

Delta Wetlands Potential Flood Protection Operations

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Acronyms and Abbreviations

af	acre-feet
cfs	cubic feet per second
CVP	Central Valley Project
DMC	Delta-Mendota Canal
DSM2	Delta Simulation Model II
DWR	California Department of Water Resources
IEP	Interagency Ecological Program
msl	mean sea level
NGVD29	National Geodetic Vertical Datum of 1929
SWP	State Water Project
TAF	thousand acre-feet
USGS	U.S. Geological Survey

Delta Wetlands Potential Flood Protection Operations

Executive Summary

This report describes potential reductions in peak tidal elevations in the central Delta associated with diverting water onto two central Delta islands, Webb Tract and Bacon Island, for flood protection purposes. The risk of flooding (i.e., levee overtopping) in the central Delta might be reduced if weirs could be operated to briefly divert high flows onto the proposed Delta Wetlands (DW) water storage islands at times when both tides and Delta inflow are high. It should be noted that such high tide events are highly predictable, and last only a few hours. Reductions in the peak tide elevations would not have to be large to be useful. This secondary benefit from the in-Delta storage islands would require appropriate weirs and gates to control the large diversions during high tide periods.

This analysis evaluated the effect of diverting 20,000 cfs onto each island during peak flood events over multiple weirs with gates. The construction of weirs and gates to allow 5,000 cfs diversions is feasible. Weirs with gates constructed in the Webb Tract and Bacon Island levees could allow relatively high flows to enter the islands in a controlled manner. Operable gates would be opened during peak tidal events. The proposed flood protection diversion weirs would need operable gates that were reliable even during power failure, to ensure that the gates could be closed once the peak tide elevation began to decrease each day. Large gates (i.e., vertical sluice gates or pivoting gates like the Clifton Court intake gates) that could be closed by gravity alone could be designed to allow diversions of about 5,000 cfs with a width of about 75 feet and a depth of about 10 feet. Perhaps three gates with widths of 25 feet would be a practical design. Electrical motors with lifting cables or hydraulic lifting cylinders would be needed to lift the gates open.

The DSM2 model was used to accurately simulate historical tidal elevations and flows in the central Delta during the January 1997 high-flow event. This simulation period was used to evaluate the effects of diverting water onto Webb Tract and Bacon Island during the peak tidal elevation periods of January 3–12, 1997. The effects of these diversions are limited by the influence of tidal flows on the tidal elevations in the central Delta. The basic flood protection scenario assumed that a combined diversion of 40,000 cfs (i.e., four 5,000 cfs weirs with gates on each island) would occur for 6 hours each day. The total volume diverted would be about 10 taf/day onto each island. Because each storage island

has a volume of about 100 taf, flood protection diversions could occur for only about 10 days. The simulated diversions occurred for 10 consecutive days, but actual operations would target days with the highest tidal elevations. The simulated combined diversions of 40,000 cfs for 6 hours each day were large enough to reduce the average peak tidal elevations in the central Delta by 3-4 inches.

In all flood protection scenarios, the largest average reductions in simulated peak tidal elevation occurred near the upstream end of Bacon Island (Middle River at Bacon Island and Old River at Los Vaqueros intake), but the reductions at most other locations in the south Delta were about the same as the reductions at the upstream end of Bacon Island. An extreme combined diversion rate of 80,000 cfs was simulated to evaluate the greatest possible reduction in higher-high tide elevations. Although this extreme diversion rate reduced the peak tide elevations by about 5-7 inches in the central Delta, these large diversions could be sustained for only 4 days before Webb Tract and Bacon Island would be filled. Accurate forecasts of tidal elevations will be required to properly operate the flood protection gates. This should be possible because the greatest flooding risk in the central Delta is the higher-high tides during spring-tide periods of months with large storm inflows, such as occurred during January 1997.

Introduction

This report describes potential reductions in peak water surface elevations in the central Delta associated with diverting water onto two central Delta islands, Webb Tract and Bacon Island, for flood protection purposes. The risk of flooding in the central Delta might be reduced if weirs could be operated to briefly divert high flows onto their proposed water storage islands when tidal elevations are predicted to potentially overtop levees during higher-high tide events when Delta inflow is high. This secondary benefit from the DW storage islands would require appropriate weirs and gates to control the large diversions during high tide periods.

In a riverine situation, large diversions would have a clear effect on water surface elevations upstream of the diversion. In the Delta, however, the effect of diversions on tidal elevations is not immediately obvious because water that is diverted might be replaced by increased tidal inflow. Decreases in Delta tidal elevations produced by diversions may not be large, but there are times when a few inches might determine whether levees are overtopped. Even if levees are generally raised, it is likely that some places still will be subject to potential flooding because of levee slumping, wave overtopping, and unusual ocean tide (at Martinez). Some central Delta levee locations could benefit from even small reductions in peak water surface elevations.

Potential tidal elevation reductions associated with diversions onto Webb Tract and Bacon Island were evaluated using the California Department of Water Resources (DWR) Delta Simulation Model II (DSM2). DSM2 was developed by DWR for simulating hydrodynamic, water quality, and particle-tracking

conditions in the Delta. Water surface elevations calculated by DSM2 and all elevations in this report are presented in feet above mean sea level (msl) using the National Geodetic Vertical Datum of 1929 (NGVD29). The accuracy of the DSM2 model has been generally demonstrated by the calibration and validation work performed by DWR and reported on their website at:

<http://modeling.water.ca.gov/delta/studies/validation2000>

For this study, only the hydrodynamic portion of the model, HYDRO, was needed. Potential tidal elevation reductions were assessed by simulating tidal elevation both with and without the Delta Wetlands peak tide flood diversions during the high-flow event of January 1997. Diversions to Webb Tract and Bacon Island were evaluated separately and in combination. Diversions onto the islands were evaluated at two flow levels (20,000 cubic feet per second [cfs] and 40,000 cfs) with the diversions lasting 2 or 6 hours during higher-high tide each day.

Simulation of Historical Conditions

Inflows

Delta hydrologic conditions during the flood flows of January 1997 were simulated with DSM2 to develop a baseline for assessing the tidal elevation effects of diverting water onto Webb Tract and Bacon Island. The 1997 San Joaquin River flood conditions are described in a 1999 DWR report, *The Hydrology of the 1997 New Year's Flood: Sacramento and San Joaquin River Basins*. In January 1997, extremely high flows entered the Delta at the beginning and also at the end of the month. During this month, the peak flows of the Central Valley Rivers were, on average, close to the 100-year recurrence interval California Department of Water Resources 1999).

Peak San Joaquin River water surface elevation on January 5 at Vernalis was 34.9 feet, approximately 6 feet above the flood elevation California Department of Water Resources 1999). However, at this point, levees were beginning to break upstream (e.g., along the San Joaquin River between Mossdale and the Tuolumne River and along the Stanislaus River), and water was beginning to flow outside the levees. In the south Delta, the Paradise Cut levees broke on January 9, 1997 (National Weather Service Flood Summary 1997).

During January 1997, the measured Vernalis flows did not include flow through levee breaks that may have bypassed the gage section California Department of Water Resources 1999). The sum of the measured flows upstream of Vernalis and comparison of measured and simulated water surface elevations downstream of Vernalis were used to estimate the January flows at Vernalis (Figure 1).

The measured and simulated water surface elevations at Vernalis (Figure 2) do not match because the measured values include only the water that was contained within the levees, which is less than the estimated total Delta inflow at Vernalis.

Simulated Flows and Tidal Elevations

The dates of January 8–10, 1997, were chosen to evaluate the general hydrologic patterns during the period of peak San Joaquin River flows and high tidal elevations. Average flows simulated for January 8–10, 1997, are shown in Figure 3. The average Vernalis flow was about 59,000 cfs, considerably above the design flow for the levees of about 52,000 cfs. Simulated diversion into Paradise Cut was about 16,000 cfs. Flows in the San Joaquin River at Mossdale were approximately 43,000 cfs. This flow was split almost evenly at the head of Old River. The combined flow in Middle River, Grant Line Canal, and Old River therefore was about 38,000 cfs, with most of the water flowing through Grant Line Canal. About 5,000 cfs flowed into Middle River. Of the approximately 33,000 cfs flowing west through Grant Line Canal and Old River, an average of 4,500 cfs was exported at the Central Valley Project (CVP) and State Water Project (SWP) export pumps.

Approximately 29,000 cfs flowed downstream of Clifton Court Forebay with about 9,000 cfs (30%) flowing down Victoria Canal and 20,000 cfs (70%) down Old River. When the flow in Middle River combined with the flow in Victoria Canal, the total Middle River flow was brought to approximately 14,000 cfs. Near Woodward Island (i.e., Woodward Canal and Santa Fe Cut), some of the Old River flow moved east to Middle River. As a result, near Bacon Island the flow in Middle River was slightly higher than the flow in Old River (17,724 cfs versus 14,264 cfs, respectively). The simulated flow split between Old River and Middle River near Bacon Island is corroborated by U.S. Geological Survey (USGS) flow measurements (Figure 4) that show the Middle River flows being a little higher than the Old River flows under high-flow conditions (i.e., greater than 10,000 cfs).

During January 8–10, 1997, net flow in the San Joaquin River between Brandt Bridge and Disappointment Slough was approximately 20,000 cfs (Figure 3). Downstream of Disappointment Slough, the San Joaquin River was joined by other flows to produce a net flow of 31,755 cfs at Venice Island. Approximately 35% of this San Joaquin River flow at Venice Island flowed south around Webb Tract, with the remainder going north. At Jersey Point, most of the central and south Delta flows merged along with 5,000 cfs from Threemile Slough for a total of about 80,000 cfs.

Tidal variation in the DSM2 model is driven by the tidal elevation at Martinez (Figure 5). At Martinez, the measured tidal elevation was at a peak of 5 feet during the higher-high tides of January 8–10, 1997. This was a spring-tide period with minimum (lower-low) tidal elevations of -2 feet, giving a daily tidal range of about 7 feet. The simulated average tidal elevations for the higher-high tides on these dates are shown for other locations in the Delta in Figure 6.

Near Webb Tract, the peak tidal elevation was at 5.7 feet, about 9 inches above the peak tidal elevation at Martinez. At Bacon Island, the peak tidal elevations were approximately 1 foot higher than the peak tidal elevations at Martinez. Throughout much of the Delta, the peak tidal elevations were less than 1 foot

higher than the Martinez elevations. As far upstream as Clifton Court Forebay and the San Joaquin River near Stockton, the peak water surface elevations were about 2–3 feet higher than at Martinez. Upstream of these locations, however, there was a strong water surface gradient, with the peak water surface elevations in the San Joaquin River at Mossdale being about 22 feet (17 feet higher than at Martinez).

The peak tidal elevations and the variations in tidal elevations indicate that throughout much of the south Delta, the tide has a strong influence on water surface elevation. To be effective, diversions for flood protection purposes in this area will need to be large enough to counter the tidal inflows. On the other hand, because much of the central Delta has similar tidal elevations, flood protection diversions that are able to reduce the water surface elevations likely would have a widespread effect.

Comparison of Simulated and Measured Flows and Tidal Elevations

For the purposes of assessing flooding and flood protection measures, the ability of the model to simulate tidal elevation is important. The simulated tidal elevations in the south Delta for the estimated January 1997 Vernalis flows are compared to measured tidal elevations in the central and south Delta. The measured tidal elevations were obtained from the Interagency Ecological Program (IEP) web site (<http://www.iep.water.ca.gov/dss/>). This web site also contains measured flows for January 1997 at four locations in the central Delta: Old River at Bacon Island, Middle River at Bacon Island, Dutch Slough near Jersey Island, and the San Joaquin River at Jersey Point.

Figure 7 shows the tidal elevations downstream of the San Joaquin River flow split at the head of Old River (the San Joaquin River at Brandt Bridge and Old River at the head). Brandt Bridge is far enough downstream from the head of Old River that the tidal elevation is almost 5 feet lower and has a much more noticeable tidal signal than the tidal elevation at the head of Old River. Peak tidal elevations measured and simulated at Brandt Bridge were about 15 feet msl during January 8 and 9, whereas they were about 20 feet msl at the head of Old River. One potential source of error in the model for this region is the difficulty in estimating San Joaquin River flows and diversions into Paradise Cut, especially after the Paradise Cut levee failure on January 9, 1997.

Figure 8 shows the simulated and measured tidal elevations in the south Delta upstream of the CVP and SWP exports. The measured and simulated peak tidal elevations in Old River at the Delta-Mendota Canal (DMC) barrier location (no barrier installed) were about 8 feet msl, whereas the measured and simulated peak tidal elevations in Grant Line Canal at the Tracy Boulevard Bridge (farther upstream than the DMC barrier location) were about 10.5 feet msl. As expected, the tidal variation was higher at the DMC barrier site with the lower tidal elevation. The DSM2 model matched the measured tidal elevations at these

south Delta locations fairly well, with the simulated tidal elevations generally being within 0.5 foot of the measured tidal elevations.

Figure 9 shows the measured and simulated tidal elevation and tidal flow in the San Joaquin River at Jersey Point. At Jersey Point, the model properly simulated the pattern of tidal elevations through the month, although the simulated maximum elevation of about 5.5 feet msl on January 3-5 is about 1 foot lower than the measured maximum tide of 6.5 feet msl on January 5. The tidal flows at Jersey Point are very large, about 150,000 cfs during most of the month. The flood-tide flows are reduced during periods of peak flood flows. There is some potential that, just as the San Joaquin River inflow was uncertain at this time, the total inflow to the Delta from other sources also may have been underestimated. Measured and simulated flows at Jersey Point indicate that there is some potential that the Delta inflow values used as model input could have been a little low. In general, however, the model accurately simulates the tidal range of flows and elevations at Jersey Point and Threemile Slough.

Figure 10 shows the simulated and measured tidal elevations in Threemile Slough, connecting the San Joaquin River with the Sacramento River upstream of Jersey Point. The simulated maximum tidal elevations of about 5.5 feet msl on January 3-5 were about 0.75 foot lower than the maximum measured tidal elevation on January 5. Because these two locations are within 5 miles of each other, the datums for these measured tidal elevations may be slightly offset.

Figure 11 shows the measured and simulated tidal elevations and tidal flows in Dutch Slough, connecting Franks Tract with Big Break. The tidal flows of about 10,000 cfs are much less than at Jersey Point. The simulated tidal elevation range was about 3.5 feet during the peak flood flows of January 8-10, 1997, with a maximum simulated tidal elevation of about 5.5 feet msl. The simulated tidal elevations matched the measured tidal elevations available for the second half of the month.

