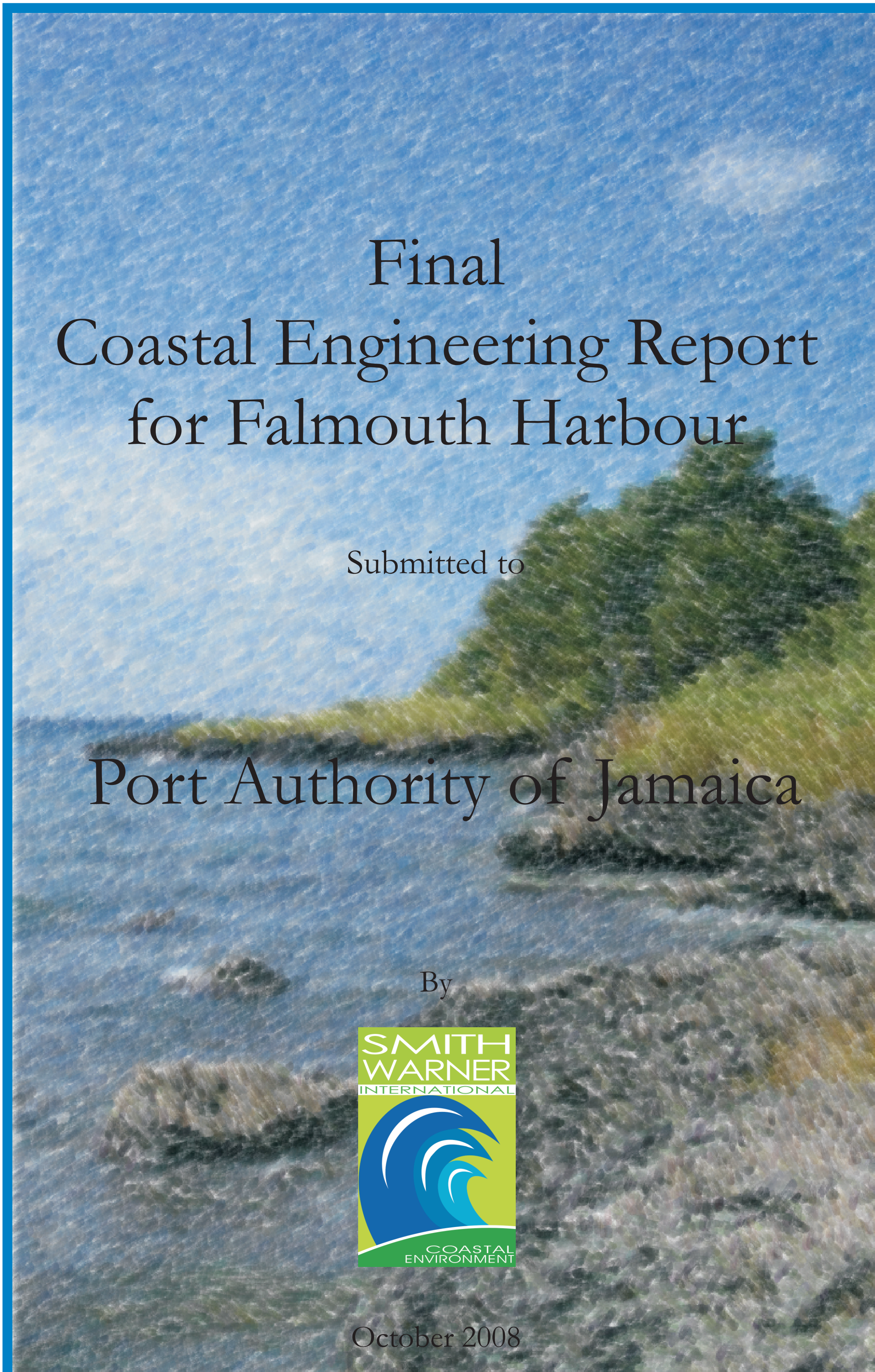

Final
Coastal Engineering Report for Falmouth Harbour

Submitted to

Port Authority of Jamaica

By

SMITH WARNER INTERNATIONAL
COASTAL ENVIRONMENT

October 2008

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1 Project Background

The Port Authority has plans to construct a cruise ship facility at Falmouth Harbour. In order to accommodate the vessels, land-filling is planned adjacent to the shoreline along with dredging of the entrance channel in order to increase its width and depth. As part of the Environmental Impact Assessment, it was necessary to determine how these changes to the seabed will affect nearshore circulation patterns and sediment transport. Of particular interest is the potential impact on the bioluminescent dinoflagellates that inhabit the estuary (Glistening Waters Lagoon). In addition to the effects on the circulation patterns, the modifications will likely also alter the wave conditions and sediment transport patterns, and these impacts need to be quantified for the EIA.

A methodology was proposed to examine these impacts on the environment including data collection and modeling of the proposed modification using computer-based current, wave and sediment models. Data collection included the deployment of an acoustic Doppler current profiler, which measures water movement throughout the water column. This instrument was deployed in mid-August 2008, and retrieved the third week of September 2008. In order to comply with the project timeline, some of the computer modeling was undertaken at the same time as the data collection, which facilitated the early submission of a preliminary engineering report.

Once the data collection was complete, the computer modeling was calibrated against the measured data, in order to provide an increased confidence level in the predicted impacts of the proposed modifications. The calibration process confirmed the presence of a stratified water column, thereby giving confidence to the results and to the use of the model in a predictive role. This document represents the final report for this investigation, and documents the impact that the selected layout might have on the ambient current, wave, and sediment conditions.

2 Data Collection Programme

The instrument chosen for the data collection programme was a RD Instruments Acoustic Doppler Current Profiler (ADCP). An ADCP operates using acoustic signals, and determines the current speed and direction by detecting the Doppler shift of reflected acoustic signals, which bounce off particles moving with the water. Using multiple acoustic "pings", it is possible to divide the water column into different distinct layers and to simultaneously determine the speed and direction of the water movement within each layer as shown in Figure 2.1.

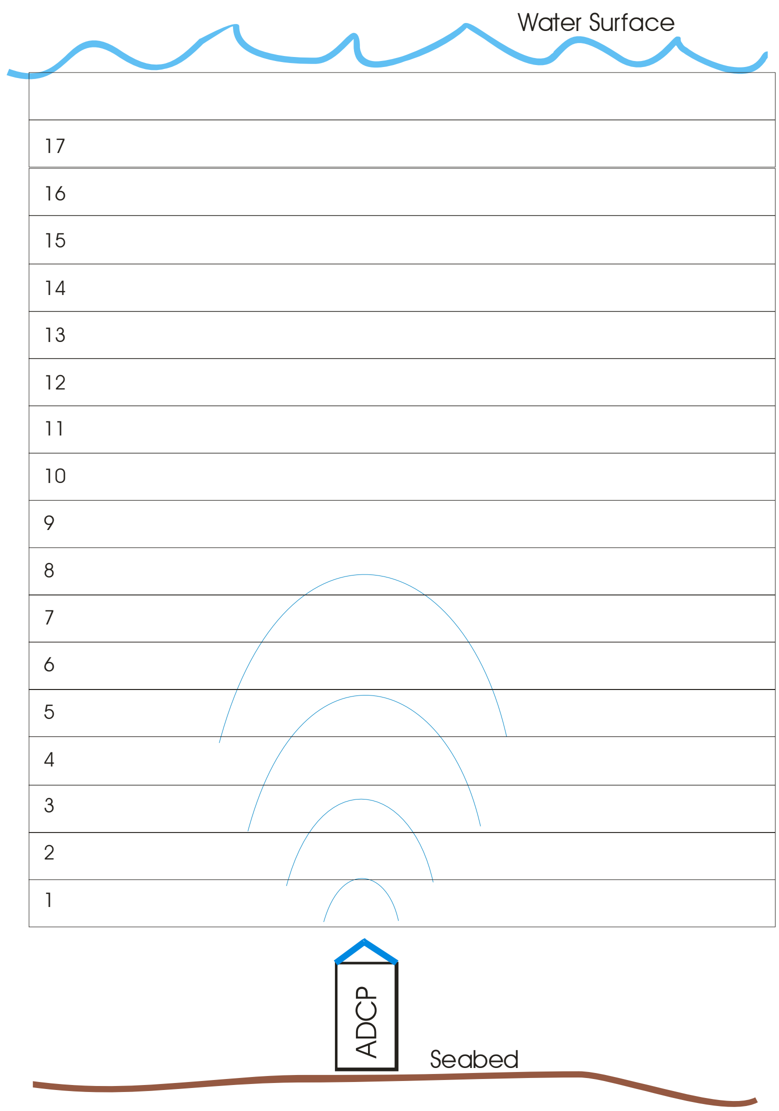


Figure 2.1 **Operation of acoustic Doppler current profile (ADCP)**

An Acoustic Doppler Current Profiler (ADCP) instrument was obtained and shipped from a US based leasing company to Jamaica on August 11th, 2008. The instruments were deployed on the seabed on August 23rd, following clearance from customs and preparation of the instrument.

The instrument was deployed in a water depth of approximately 7-10m at the location shown in Figure 2.2. The instrument was mounted on the seabed in an aluminum frame similar to that shown in Figure 2.3.

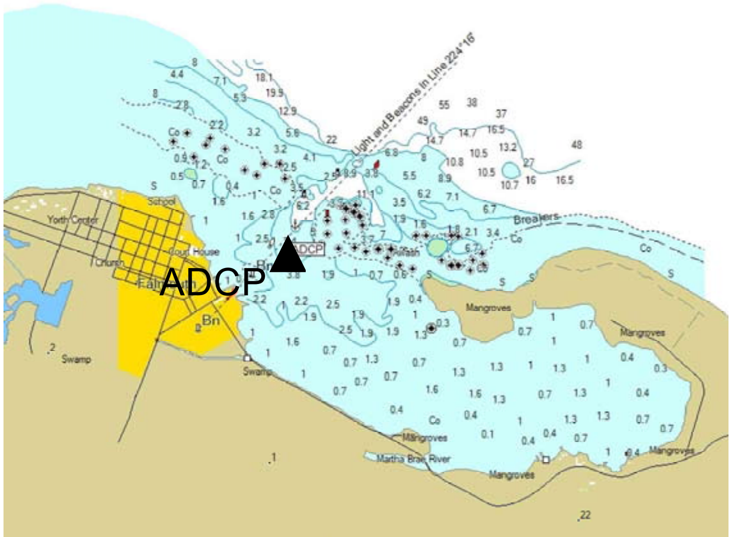


Figure 2.2 Location of Current Meter

Figure 2.3 ADCP mounted on aluminium frame

The instrument was set to record current speed and direction in approximately 20 bins, each 0.25 metres thick. Readings were made every 20 minutes, along with the tide level and the water temperature at the seabed. In addition to the current measurements, the ADCP is also capable of determining wave conditions. These readings were also made every hour for the duration of the monitoring programme.

On September 21st, 2008 the instrument was recovered and the data was downloaded for analysis. The instrument therefore recorded 29 days of data. It was inspected and shipped out on September 26th, 2008, reaching the leasing company on September 30th, 2008.

3 Results

3.1 Temperature

The RD Instruments ADCP measures water temperature using a sensor located in the casing. In this case, it is therefore measuring water temperature 0.6m above the seabed. Figure 3.1 shows the results and indicates two distinct regimes occurring during the measurement period. The first occurs between the start of the measurement period and August 28th, and again between Sept 13th and the end of the measurement period. During these periods, the temperature fluctuates daily by approximately 0.5°C. It is not clear whether this is due to solar radiation or due to the movement of stratified water bodies moving past the instrument. Between August 28th and August 30th, the temperature dropped by 3°C, and then slowly recovered over the following two weeks. This period of rapid drop in water temperature appears to coincide with the heavy rains associated with the passage of Hurricane Gustav, which hit Jamaica on Thursday, August 28th 2008.

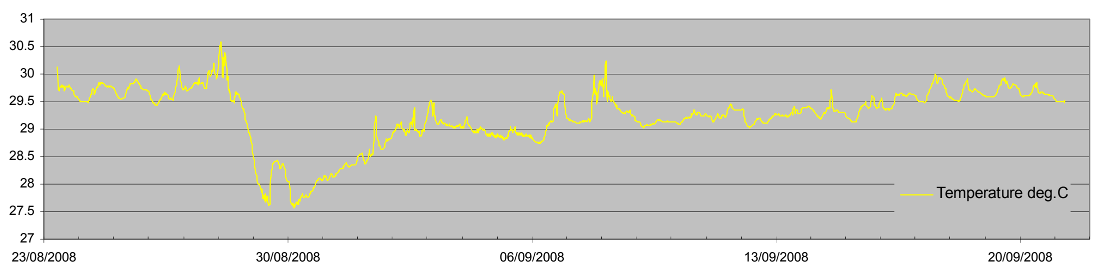


Figure 3.1 **Measured water temperatures at Falmouth**

3.2 Tides

The following plot shows the measured tides for Falmouth during the measurement period and indicates the presence of Spring and Neap tides with a maximum range of approximately 0.5m. The tide signal also reveals a semi-diurnal tide, meaning that there are two highs and lows per day, often of unequal magnitude.

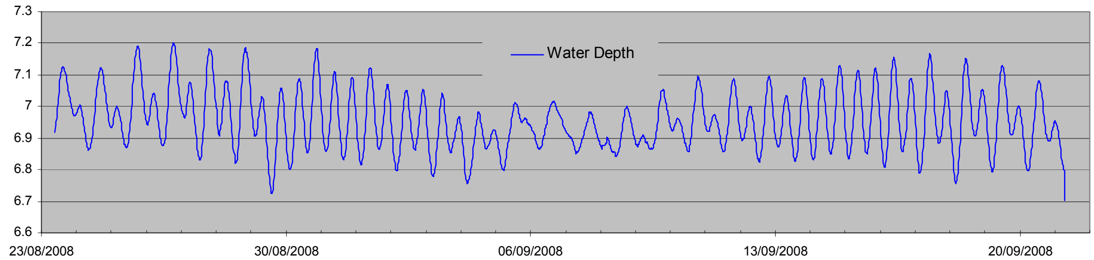


Figure 3.2 Measured Tides

3.3 River Flow

The following plot shows flow of the Martha Brae River (Source: WRA) during the time of the current measurements. The passage of Hurricane Gustav can be seen as the flow increases from approximately 15 m^3/s to 50 m^3/s. The flow remained at this elevated level for several days, and indeed did not revert to its normal flow level.

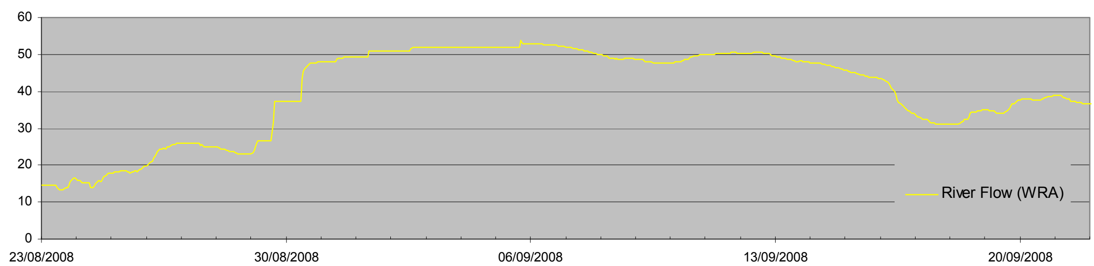


Figure 3.3 Measured river flow rates (m^3/s) on Martha Brae River, Water Resources Authority

3.4 Winds and Wave Heights

The following plot shows the wind speed measured at Montego Bay and the wave heights measured by the ADCP inside Falmouth Harbour. The daily wave height appears to vary between 0.1 and 0.2m in height. In the second half of September, the daily increase in the wind speed appears to correlate with a minor increase in the wave height. The measured wave heights reach a maximum of 0.75m during the passage of Hurricane Gustav, and on two other occasions during the monitoring period the height increases above 0.3m to levels of 0.4m and 0.6m respectively. It is apparent from the wind records, however, that these wave conditions were associated with distant weather systems and were not locally generated, otherwise there would be a noticeable increase in the wind speed associated with each increase in the wave height.

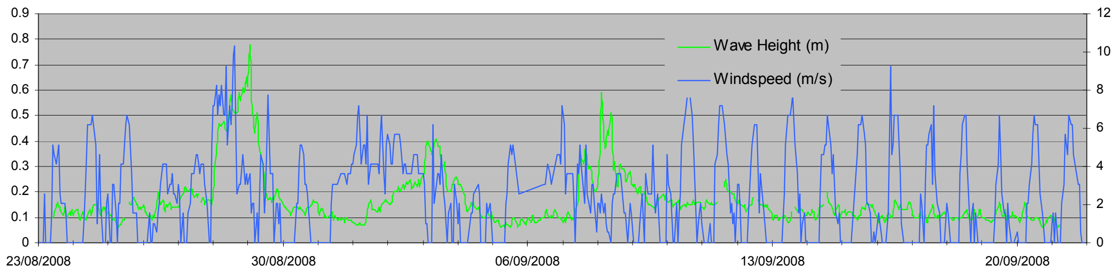


Figure 3.4 **Measured wind speed (Montego Bay) and wave heights**

3.5 Temperature and Salinity Profiles

Salinity/Temperature profile measurements were carried out using a Hydrolab H2O SOND instrument throughout the water column. The measurements were taken at several locations within Falmouth Harbour to investigate the salinity/temperature stratification that occurs under normal conditions. The measured data was used in the final model calibration so that the final model represented, as closely as possible, the true salinity and temperature distribution within Falmouth Harbour. The locations of measurement are labeled ST1 to ST7 representing Site 1 to Site 7 as shown in Figure 3.5 below. The results of the measured salinity and temperature data are also shown.

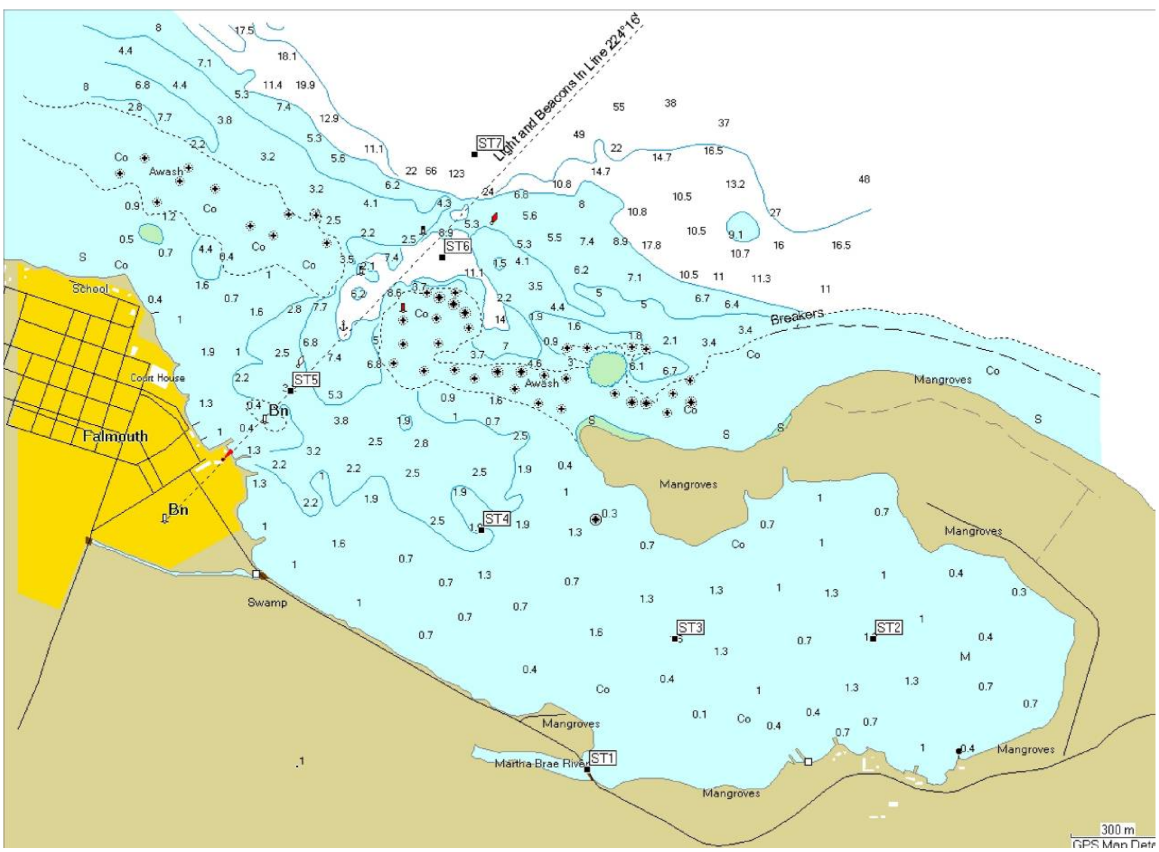
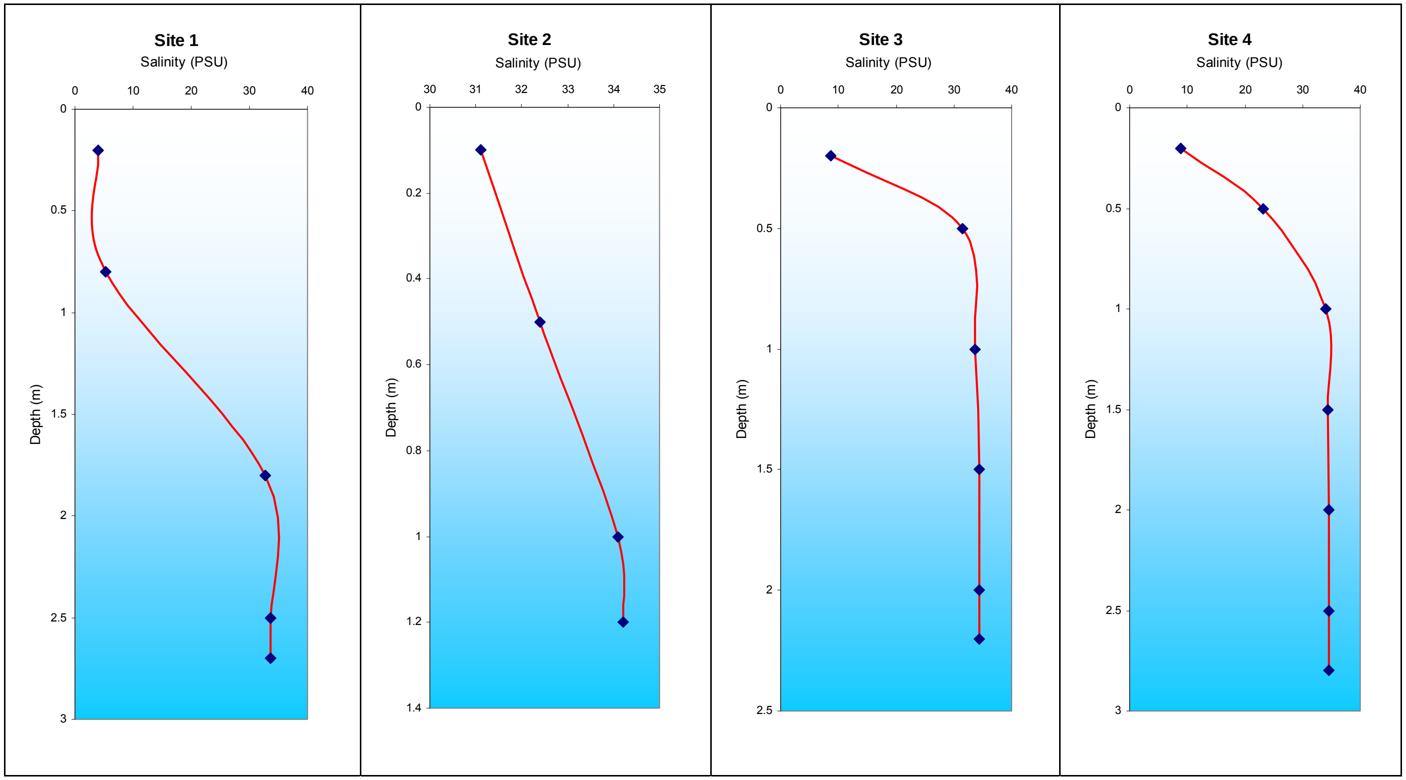


Figure 3.5 Locations of Measured Salinity/Temperature Data


Site 1
Salinity (PSU)
Depth (m)
Site 2
Salinity (PSU)
Depth (m)
Site 3
Salinity (PSU)
Depth (m)
Site 4
Salinity (PSU)
Depth (m)

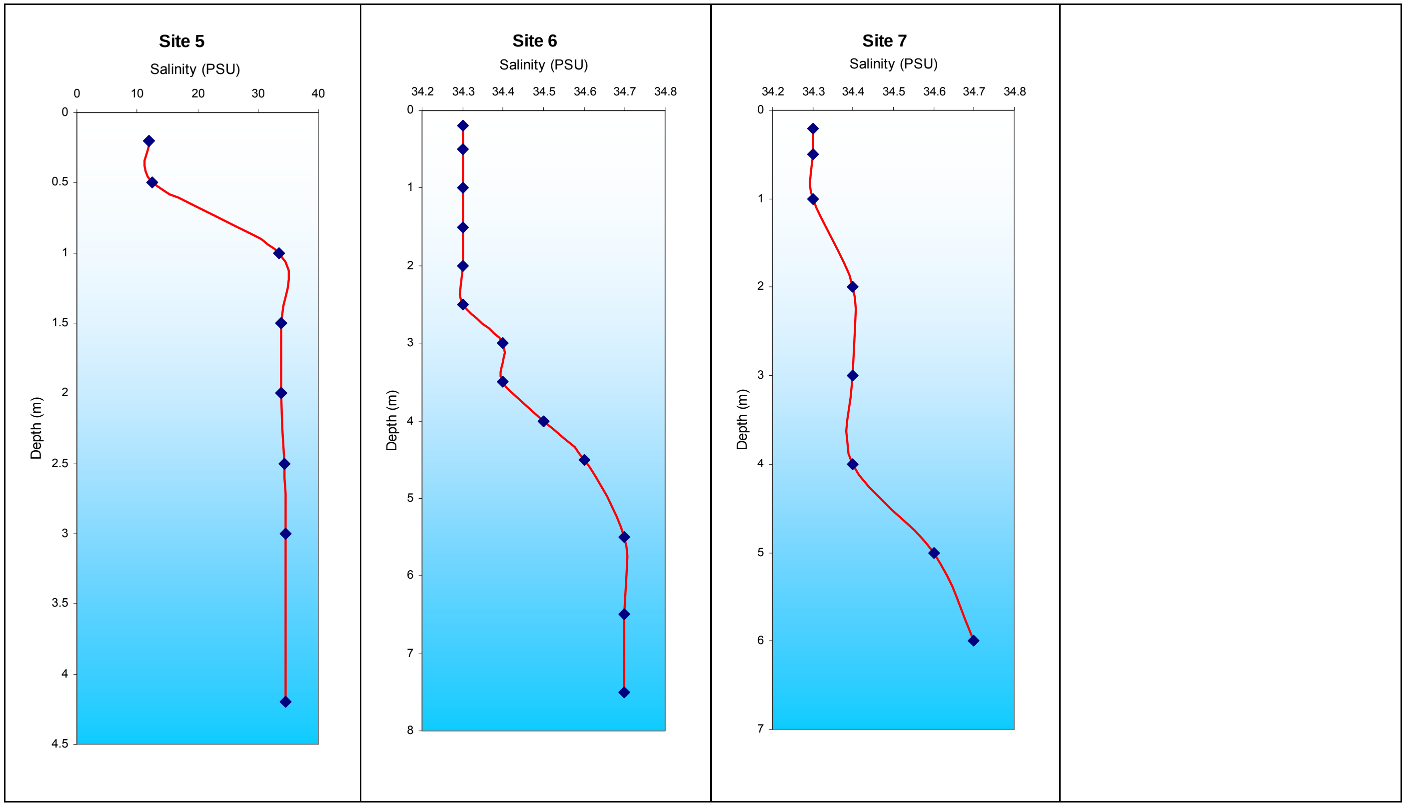
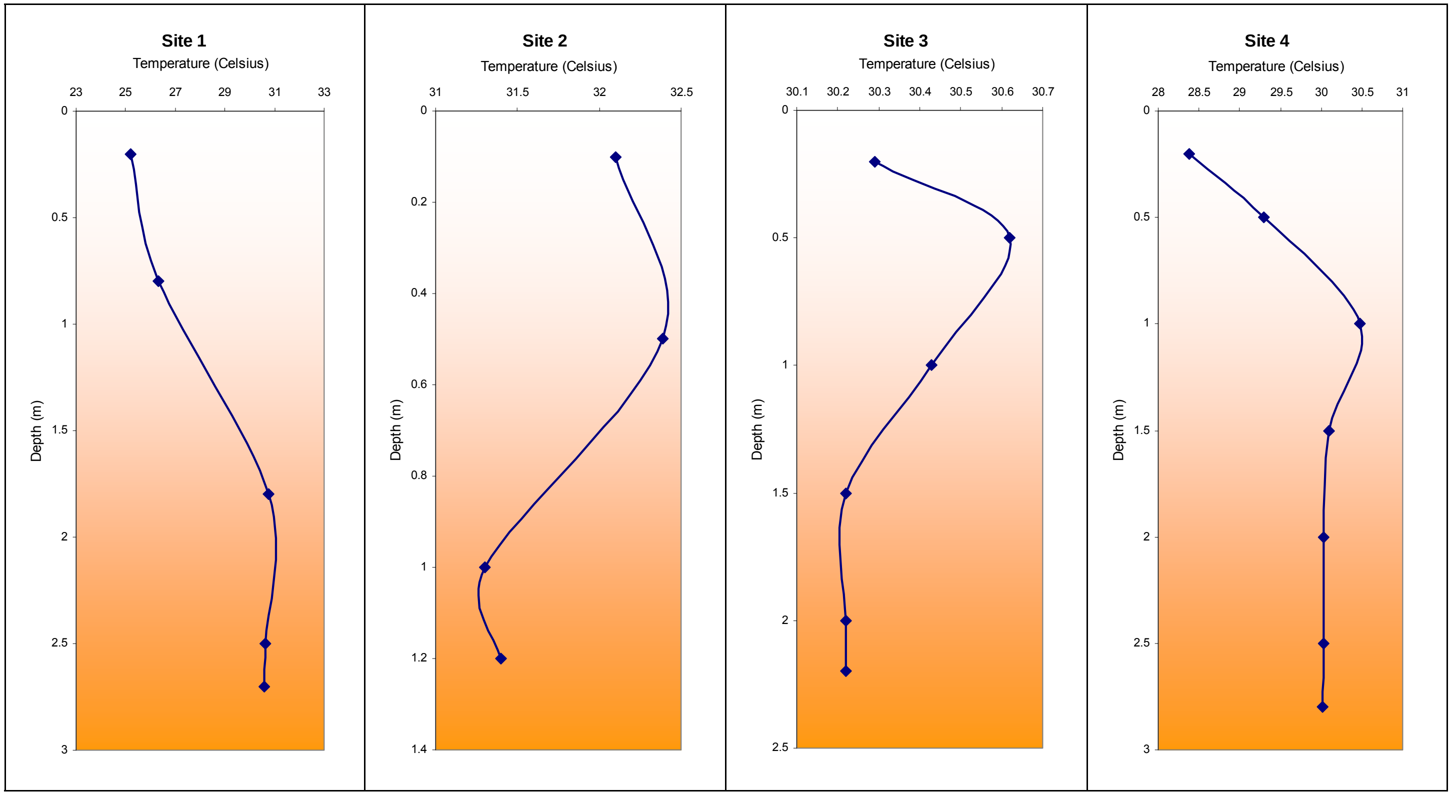


Figure 3.6 Measured Salinity Data


Site 1
Temperature (Celsius)
23 25 27 29 31 33
Depth (m)
0 0.5 1 1.5 2 2.5 3
Site 2
Temperature (Celsius)
31 31.5 32 32.5
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Site 3
Temperature (Celsius)
30.1 30.2 30.3 30.4 30.5 30.6 30.7
Depth (m)
0 0.5 1 1.5 2 2.5
Site 4
Temperature (Celsius)
28 28.5 29 29.5 30 30.5 31
Depth (m)
0 0.5 1 1.5 2 2.5 3

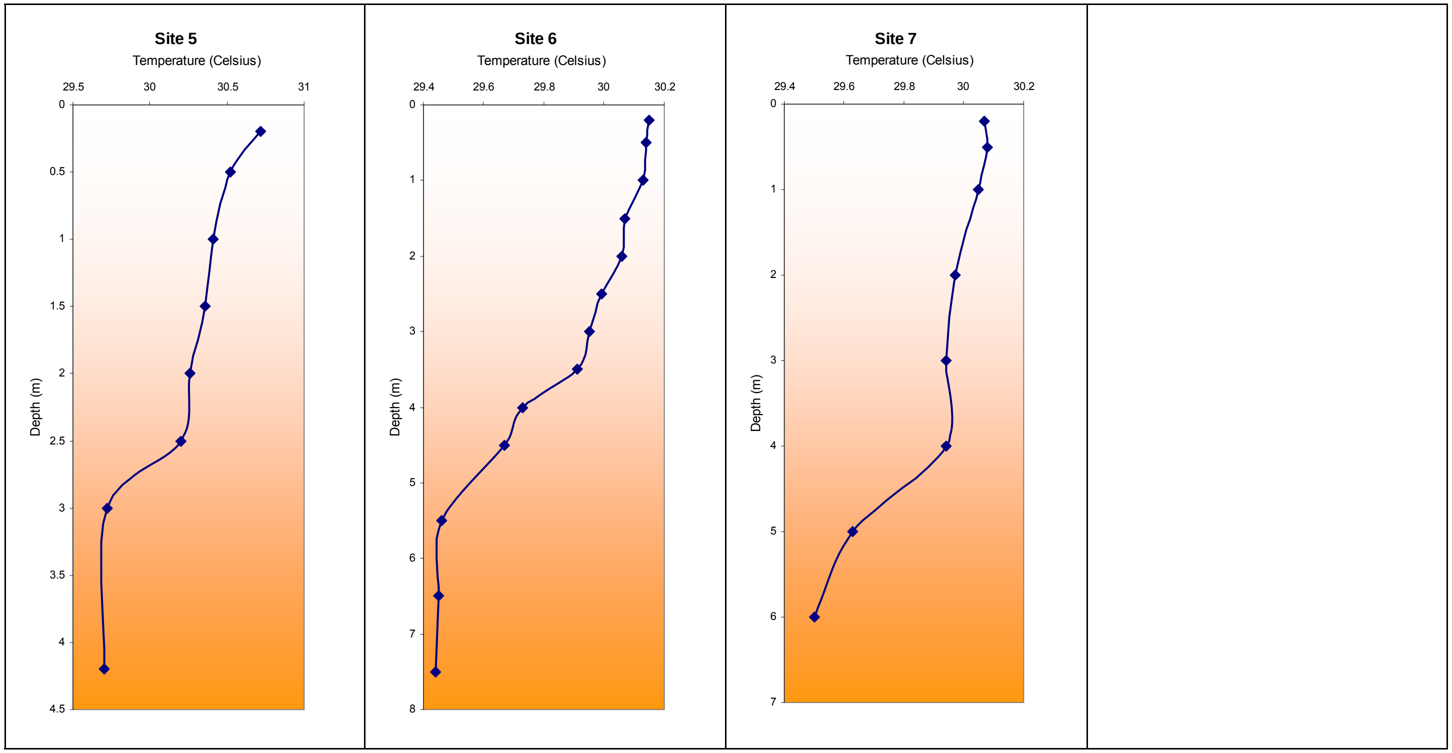


Figure 3.7 Measured Temperature Data

Site 1 (ST1) is located at the mouth of the Martha Brae River. The results show significant stratification occurring even at the mouth of the river, with salinity readings near the seabed of 33.6 PSU, while near the surface salinity was in the range of 4 to 5 PSU. At the river mouth there are two different water bodies present, fresh water from the river and saline water from the ocean.

