Appendix J - Hydrology and Drainage

Environmental Statement
East-West Arterial Extension:
Section 2 (Woodland Drive – Lookout Road)
Section 3 (Lookout Road – Frank Sound Road)

Appendix J.1 – Hydraulic and Hydrologic Studies of EWA, Memorandum 1 – Preliminary Rainfall Analysis – RVE

Hydraulic and Hydrologic Studies of Proposed East-West Arterial Highway Expansion

Memorandum 1- Preliminary Rainfall Analysis

Prepared For:

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List of Abbreviation

CI: Cayman Islands

FDOT: Florida Department of Transportation IDF:

Intensity-Duration-Frequency

NOAA: USA National Oceanic and Atmospheric Administration NRA:

National Roads Authority in Cayman

NRCS: USA National Resources and Conservation Service

WA: Water Authority - Cayman

Introduction

This rainfall analysis memorandum has been prepared under the pre-project hydraulic and hydrologic studies related to the National Roads Authority (NRA) proposed East-West (EW) Arterial Highway Expansion Project on Grand Cayman Island. Remington & Vernick Engineers has been retained to prepare a Hydraulic and Hydrologic study for the proposed EW Arterial Expansion by NRA. This report analyzes the Grand Cayman Island rainfall data to determine the intensity-duration-frequency amounts for various rainfall events and the rainfall distribution.

Various short term and long-term rainfall data in different time steps were provided by the client. Data was analyzed for quality control then used to determine the design storms to be used in the proposed highway drainage infrastructure of the study area. To better represent and understand the rainfall data, descriptive statistical parameters including maximum, minimum, average, median, and 1st Quartile and 3rd Quartile of the rainfall or calculated rainfall were calculated. Frequency analysis, correlation and regression methods were used to study of the similarity of the weather station as well as prediction of the events with various return periods.

Grand Cayman Island Climate

In general, based on the Köppen- Geiger climate map, the climate of the Cayman Islands is a combination of tropical hot and humid throughout the year, with a dry, relatively cold months from late November to mid-April [1]. The average amount of precipitation is almost 1,400 millimeters (55.10 inches) per year, and the wettest months are September and October.

