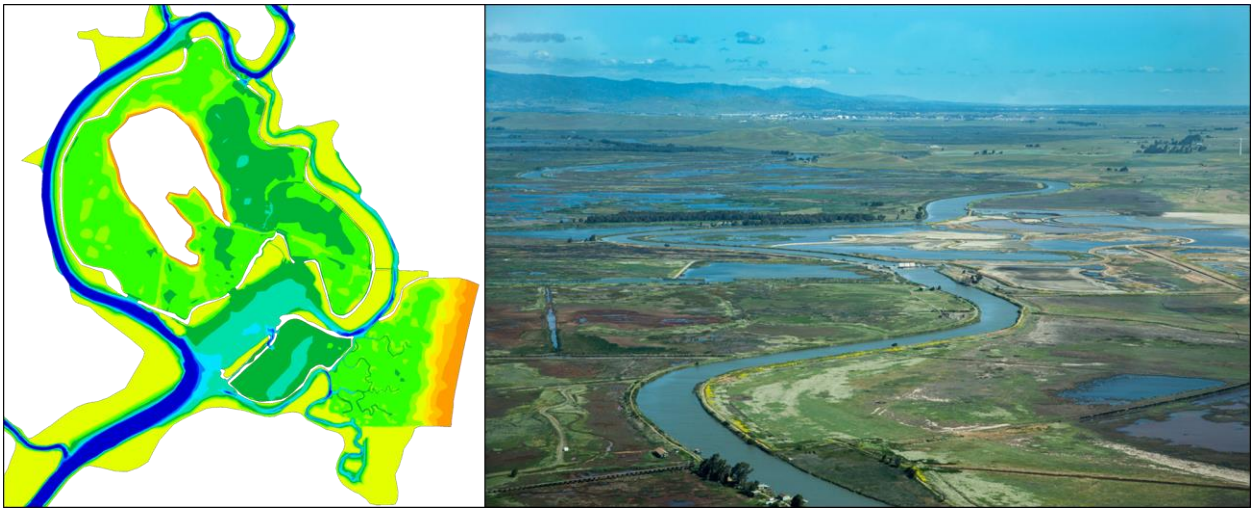
RMA RESOURCE MANAGEMENT ASSOCIATES
WATER RESOURCES ENGINEERING

Modeling of Local and Regional Impacts of the Proposed Arnold and Bradmoor Island Tidal Marsh Restorations, Suisun Marsh, California



TECHNICAL MEMORANDUM

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EXECUTIVE SUMMARY

The RMA Bay-Delta numerical model for flow and water quality was applied to evaluate local and regional impacts of the proposed 490-acre Bradmoor Island (Bradmoor) and 180-acre Arnold Slough (Arnold) tidal marsh restoration projects.

Initial screening simulations were performed to select a preferred alternative for Arnold. Final simulations were performed with combined restoration of Arnold and Bradmoor Island, utilizing the final Bradmoor Island alternative selected during previous modeling efforts by DWR.

The final Arnold alternative included lowering levees to marsh plain elevation, three breaches to external sloughs, dredging of some existing interior channels and filling of borrow ditches adjacent to existing levees. The selected Bradmoor Island alternative included five external breaches and lowering of two internal levees.

The final analysis was performed for the dry/critically dry period of January through December of 2013.

Hydrodynamic impacts included increased velocities and tidal prism in local channels. Velocity increases occurred through the main flow channel of Nurse Slough below the restoration site. At the point in the channel where highest velocities occur, peak ebb tide velocities increased from approximately 2.6 ft/s for the Base case to 3.5 ft/s with Restoration. Tidal prism increased by approximately 56%.

Restoration impacts on stage and tidal range were minimal. During 2013, the monthly average reduction in mean higher high water was 0.1’ or less and the monthly average increase in mean lower low water was 0.06’ or less.

In Bradmoor Island wetland areas were fully inundated and all but the eastern edge of Arnold was fully inundated at MHHW.

Monthly average residence times in Bradmoor Island ranged from approximately 1.6 days to 2.8 days and in Arnold the range was approximately 0.6 to 1.2 days.

Particle track modeling results indicate that Restoration reduced residence time in Nurse Slough by approximately 1.5 days and increased the percentage of particles spending a day or less in Nurse Slough by approximately 13% relative to Base.

Salinity impacts due to Restoration included decreases or very small increases in monthly averaged salinity at locations east of Collinsville. Salinity increases of 3-4% occurred at Collinsville during the summer and early fall. Salinity increases occurred at Beldon’s Landing, particularly when the Suisun Marsh Salinity Control Gates were operating, due to decreased net flow in Montezuma Slough.

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INTRODUCTION

This report provides a detailed description of numerical modeling for the proposed Bradmoor Island and Arnold tidal restoration projects. Local hydrodynamic impacts and local and regional salinity impacts resulting from the restoration are evaluated. Electrical conductivity (µmhos/cm), or EC, was modeled as a surrogate for salinity. Residence time simulations were performed to evaluate typical residence time of water volumes within the restoration sites. Particle track modeling was used to assess particle exposure time in Nurse Slough. Details are provided describing model boundary condition data sources and the application of boundary conditions in the model.

Background

Tidal habitat restoration is being proposed for Bradmoor and Arnold, two adjacent sites in the Nurse Slough area of Suisun Marsh that currently operate as managed wetlands (duck clubs). Bradmoor is approximately 480 acres and Arnold is approximately 180 acres.

Objectives

The objective of this study was to evaluate expected tidal range in the restoration sites, impacts on local velocities and tidal range, local and regional salinity impacts resulting from the restoration and residence time within the restoration sites. Particle track modeling was used to examine particle exposure time in Nurse Slough and travel time to Montezuma Slough to assess food production and export.

RMA BAY-DELTA MODEL

The RMA Bay-Delta model has been used for this analysis. The RMA Bay-Delta model is a well-established tool for analysis of hydrodynamic and water quality impacts of proposed projects in the San Francisco Bay, Suisun Marsh and the Sacramento-San Joaquin Delta.

The RMA Bay-Delta Model was chosen for this study due to its ability to provide sufficiently accurate simulation of Bay-Delta-wide hydrodynamics and water quality transport and its ability to perform predictive simulations to evaluate the impacts of proposed tidal marsh restoration. The RMA Bay-Delta Model utilizes the RMA2 hydrodynamics and RMA11 water quality transport finite element computational engines. The finite element model formulation allows use of an unstructured computation mesh where resolution can be increased locally to represent the topographic details of a restoration site. RMA2 and RMA11 engines support combining two-dimensional depth-averaged (2-D) computational elements and one-dimensional cross-sectionally averaged (1-D) elements in a single mesh. In the RMA Bay-Delta Model all large channels, embayments, and tidal marsh restoration areas are represented in 2-D. The model has been shown to provide accurate simulation of tidal exchange through constrictions, such as levee breaches into a restoration site, based on the breach geometry, site topography, and friction parameter (Manning's n value) estimated within typical accepted range.

The RMA Bay-Delta Model does not directly simulate the effects of stratified flow, which would require application of a three-dimensional (3-D) model. The effects of stratification

are approximately incorporated into the model through calibration exercises where mixing coefficients are adjusted to best represent the observed salinity field for a historic period.

Model coefficients have been added to RMA11 that increase dispersion with higher horizontal salinity gradients to account for strengthened gravitational circulation. Dispersion associated with gravitation circulation is based on a horizontal Richardson number. The dispersion computations rely on the horizontal density gradient, depth of water and tidally averaged shear velocity, following the method in Gross et al. (2009). The Richardson number is scaled by calibrated linear and power coefficients to provide an extra dispersion term in RMA11.

Geometric Extents

RMA's San Francisco Bay - Sacramento–San Joaquin Delta network was developed using an in-house GIS-based graphical user interface program (RMA, 2003). The program allows for development of the finite element mesh over layers of bathymetry points and bathymetry grids, GIS shapefiles and aerial images.

The RMA Bay-Delta model, shown in Figure 1, extends from the Golden Gate at the west end to the Sacramento River at the confluence with the American River, and to the San Joaquin River near Vernalis. A two-dimensional depth-averaged approximation is used to represent the San Francisco Bay, Suisun Bay region and the other open water, major channels of the Delta, and upper Suisun Slough and Nurse Slough in Suisun Marsh. The other Delta and Suisun Marsh channels and tributary streams are represented using a one-dimensional cross-sectionally averaged approximation.

For the purpose of this project, grid enhancements were made in sloughs connecting to the Arnold project site. Bradmoor, Arnold and all adjacent sloughs are represented fully in 2-D.

A detail view of the project area is shown in Figure 2. The development of the project grid is discussed further in the Project Configuration section.

Bay-Delta Bathymetry

Bay-Delta model bathymetry is shown in Figure 1 for the Base case. A comparison of Base and final Restoration case model bathymetry in the project region is shown in Figure 2. For all areas of the RMA2 model grid, the most current, best quality bathymetric data were used to set grid elevations.

Elevation data points to set model grid elevations within the Arnold site were collected by WWR and provided to RMA by DWR.

Bay-Delta geometry has been updated with recent data collected and posted on the Department of Water Resources (DWR) DEM website:
http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/modelingdata/DEM.cfm.

And DWR's Delta Bathymetry Catalog:
https://gis.water.ca.gov/app/bathymetry/

Bathymetry in the Cache Slough area were set using bathymetric data collected in 2012 by DWR (DWR, 2012) and Environmental Data Solutions (EDS, 2013), in 2009 by cbec (cbec, 2011) and in 1997 and 2005 by USACE data (USACE, 2005 and 2002). Coarsely space single beam transects from the Central Valley Floodplain Evaluation and Delineation (CVFED) (cbec, 2011) were used to set model elevations in various locations in the northern Delta and Sacramento River.

For all other areas, bottom elevations and the extent of mudflats were based on bathymetry data collected by NOAA, DWR, USACE and USGS. These datasets have been compiled by DWR and can be downloaded from DWR's Cross Section Development Program (CSDP) website at http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/csdp/csdp.cfm. Topography data from DWR's Delta LiDAR survey (2007) was used where elevation data for channel banks, tidal marsh and flood plains was not available from the other sources.

A detailed description of model refinements in the vicinity of the Restoration projects is discussed in the Project Configuration section.

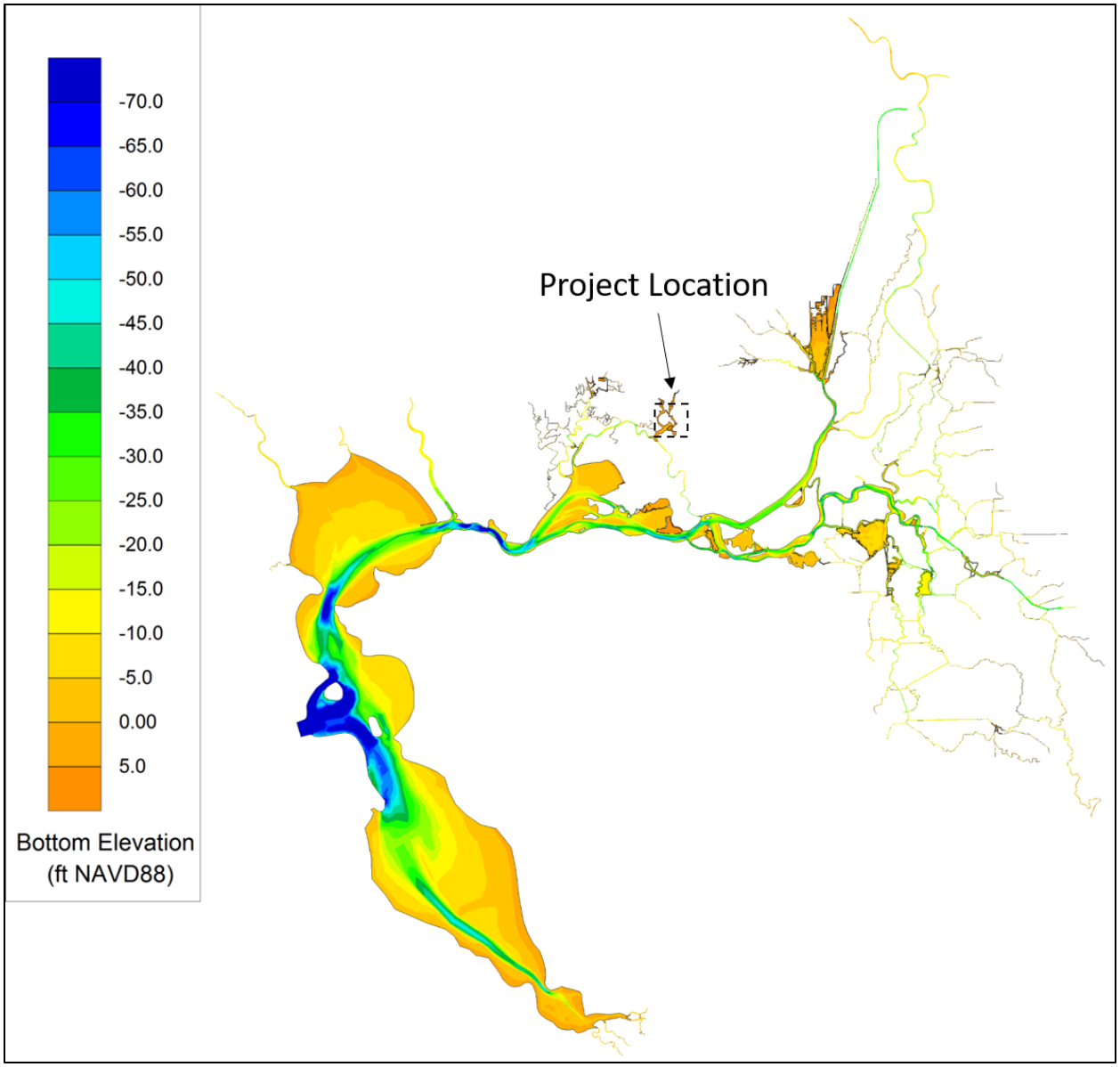

Figure 1 Base case model bathymetry.

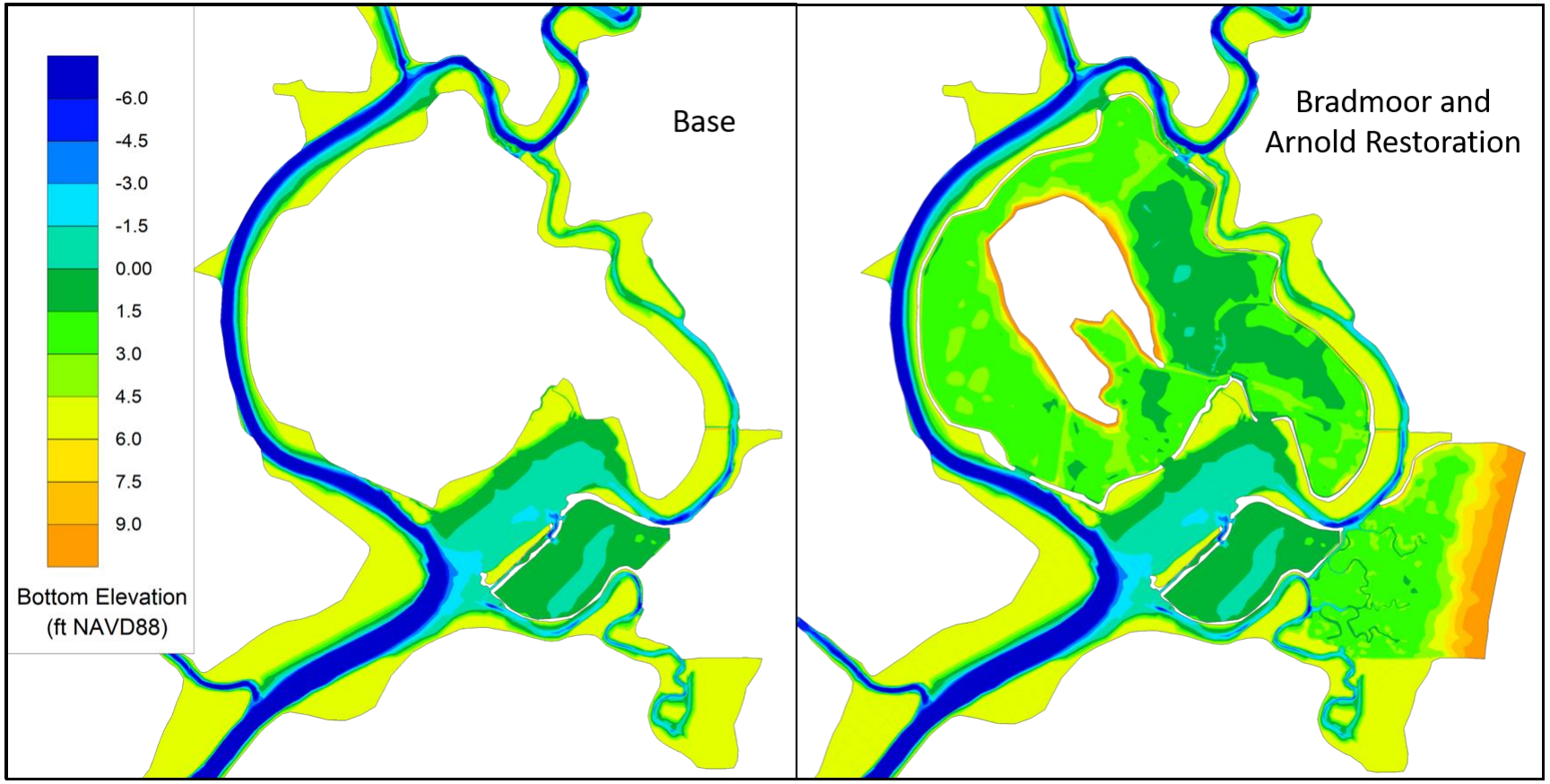

Figure 2 Model bathymetry in the project vicinity for the Base and Restoration configurations.

BOUNDARY CONDITIONS

The RMA Bay-Delta hydrodynamic model operation requires specification of the tidal stage at the Golden Gate and inflow and withdrawal rates at other external boundaries as shown in Figure 3.

Initial Alternative screening hydrodynamic and residence time simulations for Arnold were performed for April - July 2004, to parallel screening simulations performed by DWR for Bradmoor Island. Delta outflow for the 2004 analysis period is plotted in Figure 4.

For the final Restoration scenario, simulations of hydrodynamic and water quality models were run for the January – December 2013 period. The 2013 period includes dry and critically dry conditions (see http://cdec.water.ca.gov/cgi-progs/iodir/wsihist). Delta outflow is plotted in Figure 5. This period was selected due to low flow conditions and data availability.

Boundary conditions are detailed in the Appendix.

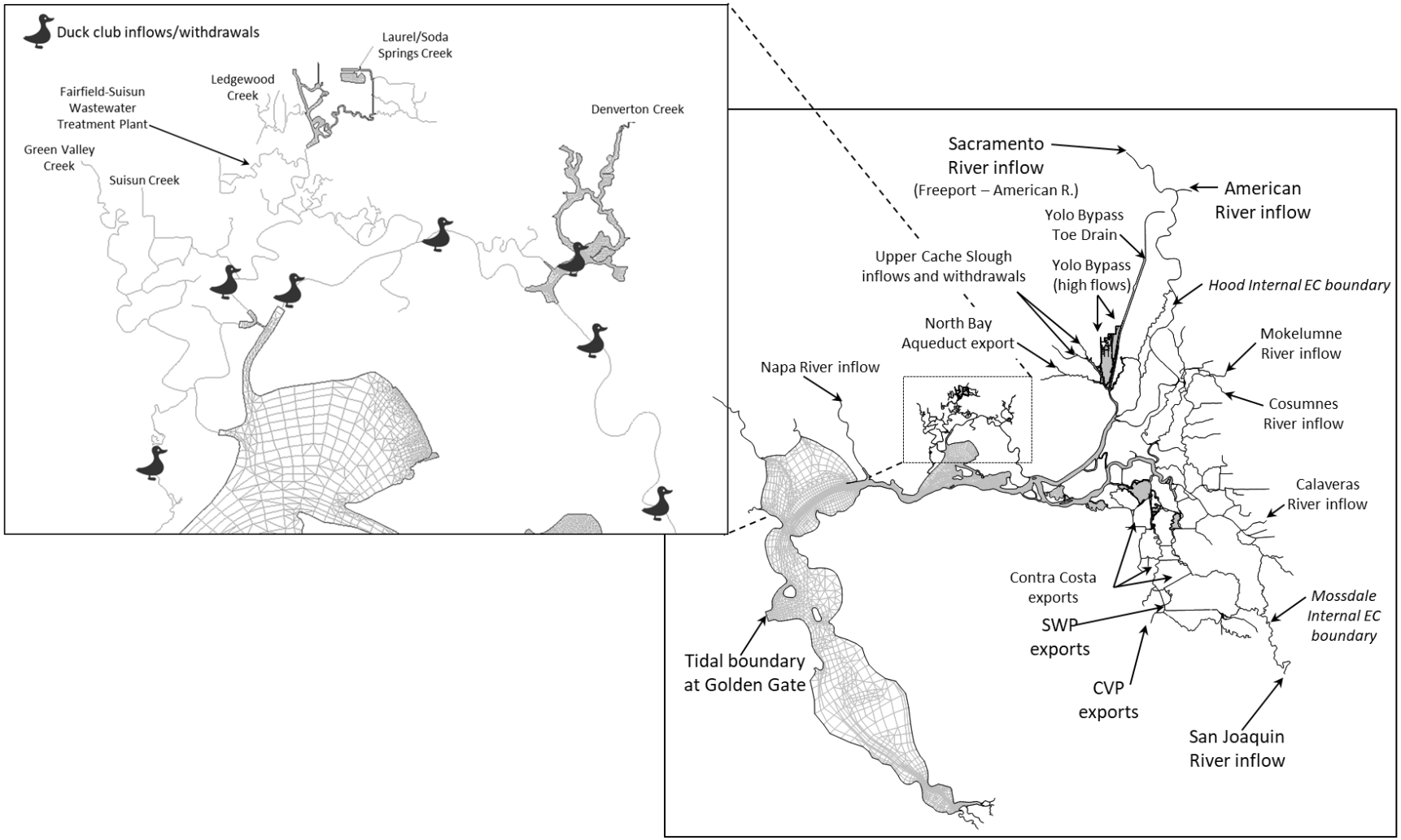

Figure 3 Model boundary condition locations.

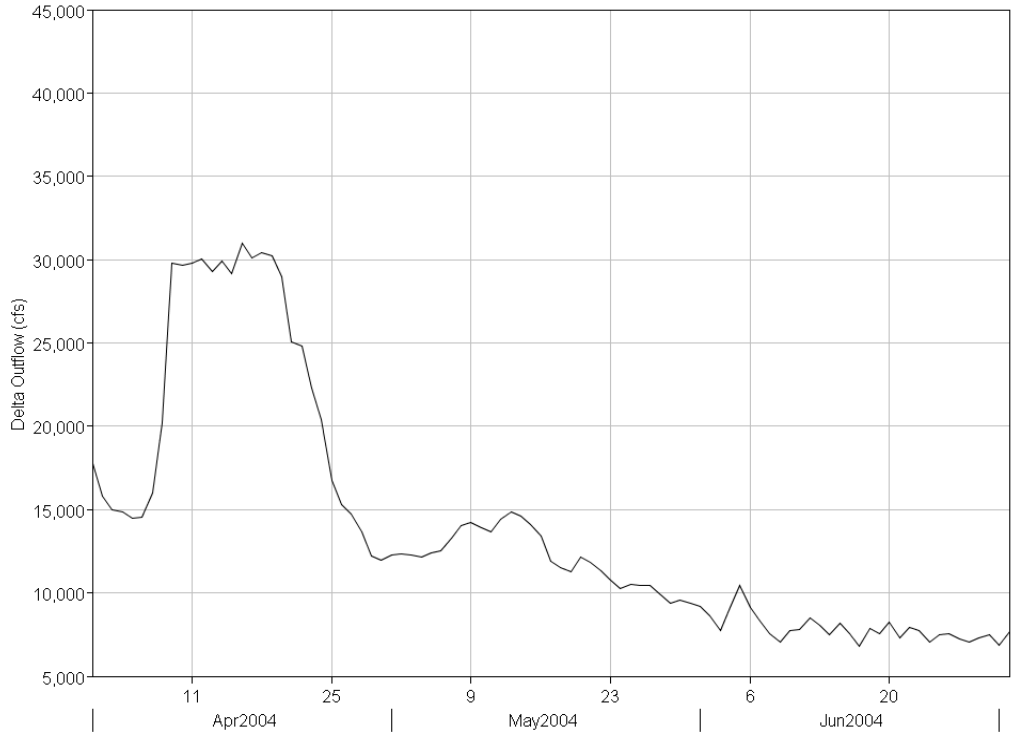

Figure 4 Delta outflow for the 2004 analysis period.

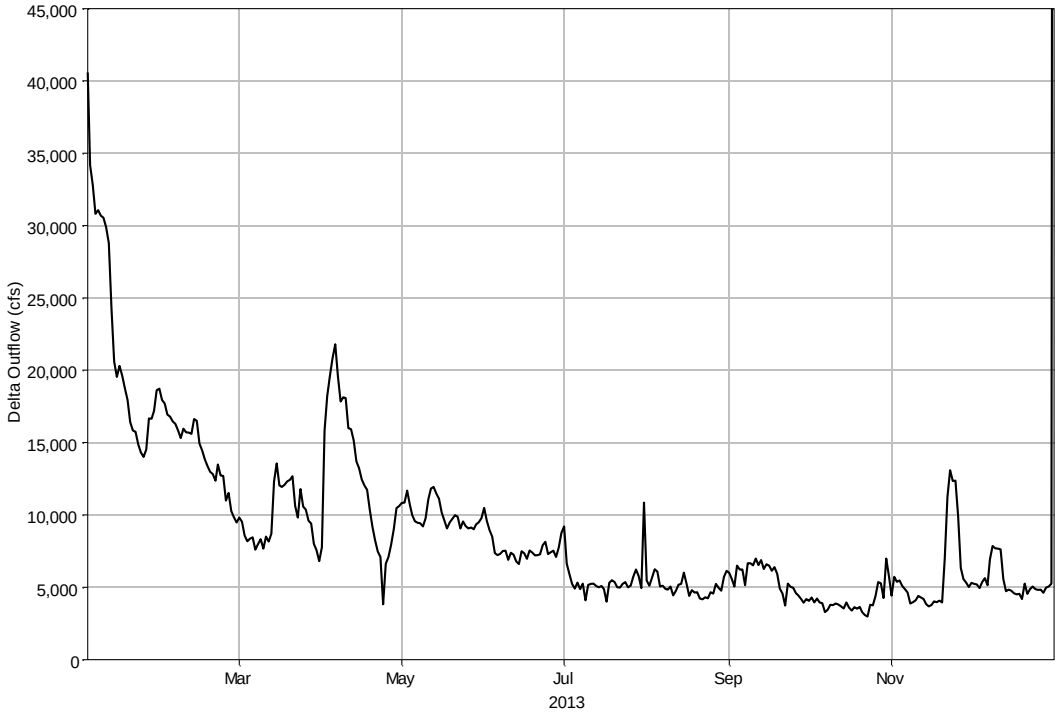

Figure 5 Delta outflow for the 2013 analysis period.

CALIBRATION CHECK

To assure that the Base model is in good agreement with observed data following the grid enhancements in the vicinity of the Restorations, a quick calibration check was done. The April – December 2013 computed Base stage and EC were compared with observed data at National Steel, Blacklock, Beldon's Landing and Hunter Cut (see Figure 6 for location map). Stage results in Figure 7 through Figure 10 show the modeled stage is generally in good agreement with observed values during the summer period and slightly high during the fall. The tidally averaged stage is as much as 0.6 ft higher than observed in the winter on the eastern side of the Marsh and 0.3 ft higher on the western side. The mean computed stage for the entire period ranges from 0.03 to 0.36 ft above observed. The varying difference over the year in computed and observed average stage produces the scatter in the linear regression plots. The tidal amplitudes are in good agreement with observed, with ratios ranging from 0.9 to 1.0 averaged over the simulation.

EC results are shown in Figure 11 through Figure 14. Overall, the model does a reasonably good job of reproducing observed EC values in Suisun Marsh. The model produces the best results during the summer months and early fall months, and tends to be slightly low during the winter and spring. Because of uncertainties in the boundary conditions, particularly the duck club flows, some deviations from observed data can be expected. Model results are especially low at National Steel. Strong salinity gradients at the upstream end of Montezuma Slough can make it challenging for the model to match observed data at this location. The higher salinity is shifted downstream in the model compared with observed data.

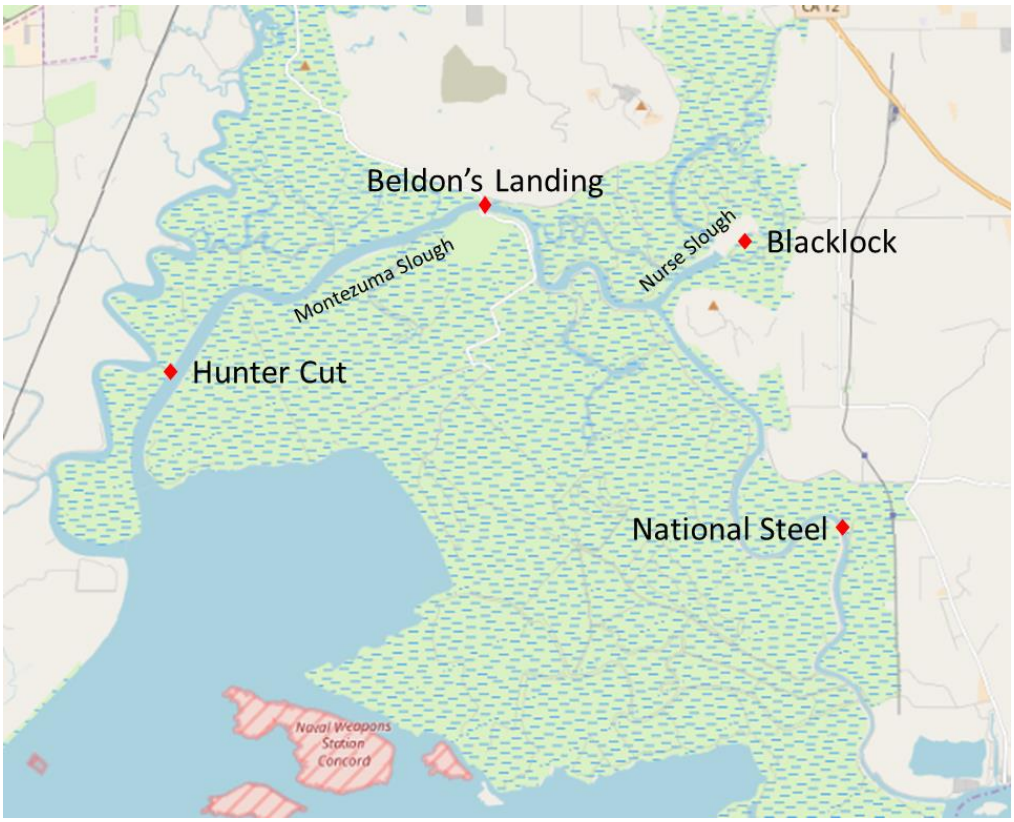

Figure 6 Suisun Marsh stage and EC calibration check locations.

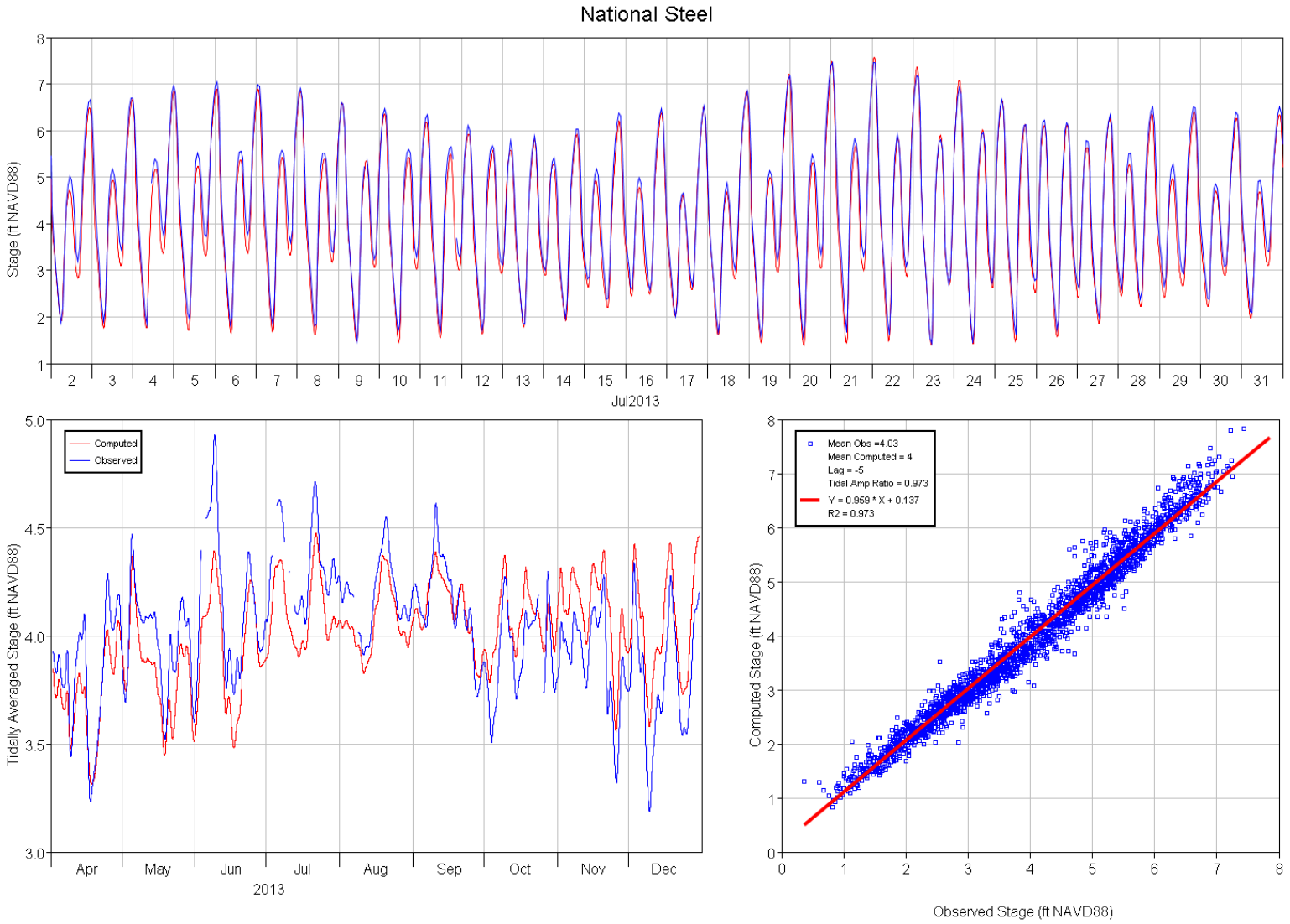

Figure 7 Base case computed and observed stage at National Steel for April 1 – December 31, 2013.

