PNWD-3813

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Hydrodynamic Modeling Analysis for McGlinn Island Causeway Feasibility Study

Zhaoqing Yang
Tarang Khangaonkar

March 2007

Prepared for
Skagit River System Cooperative

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Battelle—Pacific Northwest Division
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Summary

A hydrodynamic assessment was conducted in support of the Skagit River System Cooperative's efforts to evaluate the feasibility of achieving restoration goals through modifications at the McGlinn Island Causeway in the northern corner of the Skagit River Delta. To assist in evaluating the effects of proposed restoration alternatives, the Skagit Bay hydrodynamic model, initially developed for the Rawlins Road Study for the Skagit Watershed Council, was first updated with new bathymetry data and was used for this analysis.

Two restoration alternatives were evaluated in this study:

1. Alternative 1: Allow additional freshwater discharge to the Swinomish Channel from the North Fork branch during low tide by lowering the jetty elevation or creating an opening in the jetty.

2. Alternative 2: Create a diversion from Dunlap Bay to the Swinomish Channel along the thalweg of the historical natural channel.

The configurations of these two alternatives are at an exploratory conceptual level and are therefore not for the purpose of creating an engineering design. Instead, these analyses provide a preliminary hydrodynamic response of the system to proposed alternatives. The information is useful in addressing the feasibility of the restoration alternatives and their capability to convey more freshwater into the Swinomish Channel from the North Fork River to help fish migration.

This paper provides background information about the study area and the drivers for conducting the study. The methodology is explained, including a description of the method for obtaining data and the model used to conduct the simulations. Finally, the results of the study are described along with the scope of the study and the work that remains to be done.

Acronyms

3-D	three-dimensional
DEM	Digital Elevation Model (Puget Sound)
FVCOM	Finite Volume Coastal Ocean Model
LIDAR	light detection and ranging
MLLW	mean lower low water (line)
MSL	mean sea level
NAD83	North American Datum of 1983
SRSC	Skagit River System Cooperative
SWC	Skagit Watershed Council
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
XTide	harmonic tide clock and tide predictor

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1.0 Introduction

1.1 Background

The Skagit River System Cooperative (SRSC) is currently conducting the McGlinn Island Causeway Feasibility study with funding provided by the Salmon Recovery Fund Board. The overall objective of the McGlinn Island Causeway Feasibility study is to evaluate the potential of restoring historical connectivity between the North Fork Skagit River and the Swinomish Channel (the channel that connects Skagit Bay to Padilla Bay). Dredging of the Swinomish Channel began in the 1890s so local farmers could transport goods to market. Dredge spoils were used to build a causeway between LaConnor and McGlinn Island to block sediment transport from the river to the channel. A jetty was built in 1938 to further restrict river-channel connectivity. The causeway and jetty have also greatly restricted juvenile salmonid access to extensive rearing habitat in Padilla Bay. In addition to the physical obstruction of migratory pathways for juvenile (and returning adult) salmon, reduced freshwater input to the channel has greatly increased channel salinity and created a physiological barrier for juvenile chinook, which are very sensitive to high salinity. Restoring river-channel connectivity is necessary to allow juvenile salmon to access rearing habitat in Padilla Bay. It is also a necessary precursor to further salmon habitat restoration along the channel. The restoration goal is to maximize fish passage from the river through the channel to Padilla Bay while minimizing sediment input to the channel.

SRSC contracted with Battelle to provide hydrodynamic modeling support to the McGlinn Island Feasibility Study. As part of another study, Battelle had previously constructed a hydrodynamic model of the Skagit River Estuary (Yang and Khangaonkar 2006). The approach selected was to improve the resolution and the coverage provided by the existing model so that it can be used to answer some of the questions as part of the McGlinn Island Causeway Feasibility Study.

The scope of hydrodynamic modeling evaluation presented in this report includes the effort associated with incorporating newly available bathymetry into the existing hydrodynamic model and extending the model domain up through Swinomish Channel to the entrance to Padilla Bay. This modeling study also includes a validation of the improved hydrodynamic model for a separate time period that is different from the original calibration, using new data collected by U.S. Geological Survey in 2006. After the model validation, the model was applied to simulate the salinity changes in Swinomish Channel for different restoration alternatives under consideration by SRSC. The results of this modeling analysis can then be used as part of the McGlinn Island Study to evaluate the feasibility of the proposed restoration alternatives to provide the desired conveyance for fish migration and reasonable amounts of freshwater for creating a brackish-water environment in the Swinomish Channel and Padilla Bay.

1.2 Study Area

The Skagit River estuary and Skagit Bay are located at the north end of the Whidbey Basin of the Puget Sound estuarine system (Figure 1-1). Skagit Bay connects to the Saratoga Passage at the south, which leads to the Puget Sound Main Basin through Possession Sound. Skagit Bay connects to the Strait of Juan de Fuca through Deception Pass at the north end of the Whidbey Basin. The Skagit River is the largest river in the Puget Sound estuarine system. It discharges nearly 39% of the total sediment and more than 20% of the freshwater into Puget Sound. The Skagit River Delta is a complex estuarine system, which is bounded by the North Fork of the Skagit River, Skagit Bay, and the South Fork of the Skagit River. A large tidal mudflat area exists at the mouth of the estuary, and most of the northeastern region of the bay is above the mean lower low water (MLLW) line. The mainstem of the Skagit River splits into the North Fork and the South Fork, which branches at river mile 9.5 near Mt. Vernon, Washington. The flow through these two branches is tidally influenced. The tidal influence extends nearly 15 miles upstream from the mouth up to Mount Vernon. At low tide, roughly one-third of the river flow passes through the South Fork, and two-thirds in the North Fork (Pickett 1997). The deepest region in the bay is about 30 m below mean sea level (MSL) near the southern entrance of the bay. A deep channel exists along the Whidbey Island shoreline of Skagit Bay, which extends north towards Deception Pass. Skagit Bay is subjected to tides from Puget Sound, primarily propagating from the south. Density-induced currents are also important in Skagit Bay because of salinity stratification and a strong freshwater front produced by Skagit River flow.

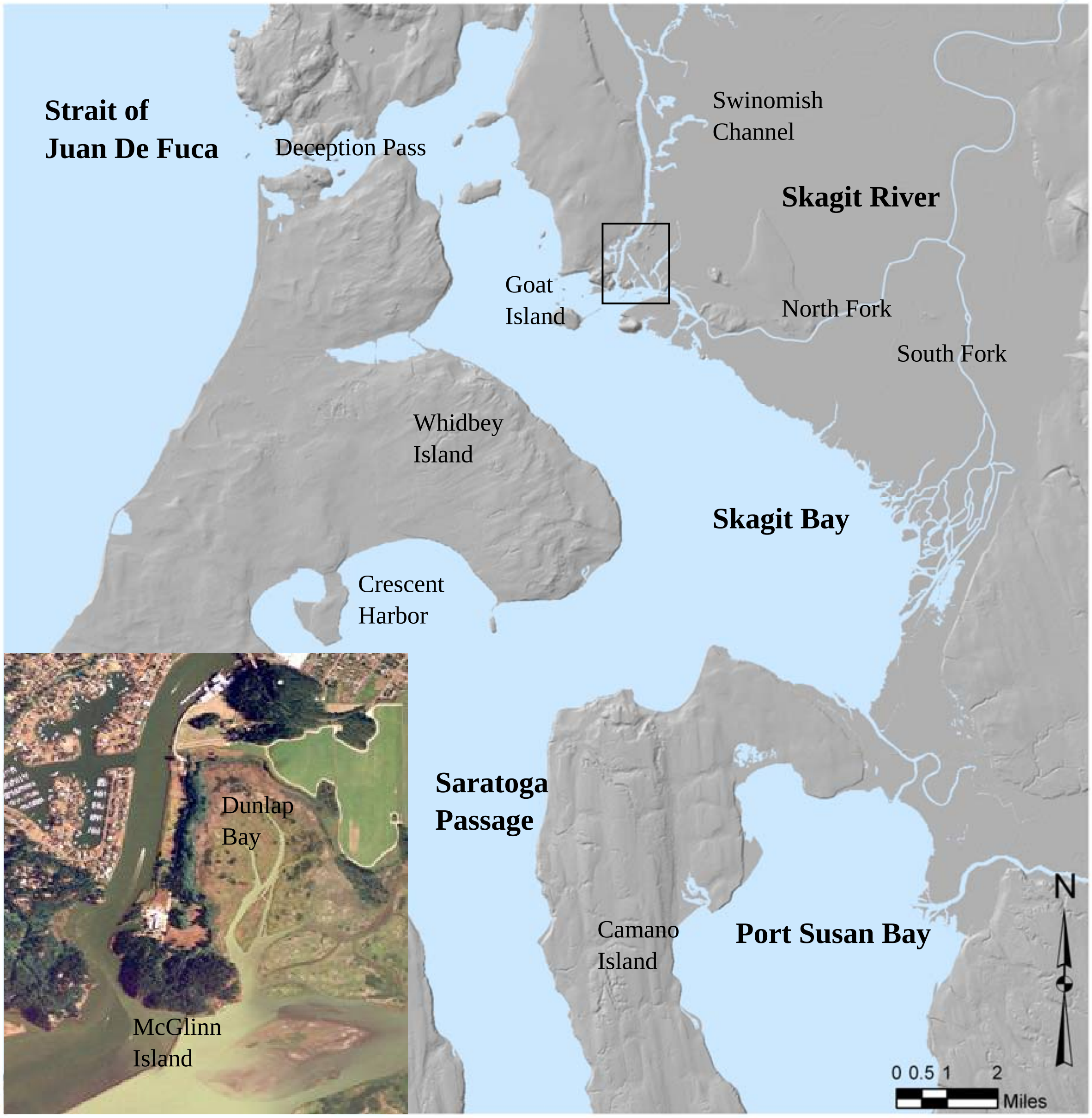
1.3 Study Objectives and Approach

The specific objectives of the hydrodynamic modeling analysis for the McGlinn Island study are listed below along with the approach.

1. <u>Incorporation of New Light Detection and Ranging (LIDAR) and Swath Bathymetry Data</u>: The existing Skagit River and Skagit Bay hydrodynamic model was developed using the existing bathymetry data from the University of Washington's Puget Sound Digital Elevation Model (DEM). While this data set provides sufficient resolution and good accuracy in the deep coastal region, there is insufficient accuracy for most of the tidal mudflat area in Skagit Bay. This limitation in model bathymetry affects the accuracy and confidence in the model results and could result in unrealistic predictions. This in turn can affect the restoration evaluations using the model. Therefore, it is critical to improve the model bathymetry with more accurate and higher resolution data. In this task, the approach selected was to update the model bathymetry in the mudflats area with the LIDAR data and the swath data provided by SRSC.

2. <u>Validation of Improved Model with Existing and New Field Data</u>: Following model improvement, it is an important step to re-confirm that the original calibration is still applicable. The model can then be validated using new field-measured data collected during a different flow period.

3. <u>Application of the Model for Two McGlinn Causeway Alternatives</u>: Following model validation, the objective is to simulate two McGlinn Causeway restoration alternatives. The objective is to evaluate the capability of the proposed McGlinn Causeway restoration alternatives to increase the freshwater plume dispersion and salmon migration through the channel to Padilla Bay.



Note:

- Data Source: Topography of the Puget Sound lowlands from the University of Washington

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FIGURE 1-1

Study Area—Skagit River Estuary

Skagit River System Cooperative
La Conner, WA

2.0 Methodology

2.1 Introduction

The model selected for this study is the Finite Volume Coastal Ocean Model (FVCOM) developed by the University of Massachusetts (Chen et al. 2003). FVCOM is a three-dimensional (3-D) hydrodynamic model that can simulate wetting-drying and tide- and density-driven circulation in an unstructured, finite element framework. The unstructured grid model framework of FVCOM is specially suited to the Skagit River Delta and Bay, which has complex shoreline geometry and complicated dynamic physical processes in the intertidal zone. FVCOM solves the 3-D momentum, continuity, temperature, salinity, and density equations in an integral form. A sigma-stretched coordinate system was used in the vertical plane to better represent the irregular bathymetry. The model employs the Mellor Yamada level 2.5 turbulent closure scheme for vertical mixing and the Smagorinsky scheme for horizontal mixing. The model has been successfully applied to simulate hydrodynamics and transport processes in lakes and estuaries (Zheng et al. 2003; Chen et al. 2004).

2.2 Model Setup

The hydrodynamic model setup for Skagit Bay consists of two procedures: 1) construction of an unstructured model grid in the study area and 2) specification of the model boundary conditions and forcing mechanisms. These two procedures are described in detail below.

2.2.1 Model Grid and Bathymetry Update

The Skagit Bay hydrodynamic model was initially developed for the Rawlins Road study for the Skagit Watershed Council. After the initial model development, it became apparent that the simulations of hydrodynamics in the intertidal zone could be affected by the accuracy of the bathymetry data. Therefore, a model improvement consisting of updating the model bathymetry with lidar data collected by SRSC and U.S. Geological Survey (USGS) in the Skagit Bay mudflat region was conducted as part of this study. The model grid was also extended to the Swinomish Channel for the purpose of this study. The updated Skagit model grid is shown in Figure 2-1. The model grid represents the physical study area overlaid by the computational grid that defines the model boundaries and model cells.

The model element size varied from 16 m near the mouth of the estuary to 400 m at the south entrance of Skagit Bay. The model grid resolution was gradually reduced away from the estuarine delta to the open boundaries to maintain the computational efficiency of the model. The model consists of 9,122 elements and 5,496 nodes in the horizontal plane. To predict salinity stratification more accurately, 25 uniform vertical layers were specified in the water column in a sigma-stretched coordinate system. The model was set up in Universal Transverse Mercator (UTM) North American Datum (NAD) 83 (Zone 10) coordinates in the horizontal plane with reference to MSL in the vertical direction. Water depths in most of Skagit Bay are less than 5 m. The deepest water is 40 m near Deception Pass in the north of the model domain. Figure 2-2 shows the model bathymetry.

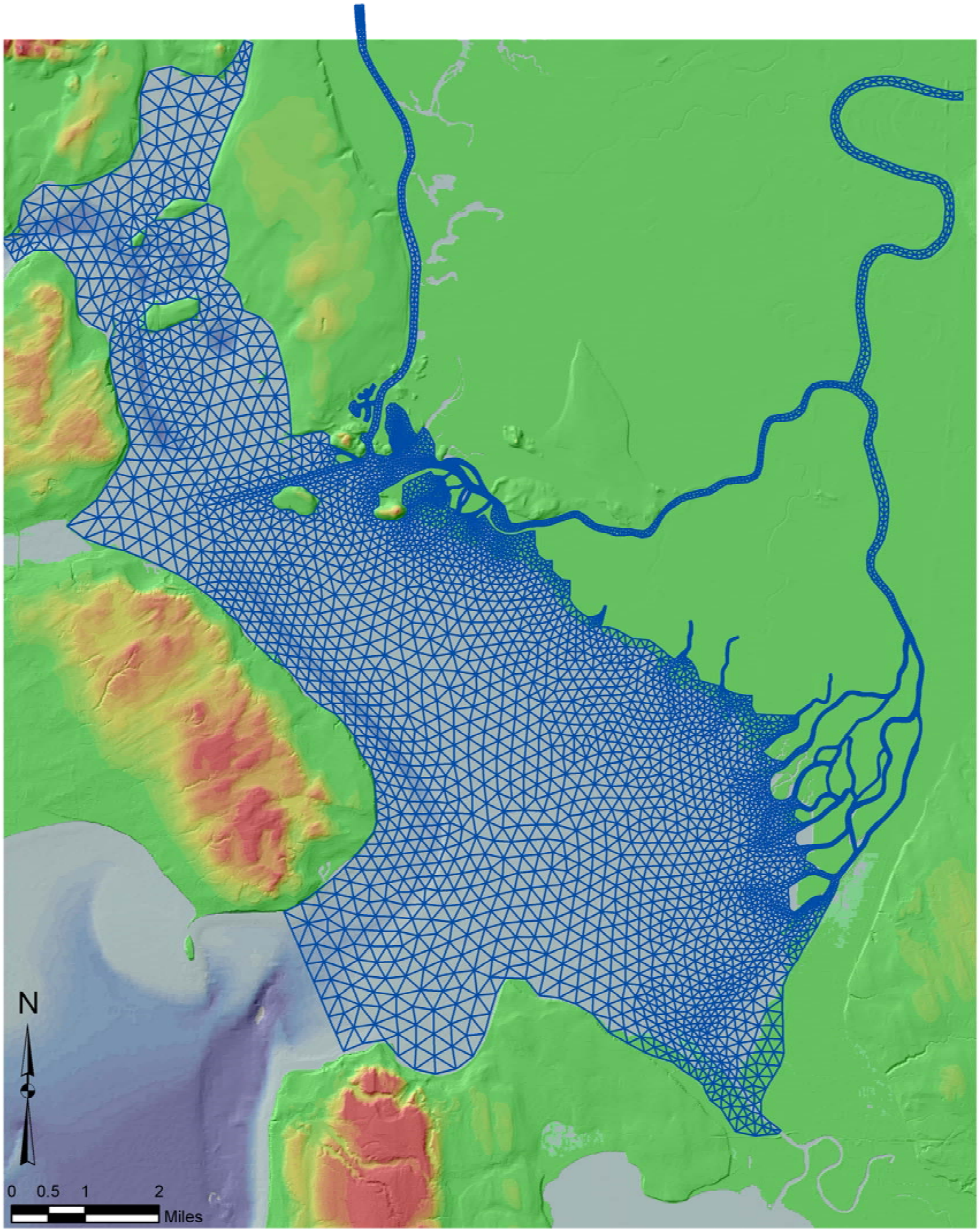
2.2.2 Model Boundary Condition

Open boundary conditions specified were tidal elevations predicted using the XTide[a] program based on National Oceanic Service algorithms. Tidal elevations were specified at the following three open boundaries: 1) the mouth of Skagit Bay, 2) Deception Pass, and 3) the Swinomish Channel. There were no salinity data available along the open boundaries. Salinity profiles along the open boundaries were initially estimated based on historical data in the Puget Sound area and further adjusted during model calibration. At the water surface, wind stress was specified. Wind stress was applied uniformly to the entire model domain.

