APPENDIX F

Hydrodynamic Analysis of 2-Gates Near Field Effects

HYDRODYNAMIC ANALYSIS OF

2-GATES FISH PROTECTION DEMONSTRATION PROJECT

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1. INTRODUCTION

1.1 PURPOSE

The purpose of this hydrodynamic study was to provide information and an evaluation of the 2-Gates Fish Protection Demonstration Project with regard to the issues of conveyance, flood stage, potential for scour of channel and/or levees, and vessel navigation resulting from the Project.

1.2 SCOPE OF WORK

This report is to present findings of the hydrodynamic analyses of the Project. The objectives of the study were to assess the effects from the Project on:

- Conveyance - to assess changes in cross-sectional flow area at the barriers and changes in the conveyance volumes in Old River, Middle River and Connection Slough;
- 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 barriers for the *gates open, non-operation* period.

2. APPROACH

For this study, 1-dimensional and 2-dimensional numerical models were developed to assess the potential hydrodynamic effects from the 2-Gates Fish Protection Demonstration Project (Project), including a comparison of the total conveyance and cross-sectional flow-areas of the proposed versus the existing conditions.

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. Additional 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 for the *gates open, non-operation* period. Simulations were conducted to compare the currents with and without the barriers. These flow patterns and velocities were used to assess the potential for scour and develop recommendations for the rock aprons and other rip-rap, if needed. These flow patterns and velocities were also used to assess potential effects on navigation.

2.1 NUMERICAL MODEL SELECTOR

The Danish Hydraulic Institute's MIKE-11 and MIKE-21 models were chosen for this study. MIKE-11 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. MIKE-21 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 Metropolitan Water District (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 STUDY AREA

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 hydraulic conditions. The study area used for the 2-dimensional coarse grid is similar to the 1-dimensional model; for the 2-dimensional fine grid, the study area roughly matched the extent of the 2008 EDS survey data.

2.4 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 Project was inserted into the DSM-2 model which completely blocked flow until barrier overtopping occurred.

2.5 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 of the model to observed values during the flood-event in February 1998. Figures 2.7 and 2.8 illustrate the stage and flow calibration 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.

2.6 MIKE-21 MODEL SETUP

To evaluate the anticipated peak water velocity through the Project facilities with the gates in the open condition, 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. A fine-scale MIKE-21 model, with a 0.5-meter grid spacing, was used to investigate the detailed flow patterns through the open gates.

An additional MIKE-21 model was developed with a larger study area than the fine-scale model and a 1-meter grid spacing. This model was used to investigate the flow patterns and velocities near the in-channel tule-islands north and south of the Old River gates, both for the Project in the non-operation period and for the existing condition. The results of this modeling are summarized in Appendix A.

3. RESULTS

Using the calibrated model described in the previous section, existing conditions were simulated for comparison with the proposed conditions with the 2-Gates Fish Protection Demonstration Project in place. Simulation results for the MIKE-11 and MIKE-21 modeling are described in this section. The comparison of conveyance and cross-sectional area at the proposed Old River and Connection Slough gates are also described below.

3.1 CONVEYANCE ANALYSIS

The comparison of cross-sectional flow area for the existing channels in Old River and Connection Slough versus the proposed gate openings at various water surface elevations are presented in Tables 3.1 and 3.2 below.

Table 3.1 Comparison of Old River Cross-Sectional Area

Water Surface Elevation (ft NAVD88)	**Existing Cross-Sectional Area** (sq.ft)	**Proposed Cross-Sectional Area, Sill @-19'** (sq.ft)	**Percent Reduction in Cross-Sectional Area**
2	12,881	3,570	-72%
2.4 (MLLW)	13,187	3,638	-72%
3 (MLW)	13,650	3,740	-73%
4	14,429	3,910	-73%
5	15,218	4,080	-73%
6	16,016	4,250	-73%
6.6 (Top of Barrier)	16,499	4,352	-74%

Table 3.2 Comparison of Connection Slough Cross-Sectional Area

Water Surface Elevation (ft NAVD88)	**Existing Cross-Sectional Area** (sq.ft)	**Proposed Cross-Sectional Area, Sill @-19'** (sq.ft)	**Percent Reduction in Cross-Sectional Area**
2	7,346	3,570	-51%
2.4 (MLLW)	7,492	3,638	-51%
3 (MLW)	7,710	3,740	-51%
4	8,079	3,910	-52%
5	8,456	4,080	-52%
6	8,842	4,250	-52%
6.6 (Top of Barrier)	9,077	4,352	-52%

The MIKE-11 model was also used to compare the existing versus the proposed conveyance volumes in Old and Middle Rivers over a 19-day period in August 1997, which spans a full spring-neap tidal cycle. The proposed 2-Gate condition was modeled with the gates open over the 19-day period. Table 3.3 below presents the results for net conveyance volume. Negative conveyances represent a condition where the net volume is moving upstream.

Table 3.3 Comparison of Conveyance Volumes Over a Spring-Neap Tide Cycle

MIKE-11 Model Location	Net Conveyance Volume for Existing Condition (ac-ft)	Net Conveyance Volume for Gates-Open Condition (ac-ft)	Percent Change in Net Conveyance Volume
Old River at Gate	-3,192	-2,727	-15%
Connection Slough at Gate	428	202	-53%
Old River north of Woodward R.R. Cut	-4,137	-3,955	-4%
Middle River north of Woodward R.R. Cut	-3,165	-3,206	1%
Middle River downstream of Connection Slough & Latham Slough	-3,427	-3,272	-5%

3.2 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 3.4 and 3.5 list the daily peak water surface elevations without gates and the resultant difference in peak stage with the gates 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 2-Gates Fish Protection Demonstration Project 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 B of this report.

The basis of the flood stage analysis was comparing water levels for the existing condition versus the condition with gates open. The 100-year return period flood stage in this portion of the Delta is approximately 10-ft (NAVD88), while the top of the barriers are set at 6.6-ft (NAVD88). Therefore, flood-flows overtop the barrier. It was assumed for this analysis that the gates would remain open during a flood event. The CCWD's DSM-2 results presented in Appendix B present a conservative comparison of the existing condition versus the gates closed condition.

Table 3.4 Changes in Peak Stage at the Old River Gate

Date	No Gates Peak Stage (ft NAVD88)	Change in Peak Stage Upstream of Gate (ft)	Change in Peak Stage Downstream 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 3.5 Changes in Peak Stage at the Connection Slough Gate

Date	No Gates Peak Stage (ft NAVD88)	Change in Peak Stage Upstream of Gate (ft)	Change in Peak Stage Downstream 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

3.3 SCOUR STUDY

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 approximately 0.02% at the USGS gage, occurring approximately 2 hours/year. These results show a peak local velocity of 4.1 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. These peak velocities dissipated to less than 3 ft/s approximately 1000-ft away from the gates; 3 ft/s is the reference velocity the DWR uses for indicating the potential for scour in the Delta (*Paul Marshal, DWR*). The

MIKE-21 figures show velocity in units of meters/second; to convert these results to feet/second, multiply the values by 3.28.

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 approximately 1.2% at the USGS gage, occurring approximately 9 hours/month. These results show a peak local velocity of 3.8 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 approximately 10 hours/year. These results show a peak local velocity of 3.6 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 approximately 1% within Connection Slough, occurring approximately 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 approximately 1% within Connection Slough, occurring approximately 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.

3.4 NAVIGATION STUDY

The 2-Gates barrier system will provide a 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 barrier does increase local flow velocity due to a constriction on the channel cross-section. The Delta Cross Channel (DCC), operated by the San Luis and Delta-Mendota Water Authority for many years, typically experiences velocities of 3 – 4 knots without boat passage problems at their gates. A velocity of 3.5 knots (6 ft/s), which is rarely exceeded under existing conditions in Old River is used as the limiting passage velocity criteria.

Peak local velocities through the gate were determined from the MIKE-21 modeling analyzed in Section 3.2.1 for the *gates open, non-operation* period. Peak velocities through the gates were less than 3.5 knots. The results are listed in Table 3.6 below.

Table 3.6 MIKE-21 Results for , *Non-Operation* Period

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	4.1	2.4	Figure 3.7
Old River	Flood tide	1.2%	9 hrs/mo	3.8	2.3	Figure 3.8
Old River	Ebb tide	0.1%	10 hrs/yr	3.6	2.1	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

4. SUMMARY

The following summary of the analyses conducted herein can be stated as follows.

4.1 CONVEYANCE

While the barriers reduce the channel cross-section 72% at Old River, the reduction in conveyance volume is only about 15%. At Connection Slough the reduction in cross-section is about 51% with a corresponding reduction in conveyance of about 53%, but the net conveyance of Connection Slough is less than about 10% of the conveyance at Old River. The impact on Middle River conveyance ranges from a 1% increase near the Railroad Cut to a 5% decrease near the Connection Slough/Middle River confluence. These results reflect barriers with gates open and stages below the top of the barrier.

4.2 FLOOD STAGE

The difference in flood stage with and without the project for the largest recorded flood peaks was analyzed in this study and 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.

4.3 SCOUR AND VESSEL NAVIGATION

For the *gates open, non-operation* period 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 the potential for scour in the Delta.

Old River does show local peak 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 potentially 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.

Old River and Connection Slough both show local peak velocities also well below the 3.5 knot vessel passage velocity criteria.