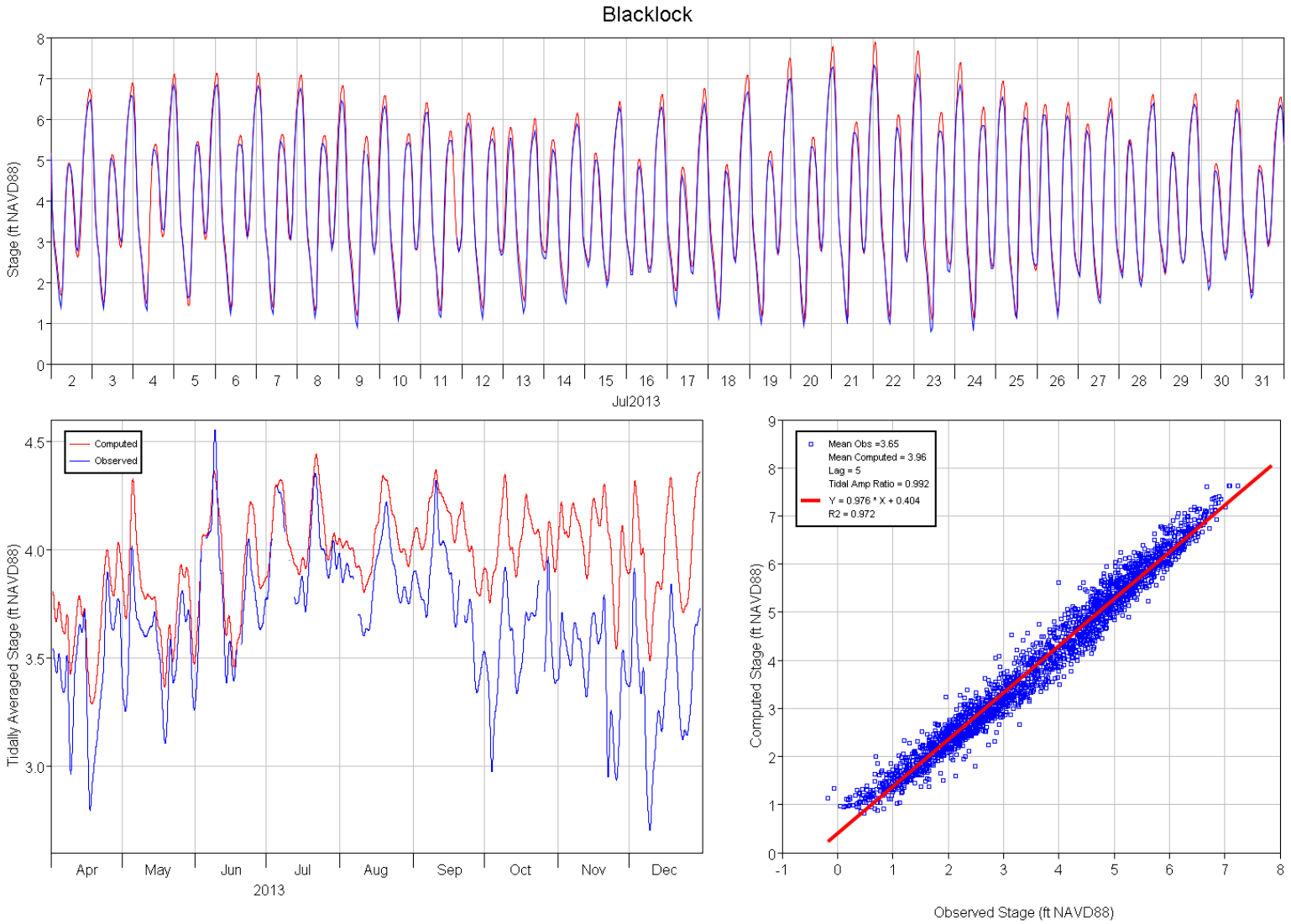

Figure 8 Base case computed and observed stage at Blacklock for April 1 – December 31, 2013.

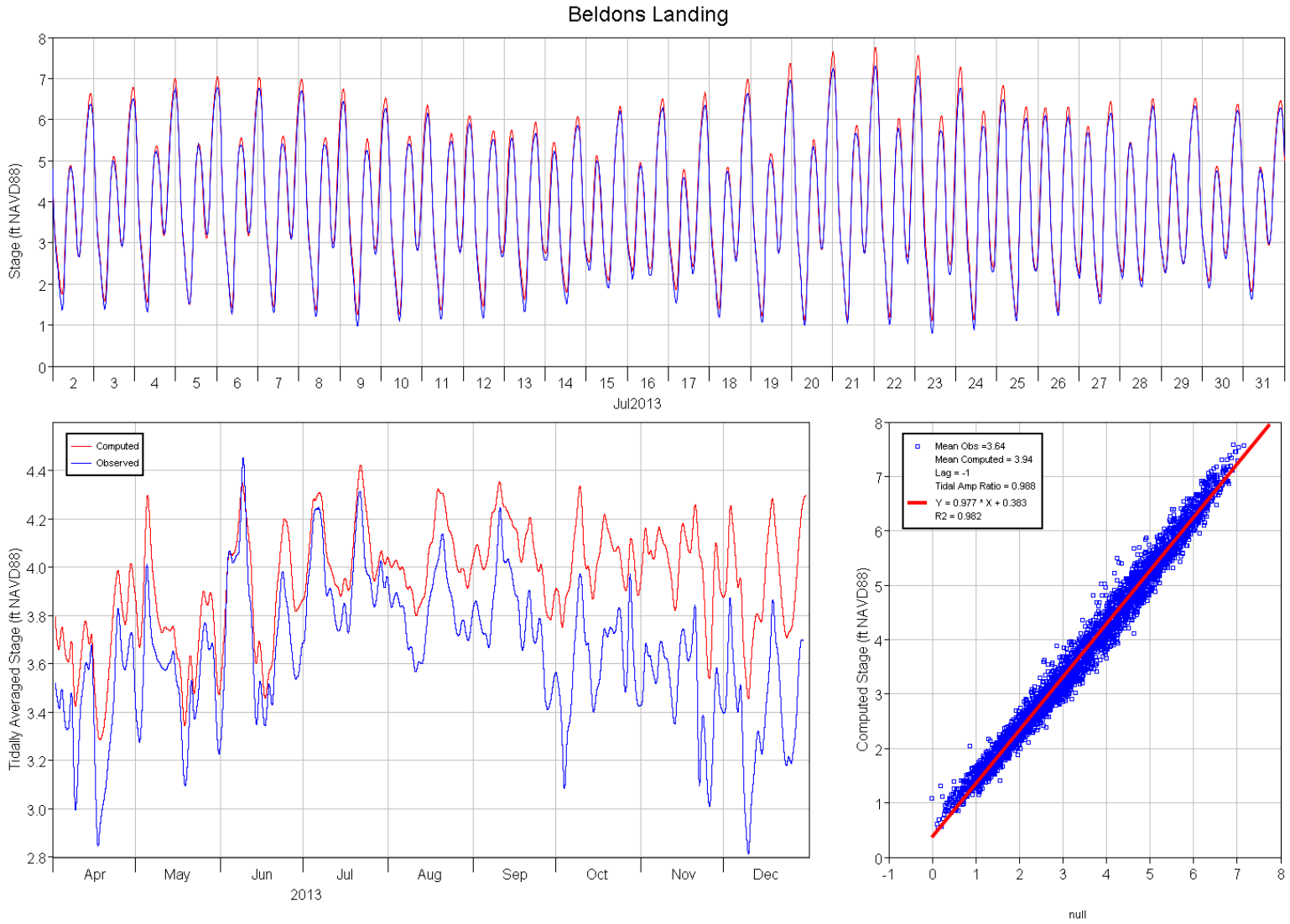

Figure 9 Base case computed and observed stage at Beldon's Landing for April 1 – December 31, 2013.

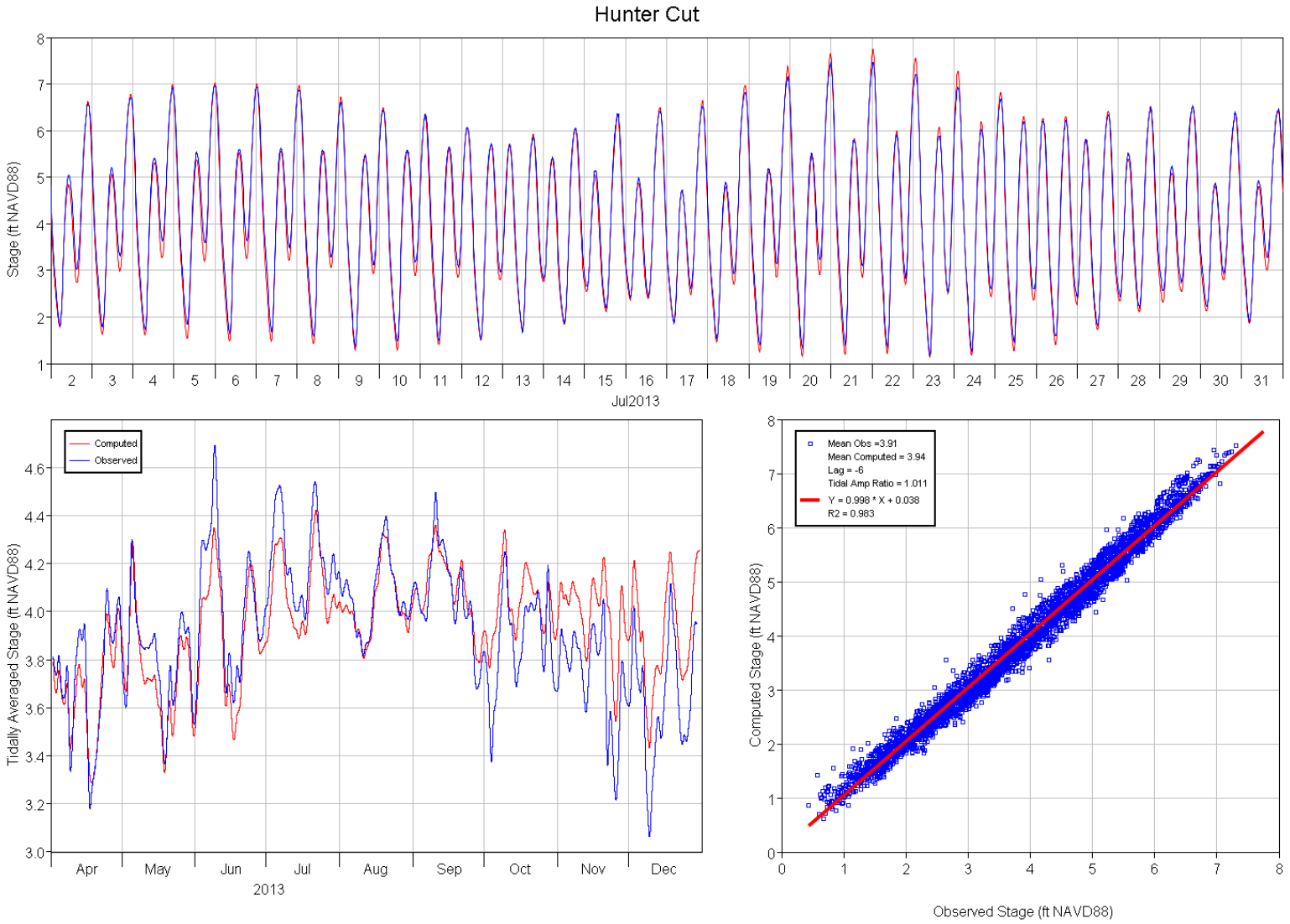

Figure 10 Base case computed and observed stage at Hunter Cut for April 1 – December 31, 2013.

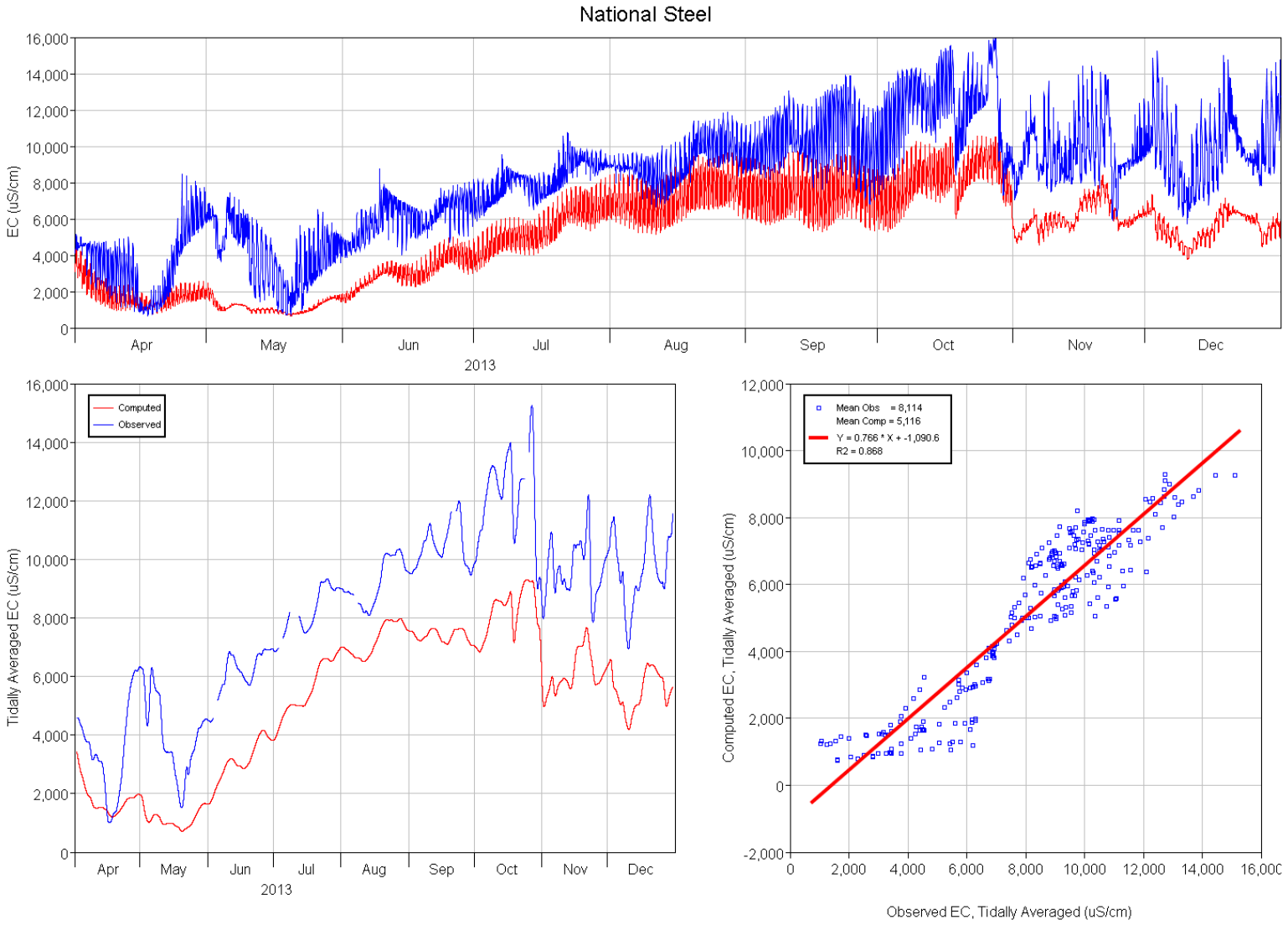

Figure 11 Base case computed and observed EC at National Steel for the April 1 – December 2013 simulation period.

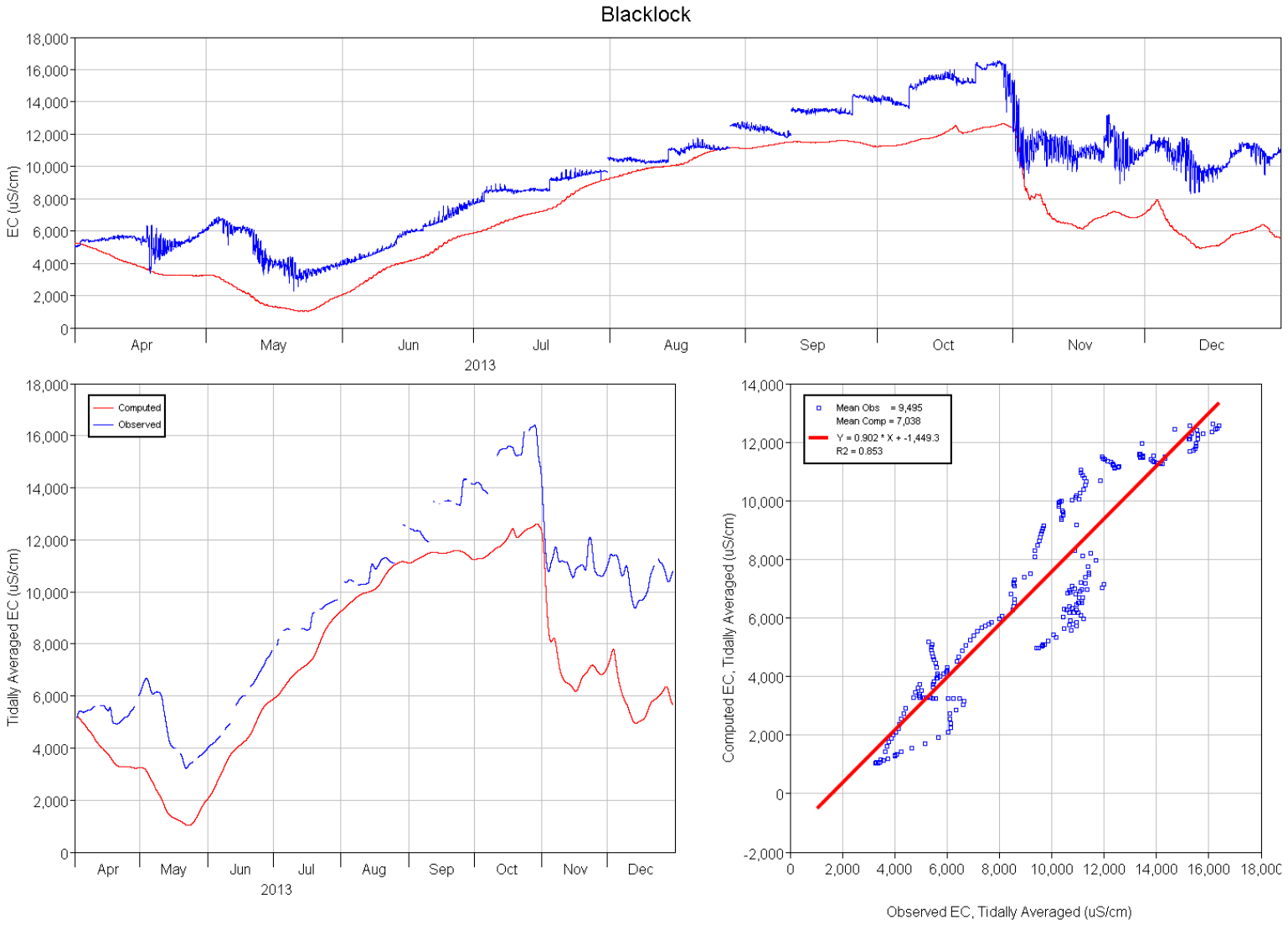

Figure 12 Base case computed and observed EC at Blacklock for the April 1 – December 2013 simulation period.

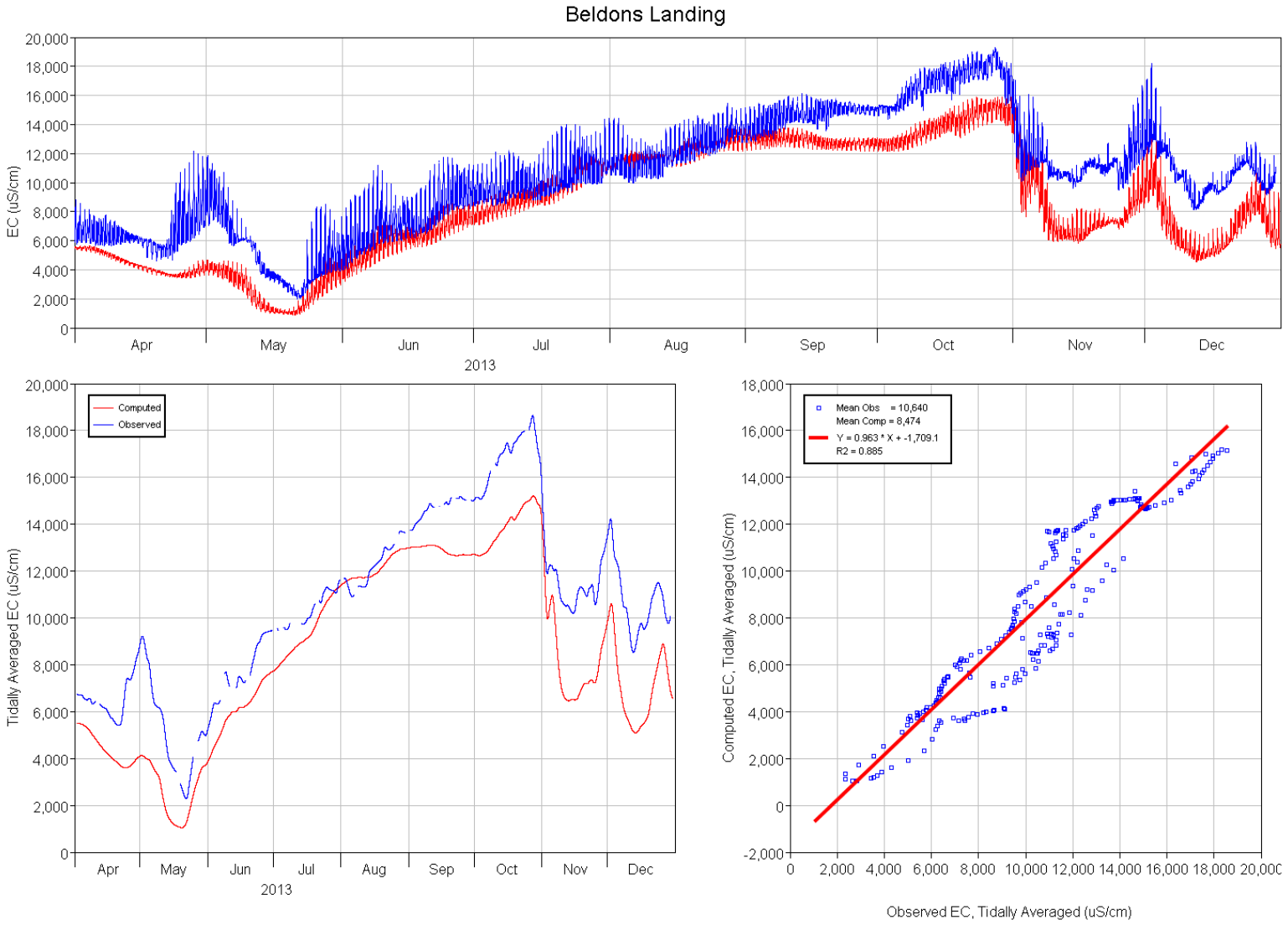

Figure 13 Base case computed and observed EC at Beldon's Landing for the April 1 – December 2013 simulation period.

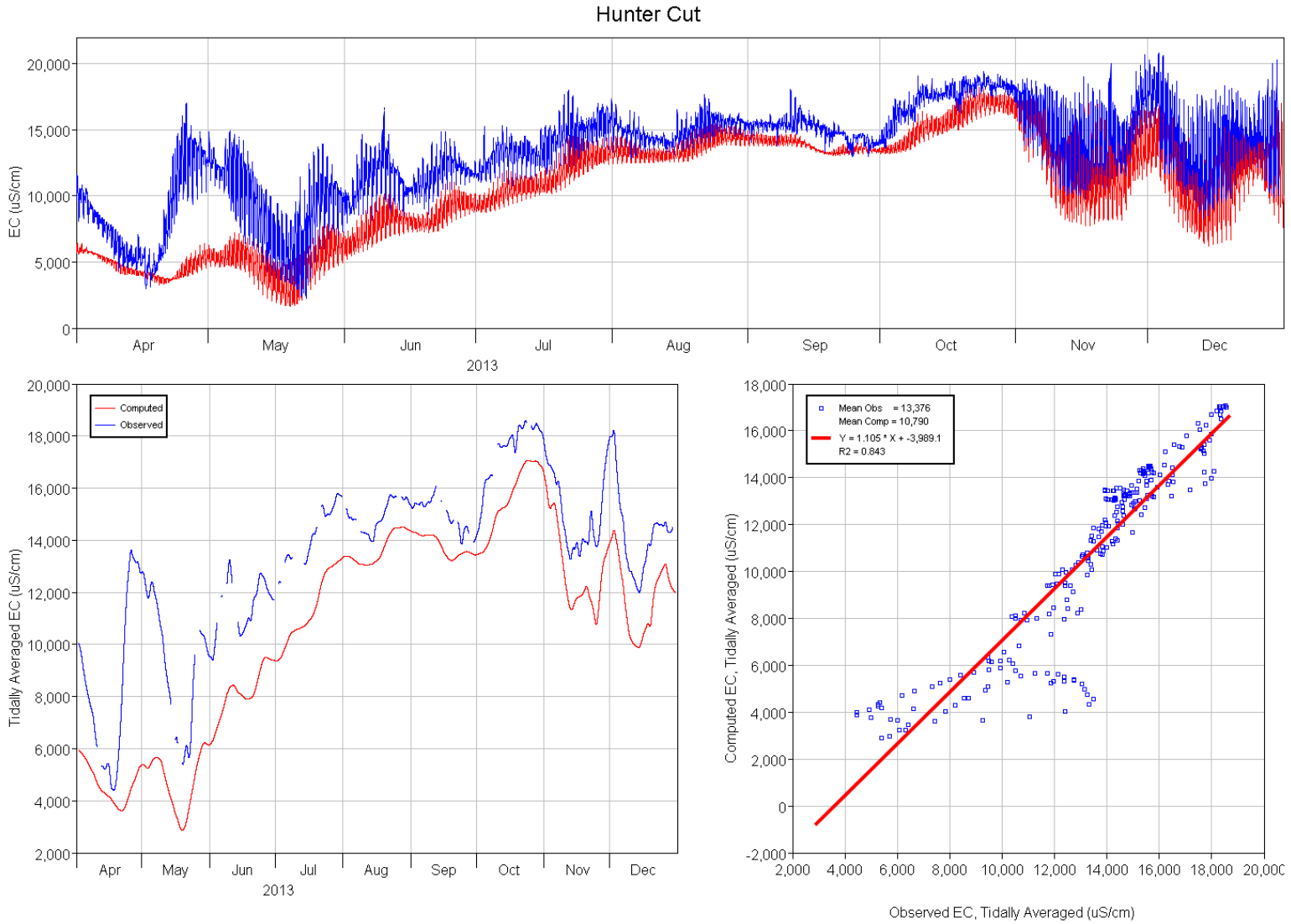

Figure 14 Base case computed and observed EC at Hunter Cut for the April 1 – December 2013 simulation period.

PROJECT CONFIGURATION

Existing condition model geometry within Arnold was developed based on point elevation data collected by WWR and provided by DWR, where available, and based on Coastal Conservancy LiDAR data (https://www.coast.noaa.gov/dataviewer/#/lidar/search/) elsewhere. A visual representation of the WWR elevation data sets is provided in Figure 15 and the LiDAR data coverage is shown in Figure 16.

For the proposed Arnold Restoration project, three preliminary configurations were analyzed and then a final modified configuration was chosen for additional analysis. Alternatives 1-3 are shown in Figure 17 through Figure 19, with the final selected alternative design, a modified version of Alternative 1, shown in Figure 20. Table 1 summarizes final Arnold restoration Alternative breach and channel geometry corresponding to the labeled features in Figure 21.

The Bradmoor Island restoration grid was provided by DWR. RMA made some modifications to the grid to develop a more accurate representation of existing conditions in and around the restoration site. Table 2 summarizes final Bradmoor Island restoration configuration (selected previously by DWR) site feature geometry corresponding to the labeled features in Figure 22.

Figure 23 shows the final model grid developed for the Arnold and Bradmoor restoration sites and vicinity, and the inclusion of the restoration grid into the greater RMA Bay-Delta model grid. A 3-D perspective view of the final model grid for the restoration sites is presented in Figure 24.

Table 1 Final Arnold Restoration Alternative site feature geometry (for locations, see Figure 21).

Site Feature	Description	Bottom Width	Bottom Elevation (NAVD88)
B1	External Levee Breach	243′	-1.3′
B2	External Levee Breach	63′	-3.9′
B3	External Levee Breach	72′	-1.6′
C1	Dredge Existing Channel	12′-16′	-1.3′
C2	Dredge Existing Channel	13′-20′	-0.7′
C3	Dredge Existing Channel	25′-40′	-2.0′

Table 2 Final Bradmoor Island Restoration alternative site feature geometry (for locations, see Figure 22).

Site Feature	Description	Bottom Width	Bottom Elevation (NAVD88)
B1	External Levee Breach	210′	0′
B2	External Levee Breach	199′	-3.3′
B3	External Levee Breach	203′	0.6′
B4	External Levee Breach	206′	-0.7′
B5	External Levee Breach	196′	0.7′
B6	External Levee Breach	254′	0′
D1	Existing Ditch	27′-35′	-1.3′
D2	Existing Ditch	10′-19′	-0.7′
D3	Existing Ditch	56′-75′*	-2.0′
L1	Internal Levee	--	3.6′
L2	Internal Levee	--	3.2′

**D3 is a V-shaped ditch, listed widths are top widths*

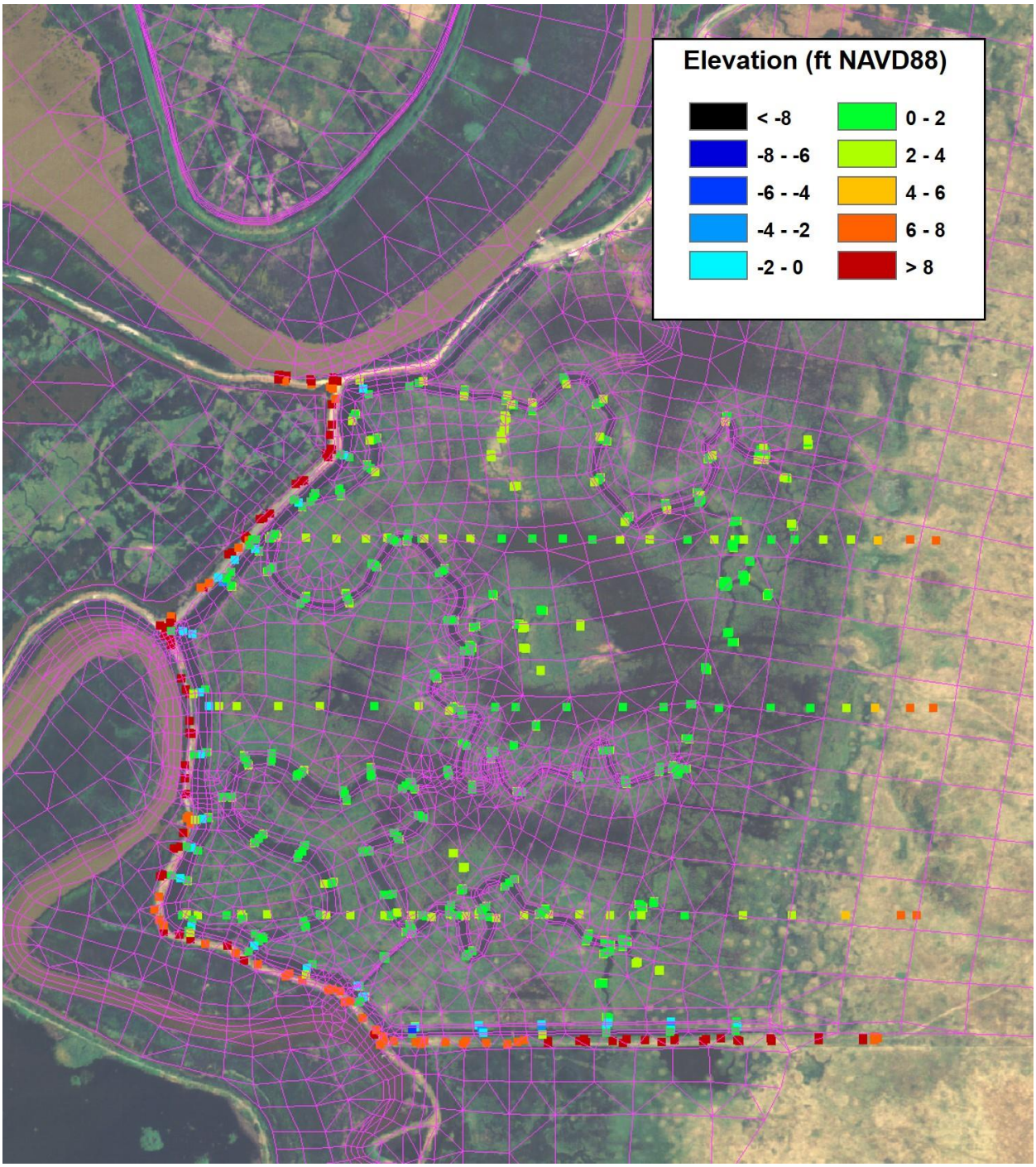

Figure 15 Locations of point elevation data collected by WWR in Arnold.

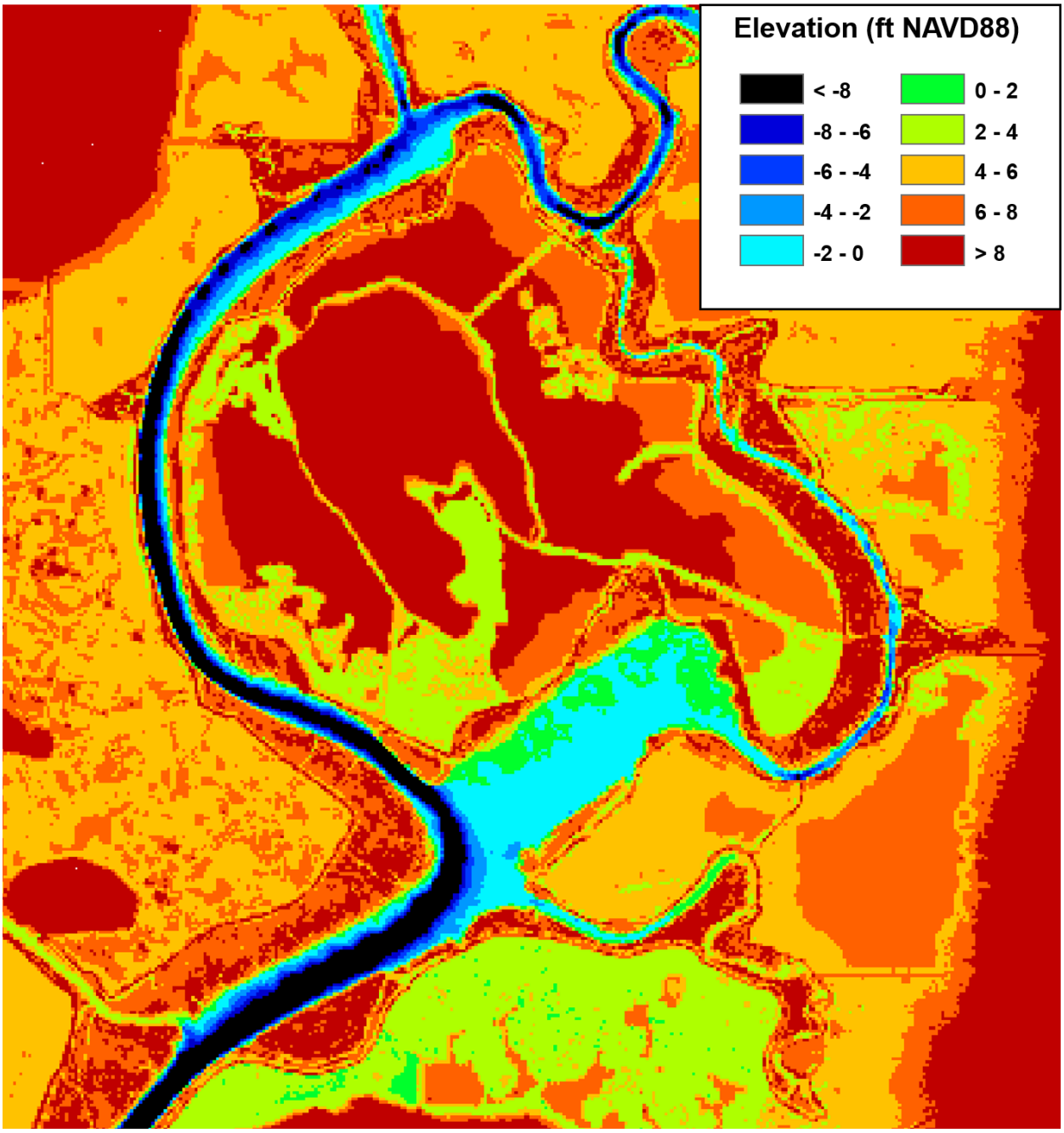

Figure 16 Coastal Conservancy LiDAR data coverage in the Arnold and Bradmoor Island vicinity.

