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Champlain Creek Tidal Assessment
Chatham, Massachusetts

Geosyntec consultants

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COMMONWEALTH OF MASSACHUSETTS
Division of Ecological Restoration

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Executive Summary

Champlain Creek runs northwest from its mouth on the Mitchell River, near the intersection of the Mitchell River with Stage Harbor in Chatham, Massachusetts. The creek flows under Stage Harbor Road via a 16-inch metal pipe, which appears to be cracked and damaged at both the inlet and outlet.

The Champlain Creek tidal restriction is identified in the Cape Cod Atlas of Tidally Restricted Salt Marshes (2001), and is a Massachusetts Division of Ecological Restoration Priority Project. A 2011 tidal assessment, characterized the magnitude of the tidal restriction created by the undersized and dilapidated culvert under Stage Harbor Road. The goal of this restoration project is to restore tidal hydrology to the 18-acre Champlain Creek Salt Marsh by replacing the undersized culvert with a structure sized appropriately to convey the full tidal range.

Using a one-dimensional hydraulic model, several culvert replacement scenarios were simulated to determine the appropriate size to convey the full tidal range from the harbor into the marsh. The model geometry was developed using a combination of LiDAR and field surveyed elevation data. Downstream tidal water surface elevations driving the model behavior were obtained from tidal monitoring data collected in May 2011.

The existing conditions model results indicated that the model performed similar to observed conditions when predicting the high tide water surface elevations within the marsh. The size of the culvert under Stage Harbor Road was then iteratively increased up to a span of 15 ft to determine which culvert sizes would most effectively reduce the tidal restriction. Culverts with spans greater than 8 ft were most effective, and ultimately an 8'x6' box culvert and a 10'x6' box culvert were chosen for in-depth modeling and investigation.

Modeling results showed that the two potential culverts are effective at significantly reducing the tidal restriction. Additionally, velocities within in the culverts are expected to be sufficient to prevent siltation and allow the culvert to function with minimal maintenance. Results also showed that full restoration of tidal cycling to Champlain Creek has the potential to inundate several upstream structures, including a footbridge, Atwood Lane, and the Harbormaster's workshop. These impacts will need to be addressed at future stages of the project prior to implementation of the proposed culvert replacement.

Project Background

Champlain Creek runs northwest from its mouth on the Mitchell River, near the intersection of the Mitchell River with Stage Harbor in Chatham, Massachusetts. The creek flows under Stage Harbor Road via a 16-inch reinforced concrete pipe, which is cracked and damaged at both the inlet and outlet and partially covered by silt/sediment. The seaward opening is buried under rocks in the channel bed. The seaward channel is approximately 10 to 15 feet wide and 60 feet long with a parking lot retaining wall serving as the southern bank, while marsh is located along the northern bank. The channel narrows slightly upstream of the road to approximately 10 feet wide. Visual indicators of a restriction include scouring and erosion both seaward and upstream of the pipe.

To assess the severity of the restriction, water level data was collected by Geosyntec Consultants in May 2011. Data collected during this monitoring period provided the tidal metrics listed in Table 1. The results indicate a difference of 1.55 ft exists between the tidal maximum downstream and upstream of the culvert.

Table 1. Champlain Creek Tidal Metrics

Tidal Metrics	Existing conditions	
	Upstream Water Elevation (ft)	Downstream Water Elevation (ft)
Mean Higher-High Water	1.35	2.17
Mean High Water	1.24	1.78
Mean Tide Level	0.28	-0.08
Mean Low Water	-0.68	-1.95
Mean Lower-Low Water	-0.74	-2.21
Tidal Maximum	1.55	3.09
Tidal Minimum	-0.93	-2.49
Mean Tide Range	1.91	3.74

This report describes the methodology and results of hydraulic modeling of the culvert and marsh system. The goal of the model is to determine what size culvert under Stage Harbor Road is sufficient to remove the existing tidal restriction. The model results include the effect of the proposed replacement culvert on upstream water surface elevations and on stream velocities in and around the culvert.

Model Background and Methodology

Model Geometry

Champlain Creek and its surrounding marsh system were modeled using HEC-RAS, a one-dimensional hydraulic model developed by US Army Corps of Engineers. HEC-RAS represents riverine systems using stream and reach centerlines, stream cross sections, in- and off-line storage areas, and hydraulic control structures such as weirs, bridges, and culverts. Water surface profiles are calculated for the system for a variety of boundary conditions, in particular, a time-varying downstream water surface elevation capable of representing tidal cycles.

Model geometry was created in HEC-RAS using the ArcGIS extension HEC-GeoRAS 10. Using HEC-GeoRAS, the features of the hydraulic system were digitized and exported to HEC-RAS. Attachment 1 shows the features that were digitized using HEC-GeoRAS and these features include:

- *Main stream channel centerline and banks* which proceed upstream west from the culvert at Stage Harbor Road to a footbridge at the western side of the marsh, at which point the stream turns north.

- *Side channel centerline and banks* which proceed upstream north from a junction with the main channel just south of the tennis court at Parcel 13A-42-H20 and continues under Atwood Lane.
- *Storage Area 1* which is a broad open marsh area located south of Honeysuckle Lane and contains a ponded area in its eastern half. This storage area is connected in-line with the main channel and side channel described above.
- *Storage Area 2* which is a broad open marsh area located approximately 500 ft upstream of the culvert at Stage Harbor Road, and is connected laterally to the main channel.
- *Channel centerline and banks* for two tributaries north of Honeysuckle Lane which contribute to Storage Area 1.

LiDAR data covering the extent of the project area was used to extract elevation data at cross sections and storage areas. For cross sections, elevation data was extracted along the section at 3 foot station intervals. A total of 71 cross sections were created from extracted LiDAR data at key locations along the stream reaches. HEC-RAS was used to create interpolated cross sections between these 71 extracted cross sections at a maximum 10 foot interval (smaller intervals were used in locations that required more detail for model stability, i.e. around culverts and other restrictions). For storage areas, LiDAR elevation data was used to create a stage-storage curve at 0.5 foot stage intervals.

Since LiDAR data fails to capture detailed in-stream geometry, field-survey data was used to estimate a representative stream bed cross section. Field-survey data collected by Outermost Land Survey, Inc., between May 29, 2012 and June 1, 2012 was used to calculate an average bottom width and logitudinal slope for the stream sections (Figure 1). A channel with the calculated bottom width and slope was then 'cut' into the cross sectional geometry along the stream centerlines using the "Channel Design/Modification Editor" tool included in HEC-RAS.

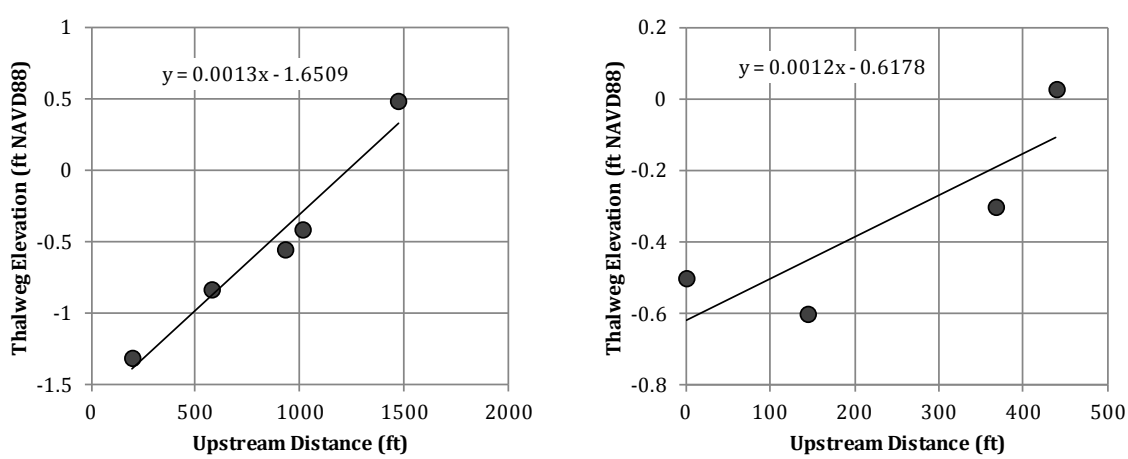

Figure 1. Average longitudinal slopes along main stream channel (left, slope = 0.0013 ft/ft) and side stream channel (right, slope = 0.0012 ft/ft).

The following control structures (culverts, bridges, etc.) were added manually to the model geometry:

1. 16" RCP Culvert under Stage Harbor Road (upstream invert = -1.8 ft NAVD88, downstream invert = -2.6 ft NAVD88);
2. 24" HDPE Culvert under Atwood Lane (upstream invert = 0.2 ft NAVD88, downstream invert = 0.0 ft NAVD88);
3. Foot bridge south of tennis court;
4. 24" CMP and 10" plastic/clay culverts under Honeysuckle Lane; and
5. Lateral transfer section to exchange water between the main stream channel and Storage Area 2. The structure is based on the geometry of a restrictive section between the Main Channel floodplain and Storage Area 2 (Figure 2).

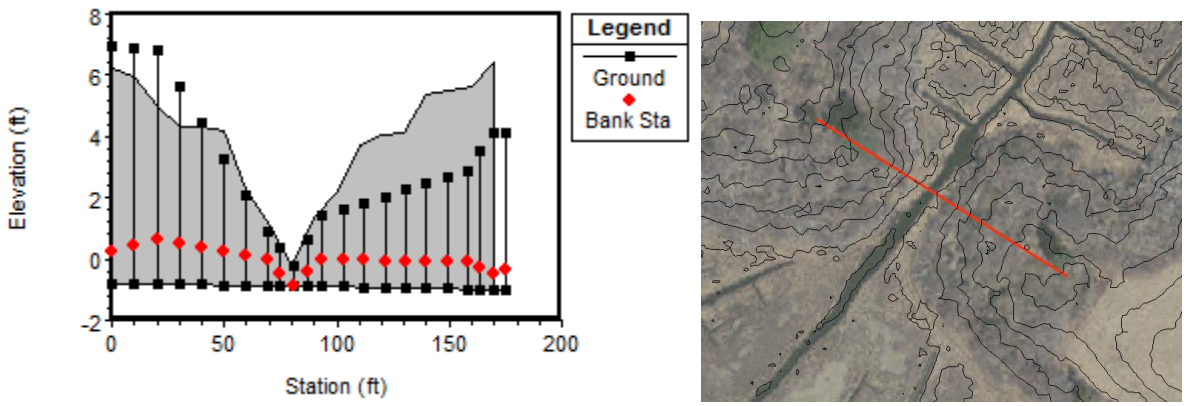

Figure 2. Lateral transfer structure geometry (left) and location (right).

Seaward tidal boundary

The functioning of the existing and proposed culverts under Stage Harbor Road was simulated using three records of tidal water surface elevations over a five-day period.

- Tidal scenario 1: Observed tidal record based on water surface elevations collected by Geosyntec Consultants from May 13 – 18, 2011. During this five day period, the highest high tide of the 2011 monitoring data (3.09 ft NAVD88) was observed.
- Tidal scenario 2: The tidal record from May 13 – 18, 2011, scaled in such a way that the highest high tide is equal to 3.72 ft NAVD88, the highest high tide observed by Louis Berger Consultants during a monitoring period in 2006.
- Tidal scenario 3: The tidal record from May 13 – 18, 2011, scaled in such a way that the high and low tides are increased by 1.38 and 0.82 feet, respectively, to account for 50-year sea level rise estimates.

Tidal scenarios 2 and 3 were scaled using a sinusoidal curve (sin curve). For Tidal scenario 2, a sin curve whose peaks correspond with high tide and which oscillated between 0 and 0.63 feet was added to the values in Tidal scenario 1 so that low tides remained constant and high tides were

increased by 0.63 feet (3.09 ft + 0.63 ft = 3.72 ft). For Tidal scenario 3, a similar sin curve which oscillated between 0.82 and 1.38 feet was added to the water surface elevations of Tidal scenario 1 (Figure 3). A discussion of the calculation of the sea level rise scaling values is provided in Appendix 1.

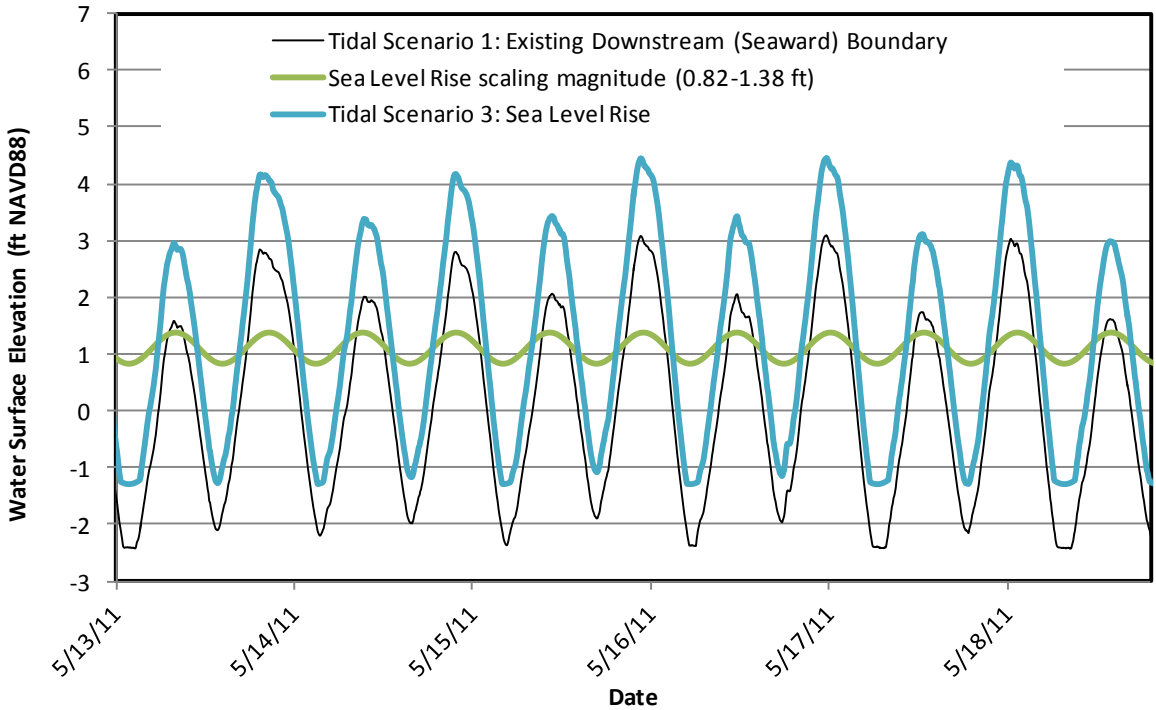

Figure 3. Scaling of tidal record to represent Tidal scenario 3, Sea Level Rise.

The final tidal scenario investigated, Tidal scenario 4, involved modeling of a 100-year storm event. FEMA flood maps indicate that the 100-year storm elevation at Stage Harbor Road is 10 feet NGVD29. This elevation was converted to 9.11 feet, NAVD88 using the NOAA conversion program, VDatum (http://vdatum.noaa.gov/). This tidal scenario involved setting the initial water surface elevation to 9.11 feet, NAVD88, then allowing the downstream boundary to return to a normal tidal cycle. The purpose of the scenario is to observe the effects of the proposed culverts on the time it takes for the water surface elevations upstream of the culvert to return to normal (i.e. the time it would take for the marsh to drain after a major flood event).

Upstream boundary

Due to the lack of flow measurement data for the system and the general difficulty of distinguishing base flow from tidal flow, the upstream boundary flow was treated as a model calibration parameter. Upstream flows were applied to the two incoming tributaries north of Honeysuckle Lane. They were made as low as possible while still maintaining model stability (extreme low flows tend to cause model oscillations/errors) and adjusted to obtain a fit between the modeled and measured marsh water surface elevations. The estimated total flow in the two incoming tributaries based on these parameters is 0.9 cubic feet per second (cfs).

Existing Conditions Results

Existing conditions were modeled using Tidal scenario 1 and the geometry for the existing 16 inch culvert under Stage Harbor Road. The model simulation was run for a period of 10 days. The first half of the simulation allows the model to reach an equilibrium state. The second half of the simulation time was used for model validation and reflects the monitoring period of 5/13/2011 to 5/18/2011. During this time, maximum observed downstream (seaward) water surface elevation was 3.09 ft NAVD88. The maximum observed upstream (marsh) water surface elevation was 1.55 ft NAVD88. The existing conditions model predicted a maximum upstream (marsh) water surface elevation of 1.50 ft NAVD88. Modeled upstream high tide water surface elevation varied from the observed upstream high tide water surface elevation by 0.05 feet, which is 3% of the observed upstream tidal range of 1.91 feet. Figure 4 shows the modeled and measured water surface elevations for the 5 day validation period and Attachment 1 shows the extent of inundation in the marsh under existing conditions.

