figure 4.24. Change in GLE versus difference in stage at maximum germination season discharge preceding each survey at the pure panel APs (Kendall's $\tau = 0.61$, $p=<0.0001$).

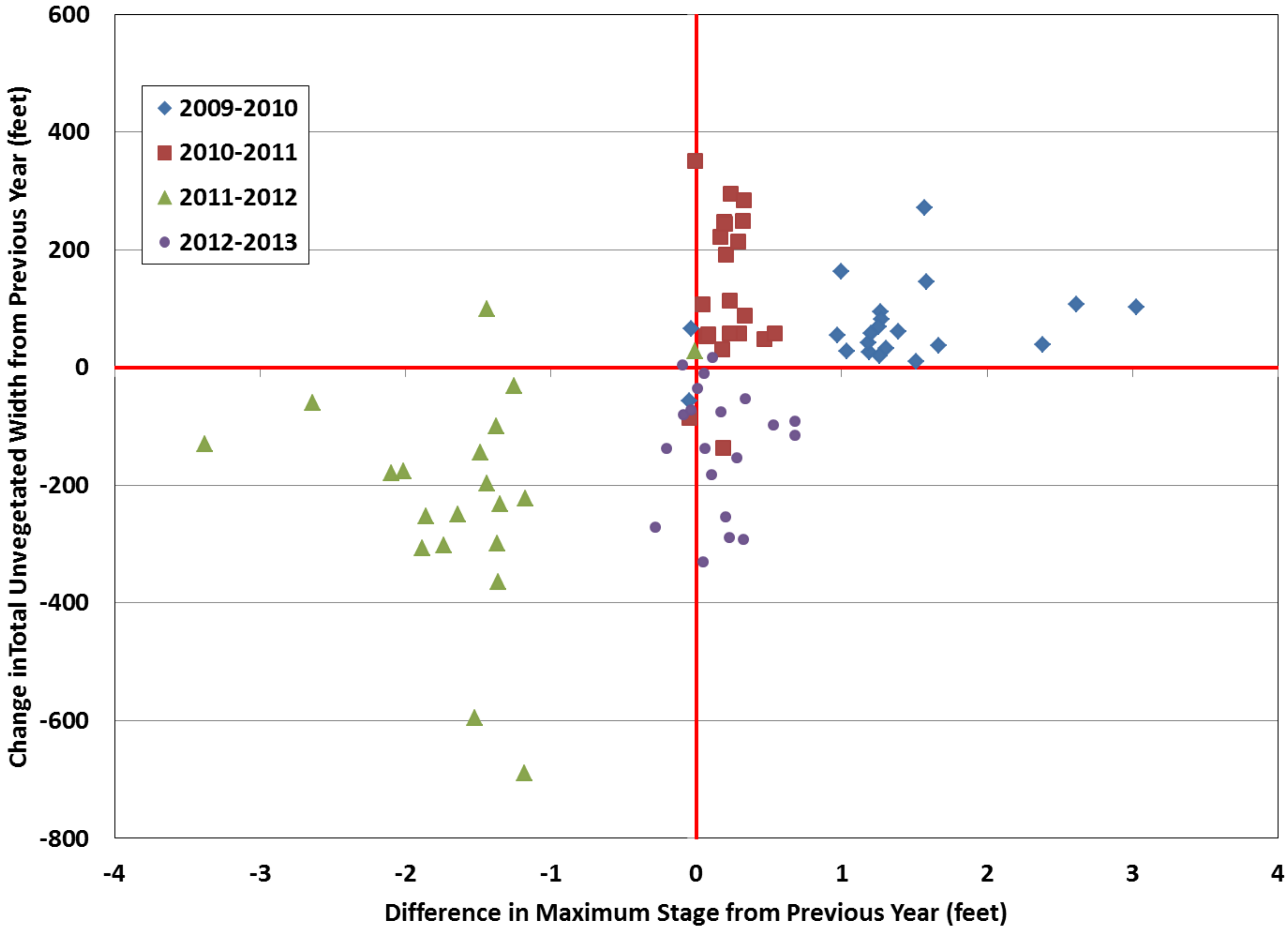


Figure 4.25. Change in total unvegetated channel width versus difference in stage at maximum mean daily flow preceding each survey at the pure panel APs (Kendall's τ = 0.39, p=<0.0001).

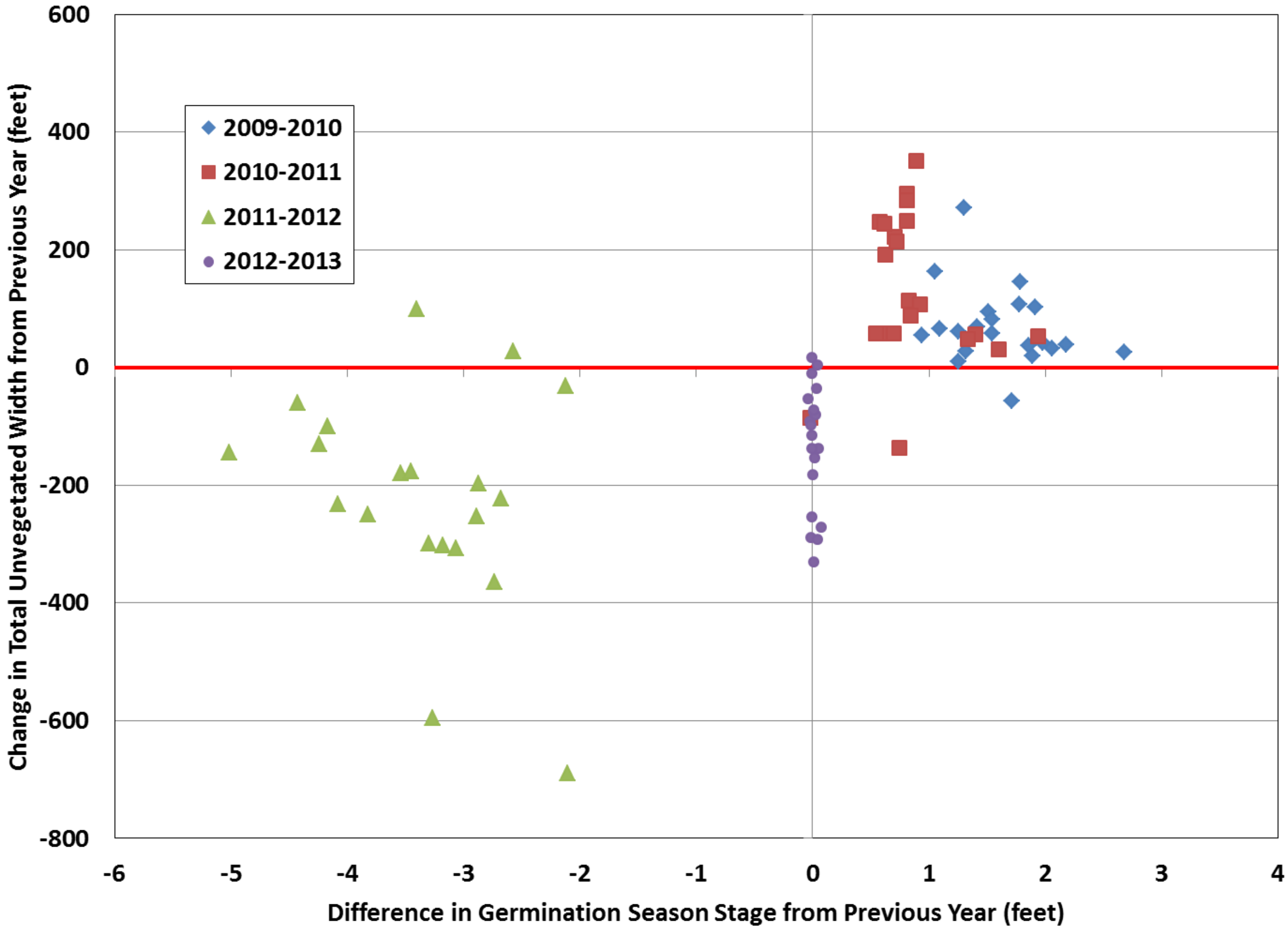


Figure 4.26. Change in total unvegetated channel width versus difference in stage at mean discharge during the germination season at the pure panel APs (Kendall's τ = 0.40, p=<0.0001).

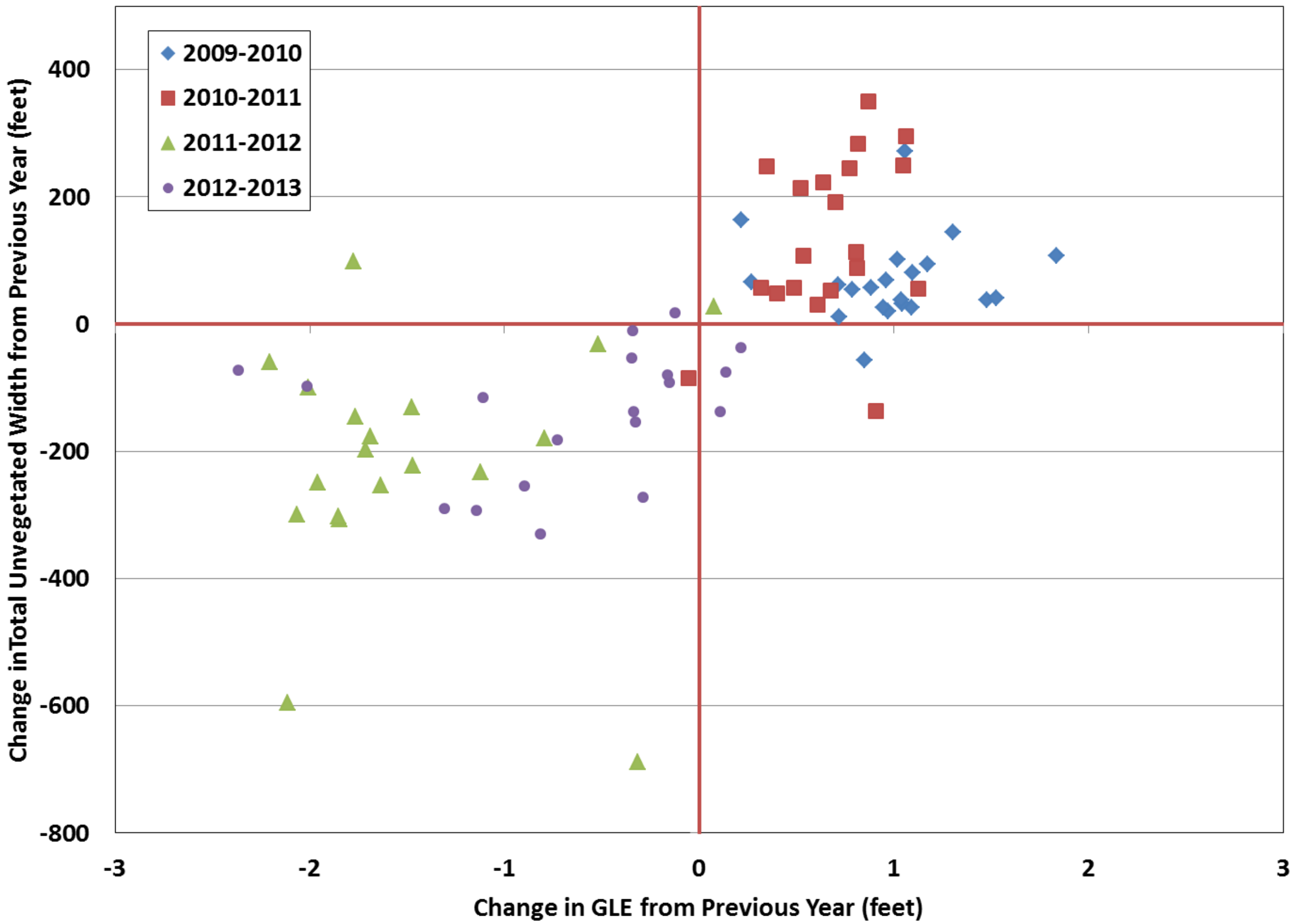


Figure 4.27. Change in total unvegetated channel width versus difference in stage at mean discharge during the germination season at the pure panel APs (Kendall's $\tau = 0.51$, $p=<0.0001$).

Collectively, all of the results in this section show that both the GLE and unvegetated channel width are responsive to the magnitude of the preceding flows, with the strongest correlation between the GLE and the mean germination season discharge. This result suggests that inundation that prevents new vegetation and annual species from growing on the sand bars and low elevation areas along the margins of the channel are the key factor in maintaining the unvegetated channel width.

4.3 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.*

Priority Hypothesis Flow 5 postulates that increasing the magnitude and duration of the annual peak discharge will increase riparian plant mortality along the margins of the river, with potentially different relationships for different species. The following section specifically focuses on the relative influence of spraying versus peak flows on the distribution and frequency of common reed (*phragmites australis*). The analysis was performed using the data from the pure panel APs, since only one data set is available for the majority of the rotating panel points. (The first set of rotating points was sampled for the second time in 2013.) Common reed was one of the most prevalent species in the reach during the initial (2009) monitoring survey, in terms of both frequency of occurrence (3rd highest frequency of the sampled species behind perennial ragweed and purple loosestrife) and percent cover (highest of sampled species) (Figures 3.14 and 3.19). The amount of common reed in the overall reach declined substantially between 2009 and 2010, remained relatively constant between 2010 and 2011, declined again between 2011 and 2012, and then increased by a small amount between 2012 and 2013 (**Figure 4.28**). The variability in the averages among the individual APs was, however, quite high.

Based on the percent cover data, common reed was most prevalent in three specific portions of the overall study reach in 2009: AP23 through AP29 near and upstream from Kearney, AP17 and AP19 just upstream from Shelton, and AP1 and AP2 at the downstream end of the reach (**Figure 4.29**). A substantial amount of common reed was also present at AP3 near Grand Island, AP35 in the North Channel at Jeffreys Island and at AP39 just downstream from the Lexington Bridge. With the exception of AP17, the amount of common reed decreased at all of these anchor points in 2010 (Figure 4.29). At AP17, common reed increased from about 10-percent cover in 2009 to over 16 percent in 2011. The amount of common reed continued to decline at most of the anchor points from 2010 to 2011; however, substantial increases occurred at AP19, AP23, AP27 and AP39. Generally low levels of common reed persisted through 2013, with a small decrease at 7 of the 20 pure panel APs and a small increase at 13 of the 20.

A wide range of flows, weather conditions, and Program activities occurred during the five-year monitoring period that could potentially affect the quantity and distribution of common reed along the reach. Flow conditions could impact growth of common reed and other in-channel vegetation in at least three ways: (1) during low to moderate flows, the river provides a source of irrigation, increasing growth potential, (2) high flows during the germination season can inundate the surfaces on which the plants grow, limiting plant growth, and (3) during extremely high flows, plants can be removed due to scour around the base of the plants and uprooting due to direct shear or through lateral erosion and undercutting of the plant roots. Weather could also be a factor because growth of most species tends to be stronger during warm, wet periods than

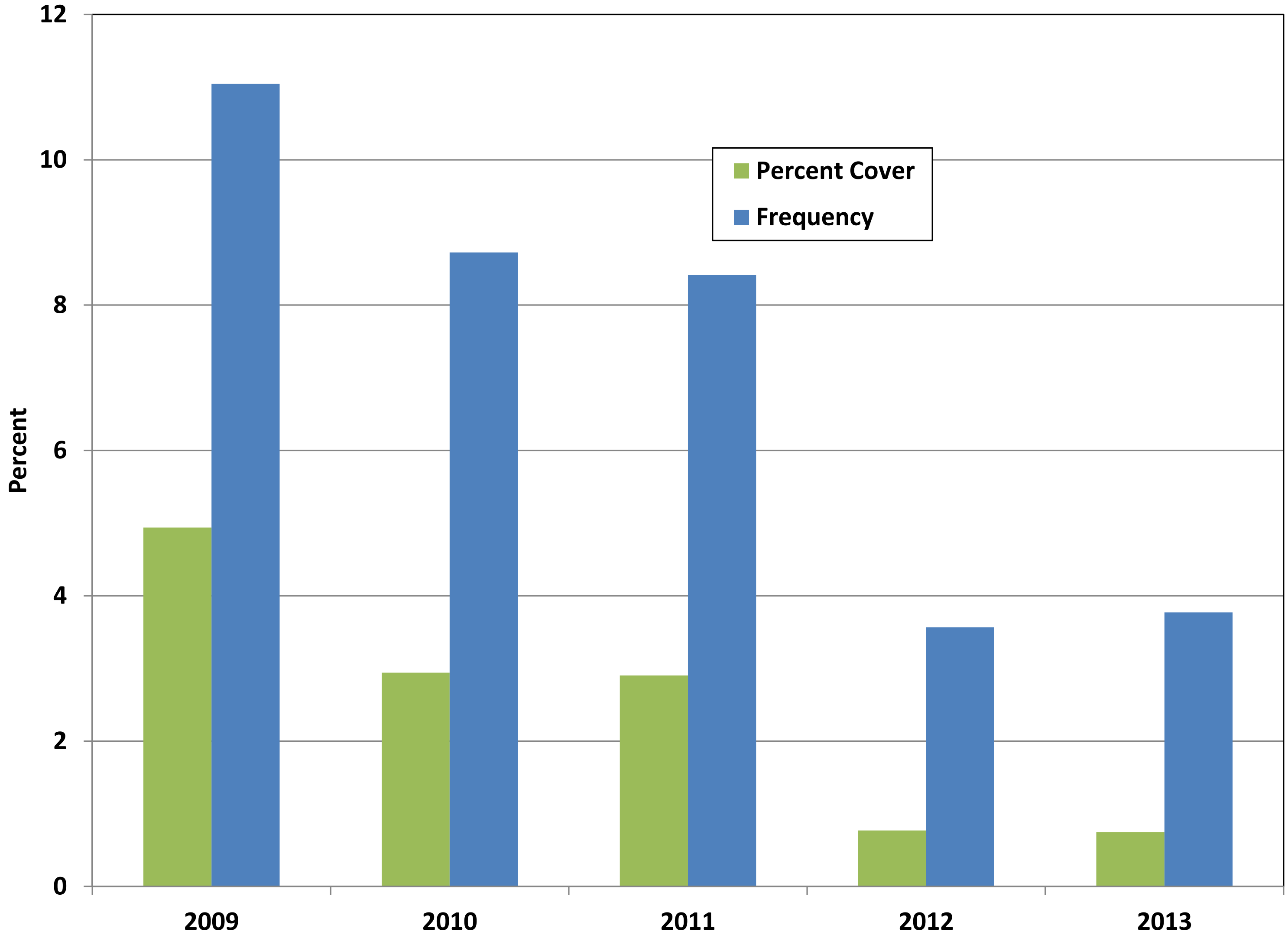


Figure 4.28. Average frequency of occurrence and percent cover for common reed (*phragmites australis*) among the individual anchor points.

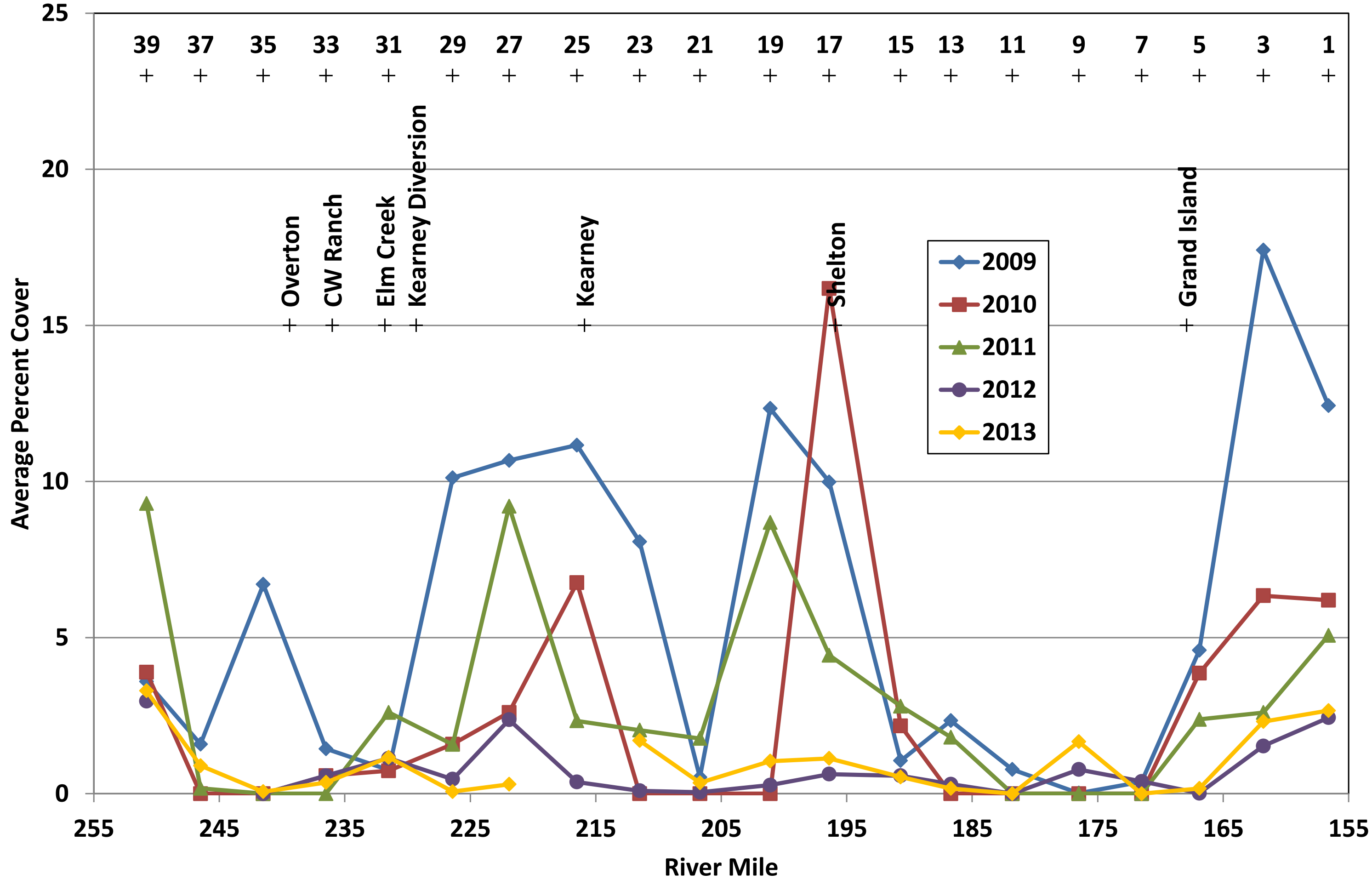


Figure 4.29. Average percent cover of common reed (*phragmites australis*) at the pure panel anchor points during the five monitoring periods.