2.3 Model Validation for the Period of June 6 to 23, 2005

After the model was updated with bathymetry data, it was validated with the same data set (from June 6 to 23, 2005) collected for the Rawlins Road study. All the model parameters remained the same as model calibration. Figures 2-3 to 2-5 show the comparisons of model results and field-data. The model and data comparison results indicated that the updated model maintained at least the same level of accuracy at the observation stations. Predicted surface velocity and salinity at flood and ebb tides are shown in Figures 2-6 to 2-9. Model results indicated that a large area of tidal mudflat became dry during ebb tide, which agreed well with the general observation and knowledge of the Skagit Bay system. Detail discussion of model results can be found in Yang and Khangaonkar (2006).

(a) XTide = Harmonic tide clock and tide predictor



Note:

- Number of elements = 9,122
- Number of nodes = 5,496

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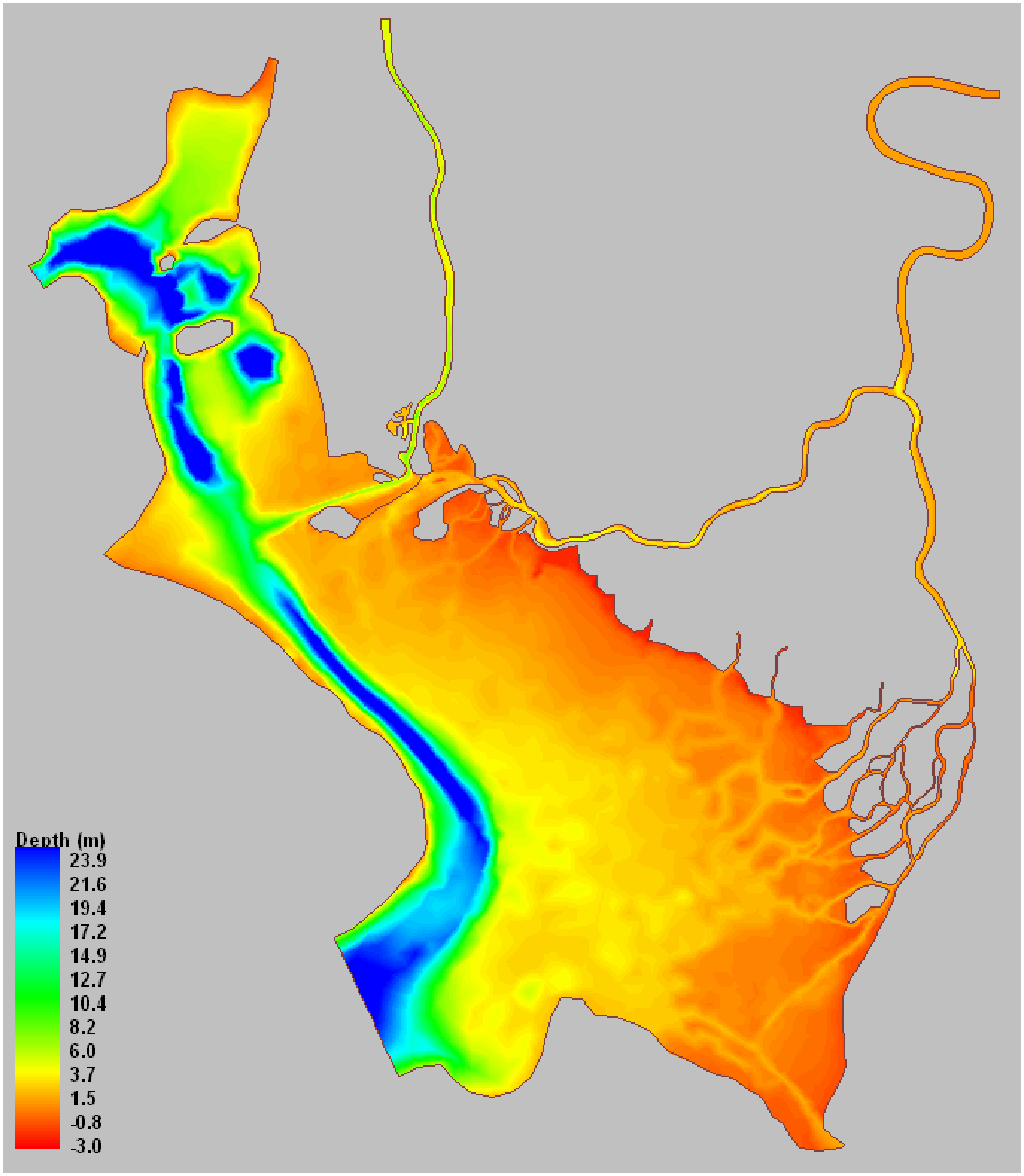
FIGURE 2-1

FVCOM Model Grid for Skagit Bay Including Swinomish Channel

Skagit River System Cooperative
La Conner, WA



Note:

- Water depths are relative to mean sea level (MSL).
- Negative values indicate depth above MSL.

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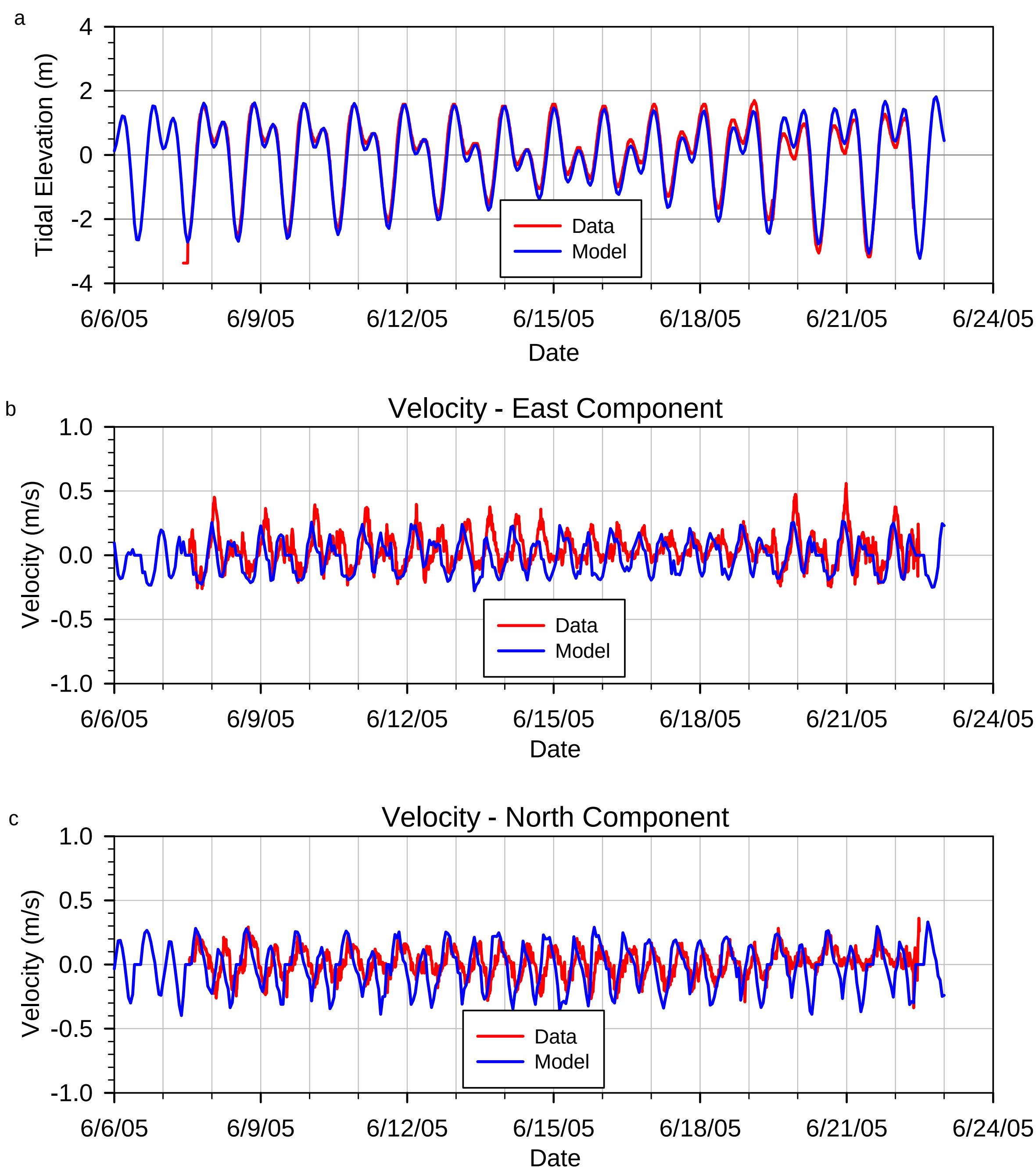
FIGURE 2-2

Hydrodynamic Model Bathymetry for Skagit Bay

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in the Pacific Time Zone.

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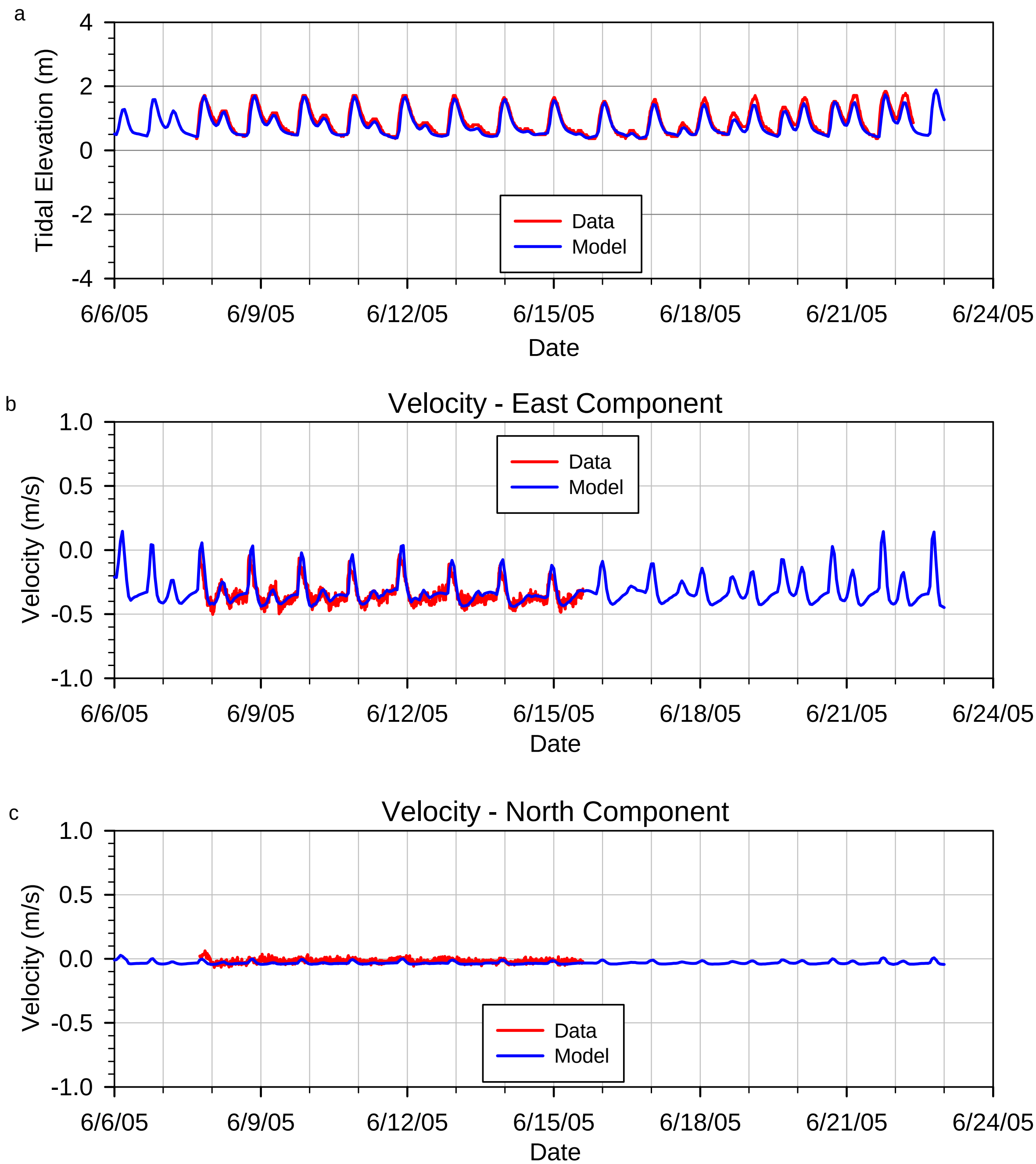
FIGURE 2-3

Comparisons of Tidal Elevations and Velocities at the Skagit Bay Station

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in the Pacific Time Zone.

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FIGURE 2-4

Comparisons of Tidal Elevations and Velocities at the North Fork Skagit River

Skagit River System Cooperative
La Conner, WA

Note:

- Times are in the Pacific Time Zone.

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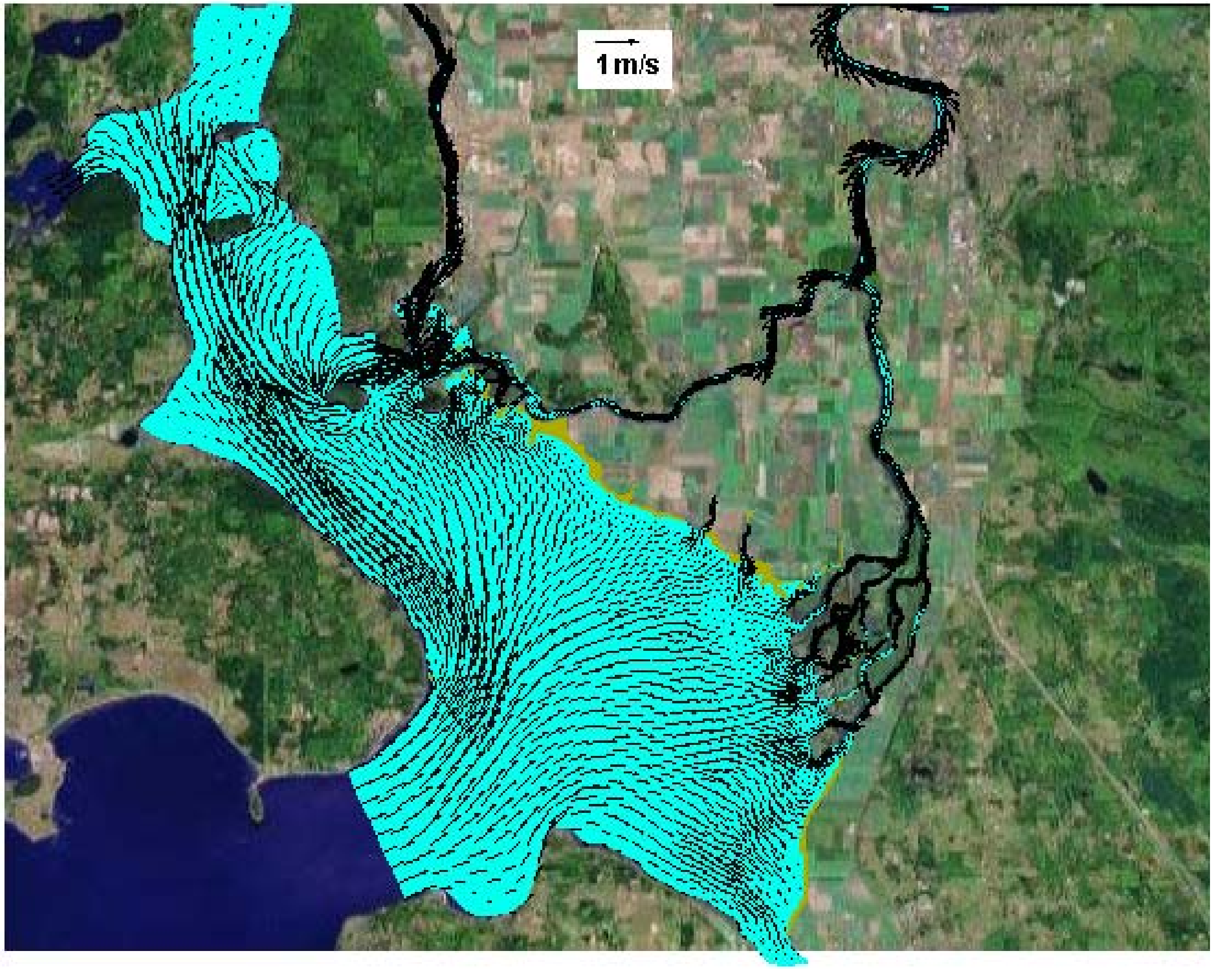
FIGURE 2-5

Comparisons of Salinities at the Skagit Bay and North Fork Stations

Skagit River System Cooperative
La Conner, WA



Note:

- Model result corresponds to 06/08/2005, 7:00 pm.
- Indicates dry area.