Figure 12 shows the measured and simulated tidal elevations and tidal flows in Old River at Bacon Island, just upstream of Rock Slough. The tidal flows are about 10,000 cfs, but the net downstream flows of about 12,000 cfs reduce the flood-tide flows substantially. The measured tidal elevation range was simulated well, with a minimum elevation of about 2.5 feet msl and a maximum measured and simulated tidal elevation of about 6 feet msl during the January 8-10 flood peak.

Figure 13 shows the measured and simulated tidal elevations and tidal flows in Middle River at the upstream end of Bacon Island. The measured and simulated tidal flows in Middle River were a little higher than in Old River, and the measured and simulated tidal elevations were about 0.1 foot higher in Middle River. The tidal flow variations were similar to those in Old River at Bacon. The maximum simulated tidal elevations in Middle River at Bacon Island were about 6.1 feet msl. Both the model and measurements show that slightly more flow goes down Middle River than Old River at high flows near Bacon Island.

Figure 14 shows the measured and simulated tidal elevations in Middle River upstream of Victoria Canal at the SR 4 Bridge and at Tracy Boulevard. The maximum measured tidal elevation on January 8–10, 1997 was about 6.9 feet at SR 4 Bridge and about 7.1 feet at Tracy Boulevard. The minimum tidal elevation was about 4.0 feet at SR 4 Bridge and about 4.5 feet at Tracy Boulevard.

The tidal elevations simulated by DSM2 properly matched tidal elevations that were measured in the central Delta during January 1997. Although the simulated tidal elevations were about 1.0 foot lower than measured at Jersey Point and about 0.5 feet lower than measured at Threemile Slough, the match between simulated elevations and measured elevations was much better at other central Delta locations along Old and Middle Rivers. Any errors in model calculations of tidal elevations are not likely to have a large effect on the accuracy of the estimated changes in tidal elevations associated with diverting water onto Webb Tract and Bacon Island for flood protection purposes. Forecasting the maximum higher-high tidal elevations during the spring-tide periods of a month with high Delta inflows should be sufficiently accurate to allow flood protection operations to be coordinated properly. Several days of flood protection can be provided to reduce the peak tidal elevations by several inches.

Conceptual Design for Diversion Weirs and Operable Gates

All scenarios evaluated with the DSM2 model assumed that there were four diversion weirs around Webb Tract and four diversion weirs around Bacon Island. These diversion weirs were spaced evenly around the islands and were represented by DSM2 nodes. Most scenarios assumed a flow of 5,000 cfs through each diversion (for a total of 20,000 cfs per island) for a duration of up to 6 hours, with the diversions beginning about 3 hours before peak tidal elevation.

The construction of weirs and gates to allow 5,000 cfs diversions is feasible. Weirs with gates constructed in the Webb Tract and Bacon Island levees could allow relatively high flows to enter the islands in a controlled manner. Operable gates would be opened during peak tidal events. Relatively simple weir and gate designs are described in this section. Alternative weir and gate designs should be more carefully evaluated prior to final design and construction.

The Clifton Court Forebay gates are an example of gates in the Delta that allow the passage of large flows. There are five Clifton Court Forebay gates, each one approximately 20 feet wide and 15 feet deep at a tidal elevation of 0 feet msl. When the gates are open, approximately 15,000 cfs flows into Clifton Court Forebay, with a head difference of about 1 foot (i.e., water surface elevation 15 feet above the weir crest upstream of the weir and 14 feet above the weir crest downstream of the weir).

For Bacon Island and Webb Tract, a combined diversion of 40,000 cfs for 6 hours represents a volume of almost 10,000 acre-feet (af) per day diverted onto

each island. This is about 10% of the storage capacity of each island, which is about 100 thousand acre-feet (TAF). Because each of the islands is about 5,000 acres, a 10,000-af inflow would raise the water about 2 feet.

The ground surface elevation on Bacon Island and Webb Tract is generally between about 10 and 15 feet below sea level. During the January 3–12, 1997, evaluation period, 3 hours prior to the peak tidal elevations, the simulated tidal elevation was above 3 feet msl. The peak water surface elevations were about 6 feet msl. These land and water elevations indicate that it would be possible to have a head difference (height of water above the weir crest) of 10-13 feet if the weir crest were constructed at elevation of -7 feet msl. The gate would need to be about 15 feet high to provide some freeboard.

Free flow over a weir occurs when the downstream water surface elevation is below the weir crest. The general formula for free flow over a weir is:

$$Q = C * L * H^{1.5}$$

Where:

Q = flow (cfs),

C = the weir coefficient (ft^{1/2}/sec),

L = the width of the weir (feet), and

H = the height of the water above the crest of the weir (feet).

When the calculation is done in English units (feet and cfs), the weir coefficient for a broad-crested weir may vary between 1.25 and 3.1, depending on how broad the weir is and the depth of the water at the upstream and downstream edge of the weir (Haestad Methods Engineering Staff 2004). Based on the tables in the Handbook of Hydraulics, 2.5 is a conservative (low-end) estimate of the coefficient value.

With a coefficient of 2.5, the weir equation predicts that to attain a flow of about 5,000 cfs, a 10-foot-deep opening would have to be approximately 70 feet wide and a 5-foot-deep opening would have to be about 190 feet wide (where the depth is the height of the water above the crest of the weir). The 5-foot-deep weir would have to be more than twice as long as the 10-foot-deep weir because the velocity of the water flowing over the weir is proportional to the square root of the height of the water over the weir.

To attain a 5 or 10 foot depth at peak tide (approximately 6 feet), the weir crest would be placed at 1 or -4 feet, respectively. The velocity and flow over the weir will be lower when the tide is lower. If flow is allowed over the weir starting at a tidal elevation of 3 feet (about 3 hours prior to peak tide), the velocity and flow over the weir would be approximately 84% (6.6 / 7.9) of the value at peak stage for a 10-foot-deep weir and approximately 63% (3.5 / 5.6) of the value at peak stage for a 5-foot-deep weir (Table 1). A deeper weir will give flows that are less variable over the range of tidal elevations while the gates are operated.

Table 1. Estimated Flow and Velocity for Two Weir Configurations at Tidal Elevations of 3 Feet (3 Hours prior to Peak Tide) and 6 Feet (Peak Tide)

Tidal Elevation (feet msl)	10-Foot-Deep x 70-Foot-Wide Weir (Weir Crest at -4.0 Feet msl)			5-Foot-Deep x 190-Foot-Wide Weir (Weir Crest at 1.0 Foot msl)		
	Depth over Weir Crest (feet msl)	Velocity (ft/sec)	Flow (cfs)	Depth over Weir Crest (feet msl)	Velocity (ft/sec)	Flow (cfs)
3	7	6.6	3,241	2	3.5	1,344
4	8	7.1	3,960	3	4.3	2,468
5	9	7.5	4,725	4	5.0	3,800
6	10	7.9	5,534	5	5.6	5,311

Note: These calculations assume that the weir coefficient equals 2.5 ft^{1/2}/sec.

If water level in the reservoir builds up and rises above the crest of the weir, the weir will become submerged and the flow over the weir will be reduced somewhat. The following relationship has been established (Brater et al. 1996; Gupta 2001) for estimating flow over a submerged weir:

$$Q_s/Q = (1 - (h_2/h_1)^{1.5})^{0.385}$$

Where:

Q = Flow over a free-flowing weir,

Q_s = Flow over a submerged weir,

h₂ = height of downstream water surface elevation above the crest of the weir,

h₁ = height of upstream water surface elevation above the crest of the weir, and

This equation shows that the submersion of a weir does not have a large effect on the flow over the weir until the downstream water surface elevation approaches the upstream water surface elevation. For example, if the downstream height is 80% of the upstream height (8 feet for a 10-foot-deep weir and 4 feet for a 5-foot-deep weir), the calculated flow would be 62% of the value for a free-flowing weir (e.g., 3,082 cfs instead of 5,000 cfs). The measured flow through the Clifton Court Forebay gates indicates that the submersion of a deep broad-crested weir may have little effect on flow because the flow of approximately 15,000 cfs is about what is expected for a free-flowing weir of its size (not one that is submerged by 14 feet).

The proposed flood protection diversion weirs would need operable gates that were reliable even during power failure, to ensure that the gates could be closed once the peak tide elevation began to decrease each day. Large gates (i.e., vertical sluice gates or pivoting “tainter” gates-like the Clifton Court gates) that could be closed by gravity alone could be designed to allow diversions of about 5,000 cfs with a width of 75 feet and a depth of about 10 feet. Perhaps three

gates with widths of 25 feet would be a practical design. Electrical motors with lifting cables or hydraulic lifting cylinders would be needed to lift the gates open.

Delta Wetlands Flood Protection Scenarios

Five diversion scenarios were evaluated with the DSM2 model. All scenarios assumed that diversions occurred near the time of the daily peak tidal elevations during January 3 through January 12, 1997. The basic flood protection scenario assumed that a constant flow of 20,000 cfs was diverted onto each island with the diversion lasting for 6 hours centered on the occurrence of the peak tidal elevation. Actual diversions would vary with the water surface elevation. The other scenarios had varying rates and durations of diversions (Table 2). The effectiveness of the diversions was evaluated by comparing the tidal elevations for each scenario to the tidal elevations simulated for historical conditions.

Table 2. Scenarios Evaluated for Reduction of Peak Tidal Elevation by Diversions onto Webb Tract and Bacon Island

Scenario Name	Diversion Flow	Diversion Duration	Diversion Timing
Basic	Bacon 20,000 cfs Webb 20,000 cfs	6 hours	Centered on peak tidal elevation
Bacon	Bacon 20,000 cfs Webb 0 cfs	6 hours	Centered on peak tidal elevation
Webb	Bacon 0 cfs Webb 20,000 cfs	6 hours	Centered on peak tidal elevation
2-Hour	Bacon 20,000 cfs Webb 20,000 cfs	2 hours	1.25 hours before peak and 0.75 hours after peak
80K	Bacon 40,000 cfs Webb 40,000 cfs	6 hours	Centered on peak tidal elevation

Tidal Simulation Results

DSM2 simulations of central Delta tidal elevations are largely controlled by tidal elevations at Martinez (Figure 5). If the tidal elevations throughout the Delta matched those at Martinez, diversions onto Delta islands would not be able to provide flood protection because the tidal flows would counteract any water elevation changes caused by the diversion flows. However, water surface elevations in the Delta are affected by channel friction (water surface gradient), which controls how fast tidal flows can move in and out of the Delta, and by backwater effects from high river flows, which control the water surface gradient in the south Delta channels. Spatial variability in tidal elevations (i.e., differences from tidal elevations at Martinez) indicates the potential for large diversions to partially control the water surface elevation in the central Delta

During January 1997, the peak (higher-high tide) tidal elevations at Webb Tract were approximately 0.5 foot higher than the peak tidal elevations of about 5.0 feet msl at Martinez. Tidal elevations were increased by the backwater effect from the high flows in the San Joaquin River, Old River, and Middle River. At Bacon Island, the peak tidal elevations were about 1.0 foot higher than the peak tidal elevation at Martinez. Although the peak tidal elevations were similar to and largely controlled by the tide at Martinez, the elevation differences indicate the potential for diversions onto Webb Tract and Bacon Island to affect water surface elevation in the central Delta. The DSM2 results indicate that, despite the large tidal flows of the incoming tide, all of the simulated flood protection scenarios could create reductions of several inches in peak tidal elevations throughout the central Delta.

Basic Flood Protection Scenario

The effects of the basic Delta Wetland flood protection scenario are shown by comparing the simulated tidal elevations and tidal flows at three locations for January 1997. The differences (reductions) in tidal elevations and tidal flows between the historical and basic flood protection results are shown. The maximum tidal elevation difference between the historical and basic flood protection scenario tends to occur before the peak tidal elevation, while tidal flows are moving into the central Delta. During slack tide conditions, the continuing tidal flows reduce the initial elevation reduction provided by the large diversions onto the Delta Wetlands storage islands. The key variable of interest, however, is the reduction in peak tidal elevation, which was usually slightly less than the maximum difference in tidal elevation seen in the time-series plots. Table 3 gives the minimum, average, and maximum reduction in the higher-high tide for these 10 days at several locations in the central and south Delta.

Figure 15 shows the simulated tidal flows and elevations for the historical and basic flood protection operations at False River, located south of Webb Tract (north edge of Franks Tract). The maximum flood-tide flows increased from about 15,000 cfs to about 20,000 cfs during the 10 days of peak tides of January 3 to January 12. Because of the high river flows, these ebb-tide flows moving

toward the estuary occur during most of the day. The peak flood-tide flows from the estuary occur only during the rising tides. The peak flood-tide flows in this channel south of Webb Tract increased from about -5,000 cfs to about -15,000 cfs during the 10 days of peak tides from January 3 to January 12. The reduction in tidal flows in this channel was a maximum of about 3,000 cfs, but this difference was highest when the weir diversions were started each day and declined to about half of this difference at the end of the 6-hour diversion period. Figure 15 shows that the simulated water elevations with the basic flood protection scenario were about 0.25 foot (3 inches) less than the historical simulations in False River south of Webb Tract during the January 3 to January 12 simulated diversions. The simulated reductions in higher-high tide elevation varied from day to day, with a minimum of 2.5 inches, an average of 2.8 inches, and a maximum of 3.0 inches in False River south of Webb Tract.

Figure 16 shows the simulated differences in the tidal flows and elevations in Middle River near the south (upstream) end of Bacon Island. The peak ebb-tide flows increased from about 15,000 cfs to 25,000 cfs during the January 3 to January 12 simulated diversions. The simulated flows remained positive (downstream) even during ebb-tide periods because the river flow down Middle River of about 15,000 cfs was greater than the normal ebb-tide flow of about -10,000 cfs. The higher-high tide elevations were simulated to be about 6 feet msl during these days of peak tidal elevations. Because this location is upstream of all simulated diversions, the changes in tidal flows were relatively small. The diversions caused the tidal flows to increase slightly during peak flood-tide flows because the downstream tidal elevations were lower (i.e., higher water surface gradient). The reductions in tidal elevations were highest at about the peak tides, so the reductions from this flood protection scenario were the greatest at this location. The minimum reduction in the higher-high tide was about 3.4 inches, the average reduction was 3.8 inches, and the maximum reduction was 4.0 inches in Middle River at Bacon Island.

