MEMORANDUM

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Date:	**April 18, 2011**	Project No.:	**58343**
To:	**Dave Cline, Shannon & Wilson, Inc., WA**		
From:	**Zhaoqing Yang and Taiping Wang – PNNL**	Internal Distribution:	**Tarang Khangaonkar**
Subject:	**Hydrodynamic Modeling Analysis of Fir Island Farm Restoration – Baseline Condition**		

1 Introduction

Shannon & Wilson Inc. (S&W) contracted Battelle to provide hydrodynamic modeling analysis and consulting support in connection with Fir Island Restoration Feasibility Study. The modeling support consists of three tasks: 1) Hydrodynamic Modeling of Baseline Conditions; 2) Hydrodynamic Modeling of the Preferred Alternative and 3) Meeting Attendance.

This memorandum summarizes the modeling effort and results associated with the first task – hydrodynamic modeling of the baseline conditions. Model setup, data used, model forcing inputs and model outputs including time series of water surface elevations, salinities and velocities at selected locations near the project site are presented. Horizontal two-dimensional distributions of velocity vector and salinity at flood, ebb, low and high tides are also provided.

2 Model Setup

The Fir Island Farm project is located in the bay front of Skagit Bay (Figure 1). The model grid for project site was developed based on the existing Skagit Bay hydrodynamic model developed by PNNL[1]. A fine grid mesh with spatial resolution of meters was created for the project site. To further eliminate the effect of open boundary on the circulation and freshwater plume dynamics,

[1] **Yang, Z.**, and T. Khangaonkar, 2009. Modeling Tidal Circulation and Stratification in Skagit River Estuary Using an Unstructured Grid Ocean Model. *Ocean Modelling*, 28, 34-49. doi: 10.1016/j.ocemod.2008.07.004.

especially during high flow condition, the Skagit Bay open boundary was moved further down south to Green Bank in Saratoga Passage (Figure 2). Model bathymetry was updated with LIDAR data provided by Shannon & Wilson and survey data collected by S&W in the project site. The model consists of 20,454 nodes and 38,400 elements, and 10 uniform vertical layers. The average grid size inside the Fir Island Farm project site is about 16 m.

The model was set up for the existing condition for the period from 3/15/2003 to 4/15/2003, as requested by the project team. Tidal elevations along the open boundaries were obtained from XTide prediction (Figure 3). Skagit River flow at Mt. Vernon and wind stick from 3/15/2003 to 4/15/2003 are shown in Figures 4 and 5 respectively. The mean flow for the simulation period is 18,905 cfs, which is higher than the long-term mean of 15,000 cfs for March-April period, and significantly higher than the mean flow of 9,443 cfs during the S&W data survey period (91/2010 – 9/17/2010). Salinity boundary conditions were specified as 30 ppt at all the open boundaries through the water column. Initial conditions for water surface elevation, velocity and salinity were all set to zero.

Runoff stream flows (Brown Slough, No Name Slough and Dry Slough) in the project site were very small and assumed to be zero in the baseline simulation. There are a few of tide gates located in the study area along Brown Slough, Dry Slough and Claude O'Davis Slough. The configurations of the tide gates are listed in Table 1 and the location of the tide gates are shown in Figure 6. Most of the tidegates were flap tidegate that only allow flows out from upstream of the slough to the Skagit Bay front. There are two open tidegates in Claude O'Davis Slough that regulate flows internally within the project site and are locateed upstream of the flap tidegate in Claude O'Davis Slough. The model was configured with all the tidegates listed in Table 1. Because the small stream flows were assumed to be zero in the baseline condition, no flows were discharged through the tidegates in the simulation.

Table 1 Configurations of tide gates in the study site

ID	Name	Location	Gate/Open	Type of Gate	Size (in)	Inlet I.E. (ft)	Outlet I.E. (ft)	Length (ft)
1	East Culvert	Browns-Bay Dike	Tidegate	Screwgate	48	4.74	1.93	56.00
	Middle Culvert	Browns-Bay Dike	Tidegate	Flap-top	48	5.77	2.93	56.00
	West Culvert	Browns-Bay Dike	Tidegate	Flap-top	48	5.77	2.68	56.00
2	Mouth of Slough	Claude O' Davis	Open		15	3.14	2.12	21.00
3	South Drainage Channel	Claude O' Davis	Open		48	1.66	1.30	21.00
4	Bay Dike North	Claude O' Davis	Tidegate	Flap-top	48	0.45	0.76	59.00
	Bay Dike South	Claude O' Davis	Tidegate	Flap-top	48	0.23	0.42	59.00
5	McDonald Slough2	Dry Slough	Tidegate	Flap-top	36	0.74	0.67	24.00
6	Bay Dike (East)	Dry Slough	Tidegate	Flap-top	48	0.26	0.12	99.00
	Bay Dike (West)	Dry Slough	Tidegate	Flap-top	48	0.97	0.95	97.00

