APPENDIX H

Hydrodynamic Analysis of 2-Gates Near Field Effects

Progression of Hydrodynamic Model Deployment and Development

Model Deployment

Early in the analyses process, it was determined that complex delta smelt behavioral models would be required to, with reasonable accuracy, predict distribution, abundance and fate of delta smelt under OCAP and 2-Gates operational conditions. Because the development of such a model would be time-consuming and its success could not be accurately predicted, a decision was made to initially use the One-Dimensional (1D) DSM2 model formulation for hydrodynamic, water quality and particle tracking to determine the most favorable location of gates, their region of control and their benefits under OCAP-modified flow conditions. While this effort was taking place, the RMA team was directed to develop reasonably accurate behavioral model using a Two-Dimensional (2D) RMA formulation, as modified to characterize both the adult and larvae/juvenile dealt smelt behavior. When developed, the 2D behavioral models would be used to determine effects of the 2-Gates Project for environmental documentation purposes under OCAP-adjusted hydrodynamic conditions.

One-Dimensional DSM2 Analyses

<u>Screening of Gate Alternatives, Determination of Region of Control, and Formation of Physical and Hydraulic Barrier Against Delta Smelt Migration.</u>

The above studies used the most recent historic DSM2 simulation available from the Department of Water Resources (DWR) for analyses of 2-Gates and flow control measures. DSM2 analysis (1) evaluated hydrodynamics, fate and transport of neutrally buoyant particles for OCAP BO and 2-Gates scenarios in comparison with the historic conditions, and (2) provided technical analyses of alternatives that provide equal or better protection of delta smelt at reduced water cost compared to OCAP conditions. DSM2 simulates riverine systems, calculates stages, flows, velocities and particle transport; and simulates many mass transport processes, including salts, temperature and THM formation.

<u>One-Dimensional DSM2 Model Numerical Basis.</u>

The partial differential equations of mass and momentum in the DSM2 hydrodynamic model component (HYDRO) are based on an implicit finite difference scheme. As a one-dimensional formulation, the channel length is divided into discrete reaches and the partial differential equations are transformed into finite difference forms for the discrete reaches by integrating numerically in time and space. The resulting equations are then linearized over a single iteration in terms of incremental changes in unknown variables (flow rate and water level) using approximations from truncated series, representing a function as an infinite sum of terms calculated from the values of its derivatives at a single point. When the discretized equations are written for all computational cells at the current time and the next time lines, it forms a system of equations which are solved simultaneously using an implicit algorithm.

The DSM2 water quality numerical solution (QUAL) is based on a model in which advection-dispersion equation is solved numerically using a coordinate system where computational nodes move with the flow. Because of the stability and accuracy of this approach it was used for a network of channels with many branches and junctions. The current version of QUAL simulates about 11 constituents moving in as many as 30 branches connected at junctions. The HYDRO flow model provides the needed information to move the computational nodes with mean channel velocity in the moving coordinate system thus accounting indirectly for advection part of the transport process. The dispersion part, however, is computed directly based on input dispersion coefficient and change in concentration gradient (2_{nd} partial derivative) computed during simulation.

The DSM2 particle tracking component (PTM) computes the location of an individual particle at any time step within a channel based on velocity, flow and water level information provided by HYDRO. The longitudinal movement is based on transverse and vertical velocity profiles computed from mean channel velocity provided by HYDRO. Mean channel velocity is multiplied by a factor which depends on particle's transverse location in the channel resulting in a transverse velocity profile resulting in slower moving particles closer to the shore. Mean channel velocity is also converted to vertical velocity profile using a logarithmic profile to account for slower particles closer to the channel bottom. The longitudinal movement is then the sum of transverse and vertical velocities multiplied by time step. Particles also move across the channel and in vertical direction along the depth due to mixing. A random factor and mixing coefficients and the length of time step is used to compute the movement of particle in transverse and vertical direction.

<u>Initial Site Screening Study using DSM2 Analyses.</u>
DSM2 PTM analyses of 34 individual and combined gate alternatives in the central and south Delta were the basis of determining the optimum locations and number of gates. Two-gates on the Old River near Bacon Island and on Connection Slough provided optimum protection to delta smelt, while reducing water export cuts under OCAP operations. DSM2 analyses determined that other individual or combined gate alternatives provided less favorable water supply and fish protective benefits, channel capacity and geotechnical conditions, including: (1) two-gates on Old River at Quimby Island; (2) three-gates at Connection Slough, Railroad Cut, and Old River below Woodward; (3) four-gates on Connection Slough, Woodward and Railroad Cuts, and Old River below Woodward; (4) selective weir removal on Paradise Cut; (5) a weir on the San Joaquin River downstream of the head of Old River; and (6) Clifton Court Forebay gate tidal re-operations.

<u>Region of Control Studies using DSM2 Analyses.</u>
More than 140 PTM analyses using the DSM2 model, determined the 2-Gate Project to be very effective in controlling particle entrainment at the south Delta export facilities for a region largely bounded by the Old River, False River, Dutch Slough and Fisherman's Cut. Circulation patterns developed by one of the principle operations of the 2-Gate facilities (open on flood-tide and closed on ebb-tide) also promotes seaward movement of particles in Old River and away from the pumps. Further, operation of the 2-Gates is expected to improve water quality conditions in the south Delta.

2-Gate and Qwest Studies to form Physical/Hydraulic Control using DSM2 Analyses.
More than 320 PTM analyses determined that the 2-Gates Project operates compatibly with flow management measures on the San Joaquin River generated through OMR restriction during critical periods. These operations maintained the general distribution of adult delta smelt north and west of the region of control of the gates, forming a physical/hydraulic barrier to upstream smelt migration. Operations of the 2-Gate Project are shown to be consistent with the protective actions proposed by the U.S. Fish and Wildlife Service's OCAP Biological Opinion.

Two-Dimensional RMA-2 Analyses

Real-Time Operations under OCAP using Adult and Larvae/Juvenile Smelt Behavioral Models.

Adult Delta Smelt. To date, all of the modeling for near-term solutions have modeled adult delta smelt as neutrally-buoyant particles. While reasonably accurate for the larval stage, researchers have observed behaviors associated with turbidity and light in the adult stage. Analyses have also shown patterns of salinity and turbidity habitat may correlate with smelt abundance. Scientists have postulated that the adult smelt may be "surfing" the tides as a means of staying within their desirable habitat range. Modeling has been developed to impart habitat seeking behavior on the particles in the RMA-2 model. Once the smelt behavior model reasonably reproduced salvage patterns at the export facilities, additional simulations were done with barriers in the Old River and Connection Slough.

Larvae/Juvenile Delta Smelt. To correlate observed and modeled distributions and abundance of larvae/juvenile delta smelt, the RMA-2 and RMA-PTRK models have evaluated the full larval and juvenile delta smelt period, roughly from March through June, for differing hydrologic years. For each period, hatching rates have been determined by "tuning" to match 20mm survey observations and, if possible, observed salvage. The hatching period and mortality rates used in the simulations have been specified based on published findings from credible researchers. Delta smelt density predictions were compared with 20mm survey observations and the predicted delta smelt salvage was compared with salvage observations at the Skinner Fish Facility and the Tracy Fish Facility. Entrainment at exports, exited (flushed from) Delta, and within Delta were estimated, to determine the fate of fish by region of the Delta.

Two-Dimensional RMA Model Numerical Basis.

Resource Management Associates (RMA) has developed and refined models of the Sacramento-San Joaquin Delta system (Delta model) utilizing the RMA finite element models for surface waters (see Appendix D). The RMA models are a generalized hydrodynamic model that is used to compute two-dimensional depth-averaged velocity and water surface elevation (RMA2) and another model (RMA11) is a generalized two-dimensional depth-averaged water quality model that computes a temporal and spatial description of water quality parameters. RMA11 uses stage and velocity results from RMA2. The Delta model extends from Martinez to the confluence of the American and Sacramento Rivers and to Vernalis on the San Joaquin River. Daily average flows in the model are applied for the Sacramento River, Yolo Bypass, 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. Delta Islands Consumptive Use (DICU) values address channel depletions, infiltration, evaporation, and precipitation, as well as Delta island agricultural use. DICU values are applied on a monthly average basis and were derived from monthly DSM2 input values. 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. Dayflow and IEP database data are used to set daily average export flows for the CVP, North Bay Aqueduct and Contra Costa's exports.

2-Gate and OCAP Studies for OCAP BO Baseline and 2-Gates Conditions for Adult Delta Smelt using RMA Behavioral Analyses.

Particle simulations with habitat seeking behavior were performed for historic periods. Particles were initially seeded in regions of acceptable habitat at the start of the simulations. Adult delta smelt habitat has been characterized by salinity (EC) and turbidity. Options were added to the model to influence sensitivity to habitat gradients, chance of incorrect directional choices, and resistance to tidal flow velocity. Behavioral characteristics were adjusted to attempt to replicate take at water export facilities. Two-Gates Project operations were compatible with flow management measures of the U.S. Fish and Wildlife Service's OCAP Biological Opinion. Delta smelt distribution, entrainment and fate have been determined using modified operations scenarios for the OCAP BO baseline and OCAP + the 2-Gate Project conditions using the RMA Adult Behavioral Model from December through February for the 2000, 2002, 2004 and 2008 historic periods.

2-Gate and OCAP Studies for OCAP BO Baseline and 2-Gates Condition for Juvenile and Larvae Delta Smelt using RMA Behavioral Analyses.

These simulations used the RMA Bay-Delta Model and RMA-PTRK for passive particle tracking with post processing analysis of hatching and mortality. The hatching rates estimated for historic conditions were applied without modification to the various operations scenarios. Therefore, the effect of the revised operations on delta smelt hatching rate and distribution were reflected in the simulation results. The simulations focused on the effect of the operations on delta smelt distribution and fate after initial hatching. Simulations were conducted roughly from March through June for the 2000, 2002, 2004 and 2008 historic periods. Modified operations scenarios were simulated for revised export flows according to OCAP guidelines and OCAP + the 2-Gates Project to determine delta smelt distribution, entrainment and fate.

Hydrodynamic Analysis of 2-Gates Near-Field Effects

Near-field hydrodynamic analyses have been conducted to assess the effects from the construction and operation of the 2-Gates Project on flood stage in Old River and Connection Slough, and on navigation vessels from velocities and potential scour patterns in the vicinity of the gates. A One-Dimensional hydraulic model was developed to assess changes in flood stage of the gates. The One-Dimensional model was then utilized as the basis for developing localized, Two-Dimensional models representing the immediate vicinity of each gate barrier. Normal- and low-flow simulations were conducted using the One-Dimensional model to generate boundary conditions for the Two-Dimensional models. The higher resolution Two-Dimensional numerical models were developed for the immediate vicinity of each of the gate barriers to assess velocity distributions through and near the gates. These current magnitudes and patterns were used to assess the potential for scour and develop recommendations for the rock aprons and other rip-rap, if needed. Current velocities and patterns were also used to assess any potential effects on navigation.

HYDRODYNAMIC ANALYSIS OF

TWO GATE FISH PROTECTION PLAN

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1. INTRODUCTION

1.1 BACKGROUND

Various factors in the Sacramento-San Joaquin River Delta contribute to the movement of delta smelt toward freshwater pump intakes, where they are vulnerable to entrainment. These conditions include tidal flows, the channel geometry and connections of Franks Tract, Old River and Middle River, export pumping at the Central Valley Project (CVP) and State Water Project (SWP), along with salinity, temperature and turbidity gradients. Delta smelt is a federally and state-listed threatened species, and both the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Game (CDFG) are considering petitions to change its status to endangered.

The Two-Gate Fish Protection Plan (Plan) is designed to reduce entrainment losses of delta smelt and other sensitive aquatic species in the Sacramento-San Joaquin River Delta at SWP and CVP pumping plants, in compliance with federal and State Endangered Species Acts. At the same time, the Plan can improve water quality in Old River and improve water supply and reliability compared to that expected under current operations restrictions.

The Plan involves the installation and operation of a gate system on the Old River between Holland and Bacon islands and on Connection Slough near Middle River. Figure 1.1 illustrates the project location. It would be implemented in two phases. The first phase, or the pilot project, would involve the installation and operation of two commercially available barge modules with top-mounted butterfly gates. The second phase involves the installation and operation of long term facilities. Both the pilot project and long term system gate installations would be operated in tidal mode (closed on the flood tide and open on the ebb tide) and non-tidal mode (closed during control of San Joaquin River flow reversals or other flow conditions necessary for fish protection). The Old River and Connection Slough gates would provide effective separation of Old and Middle River flows and would be operated in a manner to allow for vessel passage. The pilot project phase operations were analyzed in this study.

1.2 PURPOSE

The purpose of this hydrodynamic study was to respond to comments received from the California Department of Water Resources (DWR) and Metropolitan Water District's (MWD) engineers regarding the issues of flood neutrality, potential for scour of channel and/or levees, and vessel navigation resulting from the construction and operation of the Two Gate Fish Protection Plan.

1.3 SCOPE OF WORK

This report is to present findings of the hydrodynamic analyses of the Two Gate Fish Protection Plan. The objectives of the study were to assess the effects from the construction and operation of the two gate barriers on:

- Flood Stage - to assess changes in flood stage of the system in Old River and Connection Slough;
- Scour and Vessel Navigation- to analyze current velocities and patterns in the vicinity of the gate barriers for the *gates fully open* and *gates opening* scenarios.

2. APPROACH

For this study, 1-dimensional and 2-dimensional numerical models were developed to assess the potential effects from the construction and operation of the Two Gate Fish Protection Plan.

A 1-dimensional hydraulic model was developed to assess changes in flood stage of the system in Old River and Connection Slough. The 1-dimensional model was then utilized as the basis for developing localized, 2-dimensional models representing the immediate vicinity of each gate barrier. Normal- and low-flow simulations were conducted using the 1-dimensional model to generate boundary conditions for the 2-dimensional models for periods when the Delta is flowing at less than flood stage, since higher velocities through the gate opening were not expected when flood flows overtop the barriers.

The higher resolution 2-dimensional numerical models were developed for the immediate vicinity of each of the gate barriers to assess velocity distributions through and near the gates. Two model scenarios, *gates fully open* and *gates opening*, were developed to analyze the hydrodynamics for each condition. Simulations were conducted to compare the currents with and without the barriers. These current magnitudes and patterns were used to assess the potential for scour and develop recommendations for the rock aprons and other rip-rap, if needed. These current velocities and patterns were also used to assess any potential effects on navigation.

For the predominantly gate-closed period of operation (late spring), questions had been raised related to opening the gates when there is a head difference on either side of the barriers and the amount of time needed to reduce this differential once the gates open. This scenario was developed to assess currents through the barrier during the transient condition when the gates are being opened, with a starting head-differential on either side of the barrier. Results from this scenario were intended for use in the scour analysis, as well as in assisting the formulation of a Gate Operations/Vessel Passage Plan (not included in this scope).

2.1 NUMERICAL MODEL SELECTOR

The Danish Hydraulic Institute's MIKE11 and MIKE21 models were chosen for this study. MIKE11 is a 1-dimensional model for simulating flows and water levels in rivers and channels and is an accepted tool for performing riverine flood studies. MIKE21 is a 2-dimensional model capable of simulating more complex tidal and riverine hydrodynamics. Both are established numerical models with a wide range of applications.

2.2 SURVEY

Channel cross-sections and longitudinal profiles were provided from MWD using bathymetry derived from the Delta Simulation Model II (DSM-2). The California DWR's website for support of the DSM-2 model provides the soundings data used in the setup of the DSM-2 model, with data primarily collected by NOAA and the DWR. The MIKE-11 model geometry was augmented using surface contours based on 2007 LiDAR mapping by the DWR. Figure 2.1 illustrates the model's bathymetry. The MIKE-21 models focused on the reaches immediately upstream and downstream of the gates, and these model geometries were developed from higher resolution multi-beam bathymetric survey data collected by EDS in 2008. The Old River site multi-beam bathymetry is shown in greater detail on Figure 2.2, and the Connection Slough site on Figure 2.3.

2.3 DOMAIN

The area used for the 1-dimensional hydraulic flood stage analysis includes Old River, Middle River, and Connection Slough. Figure 2.4 illustrates the MIKE-11 model network and shows the locations of the cross-sections used in the analysis, which extends to locations that demonstrate little to no effect of the project on existing conditions. The domain used for the 2-dimensional coarse grid is similar to the 1-dimensional model; for the 2-dimensional fine grid, the domain roughly matched the extent of the 2008 EDS survey data.

Boundary Conditions

DSM-2 modeling results for existing conditions provided by the Contra Costa Water District (CCWD) were used to develop boundary conditions for the MIKE-11 model. The CCWD also provided M&N with DSM-2 results from a "gates closed" simulation, where a representation of the gates were inserted into the DSM-2 model which completely blocked flow until overtopping at the two gate-locations. A statistical analysis of these results was used to guide the selection of starting head-differentials for the MIKE-21 *gates opening* scenario.

2.4 MIKE-11 MODEL CALIBRATION

Existing condition simulations were conducted with the MIKE-11 model for the purpose of model calibration. The model was calibrated for two periods, each of 3-5 days in duration, at the location within the model of USGS Gage ROLD024, with Manning's roughness used as the primary calibration parameter. The MIKE-11 model depth and flow results were compared against the CCWD DSM-2 model results, since DSM-2 model output was applied at the upstream and downstream boundary conditions of the MIKE-11 model. The calibrated Manning's roughness value for the model was set at 0.045, which falls within a typical range for natural channels with roughness from rocks and weeds

Figures 2.5 and 2.6 illustrate the calibration results for the flood-event in February 1998. Figures 2.7 and 2.8 illustrate the stage and flow comparison for the flood-event in January 1997. The comparison of these two periods showed a good match with the DSM-2 data; the USGS gage data is also included on the calibration graphs for reference.

2.5 MIKE-21 MODEL SETUP

To obtain velocities through the gate barriers in the *gates fully open* conditions, the model covered a limited area upstream and downstream of the gates. The gates and barrier were included as part of the model bathymetry. Stage and flux boundary conditions were obtained from the MIKE-11 model results.

For the transient *gate opening* conditions, a two-scale model was used. At the coarse scale, a 3-meter (approximately 10-foot) two-dimensional model grid was set up to cover essentially the same domain as the MIKE-11 model. This coarse-scale model was used to simulate the propagation of the disturbance wave generated when a previously closed gate is opened. Stage boundary conditions for the fine-scale model, covering a limited area upstream and downstream of the gates, were obtained from the coarse-scale model. The coarse-scale model was also used to investigate the length of time it takes for the head differential across closed gates to dissipate.

The fine-scale model, with a 0.5-meter grid spacing, was used to investigate the detailed flow patterns as the gates opened. The gate opening was simulated through a number of discrete steps: gate opening angles of 0° (closed), 5°, 10°, 20°, and every subsequent 10° step up to 90° (fully open) were used. The MIKE-21 model was used to simulate each gate position for between 10 and 20 seconds; the final condition for each short simulation was used as the starting condition for the next gate position.