Site 2 (ST2) shows a more mixed body of water. This could be due to the shallow water and slower velocities occurring within this area. This allows the sea and fresh water to mix, thereby reducing the stratification, as the difference in salinity between the surface and the seabed is only 3.1 PSU.

Sites 3, 4 and 5 (ST 3, 4 and 5) show a surface layer of fresh water resting above saline water. The average thickness of this fresh water is no more than 0.5m. The depths of the three sites are greater than 2m, therefore not allowing for a fully mixed system.

Sites 6 and 7 (ST 6 and 7), located just outside the harbour, show little or no evidence of fresh water effects.

The data gathered from this field work was used along with the measured tidal data to calibrate the final hydrodynamic model.

3.6 Currents

The plots in Figure 3.8 show the measured currents at the instrument location. These plots are called *scatter plots*, and reveal the variation in current speed and direction. Each point on the plot represents a single measurement with the speed and direction indicated by the distance from the centre and the angle from north, respectively. Results from five of the layers are shown. The results indicate that two distinct flow systems are in existence at this location. One consists of small currents oscillating around zero. A second system consists of stronger currents, ranging up to and beyond 500mm/s, or 0.5m/s, and flowing generally to the north. This second system is associated primarily with the outflow from the Martha Brae River.

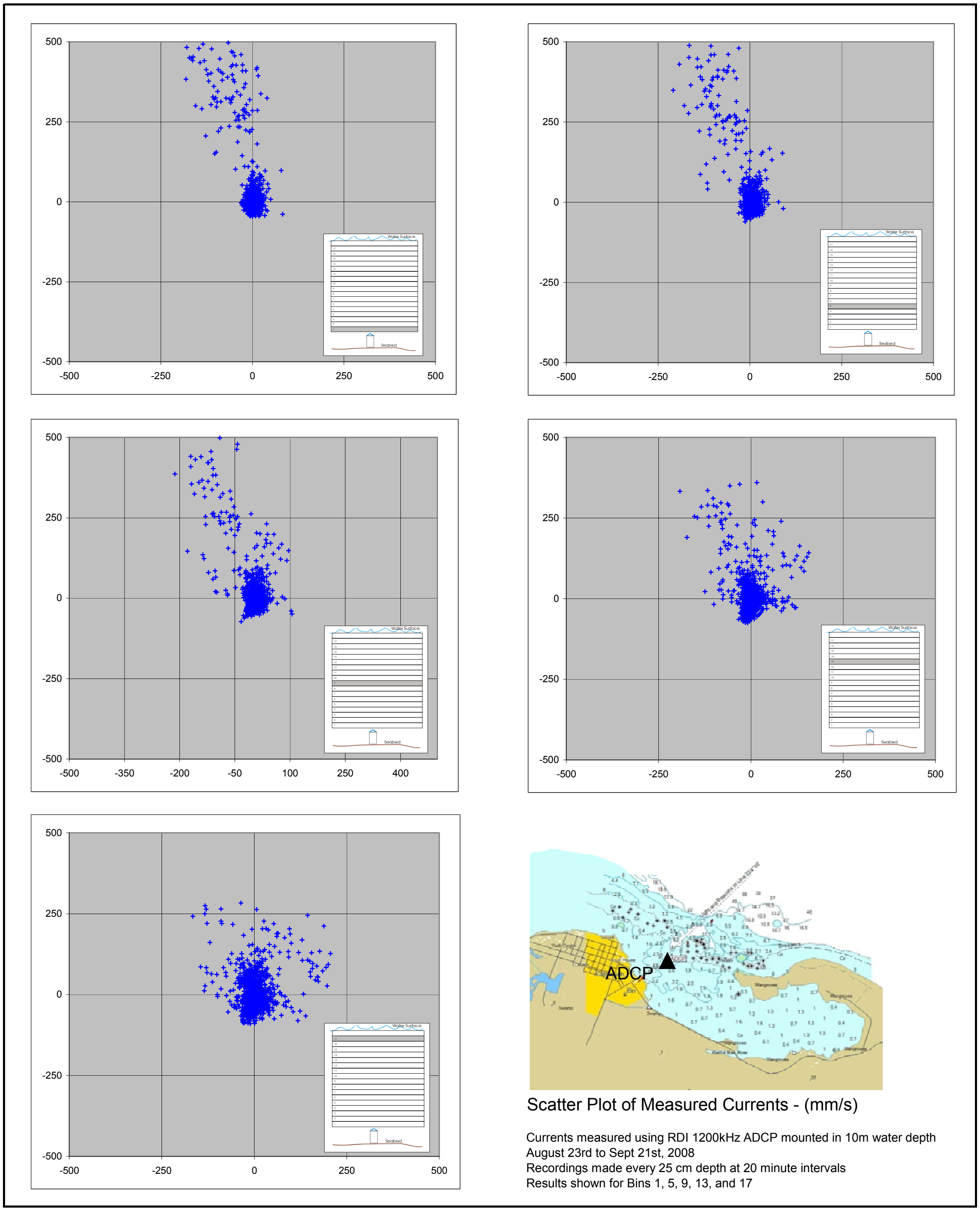


Figure 3.8 Scatter Plot of measured currents

Looking at the pre-Gustav data, (Figure 3.9) the currents appear to flow in a north-south direction, with the weaker currents occurring near the seabed. The upper layer (17) appears to have more scatter, which is expected as the influence of wind is stronger at the surface.

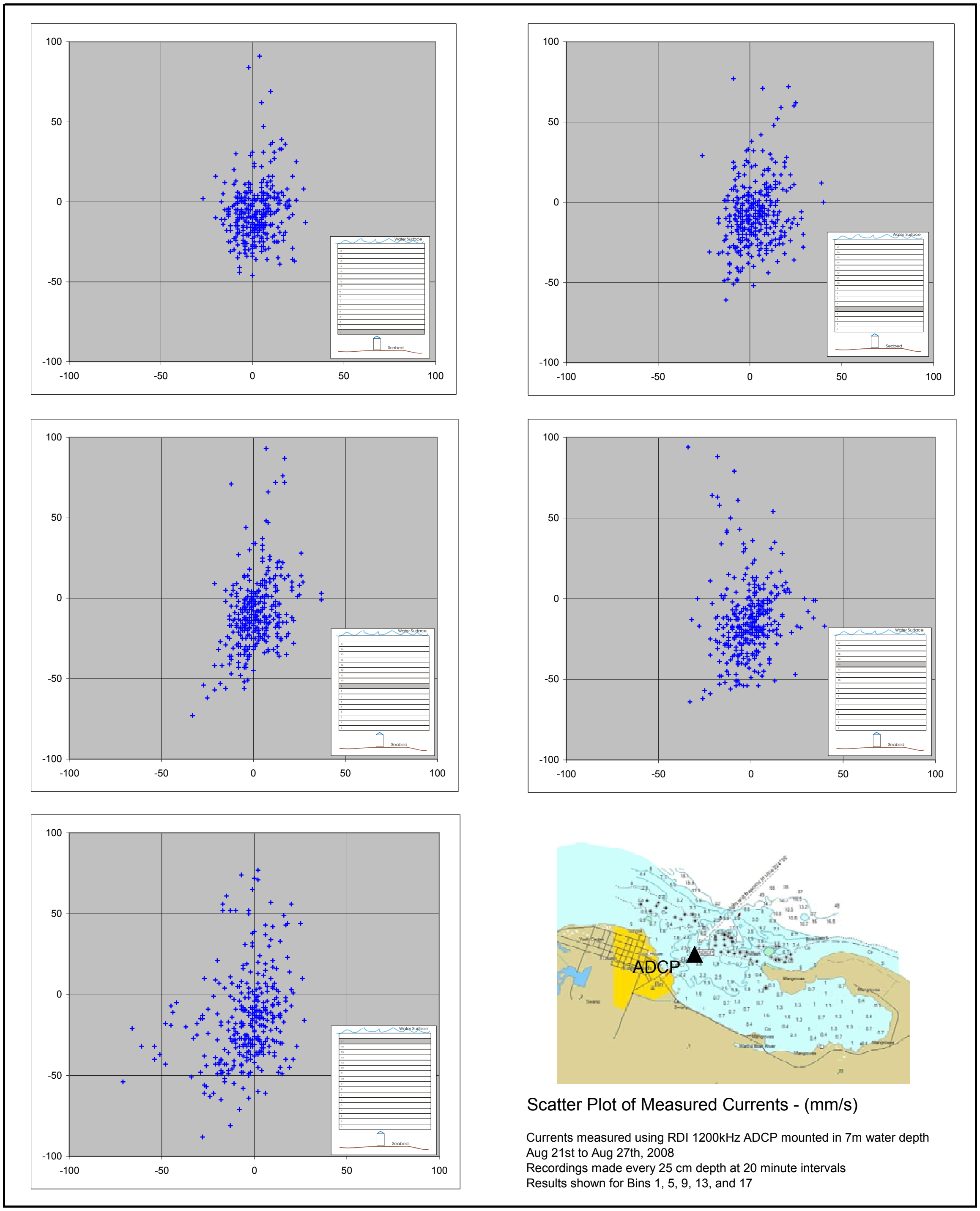


Figure 3.9 Scatter Plot of measured currents pre-Gustav data only

It is also important to understand the variation in current speed with depth during a river flood event. Figure 3.10 is a time-series plot of the North-South and East-West components of the recordings in five of the bins. The effect of Hurricane Gustav can be easily seen as the currents jump from less than 100 mm/s to almost 500 mm/s for three days. In other, non-flood periods before and after there is a noticeable periodic north-south flow which is driven by the tide as water flows in and out through the existing channel. The east-west components do not appear to be controlled in the same manner.

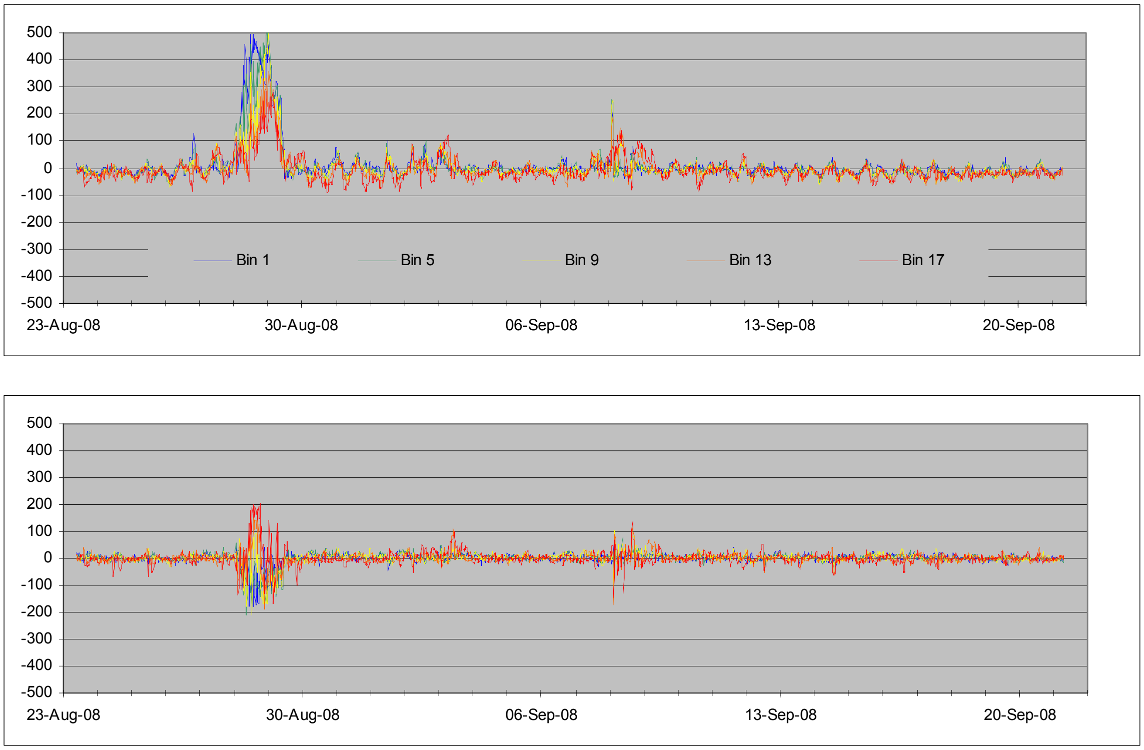


Figure 3.10 Measured North-South (upper) and East-West (lower) current speeds (mm/s) in five bins

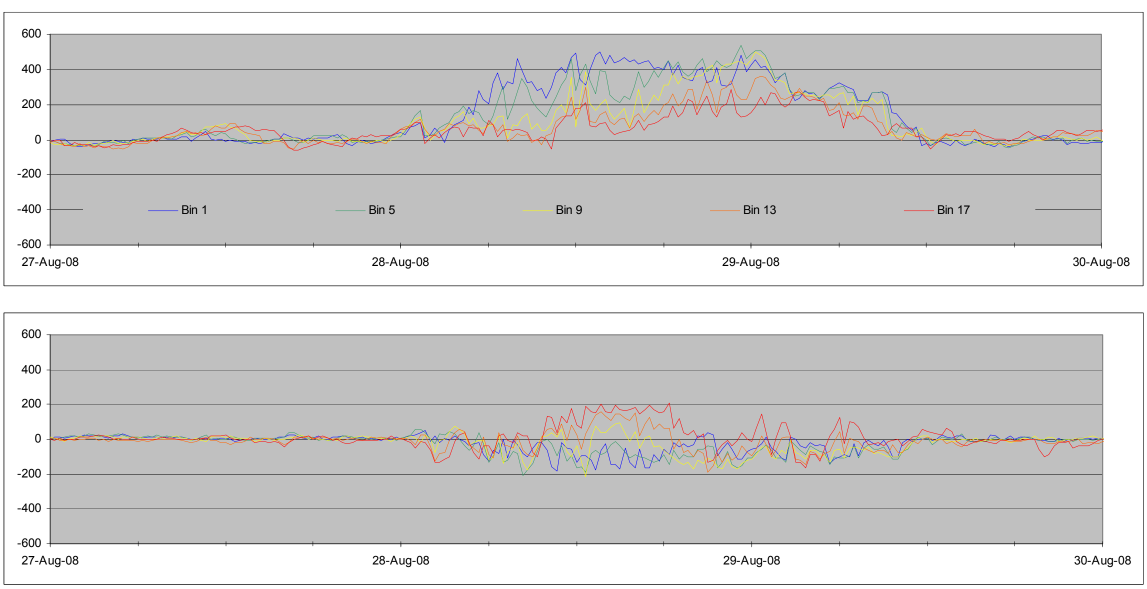


Figure 3.11 Measured North-South (upper) and East-West (lower) current speeds (mm/s) in five bins during the recorded flood flow event

In Figure 3.11, the detail during the river flood event has been expanded. Generally, the current patterns exhibit a very similar pattern, except that the bottom north current component (Bin 1) increases before the upper layers. Looking at the East component, the pattern reveals that the bottom currents move to the north-west, whereas the upper layers flow to the north-east.

In addition to the fixed current meter, the current patterns were also assessed using floating "drogues", which track the water movement through an area. For this investigation, drogues were deployed on September 19th and 20th 2008 in the Falmouth area. The positions of the floating drogues were tracked using GPS over the two day period. In almost all cases, the drogues were seen to drift to the north-west, as shown in Figure 3.12.

Figure 3.12 Drogue tracks measured on Sept 19th and 20th, 2008

The current speeds were computed based on the positions and time differences and the results are presented in the following table.

Drogue Tracking Speeds for Falmouth Harbour Option 4, Ja.

September 19th 2008, 11:30 pm - 2:50 pm

Drogue 3, 1st Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 11:31	220380	2047098				
19/09/2008 11:41	220337	2047133	55.444	-50.856	556.000	0.100
19/09/2008 11:56	220258	2047211	111.018	-45.365	912.000	0.122
19/09/2008 12:11	220194	2047293	104.019	-37.972	933.000	0.111
OUT						

Drogue 3, 2nd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 12:21	220491	2046852				
19/09/2008 12:34	220430	2046940	107.075	325.271	793.000	0.135
19/09/2008 12:47	220382	2047016	89.889	327.724	745.000	0.121
19/09/2008 13:02	220350	2047111	100.245	341.384	942.000	0.106
19/09/2008 13:18	220306	2047202	101.079	334.195	953.000	0.106
19/09/2008 13:32	220243	2047281	101.045	321.429	847.000	0.119
19/09/2008 13:50	220132	2047384	151.427	312.859	1045.000	0.145
19/09/2008 14:06	219954	2047510	218.083	305.293	975.000	0.224
OUT						

Drogue 3, 3rd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 14:16	220618	2046771				
19/09/2008 14:33	220575	2046891	127.472	340.286	963.000	0.132
19/09/2008 14:45	220516	2046959	90.028	319.054	737.000	0.122
OUT						

September 19th 2008, 11:30 pm - 2:50 pm

Drogue 2, 1st Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 11:52	220294	2046547				
19/09/2008 12:03	220285	2046543	9.849	246.038	665.000	0.015
19/09/2008 12:29	220264	2046532	23.707	242.354	1517.000	0.016
OUT						

Drogue 2, 2nd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 12:32	220434	2046687				
19/09/2008 12:44	220404	2046682	30.414	260.538	721.000	0.042
19/09/2008 12:59	220370	2046674	34.928	256.759	891.000	0.039
19/09/2008 13:15	220331	2046670	39.205	264.144	957.000	0.041
19/09/2008 13:28	220301	2046696	39.699	310.914	793.000	0.050
19/09/2008 13:43	220279	2046717	30.414	313.668	912.000	0.033
19/09/2008 13:59	220218	2046749	68.884	297.681	950.000	0.073
19/09/2008 14:22	220183	2046764	38.079	293.199	1383.000	0.028
19/09/2008 14:36	220168	2046762	15.133	262.405	844.000	0.018
19/09/2008 14:47	220158	2046758	10.770	248.199	655.000	0.016
OUT						

September 19th 2008, 11:30 pm - 2:50 pm

Drogue 1, 1st Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 11:46	220090	2046948				
19/09/2008 11:58	220068	2046971	31.828	316.273	763.000	0.042
19/09/2008 12:24	220016	2046982	53.151	281.944	1558.000	0.034
19/09/2008 12:37	220004	2046981	12.042	265.236	747.000	0.016
OUT						

Drogue 1, 2nd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
19/09/2008 12:41	220265	2047075				
19/09/2008 12:49	220245	2047075	20.000	270.000	475.000	0.042
19/09/2008 13:04	220218	2047074	27.019	267.879	894.000	0.030
19/09/2008 13:20	220189	2047093	34.670	303.232	973.000	0.036
19/09/2008 13:35	220167	2047113	29.732	312.274	913.000	0.033
19/09/2008 13:52	220149	2047147	38.471	332.103	1039.000	0.037
19/09/2008 14:11	220108	2047202	68.600	323.297	1112.000	0.062
19/09/2008 14:27	220062	2047204	46.043	272.490	946.000	0.049
19/09/2008 14:40	220026	2047200	36.222	263.660	783.000	0.046
19/09/2008 14:50	219996	2047214	33.106	295.017	599.000	0.055
OUT						

Drogue Tracking Speeds for Falmouth Harbour Option 4, Ja.

September 20th 2008, 6:50 am - 2:50 pm

Drogue 3, 1st Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 06:59	220347	2047040				
20/09/2008 07:12	220333	2047106	67.469	348.024	802.000	0.084
20/09/2008 07:26	220315	2047160	56.921	341.565	798.000	0.071
20/09/2008 07:37	220298	2047197	40.719	335.323	653.000	0.062
20/09/2008 07:48	220283	2047235	40.853	338.459	700.000	0.058
OUT						

Drogue 3, 2nd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 07:52	220216	2046909				
20/09/2008 08:01	220209	2046922	14.765	331.699	560.000	0.026
20/09/2008 08:12	220204	2046936	14.866	340.346	648.000	0.023
20/09/2008 08:21	220200	2046953	17.464	346.759	556.000	0.031
20/09/2008 08:32	220198	2046963	10.198	348.690	691.000	0.015
20/09/2008 08:44	220193	2046977	14.866	340.346	687.000	0.022
20/09/2008 08:57	220192	2046993	16.031	356.424	776.000	0.021
20/09/2008 09:08	220185	2047002	11.402	322.125	687.000	0.017
20/09/2008 09:22	220175	2047010	12.806	308.660	798.000	0.016
20/09/2008 09:34	220163	2047020	15.620	309.806	750.000	0.021
OUT						

Drogue 3, 3rd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 09:37	220309	2046611				
20/09/2008 09:52	220302	2046614	7.616	293.199	911.000	0.008
20/09/2008 10:13	220291	2046613	11.045	264.806	1217.000	0.009
20/09/2008 10:33	220273	2046597	24.083	228.366	1202.000	0.020
20/09/2008 10:51	220255	2046588	20.125	243.435	1126.000	0.018
OUT						

Drogue 3, 4th Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 10:56	220444	2046807				
20/09/2008 11:14	220406	2046840	50.329	310.972	1085.000	0.046
20/09/2008 11:30	220362	2046866	51.108	300.579	986.000	0.052
20/09/2008 11:47	220317	2046897	54.644	304.563	984.000	0.056
20/09/2008 12:07	220254	2046945	79.202	307.304	1235.000	0.064
20/09/2008 12:26	220162	2047016	116.211	307.659	1103.000	0.105
OUT						

September 20th 2008, 6:50 am - 2:50 pm

Drogue 2, 1st Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 06:55	220618	2046825				
20/09/2008 07:10	220628	2046843	20.591	389.055	896.000	0.023
20/09/2008 07:23	220642	2046857	19.799	405.000	788.000	0.025
20/09/2008 07:34	220644	2046866	9.220	372.529	668.000	0.014
20/09/2008 07:45	220649	2046871	7.071	405.000	680.000	0.010
20/09/2008 07:58	220653	2046881	10.770	381.801	757.000	0.014
20/09/2008 08:09	220655	2046890	9.220	372.529	663.000	0.014
20/09/2008 08:18	220656	2046902	12.042	364.764	553.000	0.022
20/09/2008 08:29	220651	2046915	13.928	338.962	670.000	0.021
20/09/2008 08:41	220640	2046927	16.279	317.490	694.000	0.023
20/09/2008 08:51	220635	2046946	19.647	345.256	618.000	0.032
OUT						

Drogue 2, 2nd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 08:54	220580	2046738				
20/09/2008 09:05	220580	2046731	7.000	540.000	661.000	0.011
20/09/2008 09:18	220579	2046718	13.038	184.399	813.000	0.016
20/09/2008 09:31	220575	2046711	8.062	209.745	789.000	0.010
20/09/2008 09:50	220569	2046692	19.925	197.526	1122.000	0.018
20/09/2008 10:11	220561	2046673	20.616	202.834	1232.000	0.017
20/09/2008 10:30	220552	2046665	12.042	228.366	1192.000	0.010
20/09/2008 10:49	220538	2046665	14.000	270.000	1137.000	0.012
20/09/2008 11:12	220502	2046667	36.056	273.180	1373.000	0.026
20/09/2008 11:29	220465	2046678	38.601	286.557	994.000	0.039
20/09/2008 11:45	220430	2046689	36.688	287.447	976.000	0.038
20/09/2008 12:05	220379	2046707	54.083	289.440	1224.000	0.044
20/09/2008 12:23	220332	2046726	50.695	292.011	1064.000	0.048
OUT						

September 20th 2008, 6:50 am - 2:50 pm

Drogue 1, 1st Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 06:52	220825	2046752				
20/09/2008 07:07	220814	2046780	30.083	338.552	909.000	0.033
20/09/2008 07:20	220810	2046787	8.062	330.255	792.000	0.010
20/09/2008 07:32	220810	2046787.5	0.500	360.000	696.000	0.001
20/09/2008 07:43	220809	2046789	1.803	326.310	684.000	0.003
20/09/2008 07:56	220806	2046806	17.263	349.992	744.000	0.023
20/09/2008 08:07	220805	2046816	10.050	354.289	668.000	0.015
20/09/2008 08:16	220805	2046818	2.000	360.000	562.000	0.004
20/09/2008 08:27	220807	2046819	2.236	423.435	669.000	0.003
20/09/2008 08:39	220806	2046819	1.000	270.000	670.000	0.001
20/09/2008 08:49	220806.5	2046819	0.500	450.000	634.000	0.001
20/09/2008 09:02	220805	2046819	1.500	270.000	784.000	0.002
20/09/2008 09:13	220801	2046817	4.472	243.435	653.000	0.007
OUT						

Drogue 1, 2nd Track

Time	Eastings	Northings	Distance (m)	Direction (deg)	Time Diff. (sec)	Speed (m/s)
20/09/2008 09:17	220577	2046612				
20/09/2008 09:28	220577	2046607	5.000	540.000	658.000	0.008
20/09/2008 09:49	220577	2046595	12.000	540.000	1242.000	0.010
20/09/2008 10:09	220568	2046591	9.849	246.038	1250.000	0.008
20/09/2008 10:29	220561	2046589	7.280	254.055	1197.000	0.006
20/09/2008 10:49	220545	2046596	17.464	293.629	1152.000	0.015
20/09/2008 11:11	220504	2046607	42.450	285.018	1330.000	0.032
20/09/2008 11:26	220473	2046609	31.064	273.691	897.000	0.035
20/09/2008 11:44	220434	2046615	39.459	278.746	1099.000	0.036
20/09/2008 12:05	220405	2046621	29.614	281.689	1226.000	0.024
20/09/2008 12:21	220372	2046627	33.541	280.305	1007.000	0.033
OUT						

3.7 Wave and River Current Interaction

Further investigations into the data revealed that the currents at the location of the current meter were mostly influenced by waves and not the Martha Brae River. Figure 3.13 and Figure 3.14 show the current speeds in both the Northings and Eastings directions respectively. The time series reveal that when the wave heights increase, the current speeds also increase significantly. This is most likely due to the waves breaking over the reefs, which create a wave setup within the harbour. This increase in water level therefore creates a wave-induced current which flows back offshore in a manner similar to rip currents.

Figure 3.15 shows the current speeds and the Martha Brae River flow. The current speeds start to increase significantly long before the Martha Brae River flow increases. In fact, while the Martha Brae River flow is increasing significantly from around 26 m^3/s to 50 m^3/s, the current speeds are actually falling. This indicates that the spikes in the current speeds are not induced by River flow but by wave action.

What this implies is that the hydrodynamic model would not pick up these spikes in the current measurements when the calibration process was being carried out. The model would however give predictions that should fall within the normal range of current speeds, which is between +/- 20 cm/s in the easting direction and +/- 60 cm/s in the northing direction.

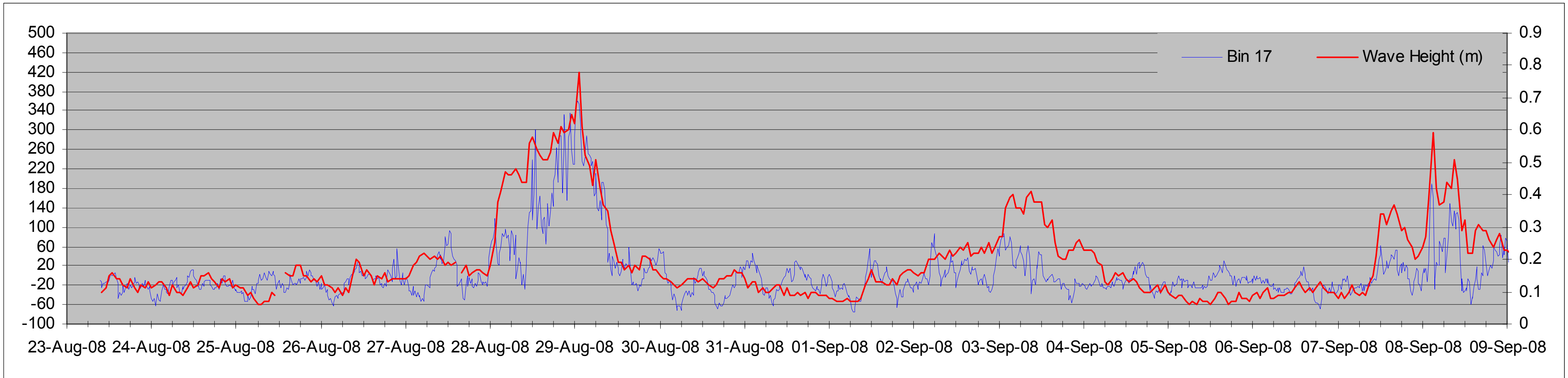


Figure 3.13 Measured current speed versus measured wave heights (Northings)

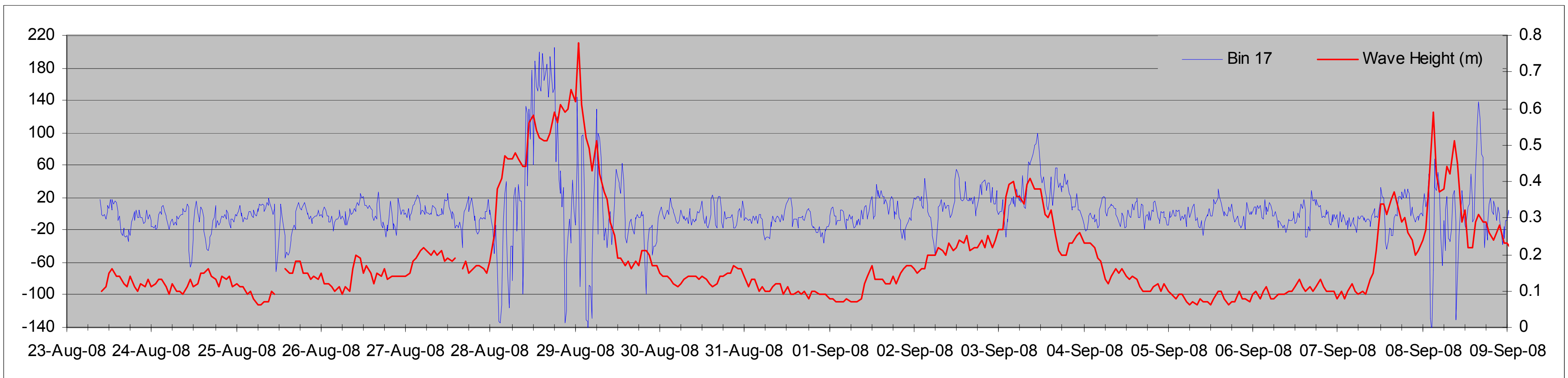


Figure 3.14 Measured current speed versus measured wave heights (Eastings)

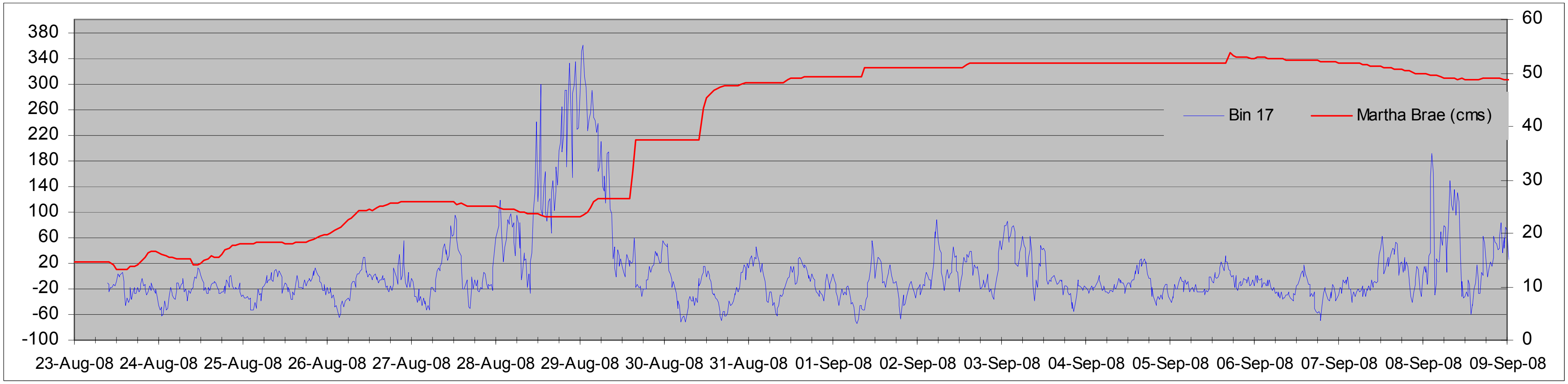


Figure 3.15 Measured current speed versus measured Martha Brae River flow (Northings)

4 Hydrodynamic Modeling

The hydrodynamic model RMA-10 was used for this project. The model uses a finite element network to define the study area. The flexibility of the RMA-10 model allows 2D and 3D elements to occur within the same model, greatly improving computational efficiency, while not restricting the ability to represent vertical stratification. The primary features of RMA-10 are:

- The solution of the Navier-Stokes equations in three-dimensions;
- The use of the shallow-water and hydrostatic assumptions;
- Coupling of advection and diffusion of temperature, salinity and sediment to the hydrodynamics;
- The inclusion of turbulence in Reynolds stress form;
- Horizontal components of the non-linear terms are included;
- A capacity to include one-dimensional, depth-averaged, laterally-averaged and three-dimensional elements within a single mesh as appropriate;
- No-, partial and full-slip conditions can be applied at both lateral boundaries;
- Partial or no-slip conditions can be applied at the bed;
- Depth-averaged elements can be made wet and dry during a simulation;
- Vertical turbulence quantities are estimated by either a quadratic parameterization of turbulent exchange or a Mellor-Yamada Level 2 turbulence sub-model.