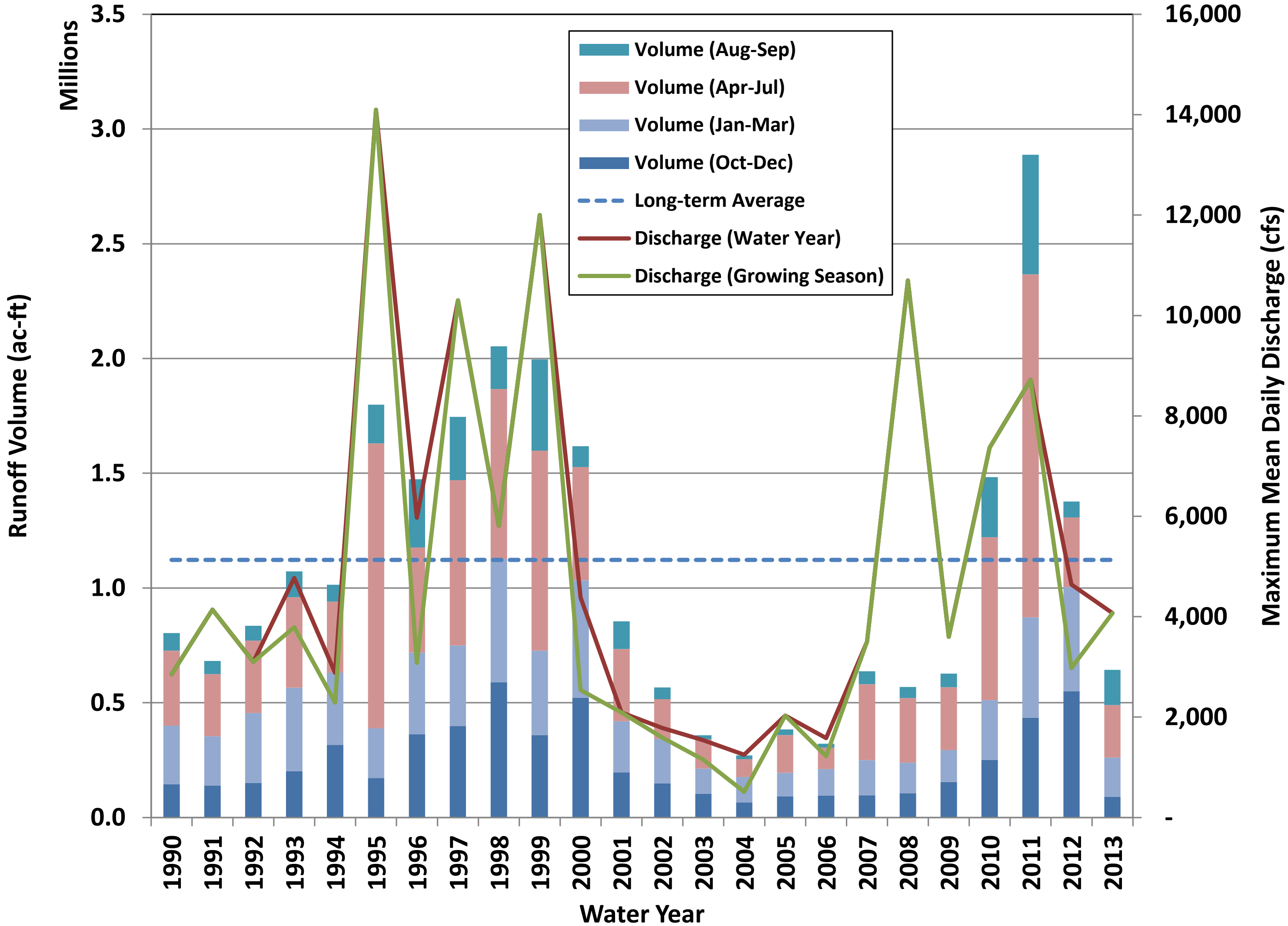


Figure 4.30. Total runoff volume at Overton during four periods of the water year and the maximum mean daily discharge during the entire water year and during the portion of the growing season between April 1 and August 1 (~time of the monitoring surveys) from WY1990 through WY2013. Long-term average volume based on gage data from WY1941 through August 2013.

either cool, dry or hot, dry conditions. Program activities that affect common reed include disking, mowing and shredding, and herbicide spraying.

Total runoff volume during WY2009 at Overton was only about 52 percent of the long-term average, and this increased to about 120 percent of average in 2010 and nearly 240 percent of average in 2011 (**Figure 4.30**). WY2012 was slightly above normal in terms of total runoff (~110 percent of average); however, the bulk of that runoff occurred during Fall 2011. The runoff during the portion of the 2012 growing season preceding the monitoring surveys (April through July) was only about 55 percent of the long-term average. WY2013 was also a very dry year, with the total runoff only about 52 percent of average (including the late-September 2013 flood), but only about 41 percent of average during the portion of the 2013 growing season from April through August. The year-to-year variability in maximum discharge was similar to the total runoff, with a relatively low maximum discharge in 2009 (3,600 cfs at Overton), high discharges in 2010 and 2011 (7,370 and 8,720 cfs, respectively), and low discharges in 2012 and 2013 (4,640 in October 2011 and 2,980 cfs during the 2012 growing season, and 4,070 cfs in Spring 2013).

Three specific variables were considered in evaluating the potential effects of flow on the prevalence of common reed:

1. Inundation depth at the maximum discharge (D_{max}),
2. Duration of inundation (Dur), and
3. Persistence of low flows during the growing season, quantified as the low flow that was equaled or exceeded 90 percent of the time (Q_{low}).

The inundation depth at the maximum discharge (D_{max}) was selected as a surrogate for the effects of high flows, since the maximum velocities and shear stresses at the individual points are not available. A two-dimensional model has been developed for the Elm Creek Complex, however, that can provide an indication of the range of anticipated velocities for different flow depths. While the hydraulic characteristics of the APs will vary to some degree from those at the Elm Creek Complex, the range of variability in the relationship between depths and velocities is probably similar. Based on a comparison of the maximum water-surface from the existing 1-dimensional HEC-RAS model with the elevations of the individual quadrats that contained common reed, about 27 percent of the quadrats were not inundated during the growing season in 2009; this decreased to only 3 percent in 2010 and 7 percent in 2011, and then increased to 74 percent in 2012 and 54 percent in 2013 (**Figure 4.31**). About ten percent of the quadrates containing common reed were inundated to a depth of at least 1.2 feet in 2009, 2.7 feet in 2010, 2.6 feet in 2011, and 0.7 feet in 2012 and 1.6 feet in 2013 (see 90% grid line in Figure 4.9). Based on results from the Elm Creek 2D model, maximum velocities at locations with depths in this range are about 6 fps, and most areas have velocities between 1.5 and 4 fps (**Figure 4.32**). Pollen-Bankhead et al. (2011) found that very high velocities, well above those that occur in the Platte River, are required to uproot established common reed plants (**Figure 4.33**); thus, it is unlikely that this process is responsible for the reduction in common reed during the monitoring period. If common reed is removed by the direct action of the water, the most likely process is through lateral erosion and undercutting of the sandbars and banklines on which the plants are growing (**Figure 4.34**). While this does occur in the study reach, field observations indicate that it occurs only in limited areas, primarily on the heads, and to a lesser extent along the margins of, sand bars. The thick, rhizomatous root structure appears to be very effective in binding the soil and limiting the rate and magnitude of lateral erosion and undercutting in areas where common reed is abundant.

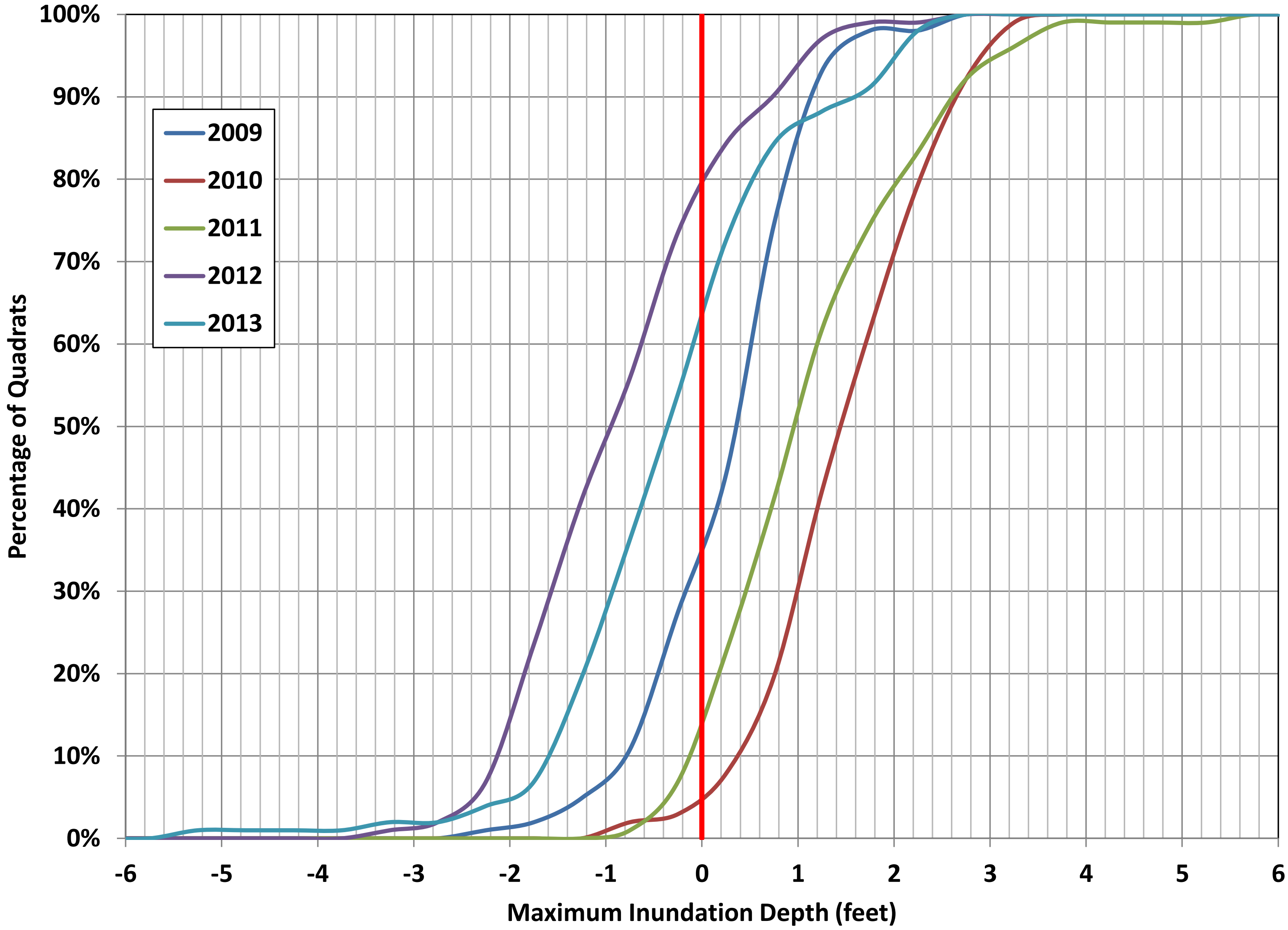
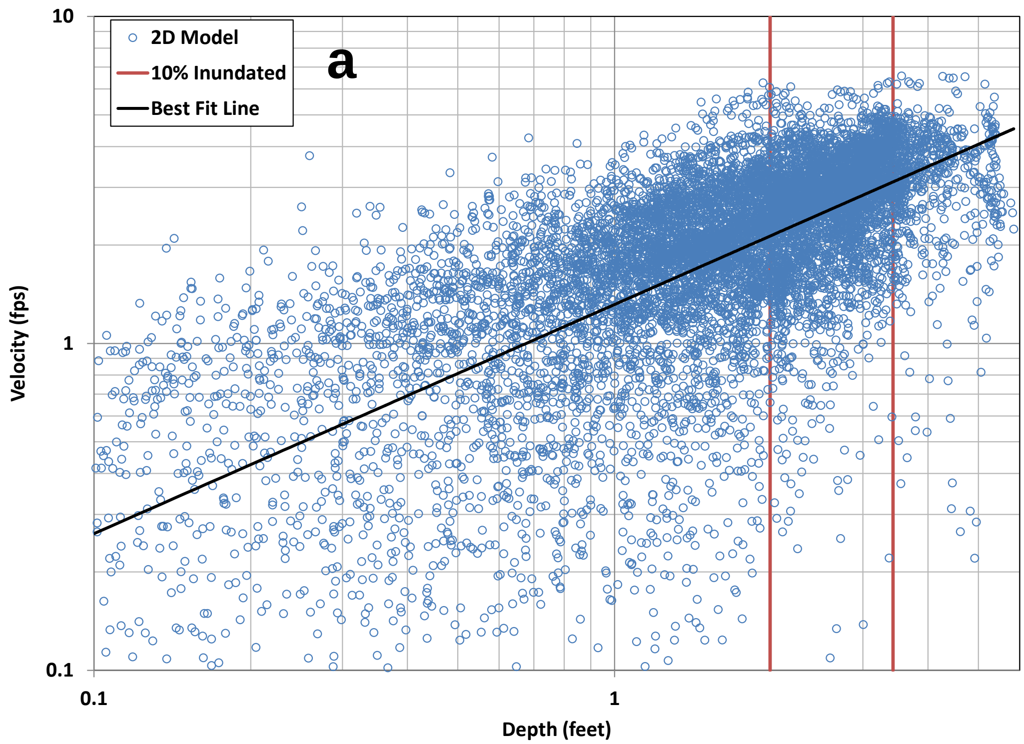


Figure 4.31. Cumulative distribution of inundation depths at the maximum discharge during the growing season for quadrats containing common reed during each of the five monitoring surveys.



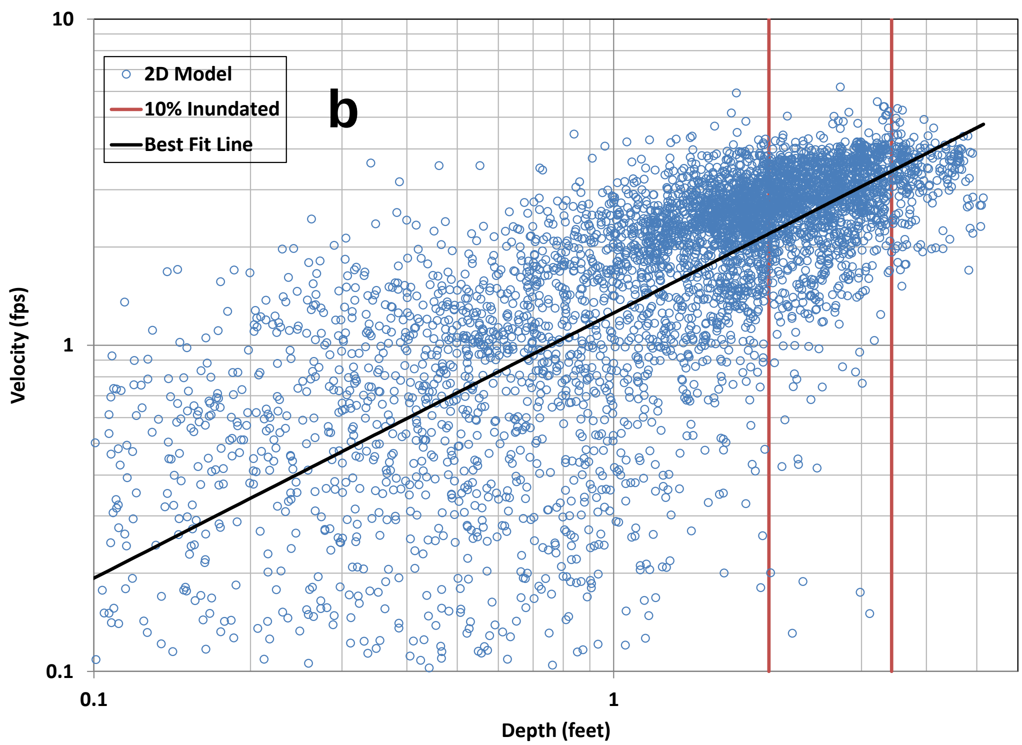


Figure 4.32. Depths and velocities from the Elm Creek 2-D model at a discharge of approximately 3.200 cfs: (a) Elm Creek Bridge to Kearney Diversion Structure, (b) downstream from Kearney Diversion Structure.

Figure 4.33. Typical lateral erosion and undercutting of the edge of a sand bar with common reed in the Elm Creek Complex.

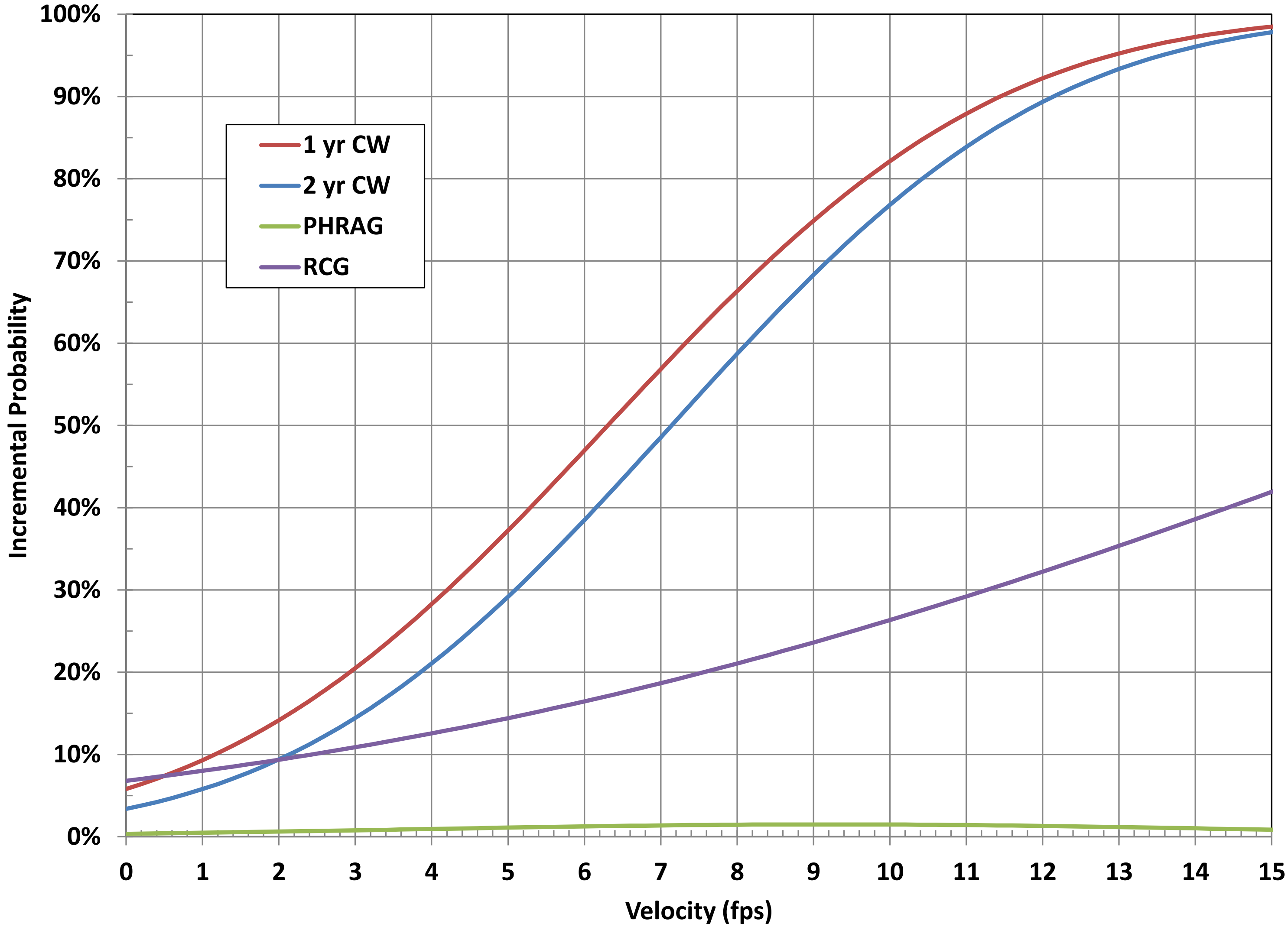


Figure 4.34. Incremental probability of plant removal for 1- and 2-year-old Cottonwood (1-year CW and 2-year CW), common reed (PHRAG) and reed canary grass (RCG) based on results from Pollen-Bankhead et al. (2011).

Weather conditions during the monitoring period varied in a manner similar to the runoff. In 2009, the total precipitation during the portion of the growing season prior to the monitoring surveys varied from about 10 inches in the portion of the reach upstream from Elm Creek to about 13.7 inches in the downstream portion of the reach (**Figure 4.35**). Precipitation during this period in 2010 ranged from about 15 inches in the upstream part of the reach to over 20 inches at Kearney and then declined to about 16.5 inches at Grand Island, and it was of similar magnitude during 2011. 2012 was very dry, with only about 7 inches of precipitation during the period at the upstream end of the reach, increasing to about 9 inches in mid-reach and declining to about 7.5 inches at Grand Island at the downstream end of the reach. Precipitation during 2013 was similar to 2009.

Based on data from the weather station at Grand Island Regional Airport [the only station in the Global Historical Climatology Network (GHCND) in close proximity to the study reach for which long-term temperature records are maintained], the normal (i.e., mean daily) temperature during April through July is 65°F. In 2009, this period was relatively cool, with mean temperature of 63.4°F, and it was slightly warmer than normal in 2010 and 2011 (65.6°F and 65.2°F, respectively), very warm in 2012 (70.3°F), and then slightly cooler than normal at about 64°F in 2013 (**Figure 4.36**). A better measure of the overall temperature regime that affects plant growth is heating degree days (HDD, also sometimes referred to as Growing Degree Days), a parameter originally developed as a measure of the energy required to heat a building in a given climate. HDD is typically computed based on the deviation of the minimum and maximum temperatures from a base temperature (65°F for the weather stations in Central Nebraska). Based on the algorithm used to compute HDD, higher values imply lower available energy and lower values imply higher available energy. The HDD values for 2009, 2010 and 2011 were all within about 10 percent of the 5-year average, while 2012 about 40 percent less (i.e., high heat energy) and 2013 was about 20 percent greater (i.e., low heat energy) than the 5-year average (Figure 4.36).

Mechanical actions performed by the Program that can affect the presence and persistence of common reed include herbicide spraying, disking, mowing and shredding on the surface of the sand bars, and in some cases, direct grading to construct new islands. The Program maintains a GIS database documenting these actions that includes the specific limits of spraying. This database was used to quantify the spraying intensity at each of the pure panel APs by identifying the individual quadrats that fall within the spraying limits, and calculating the percentage of the quadrats that were sprayed prior to each sampling period (**Figure 4.37**). Spraying typically occurs in September and October of each year, with the intensity varying along the reach, based at least in part, on the amount of common reed that is present. Spraying occurred at 7 of the 20 pure panel APs in Fall 2008, with about 10 percent of the approximately 2900 vegetation quadrats being sprayed. The spraying intensity increased significantly in Fall 2009, with at least some spraying at 13 of the 20 pure panel APs, and about 36 percent of the approximately ~4,000 quadrats being sprayed. The overall amount of spraying at the pure panel APs in Fall 2010 and 2011 was similar to 2009; however, 18 of the 20 APs received at least some spraying in 2011. Similarly, the overall amount of spraying declined in Fall 2012, with about 6 percent of the quadrats sprayed, but at least some spraying occurred at 17 of the 20 pure panel APs (**Figure 4.38**).

According to the Program database (**Table 4.2**), disking was performed at three of the pure panel APs (AP9, AP11 and AP19). The amount of common reed that was present at AP9 and AP11 in 2009 when the monitoring program began was relatively low; however, AP19 had a relatively large amount, in spite of the disking. None of these APs was sprayed in 2008.

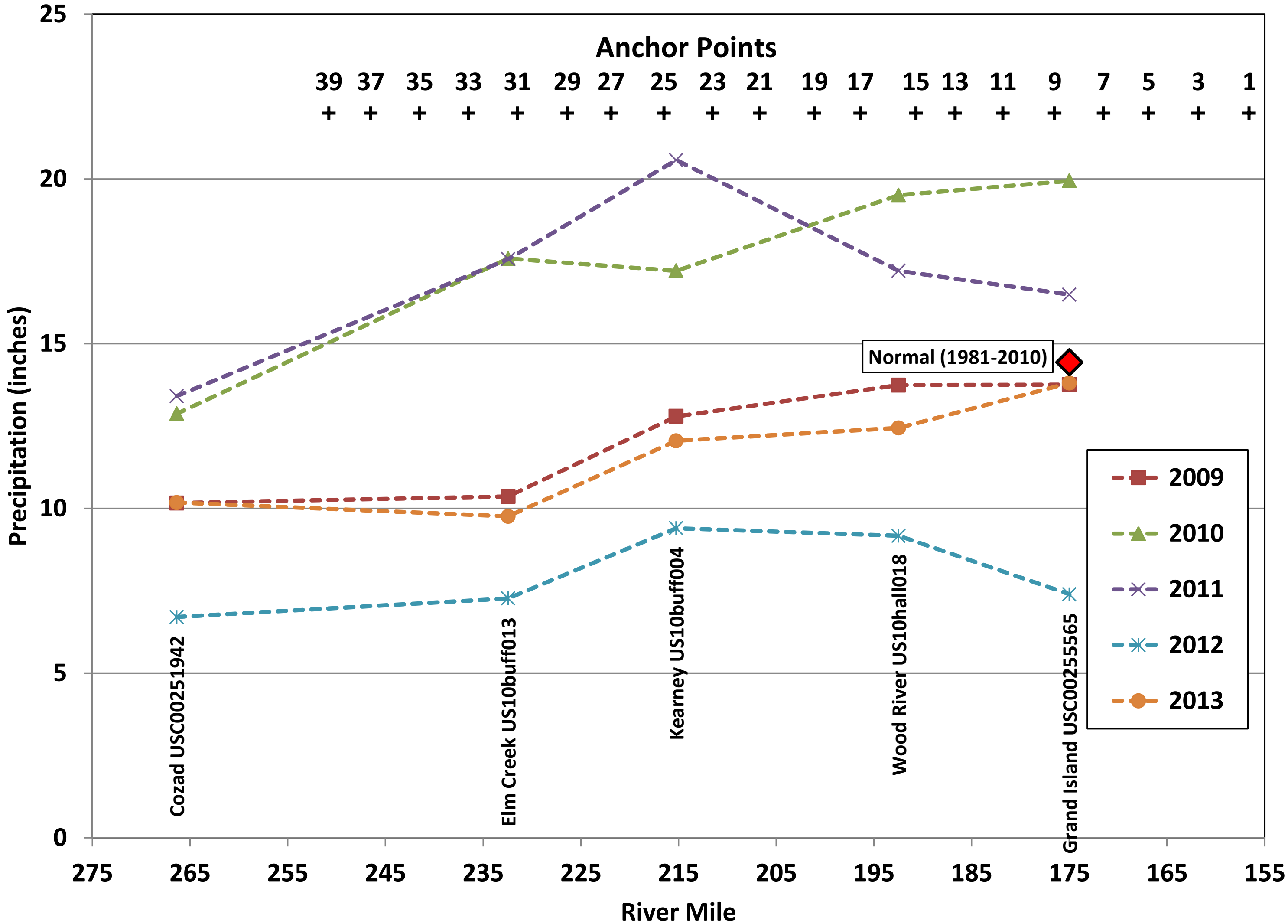


Figure 4.35. Total precipitation during the period from April through July in each of the five monitoring years at five weather stations along the project reach. Also shown is the “normal” precipitation at the Grand Island station based on data from 1981 through 2010. [Global Historical Climatology Network (GCHND) station numbers used as the data source follow the names.]