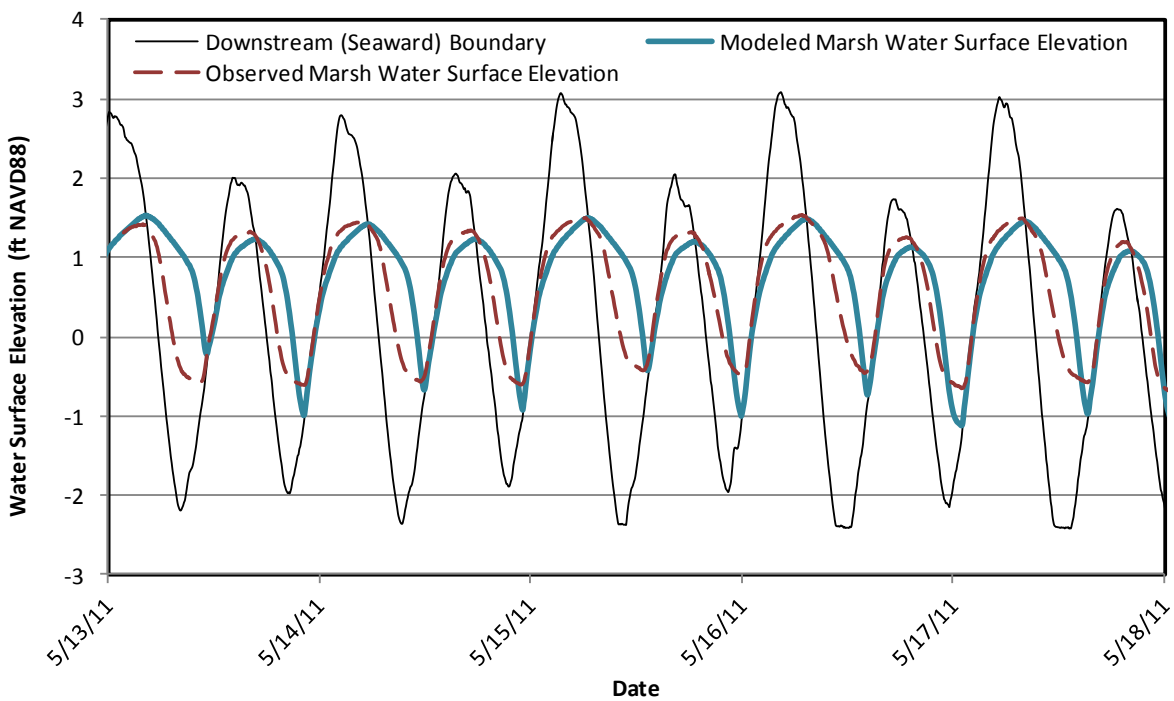

Figure 4. Existing Conditions modeling results.

The results shown in Figure 4 were obtained without significant adjustment to the original model geometry and parameters. Some calibration was performed, such as adjustment of Manning's n values in the channels and culverts, adjustment of culvert entrance and exit loss coefficients, and changes to the stage-storage curves of the storage areas. These adjustments did not result in significant changes to the model results.

The results show agreement with observed water surface elevations above approximately 1 foot NAVD88. This is the approximate elevation at which water rises above the main channel and extends out to the floodplain. However, the model predicts significant discrepencies between the observed and modeled water surface elevations below 1 foot NAVD88. The factors potentially causing these discrepencies are as follows:

- The water surface elevations below 1 foot represent water that is within the channel, where the geometry is not well represented. Since surveyed stream channel data was used to generate a "representative channel cross section," specific water surface elevations within the representative channel may not match observed values or water surface elevations within the flood plain, where LiDAR elevations were available.
- The volume within the representative channel is a fraction of the volume in the floodplain. This means that small changes in the flow of water into and out of the modeled system will have little effect when water surface elevations extend into the floodplain. However, the same small changes will have a drastic effect on water surface elevations when water is restricted to the relatively small channel area.
- Model stability requires that the channel remains flowing at all times. For this reason, the upstream boundary is represented by incoming flowrates totalling 0.9 cfs. This may not be representative of conditions during the period of May 13 – 18, 2011, when the water surface elevations were observed. The additional flow may cause water surface elevations to be elevated within the channel, but would have little effect on water surface elevations in the floodplain.
- Spending effort to finely calibrate the model for conditions within the channel would not necessarily improve the behavior of the model in proposed conditions, when upstream water surface elevations are expected to be beyond the range of observed values and for which no data exists to validate this condition.

Although these discrepencies may occur, the modeled high-tide water surface elevations upstream of the culvert mimic observed, further indicating that the existing conditions model allows a realistic volume of water to enter the marsh during a tidal cycle.

Proposed Conditions Results

A wide range of potential replacement culvert sizes were investigated by iteratively increasing the culvert size and modeling using Tidal scenario 1 (observed tidal record, May 13 – 18, 2011). The culvert geometry was the only parameter adjusted; however, in some cases with large sized culverts the in stream geometry just upstream and downstream of the culvert was modified in minor ways as to not obstruct the culvert opening. The inverts of the proposed culvert were set at the same inverts as the existing 16 inch culvert (upstream invert = -1.8 ft NAVD88; downstream invert = -2.6 ft NAVD88). After each culvert scenario, the maximum upstream water surface was recorded and compared to the downstream water surface elevation to determine what culvert size would sufficiently remove the tidal restriction. Table 2 presents the results of this iterative modeling process.

Table 2. Proposed culvert replacement scenarios and resulting tidal restriction.

Culvert Replacement Scenario	High Tide Elevation (ft NAVD88)	Tidal Restriction (ft)
Downstream Boundary	**3.09**	**-**
Existing Conditions (16")	1.5	1.59
36" Single Barrel	2.53	0.56
36" Double Barrel	2.77	0.32
4'x3' Box Culvert	2.73	0.36
6'x4' Box Culvert	2.9	0.19
8'x6' Box Culvert	3	0.09
10'x6' Box Culvert	3.04	0.05
12'x6' Box Culvert	3.06	0.03
15'x6' Box Culvert	3.07	0.02

The model results indicate that as you increase the span or culvert geometry, the incremental decrease in tidal restriction becomes less, as presented in Figure 5. One factor that causes this pattern is the stage-storage relationship of the marsh. As elevation increases within the marsh, a larger volume is required to increase the water surface elevation. A second factor is that flow rate through a culvert is dependent on both the culvert size and the head differential across the culvert. As the tidal restriction is removed, this head difference becomes smaller and balances out the positive effects of increased culvert cross sectional area.

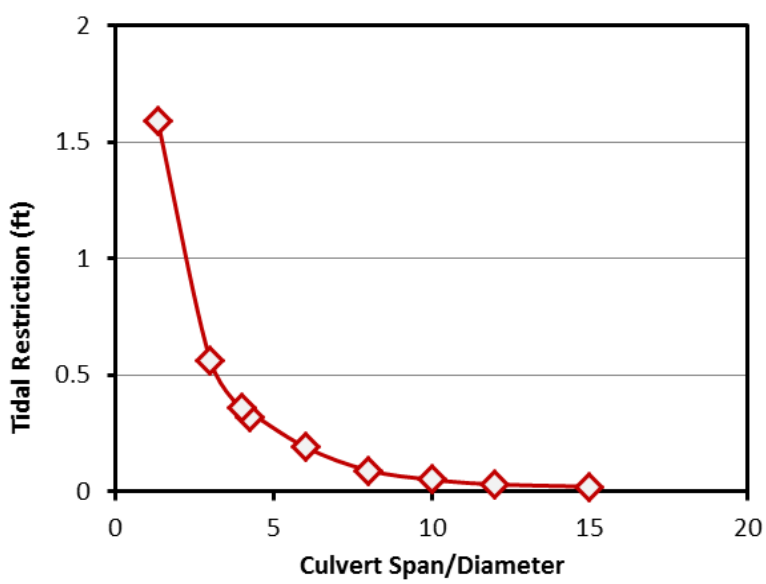

Figure 5. Culvert Span versus Tidal Restriction*

*Note: The 3 foot double barrel culvert is plotted with a span of 4.2 feet, which is an effective diameter based on the total area of the two barrels.

Due to the mathematics of modeling water surface profiles, it is unlikely that there will be a culvert size where the modeled culvert restriction will be completely removed. The span was increased up

to a 15 foot culvert span, which is the maximum span suggested by MassDOT Engineering Guidelines in the 2009 LRFD Bridge Manual. Given the inherent uncertainties of the model, it is most likely that the modeled tidal restriction of 0.02 feet for the 15 foot culvert span is not significantly different than the modeled tidal restriction of 0.09 for the 8 foot culvert span. Based on these results, the 8' x 6' foot box culvert and 10' x 6' box culvert were selected for further investigation.

For the 8'x6' box culvert and 10'x6' box culvert models, the inverts of the proposed culvert were set to -2.2 ft NAVD88, which is the average of the existing culvert inverts. In these model simulations, full water surface profiles as well as velocities at locations upstream and downstream of the proposed culvert were calculated. The rise of the culverts was also adjusted from 6 feet to 5 feet to determine if a change in rise would increase tidal restriction. A shorter rise may be needed accommodate the appropriate thickness of cover material during construction.

Water Surface Elevation Results

Water surface elevation results for the two culvert replacement scenarios are summarized in Tables 3a and 3b. The modeling results with respect to water surface elevation indicate:

- The 8'x6' box culvert does not perform significantly different than the 10'x6' box culvert with respect to water surface elevations. Both proposed culvert geometries effectively remove the tidal restriction under a variety of scenarios, including for tidal elevations that are higher than those observed by Geosyntec in the 2011 monitoring period.
- The foot bridge south of the tennis court along the western reach of the stream has the potential to become periodically inundated during high tide.
- Atwood Lane has the potential to be flooded if sea level rise occurs as predicted.
- The Harbormaster's workshop parking area just west of the culvert at Stage Harbor Road (approximate elevation range 2.6-3.5 ft NAVD88) has the potential to be flooded due to proposed culvert replacement.
- Reduction of culvert rise from 6' to 5' does not cause significant restriction during the observed tidal record, but does add minor restrictions during higher tides, including the sea level rise scenario (Table 3b).

Table 3a. Maximum Water Surface Elevations, 6 ft rise

	10'x6' Box Culvert			8'x6' Box Culvert		
	Maximum Water Surface Elevation		Tidal Restriction	Maximum Water Surface Elevation		Tidal Restriction
Tidal Scenario	Downstream	Upstream		Downstream	Upstream	
(1) Observed	3.09	3.03	0.06	3.09	2.99	0.10
(2) Scaled (highest high tide, 2006)	3.72	3.67	0.05	3.72	3.61	0.11
(3) Sea Level Rise	4.46	4.42	0.04	4.46	4.35	0.11

Table 3b. Maximum Water Surface Elevations, 5 ft rise

	10'x5' Box Culvert			8'x5' Box Culvert		
	Maximum Water Surface Elevation		Tidal Restriction	Maximum Water Surface Elevation		Tidal Restriction
Tidal Scenario	Downstream	Upstream		Downstream	Upstream	
(1) Observed	3.09	3.02	0.07	3.09	2.99	0.10
(2) Scaled (highest high tide, 2006)	3.72	3.64	0.08	3.72	3.59	0.13
(3) Sea Level Rise	4.46	4.38	0.08	4.46	4.3	0.16

Attachment 2 presents the extent of tidal inundation for the scenarios in plan view. Since water surface elevations did not differ significantly between the two proposed culvert geometries, the extent of inundation is approximately the same.

100-year flood results

A 100-year storm event was simulated using water surface elevations shown on FEMA flood insurance rate maps. The 100-year flood elevation at Stage Harbor Road is 9.1 ft NAVD88. The flood elevation was assigned as an initial condition across the marsh and time for the downstream elevations to return to a normal tidal fluctuation were calculated. Figure 6 presents the marsh drainage time and indicates that the 8'x6' culvert allows water surface elevations in the marsh to return to normal at the same rate as they do in Stage Harbor. Under existing conditions, the 16 inch culvert, the marsh requires approximately 4 additional days to return to a normal tidal cycle. The 10'x6' box culvert behaves the same as the 8'x6' culvert during the 100-year flood event.

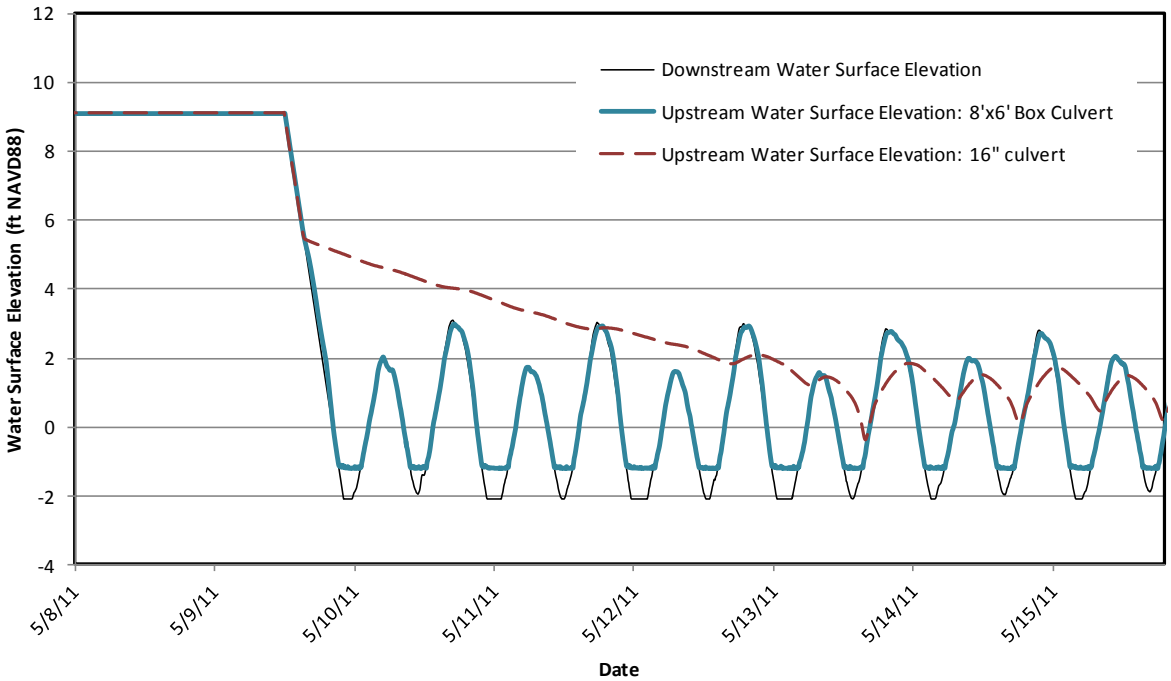

Figure 6. Marsh drainage time after 100-yr Flood Elevation.

Velocity Results

The maximum velocities upstream and downstream of the culvert for the tidal scenario 1 and the sea level rise scenario were extracted from the model for the 8'x6' and 10'x6' model scenarios, are presented in Table 4. Maximum velocities for the 10'x6' box culvert ranged from 1.4 feet per second (ft/s) upstream to 3.2 ft/s downstream and maximum velocities for the 8'x6' box culvert ranged from 1.3 ft/s upstream to 3.2 ft/s downstream, with higher velocities occurring during the sea level rise scenario.

Table 4. Maximum velocities upstream and downstream of culvert.

	10'x6' box culvert Velocity (ft/s)		8'x6' box culvert Velocity (ft/s)	
Tidal Scenario	Max Upstream	Max Downstream	Max Upstream	Max Downstream
Scenario 1	1.4	2.0	1.3	1.9
Sea Level Rise	2.0	3.2	1.6	3.2

Culvert exit velocities have implications for both scour and siltation at the mouths of the culvert. Scour due to high velocities can be mitigated by proper design of energy dissipation and channel protection at later stages of the project. Siltation which includes buildup of material around and inside the culvert cannot be as easily mitigated using engineering methods, and it's important to ensure that velocities will be high enough to flush fine sediment particles through the culvert.

The maximum modeled discharge during tidal scenario 1 (observed data) was 140 cfs for the 10'x6' culvert and 129 cfs for the 8'x6' culvert. For both culvert geometries the depth of flow in the culvert was 4.9 feet. Using Manning's equation, an energy slope (S) was estimated that would result in the given discharges for each maximum flow. An example calculation for the 10'x6' culvert is shown below:

$$Q = A \cdot \left(\frac{1.49}{n}\right) \cdot R^{2/3} \cdot S^{1/2}$$

$$A = 10ft * 4.9ft = 49ft^2$$

$$P = 10ft + 2(4.9ft) = 19.8\ ft$$

$$R = \frac{A}{P} = \frac{49}{19.8} = 2.47\ ft$$

$$Q = (49\ ft^2)\left({}^{1.49}/_{0.013}\right)\left(2.47^{2/3}\right)\left(0.00019^{1/2}\right) = 142\ cfs$$

where, Q is the discharge; A is the cross sectional area of flow; n is Manning's coefficient; R is the hydraulic radius; P is the wetted perimeter; and S is the energy slope. By iteratively adjusting S until Q matched the modeled discharge rates, velocities within the culvert were calculated to be 2.9 and 3.3 ft/s for the 10'x6' and 8'x6' box culverts, respectively.

Shields diagram was used to calculate the largest particle size that would be transported by the flows and velocities expected. The calculation for the value on the x axis of the Shields diagram (Figure 7) for the 10'x6' culvert is:

$$\frac{q^* d_s}{v} = \frac{0.153 * 0.00623}{1.4x10^{-5}\ {}^{ft^2}/_{s}} = 68.3$$

where, d_s is the particle diameter (1.9mm or 0.00623 ft); v is the kinematic viscosity of water; and q^* is equal to:

$$q^* = \sqrt{\frac{\tau^*}{\rho}} = \sqrt{\frac{0.0457}{1.94\ {}^{slugs}/_{ft^3}}} = 0.153$$

where, τ^* is the value on the y axis of the Shields diagram (Figure 7) and is calculated using an assume specific gravity of water of 62.4 lb/ft^3 and a specific gravity of the sediment of 165.5 lb/ft^3:

$$\tau^* = \frac{\gamma_f \cdot R \cdot S}{(\gamma_s - \gamma_f)d_s} = \frac{62.4 * 2.47 * 0.00019}{(165.4 - 62.4)0.00623} = 0.0457$$

By plotting these two values on the Shields diagram (Figure 7), the particle diameter estimate of 1.9 mm results in a solution that falls on the boundary that indicates incipient motion of the particle (Figure 7).