The development of a reliable oceanographic prediction model requires two main phases. The first is the creation of a 3D hydrodynamic model, which accurately predicts the current patterns and vertical temperature/salinity stratification in the Falmouth Harbour. The second phase is to modify this model to represent the proposed changes to the shoreline and seabed elevations. Finally, an analysis is made of the results of the two different models.

4.1 Mesh Construction

The mesh construction exercise involved the construction of two finite element meshes from which comparisons could be made. The first mesh was developed to represent the existing bathymetric and shoreline configuration. The second mesh represents the modified shoreline configuration with the seabed dredged for the proposed cruise ship facility, and the shoreline modified to represent the proposed land reclamation.

4.2 Model Calibration

Three new input parameters were used to calibrate the hydrodynamic model: measured tides; currents; and river flow data. Additional data such as wind will be used also to attempt to obtain some scatter within the model.

Figure 4.1 and Figure 4.2 show both the Easting and Northing directions of the measured and calibrated model over a 20-day simulation period. The hydrodynamic results show that the current speed and direction are within the range of the measured data, apart from the spikes in the current flow, as these have been shown to be actually due to wave-induced currents. The model however does fall within the normal current speed range under normal conditions. The scatter diagram also shows the modeled results falling within the range of the measured current speeds and directions.

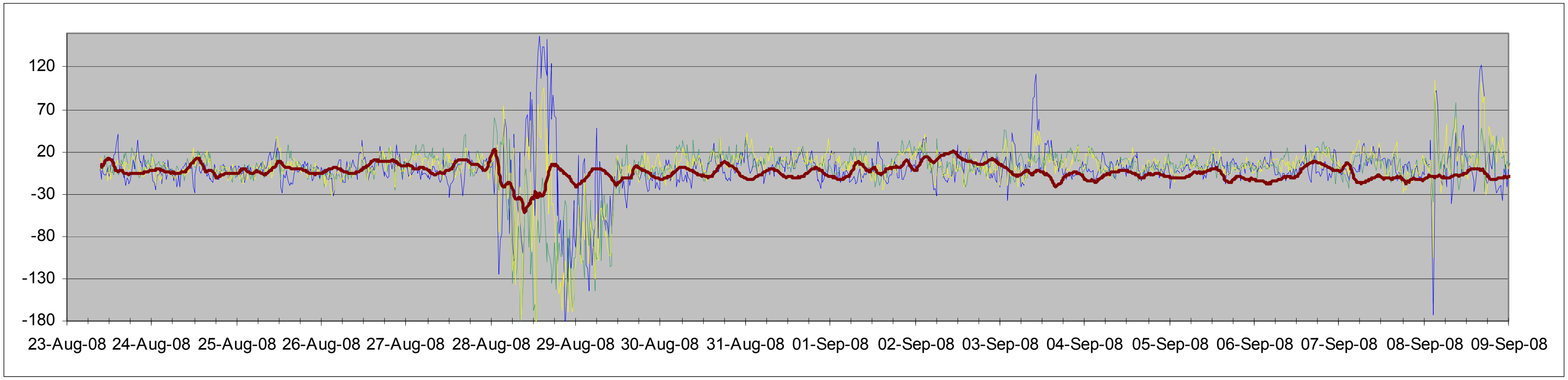


Figure 4.1 Measured data versus Calibrated RMA 10 in the Eastings direction (mm/s)

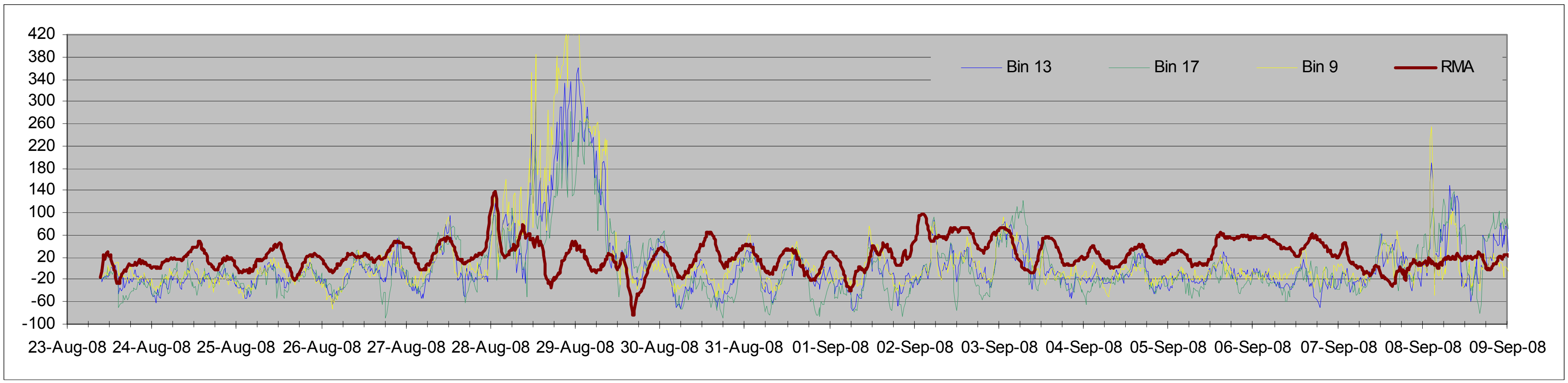


Figure 4.2 Measured data versus Calibrated RMA 10 in the Northing direction (mm/s)

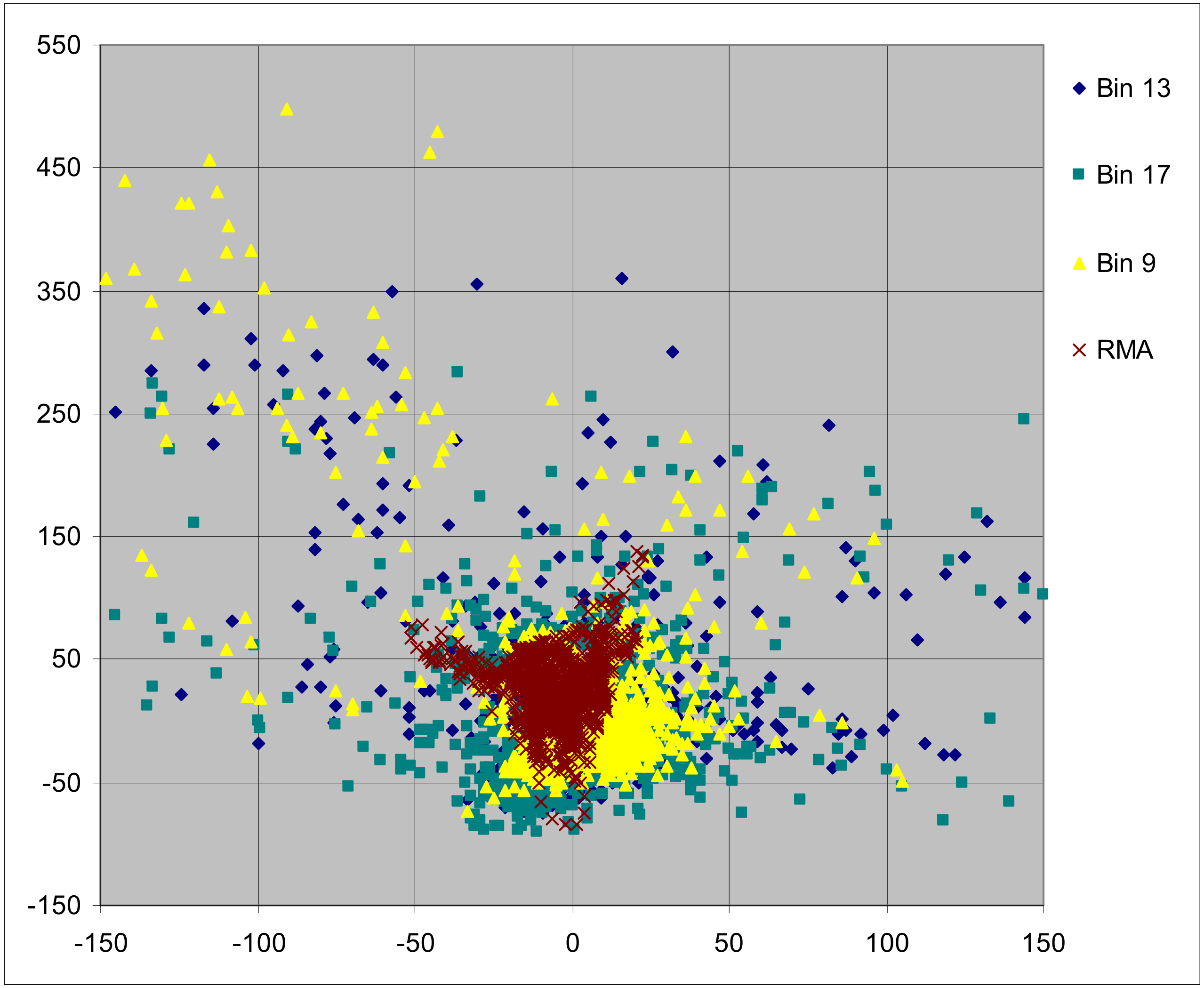


Figure 4.3 **Scatter Plot showing measured and modeled current speed and directions**

4.3 Model Simulations

The comparison of existing and proposed conditions can be investigated with more certainty results with a calibrated model and 30 days of measured tide, current and river data. To reconfirm, the magnitude of the impact of the development on currents, salinity, temperature, and sediment suspension and, in turn, their effect on dinoflagellates, can be assessed with more certainty. Both base and flood flow conditions should be investigated during rising and falling tide conditions.

4.3.1 Currents

A detailed comparison was made by evaluating the difference between the predicted current speeds and directions at two nodes, for the entire model simulation. The mesh set-up for the existing bay condition is shown in Figure 4.4, while the proposed bay configuration (including landfill and dredged area) and the locations of the investigative nodes is shown in Figure 4.5. The comparisons are shown in Figure 4.6 and Figure 4.7, representing Nodes 1104 and 491 respectively. The figures show the current speeds and directions for each time-step in the model simulation as points on the scatter diagram. The distance from the origin represents the current speed, and its direction is plotted from North (Up). If there was no change in the current patterns, then each point representing the ***proposed*** condition would overly the ***existing*** condition point. It can be seen that the predicted currents at both of these nodes do not change significantly, as most of the Existing Condition points have been masked by the Proposed Condition points, indicating virtually no change in the current patterns as a result of the proposed works.

The results for Node 1104, which is located well inside the estuary, show little or no changes between the Existing Condition and Proposed Condition currents. For Node 491, which is located closer to the dredged entrance channel and proposed landfill, there is a more noticeable change in the scatter diagram, although the shift does not appear to be significant. A significant shift would appear as an obvious change in the location of the centroid of the values, or in the range of values.

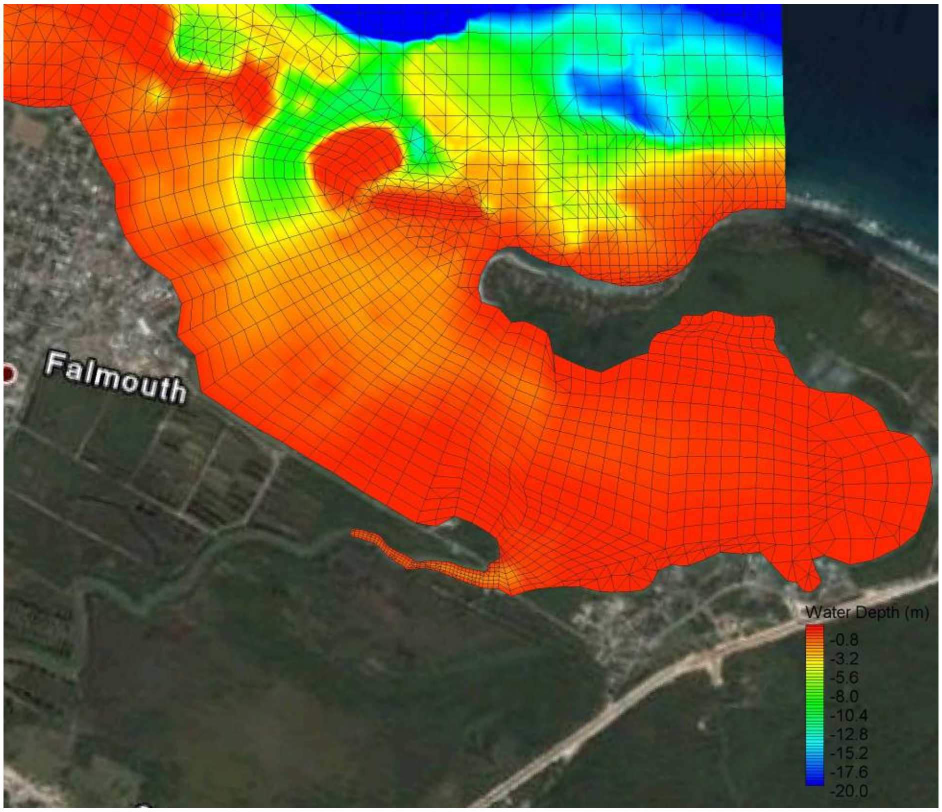


Figure 4.4 Hydrodynamic mesh representing Existing shoreline and seabed

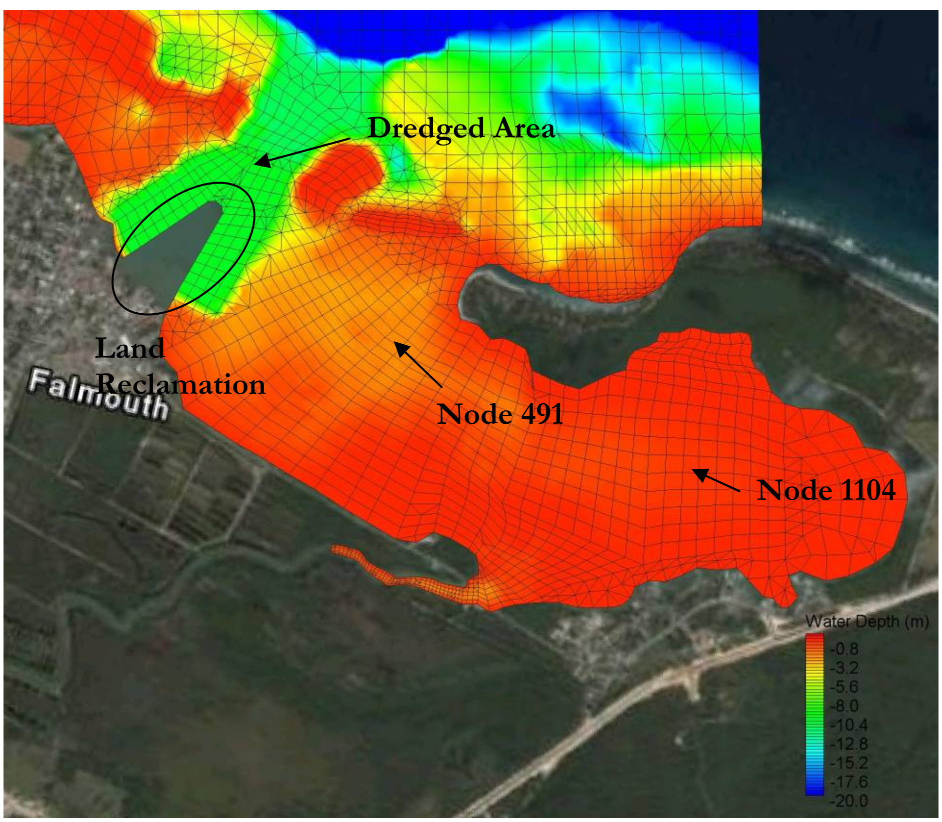


Figure 4.5 Hydrodynamic mesh representing proposed land reclamation and dredged seabed

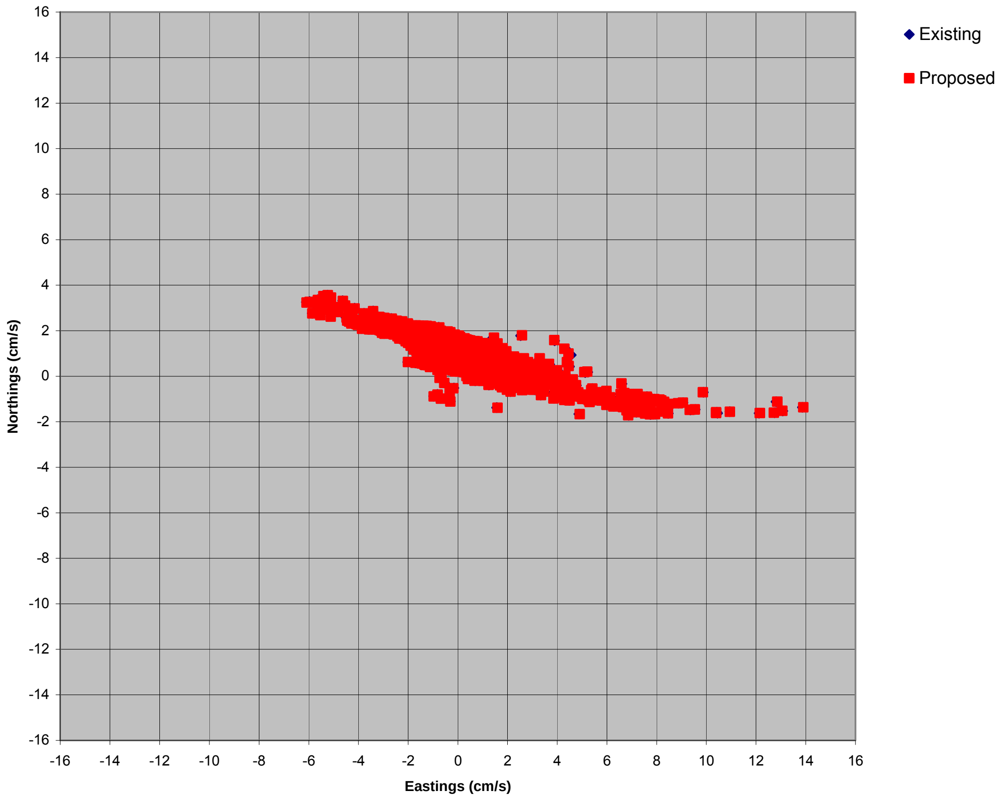


Figure 4.6 Scatter plot showing comparing existing and proposed conditions at Node 1104

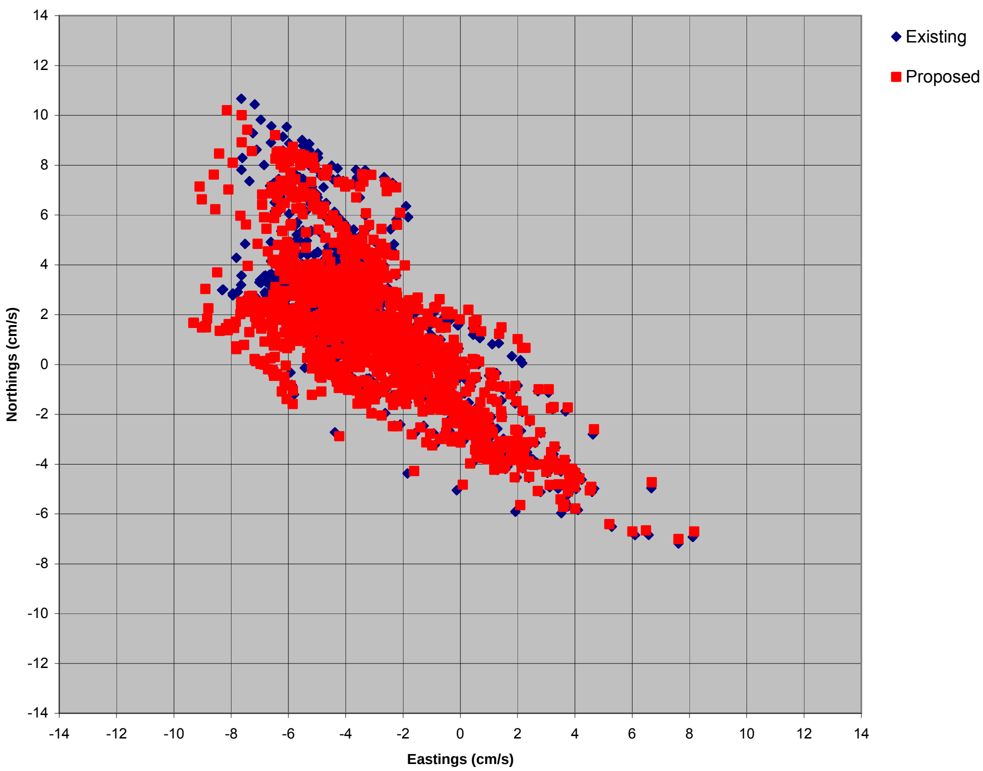


Figure 4.7 Scatter plot showing comparing existing and proposed conditions at Node 491

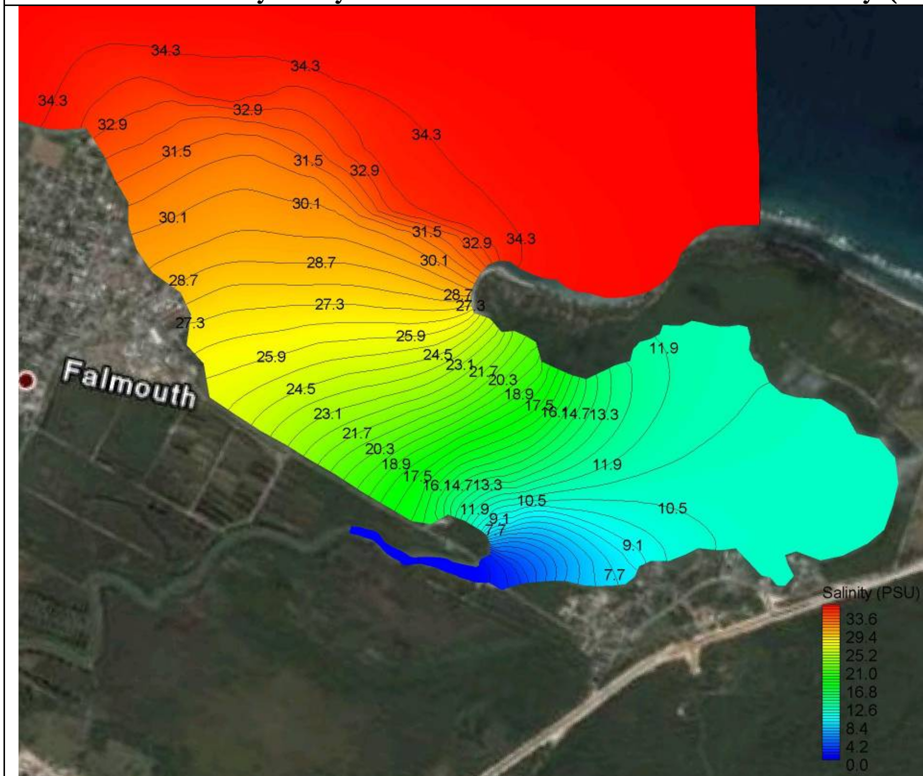
4.3.2 Salinity Results

The following plots show contours of the surface salinity during rising and falling tidal cycles for both the existing and proposed conditions (Figure 4.8 to Figure 4.11).

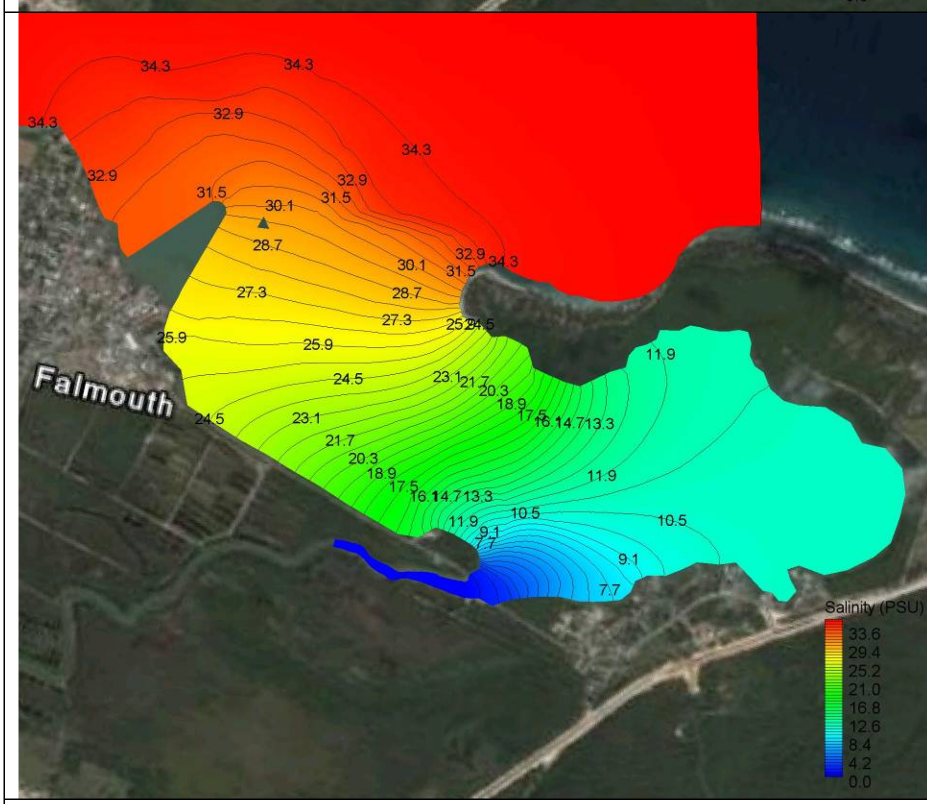
To ensure that the model is in steady state, the start of the results were plotted after a minimum of 24 hrs into the model simulation, after which rising and falling tidal cycles were simulated for normal flow and flood conditions. At node 1104 which is where the Dinoflagellates tend to reside mostly, the model shows that the existing condition has a higher concentration of saline intrusion, and the differences range between 1 to 2 PSU, with the larger differences occurring during normal flow conditions as shown in Figure 4.13.

The lack of stratification at node 1104 is due to the shallow water depths within this area (1m), therefore total mixing is expected to occur. At node 491 where the water depth is over 2.5m, there is noticeable stratification occurring as shown in Figure 4.14, however, the differences in saline concentration at node 491 is not as great as at node 1104.