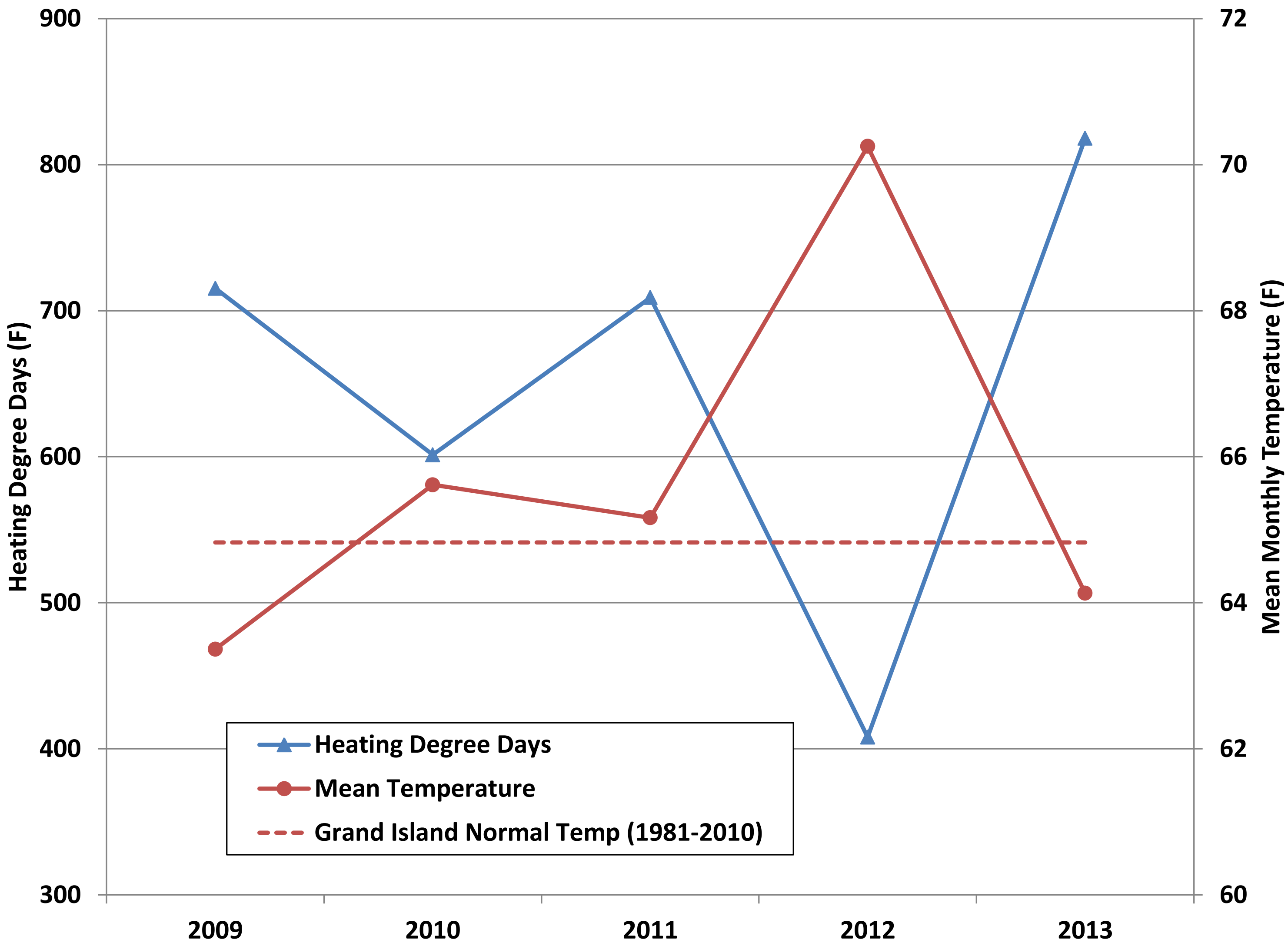


Figure 4.36. Heating degree days (HDD) and average temperature at the Grand Island Station (GCHND Sta USC00255565) during the period from April through July during the monitoring period.

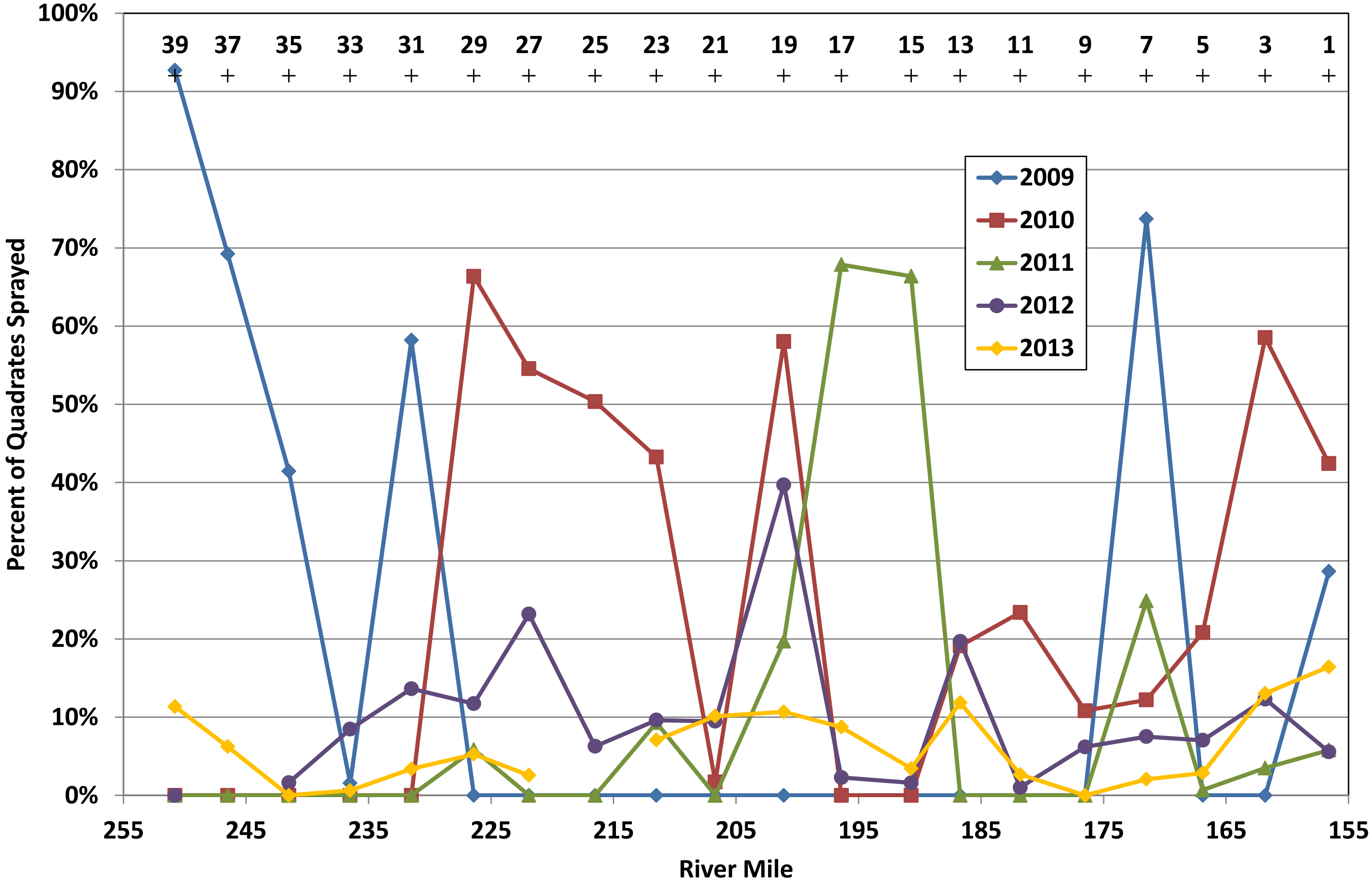


Figure 4.37. Percentage of individual vegetation sampling quadrats sprayed at each of the pure panel APs prior to each sampling period. Spraying typically occurs in early-fall; thus, the spraying indicated for each year occurred during fall of the previous year.

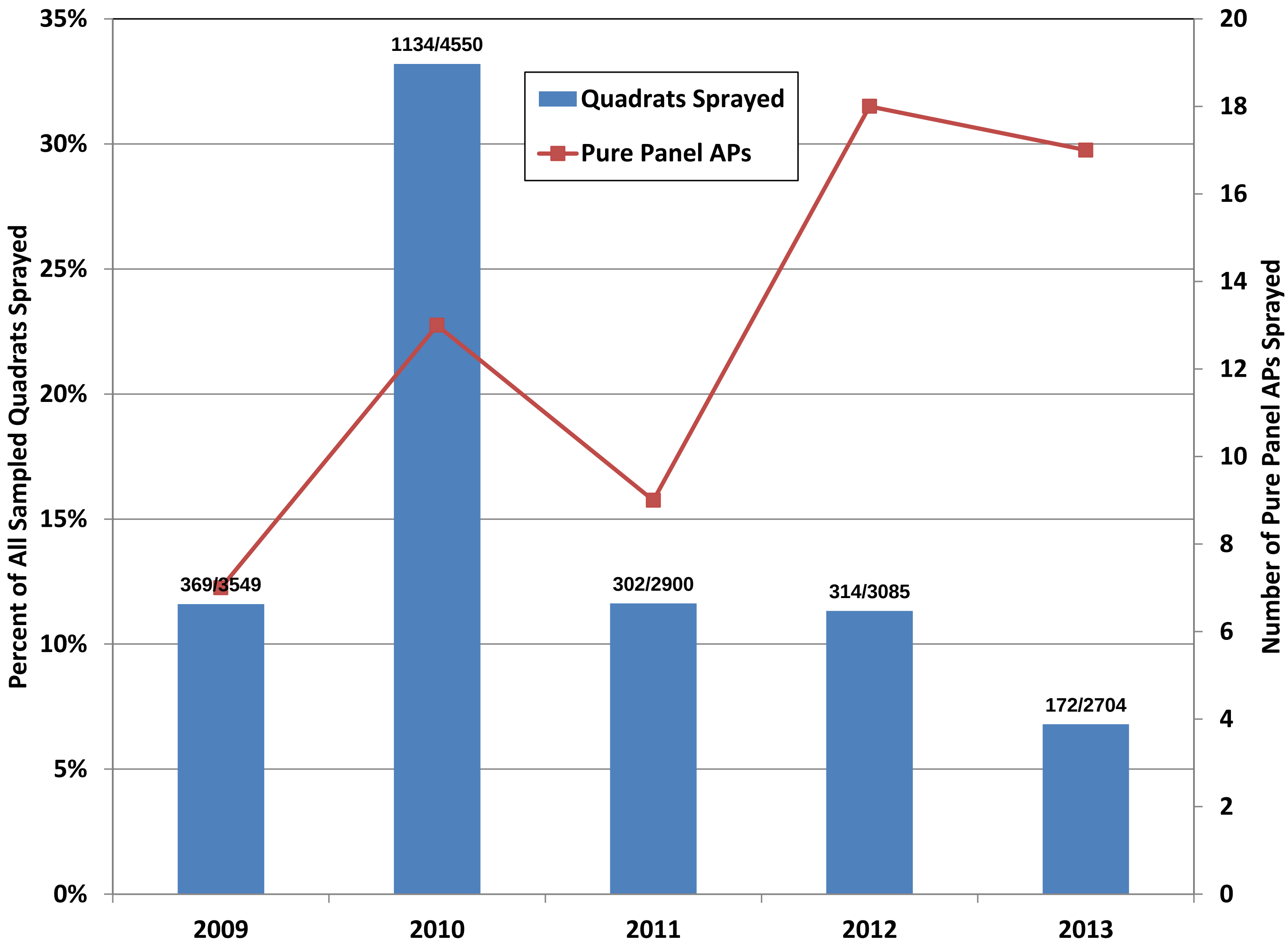


Figure 4.38. Percentage of all sampled quadrats sprayed at pure panel anchor points and number of pure panel APs receiving at least some spraying during the preceding fall of the indicated year. First number in each label is number of quadrats sprayed; second number is total number of sampled quadrats.

Table 4.2. Summary of PRRIP mechanical and other direct treatments at the APs for 2008 through 2012.

Anchor Point	Activity				
	2008	2009	2010	2011	2012
40	Shredding/Mowing	Chemical			
39	Chemical	Shredding/Mowing			
38	Tree Clearing, Chemical	Shredding/Mowing			
37a	Tree Clearing	Shredding/Mowing			
34			Shredding/Mowing		
33		Island Construction, Tree Clearing/Removal,	Off Channel Habitat	Pre-emergent, Chemical	Prescribed Fire, Noxious Weed Control, Tree Clearing
32			Shredding/Mowing, Chemical, Tree Clearing	Herbicide	Prescribed Fire, Noxious Weed Control, Shredding/Mowing
31					Shredding/Mowing
30	Discing	Chemical	Clear and Smooth, Tree clearing, Discing	Grass Seeding, Herbicide, Discing	Prescribed fire, tree clearing, Island Construction, Discing, Pre-emergent, Noxious Weed Control
29	Shredding/Mowing		Shredding/Mowing		
28	Shredding/Mowing				
24				Herbicide	
23	Spraying			Herbicide	Clear and Grub
22	Spraying			Noxious Weed Control, Seedbed Prep, Grass Seeding, Herbicide	
21	Spraying,				
20	Spraying	Chemical			
19	Discing				
18	Discing	Chemical			

Anchor Point	Activity				
	2008	2009	2010	2011	2012
16			Shredding/Mowing		
15	Spraying				
14	Discing				
13a		Shredding/Mowing			Tree Clearing, Seedbed Prep.
13				Herbicide	
12				Prescribed Fire, Herbicide, Tree/brush mulching	Discing, Pre-emergent, Shredding/Mowing
11a				Herbicide	
11	Discing			Herbicide	
10a		Chemical, Shredding/Mowing			
10	Discing				
09a		Chemical, Shredding/Mowing			
9	Discing				
08aa	Shredding/Mowing	Chemical			
8	Shredding/Mowing				
07a	Shredding/Mowing	Chemical			
06a	Shredding/Mowing	Chemical			
6	Chemical				
1	Chemical				

Shredding and mowing was conducted at AP7 and AP29 in 2008. About 75 percent of the vegetation quadrats at AP7 were sprayed and no spraying occurred at AP29 in 2008. The monitoring data indicate that little or no common reed was present at AP7, and AP29 had among the largest amounts of common reed in 2009.

Shredding and mowing occurred at four of the APs (AP9, AP13, AP37 and AP39), and a large, mid-channel islands were mechanically removed at AP33 in Fall 2009. The amount of common reed at these APs was relatively low in 2010. Aside from spraying, the only mechanical actions documented in the Program database for Fall 2010 was shredding and mowing at AP29. With the exception of AP19, AP27 and AP39, the amount of common reed present at the pure panel APs was relatively low in 2011. Spraying was the only documented Program action at the pure panel APs potentially affecting the amount of common reed in Fall 2011, and documented actions other than spraying in Fall 2012 consisted of clearing and grubbing at AP23 and shredding and mowing at AP31. Very little common reed was present at these APs in 2012.

Based on the available information related to the above factors, a multiple correlation analysis was conducted using the Spearman correlation coefficient (ρ) to assess whether there is a statistically-significant relationship between average percent cover and year-to-year change in percent cover of common reed at the pure panel APs and the following six variables:

1. Percent of quadrats at the AP sprayed (% Sprayed),
2. Maximum inundation depth (D_{max}),
3. Duration of Inundation (Dur),
4. Discharge equaled or exceeded 90 percent of the time (Q_{low}),
5. Number of heating degree days during the growing season preceding the monitoring surveys (April through July) (HDD),
6. Total precipitation during the growing season preceding the monitoring surveys (April through July) (Precip).

The Spearman coefficient is based on the ranks of the observations and not their values; thus, it does not rely on assumptions of normality and linearity. The analysis was performed only on the pure panel APs that had more than 3.5-percent average cover during the initial monitoring survey (2009) since changes at those with lower amounts provide little contrast to assess the effects of the various parameters. As illustrated in Figure 4.28, the amount of common reed changed very little at the APs that were not included in the analysis. The analysis for percent cover indicates a statistically-significant positive correlation with maximum inundation depth (ρ=0.29, p<0.036), duration of inundation (ρ=0.37, p=0.006) and the 90th percentile (low) flow (ρ=0.43, p=0.001) (i.e., increasing percent cover of common reed with increases in each of these variables) (**Table 4.3**). The analysis also indicates that there is statistically-significant positive correlation between the percent cover of common reed and total cover of all species. These results suggest that the availability of irrigation water is the primary factor in the amount of common reed in the reach. The results also indicate that the percent cover of common reed at any point in time is not strongly correlated with the intensity of spraying. This is a misleading result; however, because the spraying was focused on areas with significant amounts of common reed.

To overcome this issue, the correlation was also performed on the year-to-year change in percent cover versus the listed variables. Because data on the amount of common reed prior to the 2009 surveys are not available, the data were reduced to only the last four years of the

Table 4.3. Correlation (Spearman) and p-values for percent cover of common reed versus possible influencing variables.

Correlation matrix (Spearman):								
Variables	%Site Sprayed	Max Inund Depth (ft)	Duration of Inundation (days)	Q low (cfs)	Heating Degree Days	Total Precipitation (inches)	% Cover All Species	% Cover Phrag
%Site Sprayed	**1**	0.073	0.076	0.050	-0.254	0.136	0.145	-0.175
Max Inund Depth (ft)	0.073	**1**	**0.796**	**0.616**	-0.262	**0.748**	-0.030	**0.287**
Duration of Inundation (days)	0.076	**0.796**	**1**	**0.696**	-0.187	**0.715**	0.035	**0.371**
Q low (cfs)	0.050	**0.616**	**0.696**	**1**	-0.035	**0.799**	0.146	**0.426**
Heating Degree Days	-0.254	-0.262	-0.187	-0.035	**1**	0.001	**0.324**	0.235
Total Precipitation (inches)	0.136	**0.748**	**0.715**	**0.799**	0.001	**1**	**0.298**	0.259
% Cover All Species	0.145	-0.030	0.035	0.146	**0.324**	**0.298**	**1**	**0.355**
% Cover Common Reed	-0.175	**0.287**	**0.371**	**0.426**	0.235	0.259	**0.355**	**1**
p-values:								
%Site Sprayed	**0**	0.599	0.585	0.720	0.064	0.324	0.296	0.205
Max Inund Depth (ft)	0.599	**0**	**< 0.0001**	**< 0.0001**	0.056	**< 0.0001**	0.827	**0.036**
Duration of Inundation (days)	0.585	**< 0.0001**	**0**	**< 0.0001**	0.174	**< 0.0001**	0.800	**0.006**
Q low (cfs)	0.720	**< 0.0001**	**< 0.0001**	**0**	0.801	**< 0.0001**	0.290	**0.001**
Heating Degree Days	0.064	0.056	0.174	0.801	**0**	0.993	**0.017**	0.087
Total Precipitation (inches)	0.324	**< 0.0001**	**< 0.0001**	**< 0.0001**	0.993	**0**	**0.029**	0.059
% Cover All Species	0.296	0.827	0.800	0.290	**0.017**	**0.029**	**0**	**0.009**
% Cover Common Reed	0.205	**0.036**	**0.006**	**0.001**	0.087	0.059	**0.009**	**0**

Values in bold are different from 0 with a significance level alpha=0.05 surveys. Results of this analysis indicate that the change is negatively correlated with the percentage of quadrats sprayed (ρ=-0.43, p=0.004) and positively correlated with the number of heating degree days during the intervening growing season (ρ=0.45, p=0.003) (**Table 4.4**). Step-wise, linear, least-squares regression using these two variables indicates that the correlation is strongest with spraying (**Figures 4.39 and 4.40**); adding heating degree days does not provide statistically-significant improvement in the relationship. These results indicate that spraying significantly reduced the amount of common reed, and hotter temperatures also tended to reduce the amount. (Based on the definition of HDD, lower values mean higher temperatures). The data also show that there is essentially no correlation with maximum inundation depth, duration of inundation, persistence of low flows during the growing season, or precipitation (**Figures 4.41a-d**). The lack of correlation with maximum inundation depths and duration of inundation indicates that high flows are not effective in removing common reed.

4.4 Mechanical #2

> *Increasing the Q1.5 in the main channel by consolidating 85 percent of the flow, and aided by Program flow and a sediment balance, flows will exceed stream power thresholds that will convert main channel from meander morphology in anastomosed reaches to braided morphology with an average braiding index.*

The correlation between total unvegetated width (W_{unveg}), braiding index (BI) and percent consolidation at 8,000 cfs was determined to assess the extent to which the unvegetated width and amount of braiding are influenced by the relative amount of the total flow carried in the primary flow path. The amount of flow consolidation ranges from about 42 percent in the main branch at AP23 to 100 percent at several locations that are spread throughout the reach that represent about 32 percent of the total reach length (**Figure 4.42**). The length-weighted, average percent consolidation in the areas with less than 100 percent consolidation is about 62 percent.

The correlation between these three metrics is relatively weak, but statistically significant at the 95-percent level (**Figures 4.43 through 4.46, Table 4.5**). As discussed in Section 3.4.2, the unvegetated widths were greatest during 2011, when long-duration, high flows occurred in the reach prior to the monitoring surveys (Figure 3.18b). As discussed in Section 3.3.1, the average braiding index changed very little over the 4-year period encompassed by the surveys (Figure 3.8b), although changes did occur at some APs. Based on a two-sample t-test, the mean unvegetated width at locations with less than 85-percent flow consolidation is not significantly different from the widths at locations having greater than 85 percent consolidation (t=1.59, p=0.115), while the difference in the mean braiding index between these two data set is statistically significant (t=4.30, p<0.0001).

Management actions at AP 9 (Showmaker Island), AP21 (Rowe Sanctuary) and AP33 (Cottonwood Ranch) have likely altered (or at minimum, masked) the relationships between flow, braiding index and channel width. To assess whether the correlation is different at the sites that have not been affected by these management actions, the data for these three APs were removed, and the statistical tests repeated for the censored data sets. The result indicate that braiding index and unvegetated with are still significantly correlated with flow consolidation, and the strength of the relationship increases (Table 4.5). Based on a two-sample t-test of the censored data, the difference in average braiding index and unvegetated width at sites with 100-percent flow consolidation are significantly different from those with less than 85-percent consolidation (t=3.81, p=0.0003 for unvegetated width; t=4.30, p<0.0001 for braiding index). Based on these results, it appears that flow consolidation may result in a wider unvegetated channel and more braiding.

Table 4.4. Correlation (Spearman) and p-values for year-to-year change in percent cover of common reed versus possible influencing variables.

