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Feasibility Study of Island Development at the Pacific Entrance of the Panama Canal

Final Report, Technical Appendices

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Appendices F - J

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AUTORIDAD DEL CANAL DE PANAMA
ARTIFICIAL ISLAND FEASIBILITY STUDY

WAVE TRANSFORMATION STUDY: EXISTING CONDITIONS

DRAFT REPORT

JULY 2002

Submitted by:

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ENGINEERS

1. INTRODUCTION

In order to determine the feasibility of potential port operations to be located on new artificial islands as part of the further development of the Panama Canal system, the wave climate in the region of the potential island construction must be determined and assessed. This involves the development and evaluation of the offshore metocean data and the transformation of the offshore wave climate to the study region.

The objectives of this study are:

- To obtain and assess the offshore wave climate at the entrance to the Gulf of Panama
- To calculate the transformed wave climate in the region of the proposed artificial island project under existing conditions

This is the first part of the wave transformation study, which can be used to help determine island configuration and location for optimization of protection from wave action. The second part will involve evaluating the impact of the island construction on the wave climate.

2. ENVIRONMENTAL CONDITIONS

A preliminary evaluation of the environmental conditions impacting the site was necessary to develop the appropriate modeling strategy. The conditions considered included offshore waves, winds, tides, and extreme wave conditions.

2.1 OFFSHORE WAVE CLIMATE

A 31 year wave hindcast, from the start of 1970 through the end of the year 2000, was obtained from Oceanweather Inc. The hindcast utilized Oceanweather's GROW (Global Reanalysis of Ocean Waves) model to produce a time series of wave parameters at a location just offshore of the entrance to the Gulf of Panama. The GROW model provides global wind and wave hindcast data at grid points throughout the globe. The global oceans are divided into a 0.625 by 1.25 degree latitude/longitude grid. Wave and wind fields are archived every 3 hours. For this study, the hindcast wave data was obtained for GROW2000 model grid point 30275 and included a time series of significant wave height, wave direction, and wave period, output every three hours for the entire 31 year period (1970-2000). This data was used as the offshore deepwater wave conditions. Grid point 30275 is located at 6.875° latitude and 280.0° longitude, just offshore of the Gulf of Panama near the southwest edge of the gulf mouth, shown on Figure 2-1. This point was selected because it is located in an area that captures the wave climate from the predominant directions expected to impact the site.

Wave energy can only reach the entrance to the Gulf of Panama from a restricted directional window due to the geometric shape of the Gulf itself and the surrounding geography (as can be observed in Figure 2-1). The only significant wave energy that can affect the project site is from a window extending from south to west-southwest (180°–247.5°). The offshore fetch to the

south is limited by the shape of South America with the west coast of Ecuador blocking some of the large swells that originate near the Antarctic. The protruding point at the western part of the entrance to the Gulf of Panama limits wave energy from the northwest to west from entering the Gulf. The islands within the Gulf (especially Isla Del Ray) and the geometric configuration of the Gulf itself further shelter the study region from offshore waves. Any waves at the site generated from these restricted directions will be the result of local winds, likely resulting in shorter period waves of limited height and energy.

Figure 2-1. Overview Map and Location of Oceanweather Grid Point

To allow for more direct analyses, the raw wave hindcast data were summarized by counting the number of occurrences of particular events within defined bins, or specific ranges of values. The wave data was grouped in 0.25 meter bins, the wave period data in 2 second bins, and the wave direction data in 5 degree bins. The frequency of occurrence of specific events was summarized monthly and annually. The monthly data consisted of the total occurrences of a particular event during a given month over the 31-year time series. The annual data was of all occurrences of a particular event over the entire 31-year time series. By grouping the data this way, it was possible to calculate percent occurrence and percent exceedance values for the different wave conditions.

Joint frequency tables are provided in Appendix A for the whole period of hindcast for the following pairs of variables:

- Significant wave height (Hs) by peak wave period (Tp)
- Peak wave period (Tp) by mean wave direction (degrees clockwise from North)
- Significant wave height (Hs) by mean wave direction

2.1.1 Significant Wave Height

Figure 2-2 shows the percent occurrence of significant wave height monthly and annually. The graph illustrates that most significant wave heights are between 0.5 and 2.5 meters. Predominant wave heights are centered around 1.0-1.25 m for the months of December to April and 1.5-1.75 meters for the months of July to November.

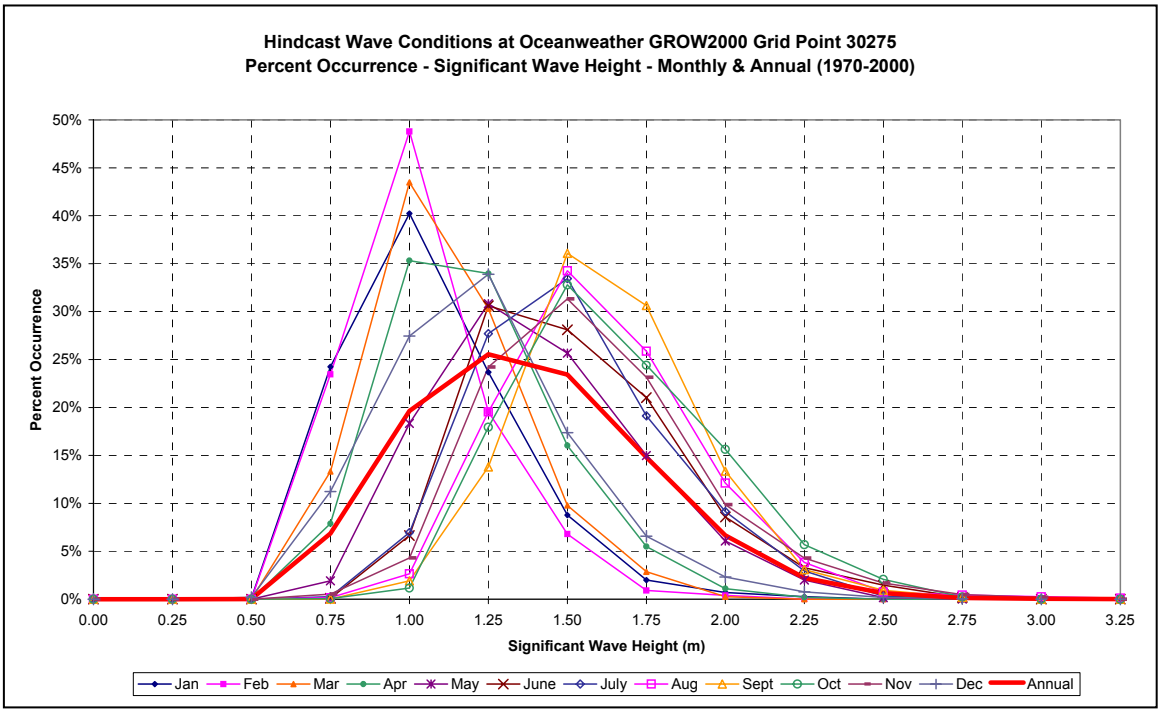

Figure 2-2. Percent Occurrence of Significant Wave Height

Figure 2-3 provides the deepwater wave exceedance curve. From the figure, it can be seen that the offshore wave climate is not particularly severe with significant wave heights rarely exceeding 2 meters.

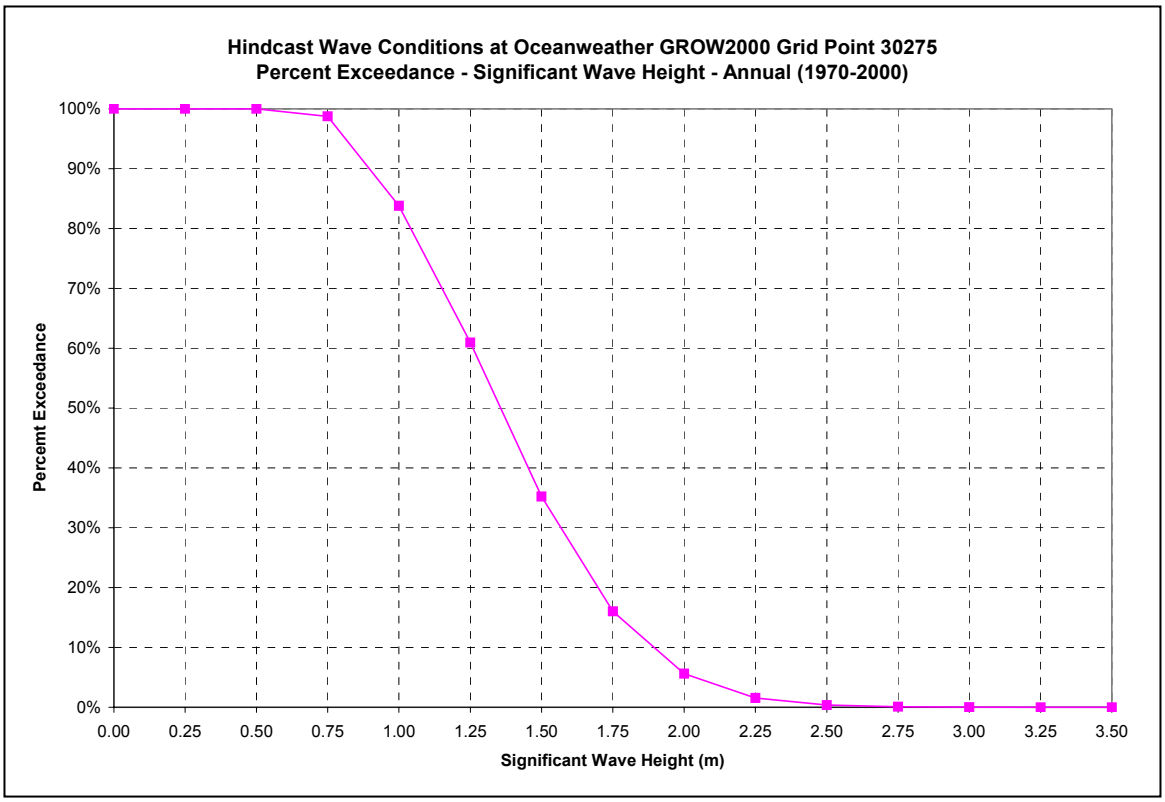

Figure 2-3. Percent Exceedance of Significant Wave Height

2.1.2 Wave Period

Figure 2-4 illustrates the percent exceedance of wave periods within the 31-year hindcast record. Over 80% of the peak offshore wave periods were between 10 and 18 seconds.

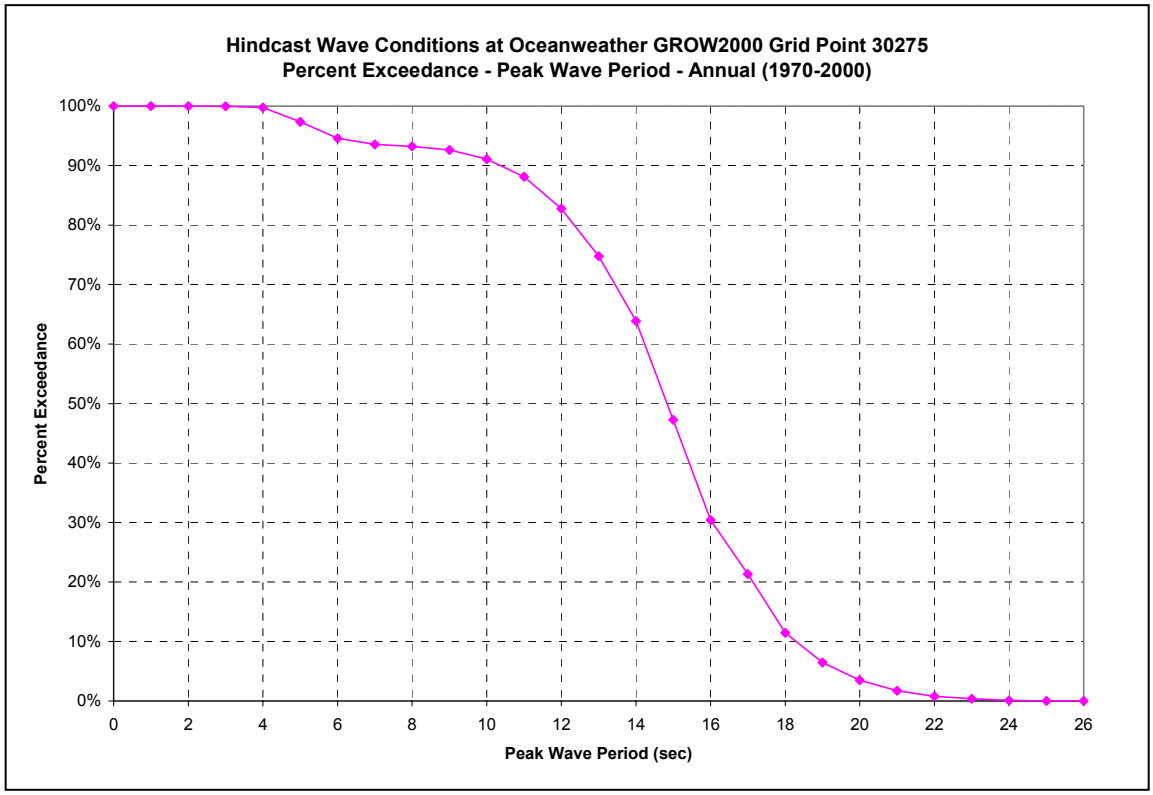

Figure 2-4. Percent Exceedance of Peak Wave Period

2.1.3 Wave and Wind Direction

The relatively small range of offshore wave directions, limited by the geographic configuration of Central and South America, is clearly illustrated in Figure 2-5. Most waves arrive at the entrance to the Gulf of Panama from 200 to 250 degrees. The offshore hindcast wind field is slightly shifted from the mean wave directions and is more distributed. The wind is not constrained by the land configuration in the same manner as waves.

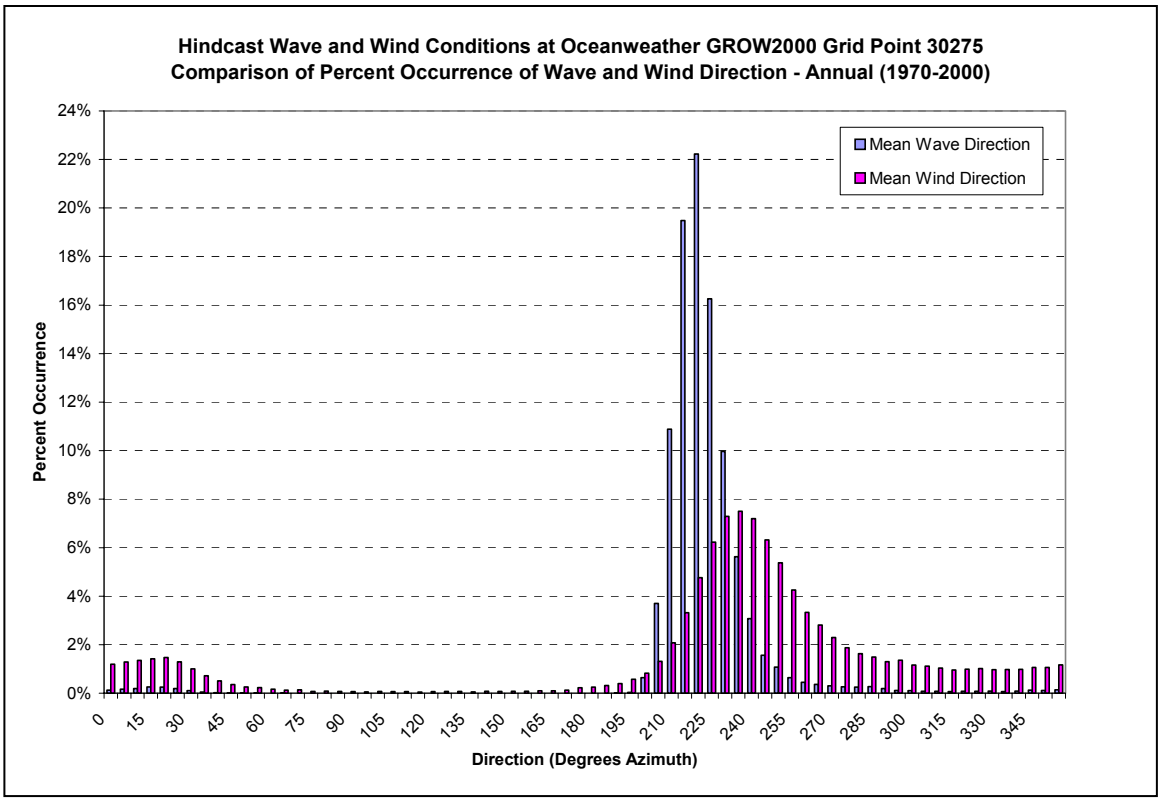

Figure 2-5. Percent Occurrence of Waves and Wind by Direction

The percent occurrences of waves by mean wave directions are graphed for monthly and annual conditions in Figure 2-6. This graph reveals little seasonal variation in the offshore wave direction.

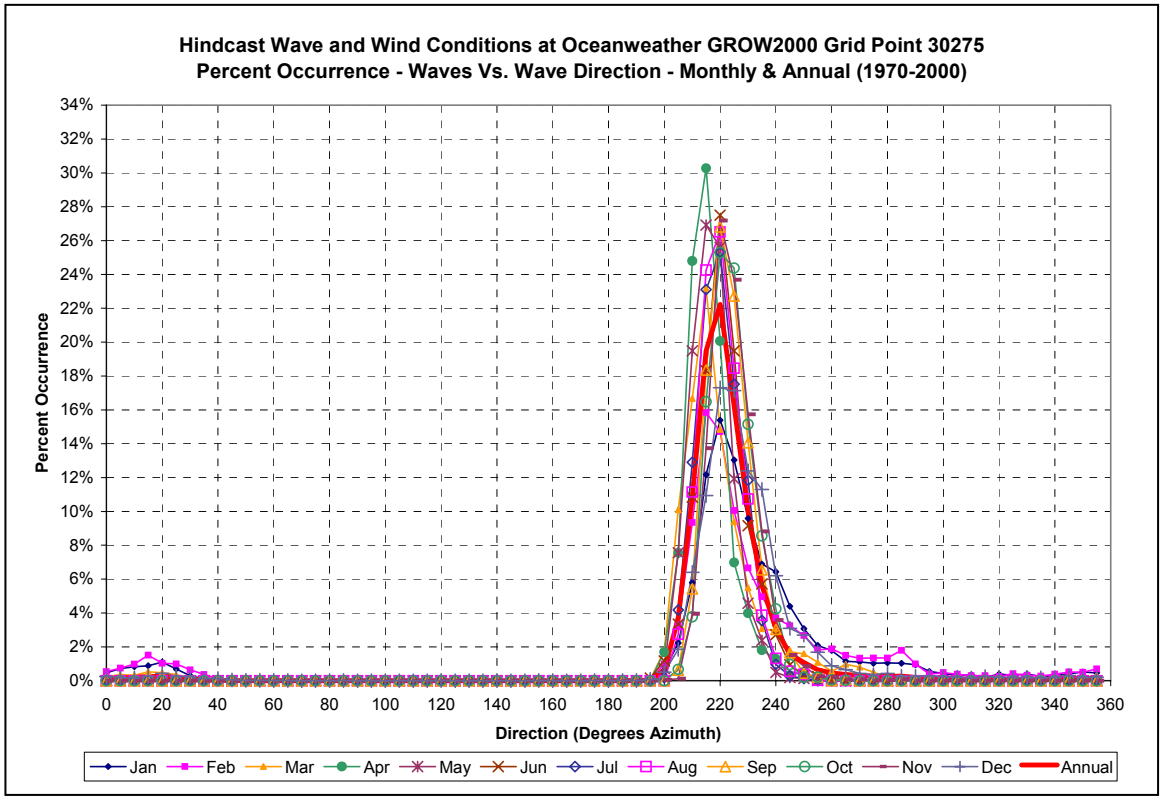

Figure 2-6. Percent Occurrence of Waves Vs. Wave Direction

2.2 TIDES

Tidal ranges for stations within the Gulf of Panama were obtained from the British Admiralty Tide Tables and are presented in Table 2.1. The overall tidal range within the Gulf is approximately 4 to 5 meters.

Table 2.1: Astronomical Tide Level Characteristics within the Gulf of Panama

TIDE LEVELS REFFERRED TO CHART DATUM (m)							
LOCATION	LAT N	LONG W	Mean High Water Springs (MHWS)	Mean High Water Neap (MHWN)	Mean Sea Level (MSL)	Mean Low Water Neap (MLWN)	Mean Low Water Spring (MLWS)
Rio Chepo*	8°59'	79°07'W	4.8	3.9	2.5	1.2	0.2
Balboa*	8°57'	79°34'W	4.9	3.8	2.6	1.1	-0.1
Punta Garachine	8°05'	78°25'W	4.2	3.3	2.2	1.1	0.2
San Telmo Bay	8°18'	78°54'W	4.2	3.3	2.1	1.1	0.2
Bahia Pina	7°34'	78°11'W	4.1	3.2	2.1	1.1	0.2
Punta Malla	7°28'	80°00'W	3.3	2.4	1.7	0.9	0.1

*Tidal stations closest to project region.

For this study, the wave transformation model was run at both MHWS and MLWS. Based on the tide level characteristics and the locations of the tidal stations relative to the project study region, the high and low tidal elevations used were 4.8 meters for MHWS and 0.2 meters for MLWS.

2.3 EXTREMAL WAVE ANALYSIS

Return periods of 2, 5, 10, 20, 50 and 100 years were computed for significant wave height. The extreme analysis was based on annual maximum significant wave heights for the 31 year hindcast record and used a Type I (Gumble) distribution approach.

Table 2.2: Return Periods and Wave Heights

Return Period (years)	Significant Wave Height (m)
2	2.6
5	2.8
10	3.0
20	3.2
50	3.4
100	3.6

3. WAVE TRANSFORMATION ANALYSIS

As deepwater waves propagate toward shore and into shallower water, they are modified both in direction and height, due to interaction with the sea floor. It is important to quantify these transformation effects so that a deepwater wave climate may be adapted to describe the nearshore climate at the site of interest. A wave model was required to transfer the offshore wave climate to the project region (proposed vicinity of the artificial islands). Regional grids were developed to take waves of various periods from deepwater to the near-shore project region.

Using the offshore hindcast data, the waves were transformed to the project site to account for refraction, diffraction and shoaling effects from changes in the bathymetry as waves propagate from offshore to the shallower near-shore project region. The wave transformation processes of shoaling, refraction, and diffraction depend on the period of the wave. Refraction and diffraction also depend on the incident wave direction.

Sophisticated models have been developed in recent years that use finite-difference or finite-element techniques to calculate the wave conditions (height and direction) at nodes (normally several hundred or thousand) defined within the boundaries of a model grid. One such model developed by the Danish Hydraulic Institute, the MIKE21 Parabolic Mild-Slope Model (PMS) was utilized for this study. The PMS model was selected due to the configuration of the Gulf of Panama. It was critical that a model, which accounted for diffraction, was selected. The process of diffraction around Punta Mala at the western edge of the entrance to the Gulf of Panama and diffraction around the islands prior to the study region plays a significant role in proper representation and modeling of the wave energy reaching the study area.

3.1 BATHYMETRY

The bathymetry data was obtained from nautical charts (Admiralty – Chart 1929: "Gulf of Panama" and Chart 1401: "Approaches to the Panama Canal") and the recently completed hydrographic survey of the study region. Current data with higher resolution of the bathymetric information in the study region, especially near the site where the water depths are shallower and wave interaction with the seafloor is increased, provides improved results for wave transformation calculations. The bathymetry for the Gulf of Panama and study region was digitized from this data. All vertical data was referenced to Chart Datum, approximately Mean Low Water Springs (MLWS). From the bathymetry of the Gulf, a smaller model region was extracted as shown in Figure 3-1.

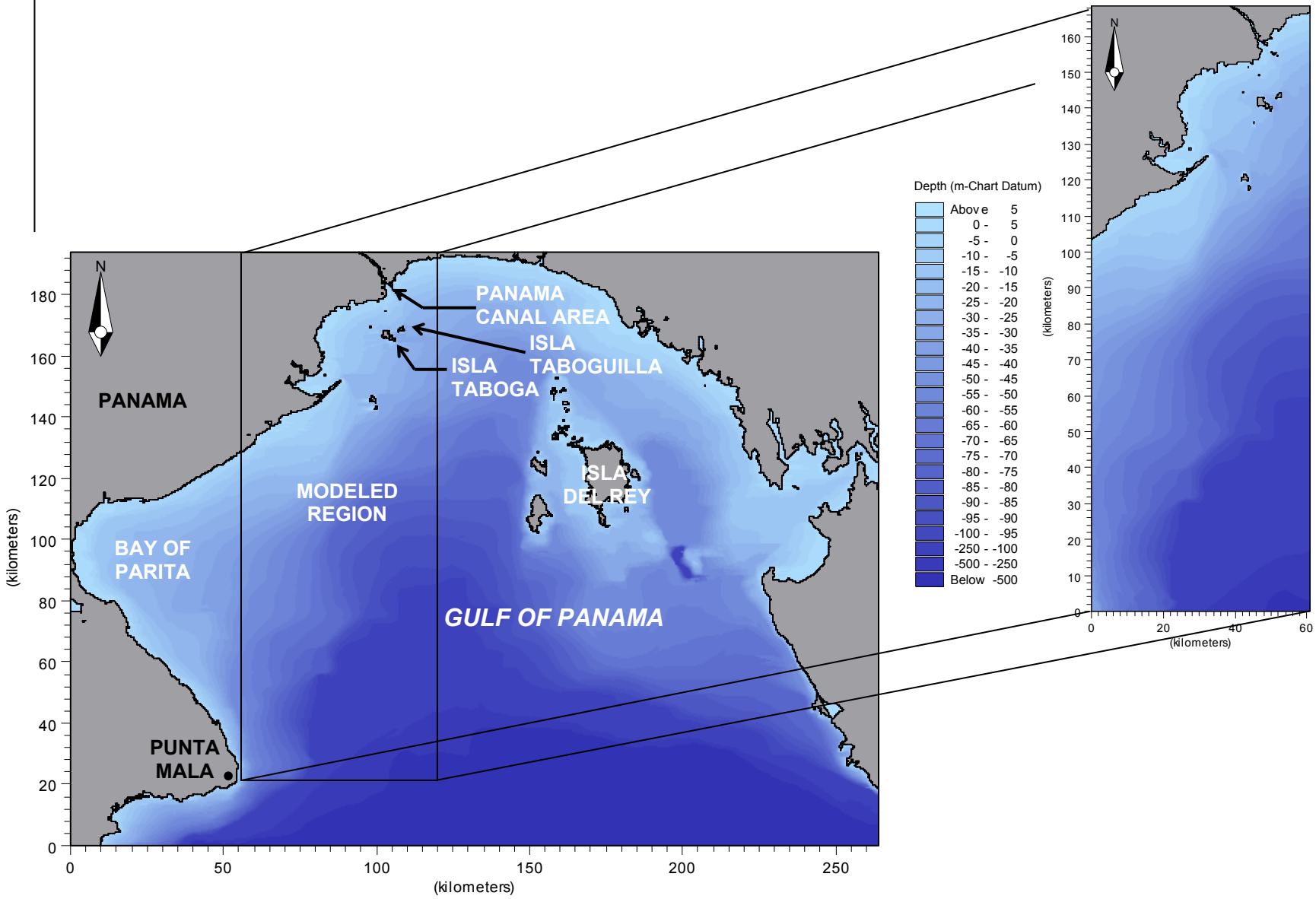

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FIGURE 3-1:
Existing Bathymetry

3.2 MODELING APPROACH

In order to transform the deepwater waves to those representing the nearshore wave climate at the site of interest, the offshore waves were divided into representative period-direction pairs. Each pair was propagated and transformed to calculate the wave climate within the study region. Refraction, shoaling, and diffraction were solved numerically over the model area by digitizing the bathymetry into an x-y grid and solving the governing equations at each grid point

The MIKE21 Parabolic Mild-Slope Model (PMS) model is a parabolic linear refraction / diffraction model that takes into account the effects of refraction and shoaling due to varying depth, diffraction along the perpendicular to the predominant wave direction and energy dissipation due to bottom friction and wave breaking. It is based on a parabolic approximation to the elliptic mild-slope equation governing the refraction, shoaling, and diffraction of linear waves propagating over a gently sloping bathymetry. The parabolic approximation simplifies the computation and is obtained by assuming waves travel in the x-direction and by neglecting diffraction along this direction. The parabolic approximation limits the allowable angle between the direction of wave propagation and the x-axis. Several techniques allowing for larger deviations in wave angle up to 60 degrees from the predominant wave direction are available within the PMS model (Padé's model and Kirby's Minimax model). The solution to the wave parameters is determined on a rectangular Cartesian grid using Crank-Nicolson finite difference techniques.

The main output data are integral wave parameters such as wave height, peak wave period, and mean wave direction.

The equation was developed assuming that the bottom slope over which the waves travel is mild, with no abrupt changes. However, models based on the mild-slope equation have been shown to perform well even when this assumption is violated. A normalized unit incident wave, specified by wave period and direction, was modeled for each period-direction component. Grid spacing was selected to provide adequate resolution of the bathymetry and the waves within reasonable computer storage and processing requirements.

3.3 MODELED WAVE CONDITIONS

Wave model runs were performed for water depths corresponding to Mean Low Water Spring (MLWS) and Mean High Water Spring (MHWS) taken as 0.2 m and 4.8 m, respectively, above bathymetry datum (chart sounding datum). Based on the previous offshore wave climate analysis, wave periods from 6 to 20 seconds and wave directions from 200 to 240 degrees were chosen for the wave transformation model runs.

Unit wave heights were modeled for each wave period-direction pair with wave periods taken every 2 seconds and with a directional interval of 5 degrees. In order to provide relatively smooth model results and to more closely represent the natural variation of actual wave

conditions, JONSWAP spectra with minor frequency and directional spreads were used to represent the offshore boundary wave conditions.

3.4 MODELING REGION

As shown in Figure 3-1, the bathymetry grid for the modeling region was approximately 60 by 168 kilometers. From the larger Gulf of Panama bathymetry grid, a computational grid with uniform spacing in both the x and y-directions of 30 x 30 meters was interpolated and used to calculate transformation of the waves with periods of 14 to 20 seconds. This provided a minimum of 10 grid points per wavelength in deepwater and adequate resolution as the wavelengths are reduced in shallower water. One of the restrictions of the PMS model is that it requires several grid points per wavelength in order to calculate the wave field correctly and remain numerically stable. For better computational accuracy, separate grids were used for the shorter wave periods. Since wavelength is proportional to the square of wave period, reduction of the wave period requires higher resolution and smaller grid spacing to satisfy the grid point to wavelength computational requirements of the PMS model. The 12-second models were run using the bathymetry grid with a higher resolution of 20 X 20 meter grid spacing.

For the 6-10 second waves, the 20-meter grid spacing resulted in too few grid cells per wavelength as the waves approached the shoreline in shallow areas, causing computational instability near the land boundaries. PMS is limited to the file size or number of grid cells and will not run for extremely large bathymetric grids. Therefore, reducing the grid spacing for the lower period runs also required reducing the extent of the bathymetry grid, to achieve a smaller file size and fewer grid points.

Figure 3-2 shows the initial model grids and the reduced bathymetry grids for the 6-10 second model runs, relative to the original modeling region. The length of the model grid was chosen based on diffraction behavior and the wave angle with respect to Punta Mala. For the shorter period waves, the grid was shortened a point in line with the shielding afforded by Punta Mala and where the water was still deep with respect to the wavelength (no refraction), thus allowing the offshore wave conditions to be representative at the boundary.

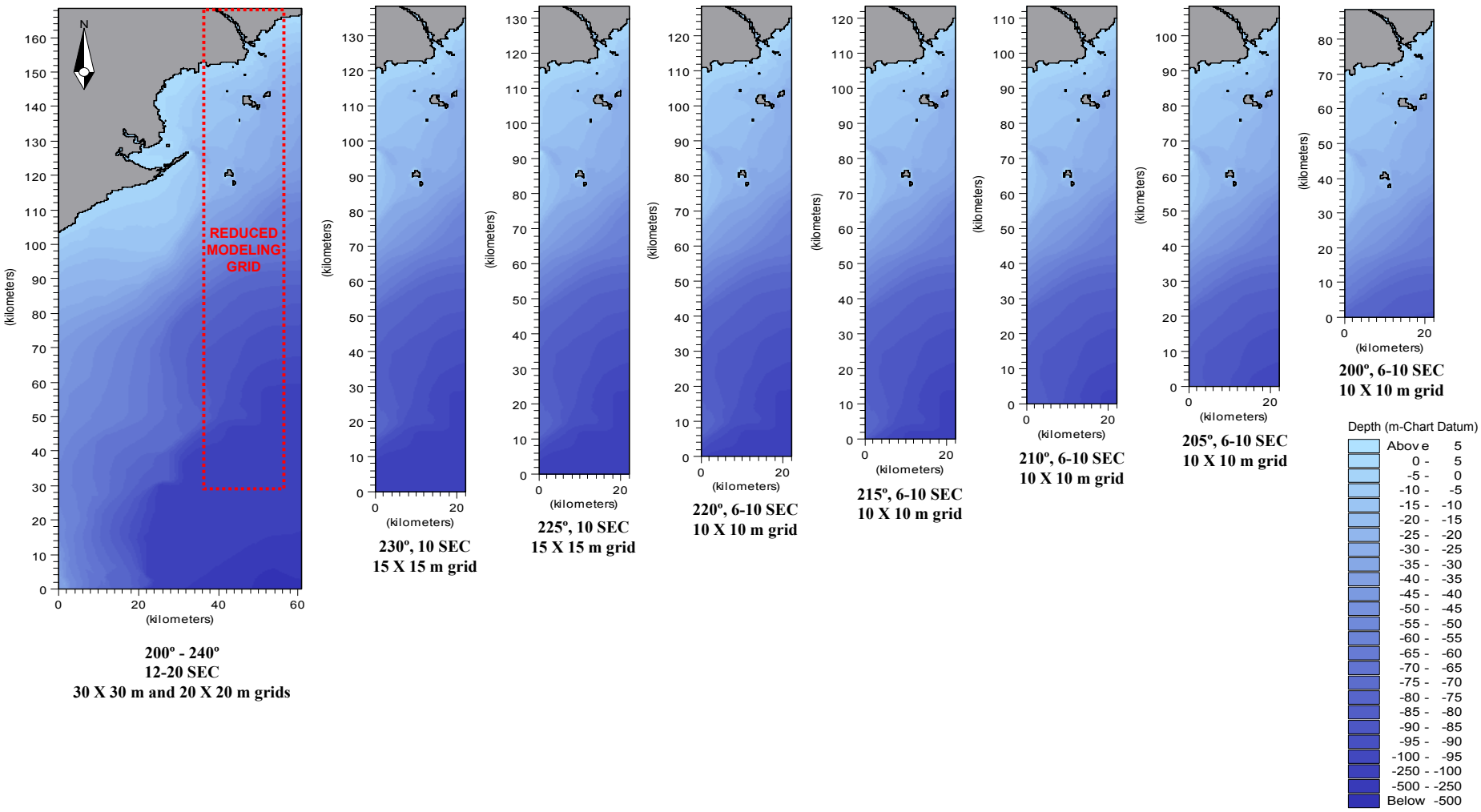

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FIGURE 3-2:
Existing Bathymetry for Reduced Modeling Grids

Table 3.1 lists the grid size used for the entire matrix of model runs. As shown in the table, some of the steeper angle model runs were eliminated. Based on the PMS results for the 12-20 second waves, it was found that the steeper directions did not result in significant energy reaching the proposed site. In the event that less than 1% of the offshore wave height remained near the site for the 12-second model runs, all lower period model runs were eliminated (e.g. 235°- 240 °). The 6-8 second model runs were likewise eliminated for the 225° -230° directions, based on the 10-second wave results.

Table 3.1: Grid size used for various model runs

Wave Direction (degrees)	**Wave Period (sec)**							
	6	**8**	**10**	**12**	**14**	**16**	**18**	**20**
200	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
205	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
210	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
215	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
220	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
225			15 m	20 m	30 m	30 m	30 m	30 m
230			15 m	20 m	30 m	30 m	30 m	30 m
235				20 m	30 m	30 m	30 m	30 m
240				20 m	30 m	30 m	30 m	30 m

3.5 MODEL RESULTS AND DISCUSSION

The results of the PMS modeling are presented in Appendix B. The results are plotted as contours of the wave transformation coefficient, which represents the combined effects of refraction, diffraction and shoaling on a unit wave height of a given mean wave direction propagating from the southern boundary of the model. The more southerly wave directions (200 degrees) result in more wave energy reaching the proposed site (landward of the two islands south of the Panama Canal Pacific entrance). As the offshore wave direction moves westward and the angle increases to 240 degrees, Punta Mala provides more shelter to the Gulf from waves originating offshore. In general, the region is fairly well sheltered form offshore waves with less than 25% (often considerably less) of the offshore wave height in the study region.

The typical wave climate in the area of the proposed artificial islands is relatively mild with the geometry of the Gulf of Panama and South America limiting the directions of waves entering the region. However, long period swell waves generated by storms in the Pacific occasionally reach the area and these long period waves can cause considerable movement of a vessel at an unprotected berth impacting container transfer operations. The placement of the artificial islands especially with respect to the shielding provided by the near-shore islands of Isla Taboga and Taboguilla (labeled on Figure 3-1) will greatly determine the amount of protection required for container vessel operations. The gap between these islands and the deeper water it contains provides a path for wave energy to get behind the islands into the proposed project region.

APPENDIX F – PART A
PERCENT OCCURRENCE – OFFSHORE WAVES

Table A-1 Percent Occurrence - Significant Wave Height by Peak Wave Period

	Peak Wave Period, Tp (sec)														
Significant Wave Height, Hs(m)	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**Total Percent Occurrence**
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.01%**	**0.01%**	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%
0.75	0.00%	**0.02%**	**0.04%**	**0.01%**	**0.06%**	**0.34%**	**1.16%**	**2.40%**	**1.67%**	**0.81%**	**0.26%**	**0.05%**	**0.02%**	0.00%	6.86%
1	0.00%	0.00%	**0.26%**	**0.03%**	**0.10%**	**0.83%**	**3.14%**	**6.36%**	**5.23%**	**2.58%**	**0.79%**	**0.24%**	**0.08%**	0.00%	19.64%
1.25	0.00%	0.00%	**1.16%**	**0.18%**	**0.29%**	**1.11%**	**3.52%**	**7.45%**	**6.89%**	**3.46%**	**1.07%**	**0.32%**	**0.09%**	0.00%	25.54%
1.5	0.00%	0.00%	**1.16%**	**0.80%**	**0.28%**	**1.20%**	**2.81%**	**6.08%**	**5.85%**	**3.65%**	**1.18%**	**0.37%**	**0.08%**	0.00%	23.45%
1.75	0.00%	0.00%	**0.02%**	**1.38%**	**0.09%**	**0.79%**	**1.79%**	**3.24%**	**3.86%**	**2.48%**	**0.87%**	**0.22%**	**0.05%**	0.00%	14.80%
2	0.00%	0.00%	0.00%	**0.90%**	**0.01%**	**0.17%**	**0.75%**	**1.42%**	**1.64%**	**1.22%**	**0.39%**	**0.12%**	**0.04%**	0.00%	6.65%
2.25	0.00%	0.00%	0.00%	**0.35%**	**0.01%**	**0.05%**	**0.12%**	**0.44%**	**0.60%**	**0.46%**	**0.14%**	**0.03%**	**0.01%**	0.00%	2.21%
2.5	0.00%	0.00%	0.00%	**0.11%**	**0.06%**	0.00%	**0.03%**	**0.08%**	**0.16%**	**0.13%**	**0.04%**	**0.01%**	0.00%	0.00%	0.63%
2.75	0.00%	0.00%	0.00%	0.00%	**0.05%**	0.00%	0.00%	**0.02%**	**0.03%**	**0.03%**	**0.01%**	0.00%	0.00%	0.00%	0.14%
3	0.00%	0.00%	0.00%	0.00%	**0.02%**	0.00%	0.00%	0.00%	**0.01%**	**0.01%**	0.00%	0.00%	0.00%	0.00%	0.04%
3.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.01%**	0.00%	0.00%	0.00%	0.00%	0.01%
Total Percent Occurrence	0%	0%	3%	4%	1%	4%	13%	28%	26%	15%	5%	1%	0%	0%	100.00%

Table A-2 Percent Occurrence - Peak Wave Period by Wave Direction

Peak Wave Period, Tp (sec)	Wave Direction (degrees azimuth) 0-180 degrees																																					
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
14	0.0%	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
16	0.0%	0.0%	0.0%	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
22	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Occurrence	0.1%	0.2%	0.2%	0.3%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Peak Wave Period, Tp (sec)	Wave Direction (degrees azimuth) 185-355 degrees																																				
	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305	310	315	320	325	330	335	340	345	350	355	Total Percent Occurrence
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.3%**	**0.5%**	**0.6%**	**0.4%**	**0.3%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%
6	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.3%**	**0.7%**	**0.8%**	**0.7%**	**0.5%**	**0.2%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.8%
8	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.2%**	**0.2%**	**0.2%**	**0.1%**	**0.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%
10	0.0%	0.0%	0.0%	**0.2%**	**0.4%**	**0.9%**	**1.1%**	**0.9%**	**0.5%**	**0.2%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%
12	0.0%	0.0%	0.0%	**0.2%**	**1.0%**	**2.3%**	**2.6%**	**2.6%**	**1.7%**	**1.1%**	**0.7%**	**0.4%**	**0.2%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	13.3%
14	0.0%	0.0%	0.0%	**0.1%**	**1.1%**	**3.2%**	**5.3%**	**5.8%**	**4.5%**	**2.9%**	**1.6%**	**0.8%**	**0.4%**	**0.3%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	27.5%
16	0.0%	0.0%	0.0%	**0.1%**	**0.7%**	**2.5%**	**5.3%**	**6.4%**	**4.4%**	**2.4%**	**1.4%**	**0.7%**	**0.4%**	**0.3%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.9%
18	0.0%	0.0%	0.0%	0.0%	**0.4%**	**1.3%**	**3.2%**	**3.6%**	**2.5%**	**1.3%**	**0.7%**	**0.4%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.9%
20	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.4%**	**1.0%**	**1.3%**	**0.8%**	**0.4%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.8%
22	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.3%**	**0.4%**	**0.3%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%
24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Occurrence	0.0%	0.0%	0.0%	0.6%	3.7%	10.9%	19.5%	22.2%	16.3%	10.0%	5.6%	3.1%	1.6%	1.1%	0.6%	0.5%	0.4%	0.3%	0.3%	0.3%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	100.0%

Table A-3 Percent Occurrence - Significant Wave Height by Wave Direction

Significant Wave Height, Hs (m)	Wave Direction (degrees azimuth) 0-180 degrees																																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.25	0.0%	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.5	0.0%	0.0%	0.0%	0.0%	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Occurrence	0.1%	0.2%	0.2%	0.3%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

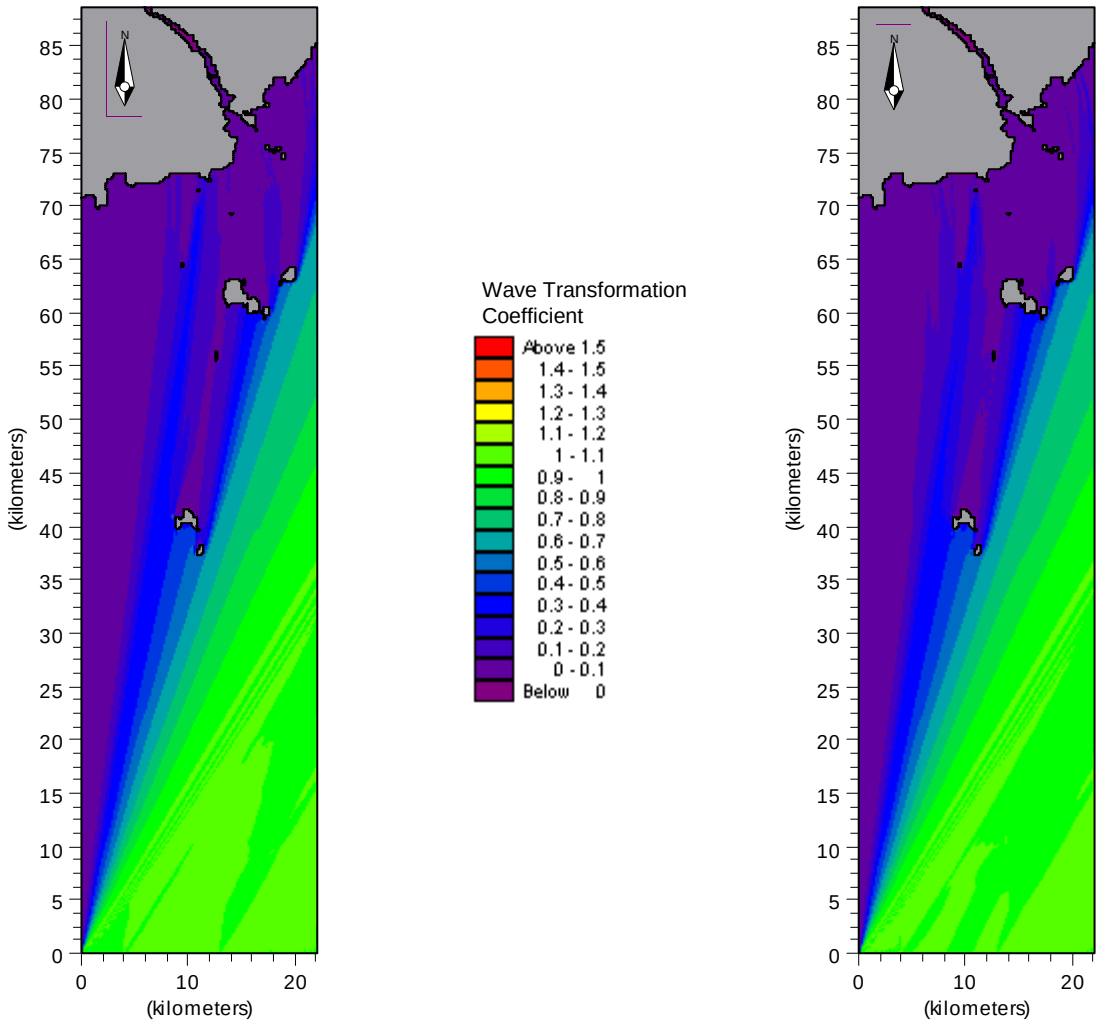
Significant Wave Height, Hs (m)	Wave Direction (degrees azimuth) 185-355 degrees																																				
	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305	310	315	320	325	330	335	340	345	350	355	Total Percent Occurrence
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.75	0.0%	0.0%	0.0%	**0.1%**	**0.2%**	**0.5%**	**0.7%**	**0.9%**	**0.8%**	**0.6%**	**0.4%**	**0.5%**	**0.4%**	**0.3%**	**0.2%**	**0.2%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.9%
1	0.0%	0.0%	0.0%	**0.3%**	**1.0%**	**2.3%**	**3.4%**	**3.5%**	**2.3%**	**1.6%**	**1.2%**	**0.9%**	**0.5%**	**0.5%**	**0.2%**	**0.2%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.1%**	**0.1%**	19.6%
1.25	0.0%	0.0%	0.0%	**0.2%**	**0.8%**	**3.0%**	**4.9%**	**5.3%**	**4.4%**	**2.9%**	**1.7%**	**0.8%**	**0.4%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.5%
1.5	0.0%	0.0%	0.0%	**0.1%**	**0.8%**	**2.5%**	**4.5%**	**5.5%**	**4.5%**	**2.8%**	**1.5%**	**0.6%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	23.4%
1.75	0.0%	0.0%	0.0%	0.0%	**0.5%**	**1.6%**	**3.4%**	**4.1%**	**2.8%**	**1.4%**	**0.5%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.8%
2	0.0%	0.0%	0.0%	0.0%	**0.2%**	**0.7%**	**1.7%**	**2.1%**	**1.0%**	**0.6%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.7%
2.25	0.0%	0.0%	0.0%	0.0%	**0.2%**	**0.3%**	**0.6%**	**0.7%**	**0.3%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%
2.5	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.2%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
2.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Occurrence	0.0%	0.0%	0.0%	0.6%	3.7%	10.9%	19.5%	22.2%	16.3%	10.0%	5.6%	3.1%	1.6%	1.1%	0.6%	0.5%	0.4%	0.3%	0.3%	0.3%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	100.0%

Table A-3 Percent Occurrence - Significant Wave Height by Wave Direction

Significant Wave Height, Hs (m)	Wave Direction (degrees azimuth) 0-180 degrees																																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.25	0.0%	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.5	0.0%	0.0%	0.0%	0.0%	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Occurrence	0.1%	0.2%	0.2%	0.3%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Significant Wave Height, Hs (m)	Wave Direction (degrees azimuth) 185-355 degrees																																				
	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305	310	315	320	325	330	335	340	345	350	355	Total Percent Occurrence
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.75	0.0%	0.0%	0.0%	**0.1%**	**0.2%**	**0.5%**	**0.7%**	**0.9%**	**0.8%**	**0.6%**	**0.4%**	**0.5%**	**0.4%**	**0.3%**	**0.2%**	**0.2%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.9%
1	0.0%	0.0%	0.0%	**0.3%**	**1.0%**	**2.3%**	**3.4%**	**3.5%**	**2.3%**	**1.6%**	**1.2%**	**0.9%**	**0.5%**	**0.5%**	**0.2%**	**0.2%**	**0.2%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.1%**	**0.1%**	19.6%
1.25	0.0%	0.0%	0.0%	**0.2%**	**0.8%**	**3.0%**	**4.9%**	**5.3%**	**4.4%**	**2.9%**	**1.7%**	**0.8%**	**0.4%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.5%
1.5	0.0%	0.0%	0.0%	**0.1%**	**0.8%**	**2.5%**	**4.5%**	**5.5%**	**4.5%**	**2.8%**	**1.5%**	**0.6%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	23.4%
1.75	0.0%	0.0%	0.0%	0.0%	**0.5%**	**1.6%**	**3.4%**	**4.1%**	**2.8%**	**1.4%**	**0.5%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.8%
2	0.0%	0.0%	0.0%	0.0%	**0.2%**	**0.7%**	**1.7%**	**2.1%**	**1.0%**	**0.6%**	**0.2%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.7%
2.25	0.0%	0.0%	0.0%	0.0%	**0.2%**	**0.3%**	**0.6%**	**0.7%**	**0.3%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%
2.5	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	**0.2%**	**0.1%**	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
2.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Percent Occurrence	0.0%	0.0%	0.0%	0.6%	3.7%	10.9%	19.5%	22.2%	16.3%	10.0%	5.6%	3.1%	1.6%	1.1%	0.6%	0.5%	0.4%	0.3%	0.3%	0.3%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	100.0%

APPENDIX F – PART B
PMS OUPUT



Water Surface at MHWS

Water Surface at MLWS

Moffatt & Nichol ENGINEERS

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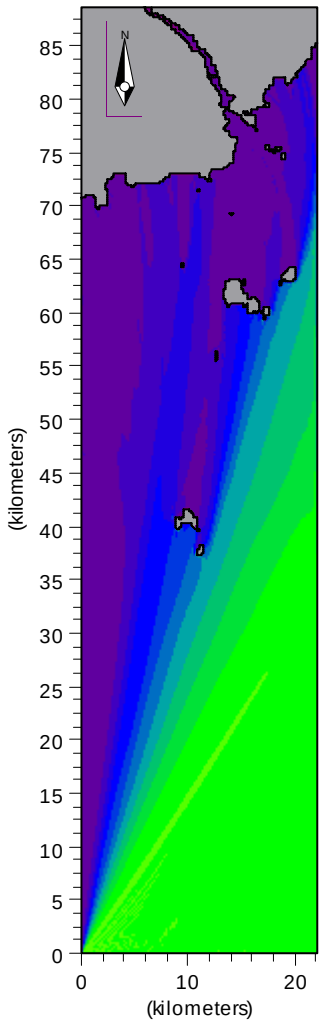
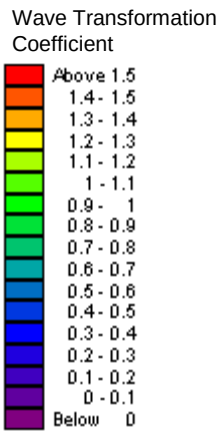
AUTORIDAD DEL CANAL DE PANAMA

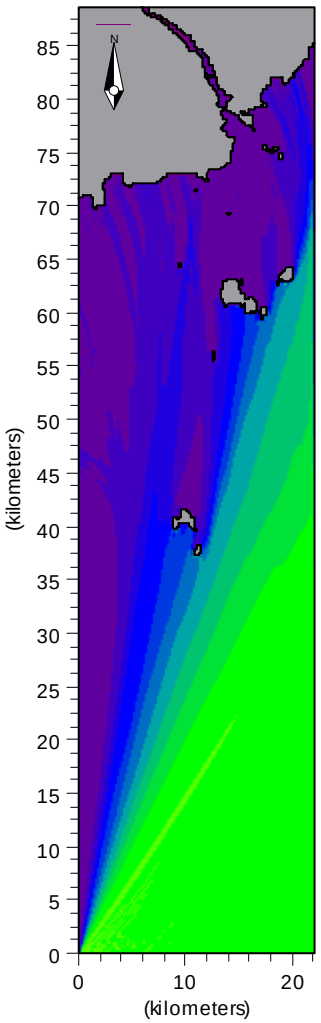
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-1:
Wave Transformation Coefficient
6 second waves from 200 degrees



Water Surface at MHWS





Water Surface at MLWS

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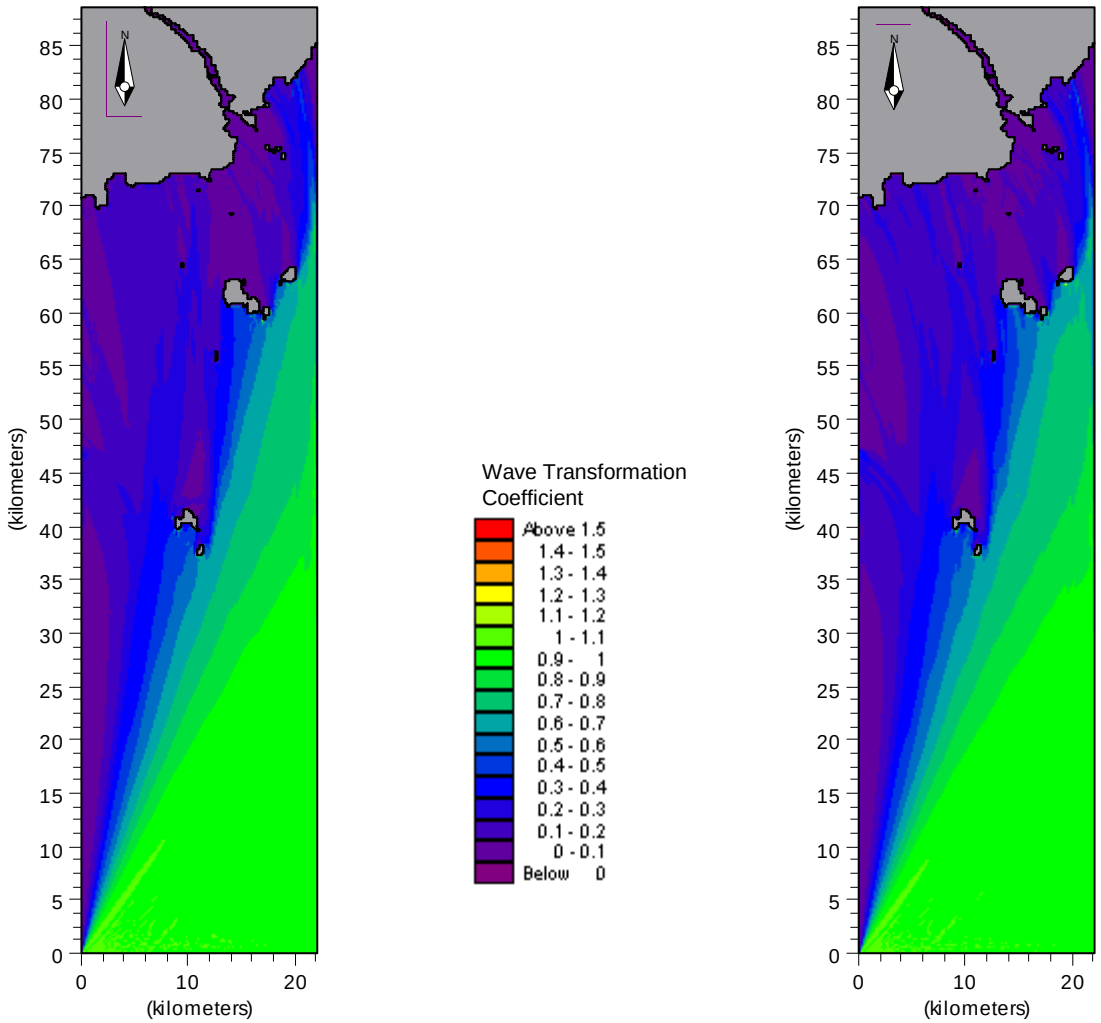
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-2:
Wave Transformation Coefficient
8 second waves from 200 degrees



Water Surface at MHWS

Water Surface at MLWS

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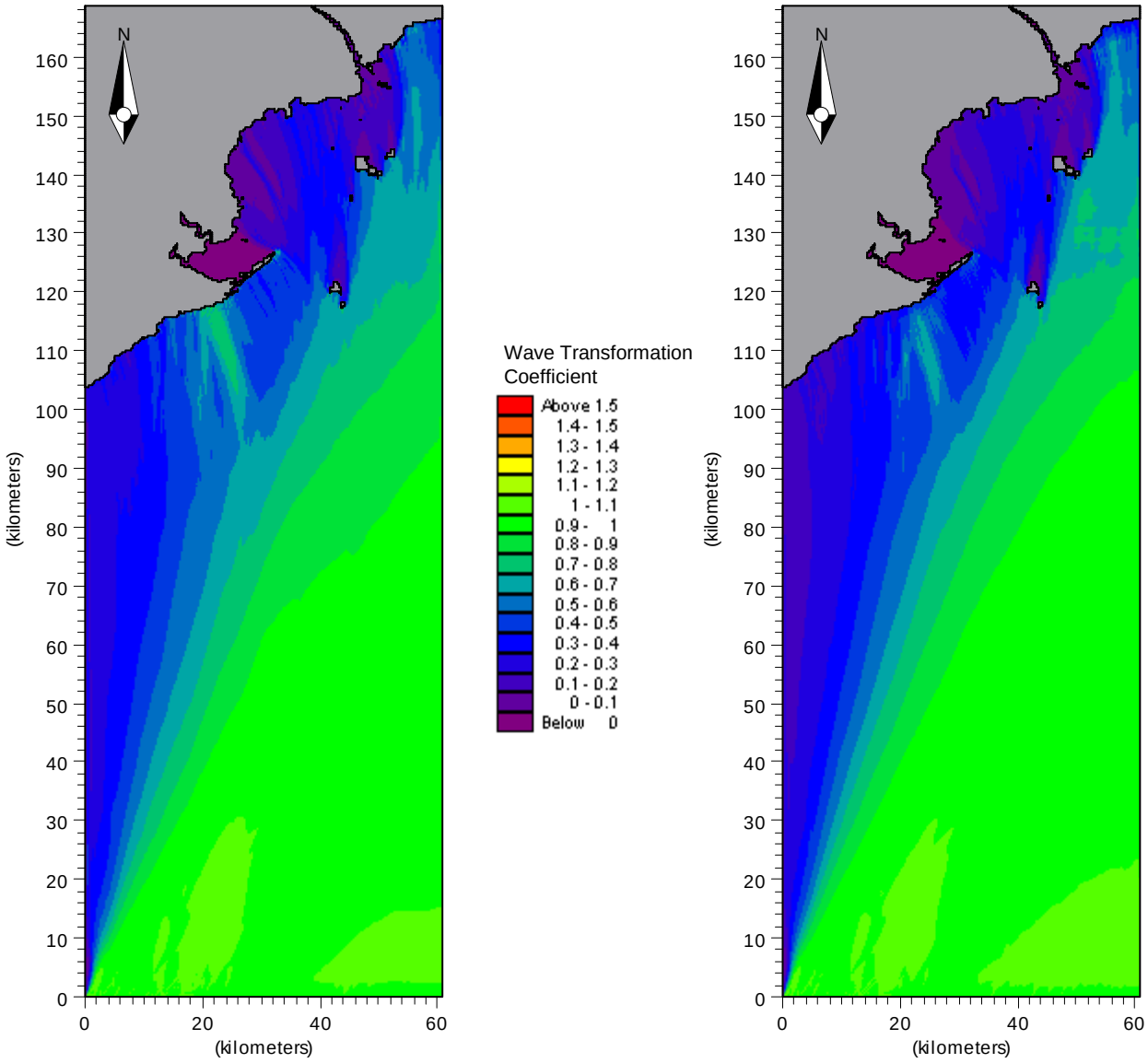
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-3:
Wave Transformation Coefficient
10 second waves from 200 degrees



Water Surface at MHWS

Water Surface at MLWS

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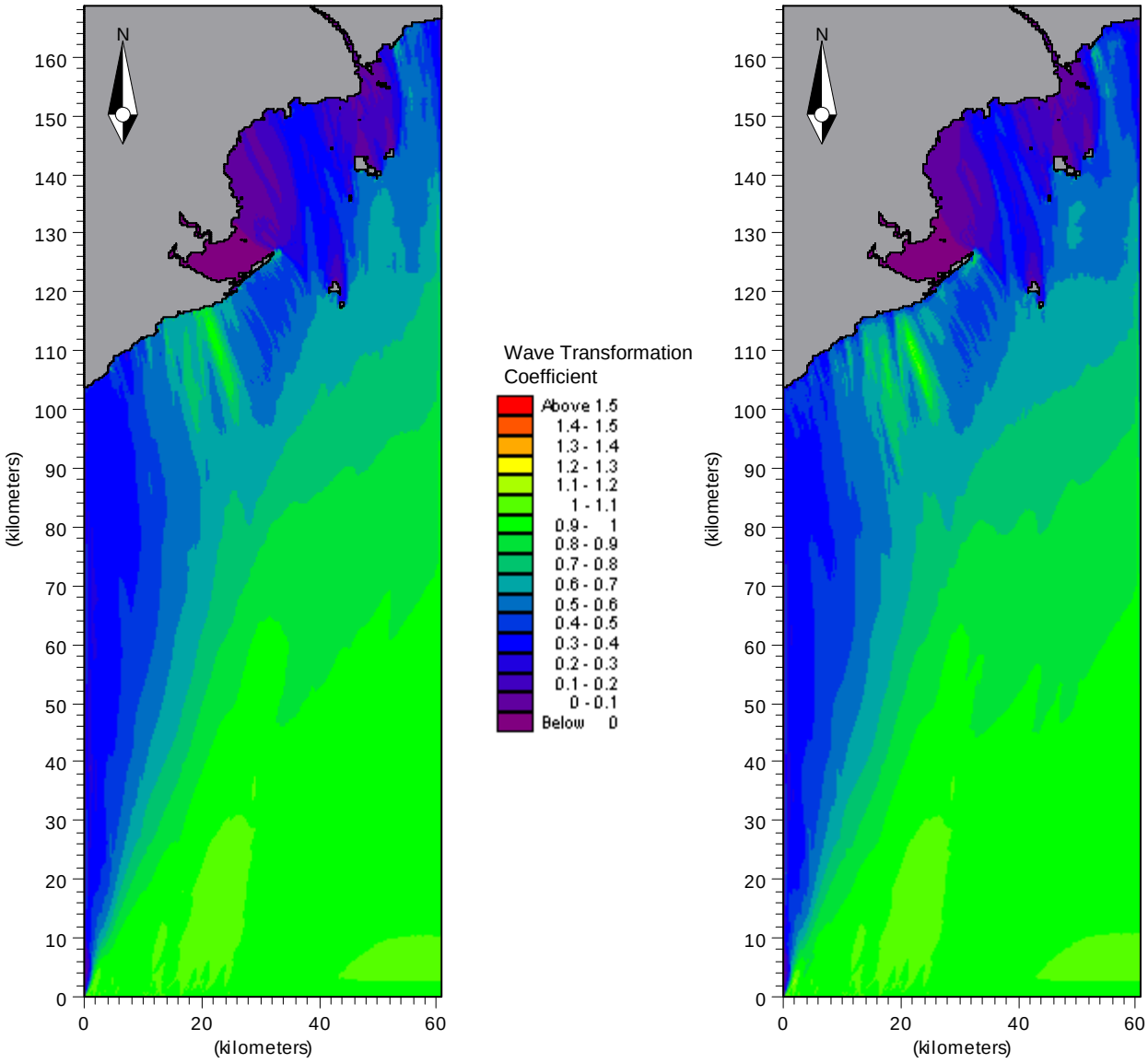
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-4:
Wave Transformation Coefficient
12 second waves from 200 degrees



Water Surface at MHWS

Water Surface at MLWS

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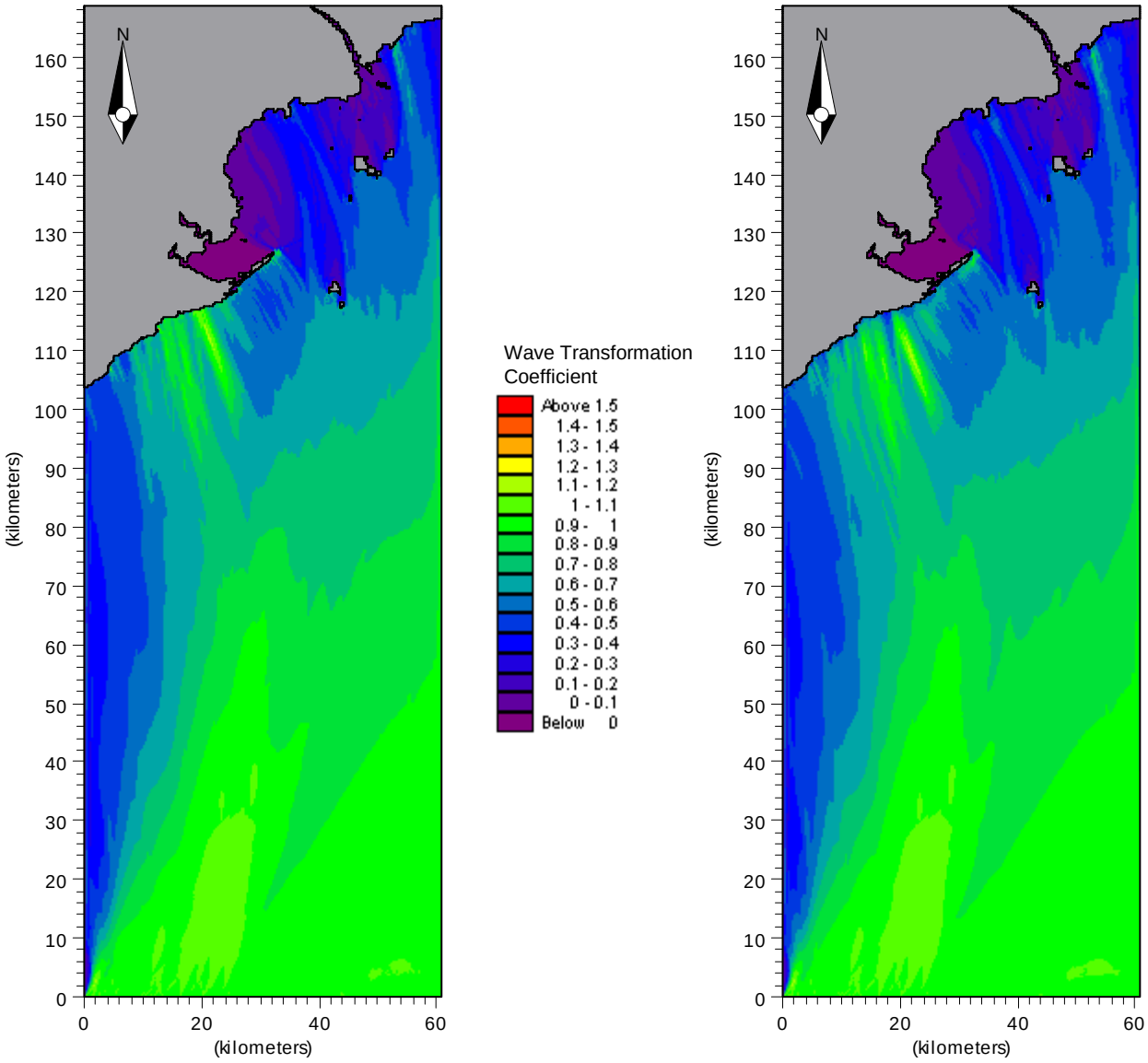
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-5:
Wave Transformation Coefficient
14 second waves from 200 degrees



Water Surface at MHWS

Water Surface at MLWS

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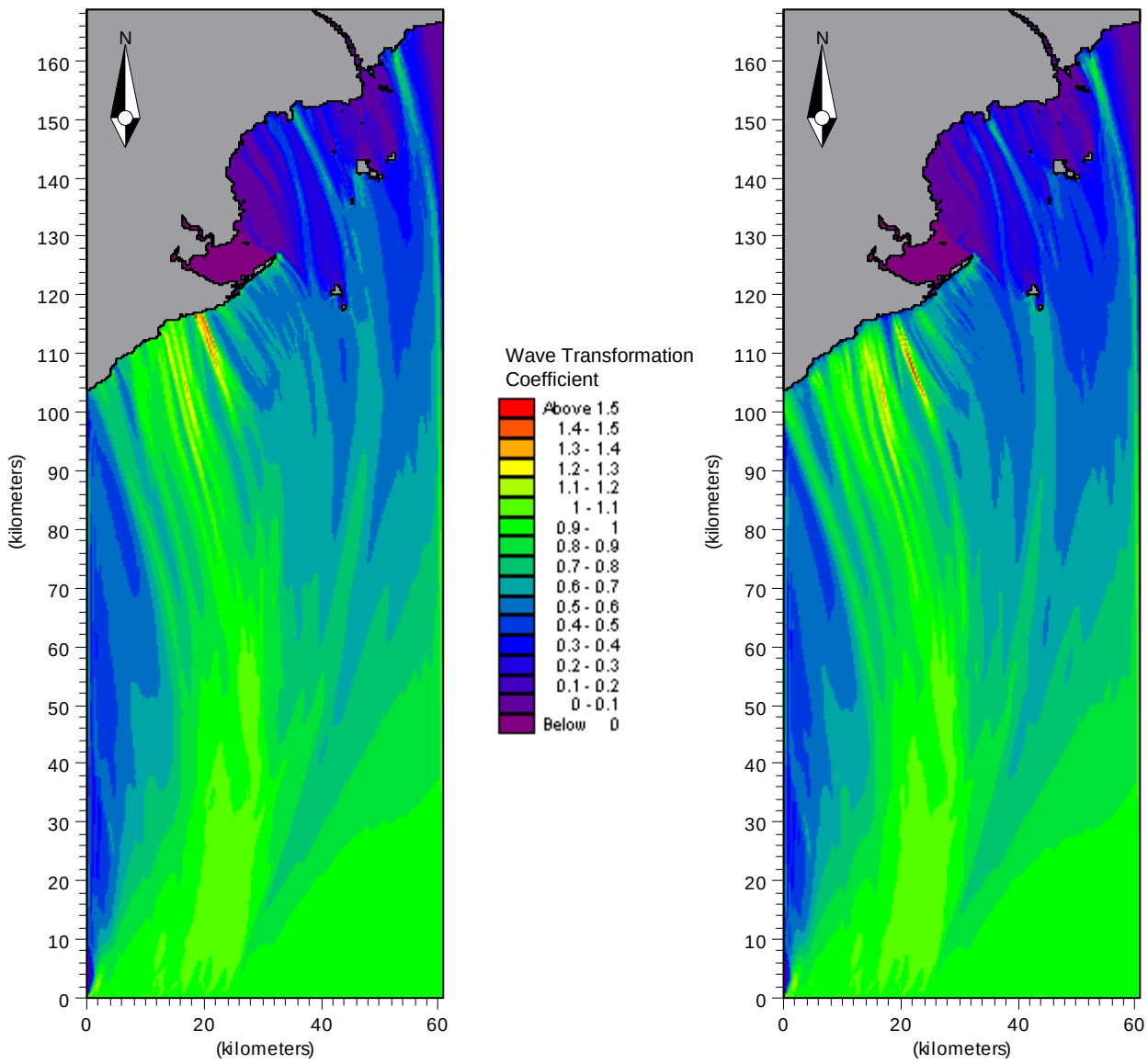
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-6:
Wave Transformation Coefficient
16 second waves from 200 degrees



Water Surface at MHWS **Water Surface at MLWS**

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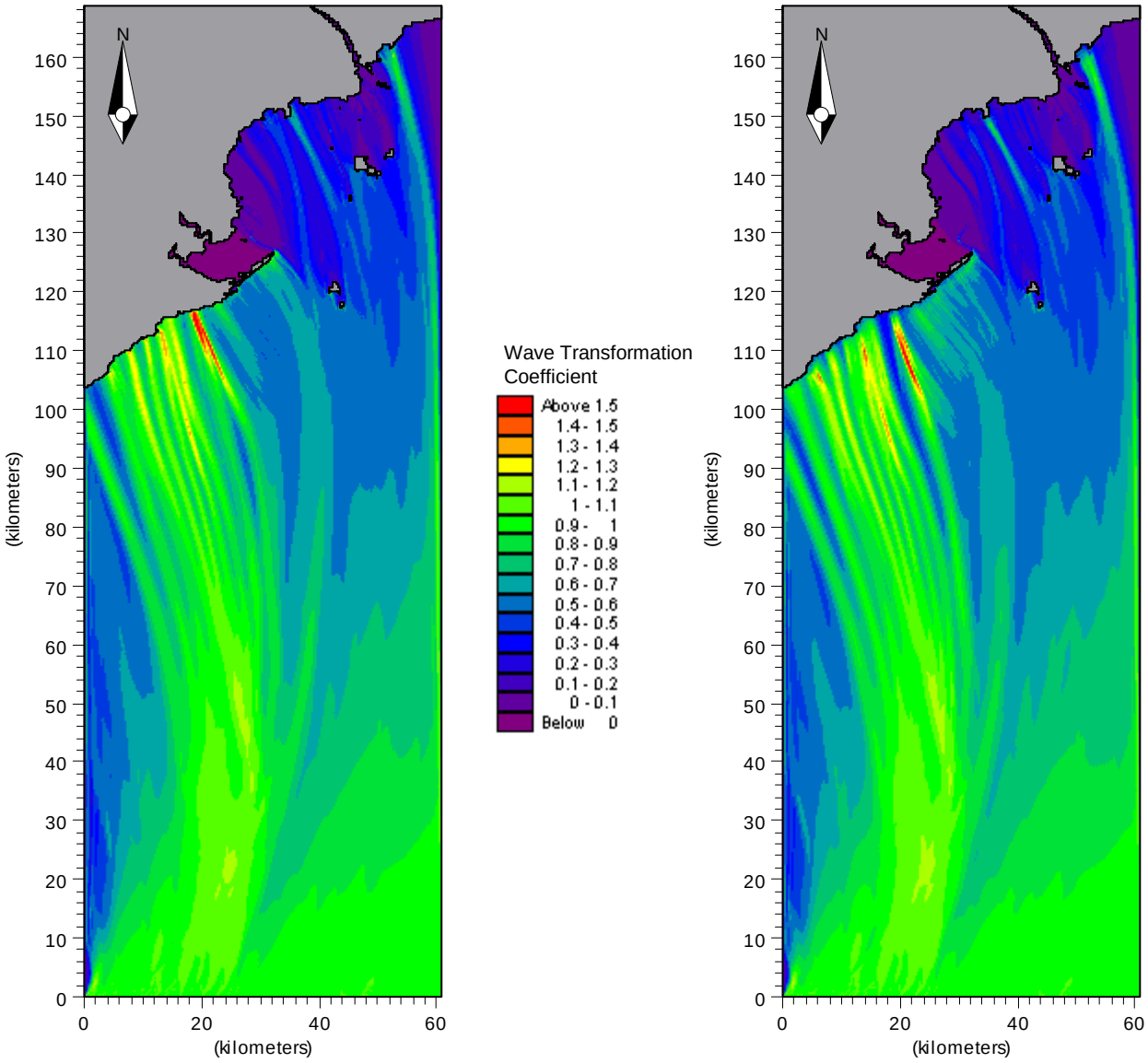
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-7:
Wave Transformation Coefficient
18 second waves from 200 degrees



Water Surface at MHWS **Water Surface at MLWS**

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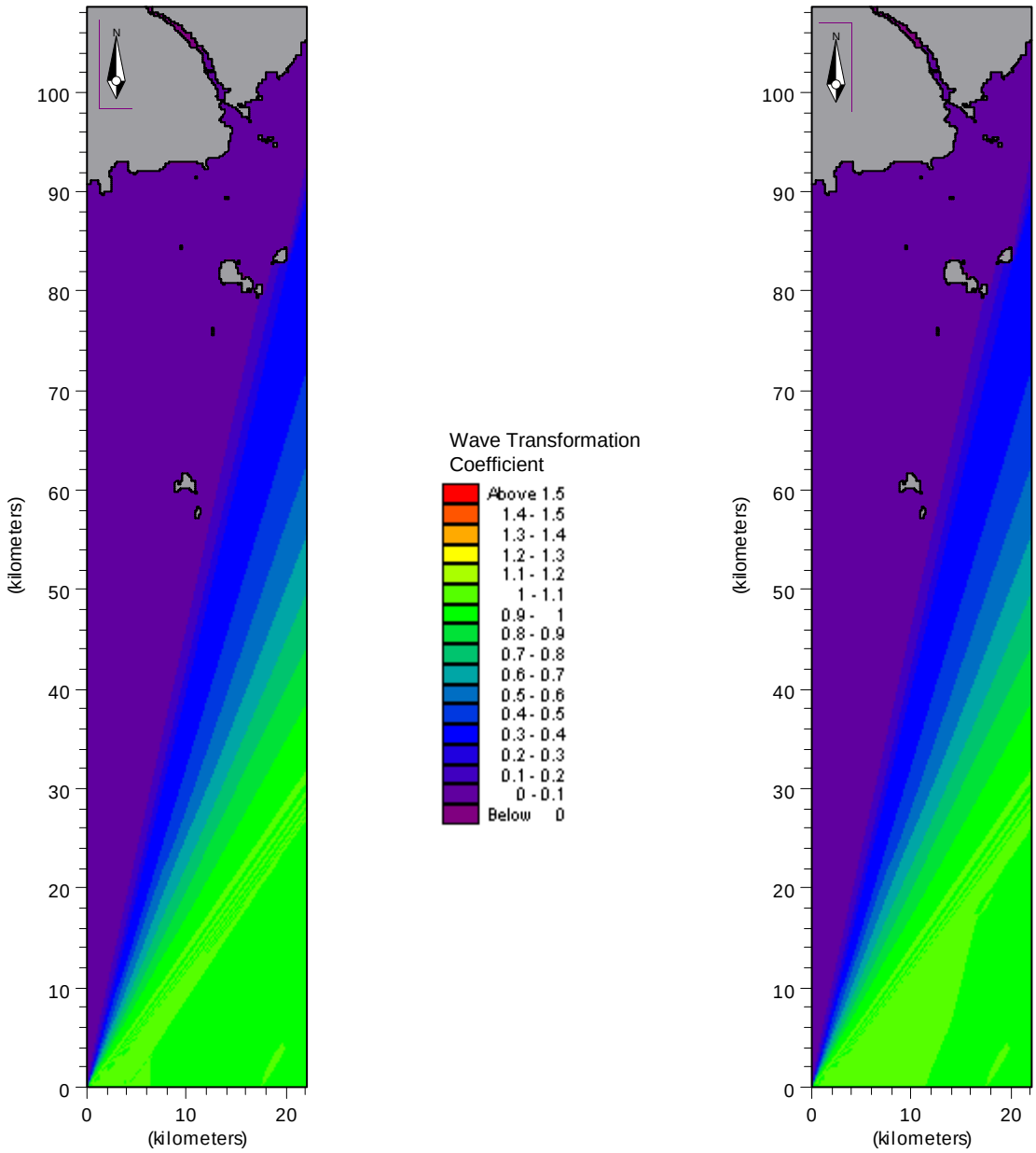
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-8:
Wave Transformation Coefficient
20 second waves from 200 degrees



Water Surface at MHWS

Water Surface at MLWS

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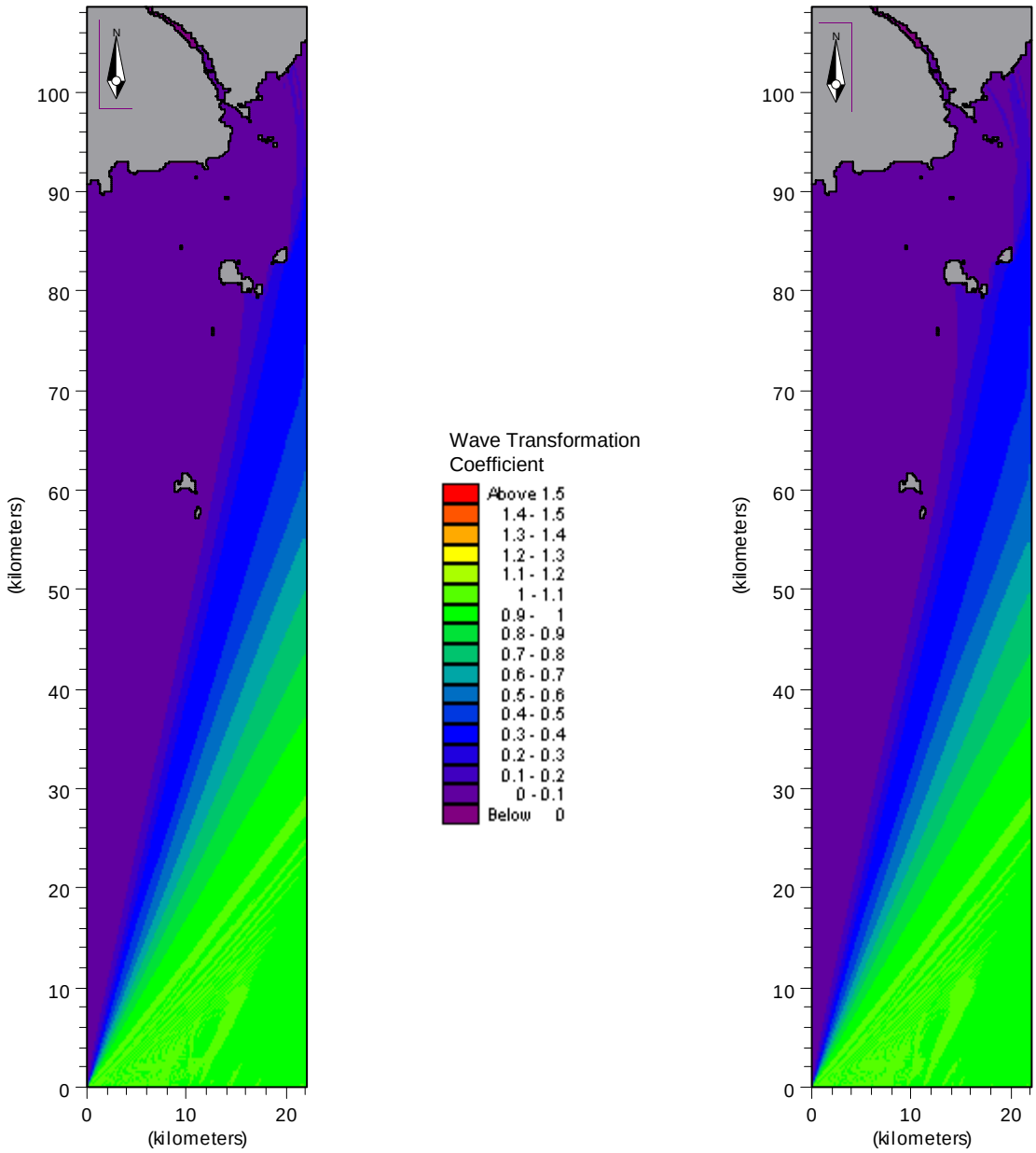
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-9:
Wave Transformation Coefficient
6 second waves from 205 degrees



Water Surface at MHWS

Water Surface at MLWS

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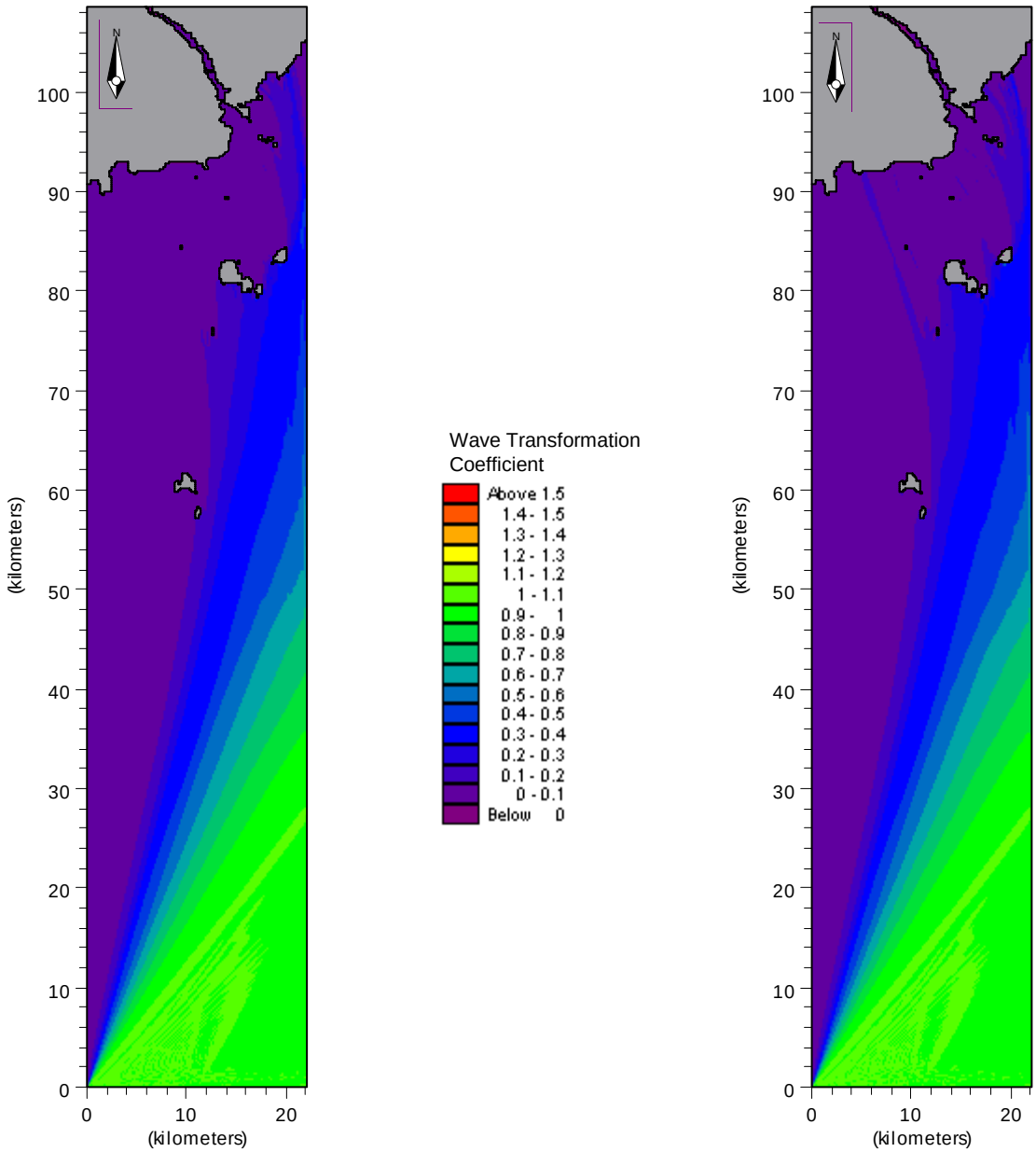
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-10:
Wave Transformation Coefficient
8 second waves from 205 degrees



Water Surface at MHWS

Water Surface at MLWS

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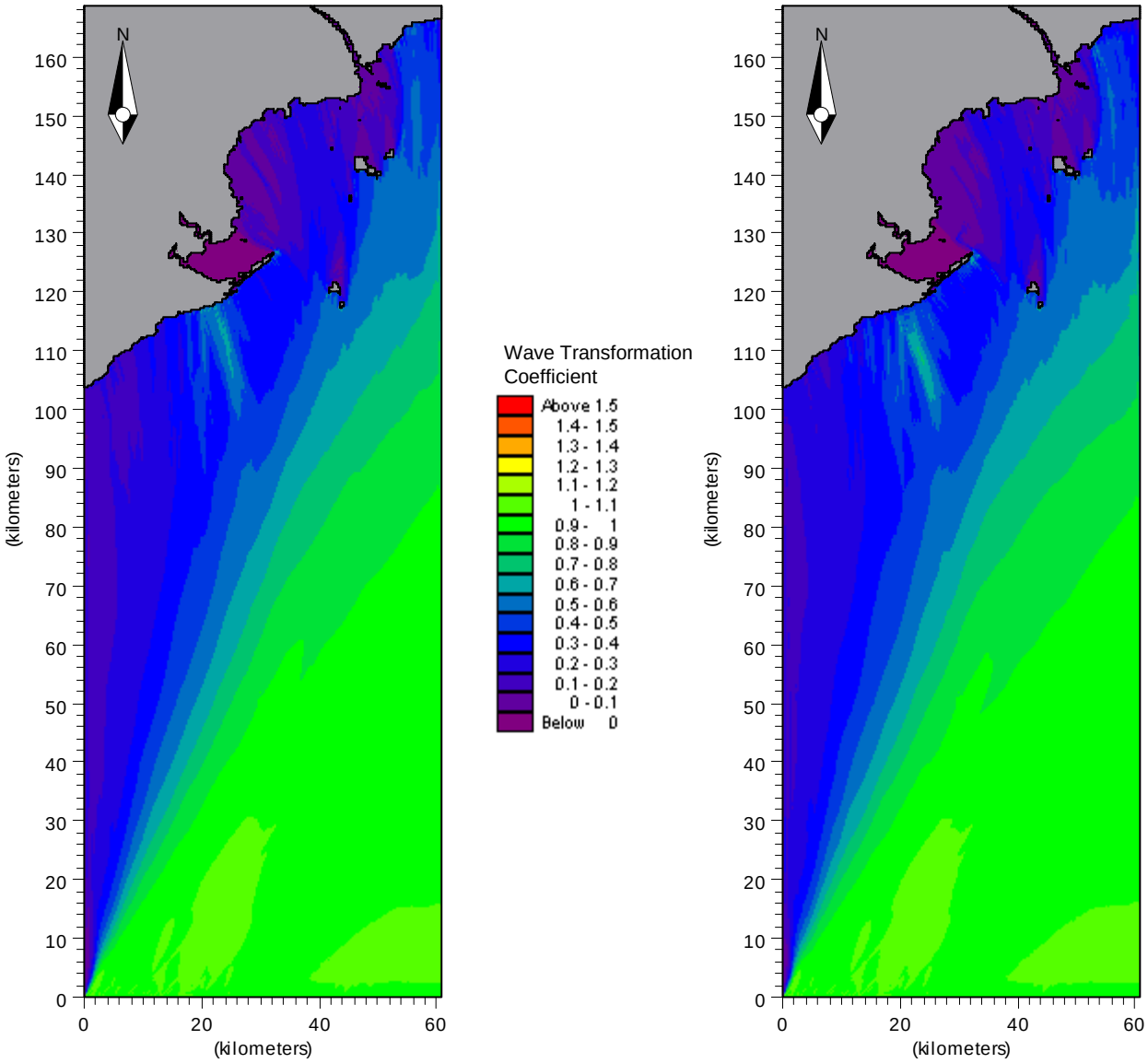
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-11:
Wave Transformation Coefficient
10 second waves from 205 degrees



Water Surface at MHWS

Water Surface at MLWS

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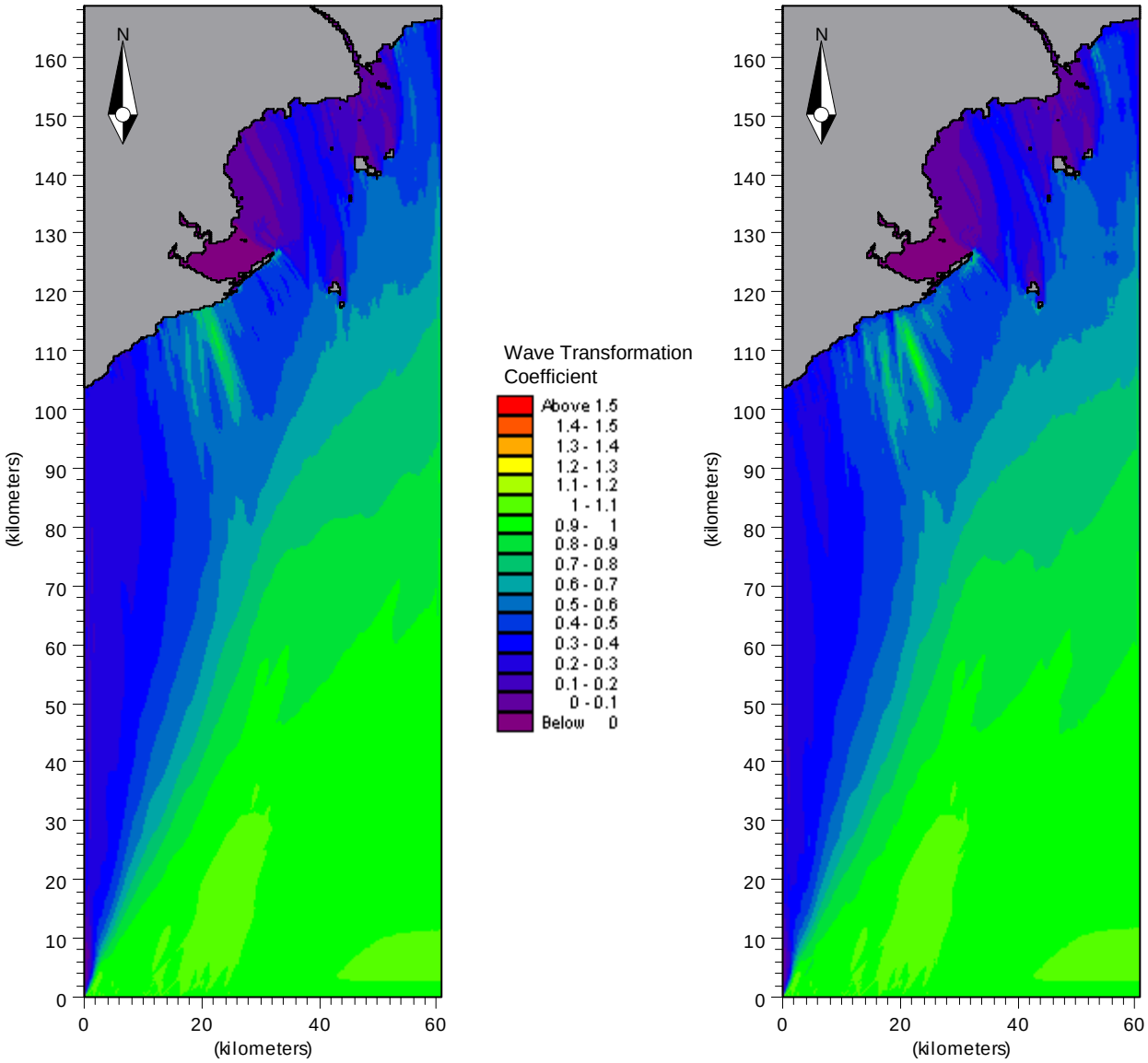
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-12:
Wave Transformation Coefficient
12 second waves from 205 degrees



Water Surface at MHWS

Water Surface at MLWS

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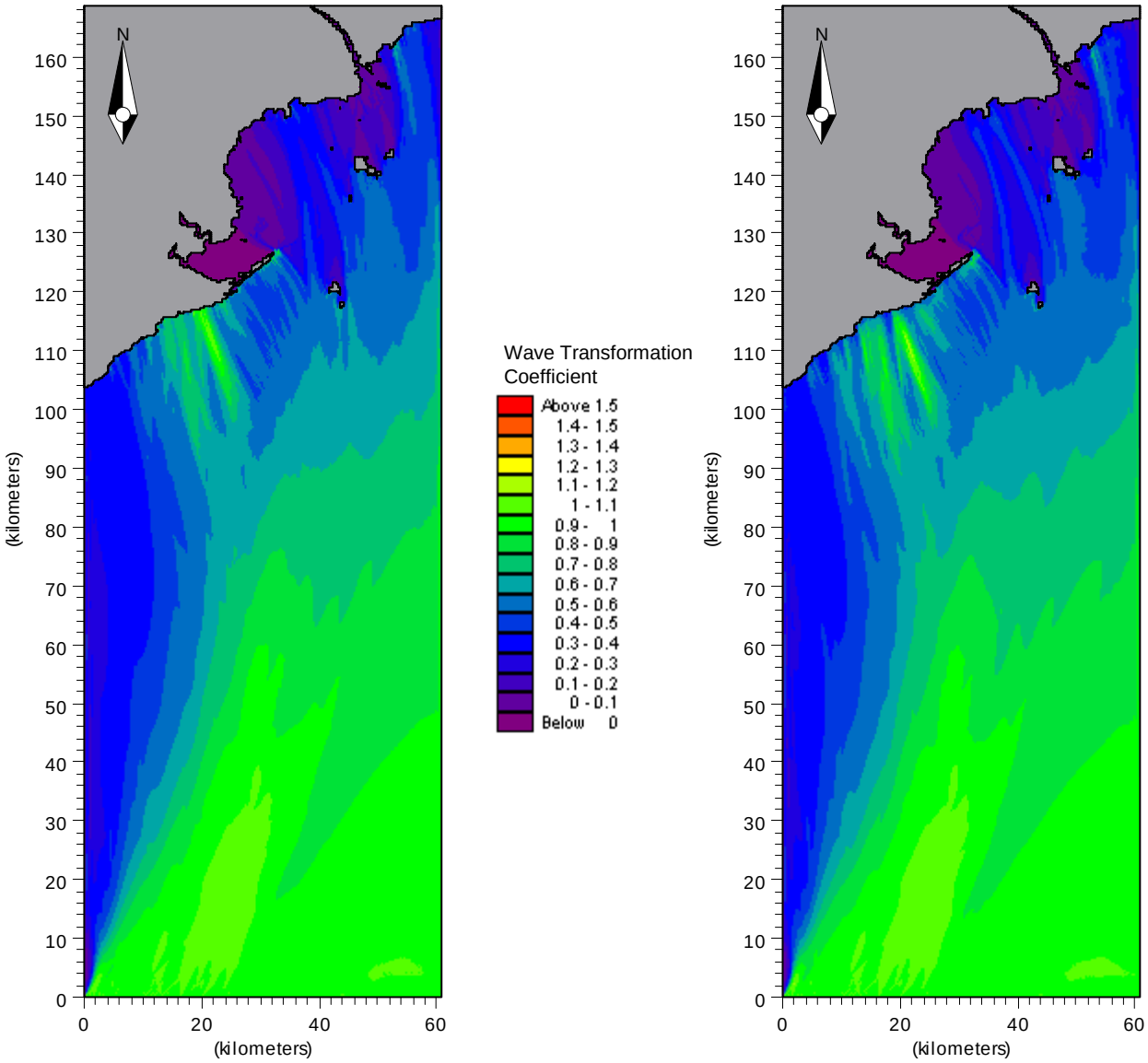
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-13:
Wave Transformation Coefficient
14 second waves from 205 degrees



Water Surface at MHWS **Water Surface at MLWS**

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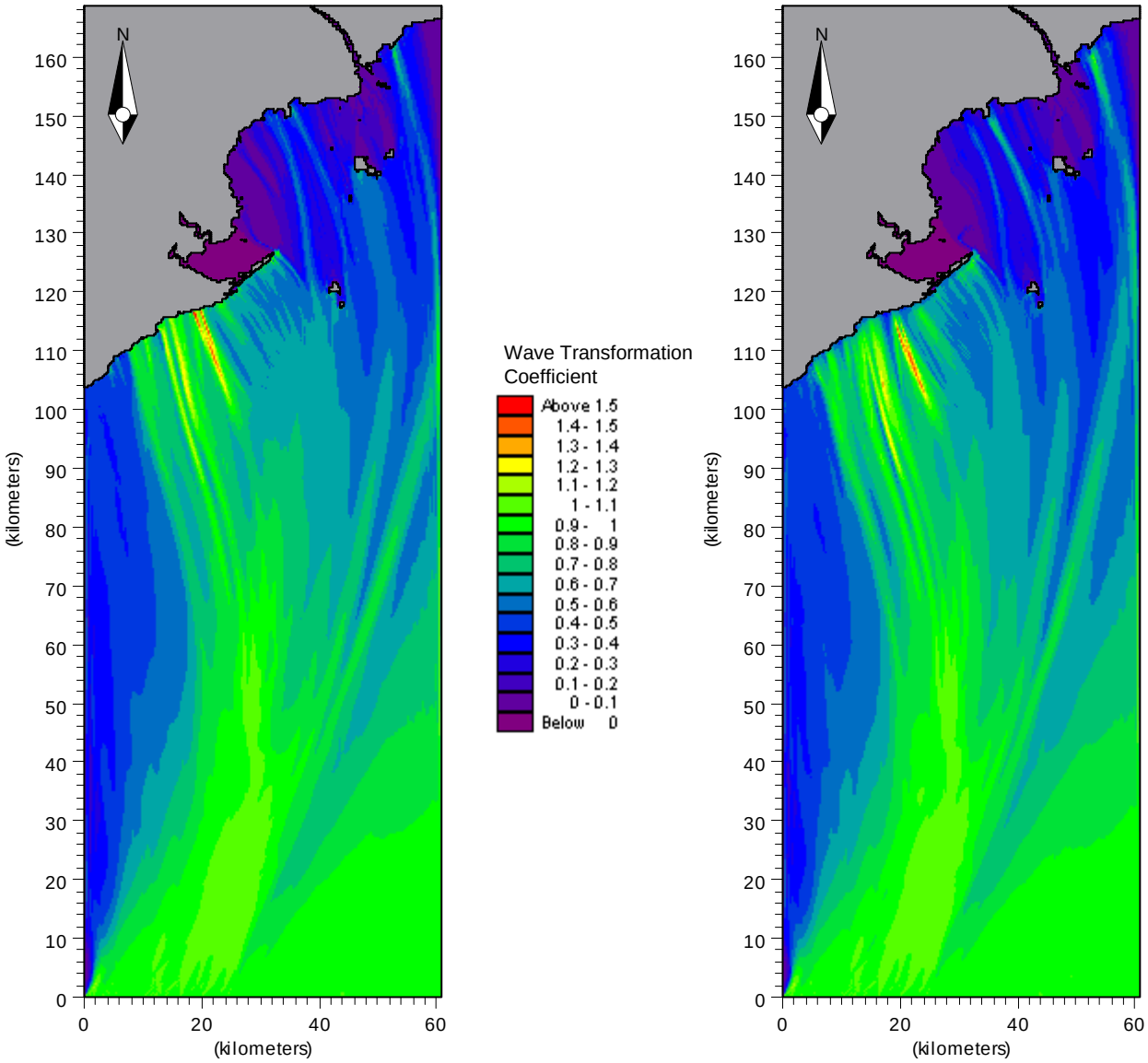
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-14:
Wave Transformation Coefficient
16 second waves from 205 degrees



Water Surface at MHWS **Water Surface at MLWS**

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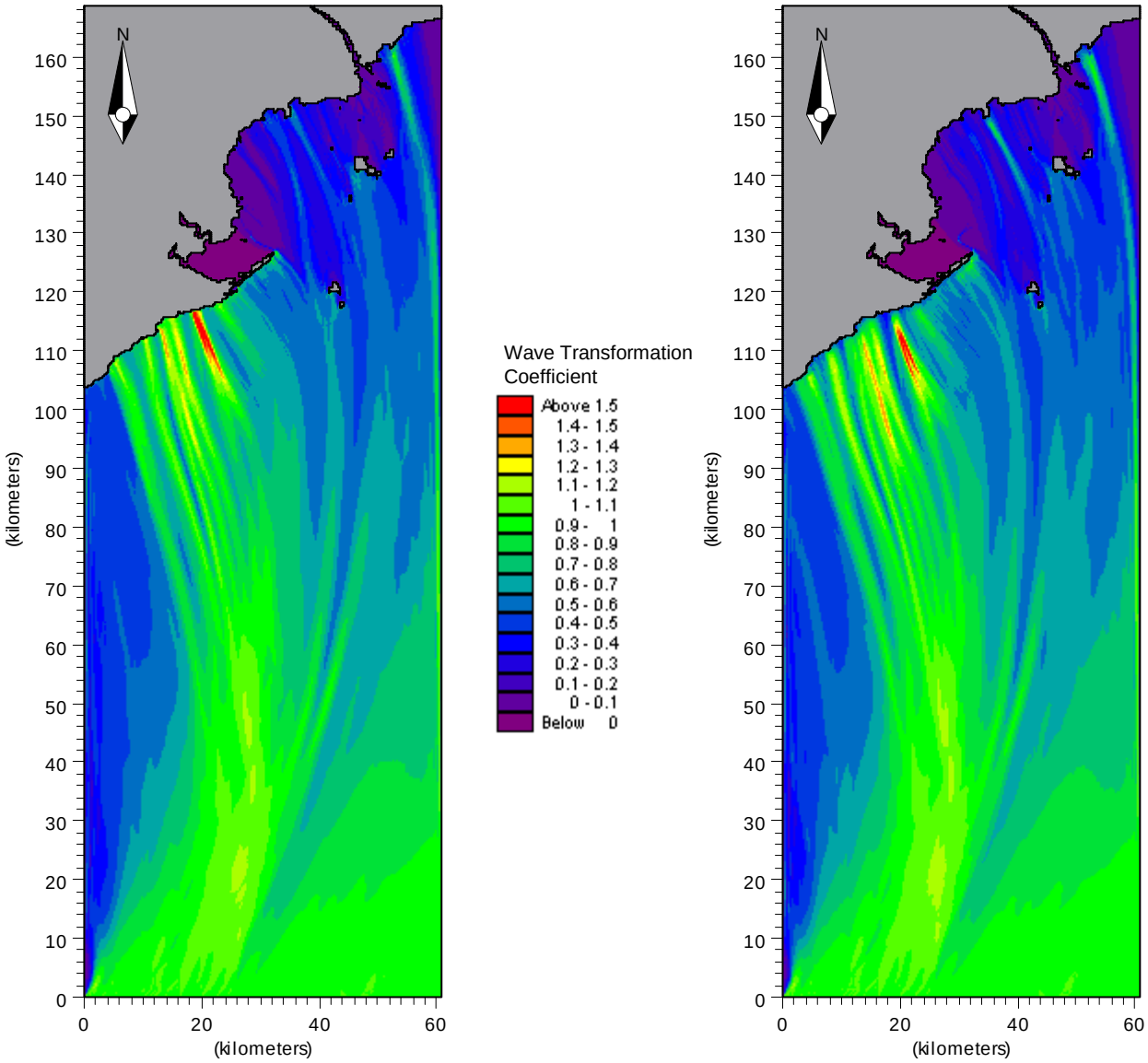
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-15:
Wave Transformation Coefficient
18 second waves from 205 degrees



Water Surface at MHWS **Water Surface at MLWS**

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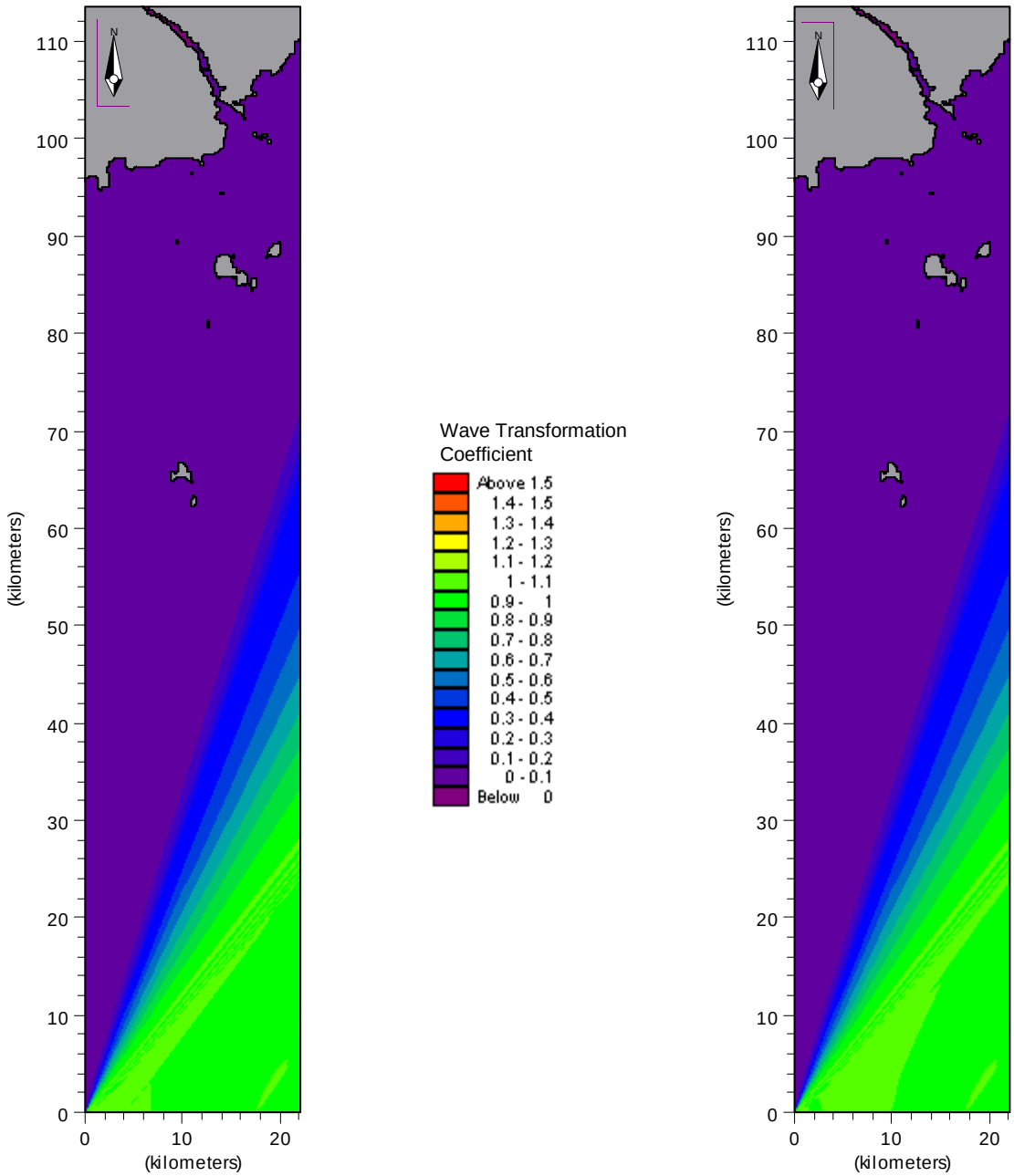
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-16:
Wave Transformation Coefficient
20 second waves from 205 degrees



Water Surface at MHWS

Water Surface at MLWS

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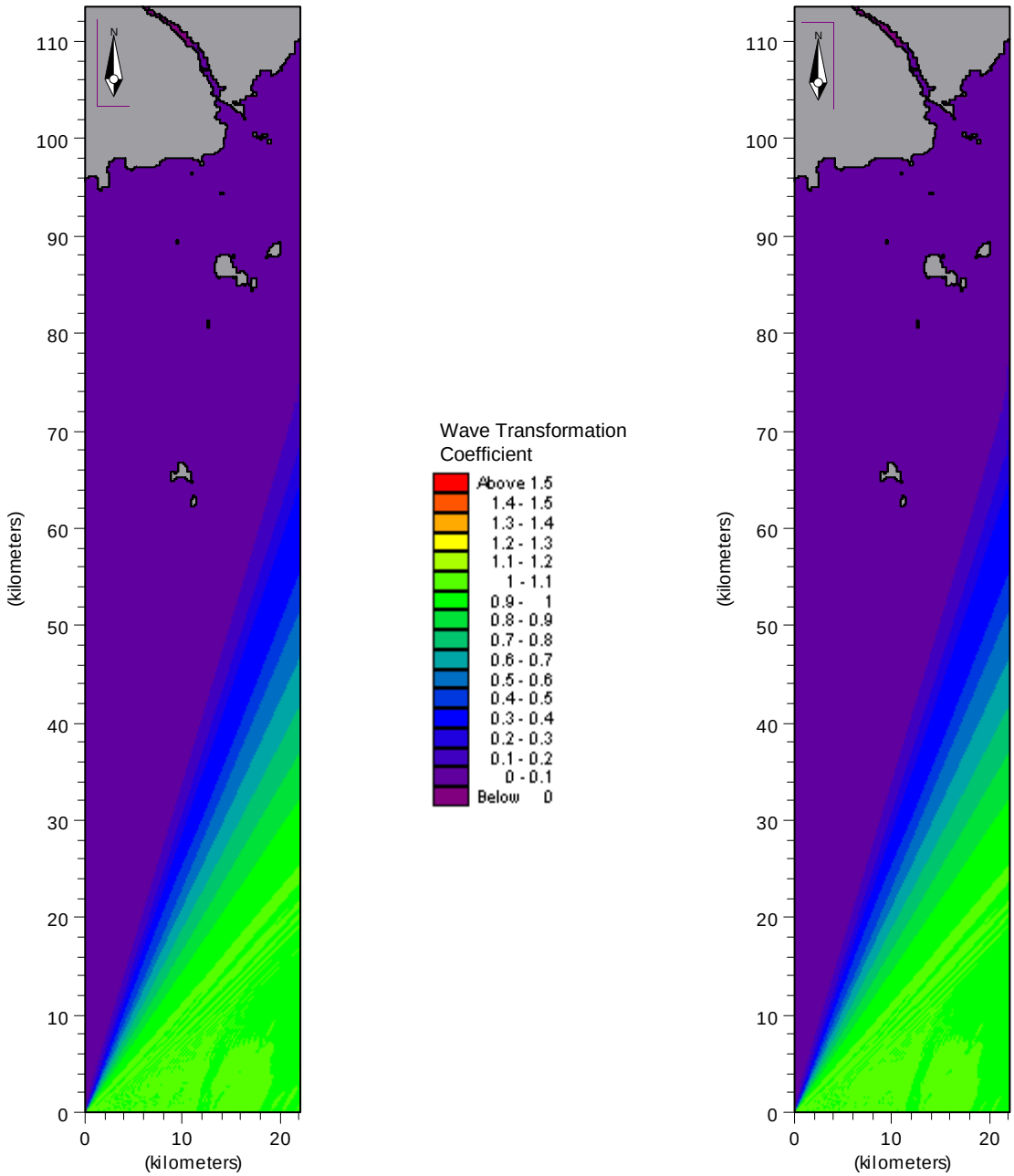
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-17:
Wave Transformation Coefficient
6 second waves from 210 degrees



Water Surface at MHWS

Water Surface at MLWS

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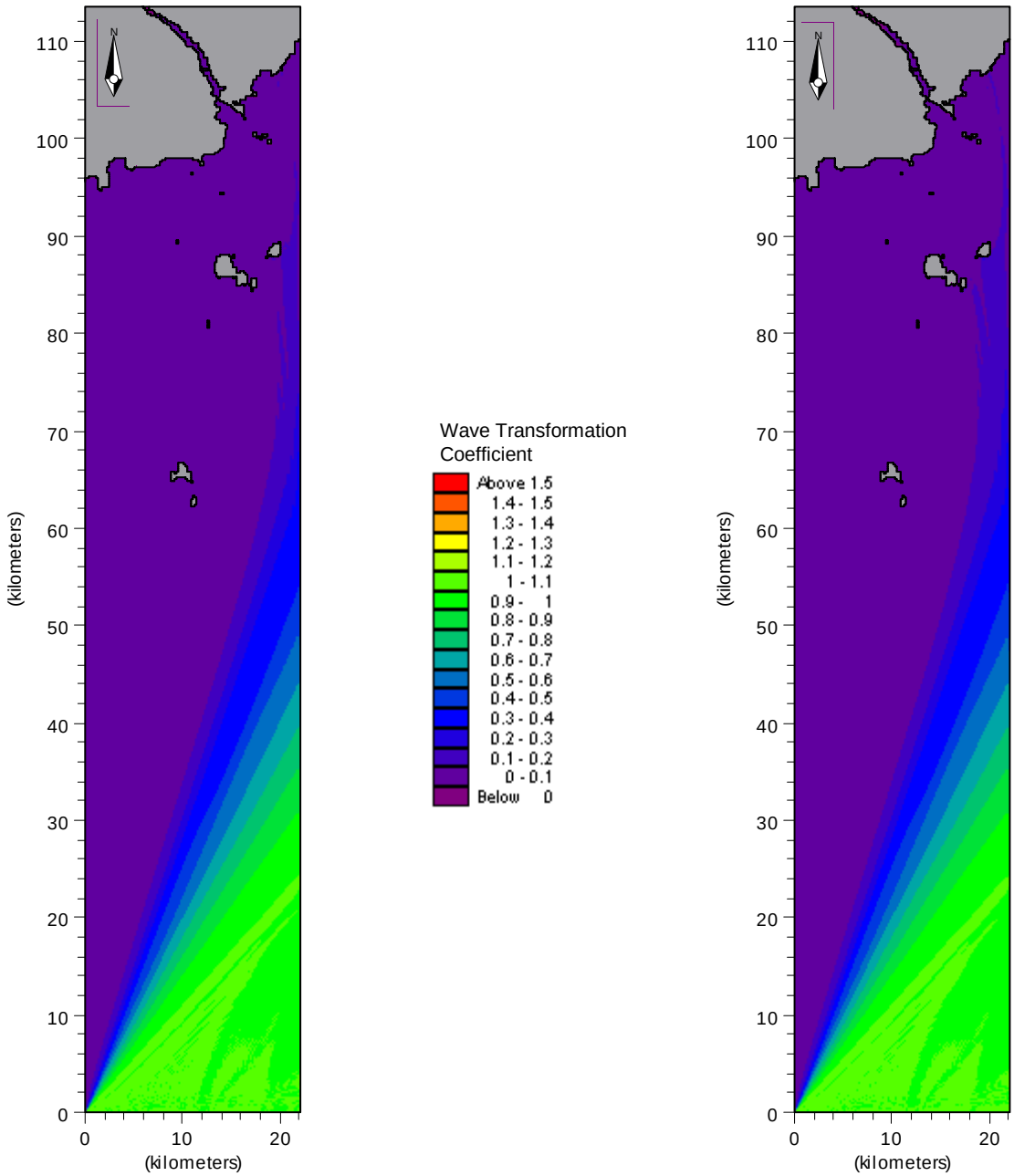
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-18:
Wave Transformation Coefficient
8 second waves from 210 degrees



Water Surface at MHWS

Water Surface at MLWS

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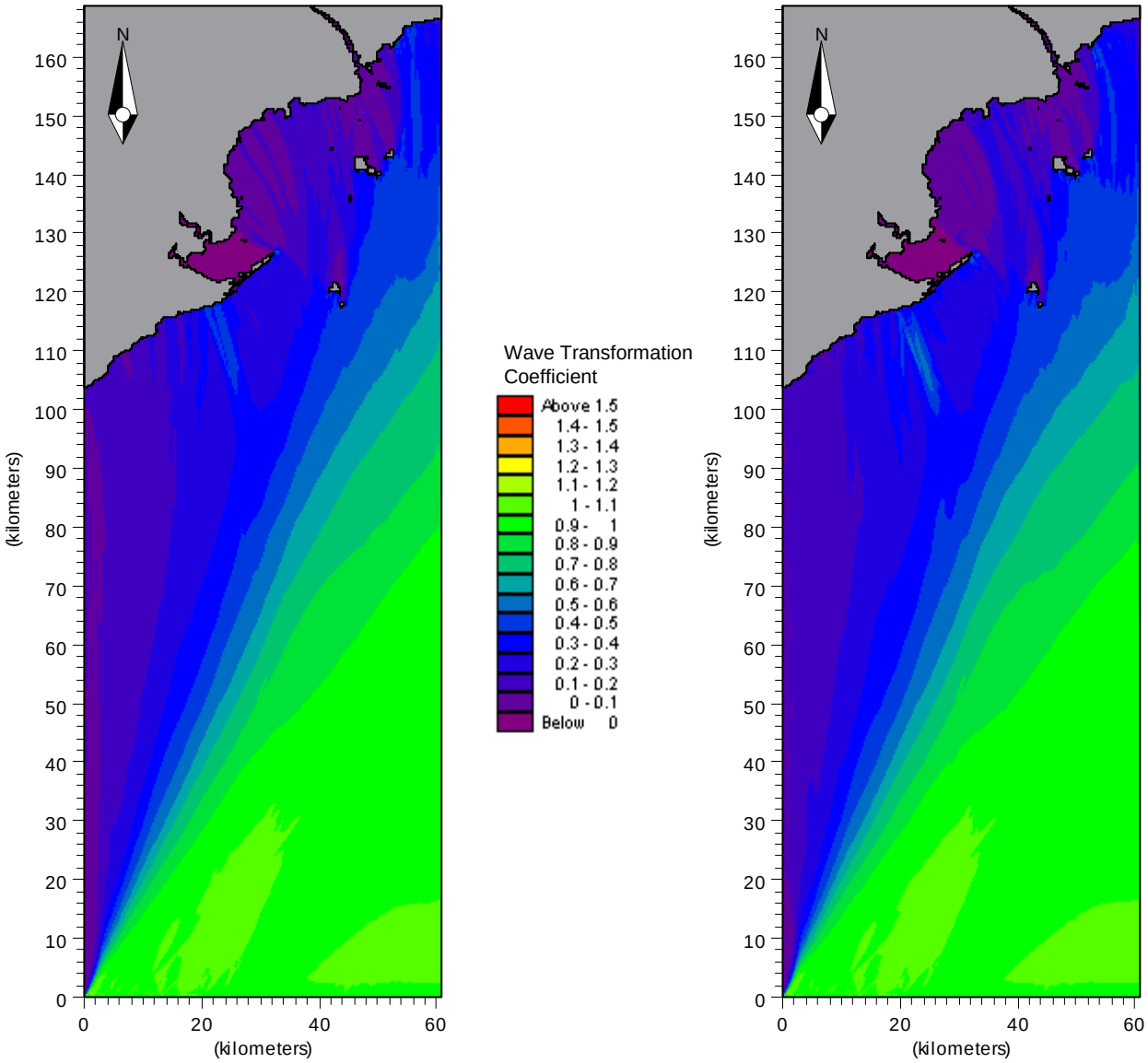
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-19:
Wave Transformation Coefficient
10 second waves from 210 degrees



Water Surface at MHWS

Water Surface at MLWS

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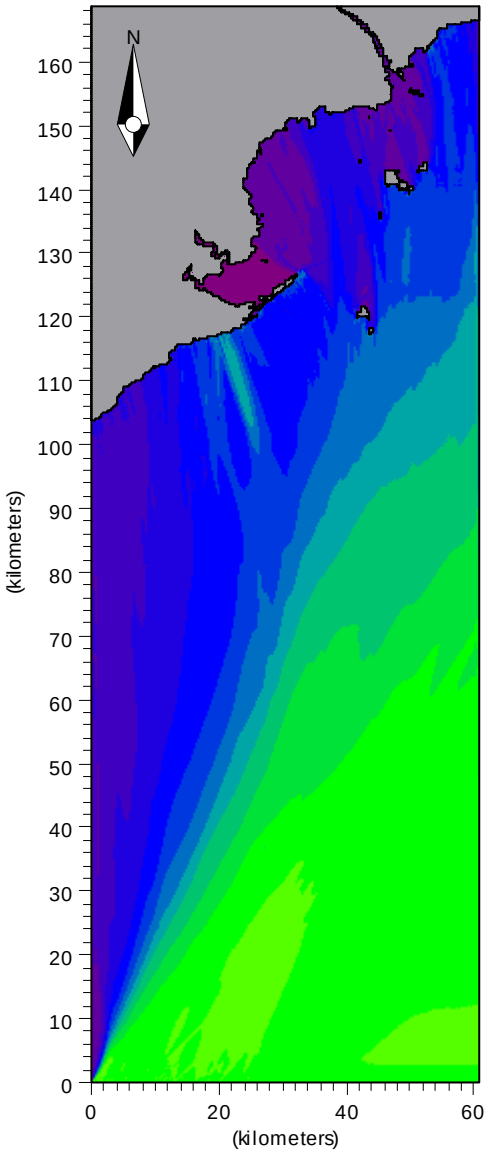
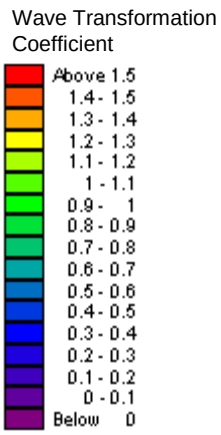
AUTORIDAD DEL CANAL DE PANAMA

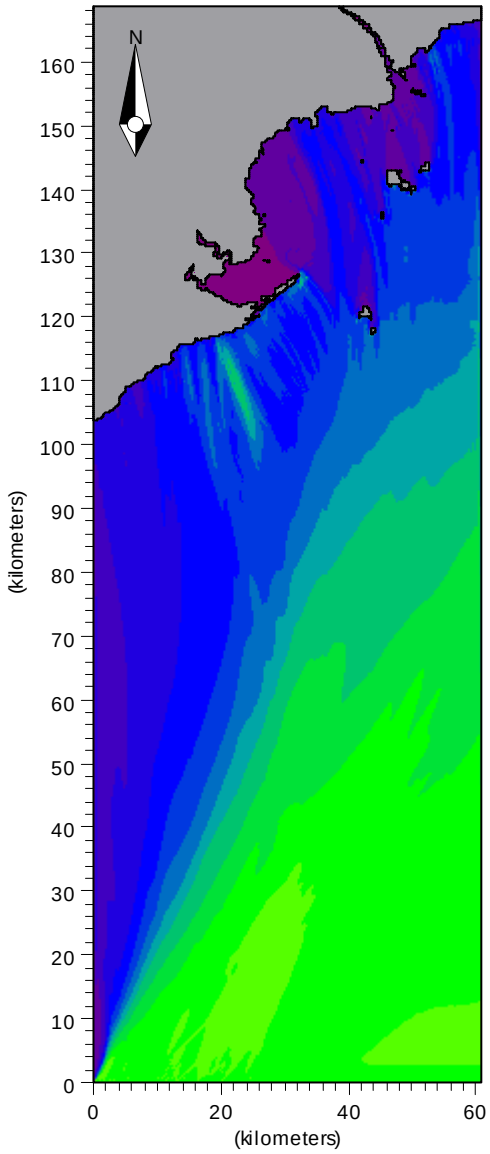
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-20:
Wave Transformation Coefficient
12 second waves from 210 degrees



Water Surface at MHWS





Water Surface at MLWS

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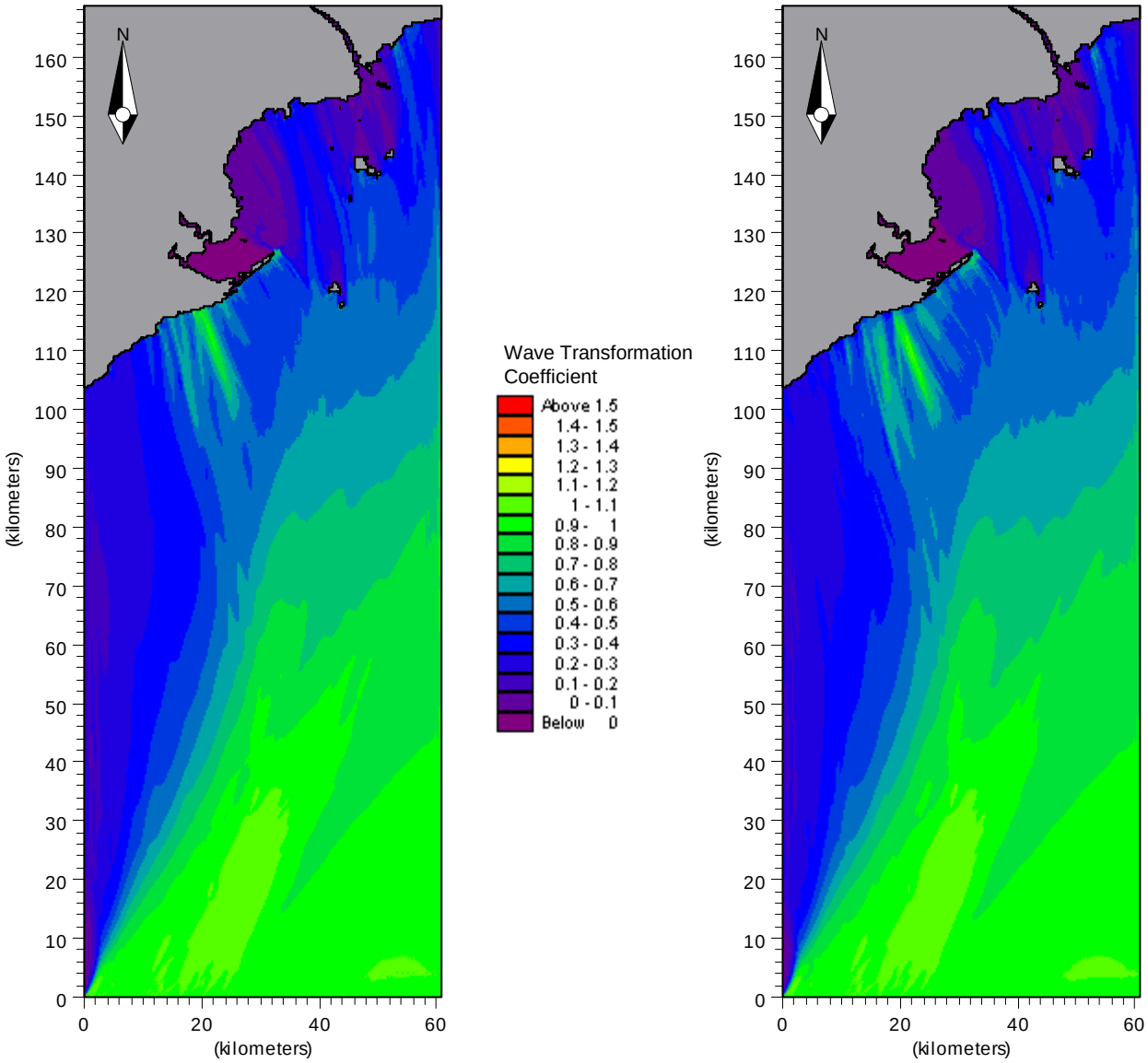
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-21:
Wave Transformation Coefficient
14 second waves from 210 degrees



Water Surface at MHWS

Water Surface at MLWS

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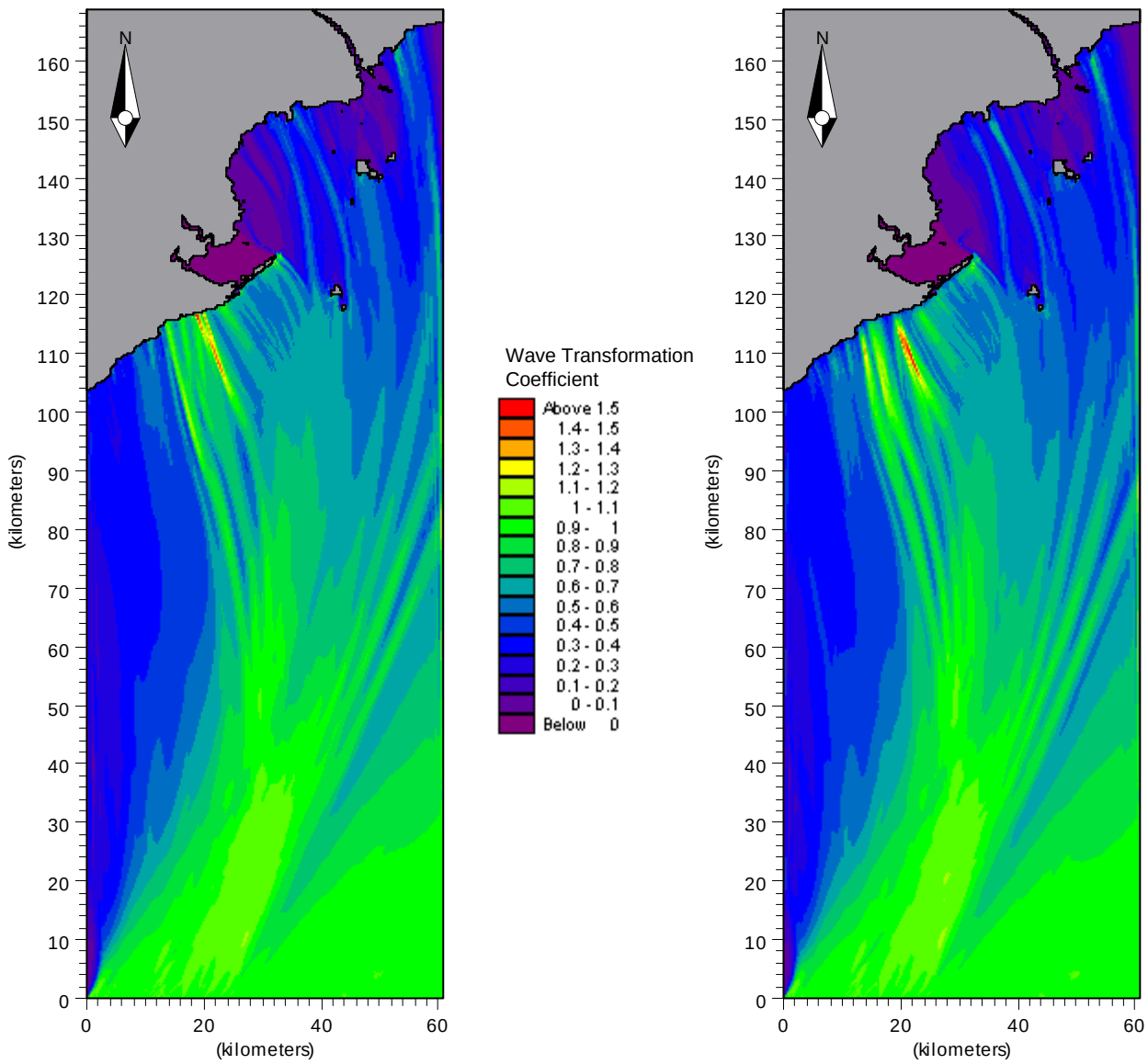
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-22:
Wave Transformation Coefficient
16 second waves from 210 degrees



Water Surface at MHWS **Water Surface at MLWS**

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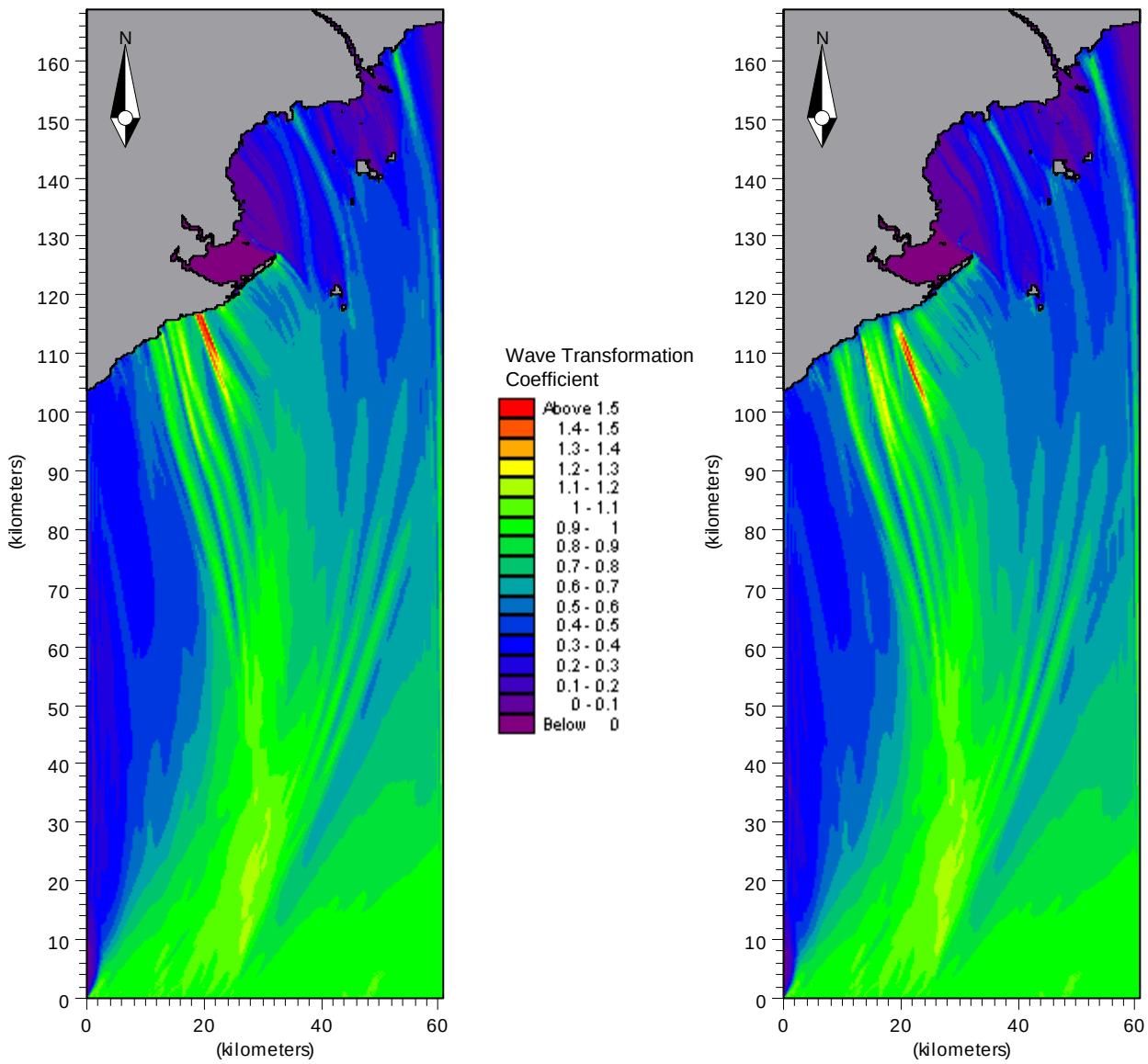
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-23:
Wave Transformation Coefficient
18 second waves from 210 degrees



Water Surface at MHWS **Water Surface at MLWS**

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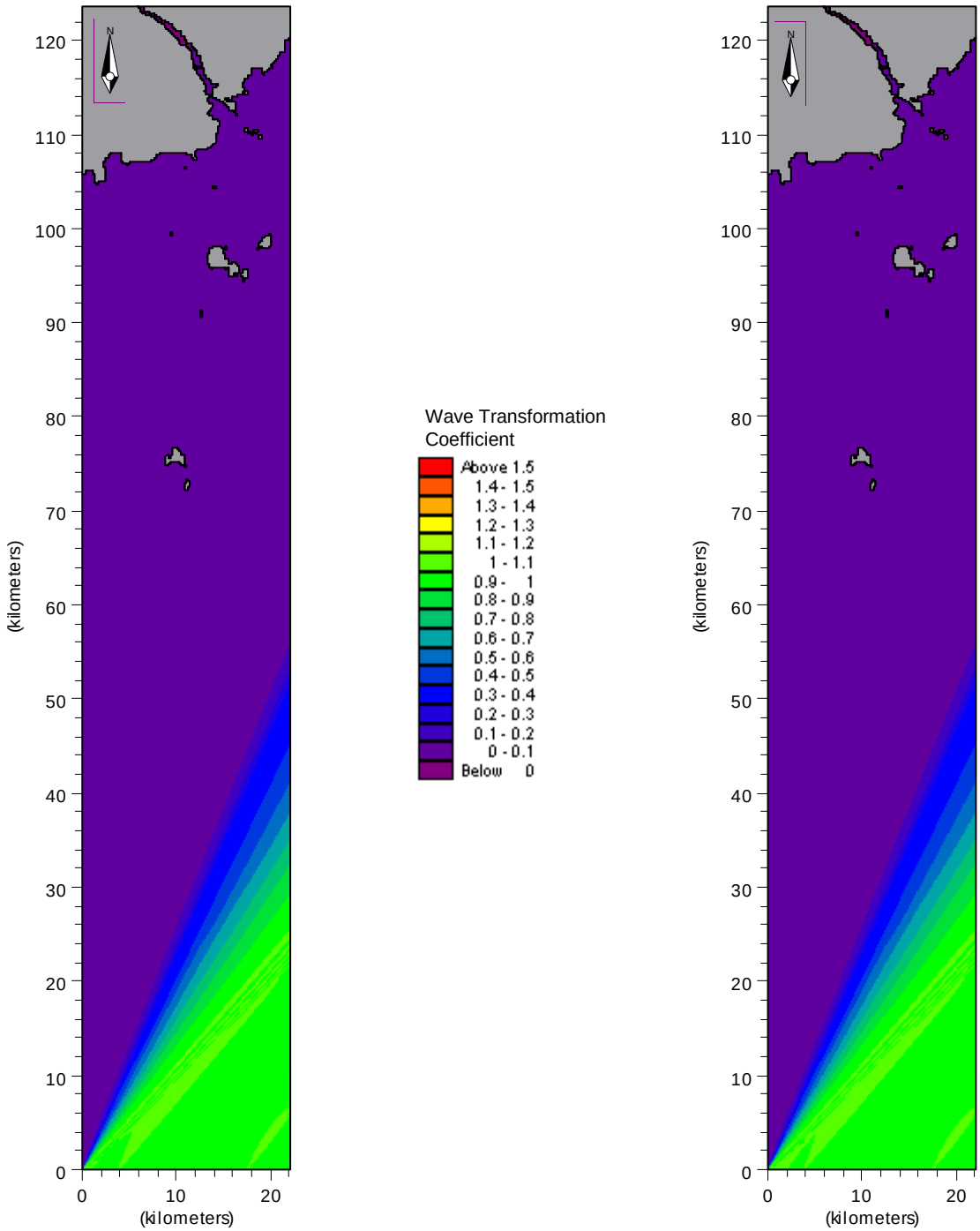
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-24:
Wave Transformation Coefficient
20 second waves from 210 degrees



Water Surface at MHWS

Water Surface at MLWS

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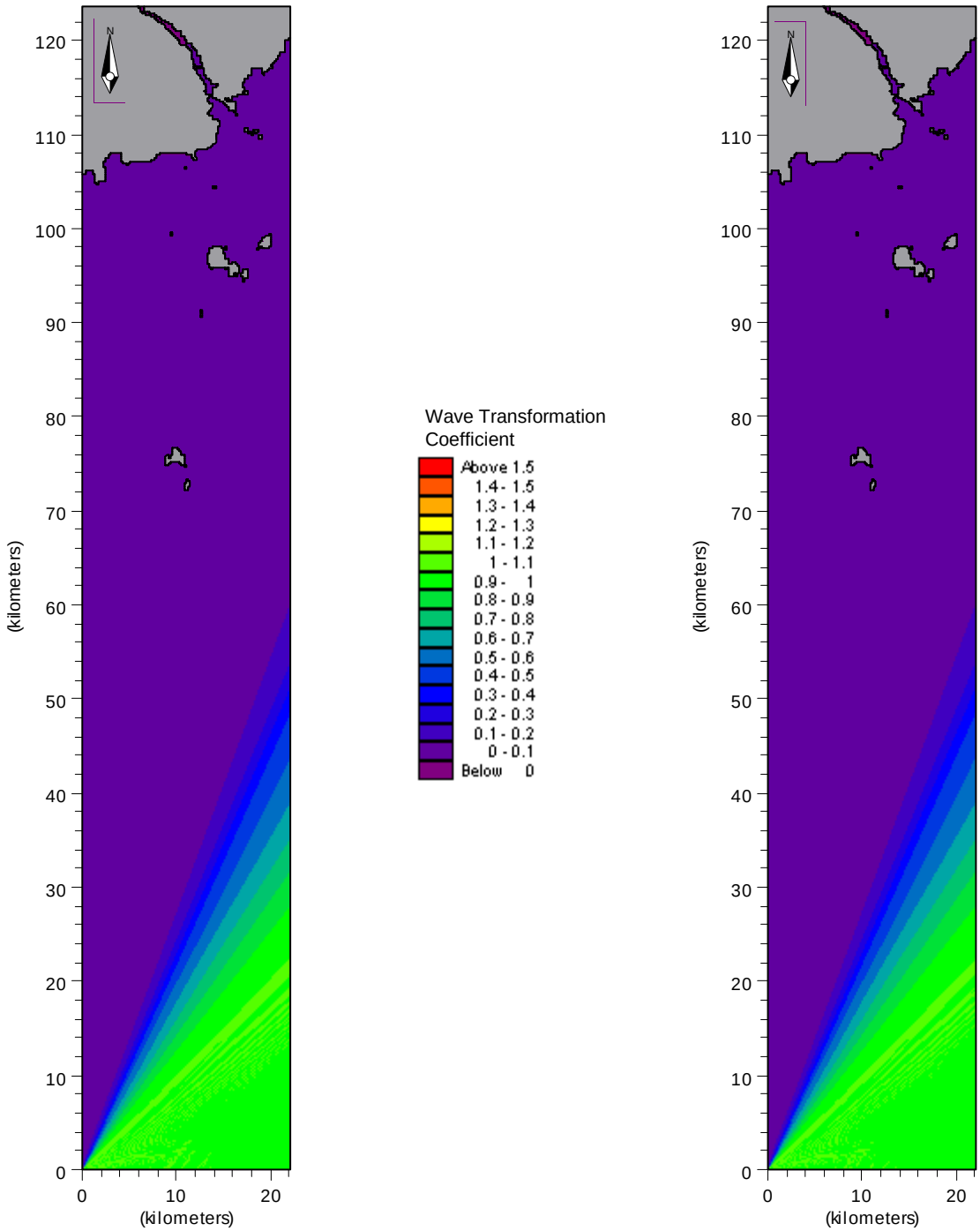
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-25:
Wave Transformation Coefficient
6 second waves from 215 degrees



