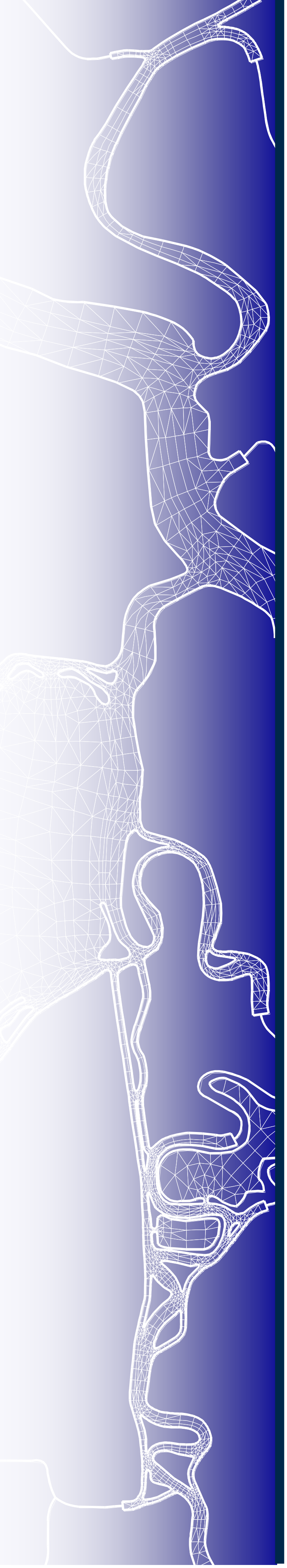
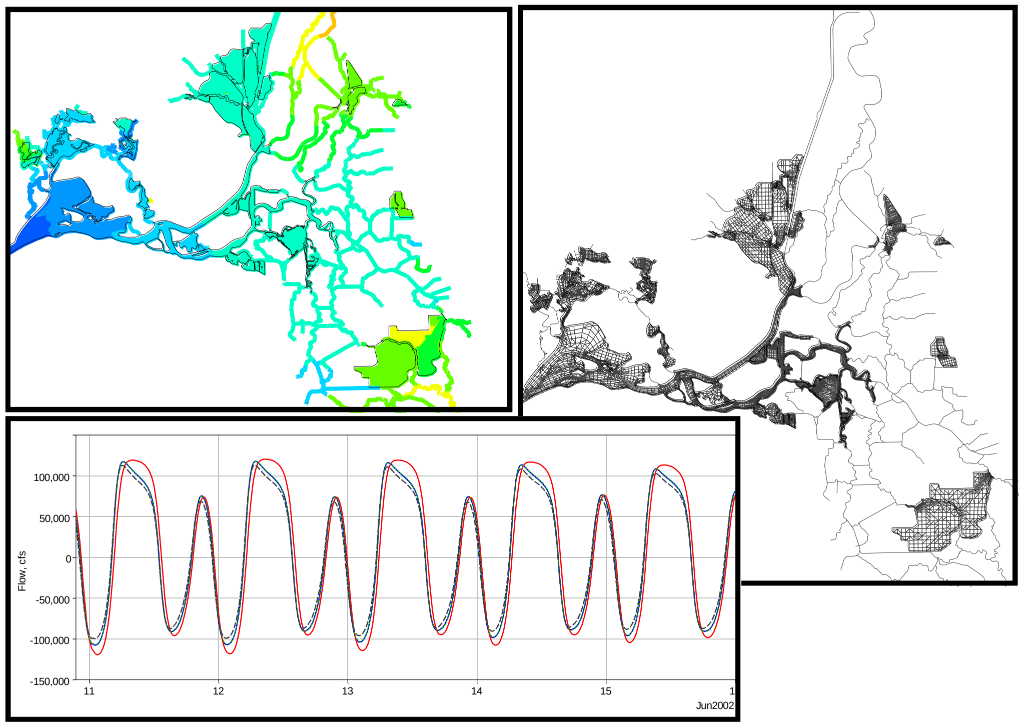
Attachment 2

Evaluation of Tidal Marsh Restoration Effects using RMA Bay-Delta Model



NUMERICAL MODELING IN SUPPORT OF BAY DELTA CONSERVATION PLAN TECHNICAL STUDY #4 – EVALUATION OF TIDAL MARSH RESTORATION EFFECTS

MARCH 2010



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BDCP Technical Study #4 – Evaluation of Tidal Marsh Restoration Effects

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1 Introduction

1.1 Background

Restoration of tidal marsh has been proposed for various regions of the Delta, denoted Restoration Opportunity Areas (ROAs), to improve habitat diversity and food availability for covered species. Preliminary assessments of tidal marsh effects on flows, stage, velocity and EC have been performed for areas throughout the Delta under three time step scenarios in the tidal marsh restoration process: Near-term (NT) with 14,000 acres of restoration; Early Long-term (ELT) with 25,000 acres of restoration and Late Long-term (LLT) with 65,000 acres of restoration. Sea level rise, climate change and modified Delta operations will be addressed in ongoing work. The effects of tidal marsh on localized and Delta-wide food and habitat, including water quality, residence time, temperature, X2, and other parameters need to be evaluated. This progress report illustrates progress to date on preliminary RMA model evaluation of tidal marsh restoration under the three time-step scenarios with historical boundary conditions.

1.2 RMA Bay Delta Model

RMA has developed and refined a numerical model of the San Francisco Bay and Sacramento-San Joaquin Delta system (Bay-Delta model) utilizing the RMA finite element models for surface waters. RMA2 (King, 1990) is a generalized free surface hydrodynamic model that is used to compute two-dimensional depth-averaged velocity and water surface elevation. RMA11 (King, 1998) is a generalized two-dimensional depth-averaged water quality model that computes a temporal and spatial description of conservative and non-conservative water quality parameters. RMA11 uses the results from RMA2 for its description of the flow field. As shown in Figure 2-1, the full model extends from the Golden Gate to the confluence of the American and Sacramento Rivers and to Vernalis on the San Joaquin River. The downstream boundary for the Delta only version of the model, shown inset in Figure 2-1, is at Martinez.

The current version of RMA's Bay-Delta model has been developed and continually refined during numerous studies over the past 11 years. One of the most important additions has been the capability to accurately represent wetting and drying in shallow estuaries. The most comprehensive calibration efforts in recent years were performed during studies for the City of Novato (RMA, 1997), the City of Palo Alto Regional Water Quality Control Plant (RMA, 1998), Central Contra Costa Sanitary District (RMA, 2000a), CALFED (RMA, 2000b), Flooded Islands Feasibility Study (RMA, 2005) and Numerical Modeling in Support of Suisun Marsh PEIR/EIS (RMA, 2008).

1.3 Objectives

The objective of this effort is to provide information to assist in the development of Tidal Marsh Habitat conservation measures and assess the anticipated changes of tidal marsh to habitat and operations parameters. Additionally, RMA model results are used to corroborate DMS2 model results. RMA has completed numerical modeling exercises and analysis of results for changes to flows, velocities, stage and EC under three time step scenarios with historical boundary conditions. Model input and output has been provided to CH2MHill for the purpose of DSM2 model corroboration.

2 Model Configuration

The RMA Bay-Delta model can be used with the tidal boundary condition applied at the Golden Gate (full Bay-Delta network) or with the tidal boundary condition applied at Martinez (Delta-only network). The Delta-only network is used when the physical or operational alternatives under consideration do not impact the flow or water quality at Martinez. Because the large-scale tidal marsh restoration configuration considered for the BDCP can impact conditions at Martinez, the RMA full-Bay-Delta network is used for most of the BDCP simulations.

Another option of the RMA Bay-Delta model is to simulate flow with or without density coupling. The RMA Bay-Delta model uses a depth-averaged and cross-sectionally averaged representation of the system that does not directly simulate density stratified flow. However, horizontal variation in density associated with variation in salinity will lead to a tilt in the water surface elevation, increasing the stage in the upstream most reaches of the Delta by as much as 1/3 of a foot. The best representation of stage throughout the system is achieved with consideration of the horizontal variation in density in the hydrodynamic simulation. Density coupling in complex two-dimensional flow regions where there are strong cross channel salinity gradients can lead to less accurate flow simulation. Simulated flow in Montezuma Slough with density coupling is generally less accurate than running the RMA model without density coupling. With these considerations in mind, the primary simulations are performed without density coupling. Then the final evaluation of stage for computation of tidal datum areas in restoration areas is made using the Delta-only version of the model with density coupling.

2.1 Base Model

Figure 2-1 shows the entire network of the Bay-Delta model used for the Base case hydrodynamic and EC simulations in this study. The inset shows the Delta version of the network used in the coupled model simulations.

The model was developed from GIS data, USGS digital line graph (DLG) and digital orthoquad (DOQ) images. Bottom elevations and the extent of mudflats were based on bathymetry data collected by NOAA, DWR, USACE and USGS. These data sets 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/index.html.

Additional data were collected around Franks Tract by DWR and the USGS in 2004. USGS 10 m resolution Delta Bathymetry grids were obtained from the Access USGS website at http://sfbay.wr.usgs.gov/access/Bathy/Delta/.

During a recent study (RMA, 2008) the finite element mesh was refined in the Suisun Marsh area. The length of the 1-D elements was reduced and additional channels were added. Overbank/fringe marsh was added as off-channel storage based on observed flow data (DWR, Suisun Marsh Branch, 2004), LIDAR elevation data and aerial photos.

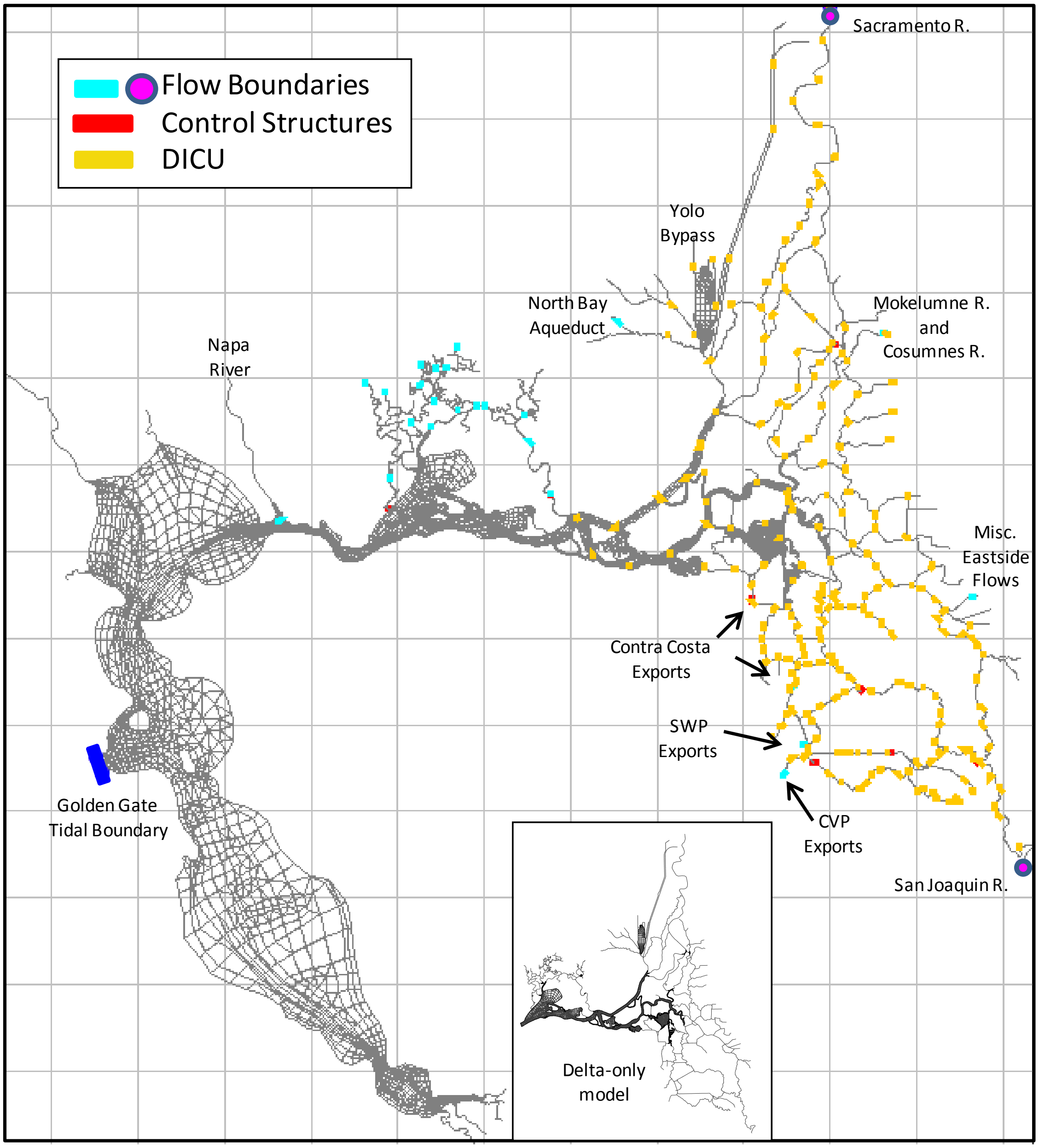


Figure 2-1 Model grid showing inflow and export locations, flow control structures and DICU. Inset shows the Delta-only version of the model used in the coupled simulations.

2.2 Restoration Cases

Three restoration cases, Near-term (NT), Early Long-term (ELT) and Late Long-term (LLT), were simulated to represent three points in time with three different total areas of restoration. Areas of restoration include Suisun Marsh, Cache Slough, West Delta, Mokelumne-Cosumnes, East Delta and South Delta. Each successive time step incorporates all restoration from the previous time step, plus additional areas.

Breach sizes and locations were generally selected to ensure that filling and draining of the tidal restoration areas was not constrained by breach geometry. For planned near term restoration areas, breach locations where used as provided by the DHCCP groups. For restoration areas that are not part of currently planned actions, breaches were generally located near the deepest part of the restoration area or where there were existing channels in the Base grid. After initial simulations all breaches were checked to assure they were not restrictive. This was done by plotting stage in the channel near the breach and just inside the breach to be sure there was no significant head loss. Any breaches that appeared to be restrictive were widened.

Roughness coefficients used within the breached areas were based on calibrated coefficients for existing flooded areas, including Liberty Island and portions of Franks Tract.

2.2.1 Near-Term Restoration

The restoration acreage goal for the Near-term (NT) restorations scenario is 14,000 acres. The modeled NT restoration scenario consists of 6,750 acres in the Cache Slough ROA, 6,450 acres in Suisun Marsh, 2,310 acres in the West Delta ROA, and 2,900 acres in the Mokelumne-Cosumnes ROA. A summary of the acreages, including areas at tidal datums, is provided in Table 2-1. Note that there are approximately 2,000 acres of existing tidal marsh included in the Suisun Marsh ROA acreages. A detail view of the NT grid is shown in Figure 2-2. Phase 1 restoration areas are in the NT grid including Meins Landing, Hill Slough and Rush Ranch in Suisun Marsh; Prospect Island, Calhoun Cut, Little Holland Tract and Yolo Ranch in Cache Slough; Decker Island, Dutch Slough and Twitchell Island and Chevron Point in the West Delta; and McCormack-Williamson Tract in Mokelumne-Cosumnes. There is no restoration in the East Delta ROA or South Delta ROA for the NT case.

Elevations for the restoration areas were set based on DWR 2007 LiDAR data (DWR, 2007a).

To provide greater channel capacity in Suisun Marsh and relieve dampening of the tidal range that results from restoration, Montezuma Slough, Suisun Slough, and Nurse Slough were widened out to the levees for the NT, ELT and LLT simulations.

The full Bay model was run first. Correlations were computed between Base and NT stage and EC at Martinez. These correlations were applied to Martinez observed stage and EC to adjust for the impacts of the restoration. The resulting correlations are as follows:

For stage, Y=0.965X+0.040 shifted -2 minutes
Where Y = NT adjusted Martinez stage and X = observed Martinez stage

For EC, Y=1.001X+191.52 shifted 8 minutes
Where Y = NT adjusted Martinez EC and X = observed Martinez EC

The adjusted Martinez stage and EC were then used as boundary conditions to run the coupled Delta-only version of the NT model.

Coupled Delta-only model results for July 2002 were used to compute tidal datums in each of the ROAs for calculation of areas only. In Figure 2-3 through Figure 2-6 are detailed views of each ROA with color contours of areas below mean lower low water (MLLW), between MLLW and mean higher high water (MHHW), between MHHW and extreme high water (EHW) and above EHW.

Table 2-1 Summary of Near-Term ROA acreages.

ROA	Area Above EHW (Ac)	Area MHHW to EHW (Ac)	Area MLLW to MHHW (Ac)	Area Below MLLW (Ac)	Total Area (Ac)	% Tidal Marsh (between MLLW and MHHW)
Suisun Marsh	128	217	2,802	3,307	6,454	43%
Cache Slough	1,818	636	3,062	1,233	6,749	45%
West Delta	258	61	1,175	812	2,306	51%
Mokelumne-Cosumnes	2	77	856	1,969	2,904	29%
East Delta	-	-	-	-	-	-
South Delta	-	-	-	-	-	-
Total	2,206	991	7,895	7,321	18,413	43%

Figure 2-2 RMA Near-Term model finite element mesh.

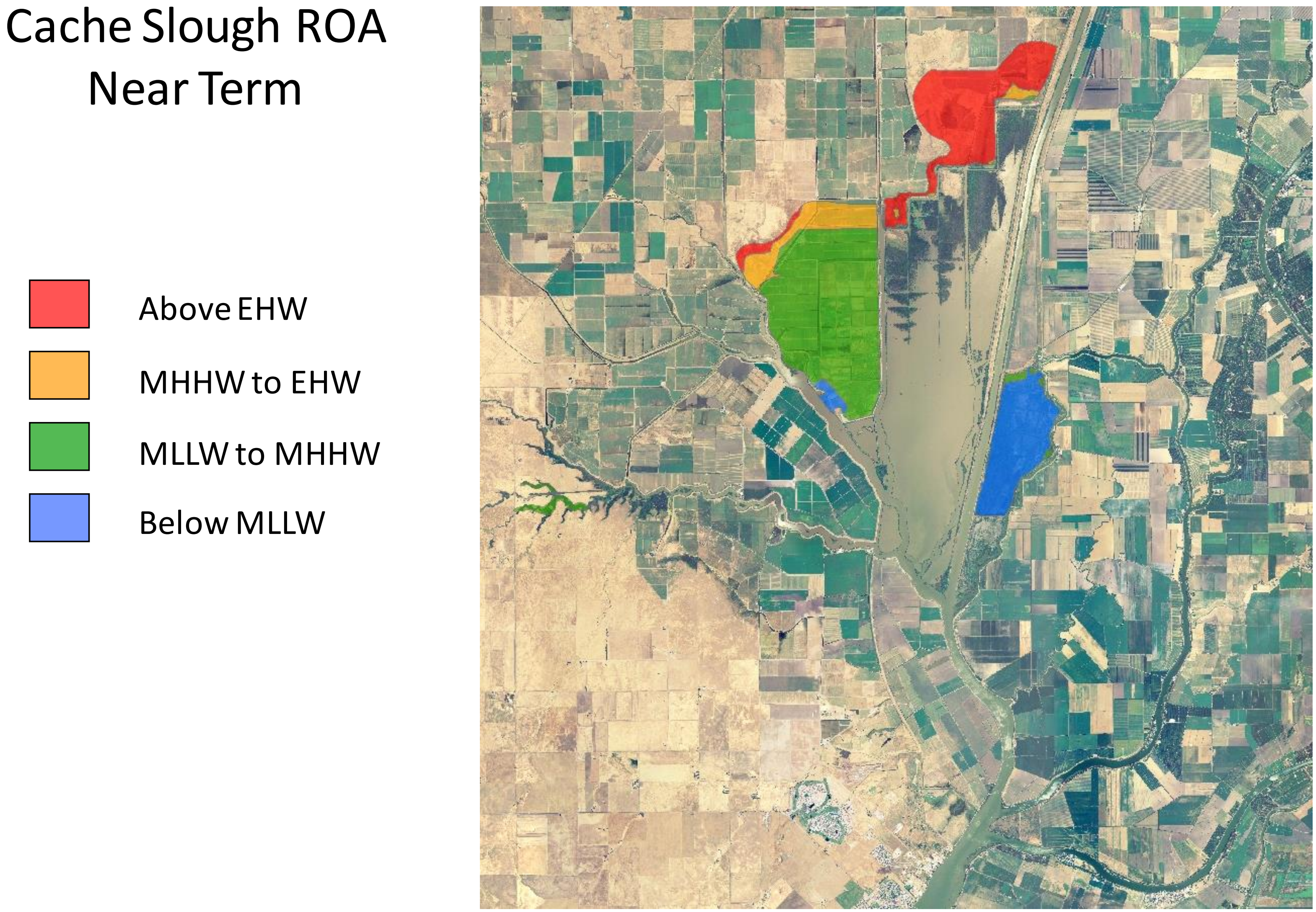


Figure 2-3 Contours of tidal datums for Cache Slough ROA, near-term.

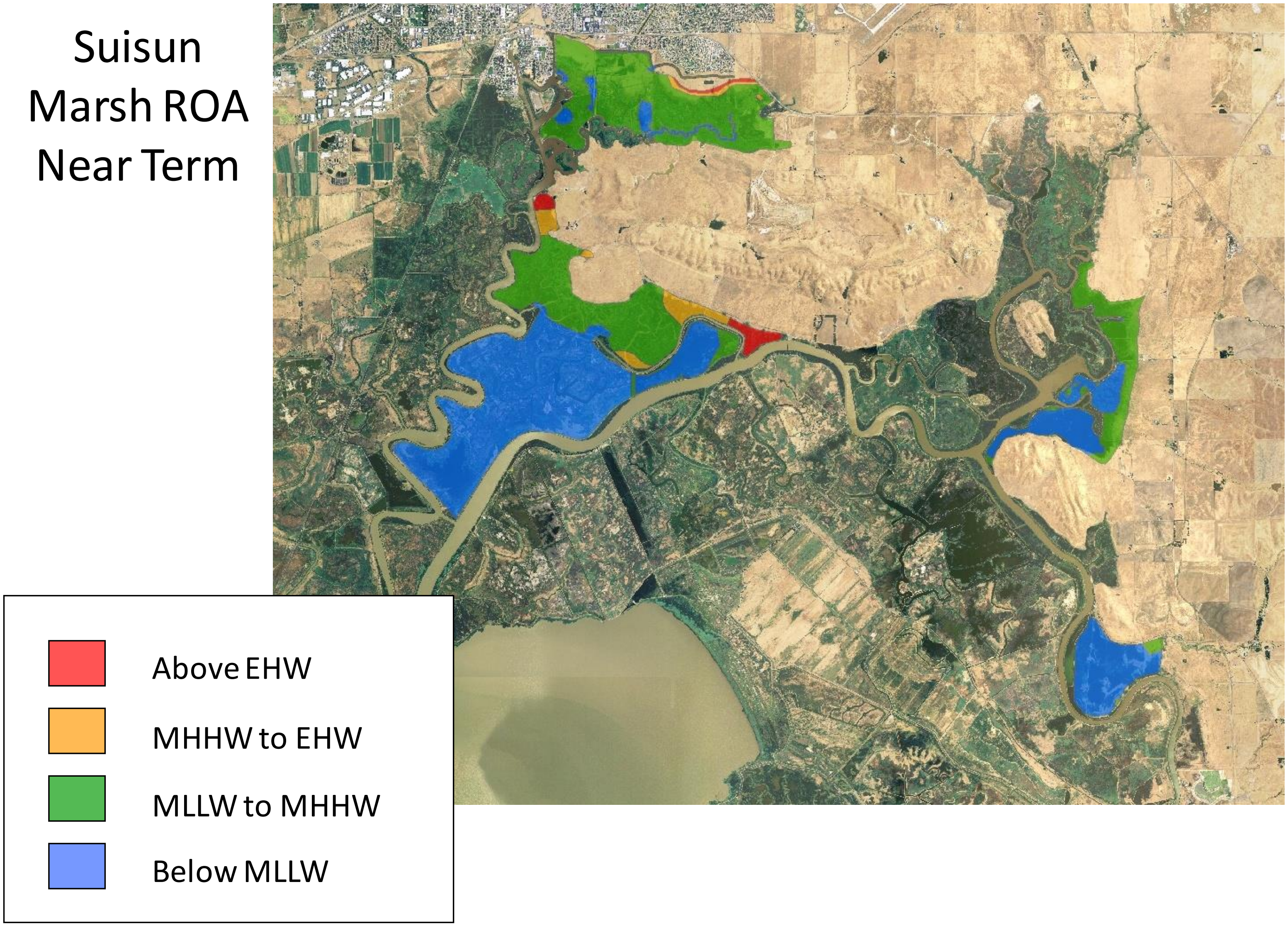


Figure 2-4 Contours of tidal datums for Suisun Marsh ROA, near-term.

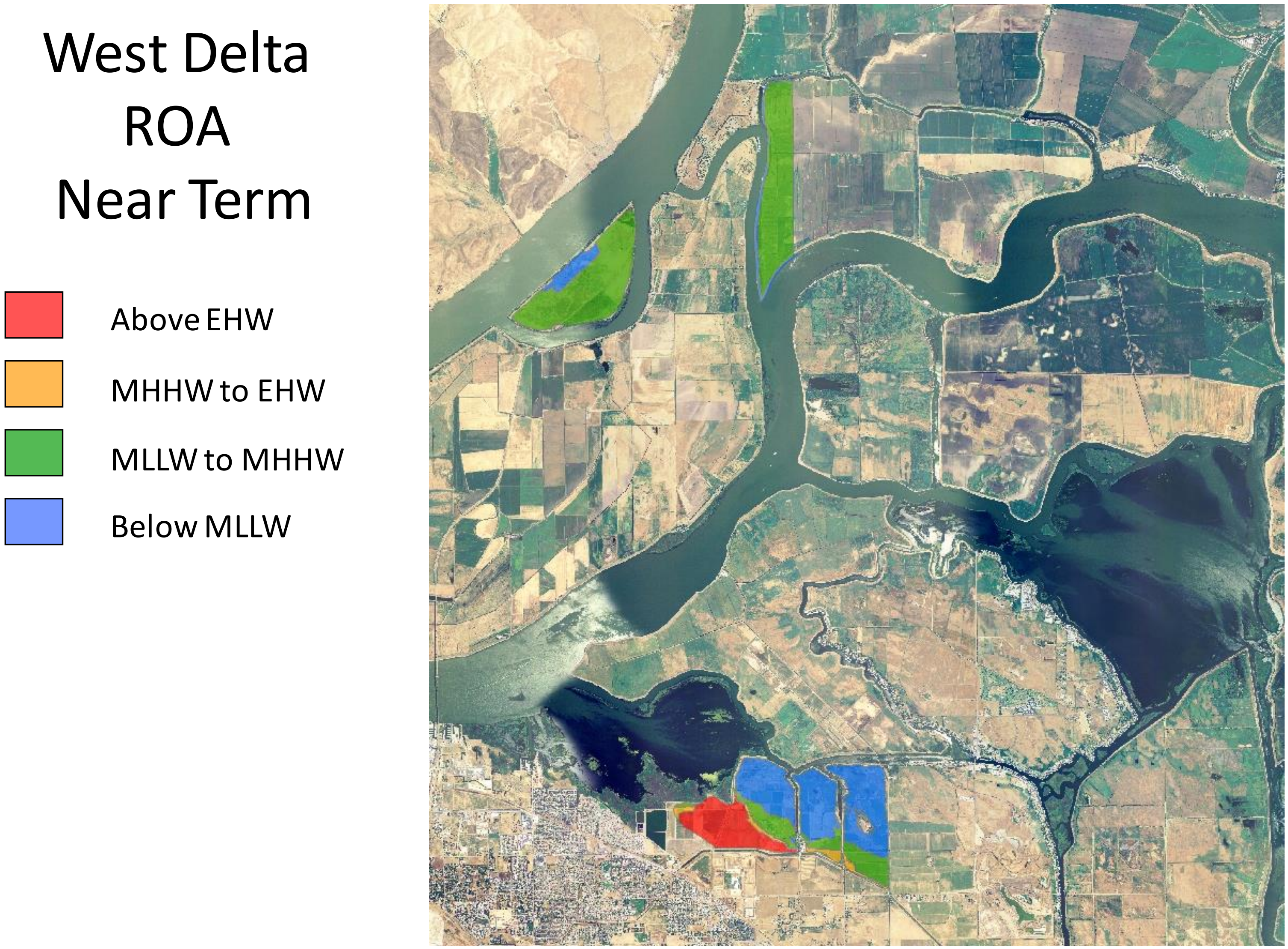


Figure 2-5 Contours of tidal datums for West Delta ROA, near-term.

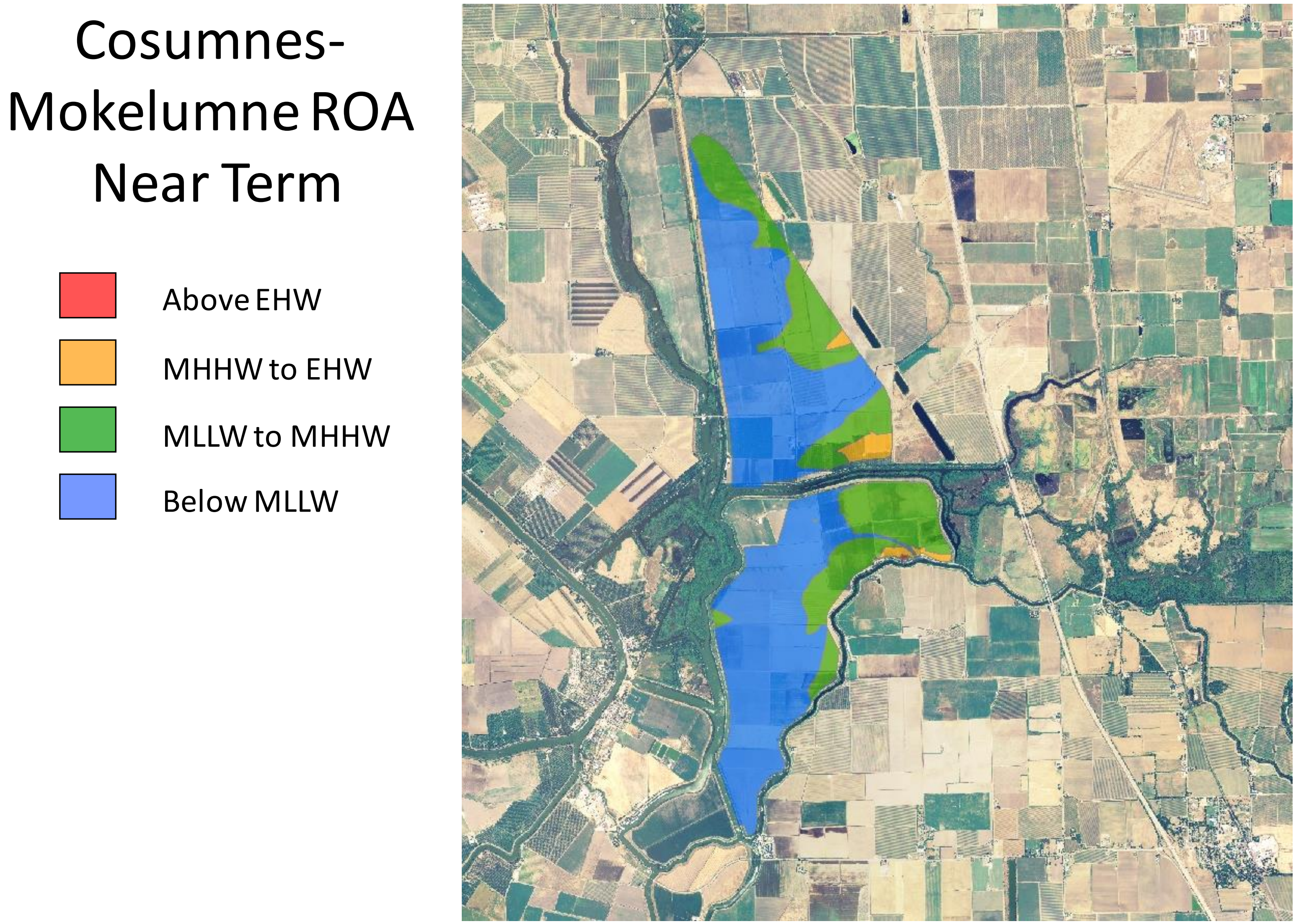


Figure 2-6 Contours of tidal datums for Cosumnes-Mokelumne ROA, near-term.

2.2.2 Early Long-Term Restoration

The restoration acreage goal for the Early Long-term (ELT) restorations scenario is 25,000 acres. The modeled ELT restoration scenario consists of 12,900 acres in the Cache Slough ROA, 8,130 acres in Suisun Marsh, 3,990 acres in the West Delta ROA, and 2,900 acres in the Mokelumne-Cosumnes ROA. A summary of the acreages, including areas at tidal datums, is provided in Table 2-2. Note that there are approximately 2,000 acres of existing tidal marsh included in the Suisun Marsh ROA acreages, therefore the overall total acreage exceeds the goal. A detail view of the ELT grid is shown in Figure 2-7. All NT areas are included in the ELT grid. There is no restoration in the East Delta ROA or South Delta ROA for the ELT case.

Elevations for the restoration areas were set based on DWR 2007 LiDAR data (DWR, 2007a).

The full Bay model was run first. Correlations were computed between Base and ELT stage and EC at Martinez. These correlations were applied to Martinez observed stage and EC to adjust for the impacts of the restoration. The resulting correlations are as follows:

For stage, $Y=0.963X+0.039$ shifted -5 minutes
Where Y = ELT adjusted Martinez stage and X = observed Martinez stage

For EC, $Y=0.999X+114.70$ shifted 10 minutes
Where Y = ELT adjusted Martinez EC and X = observed Martinez EC

The adjusted Martinez stage and EC were then used as boundary conditions to run the coupled Delta-only version of the ELT model.

Coupled Delta-only model results for July 2002 were used to compute tidal datums in each of the ROAs for calculation of areas only. In Figure 2-8 through Figure 2-11 are detailed views of each ROA with color contours of areas below mean lower low water (MLLW), between MLLW and mean higher high water (MHHW), between MHHW and extreme high water (EHW) and above EHW.

Table 2-2 Summary of Early Long-Term ROA acreages.

ROA	Area Above EHW (Ac)	Area MHHW to EHW (Ac)	Area MLLW to MHHW (Ac)	Area Below MLLW (Ac)	Total Area (Ac)	% Tidal Marsh (between MLLW and MHHW)
Suisun Marsh	159	289	3,495	4,190	8,133	43%
Cache Slough	2,944	1,669	5,946	2,338	12,897	46%
West Delta	284	38	2,743	927	3,992	69%
Mokelumne-Cosumnes	3	83	846	1,972	2,904	29%
East Delta	-	-	-	-	-	-
South Delta	-	-	-	-	-	-
Total	3,390	2,079	13,030	9,427	27,926	43%

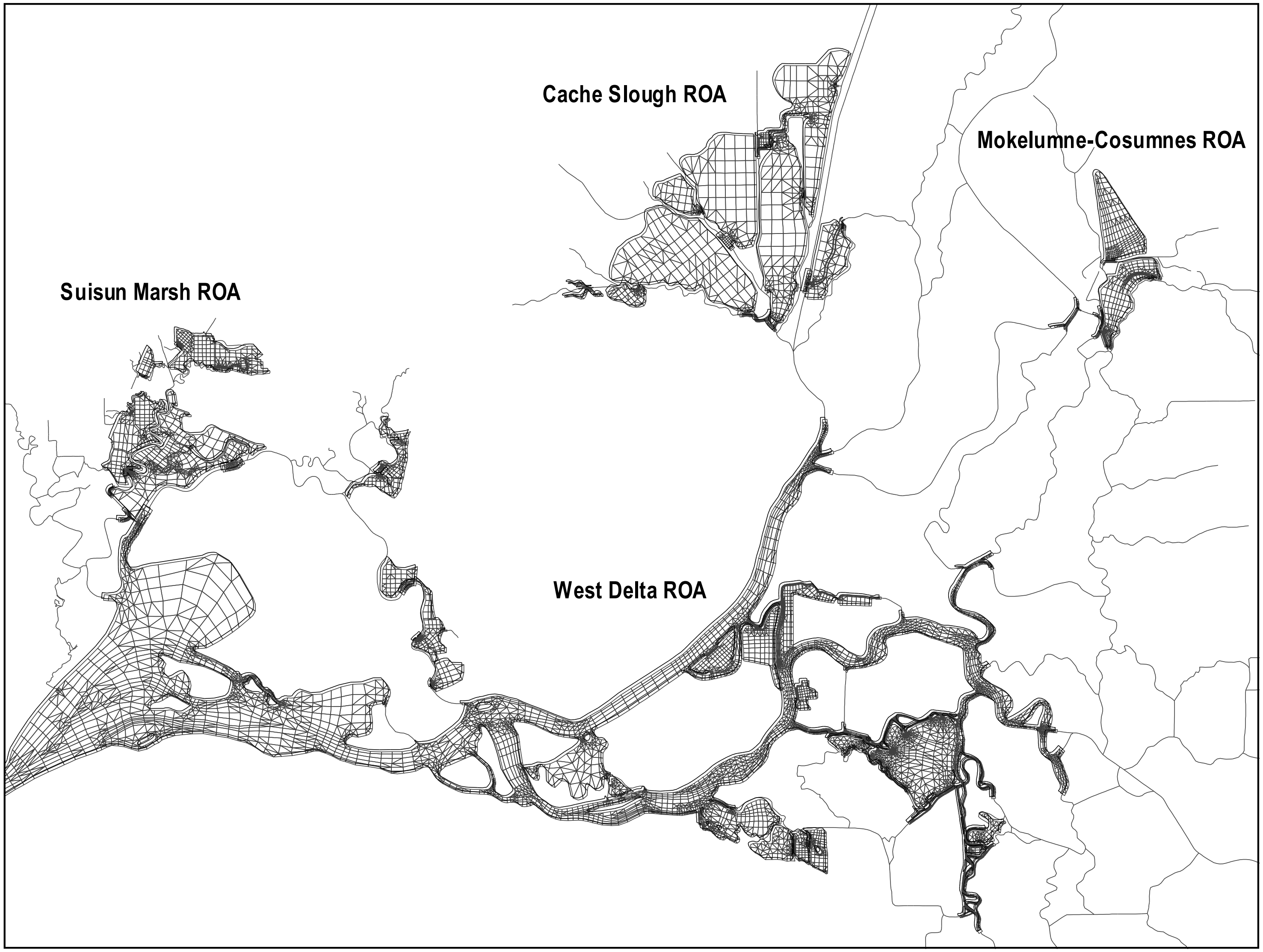


Figure 2-7 RMA Early Long-Term model finite element mesh.

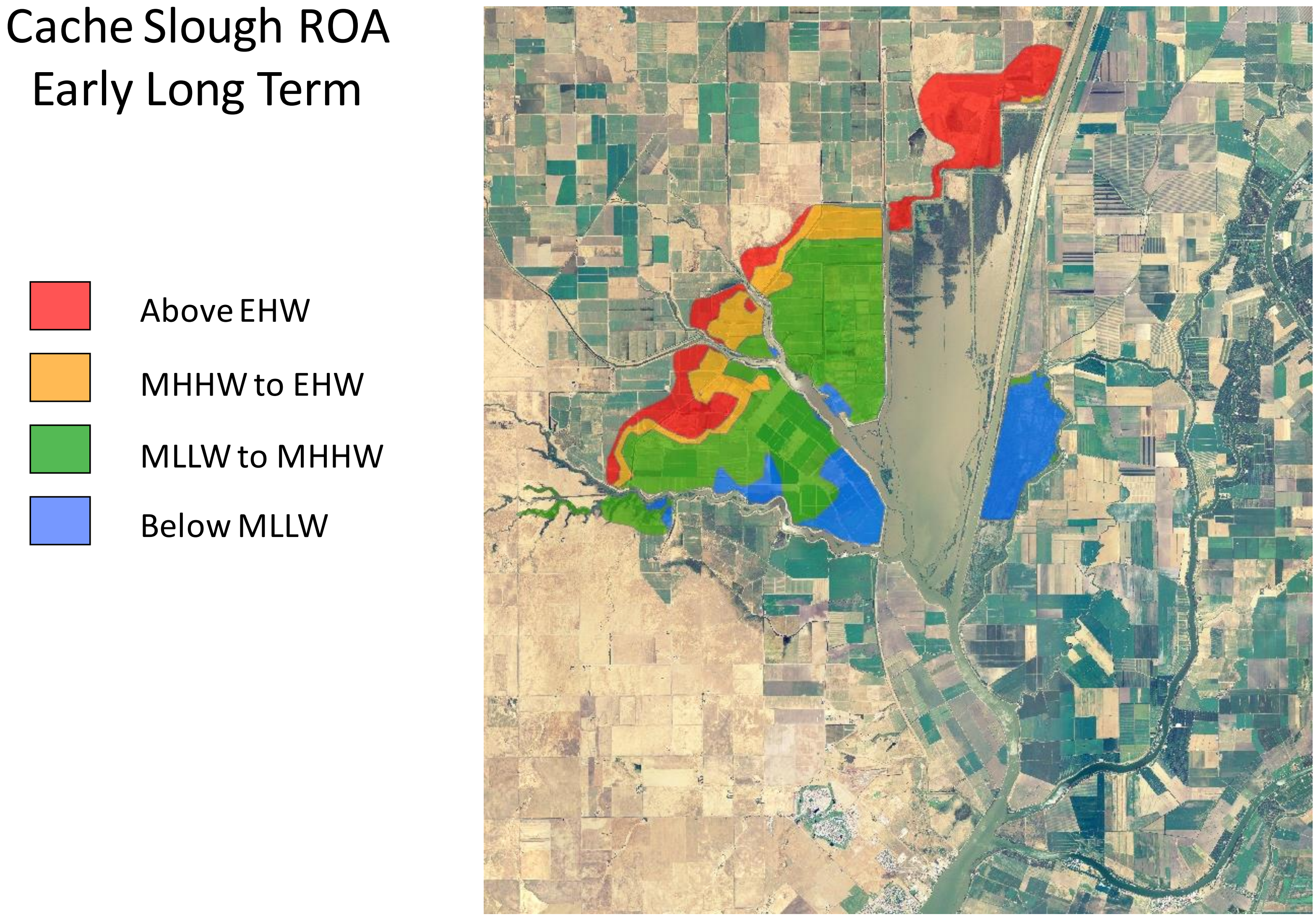


Figure 2-8 Contours of tidal datums for Cache Slough ROA, early long-term.

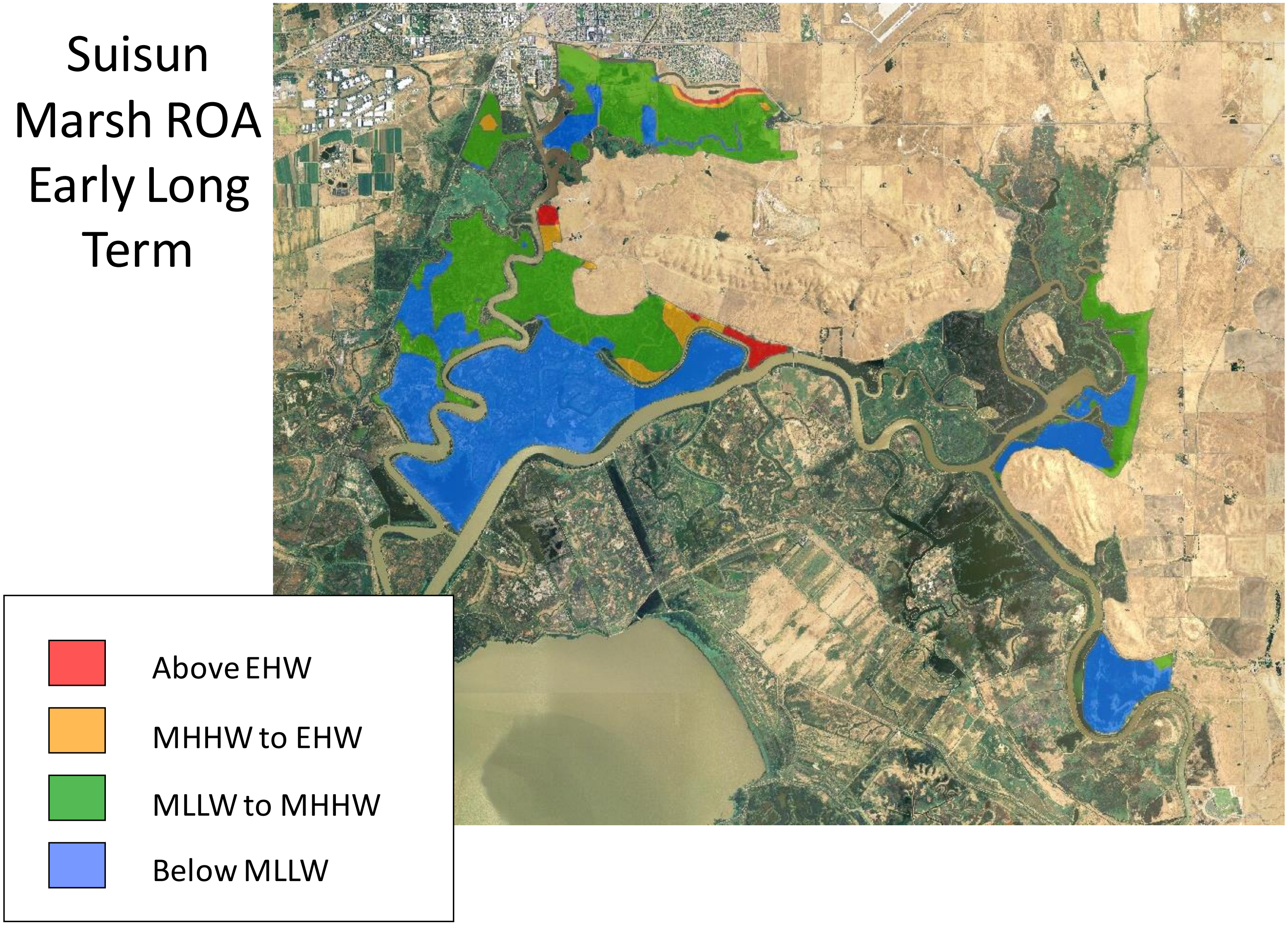


Figure 2-9 Contours of tidal datums for Suisun Marsh ROA, early long-term.

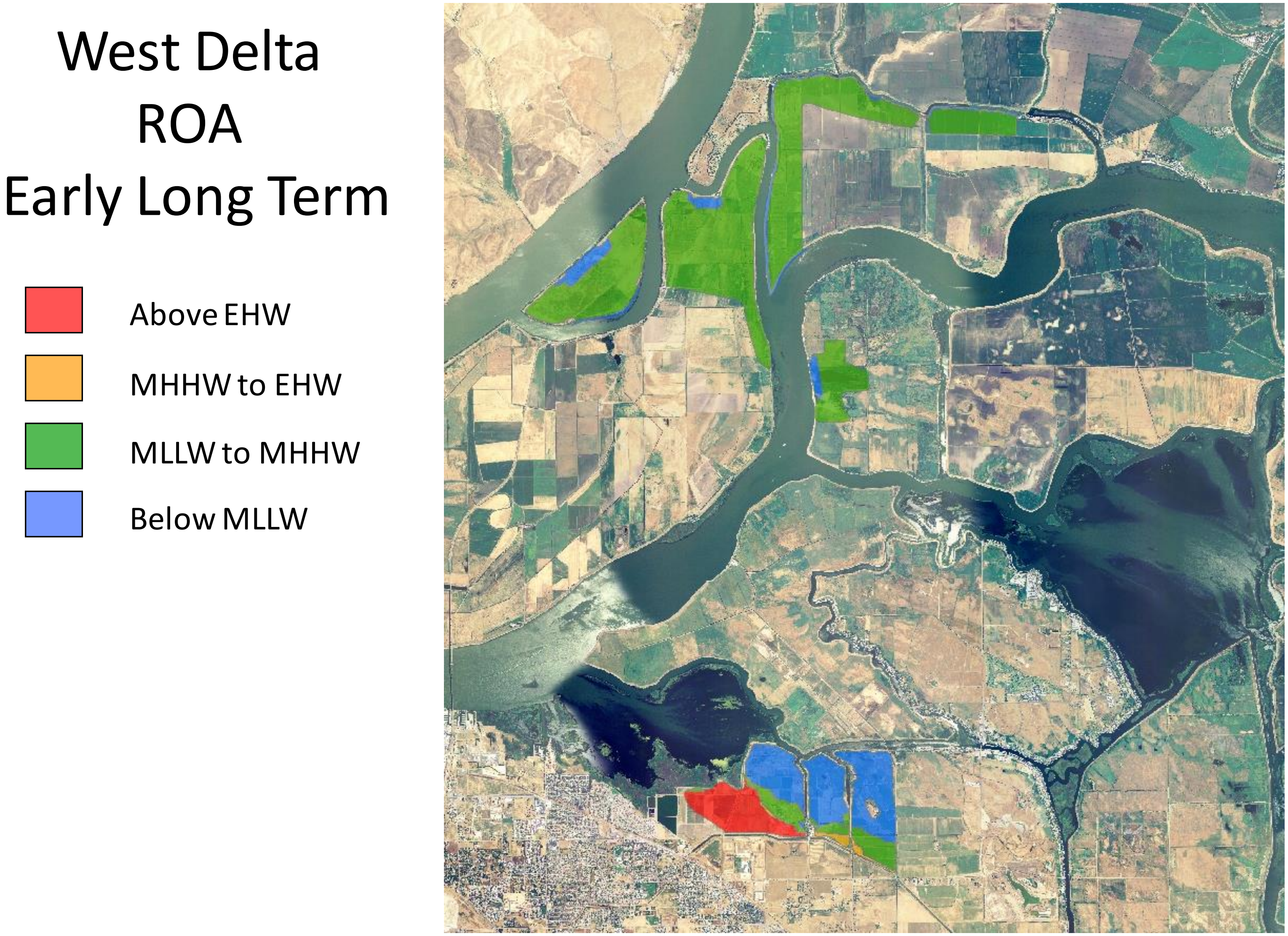


Figure 2-10 Contours of tidal datums for West Delta ROA, early long-term.

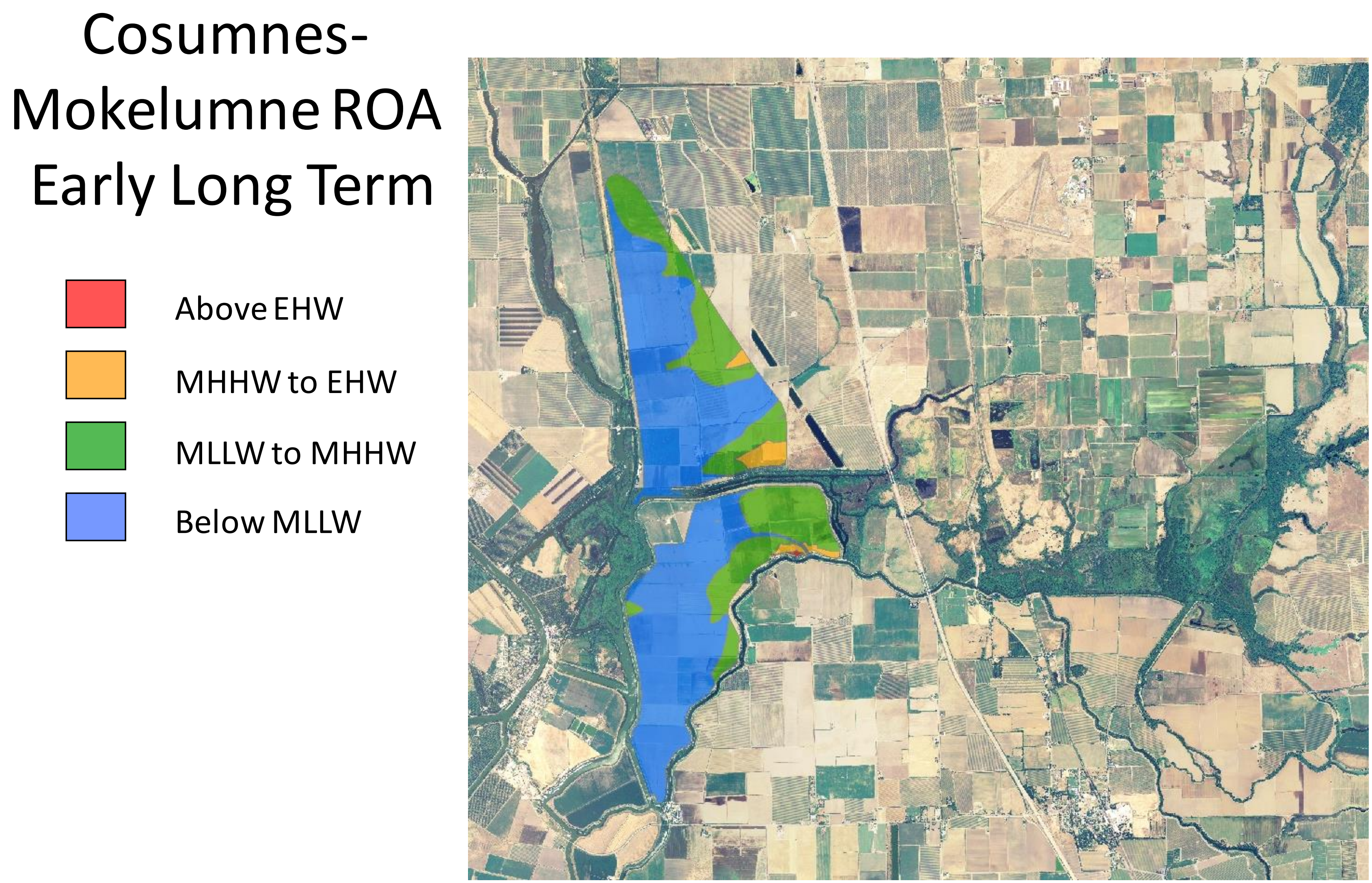


Figure 2-11 Contours of tidal datums for West Delta ROA, early long-term.

2.2.3 Late Long-Term Restoration

The restoration acreage goal for the Late Long-term (LLT) restorations scenario is 65,000 acres. The modeled LLT restoration scenario consists of 20,330 acres in the Cache Slough ROA, 14,390 acres in Suisun Marsh, 4,240 acres in the West Delta ROA, 3,290 acres in the Mokelumne-Cosumnes ROA, 2,160 acres in the East Delta ROA and 22,480 acres in the South Delta ROA. A summary of the acreages, including areas at tidal datums, is provided in Table 2-3. Note that there are approximately 2,000 acres of existing tidal marsh included in the Suisun Marsh ROA acreages, therefore the overall total acreage exceeds the goal. A detail view of the LLT grid is shown in Figure 2-12. All ELT areas are included in the LLT grid. There is additional restoration in the East Delta ROA and South Delta ROA for the LLT case.

Elevations for the restoration areas were set based on DWR 2007 LiDAR data (DWR, 2007a).

In Suisun Marsh, restoration was not expanded to the deeper areas on the Suisun Bay side of Montezuma Slough because earlier simulations indicated that restoring these deeper areas (shaded blue in Figure 2-13) would result in pronounced diminishment of the tidal range and thus less tidal marsh. A plot of stage in Montezuma Slough at Beldon's Landing is shown in Figure 2-14. The current Base, NT, ELT and LLT results are shown along with results from a preliminary simulation where the deeper areas adjacent to Montezuma Slough were restored and Montezuma Slough is not widened. The inset in Figure 2-14 shows the finite element mesh from the preliminary simulation, with deeper areas restored.

With 14,000 acres restored in Suisun Marsh for the LLT case, only a quarter of the restored area is tidal marsh (between MHHW and MLLW), even without restoring the deepest areas.

In the South Delta, a dramatic reduction in tidal range, particularly on Middle River, results in limited tidal marsh area. Of the 22,000 acres restored in the South Delta less than 10% falls in the tidal marsh range.

The full Bay LLT model was run first. Correlations were computed between Base and LLT stage and EC at Martinez. These correlations were applied to Martinez observed stage and EC to adjust for the impacts of the restoration. The resulting correlations are as follows:

For stage, $Y=0.942X+0.064$ shifted -3 minutes
Where Y = LLT adjusted Martinez stage and X = observed Martinez stage

For EC, $Y=0.996X+68.23$ shifted 13 minutes
Where Y = LLT adjusted Martinez EC and X = observed Martinez EC

The adjusted Martinez stage and EC were then used as boundary conditions to run the coupled Delta-only version of the LLT model.

Coupled Delta-only model results for July 2002 were used to compute tidal datums in each of the ROAs for calculation of areas only. In Figure 2-15 through Figure 2-16 are detailed views of each ROA with color contours of areas below mean lower low water (MLLW), between MLLW and mean higher high water (MHHW), between MHHW and extreme high water (EHW) and above EHW.

Table 2-3 Summary of Late Long-Term ROA acreages.

ROA	Area Above EHW (Ac)	Area MHHW to EHW (Ac)	Area MLLW to MHHW (Ac)	Area Below MLLW (Ac)	Total Area (Ac)	% Tidal Marsh (between MLLW and MHHW)
Suisun Marsh	205	435	3,676	10,073	14,389	26%
Cache Slough	4,080	1,955	6,878	7,421	20,334	34%
West Delta	287	39	2,954	956	4,236	70%
Mokelumne-Cosumnes	344	109	822	2,018	3,293	25%
East Delta	792	221	240	910	2,163	70%
South Delta	8,292	1,395	1,848	10,948	22,483	8%
Total	14,000	4,154	16,418	32,326	66,898	25%

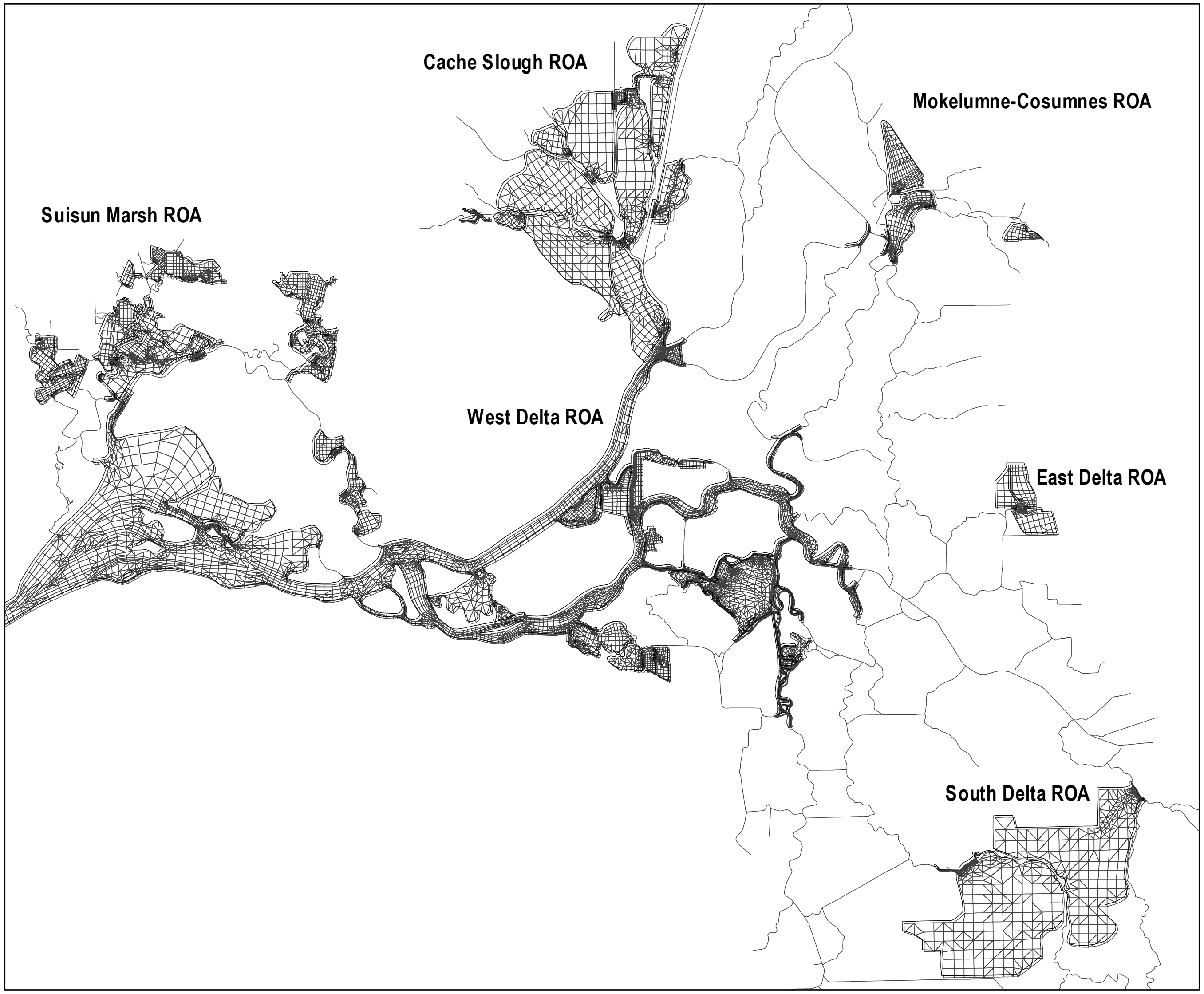


Figure 2-12 RMA Late Long-Term ROA model finite element mesh.

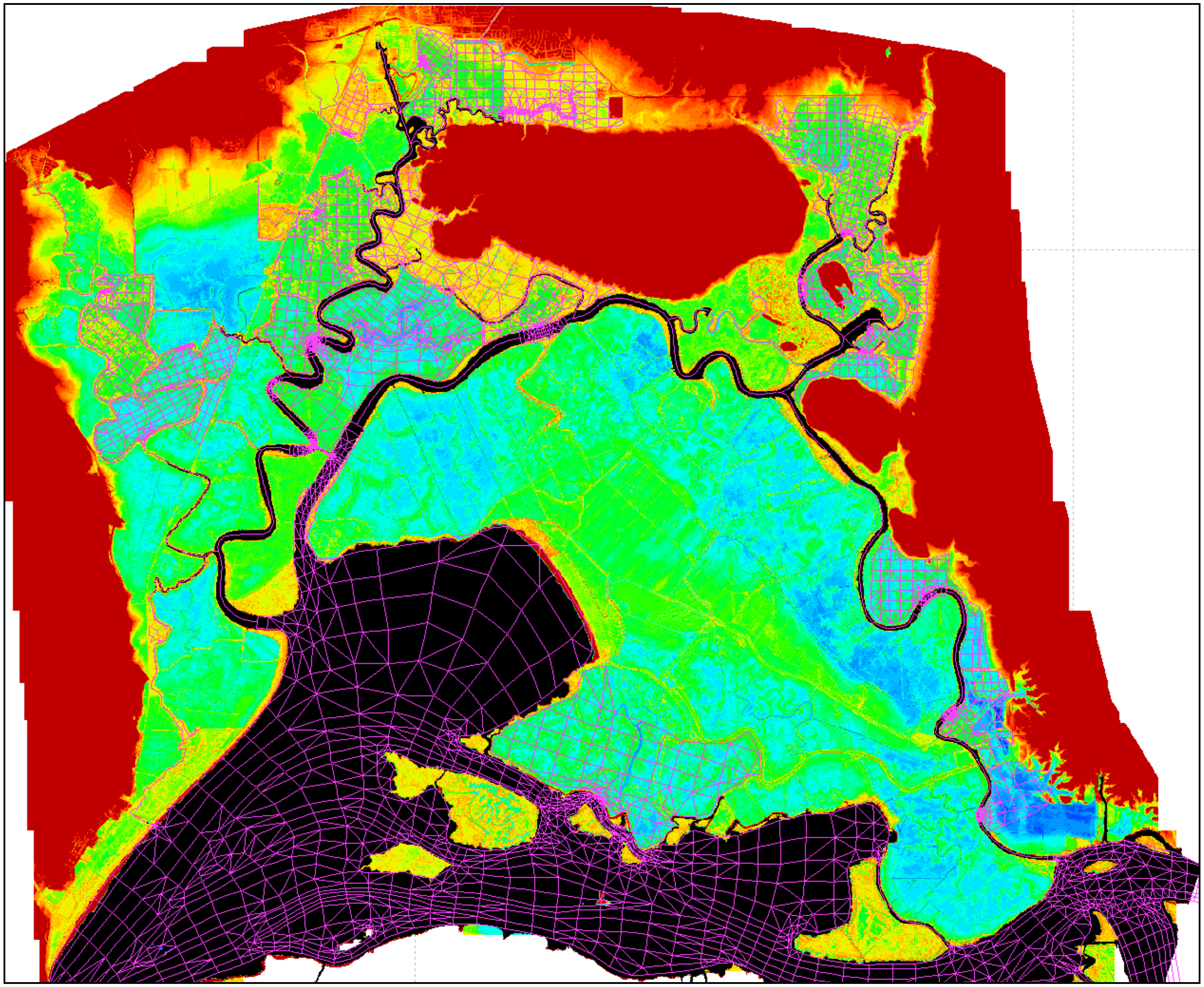
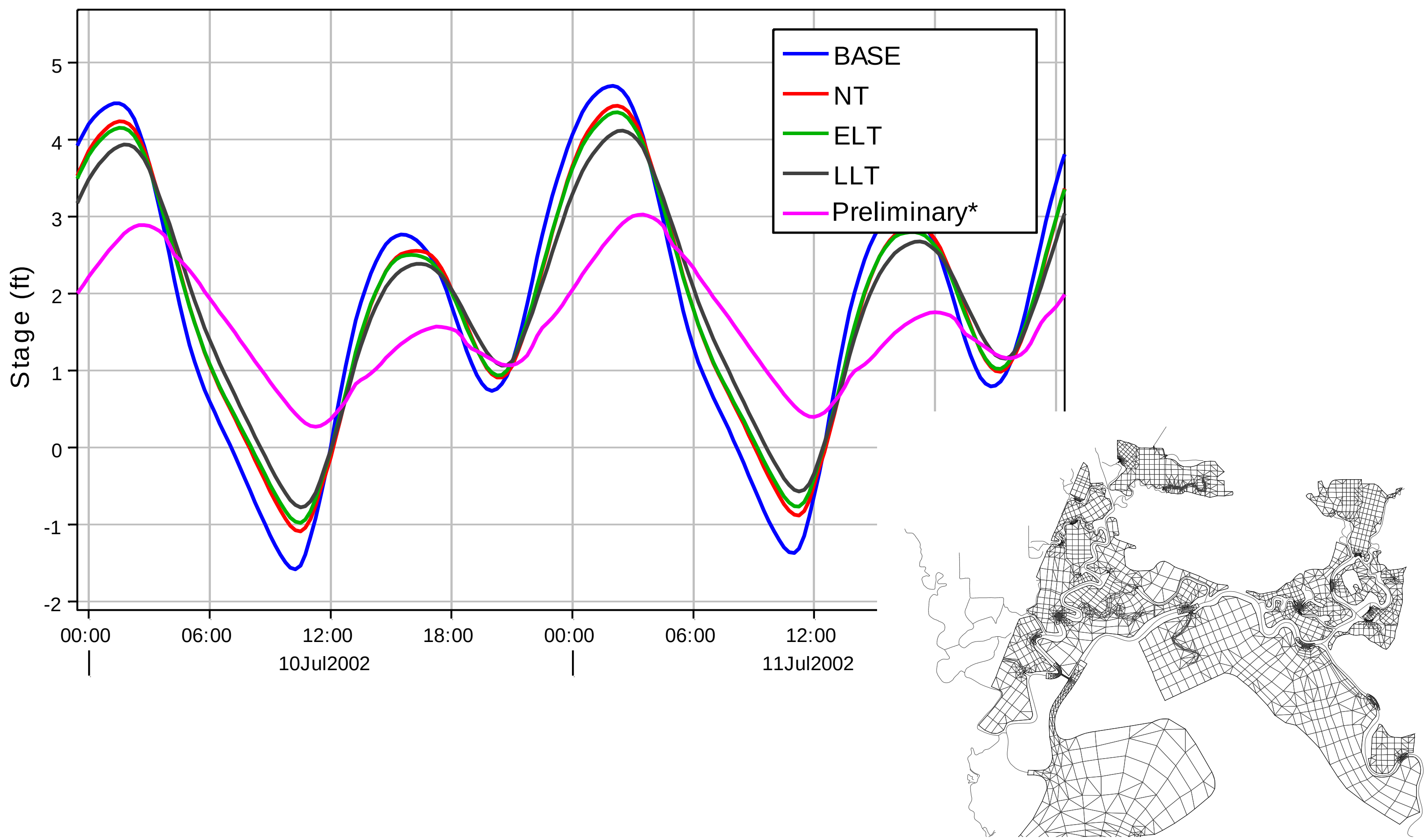


Figure 2-13 LLT grid atop elevation data in Suisun Marsh. Darker blue shades indicate lower elevations.



*Preliminary simulation – no channel modifications, extensive restoration in Suisun Marsh

Figure 2-14 Stage in Montezuma Slough at Beldon's Landing for current simulations and for a preliminary simulation with deeper areas restored in Suisun Marsh and no widening of Montezuma Slough (inset shows finite element mesh for old simulation).

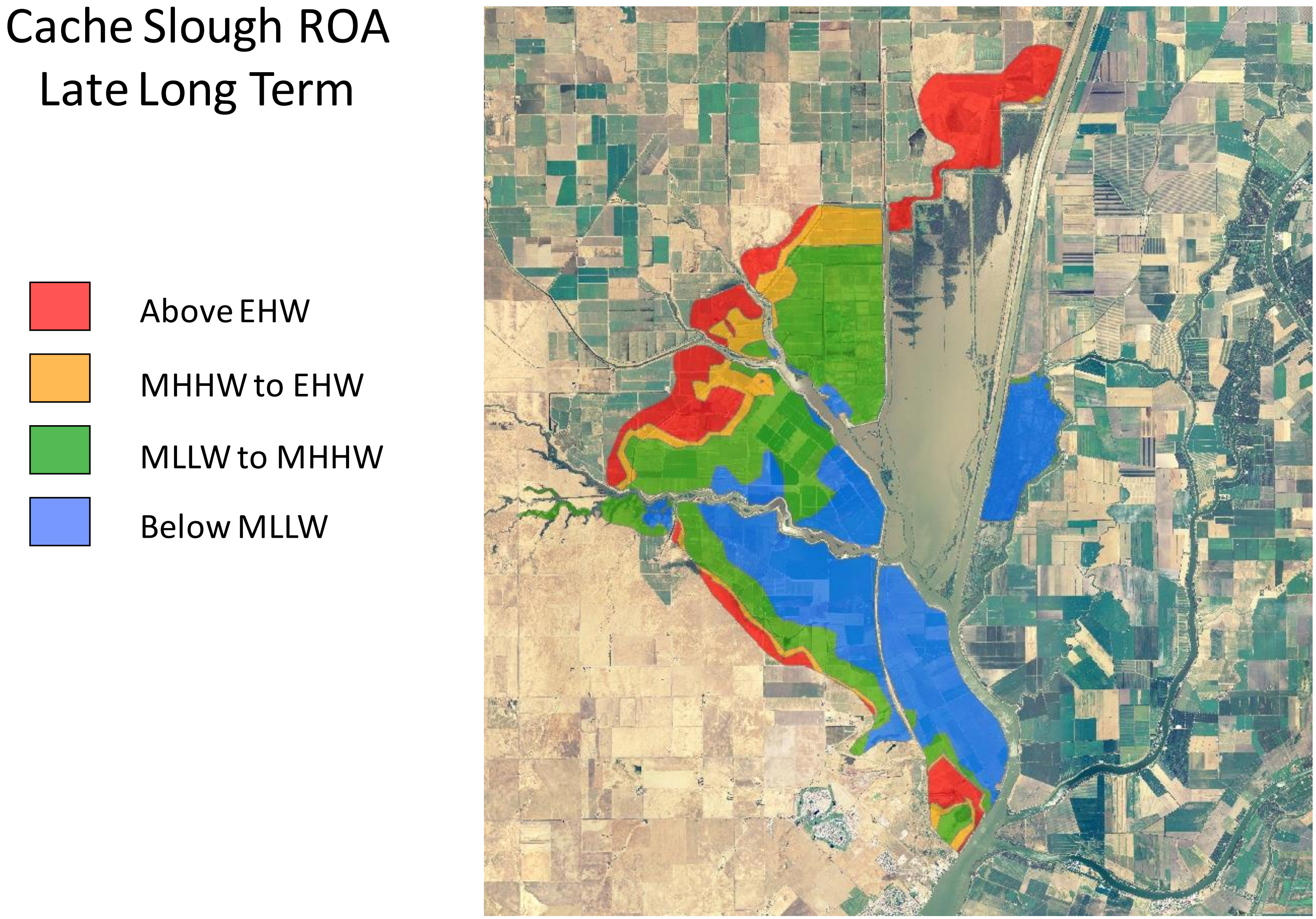


Figure 2-15 Contours of tidal datums for Cache Slough ROA, late long-term.

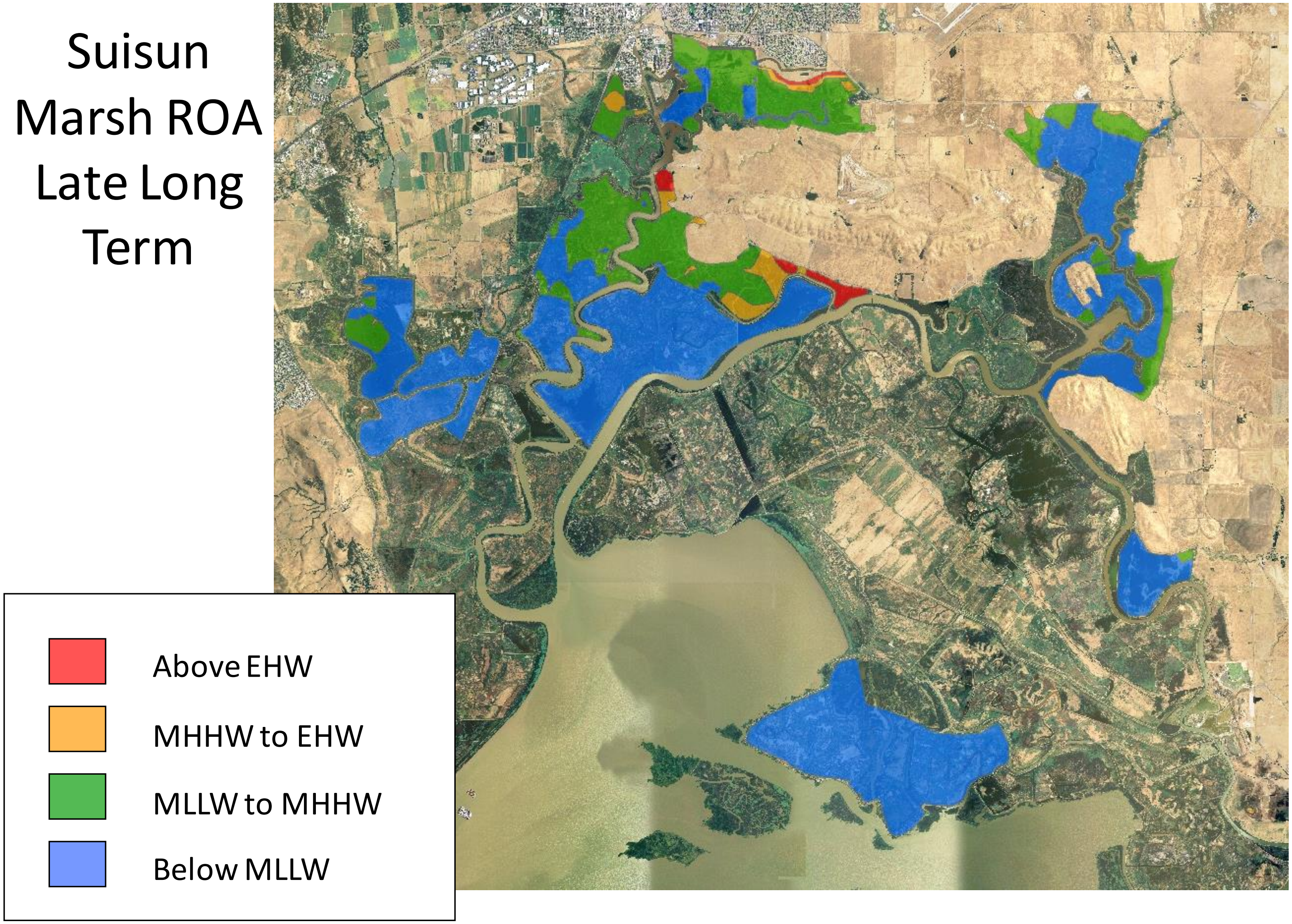


Figure 2-16 Contours of tidal datums for Suisun Marsh Slough ROA, late long-term.

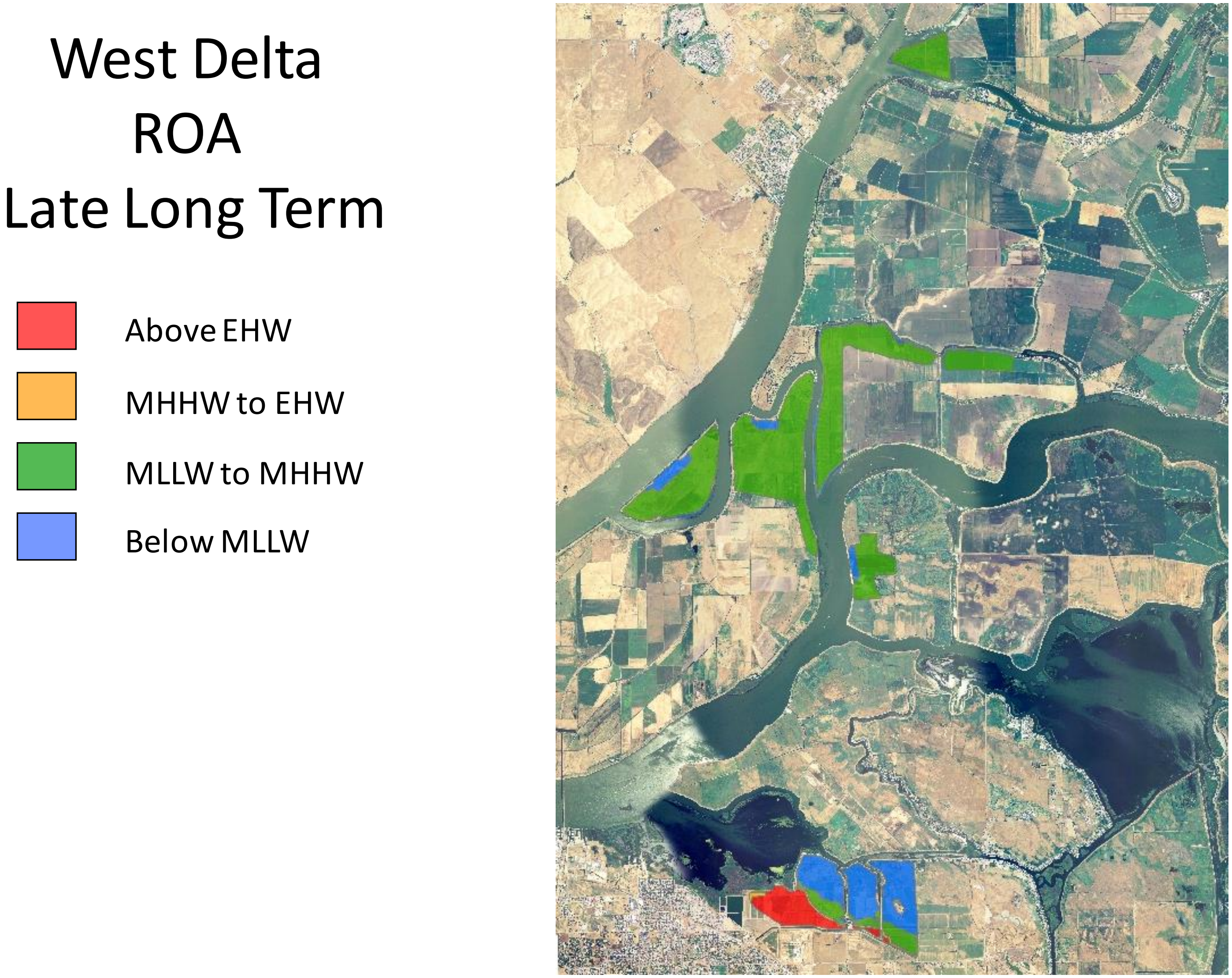


Figure 2-17 Contours of tidal datums for West Delta ROA, late long-term.

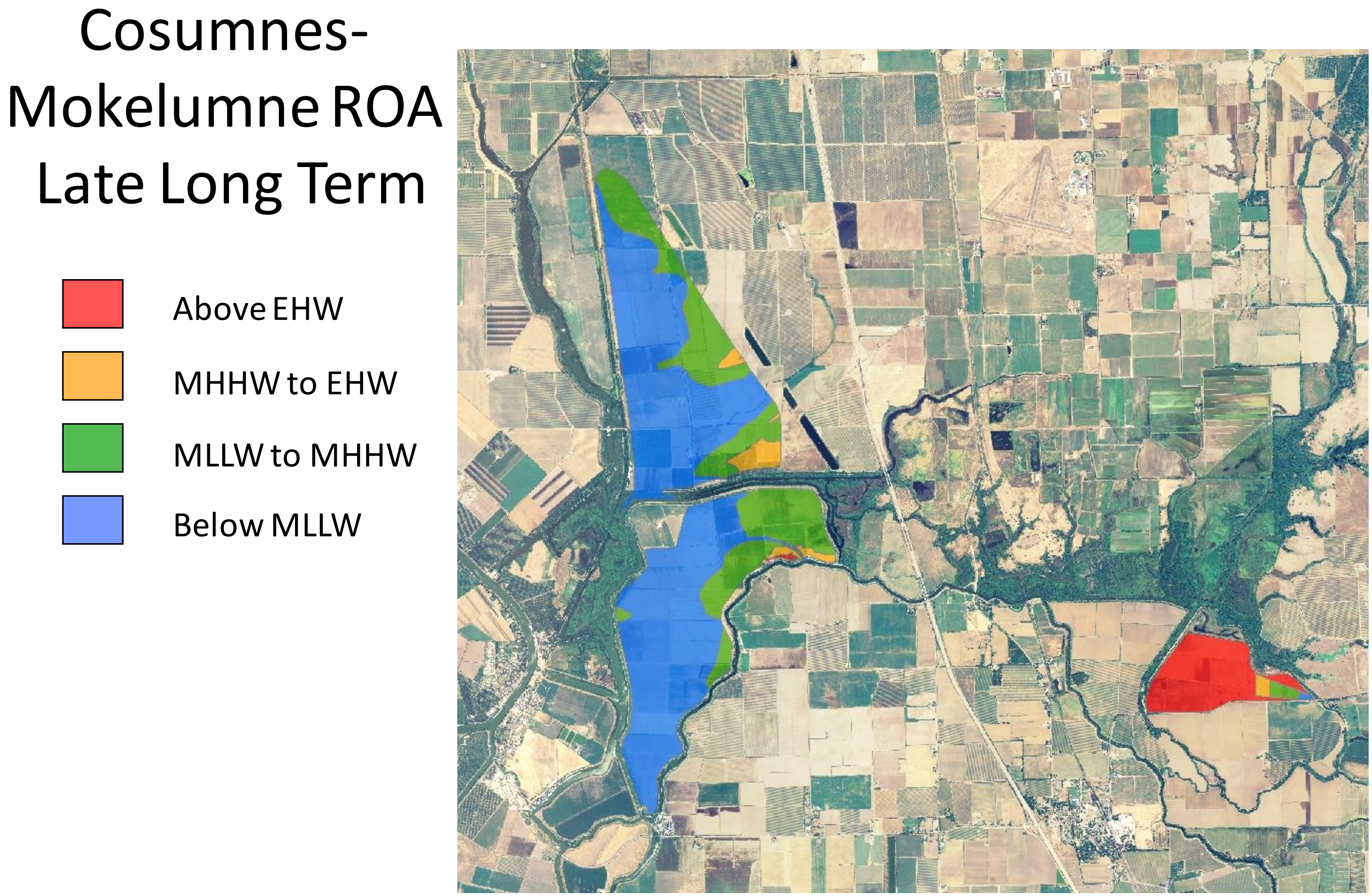


Figure 2-18 Contours of tidal datums for Cosumnes-Mokelumne ROA, late long-term.

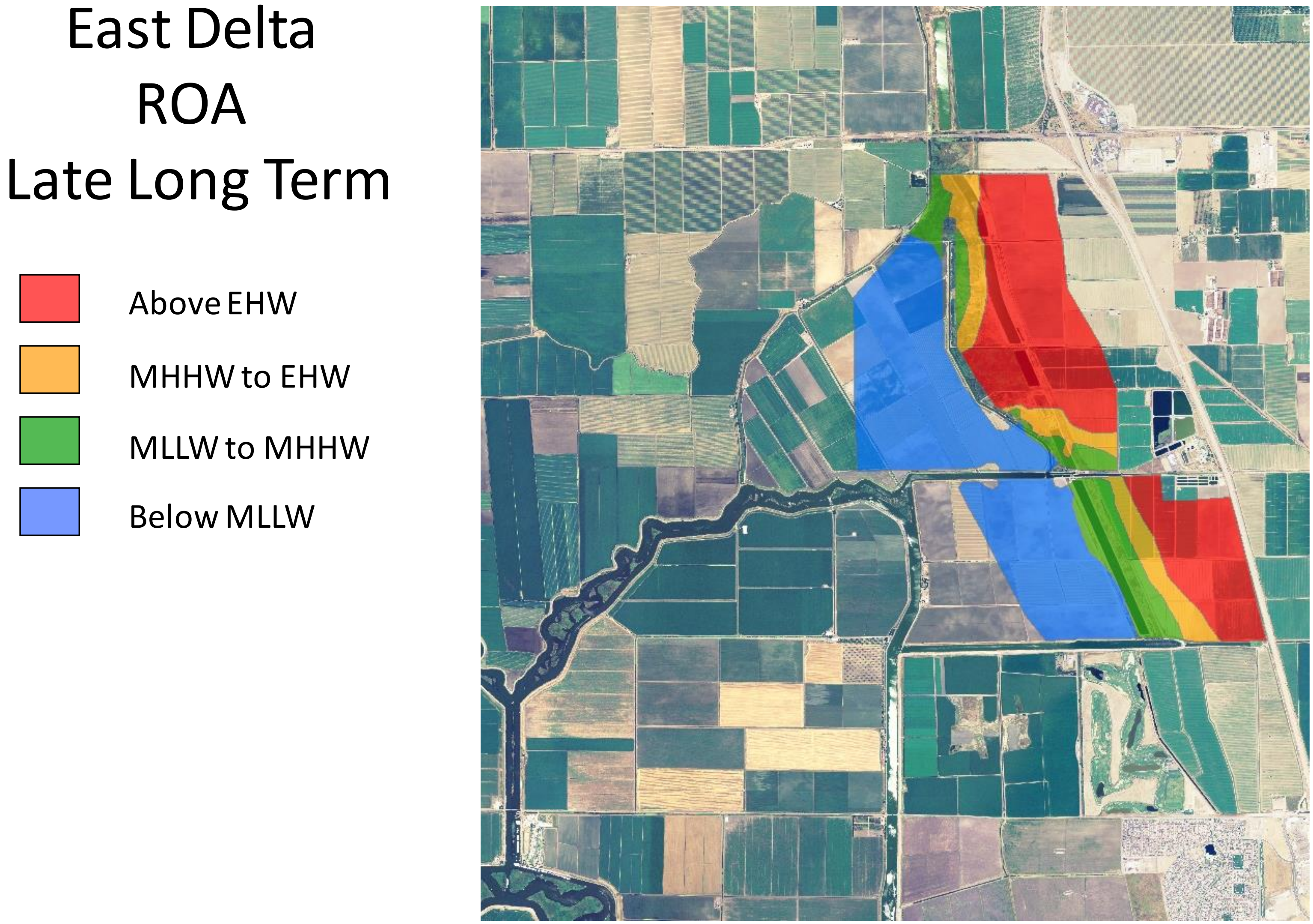


Figure 2-19 Contours of tidal datums for East Delta ROA, late long-term.

South Delta ROA Late Long Term

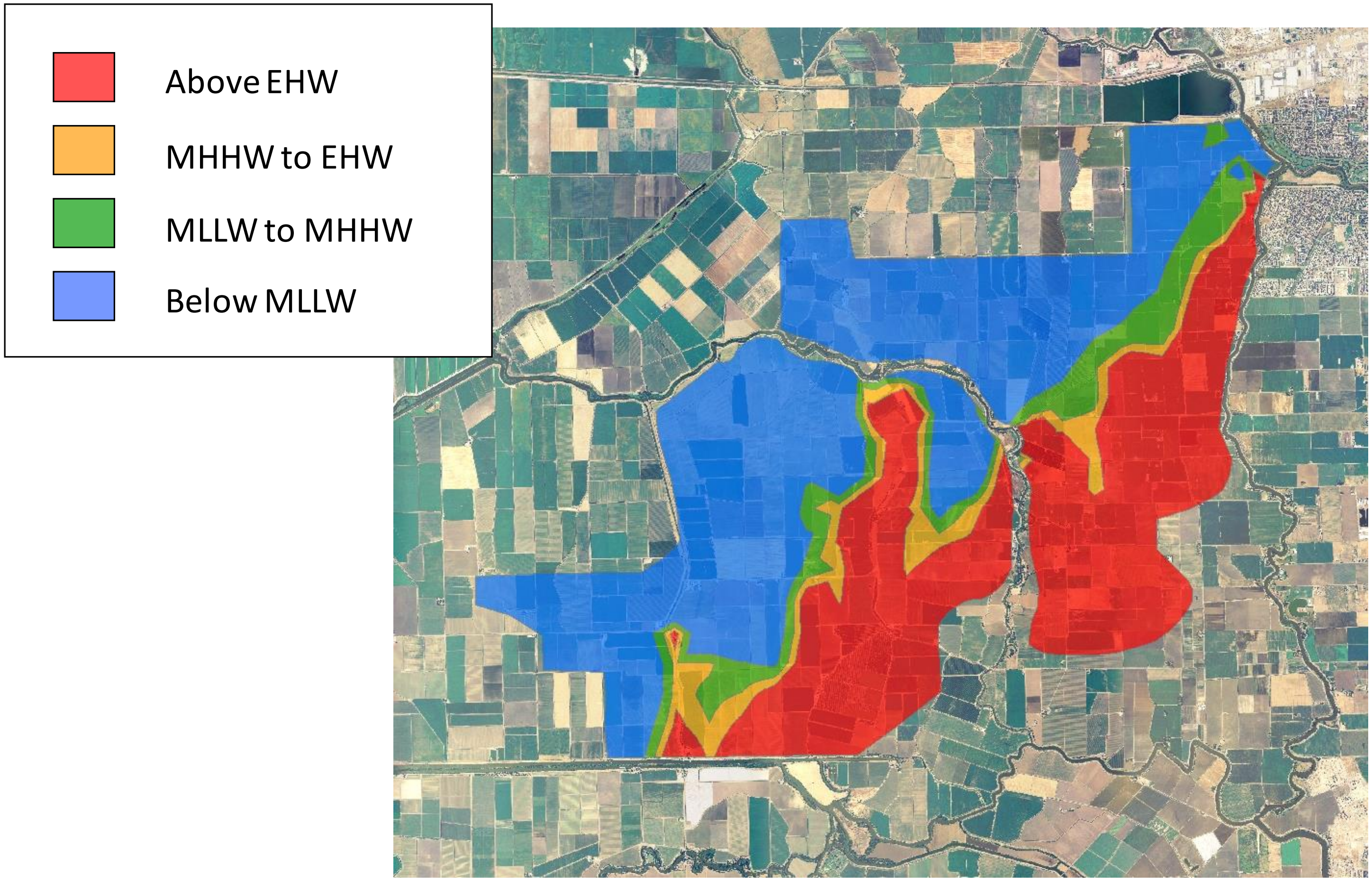


Figure 2-20 Contours of tidal datums for South Delta ROA, late long-term.

3 Boundary Conditions

The simulation period for the Base Case and the restoration scenarios was from April 2002 through December 2003. This period includes dry, above normal and below normal periods in the Sacramento and San Joaquin watersheds – Water Year 2002 was dry in both watersheds, while 2003 was above normal in the Sacramento Index and below normal in the San Joaquin Index.

Boundary conditions are specified for all inflow and outflow locations and for flow control structures. The locations of the model boundaries are shown in Figure 2-1.

3.1.1 Tidal boundary

The tidal boundary for the full Bay is set at the Golden Gate, the western boundary of the model, using observed data for the NOAA station at San Francisco. These data were smoothed using a 5 point moving average of the 6-minutes data, and shifted to NGVD + 0.1 m. The 0.1 m shift accounts for density effects between the tidal boundary and Suisun Marsh. The result at Martinez varies with Delta outflow, tidal and atmospheric conditions. An example plot of computed (Base case) and observed stage at Martinez is shown in Figure 3-2.

For the Delta-only version of the model, observed stage at Martinez was applied for the Base case, and adjusted observed Martinez stage time series were applied for the restoration cases (adjustments discussed in previous section).

3.1.2 Flows, exports, precipitation, evaporation, DICU

Inflow locations in the model are shown in Figure 2-1, with the exception of Delta Island Consumptive Use (DICU), which is discussed below. Suisun Marsh inflow locations are shown in Figure 3-1.