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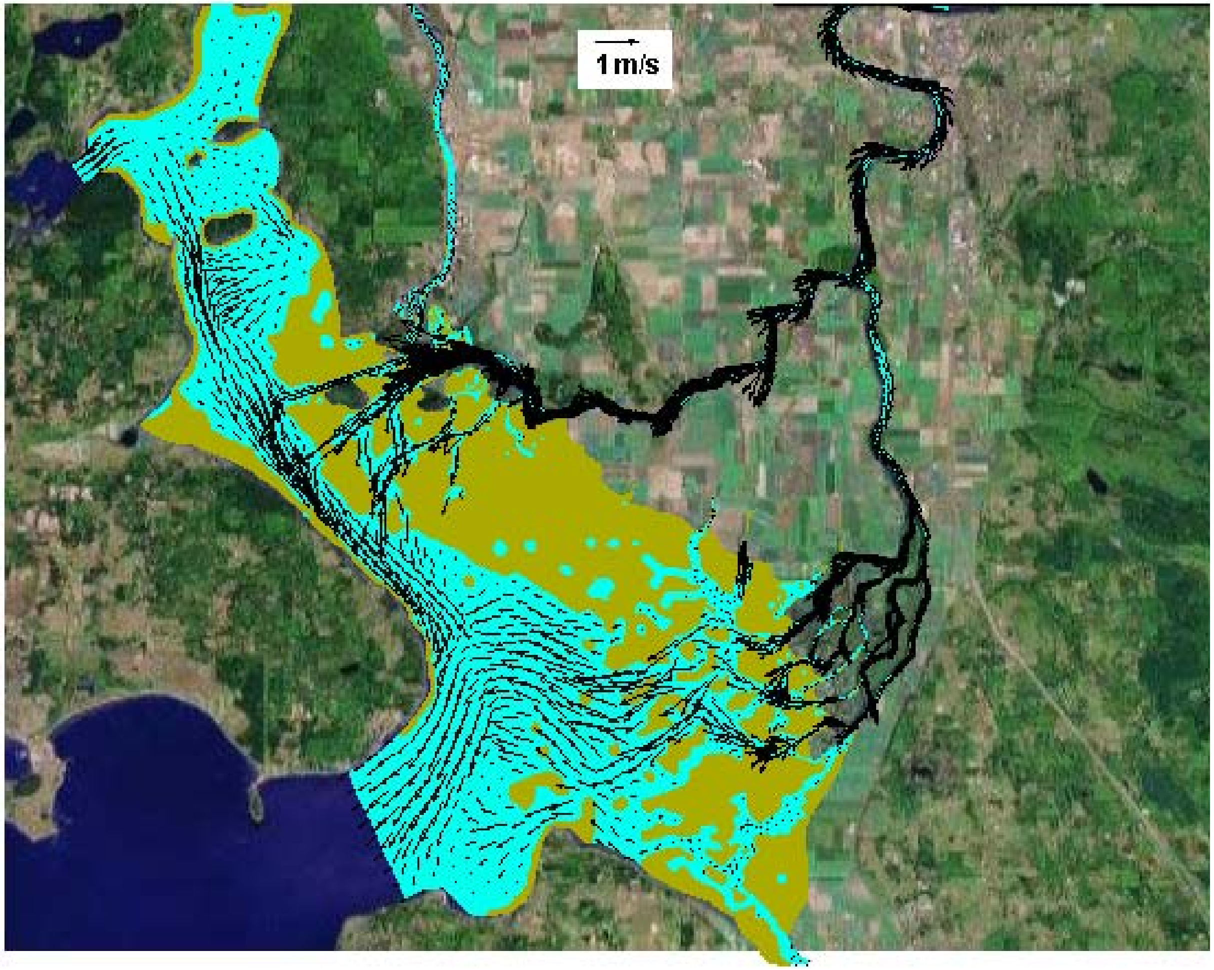
FIGURE 2-6

Skagit Bay Velocity Distribution
During Flood Tide

Skagit River System Cooperative
La Conner, WA



Note:

- Model result corresponds to 06/08/2005, 12:00 pm.
- Indicates dry area.

FIGURE 2-7

Skagit Bay Velocity Distribution During Ebb Tide

Skagit River System Cooperative
La Conner, WA

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Note:

- Model result corresponds to 06/08/2005, 7:00 pm.
- Indicates dry area.

FIGURE 2-8

Surface Salinity Distribution at Flood

Skagit River System Cooperative
La Conner, WA

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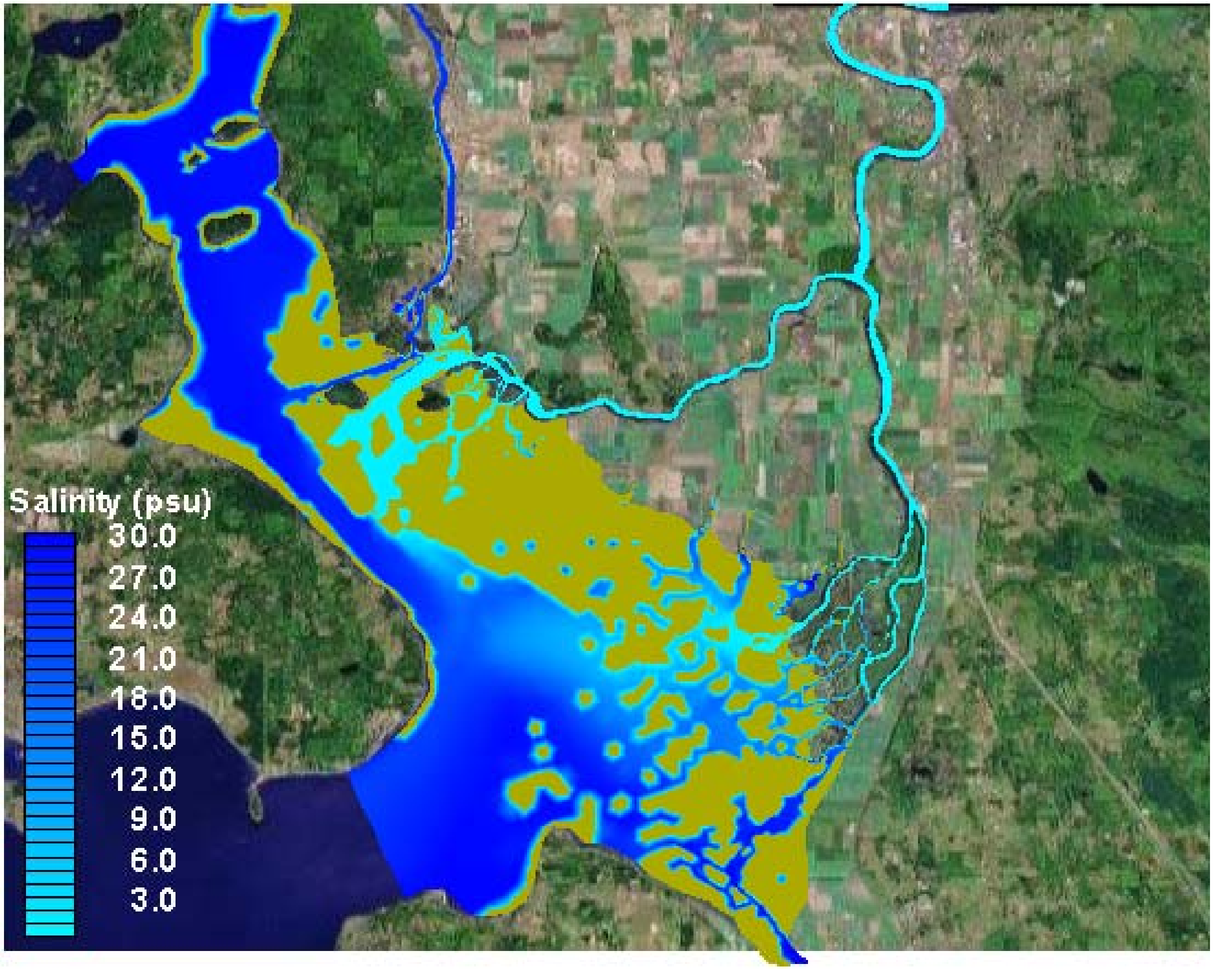

Note:

- Model result corresponds to 06/08/2005, 12:00 pm.
- Indicates dry area.

FIGURE 2-9

Surface Salinity Distribution at Ebb Tide

Skagit River System Cooperative
La Conner, WA

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2.4 Model Validation for the Period of May 1-30, 2006

The data collected for the Rawlins Road study in 2005 focused on the area of the North Fork of the Skagit River. To increase the confidence of the model with application to the McGlinn Island Causeway project, it was important to validate the model with data collected in the Swinomish Channel. USGS collected a large data set in the Skagit Bay system in 2006. Battelle received field-measured data from USGS for May of 2006. The data monitoring stations are shown in Figure 2-10.

To simulate the hydrodynamics for May 2006, data for model forcing mechanisms (tides and inflows) for this period were obtained. Tidal elevations were obtained from XTide predictions. The tidal elevations along the three open boundaries are presented in Figure 2-11. It can be seen that tides are gradually damped as they propagate from the mouth of Skagit Bay (Crescent Harbor) towards the north end of the bay (Yokeko Point) and further to the Swinomish Channel. Wind data for May 2006 were obtained from the National Weather Service for Paine Field Station at Everett, WA. The windstick plot for this new period is presented in Figure 2-12. Wind speed was in the range of 5 to 20 m/s, and the direction was primarily from the north or the south, aligned in general with the orientation of Whidbey Basin. The Skagit River inflow was obtained from the USGS gage at Mt. Vernon, WA (Figure 2-13). Figure 2-13 shows that the Skagit River flow during the first half of May 2006 was in the range of 11,000 to 17,000 cfs, which roughly corresponds to the mean annual river flow rate. In the second half of the month, a high-flow event occurred during which the river flow reached as high as 40,000 cfs. The model was set up and applied for the entire month of May 2006, corresponding to the field-data-collection period. Model parameters were retained the same as in the model calibration and validation runs.

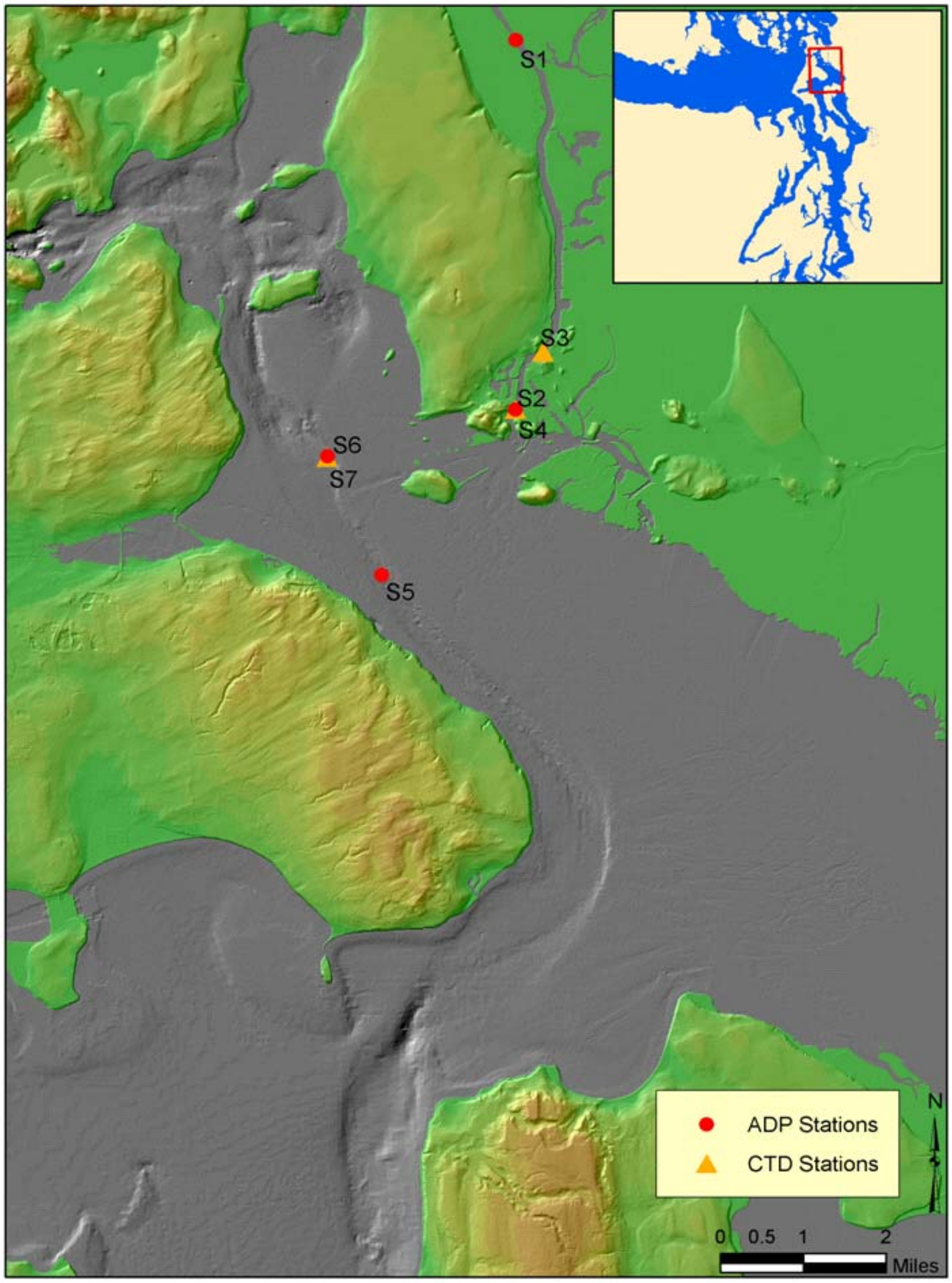
Figure 2-14 shows the comparison of model results and data at Station S1 for the period of May 1 to 16, 2006, which is located at the north end of the Swinomish Channel. Predicted tidal elevation and velocity matched the data very well. Comparisons of predicted tidal elevation (Station 4) and velocity (Station 2) to field-data at the south end of the Swinomish Channel are shown in Figure 2-15. Model results matched the data reasonably well. However, it is noted that the predicted velocities at ebb tides were under predicted at Station 2. Comparison of model results to field-data at the Skagit Bay station S5 for the period of May 16 to 31, 2006, is presented in Figure 2-16. Both predicted tidal elevation and velocity matched the field-data well. Good agreements between model results and field-data were also obtained at another Skagit Bay station, S6, near the Goat Island Jetty (Figure 2-17).

Comparisons of predicted salinity to field-data were conducted at stations 3, 4, and 7. Initial comparisons of predicted salinity at Station S3 in the Swinomish Channel indicated that the model was unable to capture a sharp salinity drop during low tides that was observed in the field-data. After consultation with SRSC and careful evaluation of bathymetry near Station S2, a leakage of freshwater through the northern section of the Goat Island jetty from the North Fork of the Skagit River to the Swinomish Channel was identified (Figure 2-18). This freshwater leakage was not previously included in the existing Skagit Bay hydrodynamic model. To simulate the leakage, a discharge of freshwater at the leaking jetty was estimated based on the water-elevation difference on both sides of the jetty. Figure 2-19 shows predicted water-surface elevations at the west and east sides of the leaking jetty. Water-surface elevations are the same on both sides of the jetty during high tides. However, during low tides, the water-surface elevation on the east side of the jetty (in the North Fork of the Skagit River) is higher than that on the west side of the jetty (Swinomish Channel) because of the presence of the jetty and the river flow. The difference (east side minus west side) of the water-surface elevations was also plotted in Figure 2-19.

The water-level difference could be as high as 2.0 m during spring tides. Because there is no measurement for the flow rate through the leaking jetty, the leakage flow rate was estimated iteratively by matching the predicted salinity to the observed data in Station S3. Figure 2-20 shows the estimated leaking flow rate through the jetty after several iterations of model runs with comparison to the measured surface salinity at Station S3. The estimated peaking flow is about 500 cfs. It is evident that the sharp drops in measured salinity correspond to the leaking flow with a phase lag of about 4 hours. The phase lag was adjusted such that the model results matched the salinity data. The leaking flow at the jetty was simulated using a source and sink approach with FVCOM. That is, on the river side of the jetty, the outflow was withdrawn based on the time history of the estimated flow rate (Figure 2-20). On the west side of the jetty, a freshwater inflow was discharged into Swinomish Channel with the same flow rate withdrawn from the river side of the jetty. It is noted that this approach is a simple approximation to simulate the effect of a leaking jetty. The model grid and the modification of bathymetry near the area of the leaking jetty will need to be refined to accurately represent the channels flushed out by the leaking water and to model the freshwater leakage and its effect on the salinity distribution in the Swinomish Channel (Figure 2-18).