Correlation matrix (Spearman):								
Variables	%Site Sprayed	Max Inund Depth (ft)	Duration of Inundation (days)	Q low (cfs)	Heatin g Degree Days	Total Precipitati on (inches)	% Cover All Species	% Cover Phrag
%Site Sprayed	**1**	0.121	0.124	0.060	-0.228	0.201	-0.154	**-0.432**
Max Inund Depth (ft)	0.121	**1**	**0.800**	**0.441**	-0.199	**0.683**	-0.244	-0.230
Duration of Inundation (days)	0.124	**0.800**	**1**	**0.673**	-0.083	**0.761**	-0.226	-0.094
Q low (cfs)	0.060	**0.441**	**0.673**	**1**	0.167	**0.777**	-0.224	-0.029
Heating Degree Days	-0.228	-0.199	-0.083	0.167	**1**	0.185	**0.564**	**0.451**
Total Precipitation (inches)	0.201	**0.683**	**0.761**	**0.777**	0.185	**1**	-0.118	-0.015
% Cover All Species	-0.154	-0.244	-0.226	-0.224	**0.564**	-0.118	**1**	**0.516**
% Cover Common Reed	**-0.432**	-0.230	-0.094	-0.029	**0.451**	-0.015	**0.516**	**1**
p-values:								
%Site Sprayed	**0**	0.438	0.427	0.702	0.141	0.194	0.323	**0.004**
Max Inund Depth (ft)	0.438	**0**	**< 0.0001**	**0.003**	0.200	**< 0.0001**	0.115	0.137
Duration of Inundation (days)	0.427	**< 0.0001**	**0**	**< 0.0001**	0.595	**< 0.0001**	0.145	0.548
Q low (cfs)	0.702	**0.003**	**< 0.0001**	**0**	0.282	**< 0.0001**	0.148	0.854
Heating Degree Days	0.141	0.200	0.595	0.282	**0**	0.233	**0.000**	**0.003**
Total Precipitation (inches)	0.194	**< 0.0001**	**< 0.0001**	**< 0.0001**	0.233	**0**	0.450	0.922
% Cover All Species	0.323	0.115	0.145	0.148	**0.000**	0.450	**0**	**0.000**
% Cover Common Reed	**0.004**	0.137	0.548	0.854	**0.003**	0.922	**0.000**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

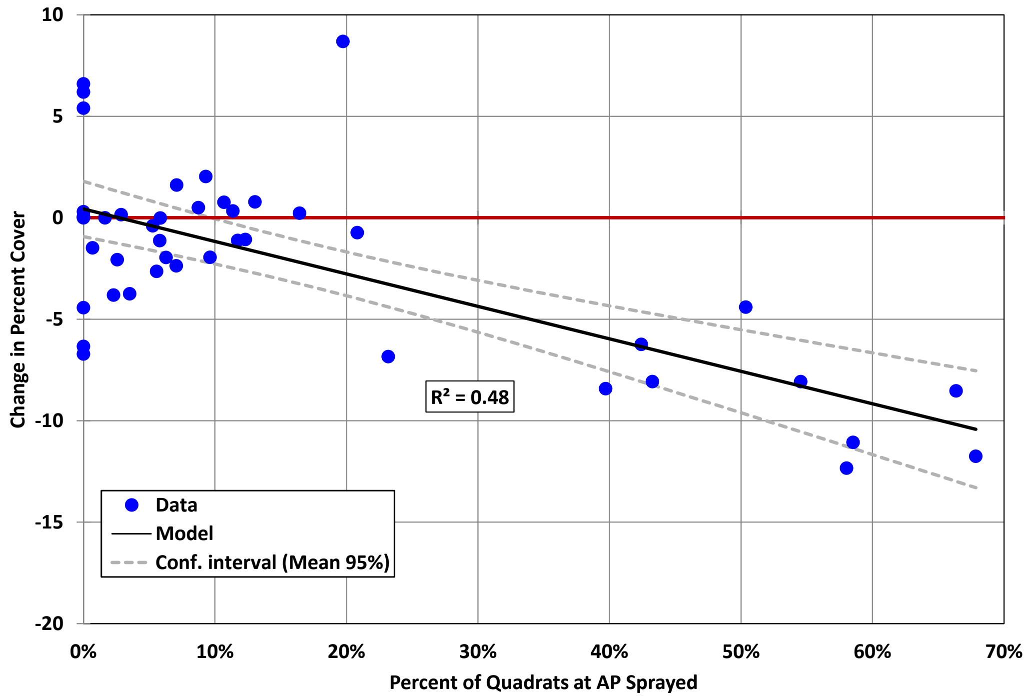


Figure 4.39. Change in percent cover of common reed versus percent of quadrats sprayed at pure panel APs with more than 3.5 percent average cover of common reed during the 2009 survey.

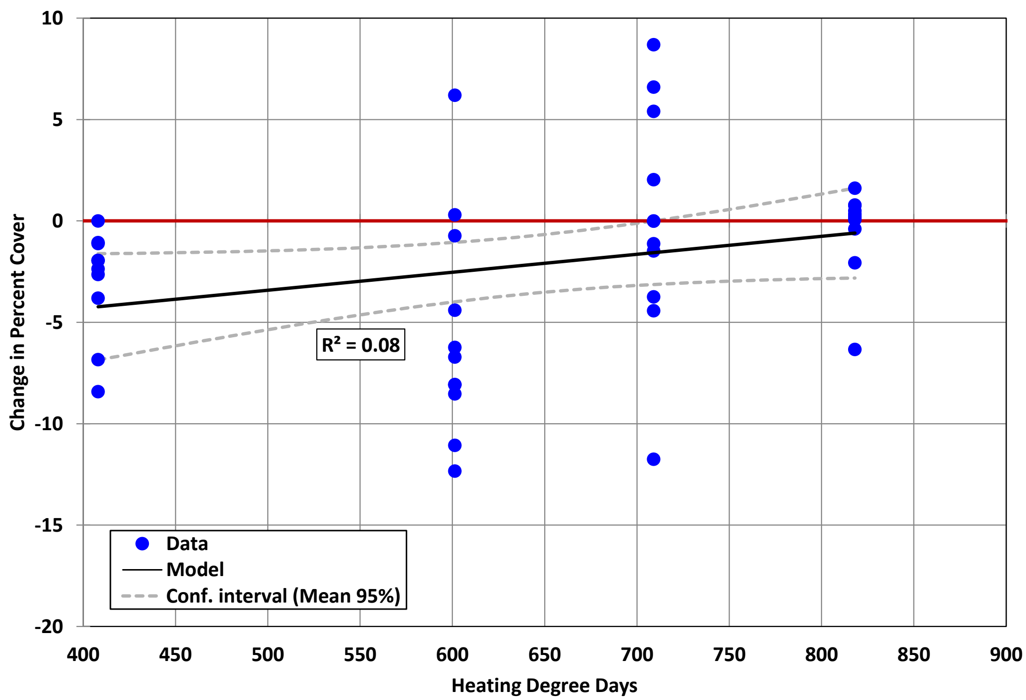


Figure 4.40. Change in percent cover of common reed versus heating degree days at pure panel APs with more than 3.5 percent average cover of common reed during the 2009 survey.

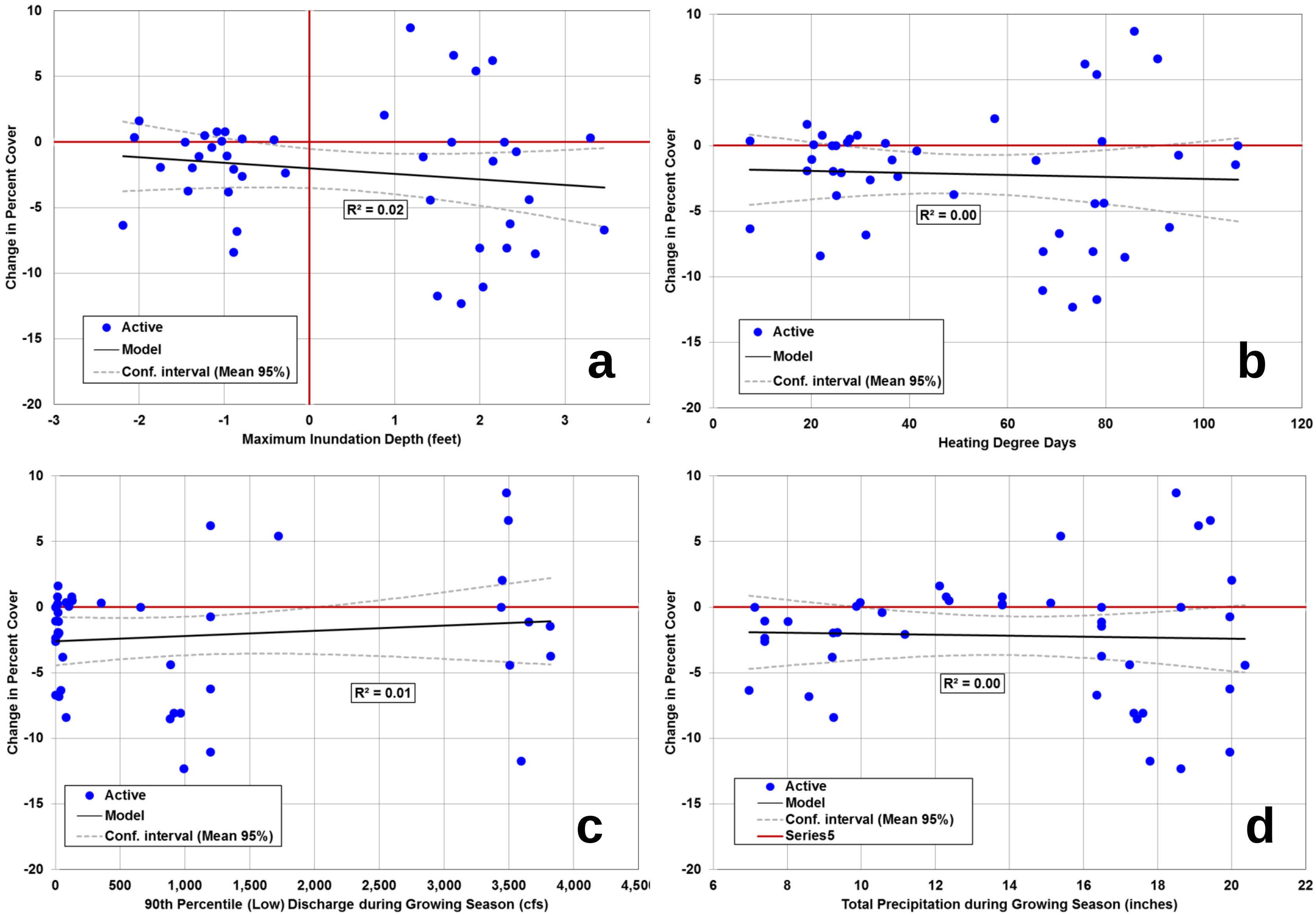


Figure 4.41. Change in percent cover of common reed versus: (a) maximum inundation depth, (b) duration of inundation, (c) 90th percentile (low) flow during growing season, (d) total precipitation during growing season.

Table 4.5. Correlation matrix for percent flow consolidation, average braiding index and average unvegetated channel width at all of the pure panel APs, and all pure panel APs, except AP9, AP21 and AP33.

Variables	All Data			Excluding AP 9, 21 and 33*		
	Flow Consolidation at 8,000 cfs	Braiding Index	Unvegetated Width (feet)	Flow Consolidation at 8,000 cfs	Braiding Index	Unvegetated Width (feet)
Correlation matrix (Kendall):						
Flow Consolidation at 8,000 cfs	**1**	**0.236**	**0.182**	**1**	**0.303**	**0.341**
Braiding Index	**0.236**	**1**	**0.186**	**0.303**	**1**	**0.248**
Unvegetated Width (feet)	**0.182**	**0.186**	**1**	**0.341**	**0.248**	**1**
p-values:						
Flow Consolidation at 8,000 cfs	**0**	**0.002**	**0.012**	**0**	**0.000**	**< 0.0001**
Braiding Index	**0.002**	**0**	**0.006**	**0.000**	**0**	**0.001**
Unvegetated Width (feet)	**0.012**	**0.006**	**0**	**< 0.0001**	**0.001**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

*Management activities at AP9, 21 and 33 may have affected the relationship.

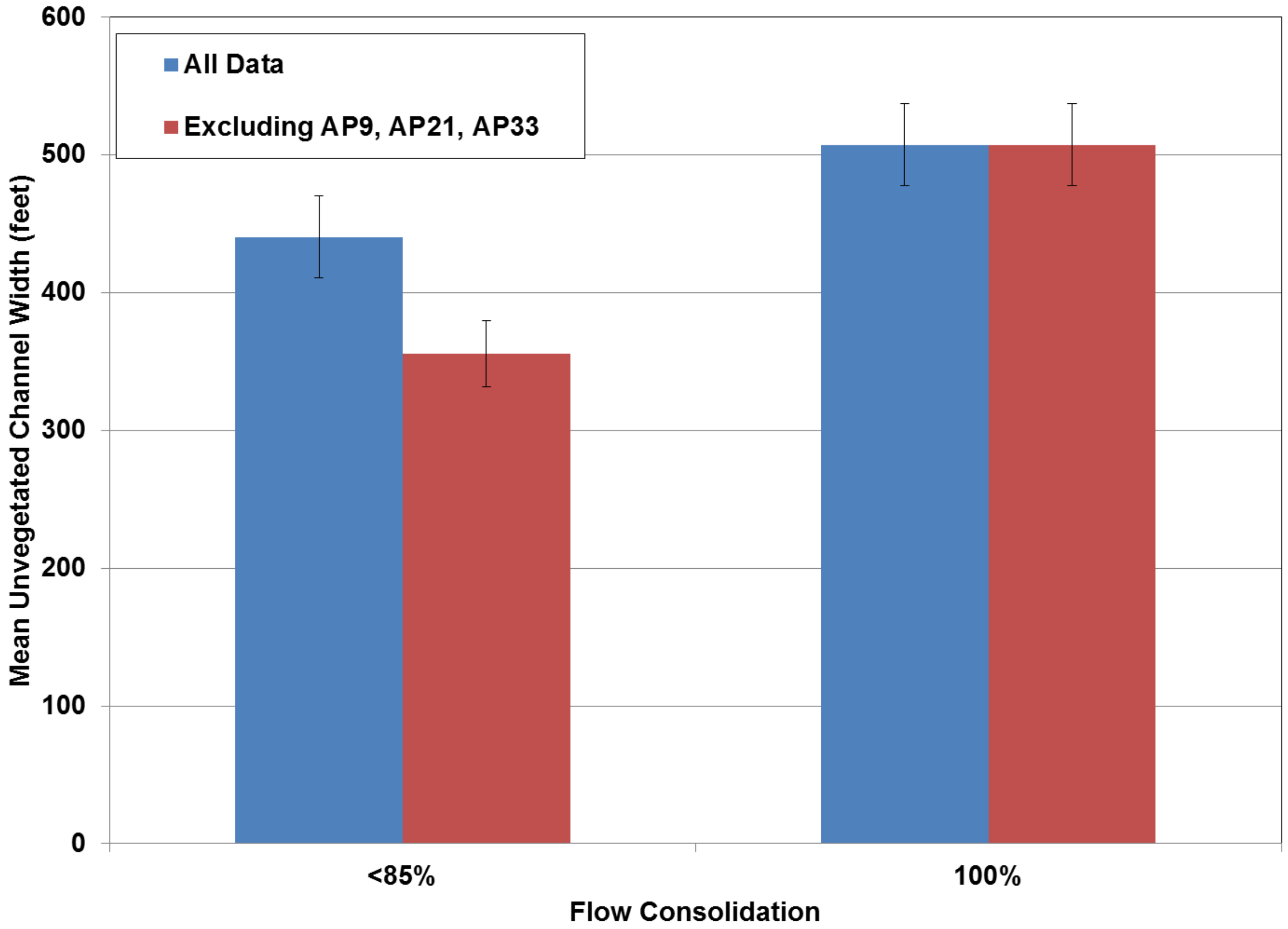


Figure 4.42a. Mean unvegetated channel width at sites with less than 85 percent flow consolidation and sites with 100-percent flow consolidation.

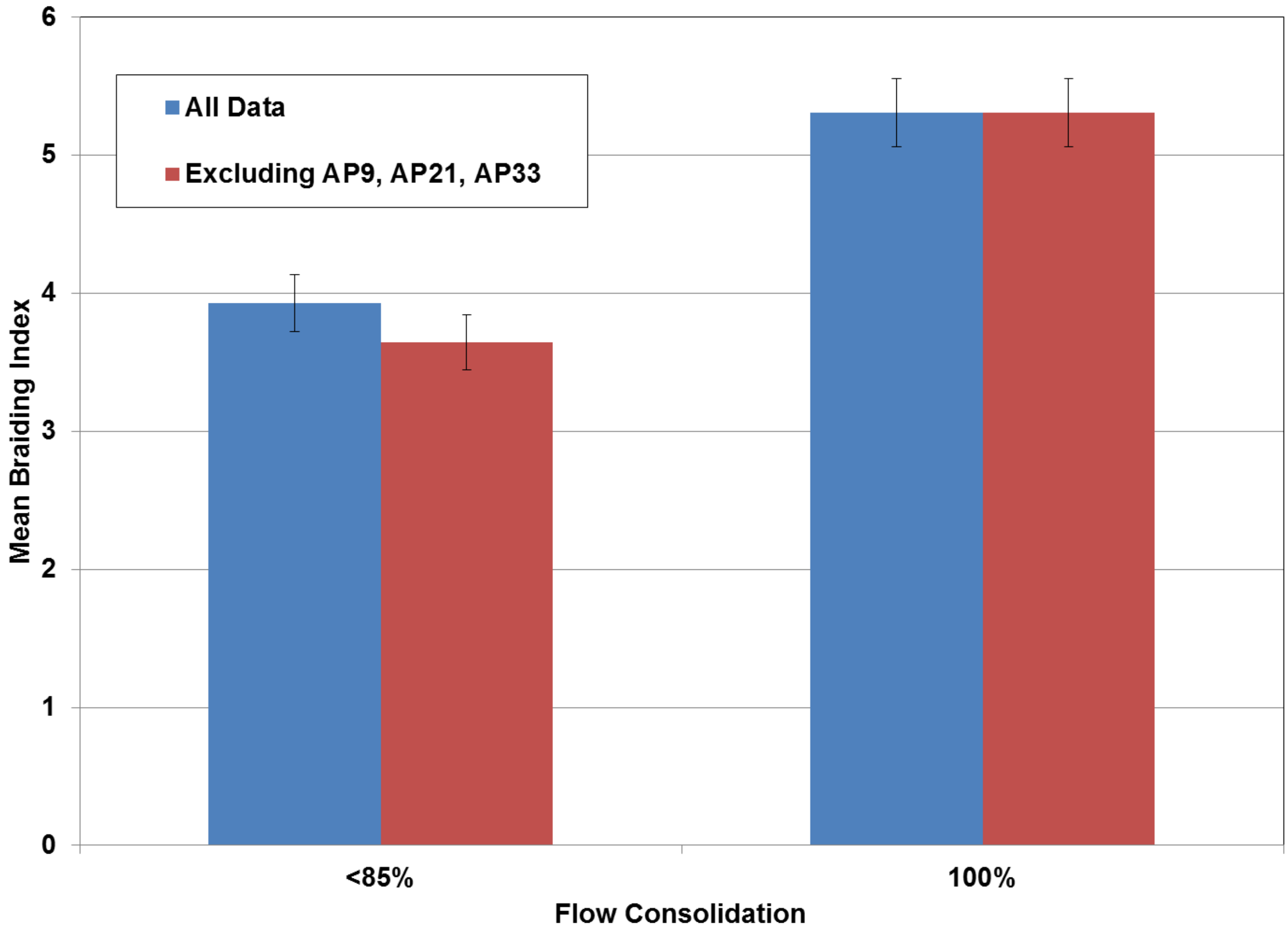


Figure 4.42b. Mean braiding index at sites with less than 85 percent flow consolidation and sites with 100 percent flow consolidation.

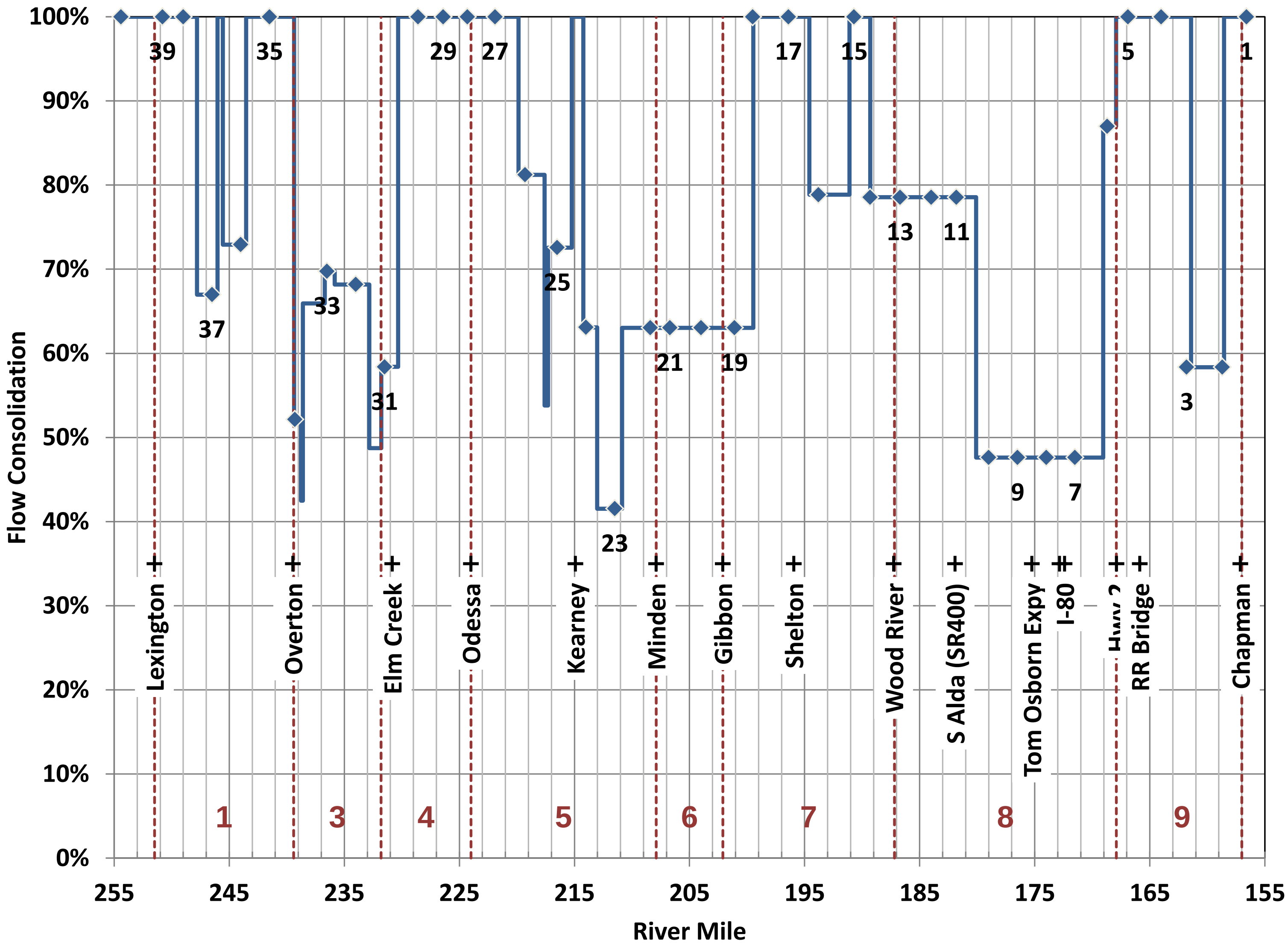


Figure 4.43. Percent flow consolidation (i.e., percent of flow in the main flow path) at 8,000 cfs.