Water Surface at MHWS **Water Surface at MLWS**

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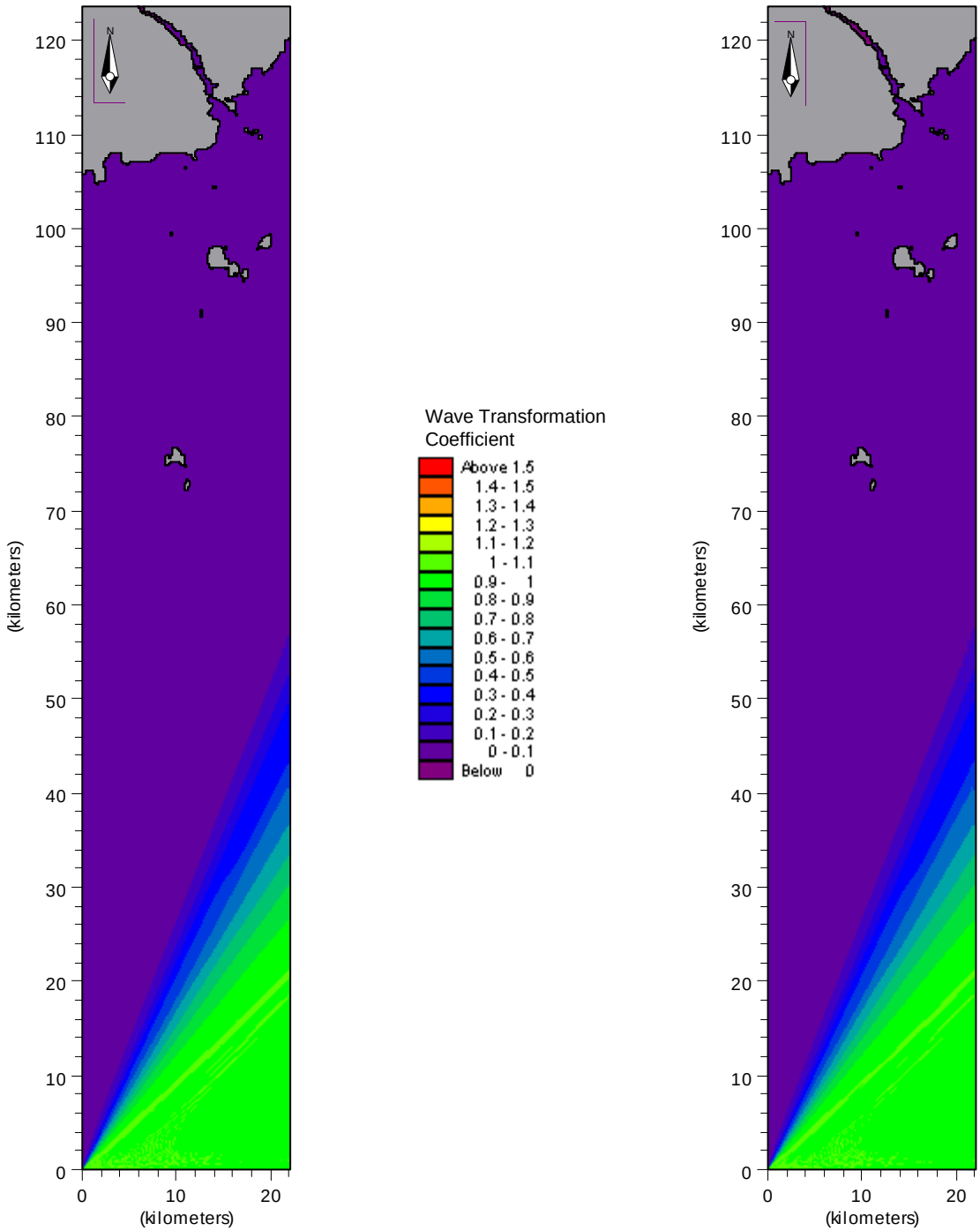
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-26:
Wave Transformation Coefficient
8 second waves from 215 degrees



Water Surface at MHWS

Water Surface at MLWS

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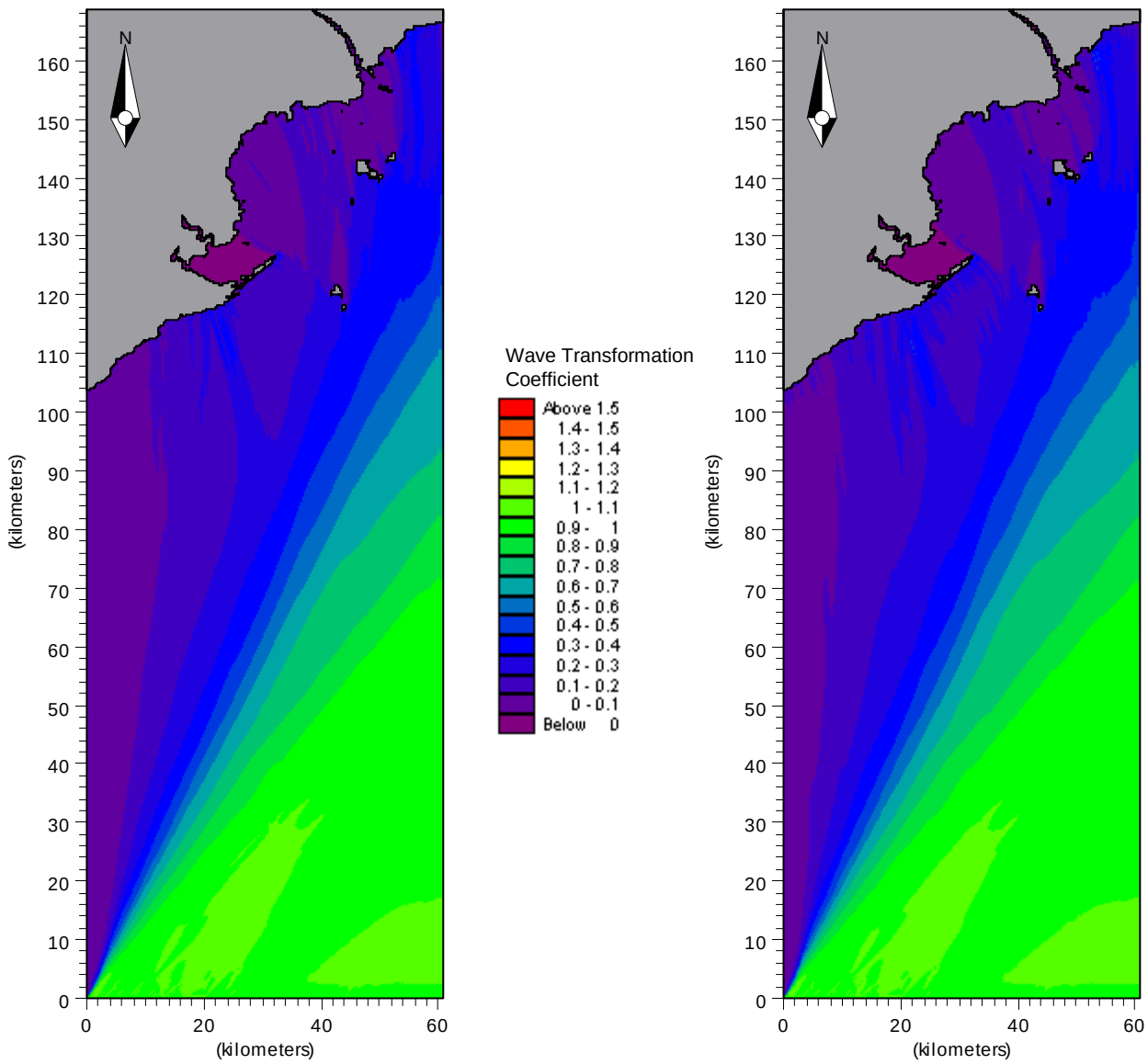
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-27:
Wave Transformation Coefficient
10 second waves from 215 degrees



Water Surface at MHWS

Water Surface at MLWS

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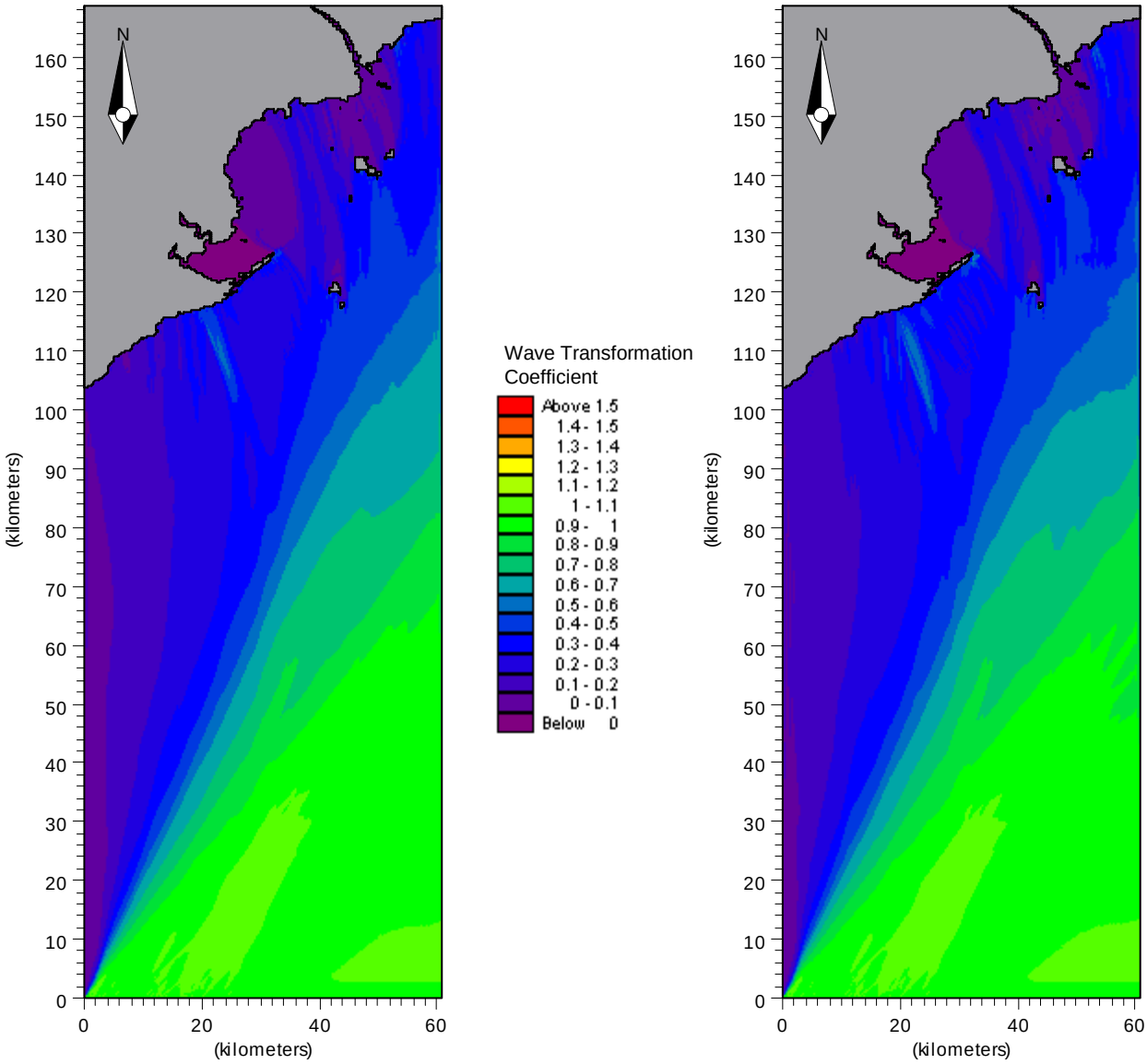
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-28:
Wave Transformation Coefficient
12 second waves from 215 degrees



Water Surface at MHWS

Water Surface at MLWS

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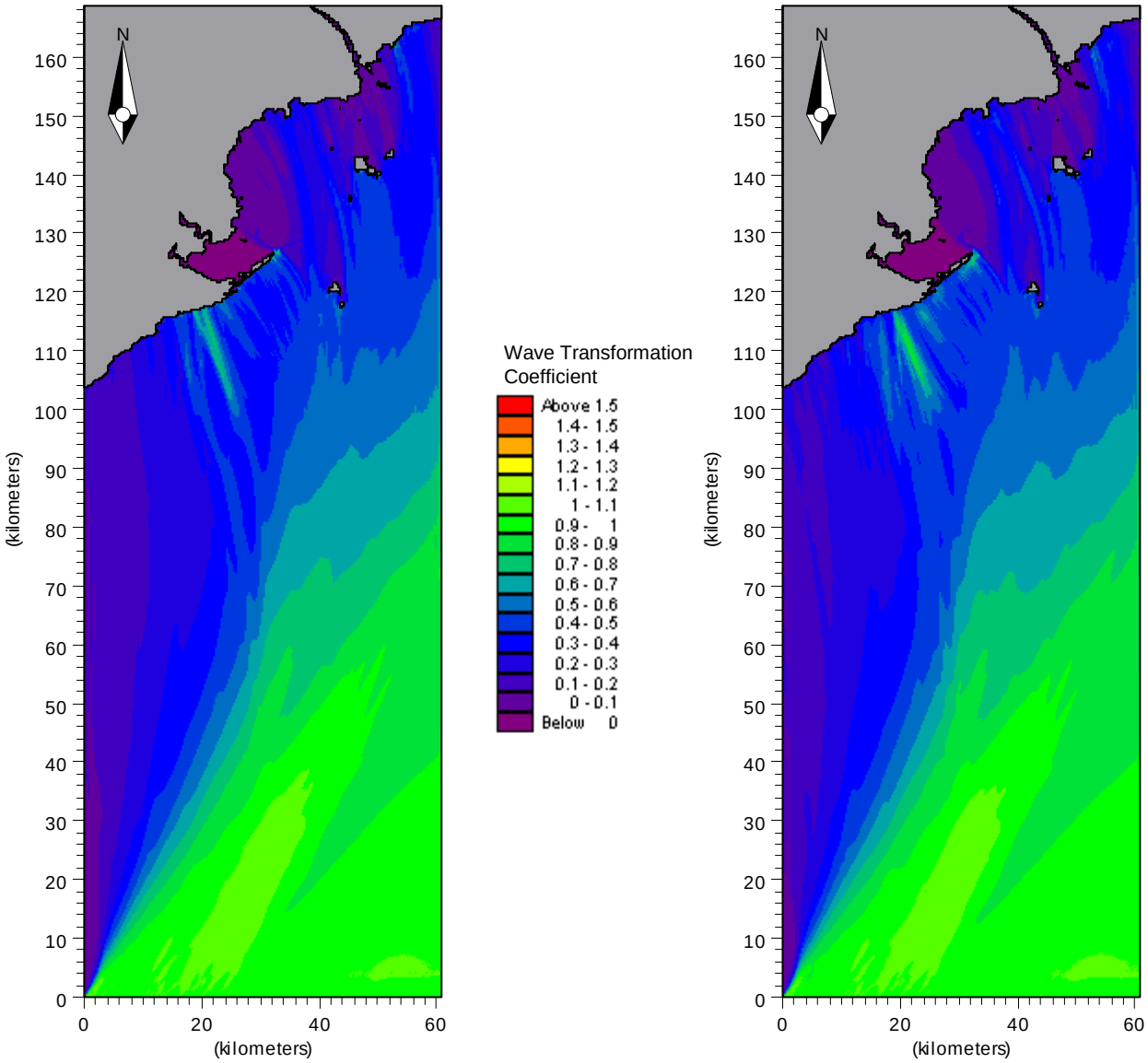
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-29:
Wave Transformation Coefficient
14 second waves from 215 degrees



Water Surface at MHWS

Water Surface at MLWS

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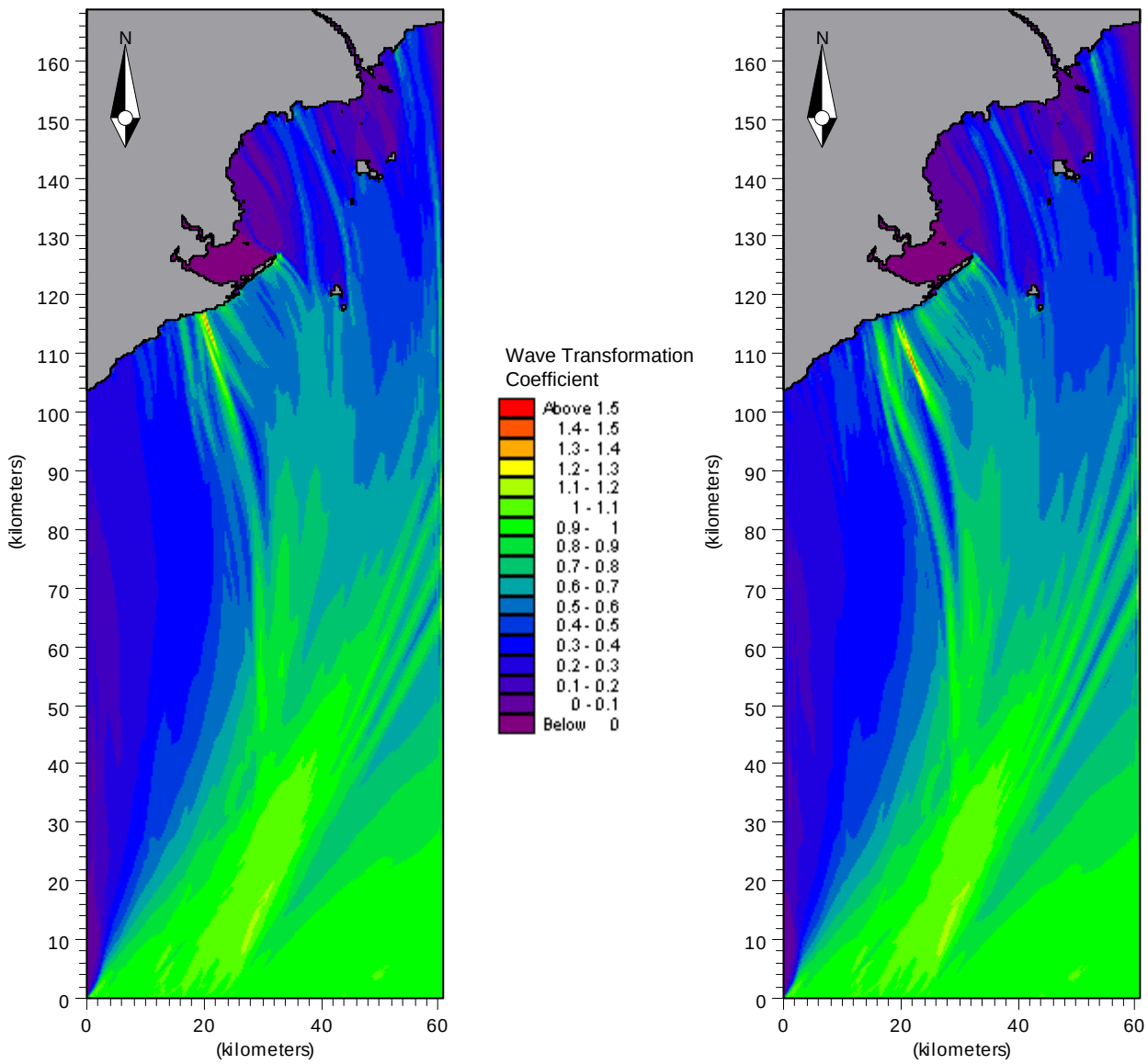
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-30:
Wave Transformation Coefficient
16 second waves from 215 degrees



Water Surface at MHWS **Water Surface at MLWS**

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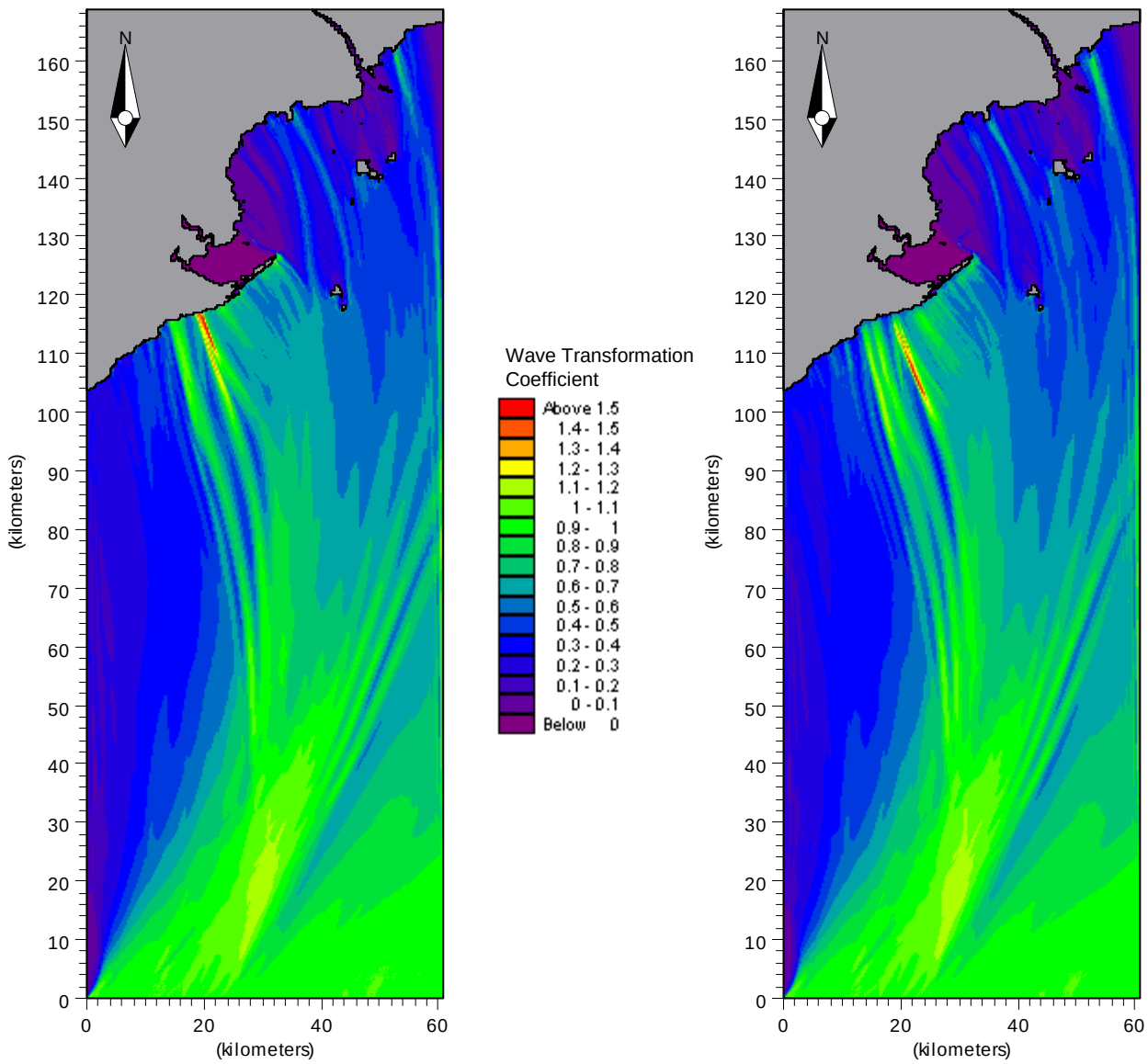
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-31:
Wave Transformation Coefficient
18 second waves from 215 degrees



Water Surface at MHWS

Water Surface at MLWS

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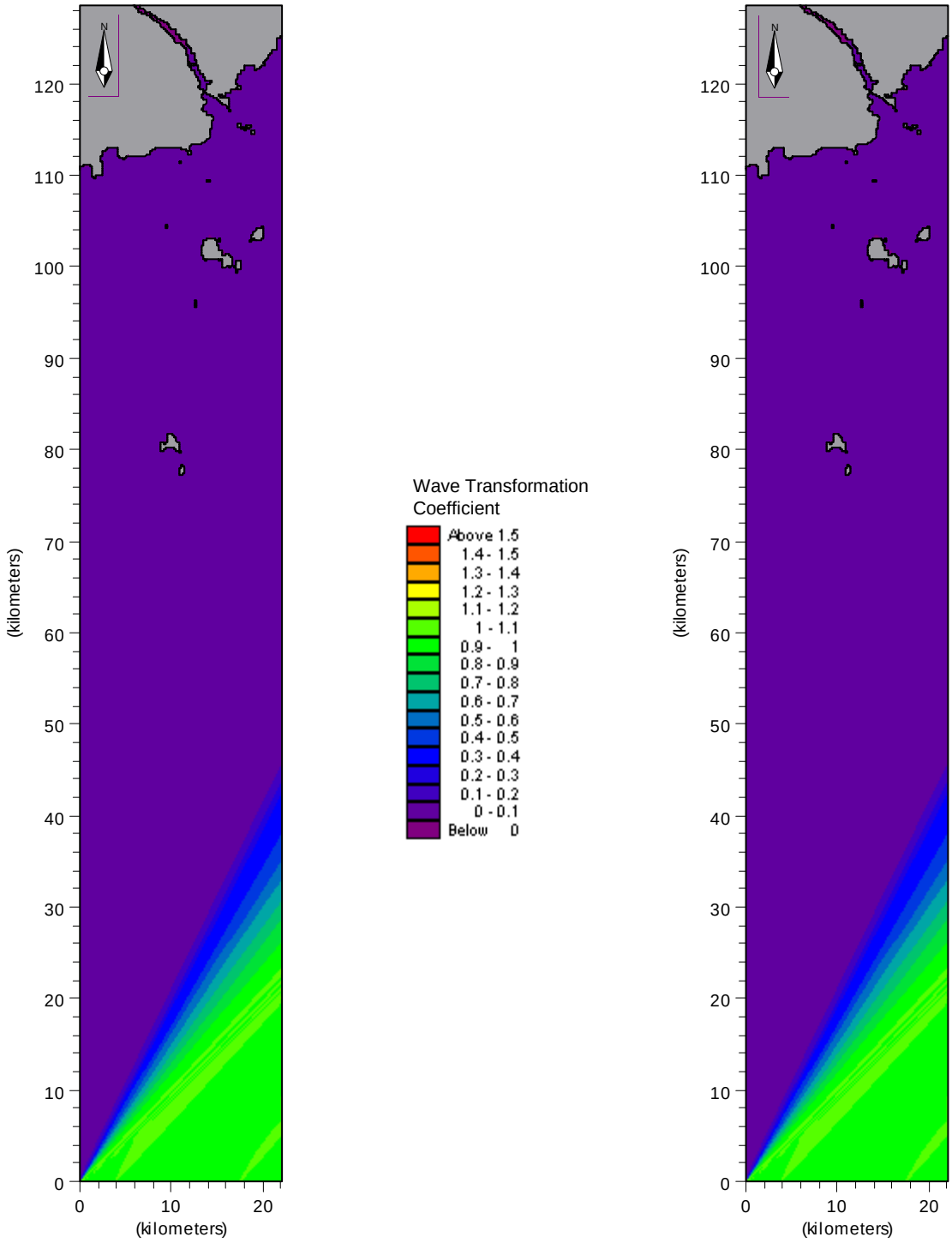
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-32:
Wave Transformation Coefficient
20 second waves from 215 degrees



Water Surface at MHWS

Water Surface at MLWS

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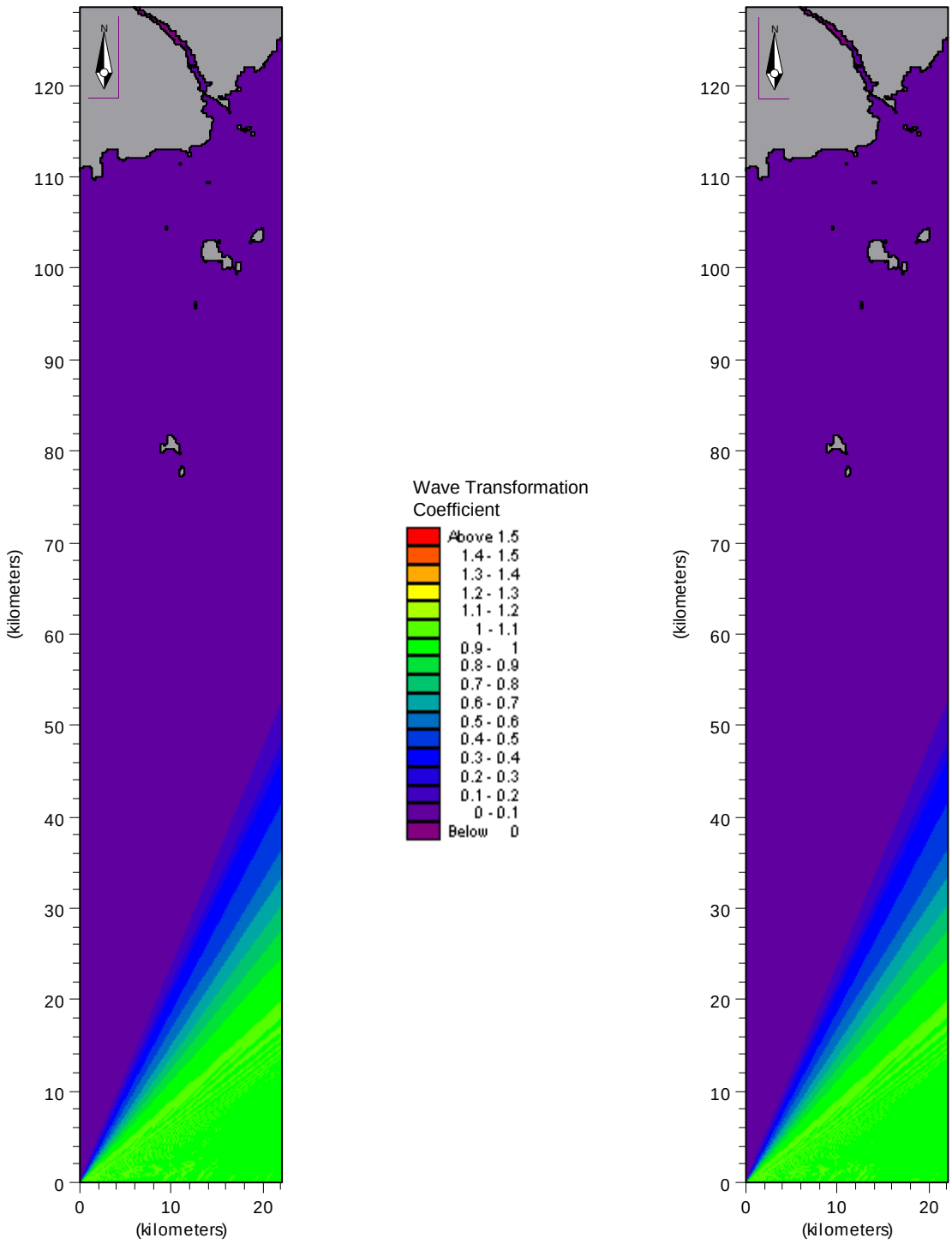
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-33:
Wave Transformation Coefficient
6 second waves from 220 degrees



Water Surface at MHWS

Water Surface at MLWS

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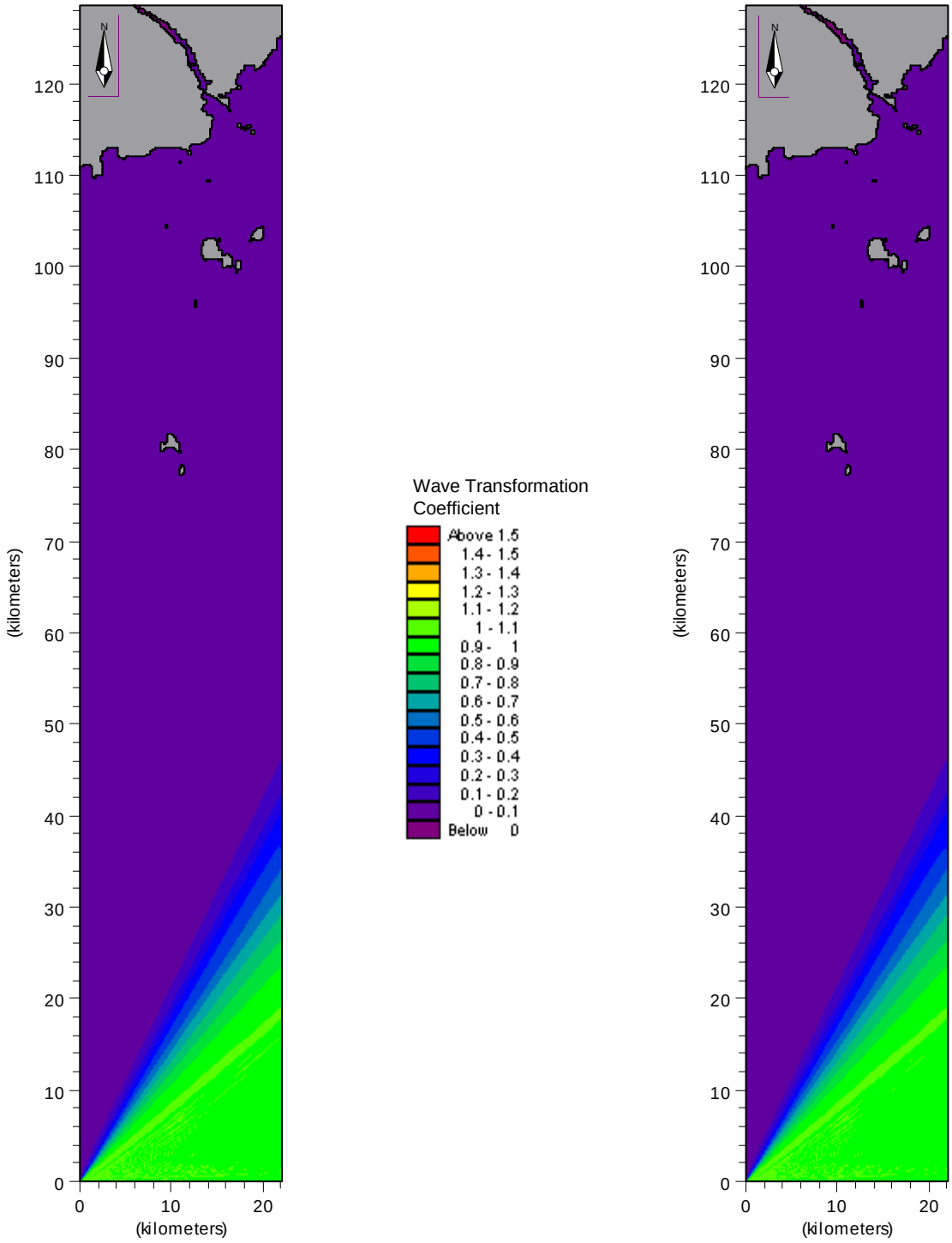
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-34:
Wave Transformation Coefficient
8 second waves from 220 degrees



Water Surface at MHWS

Water Surface at MLWS

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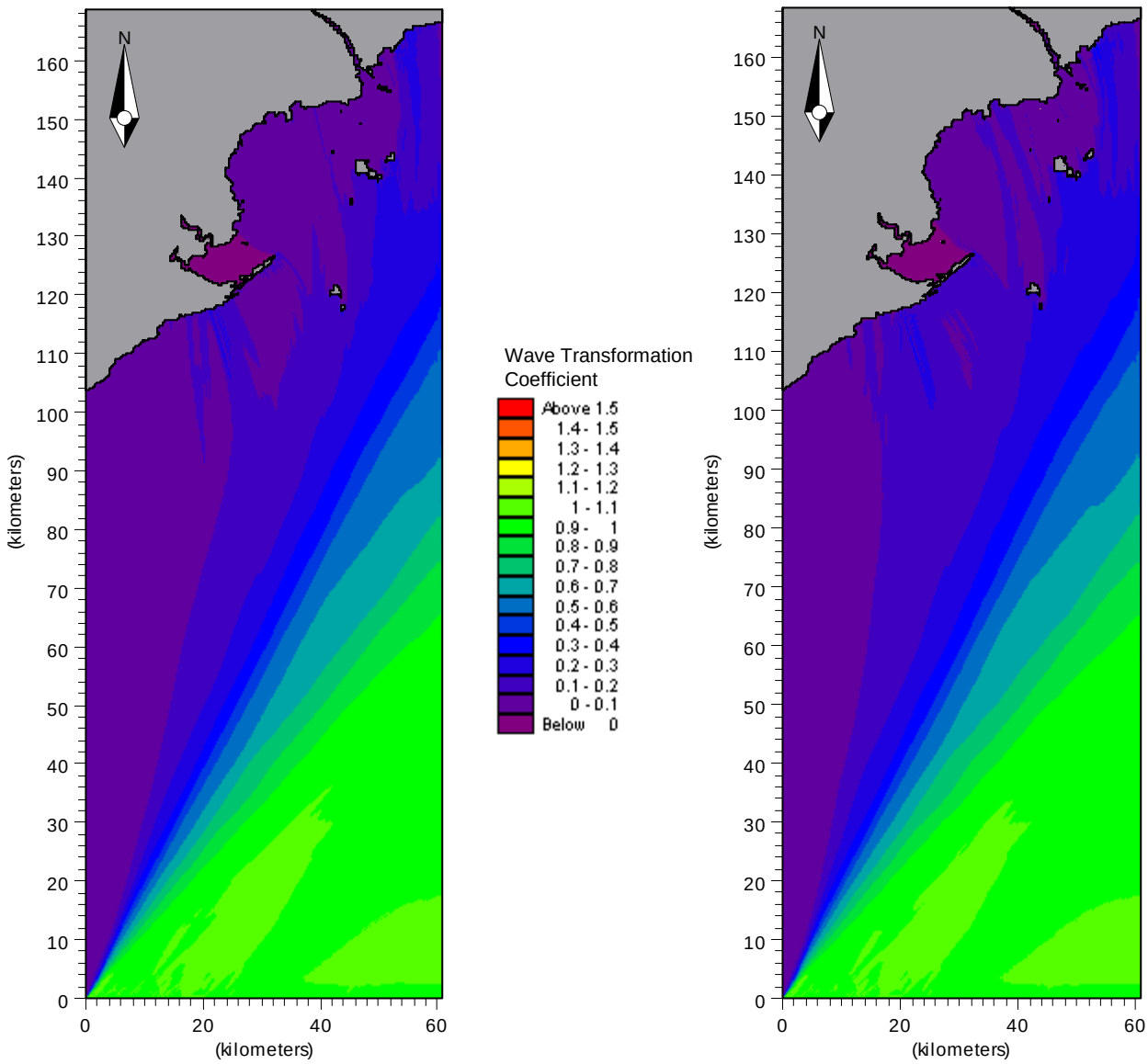
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-35:
Wave Transformation Coefficient
10 second waves from 220 degrees



Water Surface at MHWS

Water Surface at MLWS

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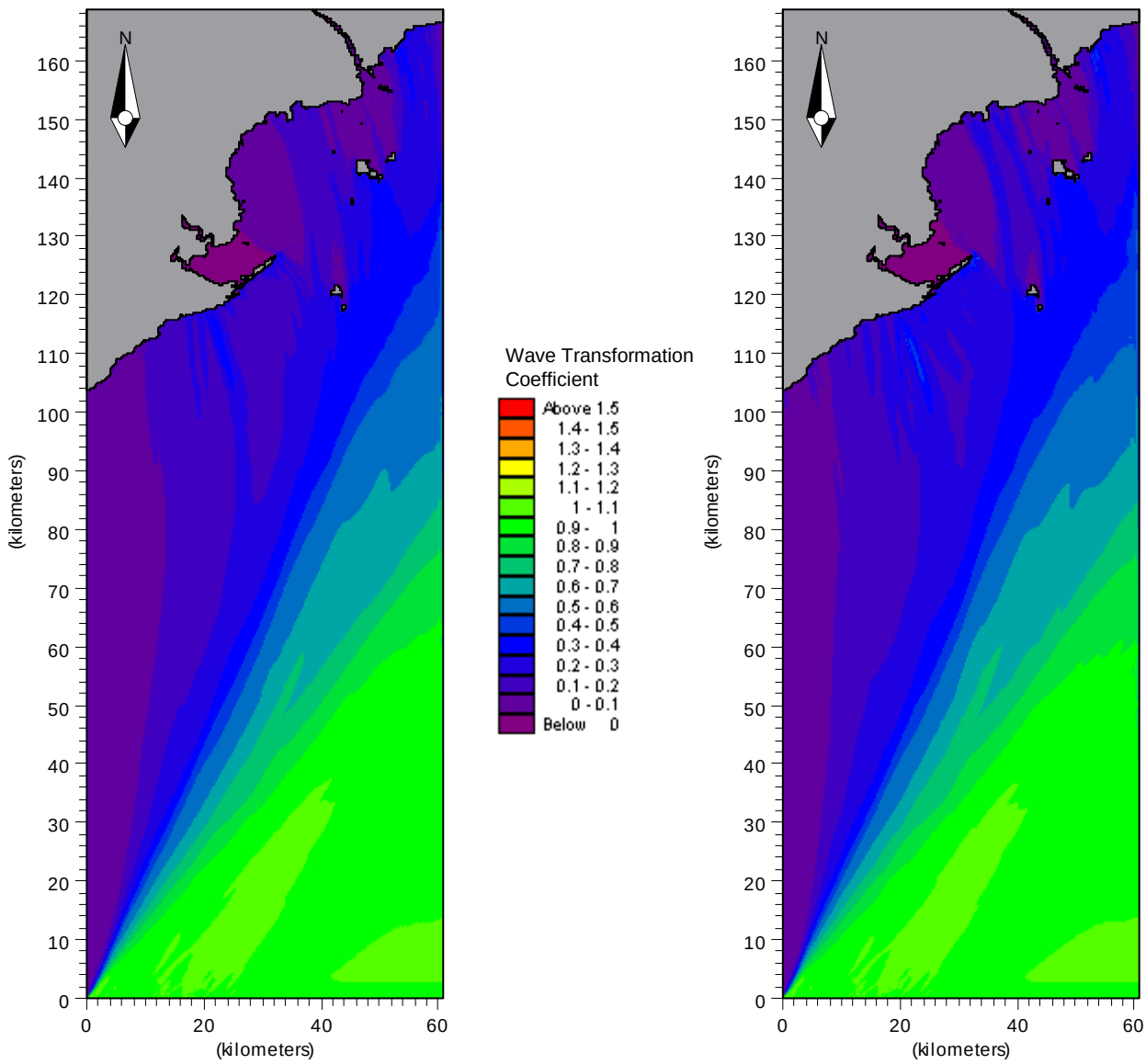
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-36:
Wave Transformation Coefficient
12 second waves from 220 degrees



Water Surface at MHWS **Water Surface at MLWS**

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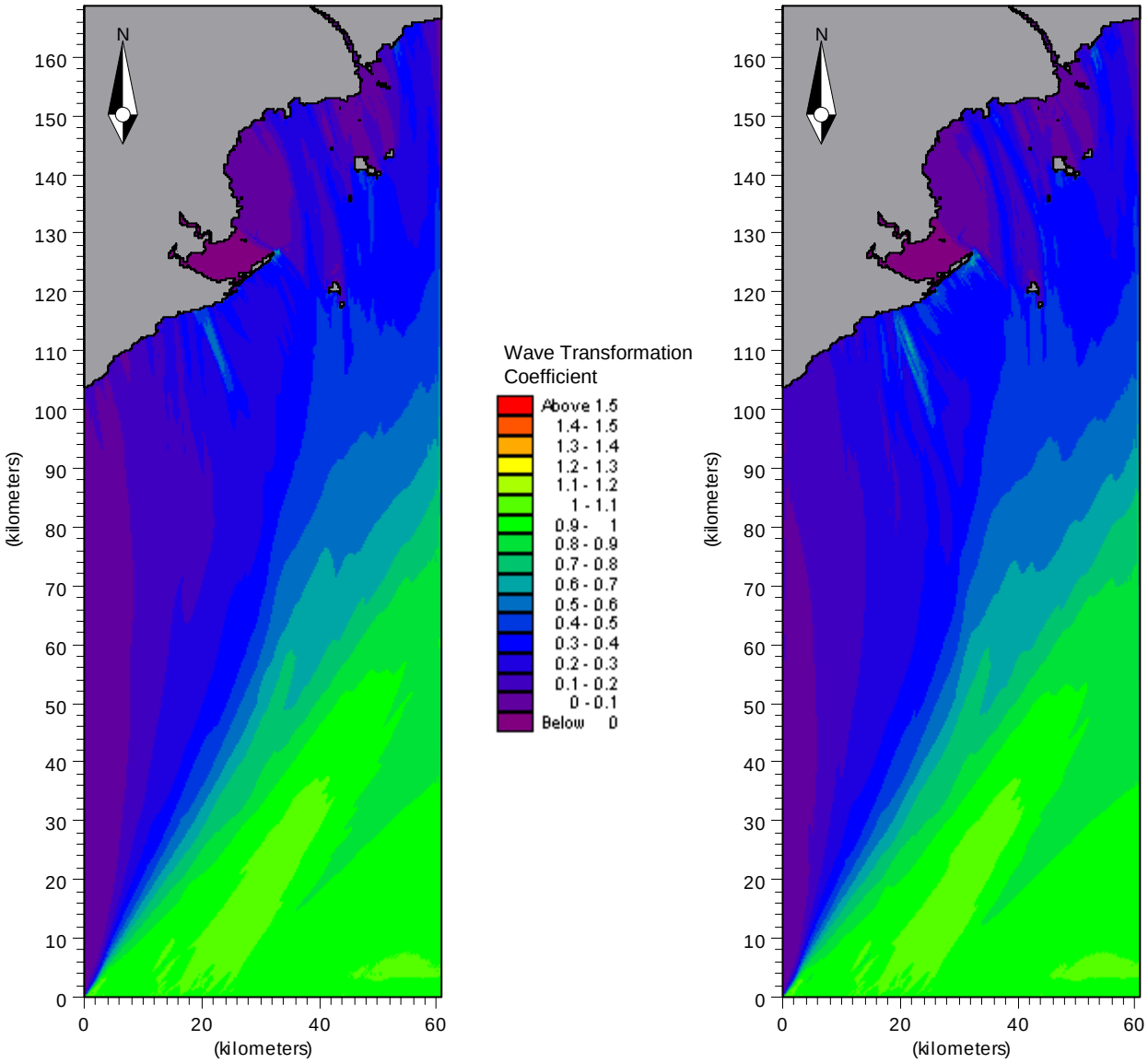
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-37:
Wave Transformation Coefficient
14 second waves from 220 degrees



Water Surface at MHWS

Water Surface at MLWS

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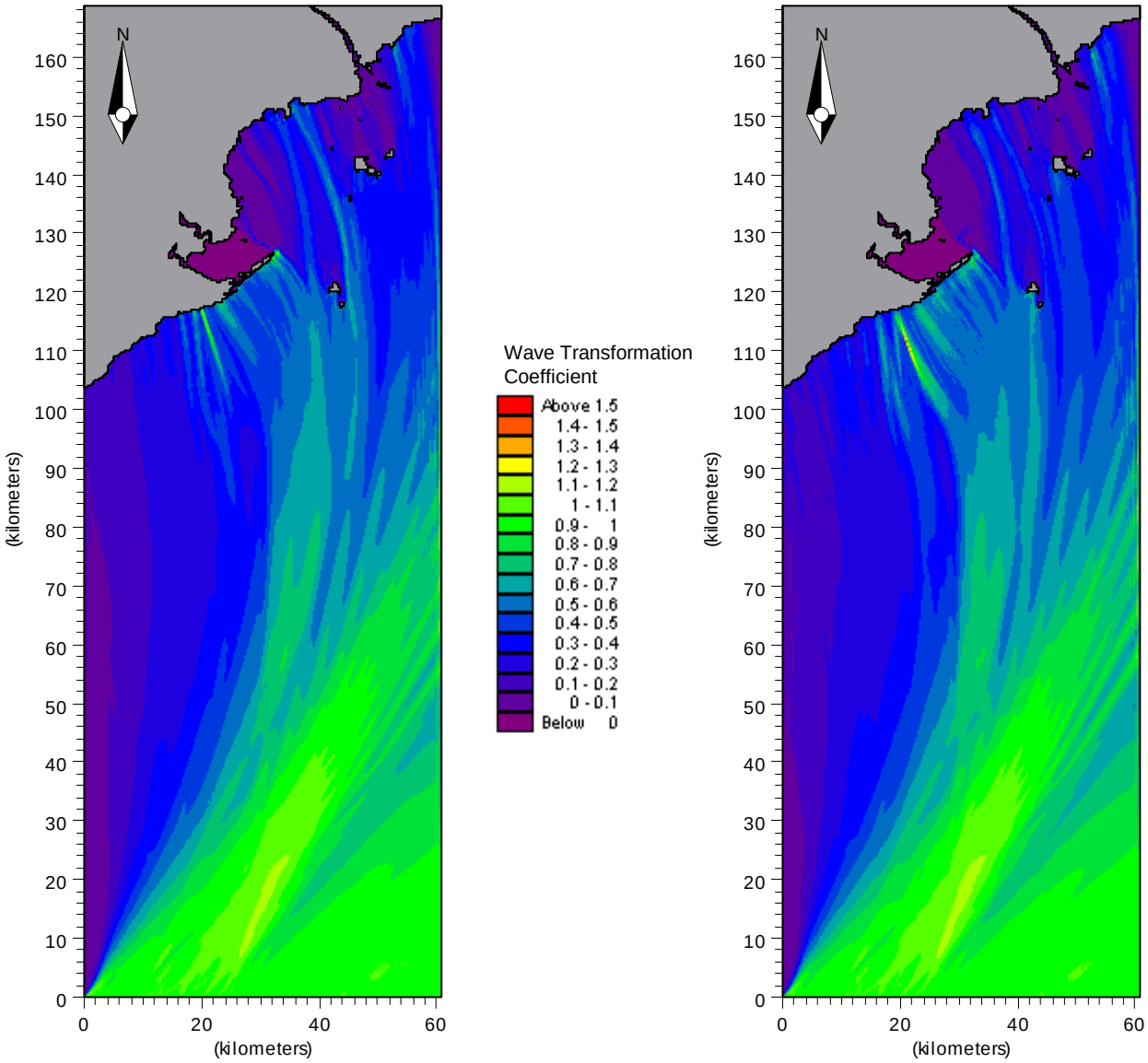
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-38:
Wave Transformation Coefficient
16 second waves from 220 degrees



Water Surface at MHWS

Water Surface at MLWS

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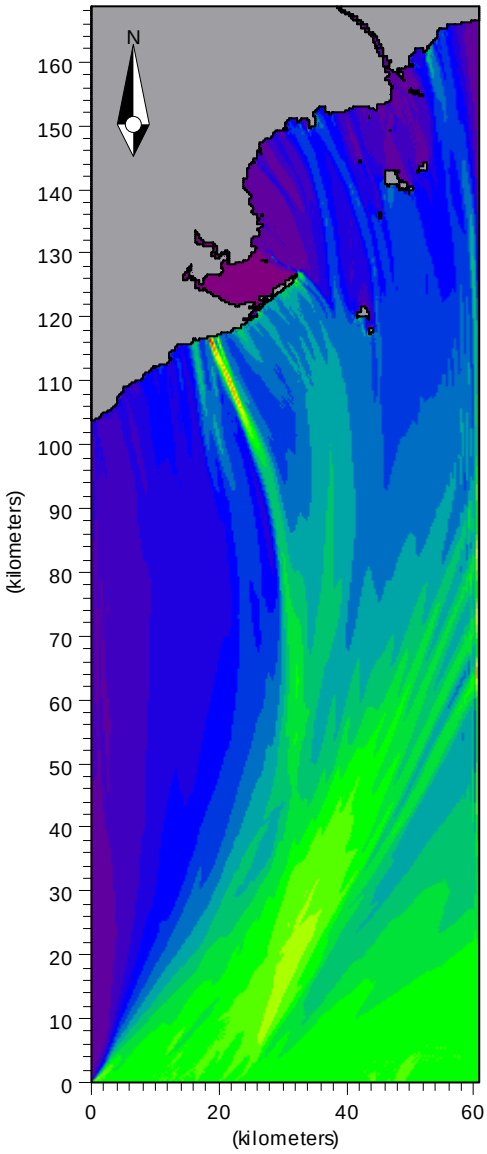
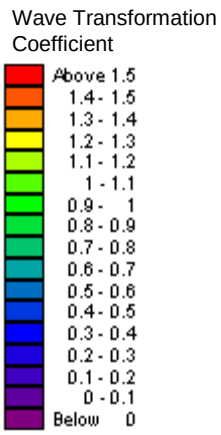
AUTORIDAD DEL CANAL DE PANAMA

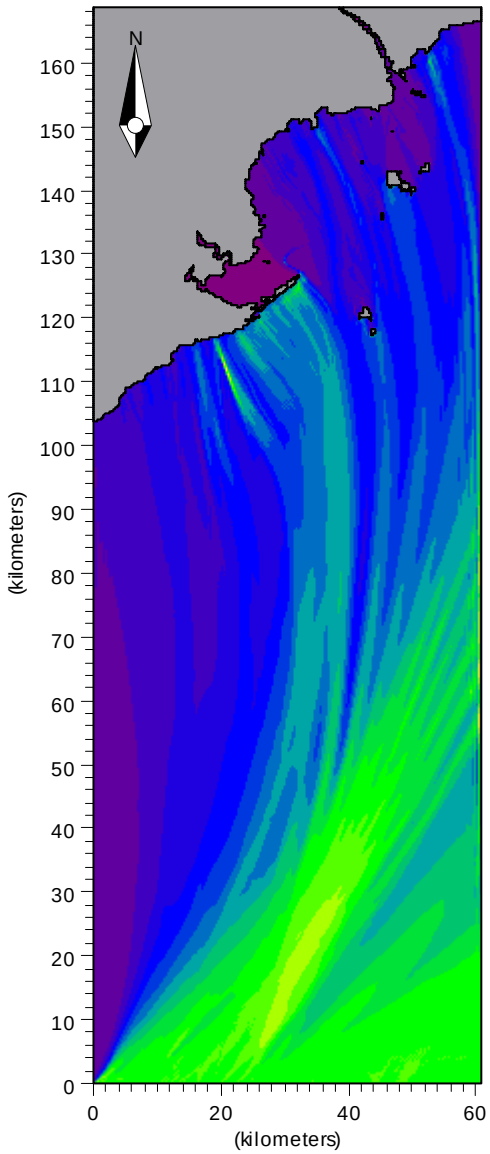
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-39:
Wave Transformation Coefficient
18 second waves from 220 degrees



Water Surface at MHWS





Water Surface at MLWS

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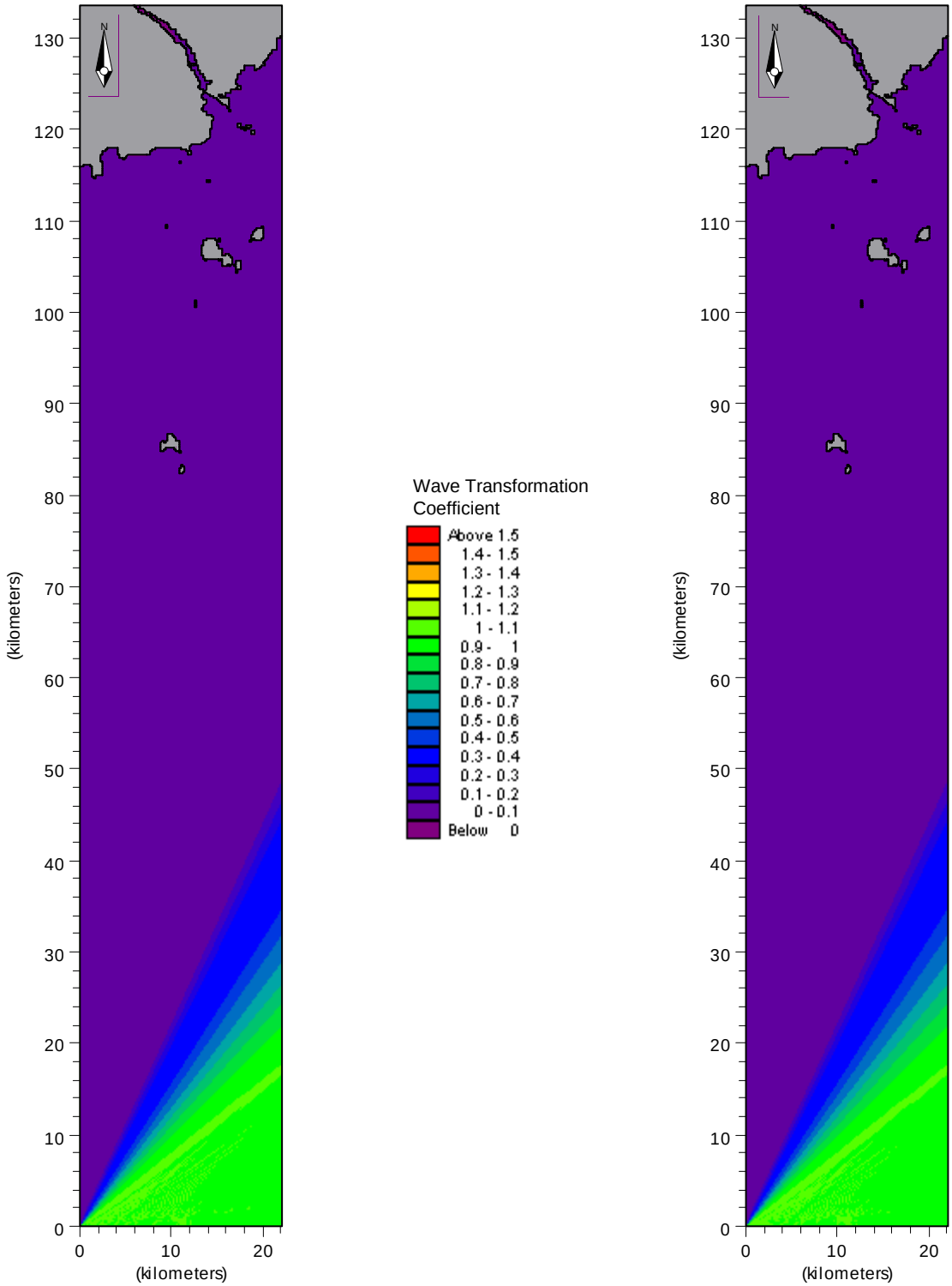
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-40:
Wave Transformation Coefficient
20 second waves from 220 degrees



Water Surface at MHWS

Water Surface at MLWS

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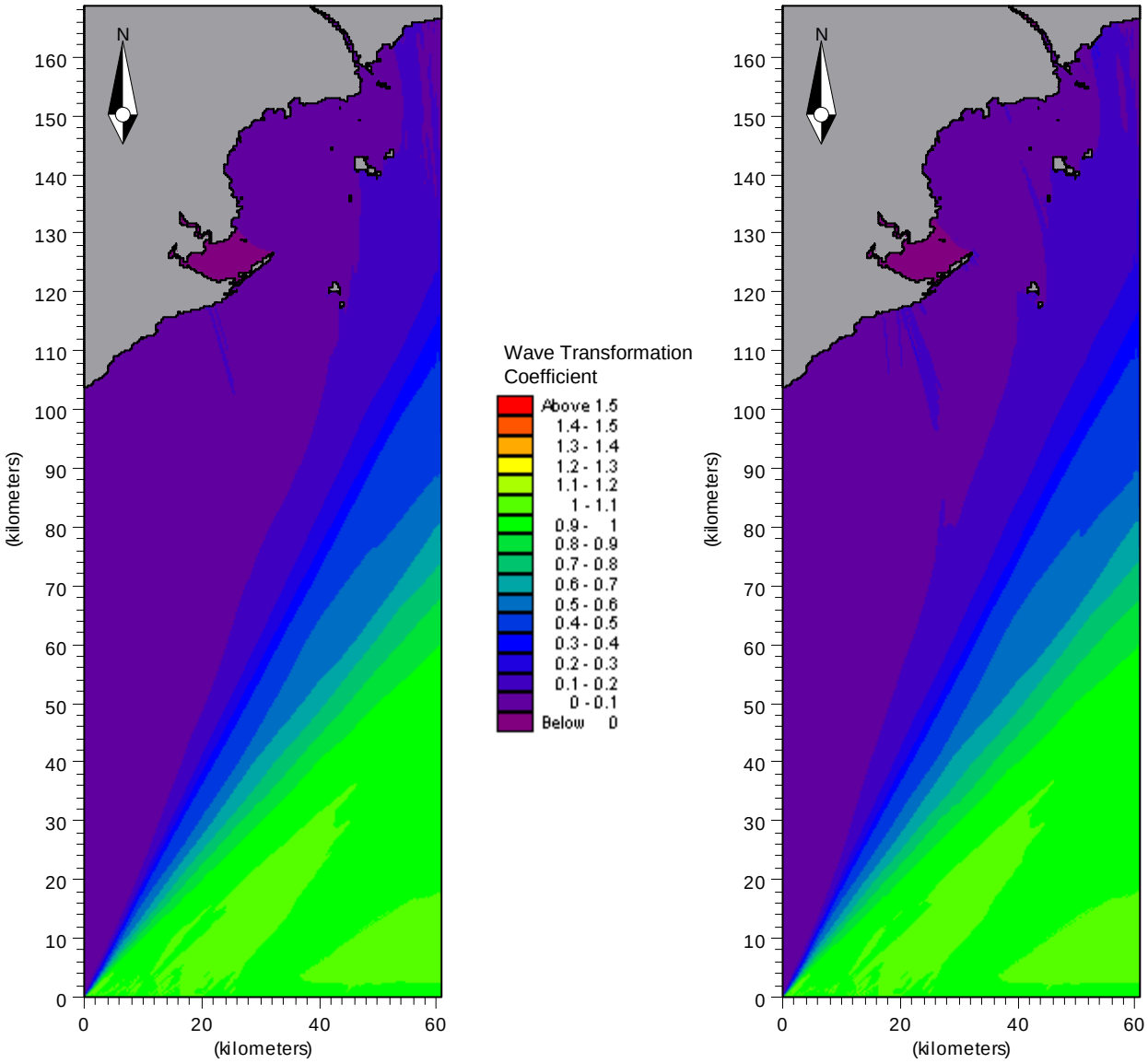
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-41:
Wave Transformation Coefficient
10 second waves from 225 degrees



Water Surface at MHWS **Water Surface at MLWS**

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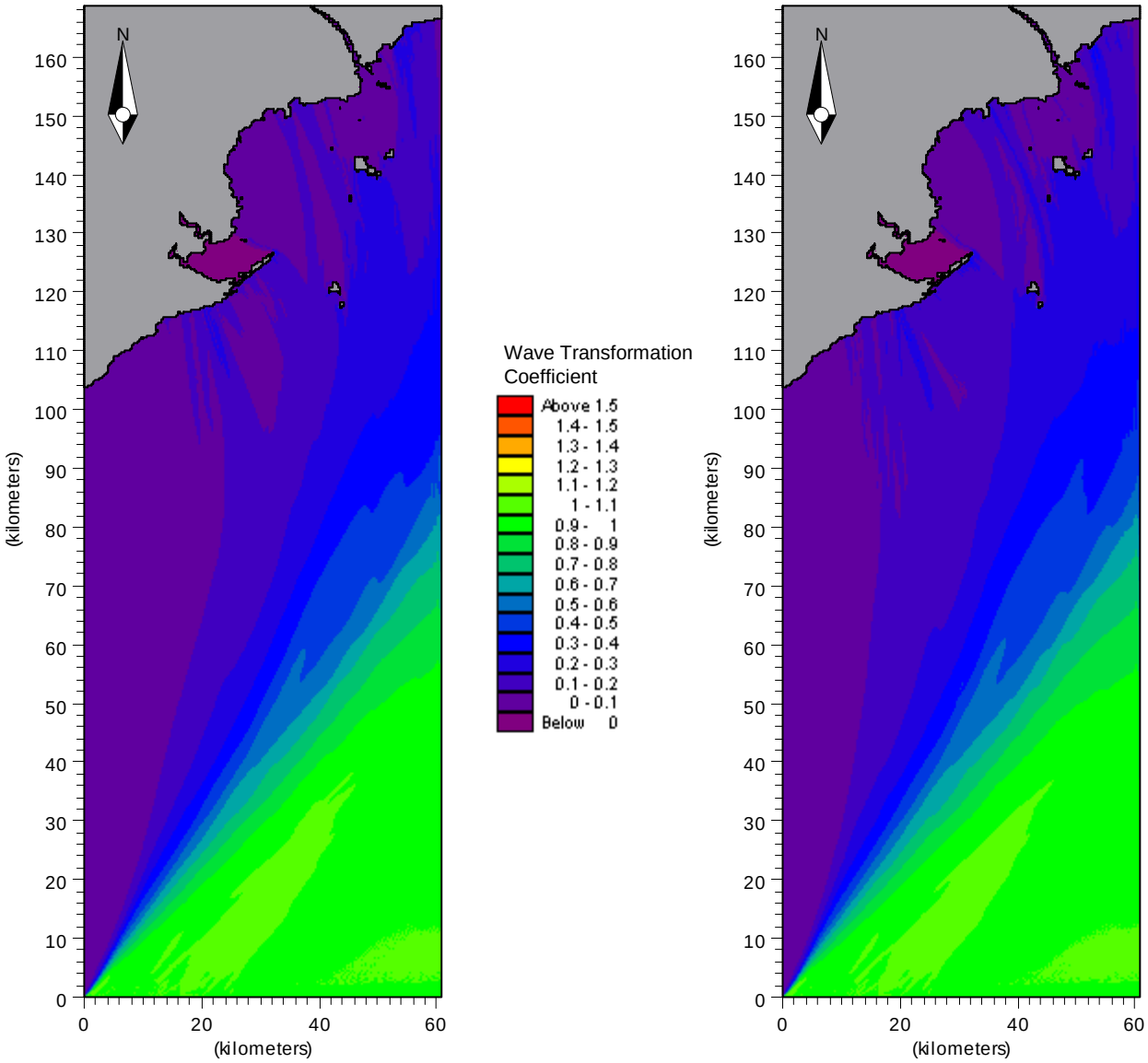
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-42:
Wave Transformation Coefficient
12 second waves from 225 degrees



Water Surface at MHWS

Water Surface at MLWS

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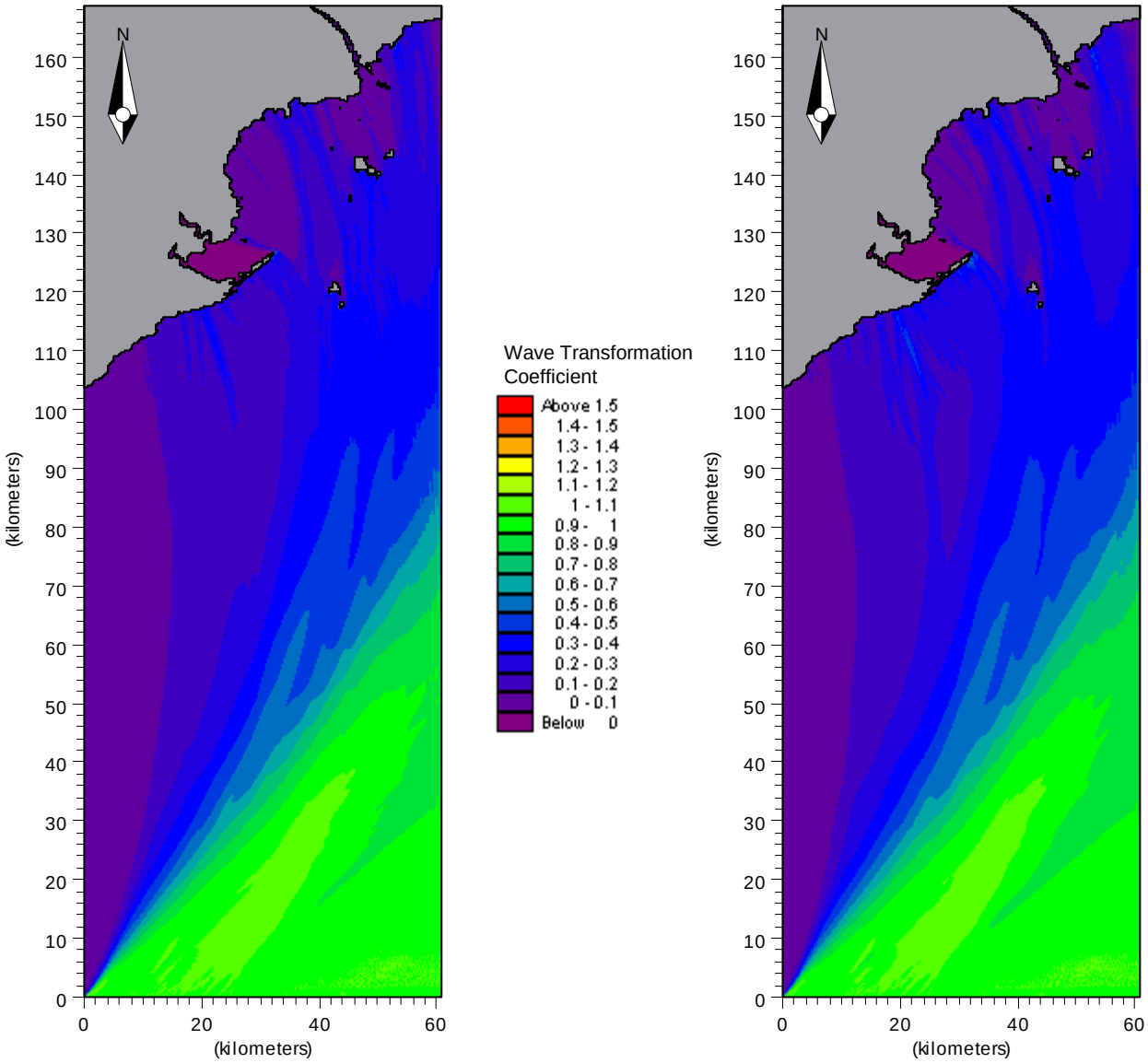
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-43:
Wave Transformation Coefficient
14 second waves from 225 degrees



Water Surface at MHWS

Water Surface at MLWS

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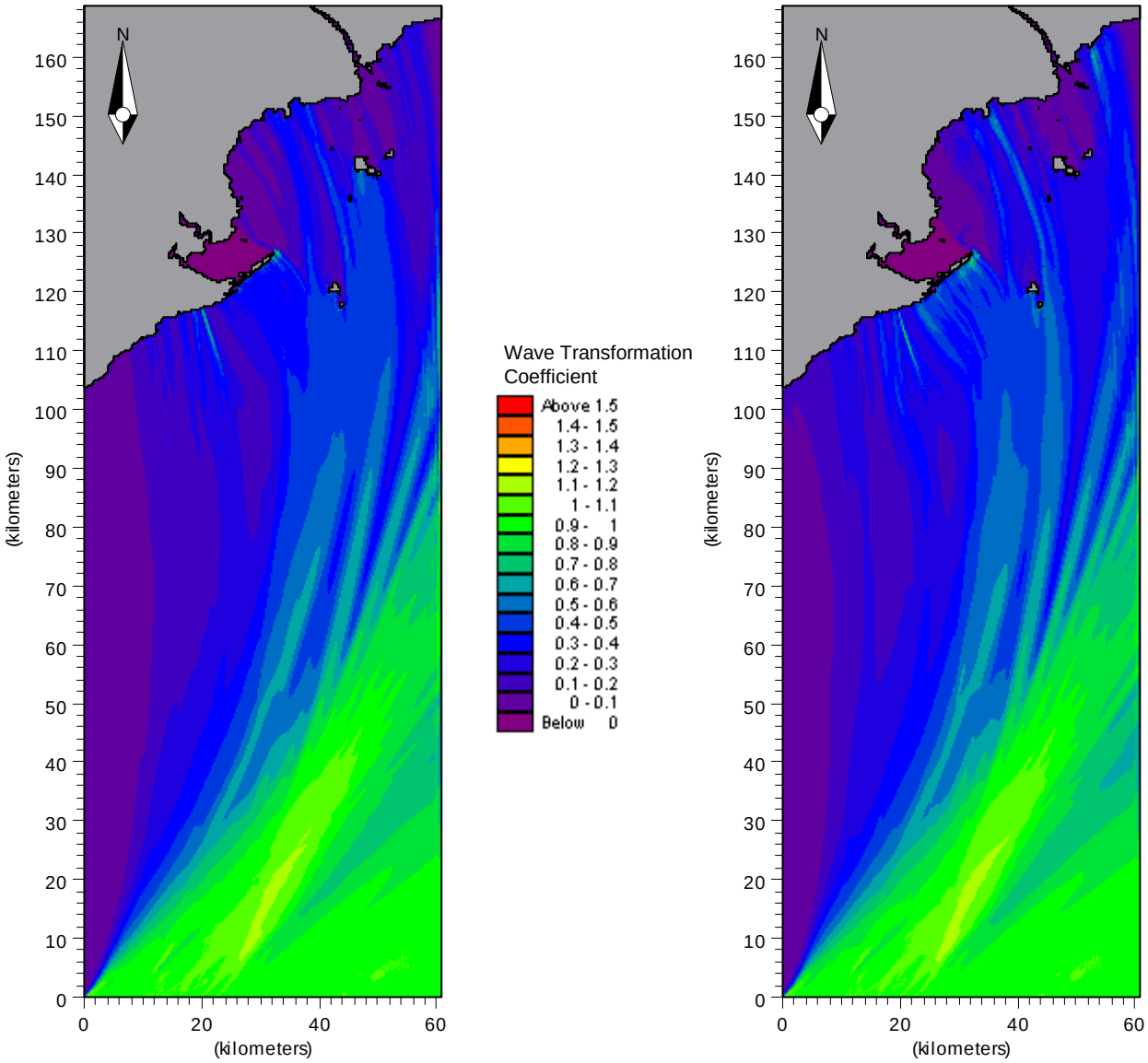
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-44:
Wave Transformation Coefficient
16 second waves from 225 degrees



Water Surface at MHWS **Water Surface at MLWS**

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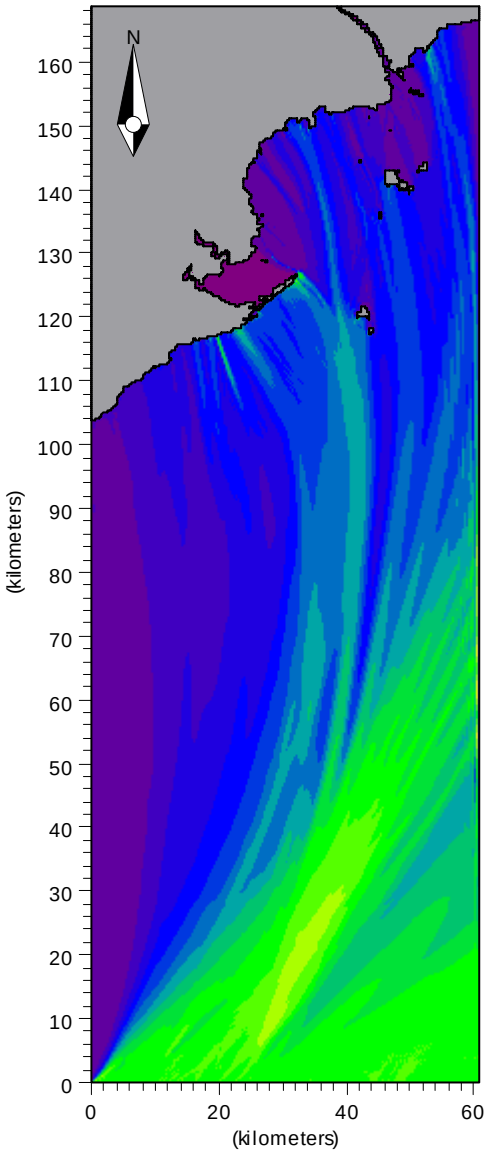
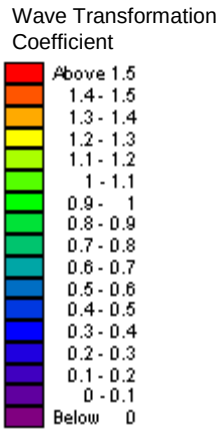
AUTORIDAD DEL CANAL DE PANAMA

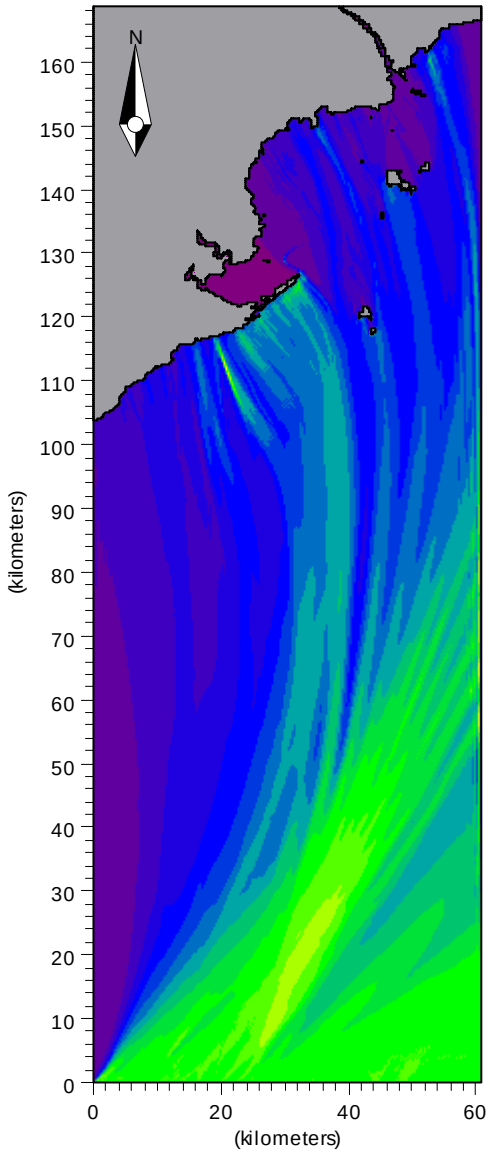
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-45:
Wave Transformation Coefficient
18 second waves from 225 degrees



Water Surface at MHWS





Water Surface at MLWS

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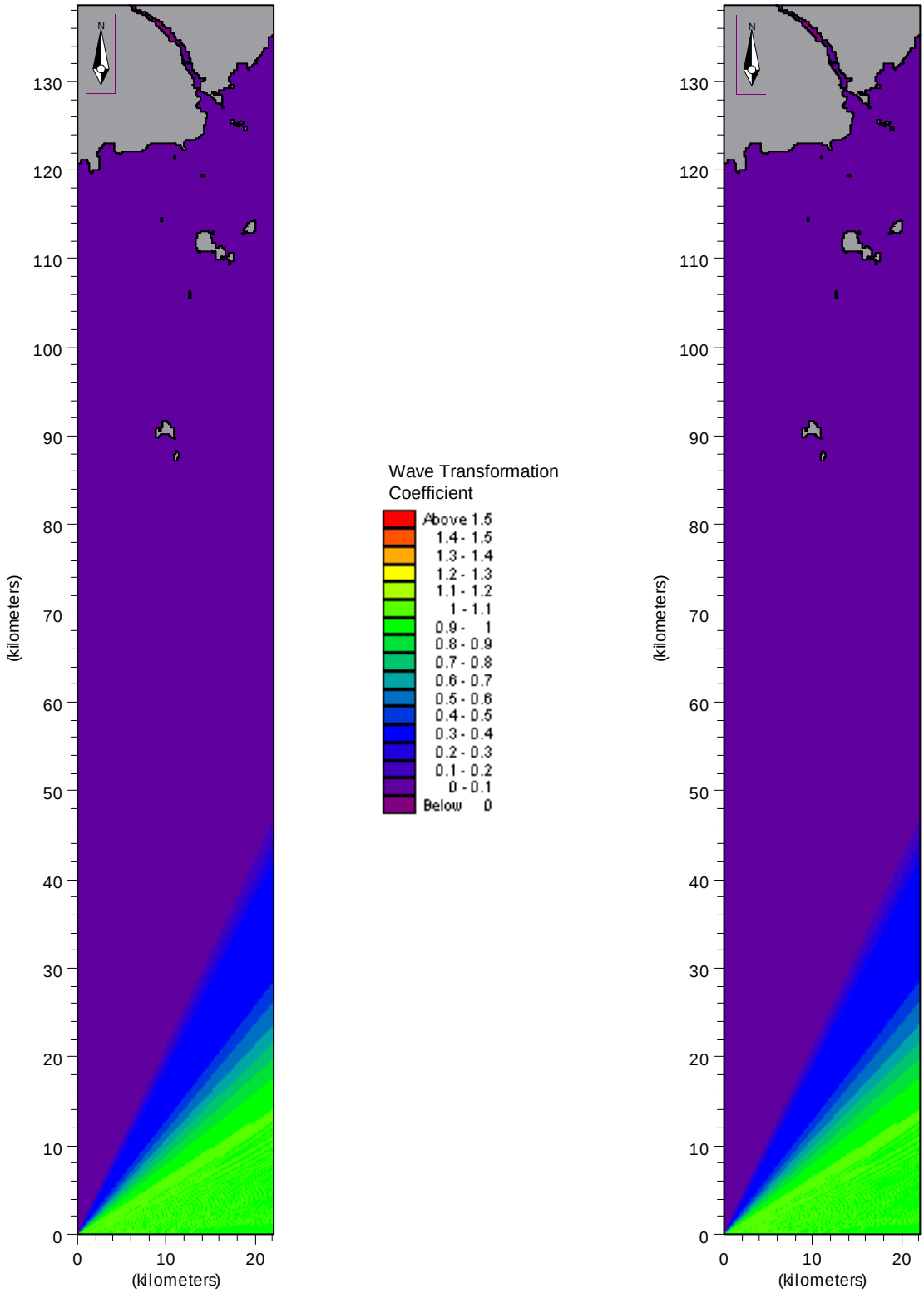
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-46:
Wave Transformation Coefficient
20 second waves from 225 degrees



Water Surface at MHWS **Water Surface at MLWS**

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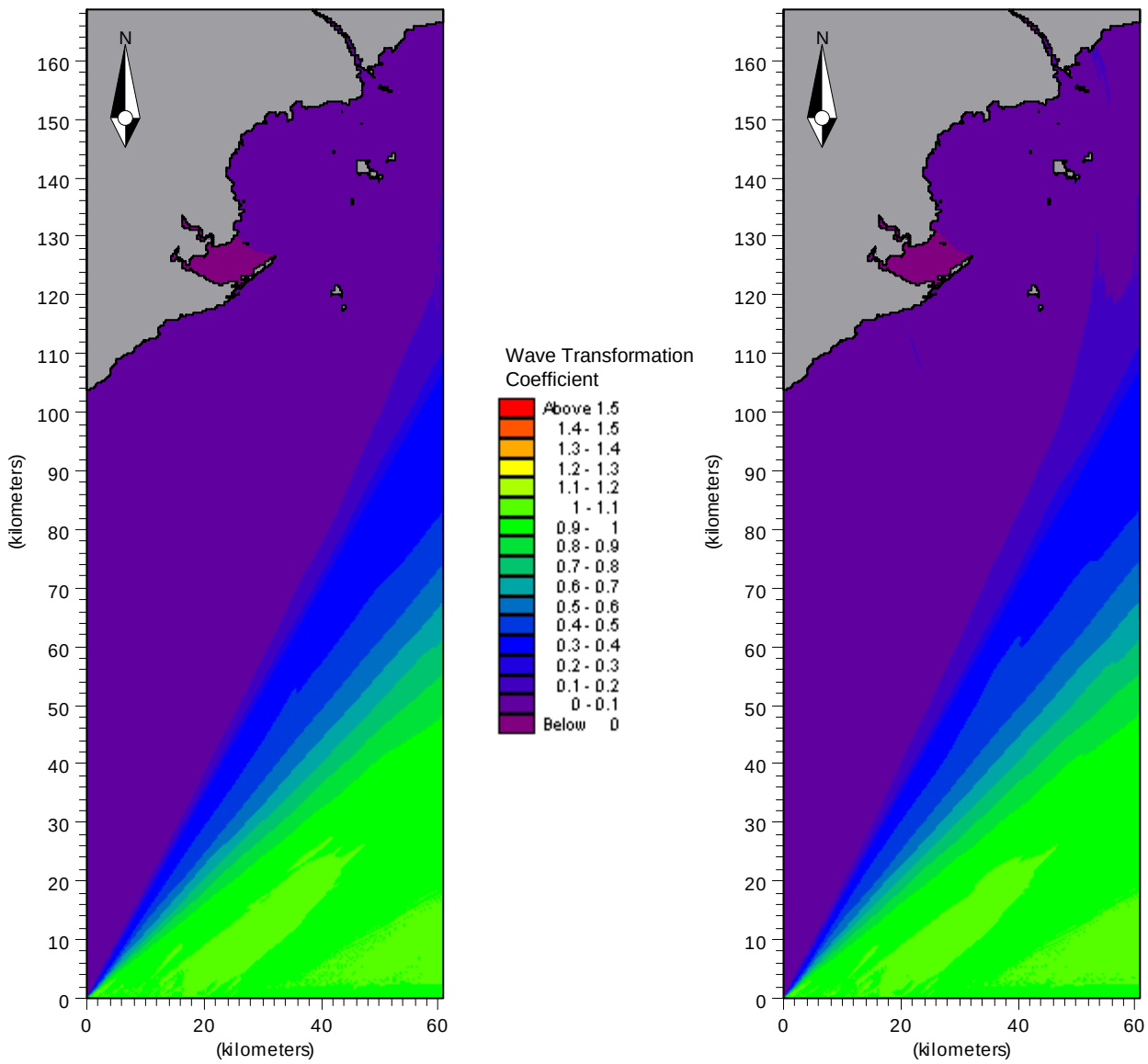
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-47:
Wave Transformation Coefficient
10 second waves from 230 degrees



Water Surface at MHWS

Water Surface at MLWS

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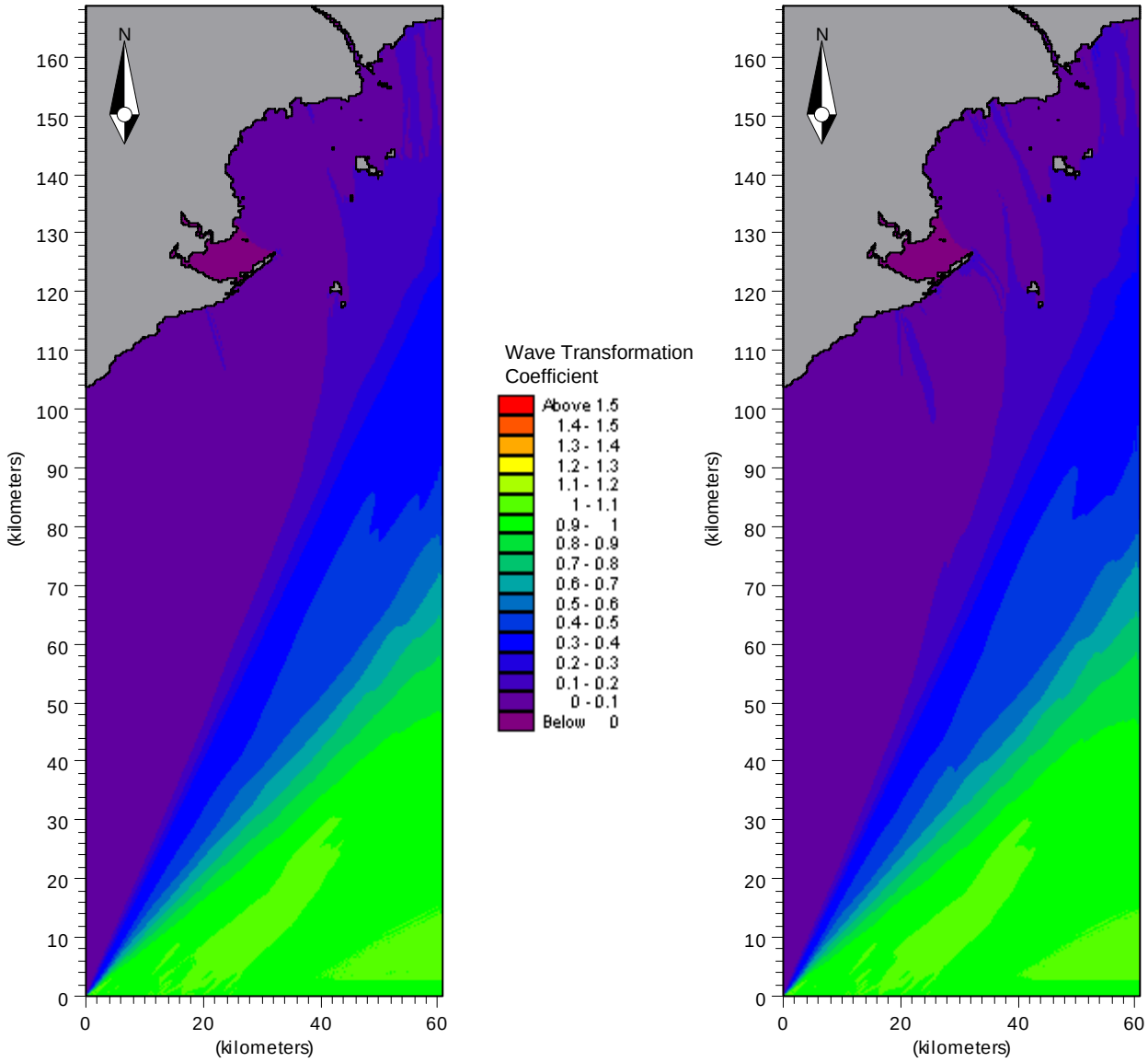
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-48:
Wave Transformation Coefficient
12 second waves from 230 degrees



Water Surface at MHWS **Water Surface at MLWS**

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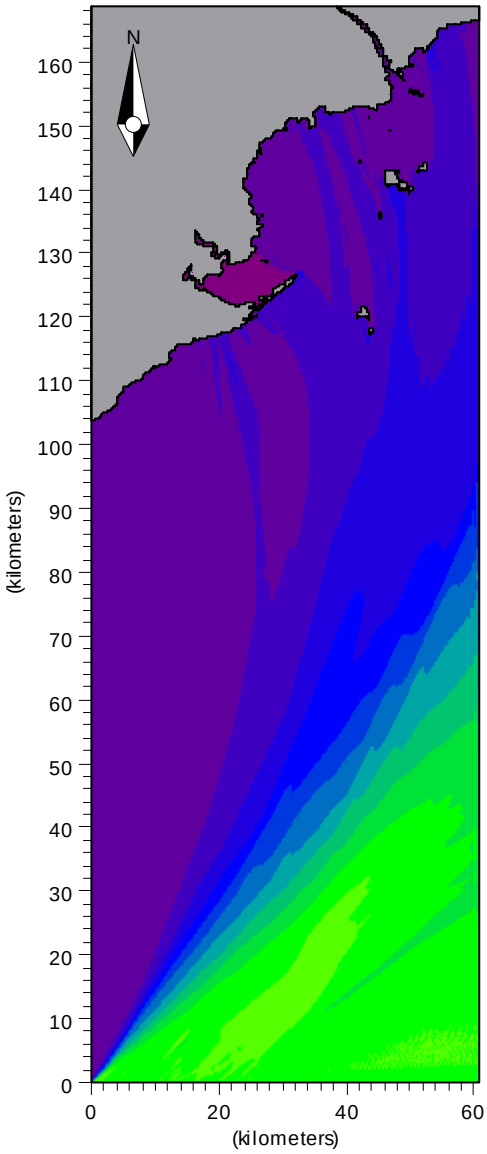
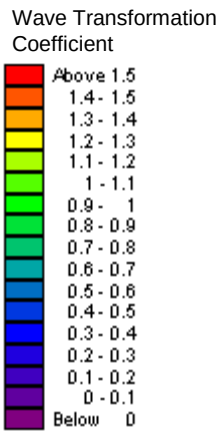
AUTORIDAD DEL CANAL DE PANAMA

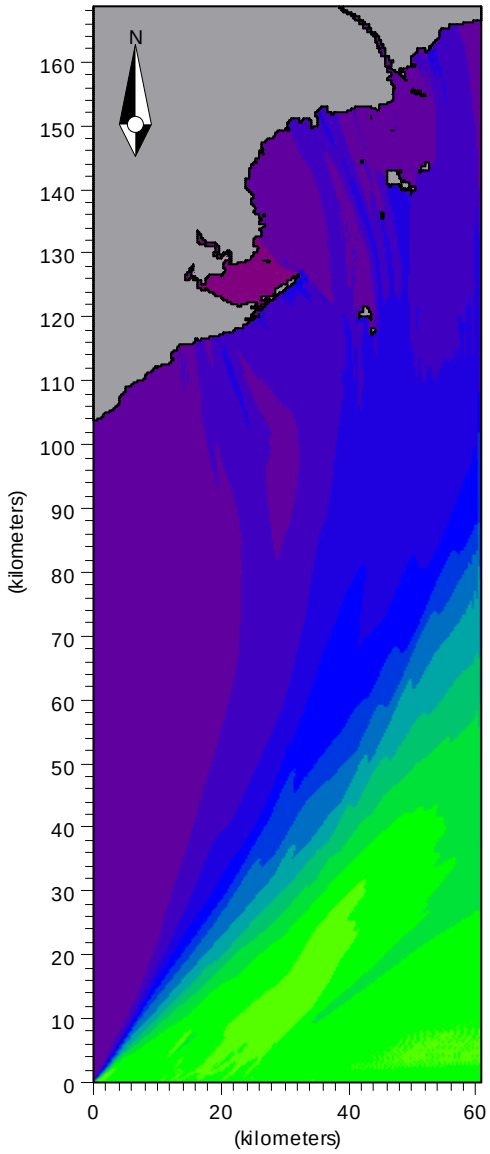
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-49:
Wave Transformation Coefficient
14 second waves from 230 degrees



Water Surface at MHWS





Water Surface at MLWS

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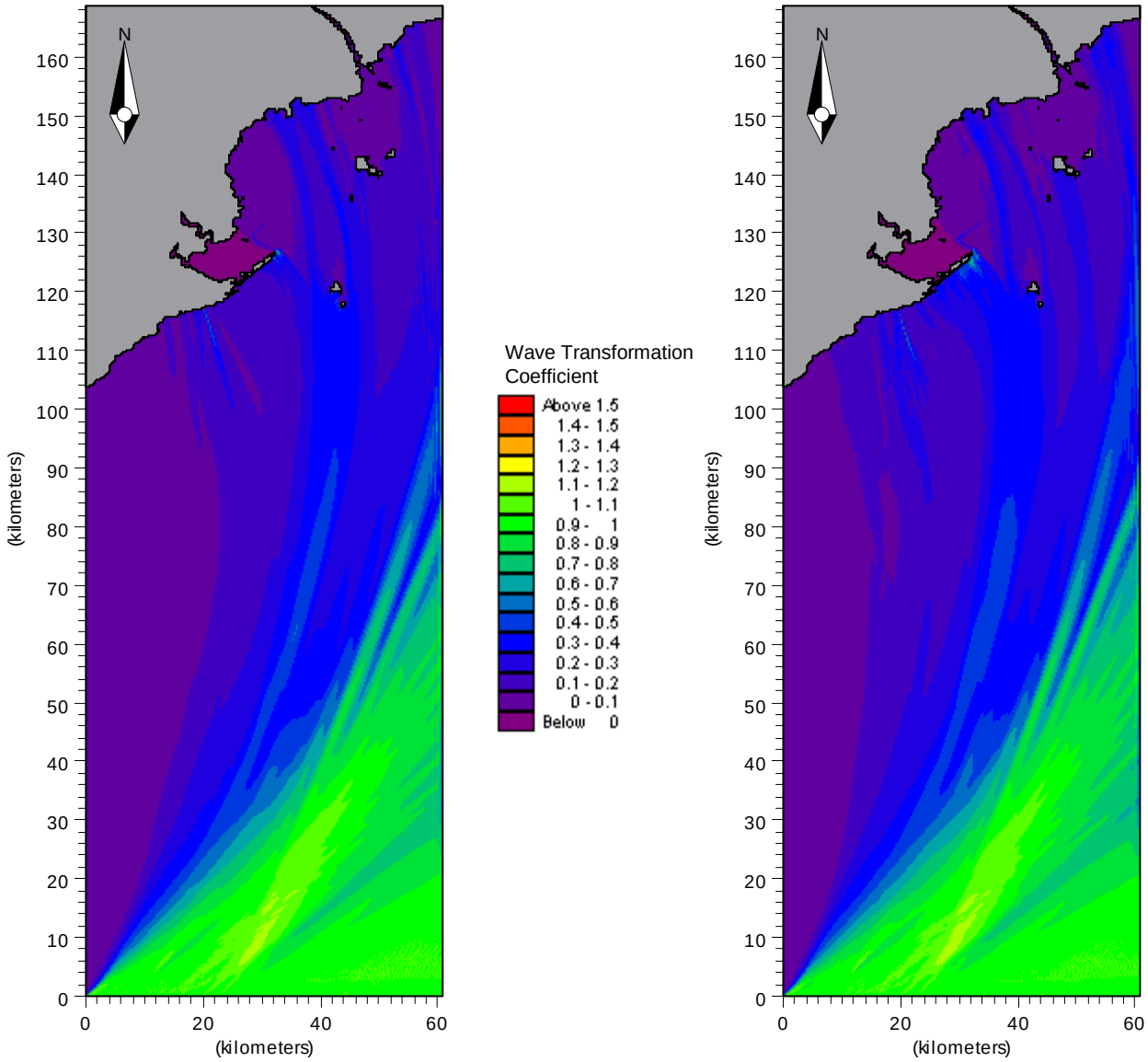
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-50:
Wave Transformation Coefficient
16 second waves from 230 degrees



Water Surface at MHWS **Water Surface at MLWS**

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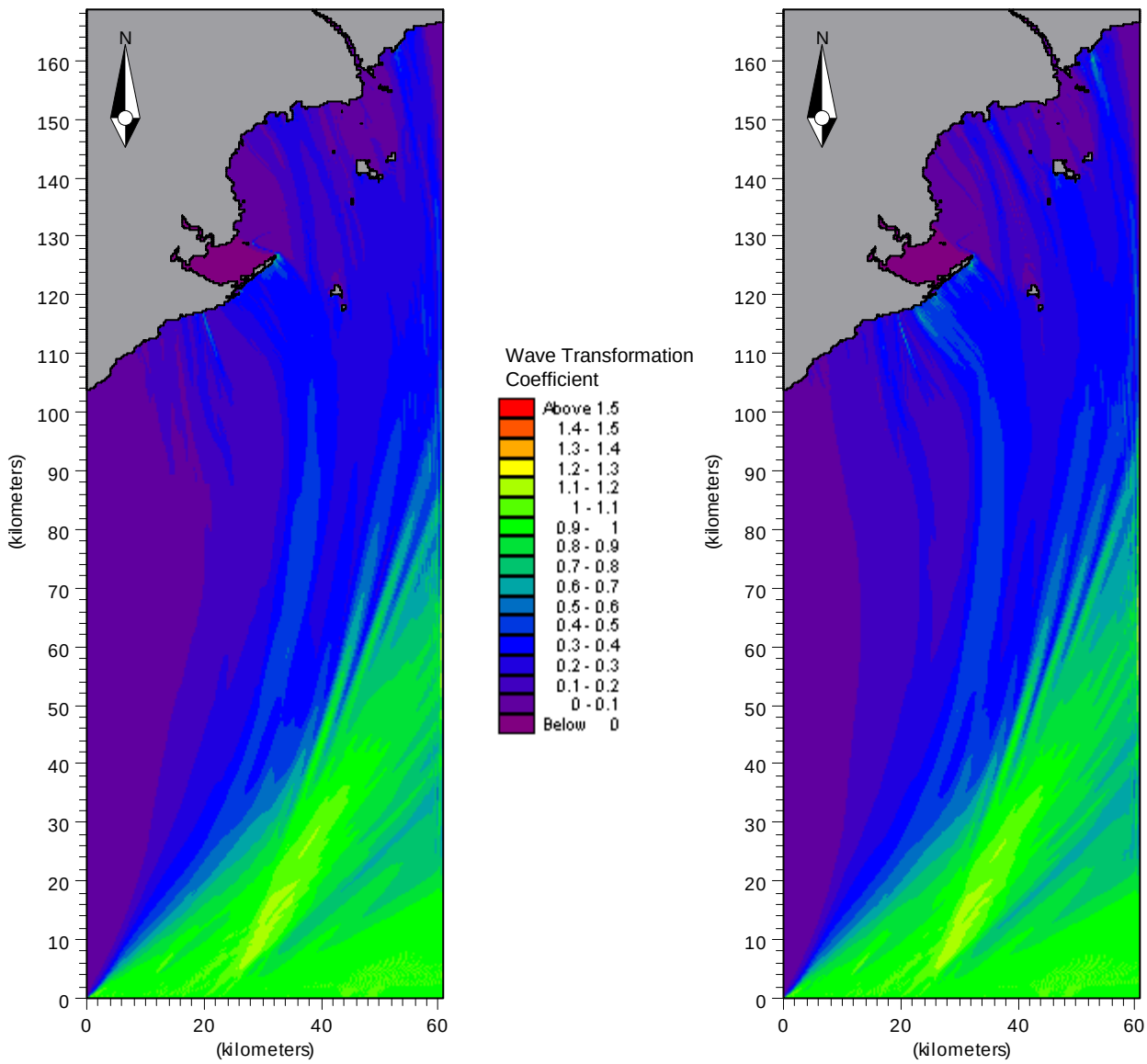
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-51:
Wave Transformation Coefficient
18 second waves from 230 degrees



Water Surface at MHWS **Water Surface at MLWS**

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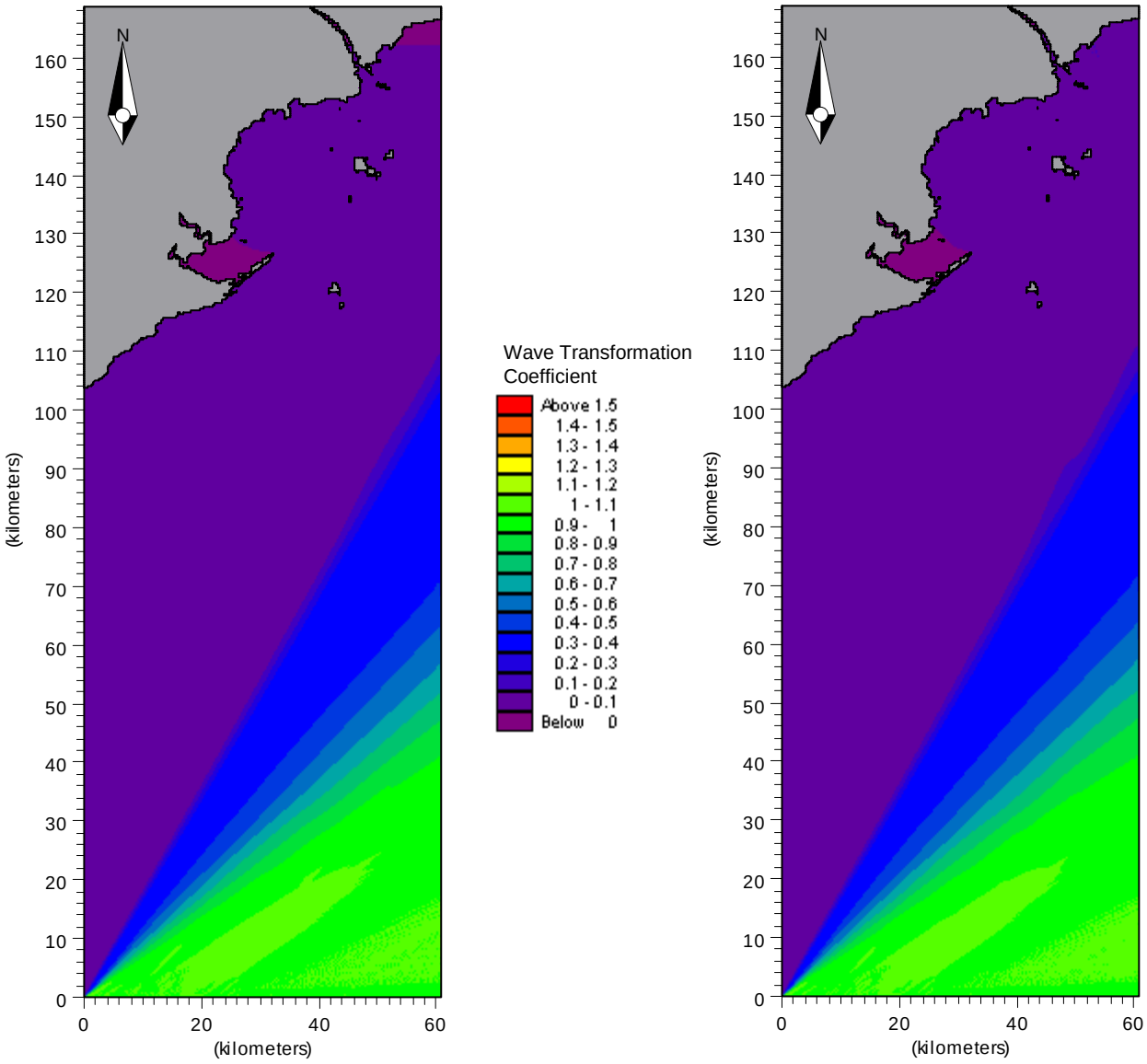
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-52:
Wave Transformation Coefficient
20 second waves from 230 degrees



Water Surface at MHWS

Water Surface at MLWS

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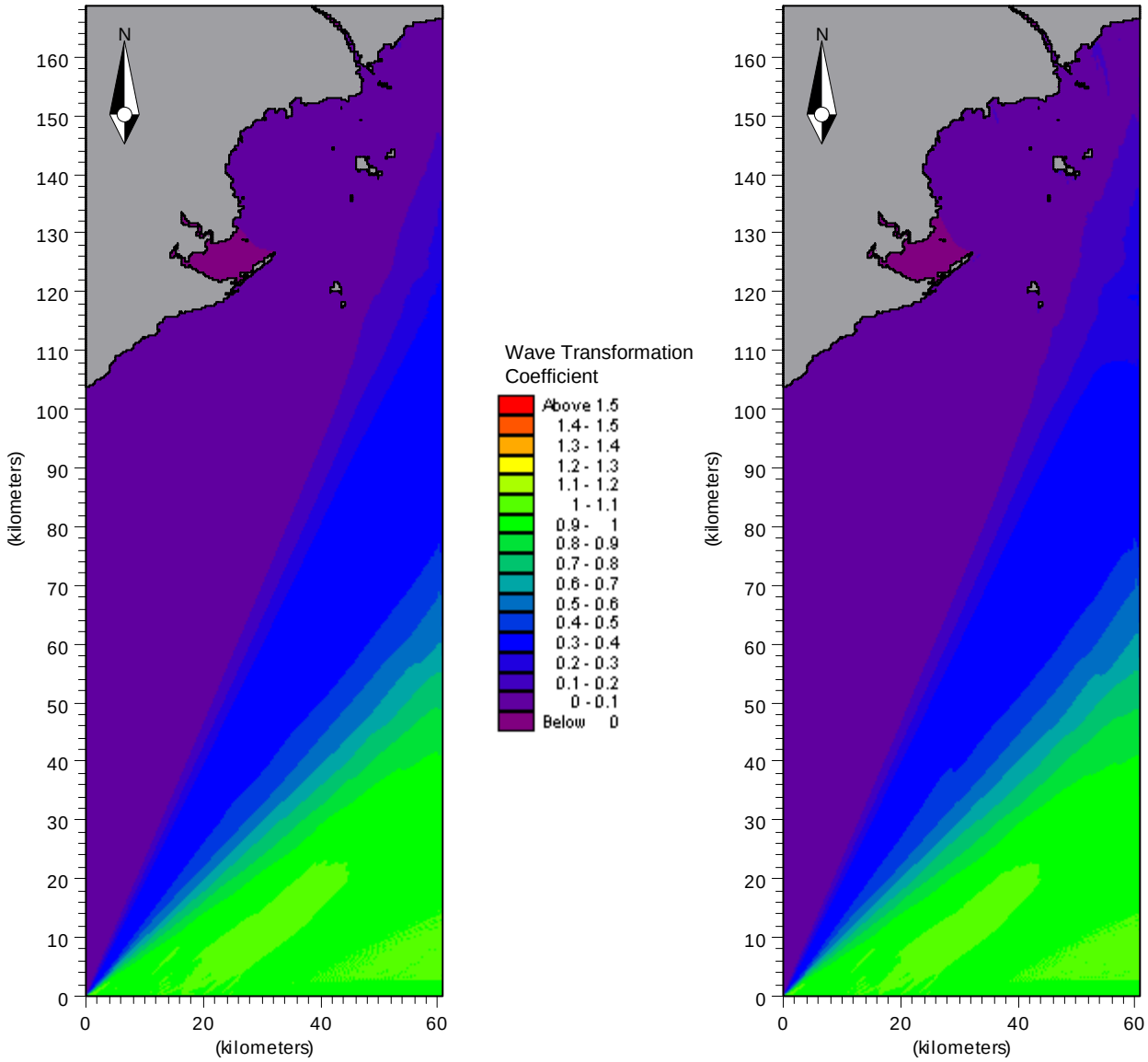
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-53:
Wave Transformation Coefficient
12 second waves from 235 degrees



Water Surface at MHWS

Water Surface at MLWS

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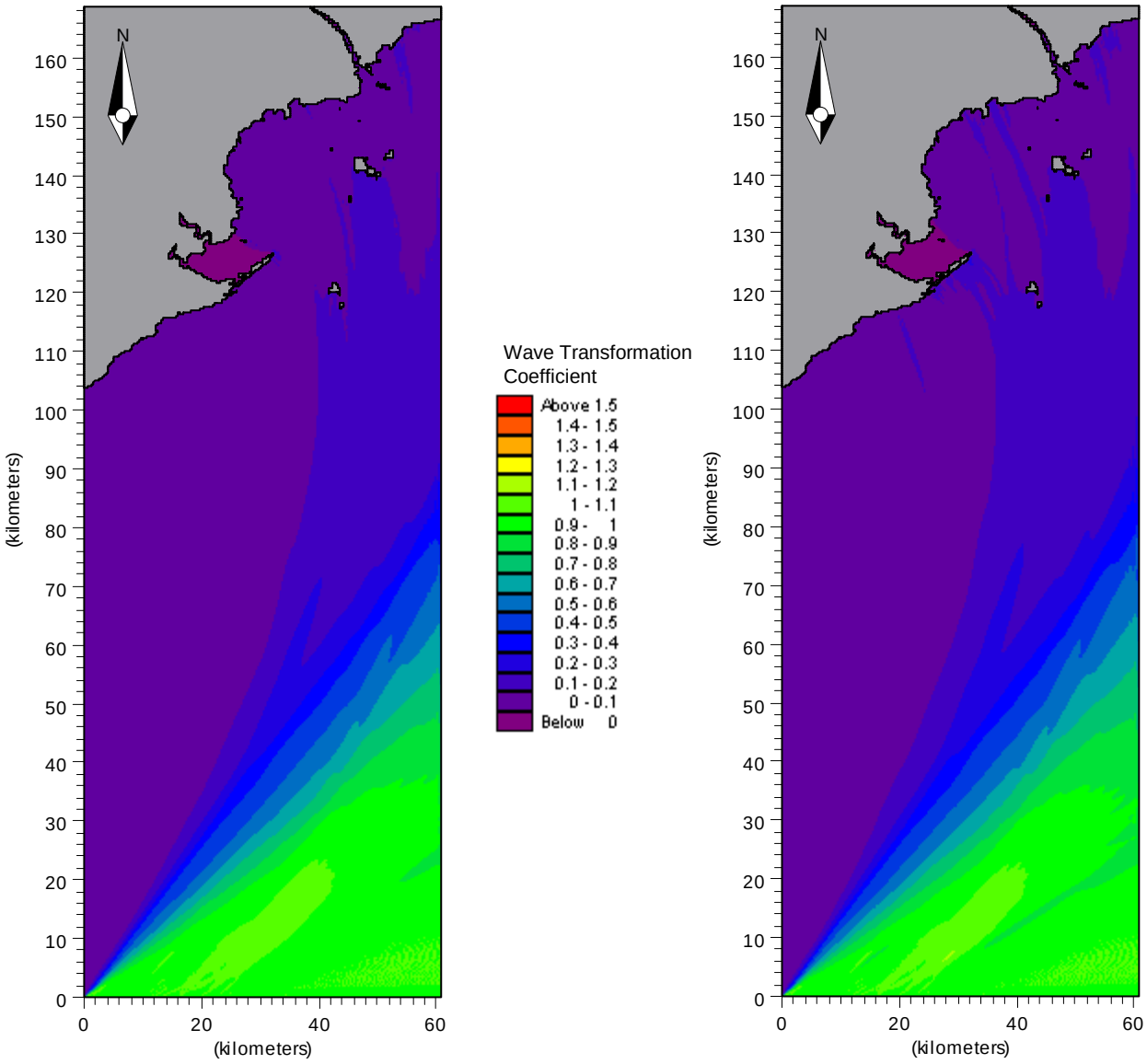
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-54:
Wave Transformation Coefficient
14 second waves from 235 degrees



Water Surface at MHWS **Water Surface at MLWS**

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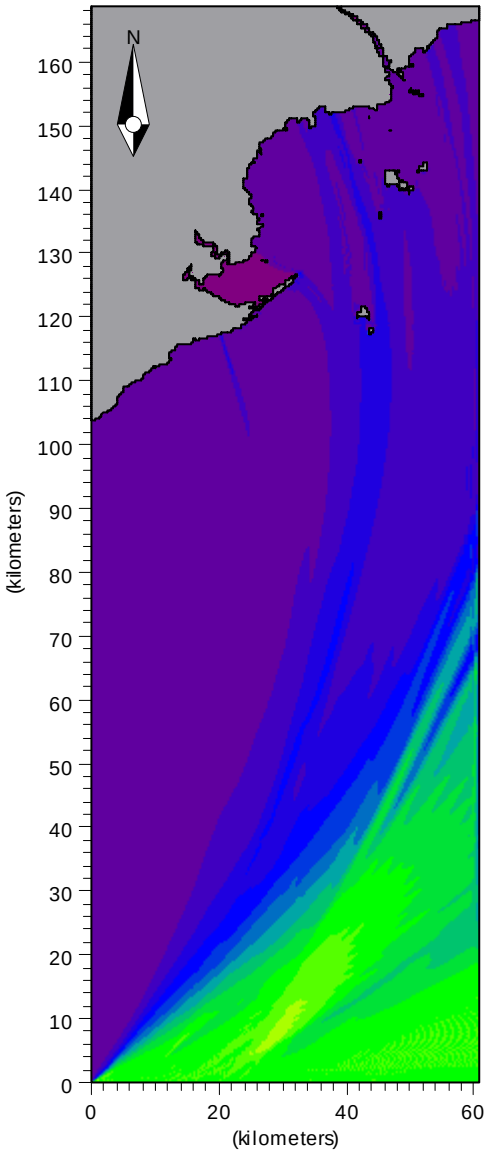
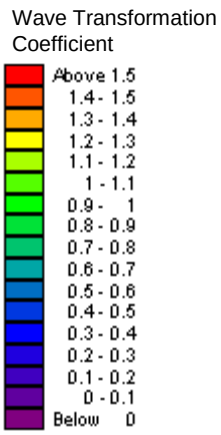
AUTORIDAD DEL CANAL DE PANAMA

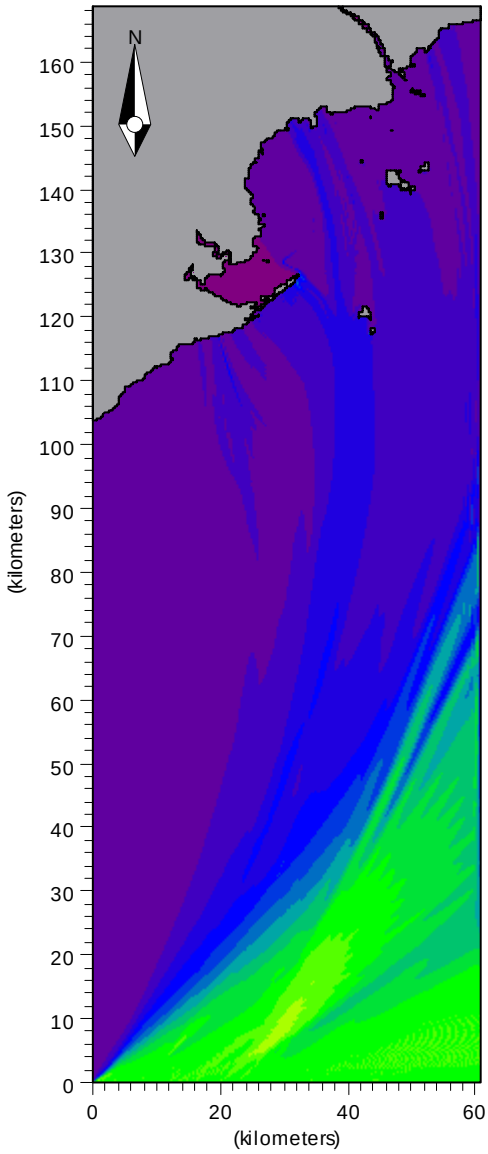
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-55:
Wave Transformation Coefficient
16 second waves from 235 degrees



Water Surface at MHWS





Water Surface at MLWS

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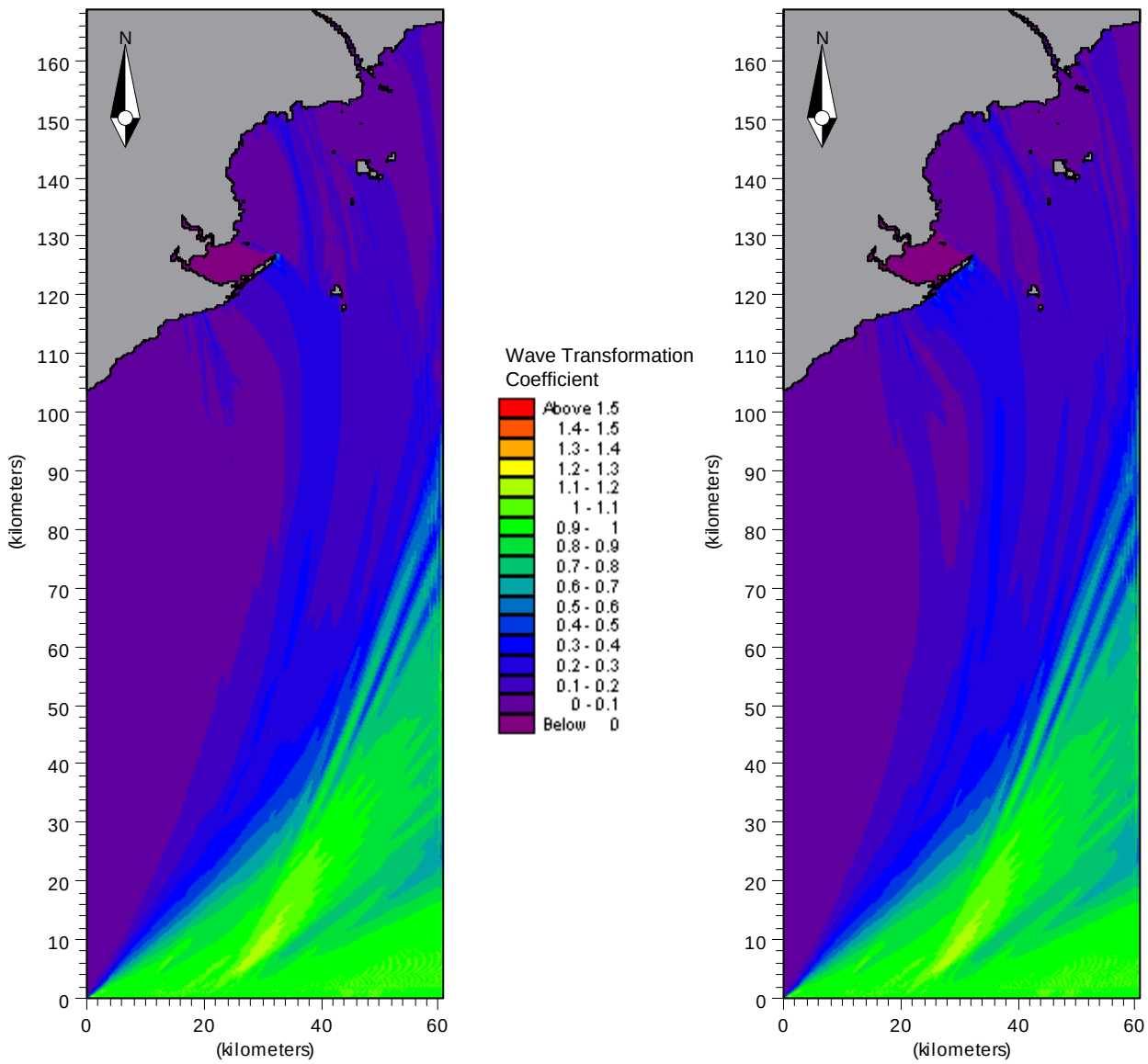
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-56:
Wave Transformation Coefficient
18 second waves from 235 degrees



Water Surface at MHWS **Water Surface at MLWS**

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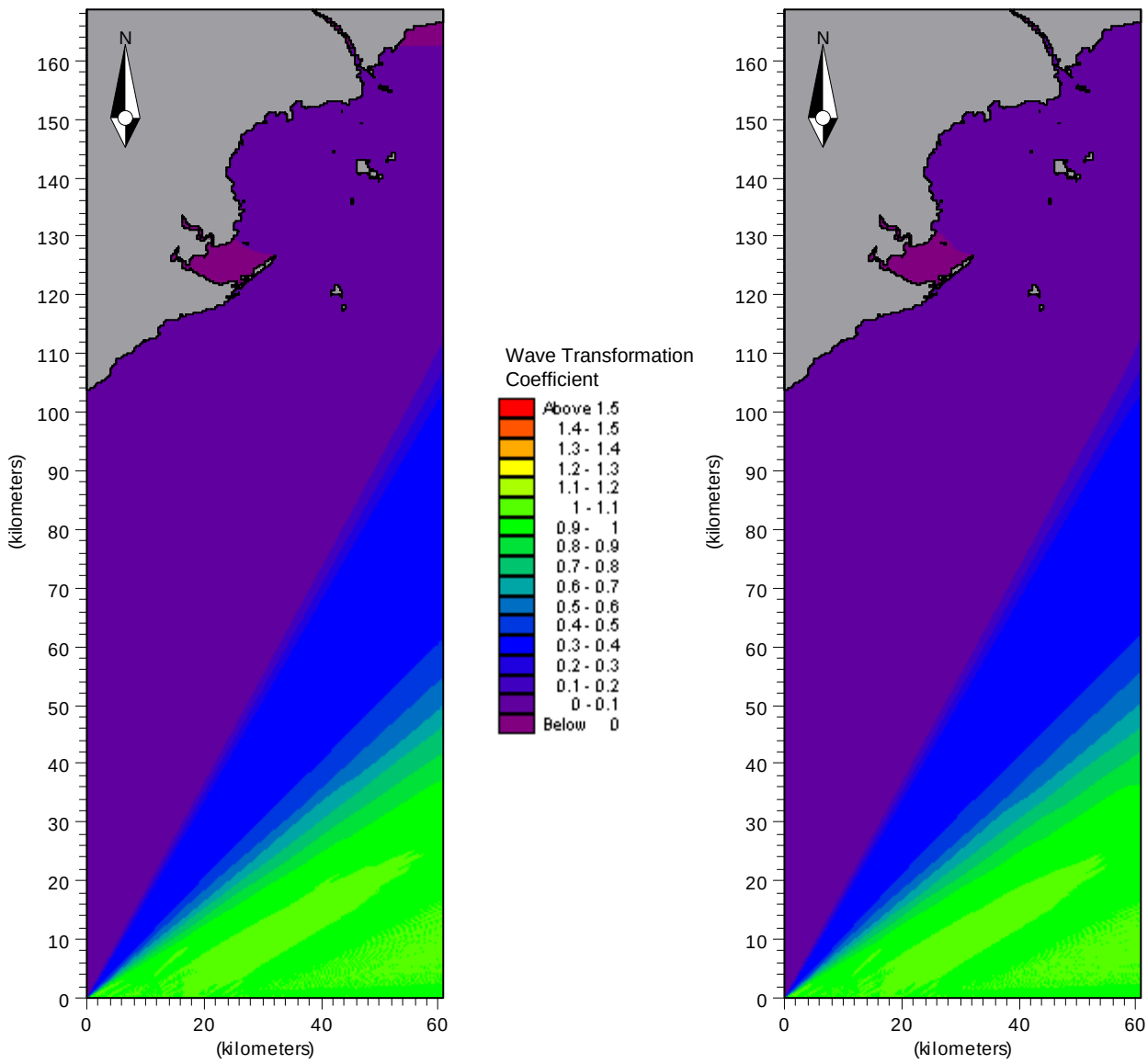
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-57:
Wave Transformation Coefficient
20 second waves from 235 degrees



Water Surface at MHWS

Water Surface at MLWS

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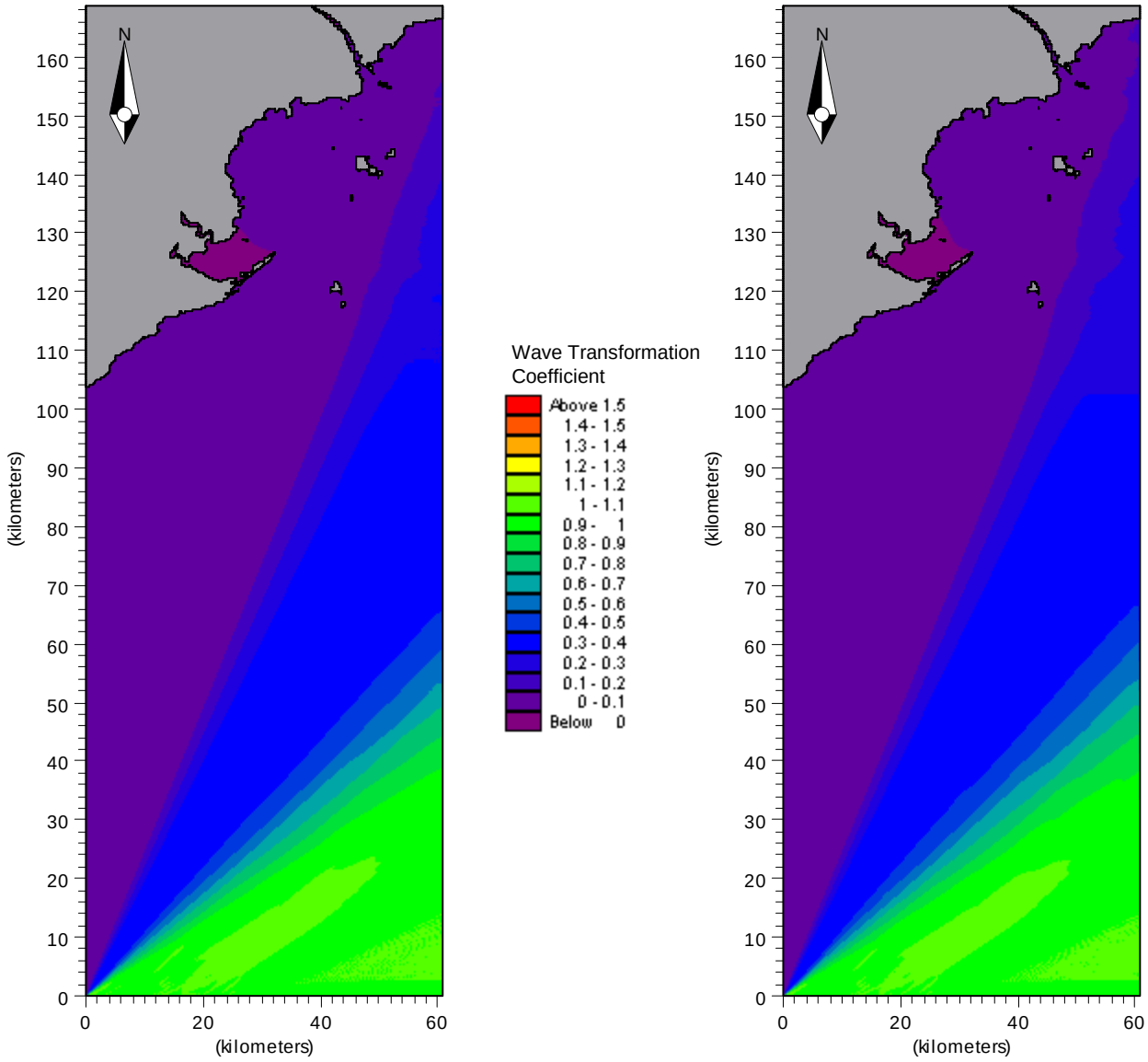
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-58:
Wave Transformation Coefficient
12 second waves from 240 degrees



Water Surface at MHWS

Water Surface at MLWS

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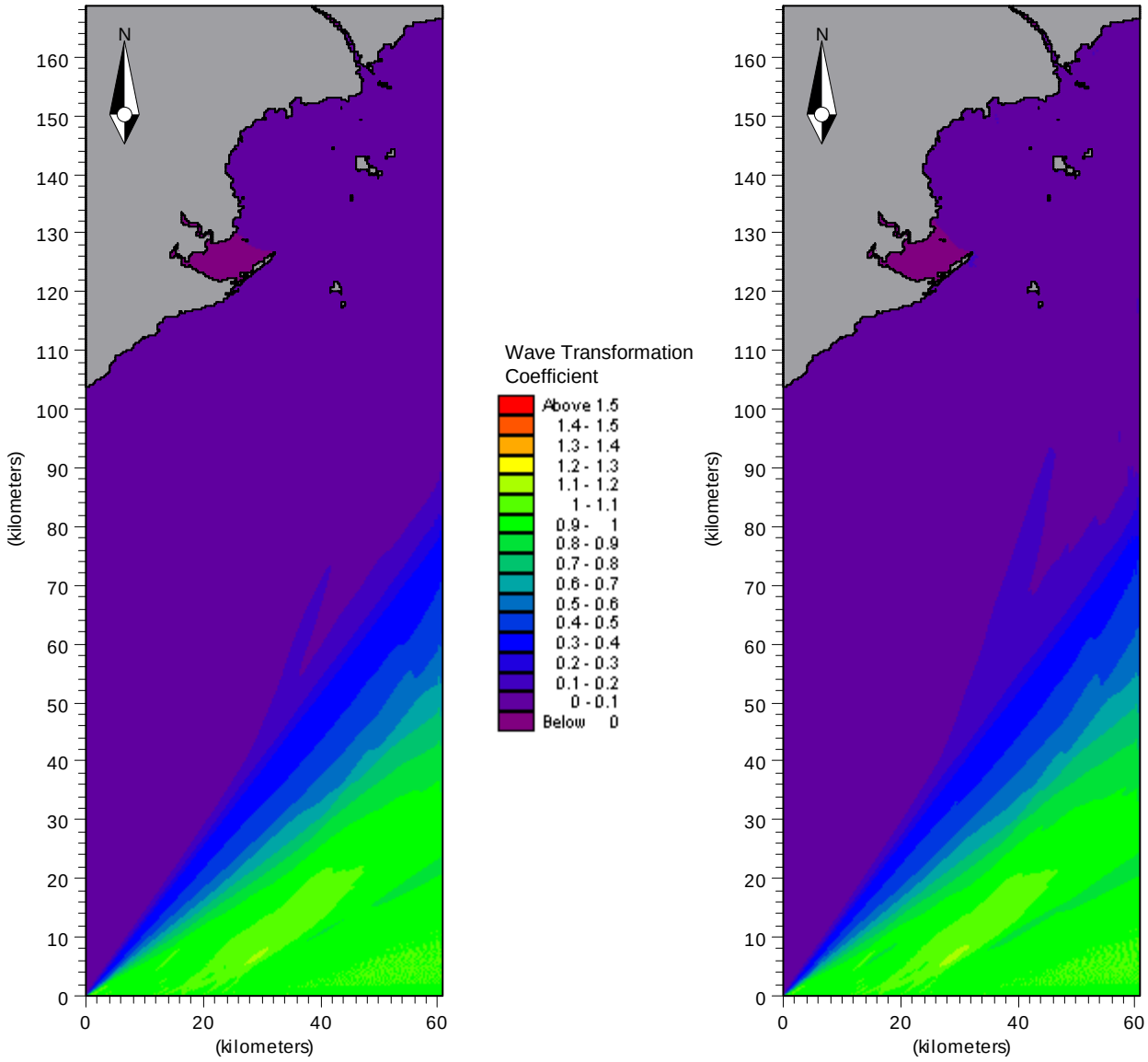
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-59:
Wave Transformation Coefficient
14 second waves from 240 degrees



Water Surface at MHWS

Water Surface at MLWS

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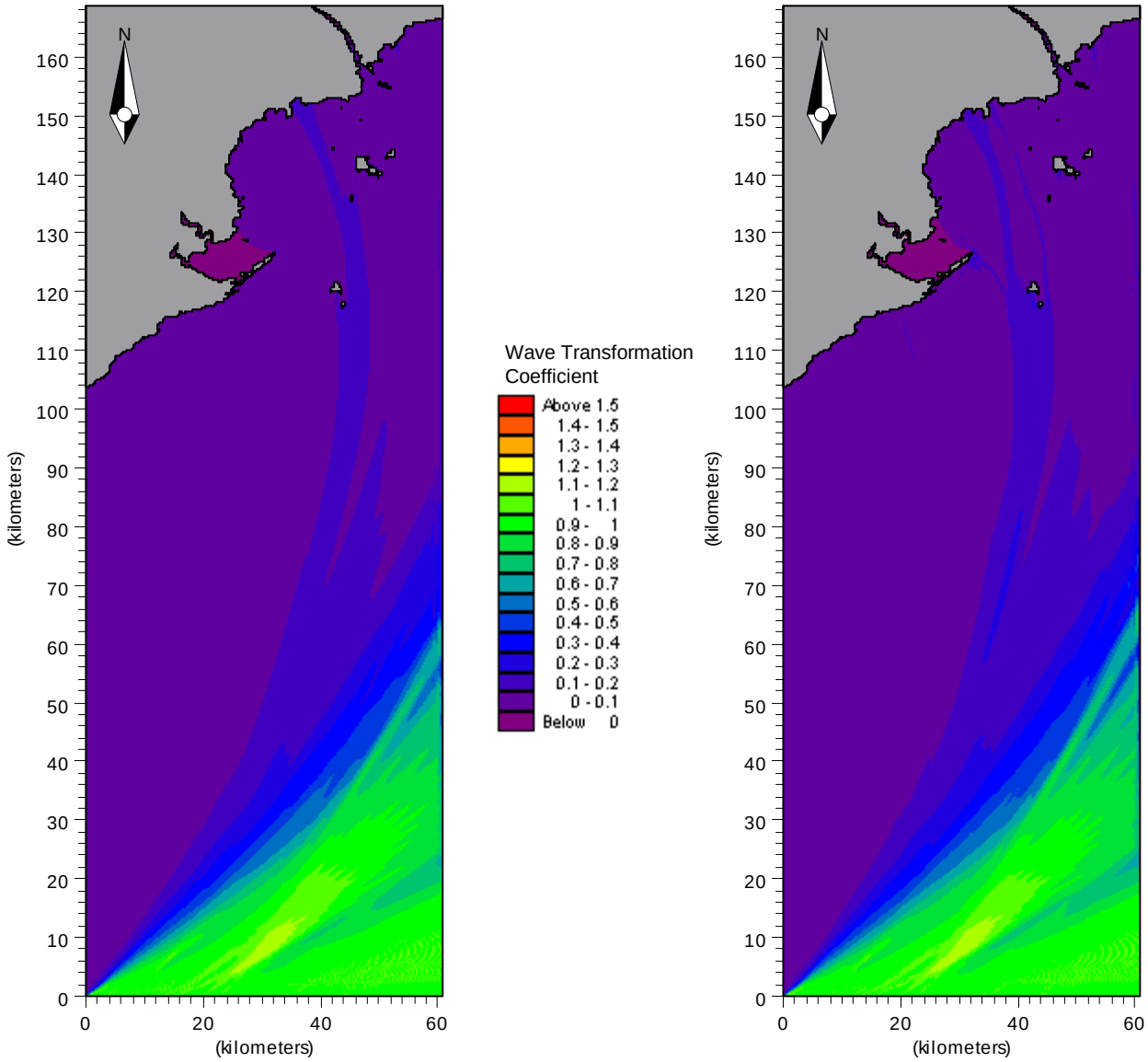
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-60:
Wave Transformation Coefficient
16 second waves from 240 degrees



Water Surface at MHWS

Water Surface at MLWS

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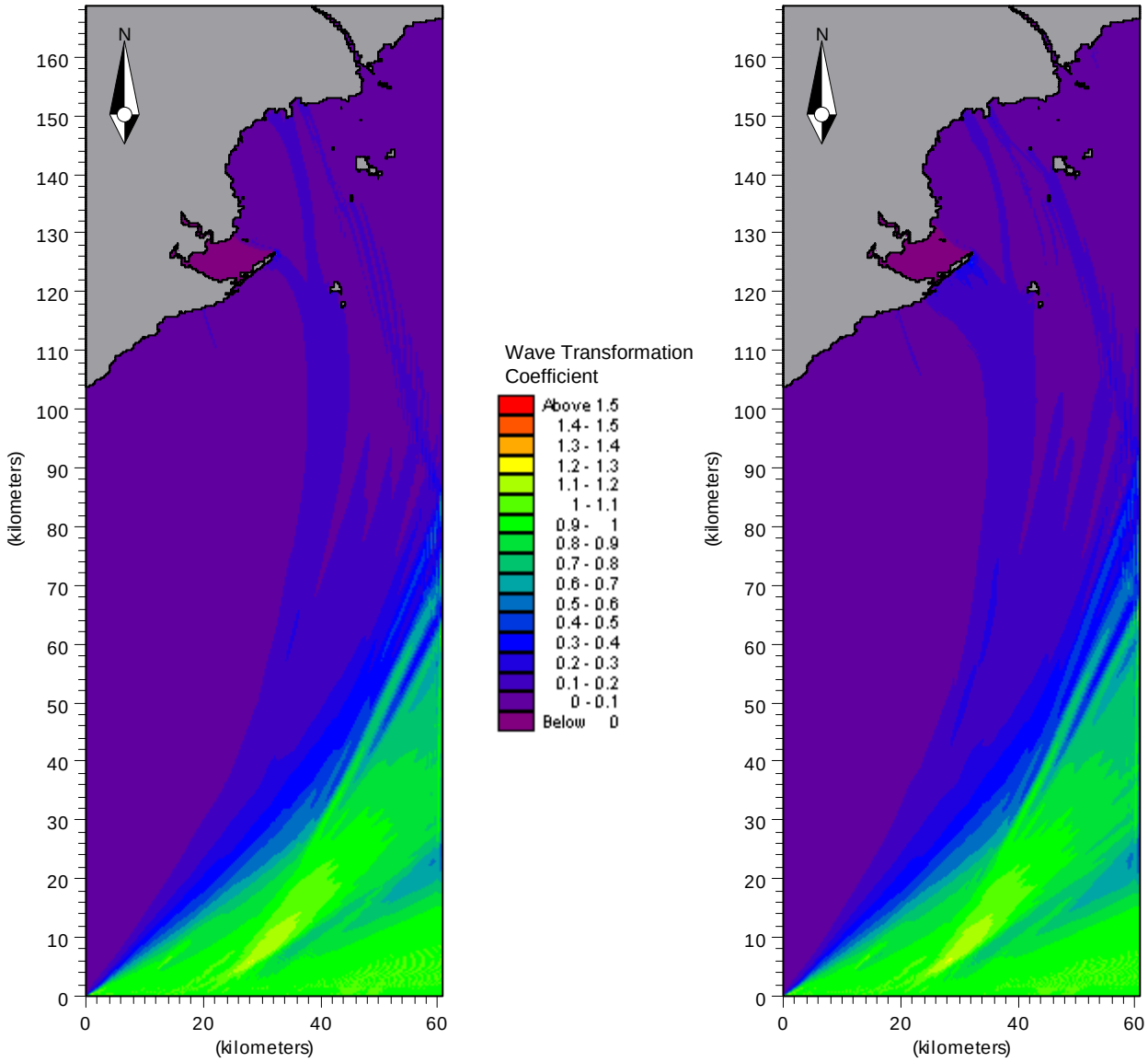
AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-61:
Wave Transformation Coefficient
18 second waves from 240 degrees



Water Surface at MHWS **Water Surface at MLWS**

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AUTORIDAD DEL CANAL DE PANAMA

ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-62:
Wave Transformation Coefficient
20 second waves from 240 degrees

WAVE TRANSFORMATION STUDY: PROPOSED ISLAND LOCATIONS ASSESSMENT

DRAFT REPORT

JULY 2003

Submitted by:

Moffatt & Nichol
ENGINEERS

1. INTRODUCTION

This brief report outlines the wave transformation and analysis study results for the proposed potential artificial island locations as part of the Panama Canal expansion. It essentially extends the wave transformation study provided in the "Wave Transformation Study: Existing Conditions – Draft Report" of July 2002 to examine the wave climate around the proposed islands.

The objective of this portion of the study was to determine and assess the wave climate conditions at the proposed island locations resulting from the propagation of the offshore waves to the edges of the islands. This information can then be used in the selection of the optimal island locations, island construction, and in decisions with respect to any shipping operations and wave protection requirements at the island locations.

2. PROPOSED ISLAND LOCATIONS

Five potential island sites were considered in this study. The possible islands are to be located south of entrance to the Panama Canal and north of Isla Taboga and Isla Taboguilla. The locations of each of the five potential islands and the associated causeway connections to land and dredged access channels are illustrated in Figure 1.

3. WAVE TRANSFORMATION ANALYSIS

The wave transformation analysis utilized the same approach as described in the earlier report examining existing wave conditions [1]. The Mike21 Parabolic Mild-Slope (PMS) model was used to calculate the transformation of the offshore waves to the proposed island locations. The PMS model was chosen for its capability to model wave changes due to the processes of shoaling, refraction , and diffraction, which is of importance in this case to represent the wave energy propagating around the existing islands offshore of the proposed artificial island sites. The previous transformation report details the existing wave climate and the modeling approach taken [1]. The primary alternation in this part of the overall study was the inclusion of the proposed islands into the bathymetry grid.

3.1 MODELED BATHYMETRY

The digitized bathymetric model grids and model regions were the same as those used previously [1] where slightly different grid sizes and spacings are used depending on the offshore wave direction and periods to be transformed. The only change to the bathymetry was the inclusion of the proposed artificial island under consideration. Each of the five potential islands was modeled separately on its own grid.

3.2 MODELED WAVE CONDITIONS

The offshore wave conditions transformed in the first part of the study [1] under existing conditions were used to determine which offshore wave conditions were to be

transformed in detail with each of the proposed islands included in the model. Existing wave conditions at the proposed island region were examined, and only wave direction-period combinations that resulted in wave transformation coefficients greater than 0.1 (wave heights of greater than 10% of the offshore wave) were modeled with the islands. Table 1 illustrates the wave conditions modeled. Model runs of unit wave height were preformed for high water (MHWS) and low water (MLWS) conditions for each direction-period pair. Each of these conditions was modeled for each of the five islands separately resulting in 300 model runs.

Table 1: Wave Conditions Modeled

Offshore Peak Wave Period (s)	Offshore Wave Direction (Az)						
	200	205	210	215	220	225	230
6	✓						
8	✓						
10	✓						
12	✓	✓	✓	✓			
14	✓	✓	✓	✓	✓		
16	✓	✓	✓	✓	✓		
18	✓	✓	✓	✓	✓	✓	
20	✓	✓	✓	✓	✓	✓	✓

Figures 2 and 3 illustrate the modeling results for an offshore wave from 200 degrees with a 16 second peak period, which resulted in some of the highest waves at the proposed island location.

4. MODEL RESULTS AND DISCUSSION

The configuration of the Bay of Panama and the sheltering presence of the natural islands (Isla Taboga, Isla Taboguilla, and Isla Uravá) result in considerable wave height reductions at the proposed island sites compared with the deepwater, offshore wave climate.

Based on the wave transformation coefficients calculated in the modeling, the offshore time series were transformed to wave time series along the exposed shorelines of each of the proposed potential islands. Conservatively, the largest wave transformation coefficient along each island face was used in the calculations. These transformed wave time series were then used to develop wave height exceedance curves along the islands. Figures 4 through 6 illustrate the percent wave height exceedance for each of the proposed potential island locations for both high and low water conditions. The figures are separated by the side of the island for which the wave height exceedances are plotted.

The deeper water channel between the existing offshore islands appears to allow some more severe wave energy to penetrate to the leeward of the island protective sheltering.

This effect can explain some of the observed modeled differences in wave climates along the sides of the various proposed artificial islands.

Based on the exceedance curves islands locations 2 and 4 appear to have the calmest wave climates. It should be noted, however, that this is based on transformation of offshore wave conditions and does not account for locally generated wind waves.

5. EXTREMAL WAVE ANALYSIS

The extremal analysis was based on the transformed annual maximum significant wave heights for the 31 year hindcast record (1970-2000) and used a Type I (Gumble) distribution approach. The transformed wave time series corresponding to the worst percent exceedance case of waves along the proposed islands was used for the analysis. The computed 100 year return period wave has a significant wave height of 0.7 meters and a likely period of approximately 17 seconds.

6. REFERENCES

1. Moffatt & Nichol Engineers, “Wave Transformation Study: Existing Conditions”, Draft Report, Autoridad del Canal de Panama, Artificiial Island Feasibility Study, July 2002.

APPENDIX G - SOCIO-ECONOMIC STUDY FOR ARTIFICIAL ISLAND SITE

AUTORIDAD DEL CANAL DE PANAMA

FEASIBILITY STUDY OF ARTIFICIAL ISLAND AT THE PACIFIC ENTRANCE TO THE PANAMA CANAL

INTERIM REPORT

SOCIO ECONOMIC OVERVIEW OF COMMUNITIES IN THE PROJECT VICINITY

MARCH 2003

MOFFATT & NICHOL ENGINEERS LOUIS BERGER GROUP

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1 INTRODUCTION

As part of a general assessment of options for disposal of excavated materials from the proposed Third Locks project at the Pacific Entrance to the Panama Canal, ACP commissioned a Pre-Feasibility[1] evaluation of the technical aspects of the construction of an artificial island located west of the Pacific Entrance Channel and due north of Taboga Island. The study concluded that the construction of the island was technical feasible and could offer significant economic benefits to the Republic of Panama. However, it also concluded that a detailed environmental and socio-economic evaluation of the impacts of the project was necessary.

This feasibility study now takes the technical, environmental and socio economic elements of the proposal to a higher level. The potential location of the island is being confirmed by geophysical and environmental evaluations of the project area, and data has been collected on water quality, shoreline conditions and other important elements of the Feasibility Study.

An important element of the data collection supporting the report is the assessment of the existing socio economic structure of the communities likely to benefit from or to be impacted by the construction of an island in the general area indicated in the Pre-Feasibility Study.

This report covers the initial data collection efforts that were undertaken in 2002 for the study. Although the study team did visit each of the communities discussed in the following paragraphs, it should be noted that no direct contacts were made to community leaders or local residents, due to the very preliminary nature of the studies and a desire to avoid unnecessary public reactions to alternatives that may be discarded later in the study process.