Figure 2-21a shows a comparison between the predicted surface salinity and the field data at Station S3. It is seen that after the first few days of model initialization, the predicted surface-salinity time history shows sharp drops during ebb tides as observed in the field-data (Figure 2-21a). A relative decrease in mean salinity is also seen in model results and field-data corresponding to the increase of freshwater inflow around May 8 to 10, 2006. Figure 2-21b shows the salinity comparison between model results and field-data at Station S4 at the bottom of the water column. The results show that the model was capable of simulating the general trend of the salinity distribution, but did not reproduce enough stratification in comparison to the surface salinity in Station S3. Figure 2-21c shows a comparison between model results and field-data at Station S7 in Skagit Bay. The salinity data were collected near the bottom of the water column. Model prediction of salinity in the bay matched the field-data reasonably well.

Overall, the updated Skagit Bay hydrodynamic model reproduced the water-surface elevations and velocities well in the bay and Swinomish Channel in May 2006. The model was able to simulate the general salinity distributions as well, particularly the sharp salinity drops observed in the Swinomish Channel with the effect of the leaking jetty. Therefore, the model can be used to evaluate the relative effects of the McGlinn Island Causeway alternatives on the salinity transport from the Skagit River estuary to the Swinomish Channel.



Note:

- Station S1: ADP 1.345 m above bottom.
- Station S2: ADP 1.35 m above bottom.
- Station S3: CTD 0.35 m below water surface.
- Station S4: CTD 0.625 m above bottom.
- Station S5: ADP 1.345 m above bottom.
- Station S6: ADP 1.35 m above bottom.
- Station S7: CTD 0.645 m above bottom.

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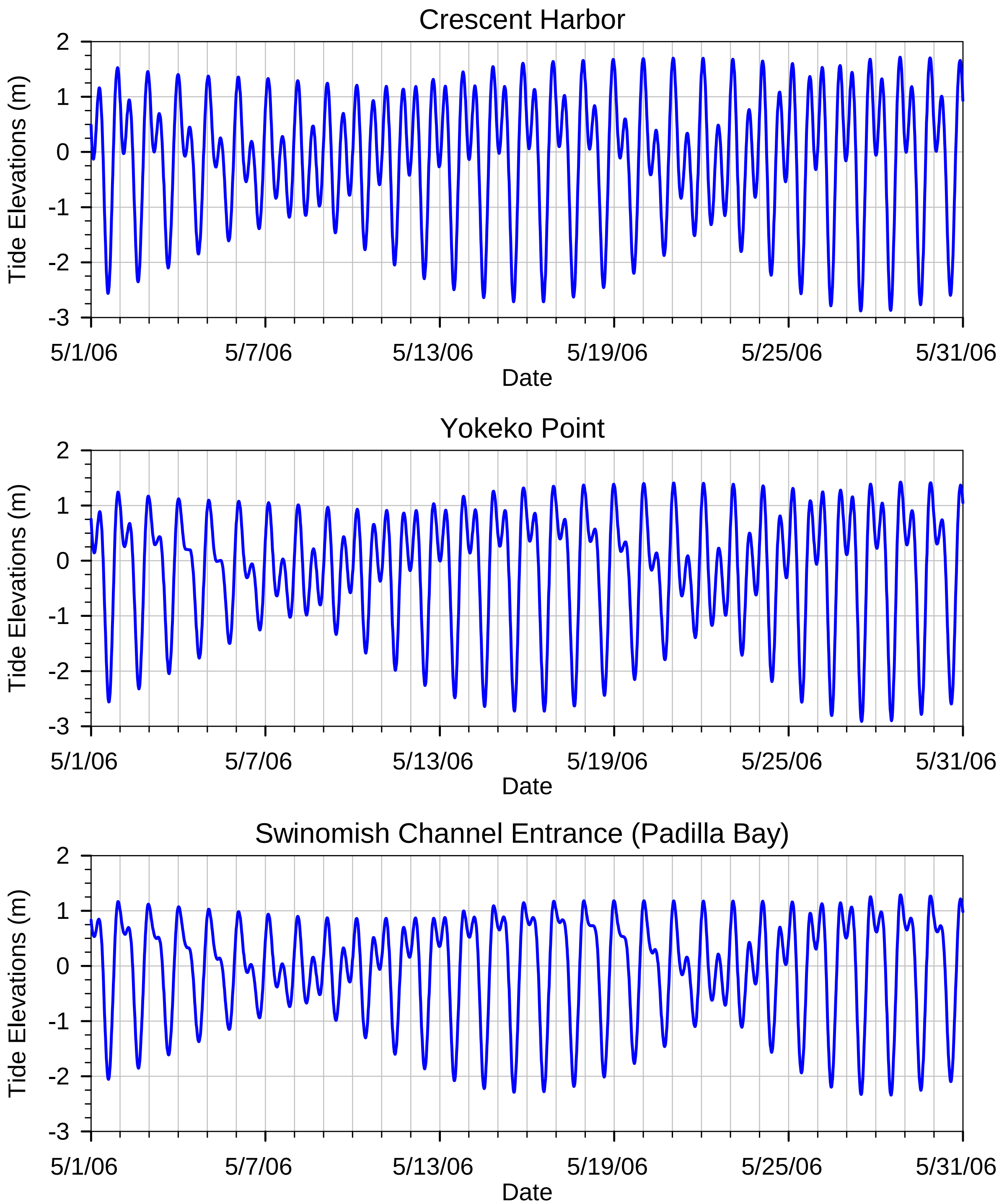
FIGURE 2-10

Locations of Monitoring Stations in Skagit Bay

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in the Pacific Time Zone.
- Tidal elevation is with reference to the MSL.

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FIGURE 2-11
Tidal Elevations at the Open Boundaries of the Model Domain

Skagit River System Cooperative
La Conner, WA

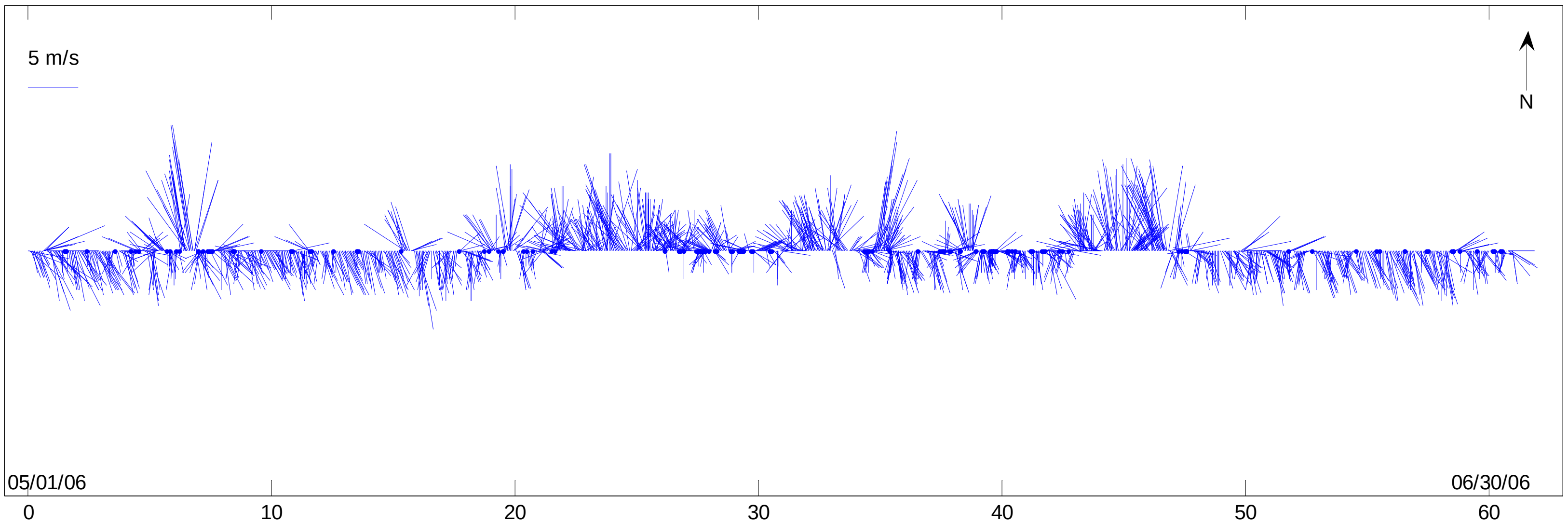

FIGURE 2-12

Wind Stick Plot at Paine Field Near Everett, WA

Skagit River System Cooperative
La Conner, WA

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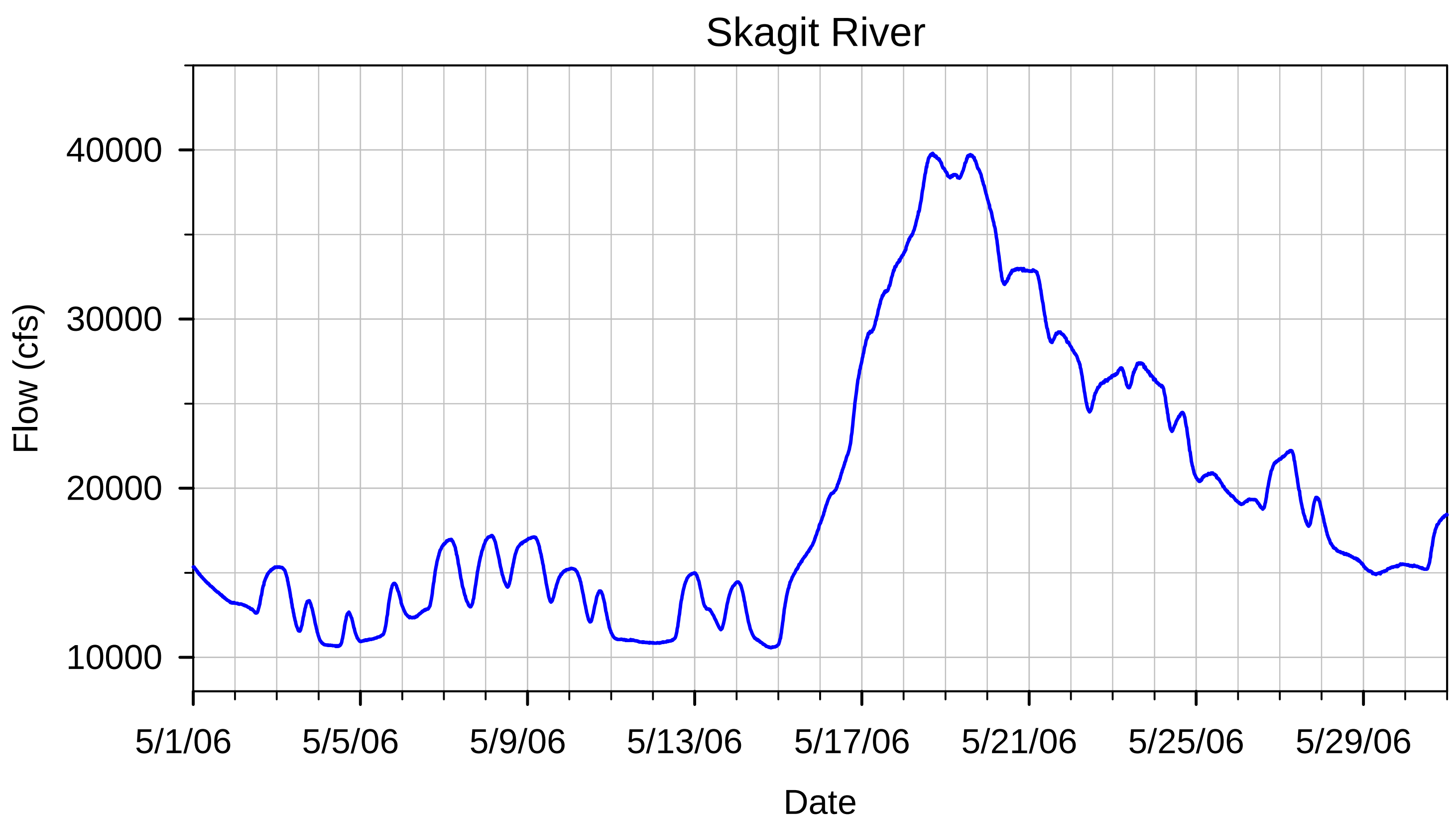

Note:

- Data were measured by USGS at Mt. Vernon, WA (RM 15.7).

FIGURE 2-13

Skagit River Flow Time History

Skagit River System Cooperative
La Conner, WA

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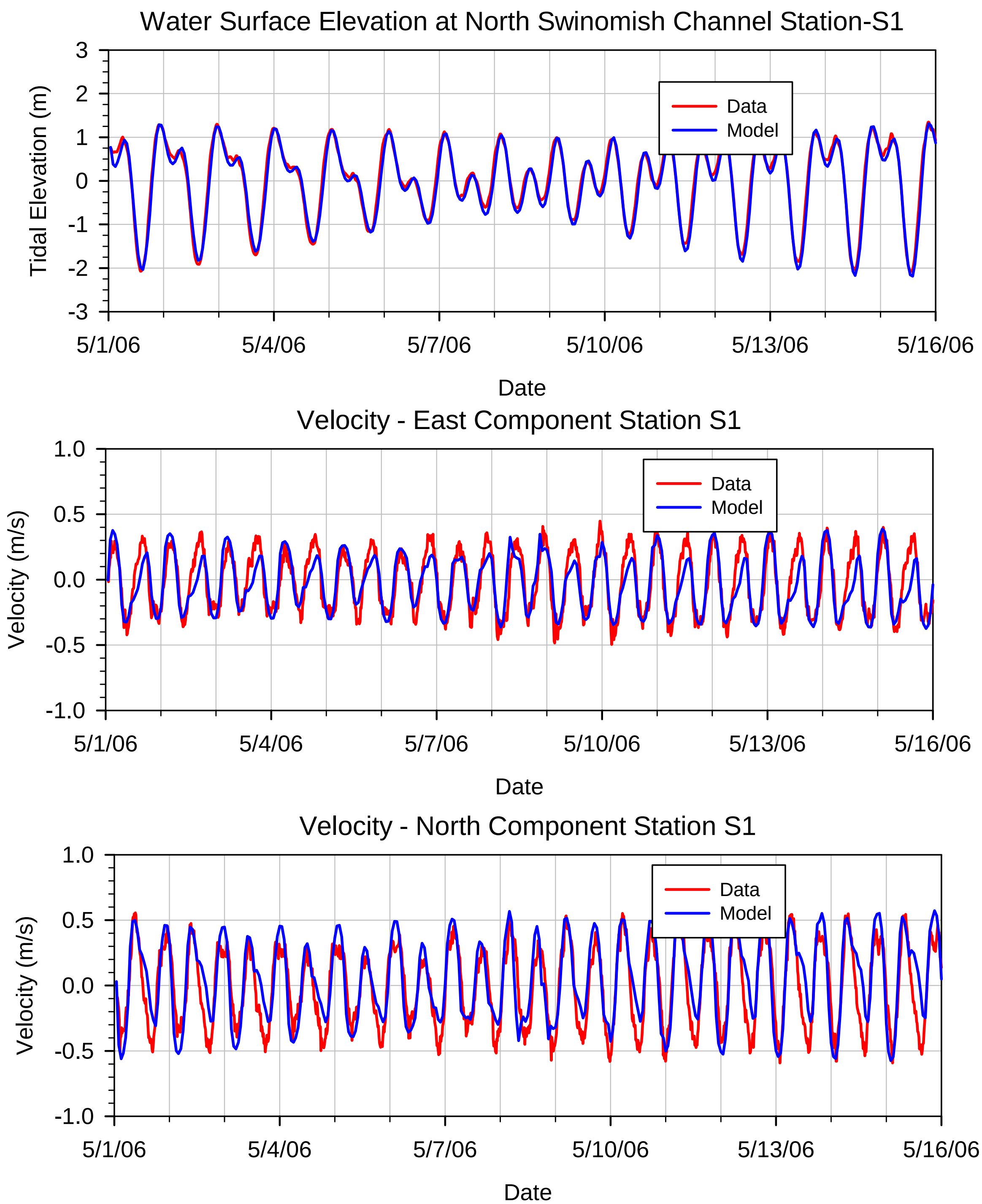

Note:

- Times are in the Pacific Time Zone.
- Tidal elevation is with reference to the MSL.