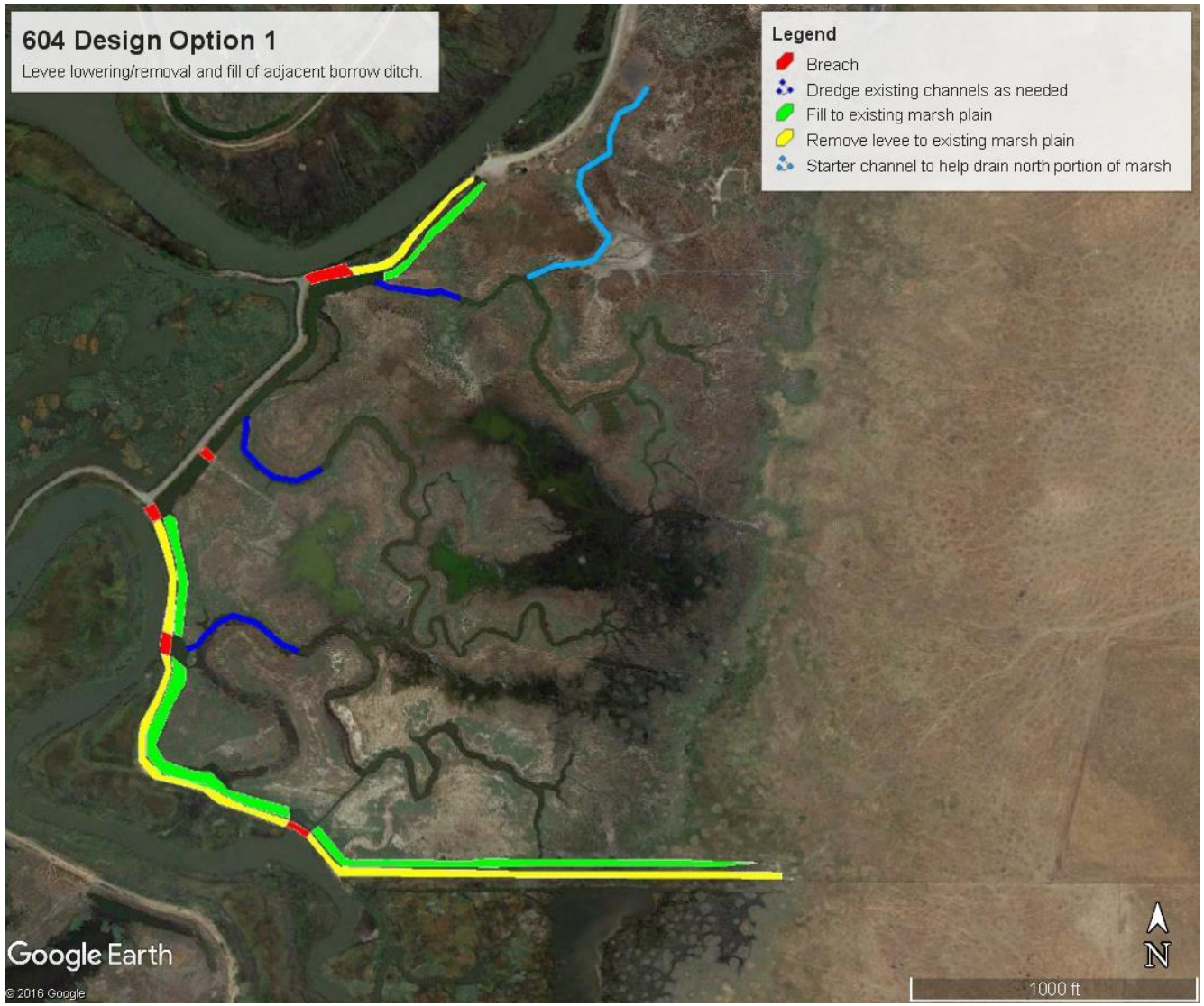

Figure 17 Arnold preliminary restoration Alternative 1.

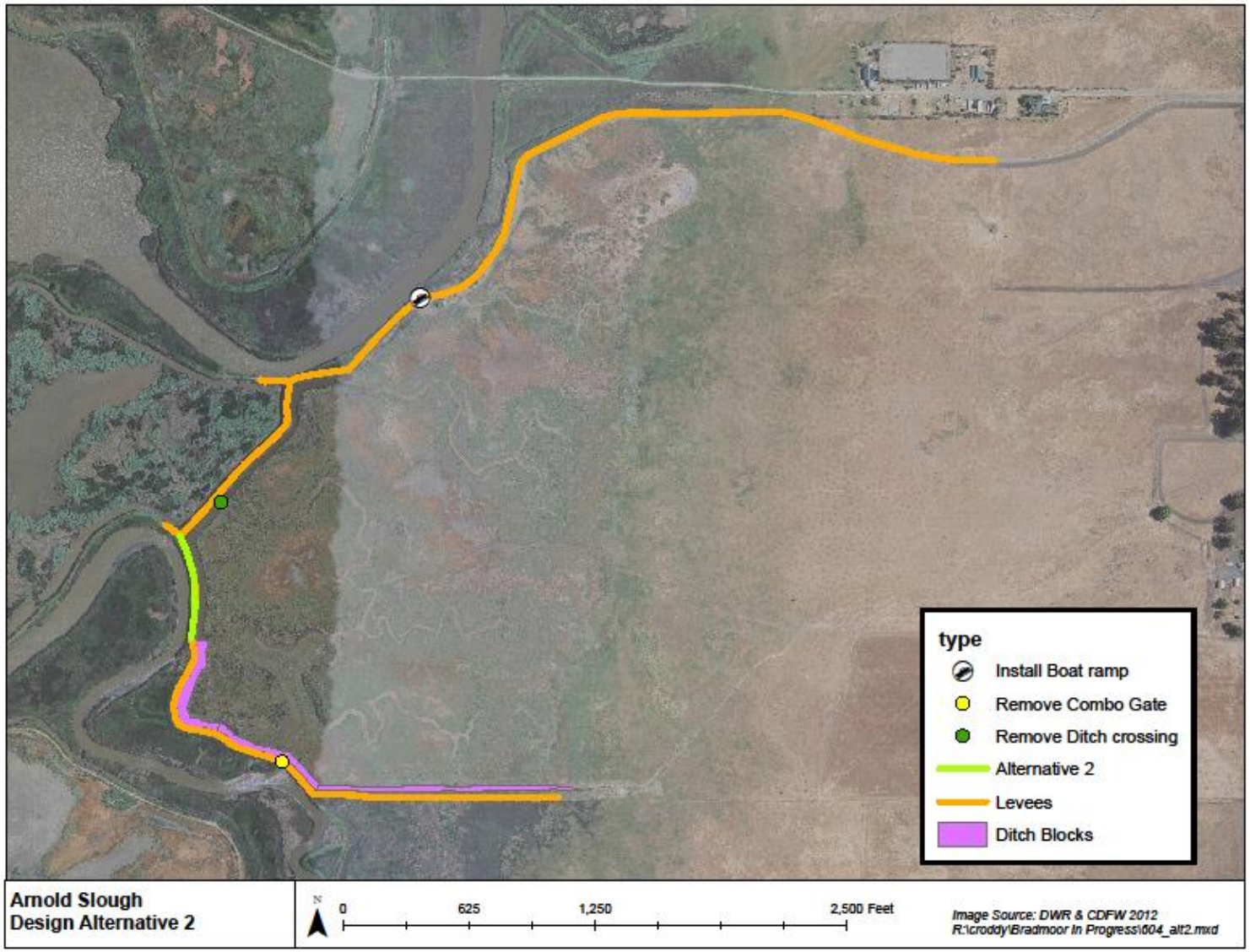

Figure 18 Arnold preliminary restoration Alternative 2.

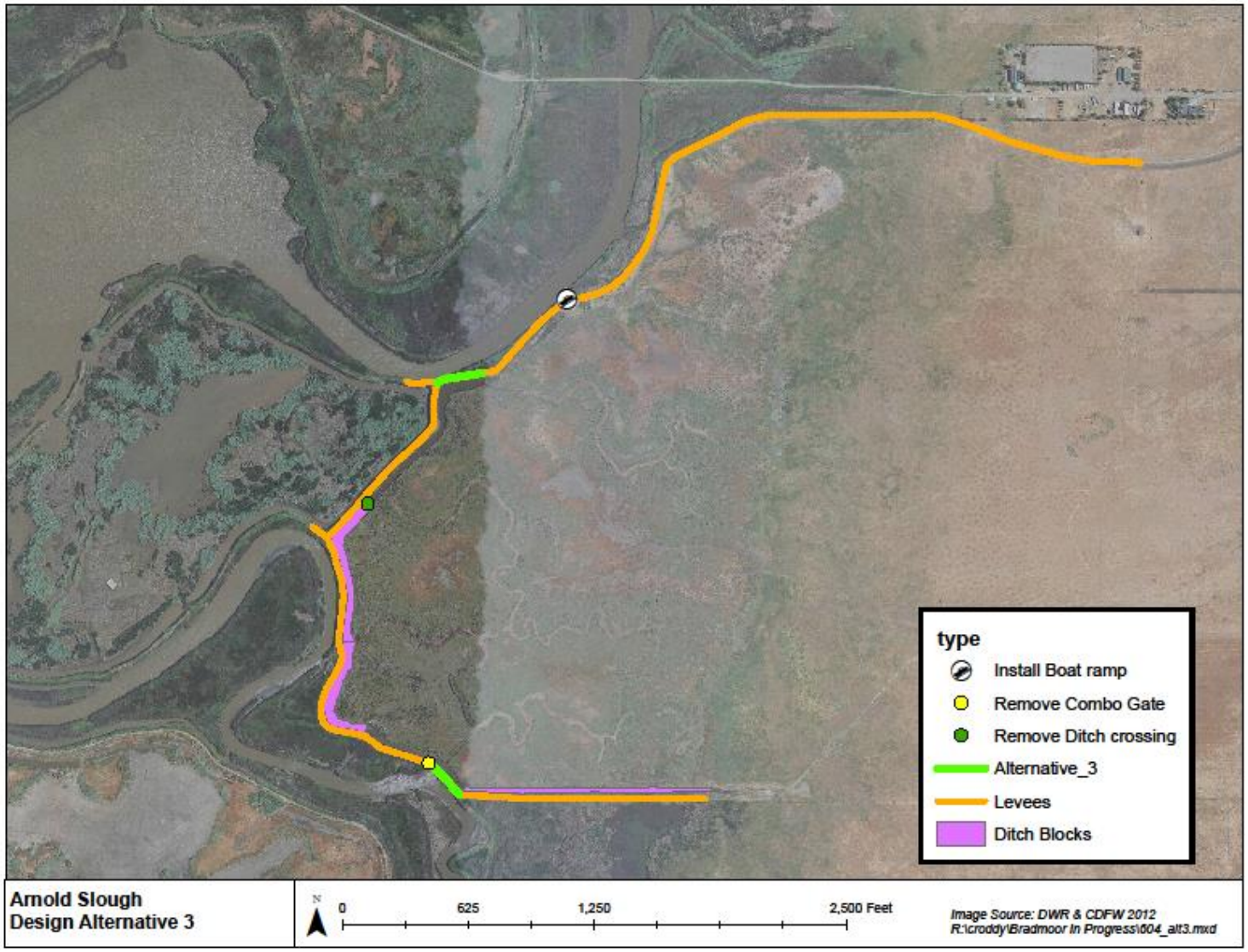

Figure 19 Arnold preliminary restoration Alternative 3.

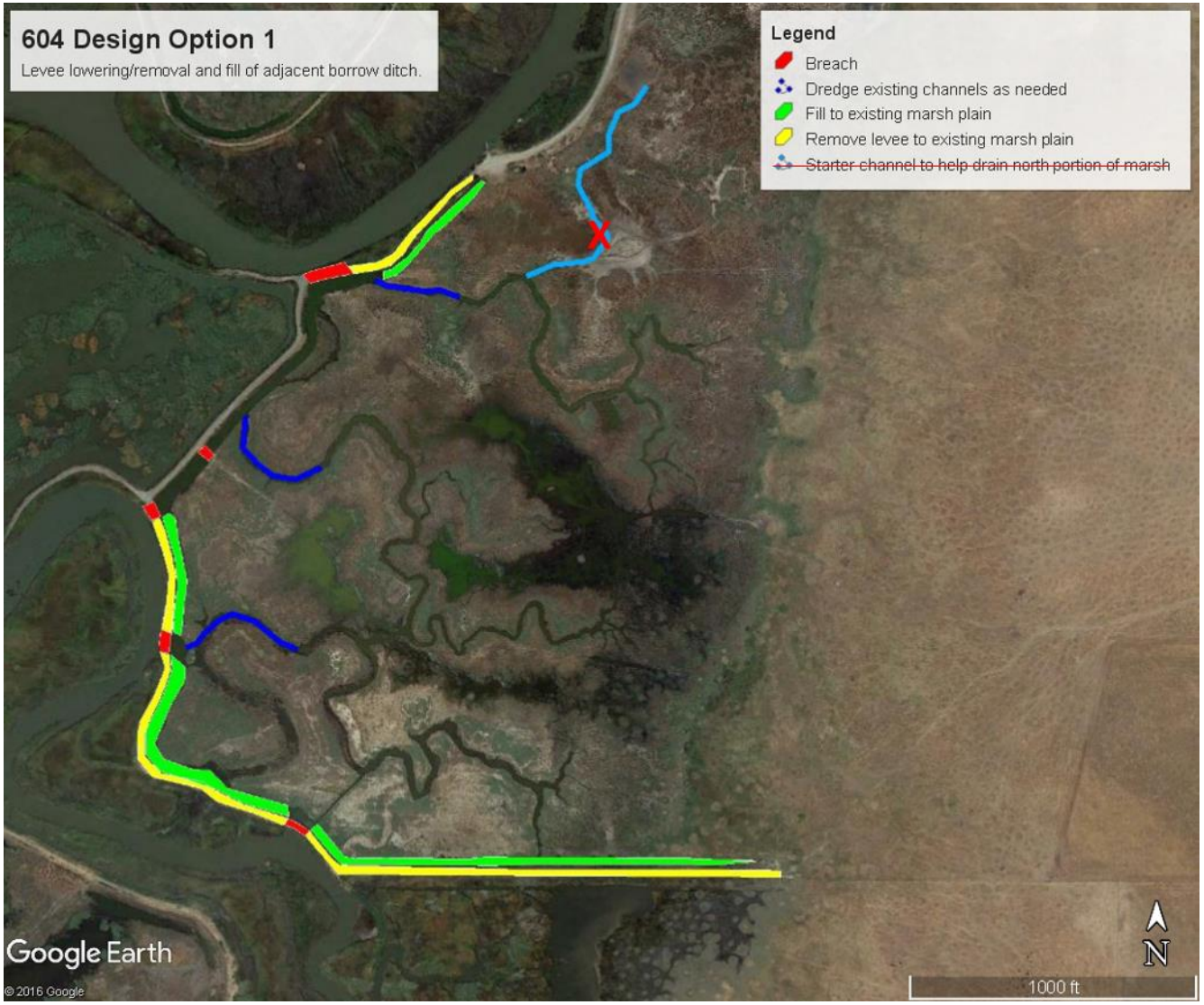

Figure 20 Arnold final restoration design: modified Alternative 1.

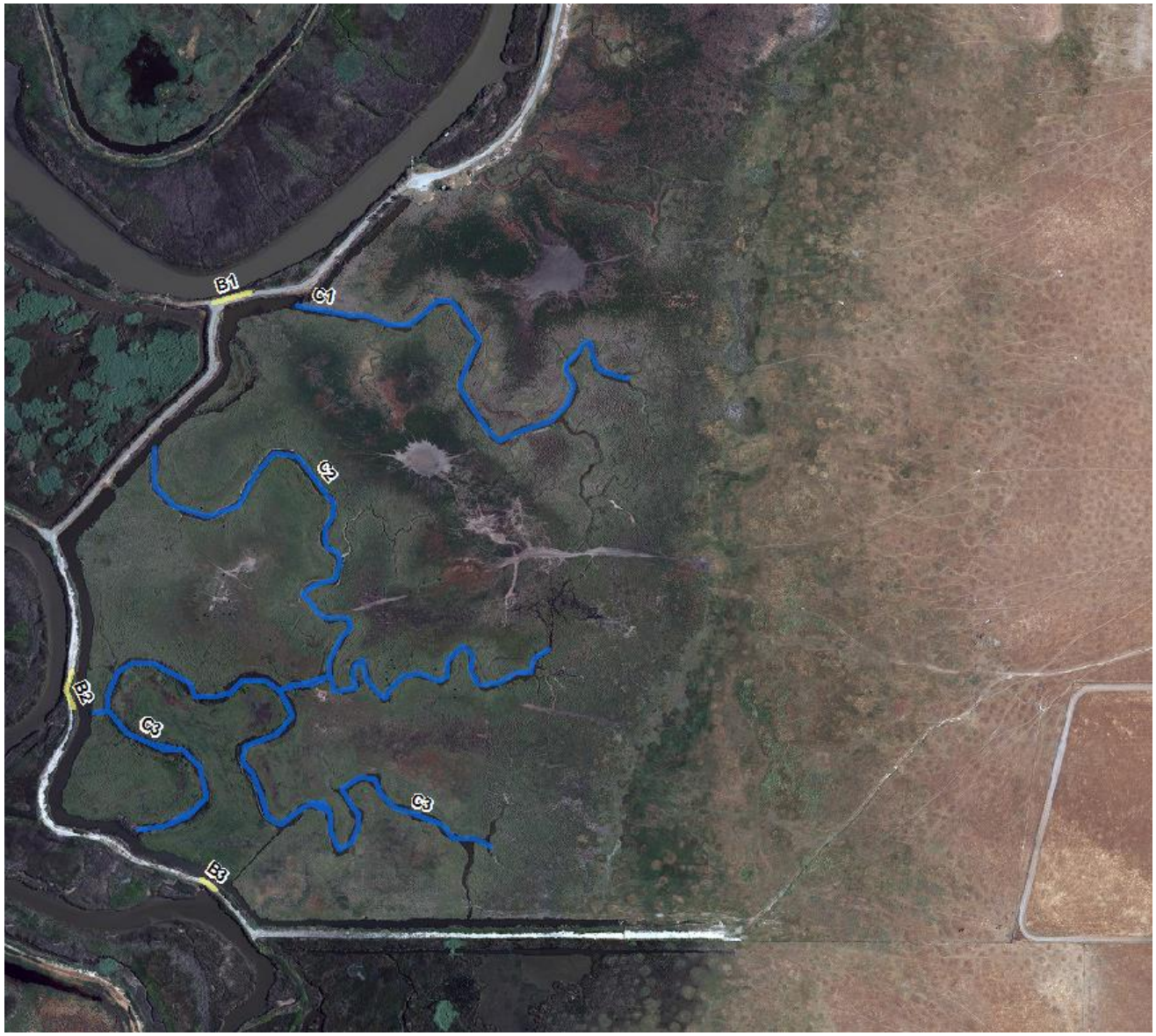

Figure 21 Arnold restoration site feature map (see Table 1).



Figure 22 Bradmoor restoration site feature map (see Table 2).

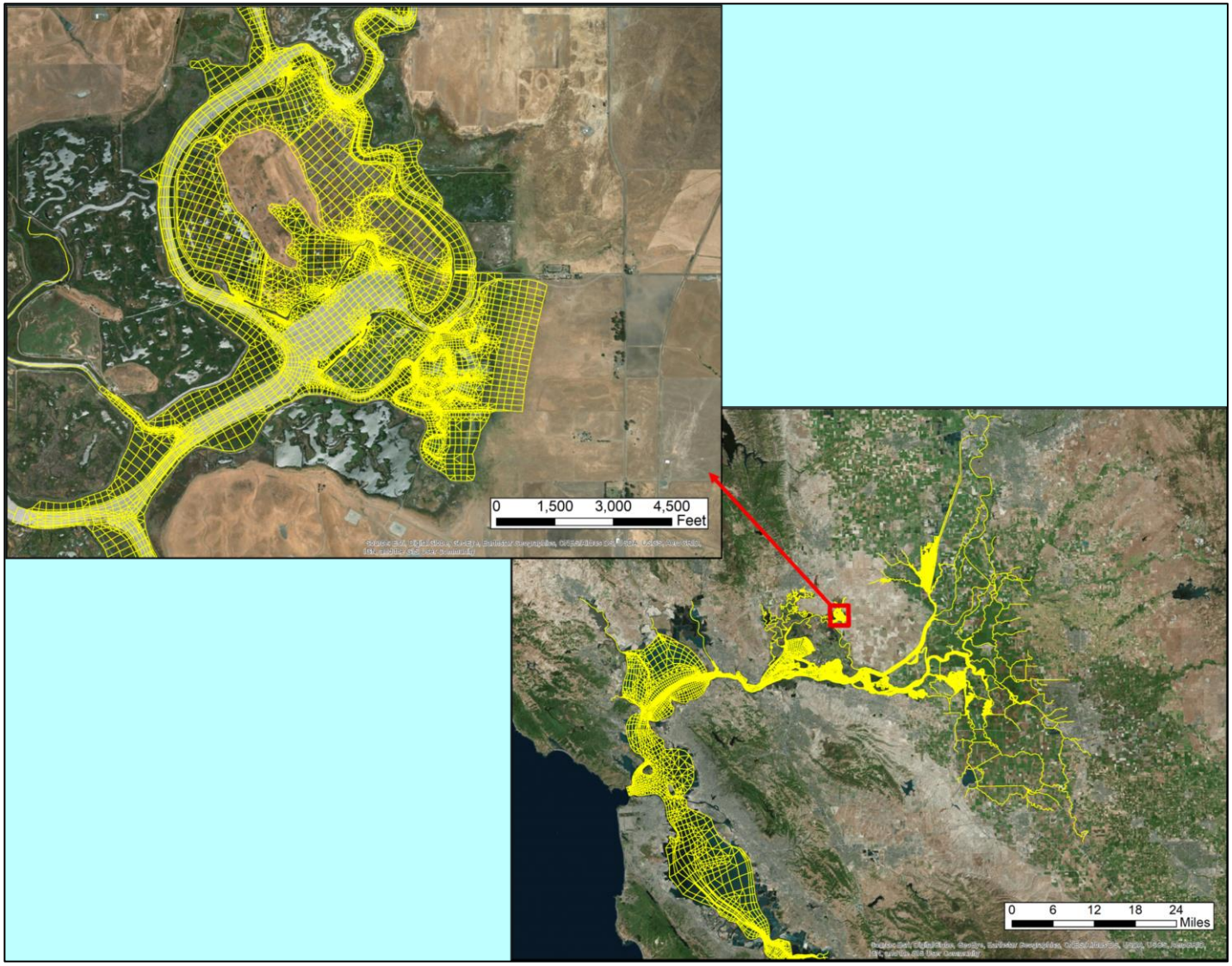

Figure 23 Numerical model network for the Bay-Delta grid and the detailed model network for the final Arnold and Bradmoor Island restoration sites.

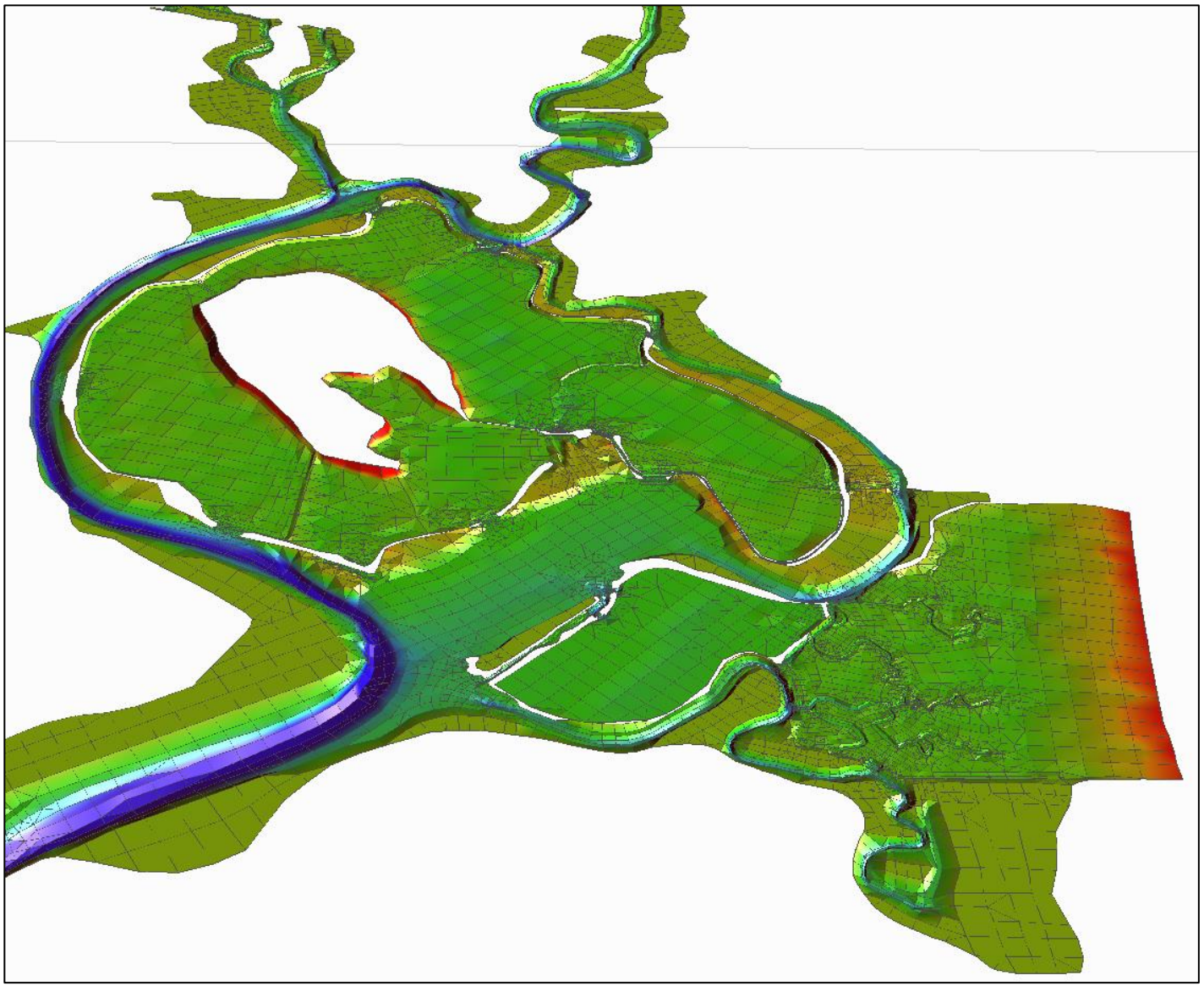

Figure 24 3-D perspective view of the Arnold and Bradmoor Island restoration grid.

ARNOLD RESTORATION ALTERNATIVES IMPACTS ANALYSIS

Hydrodynamic Impacts

June 2004 hydrodynamic simulation results for the Base case and three preliminary Arnold Restoration Alternatives were analyzed and compared to evaluate expected impact of each Alternative on tidal range, velocities and tidal prism in adjacent channels. Tidal range within the Arnold site was also examined.

Velocities

A comparison of Base case and Restoration velocities during June 2004 indicates that Arnold restoration increases velocities in Nurse Slough and near breaches. Color contours of velocity magnitude at time of peak ebb tide in Figure 25 show increases of up to 0.2 ft/s in Nurse Slough. Figure 26 shows larger increases in peak ebb tide velocities in sloughs near the Arnold breaches. The Alternative 2 configuration results in the highest velocities of approximately 4 ft/s, occurring near the western breach.

Stage and Tidal Range

Restoration impacts on stage and tidal range were minimal. In Figure 27, a comparison of Base and Arnold Restoration stage in Nurse Slough downstream of the Restoration and in Blacklock showed that Alternatives 1 and 3 increased higher high tide by approximately 0.01 ft and increased lower low tide by less than 0.01 ft. Alternative 2 decreased higher high tide by approximately 0.02 ft and increase lower low tide by 0.01 ft or less.

To assess tidal range within the Restoration site, higher high and lower low stage within Arnold, is plotted in Figure 28 for each restoration Alternative (location shown in inset map). While higher high tide is approximately the same for each alternative, lower low tide varies by as much as 1 ft among the alternatives. Alternative 1 shows the lowest stage, indicating that the site drains more completely on lower low tide, while Alternative 2 shows the highest lower low tide.

Tidal Prism

Arnold restoration increases tidal prism in Nurse Slough. Short time series of ebb and flood volume in Nurse Slough (location shown in Figure 27) for the Base and Arnold Restoration Alternatives are shown in Figure 29. The associated tidal flows are plotted in Figure 30. On average, the tidal prism is increased by 15% for Alternative 1, 11% for Alternative 2 and 14% for Alternative 3 during the 2004 simulation period.

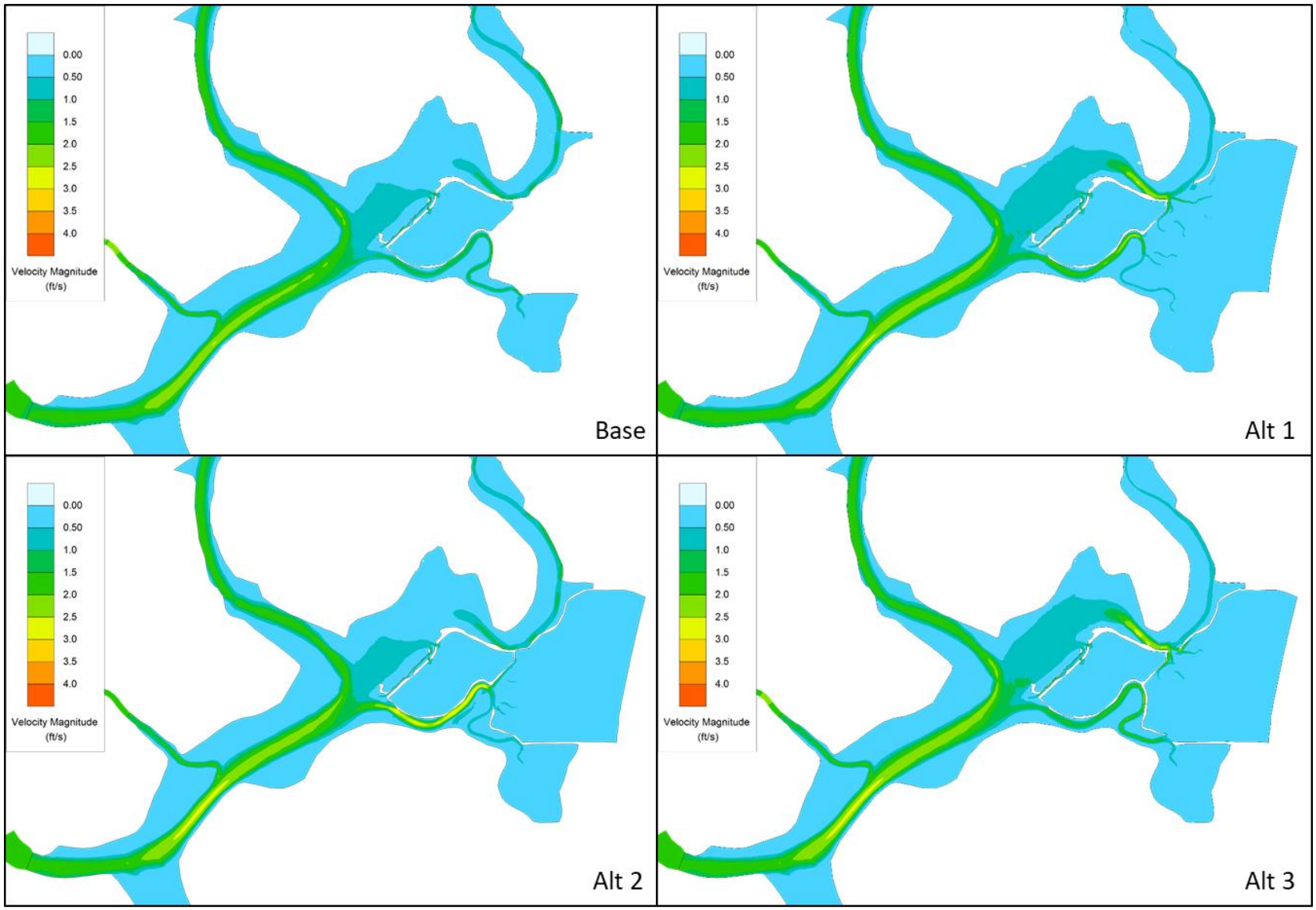

Figure 25 Peak velocities in Nurse Slough near Arnold restoration at peak ebb tide on 03 June 2004.

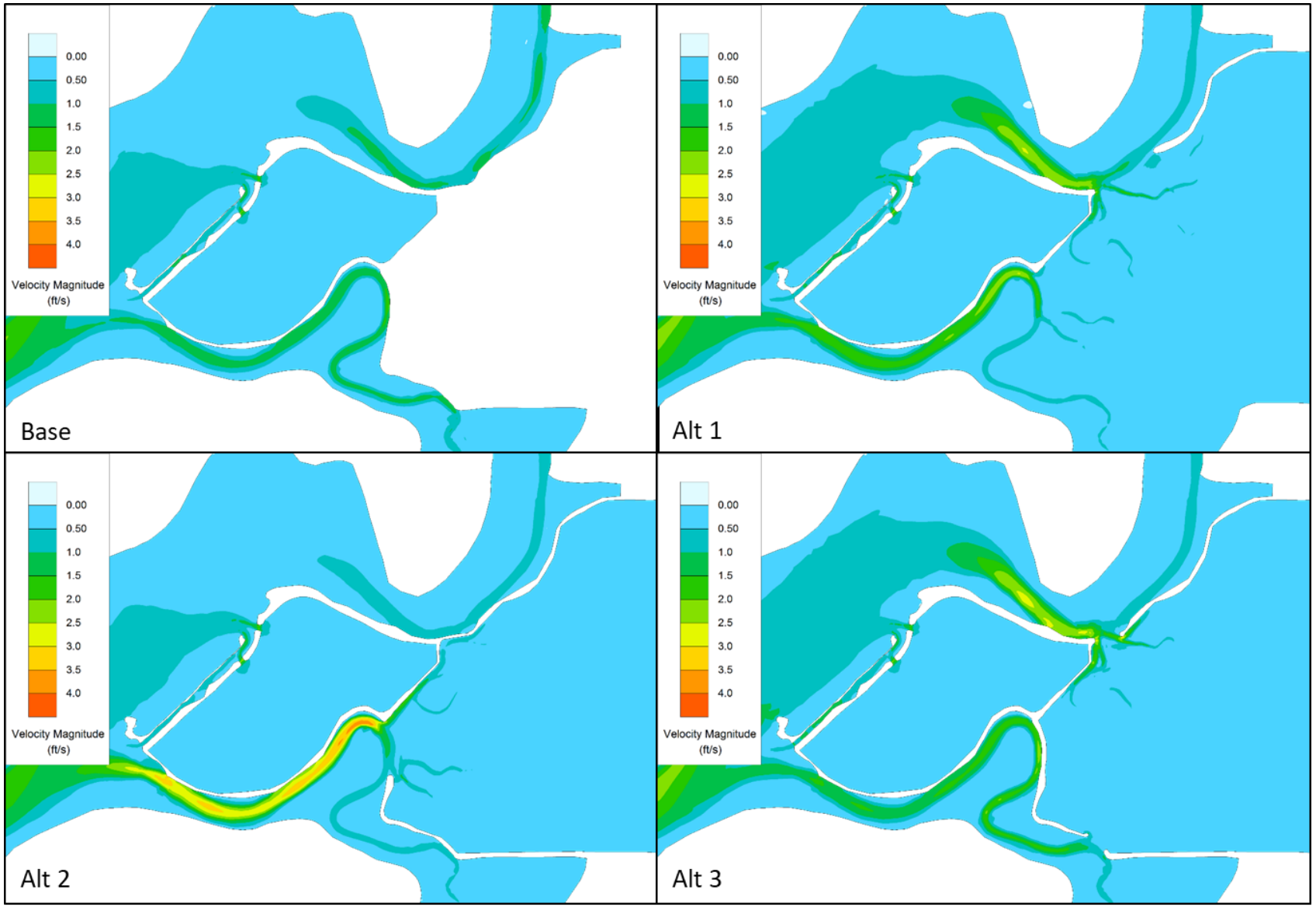

Figure 26 Peak velocities in sloughs near Arnold restoration at peak ebb tide on 03 June 2004.