Time series of daily average inflow boundary conditions are plotted in Figure 3-3 to Figure 3-6 for the 2002-2003 simulation period. These flows are applied for the Sacramento River, Yolo Bypass, Napa River, San Joaquin River, Cosumnes River, Mokelumne River, and miscellaneous eastside flows which include Calaveras River and other minor flows. The model interpolates between the daily average flows at noon each day. Data from Dayflow (http://www.iep.ca.gov/dayflow/index.html) and the IEP database (http://iep.water.ca.gov/dss/) are used to set these boundary conditions.

Estimated Fairfield Wastewater Treatment Plant (WWTP) flows are plotted in Figure 3-4 (lower) for the 2002-2003 period. The reported average dry weather flow (ADWF) for the Fairfield WWTP is 13.2 – 14.8 mgd, with a peak wet weather capacity of 34.8 mgd. During dry periods, the WWTP flow in the model was set to 14 mgd. Daily precipitation data from the CIMIS station at Suisun Valley were used to estimate wet weather flows. Total wet weather flows were 14 mgd plus an additional flow of 3.8 mgd for each inch of the previous day's precipitation.

Flow data for Suisun Creek at Putah South Canal and Green Valley Creek at Green Valley Country Club are plotted in Figure 3-5 for the 2002-2003 period. Data were provided by Solano County Water Agency. Gaps in the Suisun Creek data were filled using flows estimated from Napa River flows scaled based on drainage area. This Suisun Creek data set was in turn scaled by drainage area for application to Ledgewood and Laurel Creeks.

Delta exports applied in the model include 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 2002-2003 period in Figure 3-6. Dayflow and IEP database data are used to set daily average export flows for the CVP, North Bay Aqueduct and Contra Costa's exports.

Hourly SWP export flows for 2003 are computed using the Clifton Court gate ratings and inside and outside water levels. The flows are adjusted on a monthly basis so the total computed flow matches the monthly SWP export. For 2002, when water levels inside and outside the gates were not available, SWP exports were defined using DSM2 node 72 flow, modified to remove erroneously large flows. Further details on Clifton Court Forebay gate operations can be found in (RMA, 2000), RMA's Flooded Islands Feasibility Study (RMA, 2005), and in (DWR, 2004).

DICU flows incorporate channel depletions, infiltration, evaporation, and precipitation, as well as Delta island agricultural use (DWR, 1995). DICU values are applied on a monthly average basis and were derived from monthly DSM2 input values (DWR, 1995). Table 3-1 summarizes the total monthly diversions (incorporates agricultural use, evaporation and precipitation), drains (agricultural returns), seeps (channel depletions) and total flows used for DICU flows. Negative flows indicate net withdrawal from the system. These flows are distributed to multiple elements throughout the Delta using an in-house utility program. For the restoration cases, flooding new regions in the Delta may, in reality, change the net Delta consumptive use, possibly affecting net Delta outflow. However, for the sake of modeling DICU was applied the same for the Base and restoration simulations.

Duck club ponds are filled and drained seasonally to provide appropriate habitat and opportunity to attract migrating ducks. Flows had to be estimated to approximate diversion (filling) and return (draining) flows in the vicinity of the marsh. For modeling purposes, it was assumed that they filled at a constant rate (no tidal variation) from a depth of -1.0 ft to +1.0 ft over a 14 day period beginning October 1. The ponds were subsequently drained at a constant rate between March 1 and June 1. Flow rates were computed as the area to be filled multiplied by the depth of water (2.0 ft) divided by the time to fill or drain. No exchange between the modeled marsh flows and the duck club ponds occurred during the summer, from June 1 through October 1.

Evaporation and precipitation data were used to compute flows required to maintain ponds at a constant level from October 15 (following filling) through February. Flow volumes were based on areas for the following locations: Montezuma Slough (East, Middle and West), Suisun Slough, Nurse Slough, Morrow Island (fill only) and Roaring River. Locations of inflow/withdrawal in the Marsh are shown for the Base case mesh in Figure 3-1 – these locations are the same for the four scenarios, as applicable. For the restoration cases, some of the duck club ponds are restored and thus the duck club exchange flows are removed from the model. Those removed for each case are indicated in Figure 3-1.

Daily Suisun Valley CIMIS station precipitation data was used to compute additional inflows from tidal marsh areas during rainfall events. Areas of tidal marsh were estimated and multiplied by the daily precipitation data. Inflows from tidal marsh were input at Beldon's Landing, Boynton Slough, Cutoff Slough, First Mallard Slough, Hill Slough and Peytonia Slough. Locations are shown in Figure 3-1. As some of these areas were added into the grids for the restoration cases, they become subject to the precipitation and evaporation by element type (see Section 3.1.5) and so the inflows are removed from the model. Those removed for each case are indicated in Figure 3-1.

3.1.3 Electrical Conductivity (EC)

The western EC boundary of the full Bay model, at the Golden Gate is set at 50,000 μmhos cm^{-1}, the EC of seawater.

For the Delta-only version of the model, the average of observed top and bottom EC is applied at Martinez.

EC boundary conditions are set at all inflow boundaries. Table 3-2 gives the source of the EC boundary conditions. Figure 3-7 shows the EC time series boundary conditions at the major boundaries.

3.1.4 Gate and barrier operations

Historical Delta Cross Channel and south Delta barrier operations were included in the model for all cases with the exception of the Middle River barrier, which was kept open for the LLT simulation with restoration in the South Delta.

Historical operations of the Suisun Marsh salinity control gate (SMSCG) are used in the Base case. The gates are removed for all restoration simulations. Analysis of model results focuses on periods when gates were open for the Base case so that the impact of the change in gate operations is not a factor.

3.1.5 Precipitation and evaporation by element type

The ability to apply daily time series of precipitation and evaporation was added to the model for the Suisun Marsh simulations. In previous versions of the model, the monthly DICU inflows/outflows were the only evaporation and precipitation inputs, and these were applied to individual model elements only in the Delta. In Suisun Marsh, the impacts of evaporation and short time scale variations in precipitation were incorporated in selected areas of the grid by element type ID, and applied on a per-unit-area basis using daily time series of precipitation and evaporation data from the Suisun Valley CIMIS Station.

1	Green Valley Creek
2	Suisun Creek
3	Suisun Sl. duck clubs
4	Morrow Is. duck clubs
5	Montezuma Sl. duck clubs
6	Boynton Sl. tidal marsh
7	Fairfield WWTP
8	Ledgewood Creek
9	Peytonia Sl. tidal marsh**
10	Hill Sl. tidal marsh*
11	Laurel Creek
12	First Mallard Sl. tidal marsh
13	Cutoff Sl. tidal marsh*
14	Beldon's Landing tidal marsh*
15	Montezuma Sl. duck clubs
16	Nurse Sl. duck clubs
17	Montezuma Sl. duck clubs
18	Roaring River duck clubs

*not included in NT, ELT or LLT simulations
** not included in ELT or LLT simulations

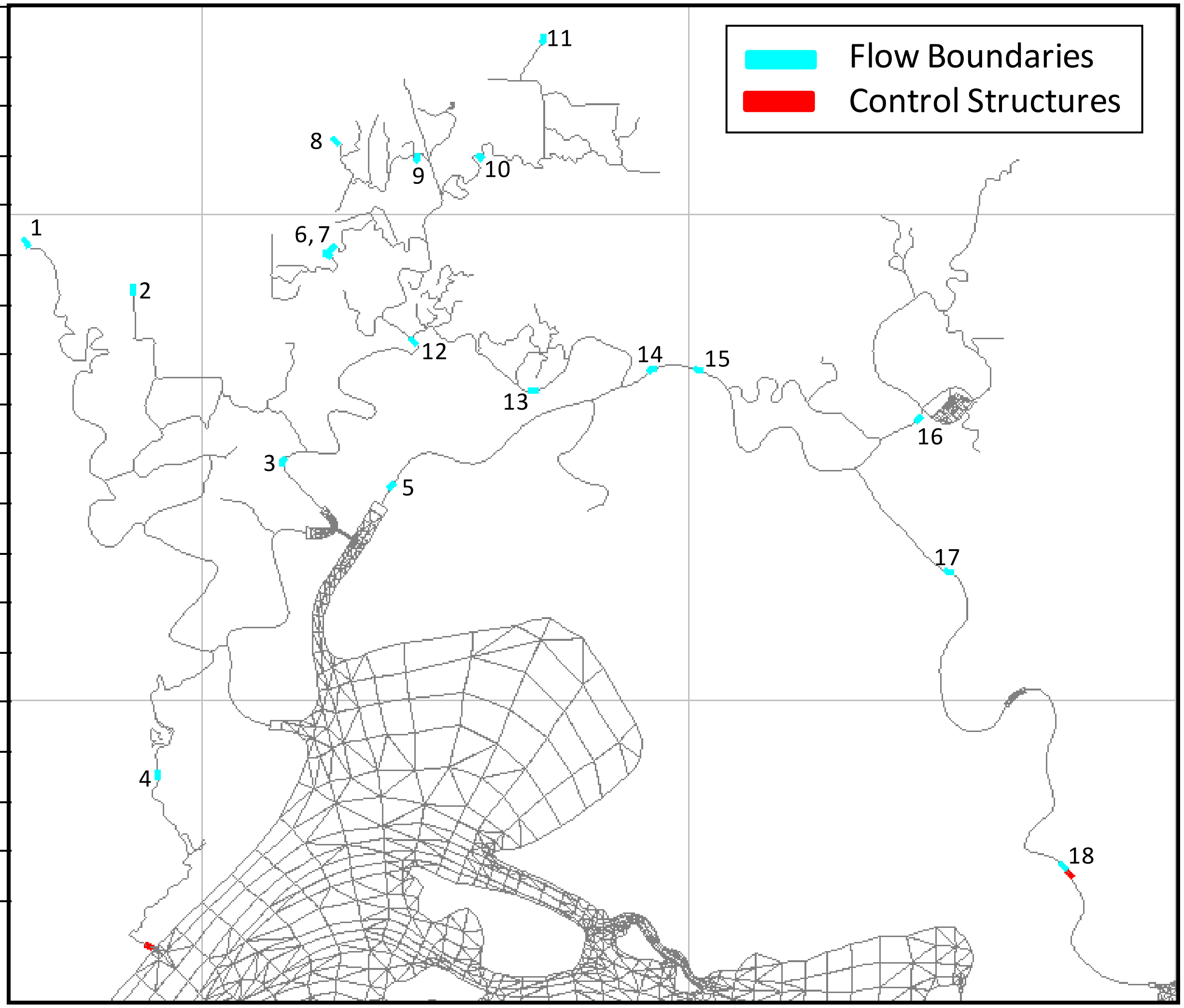


Figure 3-1 Inflow/export locations in Suisun Marsh.

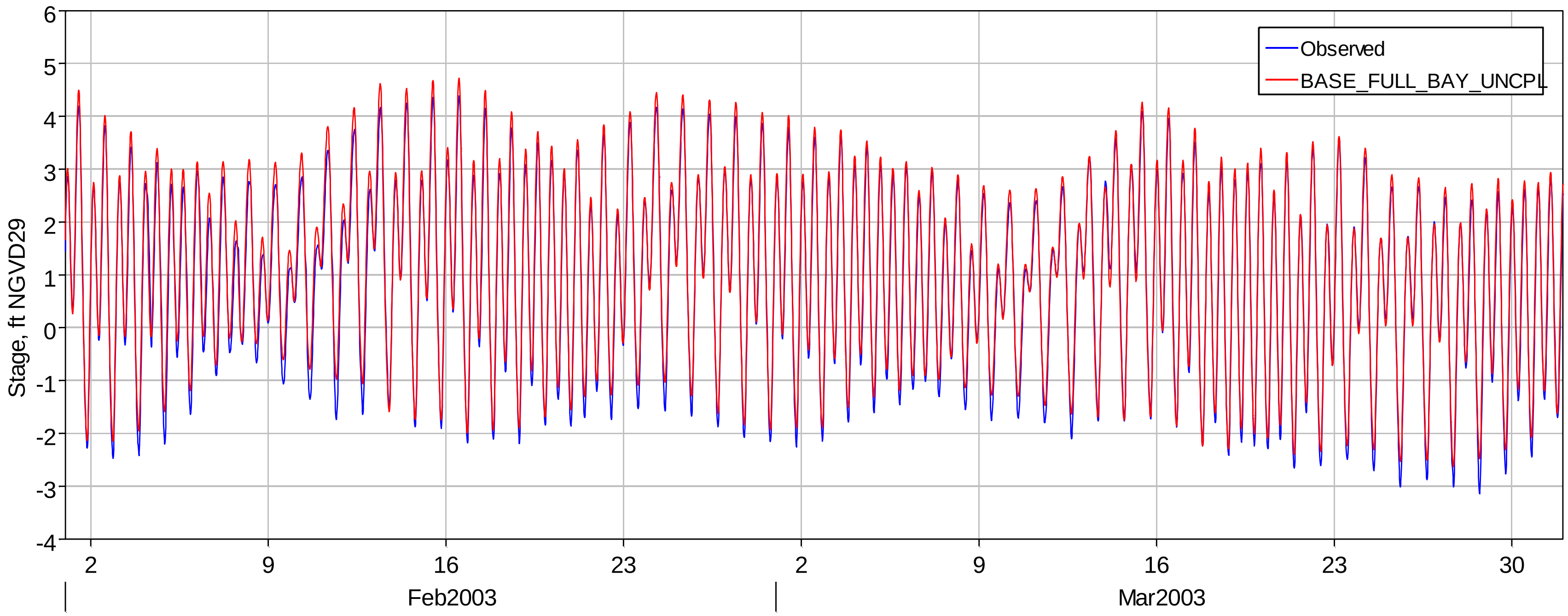


Figure 3-2 Observed and computed (using full Bay uncoupled model) stage at Martinez.

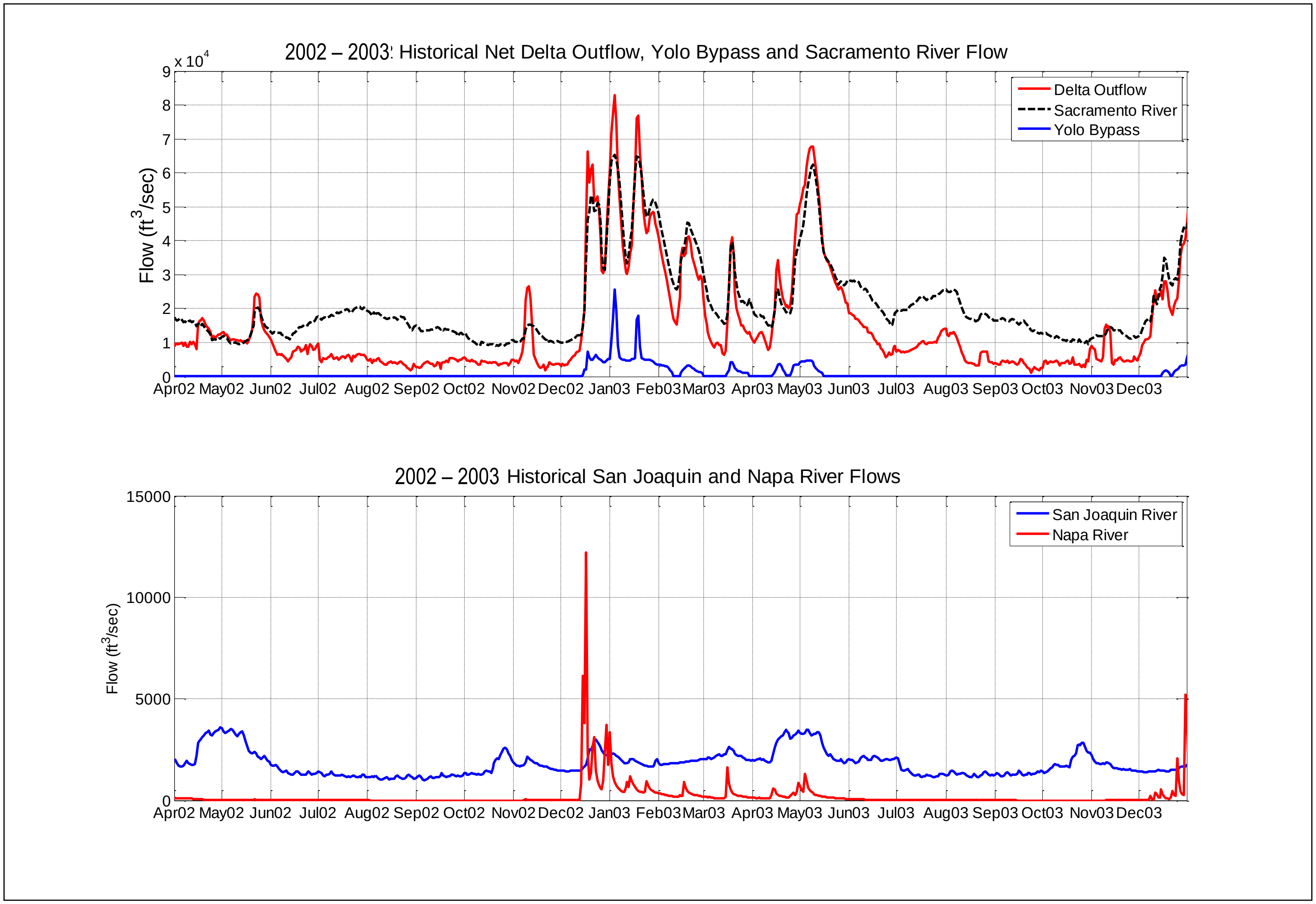


Figure 3-3 Net Delta outflow and major boundary flows for the 2002-2003 simulation period.

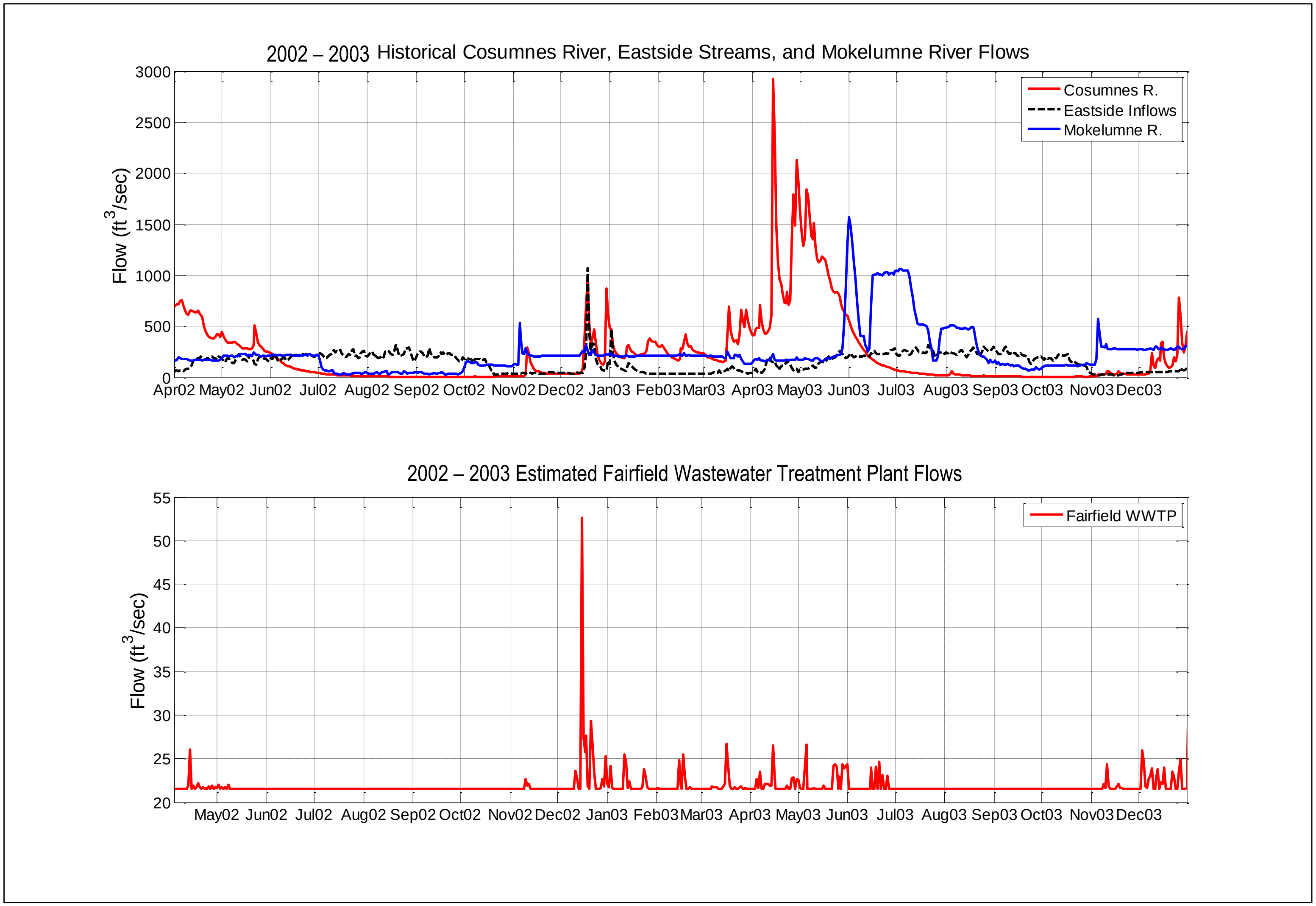


Figure 3-4 Minor boundary flows for the 2002-2003 simulation period.

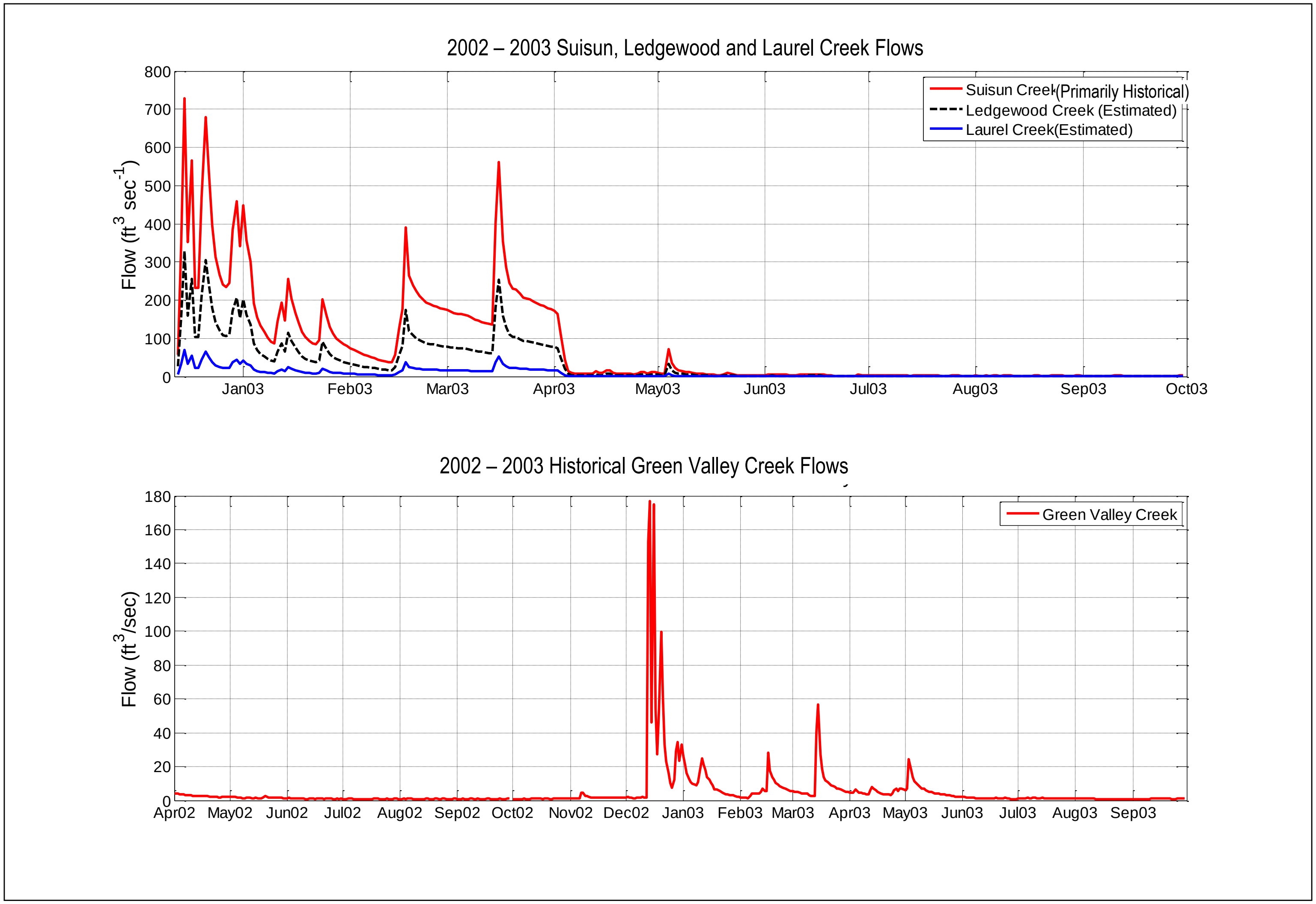


Figure 3-5 Suisun Marsh local creek flows for the 2002-2003 simulation period.

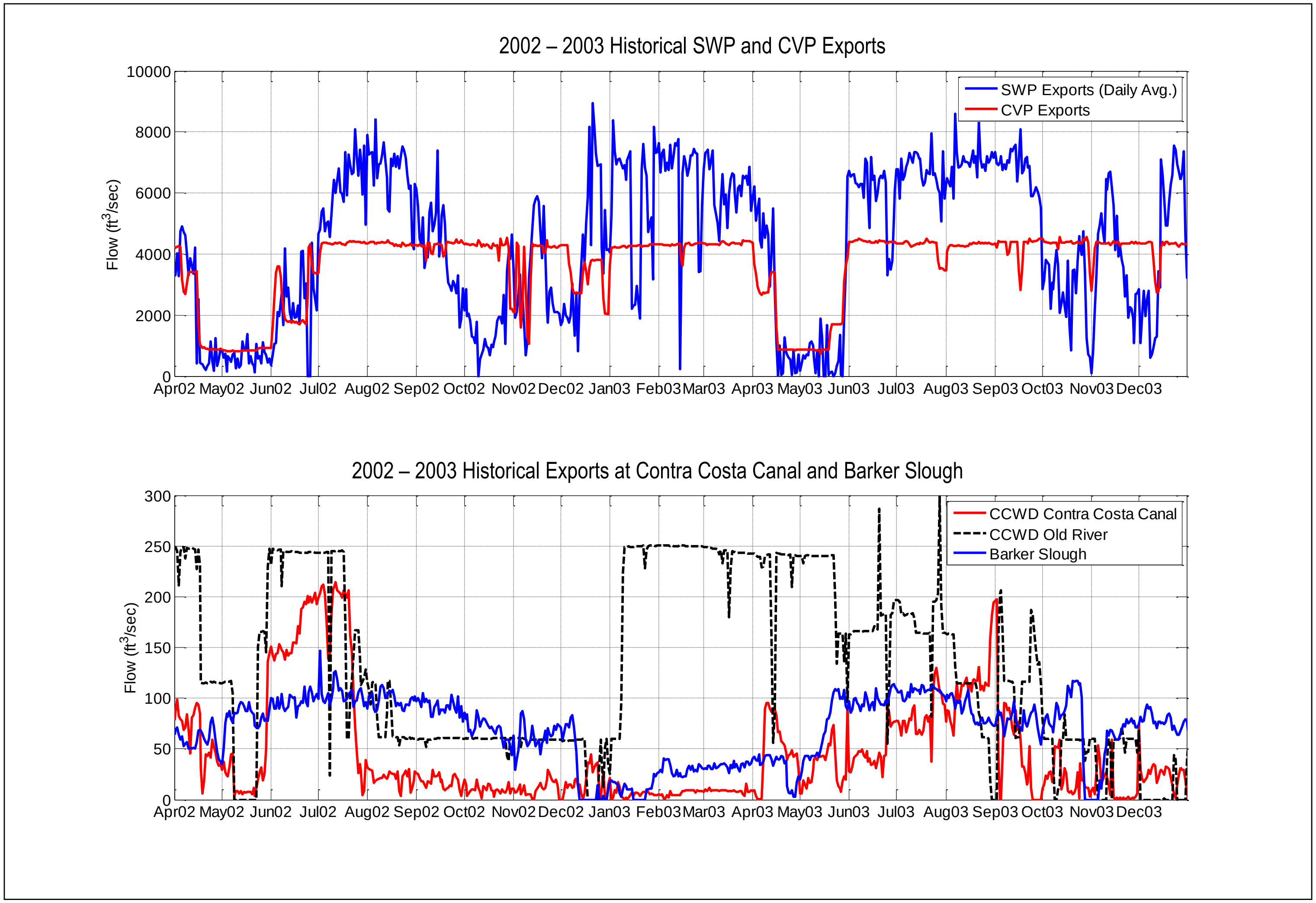


Figure 3-6 Historical exports and diversions used in the model for the 2002-2003 simulation period. Note that daily averaged SWP exports are plotted, however the model uses 15-minute inputs.

Table 3-1 Summary of monthly DICU flows ($ft^3 sec^{-1}$) for the simulation period. Negative values indicate Delta withdrawal.

Month	Diversions (-)	Drains (+)	Seeps (-)	Total
April 2002	2109.9	1121.8	1006.4	-1994.5
May 2002	3978.0	1710.4	973.4	-3241.0
June 2002	4850.2	1995.6	1006.4	-3860.9
July 2002	4943.0	2011.0	973.4	-3905.4
August 2002	2659.8	1265.9	973.4	-2367.3
September 2002	1231.2	848.4	1006.2	-1389.1
October 2002	875.2	681.1	973.2	-1167.4
November 2002	268.9	576.2	1018.0	-710.8
December 2002	429.2	2318.5	633.9	1255.4
January 2003	2.0	133.4	575.7	755.7
February 2003	62.6	873.8	714.1	97.1
March 2003	314.5	741.1	725.6	-299.0
April 2003	405.9	825.8	701.1	-281.2
May 2003	1438.8	894.3	980.5	-1525.0
June 2003	2929.1	1346.7	1006.2	-2588.6
July 2003	5254.4	2108.3	973.1	-4119.2
August 2003	2569.5	1237.3	985.8	-2318.0
September 2003	1351.0	884.2	1006.2	-1472.9
October 2003	981.1	709.1	973.1	-1245.2
November 2003	272.5	528.7	1027.2	-771.0
December 2003	429.2	1011.2	791.9	-209.9

Table 3-2 EC boundary conditions.

Boundary Location	Value (µmhos cm^{-1})	Data Source
Golden Gate	50,000	Seawater EC
Sacramento River	Time Series	DWR DSM2
Yolo Bypass	Sac. River Time Series	DWR DSM2
San Joaquin River	Time Series	DWR DSM2
DICU	Monthly Time Series	DWR's DICU model
Cosumnes River	150	Estimated
Mokelumne River	150	Estimated
Misc. Eastside Rivers	750	Estimated
Fairfield WWTP	120	Estimated
Napa River, Green Valley Creek, Suisun Creek, Ledgewood Creek, Laurel Creek	120	Estimated; Napa R. based on measured data
Duck Club Drains: Nurse Slough drain Suisun Slough drain Roaring River drain Montezuma Slough West Montezuma Slough Middle Montezuma Slough East	Estimated Using Source Time Series Data:	 Beldon's Landing Observed EC Boynton Sl. Observed EC, shifted in time Roaring River Observed EC Hunter Cut Observed EC Beldon's Landing Observed EC National Steel Observed EC
Tidal Marsh – Boynton Slough Peytonia Slough Hill Slough First Mallard Slough Cutoff Slough Beldon's Landing	Estimated Using Source Time Series Data:	 Boynton Sl. Observed EC, shifted in time Hill Slough Observed EC Hill Slough Observed EC Beldon's Landing Observed EC Beldon's Landing Observed EC Beldon's Landing Observed EC

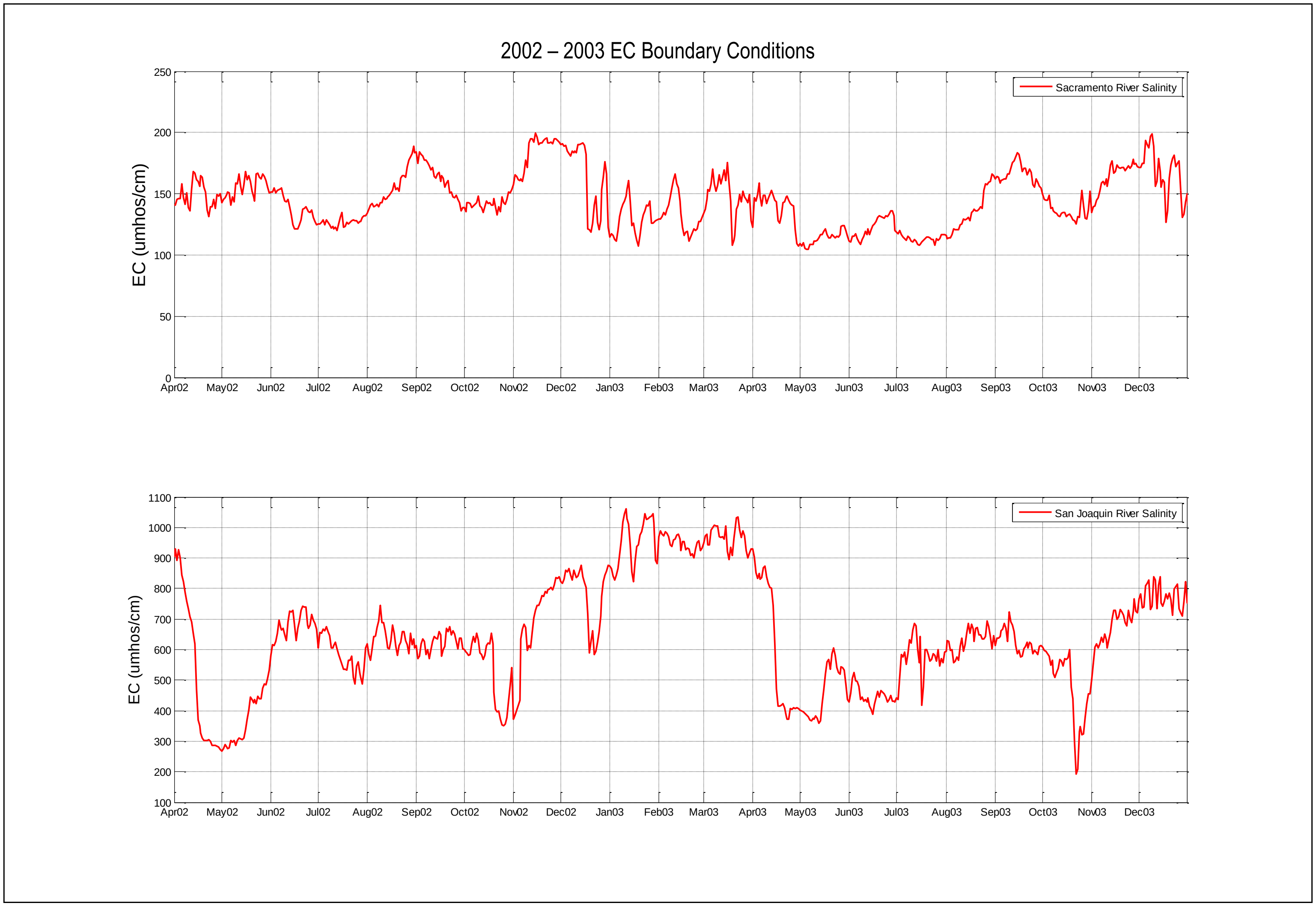


Figure 3-7 Daily EC time series used as boundary conditions for the Sacramento River and Yolo Bypass (upper) and for the San Joaquin River (lower) for the 2002-2003 simulation period.

4 Description of Analysis Types

4.1 Hydrodynamics

Time series plots of dynamic and tidally-averaged flow, and dynamic stage and velocity are provided at select locations in the Delta, as well as spatial contours of bed shear, and spatial plots and profile plots of tidal range for low flow (July 2002) conditions.

RMA model tidal datum results shown in the contour and profile plots were processed with the "RMA Tools" tidal analysis module developed by DWR (2004). Mean Lower Low Water (MLLW), Mean Sea Level (MSL), Mean Higher High Water (MHHW) and tidal range (MHHW-MLLW) were computed for July 2002. The MLLW analysis provides a measure of changes in the Lower Low minimums averaged over the month. The MHHW analysis quantifies the changes in peak Higher High stage, averaged for the month. The difference, MHHW – MLLW, in contour values provides an average diurnal range for the month. Profile plots were developed along the Sacramento River, San Joaquin River, Middle River and Montezuma Slough for MHHW, MSL and MLLW, and tidal range.

Comparison of Base levels of average diurnal range (MHHW – MLLW) with levels for the restoration cases provides a means for assessing the effects of the restoration activities, as tidal range attenuation has the potential to affect the extent of nutrient exchange and flushing, as well as temperature ranges.

For each scenario, bed shear was calculated for the low flow month of July 2002 to help identify areas of scour potential. Contour plots of bed shear for July 2002 are provided at times of peak bed shear.

4.2 Electrical Conductivity (EC)

Electrical conductivity (µmhos cm^{-1}), or EC, was modeled as a surrogate for salinity. Although the RMA11 formulation assumes transport of a conservative constituent, EC is used as a practical surrogate for modeled salinity in the Bay-Delta model for several reasons, despite concerns about its non-conservative behavior. The number and reliability of measurement locations in the Bay-Delta region is much greater for EC than for other measures of salinity. In addition, transformation relationships between EC and constituents generally considered conservative, such as chloride and Total Dissolved Solids (TDS), can introduce additional error. EC underestimates true salinity at high concentrations (DWR, 2002).

EC analyses are presented as time series plots at selected locations and as contour plots showing spatial distribution of EC around a time when restoration alternatives result in the greatest change from Base. Contour plots are also presented showing the calculated percent change from Base EC.

5 Hydrodynamic Impacts

5.1 Time series of dynamic and tidally averaged flow at select locations

Time series plots of dynamic and tidally averaged flow are provided in Figure 5-3 through Figure 5-28 at selected locations for the Base, NT, ELT and LLT scenarios to show the flow impact of each alternative in comparison with Base. Only ten days in July 2002 are shown so that the impacts of the restoration can be clearly seen.

Time series locations are shown on the Base grid in Figure 5-1 for the Delta and Figure 5-2 for Suisun Marsh.

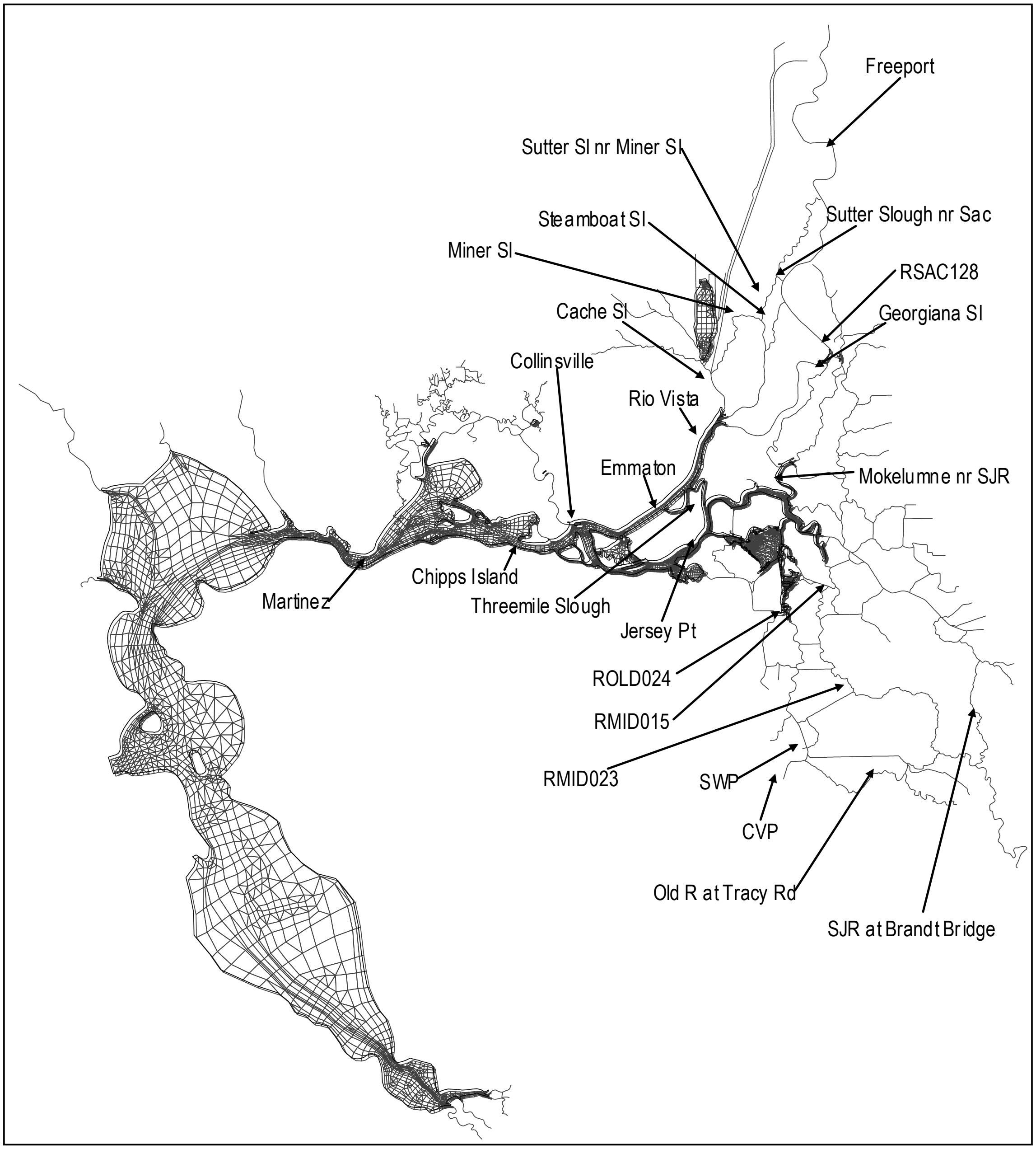


Figure 5-1 Time series plot locations in the Delta.

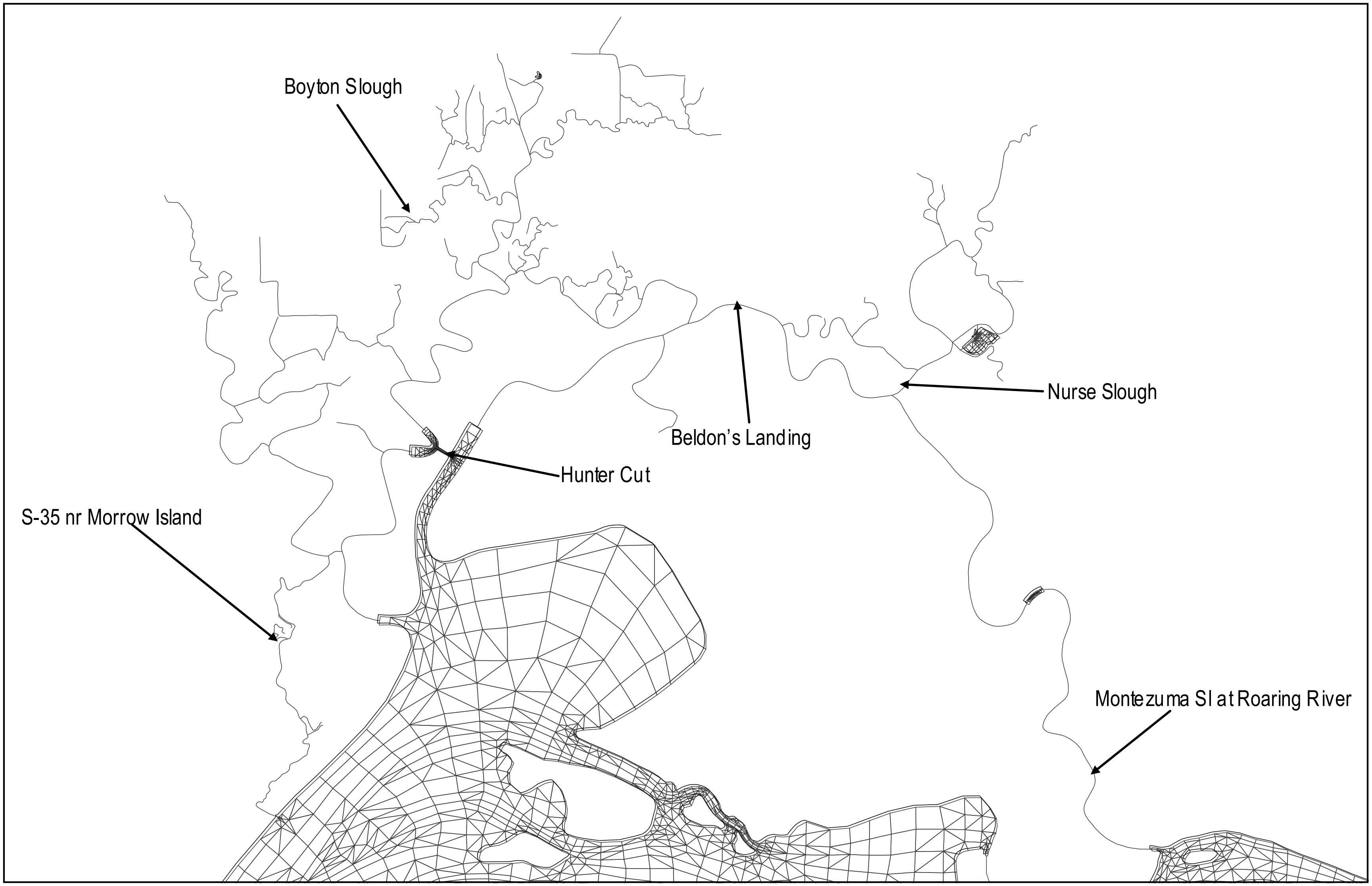
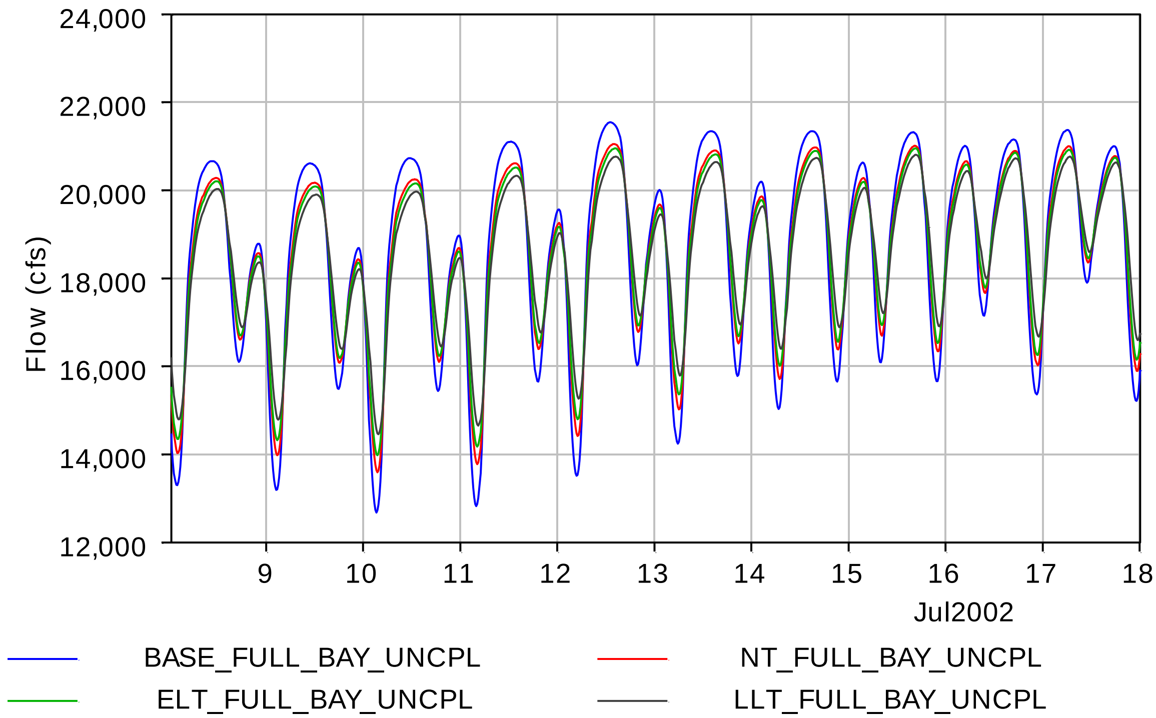


Figure 5-2 Time series plot locations in Suisun Marsh.



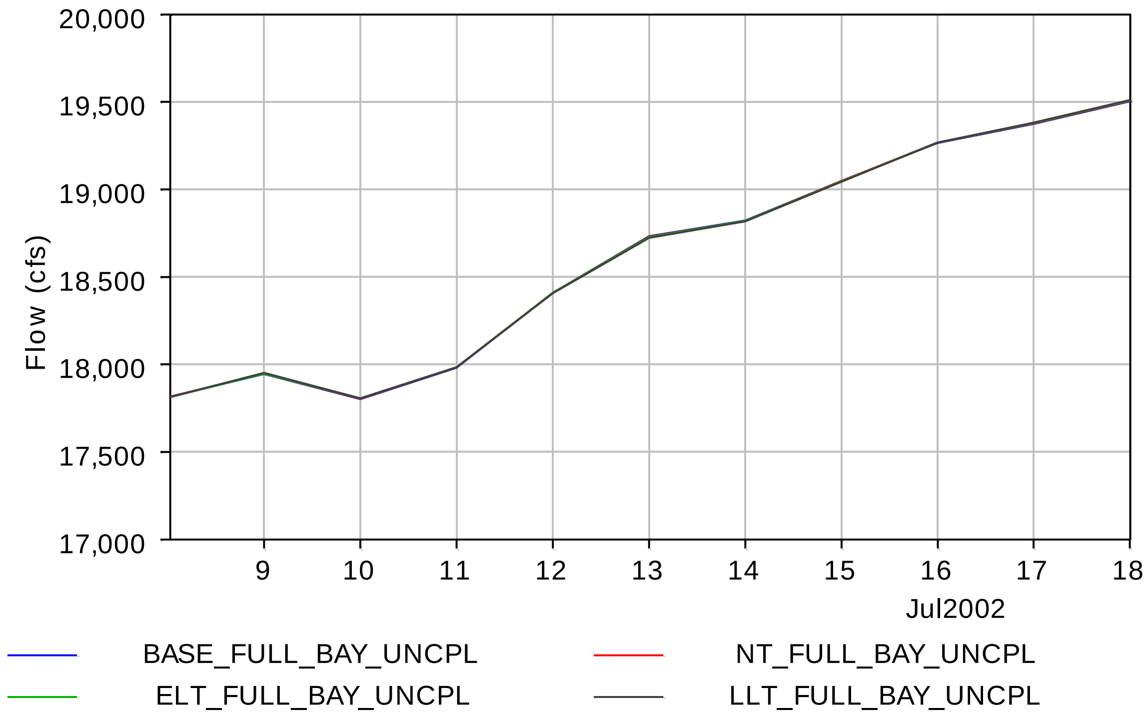


Figure 5-3 Dynamic (top) and tidally averaged (bottom) flow at Freeport for Base case, NT, ELT and LLT scenarios.

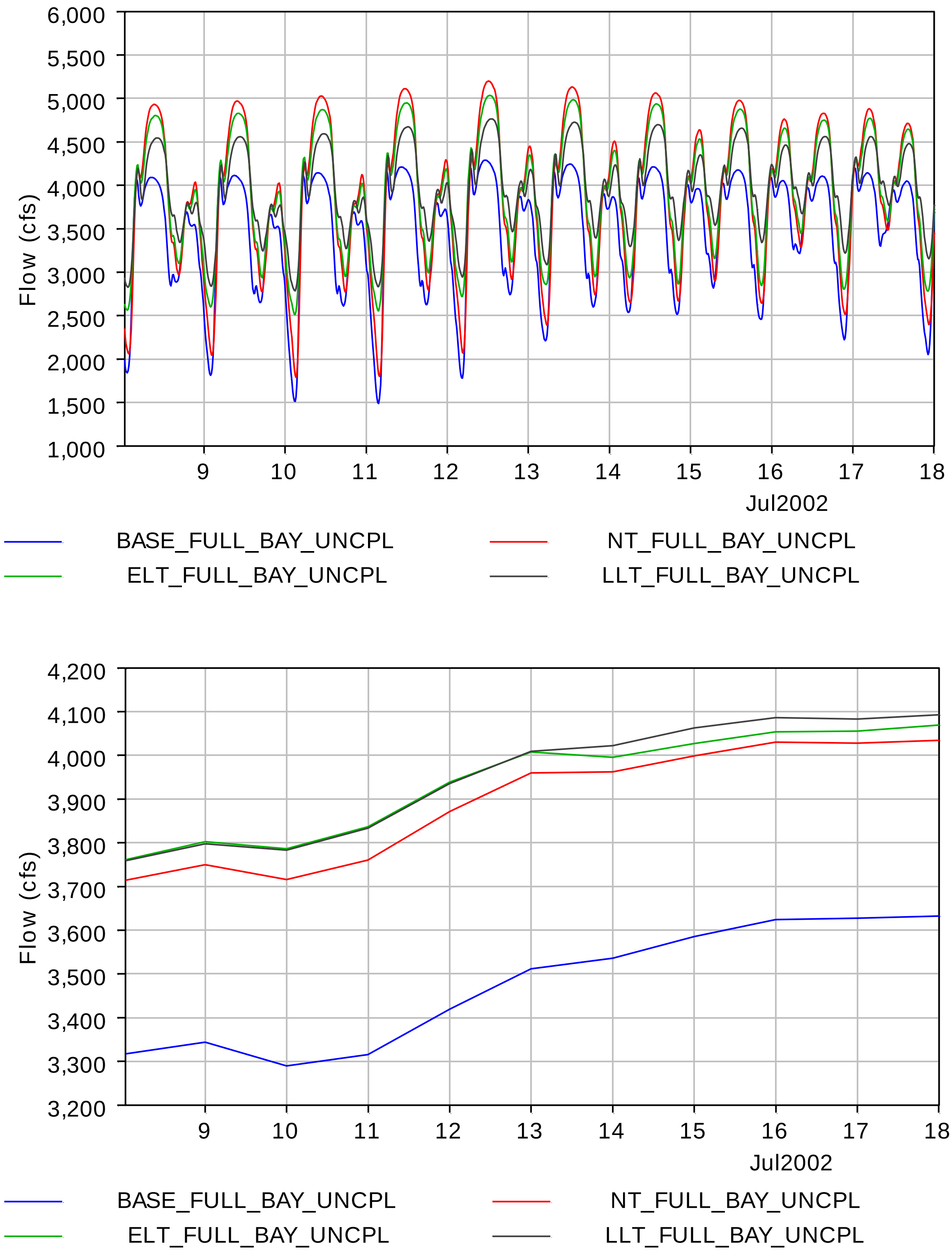


Figure 5-4 Dynamic (top) and tidally averaged (bottom) flow in Sutter Slough near Sacramento R. for Base, NT, ELT and LLT scenarios.

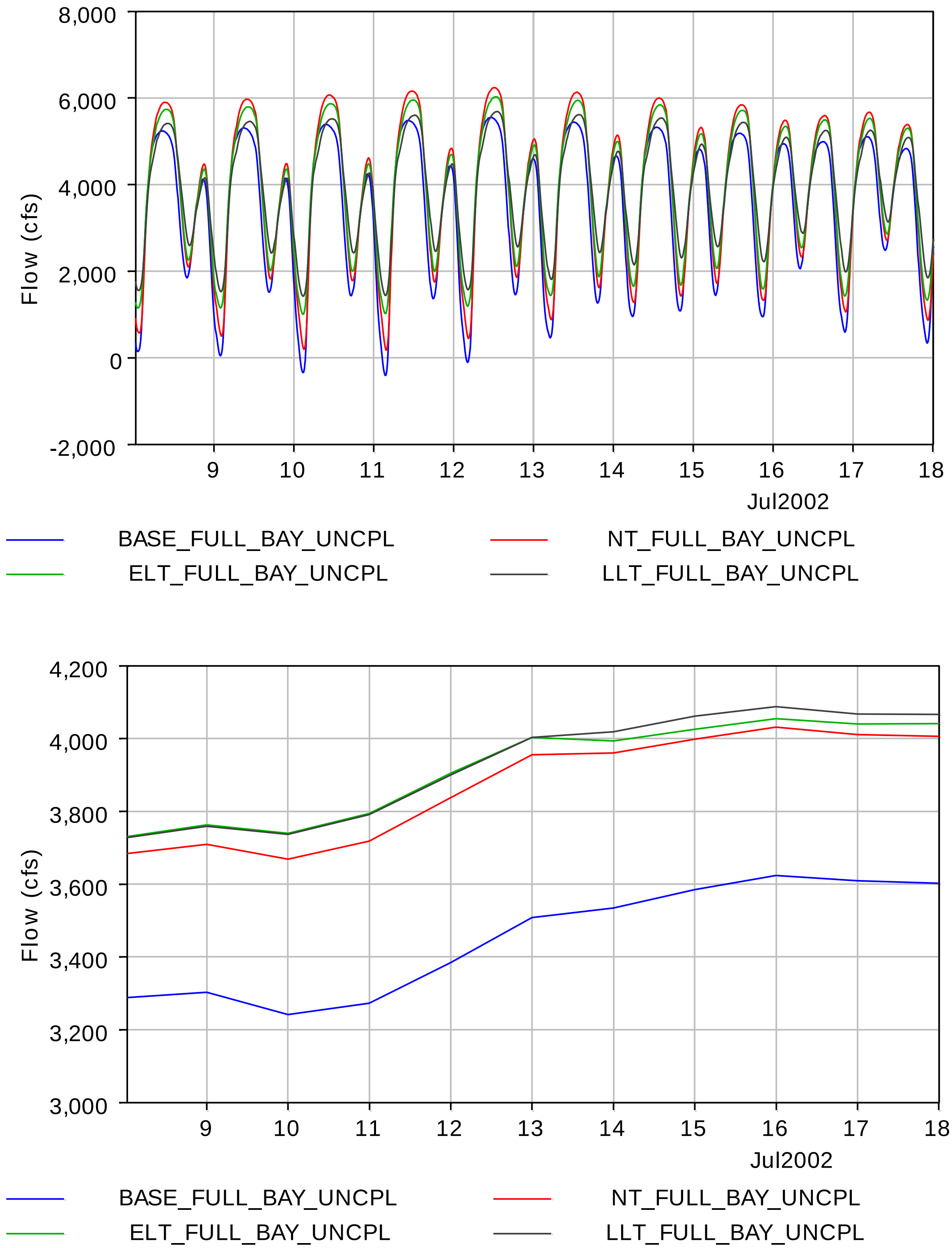
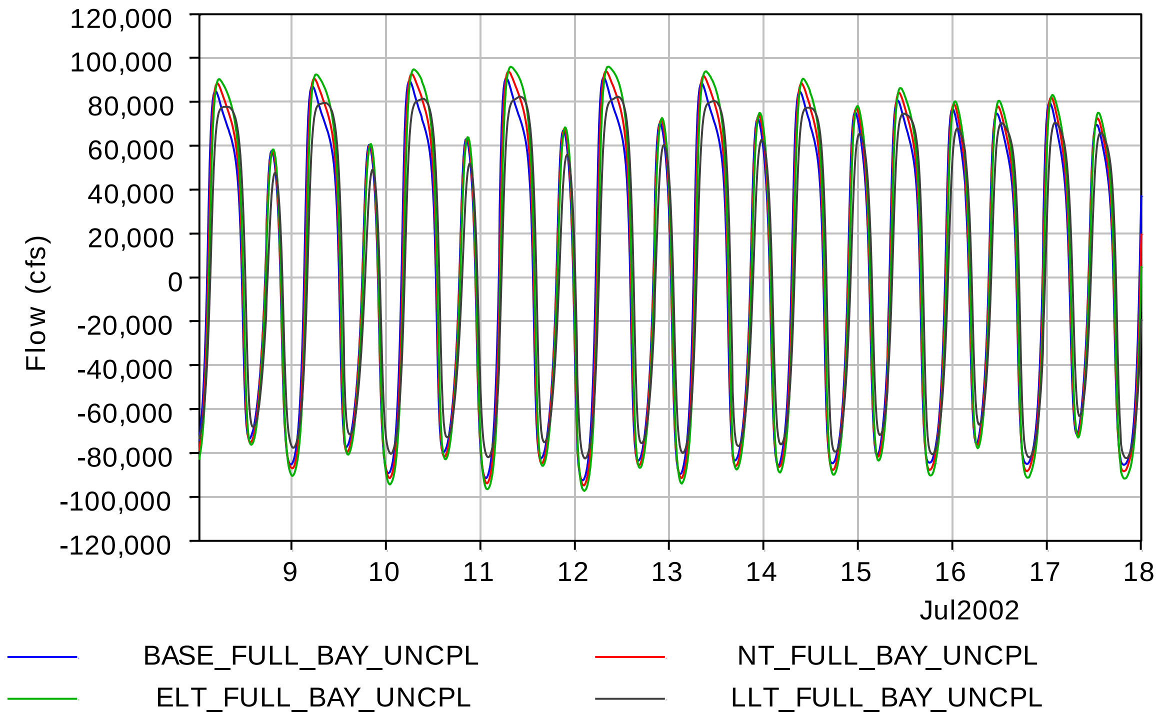


Figure 5-5 Dynamic (top) and tidally averaged (bottom) flow in Sutter Slough near Miner Slough for Base, NT, ELT and LLT scenarios.



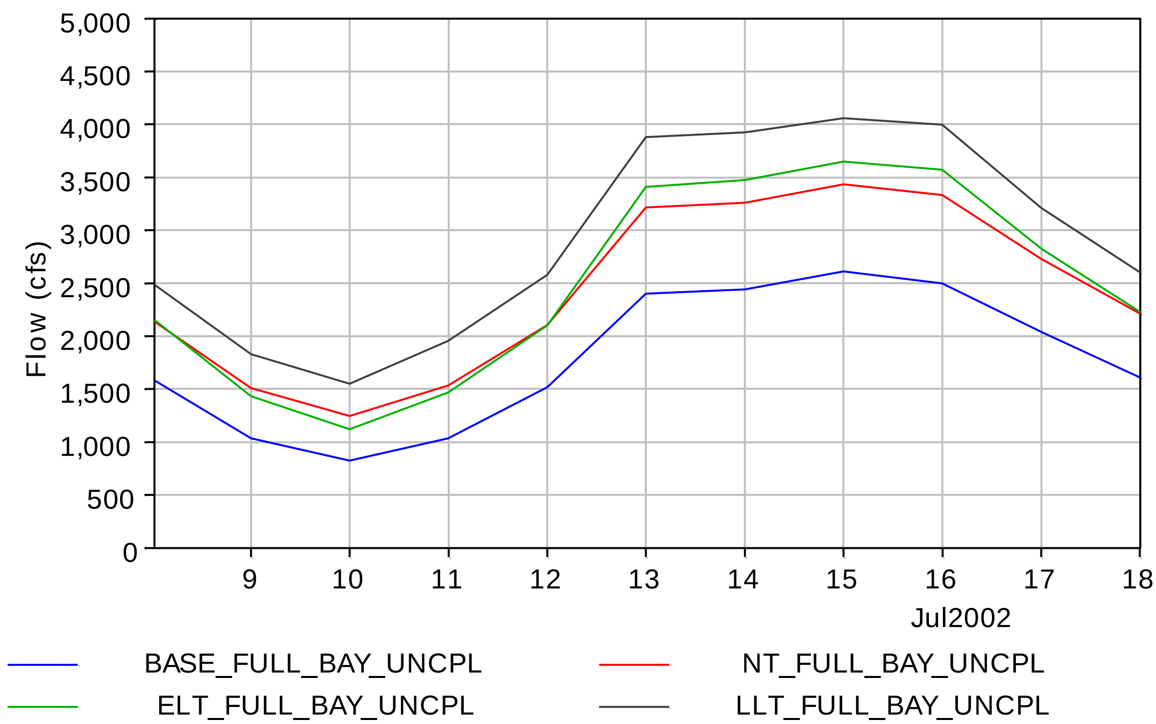
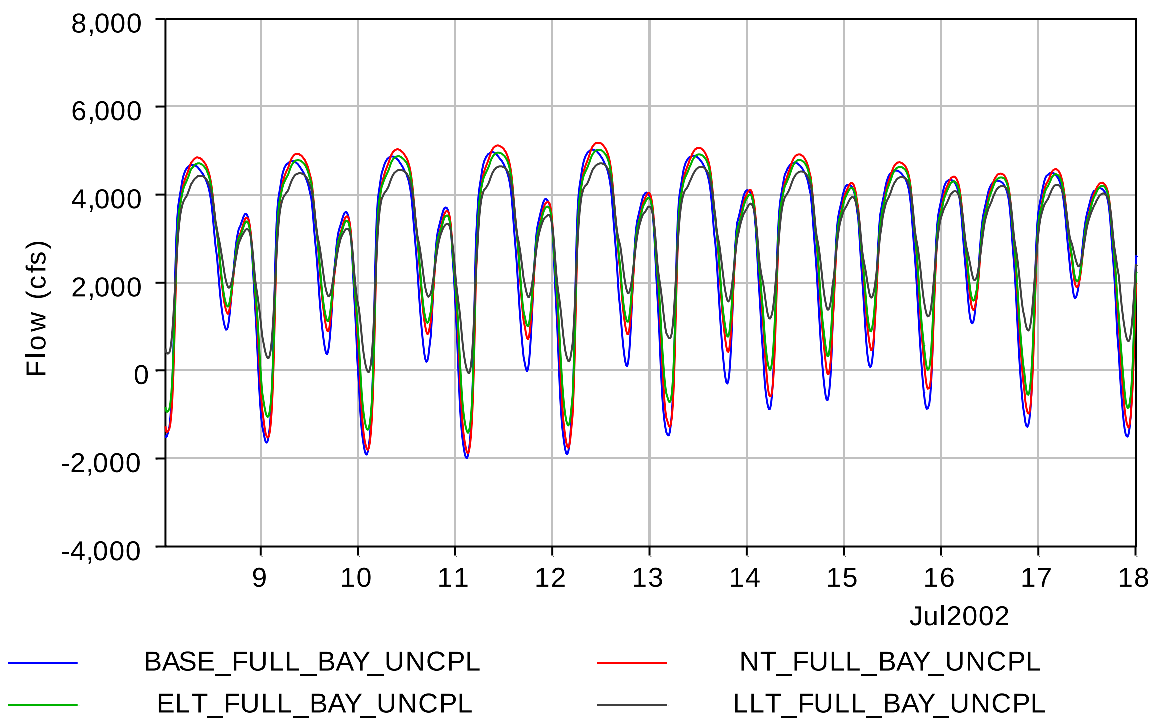


Figure 5-6 Dynamic (top) and tidally averaged (bottom) flow in Cache Slough at Ryer Island for Base, NT, ELT and LLT scenarios.



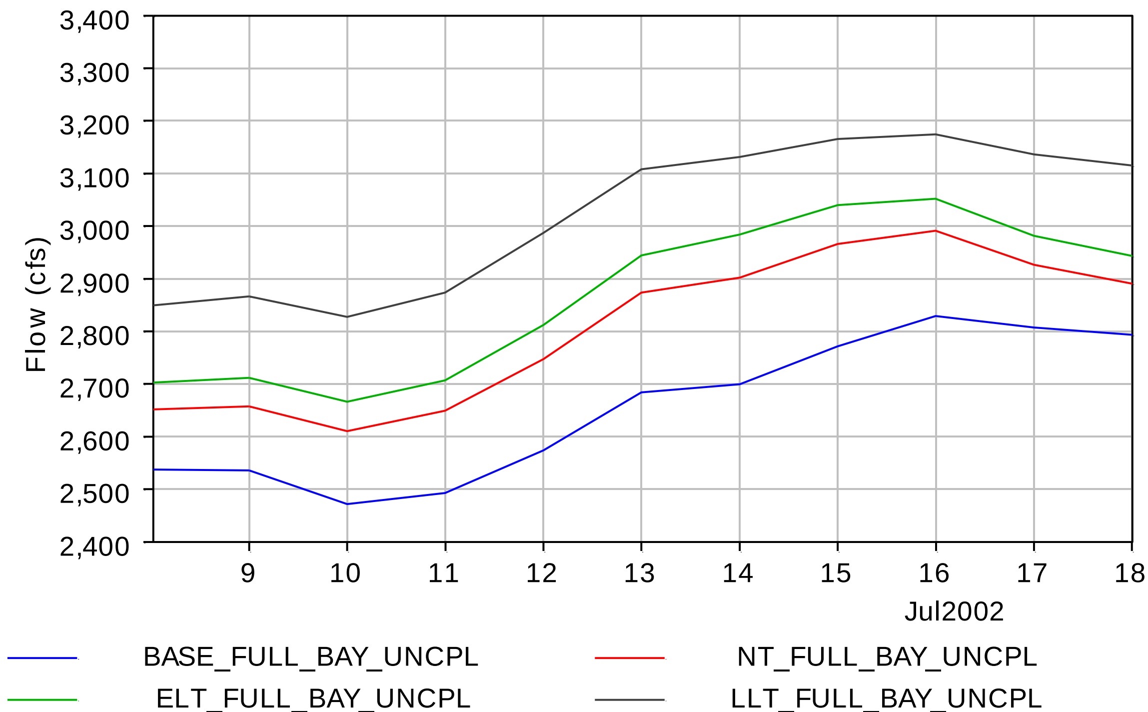


Figure 5-7 Dynamic (top) and tidally averaged (bottom) flow in Steamboat Slough for Base, NT, ELT and LLT scenarios.

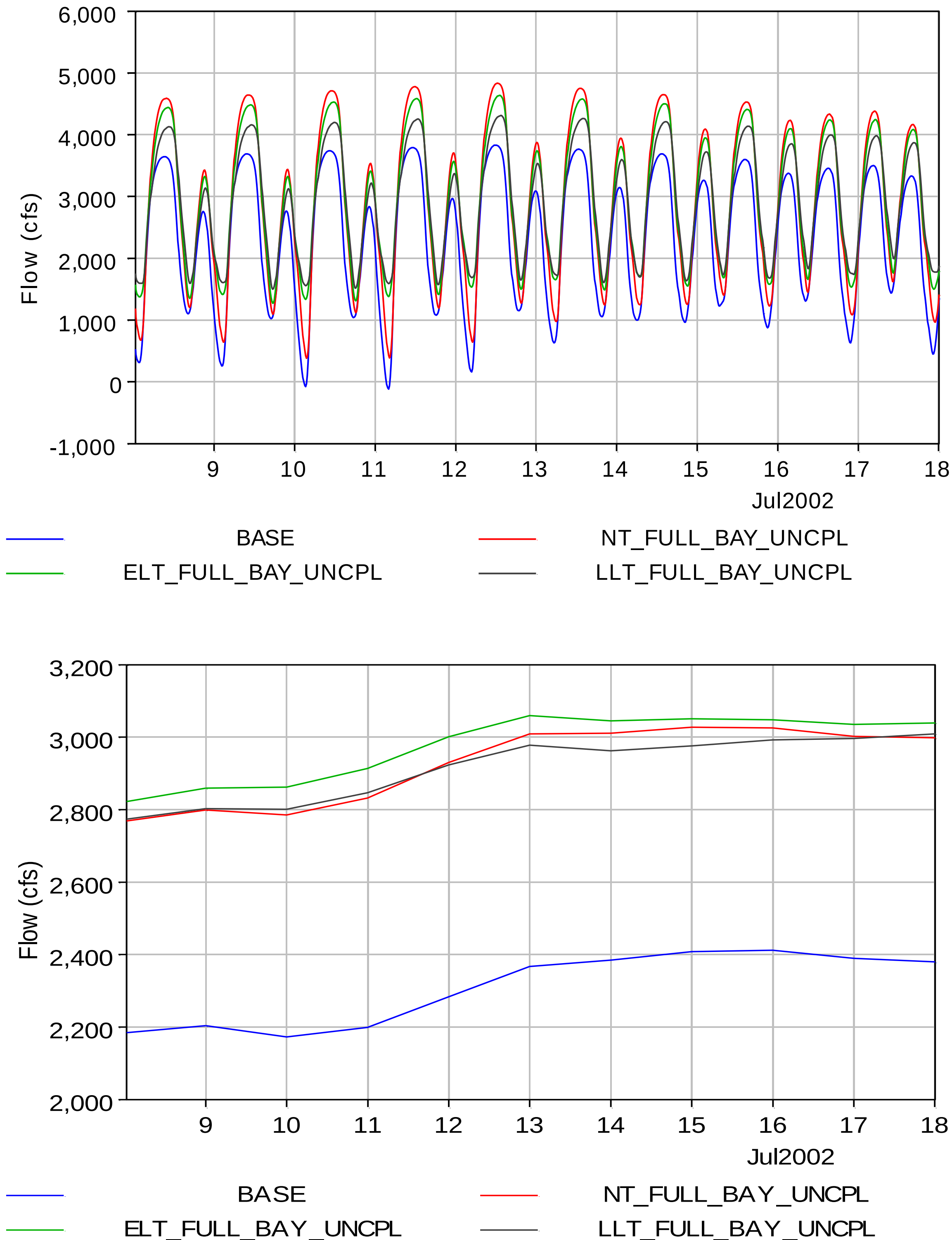


Figure 5-8 Dynamic (top) and tidally averaged (bottom) flow in Miner Slough for Base, NT, ELT and LLT scenarios.

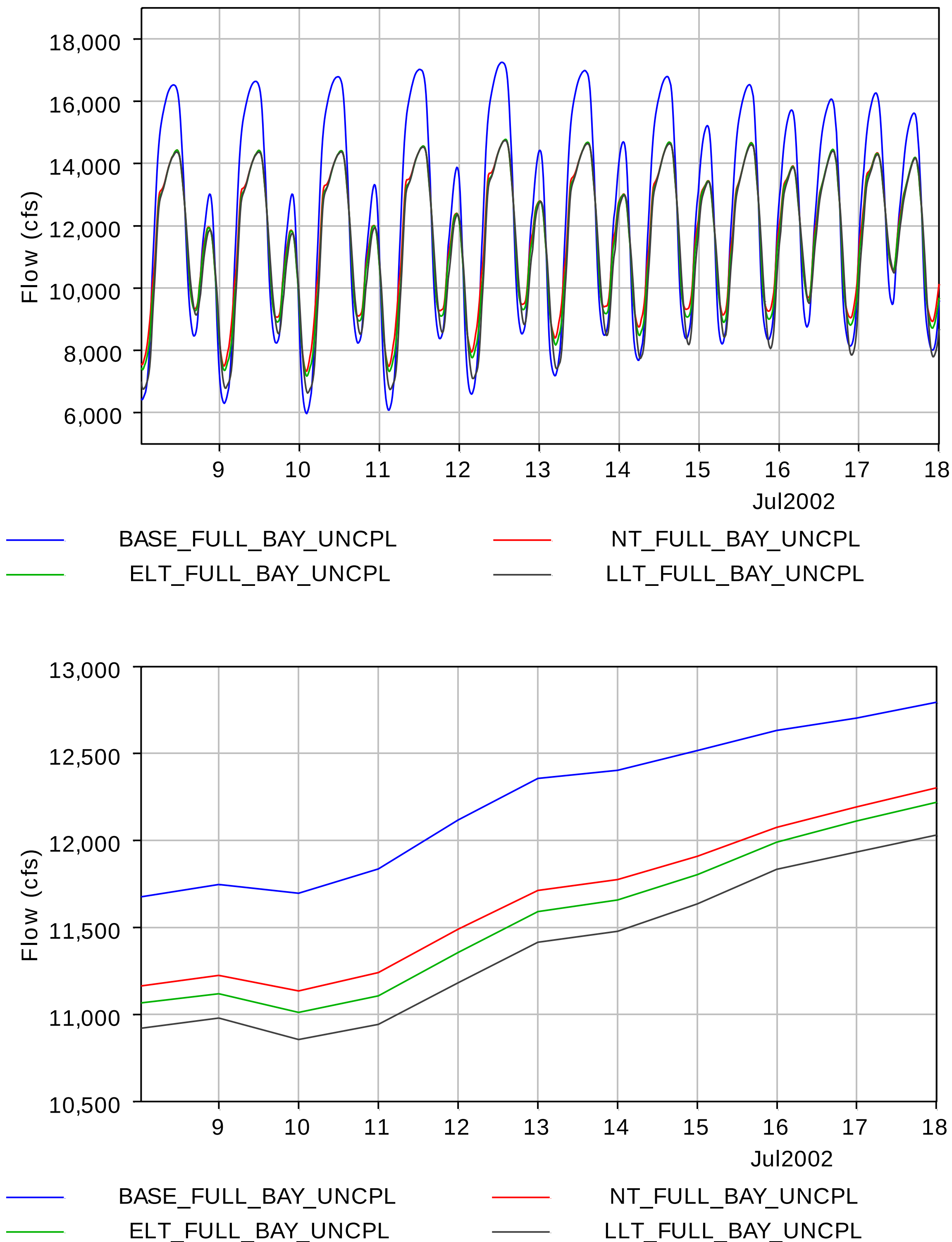
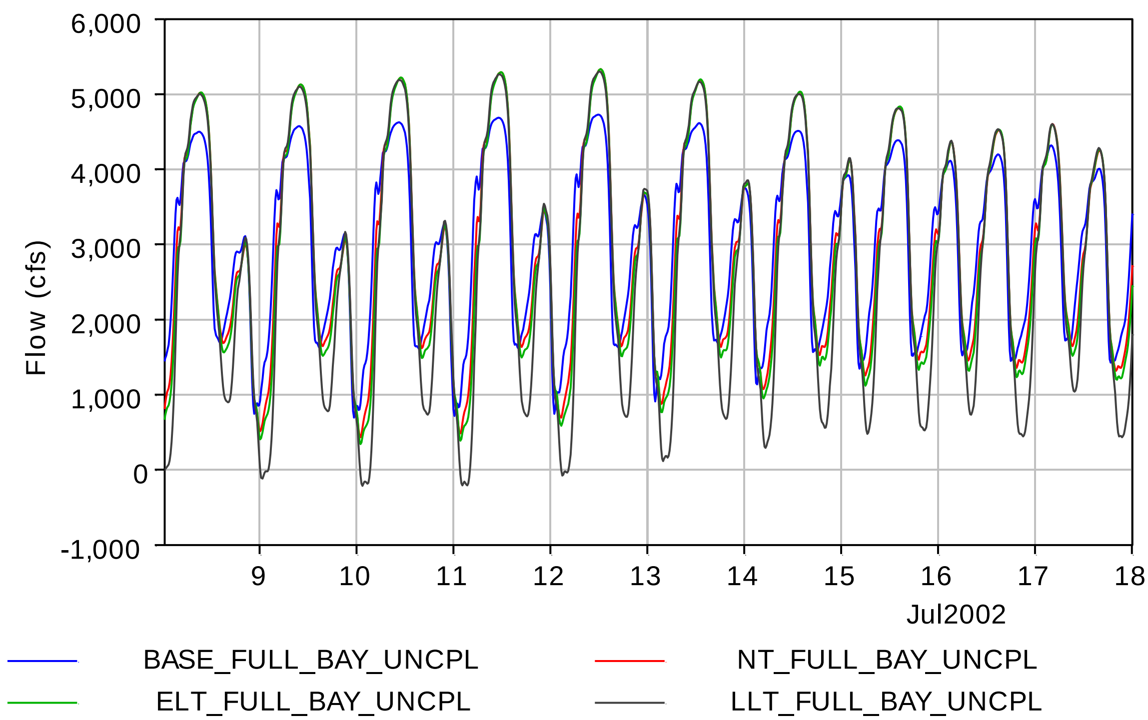


Figure 5-9 Dynamic (top) and tidally averaged (bottom) flow at RSAC128 for Base, NT, ELT and LLT scenarios.



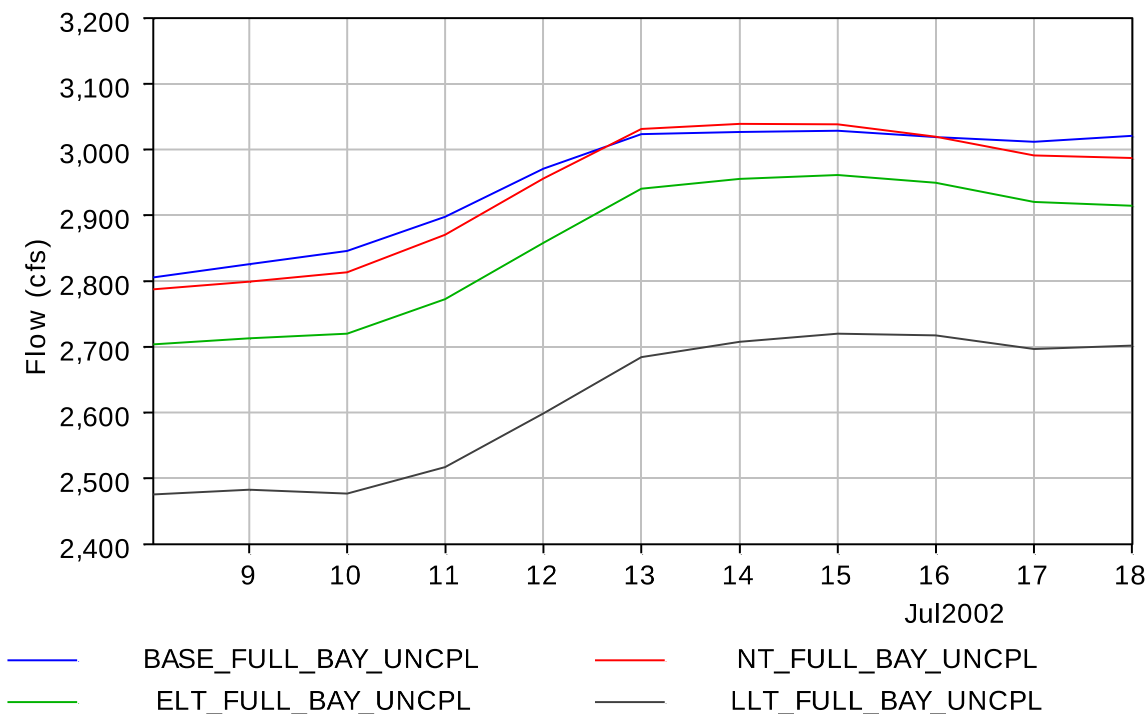
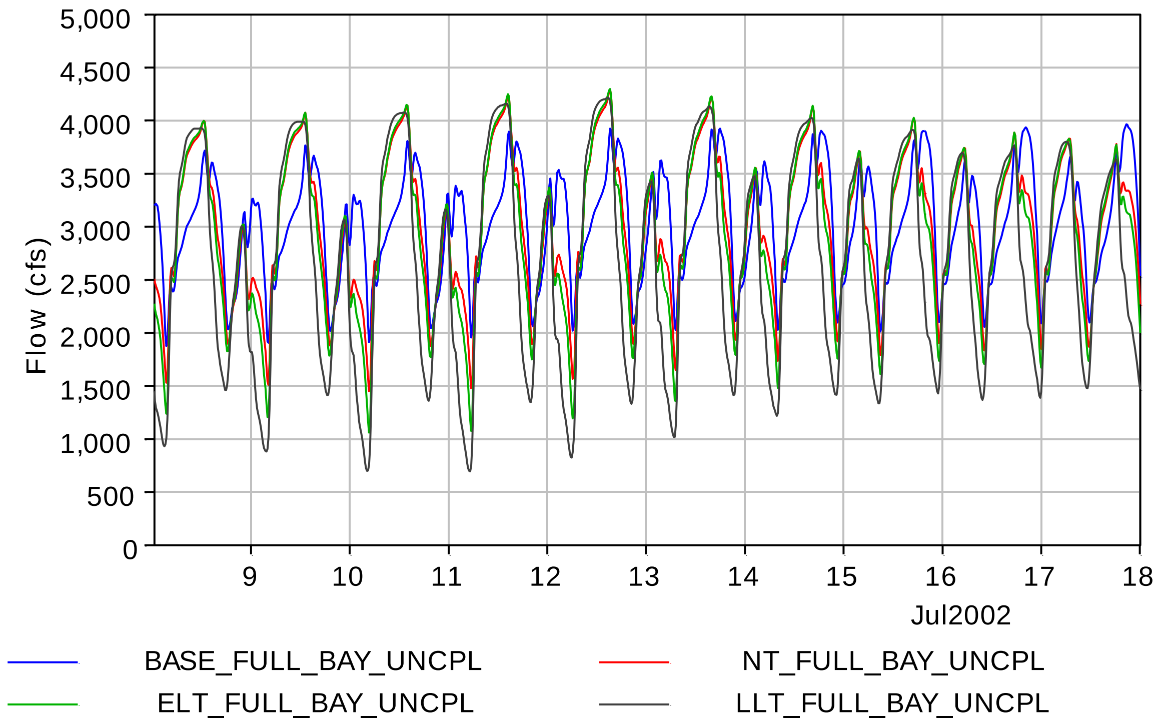


Figure 5-10 Dynamic (top) and tidally averaged (bottom) flow in Georgiana Slough at mouth for Base, NT, ELT and LLT scenarios.



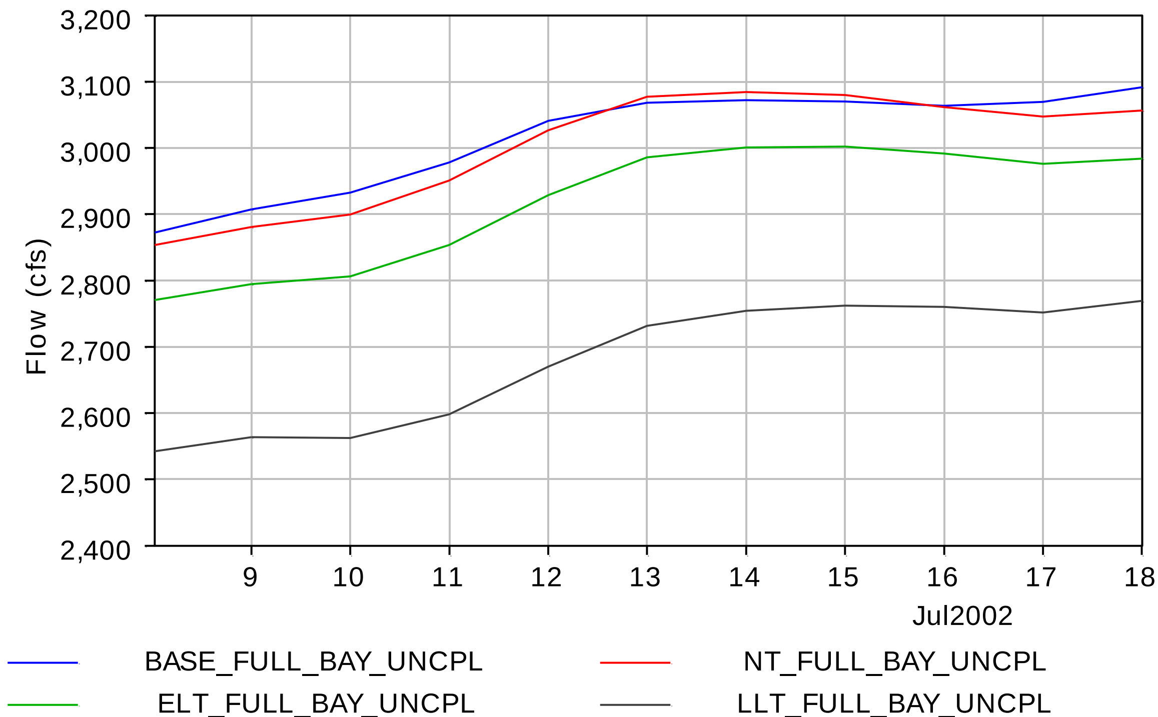
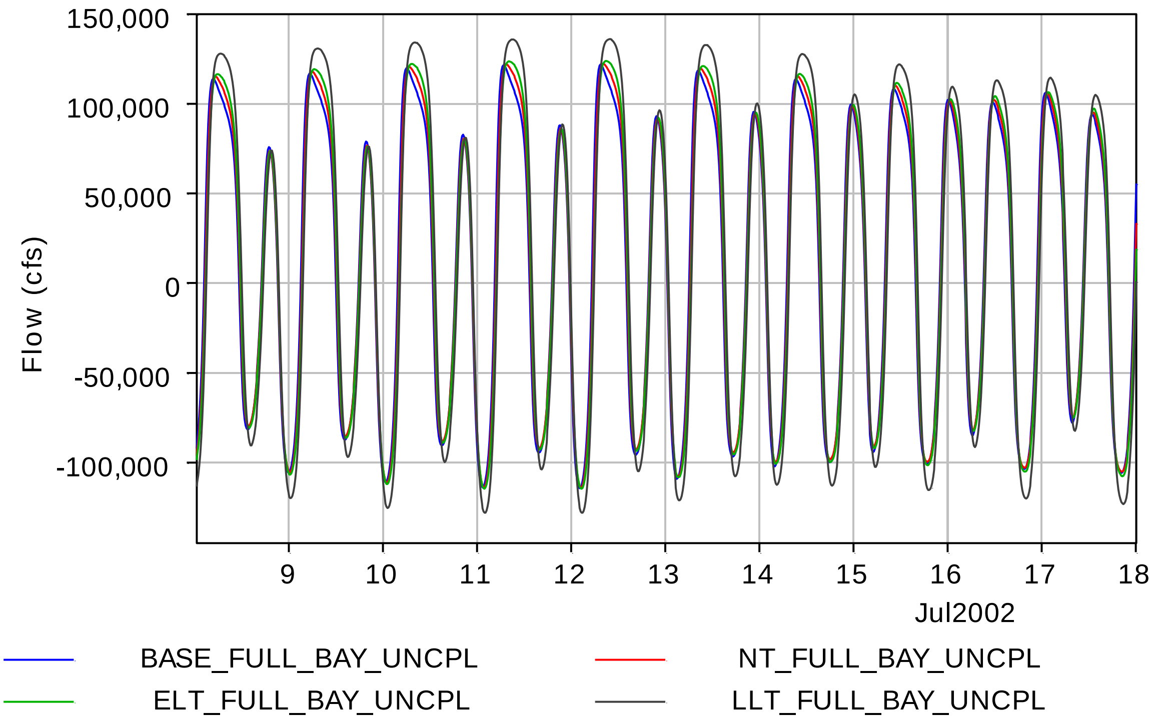


Figure 5-11 Dynamic (top) and tidally averaged (bottom) flow in Georgiana Slough at head for Base, NT, ELT and LLT scenarios.