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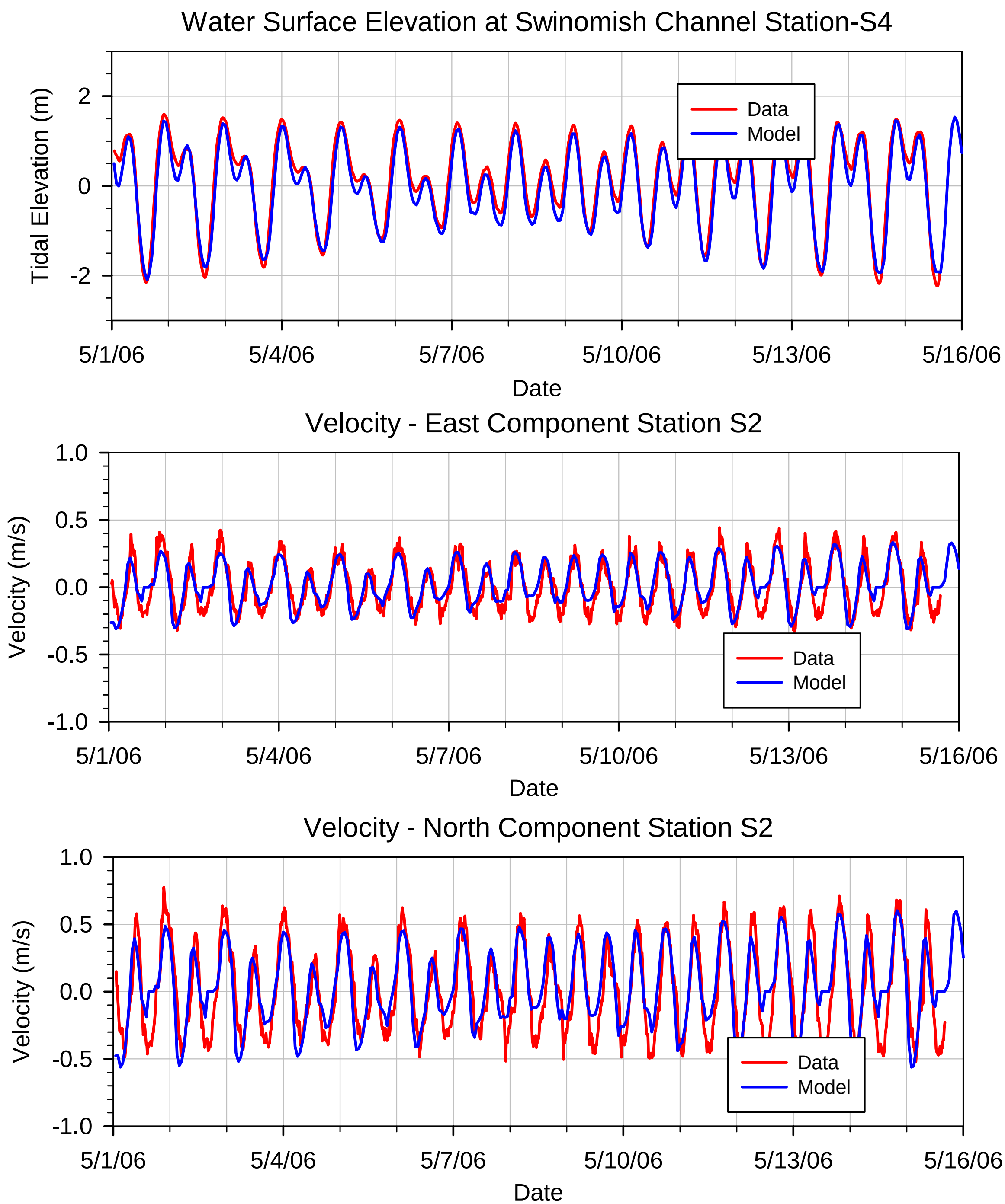
FIGURE 2-14

Comparisons of Tidal Elevations and Velocities at Station S1

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in the Pacific Time Zone.
- Tidal elevation is with reference to the MSL.

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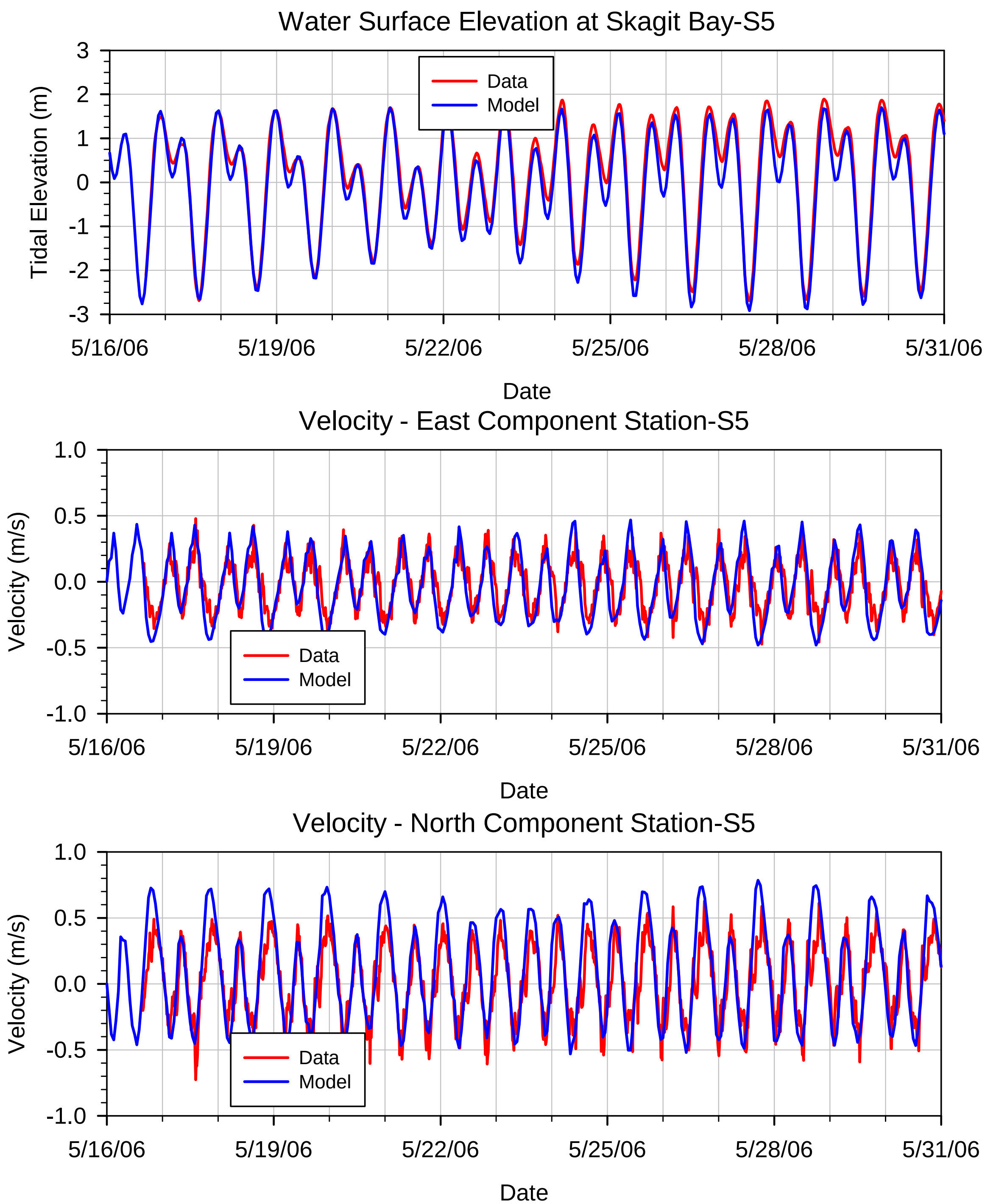
FIGURE 2-15

Comparisons of Tidal Elevations and Velocities at Station S2

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in the Pacific Time Zone.
- Tidal elevation is with reference to the MSL.

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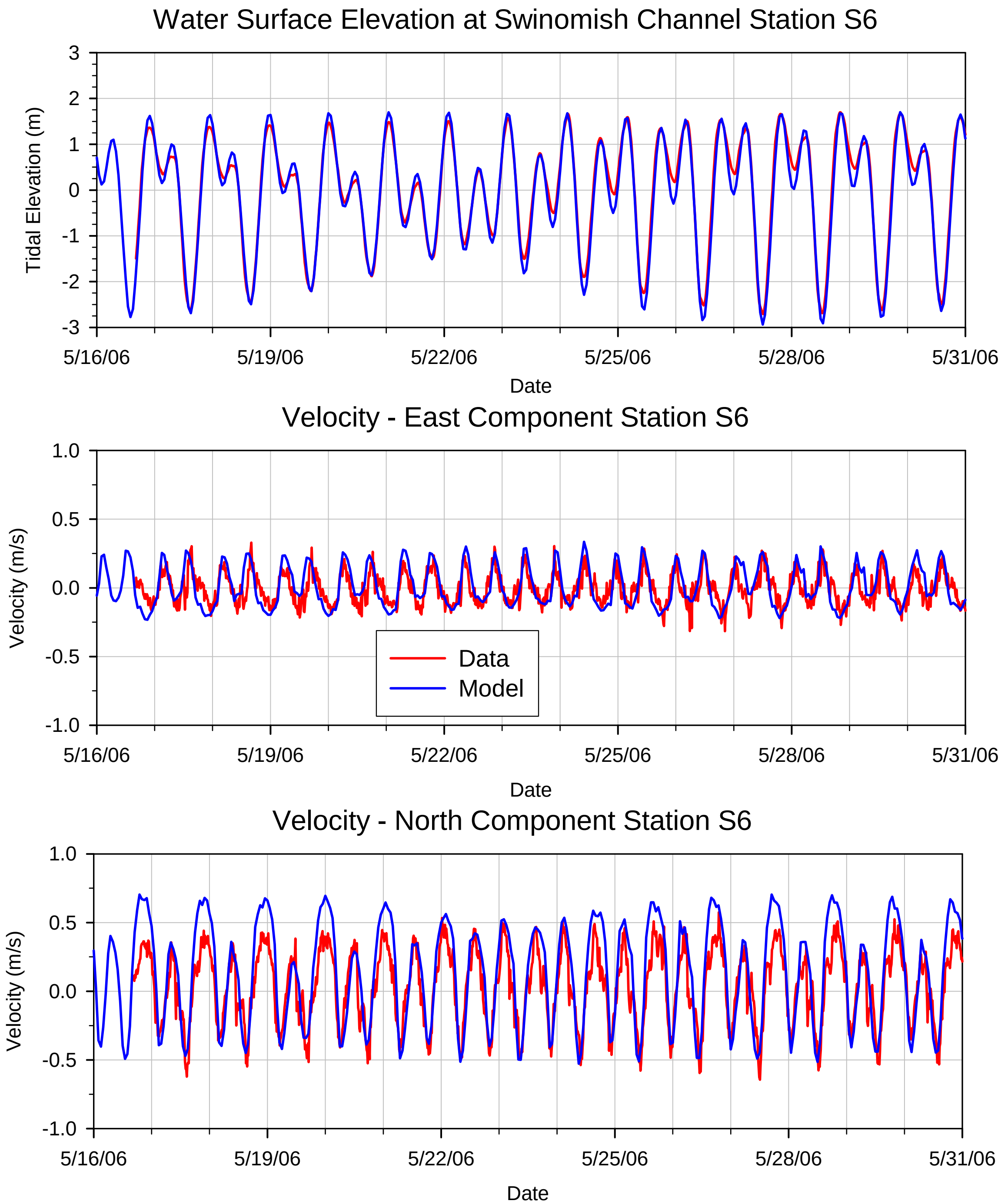
FIGURE 2-16

Comparisons of Tidal Elevations and Velocities at Station S5

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in the Pacific Time Zone.
- Tidal elevation is with reference to the MSL.

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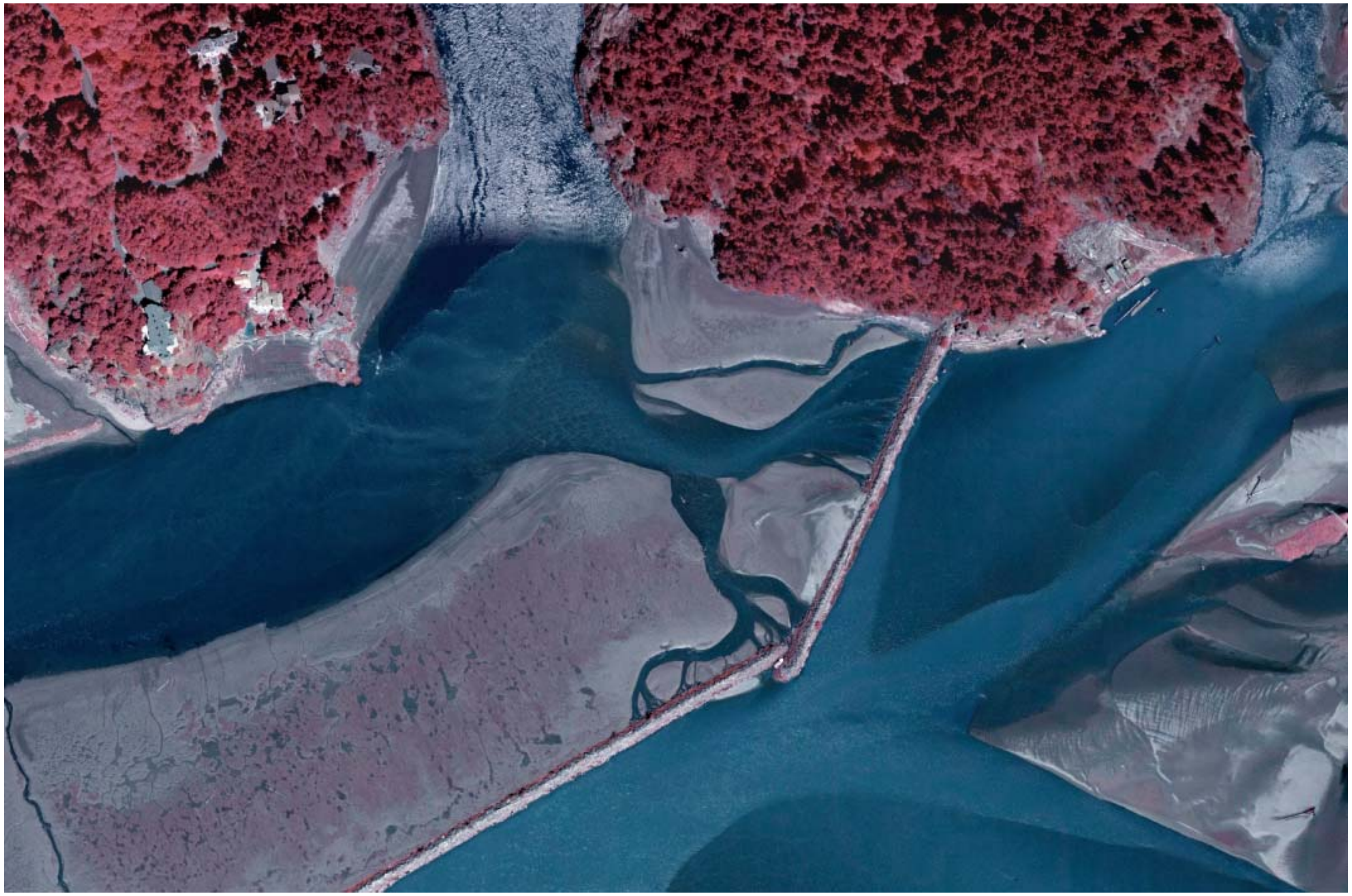
FIGURE 2-17

Comparisons of Tidal Elevations and Velocities at North Fork Skagit River

Skagit River System Cooperative
La Conner, WA



Note:

- Image was provided by SRSC.