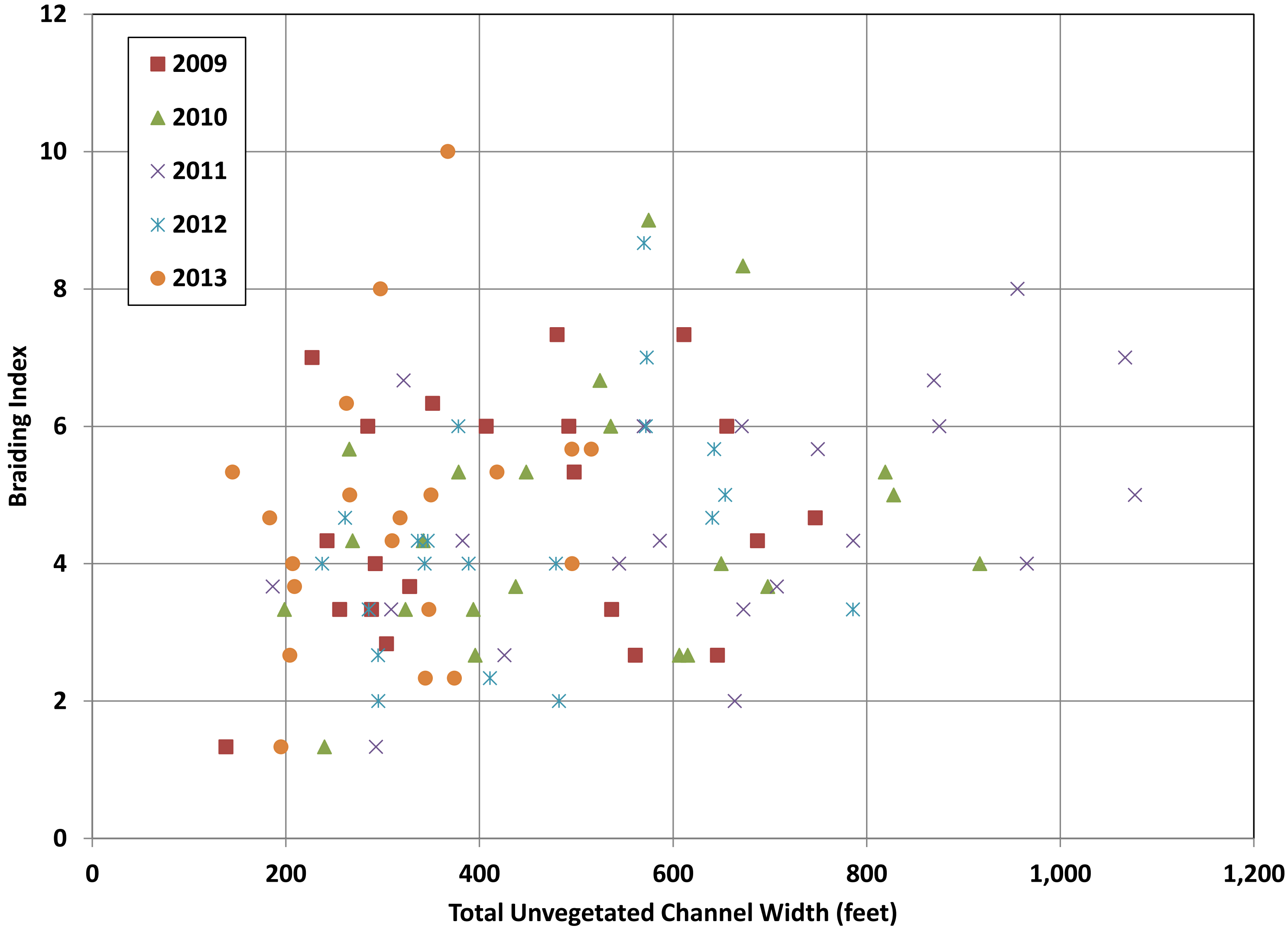


Figure 4.44. Total unvegetated channel width versus braiding index (Kendall's t = 0.19, p=0.006).

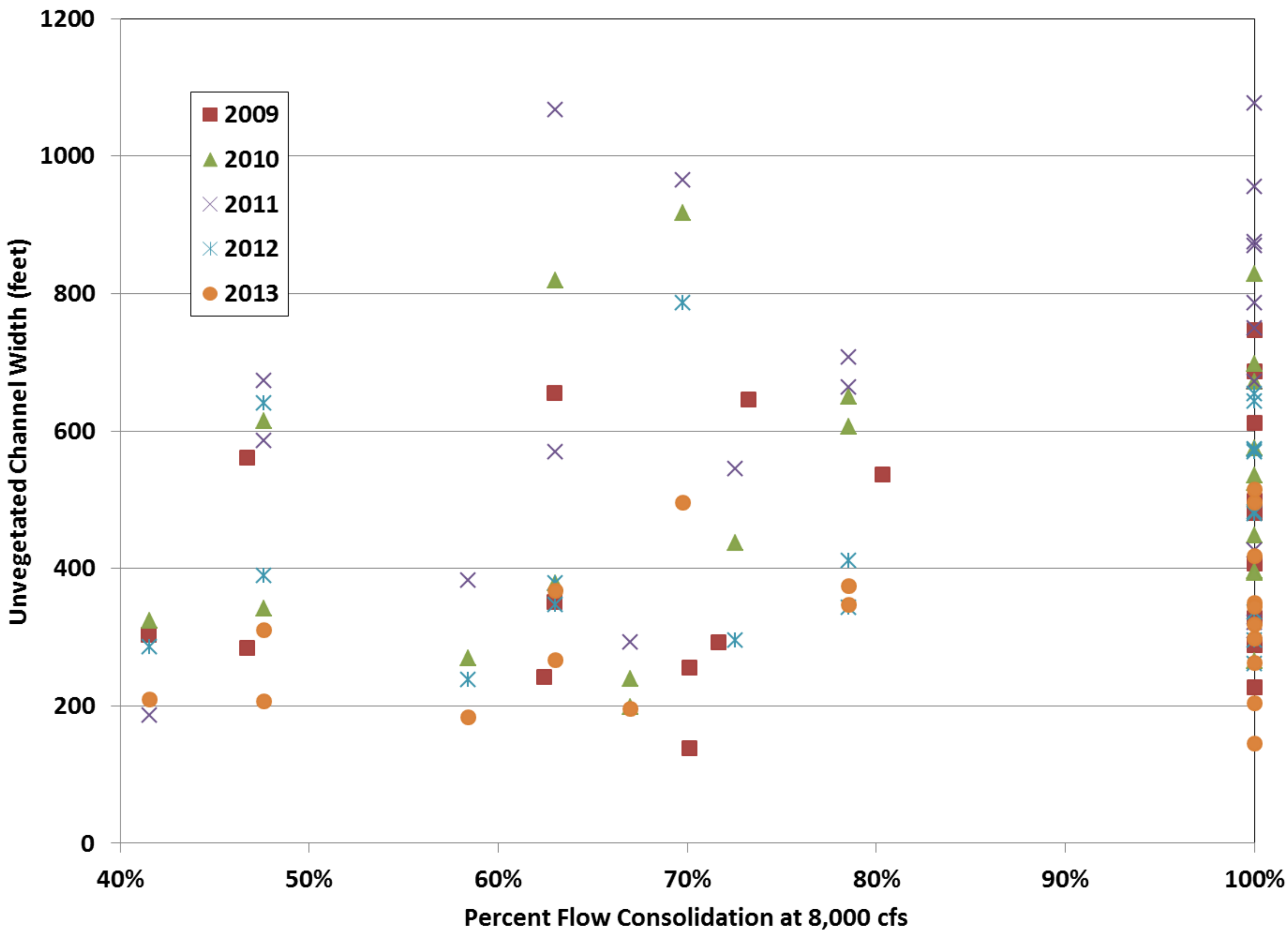


Figure 4.45. Total unvegetated channel width versus percent flow consolidation at 8,000 cfs (Kendall's t = 0.18, p=0.012).

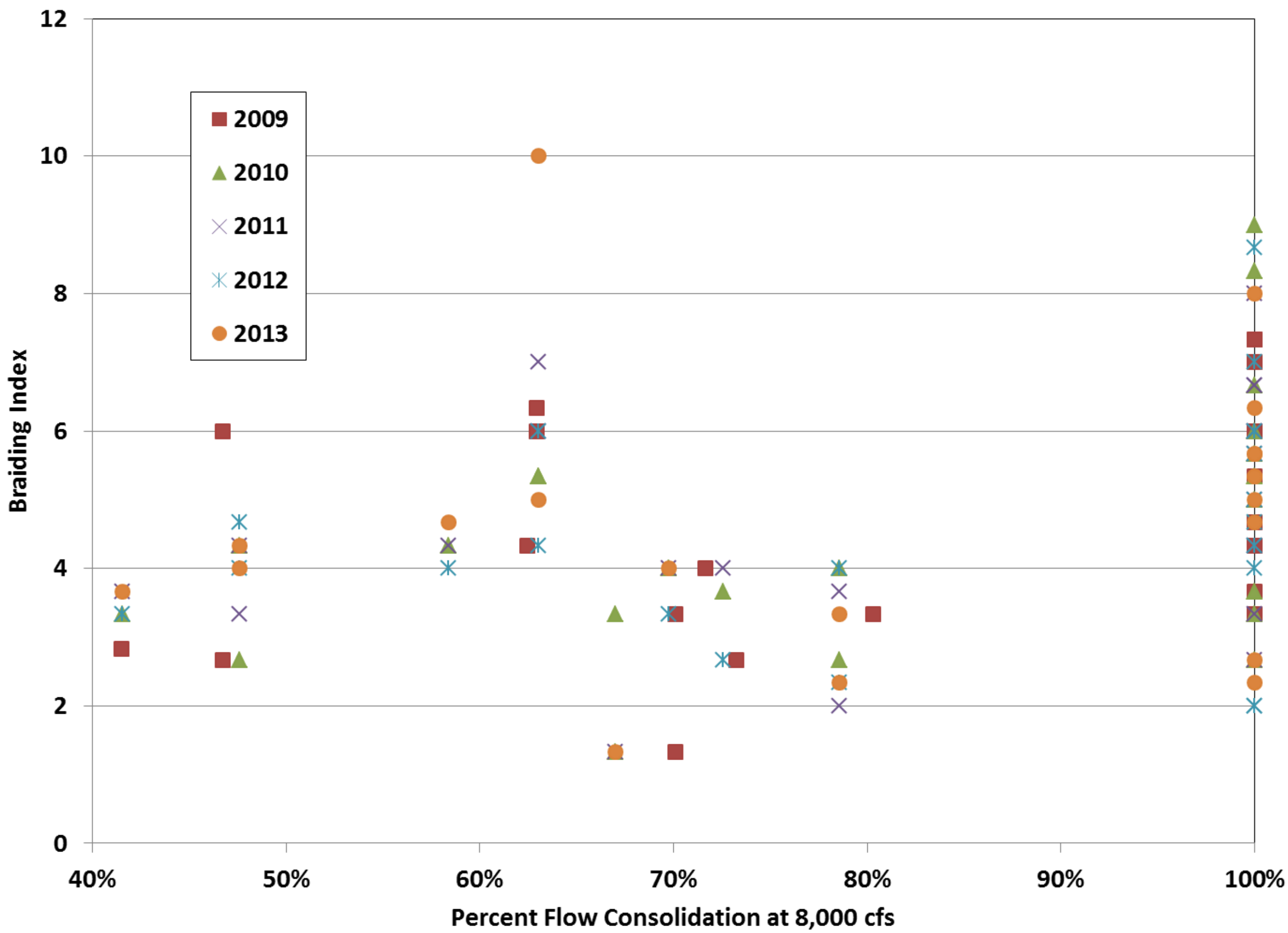


Figure 4.46. Braiding index versus percent flow consolidation at 8,000 cfs (Kendall's t = 0.24, p=0.002).

5 SUMMARY AND CONCLUSIONS

With the 2013 field season, the Platte River Geomorphic and Vegetation Monitoring Program has completed five years of detailed field monitoring, and the data have now been reduced to quantify at least 35 individual performance metrics that fall into one of the following six general categories: Hydrologic, Hydraulic, Geomorphic, Vegetation, Sediment, Whooping Crane (Table 2.2). Trend and correlation analyses were performed for essentially every relationship discussed in the DAP for the 2012 annual report (Table 2.4). To provide a more focused and in-depth analysis of key issues of concern to the Program, this annual report presents a summary of all five years of data, including spatial and temporal trends, in each of the metrics, and includes detailed analysis of specific aspects of the four hypotheses: Flow #1, Flow #3, Flow #5, Mechanical #2.

Hydrologic conditions during the monitoring period varied considerable from relatively dry years in WY2009 and WY2013 to one of the wettest years on record (WY2011) (Figure 4.13), providing good contrast to assess the response of the monitoring reach to flow conditions. Although WY2012 ranked as a relatively wet year based on the flows for the entire year, most of the flow volume occurred during Fall 2011; flows during the growing season between April 1 and the date of the monitoring surveys were also very low. In fact, the April through July runoff volumes in both 2012 and 2013 were in the lower 25^{th} percentile of years since the early-1940s. The peak discharges in 2010 and 2011 were moderately high, as well, while the 2009, 2012 and 2013 peaks (prior to the September 2013 flood) were relatively in the low to average range (**Figure 5.1**). Based on the WY1942 through WY2013 data (including the September 2013 flood peak; WY1982 through WY2013 for Kearney), the recurrence intervals of the 2009 and 2012 peaks were in the range of 1.5 years to 2 years, and the 2010 and 2011 peaks were in the range of 3 years to 5 years (**Figure 5.2**). The pre-September 2013 peak discharge shown in Figure 5.1 occurred during a short-duration, medium-flow release that was conducted by the Program in mid-April. These discharges also had a recurrence interval of about 1.5 years. For references the September 2013 flood peak had a recurrence interval of about 7 years at Overton and Kearney and about 4 years at Grand Island.

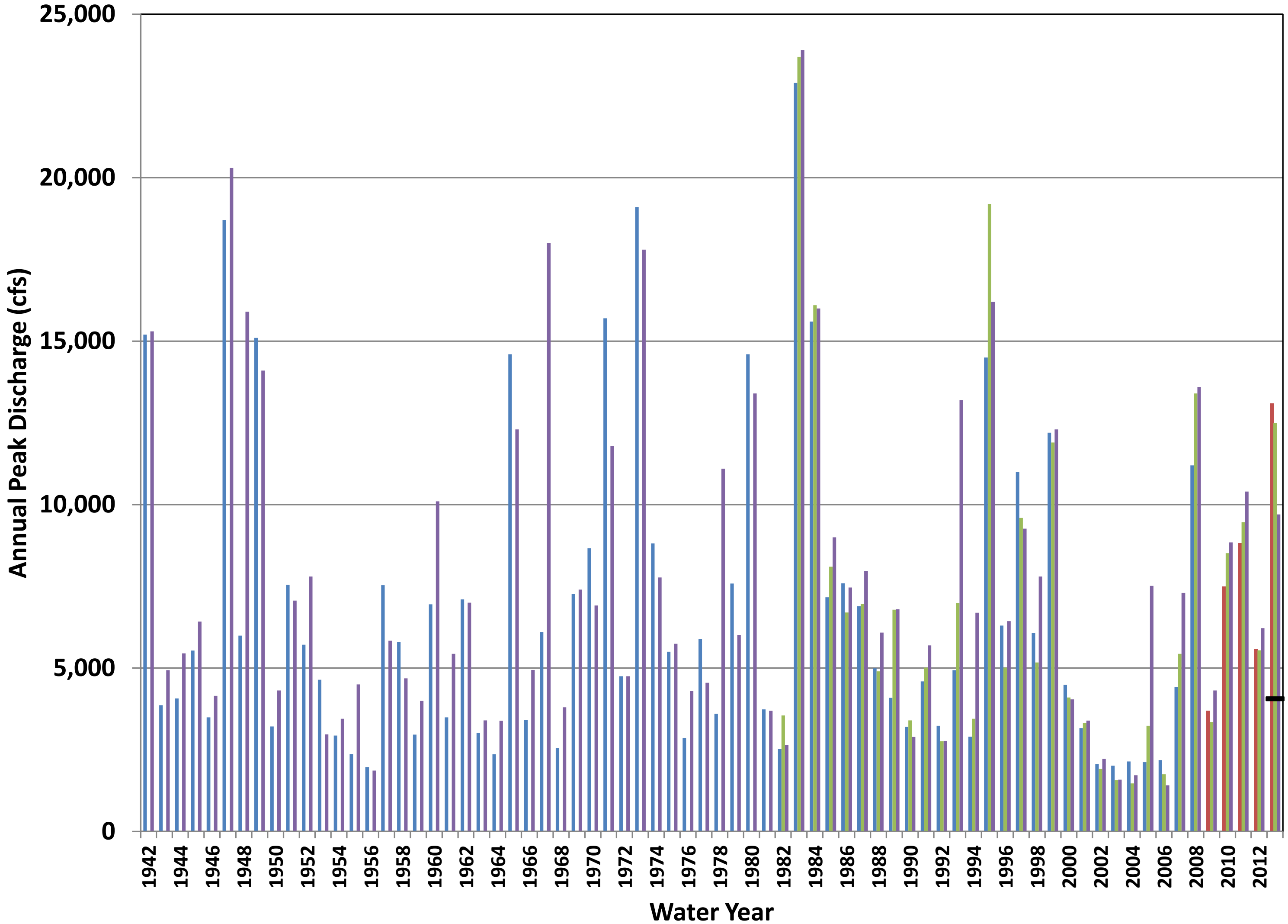


Figure 5.1. Annual peak discharges at the USGS Overton, Kearney, and Grand Island gages (note that Kearney record started in 1982). Also shown by the black mark is the approximate WY2013 peak discharges prior to the September flood at the three locations.

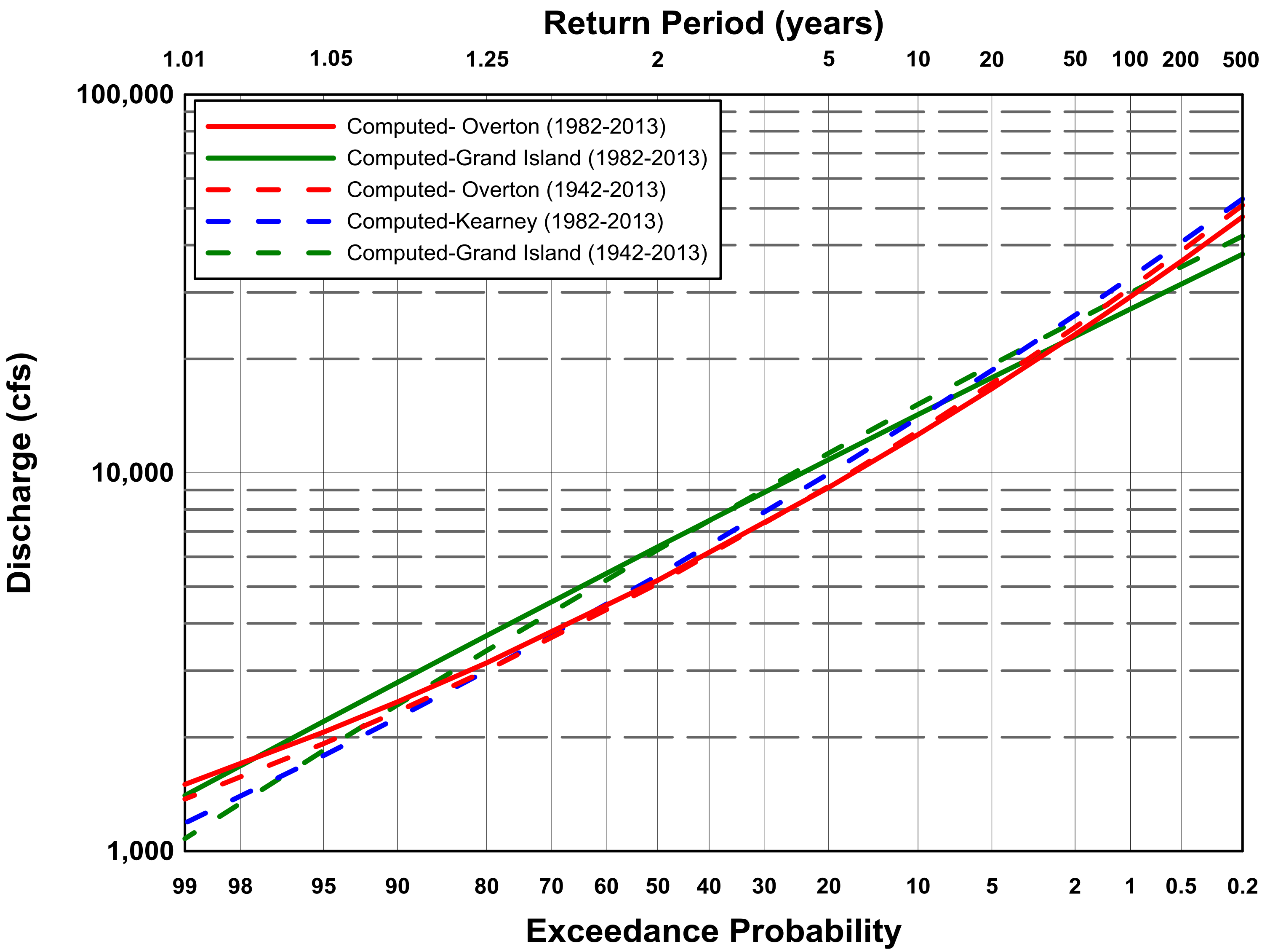


Figure 5.2. Flood frequency curves for the annual peak flows from WY1942 through WY2013 at the USGS Overton, Kearney (WY1982-WY2013, only), and Grand Island gages.

In addition to the wide range of flow conditions, flow-sediment-mechanical (FSM) actions were conducted during the monitoring period at specific locations along the reach that could potentially affect the channel characteristics at the APs where the monitoring data are being collected. These actions included the Elm Creek and Shoemaker Island Adaptive Management Experiments, the Pilot Sediment Augmentation Project at the Dyer and Cottonwood Ranch sites, additional overbank clearing and grading of sand into the channel at Cottonwood Ranch in 2009 and 2010, spraying to control common reed (*Phragmites australis*) and other introduced species in several locations along the reach. Additional, related actions were also taken at the Rowe Sanctuary that likely affect the characteristics of at least AP21.

Key observations from the spatial and temporal trend analysis of the geomorphic and vegetation data include the following:

1. The basic geomorphic and vegetation data provide a basis for evaluating a wide range of trends in the physical response of the reach to flows, Program actions and other factors.

    1.1. The reach-wide average braiding index changed very little during the period, although the index for 2012 was somewhat lower than the other years. Geomorphic Reaches 4 (Elm Creek to Odessa; Table 2.1) and 6 (Minden to Gibbon) typically had the highest braiding indices and Reaches 1 (Lexington to Overton), 2 (south channel at Jefferys Island), 3 (Overton to Elm Creek), and 8 (Wood River to Grand Island) typically had the lowest indices. The braiding index in 2013 in Reach 2 and Reach 6 were substantially higher than in previous years. The reason for the large increase in Reach 6 is not apparent, but it could be related to activities at the Row Sanctuary.

    1.2. The reach-wide average total channel width showed a modest (not statistically significant) increasing trend over the period, and the changes in year-to-year width were also very small. Geomorphic Reaches 4, 6, 7 (Gibbon to Wood River) and 9 (Grand Island to Chapman) have the largest total channel width (all exceeding 1,000 feet in all years), while Reaches 1 and 2 have the narrowest (in the range of 500 to 550 feet).

    1.3. The reach-wide average wetted channel width at 1,200 cfs was consistently in the range of 450 to 480 feet in 2009, 2010 and 2011, increased to about 515 feet in 2012 and then decreased back to about 495 feet in 2013. Reaches with the largest wetted channel width generally correspond to the reaches with the largest braiding index and total channel width (i.e., Reaches 4, 6, 7 and 9).

    1.4. The reach-wide average width-to-mean depth ratios at the 1,200-cfs water surface declined from about 175 in 2009 to about 130 in 2011, increased back to over 240 in 2012, and then declined to about 215 in 2013. Some of the apparent large change from 2011 to 2012 could be due to changes in the index water-surface elevation that are not accounted for in the existing hydraulic model that is based primarily on 2009 data. Significant effort was made to correct for these changes; however, an updated model will be necessary to insure consistency in the results. Adjustments will be made to the relevant metrics, including the width-to-depth ratios for the next annual report based on the updated model that is currently being prepared.

    1.5. Based on the transect surveys at the pure panel APs, the overall monitoring reach appears to have degraded between 2009 and 2011, aggraded significantly during 2012, and then continued to aggrade by a modest amount in 2013. The bulk of the degradation during the first two years occurred in the portion of the reach upstream from Minden, with Reach 5 showing the most degradation. The portion of the reach downstream from Minden appears to have been roughly in sediment transport balance during this period. The data indicate that all of the reaches aggraded between the 2011 and 2013 surveys, with the bulk of the aggradation occurring in the portion of the reach downstream from Minden.

1.6. The green line elevation (GLE) data indicate that the lower limit of vegetation is very responsive to flow; however, this appears to be primarily related to inundation levels that prevent annual vegetation from establishing rather than scour of the perennial species. The reach-wide average GLE was about 1 foot higher in 2010 than during the initial survey in 2009, and this increased even further to about 1.8 feet by the 2011 surveys. The low flows in 2012 and 2013 allowed the vegetation to encroach back into the channel to levels that were similar to those in 2009.