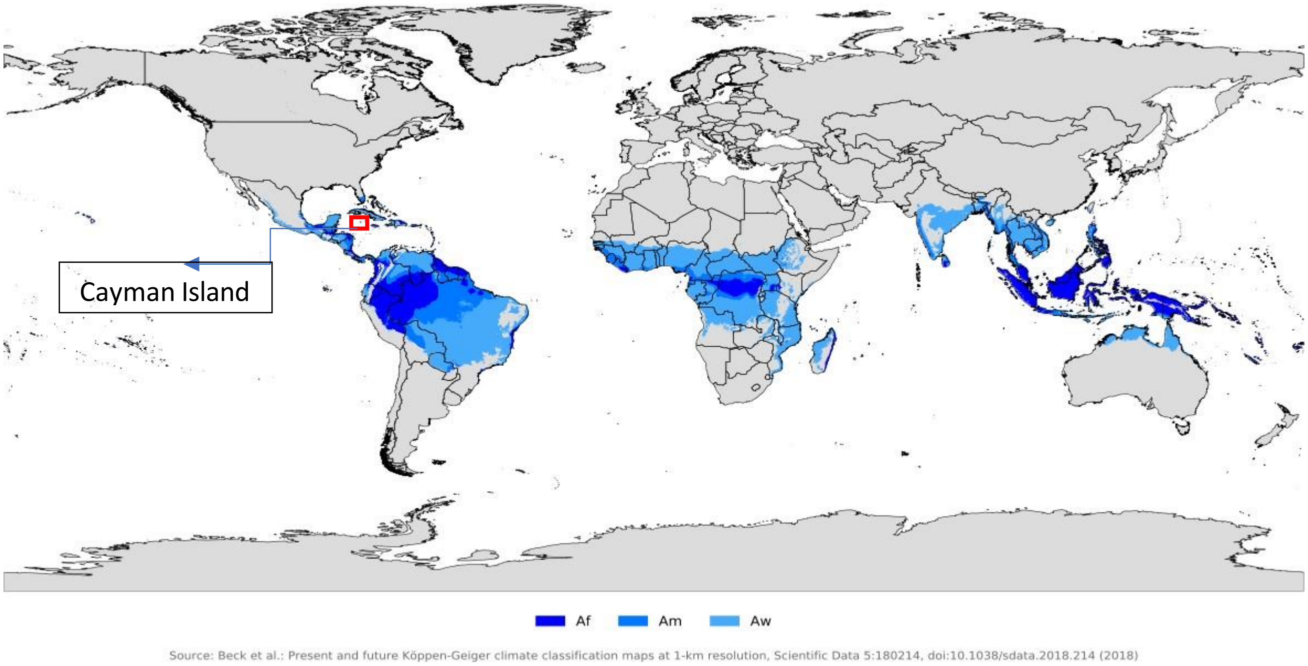


Figure 1 Köppen- Geiger classification of the study area

Rainfall Analysis

Three sets of rainfall data were received. The first two sets of data included a set of daily rainfall data of the Cayman Islands Water Authority rain gauges or weather stations data that includes, at minimum, 16 rainfall stations spanning from 1982 to 2021. The third set of data received was the hourly data of from 4 weather stations including ACWW, AGRI, CWCWB and DVNS (Figure 2). The second set of data spanned from 2009 to 2022. Table 1 shows the availability of the hourly data. HOBOware software was used for retrieving the logged data by HOBO onset data loggers. A spreadsheet of yearly totals at Grand Cayman containing the greatest 24-hour rainfall by month for years 1988 to 2022 was also received.

Method

The received data was checked for quality assurance. A correlation study was used to determine the correlation between the rain gauges. The stronger correlation shows the similarity of the recorded data between two weather stations and the missing data of one station can be estimated by the correlation relation.

The daily (24 hours) recorded data was used for maximum daily rainfall intensity analysis. Daily data is available from year 1982 to year 2021 for the majority of the rain gauges under the jurisdiction of Water Authority across Grand Cayman Island. The peak 24 hours rainfall from the weather stations were identified and then the maximum daily (average 24-hours) intensity was calculated. The data was used for rainfall intensity analysis as well as extreme event identification.

Hourly data of 4 weather stations (Figure 2) including ACWW, AGRI, CWCWB and DVNS was used for the rainfall distribution analysis. 1-minute logged rainfall data was created from the recorded data loggers information and then the 5 minutes, 10 minutes, 15 minutes, 30 minutes, hourly, 6 hours, 12 hours and 24 hours time series were generated. The developed time series were used for rainfall distribution analysis and creating Intensity-Duration-Frequency (IDF) curves. The Weibull equation (T=m/n+1) was used for return period calculation, if needed, whereas m is the rank of the event and n is the total number of the studied events.
Probability (P=1/T) also was calculated as the inverse of the return period.

Rainfall Intensity

The result of the statistical investigation for maximum 24-hours rainfall intensity is shown on Figure 1. The intensities calculated are between 3.22 mm/hr (0.13 in/hr) to 20.49 mm/hr (0.81 in/hr) with a mean of 8.15 mm/hr (0.32 in/hr). The analysis showed the value of 20.49 mm/hr (0.81 in/hr) is an extreme event that corresponds to Hurricane Ivan, 2004. A time series was generated for the 40 years data and the return period was calculated. The Figure 4 shows the graph that includes rainfall intensities versus the return periods.

The data followed a logarithmic distribution. A linear logarithmic relation with a goodness of fit of 0.97 was fitted. The regressed relation expected a 100-year return period maximum 24 hours rainfall intensity as 26.73 mm/hr (1.05 in/hr). From the calculated return periods, the probability of each event was calculated and then the cumulative probability calculated. The result of cumulative probability versus maximum 24-hours rainfall depths are shown on Figure 5. It can be concluded from Figure 5 that 50% of the events have a maximum 24 hours rainfall depth of less than 200 mm (7.87 in) corresponding to 8.33 mm/hr (0.33 in/hr) and 90% of the events have a maximum 24 hours rainfall depth less than 300 mm (11.81 in) corresponding to 12.50 mm/hr (0.49 in/hr).

Table 1 Available Hourly Data

ACWW	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
January	×	×	×	×	DA	DA	×	C	DA	DA	×	×	×	×
February	×	×	×	×	DA	DA	C	C	DA	DA	×	×	×	×
March	×	×	×	×	DA	DA	C	C	DA	DA	DA	×	×	×
April	×	×	×	×	DA	DA	C	×	DA	DA	×	×	×	×
May	×	×	×	×	DA	DA	C	×	DA	DA	×	×	×	×
June	×	×	×	×	DA	DA	C	C	DA	DA	DA	×	×	×
July	×	×	×	×	DA	DA	DA	×	DA	×	DA	×	×	×
August	×	×	×	×	DA	DA	DA	DA	DA	×	DA	×	×	×
September	×	×	×	×	DA	DA	DA	DA	DA	DA	DA	×	×	×
October	×	×	×	DA	DA	×	DA	DA	DA	DA	×	×	×	×
November	×	×	×	DA	×	DA	DA	DA	DA	×	×	×	×	×
December	×	×	×	×	DA	DA	×	DA	DA	DA	×	×	×	×