Figure 17 shows the simulated differences in the tidal flows and elevations in Old River at the Los Vaqueros intake, upstream of Bacon Island. The peak ebb-tide flows increased from about 15,000 cfs to 25,000 cfs during the January 3 to January 12 simulated diversions. The simulated flows remained positive (downstream) even during ebb-tide periods because the river flow down Old River of about 15,000 cfs was greater than the normal ebb-tide flow of about -7,000 cfs. The higher-high tide elevations were simulated to be about 6.5 feet msl during these days of peak tidal elevations. Because this location is upstream of all simulated diversions, the changes in tidal flows were relatively small. The reductions in tidal elevations were highest just after the peak tides, but the reductions from this flood protection scenario were relatively large at this location. The minimum reduction in the higher-high tide was about 3.4 inches, the average reduction was 3.7 inches, and the maximum reduction was 3.8 inches in Old River at the Los Vaqueros intake.

Table 3. Decrease in Peak Tidal Elevation Associated with the Basic Delta Wetland Flood Protection Scenario Simulated for January 3–12, 1997

Location	Simulated Peak Historical Tidal Elevation (feet)	Reduction in Peak Tidal Elevation (inches)		
		Min	Mean	Max
Middle River above Woodward Island	6.3	3.4	3.7	3.8
Columbia Cut	6.0	2.8	3.1	3.2
Turner Cut	6.0	2.9	3.1	3.4
Victoria Canal at Middle River	6.8	3.1	3.5	3.7
Victoria Canal at Old River	6.9	3.2	3.4	3.7
Clifton Court Forebay Gates	7.2	3.1	3.3	3.7
Clifton Court Clifton Court Forebay	7.2	3.1	3.3	3.7
Franks Tract (False River at Webb Tract)	5.7	2.5	2.8	3.0
Connection Slough at Middle River	6.0	3.1	3.4	3.6
Middle River at Bacon Island	6.2	3.4	3.8	4.0
Old River at Holland Cut	5.9	3.1	3.4	3.6
Old River at Rock Slough	6.0	3.4	3.6	3.7
Old River at Los Vaqueros	6.5	3.4	3.7	3.8
Old River at Clifton Court Ferry	7.3	2.9	3.3	3.7
San Joaquin River at Jersey Point	5.5	1.3	1.5	1.7
San Joaquin River at San Andreas Landing	5.8	2.6	2.9	3.0
San Joaquin River at Prisoners Point	5.8	2.8	3.0	3.1
San Joaquin River–Little Connection Slough	5.9	2.8	3.1	3.2
San Joaquin River upstream of Turner Cut	6.1	2.8	3.1	3.4
Dutch Slough	5.6	2.4	2.6	2.9
Threemile Slough at San Joaquin River	5.6	2.0	2.3	2.9
Minimum	5.5	1.3	1.5	1.7
Mean	6.2	2.9	3.2	3.4
Maximum	7.3	3.4	3.8	4.0

Table 4. Average Decrease in Peak Tidal Elevation (in inches) Associated with the Delta Wetland Flood Protection Scenarios Simulated for January 3–12, 1997

Location	Basic Scenario	Bacon Scenario	Webb Scenario	2-Hour Scenario	80K Scenario
Middle River above Woodward Island	3.7	2.1	1.6	2.5	7.7
Columbia Cut	3.1	1.6	1.5	1.7	6.2
Turner Cut	3.1	1.6	1.5	1.8	6.3
Victoria Canal at Middle River	3.5	2.0	1.5	2.2	7.0
Victoria Canal at Old River	3.4	2.0	1.4	2.1	6.9
Clifton Court Forebay Gates	3.3	2.0	1.3	1.9	6.5
Clifton Court Forebay	3.3	2.0	1.3	1.9	6.5
False River at Webb Tract	2.8	1.5	1.3	1.5	5.7
Connection Slough at Middle River	3.4	1.9	1.5	2.1	7.0
Middle River at Bacon Island	3.8	2.2	1.6	2.5	7.8
Old River at Holland Cut	3.4	1.9	1.5	2.0	7.0
Old River at Rock Slough	3.6	2.0	1.6	2.1	7.4
Old River at Los Vaqueros	3.7	2.1	1.5	2.4	7.5
Old River at Clifton Court Ferry	3.3	2.0	1.3	1.8	6.3
San Joaquin River at Jersey Point	1.5	0.7	0.8	0.1	2.7
San Joaquin River at San Andreas Landing	2.9	1.5	1.4	1.4	5.7
San Joaquin River at Prisoners Point	3.0	1.6	1.4	1.6	5.9
San Joaquin River-Little Connection Slough	3.1	1.6	1.5	1.7	6.2
San Joaquin River upstream of Turner Cut	3.1	1.6	1.5	1.7	6.3
Dutch Slough	2.6	1.5	1.2	1.0	4.9
Threemile Slough at San Joaquin River	2.3	1.2	1.2	0.9	4.3
Minimum	1.5	0.7	0.8	0.1	2.7
Mean	3.2	1.8	1.4	1.8	6.4
Maximum	3.8	2.2	1.6	2.5	7.8
80K =	80,000 cfs.				

Figure 18 shows the average higher-high tide elevation reductions at several locations in the central and south Delta with the basic flood protection scenario. There was an approximately 3-inch average decrease in peak tidal elevation throughout much of the south Delta for the January 3-12 period. The effect of the flood protection diversions was less at Jersey Point (1.5 inches) because of stronger influence of tidal flows. Upstream, the reduction did not drop off significantly until the water surface elevation (and surface gradient) was significantly higher. In the San Joaquin River upstream of Stockton and Old River and Grant Line Canal upstream of Clifton Court Forebay, the peak tidal elevations were much higher than at Martinez (>10 feet compared to 5 feet), and the effect of the flood protection diversions was less than a 2-inch reduction in peak tidal elevation.

Bacon Island Only Scenario

Figure 19 shows the simulated average reduction in the higher-high tide elevations for the Bacon Island diversion scenario. When the diversion is made at only one of the two islands, there is less reduction in peak tidal elevations in the central Delta. When the 20,000-cfs diversion was made only at Bacon Island, the highest average reduction in tidal elevations was 2.2 inches, occurring at the upstream end of Bacon Island. The reduction in peak tidal elevation at False River, which was almost 3 inches in the basic scenario, was about 1.5 inches in the Bacon Island diversion scenario. Table 4 gives the average peak tide level reduction at several central and south Delta locations for the Bacon Island diversion scenario.

Webb Tract Only Scenario

Figure 20 shows the simulated average reduction in the higher-high tide elevations for the Webb Tract diversion scenario. When the 20,000 cfs diversion was made only at Webb Tract, the highest average reduction in tidal elevations was only 1.6 inches, again near the upstream end of Bacon Island. Average reduction in peak tidal elevation near Webb Tract was 1.5 inches. Diversions onto Webb tract were not quite as effective as the diversions onto Bacon Island because the tidal elevations at Webb Tract are more strongly influenced by the tidal flows from Martinez. Table 4 gives the average peak tide level reduction at several central and south Delta locations for the Webb Tract diversion scenario.

2-Hour Scenario

Figure 21 shows the simulated average reduction in the higher-high tide elevation for the 2-hour diversion scenario. When the 40,000-cfs combined diversions onto Webb Tract and Bacon Island occurred for only 2 hours as opposed to 6 hours, the tidal elevation effect was reduced, but not by two thirds. Under the 2-hour scenario, the highest average reduction in tidal elevation was 2.5 inches near

the upstream end of Bacon Island, compared to 3.8 inches in the basic flood protection scenario (with 6-hour diversion). Focusing the diversions for 2 hours near the peak tide gave more than half of the flood protection benefit of 6 hours of diversion. It was not able to produce the full benefit because much of the benefit is attained by reducing the peak tidal volume in the central Delta. The peak tidal volume is reduced more with the longer diversion. Table 4 gives the average peak tide level reduction at several central and south Delta locations for the 2-hour diversion scenario.

80,000–Cubic Feet per Second Scenario

Figure 22 shows the simulated average reduction in the higher-high tide elevation for the 80,000-cfs combined diversion scenario. When the diversion rate was doubled from the basic flood protection scenario of 40,000 cfs, the reduction in peak tidal elevation was also approximately doubled. When 40,000 cfs was diverted onto both Webb Tract and Bacon Island for 6 hours, the highest average reduction in peak tidal elevation was 7.8 inches near the upstream end of Bacon Island. A diversion rate of 80,000 cfs for 6 hours each day could only be sustained for about 4 days because the volume on Webb Tract and Bacon Island is limited, and this diversion rate would increase the water elevations by about 4 feet/day (40,000 af/day). Accurate tidal predictions would be needed before deciding to start diversions of this magnitude. Table 4 gives the average peak tide level reduction at several central and south Delta locations for the 80,000-cfs diversion scenario.

Conclusions

Because Webb Tract and Bacon Island have relatively low land surface elevations (10 to 15 feet below sea level) and cover a large area (approximately 5,000 acres each), the volume of each island is about 100 taf at a water elevation of about 3 feet msl. It therefore would be possible to construct multiple weirs that each could allow about 5,000 cfs to flow onto the island for several hours during the peak tidal elevations for several days during major flood events such as during January 1997. The weirs would need operable gates to allow the diversion period to be controlled to correspond to peak tidal elevations. The basic flood protection scenario assumed that a combined diversion of 40,000 cfs would occur for 6 hours each day for 10 days with high forecasted peak tide elevations. The total volume diverted would be about 10 taf onto each island each day.

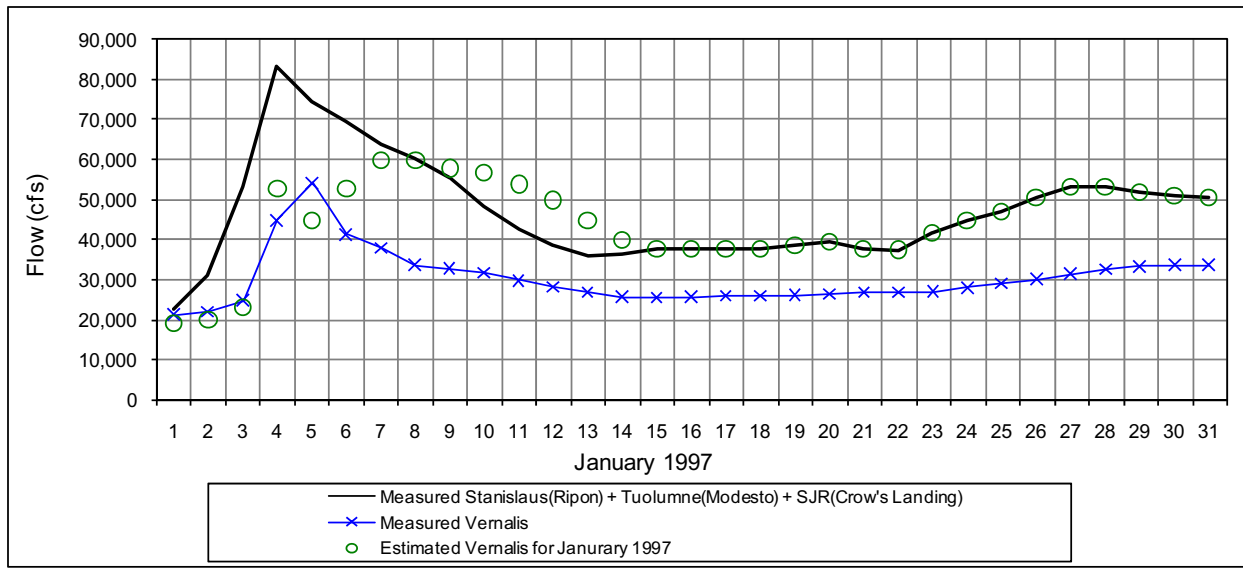
The DSM2 model was used to accurately simulate historical tidal elevations and flows in the Delta during the January 1997 high-flow event. This simulation period was used to evaluate the effects of diverting water onto Webb Tract and Bacon Island during the peak tidal elevation periods of January 3–12, 1997. The effects of these diversions are limited by the influence of tidal flows on the water surface elevations within the Delta. However, the simulated diversions were

large enough to reduce the peak tidal volume and reduce the peak tidal elevations in the central Delta by 3-4 inches.

In all flood protection scenarios, the largest average reductions in simulated peak tidal elevation occurred near the upstream end of Bacon Island (Middle River at Bacon Island and Old River at Los Vaqueros intake), but the reductions at most other locations in the south Delta were about the same as the reductions at the upstream end of Bacon Island (Table 4). The largest diversion rate of 80,000 cfs provided the greatest reduction in higher-high tide elevations of about 5-7 inches in the central Delta. However, these large diversions could be sustained for only 3–4 days before Webb Tract and Bacon Island would be filled. Because the diversions are limited to the initial empty volume in Webb Tract and Bacon Island, accurate forecasts of tidal elevations will be required to properly operate the flood protection gates. This should be possible because the greatest flooding risk in the central Delta is the higher-high tides during spring-tide periods of months with large storm inflows, such as occurred during January 1997.