1.7. The reach-wide average unvegetated channel width increased substantially from about 410 feet in 2009 to 630 feet in 2011and then declined back to only about 310 feet by 2013.

1.8. Of the four species of primary interest, the frequency of purple loosestrife, common reed and willow declined substantially between 2009 and 2011, but then showed a trend of increasing frequency in 2012 and 2013, presumably because of the high flows during the early part of the period and low flows during the last two years. In contrast, eastern cottonwood occurred relatively infrequently during the first three years, but increased substantially during 2012 and 2013, compared to the earlier years.

1.9. Purple loosestrife is most common in the portion of the reach downstream from Minden, while common reed is most common in the reaches between Elm Creek and Minden (Reaches 4 and 5), Gibbon and Wood River (Reach 7) and Grand Island and Chapman (Reach 9). Eastern cottonwood is more or less evenly distributed throughout the monitoring reach, although it occurs very infrequently in Reaches 2, 6 and 7. Willow was most common in Reaches 4 and 5 (Elm Creek to Minden) in 2009, but declined substantially in those reaches in later years. Reach 1 showed the greatest increase in frequency of willow by 2013.

1.10. The mean height of the four species of primary interest above the 1,200 cfs water-surface generally increased during the high-flow years in 2010 and 2011, and then declined during the low flows in 2012 and 2013.

1.11. The bed and bar material tends to fine in the downstream direction, with median (D_{50}) sizes of 1 mm to 2 mm in the upstream part of the reach to less than 1 mm in the downstream part of the reach. The data also indicate that the reach-wide average D_{50} of the bed material became somewhat finer over the 5-year monitoring period.

1.12. With respect to the whooping crane-related metrics, unobstructed channel widths were generally greatest during the first three years (reach-wide average of 620 to 660 feet), and then declined substantially to only about 420 feet by 2012. The 2013 data showed a substantial increase to about 525 feet. The procedures used to estimate unobstructed channel width have evolved over the monitoring period; thus, some of the differences are likely due to uncertainty associated with the measurement/calculation techniques. Starting in 2013, these width are being measured directly with a laser rangefinder to eliminate as much of the uncertainty as possible.

2. An understanding of the relative sediment transport balance along the reach is a key factor in evaluating **Hypothesis Flow #1**. The following conclusions can be drawn from the analysis presented in this report.

   2.1. Integration of the bed and suspended sand load rating curves over the applicable flow records and comparison of the resulting annual loads passing each of the bridges where the measurements were taken indicates that the segment between Darr and Overton was degradational in all four years, Overton to Kearney was degradational during the first three years and then aggradational during Survey Year (SY) 2013, Kearney to Shelton was aggradational during the first three years and then roughly in balance during SY2013, and Shelton to Grand Island was degradational during all years, although the amount of degradation in SY2013 was relatively small.

   2.2. The rating curve-based average annual sand transport balance over the four year period results in estimated sediment deficits of 110,000 tons between Darr and Overton and 61,000 tons between Overton and Kearney, an approximately 143,000 ton excess between Kearney and Shelton, and a 275,000 ton deficit between Shelton and Grand Island.

   2.3. Extrapolation of the aggradation/degradation volumes at the pure panel APs to the overall length of the measurement-bridge segments results in estimates of the sand balance that are generally quite different from the rating curve-based estimates. For example, the surveys indicate that the segment between Darr and Overton was degradational in SY2010, but aggradational in all of the following years, resulting in an average annual aggradation rate over the four year period of about 21,000 tons, compared to the rating curve-based estimate of about 110,000 tons of degradation. The survey-based estimates between Overton and Kearney showed degradation during SY2010, SY2011, and SY2013, and aggradation during SY2012, resulting in average annual degradation of about 293,000 tons over the four year period, compared to only about 61,000 tons of degradation based on the rating curves. The segment between Kearney and Shelton degraded significantly in SY2010, and also degraded by smaller amounts in SY2011 and 2013, with significant aggradation in SY2011, based on the survey data. This resulted in average annual aggradation of about 166,000 tons over the four-year period, an amount that is reasonably consistent with the rating curve-based estimate of about 143,000 tons/year. Finally, the segment between Shelton and Grand Island aggraded during SY2010, SY2012 and SY2013 and degraded in SY2011, based on the survey data, resulting in average annual aggradation of about 410,000 tons over the four-year period. As noted above, the rating-curves indicate a net deficit of about 275,000 tons per year in this segment.

   2.4. Monte Carlo simulations were performed for the sand load rating curves to quantify the uncertainty in the estimates. Using the upper and lower 95 percent confidence bands on the resulting loads, the analysis indicates that the magnitude of the uncertainty exceeds the magnitude of the differences in annual sediment loads between the measurement sites in nearly all of the years; thus, from a statistical perspective, one cannot conclude that the indicated aggradation/degradation trends are significant, and even where the general trend is significant, the actual magnitude may be quite different from the best-estimate value discussed above. Nonetheless, the distribution of the estimated loads suggests that there is a relatively high probability that at least the direction of the trend (i.e., aggradation or degradation) from these estimates is correct.

2.5. With the exception of the results for the Overton to Kearney segment in SY2010 and SY2012, the survey-based estimates of the aggradation/degradation amounts fall outside the 95 percent confidence bands on the rating curve-based estimates.

2.6. Unfortunately, data are not available to directly assess the uncertainty in the survey-based estimates. Uncertainty in these estimates stems from at least three factors: 1) uncertainty in the horizontal position and elevation of the individual survey points, 2) uncertainty in how well the three surveyed transects represent the aggradation response of the channel within the individual AP, and 3) uncertainty in how well the response at the AP represents the overall response of the river in the approximately 5-mile segment of the river represented by the AP. Tests of the data using the reported accuracy of the individual points from the RTK-GPS data logger indicate that the first source of uncertainty is very small compared to the other two sources. Based on the available information about the river away from the transects, it is likely that the uncertainty associated with other two factors is relatively large.

2.7. In general, the above results strongly indicate that the portion of the reach upstream from Kearney is degradational, with an average annual sand deficit in the range of 100,000 tons. Considering results from the surveys and the independent analysis done by both DOI Reclamation and USFWS (2006) and Tetra Tech (2010), the portion of the reach downstream from Kearney is most likely aggradational. There are, however, contradictory lines of evidence; thus, this conclusion is only weakly supported by the data. In considering these results, it is also very important to recognize that the sediment loads along the reach vary significantly from year to year because primarily on the magnitude and duration of the flows, and the overall sediment balance may change depending on the type of flow year. While long-term planning based on average annual estimates may provide a sound basis for certain decisions, changes during extreme years may actually overwhelm the anticipated changes from evaluation of the average annual sediment balance.

3. The GLE and unvegetated channel width data provide a means of assessing the extent to which the unvegetated channel width responds to flow, as postulated by **Hypothesis Flow #3**:

3.1. The reach-wide averaged green line (GLE) data indicate that the Program's benchmark of 1.5 feet above the 1,200-cfs water surface was not met in any of the years. The benchmark was, however, approached (~1.3 feet above the 1,200-cfs water surface) in SY2011 when long-duration, high flows persisted in the reach.

3.2. GLE is well correlated to both the annual peak discharge, but is even more highly correlated with the average discharge during germination season.

3.3. The total unvegetated width is also positively correlated with both the annual peak discharge and the average germination season discharge.

3.4. As expected from the above results, total unvegetated width is strongly correlated with GLE.

4. Related to **Hypothesis Flow #5**, common reed has been identified as a potentially important factor in preventing the river from sustaining the wide, braided character that is important to good quality habitat for the target species. Both the frequency of occurrence and percent cover of common reed declined during the monitoring period. Several factors that could have contributed to the decline, including Program activities, were identified, quantified, to the extent possible, and evaluated using multiple correlation analysis.

4.1. Analysis of the year-to-year changes in percent cover of common reed versus a range of potential factors shows statistically-significant, negative correlation with spraying and positive correlation with heating degree days (HDD) during the growing season, although spraying appears to be the dominant factor. This indicates that spraying has been effective in limiting the growth common reed.

4.2. Correlation of year-to-year changes in percent cover of common reed was not statistically significant for any of the other factors that were considered (i.e., maximum inundation depth, duration of inundation, 90th percentile (low) flow during growing season, and precipitation).

5. Flow consolidation is also postulated to be an important factor in maintaining the wide, braided character that is important to good quality habitat (**Hypothesis Mechanical #2**).

5.1. Both the mean unvegetated channel width and mean braiding index at APs with more than 85 percent flow consolidation are larger than at the sites with than 85 percent flow consolidation. When all sites, including those where management activities that have substantially altered the channel, are considered, the difference in mean braiding index is statistically significant, but the difference in unvegetated channel width is not. When the three APs where the management actions have occurred (AP9, AP21 and AP33) are excluded from the data sets, the differences in both variables is statistically significant.

5.2. These results suggest that flow consolidation may have a positive influence on both unvegetated channel width and the amount of braiding.

6 REFERENCES

Ayres Associates and Olsson Associates, 2010. Platte River Recovery Implementation Program, Year 1 (2009) Report, Channel Geomorphology and In-Channel Vegetation of the Central Platte River. Prepared for PRRIP, February, 52 p.

Ayres Associates and Olsson Associates, 2011. Platte River Recovery Implementation Program, Year 2 (2010) Report, Channel Geomorphology and In-Channel Vegetation of the Central Platte River. Prepared for PRRIP, March, 45 p.

Ayres Associates and Olsson Associates, 2012. Platte River Recovery Implementation Program, Year 2 (2010) Report, Channel Geomorphology and In-Channel Vegetation of the Central Platte River. Prepared for PRRIP, April, 46 p.

Cohn, T.A., and E.J. Gilroy. 1991. Estimating Loads from Periodic Records. *U.S. Geological Survey Branch of Systems Analysis Technical Report* 91.01. 81 p.

Daubenmire, R., 1959. A Canopy-Coverage Method of Vegetational Analysis. Northwest.

Duan, N., 1983. Smearing Estimate: A Nonparametric Retransformation Method. Jour. Amer. Stat. Assoc., v. 87, pp. 605-610.

Ferguson, R.I. 1986. River Loads Underestimated by Rating Curves. *Water Resources Research*, v 22(1), pp. 74–76.

Fotherby, L.M., 2008. Valley Confinement as a Factor of Braided River Pattern for the Platte River. Geomorphology. v. 103, Issue 4, pp. 562-576.

Friesen, B., Von Loh, J., Schrott, J., Butler, J., Crawford, D., and Pucherelli, M., 2000. Central Platte River 1998 Land Cover/Use Mapping Project, Nebraska, Technical Memorandum 8260-00-08, Bureau of Reclamation, U.S. Fish and Wildlife Service, Denver, Colorado.

Hirsch, R.M., Helsel, D.R., Coh, T.A., Gilroy, E.J., 1993. Statistical Analysis of Hydrologic Data. In Maidment, D.R. (ed), *Handbook of Hydrology*. McGraw Hill, Inc., pp. 17.1 – 17.55.

Kaul, B., Sutherland, D., and Rolfsmeier, S., 2011. The Flora of Nebraska; Second Edition. The School of Natural Resources, University of Nebraska–Lincoln, Lincoln Nebraska.

Lichvar, R. and Kartesz, J., 2012. North American Digital Flora: National Wetland Plant List, version 3.0. Accessed: 9 January 2013. Available: http://wetland_plants.usace.army.mil.

Murphy, P.J., Fotherby, L.M., Randle, T.J., and Simons, R., 2006. Platte River Sediment Transport and Riparian Vegetation Model. Prepared for the Bureau of Reclamation, March, 151 p.

Platte River Recovery Implementation Program, 2006. Attachment 3, Adaptive Management Plan, 254 p.

Platte River Recovery Implementation Program, 2010. PRRIP Channel Geomorphology and In-Channel Vegetation Monitoring, 24 p.

Platte River Recovery Implementation Program, 2012a. Draft Channel Geomorphology and In-Channel Vegetation Data Analysis Plan, 45 p.

Platte River Recovery Implementation Program, 2012b. Adaptive Management on the Platte River, Adaptive Management Plan, 2012 “State of the Platte” Report – Executive Summary, 68 p.

Pollen-Bankhead, Thomas, N.R., and Simon, A., 2011. DRAFT Platte River Recovery Implementation Program, Directed Vegetation Research Study, Can Short Duration High Flows be used to Remove Vegetation from Bars in the Central Platte River?, 102 p.

Rolfsmeier, S. and Steinauer, G., 2010. Terrestrial Ecological Systems and Natural Communities of Nebraska (Version IV – March 9, 2010). Nebraska Natural Heritage Program, Nebraska Game and Parks Commission. Lincoln, Nebraska. Available: http://outdoornebraska.ne.gov/wildlife/programs/legacy/pdfs/Terrestrial%20Ecological%20Systems.pdf. Science 33:43-64. Department of Botany, State College of Washington, Pullman, Washington.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004. Load Estimator (LOADEST): A Fortran Program for Estimating Constituent Loads in Streams and Rivers. Technicques and Methods Book 4, Chapter A5, U.S. Geological Survey, Reston, Virginia.

Shen, H.W. and Julien, P.Y., 1993. Erosion and Sediment Transport. In Maidment, D.R. (ed), *Handbook of Hydrology*. McGraw Hill, Inc., pp. 12.1 – 12.6.

Tetra Tech, 2010. Hydraulic and Sediment-transport Modeling for the Platte River Sediment Augmentation Feasibility Study, Nebraska. Appendix B, Modeling Evaluation, Final Platte River from Lexington to Odessa Bridges, Sediment Augmentation Experiment Alternatives Screening Study Summary Report, prepared for Platte River Recovery Implementation Program, September 7, 92 p.

Tetra Tech, 2012. Elm Creek Two-dimensional Hydraulic and Sediment-transport Modeling Report, submitted to Platte River Recover Implementation Program, October 26, 104 p.

Tetra Tech, 2013. Elm Creek FSM Annual Monitoring Report. Prepared for the Platte River Recovery Implementation Program, March, 73 p.

Tetra Tech, 2014. 2013 Elm Creek FSM Annual Monitoring Report. Prepared for the Platte River Recovery Implementation Program, April, 212 p.

The Flatwater Group, in association with Tetra Tech and HDR, 2014. Sediment Augmentation Final Pilot Study Report, prepared for the Platte River Recovery Implementation Program, April, 123 p.

U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), 2013. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401-4901 USA. Accessed: 9 January 2013. Available: http://plants.usda.gov.

U.S. Department of Interior, Bureau of Reclamation and U.S. Fish and Wildlife Service, 2006. Platte River Recovery Implementation Program, Final Environmental Impact Statement, River Geomorphology, pp. 5-57.

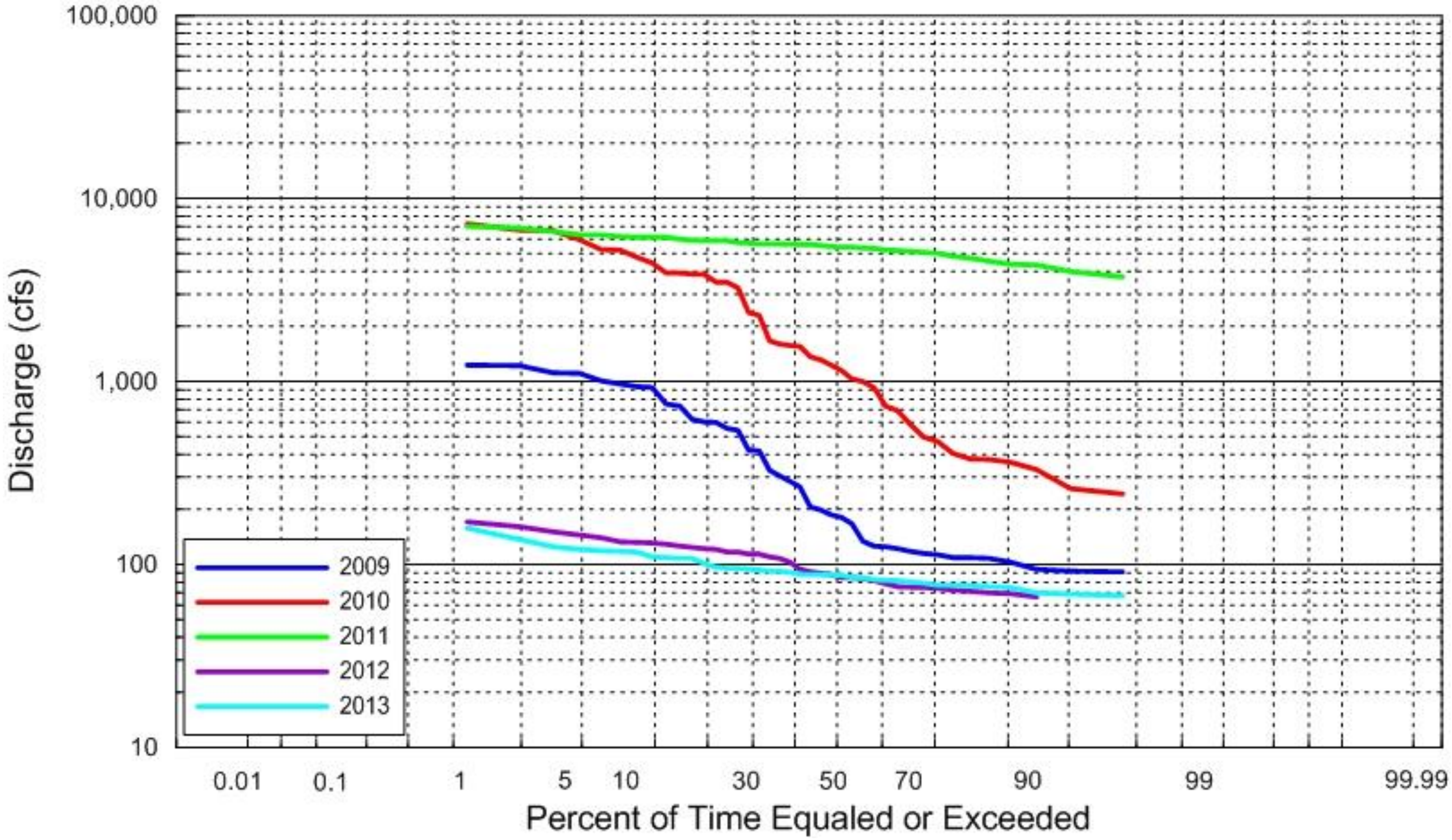
U.S. Geological Survey. 1992. Recommendations for Use of Retransformation Methods in Regression Models Used to Estimated Sediment Loads ["The Bias Correction Problem"]. *Office of Surface Water Technical Memorandum* No. 93.08. December 31.

Walling, D.E. 1977. Limitations of the Rating Curve technique for Estimating Suspended Sediment Loads, with Particular Reference to British Rivers. *In*: Erosion and Solid Matter Transport in Inland Waters, *Proceedings of Paris Symposium*. July. IAHS Publication No. 122: 34–48.

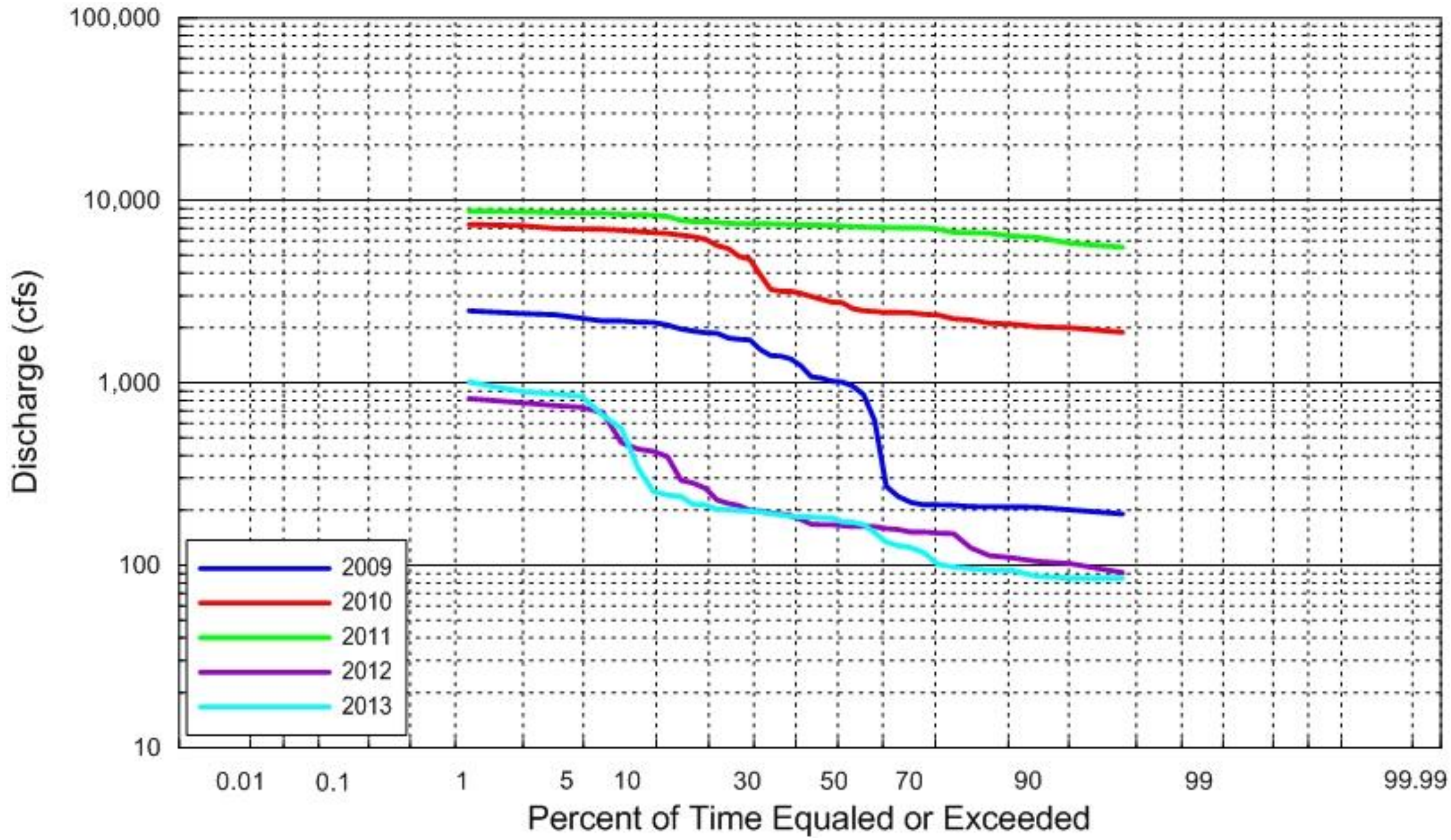
APPENDIX A.1

Mean Daily Flow-duration Curves for Germination Season

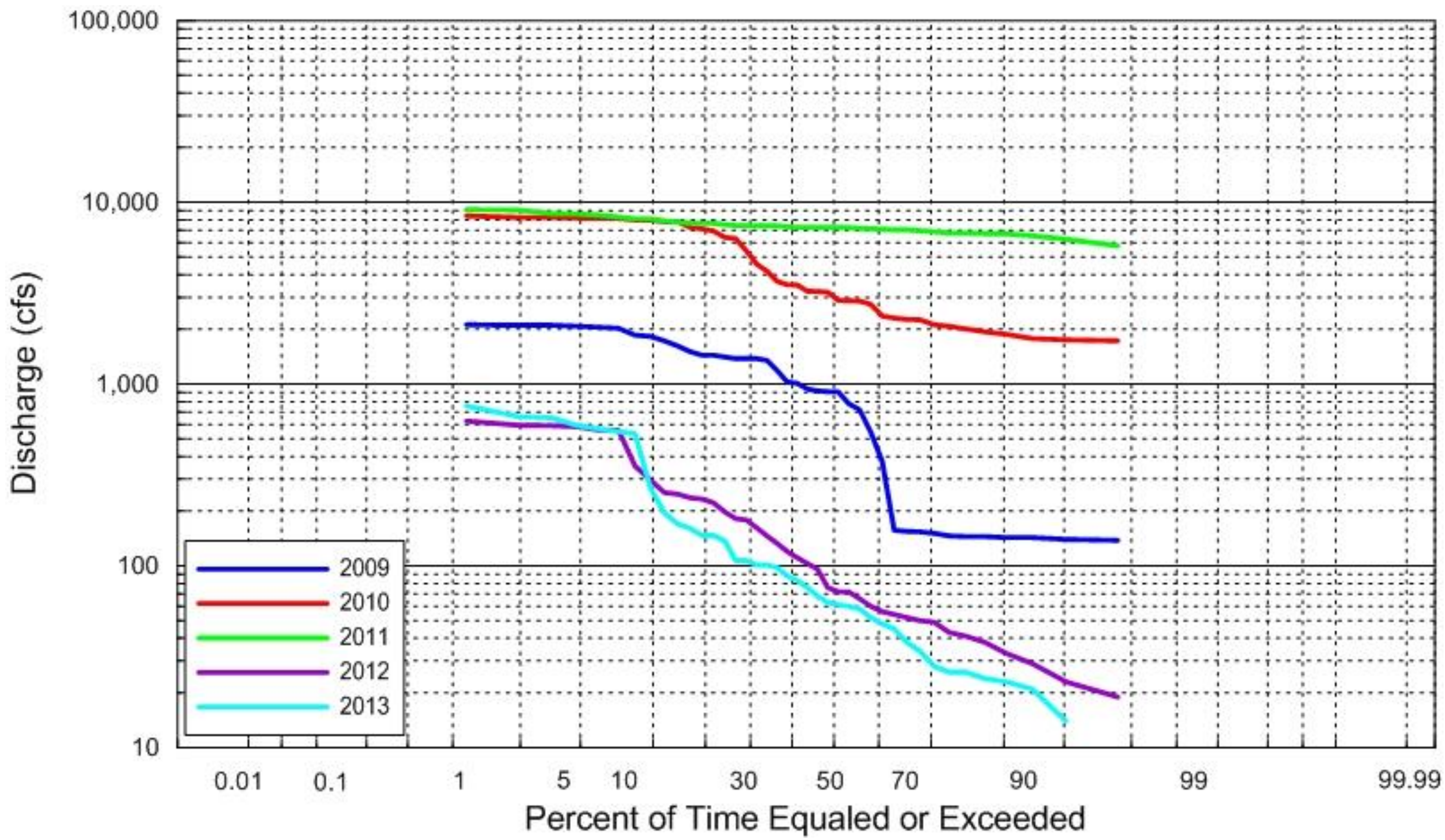
Germination Season (June 1 – July 10) for Lexington