FIGURES

Figure 1.1 Location of Project Sites

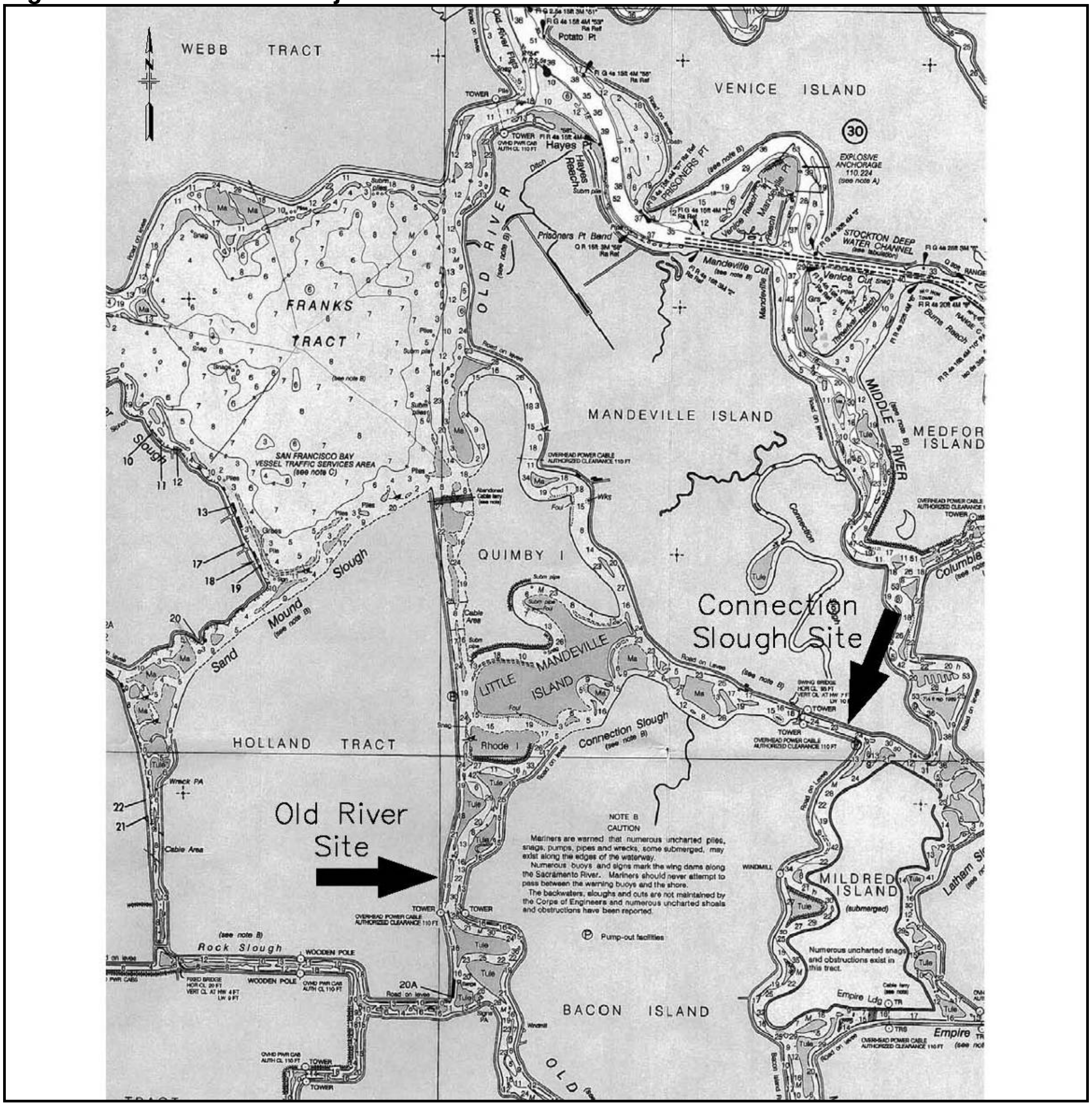

Figure 2.1 MIKE-11 Model Bathymetry and Surface Elevation

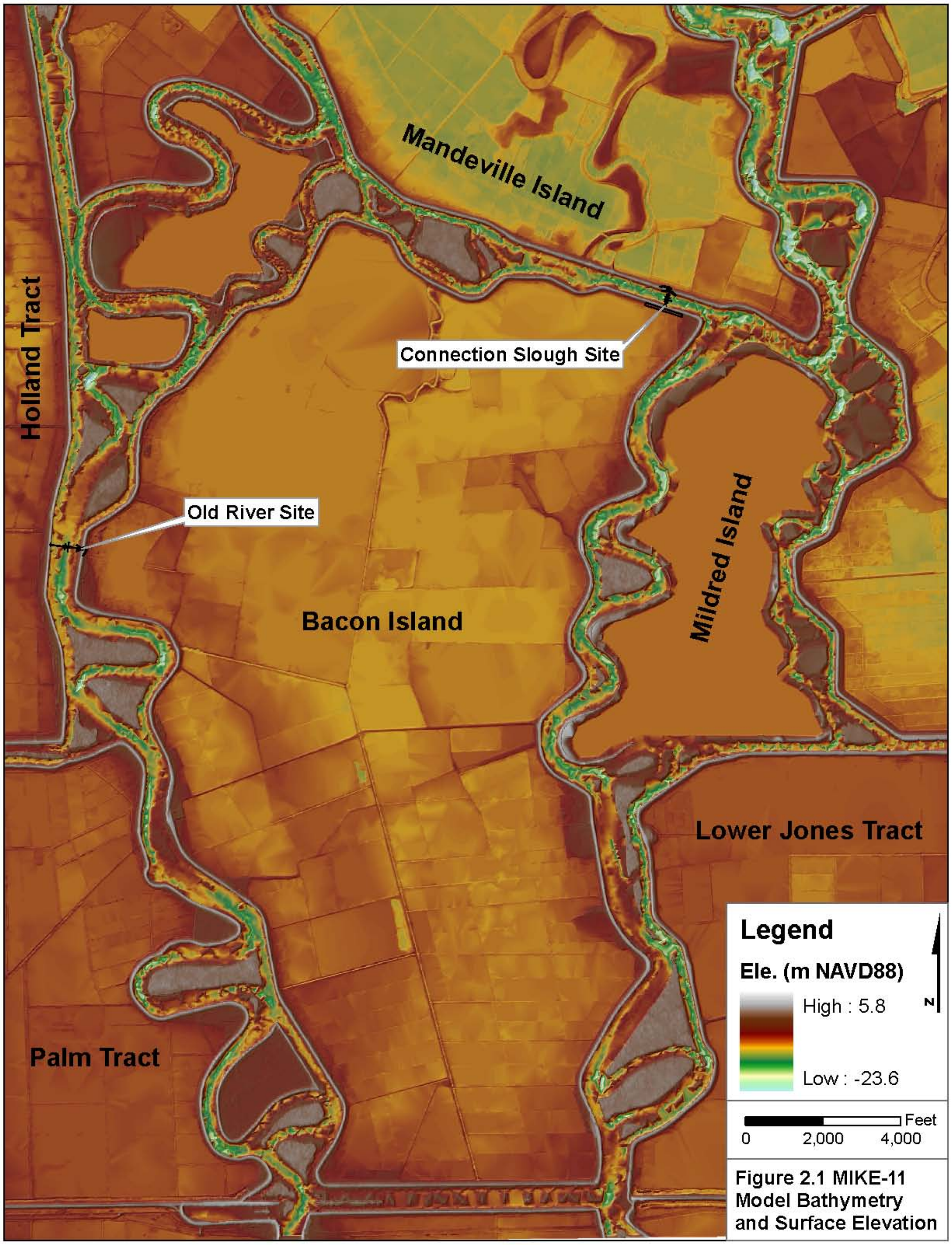

Figure 2.1 MIKE-11 Model Bathymetry and Surface Elevation

Figure 2.2 Old River Site

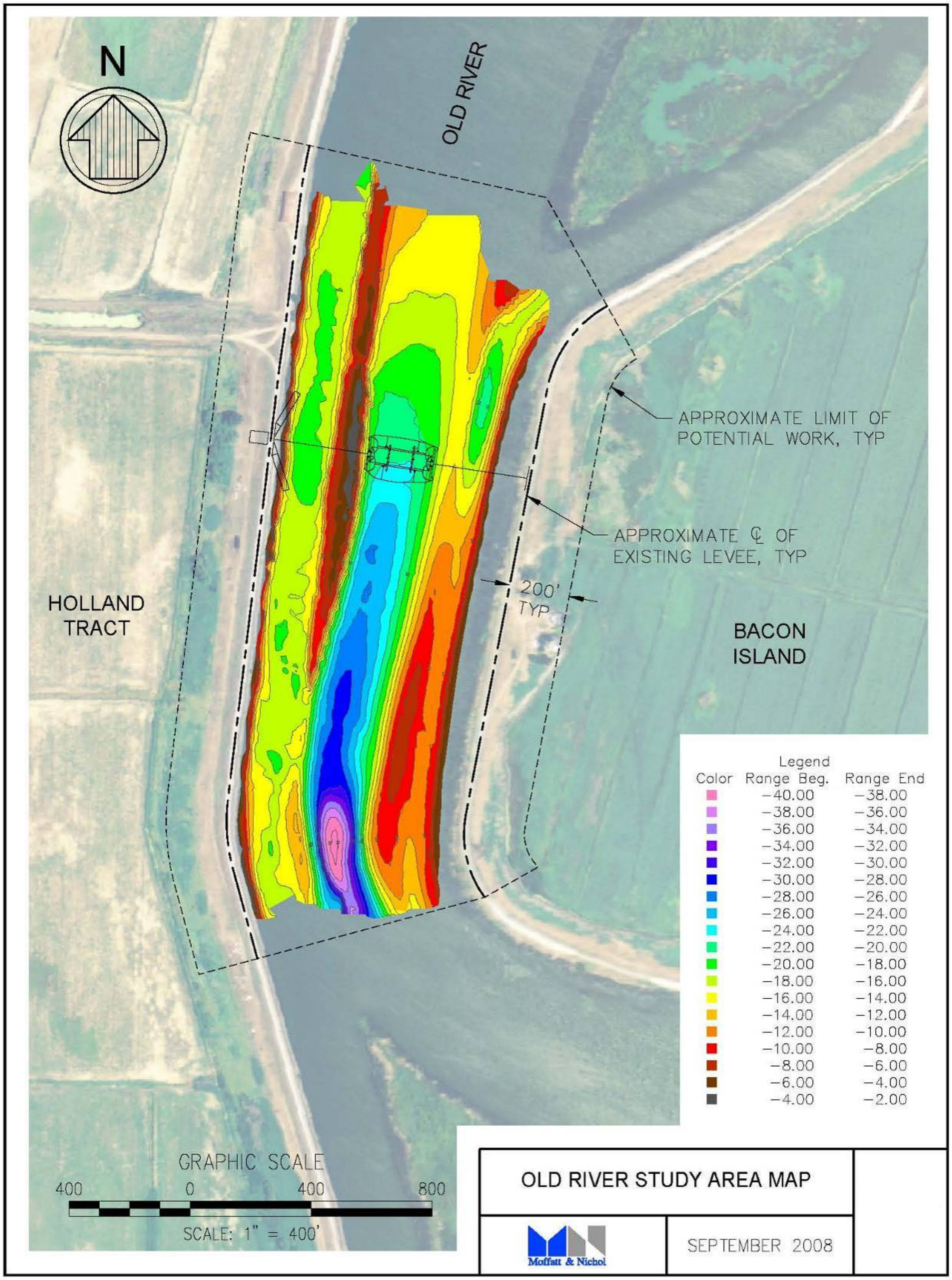

Figure 2.3 Connection Slough Site

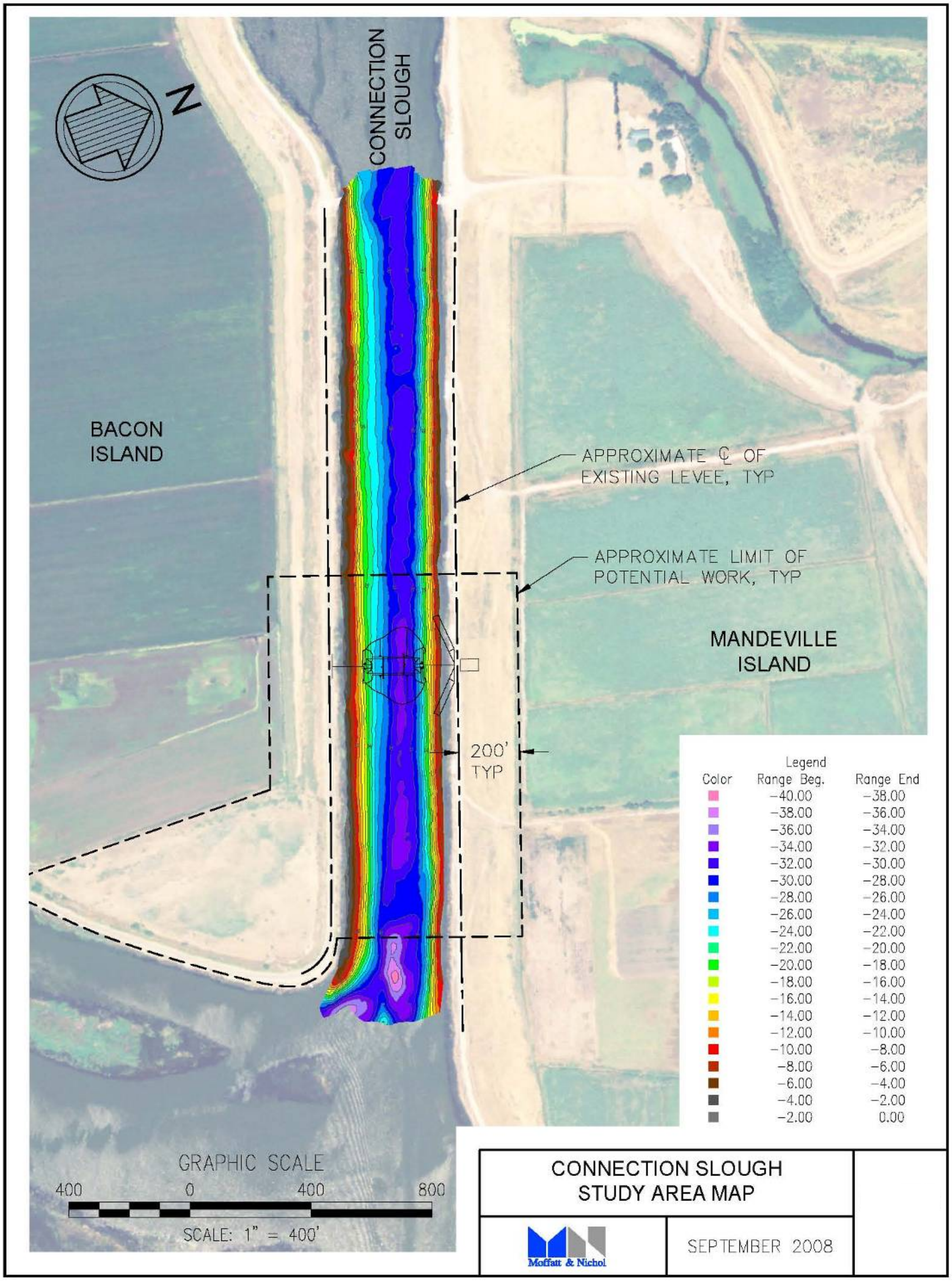

Figure 2.4 MIKE-11 Model Reaches and Cross Sections

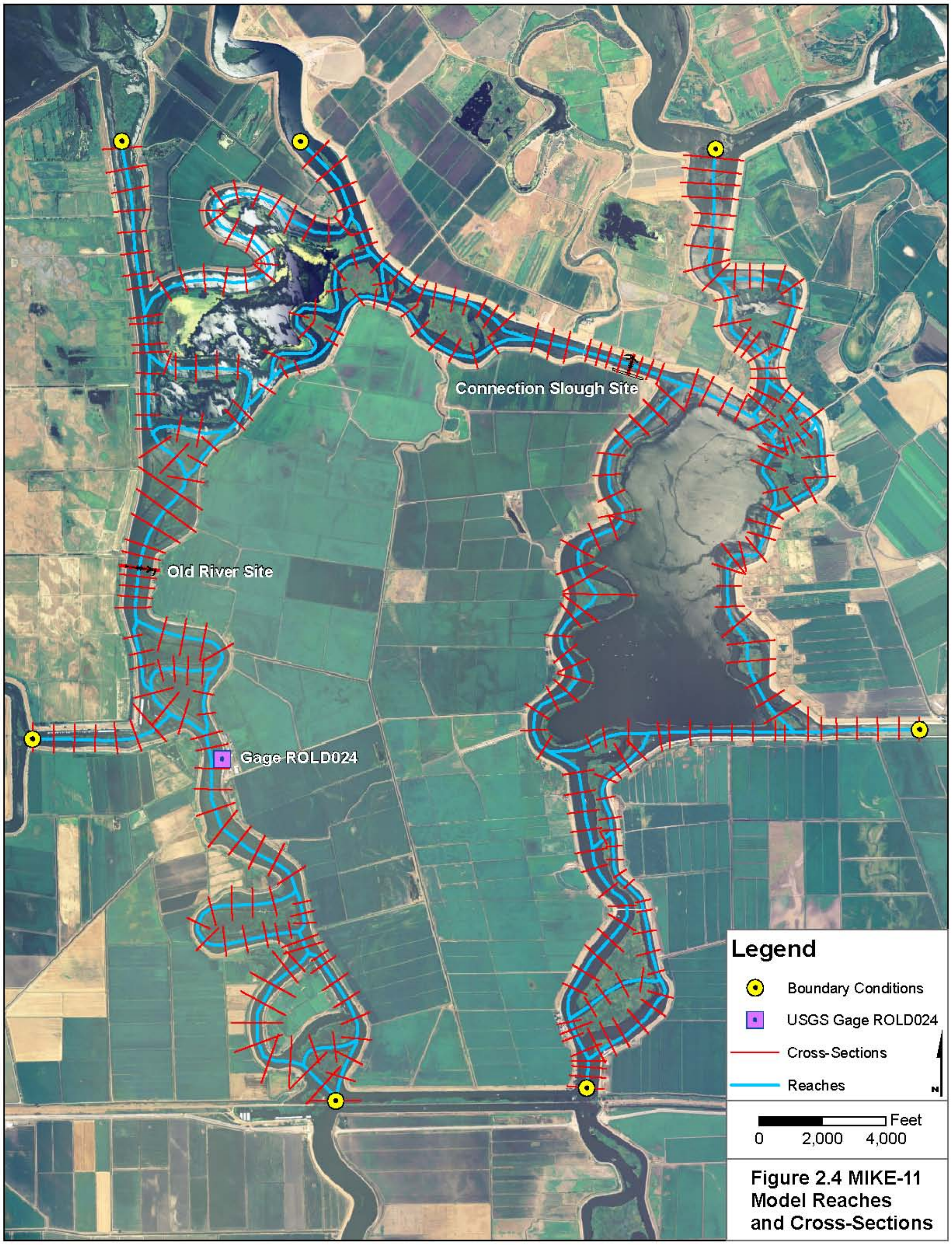

Figure 2.5 MIKE-11 Model Calibration Results, February 1998 Stages