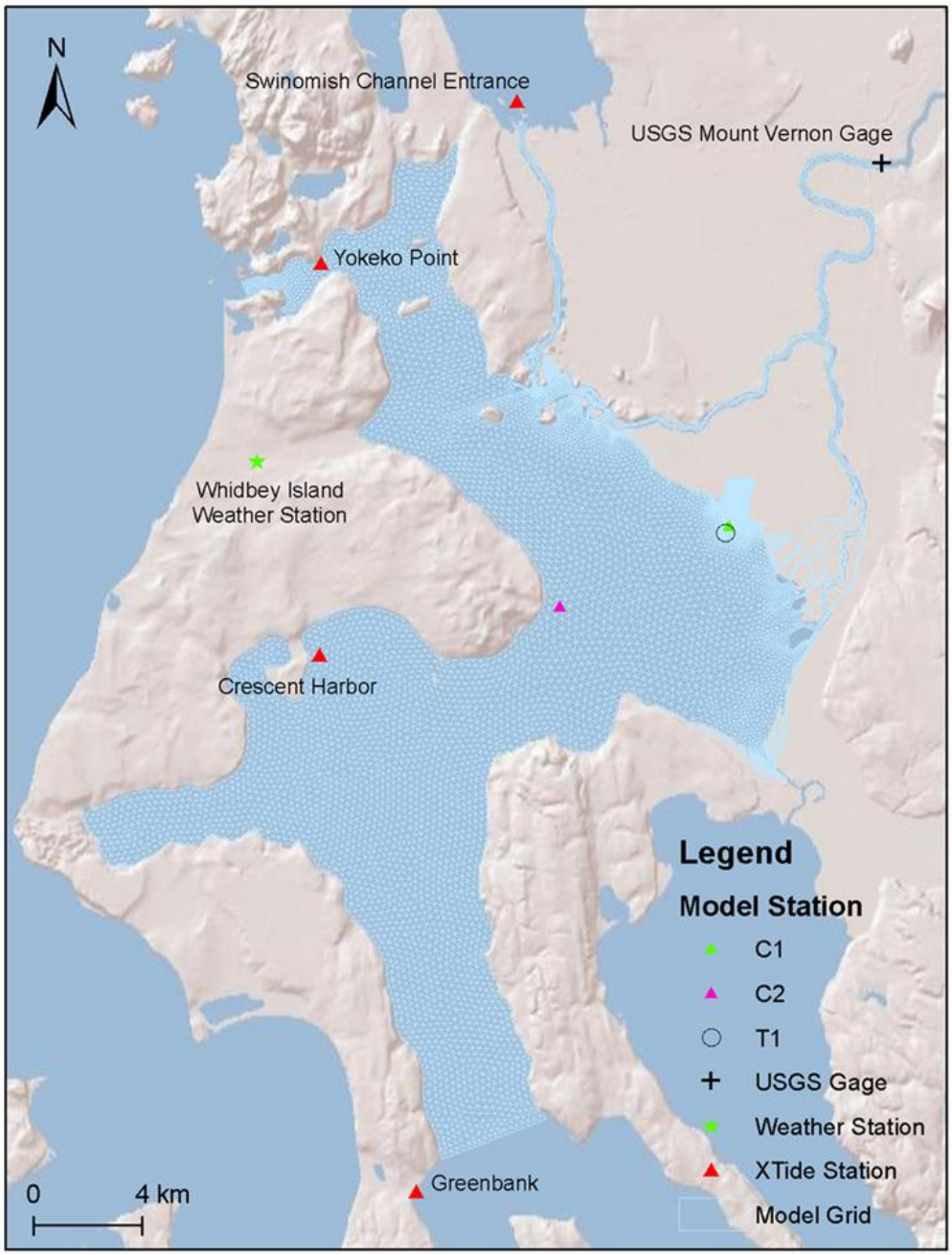

Figure 1 Study area – Skagit Bay and Fir Island Farm

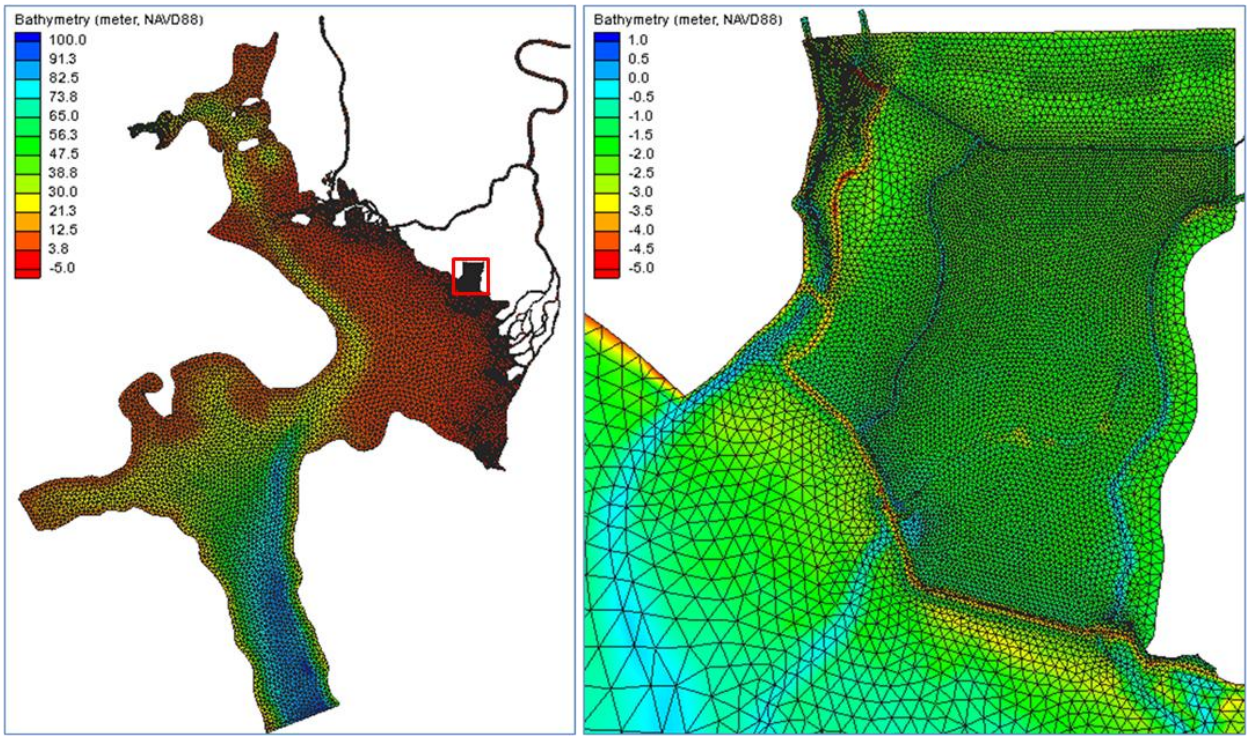

Figure 2 Model Grid of the Skagit River Estuary (with zoom-in of the project site)

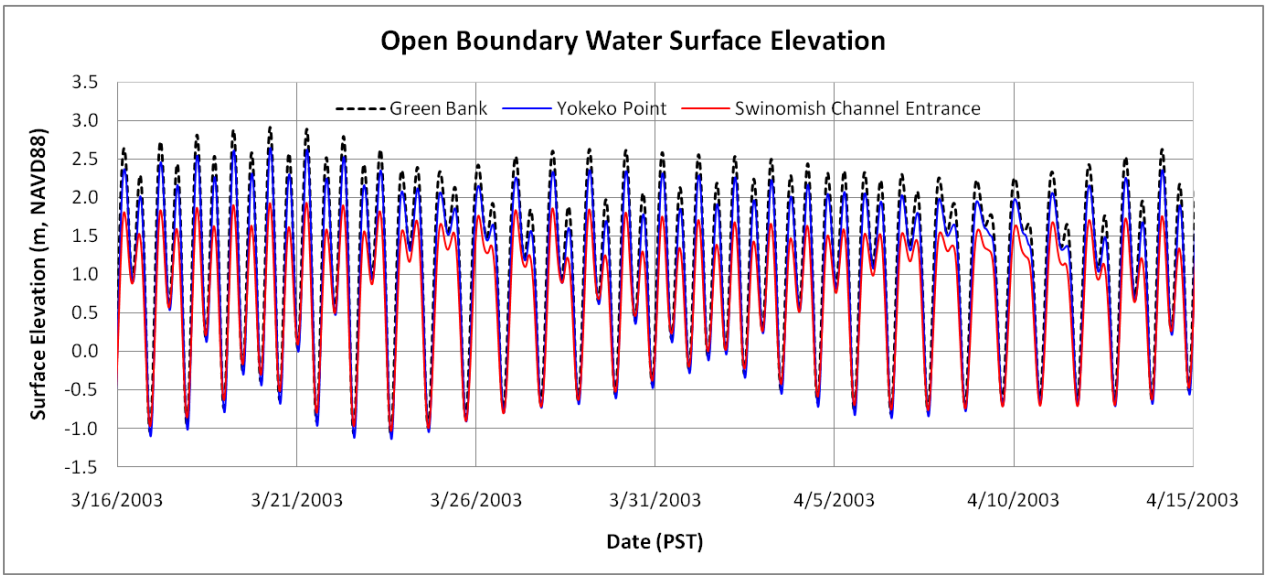

Figure 3 Tidal Elevation along the open boundaries for the period from 3/16/2003 to 4/15/2003