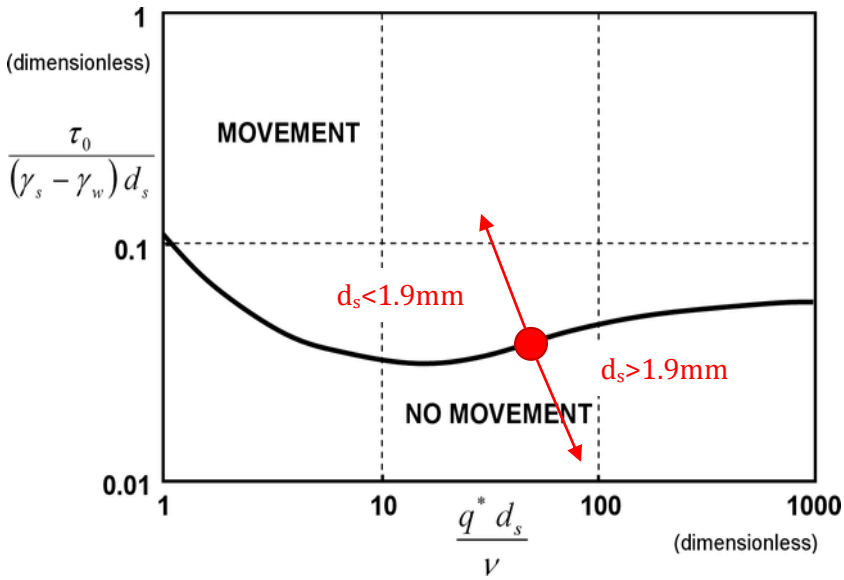

Figure 7. Shield's Diagram for 10'x6' Box Culvert at maximum flow rate.

Using this approach, Geosyntec determined that the velocities and flows within the 10'x6' culvert are sufficient to flush particles smaller than 1.9 mm ("very coarse sand"), and velocities and flows within the 8'x6' culvert are sufficient to flush particles smaller than 2.5 mm ("very coarse gravel"). As such, it is likely that the velocities resulting from tidal flow within these two culverts will be capable of flushing particles through the culvert and preventing significant siltation.

Summary

- A one-dimensional HEC-RAS model was created to model the marsh system upstream of the culvert at Stage Harbor Road in Chatham, MA. Model geometry was generated using the ArcGIS extension HEC-GeoRAS and LiDAR elevation data.
- The downstream tidal water surface elevation of the model was based on observations collected by Geosyntec Consultants in May 2011.
- The existing conditions model was able to accurately represent the high tide water surface elevations within the marsh.
- Modeling of a range of potential culvert replacement scenarios indicated diminishing returns with respect to removal of the tidal restriction for culverts with a span greater than 8 feet.
- Both the 8'x6' and 10'x6' box culverts effectively remove the tidal restriction for the range of tidal scenarios investigated.

- Both the 8’x6’ and 10’x6’ box culverts have maximum in culvert velocities capable of preventing siltation.
- Complete removal of the tidal restriction will most likely result in innundation of the footbridge, Atwood Lane, and the Harbormaster’s workshop.
- While each of the culverts (8’x6’ and 10’x6’) are viable options for replacement, the specific span and rise will most likely be determined after further investigation including: (1) the minimum road cover required above the culvert; and (2) the distances necessary to prevent the culvert from interfering with the downstream retaining wall west of the channel.

Attachment 1:

HEC-RAS Model Setup and Existing Conditions Results

300 150 0 300 600 Feet

Legend

- Tide Gage (Geosyntec, 2011)
- Cross Section
- Storage Area

Topographic Contour (ft NAVD88)

- 7 ft
- 8 ft

Notes:
1. Aerial image via MassGIS, 2008

HEC-RAS Model Setup and Existing Conditions Results

Champlain Creek
Chatham, MA

Acton, Massachusetts
JUNE 2012

Geosyntec consultants

Attachment 1

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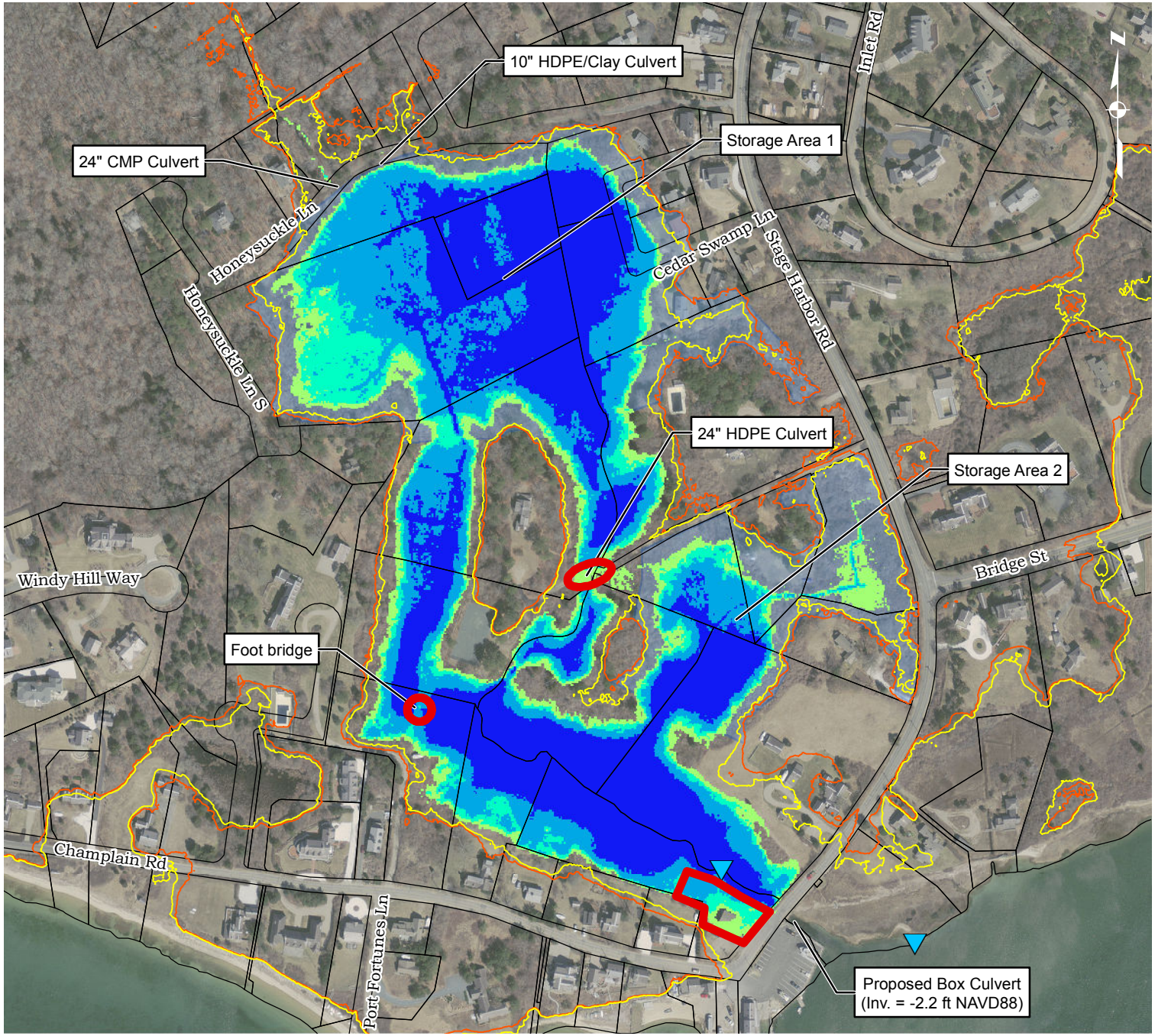
Attachment 2:

Extent of Upstream Inundation, Proposed Culverts



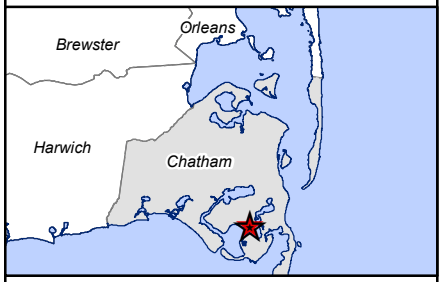
Legend

- Tide Gage (Geosyntec, 2011)
- Existing High Tide (1.5 ft NAVD88)
- Proposed High Tide, 2011 (3.0 ft NAVD88)
- Proposed High Tide, 2006 (3.6 ft NAVD88)
- Sea Level Rise High Tide (4.4 ft NAVD88)
- Storage Area

Topographic Contour (ft NAVD88)

- 7 ft
- 8 ft
- Town of Chatham Parcel Boundaries
- Potential inundation/flooding of structures

Notes:
1. Aerial image via MassGIS, 2008
2. High Tide of 2011 based on tidal record observed by Geosyntec, May 2011.
3. High Tide of 2006 based on tidal monitoring performed by Louis Berger, 2006.



Extent of Upstream Inundation Proposed 10'x6' and 8'x6' Box Culverts

Champlain Creek
Chatham, MA

Acton, Massachusetts
JUNE 2012

Geosyntec consultants

Attachment
2

Q:\GISProjects\BW0214-Champlain_Creek\ATT01a_8X6_RESULTS.mxd

Appendix 1:

Sea Level Rise Calculation

Geosyntec consultants
engineers | scientists | innovators

289 Great Road
Suite 105
Acton, MA 01720
978-263-9588
www.geosyntec.com

To: Chad Yaindl, Geosyntec Consultants
CC:
From: David Roman, Geosyntec Consultants
Date: June 15, 2012
Re: BW0214,Ph02: Boundary adjustments for future potential sea-level rise

Future Sea Level Rise Scenario

Geosyntec used the methods described in U.S. Army Corps of Engineers' circular entitled Incorporating Sea-level Change Considerations in Civil Works Programs, to calculate an estimate of future sea level rise due to climate change. The rate of sea level rise at four local NOAA monitoring stations was averaged to get an average rate of sea level rise of 2.69 mm/year (http://tidesandcurrents.noaa.gov/sltrends/msltrendstable.htm) (Table 1).

Table 1. Historic local sea level rise trends.

Location	*Rate (mm/yr)*
Boston, MA	2.63
Woods Hole, MA	2.61
Nantucket, MA	2.95
Newport, RI	2.58
AVERAGE	**2.69**

According to the U.S. Army Corps guidelines, the global rate of sea level change is 1.7 mm/year. The rate of sea level rise is predicted for Cape Cod to be approximately 2.69 mm/year, which means that there is 0.99 mm/year increase in the local rate due to vertical land movement which will remain constant regardless of climate change. The 1.7 mm/year of sea level rise due to climate change will accelerate into the future according to curves developed by National Research Council (NRC) and shown below in Figure 1.

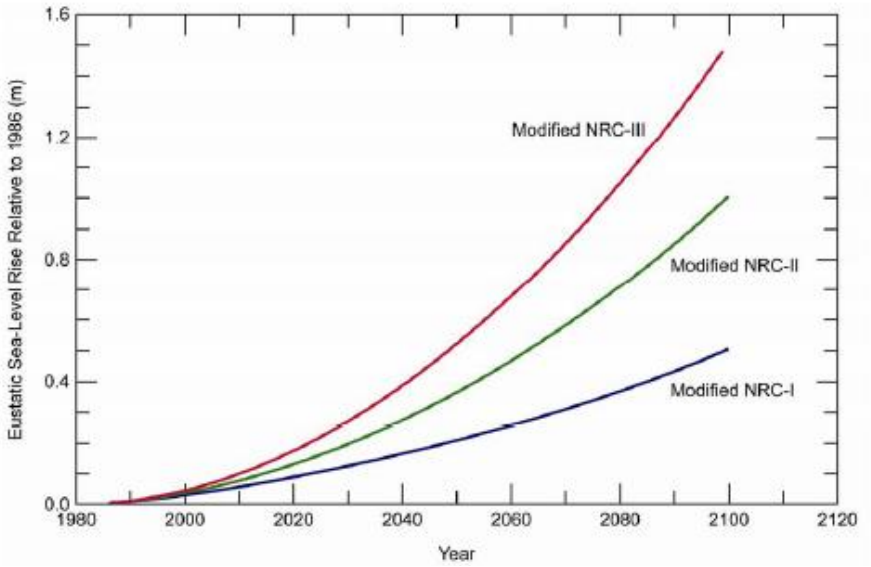


Figure 1. NRC sea level rise curves.

Using the equation for the NRC-II curve, which represents the projection of sea level rise between intermediate and extreme, Geosyntec calculated a sea level rise due to climate change for a 50 year time period of 0.4 meters. Adding in the sea level rise due to localized vertical land movement increases the estimated sea level rise to 0.45 meters (1.48 feet).

The 1.48 feet represents sea level rise that could occur in the Atlantic Ocean, which is downstream of the Project Site. To determine the amount of sea level rise at the Project Site, tide monitoring data from 5/13/2011 to 5/21/2011 was used to determine the relationship of high and low tides between the Atlantic Ocean and the Project Site. Geosyntec installed monitoring equipment at the downstream end of the culvert at the Project Site, but did not install any monitoring equipment at the mouth of Stage Harbor where the full tidal cycle from the Atlantic Ocean occurs. As a result, data was used from the closest NOAA monitoring station to the site (8447435), located in Chatham, MA; adjacent to the Tern Island Sanctuary (http://tidesandcurrents.noaa.gov/geo.shtml?location=8447435). Though the monitoring station is located behind a barrier island, tidal flow is relatively unrestricted and appears to be analogous to the Atlantic Ocean at the mouth of Stage Harbor.

As shown in Figure 2, the high tide elevations and low tide elevations at the two locations are linearly related during the time period. Therefore, the downstream boundary of the model will be adjusted to reflect sea level rise due to climate change by increasing the observed high tide elevations and low tide elevations. The correlation shown in Figure 2 indicates that a 1.48 foot rise in the Atlantic Ocean would cause a 1.38 foot rise in high tide and a .820 foot rise in low tide downstream of Stage Harbor Road. Therefore, high tides and low tides were increased in elevation, resulting in the downstream boundary condition shown in Figure 3.

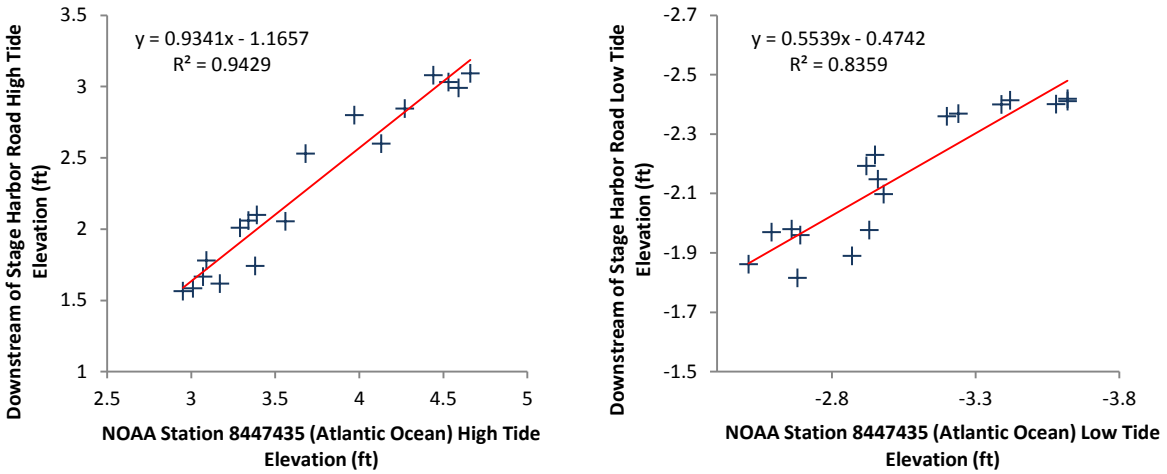


Figure 2. Relationship between high and low tides at NOAA Monitoring Station 8447435 (Atlantic Ocean) and 610 Stage Harbor Road.

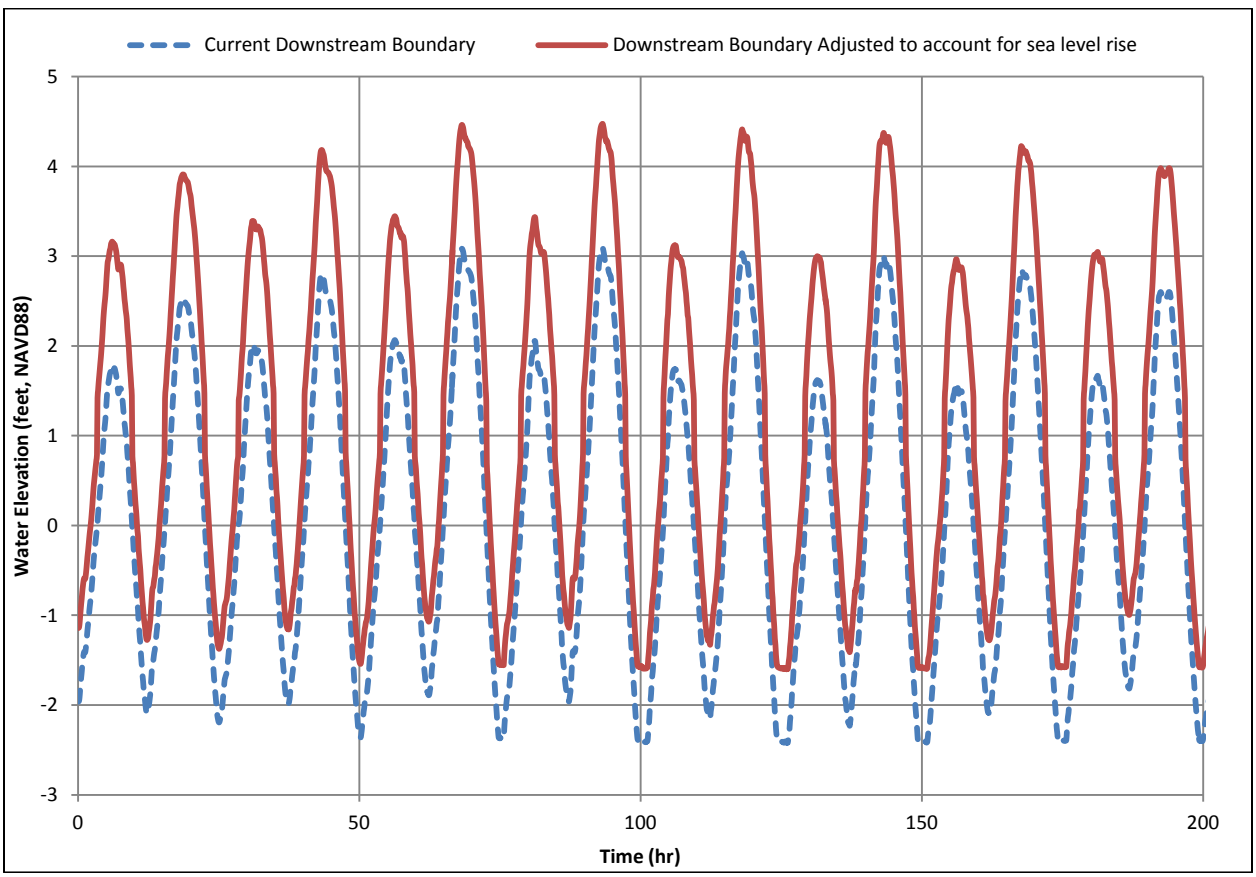


Figure 3. Downstream boundary condition adjusted for projected sea level rise.