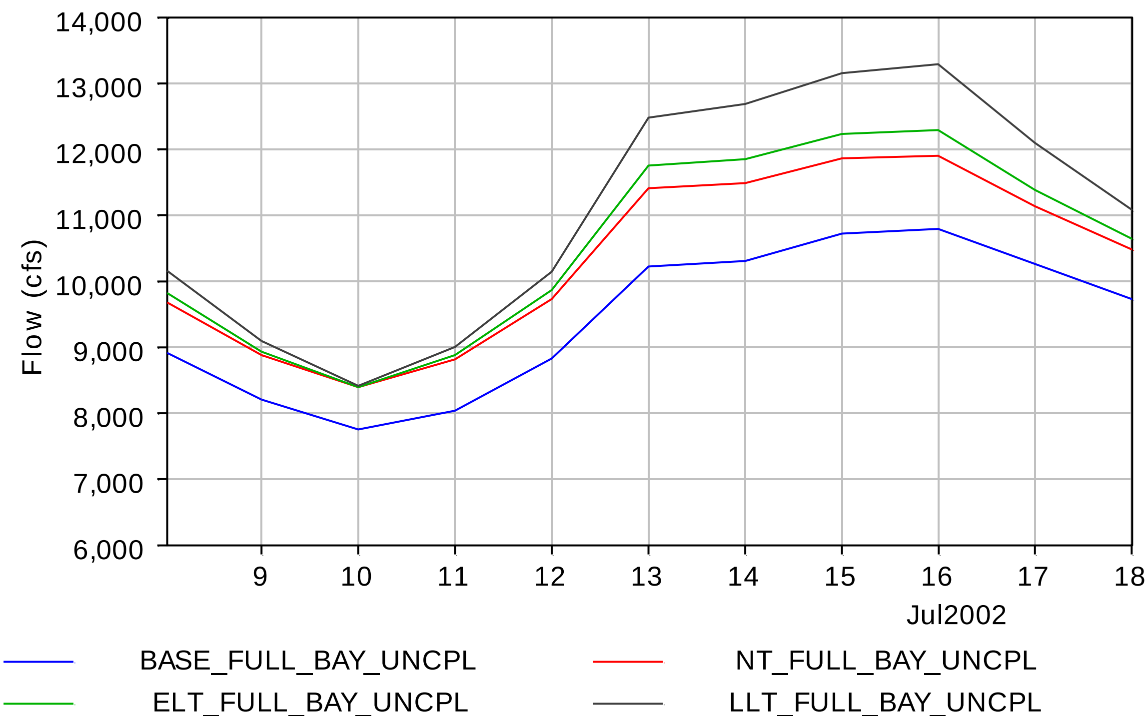
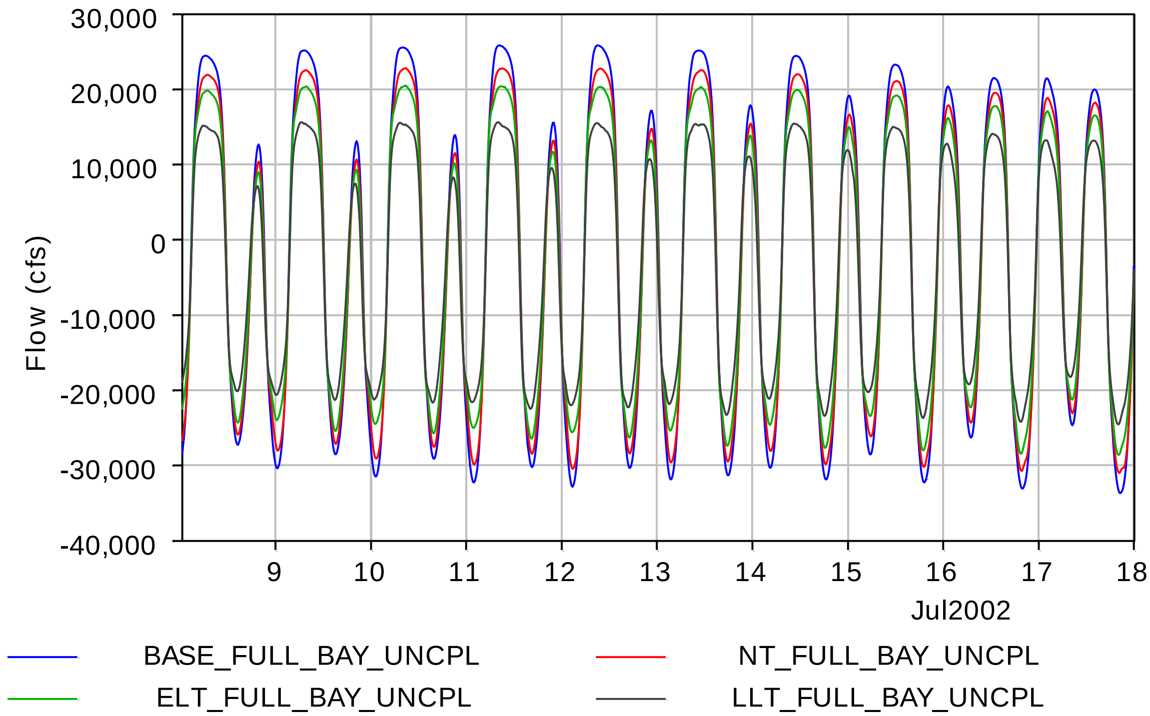


Figure 5-12 Dynamic (top) and tidally averaged (bottom) flow at Rio Vista for Base case, NT, ELT and LLT scenarios.



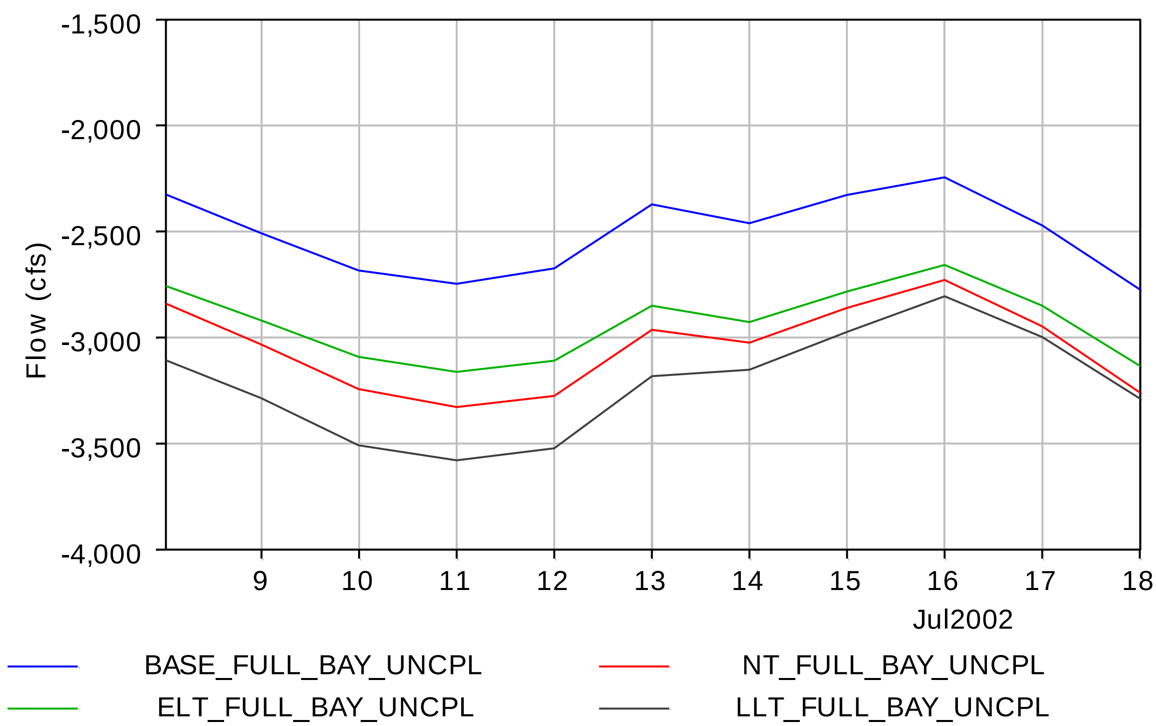
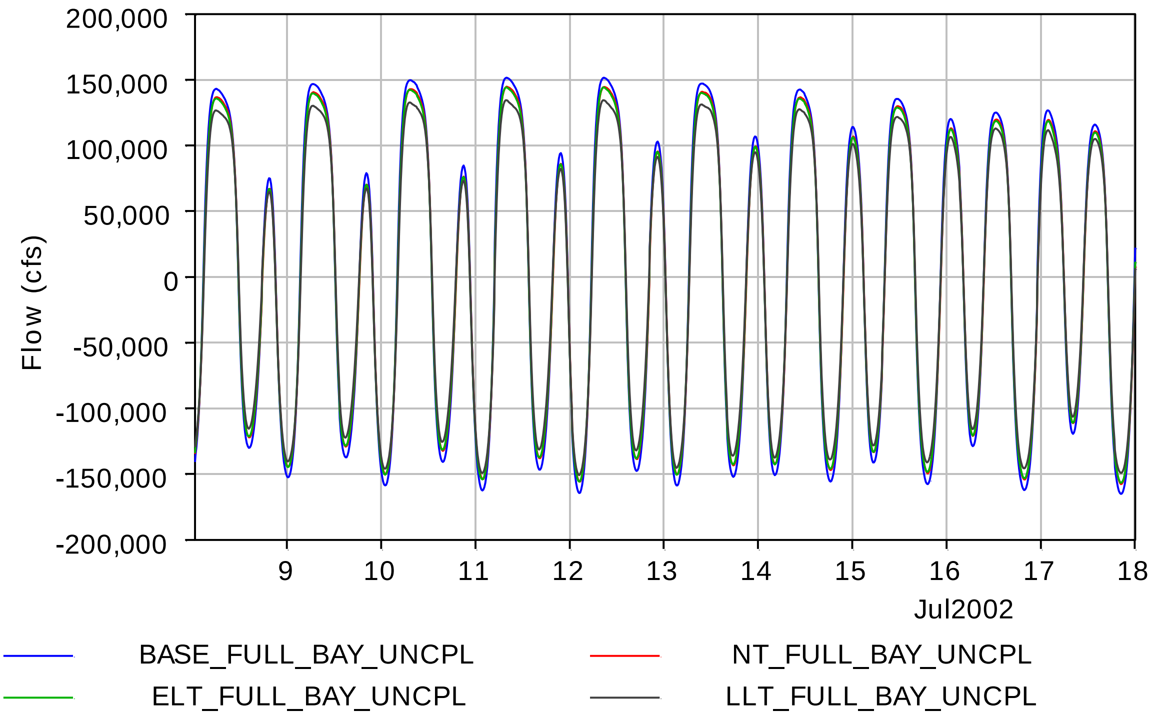


Figure 5-13 Dynamic (top) and tidally averaged (bottom) flow in Threemile Slough for Base, NT, ELT and LLT scenarios.



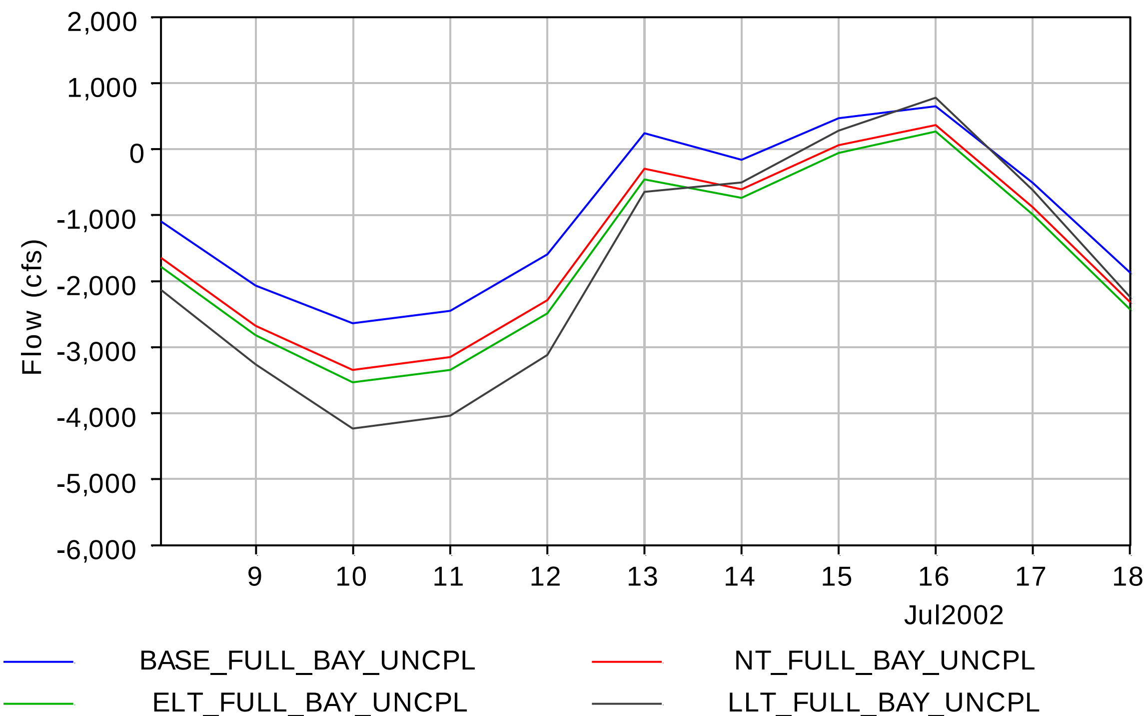
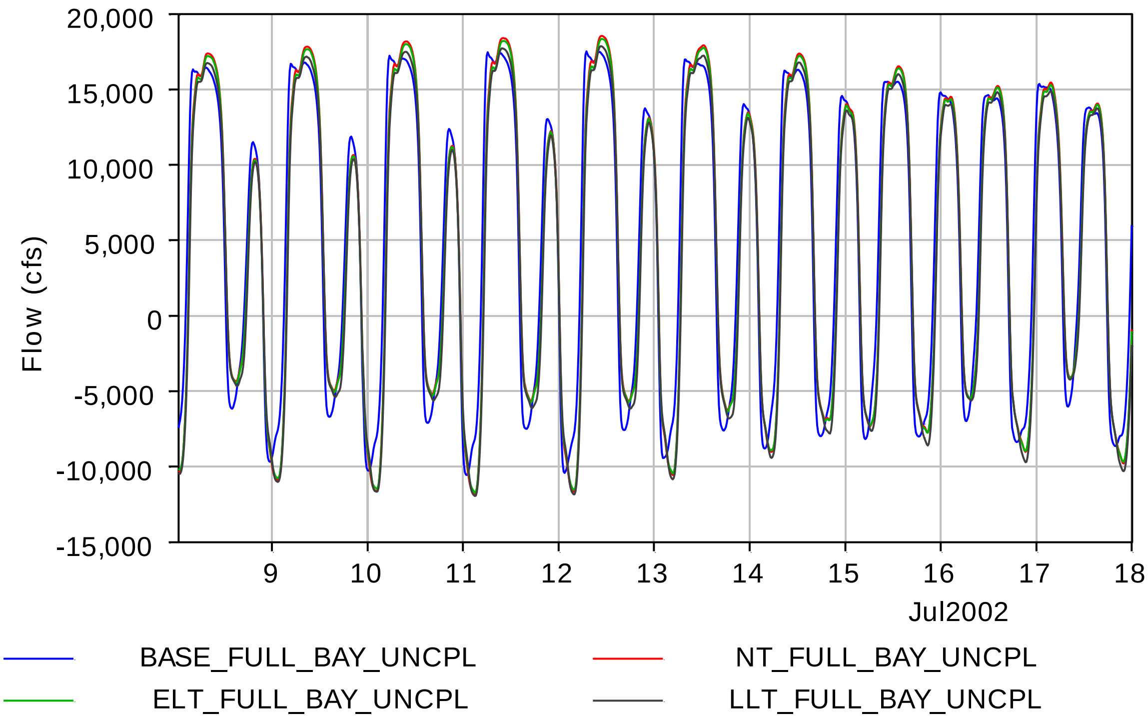


Figure 5-14 Dynamic (top) and tidally averaged (bottom) flow at Jersey Point for Base, NT, ELT and LLT scenarios.



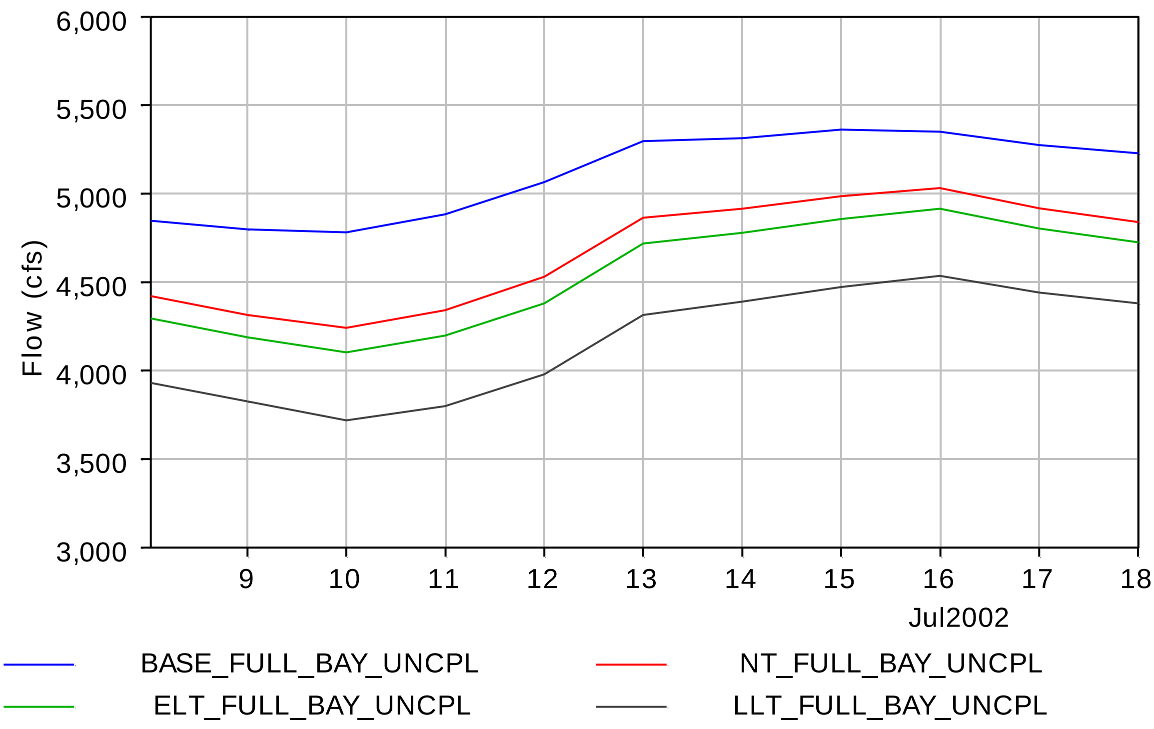


Figure 5-15 Dynamic (top) and tidally averaged (bottom) flow in Mokelumne R. near San Joaquin R. for Base, NT, ELT and LLT scenarios.

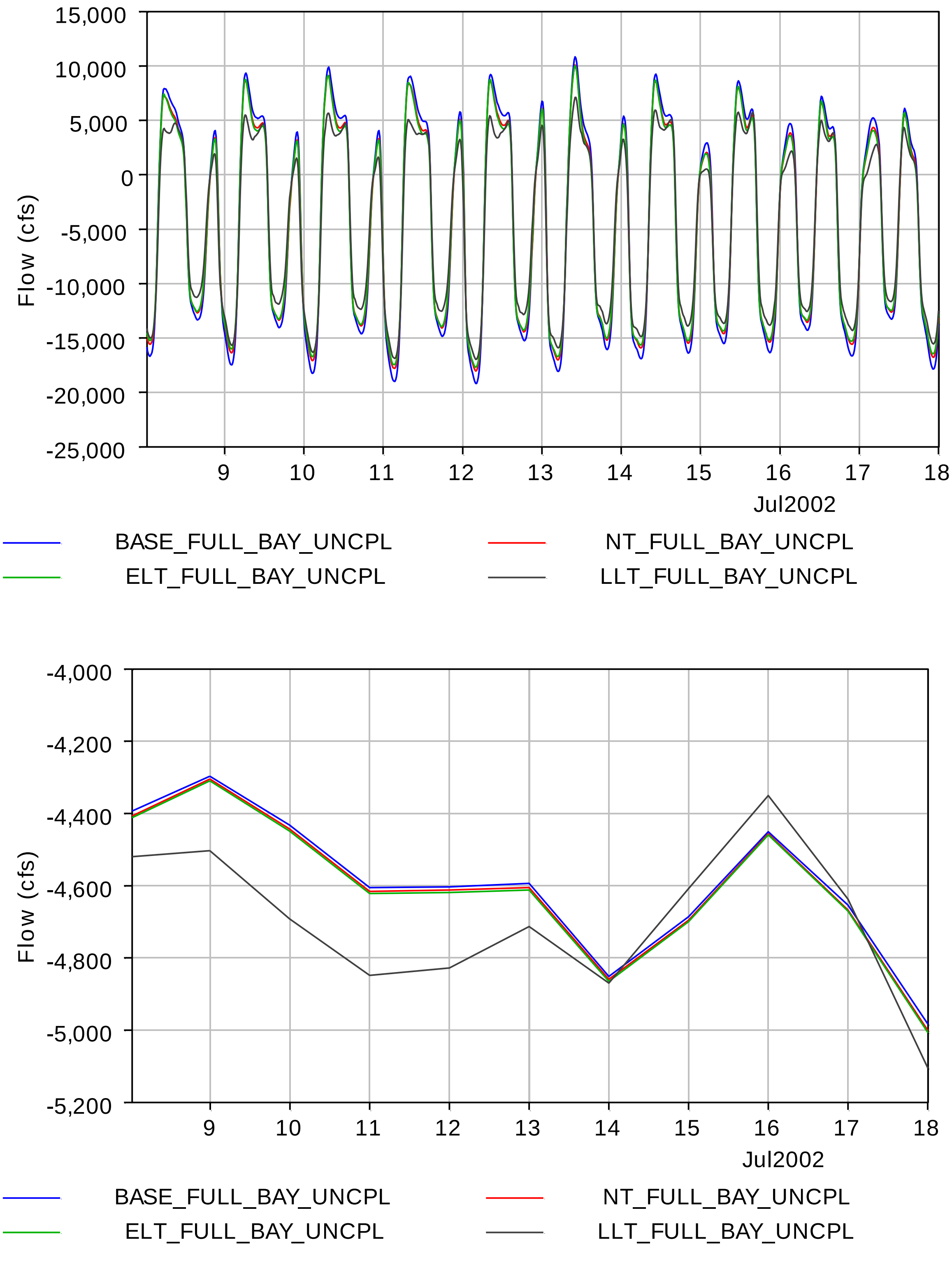
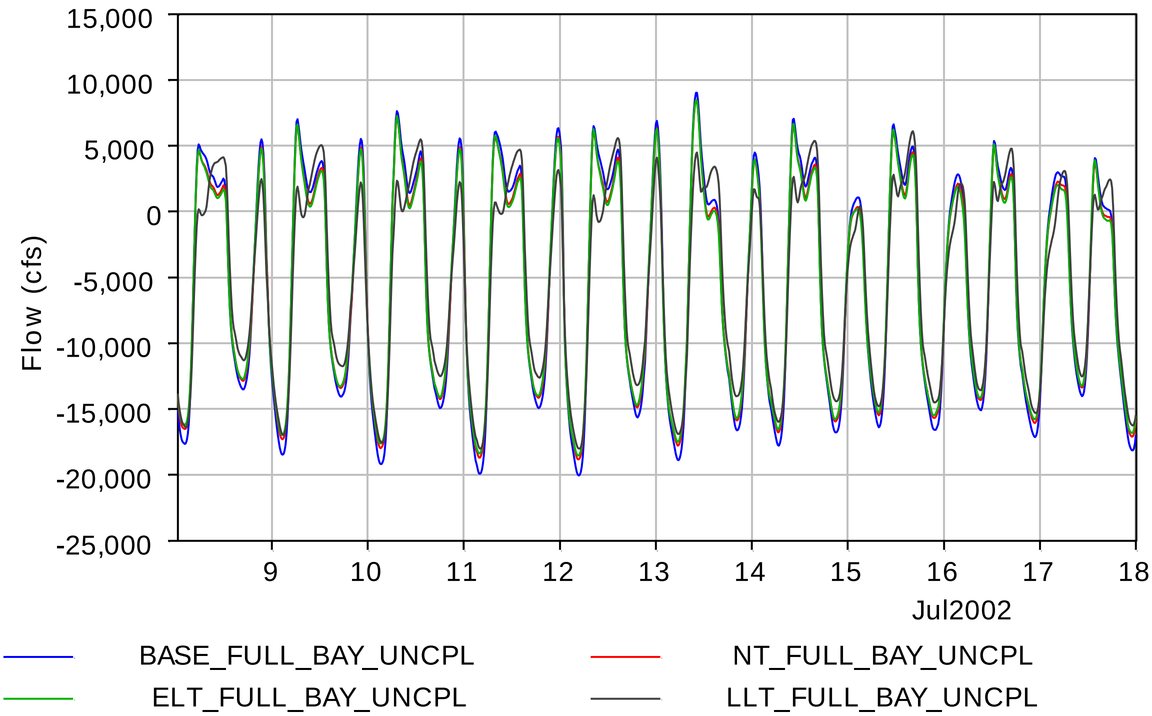


Figure 5-16 Dynamic (top) and tidally averaged (bottom) flow in Old River at Rock Slough (ROLD024) for Base, NT, ELT and LLT scenarios.



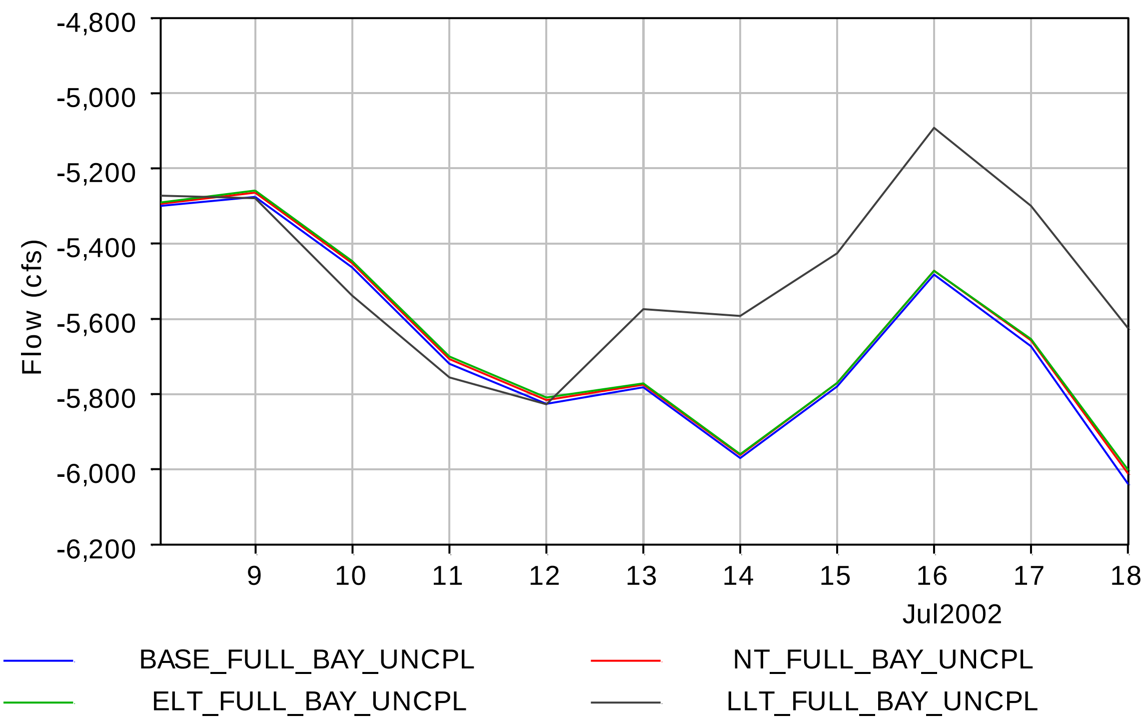


Figure 5-17 Dynamic (top) and tidally averaged (bottom) flow in Middle River (RMID015) for Base, NT, ELT and LLT scenarios.

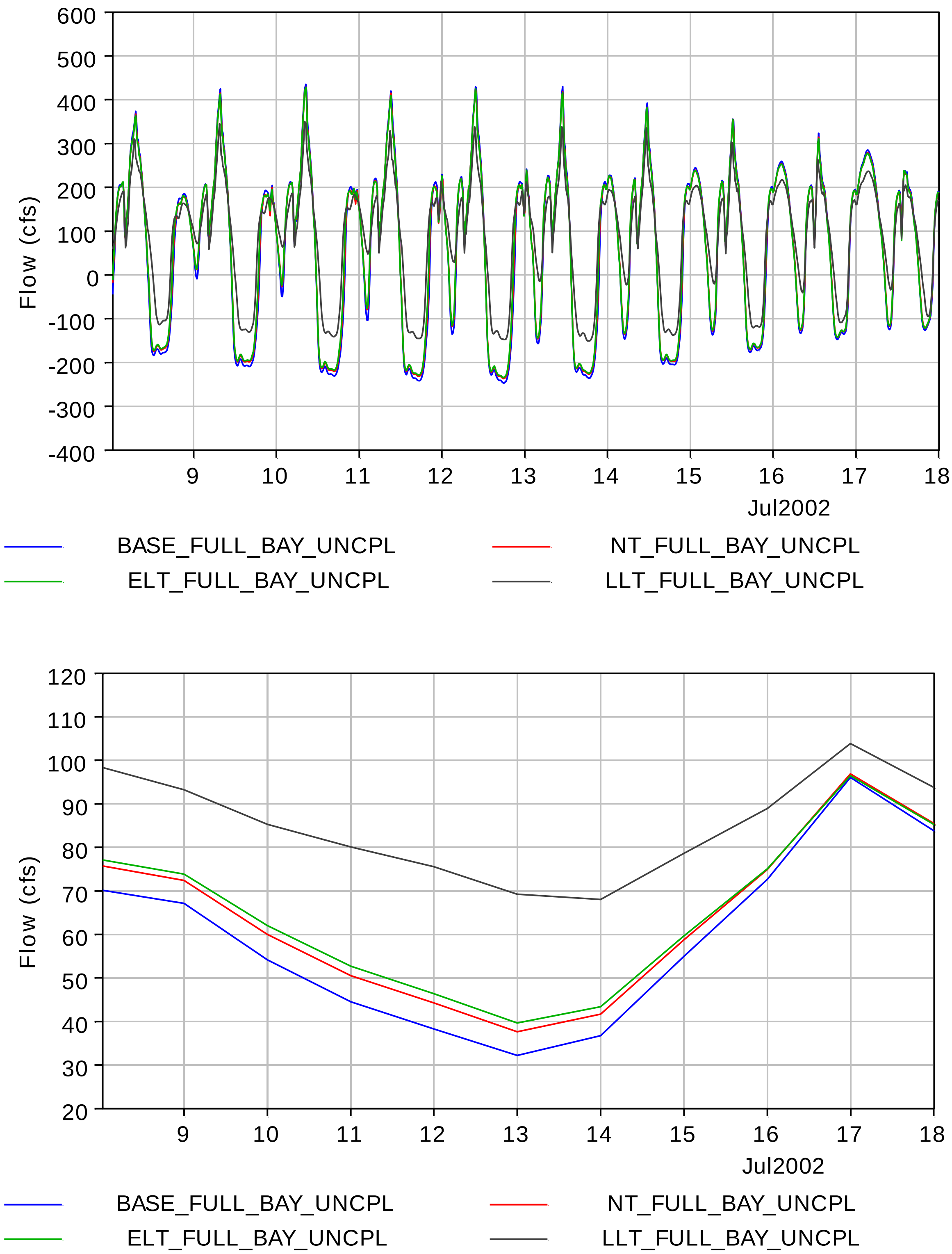
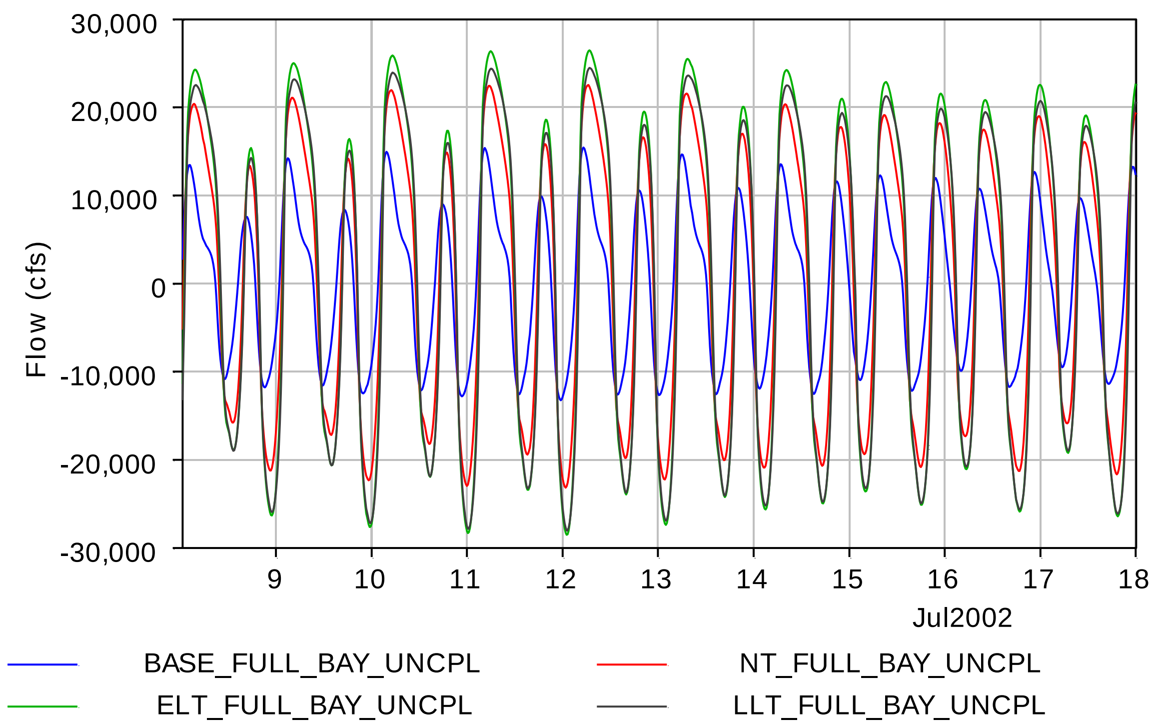


Figure 5-18 Dynamic (top) and tidally averaged (bottom) flow in Old River at Tracy Road (ROLD059) for Base, NT, ELT and LLT scenarios.



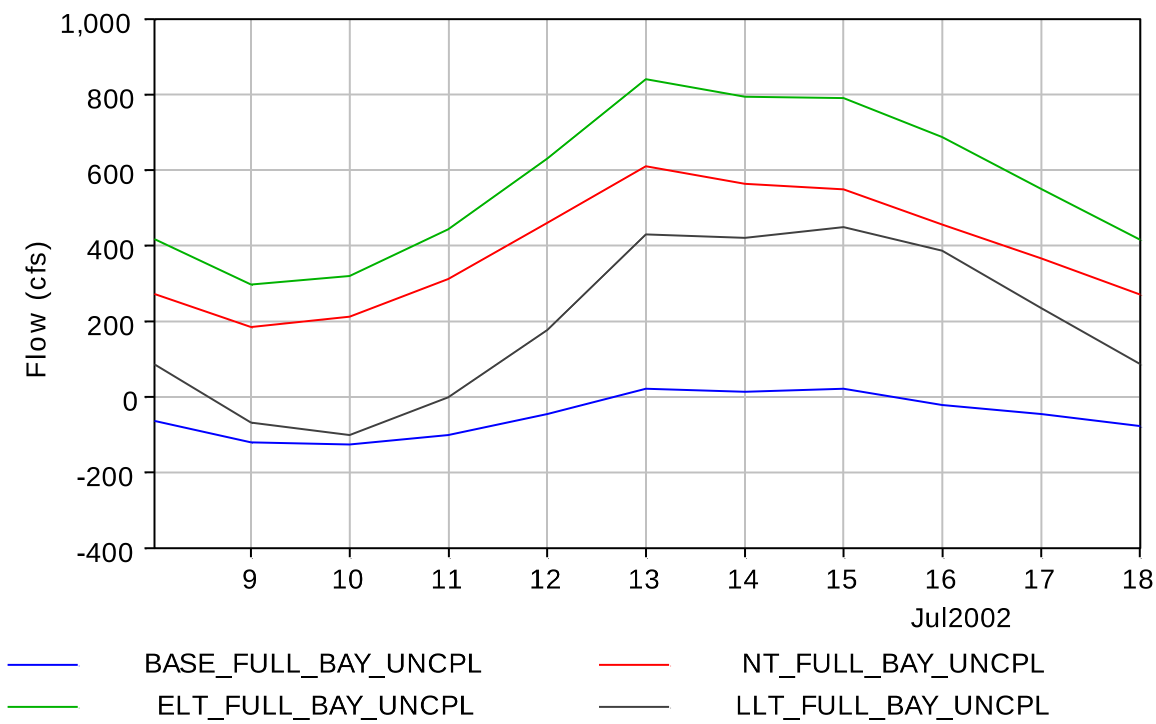


Figure 5-19 Dynamic (top) and tidally averaged (bottom) flow in Hunter Cut for Base, NT, ELT and LLT scenarios.

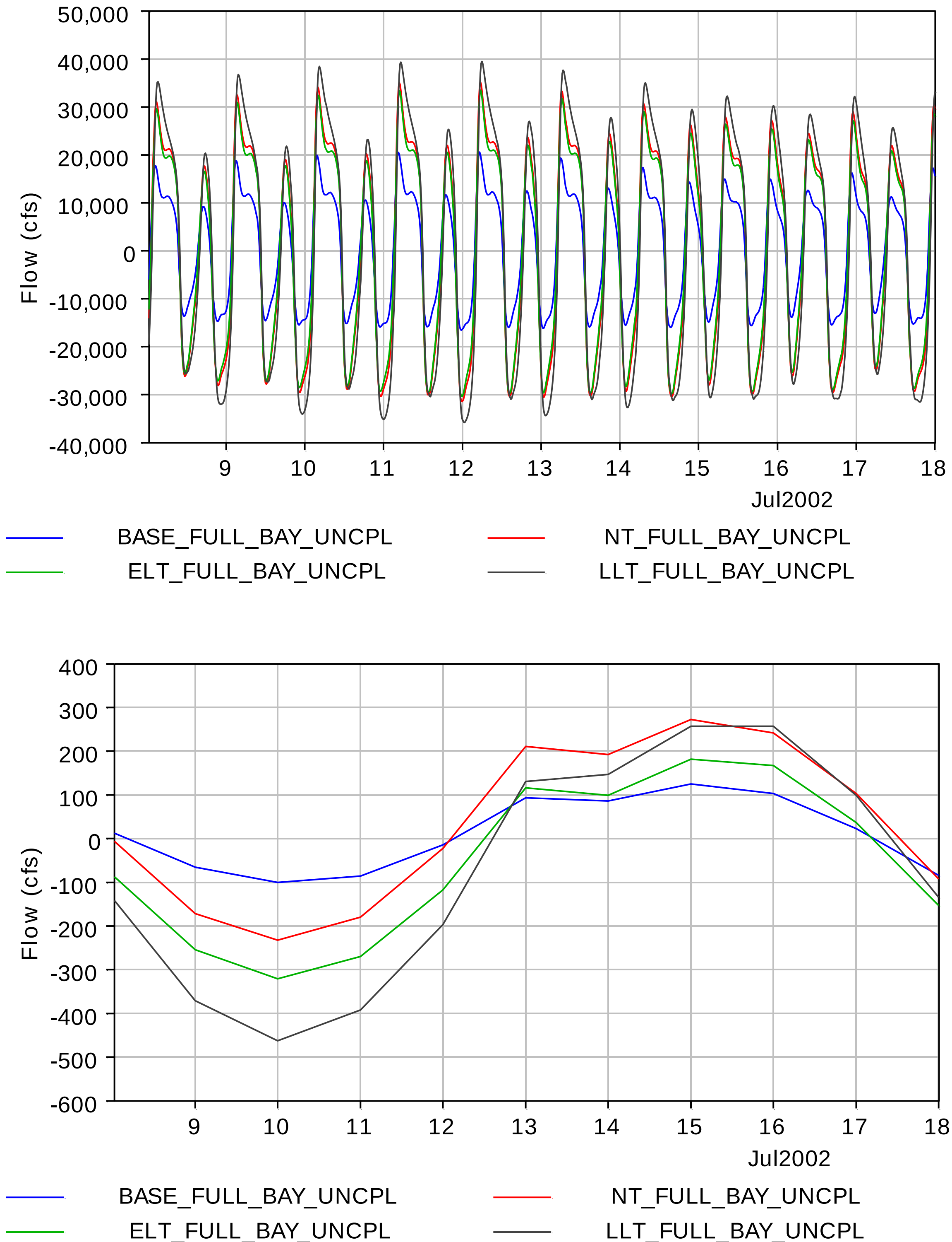
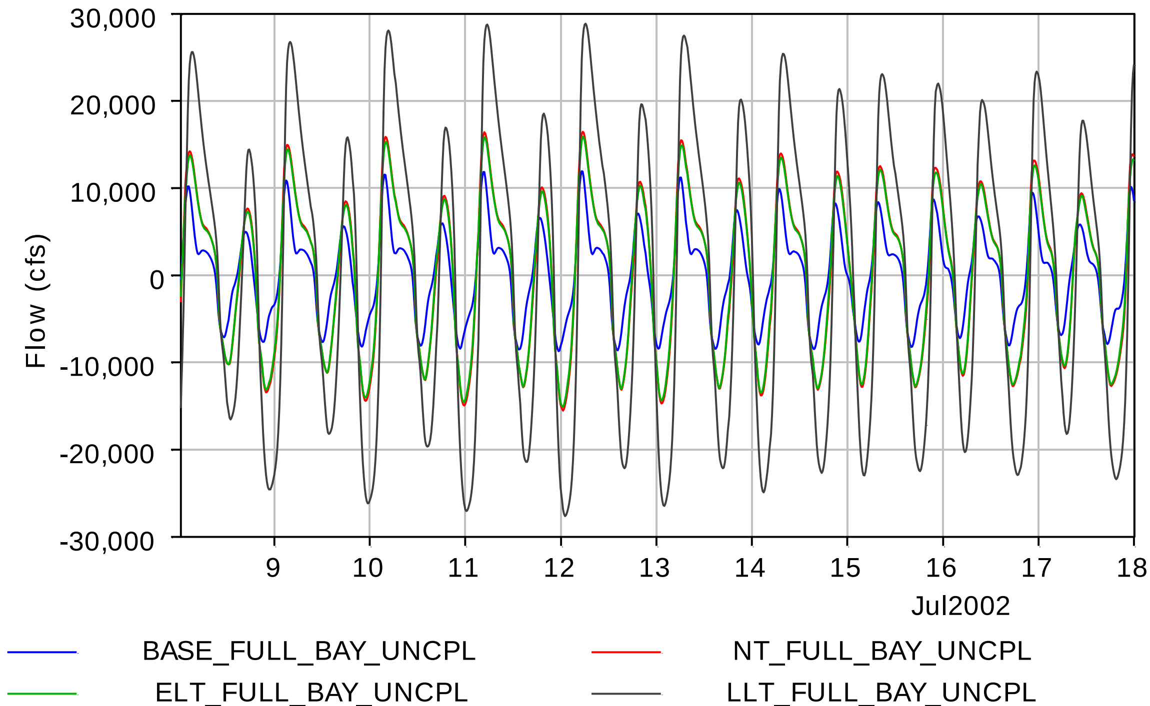


Figure 5-20 Dynamic (top) and tidally averaged (bottom) flow in Montezuma Slough at Beldon's Landing (S-49) for Base, NT, ELT and LLT scenarios.



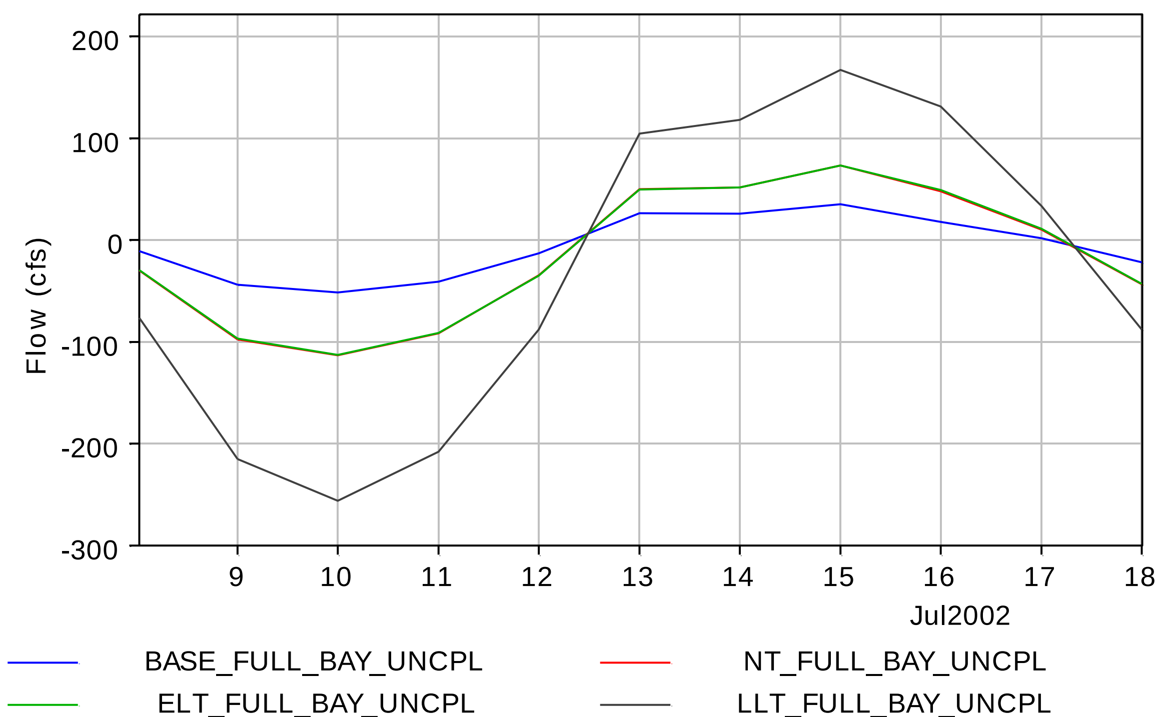
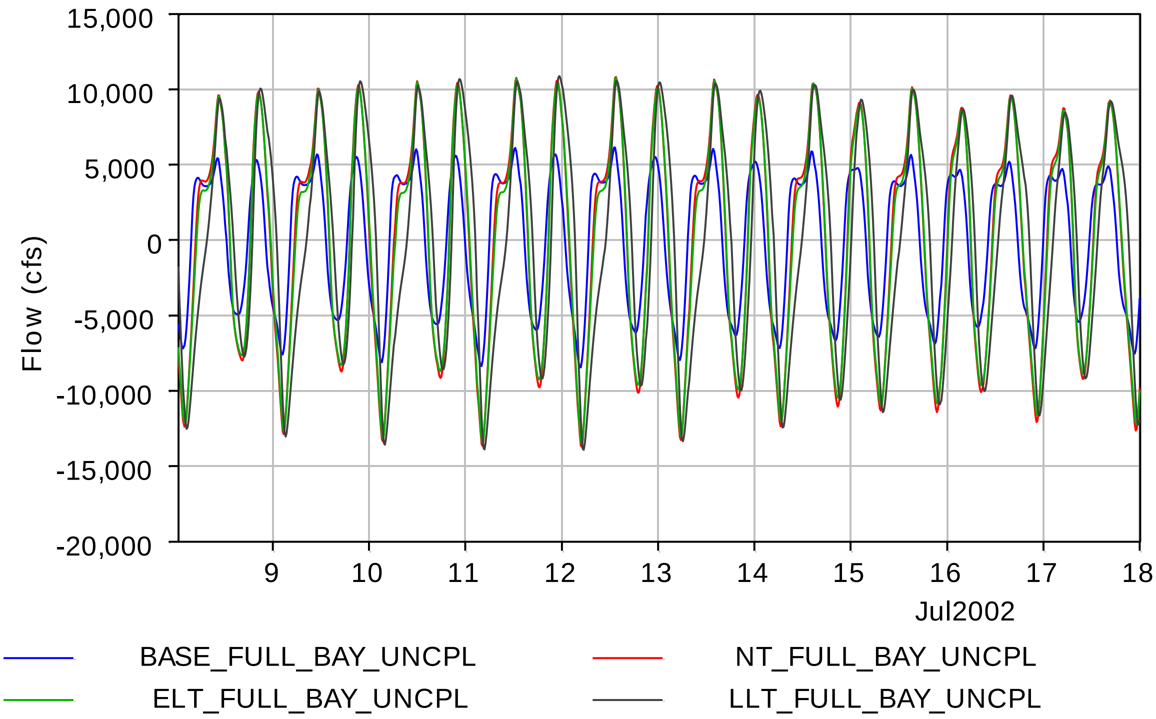


Figure 5-21 Dynamic (top) and tidally averaged (bottom) flow in Nurse Slough for Base, NT, ELT and LLT scenarios.



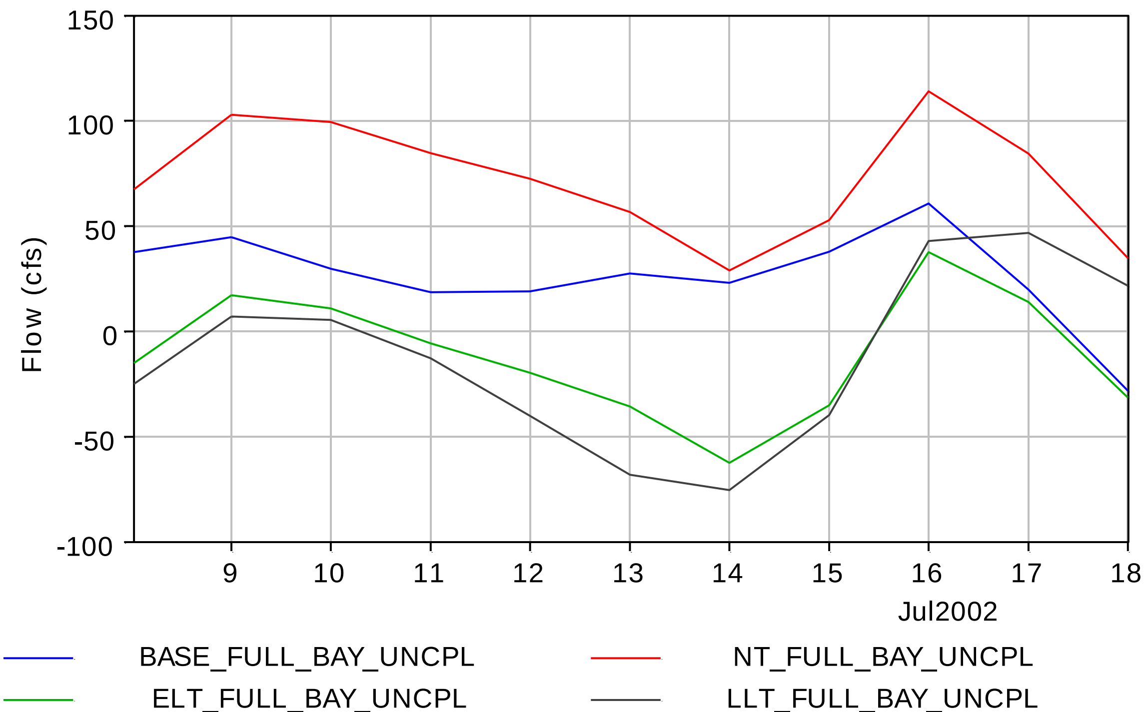
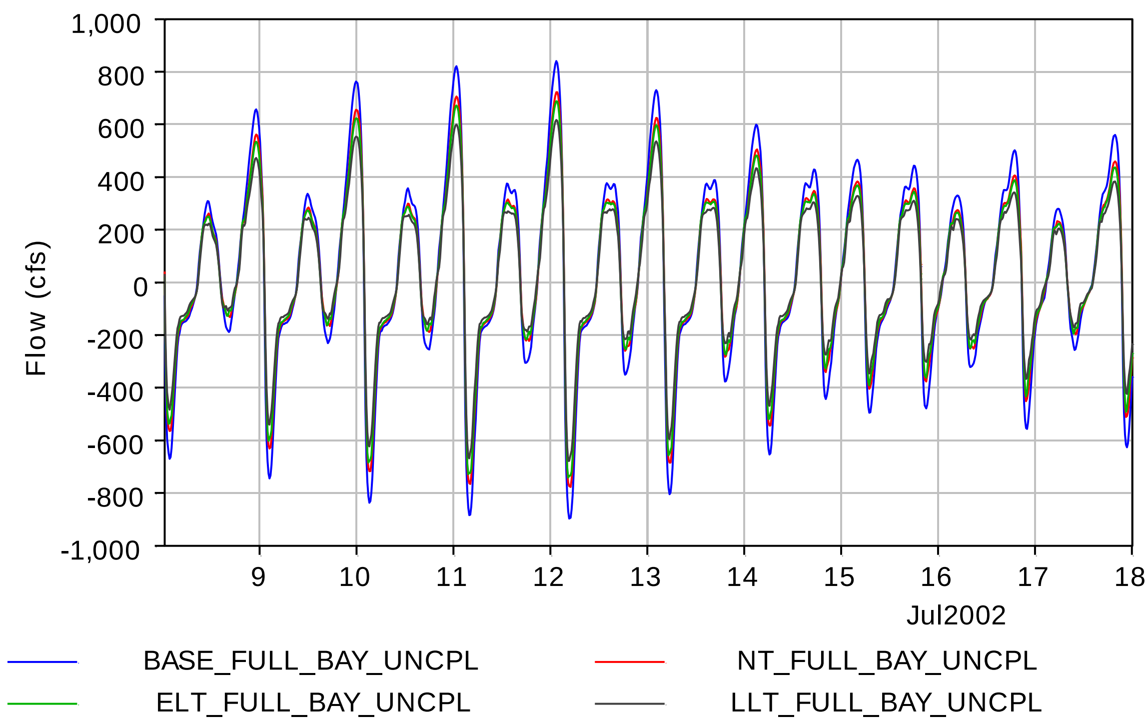


Figure 5-22 Dynamic (top) and tidally averaged (bottom) flow in Montezuma Slough at Roaring River (S-71) for Base, NT, ELT and LLT scenarios.



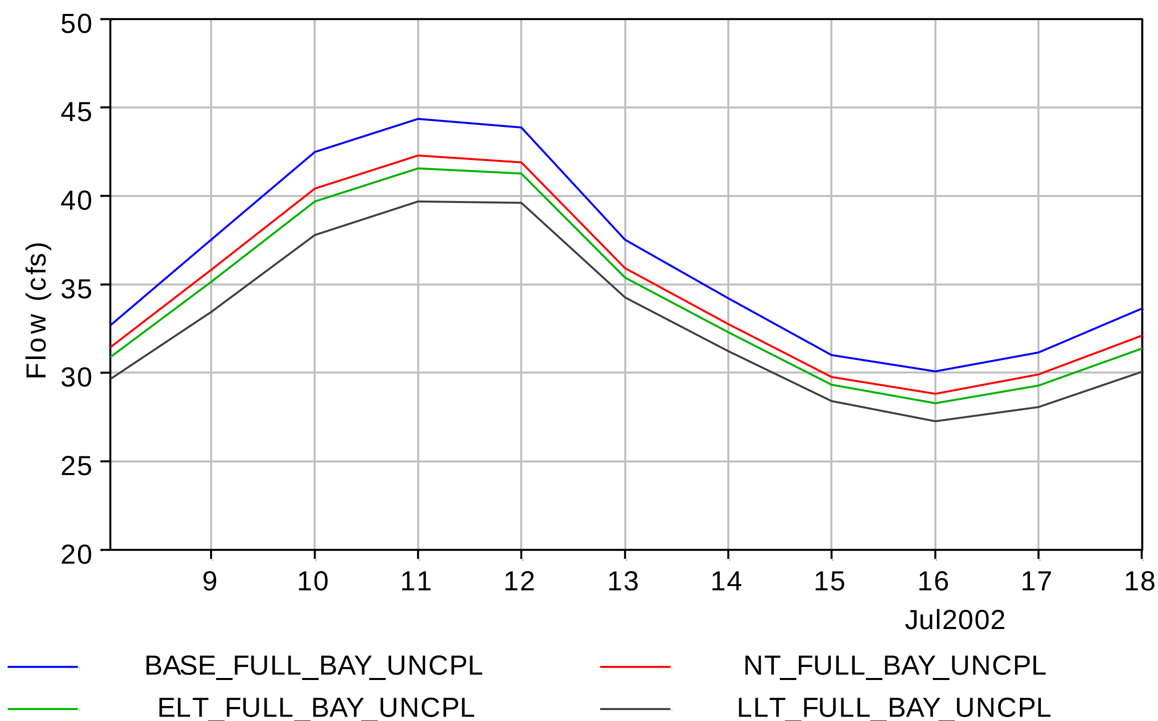
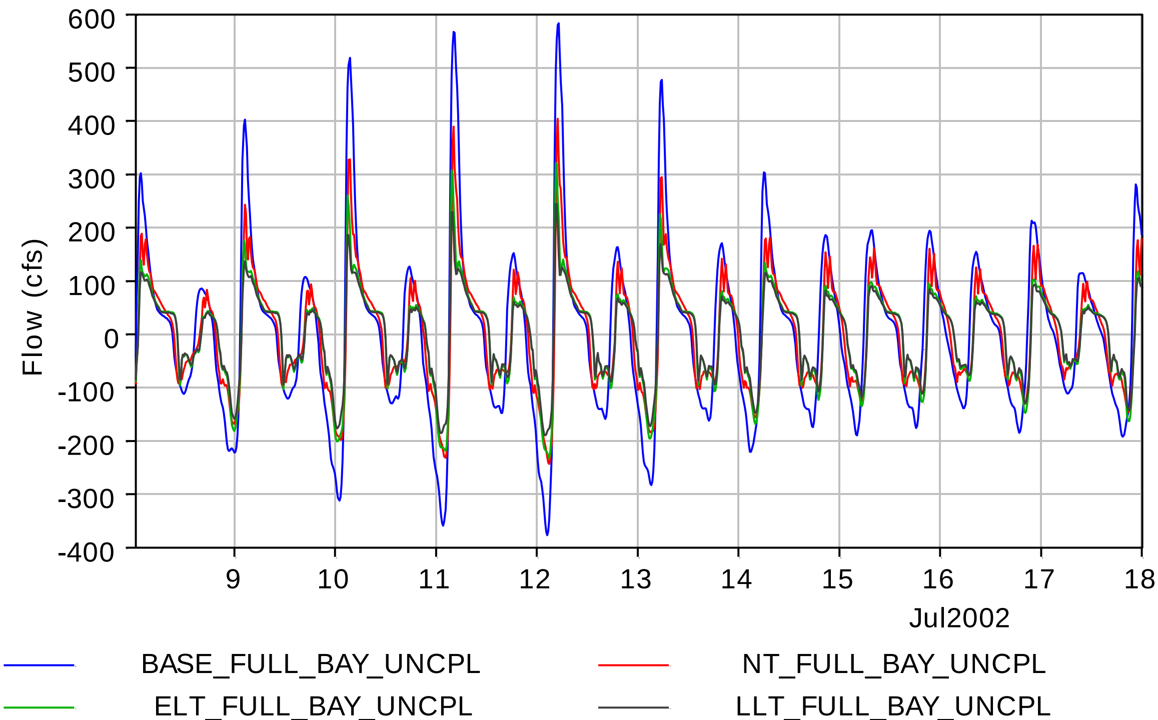


Figure 5-23 Dynamic (top) and tidally averaged (bottom) flow at S-35 near Morrow Island for Base, NT, ELT and LLT scenarios.



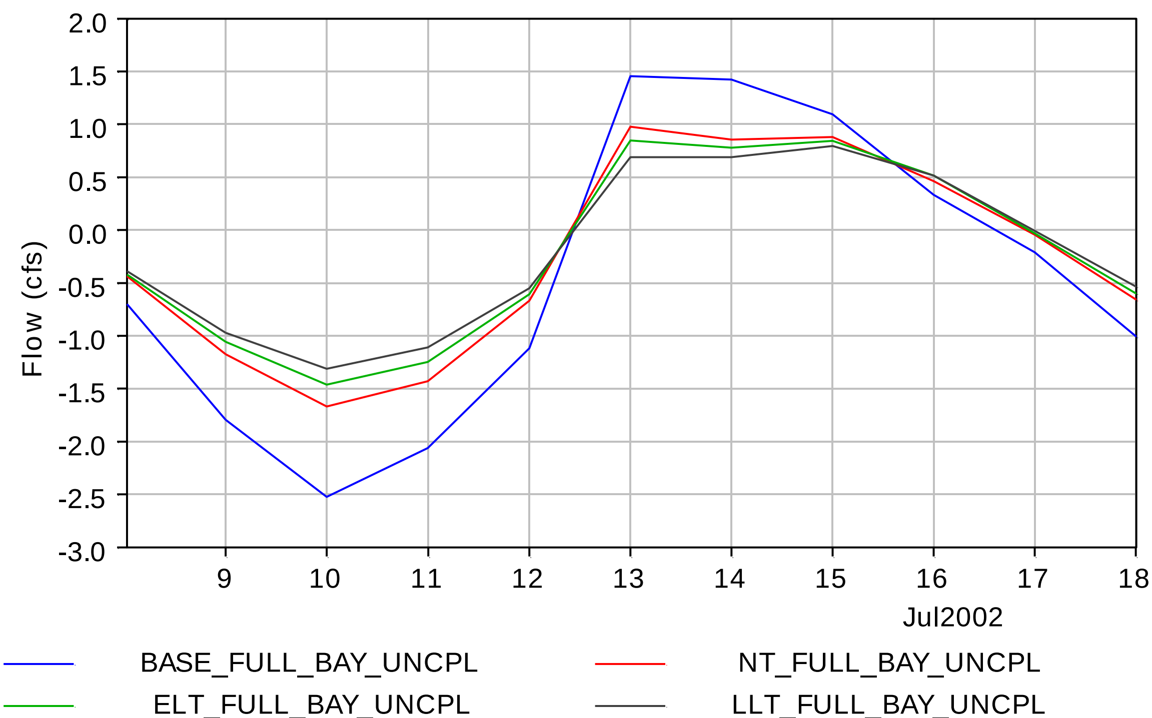
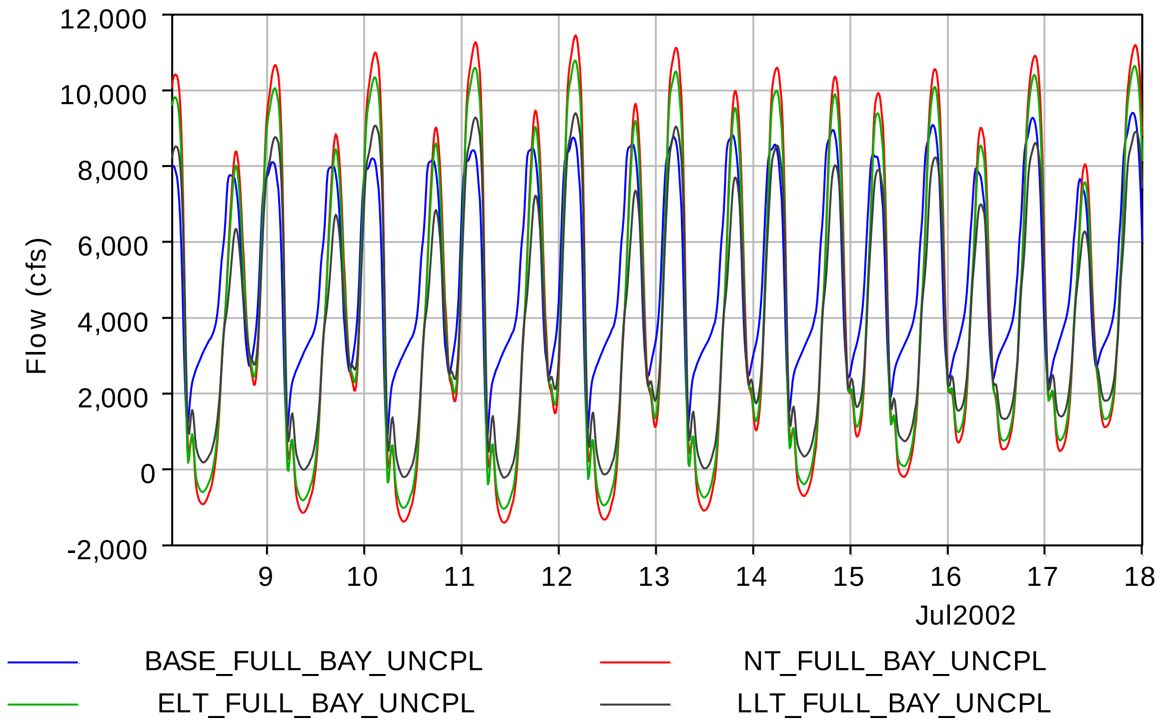


Figure 5-24 Dynamic (top) and tidally averaged (bottom) flow in Boynton Slough at S-40 for Base, NT, ELT and LLT scenarios.



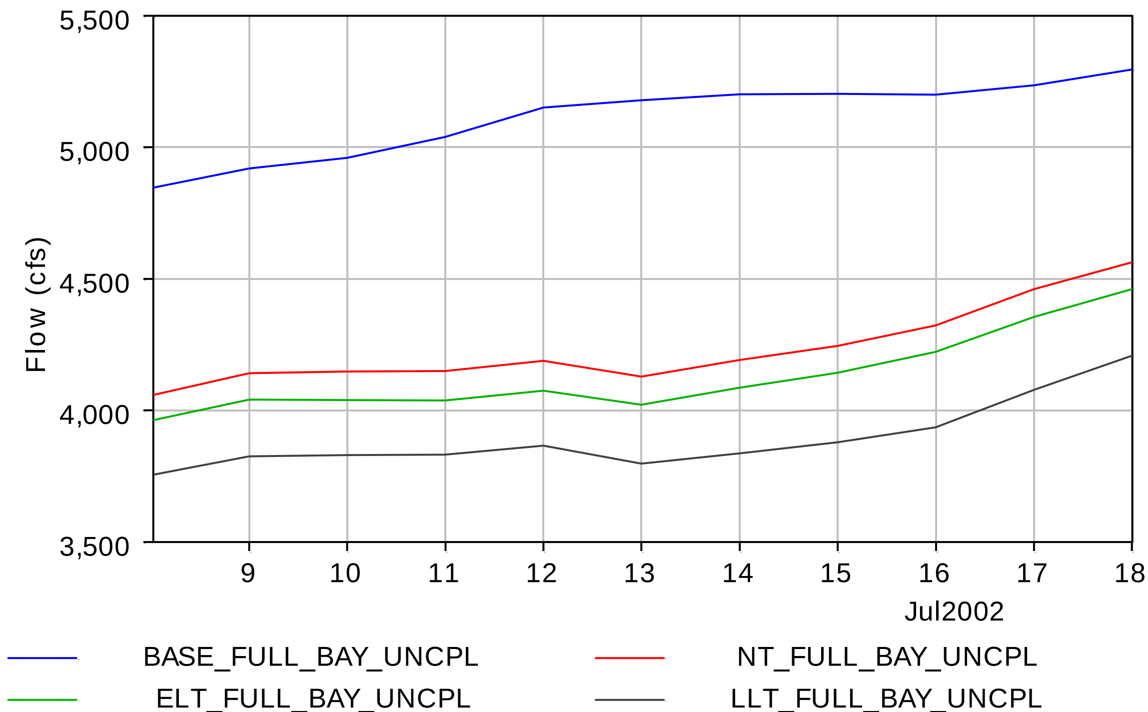


Figure 5-25 Dynamic (top) and tidally averaged (bottom) flow in the Delta Cross Channel for Base, NT, ELT and LLT scenarios.

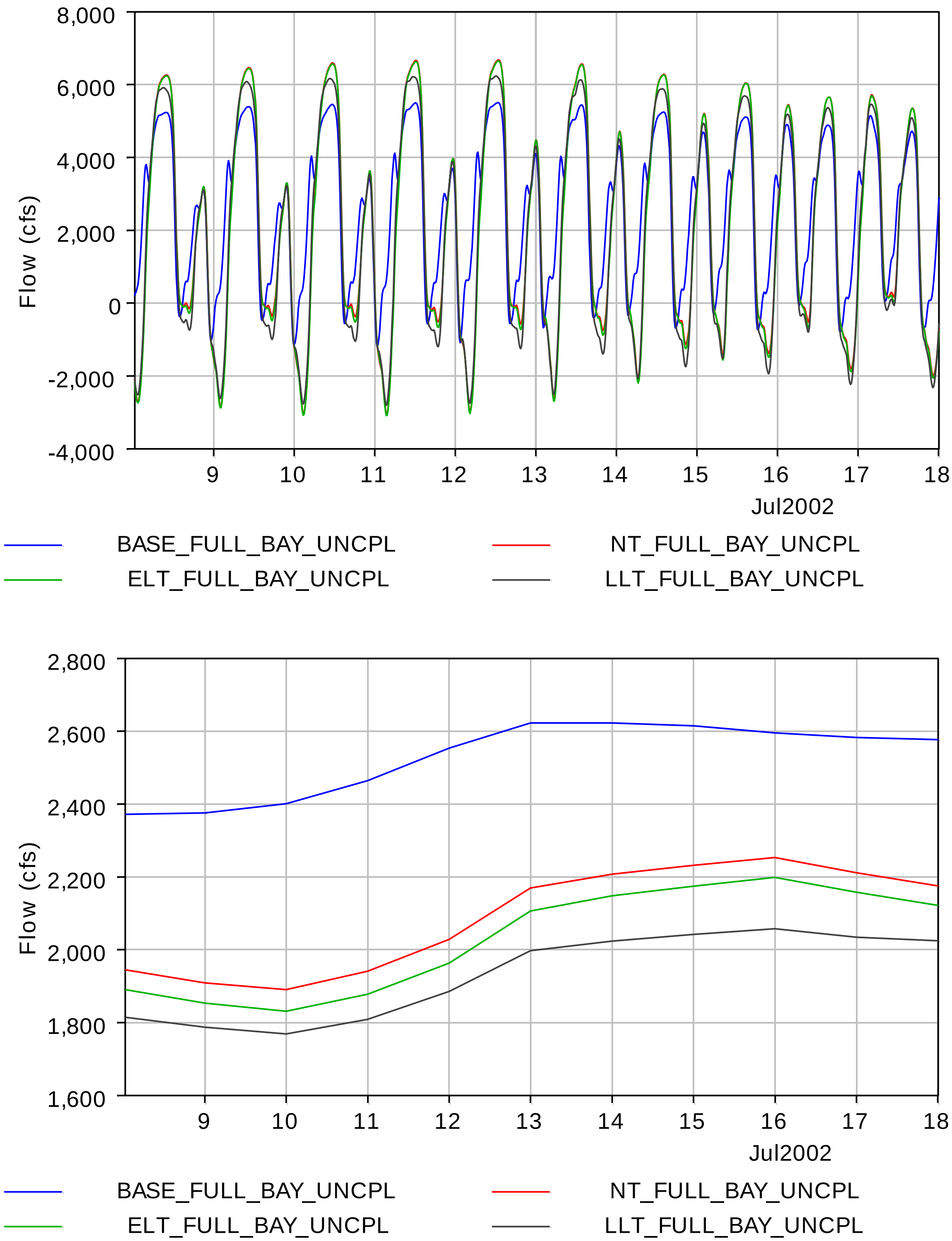
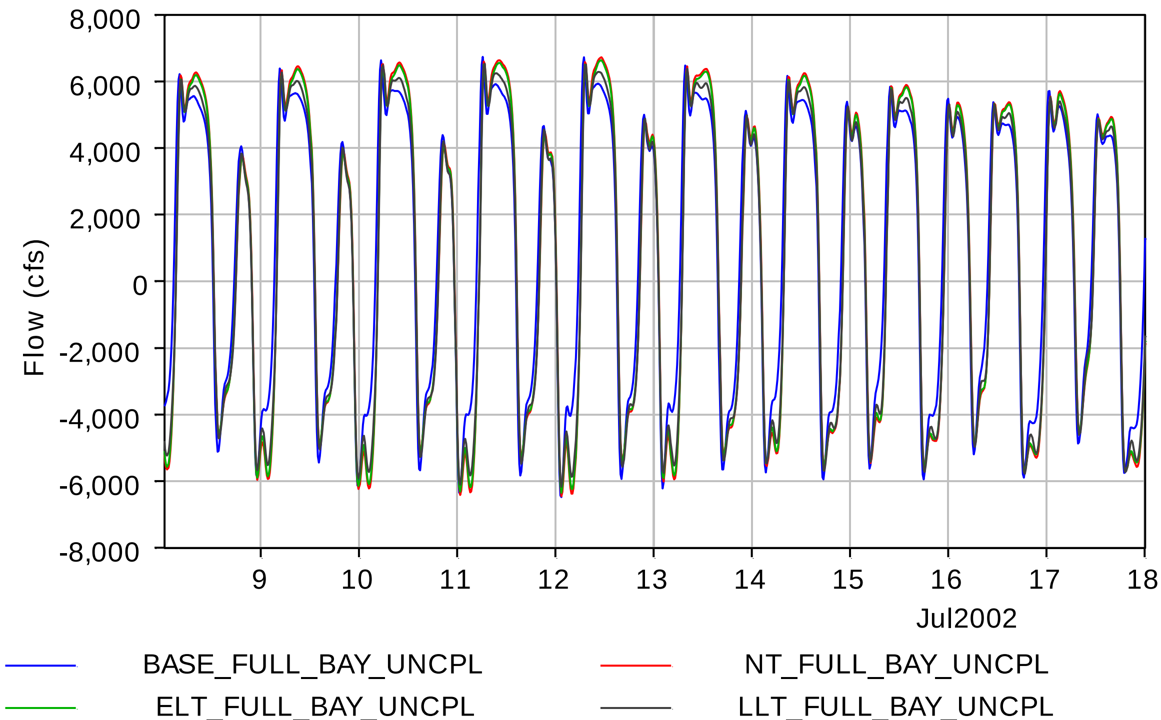


Figure 5-26 Dynamic (top) and tidally averaged (bottom) flow in Little Potato Slough for Base, NT, ELT and LLT scenarios.



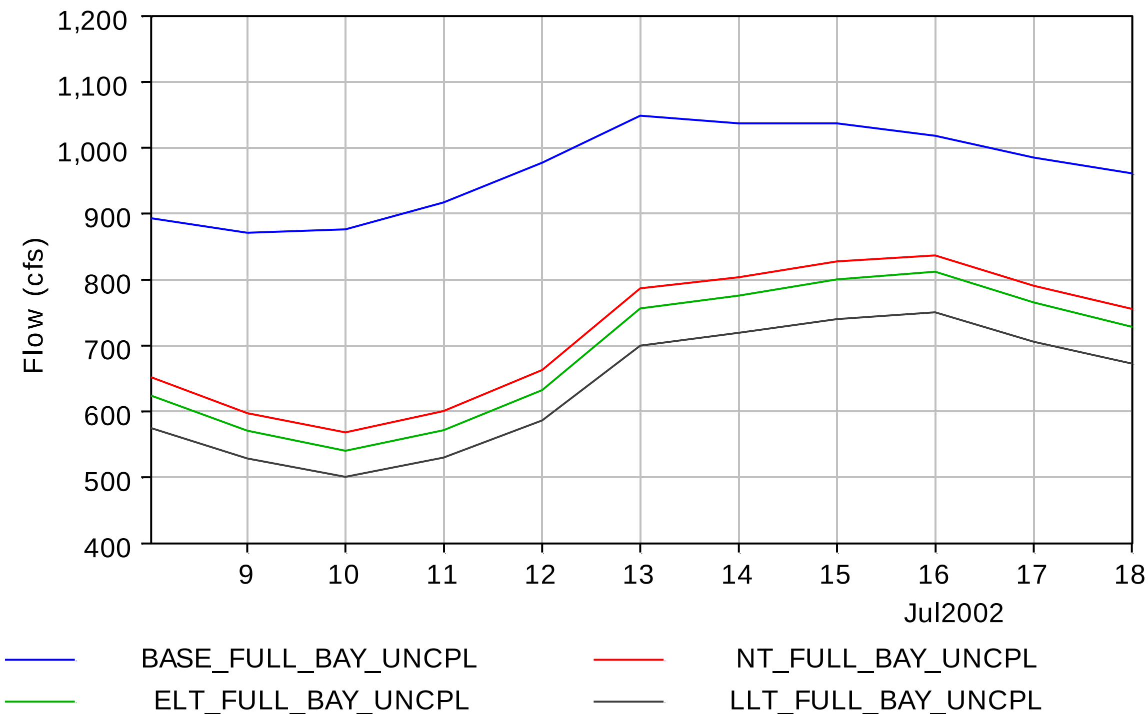


Figure 5-27 Dynamic (top) and tidally averaged (bottom) flow in south Fork Mokelumne at RSMKL008 for Base, NT, ELT and LLT scenarios.

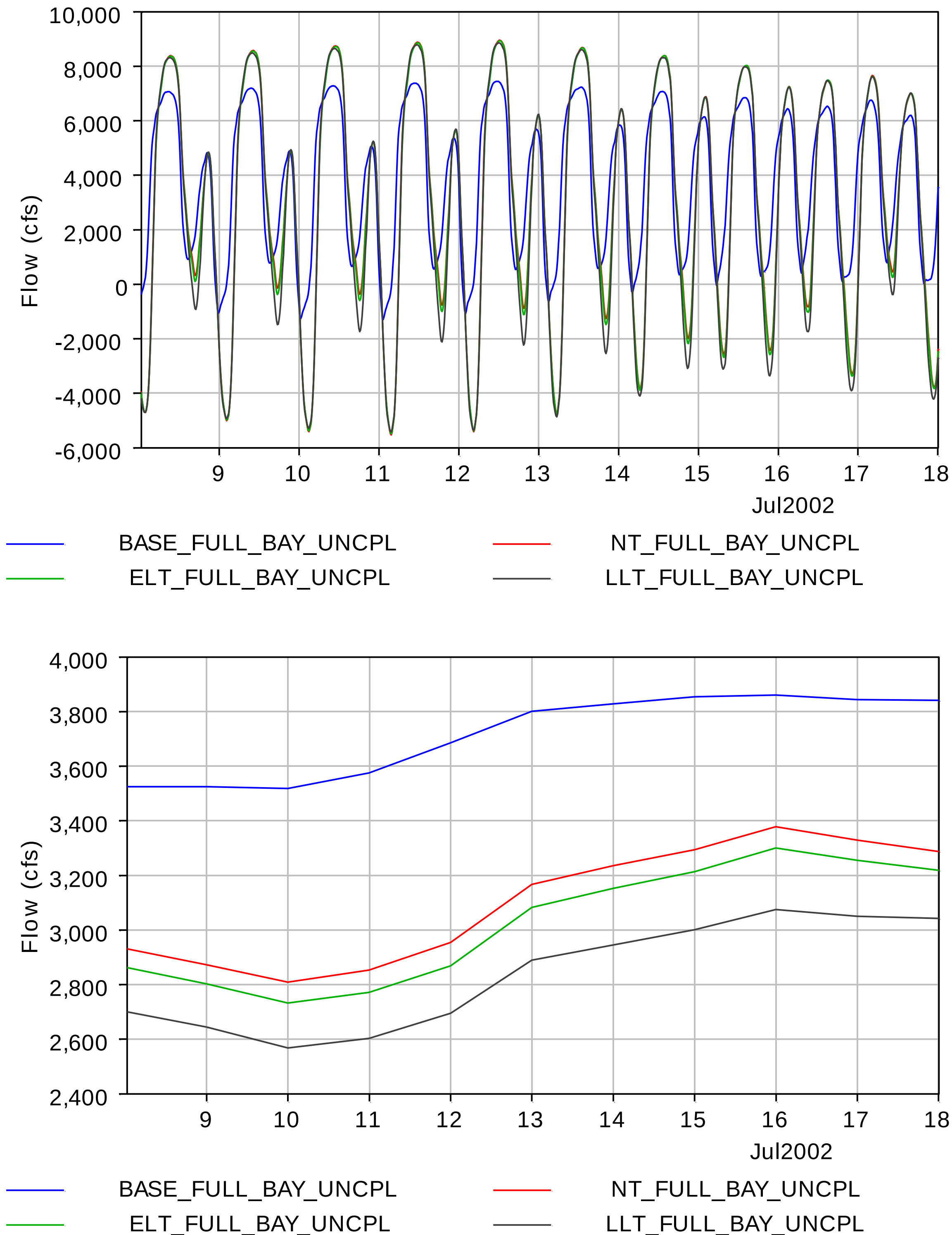


Figure 5-28 Dynamic (top) and tidally averaged (bottom) flow at mouth of north Fork Mokelumne River for Base, NT, ELT and LLT scenarios.

5.2 Tidal Flows and Net Flows

Net flows and tidal flows have been computed at several locations for the Base, NT, ELT and LLT scenarios for the period of July 1 through September 20, 2002.

Bar charts of 3-month average flows for each scenario are plotted spatially in Figure 5-29. This plot illustrates how the flow distribution changes with the restoration scenarios. Three-month average flow results for the plotted locations, in addition to several other locations throughout the Delta, are summarized in Table 5-1.

Bar charts of percent change from Base tidal flow, averaged over a 3-month period, are plotted spatially for the three restoration scenarios in Figure 5-30 and Figure 5-31. Tidal flow is computed by subtracting the mean flow $\langle Q \rangle$ from the instantaneous flow Q, giving Q′

$$Q' = Q - \langle Q \rangle$$

The tidally averaged absolute value is then computed,

$$\langle |Q'| \rangle$$

and the 3-month average is taken. For this result, the percent change from Base for each restoration scenario is listed in Table 5-2 and plotted in Figure 5-30 and Figure 5-31.

The tidal volumes, plotted in Figure 5-32 and Figure 5-33, are computed by multiplying the tidally averaged absolute value of tidal flow, Q', by the tidal cycle of 24.75 hours and dividing by four ebb/flood cycles per day.

$$V = (\langle |Q'| \rangle \text{ x } 24.75 \text{ hr x } 3600 \text{ sec/hr})/(4 \text{ ebb/flood cycles x } 43560 \text{ ft}^2\text{/ac})$$

Where Q is in cfs and V is tidal volume in Ac-ft.

Averaged flows at RSAC128, through the Delta Cross Channel and through Georgiana Slough decrease with added restoration area (Figure 5-29). Conversely, the averaged flows in the Sacramento River at Emmaton and Rio Vista increase with additional restoration area. This change appears to be from a combination of decreased tidal range on the Sacramento River near Georgiana Slough and the Delta Cross Channel and the connection of Miner Slough to the Sacramento Ship Channel through the restoration of Prospect Island.

Tidal flow results are varied (Figure 5-30 and Figure 5-31). Changes at Martinez are minimal (1-2%). Restoration in Suisun Marsh results in significant changes in tidal flow in Montezuma Slough (60-110%), particularly at the mouth. Tidal flow at the head of Montezuma Slough is increased by around 60% for all restoration cases, however with added restoration area between the NT and ELT, there is a slightly smaller increase in tidal flow because all of the added restoration is at the far eastern edge of the marsh. At Chipps Island, percent changes in tidal flow are small, ranging from -4% for the NT to -6% for the LLT. These reductions are the result of Suisun Marsh restoration. Emmaton sees the influence of reduced tidal flow from the downstream restoration in Suisun Marsh and increased tidal flow from the upstream restoration in Cache Slough. The result is a reduction of 1% for the NT, no change for the ELT and an increase of 3% for the LLT. With each time step, the area of restoration in Cache becomes proportionally larger than the Suisun restoration. This influences the shift from a slightly negative change in tidal flow for the NT to a slightly positive change for the LLT. Rio Vista is under similar influence, but more impacted by the Cache restoration. There is no change in tidal flow for the NT scenario, but tidal flow increases as more restoration area is added. There is a 2% increase for the ELT and a 12% increase for the LLT. The deeper areas added in the southern part of Cache Slough for the LLT scenario, as well as the flow-through breaches on Little Egbert, have a more pronounced impact on tidal flows than the areas of the NT and ELT scenarios. At Jersey Point, tidal flow decreases by 6% for NT and ELT and by 11% for the LLT. These decreases indicate that tidal flows at this location are impacted by downstream restoration in Suisun Marsh. In Middle River, NT, ELT and LLT tidal flows decrease by 8%, 10% and 17%, respectively. Tidal flow in Middle River is reduced by the downstream restoration for all restoration scenarios, but is further reduced by the South Delta restoration in the LLT scenario because flow out of the Union Island breach is out of phase with flow in the Middle River channel. This large, shallow restoration area fills and drains very slowly, so that when Middle River flows begin ebbing, Union Island is still filling. This is illustrated in Figure 5-103, which shows ELT and LLT ebb tide flows in Middle River (during a period when the Middle River barrier is open for both cases) while Union Island is still filling, resulting in reversed Middle River flows near the breach. Tidal flow results for the plotted locations, in addition to several other locations throughout the Delta, are summarized in Table 5-2. Note that in Cache Slough at Ryer (listed in the table), while tidal flow is increased by 4% and 7% for the NT and ELT restoration cases, respectively, it is decreased for the LLT case. This is because of the restoration of Little Egbert Tract, which is breached downstream of Cache Slough at Ryer and provides flow-through conveyance with a second breach at the upstream end.

Table 5-1 Summary of Base, NT, ELT and LLT 3-month average flows for July 1 to September 30, 2002.

	3-month Average Flows (cfs) July 1 to September 30, 2002			
	Base	**NT**	**ELT**	**LLT**
Chipps Island	4384	4412	4474	4395
Mntz Sl at Head	135	64	-10	12
Sac R at Emmaton	5873	6187	6321	6484
Sac R at Rio Vista	8256	9091	9273	9715
Cache Sl at Ryer	1535	2095	2167	2140
Georgiana Sl	2762	2755	2665	2407
DCC	4609	3767	3661	3447
SJR at Jersey Pt	-1002	-1540	-1695	-1915
Dutch Sl	-112	82	84	68
False R	-1696	-1946	-1837	-1807
Threemile Sl	-2310	-2829	-2732	-3015
SJR at San Andreas	-1719	-2508	-2750	-3218
Old R at Bacon Is	-4400	-4415	-4421	-4559
Middle R	-5403	-5389	-5384	-5233

Table 5-2 Summary of NT, ELT and LLT percent change from Base tidal flows for July 1 to September 30, 2002.

	Tidal Flow, % Change from Base, Average Jul 1 to Sep 30, 2002		
	NT	**ELT**	**LLT**
Martinez	2	1	2
Mntz Sl at Mouth	90	99	110
Mntz Sl at Head	65	61	64
Chipps Is	-4	-4	-6
Sac R at Emmaton	-1	0	3
Sac R at Rio Vista	0	2	12
Cache Sl at Ryer	4	7	-6
SJR at Jersey Pt	-6	-6	-11
False R	-5	-7	-13
SJR at San Andreas	-6	-8	-15
Mokelumne R nr SJR	1	0	0
Old R at Bacon Is	-7	-9	-20
Middle R	-8	-10	-17
SJR at RRI	-8	-9	9

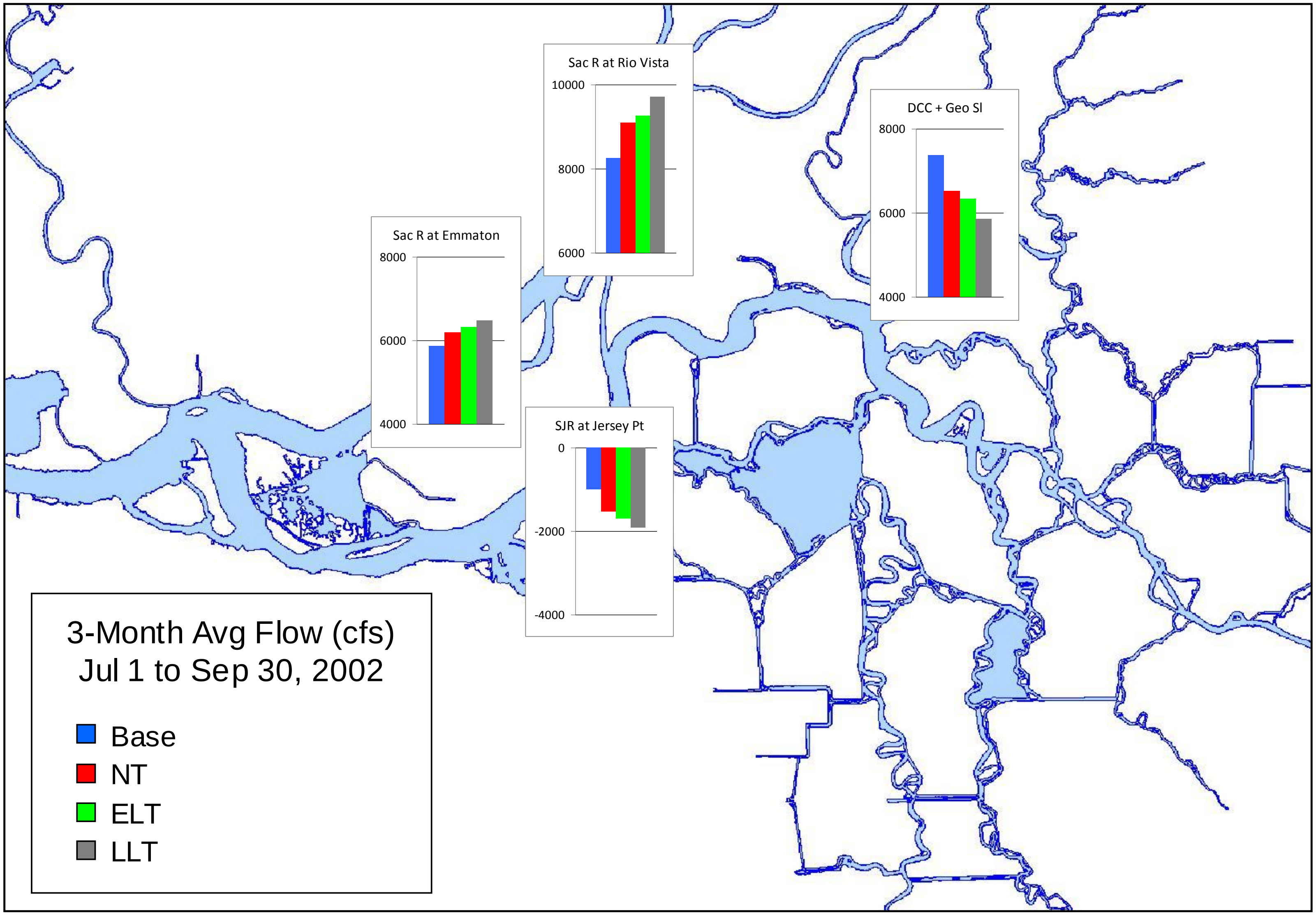


Figure 5-29 Three-month average flows for the July 1 through September 30, 2002 period for the Base case, NT, ELT and LLT scenarios.

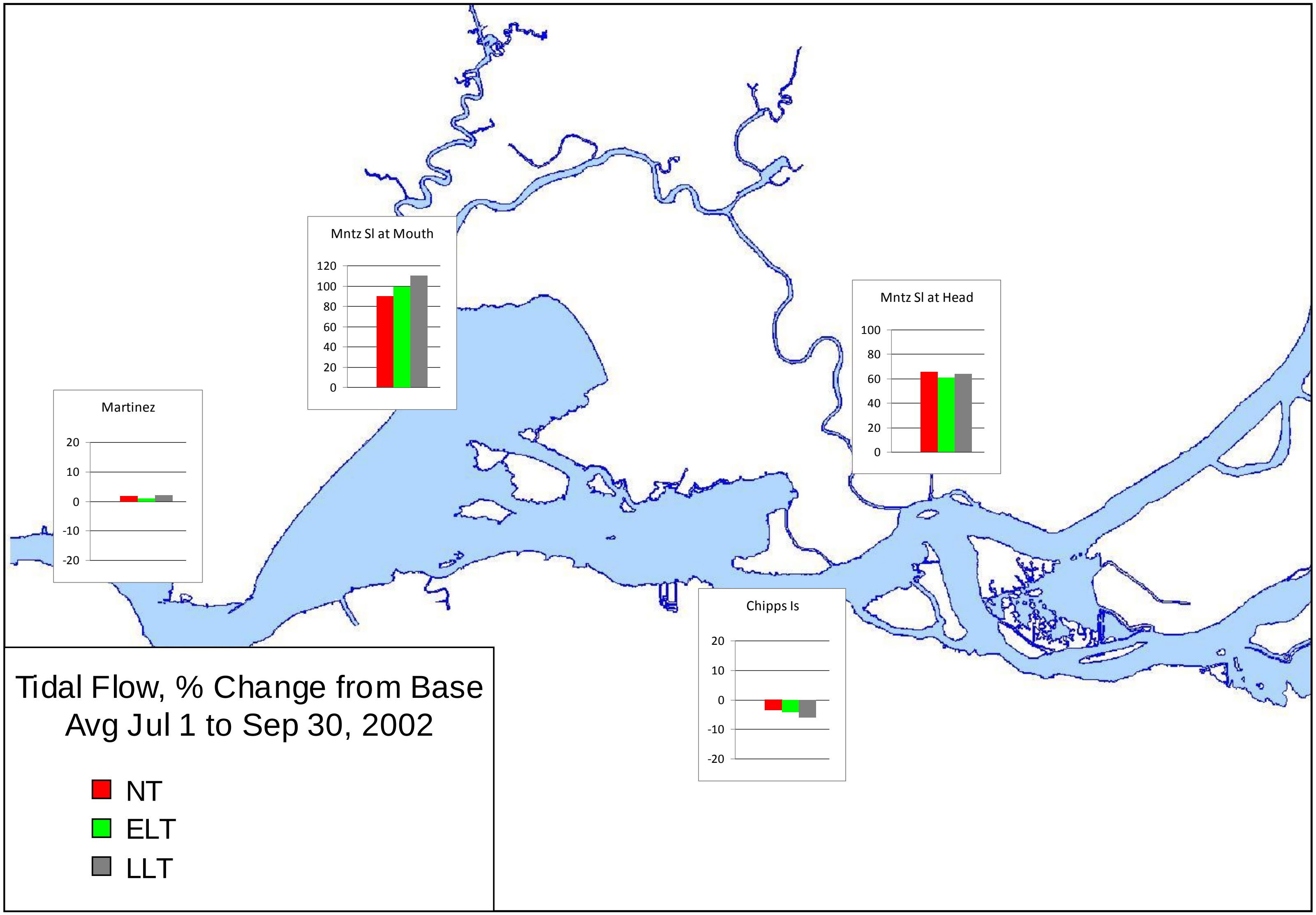


Figure 5-30 Tidal flow, percent change from Base for the July 1 through September 30, 2002 period for the Base case, NT, ELT and LLT scenarios.