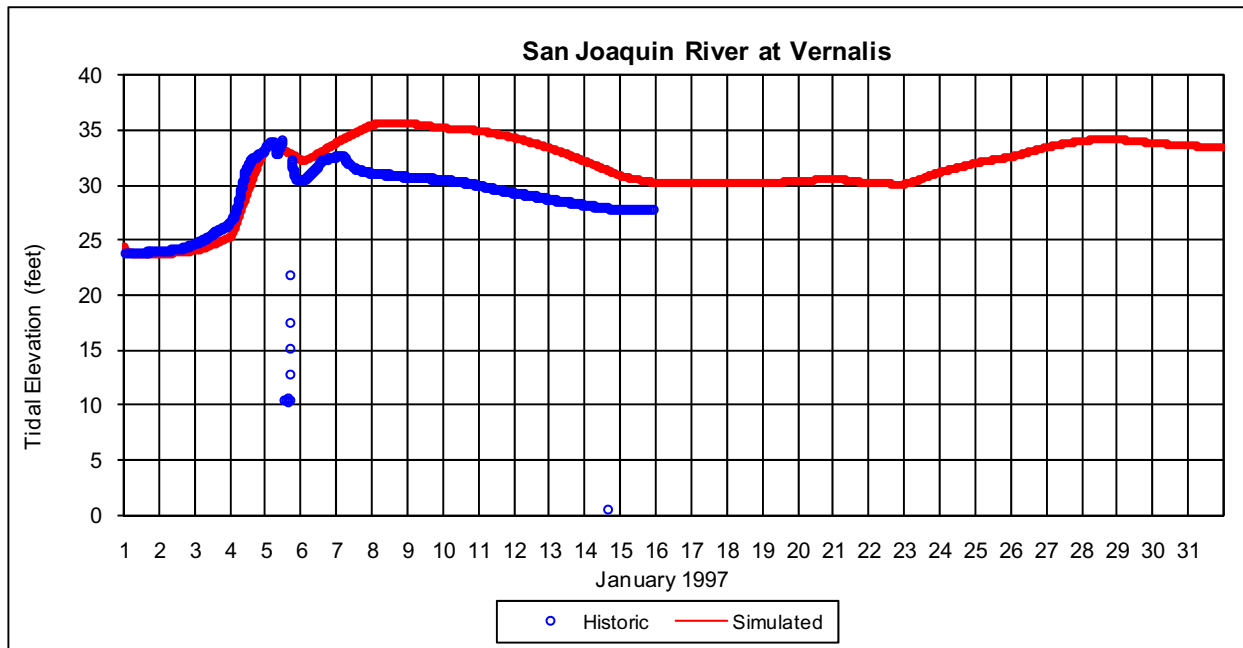
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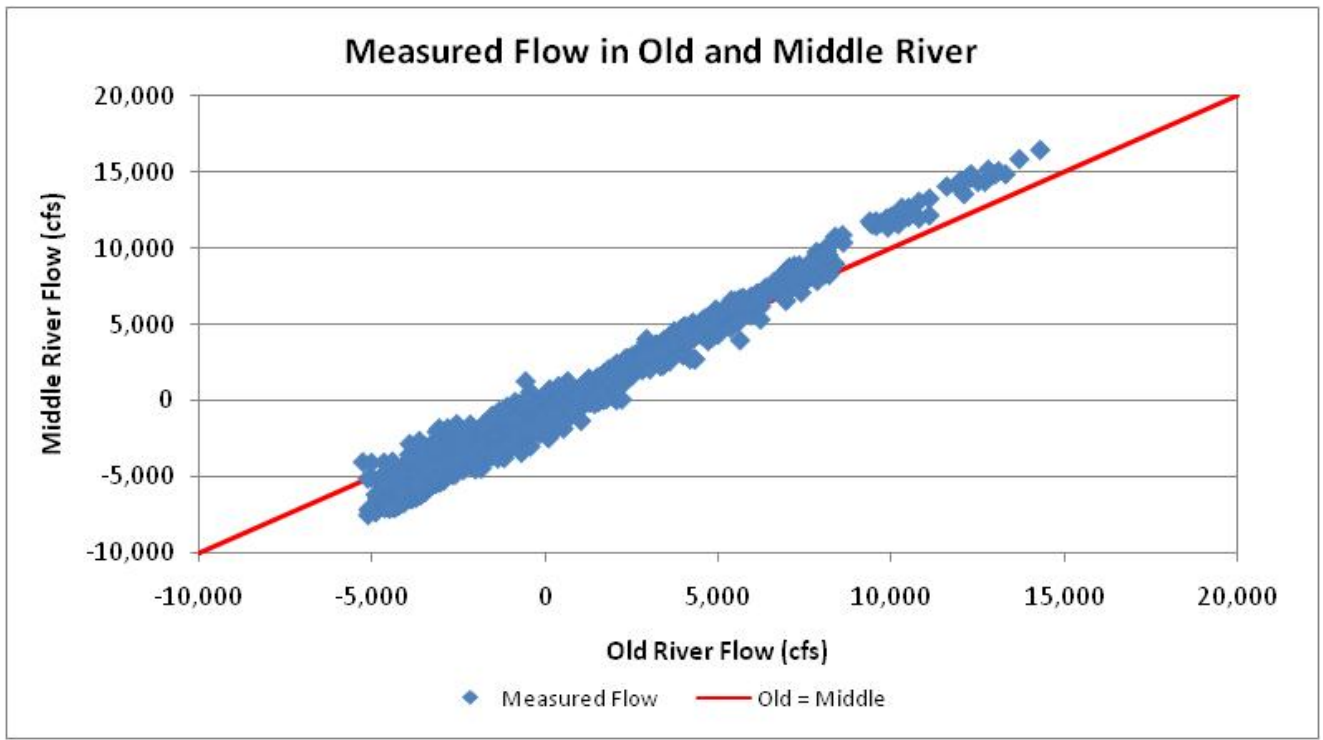
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Figure I
Measured and Estimated Daily Flows for the San Joaquin River



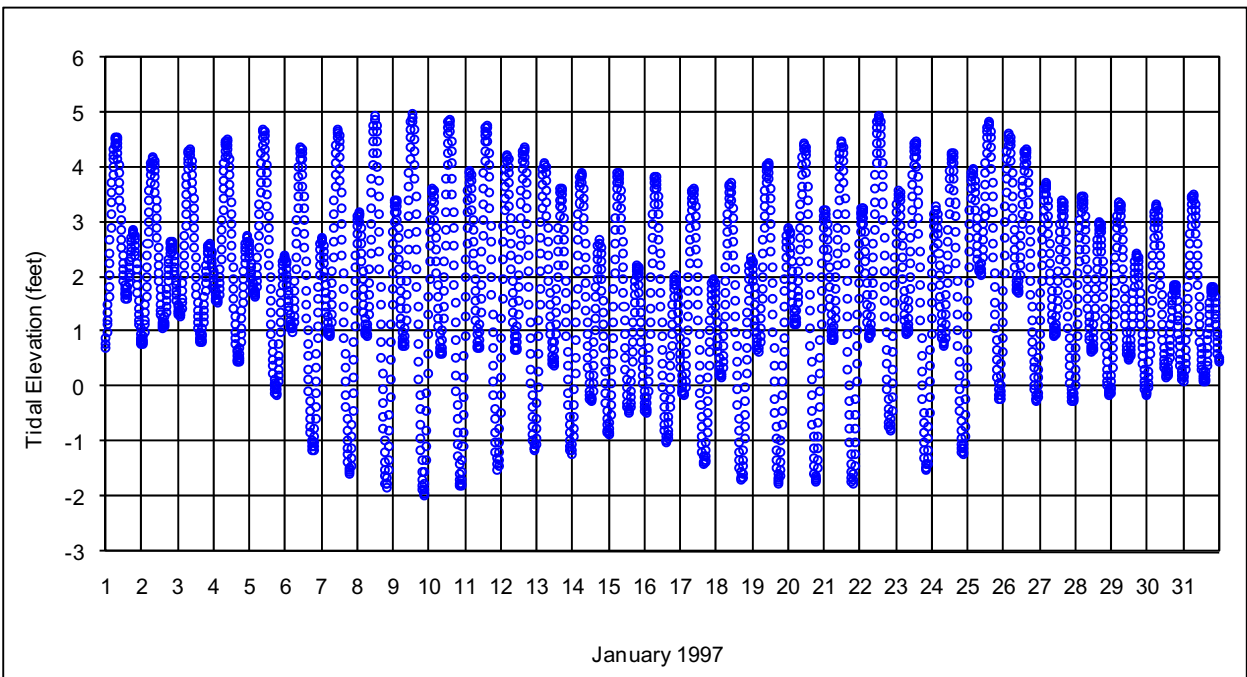
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Figure 2
Measured and Simulated Tidal Elevation at Vernalis



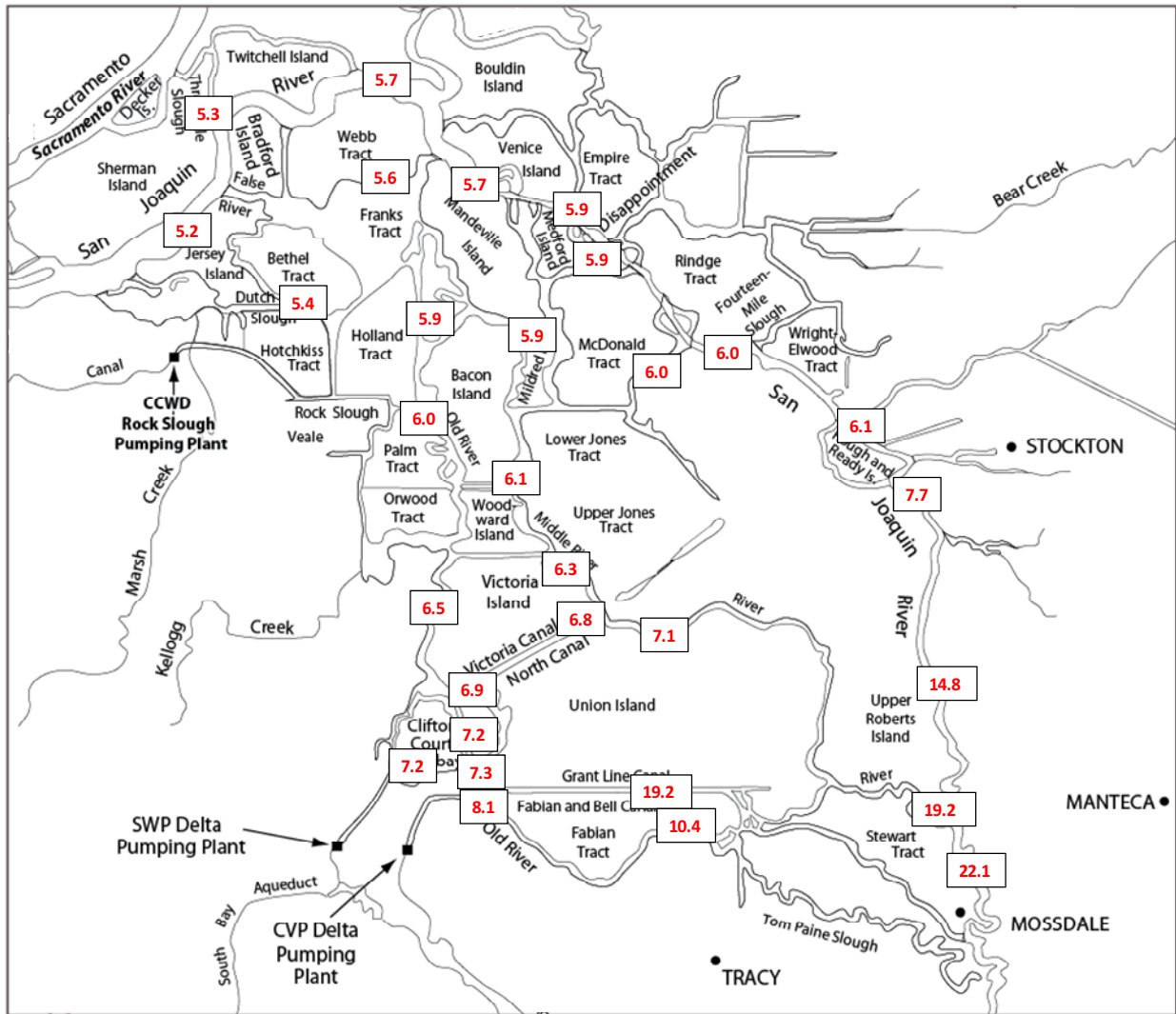
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Figure 4
Flow in Old and Middle Rivers Measured by the USGS near Bacon Island during 1987–2008



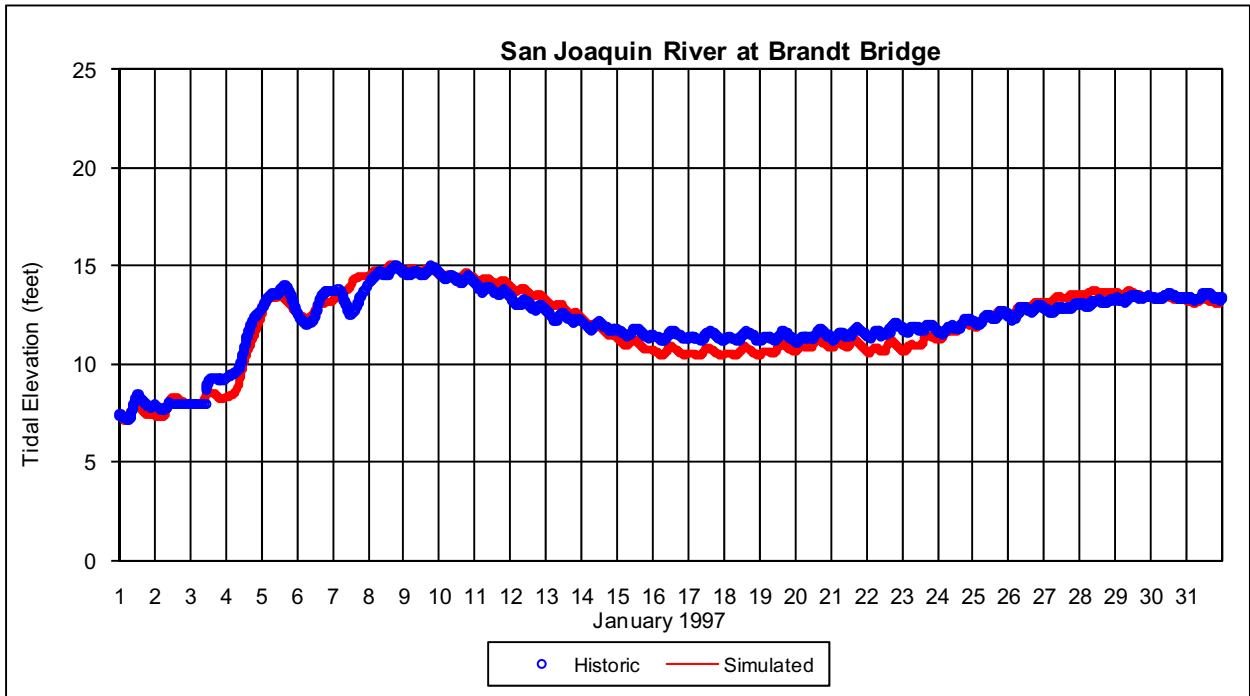
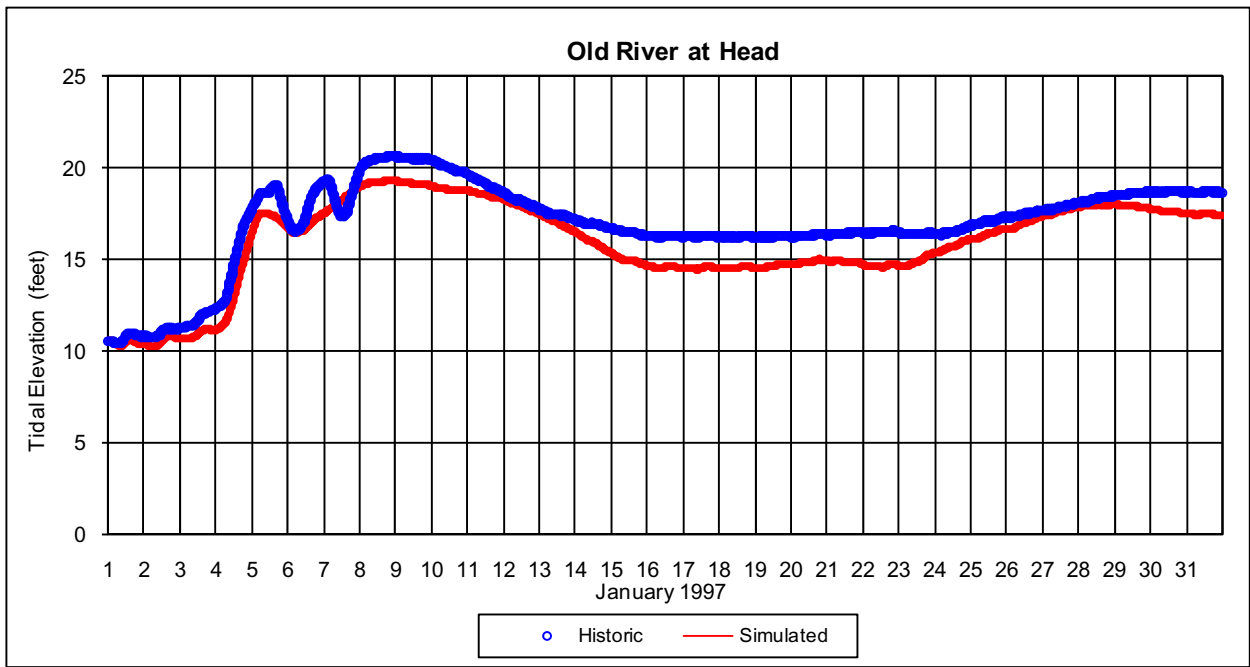
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Figure 5
Measured Tidal Elevation at Martinez