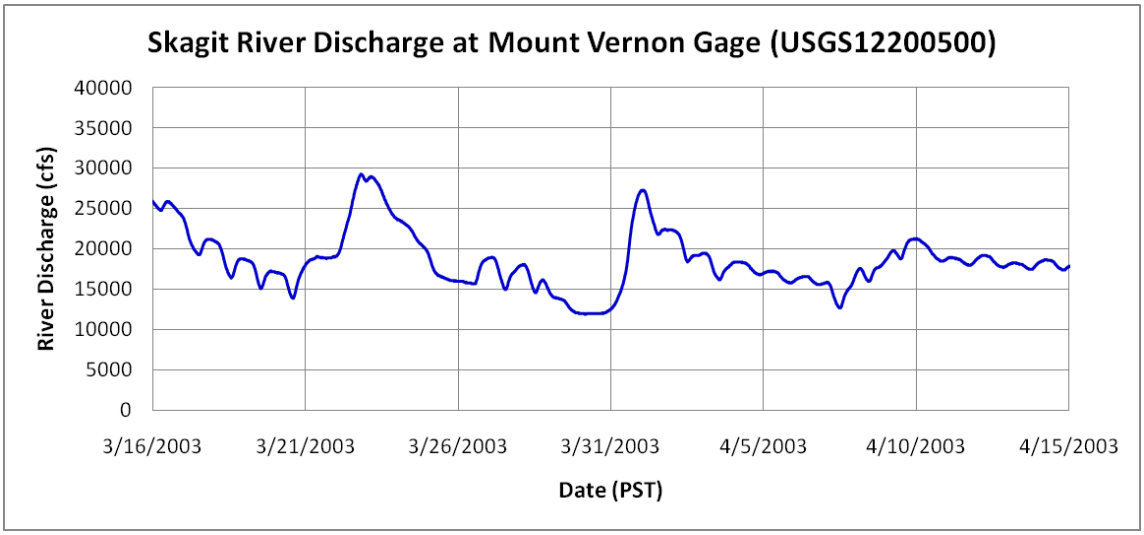

Figure 4 Skagit River flow for the period from 3/16/2003 to 4/15/2003

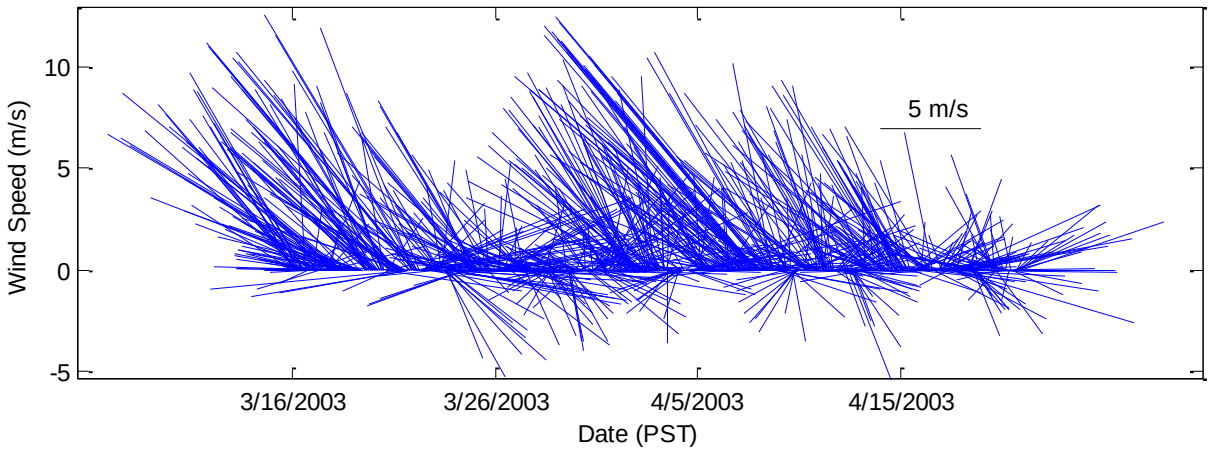

Figure 5 Wind stick for the period from 3/16/2003 to 4/15/2003 from Whidbey Island weather station

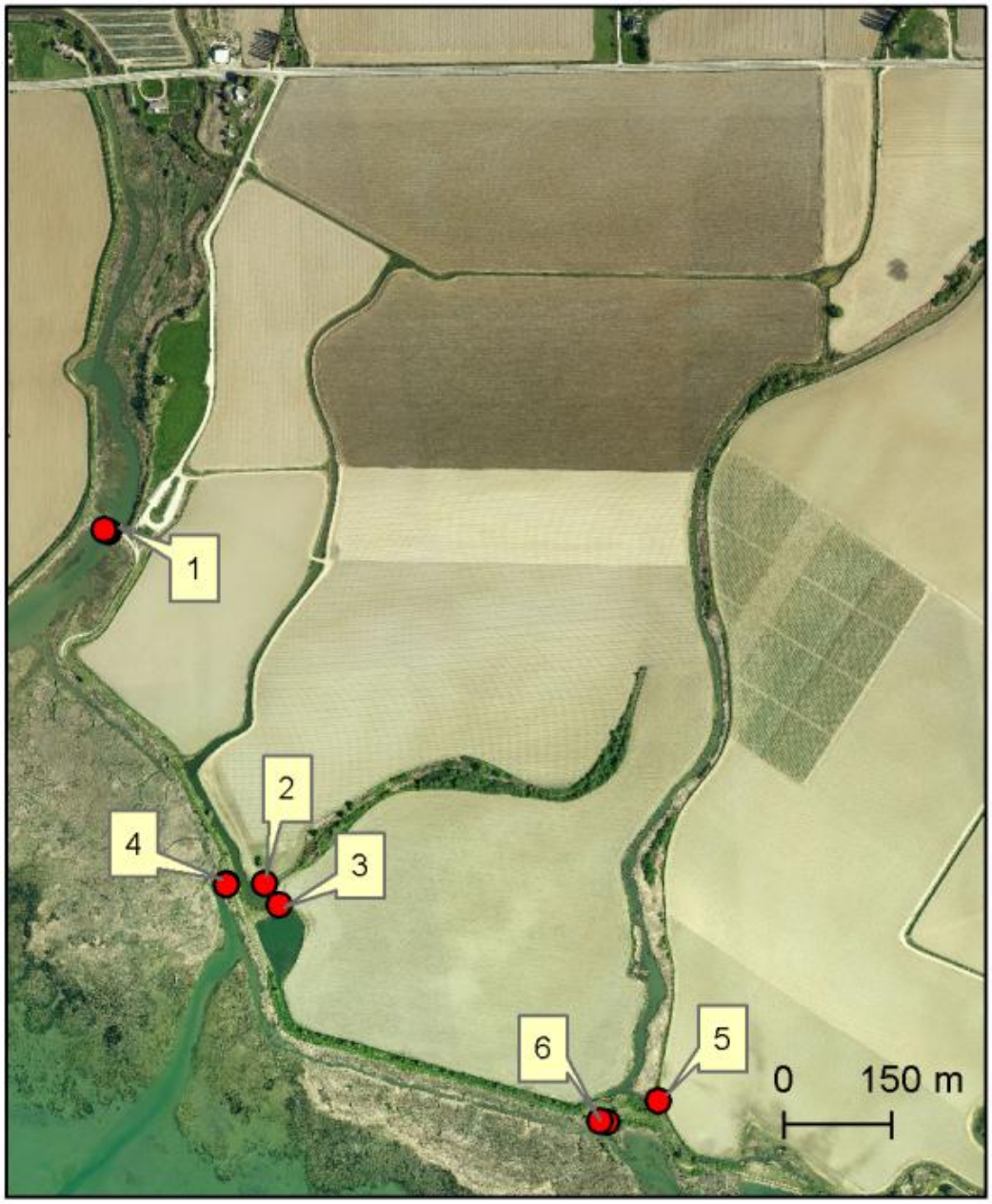

Figure 6 Locations of tidegates in the project site

3 Model Results

The Skagit Bay and Estuary model has been calibrated in previous studies for different periods (Yang and Khangaonkar, 2009). In this study, we re-validated the model performance by comparing the predicted water surface elevation to the XTide data at Crescent Bay in the model domain (Figure 1). Comparison of model results and XTide data is shown in Figure 7. The good agreement between model results and XTide data indicates that the updated model with Fir Island Farm is able to predict tides in Skagit Bay accurately.

Water surface elevation and salinity time histories at a bay front location near the project site (T1 in Figure 1) for a two-week spring-neap tidal cycle are shown in Figure 8 and 9. It is seen that water surface elevation was affected by tide flats during low tide. Depth average salinity at the same location showed large temporal variations over each tidal period, peaking up to 14 ppt during high tides and dropped down to zero during low tides (Figure 9). There was little salinity stratifications over the simulation period because of the shallow water depth near the project site.

Depth-average velocity at station C1 that is adjacent to T1 was plotted in Figure 10. Positive values indicated flood tides. Velocities at C1 were small, generally within 0.2 m/s (0.6 ft/s) and dominated by flood currents. Velocities during ebb and low tides were basically zero because the grid cell became dry as tidal elevation dropped below the ground elevation of the grid cell. For comparison, velocities at C2 station in the main channel of Skagit Bay (Figure 1) are shown in Figure 11. It is seen that tidal currents demonstrate strong diurnal inequality and spring-neap tidal cycle, with slight flood-tide dominance.

Depth-average horizontal two-dimensional (2D) velocity and salinity distributions were generated and examined in Skagit Bay at four different tidal phases. Figure 12 shows the depth-average salinity and velocity distribution at low tide. Significant part of Skagit Bay was occupied by the Skagit River plume with salinity below 5 ppt during low tide. Large areas of tide flats were shown (blank areas) in the model results and velocities in the tide flat region were very small. At flood tide, velocities in Skagit Bay increased and the freshwater plume was pushed shoreward (Figure 13). At high tide, brackish water only remained in a very narrow region along the bay front dikes (Figure 14) and velocities in the bay became small (slack before ebbing). Salinity and velocity distributions at ebb tide are shown in Figure 15.

To further examine velocity distributions near the project site. Zoom-in plots of depth-average velocities with large velocity scale at low, flood, high and ebb tides were generated and presented in Figures 16 to 19. The light blue areas represent wetted cells.