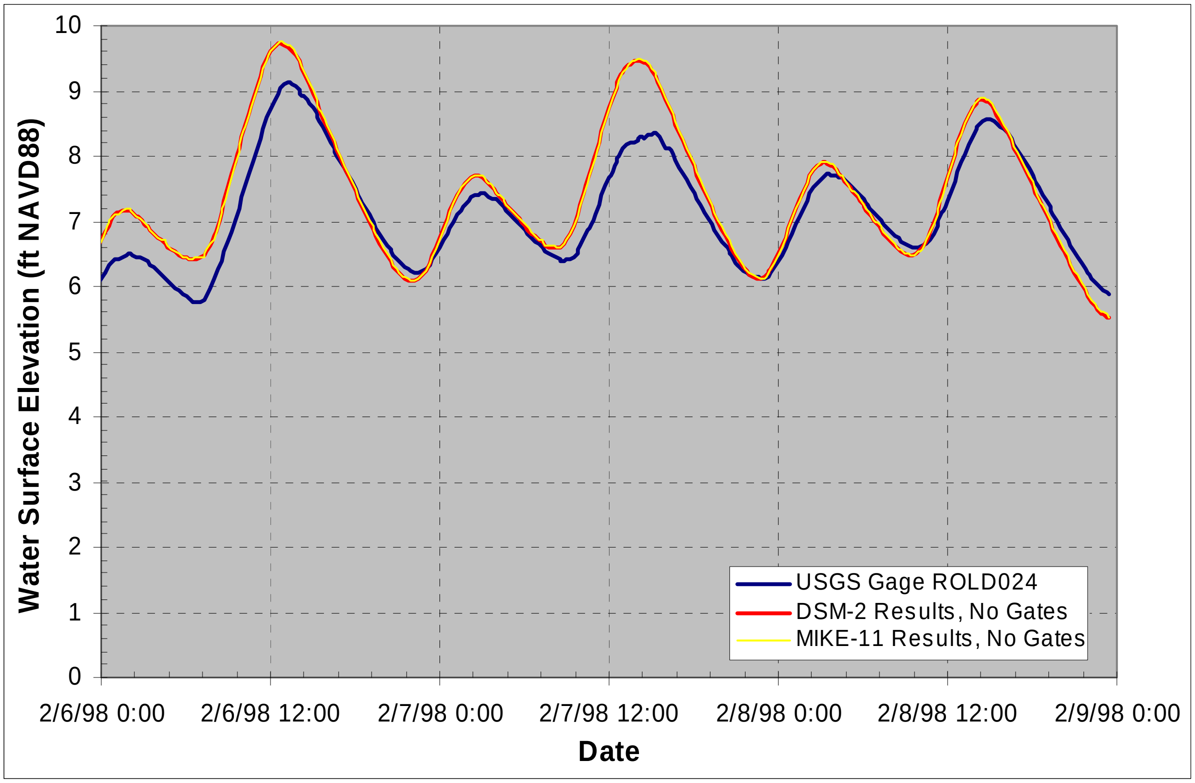

Figure 2.6 MIKE-11 Model Calibration Results, February 1998 Flows

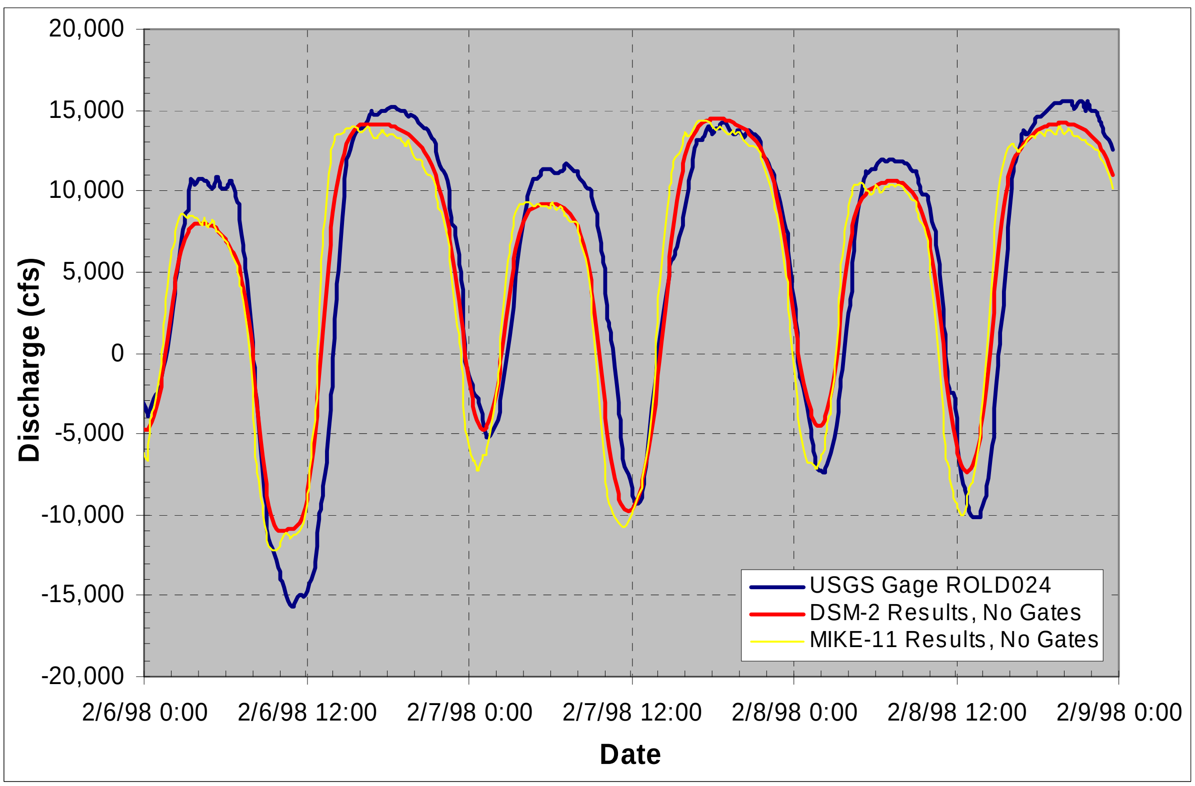

Figure 2.7 MIKE-11 Model Calibration Results, January 1997 Stages

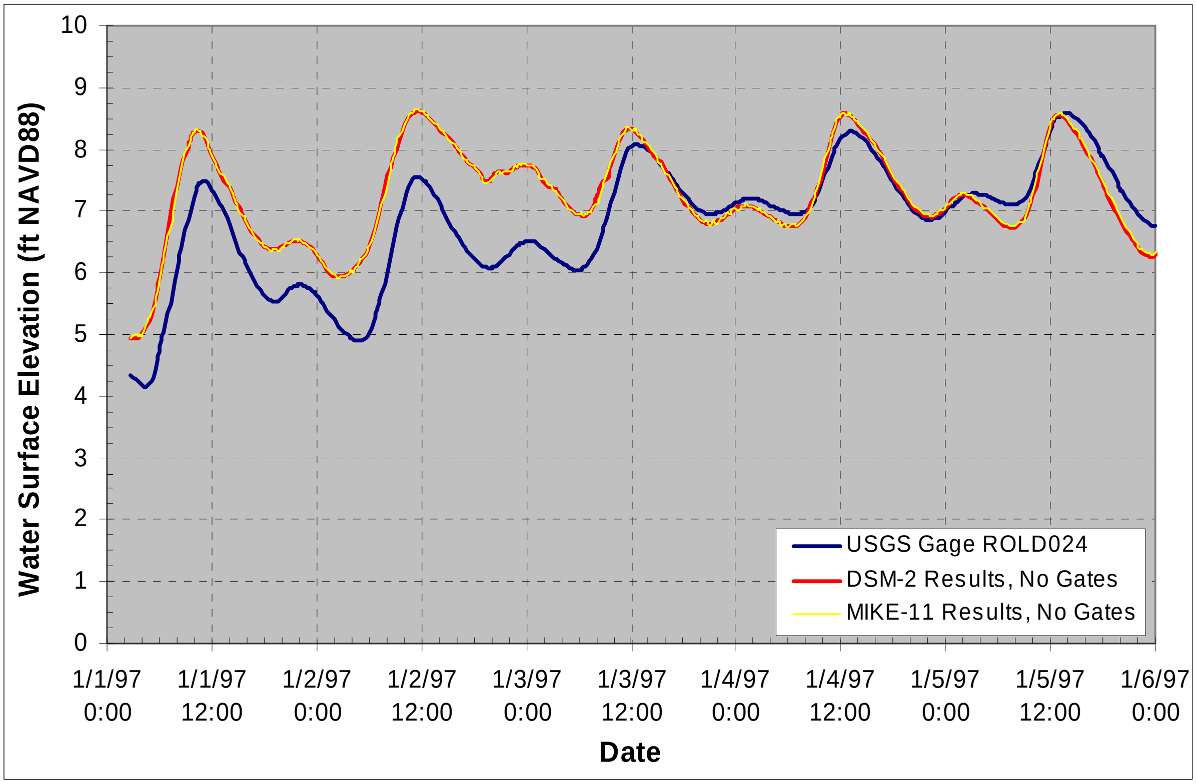

Figure 2.8 MIKE-11 Model Calibration Results, January 1997 Flows

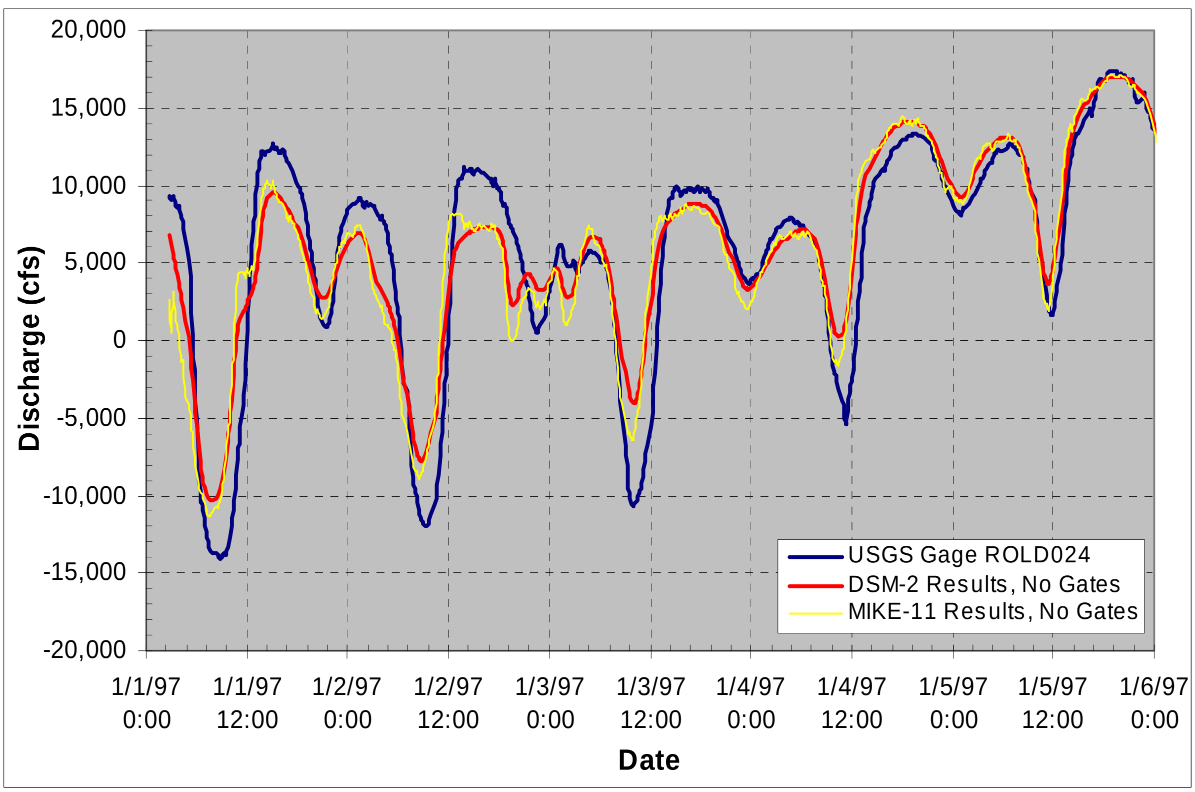

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Figure 3.1 Comparison of Stages With Gates Open and No Gates for February 1998