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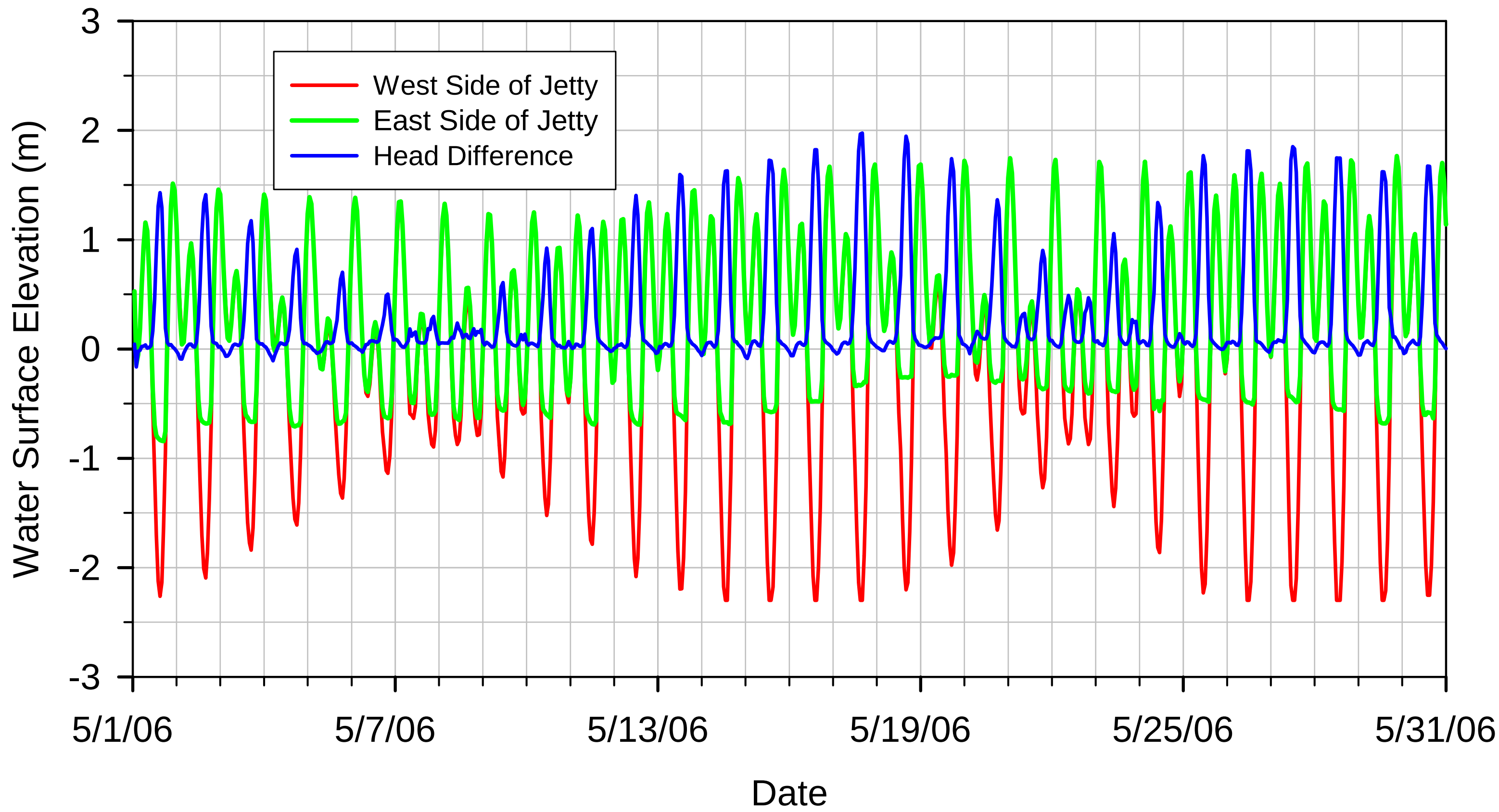
FIGURE 2-18

Leaking Jetty near the South End of the Swinomish Channel

Skagit River System Cooperative
La Conner, WA



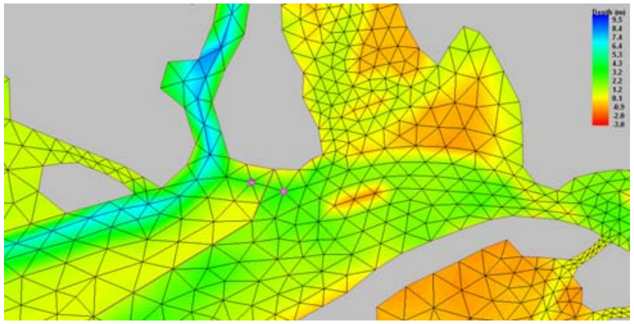


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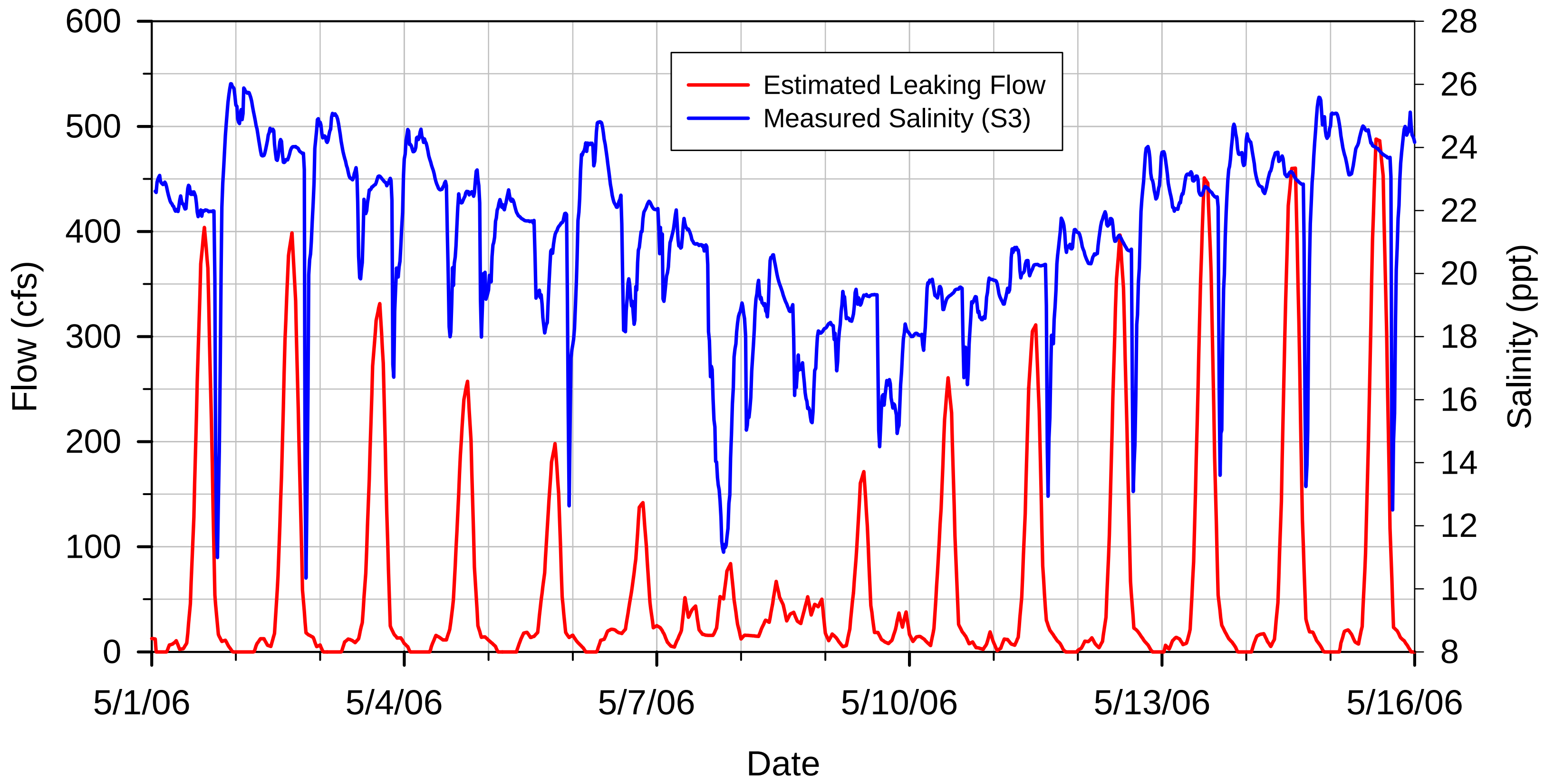
FIGURE 2-19

Predicted Water Surface Elevations at West and East Sides of the Jetty

Skagit River System Cooperative
La Conner, WA



Note:

- Times are in Pacific Time Zone.
- Water-surface elevation is with reference to the MSL.

FIGURE 2-20

Estimated Leaking Flow Through the Jetty

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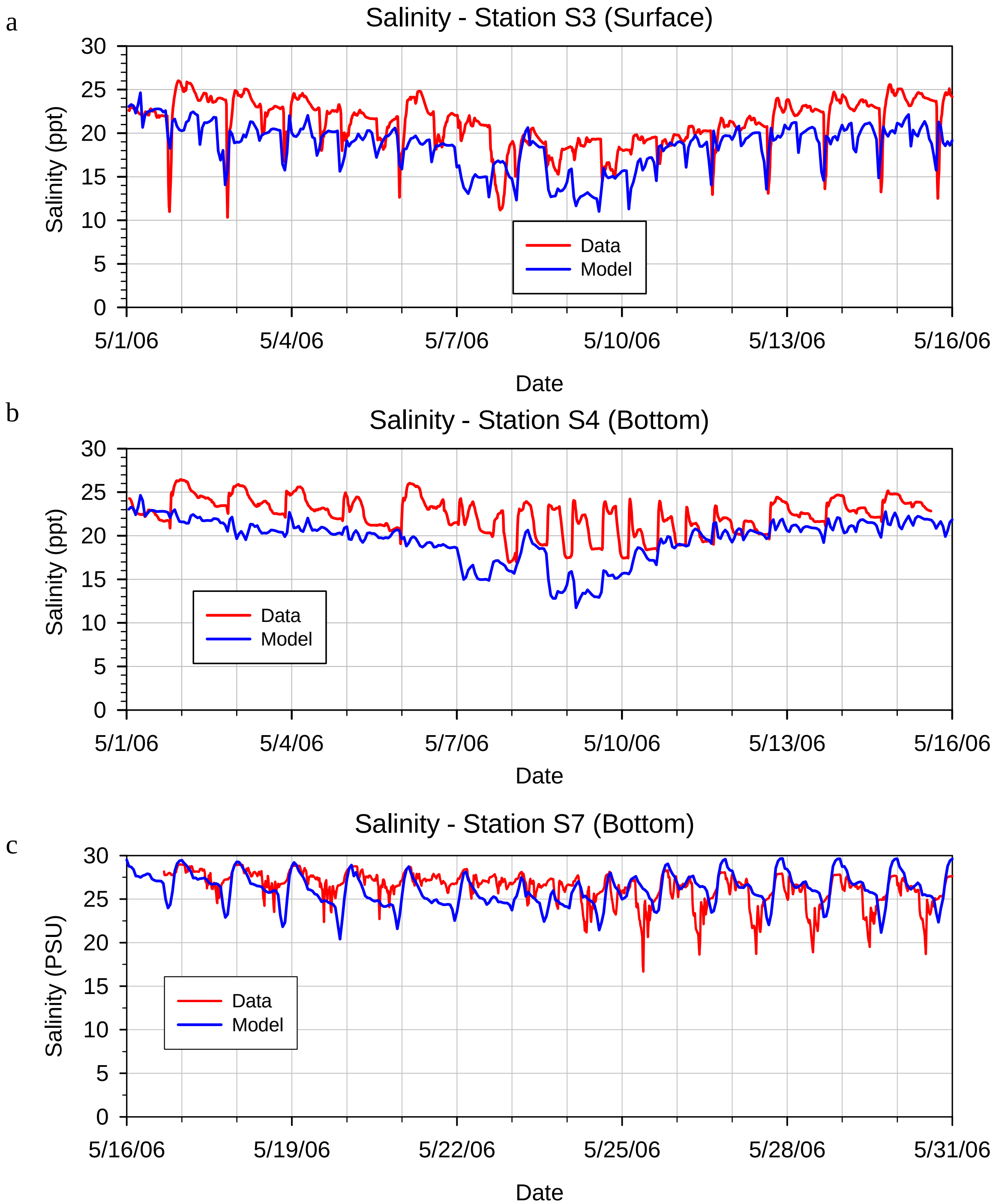

Note:

- Times are in the Pacific Time Zone.
- Tidal elevation is with reference to the MSL.

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FIGURE 2-21 a, b, c

Comparisons of Measured and Predicted Salinities at Stations S3, S4, and S7

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3.0 Model Application for Restoration Alternatives

3.1 Introduction

Once the hydrodynamic model of Skagit Bay was validated with field-data in Skagit Bay and Swinomish Channel for the existing conditions, restoration alternatives for improving salinity distribution in Swinomish Channel were evaluated with the model. One of the key factors for the salmon life cycle is nearshore habitat with availability of low-salinity water (in the range of 5 to 10 ppt) for rearing. In addition to providing direct conveyance from North Fork Skagit River to the Swinomish Channel, restoring low-salinity waters in Swinomish Channel was the desired goal. Both model results and field data for the existing condition showed that the salinity ranges in Swinomish Channel generally are in the range of 15 to 25 ppt, which is much higher than desired for fish habitat. Freshwater discharged from the North Fork currently is restricted by the McGlinn Causeway and the jetty, and is either transported to the south away from Skagit Bay during ebb tide or to the north end of the bay around the jetty during flood tide.

To reduce the salinity in the Swinomish Channel, two restoration alternatives were considered to transport more freshwater from the North Fork to Swinomish Channel. As mentioned above, in addition to providing freshwater, the alternatives would also provide the conveyance for fish migration. The alternatives considered in this study are described below.

1. <u>Alternative 1</u>: Allow additional freshwater discharge to the Swinomish Channel from the North Fork branch during low tide by lowering the jetty elevation or creating an opening in the jetty.

2. <u>Alternative 2</u>: Create a diversion from Dunlap Bay to the Swinomish Channel along the thalweg of the historical natural channel.

The improved Skagit Bay hydrodynamic model was applied to simulate the hydrodynamic and salinity response of the above alternatives. Salinity changes under alternative conditions with respect to existing conditions were compared. Simulations for the restoration alternatives were conducted for the same period as model validation conditions in May, 2006. Model parameters and forcing functions were retained at the same values as those set up during the model validation.

3.2 Model Simulations for Restoration Alternatives

3.2.1 Model Configurations for the Restoration Alternatives

To simulate the restoration alternatives for the McGlinn Island Causeway project, model grid modifications were needed. In Alternative 1, a section of the leaking jetty was completely removed and replaced with a semi-submerged weir with an arbitrary crest elevation. The existing model grid was modified to represent this change. The solid boundary representing the jetty in the existing model grid was partially removed at the north end, and the water bodies on both sides of the existing jetty were connected through new elements. The width of the opening was specified at 60 m, about one-fourth of the existing jetty length. The crest elevation at the location of the existing jetty was set to the same elevation of MSL (1.35 m above NAVD88) representing s a semi-submerged weir. The bathymetry around the existing jetty was retained at the existing condition to avoid additional cost for dredging or construction. Figure 3-1 shows a comparison of model grids and bathymetry between existing and Alternative 1 conditions.

For Alternative 2, a diversion was constructed connecting Dunlap Bay and the Swinomish Channel along a natural historical channel in Dunlap Bay. This diversion provides direct conveyance and allows freshwater from North Fork branch to enter the Swinomish Channel during ebb tide. The width of the diversion channel is about 50 m, similar to the widths of the natural tidal channels typically observed in the marsh area near the mouth of North Fork. The depth of the diversion is specified as 1.0 m below MSL. Figure 3-2 shows a comparison of model grids and bathymetry between existing and Alternative 1 conditions.

3.2.2 Model Simulations for the Restoration Alternatives

Model forcing, boundary conditions, and model parameters were set at the same values as in model validation, except the leaking flow was not considered in Alternative 1 because it was assumed that the leaking jetty would be completely reconstructed in this alternative. The model was applied for the period from May 1 to May 16, 2006.

The flow rates for discharges into the Swinomish Channel were back-calculated for both alternatives based on model response. Figure 3-3 shows the predicted flow rates and the depth-averaged salinity at the opening of the jetty. The maximum flow rate was about 1,500 cfs. Freshwater was discharged into the Swinomish Channel most of the time, especially during neap tide. Reverse flow from the Swinomish Channel to the North Fork River was observed during spring tide. The salinity of the reverse flow was generally below 10 ppt because of mixing between the freshwater from the Skagit River and the existing Swinomish Channel water. In Alternative 2, the flow rate discharged into the Swinomish Channel was similar to Alternative 1 with a maximum flow rate of 1,500 cfs. However, the reverse flow was stronger than that in Alternative 1 (see Figure 3-4). The salinity corresponding to the reverse flow was also higher than that in Alternative 1, which could reach as high as 20 ppt because of the influence from the northern open boundary condition at Padilla Bay (25 ppt).

To evaluate the effects of restoration alternatives on the salinity distribution in the Swinomish Channel, surface salinity time histories were compared between existing and alternative conditions at selected locations. Figure 3-5 shows four locations selected for comparisons of model results. Stations C1 and C2 were located at the south end and north end of both restoration sites, respectively. Station C3 was located at the midpoint of the Swinomish Channel, and Station C4 was located near the north end of the Swinomish Channel. Figures 3-6 to 3-9 show comparisons of salinity time histories at the four locations. Salinity distributions were very similar between Alternative 1 and 2 at all the locations. This was expected because the freshwater discharge rates were similar for the two alternatives. Salinities at Station C1 in the restoration conditions were reduced about 2.0 ppt compared to existing conditions. Significant drops in salinity were observed for both alternative conditions at Station C2. Salinity reduction as much as 10 ppt was observed during ebb tides. Moving towards the north, the magnitude of the salinity-reduction benefit decreased. At Stations C3 and C4, salinities for both existing and alternative conditions merged together during high tides and reached their maximum of 25 ppt during these high tides, which was controlled by the open boundary condition at the north end of the Swinomish Channel. However, salinity reduction could still be as much as 5 ppt at Station C3 and Station C4 during low tides. This indicated that salinity reduction was not persistent all the time in the Swinomish Channel. The freshwater discharged from either restoration alternative (jetty opening—Alternative 1 or Dunlap Bay diversion—Alternative 2) was isolated between each tidal cycle and transported to the north of the Swinomish Channel with the tides.