All of the data presented in the following paragraphs was obtained from public sources (e.g. hard data obtained from the Comptroller of the Republic of Panama) and through the utilization of “Observation Guidelines” (Exhibit 1). However, the team did learn that additional information (electronic data) on certain of the communities in the area is available from the Contraloría of the Republic of Panama at a relatively high cost. While there was insufficient budget in this study to cover the cost of this information, it is being collected under a separate study [2]and will be used in the final report for this Artificial Island Feasibility Study.

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[1] Preliminary Study of Island Development at the Pacific Entrance of the Panama Canal – Moffatt & Nichol & Louis Berger Group for ACP, December 2001

[2] Pacific Site Excavation and Dredging Material Disposal Alternatives Study – in progress

2 THE STUDY AREA

The initial pre-feasibility study work indicated an island location due south of the Punta Bruja – Howard AFB area, and to the north west of Taboga island. The site was selected on the basis of technical and environmental factors that included:

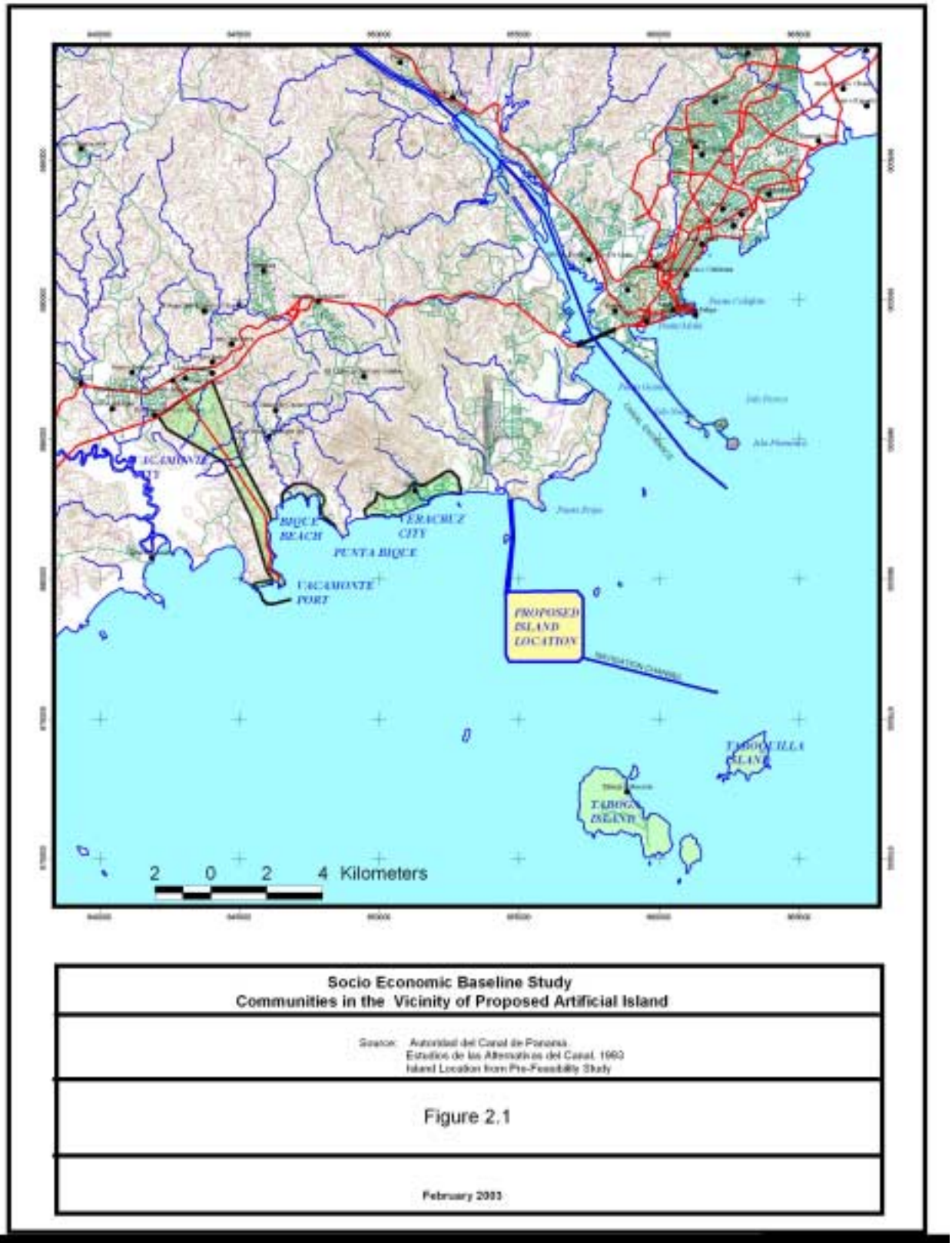
- Separation from Flight Approaches to the Howard AFB runway
- Avoidance of impacts to Veracruz Beaches
- Avoidance of environmentally sensitive areas at Punta Bruja
- Avoidance of Kobbe Beach
- Separation from Panama Canal Navigation Channels and Anchorages
- Technical and cost considerations

As noted earlier, the precise location of the island may shift once the ongoing geophysical studies have been completed. However, from a socio economic standpoint, the location indicated in Figure 2-1 gives a general indication of the proximity to the local communities in the study area.

Based on the results of the Pre-Feasibility Report, it was determined that the following communities, also shown in Figure 2-1, will be impacted or benefit from the construction of the artificial island:

- Taboga Island
- Bique Bay
- Vacamonte City
- Port of Vacamonte
- Veracruz Community

Figure 2-1: Communities Selected for Socio Economic Evaluation



The following discussion presents the results of the data collection efforts and site visits to these five communities, under three main headings:

- Community Characterization and Baseline Conditions
- Socio Economic Limitations and Potentials of the communities
- Discussion on Potential Impacts of the Project on community sectors and actors.

3 COMMUNITY CHARACTERIZATIONS

3.1 Community Characterization and Baseline Conditions

3.1.1 Taboga Island

Location & Description

The island of Taboga is located in the Pacific Ocean in the Panama Bay, 12 kms away from the capital´s coastline. It belongs to Taboga county and it is the capital of the district with the same name.

The population is distributed in the following neighborhoods: Barrio Esquivel, Barrio José Agustín Arango, Barrio Santa Rosa, Barrio Pueblo Nuevo, Barrio Congreso Arriba, Barrio La Teñidera and the Restinga, area where the Hotel Taboga and the condominium are situated. Residential houses for vacation, occupied by non resident population are located mainly in La Teñidera sector, where the Municipio of Taboga gave property rights.

Population & Housing

According to the population and housing census by the General National Comptroller, the island of Taboga reached in the year 2000 a population of 908 inhabitants, distributed in 231 houses. From the total amount, 56% (509) are men and 44 % (399) are women.

In Table 3-1 it is shown how the population in the island decreased in 2000 in relation to the years 1980 and 1990. In 1990, a slight increase of 196 individuals is observed in relation to the year 1980. The cause might be associated to events like the occupation by the USA Armed Forces in 1989 and the economic crisis.

Table 3-1: Population & Housing in Isla de Taboga Per Year

Data	1980	1990	2000
Population	1003	1199	908
Housing	222	249	231
Density per Km2	117.5	140.5	106.8

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

The surface[3] area for the island of Taboga is 8.53km^2; Table 3-1 shows the population density for year 2000 as 106.8 inhabitants per km^2, proportionally to the decrease of the island population. This can be explained by the fact that some locals have migrated to the capital to live there, as the island keeps a dependency with Panama City concerning to labor and commercial activities.

In the island of Taboga convergence several political relationships because of the concentration of municipal and public district services, such the Mayor, Municipal Courts, Health Center, National Police Post, offices from The National Environmental Authority and Electoral college.

Mobile and communication relationships out of the district (in order to cover basic needs and employment), happen through the aquatic transportation. Locals go to Panama City and Taboguilla (In this island only for employment needs).

The relationships identified are as follows:

Commercial: The provision of food (excluding fish, seafood, and some fruits easily acquired in the island) is made in the capital supermarkets with a weekly and monthly frequency, and even every fifteen days. The frequency for acquiring other items (clothing, appliances, and others), beauty parlor, and medical care, can be every three to six months, or even annually.

Labor and employment: The population goes to the job centers in Taboguilla island, where two companies are located, and employ a significant percentage of Taboga´s labor force. One of the companies is fish processing factory and the other is a recently constructed fuel oil tank farm and bunkering operation.

Educational and cultural: Includes the children, youth and other family members, who develop educational and cultural activities outside the Taboga district, generally in Panama City. These individuals come back to Taboga according to their possibilities every week, two weeks, fifteen days, monthly, or according to school vacation time.

Table 3-2 shows that the island of Taboga concentrates the largest population in the district (64.8 %), and it is a clear representative of the demographic characteristics of the area.

---

[3] **Panamanian National Atlas, 1988.**

Table 3-2: Population of Taboga District, - Corregimiento & Populated Site, Yr 2000

Population	No.	%	Density per Km^2
District of Taboga (Otoque Occidente, Otoque Oriente, Taboga City)	1,402	100.0	107.8
Taboga (Isla)	908	64.8	106.8
Otoque Occidente	295	21.0	86.8
Otoque Oriente	199	14.2	180.9

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

The island of Taboga has 66.08% of its population between the ages of 15 and 64, being the average 32 years old. There is an average of 3.7 members per house. The average of birth is 2.3 %. In 79.2 % of the houses, the men are the main source of income. Illiteracy represents 1.07%, of the adult population (refer to Table 3-3).

Table 3-3: Socio-Demographic Indicators - Island Population. Census, Yr 2000

Indicators	Value
Average of members per house	3.7
Percentage of population under 15 years of age	21.26%
Percentage of population between 15 and 64 year of age	66.08%
Percentage of population of age 65 and over	12.67%
Male indicator (number of men per 100 women)	127.6
Average age in total population	32
Percentage of houses with male as main source of income	79.18%
Percentage of houses with female as main source of income	20.82%
Average Birth rate per woman	2.3
Percentage rate for ages of 10 and over	1.07%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

It can be seen in Table 3-4**,** that in the 2000 year only 5 births were registered, reflecting a decrease related to the previous years.

In the island of Taboga there are not any health problems connected to lack of hygienic conditions and proper nourishment. The population seems to be healthy.

Table 3-4: Birth Rate in Taboga Island, Years 1996-2000

Population	**Birth Rate**				
	1996	**1997**	**1998**	**1999**	**2000**
Taboga Island	***15***	***15***	***8***	***9***	***5***

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

The island has diverse architecture. Houses with colonial style can still be appreciated, and they are wooden two-story houses, with balcony. Modern urban tendencies replace traditional styles with concrete and other materials and design.

In Table 3-5 some characteristics of houses in the years 1990 and 2000 are shown. It can be observed that there has been an improvement of the conditions related to sanitation, electricity, radio and television.

Table 3-5: Characteristics of Houses in Taboga Island

Characteristics	**1990**	**2000**
Dirt Floors	2	2
Without potable water	3	4
Without latrines	18	5
Without electricity	5	1
Wood powered cooking	3	---
Without television	28	9
Without radio	66	34
Without telephone	193	?

Coal powered cooking	---	---

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Infrastructure

Taboga Dock: There is a constant movement related to visitors, residents, workers in Taboguilla or distributors of goods that help to move merchandises from the boat to the island.

Road Infrastructure: Streets are small, narrow, and steep. Access to the ANAM office, the desalinization plant and the open landfill is through a rough road in bad condition.

Parks: There are small parks with well maintained gardens, one of them with entertainment for children. Some of the parks have been donated by a local resident. The square in front of the church has been adapted to play basket-ball.

Electricity: The company Electra is responsible for supplying electricity to the island, having the Taboga Hotel and the condominium an extra plant in case of necessity.

Water supply: IDAAN provides potable water to the community through local wells, and it is distributed by sectors every three days, reason by which most of the houses keep a deposit tank. There is a desalinization plant currently damaged and therefore, not in use.

Waste water*:* IDAAN it is constructing a plant to treat waste water. Currently, the waste water is dumped into the ocean far from the Taboga community.

Communication Network: There are 6 public phones, one of them inside the Taboga Hotel.

Services

Primary School: The Benjamín Quintero elementary school has 80 students enrolled for the year 2002 in courses from 1st to 6th grade. It also offers kindergarden education.

Teachers travel daily between Panama City and Taboga.

Secondary education (high school level) students have to go to Panama City.

Health care and Sanitation: There is a Health Center with equipment and personnel appropriated to offer services in dentistry, general medicine, maternal care, monitoring of children under 5 age, program for school health care, sexual education for youth (14 to 19 age), pregnancy control until 15 days previous to delivery (for that service, patients have to go to the capital).

There is a laboratory that offers services twice a week, also, the National Service for the Eradication of malaria (SNEM) controls once a week *Aedes Aegipty* and other disease

carriers. There has not been any case of dengue, thanks to an educational program to prevent the transmission.

The daily average of patients is 20. Personnel include a general physician, a nurse, a nurse assistant and a lab technician. Most of them come from Panama City. The medical service offered in Taboga is from Monday to Friday from 7:00 a.m. to 3:00 p.m. There are three medical tours per year going to the counties of Otoque Oriente and Occidente.

There is a boat to transport the ill to the city, in case of casualties, but sometimes it is not available as it is used for the medical tours.

There is not an office of the Social Security Agency. Retirees travel to the capital to collect their social security payments every two weeks or once a month.

Religious: There is a catholic church assisted by a priest assistant on Fridays and Saturdays. It is popular during the festivity of July 16 dedicated to Virgen del Carmen, saint patron of the island and the fishermen.

Waste disposal: Residents pay B/.1.00 monthly to the Municipality for the pick up service of solid waste. The waste is disposed openly and burnt. There are bins for garbage disposal, located in major pedestrian areas.

The Panama Municipality and the Association for the conservation of Nature (ANCON) cooperate in the cleaning of the beaches.

Municipal Cemetery: It is located on the way to the ANAM office and the open landfill.

Transportation (maritime) Panama-Taboga-Panama: Transportation in the island takes place by boats doing daily round trips between Pier 8 at Balboa Harbor, Panama City and Taboga. Transportation companies are Calipso Queen and El Expreso. The trip lasts approximately 35 minutes with a cost of B/.8.00 round trip.

Internal Transportation: A private car offers transportation services, and there are also a couple of tourist cars very practical for the small streets.

Hotels: There are two hotels on the island, the Chu Hotel located in Playa Honda, with colonial style, and Taboga Hotel, situated in La Restinga.

Taboga Municipality: It collects taxes, applies sanctions. The building where it is located also houses the offices for the mayor, municipal court, district attorney and treasury.

National Post Office: Non-existing in Taboga. There is a post-man who distributes the mail once a week.

Maritime service and public force: There are two officials working permanently, and the personnel is reinforced during week-ends and festivities.

Panama Maritime Authority (AMP) . AMP counts with an office and the Taboga dock. The personnel cares for the security of the activities (industrial, artisan, or recreational) on the sea. Problems reported by the personnel are: irregular urgency boat service, pollution

from oil spills between the Balboa and Taboga docks and the waste from the factory in Taboguilla, which is dumped into the sea from their processing.

The Port administrator and a person in charge of security work at the Taboga Dock.

National Environmental Agency (ANAM). This institution manages the wildlife refuge, a 256 ha of protected area, 95% of which is private. It is designed to enforce the importance of bird nursery. ANAM counts with a boat for the monitoring of the island. There are two officials in the building, which is situated at a remote location on the way to the desalinization plant.

Existing Organizations

The Comunal Junta: The Comunal Junta, through Law 106, is the institution for local authority with board of directors who are the president (the *county representative*), a *secretary* , a *treasurer*, an *attorney* and two *assistants*.

The Comunal Junta in Taboga, according to its President, it is not functioning because of lack of funds and permits for its activities.

The Taboga Civic Society of owners: This association is constituted by 120 members, who pay each B/. 50.00 per year. They focus on activities such as: cleaning the beach (5 people), post-signing in the parks and streets, cultural exhibitions in the gardens situated inside the monastery ruins.

Taboga Lions Club: This group functions as a donor for the community in some social needs such as health problems or petrol provision for the emergency boat, among others.

The Elementary School Parents Club. They organize activities aiming to improve the school and its cultural events.

Religious Organizations: There are two committees in charge of organizing the festivities around the Virgen del Carmen and the Cristo de los Milagros de Buga.

Organizations in the neighborhood: It was seen the existence of small organizations who self-organize to gather resources according to their activities.

The **fishermen** are not organized in any form, even though fishing is an economic activity present in every day life at the island. They support each other through solidarity and friendship.

Production Activities

Artisan fishing: It is an important economic activity for the locals, being undertaken individually or in groups of two or three. There are no more than 20 fishermen. Fish is sold to *tuna ships*, to the Taboga Hotel, to locals and in Panama city (in El Terraplen, the sea food market, restaurants and hotels). Species more frequent are: *jurel, sierra, pargo, corvina, mero, róbalo*, among others, being fished less than 1 km away from the coast. Also, some local fishermen work in the shrimp boats to get extra income.

Some of them capture lobsters, octopus and other seafood in the rocky areas close to the coast. The method of fishing in this case is the *harpoon* and the sites el Morro, sank ships and under the dock. For the fish species they fish by hand, using *fishing net.*

The ***pangas* (boats)** are wooden-made with engine. They cost approximately B/.3,500: B/. 2,000 for the boat and B/.1,500 to pay for the engine.

Agriculture: The type of agriculture found is organic, with crops from pineapple, *ñame, yucca*, mango and others. They cultivate in small pieces of land or *farms* behind the houses, deep into the island, around the East side of the island and behind Taboga Hotel.

Shops and Stores: There are 8 small permits dedicated to food selling and souvenirs. The majority of the sellers come from the central provinces in Panama.

Tourism: Taboga Island, due to its natural and cultural interest, attracts the tourists, who visit the beach and stay at the hotels during the week-ends. The tourism has provided jobs, income, and culture development, among other benefits. But the benefits come mostly from foreigner as the national visitor does not spend too much.

In the present time, income from tourism has decreased, especially from Monday to Thursday, being the Taboga Hotel almost empty during those days. Owners of second residency houses spend the week-ends at the island.

Industry: There are two enterprises that provide jobs for locals and people from the capital, the Empresa Taboguilla, a fish processing factory with 45 male employees, and the recently constructed oil tank farm and bunkering facility which employs between 10 and 15 individuals.

Informal economy: Among the informal economic activities that sustain locals at the island are the following:

- Maintenance and security of residential houses.
- Maintenance of boats.
- Distribution of merchandise and luggage from the dock.
- Aquatic tours for visitors.
- Sales of souvenirs and crafts.
- Reselling of household appliances.
- Fishing related activity:
    - The tuna fishing boats offer jobs to take fish from one boat to the reefer vessels, which come from different nations (Colombia, Venezuela, Spain, Ecuador, Puerto Rico). Labor is employed for 4, 5, 7 days, two weeks or the time needed. The average salary can reach B/. 400.00.

- Some jobs can be provided for the activity of *fishing net thrower*, which is dangerous and implies physical risk (accidents have been reported with lose of fingers due to the use of bombs for the gathering of tuna).

- Laundry service is paid to women in the island by the large boat personnel.

Formal economy: There are a significant number of formal jobs in which locals are employed, whether in official institutions (Panama City and Taboga Island) or the private sector (Taboguilla).

Social Patrimony in Taboga Island

The island of Taboga has an important historic and natural patrimony. The wildlife refuge, created in October 21, 1984, is considered to be a Sanctuary for Migratory Birds (there are between 75 to 85 thousand birds).

The following pages contain recent photographs taken at Taboga (photographs 1 to 22).

Photo 1. Plaque on the discovery of Taboga Island on 1513.

Photo 2. Visitors from Panama City arrival to Taboga pier.

Photo 3. Unloading products from arriving ships is part of the informal economy of the island.

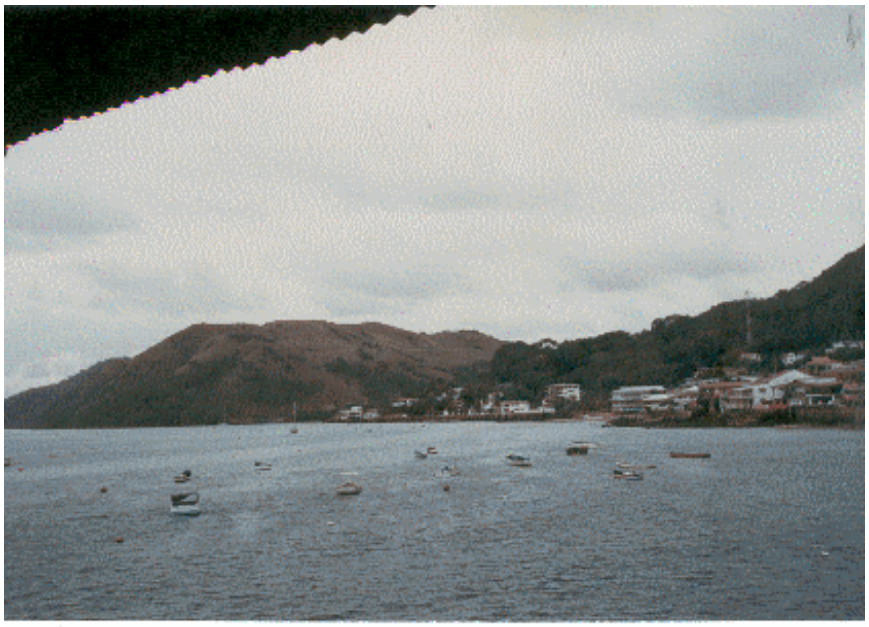


Photo 4. Panoramic View of Taboga town from pier.

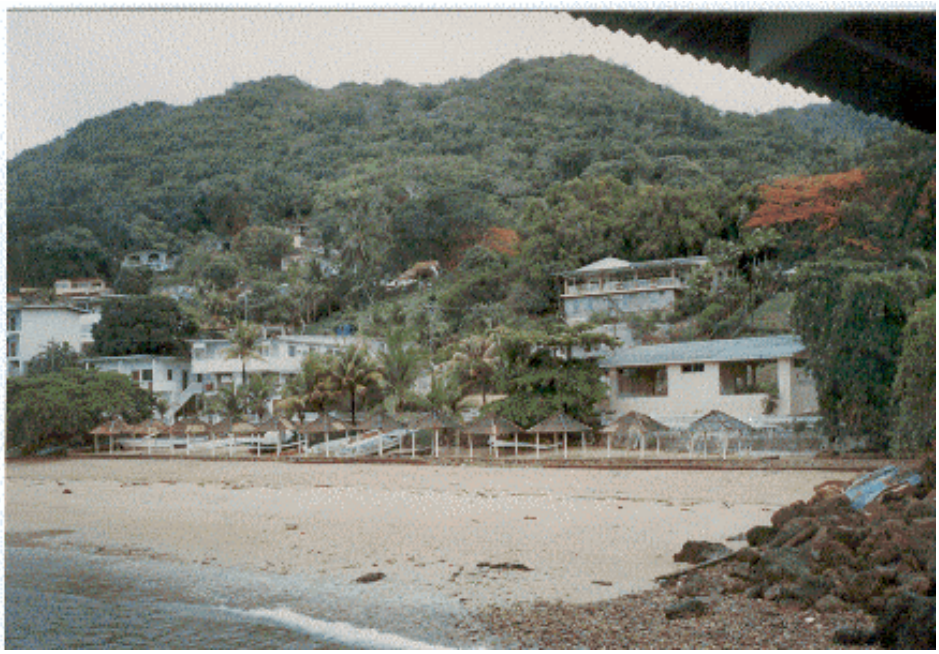


Photo 5. Small houses on Taboga Beach

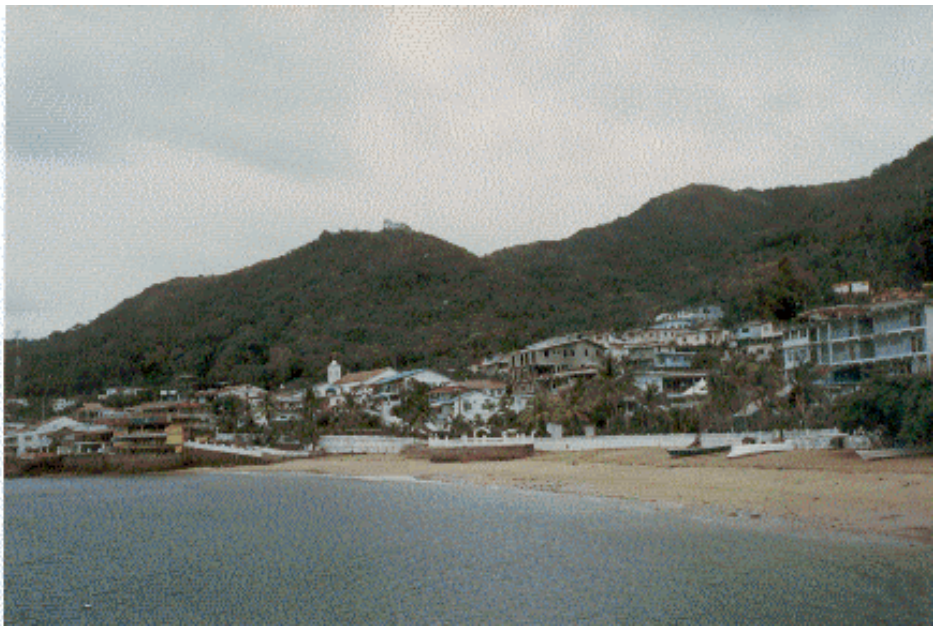


Photo 6. Panoramic View of Taboga town from pier

Photo 7. Hotel Taboga beach on low tide.

Photo 8. “El Morro” island from pier.

Photo 9. Beach in front of “El Morro”

Photo 10. Garbage washed in with the tides is collected in bags

Photo 11. Tuna ships and fish distribution takes place right in front of the island

Photo 12. Ship from Taboguilla arrives to Taboga. Ship is shuttle for workers employed ar Taboguilla's industries

Photo 13 Artisan Fishermen leaving for fishing grounds .

Photo 15. Artisan fishermen leaving for fishing grounds & anchored tuna ships.

Photo 15. Homes have tanks to store water during system's failures.

Photo 16. Desalination Plant (not in use)

Photo 17. Paved road at the access to town, and old souvenir store.

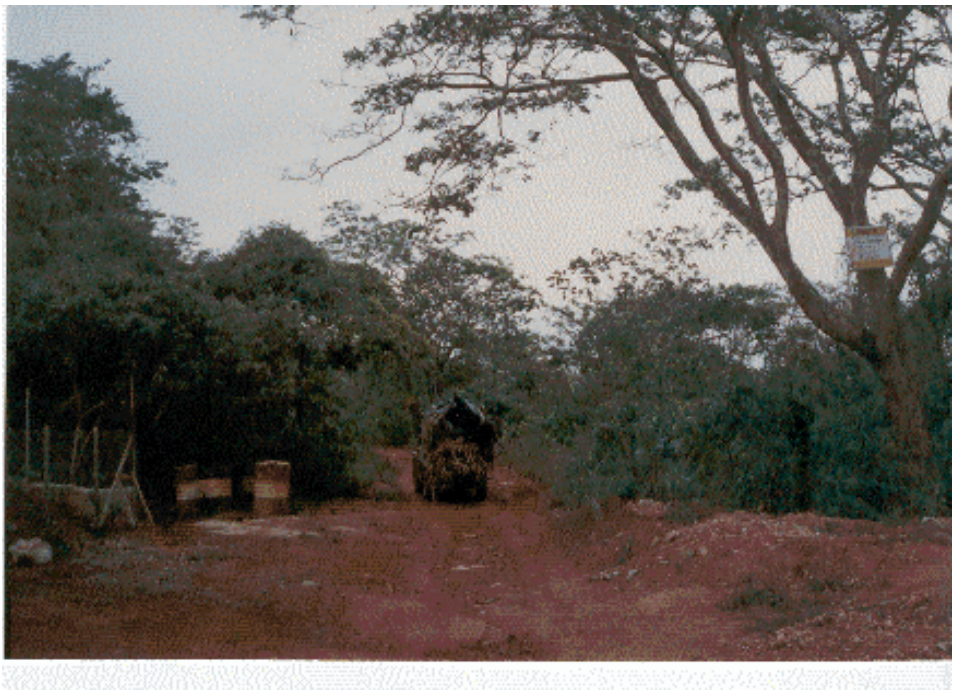


Photo 18. Garbage truck on its way to burning site.

Photo 19. Church and central square at Taboga

Photo 20. Hotel Chu in Taboga. Building is 80 years old and an example of old English architecture in the island.

Photo 21. Monastery ruins from Spanish colonial times.

Photo 22. Commemorative plaque at square.

3.1.2 Bique Beach

Location and Description

Bique Beach is a fishing community belonging to the Arraiján county, Arraiján District and Panama Province. It is located at the shoreline of the Pacific Ocean in the Panama Bay, nearby the Veracruz community. Bique village is situated inside the Gambotti family private land (farm). According to locals, the first inhabitants in the site have been there for more than 40 years.

Population and Housing

According to data from the Panama national comptroller, the community reached a population of 350 distributed in 86 houses. By comparing data from year 2000 with those from years 1980 (216) and 1990 (261), a balanced population increase can be observed.

Table 3-6: Sociodemographic Indicators for Bique Beach Population Characteristics of Houses in Taboga Island

Indicators	Value
Average of members per house	4.10
Percentage of population under 15 age	42.00%
Percentage of population between 15 and 64 age	54.86%
Percentage of population of 65 age and over	3.14%
Male indicator (number of men per 100 women)	112.1
Age average in total population	19.0
Percentage of houses with male householder	86.05%
Percentage of houses with female householder	13.95%
Average of children (surviving newborn) per woman	3.5

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Table 3-6: Sociodemographic Indicators for Bique Beach Population Characteristics of Houses in Taboga Island6 shows how the majority of the population is between 15 and 64 years of age, with an average of 19. Equally, a significant percentage under 15 can be observed, showing a young adult population with a tendency to be maintained, unless they migrate.

Local Economics

Social relations are determined by dependency among locals in Bique and nearby villages related to fish sales, and other services as shown next:

The sales of sea products are in Alto Bonito, Arraiján capital, Vista Bella, Vacamonte Port, Chumical de Veracruz and Chumical de Vacamonte. The selling is retail and in fixed places.

For provision of household appliances, clothing, and medical care they go out of the community each month, three, six or even once per year. They go to El Rey supermarket located in the county of Vista Alegre and El Machetazo supermarket located in the Juan Demóstenes Arosemena county.

Members of this community attend to the Social Security Agency (C.S.S.) in Arraiján capital and other health centers in Arraiján.

Table 3-7, shows how bad living conditions are in Bique beach.

Table 3-7: Characteristics of Occupied Houses in Playita de Bique Community

Characteristics	1990	2000
Total	60	86
Dirt Floors	19	21
Without potable water	27	2
Without latrines	13	10
Without electricity	14	6
Wood powered cooking	17	11
Without television	0	28
Without radio	28	25
Without telephone	22	86
Coal powered cooking	57	85

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Infrastructures and Services

Primary School: There are grades from the 1st to the 3rd in this school, which is the only institution present in the community. Two teachers travel daily to the school. After the 3rd grade, students enroll at San Vicente del Bique elementary, located in the neighbor community. They walk to class or use family transportation.

Secondary studies are available at new Arraijan Junior High, in the Juan Demóstenes Arosemena county, the Cristóbal Adam Urriola Junior high or the Basic Center Estela Sierra, located in the capital county.

Catholic Church: Assisted by a priest from Arraijan capital.

Potable water supply: There is a well, turbine-powered, to provide water through the pipelines to the houses.

Electricity: Through the national service.

Sanitation: Almost all houses have latrines

Solid waste management: No service provided, being the solid waste all around the houses.

Transportation and communication services: This community is dependent on land and water transportation system for daily life. The former for keeping their economic, social and cultural activities and the latter for the fishing activity, which is the main source of income for locals.

Access to the community is through the entrance to the Gambotti property, continuing through a dirt road surrounded by land with livestock.

Collective transportation service is provided by a pick-up from Bique beach to the nearby San Vicente de Bique.

Organizations

Bique beach does not have any recognized organizations.

Economic Activities

Artisan fishing: The majority of the population is dedicated to artisan fishing of corvine and cojinua, mainly, and also of shrimps.

Shell collection: All family members participate in this collective activity in the beach and the mangroves area.

Other sources of income:

- A few men work in the Gambotti family land.
- Most of the Bique women work temporally in the shrimp processing factories in Vacamonte Port. Other women work as domestic employees in nearby villages.
- Some locals have permanent or temporary jobs in Panama city, Arraiján, Chorrera and Vista Alegre.

Cultural Heritage

Artisan fishing is a traditional way of life in Bique beach.

There are some historic ruins from the colonial period, registered in the studies that have been made by the ARI on land use in the Canal area. According to the National Cultural Institute, as long as there is no specific administrative resolution, these ruins are protected by the Law No. 14, from May 5, 1985. General regulations point in these cases that it is prohibited to build in the 50 meters around the ruins. In the case of a project of great scope, required permission has to be submitted to Historical Patrimony.

The following pages contain recent photographs (numbered 23 to 30) taken during field work in Bique

The following pages contain recent photographs (numbered 23 to 30) taken during field work in Bique beach

Photo 23. Bique Beach and mangroves.

Photo 24. Panoramic view of mangroves from Bique. The access road to Vacamonte Port can be seen in the background.

Photo 25. Mangroves at Bique beach at low tide

Photo 26. “Panga” boat used by artisan fishermen.

Photo 27. During low tide the local population collects bivalves on the Bique beach.

Photo 28. Artisan fisherman repairing fishing net at Bique beach

Photo 29. Bique beach at low tide

Photo 30. Bique beach at low tide

3.1.3 Vacamonte City

Location

Ciudad Vacamonte belongs to the county of Vista Alegre, Arraiján district and Panama province. It is a relatively new community, having grown following the construction and opening of the Vacamonte Port in 1976/1977

Population and Housing

According to the census by the national comptroller, in the year 2000 Vacamonte City reached a population of 25,281 inhabitants distributed in 6,425 houses.

Table 3-8: Population of Corregimiento de Vista Alegre

Population	**2000**
Vista Alegre county.	39,097
Vacamonte City	*25,281*
Altos del Mirador	305
Residencial Vista Alegre	5,521
Vista Alegre	7,790
San Vicente de Vique	200

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

In Table 3- we can observe a significant concentration of population in relation to other inhabited places. It presents a considerable increase in 2000 as there were only 232 inhabitants in 1990.

Vacamonte City is located inside an area of fast growth such is Arraijan district, where from the decade of 1980 several villages were generated: 16 de Octubre, Los Guayacanes, 13 de Febrero, 2000, Omar, Rogelio Paredes, Loma Cobá, 7 de septiembre, Cristal, y La Paz. Part of this growth is reflected in the increase of population in Arraijan registered in the 1990 Census (61,849 inhabitants) in relation with the 1980 Census (37,186 inhabitants). On the other hand, the data for Vacamonte City reflects an intense and fast increase in the decade 1990 to 2000 (particularly in the county of Vista Alegre), linked to the development of new areas such as the urban developments in Vacamonte City. It is worth mentioning that many residents in Vacamonte City travel daily to the work areas located mainly in Panama City. For supplies they go shopping to areas like Súper Centro Mi Ciudad at the entrance to Vacamonte City or El Rey supermarket, in Vista Alegre.

The main roads used by these residents are the Panamerican highway and Panamá – Chorrera highway.

The population in Vacamonte City is constituted mainly by immigrants from Panama City and other provinces, having jobs whether in public institutions or the private sector.

Vacamonte City was initiated as a socially oriented urban project with low interest credit lines to allow low income families the possibility of purchasing new homes. Neighborhoods generated with this urban project were El Tecal, Vista Azul del Tecal, and Sol de Tecal, among others. Currently, this particular project is expanding.

Table 3-9 shows the young adult population in Vacamonte City, with ages that range from 15 to 64, being the average person 26 years old. The majority of households are sustained by working men.

Table 3-9: **Socio-Demographic Indicators for the Vacamonte City Community**

Indicators	**Value**
Average members per house	3.90
Percentage of population under 15	34.09%
Percentage of population between 15 and 64	63.64%
Percentage of population of 65 and over	2.27%
Male indicator (number of men per 100 women)	92.80
Age average in total population	26
Percentage of houses with male householder	77.44%
Percentage of houses with female householder	22.56%
Average of children (surviving newborn) per woman	1.8
Percentage of illiterate persons of 10 age and over.	1.55%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Table 3-10 shows the housing living conditions existing in the year 2000.

Table 3-10: Characteristic of Houses in Vacamonte City

Characteristics	1990	2000
Total	**37**	**6,425**
Dirt Floors	0	25
Without potable water	0	13
Without latrines	0	5
Without electricity	0	20
Wood powered cooking	0	3
Without television	0	1
Without radio	2	106
Without telephone	34	490
Coal powered cooking	0	3,177

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Infrastructure and Services

There are common public services of urban areas, such: telephone, cable TV services, electricity, sewage, pharmacies, clinics, private and collective transportation, educational centers for primary and secondary education, road infrastructure. There is access to the city through two of the main country roads: Panamá-Chorrera highway and the Panamerican highway, having the possibility of communicating with the capital and the rest of the provinces.

Photo 31. Main road in Vacamonte

The residents have several options for purchasing fresh fish, such as:

- Fish is sold mainly at the public market
- The sea food market in Vista Alegre, 3 minutes away from Vacamonte city. The market offers fish species like corvina, pargo, tuna, among others, and seafood like shrimps. This market was built by the Comunal Junta from Vacamonte. The selling places are rented to members of ASOCEPROM, (Association of buyers and retailers of sea Products) and other fish sellers. Typical purchase prices are: corvina, 0,75–0,80 cents /pound, squid to B / .1.00 by pound, shrimp tití B / 1,50 lb. and white shrimp or prawn B / 6.00 per pound.
- In the Vista Alegre supermarket (Marginal).
- Fish sale by particular vendors who work in the street. The fish comes from the Port of Vacamonte in small containers (*coolers* or *buckets*). Local vendors, being representative the case of Armando, with a fix clientele and who warrants the fish´s freshness through dedicated maintenance. He buys during the day time from artisan fishermen rather than in the Port of Vacamonte, as the fish get damaged when kept in big containers.

Economic Activities

Vacamonte City is an urban community with the majority of the population working in Panama City. Residents are not involved in fishing activities, but some individuals are linked to the fishing ships in Port of Vacamonte (captains) and others work selling fish as a by-product (it is estimated that both groups do not sum up one third of the local population).

3.1.4 Port of Vacamonte

Location and Description

The Port of Vacamonte is located in the Vista Alegre county, Arraiján district, in the Pacific coast, 20 km Southwest of Panama city, 8 km South of the Panamerican hwy, and 20 km Southeast of the International Port of Balboa.

There are 252 companies inside the port area, dedicated to export and processing of white shrimp, red shrimp, chicken, turkey and pork. The white and red shrimp (or prawn) are the main products exported to USA, Mexico, Venezuela and Spain.

Working Conditions

There are 5,220 permanent employees at the Port, including the crew of the fishing fleet that comprises approximately 20% of the total working force. Temporal employees (mainly women) working daily in this industry comprise 20% to 40% of the total working force. These employees work in the shrimp processing industry in shifts from 7:00 a.m. to 10:00 p.m. or longer, depending on the arrival time of the ships. Indirect jobs generated by these companies reach up to 25.000 men.

Female labor comes mainly from: Nuevo Emperador, Santa Clara, Bique, Río Indio, Vista Alegre, La Revertida, Omar Torrijos, Burunga, Chumical, Chorrillito, Ciudad Vacamonte, Chorrera y ciudad de Panamá.

Infrastructure and Services

The existing infrastructure and services at the Port of Vacamonte is supported by the following organizations:

- Branch of the Panama National bank,
- Fire Station,
- Red Cross Office,
- Consult and ship Office,
- Marine Resources Office,
- Customs Office,
- Ministry of Health Office (Supervised the food handling by the local companies,
- A restaurant,
- Center for gasoline distribution to the ships,
- Office for Solid Waste Collection,
- Occupational Health Clinic from the Social Security Agency. It is a care, promotion and prevention center (CAPP) for the local population.
- A shipyard

According to information given by Dr. Zoraida Rodal (General Physician) and Delia Quirós (specialist nurse in occupational health), the 10 most frequent pathologies treated by the clinic are:

- *Arthritis*
- *Lumbago* (mainly in the ship crew)
- *Rinofaryngitis*
- *Work Related Stress*, (because of long time standing at work in shifts from 8 to 14 hours)
- *Parasites*

- *Dermatitis*
- *Diarrhea*
- *Urological infections*
- *Yeast infections* in women
- *Obesity*
- *Mycosis* (in female workers due to high humidity levels)

Work related accidents include:

- Cut in the hands during shrimp processing (affecting mostly to women).
- Collisions between commercial and shrimp fishing ships.
- Accidents during ship's maintenance and repairs (frequency of these accidents is high).

A psychologist has joined the medical team in order to attend cases connected to anxiety, depression and other mental illnesses. Many are affected by drug consumption (cocaine, crack, marihuana and alcoholism, the latter mainly in women).

Full service is given only to recognized workers who pay social security fees.

In September, during the lower productivity season in the fishing activity, in-house (at companies' facilities) educational seminars are provided.

In that season, Dr. Francisco Díaz, a specialist in Labor Medicine, and regional coordinator of the *Occupational Health Program*, visits the companies to conduct these seminars. Visits are scheduled on Mondays, Wednesdays and Fridays, and have two main purposes:

To conduct a health risk assessment through several tests: *hearing , smell*, *blood pressure, vaccines, psychological evaluations*, among others.

To prepare an educational program on preventive dentistry, family planning, body posture education, noise prevention (promotion of hearing protection equipment), breath disease and allergies prevention, hygienic education, healthy life style, work stress prevention and treatment, high pressure, drug use prevention and contingency programs for natural disasters.

Table 3-11 shows the personnel employed at the *Center for Occupational health, CSS.*

Table 3-11: Personnel Employed at CSS Occupational Health Center

Personnel	Number
Labor Medicine	1
General Medicine	1
Nurse specialist in *occupational health*	1
Assistant	1
Lab technician	1
Lab assistant	1
Psychologist	1
Dentist	1
Social worker	1
Secretary	1

Source: Dr. Zoraida de Rodal.

According to Dr. Zoraida Rodal, Head Doctor in the health center, there additional personnel will be hired soon. This will include a naval engineer (to conduct risk assessments at the ships), a technician in occupational health (to asses risky working conditions), a physician (for inspections at the companies); a health educator and nurse to provide medical attention in the companies. The average of patients seen per day is 42.

Existing Organizations

National Association of the Fishing Industry (ANDELAIPP), e-mail: andelaip@sinfo.net. The Executive Director is Gustavo Justines. According to the association's members list, provided by the Maritime Authority of Panama, the association consists of:

- 7 companies dedicated to the sale of fuel, construction materials, and ship repair.
- 10 processing plants of shrimp and other seafood, all located at the port.
- 7 shrimp export companies, four of them located at the port.
- 22 fish export companies, three of them in the port.

Economic Activity at the Port of Vacamonte

There are 57 companies in the port area, ranging from micro to small and middle size ones. There are 250 shrimp ships, 20 of which fish also *dorado* and shark *by rod* in deep waters. Shrimp ships are active in deep ocean and in the San Miguel Gulf. Other fishing

areas are: from Puerto Coquira to the Darien coast, Playa Leona, Puerto Caimito, Río Hato, Chitré and Los Santos.

Catch from artisan fishing provides for the local processing companies. Ships arrive twice or three times a week. The advantage of this production system is that captures are constant, fishermen arrive to areas of abundance close to the coast, and the shrimp suffer less handling and transport damage. In addition, this system reduces costs (less petrol for boats, food for fishermen).

Industrial Fish Trade

The approximately 250 ships (each with a crew of 6), trade at the Port of Vacamonte at three levels:

1) Sales are direct to companies that ship out of the area , and also sell to supermarkets and retail. Among these companies are Sea Deli, Empaques del Marisco, Tropimar, Mar Pesca and Empacadora Alimenticia.
2) Ships sell to the association ASOCEPROM integrated by 25 members who trade in neighborhoods, houses, streets, and the local restaurant. Selling places are Vista Alegre, Arraiján, Chorrera and the Terraplén in the capital. The fish catch is retrieved from the port in *coolers* (with capacity from 300, 400, 600 to1000 pounds) and *buckets* of 30 pounds each. Main species sold are: corvine, pargo, *revoltura*, shrimp tití, prawns and squid. ASOCEPROM also keeps a selling point in the markets in Arraiján, Chorrera and Panamá.
3) The *bucketeers also* carry personal *buckets* (approximately of 30 pounds each). They are nearly 10 or 15 individuals, who resell at local level and represent an economy of subsistence. They arrive to the port premises two or three days a week.

3.1.5 Veracruz Community

Location and Description

The Veracruz community is the main urban settlement of Veracruz County, in the South Arraiján District. This community is located on the shore of the Pacific Ocean being the nearest significant community to Panama City.

Population and Housing

According to the 2000 Census, the Veracruz community reached a population of 14,936 inhabitants, distributed in 3,232 houses. Among them, 7,715 were men and 7,221 women. Table 3-**12** shows the high growth rate for the population in the last 20 years. The data for the year 2000 represents an increase of 121.5 % in relation to the decade of 1990 and 49.5% related to the decade of the 1980.

Table 3-12: Population Data for the Veracruz Community

Data	1980	1990	2000
Population	4,511	6,744	14,936
Housing	929	1,454	3,232

Source: Panamanian National Comptroller, year 2000.

The county of Veracruz has a surface area of 13.8 km2, a population of 16,748 inhabitants (year 2000 census), and a density of 1,213.6 inhabitants per km2. The Veracruz community comprises 89.18 % of the total county population.

Neighborhoods in the Veracruz community are: La Represa, Chumical, Panamá, Majagual, Canaín, Bello Horizonte, Koscuna, Esperanza No.1, Esperanza No.2 and Cerro Cabra.Locals keep a strong work relationship and dependence (family) with the capital and with the *capital* of Arraijan district. In addition, they are also connected with these cities for commercial or educational reasons (secondary school and university studies). Socio-demographic indicators are shown in Table 3-13:

Table 3-13: Sociodemographic Indicators for Veracruz Population

Indicators	Value
Average of members per house	4.5
Percentage of population under 15	33.87%
Percentage of population between 15 and 64	61.98%
Percentage of population of 65 and over	4.14%
Male indicator (number of men per 100 women)	106.8
Age average in total population	23
Percentage of houses with male householder	77.12%
Percentage of houses with female householder	22.88%
Average of children (surviving newborn) per woman	2.3
Percentage of illiterate of 10 age and over.	4.87%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Table 3-14 shows the birth rate increase in Veracruz county from 1996 to 2000, being the lowest 428 and the highest 489. Fluctuations were about 50 births keeping a constant rate

with births higher than 428 per year. The year 2000 shows a slight decrease and a rate of 39.5%. the highest rate birth took place during the year 1997 with 46.9%. According to the 2000 Census, mortality rate in the county is 5.9 per thousand inhabitants.

Table 3-14: Birth Rate in Veracruz County (1966 – 2000)

	Birth Rate				
	1996	**1997**	**1998**	**1999**	**2000**
Veracruz	**428**	**489**	**446**	***468***	**446**

Source: Panamanian National Comptroller, year 2000.

Table 3-15 shows an increase of houses with dirt floors from 38 to 272, and of houses without potable water of 6 to 225. At the end of the nineties and beginning of year 2000, several unplanned settlements were registered and stopped by the State. However, this is one of the reasons for the high number of houses with no basic infrastructure.

Table 3-15: Characteristics of Houses in Veracruz

Characteristics	**1990**		**2000**	
	Number	%	Number	%
Total number of houses	1,839	100.0	3,522	100.0
Dirt Floors	38	2.1	272	7.7
Without potable water	6	0.3	225	6.3
Without latrines	34	1.8	121	3.4
Without electricity	176	9.6	367	10.4
Wood powered cook	48	2.6	94	2.7
Without television	323	17.6	604	17.1
Without radio	326	17.7	632	17.9
Without telephone	1,231	66.9	2,212	62.8
Coal powered cooking	2	0.1	3	0.01

Source: Panamanian National Comptroller, year 2000.

Comparative Analysis of Housing and Employment in Taboga, Bique, and Veracruz

The next two tables compare the summary of housing and employment information of Taboga, Playita Bique and Veracruz. These two parameters are of significance in determining the socioeconomic situation of the population of the area.

Table 3-16 shows that the highest levels of poverty are concentrated in Bique beach. For instance, this area has the highest percentage (24%) of houses with dirt floors, and Veracruz with 3.0% in second place. The lowest percentage is found in Taboga (0.9%). Similar situation happens along the other indicators considered

Table 3-17 shows that the highest unemployment rate is found in Bique beach (17.4 %), followed by Veracruz with 10.4%, and Taboga with 7.6%. The community at Bique beach lives fundamentally on artisan fishing and clams collection.

Table 3-16: Characteristics of Houses on the Communities of Playita Bique, Taboga and Veracruz: 2000 Census

Indicators	Bique Beach		Taboga		Veracruz	
	Number	%	Number	%	Number	%
Total Number of Houses	**86**	**100**	**231**	**100**	**3,522**	**100**
With dirt floors	21	24.4	2	0.9	272	7.7
Without potable water	2	2.3	4	1.7	88	2.7
Without latrines	10	11.6	5	2.2	76	2.4
Without electricity	6	7.0	1	0.4	94	2.9
Wood fueled cooking	11	12.8	0	0.0	43	1.3
Coal fueled cooking	0	0.0	0	0.0	2	0.1
Without television	28	32.6	9	3.9	381	11.8
Without radio	25	29.1	34	14.7	520	16.1
Without in-house telephone	85	98.8	144	62.3	1834	56.7

Source: LBG, according to data from Comptroller General

Table 3-17: Population Aged 10 and Higher (Active and Non Active Economically) in Bique, Taboga And Veracruz Communities: 2000 Census

Communities	Total	Active economically %		Non active economically %
		Employed	Unemployed	
Bique Beach	245	46.20	17.4	69.6
Taboga	10065	51.2	7.6	54.4
Veracruz	1206	53.3	10.4	61.4

Source: LBG, according to data from General comptroller's office

Infrastructure

Road Infrastructure: Access to the Veracruz community is through a concrete road in bad conditions and in urgent need of repair, being worse inside the neighborhoods.

Electricity: Is provided by the Edemet Edechi company. Users pay their bills in Albrook in Panama City since there Edemet Edechi has no office in Veracruz.

Potable water supply: IDAAN provides this service. However it does not reach some sectors of the population. Houses with water supply receive the service intermittently due to water scarcity.

Communication Network: The 2000 Census reveals that a total of 1834 individuals do not have access to this service in their houses. Those that have in-house telephone service paid their bills in Albrook as there is not a Cable TV or Wireless office in Veracruz.

Basic Education: There are three primary schools in Veracruz, located one downtown, another in Barriada Coscuna, and a third one in El Chumical

Health Care: There is a Health Care Center with specialized personnel and equipment in dentistry, general medicine, and maternal care.

Solid waste collection: Collection is made by a private company that disposes in the landfill located in Chorrera.

Collective Transportation: There is a public bus system to the capital and Arraiján.

Stores: There are a significant number of local stores, mini supermarkets and pharmacies.

The Ministry of Family, the Youth and the Children*,* has an office in Veracruz, addressing the social problems related to crime activities, unemployment, and drug abuse.

National Police There is one police station in Veracruz.

District Attorney of Veracruz: established in a local facility with official personnel, among them an attorney and a secretary.

Economic Activities

Veracruz is an urban community, with commerce and services being the major economic activities. Most of the population is employed in the public and private sector. According to data provided by the General Comptroller office, there are 134 companies in the Veracruz area dedicated to, among others: fishing, mining and excavation, manufacturing industry, commerce, hotels, restaurants, transportation, storing, communication, construction, and social and health services.

These companies employ 239 persons and generate an income next to 12.3 millions of Balboas per year. The activities with the highest generation of profit (74.6% of the total income generated) are retail commerce, hotels, restaurants, and manufacturing industry. They also provide with 51.5% of the total employment of the area.

The artisan fishing activity registered an average production rate of 8,400 pounds of fish per month, representing an income of approximately 5,200 Balboas.

In addition, there are locals dedicated to tourism on the beaches, where nearly twelve selling permits were issued for food services. There is no known economic value to this activite but it is known to have their highest activity registered on week-ends.

In Veracruz, there are some companies connected to fishing activities such: Veracruz International shipyard (ship reparation); Marine Advance Propulsión Systems (ship reparation and sales of equipment); Pesquera Taboguilla S.A. (fish flour processing).

Organization

The following organizations were identified in Veracruz:

- The Comunal Junta, integrated by a board of directors and involved in activities such: channeling support to the most needed people in the county on unemployment, crime, drug abuse and other problems.
- Other organizations are: the The fishermen Association, integrated by 26 members, the Health Committee; The Primary School Parents Club; The sports committee; the catholic committee and a protestant church from Panamá.

3.2 Potentials and Limitations

3.2.1 Taboga

Potentials and Limitations

Potentials

Tourism: Tourism is a traditional activity in Taboga, generating welfare and income, although it needs to be enhanced so that the population can increase its participation, its benefits, and their standard of living. The island has a variety of natural and cultural attractions, including wildlife, beautiful scenery, or remaining historical buildings and ruins.

Taboga population: The population maintains way of life in harmony with their surrounding environment. Examples of traditional lifestyles are artisan fishing or organic agriculture practices. Fishing with nets is prohibited by a Municipal order. Institutions like the Police force and port security stress that crime is almost non-existing in the island and that some recent problems have to do with behavior from newcomers.

Taboga is an organized community with capacity for public expression. There are five organizations that care for the community and families' well being, and some environmental programs include local participation. Public opposition has been reported in relation conflicts with the electricity provider company. They rejected the change of the existing plant for another of lower capacity. In addition, the community reacted with strength when workers from the shrimp ships molested female members of the community.

Limitations

The population in Taboga is not sufficiently organized to develop tourism and to enjoy higher levels of income from this activity.

There is a decline in the amount of fishermen dedicated to artisan fishing as a consequence of lower catch levels. According to local fishermen, the activities in the Empresa Pesquera Taboguilla S.A. affect the artisan fishing. They believe that overfishing activities on sardines and marine pollution from waste discharge is damaging the fish population in the area.

Land ownership is concentrated in a few hands, having the local residents economic limitations to improve their conditions on this matter. Some families working in stores are also having difficulties, as they are not capable of buying any piece of land to foster their businesses.

A training plan aimed to enhance locals participation in defining projects that can generate additional income is absent (and would be needed).

The infrastructure and services is in need of improvement. There is not permanent supply of potable water, due to the lack of a potable water distribution system. In addition, the

desalinization plant has been out of service for a while. Supply through wells is not enough to provide for the population needs.

Pollution: It is clear that although waste waters are thrown into the sea far from the coast, it is affecting the quality of the water in the beach. Currently, the discharge of waste water is being redirected to a place out of the area of influence of the village. However, this is a temporary solution until the water treatment plant is developed.

Pollution is also generated by the discharge of waste originated in the fish processing activities of the Empresa Taboguilla, as well as the use of old equipment that leaks oil into the environment. Gases from the openly burning of solid waste represent a source of air pollution and a threat for the wildlife refuge.

Health related issues: The medical service is only provided from Monday to Friday between 7:00 a.m. to 3:00 p.m., situation that makes necessary a permanent boat for emergency cases.

Illegal hunting**.** There is a high pressure exerted on the iguana population of Taboga, Urabá y Taboguilla by illegal hunters coming from Vacamonte and Veracruz.

3.2.2 Bique Beach

Potentials and Limitations

Potentials

The beach in Bique constitutes an under utilized natural attraction with tourist potential.

In addition, the existing ruins from colonial times are of interest to the INAC, having been identified by this institution as having historical and cultural value.

Limitations

Land ownership status becomes the main problem for the community, as legally they are situated inside the Gambotti family property. This situation has prevented the access to proper public services such as a potable water system, telephone, electricity, street maintenance, and others.

There is no adequate waste management system, and garbage can be seen too close to the houses, beach and children play areas.

There is a general lack of communal organization. The community has been at the same place for 40 years, but there are not community projects. So far the locals have not been able to change their situation through negotiation with the Gambotti family, authorities and official institutions.

3.2.3 Port of Vacamonte

Potentials and Limitations

Potentials

There is a potential for increasing added value generated by recycling of byproducts of the fish industry.

In addition, like many ports around the world, ports can be developed into tourist attractions associated with the fishing industry (e.g. restaurants).

Limitations

There are serious environmental problems such as deficient environmental management of solid waste, wastewater intrusions in groundwater and the ocean, and social problems such as drugs, and gender discrimination, lack of security personnel in the port.

According to information provided by the Port administrator, Sr. Ceferino Espino, and Dr. Rodal the main problems in the Port of Vacamonte are:

- Some companies do not apply the TED, a mandatory device since 1995 that prevents turtles from being trapped and killed in the fishing nets. This situation might bring penalties imposed by import foreign companies, mainly from USA, and therefore the interruption of the port activities.
- There is scarcity of water supply inside the port premises. Only 3 to 4 containers enter the port daily and companies with bigger tanks can store larger quantities than others. This situation affects also the health clinic and their medical activities.
- It is very difficult to control quantities of sea products brought in the ships since not all the product is delivered to the port. In addition, sometimes ships enter through the repairing area of the port declaring a failure, but later on they are caught delivering sea products without notifying their activities. This situation is enhanced by the lack of security resources, both in personnel and equipment.

3.2.4 Veracruz Community

Potentials and Limitations

Potentials

Among the most important potential attractions of Veracruz is the development of external tourism, and the development of coastal areas (beach, restaurants, and other coast related facilities). The area con also increase urban development and support a local small-scale fishing industry. Due to its proximity to Panama City, Veracruz is a “dormitory-city” community. Expansion of the city could change the life style of the residents by increasing opportunities for recreation and cultural activities.

Limitations

Some identified problems are: increased unemployment, various crime types, streets deterioration, potable water scarcity and quality, social pressure imposed by week-end visitors and locals. In addition, the route to the city is to narrow to carry heavy traffic, imposing a limitations on city growth.

4 ANALYSIS OF SECTORIAL INTERESTS AND ACTORS

The magnitude of the project is of influence on the local, regional, national and international levels.

4.1 Sectors with Local, Regional and National Implications

The following sectors at local, regional and national levels, have been identified:

- Fishing sector
- Commercial sector
- Industrial sector
- Real Estate sector
- Tourism sector

The social actors of importance identified are:

- Artisan fishermen
- Industrial fishing companies
- Fishing communities
- Small sea food traders
- Companies dedicated to sea food trading
- Seafood processing companies
- Hotels and restaurants owners
- Metropolitan community
- Residential and recreational properties owners
- Land owners
- Scientific community
- Environmental NGOs
- Financial organizations.

The integrated analysis on each sector and actors, allows for an understanding of the foreseen social reaction as a consequence of the project implementation.

This gives the opportunity to asses the different potential political positions to be adopted by each sector.

Fishing

In Panama, the fishing sector is one of the most important ones because of its contribution to the national economy, and in income and in labor generation for the locals, constituting, after banana, the second export activity. According to data provided by the AMP (General Direction For Maritime resources and coasters), in the year 2001, Panama exported 110,105 metric tons of fish products, with a value of B/320 millions. There are two sub-sectors: artisan fishing and industrial fishing.

Artisan fishing:

This is an activity done close to the shoreline, with a low investment (between B/3,000 to B/7,000), with an old-fashioned technology based in a boat or "*panga*", an engine of low and middle strength, *trasmallo* or net, *lira* and *life sardine bait*. It is estimated that around of 10% of the total fish national product comes from artisan origin.

Photo 32. Ramp used for loading and unloading of merchandise at Chorrillo

In the area of influence of the Project, and depending on the alternative selected, this sub-sector might be negatively affected, particularly the communities of Bique, Taboga and Veracruz. Similarly, fishermen from the Fishermen's cooperative in El Chorrillo, located in El Chorrillo neighborhood might be affected.

The community of Taboga might be affected because of physical impact on the main fishing point, Melones, and subsequent impact on fish populations.

Photo 33. Panoramic view from Bique with fishing boats anchored in the bay

The community of Bique might be affected because the potential impact on clams population and associated economic benefits, and because the fishing route used by Bique fishermen could be affected by the location of the artificial island and/or access road.

The fisherman and small seafood trader from these communities lives in poverty conditions, particularly those from Bique and Veracrúz.

Industrial fishing

The port manages around 4,100 ships per year, 100 of which operate in international waters, and 4,000 operate in coastal national waters. (See Table 4-1).

Table 4-1: Movement of Ships and Cargo in the Port of Vacamonte

Year	Ships movement (In units) VACAMONTE			Volume movement (In metric tons) VACAMONTE		
	Int. Waters	Coast	TOTAL	Int. Waters	Coast	TOTAL
1994	33	3,010	3,043	5,810	5,627	11,437
1995	27	3,412	3,439	6,390	7,211	13,601
1996	48	3,752	3,800	11,227	10,857	22,084
1997	57	4,084	4,141	7,969	10,024	17,993
1998	108	4,093	4,201	13,150	18,136	31,286
1999	116	3,960	4,076	4,264	15,483	19,747
2000	185	3,995	4,180	8,113	13,856	21,969

Economic interests around this sector come from national level at several layers: ships owners, companies generating the processing and trading of cargo, and fishermen from Bique, who sell a big amount of their capture to the processing companies located in the port.

The port of Vacamonte generates a movement of around 250 ships and 4000 boats or *pangas*. In 1998 there was a volume movement of about 31 thousand metric tons. It has been estimated that Vacamonte has generated an average of 60 millions of balboas per year in exports during the last ten years. No direct negative impact on the activities on this port can be determined. Indirect impacts might be caused by an adverse effect on regional fishing activities.

It has been estimated that 90% of the national fishing comes from this sub-sector. As the ships operate in open waters, far from the coast, it is not foreseen any negative impact on this activity.

Commercial

The commercial activity evaluated in this study refers to Balboa Av., Calzada de Amador and the small scale seafood traders, who are linked to Bique and Veracruz communities. This trade might be affected if the artisan fishing activity is altered with the Project. Commercial activities linked to Port Vacamonte would not be impacted. The Ciudad Marina option could affect activities in Balboa Av.

Industrial

This sector is represented by processing companies located at Port Vacamonte and Taboguilla. Their activity depends on industrial fishing, and if this is not affected, the industrial sector will not be impacted.

Real Estate

Interests around this sector are based on the local and regional economies, as the alternatives Isla Artificial and Ciudad Marina could affect the land and real state value in Taboga and in Panama City, along Balboa Av. and Calzada Amador. Businesses at Balboa Av. would be impacted by Ciudad Marina option.

The Palo Seco option would have an affect on stakeholders in Calzada de Amador and further studies are warranted.

Tourism

Economic interests related to this sector are local. Some of the options under evaluation might negatively affect tourist activities located at Calzada Amador, Taboga and Balboa Av., as well as the tourist projections for Kobbe.

The Calzada de Amador area would be strongly affected with Ciudad Marina option. The Calzada is one of the sites with highest tourist interest for Panama City area. So far, investment has reached about B/32 millions in an initial program of 60 millions. In Calzada de Amador, private investment expectations for the next 20 years are B/400 millions **(**Table 4-**2)** contemplating multi-million projects like: large parking areas, yacht berthing, golf areas, malls, five stars hotels, seafood specialized restaurants, tennis club, residential areas and museum (according to the Strategic Plan for Tourist Development of Fort Amador, 1996).

In the case of Palo Seco Port option further studies are warranted.

Taboga has been considered traditionally an area of tourist importance, and it is included by IPAT in Zone 8 of the Master Plan, which fosters investments oriented to enhance the recreational potential of the place and its beautiful scenery. The Artificial Island option would affect this place by decreasing the value of the panoramic that can be appreciated from the island. In addition to Taboga Hotel, there are currently other projects with a tourist profile, such as residential areas to be built on the small island “El Morro”, as well as other projects planned by the owners of *Finca* “I Pérez”, located behind Hotel Taboga.

Tourist interests around the area are connected to the owners of hotels, restaurants, residential and recreational properties. Nationals from Panama City are known to spend week-ends at their secondary residencies of the island, especially during the dry season.

Boulevard Balboa. This is an area of great tourist attraction, and includes a shopping center, restaurants, cinemas and other amenities. The Ciudad Marina option would affect this attractive source of income for entrepreneurs. Sectors and actors involved around this

area of Panama city, have a high capacity to generate public opposition to projects that can affect their income through the media, having also strong connections among policy decision-makers.

Kobe touristic-residential projections. Kobbe is a place considered by the Authority of the Interoceanic Region (ARI), to offer great tourism potential. According to ARI projections, Kobbe area will be designated a “mixed land use area”, combining urban and tourist activities.

The projections for Kobbe area include resort-like hotel development, with recreational and residential facilities. Currently, the ARI is discussing the possibility of the development of the area by transferring rights to the private sector (such as rent, sale or other options).

As observed in Table 4-2 (Investments for Amador Causeway), between 1995 and 2000, the national government invested around 60.3 millions of Balboas in developing tourist infrastructures. In addition, the forecasted investments for the area total 330 million Balboas: Fase I – 154.3 million balboas, Fase II – 180.7 million Balboas.

Table 4-2: Investment for Amador (According to the Strategic Plan for Tourism Development. 1996. EDSA).

No.	PROJECTS	INVESTMENT (Mill.$US)
	Public investment: 1996-2000	
1	Common areas	26.8
2	Cruise ship Port	21.4
3	Golf course land fill	7.2
4	Sea front pedestrian area	2.6
5	War Museum	1.1
6	Trolley service-Welcome Center	1.2
	Sub-Total public investment	**60.3**
	Phase I: 2000-2010	
7	Golf Course	33.6
8	Commercial development	32.1
9	Naos Hotel	33.6
10	Grand Amador Hotel	48.6
11	Panama Bay Restaurant	1.2
12	Yacht club	1.7

No.	PROJECTS	INVESTMENT (Mill.$US)
13	Marina	3.0
14	Seafood Restaurants	0.5
	Sub-Total Phase I	**154.3**
	Phase II: 2010-2020	
15	Hotel de la Calzada	36.4
16	Hotel de la Plaza	36.4
17	Hotel de Golf	24.3
18	Country Club-Restaurant	2.6
19	Tennis Club	1.4
20	Commercial Development (2)	32.1
21	Hilltop Villas	19.1
22	Marina (2)	3.0
23	Touristic Villas	25.4
	Sub-Total Phase II	**180.7**
	TOTAL	**$395.3 millions**

Scientific Community

The impact identified here is not the environmental one associated with the island. This issue is identified in the environmental section of this study. However, the scientific community can express its opposition to the project due to social perceptions associated with the development of the Ecological Museum in Amador.

The following table (4-3) shows as a summary the different sectors, actors, locations, and the scope of influence.

Table 4-3: Interests, Sectors & Actors Linked to the Project & Scope of Influence

SCOPE OF INFLUENCE	ECONOMIC AND SOCIAL SECTORS	ACTORS	ACTORS LOCATION
Local	Artisan fishing	Artisan fishermen	Taboga; Bique and Veracrúz (Arraiján)
		Small scale seafood traders	Bique and Veracrúz
		Community	Taboga, Bique, Veracrúz
Regional	Industrial fishing	Industrial fishing companies	Vacamonte
	Seafood processing	Fish and seafood processing companies	Vacamonte and Taboguilla
	Seafood trade	Fish and seafood sellers at detail	Vacamonte, Bique, Veracruz
	Tourism	Hotels and restaurants owners	Taboga and Veracruz
		Metropolitan community	Panamá City
National	Real Estate	Residential properties owners	Taboga
		Community	Veracruz
		Land owners	Taboga
	Scientific	Scientific community	University of Panama
	Financial	Financial institutions	National investors
	Scientific	Scientific community	National

5 CONCLUSIONS

Certain sectors will see this project as a negative element affecting either their economic condition or social status. Other sectors will see it with positive eyes

a) In Amador the modification of the surroundings can change the attractiveness of the site, a decline or increase in real estate value could be expected. This trend cannot be defined without additional studies, such as direct surveys for contingency analyses. These studies will assist in the evaluation of the community's perception of the project. Previous sections of this study had shown a tremendous investment in the tourism development of this peninsula. Any project affecting the aesthetic of this area will have a dramatic impact on the value of real estate. On the other hand, many projects of this nature have been used to attract tourism and development.

b) Of the evaluated coastal communities Bique could be the most affected because the local natural resources (e.g. clams artisan fisheries) are their primary source of income. Therefore, any adverse effects on these resources (e.g. decline in abundance) will directly affect these communities since they base their economy on subsistence fishing activities.

c) The tourism sector of Taboga might be affected similarly to the effects described for Amador. Further studies are needed.

d) Increased employment in areas such as Veracruz and Taboga Island communities. The increased economic activity originated as a consequence of the creation of thousands of new jobs in the island complex, could lead to urban expansion and improvement in Veracruz and Taboga.

a) The economic and urban improvement of the residents of Veracruz and Taboga will produce a secondary labor wave associated with the increased need for new schools, food centers, and recreation activities.

APPENDIX H - HYDRODYNAMIC MODELING

ACP
AUTORIDAD DEL CANAL DE PANAMÁ

CONTRACT CC-3-557

Architectural and Engineering Services for Engineering Site and Assessment, Conceptual Design and Related Services

Feasibility Study for the Construction of an Artificial Island at the Pacific Entrance of the Panama Canal

Panama Bay Existing Conditions

Hydrodynamic Model

November 2002

DRAFT REPORT

Moffatt & Nichol
ENGINEERS

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1 INTRODUCTION

The Panama Canal Authority (ACP) is conducting a study of the Panama Canal to evaluate the feasibility of a construction of an artificial island at the Pacific entrance of the Panama Canal using the excavated and dredged material obtained from the proposed third Locks project and related expansion of the Panama Canal.

As part of the Feasibility Study for the Construction of an Artificial Island at the Pacific Entrance to the Panama Canal, this draft report presents part of the work associated to Task 6: the existing conditions hydrodynamic modeling.

This report summarizes the environmental conditions that are to be simulated by the numerical model, and the data that is available. Moreover, description of the numerical model and the modeling methodology are also included. Verification of the numerical model using recently collected currents and water level data in Panama Bay is also shown.

2 ENVIRONMENTAL CONDITIONS

2.1 Site description

The Gulf of Panama (Figure 2-1) is about 200 km wide (E-W direction) and 170 km long (N-S direction). There are two main groups of natural islands in the Gulf. The first group includes the islands of Taboga and Taboguilla and is located 20 km. south of Panama City. The second group, Archipielago de Las Perlas, is located in the middle of the Gulf at distance of 90 km South East of Panama City.

The entrance of the Gulf located at an approximate Latitude of 7.5^{o} N (East of Punta Mala, at the Azuero Peninsula) has depths in the order of 200 m.. South of the entrance, depth increases very rapidly reaching values between 2000 to 3000 meters at a latitude of 6° N.

The area of interest of the present study is located in Panama Bay and it is limited by the Coast of Panama along the North and West, the entrance channel to the Panama Canal on the East and Punta Chame and Otoque island on the South. The depth in this area varies from 0 to around 50 m.

2.2 Tides

Tides in Panama Bay are semidiurnal with two high waters and two low waters per day and with an approximate period of 12.25 hours. The average tidal range at the entrance of the Gulf of Panama is 1.5 m during neap tide and 3.4 m during spring tide. The tidal propagation along the Gulf follows a standing wave pattern. The tidal range amplifies from south to North due to the reflection of the tidal wave on the closed boundary at the North of Panama Bay. At Balboa the average tidal range is approximately 2.7 m during neap tide and in the order of 5.0 m during spring tide. The tidal propagation in the Gulf of Panama is described with more detail in Bennet (1965).

2.3 Currents

The currents in the Gulf of Panama are generated by tidal effects, oceanic currents and wind.

2.3.1 Tidal Currents

The tide-generated currents are associated to the tidal variability discussed in the previous section. During the filling of the bay (transition from low water to high water) the flood current's direction is to the north while during the emptying of the bay the direction of the ebb current is approximately south. The magnitude of the tidal currents varies with the tidal range presenting the highest values during spring tide and the lowest during neap tide.

2.3.2 Oceanic current

The Oceanic currents in the Eastern Pacific are very complex and they are associated to the global wind patterns related to the position of the Intertropical Convergence Zone (ITCZ). The main currents affecting the Gulf of Panama are the following:

- The Westerly moving North-Equatorial current, which is a direct result of the Trade Winds. This current moves west from Panama Bay at about 12°N.
- The Easterly Equatorial Counter Current moves in the opposite direction to the prevailing wind direction between 4° and 10° N. It is generated by the horizontal pressure gradient in the water surface elevation between the West and East pacific produced by the trade winds. The effects of the Equatorial counter-current disappear between 90° to 85° W where it is partially incorporated into the circulation of the Gulf of Panama. The tropical waters of the Gulf are displaced south by the Trade Winds forming a cyclonic (counterclockwise) circulation known as Gulf of Panama Current or Colombia current (Forsbergh, 1969; Bennett, 1965). The intensity of the current varies with the intensity of the trade winds, being the highest during the months of December to April, and the lowest from May to June.

Estimation of the net current in the Gulf of Panama has been presented in a number of publications. The Atlas of Pilot Charts presents the net average current for each calendar month. Figure 2-2 presents the current's chart for May and July (first and last month of the calibration period presented in this report). The net current for these months is very similar as it is for all months. The currents presented showed in the charts have the highest values during the months of April, May and June being 0.5 knots (0.26 m/s) south of Taboguilla Island, 0.7 knots (0.36 m/s) west of Punta Cocalito and 1 knot (0.51 m/s) west of Punta Mala. The net average flow throughout the year at the northern end of the Bay is in the order of 0.3-0.5 knots (0.15 – 0.26 m/s).

The net current of the Gulf of Panama was also estimated in Bennett, (1965) using current data collected by the former United States Navy Hydrographic Office in the western Gulf of Panama from late August to early October 1958. The measurements were taken at 5 locations (see Figure 2-3) and at three depths. Bennett calculated the net current to be about 0.35 knots (0.18 m/s) inshore at a depth of 55 ft (17 m) and 0.7 knots (0.35 m/s) offshore at approximately 100 ft (30 m) of depth.

2.3.3 Wind generated currents

When winds blow across the ocean surface, kinetic energy is transferred from the wind to surface water as a result of the friction between the two. Kinetic energy transferred to the ocean surface sets the surface layer of water in motion and generates both waves and currents. Current patterns can be affected by the local wind climate, especially in the shallow water. However, previous studies at Panama Bay concluded that the local wind has a very small impact on the magnitude and the pattern of the currents at the North end of Panama Bay (Delft Hydraulics, 1999).

2.4 Bathymetry

The usually considered South limits of the Gulf of Panama are Punta Mala on the West and Punta Piñas on the East. The line between these two points is very close to the 7.5^{o} N Latitude line, and has an approximate length of 200 km. At this location the depth is approximately 200 m. Southwards the depth increases steeply to 1000 m. and more, right outside the Gulf entrance. Northwards, a gradual decrease of the depth is broken by Las Perlas Islands. At the western part of the Gulf extensive mud flats with small slopes can be observed.

3 PANAMA BAY MODELS

3.1 Numerical model description

Models for this study were developed using the Delft3D modeling system. The system includes the DELFT3D-FLOW hydrodynamic model that solves the Navier Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumption. Vertical accelerations due to buoyancy effects and due to sudden variations in the bottom topography are not taken into account.

The model equations are solved on a staggered grid (Arakawa C-grid). The horizontal grid is an orthogonal curvilinear grid with the water level points in the middle of each cell. This type of grid is topologically rectangular but is continuously distorted to match certain boundaries. Two significant advantages of this type of grid are that the grid lines can be made to approximately line up with the natural boundaries and that the grid spacing can be varied in order to concentrate on regions of interest. In the vertical direction a scaled coordinate, the so-called s-coordinate is used. This coordinate system is boundary fitted both to the bottom and to the moving free surface. The number of layers is constant over the horizontal computational area, and therefore a set of coupled conservation equations is solved for each layer.

The model uses an Alternating Direction Implicit (ADI) numerical method for the shallow water equation. This method splits the computation of one time step into two stages (the two horizontal directions). In addition, the model uses a fully implicit method to solve the equations in the vertical. The model allows the wetting and drying of tidal flats.

The system also includes a model that solves the transport of dissolved substances or heat using an advection-diffusion equation in the three coordinate directions. This equation is formulated in a conservative form in orthogonal curvilinear co-ordinates in the horizontal and s-coordinates in the vertical. The equation is solved using a Cyclic method (Stelling and Leendertse, 1991) which is a finite difference scheme that conserves large gradients without generating artificial oscillations. The method is based on an implicit time integration and does not impose a stability condition. To ensure that the total mass is conserved, the transport equation is solved in a mass conserving flux form.

Since the horizontal and vertical grids are usually too coarse and the time step too large to resolve the turbulence scales of motion in the model, a closure model is needed. The horizontal processes are represented by the Reynold's stresses which are determined using the eddy viscosity effect. In the vertical the k-e turbulence model is applied. In this closure model, transport equations for both the turbulent kinetic energy, k, and for the energy dissipation, e, have to be solved.

3.2 Hydrographic data

3.2.1 Bathymetry

The bathymetry data was obtained from nautical charts (Admiralty – Chart 1929: "Gulf of Panama" and Chart 1401: "Approaches to the Panama Canal") (see Figure 3-1) and the recently completed

hydrographic survey of the study region. Depths were converted from Mean Low Water Springs (MLWS) to Mean Sea Level (MSL) using available tidal correction at the primary NOAA station BALBOA located at the Pacific Canal entrance.

Offshore data not covered by the aforementioned charts were obtained from the seafloor data of Smith and Sandwell, (1997) which has also been included in NOAA's ETOPO2 database. These data were derived from satellite altimetry observations combined with carefully, quality-assured shipboard echo-sounding measurements. The data is global and is gridded at 2-minute (latitude-longitude) resolution, which in the Gulf of Panama area is in the order of 3.5 km.

3.2.2 Tidal Boundary

The model tidal boundaries were obtained from the TPXO.5 (TOPEX/Poseidon Global Inverse Solution) data set from Oregon State University. TPXO.5 is a global model of ocean tides, which best fits, in a least-squares sense, the Laplace Tidal Equations and along track averaged data from 232 TOPEX/Poseidon orbit cycles. All available along track data are averaged to the chosen data sites. The methods used to compute the model are described in detail by Egbert, Bennett, and Foreman, (1994). The tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1), on a 720x335, 1/2 degree resolution, grid between latitudes of 85.75^{o}S and 81.75^{o}N. TPXO.5 reduced the RMS error of the Topex/Poseidon data from 0.348 m (no tidal correction), to 0.1108 m.

3.2.3 Tidal prediction stations

A number of NOAA tidal stations are available in the Gulf of Panama. Only Balboa is a primary station and the tidal predictions in the rest are calculated from the constituents at Balboa using some amplitude and phase corrections. A number of these stations throughout the Gulf of Panama are presented in Table 3-1. The location of these stations is shown in Figure 3-2. It was indicated in section 2.2 that the tidal range increases in the Gulf of Panama from South to North. This conclusion can also be extracted from the tidal ranges presented in table 3.1.

Table 3-1: NOAA Tidal Prediction Stations in Panama Bay

Station Name	Station Type	Longitude (deg. West)	Latitude (deg. North)	Mean Tide Range (m.)	Spring Tide Range (m.)	Mean Tide Level (m.)
Bahia Pina	Secondary	78.18	7.57	3.20	4.18	2.07
Punta Garachine	Secondary	78.42	8.08	3.32	4.33	2.13
Isla del Rey	Secondary	78.90	8.30	3.26	4.24	2.10
Rio Chepo	Secondary	79.12	8.98	3.81	4.94	2.47
BALBOA	***Primary***	79.57	8.95	3.84	5.00	2.50
Naos Island	Secondary	79.53	8.92	3.78	4.75	2.38
Taboga	Secondary	79.55	8.80	3.81	4.94	2.47
Bahia de Chame	Secondary	79.75	8.68	3.81	4.94	2.47
Punta Mala	Secondary	80.00	7.47	2.47	3.20	1.58

3.2.4 Water level observations

ACP installed four tidal gages in Panama Bay in order to record the water level variation during the months of May to September. Coordinates and temporal extent of the measured record for each station are presented in Table 3-2. The measurement locations are shown in Figure 3.2.

Table 3-2: Water level stations

Station Name	Measurement Period	Longitude (deg. West)	Latitude (deg. North)
Otoque	07/08/02 – 09/12/02	79.61	8.61
Taboguilla	07/08/02 – 09/12/02	79.52	8.81
Mine Dock	05/01/02 – 09/12/02	79.54	8.92
Contadora	06/25/02 – 09/12/02	79.04	8.63

3.2.5 Current measurements

During the period May-June 2002, ACP personnel carried out 5 current measurement campaigns in Panama Bay (ACP, 2002). Currents were measured in a number of points along three different transects: A – Rio Pacora, B – New Island and C – Punta Chame. The measurement locations along each transect are shown in Figure 3.3. The campaigns were designed with the aim of measuring the currents in the Bay at different tidal phases. Table 3.3 provides the date when each campaign took place and the tidal phase.

Table 3-3: Current measurement Campaign

Date	Tidal Phase	Tidal Range at Balboa (m.)	Transects measured
12,13 and 14 May, 2002	Small Spring Tide	4.65	A, B and C
19,20 and 21 May, 2002	Neap Tide	3.40	A, B and C
27 May, 2002	Spring Tide	5.26	B
3, 4 and 7 June, 2002	Neap Tide	2.56	A, B and C
23, 24 and 25 June, 2002	Spring Tide	4.98	A, B and C

During each measurement campaign it was intended to observe the currents at each location for different tidal stages: High tide, Ebb tide, Low tide and Flood tide. In addition, at each location currents were measured near the surface, at mid depth and near the bottom. At each depth, the current speed and direction were measured five times, with a minute separation between consecutive measurements. The mean and standard deviation can be computed from the five measurements, providing a better estimate of the current conditions measured than a single value.

3.2.6 Wind data

Average wind speed and direction are available at Balboa FAA station from the period 1985-2002. Table 3-4 presents the monthly average speed and wind directions at that station.

Table 3-4: Average Wind speed and direction at Balboa FAA

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Wind Speed (m/s)	2.17	2.42	2.45	2.26	1.80	1.56	1.73	1.66	1.56	1.55	1.64	1.75
Avg. Wind Direction	333.4	338.6	341.9	336.4	299.2	296.6	308.3	308.8	263.9	255.4	296.0	325.0

During the months of May to November (rainy season in Panama) the dominant wind direction is from the West – Southwest. Wind speeds during this period are slightly smaller than during the rest of the year. From December to April (dry season) the predominant winds are from the North-Northwest, when the northeasterly (trade) winds blow with more intensity.

Hourly winds were also available at Balboa for the period May – July 2002 when ACP measured water levels and currents in Panama Bay. Time series of wind speed and direction for this period are presented in Figure 3-4.

3.3 Regional Model

In order to propagate the tidal variability from deep water to the entrance of Panama Bay, a Regional model was first created. The model is limited by the Gulf of Panama and the coast of Colombia and at the South by the latitude of 5.5^{o}N and at the west by the Longitude 81°W (see Figure 3.1).

3.3.1 Model grid and Bathymetry

The model is built on a rectangular grid with a grid size of 2,750 x 2,750 meters and approximately 14,800 computational points. The model grid is presented in Figure 3-5. The model bathymetry has been created from the sources of data already described in section 3.2.1. Figure 3-6 shows the model bathymetry.

3.3.2 Boundary conditions

Tidal conditions at the two open boundaries have been obtained from the sea-surface elevation for eight primary harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1) from the TPXO.5 data source introduced in section 3.2.2. The two boundary conditions (South and West) are observed in Figure 3.5. Time series of predicted tides were constructed at the three extreme points of the boundaries. Along each open boundary, the model interpolates between the two specified values in order to prescribe the water level at each point of the open boundary.

3.3.3 Regional Model parameters

The following parameters have been used in the model:

- Chézy roughness coefficient – 65 $m^{1/2}/s$
- Time step – 300 sec.
- Water Density – 1,020 kg/m^3
- Acceleration of gravity – 9.78 m/s^2
- Eddy Viscosity – 100 m^2/s
- Coriolis parameter variable with Latitude

Water levels have been extracted from the model results in order to provide tidal boundary conditions for a local model. The location of the boundary of the local model with respect to the regional model is shown in Figure 3-5.

3.3.4 Model Verification

In order to verify the validity of the model to provide correct boundary conditions for the local model the model results have been compared with observations. Time series of water levels have been extracted from the model results and compared to the observed water levels at the stations listed in Table 3-2. Correlation and root mean square (RMS) error between observed and simulated water levels are presented in table 3.5. Note that the observations at Contadora have been corrected from a possible bias in the datum before calculating the error statistics.

Table 3-5: Regional model: Comparison between observed and simulated water levels

Station Name	Comparison Period	Correlation	RMS error
Otoque	07/08/02 – 07/30/02	0.998	0.174
Taboguilla	07/08/02 – 07/29/02	0.997	0.117
Mine Dock	05/14/02 – 05/31/02	0.997	0.117
Contadora	06/25/02 – 07/10/02	0.998	0.072

Figures 3-7 and 3-8 show the comparison of the observed and simulated time series of water levels. Very good agreement is obtained at all the stations and therefore it can be concluded that the regional model reproduces accurately the tidal variability in the Gulf of Panama and therefore can be used to generate tidal boundaries for the detail model.

3.4 Local Model

As described in previous section a Regional Gulf of Panama Model was used to generate boundary conditions for a local model with finer resolution at the vicinity of the project area. This section describes the Model used to simulate with high resolution the hydrodynamic conditions in the project area.

3.4.1 Model grid and Bathymetry

Local model grid extent and resolution was determined in order to fulfil the following goals:

- The model boundary for the detail model was defined far enough from the area of interest. At the same time, the boundary was created in an area where the existing currents are approximately perpendicular to the model boundary, reducing the boundary errors.
- The model boundary is defined very close to the edge of the deep areas of the Gulf, where the tides have not suffered any significant transformation due to the bathymetry.
- The location of the boundary permits the simultaneous definition of the tidal variability and an artificial tilting of the boundary that will account for a cyclonic current in Panama Bay. The local model will therefore be calibrated simultaneously to observed currents and water levels.

The boundary has been defined from Punta Mala at the Azuero Peninsula, following approximately the parallel of Latitude 7°28' N, as shown in Figure 3-5.

A curvilinear grid was created with approximately 44,000 nodes. The model grid was defined with the aim of having fine resolution at the project area and at the same time covering Panama Bay to the previously described boundary. More than half of the nodes are located within a 15 km. from the shore, which represents less than 10% of the total model area.

The largest grid size is in the order of 5.5 km., while at the vicinity of the project the grid resolution is in the order of 130 m., which was considered enough to accurately represent the different project alternatives that will be simulated as part of the study.

Figure 3-9 presents three different views of the detail model grid, where the high resolution at the project area can be observed. Model bathymetry has been created using the available data sources that has been already introduced in section 3.2.1. Figure 3-10 presents two different views of the detail model bathymetry.

3.4.2 Boundary conditions

As already described in the previous section, the open boundary has been defined from Punta Mala at the Azuero Peninsula, following approximately the parallel at Latitude 7°28' N, as shown in Figure 3-5. The boundary condition has been prescribed as the superposition of the tidal variability extracted from the regional model and a variation of the water level along the boundary that will account for the Gulf of Panama current. This variation of the water level was modified until a net current pattern similar to the one presented in the Atlas of Pilot Charts, (2001) and Bennet, (1965)

was obtained. In addition, the model was calibrated to actual observed currents (ACP, 2002) generated by the three effects described in section 2.3: tidal, oceanic and wind generated currents. Comparison of simulated and observed currents are presented in this report (see Section 4).

3.4.3 Local Model parameters

The following parameters have been applied in the Local model:

- Chézy roughness coefficient (C) as a function of depth following the expression:

  $$C = h^{1/6}/n \ [m^{1/6}/s]$$

  using constant Manning coefficient of n=0.023 $m^{1/3}/s$
- Time step – 30 sec.
- Water Density – 1,020 kg/m^3
- Acceleration of gravity – 9.78 m/s^2
- Eddy Viscosity – 1 m^2/s
- Coriolis parameter variable with Latitude

3.4.4 Wind forcing

In order to account for the effect of winds on the current pattern the Local model was forced by local winds measured at Balboa and already presented in section 3.2.6. The model computes the wind shear stress that acts on the water surface using the density of air, the wind speed and the wind drag coefficient (C_d). The wind drag coefficient was defined following Wu, (1982).

$C_d = 0.85\times10^{-3} + 0.065\times10^{-3}$ W

With W the wind speed (m/s) at 10 m above the free surface

4 LOCAL MODEL VERIFICATION – EXISTING CONDITIONS

4.1 Water levels

Simulated water levels from the Local Model were compared with predicted tides at the primary and secondary stations. In addition, the simulated water levels were compared to water levels measured by ACP. Figures 4-1 and 4-2 show time series comparison for four different stations: Mine Dock (ACP water level gauge), Balboa (tide prediction primary station), and Taboguilla and Rio Chepo (tide prediction secondary station). Good agreement (in the same order of the one obtained from the regional model) between observed (predicted) and simulated water was obtained for all the stations. It can be concluded that the Local model can be used to accurately simulate the water level in Panama Bay.

4.2 Currents

In order to verify the ability of the model to simulate current patterns in Panama Bay, model results were compared to available data. The model computes depth-averaged currents and therefore it has to be compared to a similar observed variable. It was assumed that the Gulf of Panama Current remains constant during the entire simulation. This assumption is based on the small monthly variability observed in (Atlas Pilot charts, 2001). Moreover other studies such us Bennet, (1965) and Delft Hydraulics, (1999) consider a mean net current in Panama Bay and disregard the possible variability of this current in time.

First, the simulated current patterns in the northern part of the Bay were compared to the depth-mean currents computed in Bennett, 1965 for the maximum spring range. Figures 4-3 and 4-4 presents simulated current patterns during the spring tide event of May 27th 2002 together with the estimated currents by Bennett. Bennett's currents are approximately represented as a net current of 0.35 knot (0.18 m/s) at the inshore stations and 0.7 knots (0.35 m/s) at the offshore stations. It can be observed that the model reproduces quite accurately the magnitude and direction of the currents at all the observation points. Some discrepancies in the direction of the flood current are observed at point A and for the flood and ebb currents at point E. At point E the direction of the simulated current seems to be influenced by the net current and this is not observed in Bennett's estimated currents. Based on these results it can be concluded that the model is able to reproduce quite accurately the tidal and oceanic currents in Panama Bay described by Bennett, (1965). Figures 4-5 and 4-6 presents the flow patterns in the project area for spring and neap tide conditions. The flow patterns are presented at four stages of the tide: low water, peak flood, high water and peak ebb. The influence of the Gulf of Panama current to the flow patterns in the project area is easy to be observed especially during low and high water conditions.

Model-simulated currents in Panama Bay were also compared to the currents observed during the ACP campaign described in section 3.2.5. Mean and standard deviation of the measured values at three depths are included in the comparison. It is noted that the model only solves the depth-averaged equations and therefore the model-simulated currents are depth-averaged currents. Simulated time series of flow magnitude and directions together with the observations are

presented in Appendix A. Discussion of the model results for each measurement campaign are presented in the following sections.

4.2.1 Measurement Campaign 1

During the 13th of May and along transect "A" the model reproduces reasonably well the current speed and direction at the nearshore stations (A1 and A2). At the offshore stations (A3 and A4) the first set of measurements is also well reproduced by the model. These measurements were taken from falling tide to raising tide and they indicate the existence of a predominant current moving toward the East. Measured and predicted magnitudes (~0.18 m/s) agree reasonably well. Later measurements (during rising tide) show an increase in the magnitude of the current with a predominant North – NorthEast direction. The model does not predict this increase, which is probably a consequence of the local wind. The measured current direction is toward North-Northeast, which is similar to the wind direction locally recorded, and therefore it is possible that to some extent the local wind influenced the measurements. On the other hand, if the current's increase is a consequence of an increase of the Oceanic current the observed direction will be more towards the west.

Current magnitude is generally underestimated along transect B. This is probably due to an increase in the Gulf of Panama Current that is not included in the model. It can be observed that the measured current directions have values between 250° and 300° (fluctuating around the West direction) while the model predicts larger variability (between 200° and 315°). This could be a clear indication that the west component of the current, generated by the Gulf of Panama current, is underestimated.

The model accurately estimates the observed currents along transect C. At C1 the model captures the variability in the magnitude of the peak flood and peak ebb currents. The observed directions during ebb flow that should be around 180° are instead in the order of 340°, which seem to be incorrect. In stations C2 and C3 the model does a good job reproducing the mid-depth currents and directions.

4.2.2 Measurement Campaign 2

During these 3 days (19, 20 and 21 of May) the recorded magnitude of the wind speed at Balboa FAA was quite small. During the nights the wind speed was very small (less than 2 kt) and blowing from the North, while in the afternoon the wind was blowing from the south peaking at about 3-5 kt. The influence of this wind in the model is very small and therefore during this period the observed currents will be mainly due to the effect of the tidal variability and the oceanic current.

The model reproduces quite accurately the current speed and direction in all stations. This is a period where the observed Gulf of Panama current seems to be very close to the one generated in the model.

4.2.3 Measurement Campaign 3

This campaign only took place along transect B and lasted only for one day (27th of May) due to the weather. Strong south winds of more than 10 knots were observed during the afternoon of that day. The model provides good predictions of the current speed and direction at mid depth observed along transect B. The magnitude of the Gulf of Panama current generated in the model seems to match the measured values during this period.

4.2.4 Measurement Campaign 4

During these 3 days (3, 4 and 7 of June) the recorded wind at Balboa FAA varies from small north winds during the first day to sustained south winds after the second day with magnitudes higher than 10 knots during the afternoon of the second day. During this period the tide range is in the order of 2.8 m (neap tide) and therefore the tidal currents are expected to be very small. The model reproduces reasonably well the observed magnitude of the velocity along transects A and B, especially at the nearshore stations. In Stations A3 and A4 the net current is slightly overestimated. Along transect C the model seems to overestimate the peek ebb current and underestimate the peak flood current. Although the model estimates correctly the direction of the peak ebb current in stations C2 and C3, the model estimates the peak flood current flowing towards the Northwest while the observations show it moving more towards North. This could be a clear indication that the Gulf of Panama current when the measurements were taken has weakened and its magnitude is smaller than the average value applied to the model.

The observed direction of the flow, especially at the offshore stations of transects A and B presents a high variability among bottom, mid-depth and surface. It can be observed (see for example stations A3 and A4) that in some cases the surface current flows opposite to the bottom. This high variability could be caused by an increased measurement error in the flow direction due to the very small currents measured during this period. Although this could explain most of the discrepancies between simulated and observed flow directions during campaign 4, it is also possible that part of the discrepancies could be a consequence of an overestimation of the Gulf Current oceanic, as it has been already mentioned.

4.2.5 Measurement Campaign 5

During this campaign (23, 24 and 25 of June) the recorded winds at Balboa FAA present a constant northwest direction and small magnitudes (< 5 knots). Therefore, the winds do not seem to have any significant influence in the flow patterns of Panama Bay during this period.

Although the model does a reasonable job reproducing the magnitude and direction of the flow in all the stations, there is a general discrepancy between simulated and observed flow. The model under-predicts the magnitude of the currents and at the same time it predicts flood currents to be more towards the north than observed, and ebb currents to flow more south than observed. The measured flow directions are towards northwest for the flood current and southwest for the ebb. These discrepancies also suggest that the Gulf of Panama current applied to the model is weaker than the current that was observed during this period.

5 CONCLUSIONS

A numerical model of the Gulf of Panama was developed using the Delft3D modeling system and it was calibrated to simulate the existing hydrodynamic conditions in Panama Bay. The model combines the effects of tides, winds and the Gulf of Panama current to predict water level and depth averaged currents in Panama Bay.

The Gulf of Panama current or Colombia current considered in the simulation is constant in time. This current is based on the magnitudes estimated in a number of studies (Atlas of Pilot charts, 2001; Bennet, 1965 and Delft Hydraulics, 1999): 0.15 m/s at a depth of 15 m. and 0.36 m/s at 30m. The model is able to reproduce the influence of this current in the flow conditions of the Bay. However, ACP current measurements suggest that the Gulf of Panama current is variable in time and that its magnitude can vary significantly.

The model does a very good job for situations where the observed current coincides with the average current applied to the model (for example Campaign 2). In order to accurately reproduce all the measurements a variable Gulf of Panama current has to be considered, estimated and applied to the model, which is well beyond the scope of this study. In addition, part of the discrepancies between simulated and observed currents could be associated to the fact that the model solves the depth average equations and therefore it does not include three-dimensional effects that are definitely included in the measurements.

In general it can be concluded that the model can accurately reproduce the average tidal and flow conditions in Panama Bay during conditions specially when the Gulf of Panama current is around the estimated average. The model may be used as a reliable tool for investigating the impacts that the different alternatives of artificial islands or disposal sites will have on the hydrodynamic conditions of the bay.

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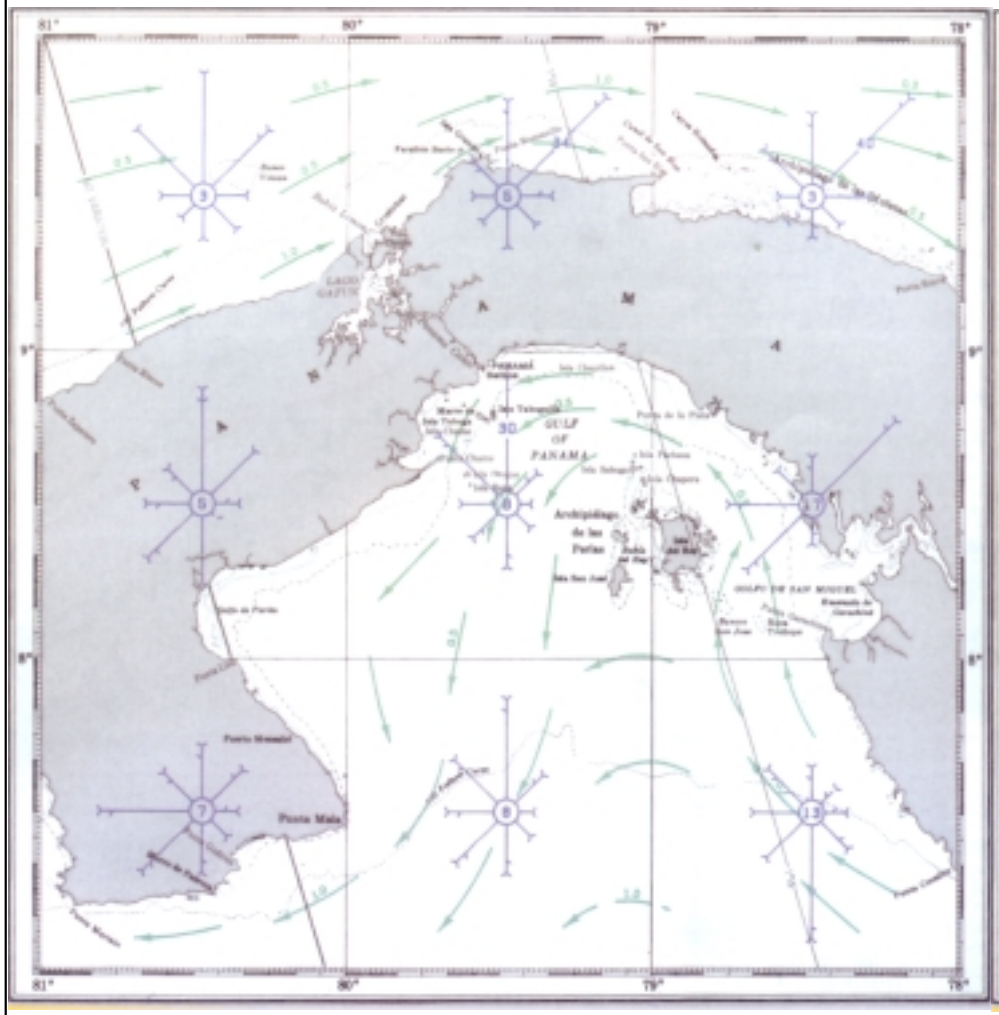
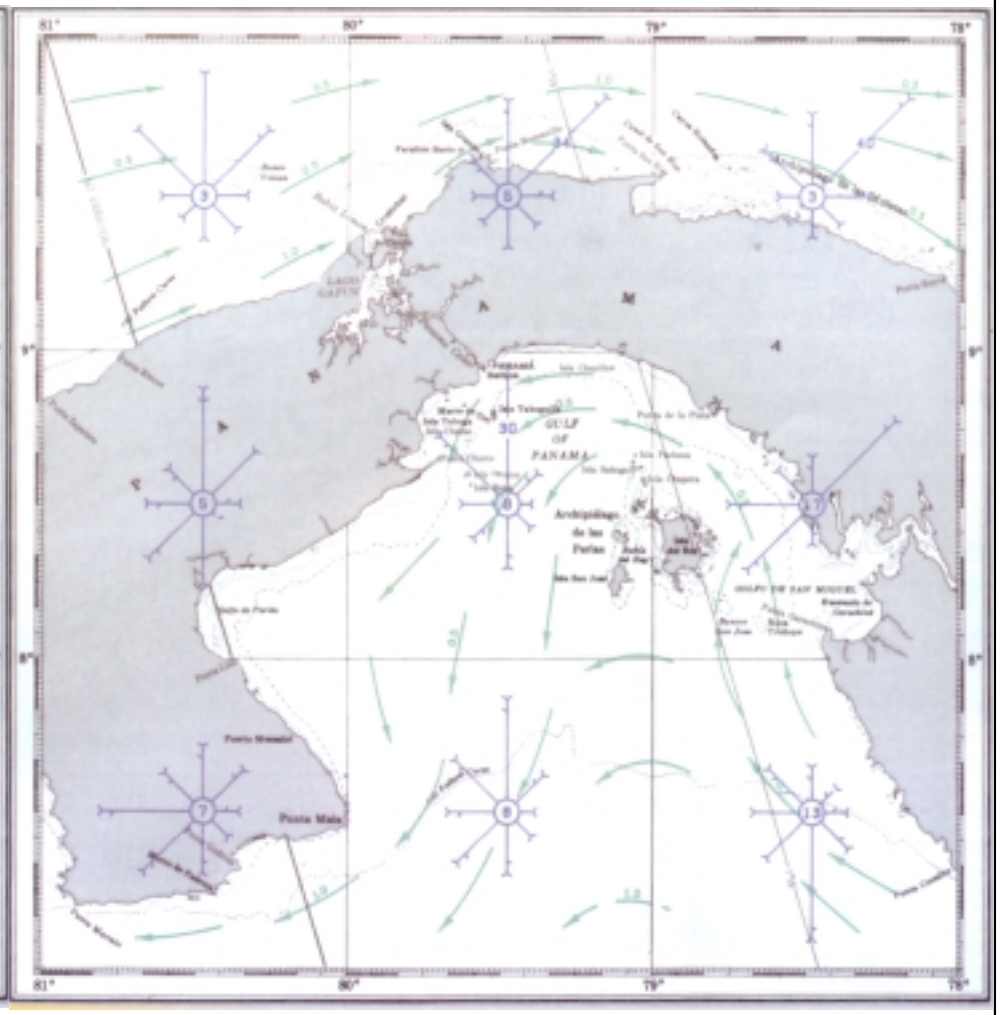
FIGURE 2-1:
Central America and Panama Map

Panama Bay currents from the Atlas of Pilot Charts



May



July

Prevailing directions of the ocean currents and averaged speed expressed in knots

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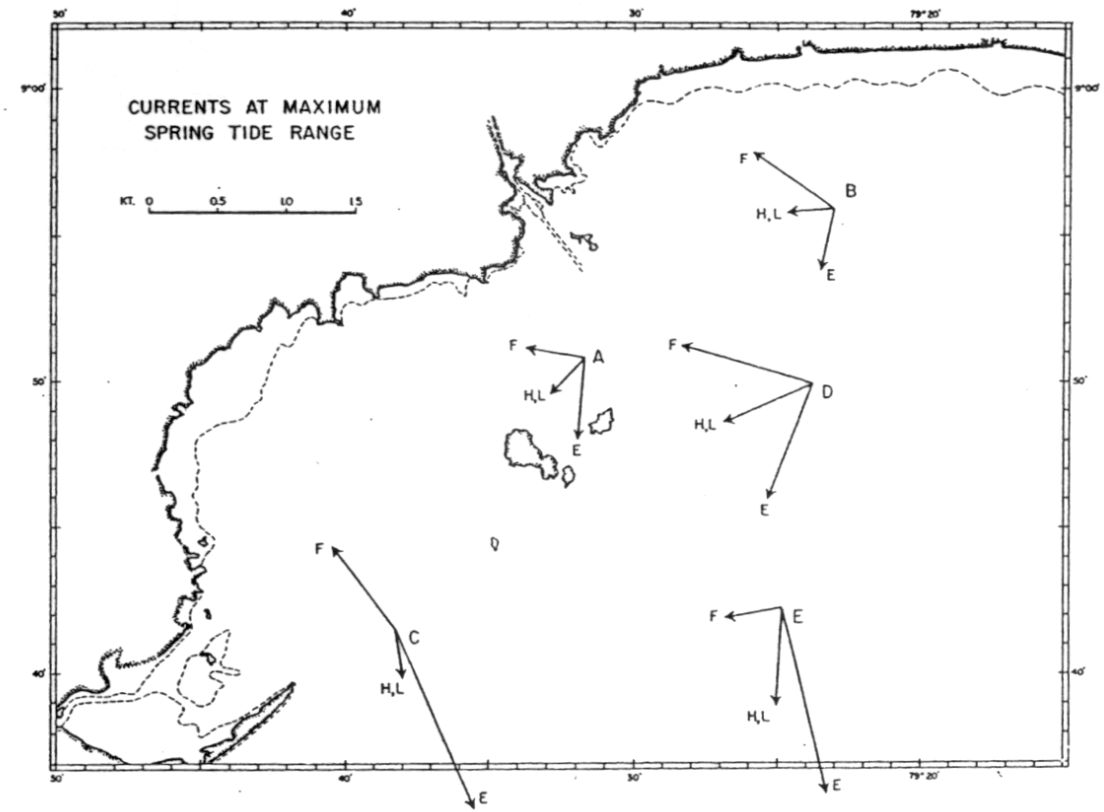
FIGURE 2-2:
Net Currents from the Atlas of Pilot Charts



After Bennett 1965. Currents at High and low water (H,L) and the half-tides (F,E) expected during tides of maximum spring range, and when the net current speed is about 0.35 knots (0.18 m/sec) inshore and 0.7 knots (0.35 m/sec) offshore.

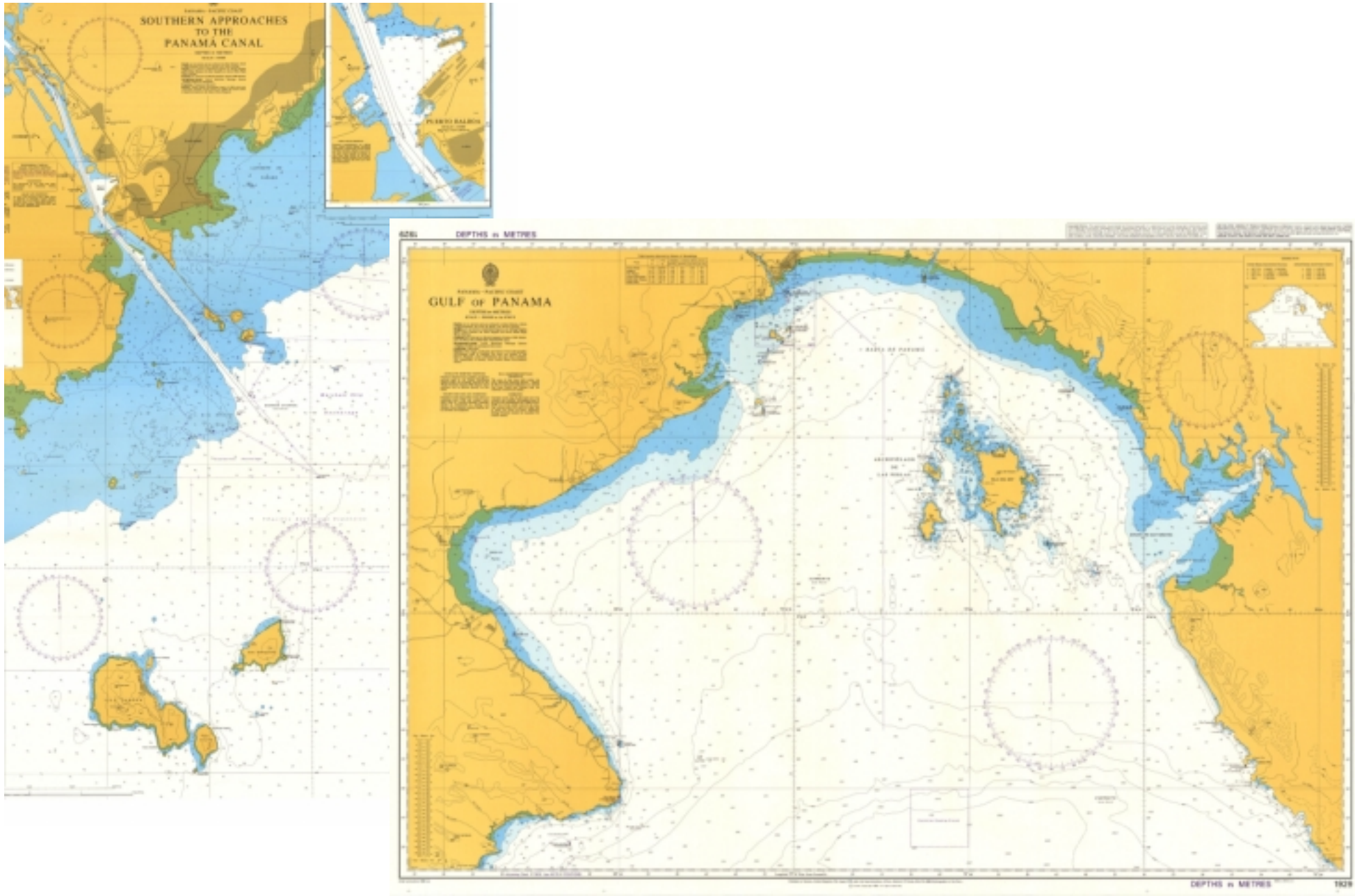


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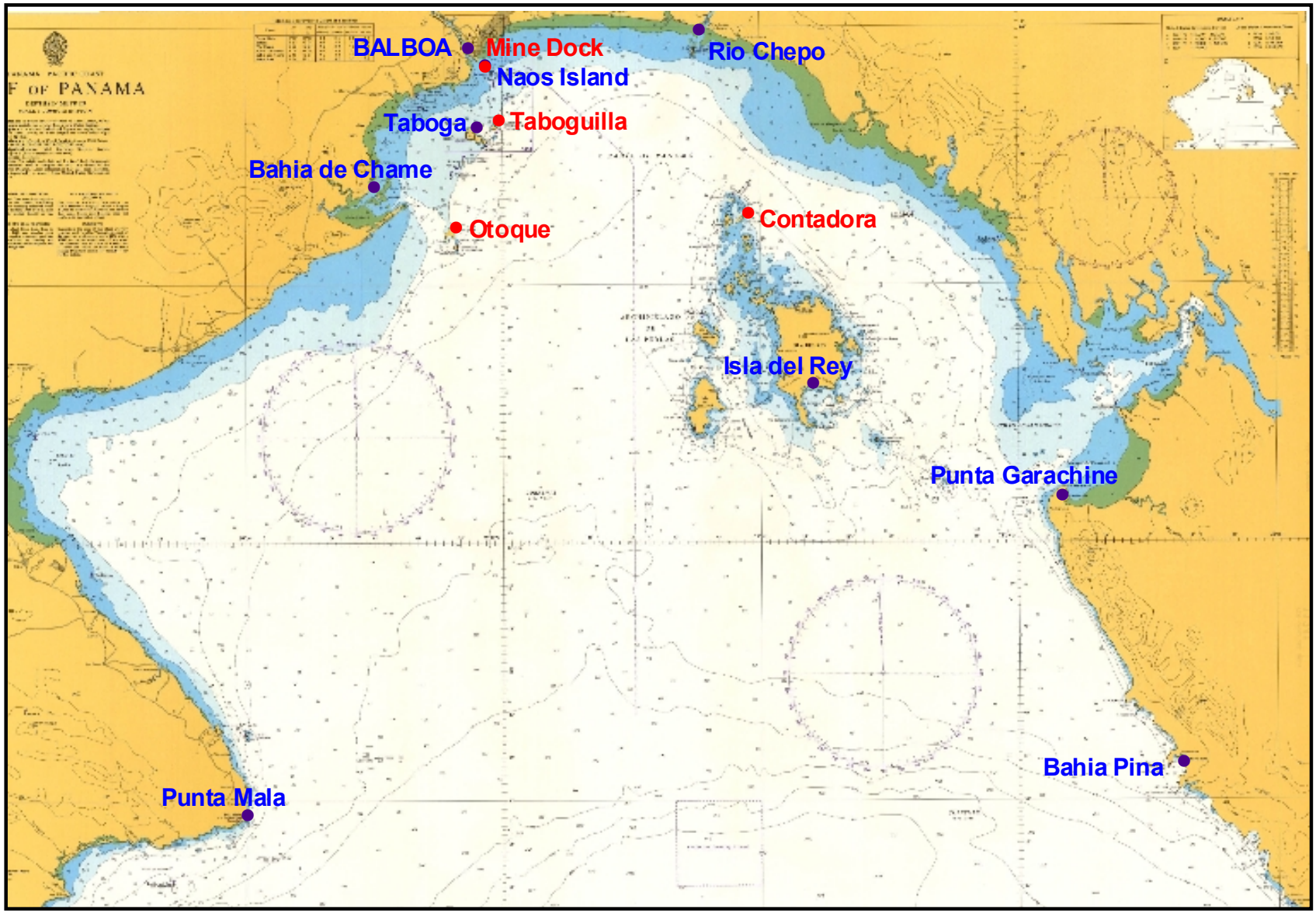
FIGURE 3-1:
NOAA charts 1929 and 1401



- NOAA predicted tides
- ACP water level measurements

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FIGURE 3-2:
Tidal prediction and ACP water level gauges

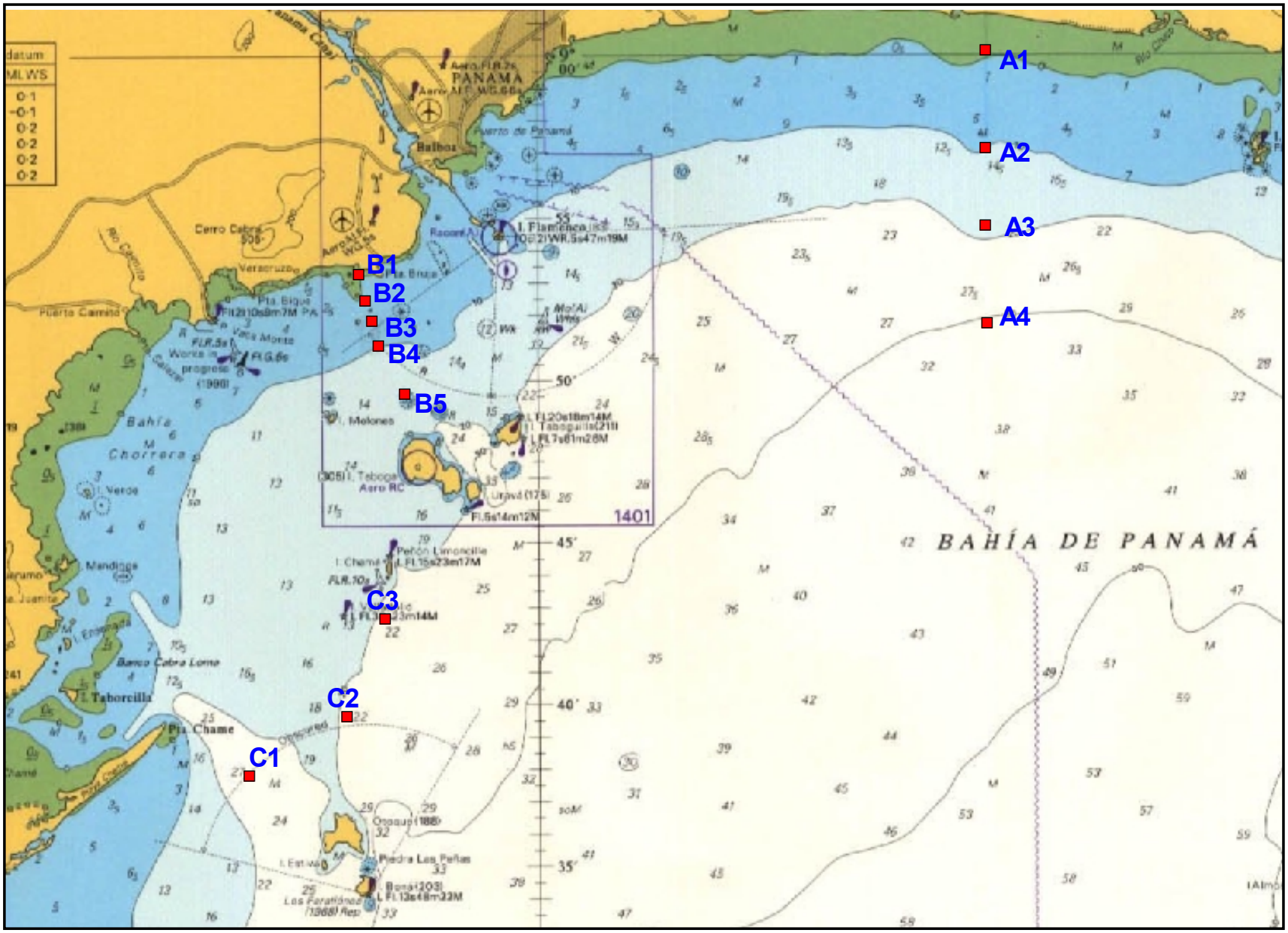

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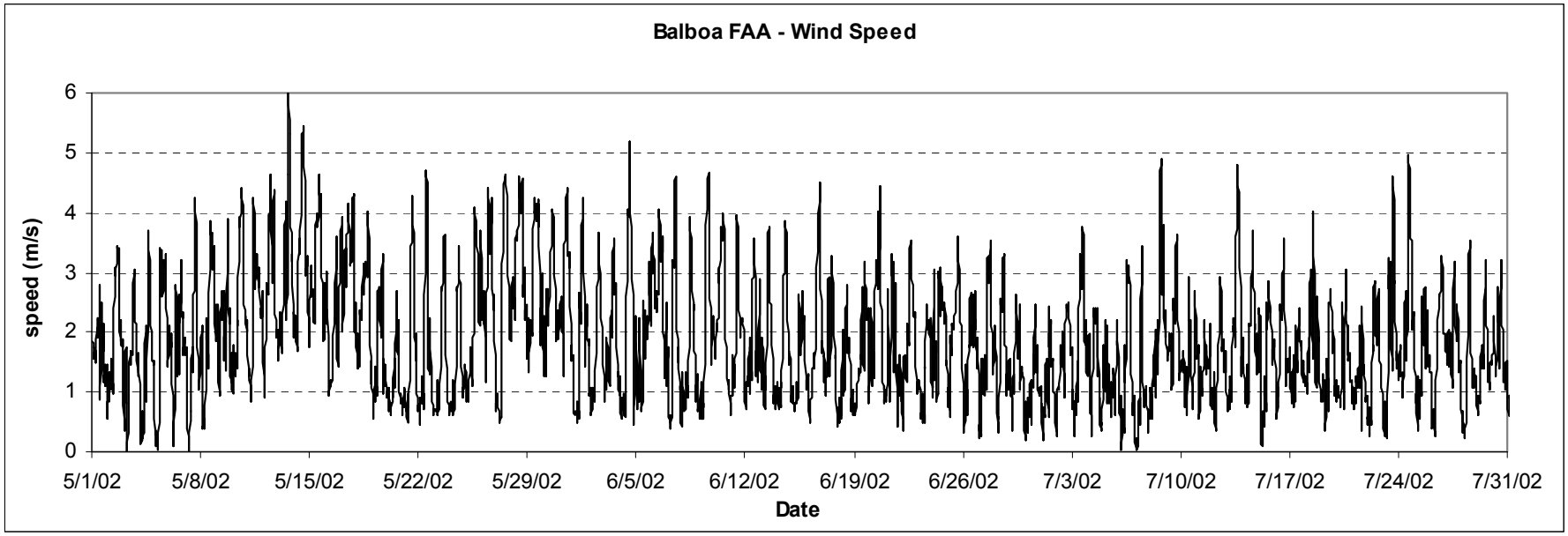
FIGURE 3-3:
ACP current measurement locations



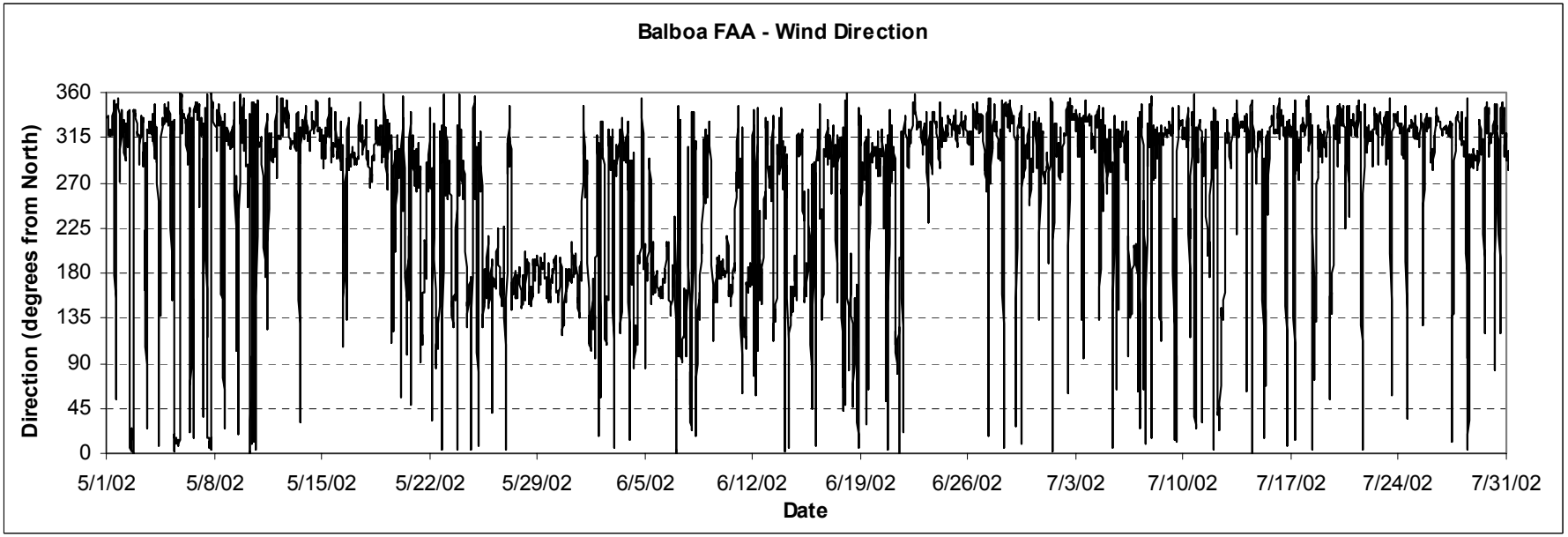


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FIGURE 3-4:
Balboa FAA - Hourly average wind speed and direction

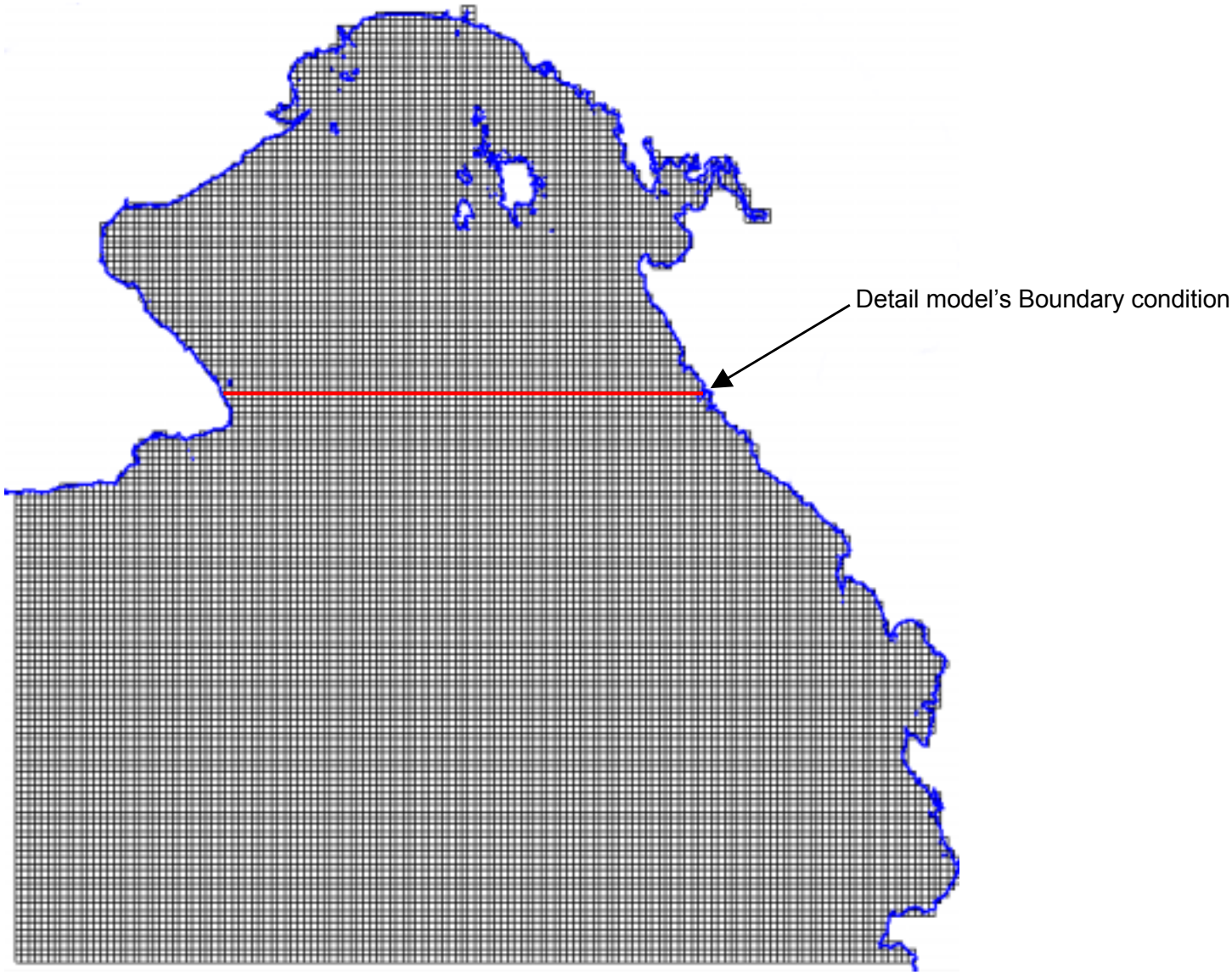

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FIGURE 3-5:
Regional Model Grid

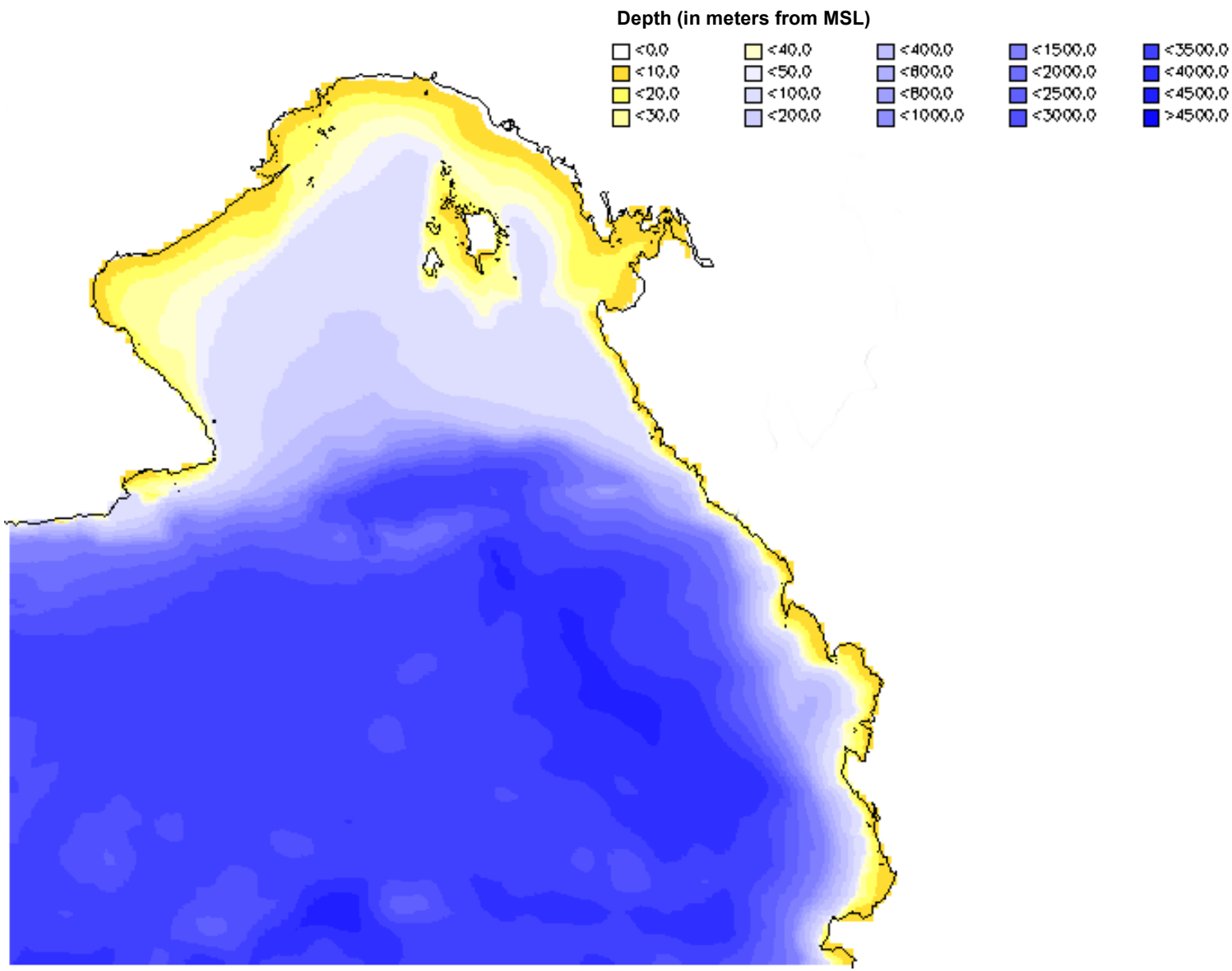

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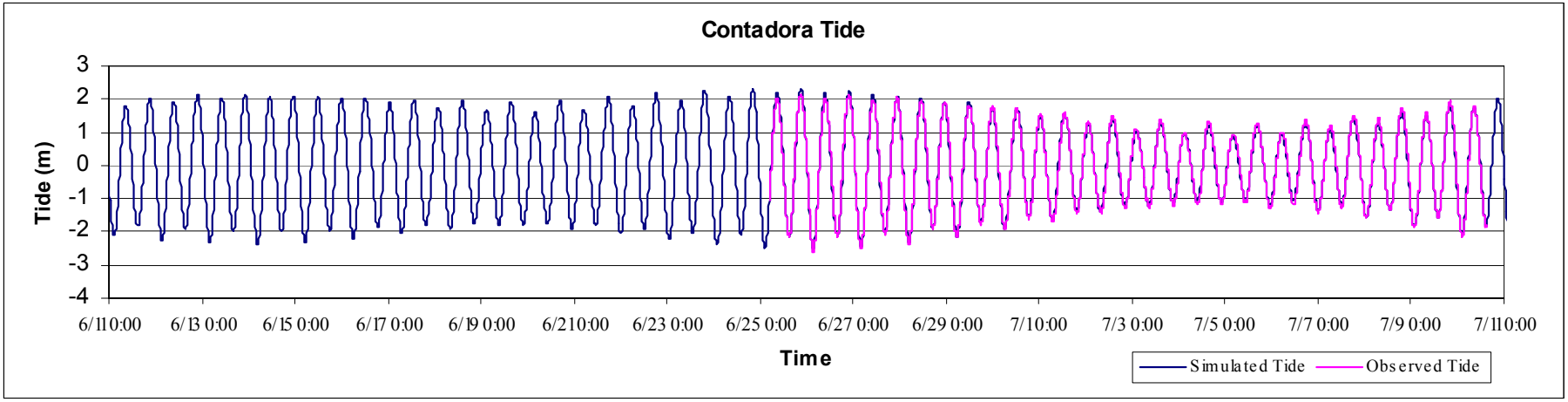
FIGURE 3-6:
Regional Model Bathymetry



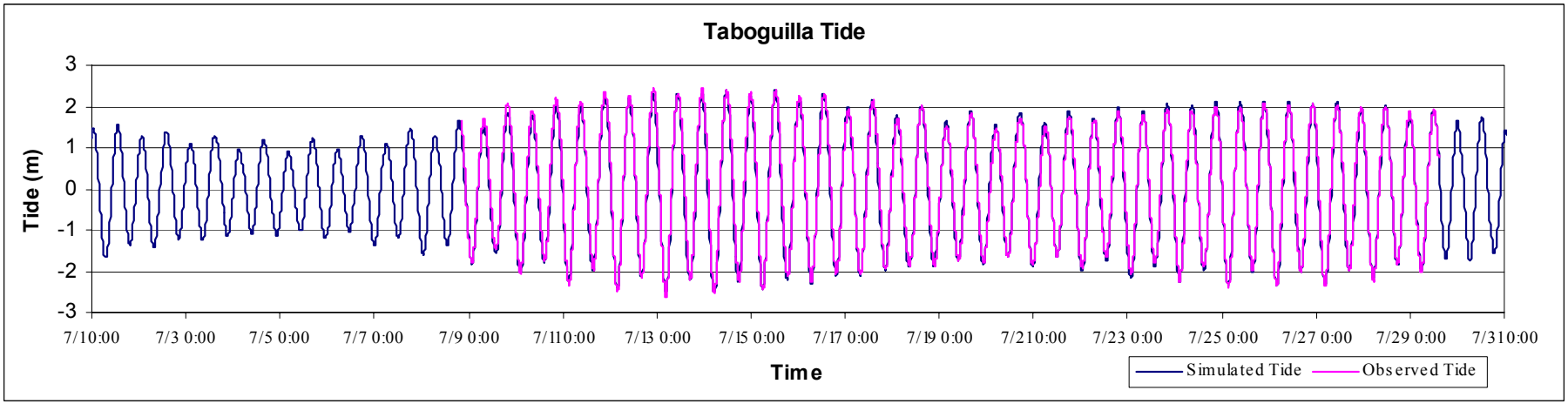


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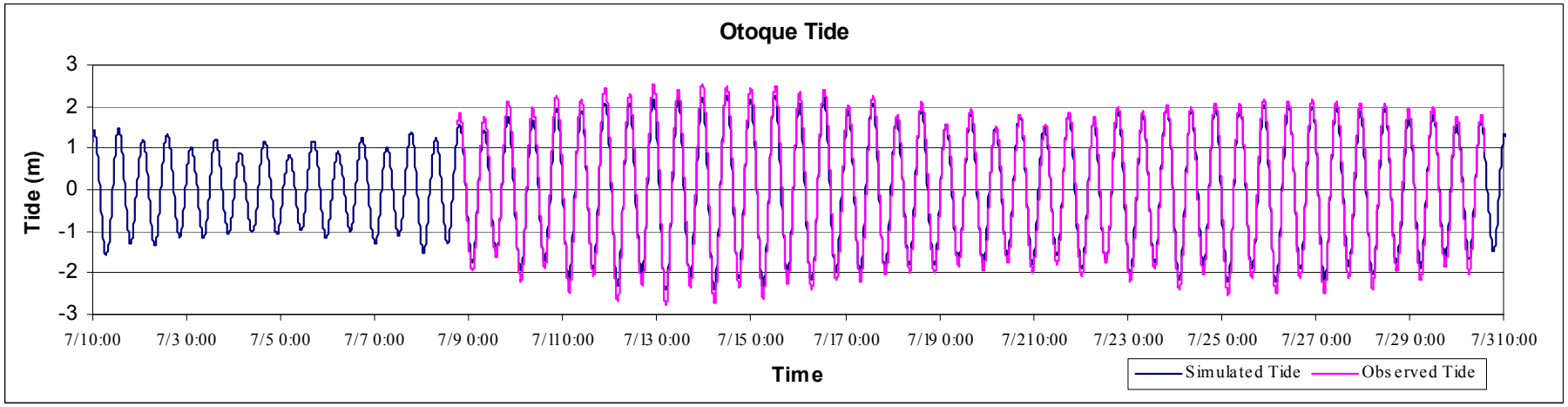
FIGURE 3-7:
Regional model Tidal Calibration. Simulated vs. Observed tides



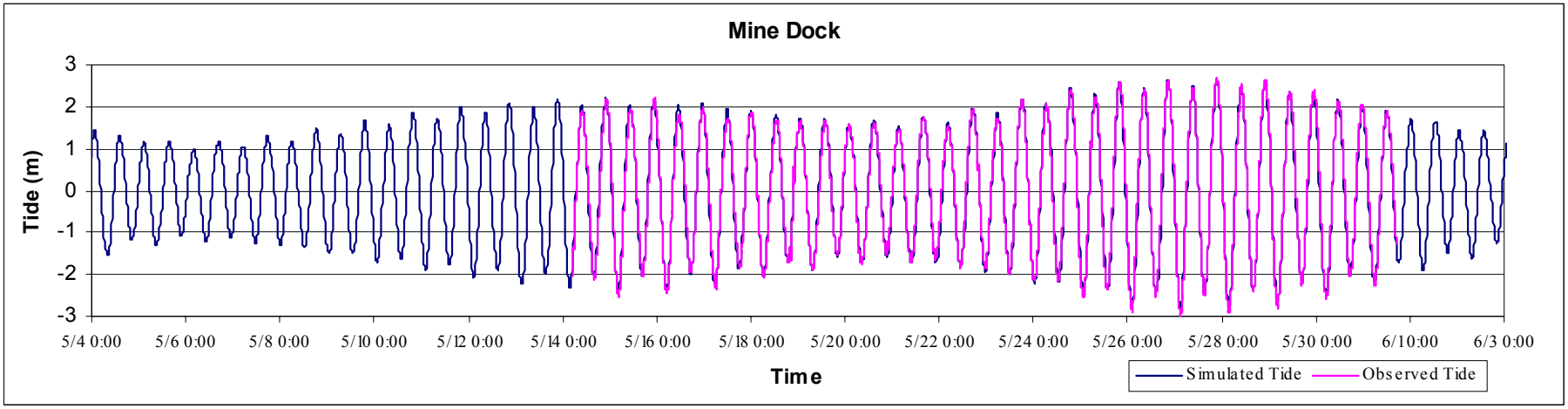


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FIGURE 3-8:
Regional model Tidal Calibration. Simulated vs. Observed tides

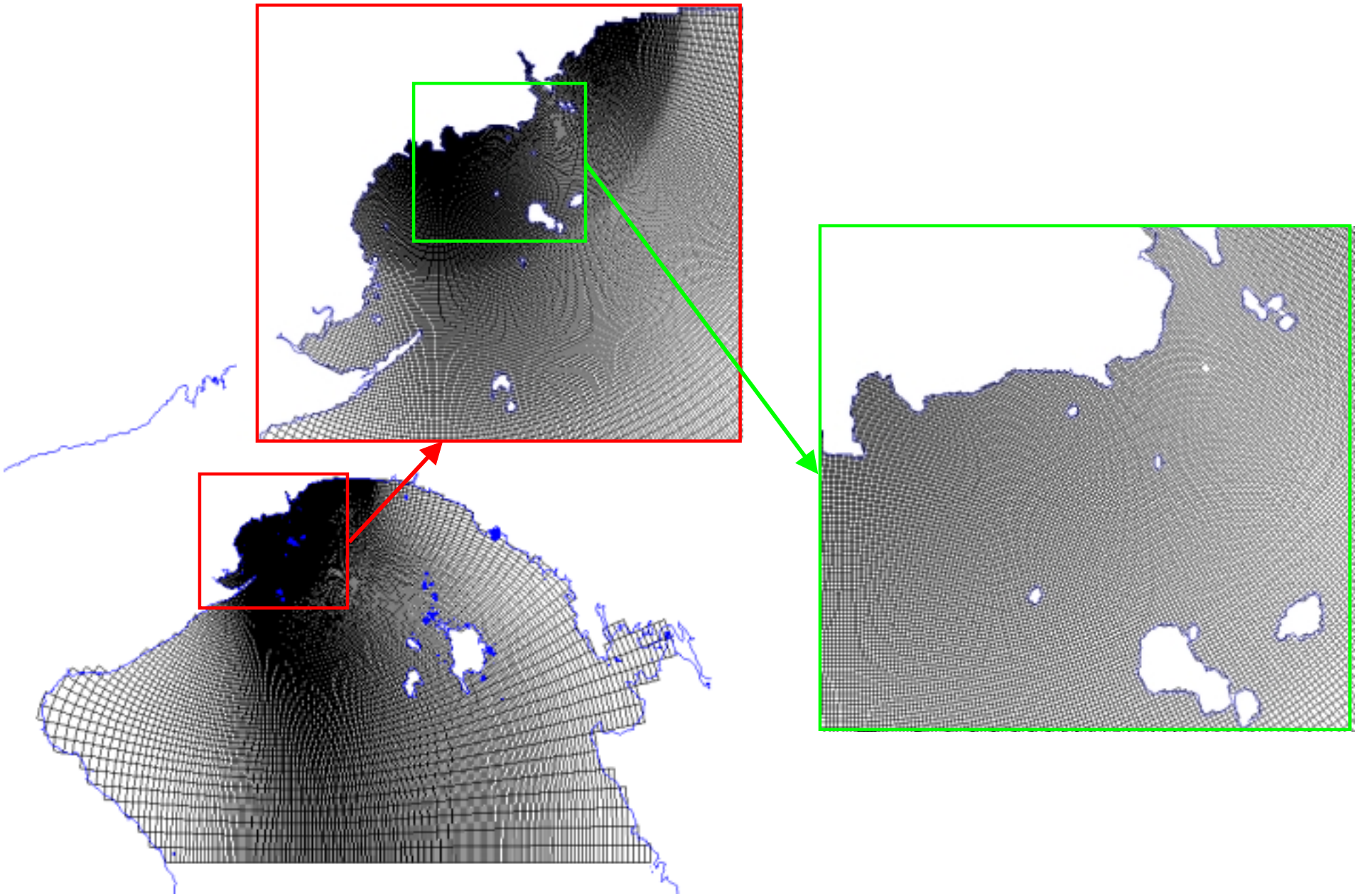

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FIGURE 3-9:
Local Model Grid

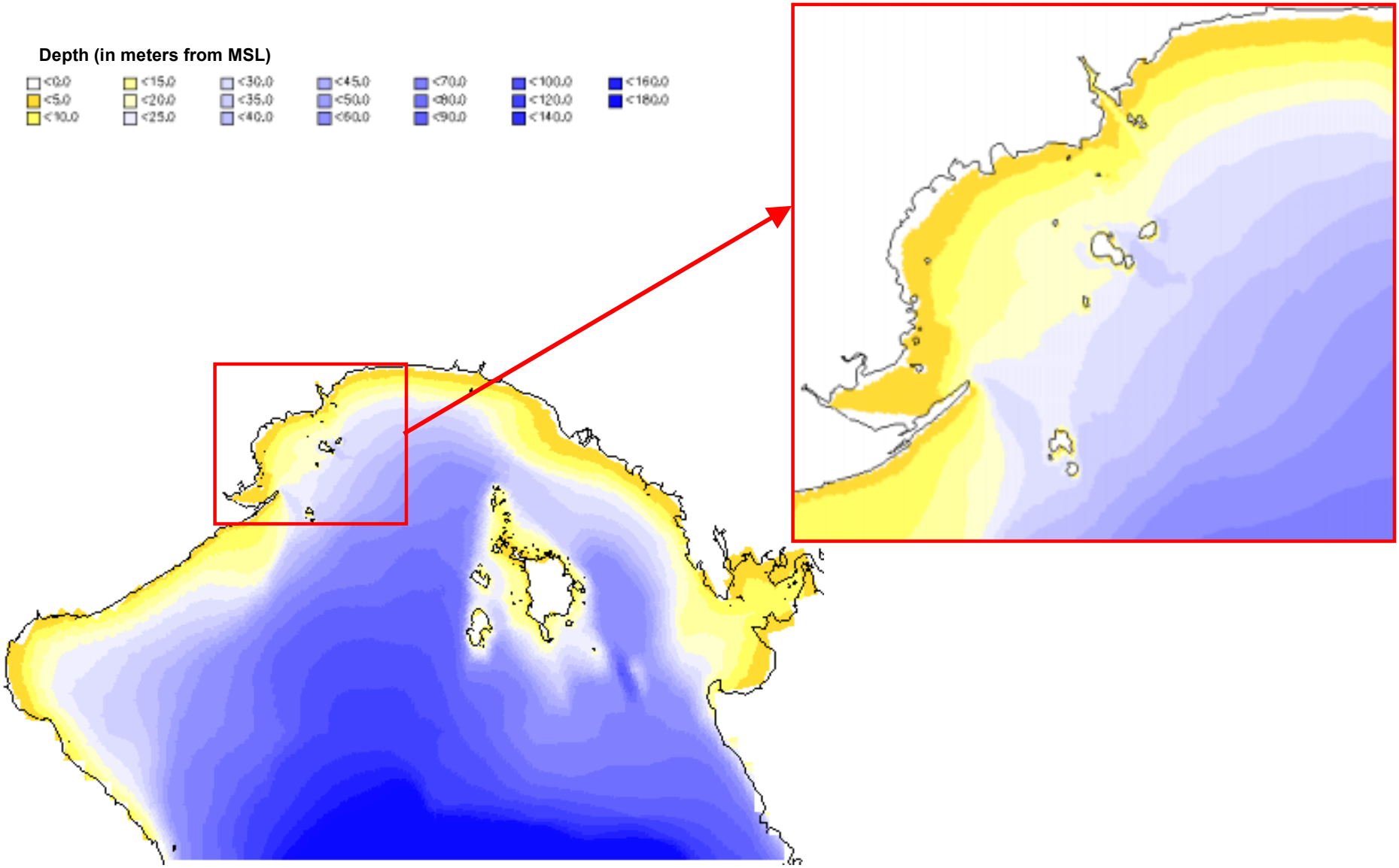

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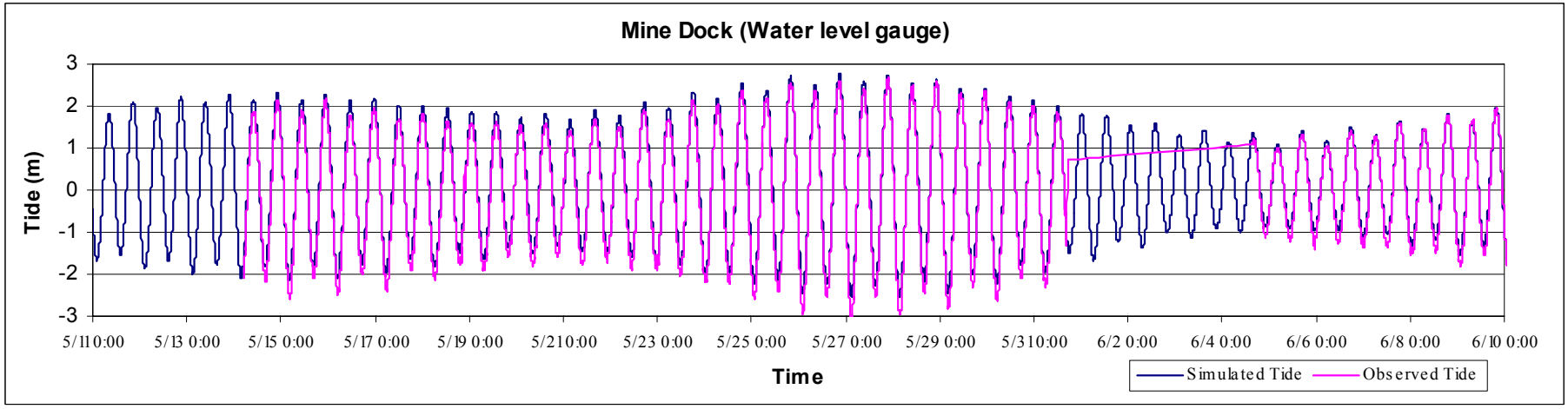
FIGURE 3-10:
Local Model Bathymetry