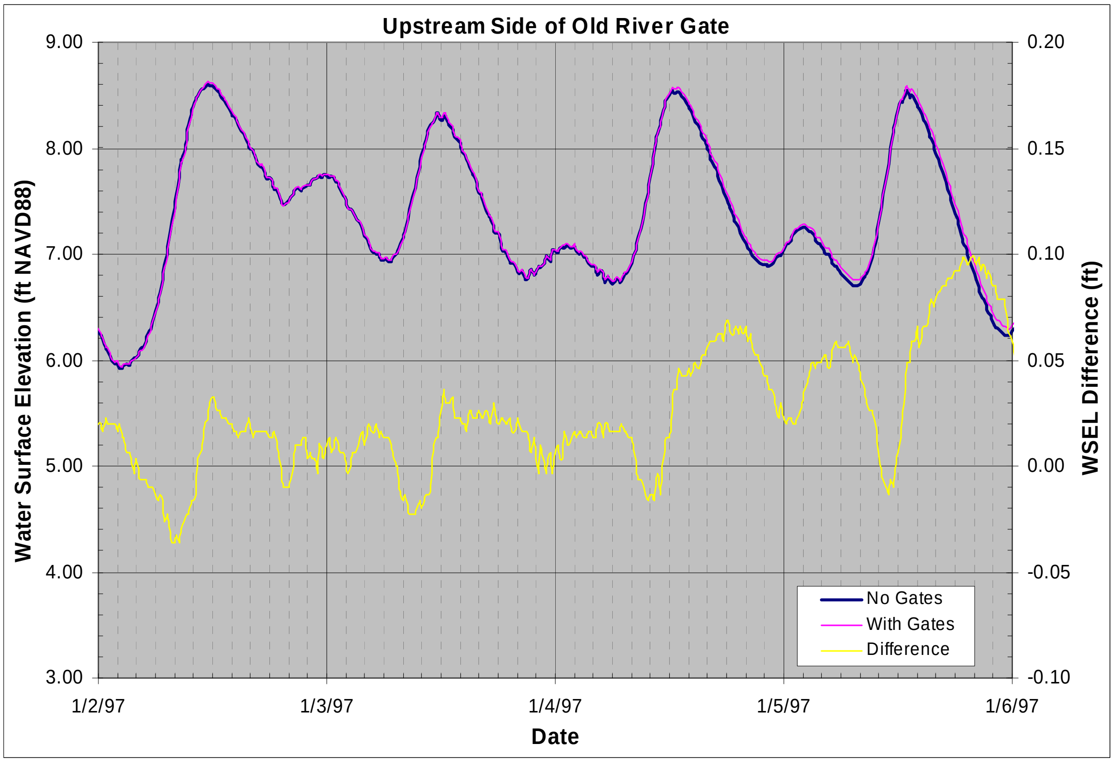

Figure 3.2 Comparison of Old River Water Surface Profiles for February 1998

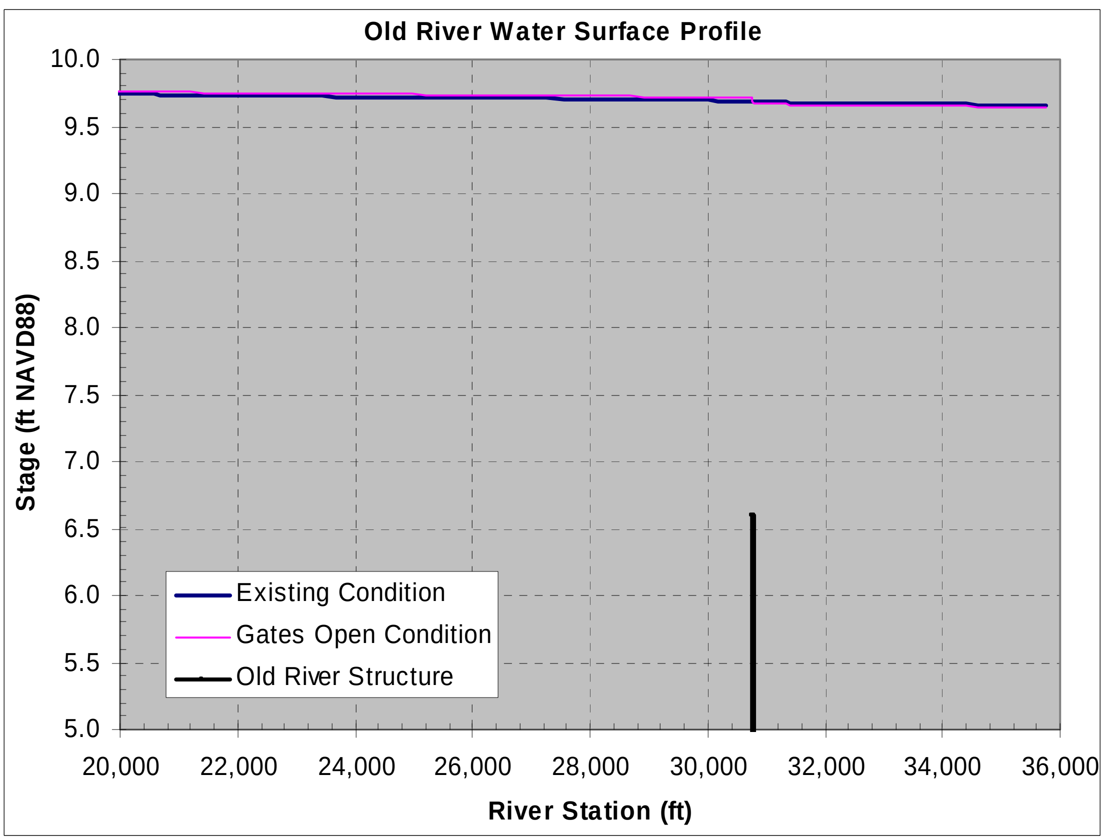

Figure 3.3 Comparison of Stages With Gates Open and No Gates for January 1997

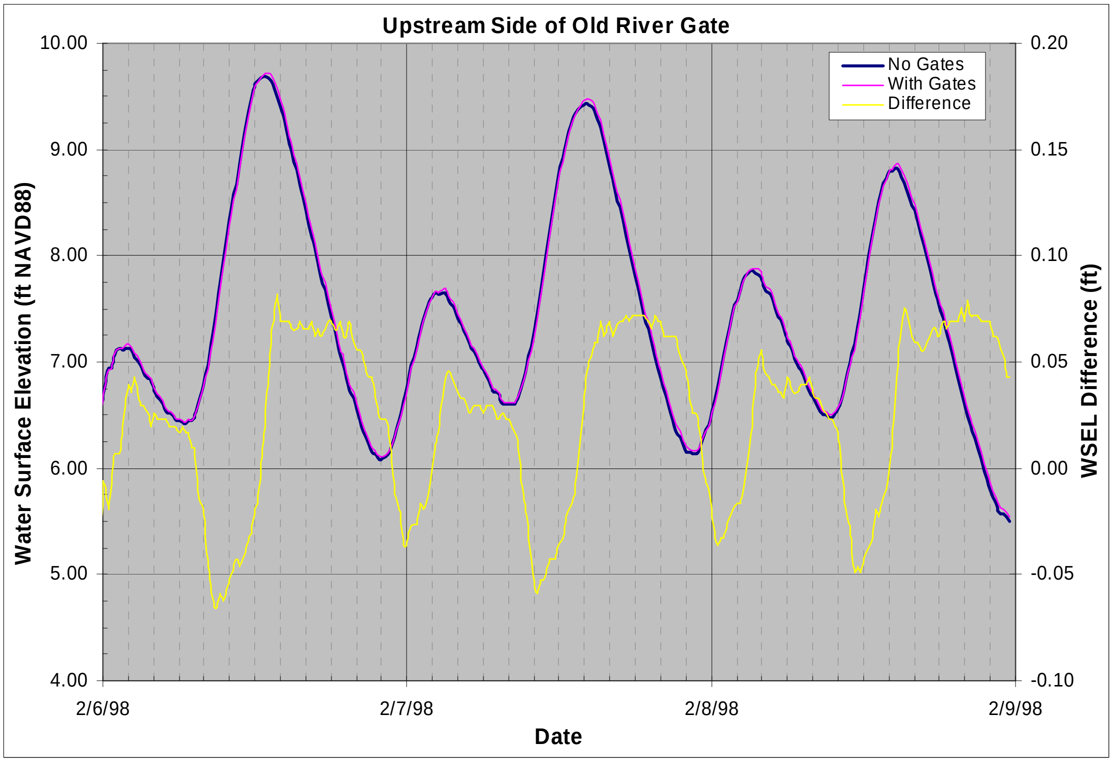

Figure 3.4 Comparison of Old River Water Surface Profiles for January 1997

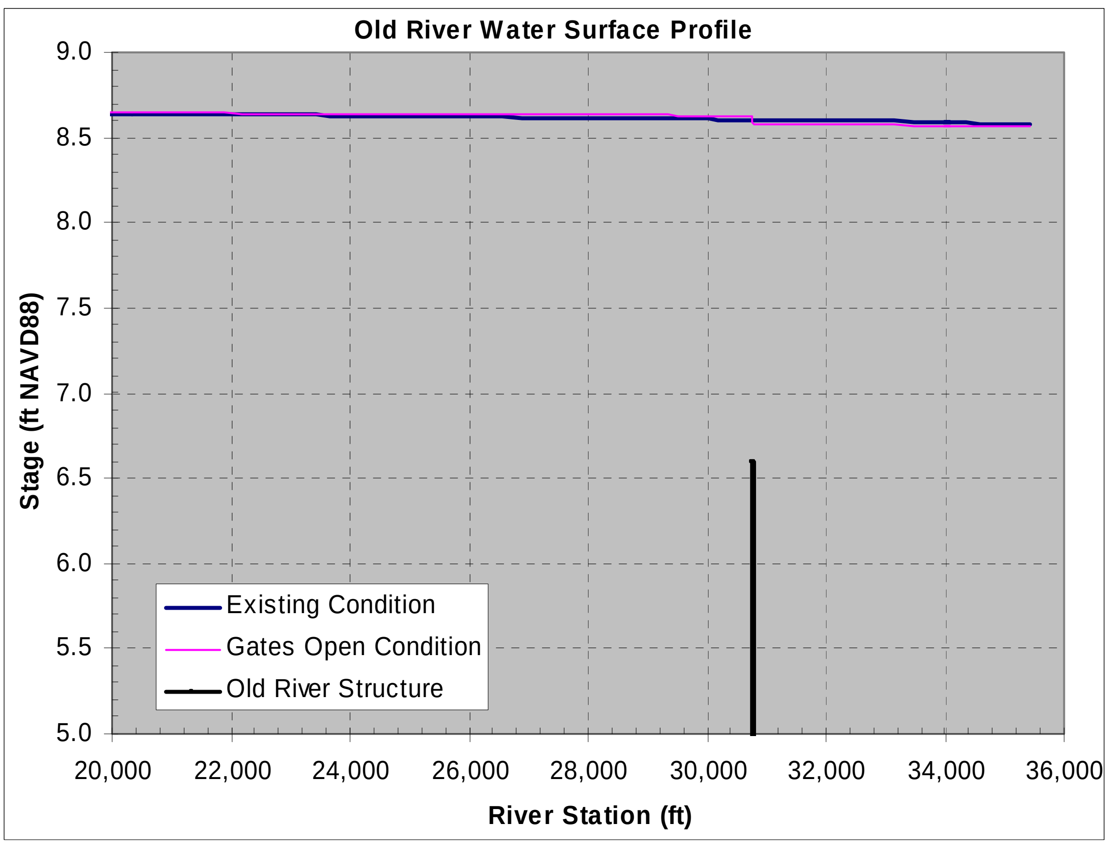

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Figure 3.5 Comparison of Stages With Gates Open and No Gates for December 2005