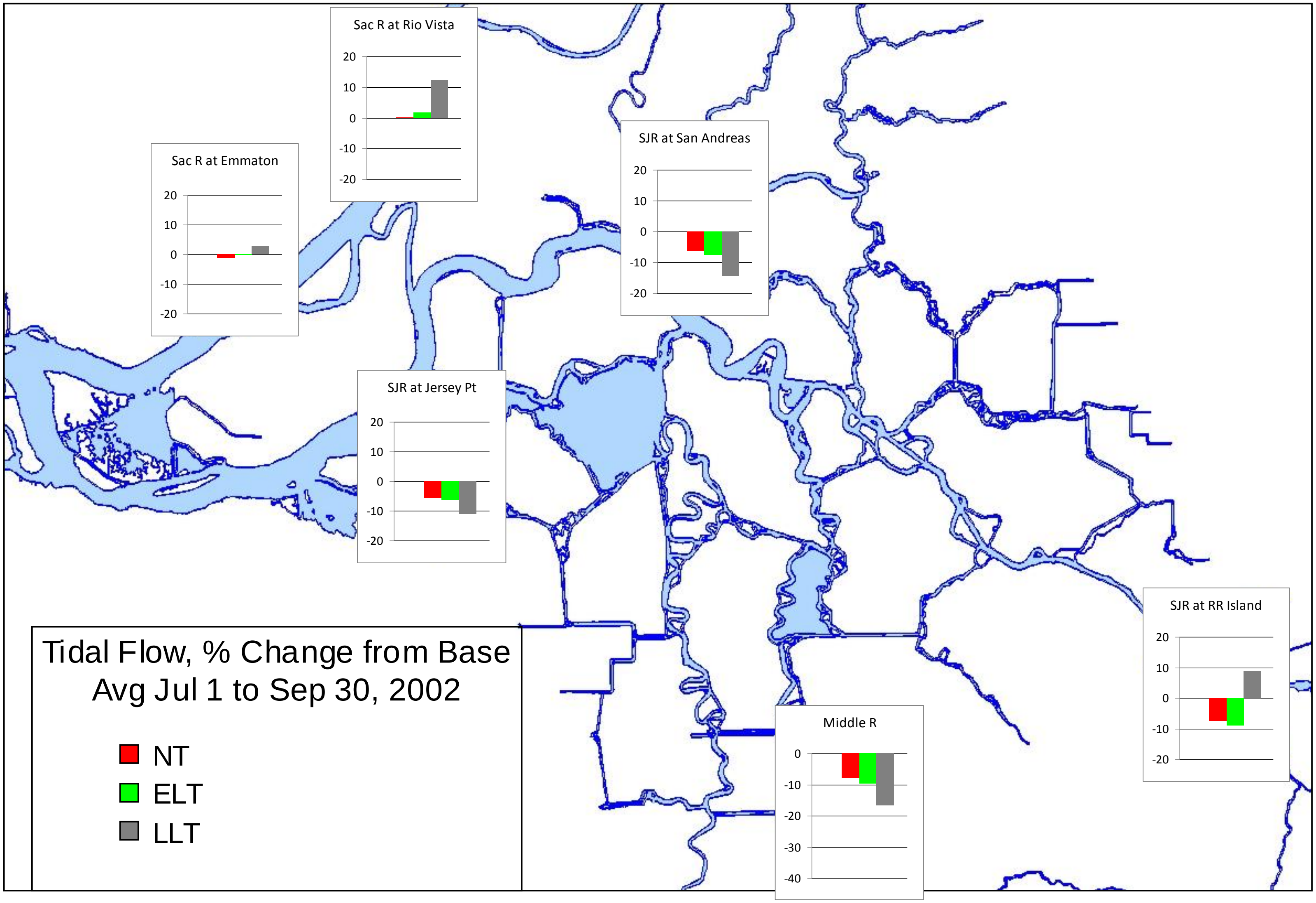


Figure 5-31 Tidal flow, percent change from Base for the July 1 through September 30, 2002 period for the Base case, NT, ELT and LLT scenarios.

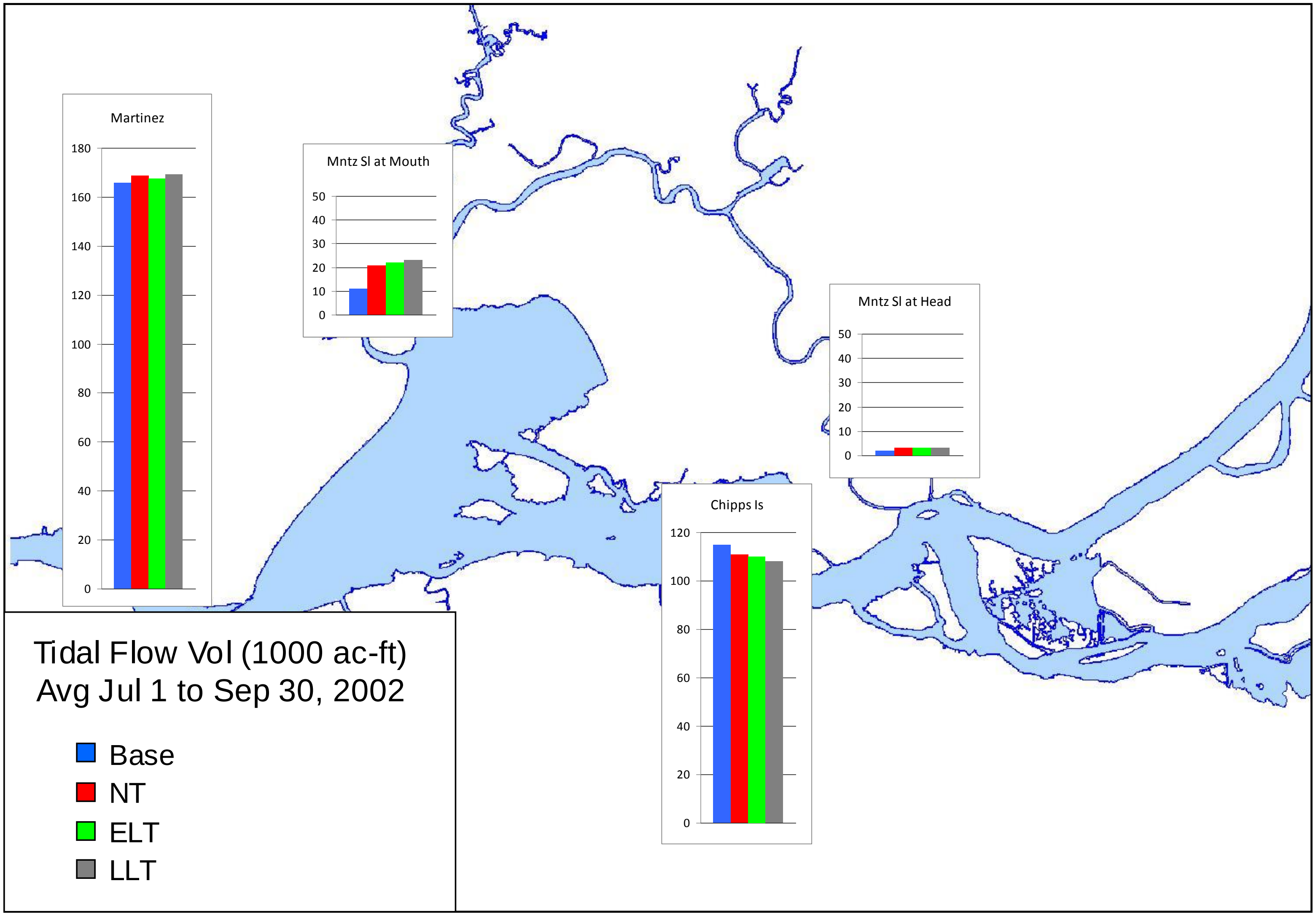


Figure 5-32 Average tidal flow volumes in the Suisun Bay region for the July 1 through September 30, 2002 period for the Base case, NT, ELT and LLT scenarios.

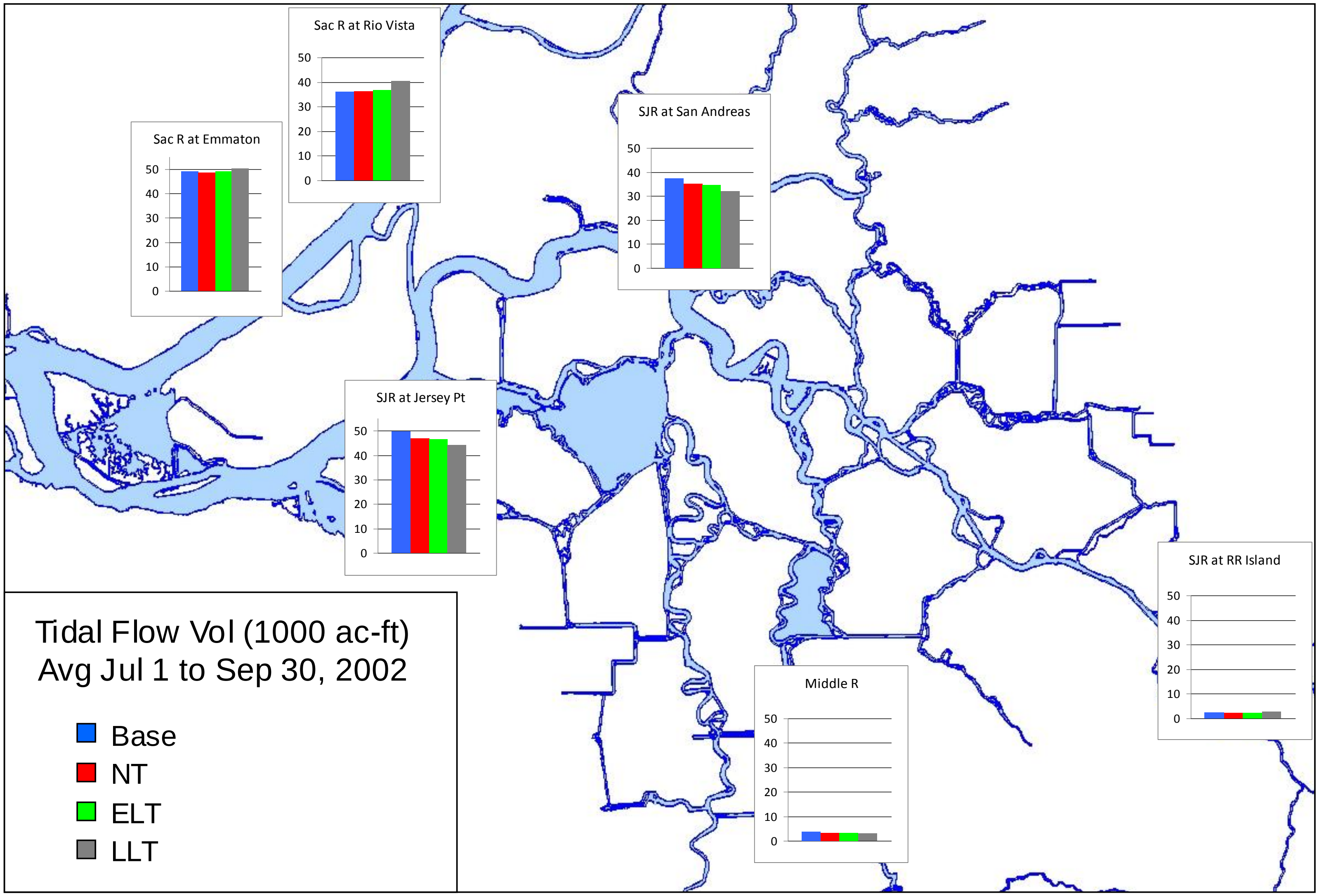


Figure 5-33 Average tidal flow volumes in the Delta for the July 1 through September 30, 2002 period for the Base case, NT, ELT and LLT scenarios.

5.3 Time series of stage at select locations

In Figure 5-34 through Figure 5-49, time series plots of stage are provided for ten days during July 2002 at selected locations for the Base, NT, ELT and LLT scenarios to show the stage impact of each restoration scenario in comparison with Base.

Time series locations are shown in Figure 5-1for the Delta and Figure 5-2 for Suisun Marsh.

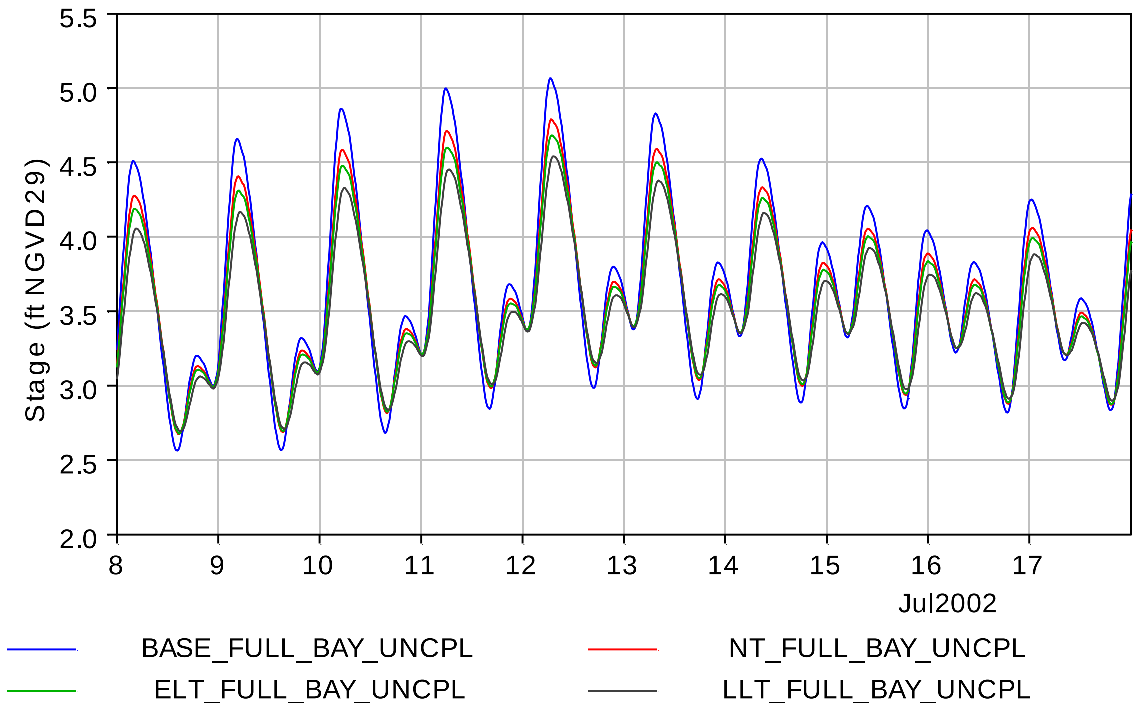


Figure 5-34 Stage at Freeport for Base case, NT, ELT and LLT scenarios.

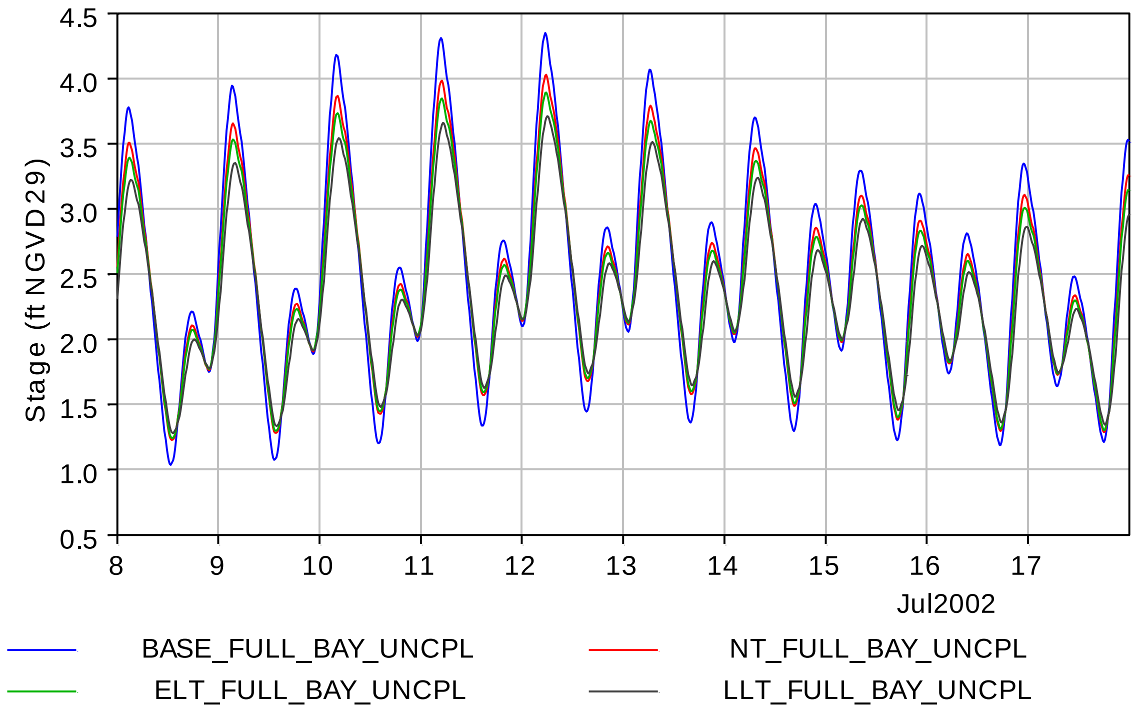


Figure 5-35 Stage in Sutter Slough near Sacramento R. for Base, NT, ELT and LLT scenarios.

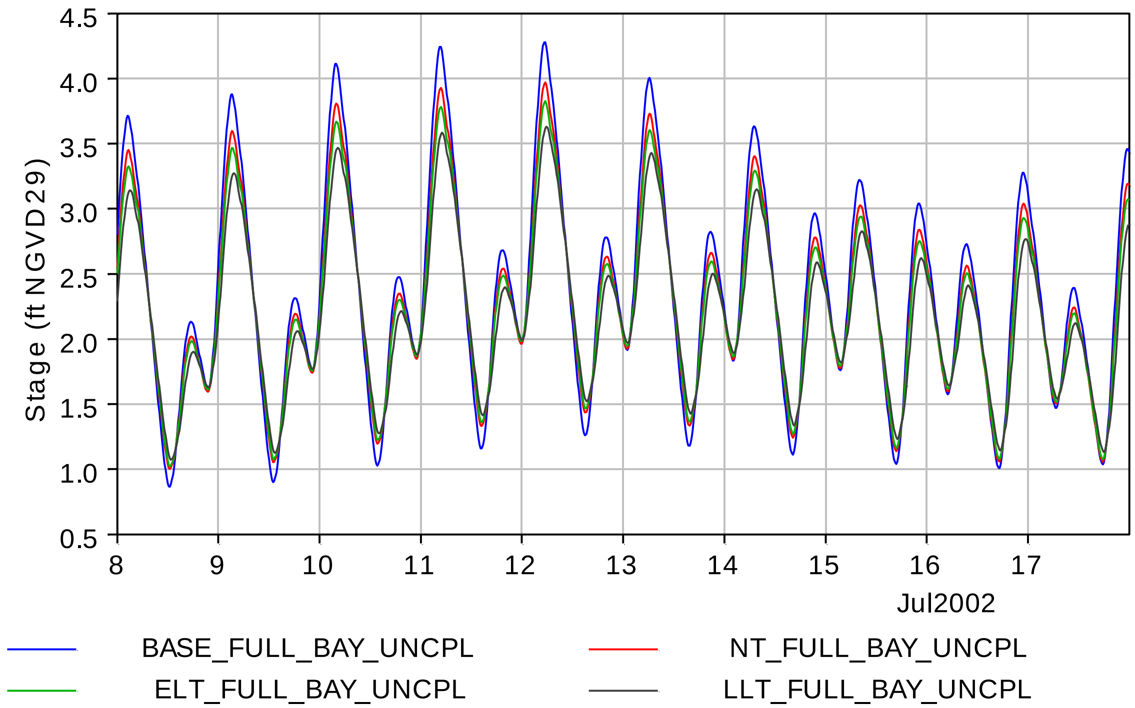


Figure 5-36 Stage in Sutter Slough near Miner Slough for Base, NT, ELT and LLT scenarios.

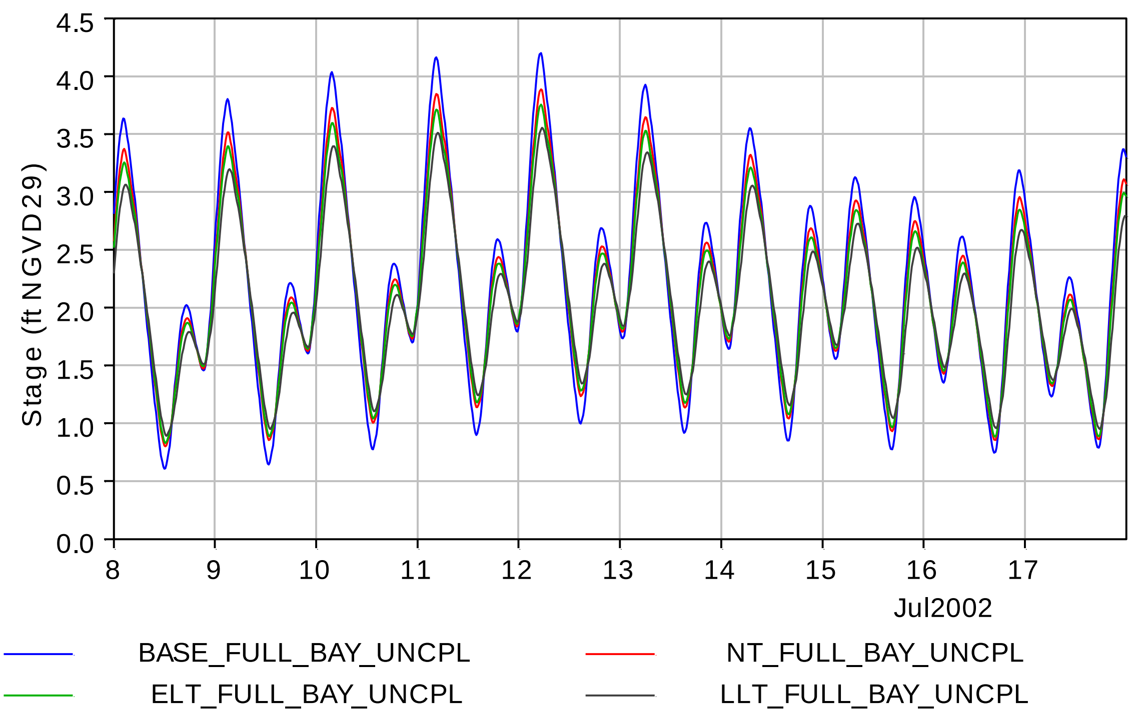


Figure 5-37 Stage in Steamboat Slough for Base, NT, ELT and LLT scenarios.

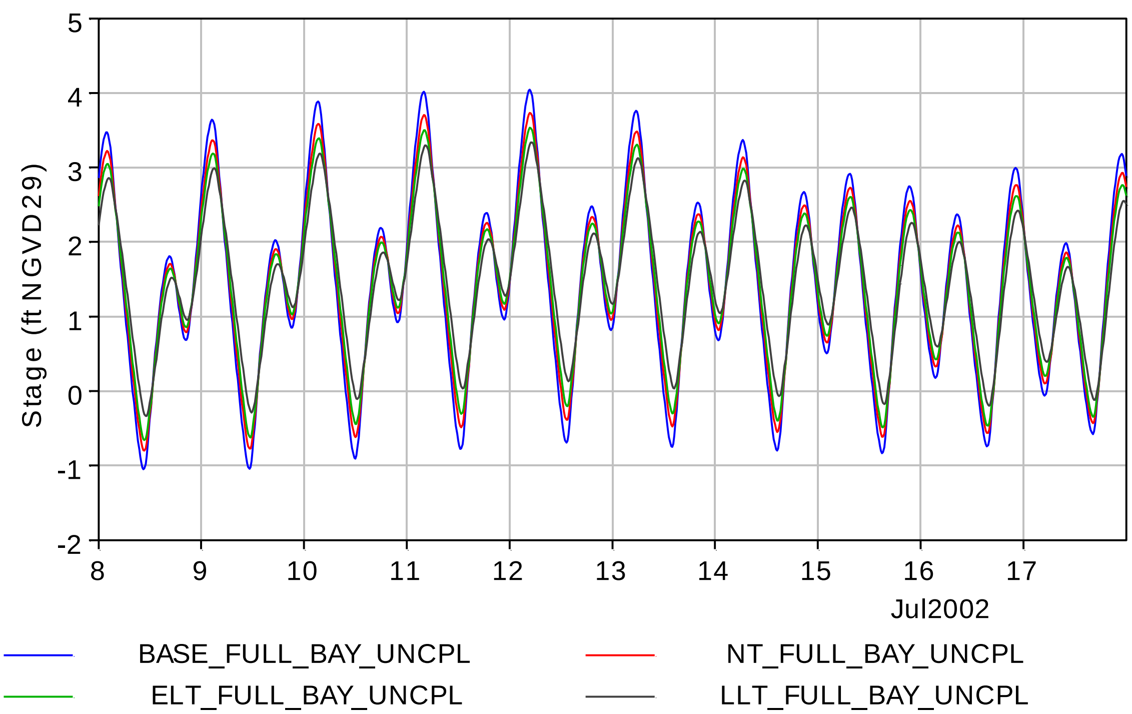


Figure 5-38 Stage in Cache Slough at Ryer Island for Base, NT, ELT and LLT scenarios.

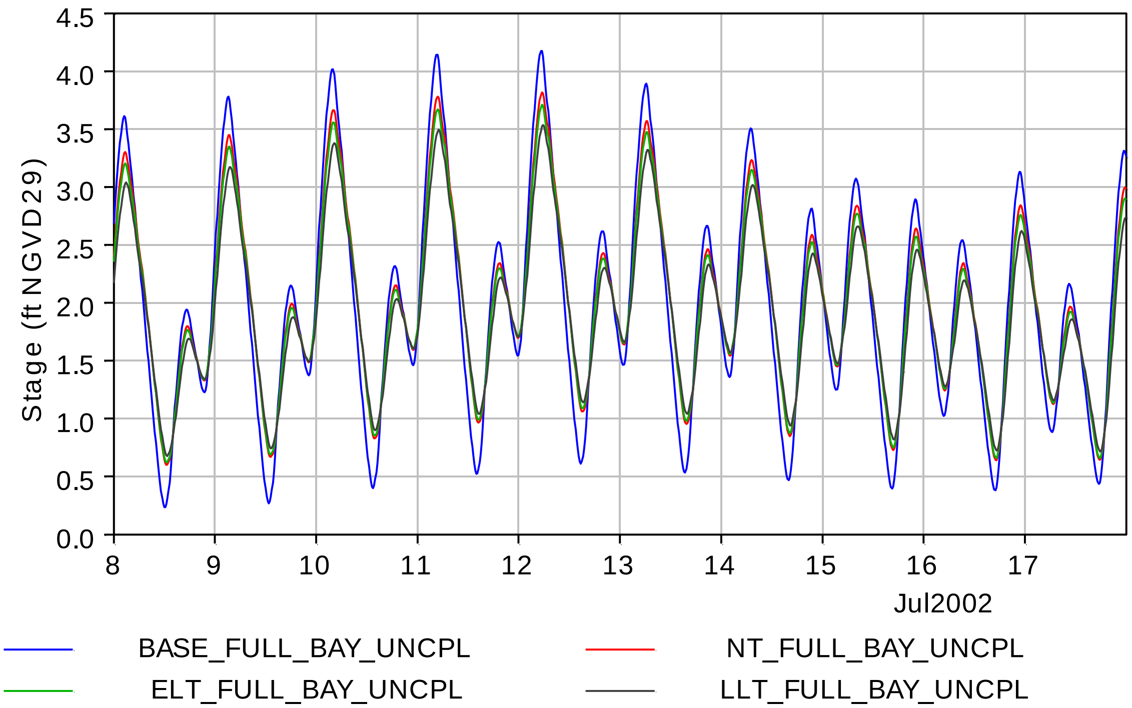


Figure 5-39 Stage at RSAC128 for Base, NT, ELT and LLT scenarios.

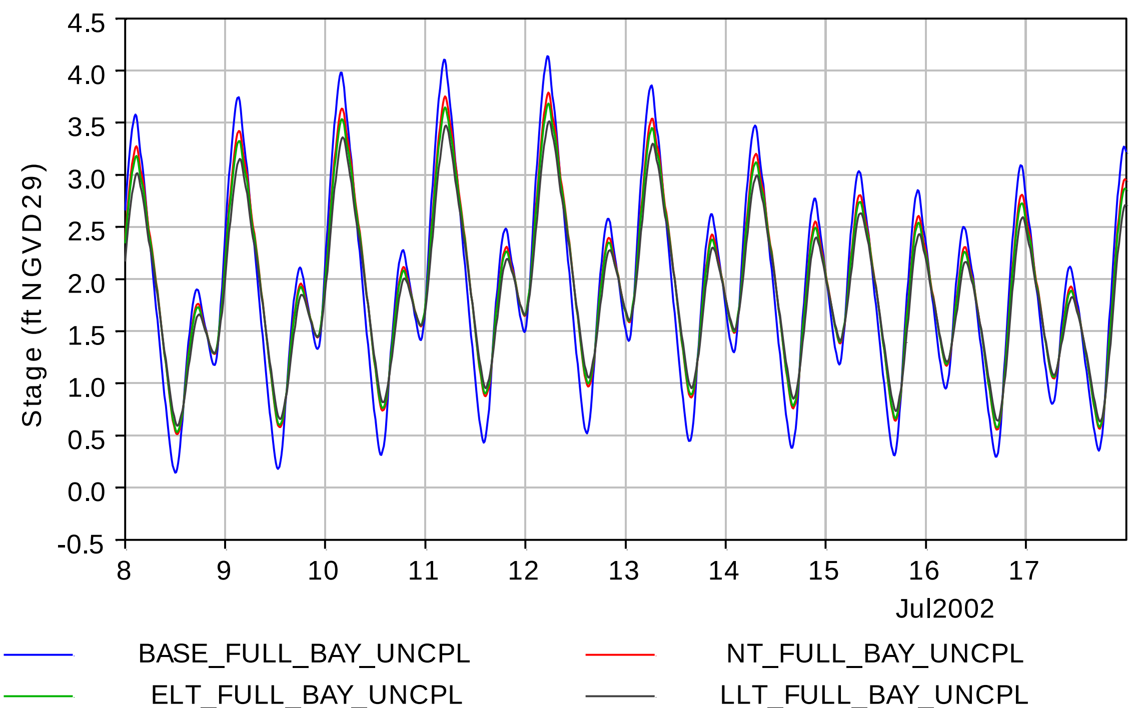


Figure 5-40 Stage in Georgiana Slough at head for Base, NT, ELT and LLT scenarios.

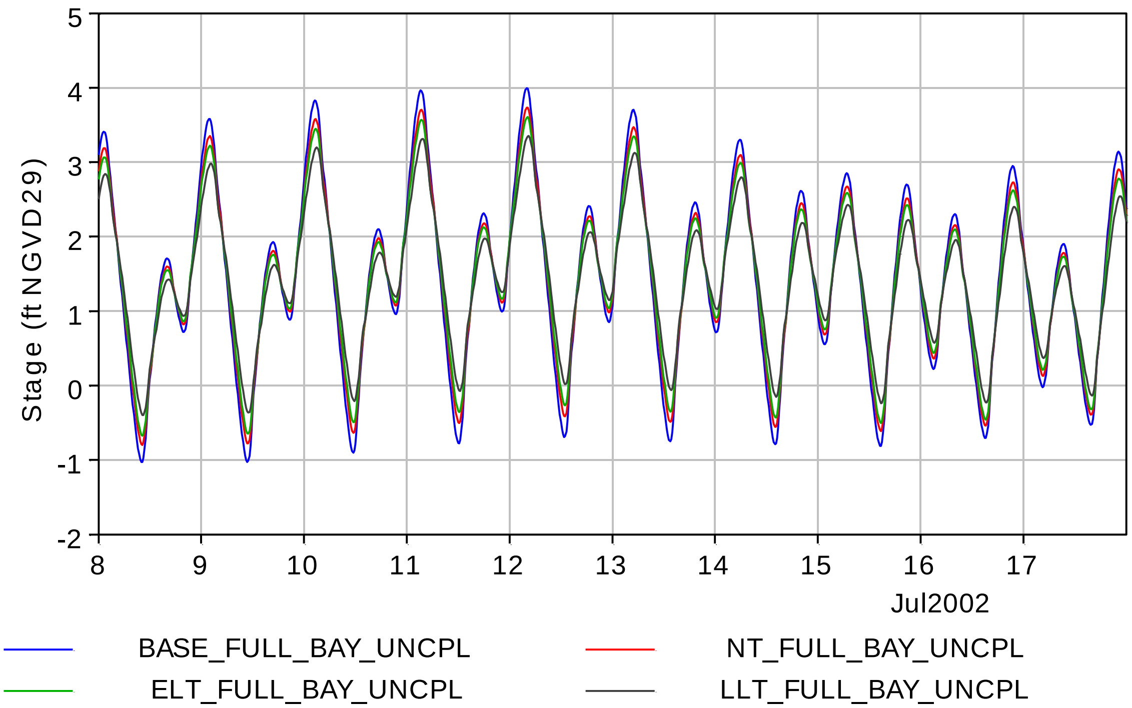


Figure 5-41 Stage at Rio Vista for Base case, NT, ELT and LLT scenarios.

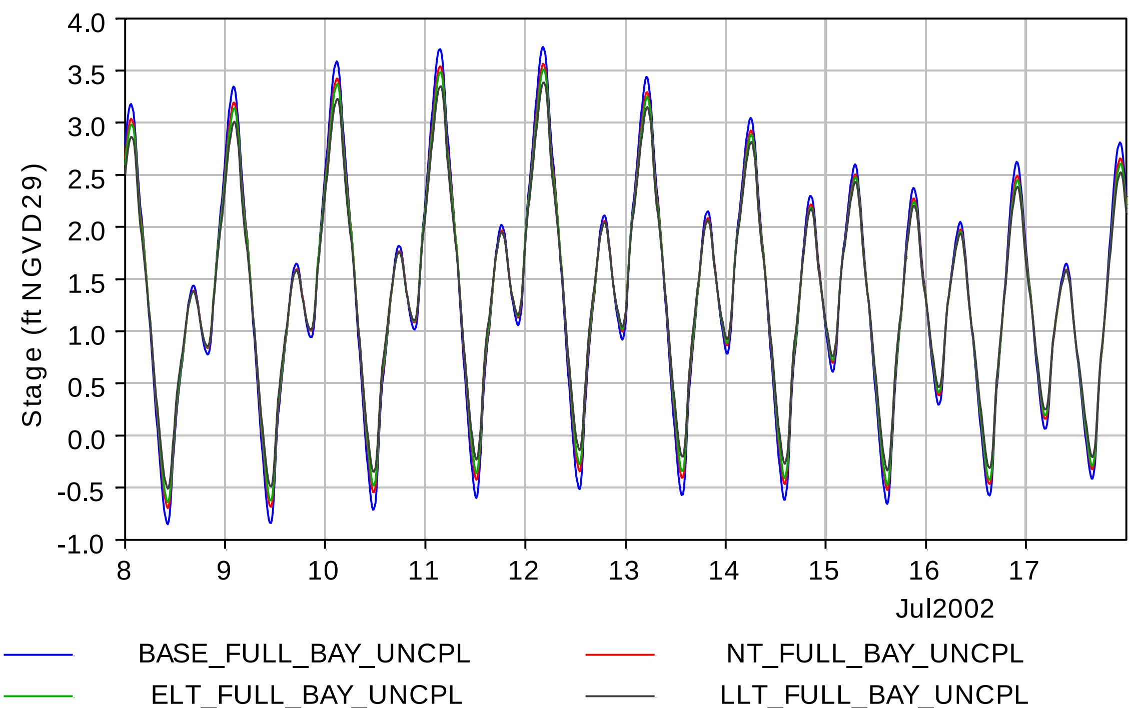


Figure 5-42 Stage in Threemile Slough for Base, NT, ELT and LLT scenarios.

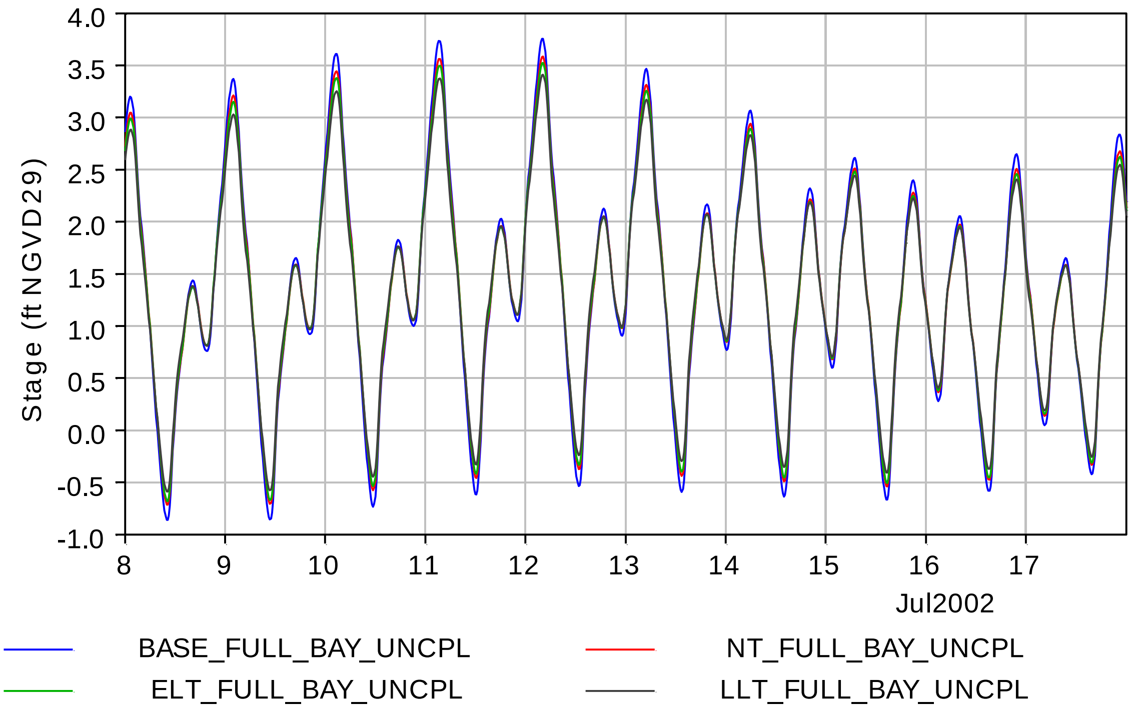


Figure 5-43 Stage at Jersey Point for Base, NT, ELT and LLT scenarios.

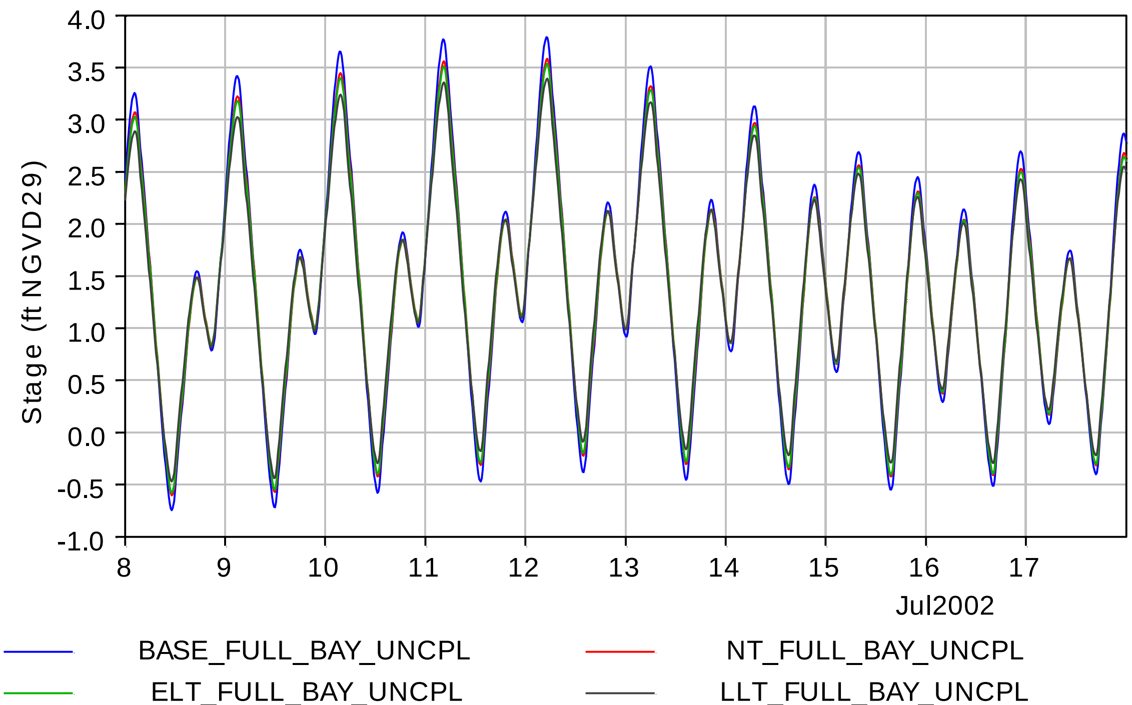


Figure 5-44 Stage in Mokelumne R. near SJR for Base, NT, ELT and LLT scenarios.

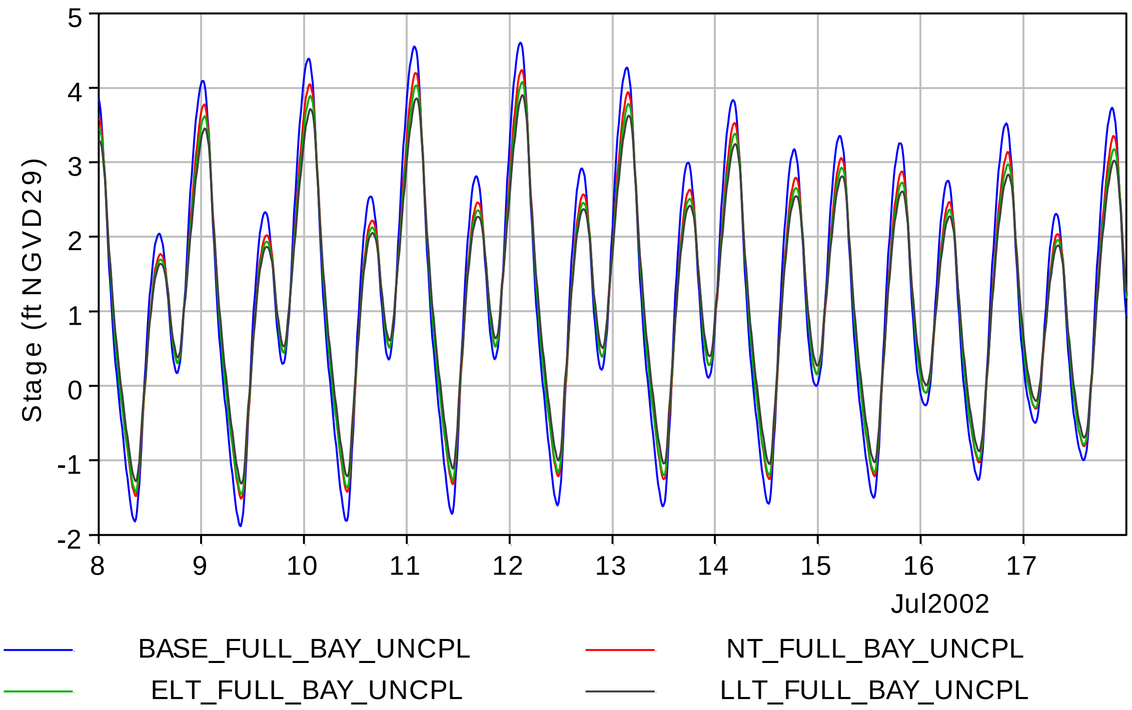


Figure 5-45 Stage in Hunter Cut for Base, NT, ELT and LLT scenarios.

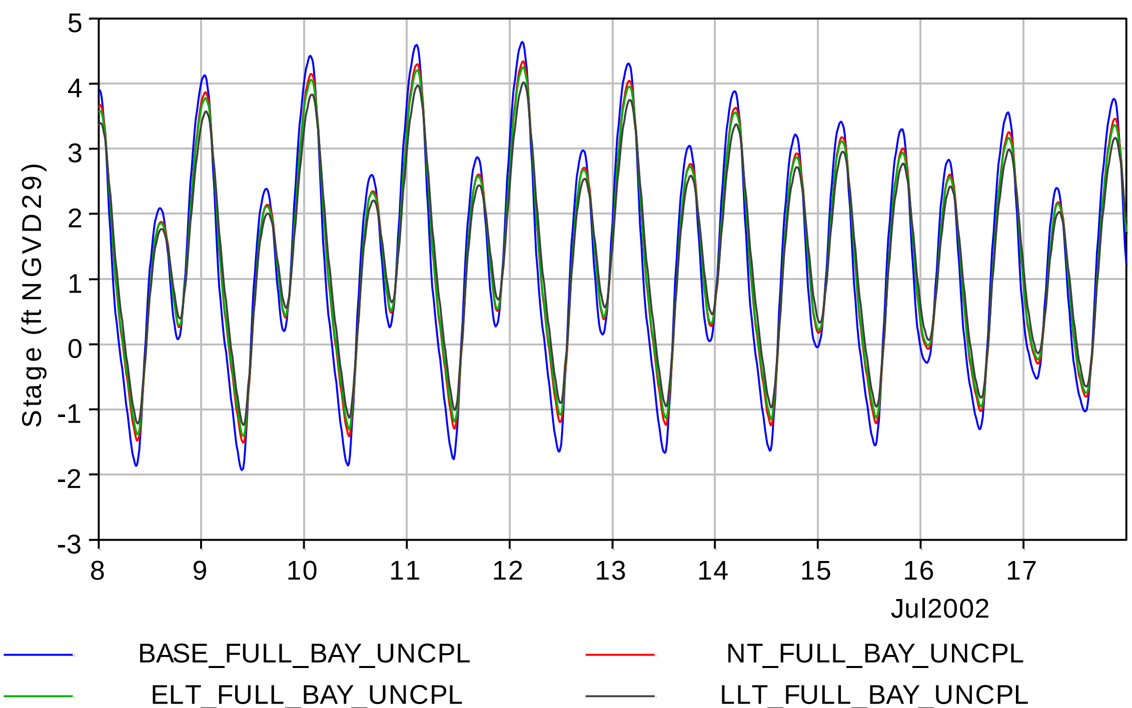


Figure 5-46 Stage in Montezuma Slough at Beldon's Landing (S-49) for Base, NT, ELT and LLT scenarios.

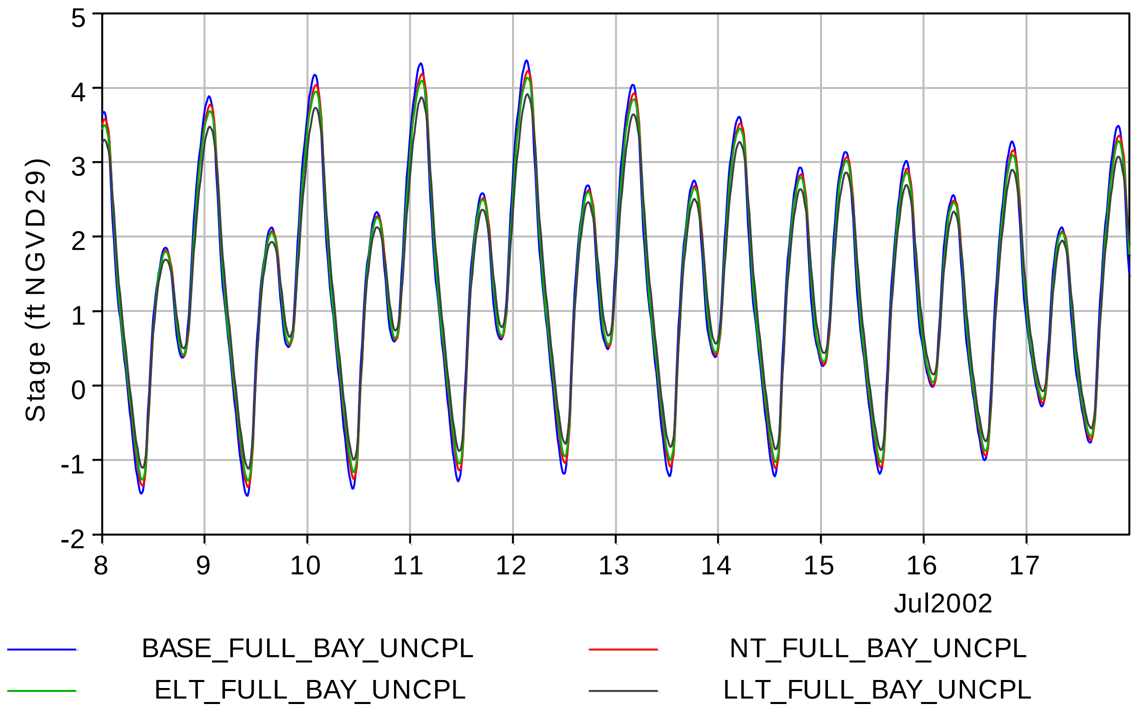


Figure 5-47 Stage in Montezuma Slough at Roaring River (S-71) for Base, NT, ELT and LLT scenarios.

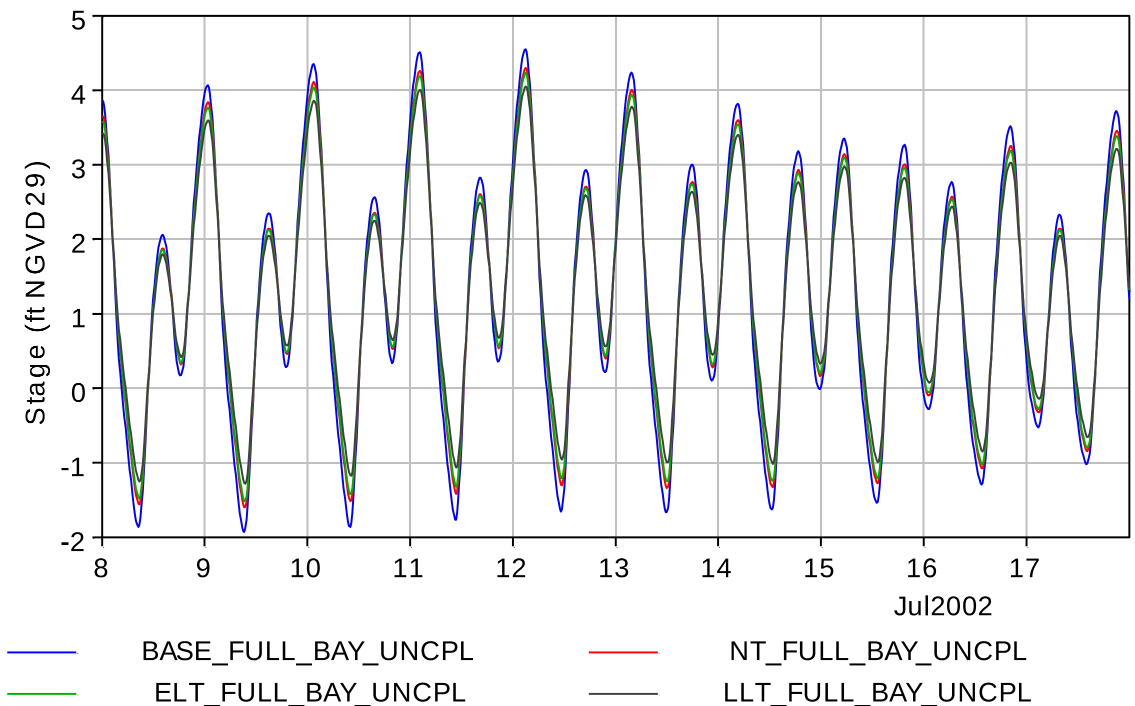


Figure 5-48 Stage at S-35 near Morrow Island for Base, NT, ELT and LLT scenarios.

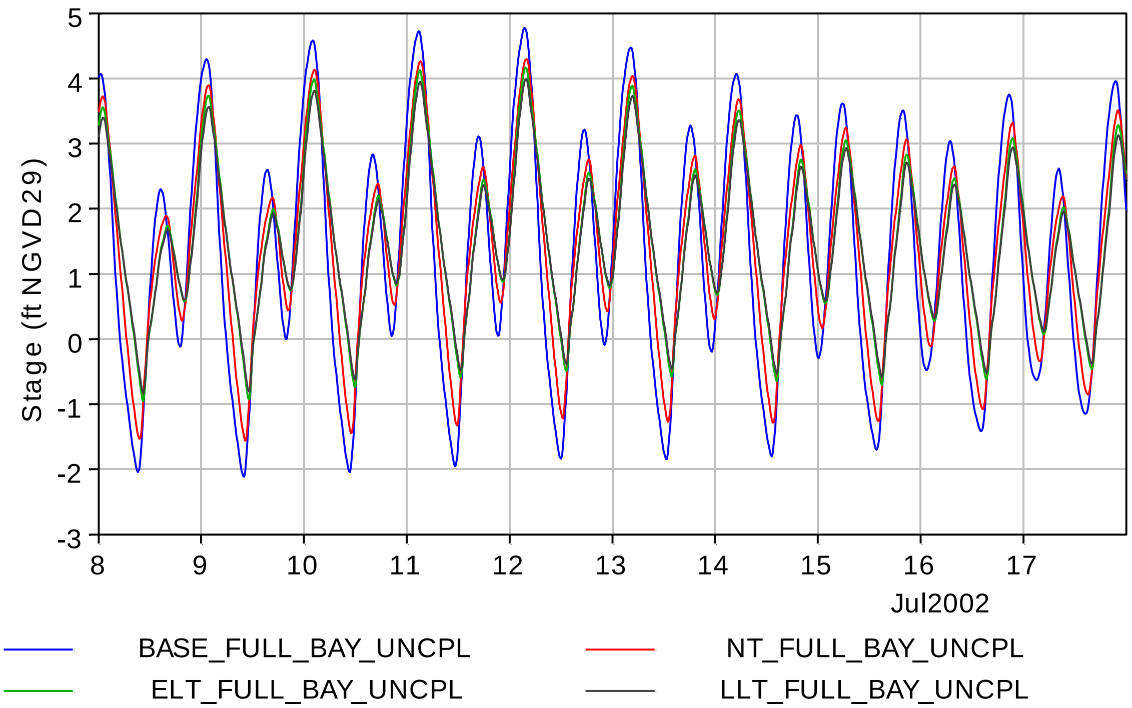


Figure 5-49 Stage in Boynton Slough at S-40 for Base, NT, ELT and LLT scenarios.

5.4 Spatial contours of MHHW, MLLW and tidal range

Spatial plots MHHW in July 2002 for the Base case and NT scenario are provided in Figure 5-50. Plots for ELT and LLT are shown in Figure 5-51. Similar plots of MLLW are provided in Figure 5-52 and Figure 5-53.

Spatial plots of tidal range (MHHW-MLLW) in July 2002 for the Base case and NT scenario are provided in Figure 5-54. Plots for ELT and LLT are shown in Figure 5-55.

Spatial plots of tidal range (Figure 5-54 and Figure 5-55) give a broad view of the impacts of restoration on tidal range. The diminishment of tidal range with each time step can be clearly seen throughout the Delta and Suisun Marsh. In addition, areas of steep gradients in tidal range indicate restricted conveyance either due to restrictive channels or shallow restoration areas.

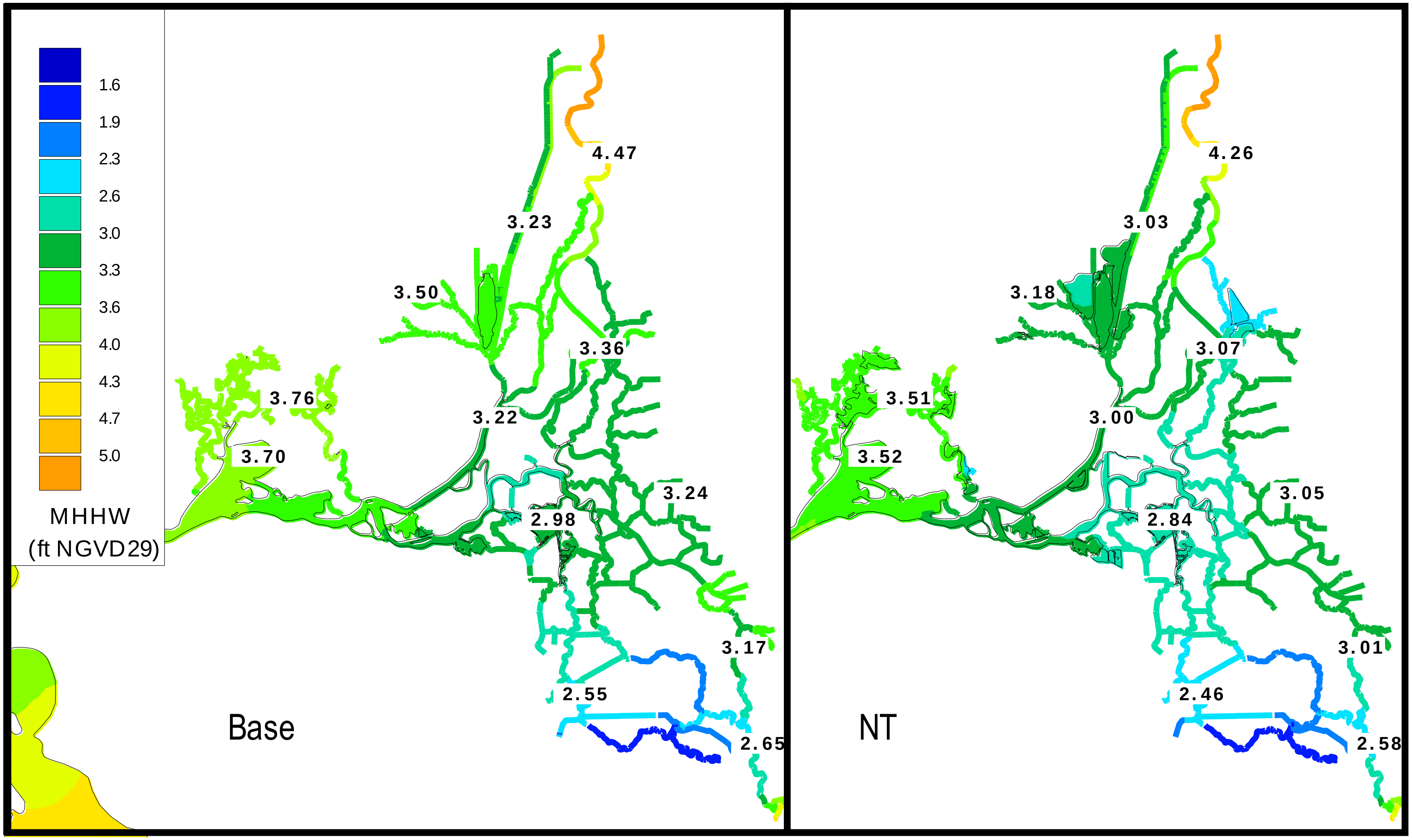


Figure 5-50 Spatial plots of MHHW for Base and NT scenarios during July 2002.

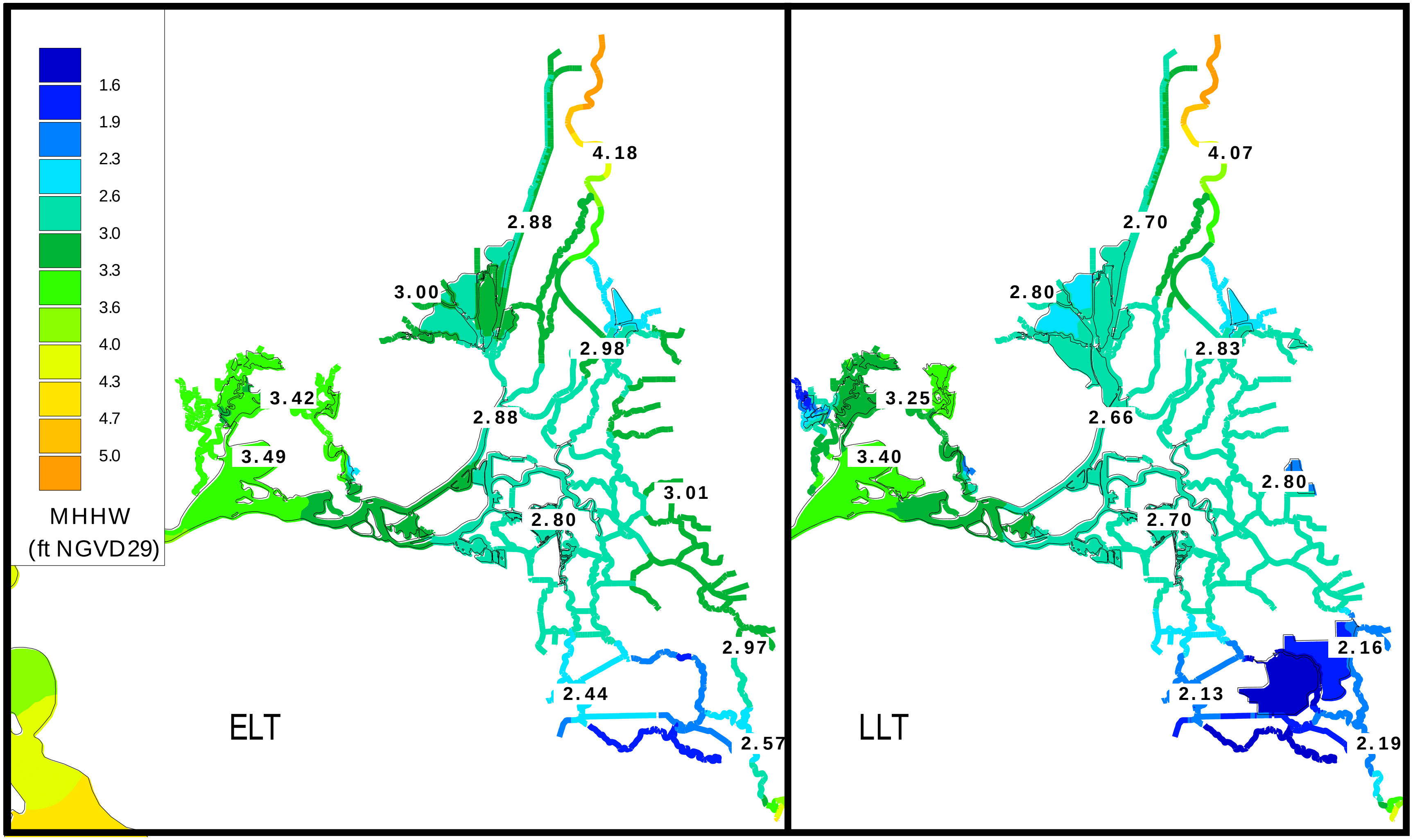


Figure 5-51 Spatial plots of MHHW for ELT and LLT scenarios during July 2002.

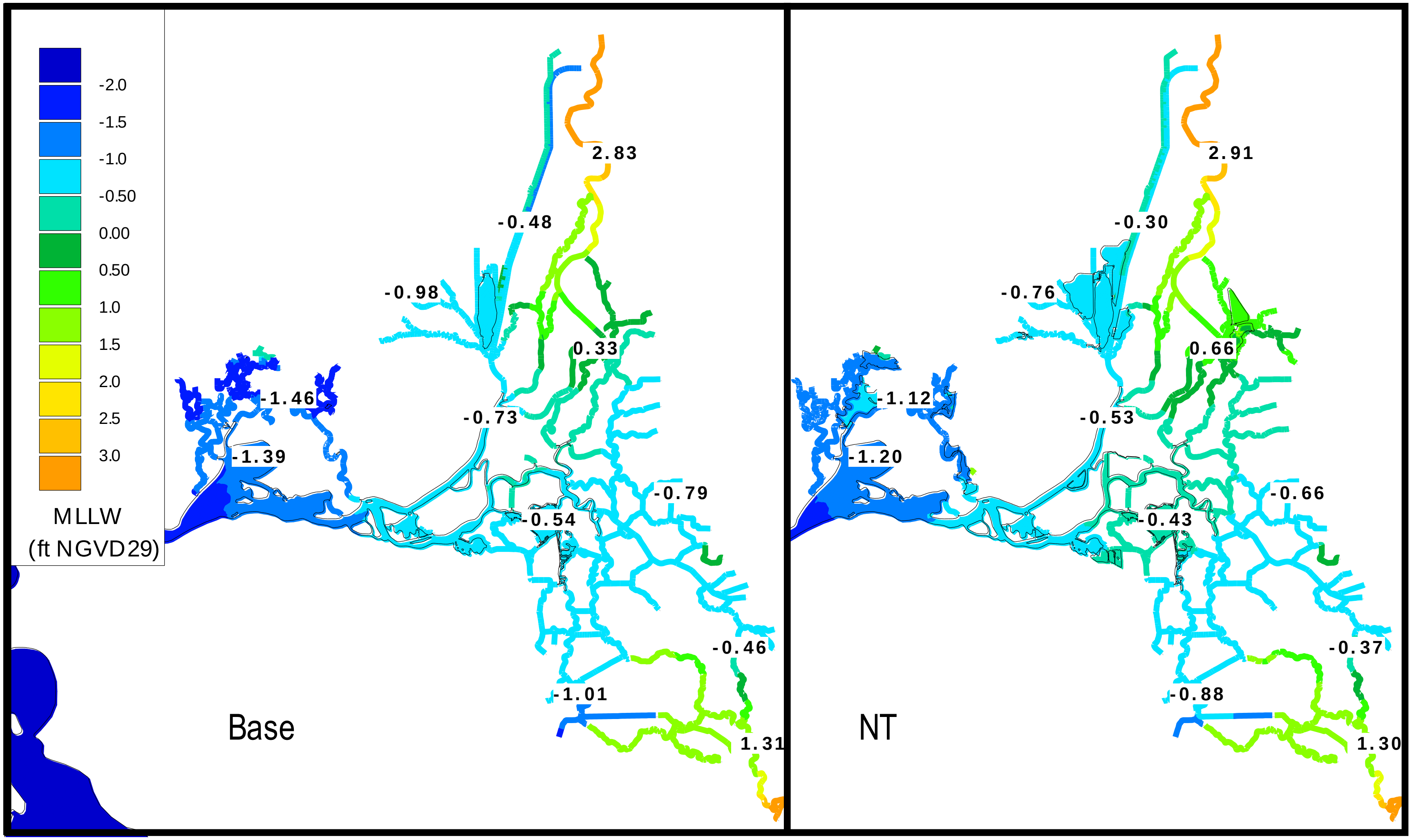


Figure 5-52 Spatial plots of MLLW for Base and NT scenarios during July 2002.

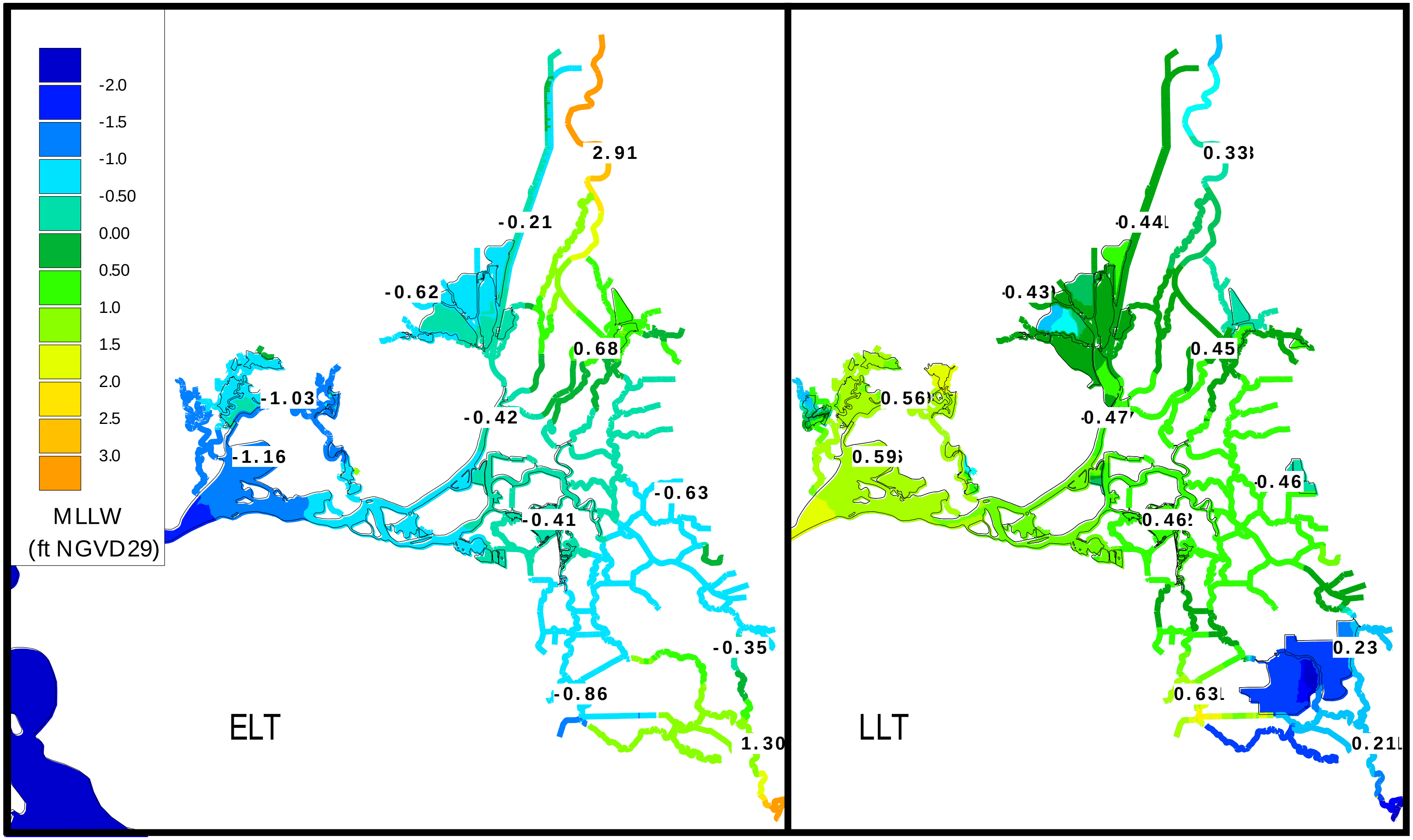


Figure 5-53 Spatial plots of MLLW for ELT and LLT scenarios during July 2002.

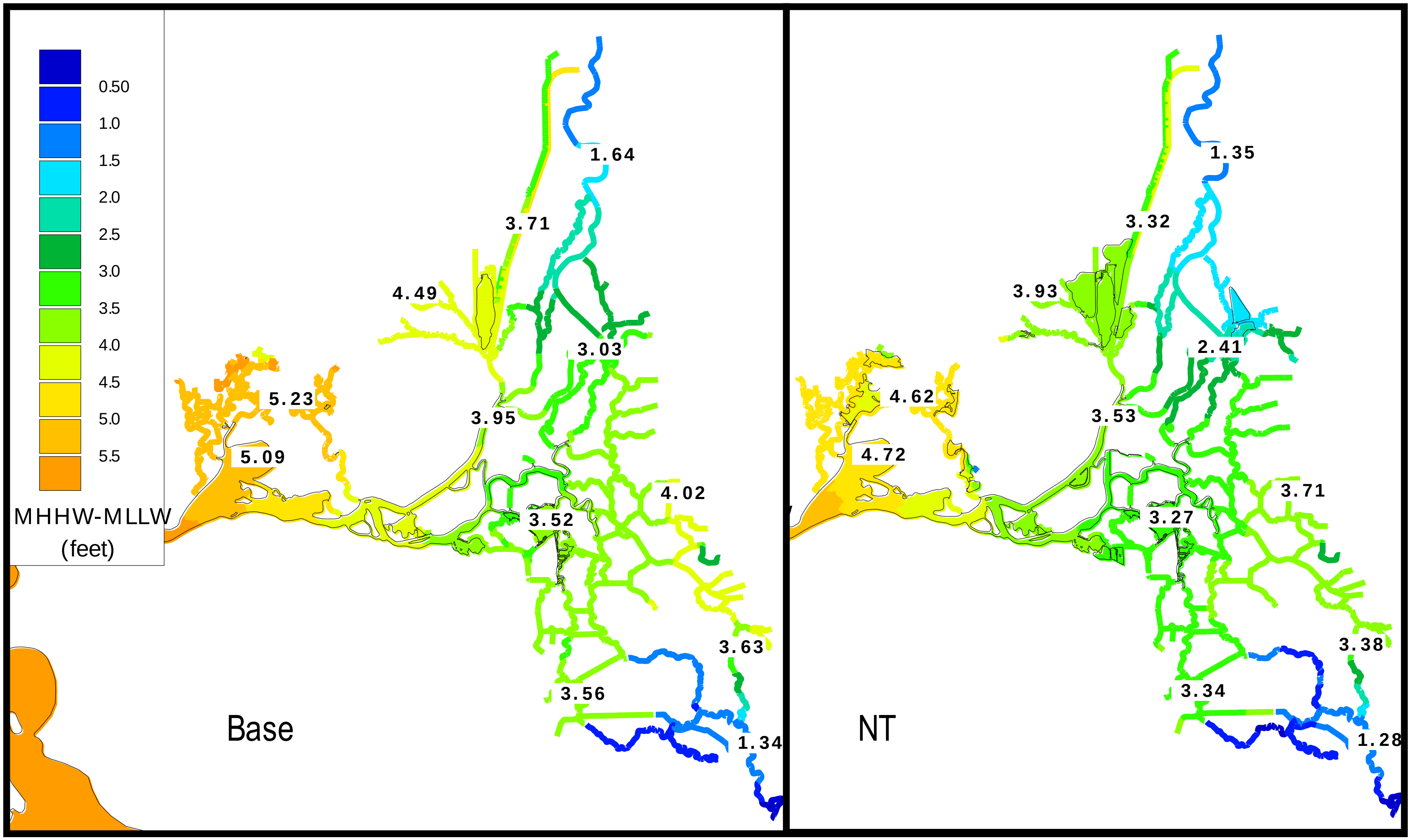


Figure 5-54 Spatial plots of tidal range (MHHW-MLLW) for Base and NT scenarios during July 2002.

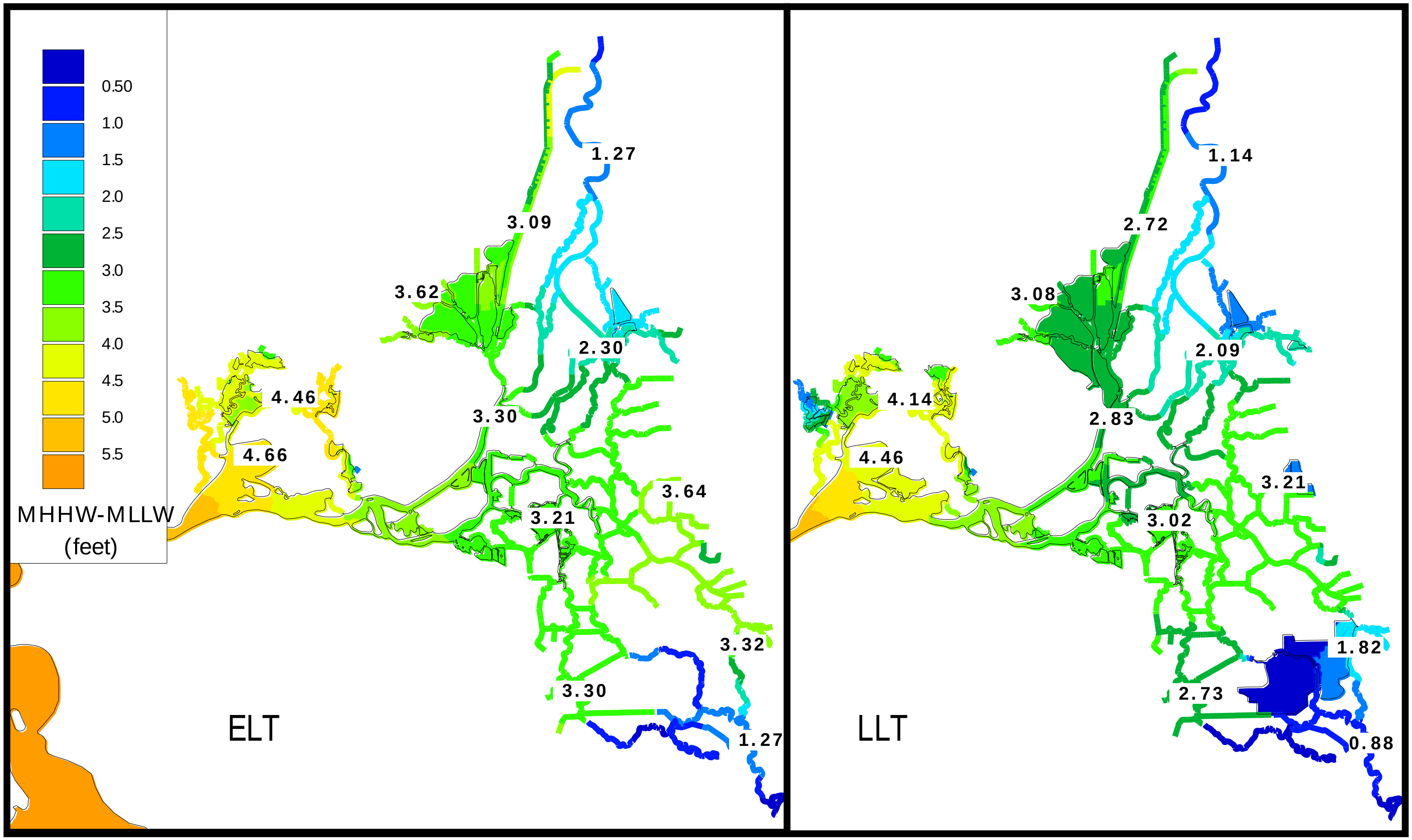


Figure 5-55 Spatial plots of tidal range (MHHW-MLLW) for ELT and LLT scenarios during July 2002.

5.5 Tidal Datum and Tidal Range Profiles

Profiles of July 2002 tidal datums (MHHW, MSL and MLLW) and tidal range for Base, NT, ELT and LLT scenarios are provided for the following.

- Sacramento River from Martinez to the upstream boundary (Figure 5-56 and Figure 5-57).
- San Joaquin River from Martinez to the upstream boundary (Figure 5-58 and Figure 5-59).
- Martinez to the upstream San Joaquin River boundary via Middle River (Figure 5-60 and Figure 5-61).
- Montezuma Slough from mouth to head (Figure 5-62 and Figure 5-63).

Inset maps for each plot show the profile locations.

Profile plots show a pronounced decrease in MHHW and an increase in MLLW along the Sacramento (Figure 5-57Figure 5-56) and San Joaquin Rivers (Figure 5-58), Middle River (Figure 5-60) and Montezuma Slough (Figure 5-62). Note that the Middle River barrier is operating during July 2002 for the Base, NT and ELT scenarios, but is open for the LLT scenario. The impact on MSL is generally small, with reductions of 0.1 ft or less. The exceptions to this are in the south Delta. In Middle River upstream of the barrier, MSL is affected by the Middle River gate status (i.e. operating for the Base case, open for the LLT case). The reduction in MSL on San Joaquin River near the Roberts Island breach is as much as 0.16'.

Tidal range is progressively diminished as more restoration area is added. In Montezuma Slough (Figure 5-63) and the Sacramento River (Figure 5-57) near Threemile Slough, tidal range reductions are as much as 1.1' for the LLT scenario. On the San Joaquin River (Figure 5-59) near the Roberts island breach, the peak reduction in tidal range is 2.1' for the LLT scenario.

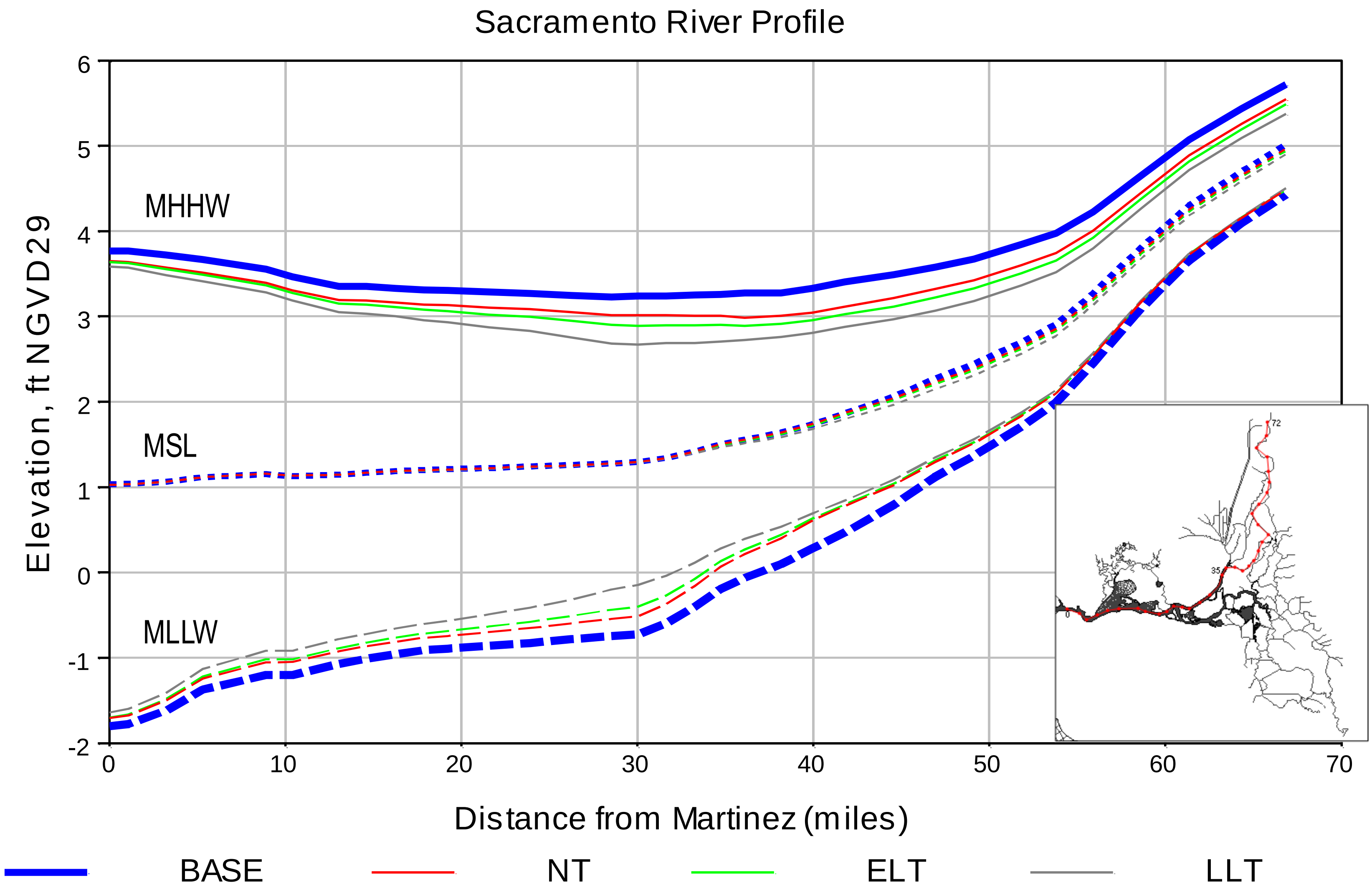


Figure 5-56 Tidal datum profiles along Sacramento River, July 2002.

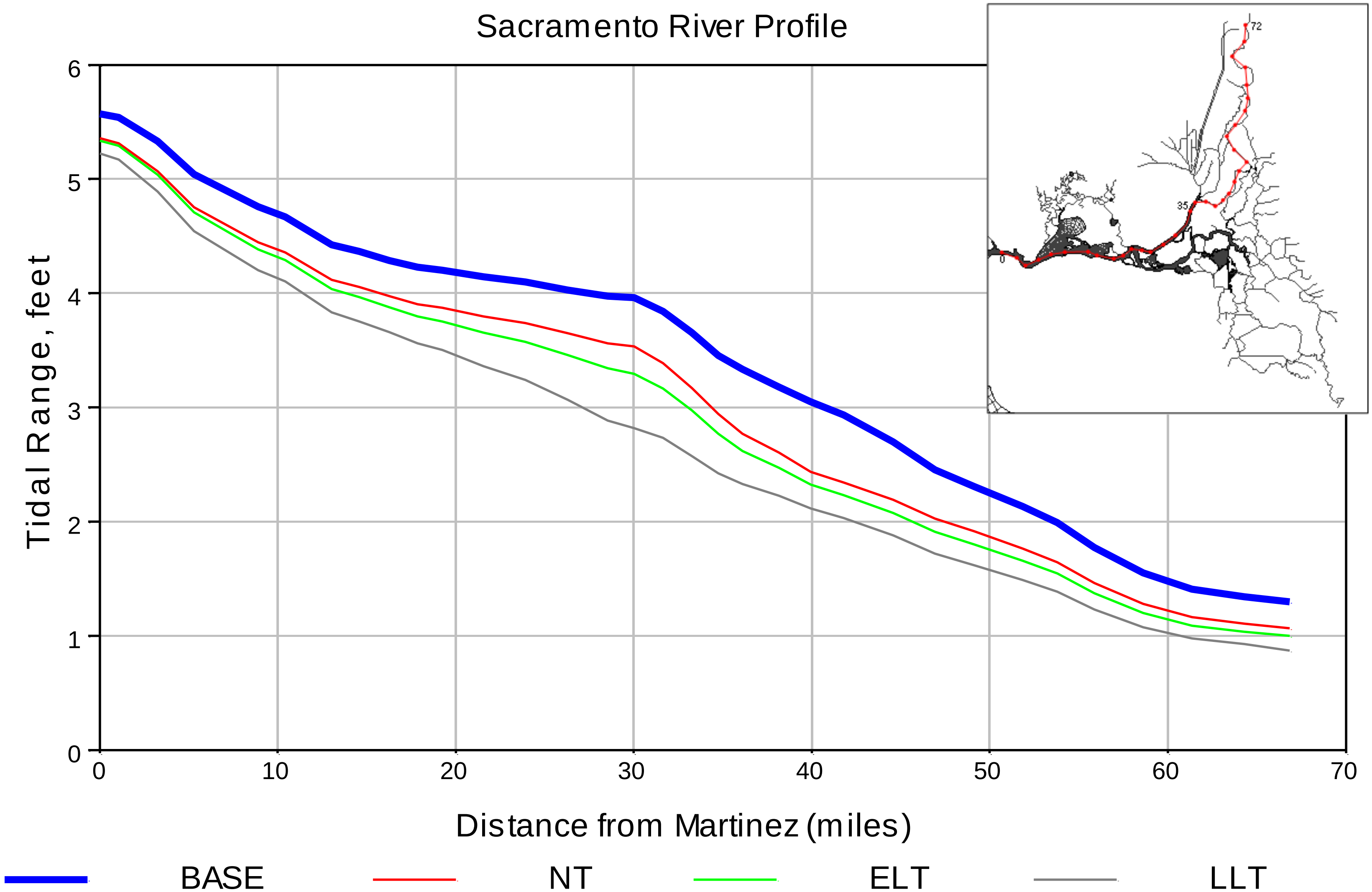


Figure 5-57 Tidal range (MHHW-MLLW) profiles along Sacramento River, July 2002.

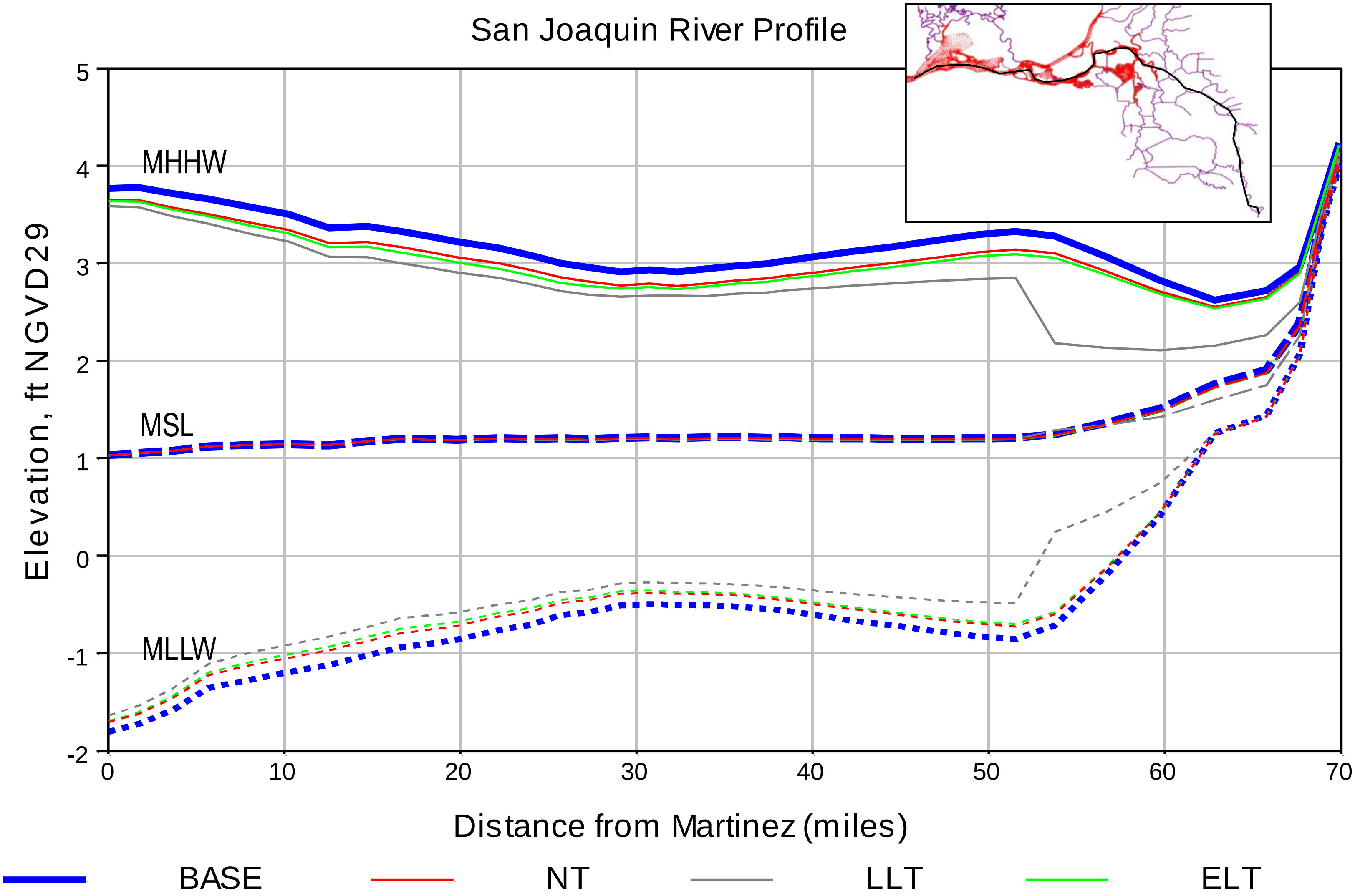


Figure 5-58 Tidal datum profiles along San Joaquin River, July 2002.

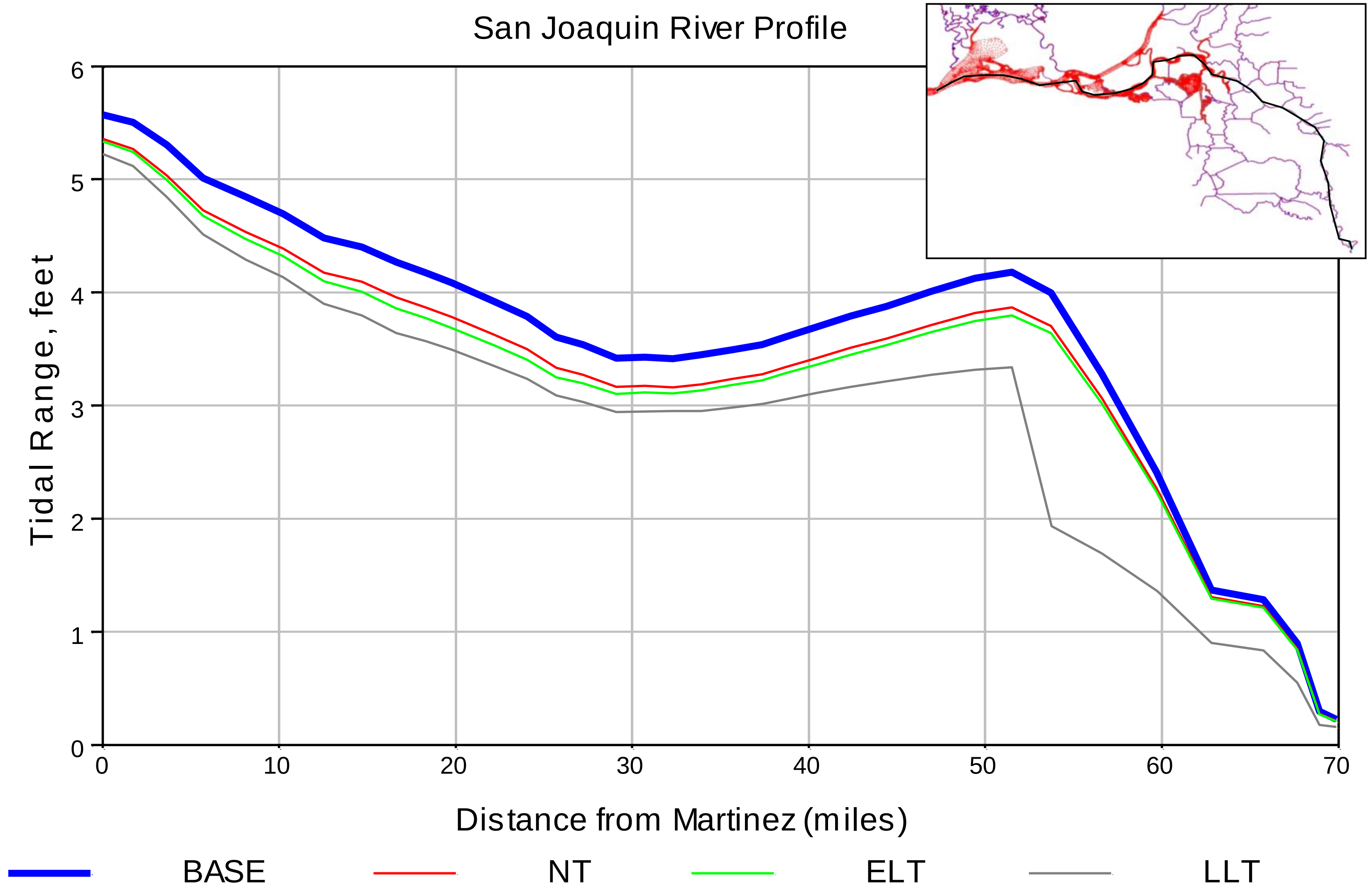


Figure 5-59 Tidal range (MHHW-MLLW) profiles along San Joaquin River, July 2002.