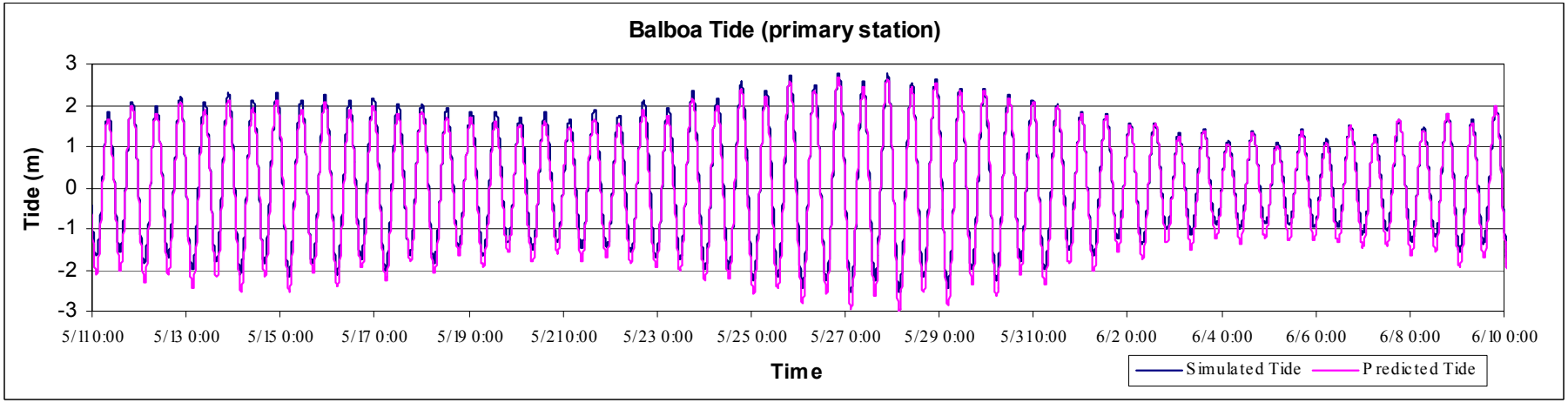


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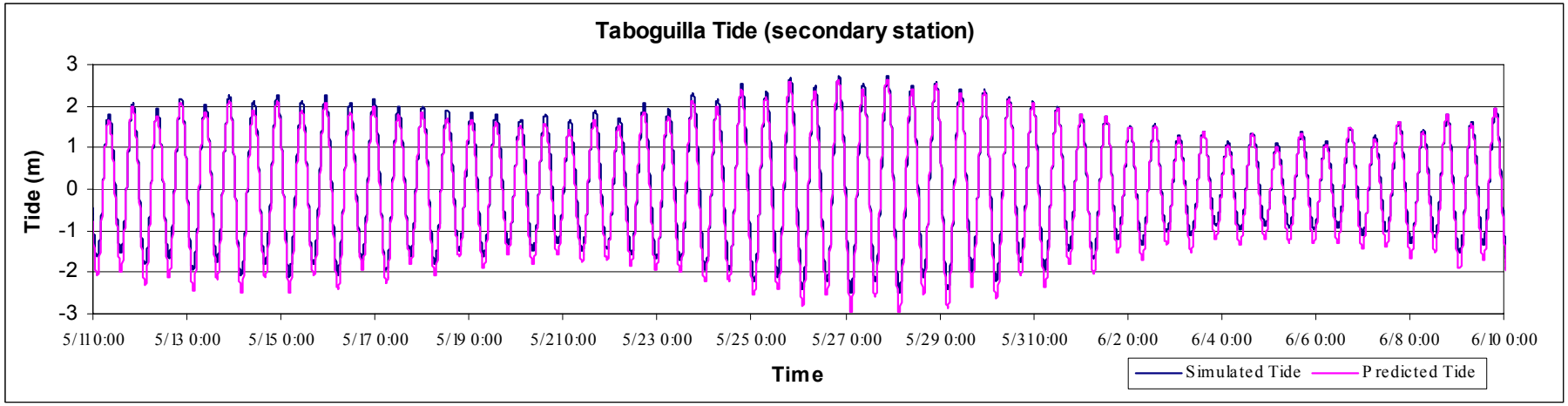
FIGURE 4-1:
Local model Tidal Calibration. Simulated vs. Observed and Predicted tides



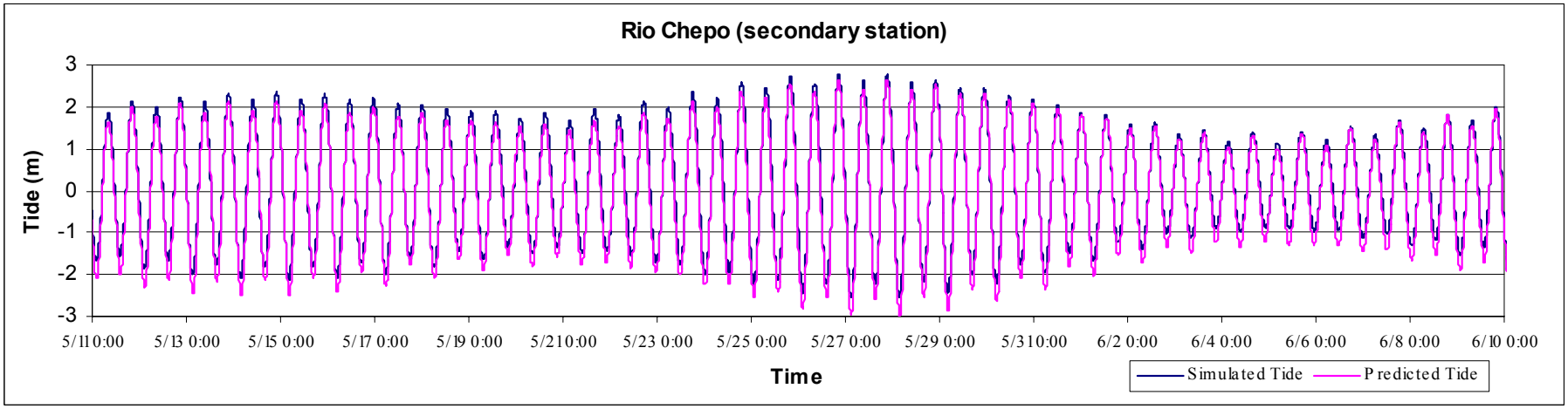


FIGURE 4-2:
Local model Tidal Calibration. Simulated vs. Predicted tides

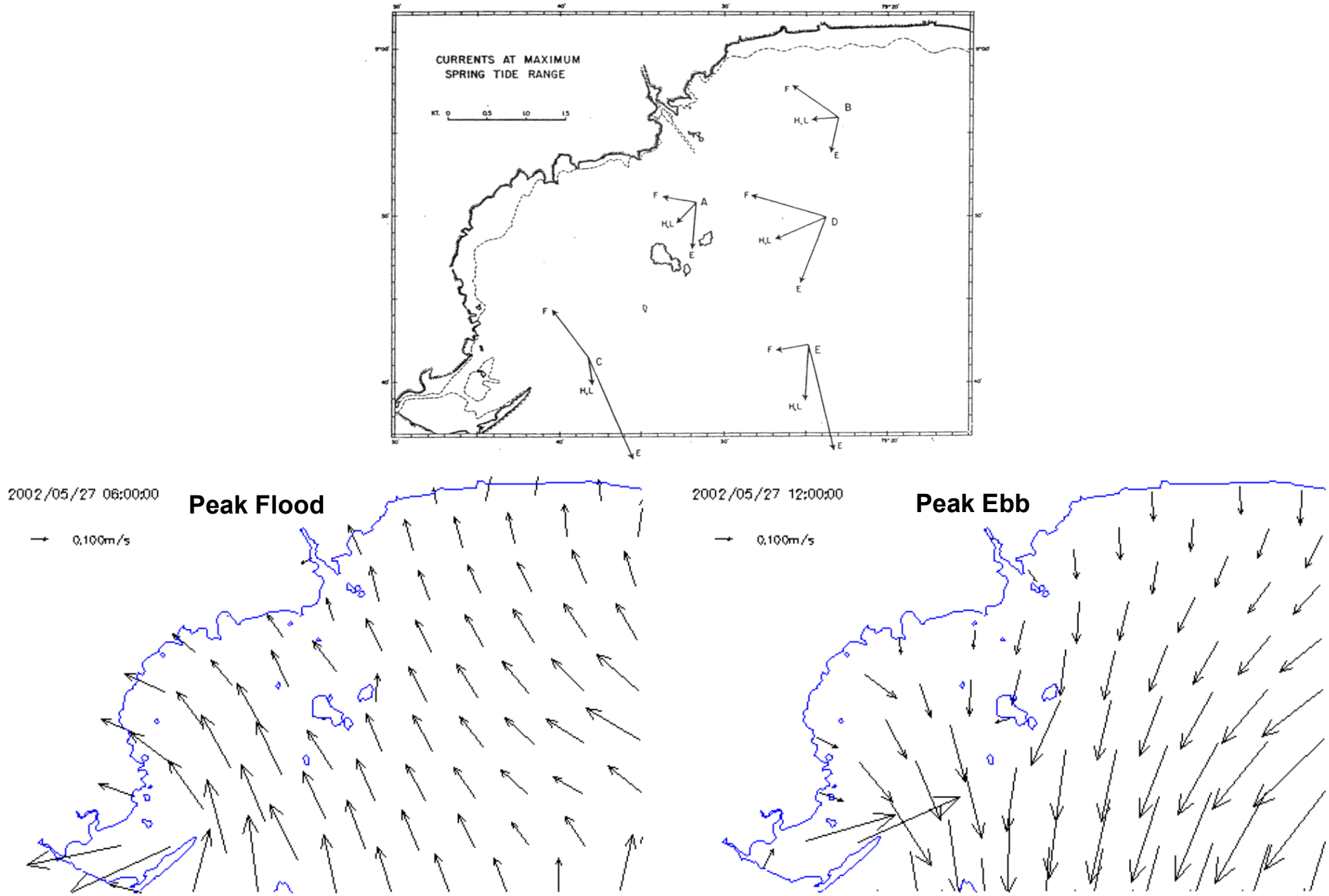


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FIGURE 4-3:
Comparison of Local model current patterns with (Bennett, 1965) during Spring tide

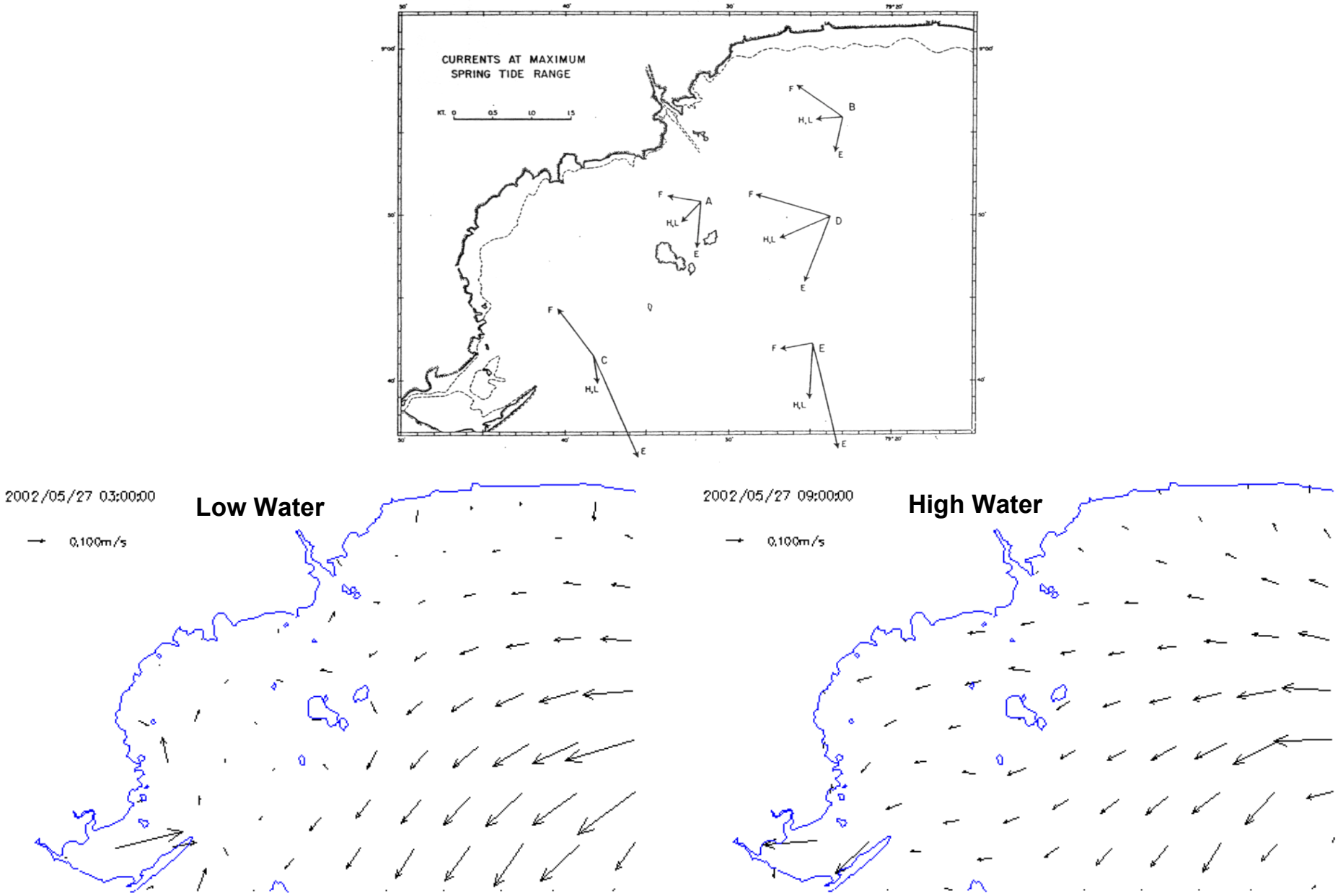

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FIGURE 4-4:
Comparison of Local model current patterns with (Bennett, 1965) during Spring tide

Local model flow patterns: SPRING TIDE

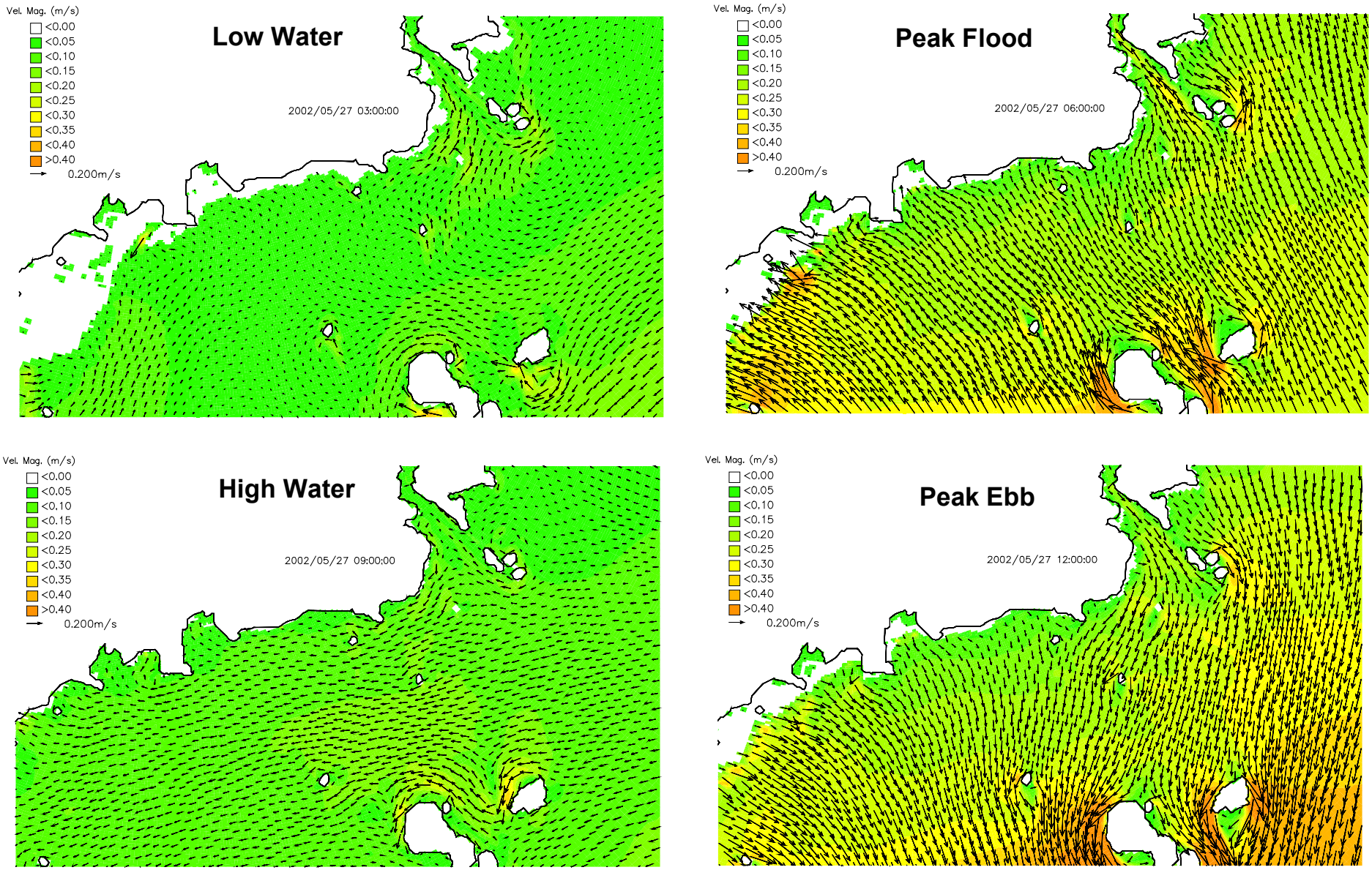

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FIGURE 4-5:
Flow patterns during spring tide
at the project site. Existing Conditions

Local model flow patterns: NEAP TIDE

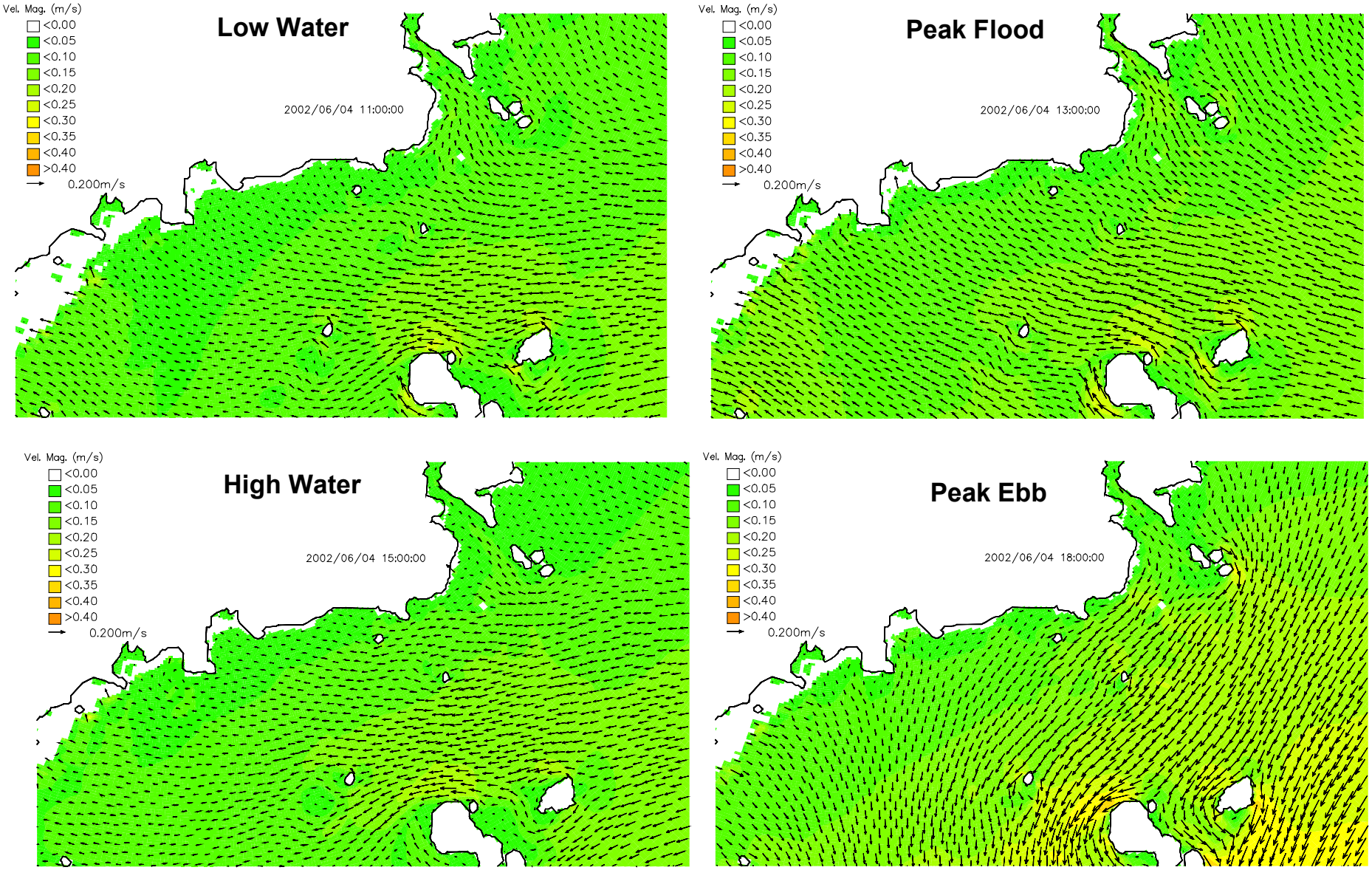

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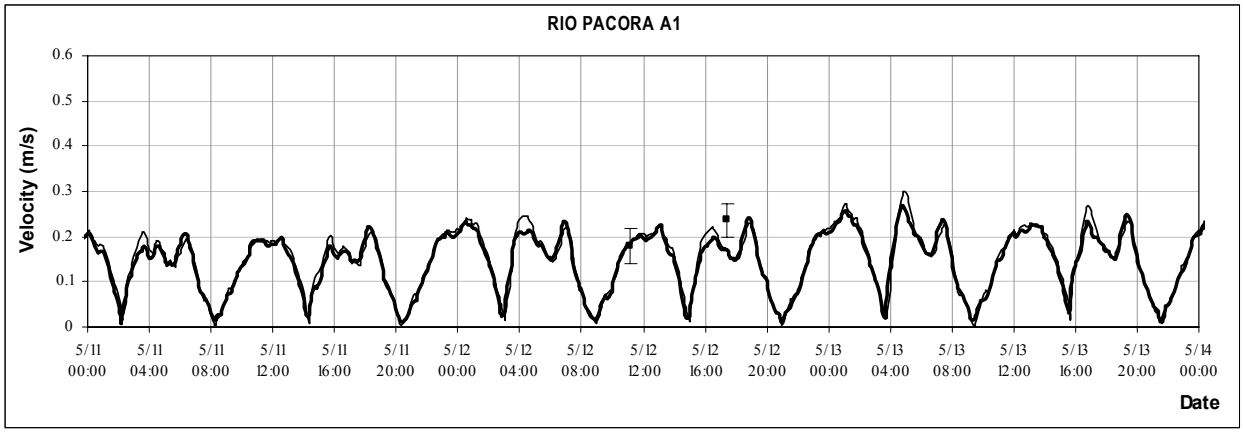
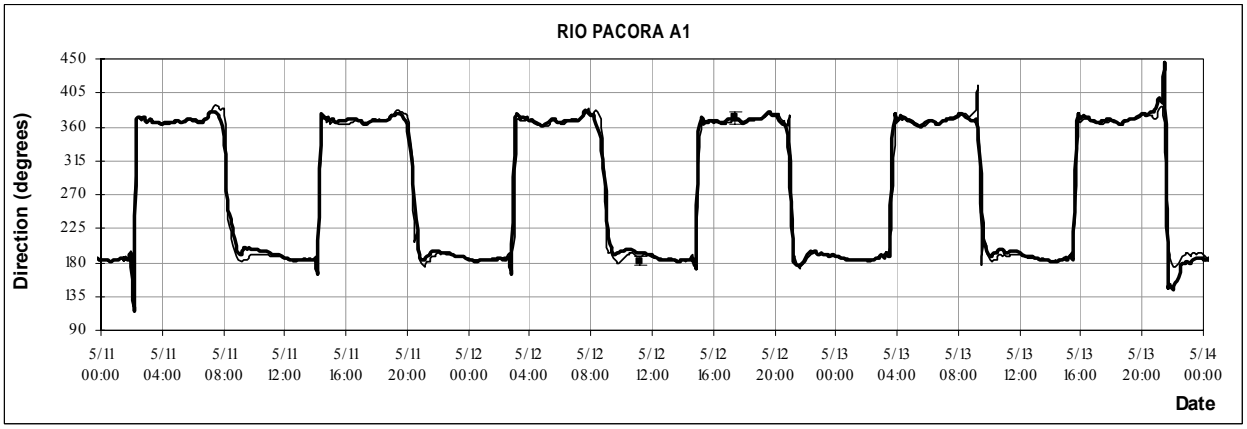
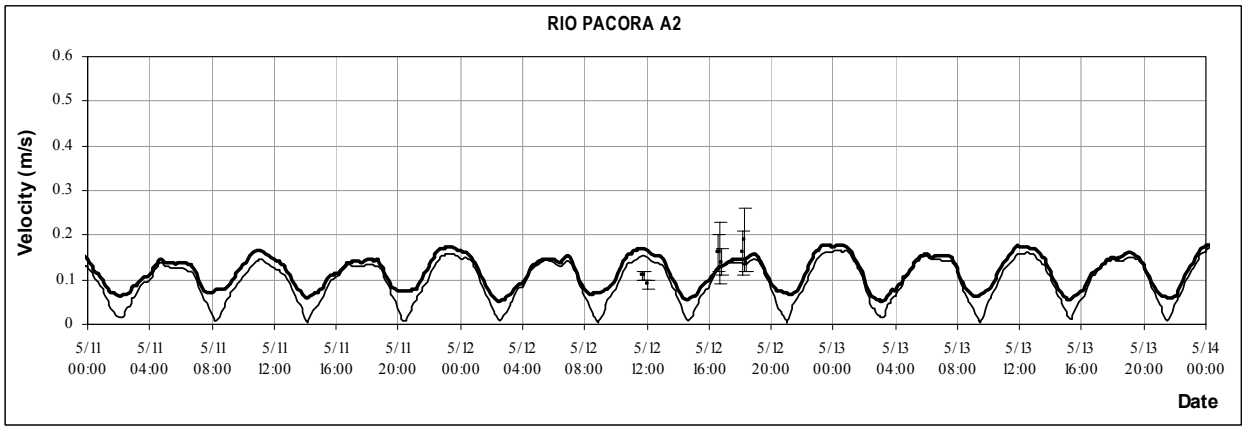
FIGURE 4-6:
Flow patterns during neap tide
at the project site. Existing Conditions

A. TIME SERIES OF CURRENT SPEED AND DIRECTION







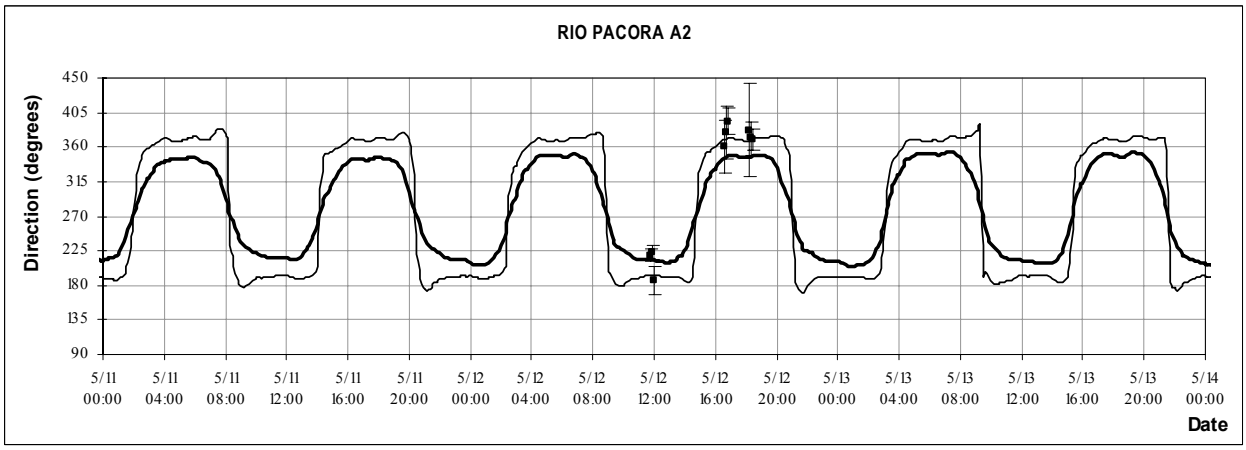


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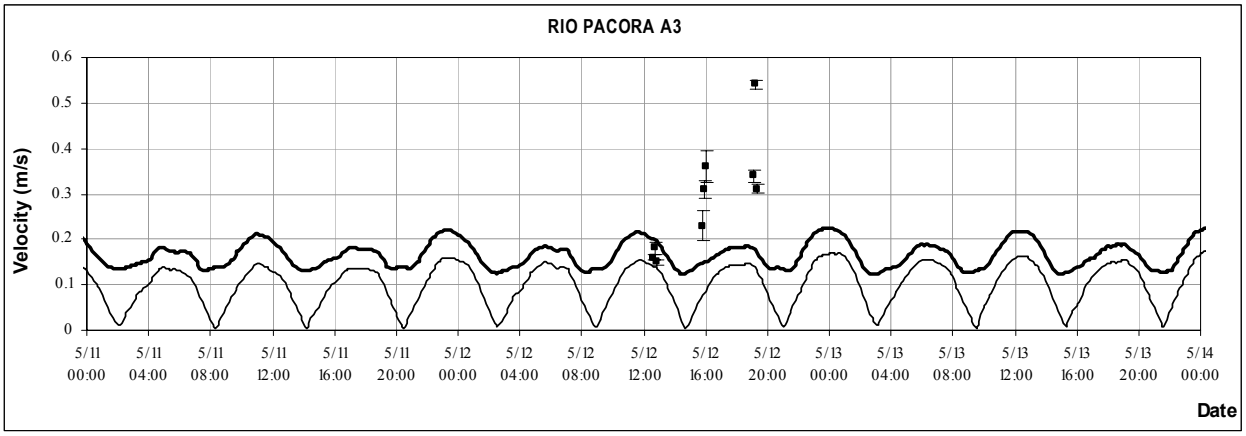
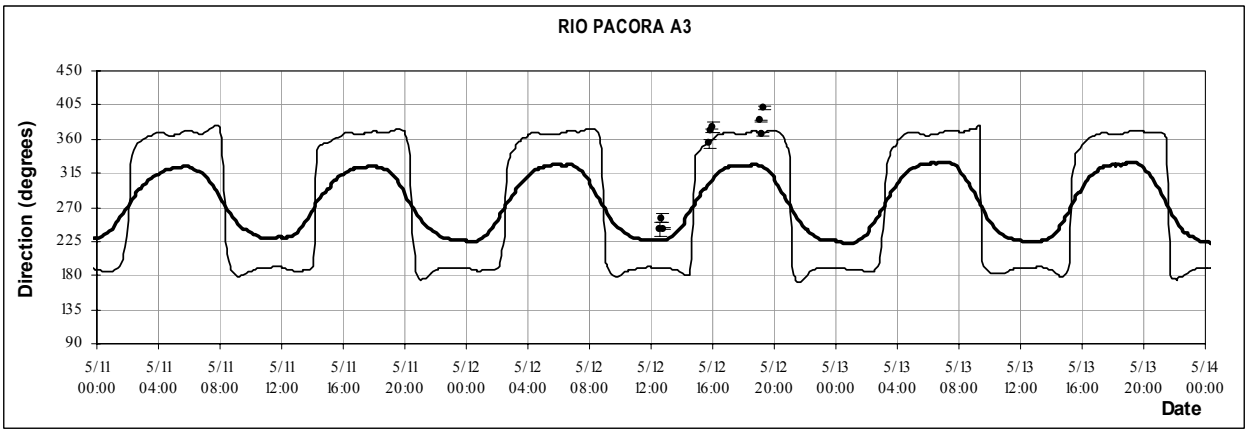
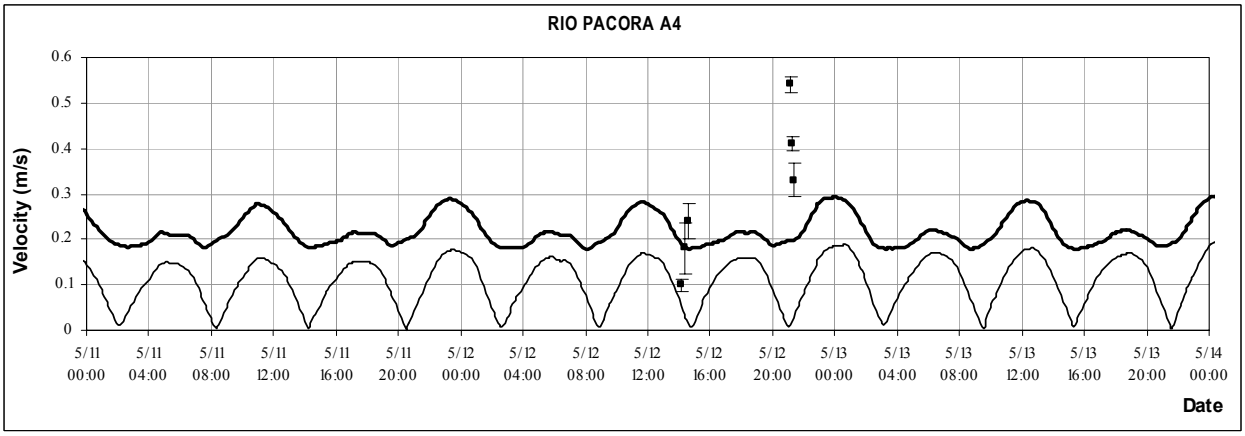
FIGURE A-1 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)







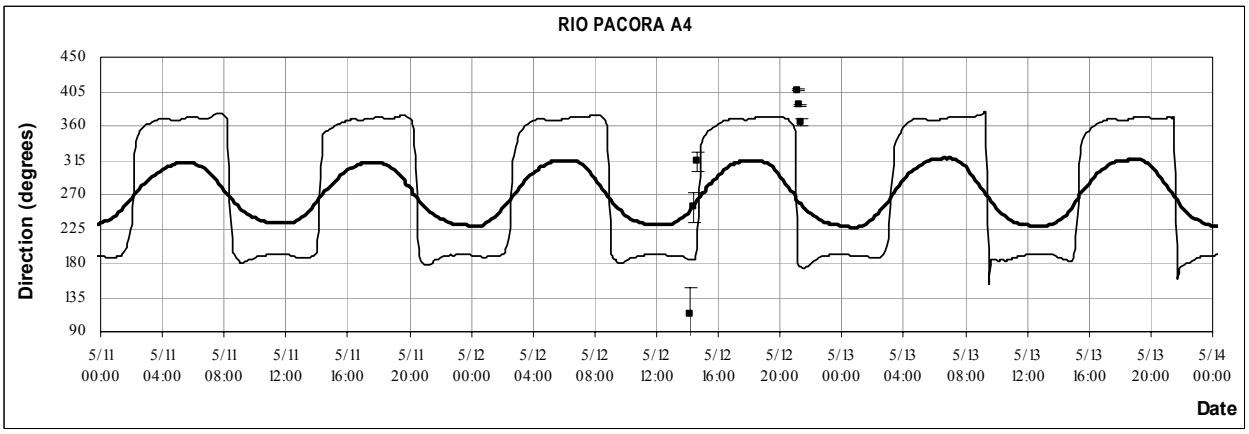


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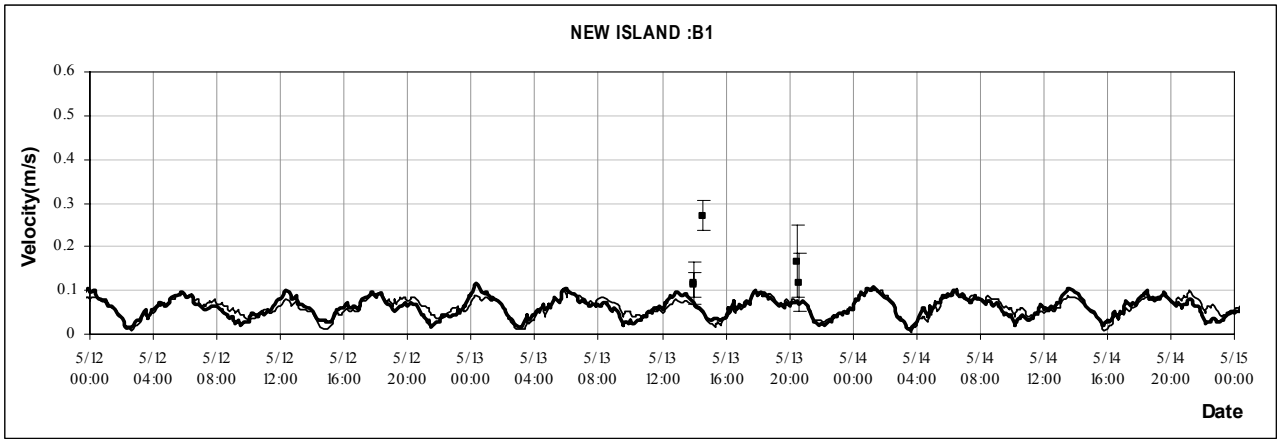
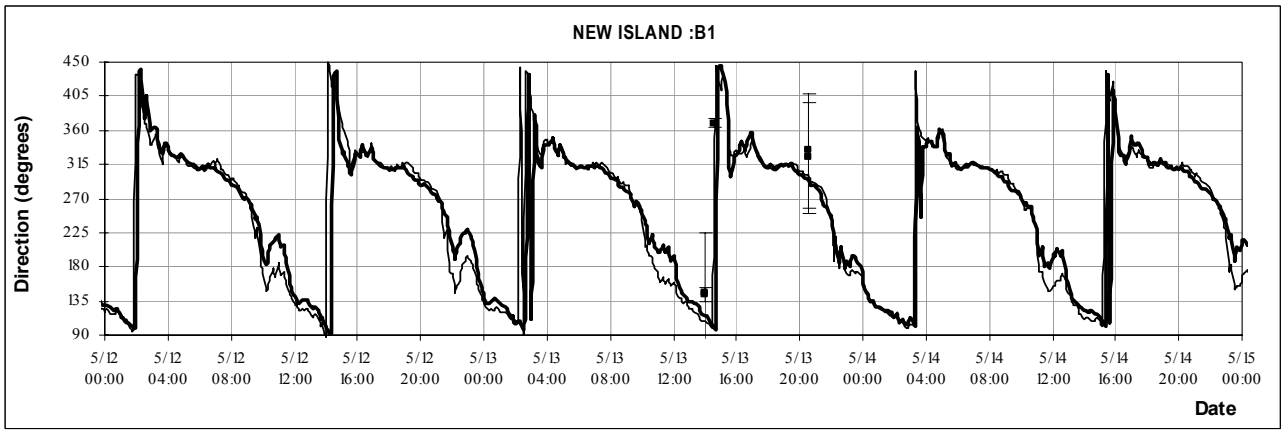
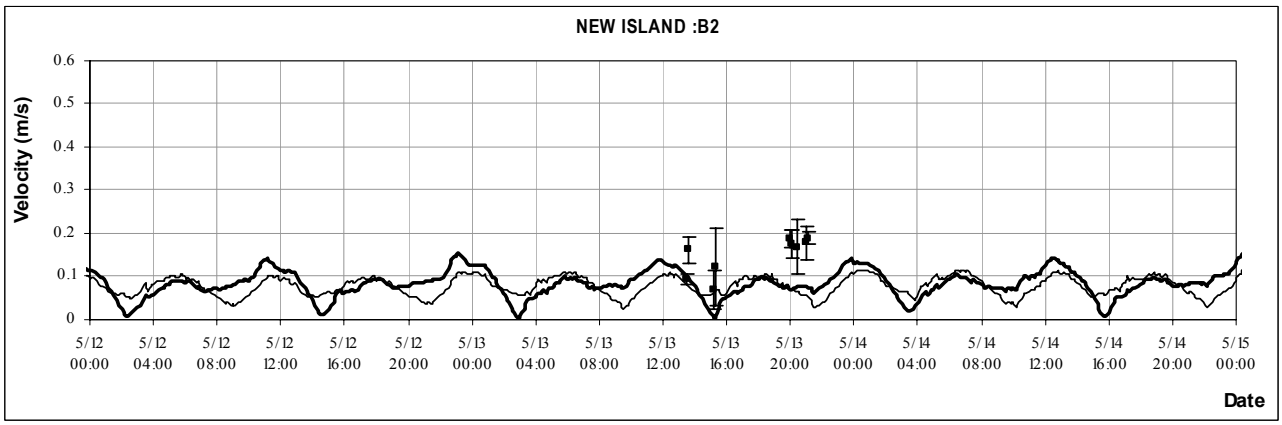
FIGURE A-2 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)







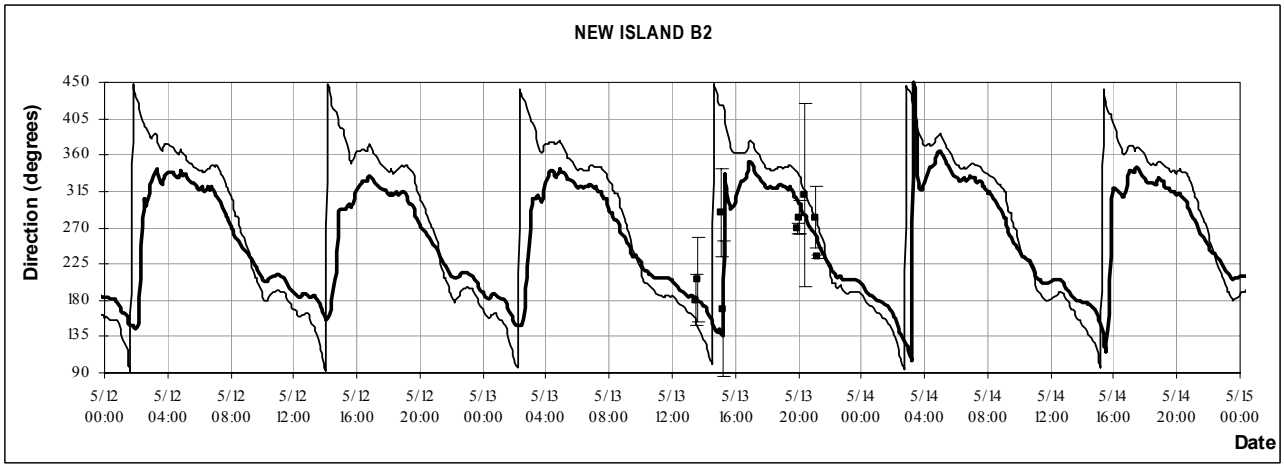


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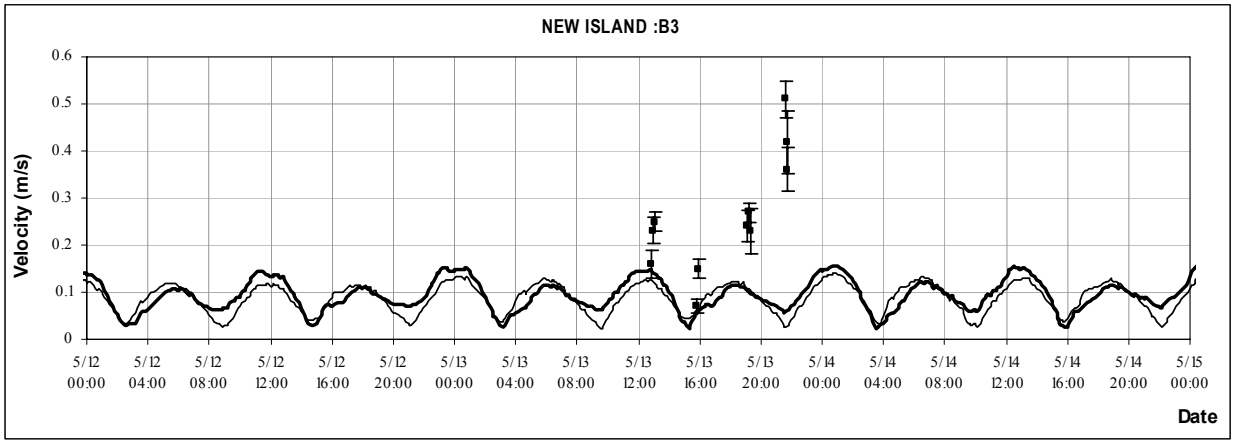
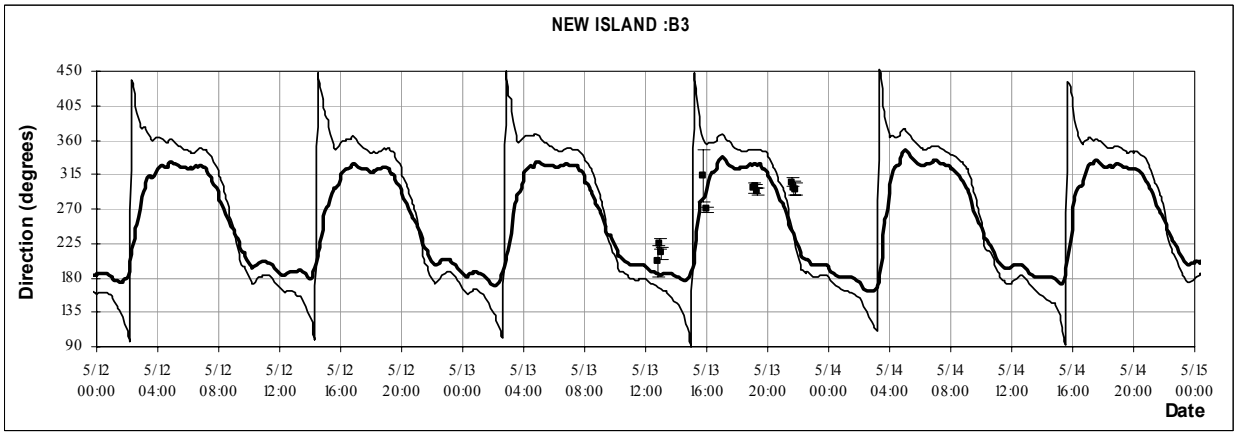
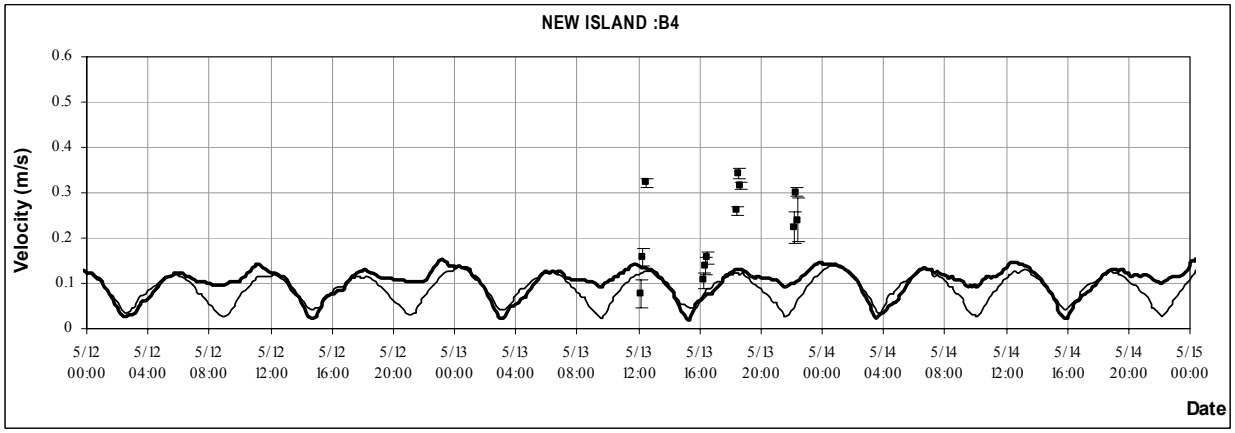
FIGURE A-3 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)







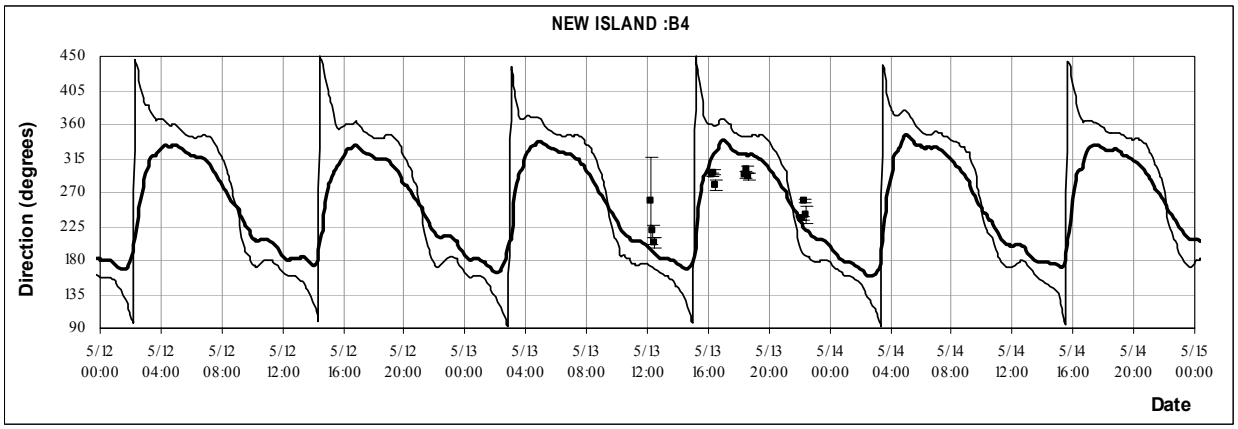


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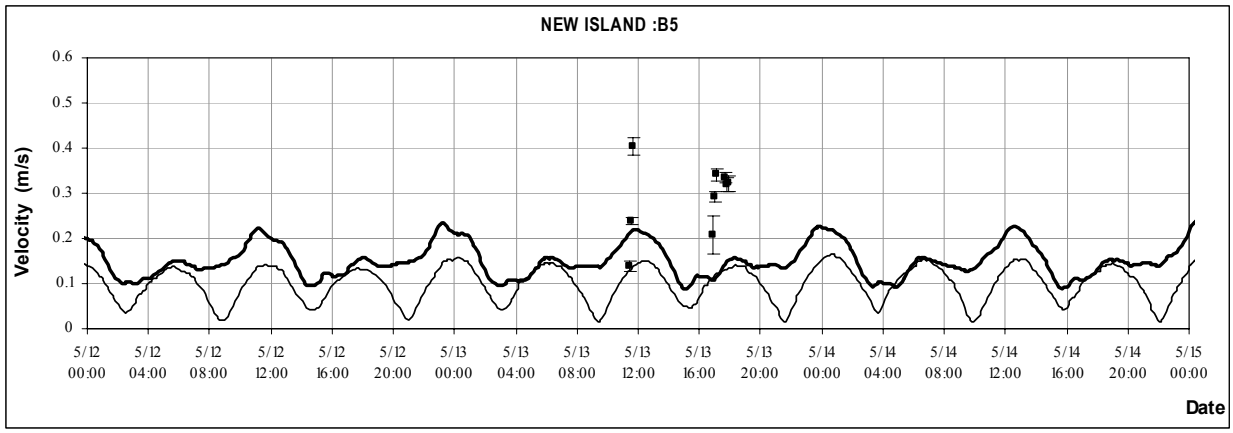
FIGURE A-4 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)



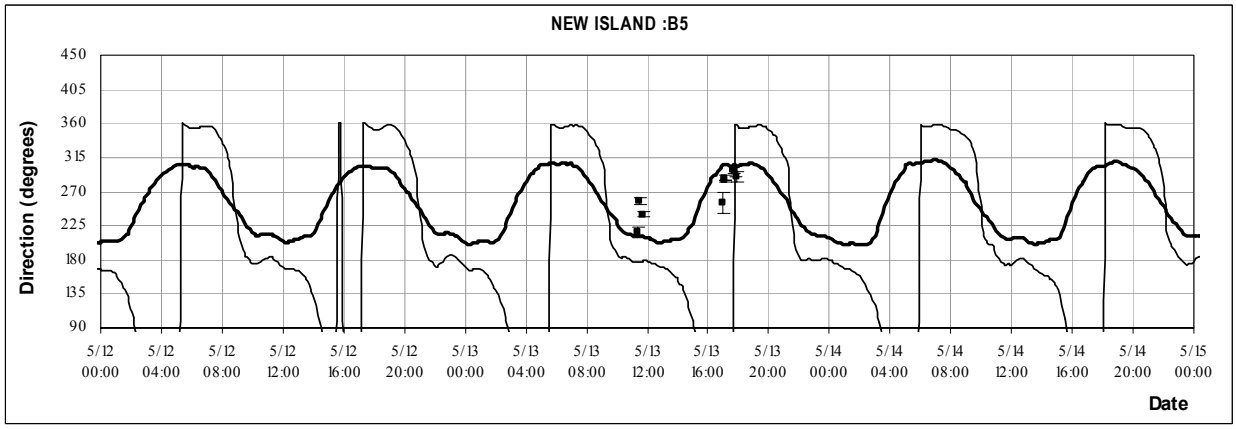


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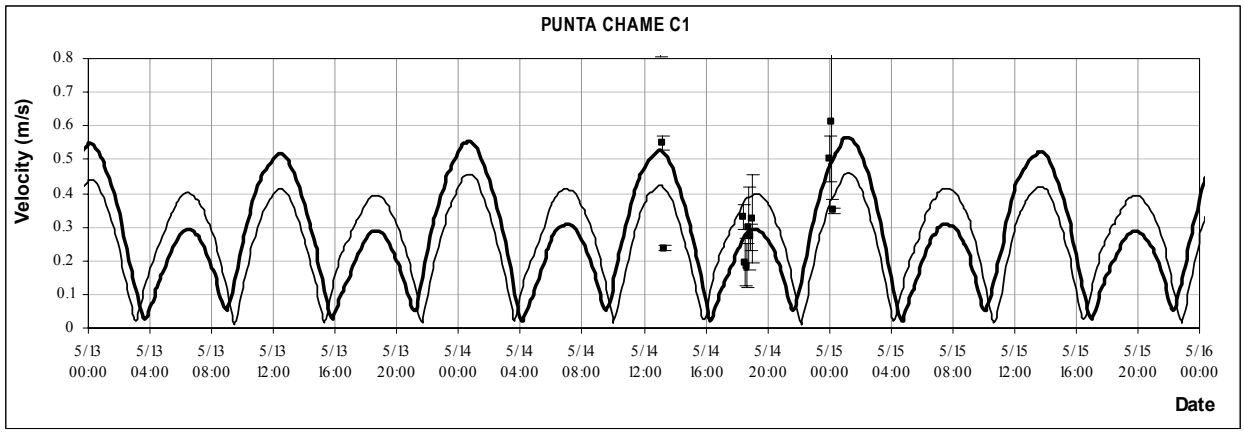
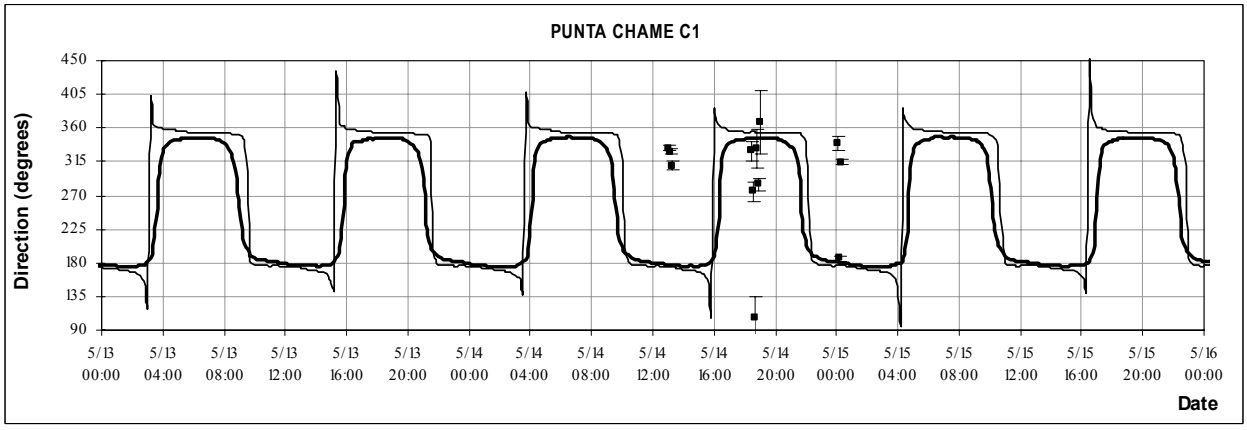
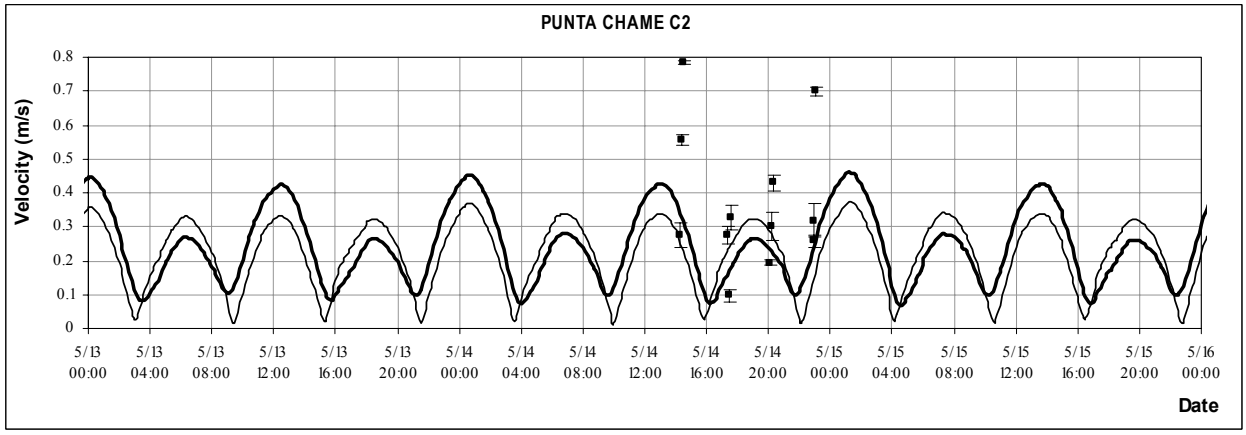
FIGURE A-5 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)







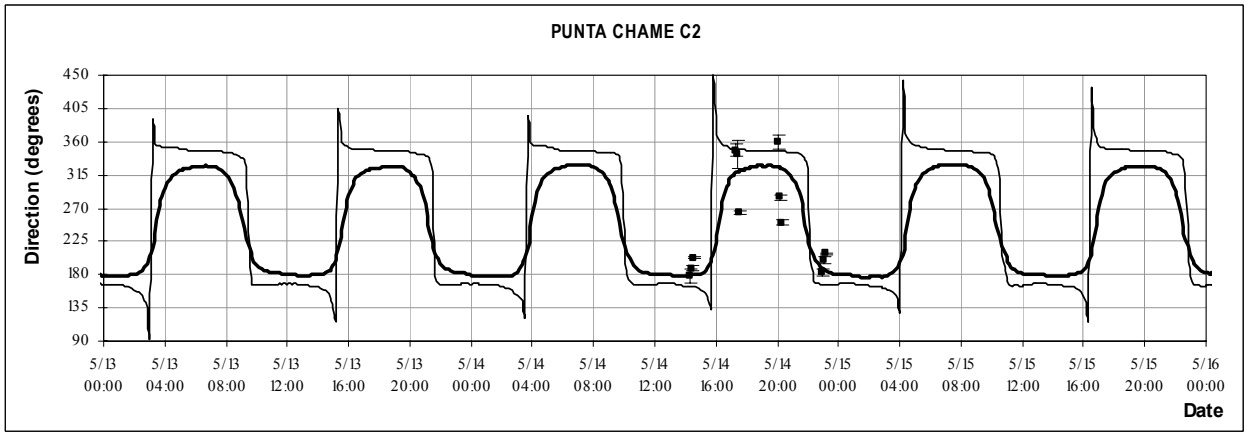


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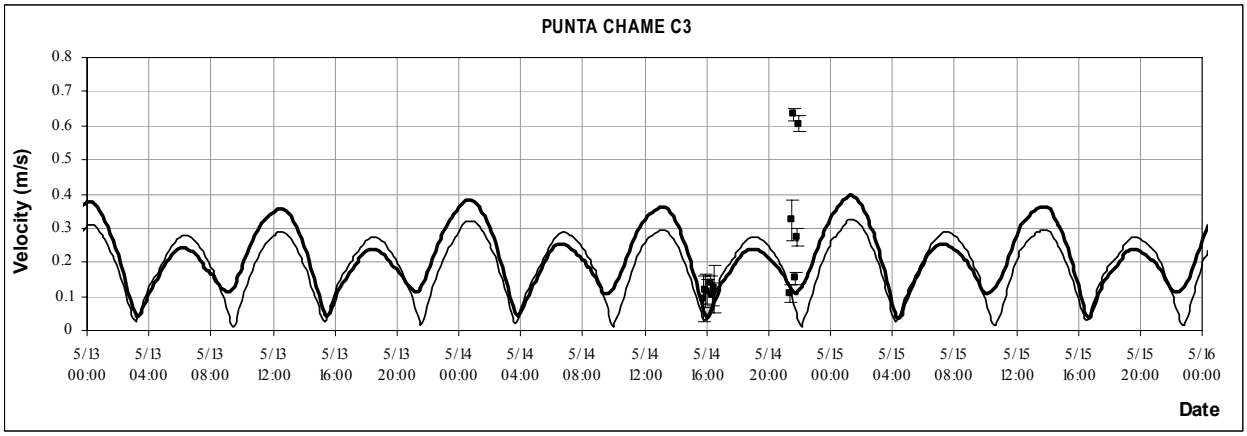
FIGURE A-6 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)



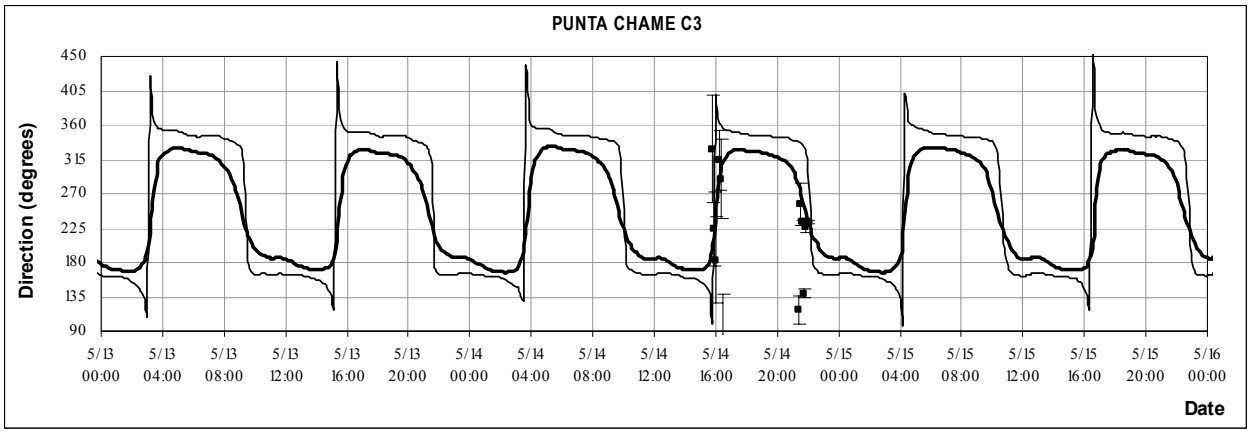


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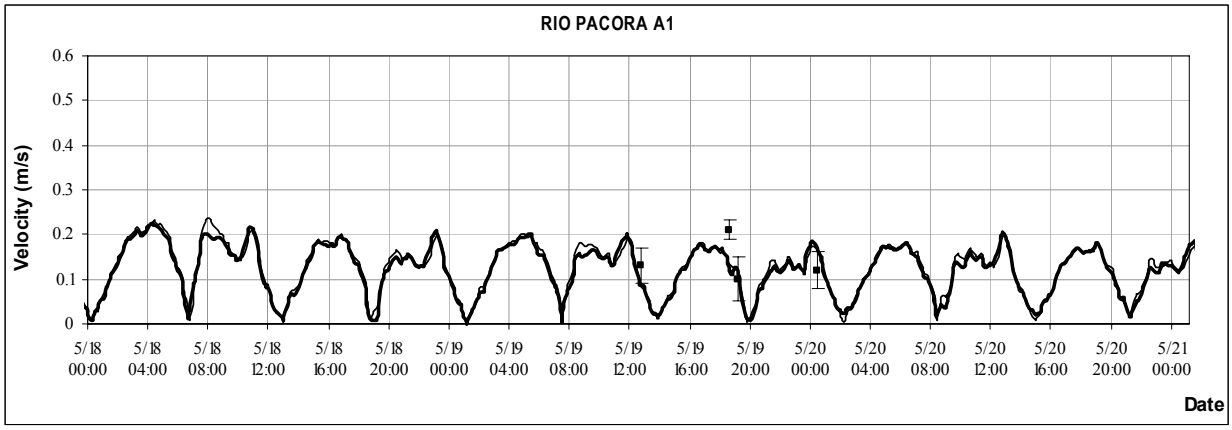
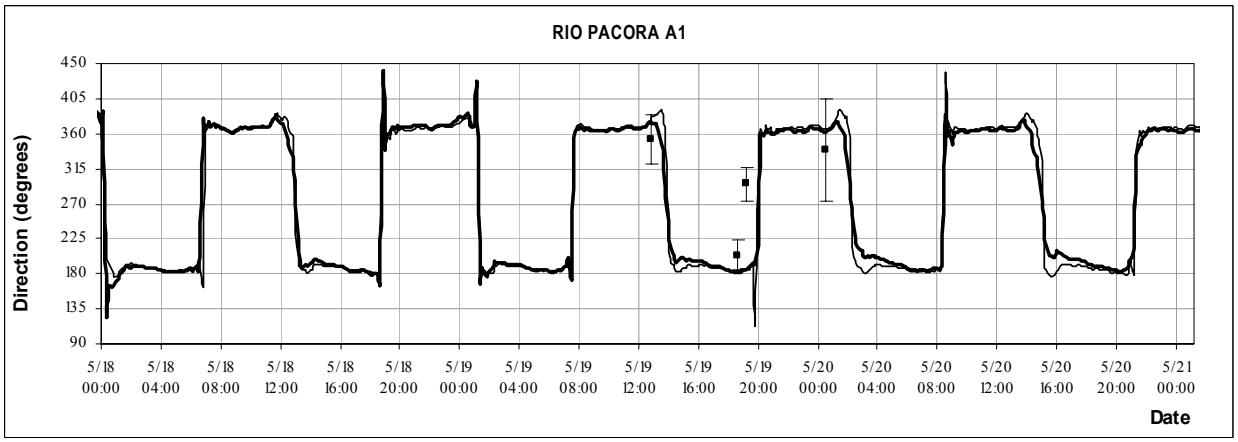
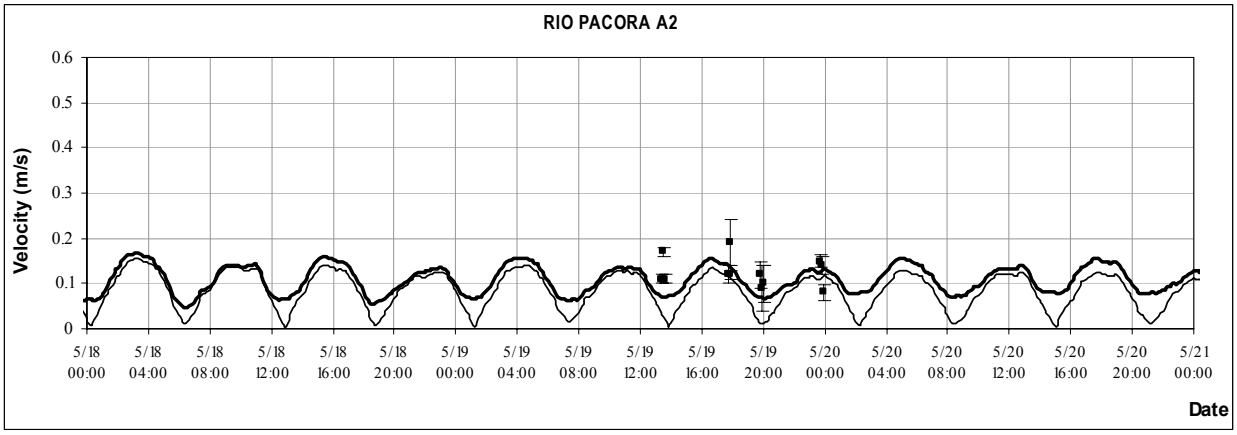
FIGURE A-7 : Campaign 1 Observed and simulated current and direction (tides and tides+GP current)







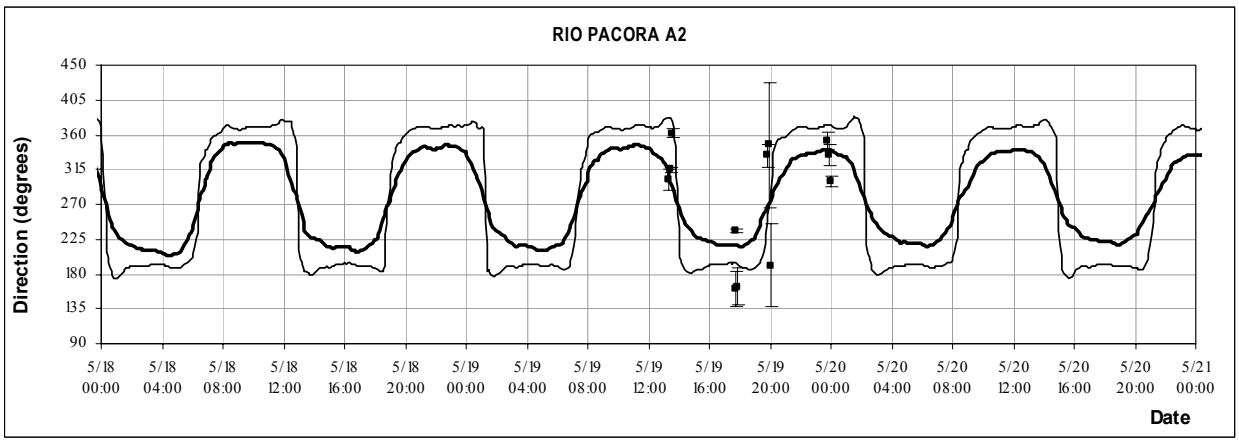


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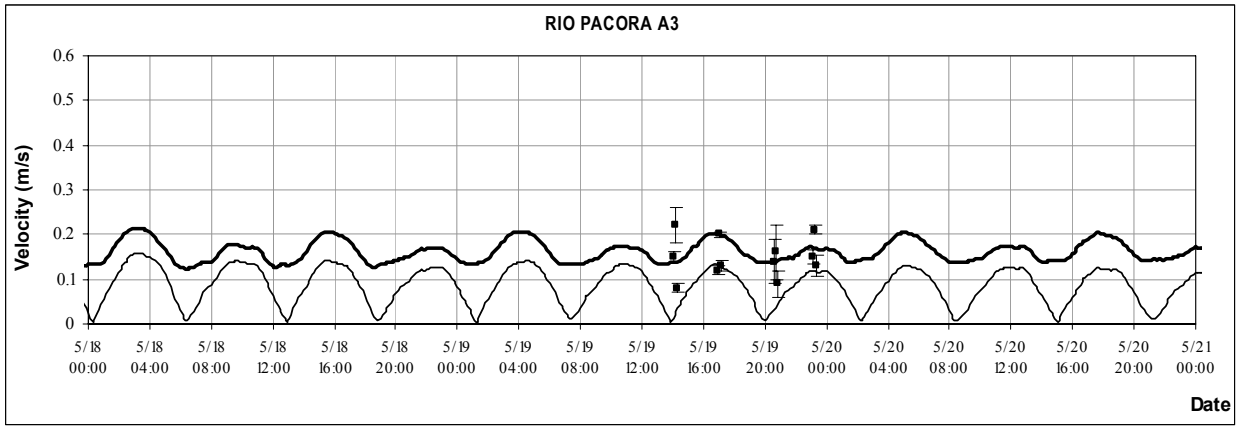
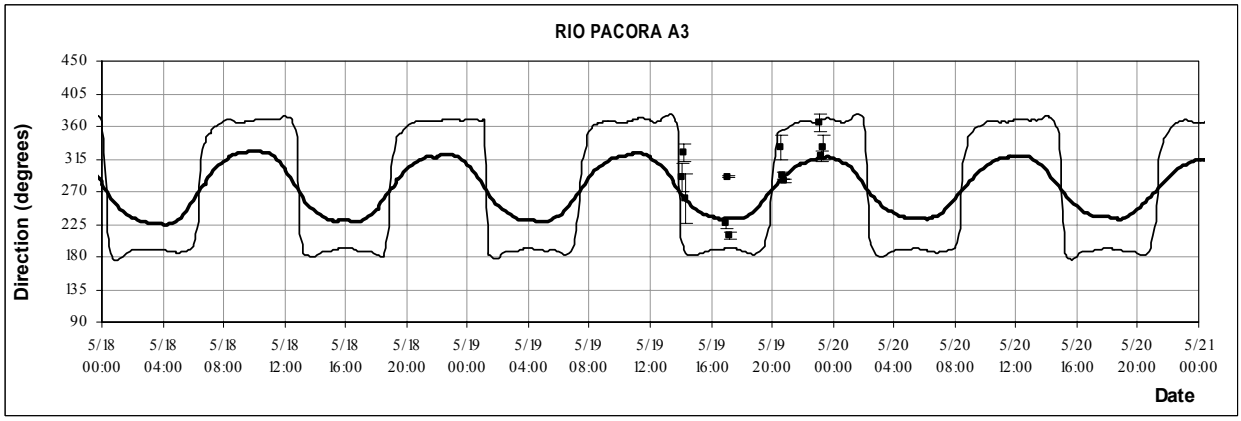
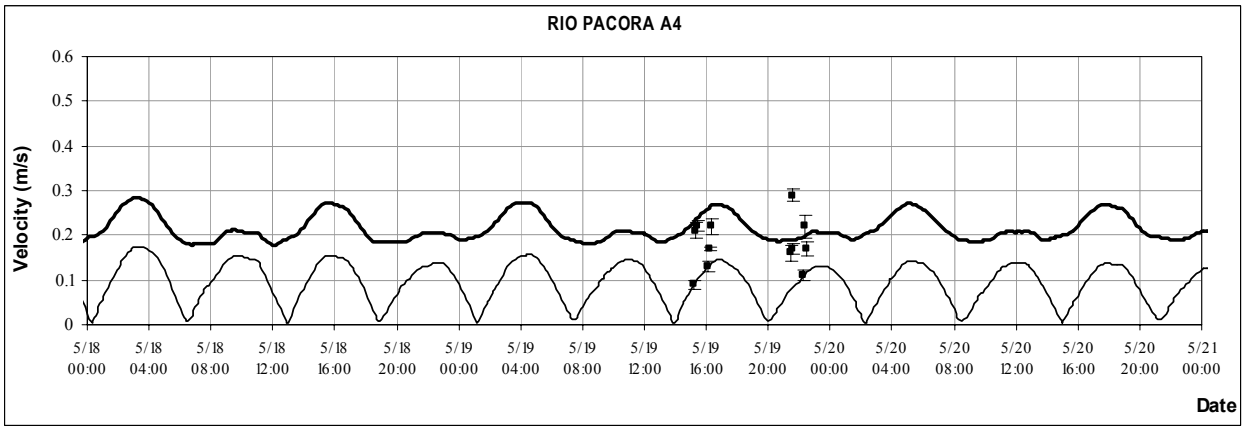
FIGURE A-8 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)







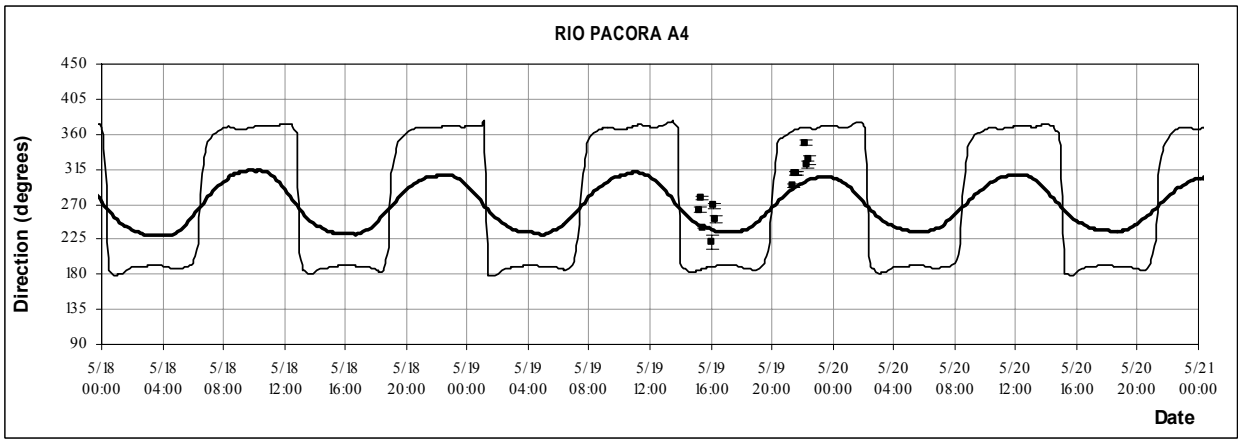


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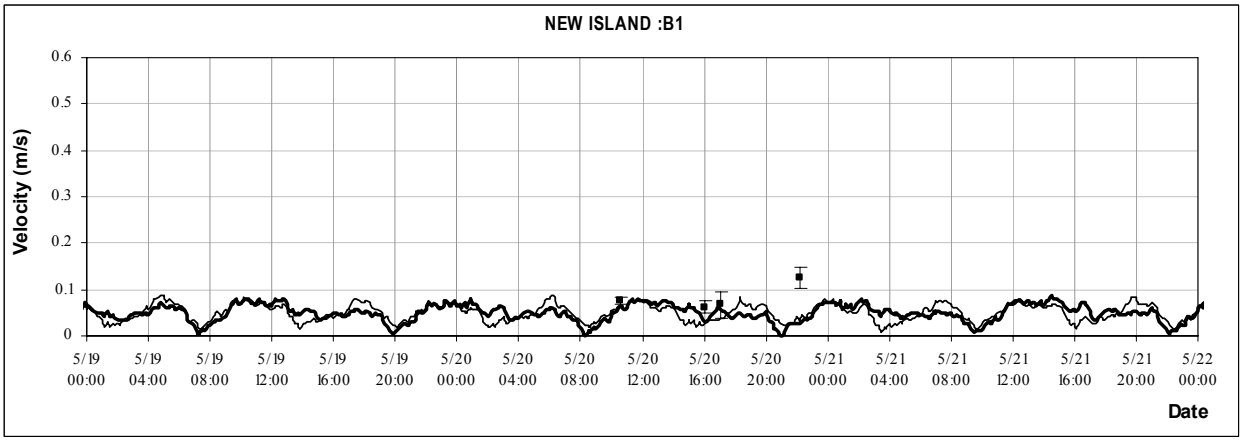
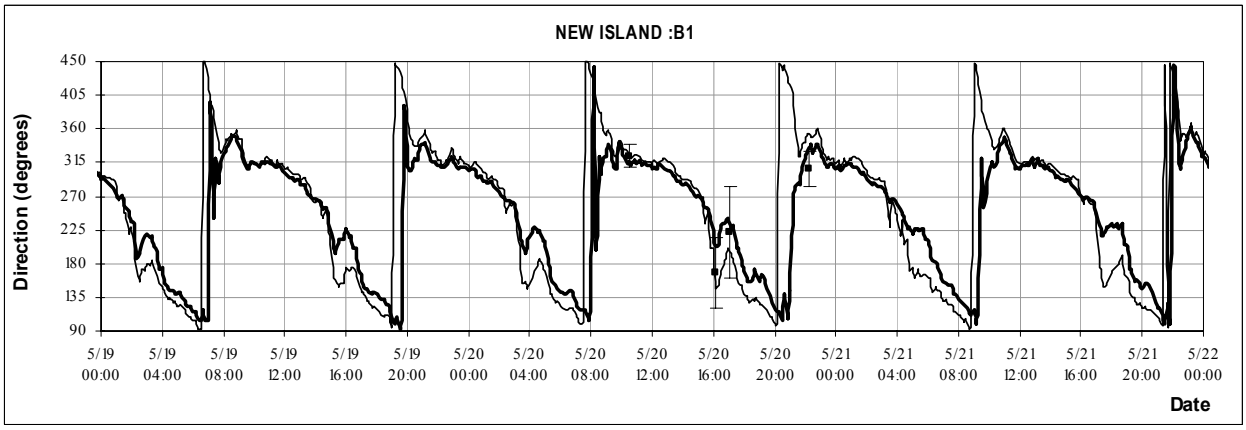
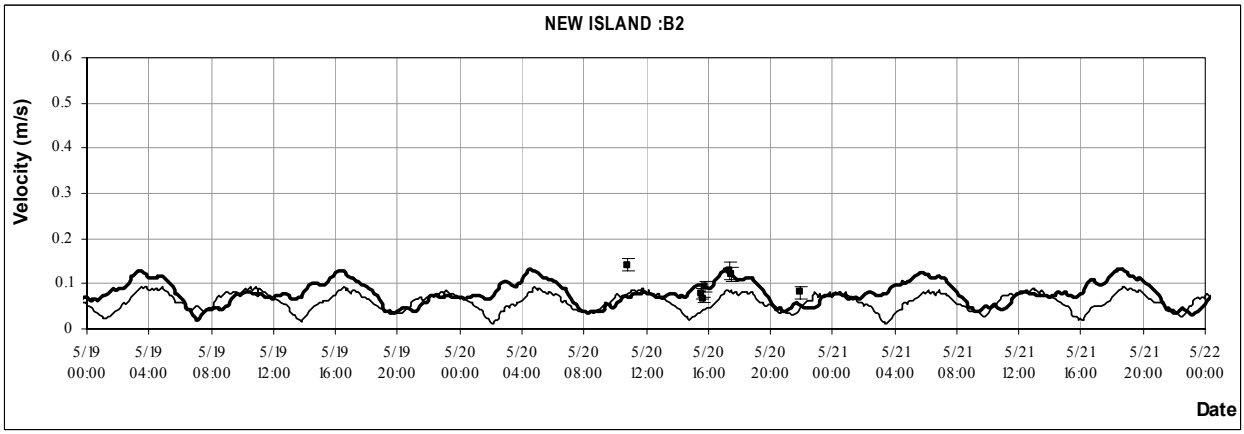
FIGURE A-9 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)







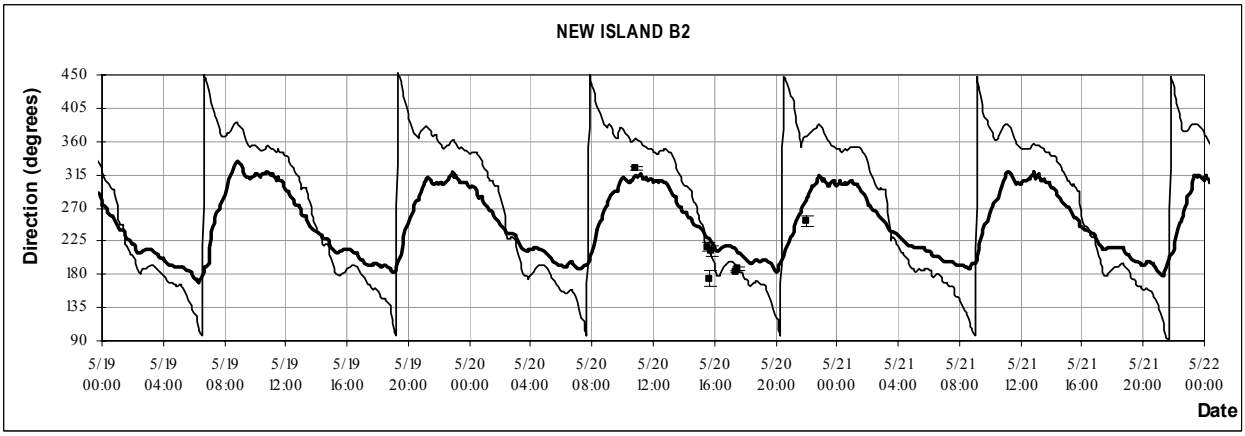


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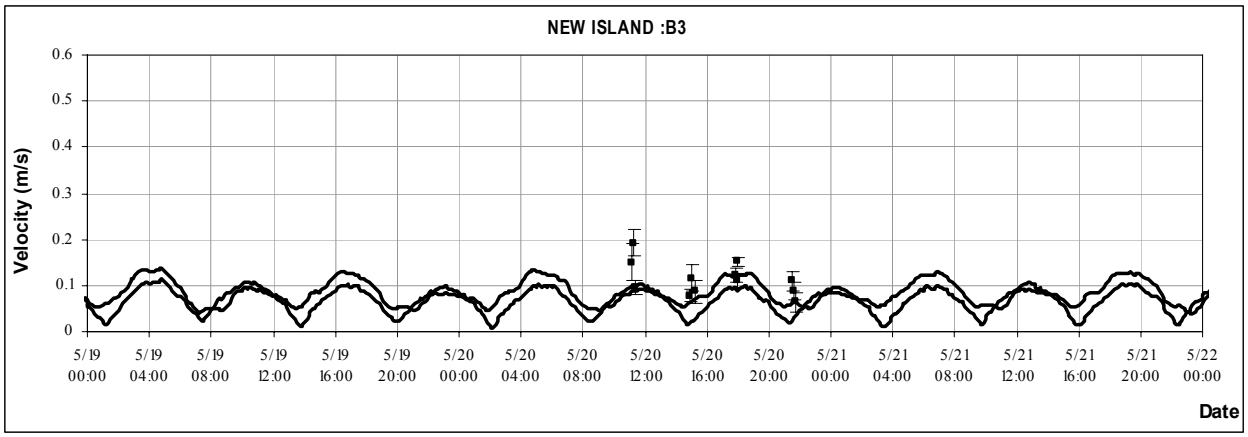
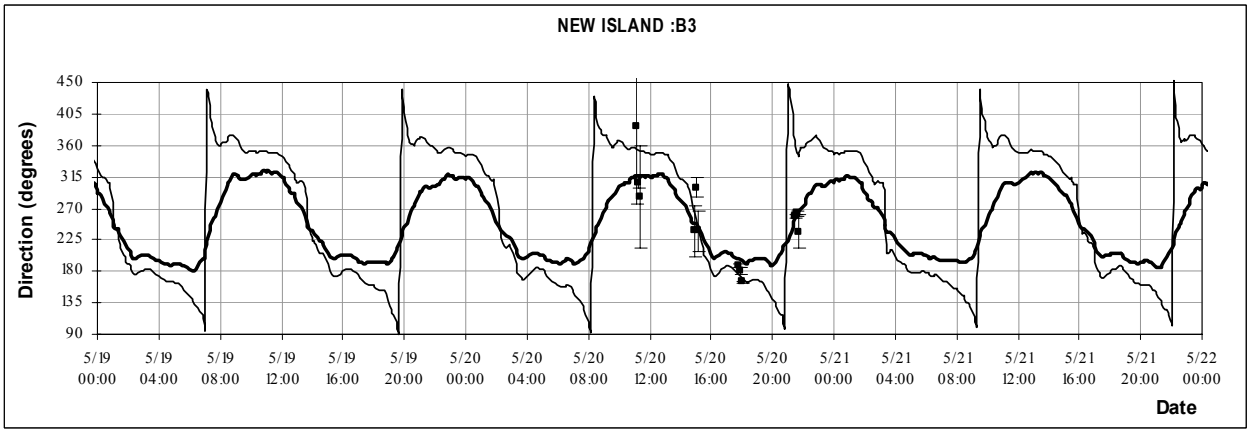
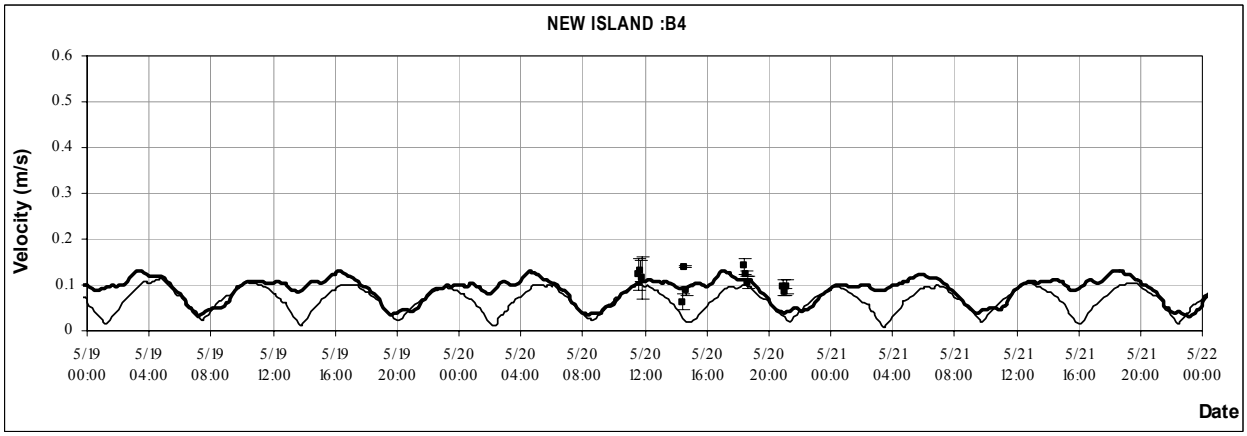
FIGURE A-10 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)







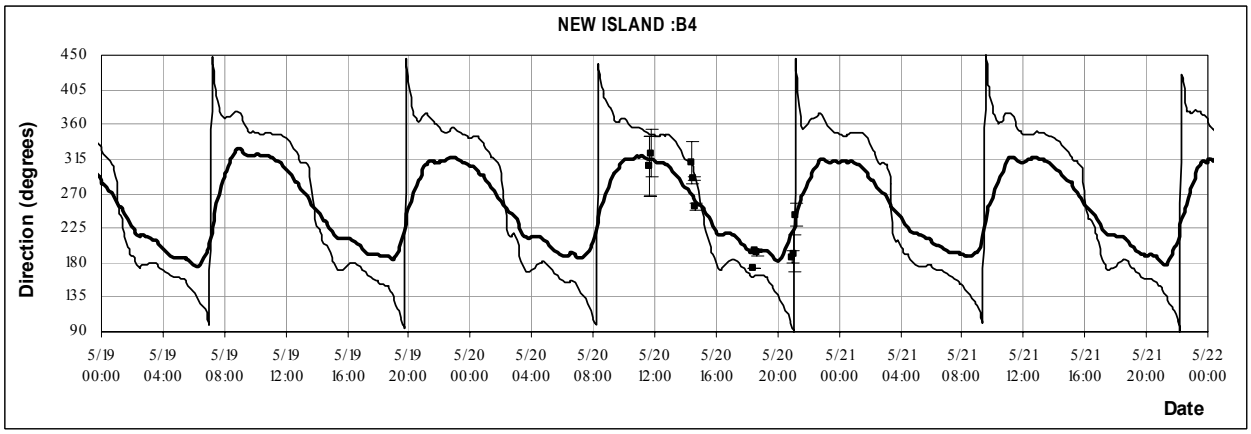


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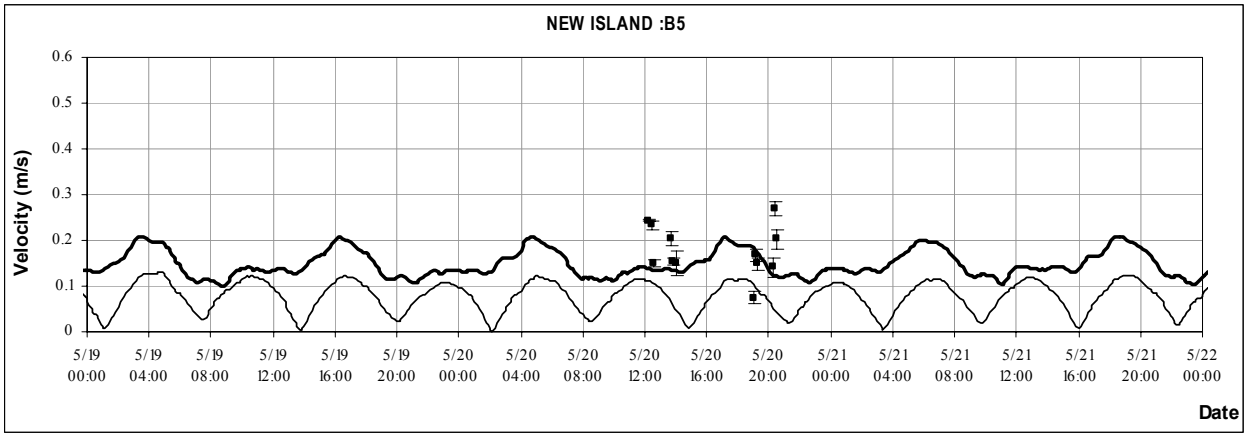
FIGURE A-11 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)



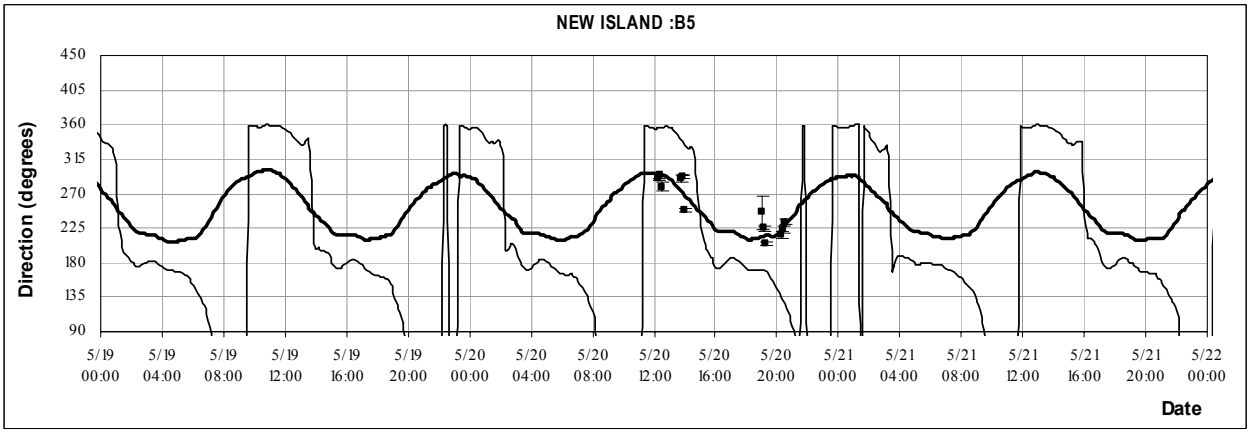


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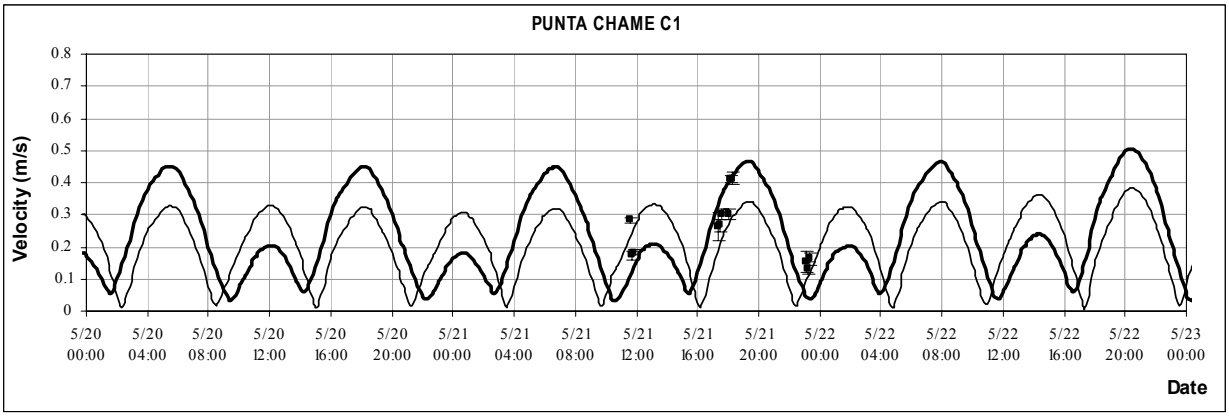
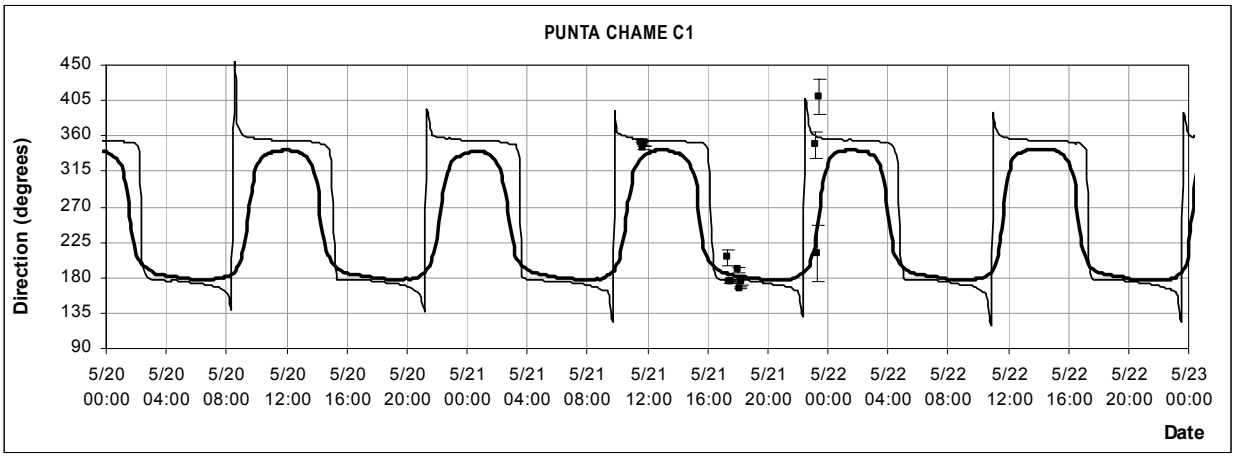
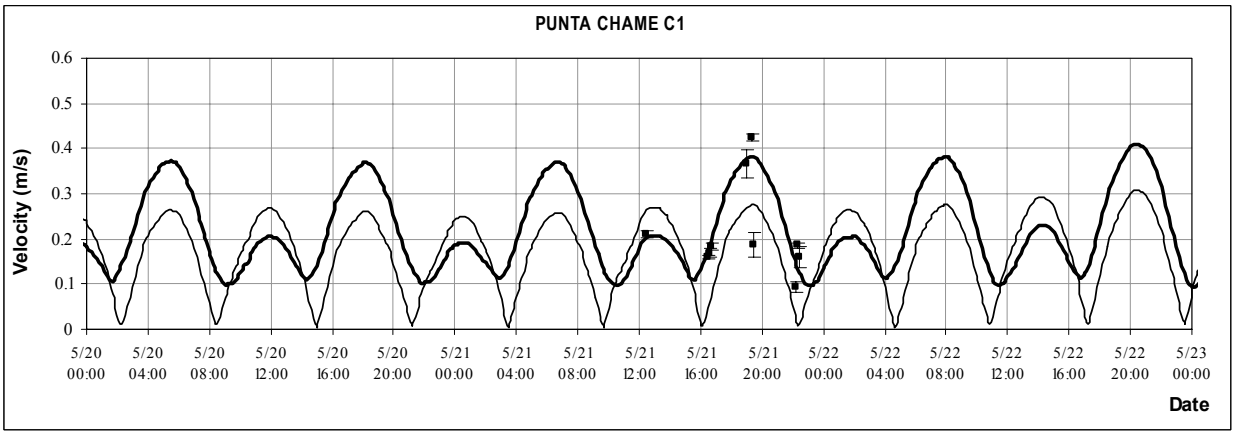
FIGURE A-12 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)







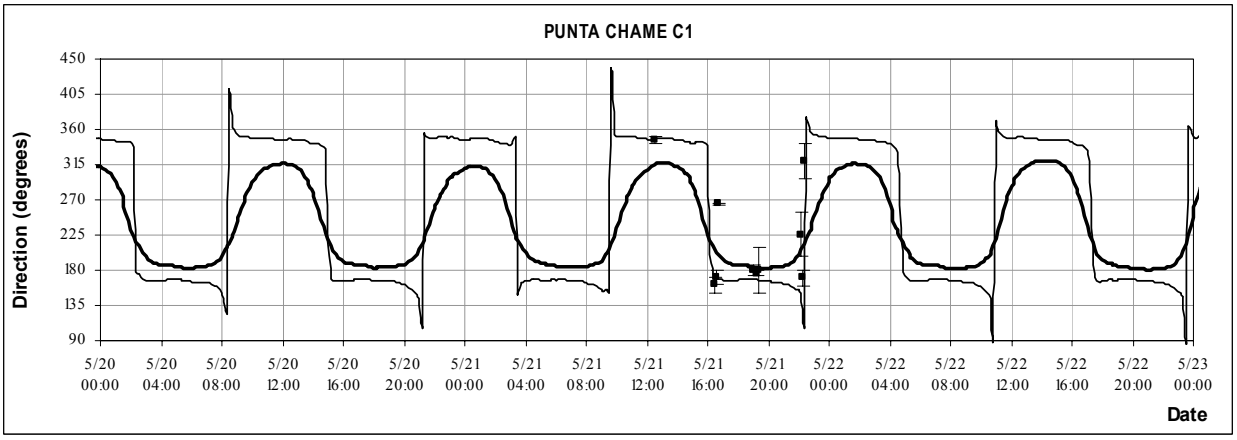


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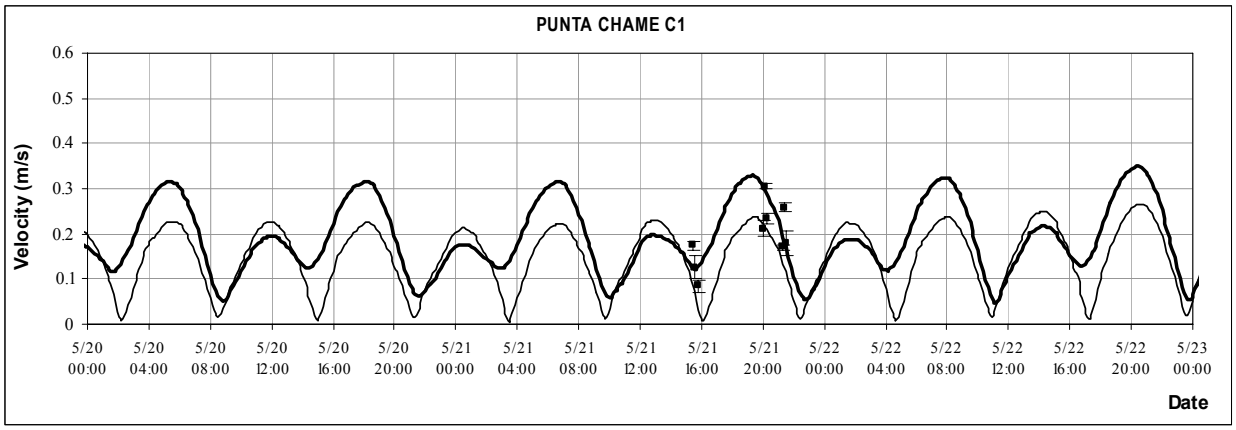
FIGURE A-13 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)



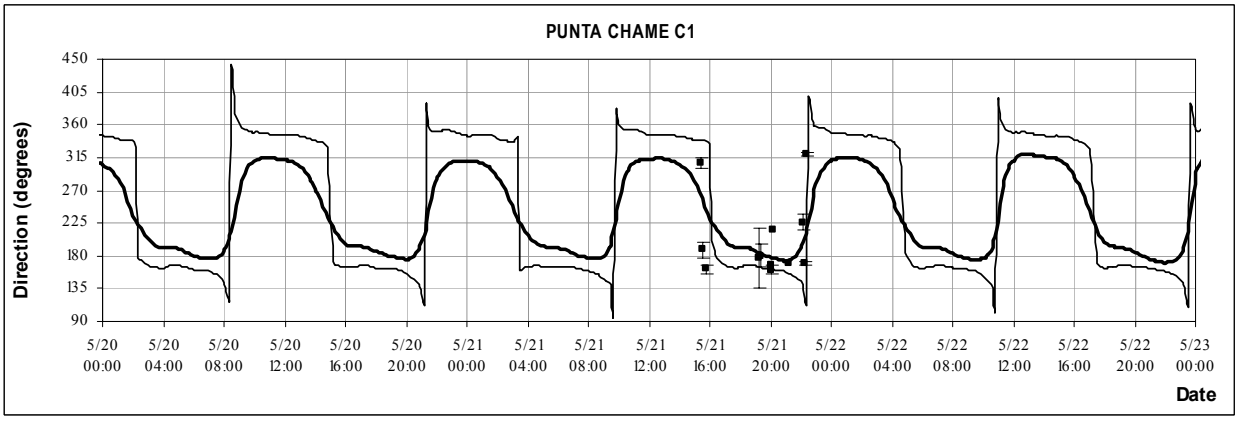
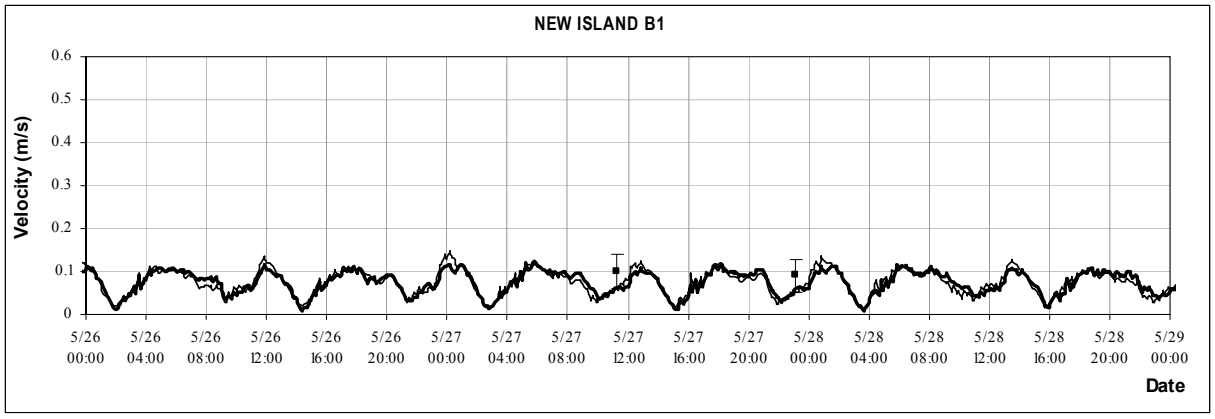
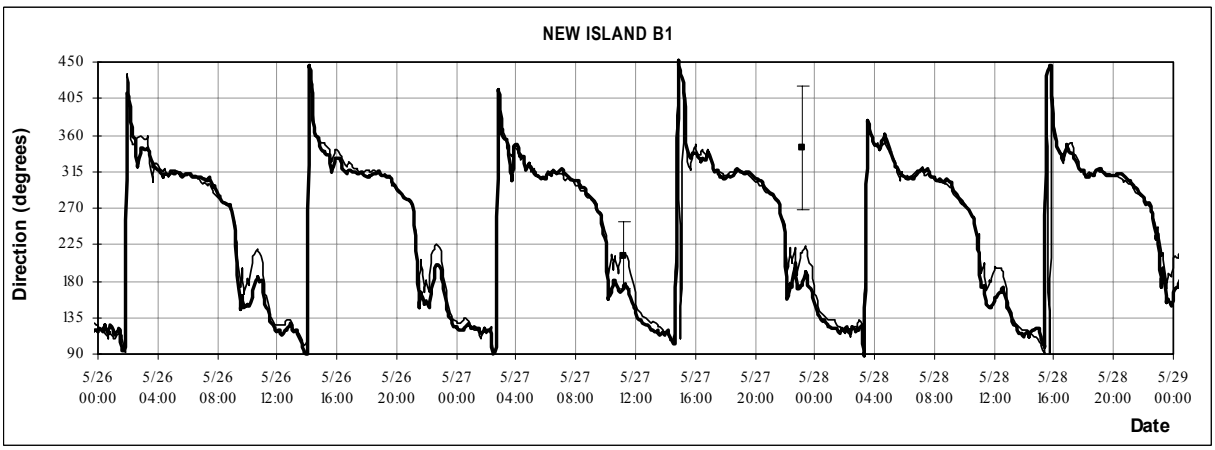
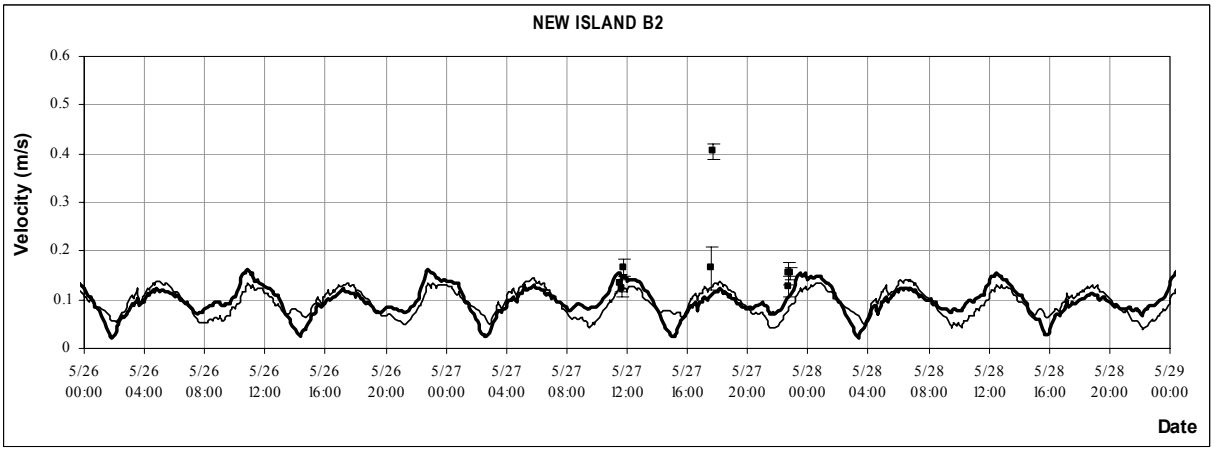


FIGURE A-14 : Campaign 2 Observed and simulated current and direction (tides and tides+GP current)







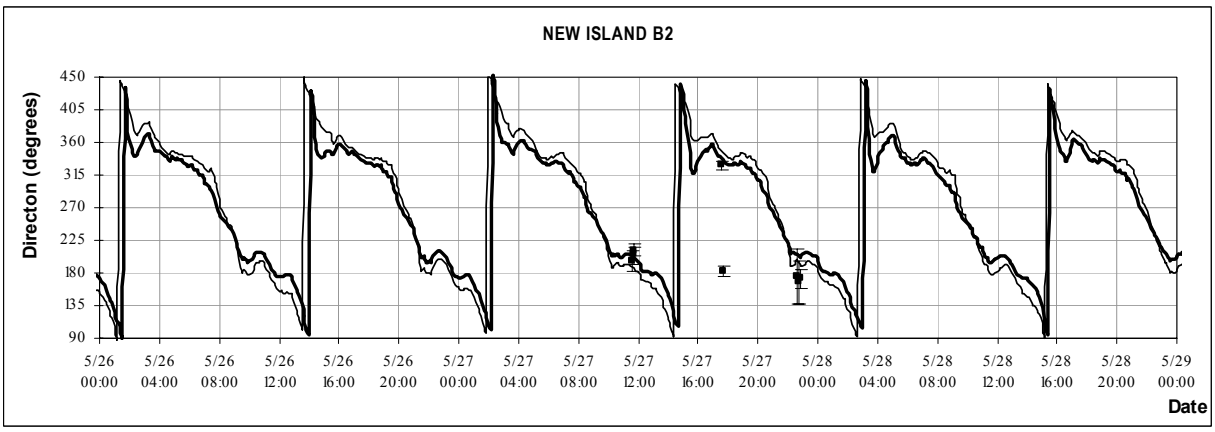


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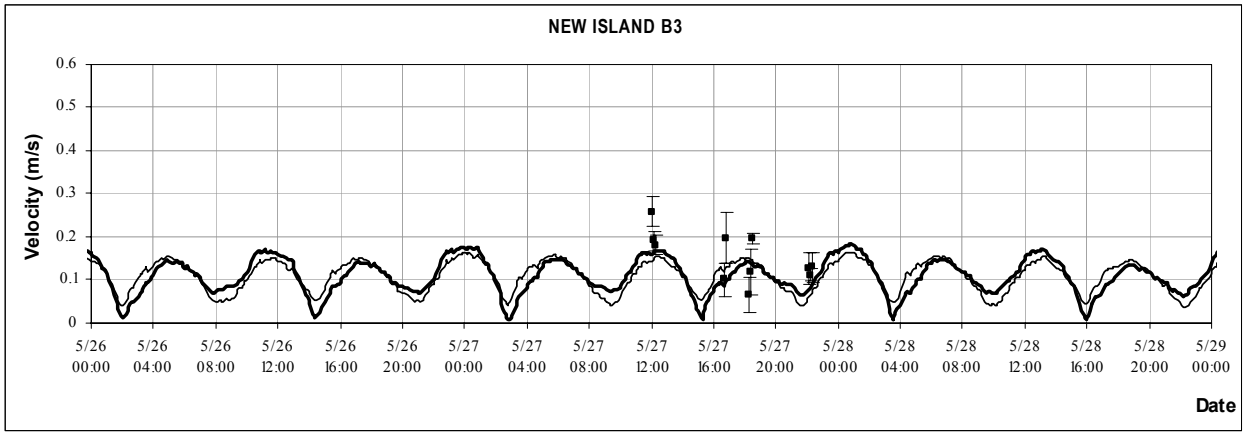
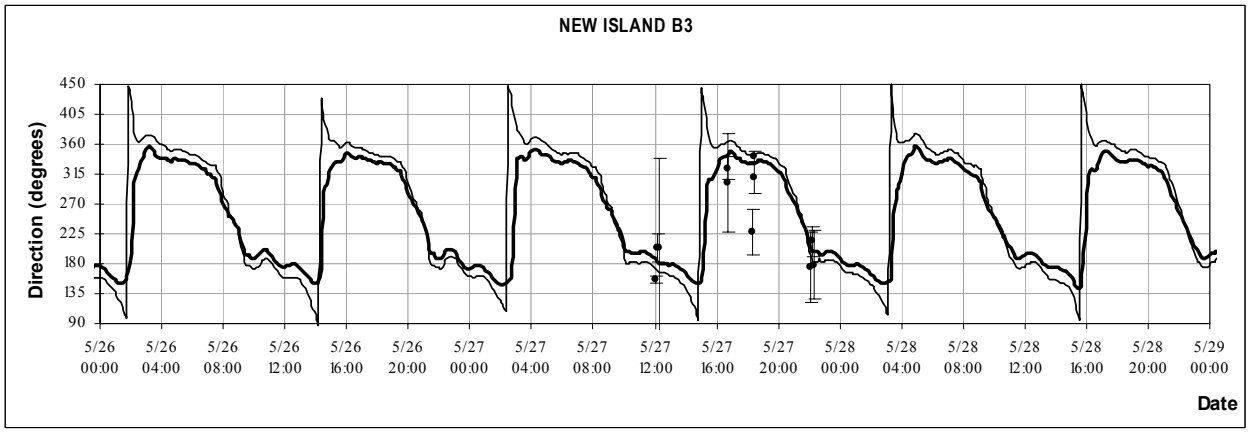
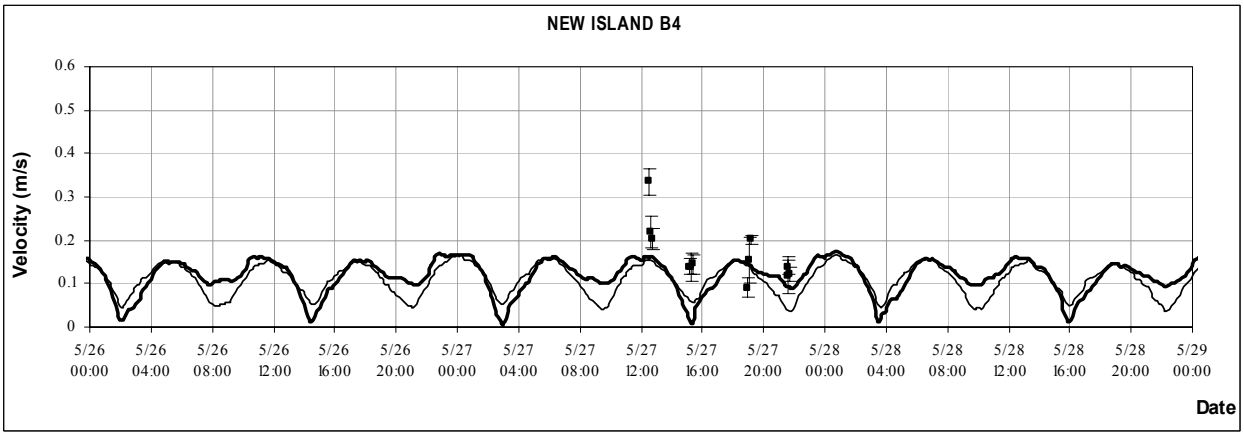
FIGURE A-15 : Campaign 3 Observed and simulated current and direction (tides and tides+GP current)







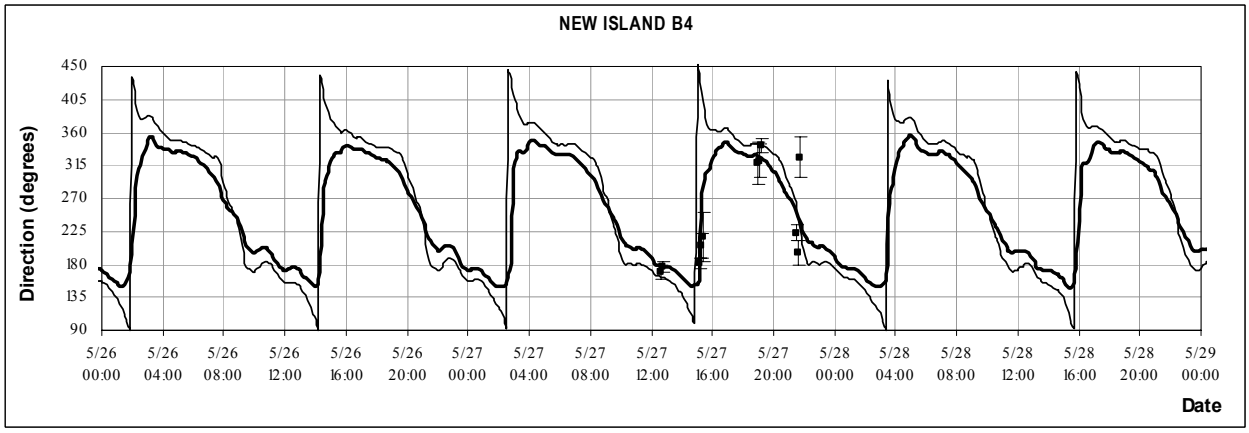


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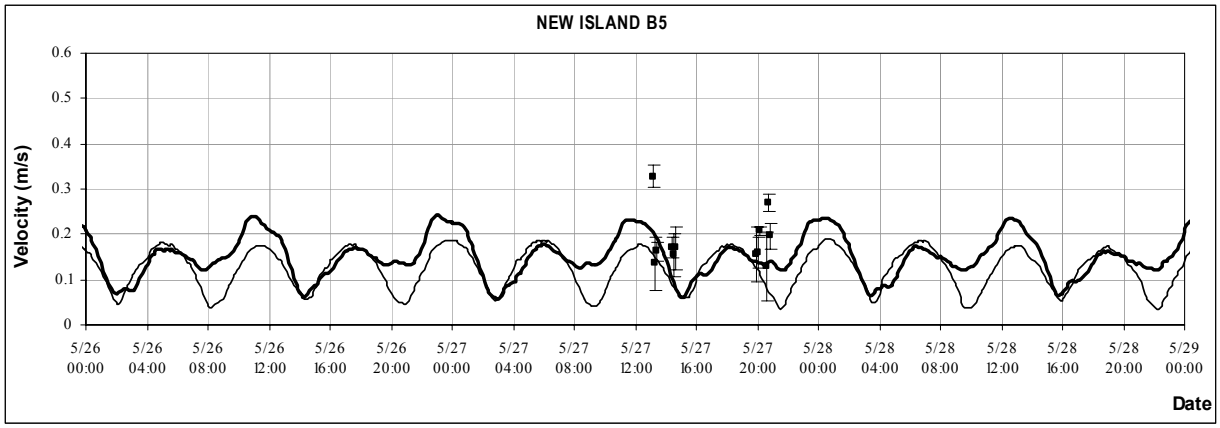
FIGURE A-16 : Campaign 3 Observed and simulated current and direction (tides and tides+GP current)



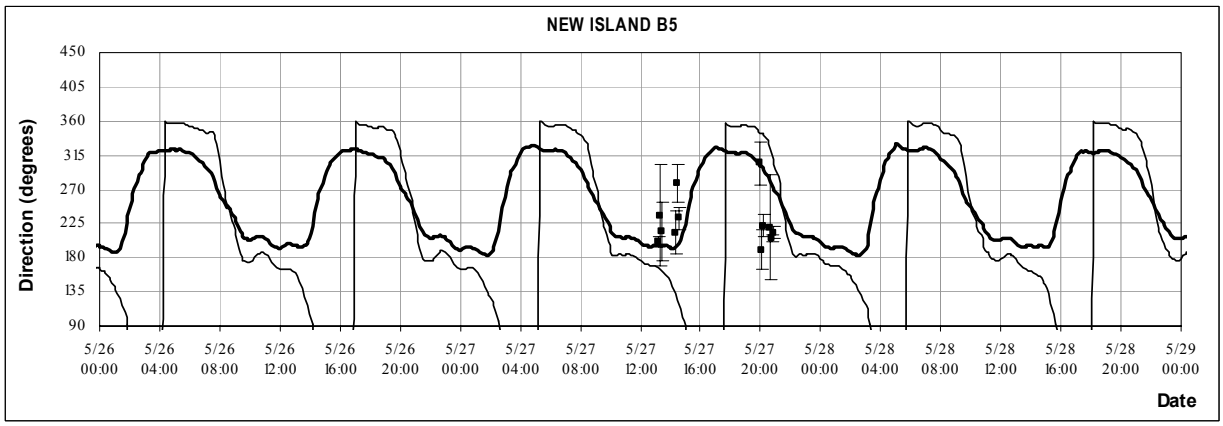


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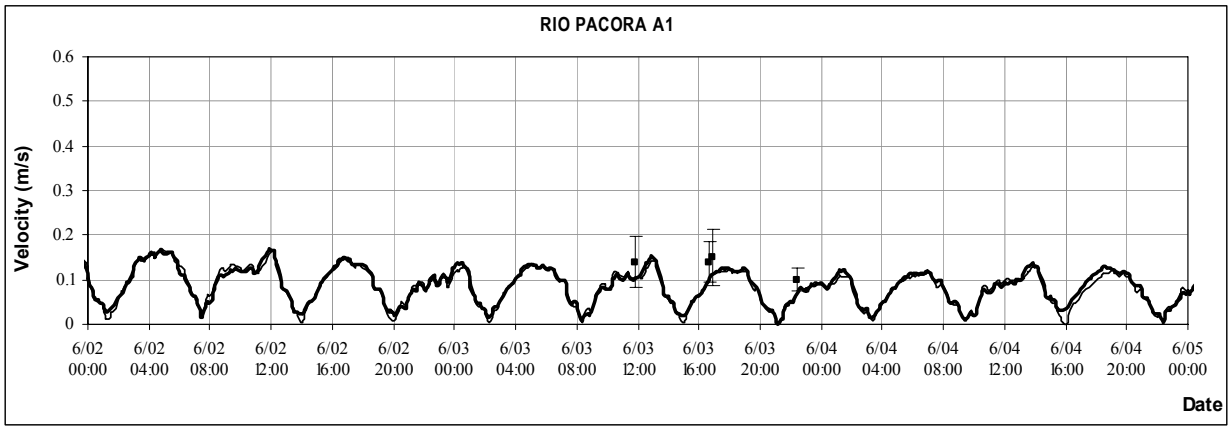
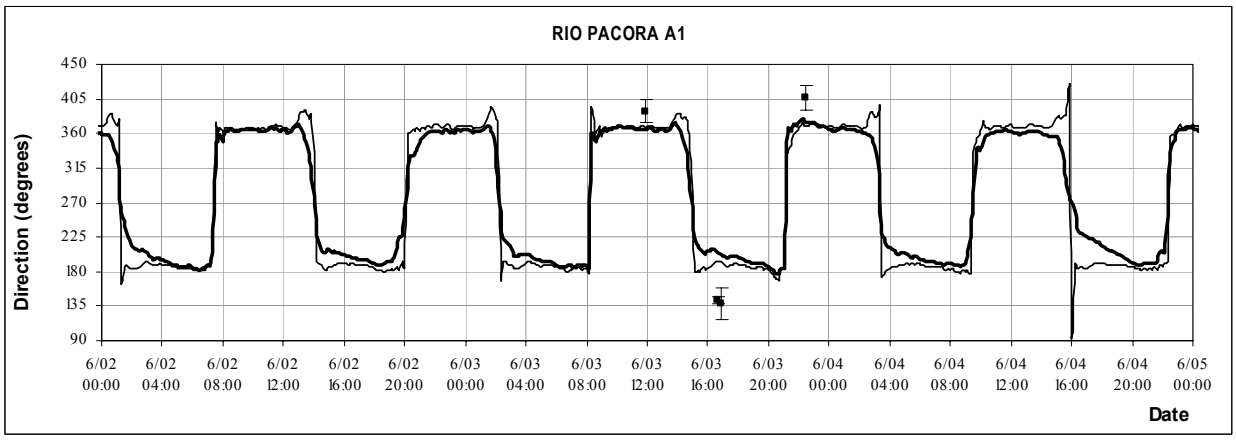
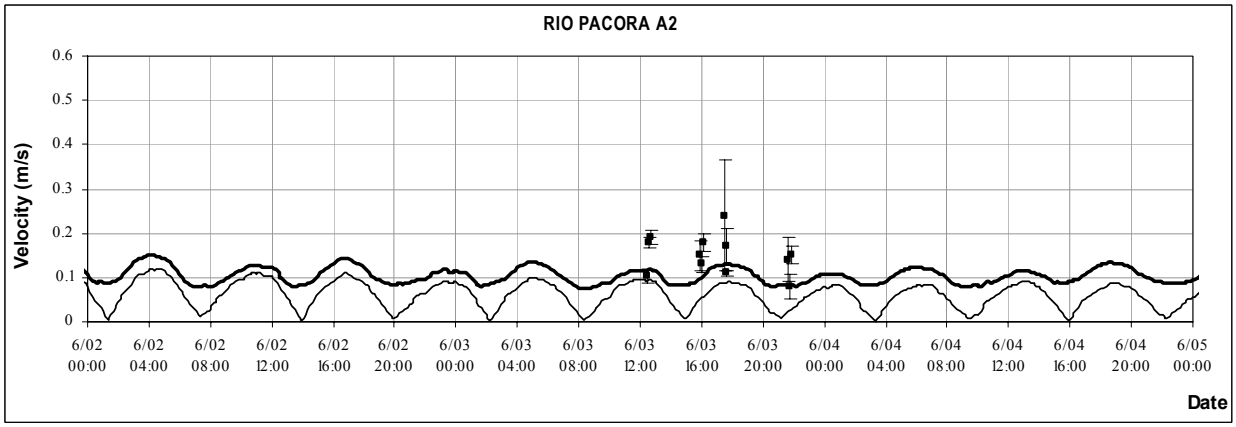
FIGURE A-17 : Campaign 3 Observed and simulated current and direction (tides and tides+GP current)







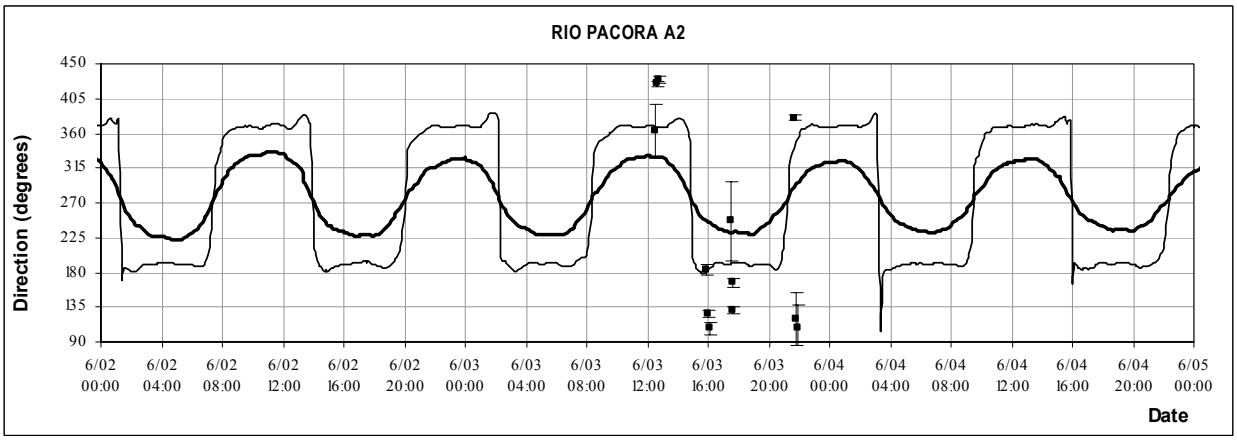


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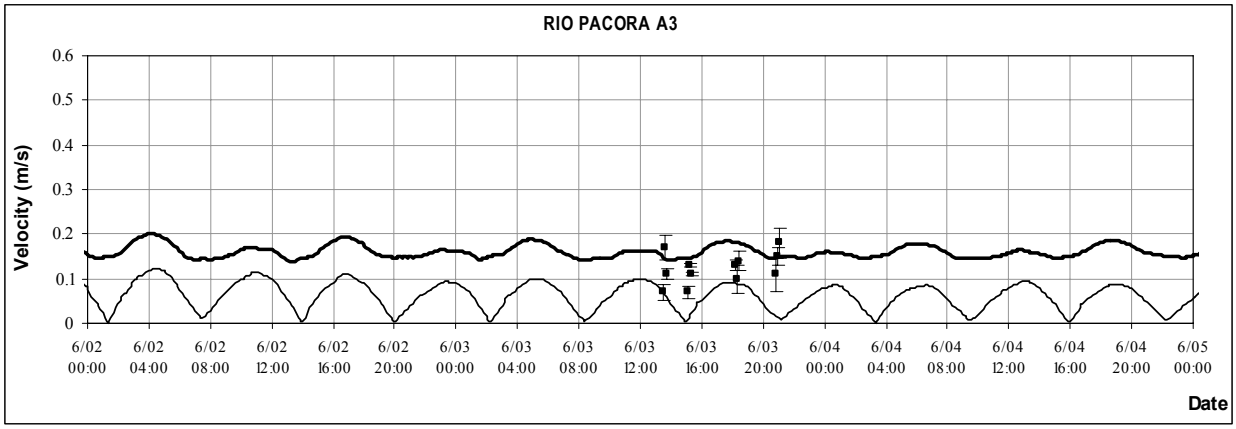
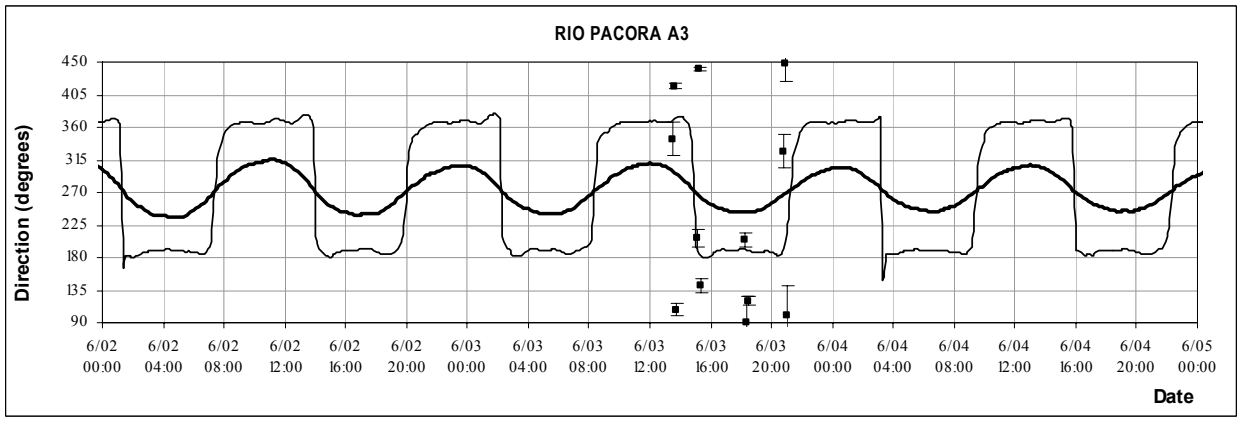
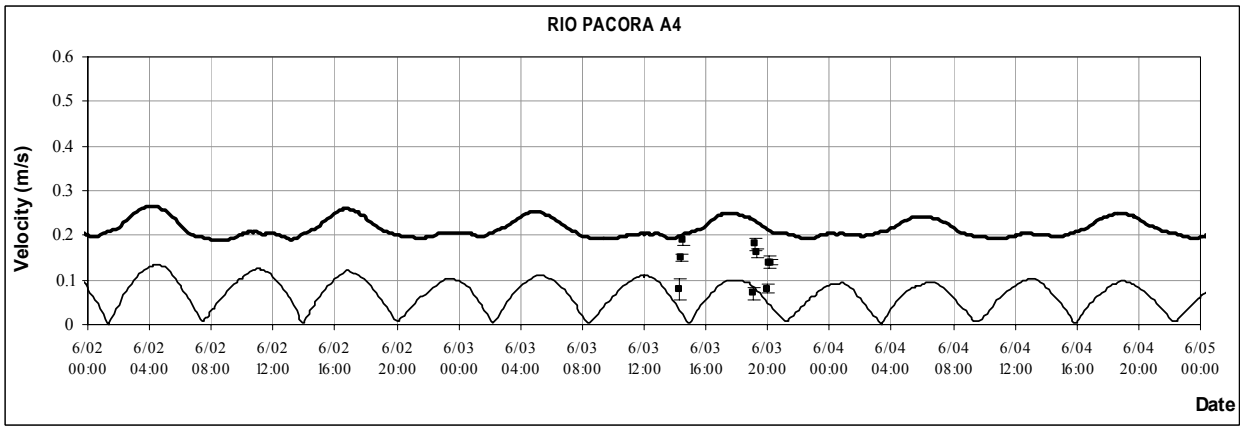
FIGURE A-18 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)







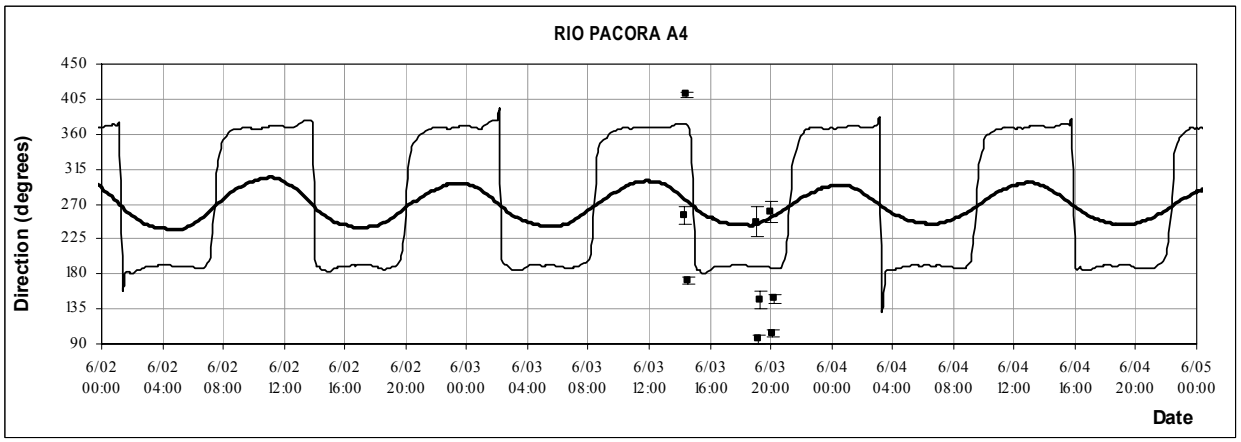


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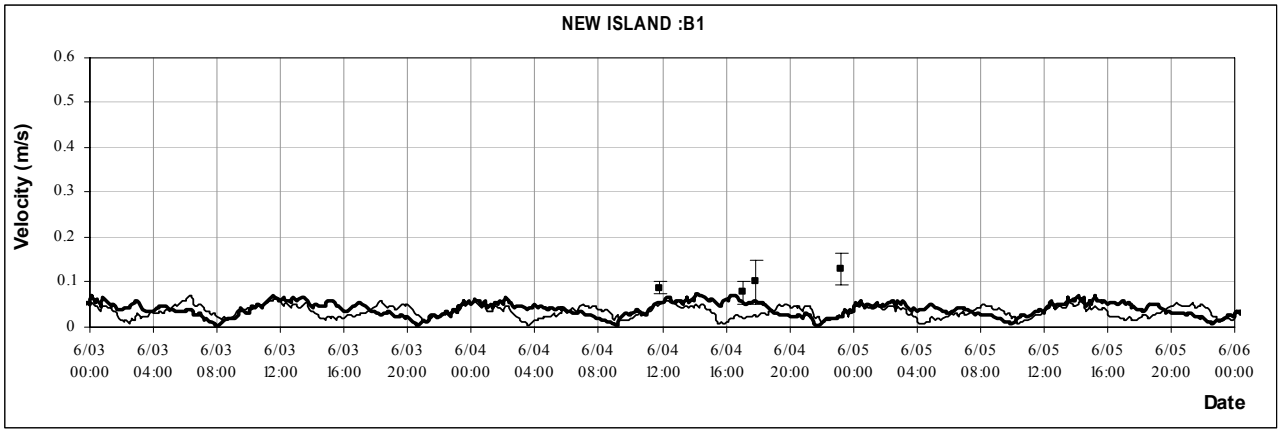
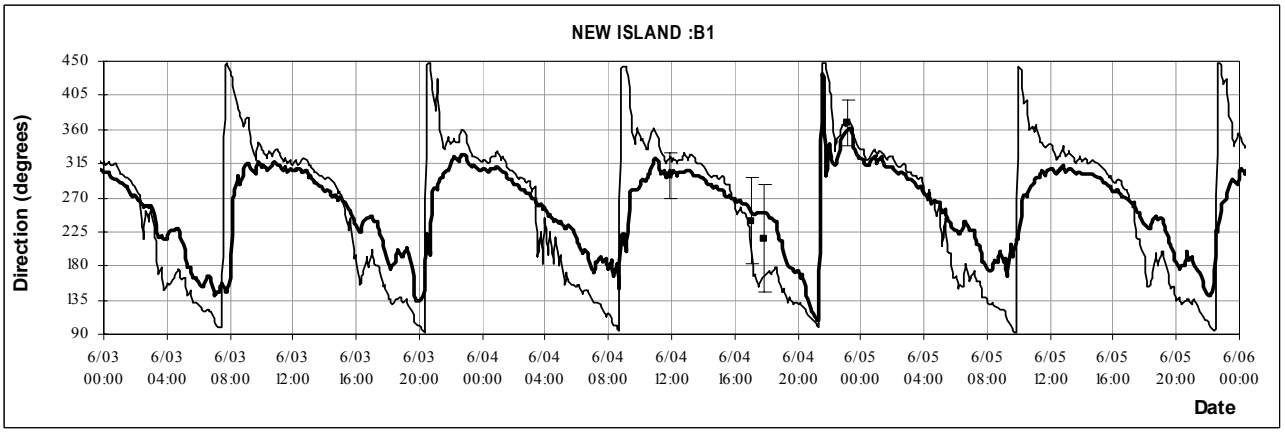
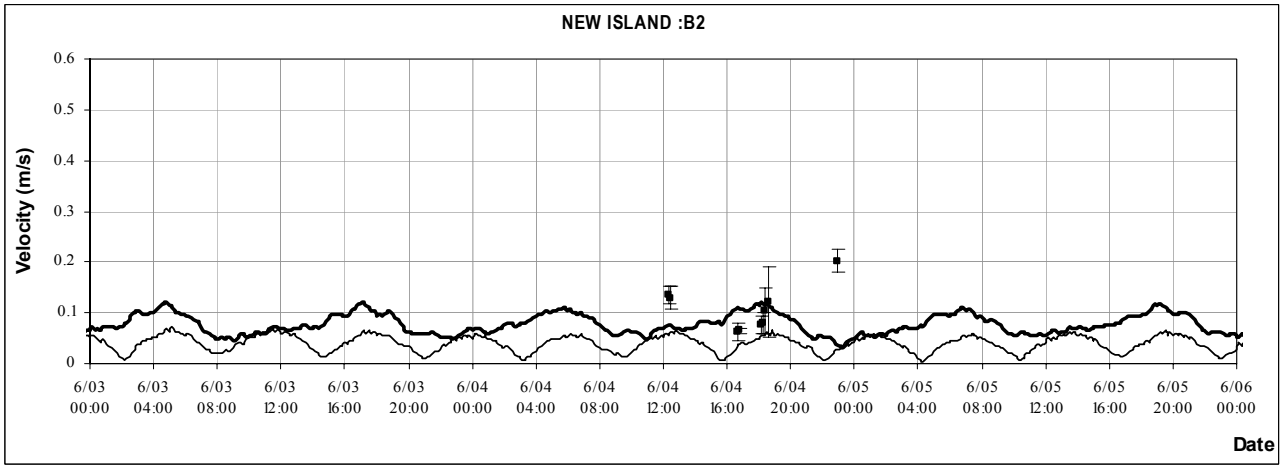
FIGURE A-19 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)