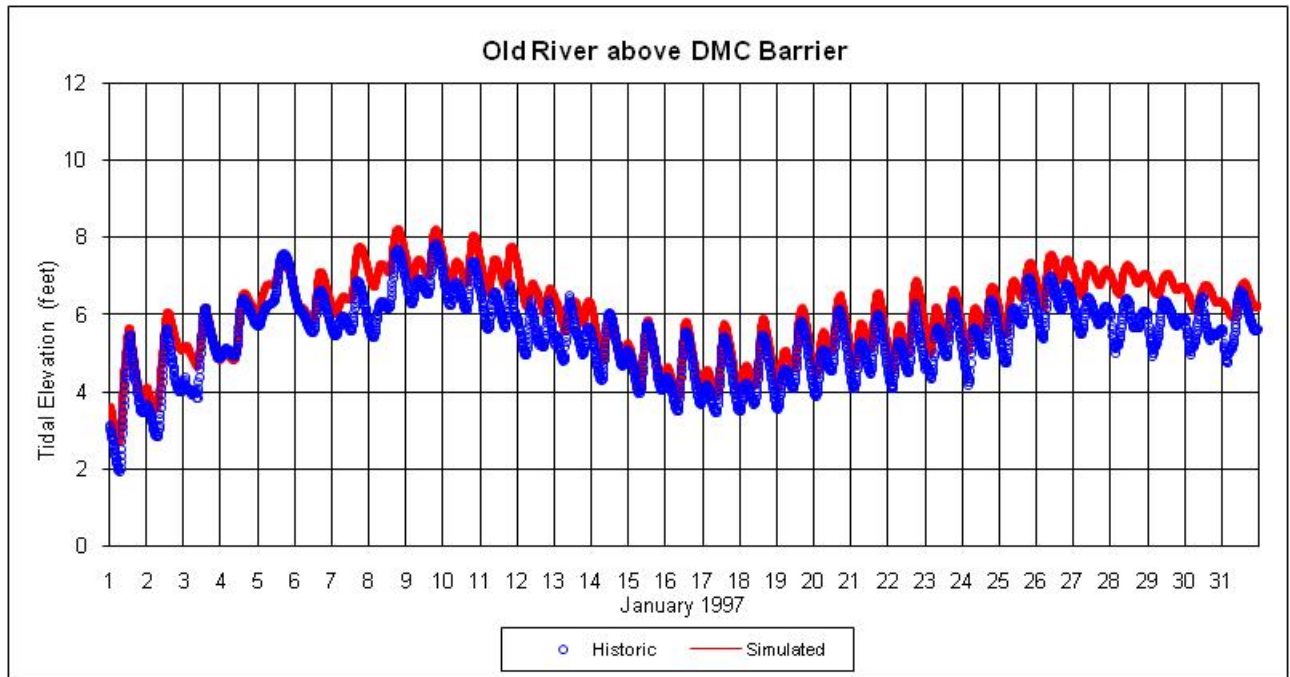
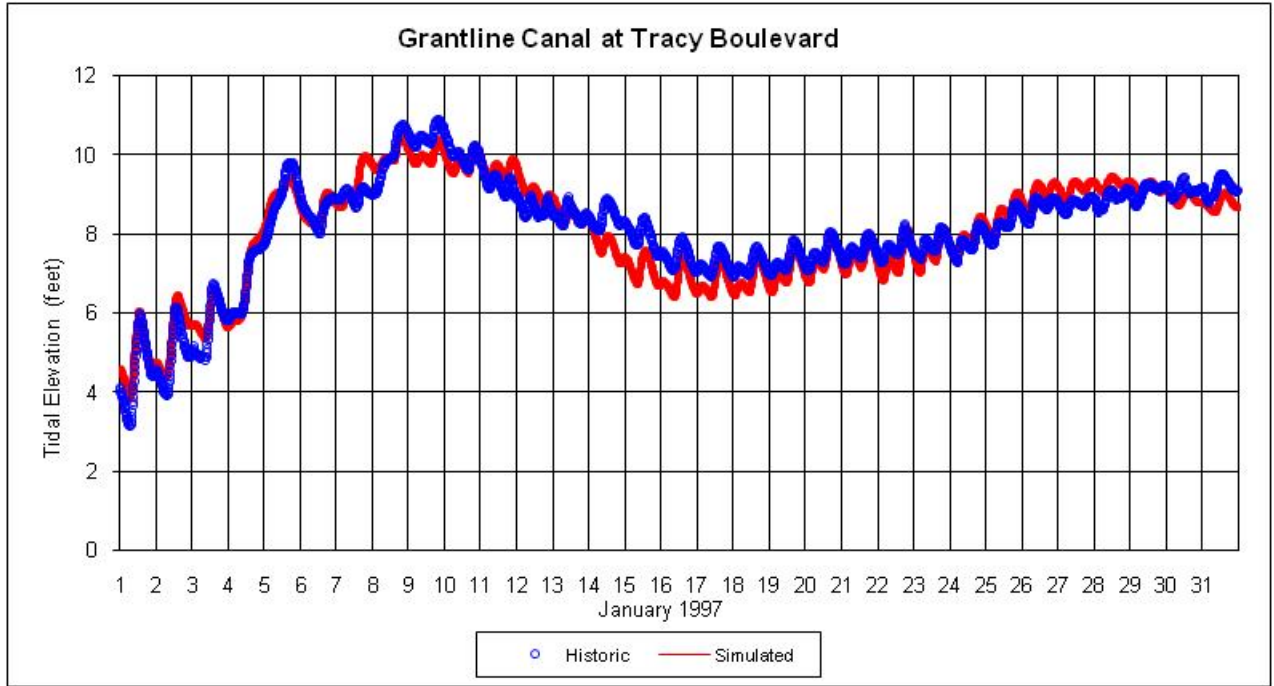
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Figure 6
Average Peak Tidal Elevations (in feet)
Simulated for January 8–10, 1997



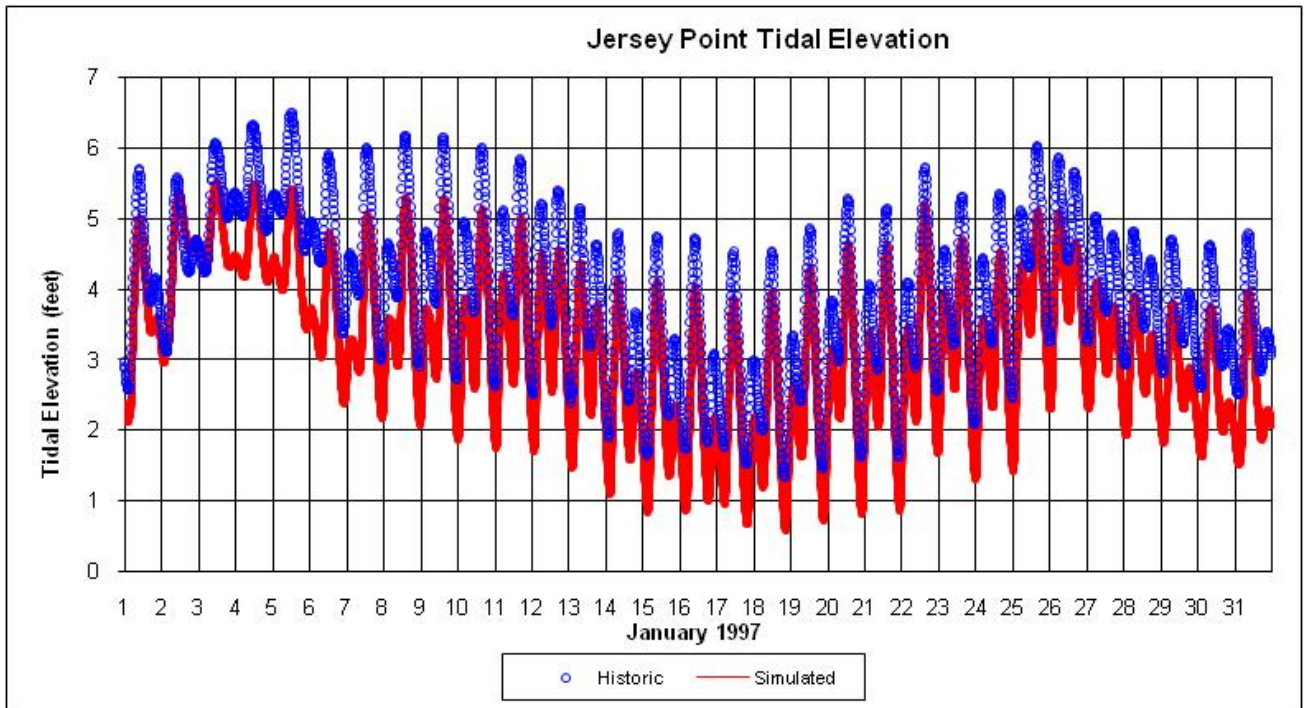
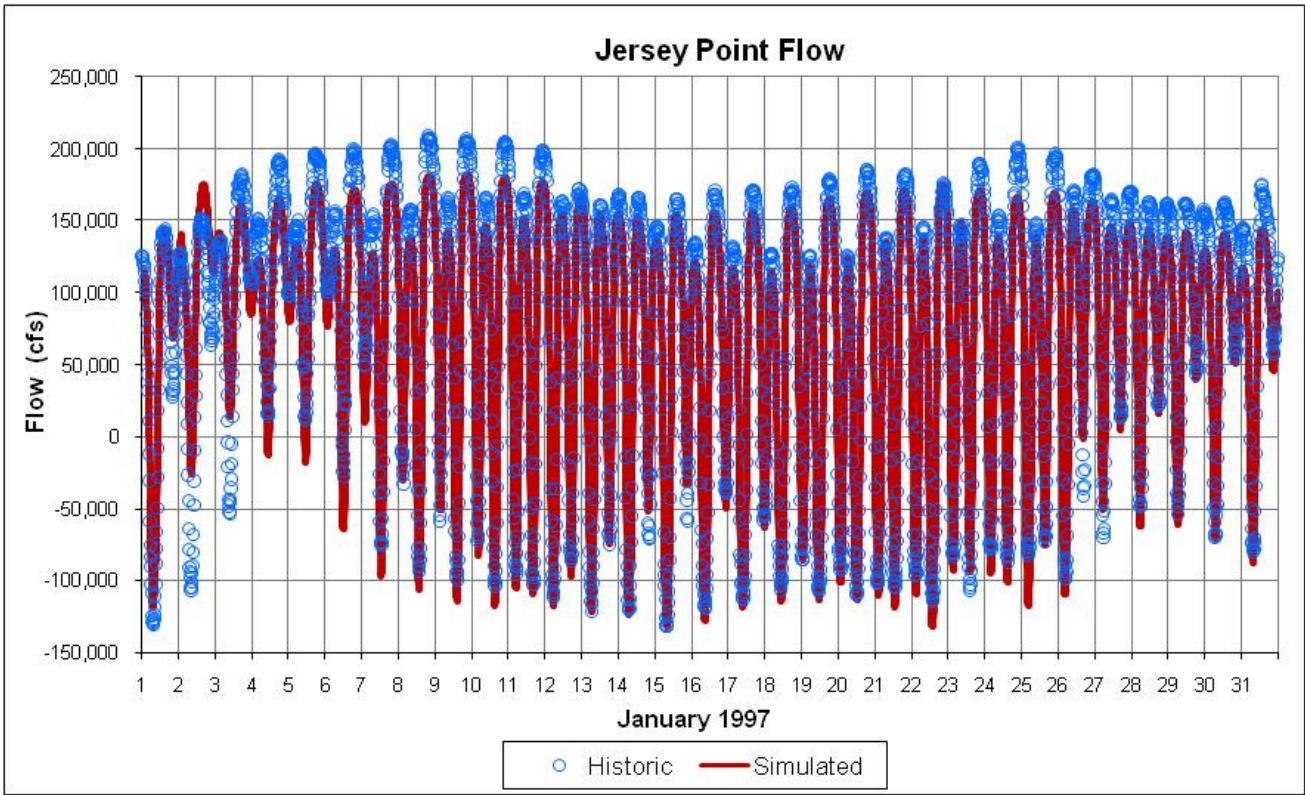
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Figure 7
Measured and Simulated Tidal Elevation
near the Head of Old River