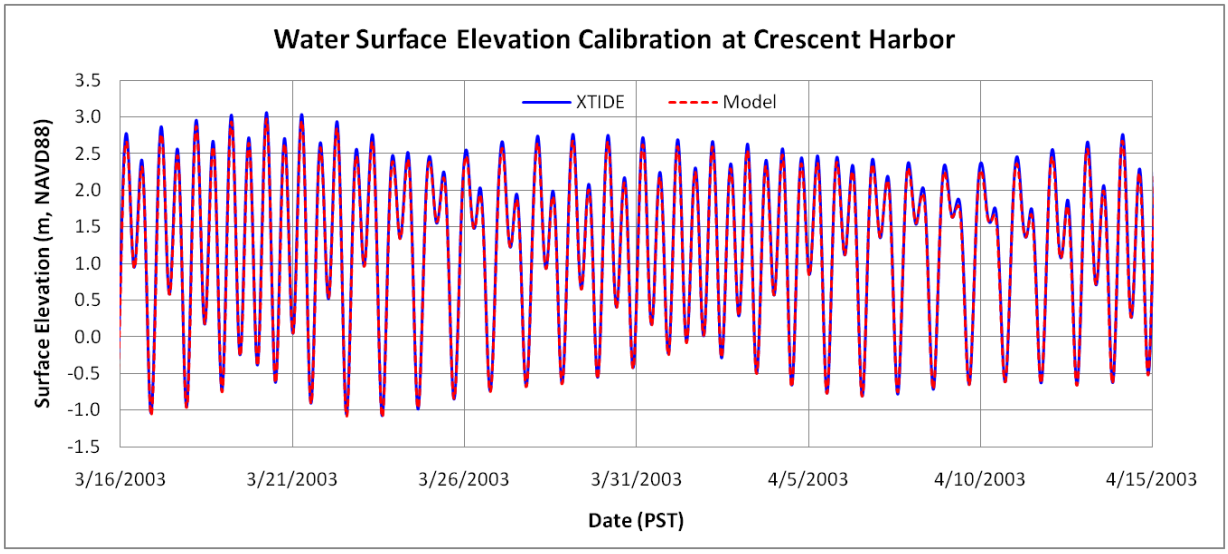

Figure 7 Water surface elevation time series comparison at Crescent Harbor station

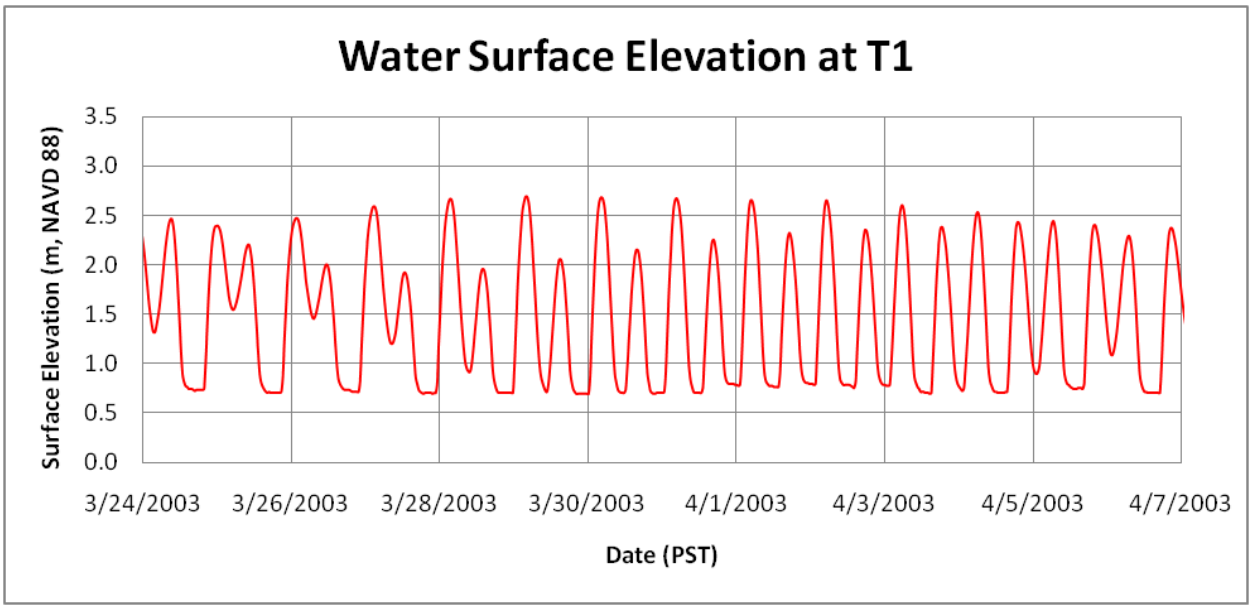

Figure 8 Water surface elevation time series at station T1

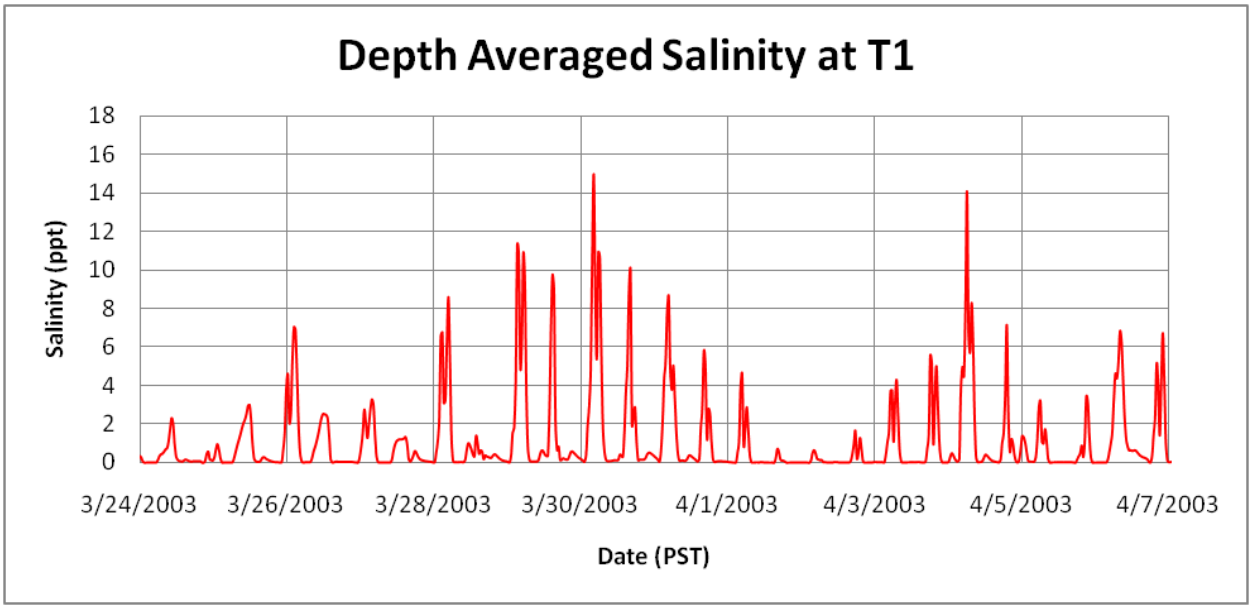

Figure 9 Water surface elevation time series at station T1

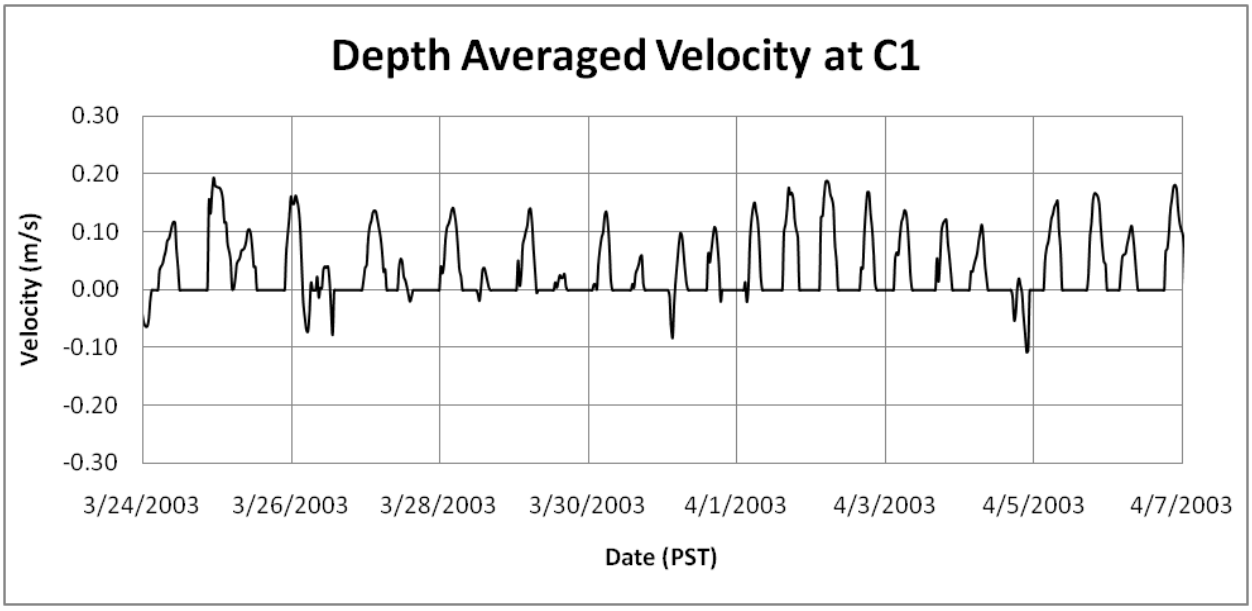

Figure 10 Depth-average velocity time series at station C1 (positive = flooding)