AGRI	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
January	×	DA	DA	×	×	DA	DA	C	×	×	DA	DA	×	×
February	×	DA	DA	×	×	DA	C	C	DA	DA	DA	DA	×	×
March	DA	DA	DA	×	×	DA	C	C	DA	DA	DA	DA	×	×
April	DA	DA	DA	×	×	DA	C	DA	DA	DA	DA	×	×	×
May	DA	DA	DA	×	×	DA	C	DA	DA	DA	DA	×	×	×
June	DA	×	DA	×	×	DA	C	C	×	DA	DA	×	×	×
July	DA	×	DA	×	×	×	×	DA	×	DA	DA	×	×	×
August	DA	×	×	×	×	DA	×	DA	×	DA	DA	×	×	×
September	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
October	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
November	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
December	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×

CWCWB	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
January	×	DA	DA	DA	×	×		C	DA	DA	DA	DA	×	×
February	×	DA	DA	×	×	×	C	C	DA	DA	DA	DA	×	×
March	DA	DA	×	×	×	×	C	C	DA	DA	DA	DA	×	×
April	DA	DA	×	×	×	DA	C	DA	DA	DA	DA	DA	×	×
May	DA	DA	×	×	×	DA	C	DA	DA	DA	DA	DA	×	×
June	DA	DA	×	×	×	DA	C	C	DA	DA	DA	DA	×	×
July	DA	DA	DA	×	×	DA	×	DA	DA	DA	DA	×	×	×
August	DA	DA	DA	×	×	DA	×	DA	DA	DA	DA	×	×	×
September	DA	DA	×	DA	×	×	×	DA	DA	DA	DA	×	×	×
October	DA	×	×	DA	×	×	DA	DA	×	DA	DA	×	×	×
November	DA	×	×	DA	×	×	DA	DA	×	DA	DA	×	×	×
December	DA	DA	×	DA	×	DA	DA	DA	×	DA	DA	×	×	×

DVNS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
January	×	×	×	DA	×	×	DA	C	×	×	×	×	×	×
February	×	×	×	DA	×	DA	C	C	×	×	×	×	×	×
March	DA	×	DA	DA	×	DA	C	C	×	×	×	×	×	×
April	DA	×	×	DA	×	DA	C	DA	×	×	×	×	×	×
May	DA	×	×	DA	×	DA	C	DA	×	×	×	×	×	×
June	DA	DA	×	DA	×	DA	C	C	×	×	×	×	×	×
July	DA	DA	×	DA	×	DA	DA	DA	×	×	×	×	×	×
August	DA	DA	×	DA	×	DA	DA	×	×	×	×	×	×	×
September	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×
October	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×
November	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×
December	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×