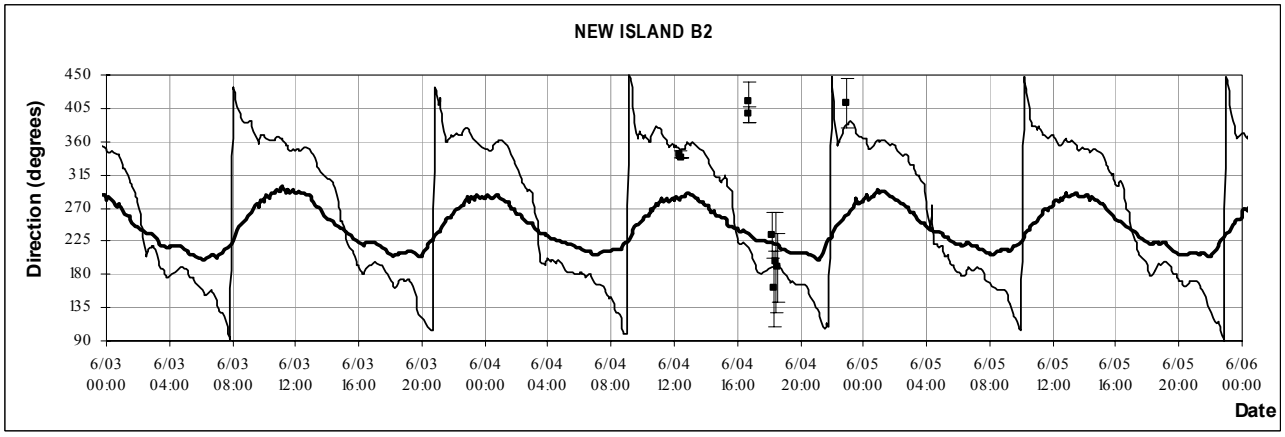


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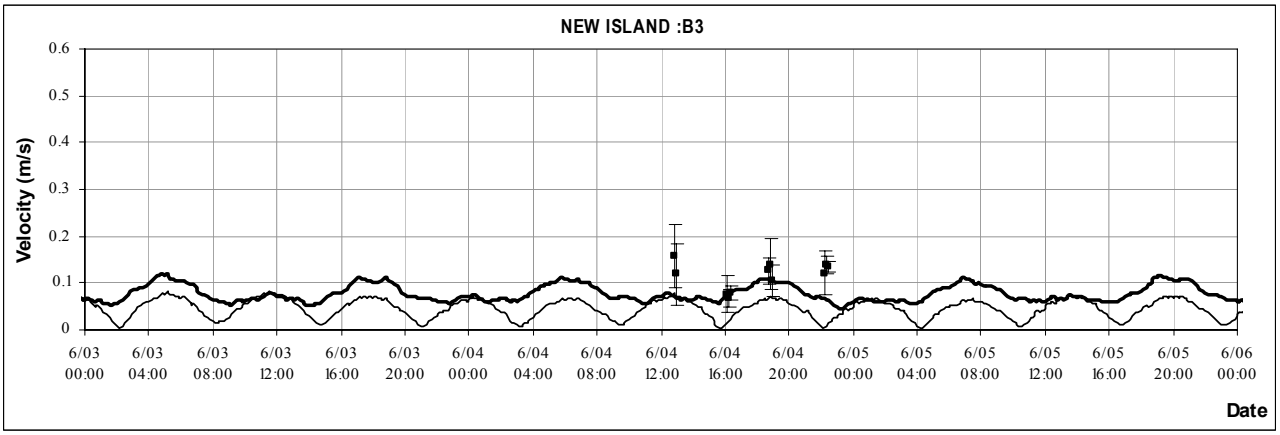
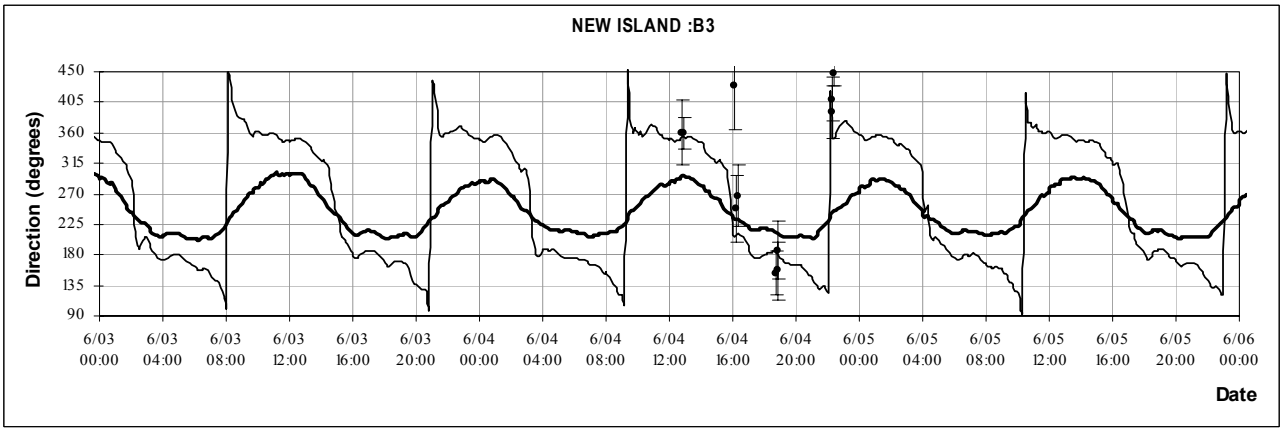
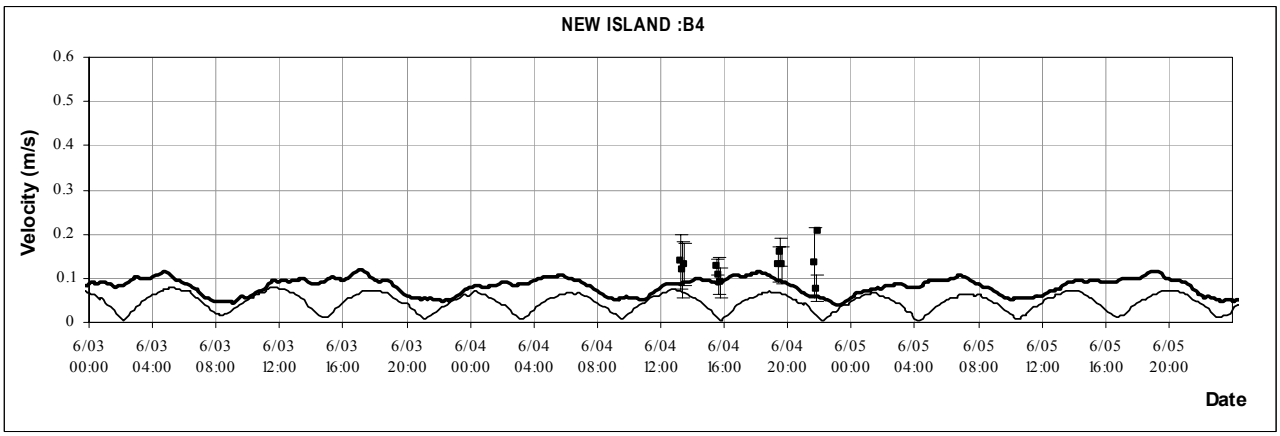
FIGURE A-20 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)







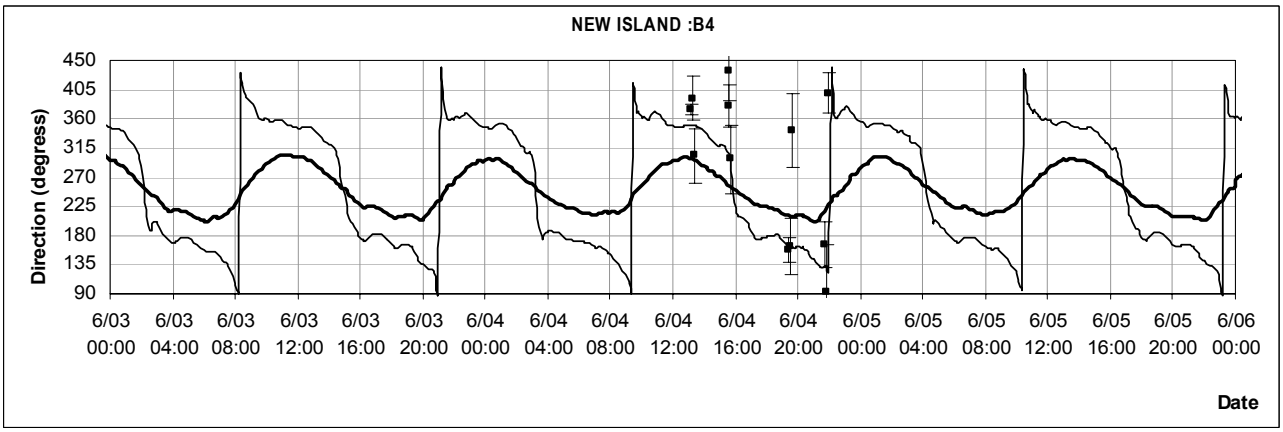


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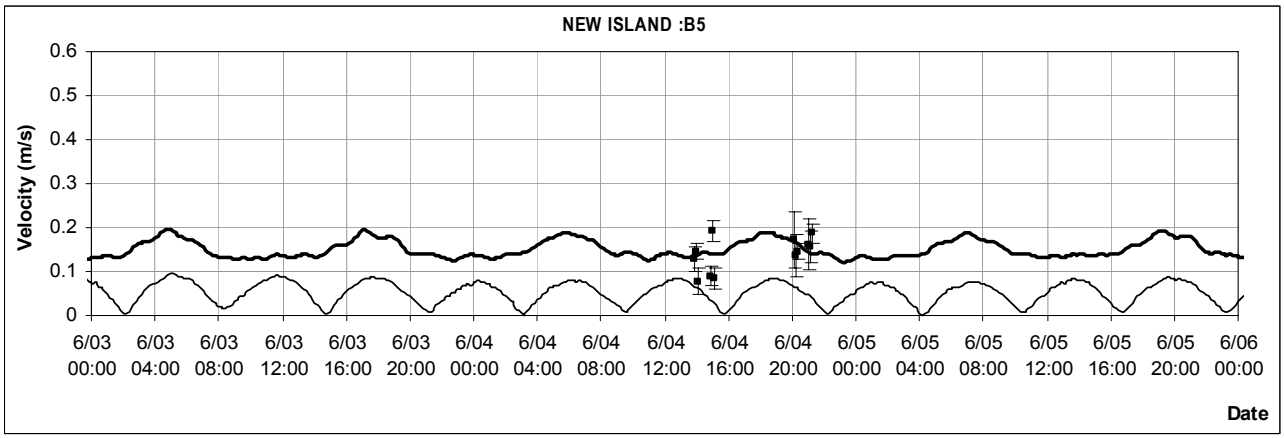
FIGURE A-21 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)



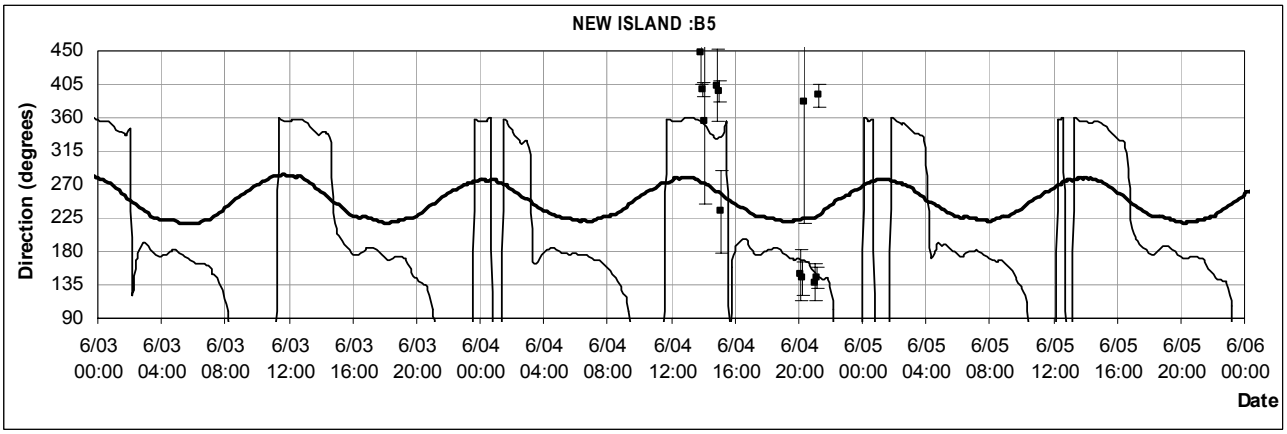


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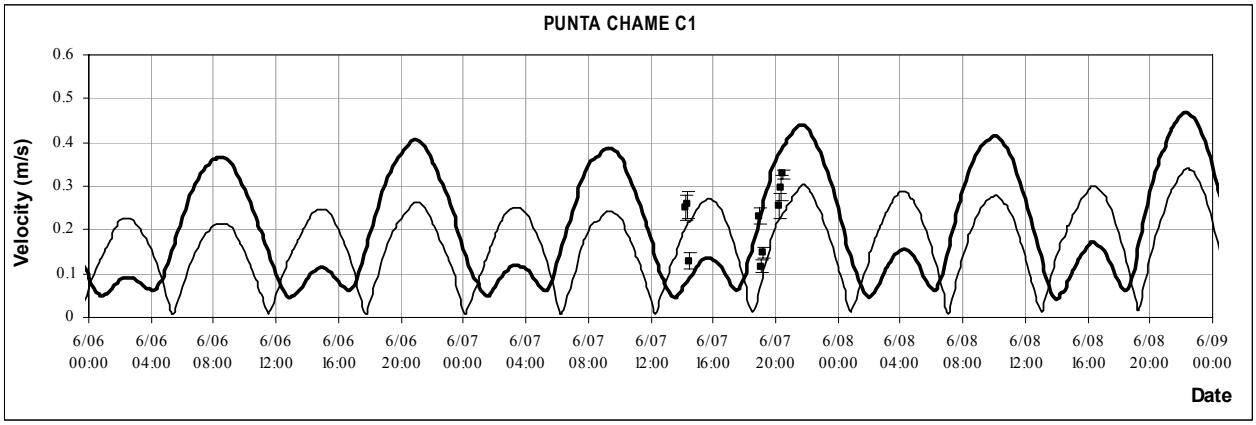
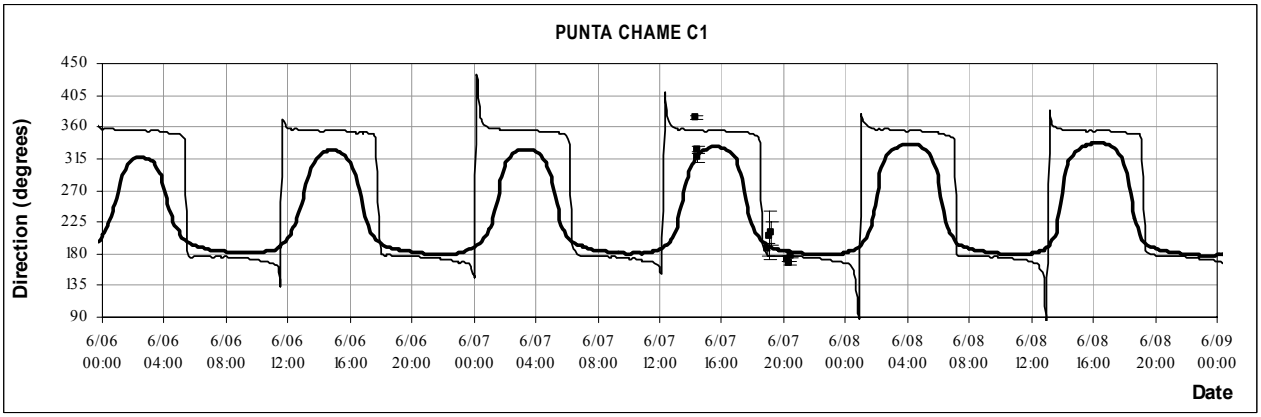
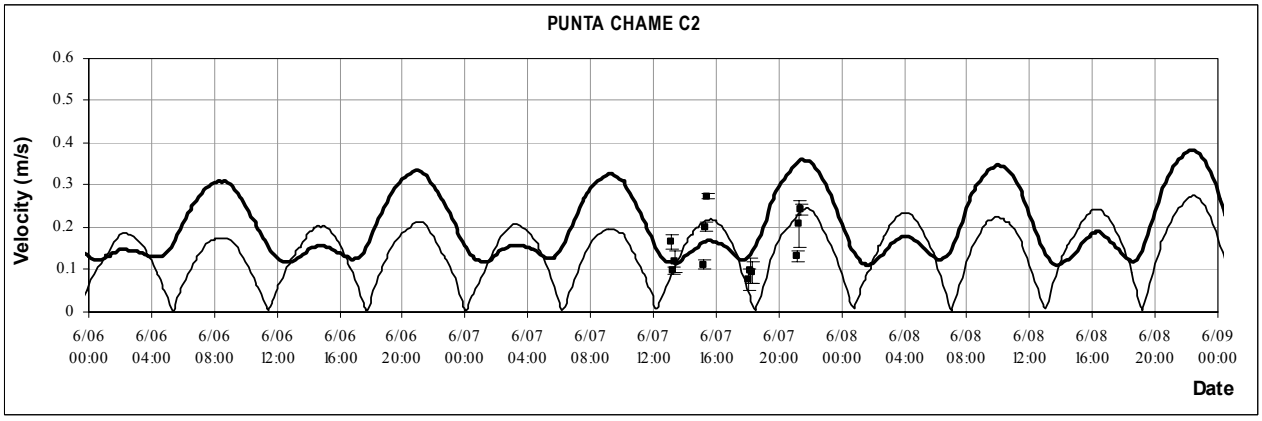
FIGURE A-22 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)







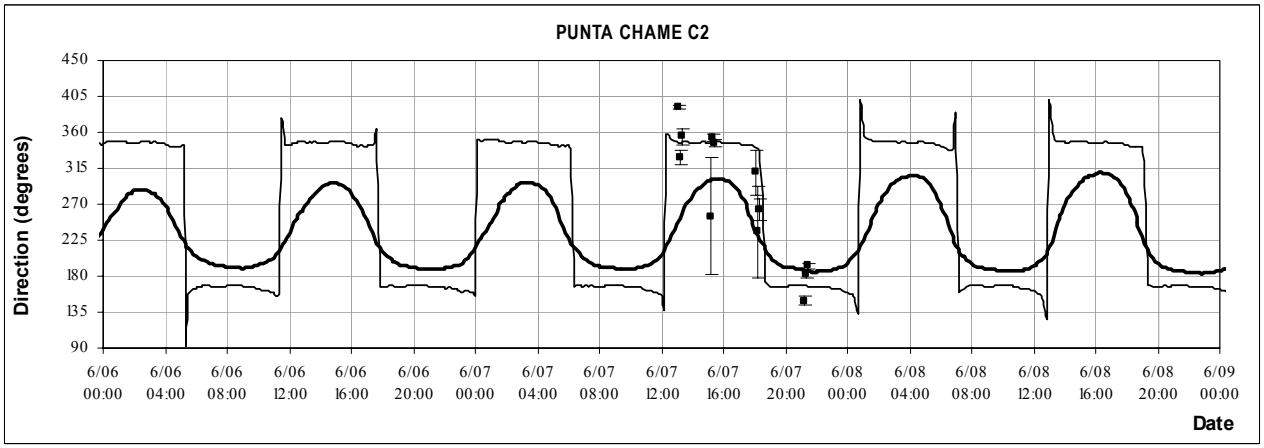


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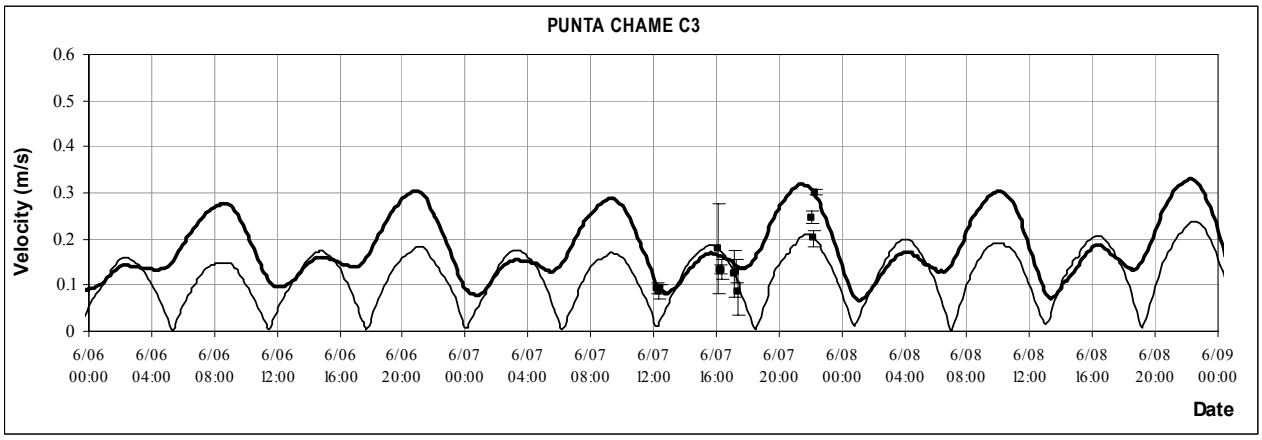
FIGURE A-23 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)



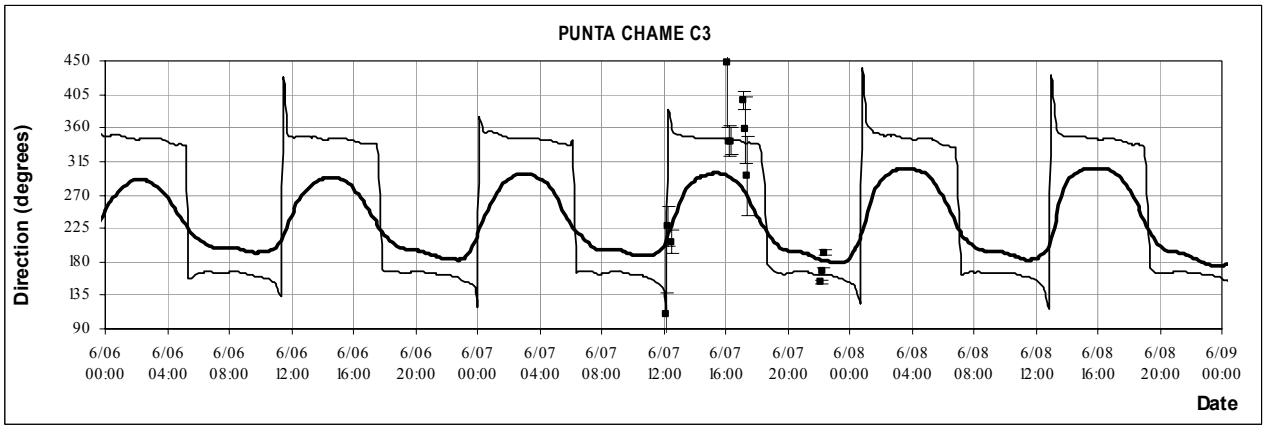


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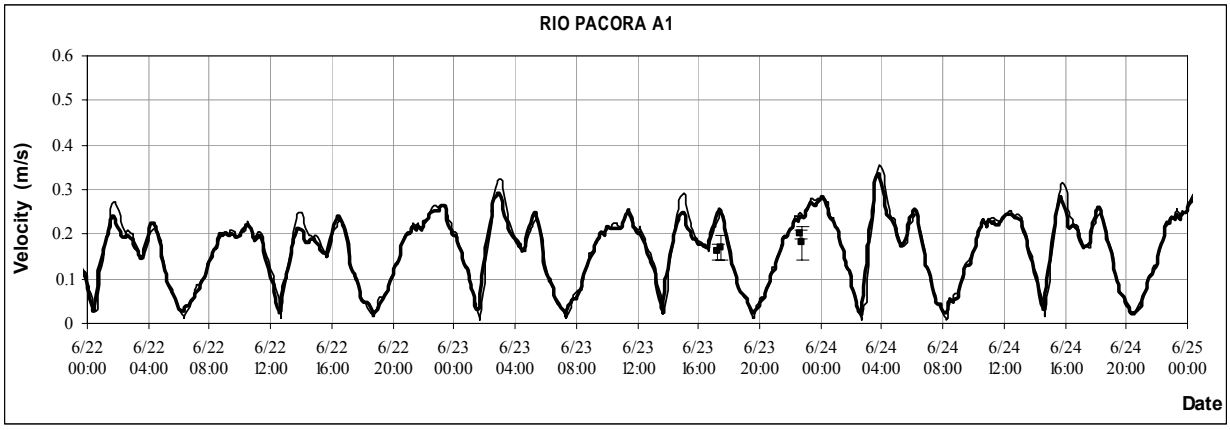
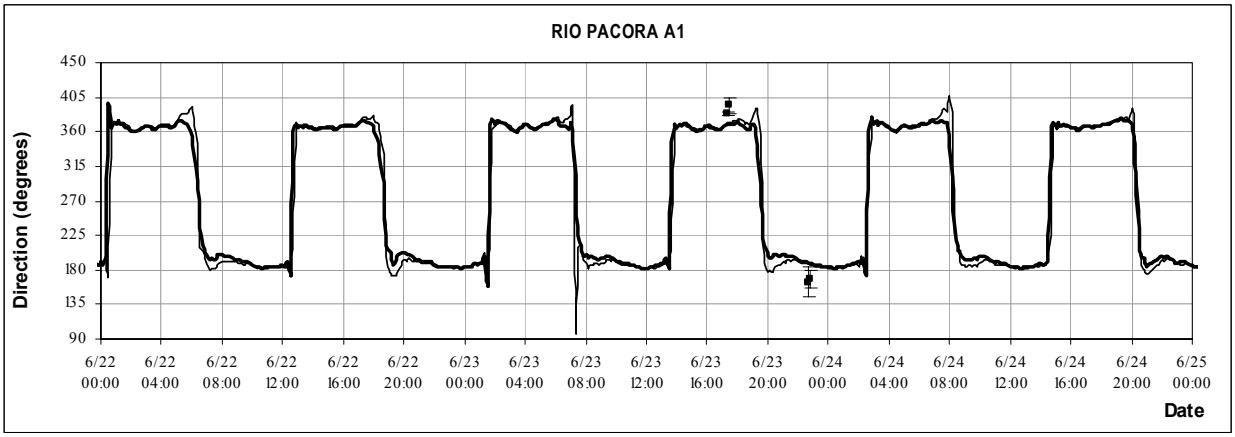
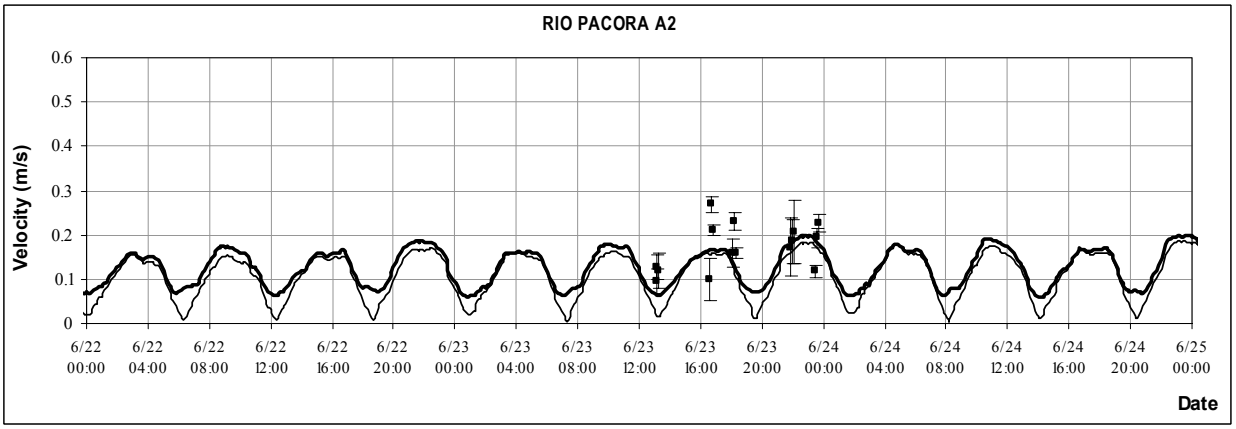
FIGURE A-24 : Campaign 4 Observed and simulated current and direction (tides and tides+GP current)







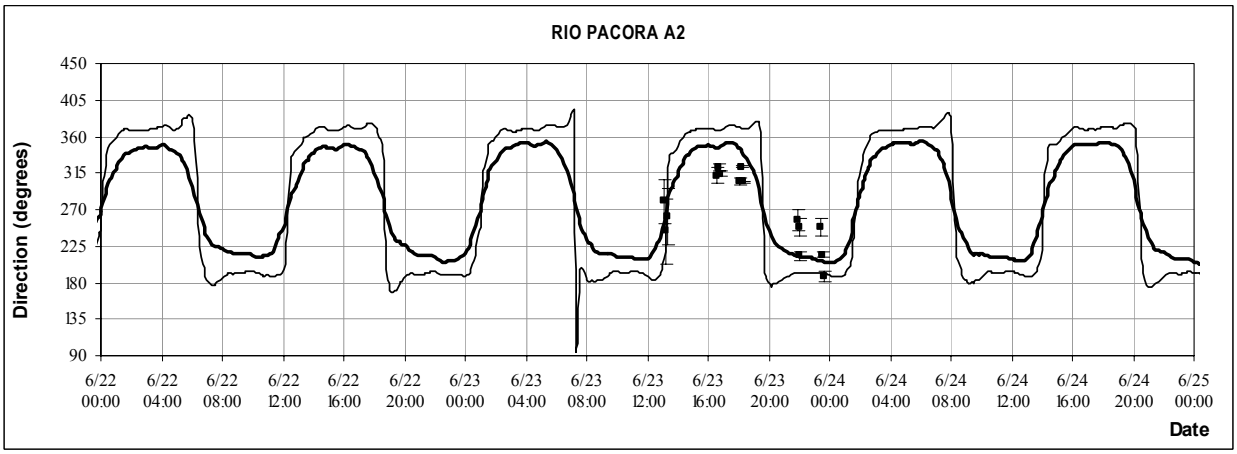


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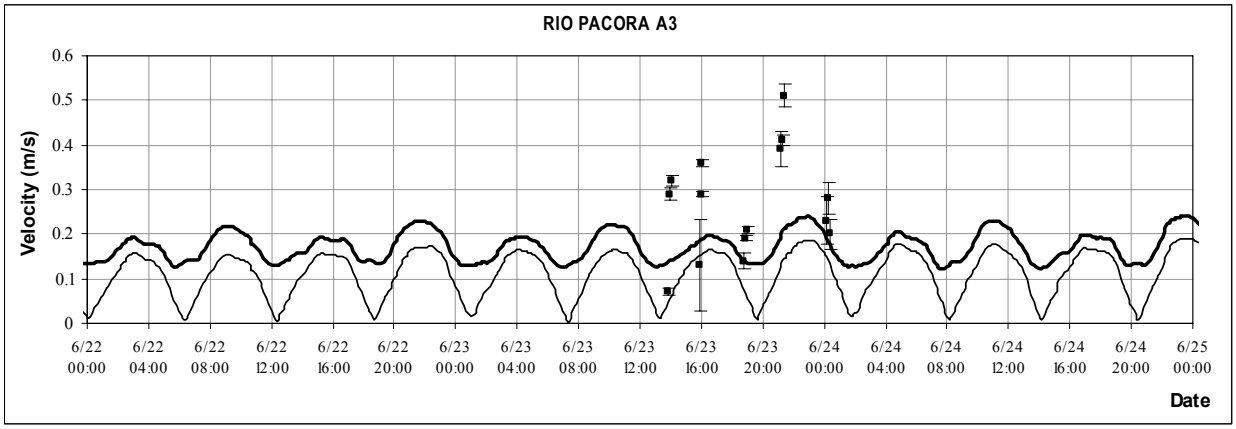
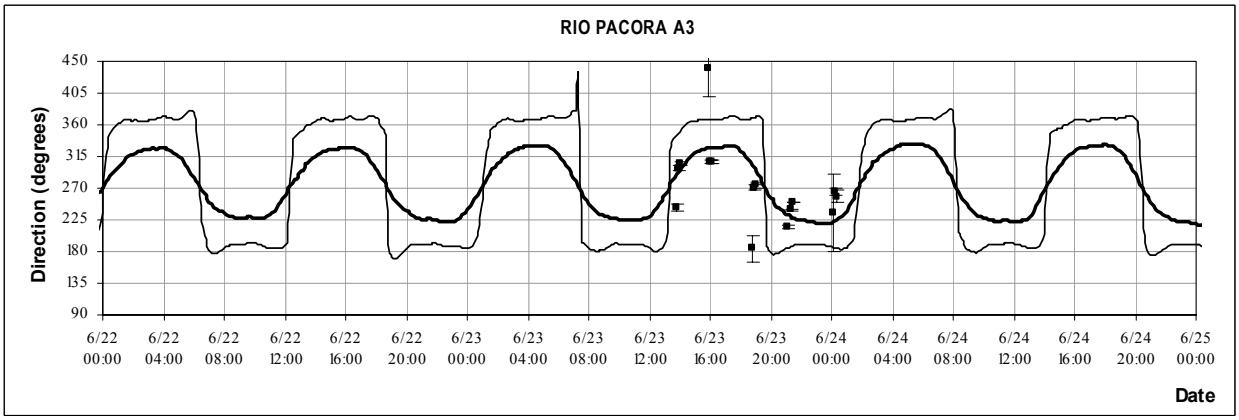
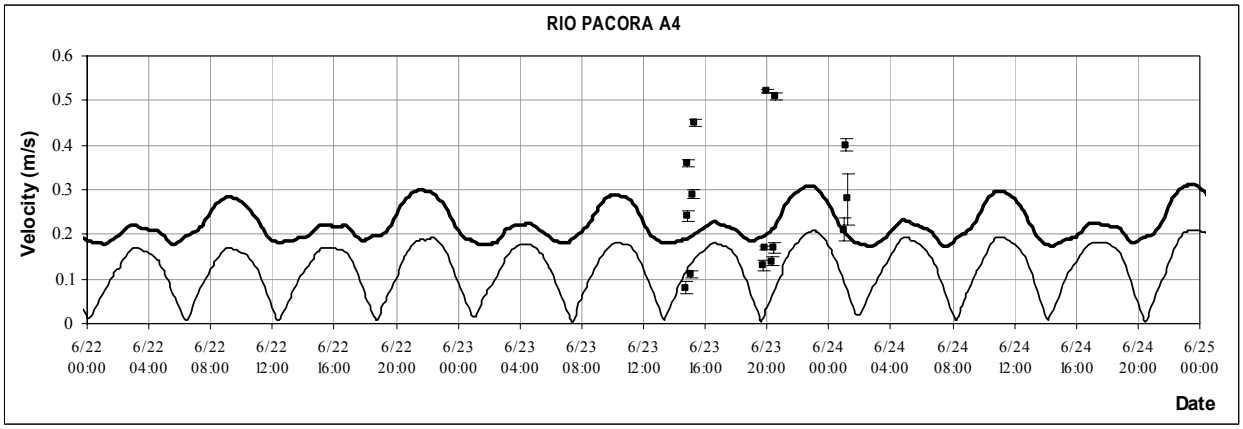
FIGURE A-25 : Campaign 5 Observed and simulated current and direction (tides and tides+GP current)







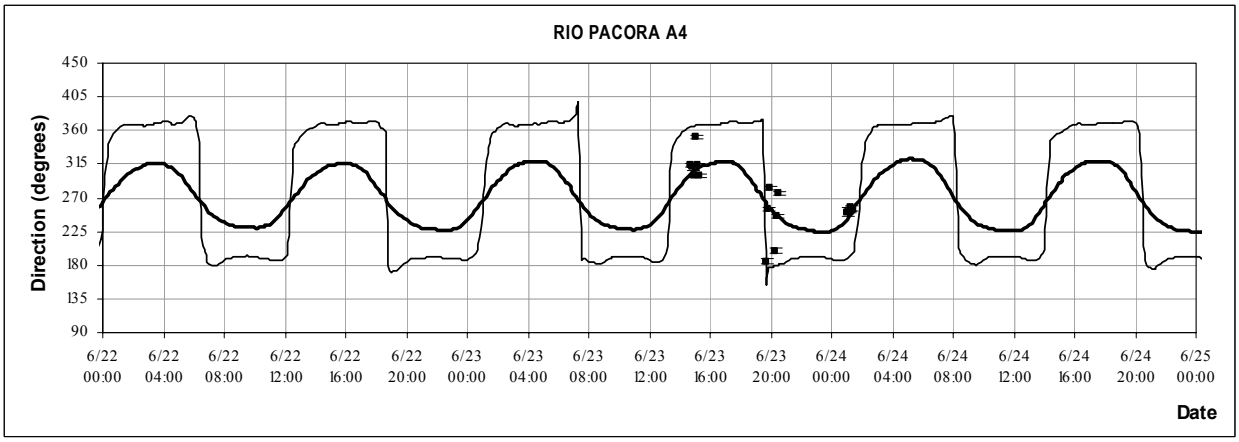


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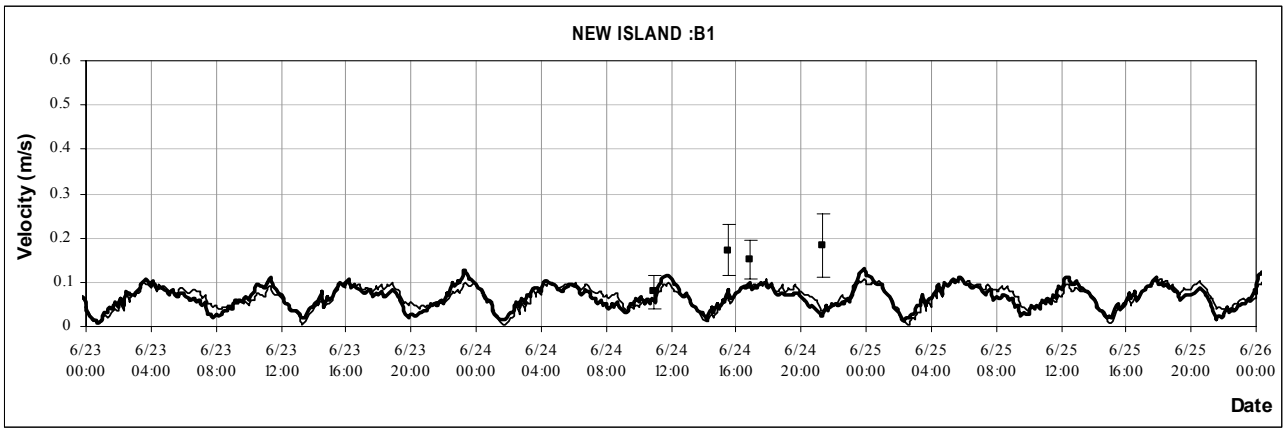
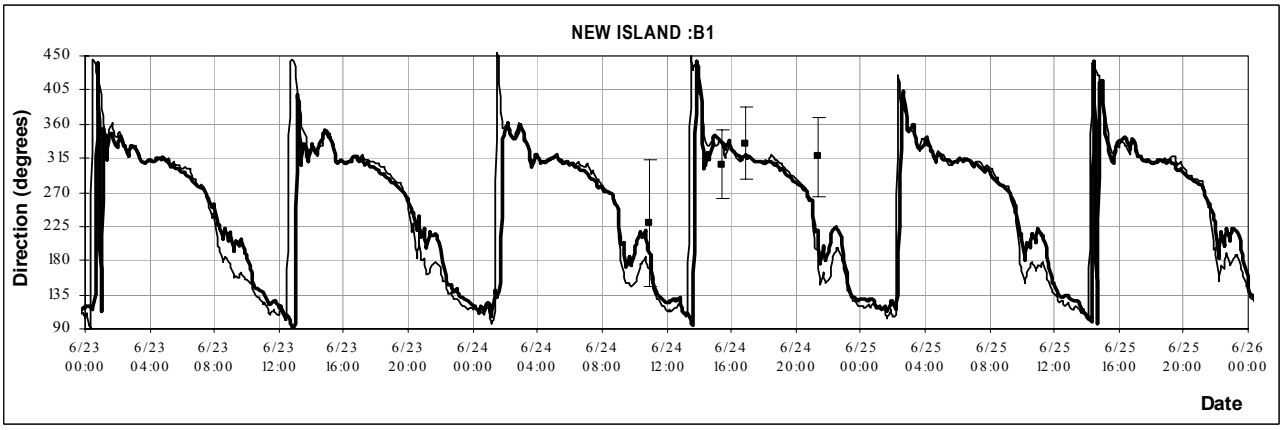
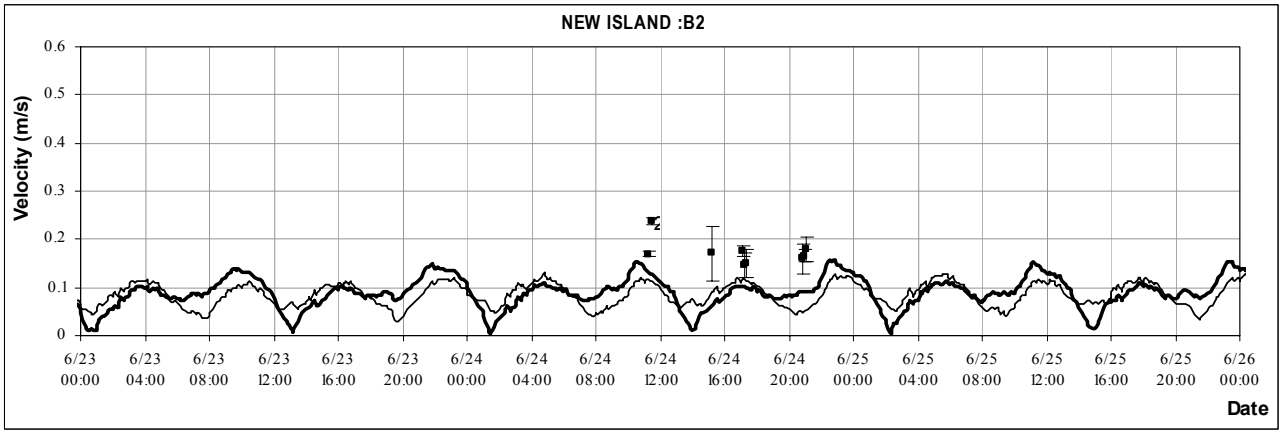
FIGURE A-26 : Campaign 5 Observed and simulated current and direction (tides and tides+GP current)







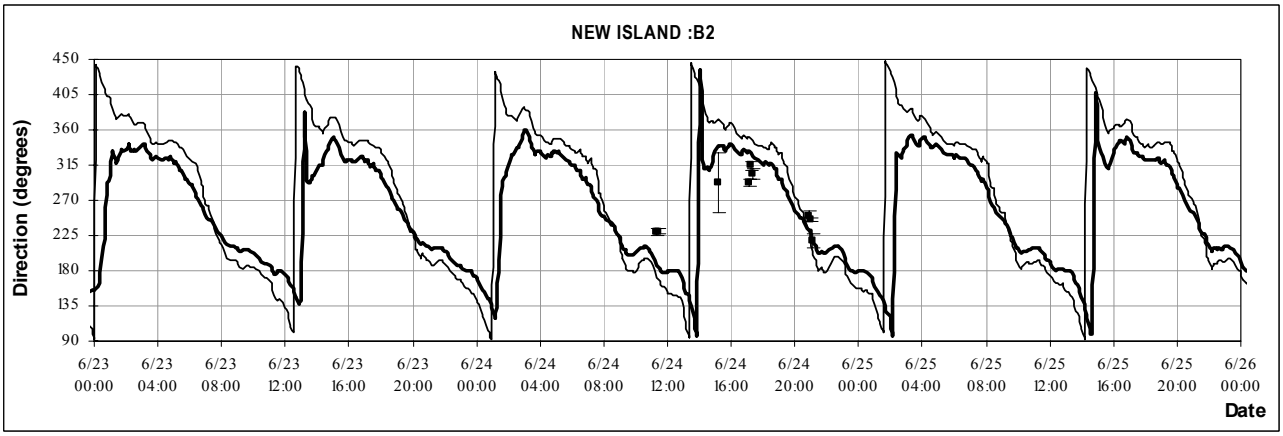


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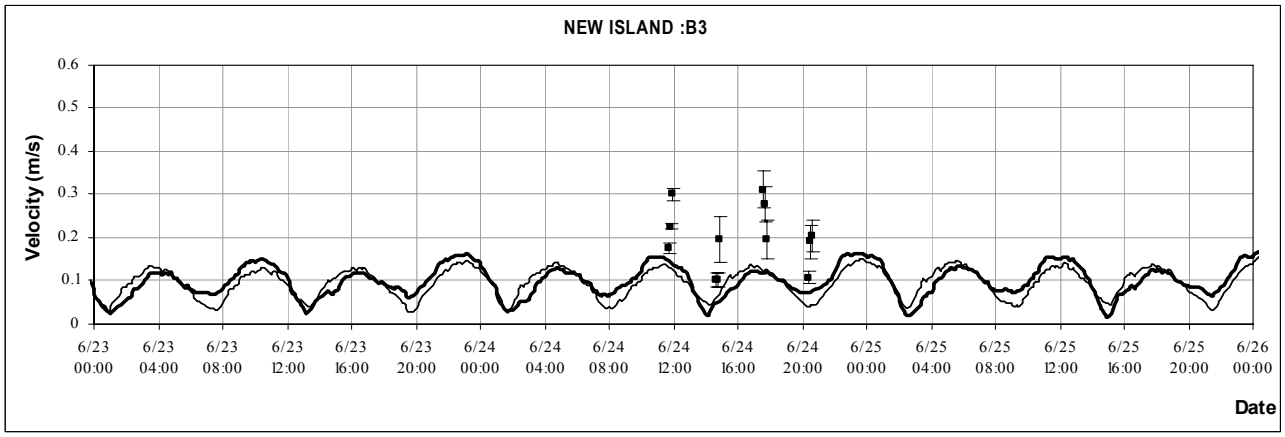
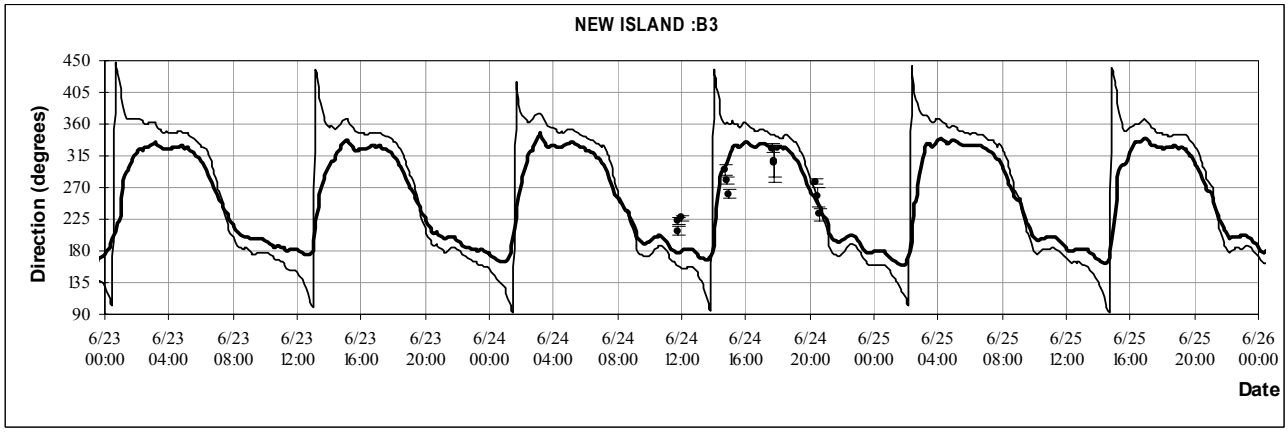
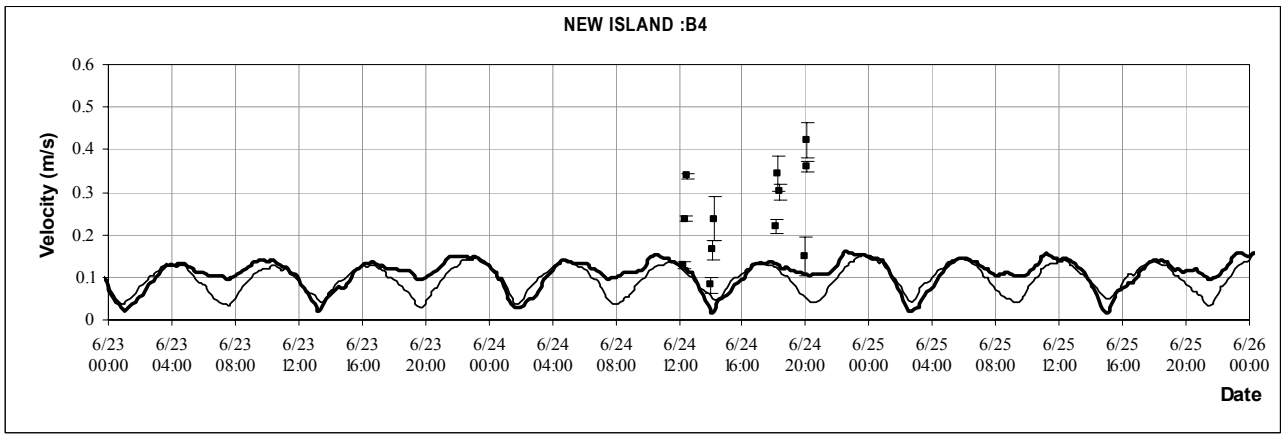
FIGURE A-27 : Campaign 5 Observed and simulated current and direction (tides and tides+GP current)







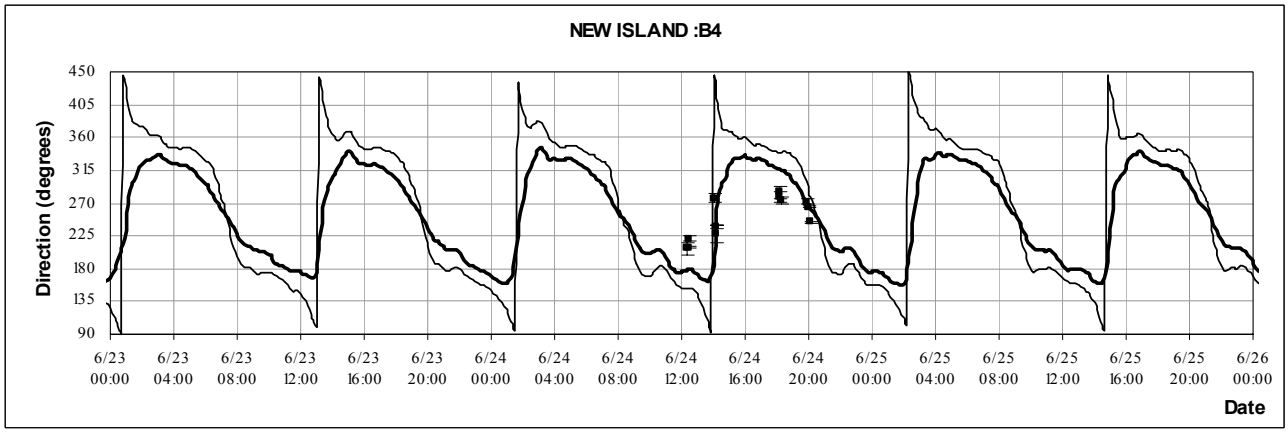


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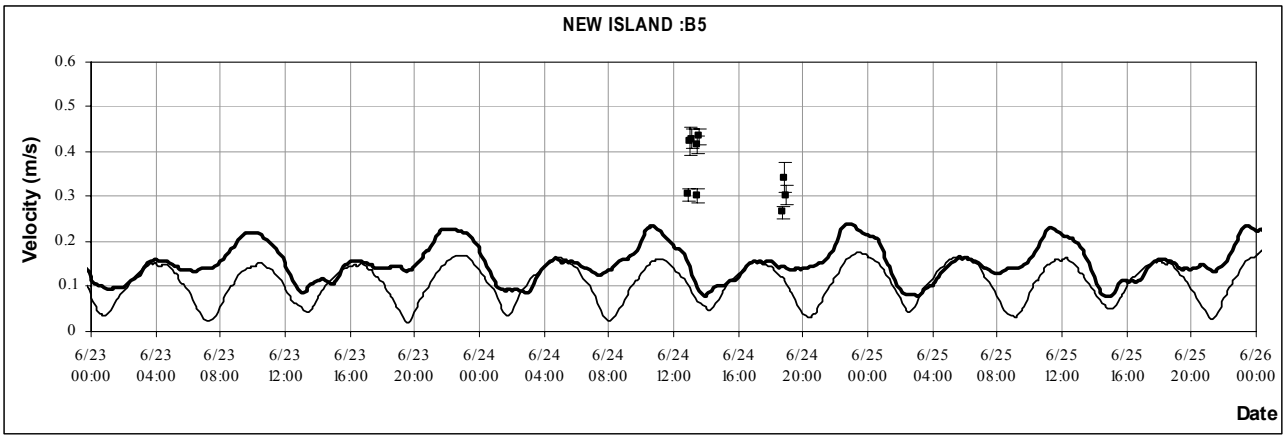
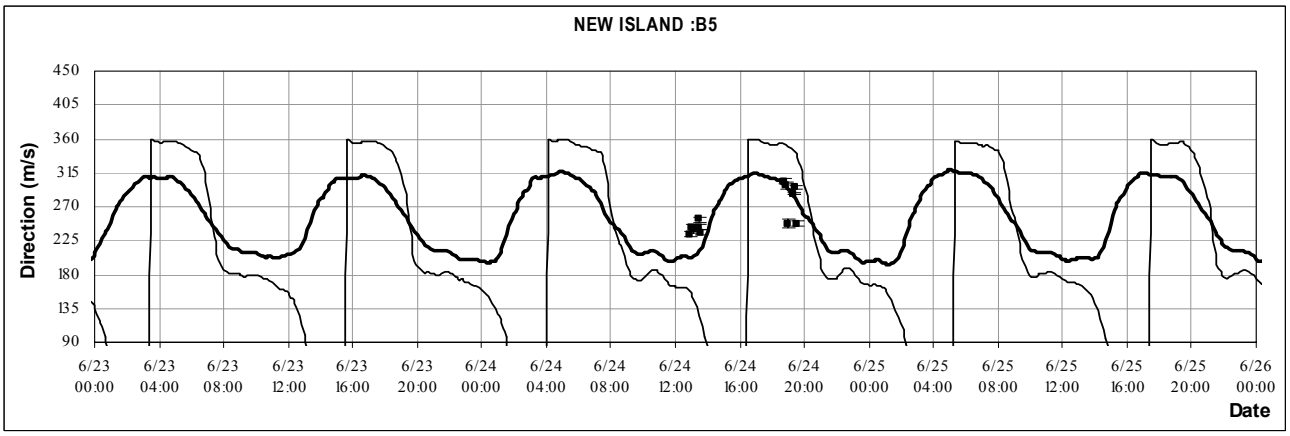
FIGURE A-28 : Campaign 5 Observed and simulated current and direction (tides and tides+GP current)





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ARTIFICIAL ISLAND FEASIBILITY STUDY

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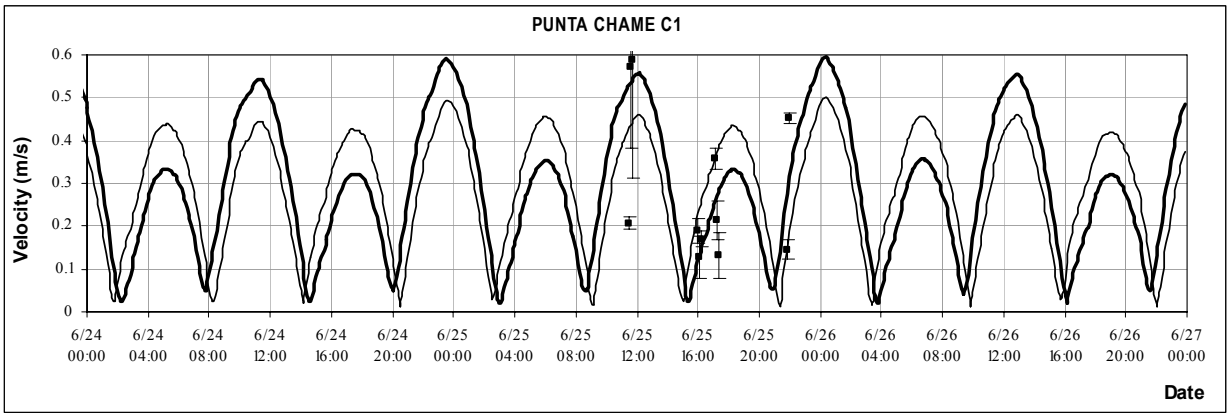

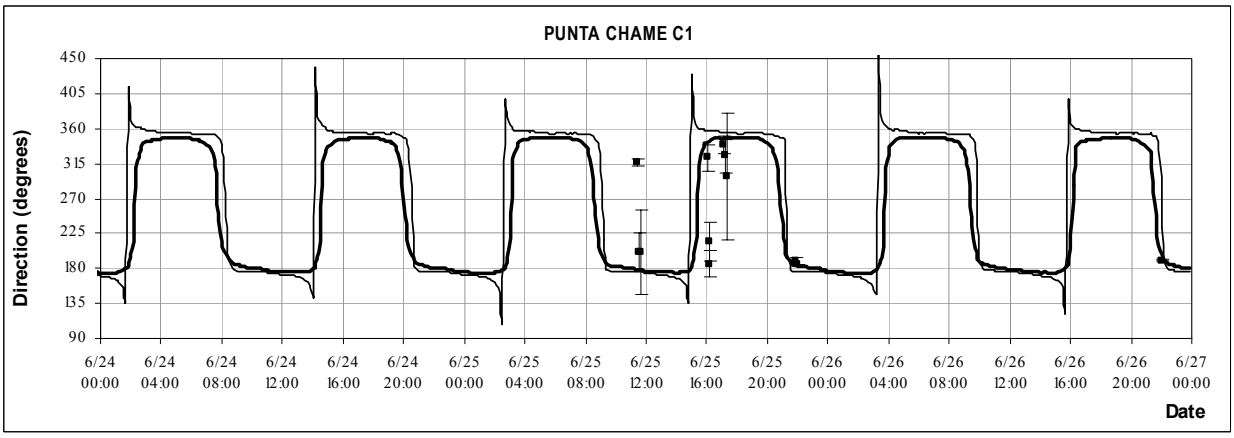

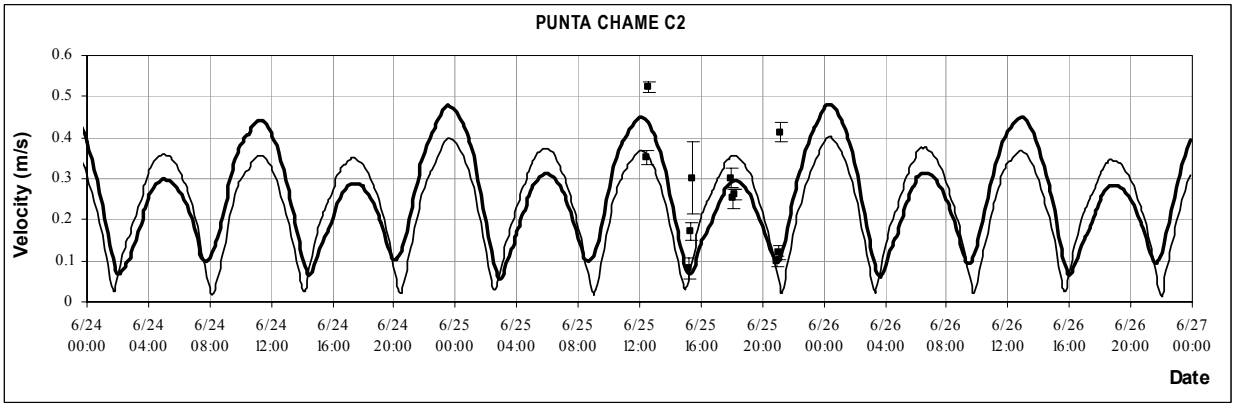

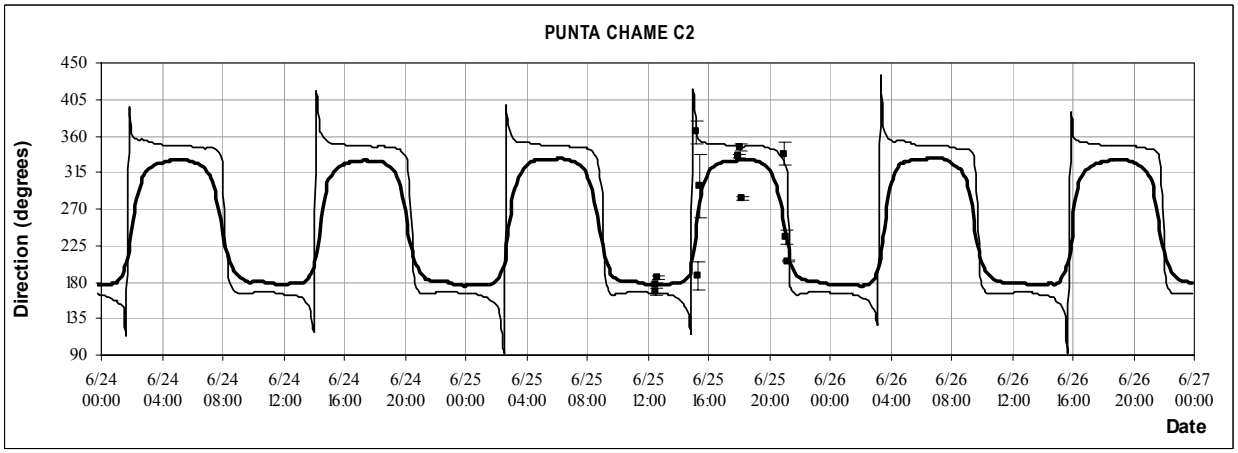

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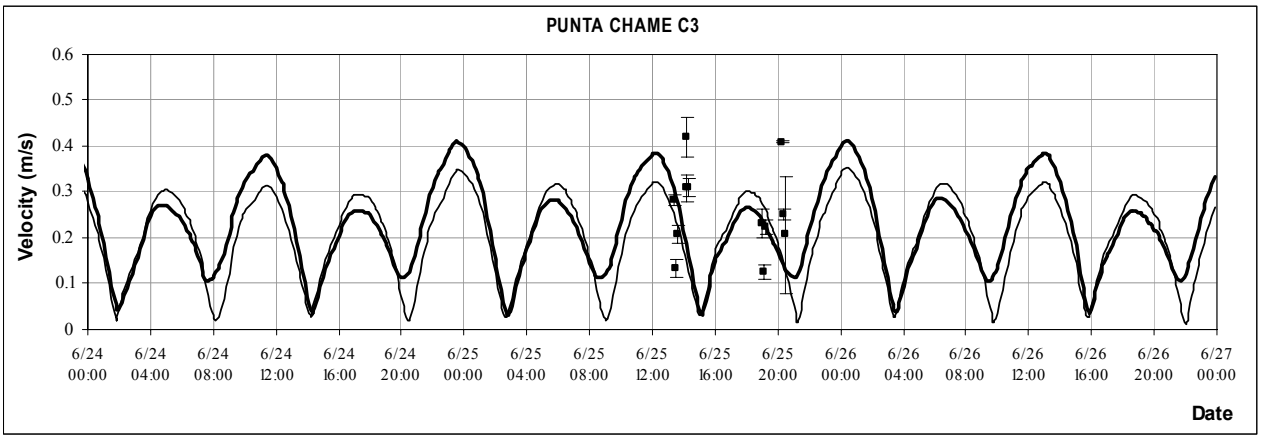
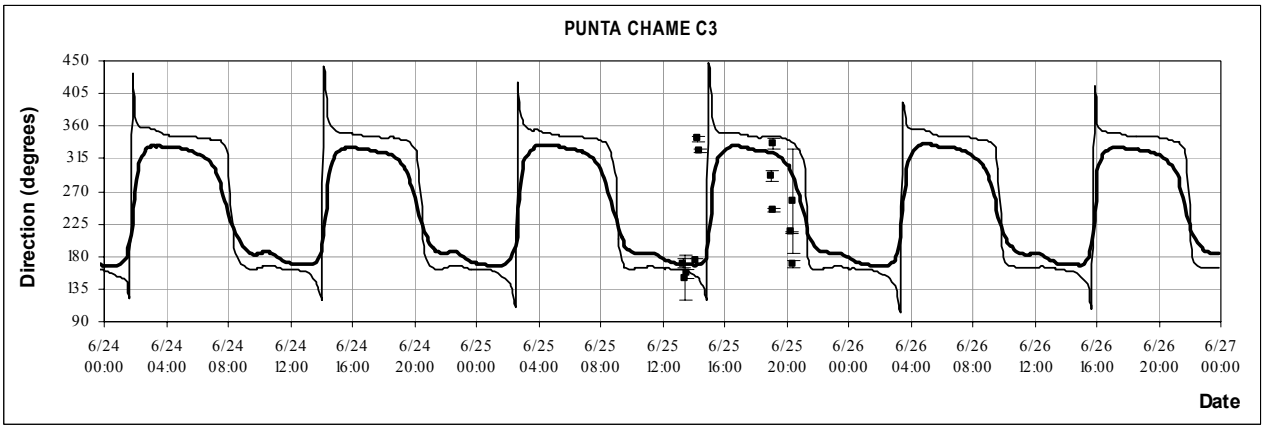
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE A-30 : Campaign 5 Observed and simulated current and direction (tides and tides+GP current)





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ARTIFICIAL ISLAND
FEASIBILITY STUDY

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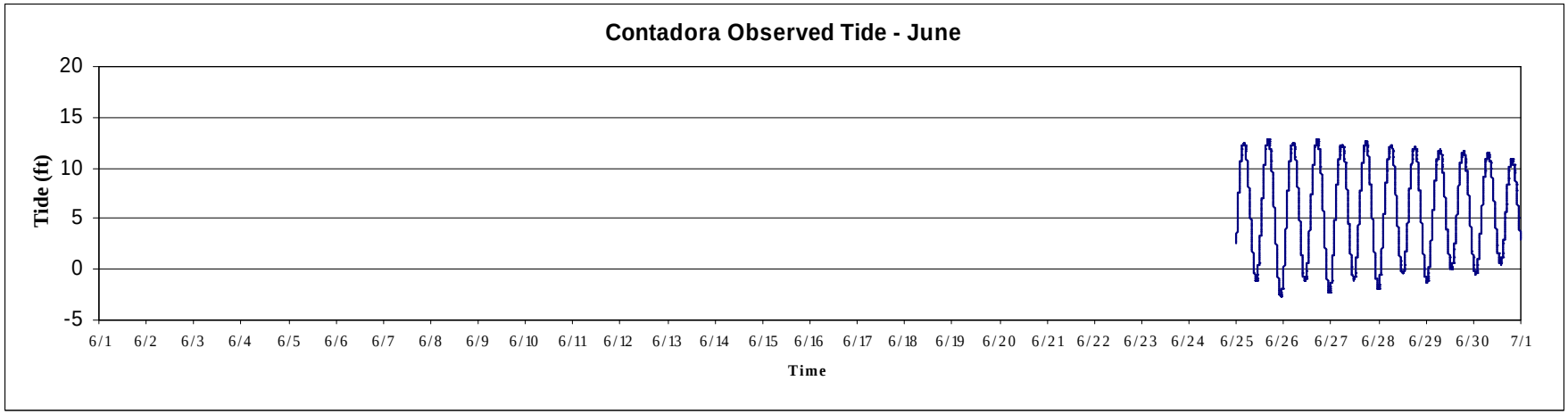
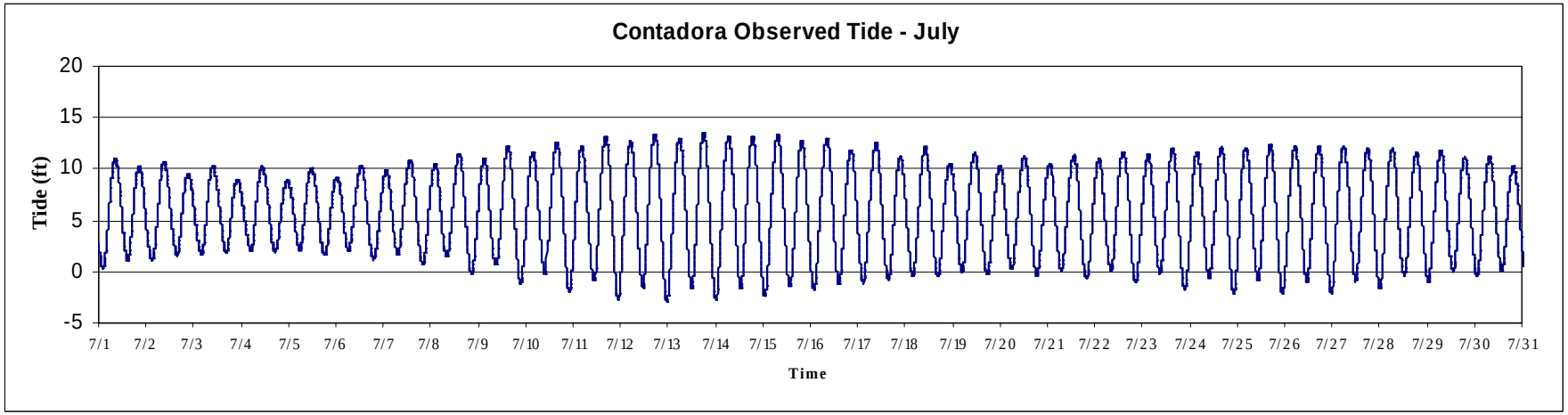
Observed and simulated current and direction (tides and tides+GP current)





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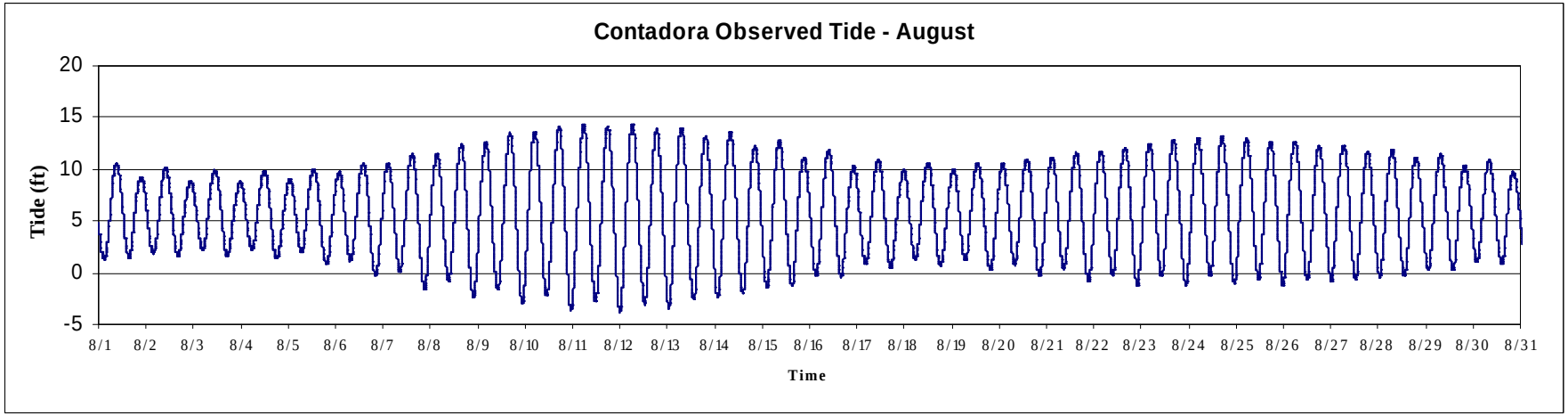
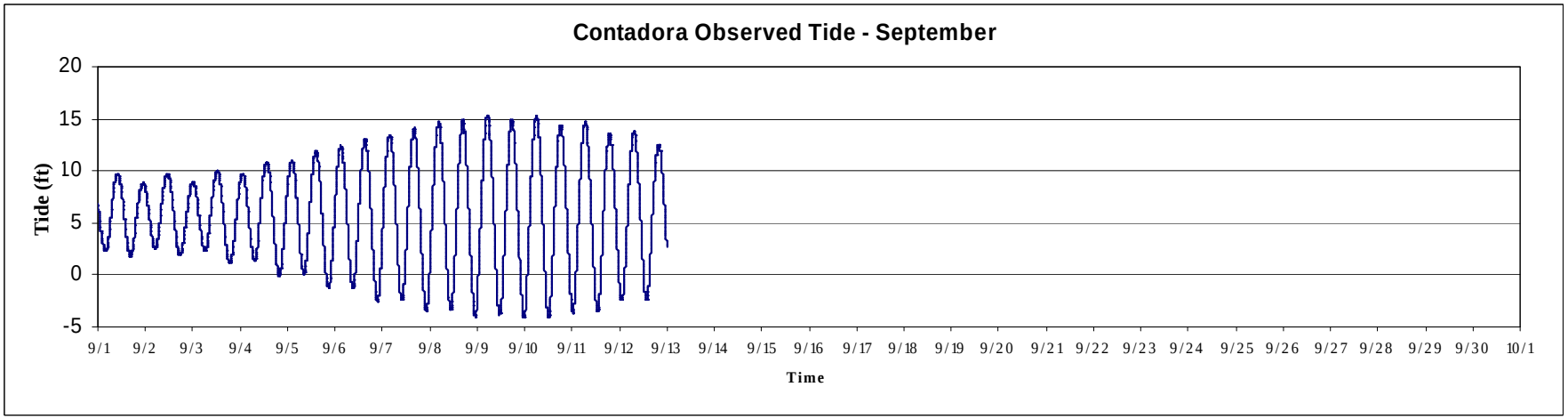
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-1:
Observed water levels at
Panama Bay by ACP





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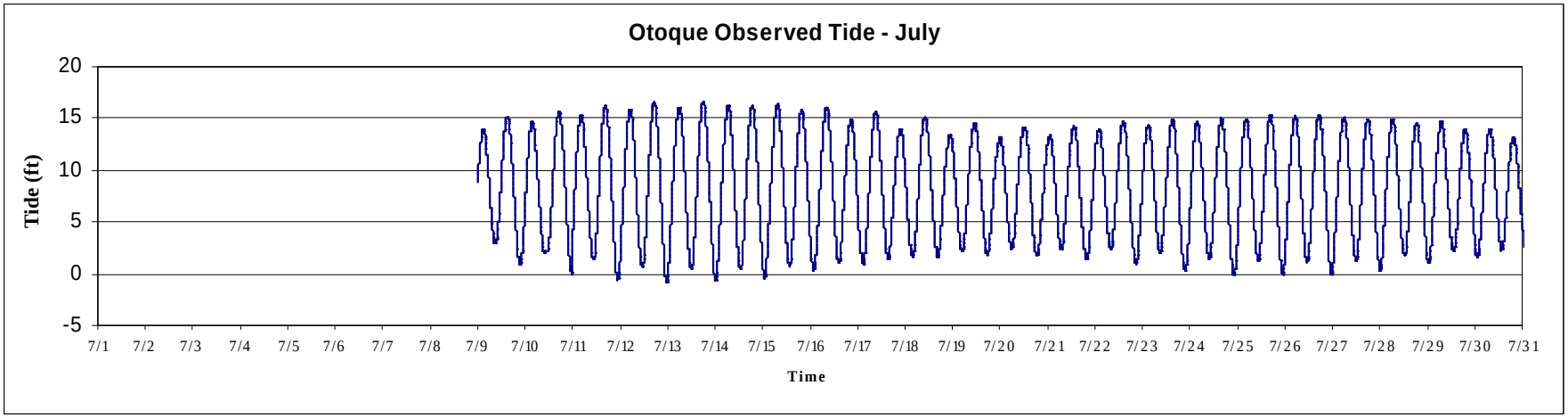
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-2:
Observed water levels at
Panama Bay by ACP



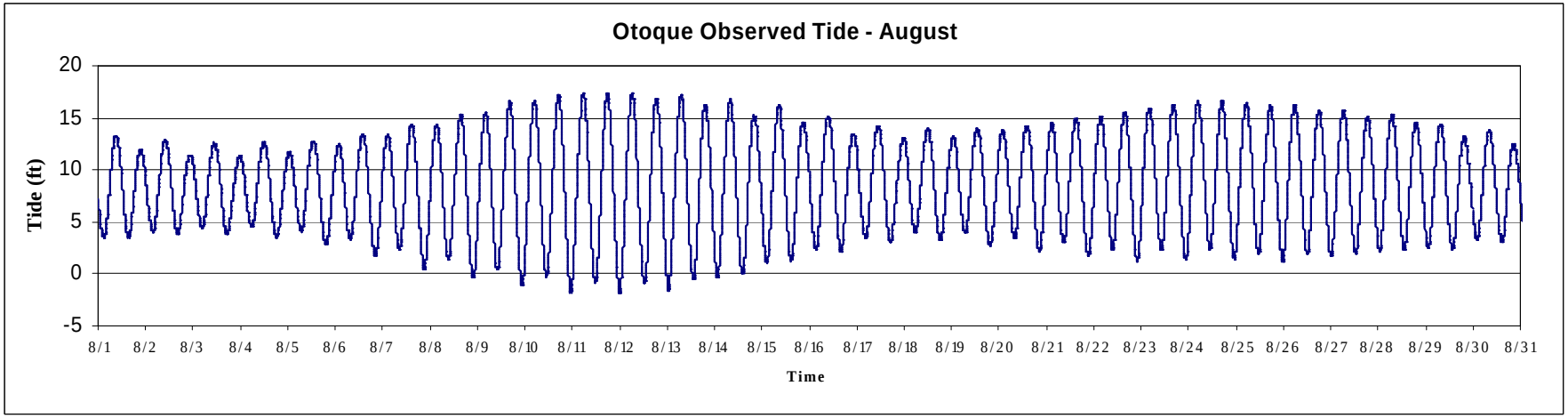


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FIGURE B-3:
Observed water levels at
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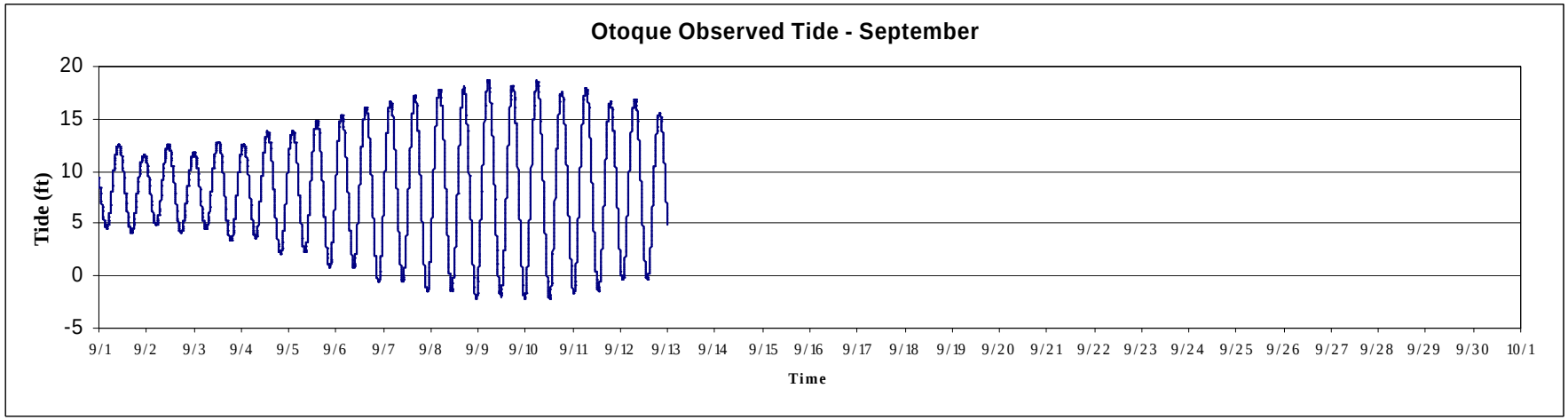

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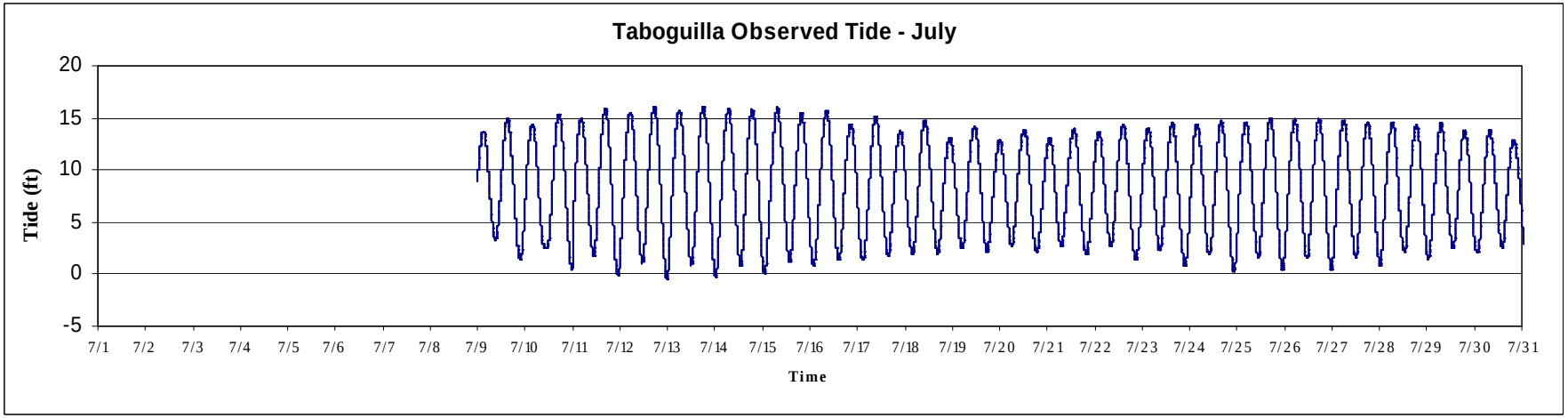
Observed water levels at
Panama Bay by ACP



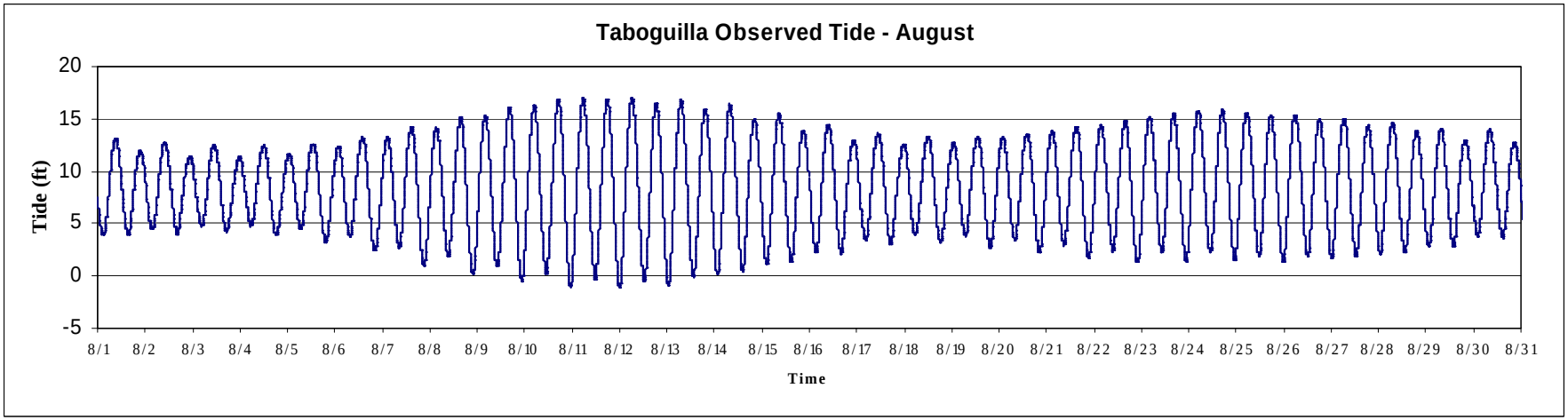


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FIGURE B-5:
Observed water levels at
Panama Bay by ACP

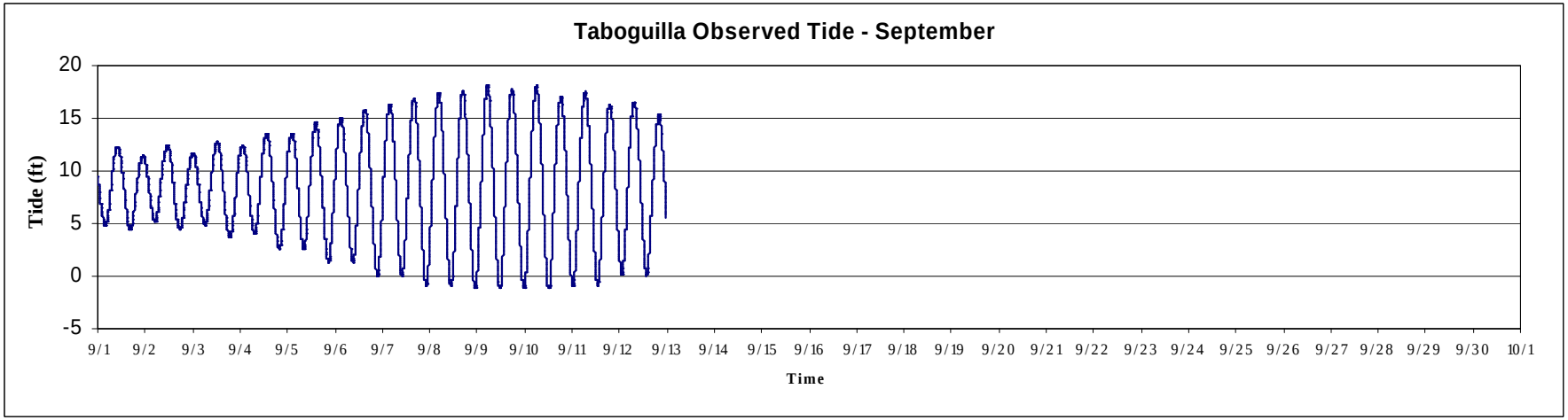

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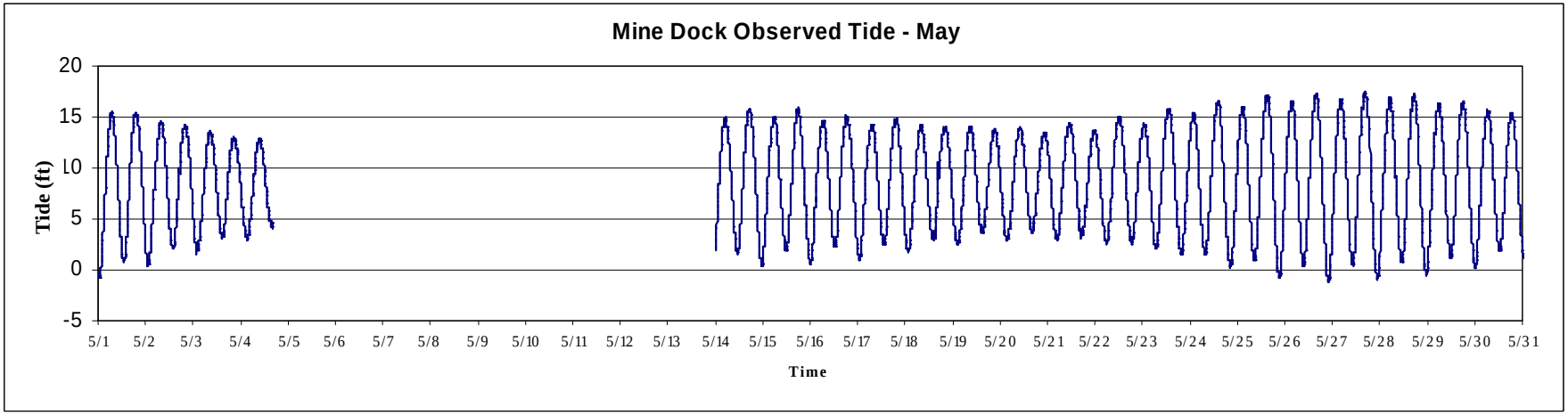
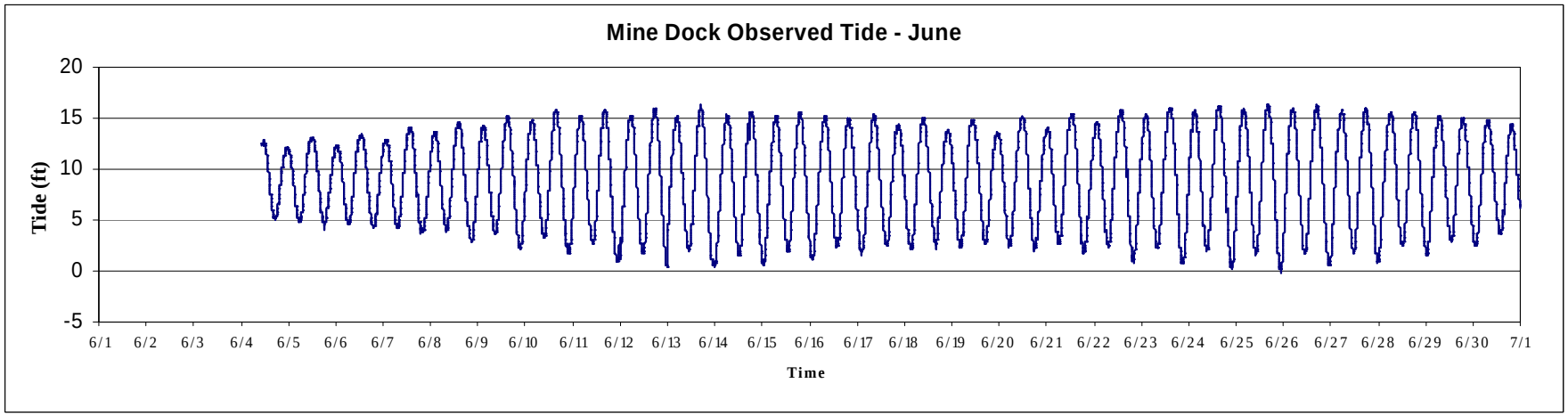
FIGURE B-6:
Observed water levels at
Panama Bay by ACP





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Observed water levels at
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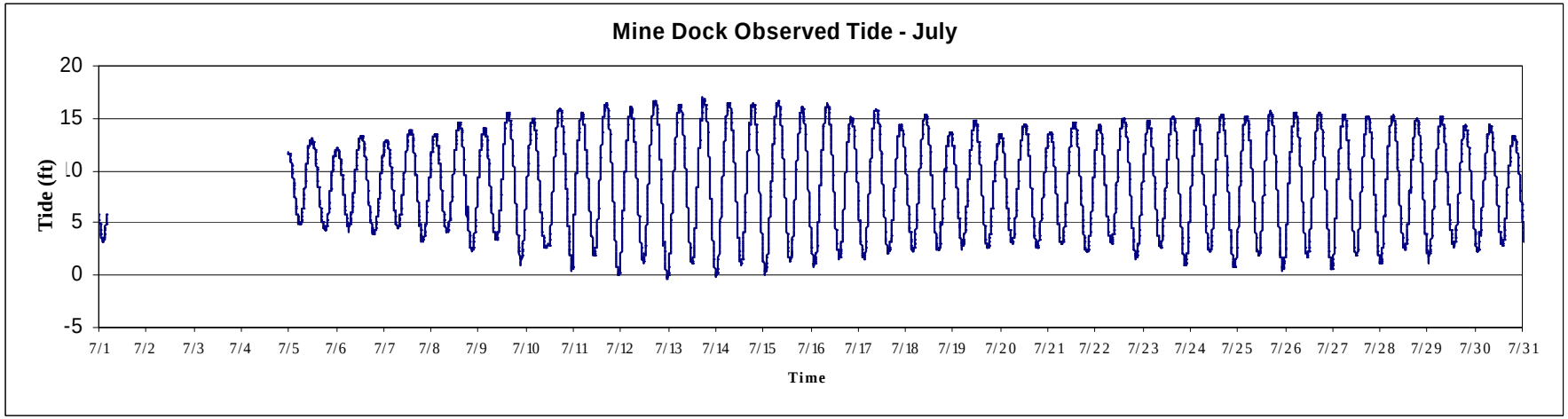

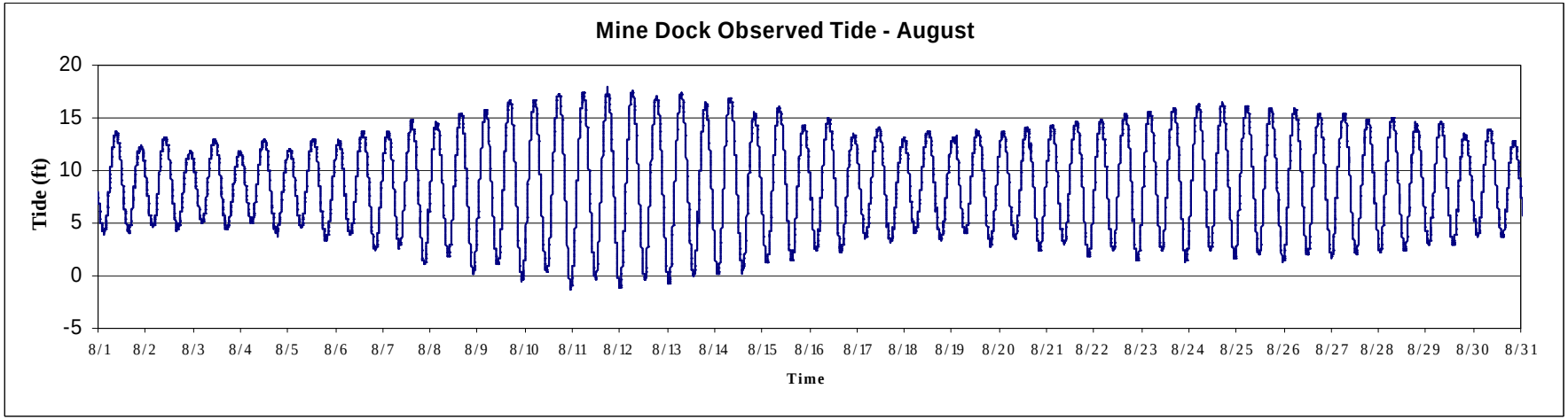

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Observed water levels at
Panama Bay by ACP

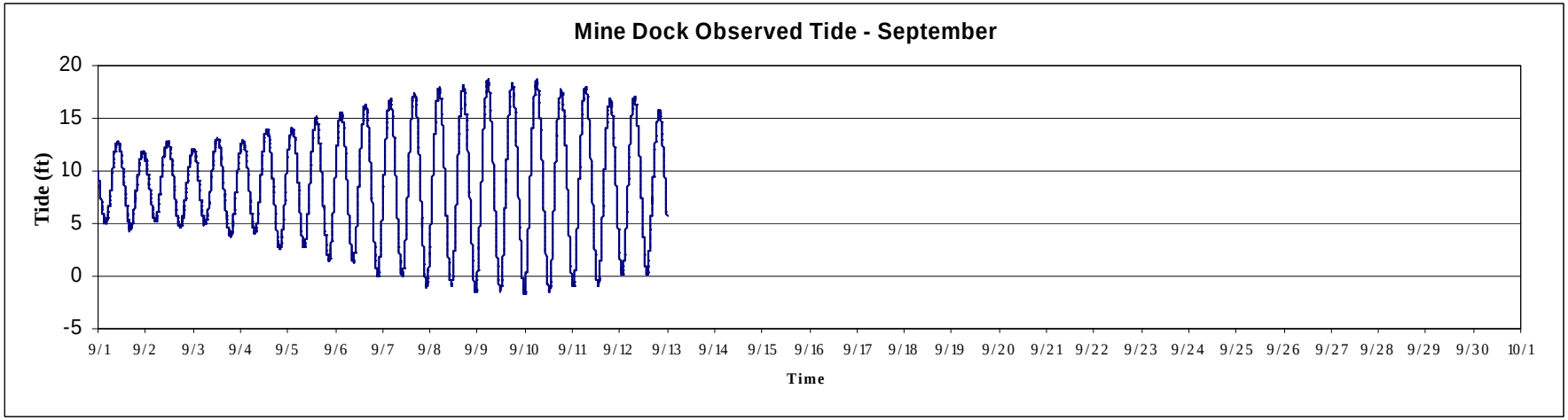

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FIGURE B-9:
Observed water levels at
Panama Bay by ACP

CONTRACT CC-3-557

Architectural and Engineering Services for Engineering Site and Assessment, Conceptual Design and Related Services

Feasibility Study for the Construction of an Artificial Island at the Pacific Entrance of the Panama Canal

Panama Bay

Assessment of Impacts on Existing Hydrodynamic and Water Quality Conditions

DRAFT REPORT

December 2003

Moffatt & Nichol
ENGINEERS

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1 INTRODUCTION

The Panama Canal Authority (ACP) is conducting a study of the Panama Canal to evaluate the feasibility of constructing of an artificial island at the pacific entrance of the Panama Canal using the excavated and dredged material obtained from the proposed Third Locks project and related expansion of the Panama Canal.

This report presents a preliminary assessment of expected hydrodynamic impacts of three alternative island sites. In addition different solutions for the connection of each of the alternative sites to mainland have been considered including causeway, trestle and causeway/trestle hybrid alternatives.

This draft report is a complement to the Panama Bay Existing Conditions Hydrodynamic Model Draft Report (ECHM 2002) submitted to ACP by Moffatt & Nichol in November 2002 and the Panama Island Alternative P1-A Assessment of Impacts on Existing Hydrodynamic and Water Quality Conditions Draft Report submitted to ACP by Moffatt & Nichol in January 2003.

2 DESCRIPTION OF ARTIFICIAL ISLAND ALTERNATIVES

Hydrodynamic and Water quality impacts in the Gulf of Panama were studied for three island alternatives (Figure 2.1). Two of them situated at locations 1 (A1) and 5 (A5) as presented in section 8.5.1 and Figure 8-10 of the Final Report "Pacific Site Disposal & Dredging Material Disposal Alternative Evaluation" October 2003 (PSDDMDAE2003) will hold the development or a marine center. The third alternative (AMU) is also located at position 1 but in this case its size and layout would be suitable for the development of a mixed use commercial, residential and public access areas. The island would be connected to the mainland via a causeway, an open pile trestle or a combination of both. The access structure would be wider for the marine center than for the commercial residential development.

Alternative A1 is based on alternative P1-A described in the PSID2001 report. The island is located immediately due east of the flight path into Howard Air Force Base, and west of the explosive cargo anchorage area. Access to the island is via a causeway-trestle combination. The nearshore section will be an open piled trestle about 200 meters long designed to allow movement of littoral material along the shoreline and passage for marine life. At approximately the mid point of the causeway, and in sufficient water depth to permit the passage of small fishing vessels, a bridge about 50-meters long will be placed. The island has a constructed area of 350 Ha and includes a 3,400 meter long offshore breakwater.

The second alternative is a variation of Alternative 5 (see report PSDDMDAE2003), with the longest side of the artificial island oriented northwest to southeast. The connection to the mainland is aligned almost parallel to the Pacific entrance channel and the dimensions of the artificial island as well as the length of the causeway are similar to those for alternative A1.

Finally, the third alternative (AMU) is a mixed use island located at the same site as alternative A1 but in the order of 800 m closer to shore. In addition the longest side of the island has been oriented east to west.

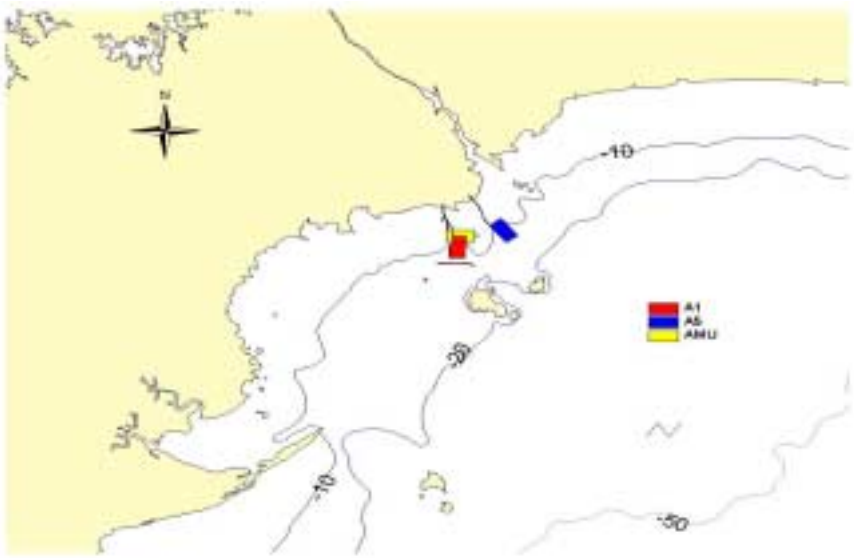


Figure 2.1 Simulated Artificial Island alternatives

3 HYDRODYNAMIC IMPACT ASSESSMENT

A numerical model based on the existing conditions model described in the ECHM2002 Draft Report was developed for each island alternative: A1, A5 and AMU. In addition three different possibilities for connecting the island to the foreshore, causeway (C), trestle (T) and a combination of both (H) were considered and simulated for each island alternative. Following is a description of how these different alternatives were implemented in the model.

3.1 Causeway

The three island alternatives were simulated with a causeway connection to the coast. A5 and AMU has been simulated with a completely closed causeway while A1 has two small openings in the causeway (see section 2), following the description presented in the PSID2001 report.

3.2 Trestle

A connection between the island and the coast using an open trestle was also simulated. The width of the trestle is 55 m. for the commercial island alternatives A1 and A5 and around 20 m for the mixed use alternative AMU. The considered layout of the piles is 15.5' x 34' (4.72 m x 10.36 m) spacing using 26” (0.66 m) diameter piles. Model grid size is typically larger than the pile diameter, therefore it is normal modeling practice to include the influence of the piles on the hydrodynamics as an additional friction term in the model. This term produces the same effect in the flow (flow reduction) as the piles do and is typically implemented as additional bottom friction. Specifically, an equivalent bottom friction manning coefficient that accounts for both the natural bottom friction and the friction due to the piles, is calculated as follows. The flow resistance due to a jetty or a bridge is dependent on the blocking of the flow by the piles. For a row of piles perpendicular to the model x-direction the flow resistance is given by the following expression (Delft3D manual):

$$C_{loss,X} = \frac{1}{2}\frac{N_X \cdot C_{drag} \cdot d_{pile}}{\Delta y}\frac{A_{tot}}{A_{eff}}$$

where

A_{tot} total cross sectional area

A_{eff} effective wet cross sectional area (A_{tot} minus area blocked by piles)

C_{drag} the drag coefficient of a pile (1.0 for smooth pile)

d_{pile} the diameter of a pile

N_X the number of piles in X-direction in the grid cell

The friction loss due to the piles is converted to manning friction coefficient. Values of the equivalent manning coefficient applied in the numerical model are presented in Table 3.2-1. Background manning coefficients are applied at every grid point of the model except those representing the trestle. The background coefficient is the same in both computational directions. The equivalent manning coefficient is smaller for the mixed use alternative AMU than for A1 and A5 due to the use of a narrower trestle.

Table 3.2-1 -Equivalent Manning coefficients due to piles

Alternative	Background Manning coeff ($s/m^{1/3}$)	X-direction Manning coeff ($s/m^{1/3}$)	Y-direction Manning coeff ($s/m^{1/3}$)
A1	0.023	0.080	0.080
A5	0.023	0.080	0.080
Mixed-Use (AMU)	0.023	0.054	0.054

3.3 Hybrid (combination of causeway and trestle)

The hybrid alternatives simulated as part of this work consist of a combination of causeway and trestle where the trestle section represents approximately one third of the total length of the connection to land. The trestle is distributed in two sections, one of 250 meters in the nearshore to avoid blocking of the flow in that area and a longer section in the area of largest flows located just north of the island. Table 3.3.1 presents the total length of the causeway/trestle alignment, the length of the two trestle segments and the percentage of open section for each alternative.

Note that the final causeway/trestle ratio should be optimized during the design phase of this project to obtain a cost efficient configuration with a relatively small disruption of the flow in the bay. This optimization could be done by performing a number of simulations for a set of different hybrid alternatives with different causeway/trestle ratios and distributions along the connection.

Table 3.3-1 -Trestle length for hybrid alternatives

Alternative	Total Length (m)	Near Island trestle (m)	Shallow water trestle (m)	% of open section
A1	3750	1050	250	35
A5	3650	1025	250	35
Mixed-Used (AMU)	3000	700	250	32

3.4 Description of Impacts

Comparison of model results for existing conditions and for the different alternatives was carried out for spring and neap tides, and for the four stages of the tide. A 14-day simulation period from 5/25/02 to 06/06/02 was selected because it includes both spring and neap tides. Figures A-1 and A-2 presents flow patterns from the existing condition model during spring and neap tides respectively (figures already presented in the ECHM2002 Draft Report). Both figures include the flow patterns during four tidal stages: Low Water (LW), Peak Flood (PF), High Water (HW) and Peak Ebb (PE). Figures similar to Figures A-1 and A-2 have been created for every simulated alternative and are included in Appendix A. In addition comparisons of the existing condition model with every alternative are also presented in Appendix A. These figures show the differences in the magnitude of the velocities and the flow patterns for each simulated alternative at each stage of the tide.

A description of the impacts observed from each island alternative is presented in the following paragraphs.

3.4.1 Alternative A1 (A1)

Model results show that the largest reduction in velocities caused by the construction of island alternative A1-Causeway (A1-C) is during neap tide. During this period the main flow direction is dominated by the Gulf of Panama Current. A disruption of the coastal current due to the causeway is observed at the four stages of the tide but especially during high water and peak ebb. This disruption is translated in a reduction of the velocity at the near shore from a range of 5-7 cm/s to 1-3 cm/s during high water and from 3-10 cm/s to 1-5 cm/s during peak ebb. North of the island the velocity was reduced from a range of 10-13 cm/s to values between 1-5 cm/s during high water. The flow is channeled through the area between the breakwater and Isla Taboga and also between the breakwater and the artificial island. This results in higher velocities distributed in a smaller area. During high water the maximum velocity increases in this area from 20 to 25 cm/s and during peak ebb from 32 to 35 cm/s. In addition, higher velocities are observed at the near coast passage and the bridge especially during high water (from 5 cm/s to 10 cm/s) and peak ebb (from 5 cm/s to 15 cm/s). This could be a potential cause for localized erosion around the piles and at the bridge channel. During spring tide the tidal flow dominates over the Gulf of Panama Current and the main flow direction at the island location is NNW during peak flood and SSW during peak ebb. A significant increase of velocities is observed around the tips of the breakwater (maximum velocity from 25 to 40 cm/s) and the NE tip of the island (maximum velocity from 20 to 30 cm/s) during these two tidal stages. These areas of higher velocities may require special provision for scour protection. During peak ebb it is also observed a decrease in the magnitude of the currents due to the causeway. The largest disruption of the coastal current is observed during high water with the maximum change observed from 17 to 5 cm/s. Also during this period high currents are observed between the breakwater and the artificial island and also at the northern passage and the bridge of the causeway. A general increase of the current magnitude, in the order of 4 cm/s, is also observed north of Isla Taboga.

Water flow is not blocked and directed south for alternatives A1-Trestle (A1-T) and A1-Hybrid (A1-H). As for alternative A1-C the largest impacts are also observed for neap tide but their magnitude is smaller. In both cases a velocity increase (in the order of 5 cm/s) is observed just north of the island. This increase is a consequence of the convergence of flow through the deepest open area along the trestle. Although the results from A1-T and A1-H are very similar, A1-H presents some blocking of the flow in the shallow water north of the island, where the longest causeway segment is located, with a reduction of the velocity from 5 to 2 cm/s.

3.4.2 Alternative A5 (A5)

The island for alternative A5 is oriented parallel to the main flow during peak flood at spring tide. Specifically for A5-Causeway (A5-C), a large amount of flow is deviated towards the Panama Canal entrance producing a significant increase (5 to 7 cm/s) of the currents in the area near the island, but also between the island and the Amador causeway. During peak ebb at spring tide the island blocks the main flow direction which is towards south. In this case a significant reduction of the velocities, from 20 to 5 cm/s, is observed west of the island and an increase of the maximum velocity from 25 to 40 cm/s to the east.

During neap tide the main flow direction is dominated by the Gulf of Panama Current. A disruption of the coastal current due to causeway is observed during high water and peak ebb. Velocities are reduced in the area along the causeway from a range of 5-10 cm/s to 1-3 cm/s. The velocity reduction is observed west of the island as well as in the area between the island and the Amador causeway. During low water and peak flood the velocity reduction is smaller.

Similar results are observed for alternatives A5-Trestle (A5-T) and A5-Hybrid (A5-H) though the area influenced by the island and connection to the foreshore is significantly smaller than for A5-C. The blocking effect of the island on flow is still observed, but due to the trestle opening there is little or no impact in the area north of the island. In addition the impacts in the vicinity of the entrance channel are greatly reduced. Although the results from A5-T and A5-H are very similar, A5-H causes some blocking of the flow in the shallow water north of the island, where most of the causeway is located especially during peak ebb, producing changes in the velocities in that area in the same order than those observed for A5-C.

3.4.3 Alternative Mixed-Use (AMU)

The footprint of the island for Alternative mixed-use (AMU) intersects the peak ebb flow and to a lesser extent the peak flood. In particular, for alternative AMU-Causeway (AMU-C) this is translated into a reduction of the velocity magnitude north of the island in the order of 5 cm/s and a significant increase at the eastern edge up to a maximum velocity of 40 cm/s. During the stages of the tide when the Gulf of Panama Current is dominant (HW and LW during Spring Tide, and HW, LW and PF during Neap Tide) reduction from 6-9 cm/s to 1-3 cm/s and blocking of the flow is observed north of the island. For alternatives AMU-Trestle (AMU-T) and AMU-Hybrid (AMU-H) the impact of the island and the connection to the coast is small, especially for AMU-T. In these two alternatives an important increase of the velocities from a maximum velocity of 13 cm/s to 25 cm/s at the north-west corner of the island is observed due to the convergence of flow through the deepest part of

the connection alignment. In general, and because this location is closer to the coast, the magnitude of the flow affected by the construction is smaller than for A1 and A5 alternatives.

3.4.4 Summary of Hydrodynamic Impacts

- Any of the island alternatives deviates the existing flows associated to the tidal and oceanic currents due to its location, size and geometry. These changes in the flow patterns are translated into a localized increase or decrease of velocities in the area situated around the island.
- In general, the impact of all the simulated alternatives on the hydrodynamic conditions of Panama Bay can be considered small and localized to the immediate project vicinity. The largest changes in the currents are always observed around the island.
- As expected, the causeway option produces the largest changes. The blocking effect forces the currents that normally flow north of the island to flow south of the island. It has to be noted here than the magnitude of the velocities on the near shore areas when most of the blocking is observed is very small under existing conditions, with typical values of 5cm/s or smaller.
- The trestle and hybrid alternatives have smaller impacts than the causeway alternative, since they do not block as much of the flow north of the island. The trestle and hybrid alternatives have a minimal impact during neap tide for high and low water which suggests a minimal disruption of the Gulf of Panama Current in the vicinity of the island
- The two alternatives that are located farther offshore (A1 and A5) produce the largest impact because they have a higher effect on the Gulf of Panama Current
- Alternative A5 produces some changes in velocities (increase and decrease depending on the tidal stage) at the Pacific entrance of the Panama Canal because of its proximity to this area.
- Smaller impacts are observed at the alignment for A1 and AMU. In this case there is small interference with the flow entering and leaving the Pacific entrance of the Panama Canal. In addition, the location of AMU minimizes among all the alternatives the impact to the Gulf o Panama current.
- Model results suggest that the shape of the island in Alternative AMU could be further optimized to avoid sharp corners that produce the highest localized changes in velocities when compared to the existing conditions case.

4 WATER QUALITY IMPACT ASSESSMENT

In order to aid in the assessment of the changes in the flow and water quality as a consequence of the artificial island construction, a model that simulates the advection and dispersion of a conservative tracer was developed for existing conditions and for each of the previously mentioned alternatives. The water quality model (Delft3D-WAQ) solves the advection-diffusion equation on the same grid developed for the hydrodynamic model of Panama Bay described in ECHM 2002. The advection-diffusion equation uses flow fields transferred from the hydrodynamic model. A conservative constituent (tracer) was continuously released at four arbitrary locations in the vicinity of the study area for the same 14-day period used in the hydrodynamic simulations. Figures comparing tracer concentration after 14 days for each alternative and existing conditions and for each of the four release points are presented in Appendix B. The release locations are:

- Offshore of Isla Flamenca
- Farfan Peninsula
- Punta Bruja
- Veracruz

Note that the tracer does not represent any specific substance (e.g., sediment, contaminants, etc). Nonetheless, modeling of tracer advection and dispersion provides an indirect measure of the potential impacts to water quality (residence time) in areas adjacent to the project.

Results from the tracer model follow the previously described findings with the hydrodynamic model: reduction of the coastal current by the island construction could lead to longer residence time in the vicinity of the artificial island. In addition, the tracer runs show that areas located far from the artificial island, such as Isla Otoque or the entrance channel should not be affected by island construction. Results for the three alternatives (A1, A5 and AMU) for the causeway case show an increase of concentration near the four release points when compared to existing conditions. On the other hand when a trestle connection to the foreshore is considered the resultant concentrations are practically identical to those obtained for existing conditions. Finally the concentrations obtained from the hybrid case are almost the same as those from the existing conditions runs, except for the Punta Bruja release point and for A1 and AMU alternatives where the concentration slightly increase at the vicinity of the release point.

4.1.1 Summary of Hydrodynamic Impacts

- For the 4 different release points, the hybrid and trestle alternatives give results very similar to existing conditions.
- Model results suggest an increase concentration at the release points and also in the vicinity of the project for the causeway only alternative.
- Because of its location, concentration after 14 days for alternatives A1 and AMU are different than those from A5 for some release points. For example, Alternative A5 presents higher concentration for a release at Farfan, due to its proximity this location.

5 ANALYSIS OF HYDRODYNAMIC IMPACTS DESCRIBED IN REPORT PSID2001

Based on the model results an analysis of some of the hydrodynamic impacts described in Table 10-1 of Report PSID2001 is presented here.

1. Hydrodynamic Impact

For all the alternatives connecting to the coast using the causeway alternative and due to the reduction of the coastal current as a consequence of the island construction, the area located northeast of the Island (east of the causeway) is a potential area for sedimentation of material carried by the coastal current from the east. In addition, there is a potential increase of the residence time in this area. In the case of alternative A1-C, areas located between the artificial island and isla Taboga present a general increase of the magnitude of the currents especially during low water and peak ebb. This flow increase indicates some potential for erosion right north of isla Taboga due to a general increase of the currents. Similar although smaller effect is observed for alternative A5-C between the island and Taboguilla and between the island and the Amador Causeway.

All the aforementioned effects are either not presented or significantly reduced when trestle or hybrid alternatives are considered.

Results from the numerical simulations, however, indicate that none of the artificial island alternatives simulated will have an effect on the general hydrodynamic patterns of Panama Bay. Effects on the currents will be limited to areas in the immediate vicinity of the project.

2. Effects to coastal resources (coral in Otoque and other areas).

Any of the simulated artificial island alternatives does not produce any change in the flow patterns in the vicinity of Isla Otoque. Comparison of velocities from the hydrodynamic and advection-dispersion showed that after the island construction changes of these variables at the vicinity of isla Otoque are negligible.

3. Contamination at beaches and western coastline

Reduction of the coastal currents indicates an increase of residence time in the vicinity of the proposed causeway when compared to the existing conditions case, especially for the most western located release points. Therefore, there is potential for an increase of concentration of any substance carried by the water that reaches this area.

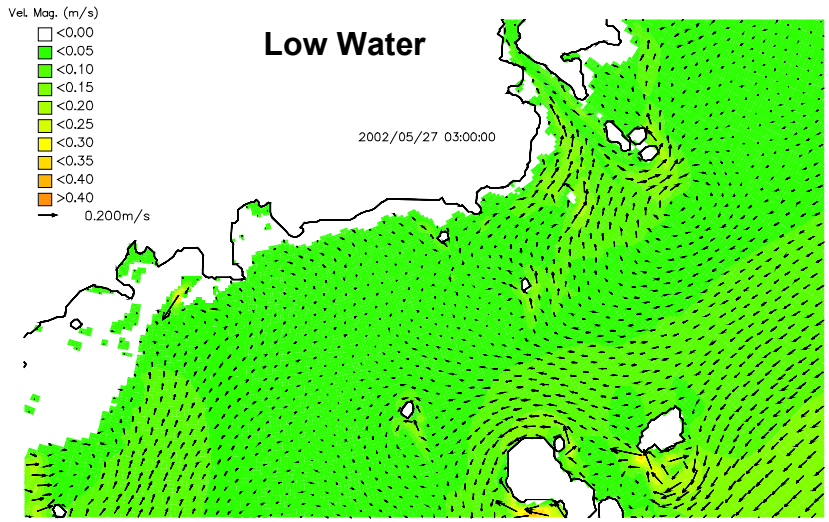
4. Increased sedimentation along the Panama Canal access channel

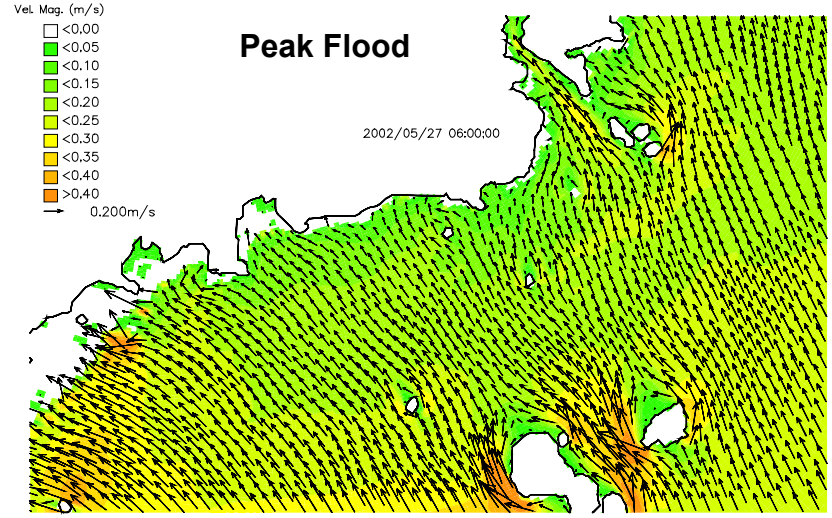
Increased sedimentation at the pacific entrance channel of the Panama Canal is not expected. Only for alternative A5 produces some changes in the velocities at the access channel due to its

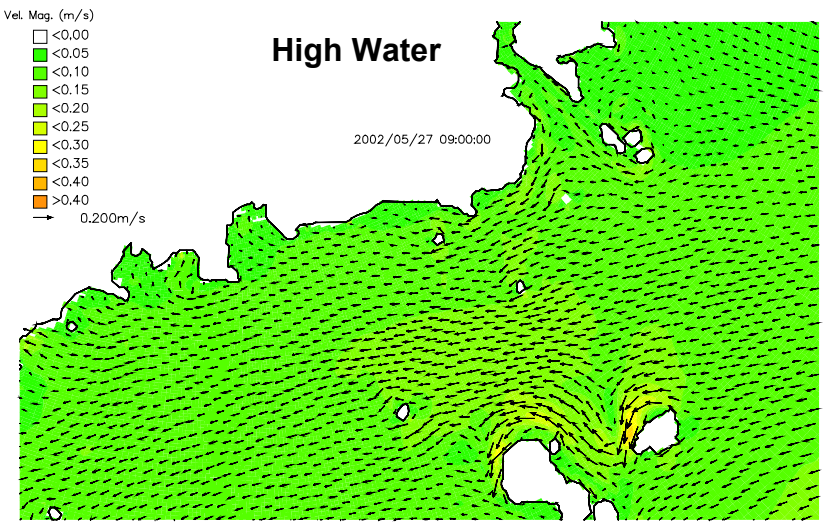
proximity. In this case and especially for the causeway (A5-C) alternative, a small increase in velocities will be expected at the entrance channel. For all the other simulated alternatives model results suggest that there will be no changes on the velocities in the area of the entrance channel due to the island construction, and therefore changes in sedimentation/erosion patterns in this area are not likely.

A. APPENDIX A – FIGURES FROM HYDRODYNAMIC SIMULATIONS

Local model flow patterns: SPRING TIDE







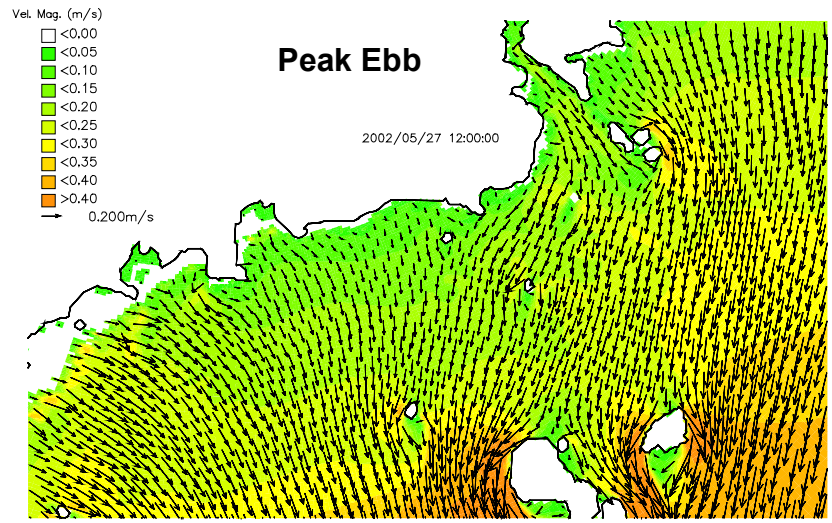


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FIGURE A-1:
Flow patterns during spring tide
at the project site. Existing Conditions

Local model flow patterns: NEAP TIDE

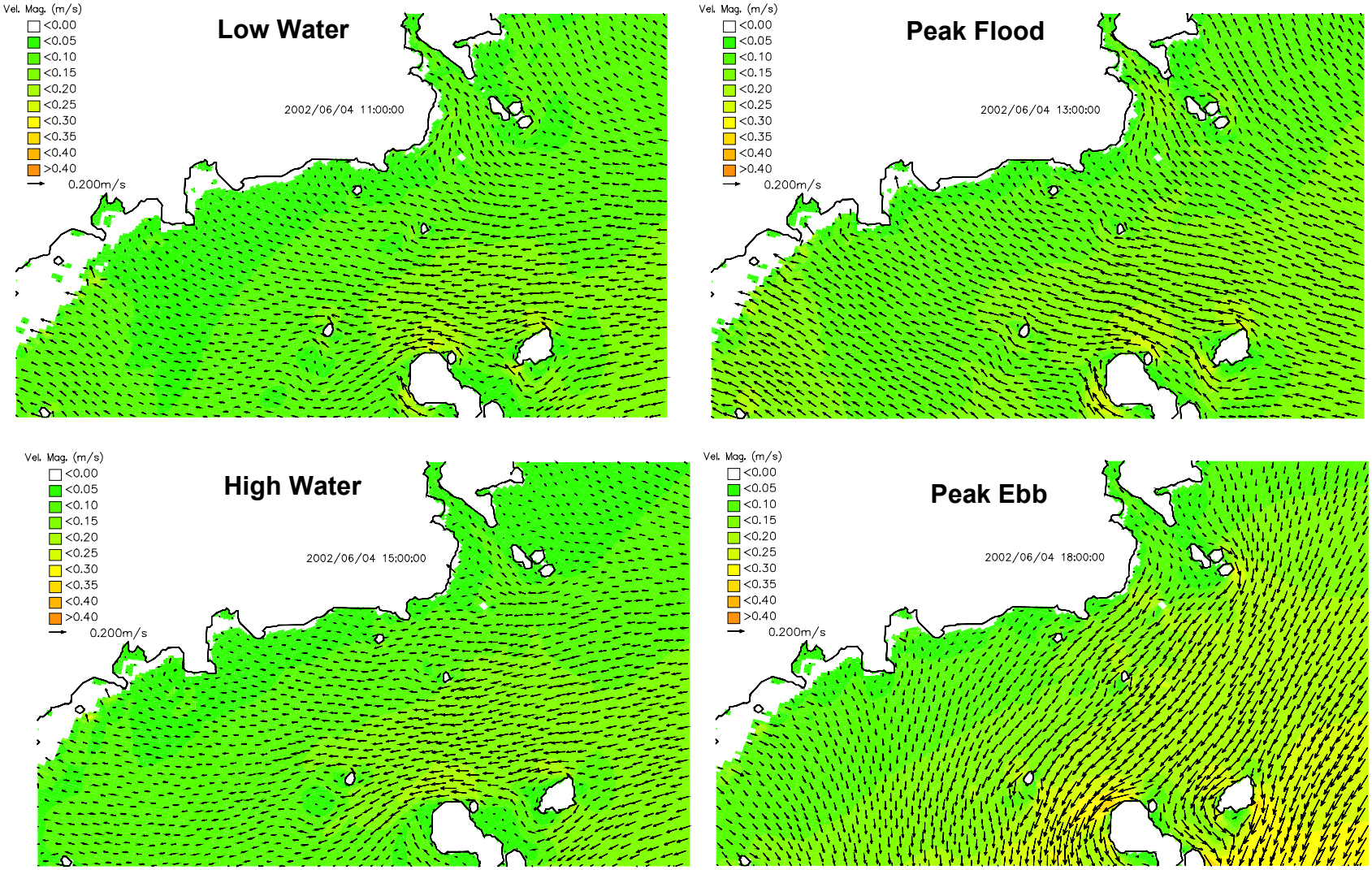

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FIGURE A-2:
Flow patterns during neap tide
at the project site. Existing Conditions

Local model flow patterns: SPRING TIDE

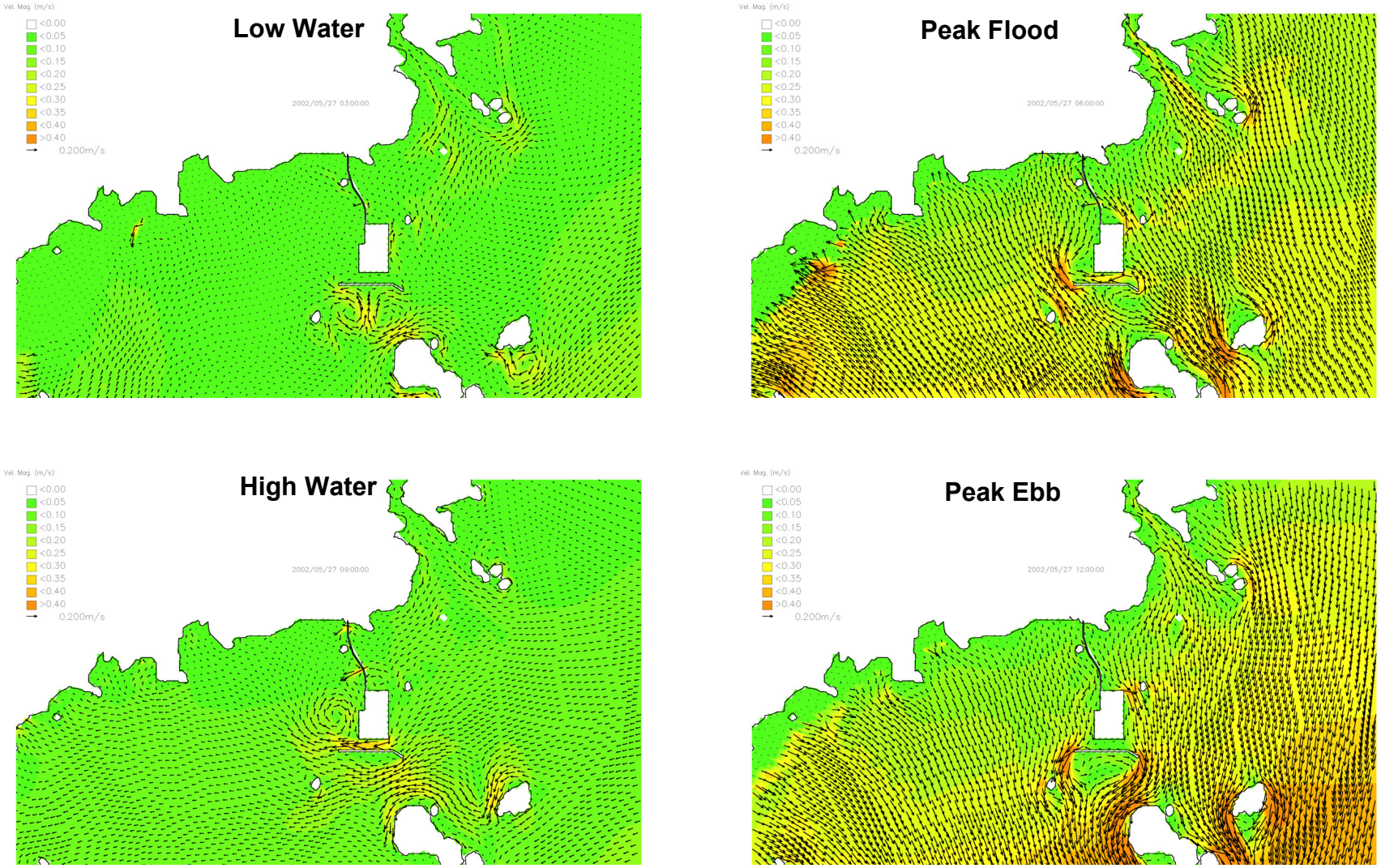

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FIGURE A-3:
Flow patterns during spring tide
at the project site. Causeway A1

Local model flow patterns: NEAP TIDE

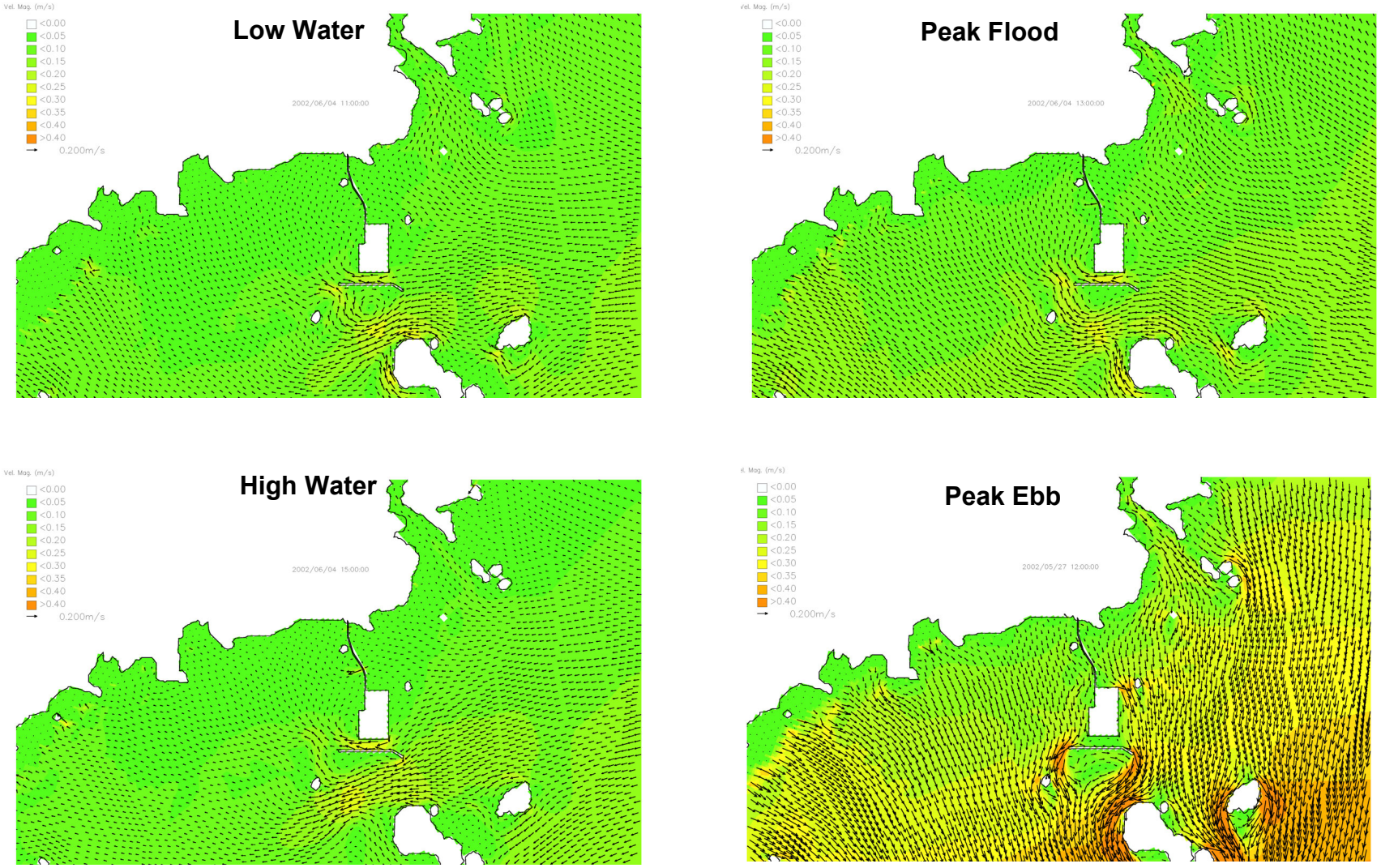

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FIGURE A-4:
Flow patterns during neap tide
at the project site. Causeway A1

Local model velocity differences and flow patterns: SPRING TIDE

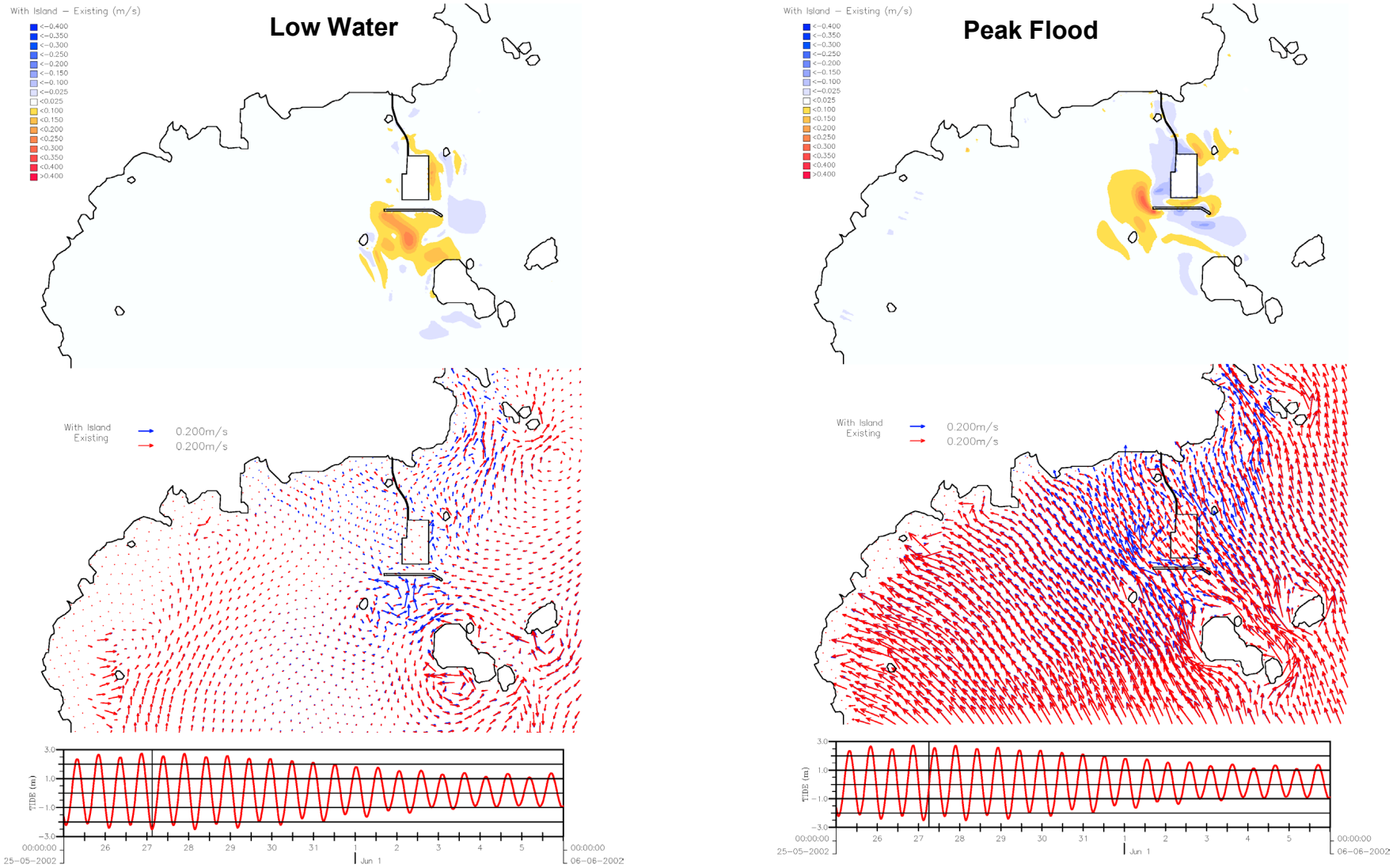

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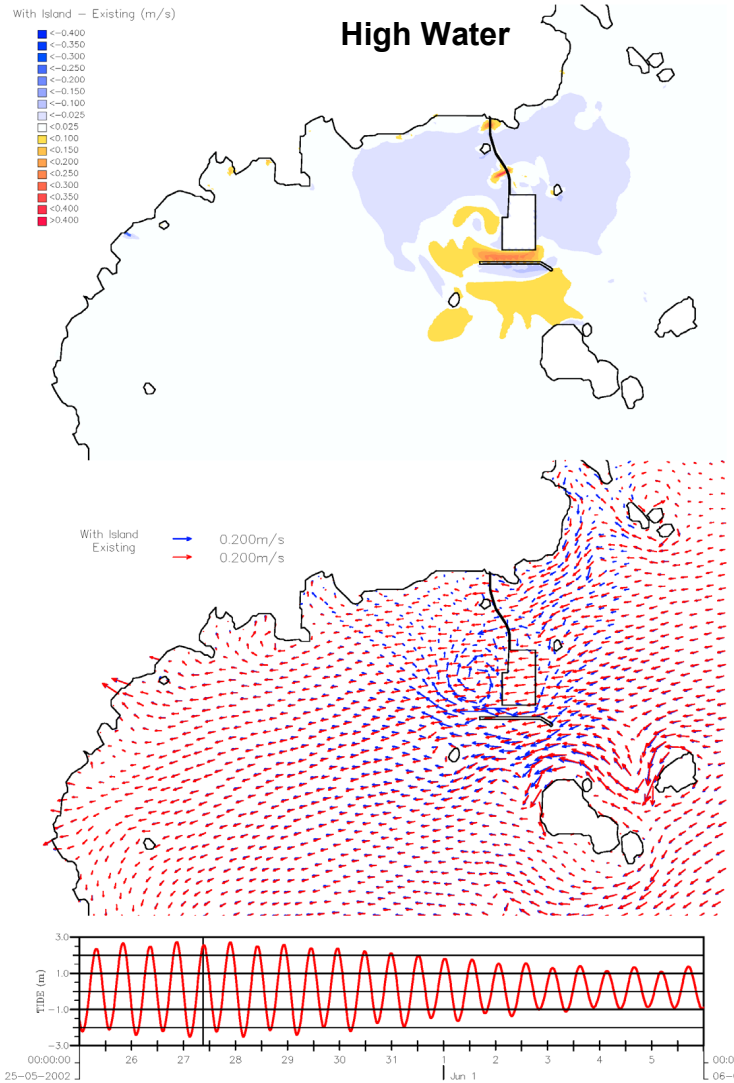
FIGURE A-5:
Velocity differences. Spring Tide (LW, PF)
Causeway A1

Local model velocity differences and flow patterns: SPRING TIDE



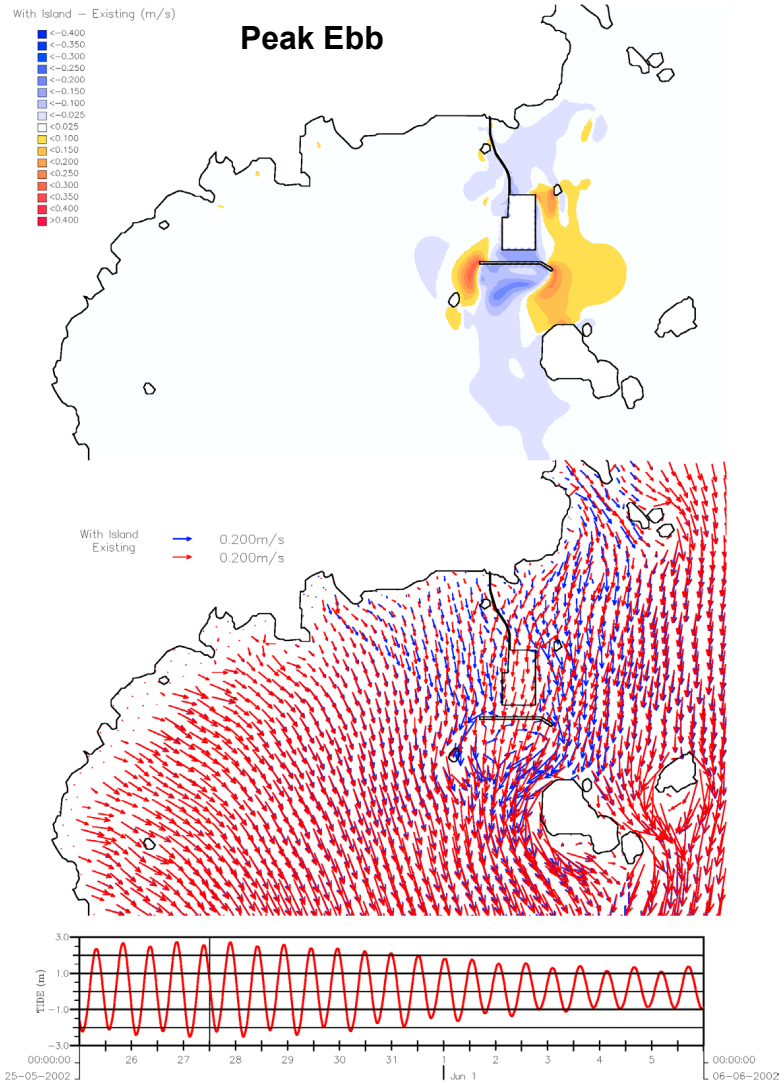


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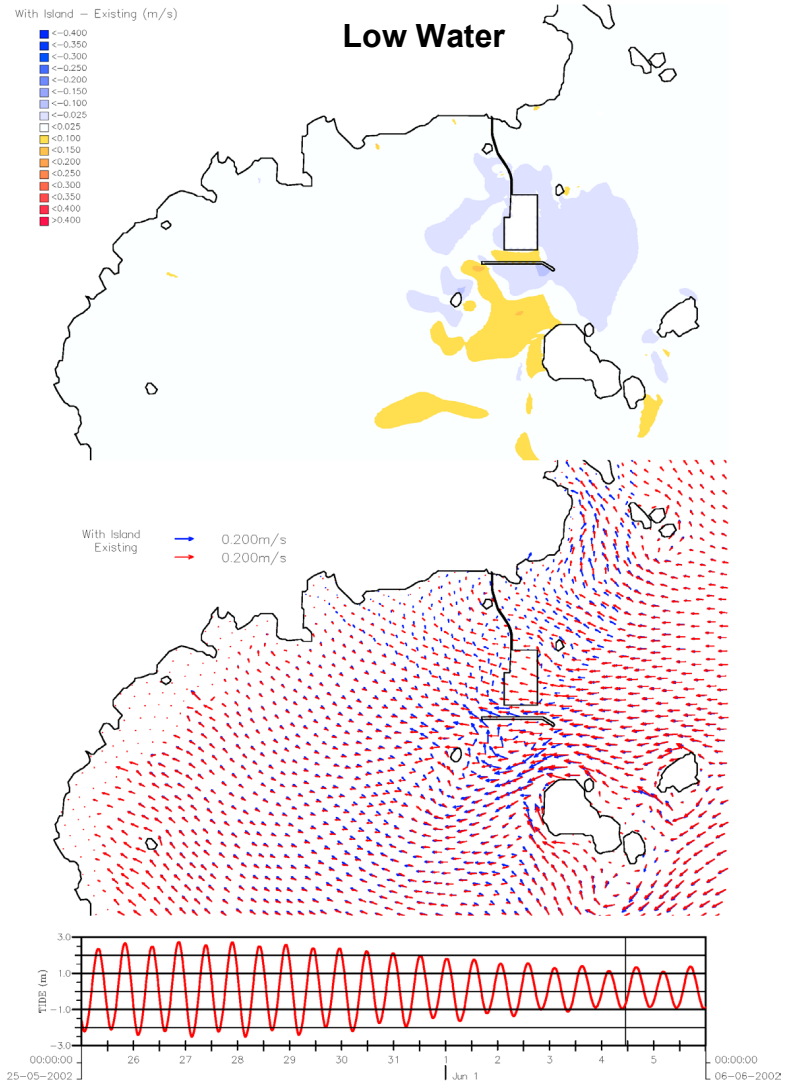
FIGURE A-6:
Velocity differences. Spring Tide (HW, PE)
Causeway A1

Local model velocity differences and flow patterns: NEAP TIDE



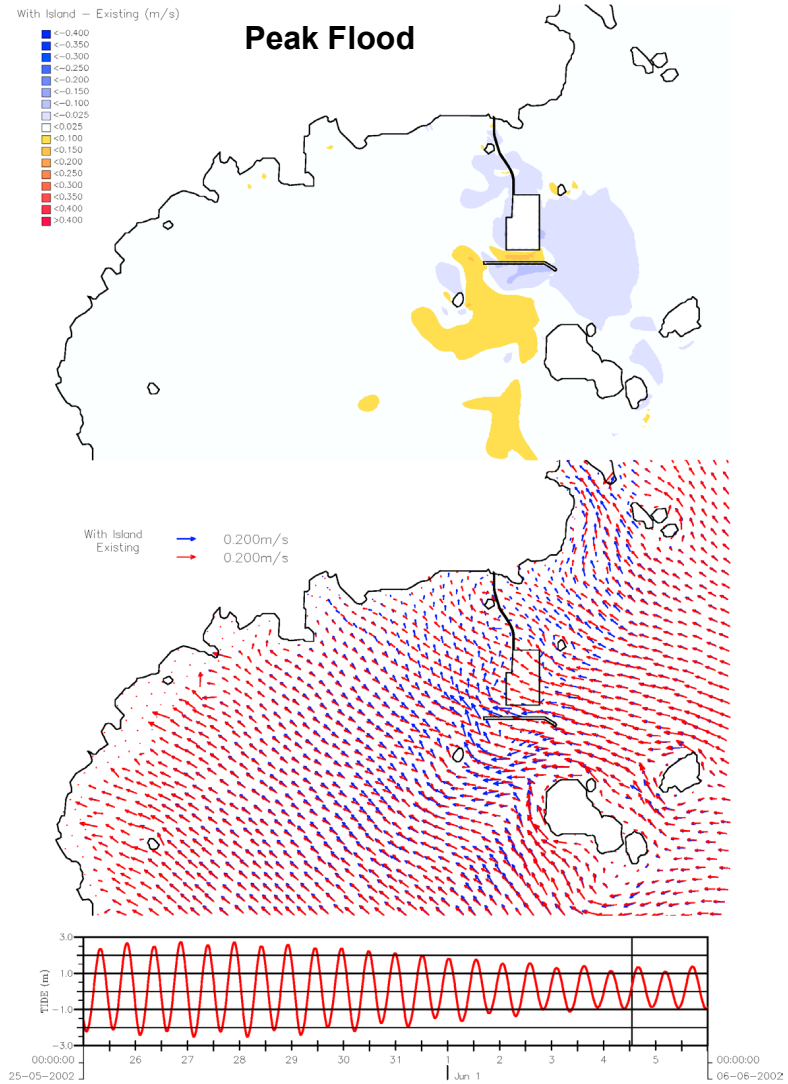


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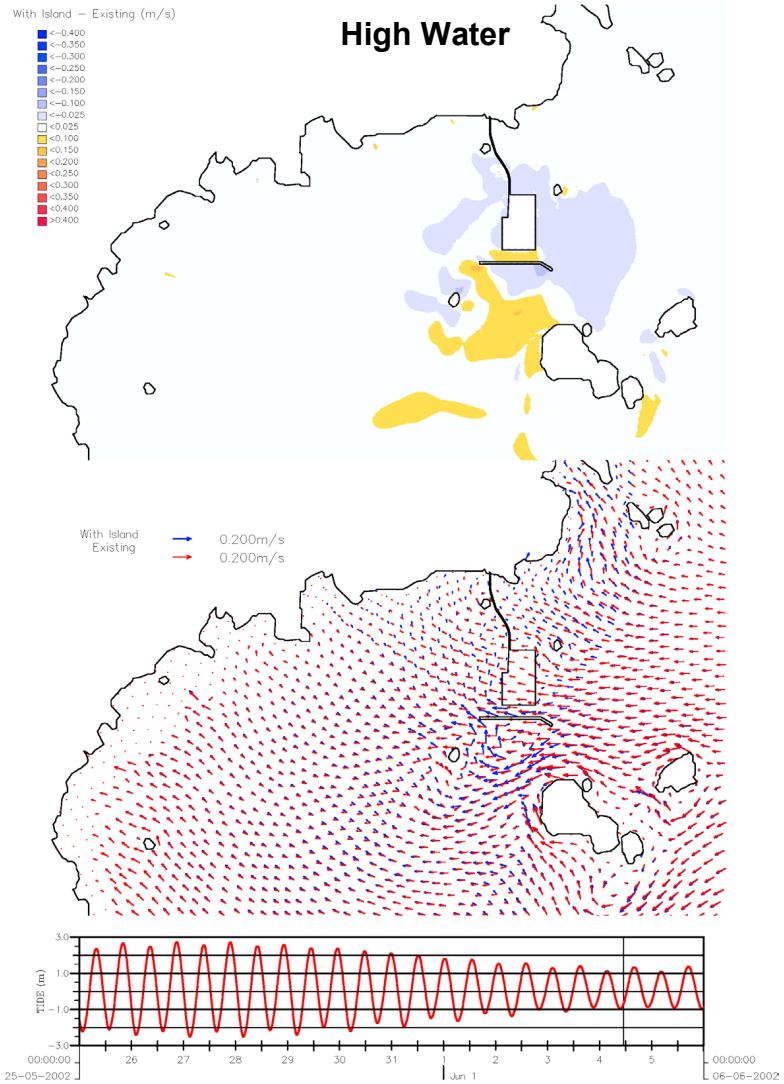
FIGURE A-7:
Velocity differences. Neap Tide (LW, PF)
Causeway A1