Falmouth Cruise ship Facility
RMA-10 2D Hydrodynamic Model Results – Surface Salinity (PSU)



Existing

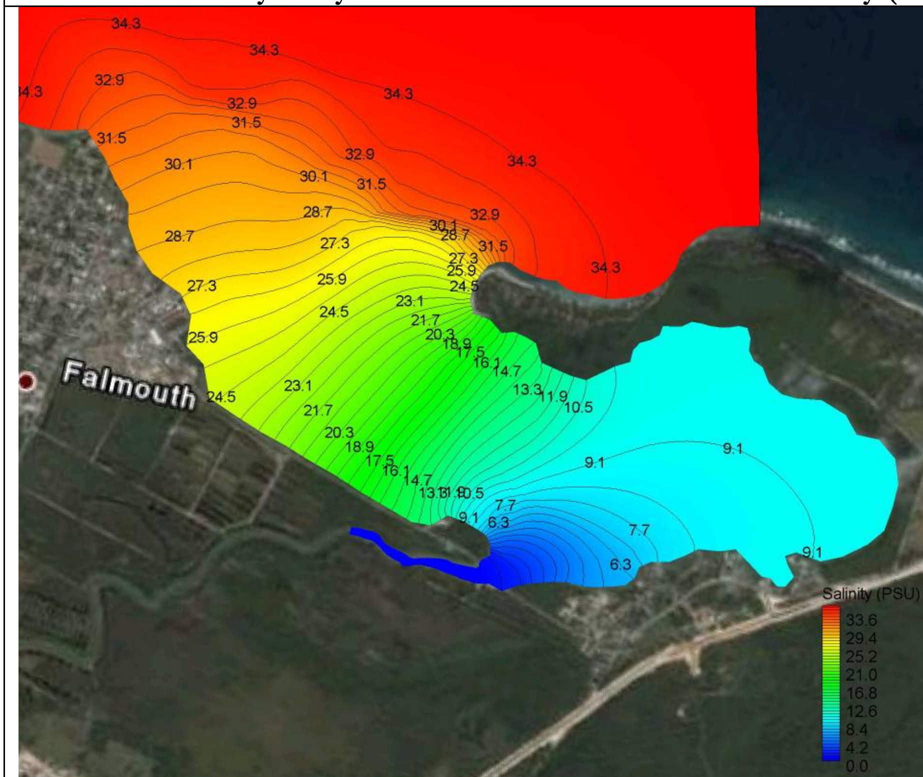


Proposed

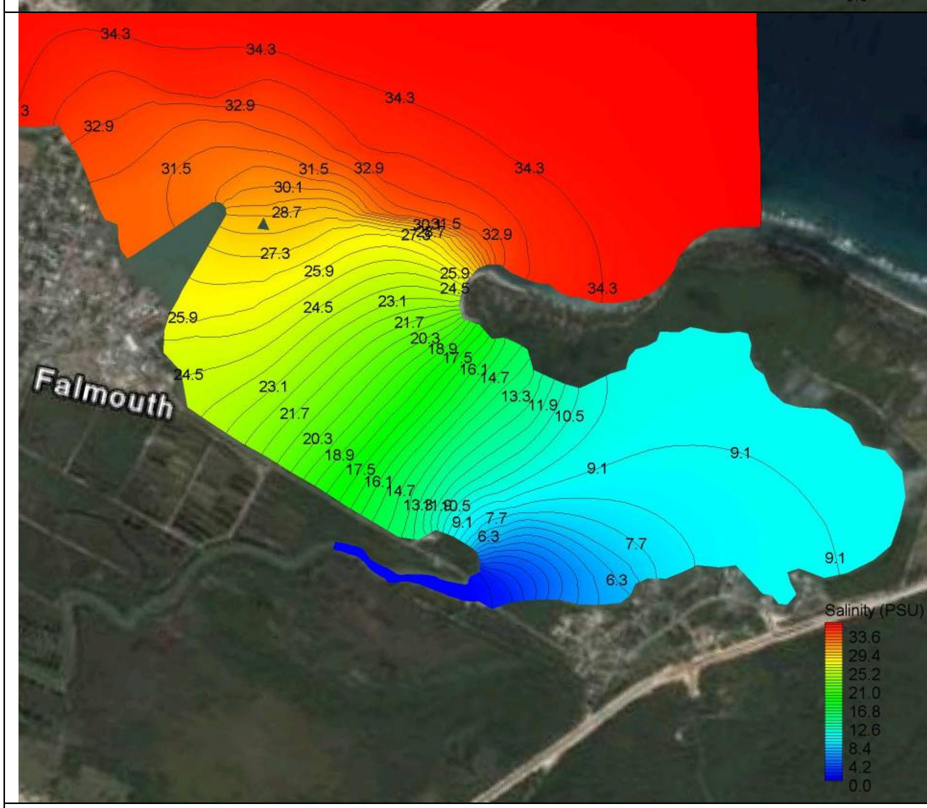
Model – Normal River Flow
Simulation time: Rising tide

Figure 4.8

Falmouth Cruise Ship Facility
RMA-10 2D Hydrodynamic Model Results – Surface Salinity (PSU)



Existing

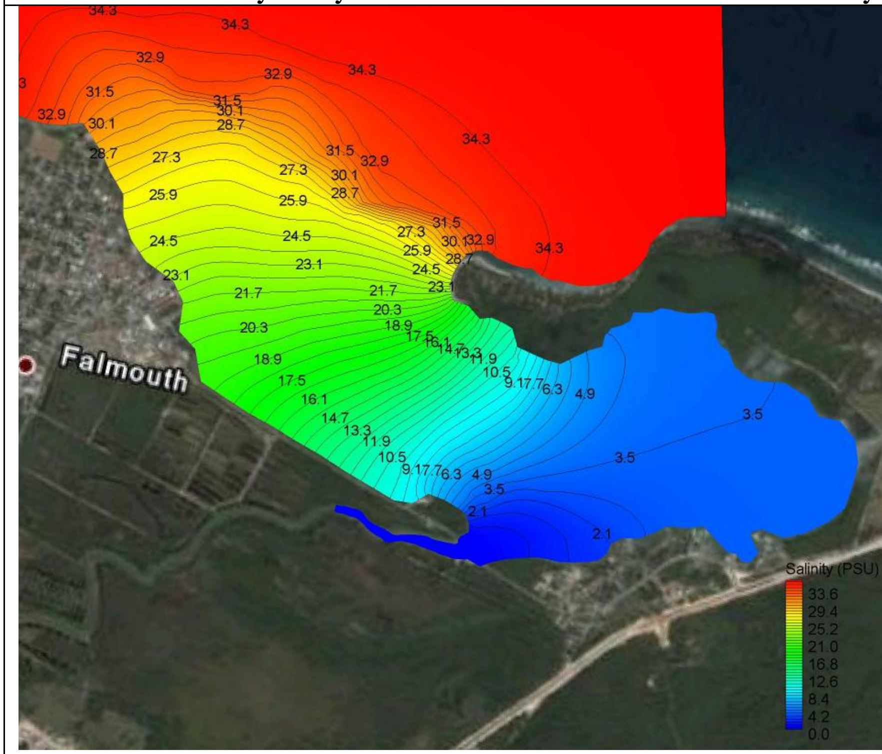


Proposed

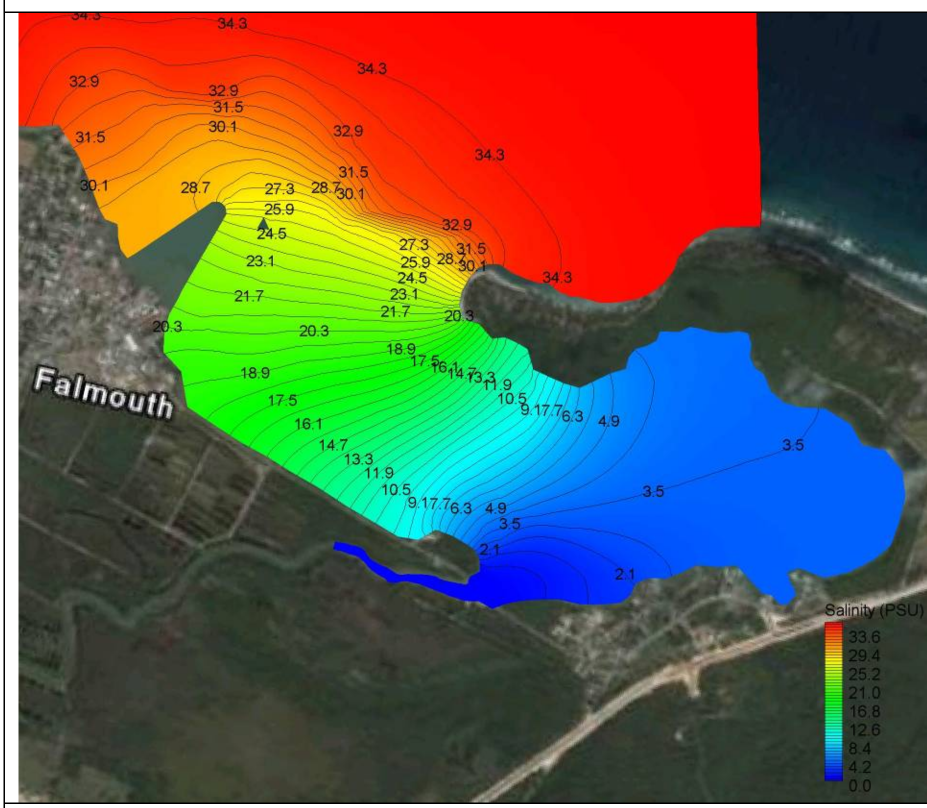
Model – Normal River Flow
Simulation time: Falling tide

Figure 4.9

Falmouth Cruise Ship Facility
RMA-10 2D Hydrodynamic Model Results – Surface Salinity (PSU)



Existing

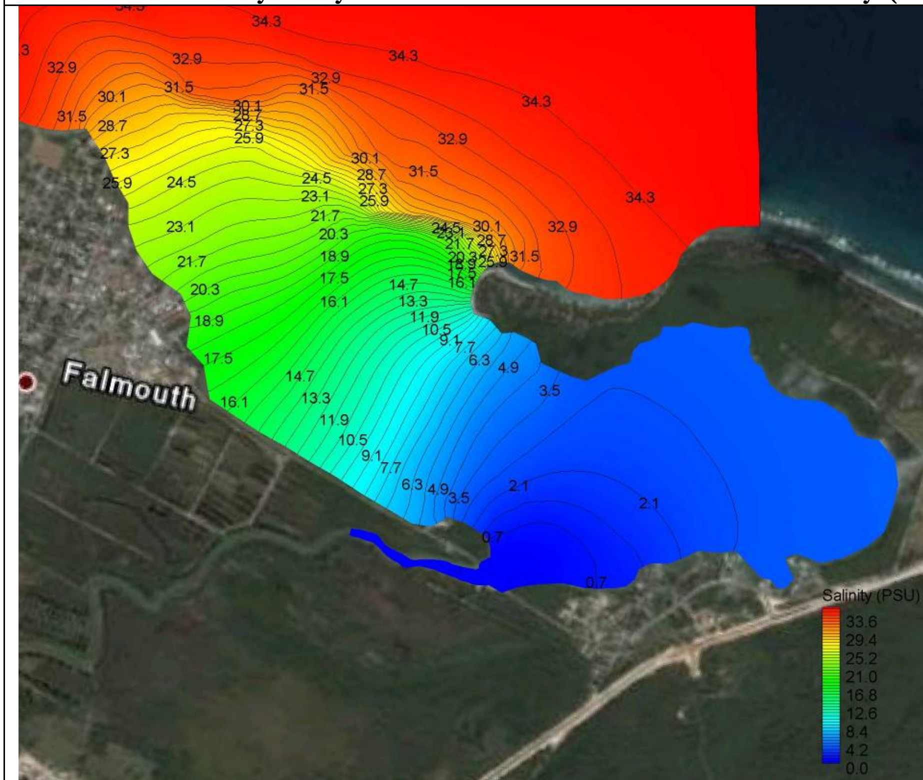


Proposed

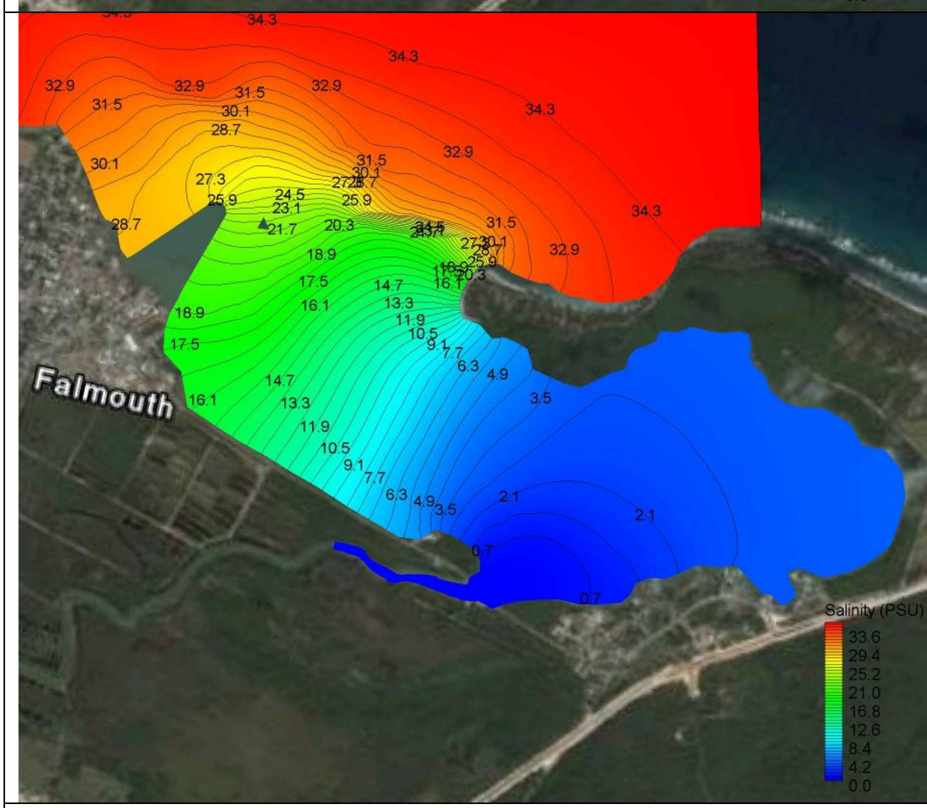
Model – Flood Conditions
Simulation time: Rising tide

Figure 4.10

Falmouth Cruise Ship Facility
RMA-10 2D Hydrodynamic Model Results – Surface Salinity (PSU)



Existing



Proposed

Model – Flood Conditions
Simulation time: Falling tide

Figure 4.11

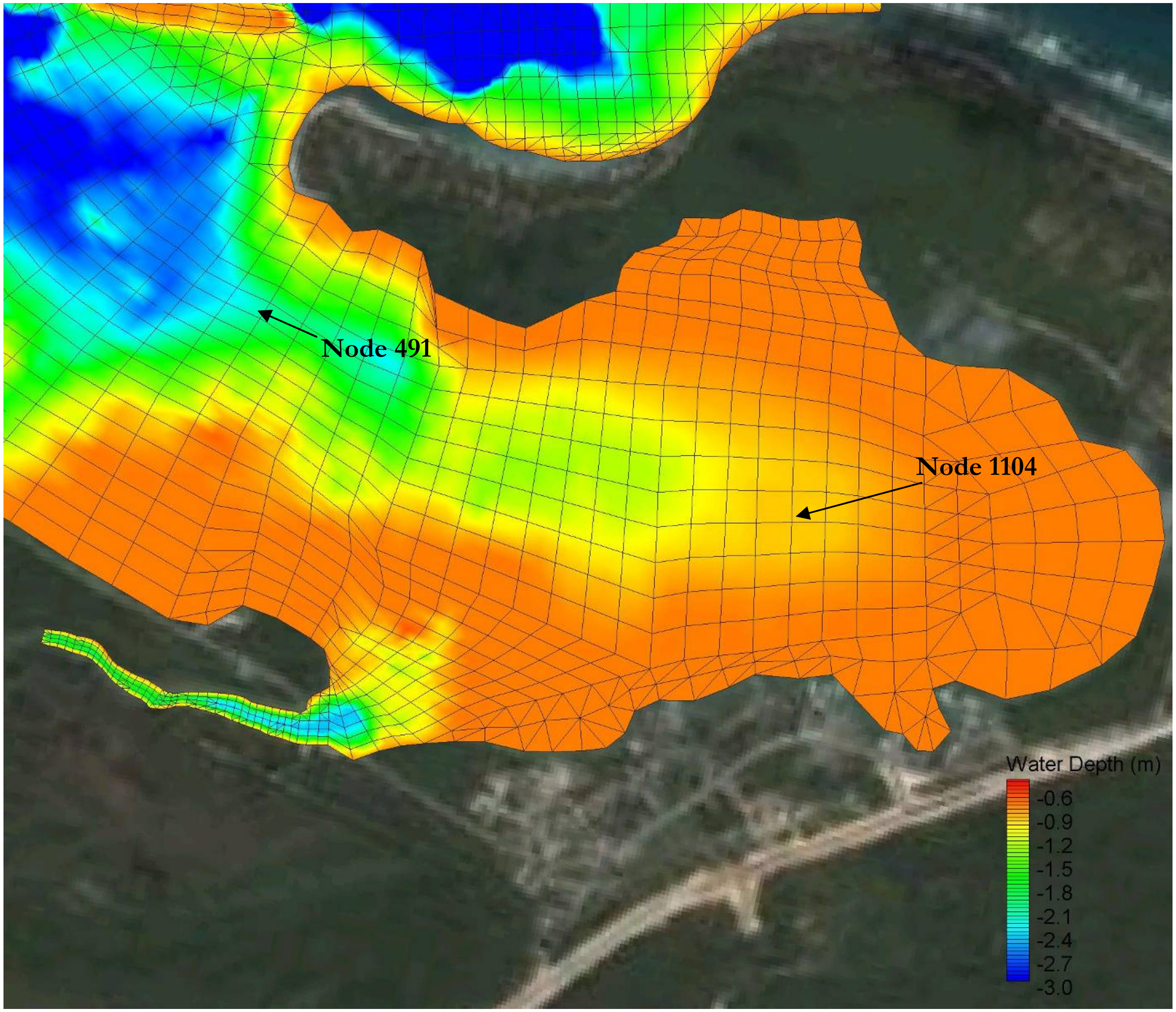


Figure 4.12 Location of Nodes selected for detailed analysis

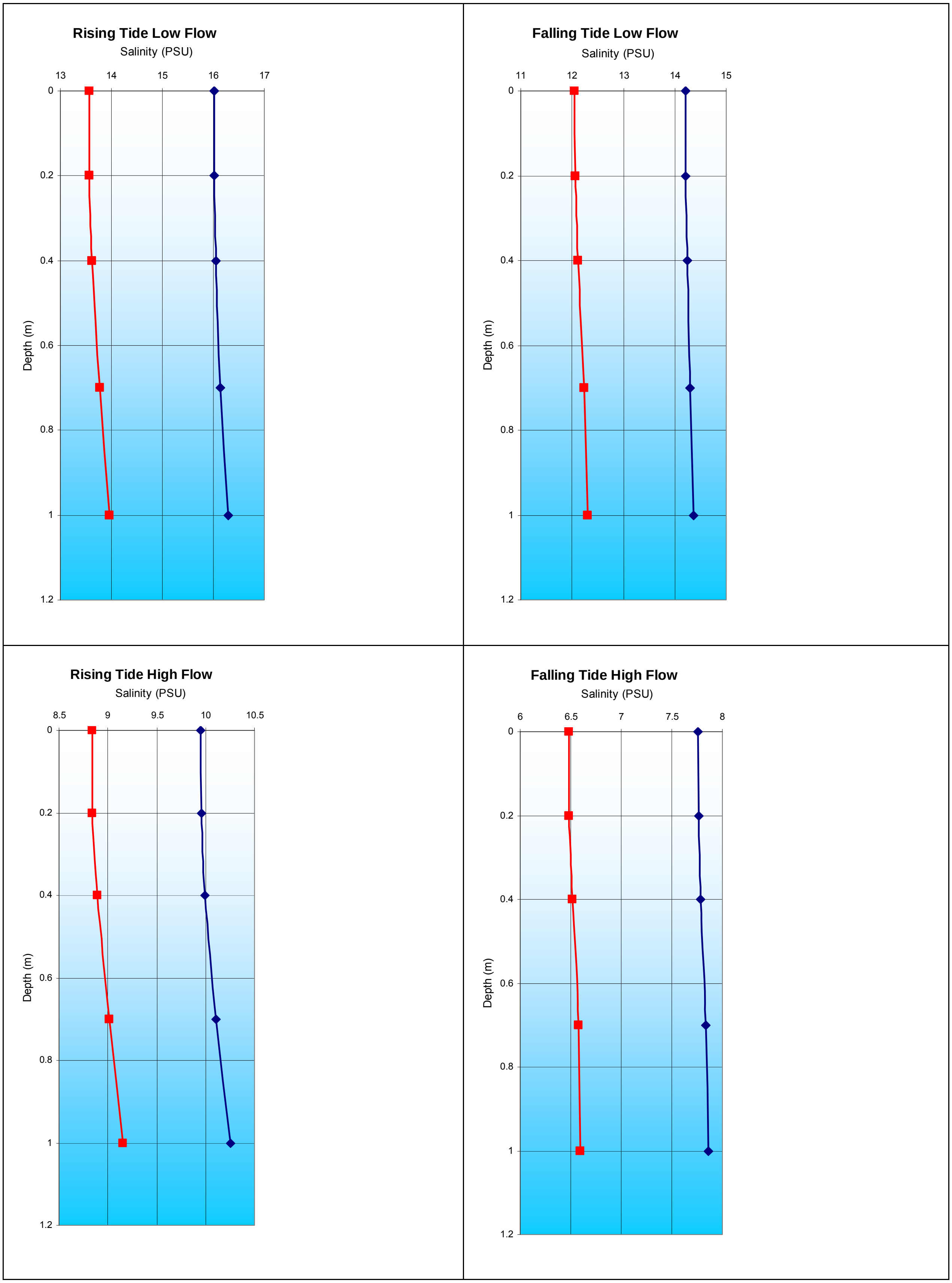


Figure 4.13 Salinity Comparison Profiles for Node 1104, existing condition is blue and proposed is red

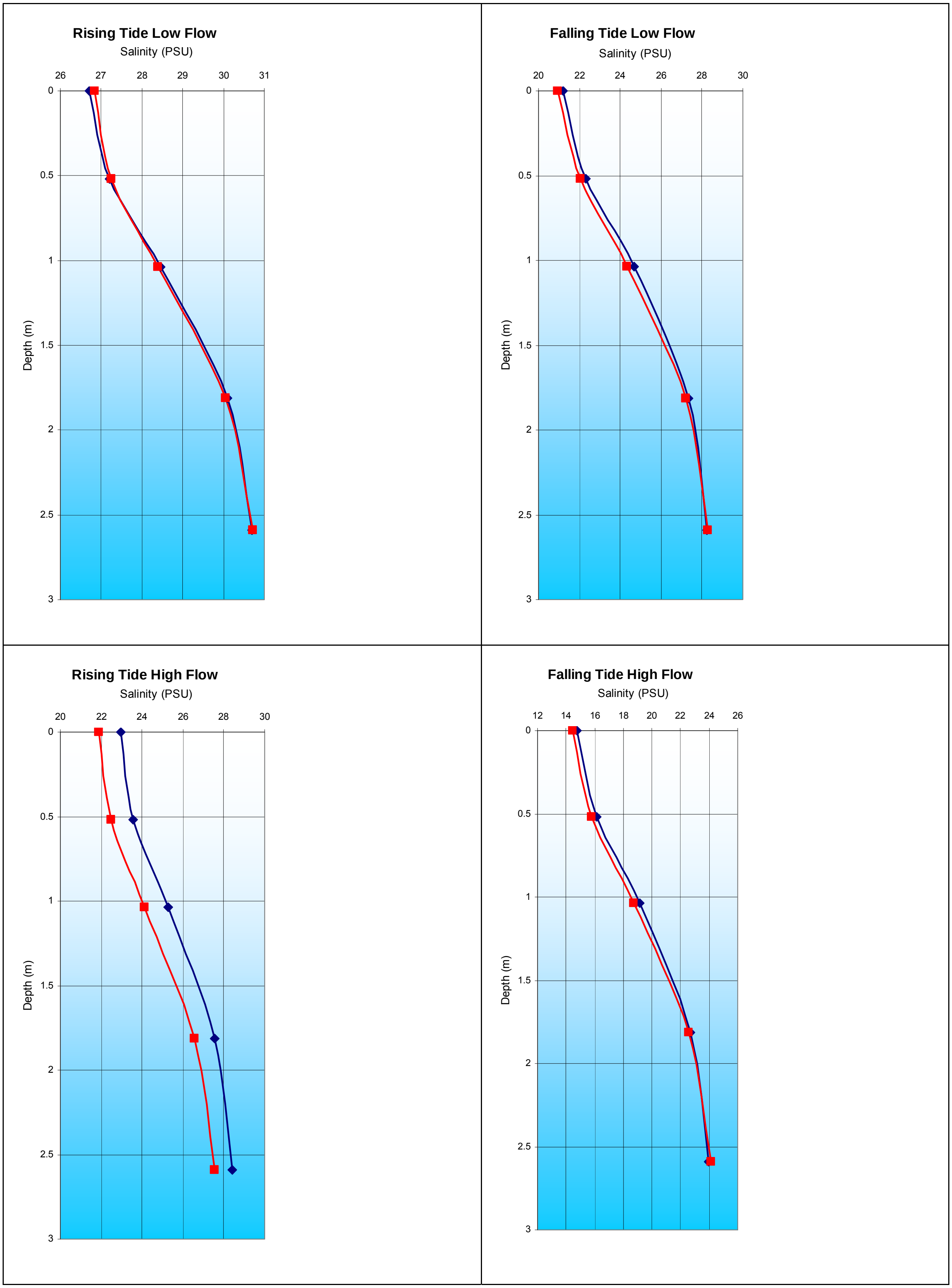


Figure 4.14 Salinity Comparison Profiles for Node 491, existing condition is blue and proposed is red

4.3.3 Temperature Results

The following plots (Figure 4.15 to Figure 4.18) show contours of the surface temperatures during rising and falling tides in both normal and flood river conditions. Each plot shows the results for the existing shoreline and bathymetry and the proposed land reclamation and entrance channel dredging.

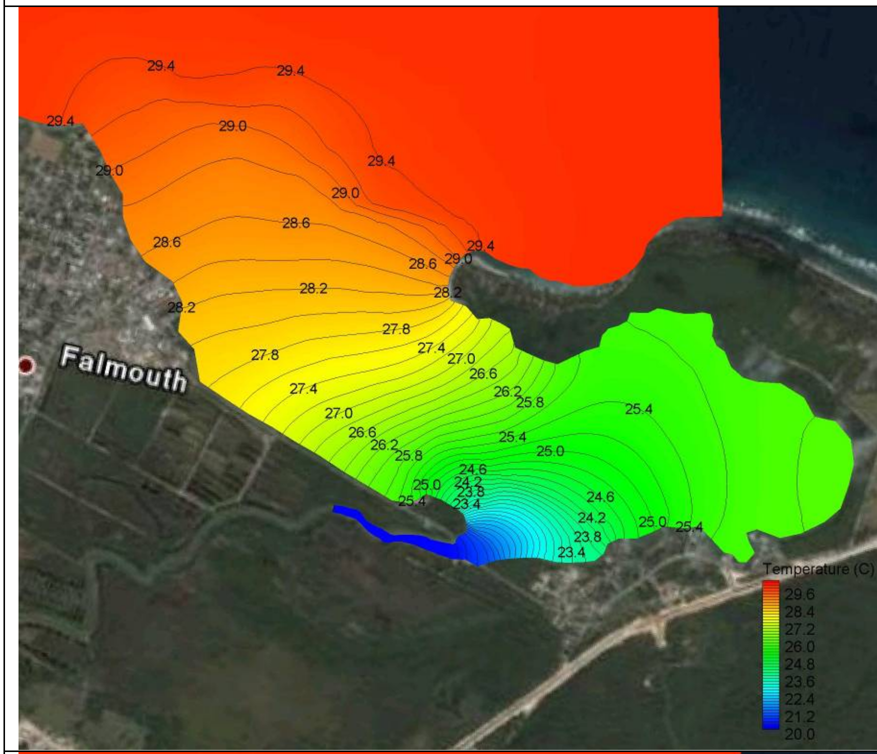
The temperature results during normal river flow conditions show an average temperature of 25ºC, with slightly warmer temperatures occurring during the rising tide as the warmer sea water enters the inner harbour. During the normal flow conditions, there are no noticeable differences between ambient and proposed conditions.

Under flood conditions, the model shows cooler water within the inner harbour due to cooler river water. The temperature drops to around 23ºC in both the ambient and proposed conditions.

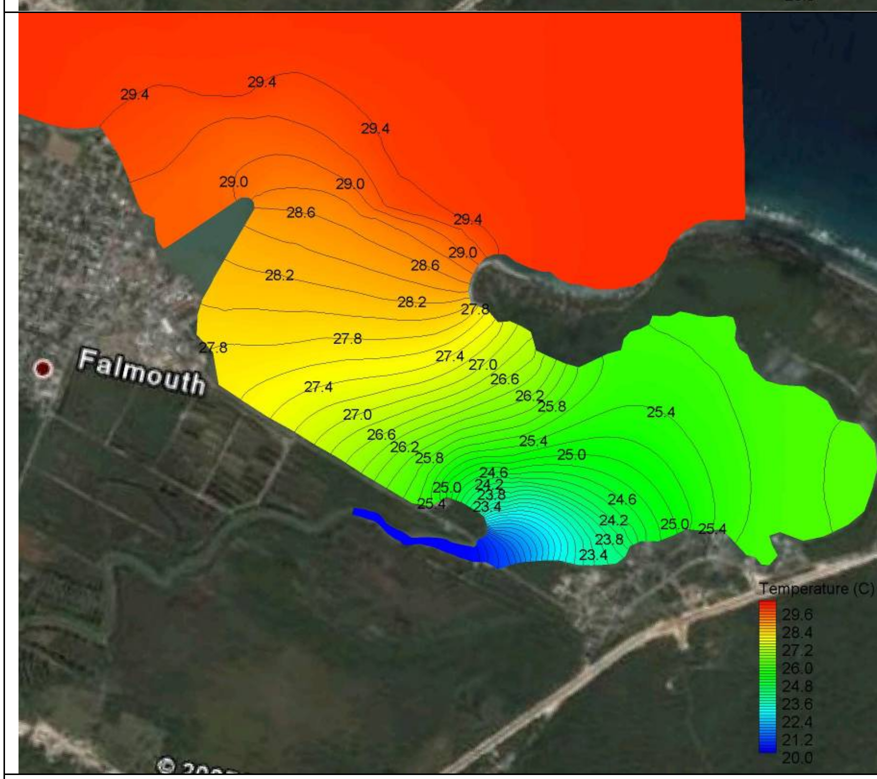
Overall, the 2-dimensional temperature model shows no significant changes in the Inner Harbour, where the dinoflagellates reside, as a result of the proposed works.

Figure 4.19 and Figure 4.20 show the temperature profiles throughout the water column at nodes 1104 and 491. Overall the model predicts slightly warmer temperatures at both nodes for the existing condition over the proposed layout. Due to the lack of measured temperature data for the Martha Brae River, the assumed temperature was a constant 20ºC.

Falmouth Cruise ship Facility
RMA-10 2D Hydrodynamic Model Results – Temperature (C)



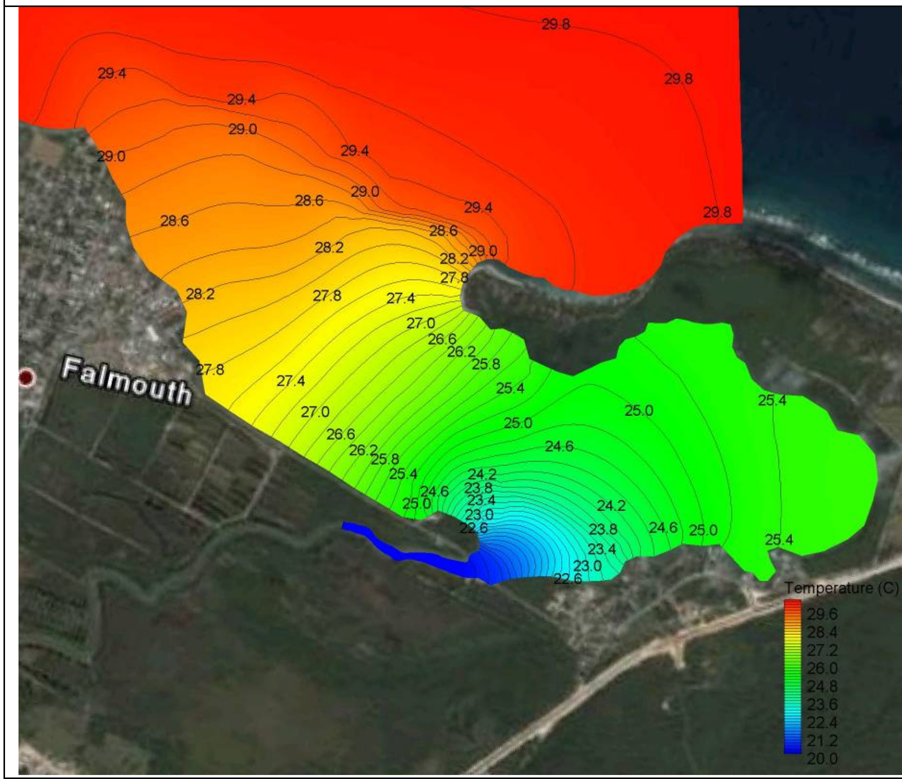
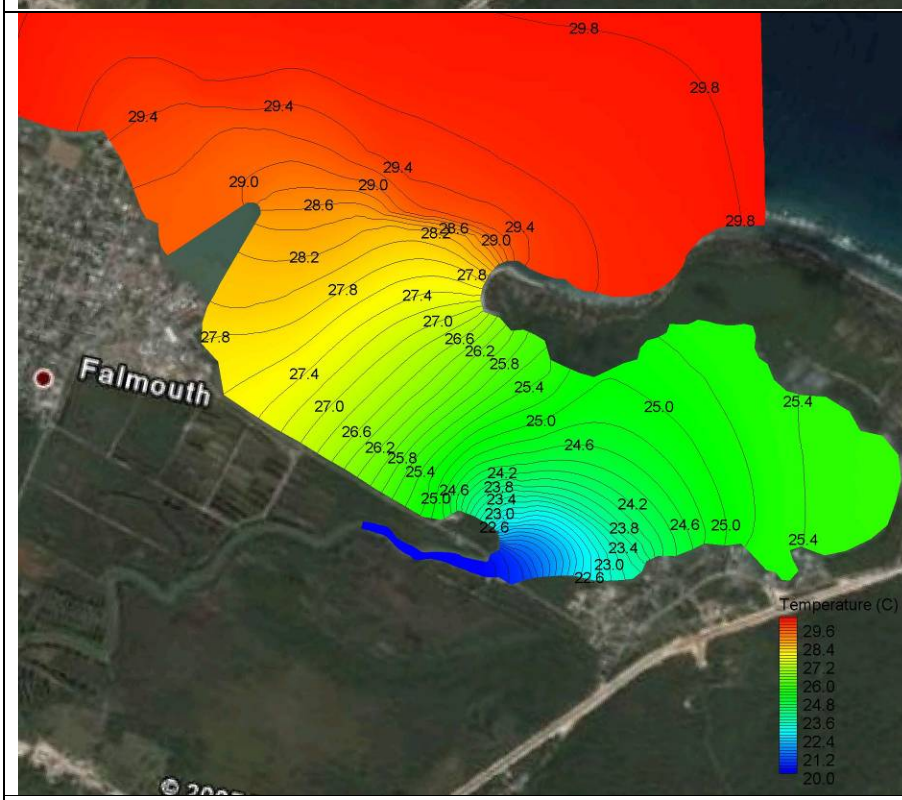
Existing