DA — Data Available

× — Data was not available

C — Data Available Among all Four Weather Station

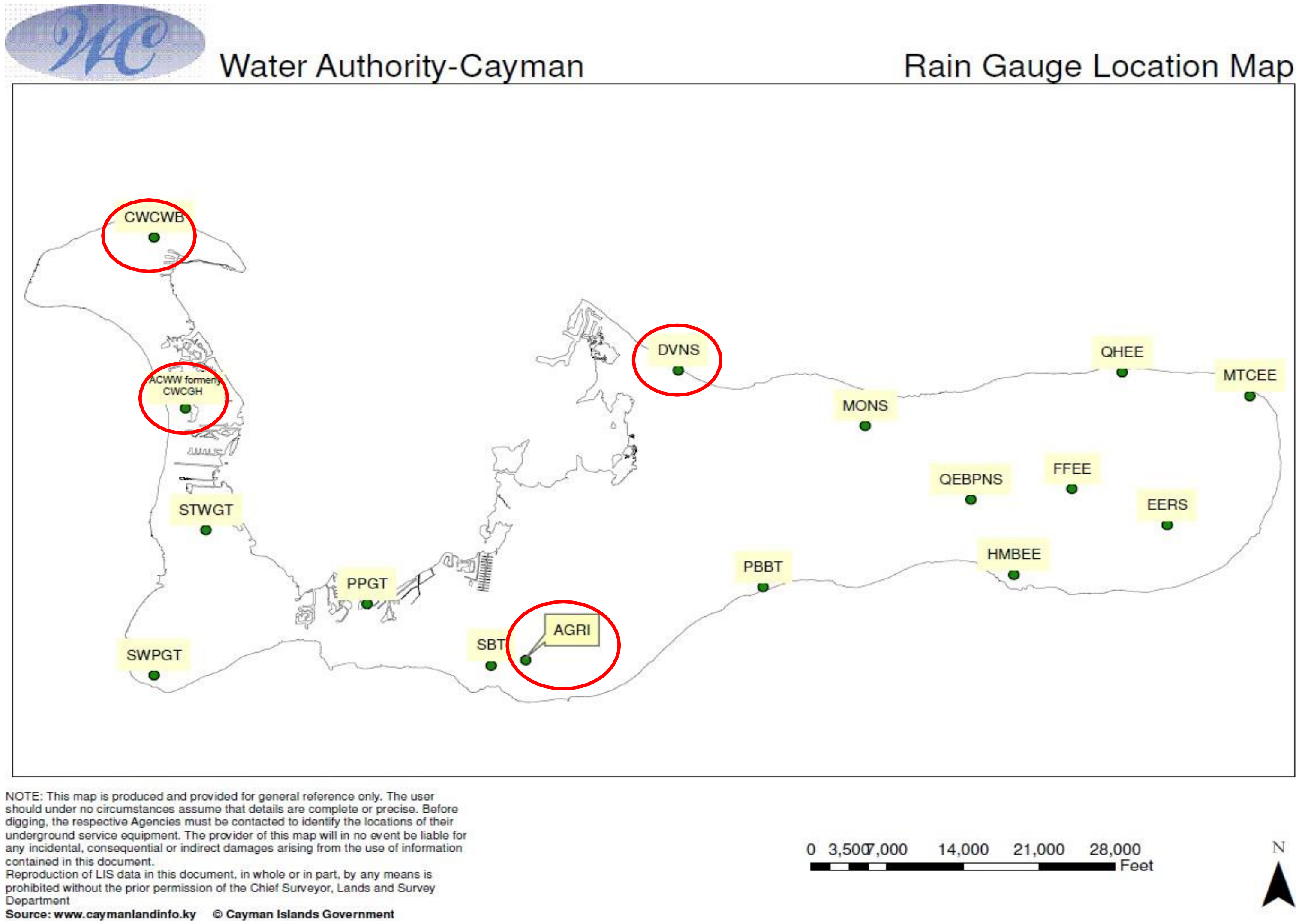


Figure 2 Map of the Cayman Island weather stations (red circled shows the station with hourly data)