3. RESULTS

Using the calibrated model described in the previous section, existing conditions were simulated for comparison with the proposed conditions with the Two Gate Fish Protection Plan in place. Simulation results for the MIKE-11 and MIKE-21 modeling are described in this section.

3.1 FLOOD STAGE ANALYSIS

Three events from the available flow record were modeled as unsteady (time-varying flows) events, including the flood event during January 1997, with a return period of about 50 years. The greatest peak-stages from the DSM-2 model occurred during the January 1997 event, the February 1998 El Nino event, and the December 2005 flood event. The modeling results for these three events at the Old River gate barrier are illustrated as both a stage-hydrograph comparison and a longitudinal water surface profile comparison in Figures 3.1 through 3.6.

Tables 3.1 and 3.2 list the daily peak water surface elevations without gates and the resultant difference in peak stage with the gates fully open at Old River and Connection Slough, respectively. The magnitude of change in flood stage for all 10 stage-peaks associated with these 3 events was less than 0.1 ft, which is not a significant difference based on the accuracy of the model. The MIKE-11 modeling results confirm the results of the DSM-2 modeling previously completed by the CCWD that the Two-Gate Fish Protection Plan has only a minimal effect on flood stage in the Delta. The previous DSM-2 analysis and results are detailed in a CCWD memorandum, provided in Appendix A of this report.

The basis of the flood stage analysis was comparing water levels for the existing condition versus the condition with gates fully open. The 100-year return period flood stage in this portion of the Delta is ~10.1-ft (NAVD88), while the top of the gate barriers are set at 6.6-ft (NAVD88). Therefore, flood-flows overtop the barrier. It was assumed for this analysis that the gates would be fully opened during a flood event. The CCWD's DSM-2 results presented in Appendix A present a comparison of the existing condition versus the gates-closed condition.

Table 3.1 Changes in Peak Stage at the Old River Gate

Date	No Gates Peak Stage (ft NAVD88)	Change in Peak Stage US of Gate (ft)	Change in Peak Stage DS of Gate (ft)
2/6/98	9.68	0.02	-0.01
2/7/98	9.43	0.04	-0.03
2/8/98	8.83	0.03	-0.03
1/2/97	8.60	0.03	-0.02
1/3/97	8.33	0.01	-0.03
1/4/97	8.54	0.03	-0.03
1/5/97	8.54	0.05	-0.04
12/28/05	8.64	-0.06	0.02
12/29/05	8.29	-0.05	0.02
12/30/05	8.95	-0.05	0.01

Table 3.2 Changes in Peak Stage at the Connection Slough Gate

Date	No Gates Peak Stage (ft NAVD88)	Change in Peak Stage US of Gate (ft)	Change in Peak Stage DS of Gate (ft)
2/6/98	9.69	0.01	-0.02
2/7/98	9.41	0.01	-0.02
2/8/98	8.79	0.01	-0.02
1/2/97	8.60	0.01	-0.03
1/3/97	8.28	0.01	-0.02
1/4/97	8.51	0.01	-0.02
1/5/97	8.50	0.01	-0.02
12/28/05	8.69	0.00	-0.01
12/29/05	8.35	0.01	-0.01
12/30/05	9.00	0.01	-0.01

3.2 SCOUR STUDY

3.2.1 Gates Fully Open

The highest velocities through the gates would occur when there are high discharges in Old River and Connection Slough, yet when stages are below the top of the barrier and flows must pass through the gate opening. Therefore, the DSM-2 results for the existing condition provided by CCCWD were analyzed to select specific periods representing higher discharge events with a stage below the top of the barriers.

Figure 3.7 illustrates the MIKE-21 results for the Old River gate during a large winter flood tide, with a peak discharge at USGS Gage ROLD024 of -18,300 cfs. A negative flow in Old River constitutes a flow moving upstream, from North to South. This flow rate has an exceedance probability of ~0.02% at the USGS gage, occurring ~2 hours/year. These results show a peak local velocity of 6 ft/s down the middle of the river in a concentrated flow, but the overall cross-sectional velocity in the river is less than 3 ft/s, which was confirmed in the 1D MIKE-11 modeling.

Figure 3.8 illustrates the MIKE-21 results for the Old River gate during a September flood tide, with a peak discharge at USGS Gage ROLD024 of -15,400 cfs. This flow rate has an exceedance probability of ~1.2% at the USGS gage, occurring ~9 hours/month. These results show a peak local velocity of 5 ft/s down the middle of the river in a concentrated flow, but again the overall cross-sectional velocity in the river is less than 3 ft/s, as confirmed in the 1D MIKE-11 modeling.

Figure 3.9 illustrates the MIKE-21 results for the Old River gate during a flood flow and ebb tide, with a peak discharge at USGS Gage ROLD024 of +17,700 cfs. This flow rate has an exceedance probability of ~0.1% at the USGS gage, occurring ~10 hours/year. These results show a peak local velocity of 5 ft/s down the middle of the river in a concentrated flow, but again the overall cross-sectional velocity in the river is less than 3 ft/s, as confirmed in the 1D MIKE-11 modeling.

Figure 3.10 illustrates the MIKE-21 results for the Connection Slough gate during a September flood tide, with a peak discharge in the DSM-2 modeling results of -8,100 cfs. A negative flow in Connection Slough constitutes a flow moving upstream, from West to East. This flow rate has an exceedance probability of ~1% within Connection Slough, occurring ~7 hours/month. These results show a peak local velocity of only 1.7 ft/s down the middle of the river in a concentrated flow.

Figure 3.11 illustrates the MIKE-21 results for the Connection Slough gate during a September ebb tide, with a peak discharge in the DSM-2 modeling results of +8,500 cfs. This flow rate has an exceedance probability of ~1% within Connection Slough, occurring ~7 hours/month. These results show a peak local velocity of only 2.2 ft/s down the middle of the river in a concentrated flow.

3.2.2 Transient Condition (During Operations)

The DSM-2 results for the gates-closed condition provided by CCWD were also analyzed to select starting head-differentials on the closed gates to simulate in MIKE-21 for the transient, gate-opening scenario. The highest transient velocities through the gates would occur when there are large hydraulic head-differentials on either side of the gate. Only the months of April through June were considered in the statistical analysis of head-differential, since the gates will be predominately closed during these months only. The gates are designed to fully open in 3 minutes; therefore the MIKE-21 simulations were based on this rate of opening.

Figures 3.12 and 3.13 show the head-differential exceedance probabilities for the Old River and Connection Slough gates, respectively, based on the gate-closed DSM-2 results. For the Old River gate, a differential of 3-ft had an exceedance probability of 0.05%, occurring for only 1 hour per year during the three months closure period. A differential of 2.5-ft had an exceedance probability of 0.7%, occurring for 15 hours per year over the three month period. A differential of 2-ft had an exceedance probability of 5%, and a differential of 1-ft had an exceedance probability of 46%.

The Connection Slough gate experienced smaller head-differentials than the Old River gate, due to lower magnitude flows in the slough. A differential of 0.5-ft had an exceedance probability of 0.5%, occurring for 10 hours per year over the three month period. A differential of 0.25-ft had an exceedance probability of 50%.

Results for the MIKE-21 simulation of the Old River gate opening with a starting head-differential of 3-ft are illustrated in Figure 3.14. The results indicate peak local velocities at the gate itself on the order of 10-11 ft/s and velocities directed at about 45° towards the Bacon Island levee on the order or 7-8 ft/s. The current rip-rap sizing for the apron around the gate barriers was based on a peak velocity of 6 ft/s.

Results for the MIKE-21 simulation of the Old River gate opening with a starting head-differential of 2-ft are illustrated in Figure 3.15. The results indicate peak local velocities at the gate itself on the order of 9 ft/s and velocities directed at about 45° towards the Bacon Island levee on the order or 4-5 ft/s.

Results for the MIKE-21 simulation of the Old River gate opening with a starting head-differential of 1-ft are illustrated in Figure 3.16. The results indicate peak local velocities at the gate itself on the order of 3 ft/s.

Results for the MIKE-21 simulation of the Connection Slough gate opening with a starting head-differential of 0.75-ft are illustrated in Figure 3.17. The results indicate peak local velocities at the gate itself on the order of 3 ft/s and velocities directed at 45° towards the eastern levee on the order or 2 ft/s.

3.3 NAVIGATION STUDY

The Two Gate Barrier System will provide a 75' clear center opening for navigation when the double butterfly gates are open. The center opening will be marked in accordance with waterway rules, and the remainder of the barrier, including the side openings that are not considered navigable because of impaired vertical clearance, will be marked to indicate the existence of the obstruction. The gate barrier does increase local flow velocity due to a constriction on the channel cross-section. A velocity of 3.5 knots (6 ft/s), which is rarely exceeded under existing conditions in Old River, was used in the previous study of vessel passage through the gates as a limiting passage velocity criteria. It was noted that the Delta Cross Channel (DCC), operated by the San Luis and Delta-Mendota Water Authority, typically experiences velocities of 3 – 4 knots without boat passage problems at the gates. Results in this section will be used to assist in the formulation of a Gate Operations/Vessel Passage Plan (not included in this scope).

3.3.1 Gates Fully Open

Peak local velocities through the gate barrier were determined from the MIKE-21 modeling analyzed in Section 3.2.1 for the gates open scenario. For every flow event simulated for the *gates fully open* scenario, peak velocities through the gates were less than 3.5 knots. The results are listed in Table 3.3 below.

Table 3.3 MIKE-21 Results for Gates Fully Open Scenario

Gate Location	Simulated Event	Exceedance Probability	Occurrence Rate	Peak Velocity Through Gates		Illustration of Velocity Patterns
				(ft/s)	(knots)	
Old River	Flood tide	0.02%	2 hrs/yr	5.7	3.4	Figure 3.7
Old River	Flood tide	1.2%	9 hrs/mo	5.4	3.2	Figure 3.8
Old River	Ebb tide	0.1%	10 hrs/yr	4.6	2.7	Figure 3.9
Connection Sl.	Flood tide	1.0%	7 hrs/mo	1.7	1.0	Figure 3.10
Connection Sl.	Ebb tide	1.0%	7 hrs/mo	2.3	1.4	Figure 3.11

3.3.2 Transient Velocities During Gate Opening

For the predominantly gate-closed period of operation (late spring), questions had been raised related to the amount of time needed to reduce the velocity through the gate barrier to an acceptable level for vessel passage once the gates open. The results are listed in Table 3.4 below. These peak velocities persist for greater than 30-minutes, and most likely don't dissipate until 3 to 4 hours after gate opening.

Table 3.4 MIKE-21 Results for Gates-Opening Scenario

Gate Location	Head-Differential Event	Exceedance Probability	Occurrence Rate	Peak Velocity Through Gates		Illustration of Velocity Patterns
				(ft/s)	(knots)	
Old River	3-ft	0.05%	1 hr/year	10 - 11	6 - 6.5	Figure 3.14
Old River	2-ft	5%	1 hr/day	9	5.3	Figure 3.15
Old River	1-ft	46%	11 hrs/day	3	1.8	Figure 3.16
Connection Sl.	0.75-ft	0.001%	5 min/year	3	1.8	Figure 3.17

4. CONCLUSIONS

The Two Gate Fish Protection barriers do not have a significant impact on flood stages in the vicinity of the gates. The difference in flood stage for the larger flood peaks analyzed in this study was less than 0.1-feet, which is considered a negligible difference. The MIKE-11 modeling results confirm the results of the DSM-2 modeling previously completed by the CCWD.

For the gates open scour velocity analysis, neither the Old River nor Connection Slough gate barriers result in a cross-sectionally averaged velocity greater than 3 ft/s, which is the reference velocity the DWR uses for indicating potential scour in the Delta. Old River does show local velocities greater than 3 ft/s down the middle of the river in a concentrated flow, but the overall cross-sectional velocity in the river is still less than 3 ft/s. Local velocities greater than 3ft/s are sufficient to mobilize sand and silt; therefore, sediment transported from the middle of the channel should be monitored for signs of excess bed form changes. Connection Slough does not appear to have any elevated-velocity issues, since the gate opening is larger relative to the width of the slough.

The MIKE-21 results for the transient, gate opening scenario with a 3-ft head-differential on the Old River gate show larger velocities directed towards the levee bank, on the order of 8 ft/s to 12 ft/s. In this scenario, the initial head-differential decreases rapidly, but does not equilibrate and instead stabilizes at a differential of ~1.25-ft with persistent velocities on the order of 11 ft/s for at least 30 minutes. However, this more extreme head-differential condition represents an infrequent event, occurring roughly 1 hour per year for the 3 months of planned gate closure.

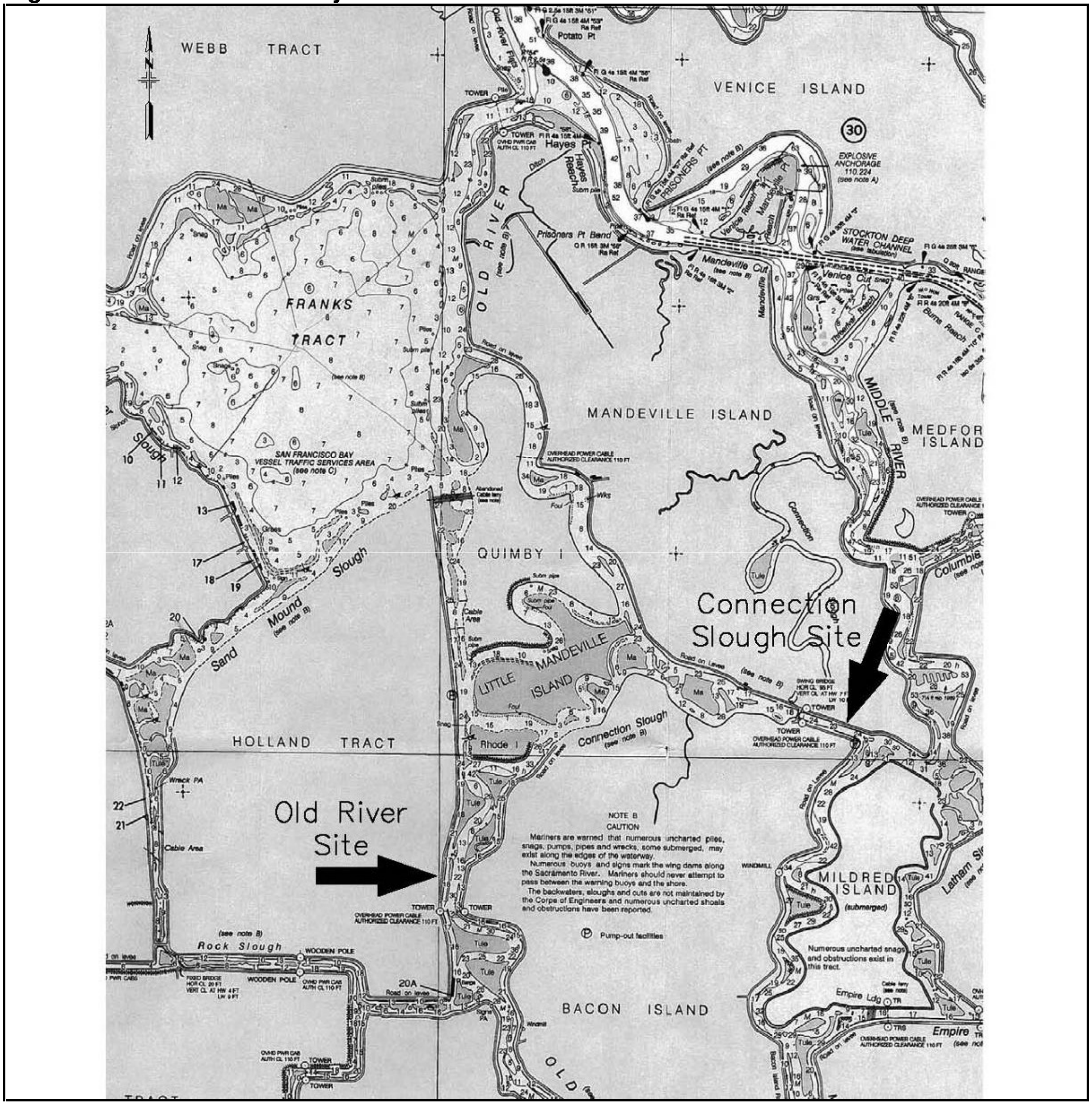
The 2-ft head-differential on the Old River gate show velocities on the order of 4 ft/s directed towards the levee bank. The initial 2-ft differential stabilizes at a differential of ~0.8-ft with persistent velocities on the order of 9 ft/s for at least 30 minutes. This head-differential condition represents a 5% exceedance probability, occurring roughly 1 hour per day for the 3 months of planned gate closure. The 1-ft head-differential on the Old River gate stabilizes at a differential of ~0.1-ft with persistent velocities on the order of 3 ft/s. By extrapolating between the three Old River differential simulations, a starting head-differential of ~1.5-ft would stabilize at the 3.5-knot limiting passage velocity criteria. A 1.5-ft differential represented an exceedance probability of 19%, occurring twice a day for ~2.3 hours each on the higher high and lower low tide. To achieve the current limiting passage velocity criteria of 3.5-knots, the Operations Plan for the Old River gate should limit opening the gate when head-differentials exceed 1.5-ft.

The stabilization of the gate velocities at a relatively high level reflect the fact that closing the gates affects the water levels through a large portion of the Delta system. Before the gates are opened, the water levels for several miles upstream of the gates are at a relatively low level. When the gates open, the system begins to equilibrate. However, because a large area of the system is affected, this takes a significant length of time. One way of looking at this is in terms of the quantity of water that must move through the gates to equilibrate the system. This quantity of water, which would normally move upstream over a period of hours (the entire flood tide), cannot squeeze through the gates in a few minutes.

To mitigate for the propagation of velocities towards the levees during a gate opening, some additional bank stabilization should be considered for the levees immediately upstream and downstream of the Old River gate on the affected side. Another alternative mitigation for the velocities directed towards the levees is to change the way the gates open. Instead of rotating both gates in the same direction, rotate the gates opposite to each other so the gates form a "V" opening, directing flows straight down the center of the channel.