By changing the downstream boundary in the model to the adjusted version shown in Figure 3, the maximum water surface elevations shows an increase from 3.09 feet to 4.47 feet and the minimum water surface shows an increase from -2.42 feet to -1.60 feet.

Appendix 2:

Selected HEC-RAS Model Output,

10’x6’ Box Culvert and 8’x6’ Box Culvert

10’x6’ Box Culvert Results

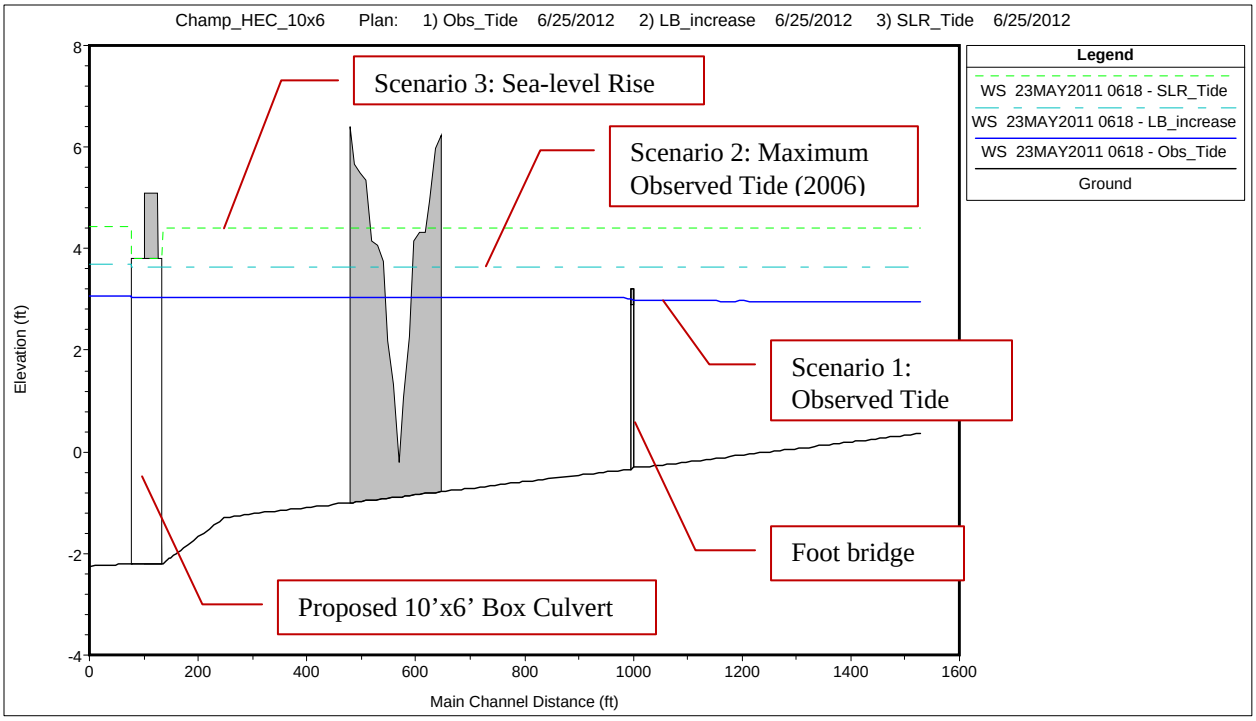


Figure 1. Water Surface Elevation profile along western stream reach.

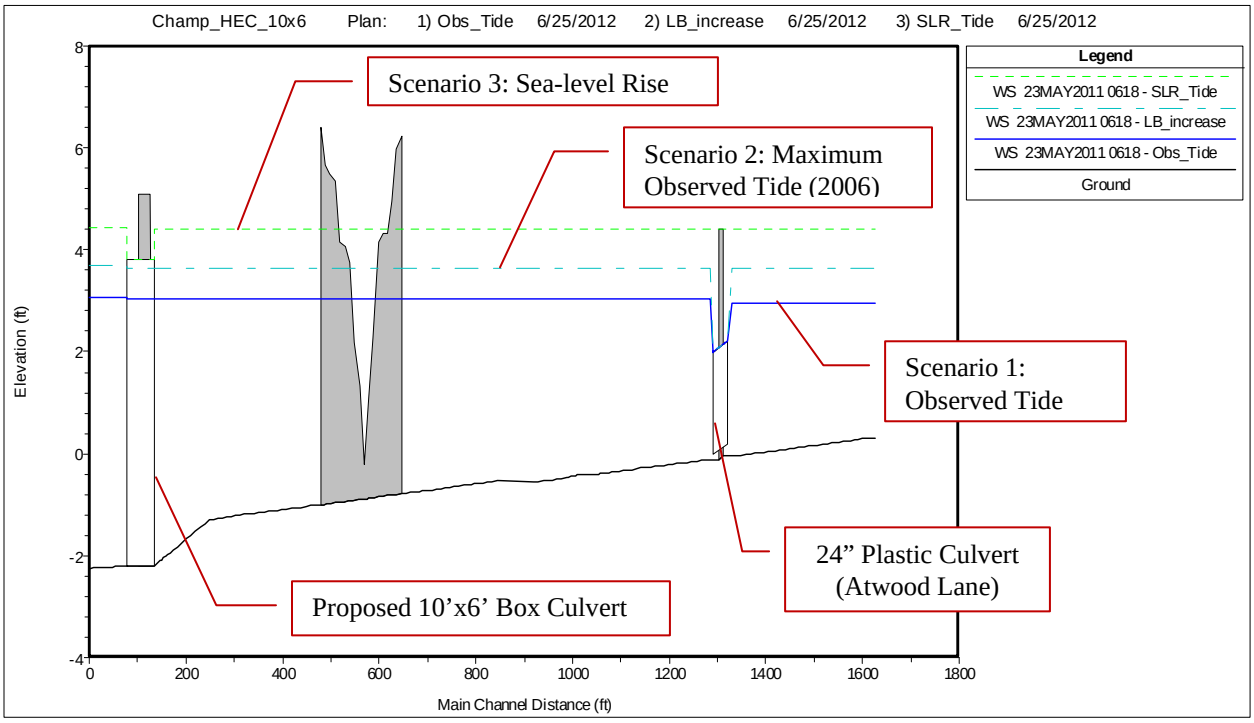
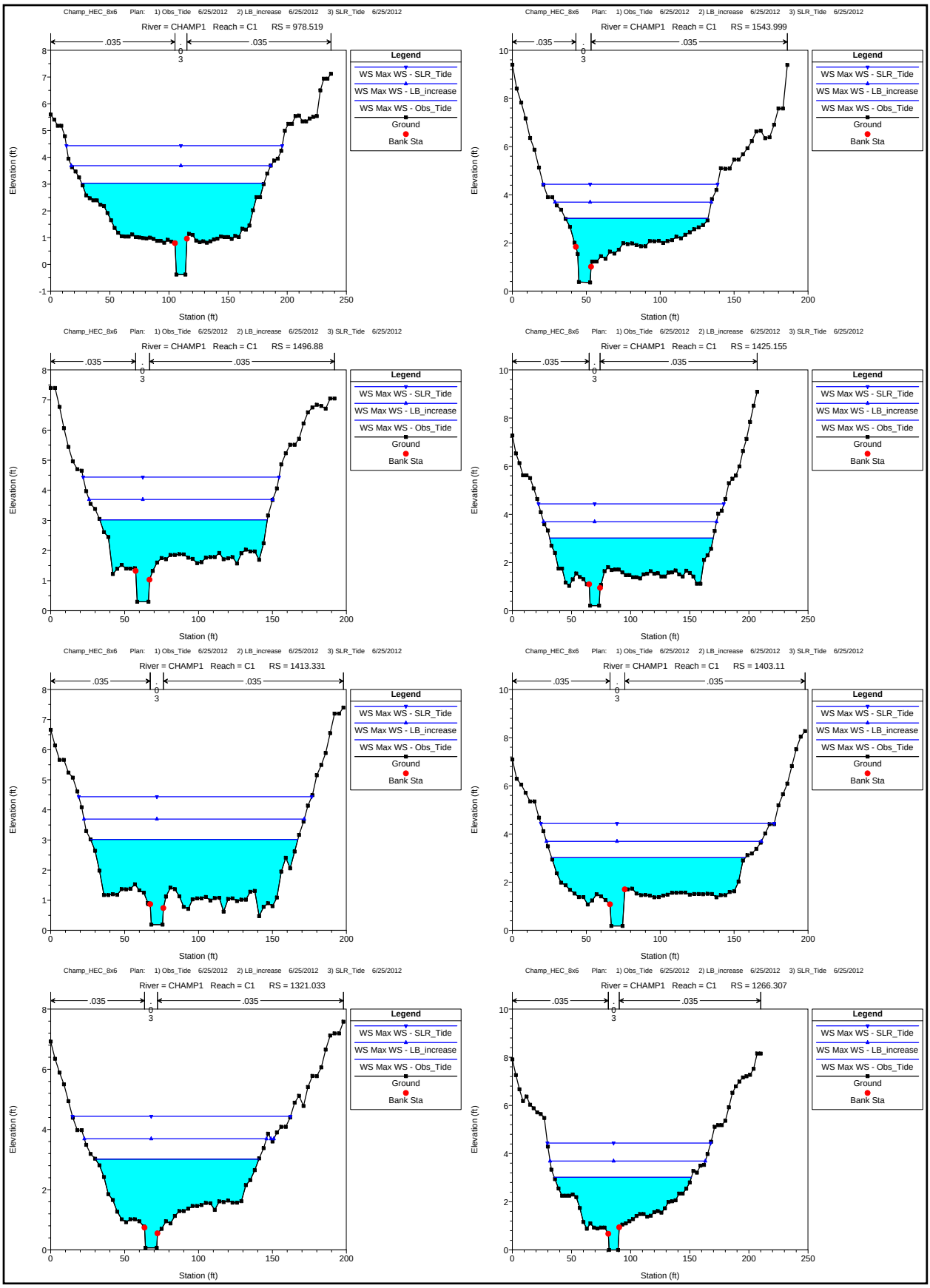