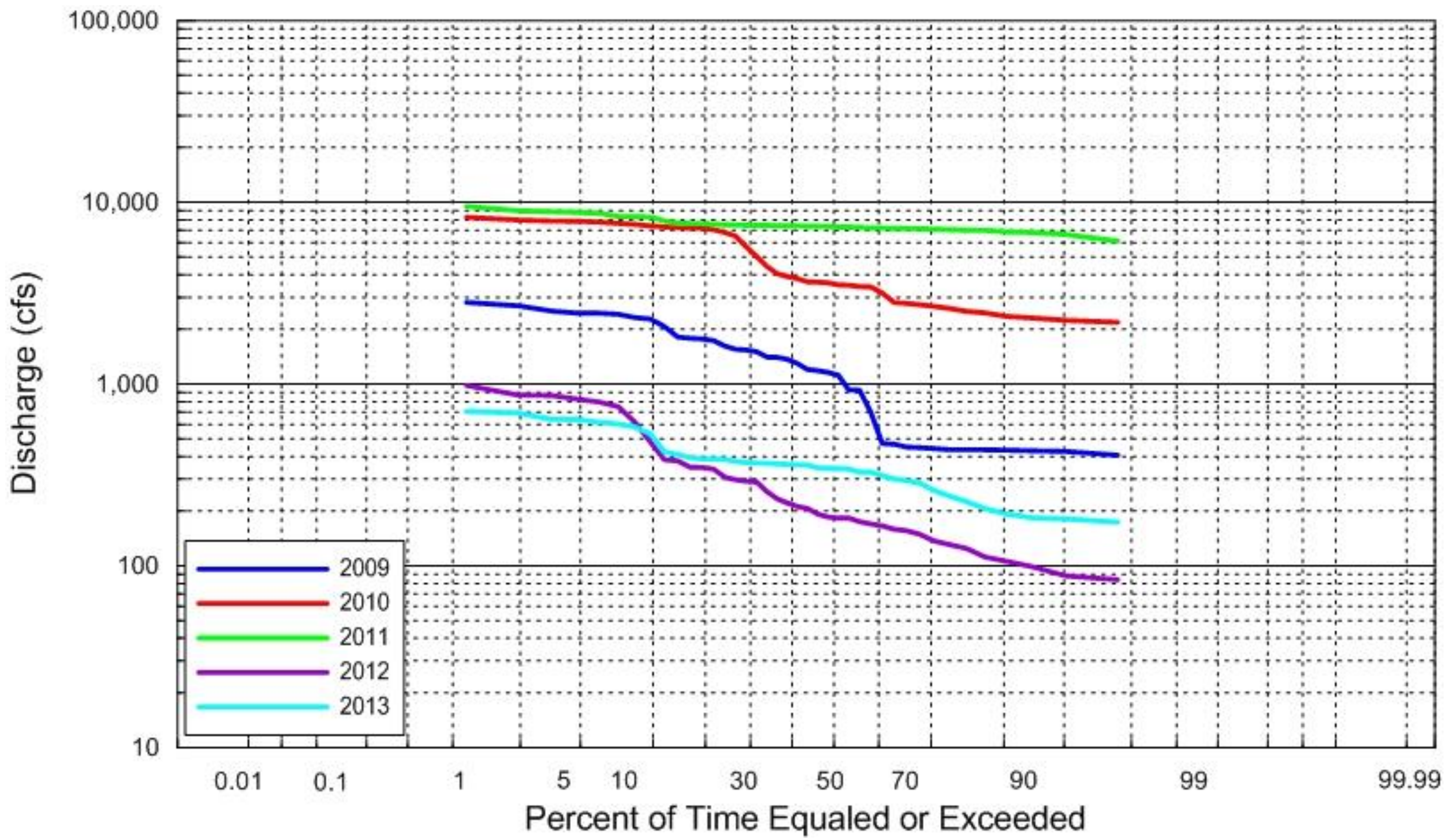
Germination Season (June 1 – July 10) for Overton



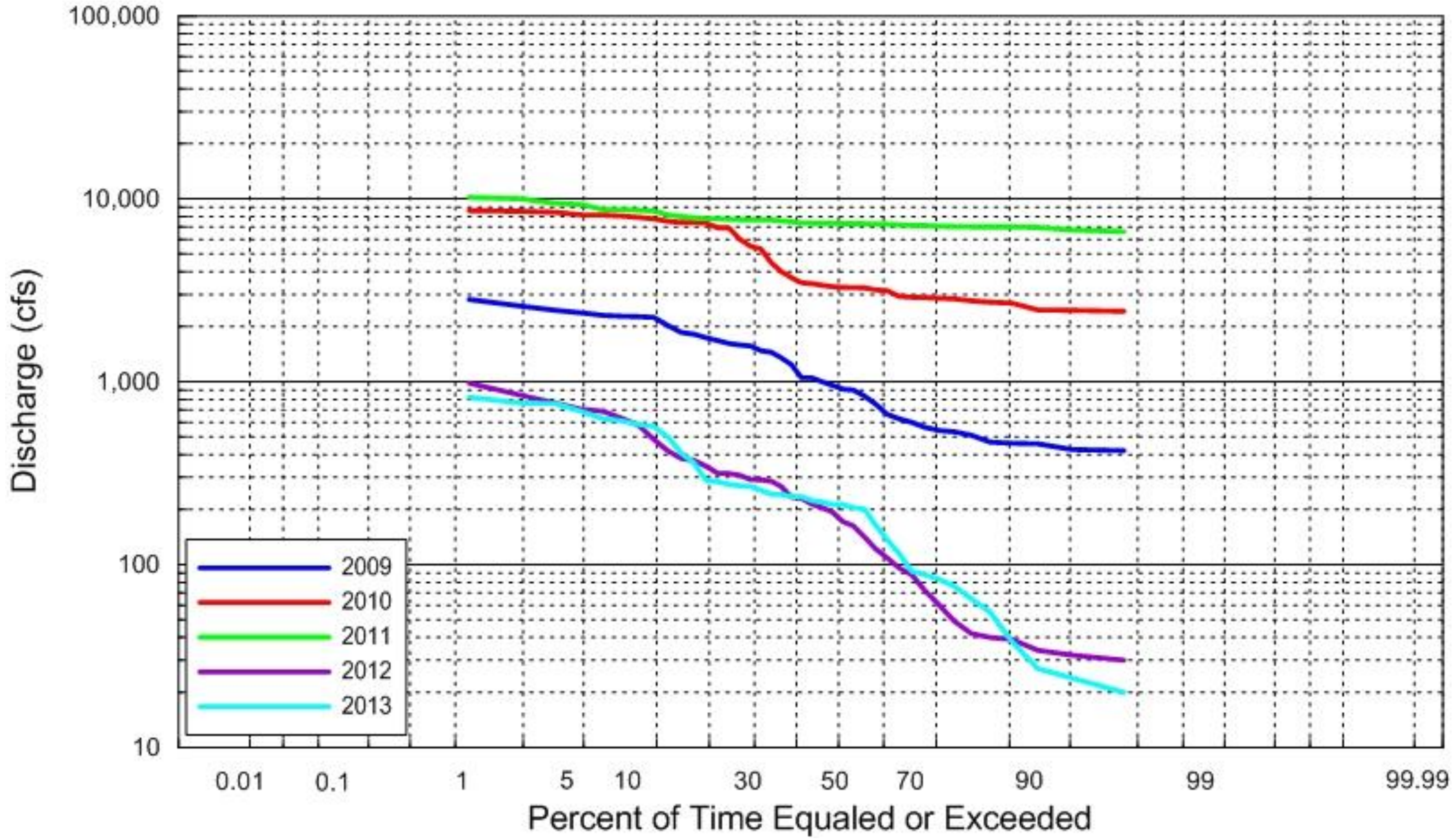
Germination Season (June 1 – July 10) for Kearney



Germination Season (June 1 – July 10) for Shelton

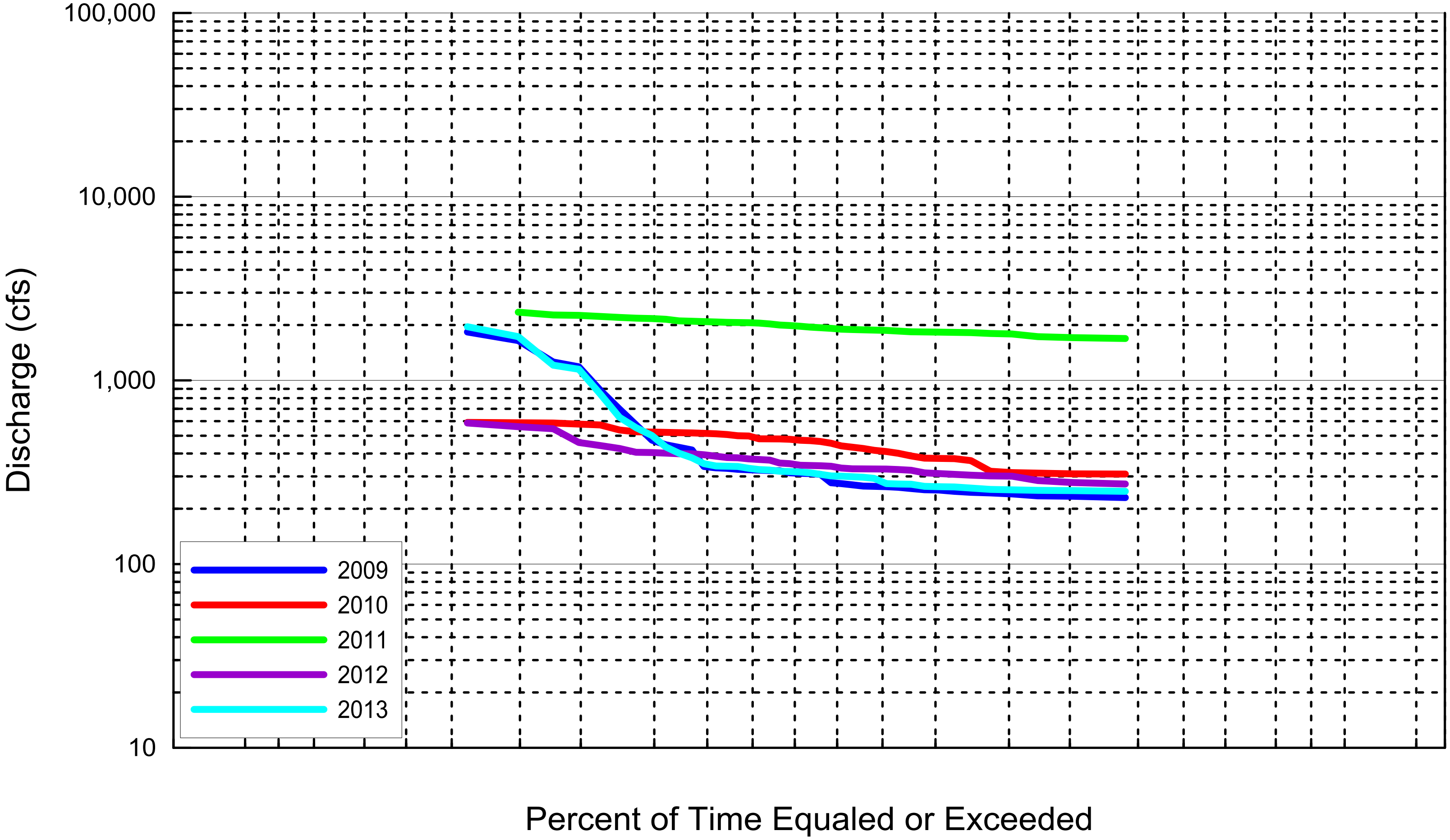


Germination Season (June 1 – July 10) for Grand Island

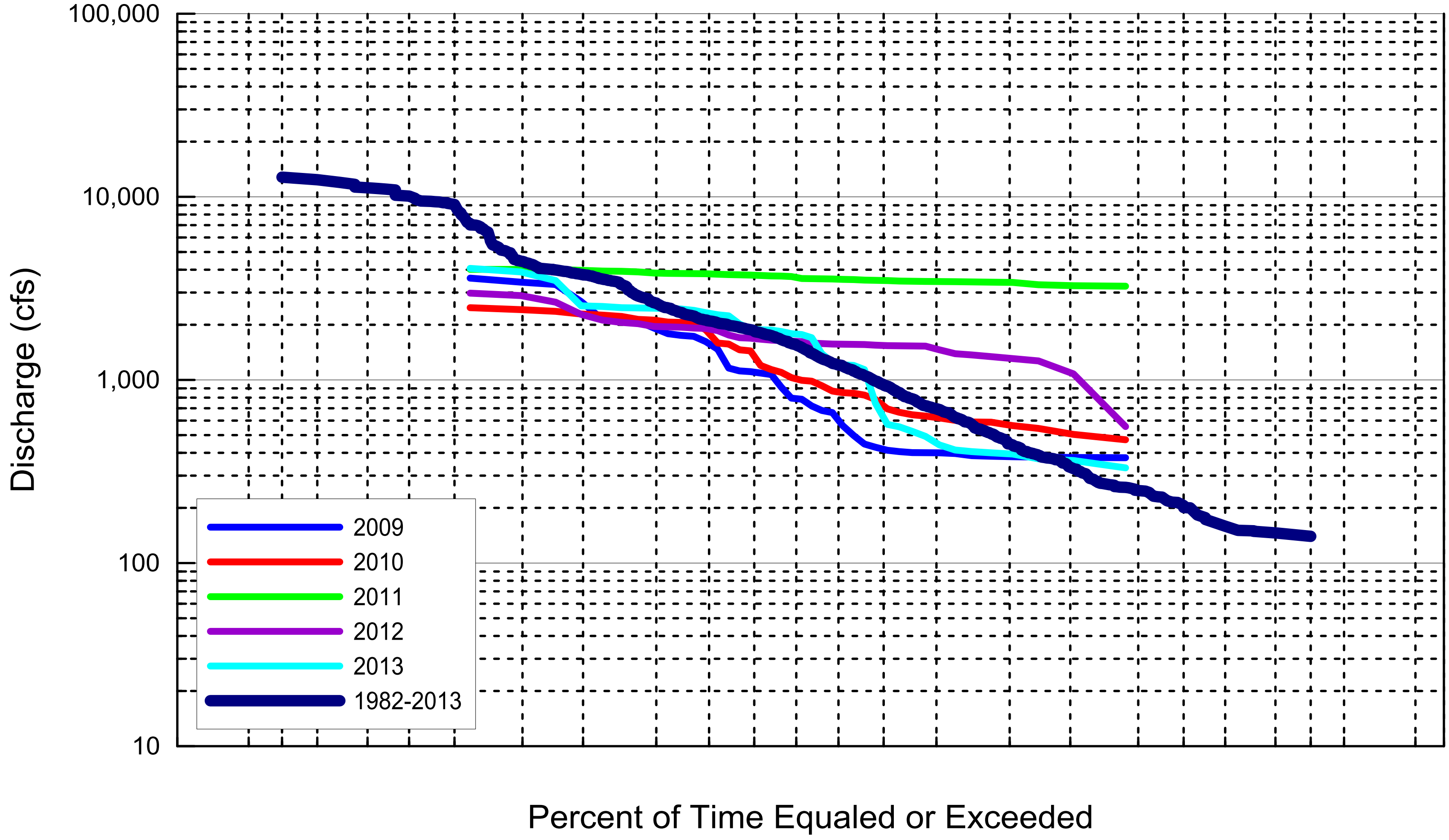


APPENDIX A.2
Mean Daily Flow-duration Curves for Spring Whooping Crane

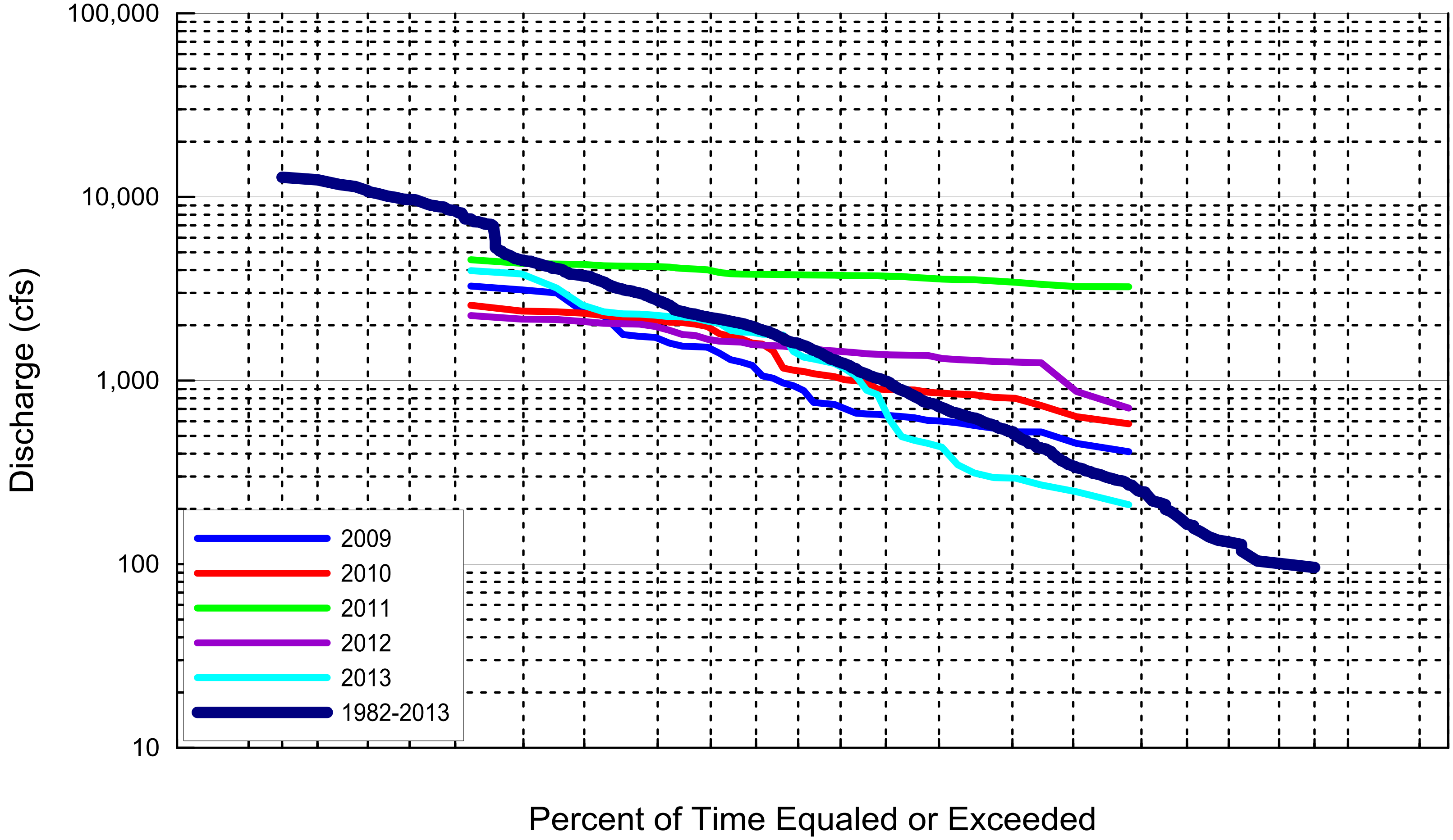
Spring Whooping Crane (June 1 – July 10) for Lexington



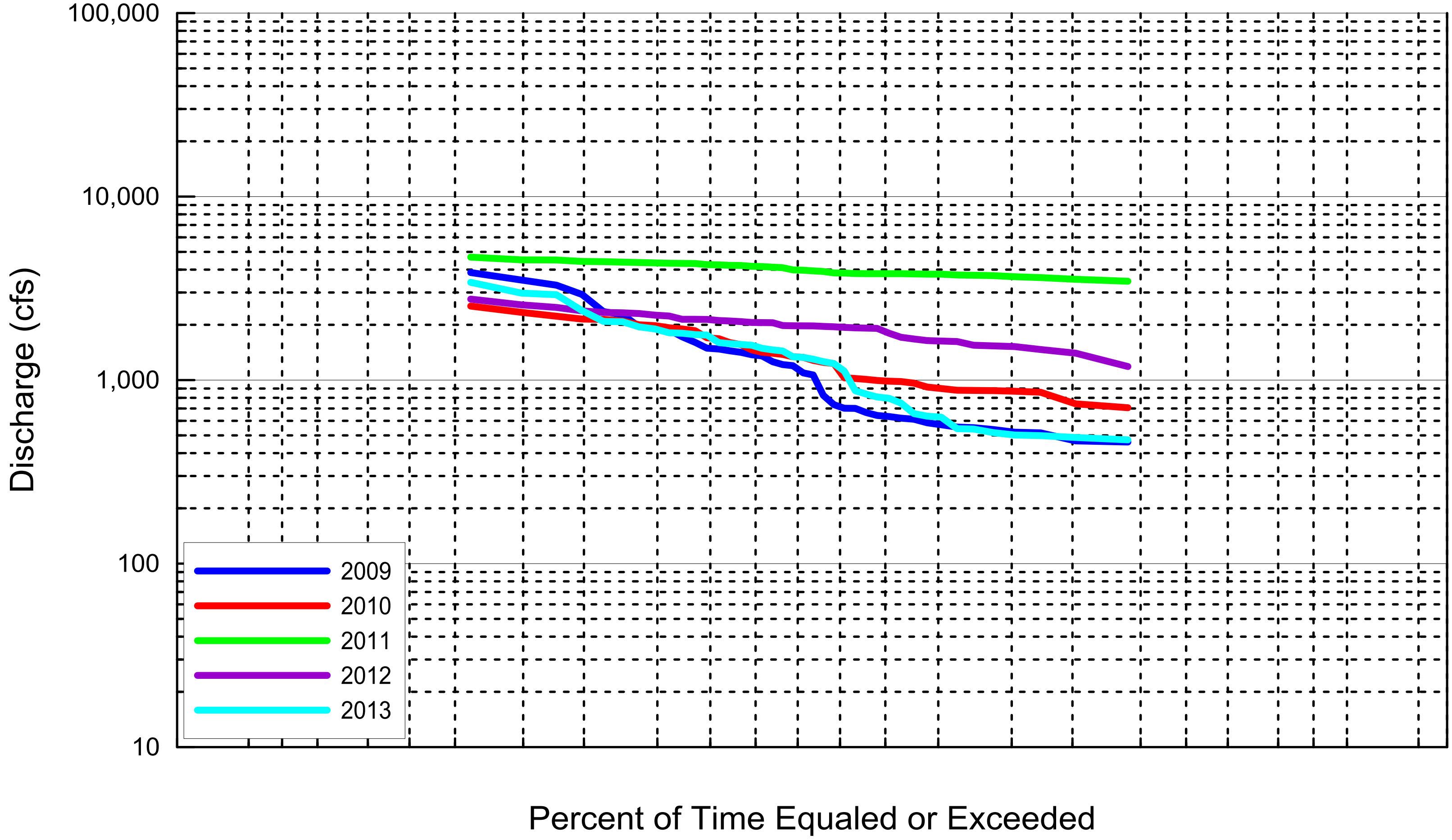
Spring Whooping Crane (June 1 – July 10) for Overton