FIGURES

Figure 1.1 Location of Project Sites



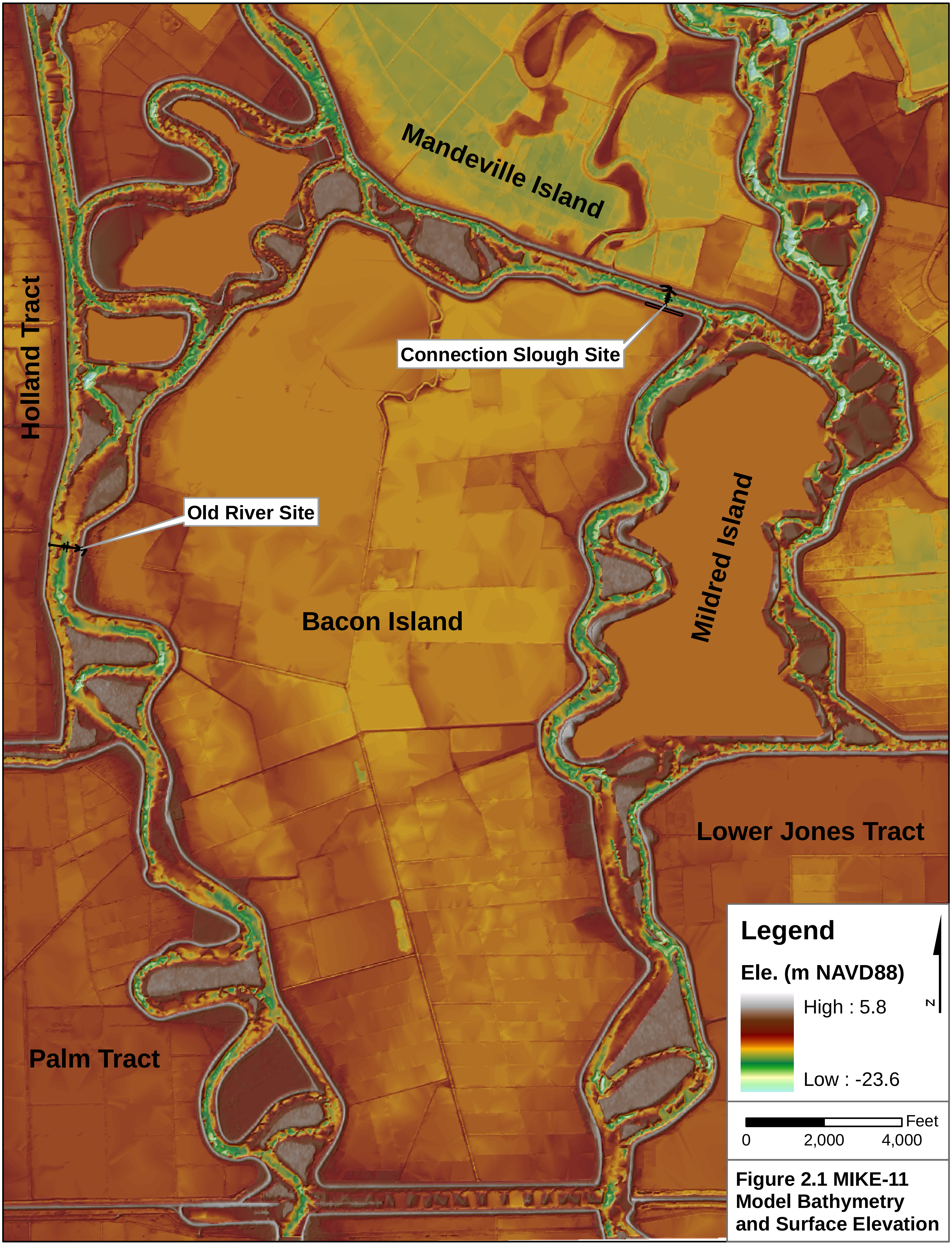


Figure 2.1 MIKE-11 Model Bathymetry and Surface Elevation

Figure 2.2 Old River Site

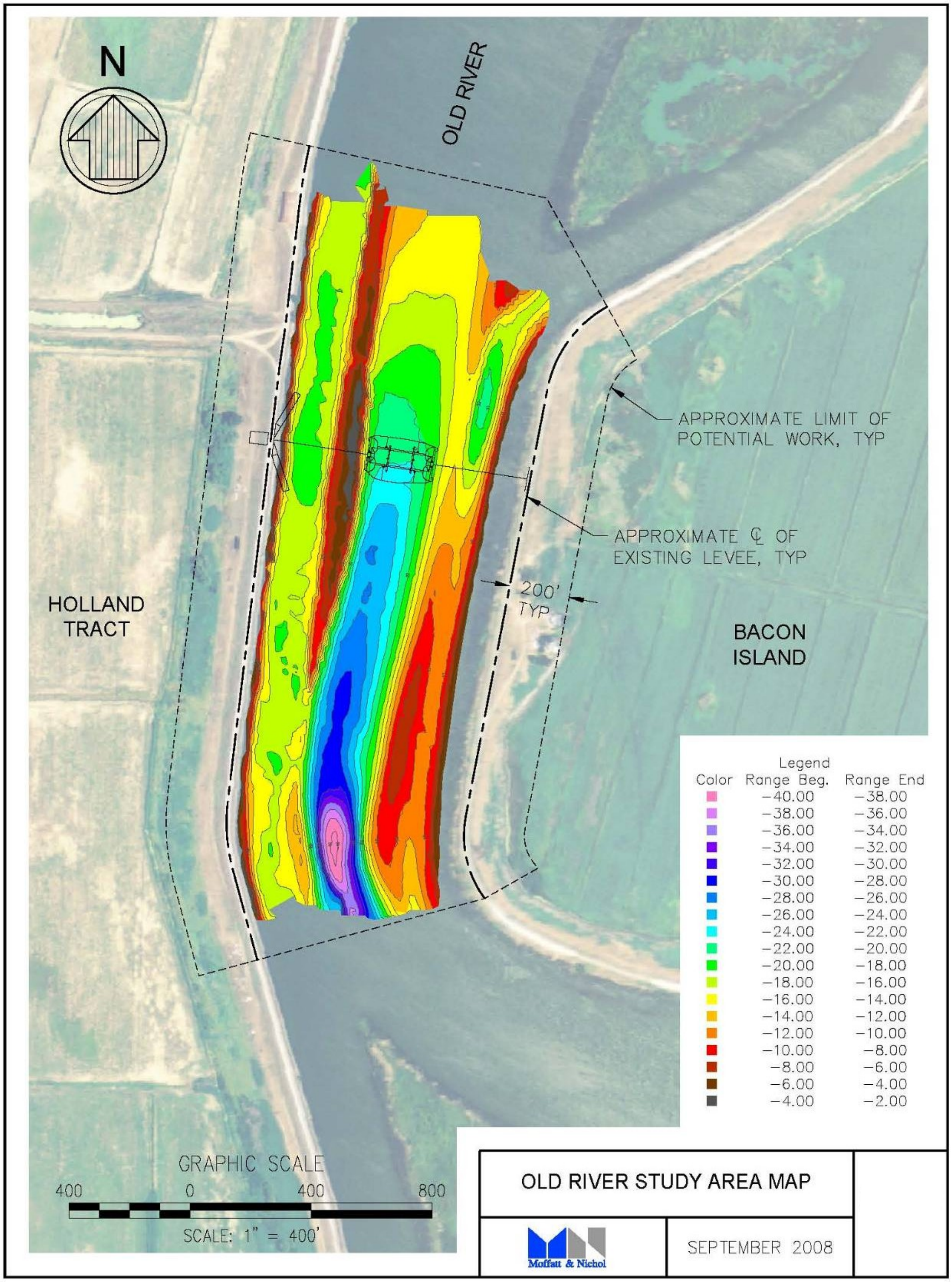
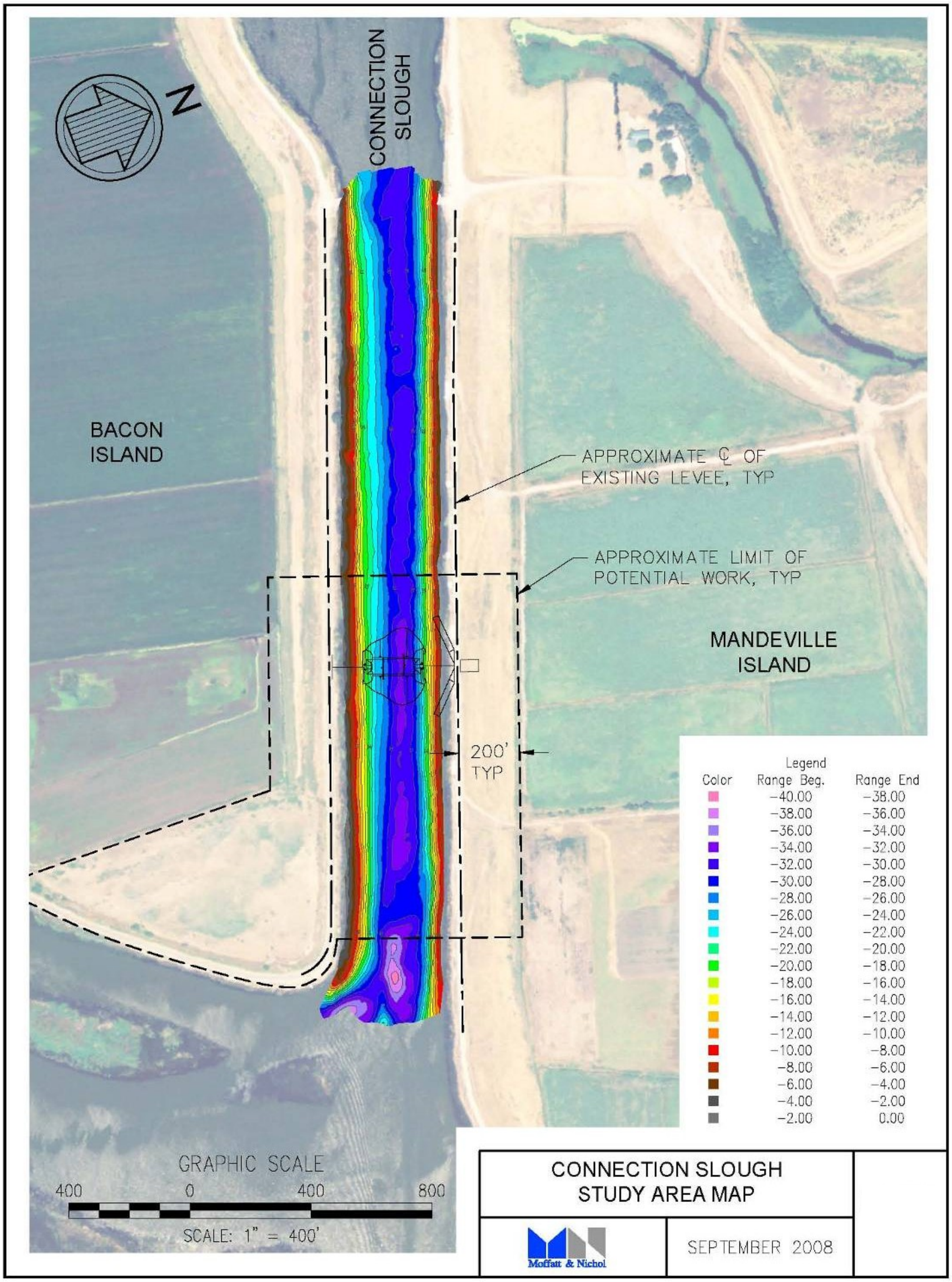