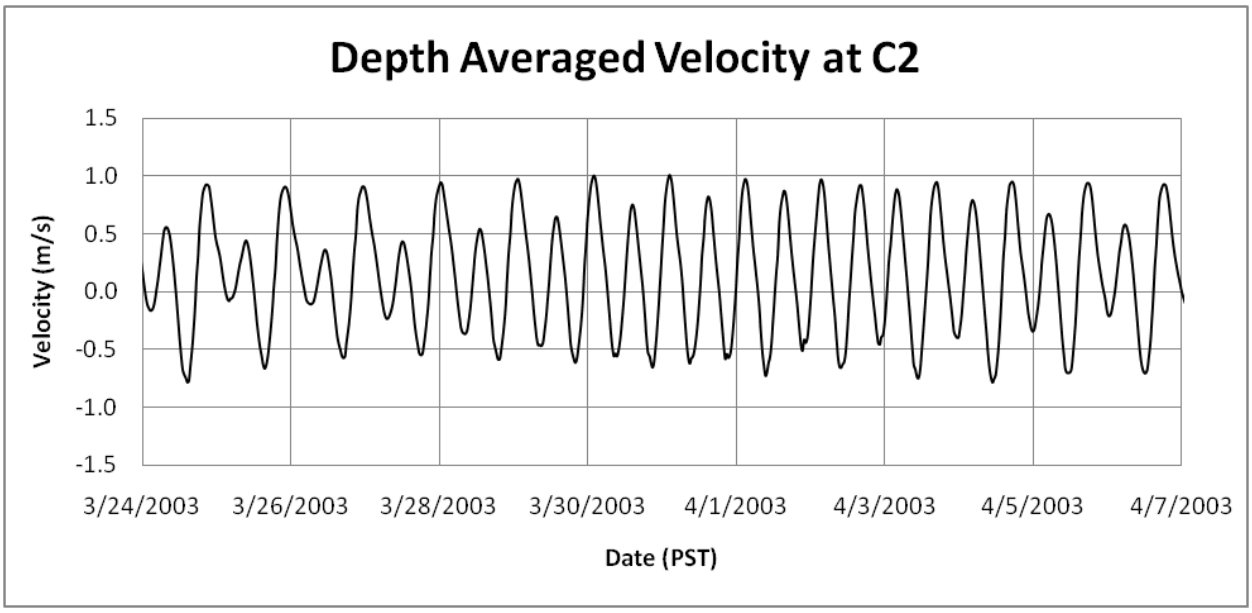

Figure 11 Depth-average velocity time series at station C2 (positive = flooding)

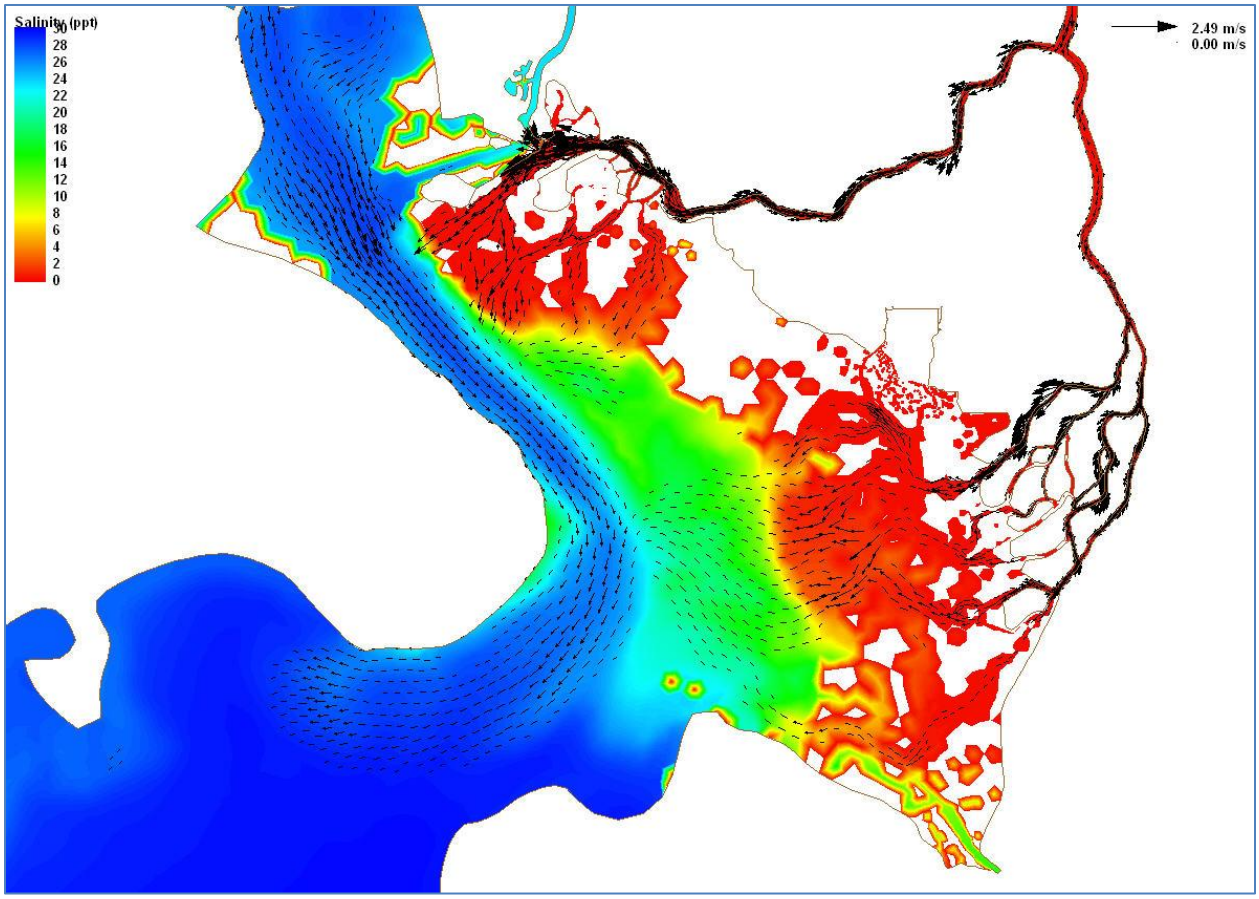

Figure 12 Depth-average velocity and salinity at low tide (4/13/2003, 8:00 PM)