Proposed

Model – Normal River flow
Simulation time: Rising tide

Figure 4.15

<table>
<tr><td colspan="1">Falmouth Cruise Ship Facility
RMA-10 2D Hydrodynamic Model Results – Temperature (C)</td><td></td></tr>
<tr><td>
</td><td>Existing</td></tr>
<tr><td>
</td><td>Proposed</td></tr>
<tr><td>Model – Normal River flow
Simulation time: Falling tide</td><td>Figure 4.16</td></tr>
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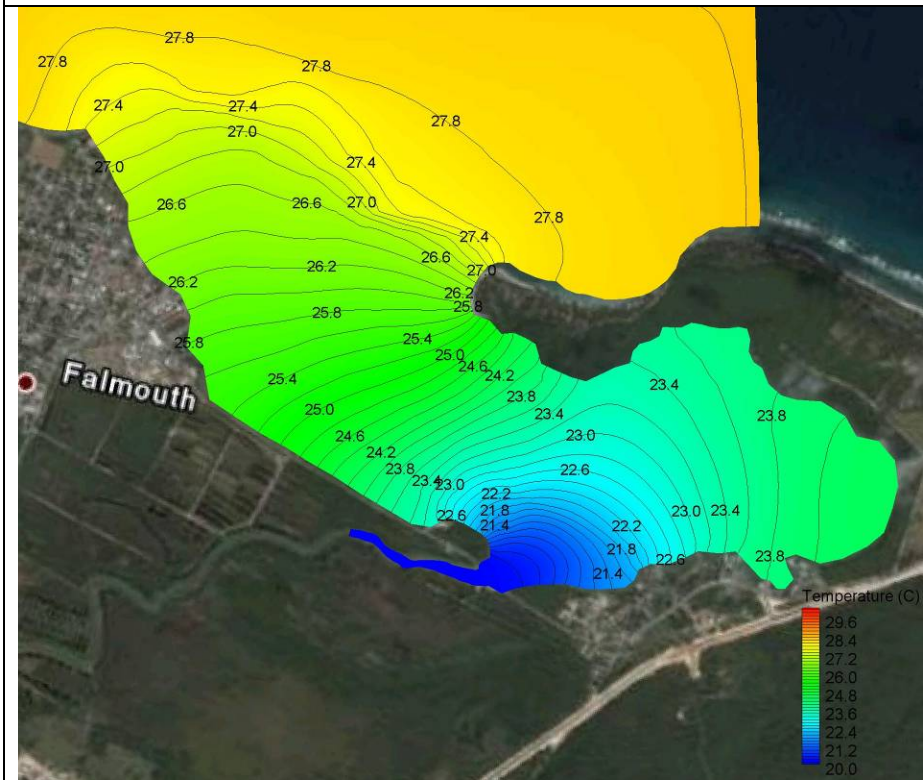
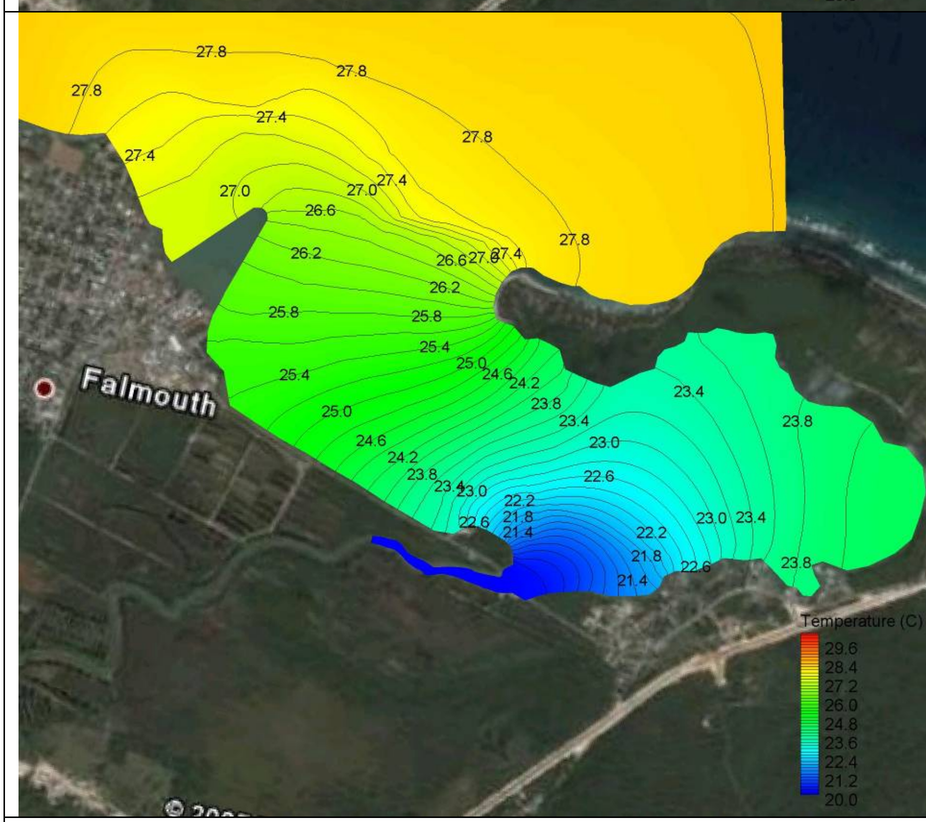
Falmouth Cruise Ship Facility
RMA-10 2D Hydrodynamic Model Results – Temperature (C)



Existing

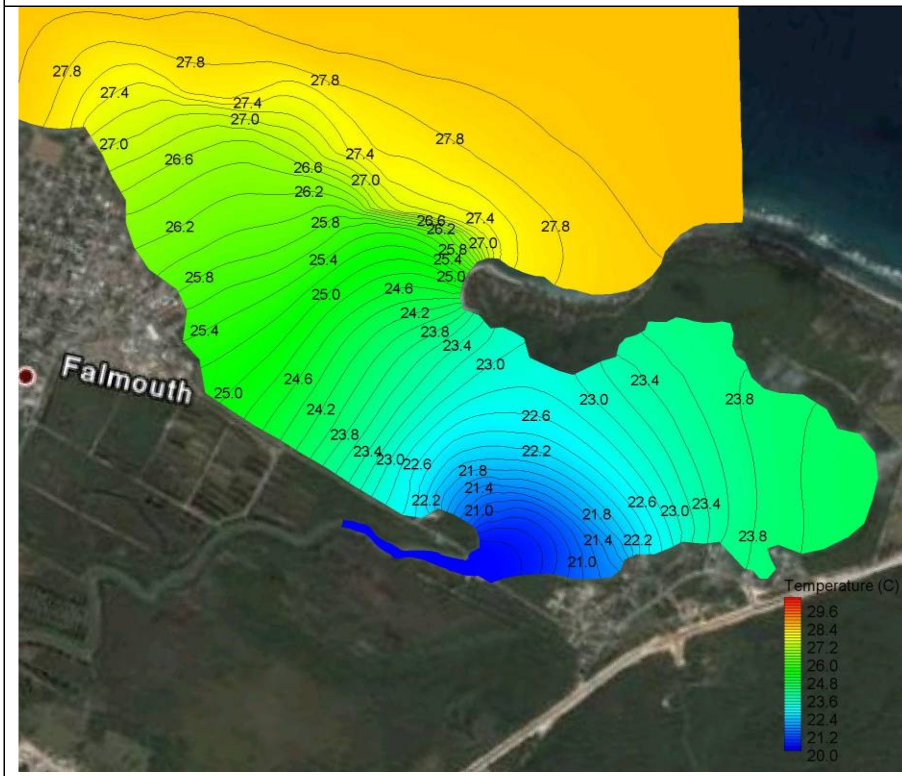


Proposed

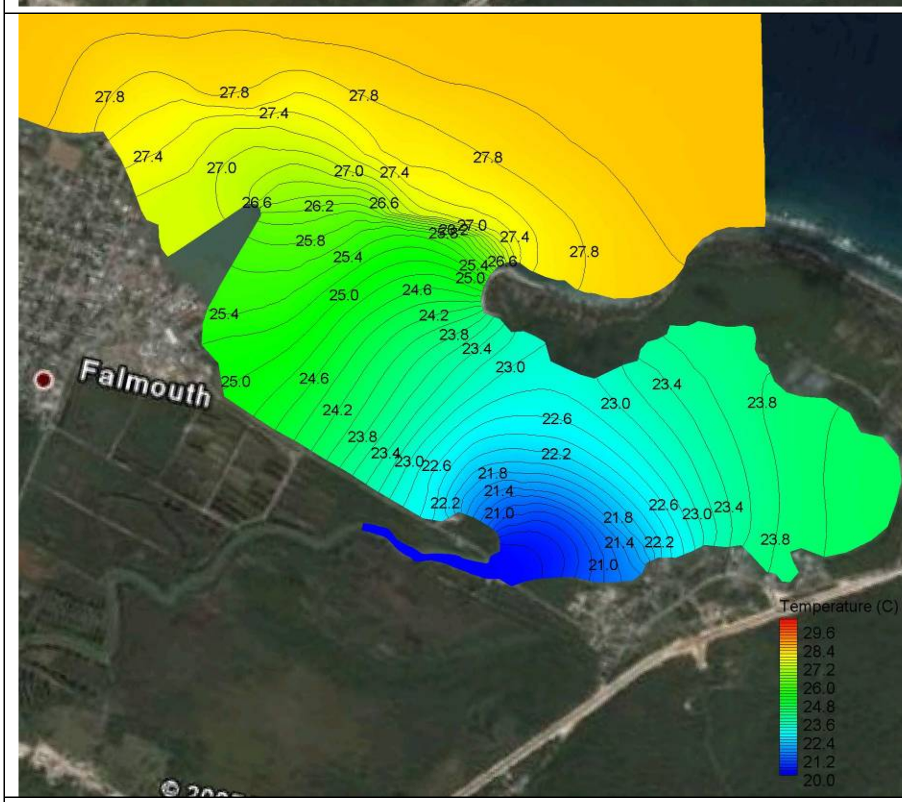
Model – Flood Conditions
Simulation time: Rising Tide

Figure 4.17

Falmouth Cruise Ship Facility
RMA-10 2D Hydrodynamic Model Results – Temperature (C)



Existing



Proposed

Model – Flood Conditions
Simulation time: Falling tide

Figure 4.18

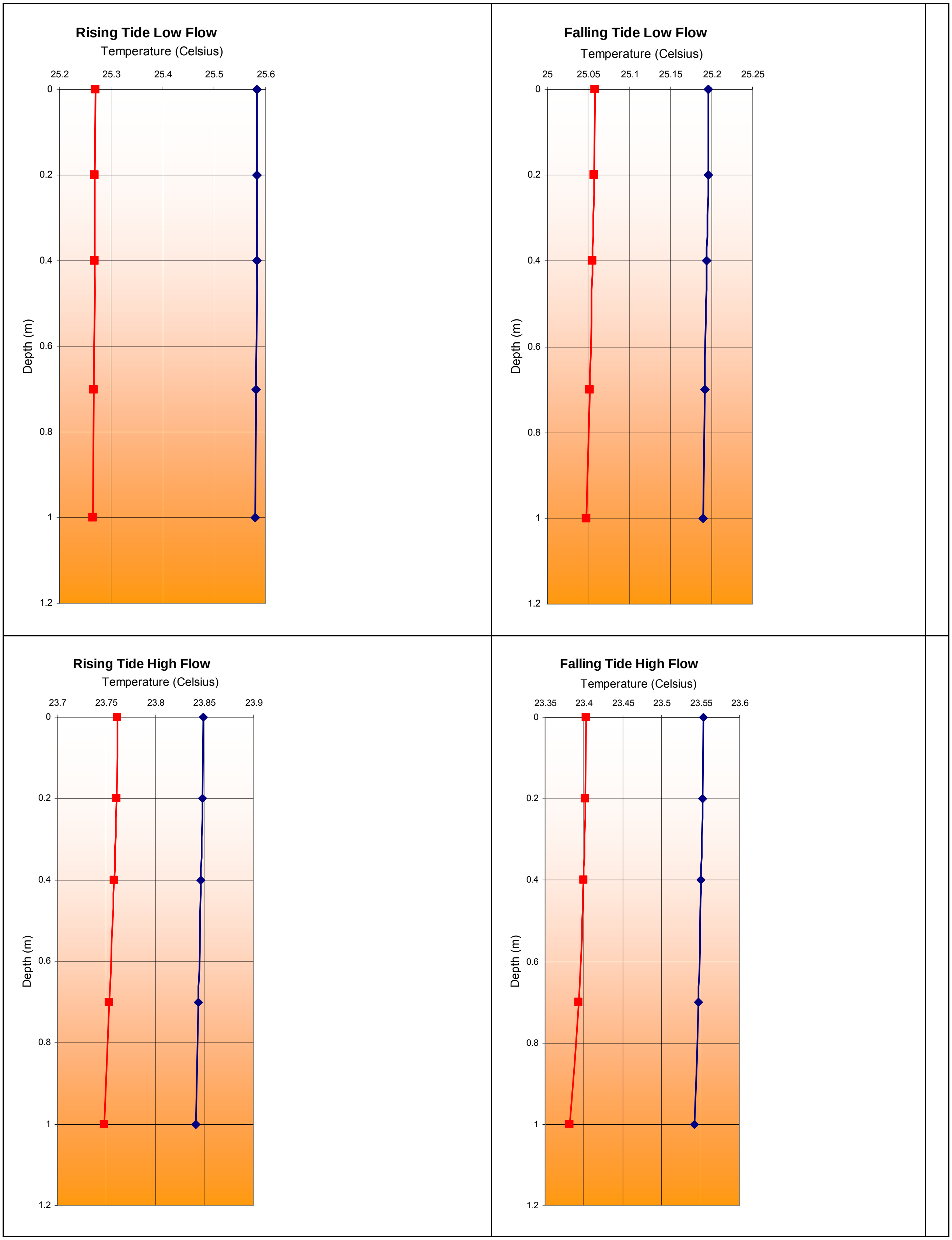


Figure 4.19 Temperature Comparison Profiles for Node 1104, existing condition is blue and proposed is red

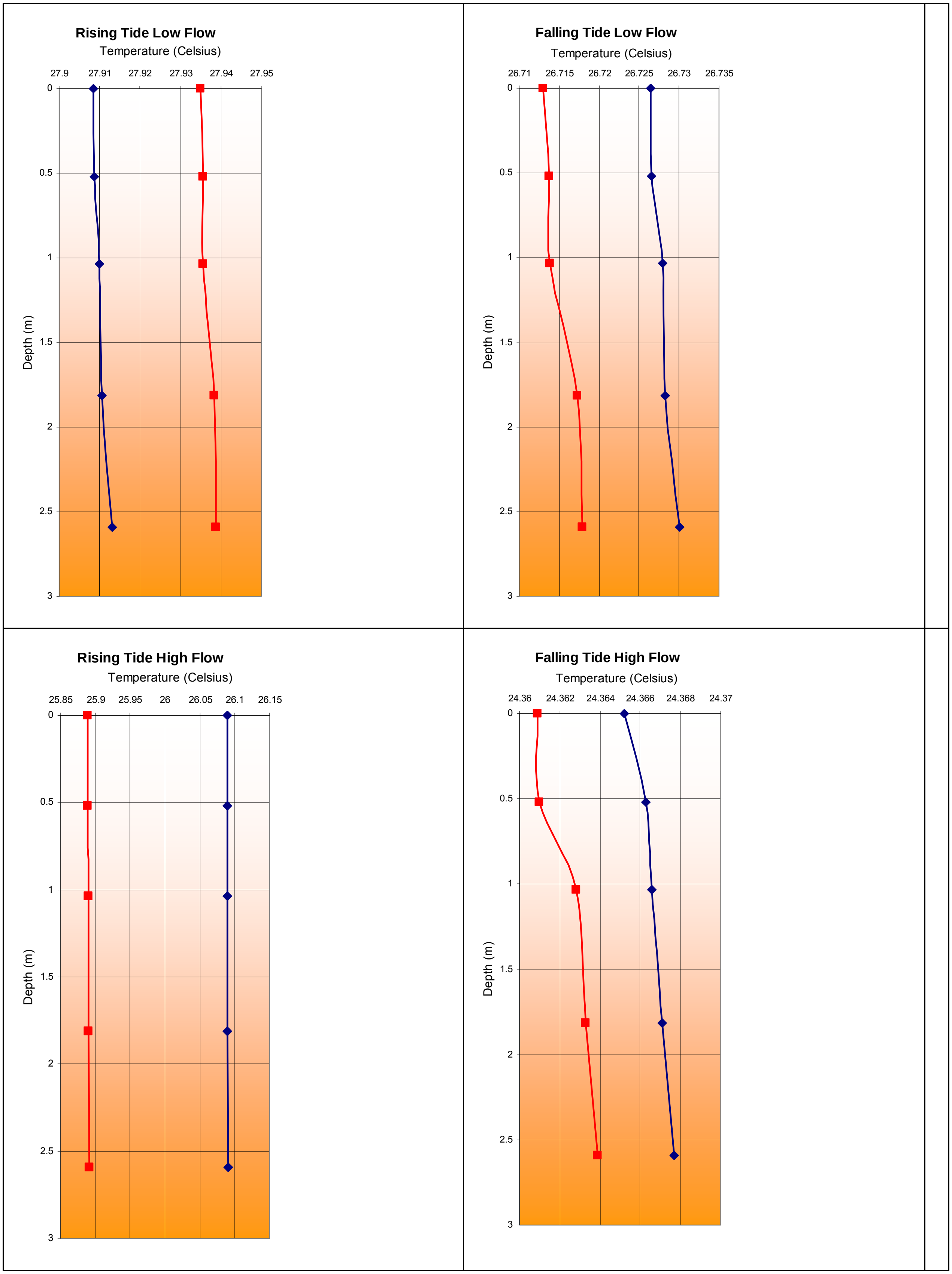


Figure 4.20 Temperature Comparison Profiles for Node 491, existing condition is blue and proposed is red

4.3.4 Suspended Sediment Results

RMA-10S was used to simulate cohesive sediment transport in the Falmouth Harbour estuary. Field investigations indicated the presence of very fine sediments. It is of interest therefore to determine the effects that the proposed landfill and dredged channel would have on the ambient sediment dynamics of cohesive sediments. This would be more pronounced in the wet season where more silt would be flowing from the Martha Brae River into the harbour. RMA-10S is a 2D morphodynamic model that simulates both non-cohesive and cohesive sediments.

With the availability of the new river flow data, measured suspended sediment data was not available, therefore, suspended sediment concentration flowing from the river was assumed to be 100 mg/l.

The planform results show the change in bed elevation that would occur under the existing and proposed conditions due to the settling of the suspended sediments out of suspension. Overall the model showed that the change in bed elevation due to an inflow of 100 mg/l of suspended sediment did not amount to more than 0.1m over the 20-day simulation. There are therefore no visible changes in bed elevation between both the existing and proposed conditions. The results of this modeling are shown in Figure 4.21 to Figure 4.25

With the proposed landfill, the suspended sediment seems to also accumulate within the dredged basin alongside the landfill. This is expected, as the suspended sediment is blocked by the structure and this could lead to a requirement for maintenance dredging during heavy rainfall events. It is very difficult to simulate the amount of sediment deposition that would occur during a significant rainfall event, therefore what is required would be for a bathymetric survey to be carried out right after the rainfall event to determine if dredging is required.

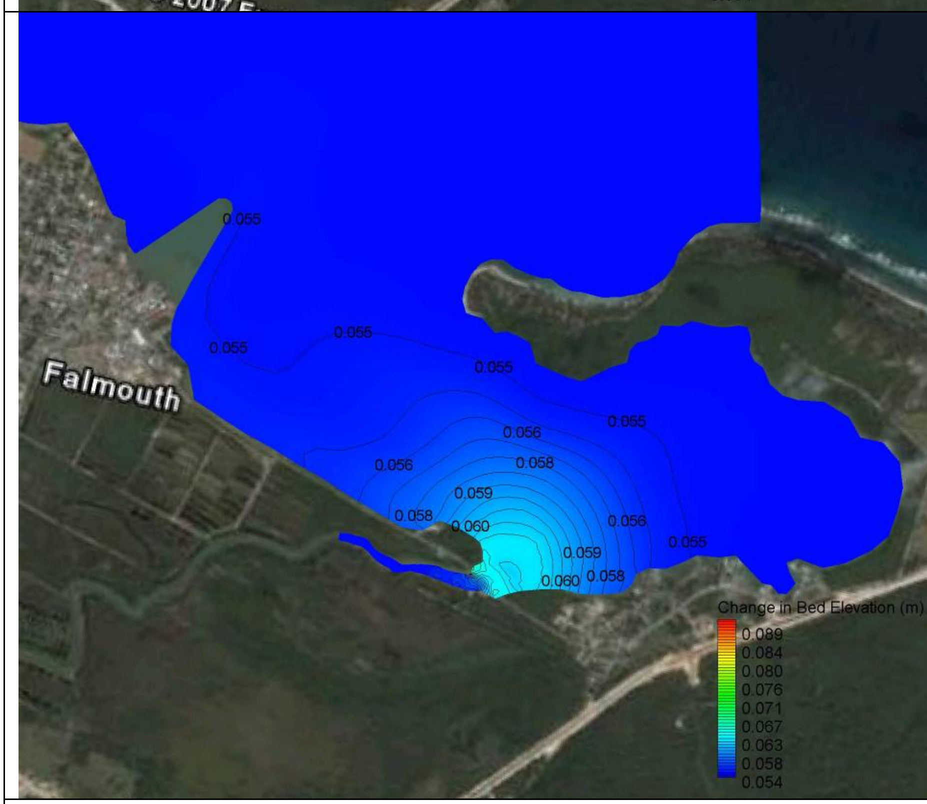
Examining a time-series of the suspended sediment concentration at nodes 1104 and 491 should give better insight on the effects that the proposed layout might have on the ambient condition.

Figure 4.26 and Figure 4.27 show the time series data for suspended sediment concentration at Nodes 1104 and 491 over a period of 20 days. The model shows no major changes in the suspended sediment concentrations during the whole simulation period. There is a noticeable increase in suspended sediment concentration when the flow increases, however, it can be seen that there are also tidal effects as the suspended sediment concentration increases and decreases in response to a noticeable tidal signal. Overall however, both the existing and proposed conditions do not show any significant changes in behaviour in respect to suspended sediment simulations.

Falmouth Cruise ship Facility **RMA-10S 2D Hydrodynamic Model Results – Change in Bed Elevation (m)**	
 	Existing
 	Proposed
Model – River flow **Simulation time: 1 day**	**Figure 4.21**

Falmouth Cruise Ship Facility
RMA-10S 2D Hydrodynamic Model Results – Change in Bed Elevation (m)

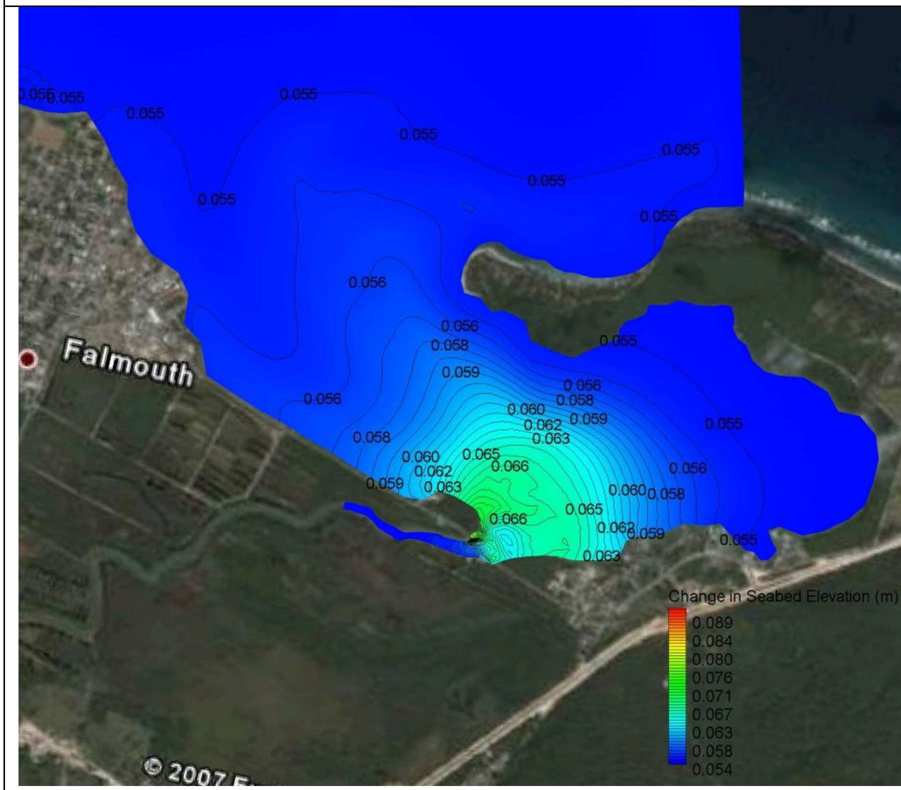
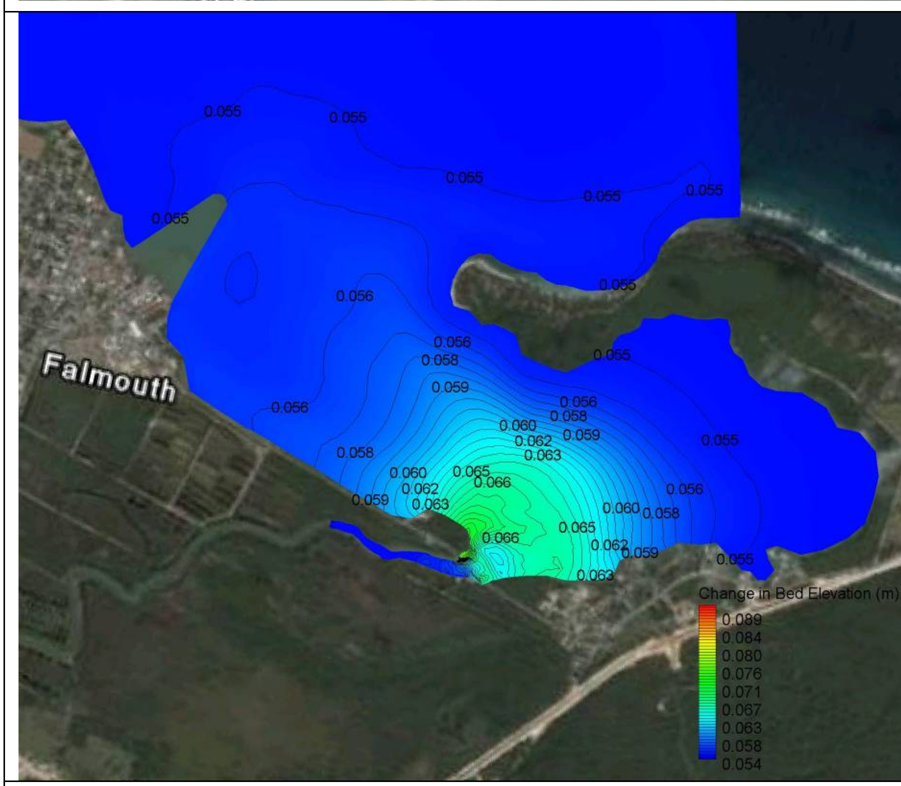
Existing



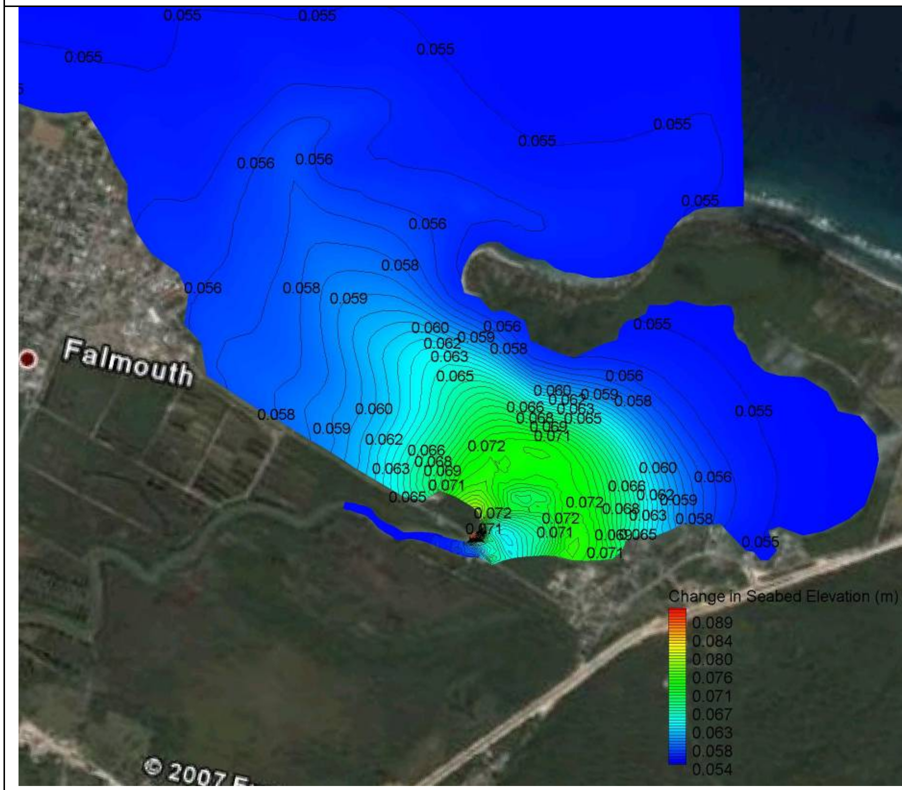
Proposed

Model – River flow
Simulation time: 5 days

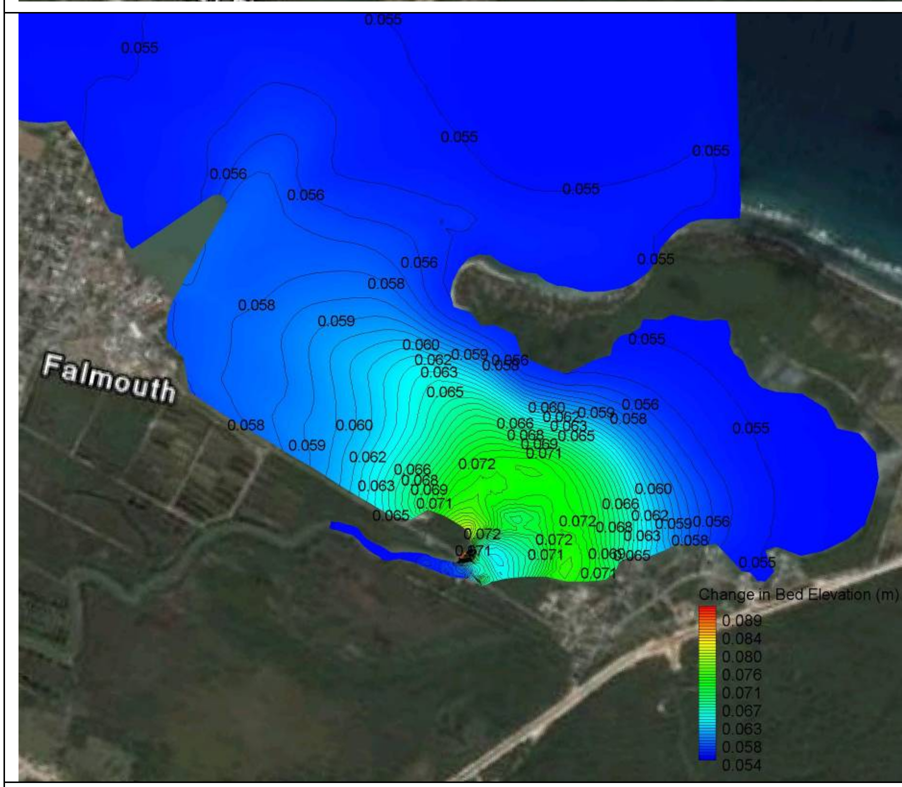
Figure 4.22

Falmouth Cruise Ship Facility **RMA-10S 2D Hydrodynamic Model Results – Change in Bed Elevation (m)**	
 	Existing
 	Proposed
Model – River flow **Simulation time: 10 days**	**Figure 4.23**

Falmouth Cruise Ship Facility
RMA-10S 2D Hydrodynamic Model Results – Change in Bed Elevation (m)