Figure 2.3 Connection Slough Site



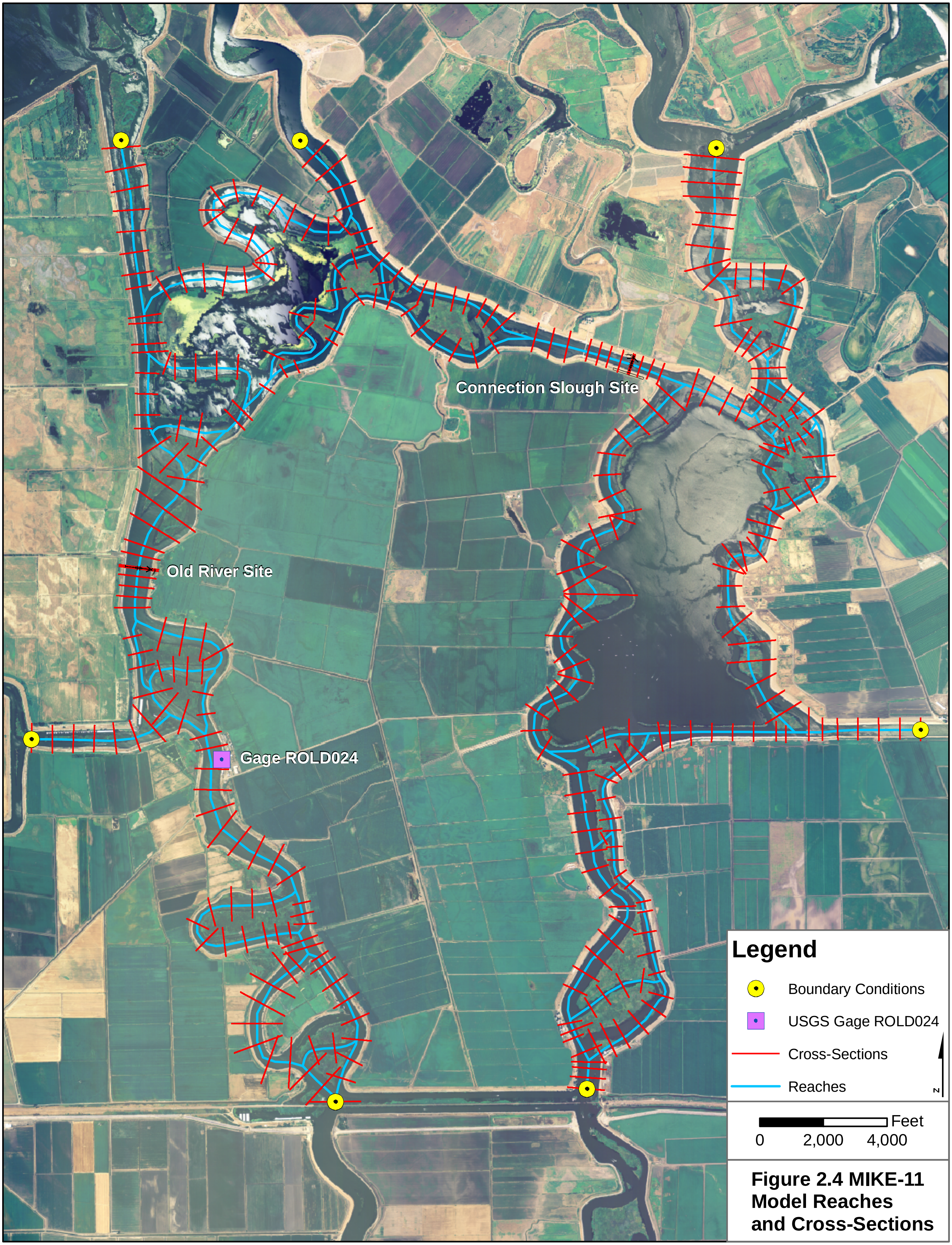


Figure 2.4 MIKE-11 Model Reaches and Cross-Sections

Figure 2.5 MIKE-11 Model Calibration Results, February 1998 Stages

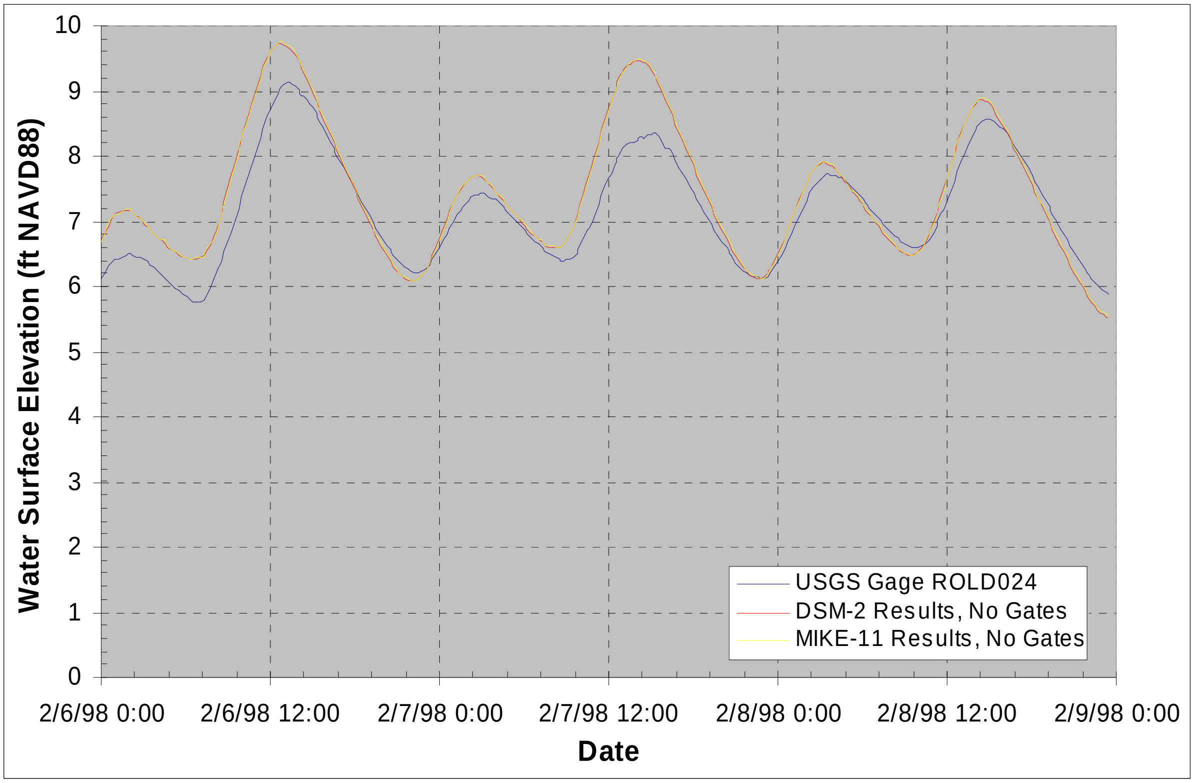


Figure 2.6 MIKE-11 Model Calibration Results, February 1998 Flows

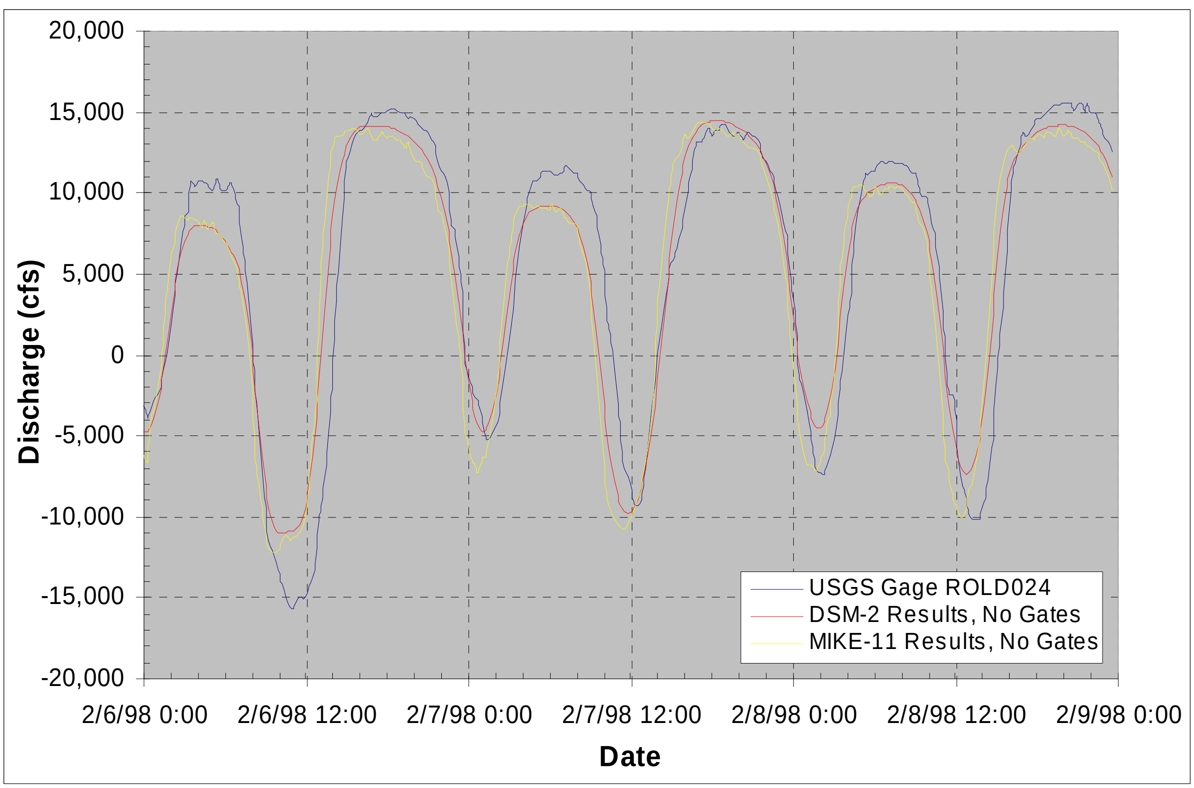


Figure 2.7 MIKE-11 Model Calibration Results, January 1997 Stages

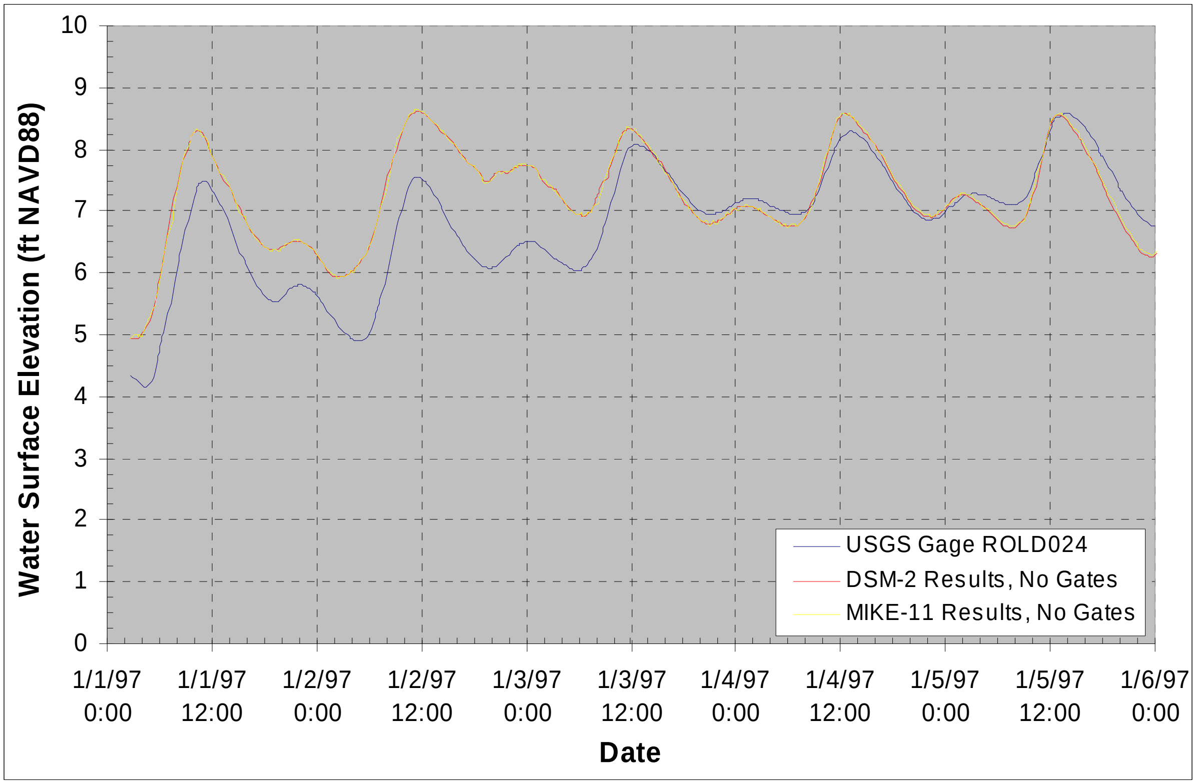


Figure 2.8 MIKE-11 Model Calibration Results, January 1997 Flows

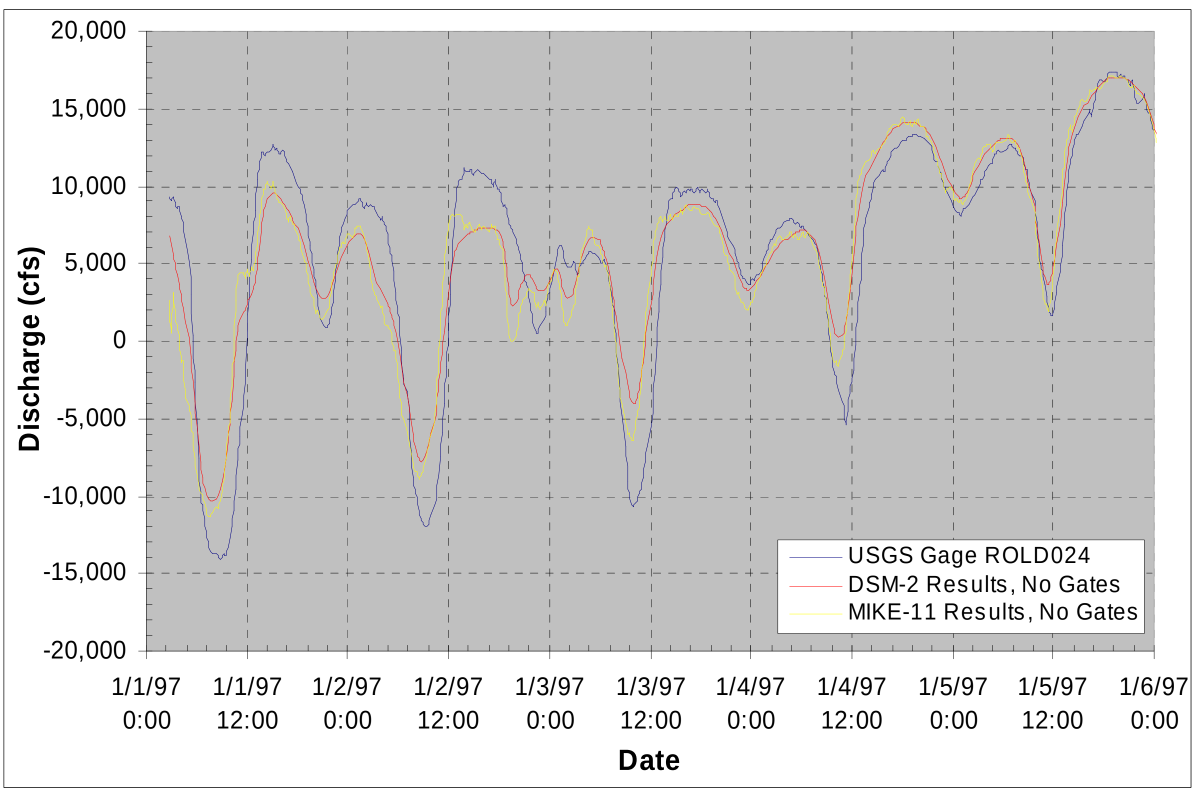


Figure 3.1 Comparison of Stages With Gates Open and No Gates for February 1998

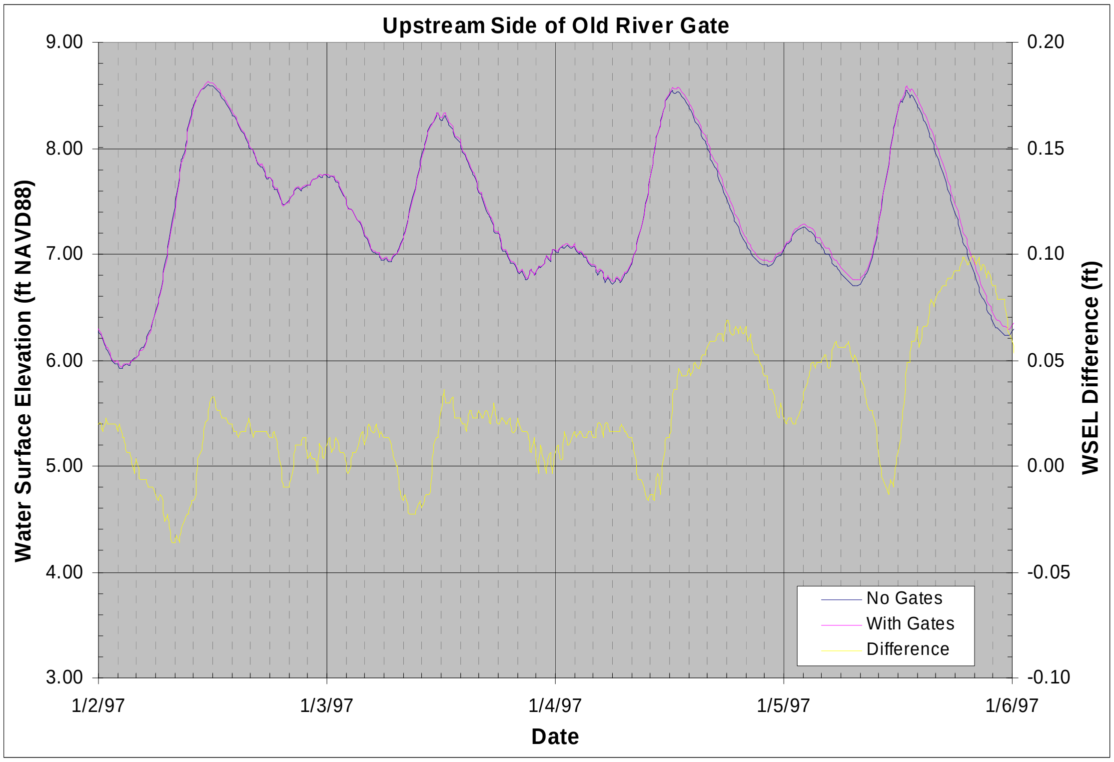


Figure 3.2 Comparison of Old River Water Surface Profiles for February 1998

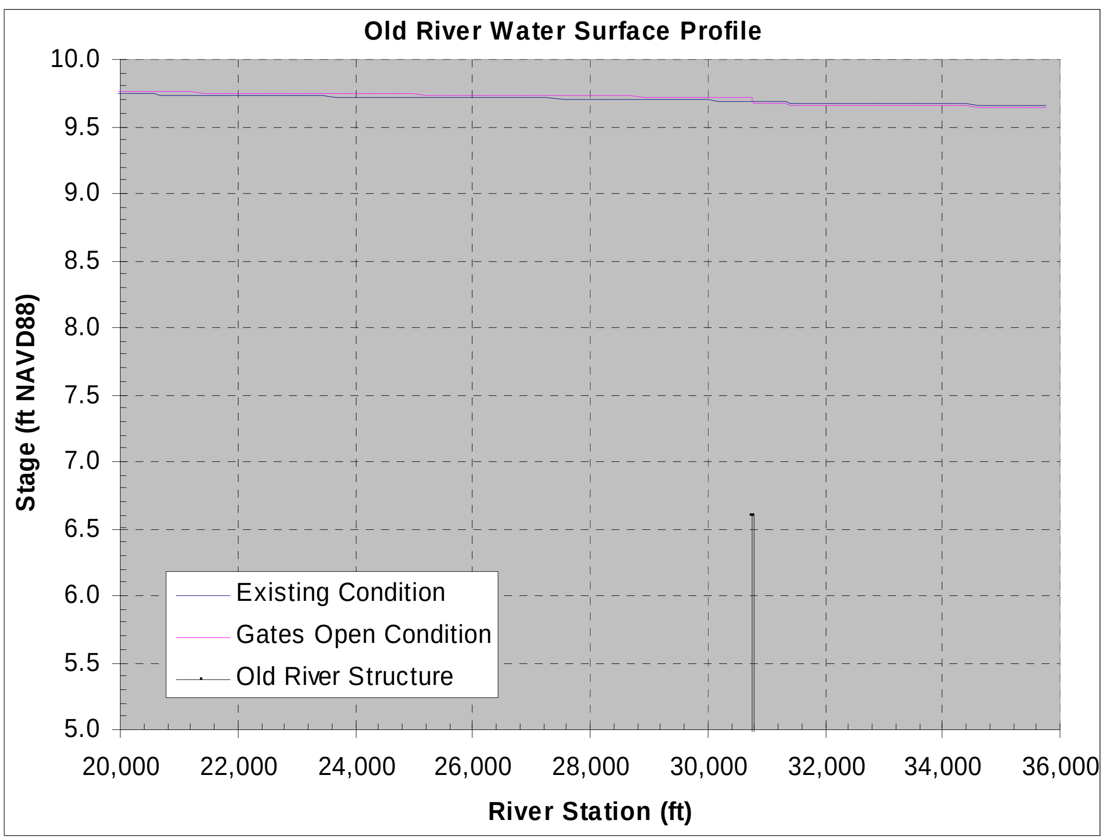


Figure 3.3 Comparison of Stages With Gates Open and No Gates for January 1997

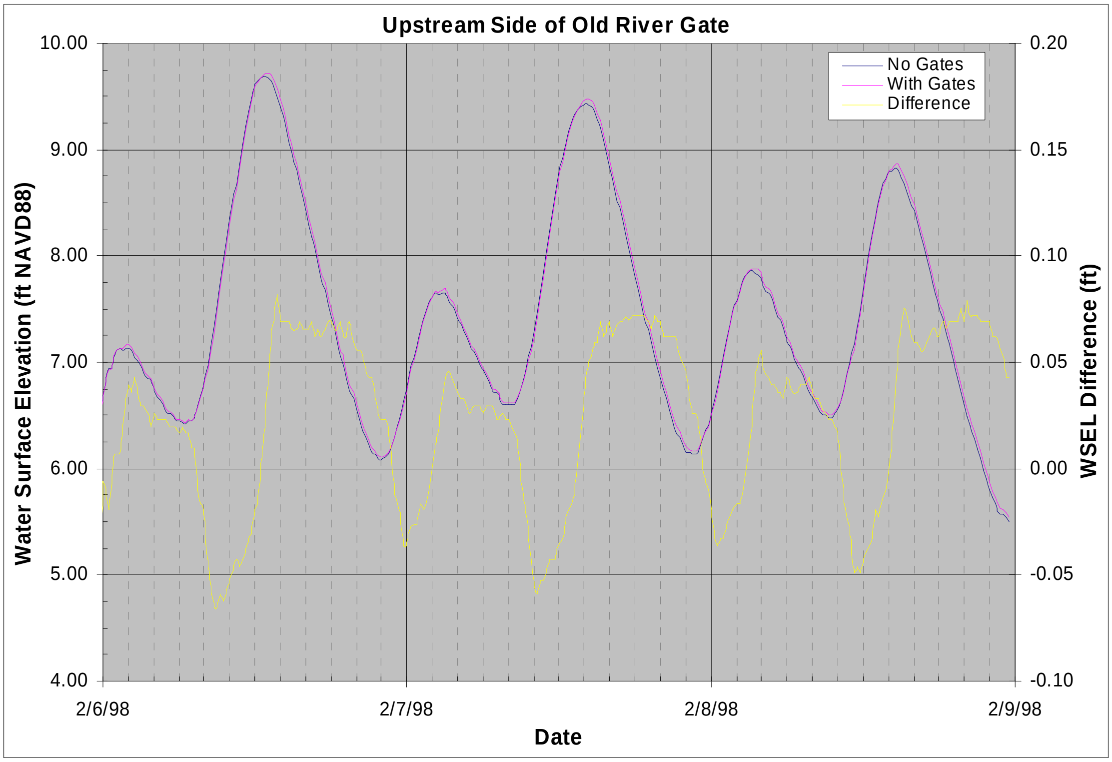


Figure 3.4 Comparison of Old River Water Surface Profiles for January 1997

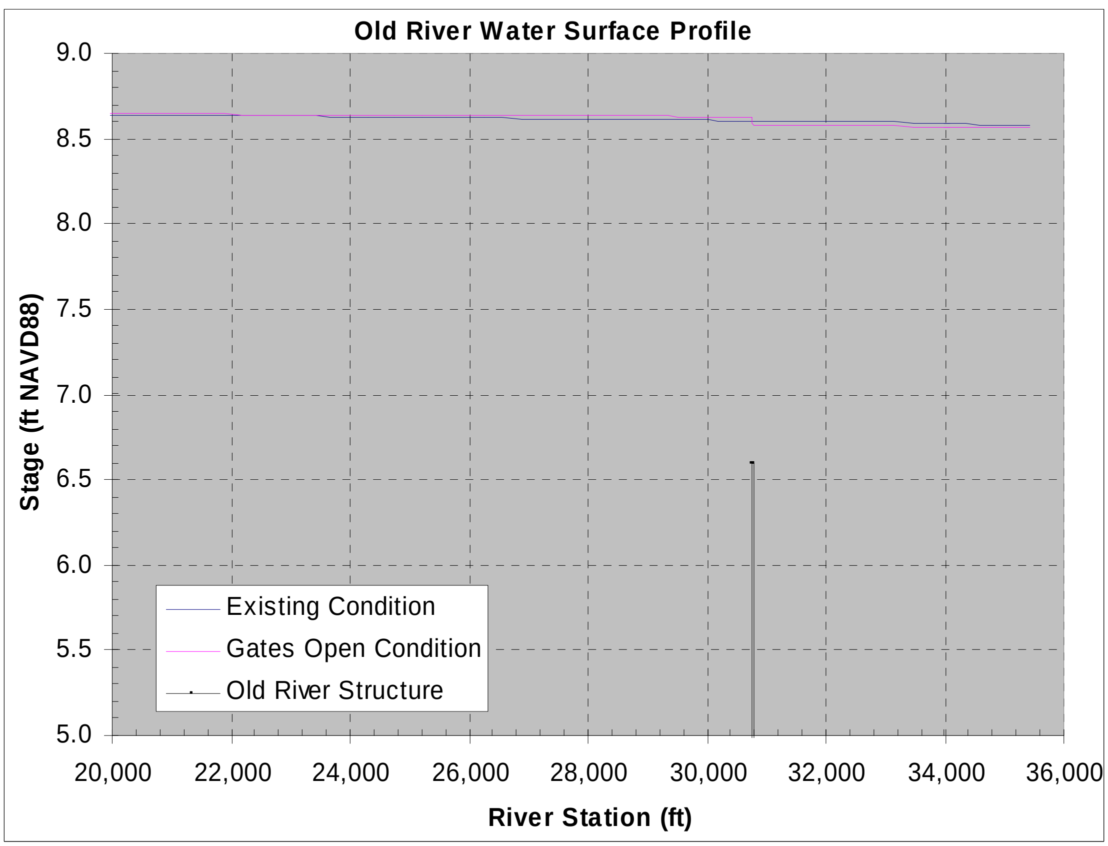


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Figure 3.5 Comparison of Stages With Gates Open and No Gates for December 2005