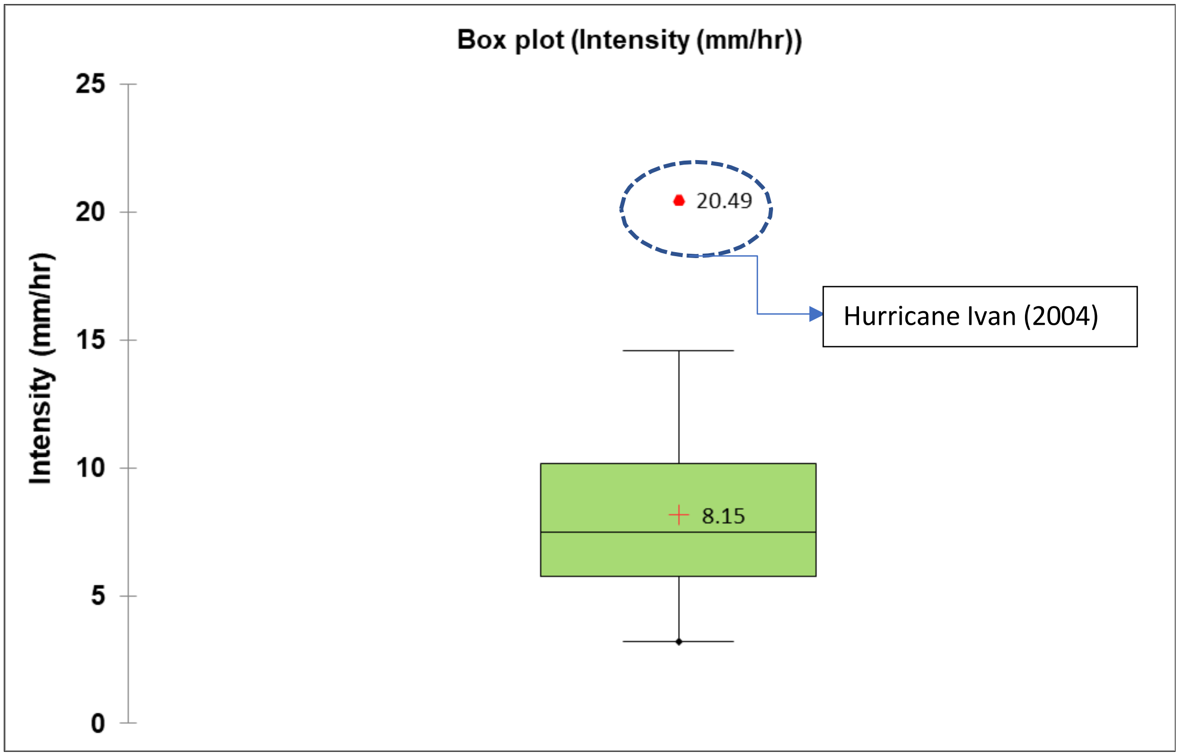


Figure 3 Maximum 24 hours rainfall intensity statistics

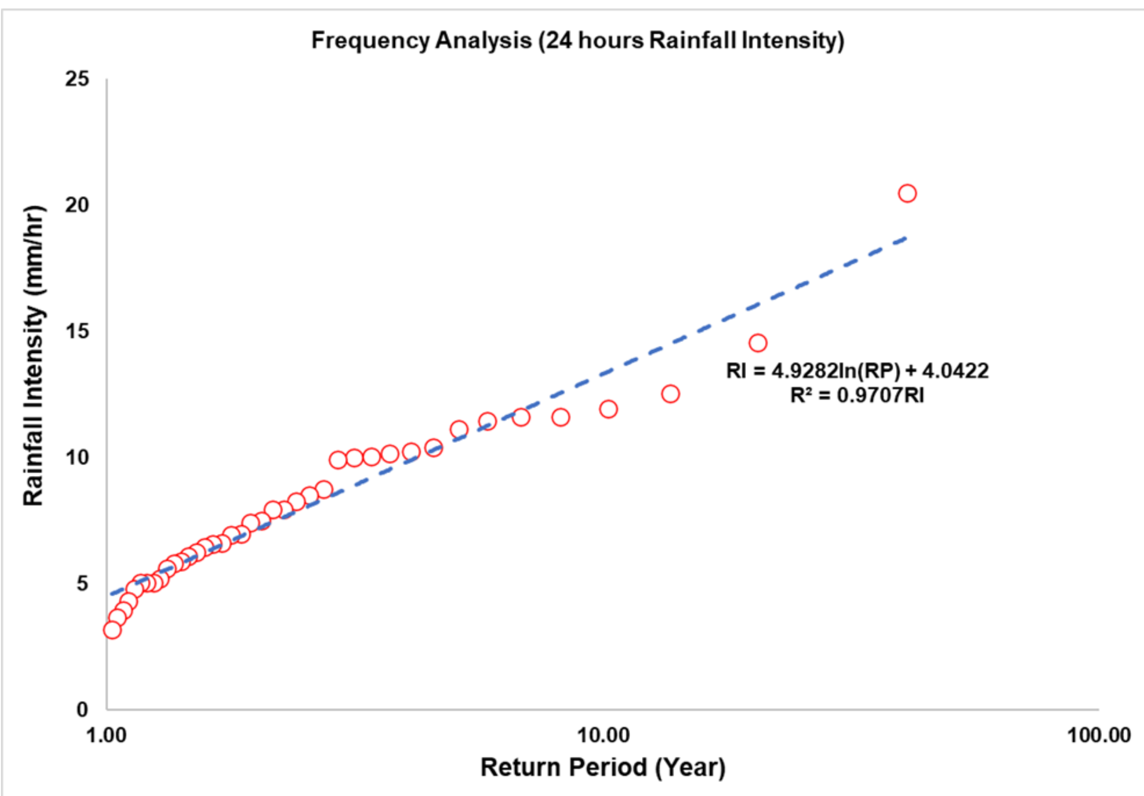


Figure 4 Maximum 24 hours rainfall intensities versus return period

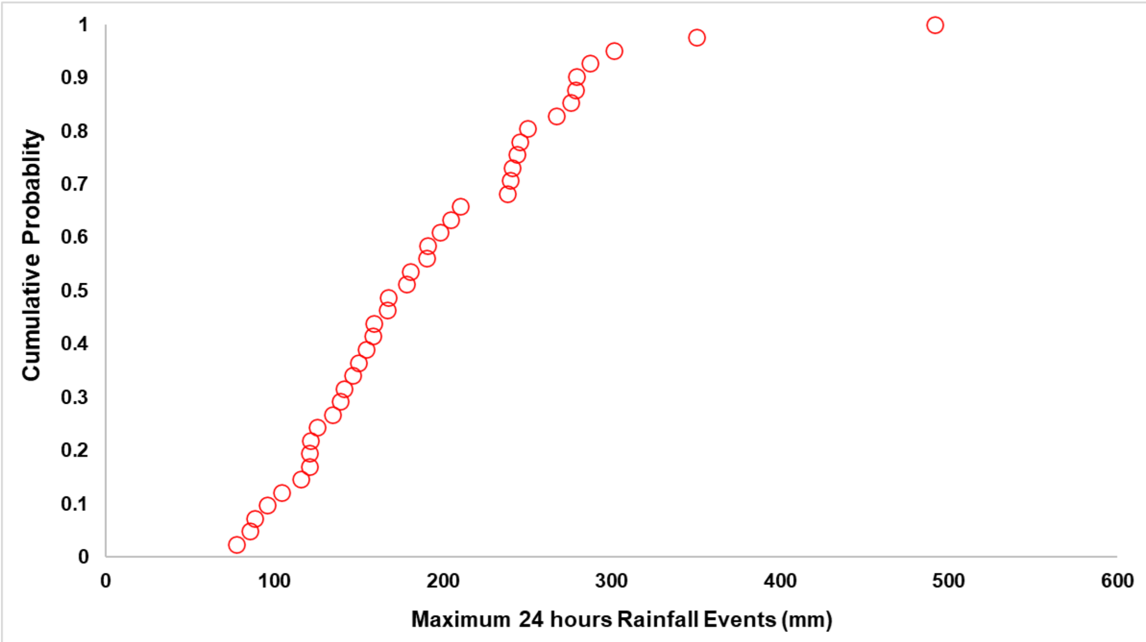


Figure 5 Cumulative probability versus maximum 24 hours rainfall depth

Hourly Rainfall Analysis

A correlation study among the rain gauges with hourly data was performed and the results are shown in the Table 2. Two periods, yellow highlighted in Table 1, in 2015 and 2016 when the data was available for all four rain gauges were selected for correlation study and the daily rainfall depths were used for analysis. CWCWB and DVNS showed the strongest correlation among the study rain gauges. The data from these two rain gauges can be used interchangeable and the missing data of one station can be estimated from the other one. The larger the correlation coefficient, the more accurate will be the predicted data.

Table 2 Correlation study among the rain gauges with hourly data

Year- Correlation (R^2)	**Rain gauge**	**ACWW**	**AGRI**	**CWCWB**	**DVNS**
2015	ACWW	1.0	0.24	0.39	0.17
	AGRI	0.24	1.0	0.4	0.33
	CWCWB	0.39	0.4	1.0	0.59
	DVNS	0.17	0.33	0.59	1.0
2016	ACWW	1.0	0.03	0.02	0.06
	AGRI	0.03	1.0	0.1	0.03
	CWCWB	0.02	0.1	1.0	0.4
	DVNS	0.06	0.03	0.4	1.0

Rainfall Distribution Analysis

Hourly data was used for distribution analysis. Each event was created from the rainfall data using a minimum of 25.4 mm (1 inch) and then 24 hours fractional rainfall depth calculated for each event. An average of the events was used for distribution analysis. Figure 6 shows the calculated distribution for the Water Authority rain gauges and its comparison with NRCS rainfall distribution and FDOT [4] in Figure 6 and the comparison with NOAA rainfall distributions and FDOT is depicted in Figure 7. While the expectation was that Grand Cayman Island follow the NRCS TYPE III rainfall distribution, the data mainly showed tendency towards the NRCS TYPE I distribution for hours 0 to 9 and the NRCS TYPE III distribution from hours 17 to 24 (Figure 6). Both the NRCS and NOAA types of distribution centered the events around mid-day and NRCS TYPE curves considered 50% of the event between hours 12 and 14 while NOAA considered 70% of the event between hours 12 and 14. FDOT uses a gradual type of distribution that centered around 12. Attachment B shows the NRCS type rainfalls across the United States. Attachments C & D shows the NOAA and FDOT rainfall distribution for various periods.