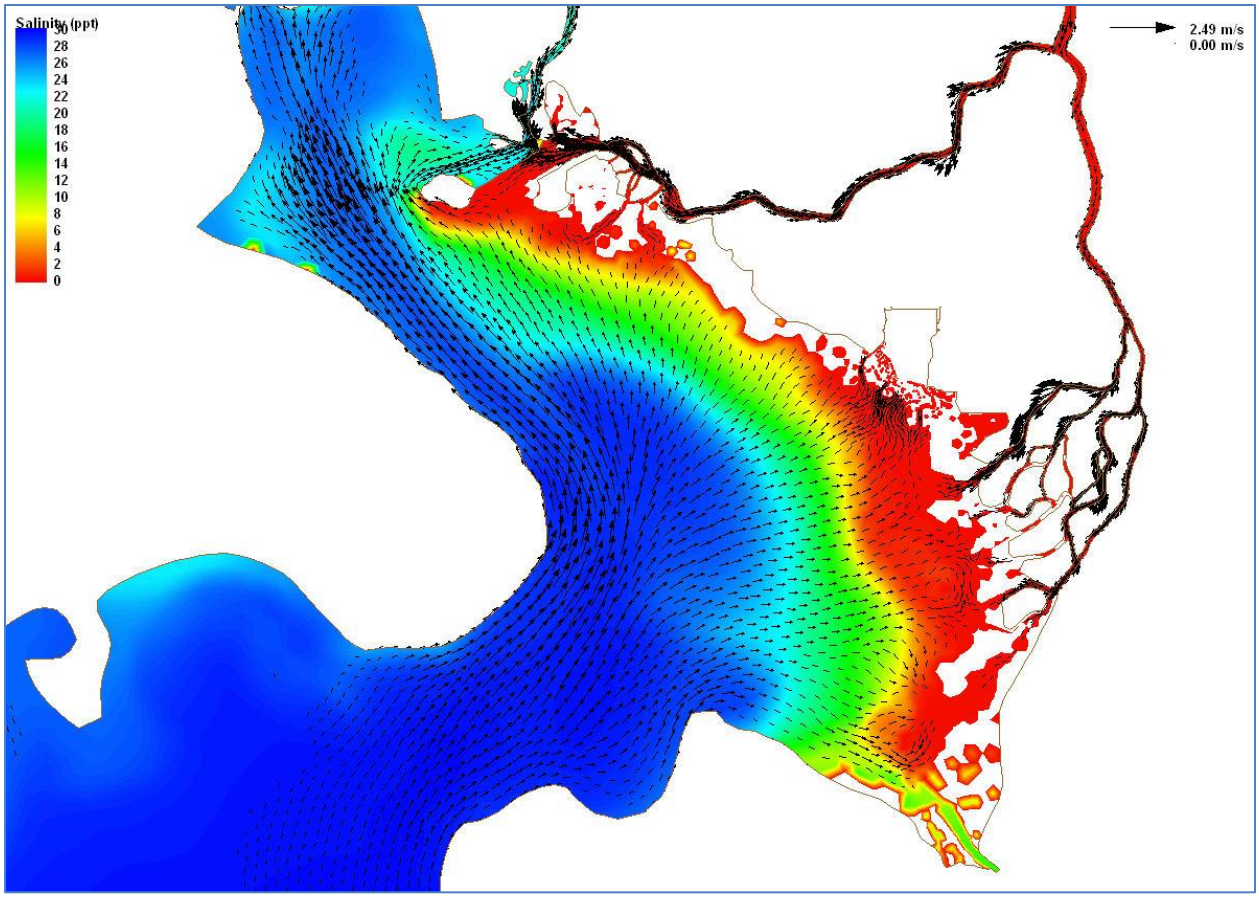

Figure 13 Depth-average velocity and salinity at flood tide (4/14/2003, 0:00 AM)

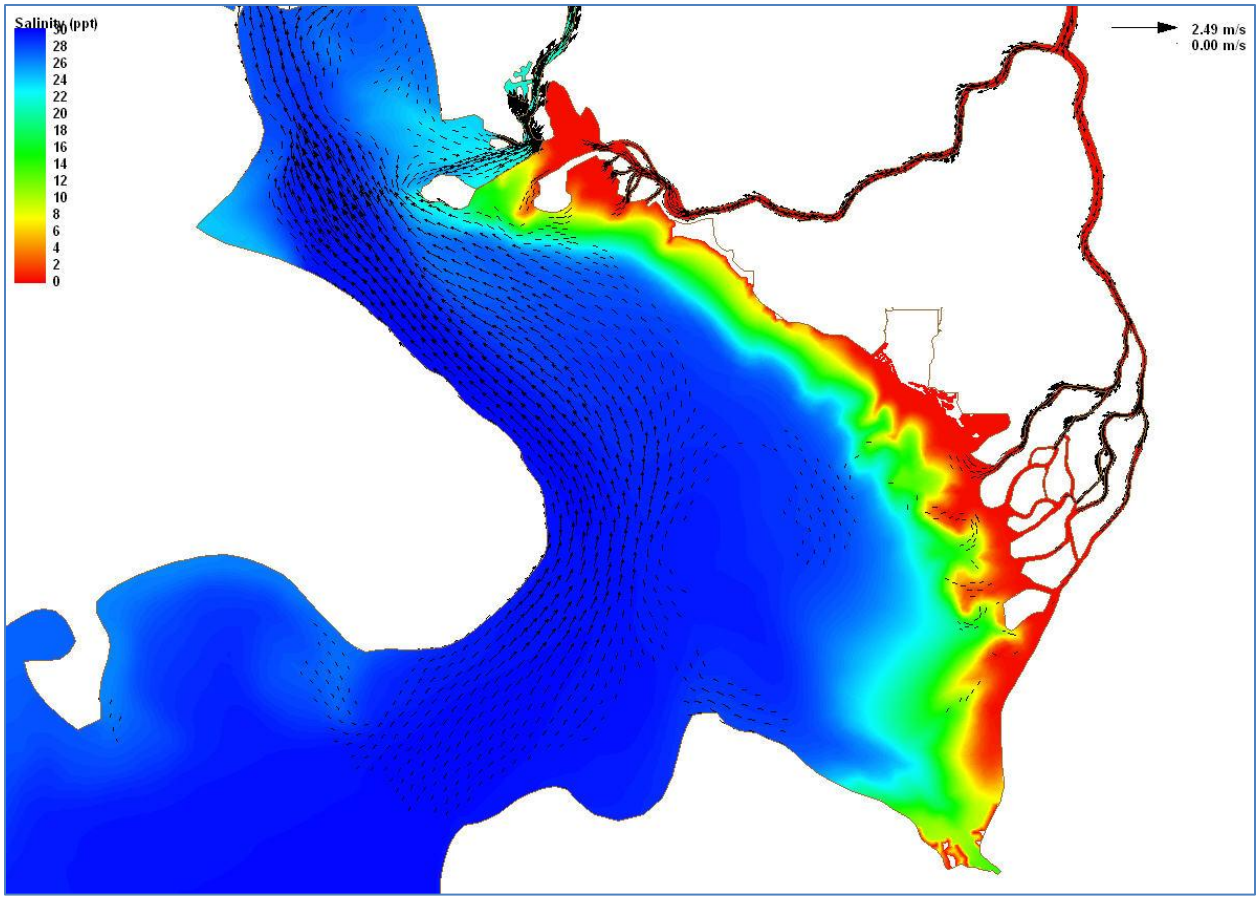

Figure 14 Depth-average velocity and salinity at high tide (4/14/2003, 3:00 AM)

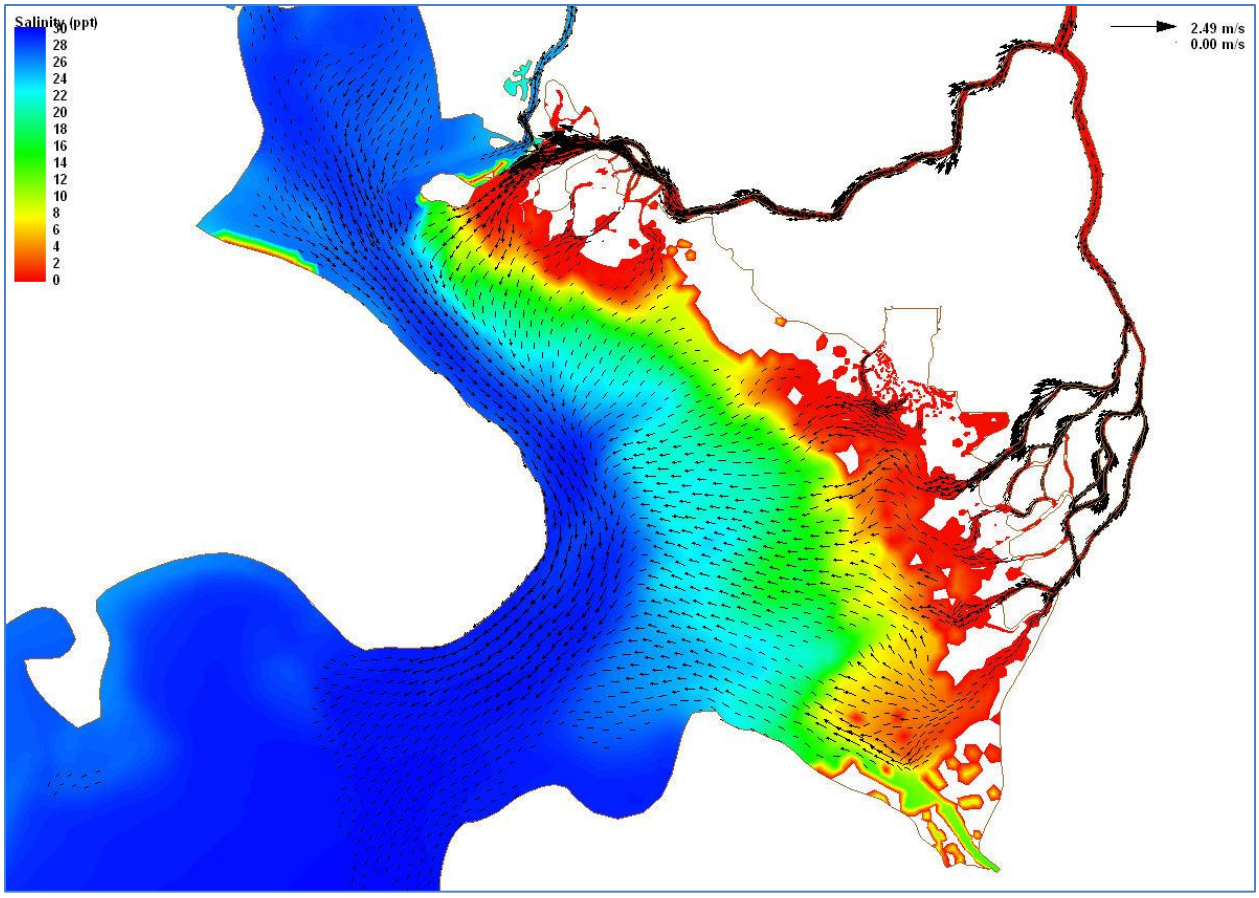

Figure 15 Depth-average velocity and salinity at ebb tide (4/14/2003, 7:00 AM)