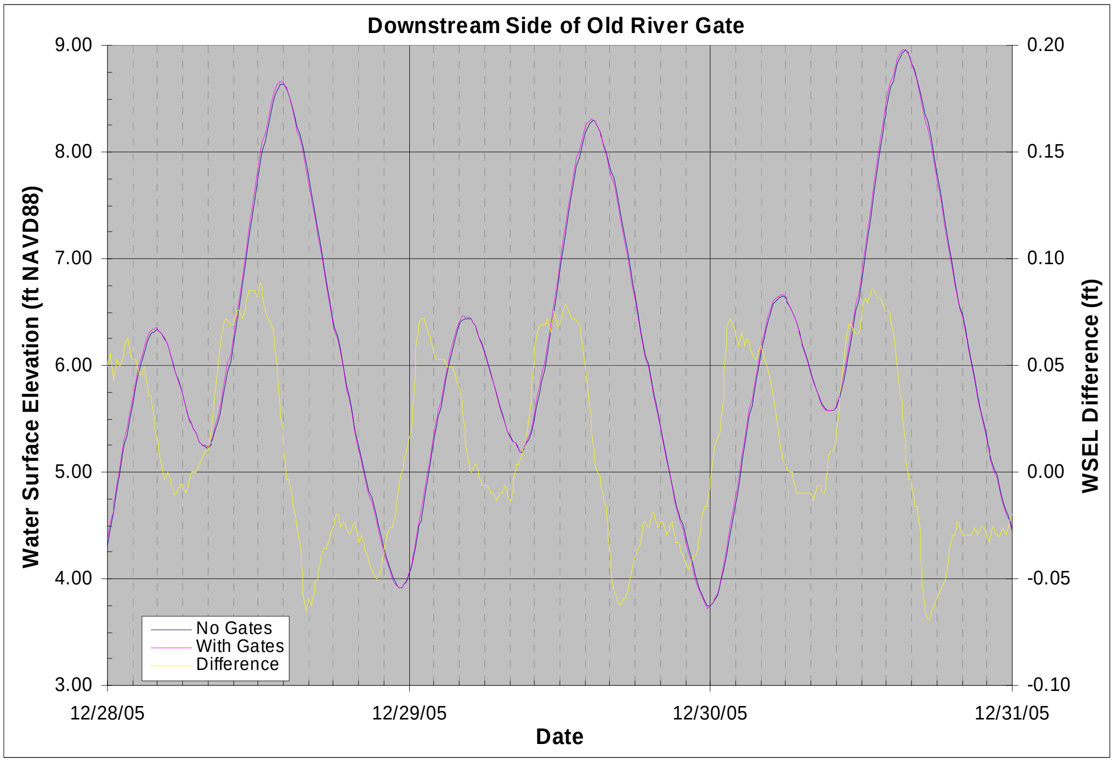

Figure 3.6 Comparison of Old River Water Surface Profiles for December 2005

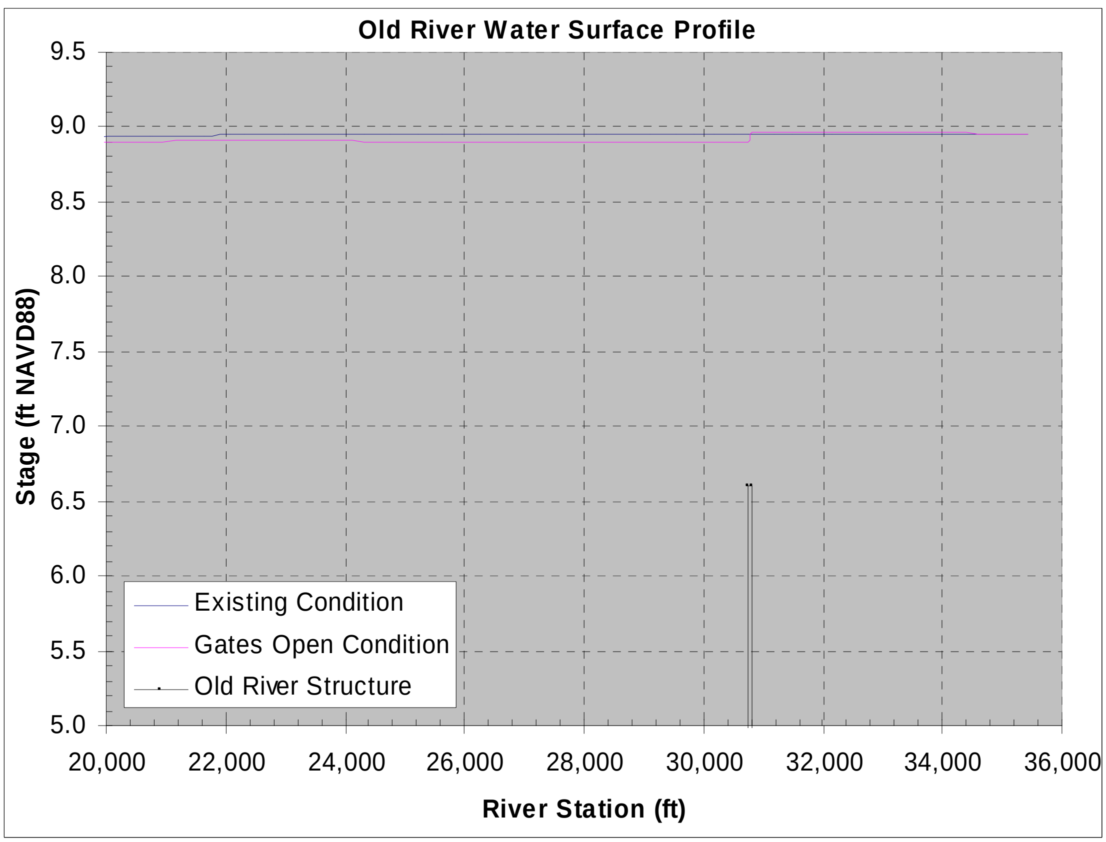

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Figure 3.7 MIKE-21 Results for Old River with Gates Open, Flood Tide with ~0.02% exceedance peak flow.

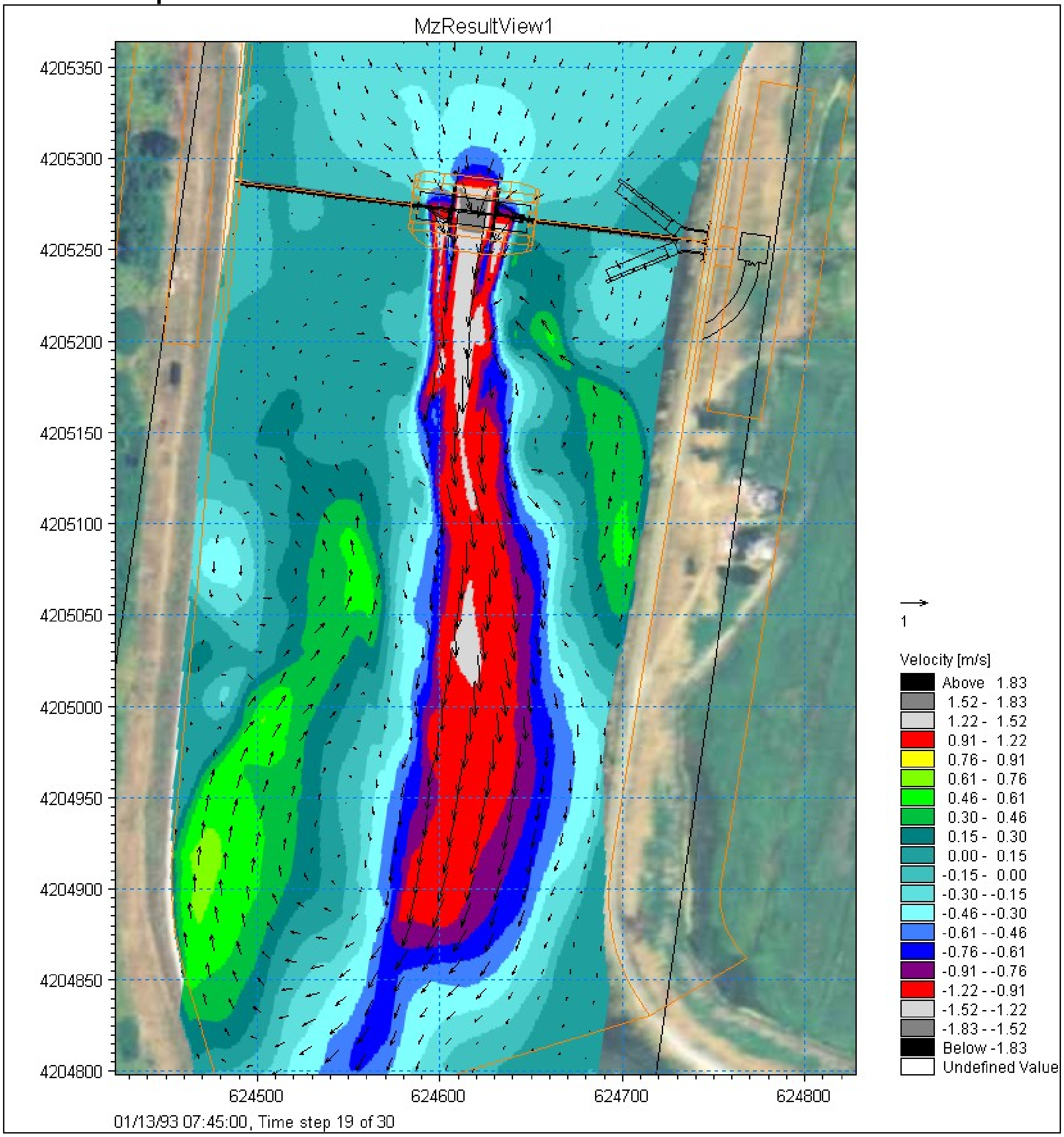

Figure 3.8 MIKE-21 Results for Old River with Gates Open, Flood Tide with ~1% exceedance peak flow.

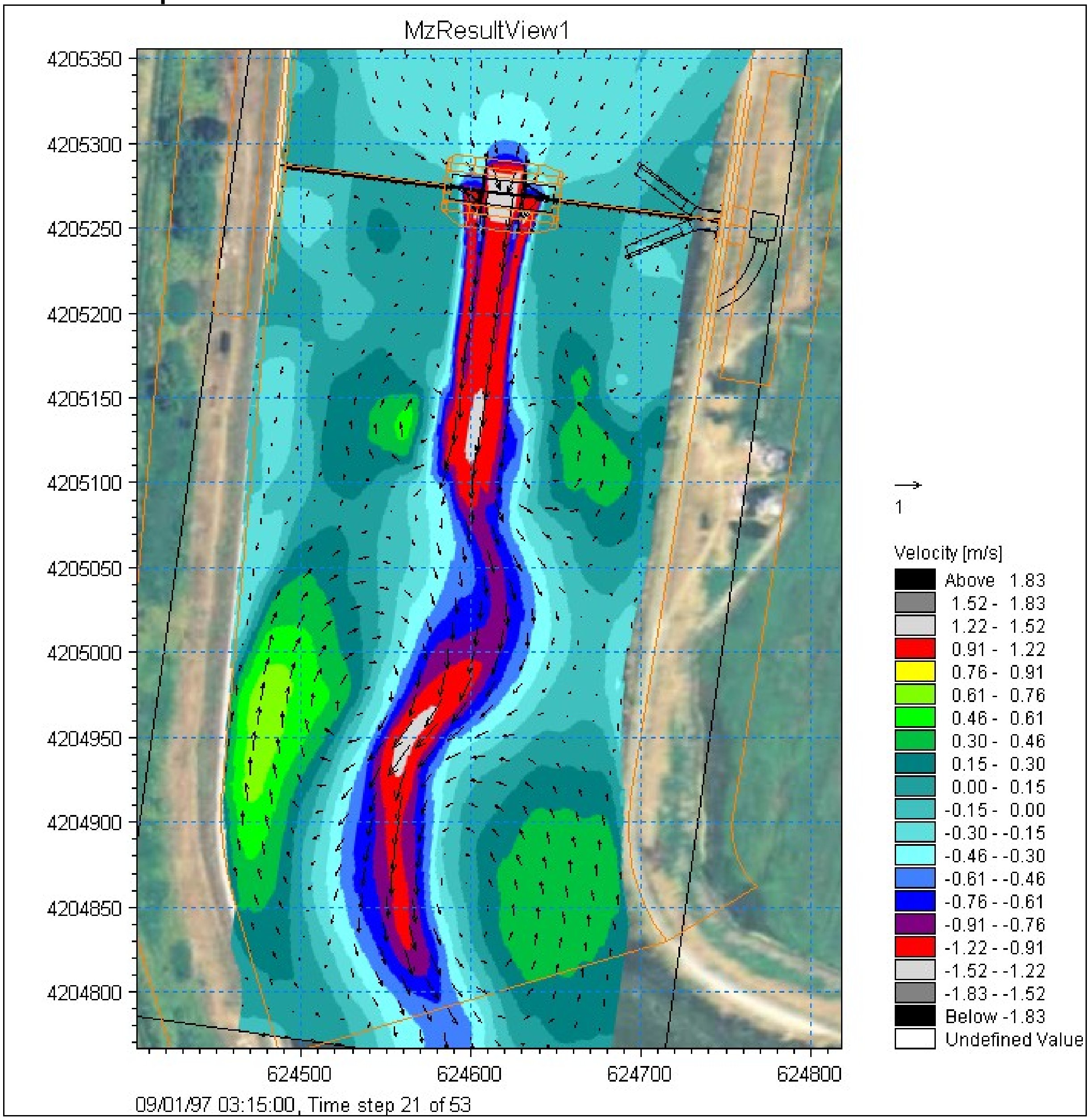

Figure 3.9 MIKE-21 Results for Old River with Gates Open, Ebb Tide with 0.2% exceedance peak flow.

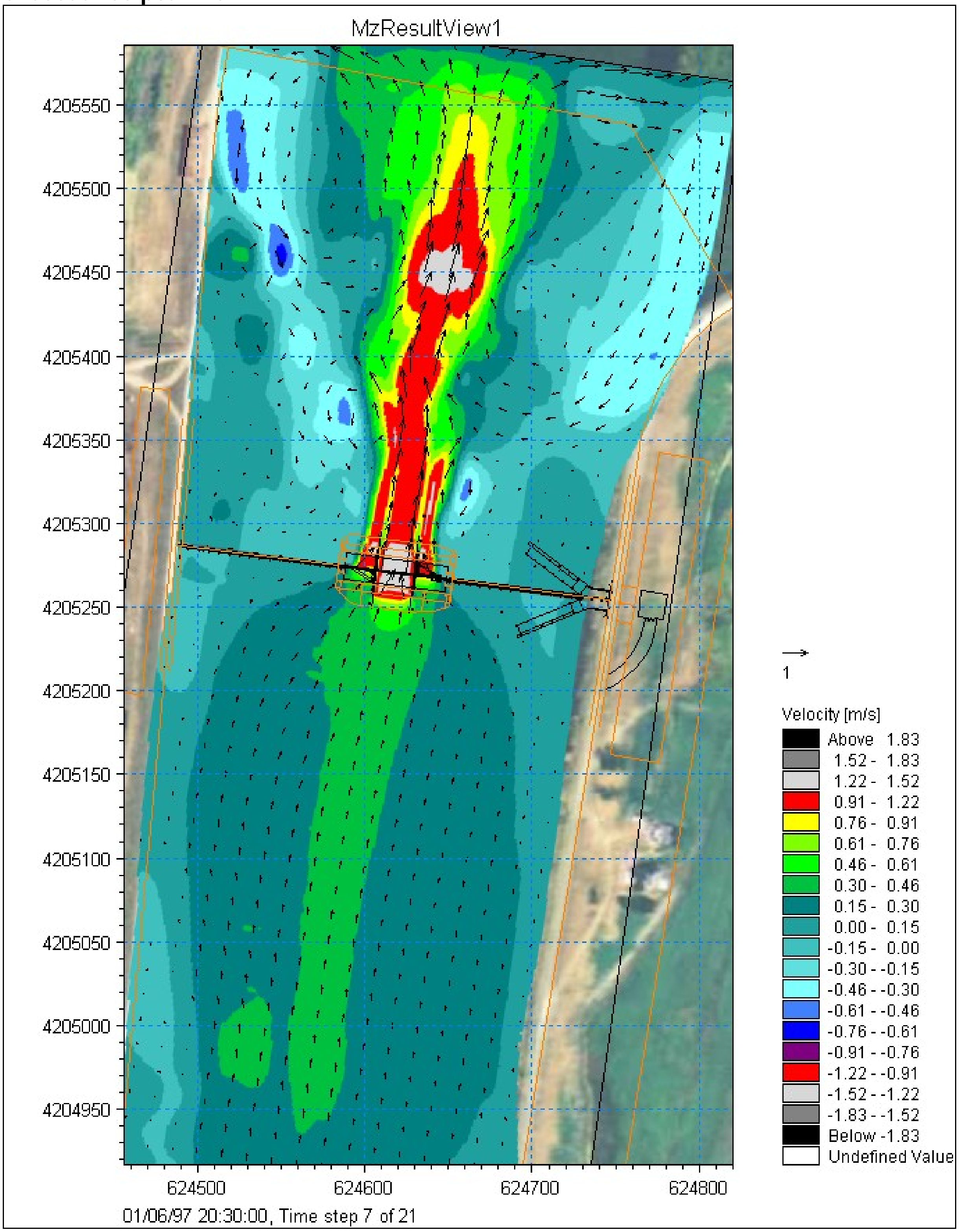

Figure 3.10 MIKE-21 Results for Connection Slough with Gates Open, Flood Tide with ~1% exceedance peak flow.