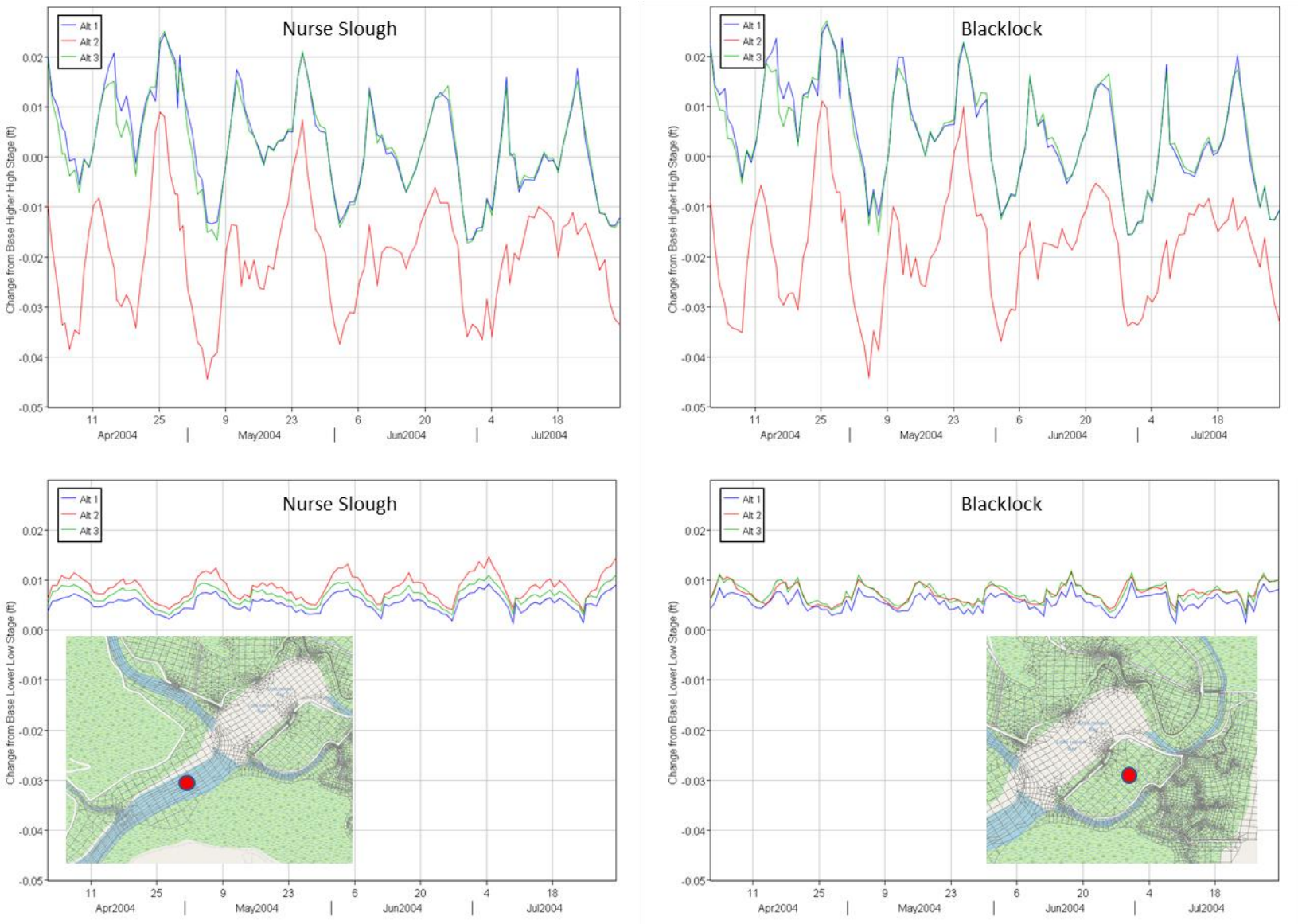

Figure 27 Restoration Alternatives change from Base stage in Nurse Slough and in Blacklock during the 2004 simulation period.

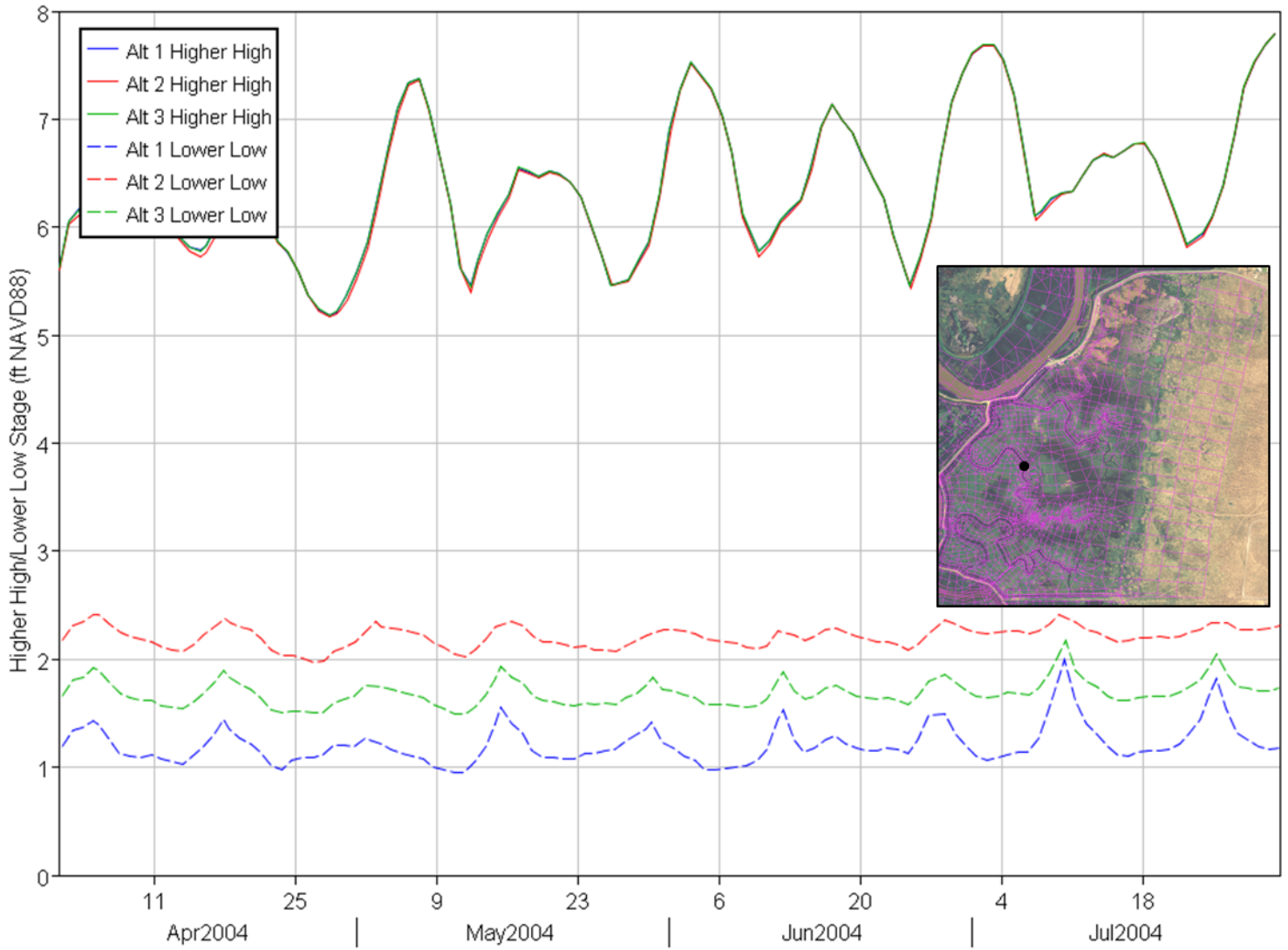

Figure 28 Higher high and lower low stage inside Arnold restoration site for the 2004 simulation period.

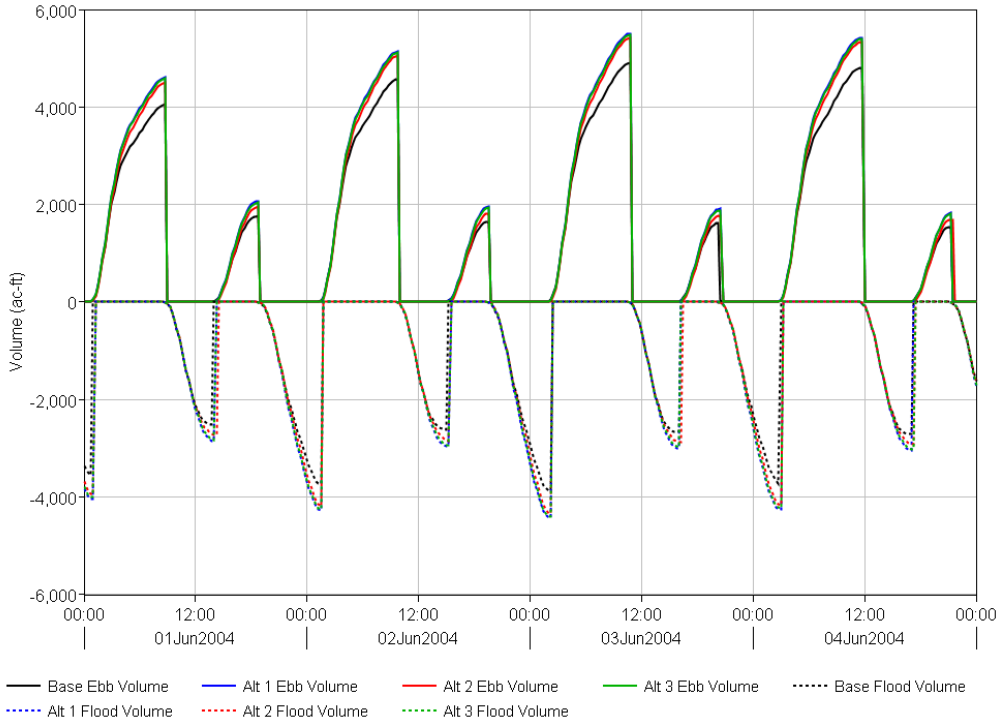

Figure 29 Nurse Slough ebb and flood volume for Base and Arnold Restoration Alternatives during June 2004.

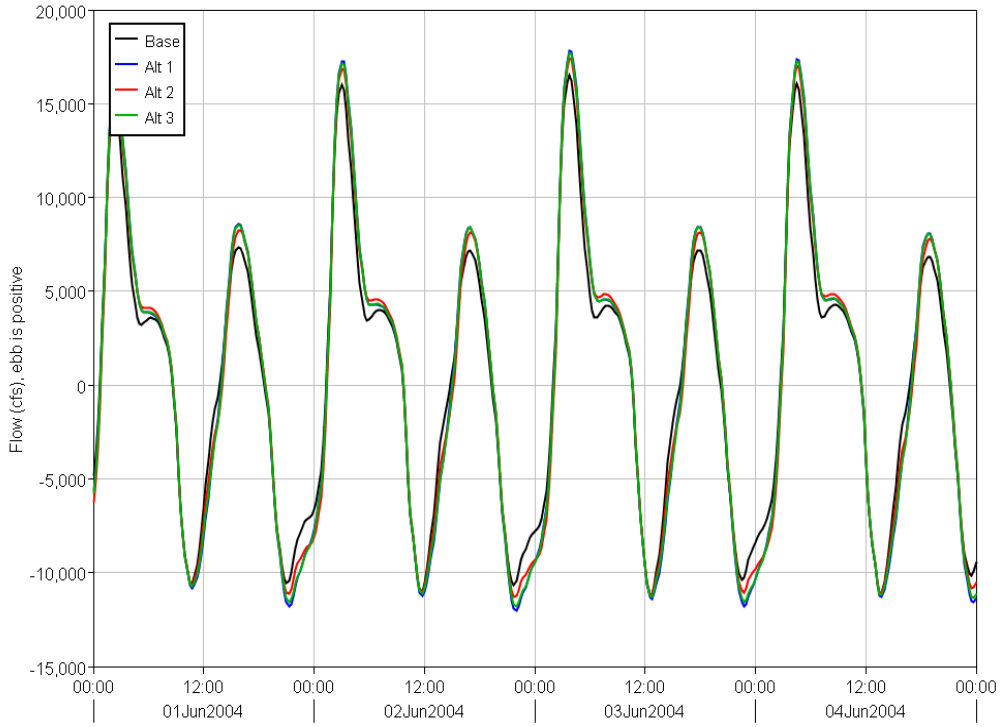

Figure 30 Nurse Slough flows for Base and Arnold Restoration Alternatives during June 2004.

Residence Time Modeling Results

Residence time simulations were performed for April – July 2004 to assess the average amount of time water has spent within the Arnold restoration site under each Alternative. These simulations utilized a water quality simulation with a volumetric tracer applied within Arnold, with results interpreted as average days of residence time.

Residence time results illustrate water volume exchange within the site. Color contour plots of monthly average residence time in July 2004 are shown in Figure 31. These plots indicate the lowest residence times (greatest water volume exchange) occur near the breaches and the highest residence times occur at the northeastern corner of the site. Monthly average residence times in Arnold in July (after the model reaches equilibrium) range from approximately 0.6 days to 1.3 days, with little variation among Alternatives.

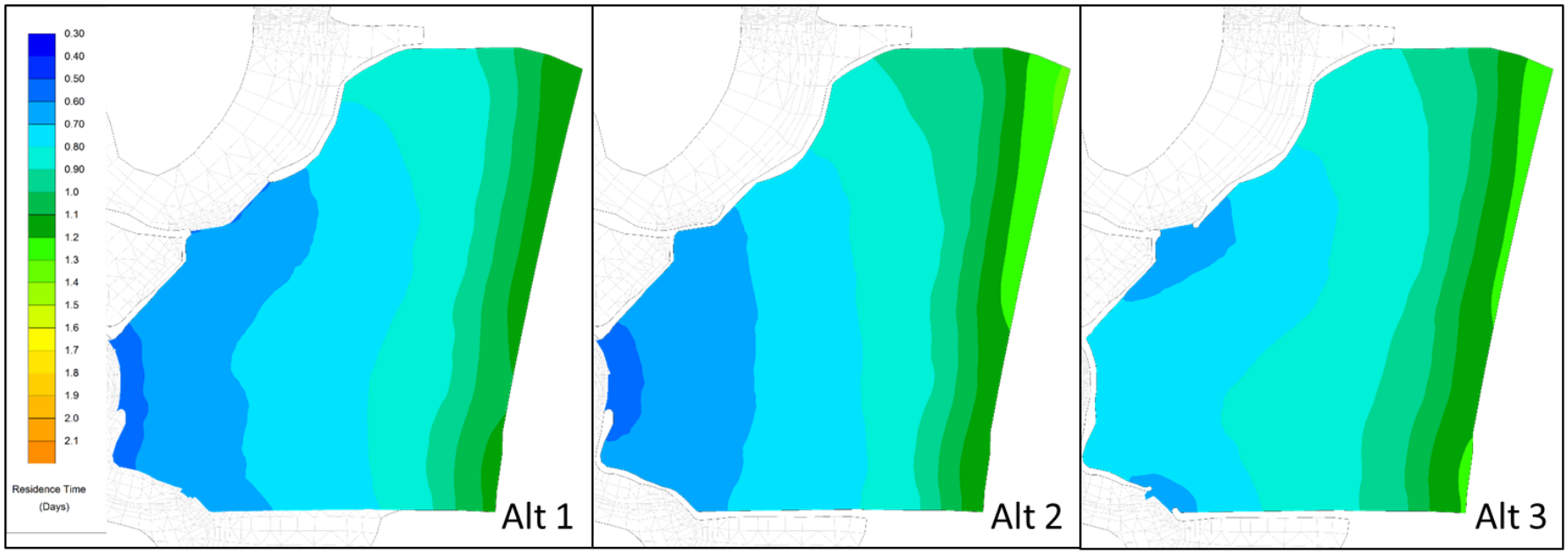

Figure 31 July 2004 monthly average residence time in Arnold for each Alternative.

Arnold Alternative Selection

DWR reviewed modeling results for the three Arnold Alternatives and selected Alternative 1 with modifications, which included eliminating one of the breaches and a starter channel (see Figure 20). All final analysis simulations used the modified Alternative 1.

FINAL ARNOLD AND BRADMOOR ISLAND RESTORATION IMPACTS ANALYSIS

In earlier efforts, DWR screened Bradmoor Island restoration alternatives and provided the final selected alternative grid to RMA. RMA updated this grid to more accurately reflect existing conditions and combined it with the selected Arnold Alternative to perform the final analysis simulations. The simulation period of January – December 2013 represents a recent low flow period.

Hydrodynamic Impacts

January – December 2013 hydrodynamic simulation results for the Base case and final combined Arnold and Bradmoor Island Restoration were analyzed and compared to evaluate expected impact of the Restoration projects on tidal range, velocities and tidal prism in adjacent channels. Tidal range within the Restoration sites were also examined.

Velocities

In Figure 32, a comparison of Base case and Restoration velocities during June 2013 shows that the restorations increase velocities in Nurse Slough. Peak ebb tide velocities increase from around 2.6 ft/s for the Base case to around 3.5 ft/s with Restoration.

Stage and Tidal Range

Restoration impacts on stage and tidal range were minimal. During 2013, the monthly average reduction in mean higher high water was 0.1’ or less and the monthly average increase in mean lower low water was 0.06’ or less. In Figure 33, a color contour plot of July 2013 MHHW in the Restoration sites shows that Bradmoor Island wetland areas are fully inundated and all but the eastern edge of Arnold is fully inundated at MHHW.

Tidal Prism

With Bradmoor Island and Arnold both restored, tidal prism in Nurse Slough (location shown in Figure 27) is increased by 56% on average over the simulation period. Short time series of ebb and flood volume in Nurse Slough for the Base and Restoration cases are shown in Figure 34. The associated tidal flows are plotted in Figure 35.

Net Flow

Restoration impacts net flow in Montezuma Slough, particularly when the Suisun Marsh Salinity Control Gates (SMSCG) are operating during parts of May, November and December of 2013 (a plot of Base case tidal flows at the SMSCG in Figure 36 illustrates periods of operation). A plot of SMSCG net flows in Figure 37 shows that during periods when the SMSCG are operating, net flows decrease by around 10 – 15% for the Restoration case relative to Base.

Tidal flows are plotted in Figure 36 for a brief period during November when the SMSCG are operating to illustrate the dynamics causing the net flow reduction for the Restoration case.

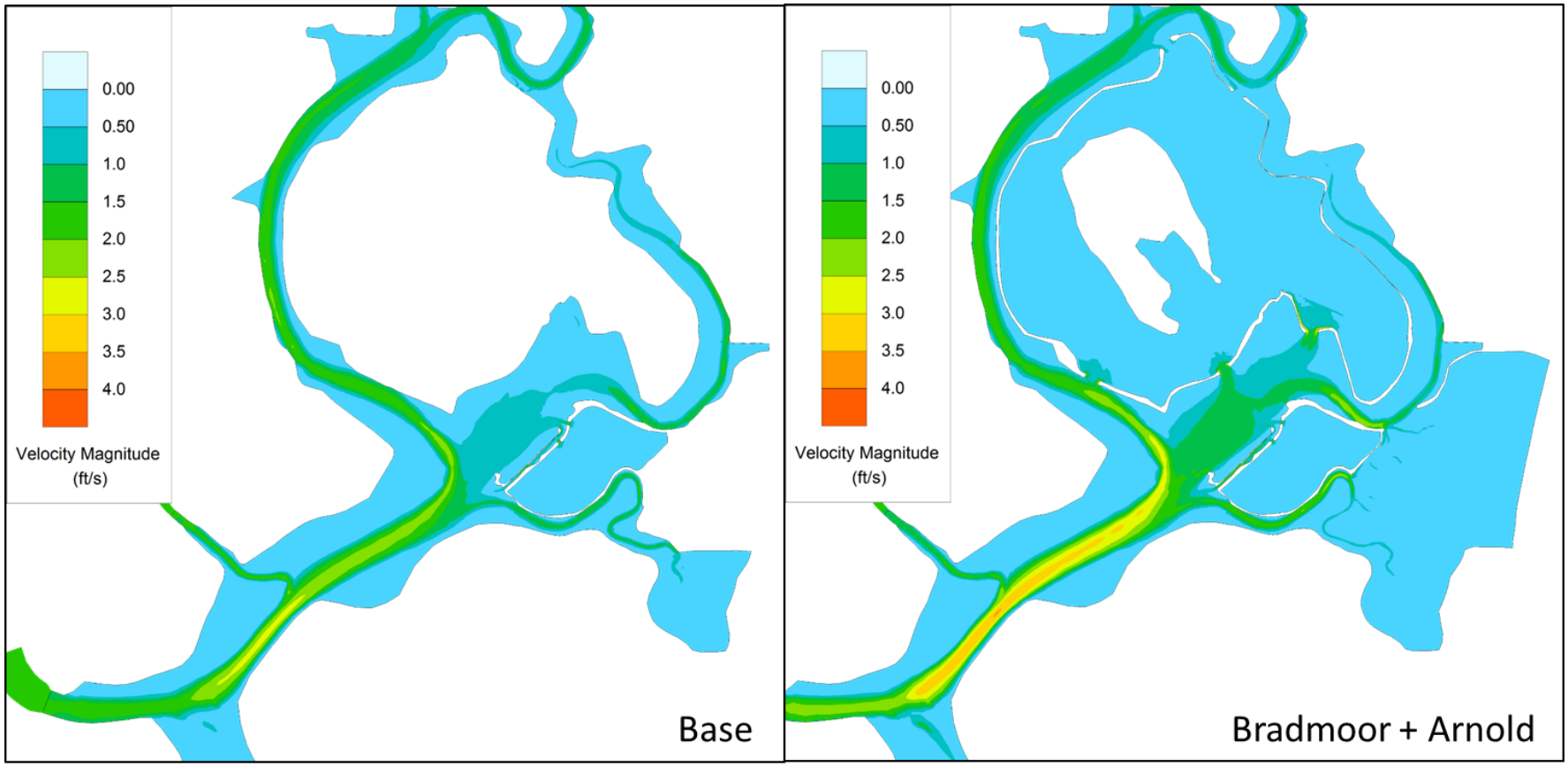

Figure 32 Peak velocities near Bradmoor and Arnold Restoration sites on 24 June 2013, during peak ebb tide.

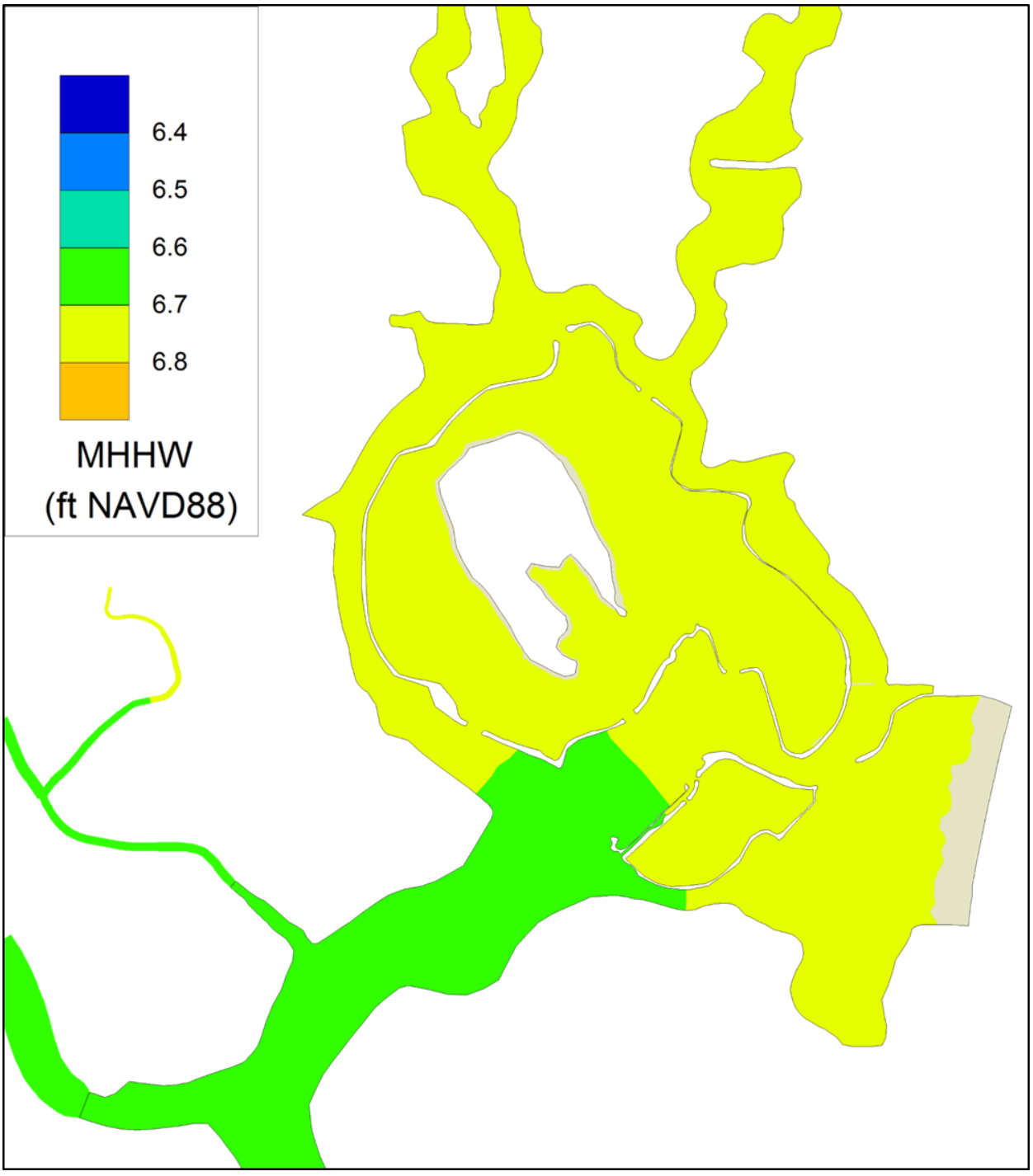

Figure 33 July 2013 mean higher high water in and near the Restoration sites.

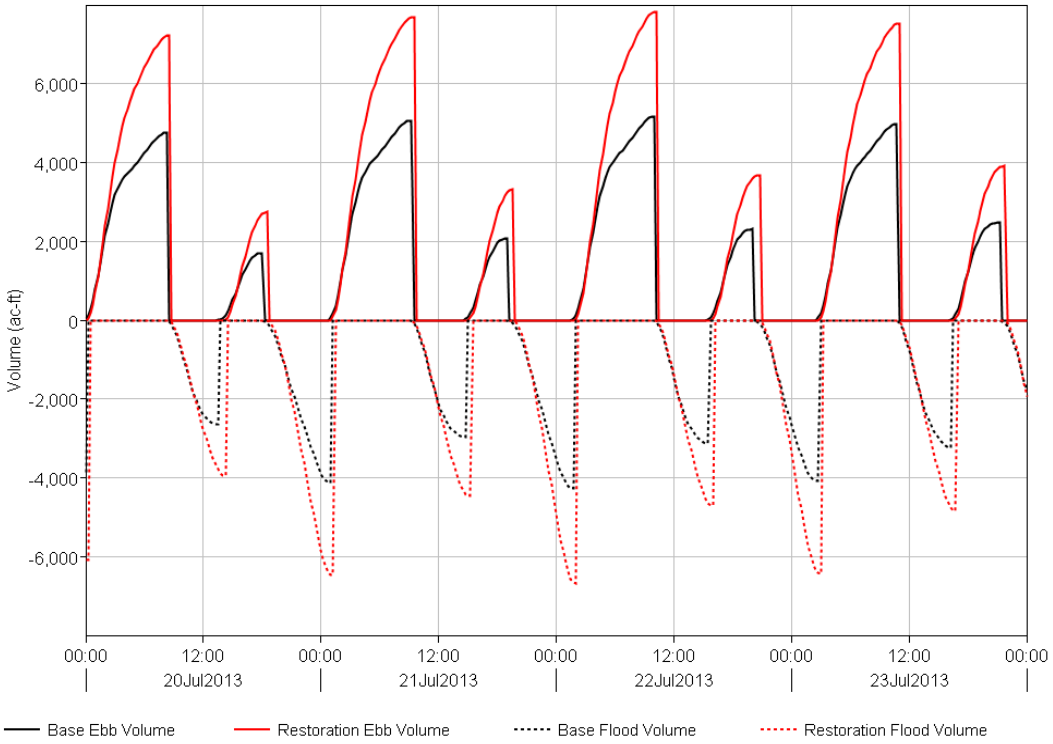

Figure 34 Nurse Slough ebb and flood volume for Base and Restoration cases during July 2013.

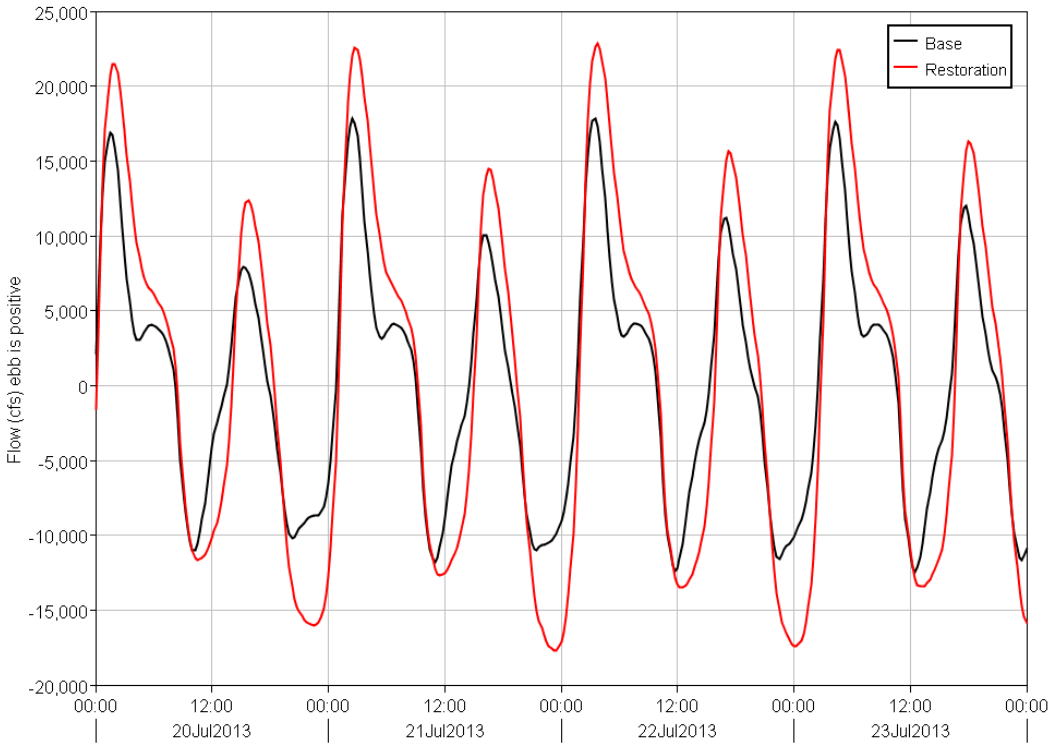

Figure 35 Nurse Slough flows for Base and Restoration cases during July 2013.

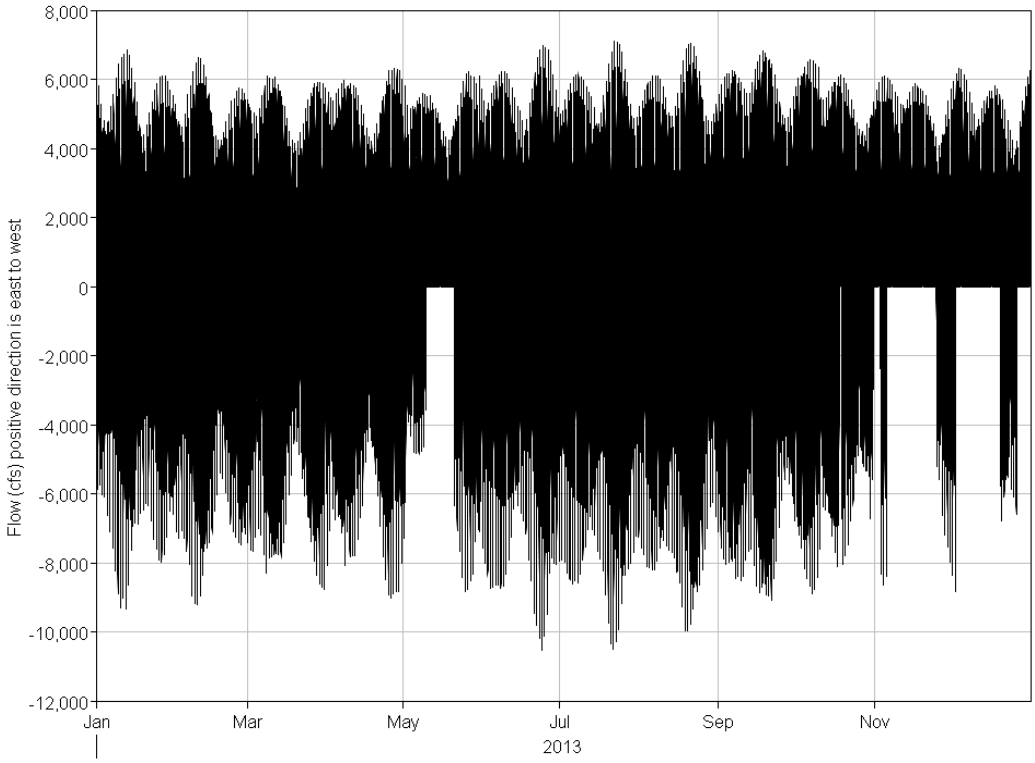

Figure 36 Base case tidal flows at Suisun Marsh Salinity Control Gates.

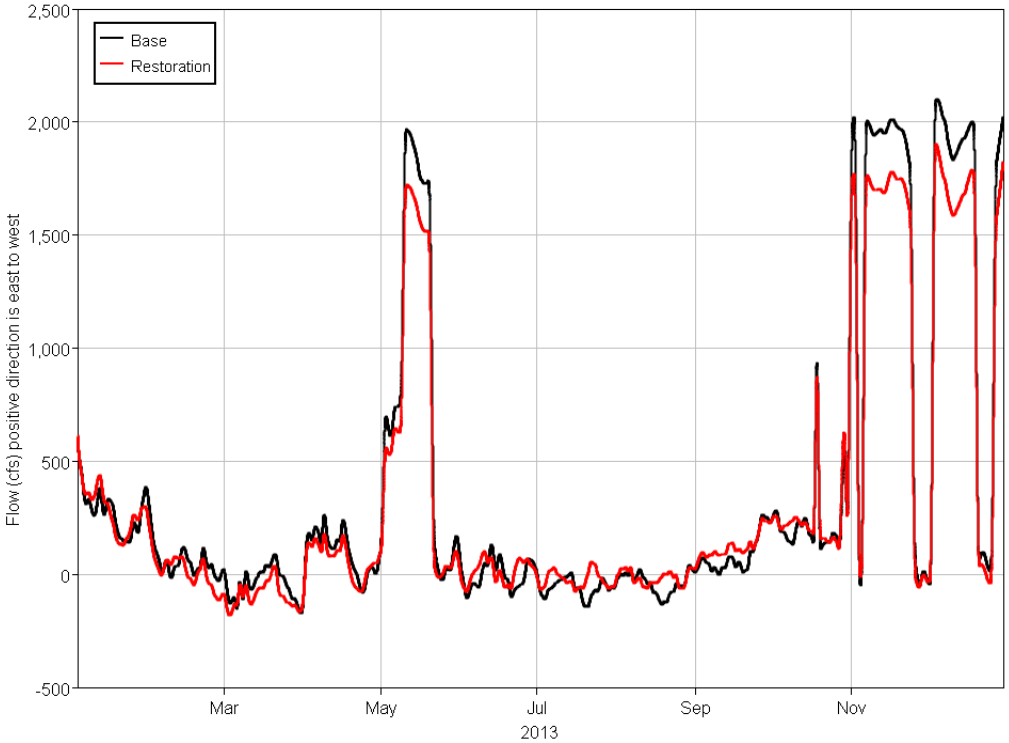

Figure 37 Base and Restoration case net flows at Suisun Marsh Salinity Control Gates.

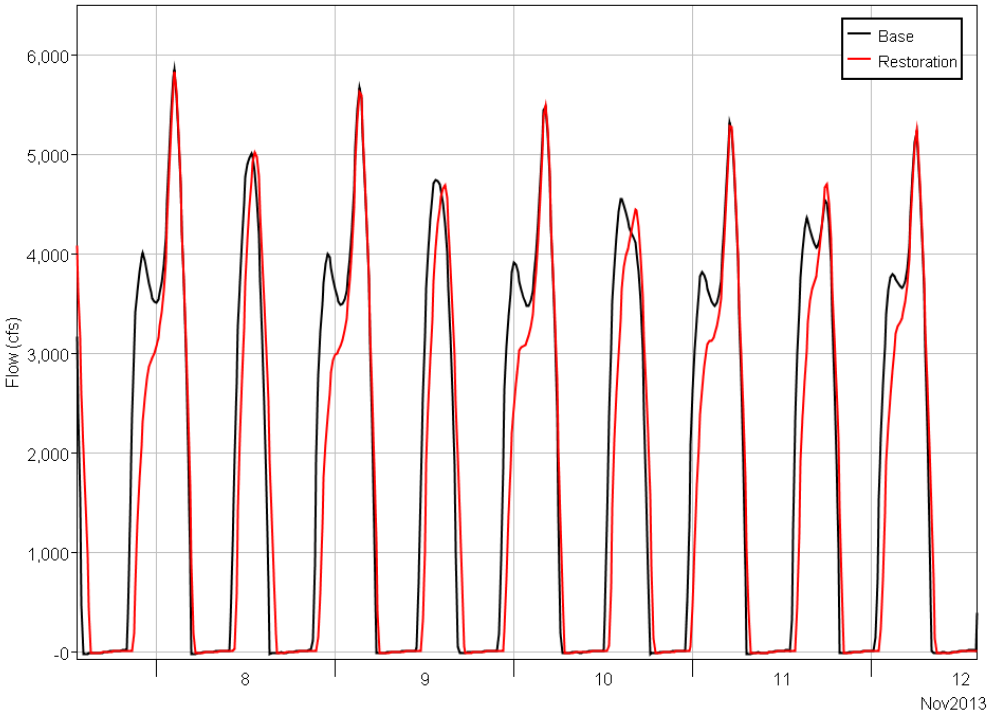

Figure 38 Base and Restoration case tidal flows at Suisun Marsh Salinity Control Gates during a period of gate operation.