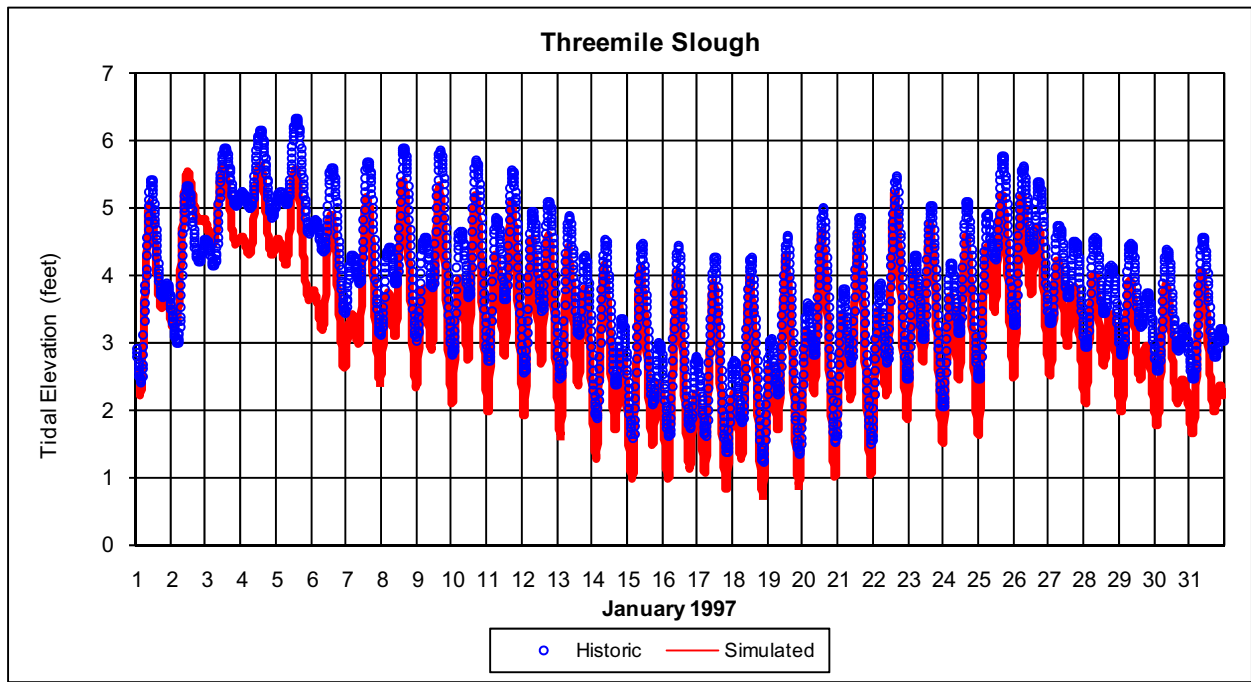
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Figure 8
Measured and Simulated Tidal Elevation in the South Delta upstream of the Export Pumps



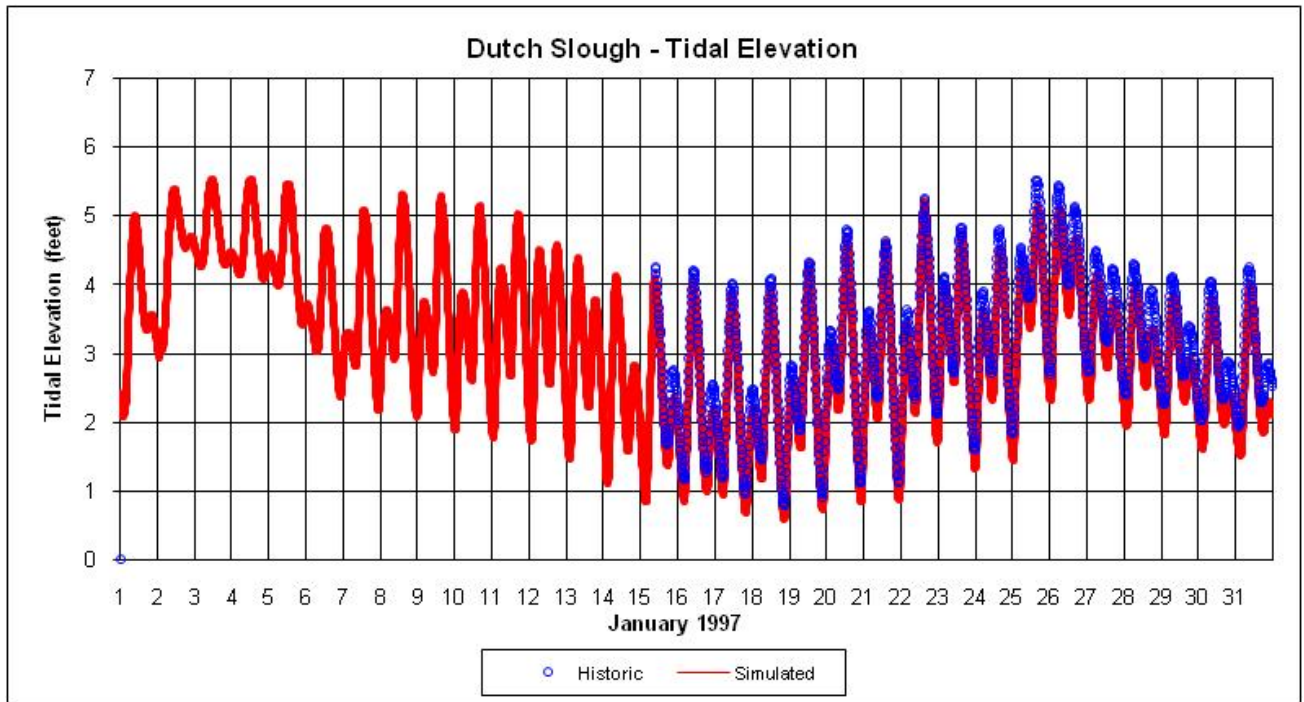
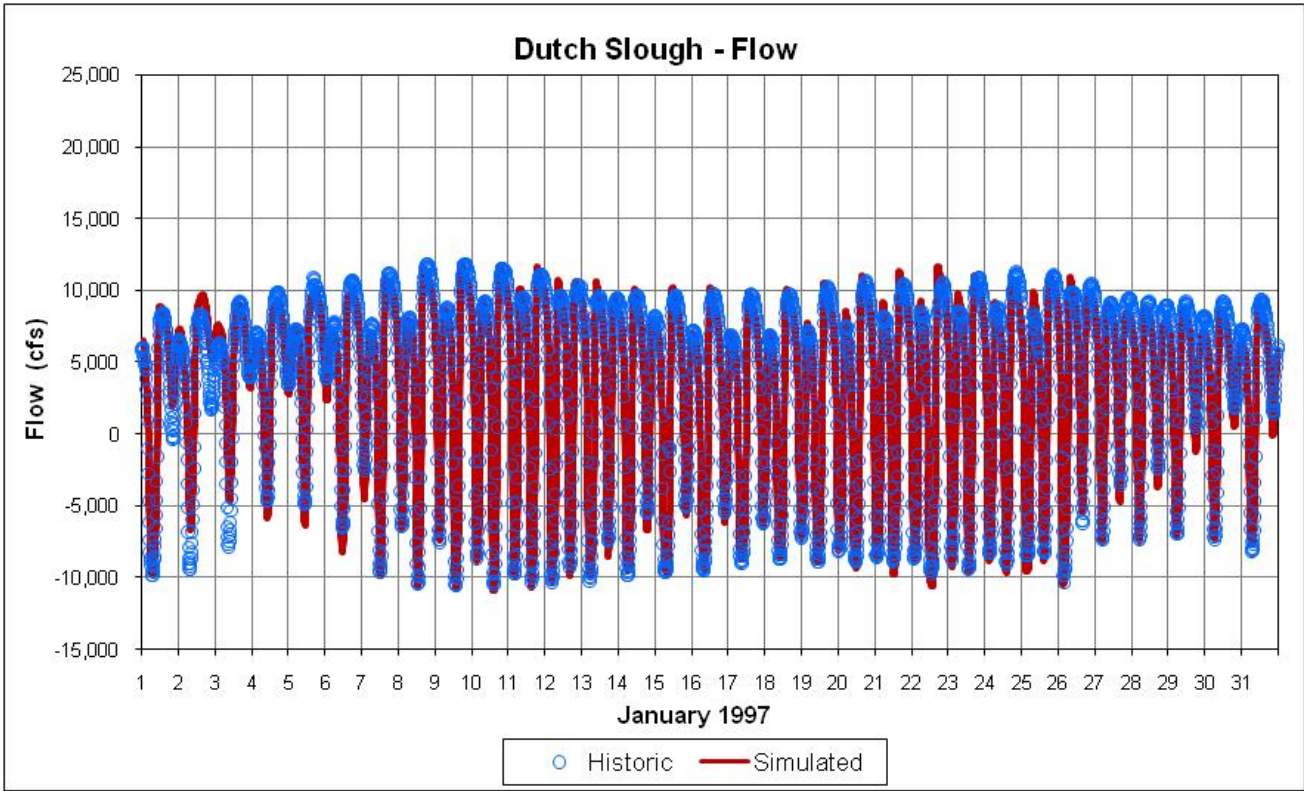
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Figure 9
Measured and Simulated Flow and Tidal Elevation in the San Joaquin River at Jersey Point



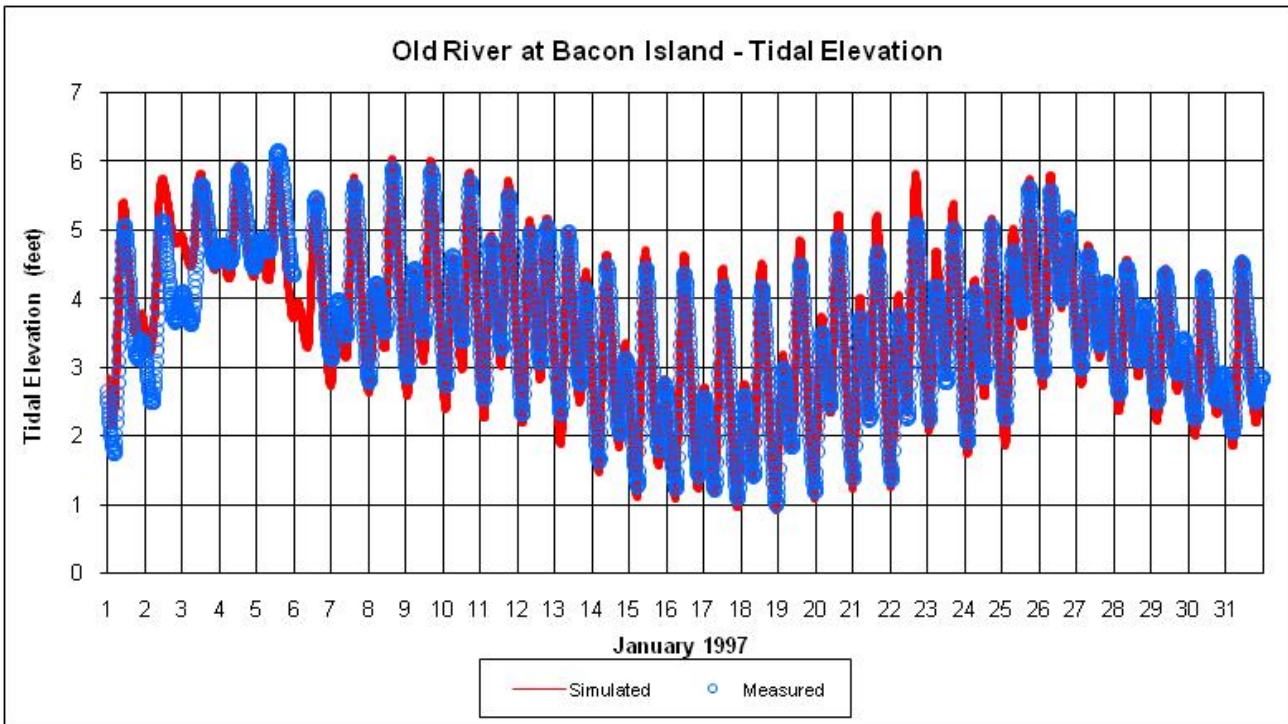
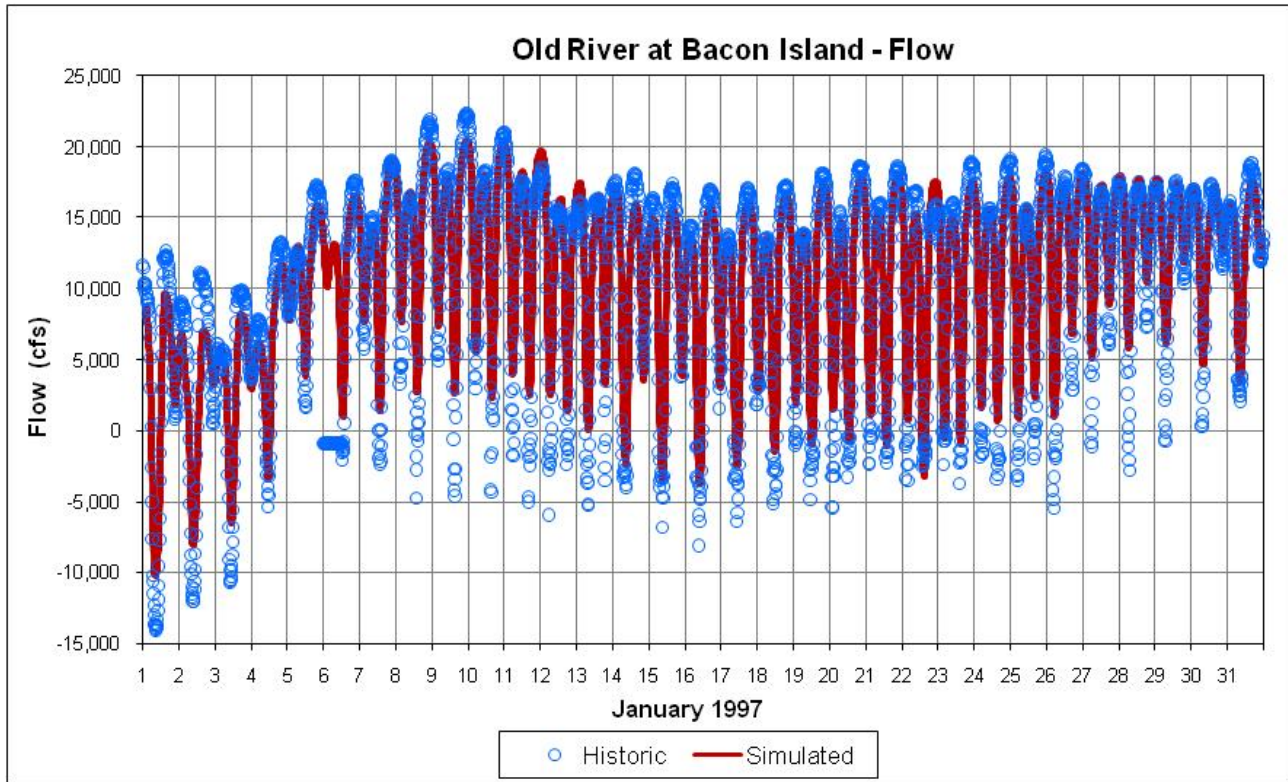
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Figure 10
Measured and Simulated Tidal Elevation in Threemile Slough near the San Joaquin River