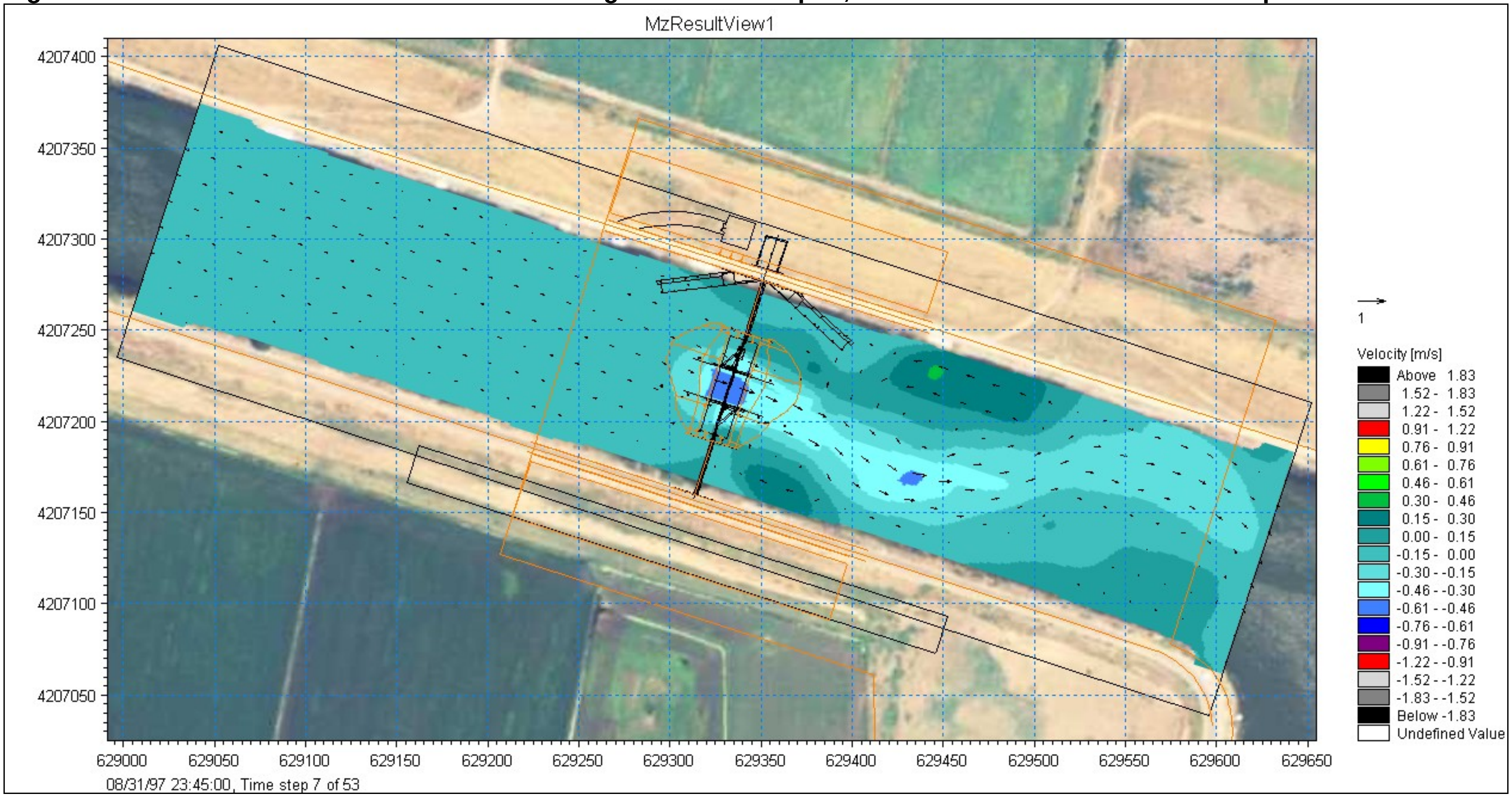

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Figure 3.11 MIKE-21 Results for Connection Slough with Gates Open, Ebb Tide ~1% exceedance peak flow.

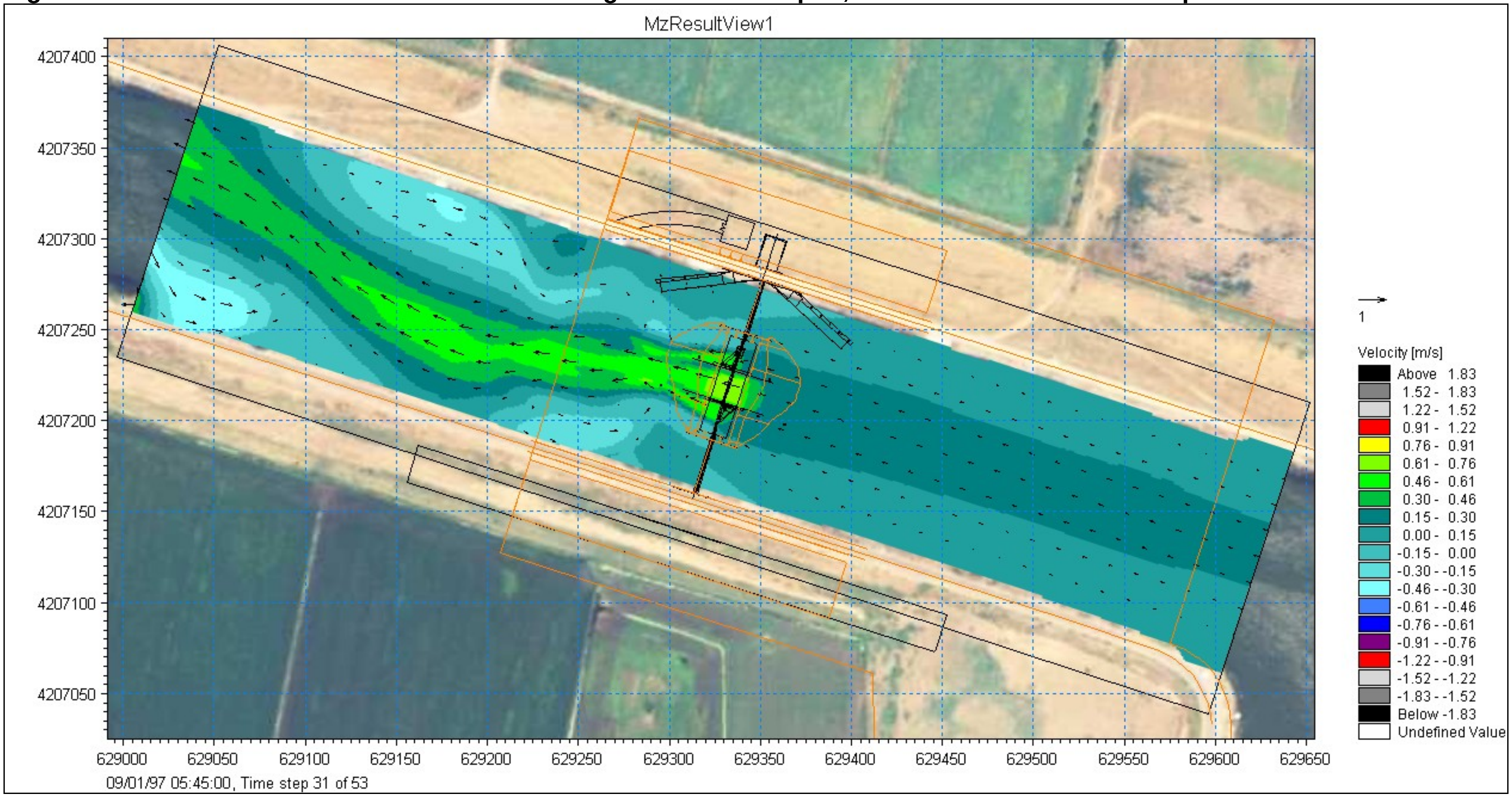


Figure 3.12 DSM-2 Results, Old River Gate-Closed Head-Differentials

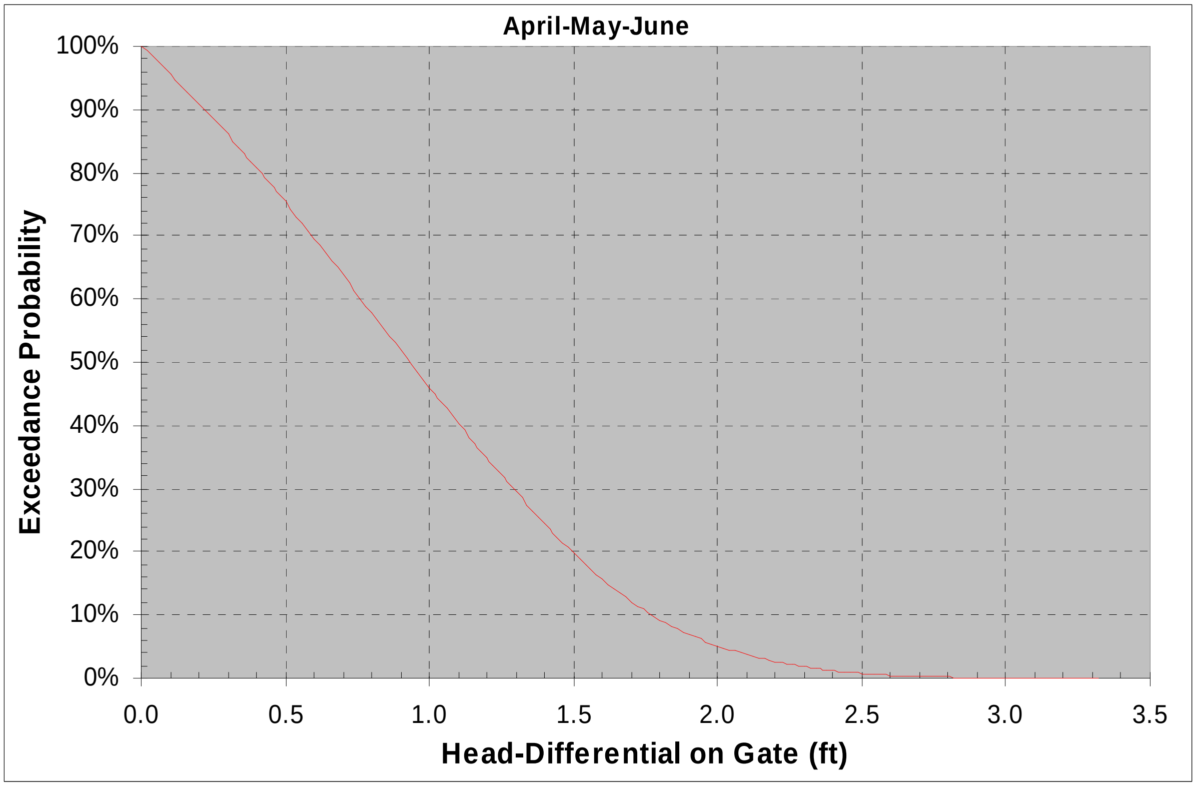


Figure 3.13 DSM-2 Results, Connection Slough Gate-Closed Head-Differentials

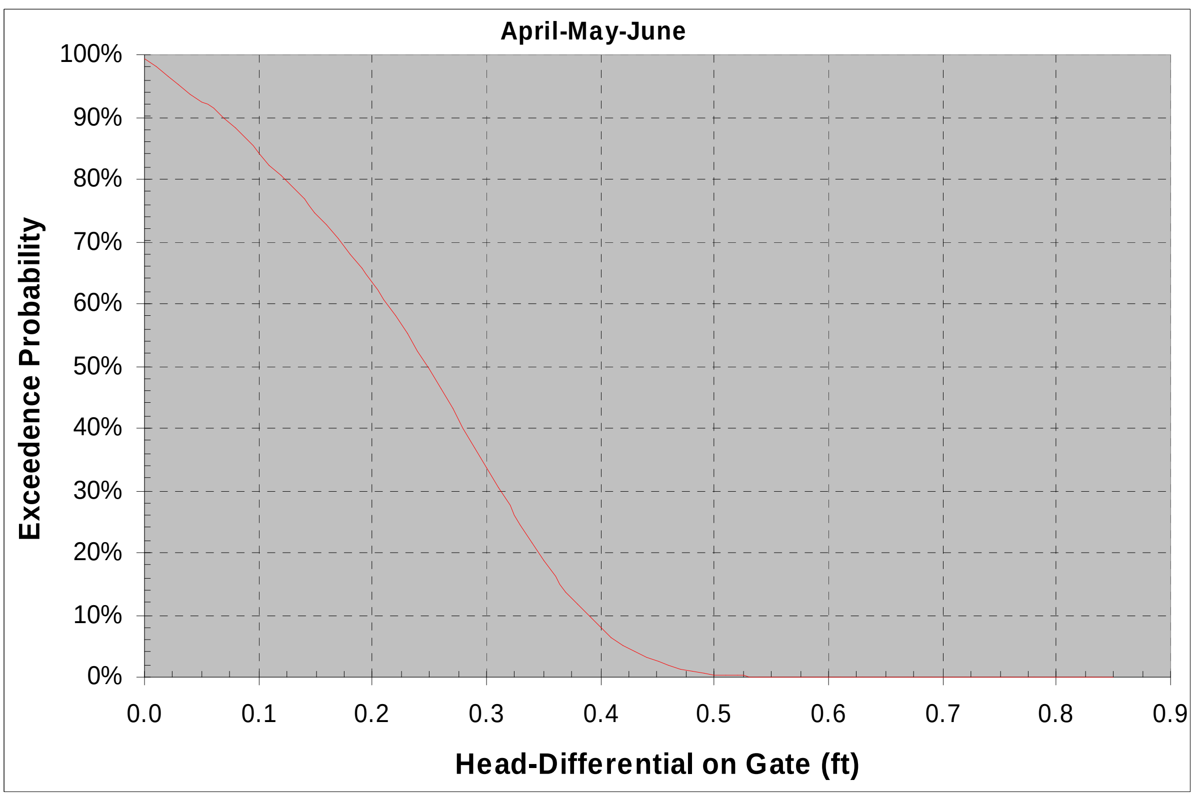


Figure 3.14 MIKE-21 Results for Old River Gate-opening, 3-ft Starting Head-differential (shown at 2-min and 3.5-min after start of opening).

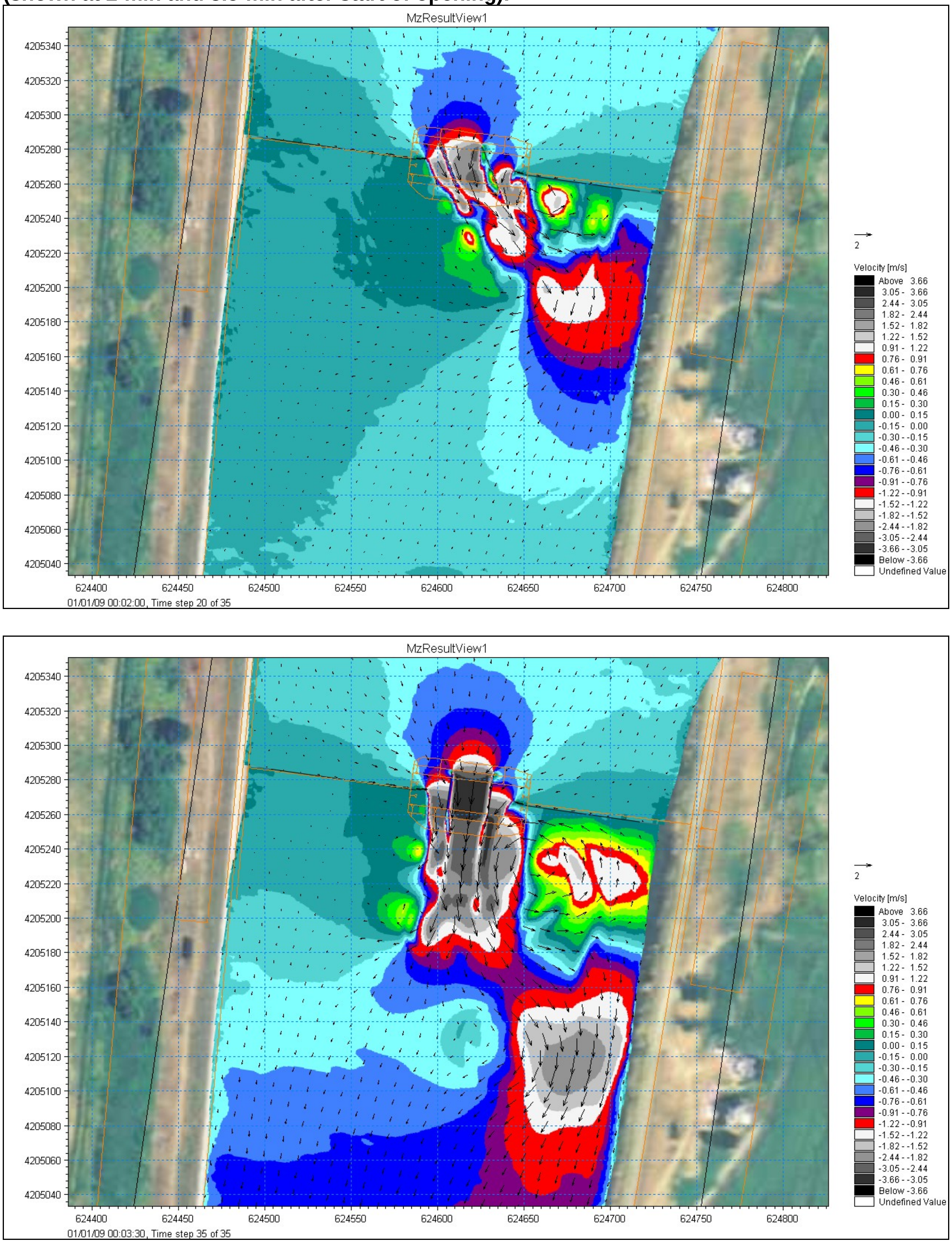


Figure 3.15 MIKE-21 Results for Old River Gate-opening, 2-ft Starting Head-differential (shown at 2-min and 5-min after start of opening).