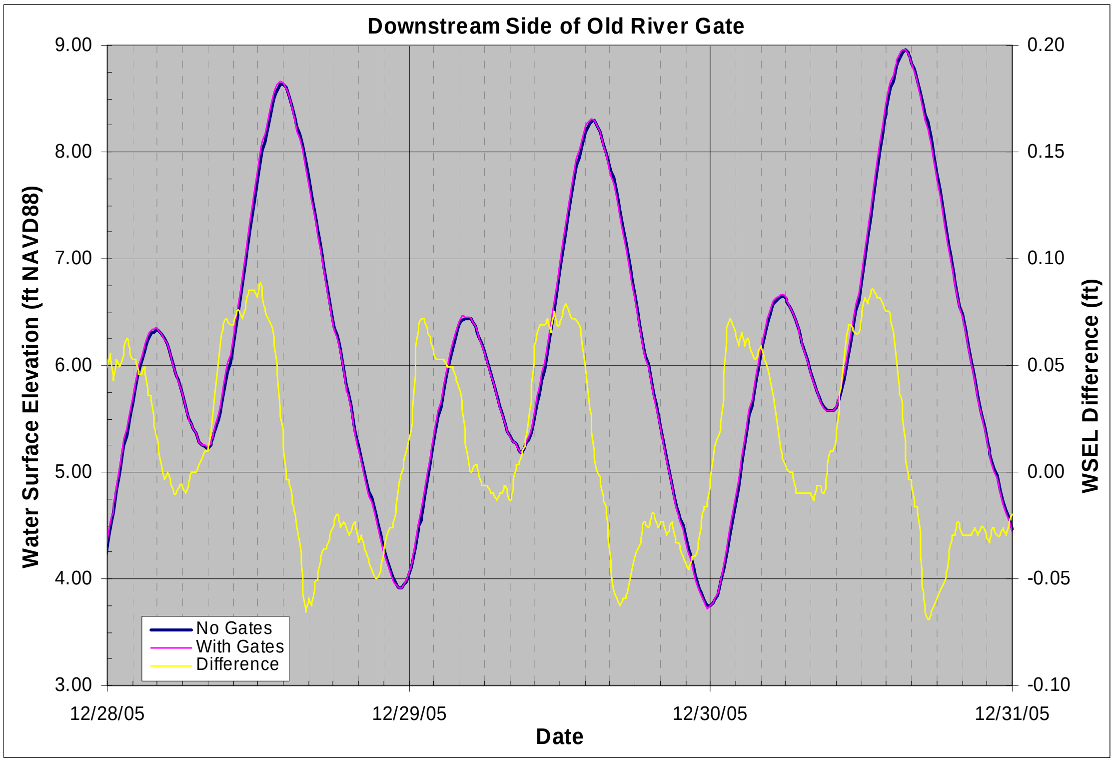

Figure 3.6 Comparison of Old River Water Surface Profiles for December 2005

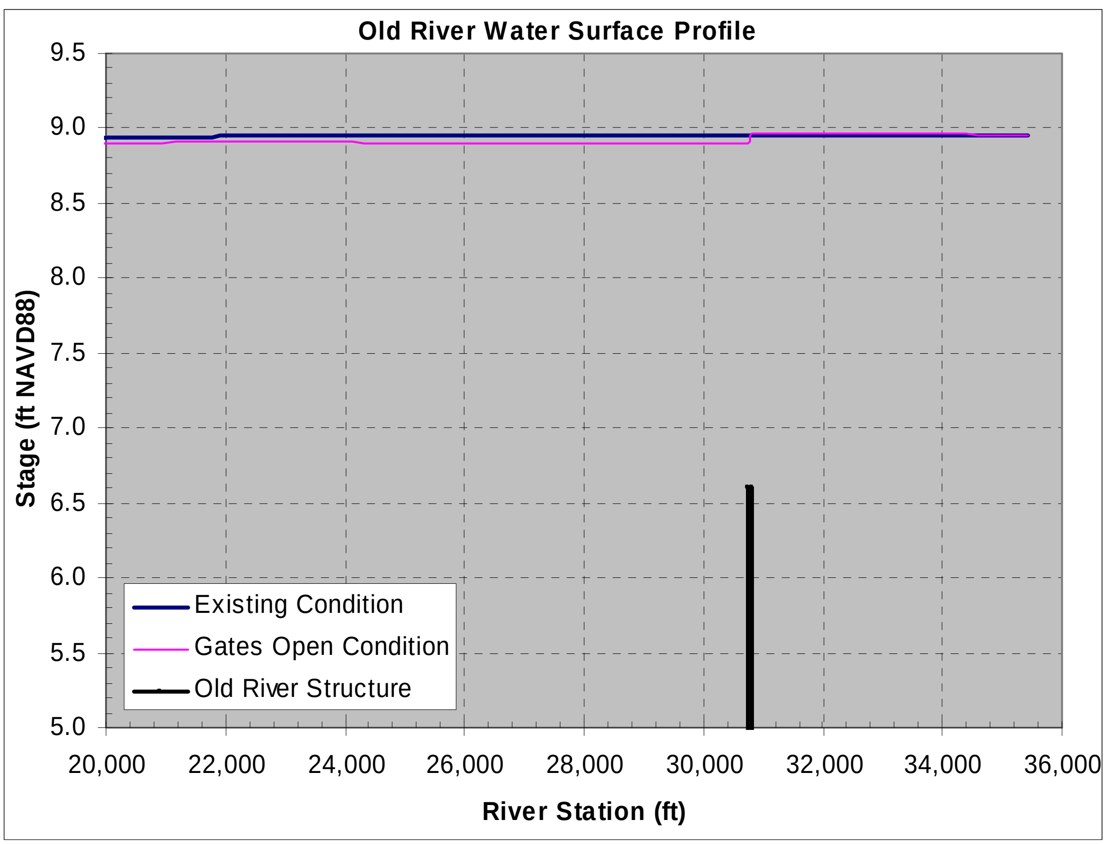

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Figure 3.7 MIKE-21 Results for Old River with Gates Open, Flood Tide with ~0.02% exceedance peak flow.

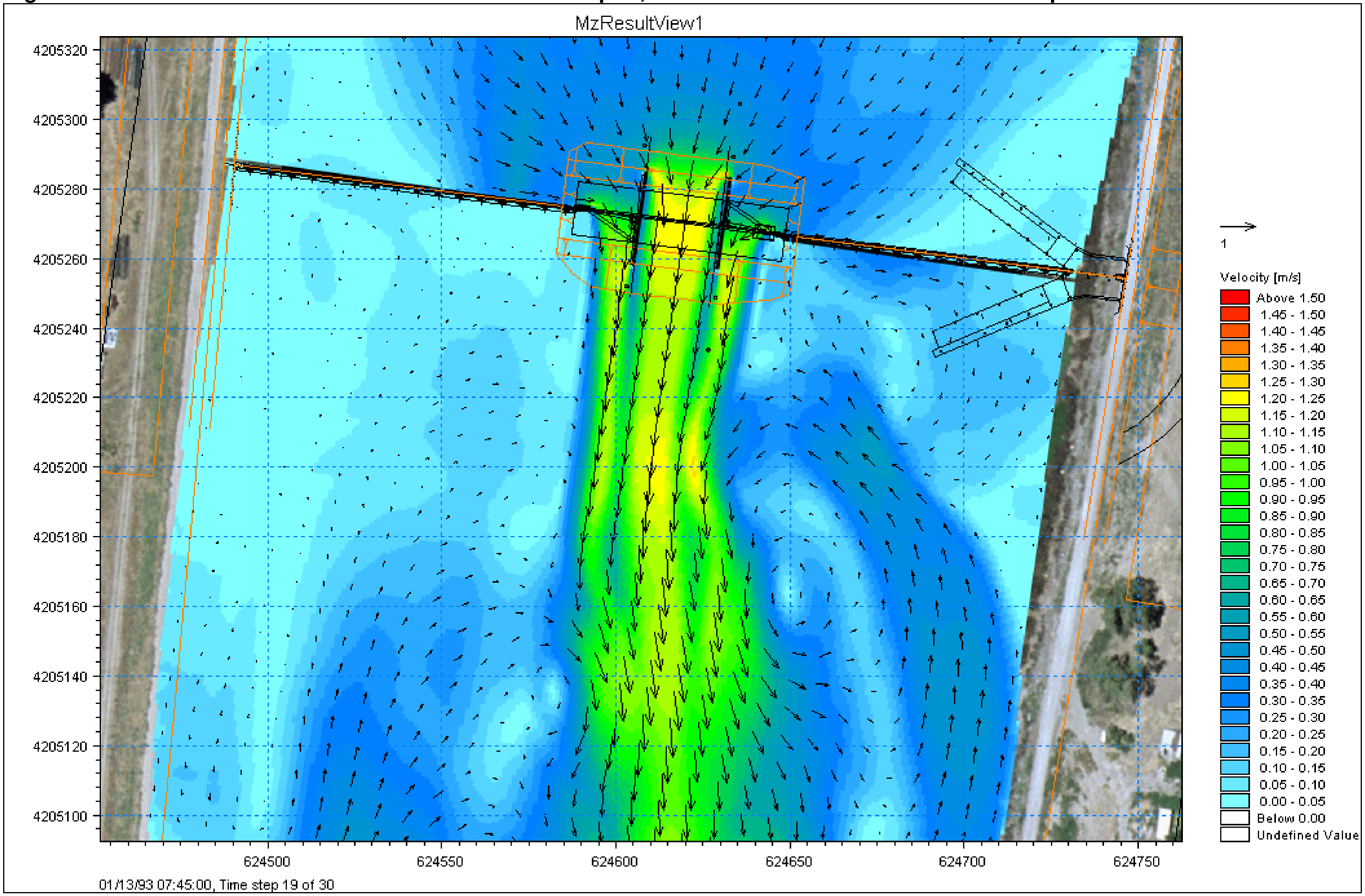

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Figure 3.8 MIKE-21 Results for Old River with Gates Open, Flood Tide with ~1% exceedance peak flow.

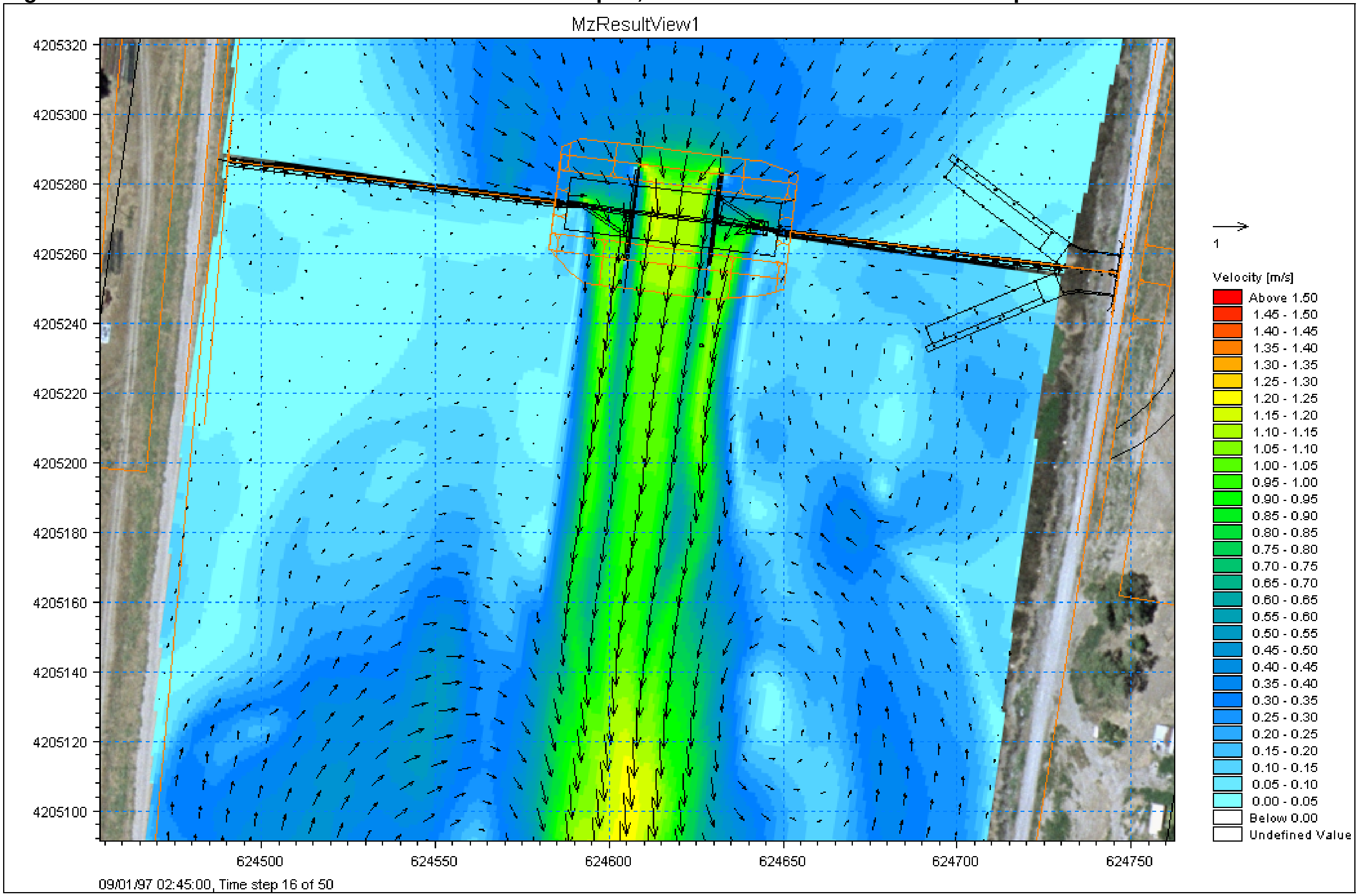

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Figure 3.9 MIKE-21 Results for Old River with Gates Open, Ebb Tide with 0.2% exceedance peak flow.