Figure 2. Water Surface Elevation profile, along eastern stream reach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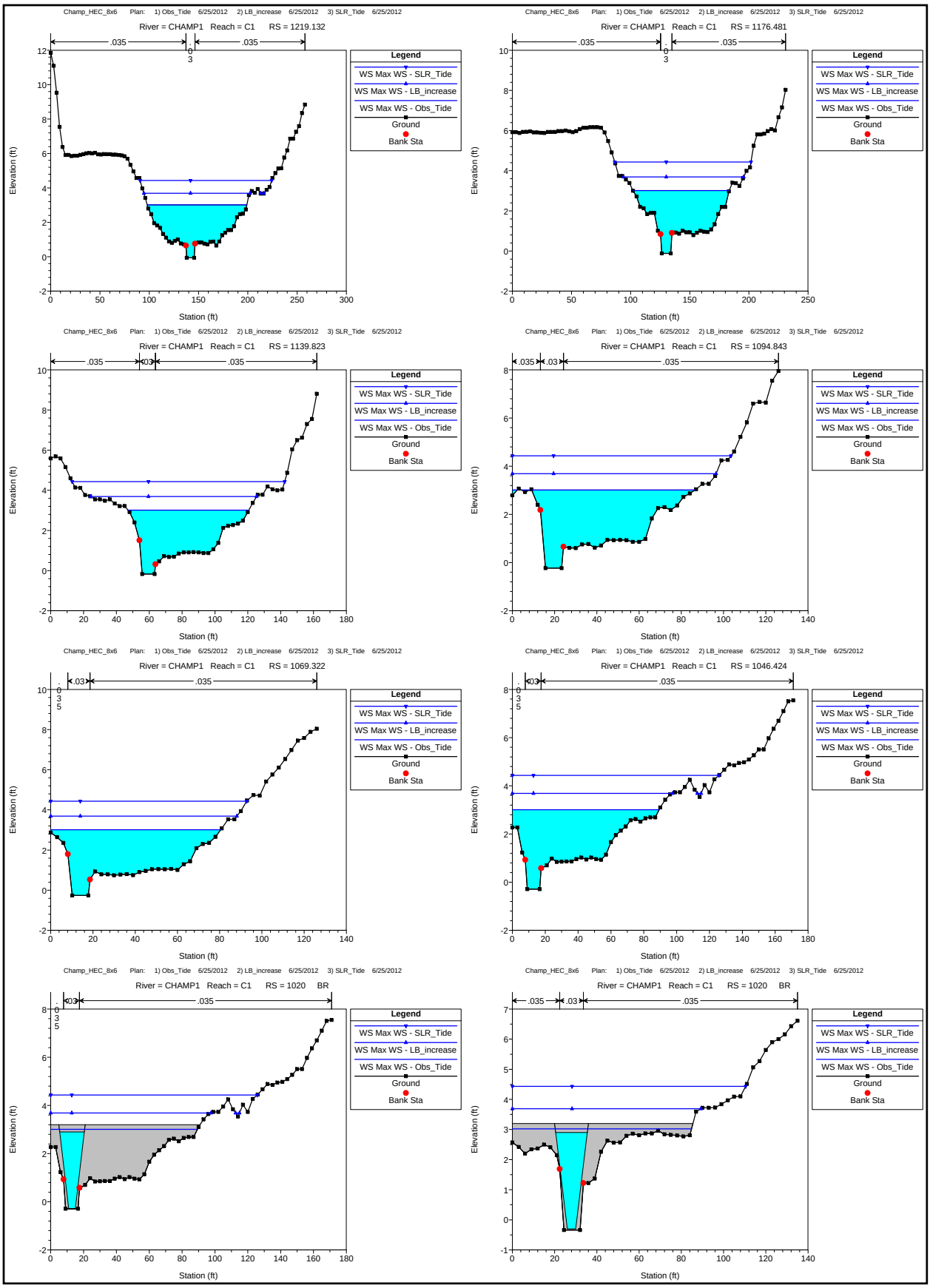
River = CHAMP1 Reach = C1 RS = 978.519
River = CHAMP1 Reach = C1 RS = 1543.999
River = CHAMP1 Reach = C1 RS = 1496.88
River = CHAMP1 Reach = C1 RS = 1425.155
River = CHAMP1 Reach = C1 RS = 1413.331
River = CHAMP1 Reach = C1 RS = 1403.11
River = CHAMP1 Reach = C1 RS = 1321.033
River = CHAMP1 Reach = C1 RS = 1266.307
.035
.035
Elevation (ft)
Station (ft)
Legend
WS Max WS - SLR_Tide
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta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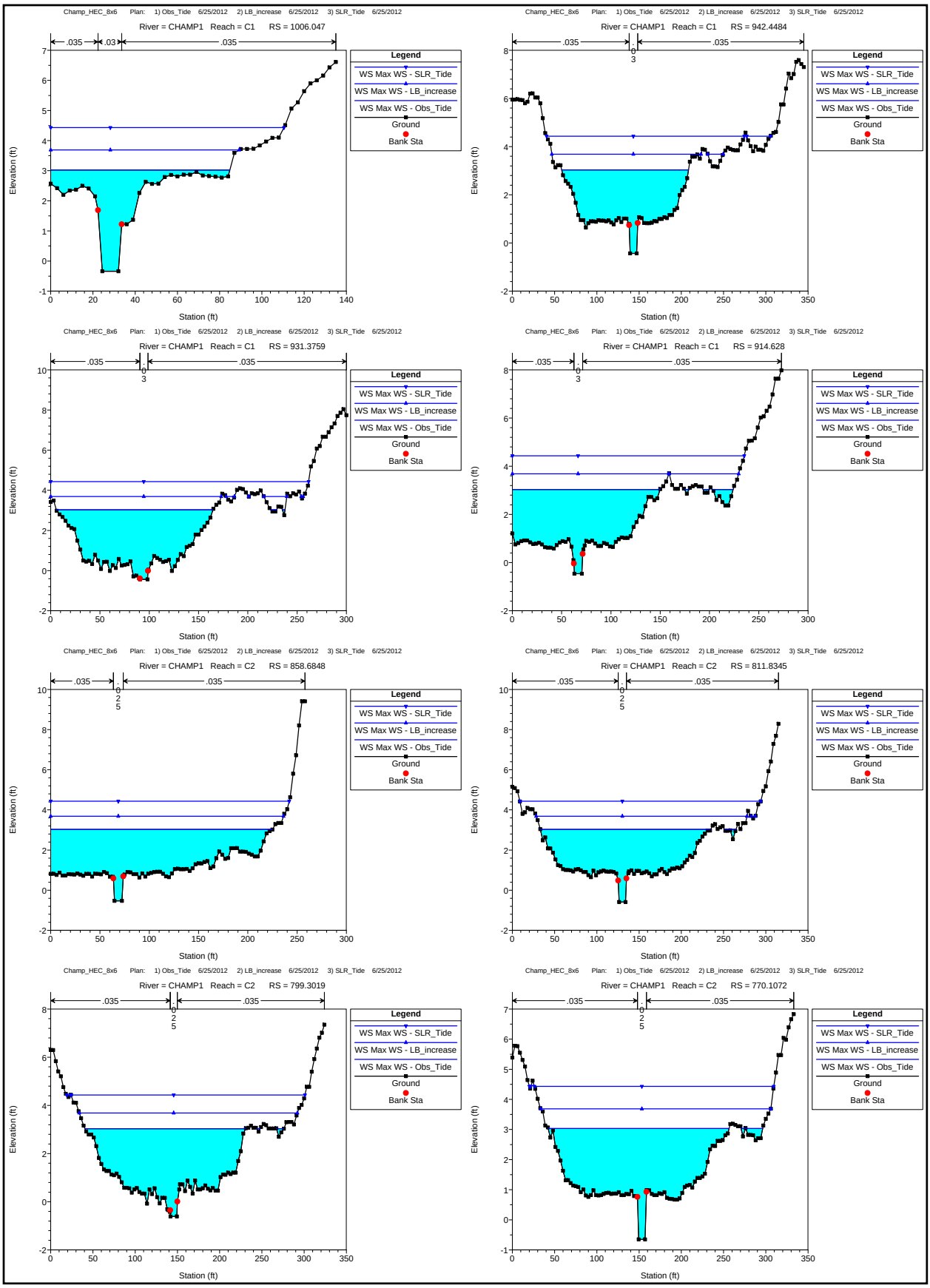
River = CHAMP1 Reach = C1 RS = 1094.843
River = CHAMP1 Reach = C1 RS = 1069.322
River = CHAMP1 Reach = C1 RS = 1046.424
River = CHAMP1 Reach = C1 RS = 1020 BR
River = CHAMP1 Reach = C1 RS = 1020 BR
.035
.03
Legend
WS Max WS - SLR_Tide
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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River = CHAMP1 Reach = C1 RS = 931.3759
River = CHAMP1 Reach = C1 RS = 914.628
River = CHAMP1 Reach = C2 RS = 858.6848
River = CHAMP1 Reach = C2 RS = 811.8345
River = CHAMP1 Reach = C2 RS = 799.3019
River = CHAMP1 Reach = C2 RS = 770.1072
.035
.03
Legend
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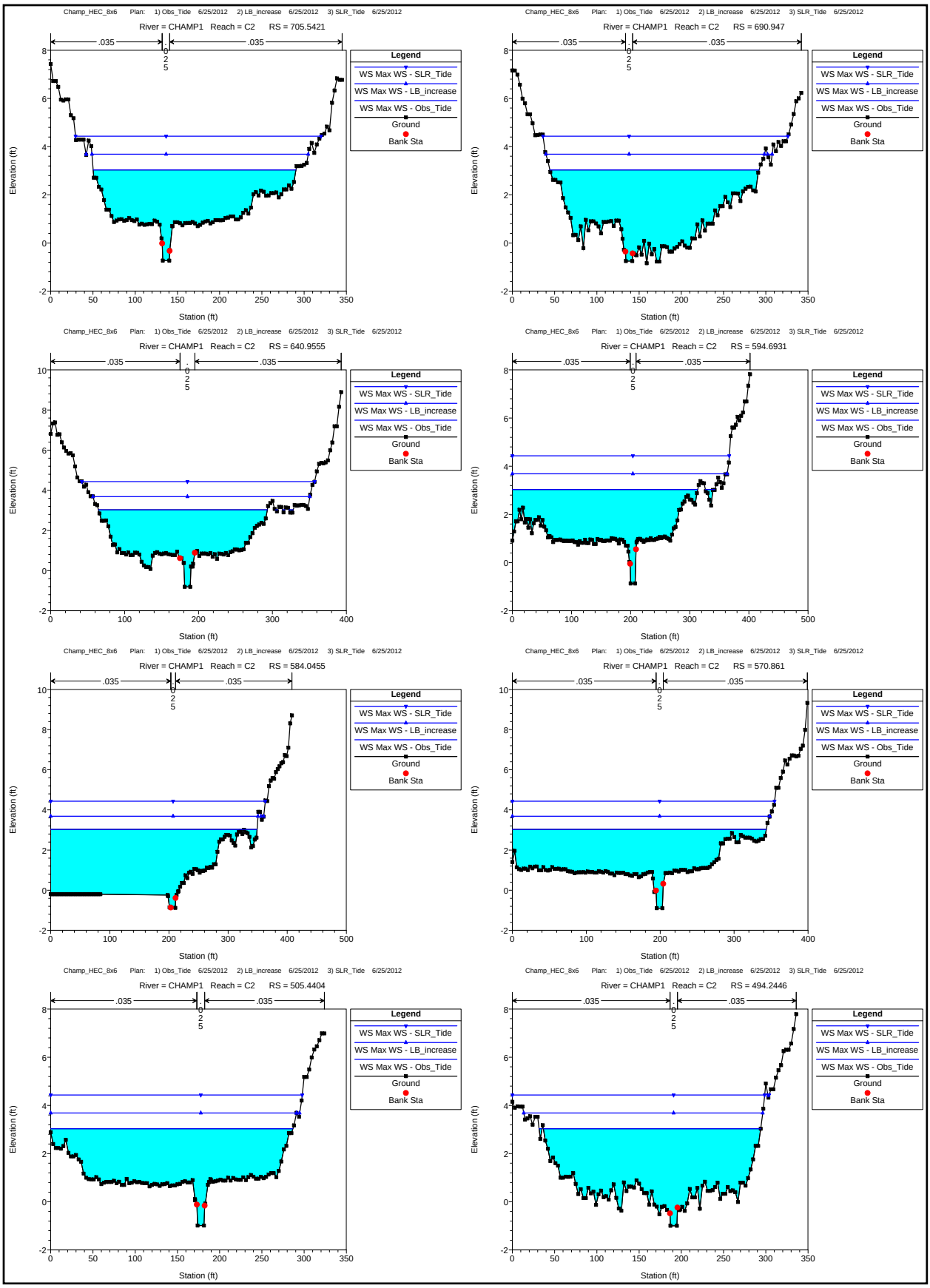
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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River = CHAMP1 Reach = C2 RS = 690.947
River = CHAMP1 Reach = C2 RS = 640.9555
River = CHAMP1 Reach = C2 RS = 594.6931
River = CHAMP1 Reach = C2 RS = 584.0455
River = CHAMP1 Reach = C2 RS = 570.861
River = CHAMP1 Reach = C2 RS = 505.4404
River = CHAMP1 Reach = C2 RS = 494.2446
.035
.025
.035
Legend
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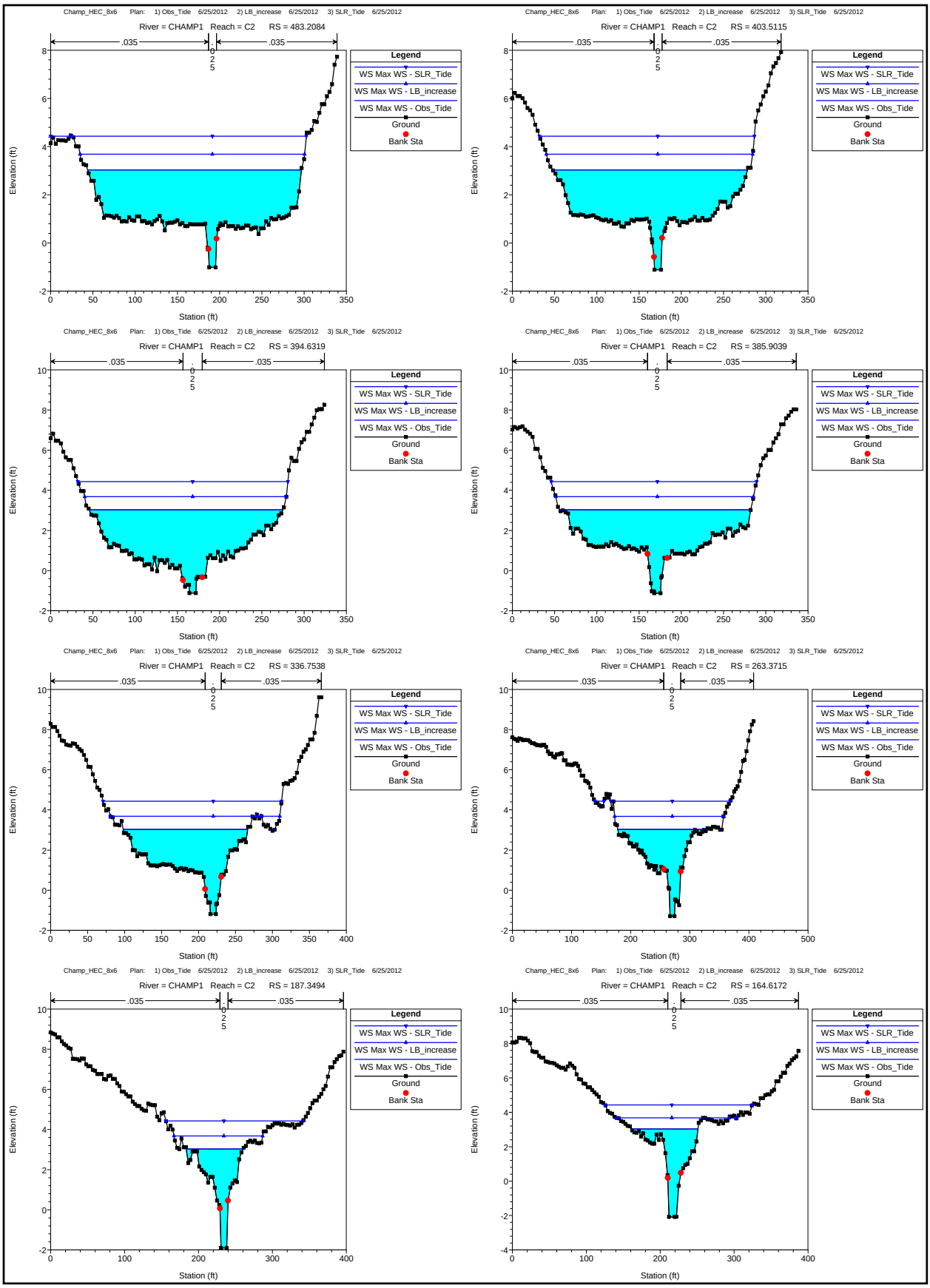
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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River = CHAMP1 Reach = C2 RS = 263.3715
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.025
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Legend
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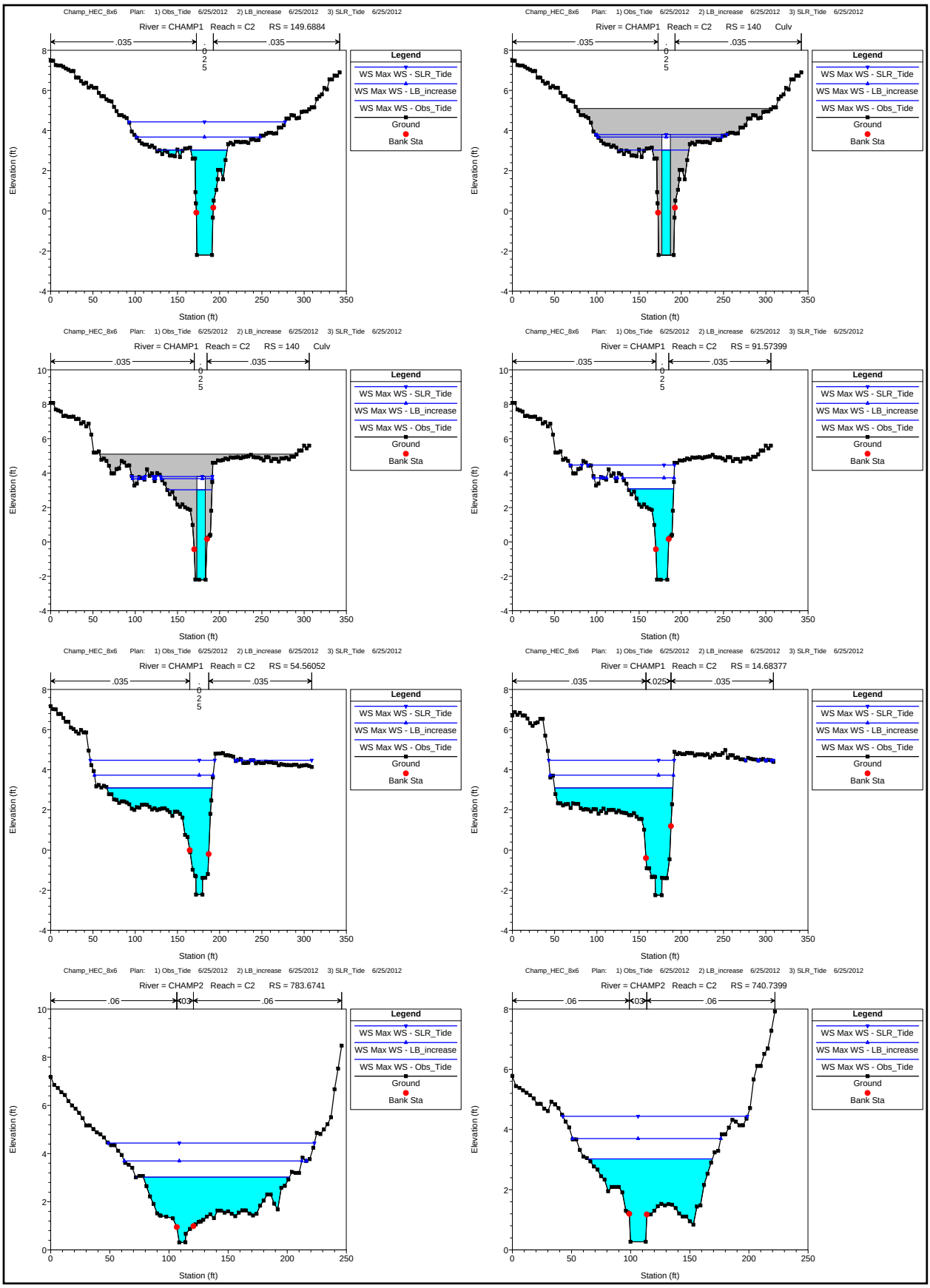
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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.025
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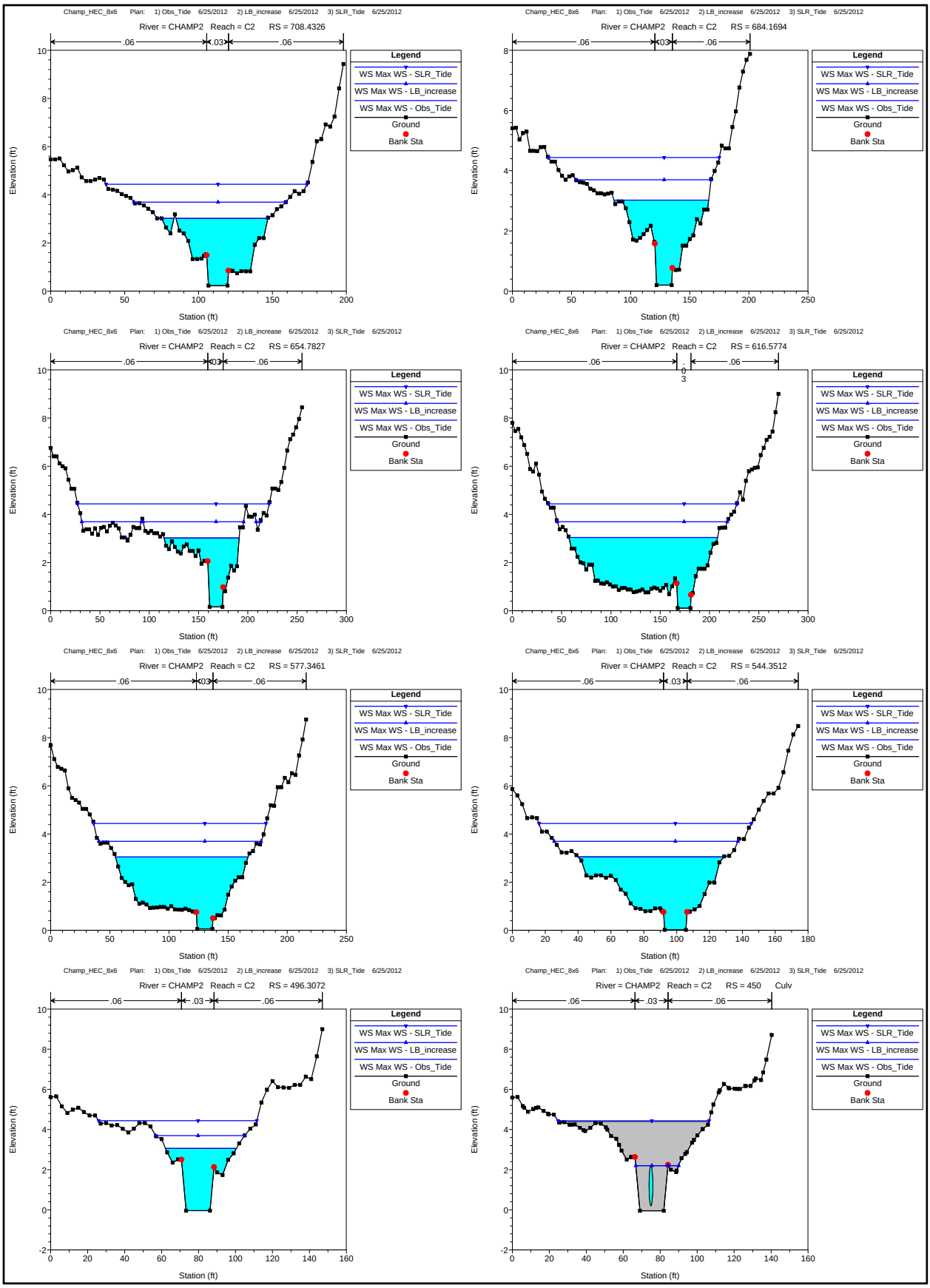
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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.06
.03
Legend
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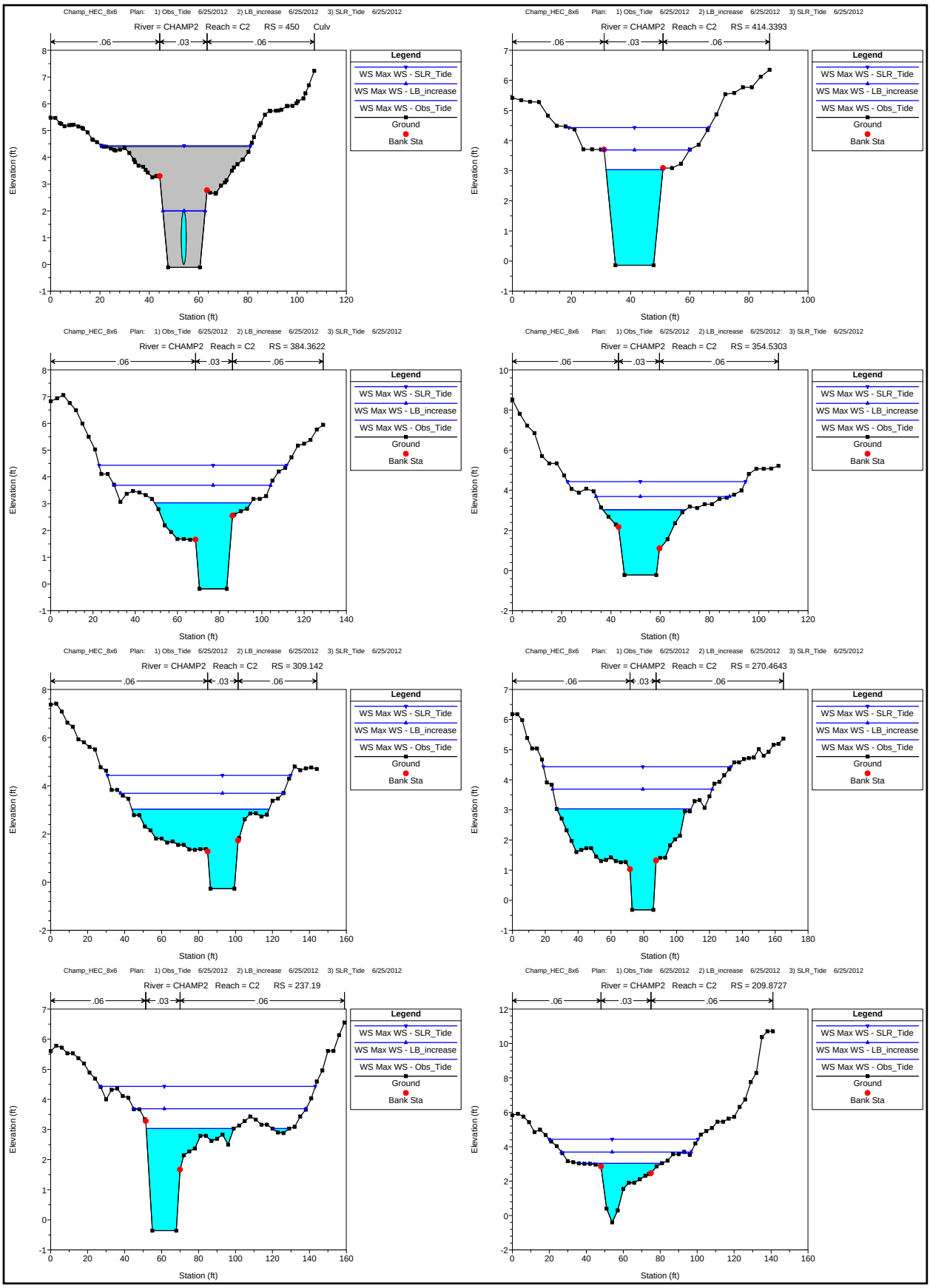
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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.03
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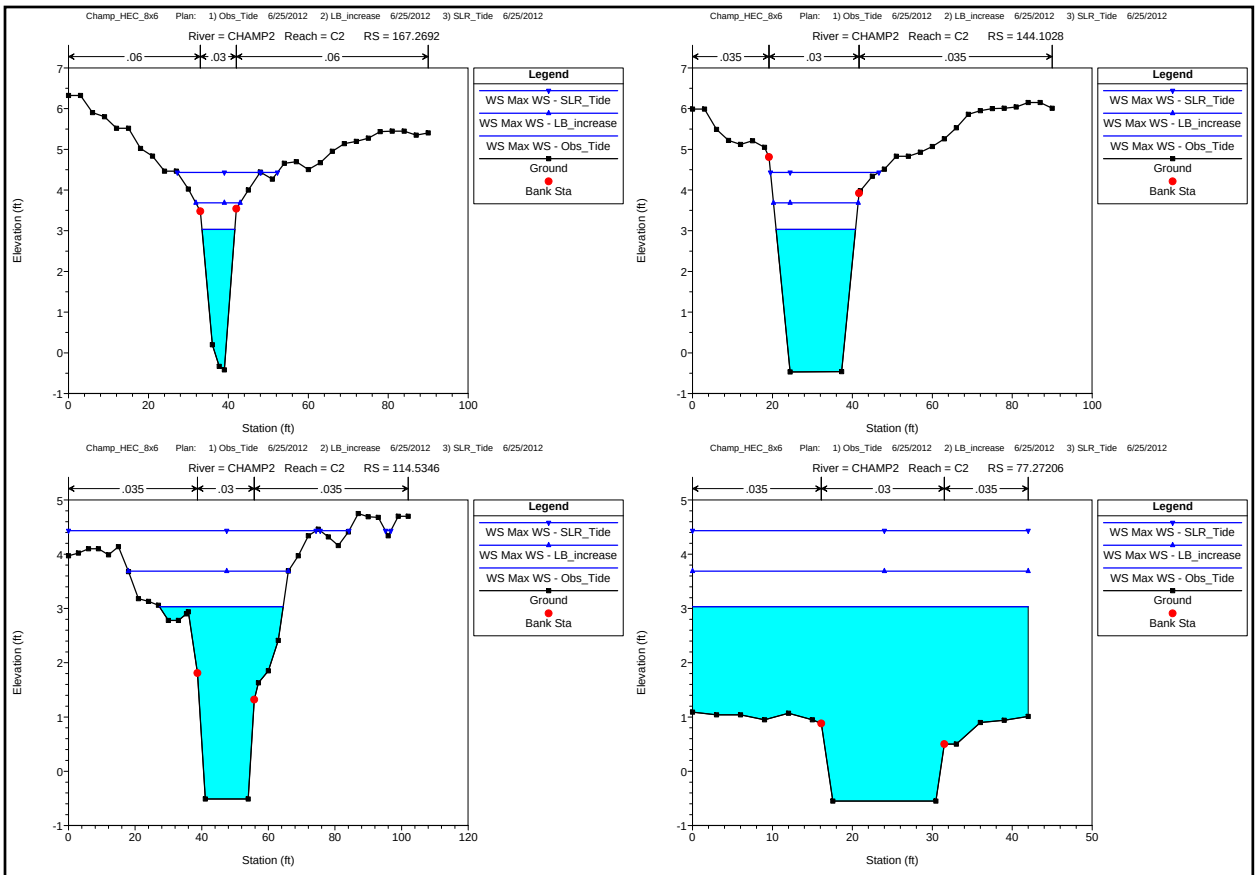
WS Max WS - LB_increase
WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)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WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)
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WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)
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WS Max WS - Obs_Tide
Ground
Bank Sta
Elevation (ft)
Station (ft)
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Ground
Bank Sta
Elevation (ft)
Station (ft)