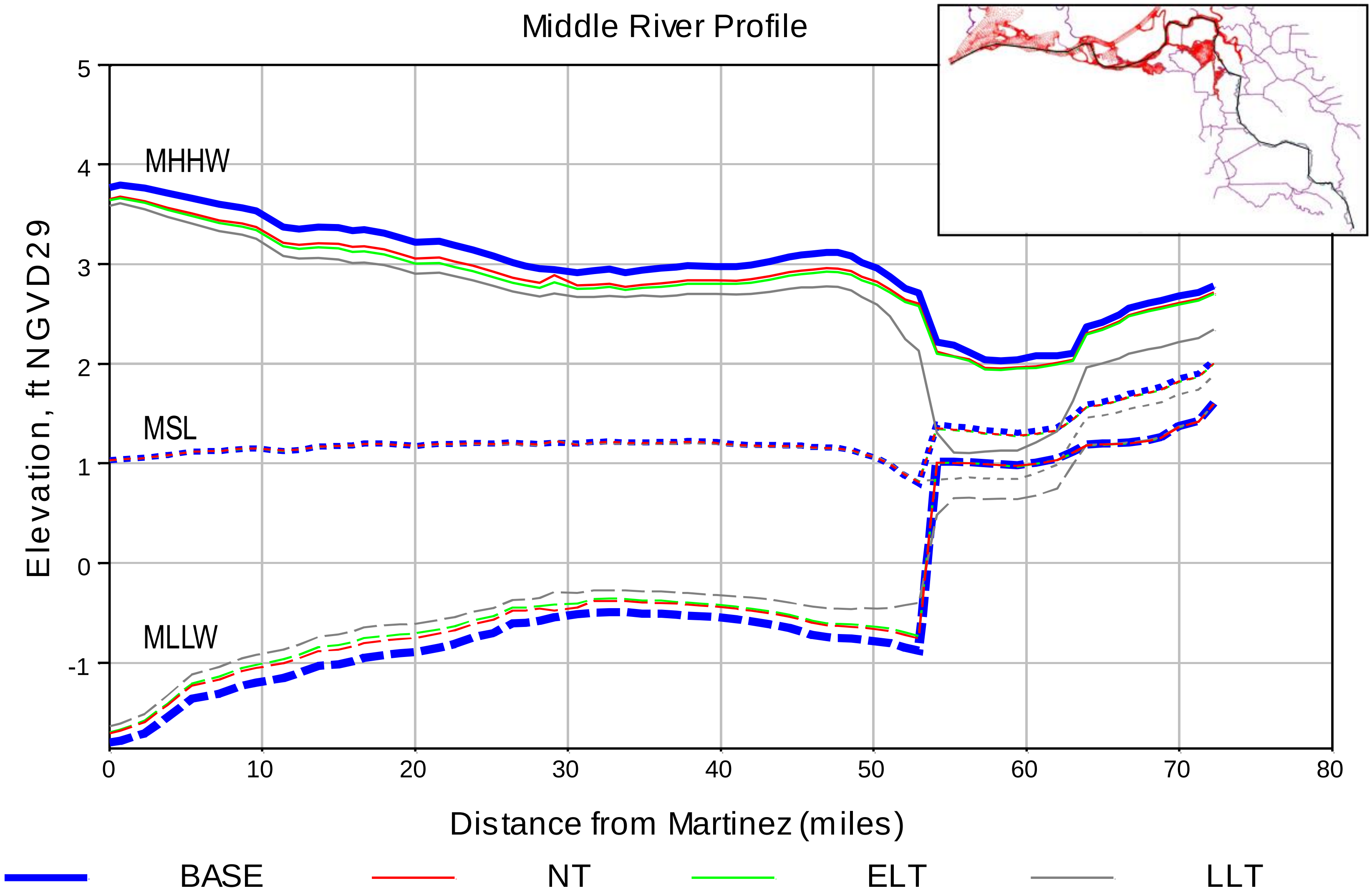


Figure 5-60 Tidal datum profiles from Martinez to San Joaquin River via Middle River, July 2002.

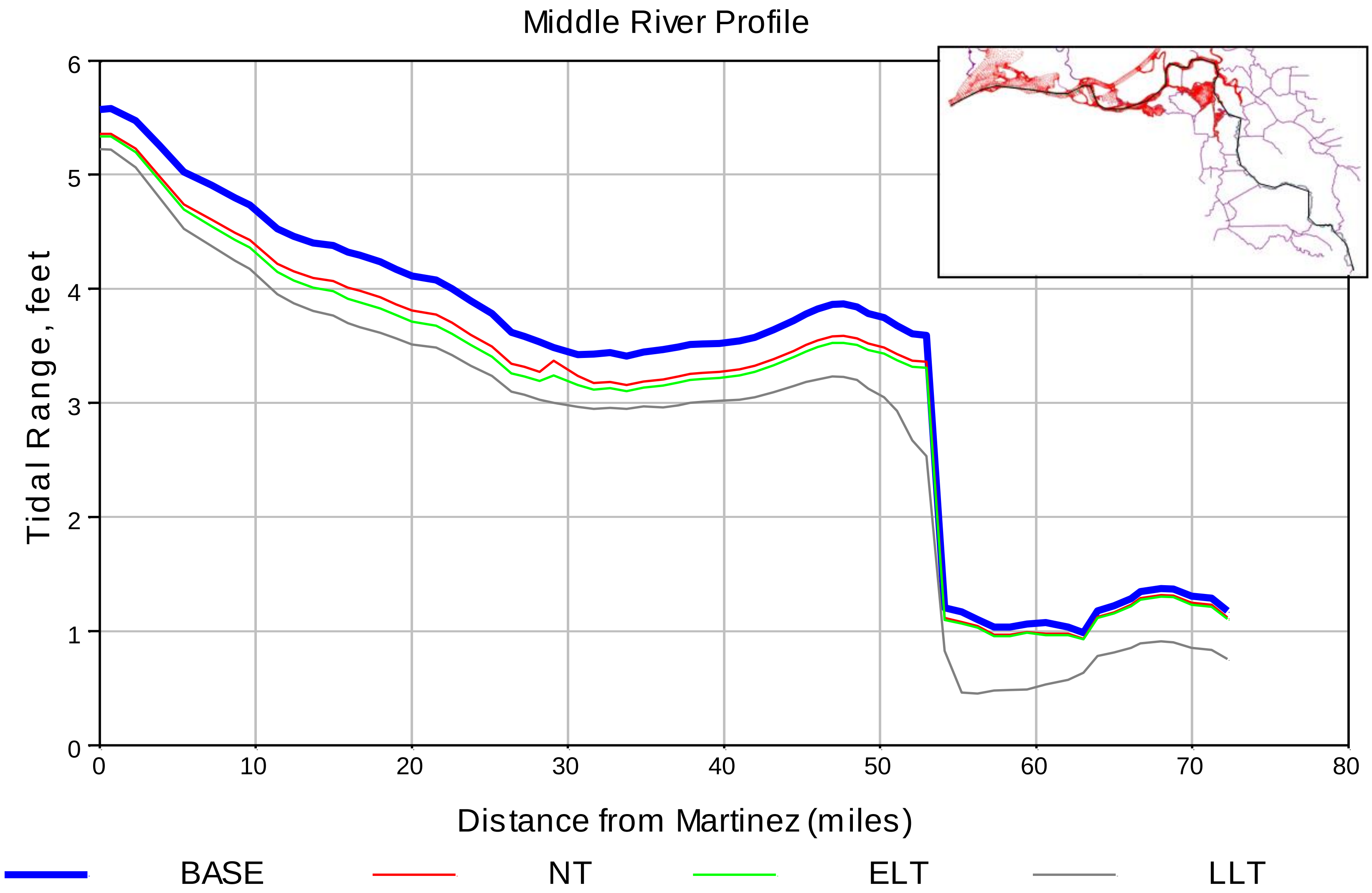


Figure 5-61 Tidal range (MHHW-MLLW) profiles from Martinez to San Joaquin River via Middle River, July 2002.

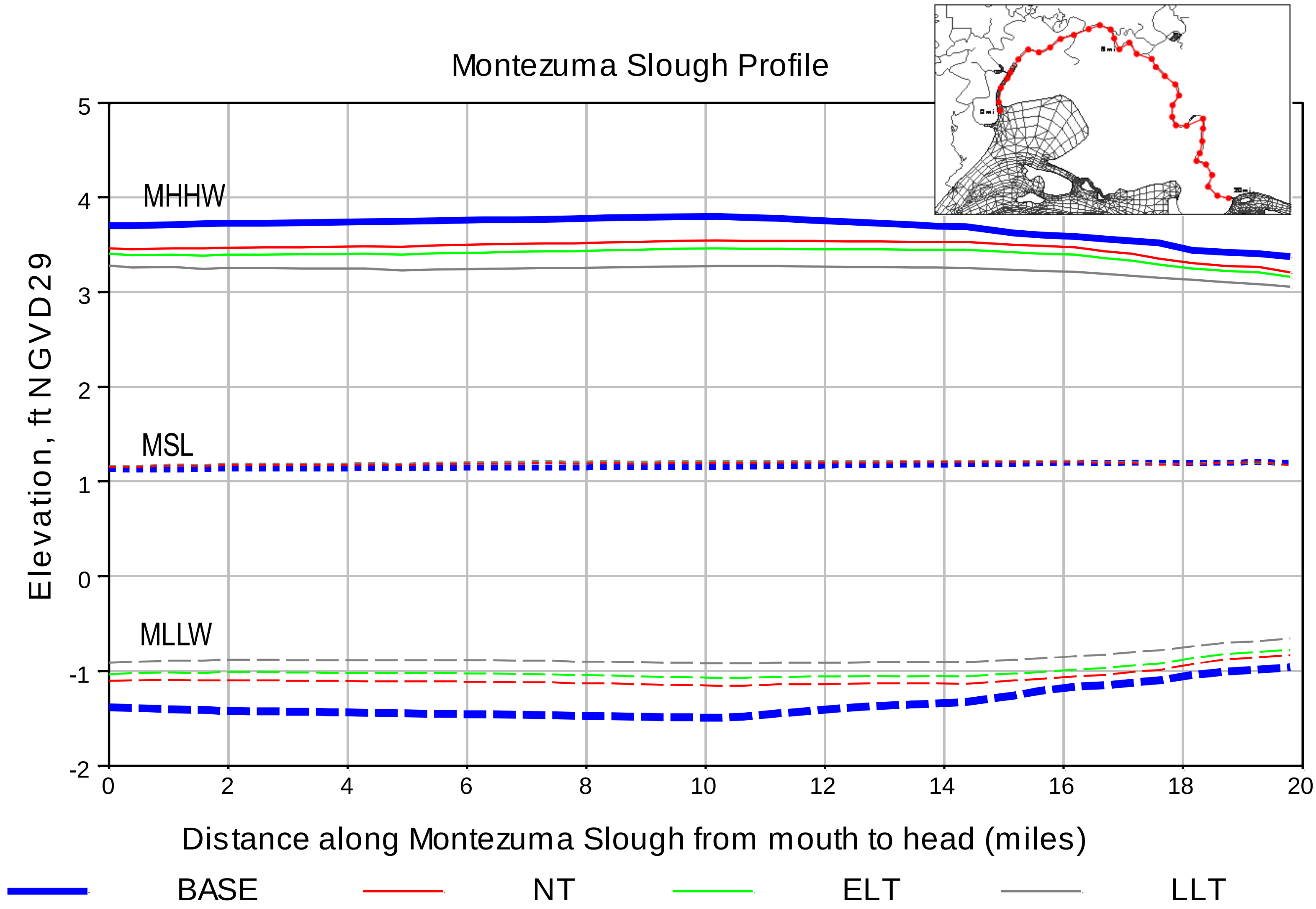


Figure 5-62 Tidal datum profiles along Montezuma Slough from mouth to head, July 2002.

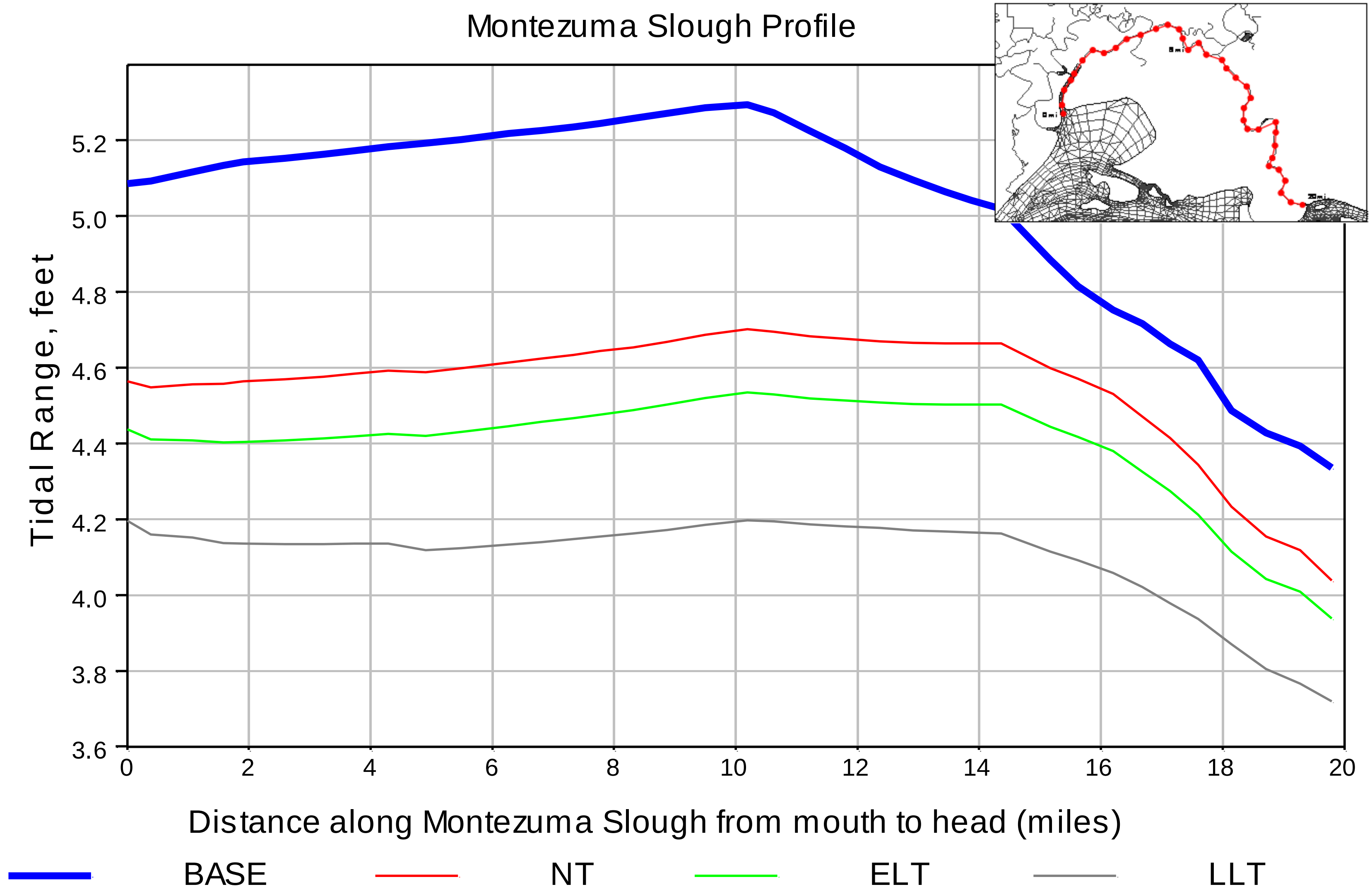


Figure 5-63 Tidal range (MHHW-MLLW) profiles along Montezuma Slough from mouth to head, July 2002.

5.6 Time Series Plots of Velocity at Select Locations

Time series plots of velocity are provided in Figure 5-64 through Figure 5-81 at selected locations for the Base case and restoration alternatives to show the velocity impact of each alternative in comparison with Base. Only ten days during July 2002 are shown so that the restoration impacts can be more clearly seen.

Time series locations are shown in Figure 5-1for the Delta and Figure 5-2 for Suisun Marsh.

Velocities tend to increase downstream of restoration areas (for example LLT restoration in Nurse Slough increases velocities, Figure 5-78) and decrease upstream of restoration areas (for example RSAC128, Figure 5-70). Results are varied in locations with both upstream and downstream restoration. For example at Jersey Point (Figure 5-74) peak flood and ebb velocity magnitudes are reduced for all restoration scenarios. NT and ELT velocity peaks are virtually the same, while the LLT peaks are reduced slightly more. At Rio Vista (Figure 5-72) peak ebb velocity magnitudes increase with added restoration area. Peak flood velocity magnitudes for the NT and ELT do not vary from Base while increases are seen for the LLT scenario. Threemile Slough velocity magnitudes decrease with added restoration area. The largest velocity increases occur in Hunter Cut. ELT results in slightly more increase in ebb tide velocity peaks relative to the LLT at this location, while the two cases have very similar increases in peak flood tide velocity magnitude.

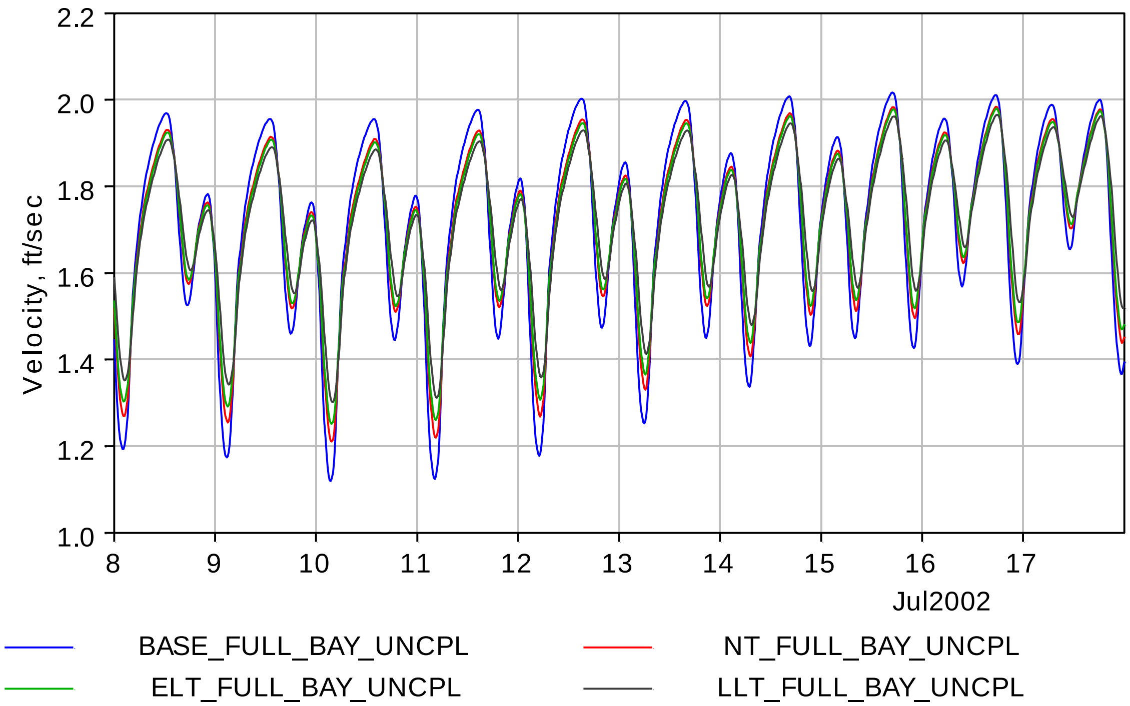


Figure 5-64 Velocity at Freeport for Base case, NT, ELT and LLT scenarios.

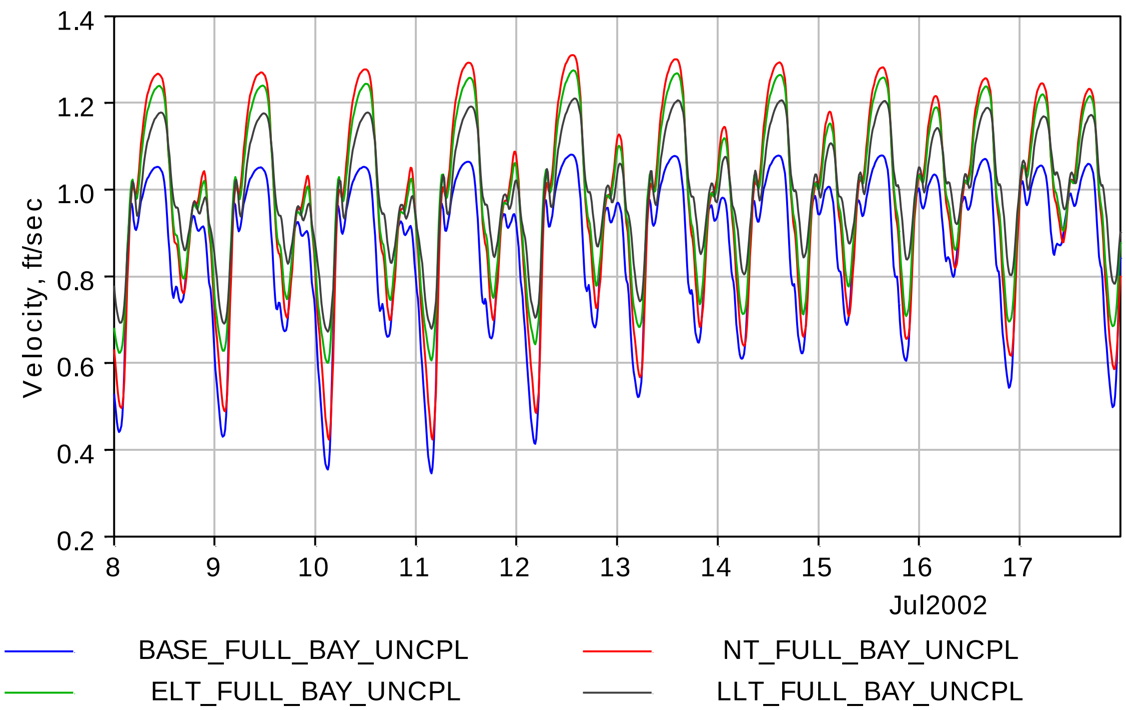


Figure 5-65 Velocity in Sutter Slough near Sacramento R. for Base, NT, ELT and LLT scenarios.

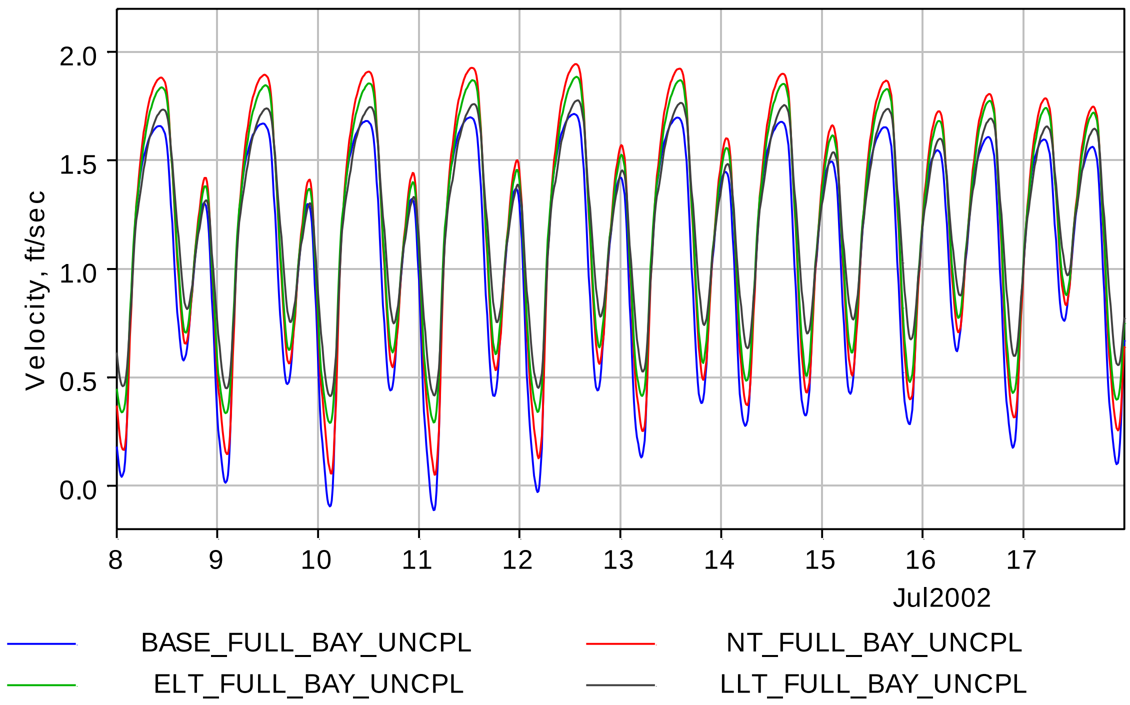


Figure 5-66 Velocity in Sutter Slough near Miner Slough for Base, NT, ELT and LLT scenarios.

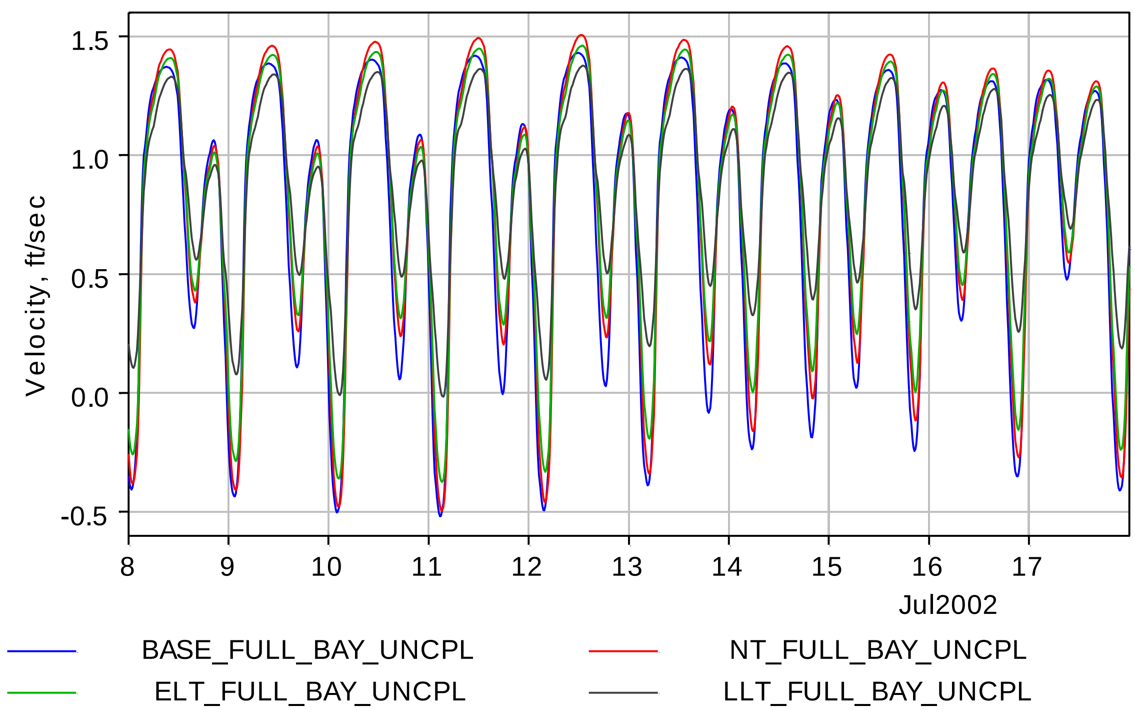


Figure 5-67 Velocity in Steamboat Slough for Base, NT, ELT and LLT scenarios.

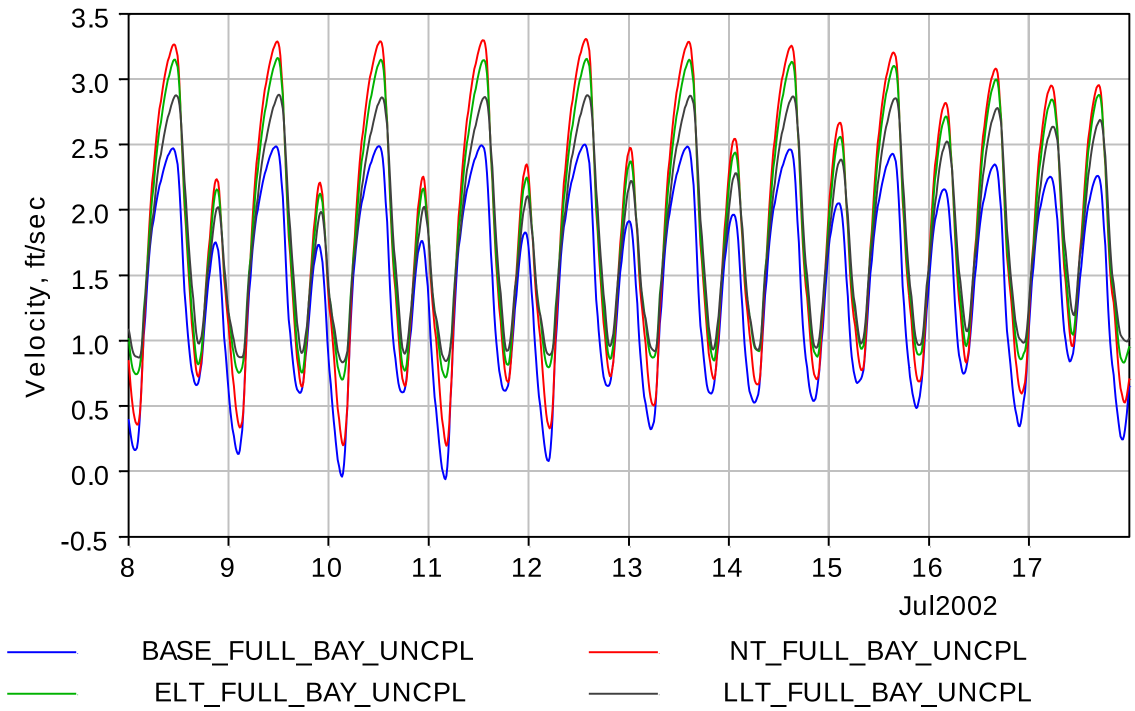


Figure 5-68 Velocity at Miner Slough for Base, NT, ELT and LLT scenarios.

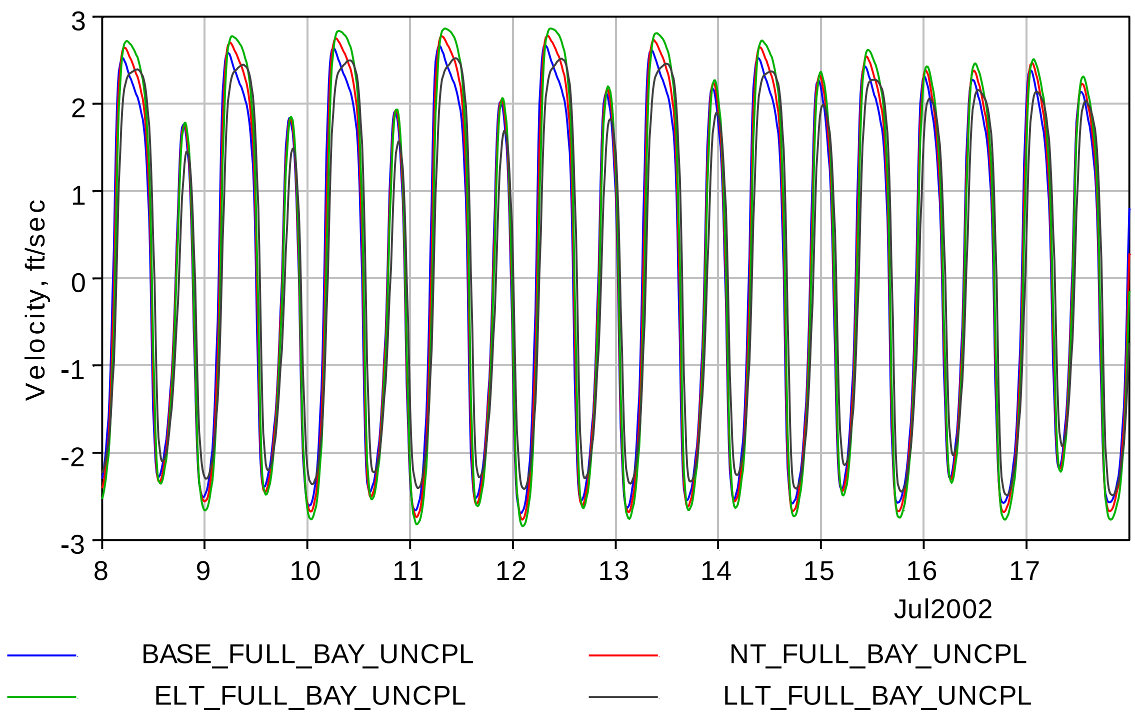


Figure 5-69 Velocity in Cache Slough at Ryer Island for Base case and Suisun Marsh and Cache Slough restoration scenarios.

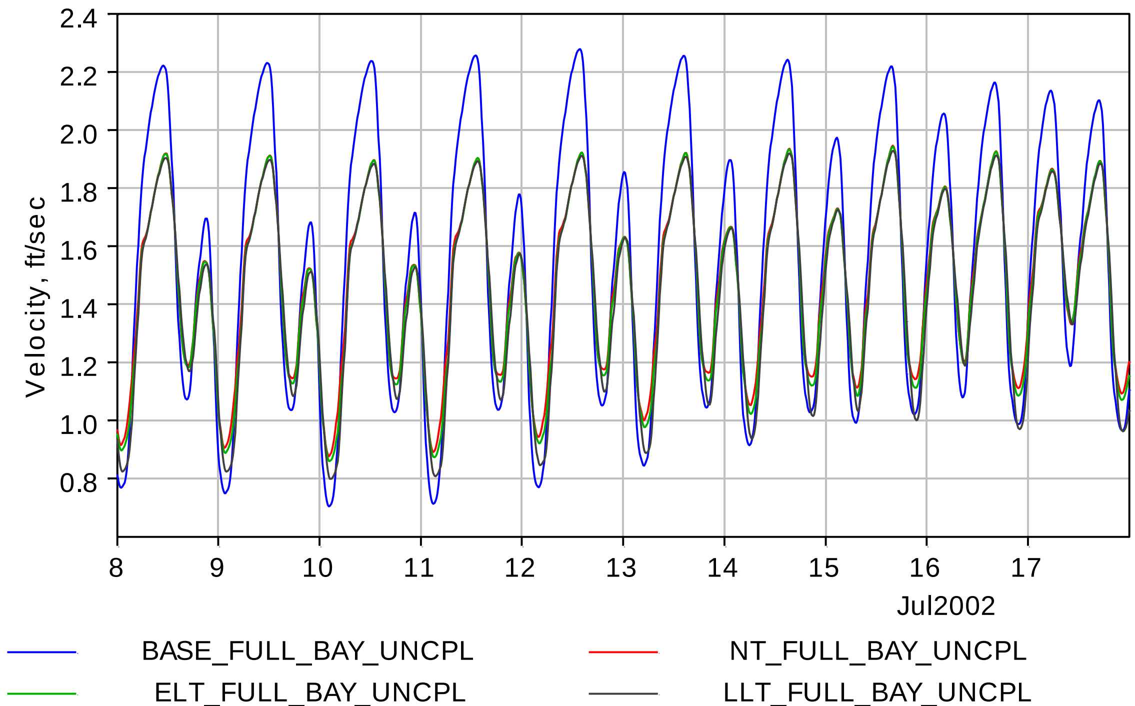


Figure 5-70 Velocity at RSAC128 for Base, NT, ELT and LLT scenarios.

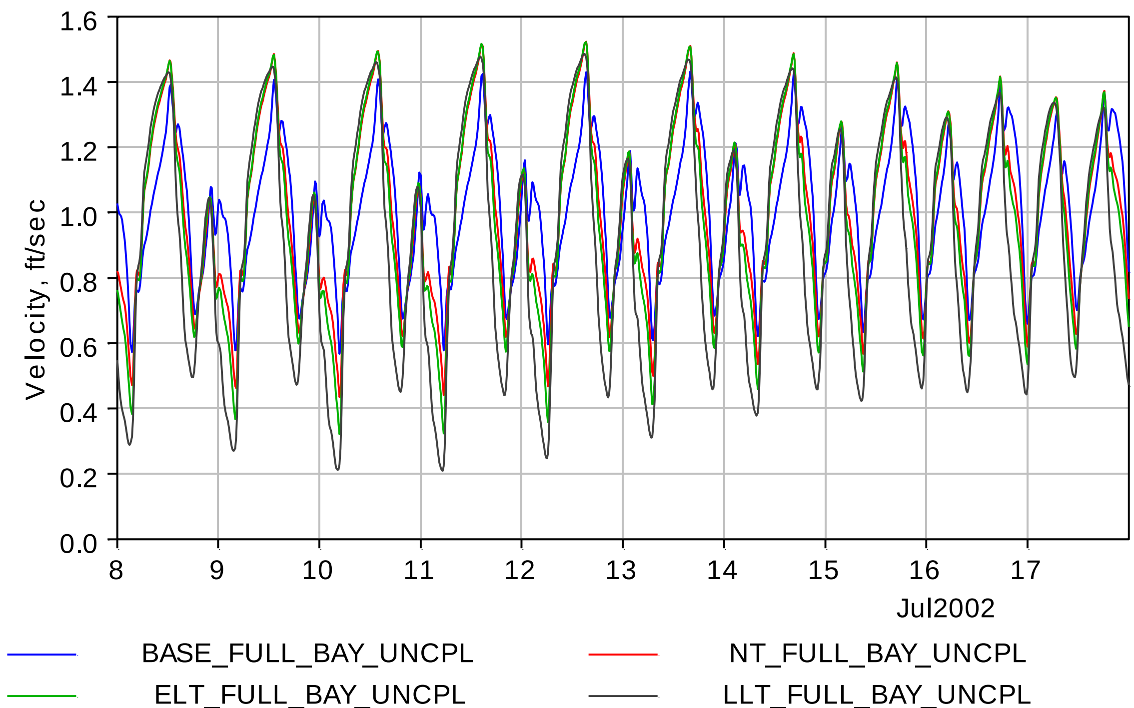


Figure 5-71 Velocity in Georgiana Slough at head for Base, NT, ELT and LLT scenarios.

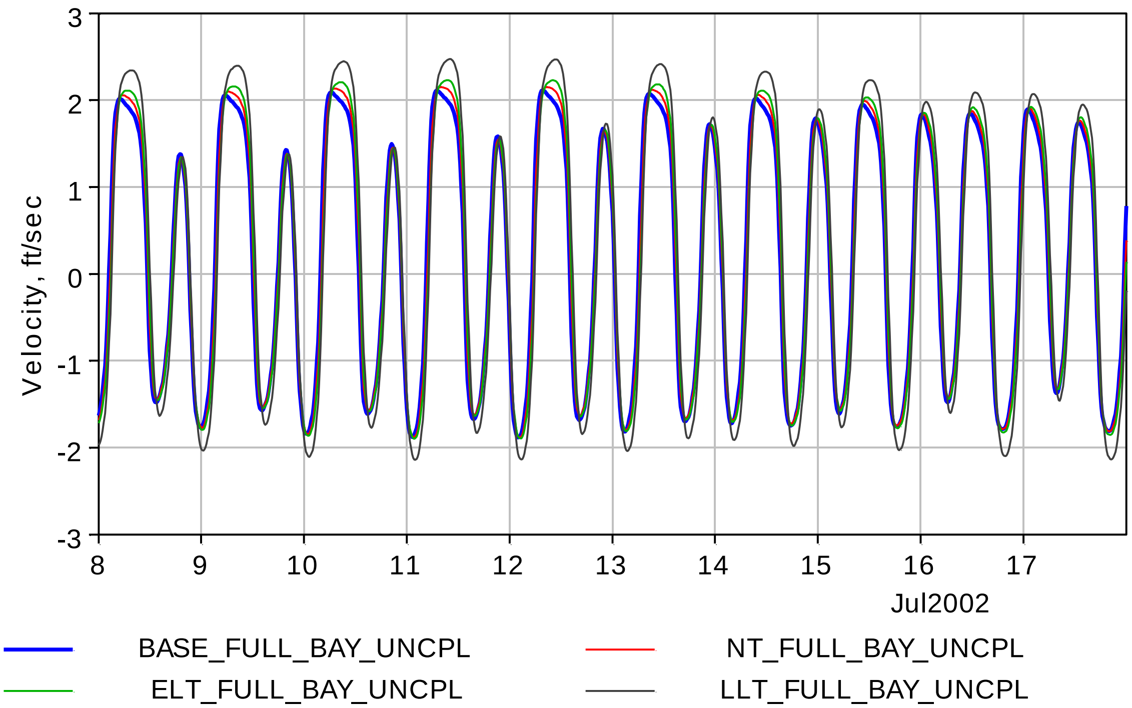


Figure 5-72 Velocity at Rio Vista for Base case, NT, ELT and LLT scenarios.

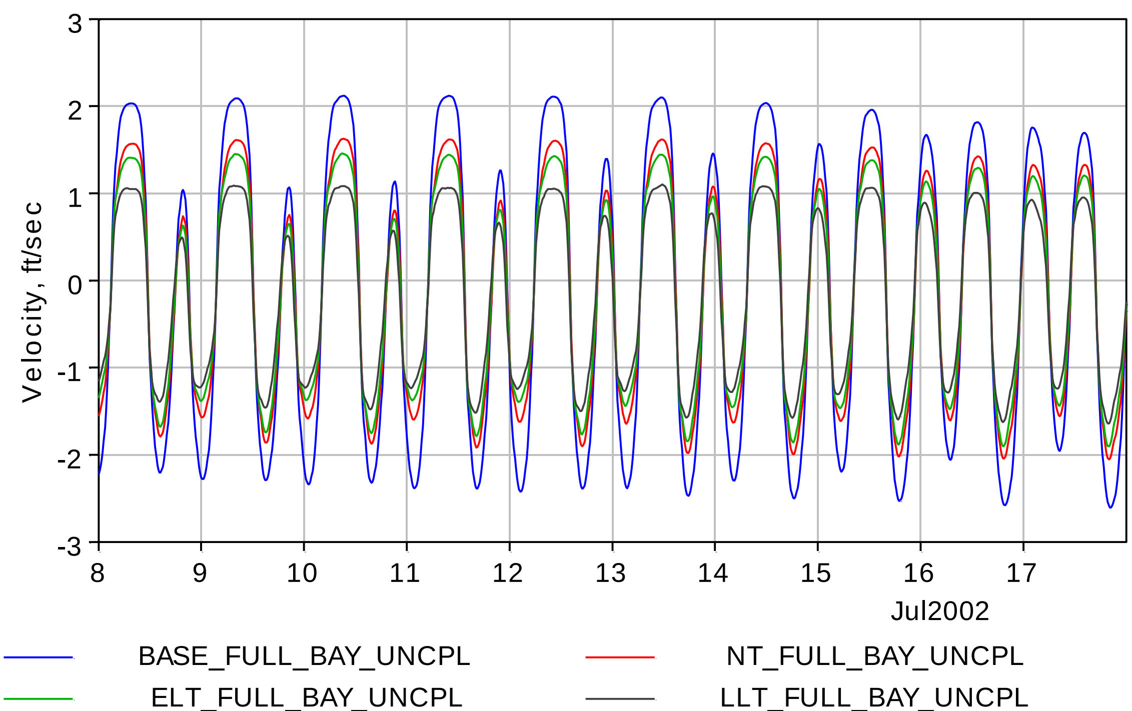


Figure 5-73 Velocity in Threemile Slough for Base, NT, ELT and LLT scenarios.

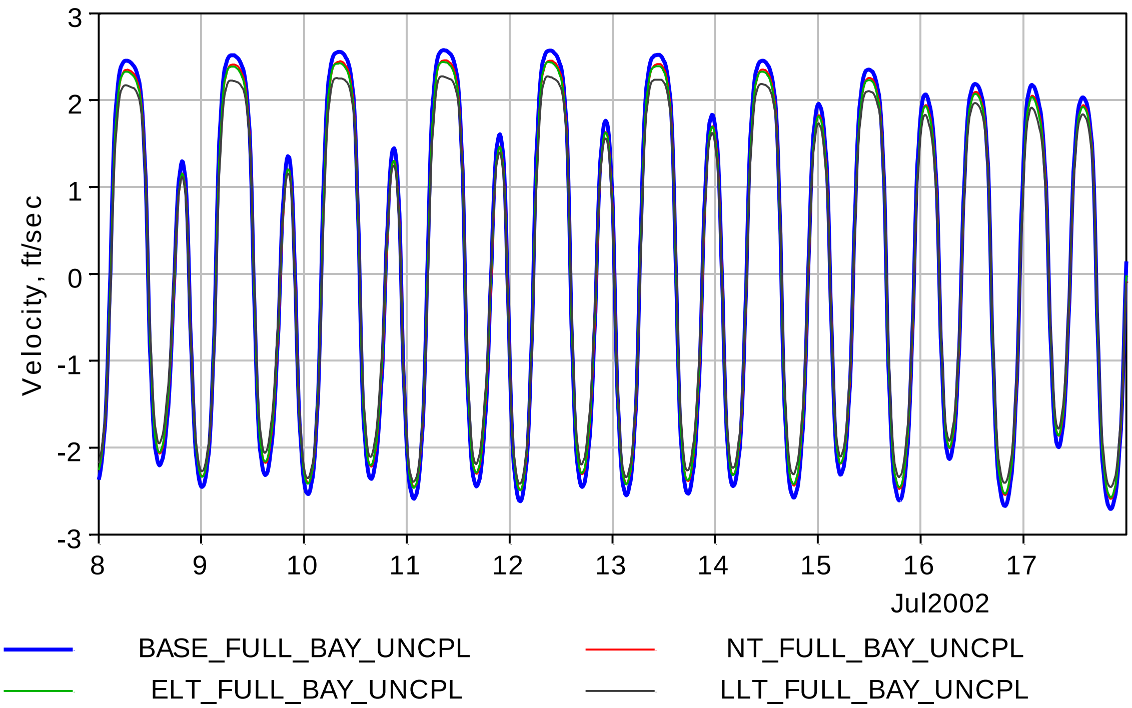


Figure 5-74 Velocity at Jersey Point for Base, NT, ELT and LLT scenarios.

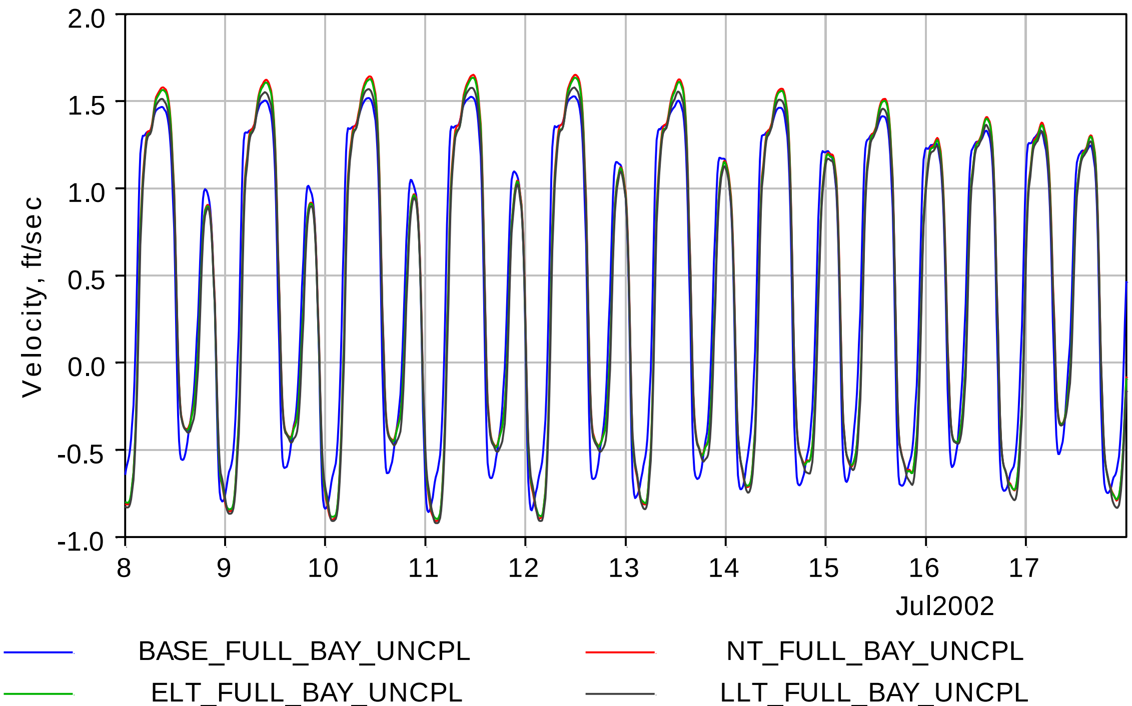


Figure 5-75 Velocity in Mokelumne R. near San Joaquin R. for Base, NT, ELT and LLT scenarios.

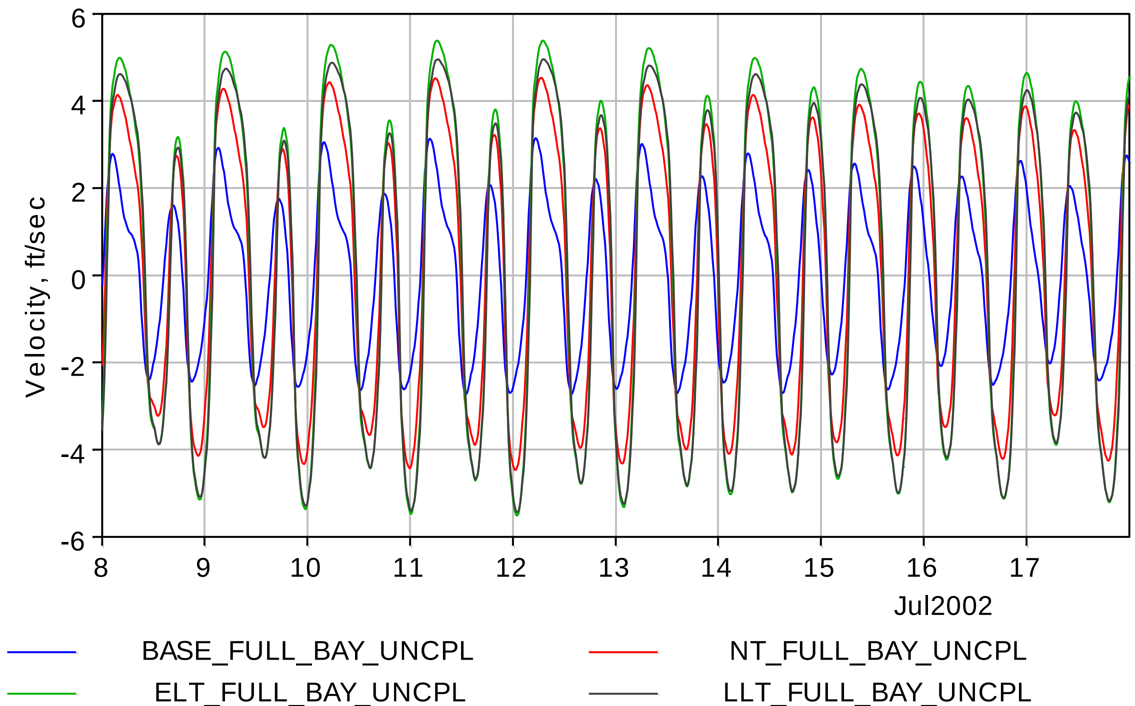


Figure 5-76 Velocity in Hunter Cut for Base, NT, ELT and LLT scenarios.

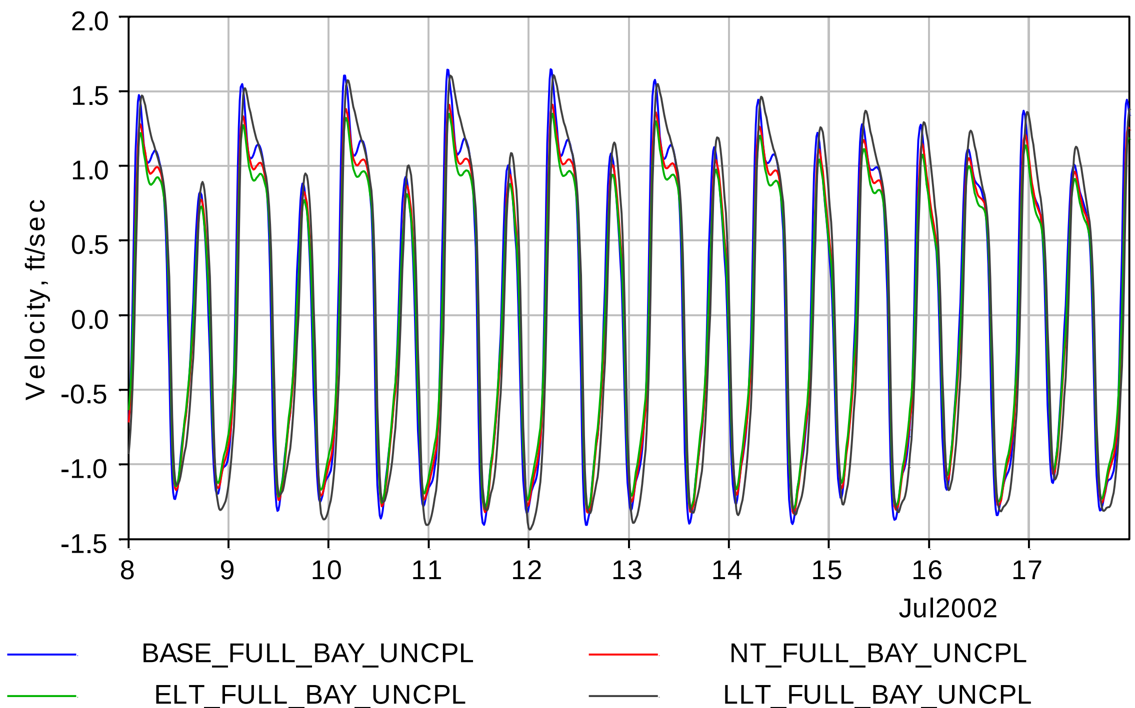


Figure 5-77 Velocity in Montezuma Slough at Beldon's Landing (S-49) for Base, NT, ELT and LLT scenarios.

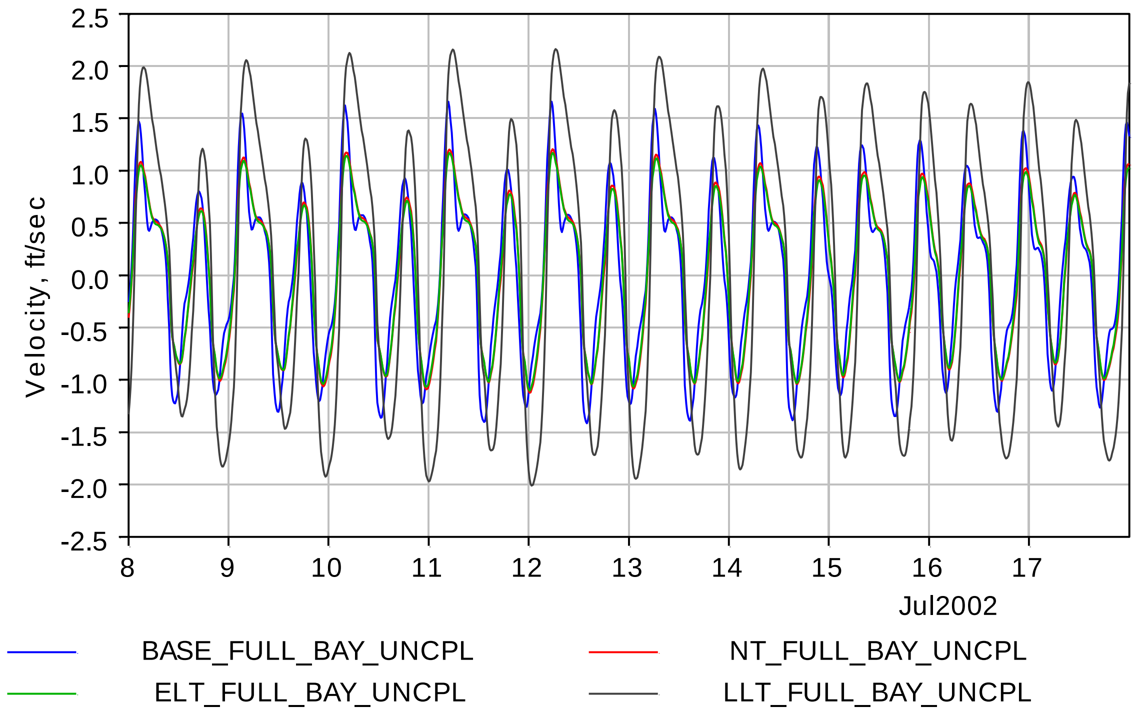


Figure 5-78 Velocity in Nurse Slough for Base, NT, ELT and LLT scenarios.

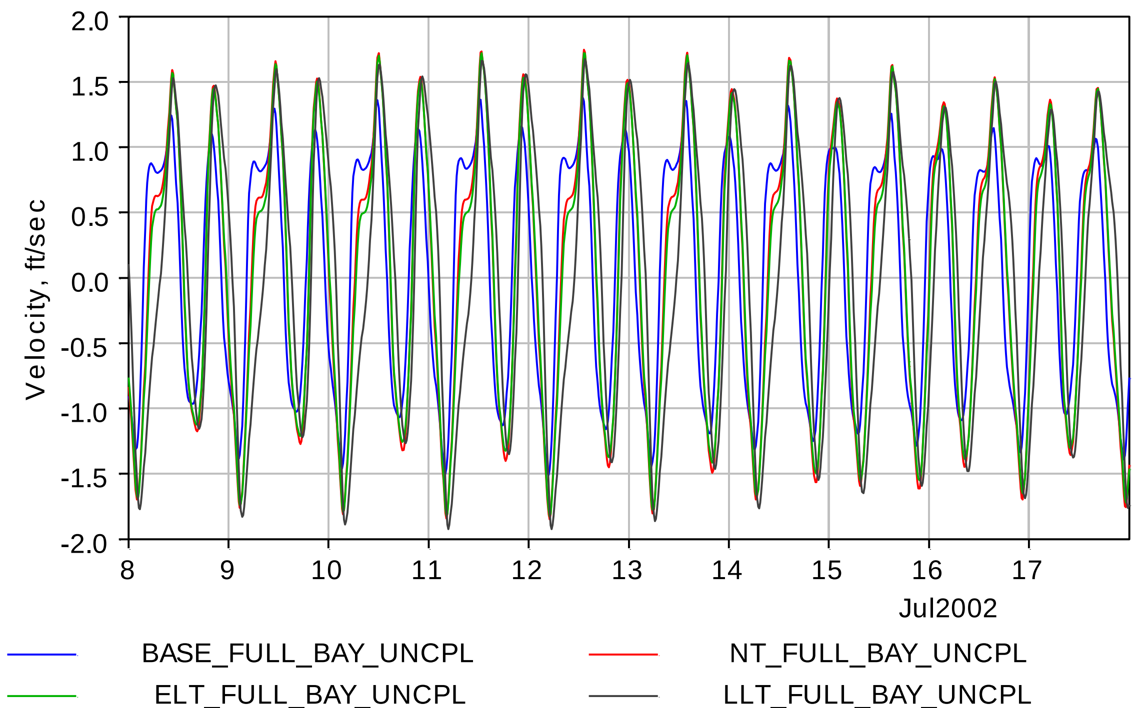


Figure 5-79 Velocity in Montezuma Slough at Roaring River (S-71) for Base, NT, ELT and LLT scenarios.

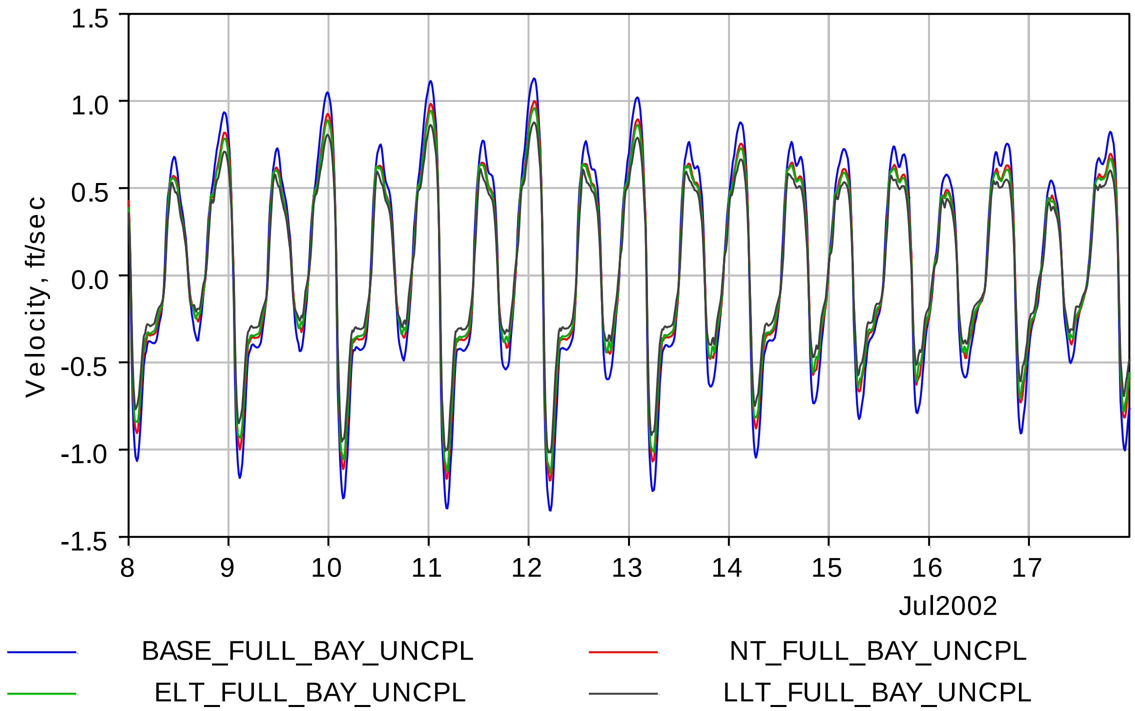


Figure 5-80 Velocity at S-35 near Morrow Island for Base, NT, ELT and LLT scenarios.

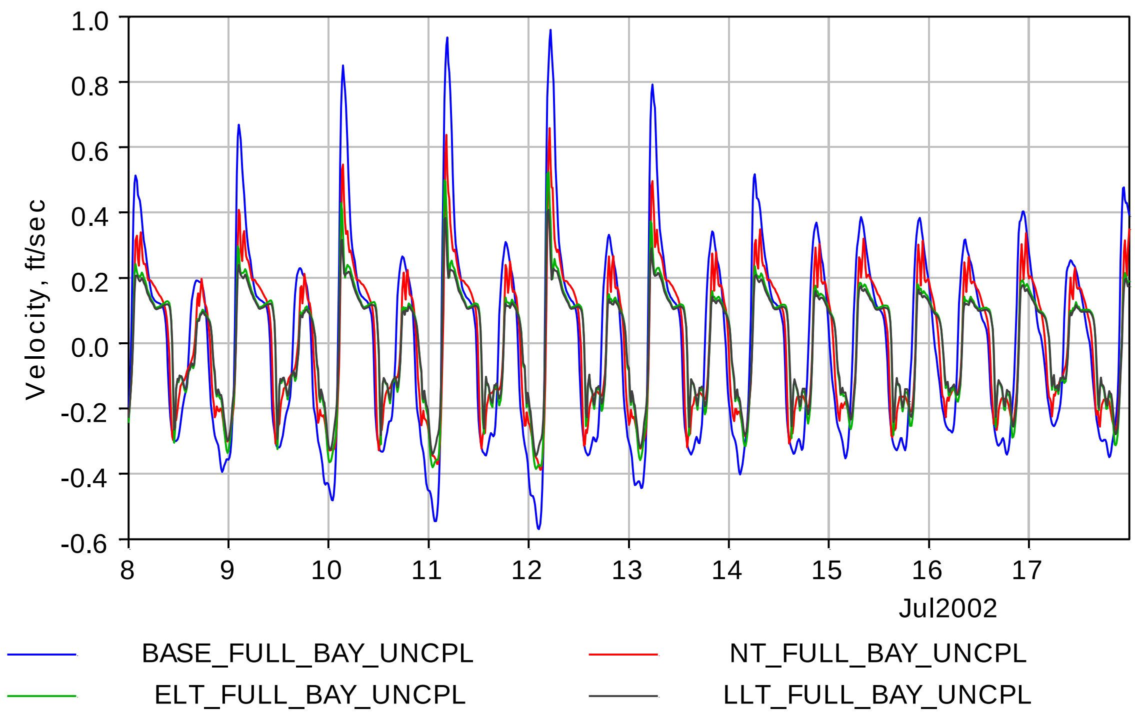


Figure 5-81 Velocity in Boynton Slough at S-40 for Base, NT, ELT and LLT scenarios.

5.7 Bed Shear

For the Base, ELT and LLT scenarios, bed shear was calculated for the low flow month of July 2002 to help identify areas of potential scour under low flow conditions.

Contour plots of bed shear for the ELT and LLT scenarios are shown in comparison with Base case for areas where bed shear is highest and where restoration results in significant increases in bed shear. Red rectangles in Figure 5-82 indicate the areas examined. Times are chosen to show the highest values.

Results are shown in Figure 5-83 through Figure 5-101.

Contour plots of bed shear for the ELT and LLT scenarios in comparison with Base case show that high bed shear values for both the ELT and LLT scenarios occur in Cache Slough (Figure 5-83 and Figure 5-84), Miner Slough (Figure 5-85 and Figure 5-86), west of the Delta Cross Channel (Figure 5-87 and Figure 5-88), Snodgrass Slough (Figure 5-91 and Figure 5-92), Dutch Slough (Figure 5-89 and Figure 5-90), Suisun Slough (Figure 5-93 and Figure 5-94), Montezuma Slough at head and mouth (Figure 5-97 and Figure 5-98), and Hunter Cut (Figure 5-95 and Figure 5-96). For the LLT case only, high bed shear values occur near the East Delta ROA (Figure 5-99), in Middle River near Union Island (Figure 5-100) and in San Joaquin River near Roberts Island (Figure 5-101).

The greatest increases and highest bed shear values occur in Hunter Cut, where bed shear exceeds 3 N/m^2 for both the ELT and LLT scenarios. A higher ranging bed shear contour scale had to be used for the Hunter Cut plots to best display the high values.

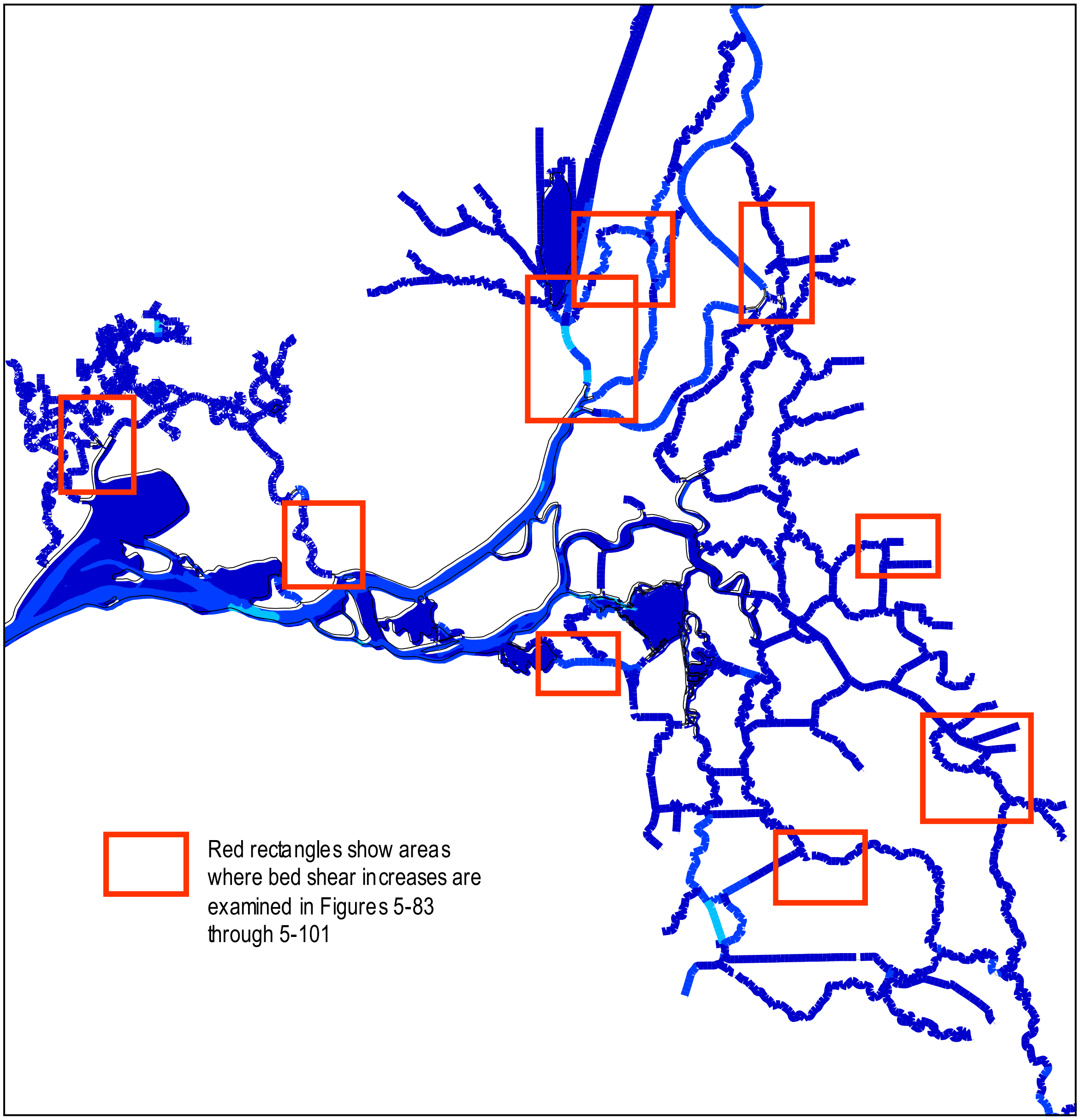


Figure 5-82 Map showing areas where bed shear increases are examined in Figure 5-83 through Figure 5-101.

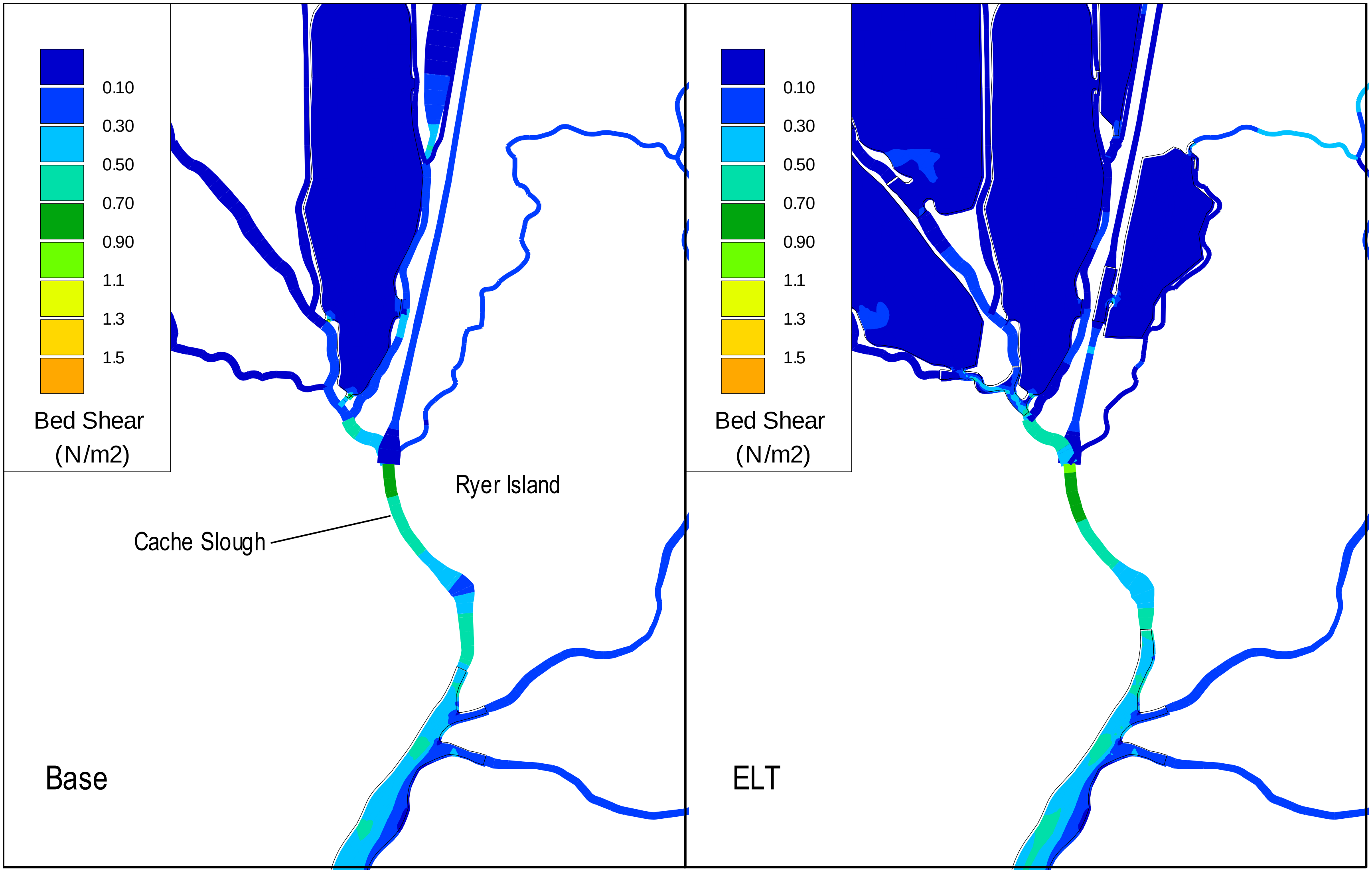


Figure 5-83 Bed shear in the Cache Slough area for the Base case and ELT scenario during July 2002.

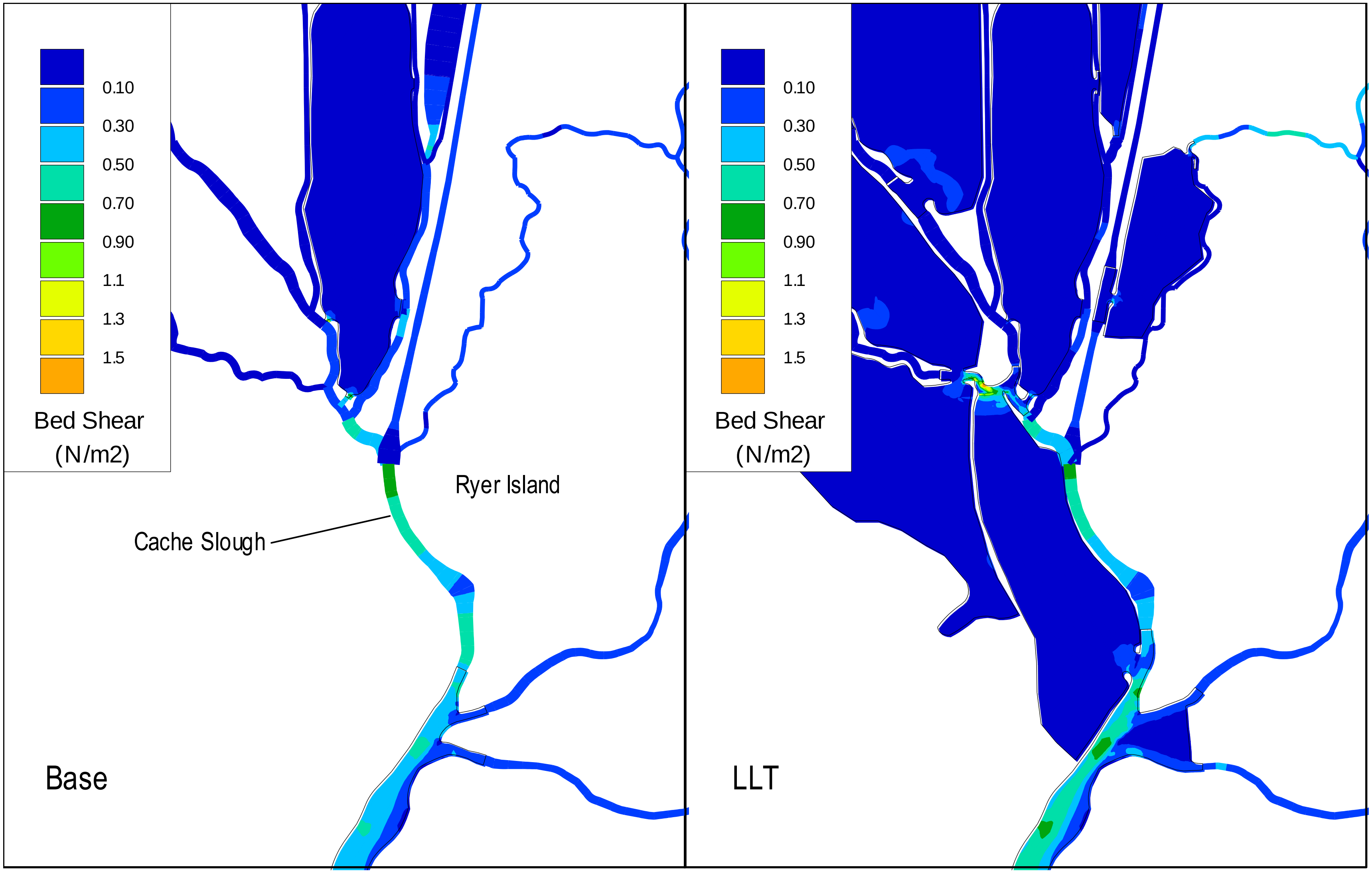


Figure 5-84 Bed shear in the Cache Slough area for the Base case and LLT scenario during July 2002.

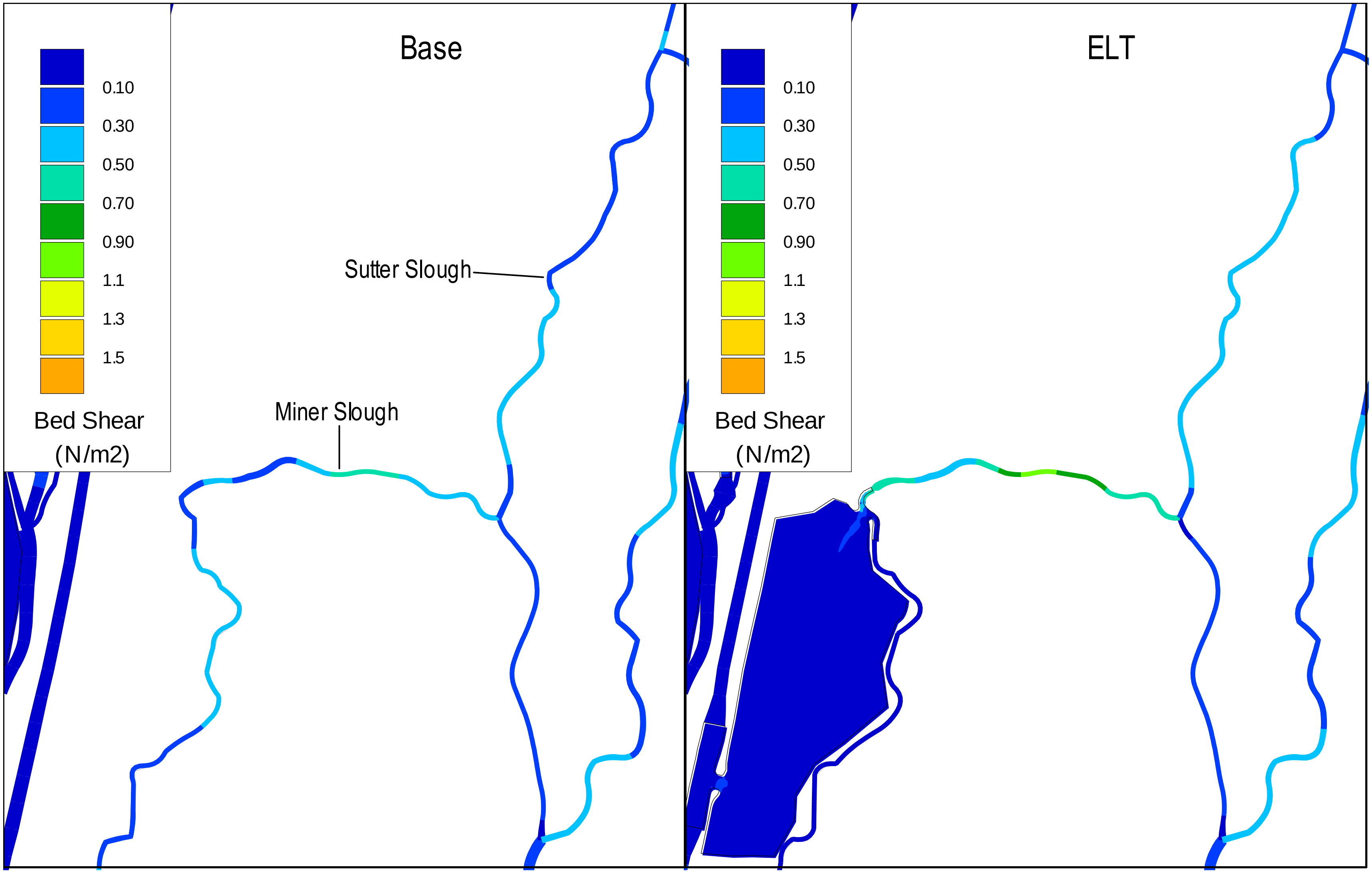


Figure 5-85 Bed shear in Miner Slough for the Base case and ELT scenario during July 2002.

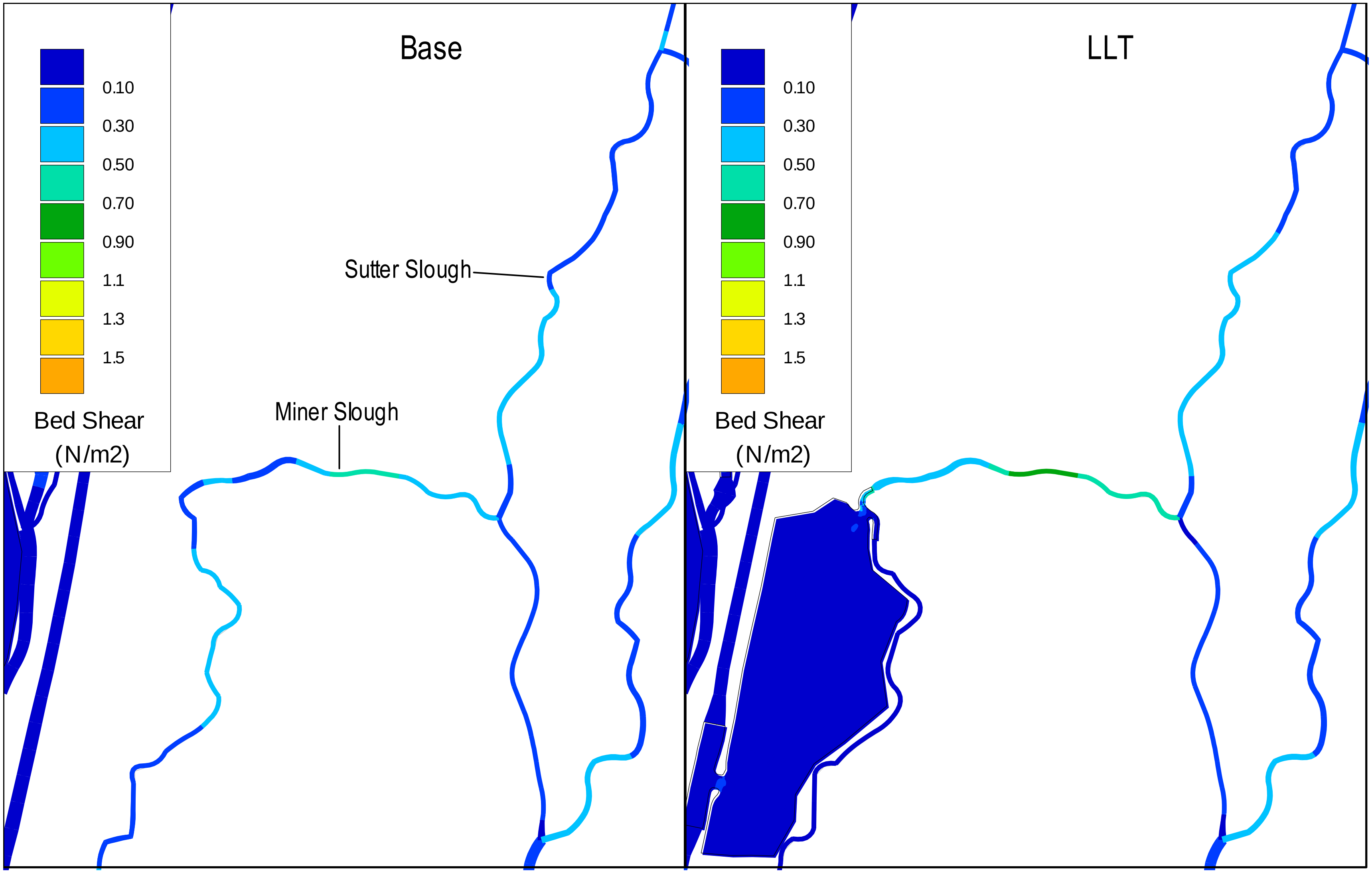


Figure 5-86 Bed shear in Miner Slough for the Base case and LLT scenario during July 2002.

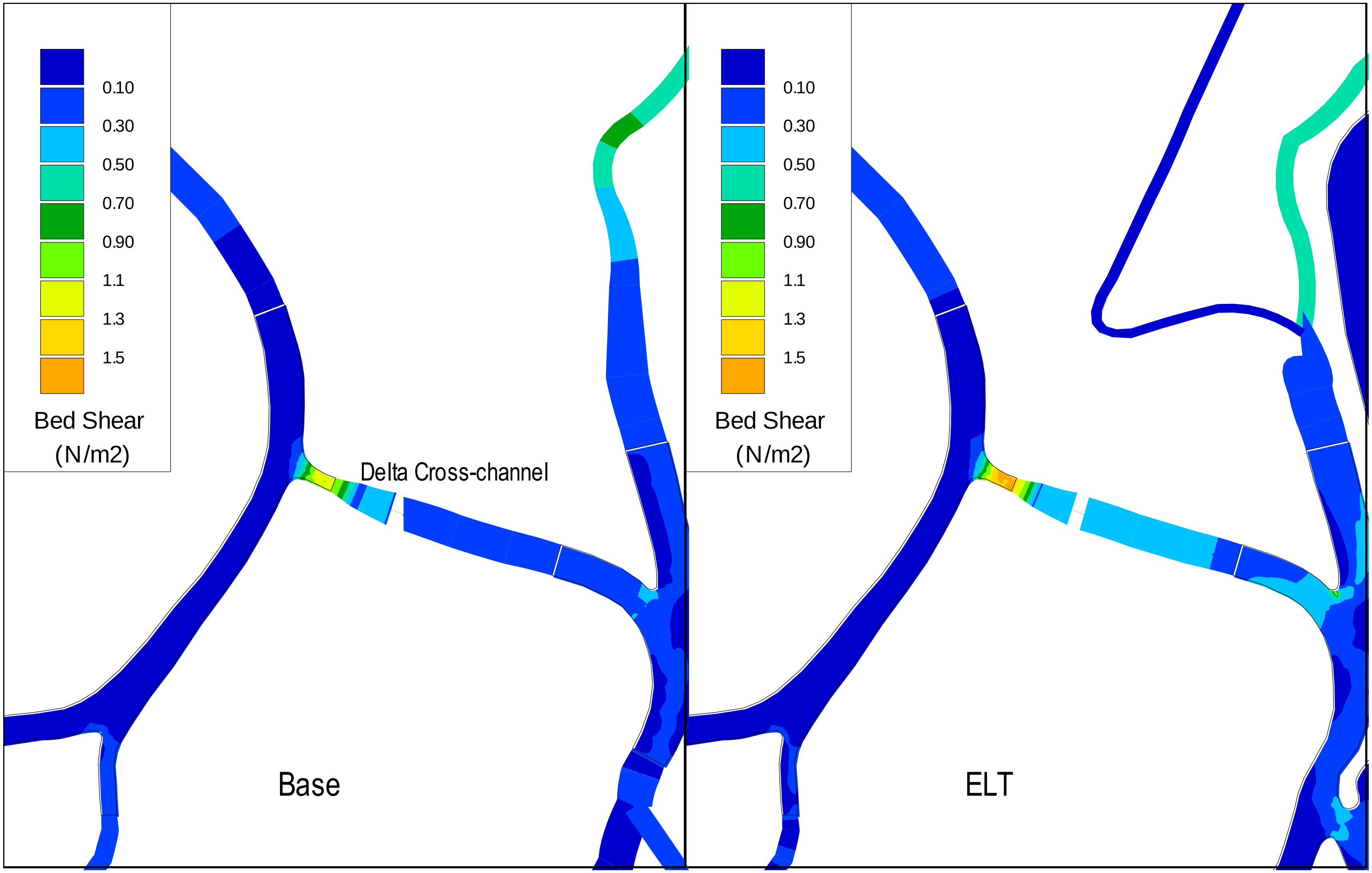


Figure 5-87 Bed shear near the Delta Cross Channel for the Base case and ELT scenario during July 2002.

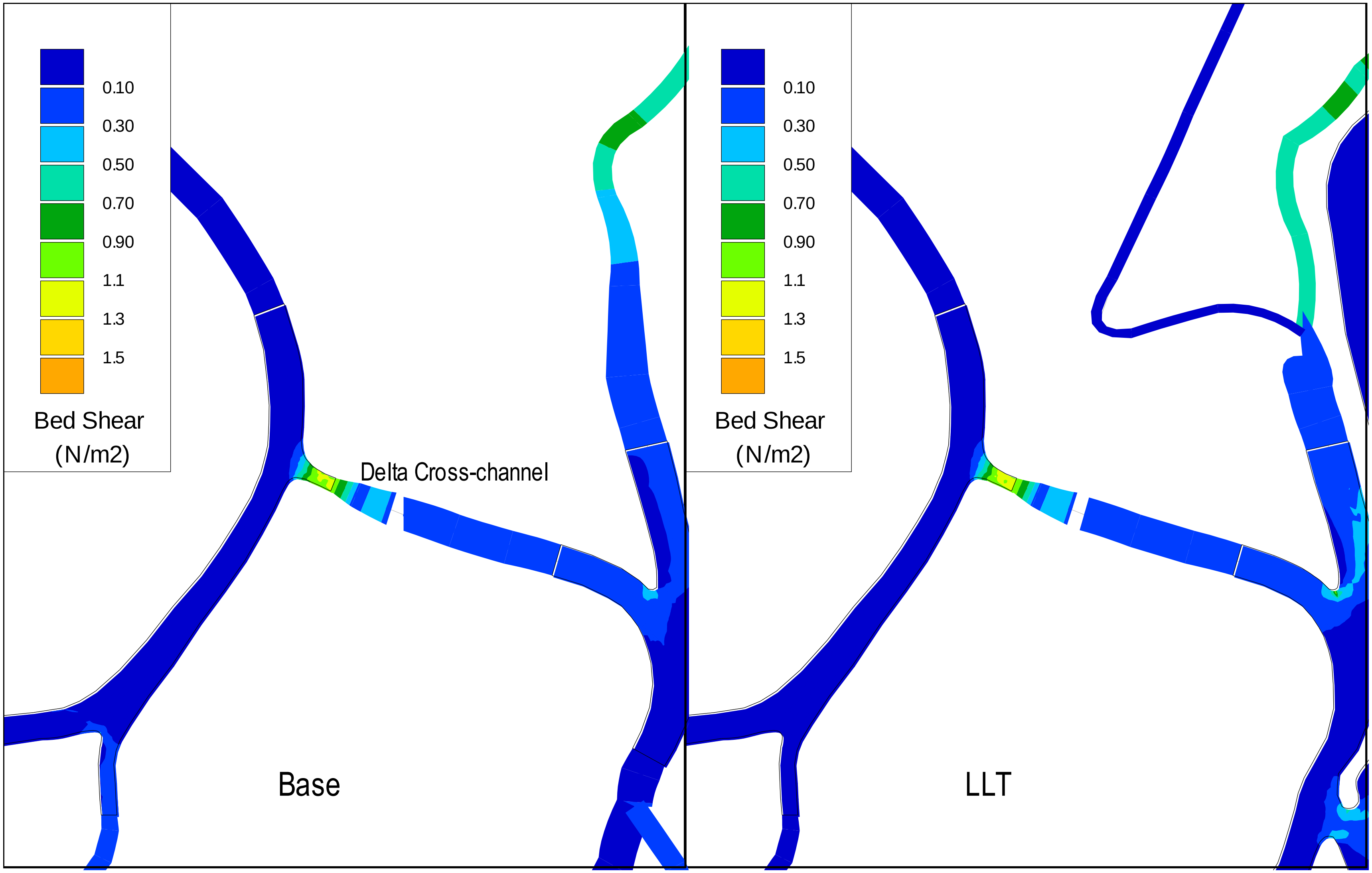


Figure 5-88 Bed shear near the Delta Cross Channel for the Base case and LLT scenario during July 2002.