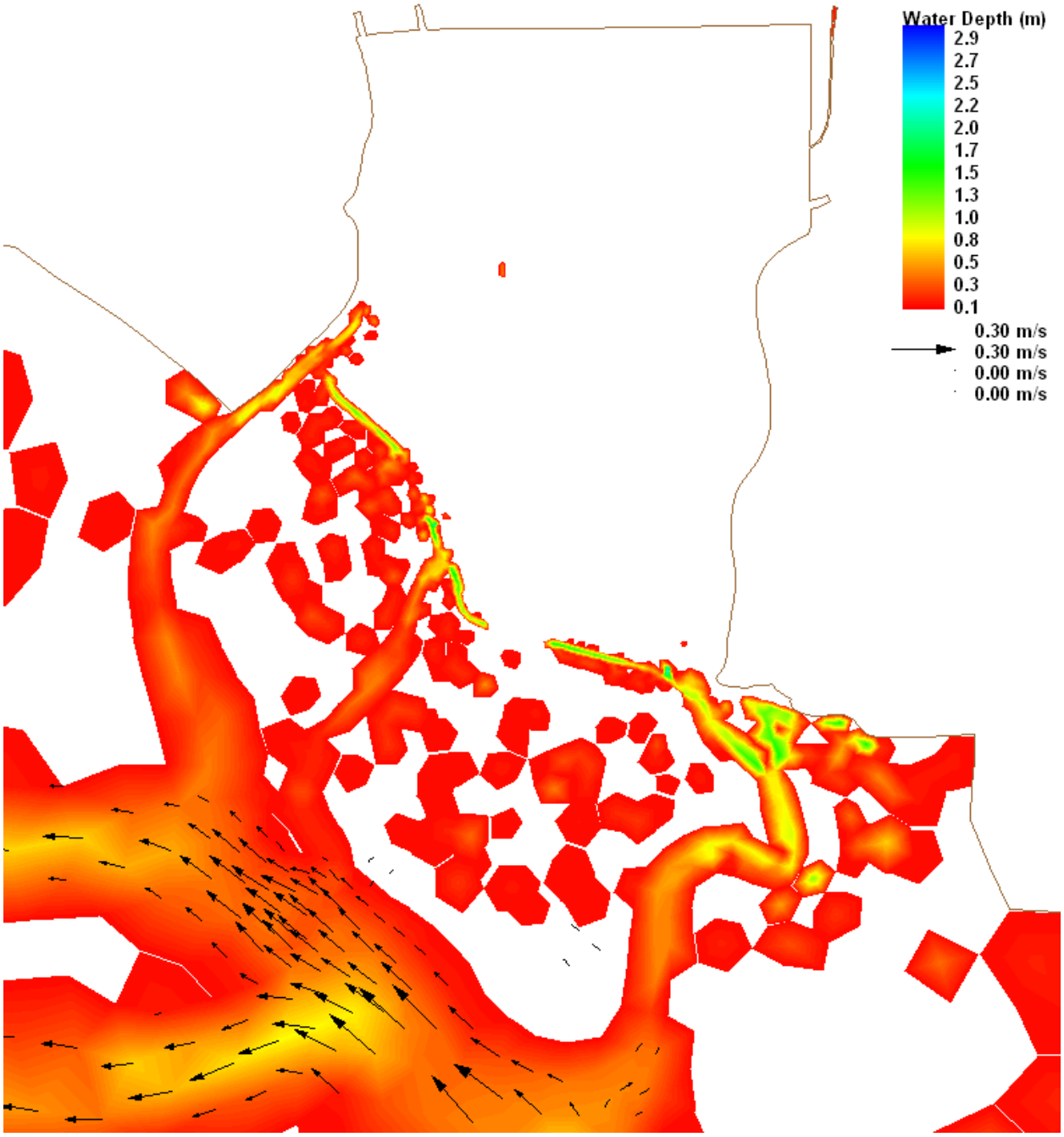

Figure 16 Depth-average velocity at low tide near Fir Island Farm (4/13/2003, 8:00 PM)

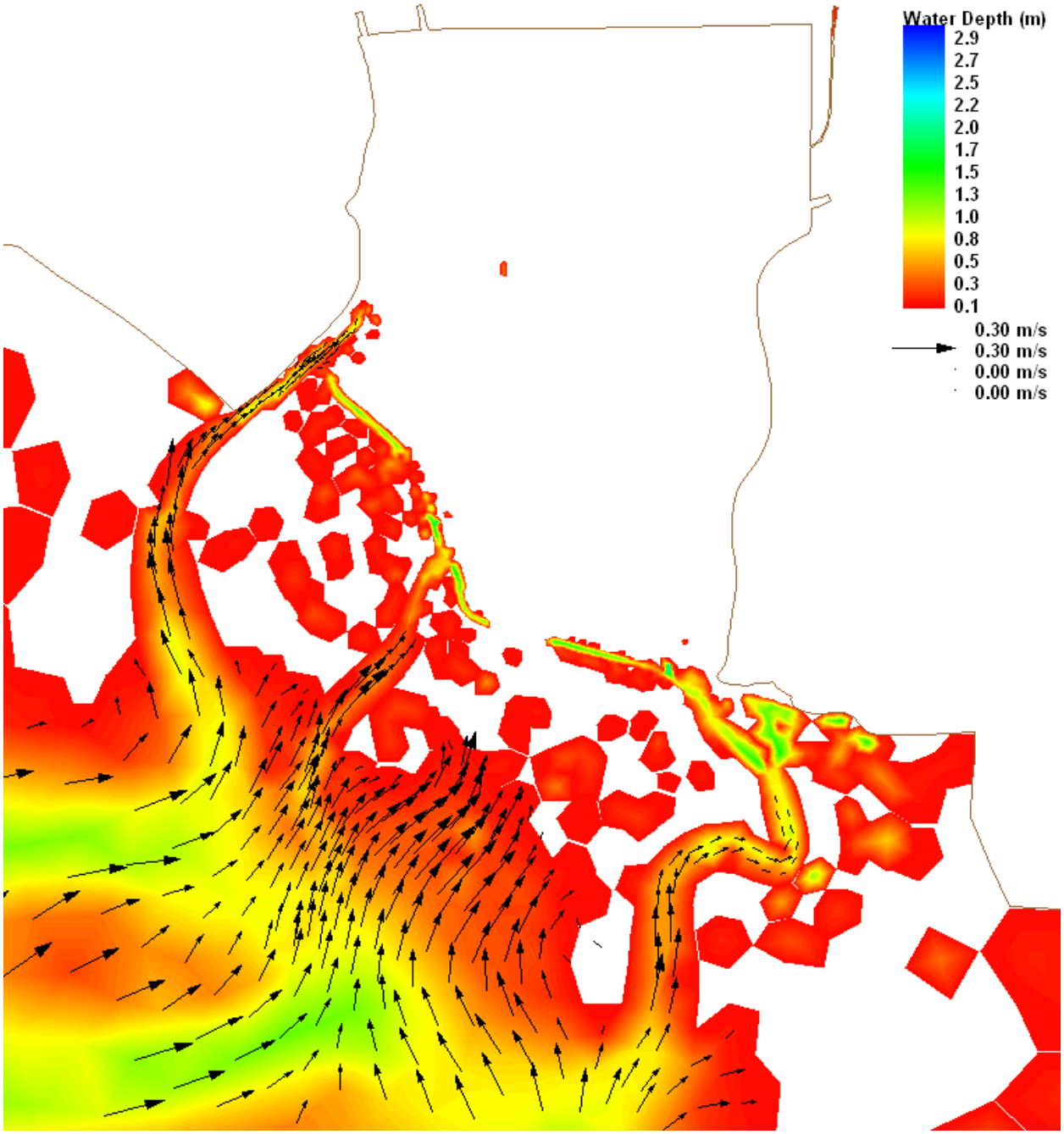

Figure 17 Depth-average velocity at flood tide near Fir Island Farm (4/14/2003, 0:00 AM)