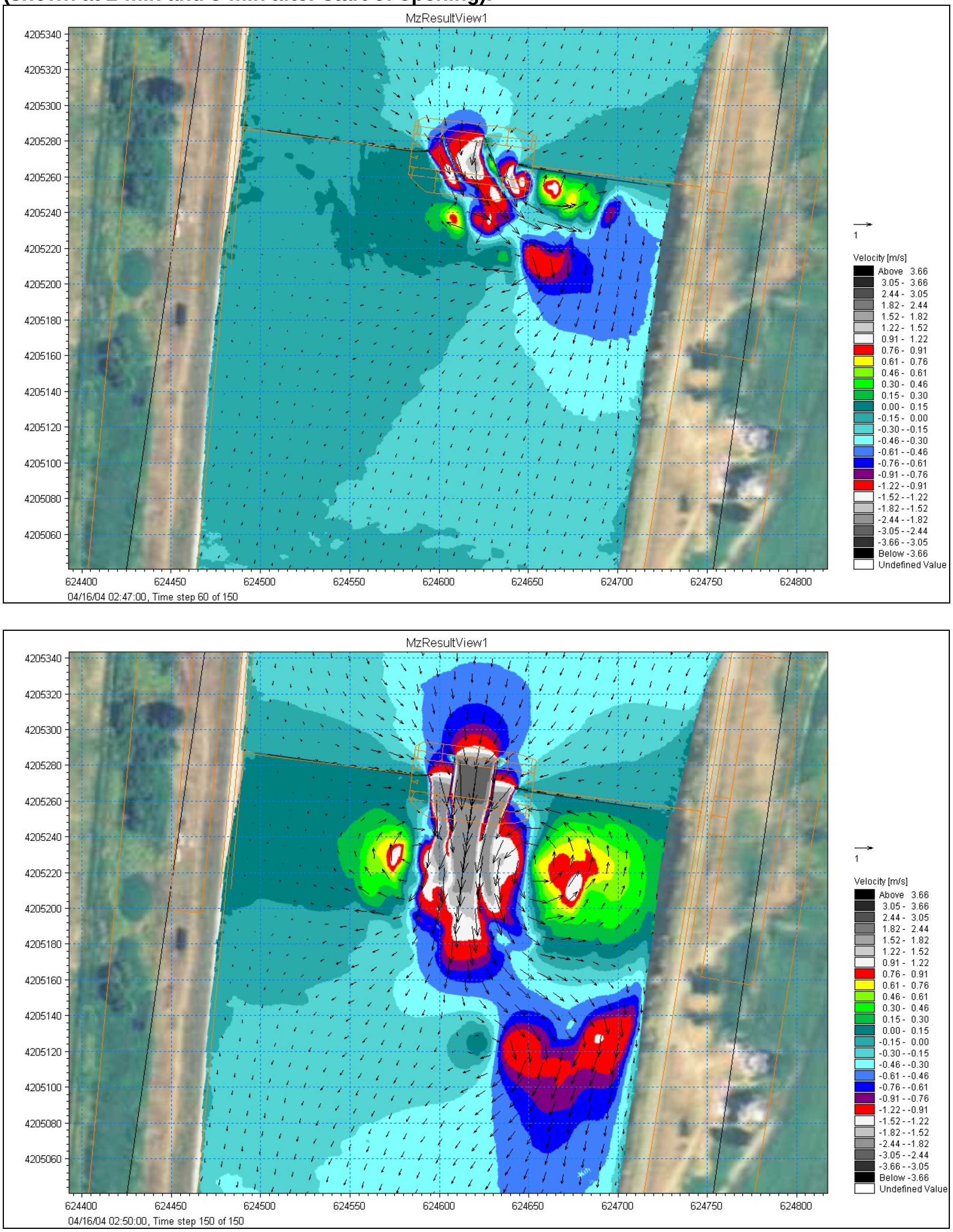
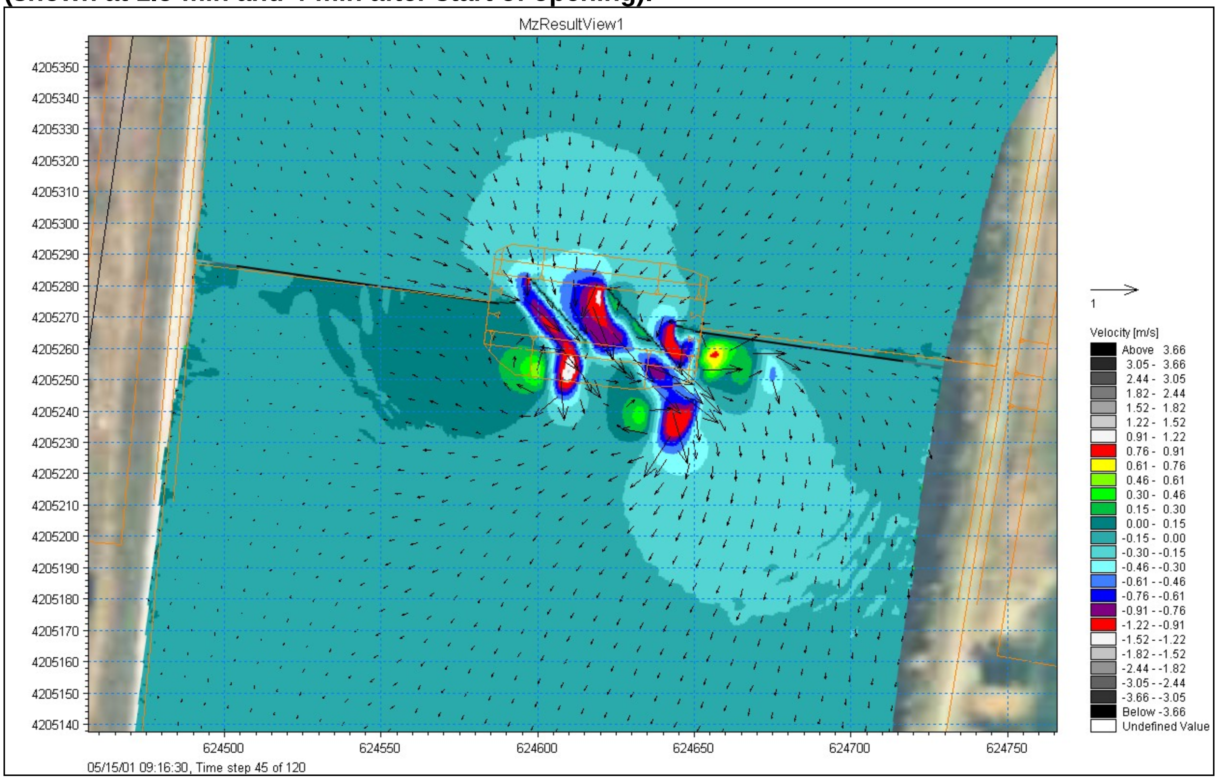


Figure 3.16 MIKE-21 Results for Old River Gate-opening, 1-ft Starting Head-differential (shown at 1.5-min and 4-min after start of opening).



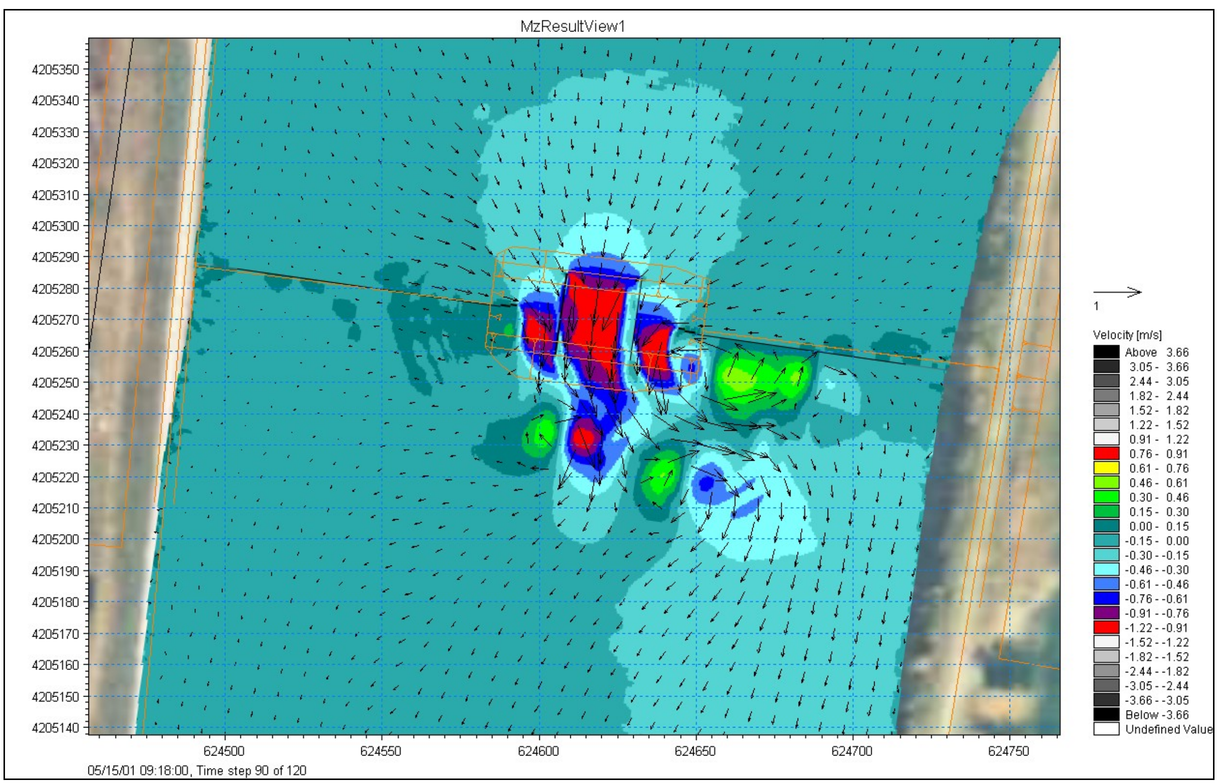
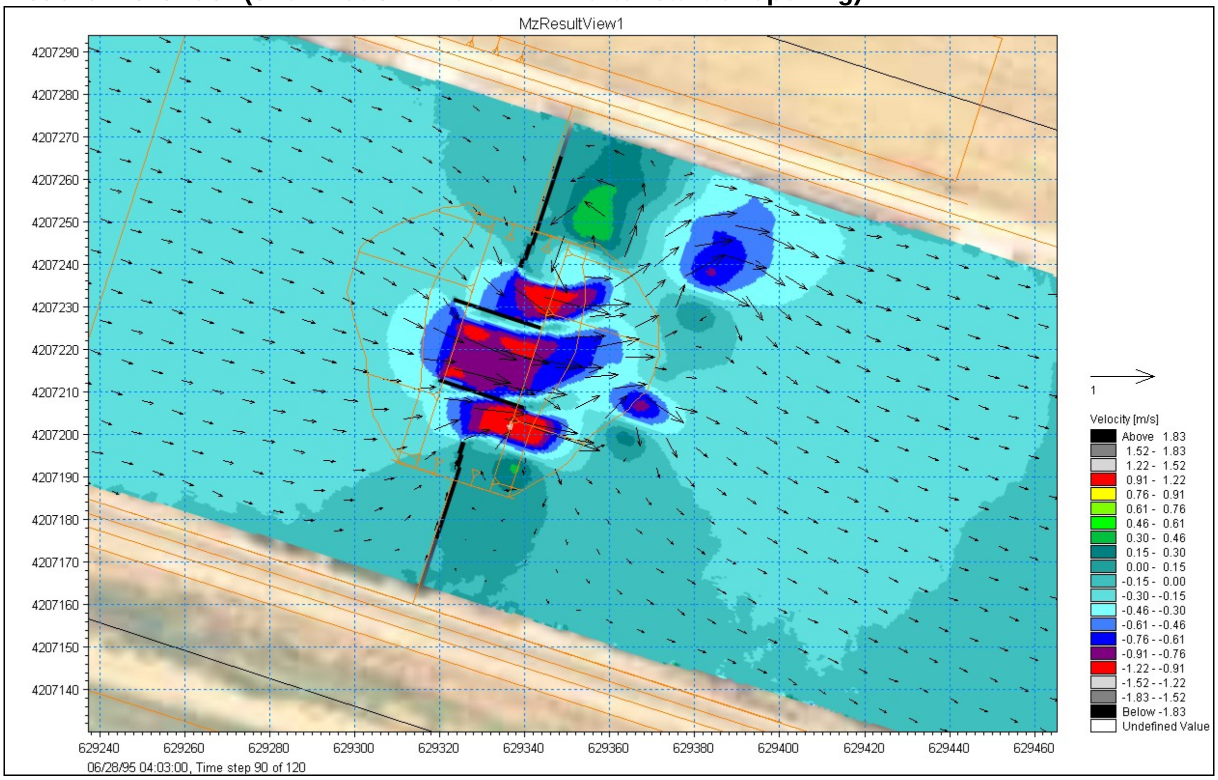
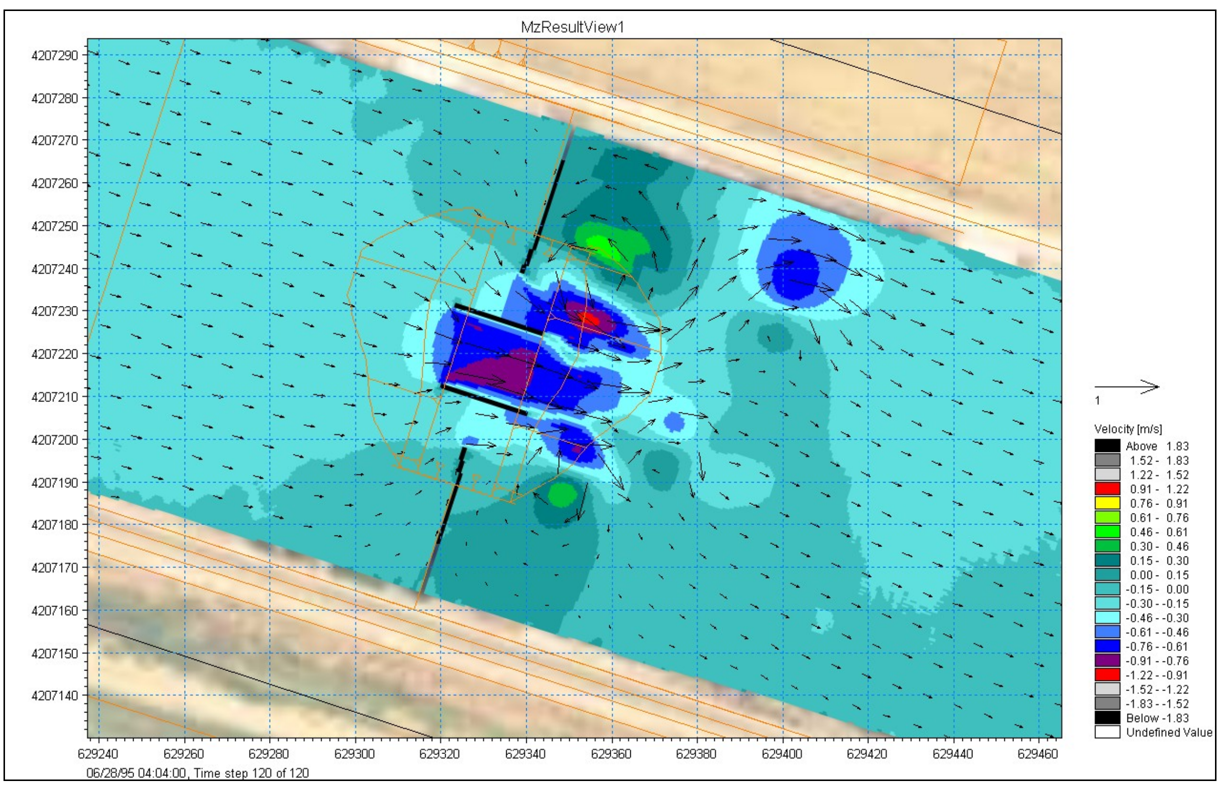


Figure 3.17 MIKE-21 Results for Connection Slough Gate-opening, 0.75-ft Starting Head-differential (shown at 3-min and 4-min after start of opening).





APPENDIX A

CONTRA COSTA WATER DISTRICT
Technical Memorandum

DATE: November 26, 2008

PREPARED BY: Brett T. Kawakami, Associate Water Resources Specialist

SUBJECT: CCWD DSM2 Flood Analysis for 2-Barrier Project

PURPOSE: This memorandum describes the hydrodynamic modeling using the Delta Simulation Model, Version 2 (DSM2) that was performed by Contra Costa Water District (CCWD) to determine potential flood effects of the proposed 2-Barrier project. Results of this analysis show no significant flood impacts based on a 16 year historical DSM2 analysis (1991-2005), provided the gates are left open during high water events.

Delta Hydrodynamic Model – DSM2

DSM2 is a one-dimensional model developed by the Department of Water Resources (DWR) for simulating hydrodynamics, water quality, and particle tracking in a network of riverine or estuarine channels (DWR,2000). The model is used by DWR and others to perform operational and planning studies of the Delta. Details of the model, including source codes, model calibration, and model performance, are available from the DWR Bay-Delta Office, Modeling Support Branch. Documentation of model development is discussed in annual reports to the SWRCB which are available at: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm. DSM2 is a widely used model for studying issues pertaining to flow, water elevations, water quality and fisheries issues in the Delta and is well calibrated for flow, stage and water quality (Nader-Tehhrani, 2001;Thein and Nader-Tehrani, 2006).

The Hydro module of DSM2, applied to the Delta, simulates tidal hydrodynamics (channel stage, flow, and water velocity) using a 15-minute time step. For the 2-barrier project, DSM2 Hydro was used to evaluate changes in stage and flow in the vicinity of the barriers. In this analysis, results from use of the Hydro module are used to determine potential flood impacts from implementation of the 2-Barrier Project. A discussion of the DSM2 setup, results and conclusions are provided.

DSM2 Setup

DSM2 (DWR, 2000) was used to simulate the effect of installing temporary barriers in the vicinity south of Franks Tract in Old River and Connection Slough. The simulations were based on the most recent historical DSM2 setup available from DWR and were conducted from 1991-2005.

Gate locations and dimensions

The barriers will consist of sunken barges in Old River and Connection Slough with operable gates placed on top (Moffatt and Nichol, 2008). The barriers with the gates closed are modeled in DSM2 as single gates that extend the width of the channels. The barriers with the gates open are modeled as notched weirs that allow flow through an area defined by the dimensions of the gates (see below). The barriers were placed at DSM2 Channels 111 (Old River) and 248 (Connection Slough). Gate dimensions are as follows:

- Gate width: 170 feet (ft)
- Bottom elevation of gate: -13 ft NAVD88 (-15.4 ft NGVD29)
- Top elevation of gate: 6.6 ft NAVD88 (4.2 ft NGVD29)

Elevations were converted from NAVD88 to NGVD29 for use in DSM2.

Scenario Descriptions

The DSM2 scenarios used in the flood analysis are described in **Table 1**. For the purposes of the analysis, the gates were not operated and were considered either open or closed for the entire simulation. The No Gates scenario represents the base case used for comparison. All scenarios used the same set of unmodified historical boundary flows and operations.