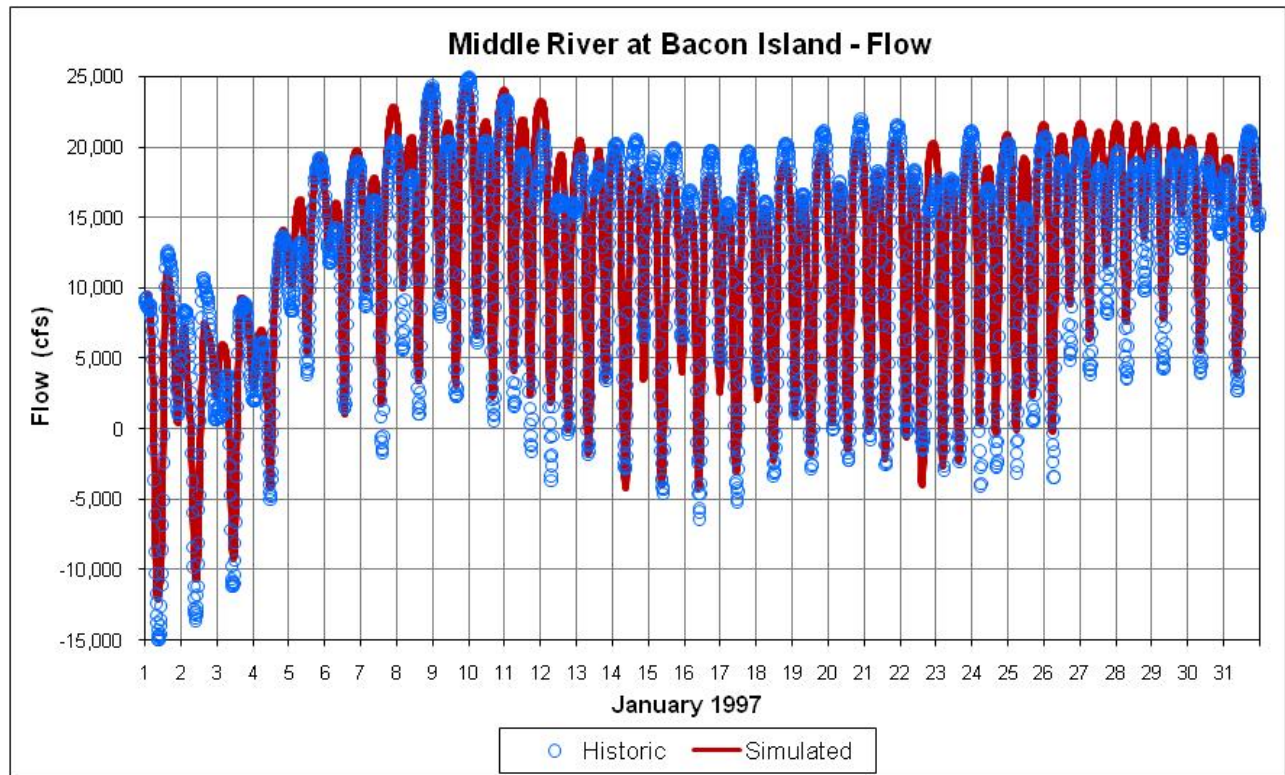
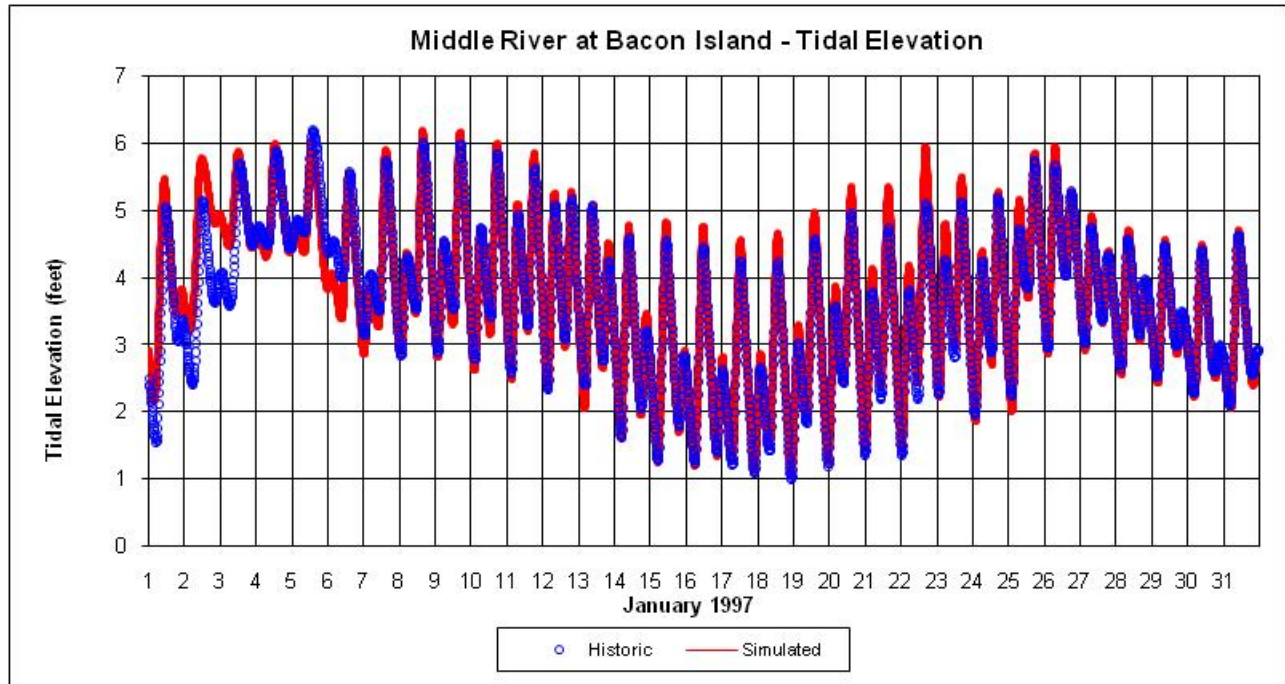
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Figure II
Measured and Simulated Flow and Tidal Elevation in Dutch Slough near Jersey Island



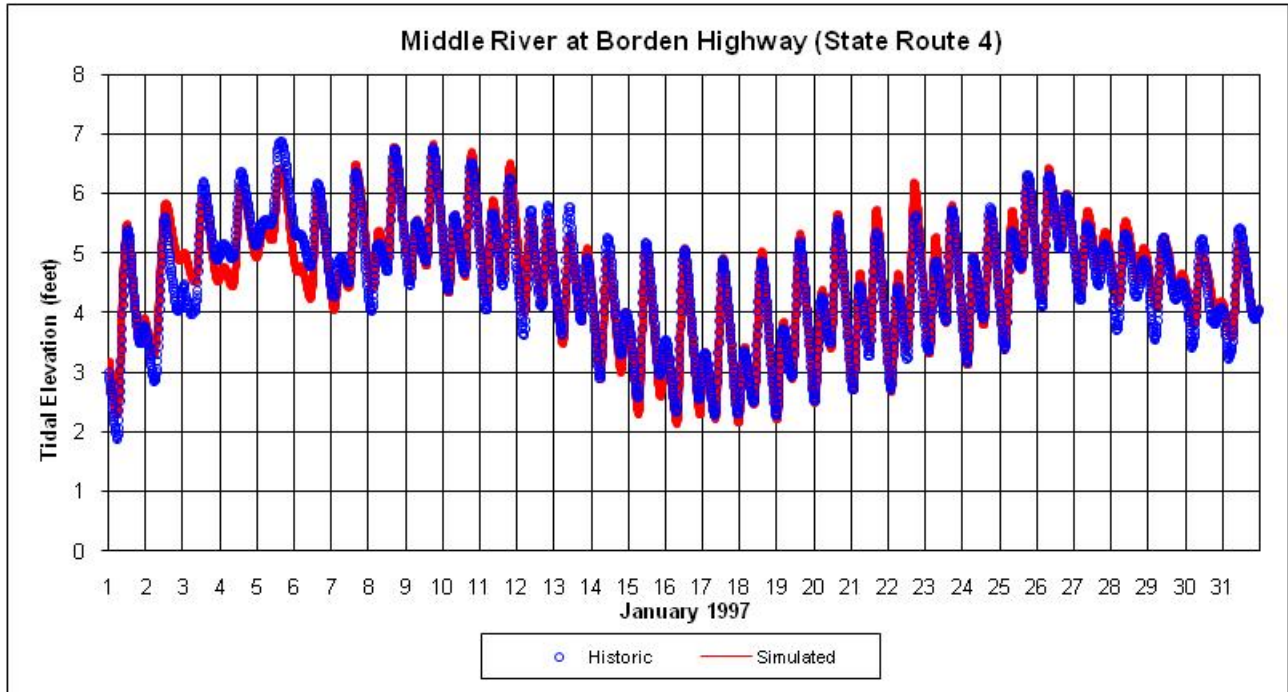
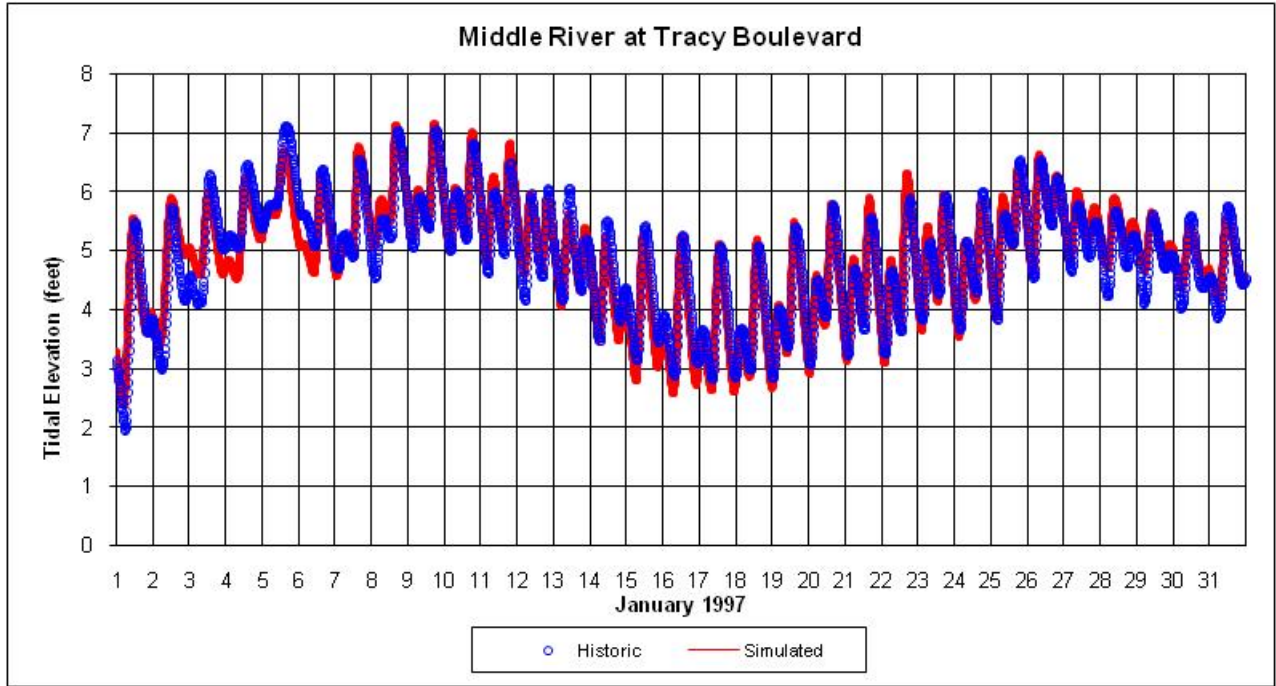
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Figure 12
Measured and Simulated Flow and Tidal Elevation in Old River at Bacon Island

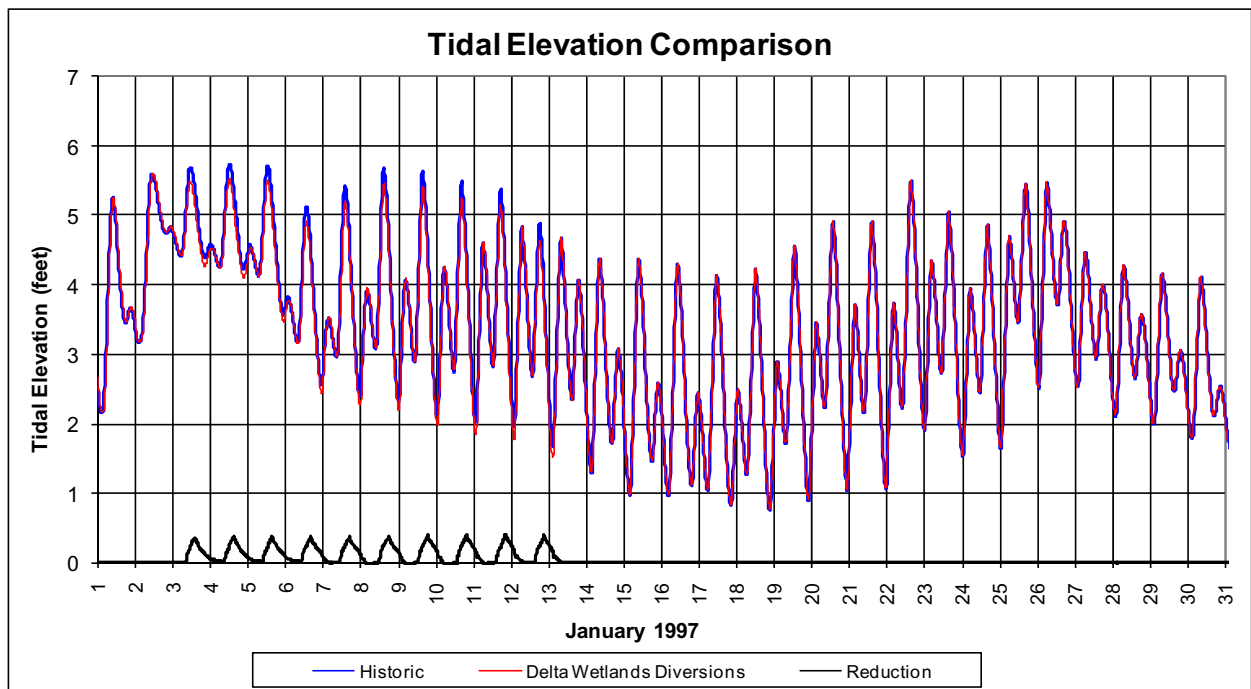
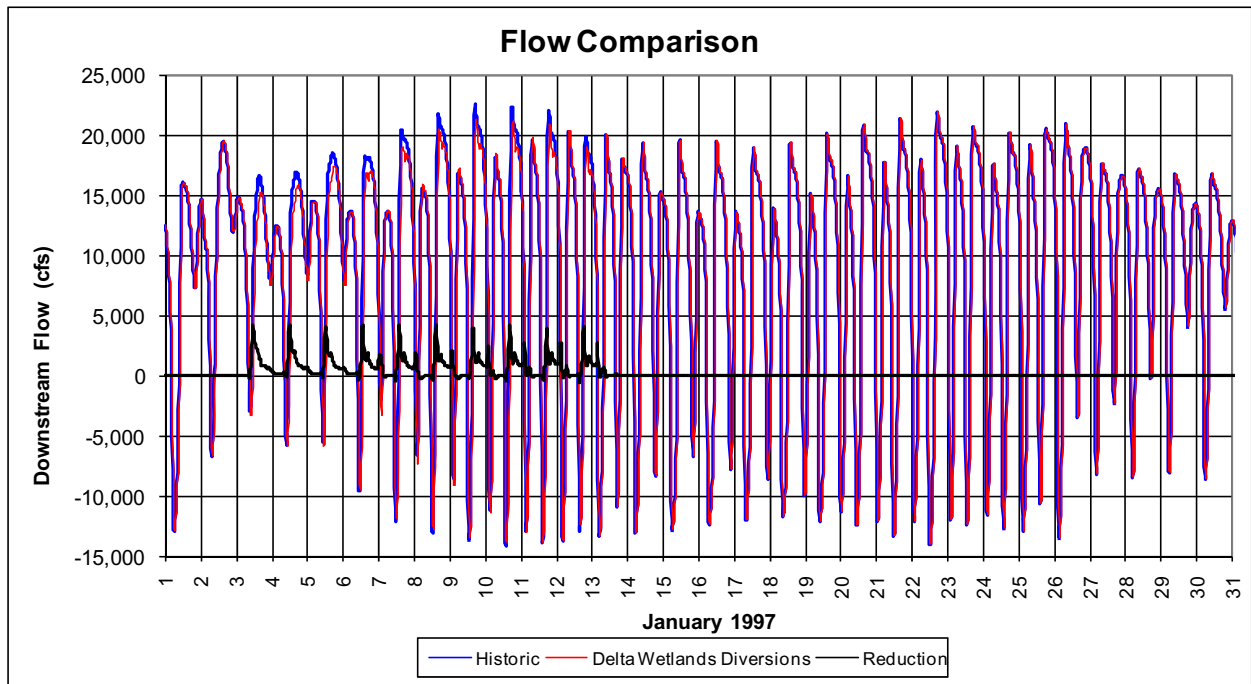