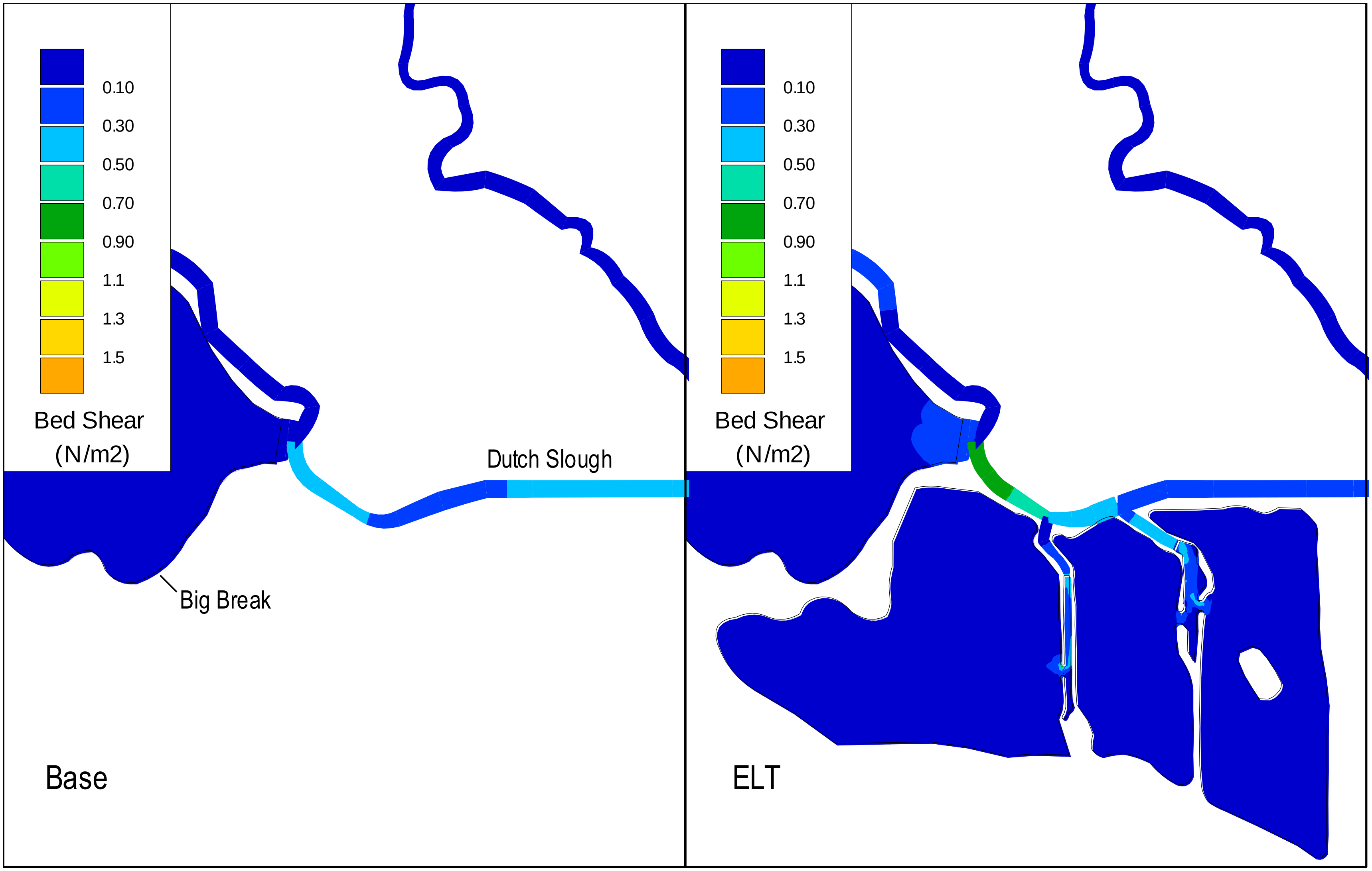


Figure 5-89 Bed shear in Dutch Slough for the Base case and ELT scenario during July 2002.

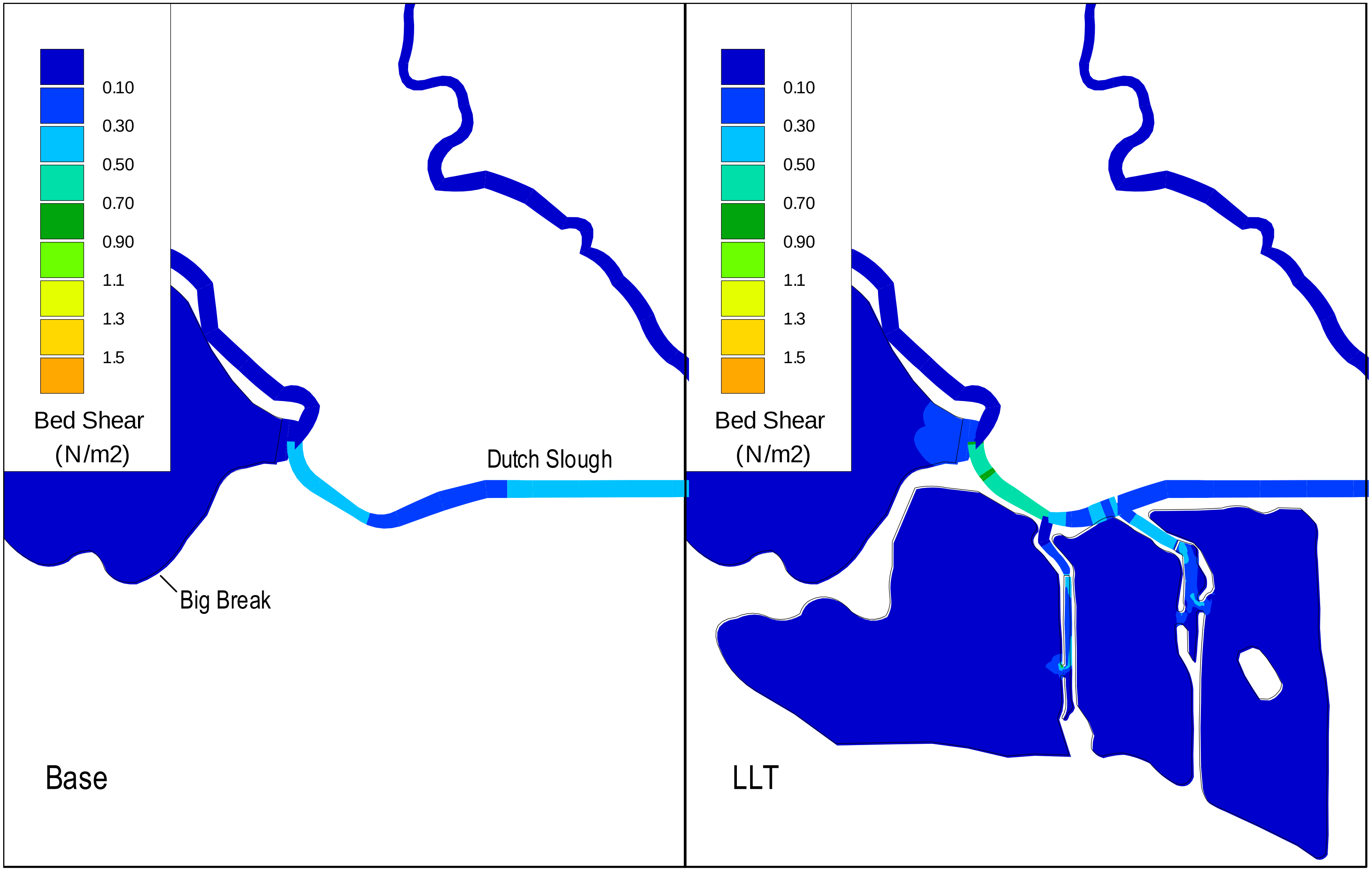


Figure 5-90 Bed shear in Dutch Slough for the Base case and LLT scenario during July 2002.

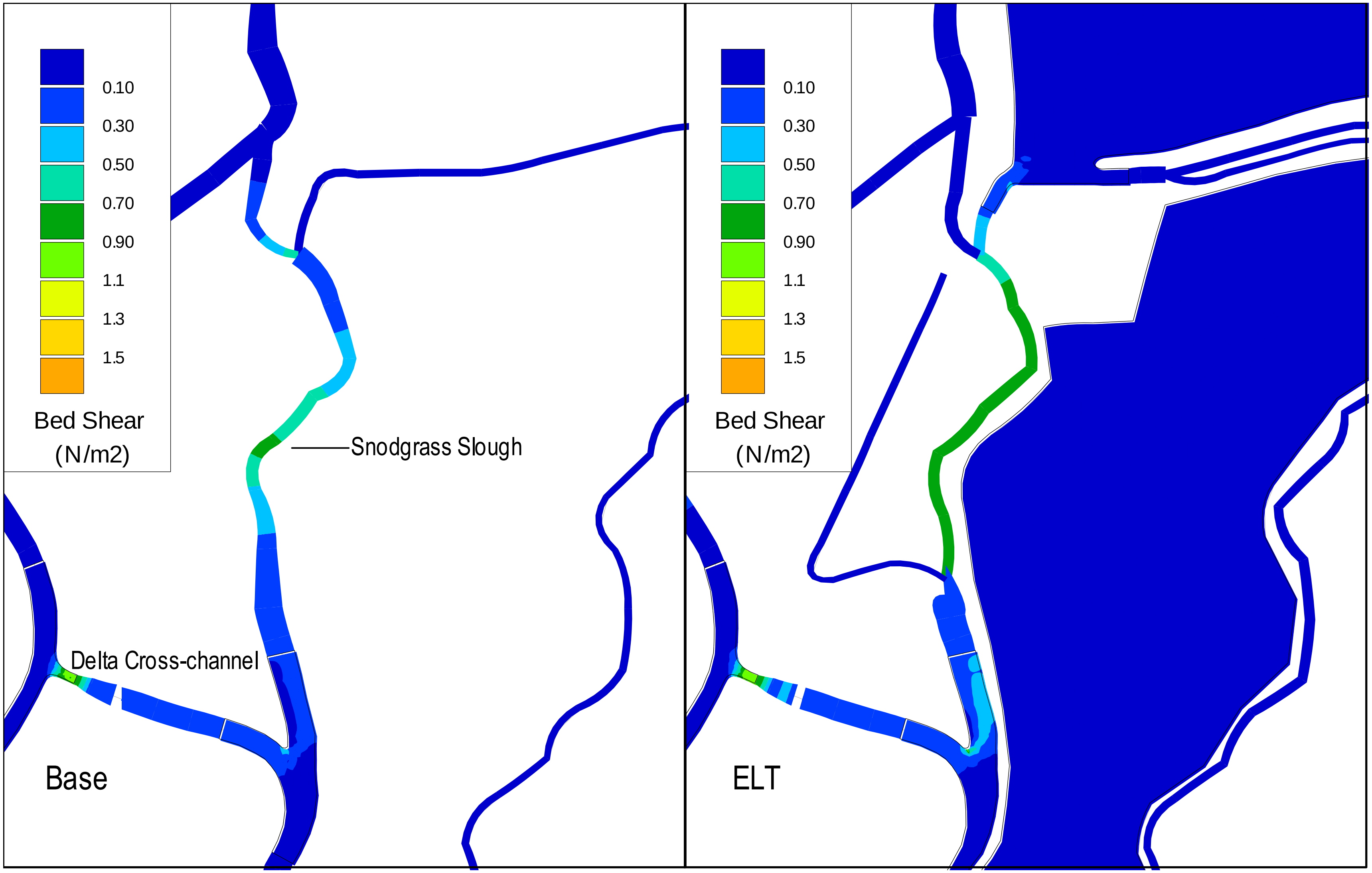


Figure 5-91 Bed shear in Snodgrass Slough for the Base case and ELT scenario during July 2002.

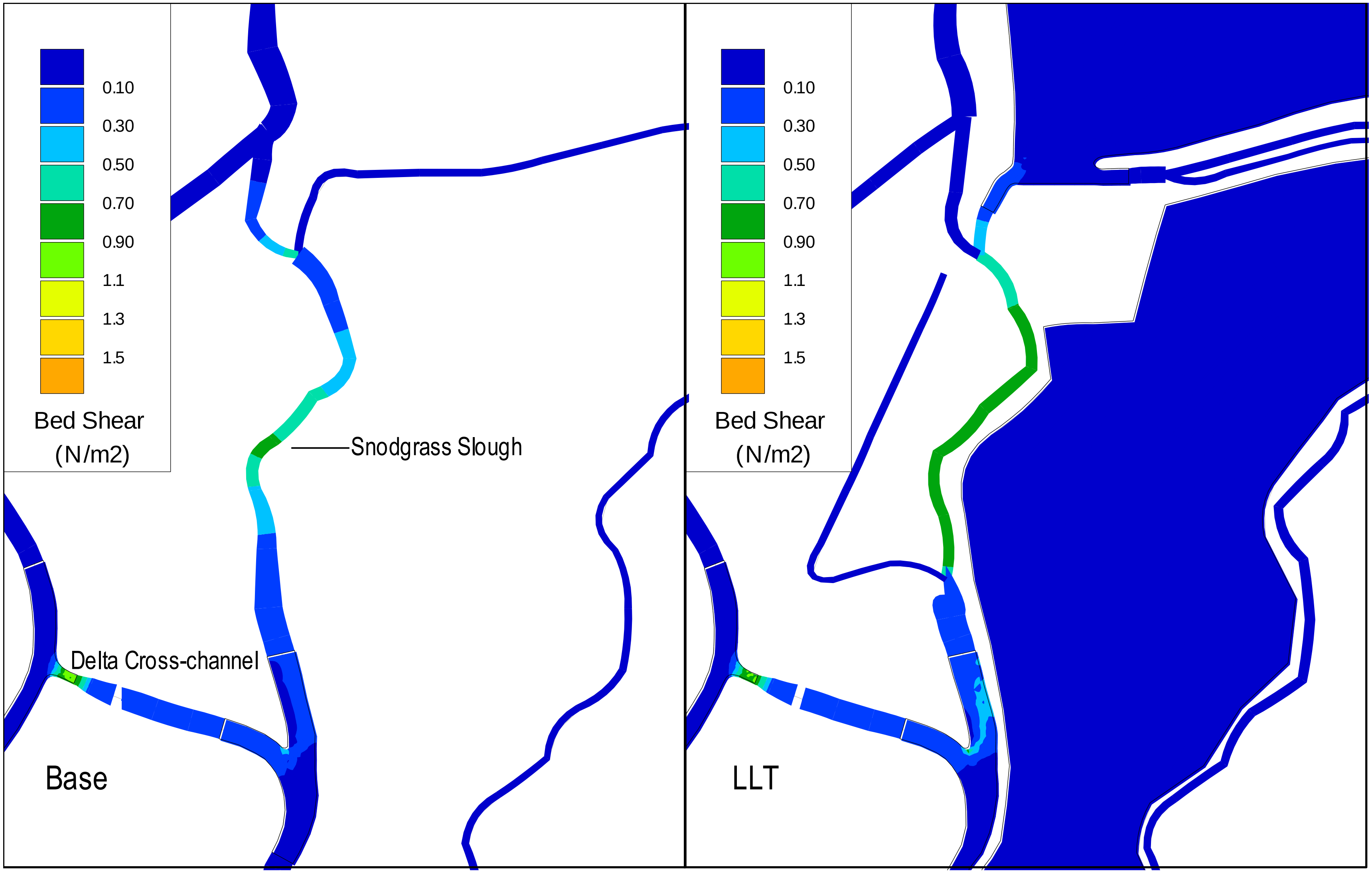


Figure 5-92 Bed shear in Snodgrass Slough for the Base case and LLT scenario during July 2002.

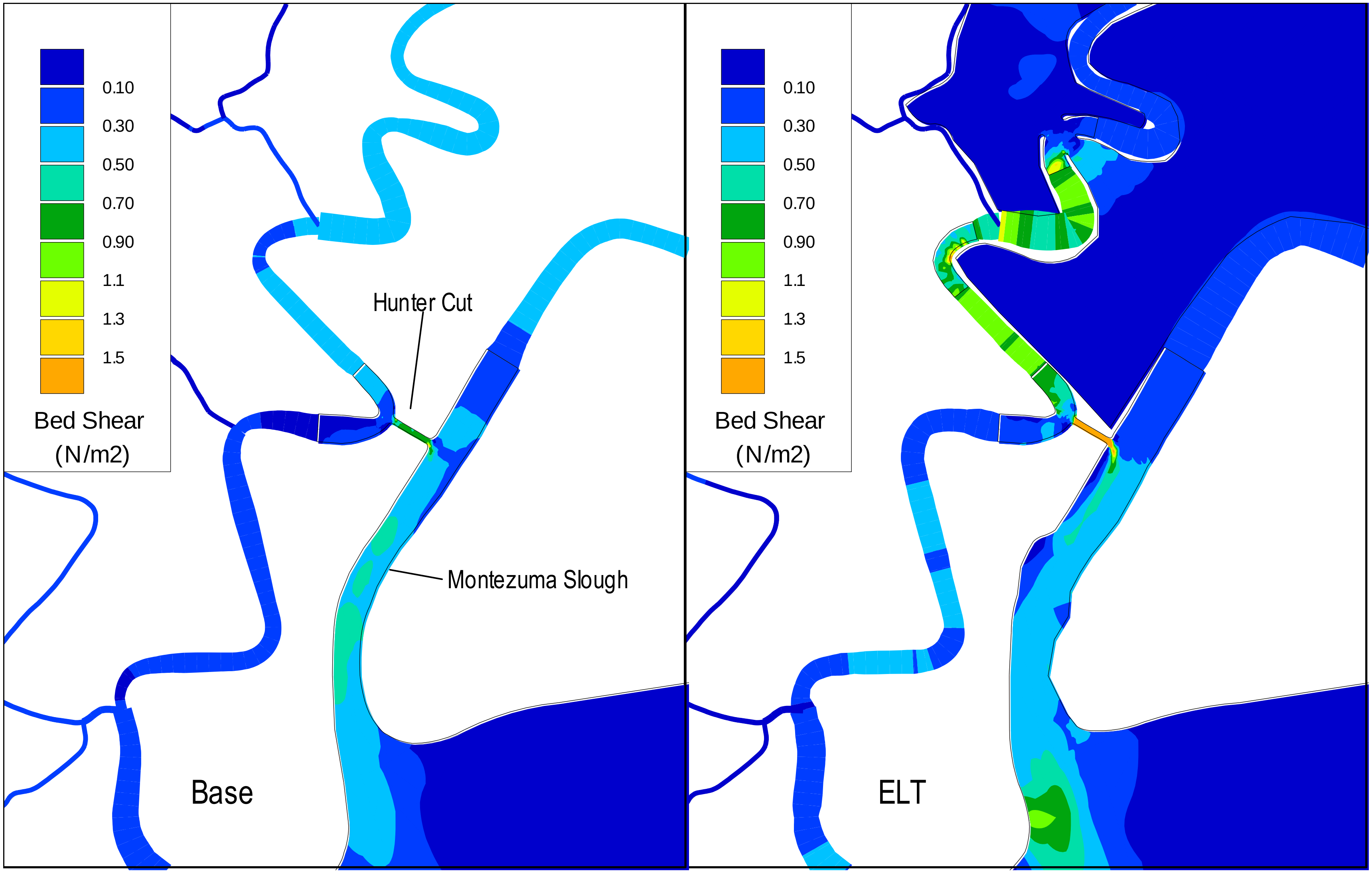


Figure 5-93 Bed shear in Suisun Slough and mouth of Montezuma Slough for the Base case and ELT scenario during July 2002.

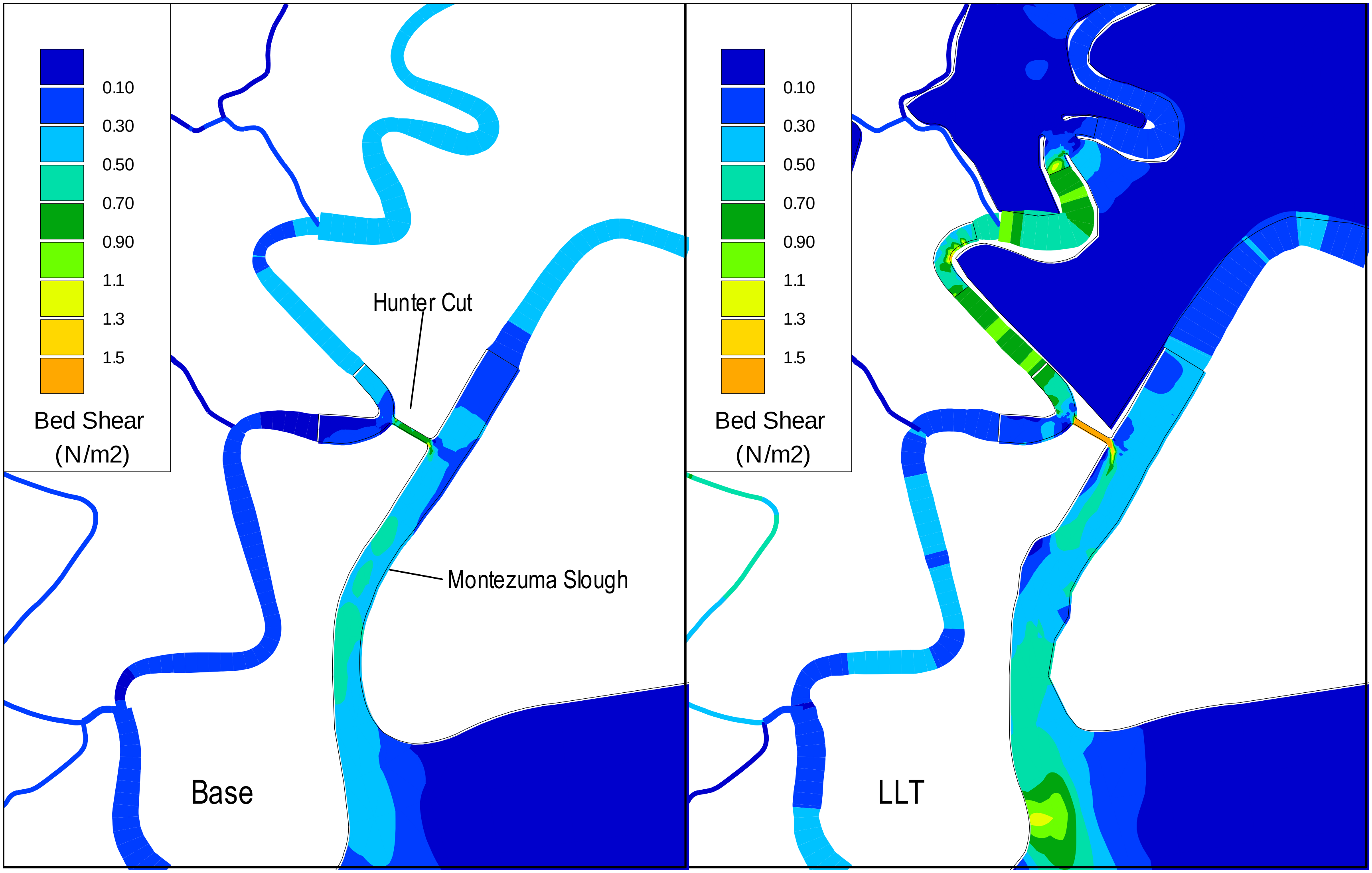


Figure 5-94 Bed shear in Suisun Slough and mouth of Montezuma Slough for the Base case and LLT scenario during July 2002.

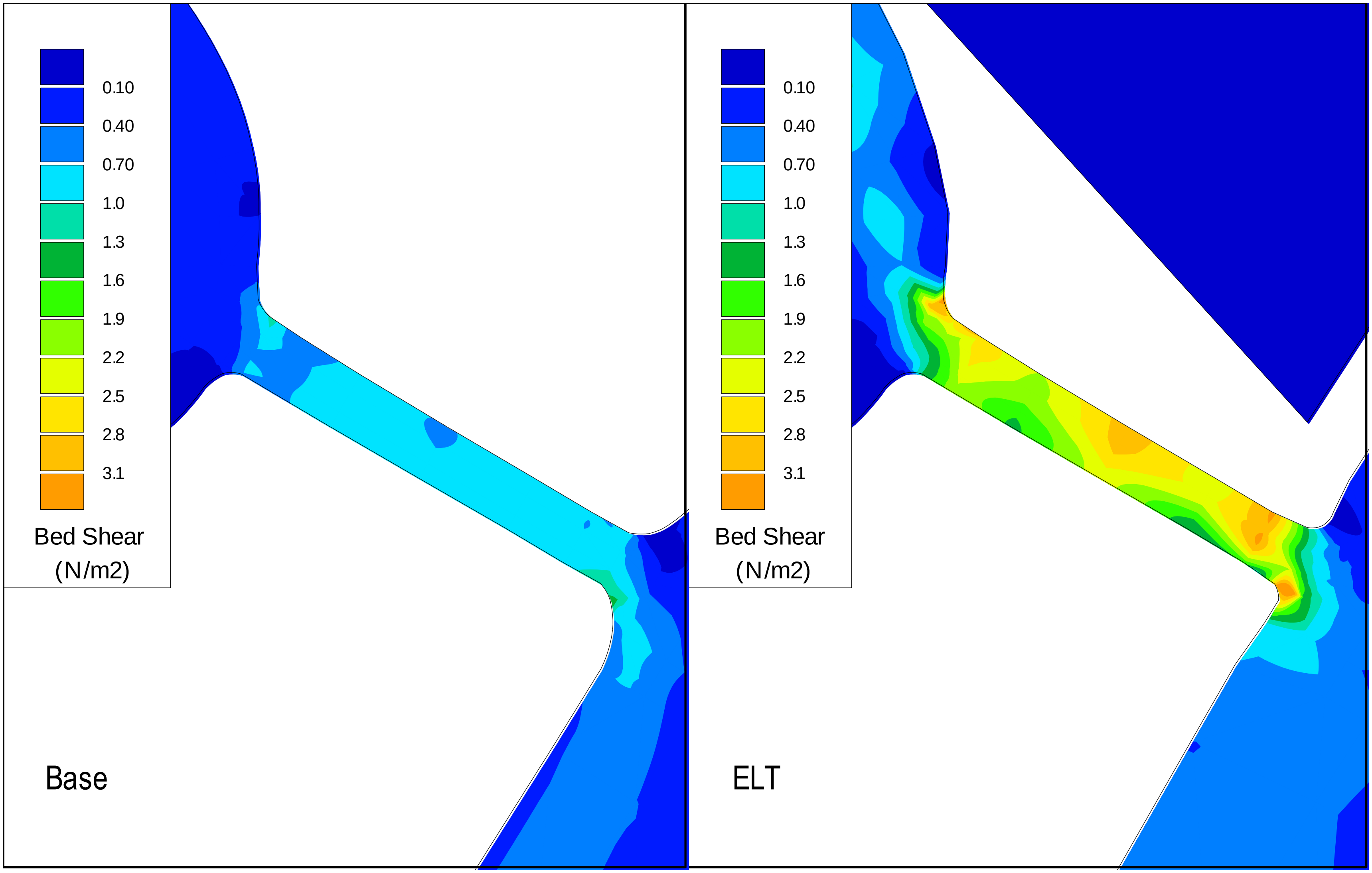


Figure 5-95 Bed shear in Hunter Cut for the Base case and ELT scenario during July 2002. NOTE BED SHEAR SCALE DIFFERS FROM PREVIOUS PLOTS.

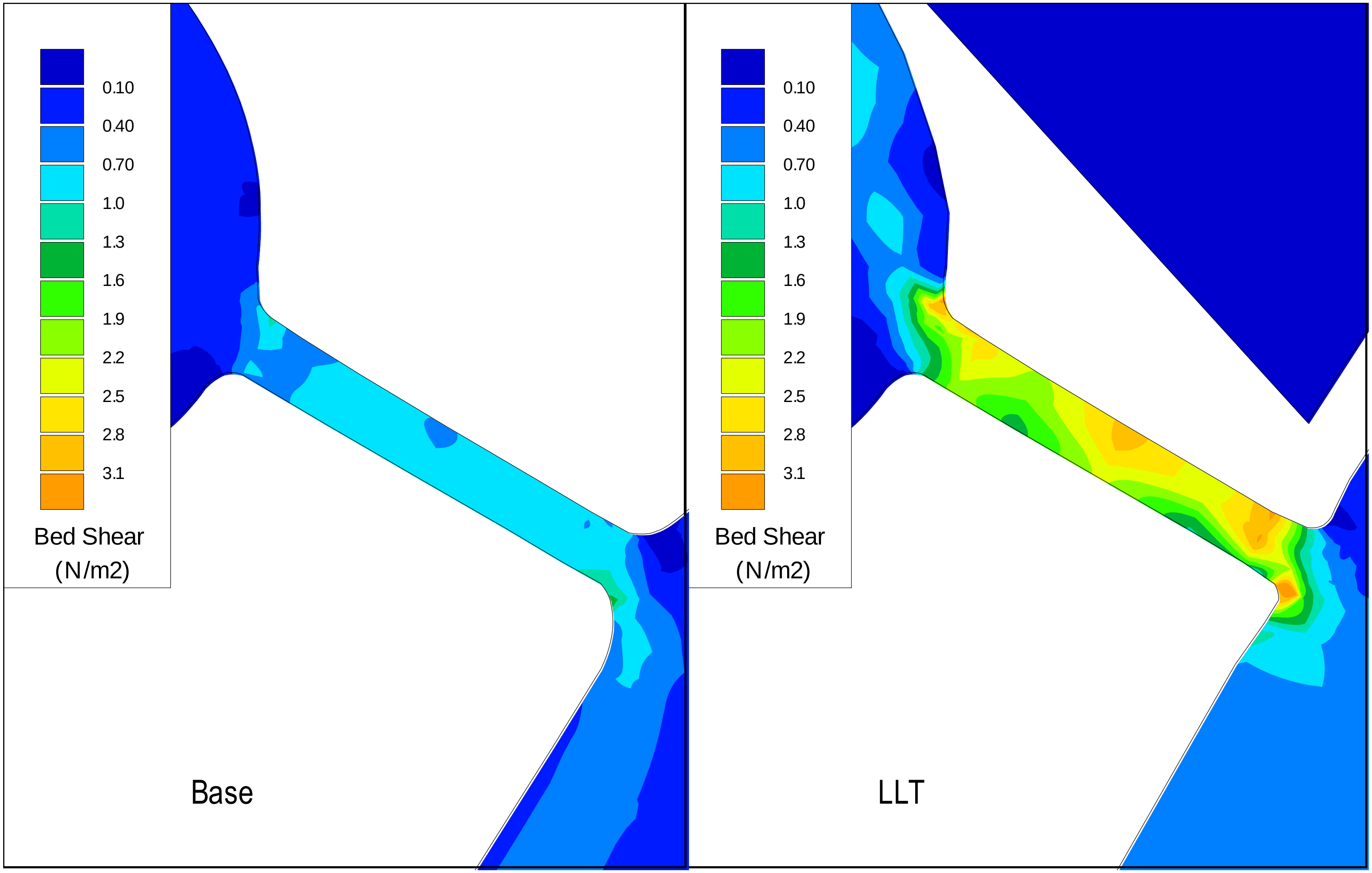


Figure 5-96 Bed shear in Hunter Cut for the Base case and LLT scenario during July 2002. NOTE BED SHEAR SCALE DIFFERS FROM PREVIOUS PLOTS.

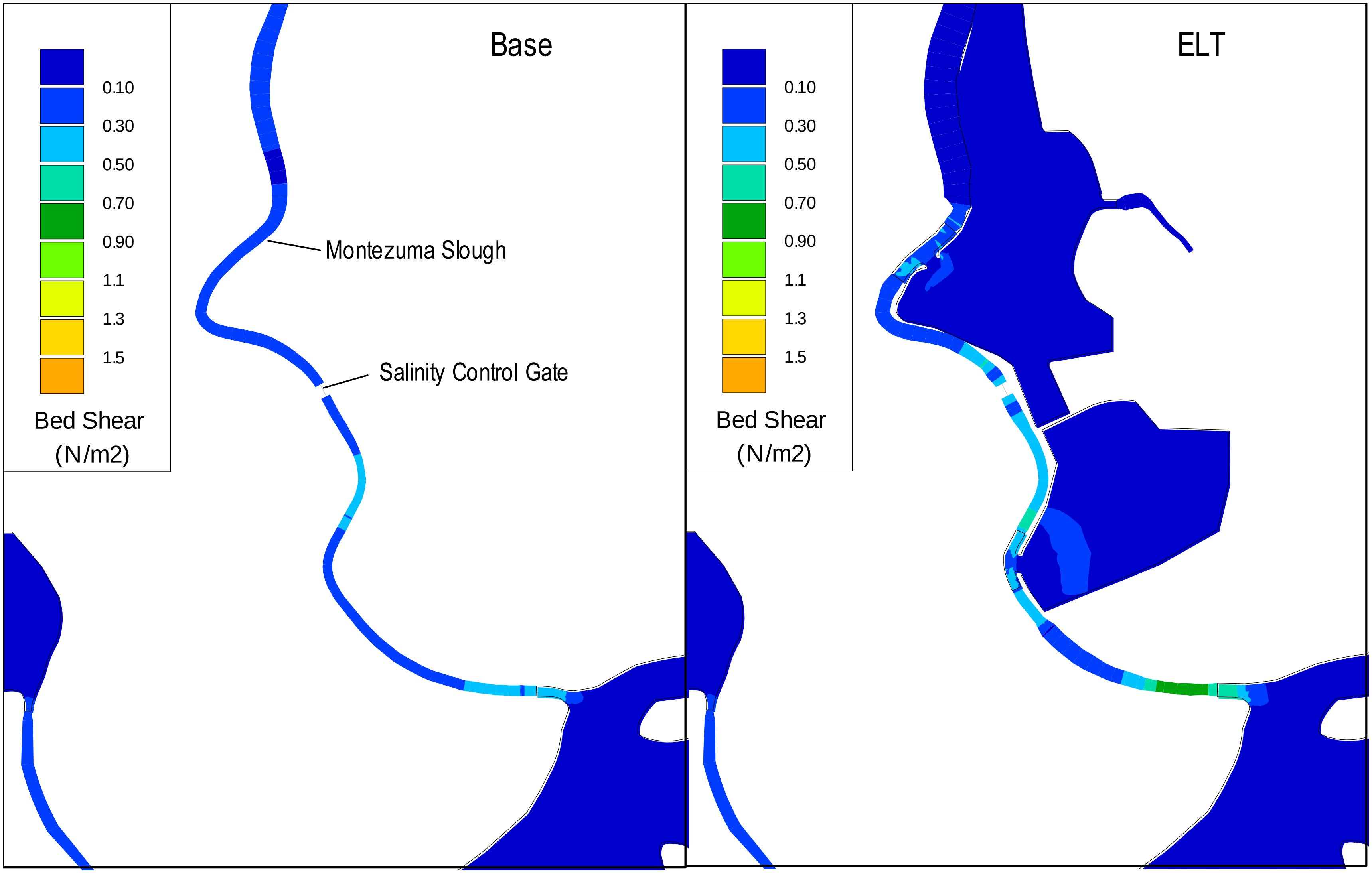


Figure 5-97 Bed shear in Montezuma Slough at head for the Base case and ELT scenario during July 2002.

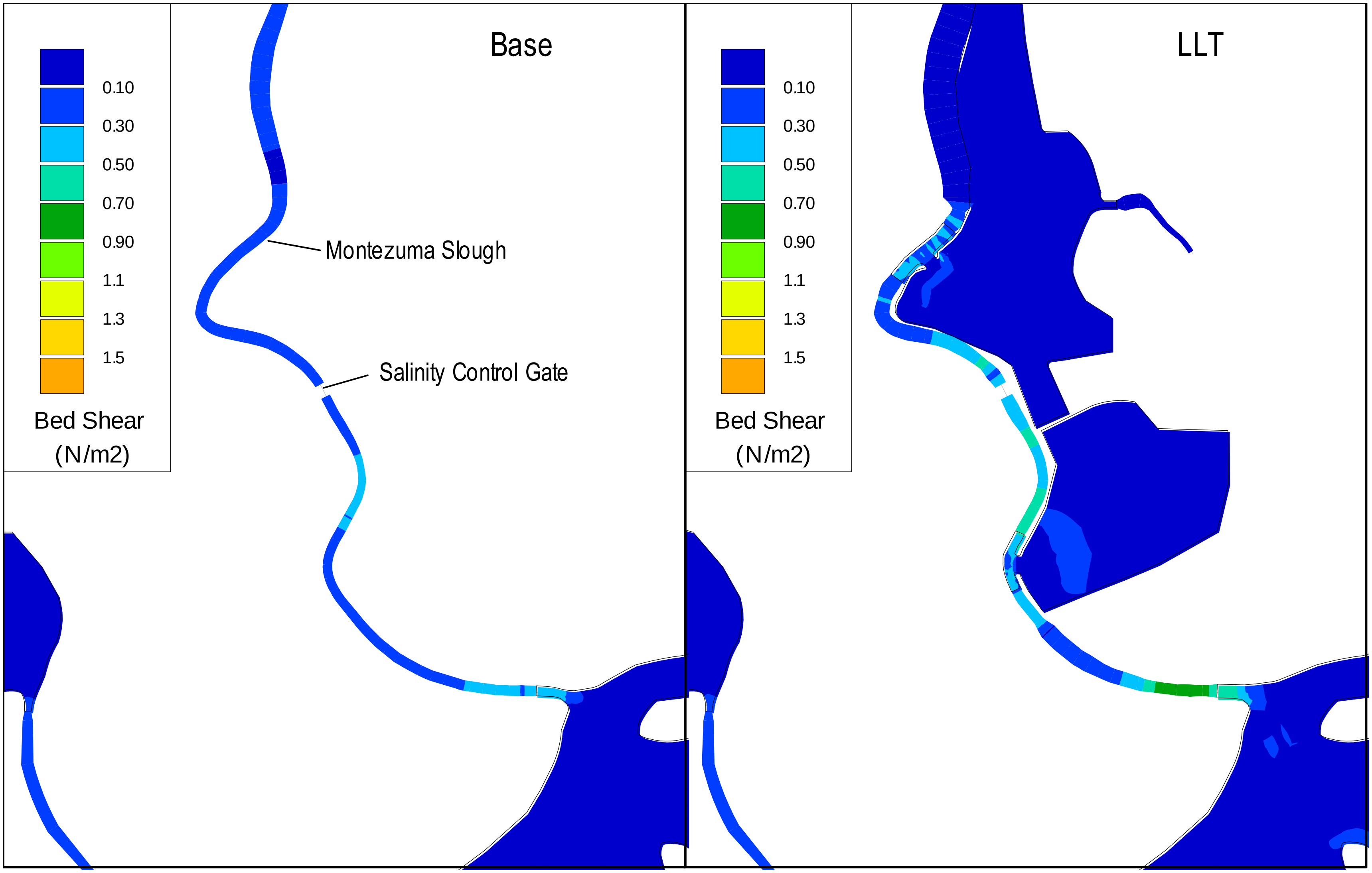


Figure 5-98 Bed shear in Montezuma Slough at head for the Base case and LLT scenario during July 2002.

Figure 5-99 Bed shear near East Delta ROA for the Base case and LLT scenario during July 2002.

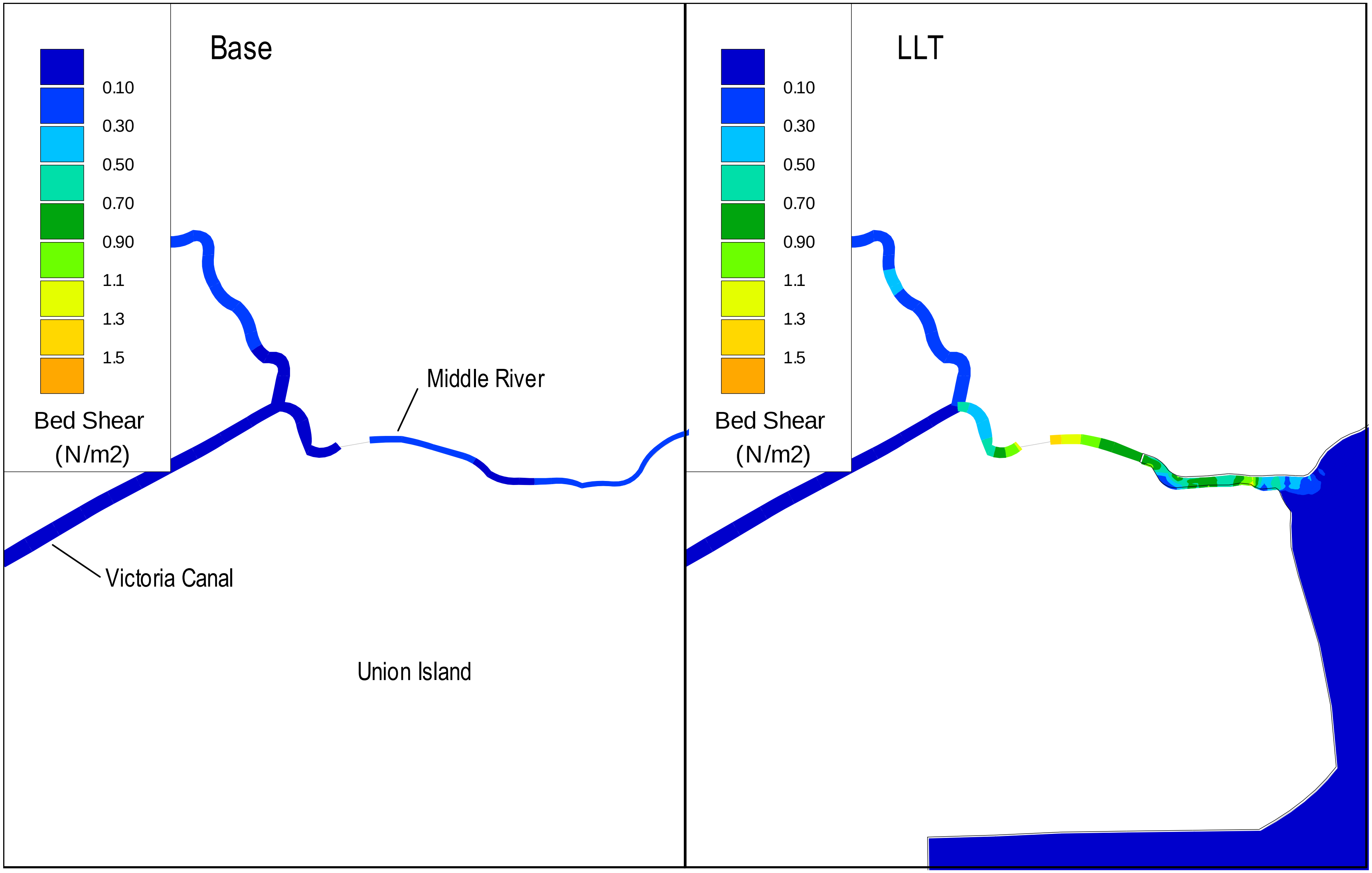


Figure 5-100 Bed shear in Middle River near Union Island for the Base case and LLT scenario during July 2002.

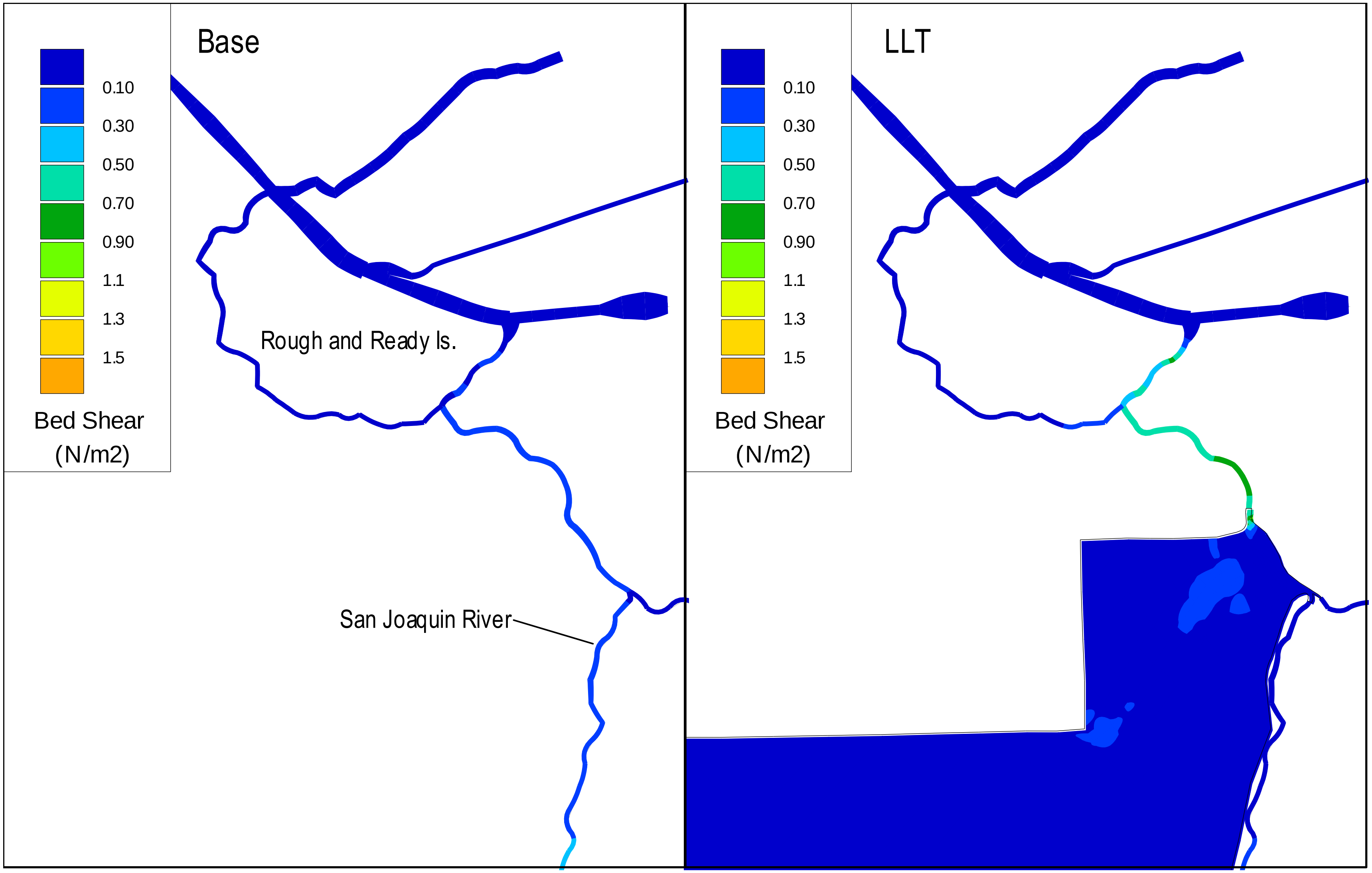


Figure 5-101 Bed shear in San Joaquin River near Roberts Island for the Base case and LLT scenario during July 2002.

5.8 Hydrodynamics summary

The hydrodynamic impacts of tidal marsh restoration vary by location and by the placement and size of restoration areas. The impacts include

- Transfer of net flows within the Delta
- Increase in the volume filling and draining during a spring-neap cycle
- Change in tidal flow volume at specific channel locations
- Reduction in stage range
- Changes in channel velocity and bed shear

Transfer of Net Flow from Georgiana Slough and the Delta Cross Channel toward the Sacramento River

Averaged flows at RSAC128, through the Delta Cross Channel and through Georgiana Slough decrease with added restoration area (Figure 5-29). Conversely, the averaged flows in the Sacramento River at Emmaton and Rio Vista increase with additional restoration area. This change appears to be from a combination of decreased tidal range on the Sacramento River near Georgiana Slough and the Delta Cross Channel and the connection of Miner Slough to the Sacramento Ship Channel through the restoration of Prospect Island.

Figure 5-8 shows for the NT, ELT and LLT there is about a 600 cfs increase in tidally averaged flow for Miner Slough upstream of the Prospect Island breach opening. The connection between Miner Slough and the Ship Channel through Prospect Island thus appears to increase the overall conveyance capacity between the Sacramento River above the DCC through Sutter and Steamboat Sloughs to the lower Sacramento River system. However, Table 5-1 shows averaged flow for the Sacramento River at Rio Vista increases from Base 835 cfs for the NT, 1017 cfs for the ELT, and 1459 cfs for the LLT. Thus the channel through Prospect Island is not the only mechanism for the flow transfer from Georgiana Slough and the DCC to the Sacramento River at Rio Vista.

The simulations performed in earlier stages of the study examining the restoration areas (e.g. Cache Slough ROA, Suisun Marsh ROA) on an individual basis, although not included in the current report, are useful to help understand the contributing impacts of the individual restoration areas. The previous Cache Slough restoration simulation, with only a single breach on Prospect Island, does shift some flow from Georgiana Slough and the Cross Channel to Rio Vista, indicating that the Cache Slough ROA, regardless of the Prospect Island breach configuration, is at least partly the cause of the flow shift seen in the current results. The previous individual Suisun Marsh ROA simulation showed a small shift in flow from Georgiana Slough and the Cross Channel to Rio Vista.

Increase in Volume filling and draining the Delta between Spring and Neap Tide Cycle

In general, there are overall increases in the fluctuations in tidally averaged flow over the neap-spring tide cycle downstream of the restoration areas. Average water surface elevation increases in the restoration areas during the spring tide period and decreases during the neap tide period. An example of this action is shown in Figure 5-102, a plot of stage and tidally averaged stage for the LLT case in “Egbert A”, a restoration area in Cache Slough. With this increasing and decreasing average water surface elevation, the restoration areas are “filling” up to the peak of the spring tide and "draining" afterwards. This phenomenon is seen in the tidally averaged flow time series for Nurse Slough (Figure 5-21) and Beldon's Landing (Figure 5-20). The tidally averaged flow for Boynton Slough shows the opposite effect (Figure 5-24). There is no restoration area upstream of the Boynton Slough flow location. Tidal range and tidal flow is reduced in Boynton Slough for each restoration step of Suisun Marsh. In the San Joaquin River at Jersey Point (Figure 5-14), the fluctuations in the tidally averaged flows over the spring-neap cycle are superimposed over changes in monthly averaged flows for each restoration case. During the spring tide period (before peak spring tide) the LLT tidally averaged value is less than the Base value. During the transition to the neap tide, the LLT tidally averaged flow exceeds the Base case value.

Change in Tidal Flow Volume

Tidal flow results are varied (Figure 5-30 and Figure 5-31). Changes at Martinez are minimal (1-2%). Restoration in Suisun Marsh results in significant changes in tidal flow in Montezuma Slough (60-110%), particularly at the mouth. Tidal flow at the head of Montezuma Slough is increased by around 60% for all restoration cases, however with added restoration area between the NT and ELT, there is a slightly smaller increase in tidal flow because all of the added restoration is at the far eastern edge of the marsh. At Chipps Island, percent changes in tidal flow are small, ranging from -4% for the NT to -6% for the LLT. These reductions are the result of Suisun Marsh restoration. Emmaton sees the influence of reduced tidal flow from the downstream restoration in Suisun Marsh and increased tidal flow from the upstream restoration in Cache Slough. The result is a reduction of 1% for the NT, no change for the ELT and an increase of 3% for the LLT. With each time step, the area of restoration in Cache becomes proportionally larger than the Suisun restoration. This influences the shift from a slightly negative change in tidal flow for the NT to a slightly positive change for the LLT. Rio Vista is under similar influence, but more impacted by the Cache restoration. There is no change in tidal flow for the NT scenario, but tidal flow increases as more restoration area is added. There is a 2% increase for the ELT and a 12% increase for the LLT. The deeper areas added in the southern part of Cache Slough for the LLT scenario, as well as the flow-through breaches on Little Egbert, have a more pronounced impact on tidal flows than the areas of the NT and ELT scenarios. At Jersey Point, tidal flow decreases by 6% for NT and ELT and by 11% for the LLT. These decreases indicate that tidal flows at this location are impacted by downstream restoration in Suisun Marsh. In Middle River, NT, ELT and LLT tidal flows decrease by 8%, 10% and 17%, respectively. Tidal flow in Middle River is reduced by the downstream restoration for all restoration scenarios, but is further reduced by the South Delta restoration in the LLT scenario because flow out of the Union Island breach is out of phase with flow in the Middle River channel. This large, shallow restoration area fills and drains very slowly, so that when Middle River flows begin ebbing, Union Island is still filling. This is illustrated in Figure 5-103, which shows ELT and LLT ebb tide flows in Middle River (during a period when the Middle River barrier is open for both cases) while Union Island is still filling, resulting in reversed Middle River flows near the breach. In Cache Slough at Ryer, while tidal flow is increased by 4% and 7% for the NT and ELT restoration cases, respectively, it is decreased for the LLT case. This is because of the restoration of Little Egbert Tract, which is breached downstream of Cache Slough at Ryer and provides flow-through conveyance with a second breach at the upstream end.

Reduction of Stage Range

Restoration diminishes tidal range throughout the system. Profile plots show a pronounced decrease in MHHW and an increase in MLLW along the Sacramento (Figure 5-57Figure 5-56) and San Joaquin Rivers (Figure 5-58), Middle River (Figure 5-60) and Montezuma Slough (Figure 5-62). Note that the Middle River barrier is operating during July 2002 for the Base, NT and ELT scenarios, but is open for the LLT scenario. The impact on MSL is generally small, with reductions of 0.1 ft or less. The exceptions to this are in the south Delta. In Middle River upstream of the barrier, MSL is affected by the Middle River gate status (i.e. operating for the Base case, open for the LLT case). The reduction in MSL on San Joaquin River near the Roberts Island breach is as much as 0.16'.

Spatial plots of tidal range (Figure 5-54 and Figure 5-55) give a broad view of the impacts of restoration on tidal range. The diminishment of tidal range with each time step can be clearly seen throughout the Delta and Suisun Marsh. In addition, areas of steep gradients in tidal range indicate restricted conveyance either due to restrictive channels or shallow restoration areas. This is further discussed below, in relation to bed shear.

Profile plots of tidal range indicate that it is progressively diminished as more restoration area is added. In Montezuma Slough (Figure 5-63) and the Sacramento River (Figure 5-57) near Threemile Slough, tidal range reductions are as much as 1.1' for the LLT scenario. On the San Joaquin River (Figure 5-59) near the Roberts island breach, the peak reduction in tidal range is 2.1' for the LLT scenario.

Change in Velocity and Bed Shear

Velocities tend to increase downstream of restoration areas (for example LLT restoration in Nurse Slough increases velocities, Figure 5-78) and decrease upstream of restoration areas (for example RSAC128, Figure 5-70). Results are varied in locations with both upstream and downstream restoration. For example at Jersey Point (Figure 5-74) peak flood and ebb velocity magnitudes are reduced for all restoration scenarios. NT and ELT velocity peaks are virtually the same, while the LLT peaks are reduced slightly more. At Rio Vista (Figure 5-72) peak ebb velocity magnitudes increase with added restoration area. Peak flood velocity magnitudes for the NT and ELT do not vary from Base while increases are seen for the LLT scenario. Threemile Slough velocity magnitudes decrease with added restoration area. The largest velocity increases occur in Hunter Cut. ELT results in slightly more increase in ebb tide velocity peaks relative to the LLT at this location, while the two cases have very similar increases in peak flood tide velocity magnitude.

Contour plots of bed shear for the ELT and LLT scenarios in comparison with Base case show that high bed shear values for both the ELT and LLT scenarios occur in Cache Slough (Figure 5-83 and Figure 5-84), Miner Slough (Figure 5-85 and Figure 5-86), west of the Delta Cross Channel (Figure 5-87 and Figure 5-88), Snodgrass Slough (Figure 5-91 and Figure 5-92), Dutch Slough (Figure 5-89 and Figure 5-90), Suisun Slough (Figure 5-93 and Figure 5-94), Montezuma Slough at head and mouth (Figure 5-97 and Figure 5-98), and Hunter Cut (Figure 5-95 and Figure 5-96). For the LLT case only, high bed shear values occur near the East Delta ROA (Figure 5-99), in Middle River near Union Island (Figure 5-100) and in San Joaquin River near Roberts Island (Figure 5-101).

The greatest increases and highest bed shear values occur in Hunter Cut, where bed shear exceeds 3 N/m^2 for both the ELT and LLT scenarios. A higher ranging bed shear contour scale had to be used for the Hunter Cut plots to best display the high values.

Potential areas of higher bed shear can also be seen in the color contour plots of tidal range in Figure 5-54 and Figure 5-55. Steep gradients of tidal range indicate restrictive channels. Examples of restrictive channels leading to restoration areas in the LLT scenario are eastern Suisun Marsh, the East Delta restoration area and the South Delta restoration area. Note that while the Base, NT and ELT scenarios show a sudden diminishment of tidal range in upstream Middle River, this is the result of the operation of the Middle River barrier. For the LLT scenario, this barrier is open and the steep tidal range gradient does indicate channel restriction.

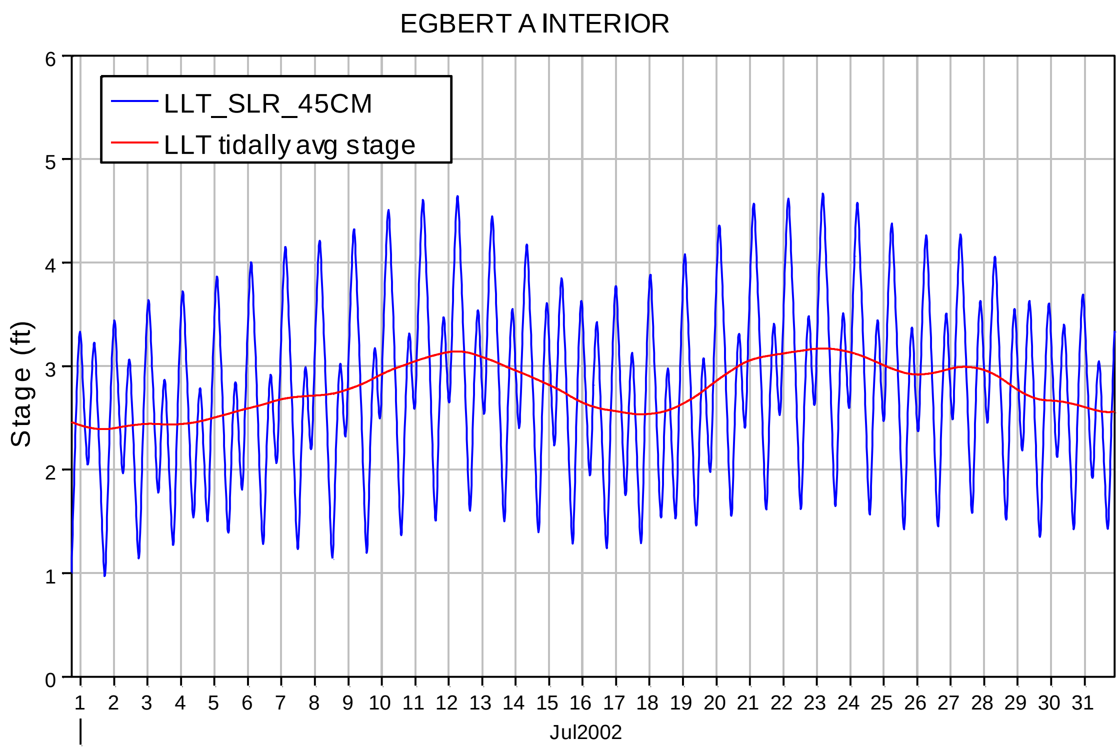


Figure 5-102 Stage and tidally averaged stage in "Egbert A" in the Cache Slough restoration area for the LLT scenario.

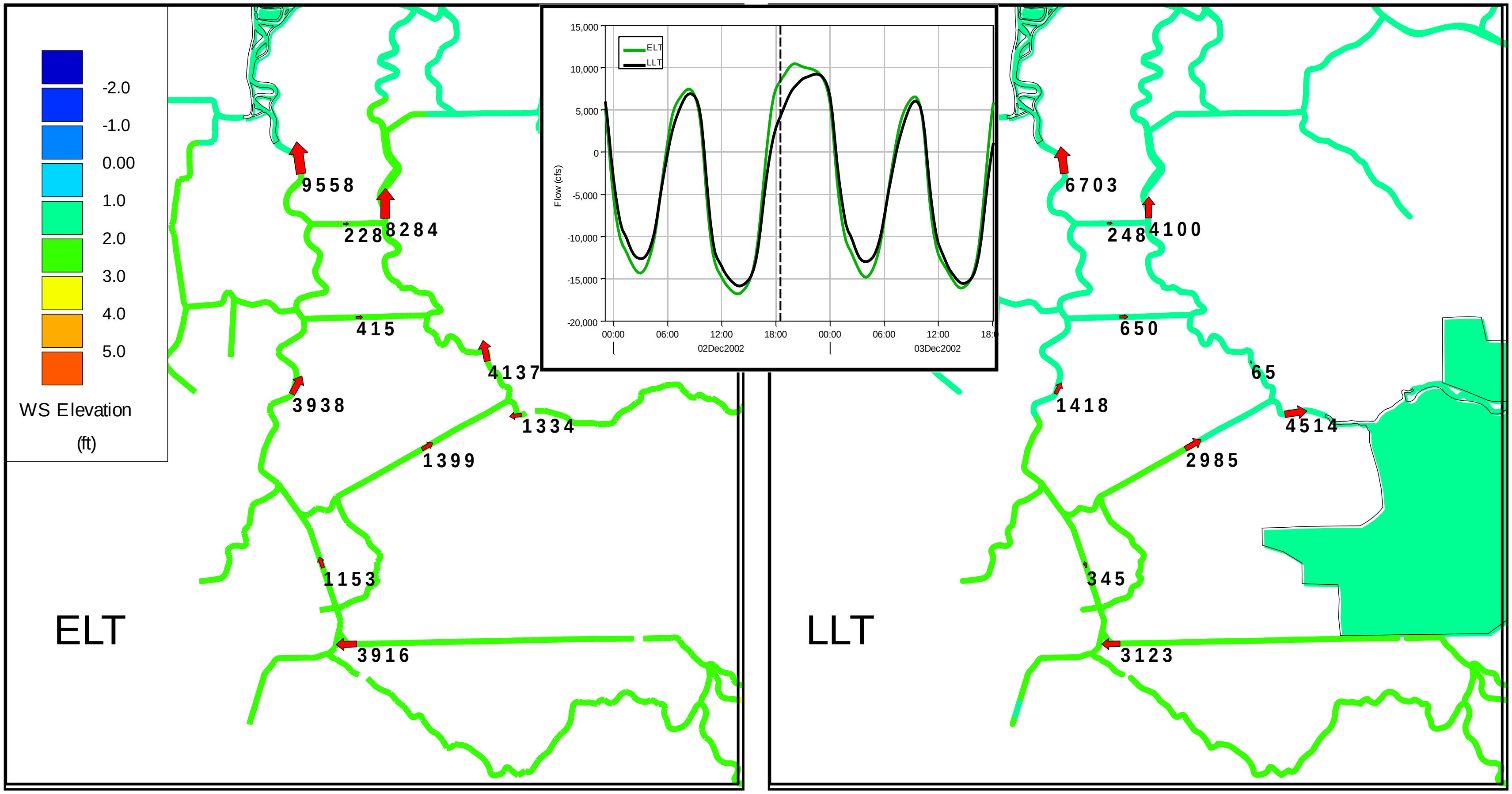
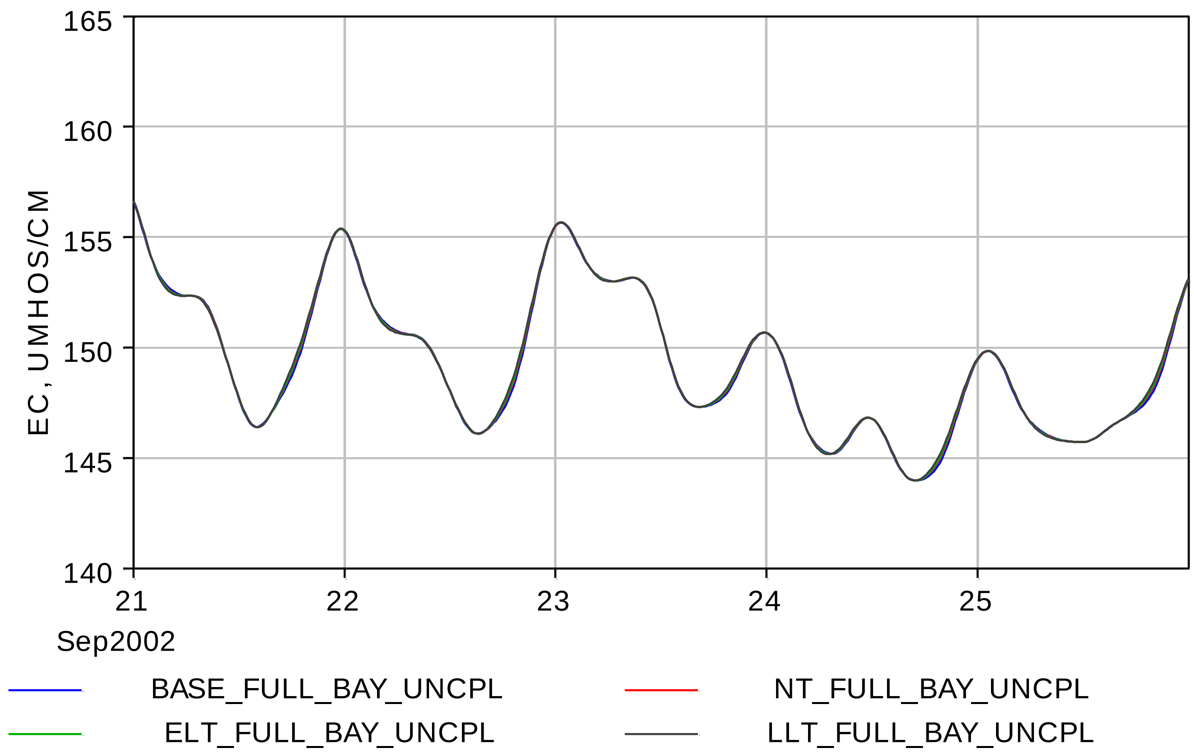


Figure 5-103 Illustration of reduced tidal flow in Middle River for the LLT scenario relative to the ELT scenario. Red arrows are scaled to flow, indicated in cfs.

6 Electrical Conductivity (EC)

6.1 Dynamic and Tidally averaged EC time series

Time series plots of EC during the end of September 2002 and tidally averaged EC for the entire simulation period (April 2002 through December 2003) are plotted for the Base case, NT, ELT and LLT restoration scenarios at select locations in Figure 6-1 through Figure 6-24. Note that the EC scales vary for all plots.



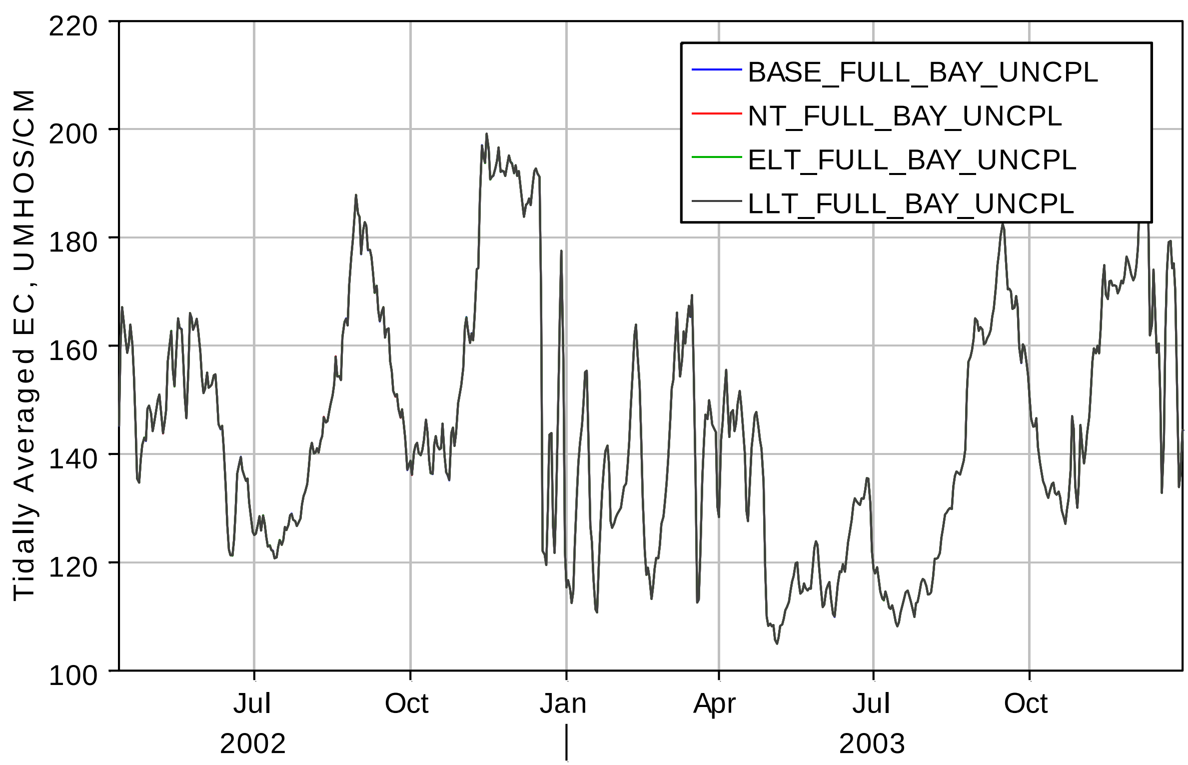
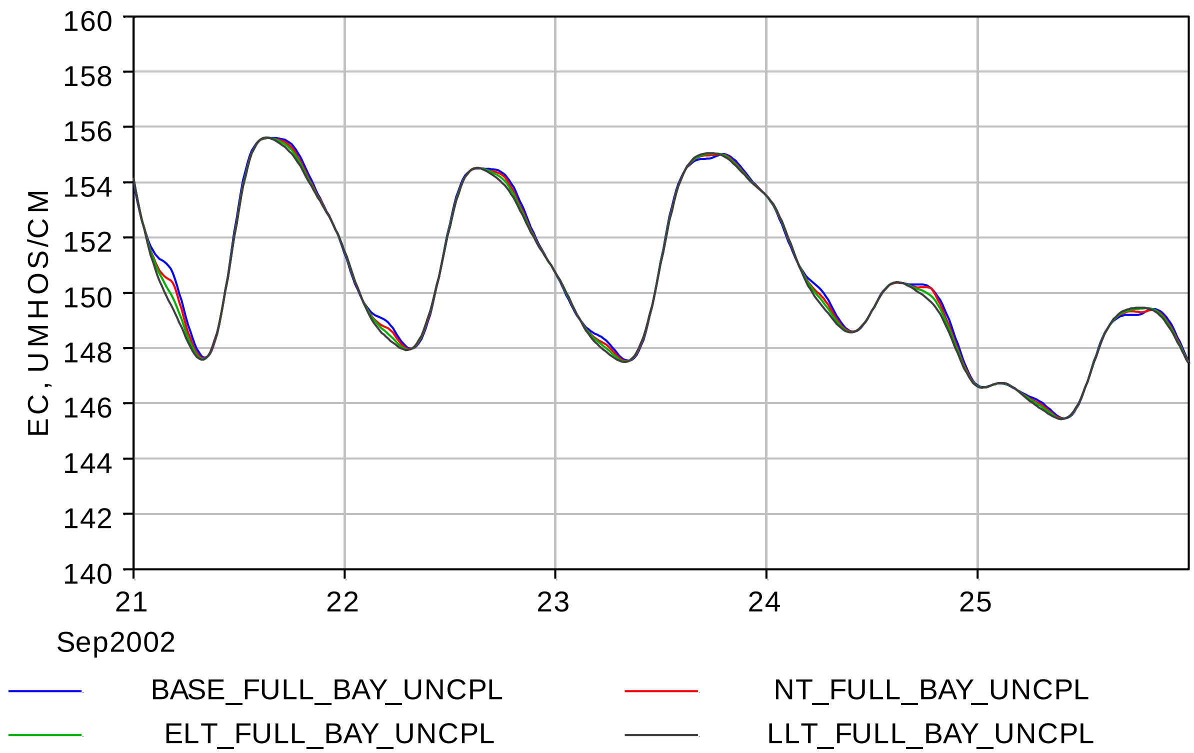


Figure 6-1 EC and tidally averaged EC at Freeport for Base case, NT, ELT and LLT scenarios.



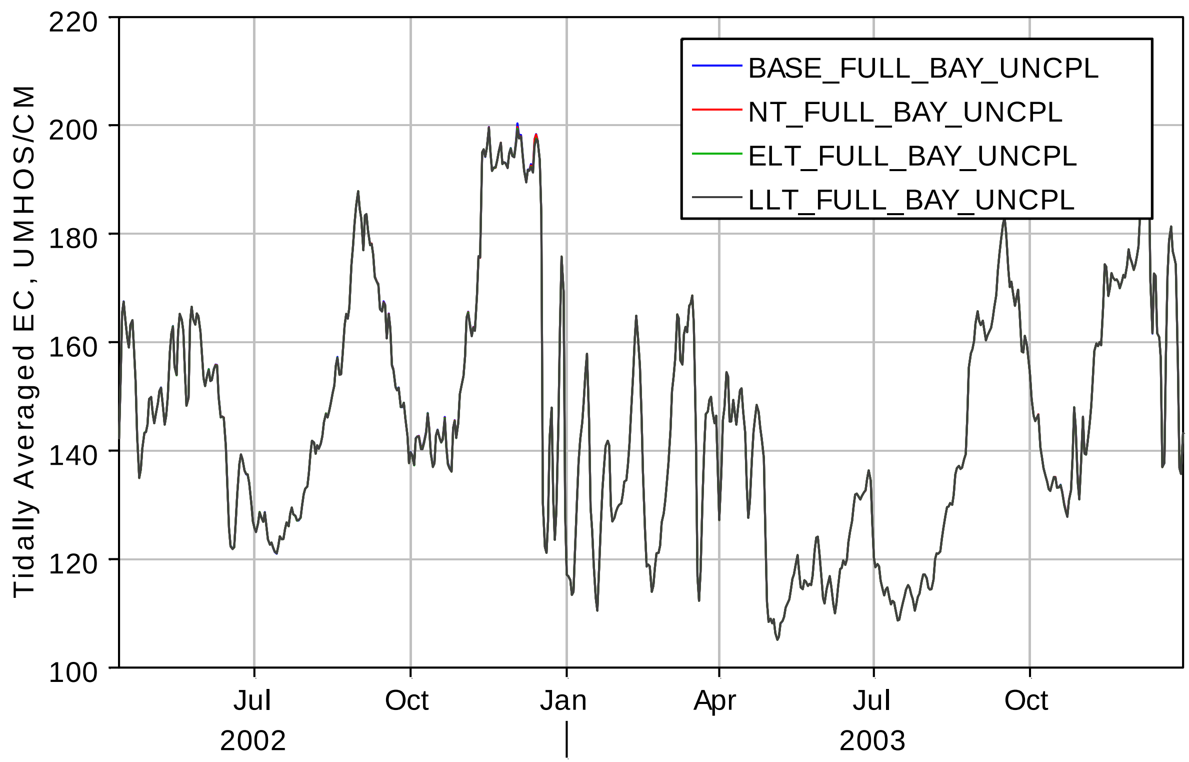
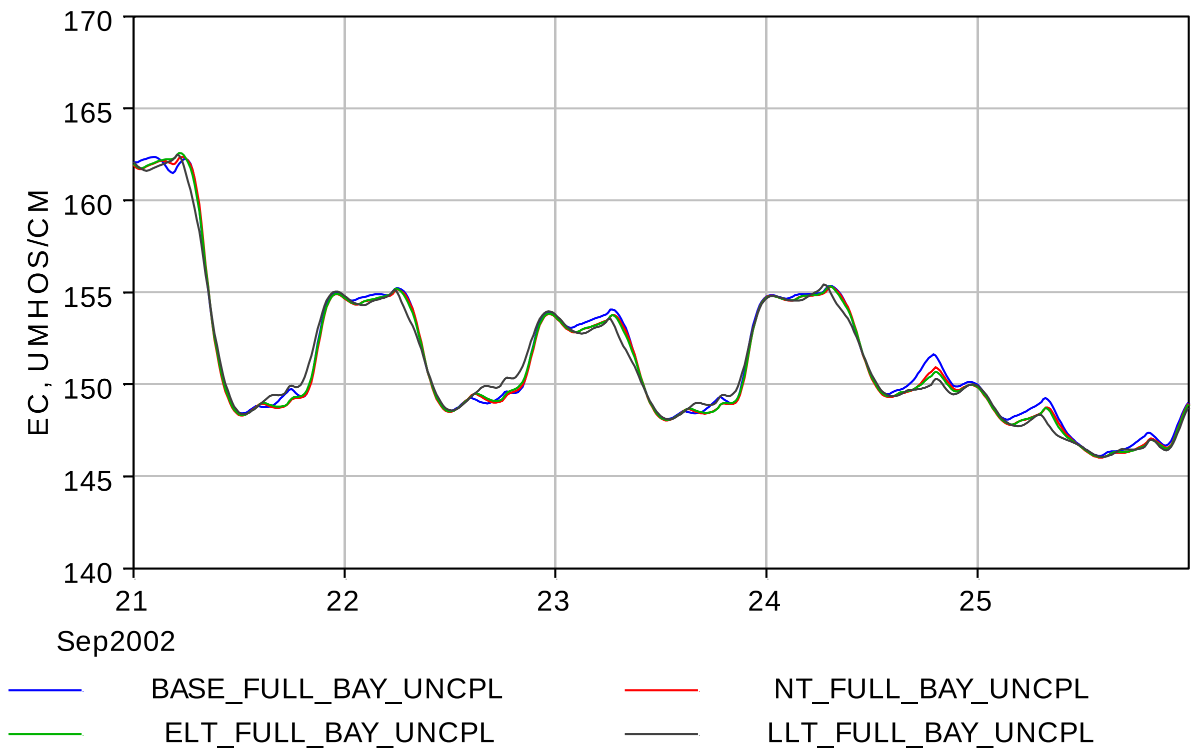


Figure 6-2 EC and tidally averaged EC in Sutter Slough near Sacramento R. for Base, NT, ELT and LLT scenarios.



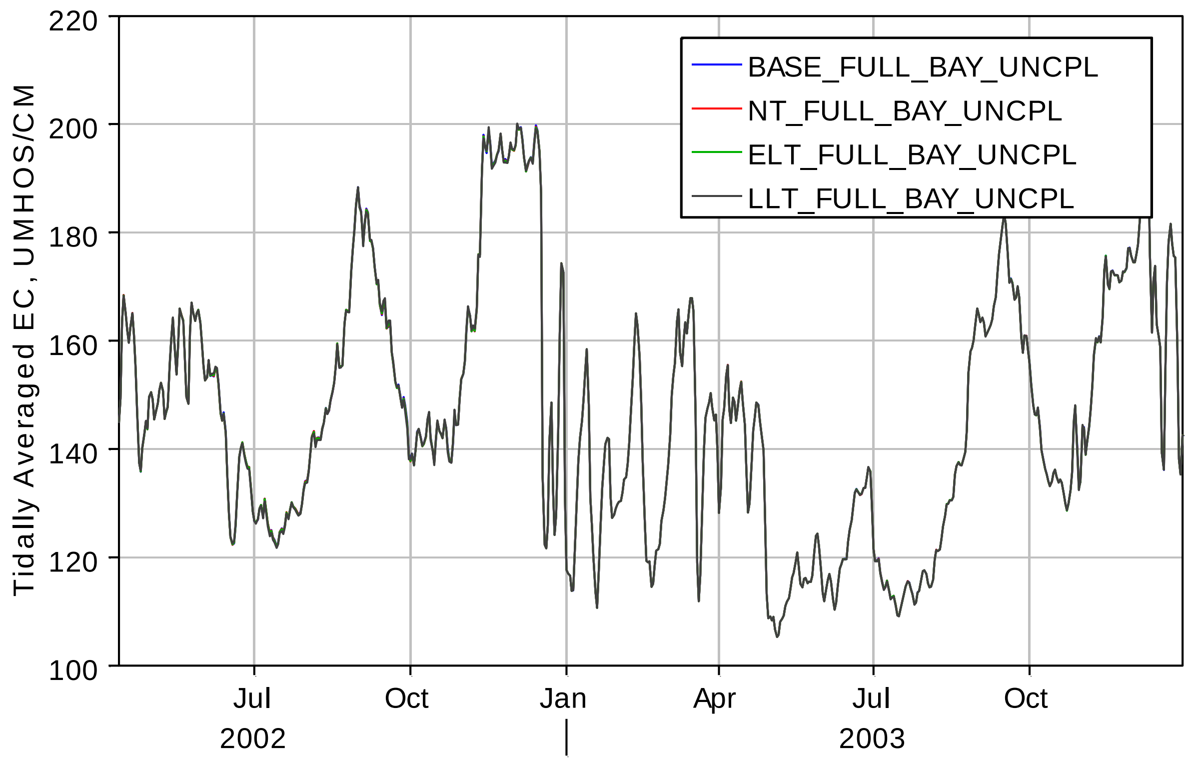
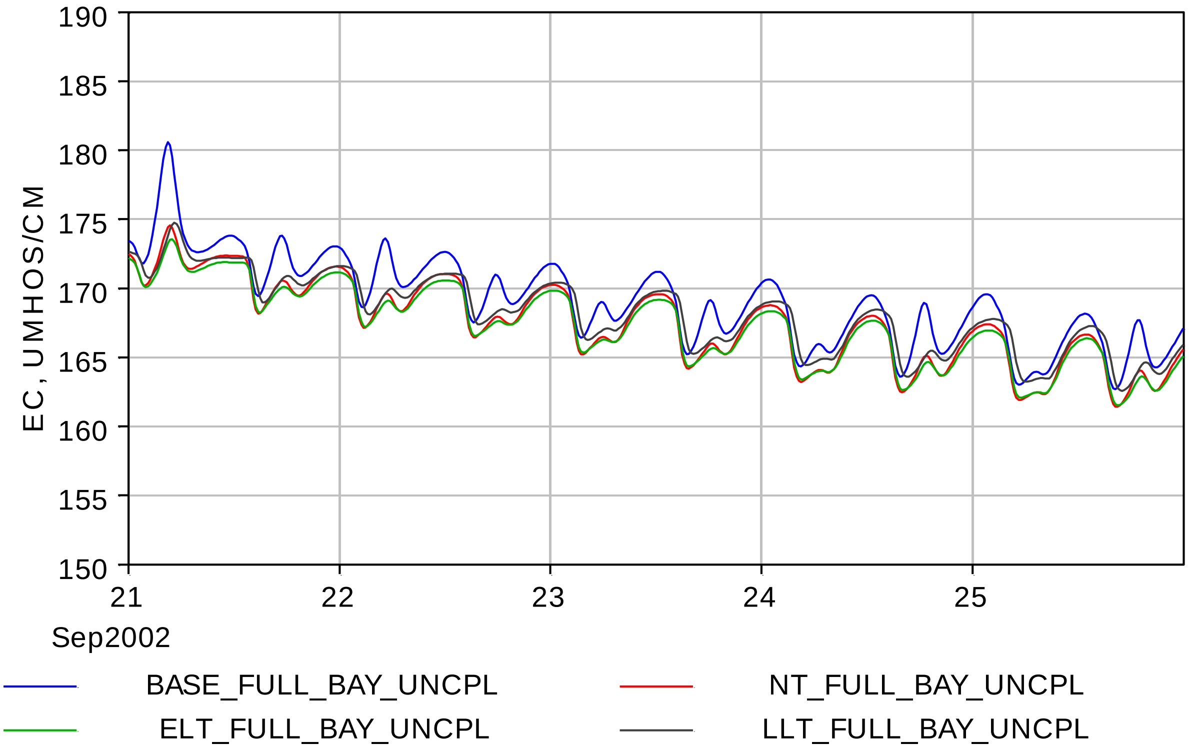


Figure 6-3 EC and tidally averaged EC in Steamboat Slough for Base, NT, ELT and LLT scenarios.



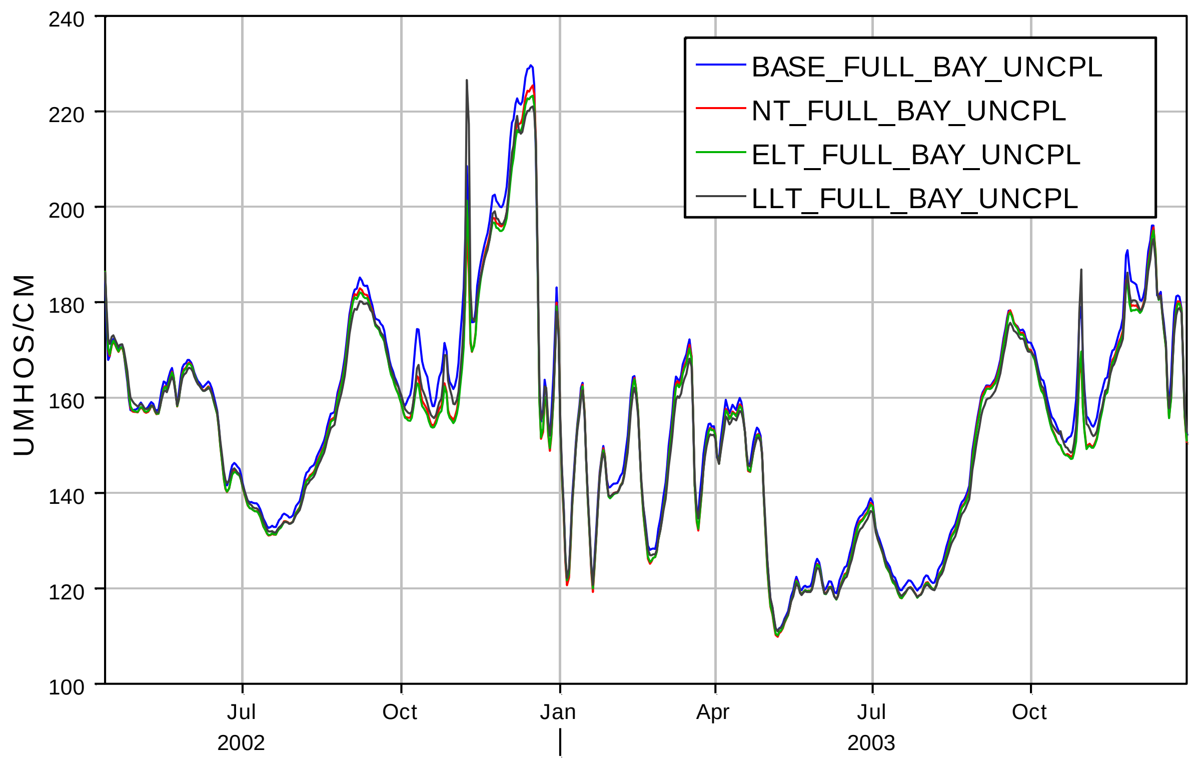
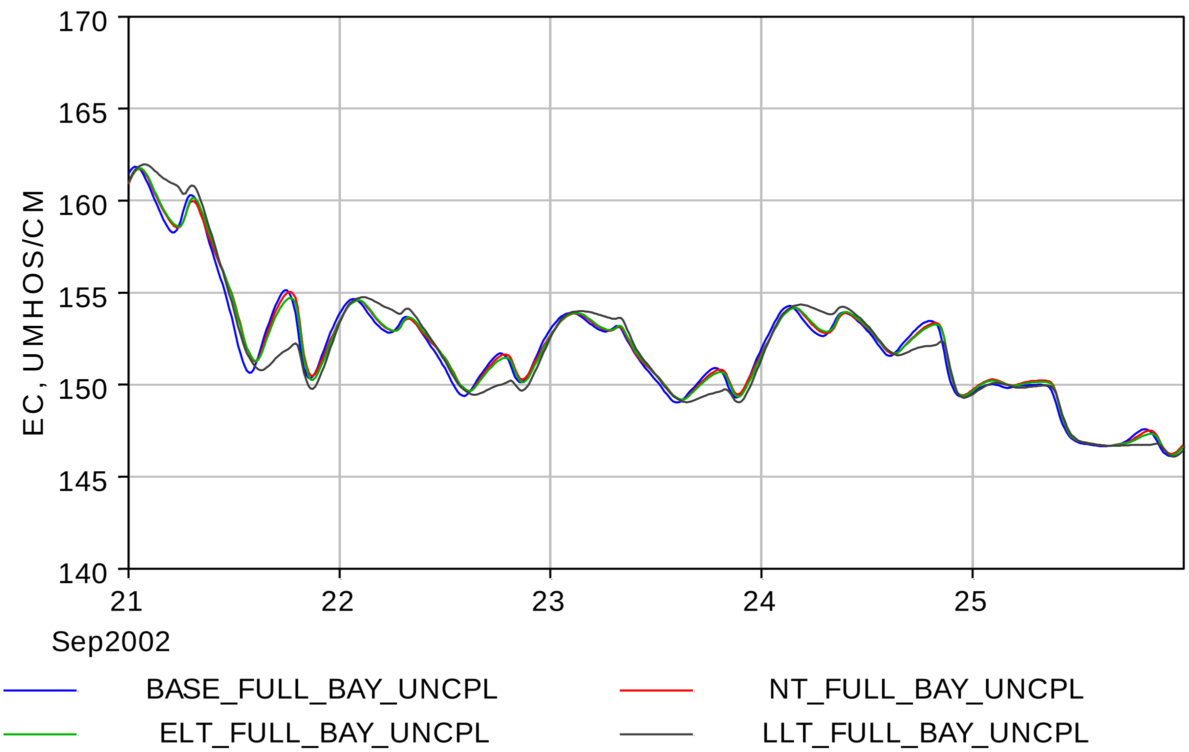


Figure 6-4 EC and tidally averaged EC in Cache Slough at Ryer Island for Base, NT, ELT and LLT scenarios.



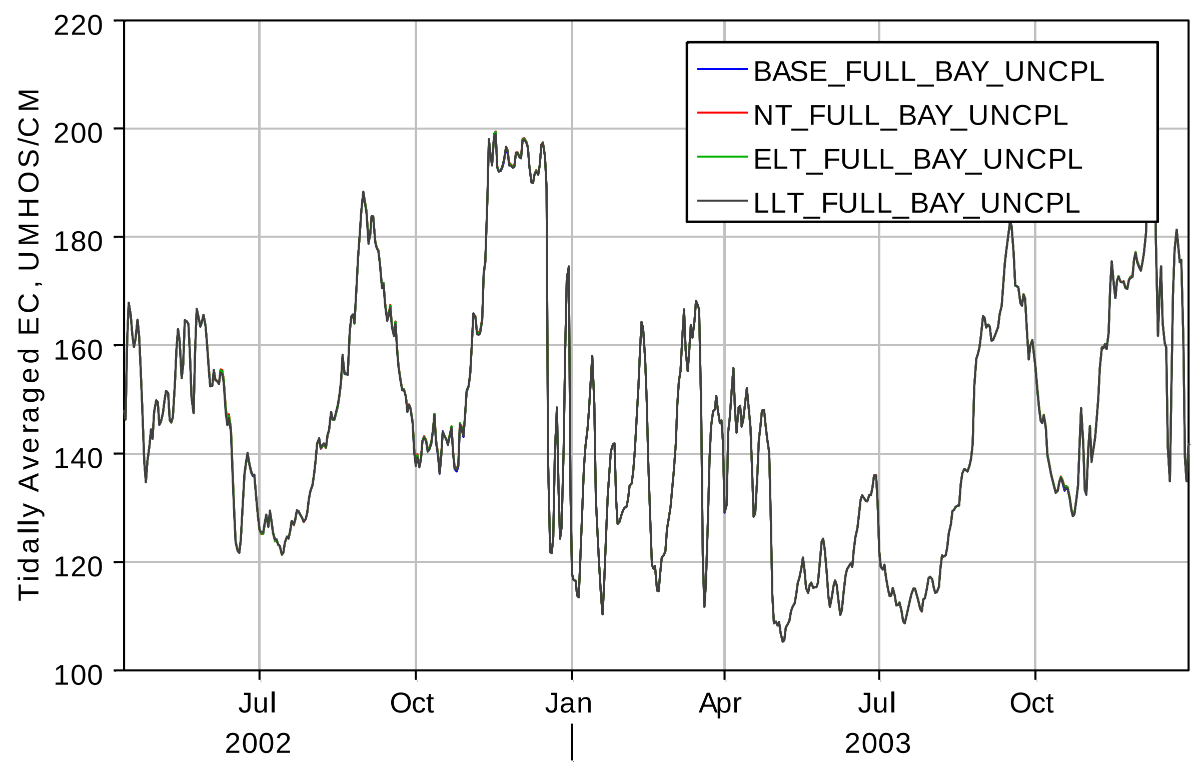


Figure 6-5 EC and tidally averaged EC in Georgiana Slough at head for Base, NT, ELT and LLT scenarios.