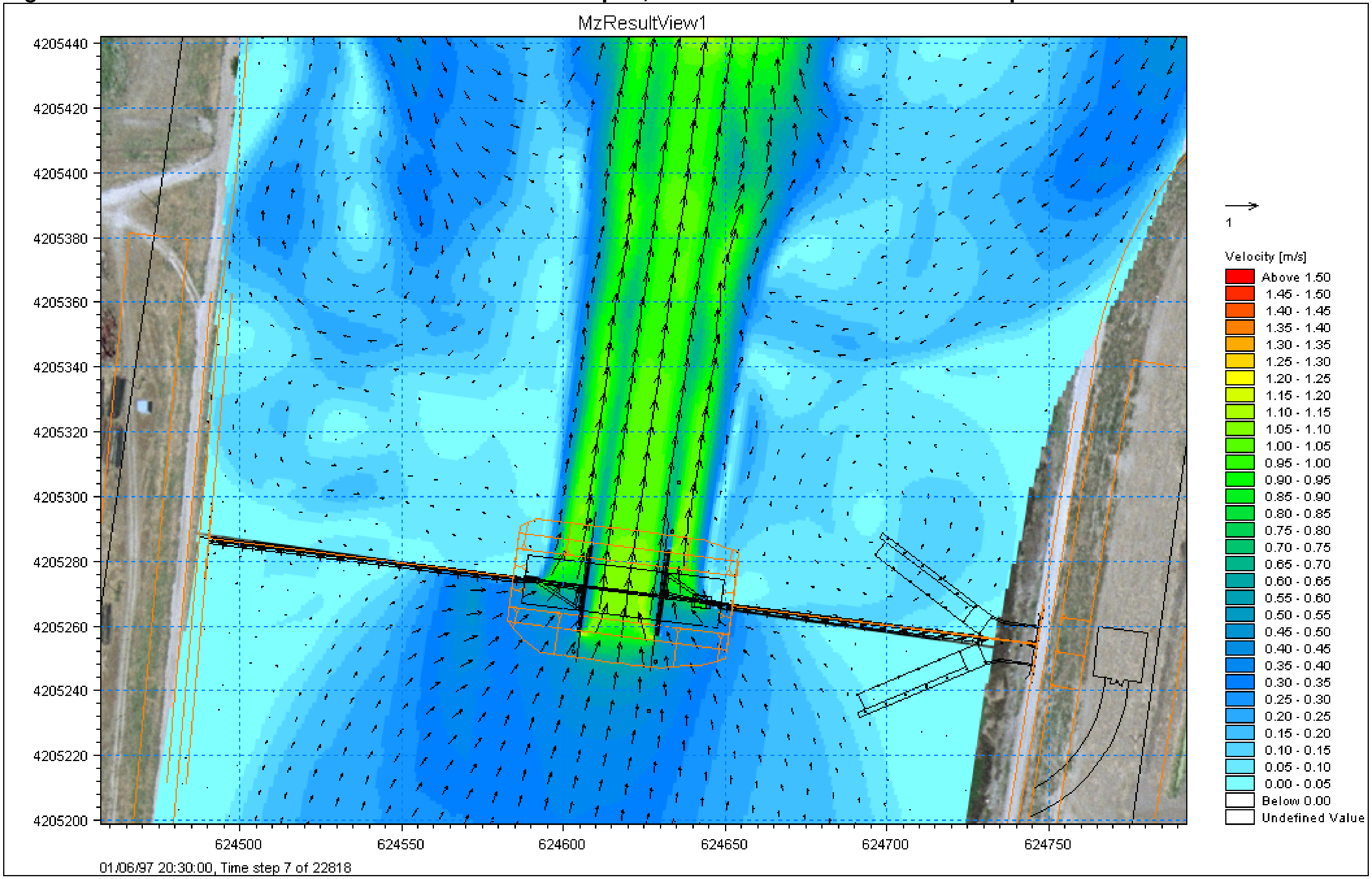

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Figure 3.10 MIKE-21 Results for Connection Slough with Gates Open, Flood Tide with ~1% exceedance peak flow.

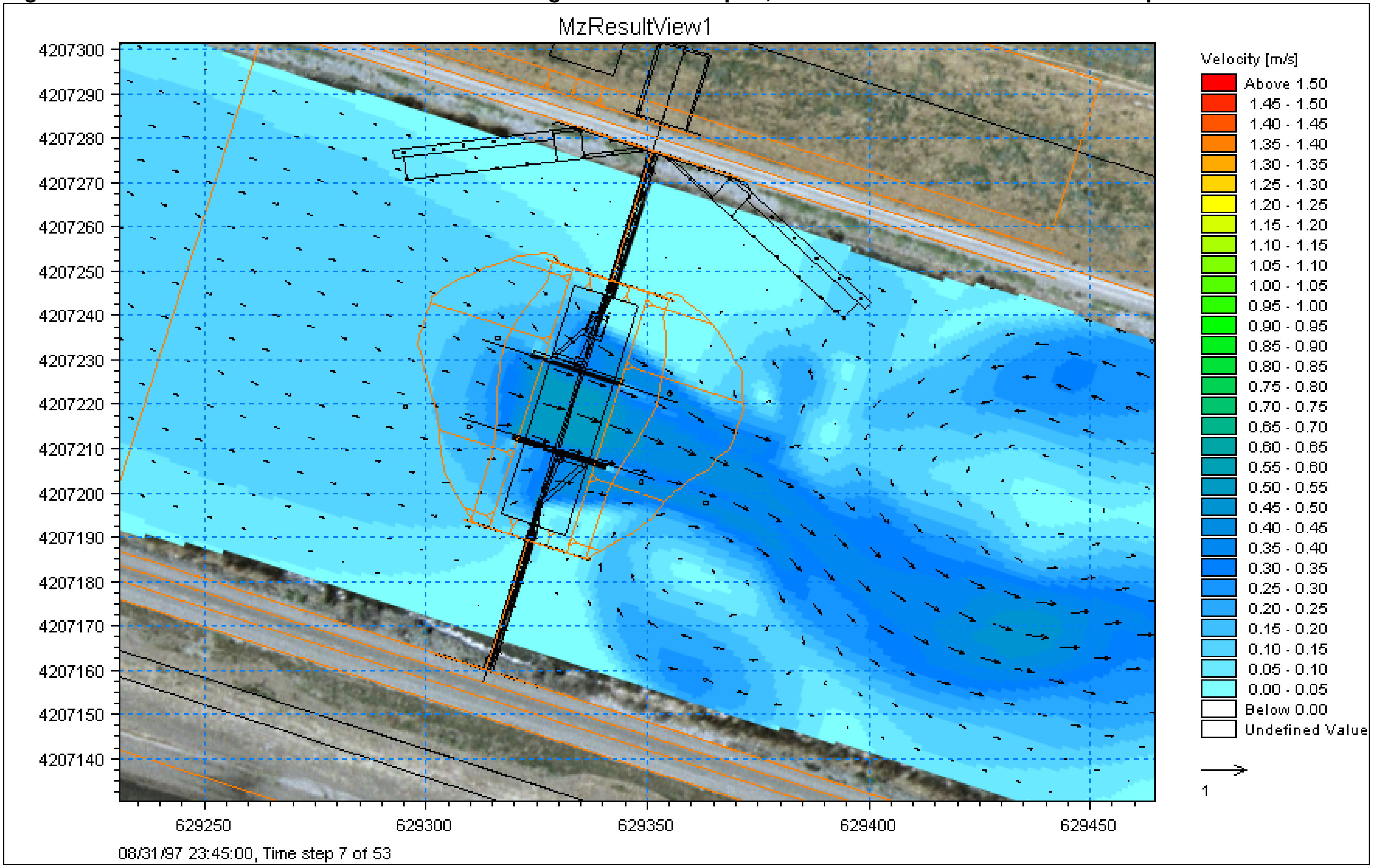

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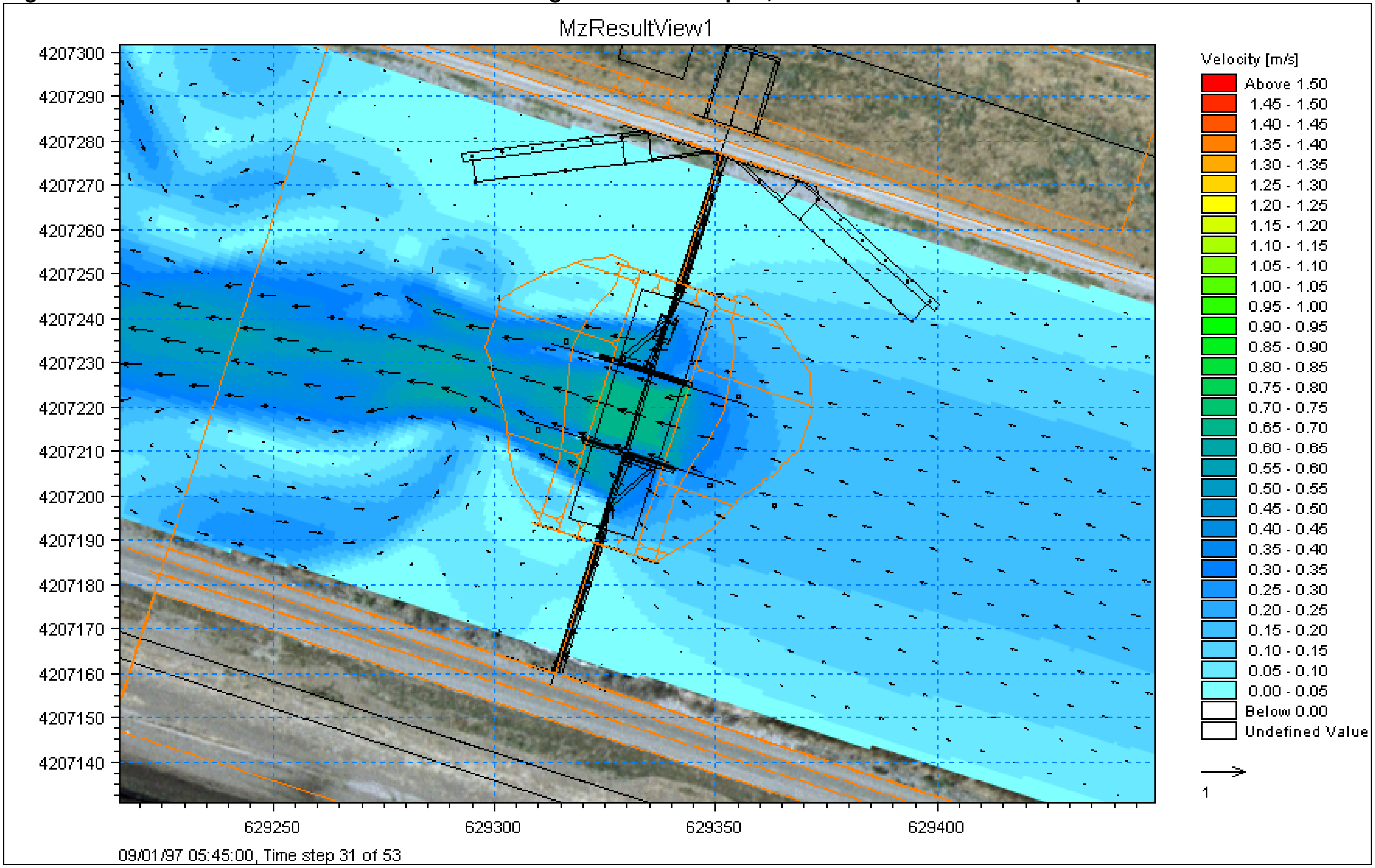
Figure 3.11 MIKE-21 Results for Connection Slough with Gates Open, Ebb Tide ~1% exceedance peak flow.



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APPENDIX A

Analysis of Project Flow Velocities with Extended Study Area

Surface water flow rates near the Old River and Connection Slough project sites would be modified by the installation of the sheet piles and gates. Figure A.1 shows a typical high water velocity on a flood tide in the Old River channel with the gates open but other project facilities installed. Peak flow rates through the open gate restriction would exceed 5 feet/second, and a reverse flow is predicted upstream of the gates. The increased flow rate would decrease to approximately existing conditions, less than 2 feet/second prior to the in-channel island and eastern trending oxbow north of Rock Slough.

Under ebb conditions, the increased water velocity can reach the in-channel islands north of the gates. Figure A.2 and Figure A.3 show the peak ebb velocities for two ebb tides in January and February 1997, in cases where the water surface elevation at the time of the peak velocity does and does not flood the islands. As with the flood velocities, peak flow rates through the open gate restriction would exceed 5 feet/second, with velocities in the vicinity of the in-channel islands generally being less than 2 feet/second. The model results do show one location on the flooded island, near the south end of the triangular island located directly north of the gate, where the flow velocities barely exceed 3 feet/second. However, this is likely an overestimate, because the location in question is on the island and likely overgrown with tules – which would increase the surface roughness and so decreases the flow velocities significantly in that area.

The flow velocity of 3 feet /second is observed on occasion in Old River based on DSM-2 modeling results. Thus, the Project velocities shown here (less than 2 feet per second) do not exceed present peak velocities at the in-channel islands. For reference, the existing condition flood tide velocities for the January 1993 tide are shown in Figure A.4, and the existing condition peak ebb velocities for the February 1997 tide are shown in Figure A.5. Additionally, the velocities shown here are less than required to scour channels for all soil types other than noncohesive fine sands and silts (e.g., ASCE Manuals and Reports of Engineering Practice No. 77). The tule islands, in contrast, can be considered cohesive sediment and are furthermore stabilized by the vegetation. If the tule stands remain in good health – and there is no reason to suppose otherwise – the peak flow velocities shown here are not anticipated to exacerbate erosion on the in-channel islands.