Local model velocity differences and flow patterns: NEAP TIDE



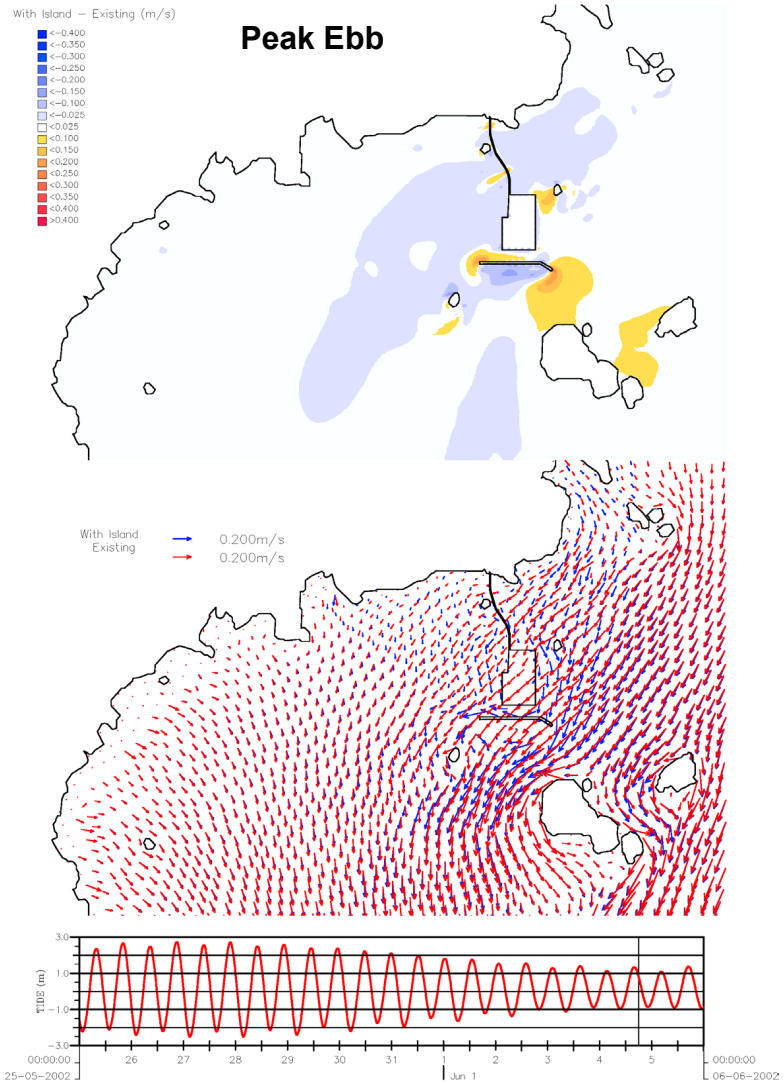


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FIGURE A-8:
Velocity differences. Neap Tide (HW, PE)
Causeway A1

Local model flow patterns: SPRING TIDE

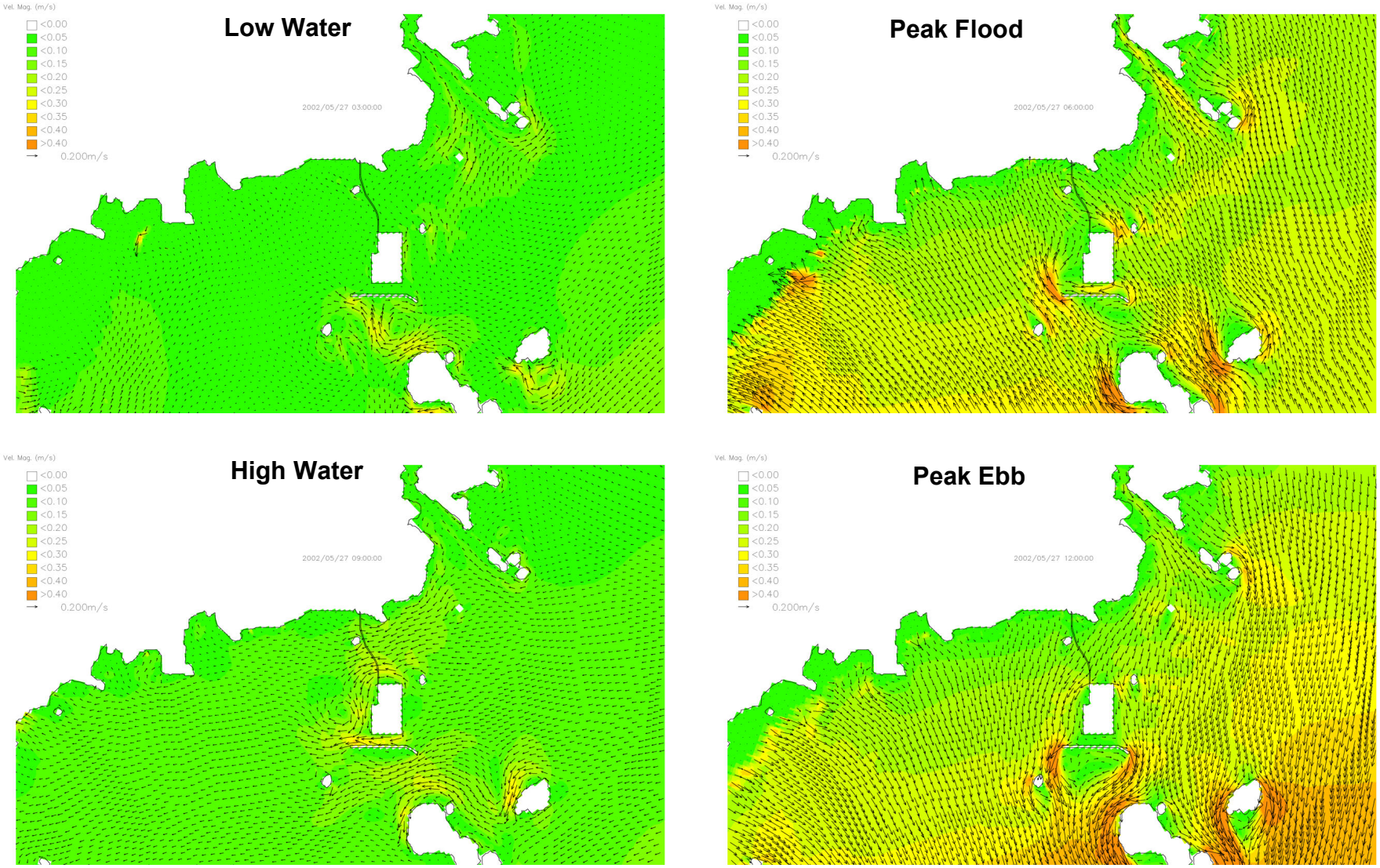

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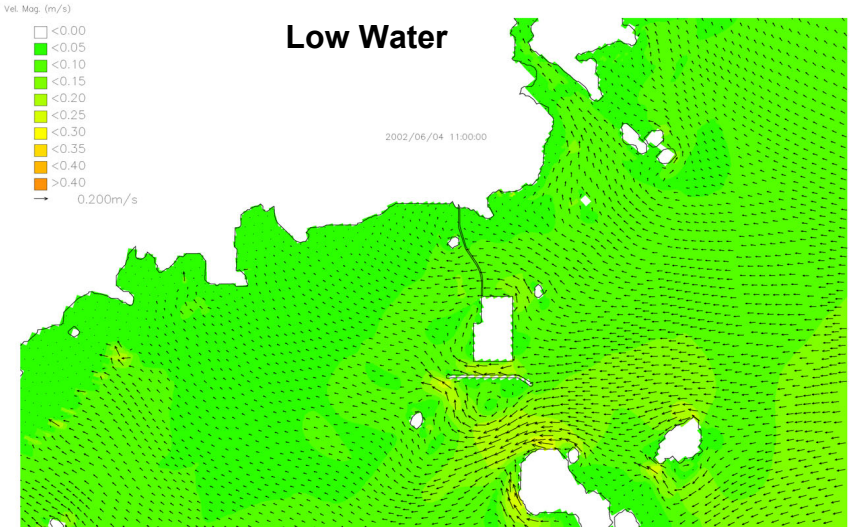
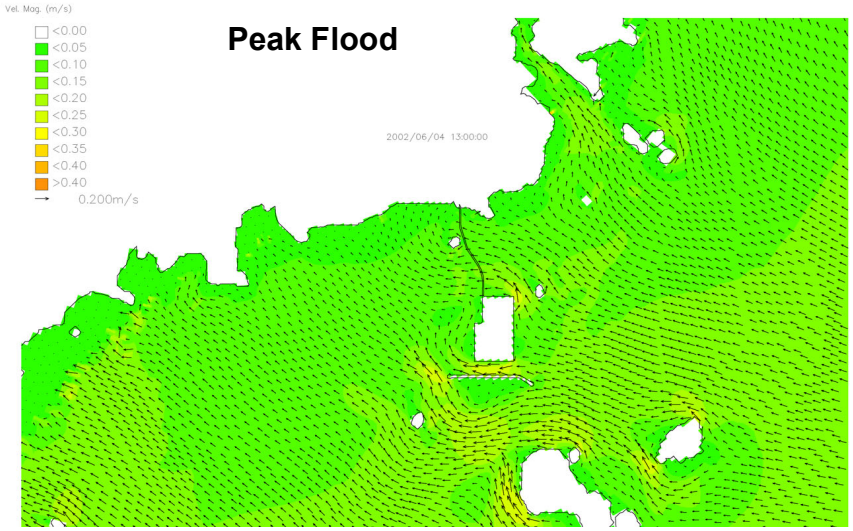
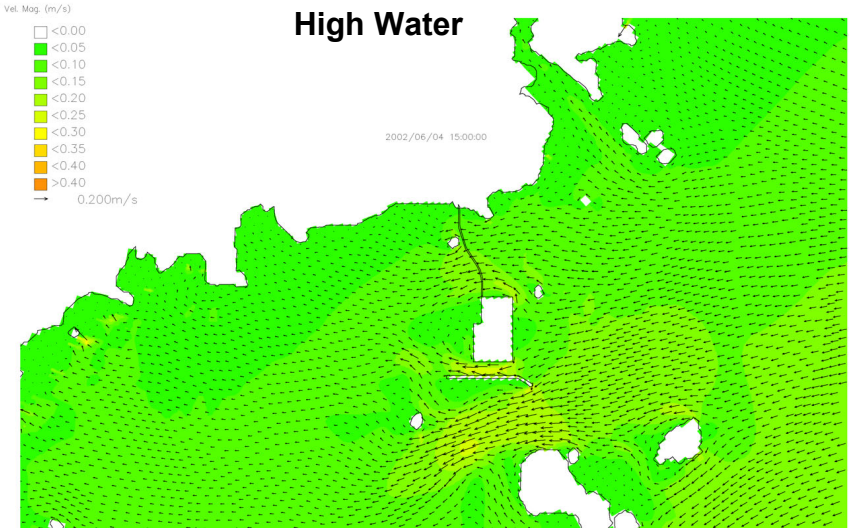
FIGURE A-9:
Flow patterns during spring tide
at the project site. Trestle A1

Local model flow patterns: NEAP TIDE







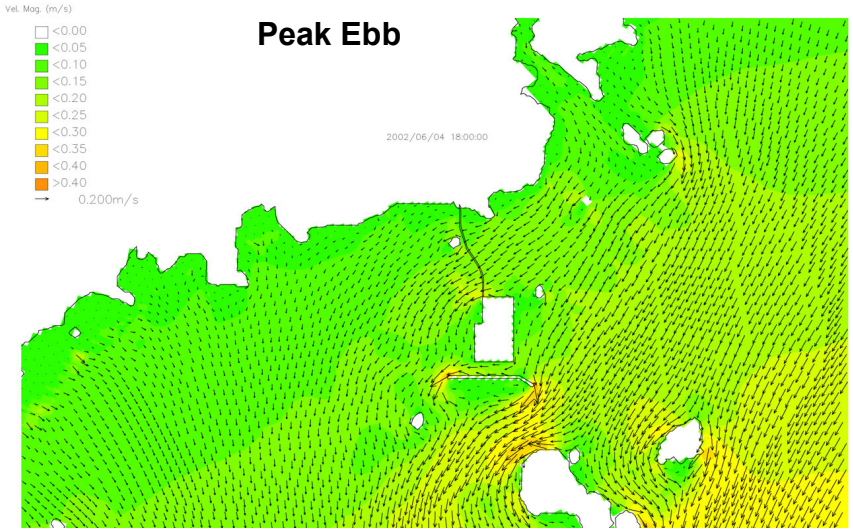


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FIGURE A-10:
Flow patterns during neap tide
at the project site. Trestle A1

Local model velocity differences and flow patterns: SPRING TIDE

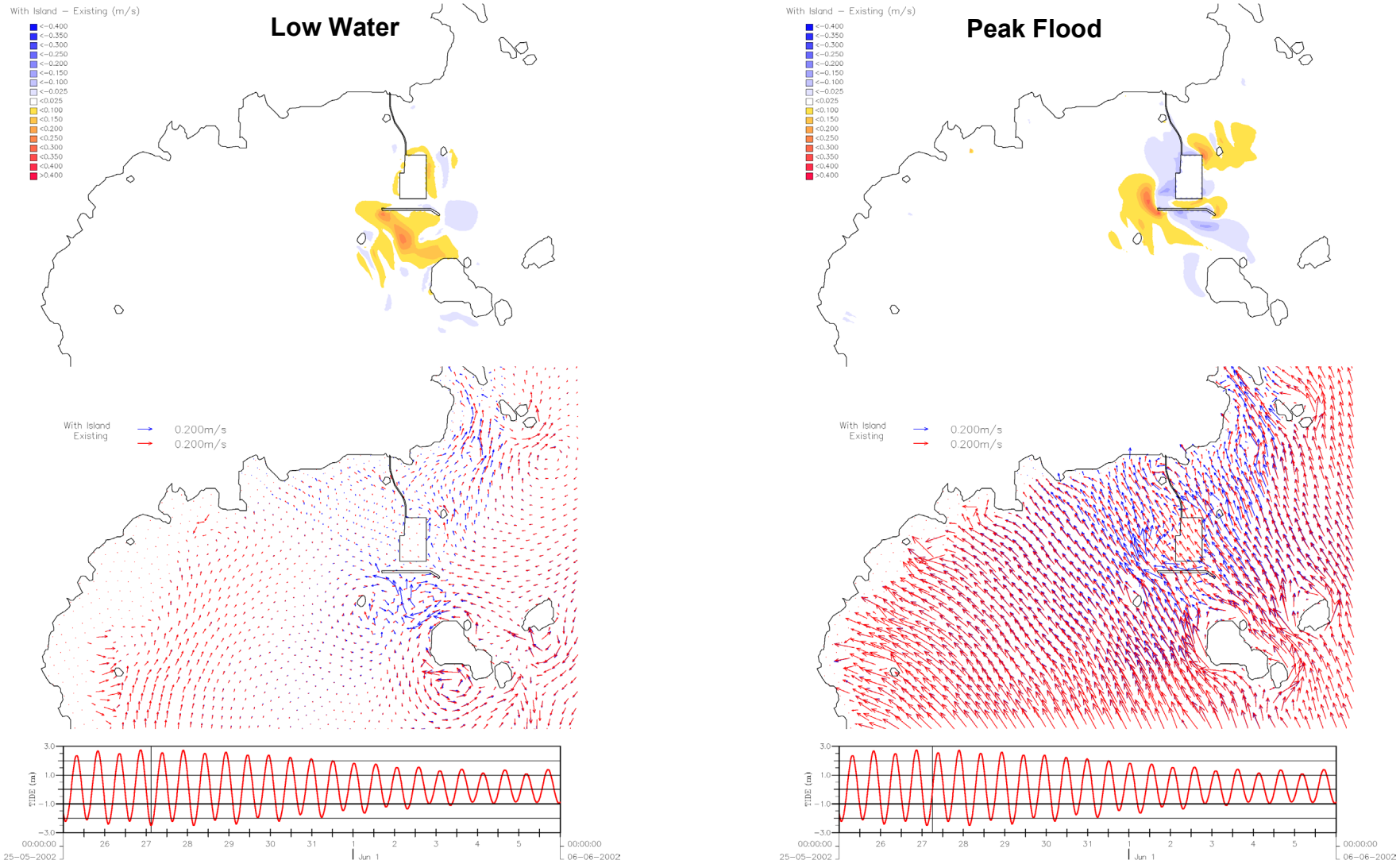

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FIGURE A-11:
Velocity differences. Spring Tide (LW, PF)
Trestle A1

Local model velocity differences and flow patterns: SPRING TIDE

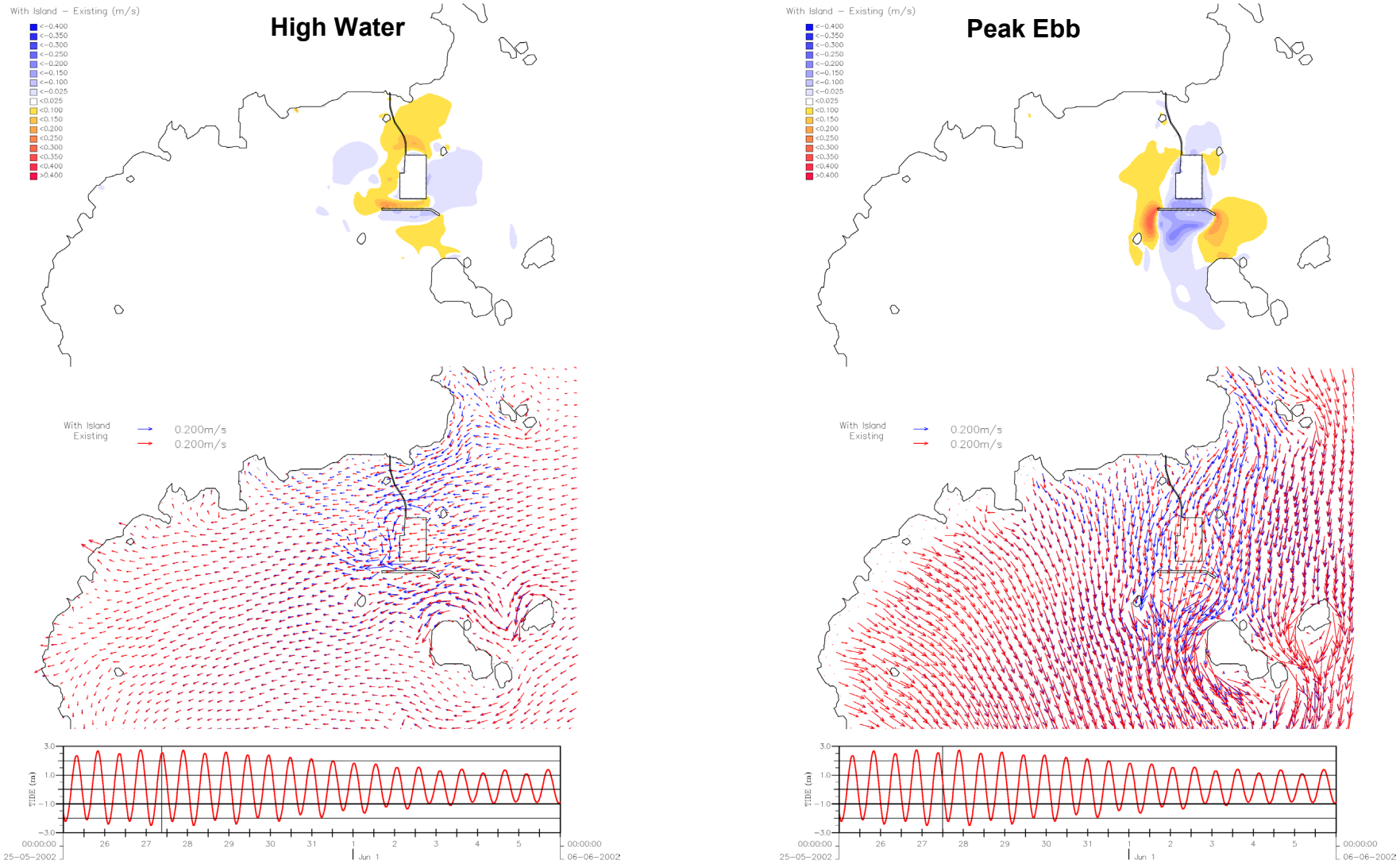

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FIGURE A-12:
Velocity differences. Spring Tide (HW, PE)
Trestle A1

Local model velocity differences and flow patterns: NEAP TIDE

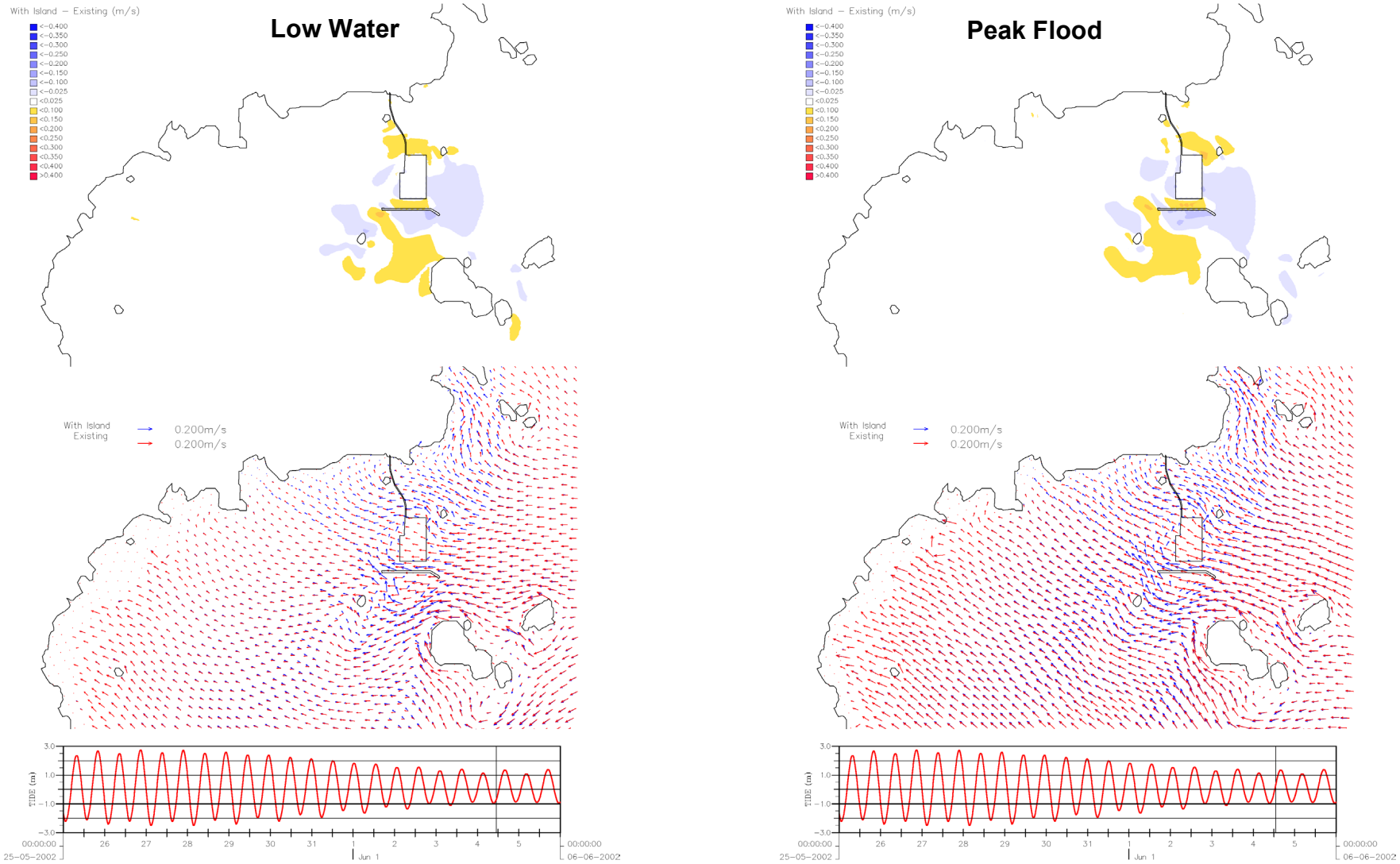

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FIGURE A-13:
Velocity differences. Neap Tide (LW, PF)
Trestle A1

Local model velocity differences and flow patterns: NEAP TIDE

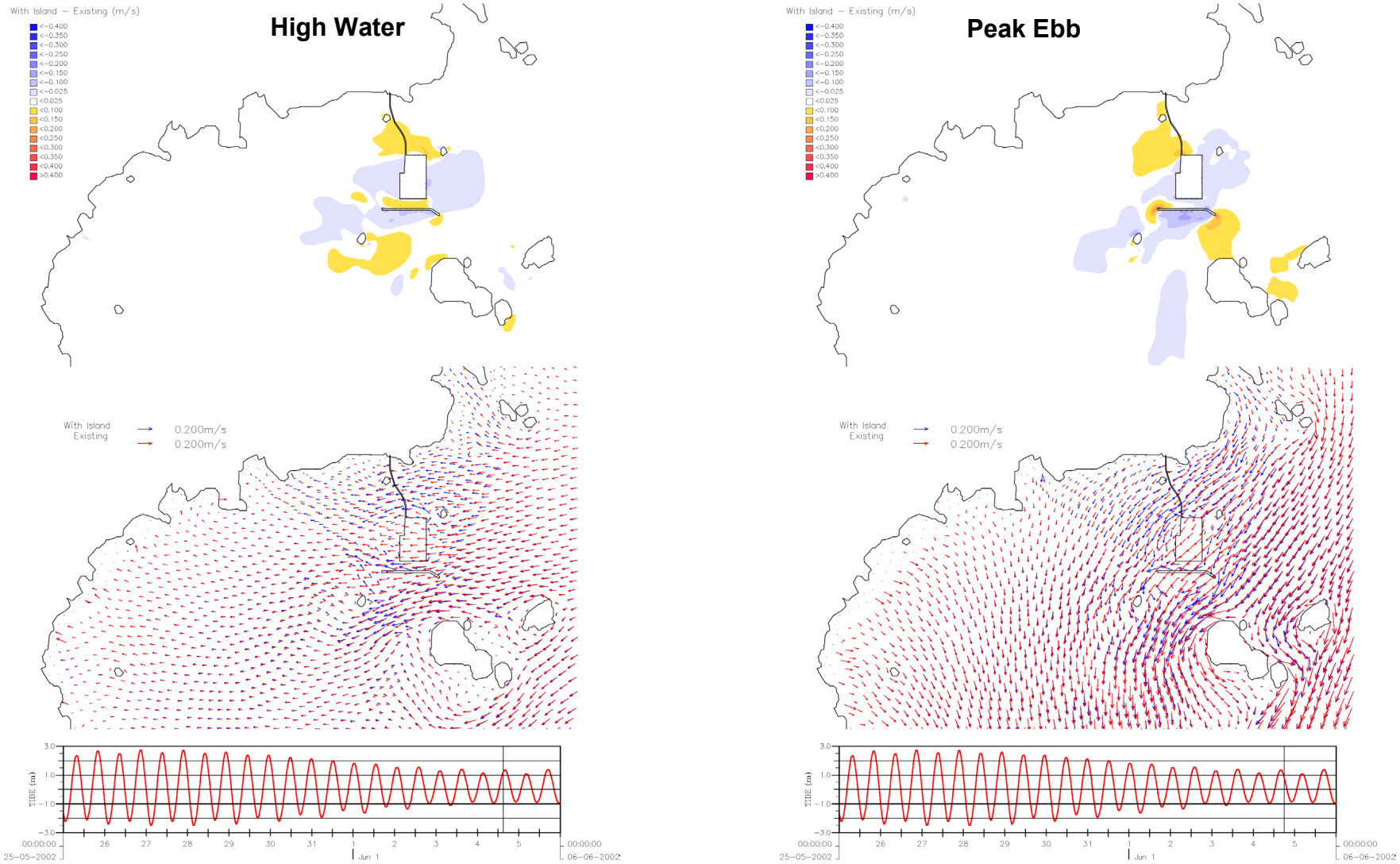

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FIGURE A-14:
Velocity differences. Neap Tide (HW, PE)
Trestle A1

Local model flow patterns: SPRING TIDE

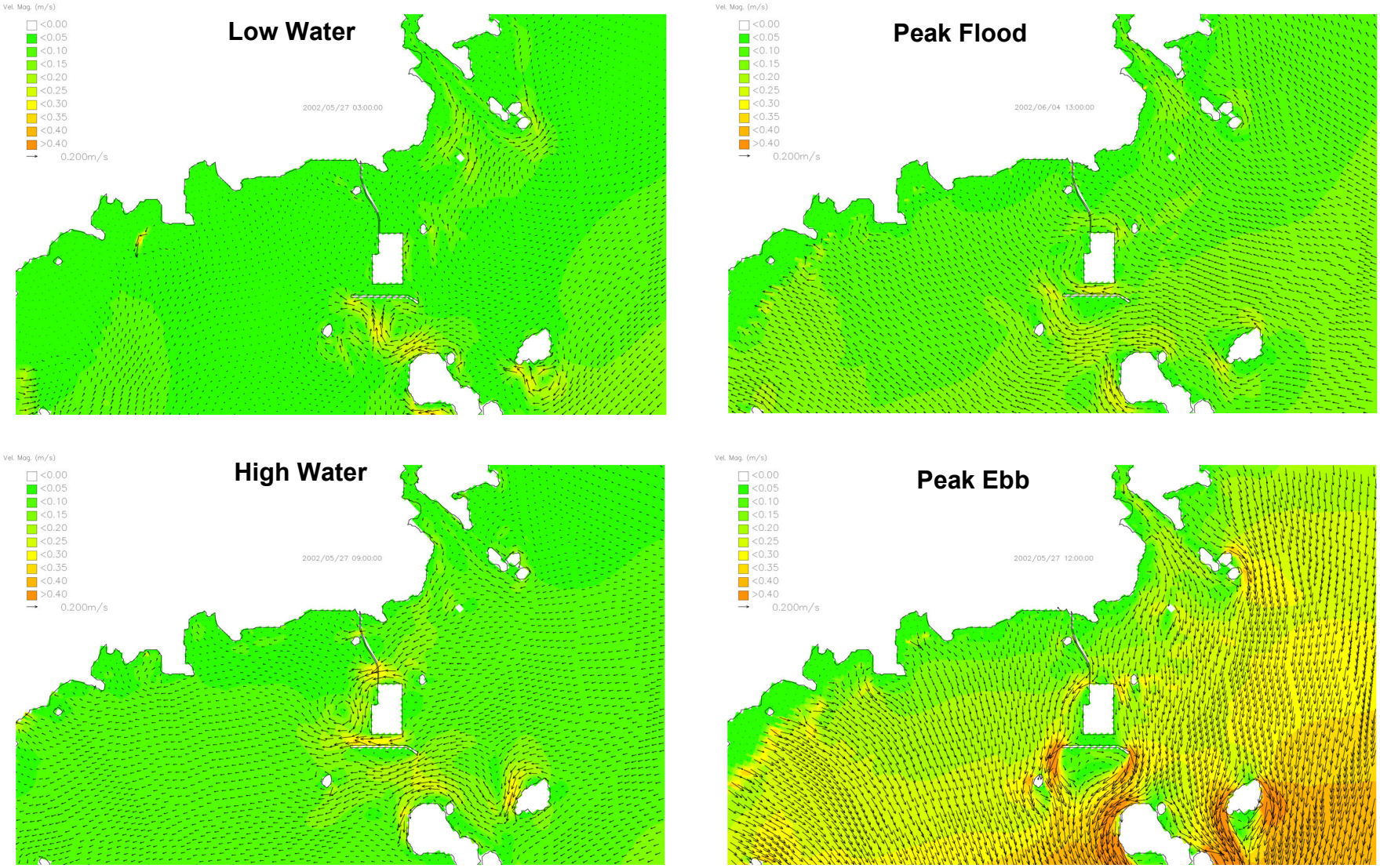

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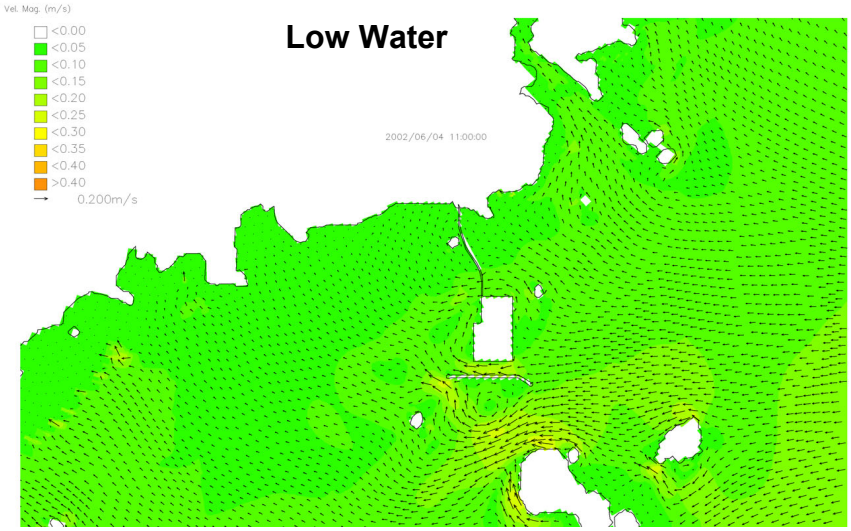
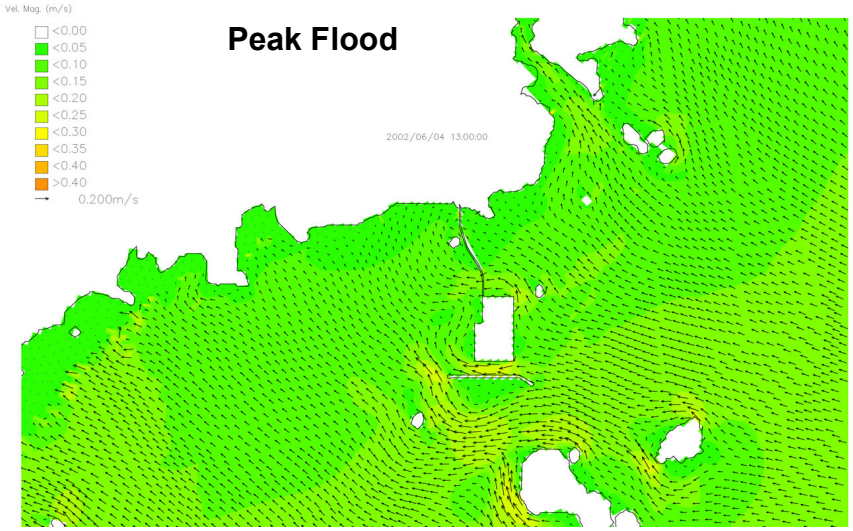
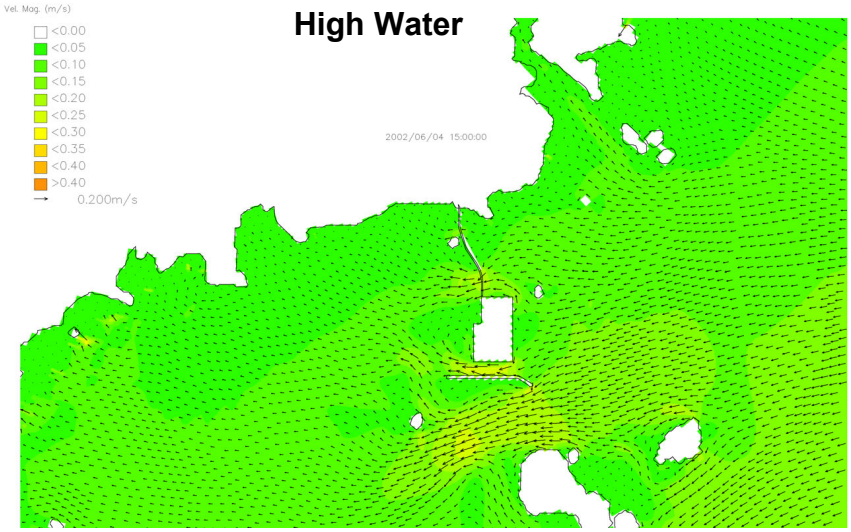
FIGURE A-15 :
Flow patterns during spring tide
at the project site. Hybrid A1

Local model flow patterns: NEAP TIDE







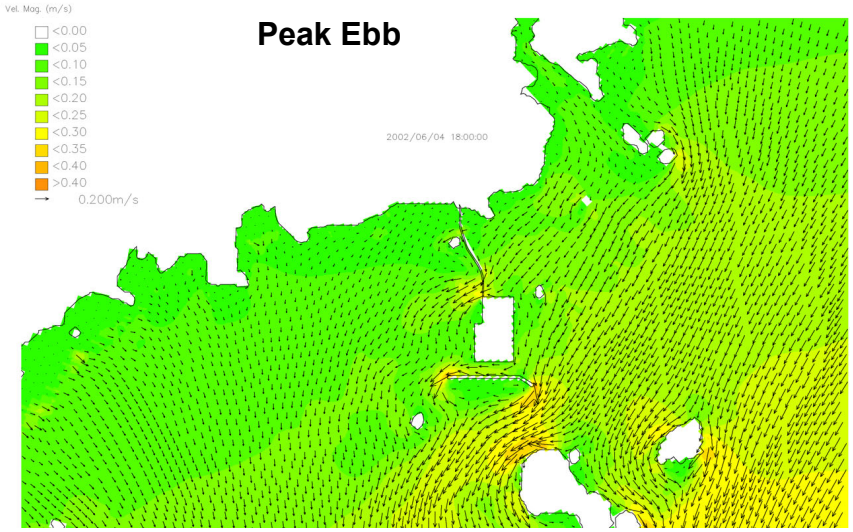


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FIGURE A-16 :
Flow patterns during neap tide
at the project site. Hybrid A1

Local model velocity differences and flow patterns: SPRING TIDE

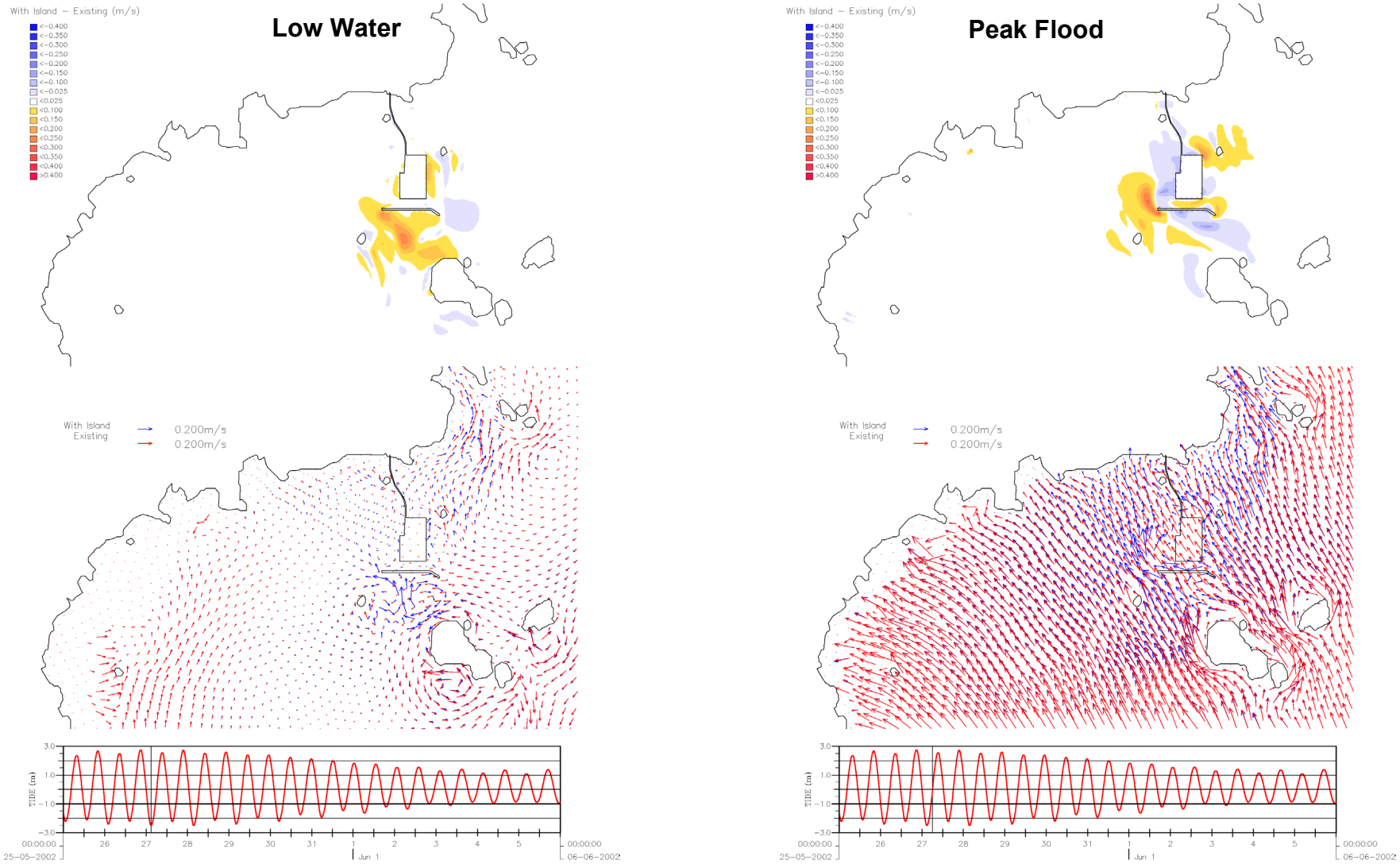

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FIGURE A-17:
Velocity differences. Spring Tide (LW, PF)
Hybrid A1

Local model velocity differences and flow patterns: SPRING TIDE

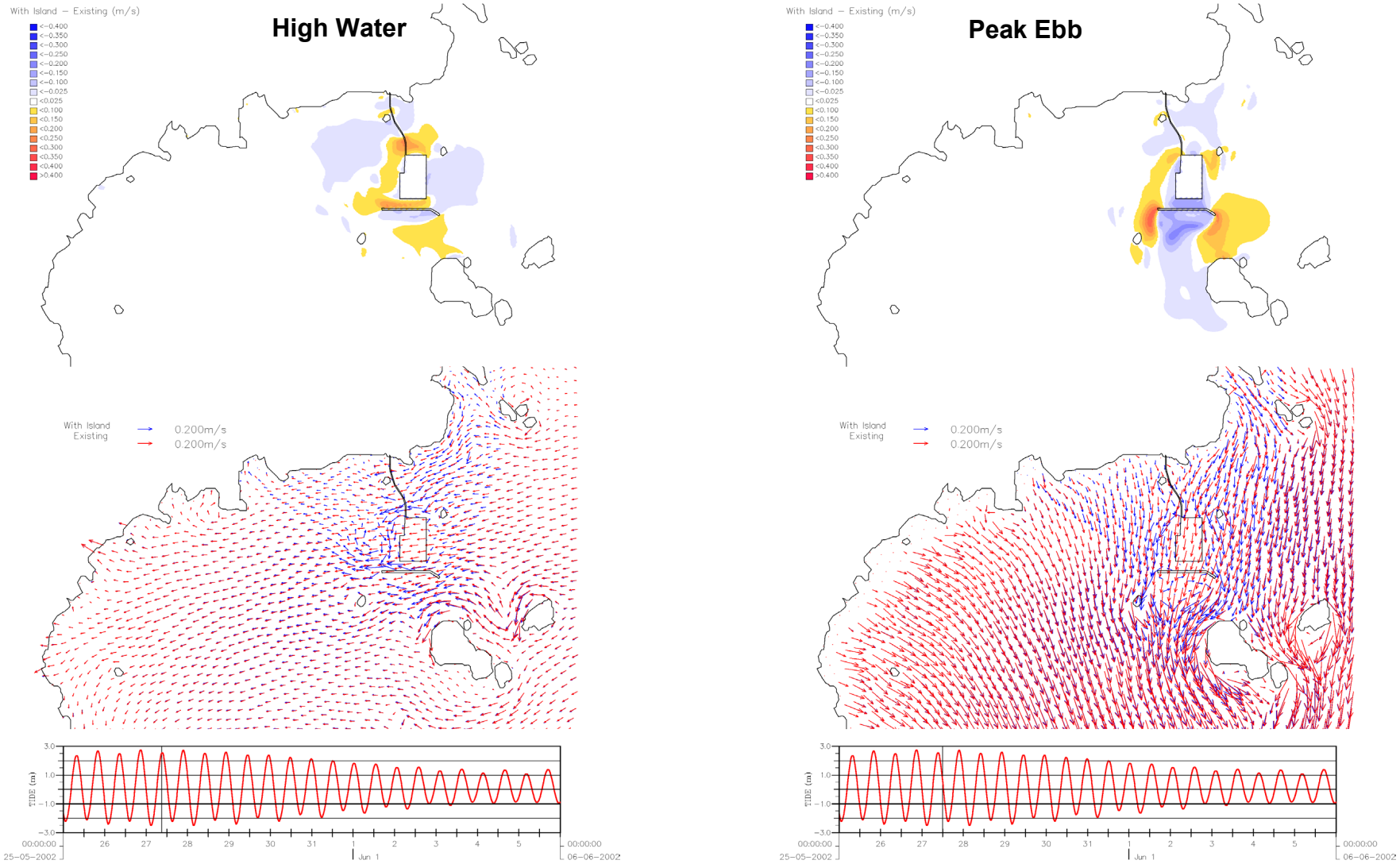

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FIGURE A-18:
Velocity differences. Spring Tide (HW, PE)
Hybrid A1

Local model velocity differences and flow patterns: NEAP TIDE

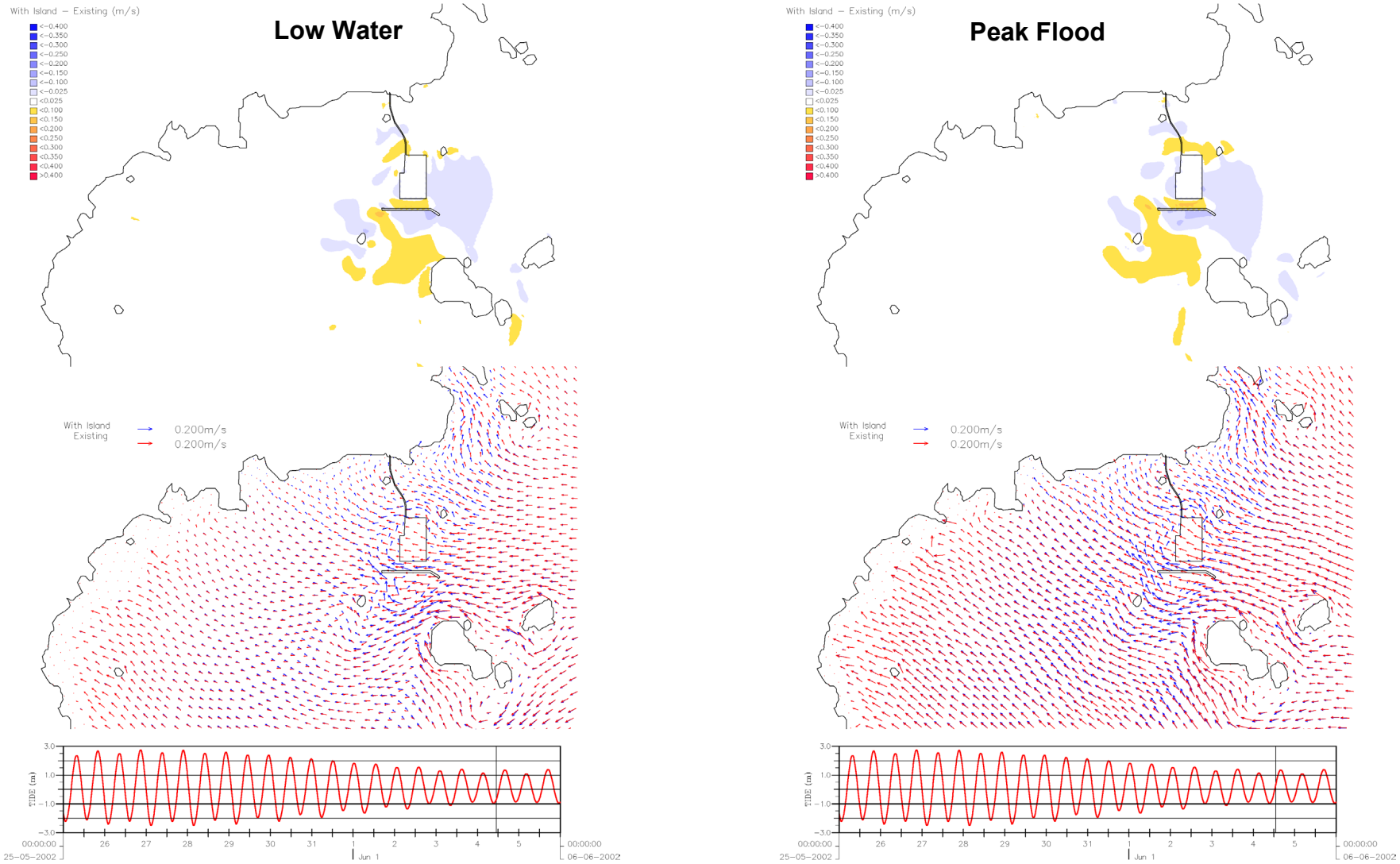

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FIGURE A-19:
Velocity differences. Neap Tide (LW, PF)
Hybrid A1

Local model velocity differences and flow patterns: NEAP TIDE

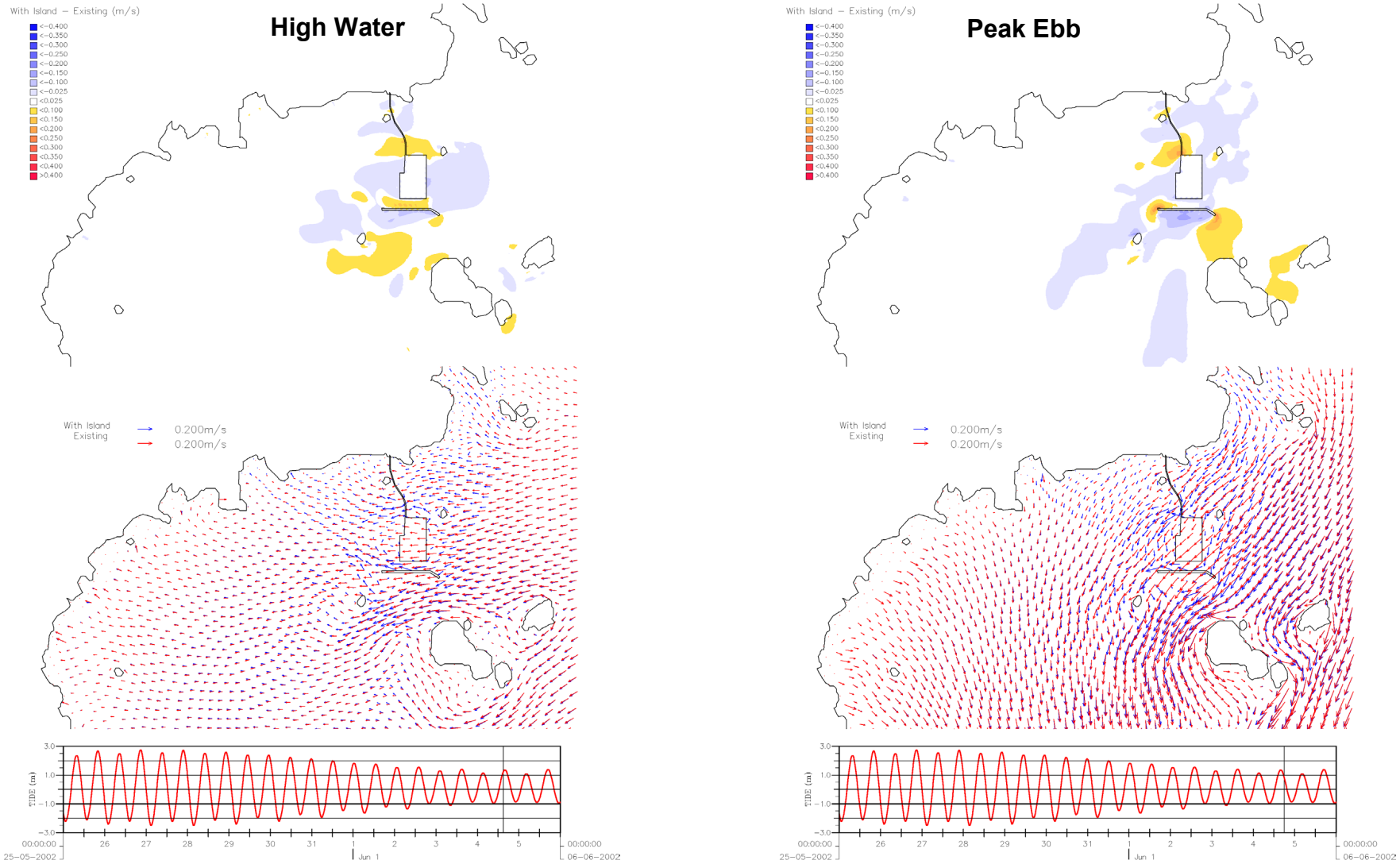

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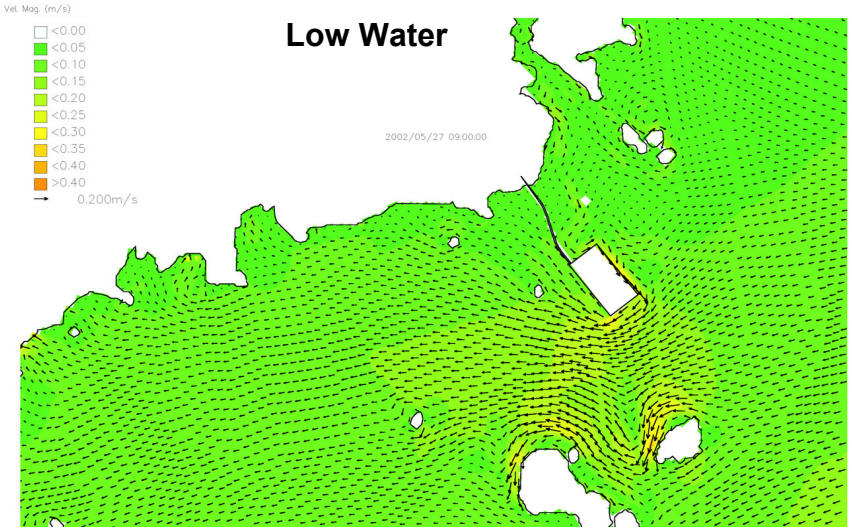
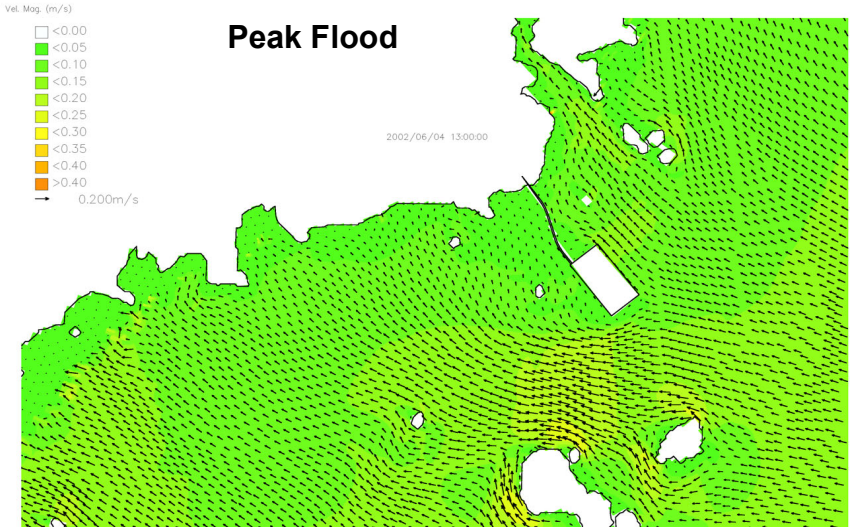
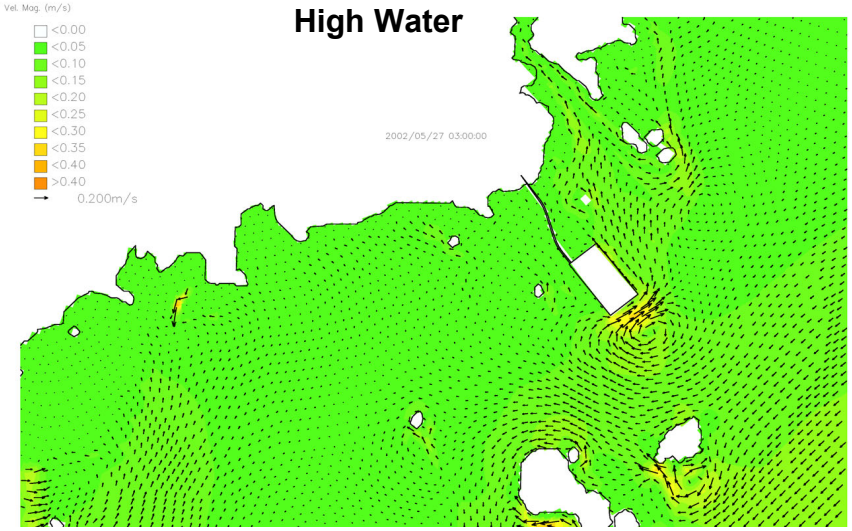
FIGURE A-20:
Velocity differences. Neap Tide (HW, PE)
Hybrid A1

Local model flow patterns: SPRING TIDE







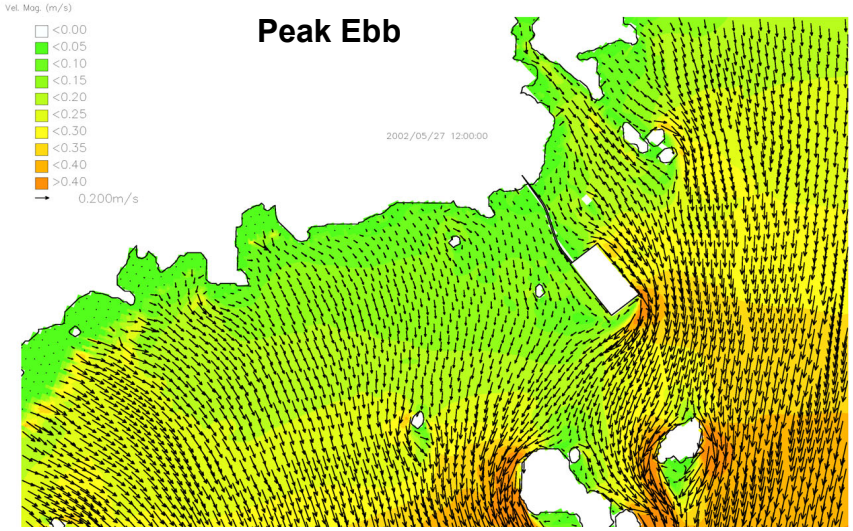


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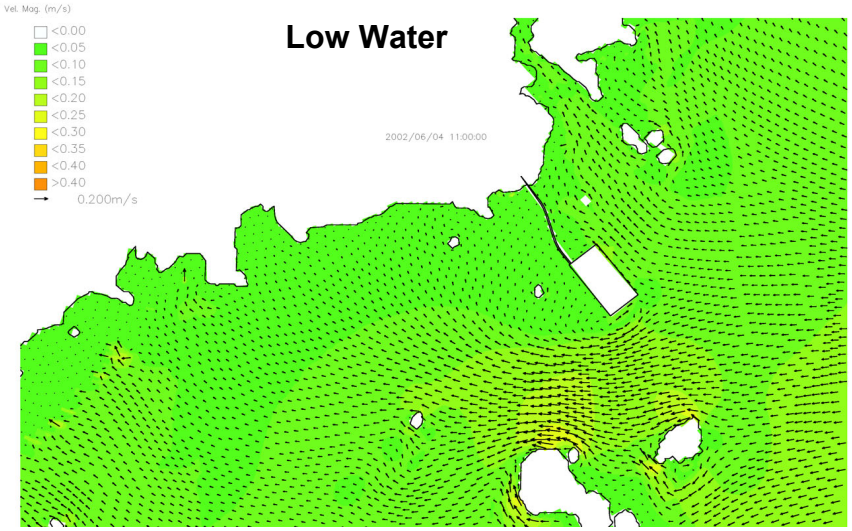
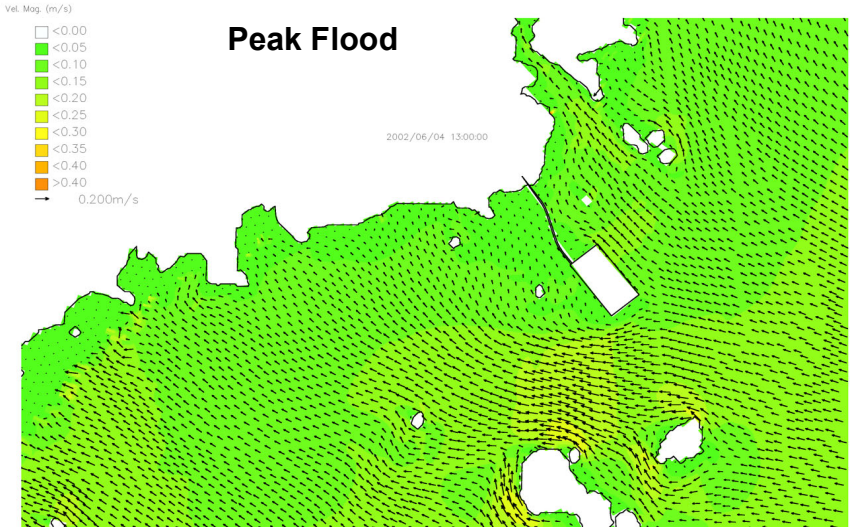
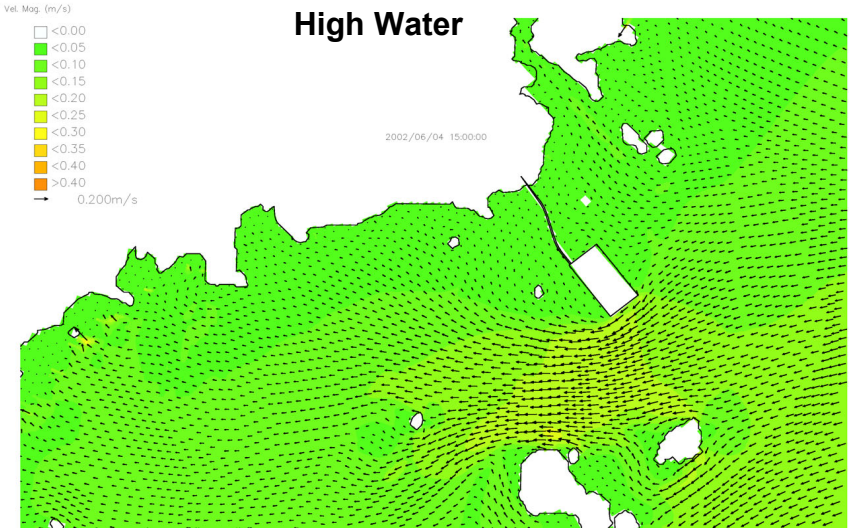
FIGURE A-21:
Flow patterns during spring tide
at the project site. Causeway A5

Local model flow patterns: NEAP TIDE







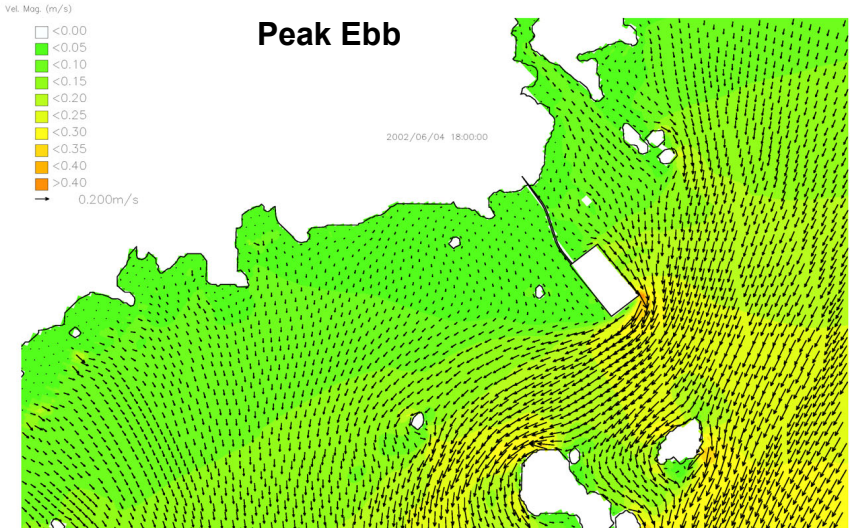


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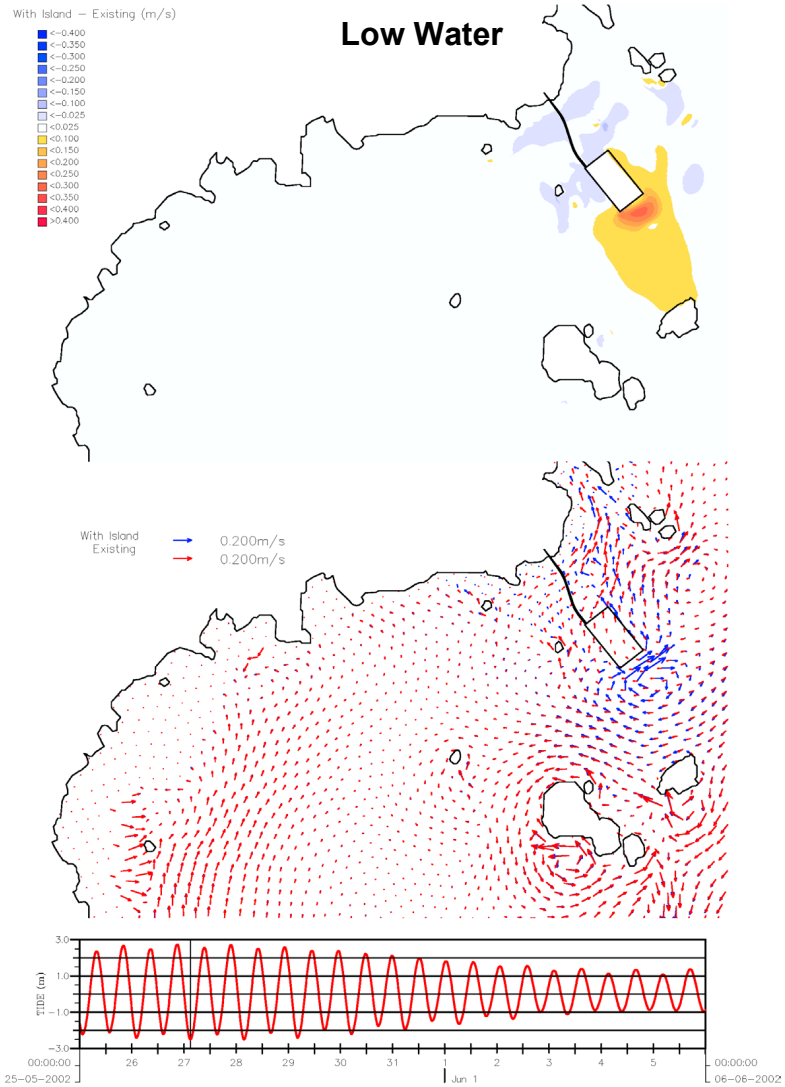
FIGURE A-22:
Flow patterns during neap tide
at the project site. Causeway A5

Local model velocity differences and flow patterns: SPRING TIDE



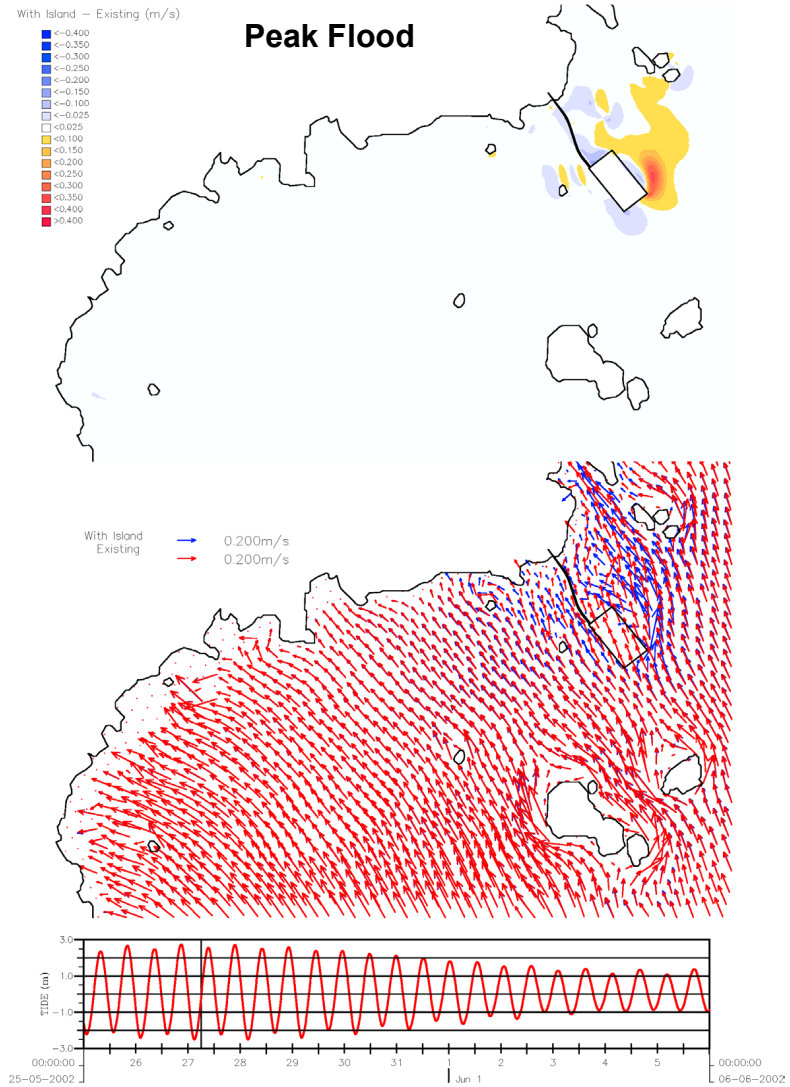


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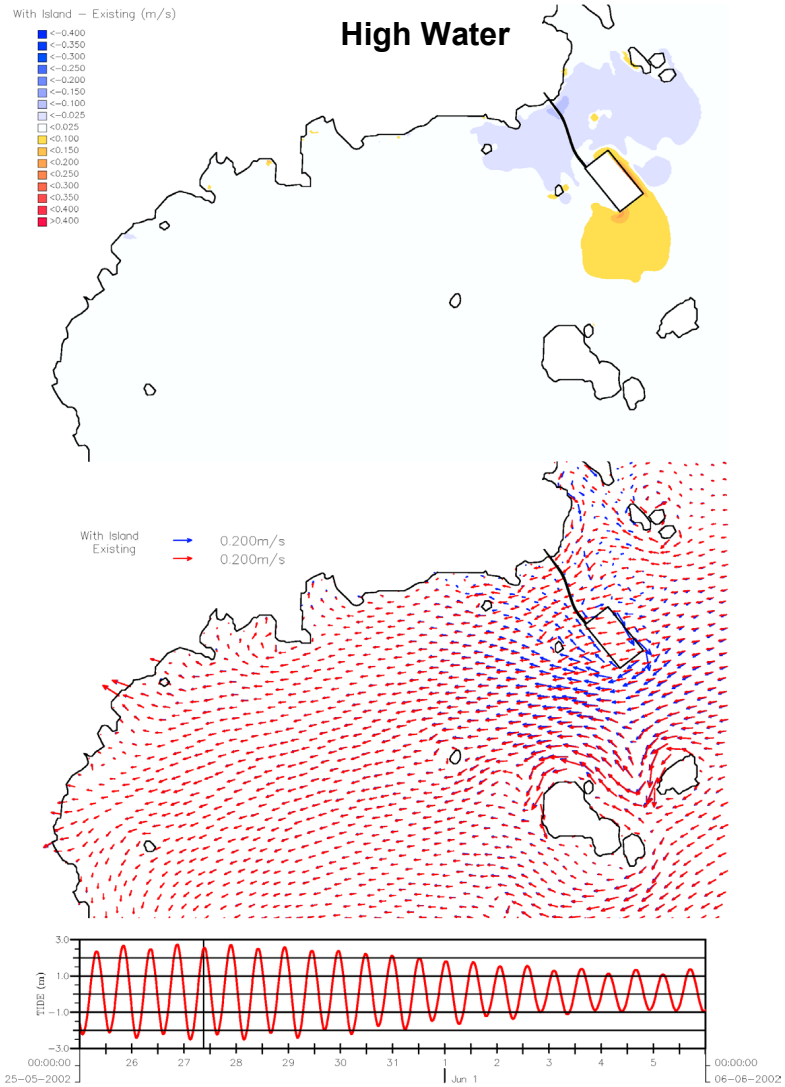
FIGURE A-23:
Velocity differences. Spring Tide (LW, PF)
Causeway A5

Local model velocity differences and flow patterns: SPRING TIDE



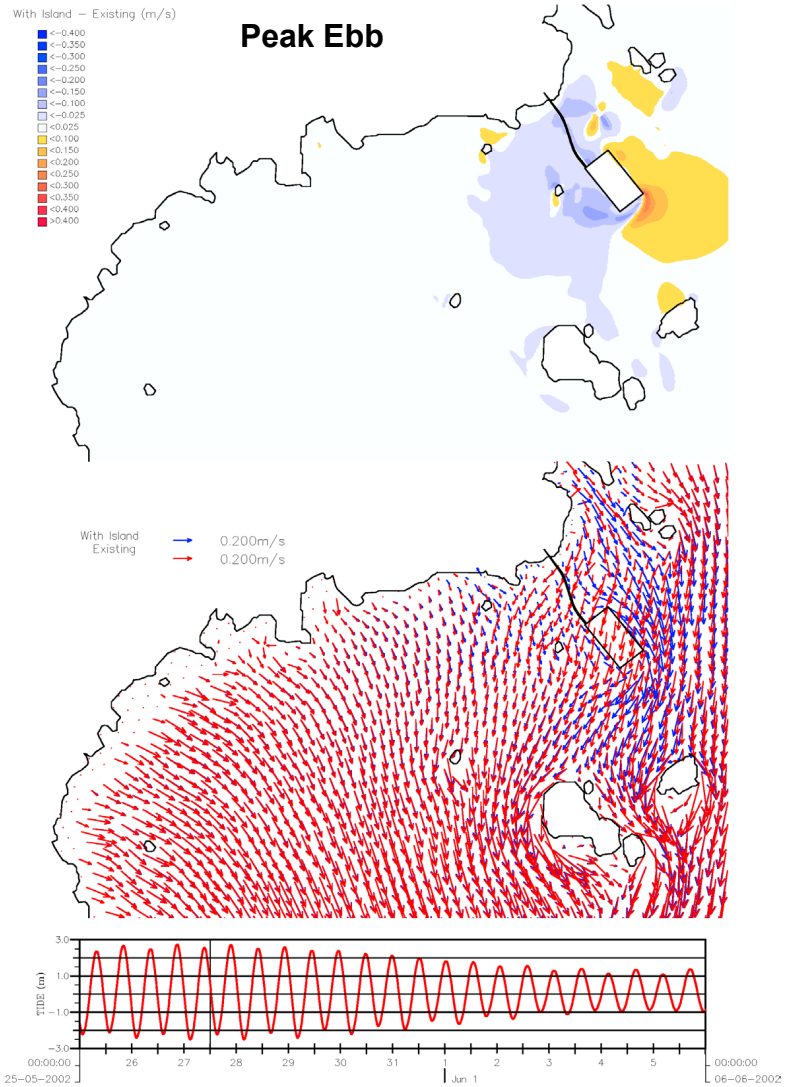


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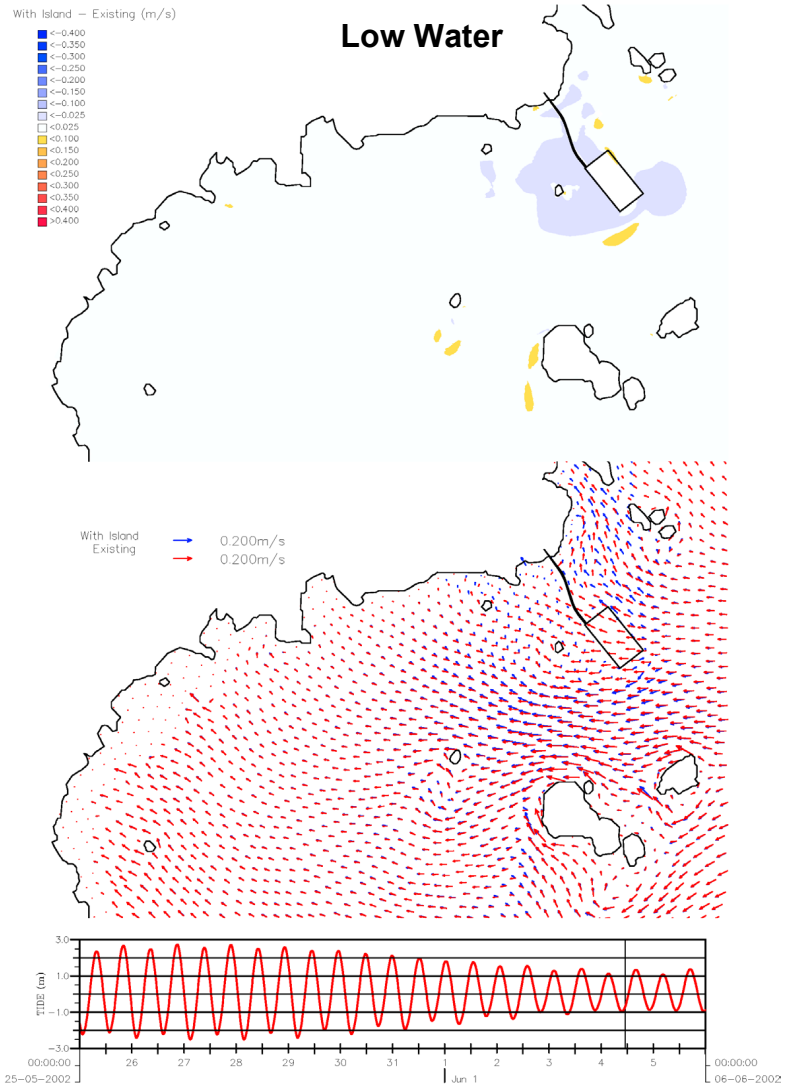
FIGURE A-24:
Velocity differences. Spring Tide (HW, PE)
Causeway A5

Local model velocity differences and flow patterns: NEAP TIDE



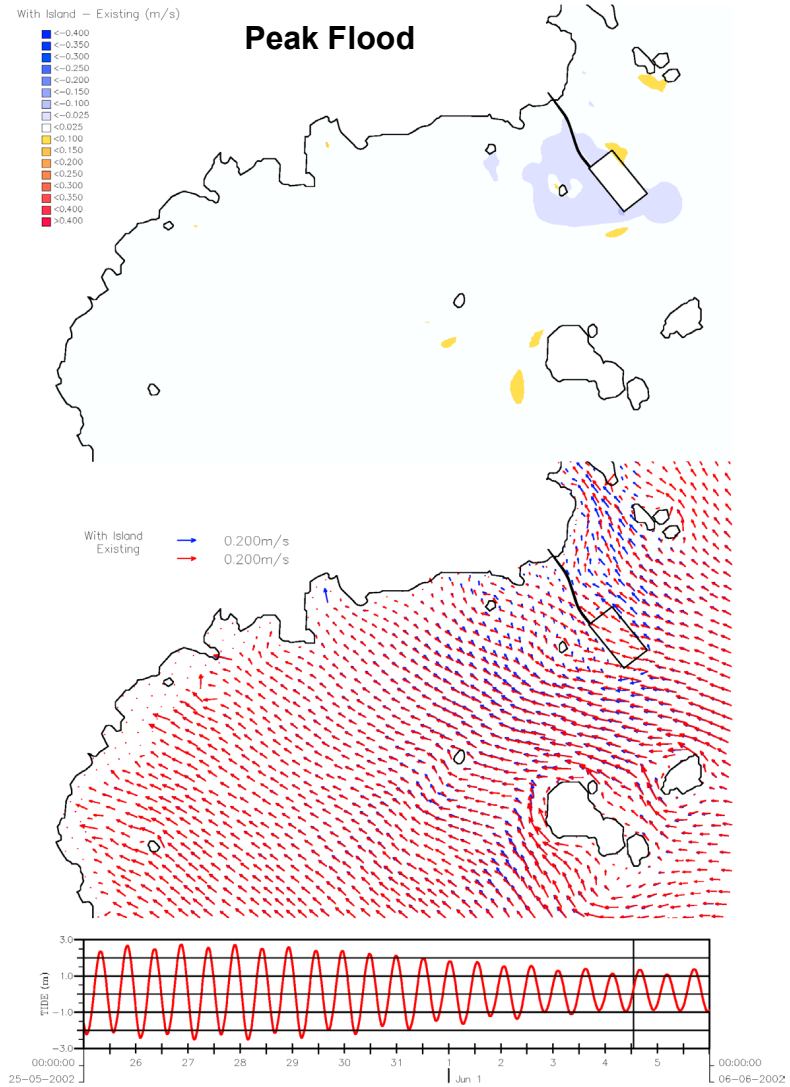


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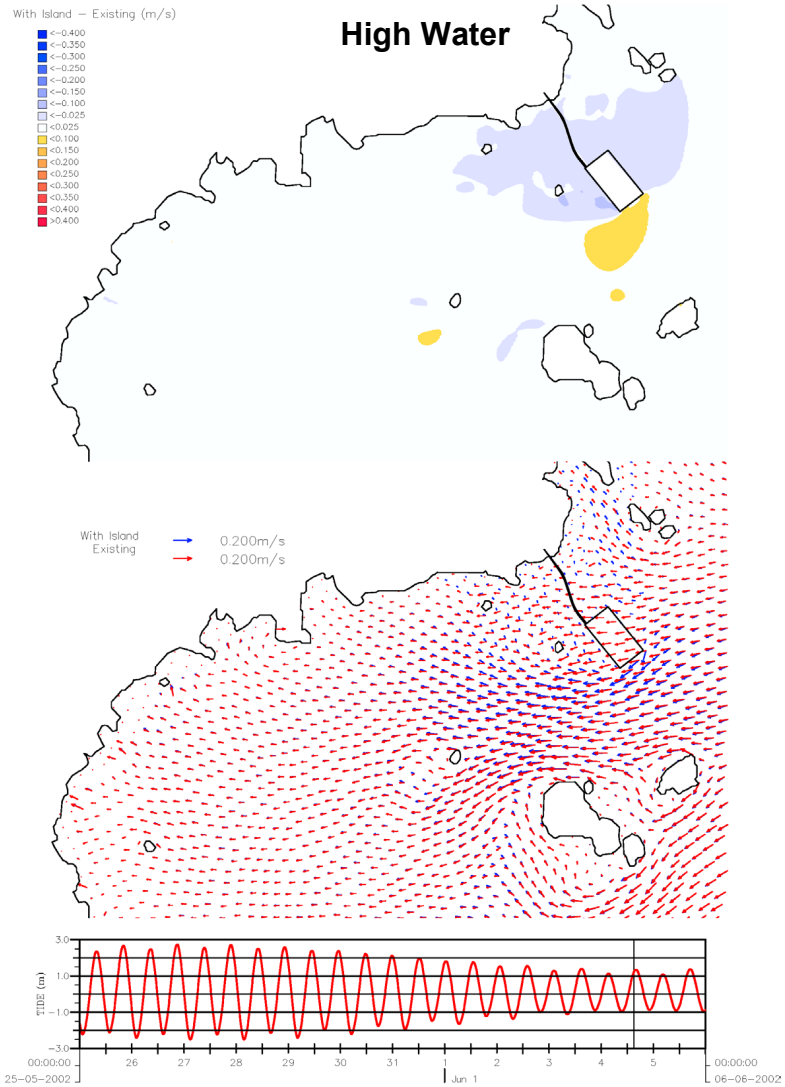
FIGURE A-25:
Velocity differences. Neap Tide (LW, PF)
Causeway A5

Local model velocity differences and flow patterns: NEAP TIDE



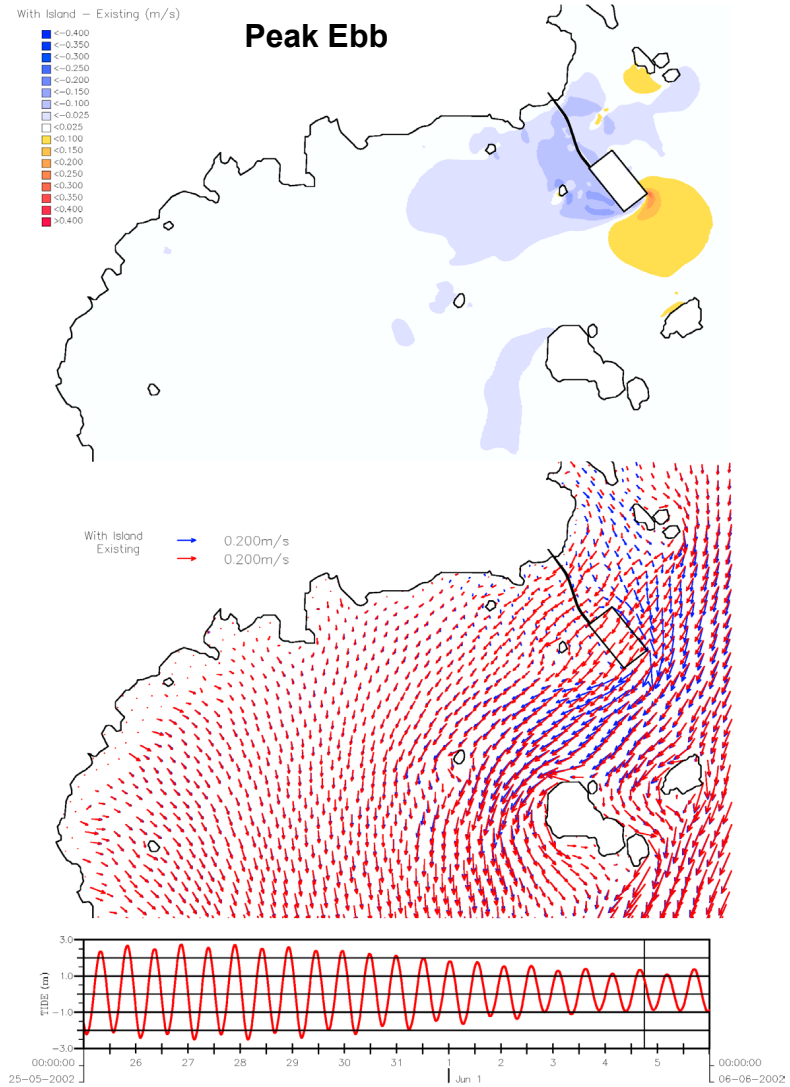


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FIGURE A-26:
Velocity differences. Neap Tide (HW, PE)
Causeway A5

Local model flow patterns: SPRING TIDE

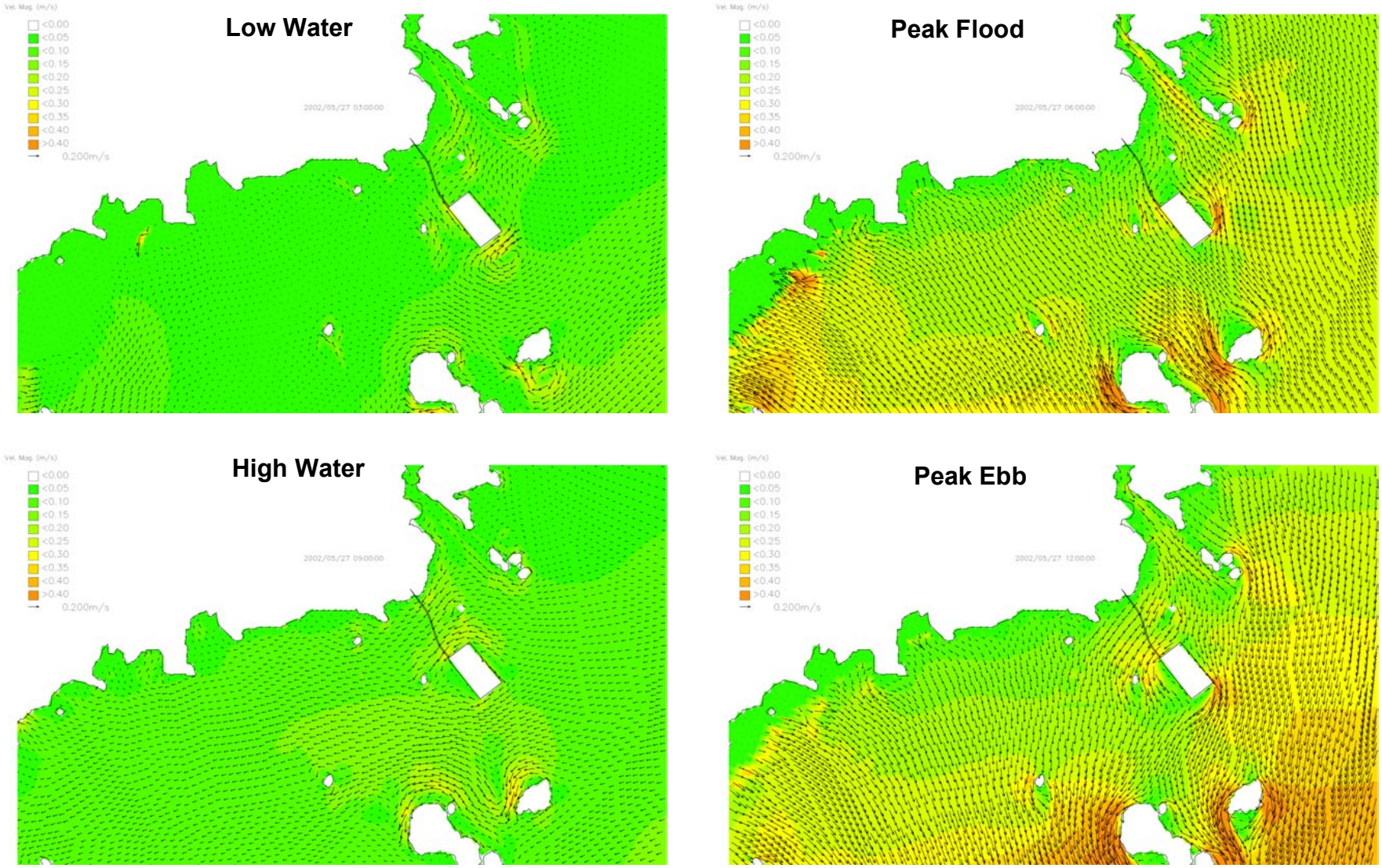

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FIGURE A-27:
Flow patterns during spring tide
at the project site. Trestle A5

Local model flow patterns: NEAP TIDE

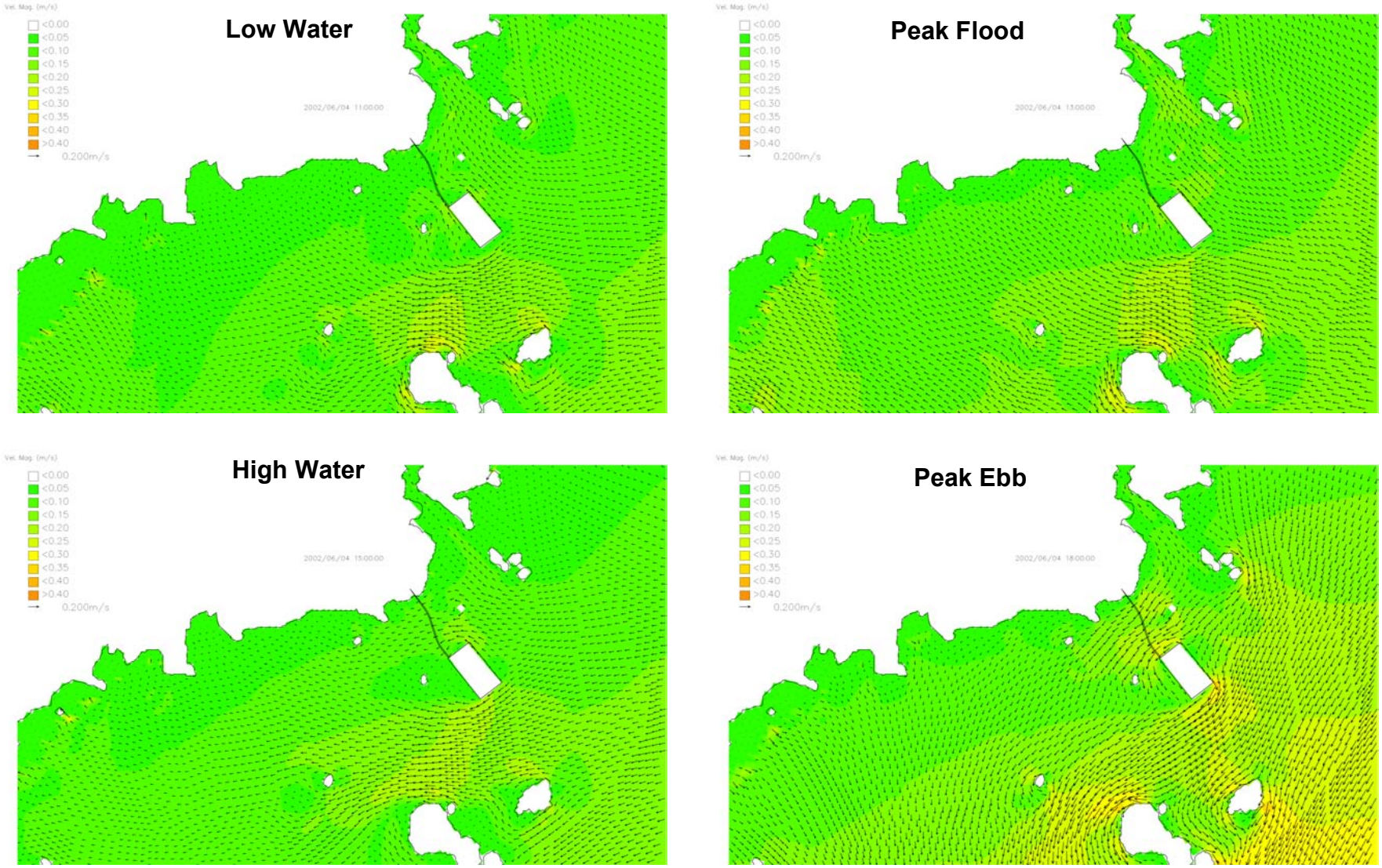

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FIGURE A-28:
Flow patterns during neap tide
at the project site. Trestle A5

Local model velocity differences and flow patterns: SPRING TIDE

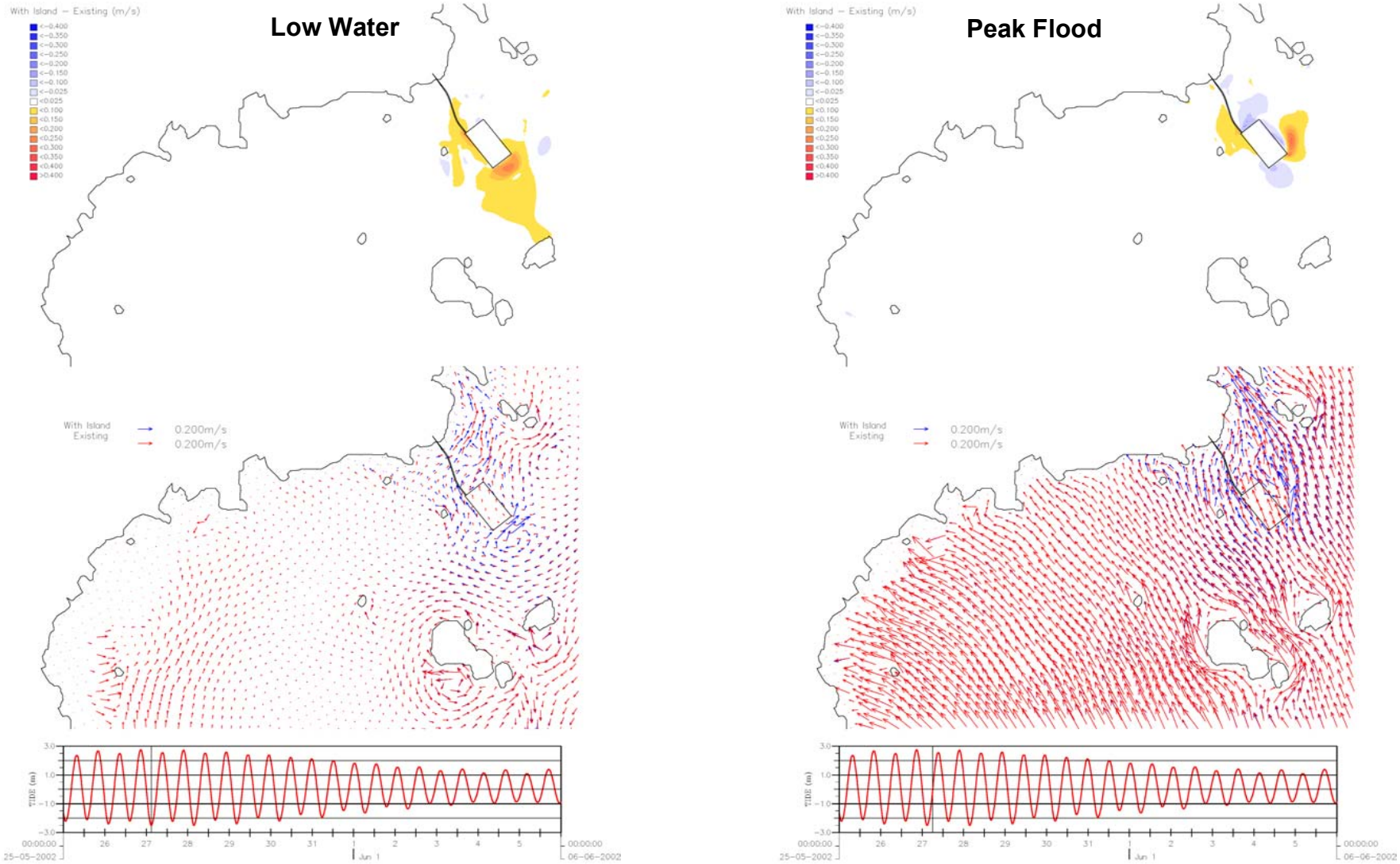

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FIGURE A-29
Velocity differences. Spring Tide (LW, PF)
Trestle A5

Local model velocity differences and flow patterns: SPRING TIDE

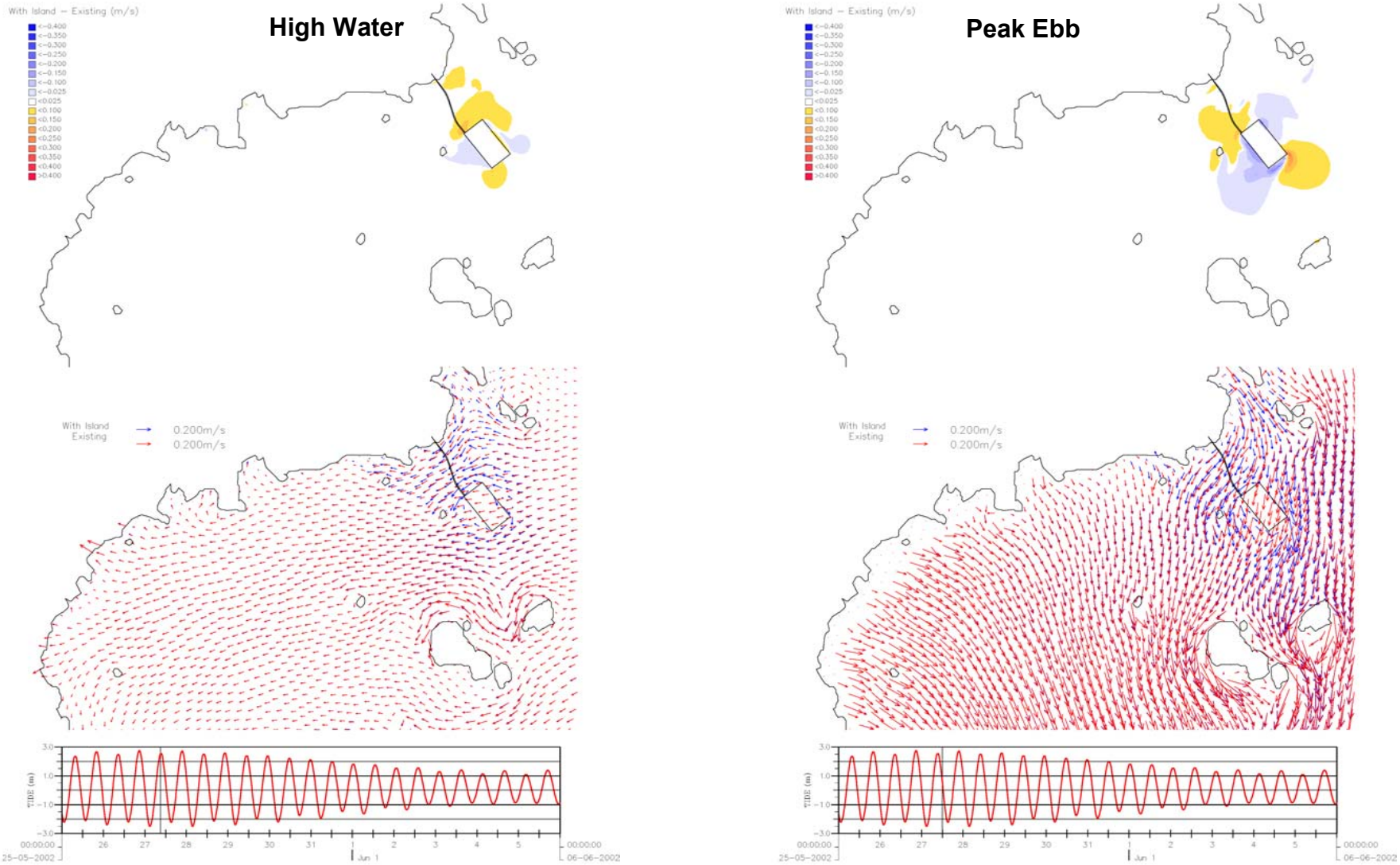

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FIGURE A-30:
Velocity differences. Spring Tide (HW, PE)
Trestle A5

Local model velocity differences and flow patterns: NEAP TIDE

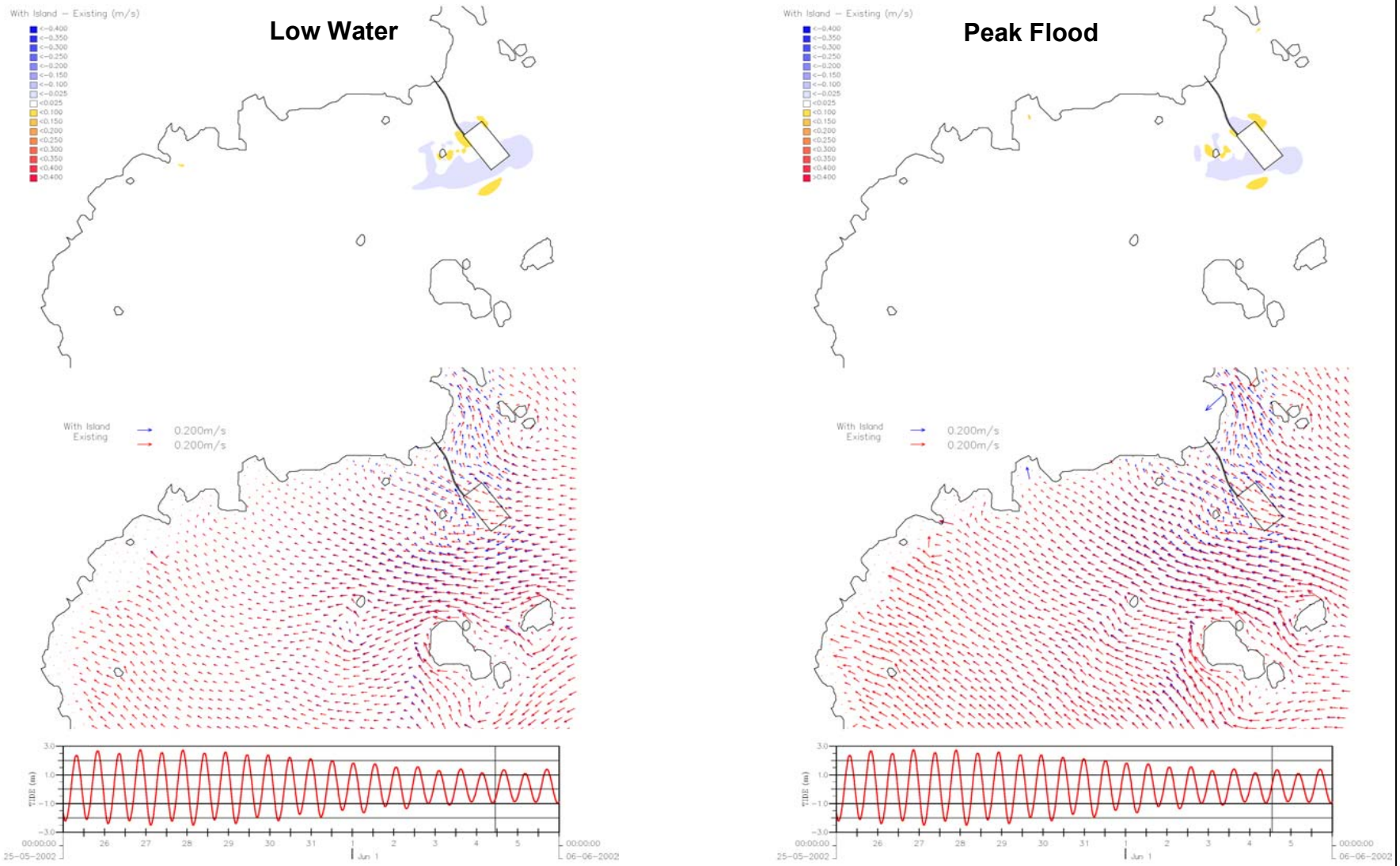

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FIGURE A-31:
Velocity differences. Neap Tide (LW, PF)
Trestle A5

Local model velocity differences and flow patterns: NEAP TIDE

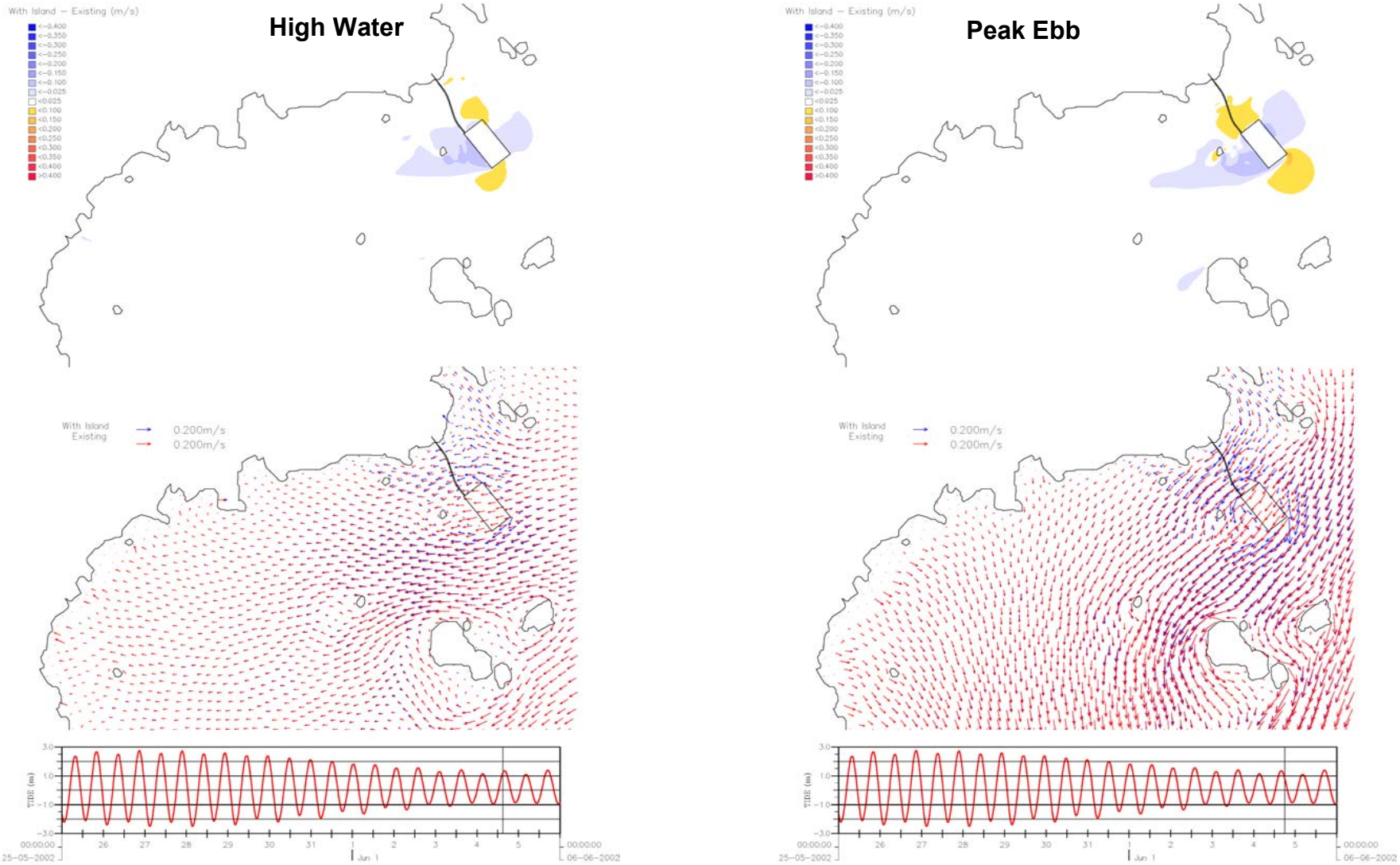

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FIGURE A-32:
Velocity differences. Neap Tide (HW, PE)
Trestle A5

Local model flow patterns: SPRING TIME

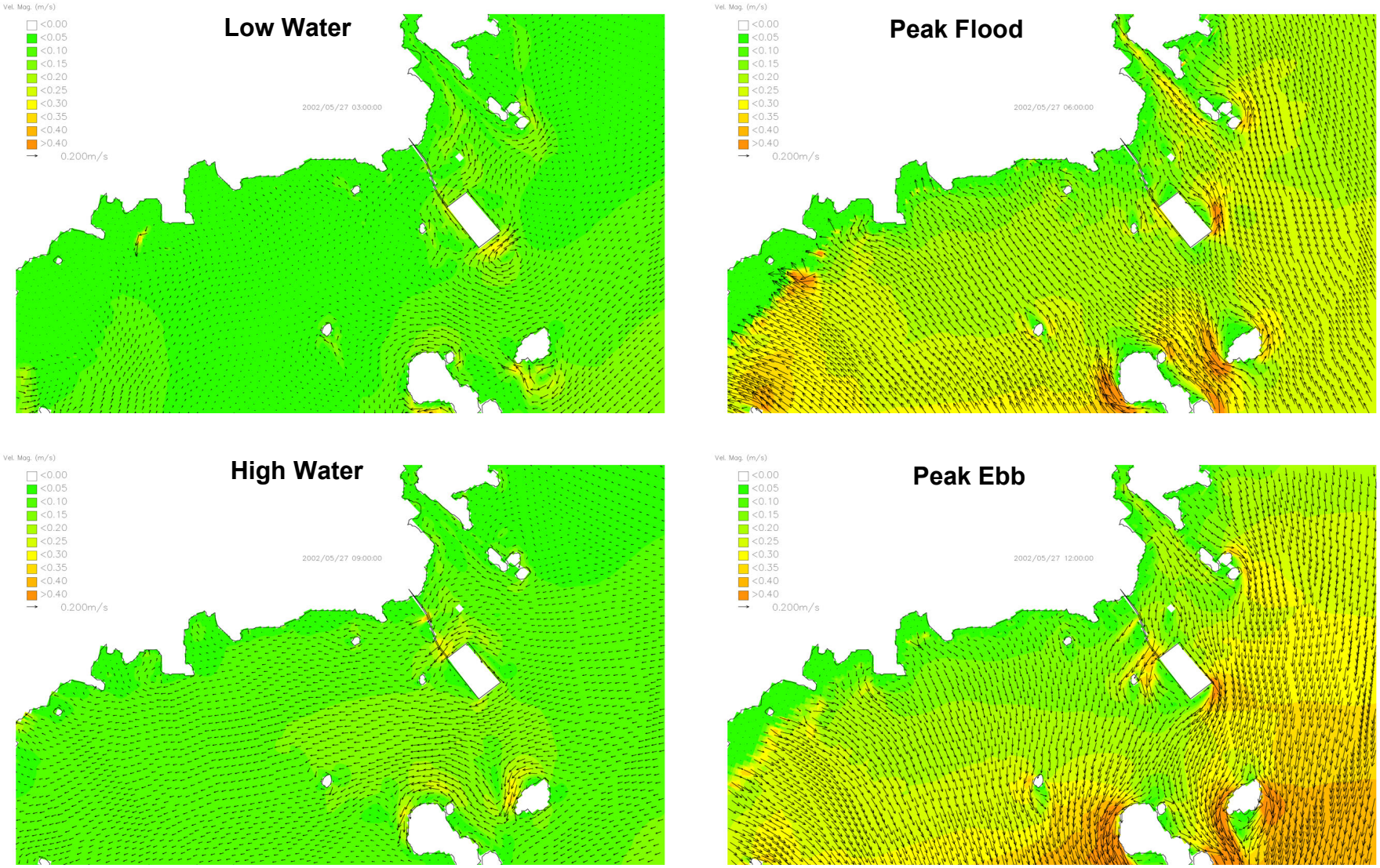

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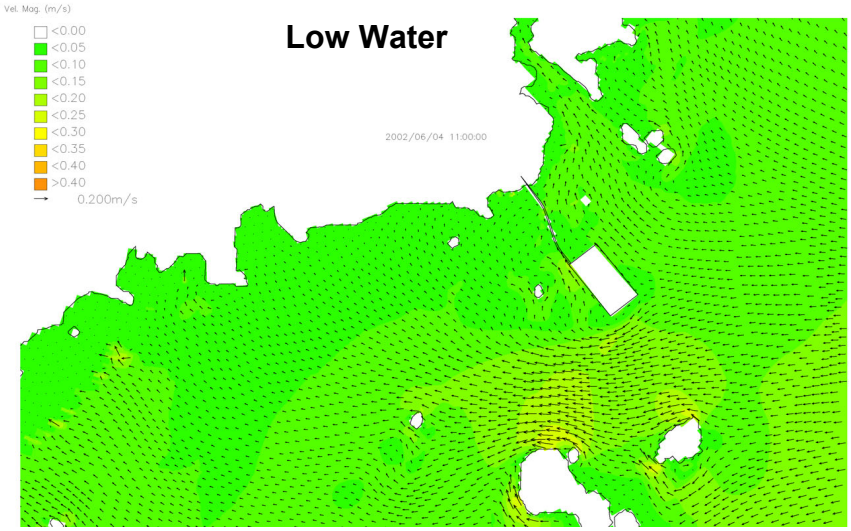
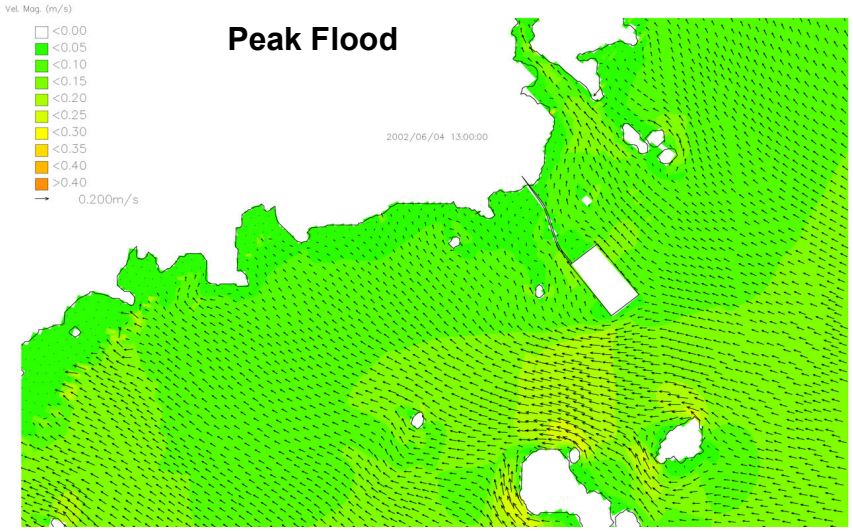
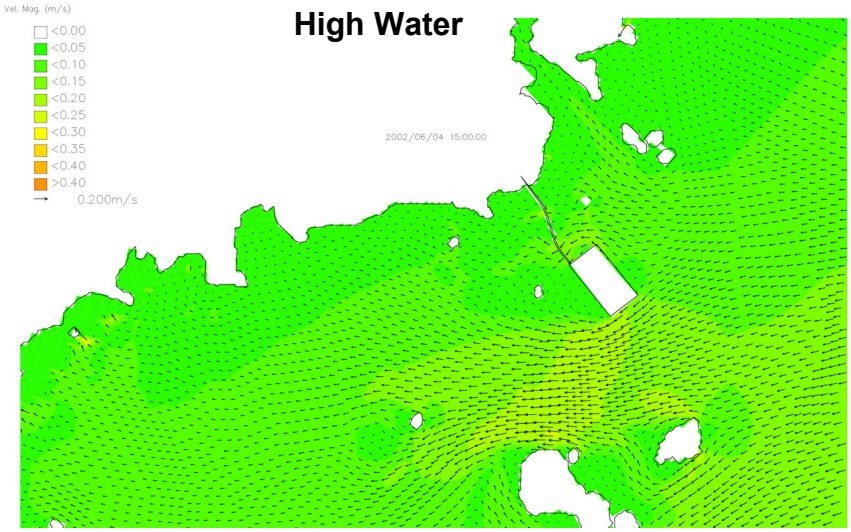
FIGURE A-33:
Flow patterns during spring tide
at the project site. Hybrid A5

Local model flow patterns: NEAP TIDE







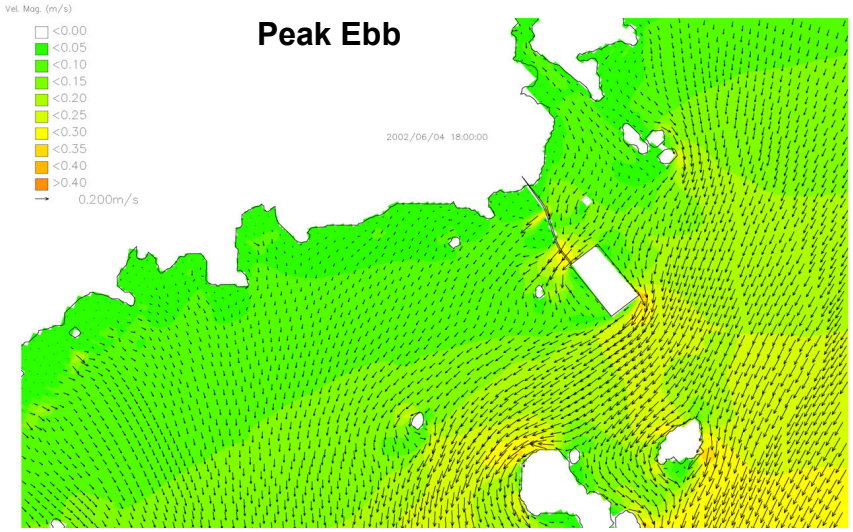


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FIGURE A-34:
Flow patterns during neap tide
at the project site. Hybrid A5

Local model velocity differences and flow patterns: SPRING TIDE

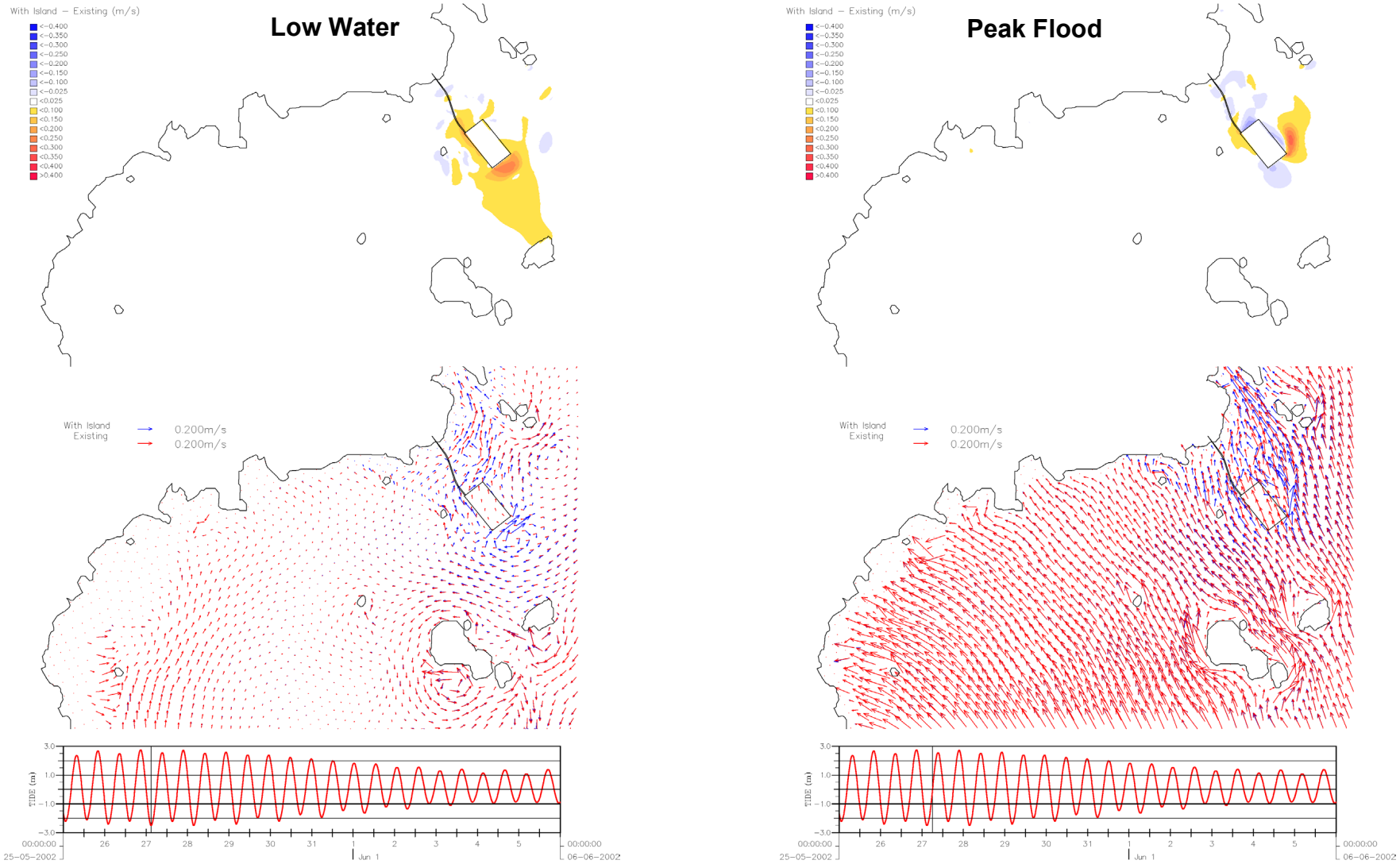

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FIGURE A-35:
Velocity differences. Spring Tide (LW, PF)
Hybrid A5

Local model velocity differences and flow patterns: SPRING TIDE

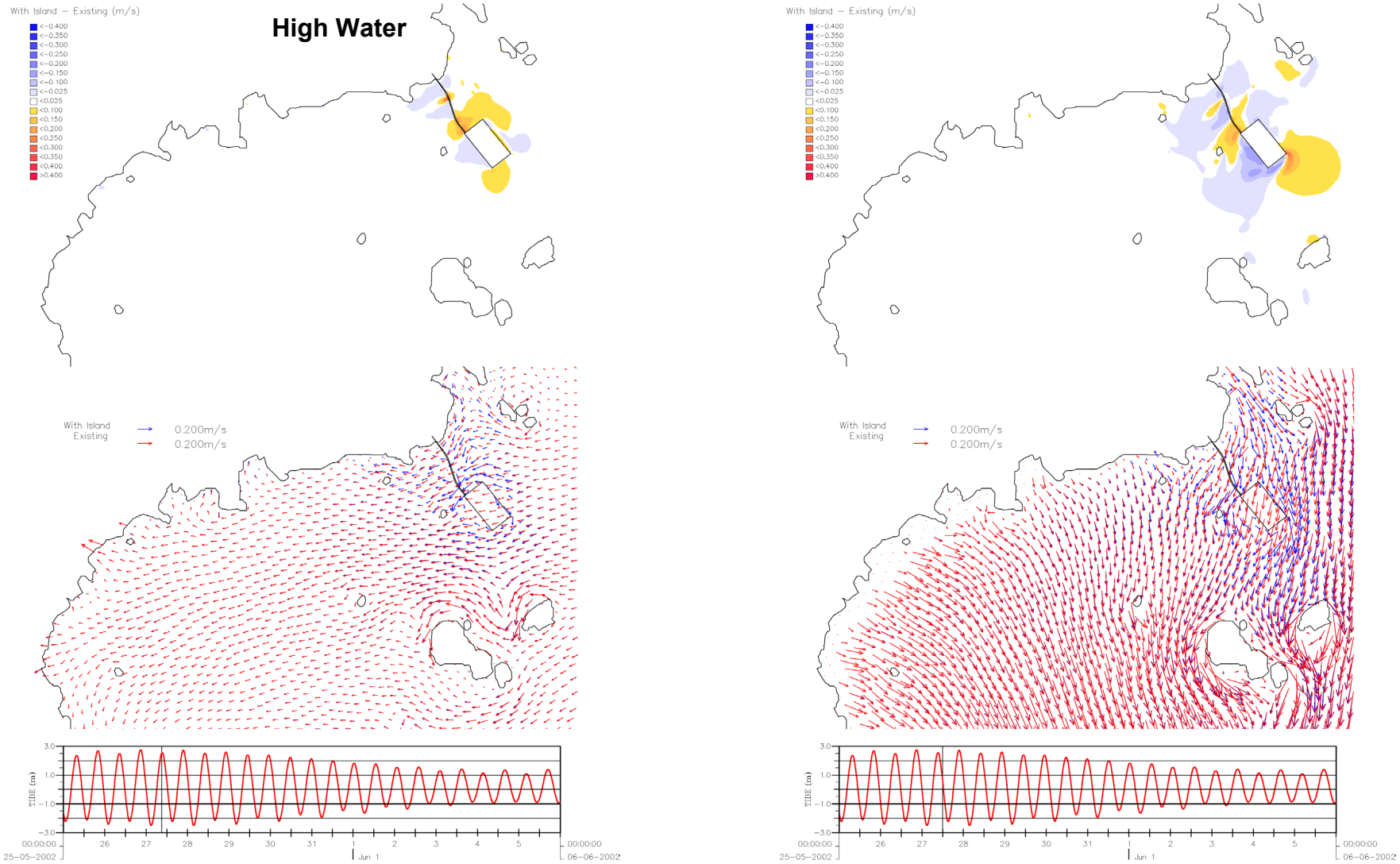

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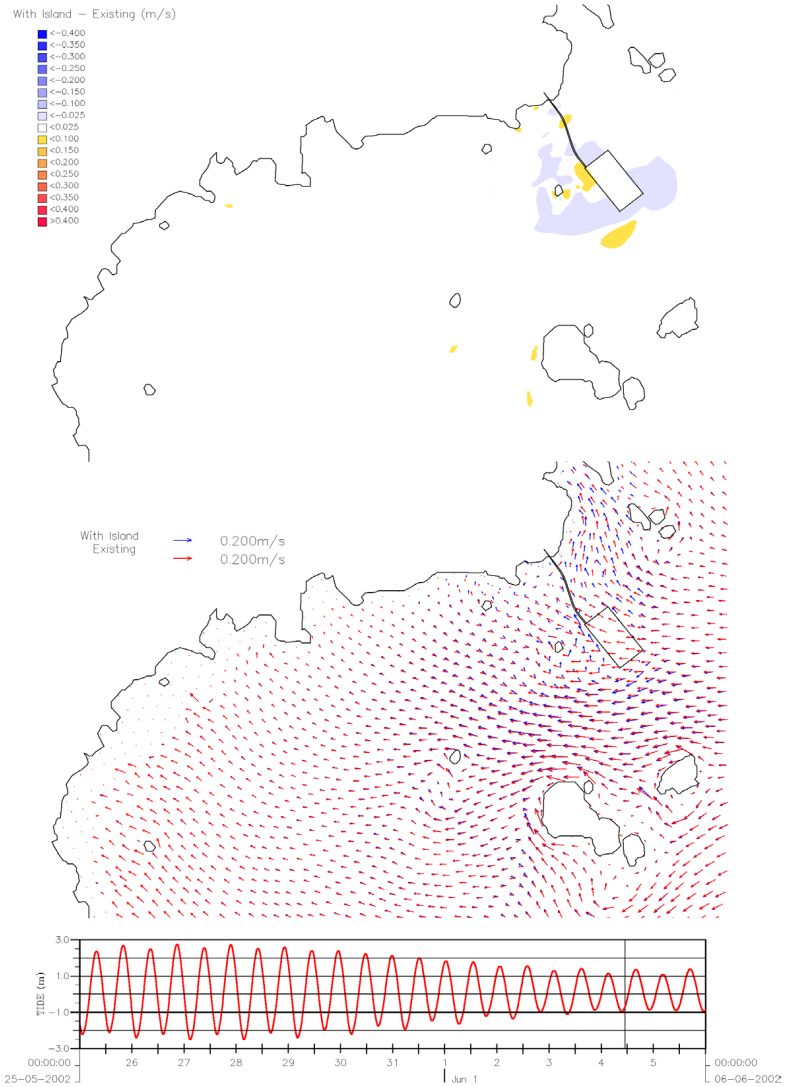
FIGURE A-36:
Velocity differences. Spring Tide (HW, PE)
Hybrid A5

Local model velocity differences and flow patterns: NEAP TIDE



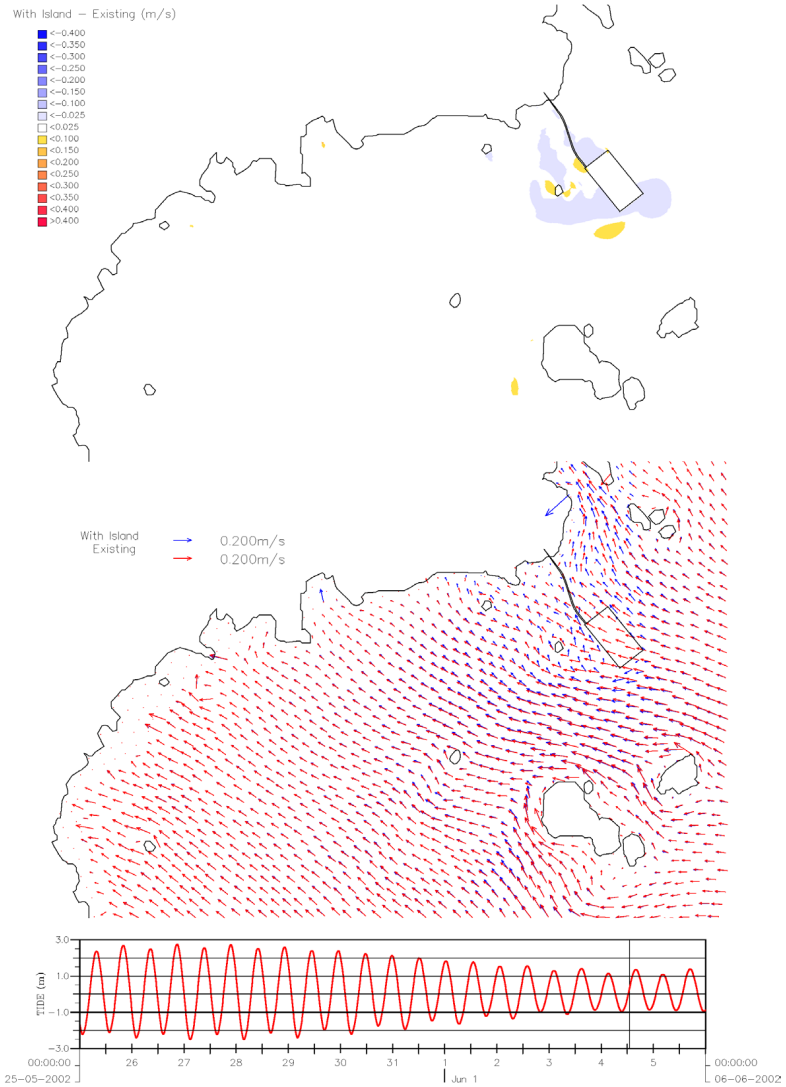


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FIGURE A-37:
Velocity differences. Neap Tide (LW, PF)
Hybrid A5

Local model velocity differences and flow patterns: NEAP TIDE

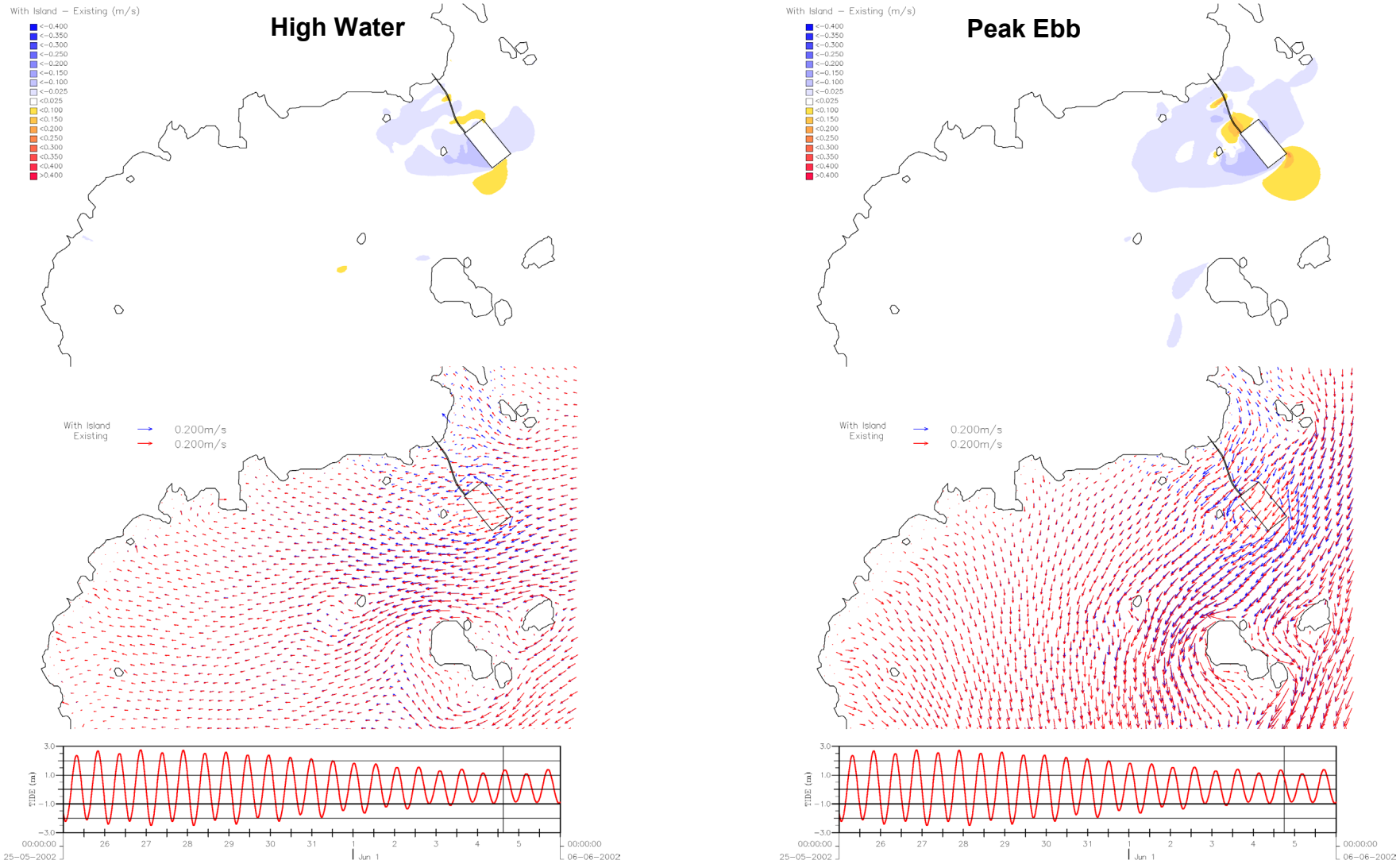

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FIGURE A-38:
Velocity differences. Neap Tide (HW, PE)
Hybrid A5

Local model flow patterns: SPRING TIDE

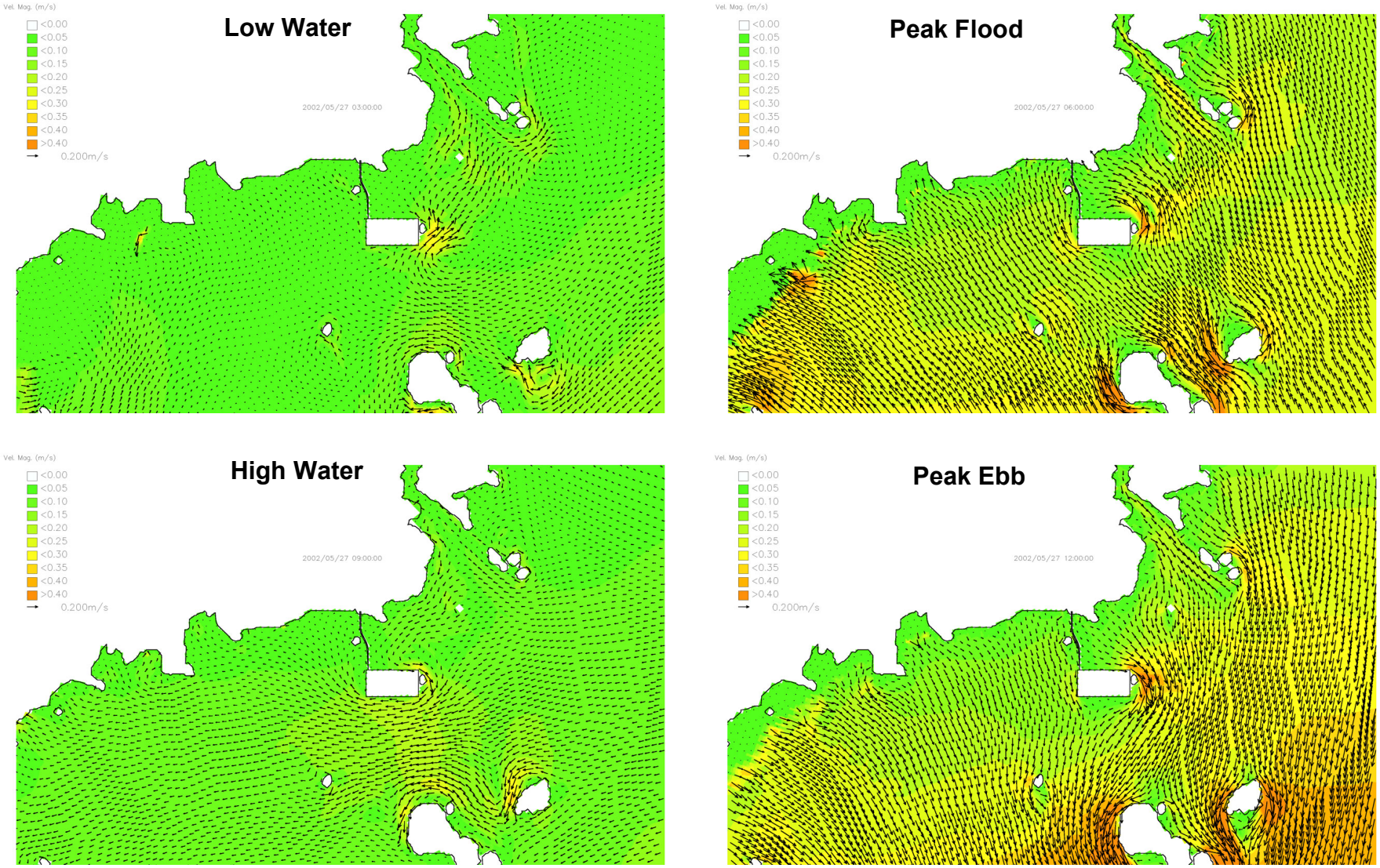

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FIGURE A-39:
Flow patterns during spring tide
at the project site. Causeway AMU