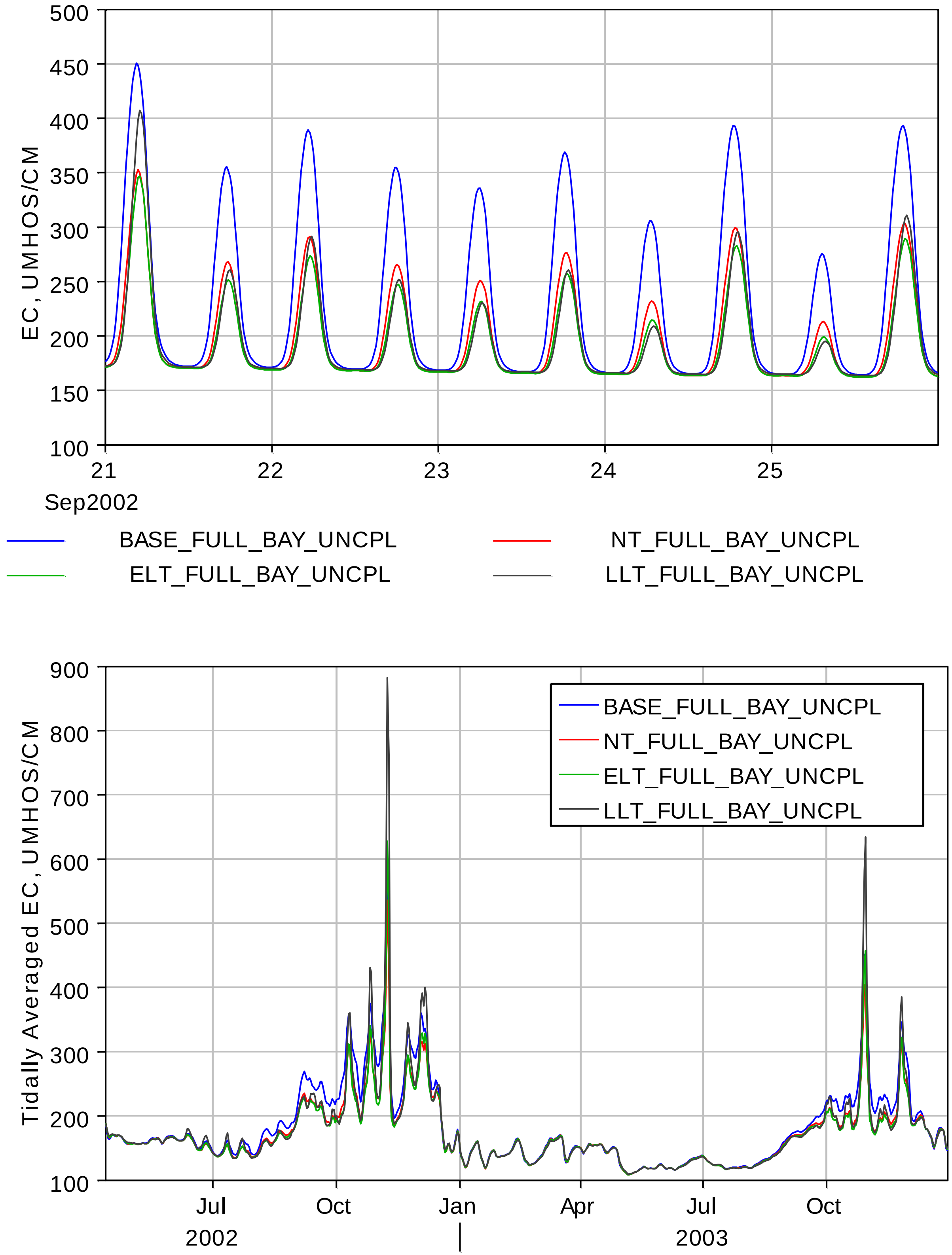


Figure 6-6 EC and tidally averaged EC at Rio Vista for Base case, NT, ELT and LLT scenarios.

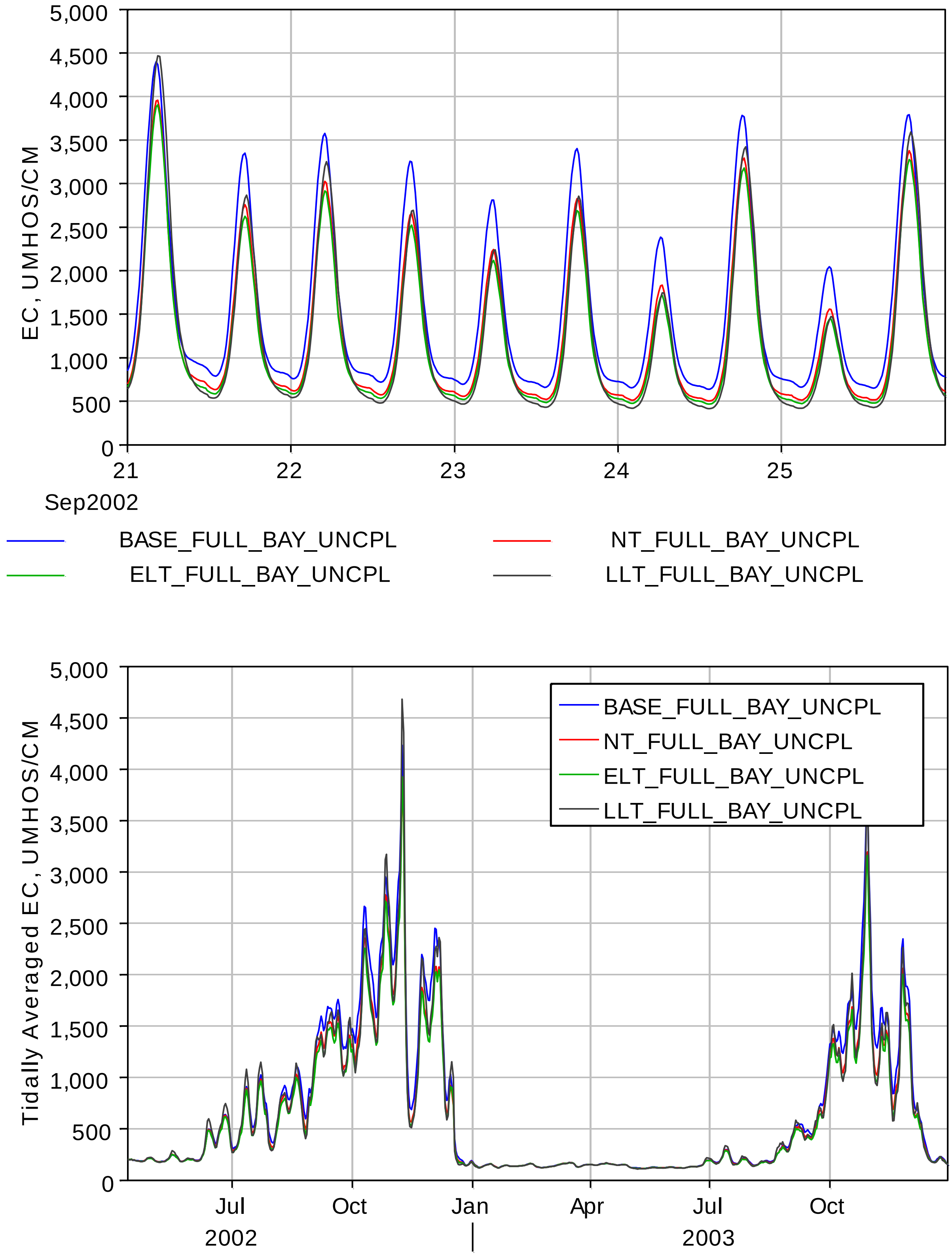
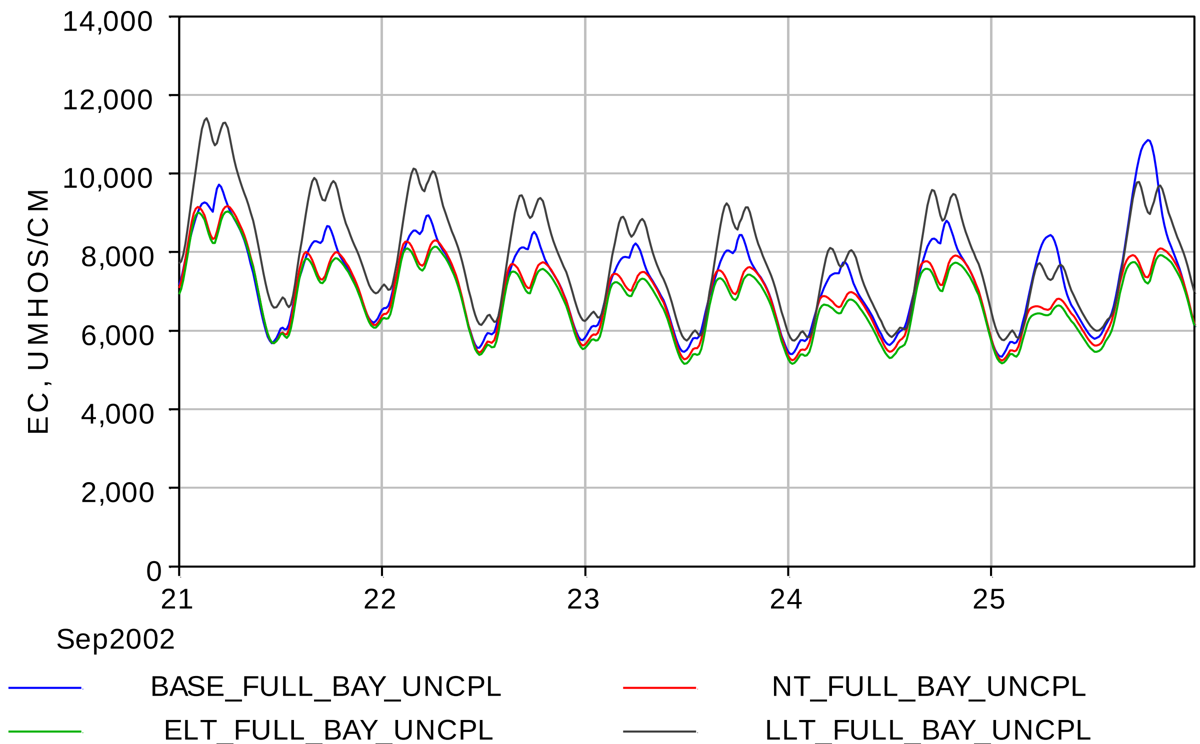


Figure 6-7 EC and tidally averaged EC at Emmaton (RSAC092) for Base, NT, ELT and LLT scenarios.



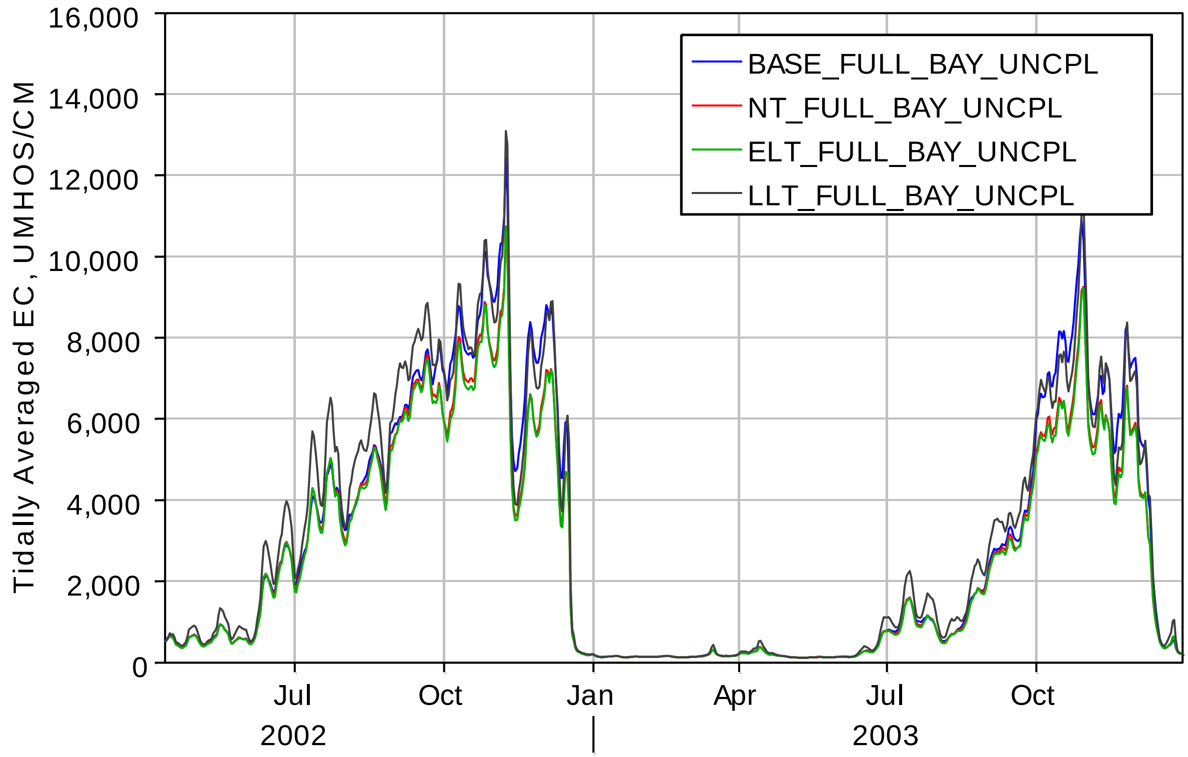
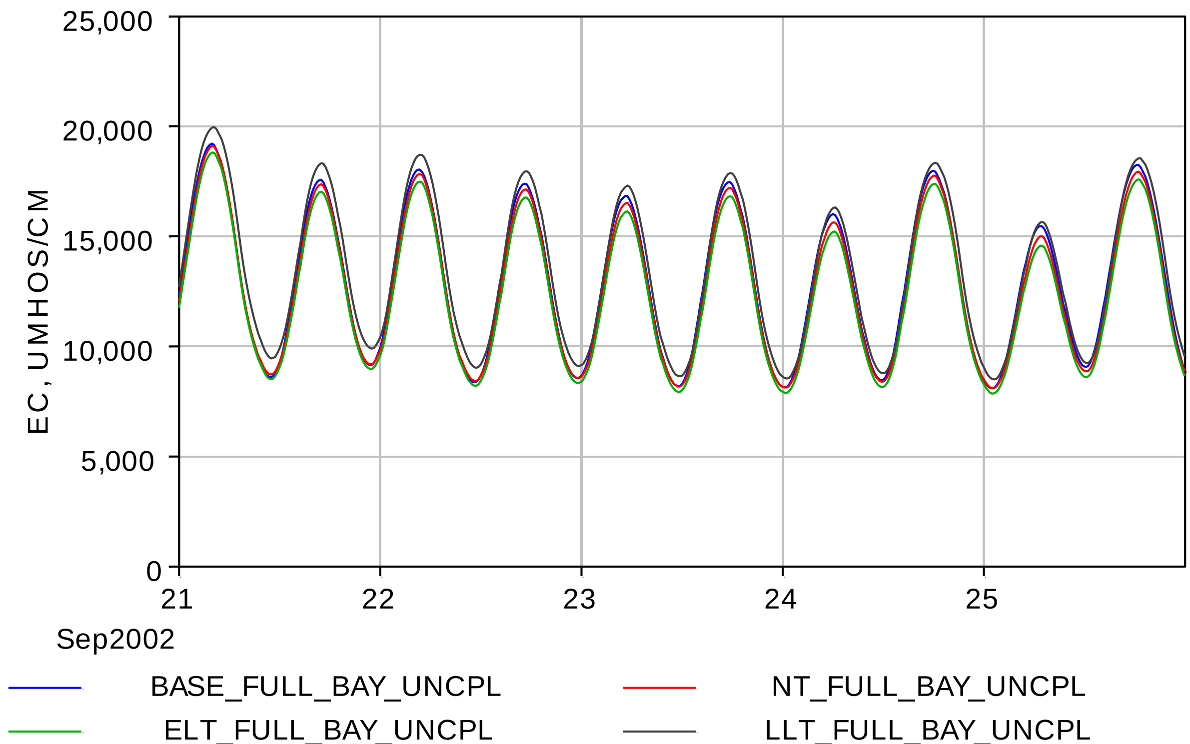


Figure 6-8 EC and tidally averaged EC at Collinsville (RSAC081) for Base, NT, ELT and LLT scenarios.



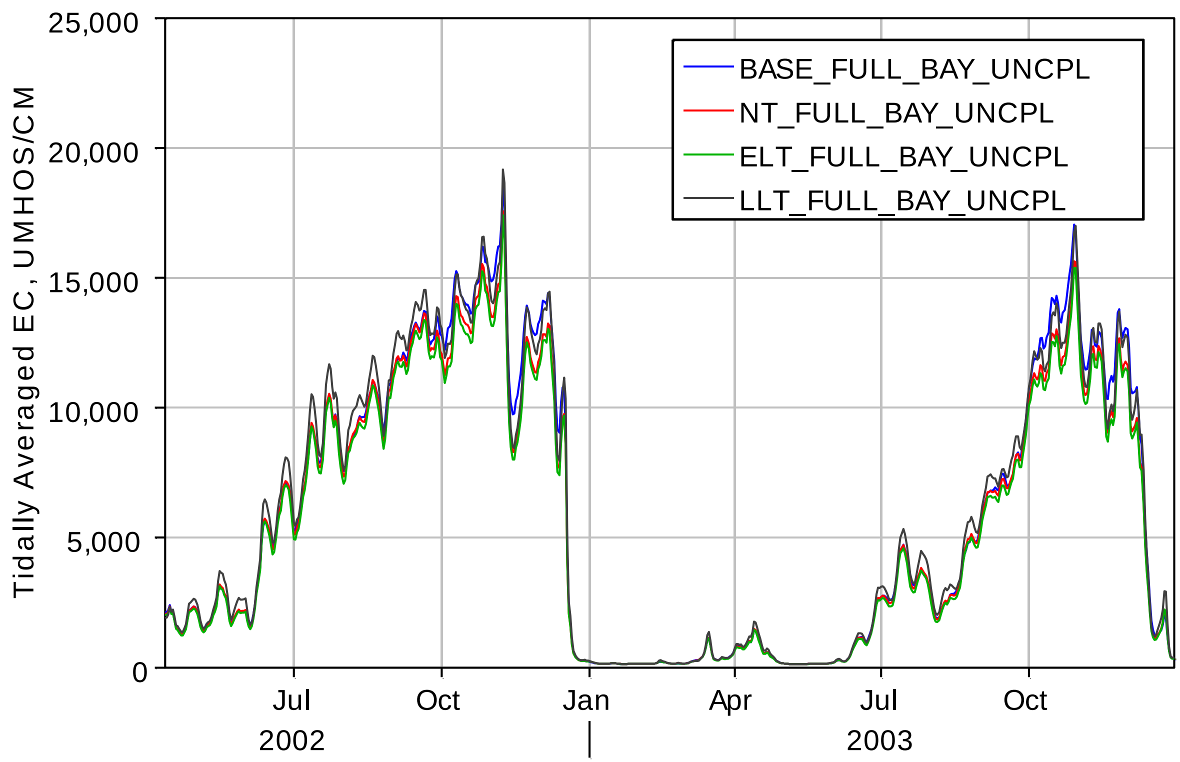
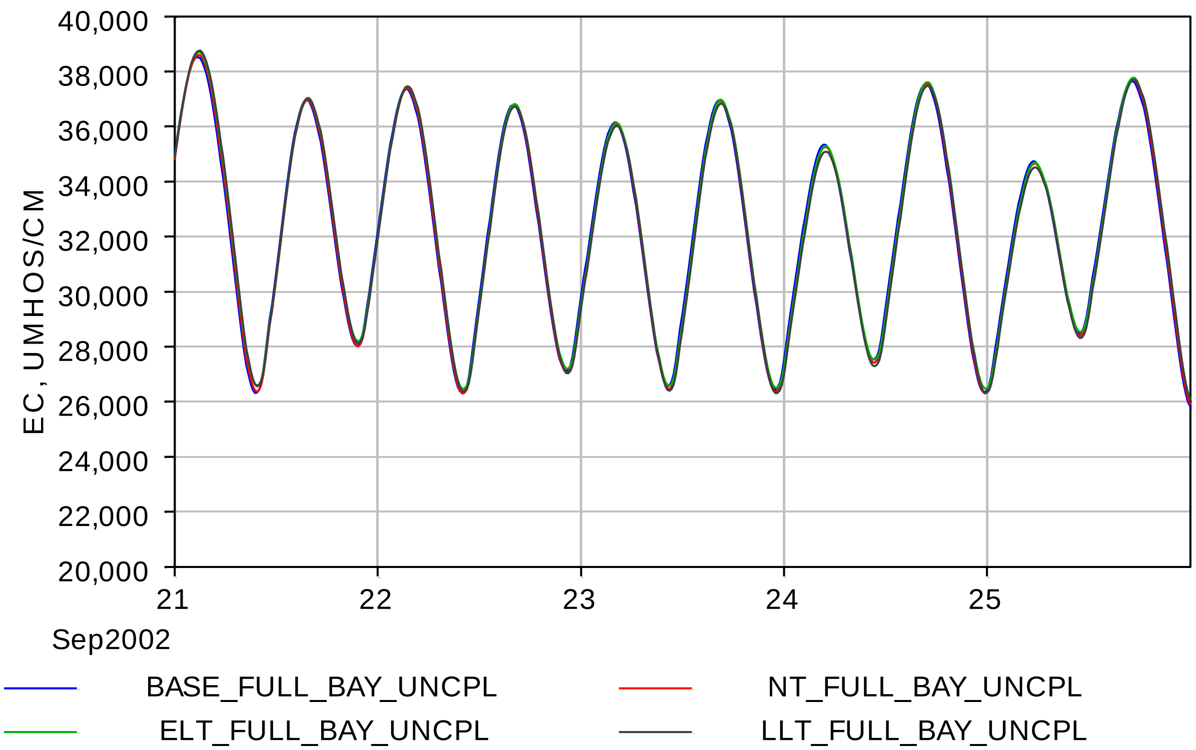


Figure 6-9 EC and tidally averaged EC at Chipps Island (RSAC075) for Base, NT, ELT and LLT scenarios.



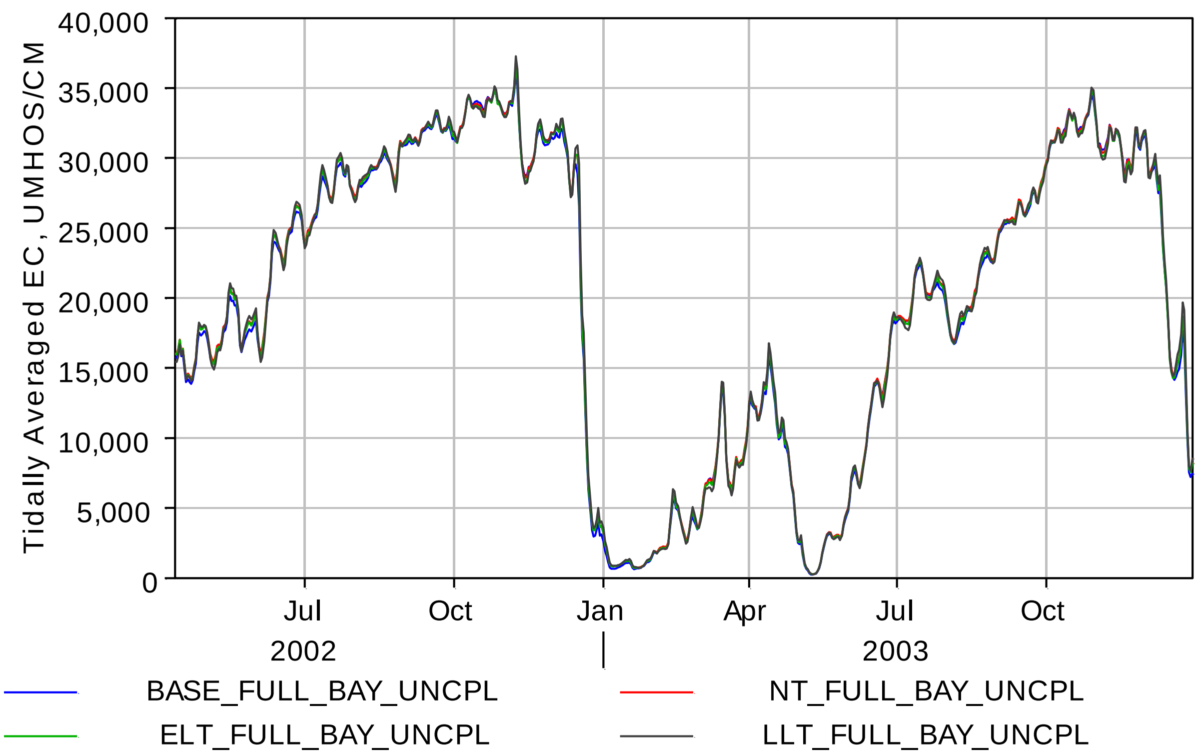
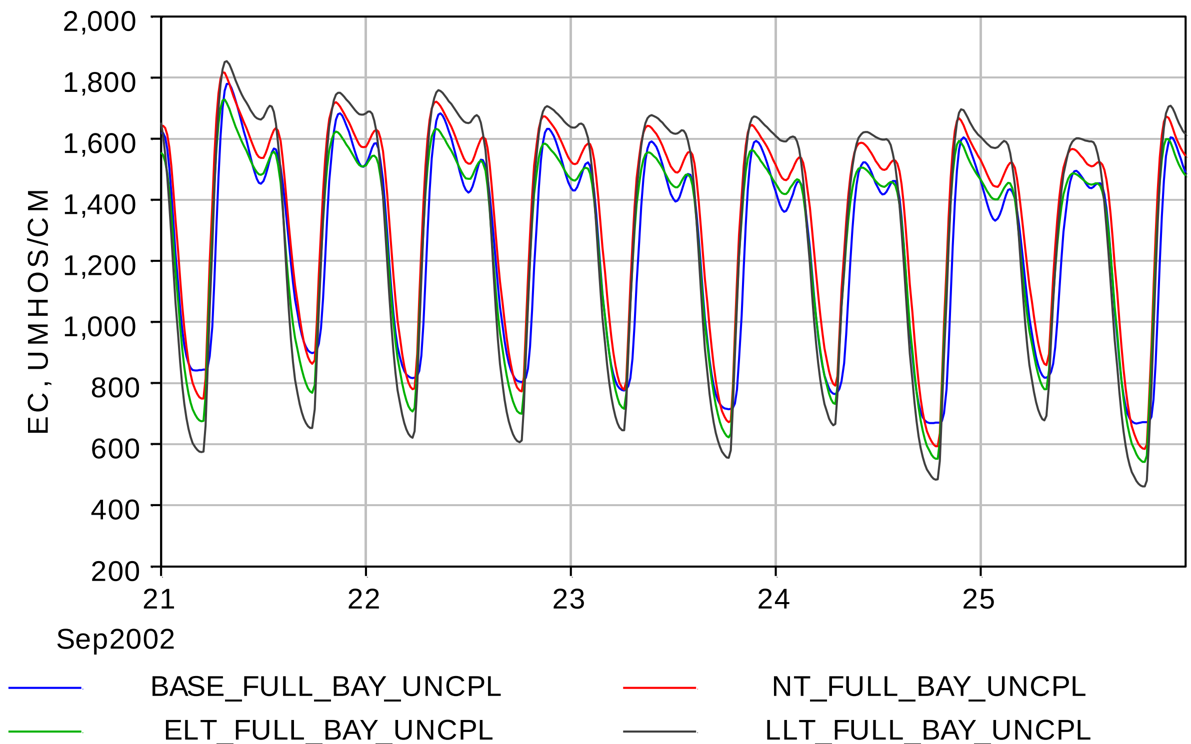


Figure 6-10 EC and tidally averaged EC at Martinez (RSAC054) for Base, NT, ELT and LLT scenarios.



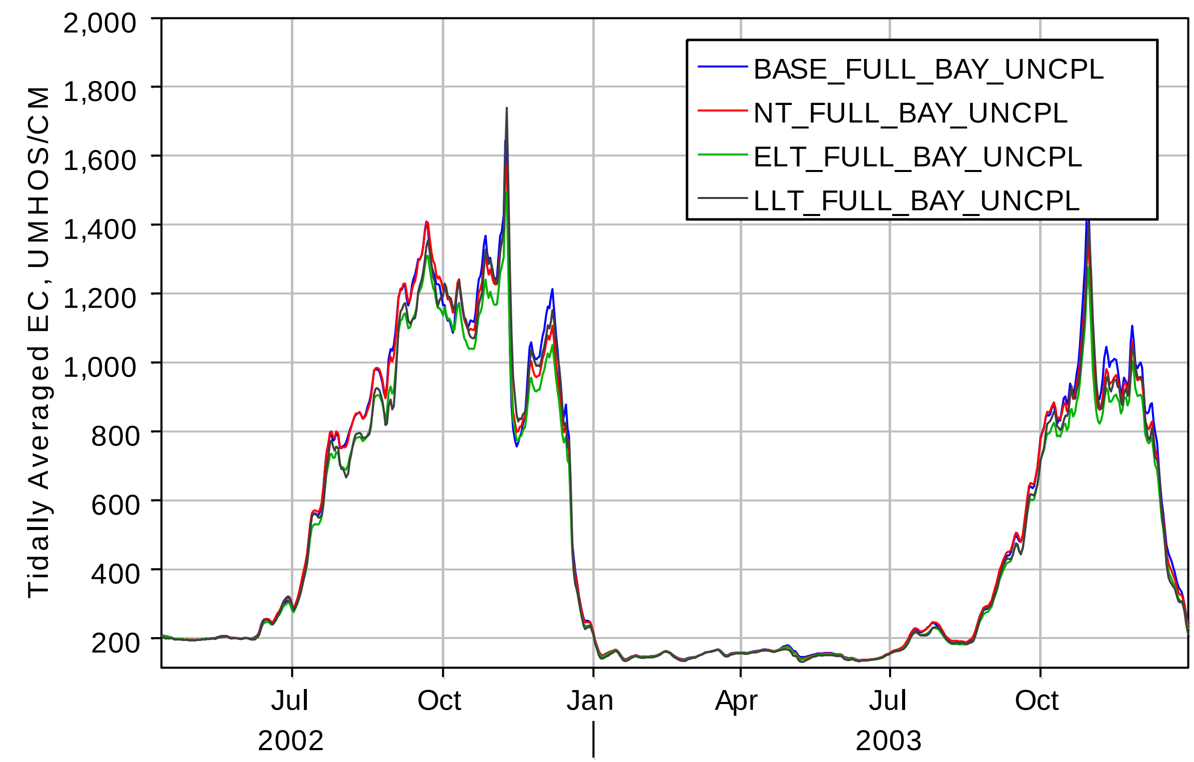


Figure 6-11 EC and tidally averaged EC in Threemile Slough for Base, NT, ELT and LLT scenarios.

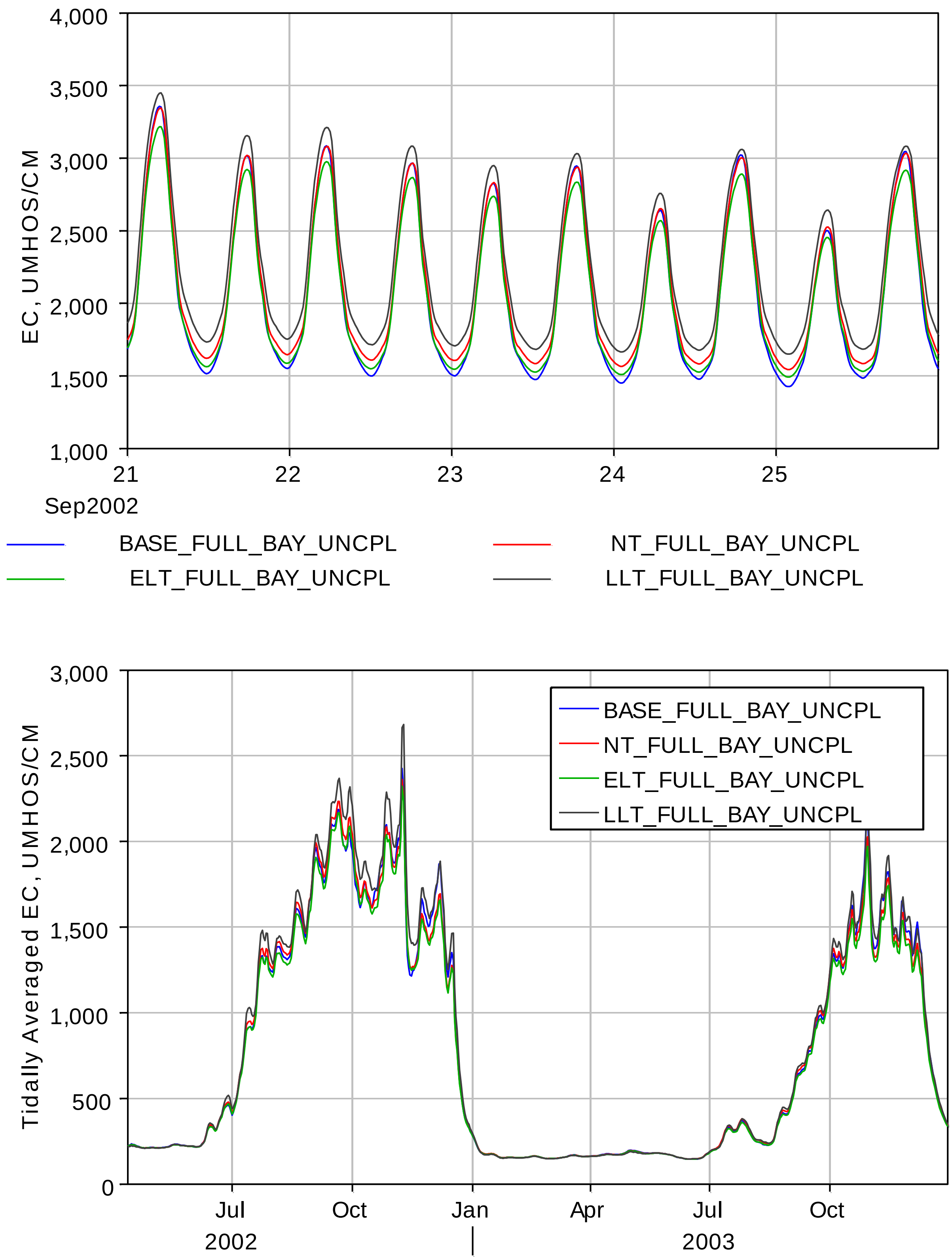
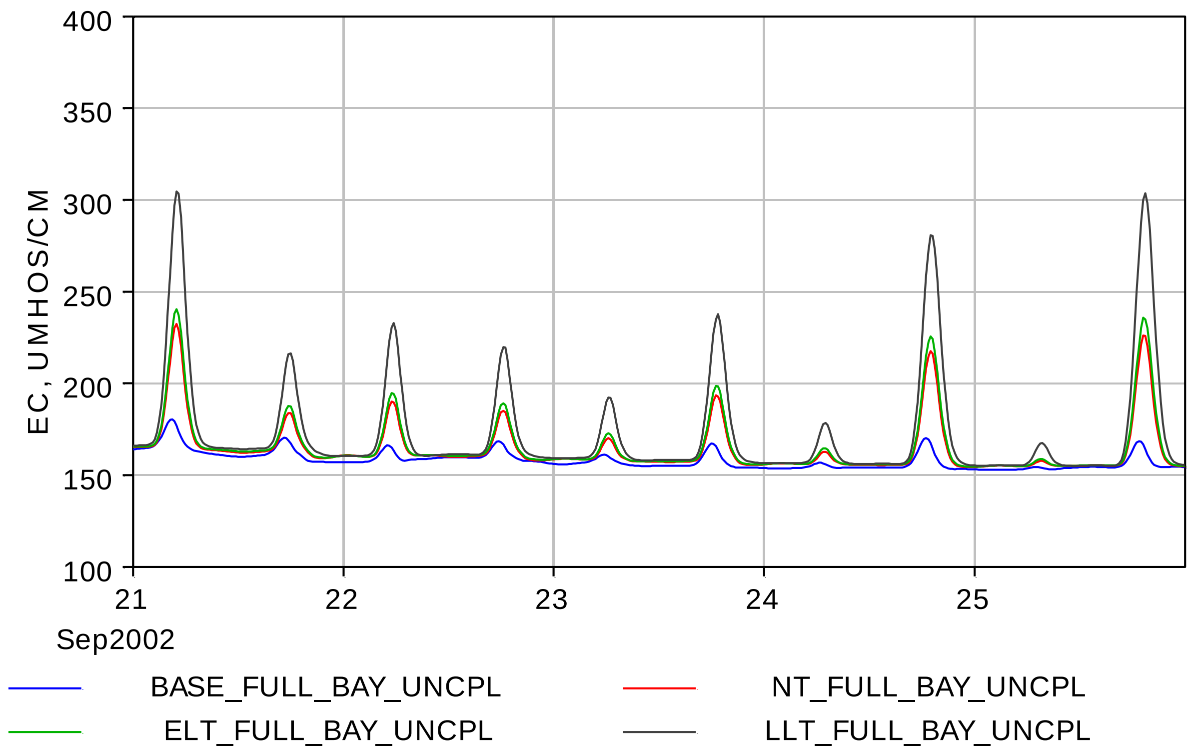


Figure 6-12 EC and tidally averaged EC at Jersey Point for Base, NT, ELT and LLT scenarios.



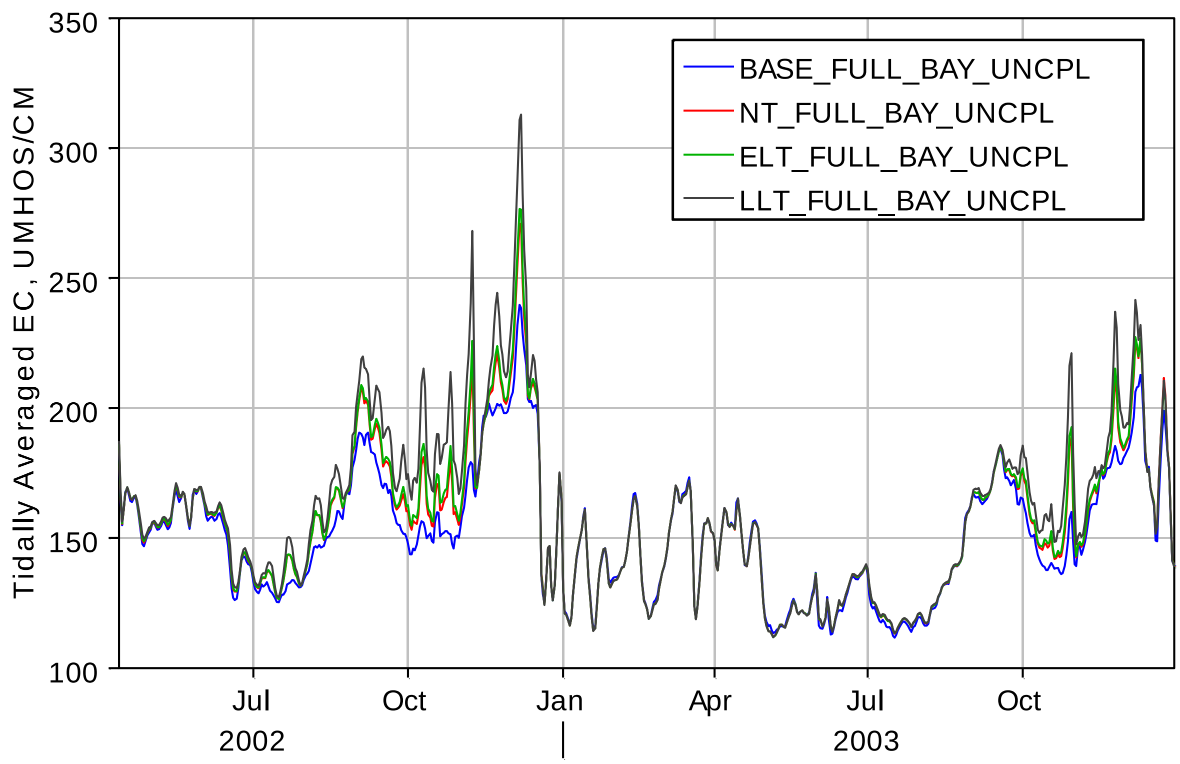
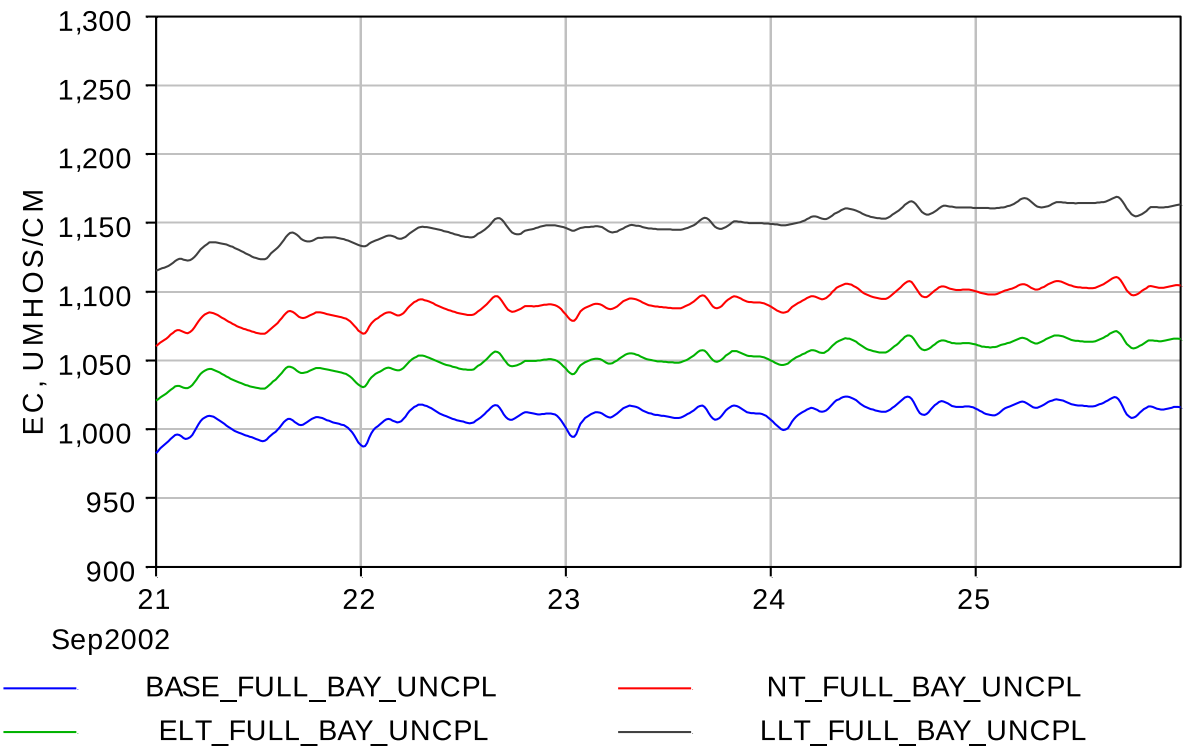


Figure 6-13 EC and tidally averaged EC in Mokelumne R. near San Joaquin R. for Base, NT, ELT and LLT scenarios.



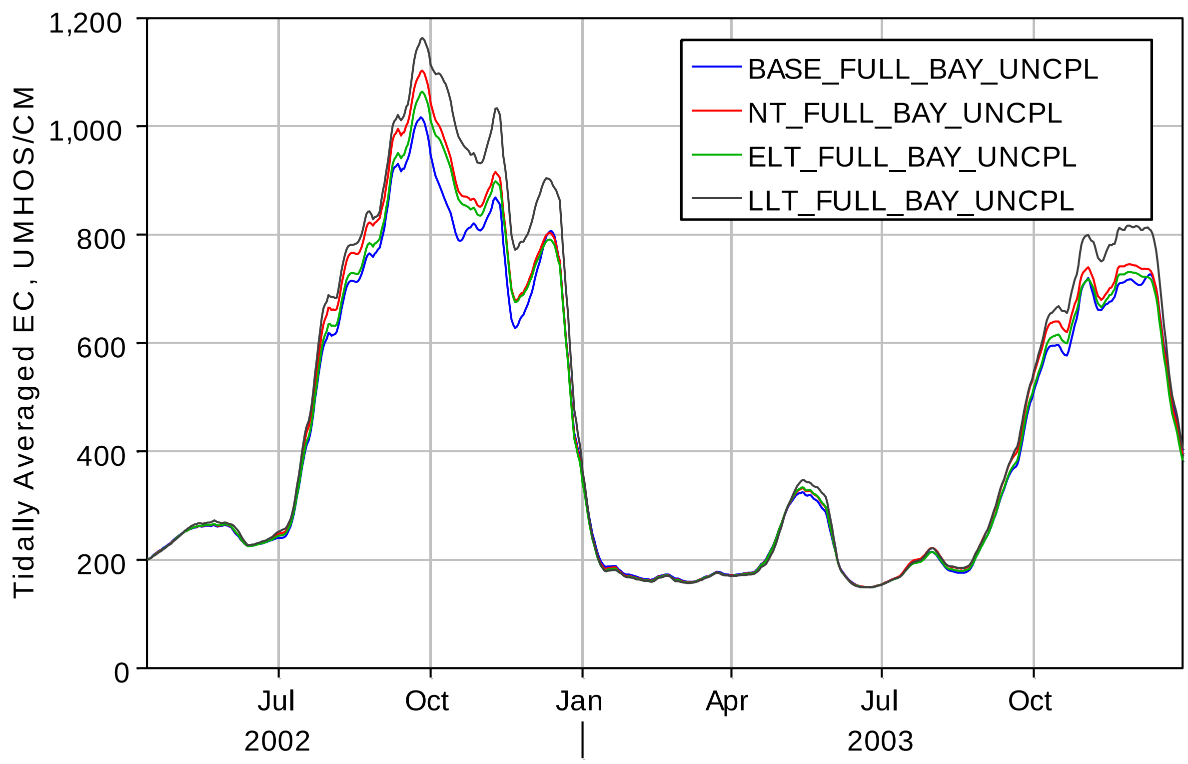
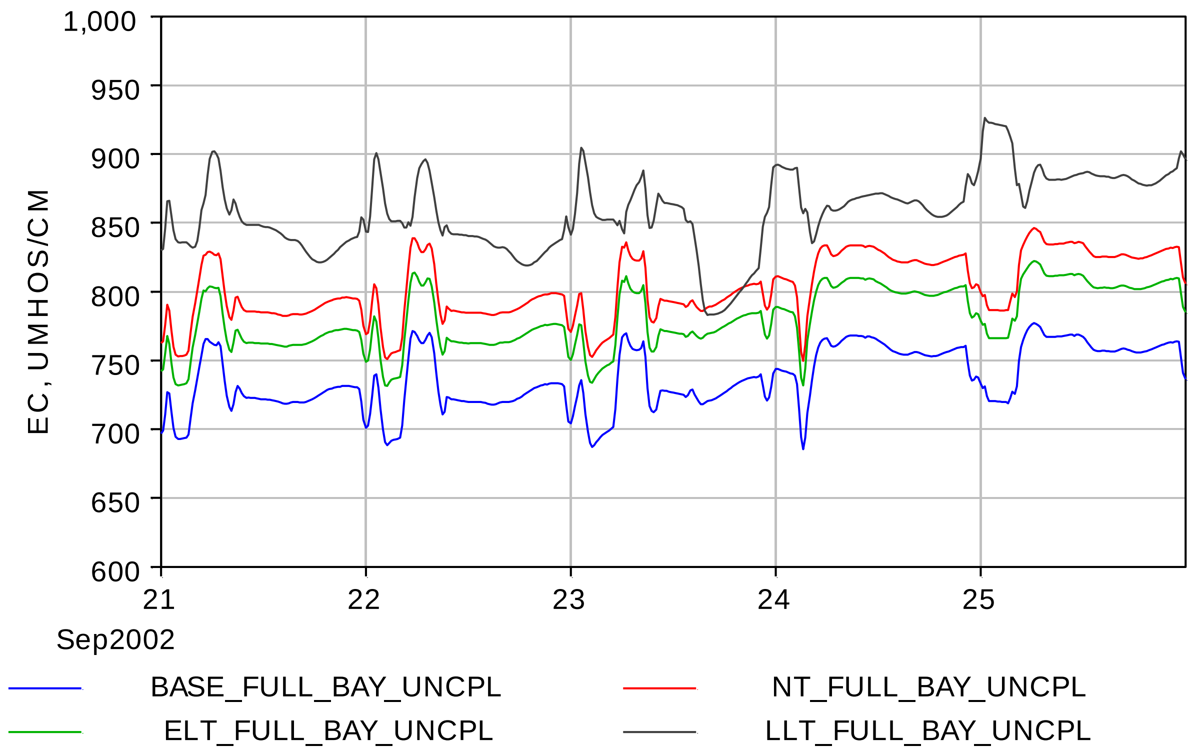


Figure 6-14 EC and tidally averaged EC in Old River at Rock Slough (ROLD024) for Base, NT, ELT and LLT scenarios.



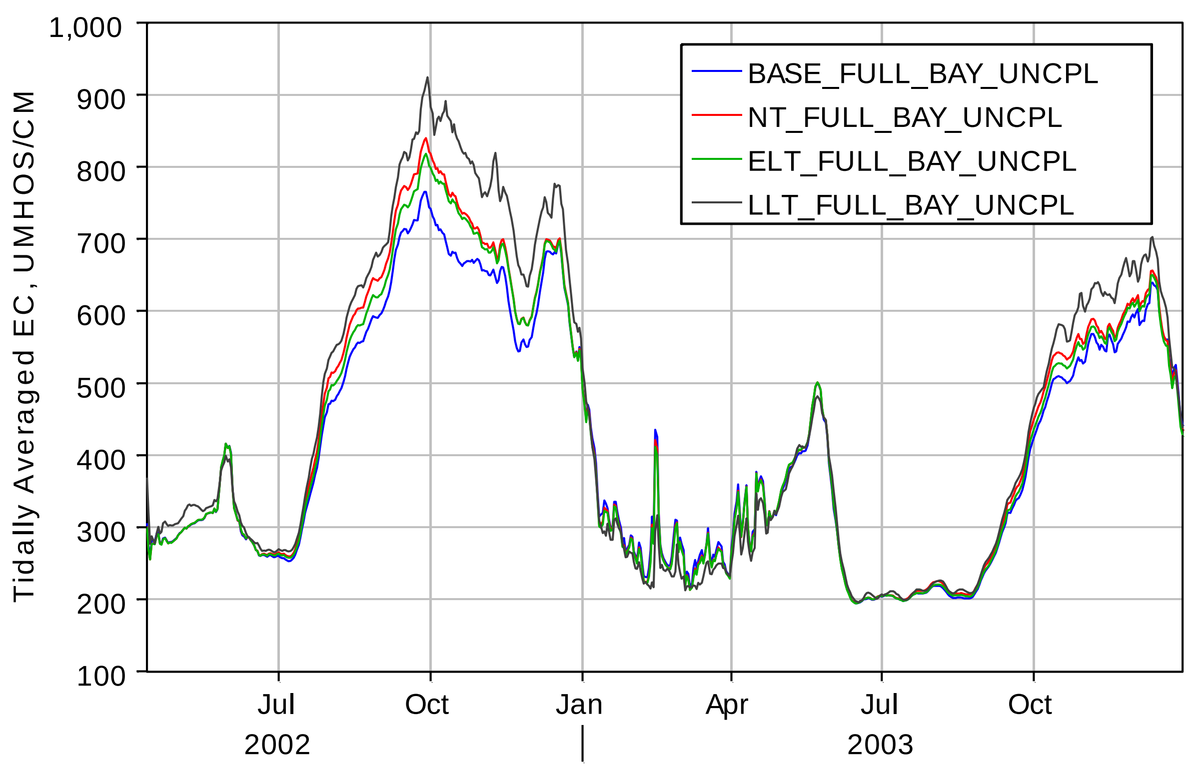
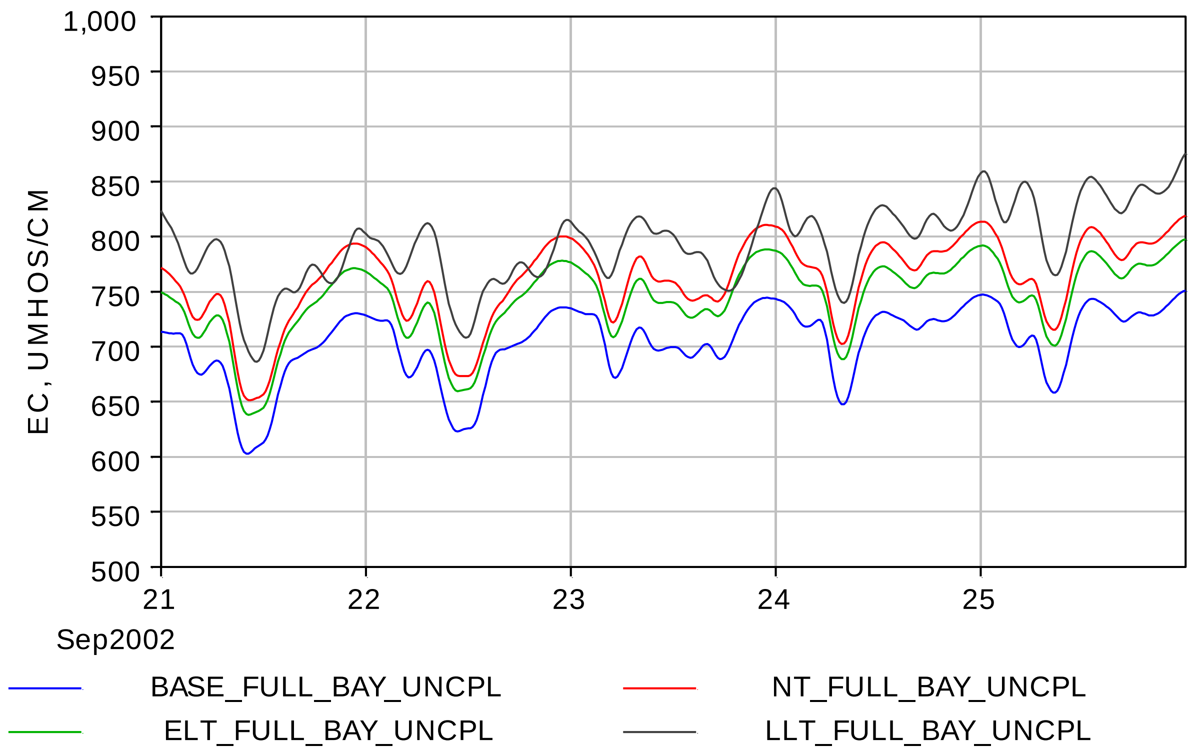


Figure 6-15 EC and tidally averaged EC at the SWP for Base, NT, ELT and LLT scenarios.



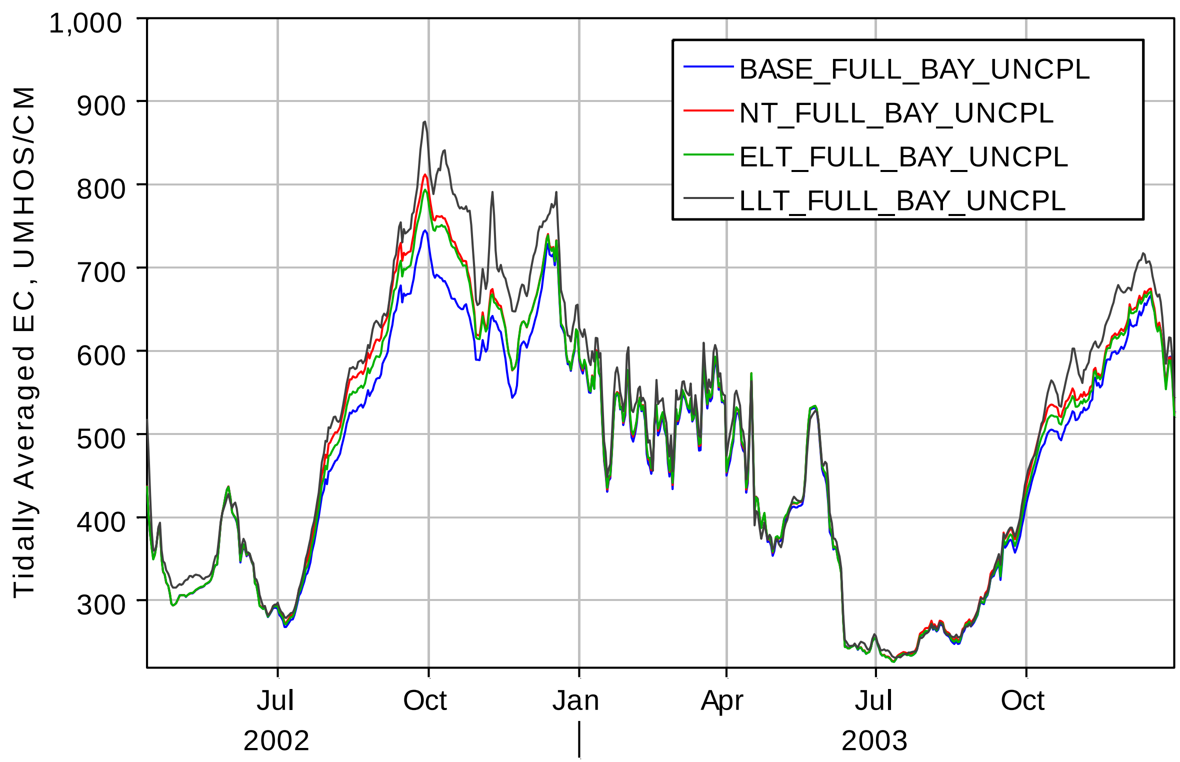
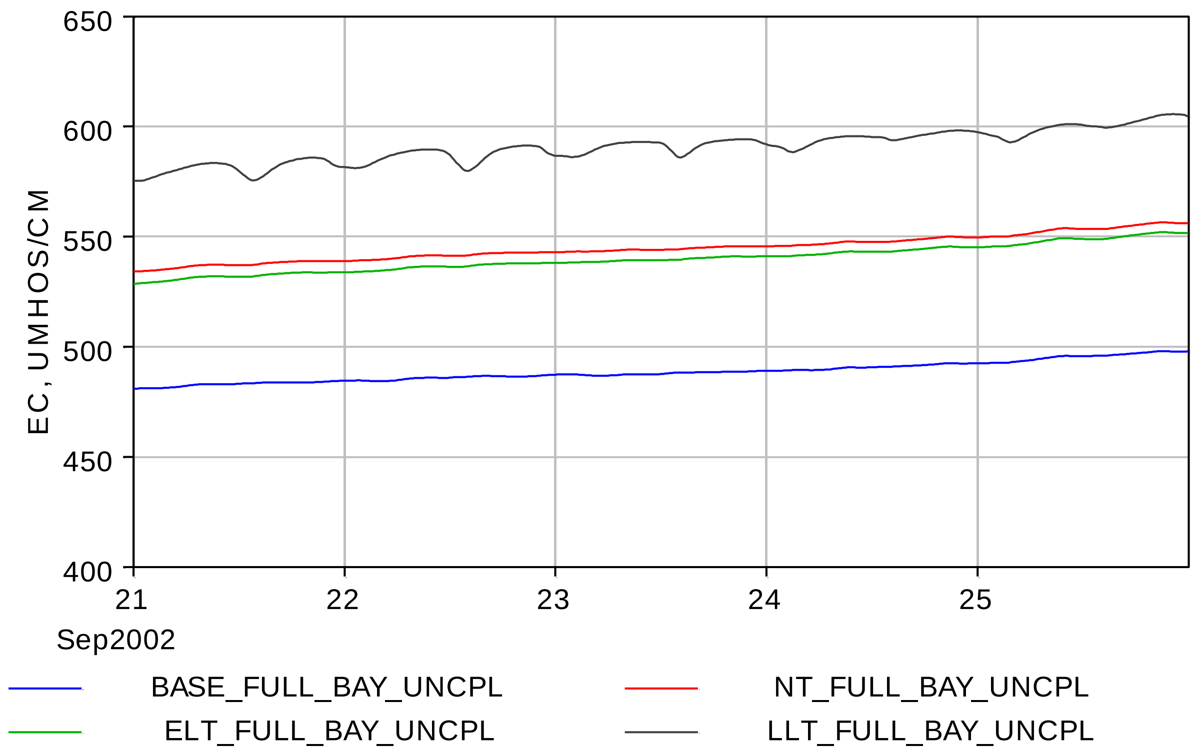


Figure 6-16 EC and tidally averaged EC at the CVP for Base, NT, ELT and LLT scenarios.



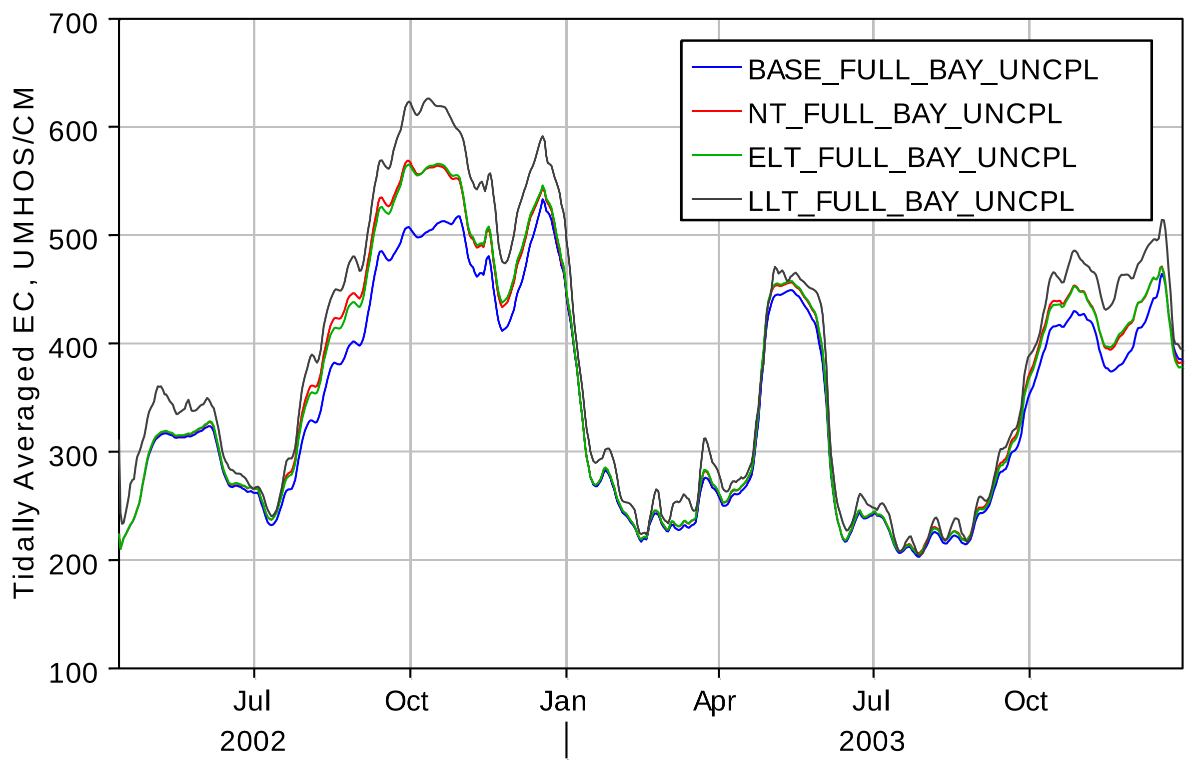
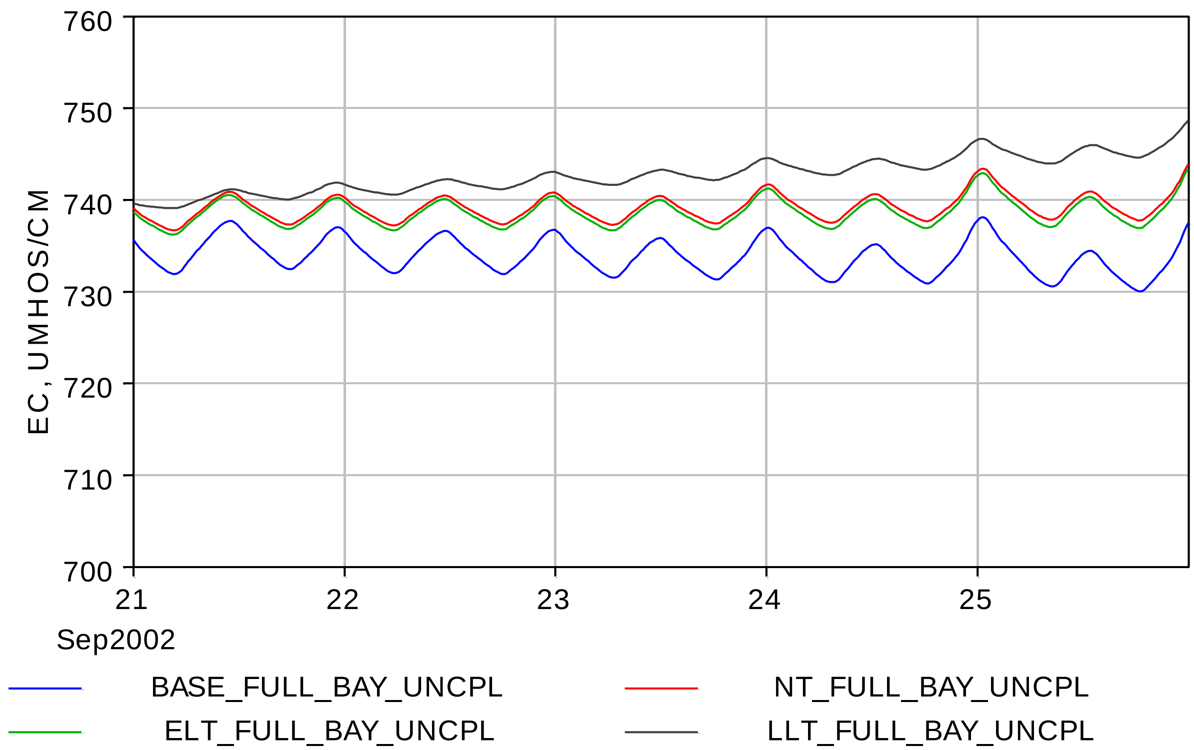


Figure 6-17 EC and tidally averaged EC in Middle River (RMID023) for Base, NT, ELT and LLT scenarios.



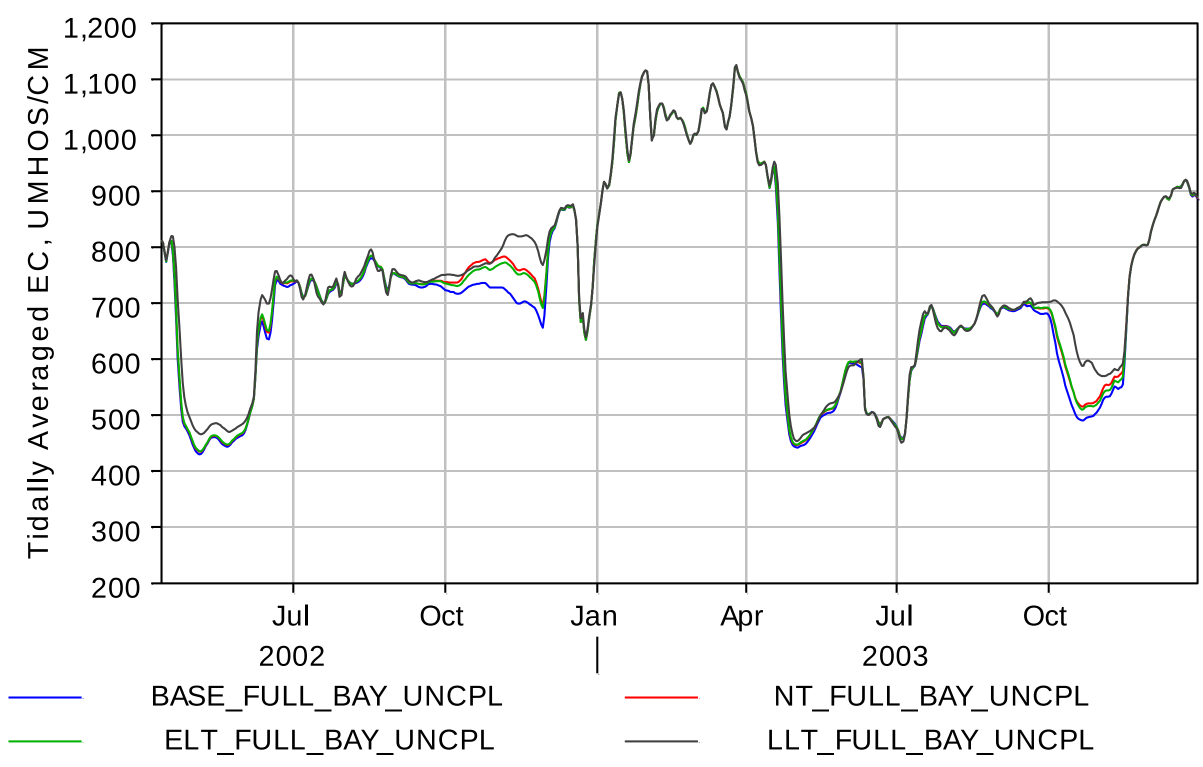


Figure 6-18 EC and tidally averaged EC in Old River at Tracy Road (ROLD059) for Base, NT, ELT and LLT scenarios.

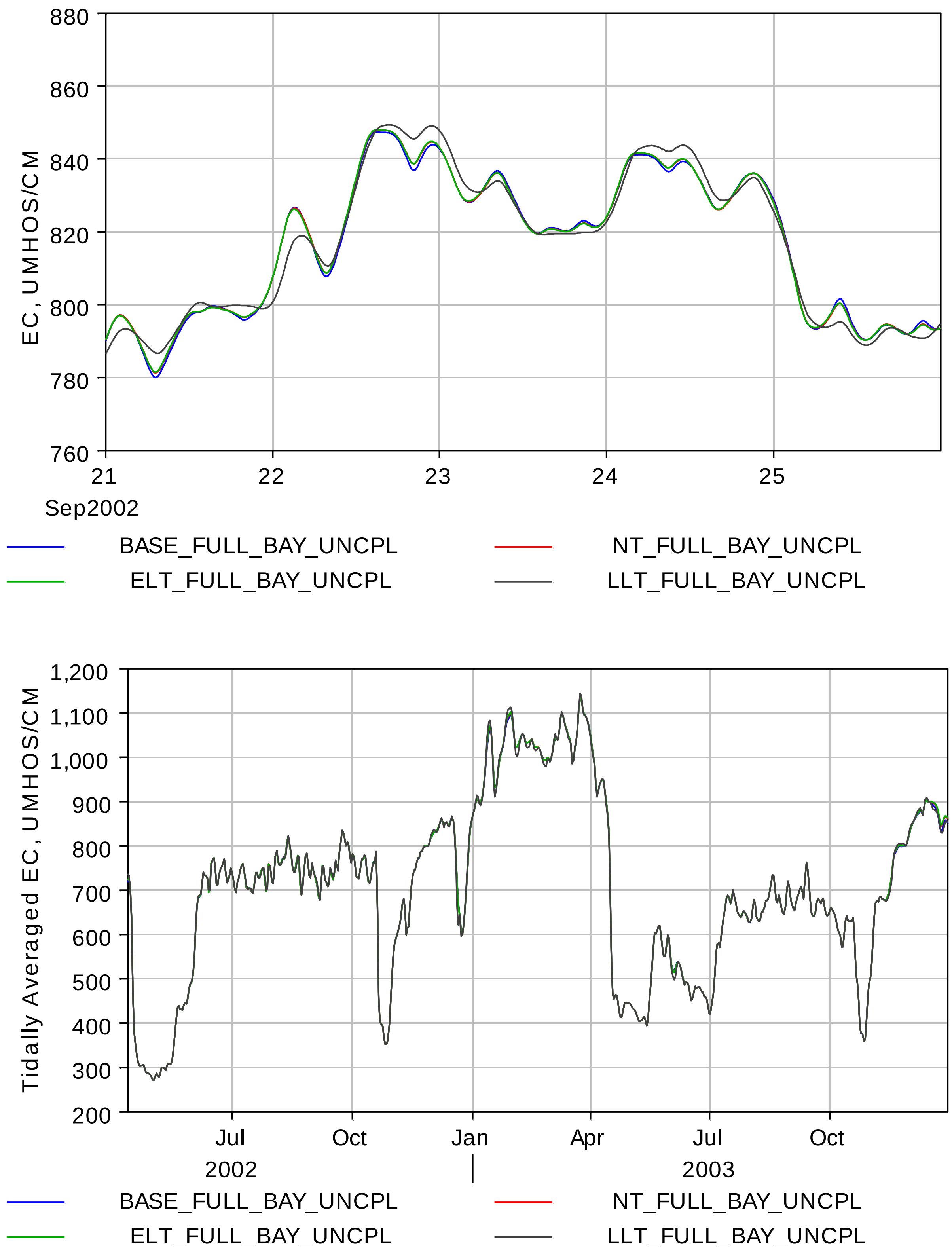


Figure 6-19 EC and tidally averaged EC in San Joaquin R at Brandt Bridge for Base, NT, ELT and LLT scenarios.

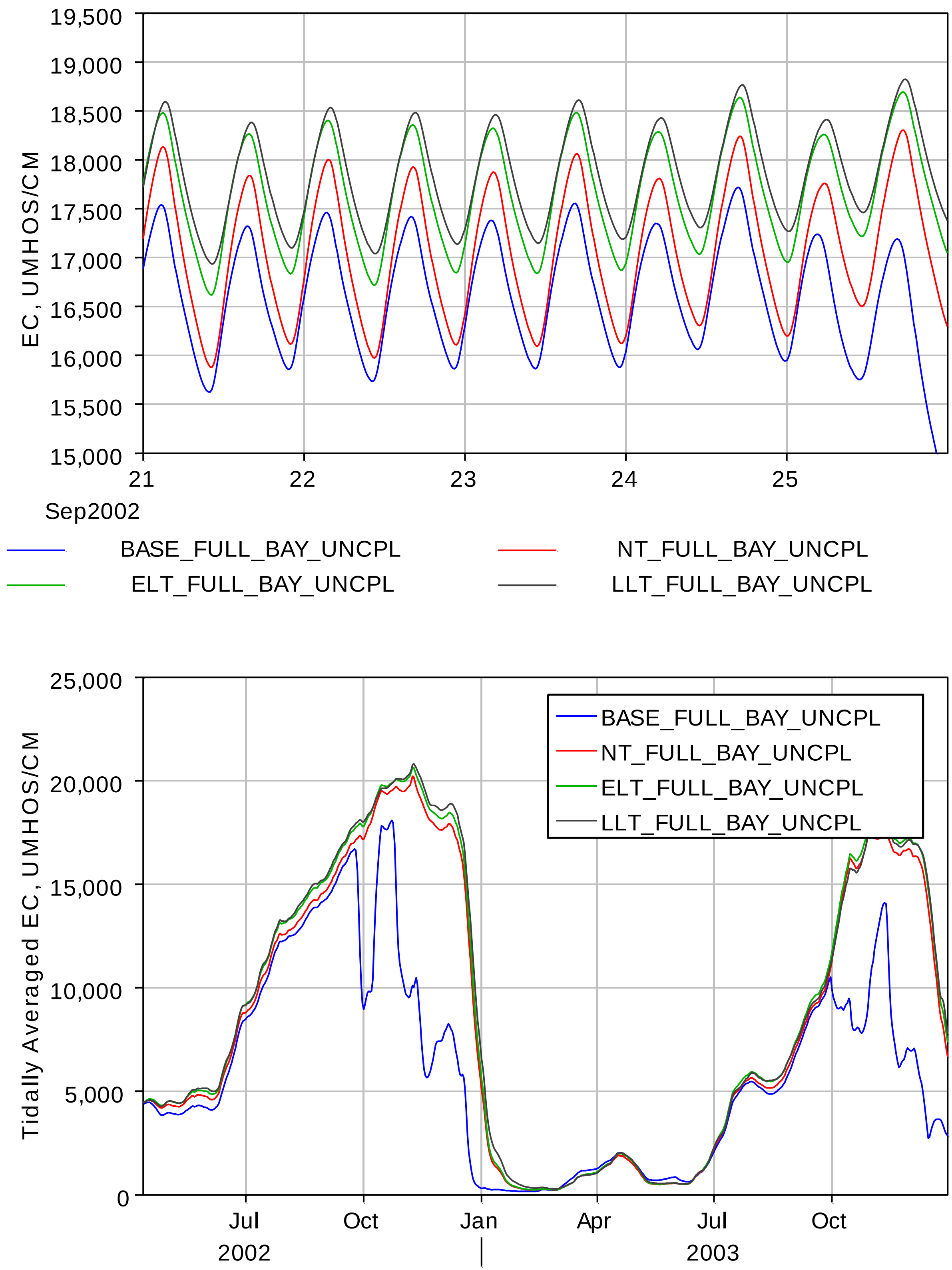
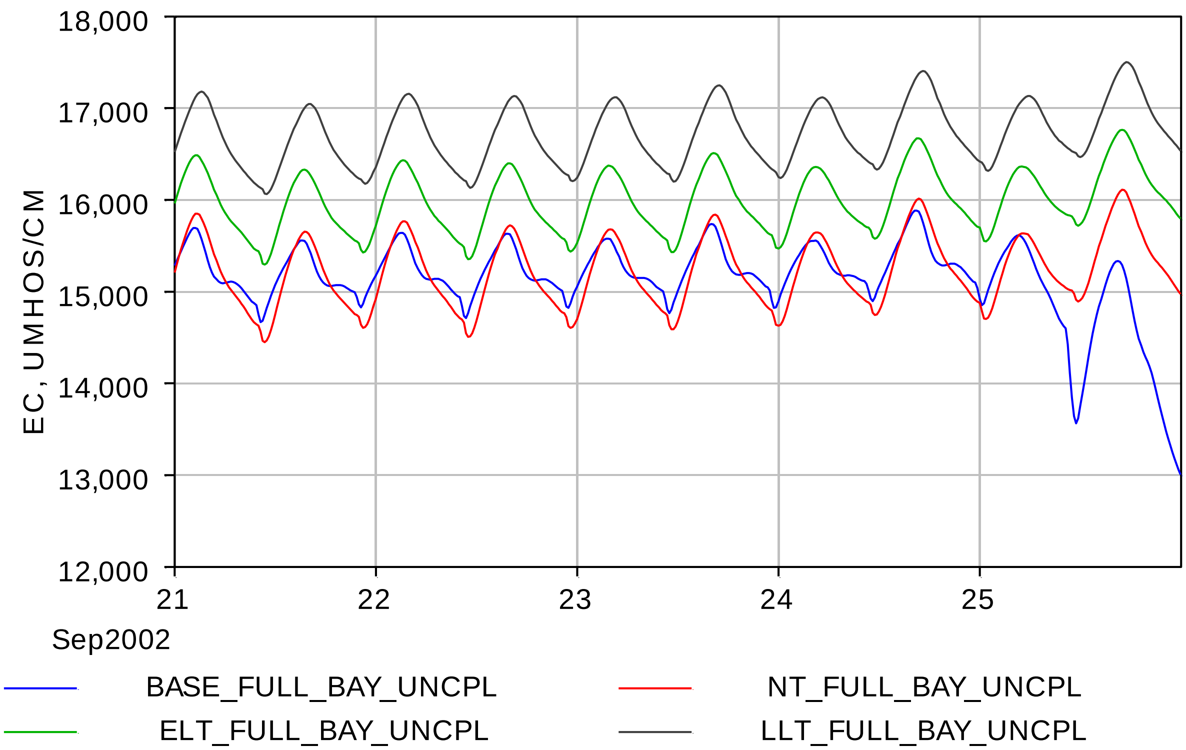


Figure 6-20 EC and tidally averaged EC in Montezuma Slough at Beldon's Landing for Base, NT, ELT and LLT scenarios.



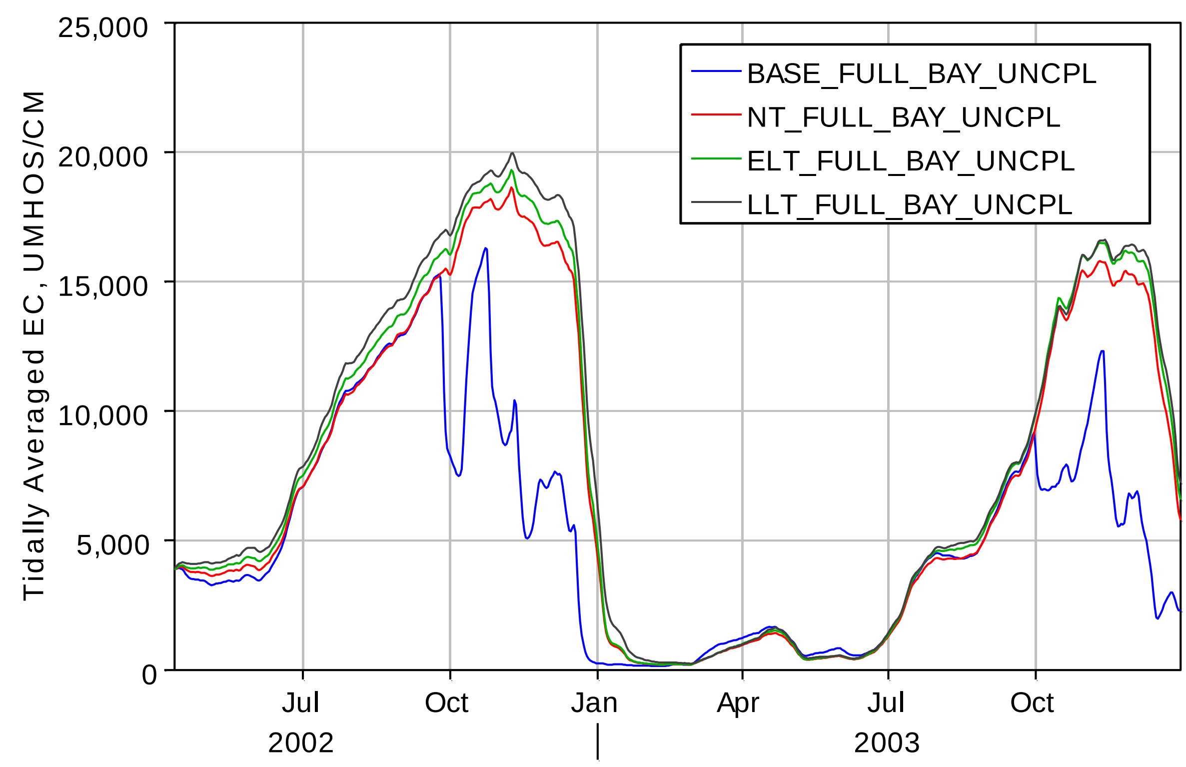
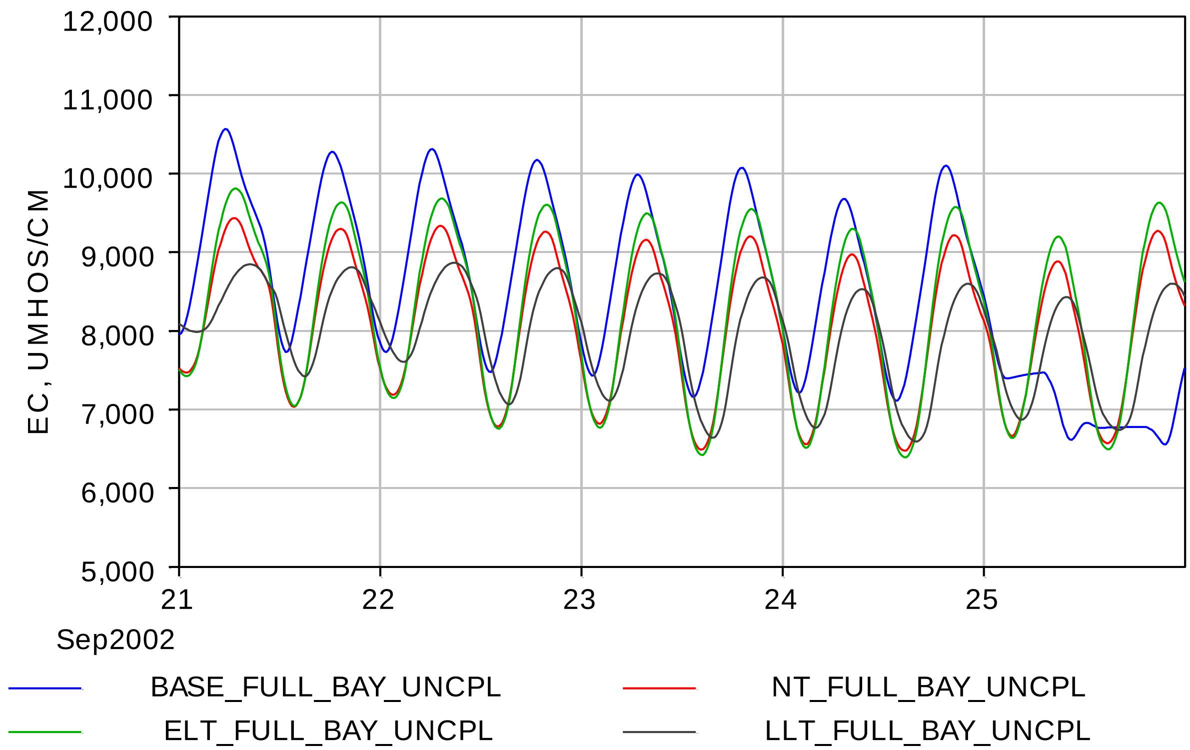


Figure 6-21 EC and tidally averaged EC in Nurse Slough for Base, NT, ELT and LLT scenarios.



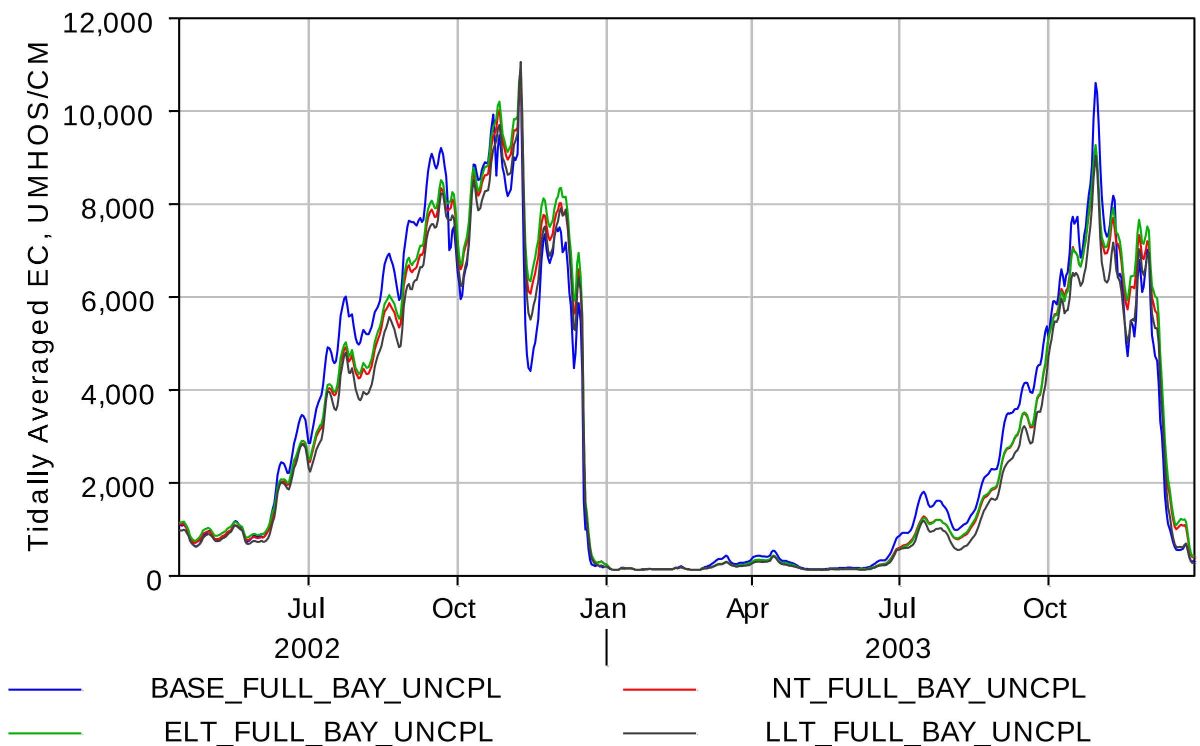


Figure 6-22 EC and tidally averaged EC in Montezuma Slough at Roaring River for Base, NT, ELT and LLT scenarios.

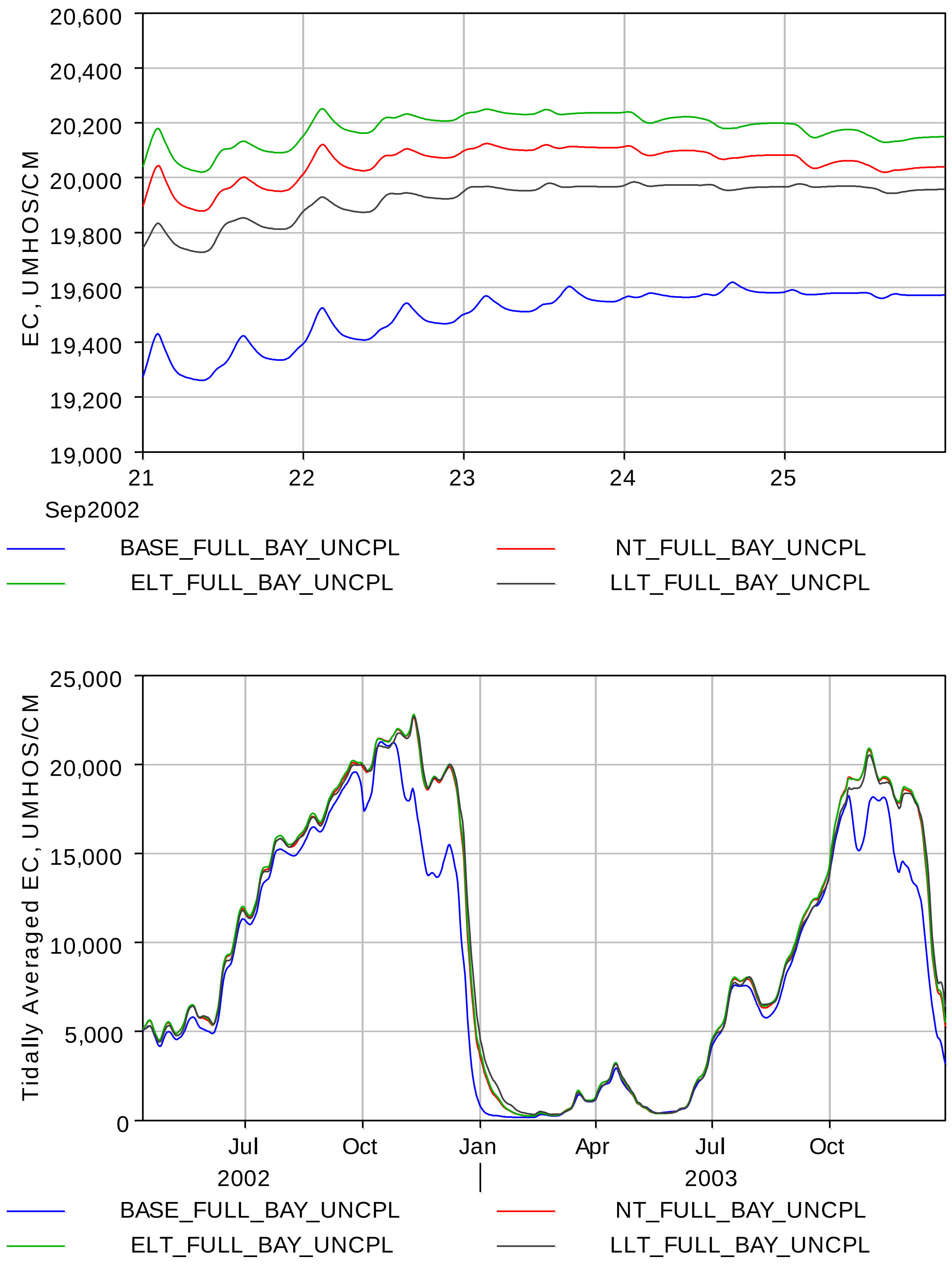
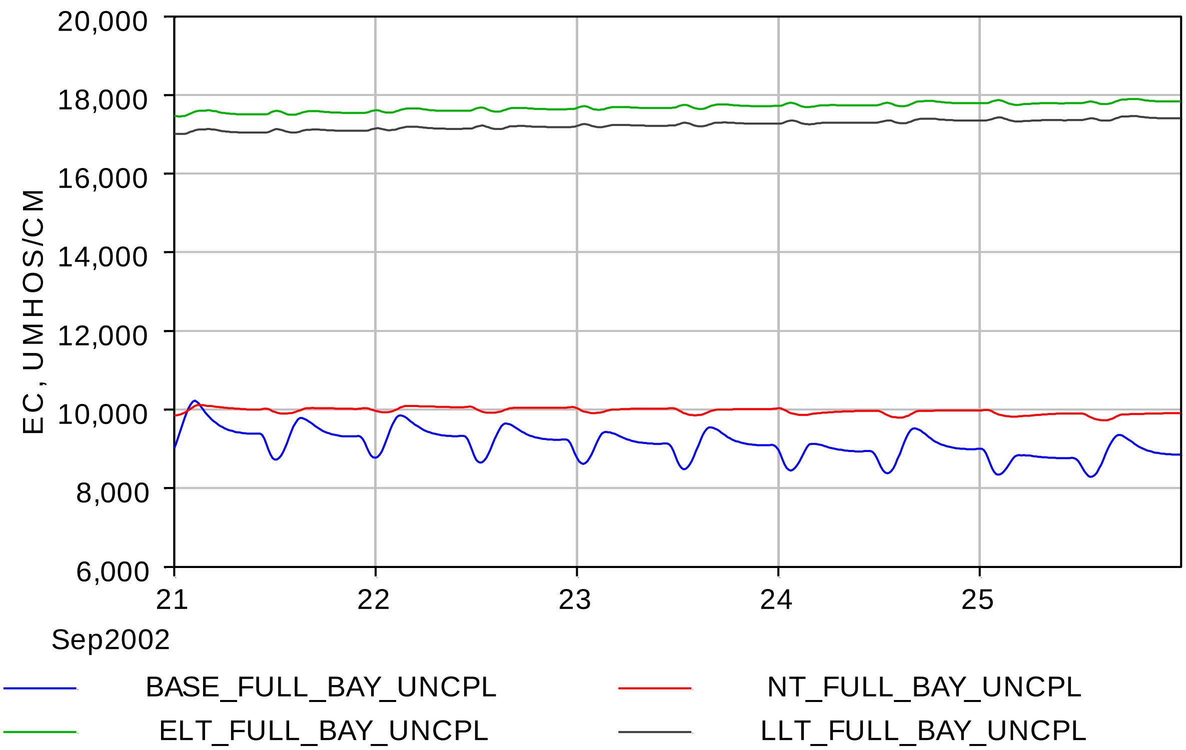


Figure 6-23 EC and tidally averaged EC at S-35 near Morrow Island for Base, NT, ELT and LLT scenarios.