Figure A.1. Typical high flood velocities, January 13 1993

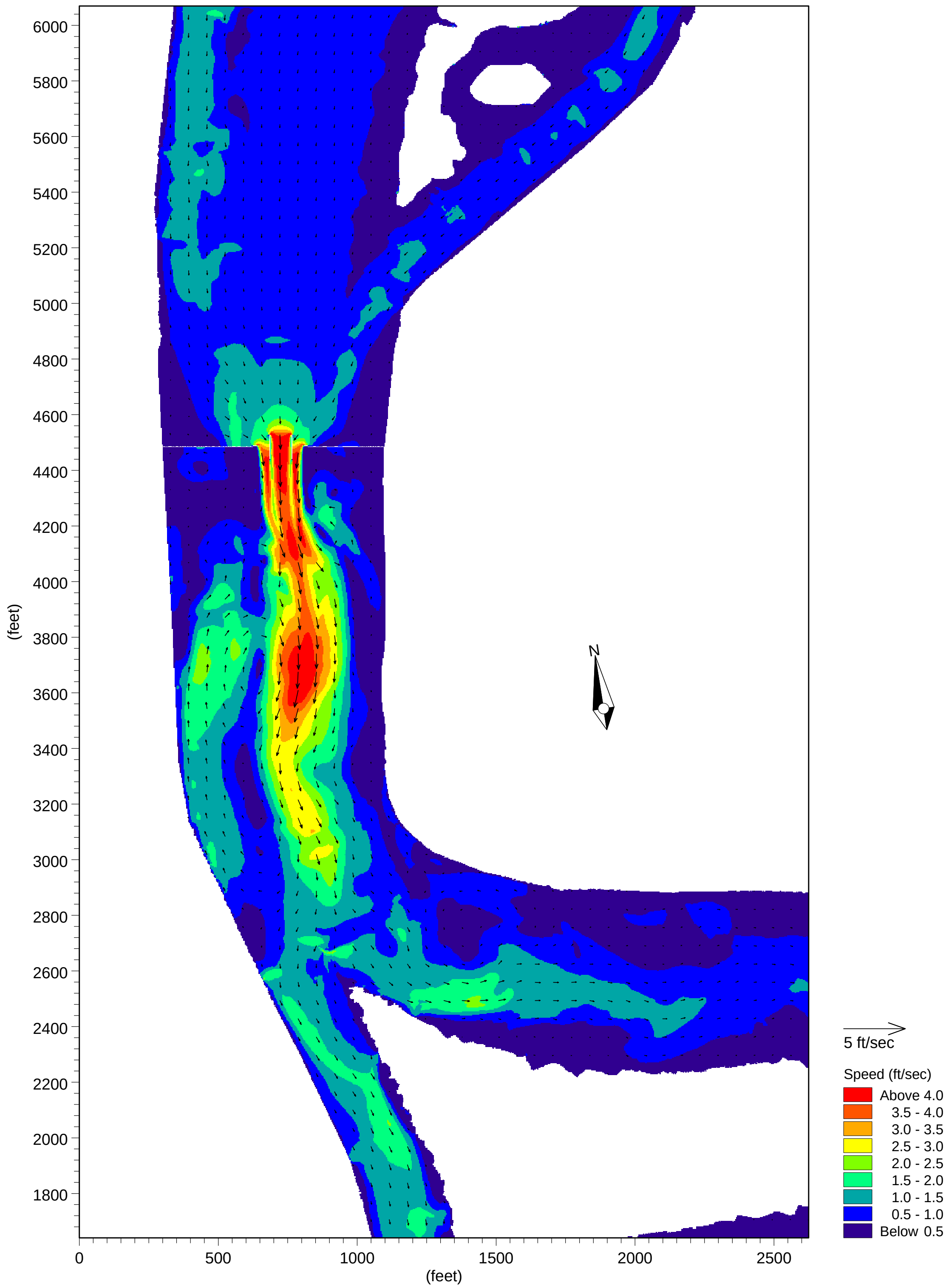

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Figure A.2. Peak ebb velocities, islands not flooded, February 21 1997

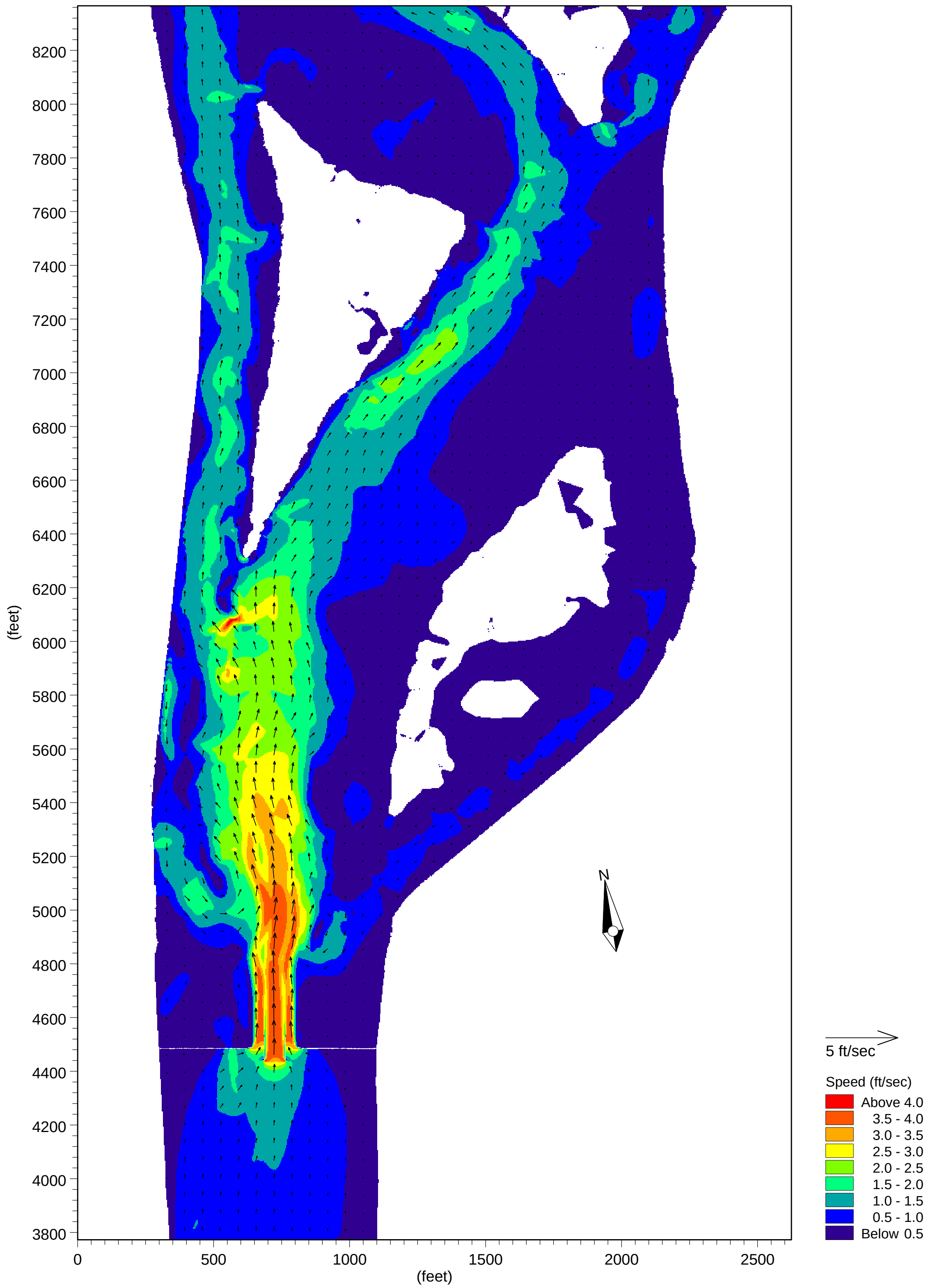

Figure A.3. Peak ebb velocities, islands partly flooded, January 6 1997

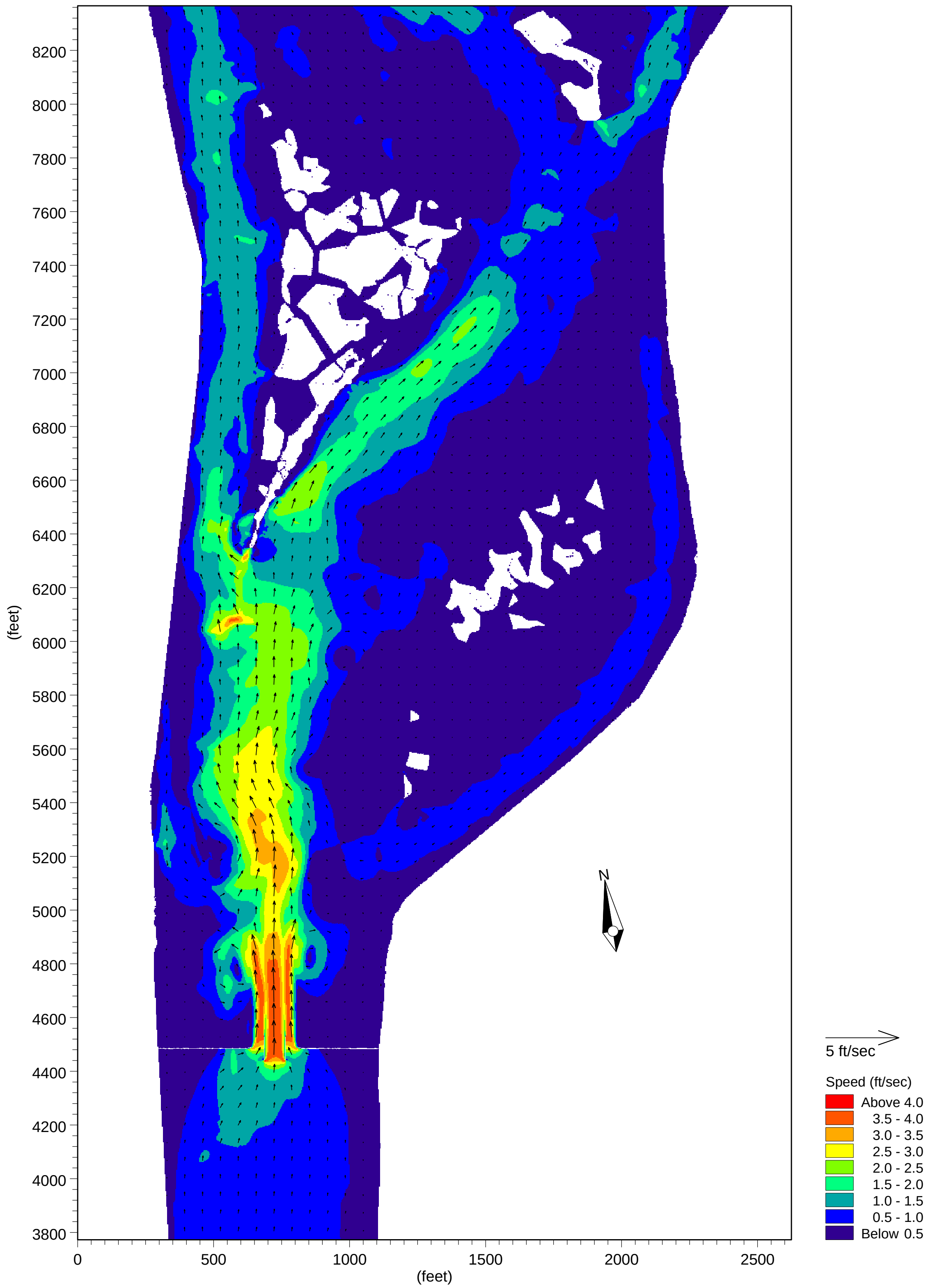

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Figure A.4. Existing condition high flood velocities, January 13 1993