Local model flow patterns: NEAP TIDE

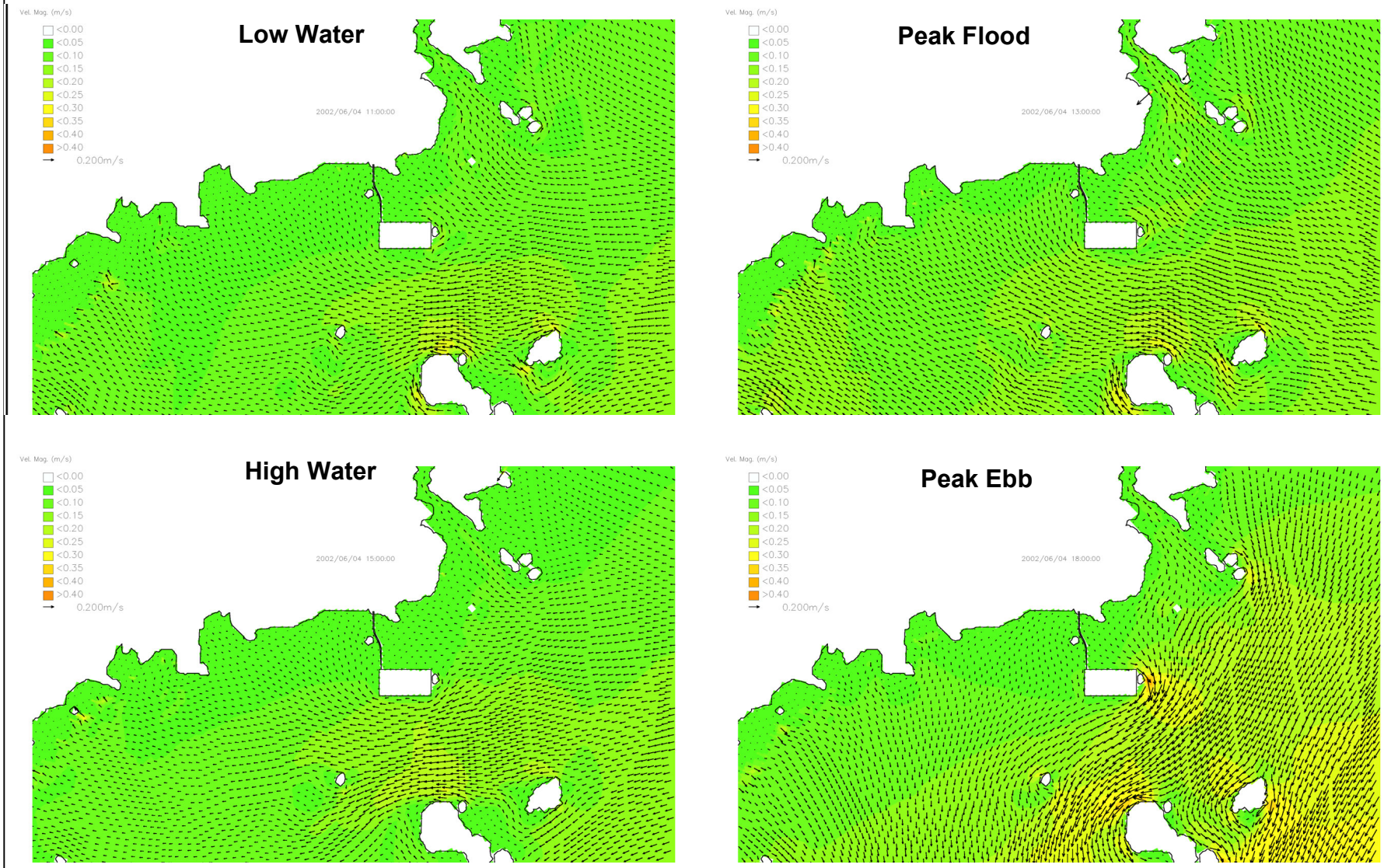

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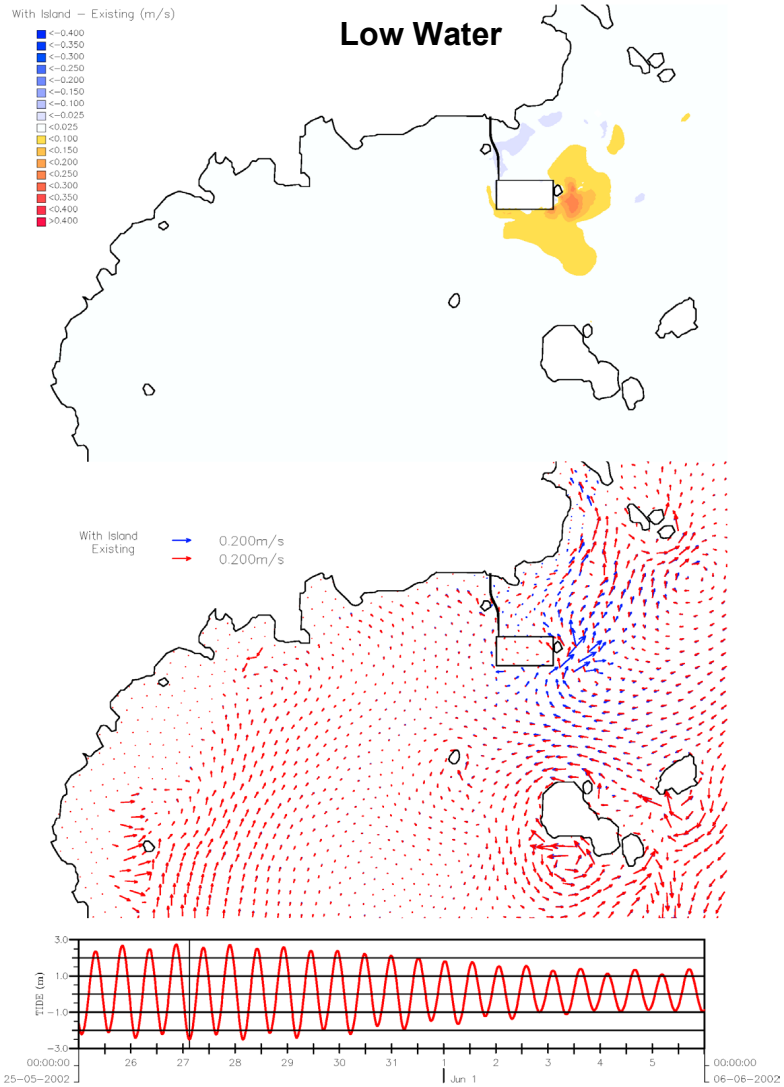
FIGURE A-40:
Flow patterns during neap tide
at the project site. Causeway AMU

Local model velocity differences and flow patterns: SPRING TIDE



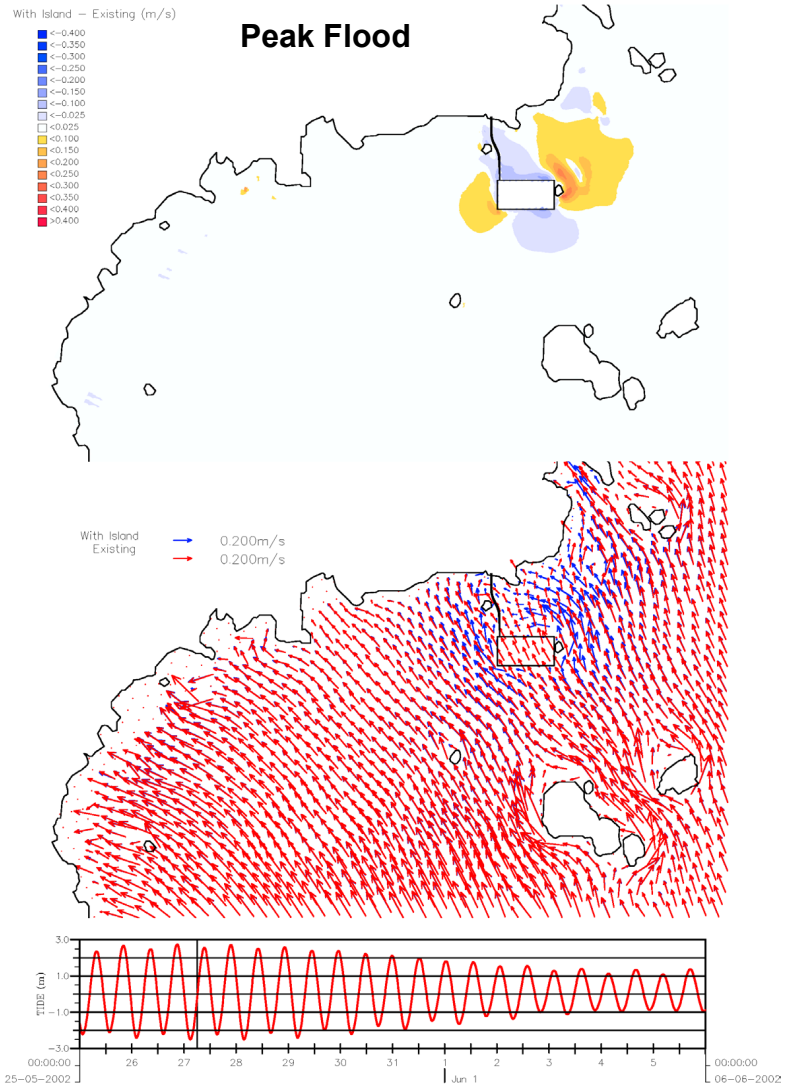


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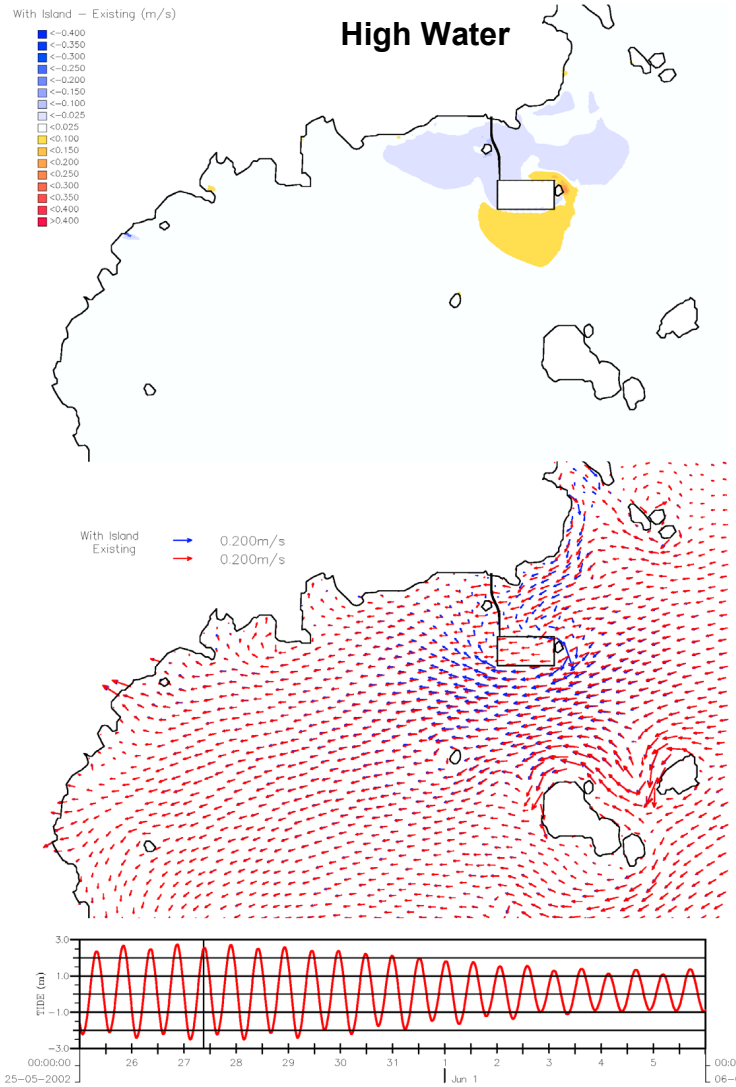
FIGURE A-41:
Velocity differences. Spring Tide (LW, PF)
Causeway AMU

Local model velocity differences and flow patterns: SPRING TIDE



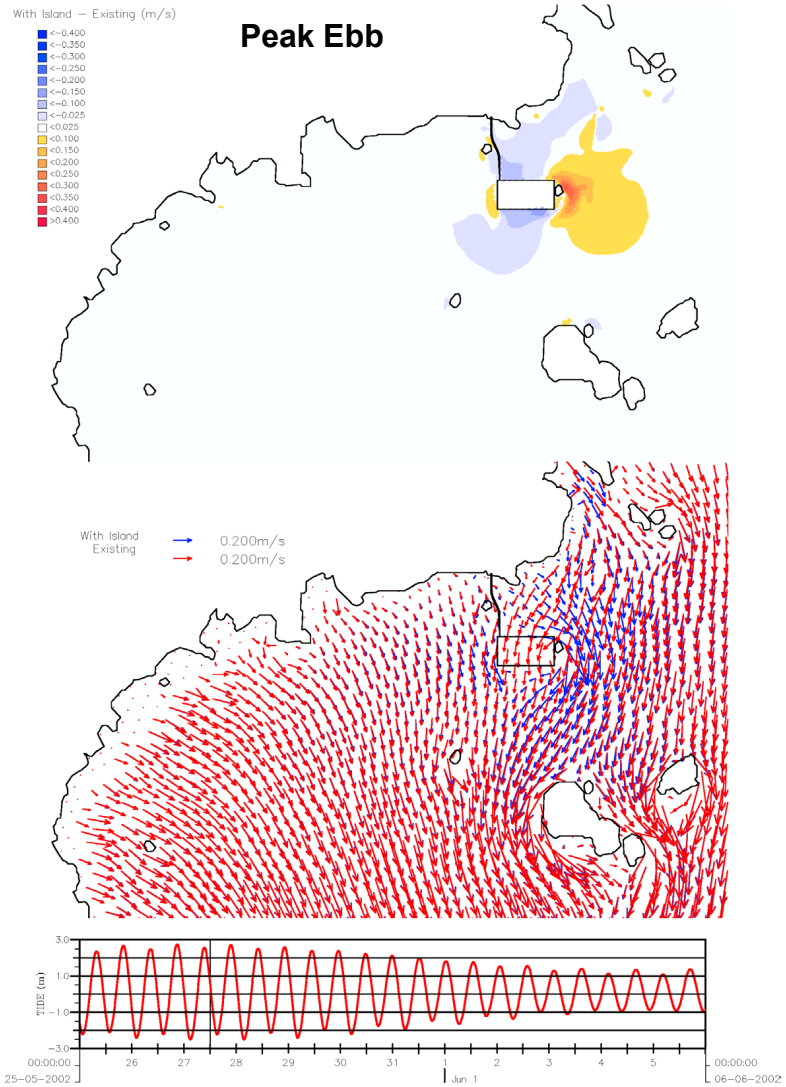


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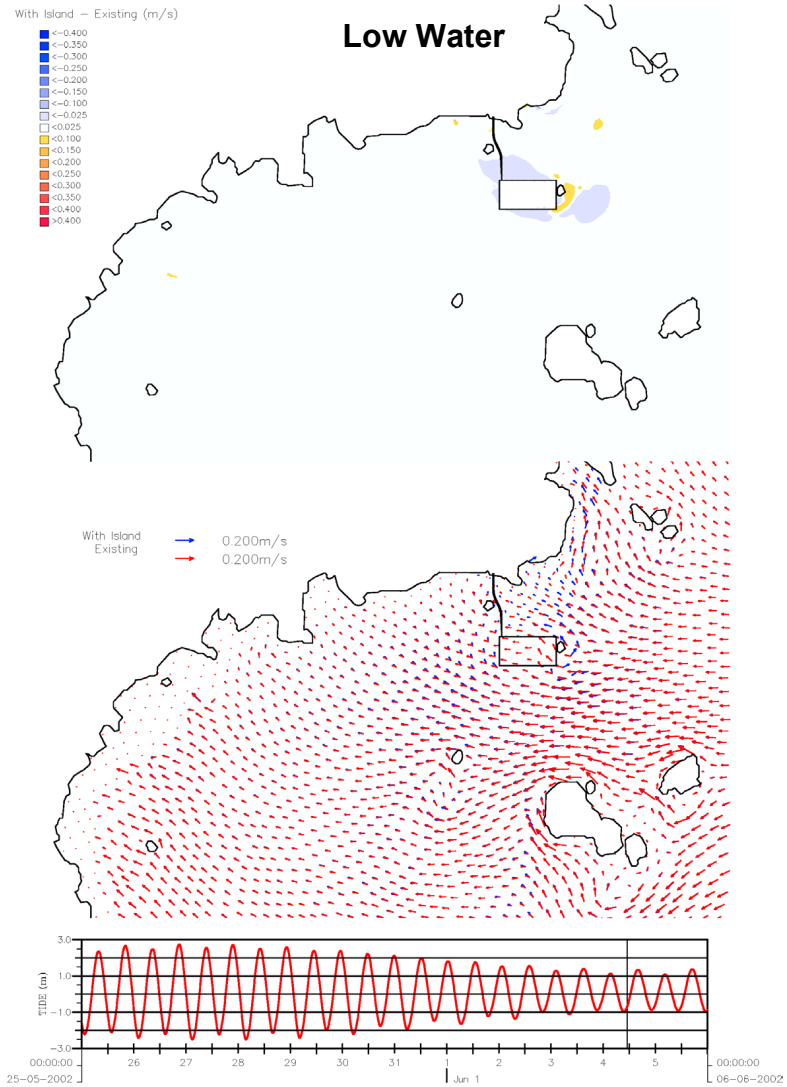
FIGURE A-42:
Velocity differences. Spring Tide (HW, PE)
Causeway AMU

Local model velocity differences and flow patterns: NEAP TIDE



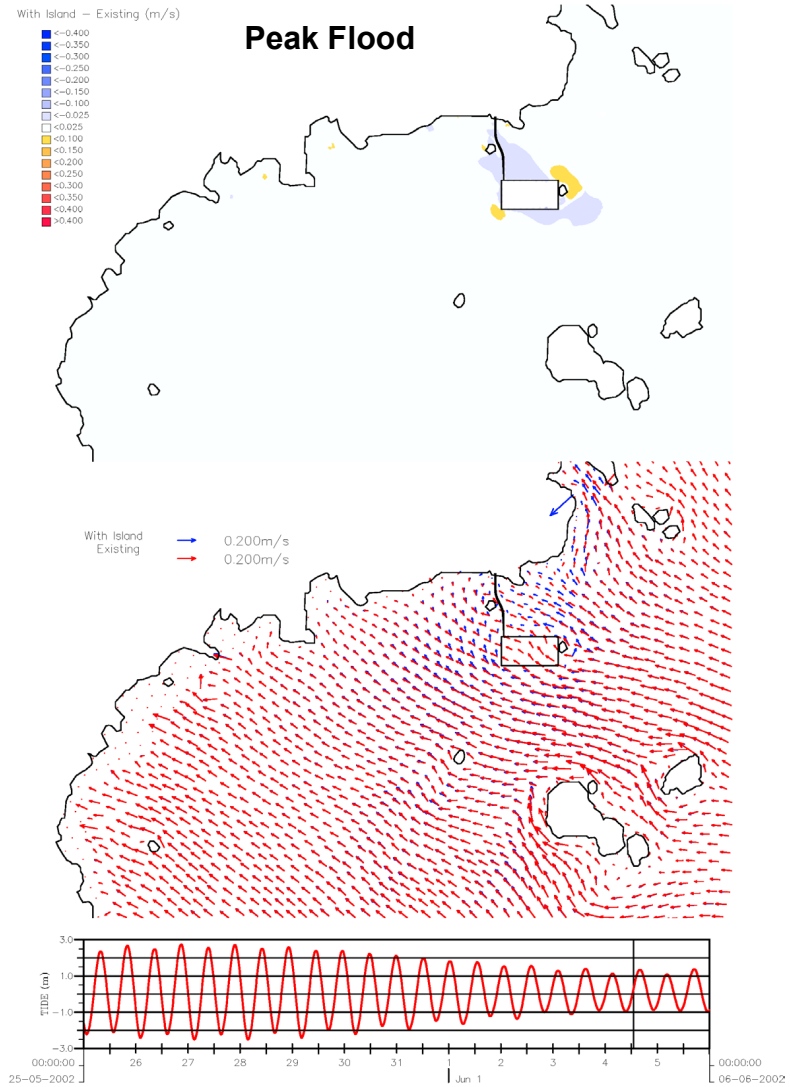


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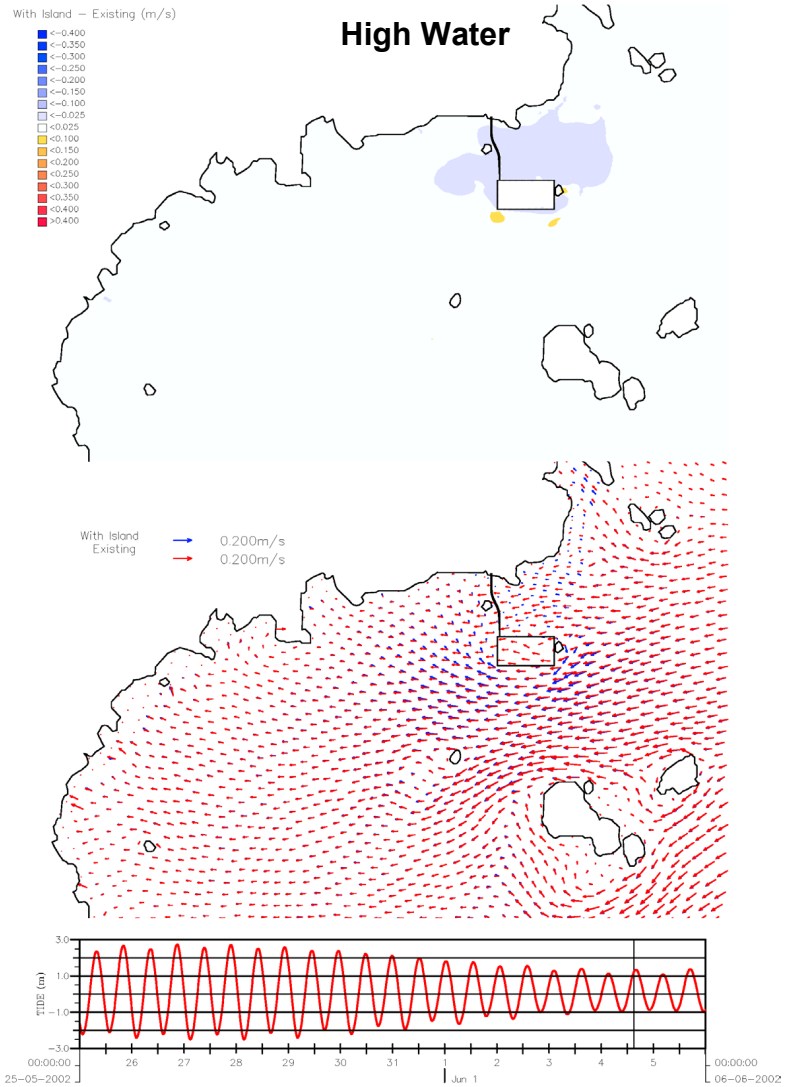
FIGURE A-43:
Velocity differences. Neap Tide (LW, PF)
Causeway AMU

Local model velocity differences and flow patterns: NEAP TIDE



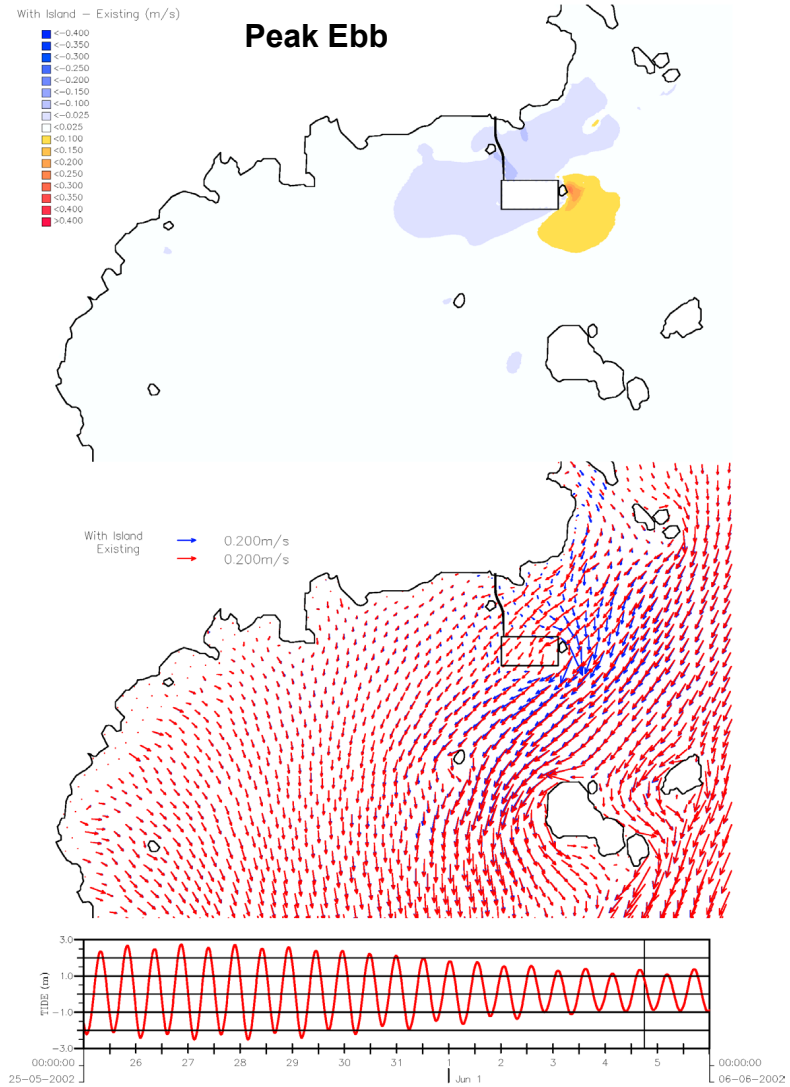


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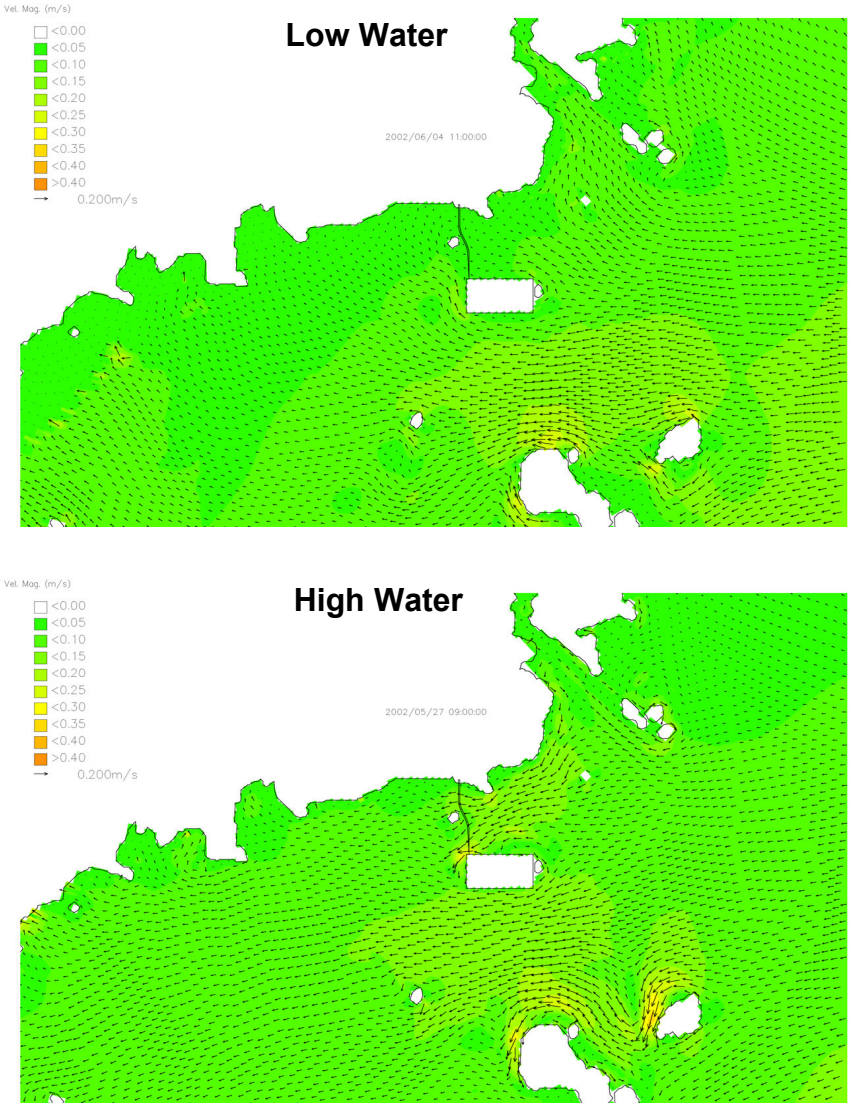
FIGURE A-44:
Velocity differences. Neap Tide (HW, PE)
Causeway AMU

Local model flow patterns: SPRING TIDE



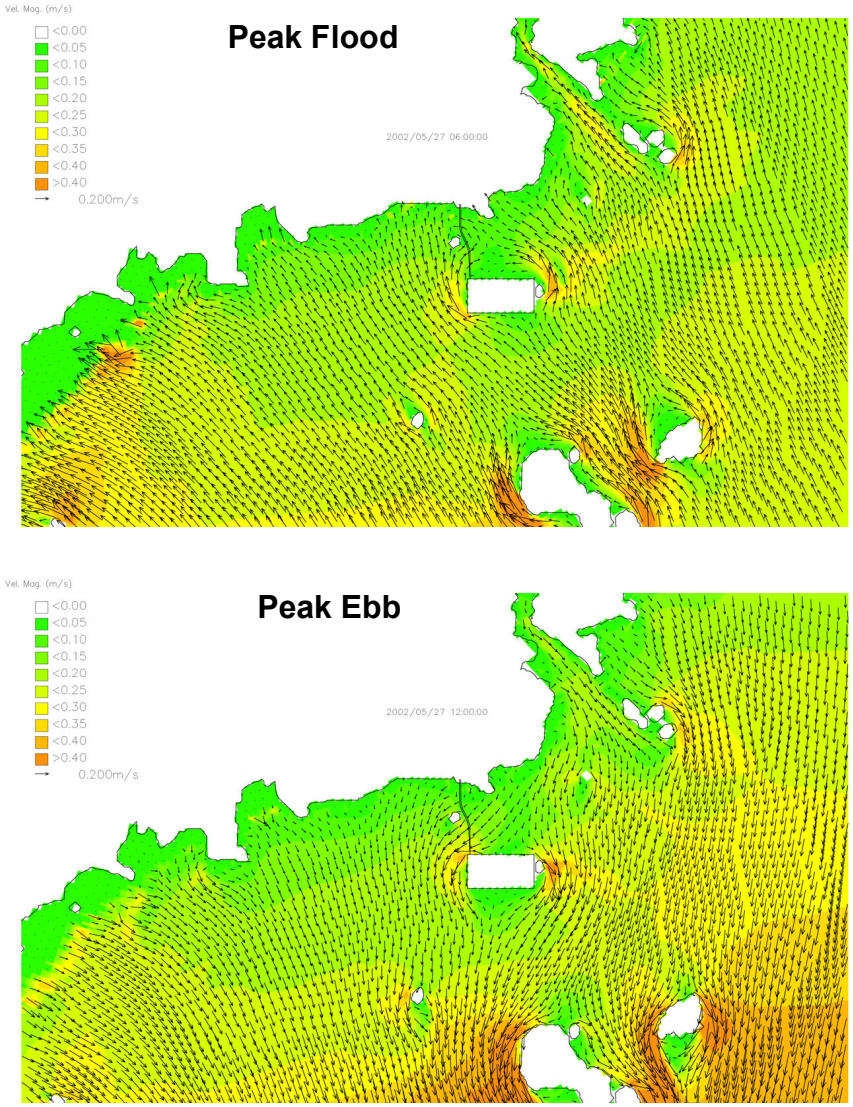


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FIGURE A-45:
Flow patterns during spring tide
at the project site. Trestle AMU

Local model flow patterns: NEAP TIDE

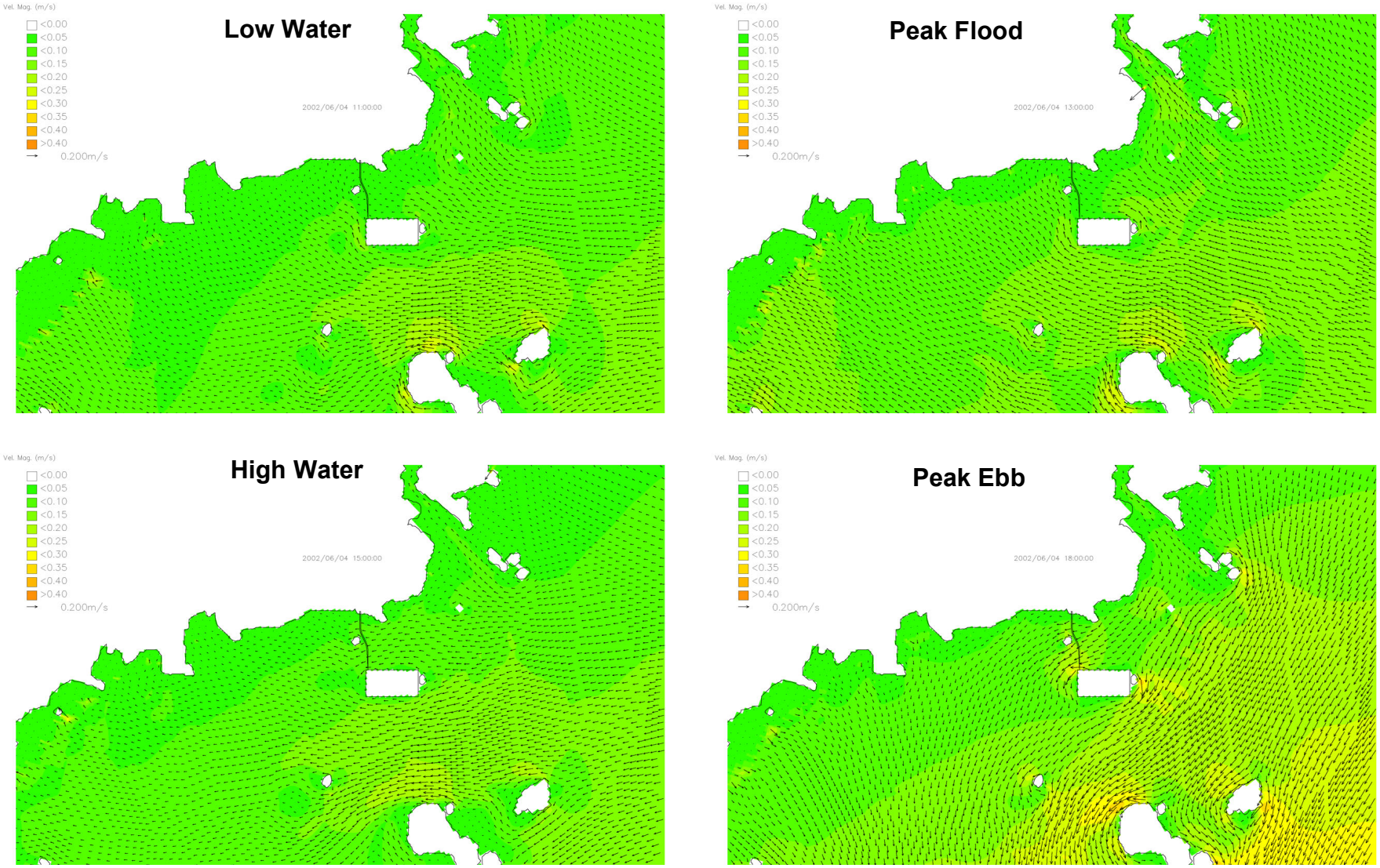

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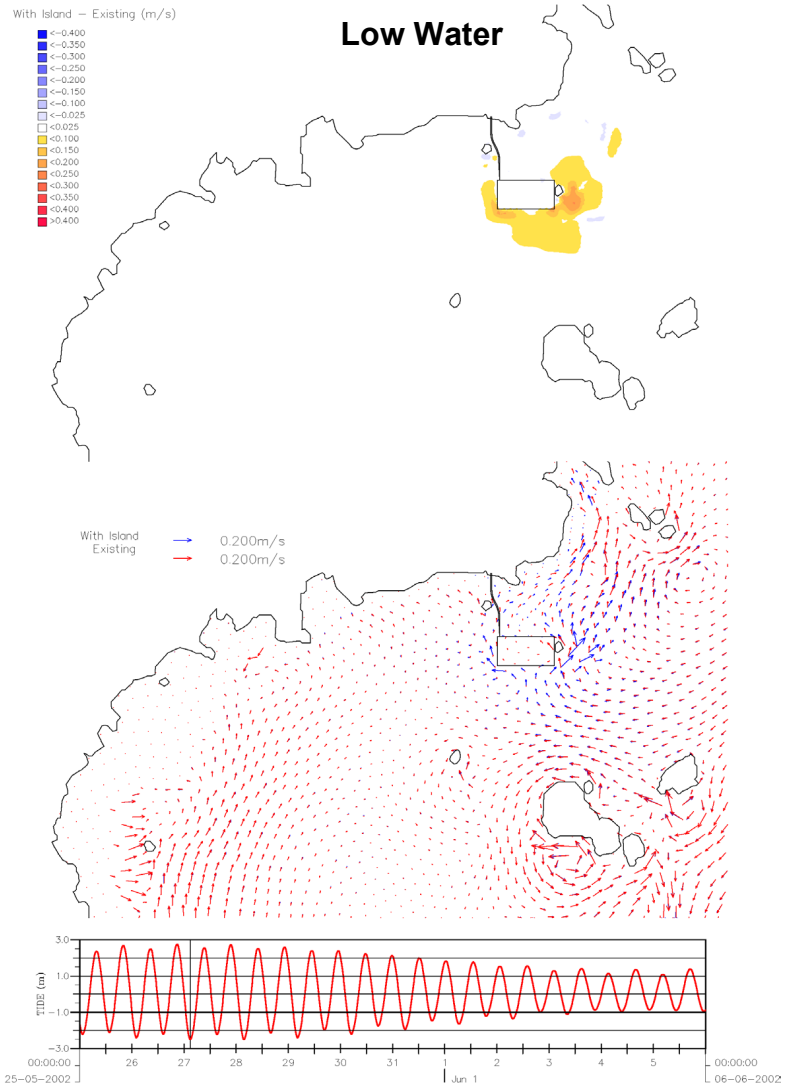
FIGURE A-46:
Flow patterns during neap tide
at the project site. Trestle AMU

Local model velocity differences and flow patterns: SPRING TIDE



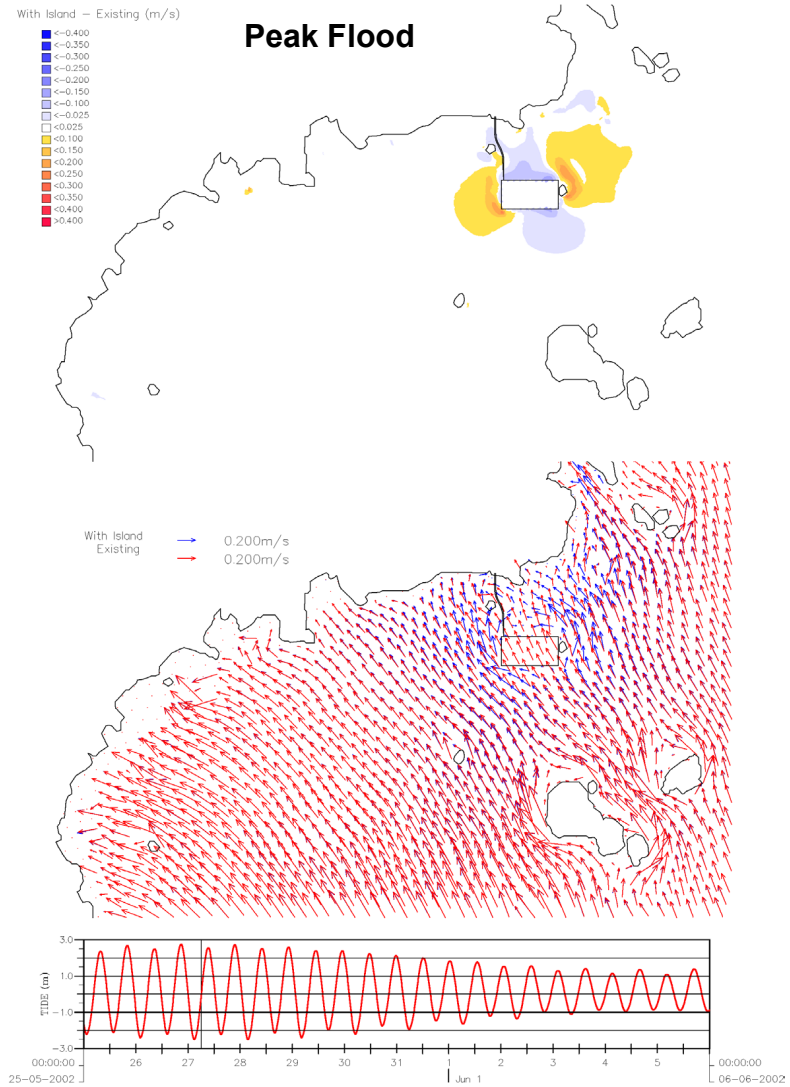


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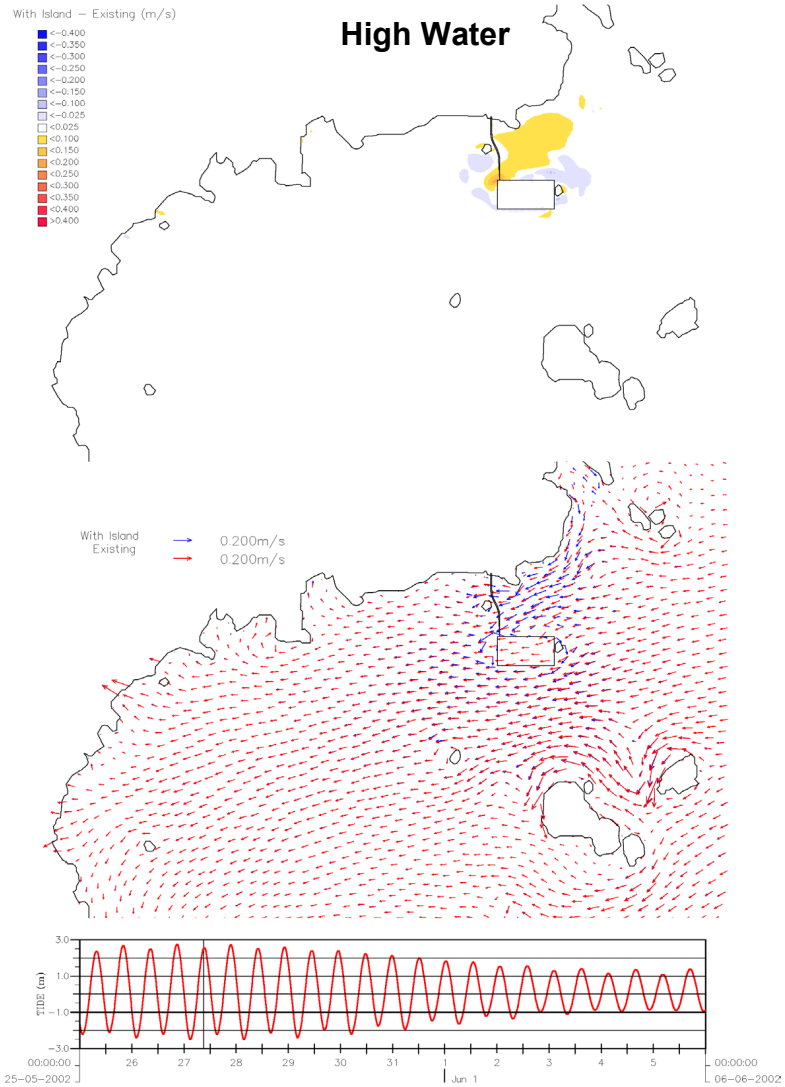
FIGURE A-47:
Velocity differences. Spring Tide (LW, PF)
Trestle AMU

Local model velocity differences and flow patterns: SPRING TIDE



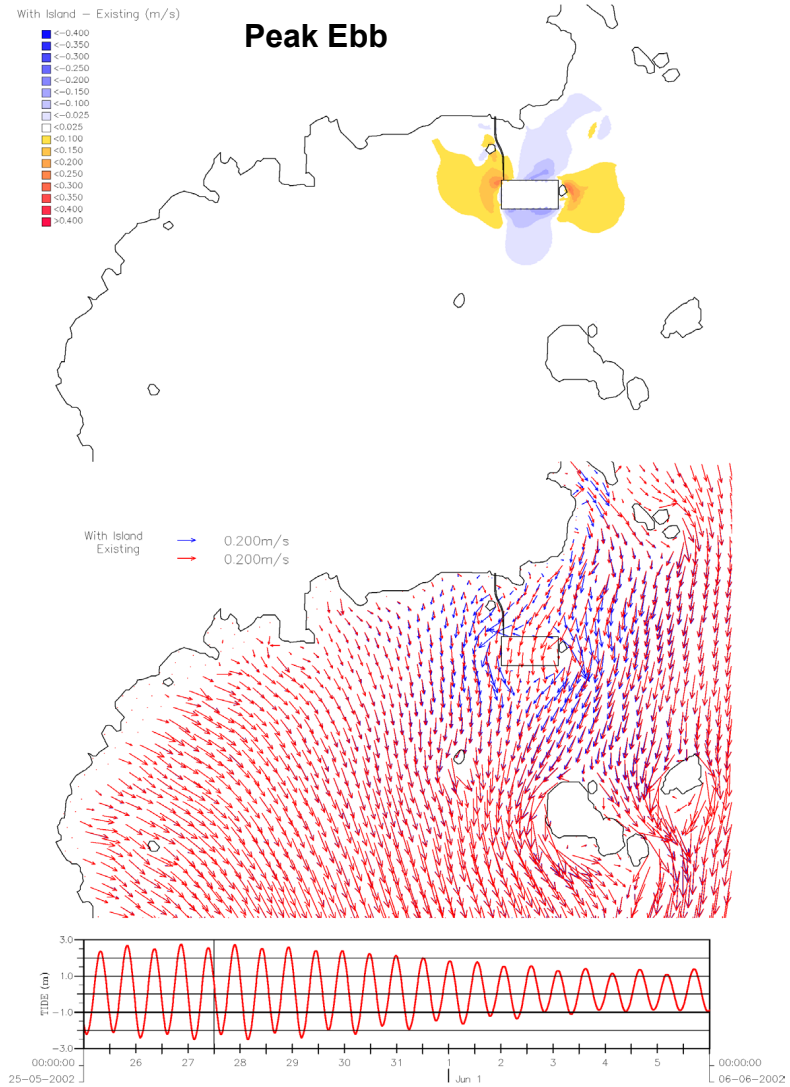


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FIGURE A-48:
Velocity differences. Spring Tide (HW, PE)
Trestle AMU

Local model velocity differences and flow patterns: NEAP TIDE

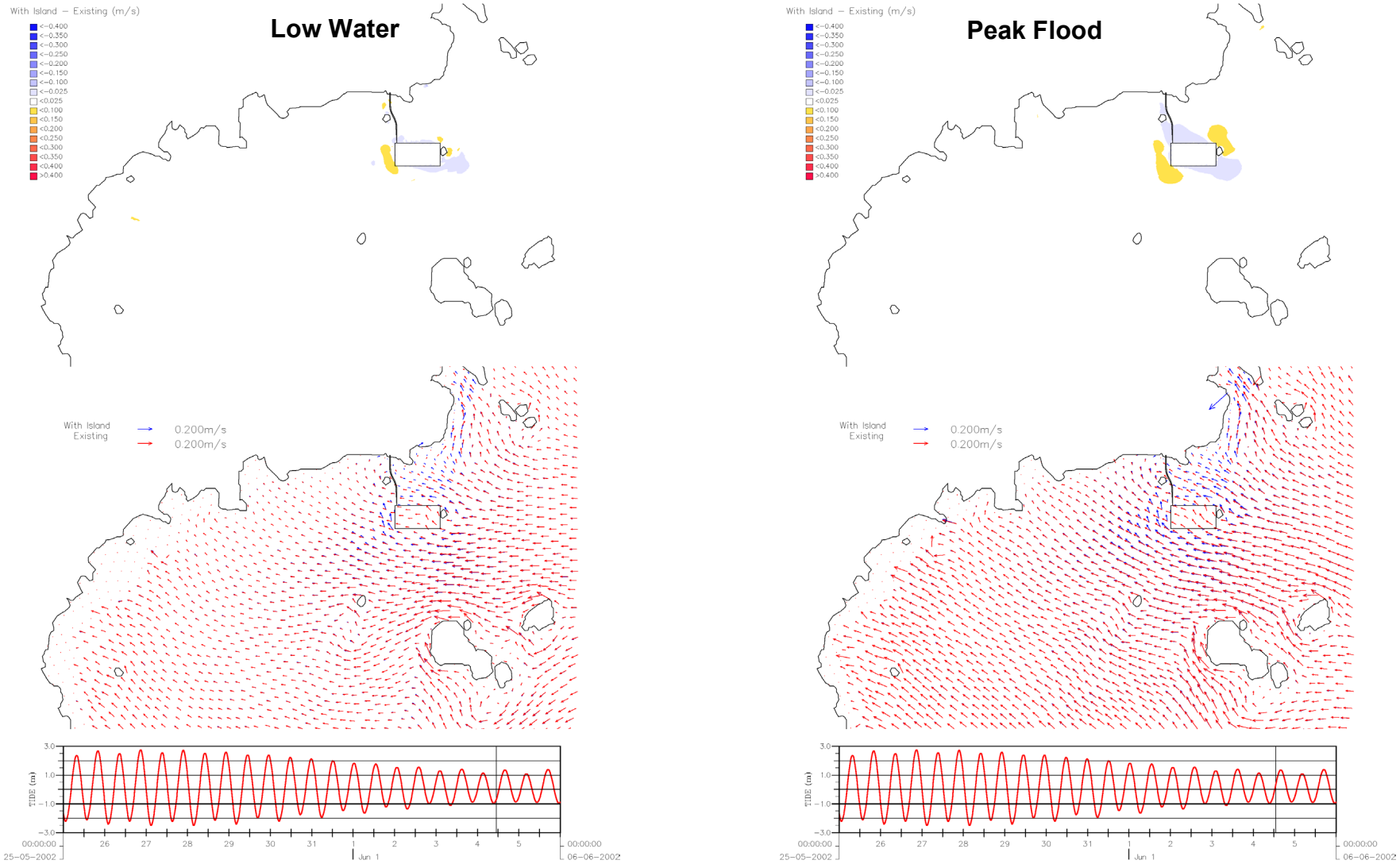

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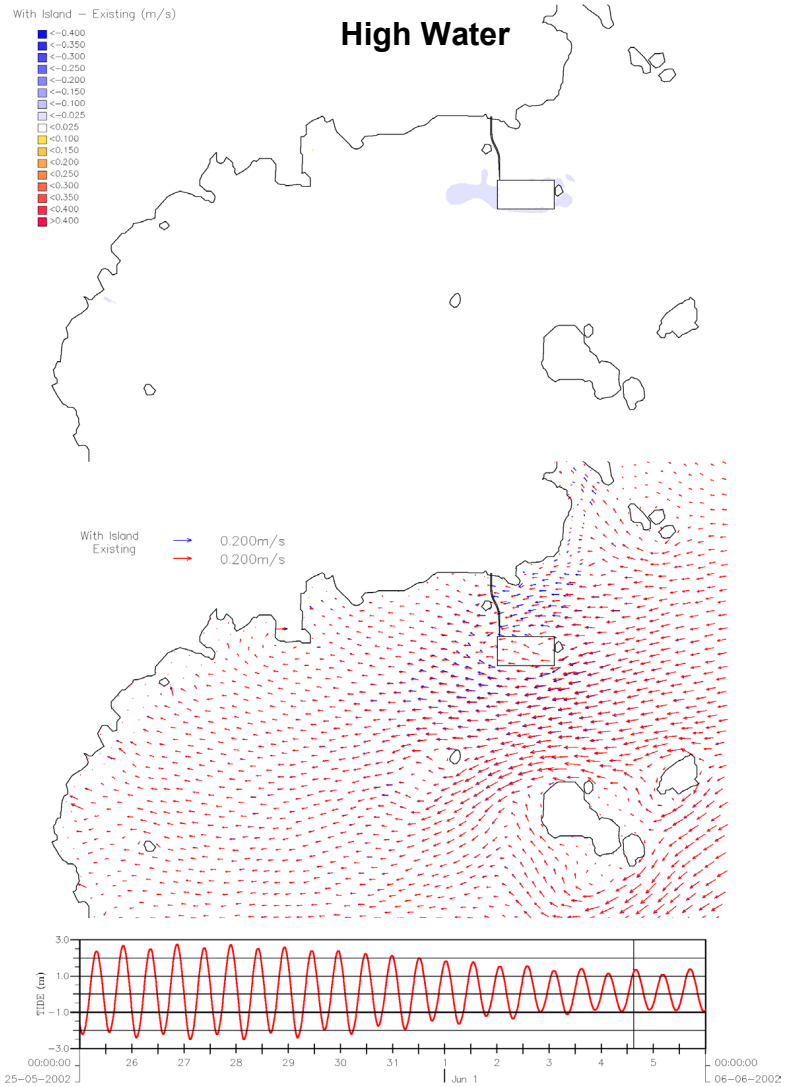
FIGURE A-49:
Velocity differences. Neap Tide (LW, PF)
Trestle AMU

Local model velocity differences and flow patterns: NEAP TIDE



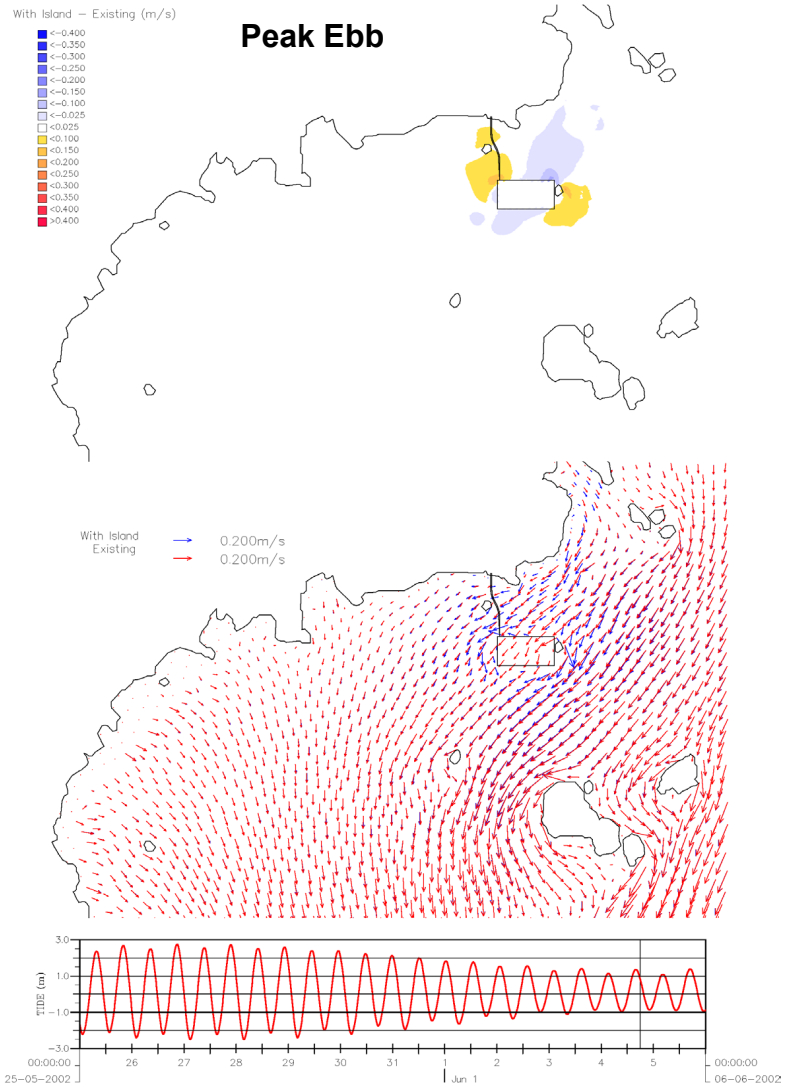


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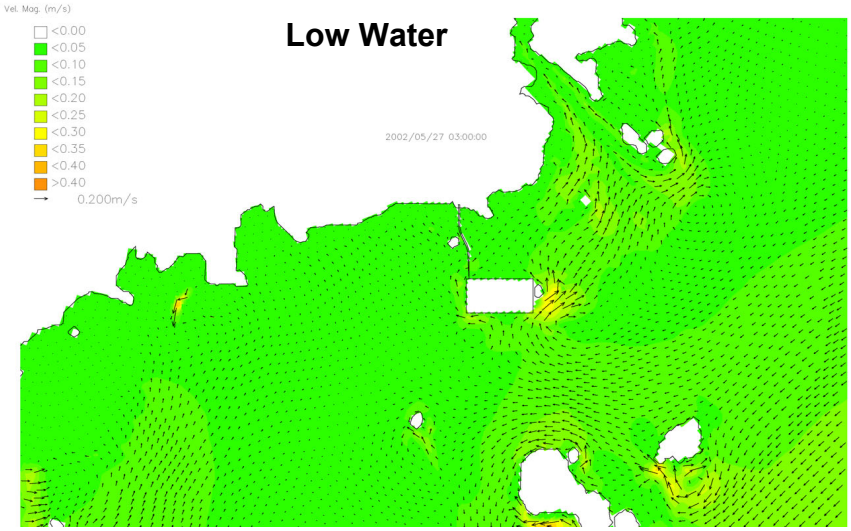
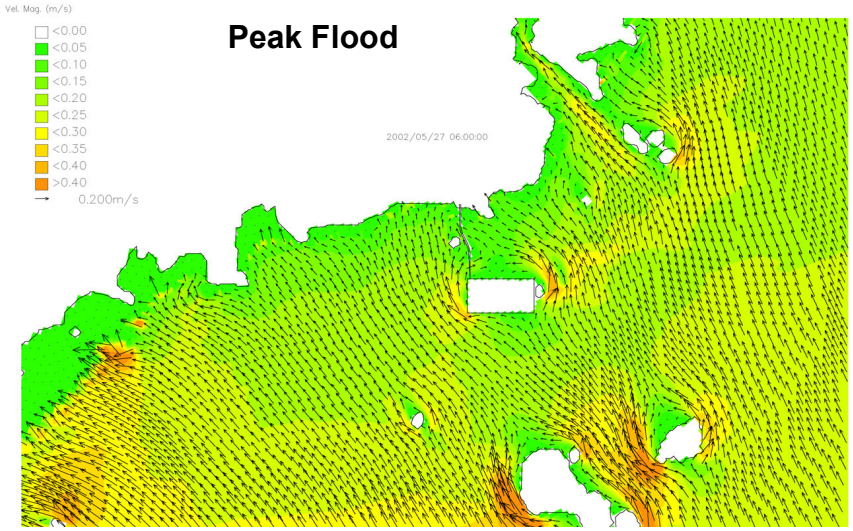
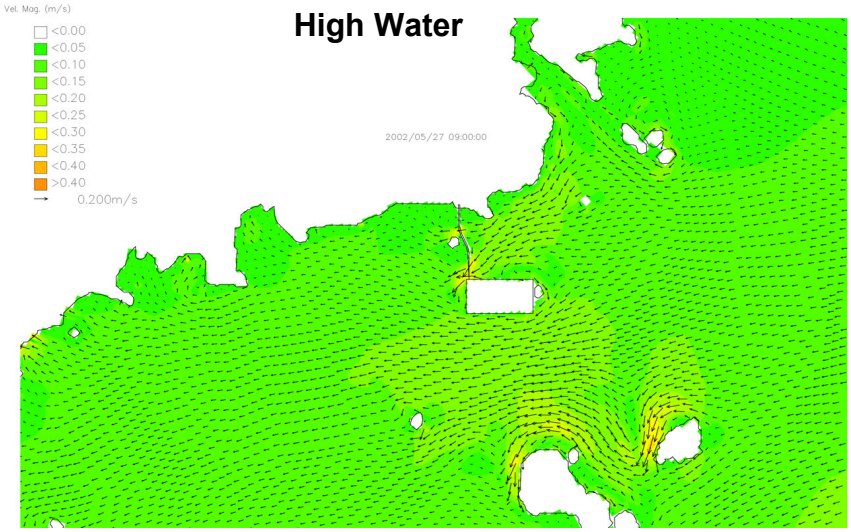
FIGURE A-50:
Velocity differences. Neap Tide (HW, PE)
Trestle AMU

Local model flow patterns: SPRING TIDE







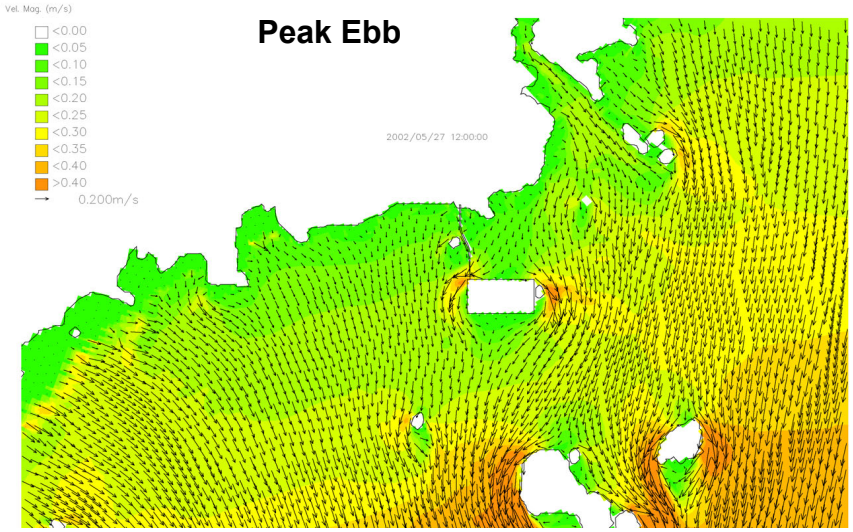


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FIGURE A-51:
Flow patterns during spring tide
at the project site. Hybrid AMU

Local model flow patterns: NEAP TIDE

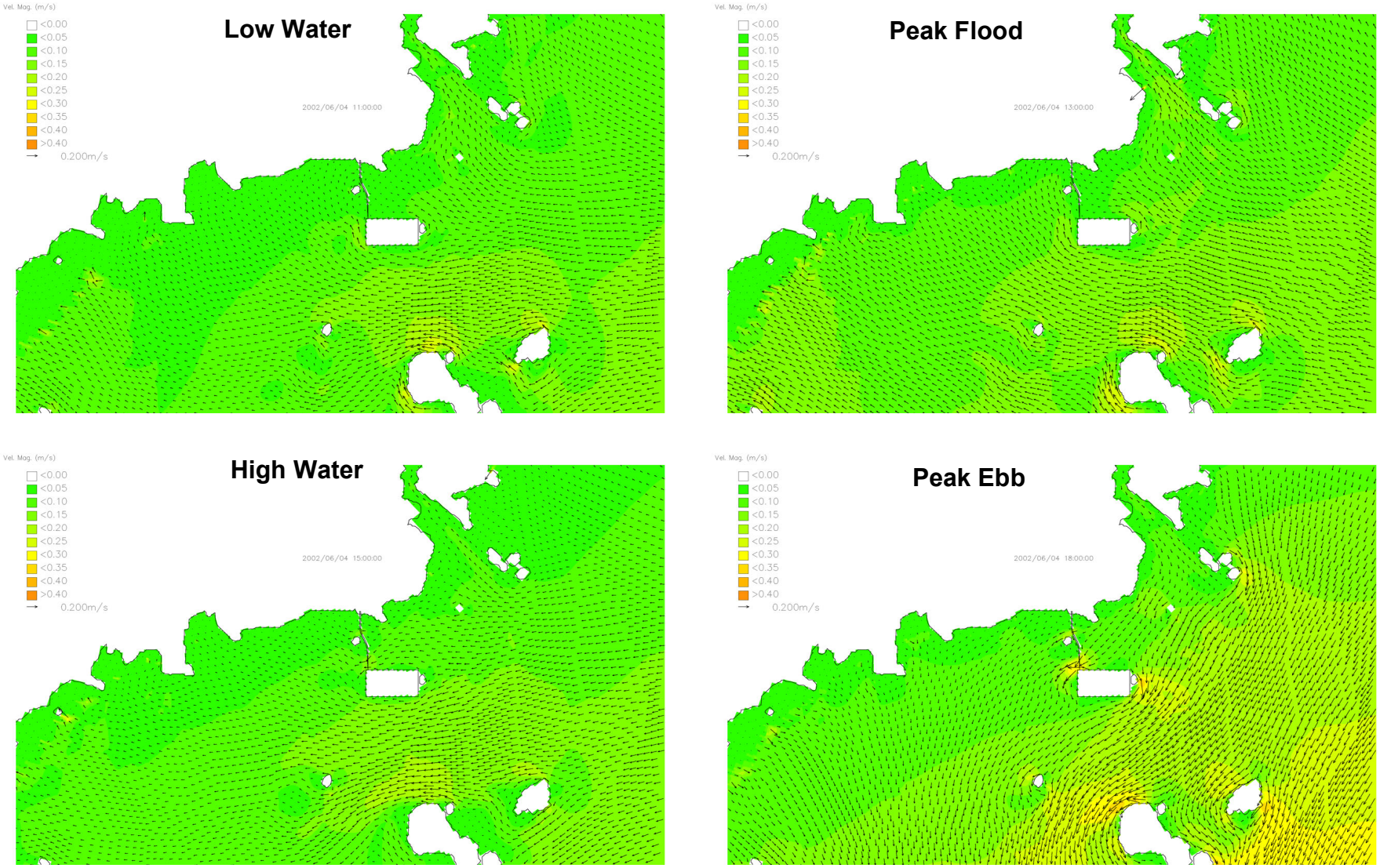

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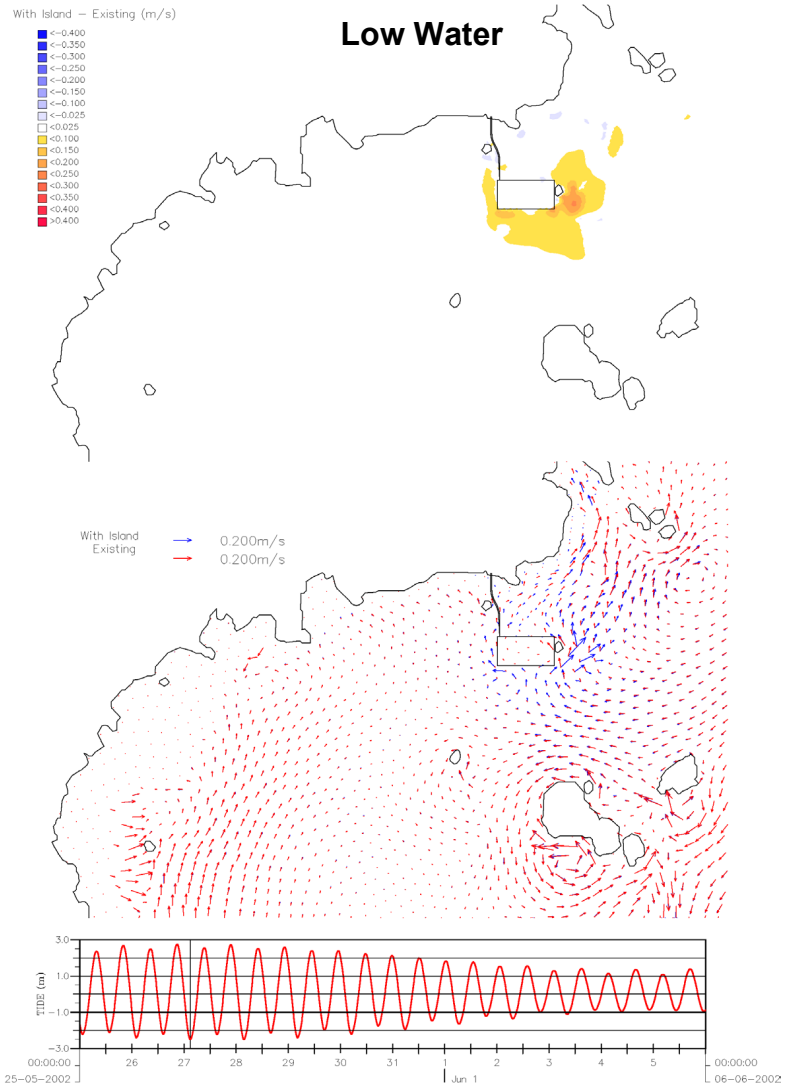
FIGURE A-52:
Flow patterns during neap tide
at the project site. Hybrid AMU

Local model velocity differences and flow patterns: SPRING TIDE



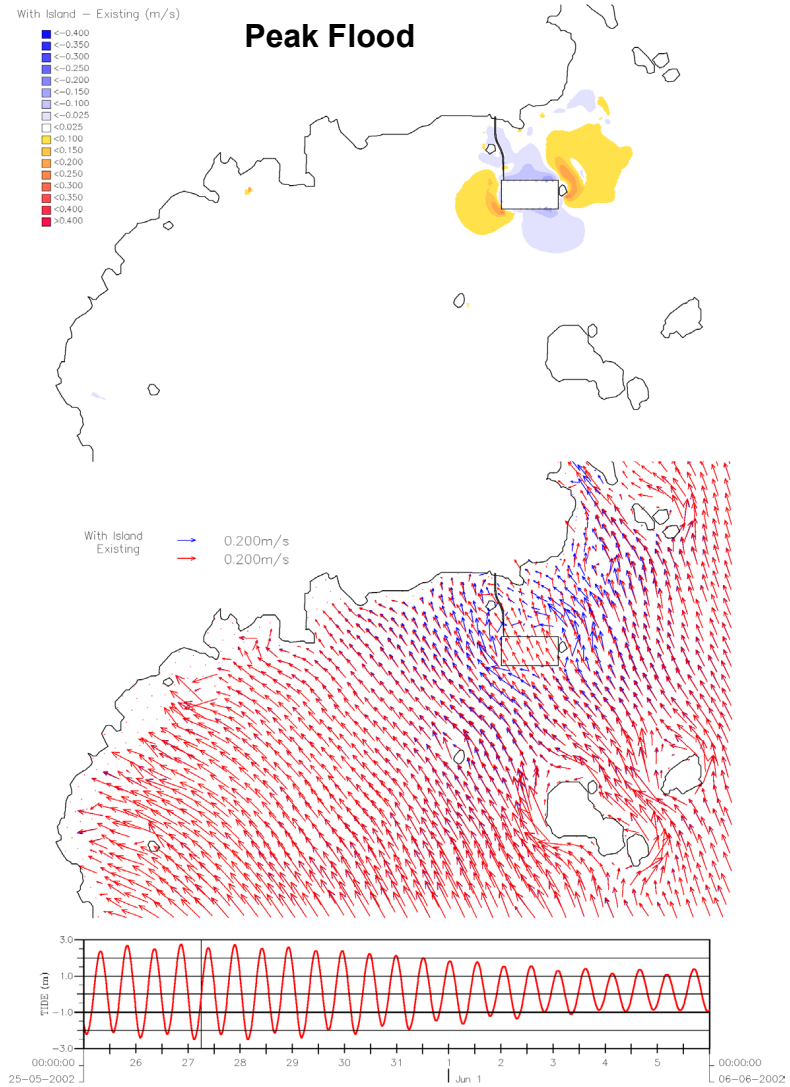


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FIGURE A-53:
Velocity differences. Spring Tide (LW, PF)
Hybrid AMU

Local model velocity differences and flow patterns: SPRING TIDE

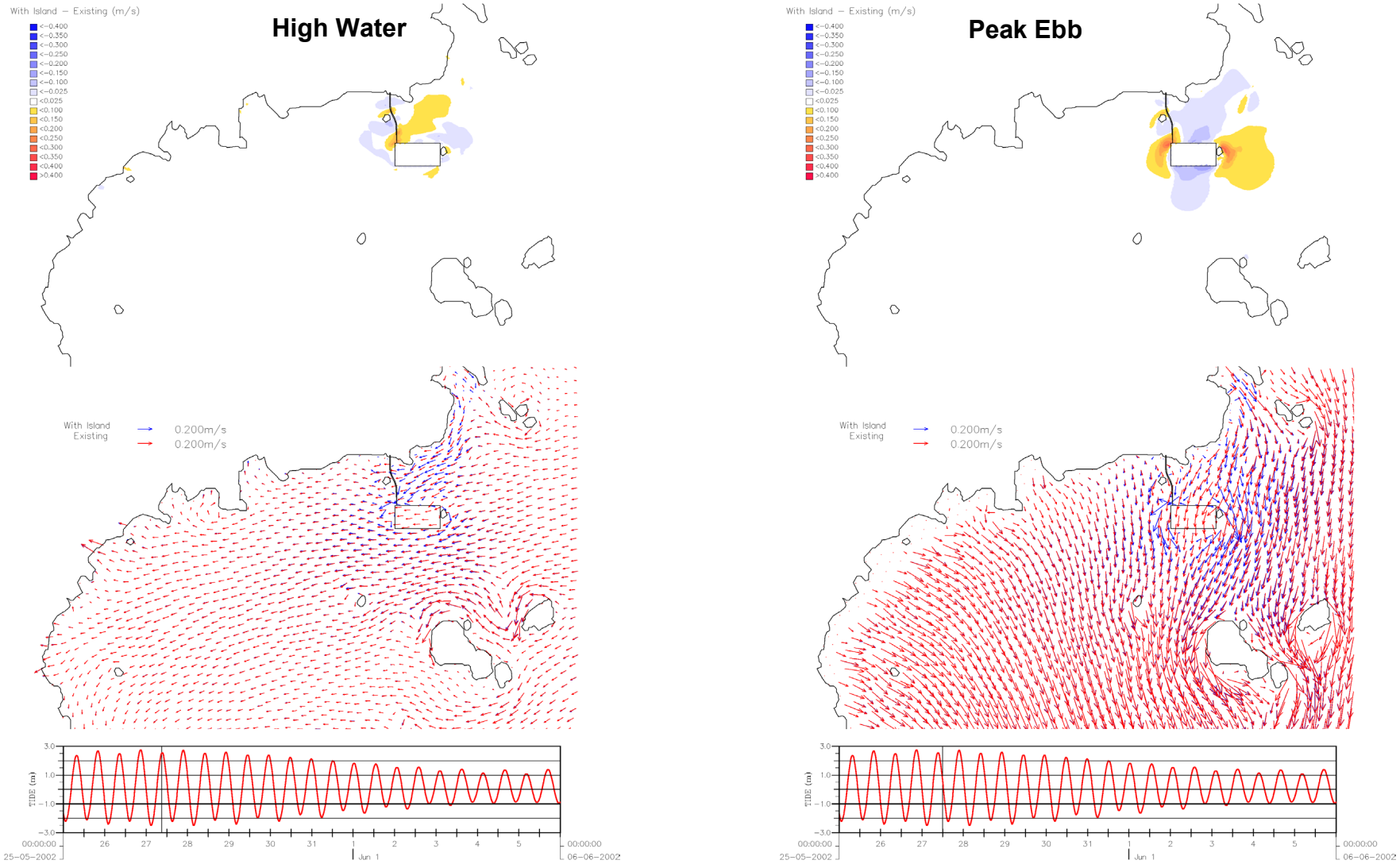

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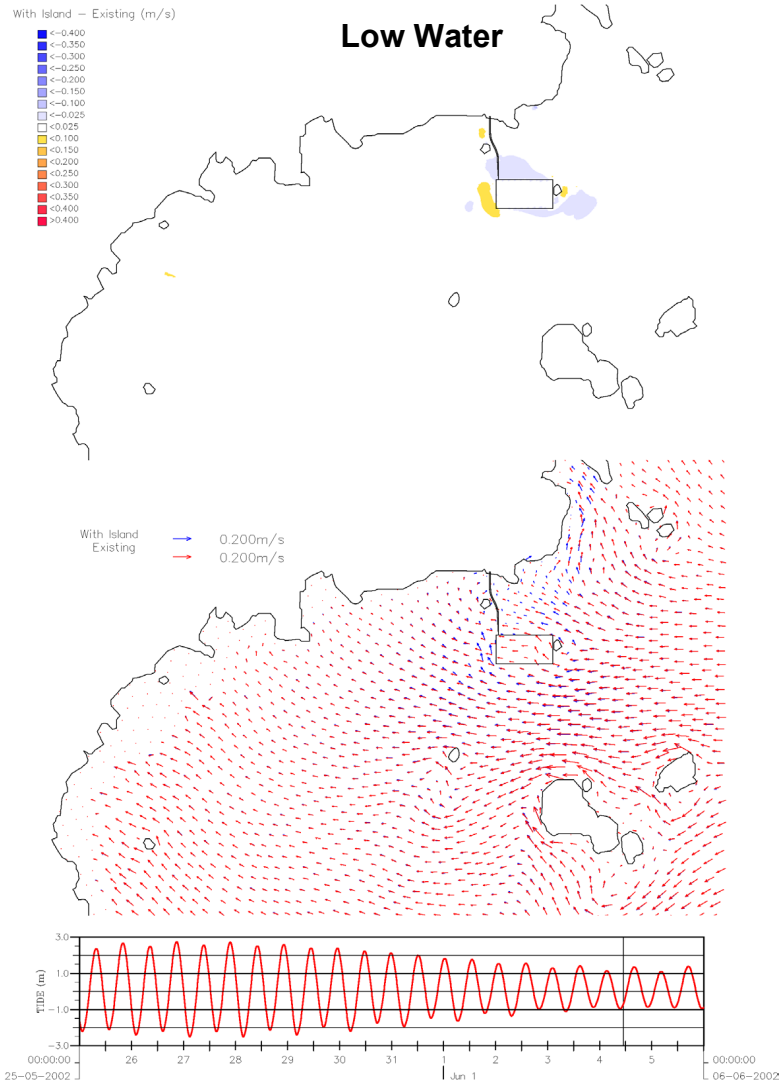
FIGURE A-54:
Velocity differences. Spring Tide (HW, PE)
Hybrid AMU

Local model velocity differences and flow patterns: NEAP TIDE



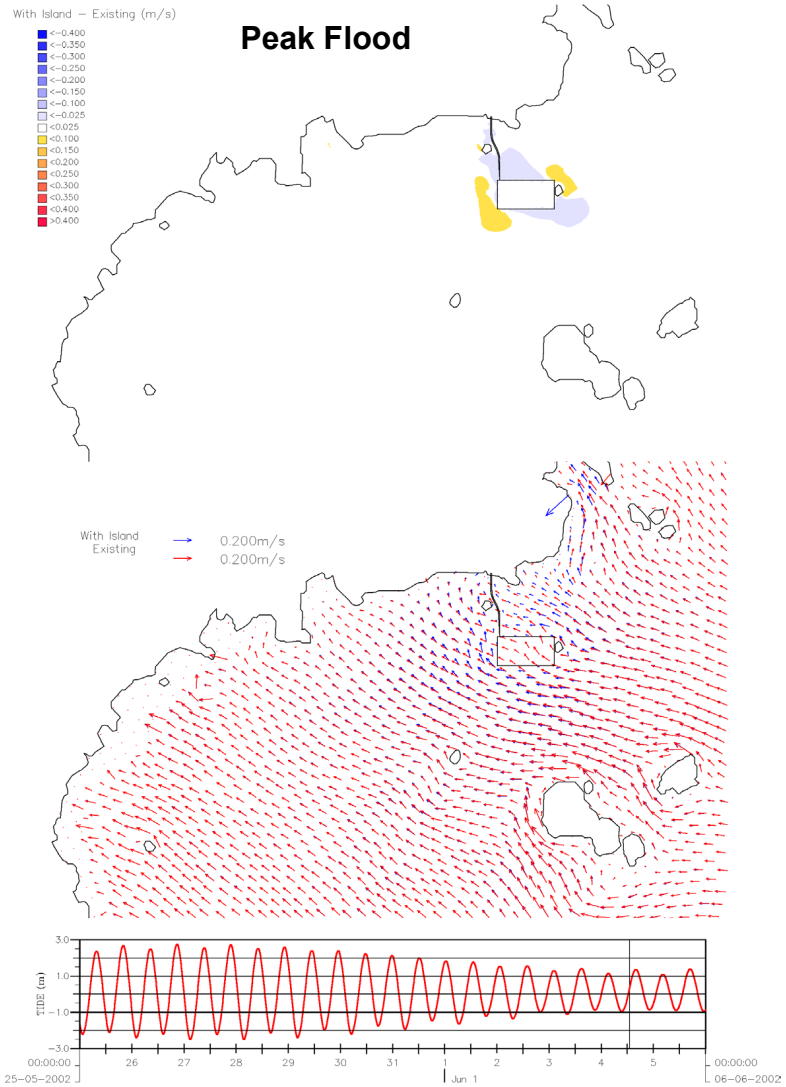


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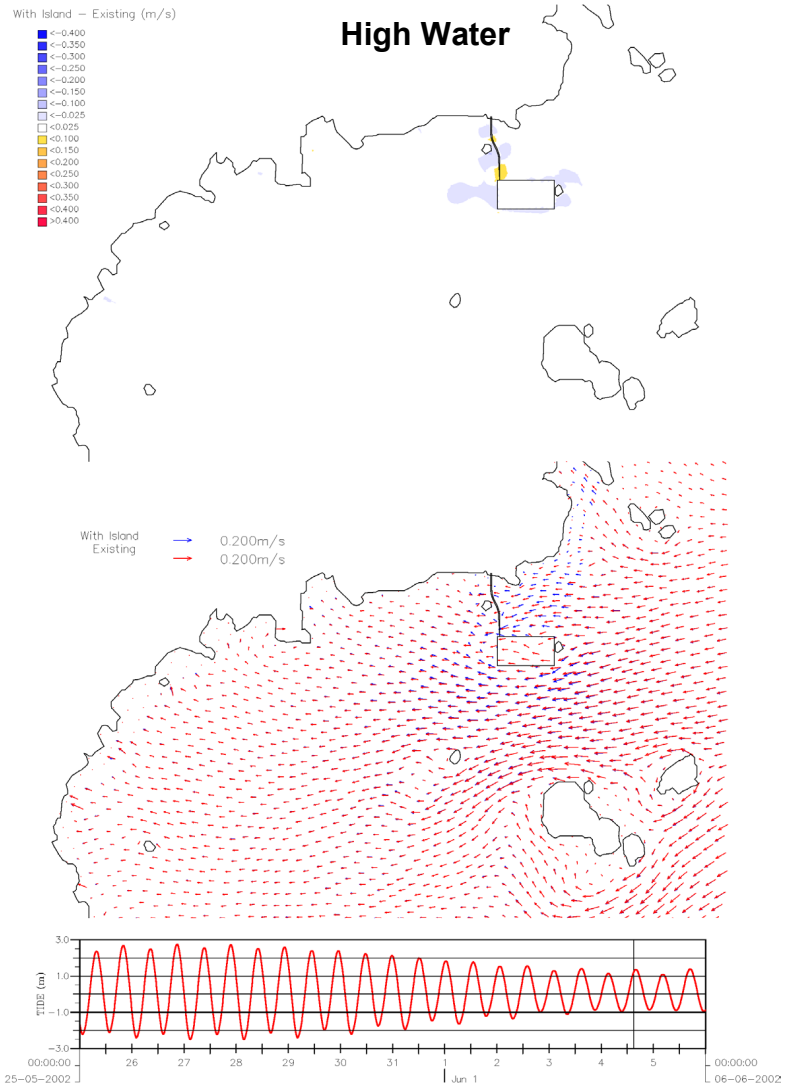
FIGURE A-55:
Velocity differences. Neap Tide (LW, PF)
Hybrid AMU

Local model velocity differences and flow patterns: NEAP TIDE



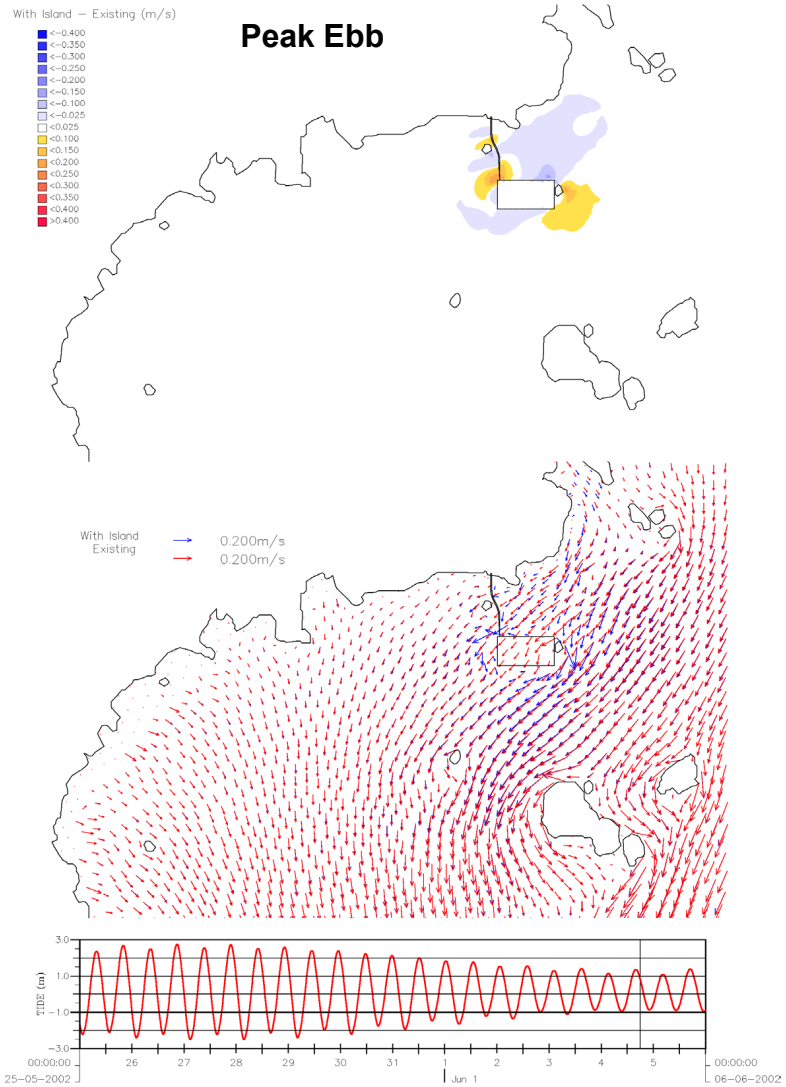


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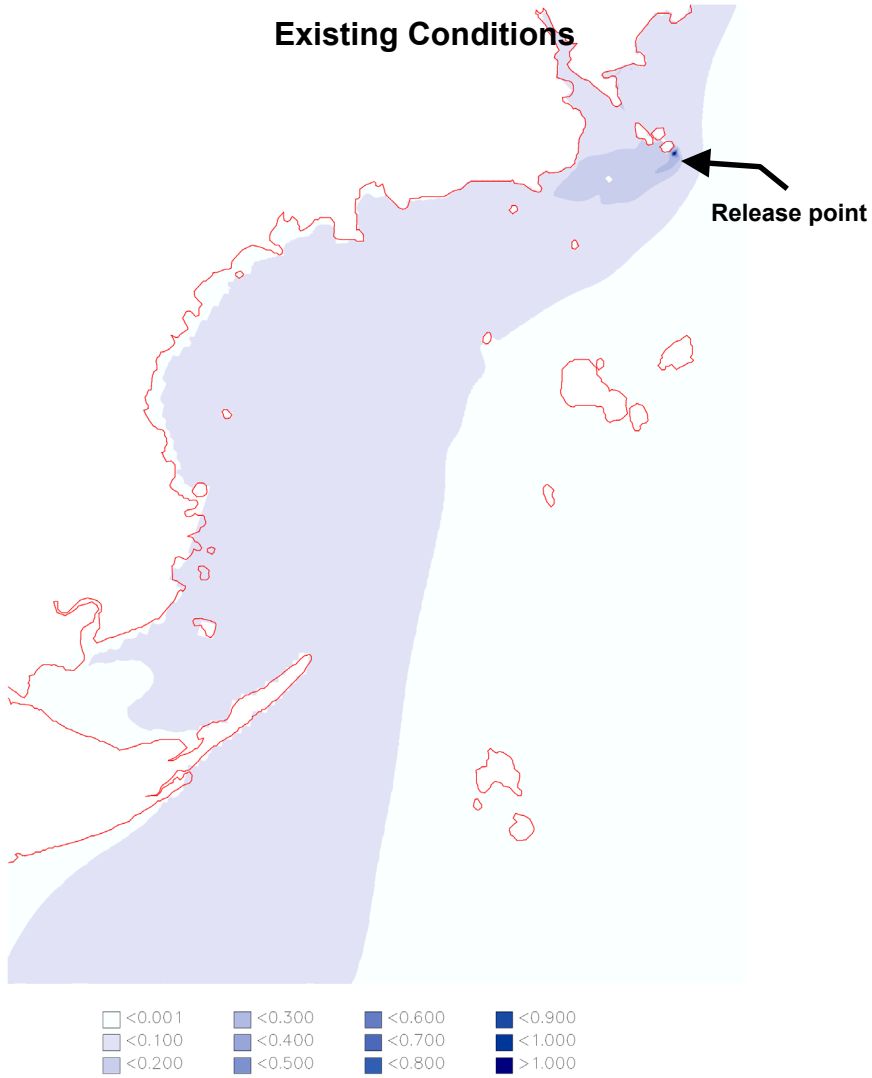
FIGURE A-56:
Velocity differences. Neap Tide (HW, PE)
Hybrid AMU

APPENDIX B – FIGURES FROM WATER QUALITY SIMULATIONS

Conservative tracer simulation: Release point Flamenca



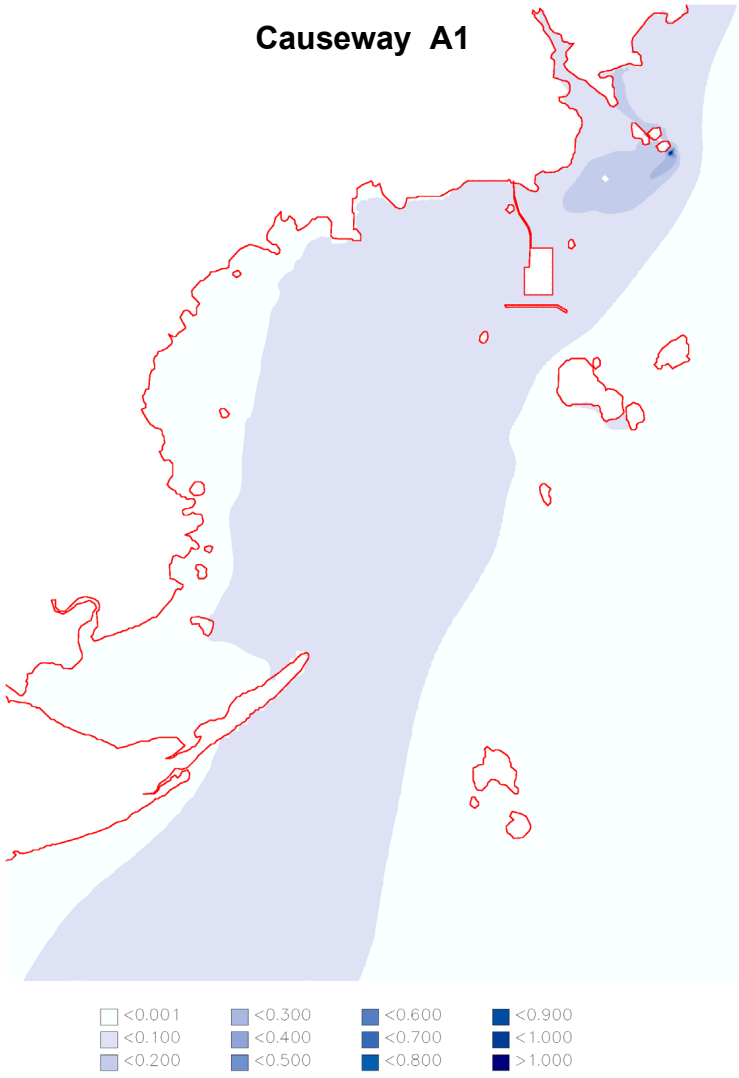


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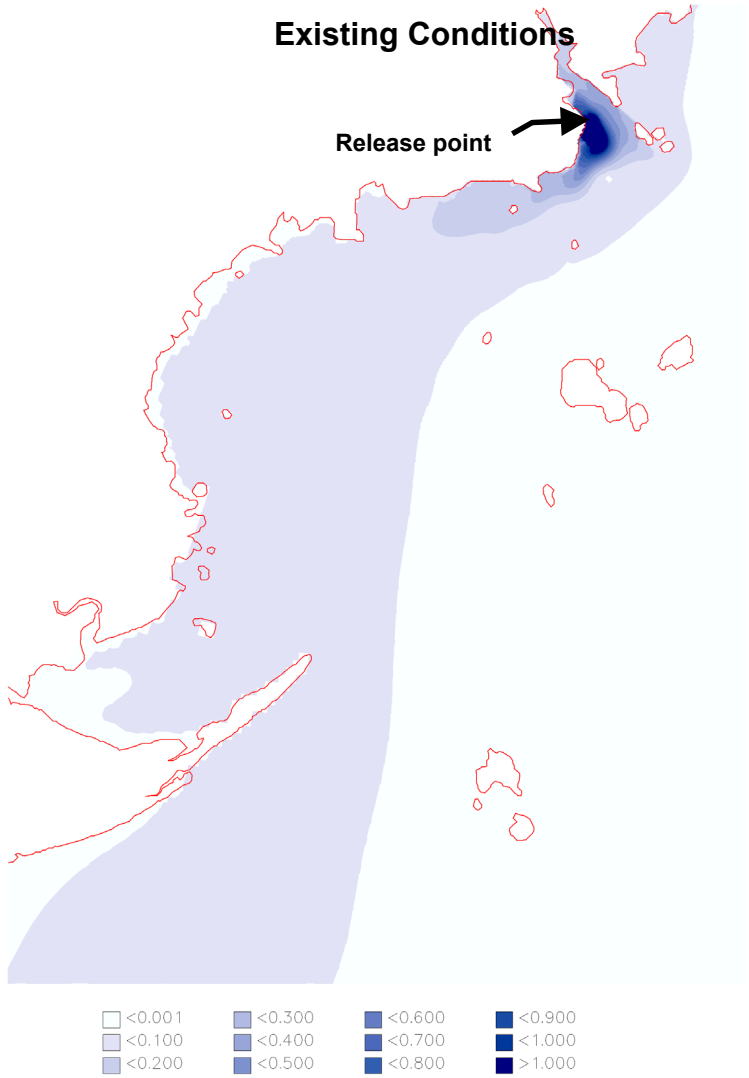
FIGURE B-1:
Concentration after 14 days
Release Point Flamenca -A1-C

Conservative tracer simulation: Release point Farfan



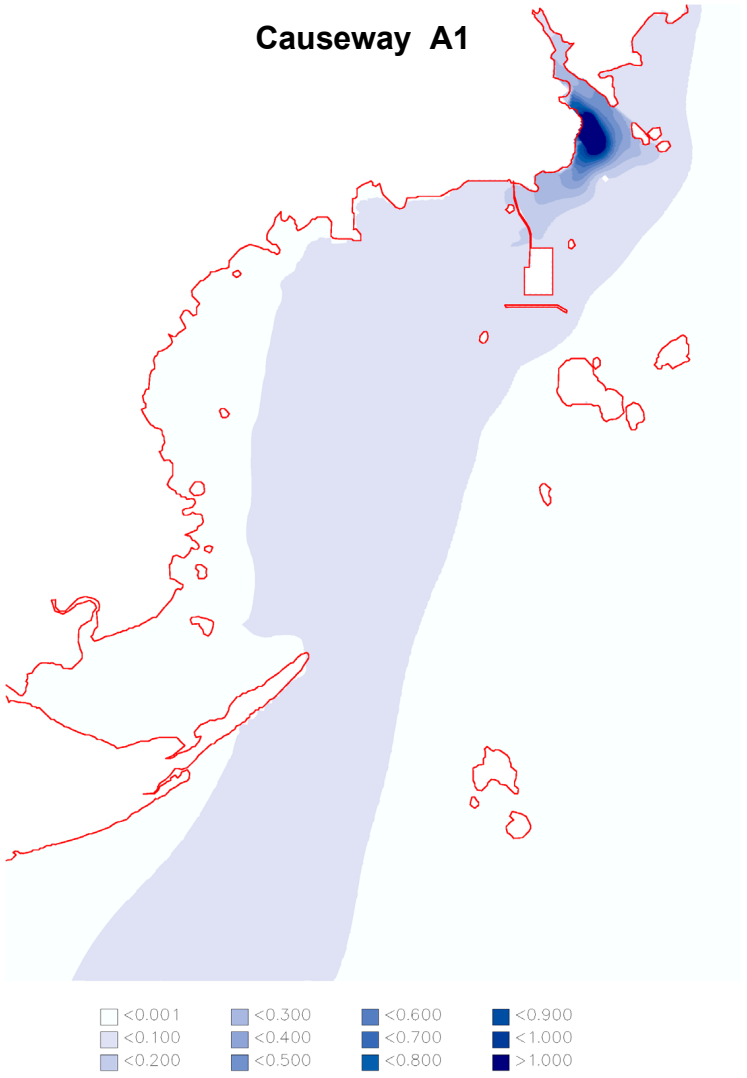


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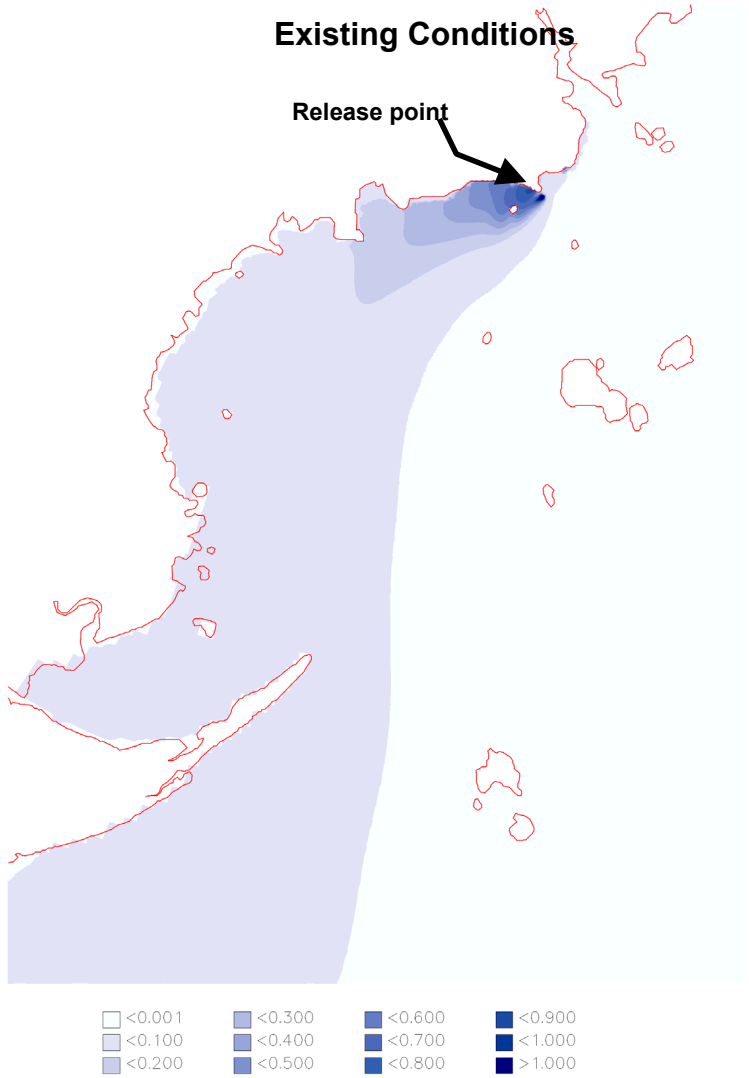
FIGURE B-2:
Concentration after 14 days
Release Point Farfan-A1-C

Conservative tracer simulation: Release point Punta Bruja



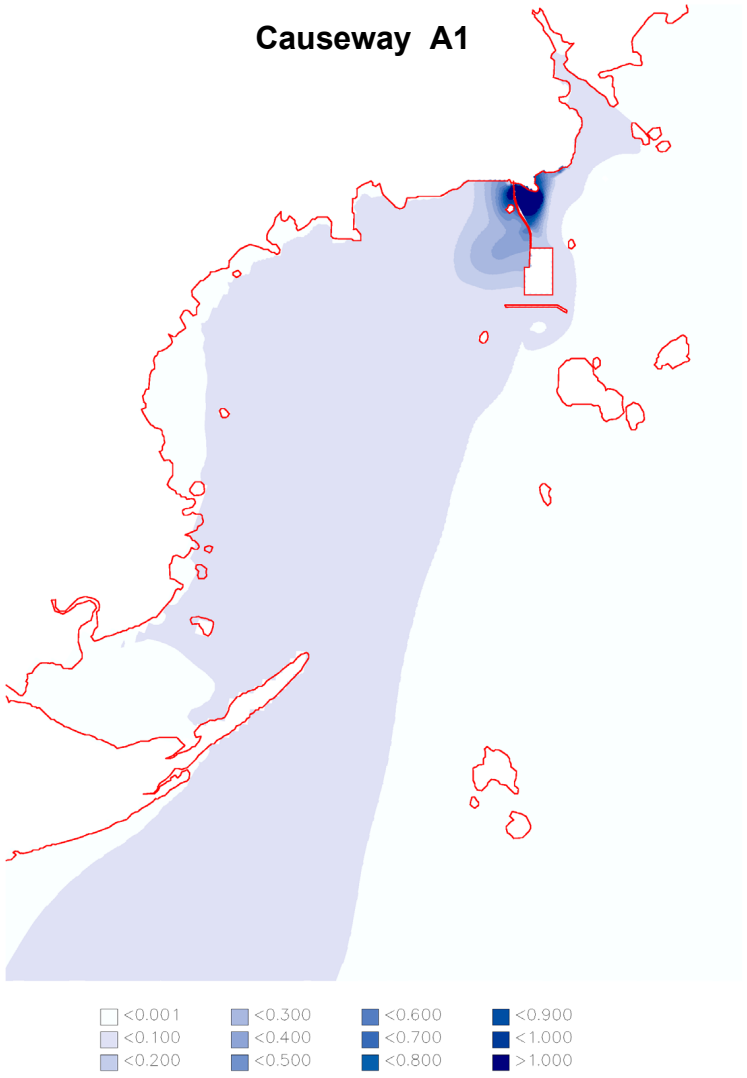


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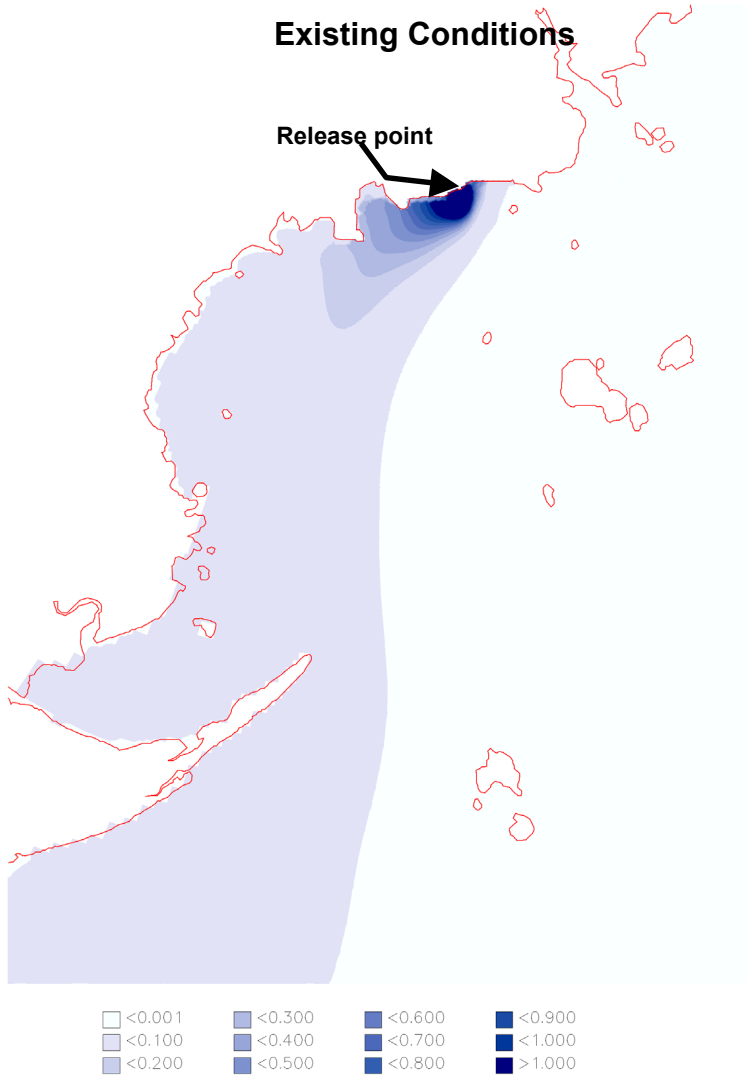
FIGURE B-3:
Concentration after 14 days
Release Point Punta Bruja-A1-C

Conservative tracer simulation: Release point Veracruz



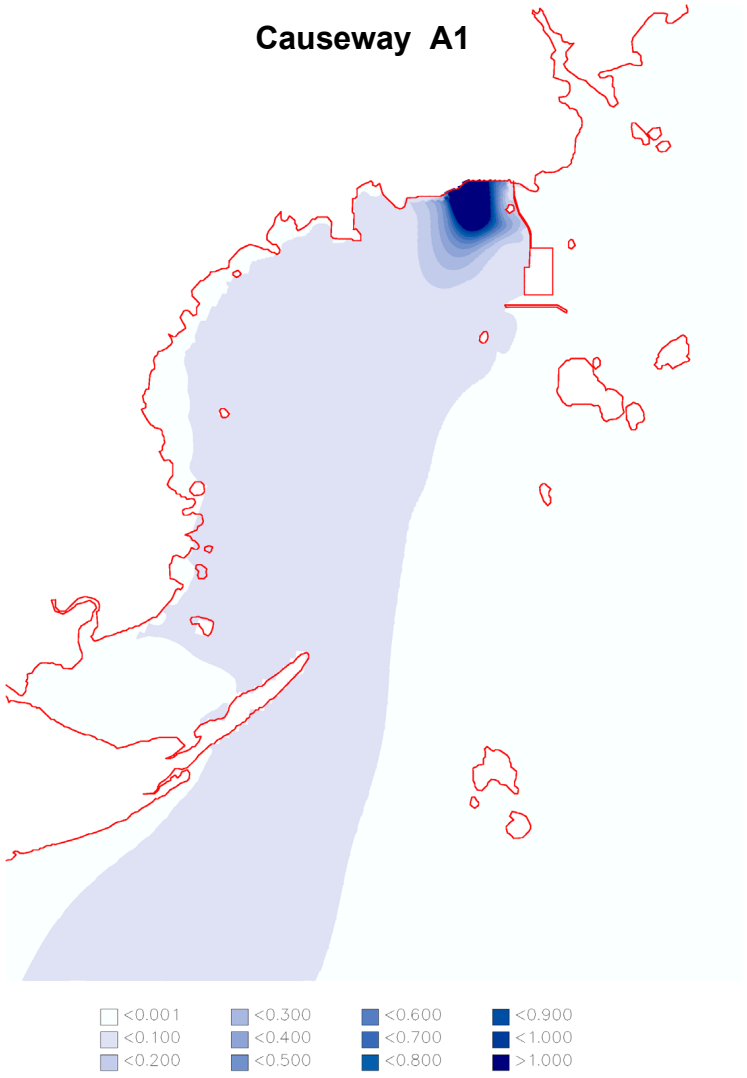


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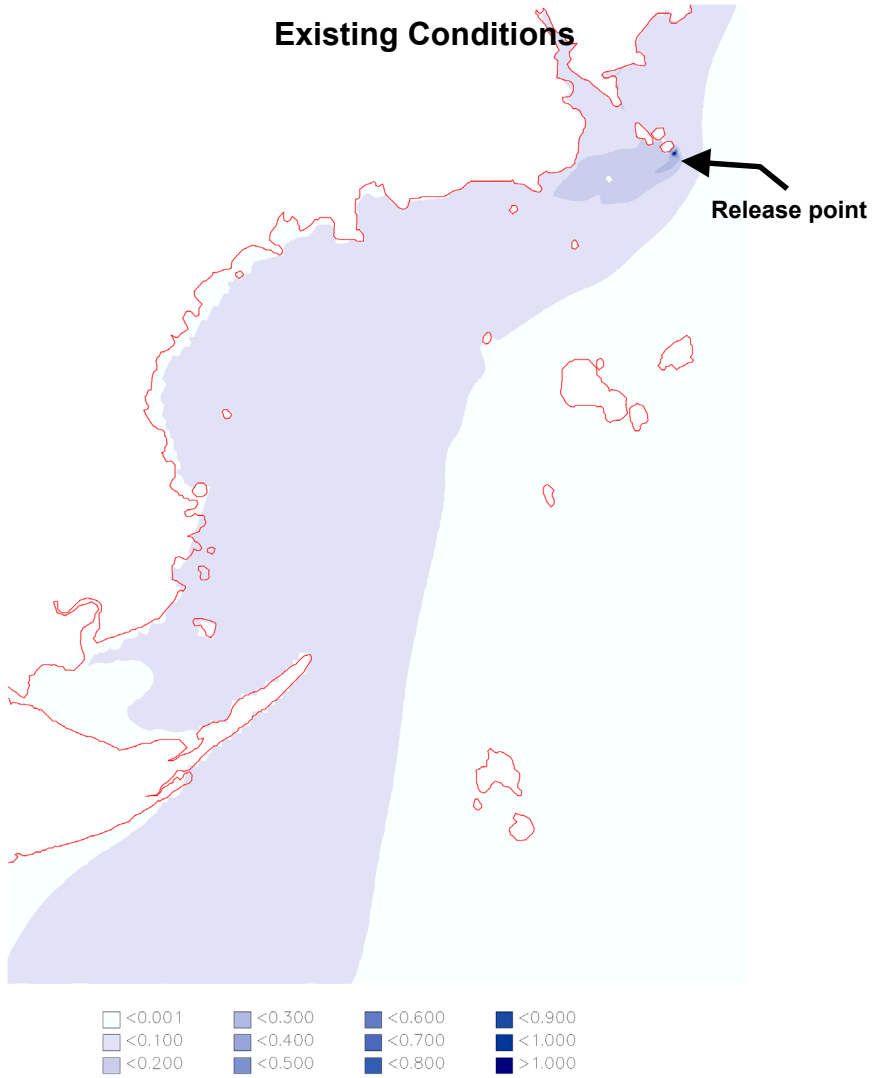
FIGURE B-4:
Concentration after 14 days
Release Point Veracruz-A1-C

Conservative tracer simulation: Release point Flamenca



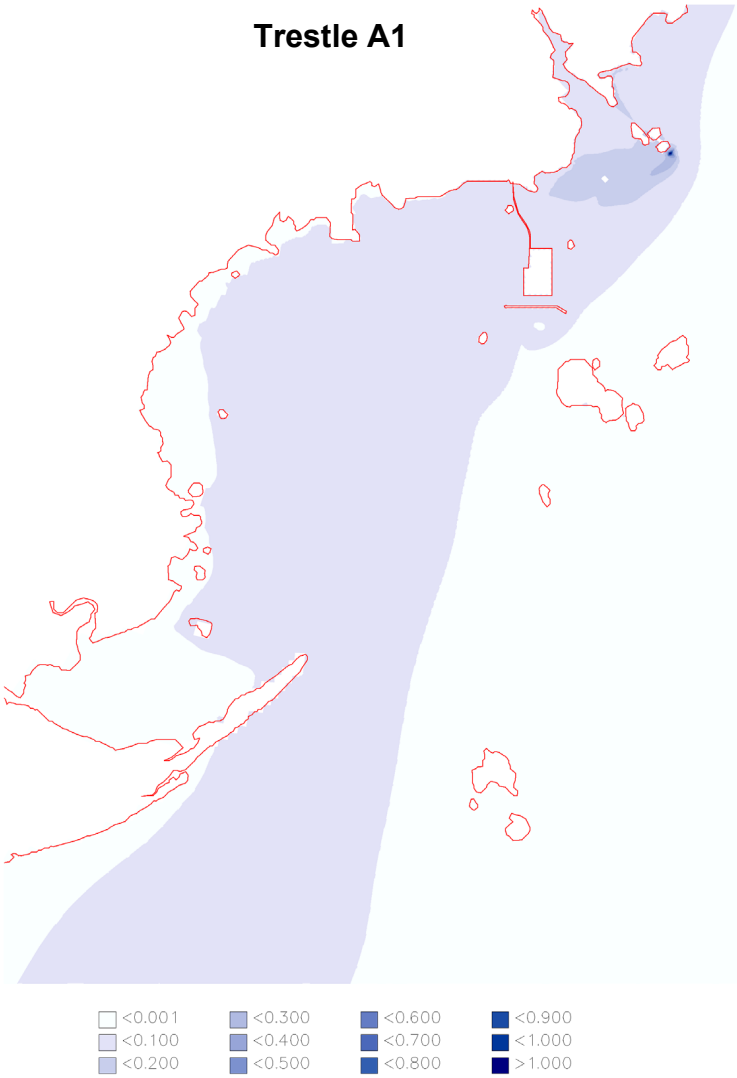


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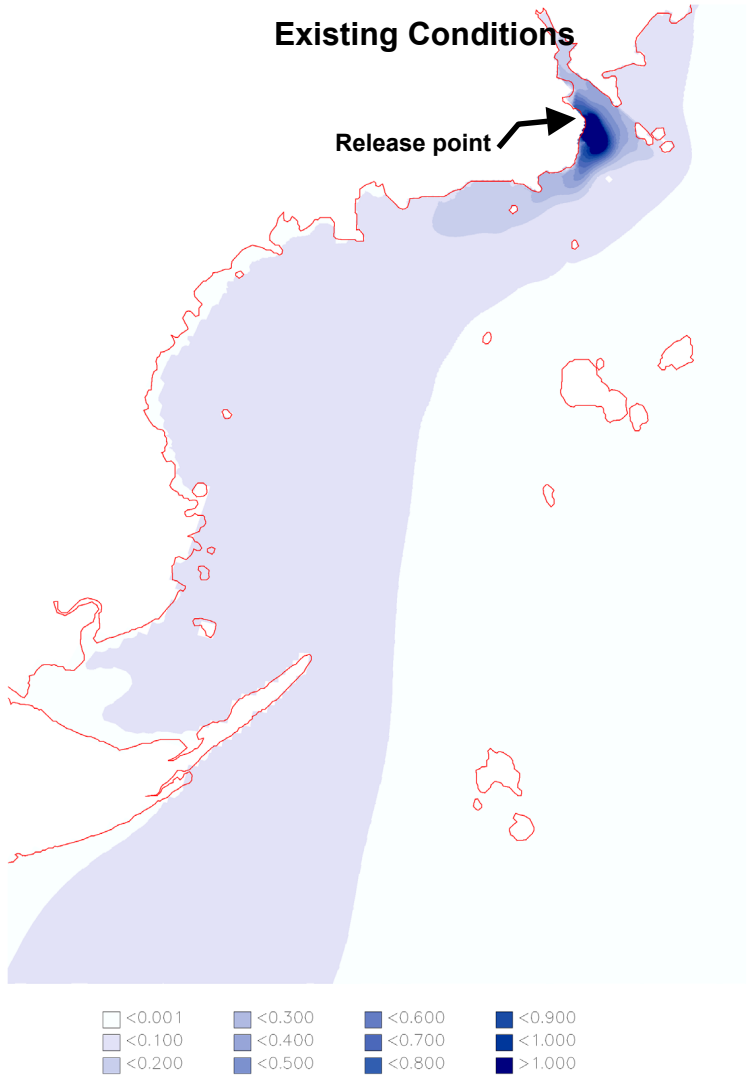
FIGURE B-5:
Concentration after 14 days
Release Point Flamenca-A1-T

Conservative tracer simulation: Release point Farfan



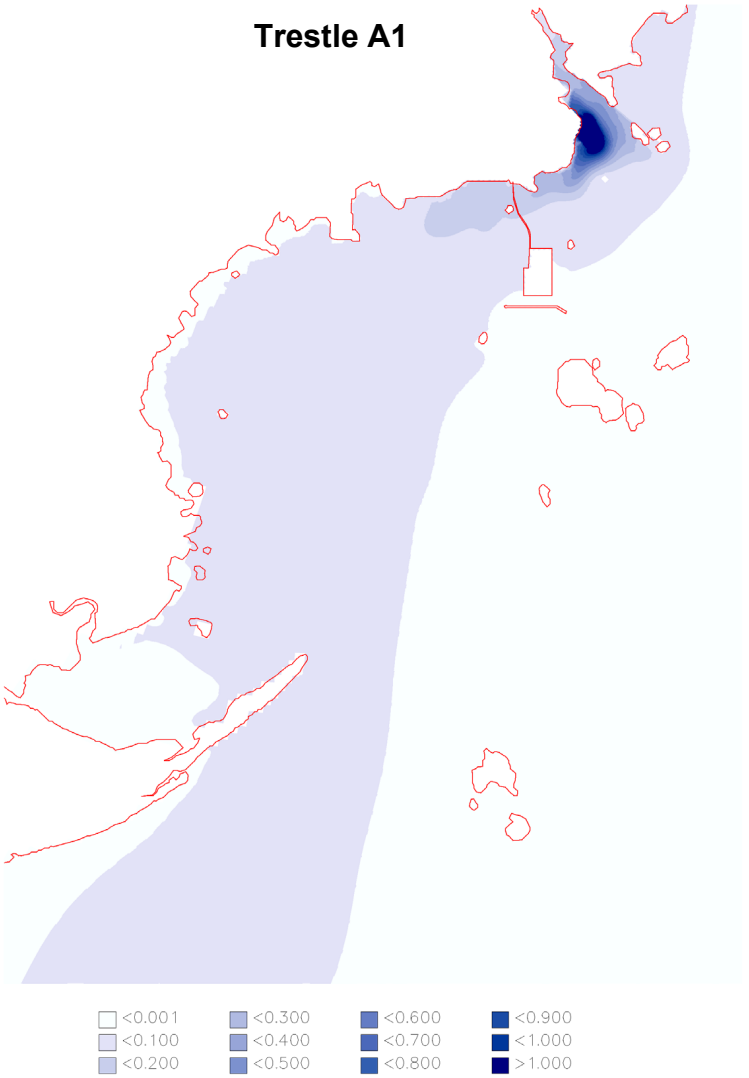


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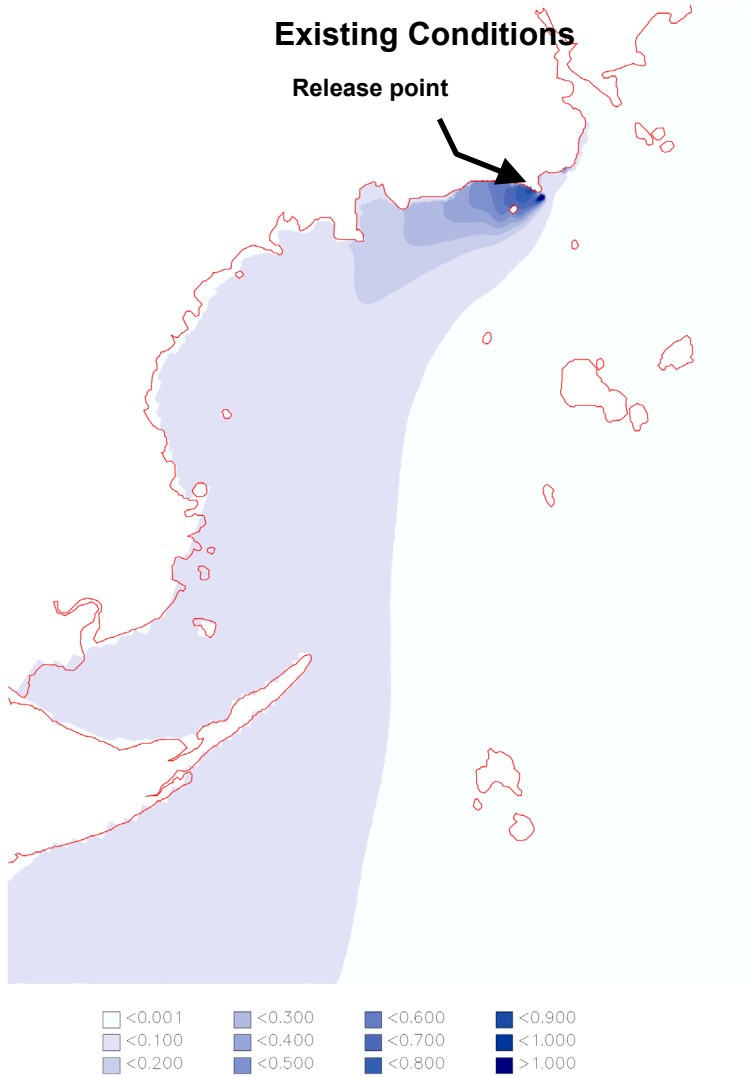
FIGURE B-6:
Concentration after 14 days
Release Point Farfan-A1-T

Conservative tracer simulation: Release point Punta Bruja



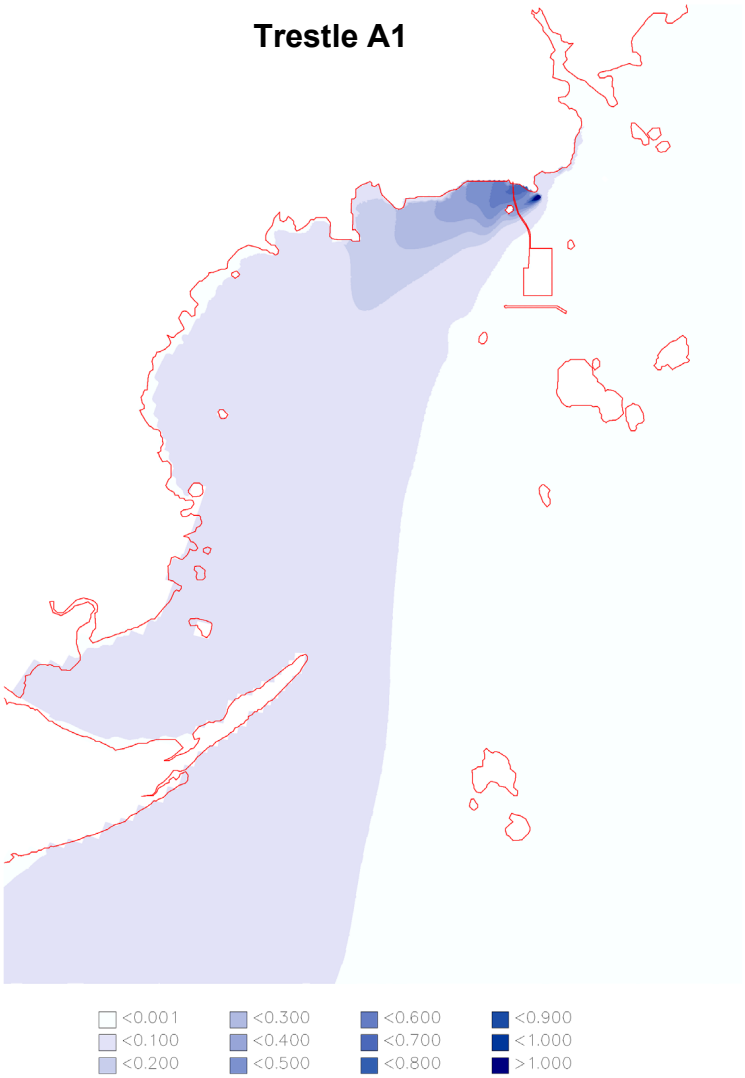


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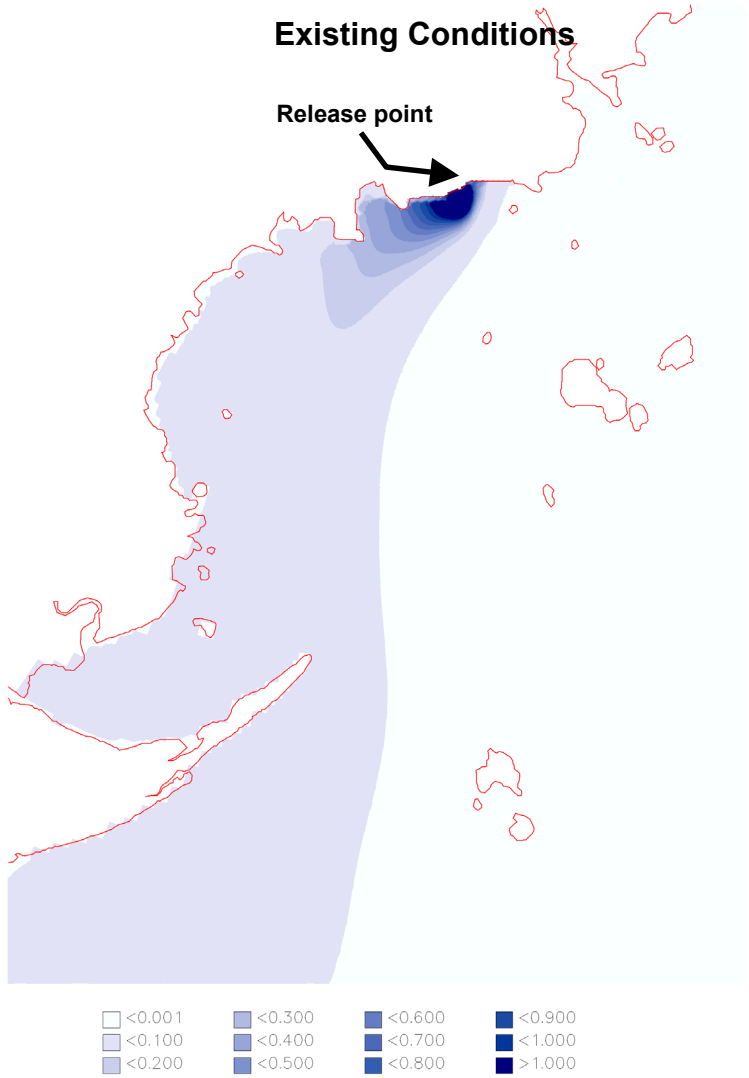
FIGURE B-7:
Concentration after 14 days
Release Point Punta Bruja-A1-T

Conservative tracer simulation: Release point Veracruz



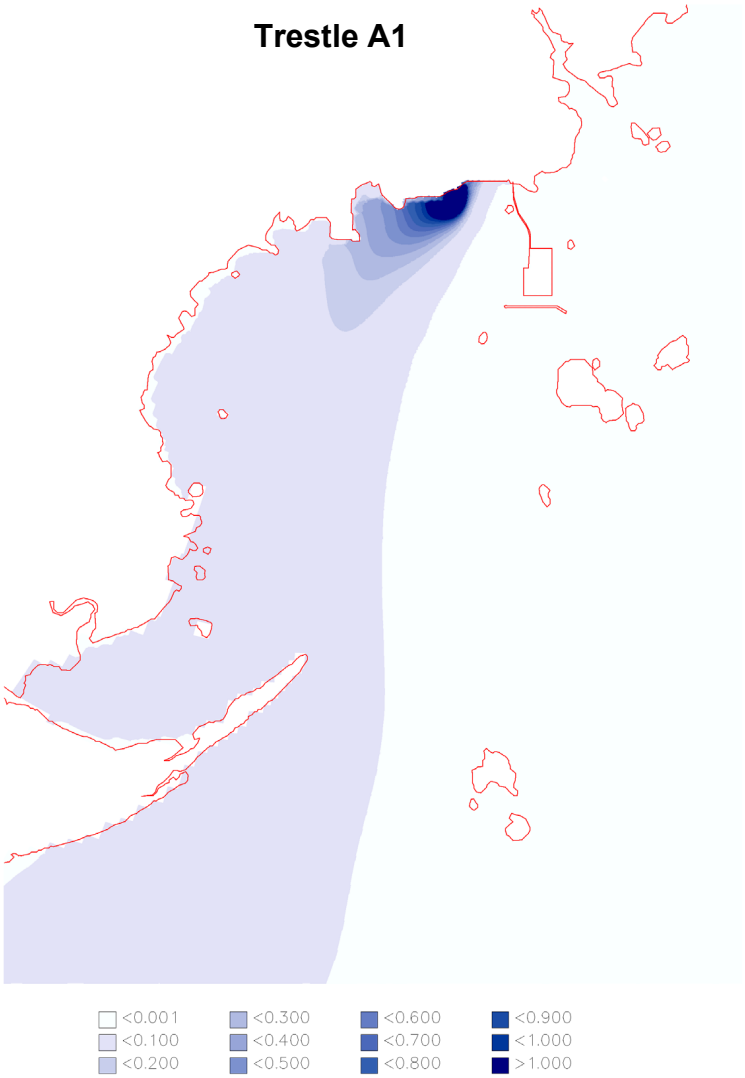


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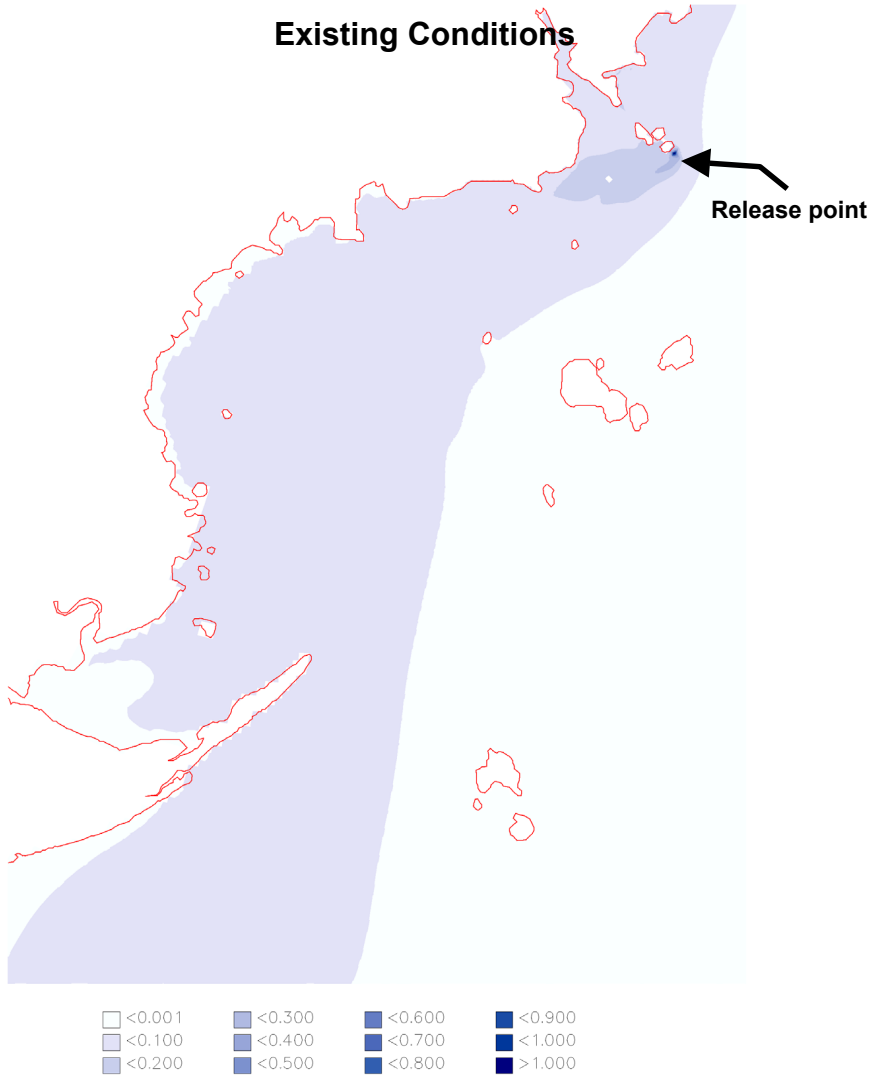
FIGURE B-8:
Concentration after 14 days
Release Point Veracruz-A1-T

Conservative tracer simulation: Release point Flamenca



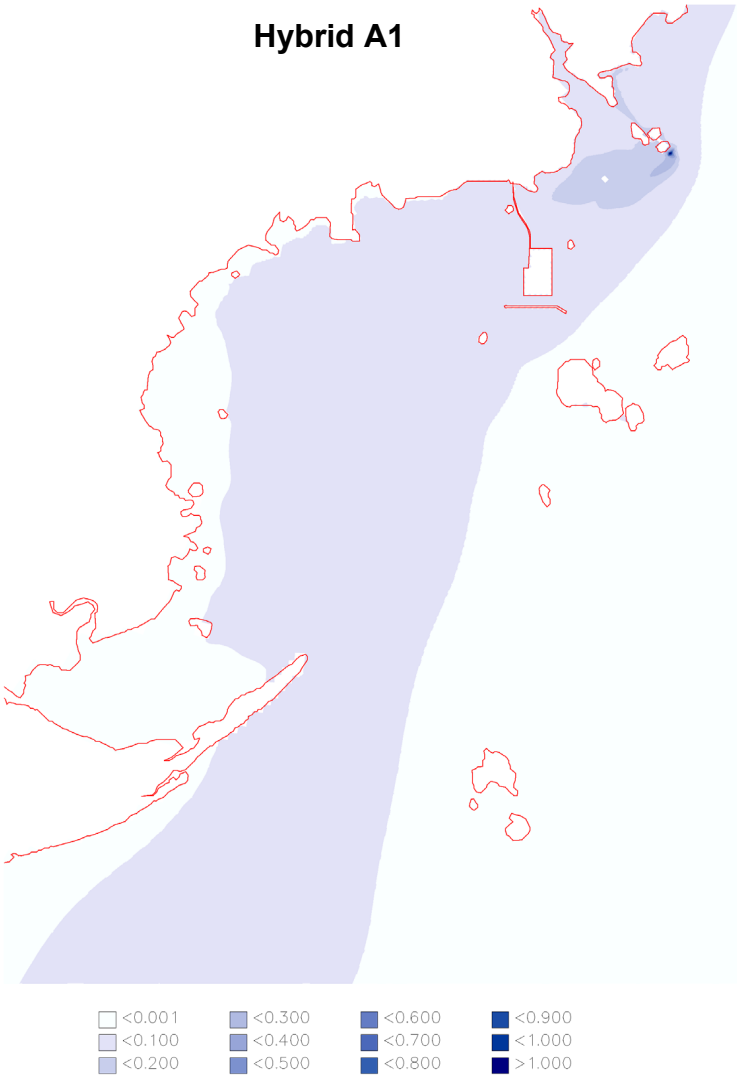


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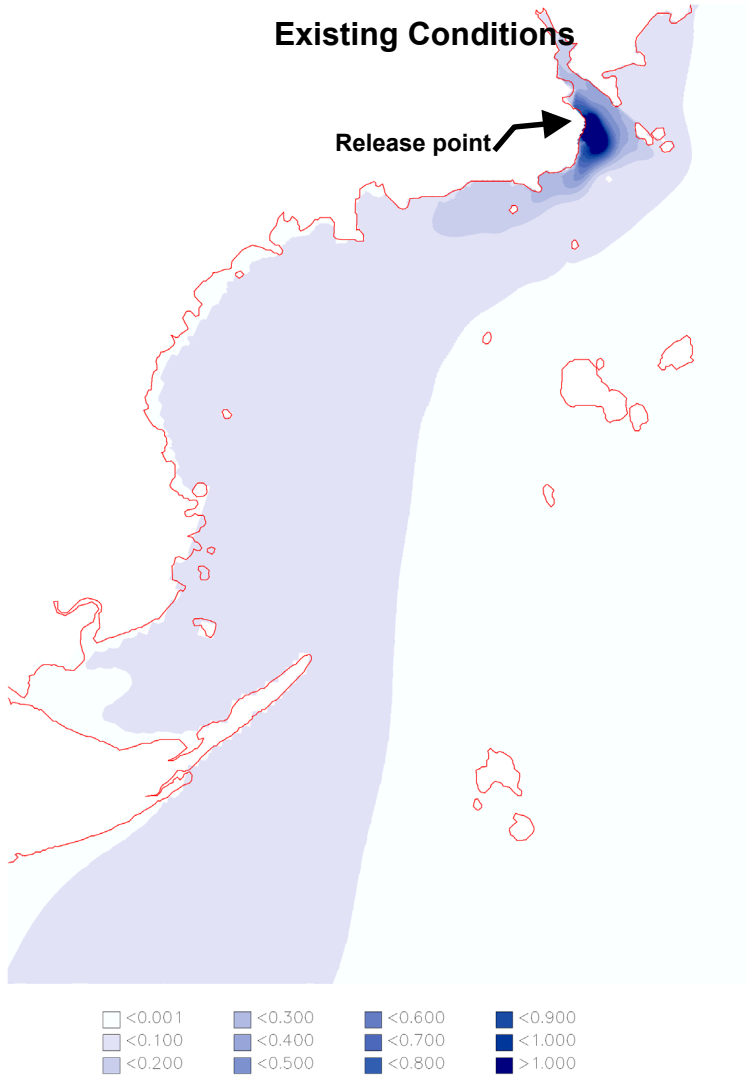
FIGURE B-9 :
Concentration after 14 days
Release Point Flamenca-A1-H

Conservative tracer simulation: Release point Farfan



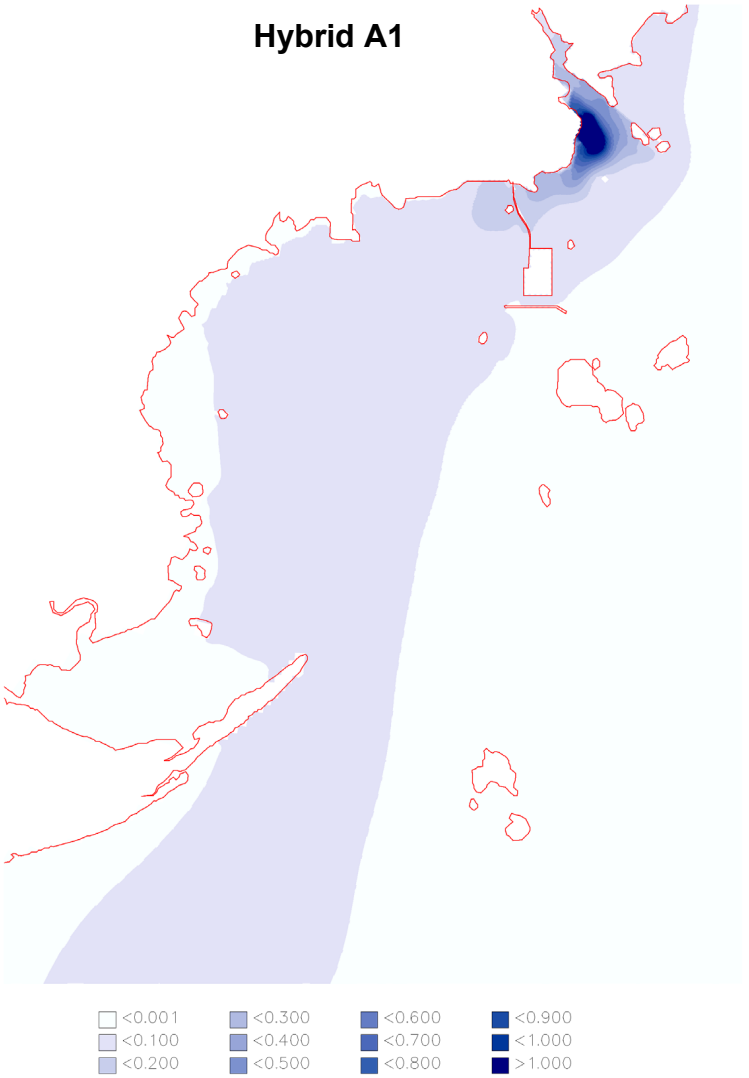


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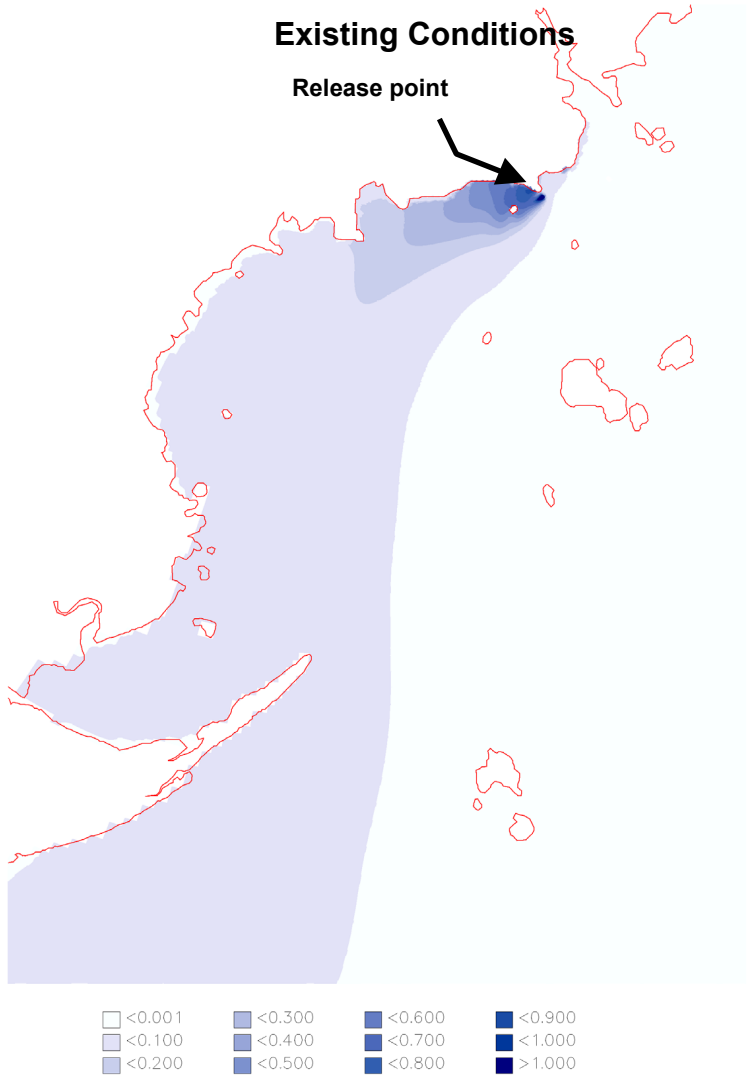
FIGURE B-10:
Concentration after 14 days
Release Point Farfan-A1-H

Conservative tracer simulation: Release point Punta Bruja



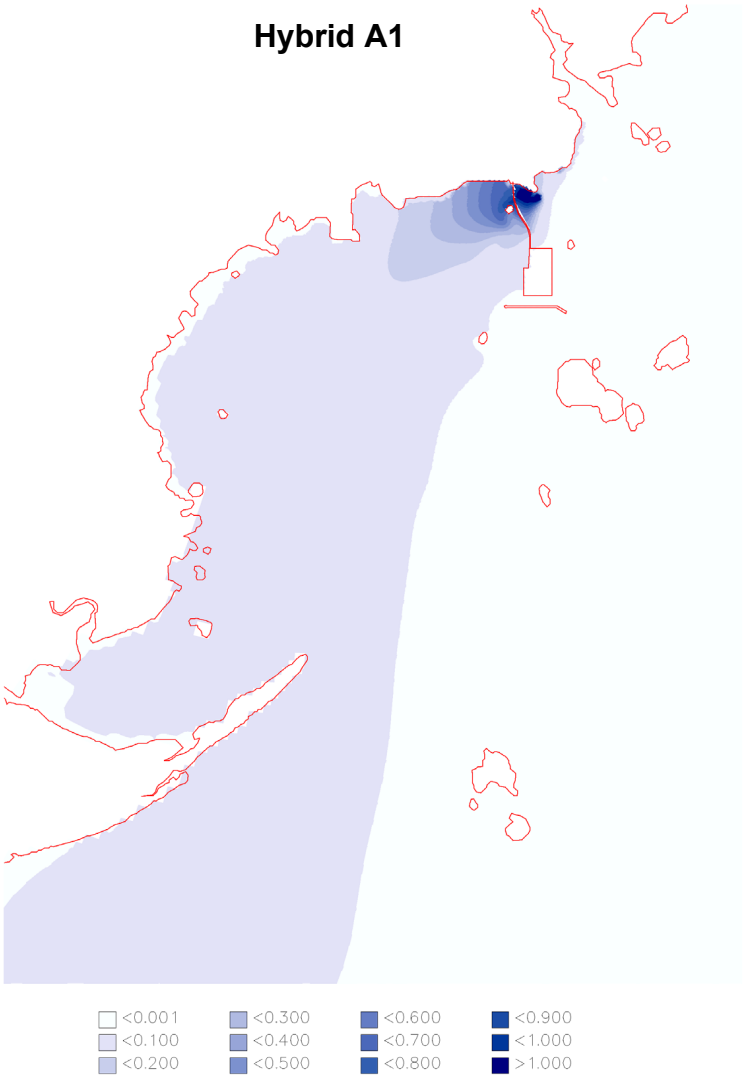


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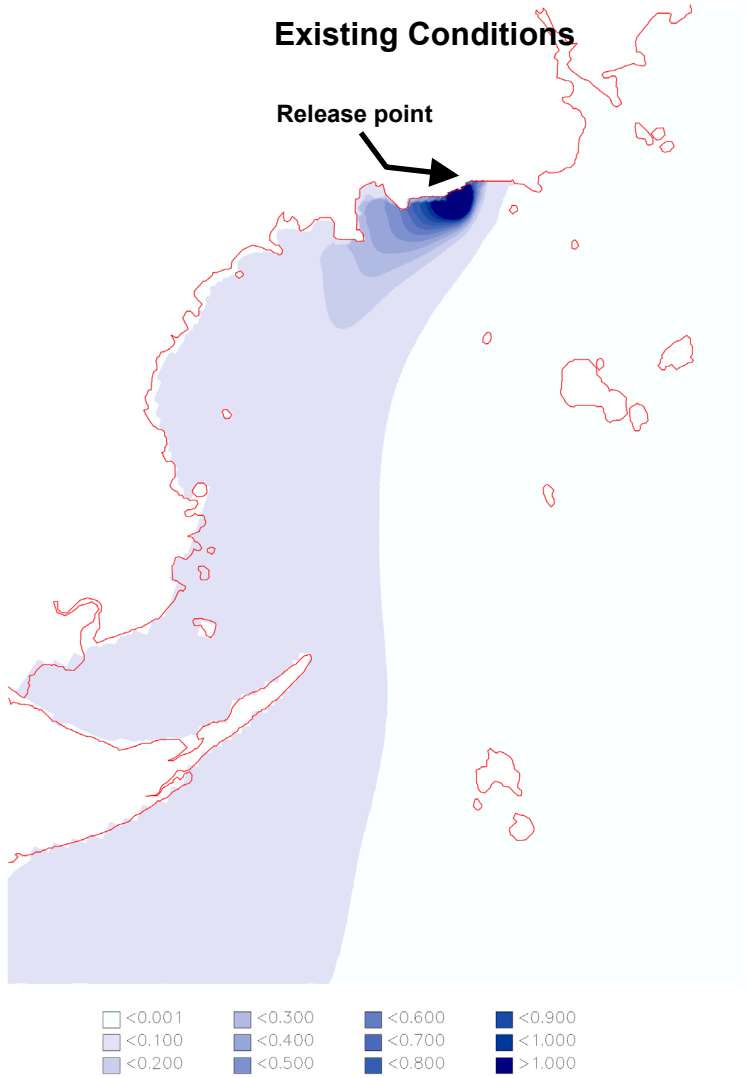
FIGURE B-11:
Concentration after 14 days
Release Point Punta Bruja-A1-H