Bradmoor Island Residence Time Modeling Results

Residence time simulations were performed for April – July 2013 to assess the average amount of time water has spent within the Bradmoor Island restoration site. These simulations utilized a water quality simulation with a volumetric tracer applied within Bradmoor Island, with results interpreted as average days of residence time. Note that although the analysis is of Bradmoor Island only, both restoration sites are included in the model grid.

Residence time results illustrate water volume exchange within the site. A color contour plot of monthly average residence time in July 2013 is shown in Figure 39. This plot indicates that the lowest residence times (greatest water volume exchange) occur near the southern breaches and the highest residence times occur midway between the northern and southern breaches. Monthly average residence times in Bradmoor Island in July (after the model reaches equilibrium) range from approximately 1.6 days to 2.8 days.

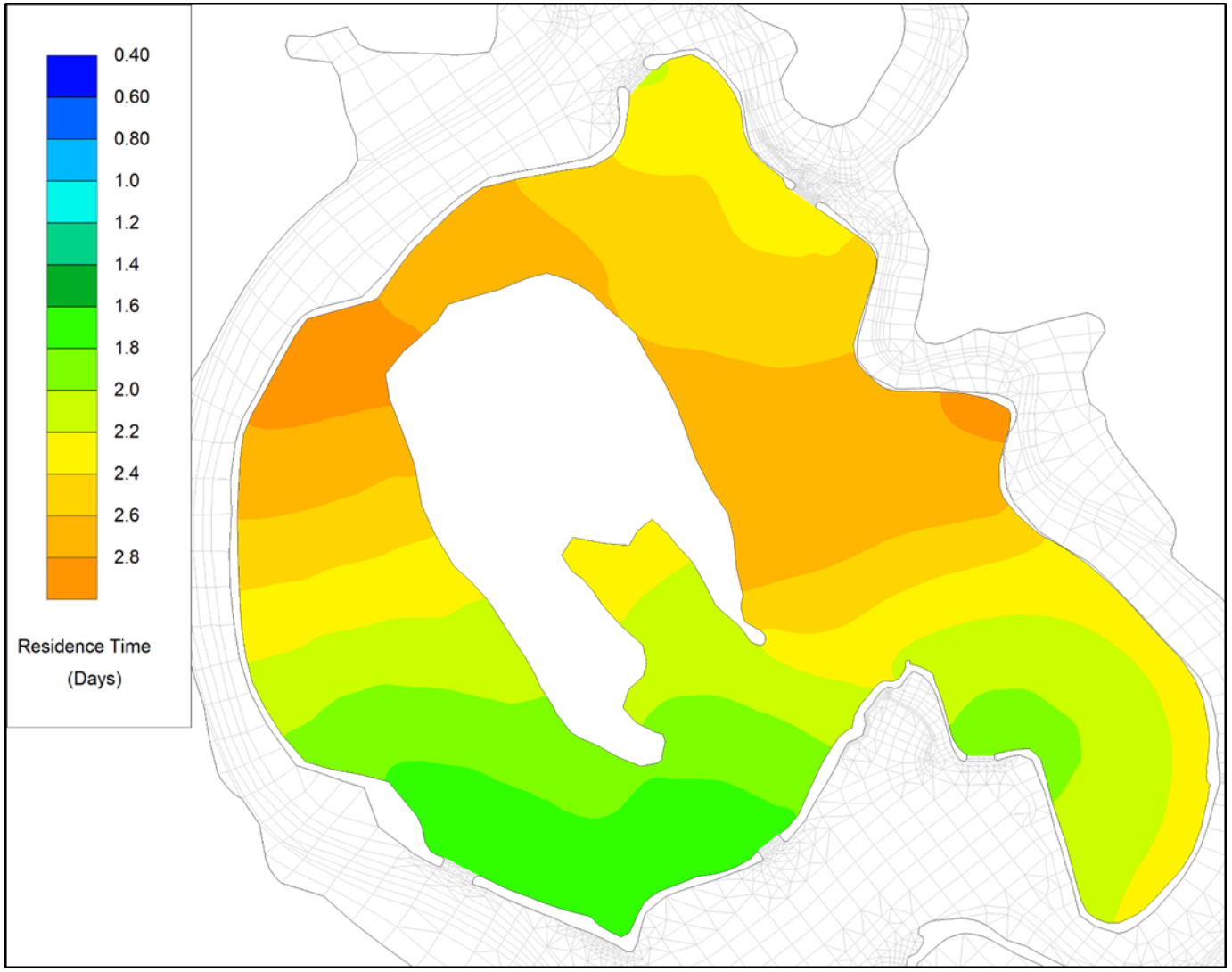

Figure 39 July 2013 monthly average residence time in Bradmoor Island.

Particle Track Modeling Results

Particle tracking simulations were performed for July 1 – July 28, 2013 to assess the impact of the combined Bradmoor and Arnold Restorations on particle residence time in Nurse Slough. All restoration particle simulations used the hydrodynamic model results with both Bradmoor and Arnold restored. Four particle simulations were performed, each with 3000 particles dropped every 2 hours for the first 14 days of the simulation. Any particles dropped in dry areas were removed from the simulation. For the Base case, particles were dropped within Nurse Slough as shown in Figure 40. Three Restoration case simulations were performed:

1. Particles dropped in Nurse Slough outside Restoration areas, as shown in Figure 41. Purpose: to assess impact of Restorations on Nurse Slough residence times, directly comparable to the Base case.
2. Particles dropped in Nurse Slough, including Restoration areas, as shown in Figure 42. Purpose: to assess overall residence time in Nurse Slough, including Restoration areas.
3. Particles dropped in Bradmoor only, as shown in Figure 43. Purpose: to assess residence time of Bradmoor particles in Nurse Slough under final restored condition.

Particles reaching Montezuma Slough were killed and particle age was logged. Results at the end of the 28-day simulation period are summarized in Table 3. Results indicate that Restoration reduces residence time in Nurse Slough. Average age of Nurse Slough particles when reaching Montezuma Slough is reduced by 1.5 days due to Restoration of Bradmoor Island and Arnold and the percentage of particles spending one day or less in Nurse Slough is increased by 13%. Figure 44 shows the distribution of particle age when reaching Montezuma Slough for each of the particle simulations.

Table 3 Summary of particle modeling results.

Modeled Condition	Particle drop location	% of Particles Reaching Montezuma Slough	Average particle age when reaching Montezuma Slough (days)	% of particles spending one day or less in Nurse Slough
Base	Nurse Slough	92	5.1	28
Restoration	Nurse Slough	96	3.6	41
Restoration	Nurse Slough and Restoration Sites	97	3.7	35
Restoration	Bradmoor	97	4.6	17

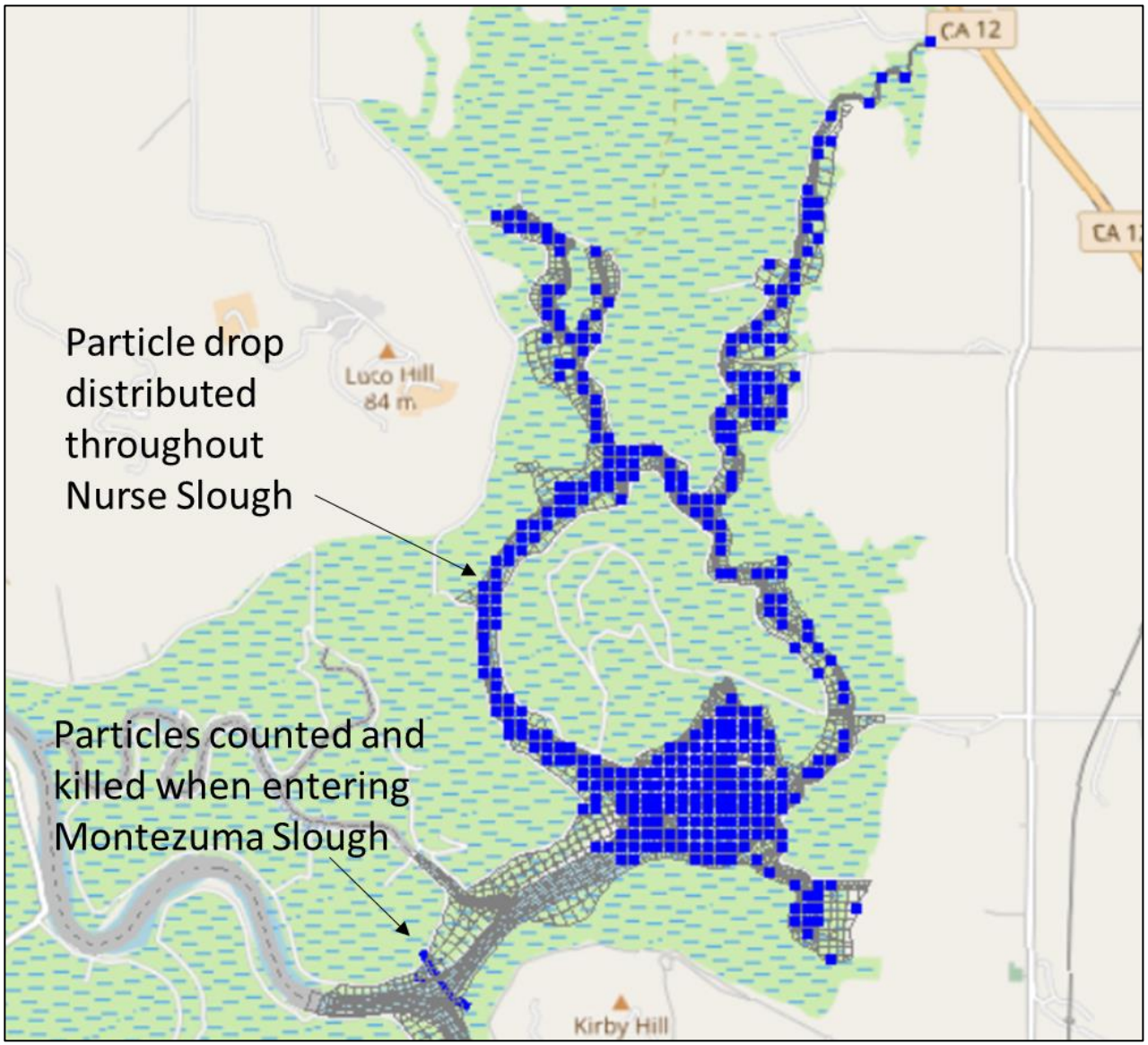

Figure 40 Base case particle drop locations and particle kill line.

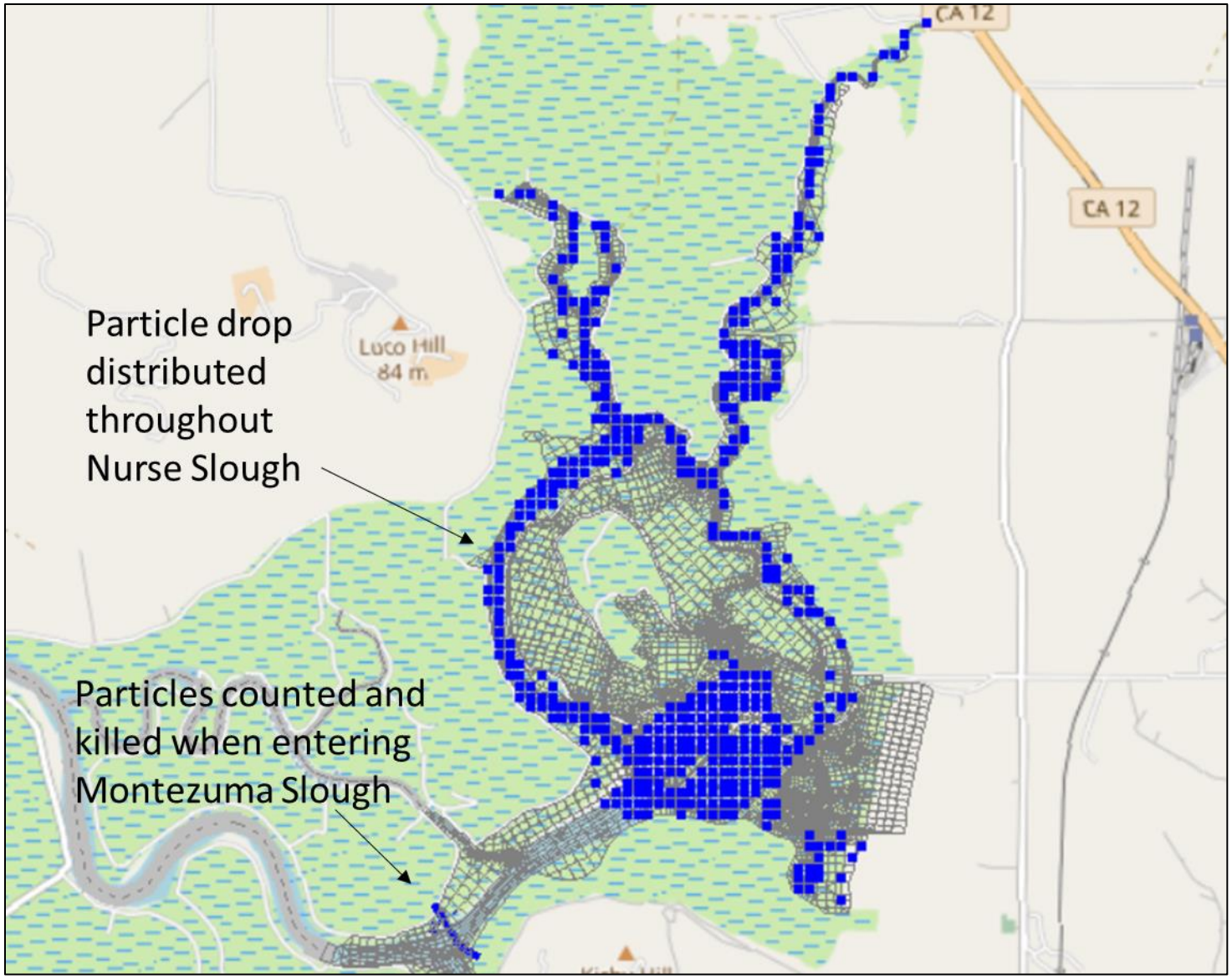

Figure 41 Restoration case Nurse Slough particle drop locations outside Restoration sites, and particle kill line.

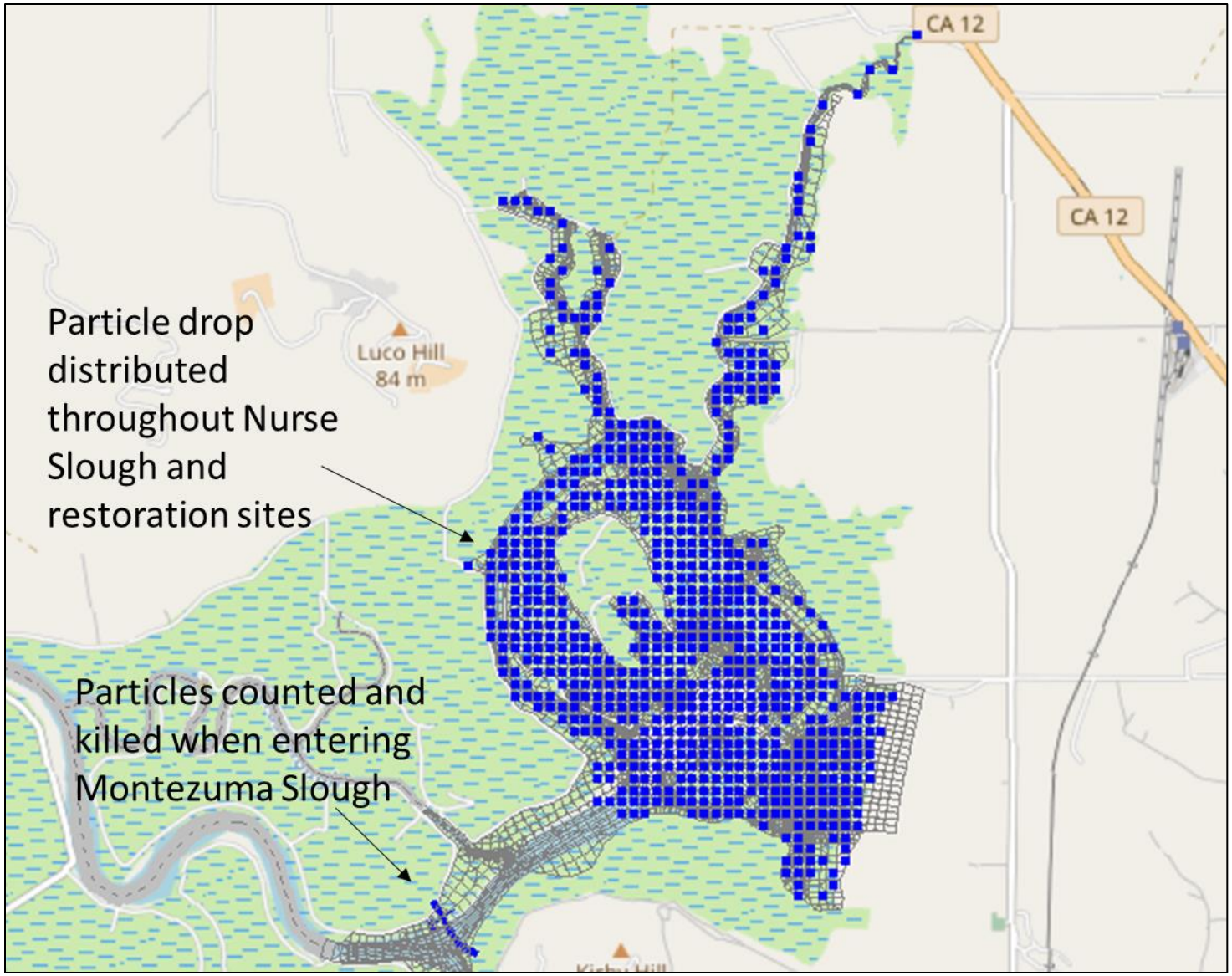

Figure 42 Restoration case Nurse Slough and Restoration sites particle drop locations, and particle kill line.

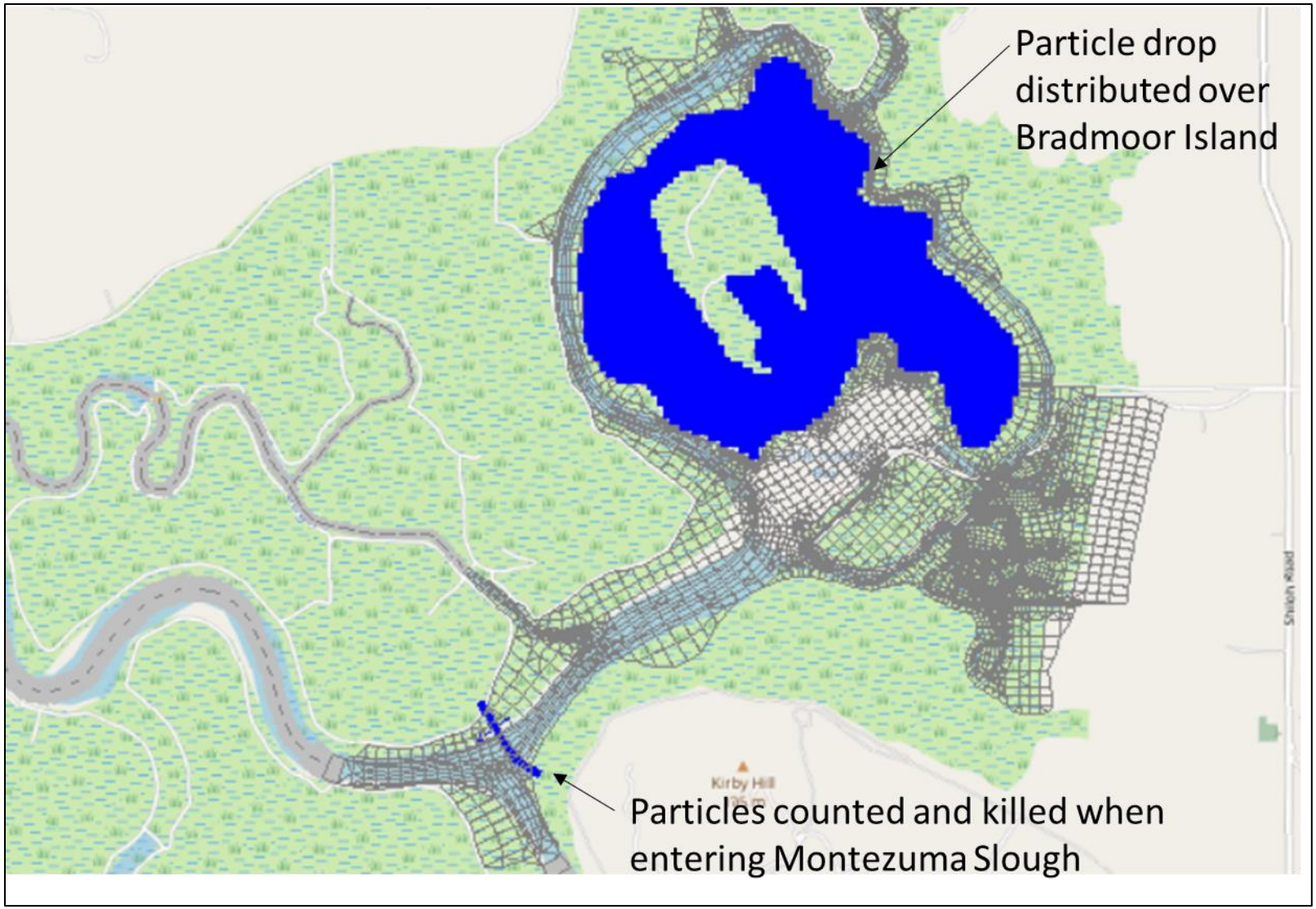

Figure 43 Restoration case Bradmoor Island particle drop locations, and particle kill line.

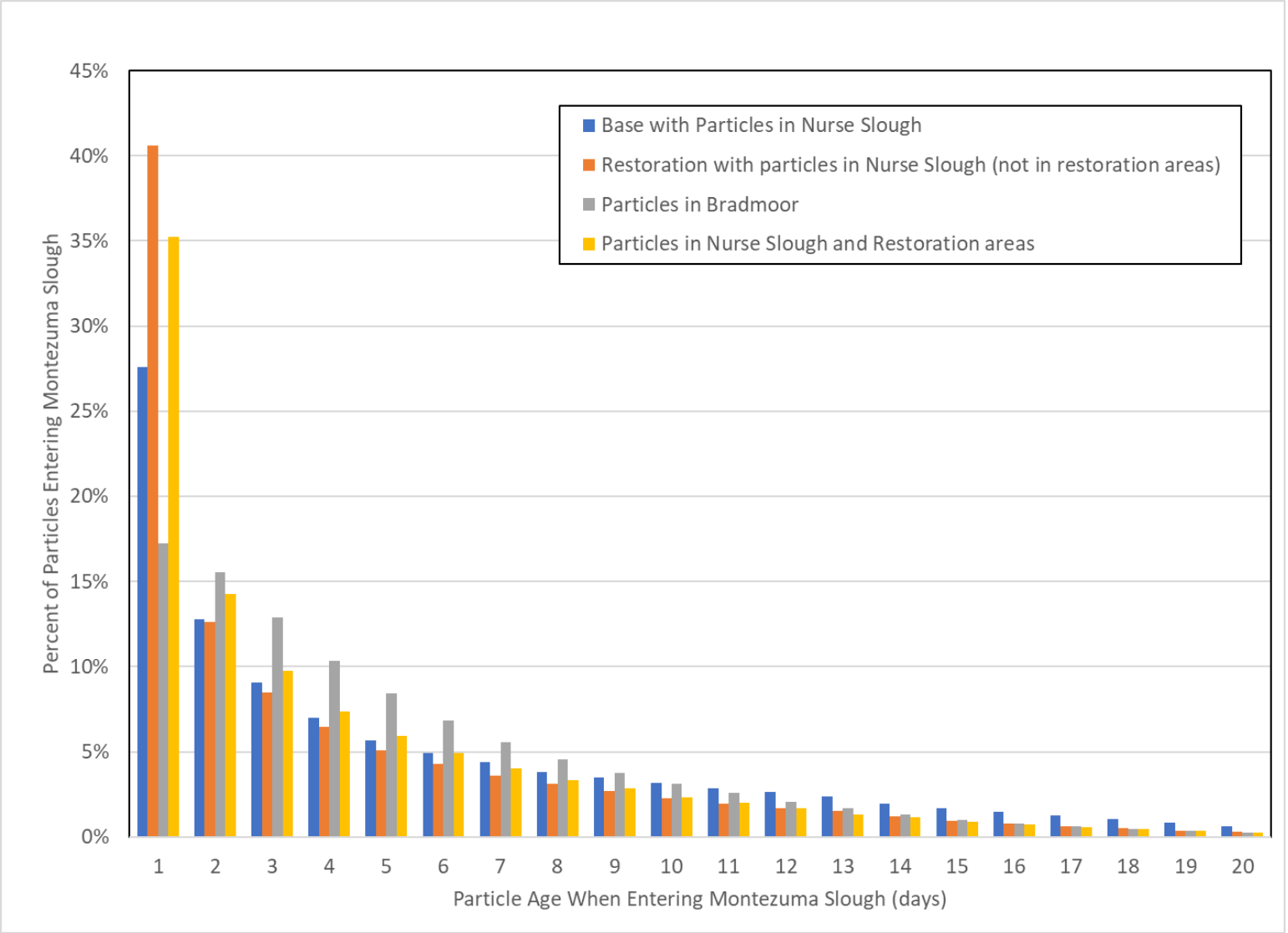

Figure 44 Distribution of particle age when entering Montezuma Slough.

EC Impacts

EC simulations were performed for the 2013 period to assess the potential impacts of the Bradmoor Island and Arnold Restorations on local and regional EC. April through December results are considered for analysis, leaving January through March for model spin-up.

Table 4 summarizes monthly average Base EC, Restoration change from Base EC and percent change from Base EC at key locations (see Figure 45 for locations). Results indicate that Restoration resulted in decreases or very small increases in monthly averaged salinity at locations east of Collinsville. Salinity increases of 3-4% occurred at Collinsville during the summer and early fall. Salinity increases occurred at Beldon's Landing, particularly when the Suisun Marsh Salinity Control Gates were operating, due to decreased net flow in Montezuma Slough (see Figure 37).

From the September and November results for the Base and Restoration simulations, EC percent change from Base was computed throughout the model network. Example spatial plots of daily average percent change from Base EC for the Restoration case are provided for 10 Sep 2013 and 10 Nov 2013 in Figure 46 and Figure 47, respectively. The SMSCG were open in September and operating during most of November.

The September results show small changes in the Delta, salinity increases in Nurse Slough and around Beldon's Landing, and salinity decreases as high as 9% between the head of Montezuma Slough and Nurse Slough. In November, the peak salinity increases in Suisun Marsh are larger and shifted west out of Nurse Slough. Salinity decreases through the central and south Delta range from approximately 0.3 to 1.6%.

Table 4 Monthly average Base, Restoration change from Base and percent change from Base EC.

	Beldon's Landing			Sac at Mallard			Collinsville			Emmaton			Rio Vista		
	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base
Apr 2013	4426	245	5.5%	1845	-19.3	-1.0%	567	19	3.4%	218	-0.8	-0.4%	190	-0.1	0.0%
May 2013	2588	396	15.3%	3223	-59	-1.8%	1104	9	0.8%	269	-3.3	-1.2%	179	-0.1	-0.1%
Jun 2013	6096	246	4.0%	4839	-33	-0.7%	1816	75	4.1%	399	-5.0	-1.3%	178	-0.3	-0.2%
Jul 2013	9421	177	1.9%	7100	-28	-0.4%	2983	117	3.9%	516	-6.8	-1.3%	158	-0.4	-0.2%
Aug 2013	12120	193	1.6%	8160	-32	-0.4%	3542	117	3.3%	574	-7.7	-1.3%	178	-0.4	-0.2%
Sep 2013	12884	102	0.8%	7660	-26	-0.3%	3347	104	3.1%	630	-6.8	-1.1%	208	-0.6	-0.3%
Oct 2013	13936	190	1.4%	10160	-36	-0.4%	5156	113	2.2%	1271	-11.7	-0.9%	247	-1.7	-0.7%
Nov 2013	8156	526	6.4%	11553	-143	-1.2%	6356	-52	-0.8%	1406	-28.5	-2.0%	257	-2.3	-0.9%
Dec 2013	7049	440	6.2%	10671	-170	-1.6%	5728	-78.3	-1.4%	1276	-33	-2.6%	277	-2.6	-0.9%

	Antioch			Jersey Point			San Andreas Landing			Rock Slough			Old River at Hwy 4		
	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base
Apr 2013	395	-1.7	-0.4%	249	-0.3	-0.1%	201	-0.1	-0.1%	352	0.0	0.0%	359	-0.1	0.0%
May 2013	622	-10.7	-1.7%	276	-1.5	-0.5%	218	-0.2	-0.1%	357	0.1	0.0%	349	0.2	0.0%
Jun 2013	1086	-8	-0.7%	362	-3.1	-0.9%	199	-0.4	-0.2%	313	-0.8	-0.2%	307	-1	-0.2%
Jul 2013	2079	-1	0.0%	756	-2	-0.2%	250	-0.4	-0.2%	355	-1.4	-0.4%	323	-1	-0.4%
Aug 2013	2671	4	0.1%	1127	1	0.1%	359	0.3	0.1%	557	-1.1	-0.2%	489	-1	-0.2%
Sep 2013	2335	5	0.2%	997	2	0.2%	338	0.4	0.1%	658	0.1	0.0%	552	0	0.0%
Oct 2013	3130	-2	-0.1%	962	-4	-0.4%	290	-0.7	-0.3%	502	-0.7	-0.1%	439	-1	-0.2%
Nov 2013	3754	-51	-1.4%	1196	-13.7	-1.1%	355	-2.0	-0.6%	569	-3.6	-0.6%	524	-3	-0.6%
Dec 2013	3450	-69	-2.0%	1163	-22.3	-1.9%	421	-4.3	-1.0%	643	-6.9	-1.1%	579	-6	-1.1%

	SWP			CVP			Victoria Canal		
	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base	Base	Change from Base	% Change from Base
Apr 2013	493	-0.1	0.0%	548	-0.2	0.0%	356	0.0	0.0%
May 2013	328	0.1	0.0%	332	0.0	0.0%	362	0.3	0.1%
Jun 2013	333	-0.4	-0.1%	387	-0.3	-0.1%	305	-0.1	0.0%
Jul 2013	298	-1	-0.3%	293	-0.8	-0.3%	240	-0.4	-0.2%
Aug 2013	432	0	-0.1%	400	-0.6	-0.1%	292	-0.2	-0.1%
Sep 2013	498	0	0.0%	483	0.0	0.0%	348	0.0	0.0%
Oct 2013	418	-1	-0.1%	434	-0.4	-0.1%	342	-0.4	-0.1%
Nov 2013	506	-2.3	-0.5%	536	-1.7	-0.3%	408	-1.7	-0.4%
Dec 2013	589	-4.8	-0.8%	665	-3.4	-0.5%	464	-4.0	-0.9%

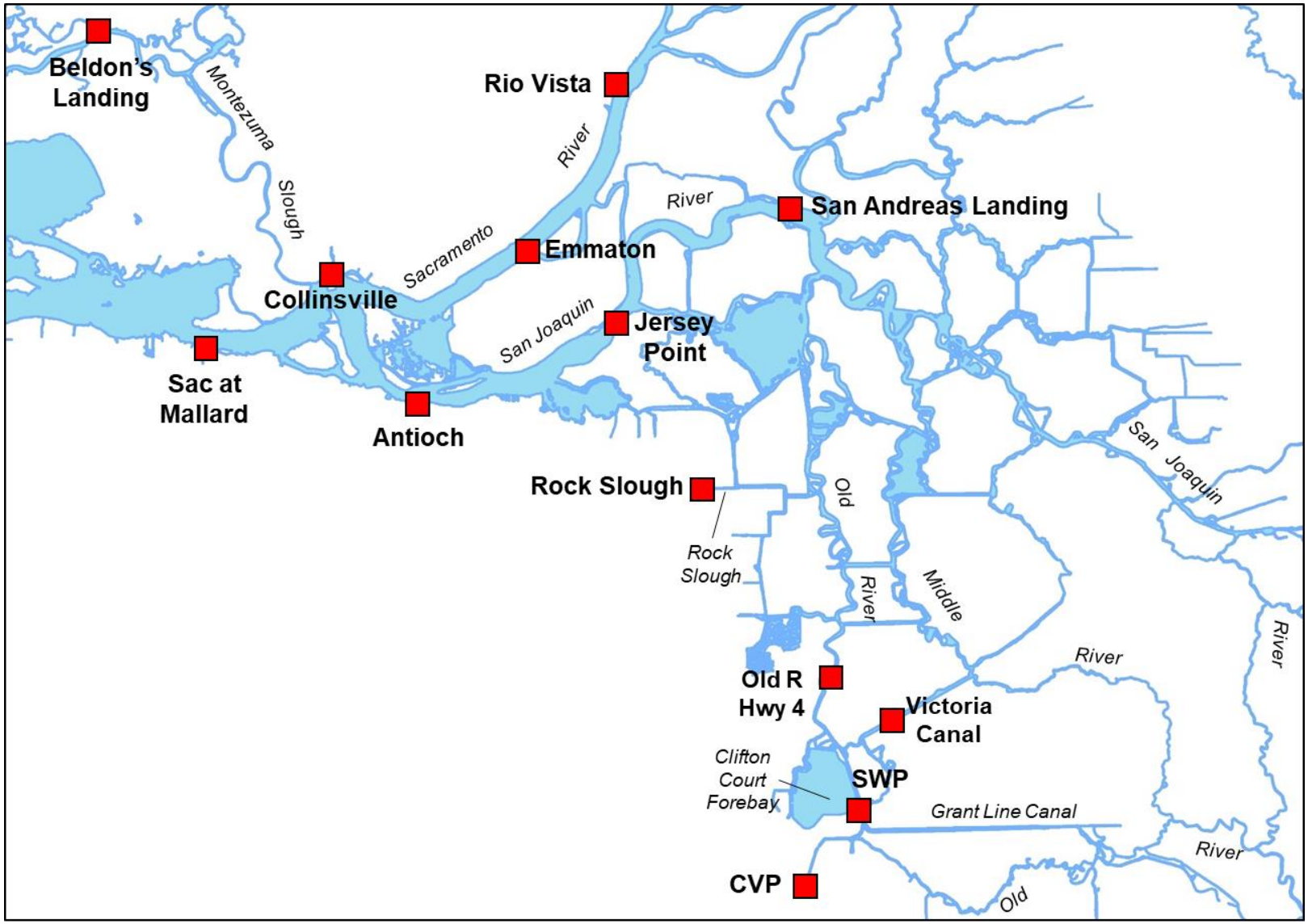

Figure 45 EC output locations.