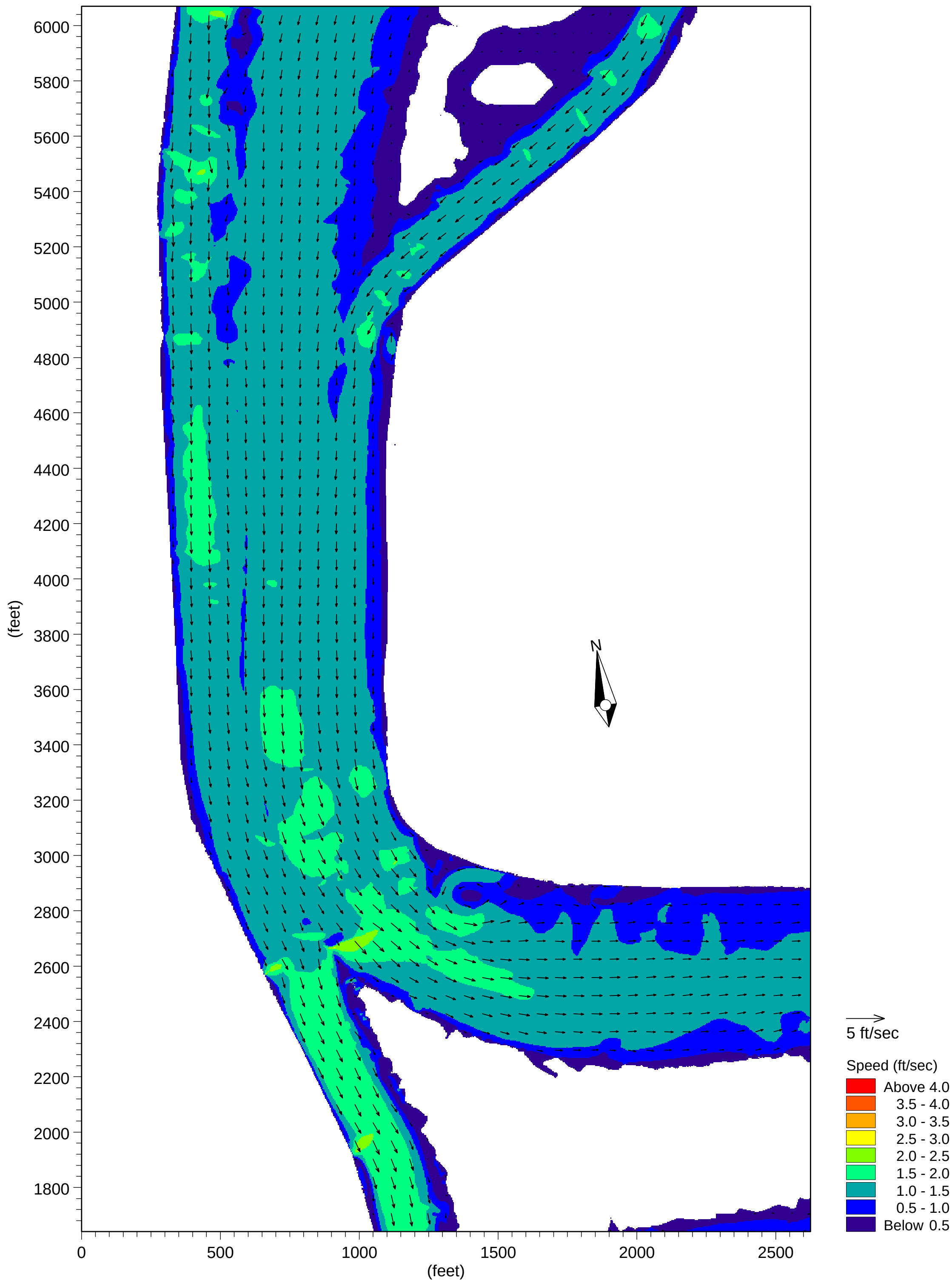

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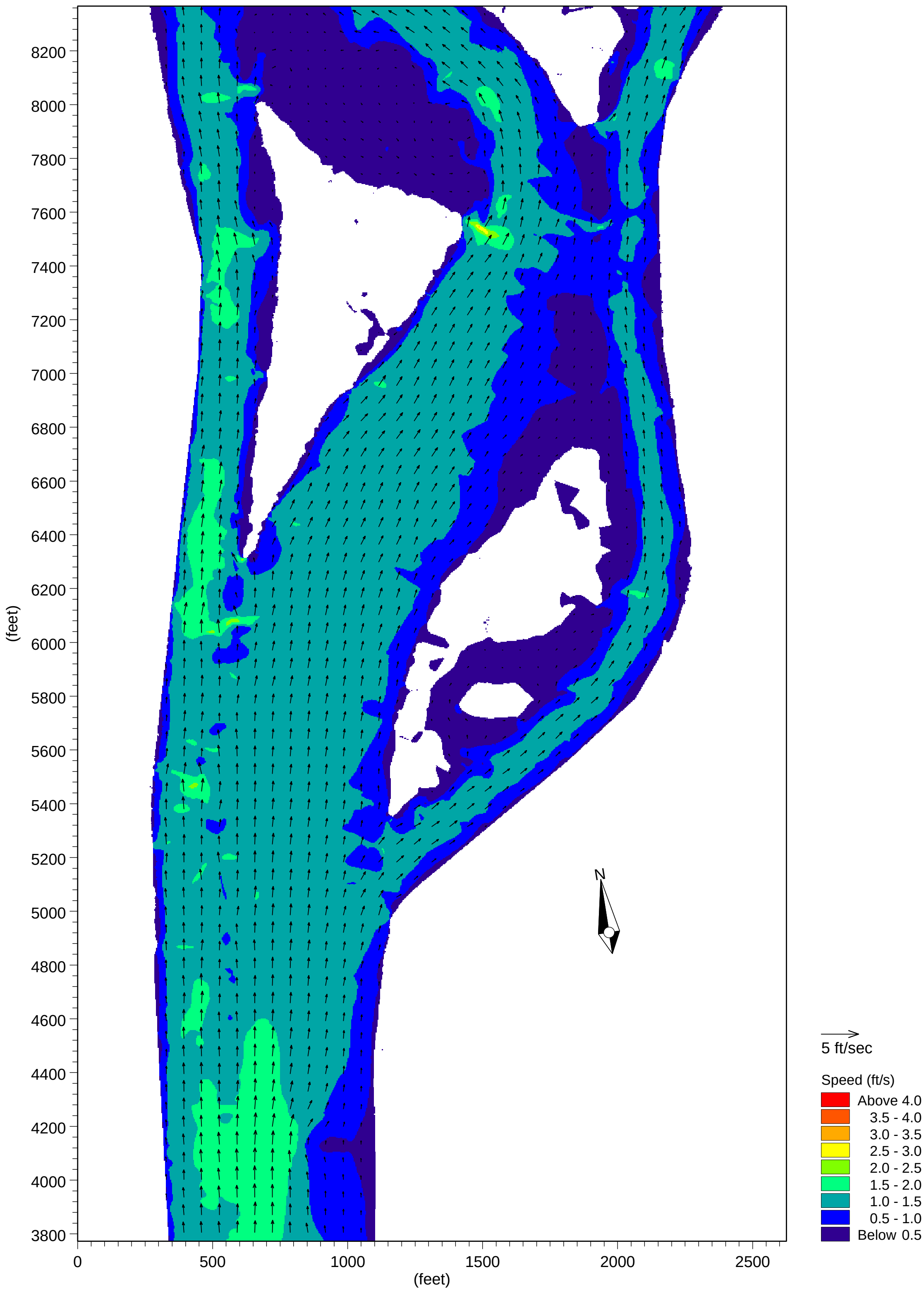
Figure A.5. Existing condition peak ebb velocities, February 21 1997



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APPENDIX B

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

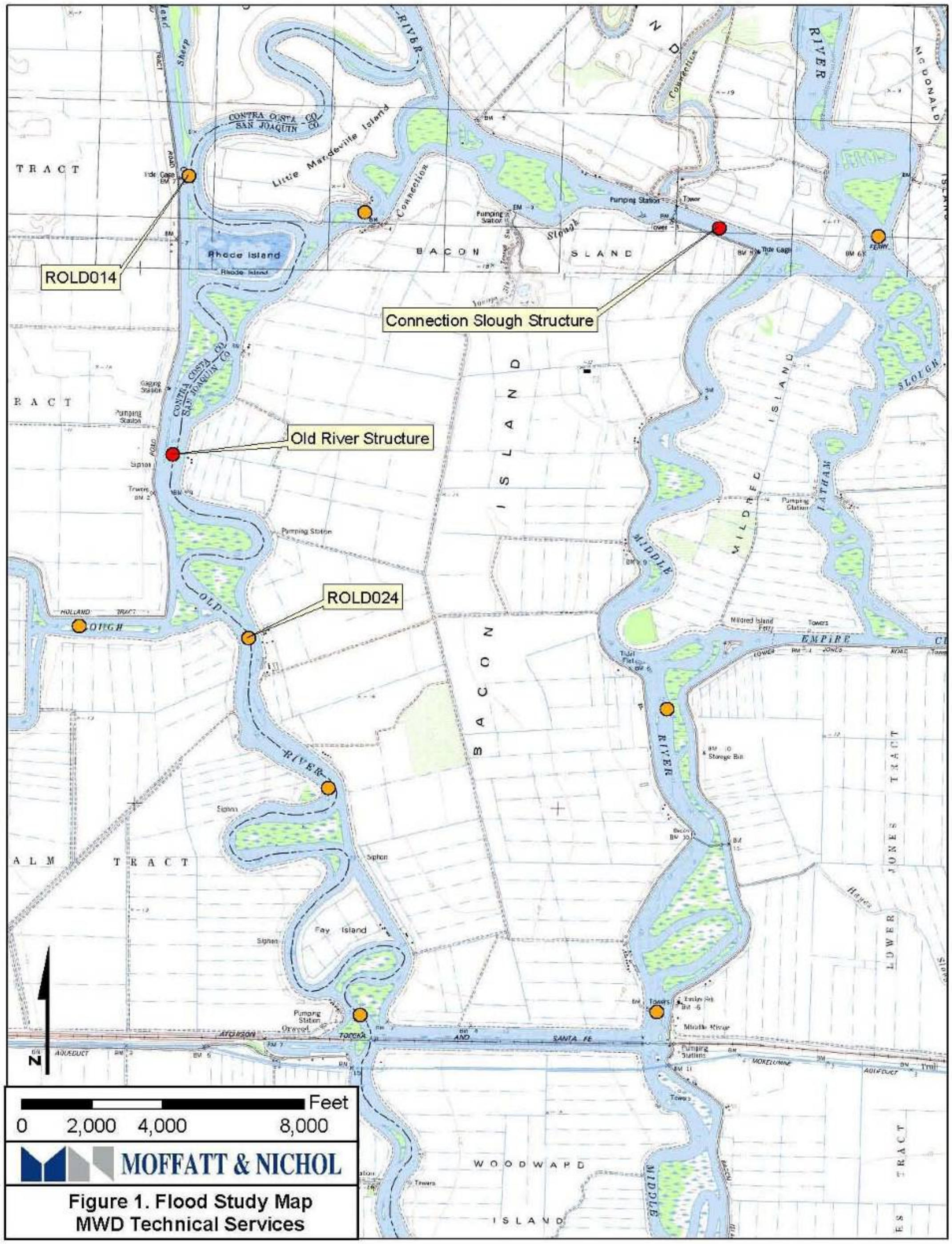


Figure 1: Location of Old River and Connection Slough Barriers and ROLD014 and ROLD024

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)

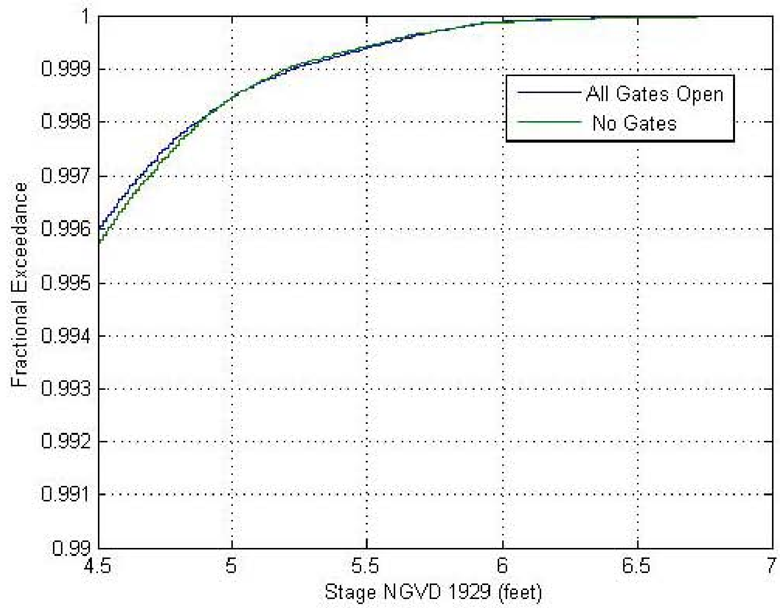


Figure 3: Cumulative Distribution Function Plot of Stage for ROLD014 (1992-2005)

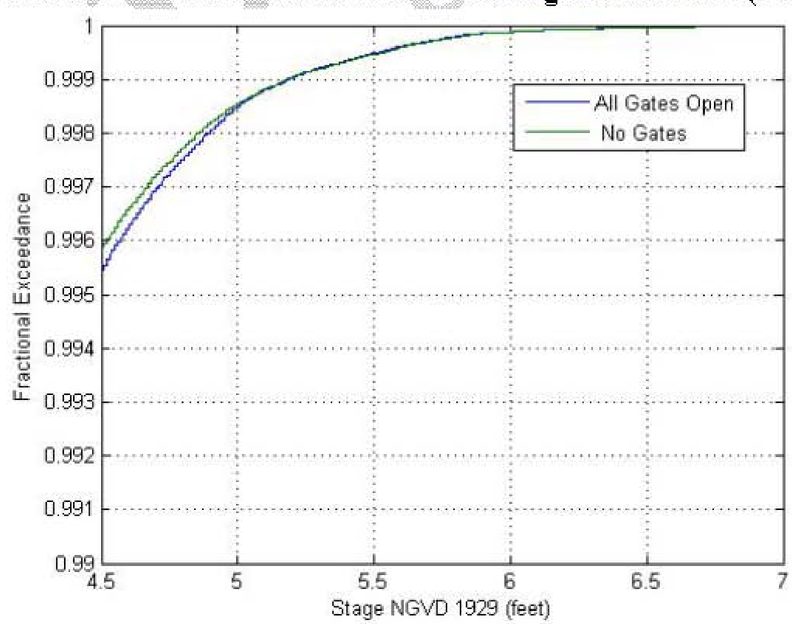
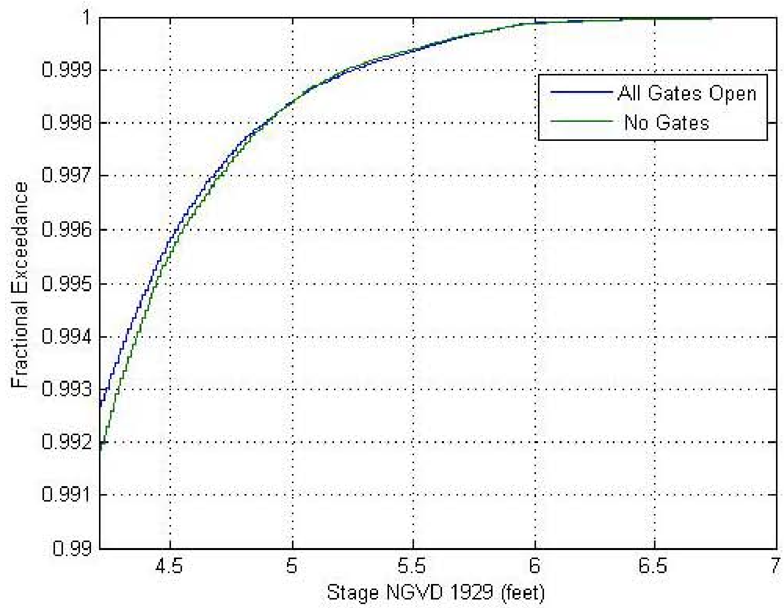


Figure 4: Cumulative Distribution Function Plot of Stage for ROLD024 (1992-2005)



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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