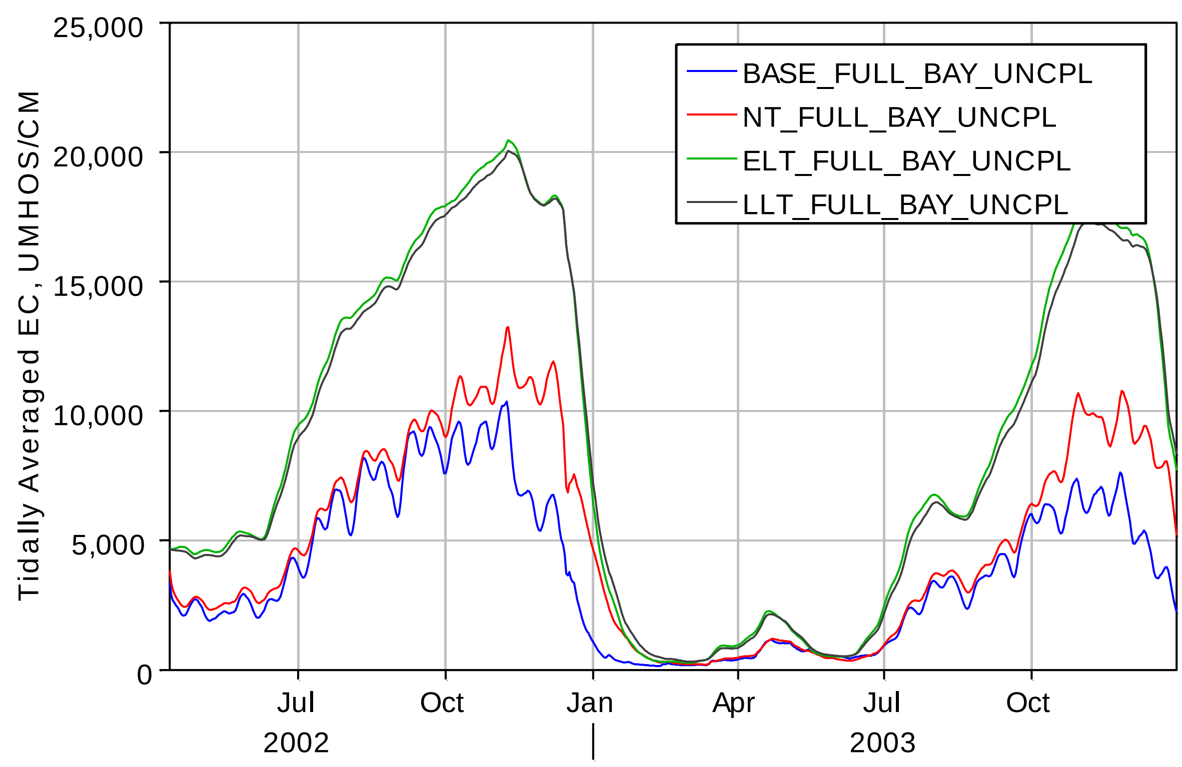


Figure 6-24 EC and tidally averaged EC in Boynton Slough at S-40 for Base, NT, ELT and LLT scenarios.

6.2 Spatial plots of EC and Change from Base EC

Maximum changes from Base case EC for each of the restoration scenarios tend to occur around the end of September and in October, 2002. In Suisun Marsh, larger changes results from elimination of SMSCG operations, for example from September 25 through October 8, 2002. For each restoration scenario, spatial plots are provided in Figure 6-25 through Figure 6-33 of percent change from Base case EC (computed using tidally averaged results). Side by side comparisons of tidally averaged Base case and restoration scenario EC are shown in Figure 6-34 through Figure 6-42. All spatial plots show 24 September 2002 so that the changes resulting from elimination of SMSCG operations does not impact the results. Several different views and different EC scales are used to emphasize different areas.

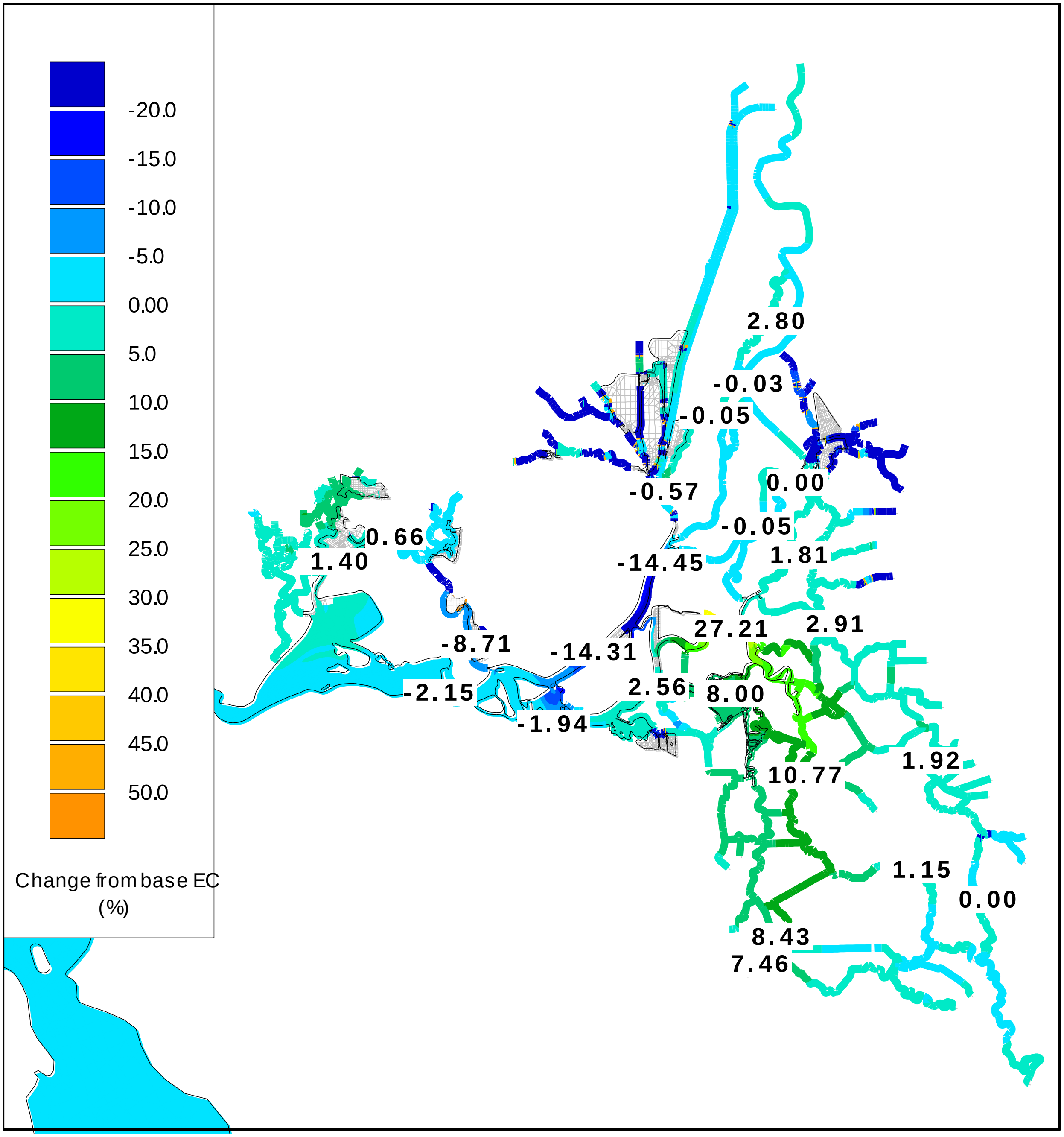


Figure 6-25 Percent Change from Base tidally averaged EC on 24 September 2002 for NT scenario.

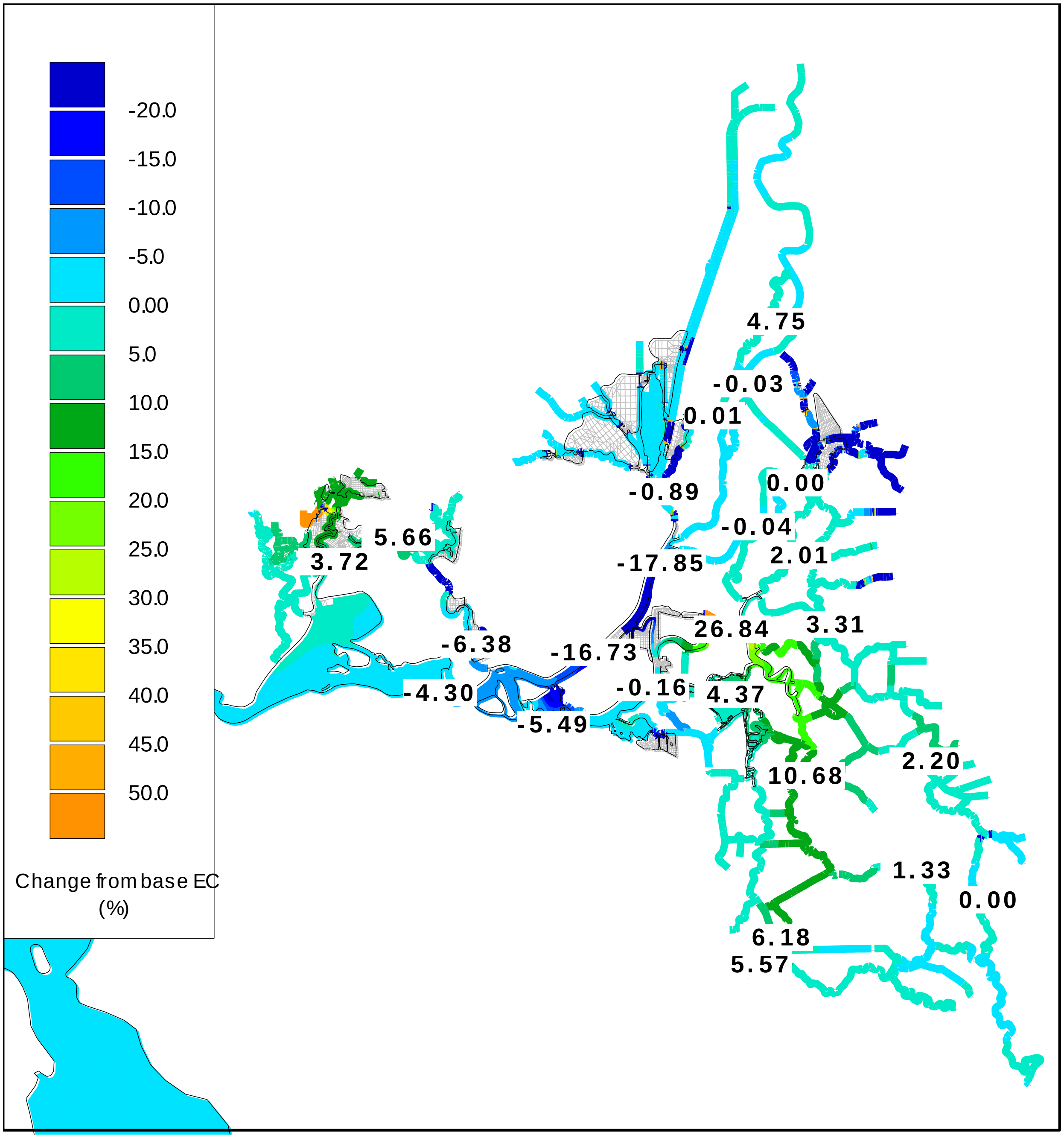


Figure 6-26 Percent Change from Base tidally averaged EC on 24 September 2002 for ELT scenario.

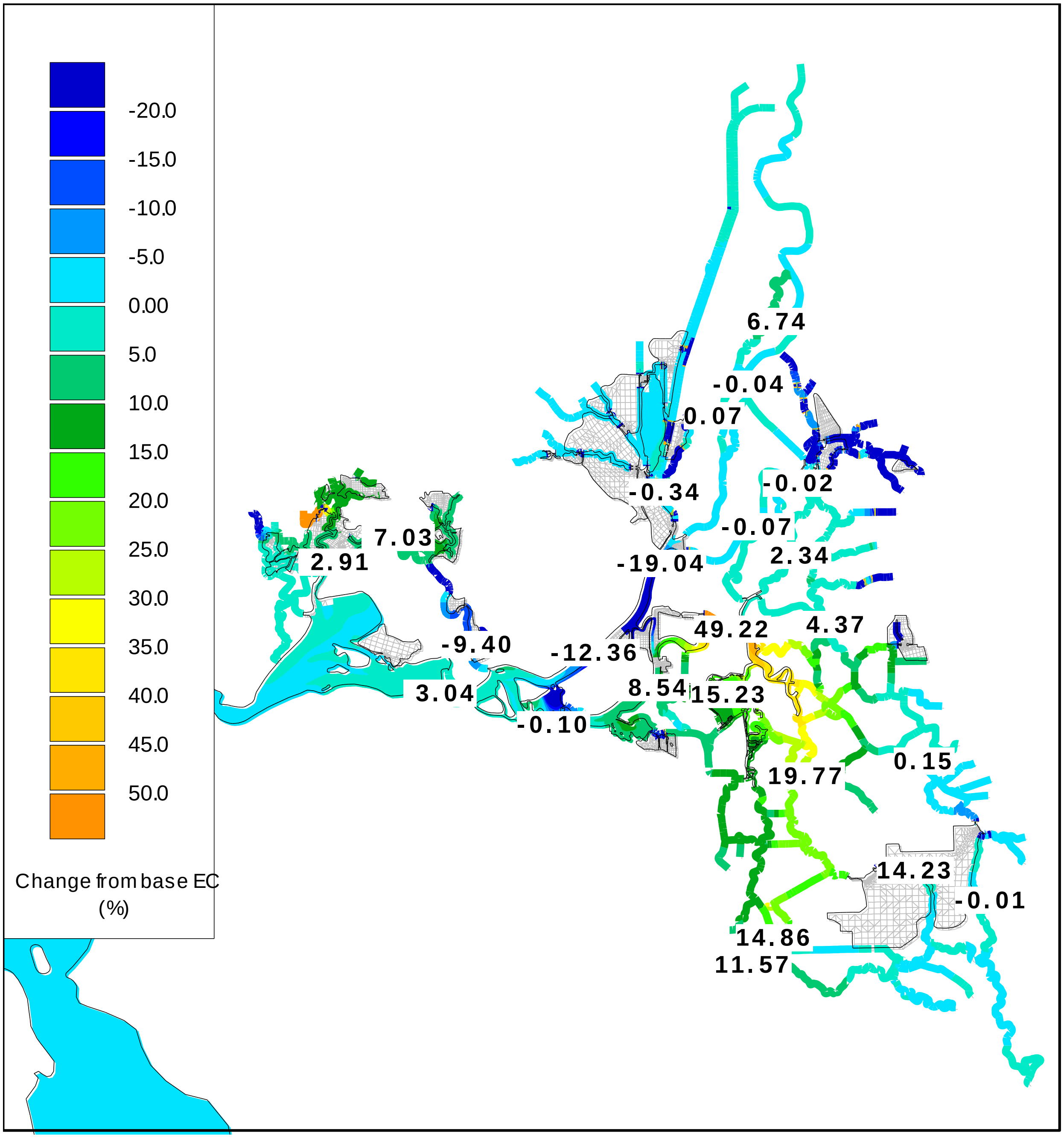


Figure 6-27 Percent Change from Base tidally averaged EC on 24 September 2002 for LLT scenario.

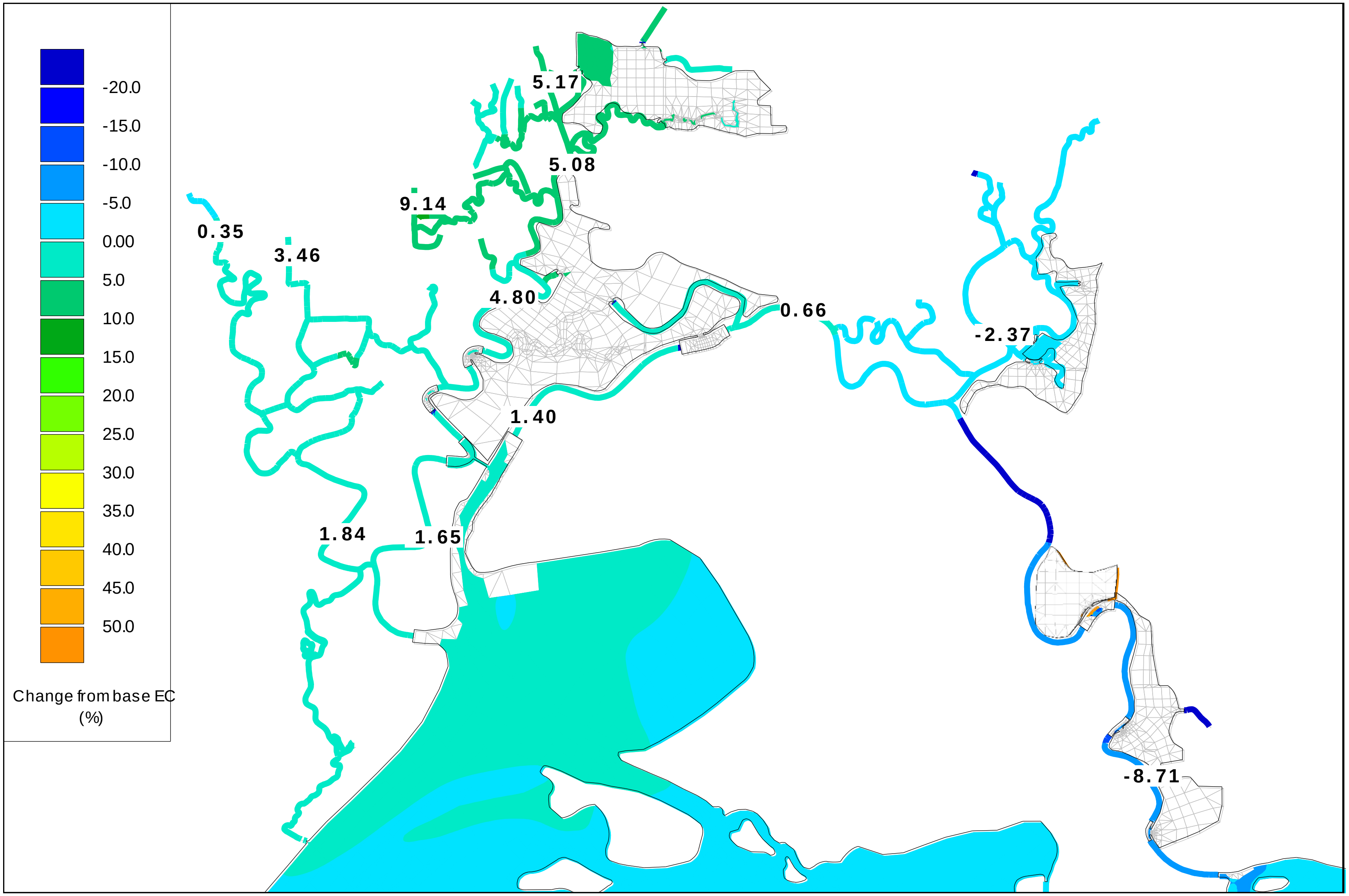


Figure 6-28 Percent Change from Base tidally averaged EC in the Suisun Marsh area on 24 September 2002 for the NT scenario.

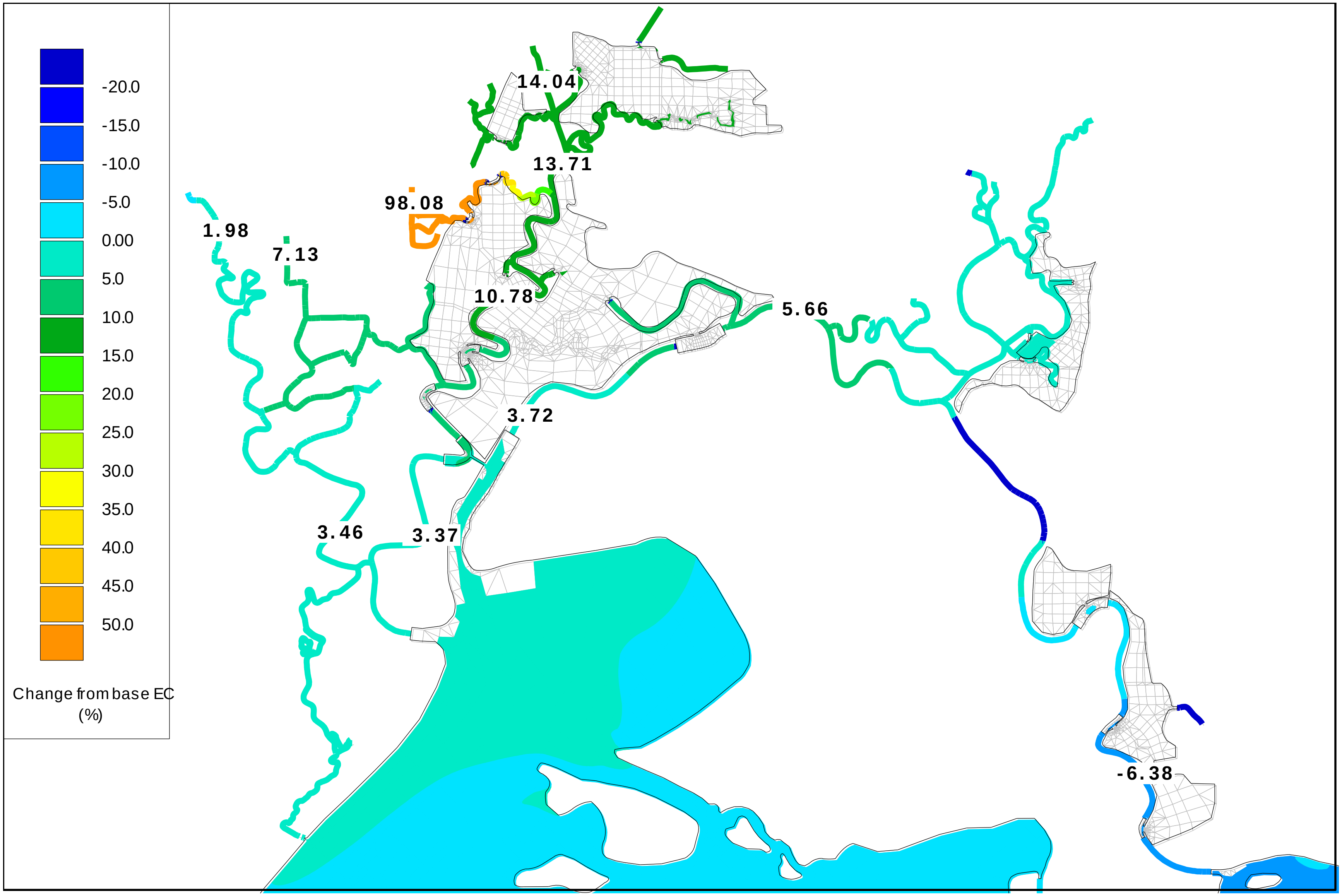


Figure 6-29 Percent Change from Base tidally averaged EC in the Suisun Marsh area on 24 September 2002 for the ELT scenario.

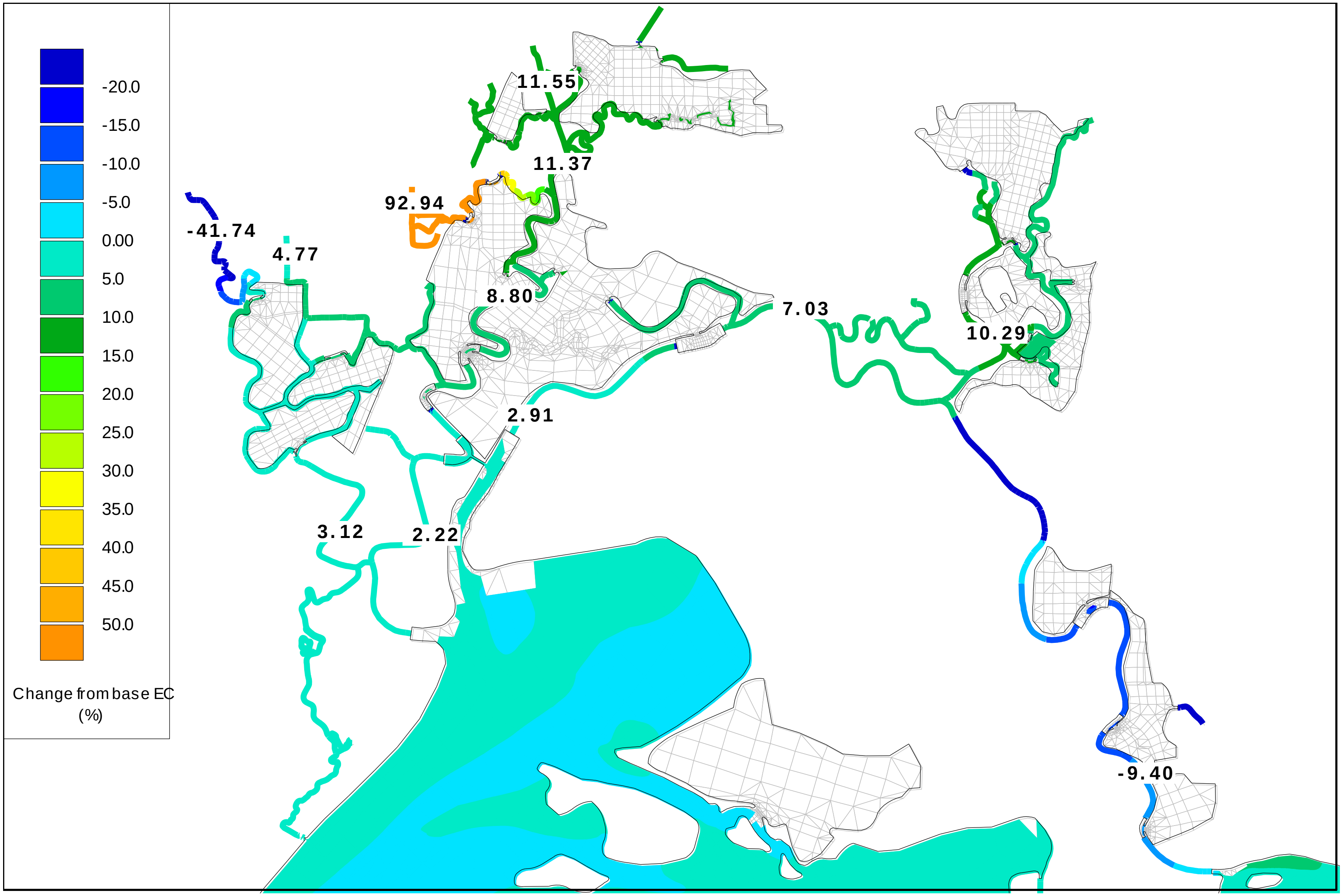


Figure 6-30 Percent Change from Base tidally averaged EC in the Suisun Marsh area on 24 September 2002 for the LLT scenario.

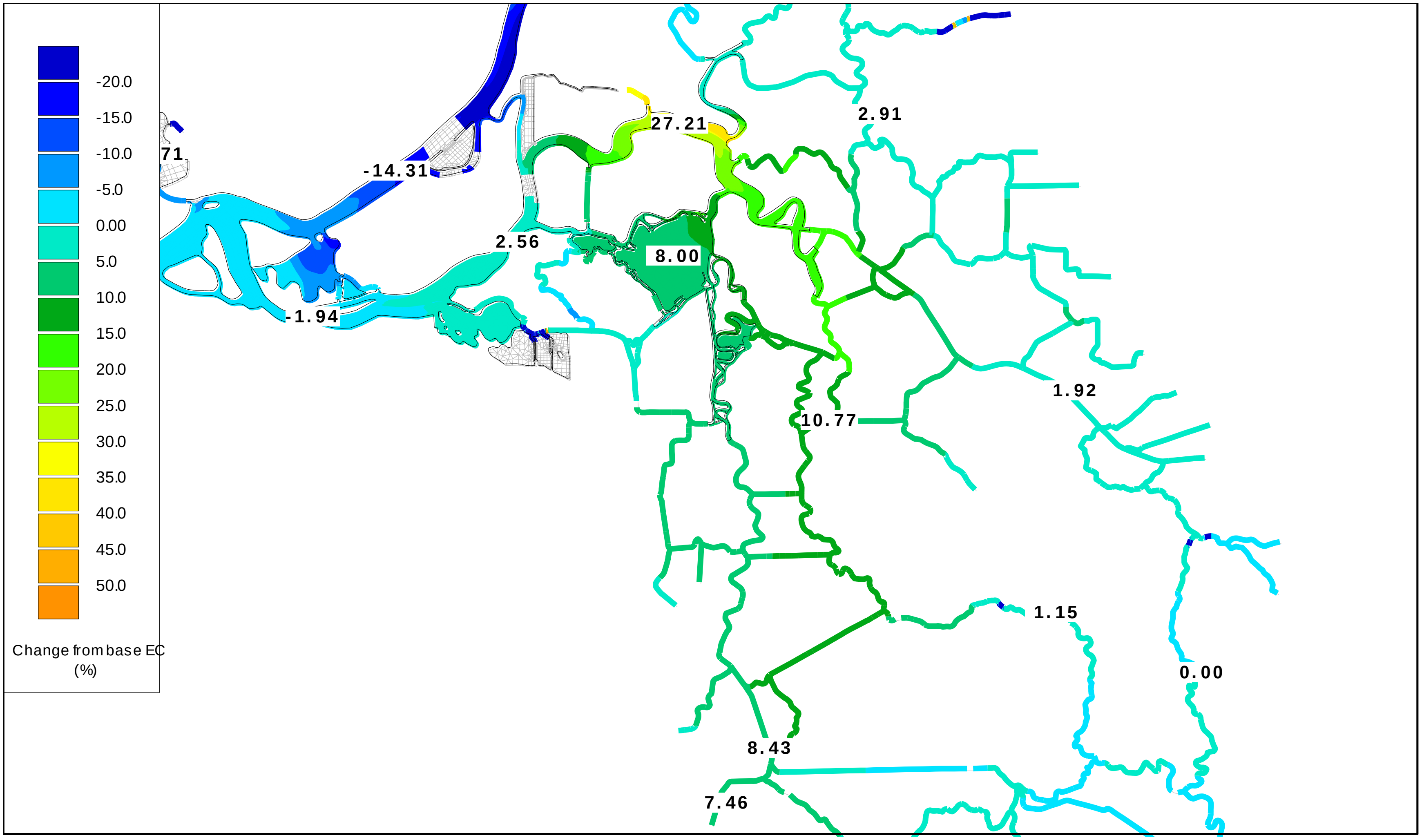


Figure 6-31 Percent Change from Base tidally averaged EC in the central and south Delta on 24 September 2002 for the NT scenario.

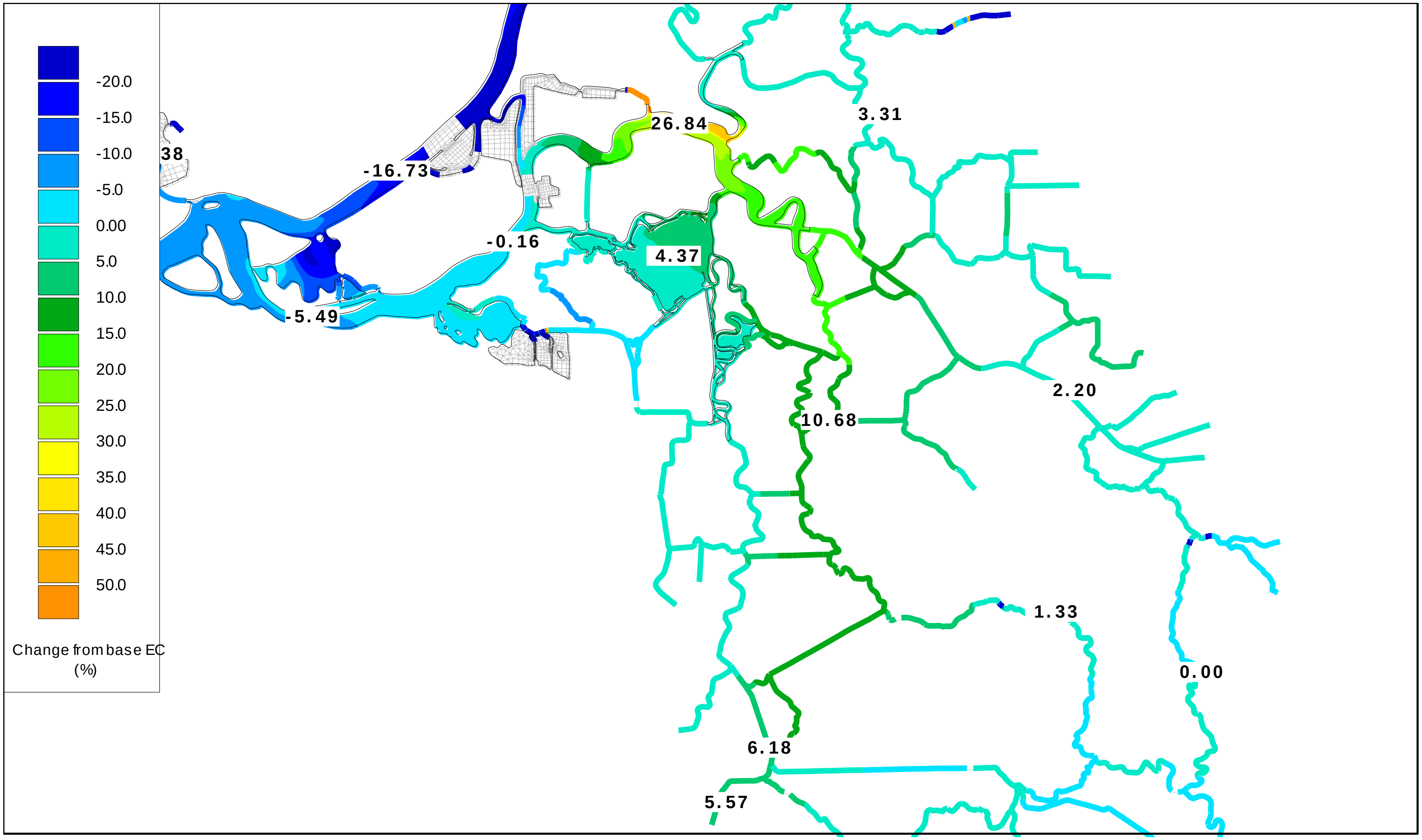


Figure 6-32 Percent Change from Base tidally averaged EC in the central and south Delta on 24 September 2002 for the ELT scenario.

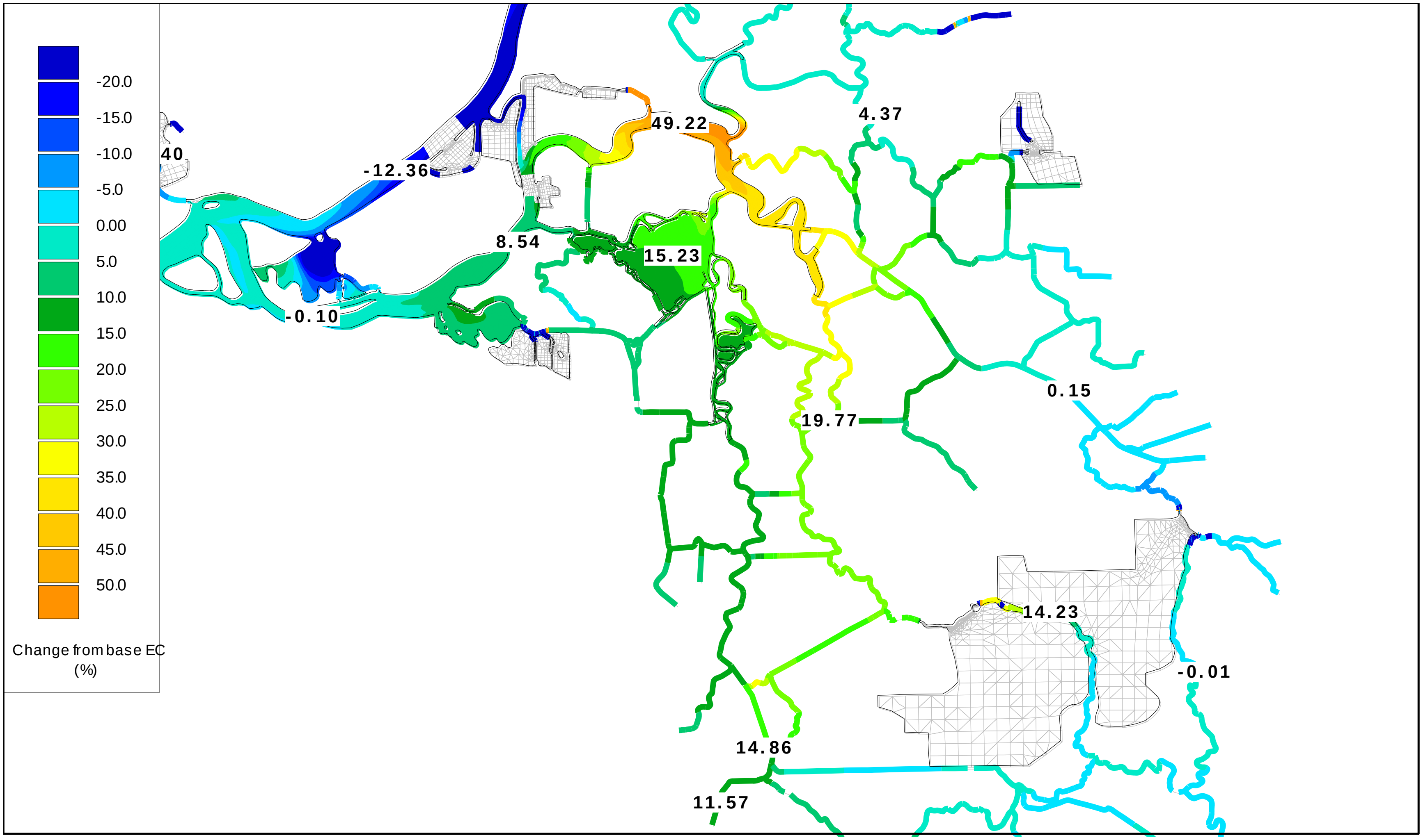


Figure 6-33 Percent Change from Base tidally averaged EC in the central and south Delta on 24 September 2002 for the LLT scenario.

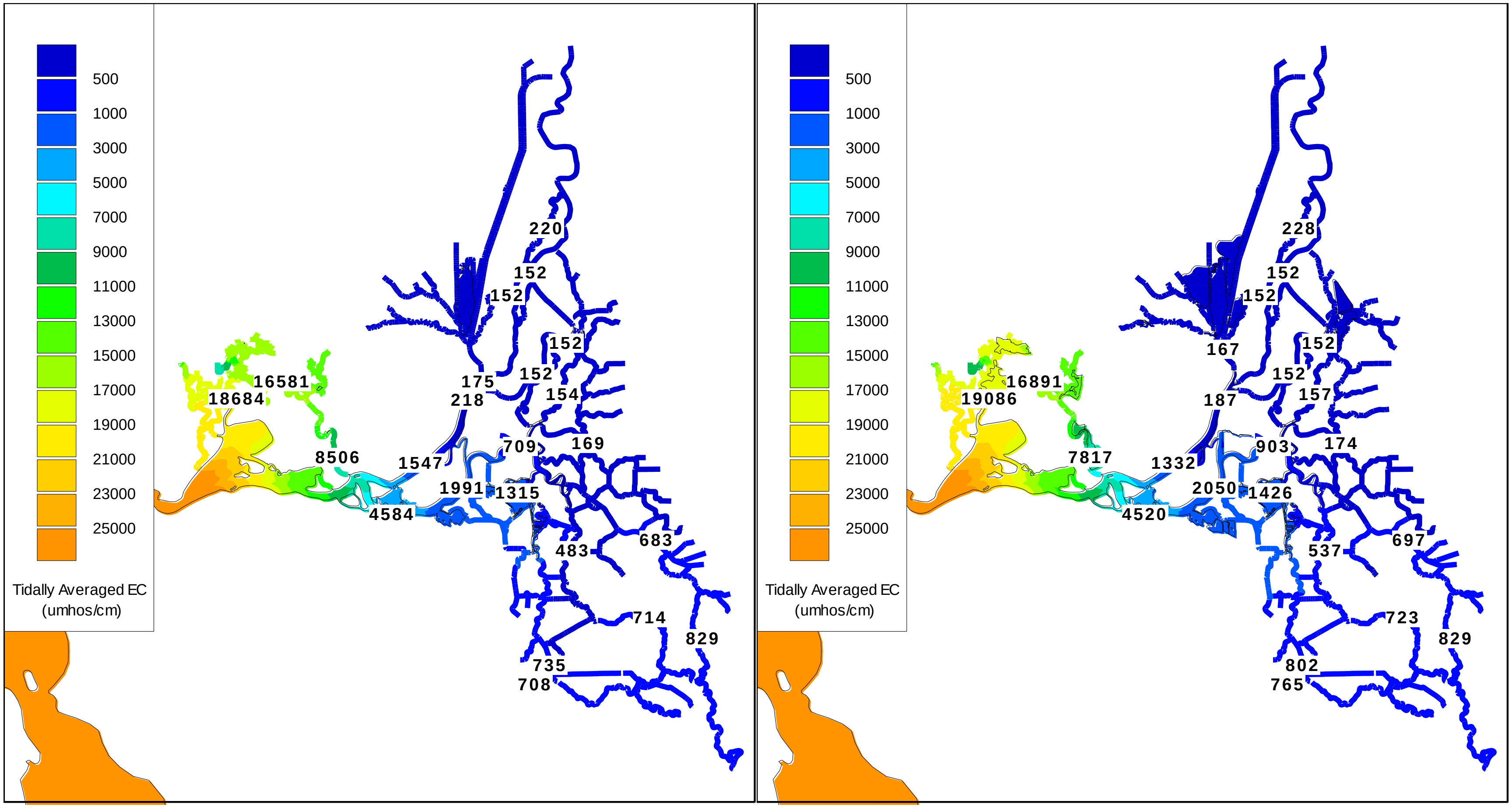


Figure 6-34 Base Case and NT tidally averaged EC on 24 September 2002.

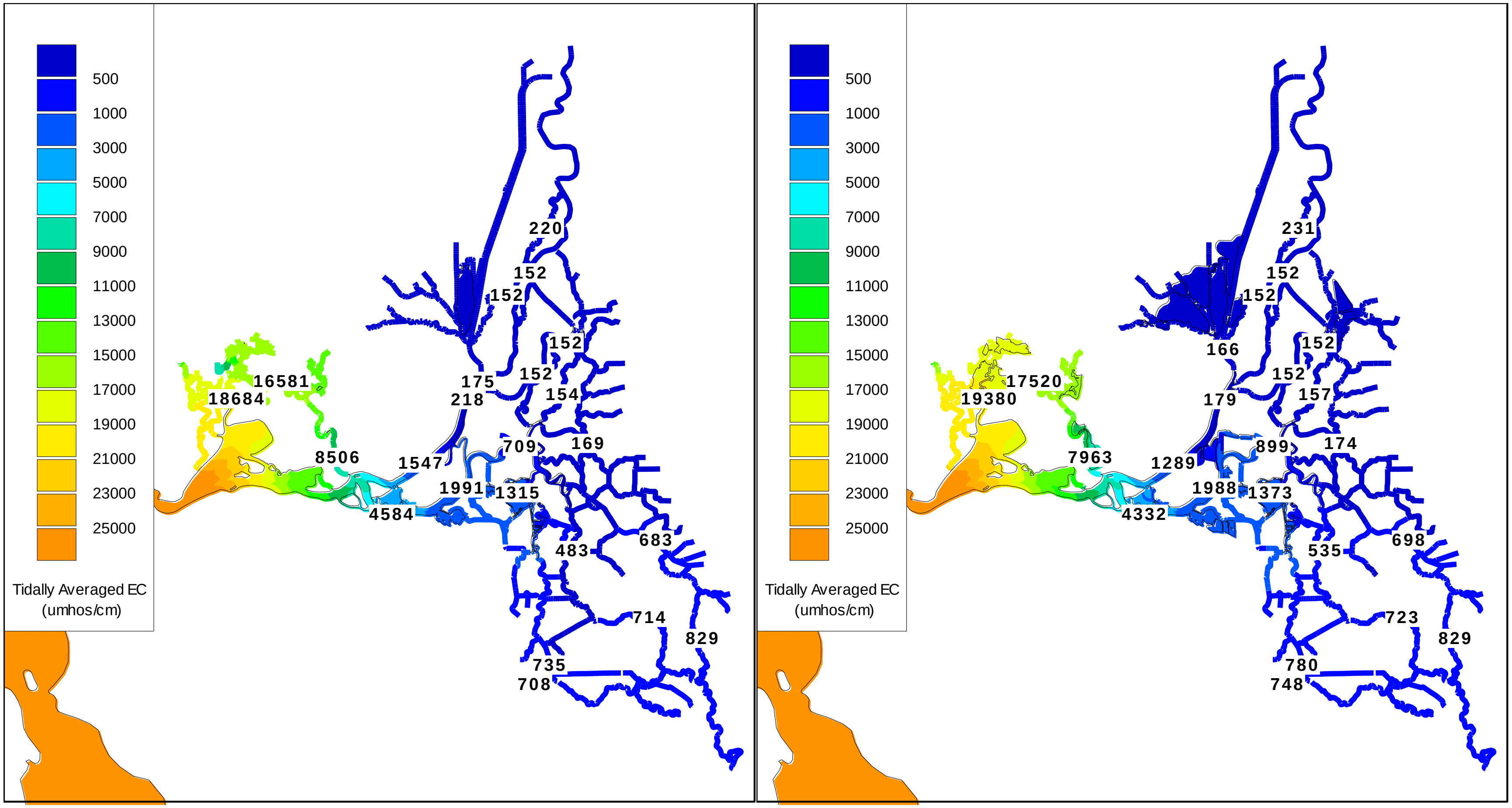


Figure 6-35 Base Case and ELT tidally averaged EC on 24 September 2002.

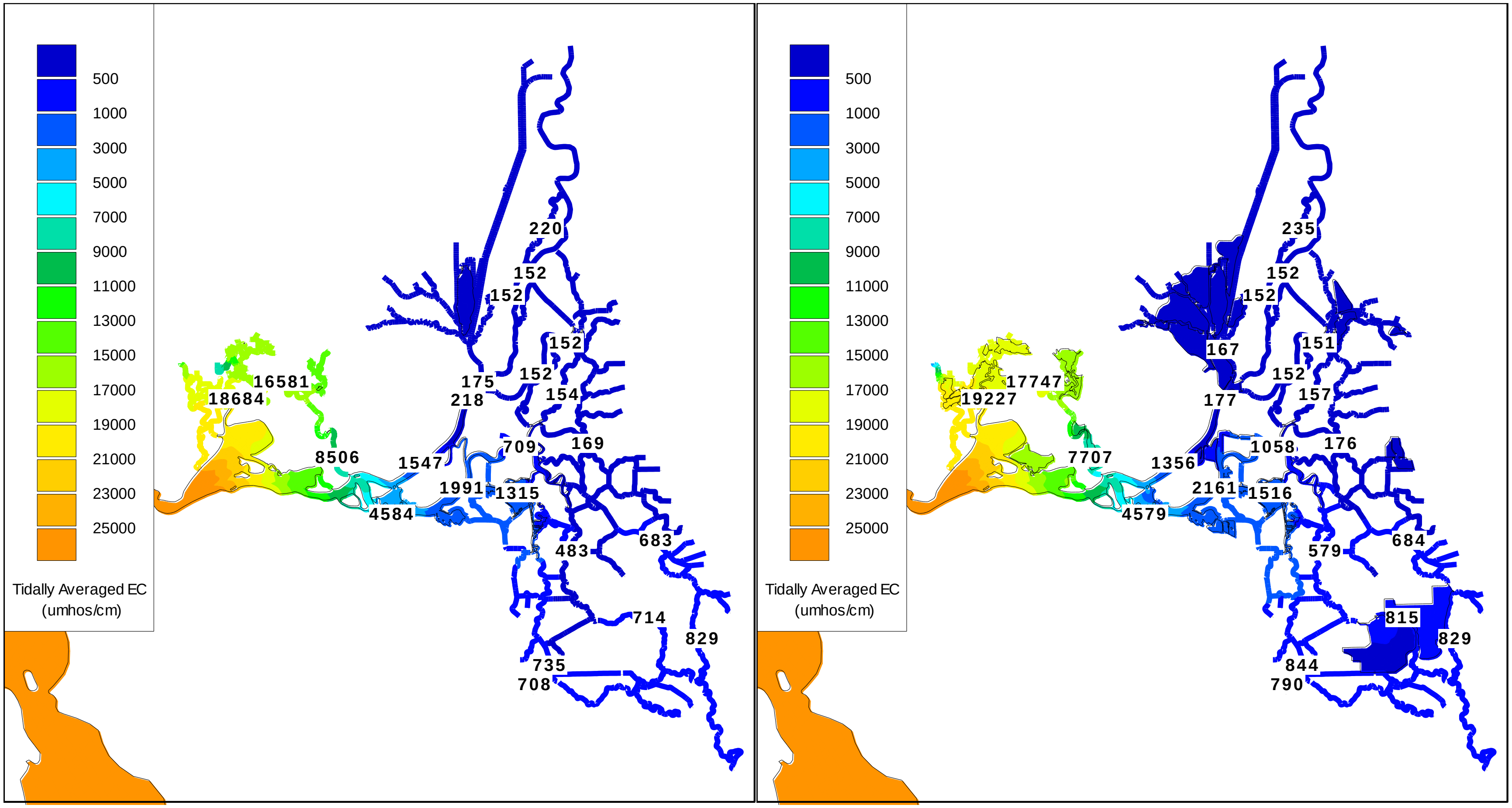


Figure 6-36 Base Case and LLT tidally averaged EC on 24 September 2002.

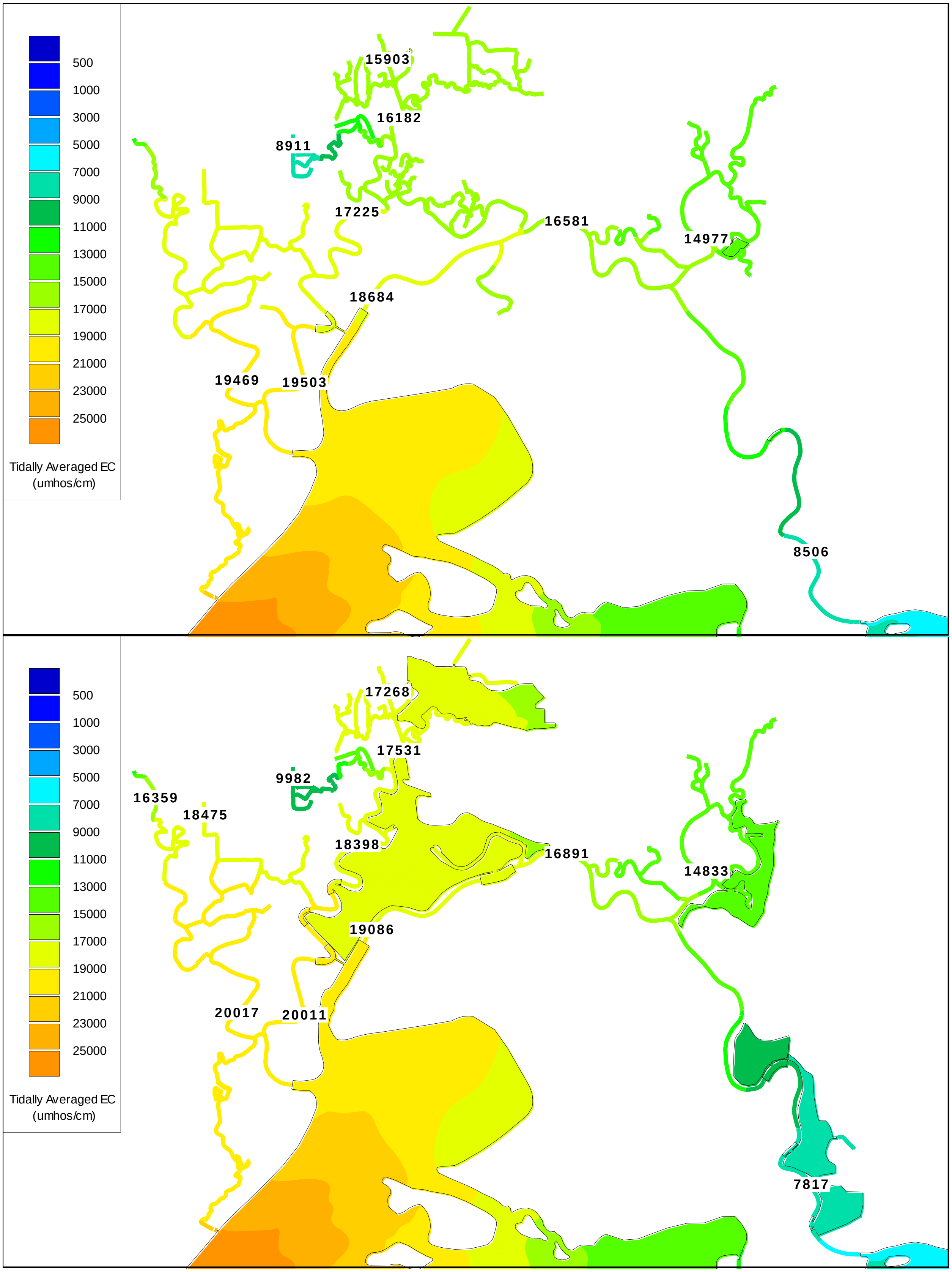


Figure 6-37 Base Case and NT tidally averaged EC in the Suisun Marsh area on 24 September 2002.

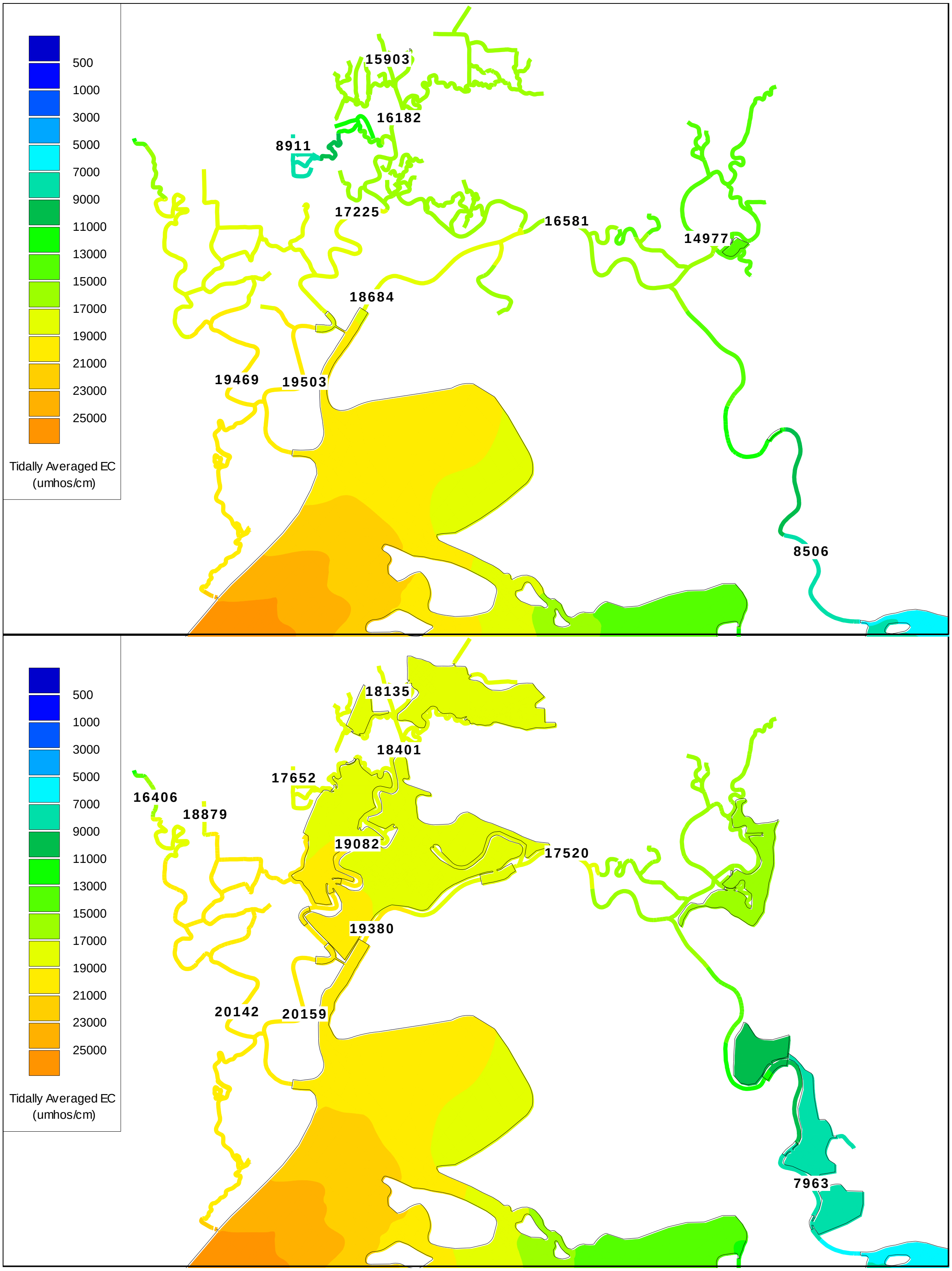


Figure 6-38 Base Case and ELT tidally averaged EC in the Suisun Marsh area on 24 September 2002.

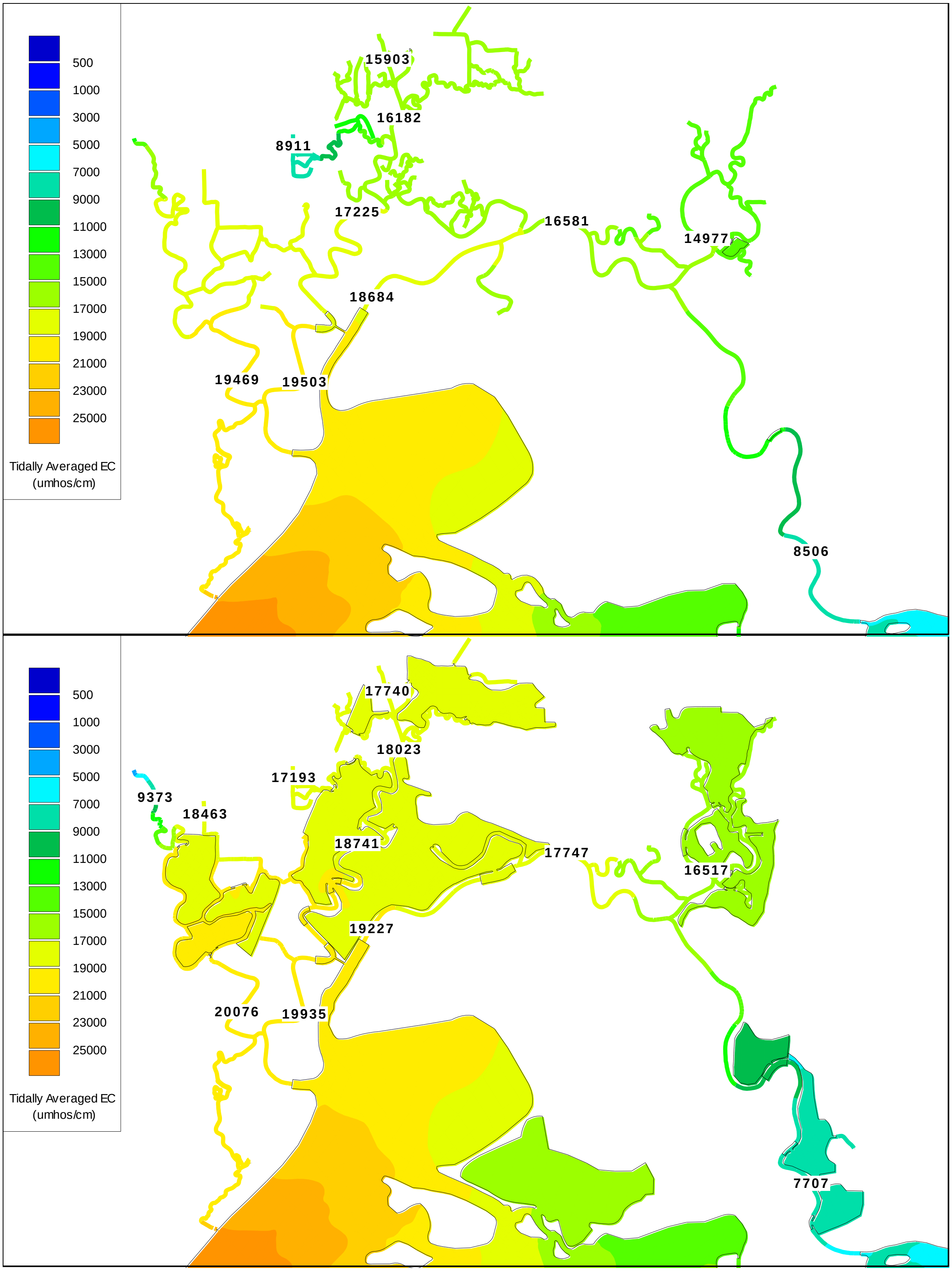


Figure 6-39 Base Case and LLT tidally averaged EC in the Suisun Marsh area on 24 September 2002.

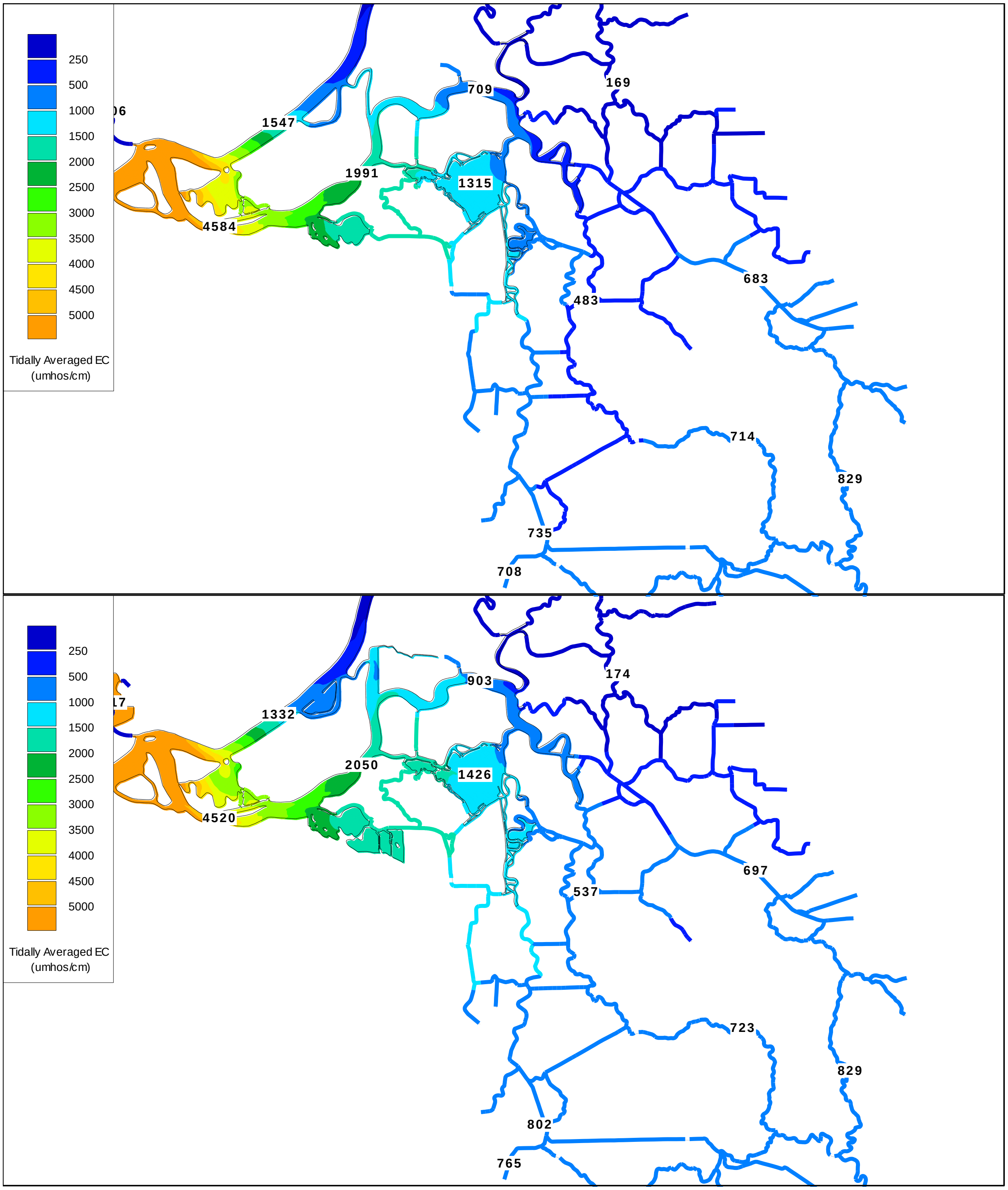


Figure 6-40 Base Case and NT tidally averaged EC in the Delta on 24 September 2002.

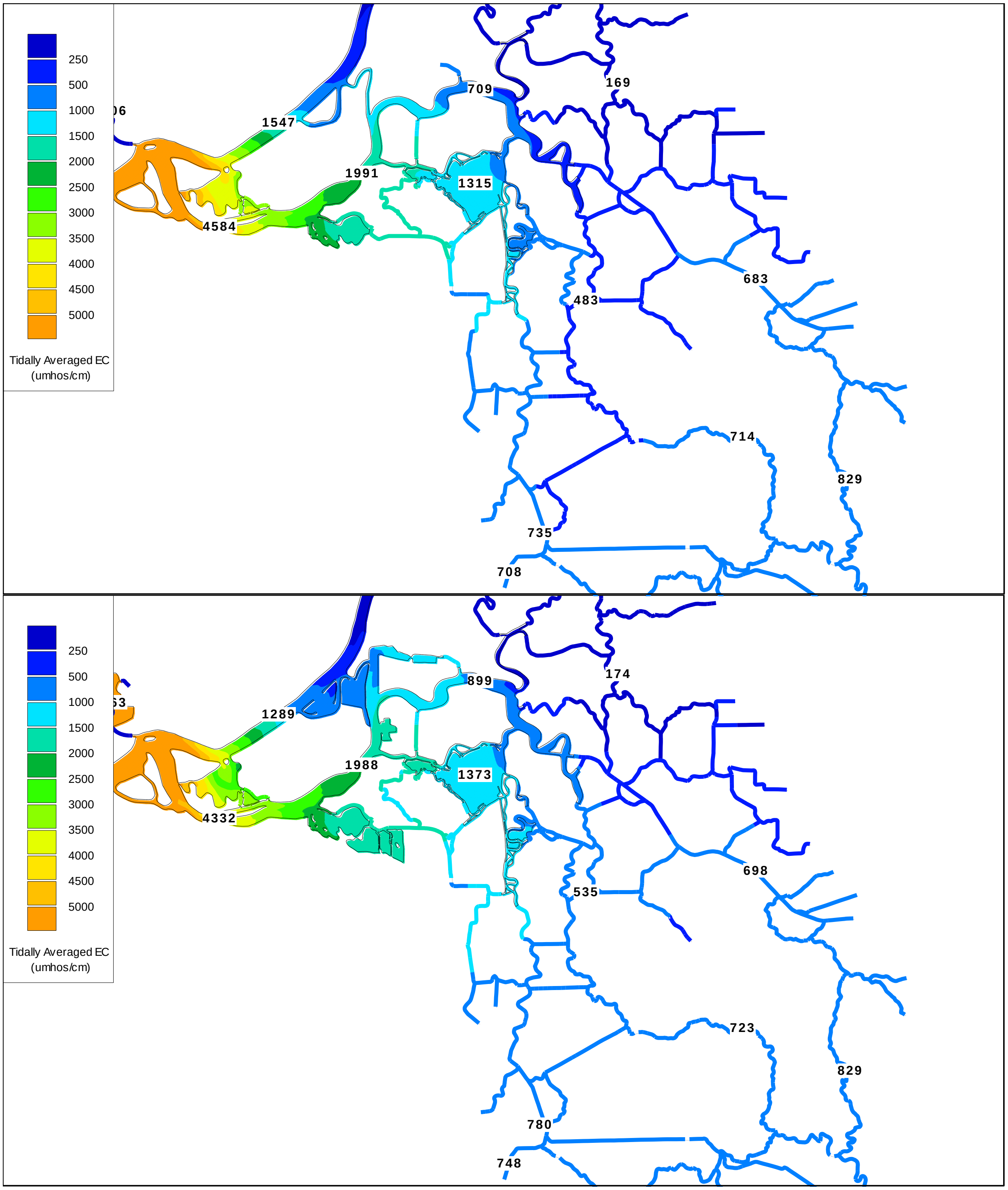


Figure 6-41 Base Case and ELT tidally averaged EC in the Delta on 24 September 2002.

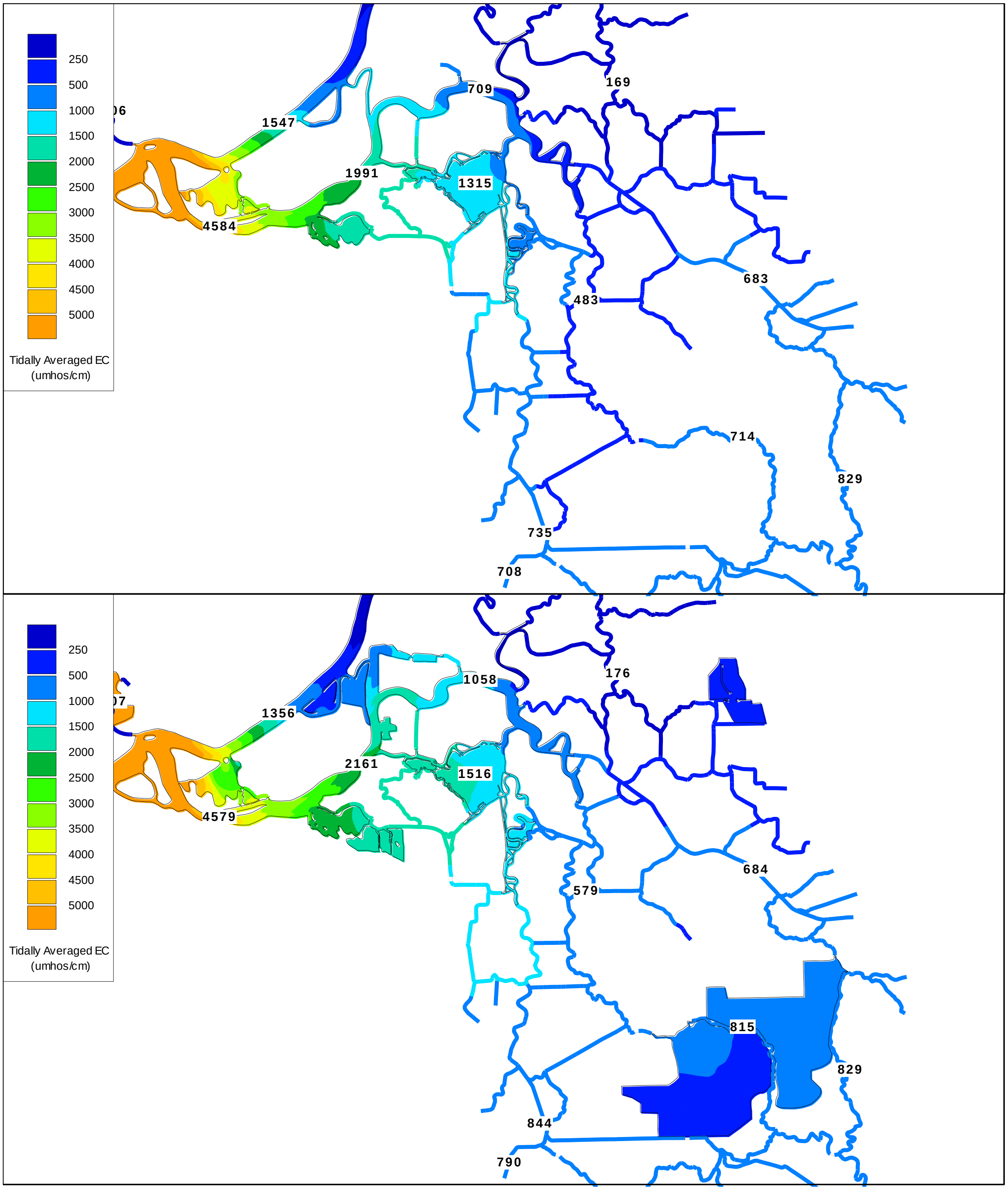


Figure 6-42 Base Case and LLT tidally averaged EC in the Delta on 24 September 2002.

6.3 EC Summary

The distribution of salinity in the Delta is a function of the overall flow balance, net flow distribution, and dispersive mixing associated with tidal flows. Specific impacts of tidal marsh restoration include

- Net flow transfer from the Georgiana and Mokelumne flow corridor to the Sacramento River allows increased dispersion of salt into the central Delta
- Increases or decreases in tidal flows tends to respectively increase or decrease dispersion of salt
- Adding restoration areas along the main axis of the estuary where strong salinity gradients are present will increase mixing of salt by tidal trapping

The tidal and net (or averaged) flow changes discussed in the "Hydrodynamic Impacts" section act to change the salinity distribution in the Delta, Suisun Bay and Suisun Marsh. If examined on an individual basis, EC increases downstream of a restoration area because of increased tidal flow and tidal mixing. Upstream of a restored area, tidal range, and thus tidal flow and mixing, are reduced, and EC is reduced. Results from previous BDCP work illustrate this well, as the restoration areas were simulated individually. Tidally averaged EC at Emmaton for the Base case, Cache Slough restoration and Suisun Marsh restoration from the previous work are plotted in Figure 6-43. At this location, Cache Slough restoration (upstream) increases EC above base, while Suisun Marsh restoration (downstream) reduces EC.

Restored areas directly connected to main channels (Sacramento or San Joaquin River), where EC of the main channel varies over the tidal cycle, increase EC in the region due to tidal trapping. Tidal trapping refers to the dispersive mechanism by which differences in tidal phase between a main channel and side channel or embayment create a net horizontal dispersion, in this case, of EC. Examples of this include restoration off of Suisun Bay and in the West Delta ROA. An illustration of tidal trapping off of Suisun Bay from the LLT scenario is shown in Figure 6-44. The arrow in the first frame shows the restoration area involved.

The BDCP Plan considers multiple restoration areas. As a result, there is a complex interaction among the various restoration areas in the Suisun Marsh and Delta that effects the overall salinity distribution. A downstream restoration may initially reduce salinity at a location in the Delta by reducing tidal flow and tidal mixing. Salinity at the location may later increase as restoration proceeds upstream and tidal flow and tidal mixing increase. The simulations performed in earlier stages of the study examining the restoration areas (e.g. Cache Slough ROA, Suisun Marsh ROA) on an individual basis, although not included in the current report, are referenced in the current discussion to help understand the contributing impacts of the individual restoration areas.

Salinity Changes in Suisun Marsh

Restoration in the Suisun Marsh decreases the tidal flow and overall tidal mixing for the Delta east of Chipps Island (for example at Emmaton, Figure 6-44). EC is seen to decrease in eastern Suisun Bay and the area of the Sacramento River - San Joaquin River confluence for the NT and ELT cases (Figures 6-25 and 6-26). EC slightly increases near Chipps Island and the confluence for the LLT (Figure 6-27). This partly reflects the increased salinity mixing with tidal trapping from the restoration of the southern portion of Grizzly Island directly connected to Suisun Bay. Cache Slough restoration also increases EC at this location. The changes in EC at the confluence propagate further east into the Delta.

Within the Suisun Marsh, the results for the three time steps are mixed. Breach locations impact the results. In general, with more restoration off of Suisun Slough, the transition from positive to negative changes in EC moves further east. Looking at the tidally averaged results on September 24, 2002, for the NT case (Figure 6-28), EC increases to the west of Beldon's Landing and decreases to the east. For the ELT case (Figure 6-29), the point of transition is near Meins Landing. But for the LLT case (Figure 6-30), with extensive restoration off of Nurse Slough, the point of transition shifts back downstream toward Nurse Slough. In Suisun Marsh, the dramatic increases in EC during the fall are the result of removal of the SMSCG, however on September 24, 2002 gates are not operating in the Base case.

There are also some localized effects in Suisun Marsh. For example in Boynton Slough for the Base and NT cases (Figure 6-37), low EC discharge from the Fairfield WWTP is very evident because it is a dead end slough. But when the area south of Boynton Slough is breached in multiple locations for ELT and LLT (Figure 6-38 and Figure 6-39), Boynton Slough is flushed with higher EC water, dramatically changing the concentrations at this location. In Goodyear Slough at Morrow Island, EC increases for the NT and ELT cases as the restoration areas off of Suisun Slough draw more high EC water up Suisun Slough, affecting EC in Goodyear Slough. But for the LLT case, the EC increases to a lesser degree relative to NT and ELT at this location because restoration to the east increases tidal flow in that direction and pulls the higher EC water away from Goodyear Slough, where tidal flow is decreased.

Salinity Changes in the North Delta

The most significant restoration related changes in the averaged flows affecting the Delta salinity regime are the changes in the north Delta. As restoration area is added with each time step, net flow increases in Sacramento River and decreases in Georgiana Slough and Delta Cross Channel (Figure 5-29). The decrease in freshwater coming down Georgiana Slough and Mokelumne River results in increased EC, for each of the restoration cases, in the San Joaquin River around San Andreas Landing and on down into the South Delta (Figure 6-25 through Figure 6-27). Greater flows in the Sacramento River help to push Sacramento River EC lower, downstream of Georgiana Slough and the Cross Channel. However, these decreases are somewhat offset by increased tidal flow and tidal mixing with restoration near Cache Slough, and EC is brought back toward the Base case as new area is added for the later restoration time steps. The changes in Delta EC caused by the changes in the tidal flows are superimposed upon the changes in EC resulting from the altered averaged flows.

Salinity Changes in the Central and Western Delta

At Jersey Point (Figure 6-12) there are many factors affecting EC for the restoration scenarios, resulting in increased EC for NT, greater increases for LLT and reduced EC for ELT. Restoration in Suisun Marsh off of the internal channels reduces EC. Restoration off of Suisun Bay increases EC at Jersey Point due to tidal trapping (RMA, 2000b). Cache Slough and Mokelumne-Cosumnes restorations likely cause slight increases at Jersey Point. Jersey Point EC for LLT is the highest of all cases. The Jersey Point results are reflected into the south Delta in Old River (Figure 6-14) and at the exports (Figure 6-15 and Figure 6-16) where the EC increase for ELT is slightly less than that for the NT. In Middle River (Figure 6-17), the differences between NT and ELT are more subtle and the increases for ELT are actually greater than for NT later in the fall.

The impacts of the West Delta ROA on EC are generally unclear. Preliminary test simulations (not discussed in this report) with the ELT West Delta area removed indicate that the West Delta ROA (not including the tip of Grand Island) may cause small EC increases, on the order of 5-10%, on the Sacramento River at Emmaton and Rio Vista, and small decreases, on the order of 2%, in the south Delta. There were no significant impacts at Jersey Point.

Salinity Changes near the South Delta Exports

For the restoration cases, EC at the exports increased by about 5 to 15% on 24 September 2002. Peak tidally averaged EC at the CVP was 744 umhos/cm for Base and 875 umhos/cm for LLT. Peak tidally averaged EC at the SWP was 765 umhos/cm for Base and 924 umhos/cm for LLT. These peaks all occurred at the end of September 2002.

Incremental Impact of Near Term, Early Long Term, and Late Long Term Restoration

The incremental change in EC from the Base condition through NT, ELT, and LLT restoration is a function of competing mechanisms acting affecting salt intrusion. As modeled, the ELT configuration shows generally less increase in EC in the central and southern Delta than do the NT or LLT configurations. This result is counter-intuitive since the restoration acreage of the ELT is between the NT and LLT configurations. However, it can be explained considering the changes in tidal flow, net flow, and tidal trapping and how these changes affect salt intrusion into the central Delta.

At Chipps Island there is a decreasing trend in tidal flow from Base to NT to ELT to LLT configurations, which would result in reduced mixing of salt from Suisun Bay toward the western Delta. This trend is observed in the NT and ELT results, however in the LLT configuration EC increased near the confluence. This is apparently due to the addition of the restoration area at the southern end of Grizzly Island causing increased mixing through tidal trapping, which overwhelms the impact of reduced tidal flow.

There is an increasing transfer of net flow from Georgiana Slough and the Delta Cross Channel toward the Sacramento River from Base to NT to ELT to LLT configurations. This reduces “QWEST” along the San Joaquin River and makes the net flow at Jersey Point more negative during periods of high exports while increasing downstream flow at Emmaton on the Sacramento River. This should result in decreasing EC at Emmaton and increasing EC at Jersey Point and on into the central Delta. The model results do show decreasing trend in EC at Emmaton. However, at Jersey Point, the ELT configuration has a smaller increase in EC than the NT or LLT configurations relative to the Base condition. The competing mechanism of reduced mixing due to reduction in tidal flow at Chipps Island, Jersey Point and in the central Delta apparently mitigates the shift in net flow in the ELT configuration. In the LLT configuration, the increase in mixing due to tidal trapping from the Grizzly Island restoration noted above leads to increases in EC all the way into the central Delta.

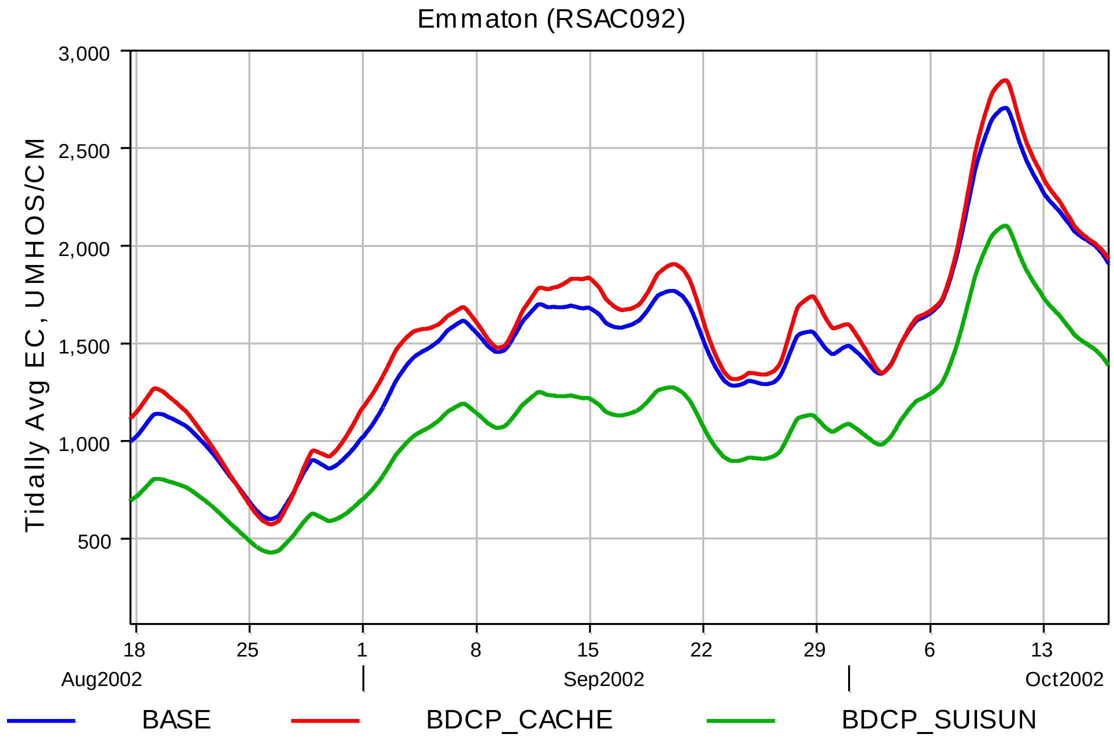


Figure 6-43 Tidally averaged EC at Emmaton for Base case, Cache Slough restoration and Suisun restoration from previous BDCP study analyzing restoration areas separately.

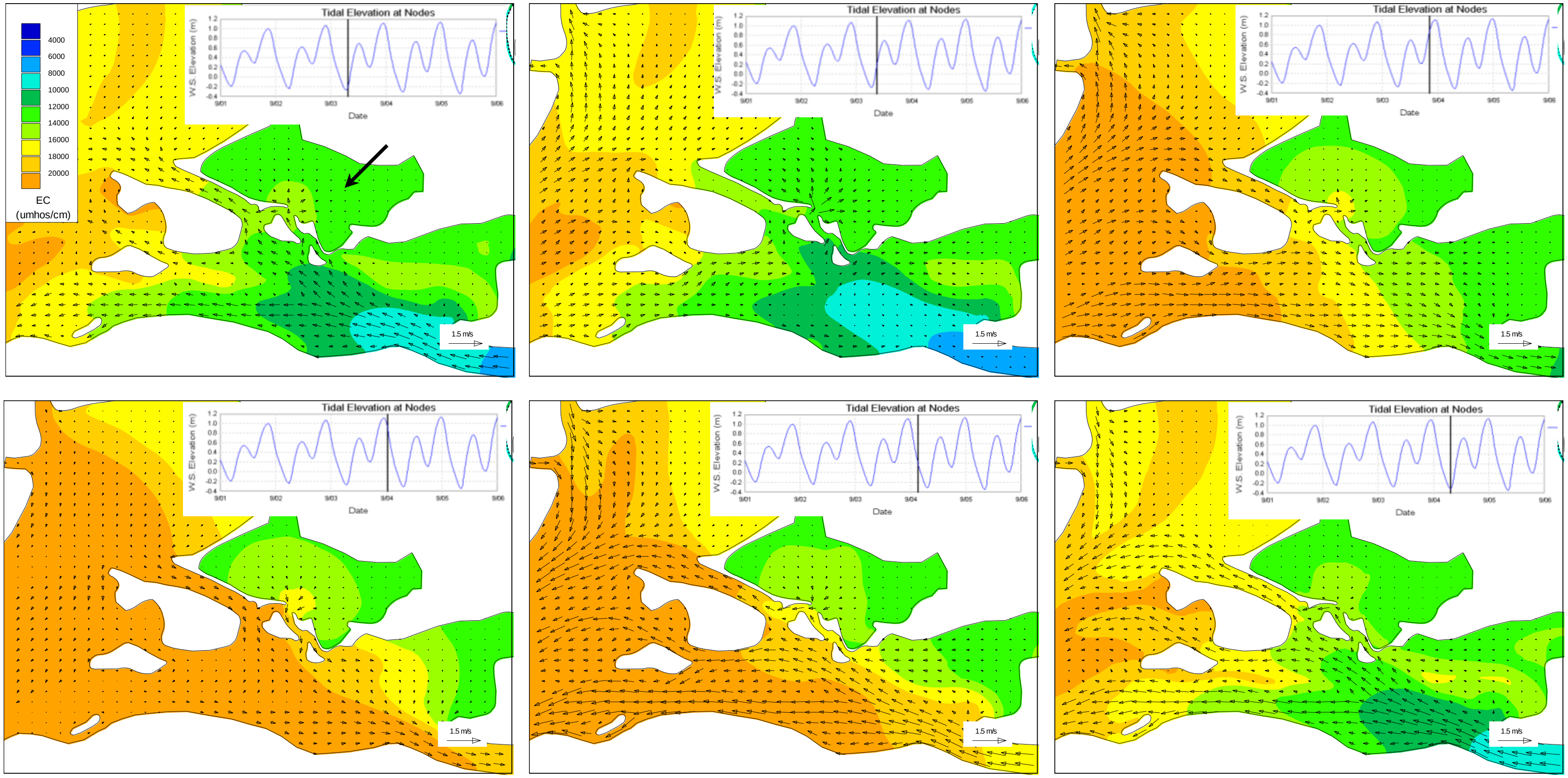


Figure 6-44 Illustration of tidal trapping from LLT scenario. Arrow in first frame indicates restoration area involved.

7 Concluding Comments

The first phase of NT, ELT and LLT simulations is complete. Simulations were performed for the 2002-2003 period with historical stage, inflow, export and EC boundary conditions. Historical gate and barrier operations were used with the exception of the Montezuma Slough gate, which was removed for all restoration simulations, and the Middle River barrier, which remained open for the LLT simulation.

Key observations from the restoration simulation results were as follows.

- Restoration resulted in a reduction in tidal range throughout the Delta and Suisun Marsh, with peak reductions of about 1.1 ft occurring in the central Delta and in Montezuma Slough.
- Restoration resulted in reduction of average flows in Georgiana Slough and the Delta Cross Channel, which caused EC increases in the San Joaquin River in the vicinity of San Andreas Landing.
- Restoration resulted in increased net flows in Sacramento River below the Cross Channel, which reduced EC at Rio Vista and Emmaton.
- EC increases downstream of a restoration area because of increased tidal flow and tidal mixing.
- Upstream of a restored area, tidal range, and thus tidal flow and mixing, are reduced, and EC tends to be reduced.
- EC at the exports was increased by 5-15% during September 2002, as a result of the restoration scenarios.
- Restored areas directly connected to main channels (Sacramento or San Joaquin River), where EC of the main channel varies over the tidal cycle, increase EC in the region due to tidal trapping.
- Under restoration scenarios, existing channels appear to be restrictive in Suisun Marsh near LLT eastern restoration areas, in Hunter Cut, and in Montezuma Slough (Montezuma Slough was modeled with a widened channel to eliminate this restriction); in the channel leading into the East Delta restoration area; Cache Slough at Ryer Island and near Liberty Island; and Middle River at the South Delta restoration area.
- The incremental change in EC from the Base condition through NT, ELT, and LLT restoration is a function of competing mechanisms affecting salt intrusion. As modeled, the ELT configuration shows generally less increase in EC in the central and southern Delta than do the NT or LLT configurations. This result is counter-intuitive since the restoration acreage of the ELT is between the NT and LLT configurations. However, it can be explained considering the changes in tidal flow, net flow, and tidal trapping and how these changes affect salt intrusion into the central Delta.

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