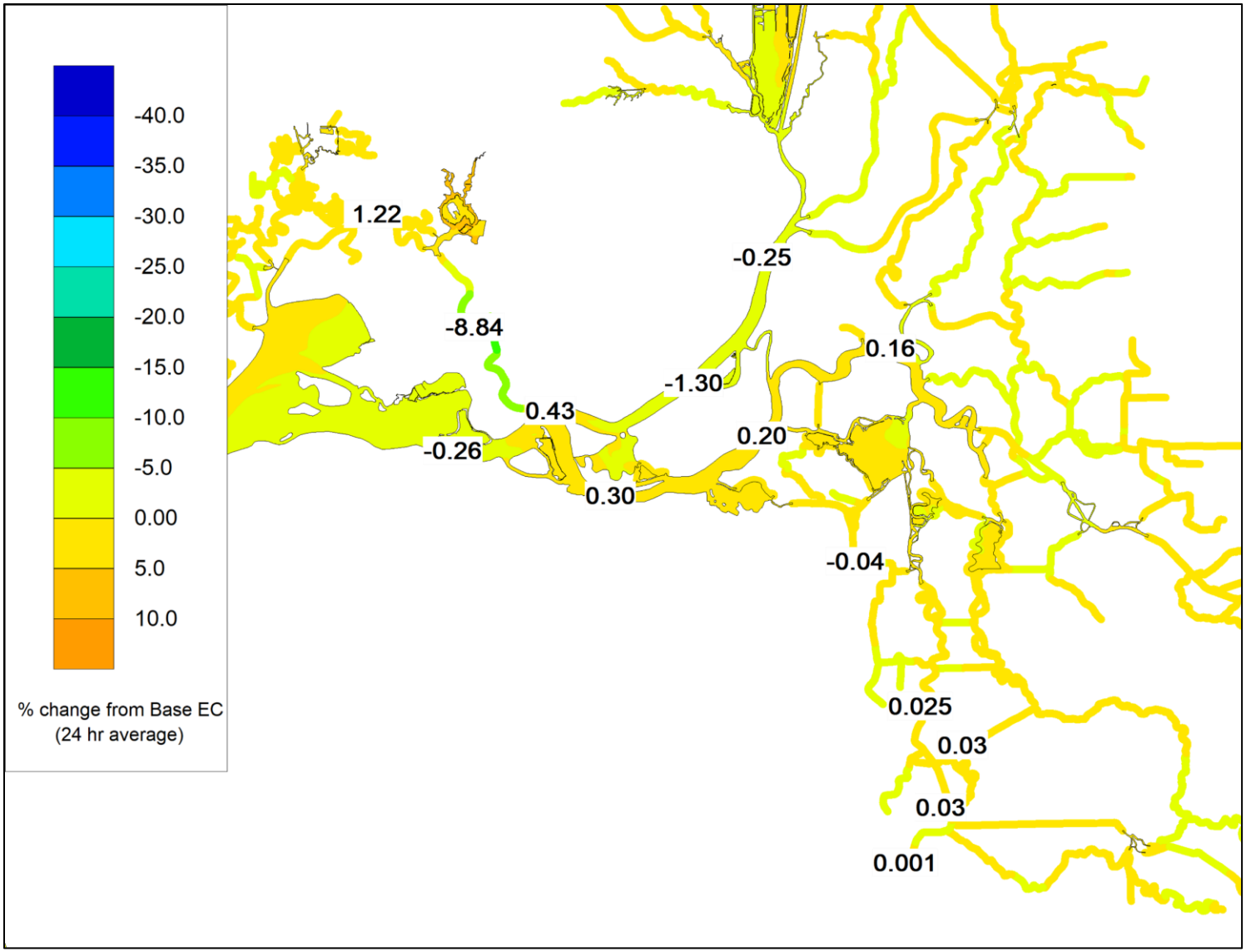

Figure 46 Bradmoor Island and Arnold Restoration case, 24-hour average percent change from Base EC on 10 Sep 2013.

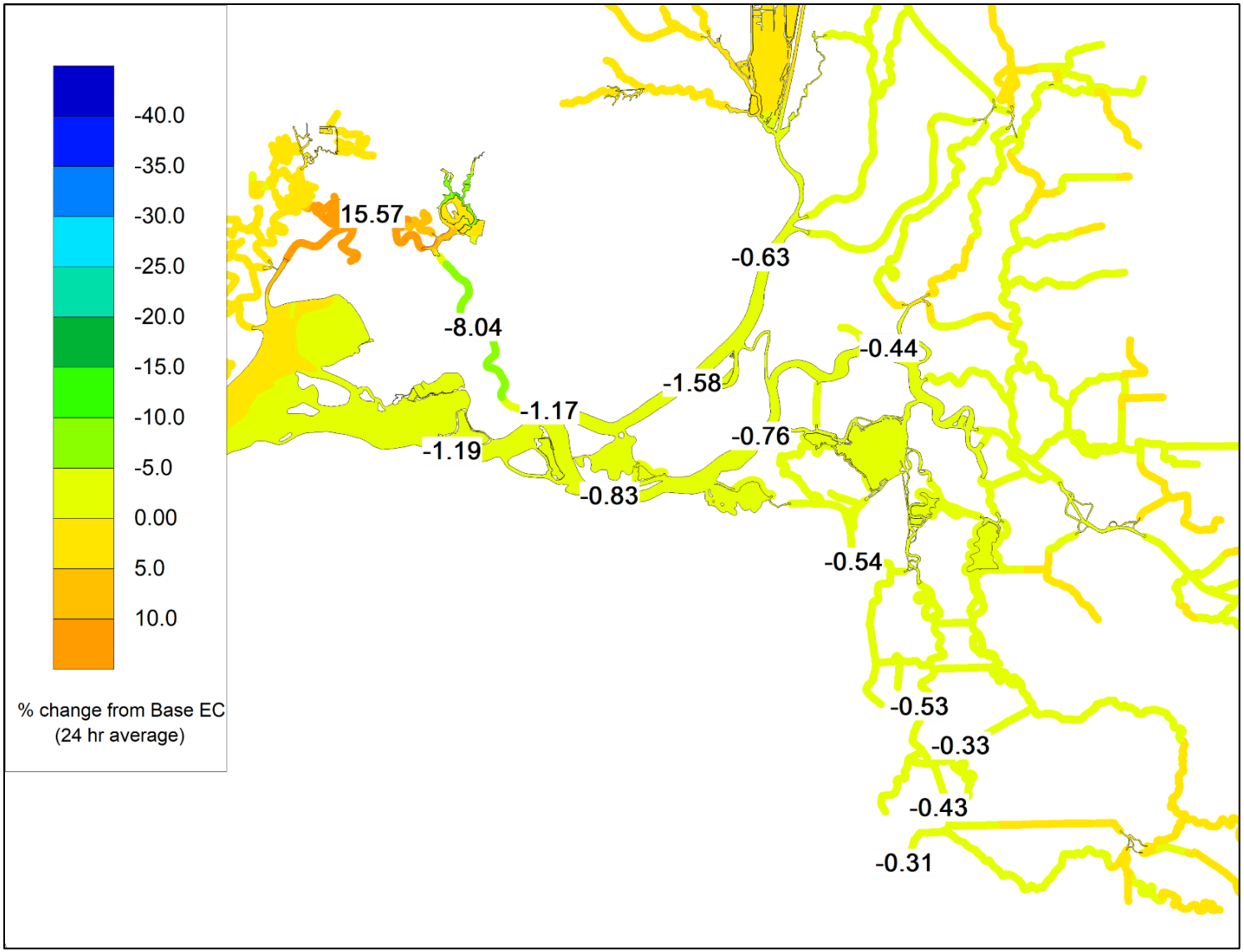

Figure 47 Bradmoor Island and Arnold Restoration case, 24-hour average percent change from Base EC on 10 Nov 2013.

SUMMARY

The RMA Bay-Delta numerical model for flow and water quality was applied to evaluate local and regional impacts of the proposed 490-acre Bradmoor Island and 180-acre Arnold tidal marsh restoration projects.

Initial screening simulations were performed to select a preferred alternative for Arnold. Hydrodynamic and residence time simulations were performed to assess three alternative restoration configurations. DWR reviewed modeling results and selected a final preferred alternative with modifications. The final Arnold alternative included lowering levees to marsh plain elevation, three breaches to external sloughs, dredging of some existing interior channels and filling of borrow ditches adjacent to existing levees.

Earlier modeling efforts by DWR resulted in selection of a preferred Bradmoor Island Restoration alternative, which was provided to RMA. The selected Bradmoor Island alternative included five external breaches and lowering of two internal levees.

Final simulations were performed with combined selected restoration alternatives for Arnold and Bradmoor Island. The final analysis was performed for the dry/critically dry period of January through December of 2013. Hydrodynamics, salinity, residence time and particle exposure time were analyzed.

Hydrodynamic impacts included increased velocities and tidal prism in local channels. Velocity increases occurred through the main flow channel of Nurse Slough below the restoration site. At the point in the channel where highest velocities occur, peak ebb tide velocities increased from approximately 2.6 ft/s for the Base case to 3.5 ft/s with Restoration. Tidal prism increased by approximately 56%.

Restoration impacts on stage and tidal range were minimal. During 2013, the monthly average reduction in mean higher high water was 0.1’ or less and the monthly average increase in mean lower low water was 0.06’ or less.

In Bradmoor Island wetland areas were fully inundated and all but the eastern edge of Arnold was fully inundated at MHHW.

Monthly average residence times in Bradmoor Island ranged from approximately 1.6 days to 2.8 days and in Arnold the range was approximately 0.6 to 1.2 days.

Particle track modeling results indicate that Restoration reduced residence time in Nurse Slough by approximately 1.5 days and increased the percentage of particles spending a day or less in Nurse Slough by approximately 13% relative to Base.

Salinity impacts due to Restoration included decreases or very small increases in monthly averaged salinity at locations east of Collinsville. Salinity increases of 3-4% occurred at Collinsville during the summer and early fall. Salinity increases occurred at Beldon’s Landing, particularly when the Suisun Marsh Salinity Control Gates were operating, due to decreased net flow in Montezuma Slough.

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APPENDIX

Model Boundary Conditions

The RMA Bay-Delta hydrodynamic model operation requires specification of the tidal stage at the Golden Gate and inflow and withdrawal rates at other external boundaries as shown in Figure 3. Water quality model operation requires specification of quality boundary conditions at the stage and inflow boundaries.

The tidal boundary was set at Golden Gate using observed 6-minute NOAA stage data and a constant EC of 50,000 umhos/cm.

Inflows include:

Sacramento River above American River
American River near Sacramento
San Joaquin River near Vernalis
Yolo Bypass and Yolo Bypass Toe Drain
Mokelumne River near Thornton
Cosumnes River
Calaveras River near Stockton
Lindsey Slough, Upper Cache and Hass Slough inflows
Napa River

Suisun Marsh flows include:

Denverton Creek
Green Valley Creek
Laurel/Soda Springs Creek
Ledgewood Creek
Suisun Creek
Fairfield wastewater treatment plant
Duck Club inflows and withdrawals
Roaring River withdrawals

Exports/Diversions include:

State Water Project (SWP), Clifton Court Forebay gates.
Central Valley Project (CVP) Tracy Pumping Plant
Contra Costa Water District (CCWD) intakes at Rock Slough, Old River and Victoria Canal
North Bay Aqueduct (NBA), Barker Slough Pumping Plant
Delta Island Consumptive Use (DICU), throughout Delta
Lindsey Slough, Upper Cache and Hass Slough diversions

The following boundary condition data sources were used:

- CDEC: http://cdec.water.ca.gov
- DWR-DAYFLOW: http://www.water.ca.gov/dayflow/
- DWR-DES (Division of Environmental Services): http://www.water.ca.gov/environmentalservices/

- DWR-DMS (Delta Modeling Section): http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/
- DWR-NCRO (North Central Region Office): http://www.cd.water.ca.gov/
- DWR-WDL (Water Data Library): http://www.water.ca.gov/waterdatalibrary/
- SCWA (Solano County Water Agency): http://www.scwa2.com/
- USGS-NWIS (National Water Information System): http://waterdata.usgs.gov/nwis
- NOAA (National Oceanic and Atmospheric Administration): http://tidesandcurrents.noaa.gov/map/

DICU flows are applied on a monthly average basis for all simulation periods. These flows incorporate channel depletions, infiltration, evaporation, and precipitation, as well as Delta island agricultural use. DICU flow and EC values and were derived from monthly DSM2 input values (DWR, 1995).

Gate and barrier operations are also included in the model. Permanent gates and temporary barriers represented in the model include the Delta Cross Channel, Old River near Tracy (DMC) barrier, Old River at Head barrier, Middle River barrier, Montezuma Slough salinity control gates and Grant Line Canal barrier. The historical operation schedules for these structures are available over the Web.

Delta Cross Channel gates:
http://www.usbr.gov/mp/cvo/vungvari/Ccgates.pdf

Suisun Marsh Salinity Control Gates:
http://www.water.ca.gov/suisun/docs/histsmscgopnew.pdf

South Delta Temporary Barriers
- Old River near Tracy (DMC) temporary barrier
- Old River at Head temporary barrier
- Middle River temporary barrier
- Grant Line Canal temporary barrier

http://baydeltaoffice.water.ca.gov/sdb/tbp/web_pg/tempbar/weekly.cfm

April - July 2004 Boundary Conditions

Alternative screening hydrodynamic and water quality models were run for April - July 2004. The focus was on evaluating hydrodynamics and residence time in Suisun Marsh, and therefore the Jones Tract breach event was not modeled.

Tide

The Golden Gate tidal boundary stage shown in Figure 48 was set using 6-minute NOAA tide data at San Francisco. The vertical datum is NAVD88. The data were smoothed using a Butterworth filter and shifted upward by 0.3 ft to account for density effects.

Inflows

Time series of daily average inflow boundary conditions are plotted in Figure 49 and Figure 50 for the 2004 simulation period. These flows are applied for the Sacramento River, Yolo Bypass/Cache Slough area inflows, San Joaquin River, Cosumnes River, Mokelumne River, Calaveras River and Napa River.

Exports

Delta exports applied in the model include Clifton Court (SWP), CVP, Contra Costa exports at Rock Slough and Old River intakes, and North Bay Aqueduct intake at Barker Slough. Exports are plotted for in Figure 51 and Figure 52 for the 2004 simulation period. Although hourly export flows are applied at the SWP, daily averages are plotted for ease of viewing.

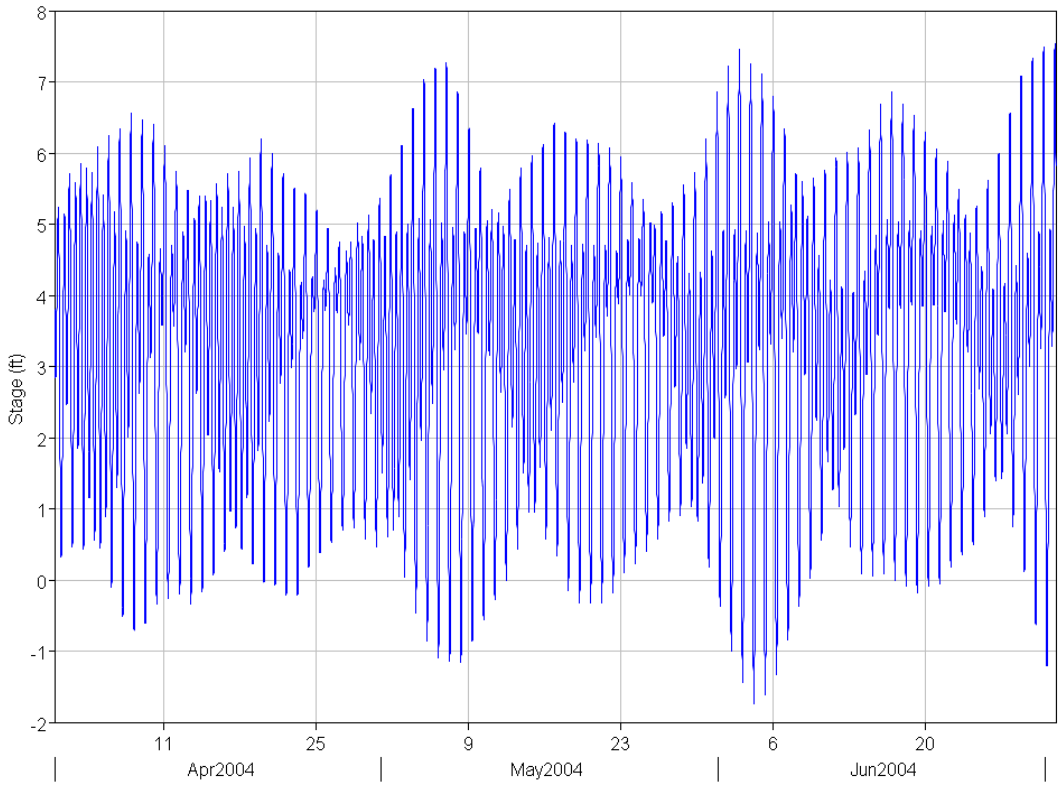


Figure 48 San Francisco stage applied at tidal boundary for the 2004 simulation period.

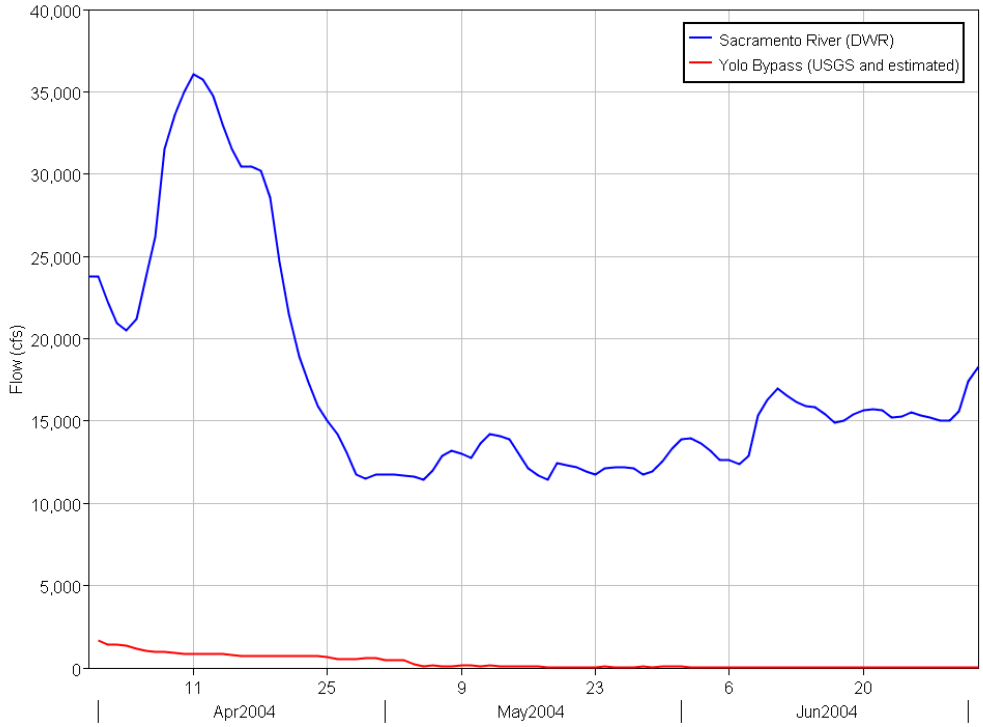


Figure 49 Sacramento River and Yolo Bypass inflow boundary conditions for the 2004 simulation period.

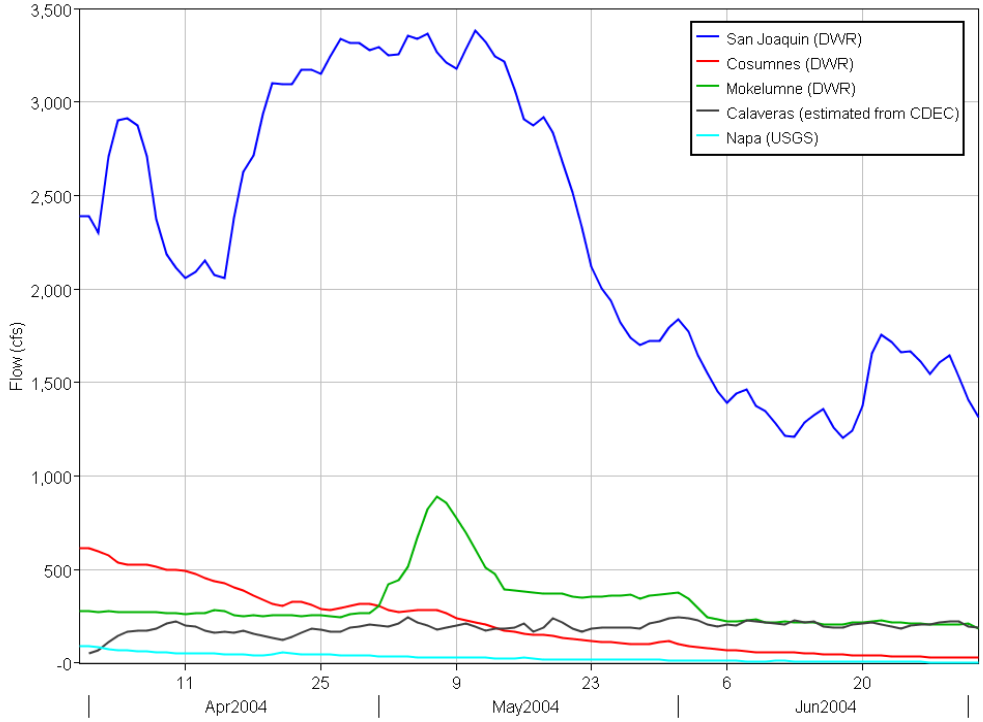


Figure 50 San Joaquin River, Cosumnes River, Mokelumne River, Calaveras River and Napa River inflow boundary conditions for the 2004 simulation period.

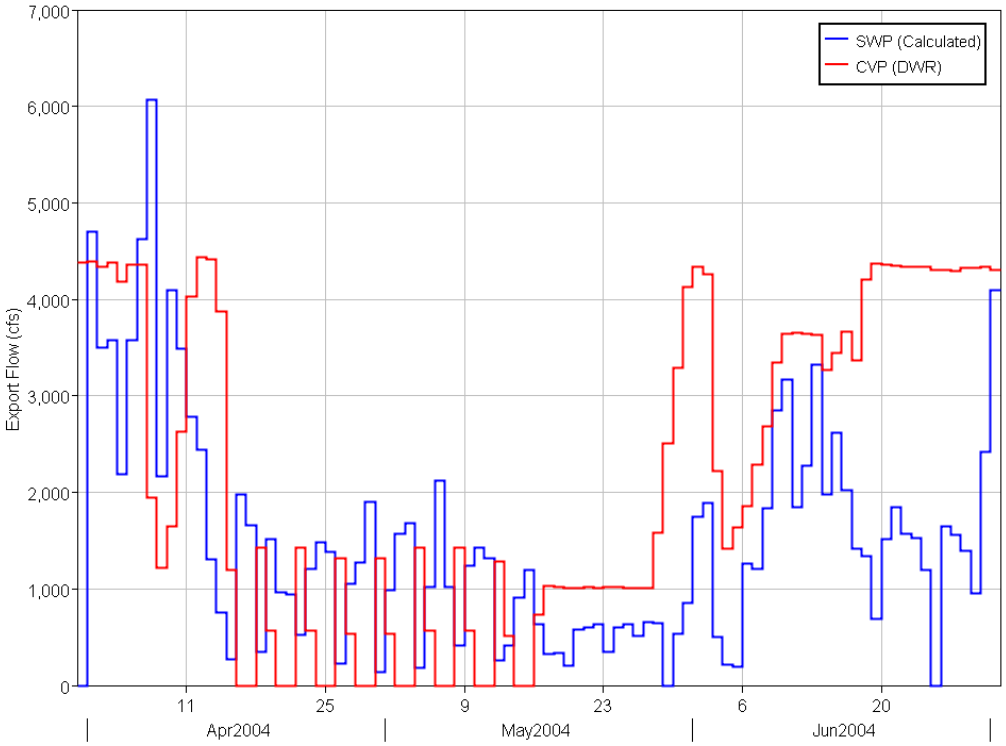


Figure 51 Clifton Court and CVP export boundary conditions for the 2004 simulation period.

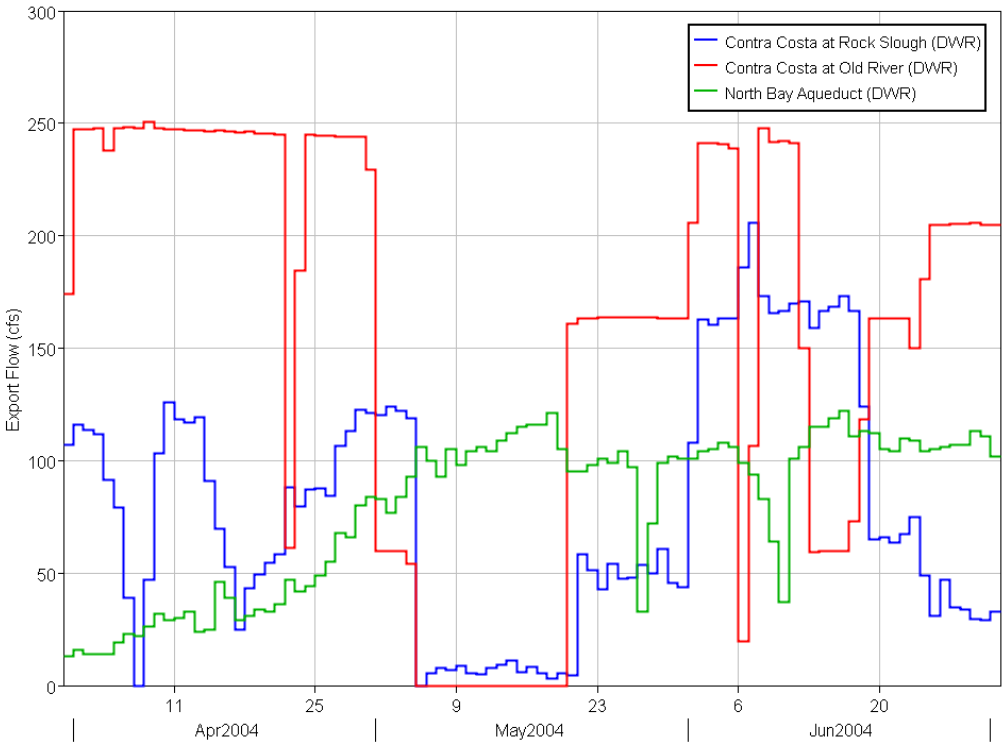


Figure 52 Contra Costa and North Bay Aqueduct export boundary conditions for the 2004 simulation period.

2013 Boundary Conditions

Hydrodynamic and water quality models were run for the January – November 2013 period. January – April were used for model spin-up and May through November was used for EC impact analysis. This period includes dry and critically dry conditions (see http://cdec.water.ca.gov/cgi-progs/iodir/wsihist).

Tide

The Golden Gate tidal boundary stage shown in Figure 53 was set using 6-minute NOAA tide data at San Francisco. The vertical datum is NAVD88. The data were smoothed using a Butterworth filter and shifted upward by 0.46 ft to account for density effects.

Inflows

Time series of daily average inflow boundary conditions are plotted in Figure 54 to Figure 56 for the 2013 simulation period. These flows are applied for the Sacramento River, American River, Yolo Bypass/Cache Slough area inflows, San Joaquin River, Cosumnes River, Mokelumne River, Calaveras River and Napa River.

Suisun Marsh Flows

Additional boundary conditions within Suisun Marsh include several creek inflows, the Fairfield-Suisun Waste Water Treatment Plant discharge into Boynton Slough (Figure 60), Roaring River withdrawals and duck club inflows and withdrawals (Figure 61). The Roaring River withdrawals were calculated using the RRDS Intake calculator formulas develop by Brad Tom of the DWR. Duck club inflows and withdrawals were estimated based on duck club acreages and seasonal water operations. The total duck club flows plotted in Figure 61 are divided into regional flows based on acreage and applied at the six duck club locations shown in Figure 3.

Daily precipitation minus evaporation from the CIMS station at Concord was applied throughout Suisun Marsh.

Local creek inflow data collection was stopped in 2006, therefore inflows for local creeks (e.g. Green Valley Creek, Suisun Creek, Ledgewood Creek and Laurel Creek) were estimated based on Napa River flow data and drainage area.

Exports

Delta exports applied in the model include Clifton Court (SWP), CVP, Contra Costa exports at Rock Slough and Old River intakes, and North Bay Aqueduct intake at Barker Slough. Exports are plotted for the 2013 period in Figure 57 and Figure 58. Although 10-minute export flows are applied at the SWP, daily averages are plotted for ease of viewing.

EC

Time series of EC are applied at major River inflows as shown in Figure 60 and Figure 62. Cache Slough inflow EC is set constant at 350 µmhos/cm. Napa River, Fairfield wastewater treatment plant inflow and all Suisun creek flows are set constant at 120 µmhos/cm. EC for Suisun Marsh duck club inflows is estimated based on available observed data during flood-up period.

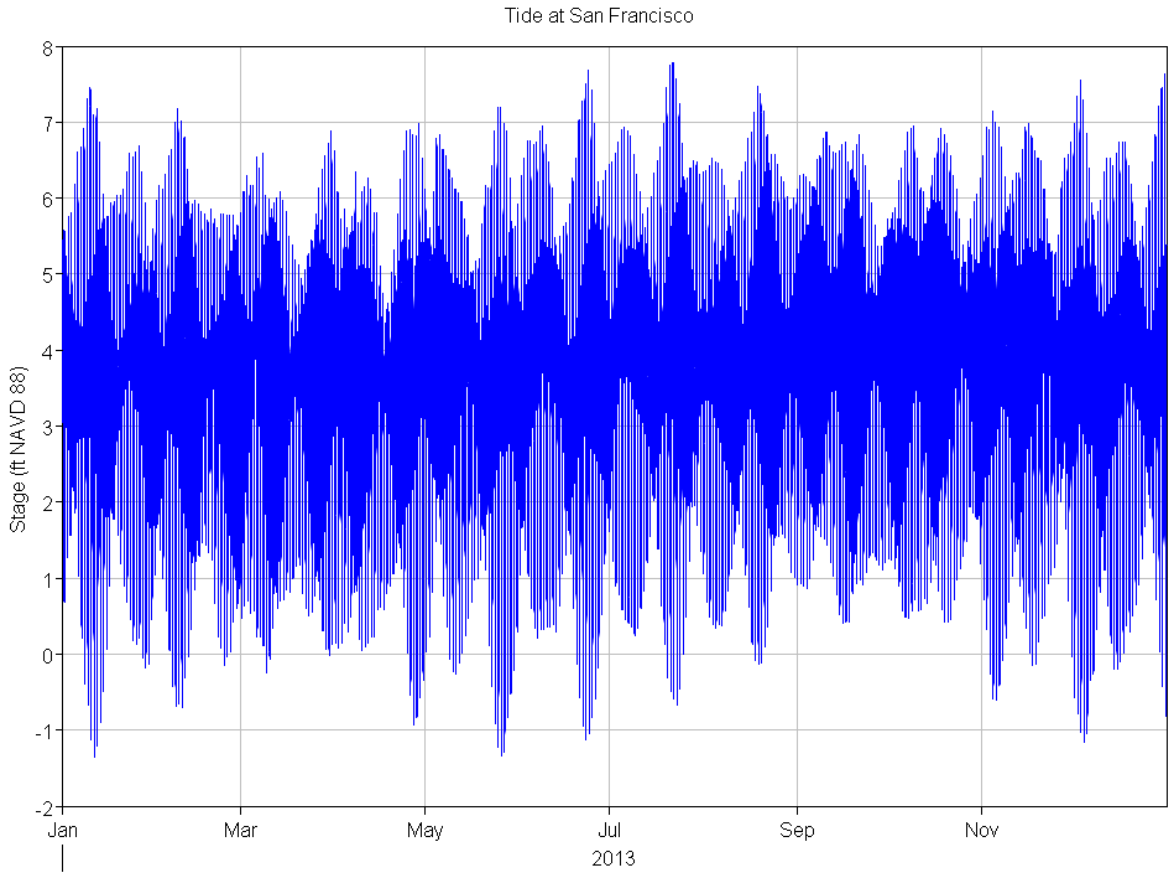


Figure 53 San Francisco stage applied at tidal boundary for the 2013 simulation period.

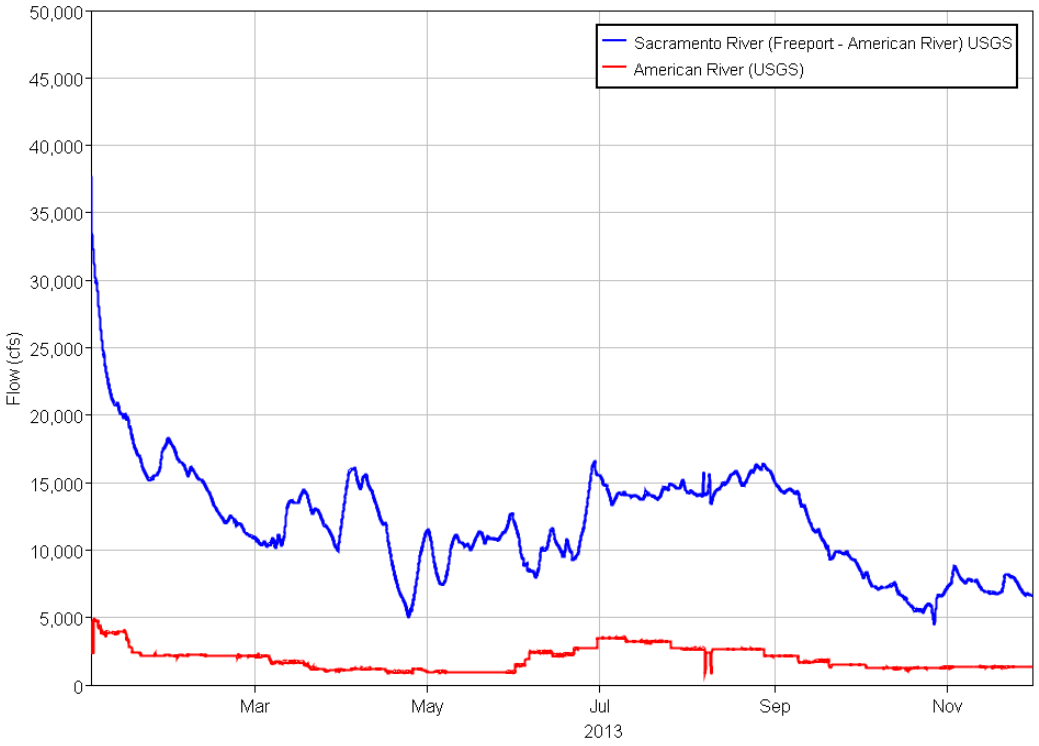


Figure 54 Sacramento River and American River inflow boundary conditions for the 2013 simulation period.

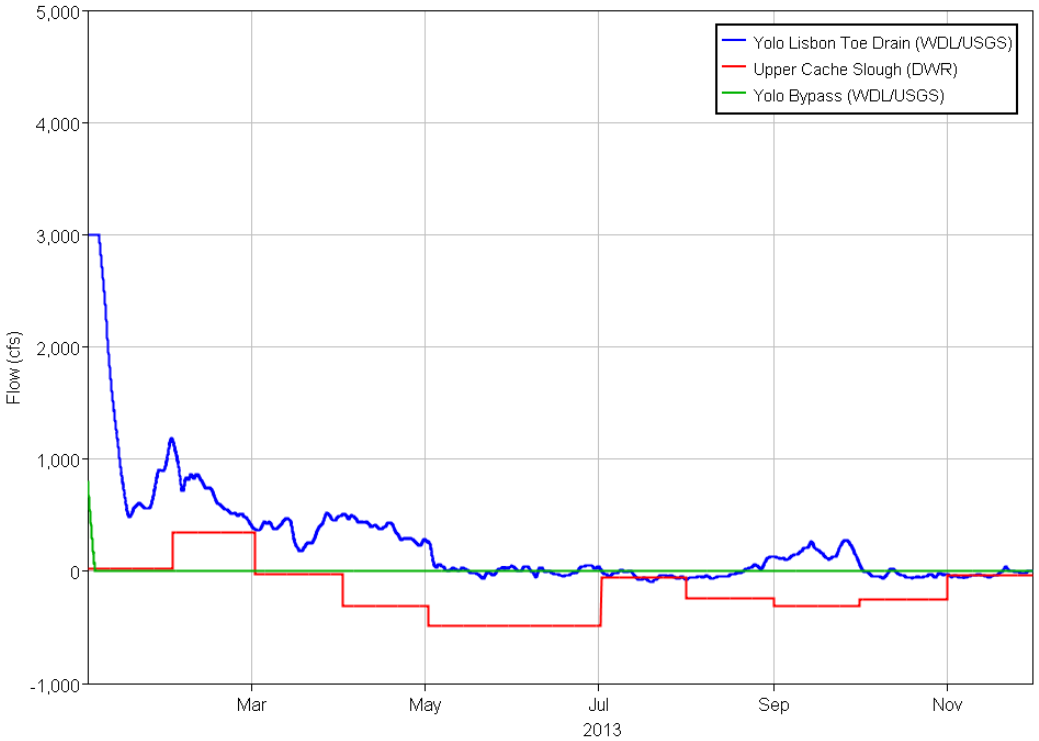


Figure 55 Yolo Bypass/Cache Slough area inflow boundary conditions for the 2013 simulation period.