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Figure 13
Measured and Simulated Flow and Tidal Elevation in
Middle River at Bacon Island

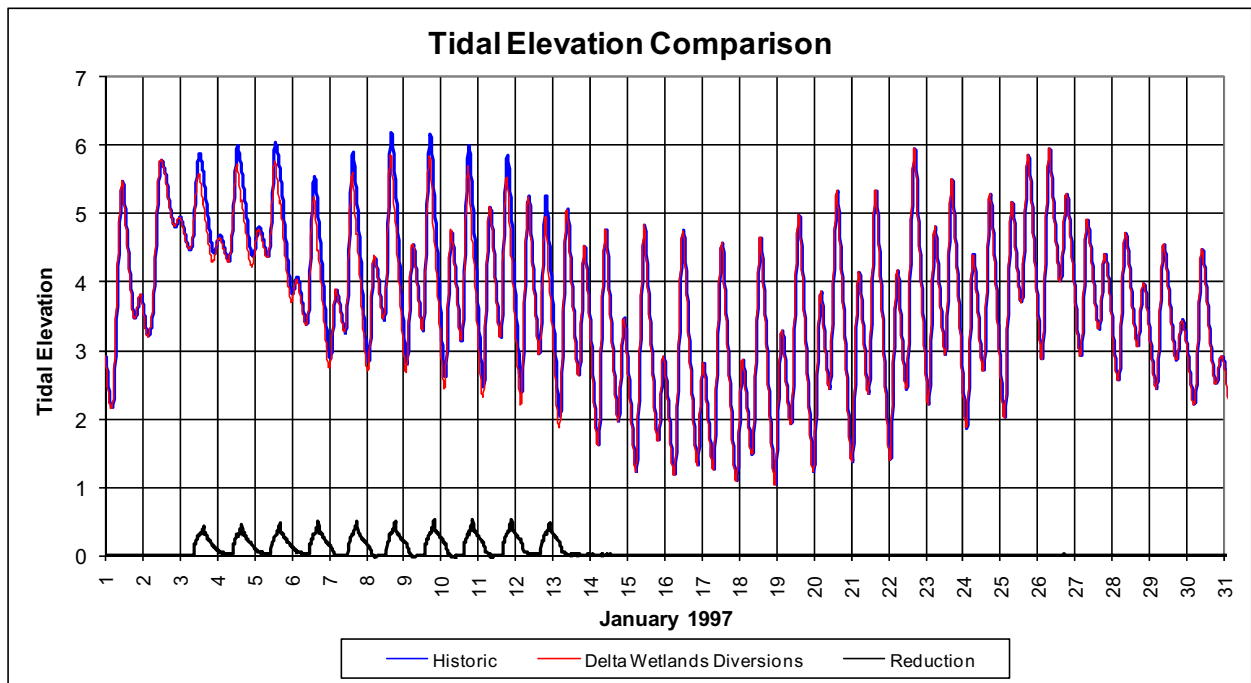
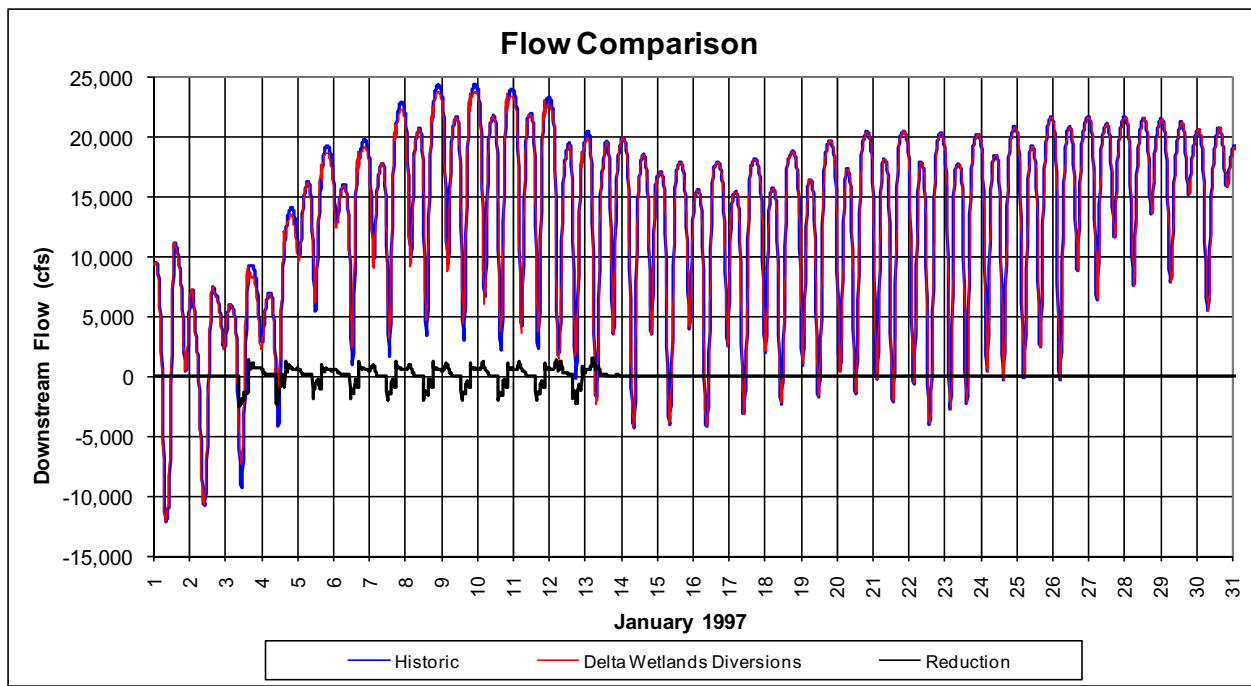


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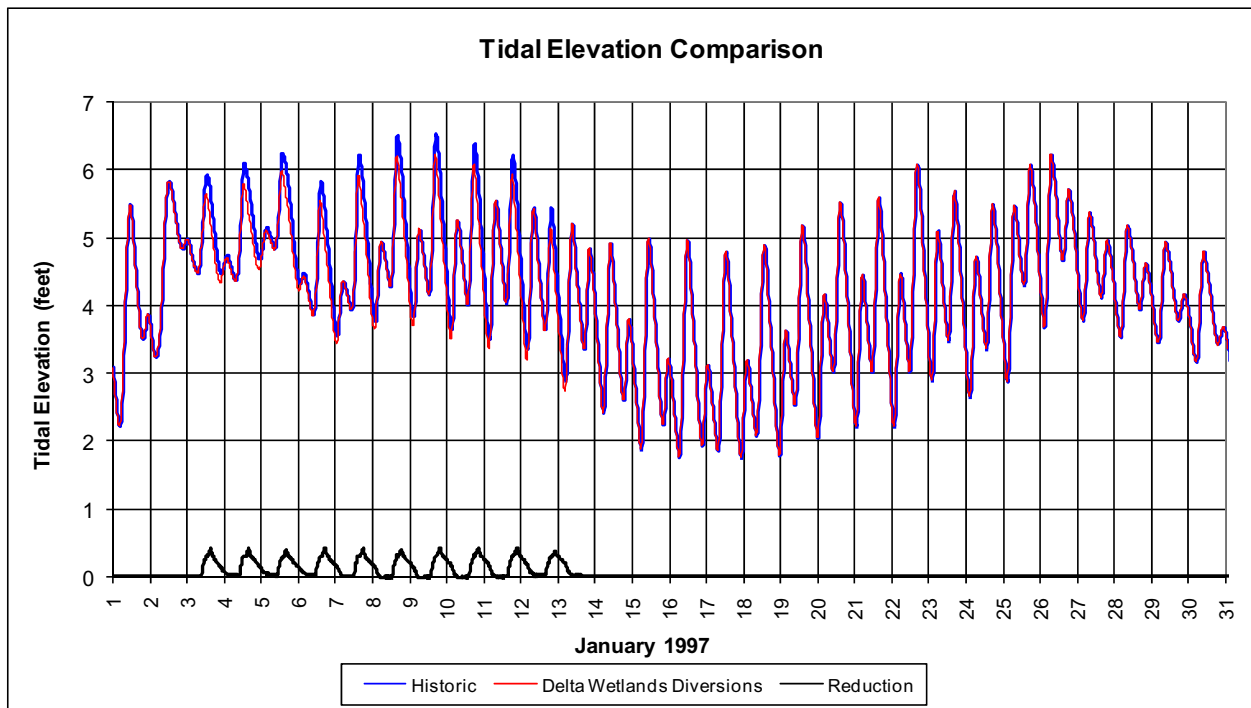
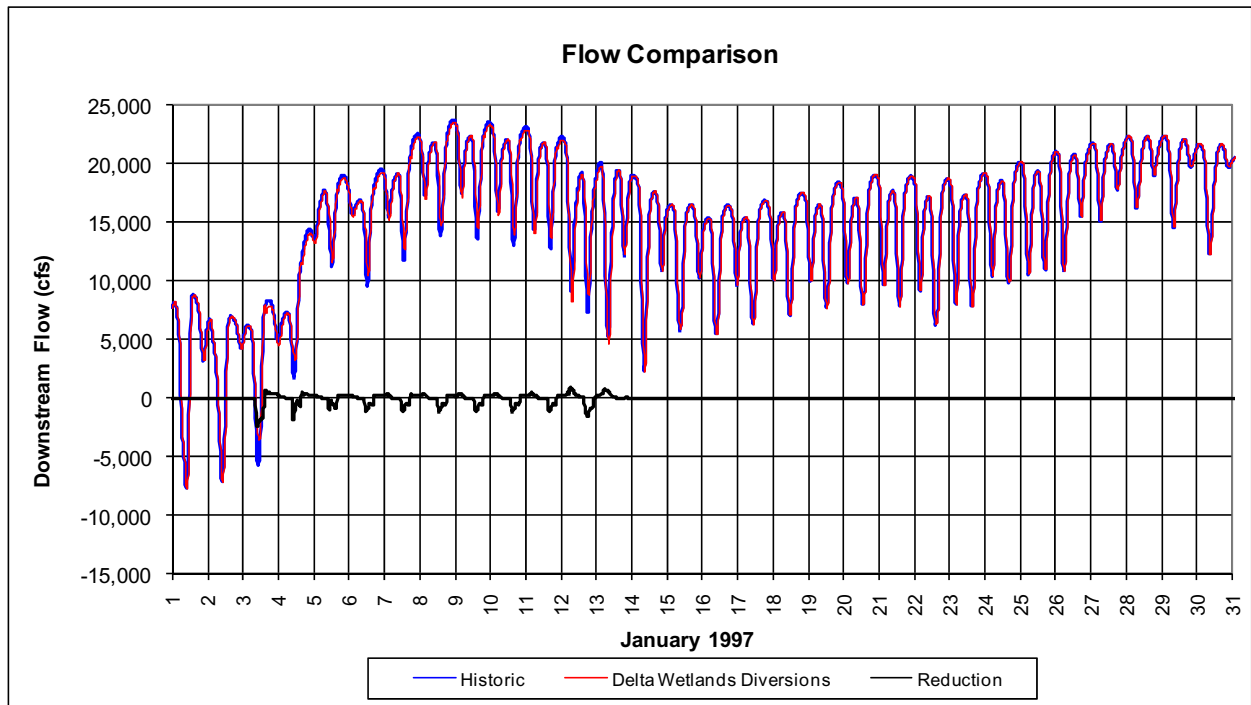
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Figure 15
Flow and Tidal Elevation in False River South of Webb Tract
Simulated for the Basic Delta Wetlands Flood Protection
Scenario Compared to Historical Conditions in January 1997



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Figure 16
Flow and Tidal Elevation in Middle River at Bacon Island
Simulated for the Basic Delta Wetlands Flood Protection
Scenario Compared to Historical Conditions in January 1997



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Figure 17
Flow and Tidal Elevation in Old River at Los Vaqueros (State Route 4) Simulated for the Basic Delta Wetlands Flood Protection Scenario Compared to Historical Conditions in January 1997