Conservative tracer simulation: Release point Veracruz



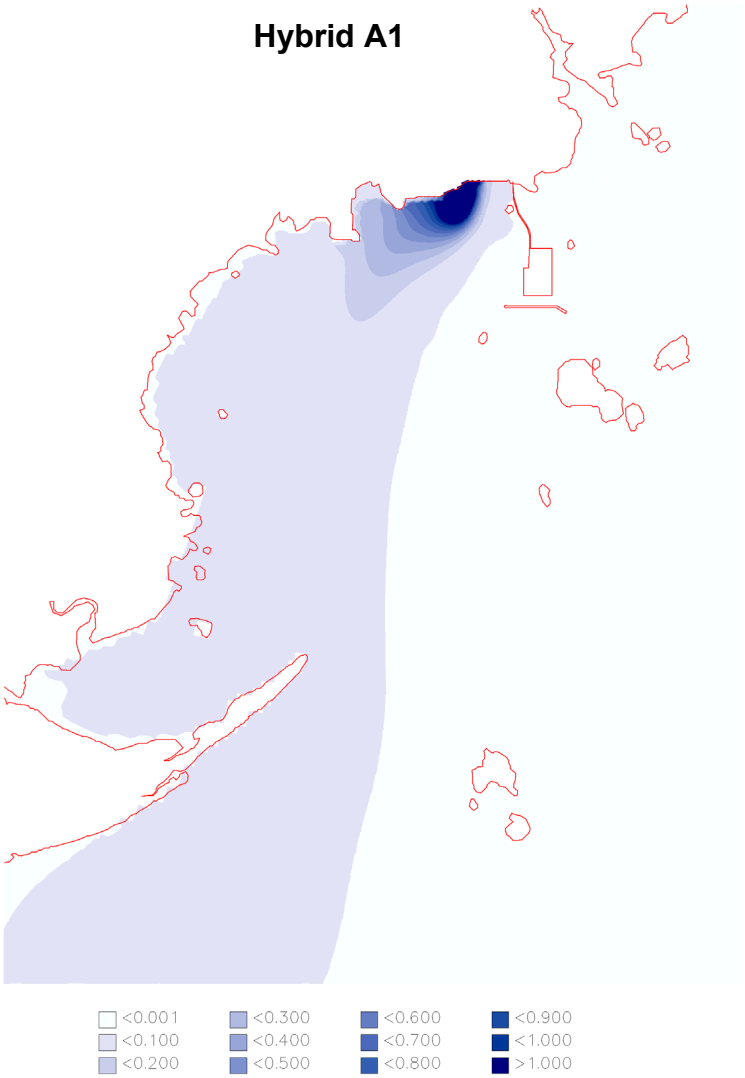


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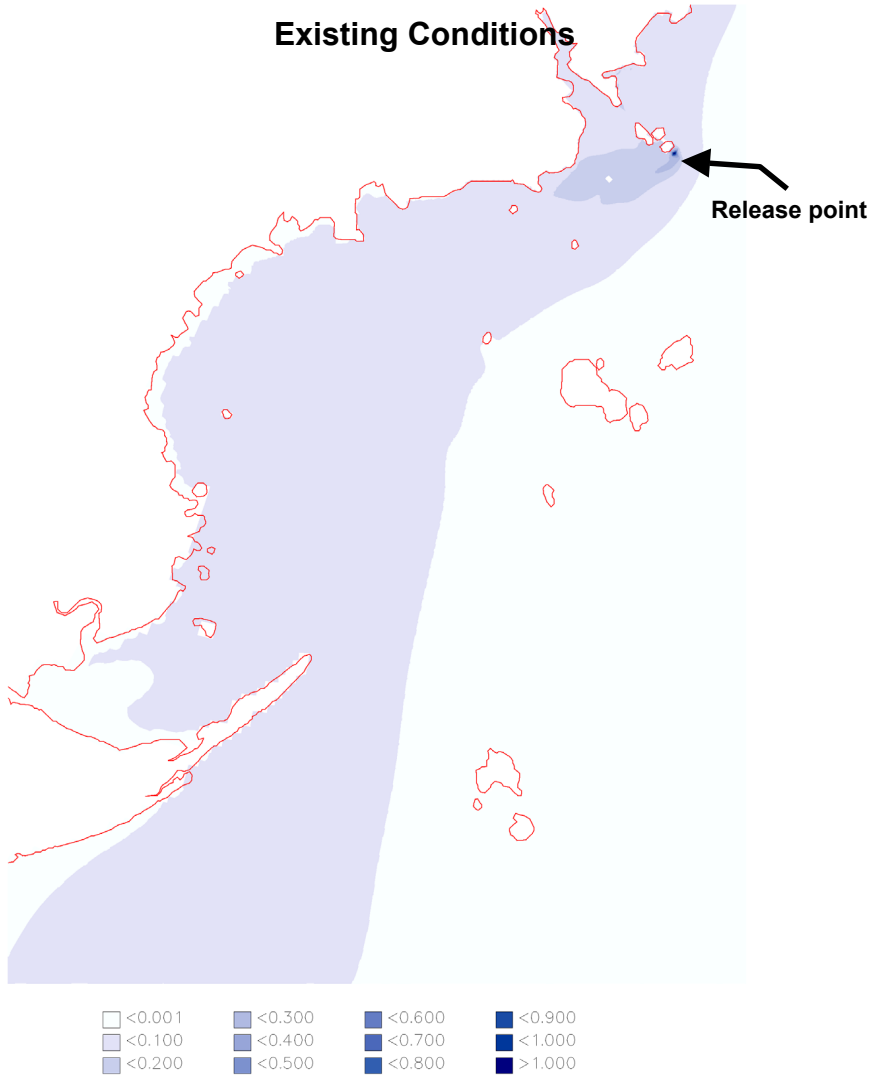
FIGURE B-12 :
Concentration after 14 days
Release Point Veracruz-A1-H

Conservative tracer simulation: Release point Flamenca



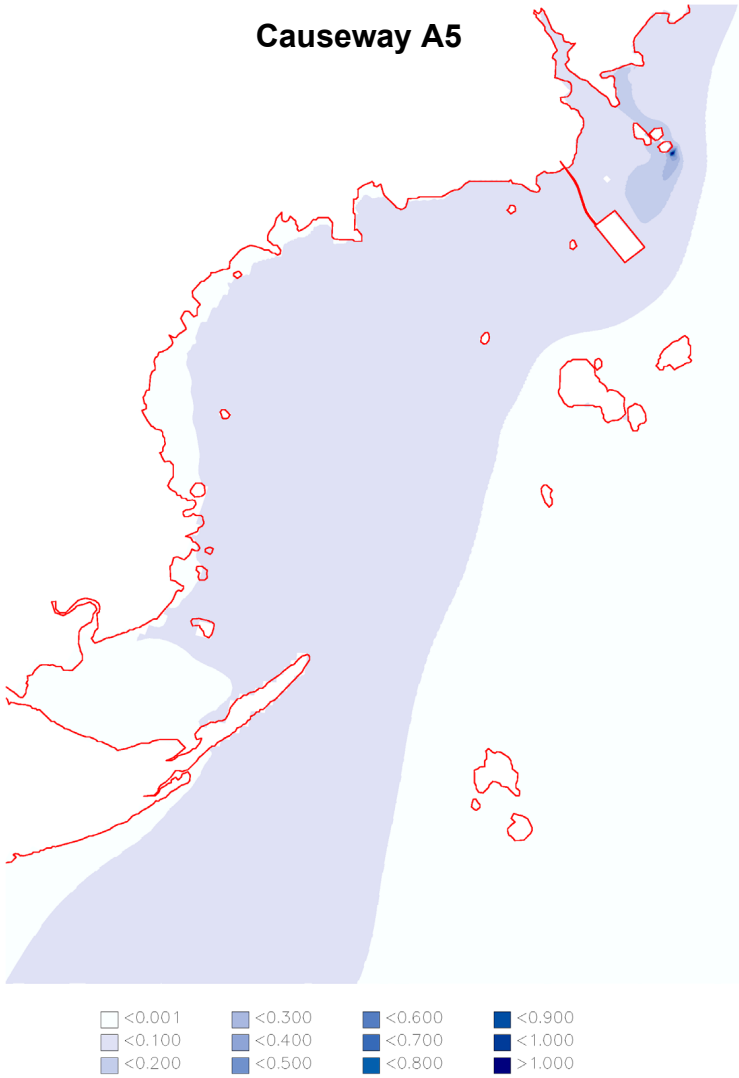


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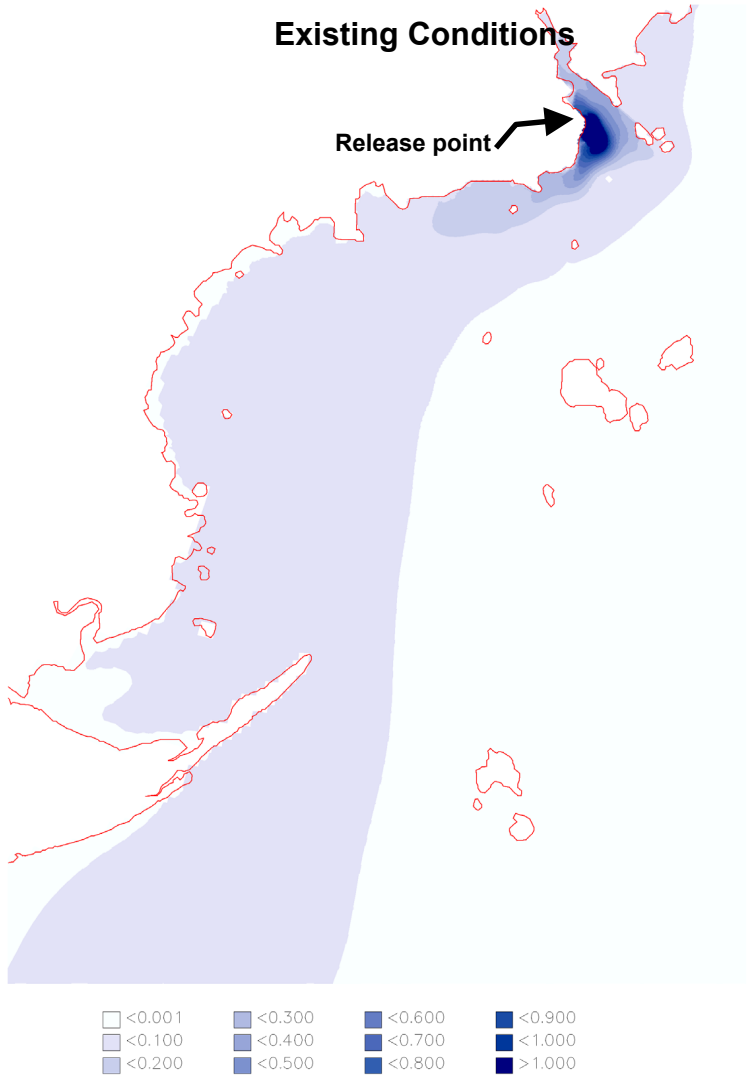
FIGURE B-13:
Concentration after 14 days
Release Point Flamenca-A5-C

Conservative tracer simulation: Release point Farfan



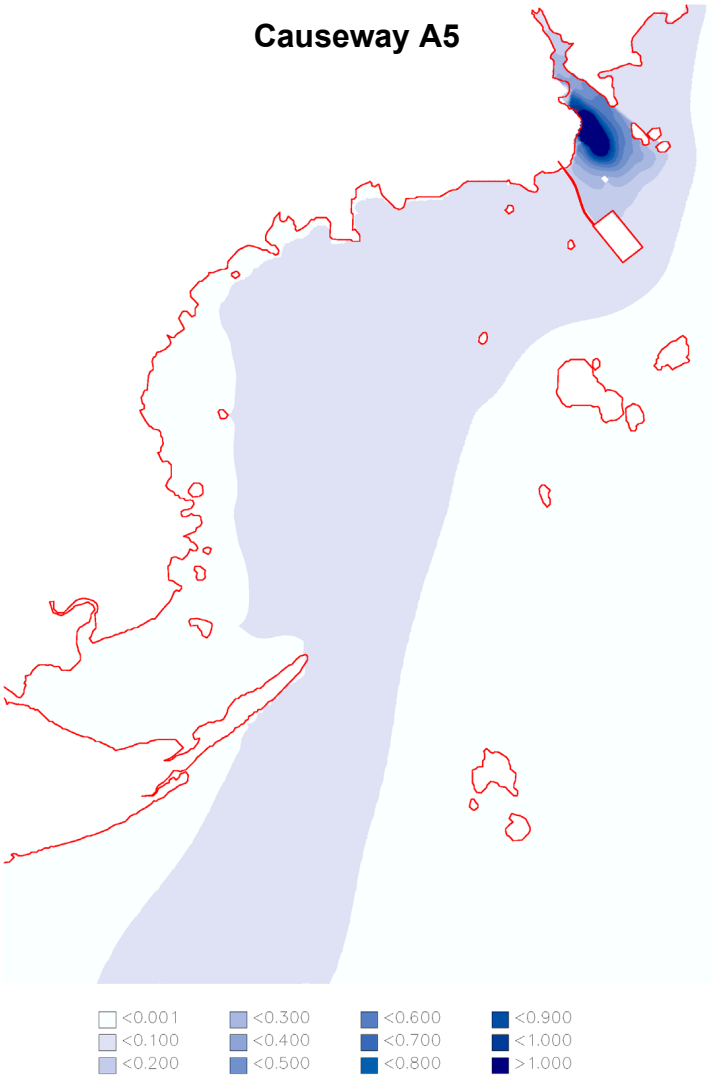


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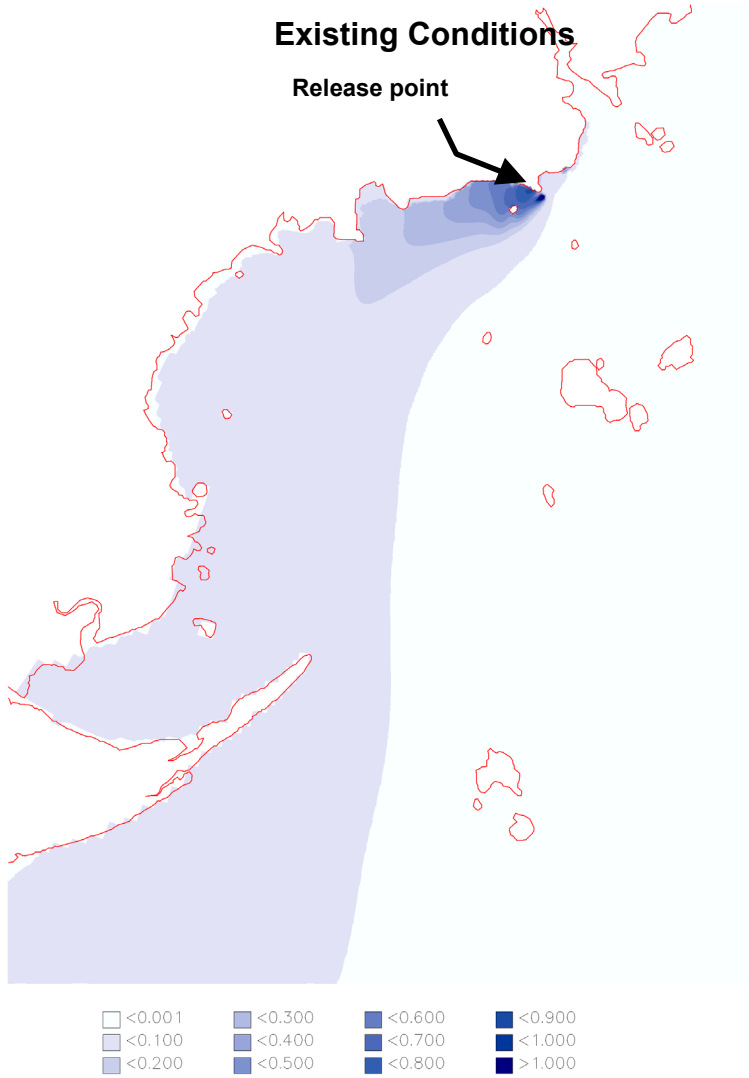
FIGURE B-14:
Concentration after 14 days
Release Point Farfan-A5-C

Conservative tracer simulation: Release point Punta Bruja



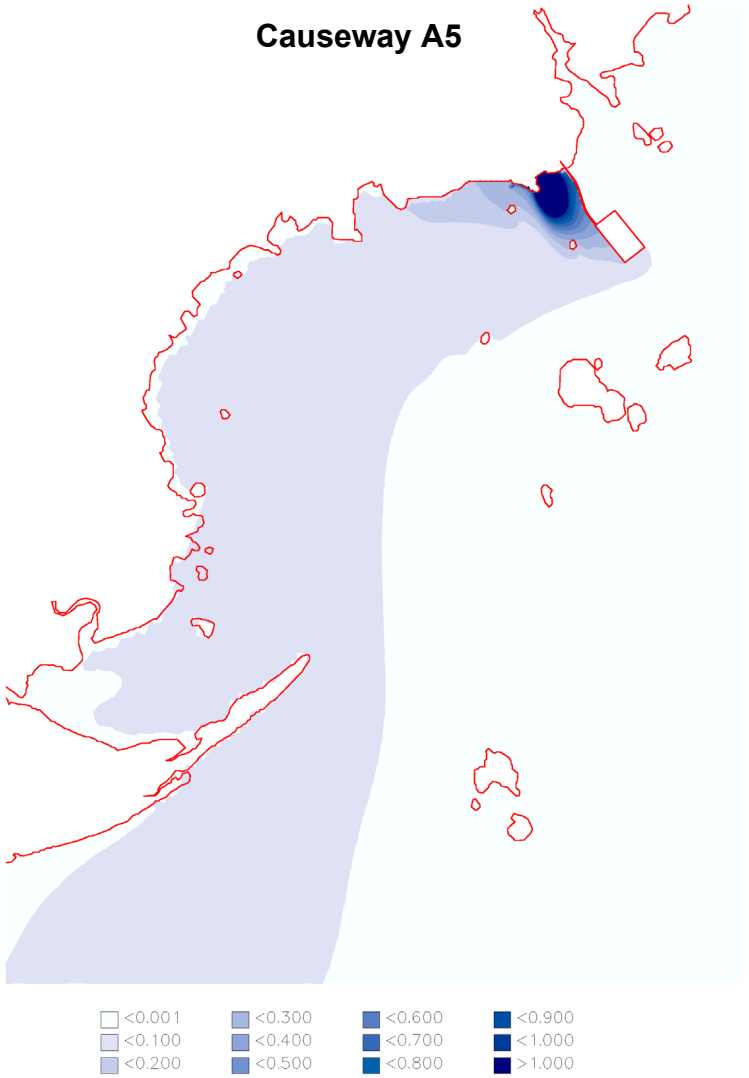


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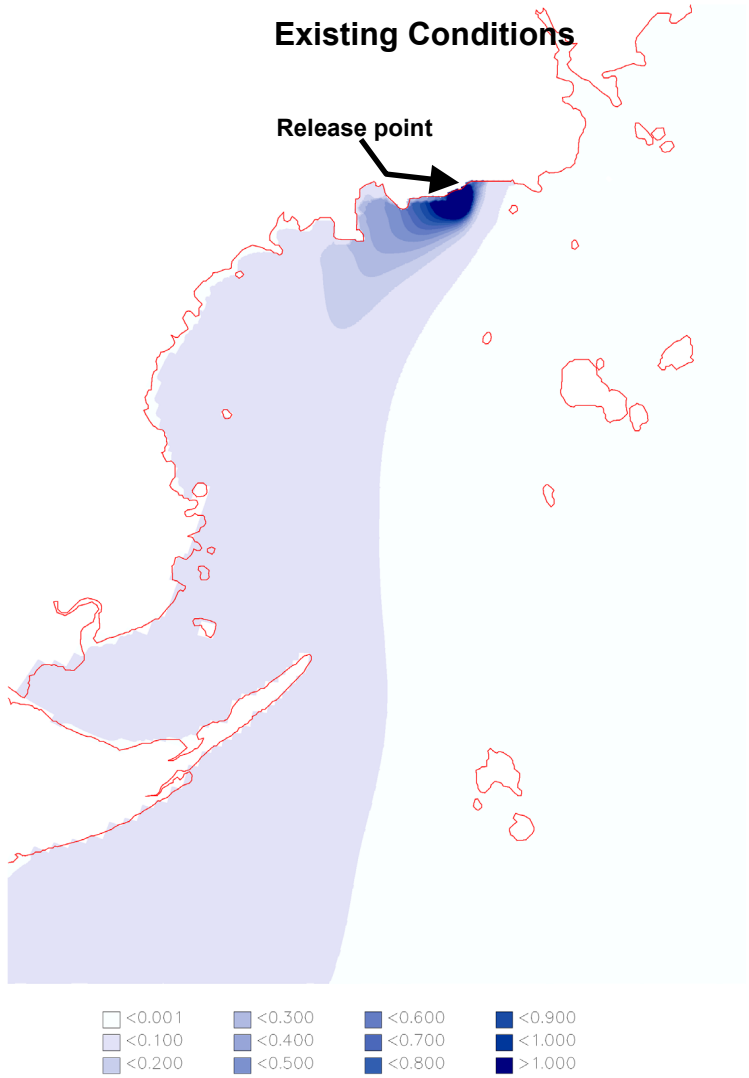
FIGURE B-15:
Concentration after 14 days
Release Point Punta Bruja-A5-C

Conservative tracer simulation: Release point Veracruz



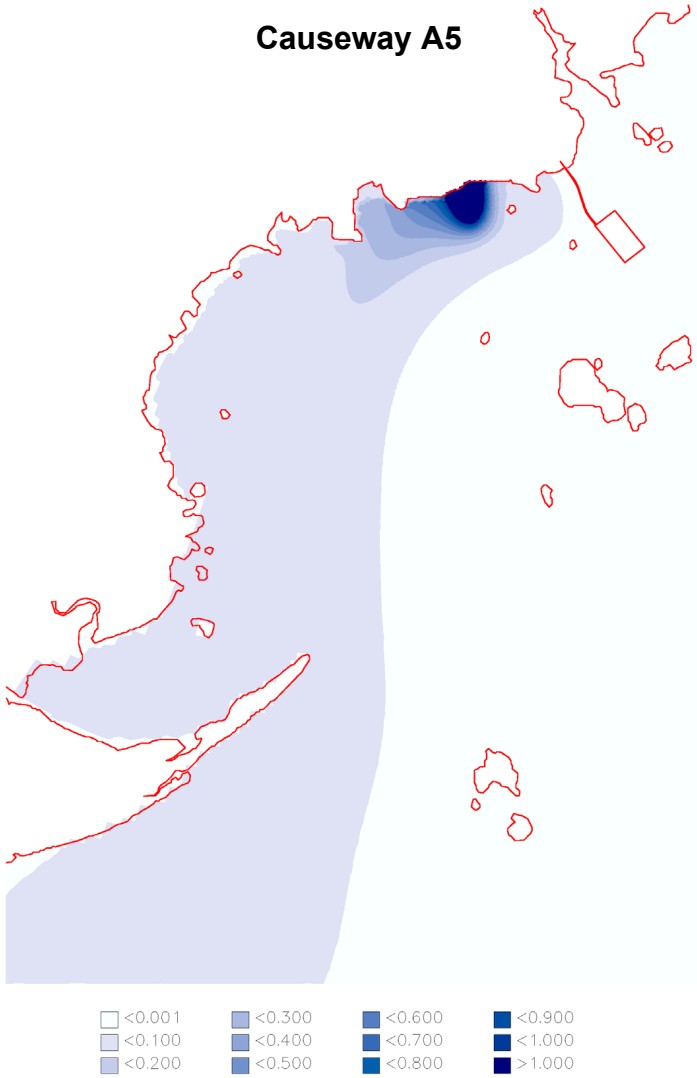


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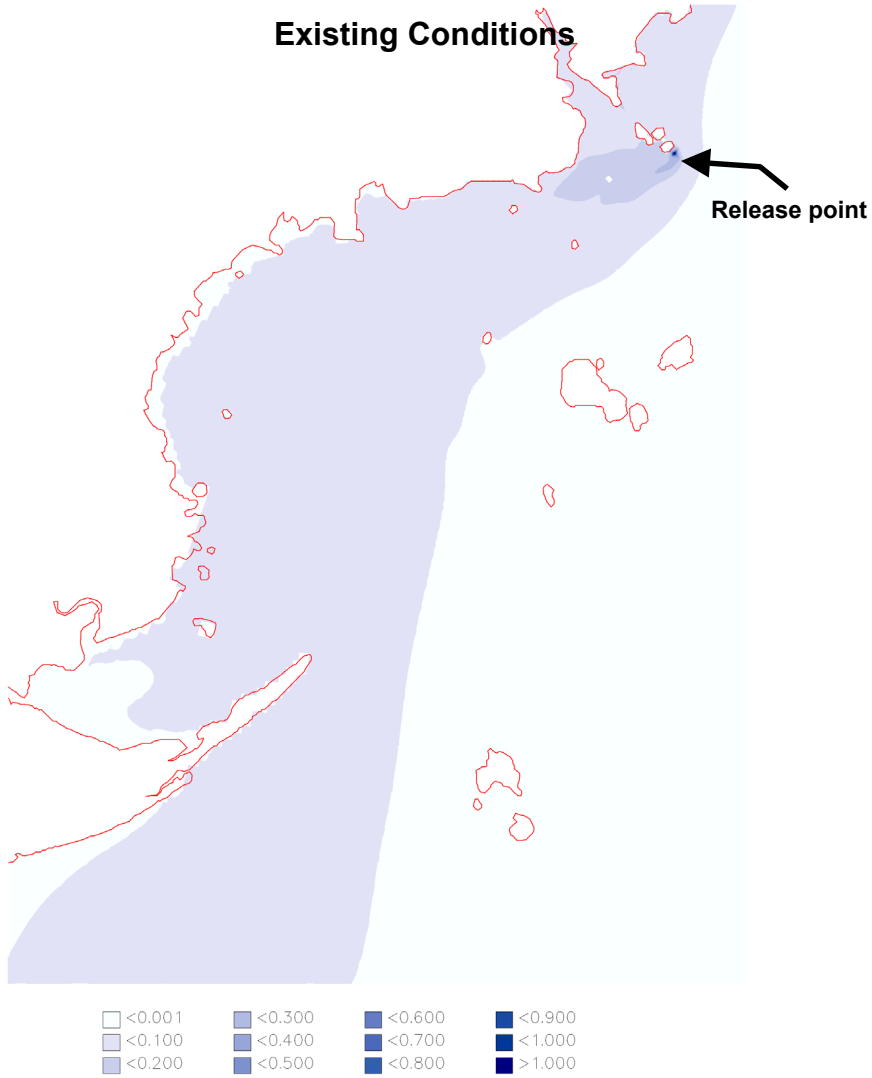
FIGURE B-16:
Concentration after 14 days
Release Point Veracruz-A5-C

Conservative tracer simulation: Release point Flamenca



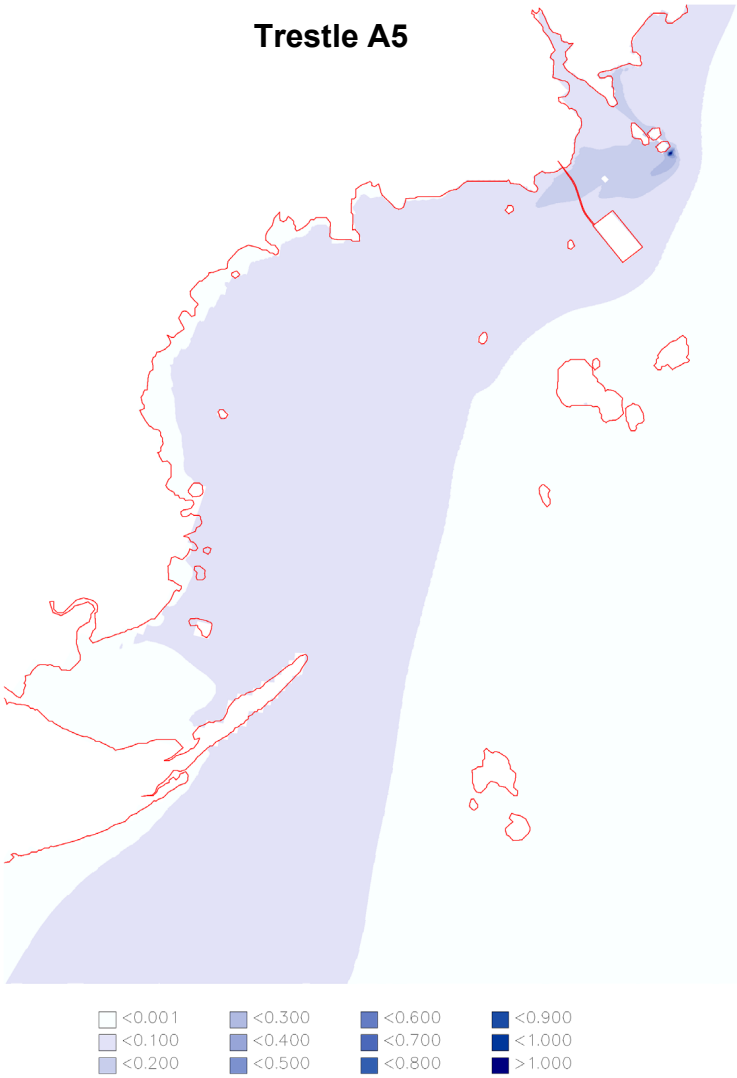


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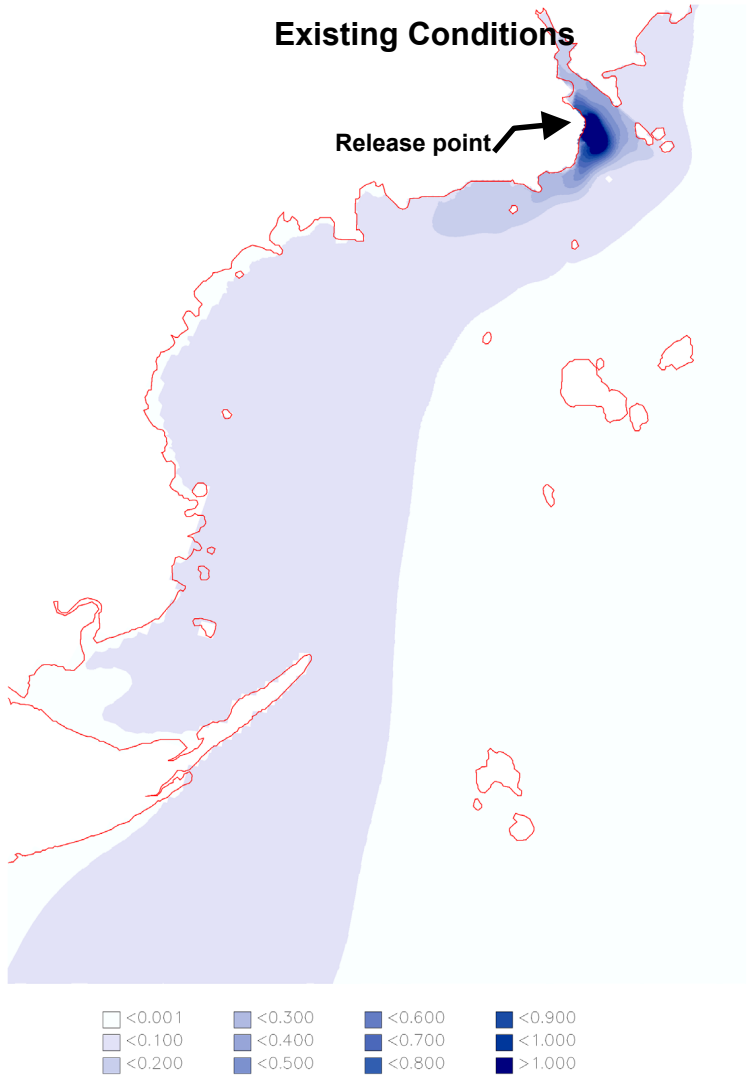
FIGURE B-17:
Concentration after 14 days
Release Point Flamenca-A5-T

Conservative tracer simulation: Release point Farfan



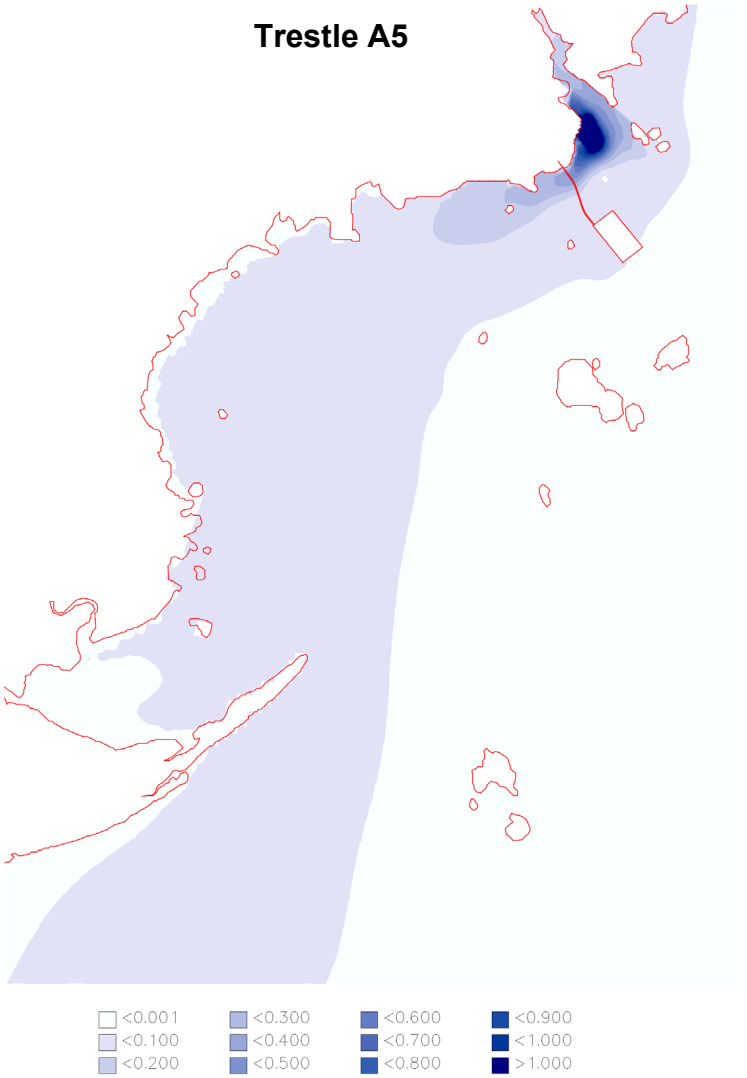


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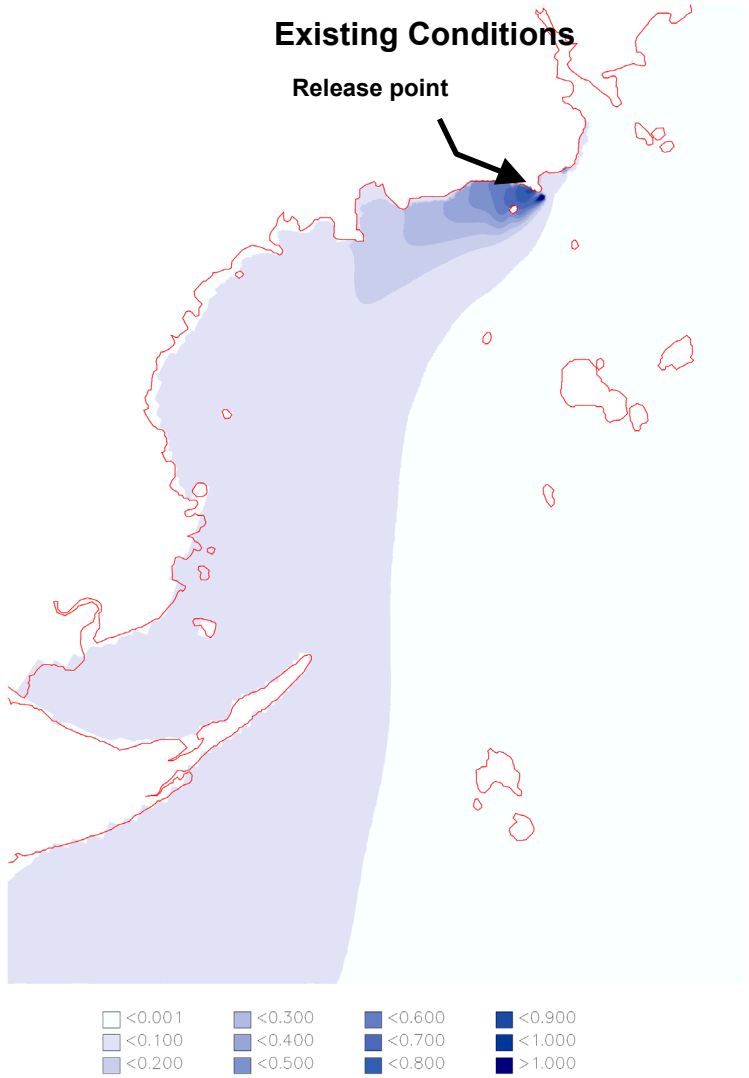
FIGURE B-18:
Concentration after 14 days
Release Point Farfan-A5-T

Conservative tracer simulation: Release point Punta Bruja



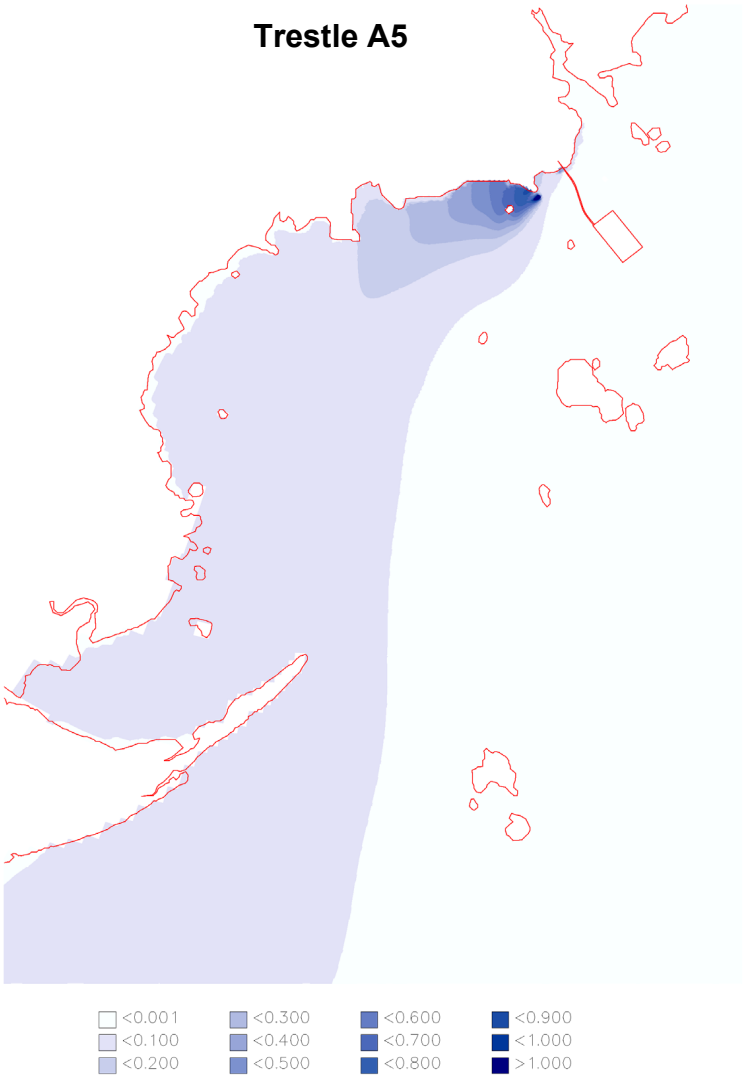


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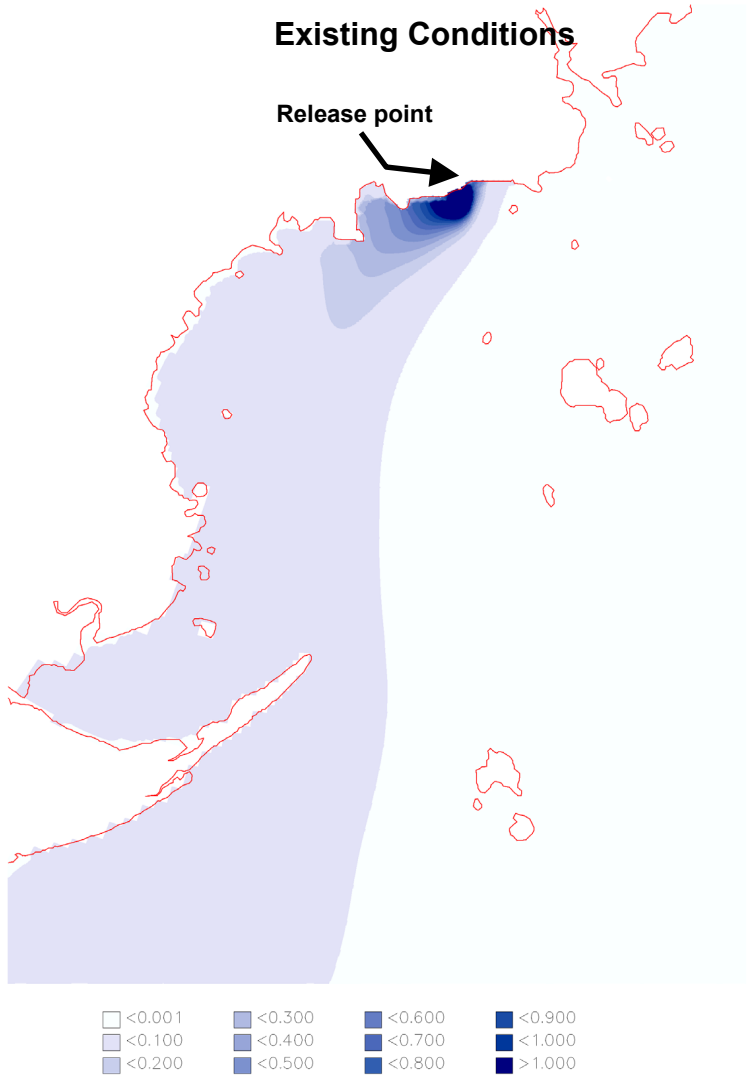
FIGURE B-19:
Concentration after 14 days
Release Point Punta Bruja-A5-T

Conservative tracer simulation: Release point Veracruz



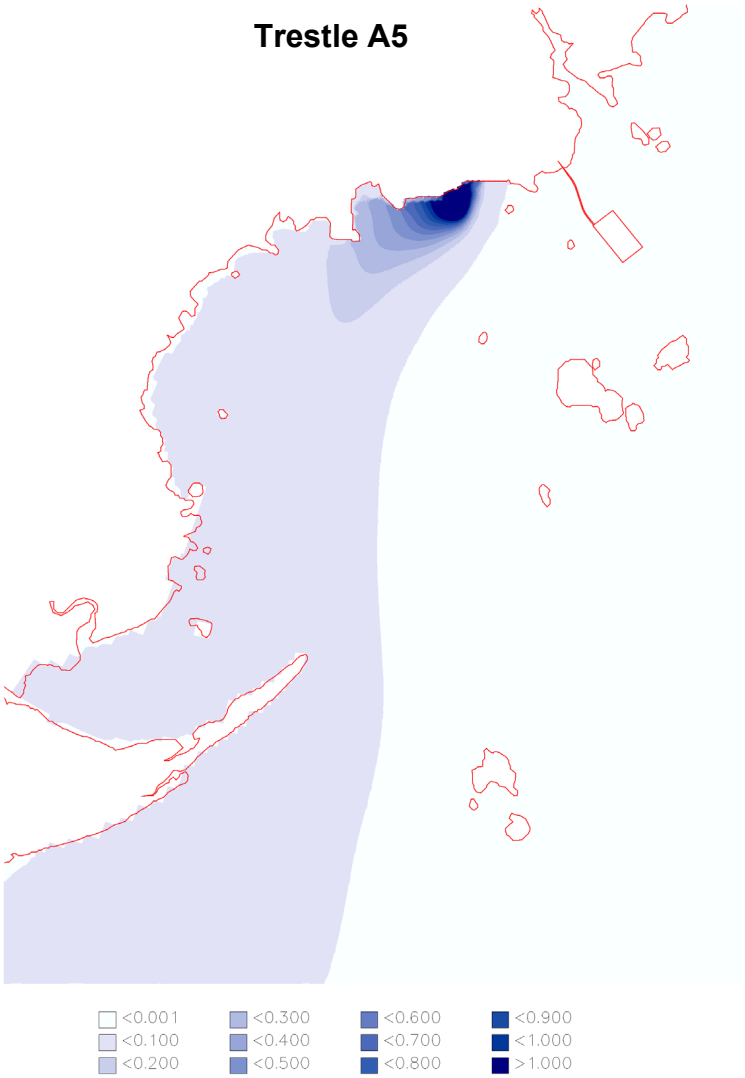


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FIGURE B-20:
Concentration after 14 days
Release Point Veracruz-A5-T

Conservative tracer simulation: Release point Flamenca

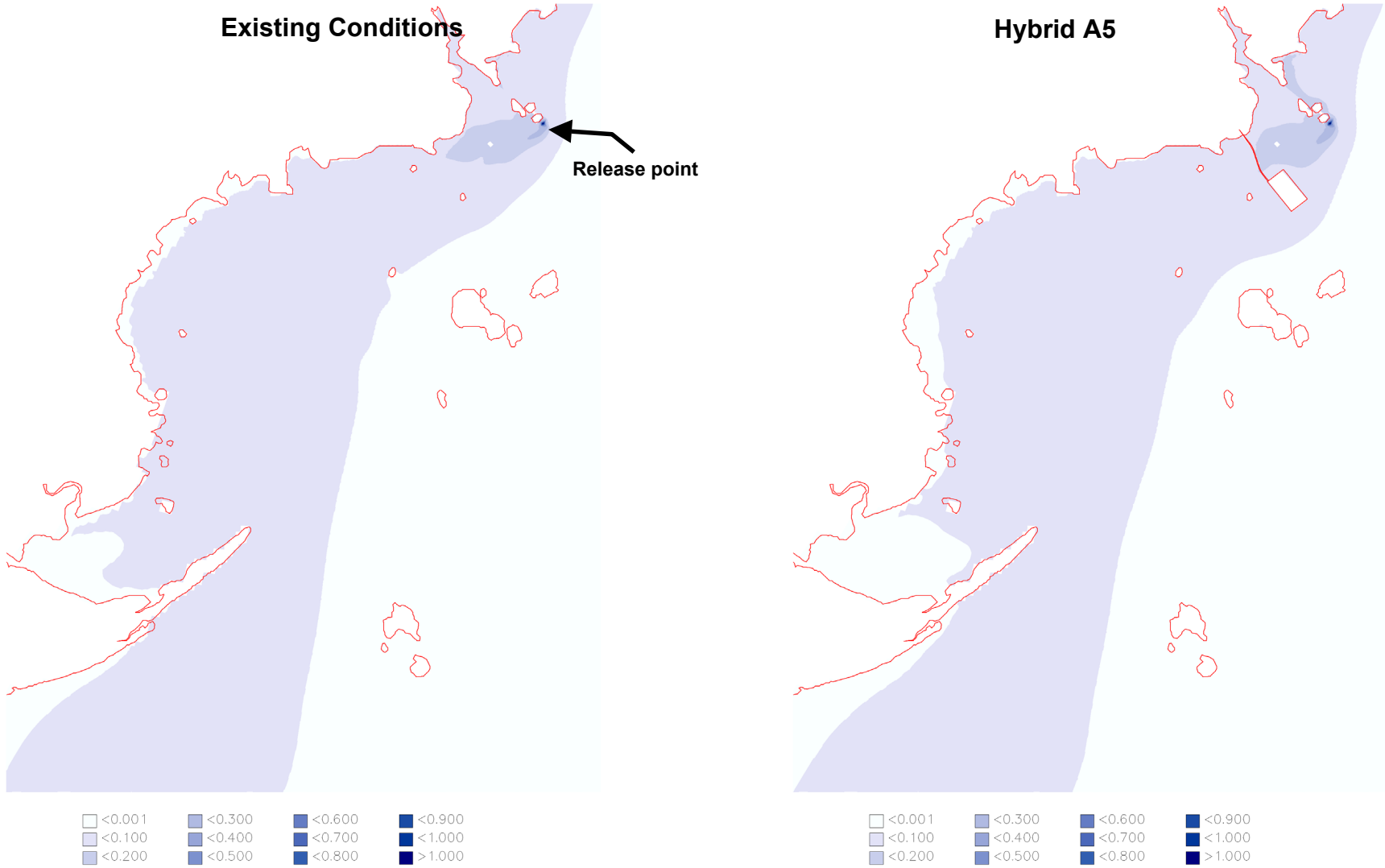

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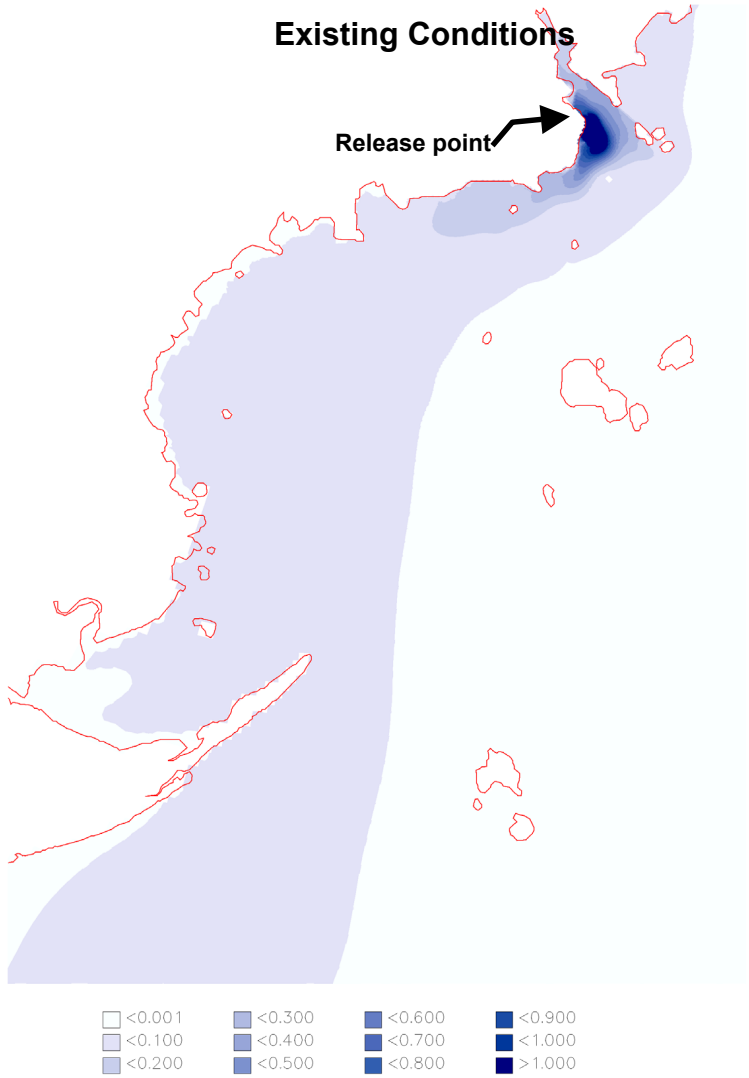
FIGURE B-21:
Concentration after 14 days
Release Point Flamenca-A5-H

Conservative tracer simulation: Release point Farfan



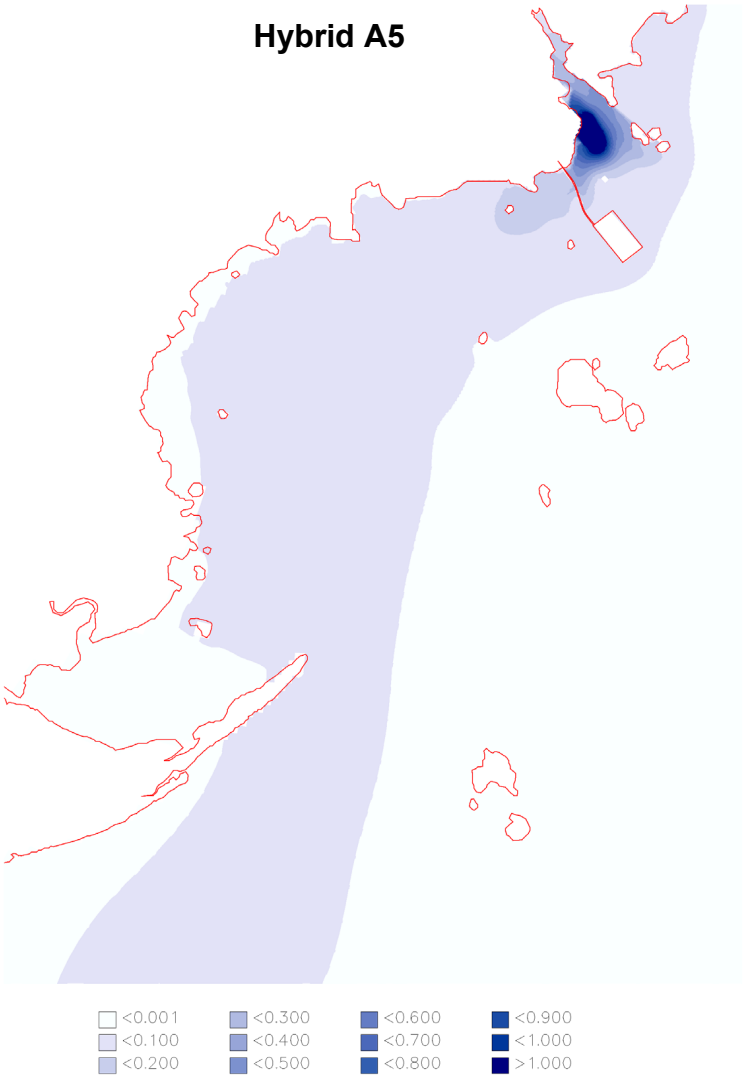


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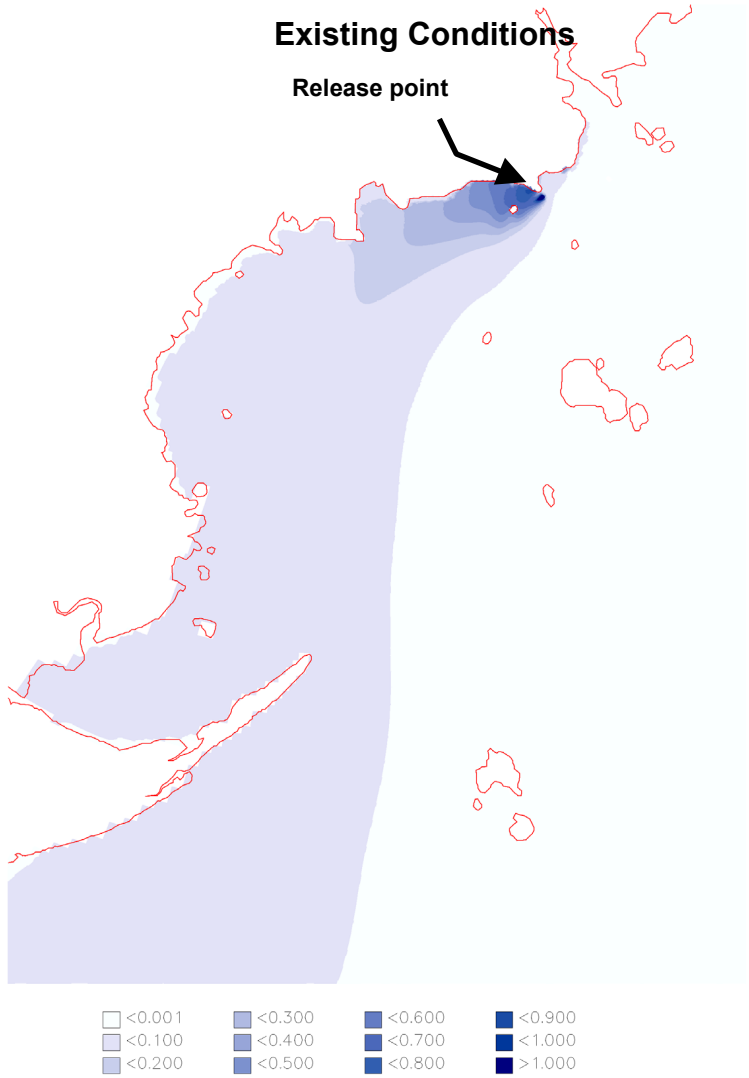
FIGURE B22:
Concentration after 14 days
Release Point Farfan-A5-H

Conservative tracer simulation: Release point Punta Bruja



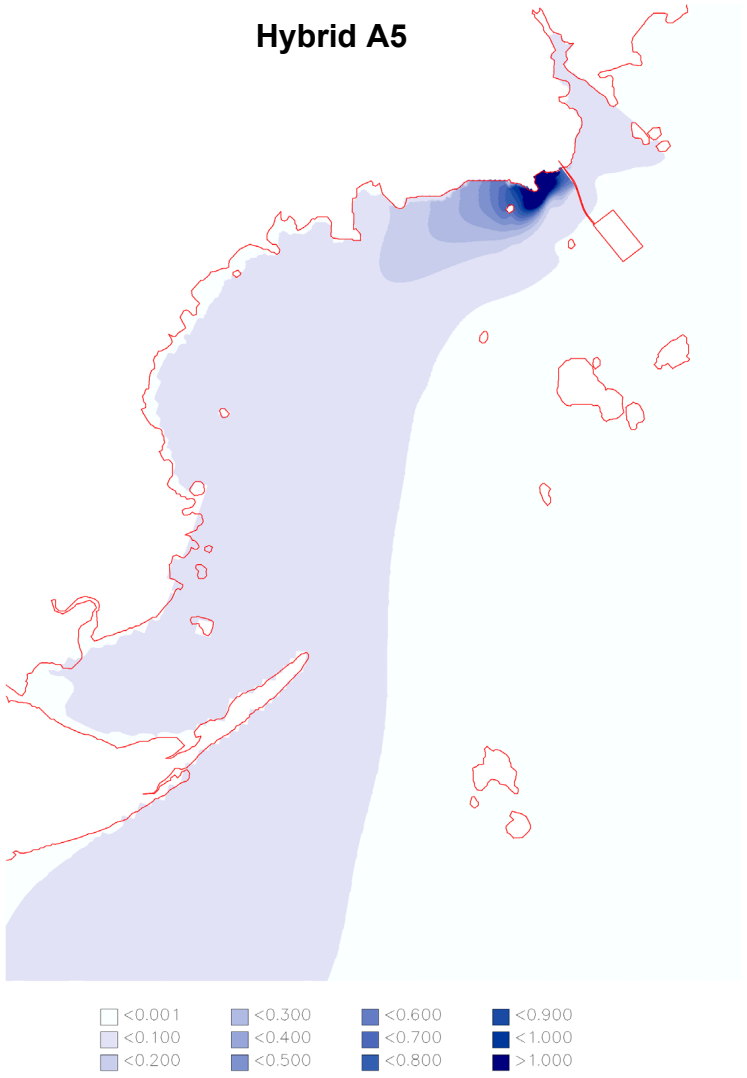


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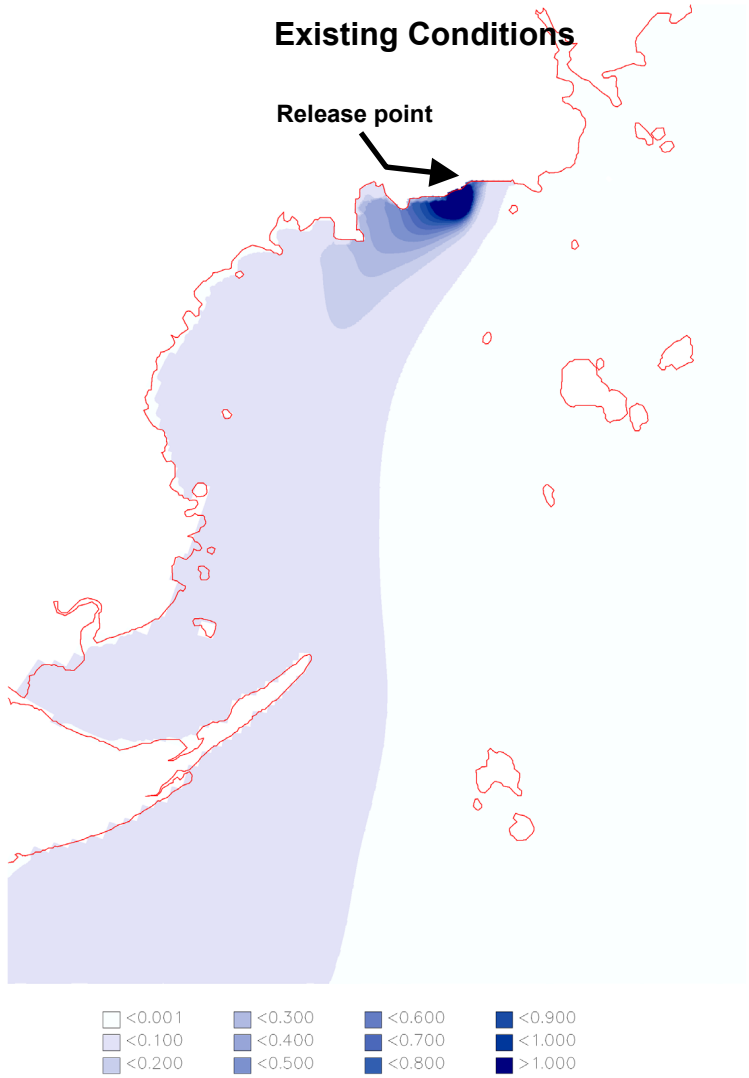
FIGURE B-23:
Concentration after 14 days
Release Point Punta Bruja-A5-H

Conservative tracer simulation: Release point Veracruz



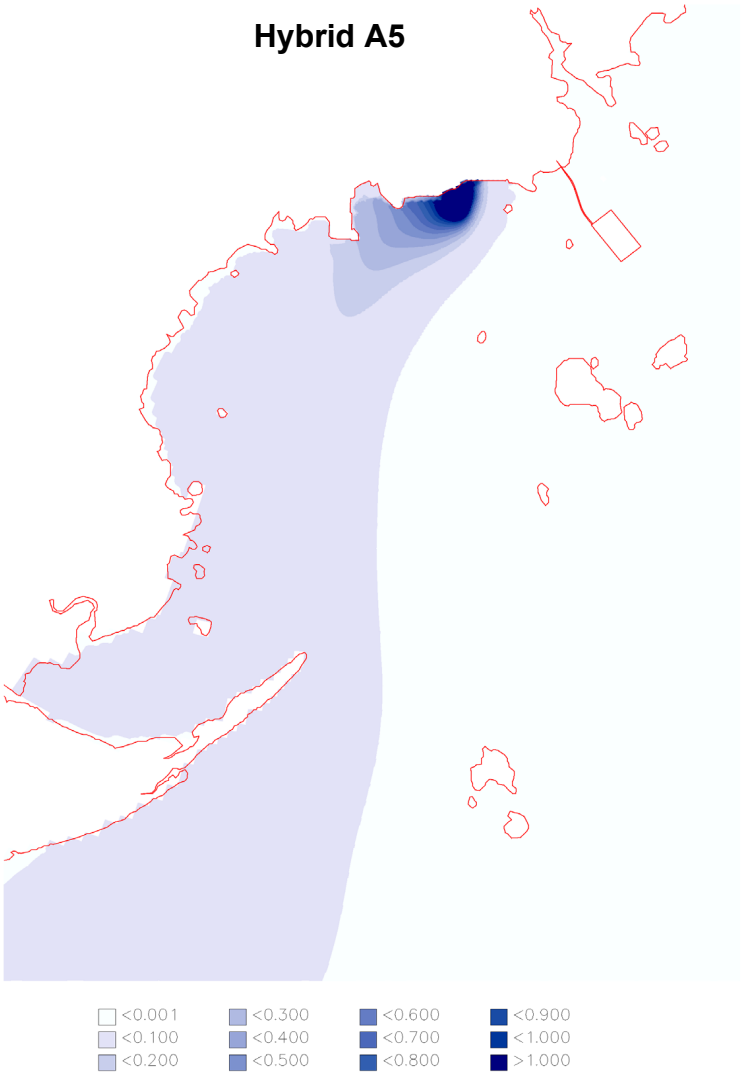


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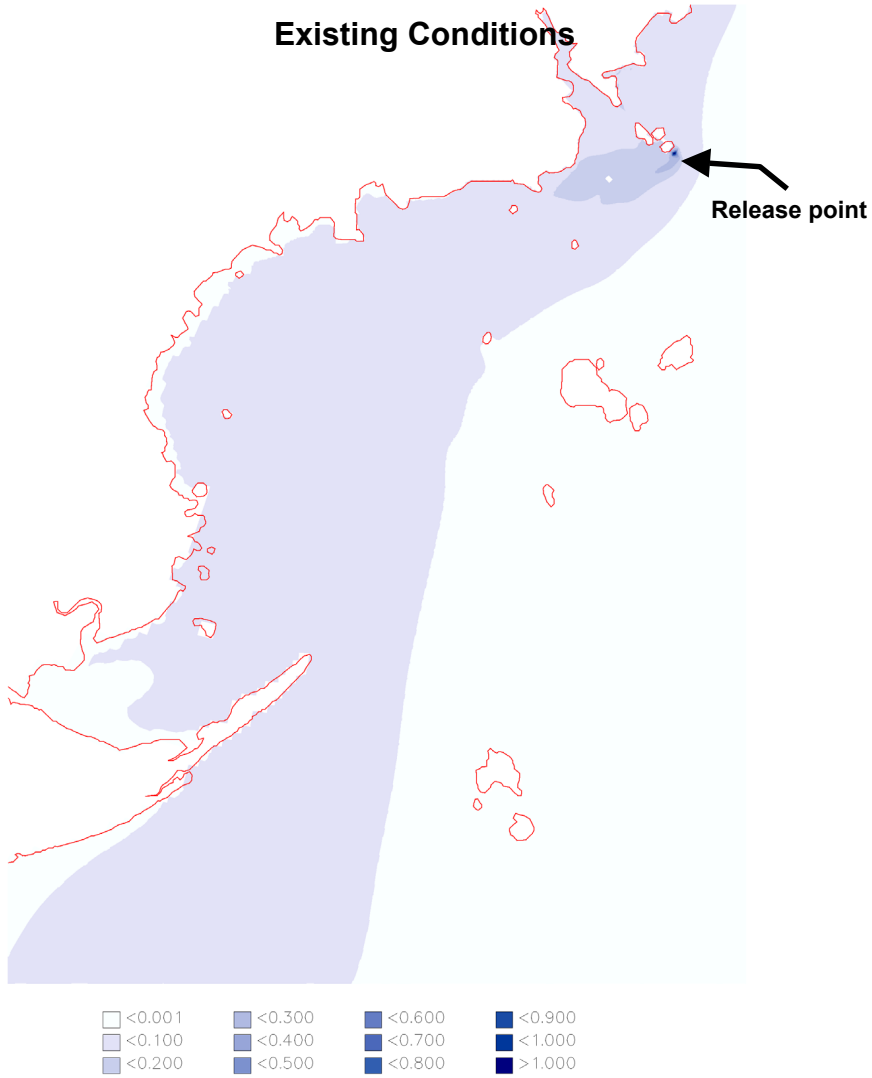
FIGURE B-24:
Concentration after 14 days
Release Point Veracruz-A5-H

Conservative tracer simulation: Release point Flamenca



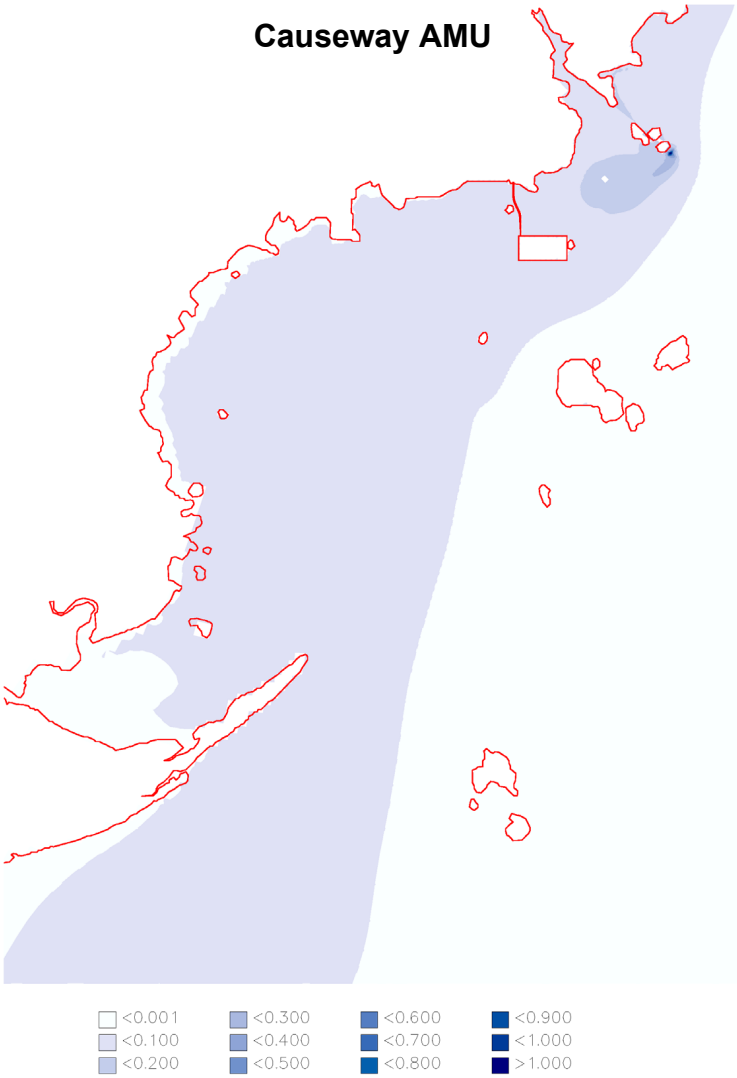


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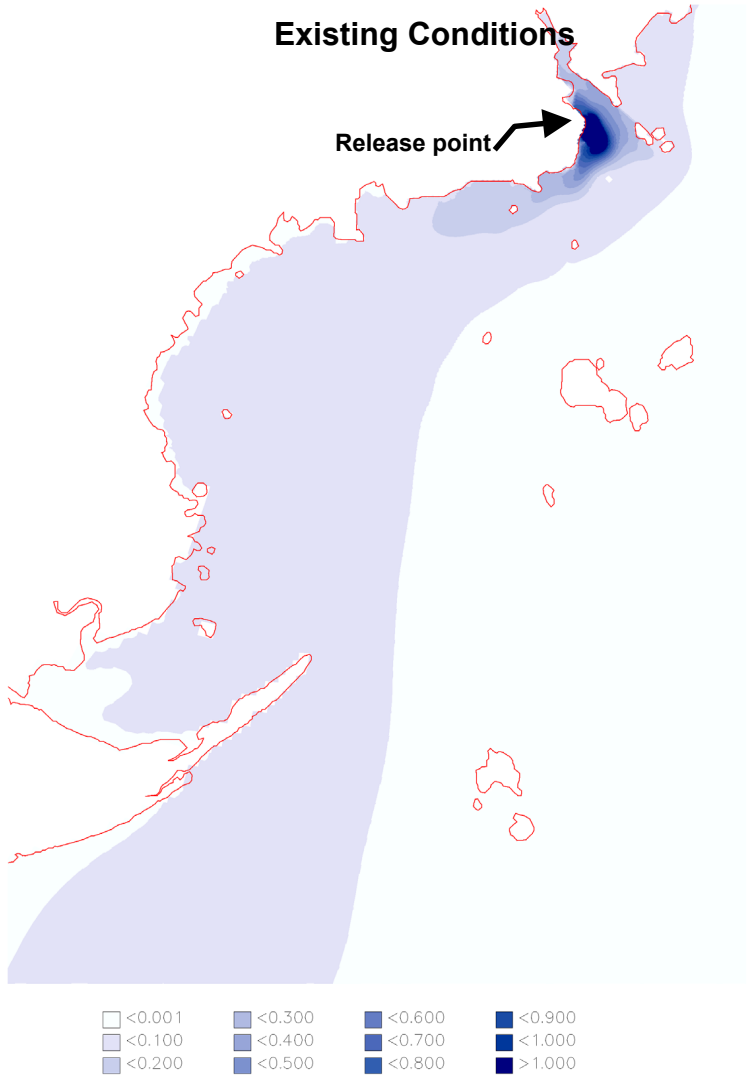
FIGURE B-25:
Concentration after 14 days
Release Point Flamenca - AMU-C

Conservative tracer simulation: Release point Farfan



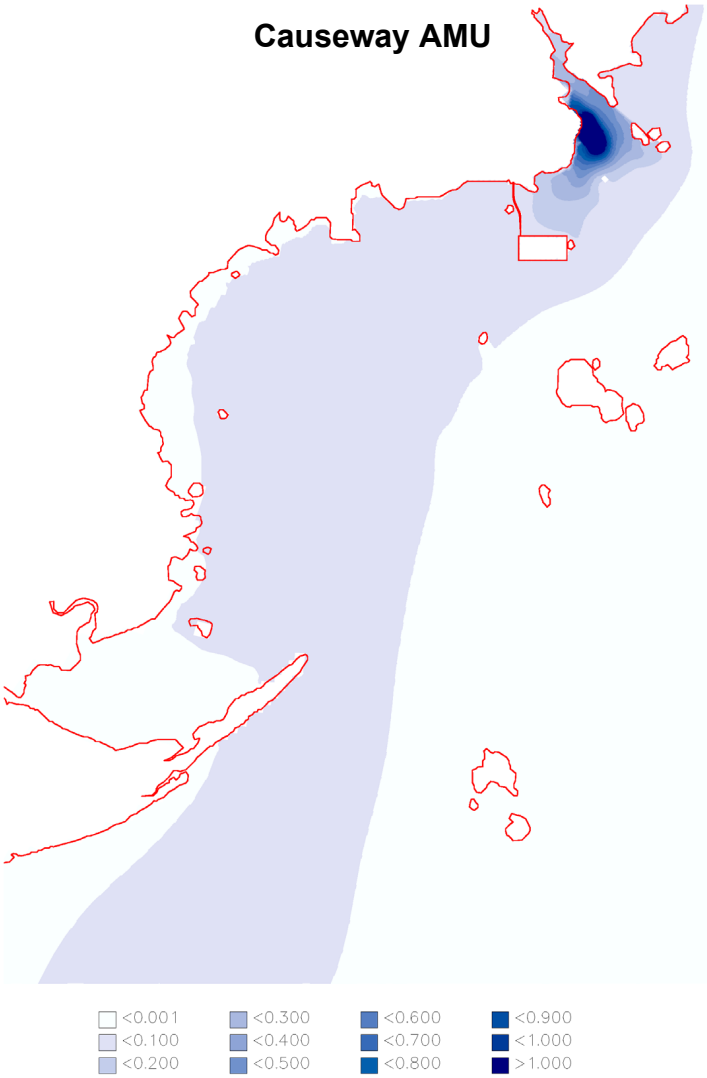


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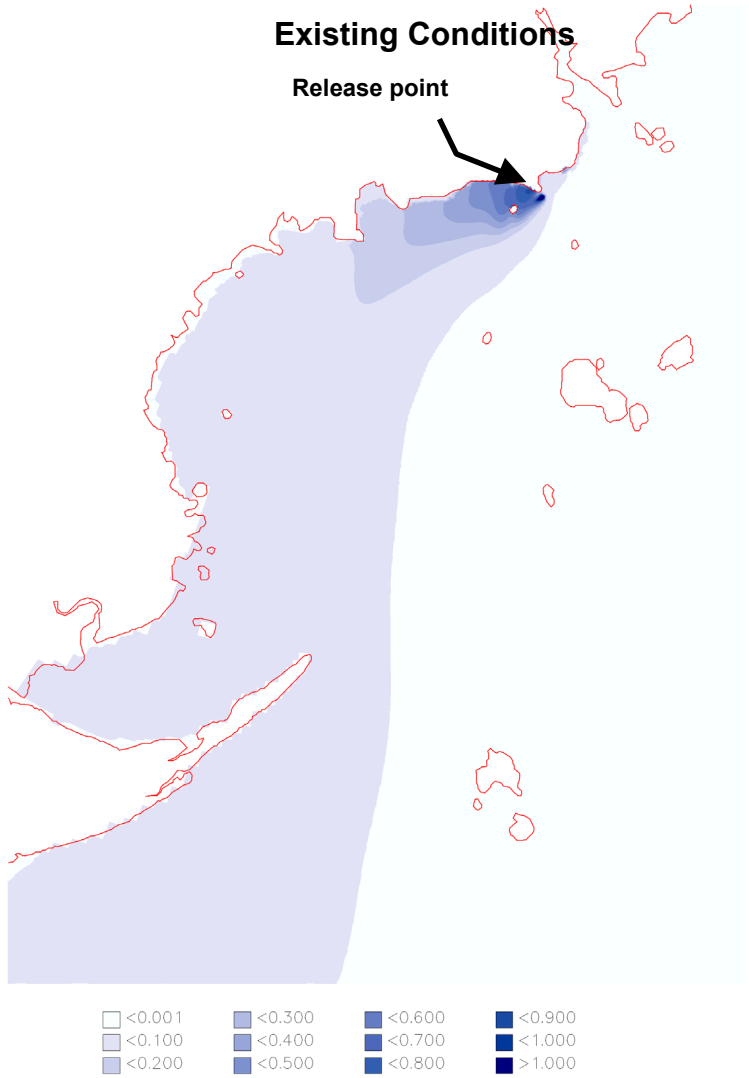
FIGURE B-26:
Concentration after 14 days
Release Point Farfan - AMU-C

Conservative tracer simulation: Release point Punta Bruja



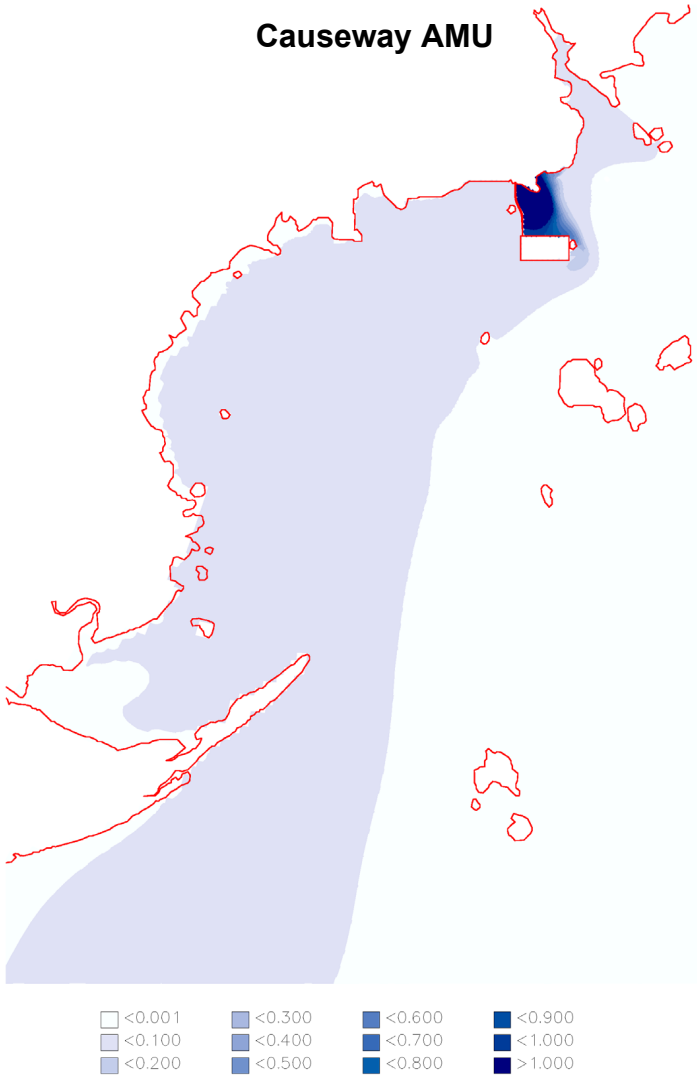


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FIGURE B-27:
Concentration after 14 days
Release Point Punta Bruja - AMU-C

Conservative tracer simulation: Release point Veracruz

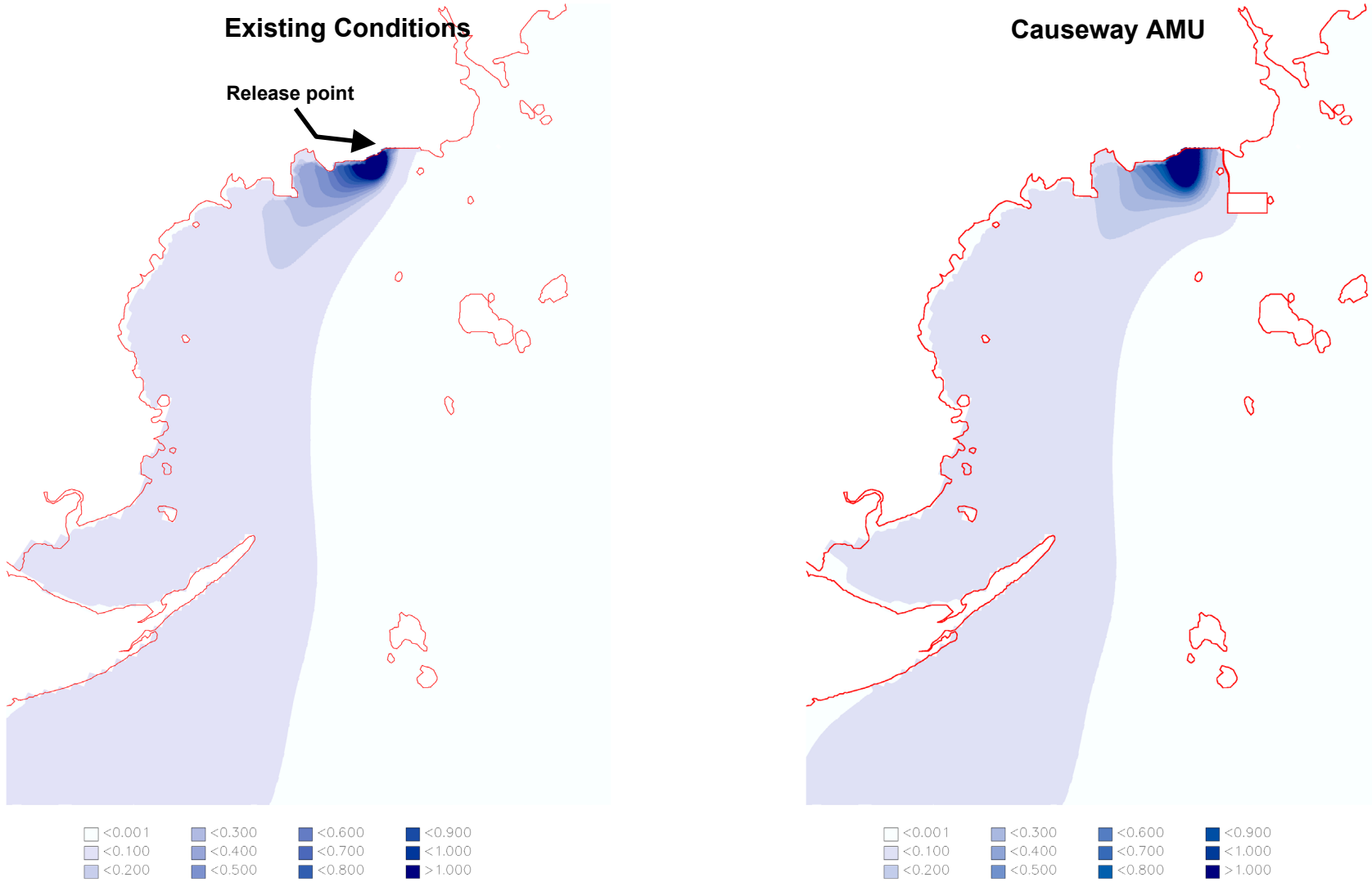

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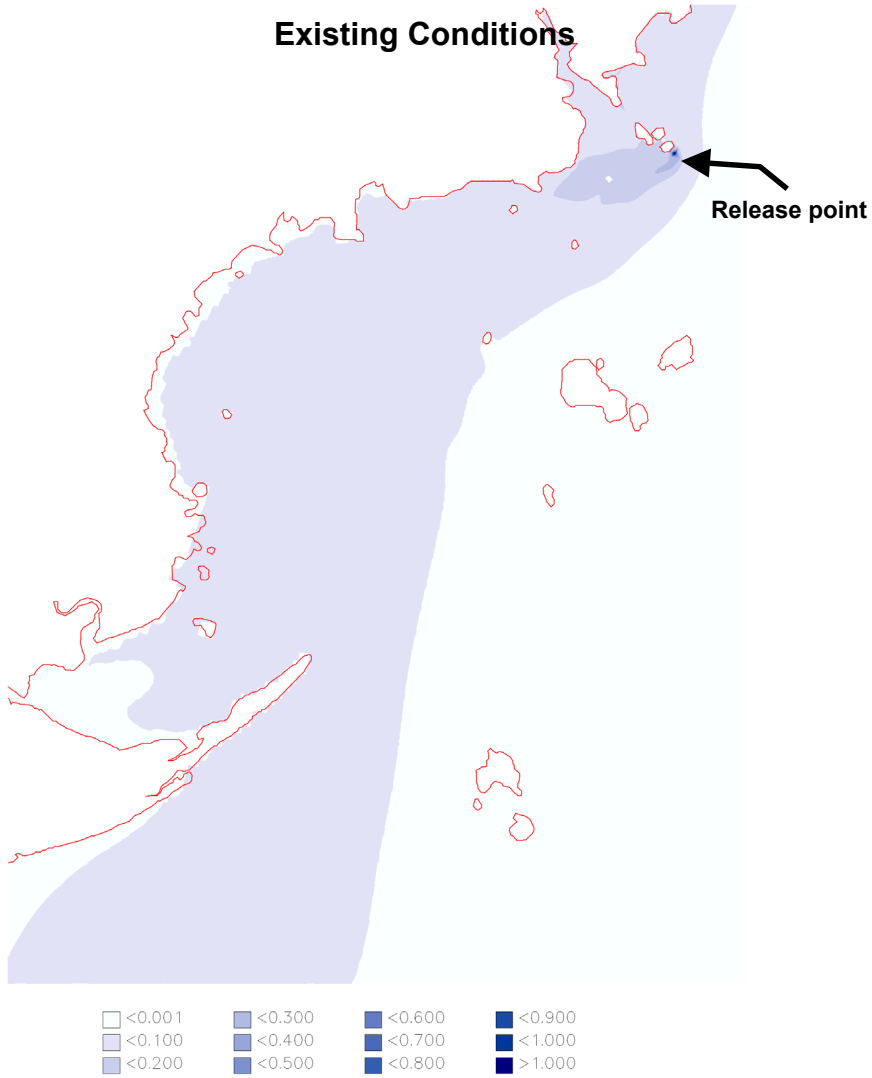
FIGURE B-28:
Concentration after 14 days
Release Point Veracruz - AMU-C

Conservative tracer simulation: Release point Flamenca



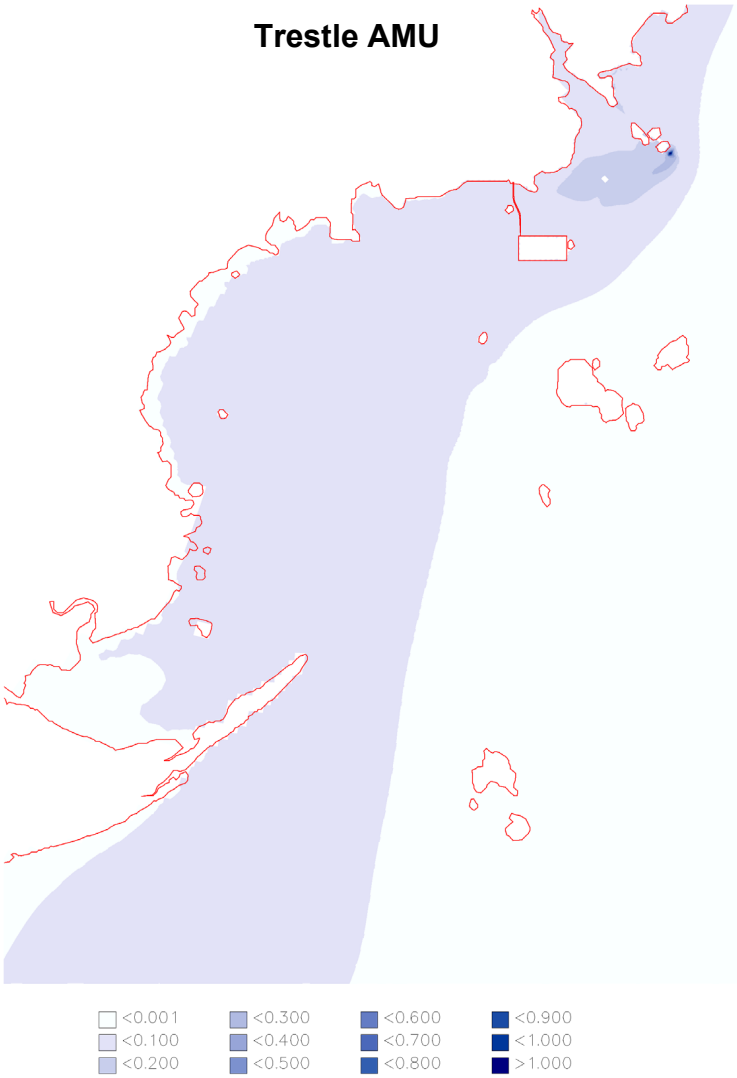


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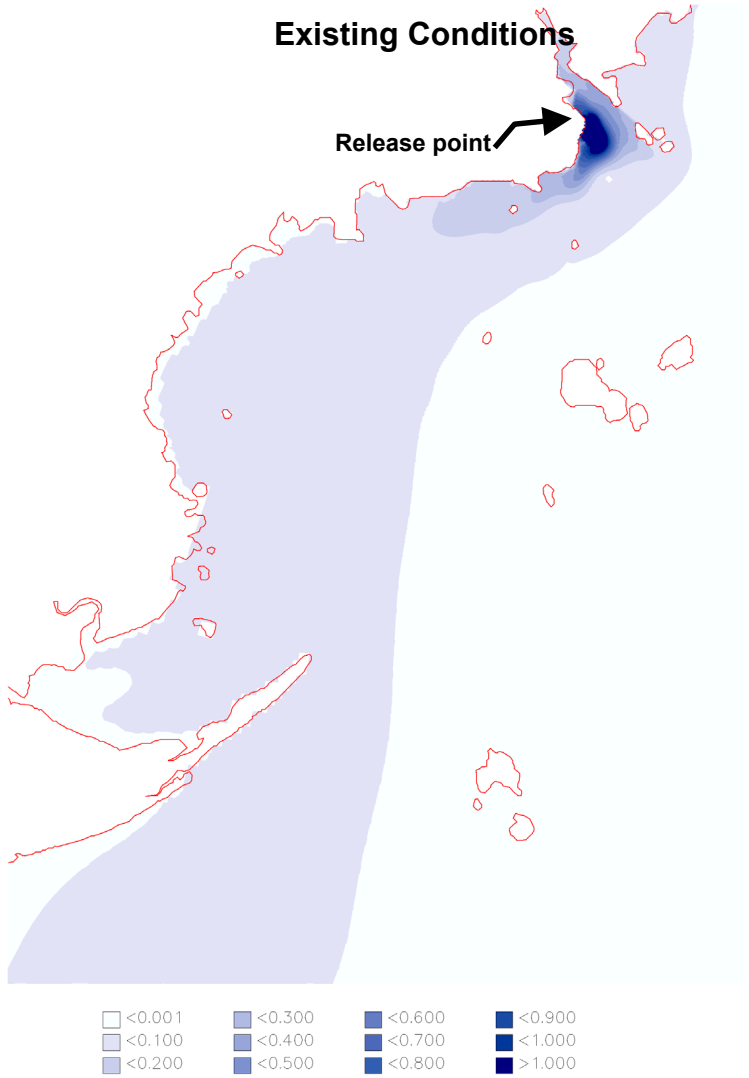
FIGURE B-29:
Concentration after 14 days
Release Point Flamenca - AMU-T

Conservative tracer simulation: Release point Farfan



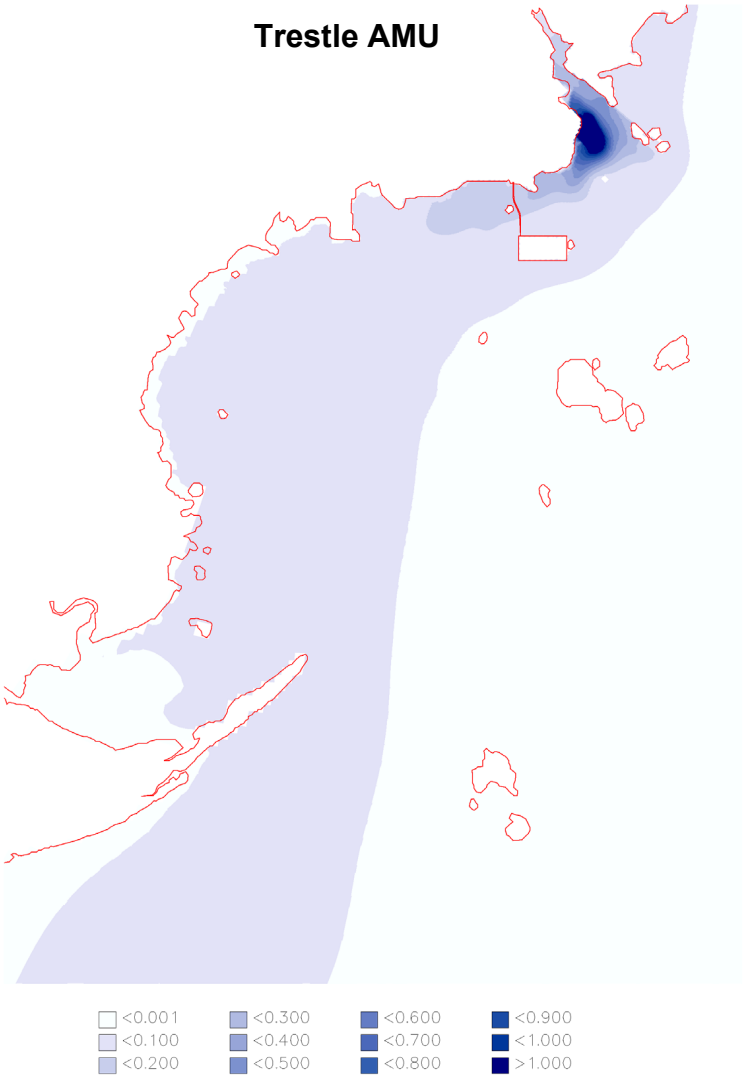


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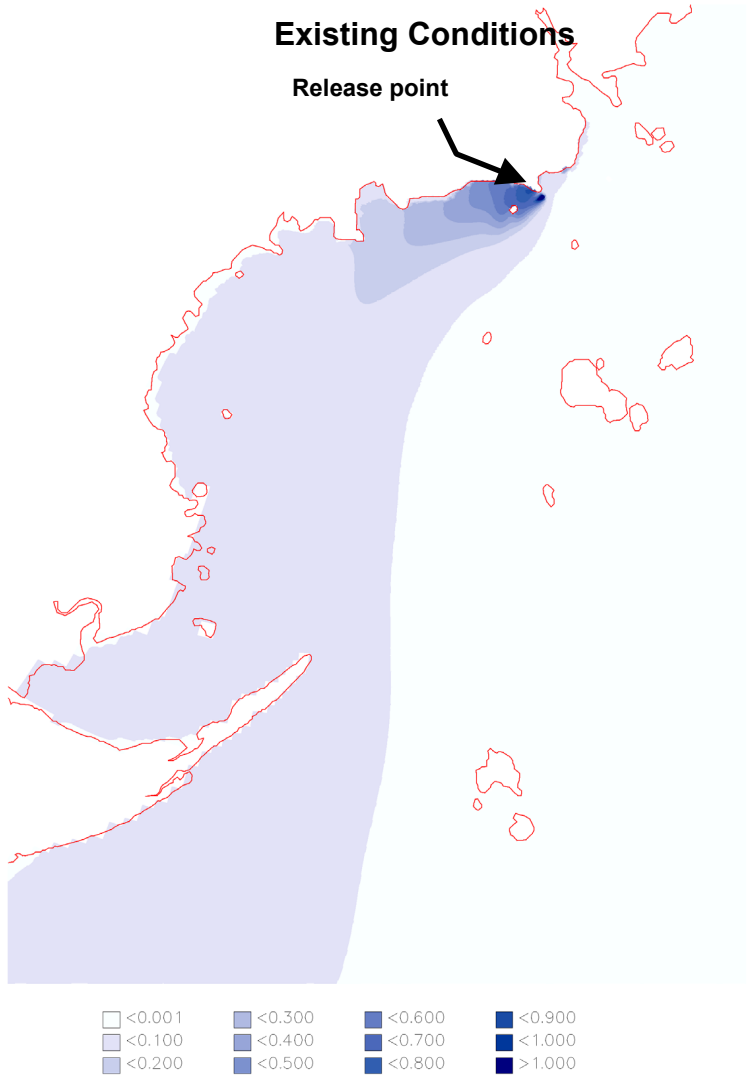
FIGURE B-30:
Concentration after 14 days
Release Point Farfan - AMU-T

Conservative tracer simulation: Release point Punta Bruja



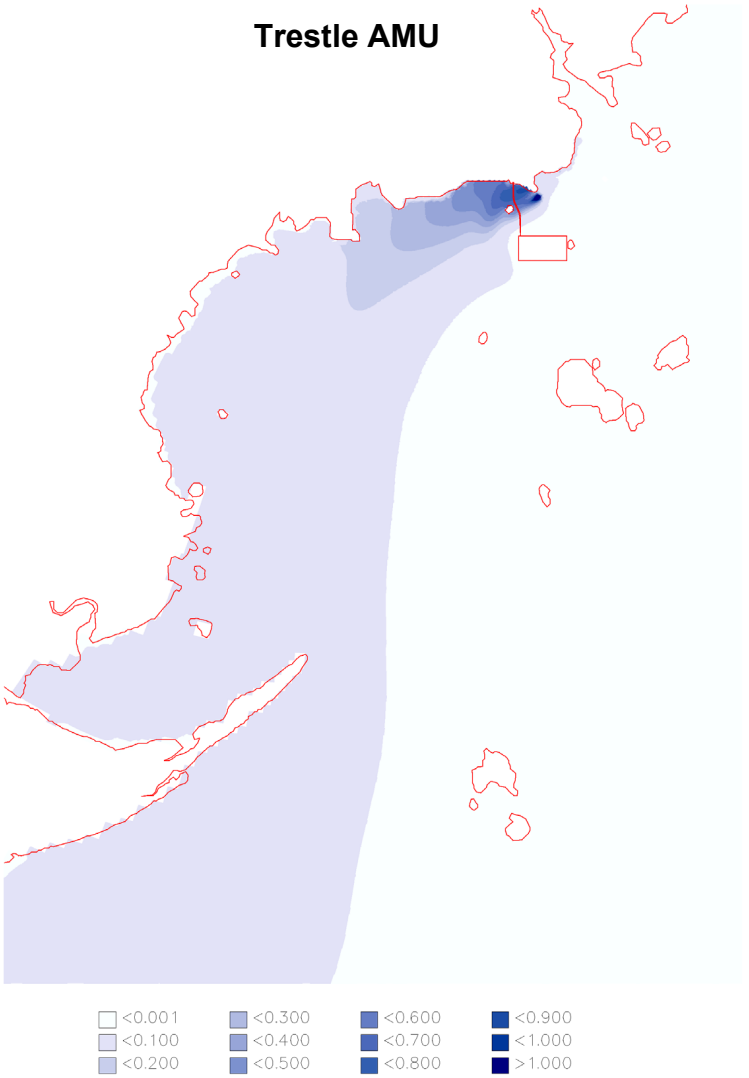


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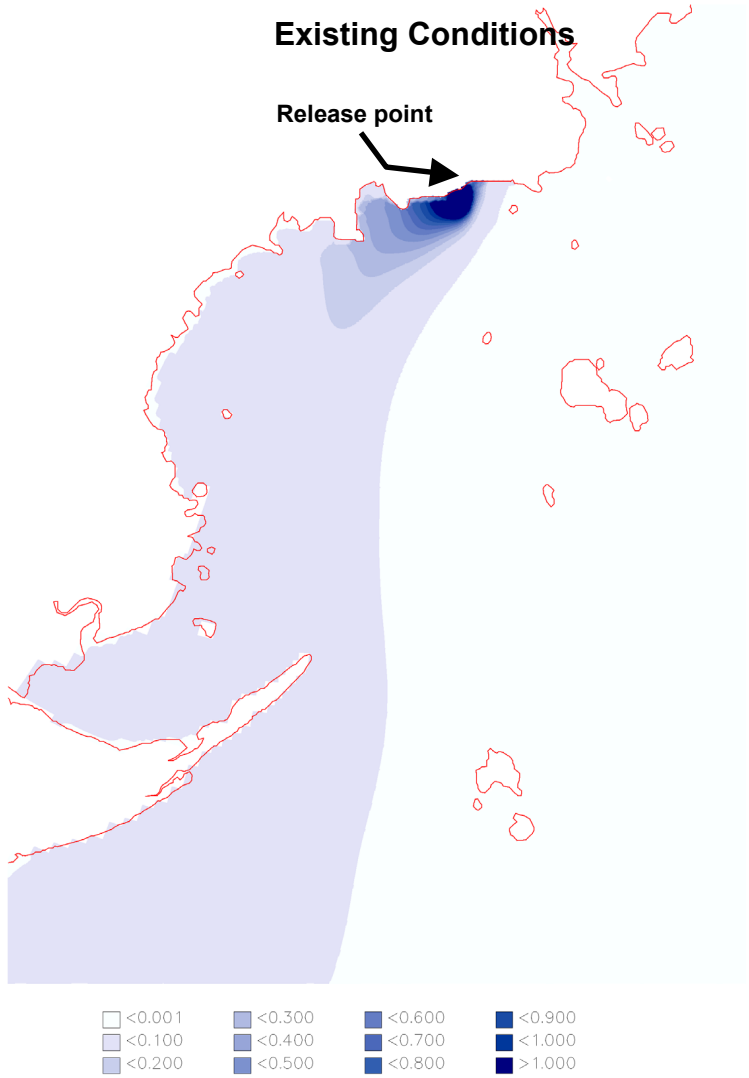
FIGURE B-31:
Concentration after 14 days
Release Point Punta Bruja - AMU-T

Conservative tracer simulation: Release point Veracruz



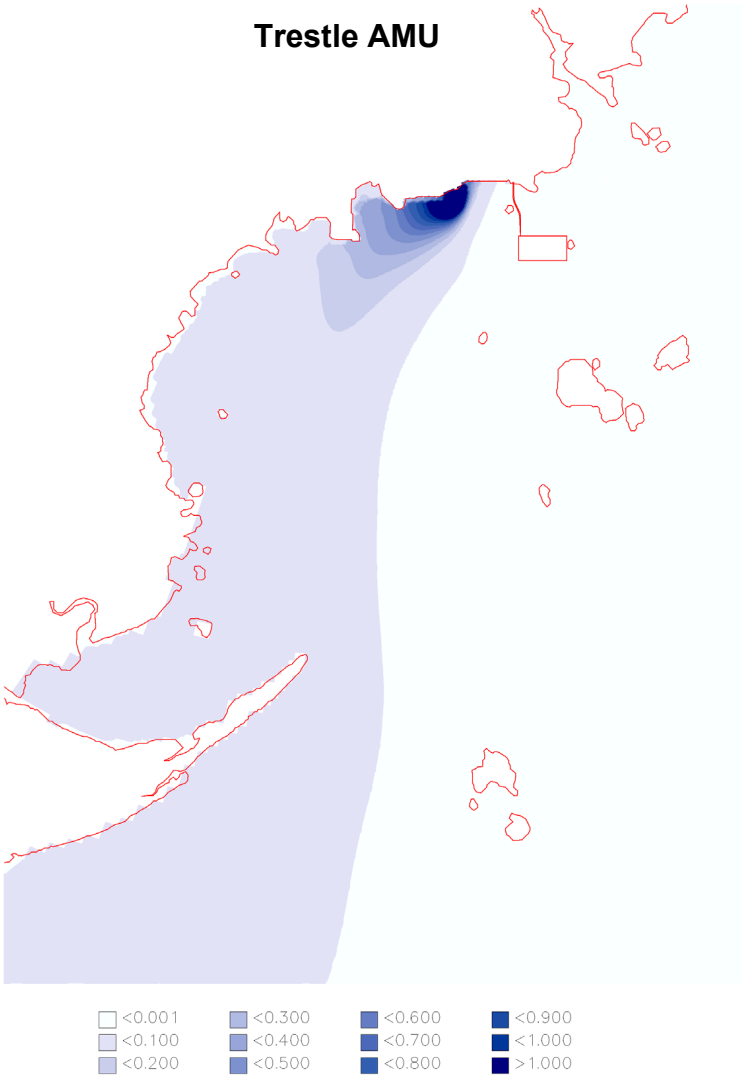


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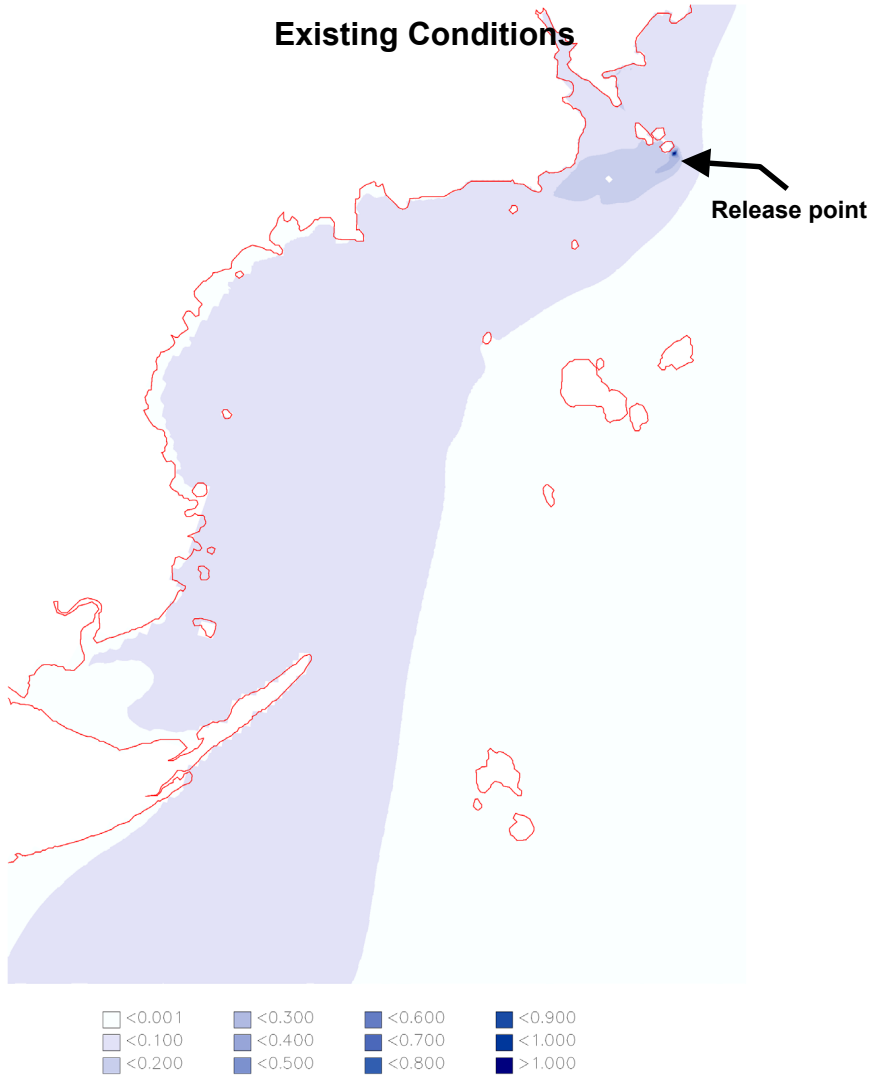
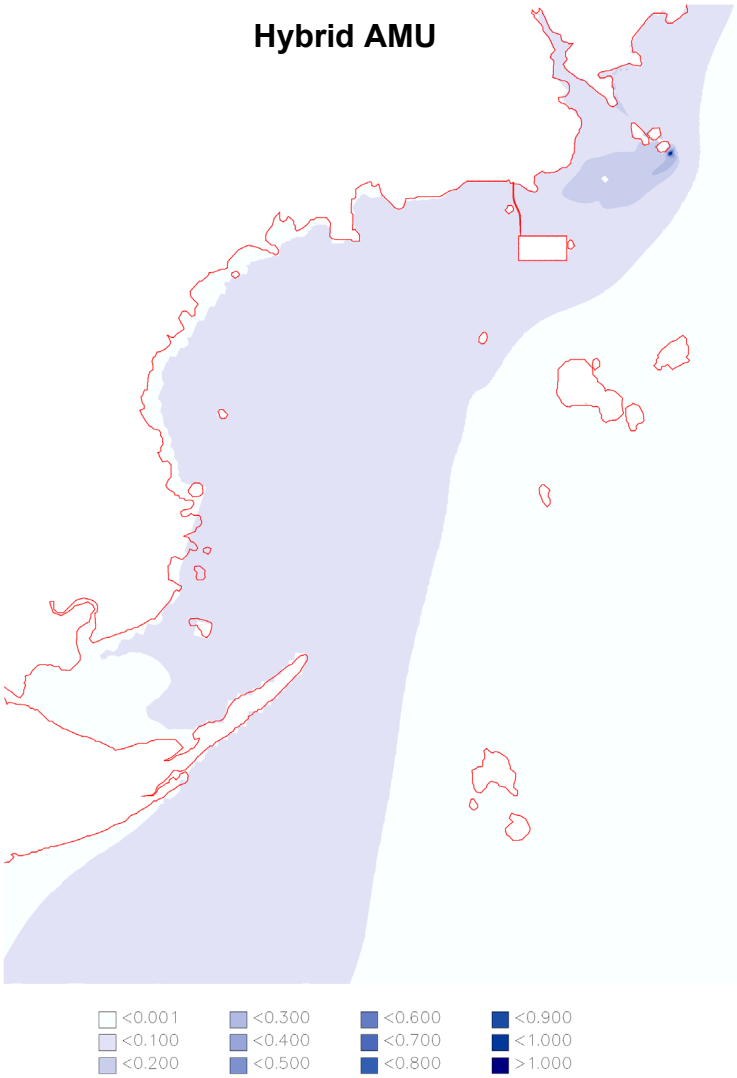
FIGURE B-32:
Concentration after 14 days
Release Point Veracruz- AMU-T

Conservative tracer simulation: Release point Flamenca





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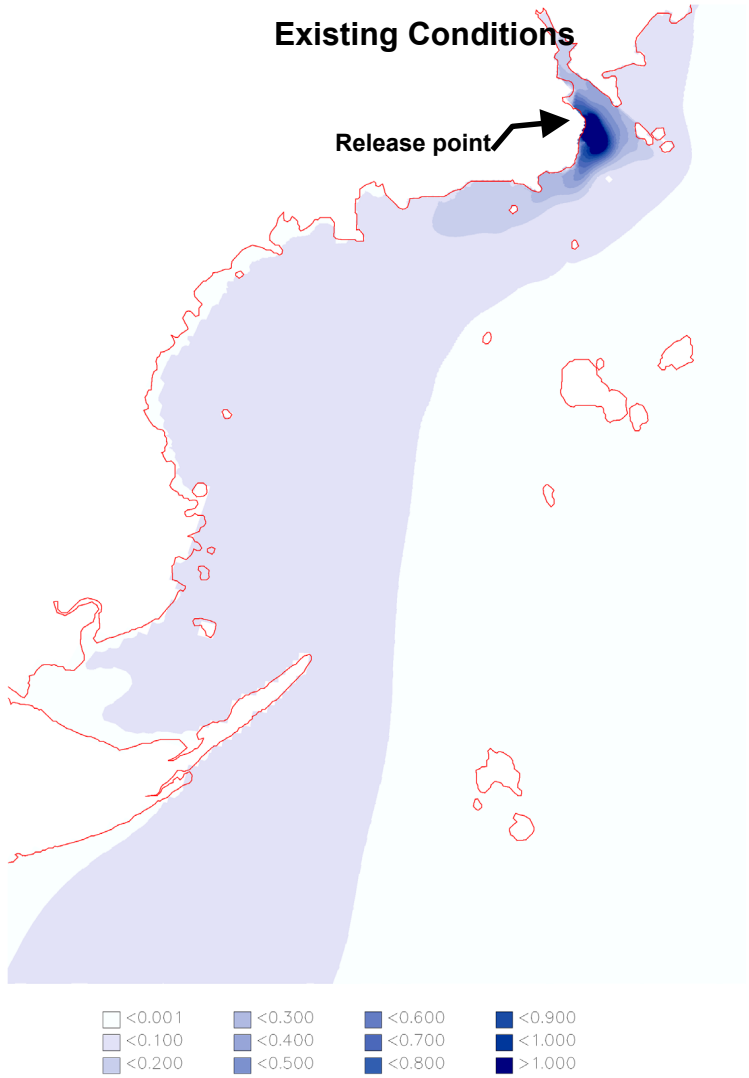
ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-33:
Concentration after 14 days
Release Point Flamenca - AMU-H

Conservative tracer simulation: Release point Farfan



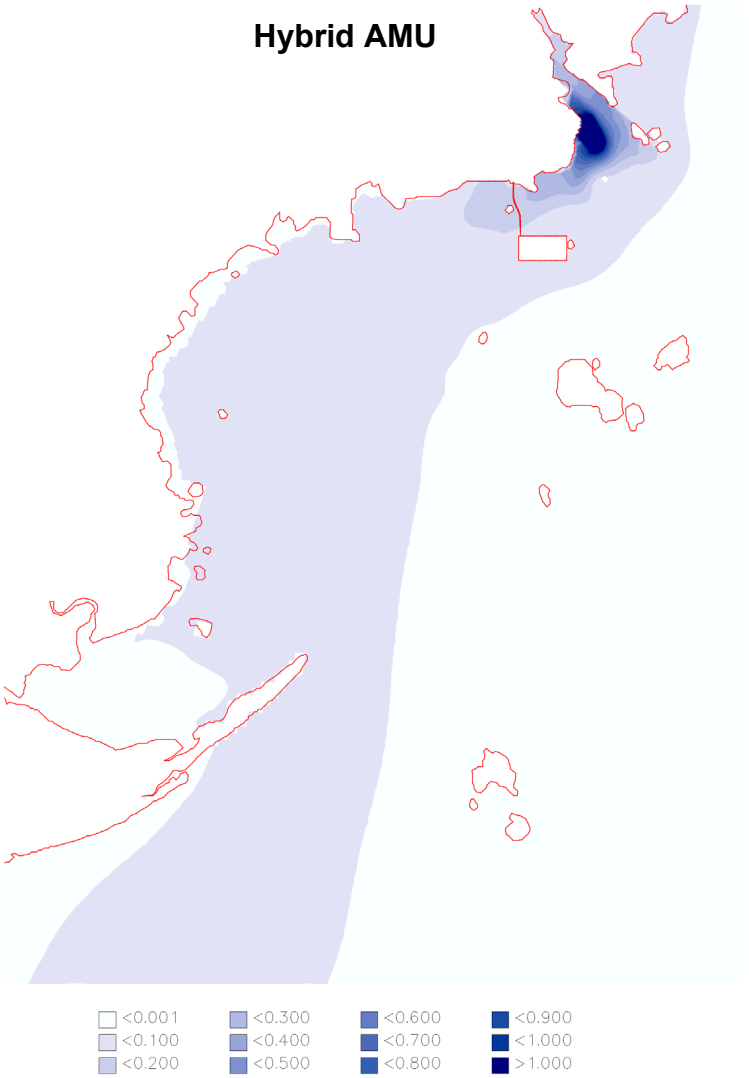


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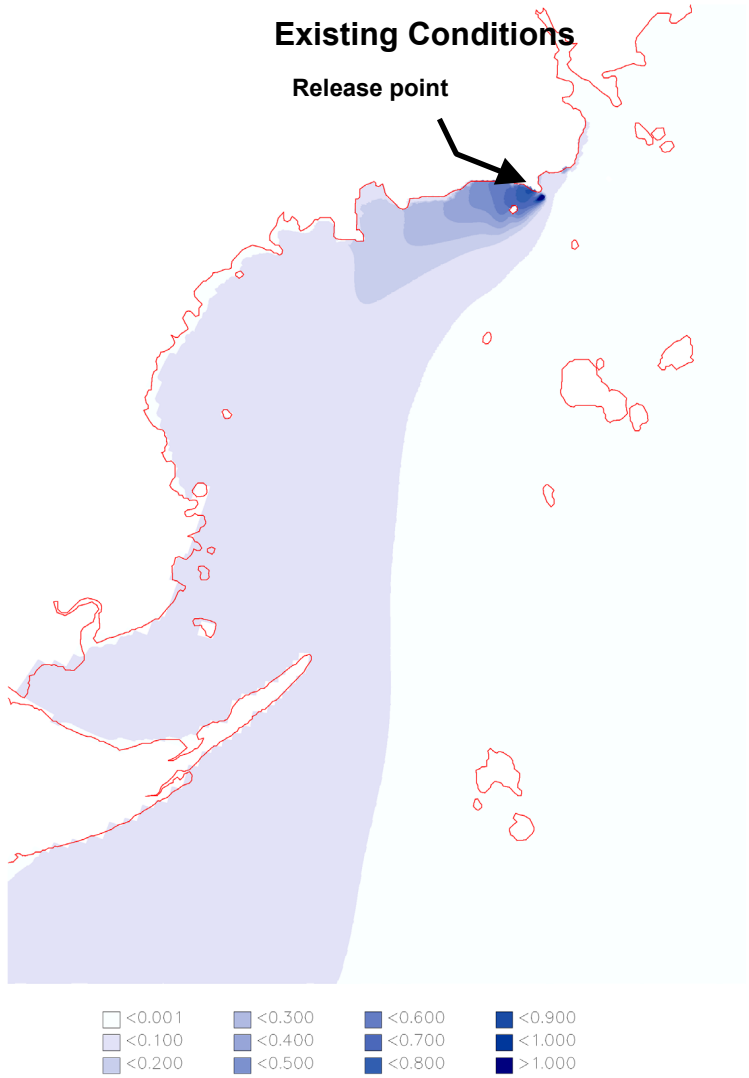
FIGURE B-34:
Concentration after 14 days
Release Point Farfan - AMU-H

Conservative tracer simulation: Release point Punta Bruja



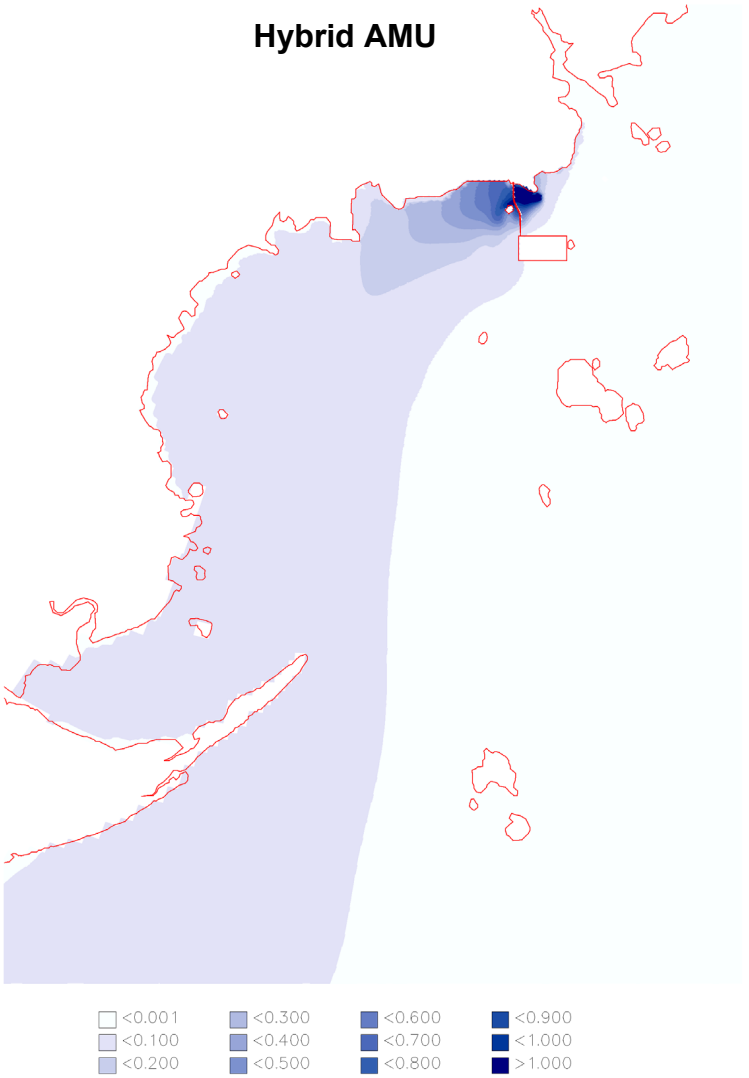


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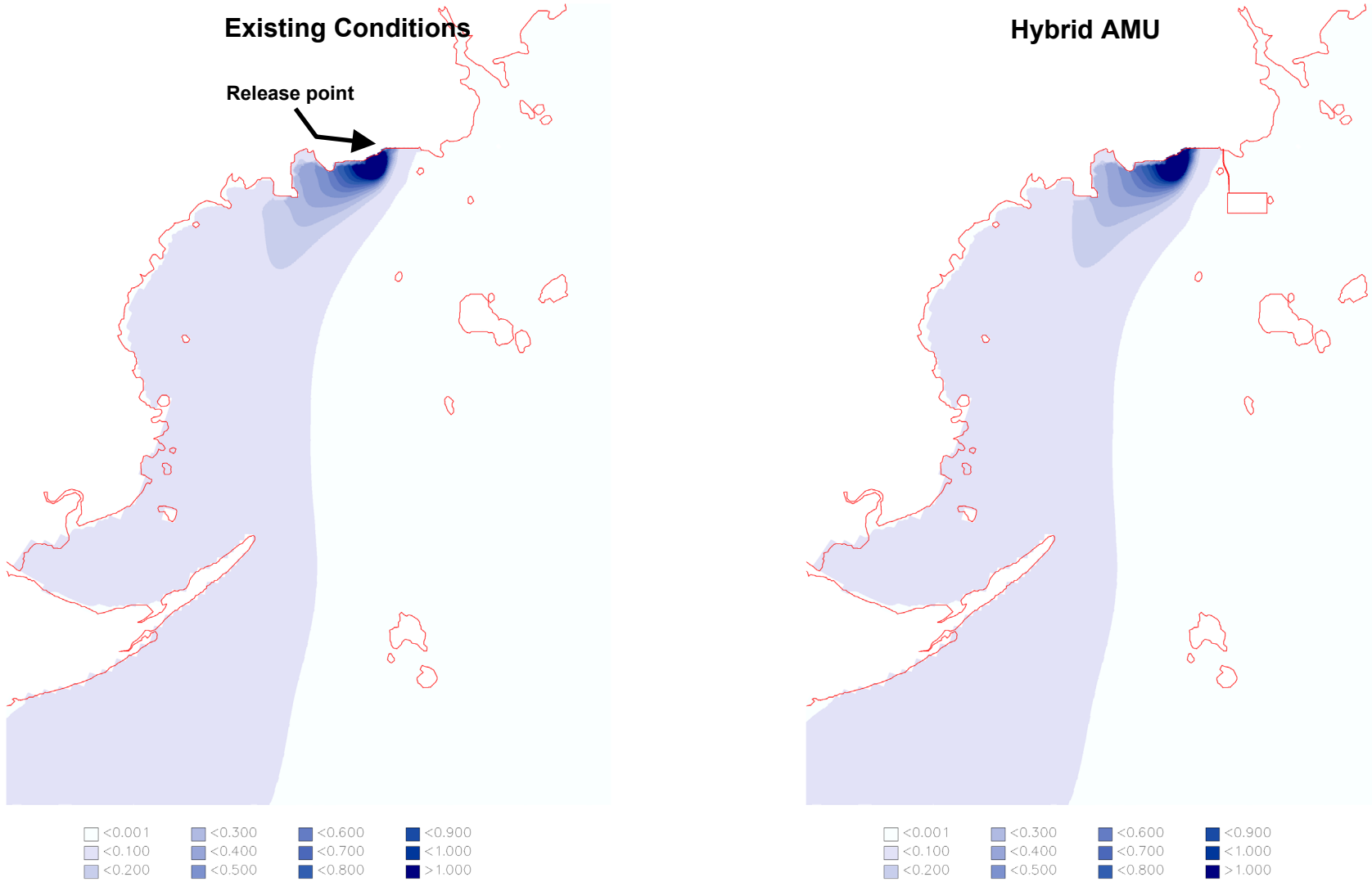
FIGURE B-35:
Concentration after 14 days
Release Point Punta Bruja - AMU-H

Conservative tracer simulation: Release point Veracruz



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ARTIFICIAL ISLAND FEASIBILITY STUDY

FIGURE B-36:
Concentration after 14 days
Release Point Veracruz - AMU-H

APPENDIX I - COST ESTIMATES

Island Location Analysis

!	Description	Unit	Unit Rate (US$)	PS-0 (Prelim Study Site)	PS-1	PS-2	PS-3	PS-4	PS-5	MS-1	Comments
	General Data										
1	Island Area	Ha		358.5	401.8	378.0	378.0	363.9	385.7	354.0	
2	Causeway Length	m		3,800	3,850	4,530	4,600	4,450	3,270	1,300	Island 3 Option
3	Causeway Bridge Approaches (MSE Wall)	m2		26,000	26,000	26,000	26,000	26,000	26,000	0	Cost Item 30
4	Shoreline Trestle Length	m		200	200	200	200	200	200	0	
5	Boat Bridge Length	m		100	100	100	100	100	100	0	
6	Offshore Trestle Length	m		100	100	100	100	100	100	0	
	Fill Calculations										
7	Island settlement	m		1.75	1.75	1.75	1.75	1.75	1.75	1.25	
8	Shrinkage Factor	%		90%	90%	90%	90%	90%	90%	90%	
	Material Utilization										
9	Material Available from Locks	m3		90,155,000	90,155,000	90,155,000	90,155,000	90,155,000	90,155,000	90,155,000	Includes 30% bulking factor
10	Material from Dredging (@ 80% of dredged vol)	m3		7,649,520	12,818,160	10,668,720	7,608,080	6,652,880	5,909,920	-	
11	Total Material Available [2]	m3		97,804,520	102,973,160	100,823,720	97,763,080	96,807,880	96,064,920	90,155,000	
12	Unfactored Island Fill (incl settlement)	m3		78,729,150	88,629,800	85,829,700	82,222,350	81,714,000	82,384,100	55,926,000	Calculated from DTM
13	Island Fill (incl 90% shrinkage + settlement)	m3		86,497,433	97,472,556	94,387,333	90,388,167	89,825,033	90,599,289	62,140,000	Cost Item 28
14	Island Revetment	m3		979,400	1,005,000	979,000	970,000	968,300	938,600		
15	Island Fill (relief contouring)									27,834,556	16m of relief
16	Causeway Core	m3		3,189,647	3,359,000	4,473,941	4,779,529	4,640,600	3,360,782		Cost Item 29
17	Causeway Bridge Approaches	m3		666,667	666,667	666,667	666,667	666,667	666,667	-	Cost Item 29
18	Causeway Armor	m3		650,000	540,000	707,000	713,000	676,400	497,100		
19	Breakwater	m3		5,777,800	-	-	-	-	-	-	Cost Item 30
20	Total Volume Utilized [1]	m3		97,760,947	103,043,222	101,213,941	97,517,363	96,777,000	96,062,438	89,974,556	
21	Volume Remaining (2 - 1)	m3		43,573	(70,062)	(390,221)	245,717	30,880	2,482	180,444	
	Dredging Calculations										
22	Dredging in Soft Material	m3		8,246,300	10,104,000	8,476,300	6,871,350	6,129,260	6,659,850	-	Cost Item 37
23	Dredging in Weathered Rock **	m3		633,640	2,476,150	2,099,500	1,086,250	909,440	517,350	-	Calculated from DTM - Cost Item 38
24	Dredging in Dense Rock	m3		681,960	3,442,550	2,760,100	1,552,500	1,277,400	210,200	-	Calculated from DTM - Cost Item 39
25	Dredging in Rock	m3		1,315,600	5,918,700	4,859,600	2,638,750	2,186,840	727,550	-	
26	Dredging Totals	m3		9,561,900	16,022,700	13,335,900	9,510,100	8,316,100	7,387,400	-	Calculated from DTM

Cost Summary

	Transportation Costs										
27	Transportation to Island Site via Rail (Includes rough-grading of causeway + island)	m3	$ 4.90	$ 441,759,500	$ 441,759,500	$ 441,759,500	$ 441,759,500	$ 441,759,500	$ 441,759,500	$ 441,759,500	Average cost of transportation, Includes rough-grading of island and causeway
	Construction Costs										
28	Island Revetment	m3	$ 15.00	$ 14,691,000	$ 15,075,000	$ 14,685,000	$ 14,550,000	$ 14,524,500	$ 14,079,000	$ -	Includes revetment costs
29	Causeway Armor	m3	$ 20.00	$ 13,000,000	$ 10,800,000	$ 14,140,000	$ 14,260,000	$ 13,528,000	$ 9,942,000	$ -	Includes fill for bridge approaches
30	Causeway Bridge Approaches (MSE Wall)	m2	$ 450.00	$ 11,700,000	$ 11,700,000	$ 11,700,000	$ 11,700,000	$ 11,700,000	$ 11,700,000	$ -	
31	40.1m-wide Shoreline Trestle	m	$ 42,460.00	$ 8,492,000	$ 8,492,000	$ 8,492,000	$ 8,492,000	$ 8,492,000	$ 8,492,000	$ -	
32	21.7m-wide Trestle (Mixed_use Option)	m	$ 22,977.11	$ -	$ -	$ -	$ -	$ -	$ -	$ 29,870,239	
33	100m Fishing Boat Bridge	m	$ 60,980.00	$ 6,098,000	$ 6,098,000	$ 6,098,000	$ 6,098,000	$ 6,098,000	$ 6,098,000	$ -	
34	40.1m-wide Offshore Trestle	m	$ 63,690.00	$ 6,369,000	$ 6,369,000	$ 6,369,000	$ 6,369,000	$ 6,369,000	$ 6,369,000	$ -	
35	Breakwater	m	$ 15.00	$ 86,667,000	$ -	$ -	$ -	$ -	$ -	$ -	
36	**Total Construction Costs**			$ 147,017,000	$ 58,534,000	$ 61,484,000	$ 61,469,000	$ 60,711,500	$ 56,680,000	$ 29,870,239	
	Dredging Costs										
37	Dredging in Soft Material	m3	$ 2.00	$ 16,492,600	$ 20,208,000	$ 16,952,600	$ 13,742,700	$ 12,258,520	$ 13,319,700	$ -	
38	Dredging in Weathered Rock **	m3	$ 12.00	$ 7,603,680	$ 29,713,800	$ 25,194,000	$ 13,035,000	$ 10,913,280	$ 6,208,200	$ -	
39	Dredging in Dense Rock	m3	$ 25.00	$ 17,049,000	$ 86,063,750	$ 69,002,500	$ 38,812,500	$ 31,935,000	$ 5,255,000	$ -	
40	**Total Dredging Costs**			$ 41,145,280	$ 135,985,550	$ 111,149,100	$ 65,590,200	$ 55,106,800	$ 24,782,900	$ -	
41	**Totals**	**$**		**$ 629,921,780**	**$ 636,279,050**	**$ 614,392,600**	**$ 568,818,700**	**$ 557,577,800**	**$ 523,222,400**	**$ 471,629,739**	
42	**Island Area**	Ha		358.5	401.8	378.0	378.0	363.9	385.7	354.0	
43	**Cost per m2**	$/m2		$ 175.71	$ 158.36	$ 162.54	$ 150.48	$ 153.22	$ 135.66	$ 133.23	

*** Assumed weathered rock layer thickness of 1.5m*

Island Location Analysis

!	Description	Unit	Unit Rate (US$)	PS-6	Comments
	General Data				
1	Island Area (PS-6)	Ha		203.2	
1	Island Area (MS-2)	Ha		216.0	
2	Causeway Length	m		200	Island 3 Option
2	Causeway Bridge Approaches (MSE Wall)	m2		0	Cost Item 28
3	Shoreline Trestle Length	m		200	
3	Boat Bridge Length	m		0	
4	Offshore Trestle Length	m		0	
	Fill Calculations				
5	Island settlement	m		1.75	
6	Shrinkage Factor	%		85%	
	Material Utilization				
7	Material Available from Locks	m3		90,155,000	Includes 30% bulking factor
8	Material from Dredging (@ 80% of dredged vol)	m3		5,909,920	
9	Total Material Available [2]	m3		96,064,920	
10	Unfactored Island Fill - PS-6 (incl settlement)	m3		17,540,700	Calculated from DTM
11	Unfactored Island Fill - MS-2 (incl settlement)	m3		38,473,000	Calculated from DTM
11	Island Fill - PS-6 (incl shrinkage + settlement)	m3		23,257,818	Cost Item 26
12	Island Fill - MS-2 (incl shrinkage + settlement)	m3		45,262,353	Cost Item 27
12	Island Revetment	m3		934,300	
13	Island Fill (15m relief contouring on MS-2)	m3		20,470,588	16m of relief
14	Causeway Core	m3		-	Cost Item 27
15	Causeway Bridge Approaches	m3		-	Cost Item 27
16	Causeway Armor	m3		-	
17	Breakwater	m3		-	Cost Item 28
18	Total Volume Utilized [1]	m3		89,925,059	
19	Volume Remaining (2 - 1)	m3		6,139,861	
	Dredging Calculations				
20	Dredging in Soft Material	m3		6,659,850	Cost Item 35
21	Dredging in Weathered Rock **	m3		517,350	Calculated from DTM - Cost Item 36
22	Dredging in Dense Rock	m3		210,200	Calculated from DTM - Cost Item 37
23	Dredging in Rock	m3		727,550	
24	Dredging Totals	m3		7,387,400	Calculated from DTM

Cost Summary

	Transportation Costs				
25	Transportation to Island Site via Rail (Includes rough-grading of causeway + island)	m3	$ 4.90	$ 440,632,788	Average cost of transportation, Includes rough-grading of island and causeway
	Construction Costs				
26	Island Revetment	m3	$ 15.00	$ 14,014,500	Includes revetment costs
27	Causeway Armor	m3	$ 20.00	$ -	Includes fill for bridge approaches
28	Causeway Bridge Approaches (MSE Wall)	m2	$ 450.00	$ -	
29	40.1m-wide Shoreline Trestle	m	$ 42,460.00	$ 8,492,000	
30	21.7m-wide Trestle (Mixed_use Option)	m	$ 22,977.11	$ -	
31	100m Fishing Boat Bridge	m	$ 60,980.00	$ -	
32	40.1m-wide Offshore Trestle	m	$ 63,690.00	$ -	
33	Breakwater	m	$ 15.00	$ -	
34	**Total Construction Costs**			$ 22,506,500	
	Dredging Costs				
35	Dredging in Soft Material	m3	$ 2.00	$ 13,319,700	
36	Dredging in Weathered Rock **	m3	$ 12.00	$ 6,208,200	
37	Dredging in Dense Rock	m3	$ 25.00	$ 5,255,000	
38	**Total Dredging Costs**			$ 24,782,900	
39	**Totals**	**$**		**$ 487,922,188**	
40	**Island Area**	Ha		203.2	
41	**Cost per m2**	$/m2		$ 240.12	

*** Assumed weathered rock layer thickness of 1.5m*

PRELIMINARY COST ESTIMATE		DATE PREPARED 30-Jan-04
CLIENT **AUTORIDAD DEL CANAL DE PANAMA**	PROJECT NO. **4594-06**	
	ESTIMATED BY **MOFFATT & NICHOL**	
PROJECT TITLE **Island Feasibility Study**	STATUS OF DESIGN **Feasibility**	

Structures Costs

Item	Quantity	Unit	Unit Cost	Total
Structure				
40.1m-wide Trestle	200	m	$42,456.08	$8,491,215
21.4m-wide Trestle	3,820	m	$18,522.60	$70,756,318
Causeway Bridge Approaches (MSE Wall)	26,000	m^2	$450.00	$11,700,000
Causeway Bridge	100	m	$60,977.91	$6,097,791

Estimated Cost - Permanent Trestle

Item	Units	Unit Price	Quantity	Cost
Dimensions				
Length	m		200.0	
Width	m		41.3	
Piles				***$2,317,909***
20" Square P/C P/S Concrete Piles	m	$238.59	2,880	*$687,148*
20" Square Load Test	ea	$20,984.15	2	*$41,968*
PDA Dynamic Test	ea	$4,185.51	10	*$41,855*
20" Pile Cutoff	ea	$70.02	189	*$13,233*
Drill & Socket Piles	m	$2,219.54	691	*$1,533,704*
Deck				***$4,982,733***
CIP Concrete Topping	m^3	$847.37	1,239	*$1,049,890*
Concrete Closure Slab	m^3	$847.37	258	*$218,621*
CIP Concrete Bent Caps	m^3	$847.37	1,300	*$1,101,579*
Utililty Vault	m^3	$847.37	200	*$169,474*
P/C P/S Panels	m^3	$1,040.06	2,232	*$2,321,419*
Barrier Rails	m	$147.50	400	*$58,999*
Traffic Divider	m	$168.14	200	*$33,627*
Striping and Signage	LS	$29,125.00	1	*$29,125*
Rail Road				***$1,190,573***
Rail Road Ballast and Tie	m	$335.47	200	*$67,095*
P/C conc. Boxe girders	ea	$13,048.00	80	*$1,043,840*
Barrier Rails	m	$147.50	400	*$58,999*
Rails	m	$51.60	400	*$20,640*
TOTAL				**$8,491,215**

Cost per square meter	***$1,027.99***
Cost per linear meter	***$42,456.08***

31.5m-wide trestle

Cost per linear meter	$32,381.75

Estimated Cost - Temporary Trestle

Item	Units	Unit Price	Quantity	Cost
Dimensions				
Length	m		3,820.0	
Width	m		21.4	
Piles				**$20,835,917**
HP 14x117 Piles	m	$144.82	35,022	$5,071,963
Load Test	ea	$20,320.00	2	$40,640
PDA Dynamic Test	ea	$4,287.50	10	$42,875
Pile Cutoff	ea	$70.02	1,915	$134,084
Drill & Socket Piles	m	$2,219.54	7,004	$15,546,355
Deck				**$49,920,401**
CIP Concrete Topping	m^3	$847.37	12,208	$10,344,403
Concrete Closure Slab	m^3	$847.37	2,413	$2,044,651
CIP Concrete Bent Caps	m^3	$847.37	12,236	$10,368,669
P/C P/S Panels	m^3	$1,040.06	24,415	$25,393,493
Barrier Rails	m	$147.50	7,640	$1,126,900
Traffic Divider	m	$168.14	3,820	$642,286
TOTAL				**$70,756,318**

Cost per square meter	***$865.54***
Cost per linear meter	***$18,522.60***

Pile Length	18.288

Estimated Cost - Boat Bridge (100m L x 41.3m W)

Item	Units	Unit Price	Quantity	Cost
Dimensions				
Length	m		100.0	
Width	m		41.3	
RAIL BRIDGE				**$1,914,545**
Piles				**$550,537**
20" Square P/C P/S Concrete Piles	m	$238.12	1,280	$304,829
20" Square Load Test	ea	$20,320.00	2	$40,640
PDA Dynamic Test	ea	$4,287.50	8	$34,300
20" Pile Cutoff	ea	$70.02	120	$8,402
Drill & Socket Piles	m	$2,219.57	73	$162,366
Substructure				**$790,495**
Pile Cap	m^3	$847.37	802	$679,389
Reinforced Concrete Column	m^3	$847.37	107	$90,528
Elastomeric Bearings	ls	$7,620.00	1	$7,620
Concrete End bents	m^3	$847.37	15	$12,957
Superstructure				**$573,514**
Precast Segmental Box Girder	m^3	$851.20	596	$507,616
Railroad Ballast and Ties	m	$364.14	100	$36,405
Barrier Rails	m	$147.50	200	$29,492
TRUCK BRIDGE				**$4,183,246**
Piles				**$931,014**
20" Square P/C P/S Concrete Piles	m	$238.12	2,304	$548,692
20" Square Load Test	ea	$20,320.00	2	$40,640
PDA Dynamic Test	ea	$4,287.50	8	$34,300
20" Pile Cutoff	ea	$70.02	216	$15,124
Drill & Socket Piles	m	$2,219.57	132	$292,259
Substructure				**$1,724,219**
35mx10mx2m Pile Cap	m^3	$847.37	1,406	$1,191,544
3-Reinforced Concrete Columns	m^3	$847.37	340	$287,938
Reinforced Concrete Bent Cap	m^3	$847.37	225	$190,471
Elastomeric Bearings	ls	$7,620.00	1	$7,620
Concrete End bents	m^3	$847.37	55	$46,646
Superstructure				**$1,528,013**
12-Modified Type VI P/S Girders	m	$594.00	1,200	$712,613
Precast Prestressed Deck Panels	m^2	$68.47	2,157	$147,729
CIP Concrete Topping	m^3	$847.37	522	$442,704
Barrier Rails	m	$147.50	200	$29,492
Traffic Divider	m	$168.14	100	$16,814
Striping and Signage	LS	$29,125.00	1	$29,125
Utility Vault	m^3	$847.37	176	$149,536
TOTAL				**$6,097,791**

Cost per square meter	***$1,476.46***
Cost per linear meter	***$60,977.91***

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-0

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	3850	m	Total causeway length (excluding trestle and bridge)
Settlement	1.25	m	
Avg. Height	7.9	m	Includes 1.75m settlement
Avg. Height (incl settement)	15.15	m	
Crest Width	55	m	Preliminary Design
Avg. Base Width	115.6	m	Calculated
Avg. Sectional Area - Armor	169	m^2	
Sectional Area - Core	1123.295	m^2	
Material consumed			
Bridge Approaches	**666,667**		used in retained-earth approaches
Causeway Fill Volume - Total	**3,666,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**650,650**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**3,016,017**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	8,100	m	Based on layout as shown in report Figure 9-5
Average Island Height Above Seabed	20.95	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	117.11	m^2	
Armor Volume	**948,624**	m^3	Used for revetment cost item
Breakwater Volume Calcs			
Length	3400	m	Refer report Figure 9-5
Bottom elevation (MLWS)	26.95	m	Includes 3m settlement
Avg. Sectional Area - Armor	301	m^2	
Sectional Area - Armor	442.00	m^2	Refer report Figure 9-4 for typical geometry
Sectional Area - Core	1053.00	m^2	Refer report Figure 9-4 for typical geometry
Material consumed			
Armor Volume	**1,560,000**	**m^3**	30% of total volume
Core Volume	**3,640,000**	**m^3**	70% of total volume
Total Volume	**5,200,000**	**m^3**	Volume of rock required for breakwater (DTM volume + shrinkage + settlement)

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-1

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	3860	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	1.3	m	
Average Depth	5.2	m	Includes 1.75m settlement
Average Height Above Seabed	12.5	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	104.8	m	Calculated
Avg. Sectional Area - Armor	139.0	m^2	
Sectional Area - Core	855.8	m^2	
Material consumed			
Bridge Approaches	**666,667**		used in retained-earth approaches
Causeway Fill Volume - Total	**3,666,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**536,540**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**3,130,127**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	8,540	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	13.3	m	
Average Height Above Seabed	21.1	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	117.67	m^2	
Armor Volume	**1,004,928**	m^3	Used for revetment cost item

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-2

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	4530	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	1.3	m	
Average Depth	6.7	m	Includes 1.75m settlement
Average Height Above Seabed	14.0	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	110.8	m	Calculated
Avg. Sectional Area - Armor	156.0	m^2	
Sectional Area - Core	1000.5	m^2	
Material consumed			
Bridge Approaches	**666,667**		used in retained-earth approaches
Causeway Fill Volume - Total	**3,666,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**706,680**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**2,959,987**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	8,200	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	13.6	m	
Average Height Above Seabed	21.4	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	119.35	m^2	
Armor Volume	**978,671**	m^3	Used for revetment cost item

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-3

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	4600	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	1.3	m	
Average Depth	6.6	m	Includes 1.75m settlement
Average Height Above Seabed	13.9	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	110.4	m	Calculated
Avg. Sectional Area - Armor	155.0	m^2	
Sectional Area - Core	990.4	m^2	
Material consumed			
Bridge Approaches	**666,667**		used in retained-earth approaches
Causeway Fill Volume - Total	**3,666,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**713,000**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**2,953,667**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	8,200	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	13.4	m	
Average Height Above Seabed	21.2	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	118.23	m^2	
Armor Volume	**969,503**	m^3	Used for revetment cost item

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-4

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	4450	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	1.3	m	
Average Depth	6.4	m	Includes 1.75m settlement
Average Height Above Seabed	13.6	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	109.4	m	Calculated
Avg. Sectional Area - Armor	152.0	m^2	
Sectional Area - Core	965.9	m^2	
Material consumed			
Bridge Approaches	**666,667**		used in retained-earth approaches
Causeway Fill Volume - Total	**3,666,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**676,400**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**2,990,267**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	8,000	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	13.9	m	
Average Height Above Seabed	21.7	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	121.03	m^2	
Armor Volume	**968,217**	m^3	Used for revetment cost item

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-5

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	3270	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	1.3	m	
Average Depth	6.4	m	Includes 1.75m settlement
Average Height Above Seabed	13.6	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	109.4	m	Calculated
Avg. Sectional Area - Armor	152.0	m^2	
Sectional Area - Core	965.9	m^2	
Material consumed			
Bridge Approaches	**666,667**		used in retained-earth approaches
Causeway Fill Volume - Total	**3,666,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**497,040**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**3,169,627**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	8,210	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	12.7	m	
Average Height Above Seabed	20.5	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	114.32	m^2	
Armor Volume	**938,559**	m^3	Used for revetment cost item

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site PS-6

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	200	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	0.5	m	
Average Depth	-1.0	m	Includes 1.75m settlement
Average Height Above Seabed	5.5	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	77	m	Calculated
Avg. Sectional Area - Armor	61.0	m^2	
Sectional Area - Core	302.0	m^2	
Material consumed			
Bridge Approaches	**-**		used in retained-earth approaches
Causeway Fill Volume - Total	**66,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**12,200**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**54,467**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	5,710	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	3.6	m	
Average Height Above Seabed	11.4	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	63.45	m^2	
Armor Volume	**362,291**	m^3	Used for revetment cost item

Panama Artificial Island Feasibility Study

Island Volume Calculations-

Site MS-2

Item	Quantity	Unit	Comments
Causeway Volume Calcs			
Length	200	m	Total causeway length (excluding trestle and bridge)
Finished Elevation	6.0		
Settlement	0.5	m	
Average Depth	-1.0	m	Includes 1.75m settlement
Average Height Above Seabed	5.5	m	
Crest Width	55.0	m	Preliminary Design
Avg. Base Width	77	m	Calculated
Avg. Sectional Area - Armor	61.0	m^2	
Sectional Area - Core	302.0	m^2	
Material consumed			
Bridge Approaches	**-**		used in retained-earth approaches
Causeway Fill Volume - Total	**66,667**	**m^3**	Volume of rock required for causeway (DTM volume + shrinkage + settlement)
Causeway Volume- Armor	**12,200**	**m^3**	Calculated from Avg Area x Length - for cost estimate
Causeway Volume- Core	**54,467**	**m^3**	Total volume - armor volume
Island Assumptions/Criteria			
MHWS Elevation (PLD)	2.7	m	
Freeboard Allowance	3.3	m	
Finished Surface Elevation (PLD)	6		
Island Revetment Volume Calcs			
Perimeter (revetment) Length	6,000	m	Based on layout as shown in report Figure 9-5
Finished Elevation (PLD)	6.0	m	
Settlement	1.8	m	
Average Depth	9.3	m	
Average Height Above Seabed	17.1	m	
Revetment Side Slopes	2H:1V		
Sectional Area - Armor	95.31	m^2	
Armor Volume	**571,874**	m^3	Used for revetment cost item

APPENDIX J - BIBLIOGRAPHY

BIBLIOGRAPHY

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