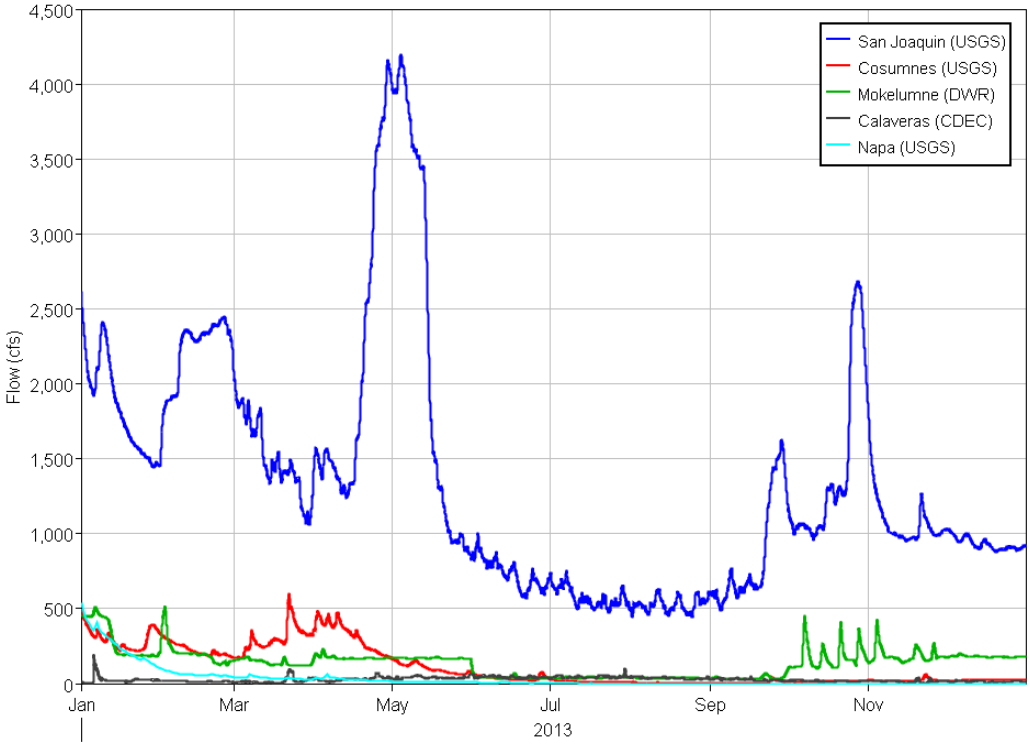


Figure 56 San Joaquin River, Cosumnes River, Mokelumne River, Calaveras River and Napa River inflow boundary conditions for the 2013 simulation period.

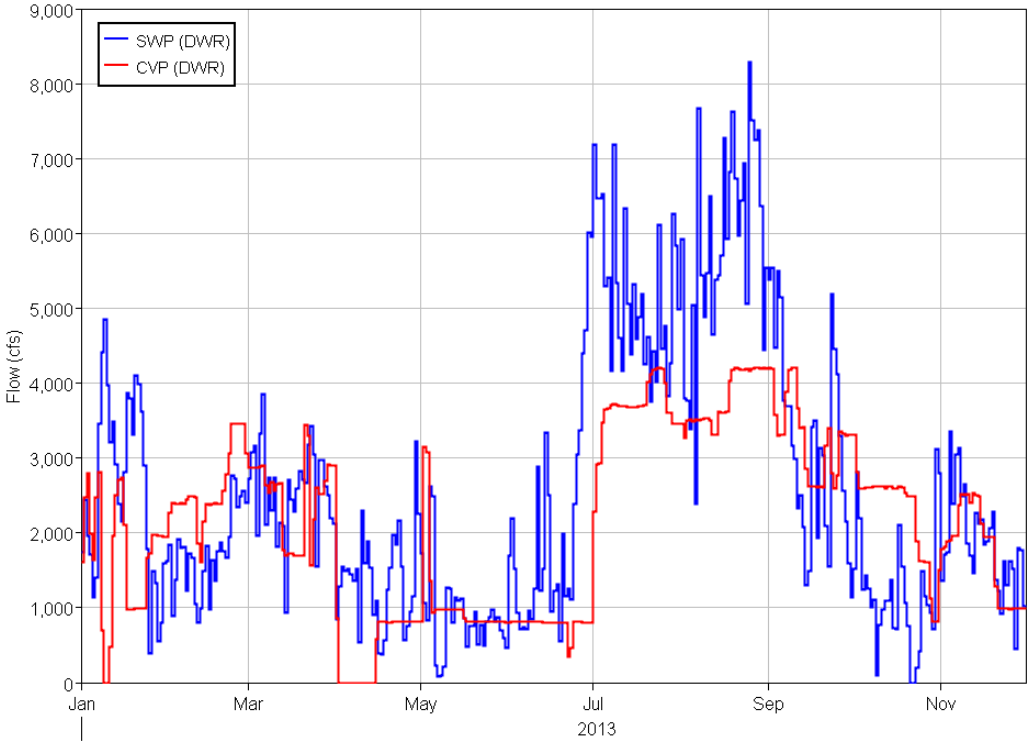


Figure 57 Clifton Court and CVP export boundary conditions for the 2013 simulation period.

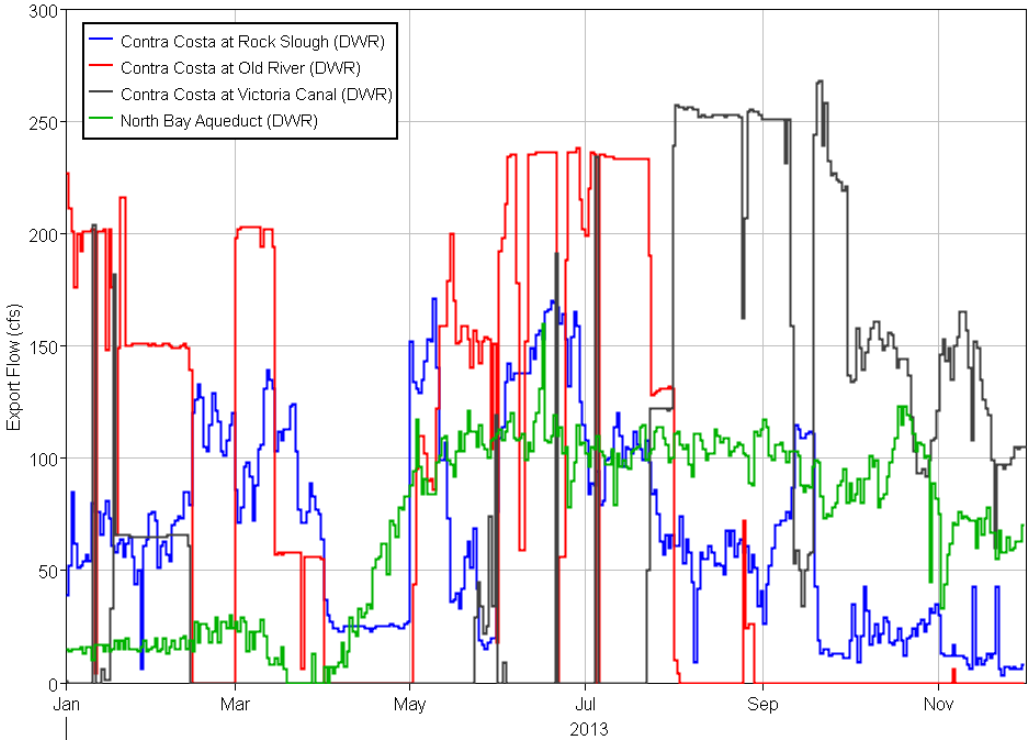


Figure 58 Contra Costa and North Bay Aqueduct export boundary conditions for the 2013 simulation period.

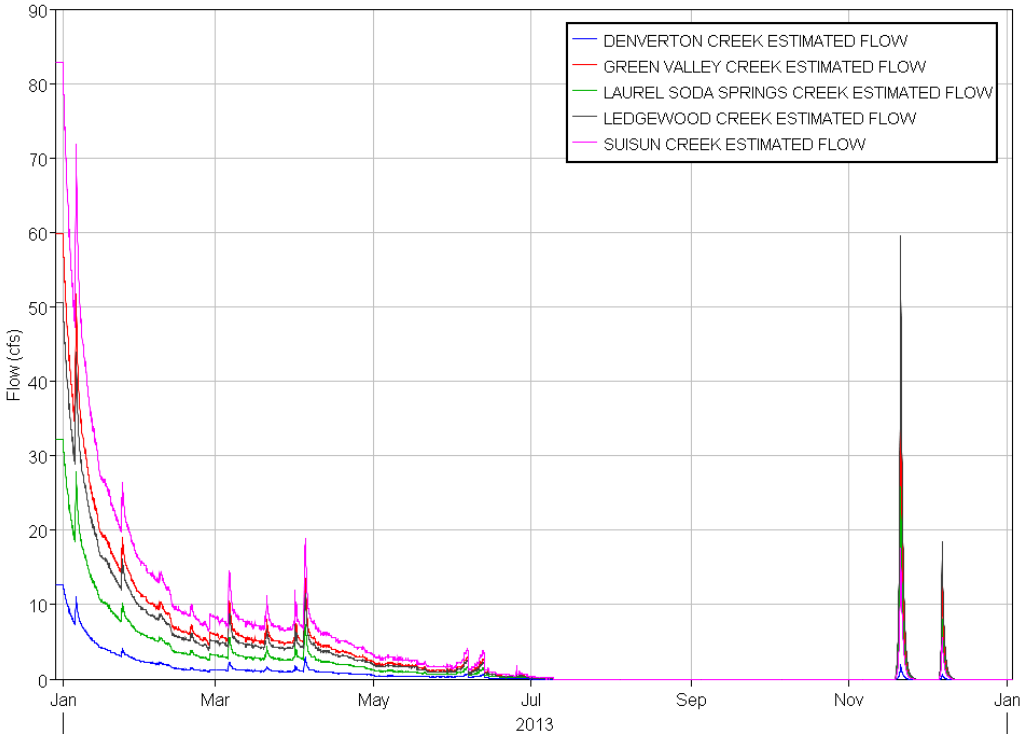


Figure 59 Suisun Marsh estimated creek flows for the 2013 simulation period.

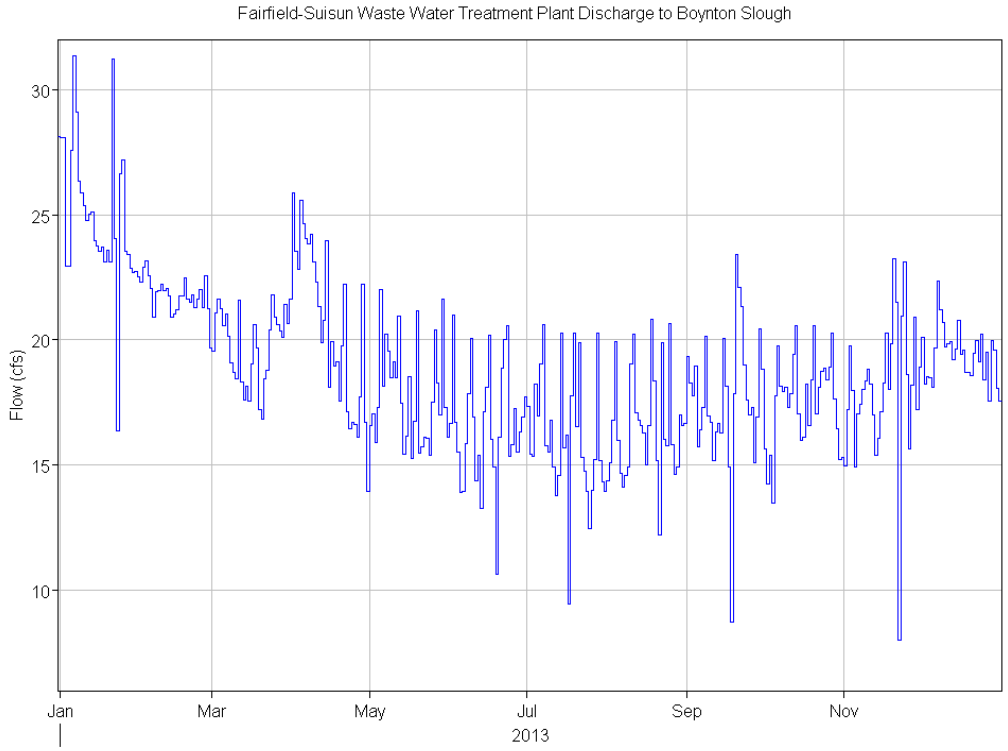


Figure 60 Fairfield-Suisun Waste Water Treatment Plant Discharge to Boynton Slough for 2013 simulation period.

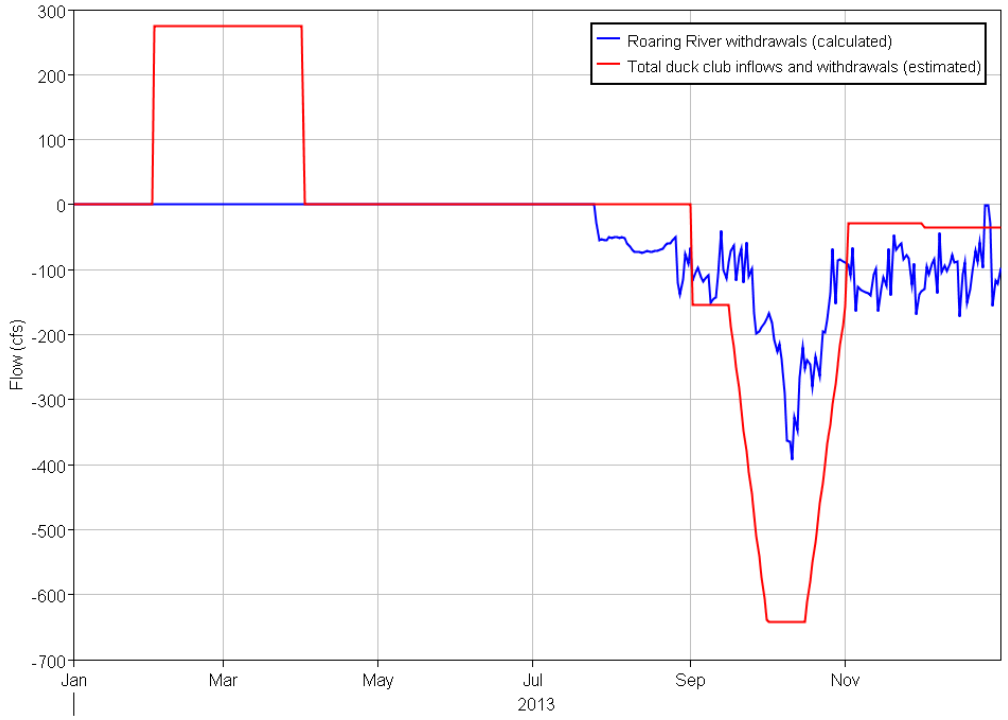


Figure 61 Calculated Roaring River withdrawals and estimated Suisun Marsh duck club inflows and withdrawals for the 2013 simulation period.

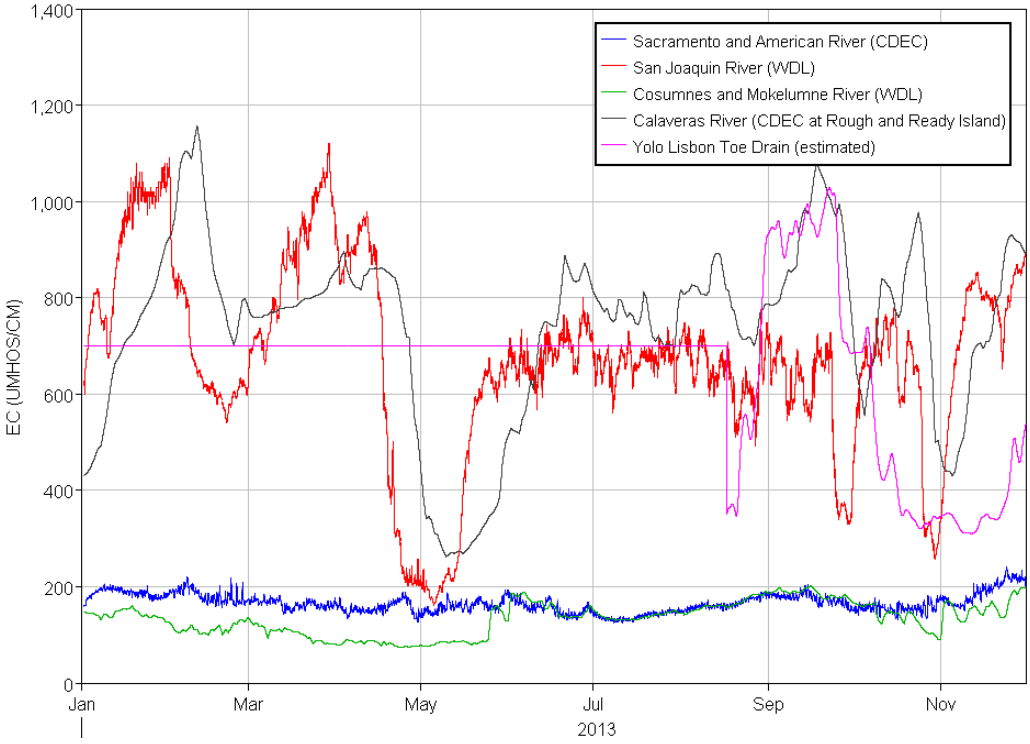
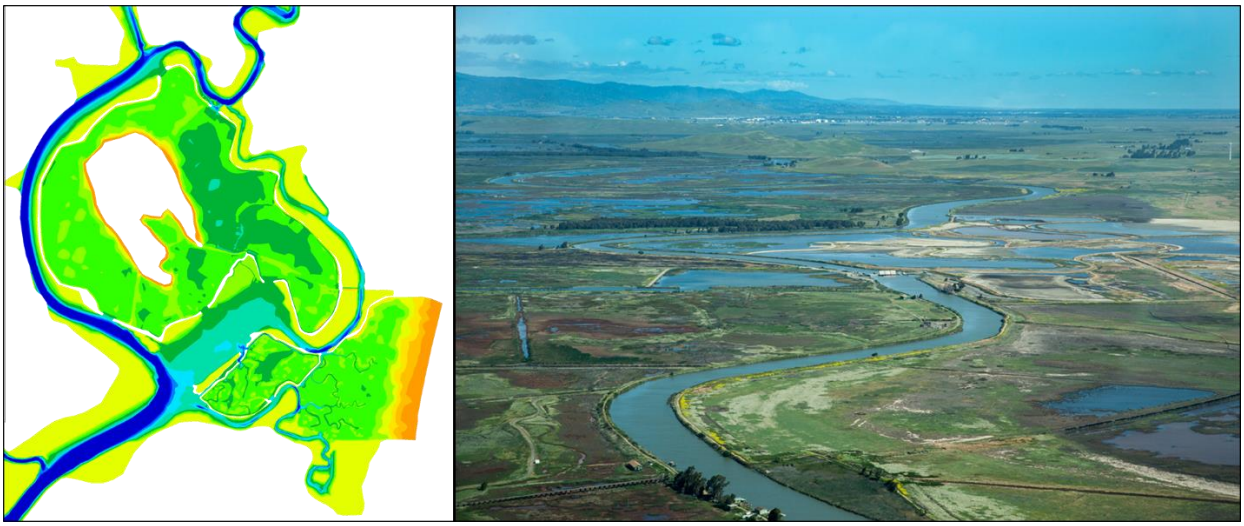


Figure 62 Time-varying EC boundary conditions for the 2013 simulation period.

RMA RESOURCE MANAGEMENT ASSOCIATES
WATER RESOURCES ENGINEERING

Modeling of Local and Regional Impacts of the Proposed Arnold and Bradmoor Island Tidal Marsh Restorations, Suisun Marsh, California



TECHNICAL MEMORANDUM ADDENDUM

September 2018

Prepared For:
Department of Water Resources
Suisun Marsh Branch

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EXECUTIVE SUMMARY

This addendum is provided to update hydrodynamic impact analysis for the Bradmoor and Arnold Restoration project under new proposed project configurations. Compared with the Restoration configuration that the original modeling analysis was based on, the updated configurations have approximately a 50% reduction in the northern Arnold breach (breach B1) size and an additional breach on the southern Blacklock levee. Two variations of the Blacklock breach were modeled: a 20′ wide breach and a 100′ wide breach. In addition, the existing condition grid of Blacklock was updated based on the most recent available data.

The hydrodynamic analysis period was June – July 2013.

Velocity, stage and tidal prism impacts for the latest configurations were found to be nearly identical for the two Blacklock breach widths, and very similar to the previous Restoration configuration impacts.

Hydrodynamic impacts included increased velocities and tidal prism in local channels. Velocity increases occurred through the main flow channel of Nurse Slough below the restoration site. At the point in the channel where highest velocities occur, peak ebb tide velocities during the simulation period increased from approximately 2.7 ft/s for the Base case to 3.6 ft/s with Restoration. Average July 2013 tidal prism in Nurse Slough increased by approximately 58% during.

A comparison of July 2013 velocities for the two restoration cases near the proposed Blacklock breach shows that peak velocity for the 100′ wide breach is approximately 1.6 ft/s, while the 20′ breach produces a slightly higher peak velocity of 2.3 ft/s.

Restoration impacts on stage and tidal range were minimal. During July 2013, the monthly average reduction in mean higher high water was 0.08′ and the monthly average increase in mean lower low water was 0.05′.

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Table 1 Updated Arnold Restoration Alternative site feature geometry (for locations, see Figure 4). 4

INTRODUCTION

This addendum provides a brief analysis of hydrodynamic modeling results for updated versions of the proposed Bradmoor Island and Arnold tidal restoration projects, now also including a breach on Blacklock. Local hydrodynamic impacts resulting from the restoration are evaluated.

Background

Detailed modeling analyses of proposed tidal habitat restoration of Bradmoor and Arnold was previously performed. Due to a modification of the previously modeled Arnold configuration and the addition of a proposed breach of the southern Blacklock levee, new model simulations were needed. Whereas previous analyses included hydrodynamics, salinity, residence time and particle tracking, the current analysis will address hydrodynamic impacts only.

Objectives

The objective of this study was to evaluate expected tidal range in the restoration sites and restoration impacts on local velocities and tidal range.

PROJECT CONFIGURATION

Existing condition model geometry within Blacklock was updated based on the 2018 DEM of the Nurse-Denverton Slough complex developed by UC Davis Center for Watershed Sciences, 2010 Coastal Conservancy LiDAR data ground points and aerial images from Google Earth and Bing. The DEM in Blacklock was developed from 2011 CVFED multi-beam sonar survey bathymetry data and 2004 DWR DEM topography.

Two new restoration grids were developed. Both included the final version of Bradmoor from the previous modeling efforts and a slightly modified version of Arnold Alternative 1. Arnold Alternative 1 was modified with a reduction in the size of breach B1 from 243’ to 120’. The new restoration scenarios each included a breach on the south side of Blacklock, replacing an existing pipe. The breach elevation was set at -1.6’ and the width was 20’ for one scenario and 100’ for the second scenario. A comparison of Base and restoration bathymetry is shown in Figure 1.

Figure 2 shows the updated model grid developed for the Arnold, Bradmoor and Blacklock (100’ breach scenario) restoration sites and vicinity, and the inclusion of the restoration grid into the greater RMA Bay-Delta model grid. A 3-D perspective view of the updated model grid for the restoration sites is presented in Figure 3.

Table 1 Updated Arnold Restoration Alternative site feature geometry (for locations, see Figure 4).

Site Feature	Description	Bottom Width	Bottom Elevation (NAVD88)
B1	External Levee Breach	120′	-1.3′
B2	External Levee Breach	63′	-3.9′
B3	External Levee Breach	72′	-1.6′
C1	Dredge Existing Channel	12′-16′	-1.3′
C2	Dredge Existing Channel	13′-20′	-0.7′
C3	Dredge Existing Channel	25′-40′	-2.0′

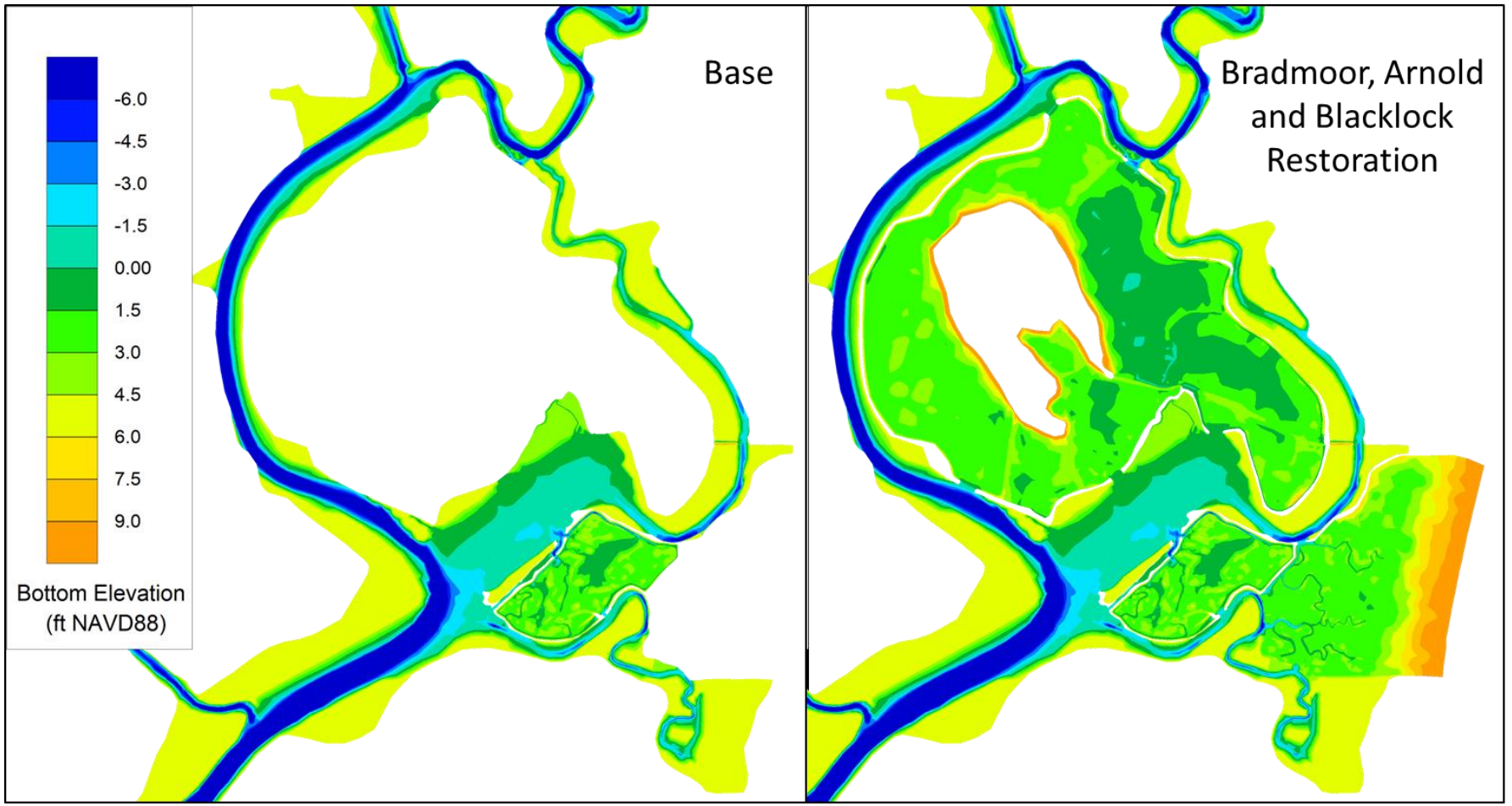

Figure 1 Model bathymetry in the project vicinity for the Base and Restoration configurations.

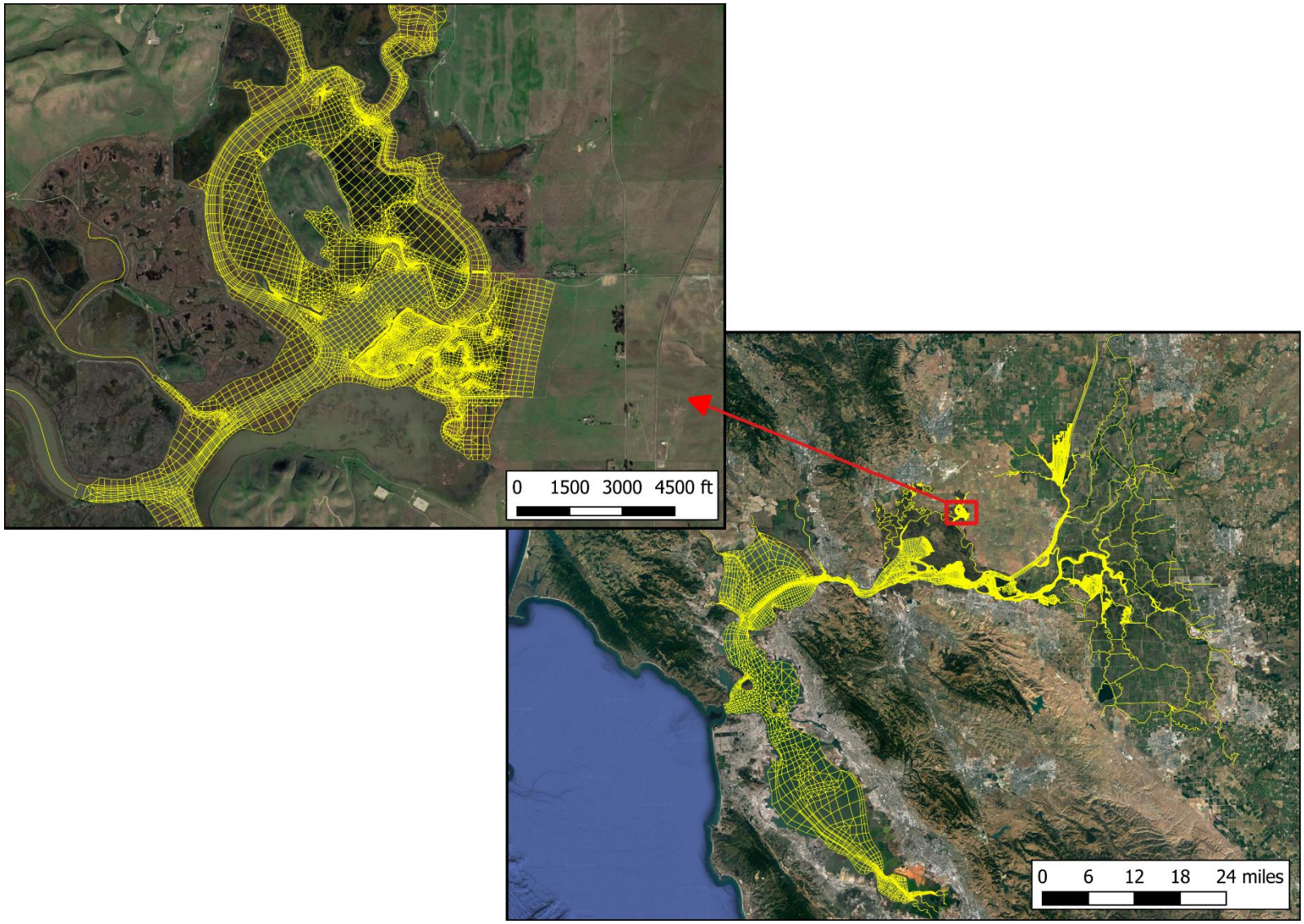

Figure 2 Numerical model network for the Bay-Delta grid and the detailed model network for the updated Arnold, Bradmoor and Blacklock restoration sites.

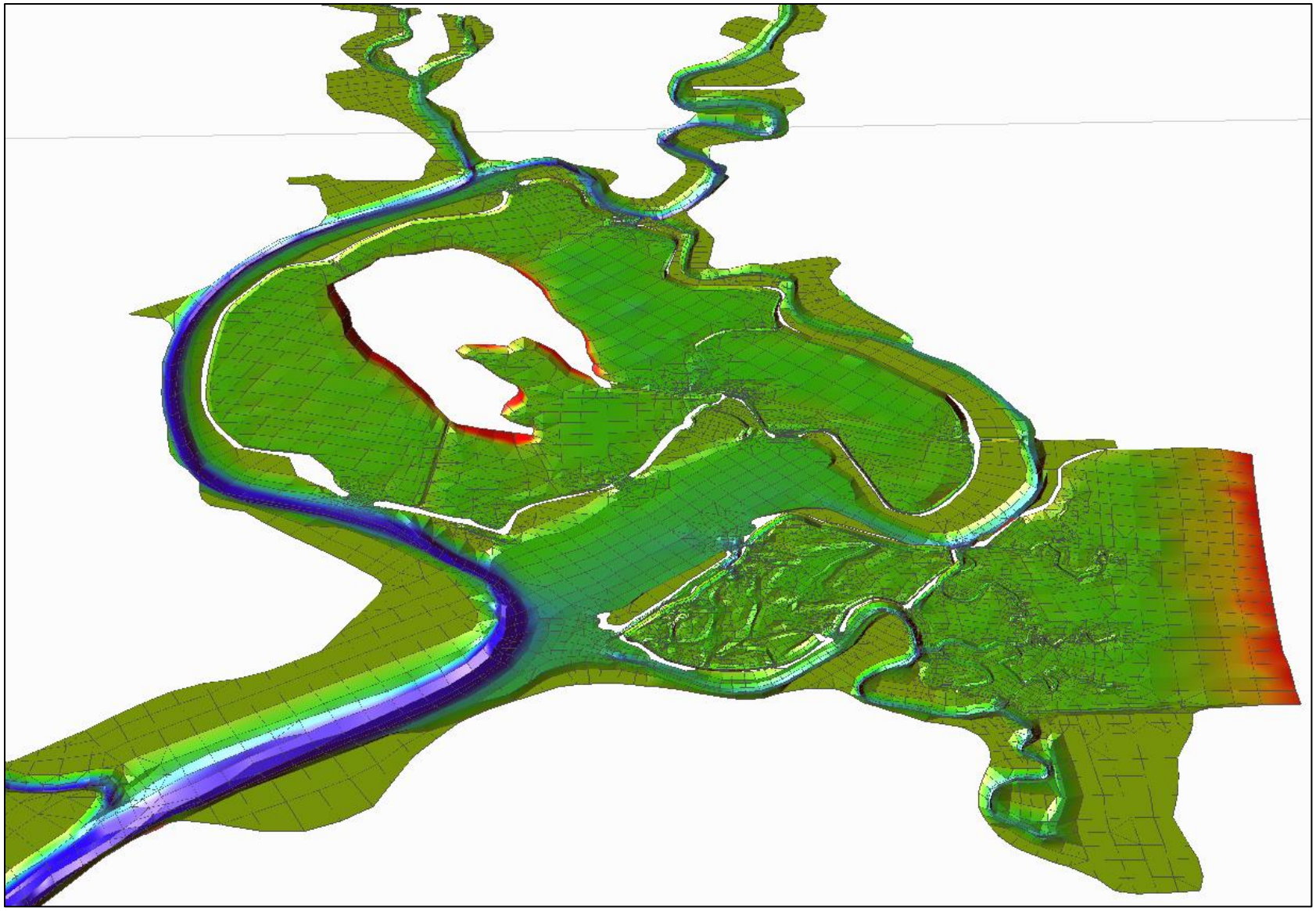

Figure 3 3-D perspective view of the Arnold, Bradmoor Island and Blacklock restoration grid.