Existing

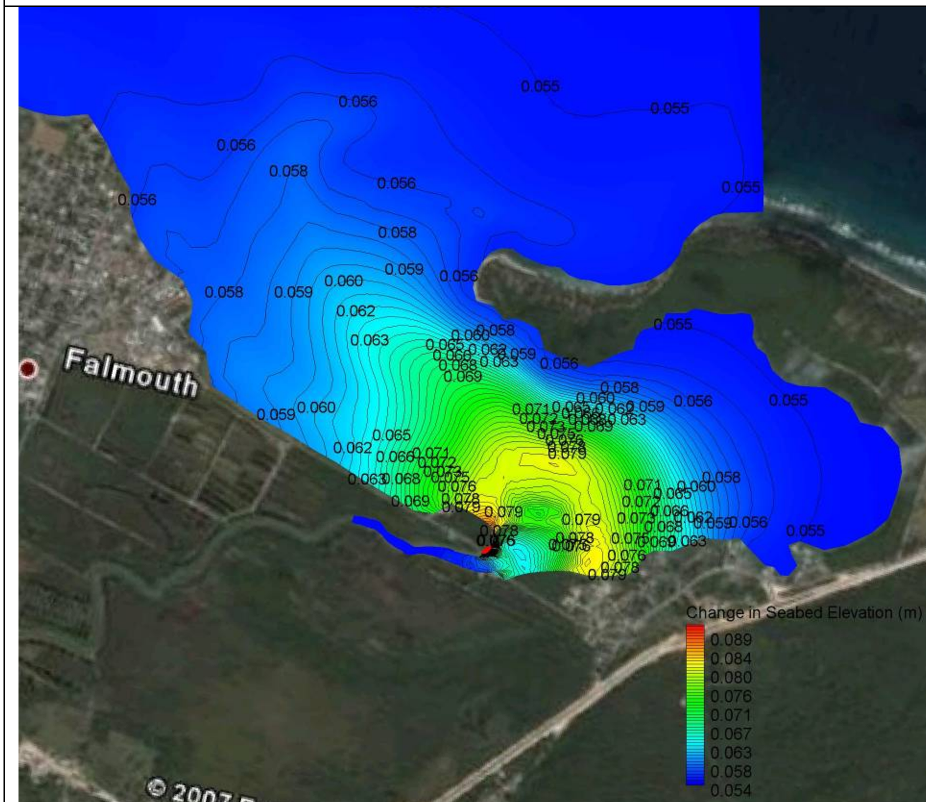


Proposed

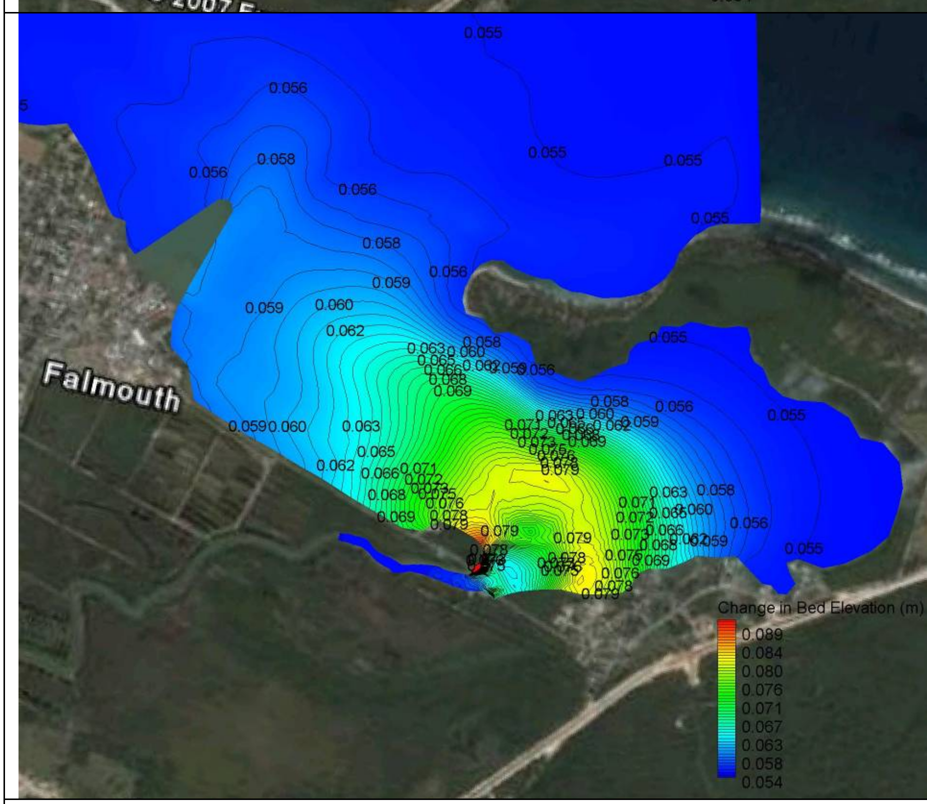
Model – River flow
Simulation time: 15 days

Figure 4.24

Falmouth Cruise Ship Facility
RMA-10S 2D Hydrodynamic Model Results – Change in Bed Elevation (m)



Existing



Proposed

Model – River flow
Simulation time: 20 days

Figure 4.25

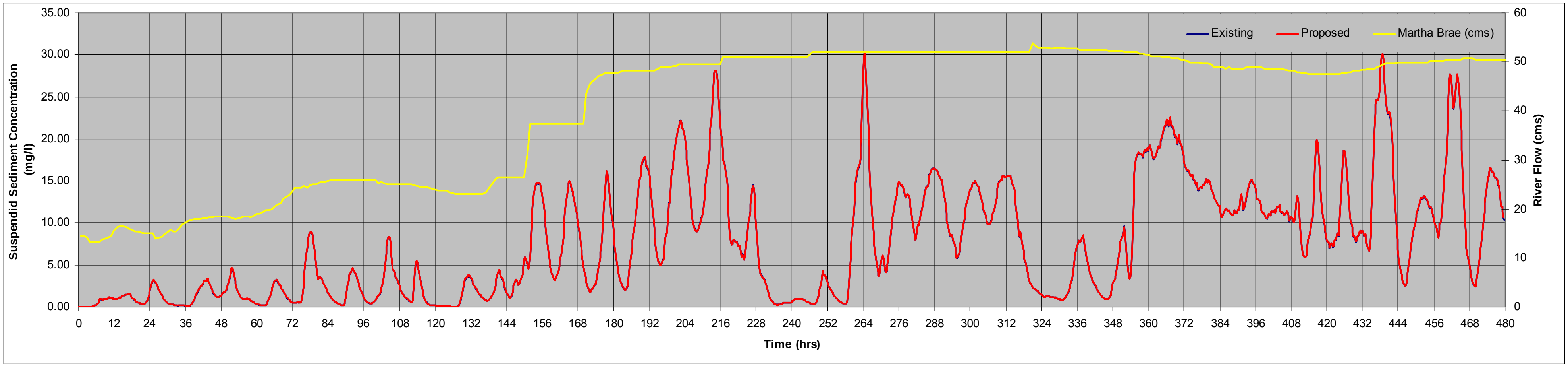


Figure 4.26 Time Series showing suspended sediment concentration for Node 1104 for existing and proposed layouts

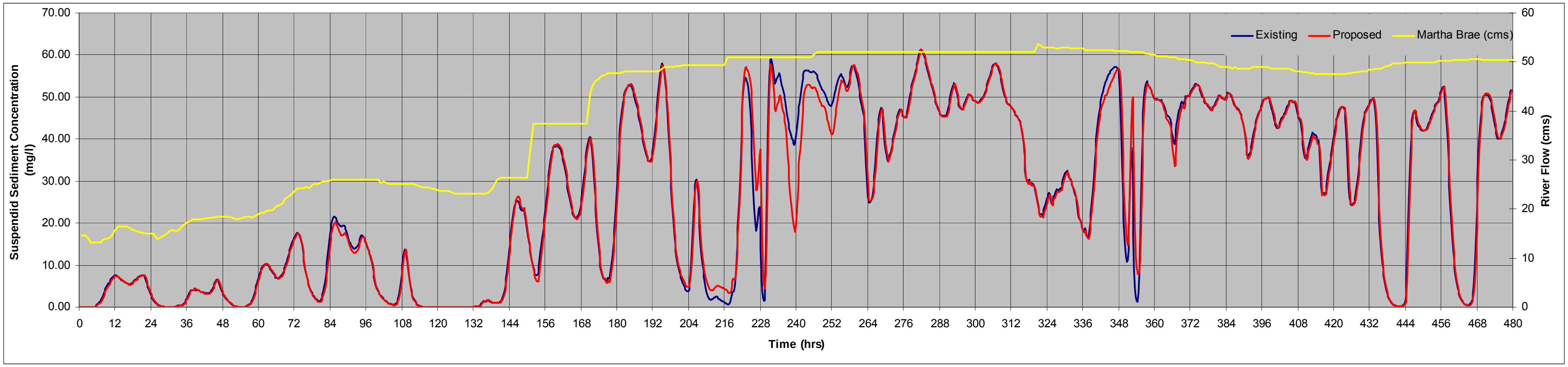


Figure 4.27 Time Series showing suspended sediment concentration for Node 491 for existing and proposed layouts

5 Sediment Transport (Sand)

In order to assess the impacts of the proposed land reclamation and dredging on the transport of sand, it was first necessary to determine the baseline conditions and then simulate the modifications to the nearshore area using computer models. For the transport of sand, the principal agent is waves, and it is therefore necessary to define the wave conditions offshore and then transform them to the nearshore zone.

The daily deepwater wave climate was described by a 7-year database generated by the global computer wave model WAVEWATCH III. This model has been maintained by NOAA in operational mode for several years and is widely used in coastal engineering projects. Figure 5.1 shows the distribution of wave heights and directions extracted from points off the coast of Jamaica. The distribution is represented by rose plots, where the radius is proportional to the percentage of occurrence. For Falmouth Harbour, Node 5 has been selected to represent the daily deep water wave heights. It can be seen here that the vast majority of waves come from the East quadrant.

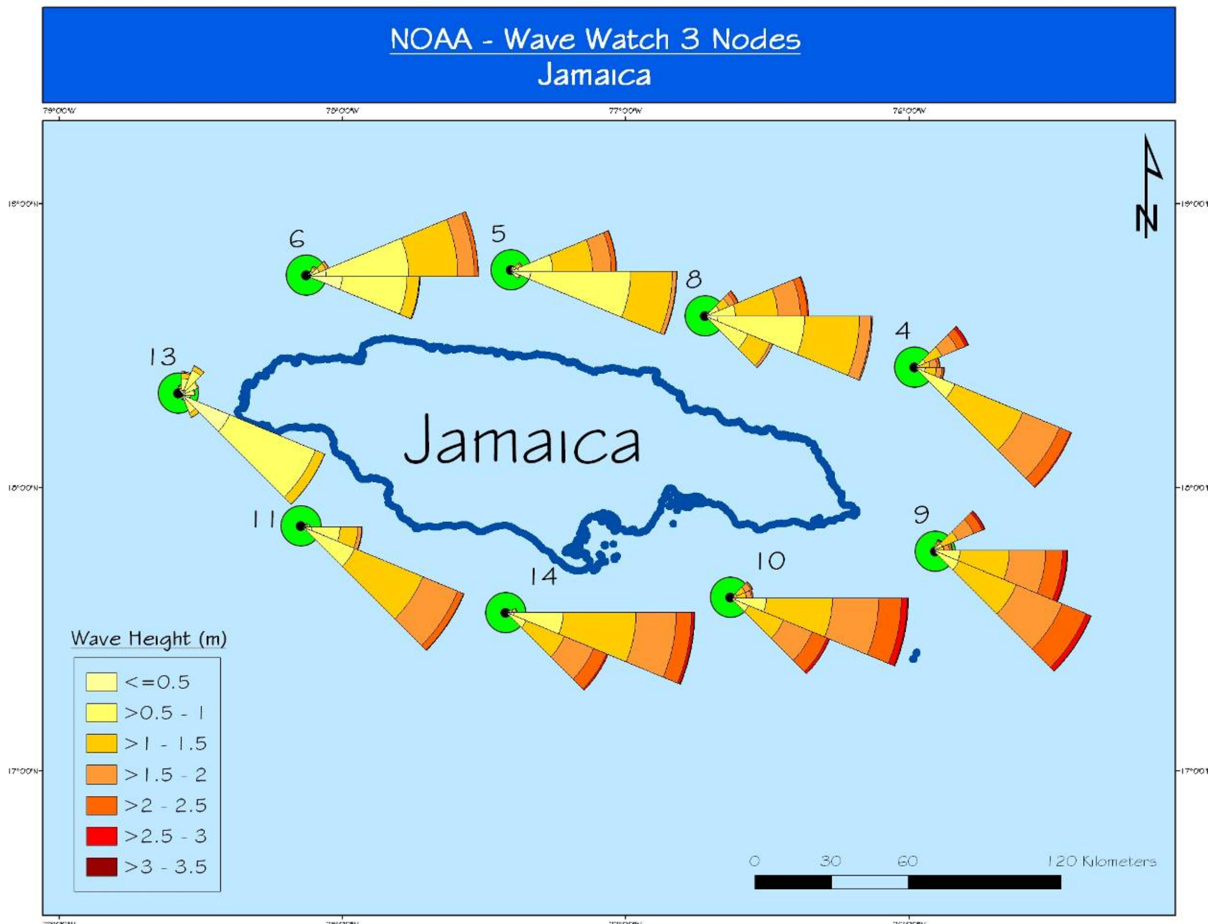


Figure 5.1 Wave Watch III nodes representing the daily wave climate off the Jamaican coast

Statistical analyses were used to extract the exceedance probability of wave heights (Figure 5.2). The 10% exceedance wave heights only occur from the east at a value of 2.4m. The 1% occurs for waves from the north-east and north with 2.1 and 0.95m wave heights respectively. These waves are likely produced by low pressure systems passing just north of the coast of Jamaica.

The 1% exceedance waves were transformed using the nearshore transformation model. Results for the east direction, representing the worst-case scenario, are plotted in Figure 5.3 and Figure 5.4, for the original and proposed scenarios respectively. While the reef line offers good protection to the coast, the harbour entrance allows waves to go inside the bay with heights of between 0.6m and 1m. The deepening of the harbour channel would allow larger waves to go inside the harbour during regular storms. The results show that the tip of the pier would be hit by waves of between 1 and 1.5m high. Away from the proposed structure and entrance channel, the main difference in the two scenarios appears to be an increase in wave heights caused by wave reflection from the land reclamation area.

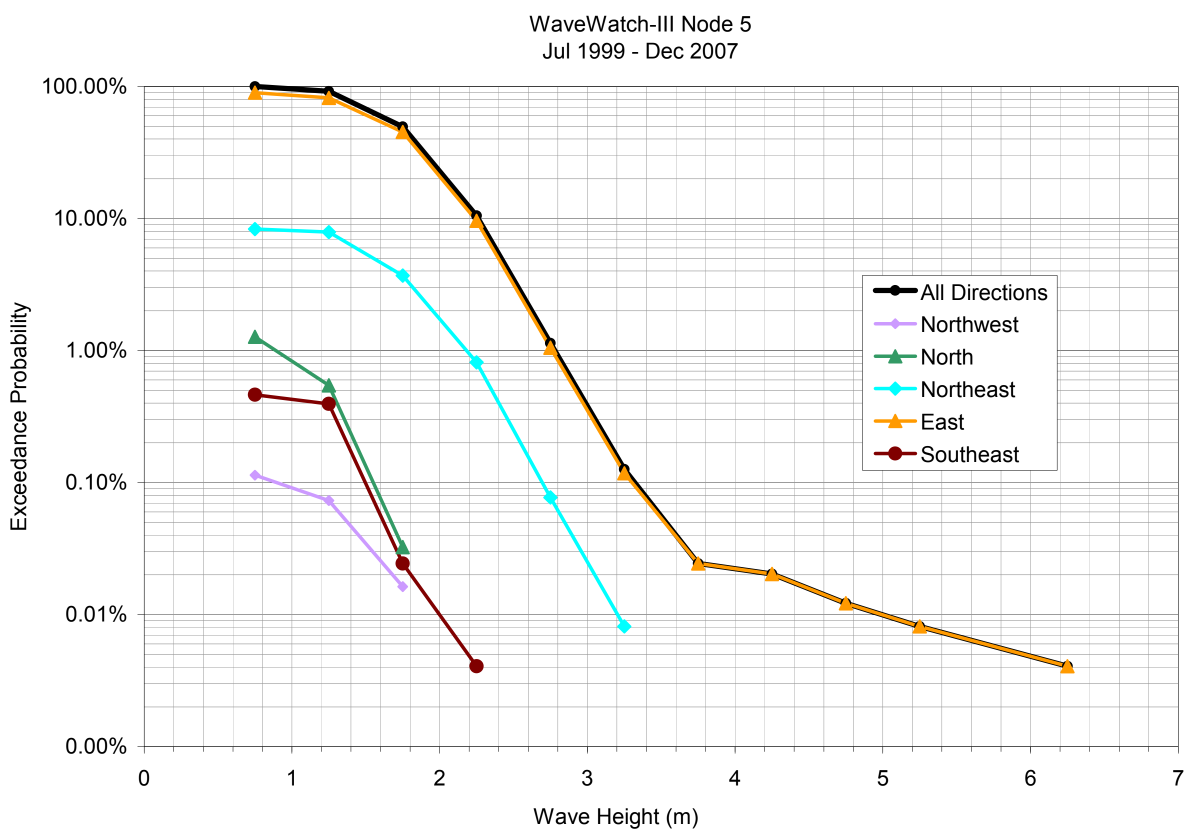


Figure 5.2 Exceedance probability of wave heights off Falmouth Harbour based on WaveWatch-III database

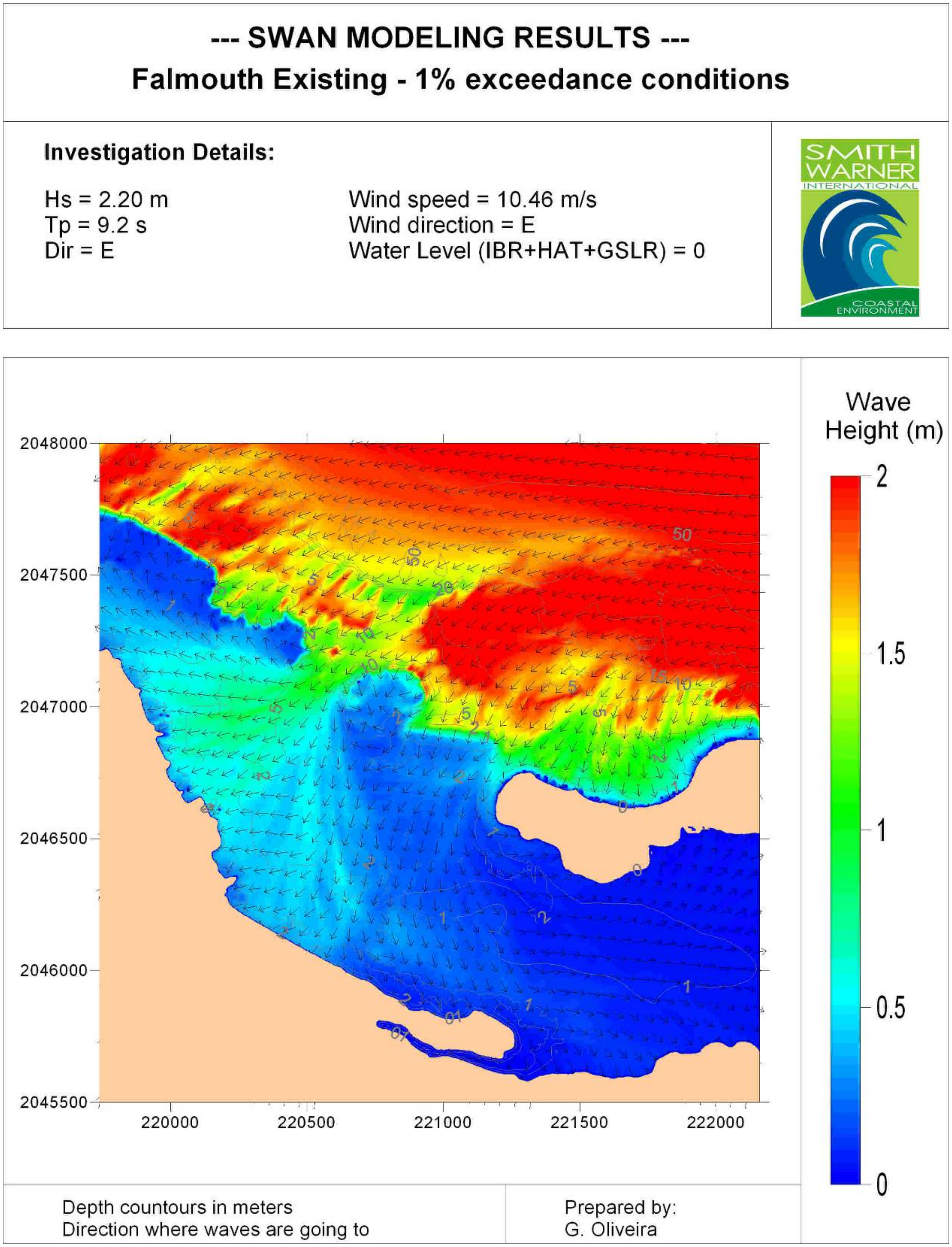


Figure 5.3 Nearshore wave heights for 1% exceedance waves coming from the east, existing scenario

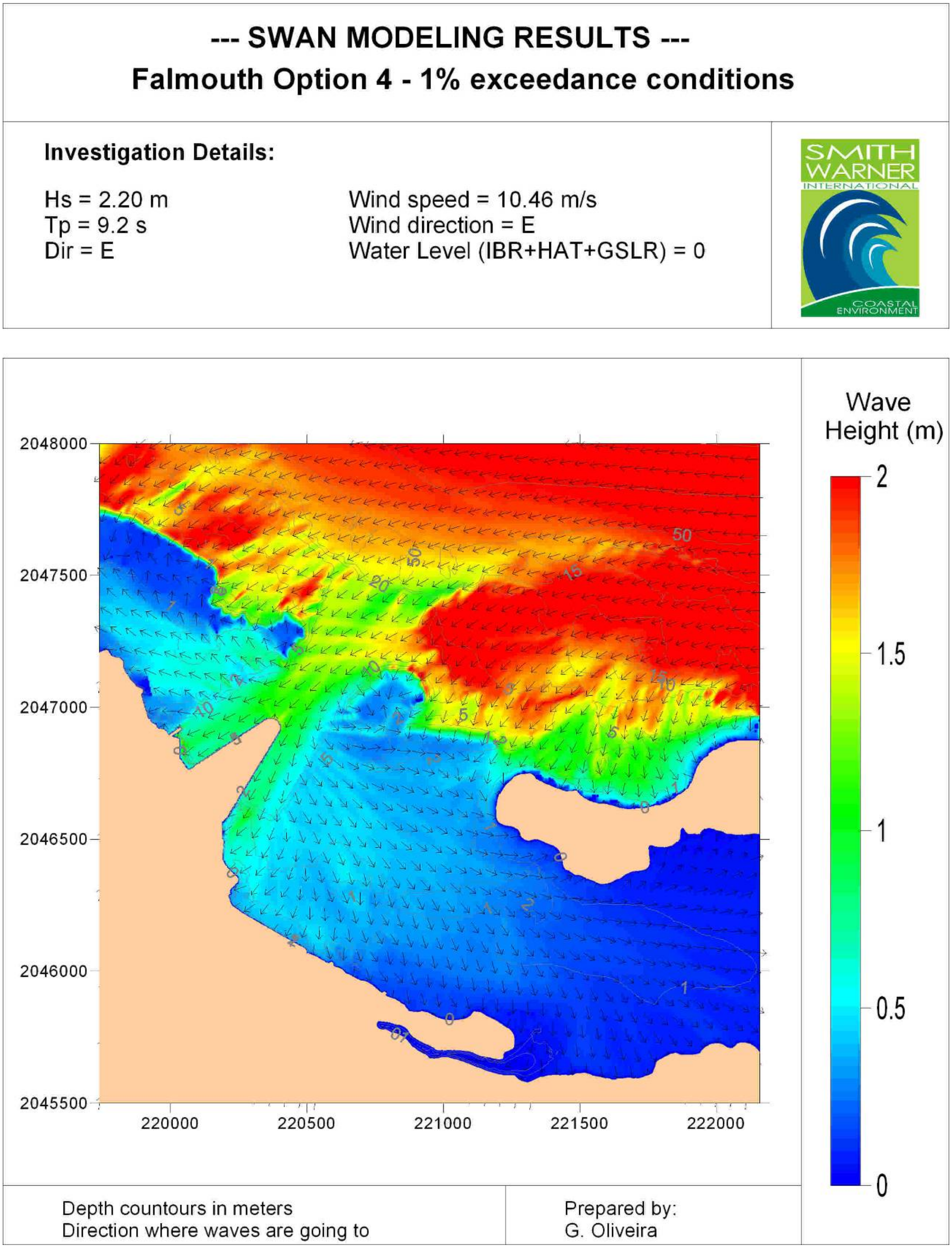


Figure 5.4 Nearshore wave heights for 1% exceedance waves coming from the east, proposed scenario (Option 4)

A time-series using the last three years of WaveWatch III data from the same node was fed into SWAN to get the nearshore wave conditions necessary for an accurate analysis of alongshore sediment transport within and along Falmouth Harbour. The results were extracted from several points. The computed directional distribution of wave heights for each point is shown in Figure 5.5 below. The wave heights approach from a broad range of directions and tend to be very small, less than 0.5m in height. At the harbour entrance the waves become more directional and larger.

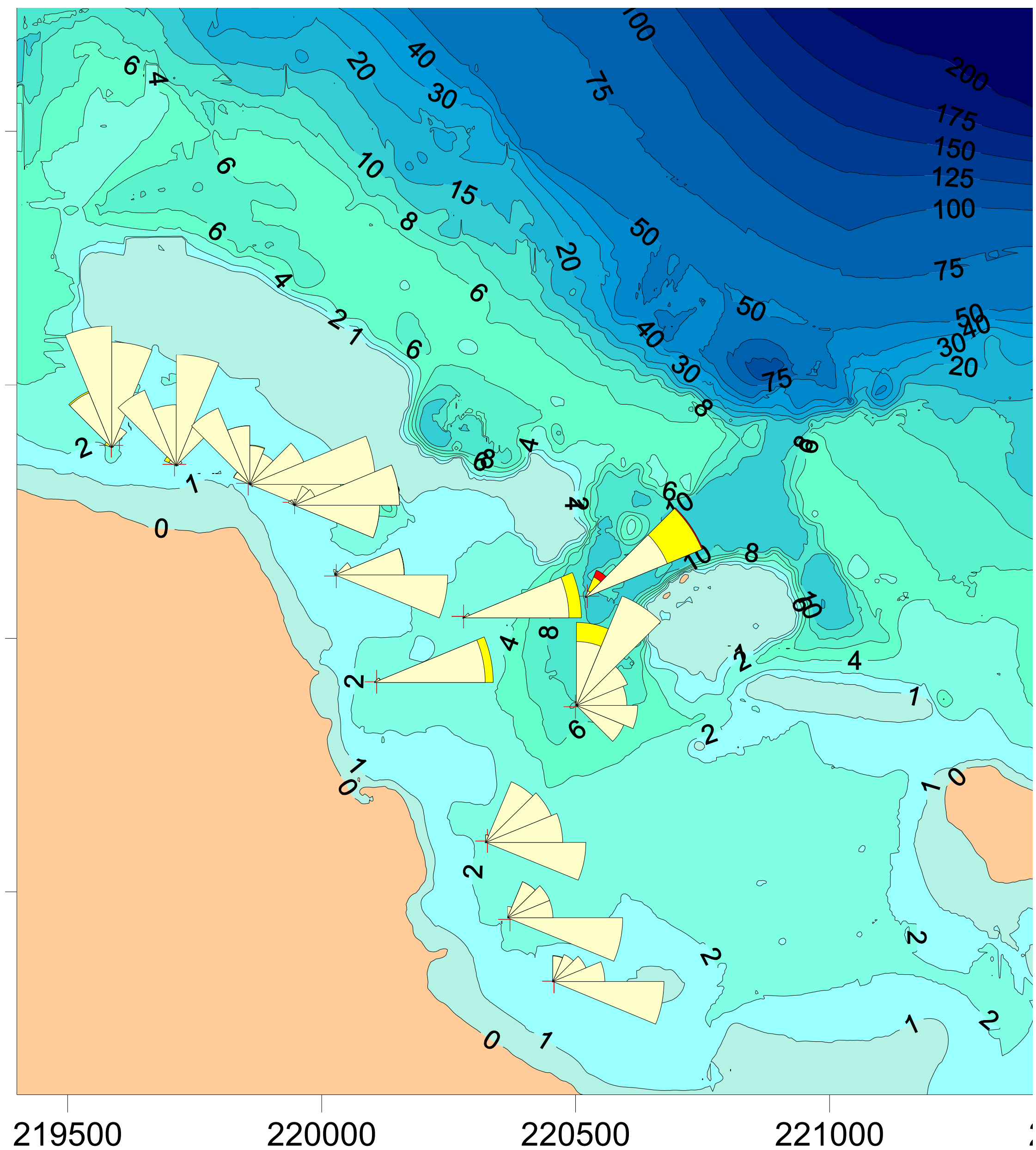
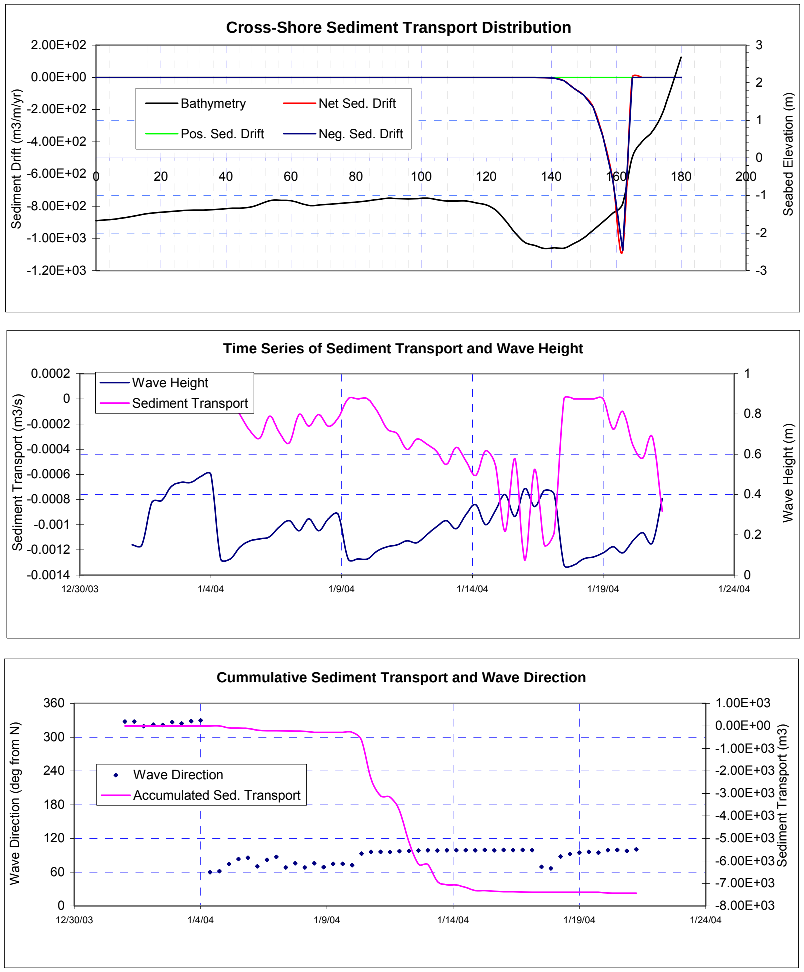
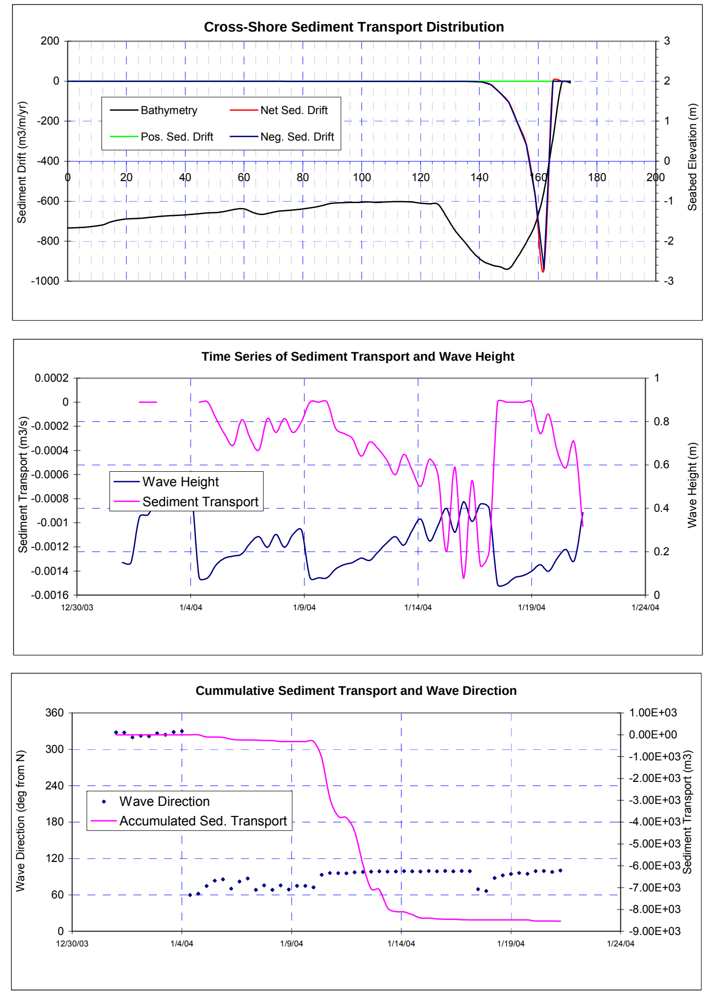


Figure 5.5 Directional Distribution of wave heights computed by SWAN during the period 2005-2007

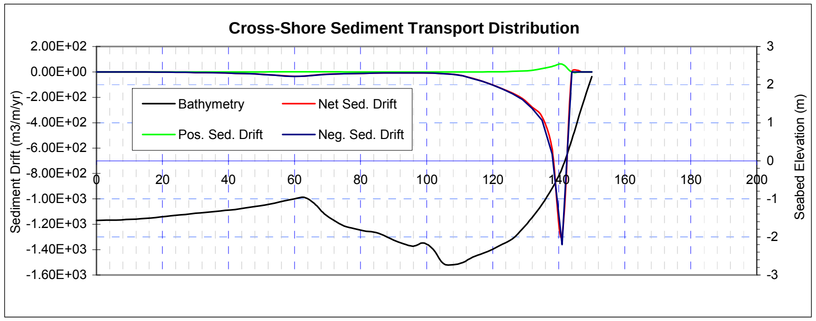
In order to examine how changes to the shoreline and nearshore bathymetry would affect alongshore sediment transport, the model LITPACK was used. This model computes the sediment transport across a profile using the sediment characteristics and wave conditions as the main factor. Wave conditions encompassing the 7 year database were grouped into a number of representative "bins" of similar wave height, period, and direction. The SWAN model was then used to derive nearshore wave conditions for both the existing and proposed seabed configurations at 8 profile locations. Profiles were selected to the northwest and southeast of the proposed channel entrance, in order to assess the updrift and downdrift impacts. For each of these profiles, the two different wave conditions were used as input to determine the impact of the structures on the alongshore sediment transport rates. For three of the central profiles, their shape and sediment characteristics were also altered in order to represent the proposed configuration. The results are presented in the following graphs.