8’x6’ Box Culvert Results

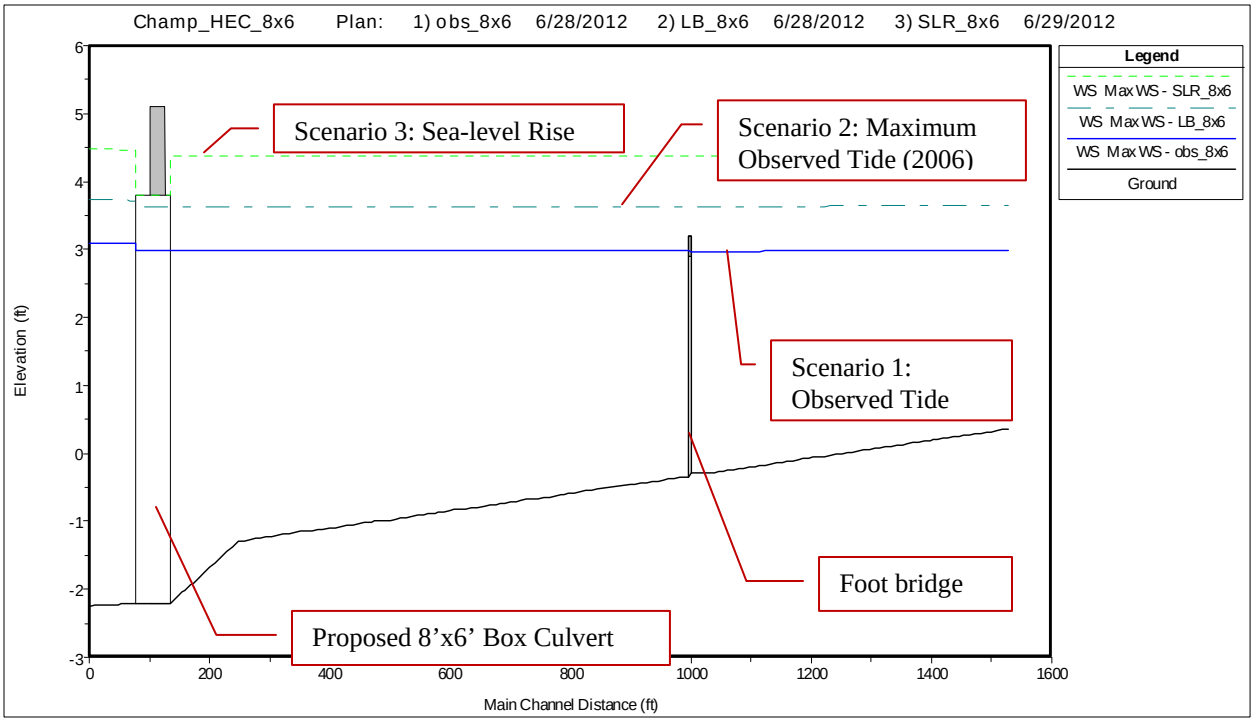


Figure 1. Water Surface Elevation profile along western stream reach.

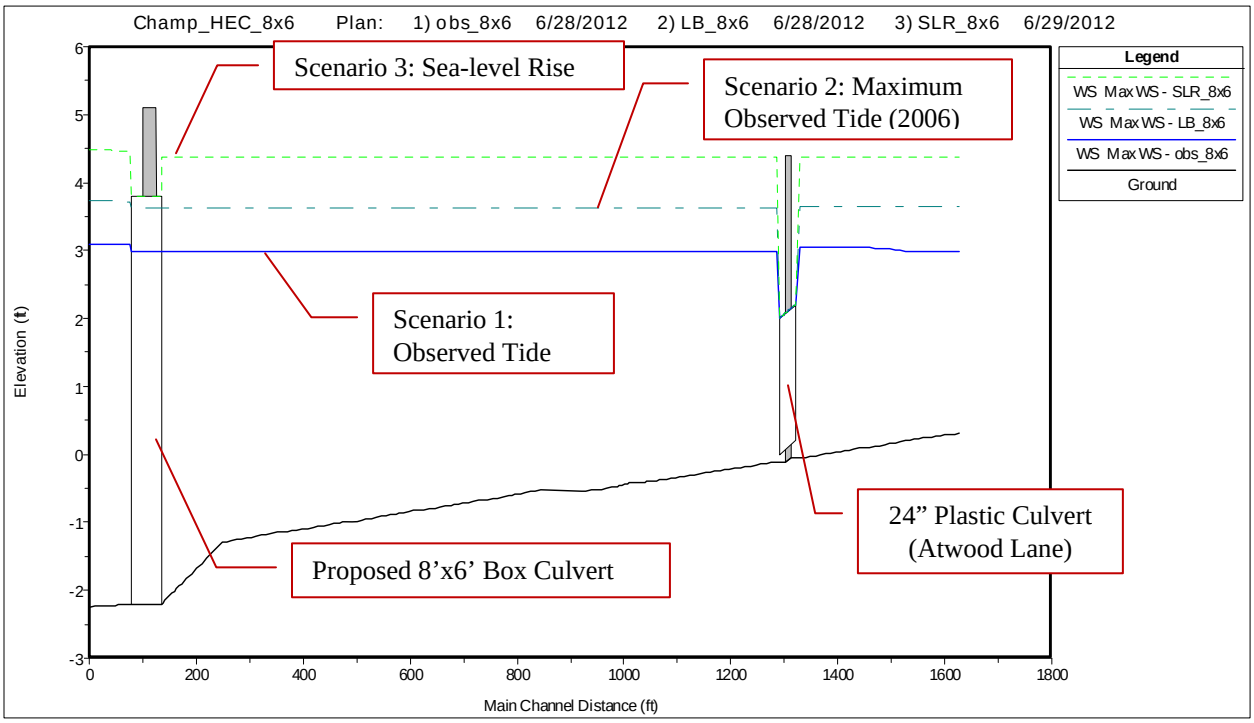
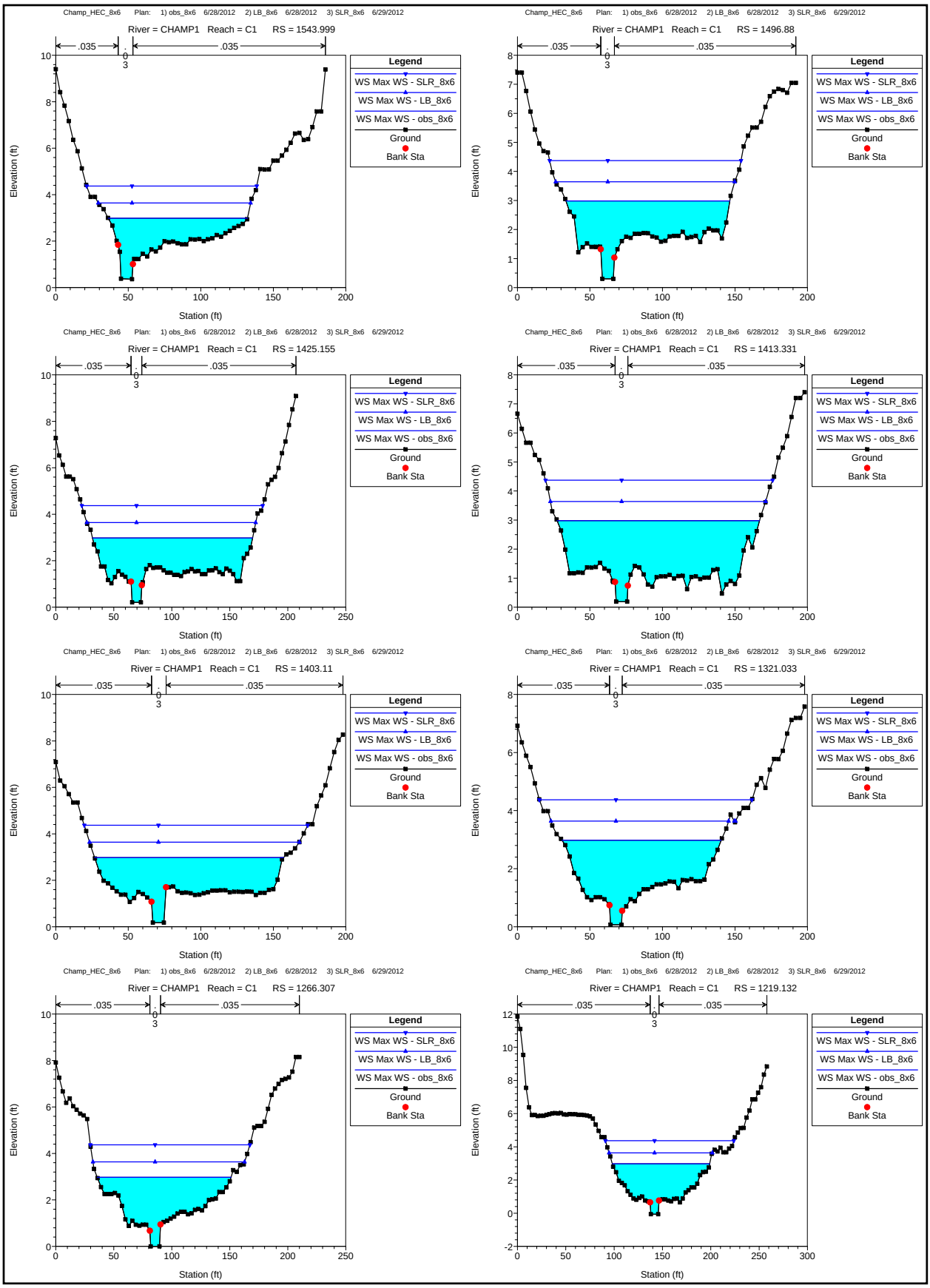