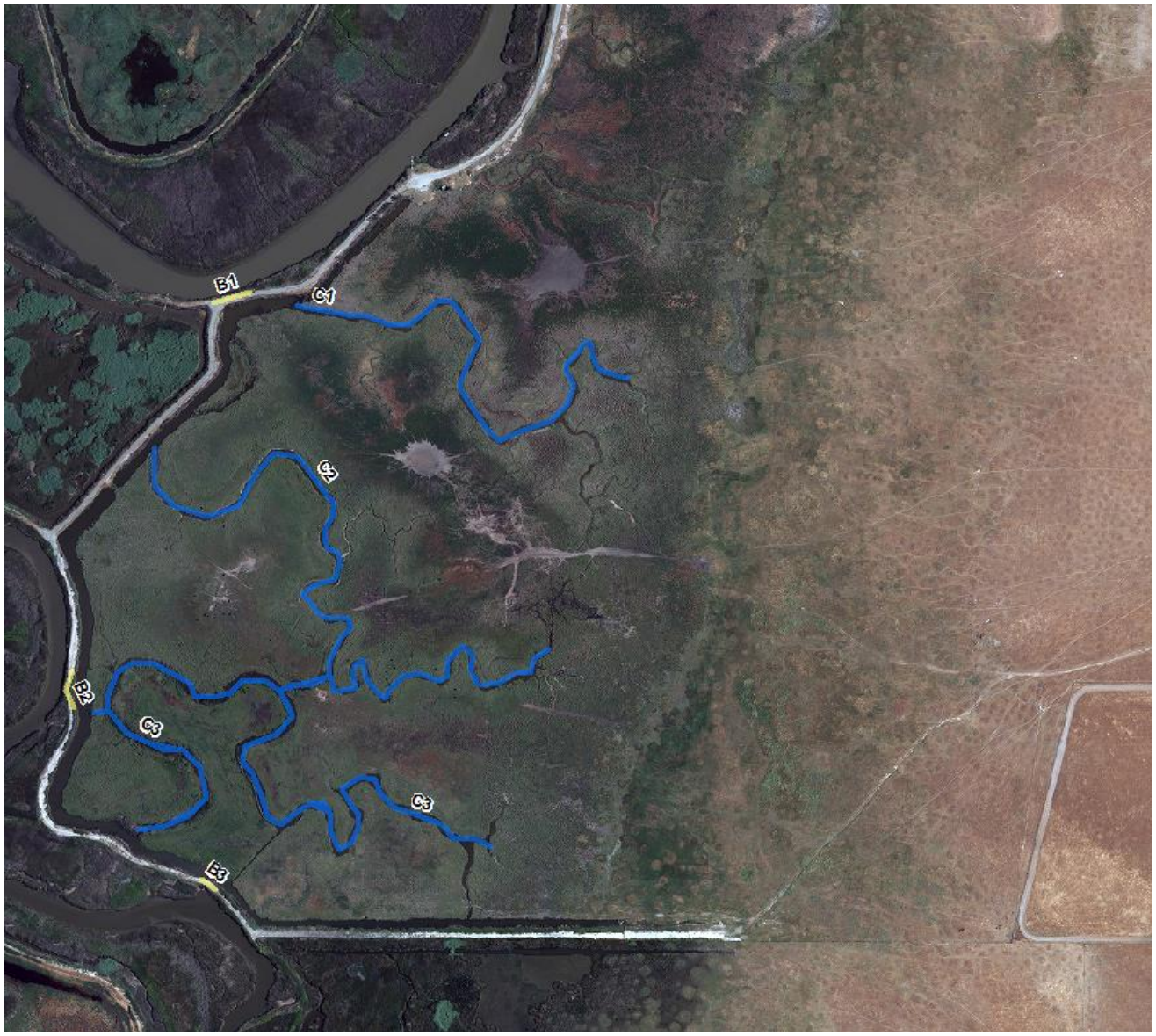

Figure 4 Arnold restoration site feature map (see Table 1).

HYDRODYNAMIC IMPACTS

June – July 2013 hydrodynamic simulation results for the updated Base case and latest combined Arnold, Bradmoor Island and Blacklock Restoration alternatives were analyzed and compared to evaluate expected impact of the Restoration projects on tidal range, velocities and tidal prism in adjacent channels. Tidal range within the Restoration sites were also examined. Analysis results for the two Restoration cases were nearly identical, therefore all references to Restoration impacts refer to both scenarios.

Velocities

In Figure 5, a comparison of Base case and Restoration velocities during June 2013 shows that the restorations increase velocities in Nurse Slough. Velocity results for the two Restoration alternatives are similar. Peak ebb tide velocities increase from around 2.7 ft/s for the Base case to around 3.6 ft/s with Restoration. These results are within 0.1 ft/s of the previous Alternative 1 velocities.

In the Restoration cases, velocities are increased in the channels approaching the Arnold breaches. In the Base case, velocities in the channel south of Blacklock and east of Arnold, approaching the location of Arnold breach B2 (see Figure 6) peak at approximately 1.8 ft/s. With Restoration, velocities in this channel peak at around 2.8 ft/s. Velocities in the channel approaching the northern Arnold breach B1 location (see Figure 7) peak at 1.6 ft/s in the Base case and 2.4 ft/s in the Restoration cases.

Compared with the previous Alternative 1 Restoration results, velocities near B1 are slightly lower and velocities near B2 are slightly higher, however none of the velocity differences between the previous and current configurations are greater than 0.3 ft/s.

Figure 8 shows peak velocities in June 2013 near the proposed Blacklock breach for the 100′ wide and 20′ wide breach cases. For the wider breach, velocities peak at approximately 1.6 ft/s. The narrower breach results in a slightly higher peak velocity of 2.3 ft/s.

Plots of velocities and velocity vectors within Blacklock for the Base and Restoration case shown in Figure 9 illustrate that there is flow through the site with the proposed Blacklock breach. The 100′ breach case is shown. The 20′ breach case results are similar.

Stage and Tidal Range

Restoration impacts on stage and tidal range were minimal. During July 2013 the average reduction in mean higher high water (MHHW) in Nurse Slough downstream of the Restoration was 0.08′ and the increase in mean lower low water (MLLW) was 0.05′. For comparison, previous Alternative 1 results for the same period showed a 0.06′ reduction in MHHW and a 0.05′ increase in MLLW. A short time series of Base and Restoration case stage in Nurse Slough is plotted in Figure 10.

In Figure 11, a color contour plot of July 2013 MHHW in the Restoration sites shows that Bradmoor Island wetland areas are fully inundated and all but the eastern edge of Arnold is fully inundated at MHHW.

Tidal Prism

With Bradmoor Island and Arnold both restored and the southern Blacklock breach, tidal prism in Nurse Slough is increased by 58% on average during July 2013 This is the same increase seen over the same period in the previous Alternative 1 results.

Short time series of ebb and flood volume in Nurse Slough for the Base and Restoration cases are shown in Figure 12. The associated tidal flows are plotted in Figure 13.

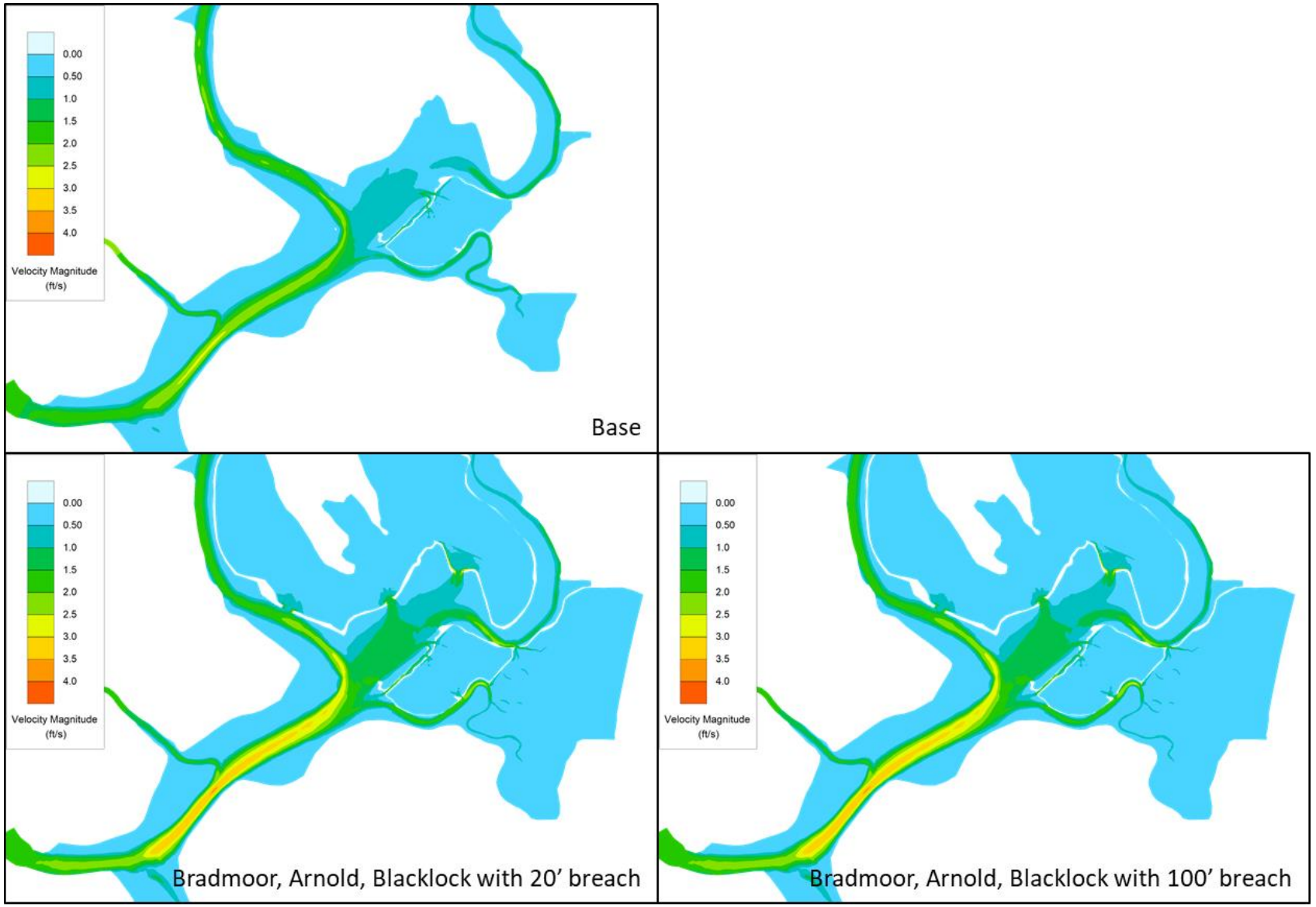

Figure 5 Base and Restoration alternatives peak velocities in Nurse Slough on 24 June 2013, during peak ebb tide.

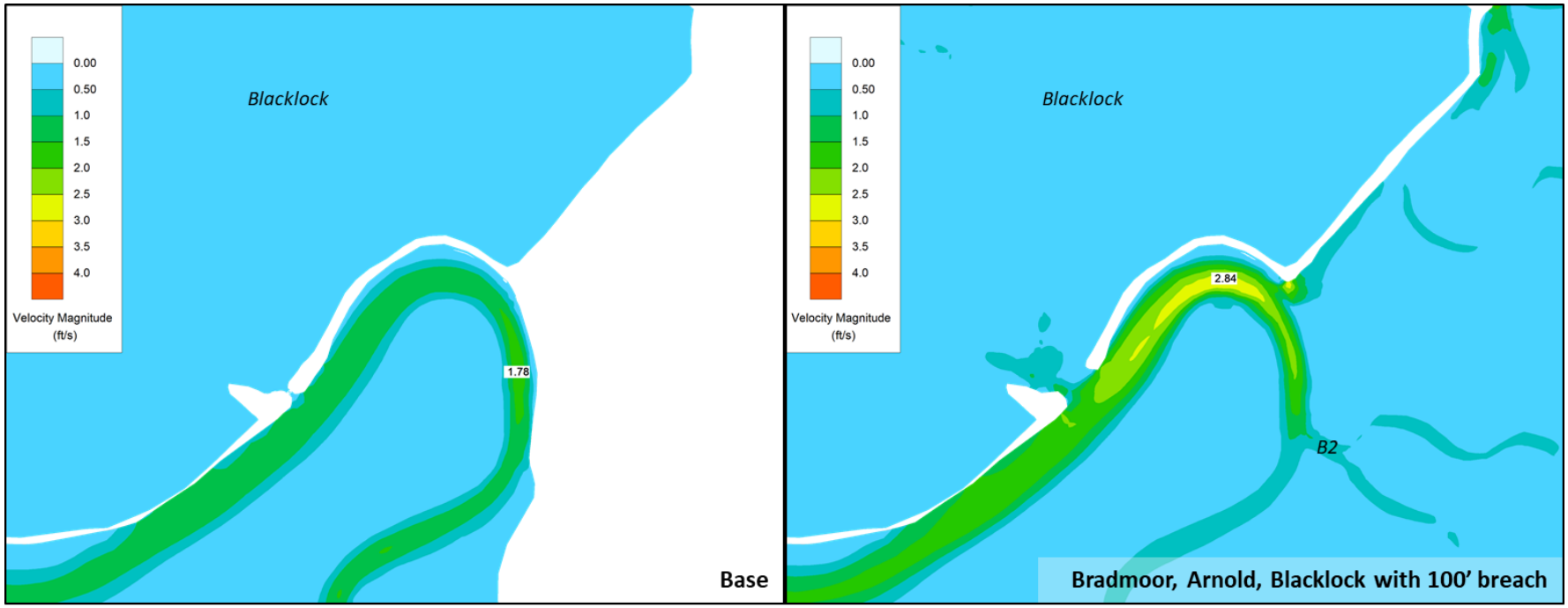

Figure 6 Base and Restoration alternatives peak velocities in channel near Arnold breach B2 on 24 June 2013, during peak ebb tide.

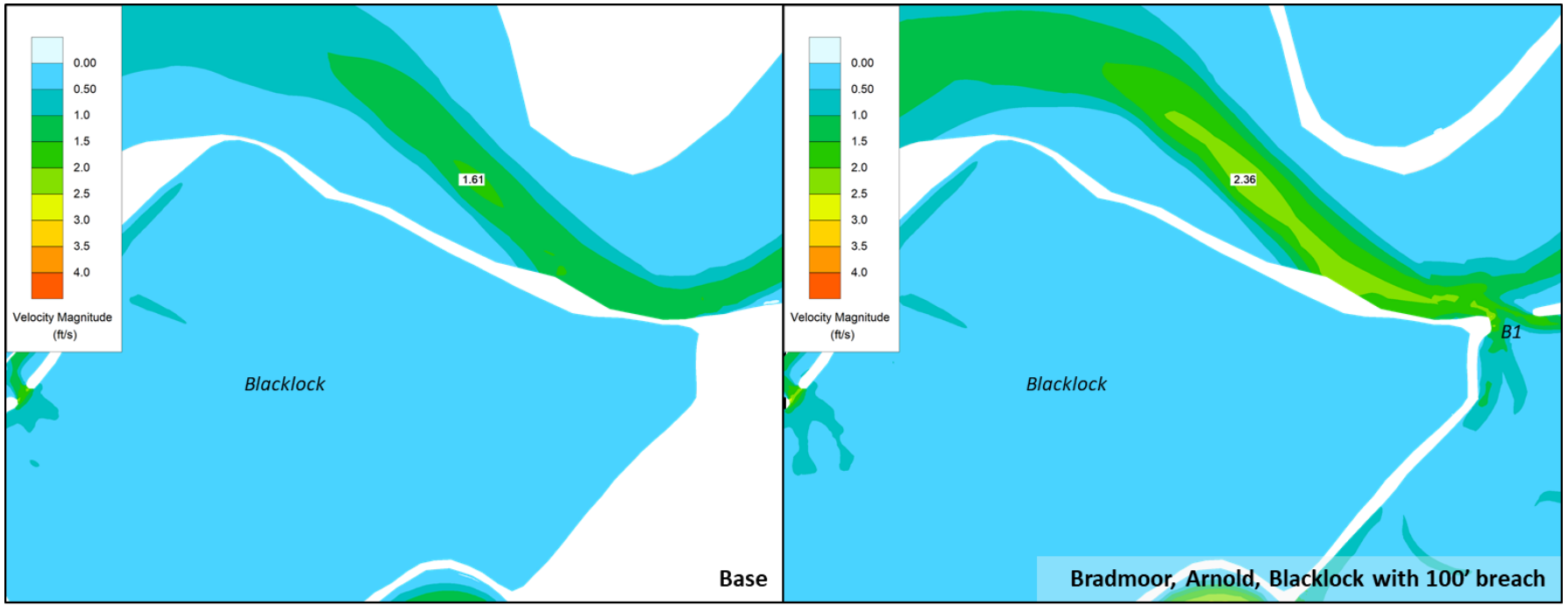

Figure 7 Base and Restoration alternatives peak velocities in channel near Arnold breach B1 on 24 June 2013, during peak ebb tide.

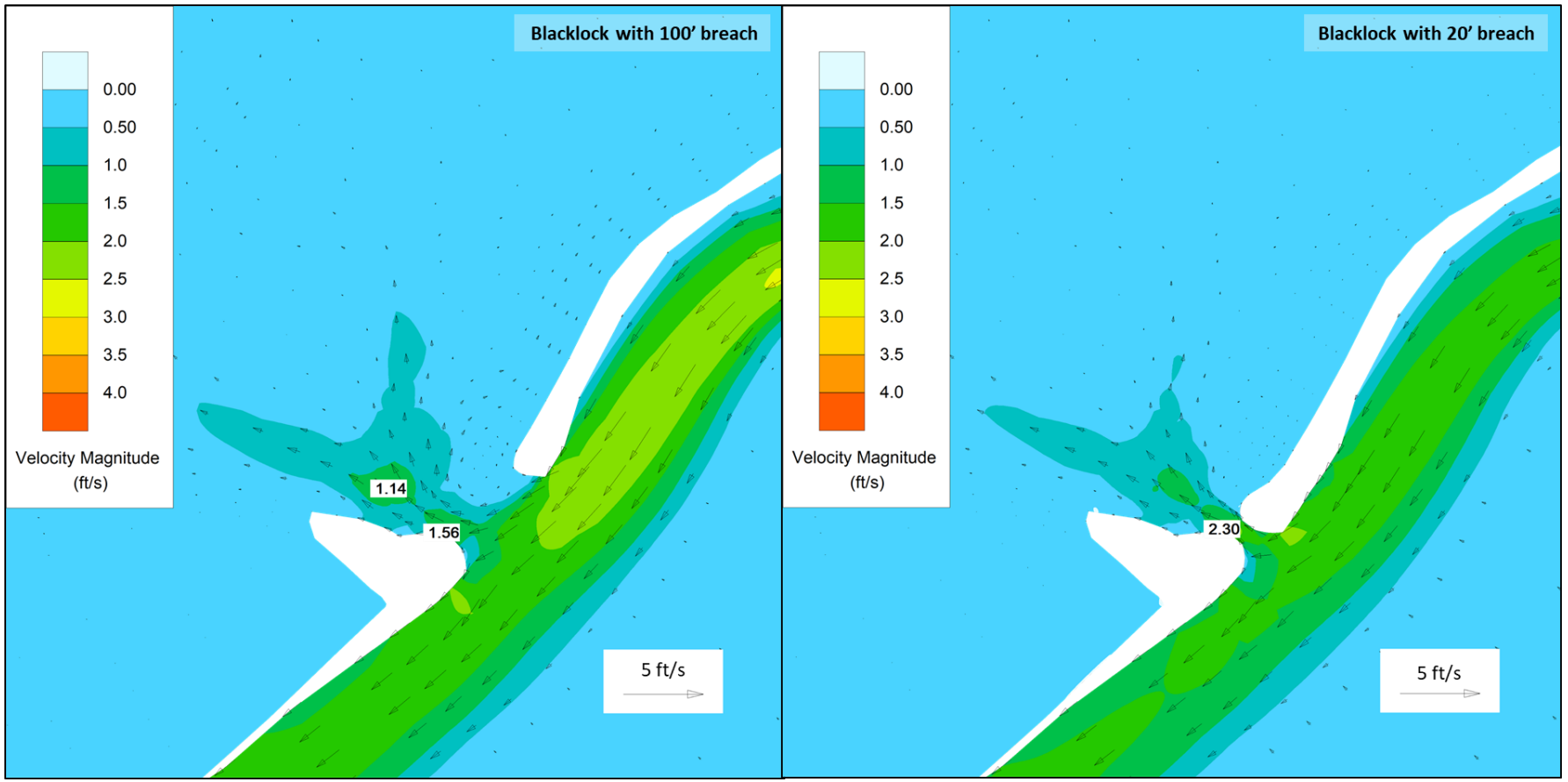

Figure 8 Peak velocities on 24 June 2013 near the proposed 100' wide and 20' wide Blacklock breach.

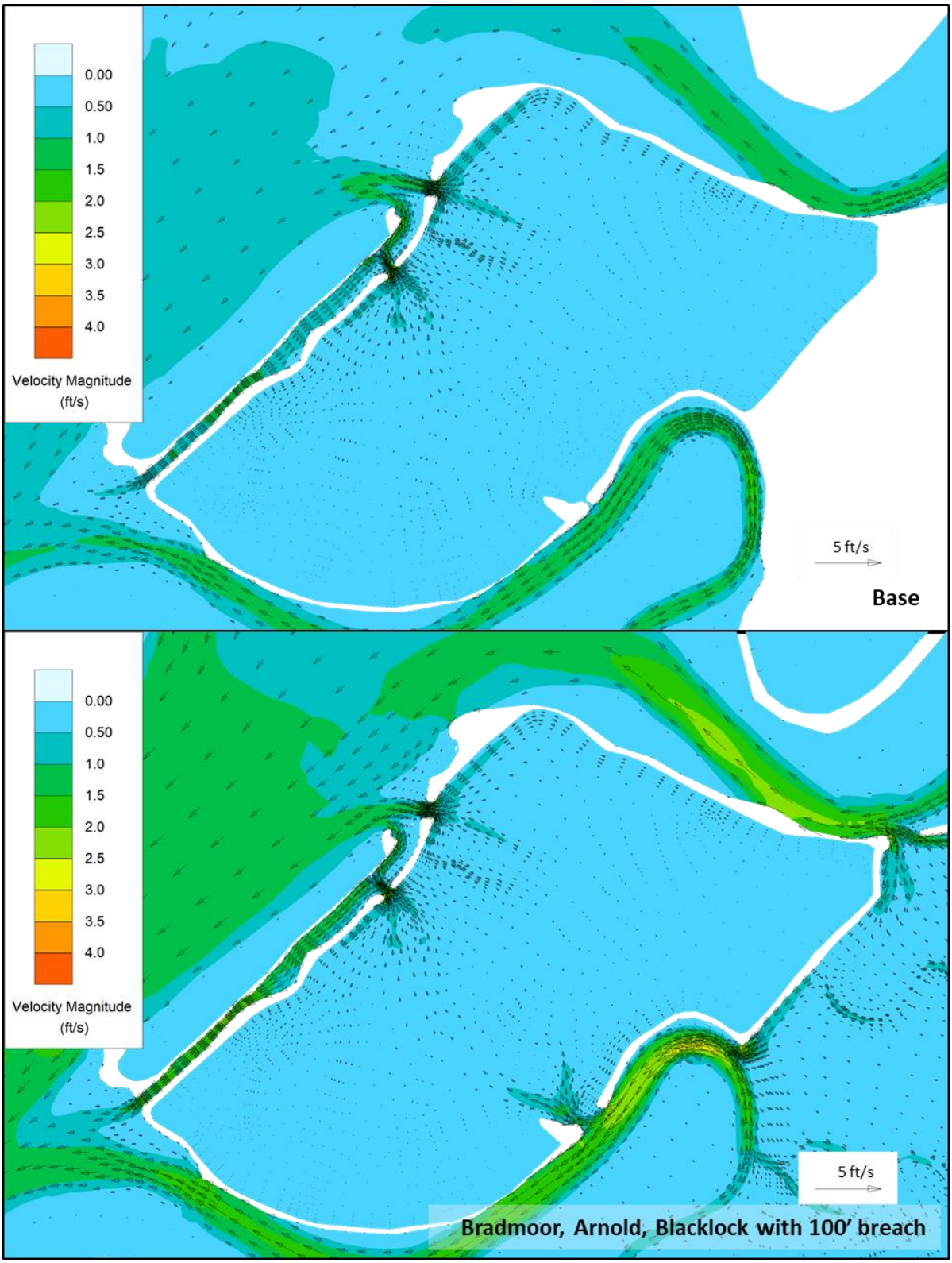

Figure 9 Velocity vectors in Blacklock for Base and Restoration case, illustrating flow through the site with the proposed 100′ breach.

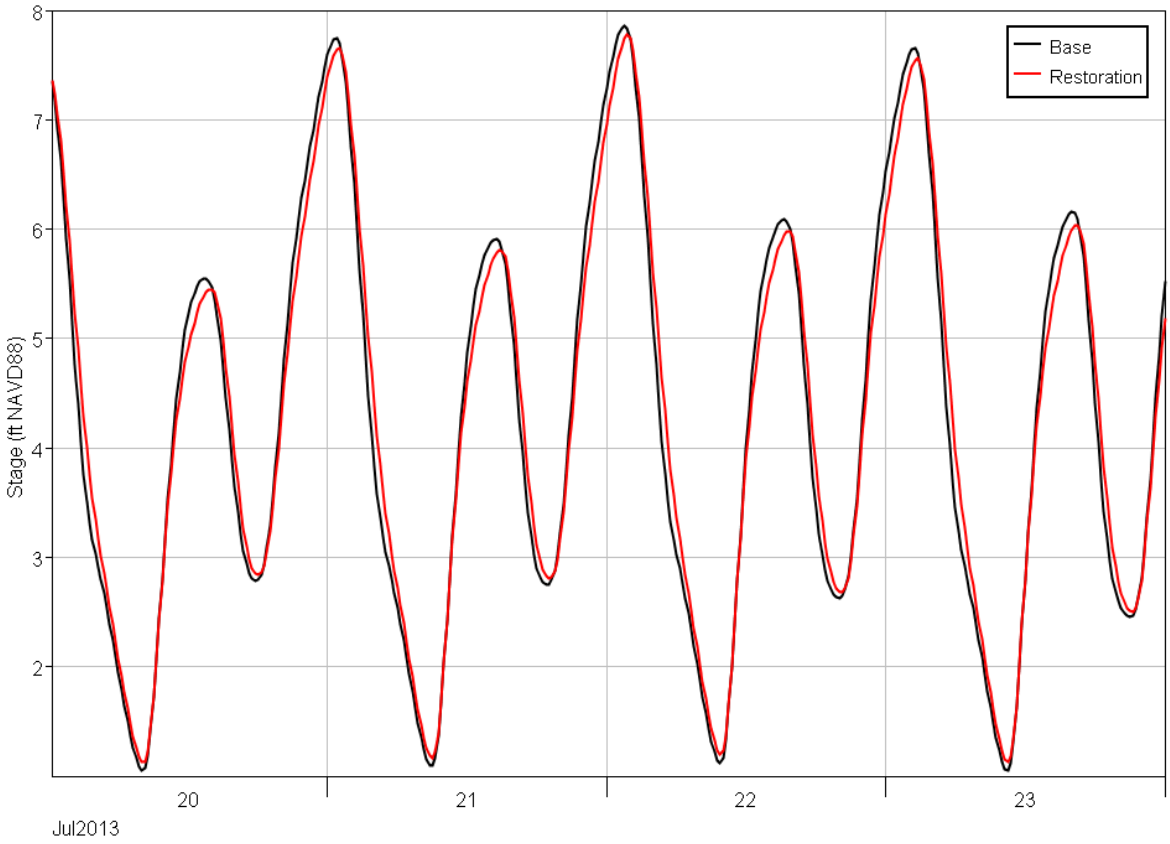

Figure 10 Nurse Slough stage for Base and Restoration cases during July 2013.

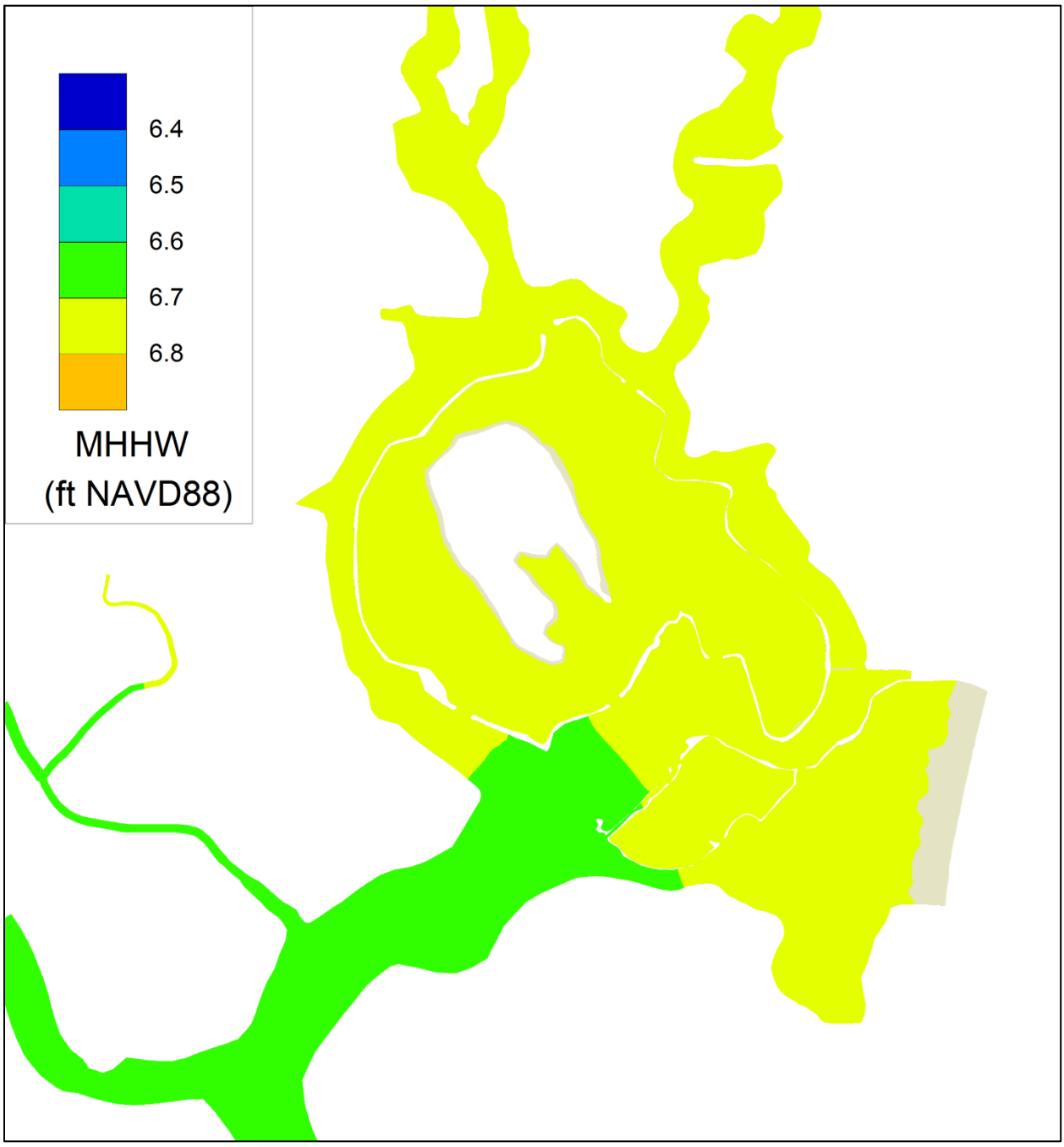

Figure 11 July 2013 mean higher high water in and near the Restoration sites.

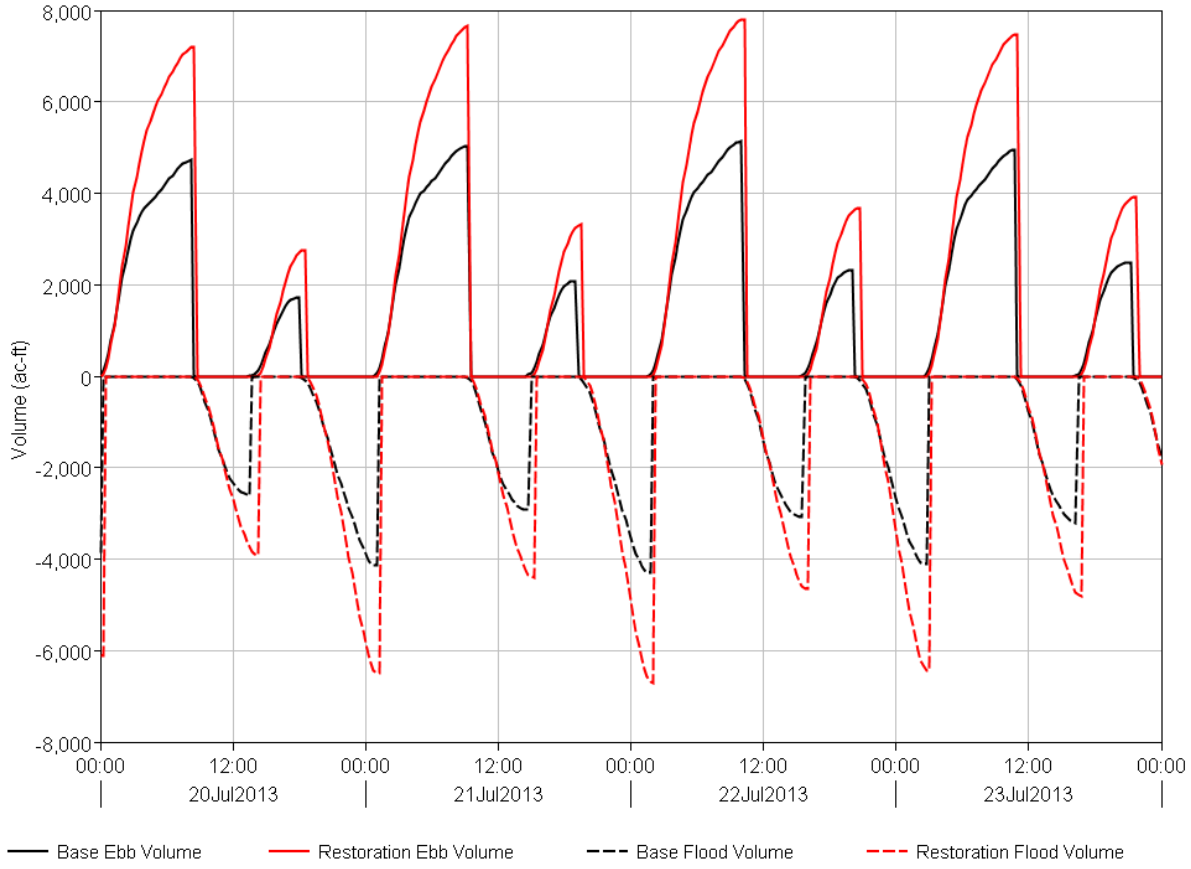

Figure 12 Nurse Slough ebb and flood volume for Base and Restoration cases during July 2013.

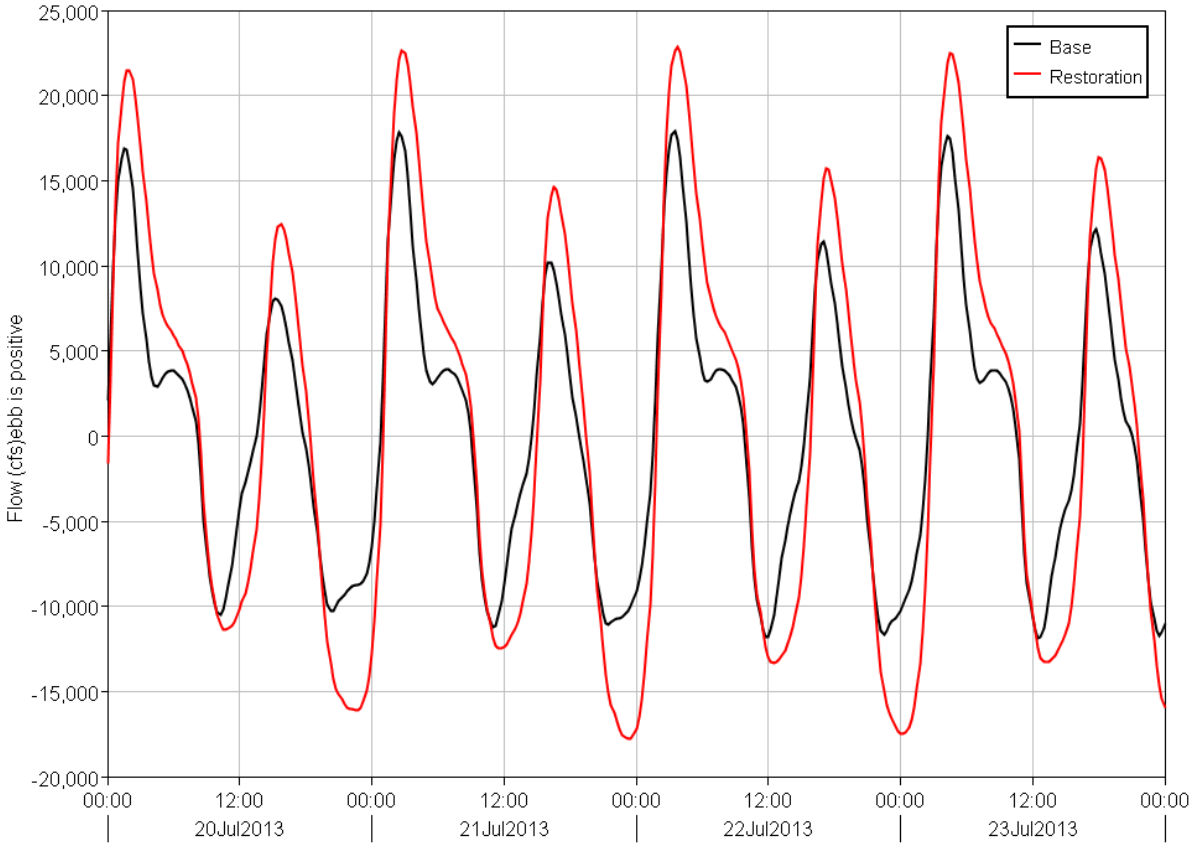

Figure 13 Nurse Slough flows for Base and Restoration cases during July 2013.