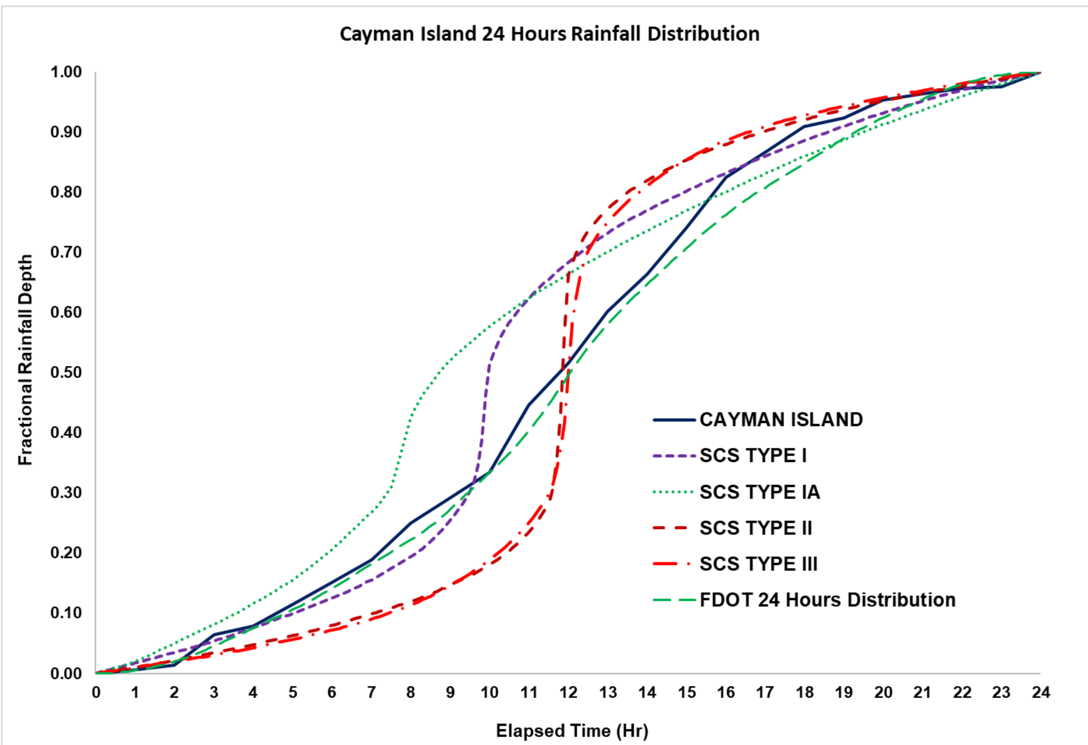


Figure 6 Estimated Grand Cayman Island rainfall distribution with regards to the NRCS distributions and the FDOT distribution

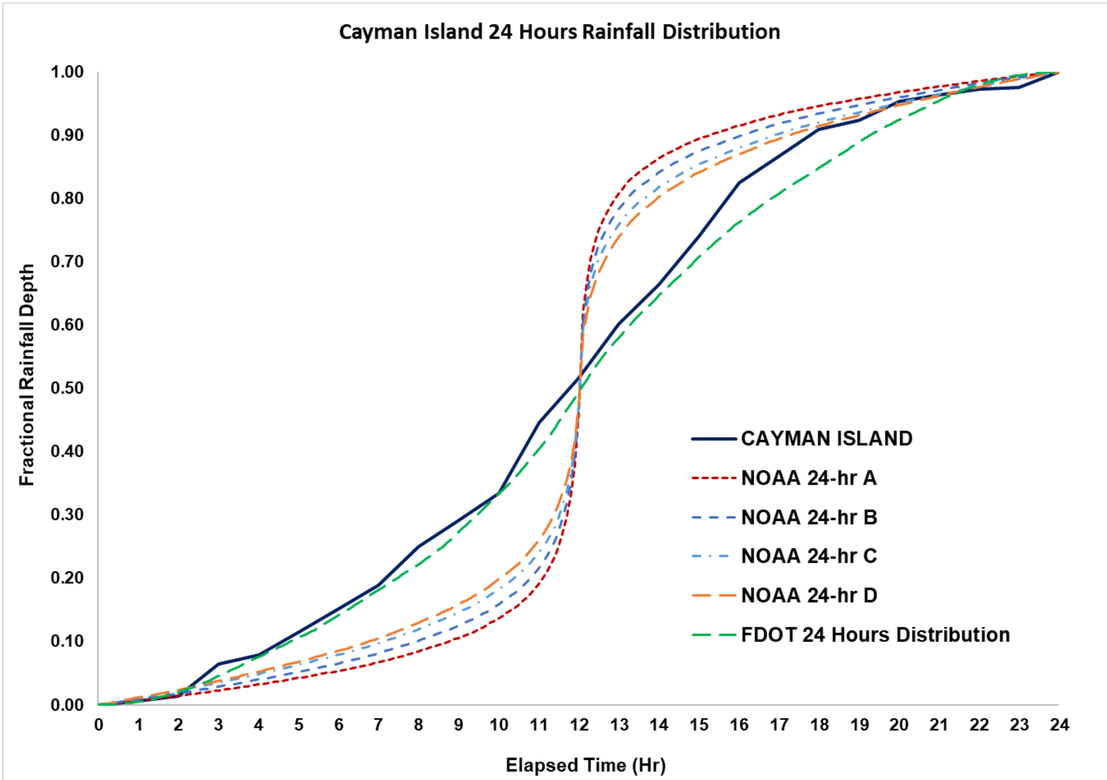


Figure 7 Estimated Grand Cayman Island rainfall distribution with regards to the NOAA distributions and the FDOT distribution

IDF Curves

For the generated time series with 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 6 hours, 12 hours, and 24 hours durations, associated rainfall intensities and return periods were calculated then the values were used for generating IDF curves. Initial IDF curves for the study area are shown in the Figure 8. As expected, the graph shows that the larger intensities are as the result of shorter duration rainfall events.