Figure 2. Water Surface Elevation profile, along eastern stream reach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River = CHAMP1 Reach = C1 RS = 1321.033
River = CHAMP1 Reach = C1 RS = 1266.307
River = CHAMP1 Reach = C1 RS = 1219.132
.035
.03
.035
Legend
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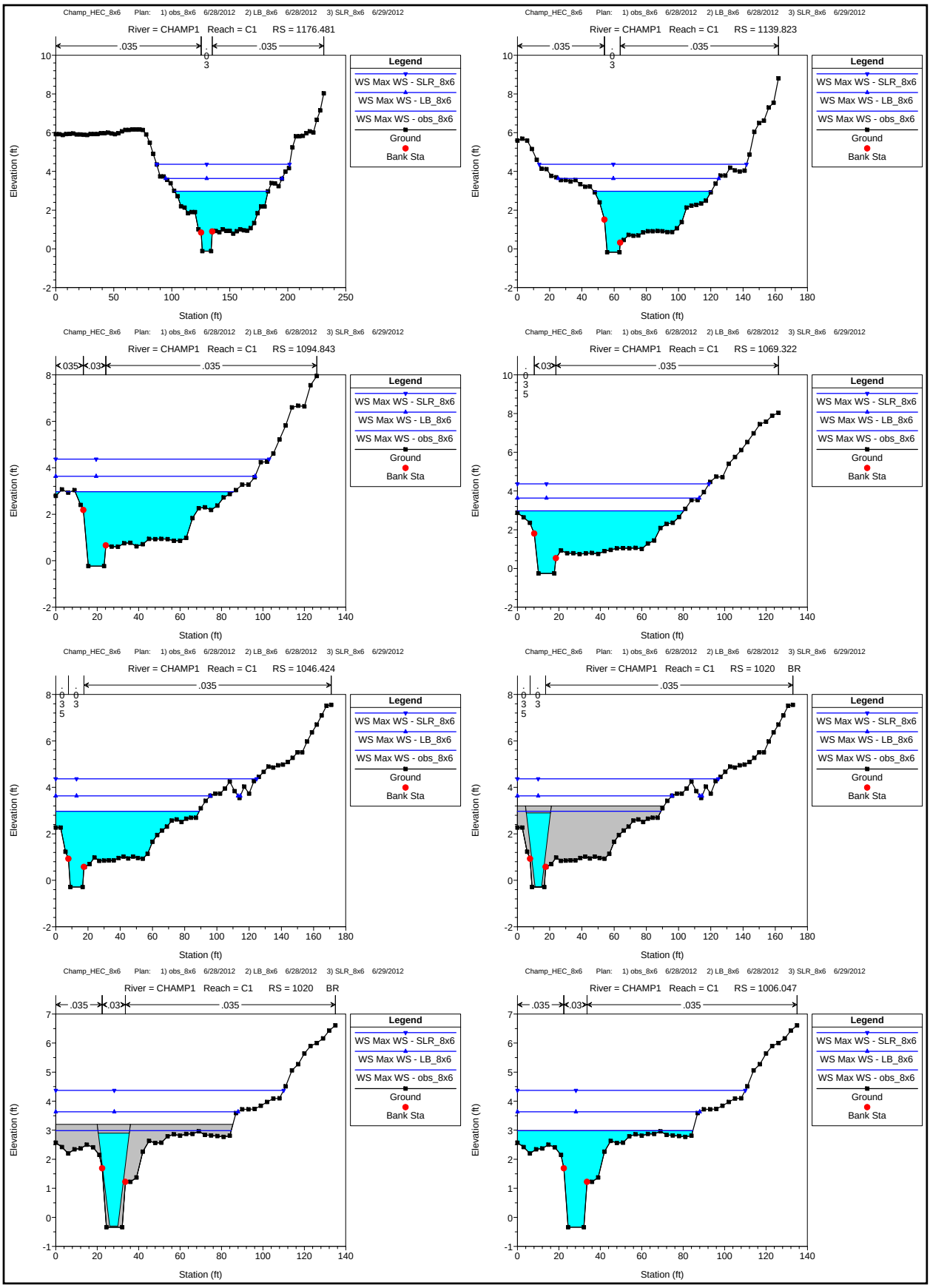
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)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River = CHAMP1 Reach = C1 RS = 1020 BR
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River = CHAMP1 Reach = C1 RS = 1006.047
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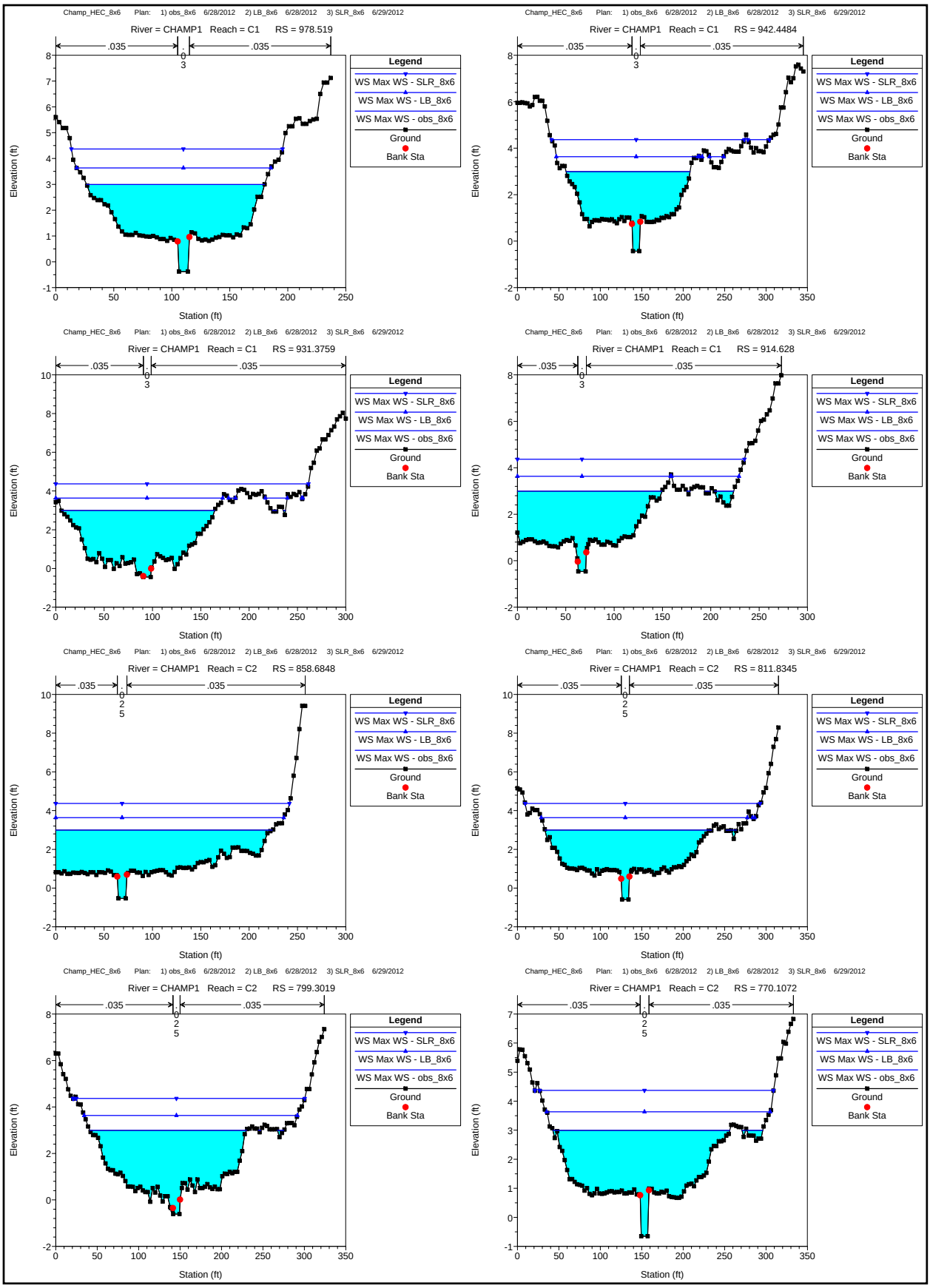
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)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River = CHAMP1 Reach = C2 RS = 858.6848
River = CHAMP1 Reach = C2 RS = 811.8345
River = CHAMP1 Reach = C2 RS = 799.3019
River = CHAMP1 Reach = C2 RS = 770.1072
.035
.03
.025
Legend
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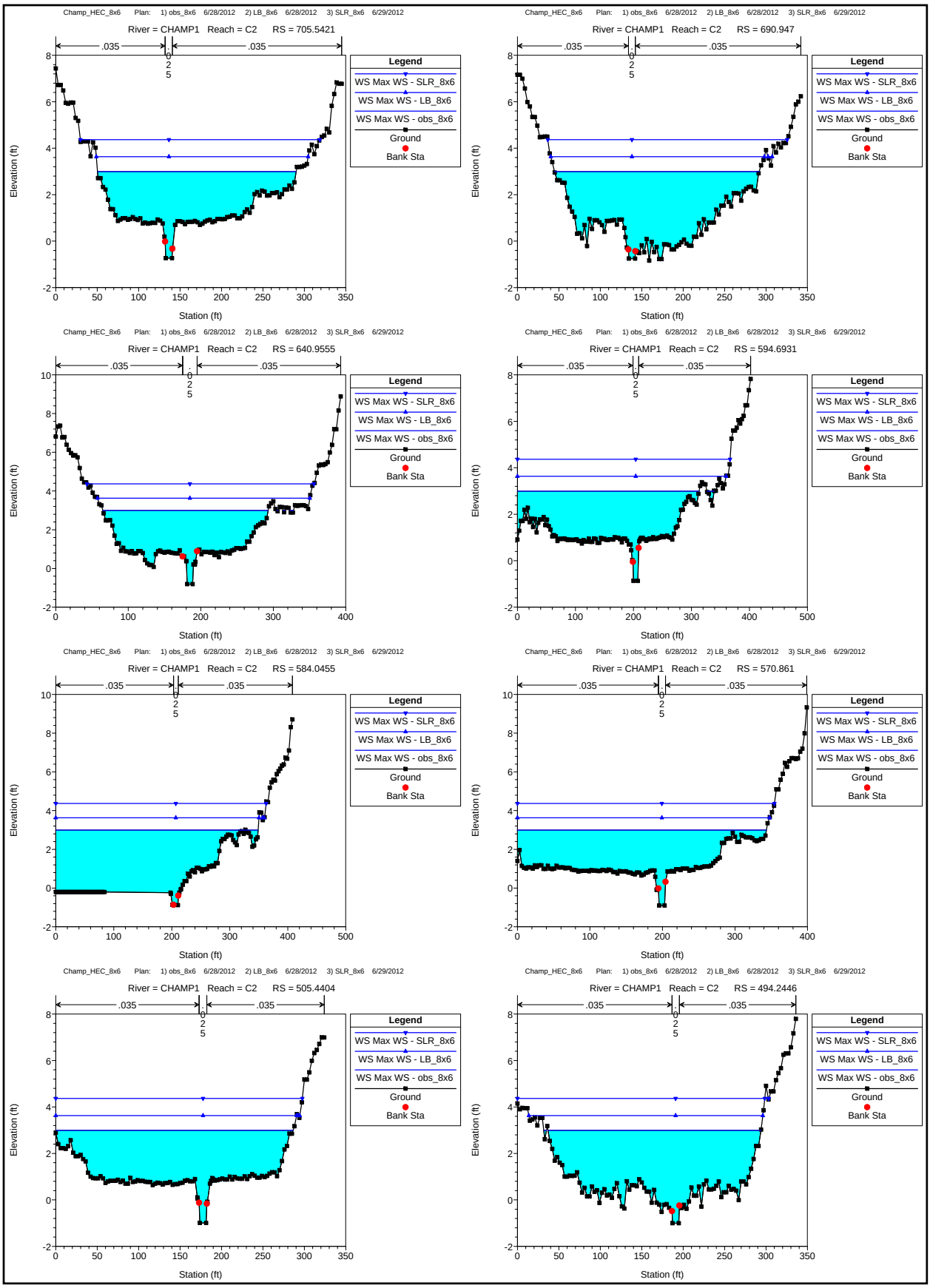
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)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River = CHAMP1 Reach = C2 RS = 494.2446
.035
.025
.035
Legend
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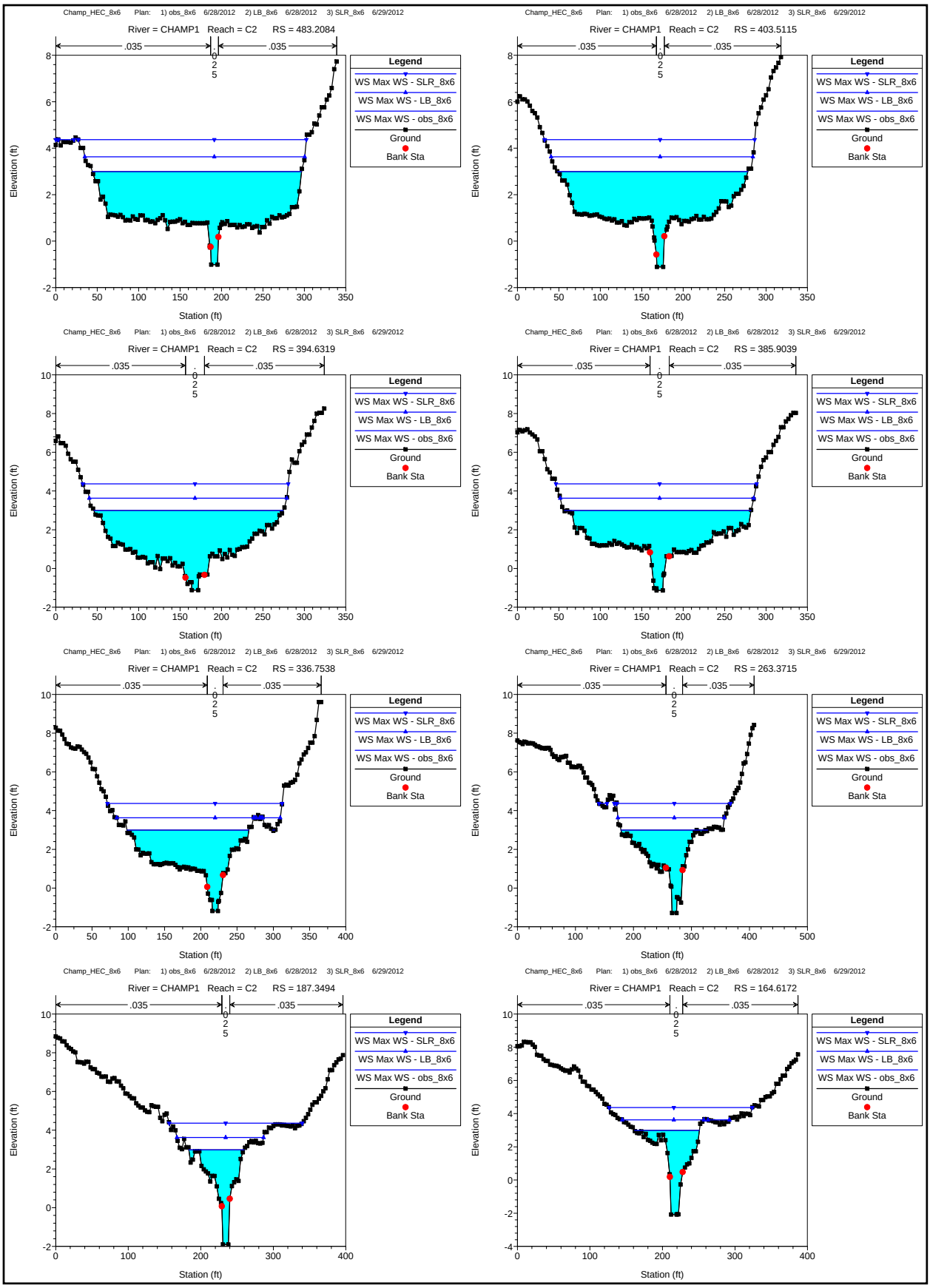
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)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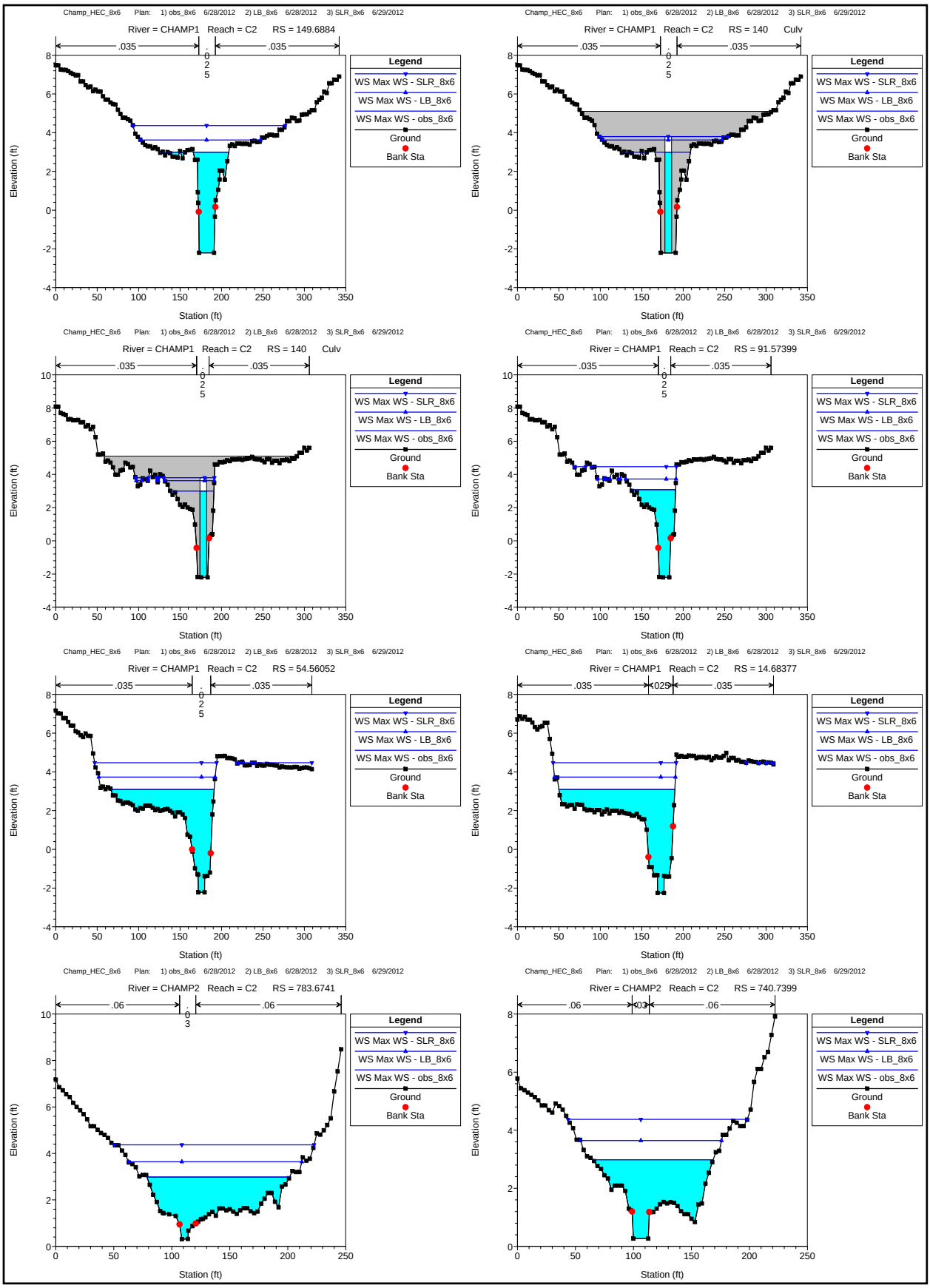
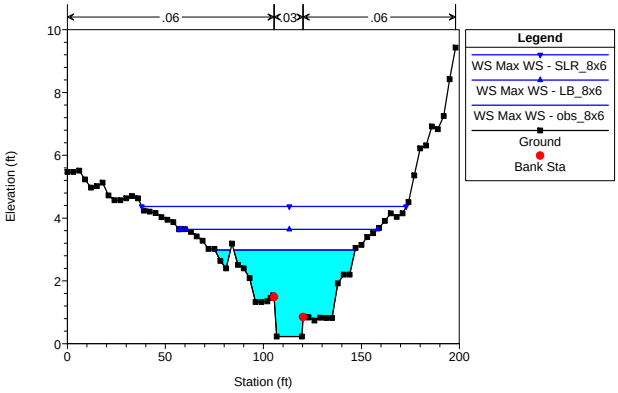
River = CHAMP1 Reach = C2 RS = 263.3715
River = CHAMP1 Reach = C2 RS = 187.3494
River = CHAMP1 Reach = C2 RS = 164.6172
.035
.025
.035
Legend
WS Max WS - SLR_8x6
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)


Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012
River = CHAMP1 Reach = C2 RS = 149.6884
River = CHAMP1 Reach = C2 RS = 140 Culv
River = CHAMP1 Reach = C2 RS = 140 Culv
River = CHAMP1 Reach = C2 RS = 91.57399
River = CHAMP1 Reach = C2 RS = 54.56052
River = CHAMP1 Reach = C2 RS = 14.68377
River = CHAMP2 Reach = C2 RS = 783.6741
River = CHAMP2 Reach = C2 RS = 740.7399
.035
.025
.06
.03
Legend
WS Max WS - SLR_8x6
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)

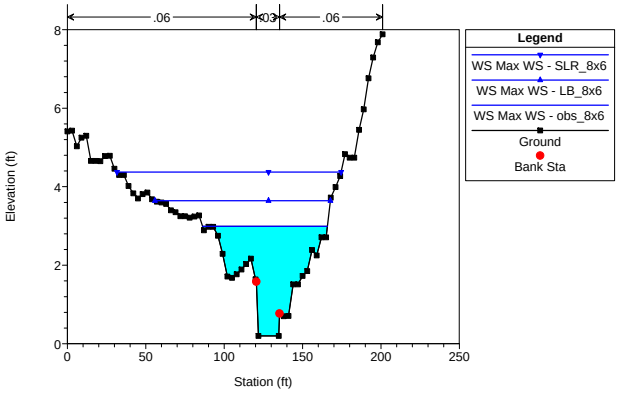
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

River = CHAMP2 Reach = C2 RS = 708.4326



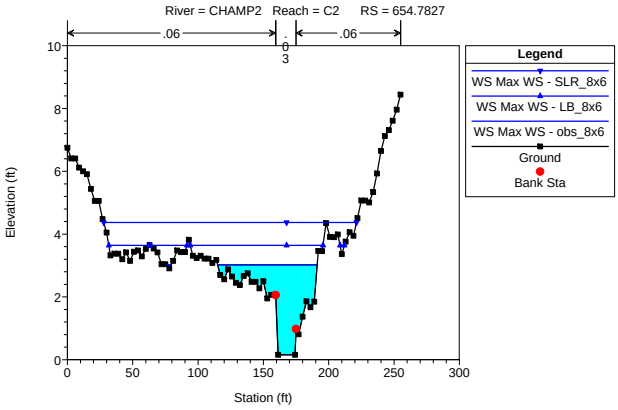
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

River = CHAMP2 Reach = C2 RS = 684.1694



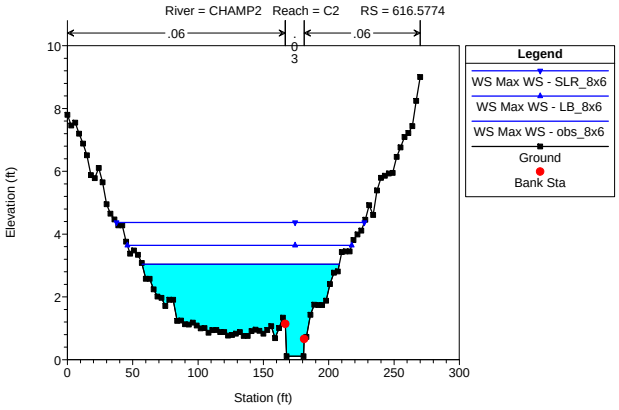
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

River = CHAMP2 Reach = C2 RS = 654.7827



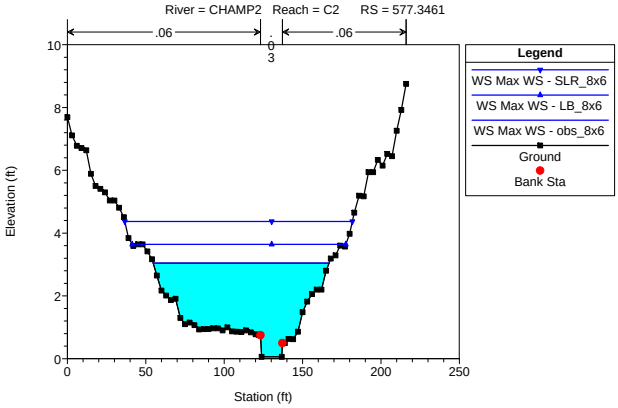
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

River = CHAMP2 Reach = C2 RS = 616.5774



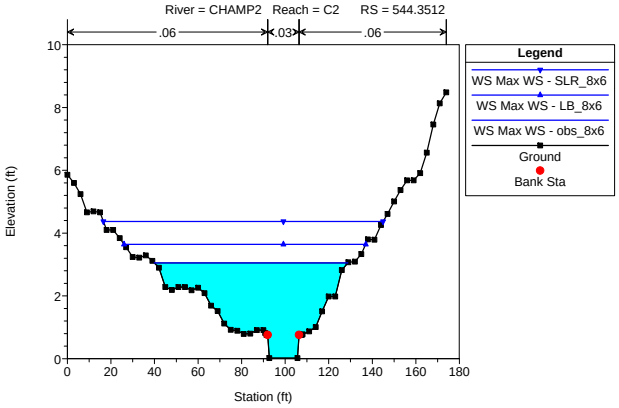
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

River = CHAMP2 Reach = C2 RS = 577.3461



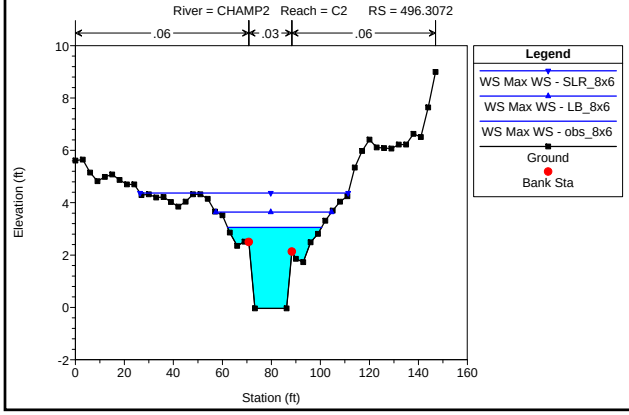
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

River = CHAMP2 Reach = C2 RS = 544.3512



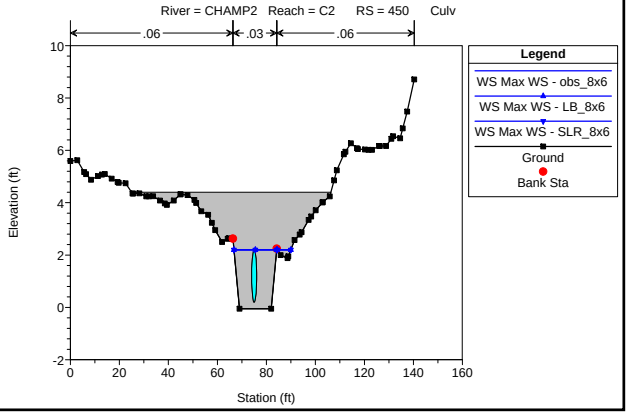
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

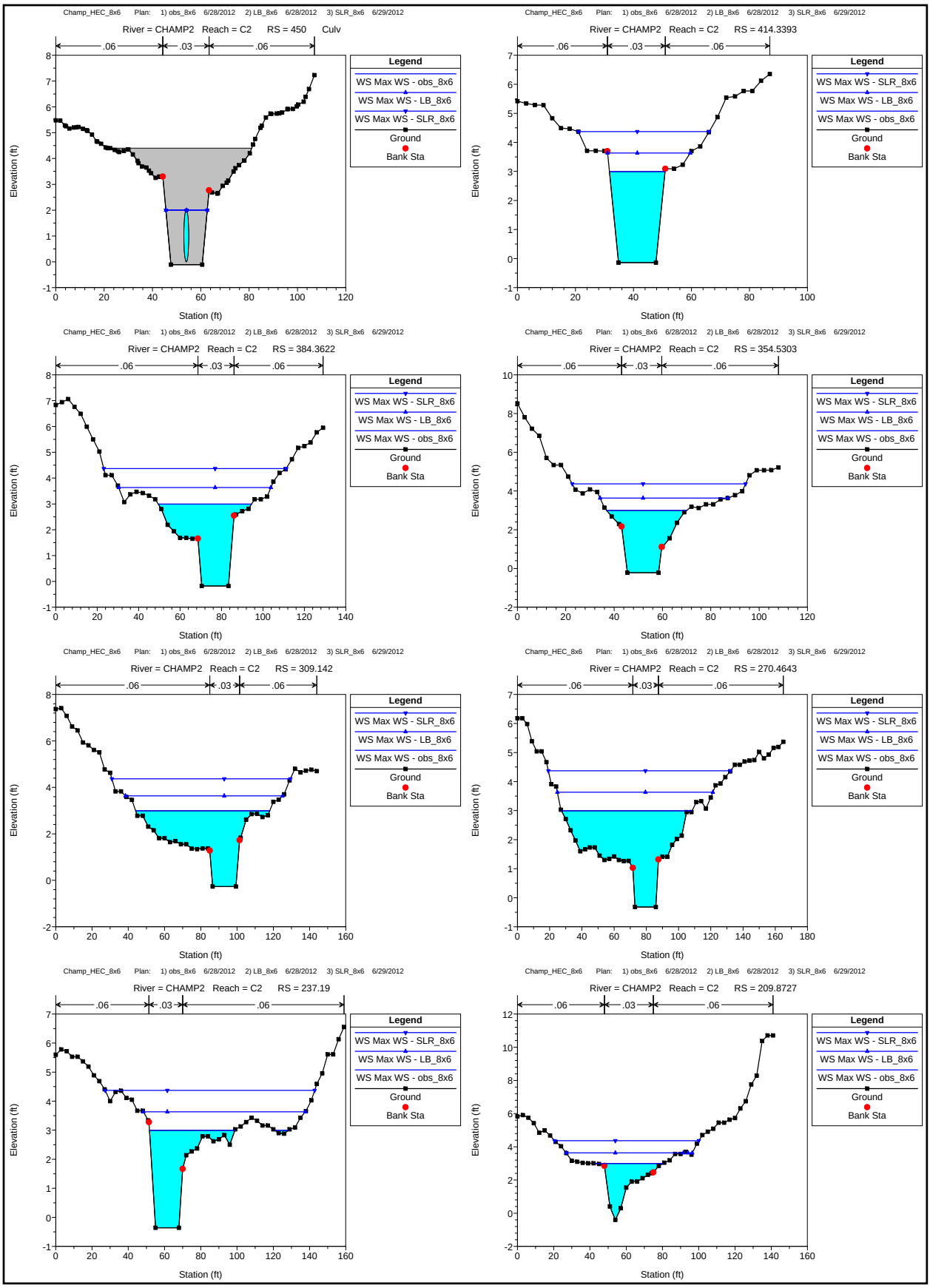
River = CHAMP2 Reach = C2 RS = 496.3072

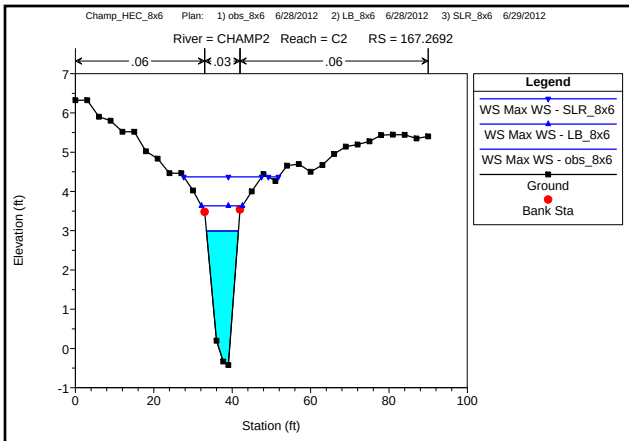


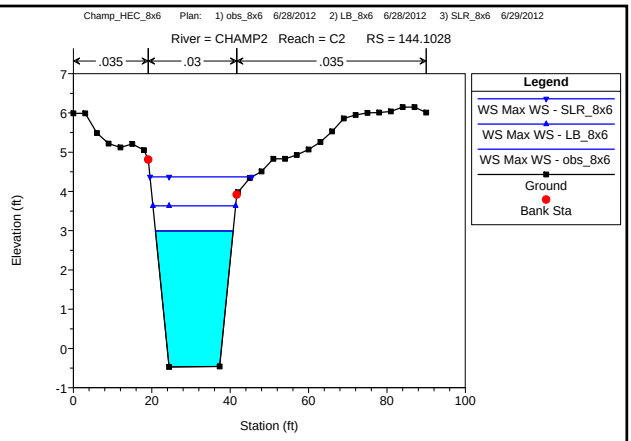
Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012

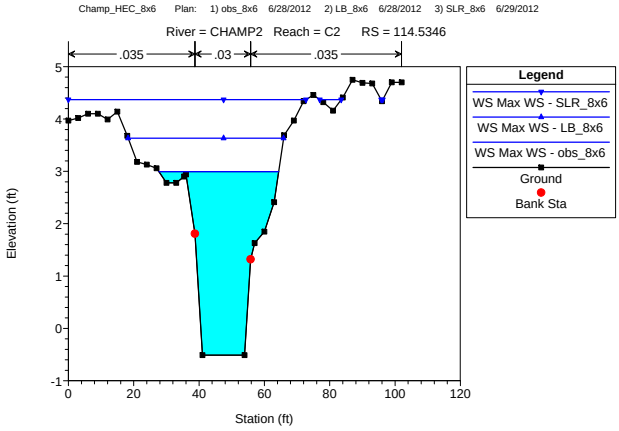
River = CHAMP2 Reach = C2 RS = 450 Culv

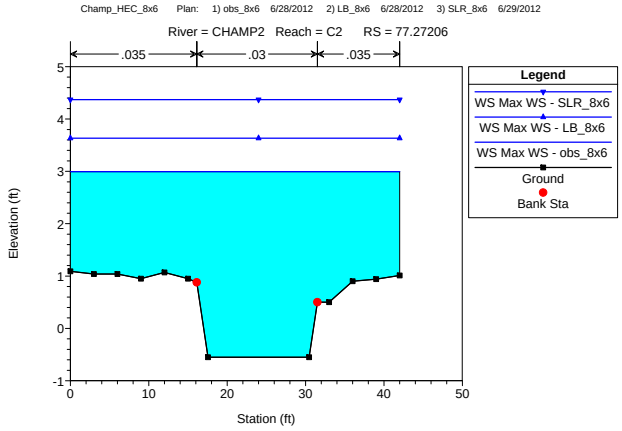



Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012
River = CHAMP2 Reach = C2 RS = 450 Culv
River = CHAMP2 Reach = C2 RS = 414.3393
River = CHAMP2 Reach = C2 RS = 384.3622
River = CHAMP2 Reach = C2 RS = 354.5303
River = CHAMP2 Reach = C2 RS = 309.142
River = CHAMP2 Reach = C2 RS = 270.4643
River = CHAMP2 Reach = C2 RS = 237.19
River = CHAMP2 Reach = C2 RS = 209.8727
.06
.03
Legend
WS Max WS - obs_8x6
WS Max WS - LB_8x6
WS Max WS - SLR_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)


Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012
River = CHAMP2 Reach = C2 RS = 167.2692
.06
.03
.06
Legend
WS Max WS - SLR_8x6
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)


Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012
River = CHAMP2 Reach = C2 RS = 144.1028
.035
.03
.035
Legend
WS Max WS - SLR_8x6
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)


Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012
River = CHAMP2 Reach = C2 RS = 114.5346
.035
.03
.035
Legend
WS Max WS - SLR_8x6
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)


Champ_HEC_8x6 Plan: 1) obs_8x6 6/28/2012 2) LB_8x6 6/28/2012 3) SLR_8x6 6/29/2012
River = CHAMP2 Reach = C2 RS = 77.27206
.035
.03
.035
Legend
WS Max WS - SLR_8x6
WS Max WS - LB_8x6
WS Max WS - obs_8x6
Ground
Bank Sta
Elevation (ft)
Station (ft)