Alternative 1 | Existing Condition

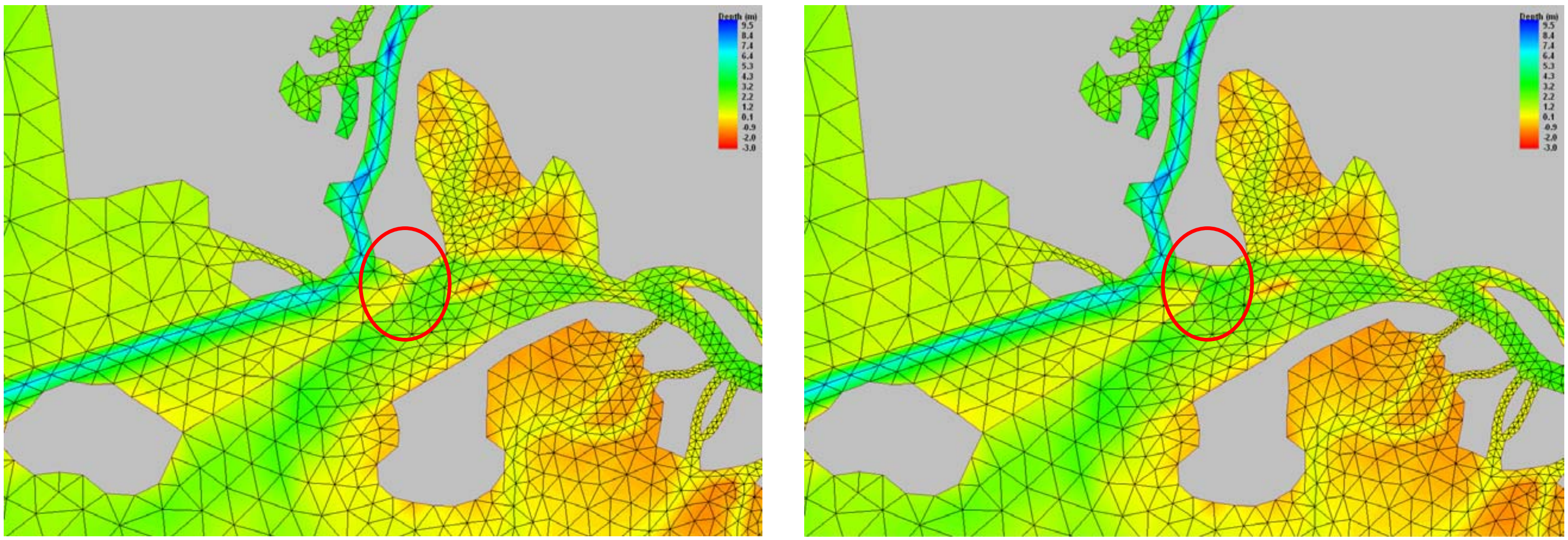

FIGURE 3-1

Alternative 1—Opening at the North End of the Existing Leaking Jetty

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Alternative 2

Existing Condition

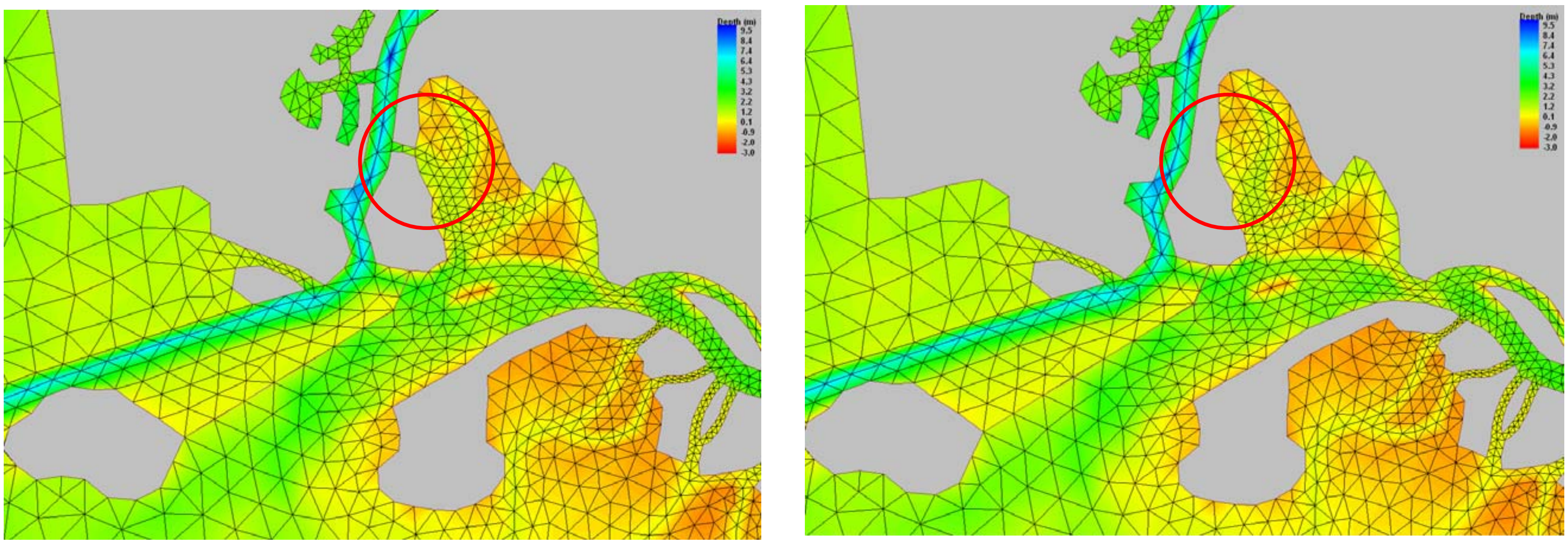

FIGURE 3-2

Alternative 2—Diversion Connecting the Dunlap Bay and the Swinomish Channel

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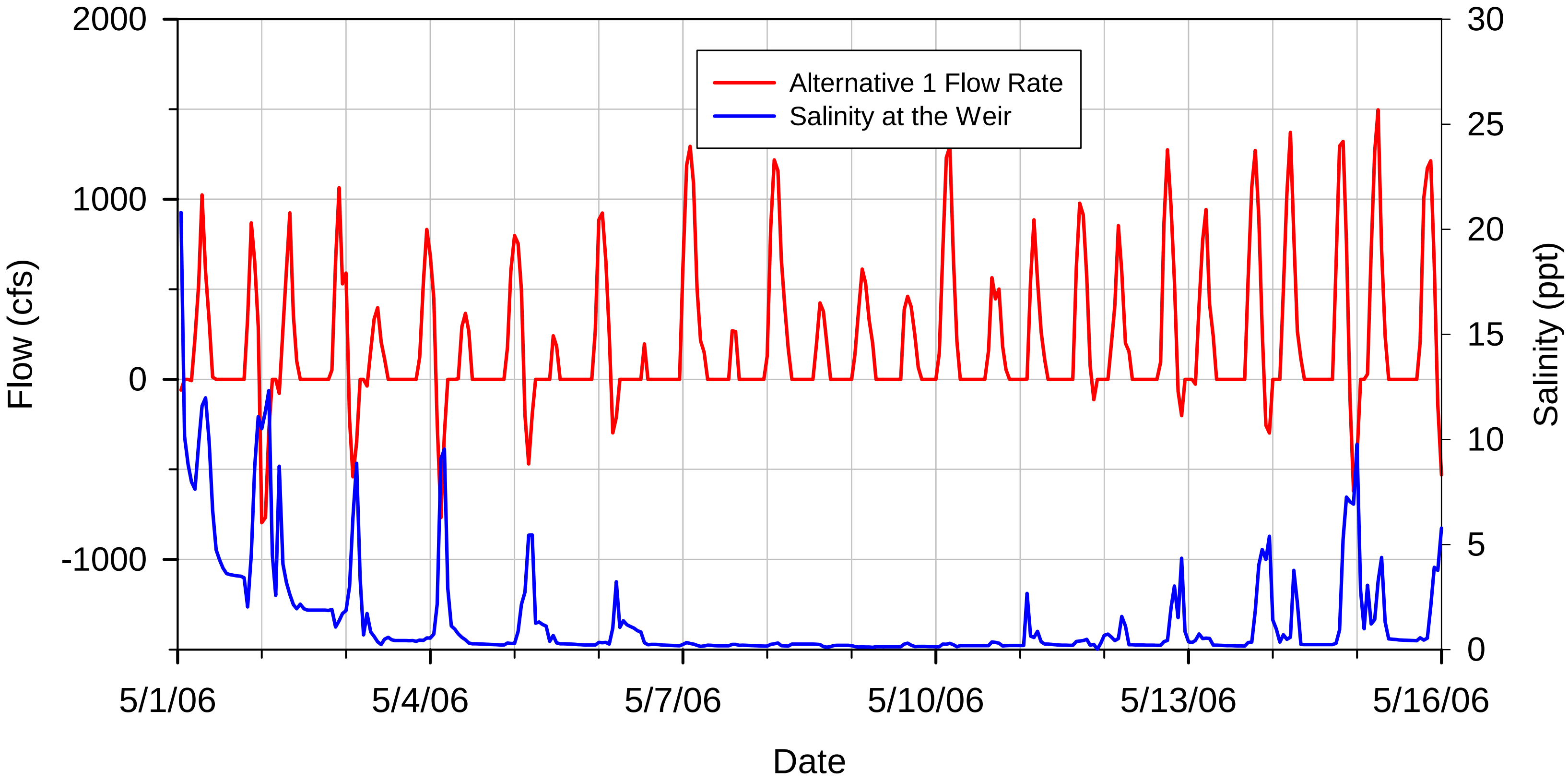

Note:

- Times are in the Pacific Time Zone.
- Positive Flow is towards the Swinomish Channel.

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FIGURE 3-3

Predicted Flow and Salinity Across the Weir

Alternative 1

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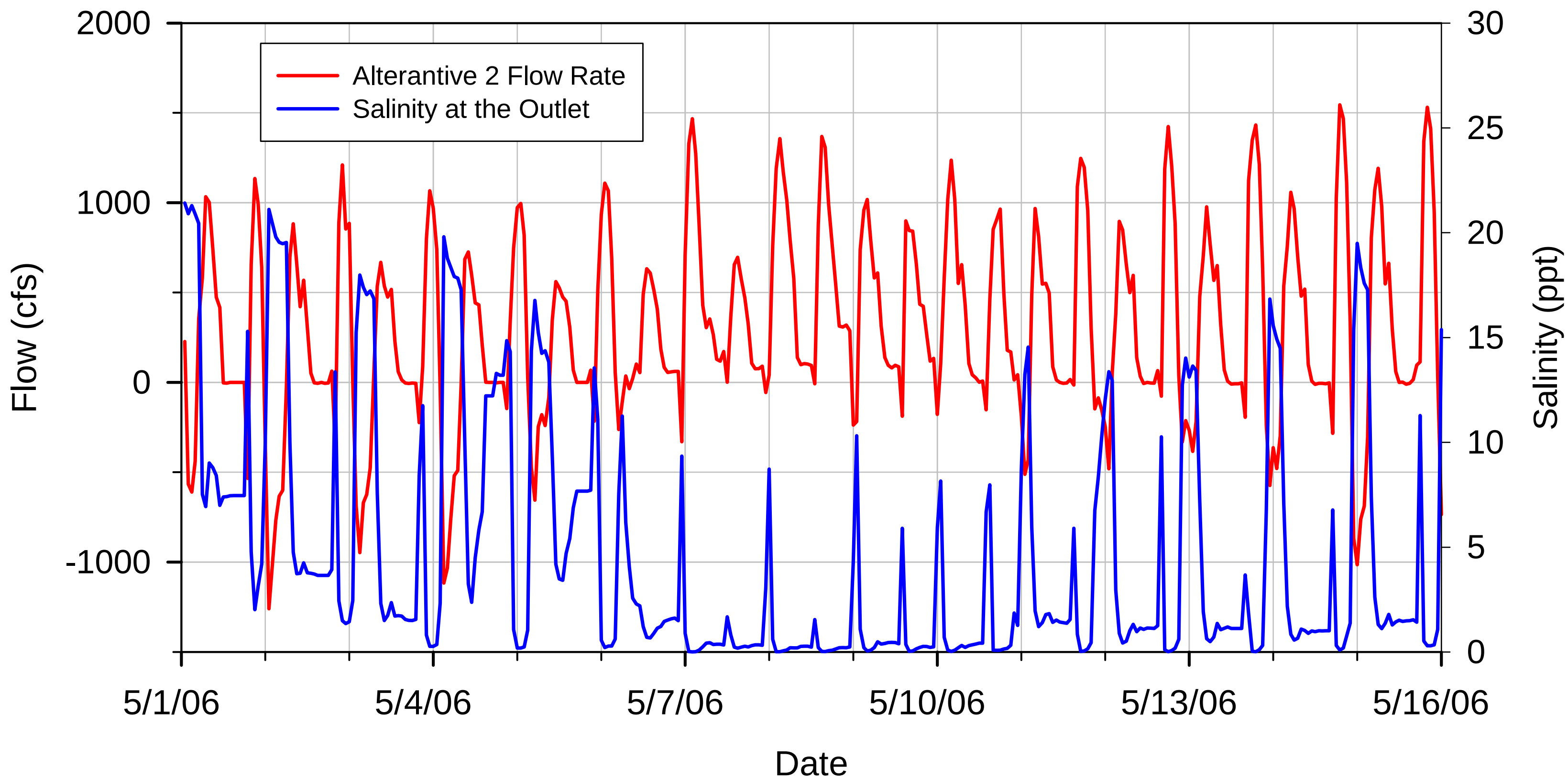

Note:

- Times are in the Pacific Time Zone.
- Positive Flow is towards the Swinomish Channel.

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FIGURE 3-4

Predicted Flow and Salinity Through the Diversion

Alternative 2

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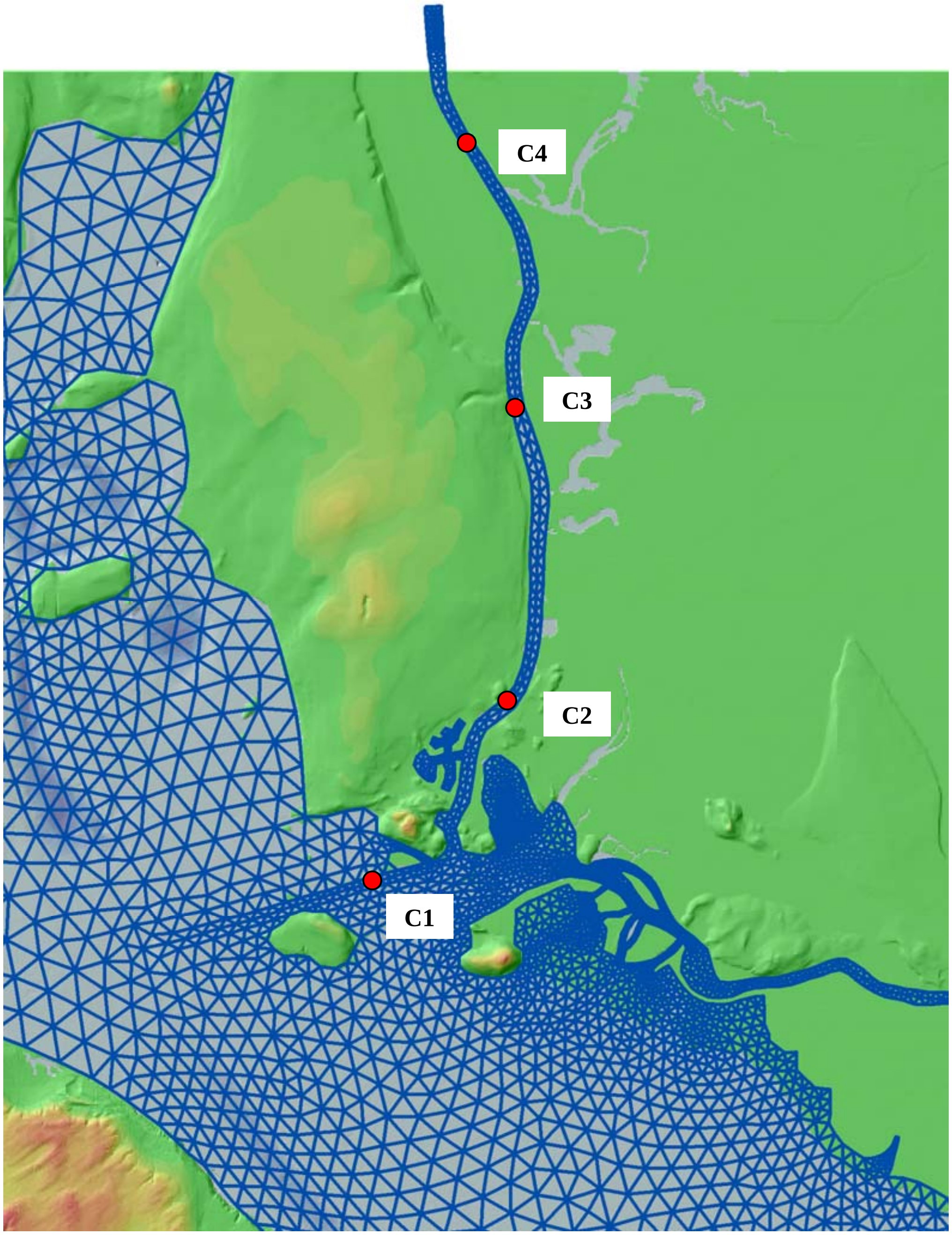