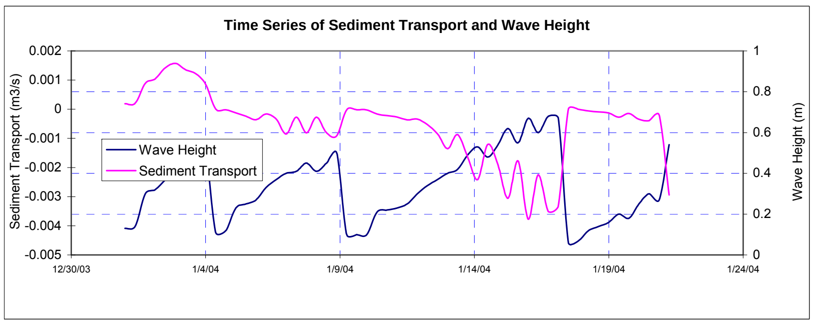


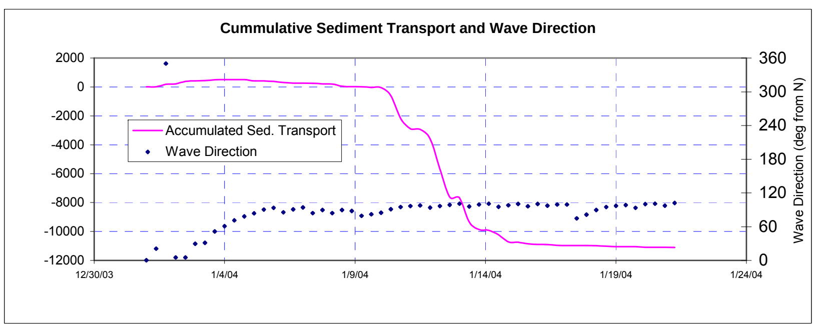
Project:	Jamaica - Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	Octobe, 2008
Profile:	Number: 1	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
	Location: **Famouth Harbour**		
Wave Climate:	Source: Litpack		
	Period: **Jan 2004 - Nov 2007**		



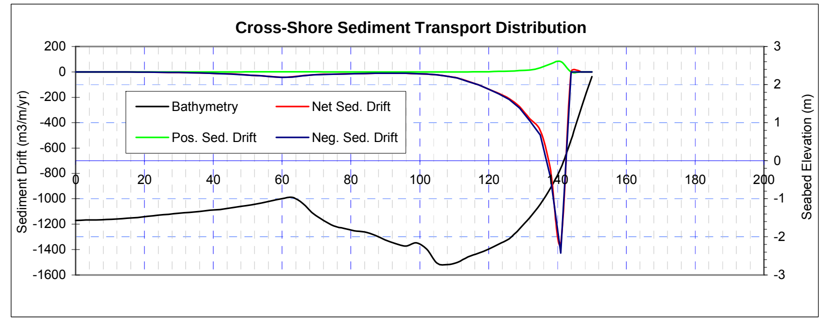
Project:	Jamaica - Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	October, 2008
Profile:	Number: 1	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
	Location: **Falmouth Option 4**		
Wave Climate:	Source: Litpack		
	Period: **Jan 2004 - Nov 2007**		

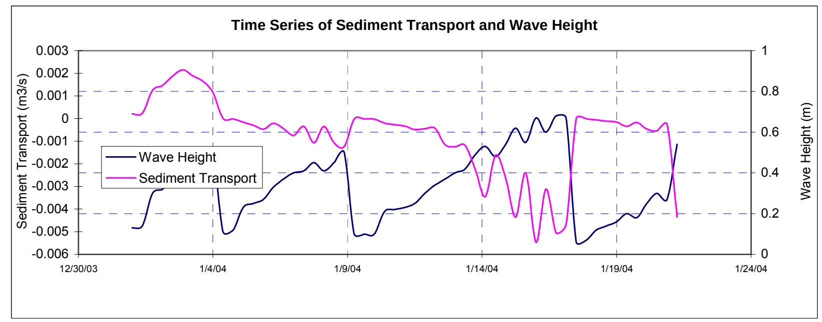


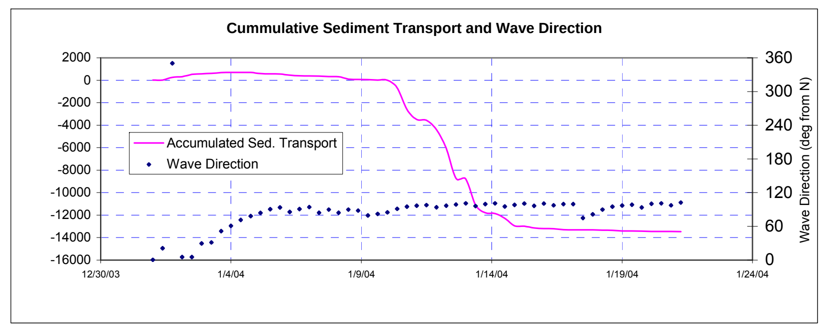




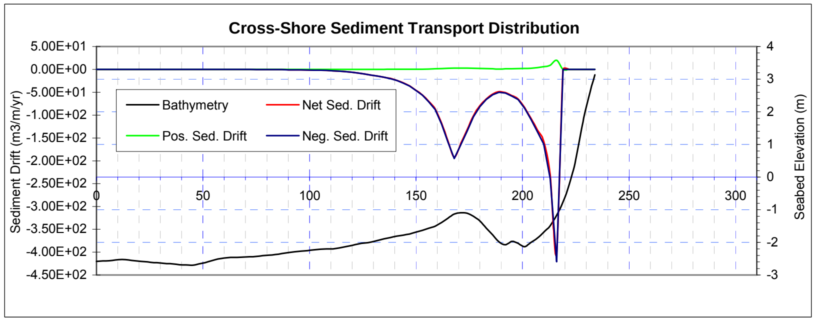
Project:	Jamaica - Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	September,2008
Profile: Number:	2	Notes: Positive transport is towards the north and negative transport is towards the south	
Profile: Location:	**Falmouth Harbour**		
Wave Climate: Source:	Litpack		
Wave Climate: Period:	**Jan 2004 - Nov 2007**		

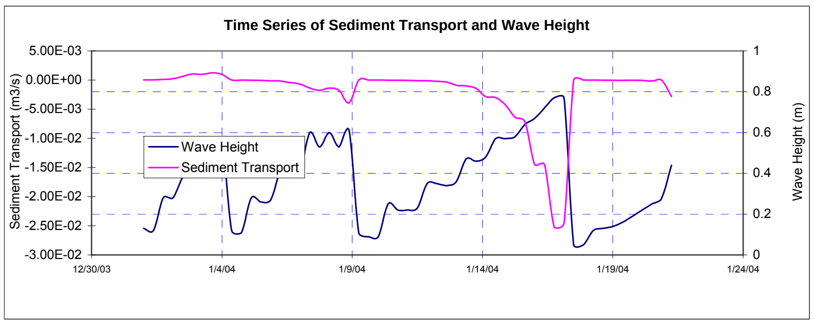


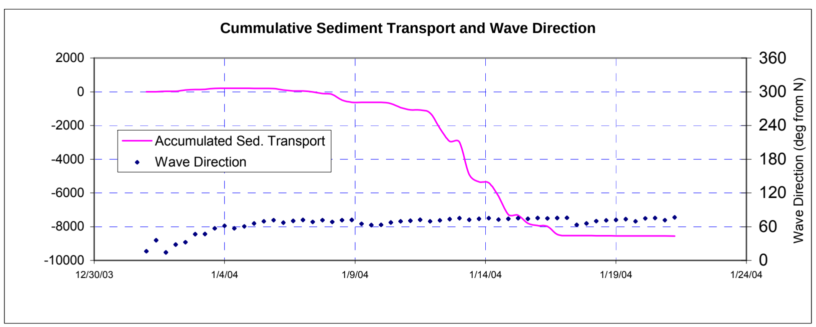




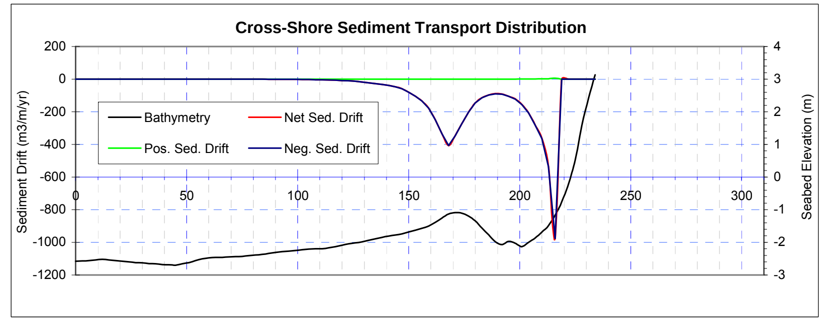
Project:	Jamaica -Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	October, 2008
Profile: Number:	2	Notes: Positive transport is towards the north and negative transport is towards the south	
Profile: Location:	**Falmouth Option 4**		
Wave Climate: Source:	Litpack		
Wave Climate: Period:	**Jan 2004 - Nov 2007**		

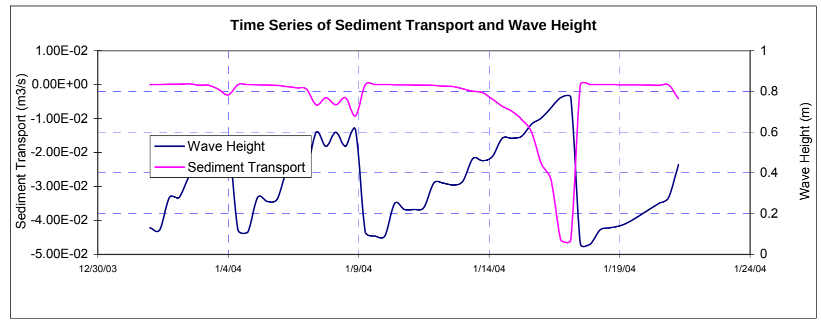


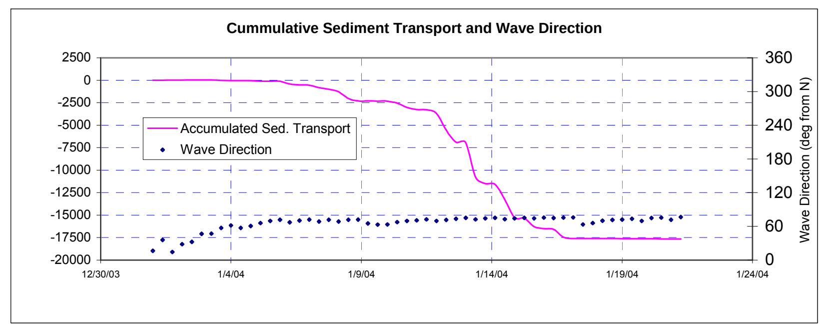




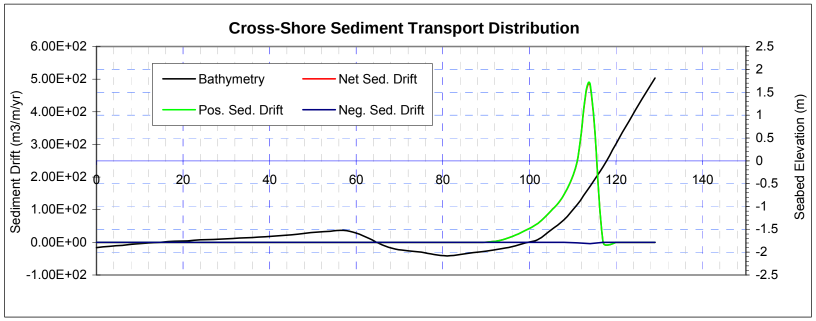
Project:	Jamaica - Falmouth Option 4		Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results		Date:	October, 2008
Profile:	Number:	3	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
	Location:	**Falmouth Harbour**		
Wave Climate:	Source:	Litpack		
	Period:	**Jan 2004 - Nov 2007**		

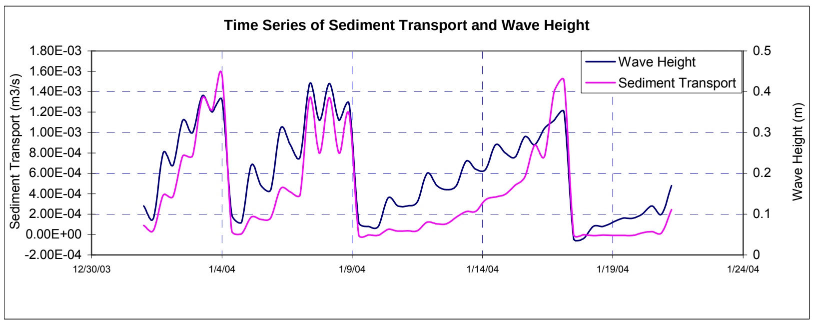


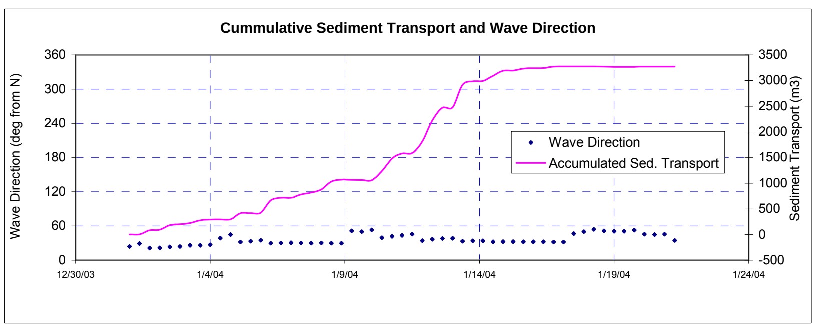




Project:	Jamaica -Falmouth Option 4		Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results		Date:	October, 2008
Profile:	Number:	3	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
	Location:	**Falmouth Option 4**		
Wave Climate:	Source:	Litpack		
	Period:	**Jan 2004 - Nov 2007**		







Project:	Jamaica - Falmouth Option 4		Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results		Date:	October, 2008
Profile:	Number:	4	Notes: Positive transport is towards the north and negative transport is towards the south	
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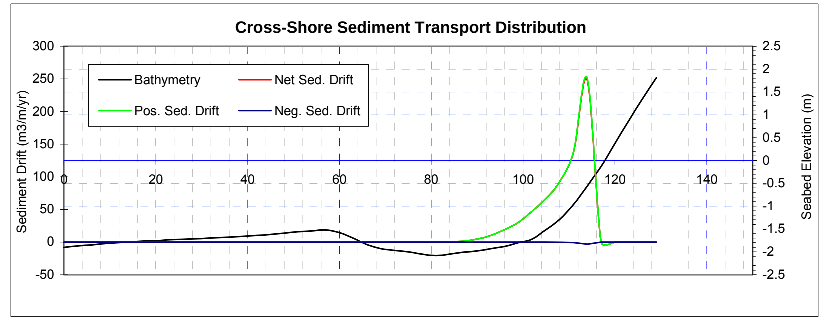
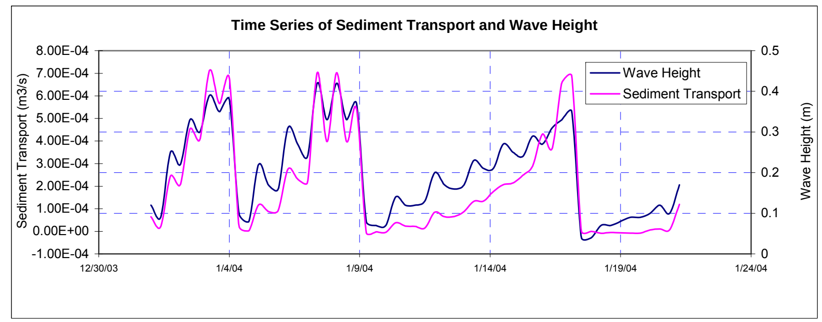
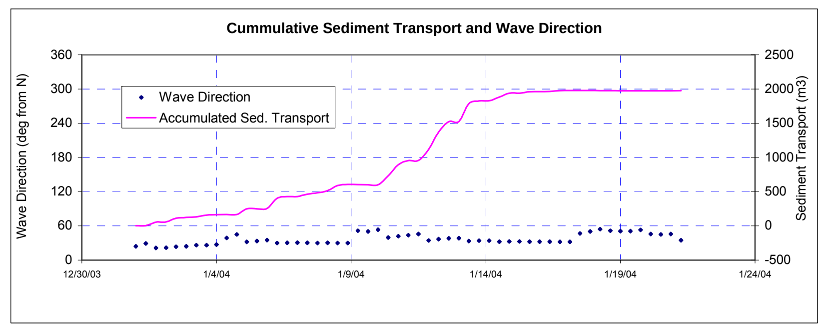
Wave Climate:	Source:	Litpack		
	Period:	**Jan 2004 - Nov 2007**		







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Title:	Litdrift Model Results		Date:	October, 2008
Profile:	Number:	4	Notes: Positive transport is towards the north and negative transport is towards the south	
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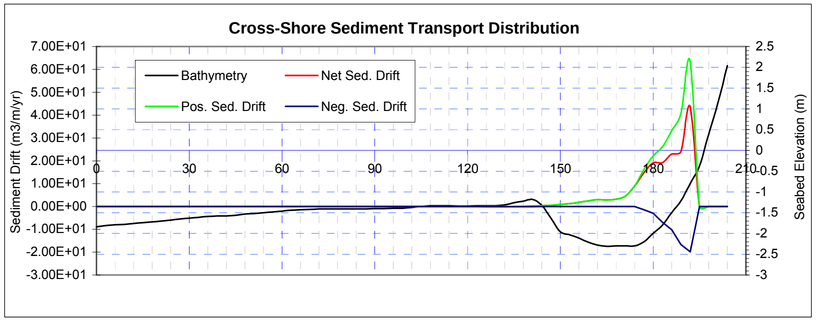
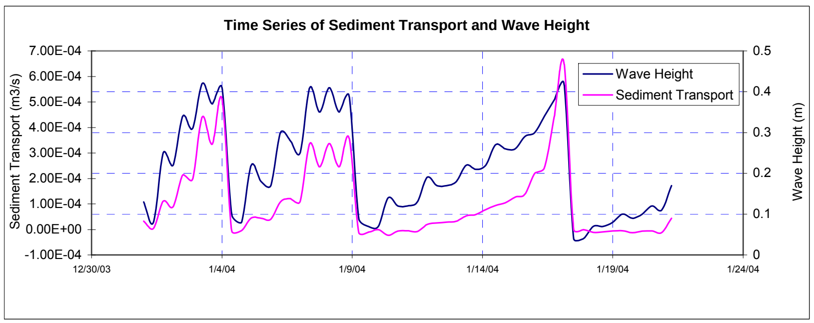
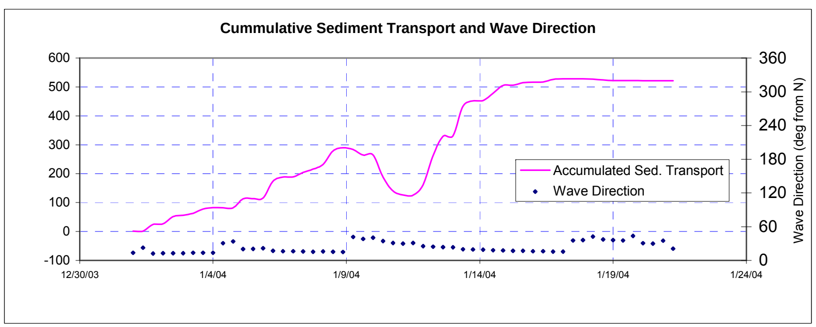
Wave Climate:	Source:	Litpack		
	Period:	**Jan 2004 - Nov 2007**		







Project:	Jamaica - Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	October, 2008
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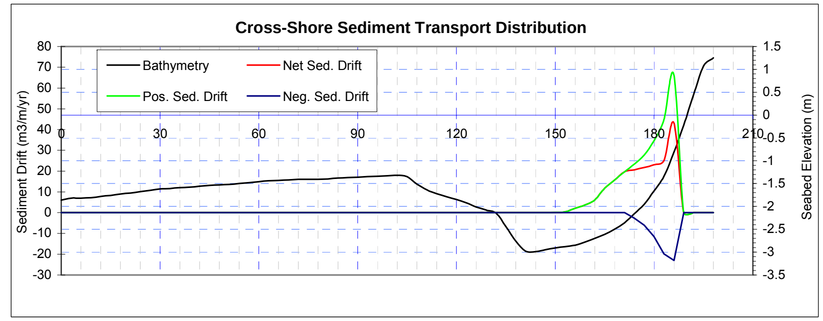
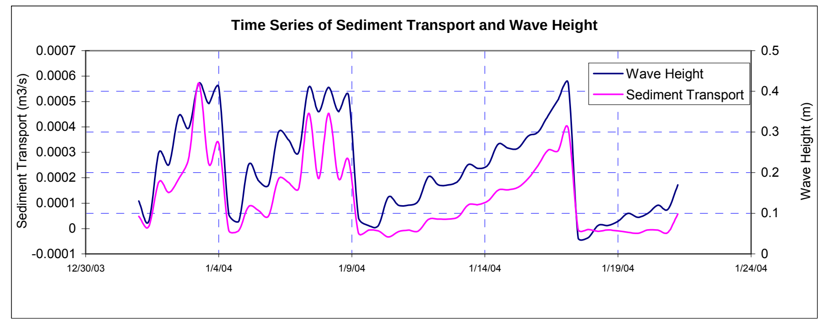
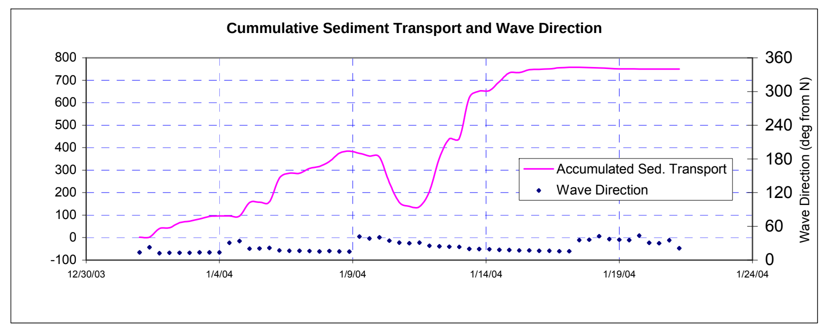
Wave Climate:	Source: Litpack Period: **Jan 2004 - Nov 2007**		







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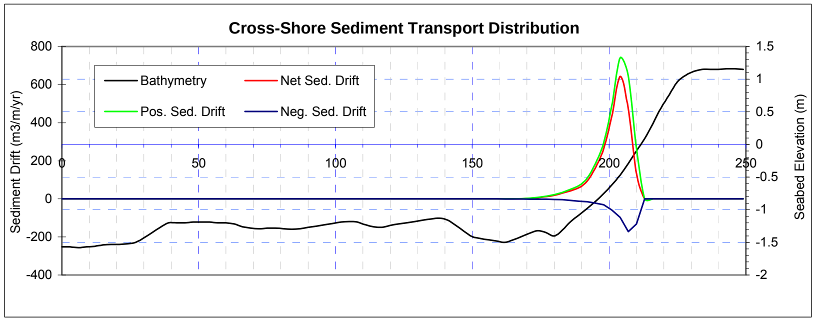
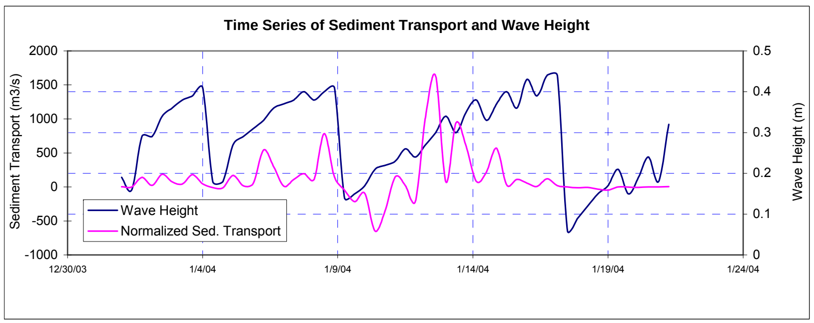
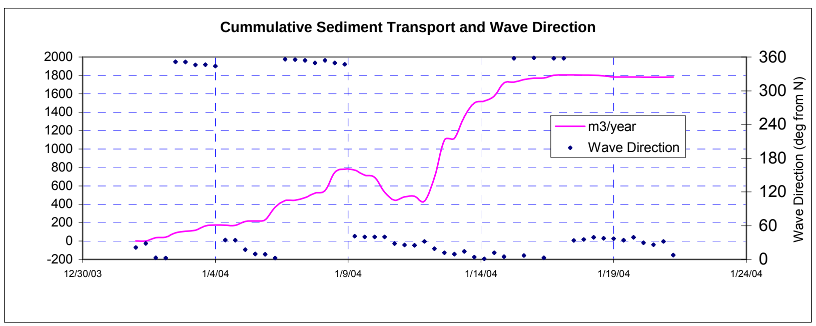
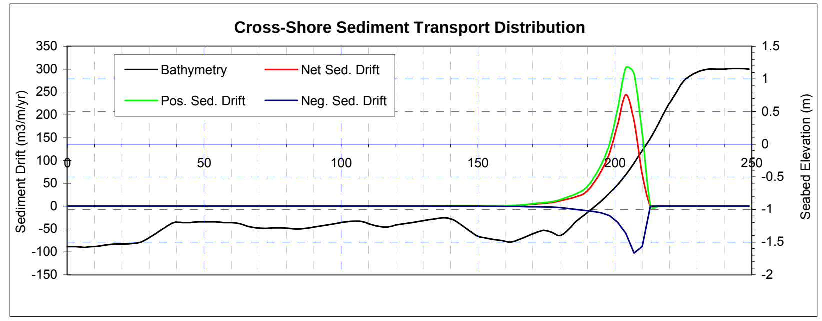
Title:	Litdrift Model Results	Date:	October, 2008
Profile:	Number: 5 Location: **Falmouth Option 4**	Notes: Positive transport is towards the north and negative transport is towards the south	
Wave Climate:	Source: Litpack Period: **Jan 2004 - Nov 2007**		

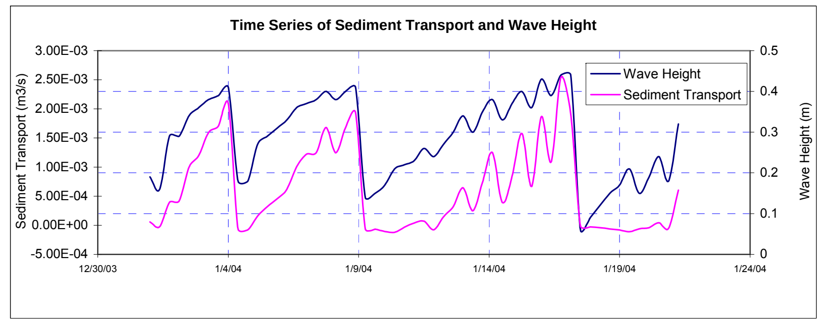


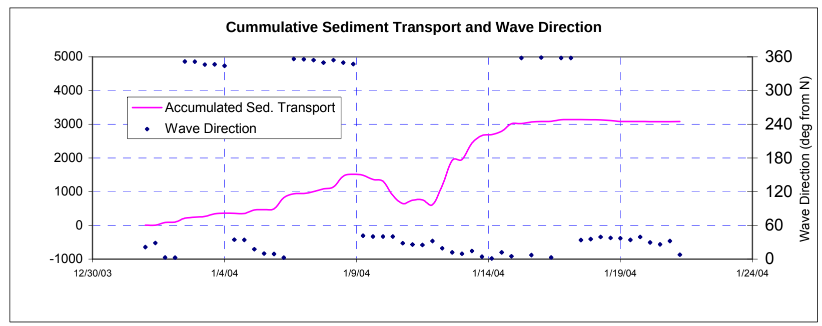




Project:	Jamaica - Falmouth Option 4		Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results		Date:	October, 2008
Profile:	Number:	6	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
	Location:	**Falmouth Harbour**		
Wave Climate:	Source:	Litpack		
	Period:	**Jan 2004 - Nov 2007**		







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Title:	Litdrift Model Results		Date:	October, 2008
Profile:	Number:	6	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
	Location:	**Falmouth Option 4**		
Wave Climate:	Source:	Litpack		
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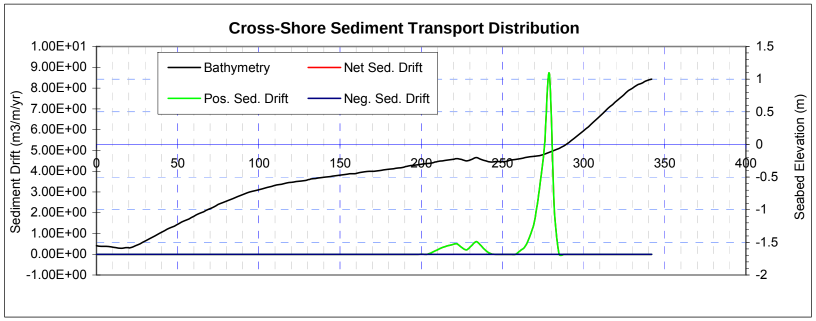
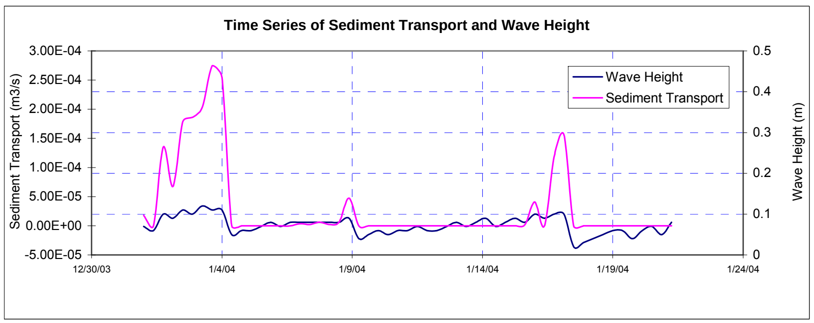
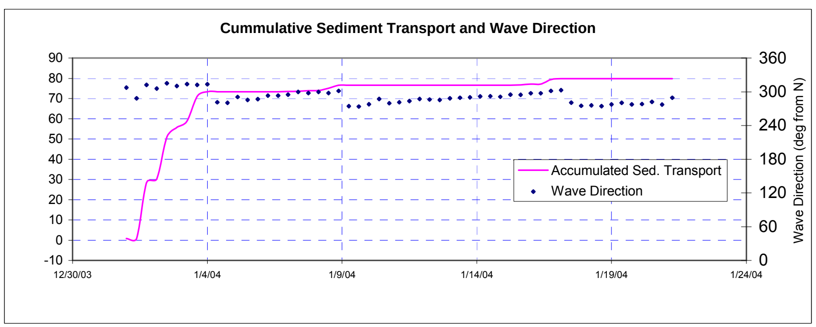
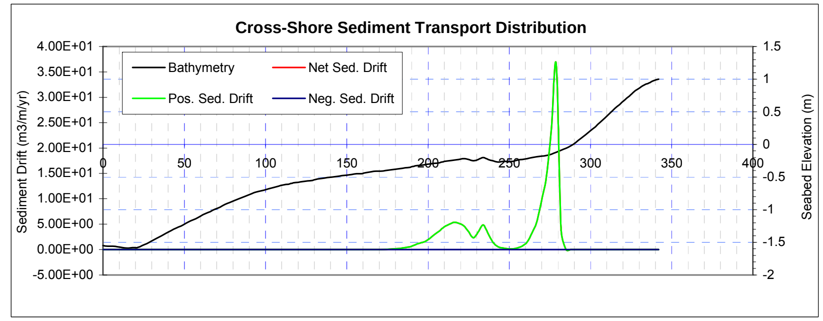
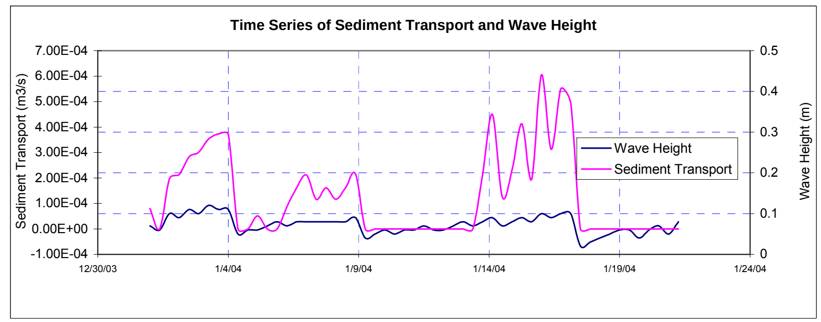