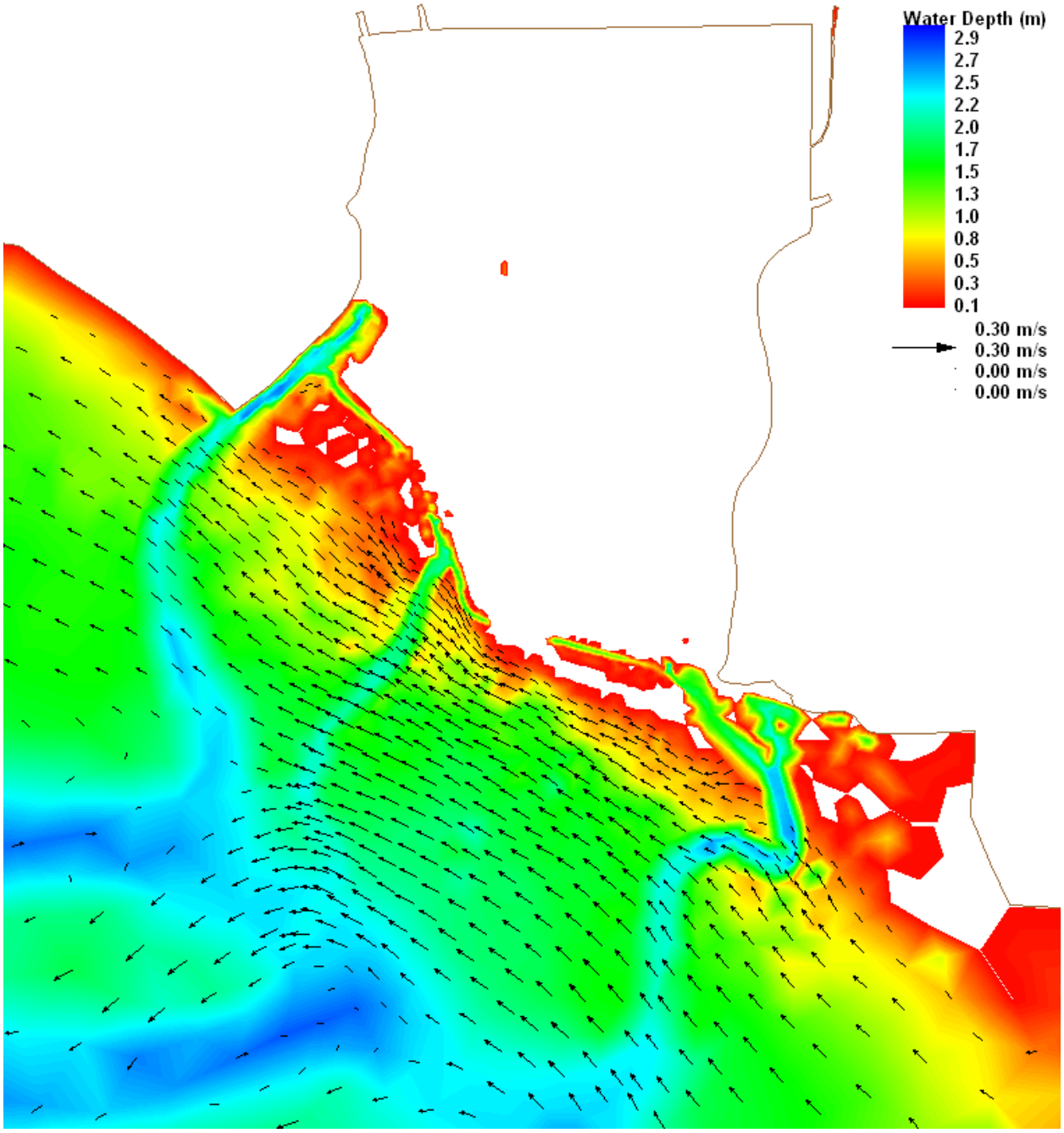

Figure 18 Depth-average velocity at high tide near Fir Island Farm (4/14/2003, 3:00 AM)

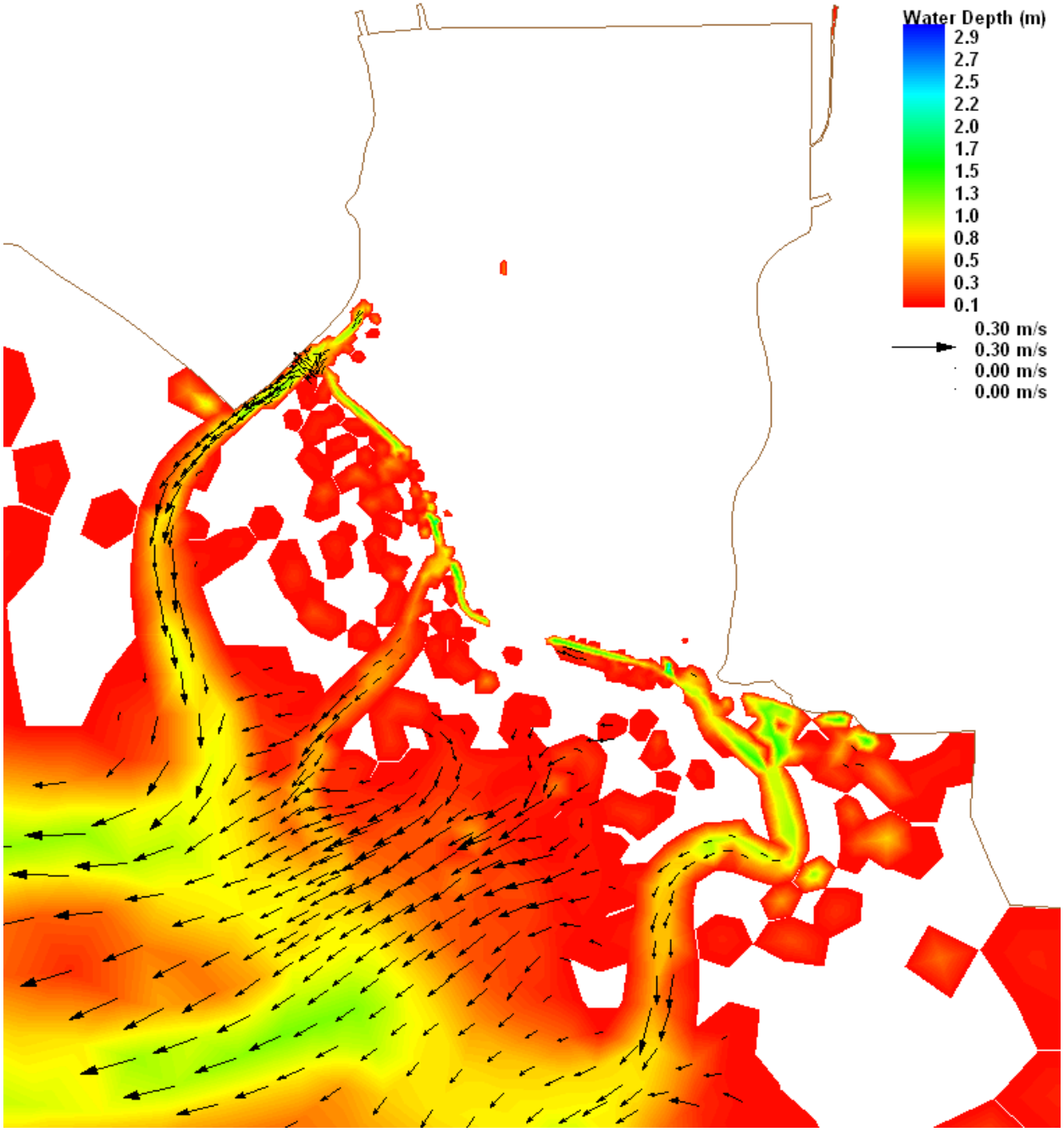

Figure 19 Depth-average velocity at ebb tide near Fir Island Farm (4/14/2003, 7:00 AM)