Table 1: DSM2 Scenarios

Scenario	Description
No Gates	Barriers are not installed.
Gates Closed	Barriers are installed and gates closed year round. Flow only occurs when gate is overtopped.
Gates Open	Barriers are installed and gates left open year round. Flow occurs through the gate opening.
Gates Open (0.2 Coefficient)	Same as "Gates Open" scenario with an additional weir friction coefficient of 0.2 applied.

Results

Stage information was output at 15 minute intervals immediately upstream and downstream of both barriers, as well as at other selected locations. The results were provided on CD-ROM to DWR in MATLAB and ASCII format in August, 2008 (CCWD, 2008). All stage results in this discussion are given in the NGVD 1929 datum.

Maximum annual stage impact

For each scenario, the highest stage in each water year of the simulation (maximum annual stage) was identified at four locations immediately upstream and downstream of the Connection Slough and Old River barriers. The changes in maximum annual stage between the with-gate scenarios and the No Gates scenario were determined. Maximum annual stage exceeded the top of the gate elevation (4.2 ft) in all years and scenarios. A comparison between the Gates Closed and No Gates scenario is shown in **Table 2.** Bold numbers indicate the highest increase for a given location over the entire simulation period. The highest increase to the maximum annual stage was 0.23 ft, which occurred in 1997 at the upstream side of Old River. In all other years, the maximum increase was 0.16 ft or lower.

Table 2: Changes in Stage at Maximum Annual Stage for Gates Closed versus No Gates scenario

Year	No Gates Scenario Maximum Annual Stage (feet) NGVD 1929	Change in Maximum Annual Stage (feet)* Compared to No Gates Scenario			
		Connection Slough U/S of Barrier	Connection Slough D/S of Barrier	Old River U/S of Barrier	Old River D/S of Barrier
1992	4.90	-0.01	0.02	-0.48	0.06
1993	5.00	-0.02	0.03	-1.03	0.08
1994	4.83	-0.03	**0.08**	-1.44	**0.16**
1995	5.93	**0.05**	-0.02	0.01	-0.01
1996	5.22	0.04	0.02	-0.41	0.06
1997	5.93	0.04	-0.09	**0.23**	-0.07
1998	7.08	0.01	-0.03	-0.07	-0.02
1999	4.52	0.00	0.03	-0.47	0.11
2000	4.97	-0.03	0.06	-0.84	0.12
2001	4.93	-0.02	0.01	-0.55	0.07
2002	5.10	-0.04	-0.03	-0.50	0.01
2003	5.41	-0.08	-0.06	-0.65	-0.03
2004	5.26	-0.06	0.03	-1.39	0.09
2005	5.49	-0.04	0.01	-0.93	0.07

Bold indicates maximum increase observed at the location for all years

In the comparison between the Gates Open and No Gates scenarios shown in **Table 3**, the increase in maximum annual stage in 1997 was reduced to 0.01 ft, and the maximum for all years was 0.02 ft, occurring in 2004. Thus, leaving the gates open (barriers installed) during periods of high flows greatly reduces the impact at the maximum stage.

Table 3: Changes in Stage at Maximum Annual Stage for Gates Open versus No Gates scenario

Year	No Gates Scenario Maximum Annual Stage (feet) NGVD 1929	Change in Maximum Annual Stage (feet)* Compared to No Gates Scenario			
		Connection Slough U/S of Barrier	Connection Slough D/S of Barrier	Old River U/S of Barrier	Old River D/S of Barrier
1992	4.90	**0.00**	0.00	-0.13	-0.01
1993	5.00	**0.00**	0.00	-0.21	0.00
1994	4.83	**0.00**	0.01	-0.31	0.02
1995	5.93	**0.00**	-0.01	-0.02	-0.01
1996	5.22	**0.00**	0.00	-0.14	0.00
1997	5.93	**0.00**	-0.03	**0.01**	-0.02
1998	7.08	**0.00**	0.00	-0.03	-0.01
1999	4.52	**0.00**	0.00	-0.16	0.01
2000	4.97	**0.00**	**0.01**	-0.26	0.01
2001	4.93	**0.00**	0.00	-0.15	0.00
2002	5.10	-0.01	-0.01	-0.13	0.00
2003	5.41	-0.01	-0.01	-0.14	-0.01
2004	5.26	-0.01	0.00	-0.28	**0.02**
2005	5.49	**0.00**	0.00	-0.26	0.01

Bold indicates maximum increase observed at the location for all years

We conducted a sensitivity analysis by rerunning the Gates Open scenario with a conservative friction coefficient of 0.2 applied, which serves to constrict the flow allowed through the gates significantly. As shown in **Table 4**, the Gates Open (with 0.2 Coefficient) showed a maximum increase in maximum annual stage of 0.42 ft versus the No Gates scenario. There were also other instances, mostly at the Old River barrier downstream, where changes in maximum annual stage exceed 0.1 ft, although the highest increase is at 0.14 ft. The increases in stage are unexpectedly higher for the Gates Open (with 0.2 Coefficient) than the Gates Closed scenario. This is due to the fact that overtopping is not properly simulated in DSM2 for the Gates Open scenarios. When stage exceeds the top of the gate elevation, flow should be allowed across the entire length of the barrier, which is what does occur in the Closed Gate scenario simulation. However, in the Open Gate scenarios, the gate is essentially modeled as a notched weir, and due to a DSM2 limitation, flow is only allowed through the notched portion no matter how high the stage, leading to artificially higher stages to occur in the simulation. Thus, if overtopping were properly accounted for, the increases in stage would be lower.

Table 4: Changes in Stage at Maximum Annual Stage for Gates Open (with 0.2 Coefficient) versus No Gates scenario

Year	No Gates Scenario Maximum Annual Stage (feet) NGVD29	Change in Maximum Annual Stage (feet) Compared to No Gates Scenario			
		Connection Slough U/S of Barrier	Connection Slough D/S of Barrier	Old River U/S of Barrier	Old River D/S of Barrier
1992	4.90	-0.01	0.01	-0.47	0.04
1993	5.00	-0.01	0.03	-0.90	0.08
1994	4.83	-0.02	**0.07**	-1.28	**0.14**
1995	5.93	**0.02**	-0.03	0.12	-0.03
1996	5.22	**0.02**	0.02	-0.42	0.07
1997	5.93	**0.02**	-0.09	**0.42**	-0.07
1998	7.08	0.00	-0.05	0.08	-0.03
1999	4.52	0.00	0.02	-0.54	0.08
2000	4.97	-0.01	0.05	-0.80	0.11
2001	4.93	-0.01	0.02	-0.57	0.06
2002	5.10	-0.03	-0.01	-0.50	0.03
2003	5.41	-0.04	-0.01	-0.54	0.01
2004	5.26	-0.03	0.05	-1.15	0.11
2005	5.49	-0.02	0.05	-0.86	0.11

Bold indicates maximum increase observed at the location for all years

Changes in maximum annual stages for the Gates Open were also checked for two locations (ROLD014 and ROLD024) at some distance (less than a mile) upstream and downstream of the barriers **(See Figure 1 for locations).** Examination confirmed that the maximum increase was small (0.02 ft) at each location. The stage output for a number of other locations along Old and Middle Rivers were also examined and these showed a maximum increase of less than 0.04 ft when the gates were opened.

Fractional Exceedance Plots

Cumulative distribution function curves for stage output from the simulations were generated for the Gates Open and No Gates scenario at the OR Upstream barrier, ROLD014, and ROLD024 locations. The comparison between the two scenarios at is shown in **Figures 2 thru 4.** The figures illustrate that the there is not a

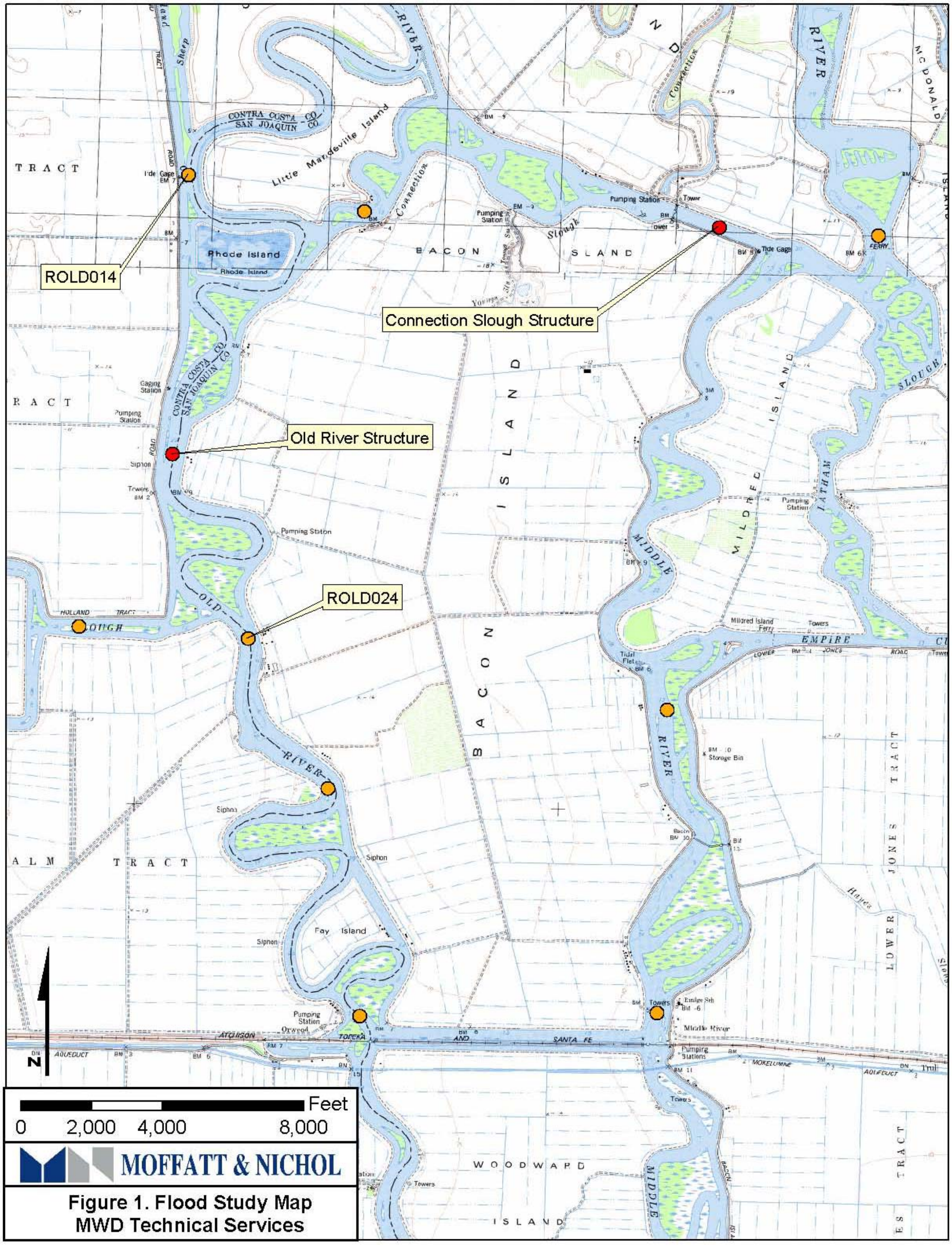


Figure 1: Location of Old River and Connection Slough Barriers and ROLD014 and ROLD024

significant difference in frequency distribution of stage between the Gates Open and No Gates scenarios for the three locations.

Figure 2: Cumulative Distribution Function Plot of Stage for OR Barrier upstream (1992-2005)

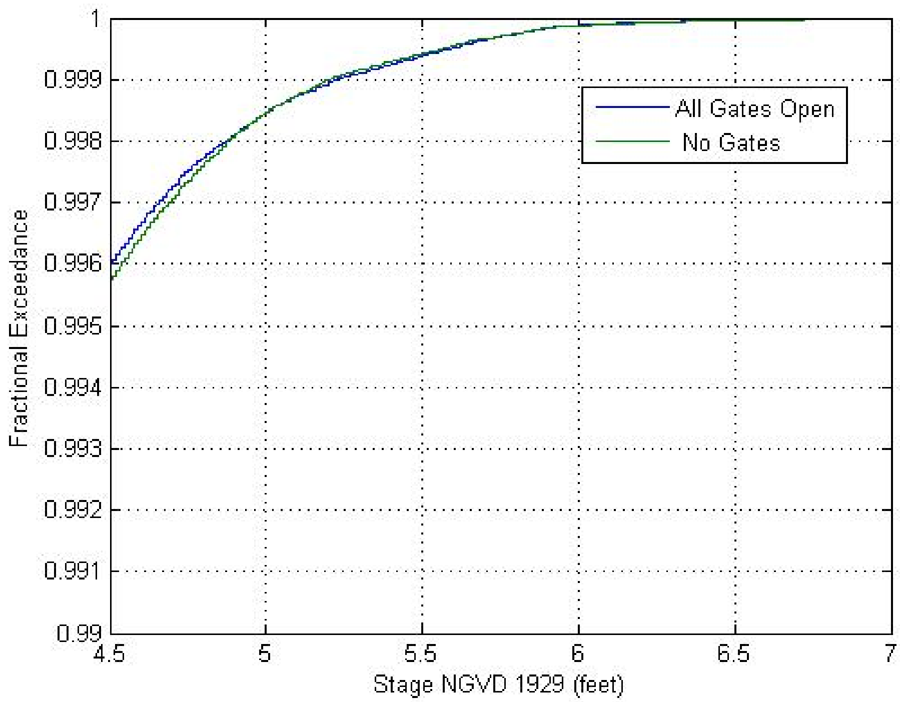


Figure 3: Cumulative Distribution Function Plot of Stage for ROLD014 (1992-2005)

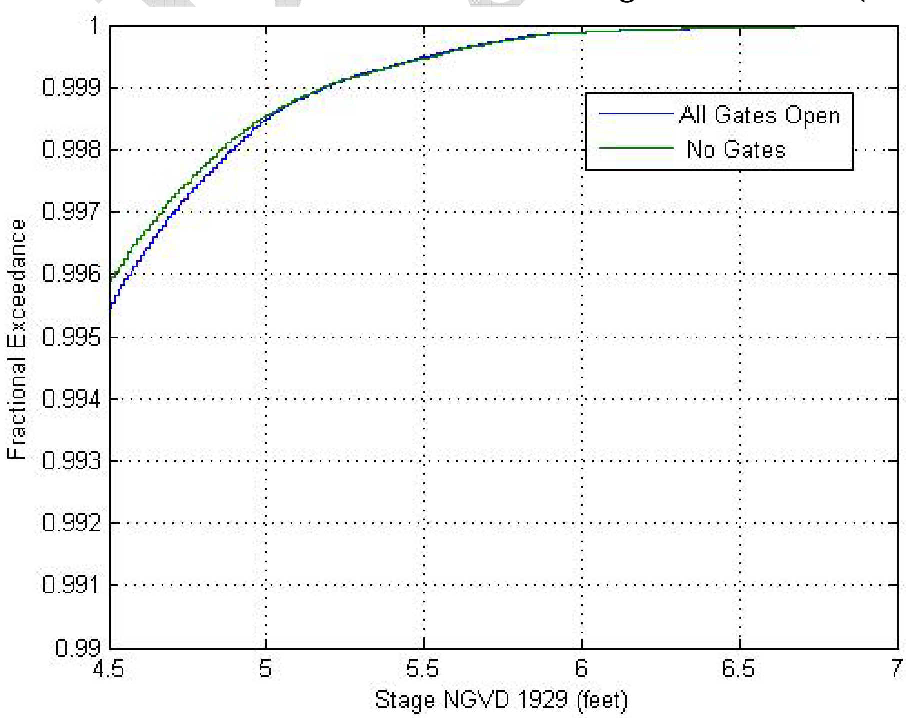
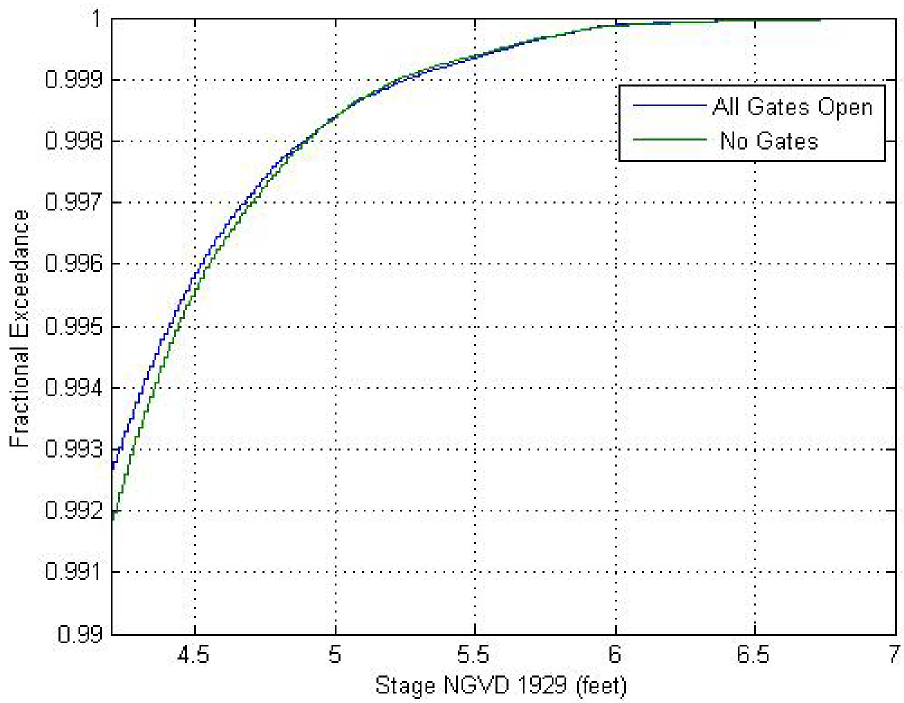


Figure 4: Cumulative Distribution Function Plot of Stage for ROLD024 (1992-2005)



Conclusions

The results of this analysis demonstrate that installation of barriers at Connection Slough and Old River with gates open does not significantly increase stage levels nor result in substantial increases in frequency of higher stages. The analysis confirms that this is true both at the barriers themselves (immediately upstream and downstream) and at locations some distance upstream and downstream from the barriers (ROLD014, ROLD024). The maximum observed increase in maximum annual stage for these locations was small (less than 0.23 feet or about 2.5 inches) when the gates were left closed. When the gates were left open, the maximum increase was reduced to below 0.02 ft. Analysis of stage at other locations along Old and Middle Rivers showed a maximum increase with gates open of 0.04 ft. The cumulative distribution function analysis shows that there is not a significantly higher incidence of high stage levels when the barriers are in with gates open versus when no barriers are present.

This analysis confirms the need to flexibly manage the barriers in response to actual hydrologic conditions such as flood and high water events. Mechanisms for monitoring flow conditions and adjusting gate position are being incorporated into the operational plans for the 2-Barrier Project.

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