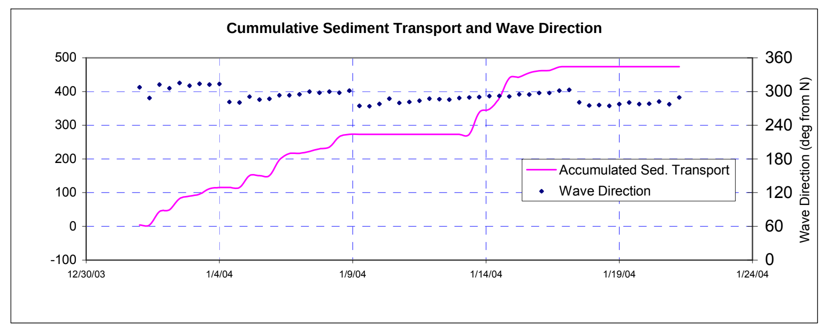




Project:	Jamaica - Falmouth Option 4		Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results		Date:	September,2008
	Number:	7	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
Profile:	Location:	**Falmouth Harbour**		
	Source:	Litpack		
Wave Climate:	Period:	**Jan 2004 - Nov 2007**		







Project:	Jamaica - Falmouth Option 4		Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results		Date:	October, 2008
	Number:	7	Notes: Positive transport is towards the north and negative transport is towards the south	SMITH WARNER INTERNATIONAL COASTAL & ENVIRONMENTAL ENGINEERING
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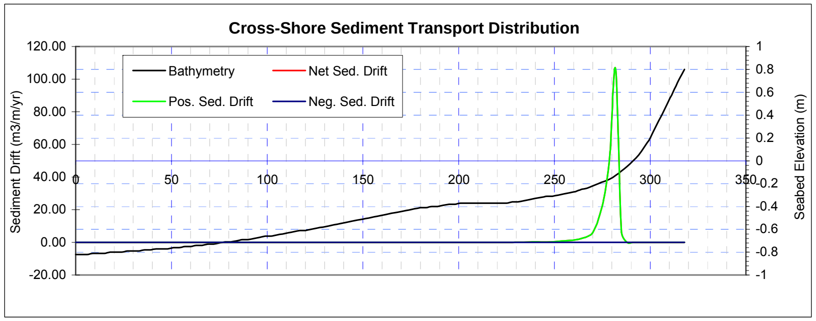
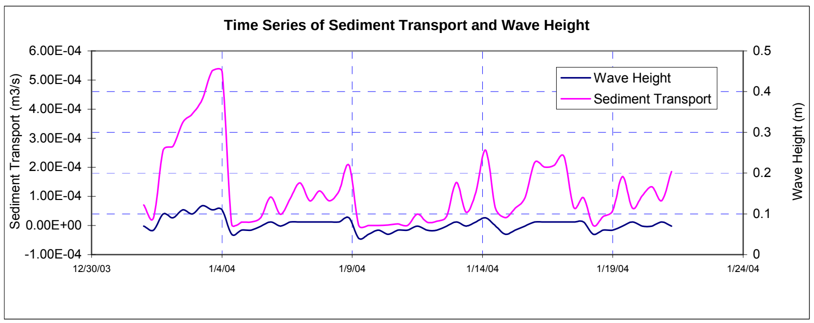
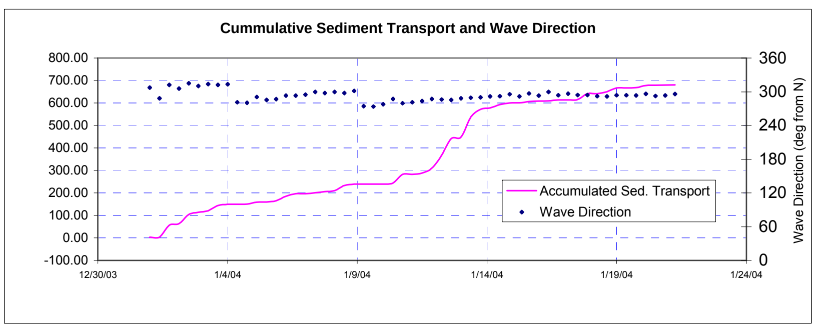
Wave Climate:	Period:	**Jan 2004 - Nov 2007**		







Project:	Jamaica - Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	October, 2008
Profile: Number:	8	Notes: Positive transport is towards the north and negative transport is towards the south	
Location:	Falmouth Harbour		
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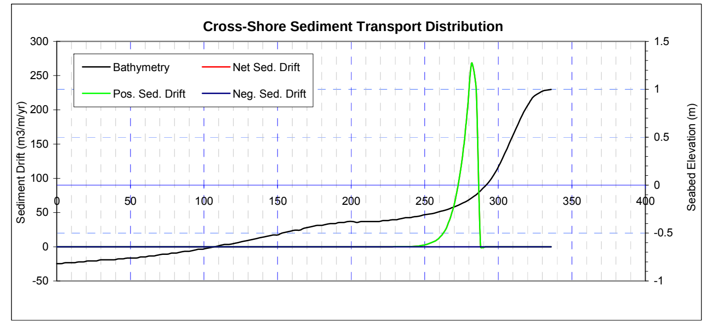
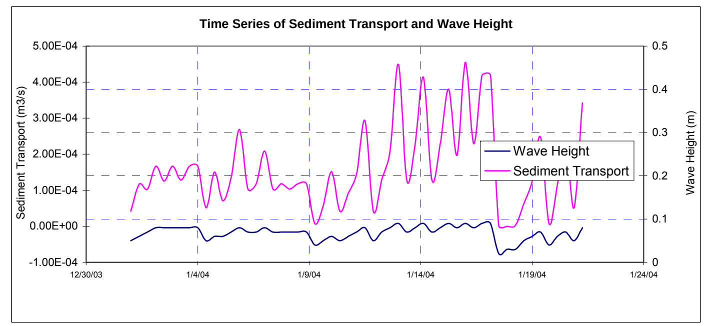
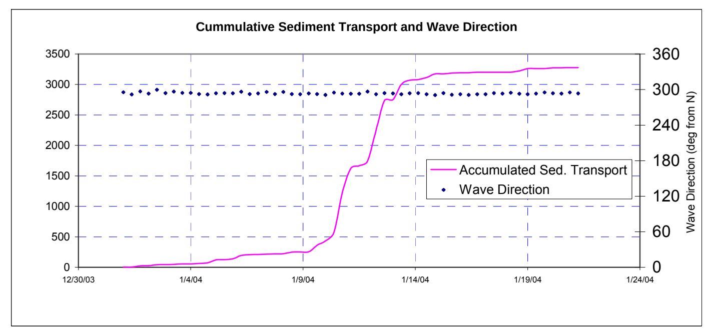
Period:	Jan 2004 - Nov 2007		







Project:	Jamaica -Falmouth Option 4	Prepared by:	Gustavo Oliveira
Title:	Litdrift Model Results	Date:	October, 2008
Profile: Number:	8	Notes: Positive transport is towards the north and negative transport is towards the south	
Location:	Falmouth Option 4		
Wave Climate: Source:	Litpack		
Period:	Jan 2004 - Nov 2007		

Table 5-1 outlines the average annual transport rate in m^3 for each of the profiles, the locations of which are shown in Figure 5.6.

Table 5-1 Annual Transport Rates (m^3)

Profile	Existing	Option 4
1	-1859	-4414
2	-2775	-3370
3	-2140	-2133
4	818	493
5	130	187
6	445	770
7	20	120
8	170	820

The first finding of this analysis is that the sediment transport is negative for profiles 1 – 3 and is positive for the remainder of the shoreline. Negative transport means sediment movement to the northwest, whereas positive transport is to the southeast. Waves propagating through the existing entrance channel therefore tend to move sediment away from the entrance. This would suggest that the proposed cruise ship dock is located at the null point of potential alongshore sediment transport.

In the upper reaches of the estuary, the sediment transport due to waves is predicted to be to the south-east. This is supported by the morphological features, including the mouth of the Martha Brae River, which has moved south-east over the years by alongshore sediment transport.

The results indicate that there is an increase in the alongshore sediment transport, in both directions as a result of the proposed entrance channel and cruise ship dock. The consequences of this increase in alongshore sediment transport rate are expected to be quite minimal in both directions. To the south, the shoreline is already protected by a rock revetment, so the potential for beach erosion is limited. Adjacent to the mouth of the Martha Brae River, the impacts of changes to the wave-induced sediment transport may result in a shift in the beach or nearshore sediment bars that occur in that area. To the north, the shoreline is already protected by a series of seawalls and revetments, so the potential for downdrift erosion is limited. Furthermore, the development plan calls for the construction of additional revetment along portions of this shoreline, thereby further decreasing the possible impact of an increase in the alongshore sediment transport rate.

Based on the results obtained, it is recommended that a programme of beach profile monitoring be set up in the vicinity of the mouth of the Martha Brae River. These profiles should be spaced approximately 50m apart, should cover a total length of shoreline of approximately 500m and should span both sides of the river mouth.

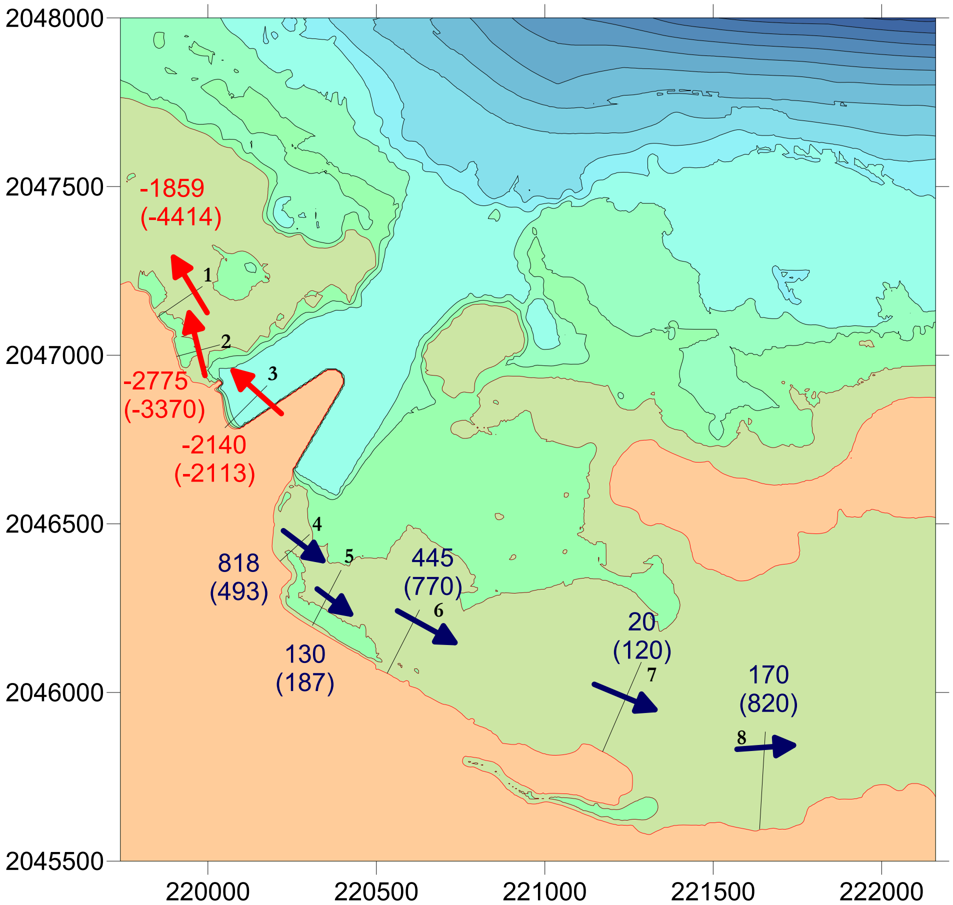


Figure 5.6 Summary of computed alongshore sediment transport rates using existing and (Option 4) seabed and shoreline configurations (m³/yr)

6 Comparison of Preliminary Results of Option 4 and Option 6 Layouts

The National Environmental Protection Agency (NEPA) requested that a comparison be made between the previous layout that was investigated by Smith Warner International Ltd., which was the Option 6 layout, and this current layout, Option 4. The aspects to be investigated would be the current speeds, directions, salinity and the temperature. Suspended sediment would not be looked at as this had not been investigated for the Option 6 layout. To compare both layouts, Nodes 469 and 604 were used, which represent the nodes used in the previous Option 6 investigations.

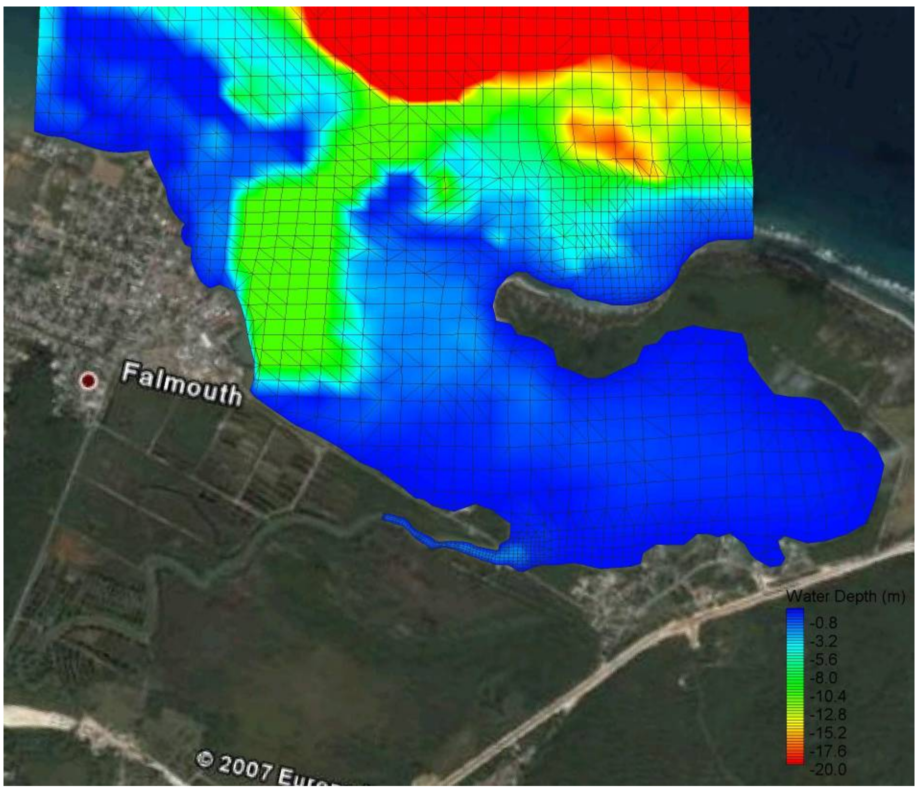


Figure 6.1 **Option 6 layout**

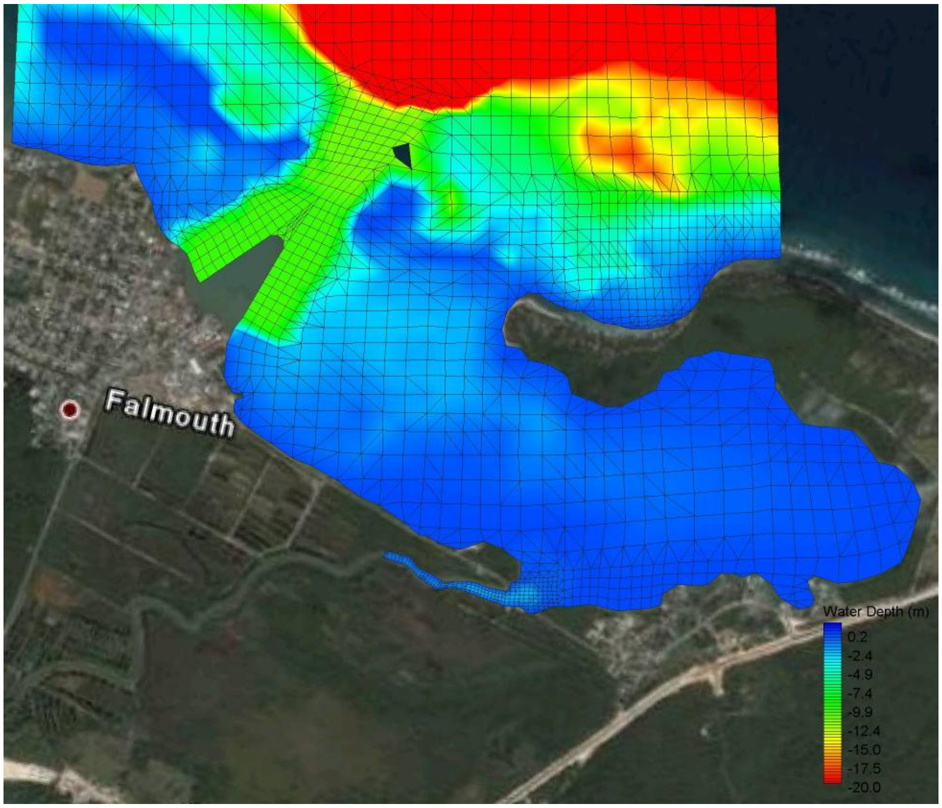


Figure 6.2 Option 4 Layout

6.1 Current Speed and Direction

The first comparison involved the investigation of the current speeds and direction of both options to determine whether they differ significantly. Figure 6.3 and Figure 6.4 show the scatter plots for both option 4 and option 6 layouts. The results show that the layouts do not differ significantly in current speeds. Node 604 shows a slight difference in the current direction, but it is a negligible difference. It can be concluded that both options do not differ significantly in terms of current speed and direction, based on the preliminary investigations.

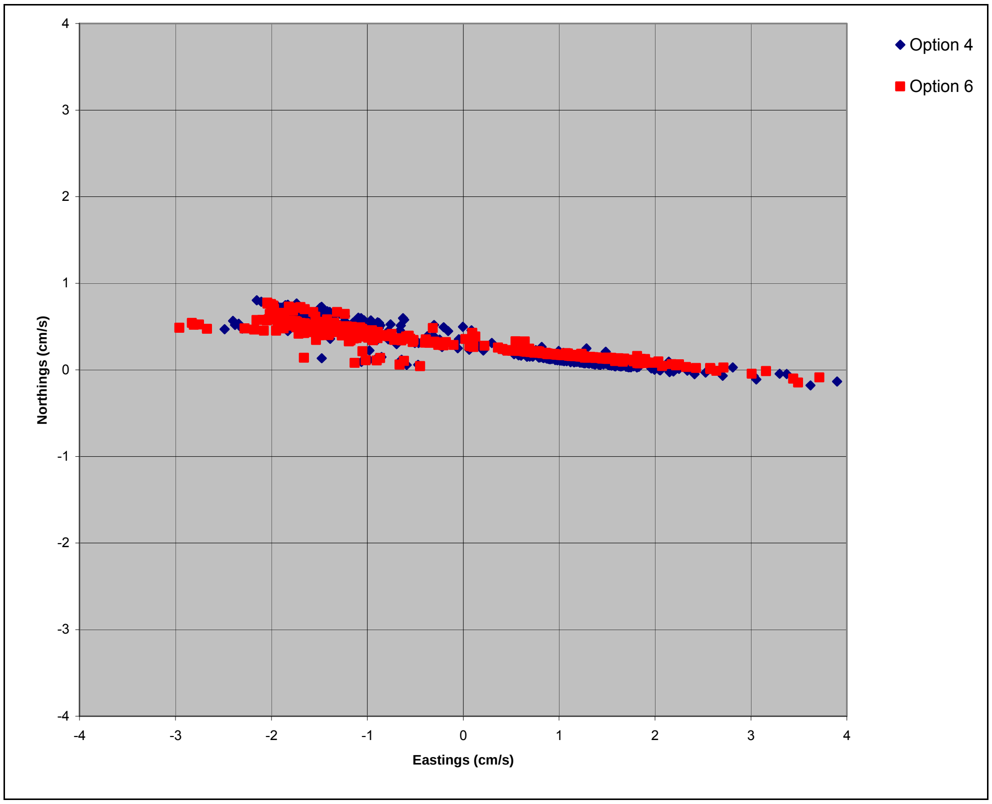


Figure 6.3 **Current speed and direction at node 469**

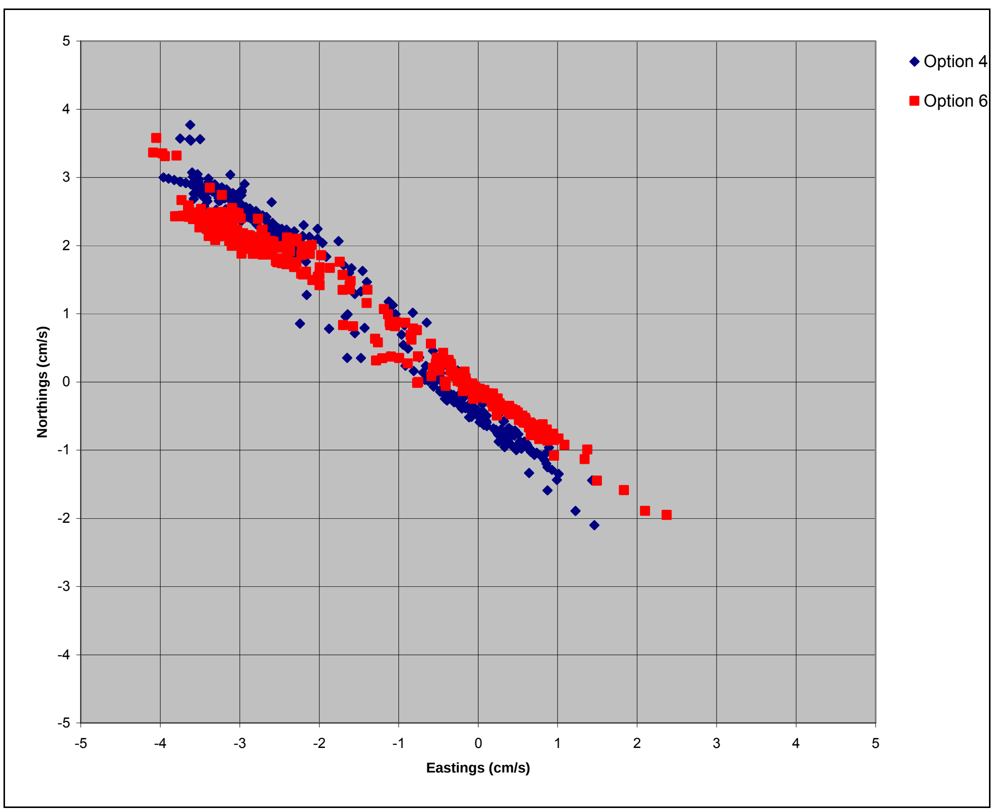


Figure 6.4 **Current speed and direction at node 604**

6.2 Salinity

The model shows that Option 6 allows the passage of more saline water to enter the Inner Harbour; which might bode well for the dinoflagellates. However, in the preliminary reports, both options showed higher saline concentrations within the Inner Harbour than the existing condition, so based on those preliminary results, both options should not result in poor conditions for the dinoflagellates, from the view of salinity concentrations. The comparison is shown in Figure 6.5 and Figure 6.6.

6.3 Temperature

The results of the simulation show that Option 6 has slightly warmer water temperatures entering the Inner Harbour. This would be expected as Option 6 showed more saline concentration than Option 4. In terms of having the least influence on ambient conditions, Option 4 would be the better choice, as can be seen in both the saline and temperature simulations. Comparisons are shown in Figure 6.7 and Figure 6.8.

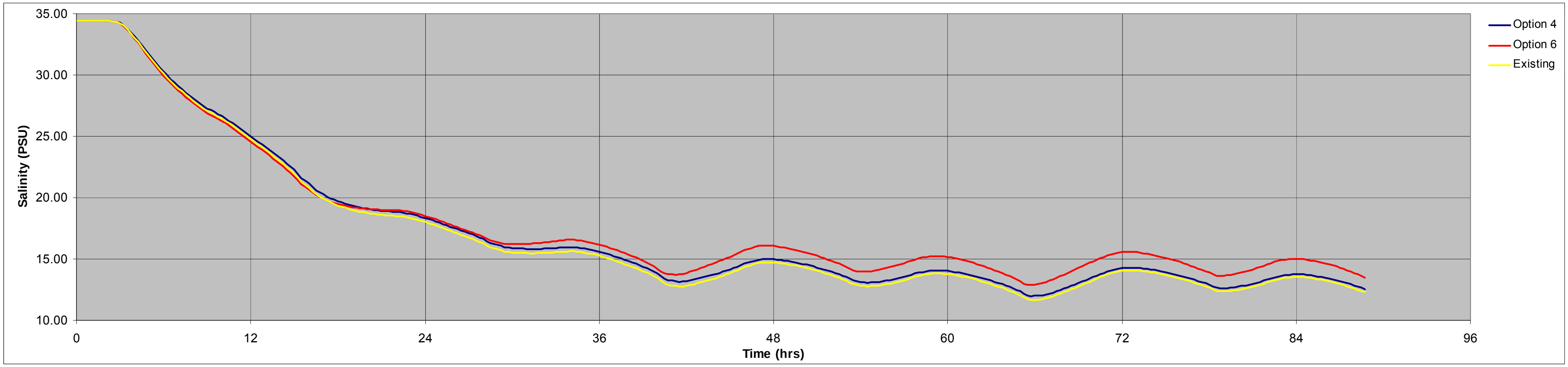


Figure 6.5 Salinity Comparison at node 469

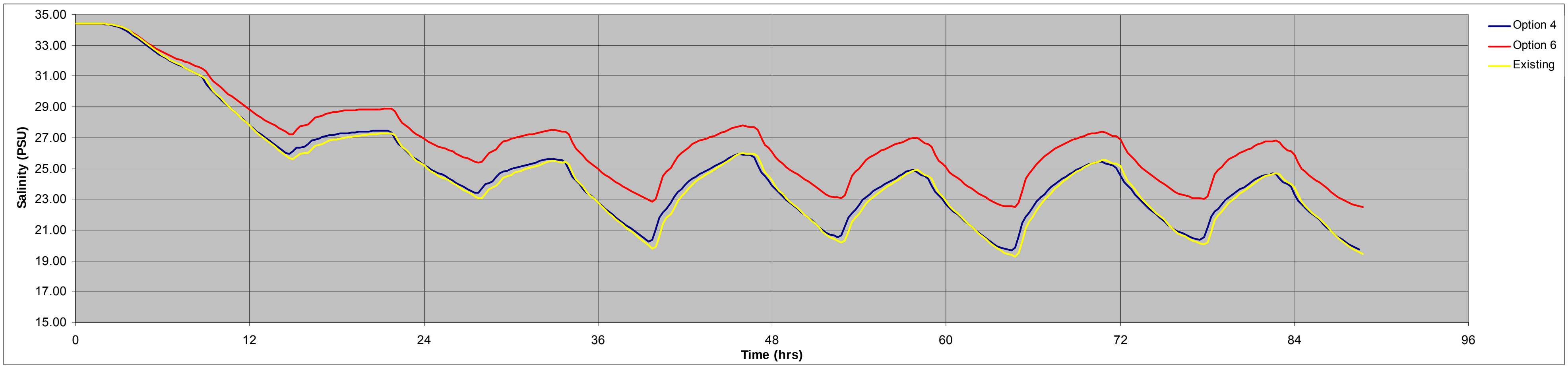


Figure 6.6 Salinity Comparison at node 604

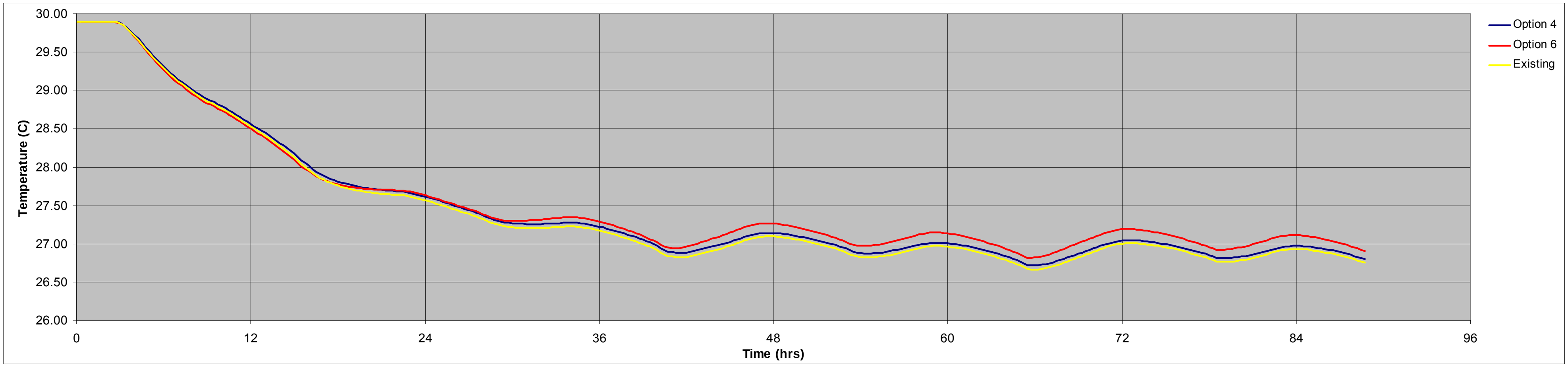


Figure 6.7 Temperature Comparison at node 469

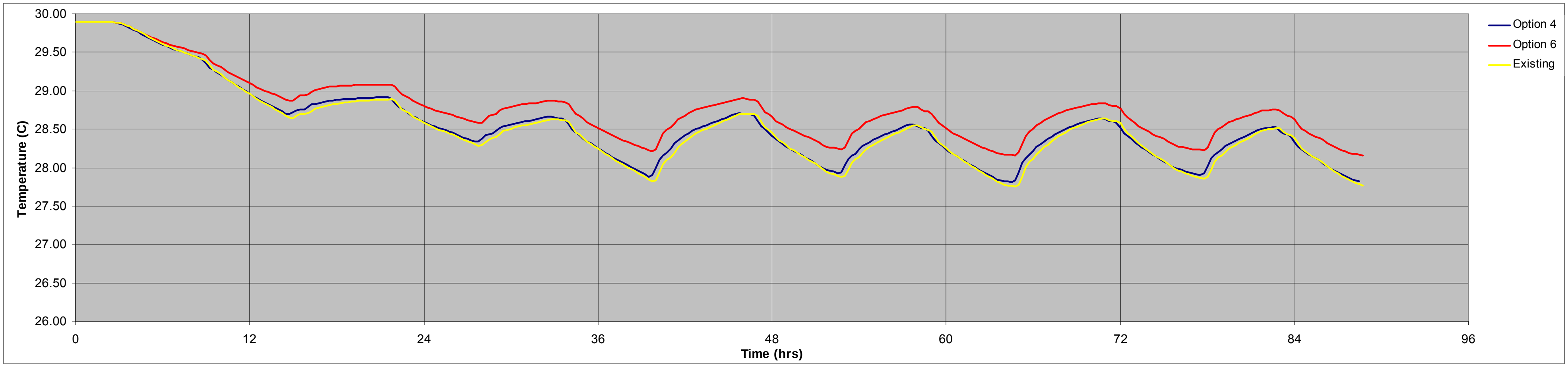


Figure 6.8 Temperature Comparison at node 604

7 Conclusions and Recommendations

The measured data showed that wave-induced currents had a significant impact on the current speeds and directions at certain times during the data collection period.

The model calibration was able to represent the measured data well for most of the data collection program. The hydrodynamic model was unable to simulate the wave-induced currents, however, this was due to the passing of Hurricane Gustav, so it was an event-driven condition.

The final analysis of impacts revealed that the proposed dredging and land reclamation in Falmouth Harbour will have only minor impacts on the circulation patterns within the estuary. Comparisons using the hydrodynamic model RMA-10 revealed that the currents within the area where the dinoflagellates inhabit, and closer to the dredged channel, did not change significantly. The range and distribution of the currents predicted for both existing and proposed shoreline and seabed configurations were found to be very similar.

Analysis of 3-D model results of temperature and suspended sediment concentrations also found little difference between two scenarios at the analysis points. However, the salinity concentrations under the existing conditions were found to be noticeably higher than the proposed layout, especially under normal conditions.

The comparison of the preliminary studies between Option 4 and Option 6 showed similar current speeds and directions. Option 6 showed higher saline concentrations than Option 4 and also warmer temperatures at both locations.

For non-cohesive sediment transport (i.e. sand), the model showed an increase in alongshore sediment transport as the dredging scenario shows a significant increase in wave height, by at least 50%, from the wave height observed for the existing conditions. The dredging scenario allows for more wave energy to penetrate into the wharf area, which can be potentially more damaging and as a consequence cannot be neglected when designing the structure. The increase in alongshore sediment transport in both directions is not, however, considered to be significant as there are a number of revetments and seawalls in place to prevent the erosion of beaches. The development plan also includes for the construction of a number of revetments to further reduce erosion. Nevertheless, in the vicinity of the Martha Brae River mouth, it is recommended that a programme of beach profile monitoring be set up, with quarterly monitoring to be carried out at spacings as specified previously.