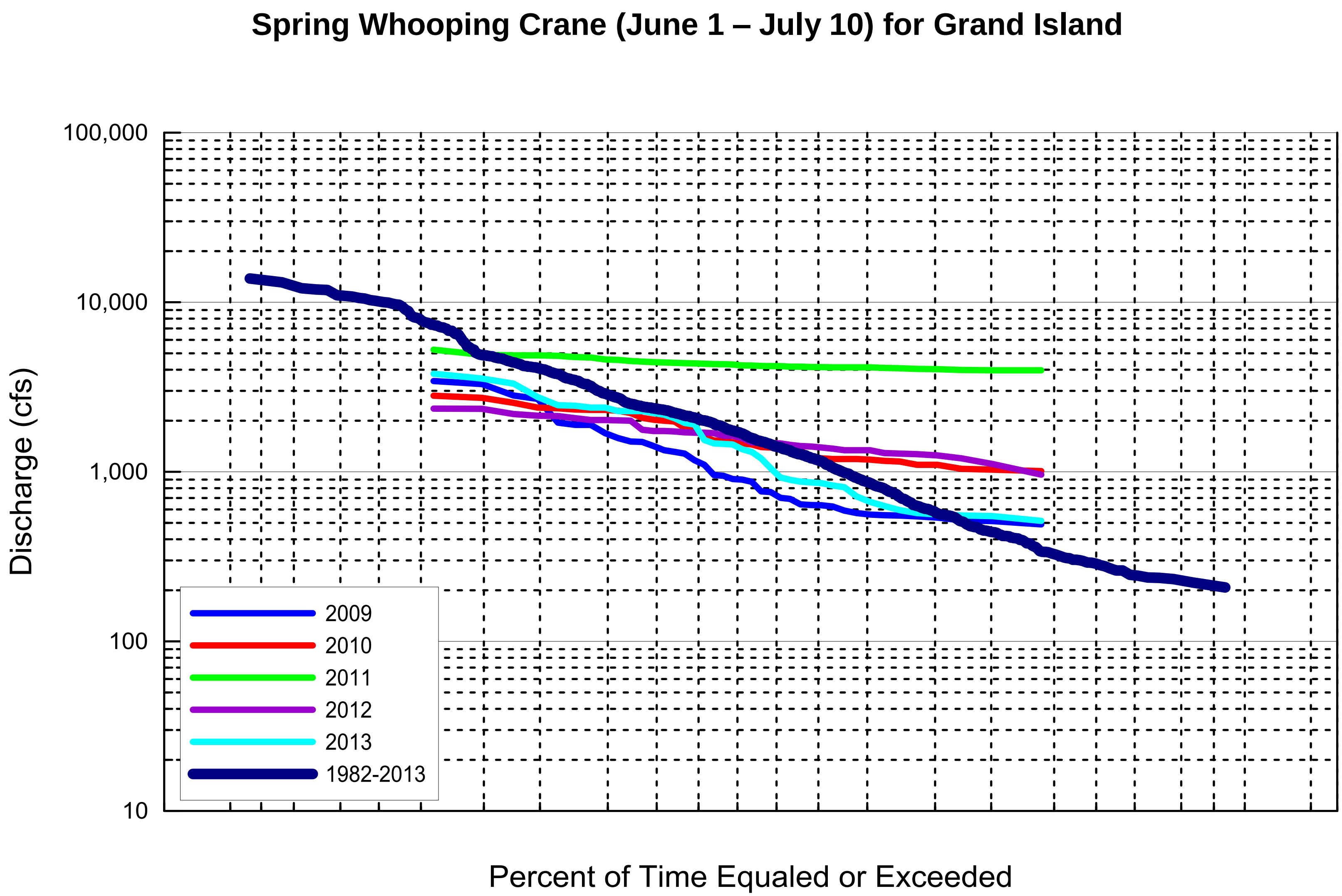


Spring Whooping Crane (June 1 – July 10) for Kearney



Spring Whooping Crane (June 1 – July 10) for Shelton

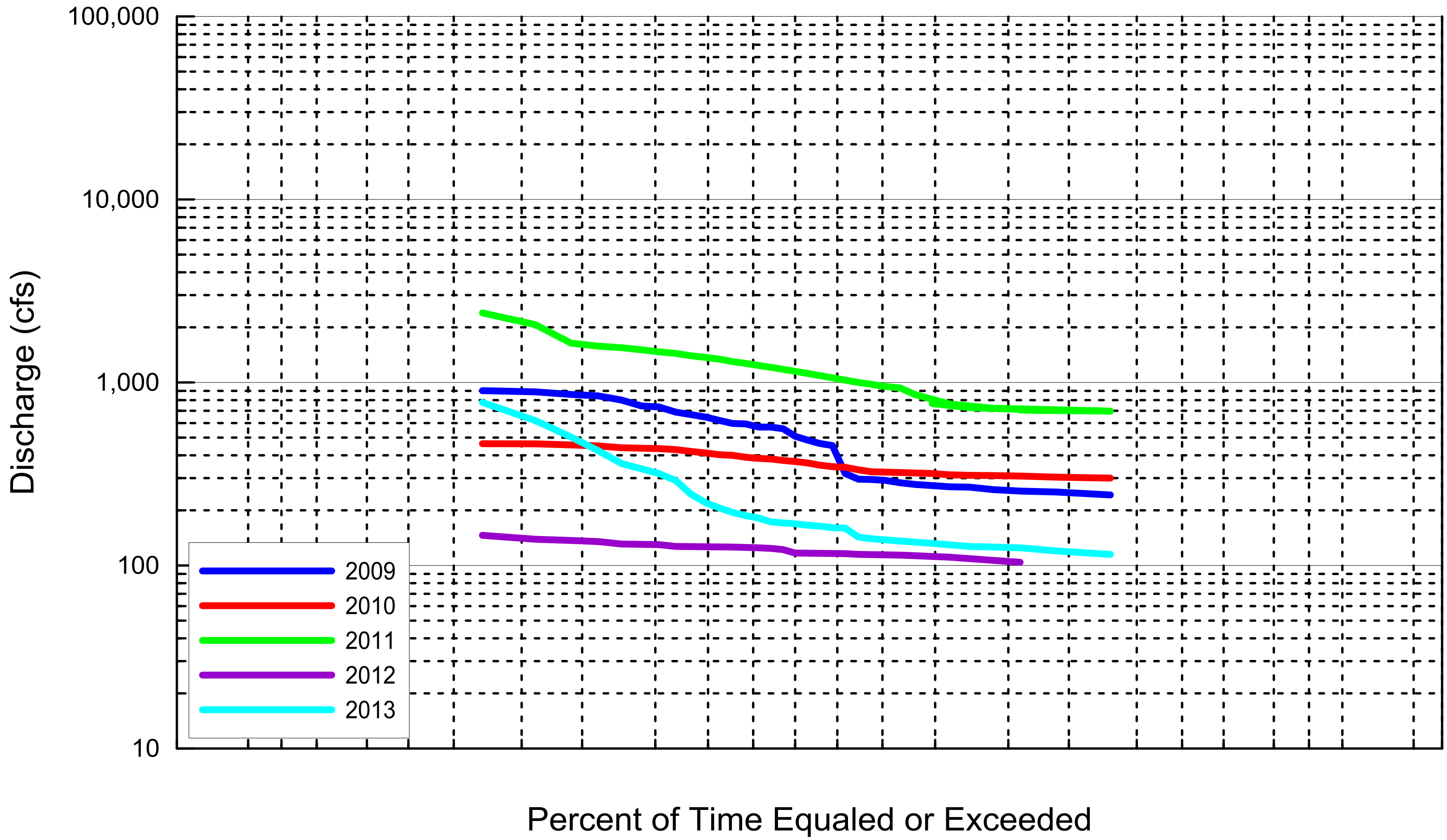




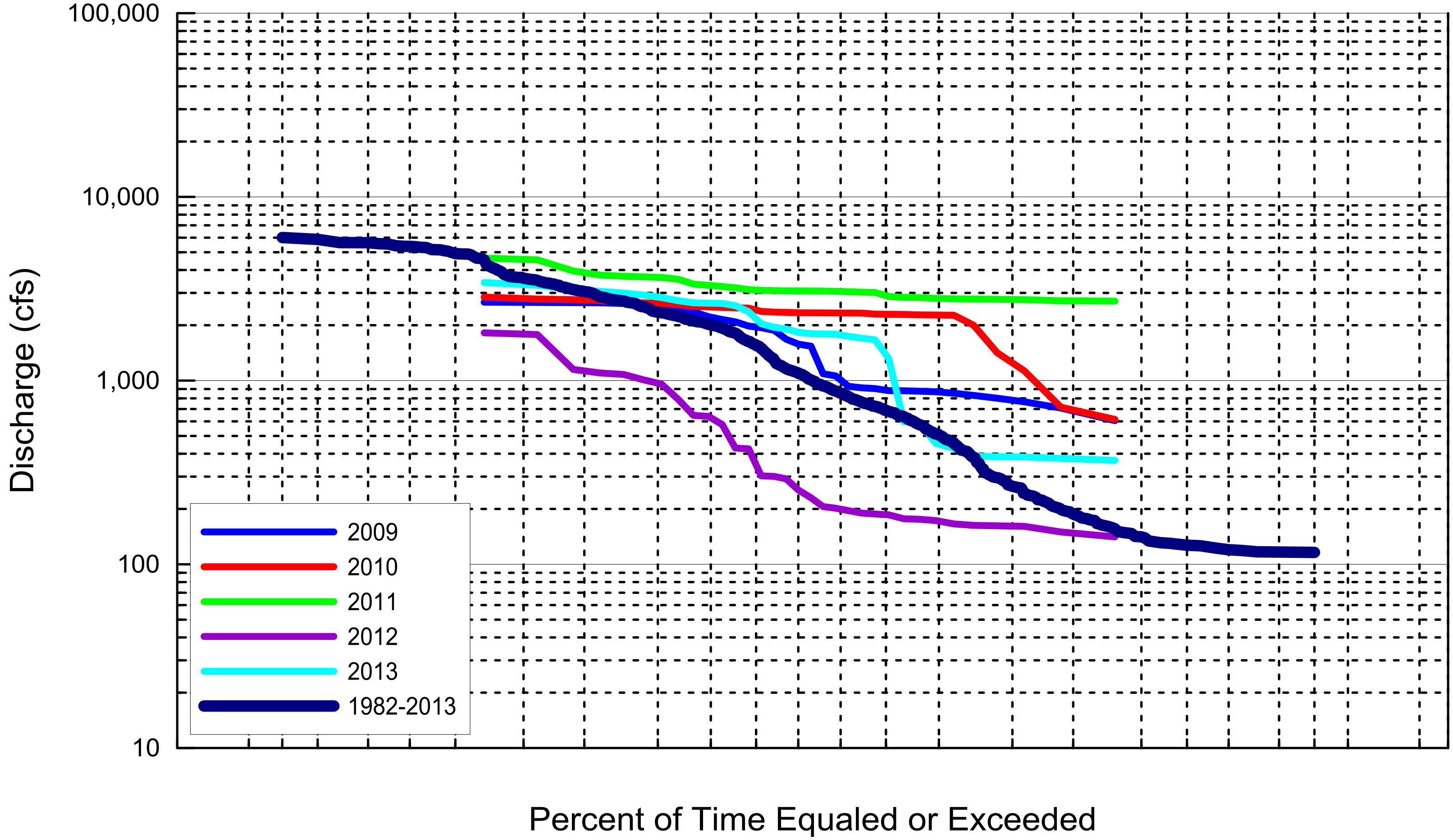
Spring Whooping Crane (June 1 – July 10) for Grand Island
100,000
10,000
1,000
100
10
Discharge (cfs)
Percent of Time Equaled or Exceeded
2009
2010
2011
2012
2013
1982-2013

APPENDIX A.3
Mean Daily Flow-duration Curves for Fall Whooping Crane

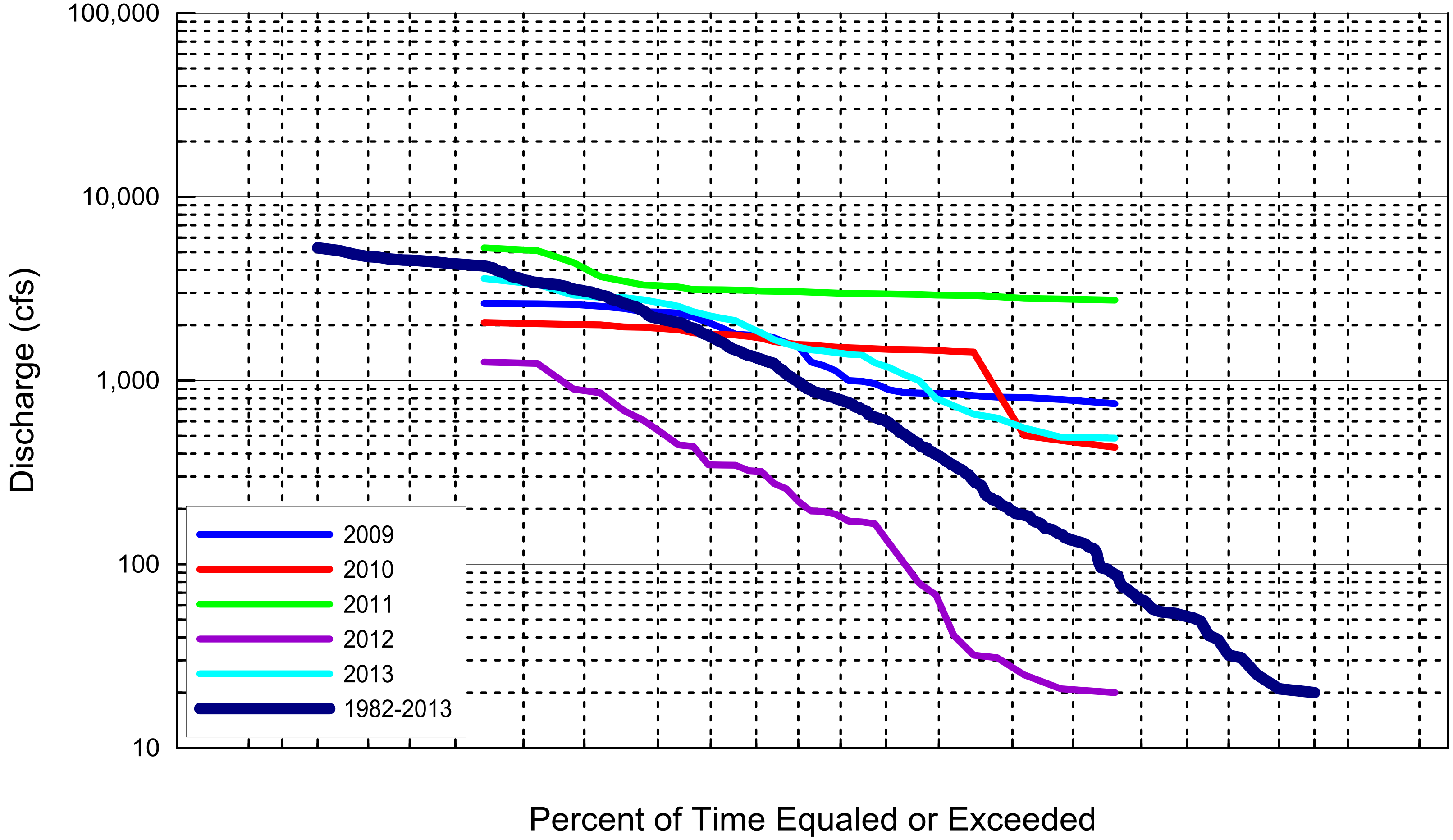
Fall Whooping Crane (June 1 – July 10) for Lexington



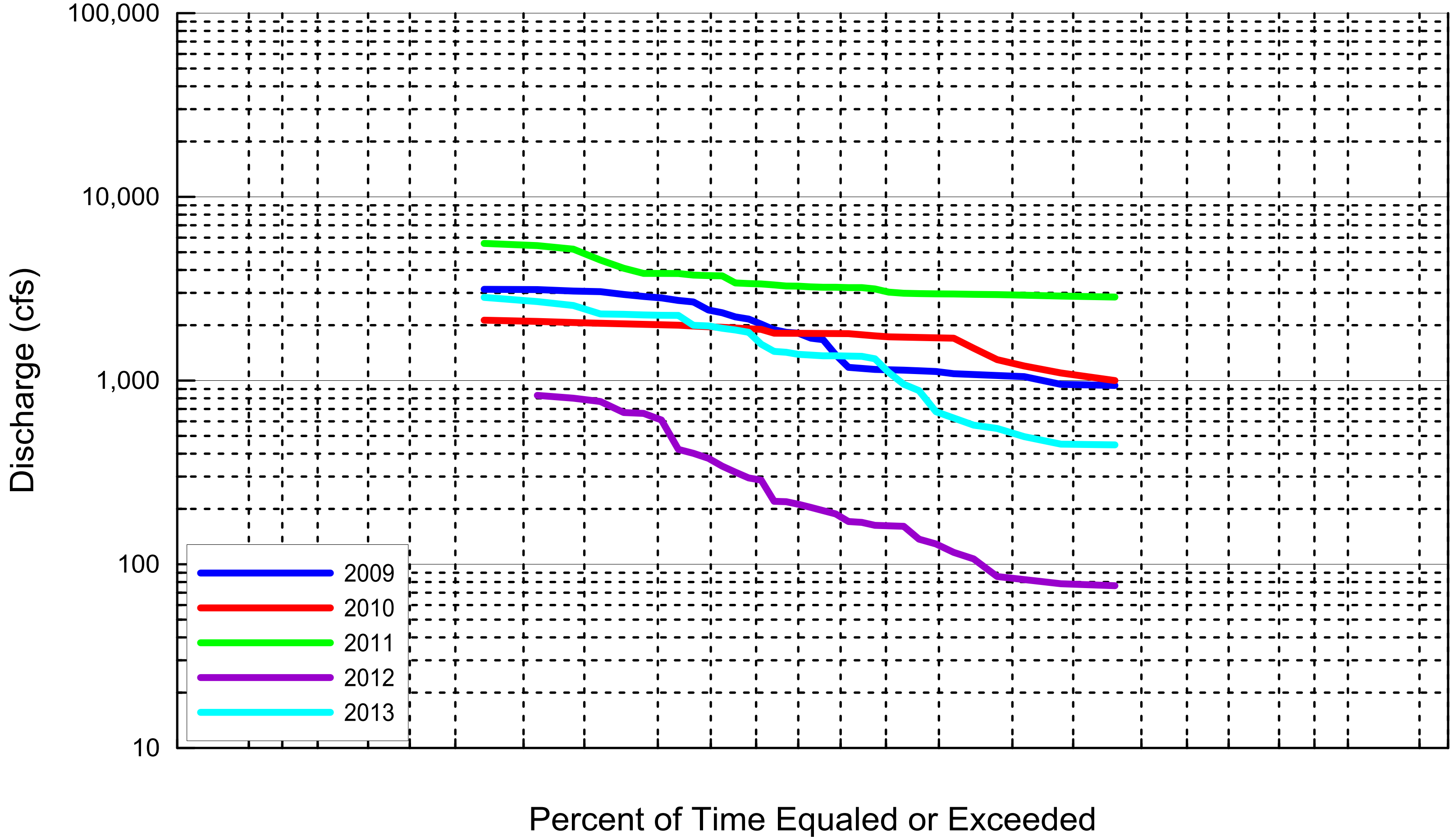
Fall Whooping Crane (June 1 – July 10) for Overton



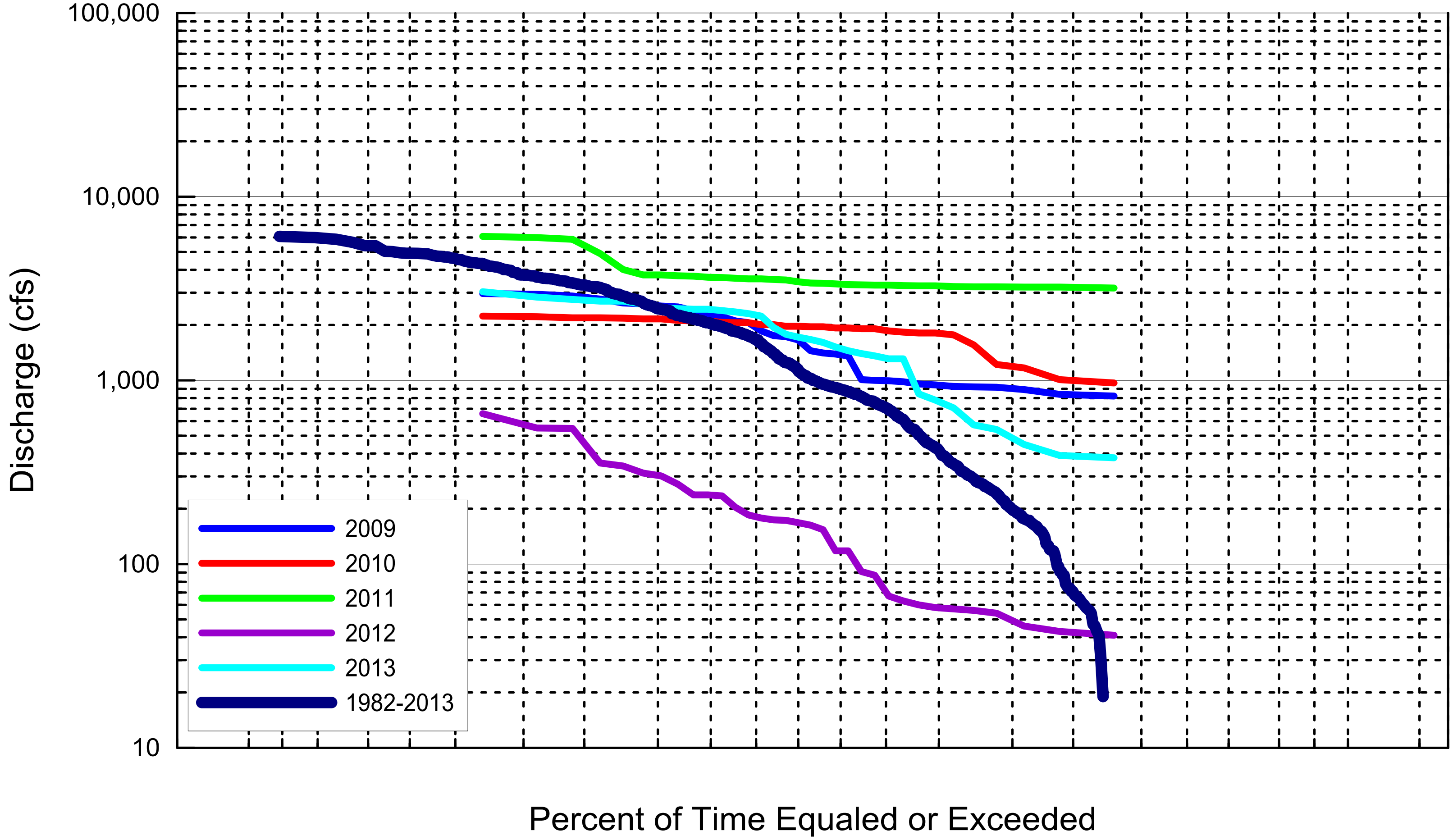
Fall Whooping Crane (June 1 – July 10) for Kearney



Fall Whooping Crane (June 1 – July 10) for Shelton



Fall Whooping Crane (June 1 – July 10) for Grand Island



APPENDICES B.1 through B.5

Appendix B.1: Summary of Geomorphic and Selected Vegetation Metrics - 2013
Appendix B.2: Summary of Geomorphic and Selected Vegetation Metrics - 2012
Appendix B.3: Summary of Geomorphic and Selected Vegetation Metrics - 2011
Appendix B.4: Summary of Geomorphic and Selected Vegetation Metrics - 2010
Appendix B.5: Summary of Geomorphic and Selected Vegetation Metrics - 2009

Appendix B.1-B.5.xlsm

APPENDIX C
Vegetation Data

Veg_Master_Data_Platte_09-13.xlsx