FIGURE 3-5

Selected Locations for Salinity Comparisons

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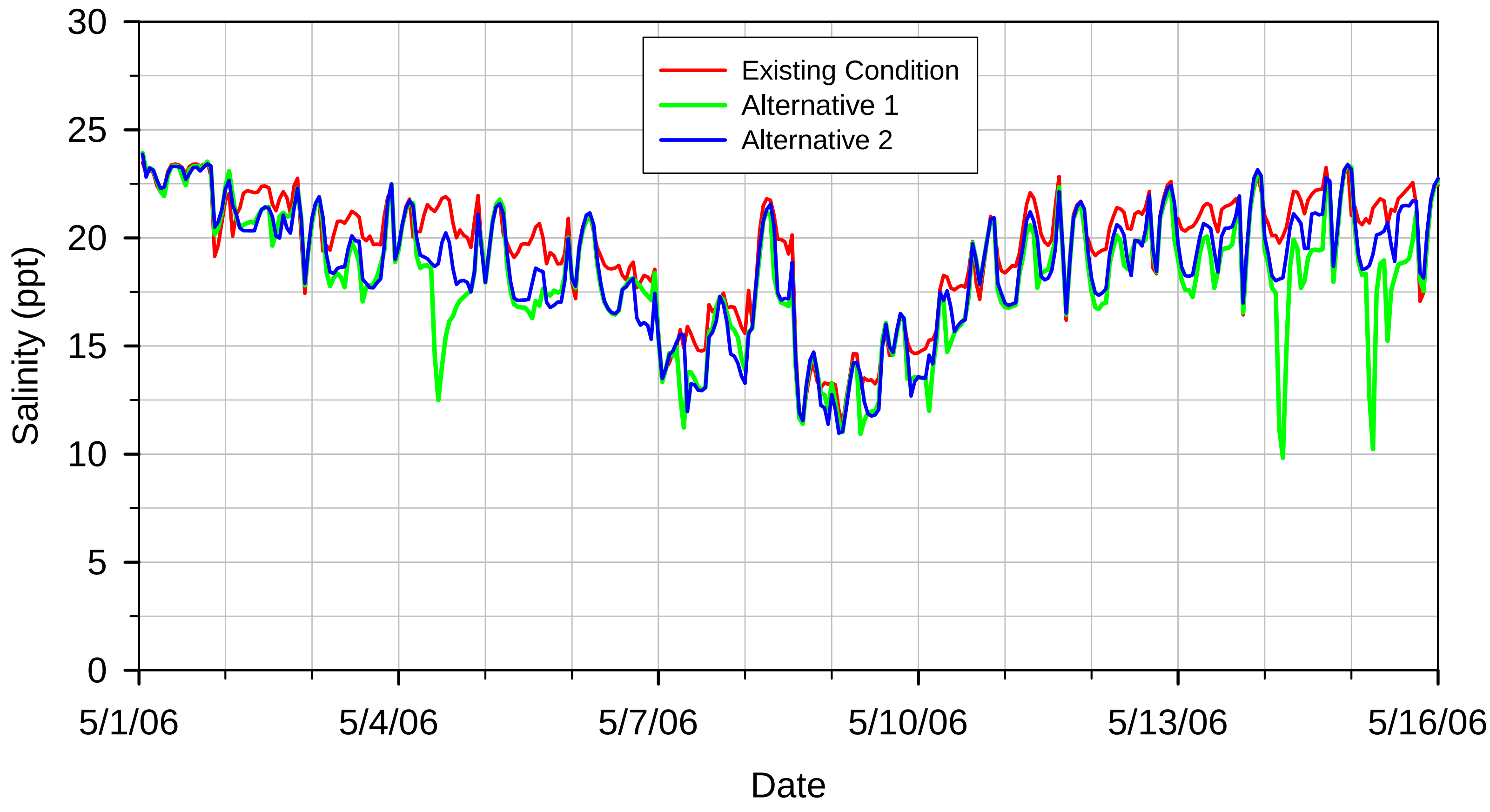

Note:

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FIGURE 3-6

Comparison of Predicted Surface Salinity
Time Series at Station C1

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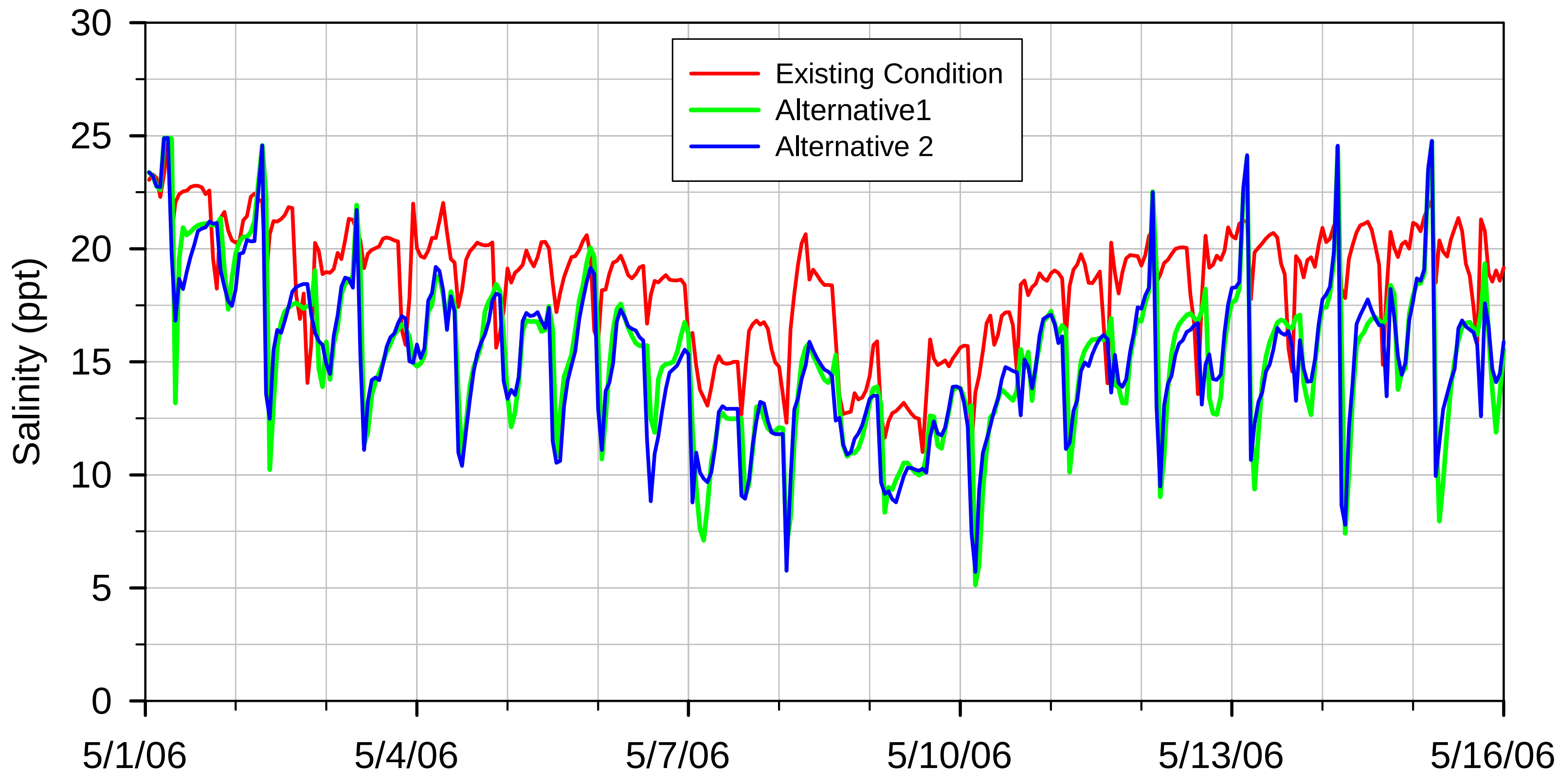

Note:

- Times are in the Pacific Time Zone.

FIGURE 3-7

Comparison of Predicted Surface Salinity
Time Series at Station C2

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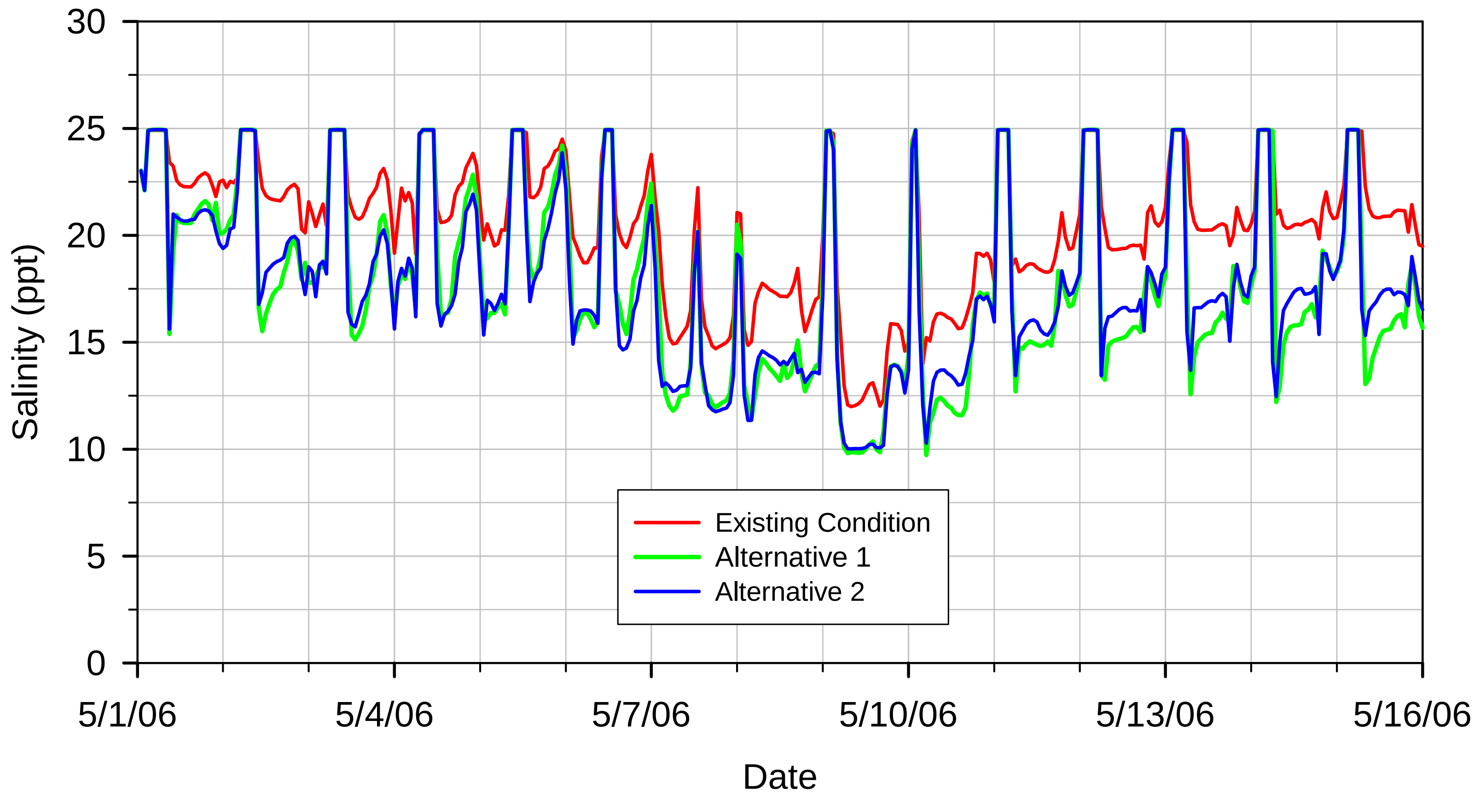

Note:

- Times are in the Pacific Time Zone.

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FIGURE 3-8

Comparison of Predicted Surface Salinity
Time Series at Station C3

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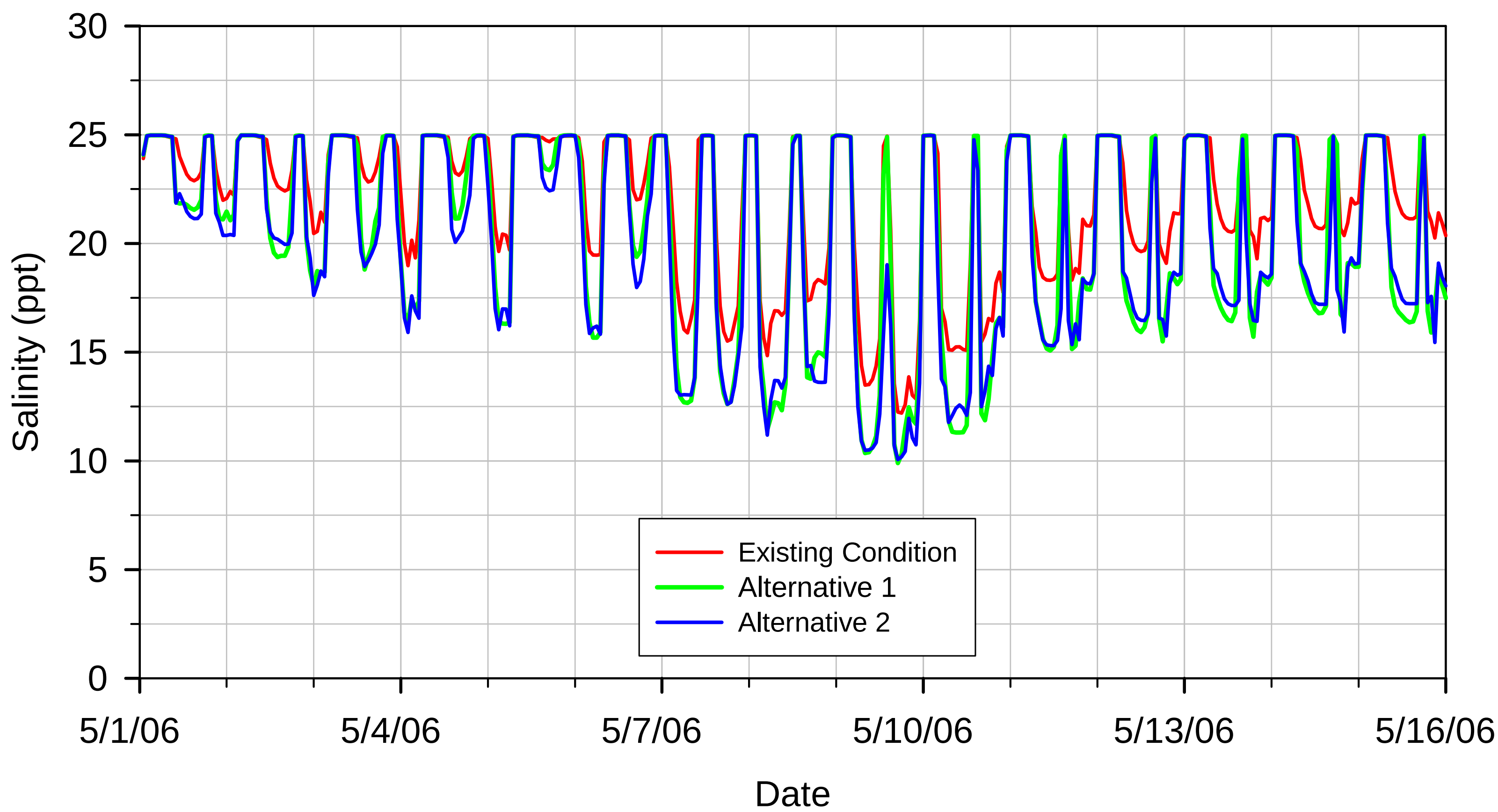

Note:

- Times are in the Pacific Time Zone.

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FIGURE 3-9

Comparison of Predicted Surface Salinity
Time Series at Station C4

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4.0 Conclusions

The overall conclusion of this modeling study is that it is feasible to improve salinities in the Swinomish Channel using either alternative considered in this study. Alternative 1 would allow freshwater discharge to the Swinomish Channel from the North Fork branch of the Skagit River during low tide by lowering the jetty elevation or creating an opening in the jetty. Alternative 2 would create a diversion from Dunlap Bay to the Swinomish Channel along the thalweg of the historical natural channel. Field-measured salinity data showed a sharp freshwater signal in the Swinomish Channel during ebb tides. It was observed that this sharp salinity drop every day during low tides was due to the leaking jetty next to McGlinn Island. The leaking flow rate was estimated by a trial-and-error approach by matching the model results to the data. The effect of the leaking jetty was simulated using the source and sink option flow in the FVCOM model. To simulate the effect of the leaking jetty accurately, further refinement of model bathymetry and the grid, as well as the observed leaking flow rate as a function of water surface elevation, are required.

Although salinities in the Swinomish Channel could be improved, model results did not show evidence that a thin, fresh water lens could exist persistently at the water surface despite the availability of additional freshwater. Vertical distribution of salinity in the Swinomish Channel ranged from relatively well-mixed to partially stratified.

5.0 References

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