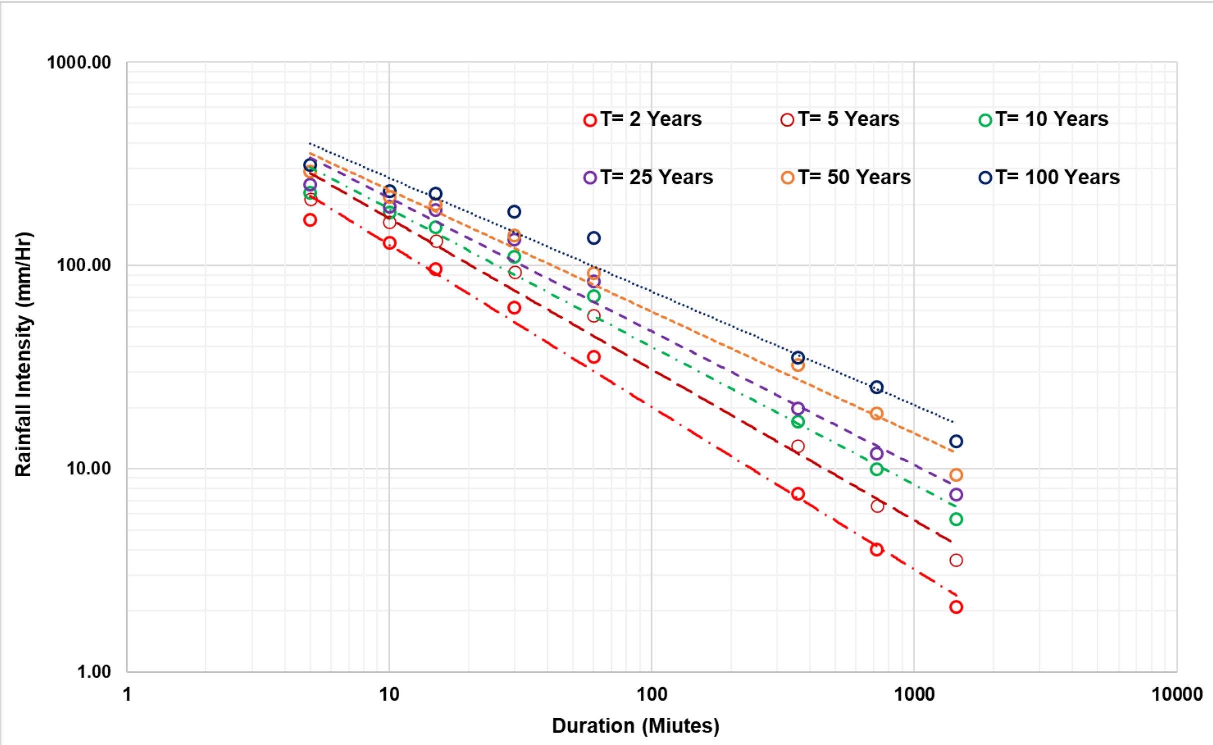


Figure 8 Calculated IDF curves for the study area

Conclusion

The available daily and hourly rainfall data was analyzed in this report. As it was discussed in earlier literature, there are a number of missing information and a lack of a long-term rainfall data in the study area that precludes identifying the IDF curves precisely [2]. The results of the IDF analysis correlate with the results presented by Baird and Associates [3] for the Cruise Berthing Facility (2015). Larger values for both the IDF curves and 25-years rainfall intensity were calculated. Additionally, it is demonstrated that the overall rainfall distribution shows a good agreement with FDOT rainfall distribution pattern.

References

1 Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences, 11(5), 1633-1644.

2 Lumbroso, D. M., et al. "The challenges of developing rainfall intensity–duration– frequency curves and national flood hazard maps for the Caribbean." Journal of Flood Risk Management 4.1 (2011): 42-52.

3 Baird and Associates (2015) Storm Water Master Plan Report for the Cayman Island Government Cruise Berthing Facility.

4 FDOT Drainage Design Guide (2019). State Of Florida Department of Transportation. Office Of Design, Drainage Section, Tallahassee, Florida

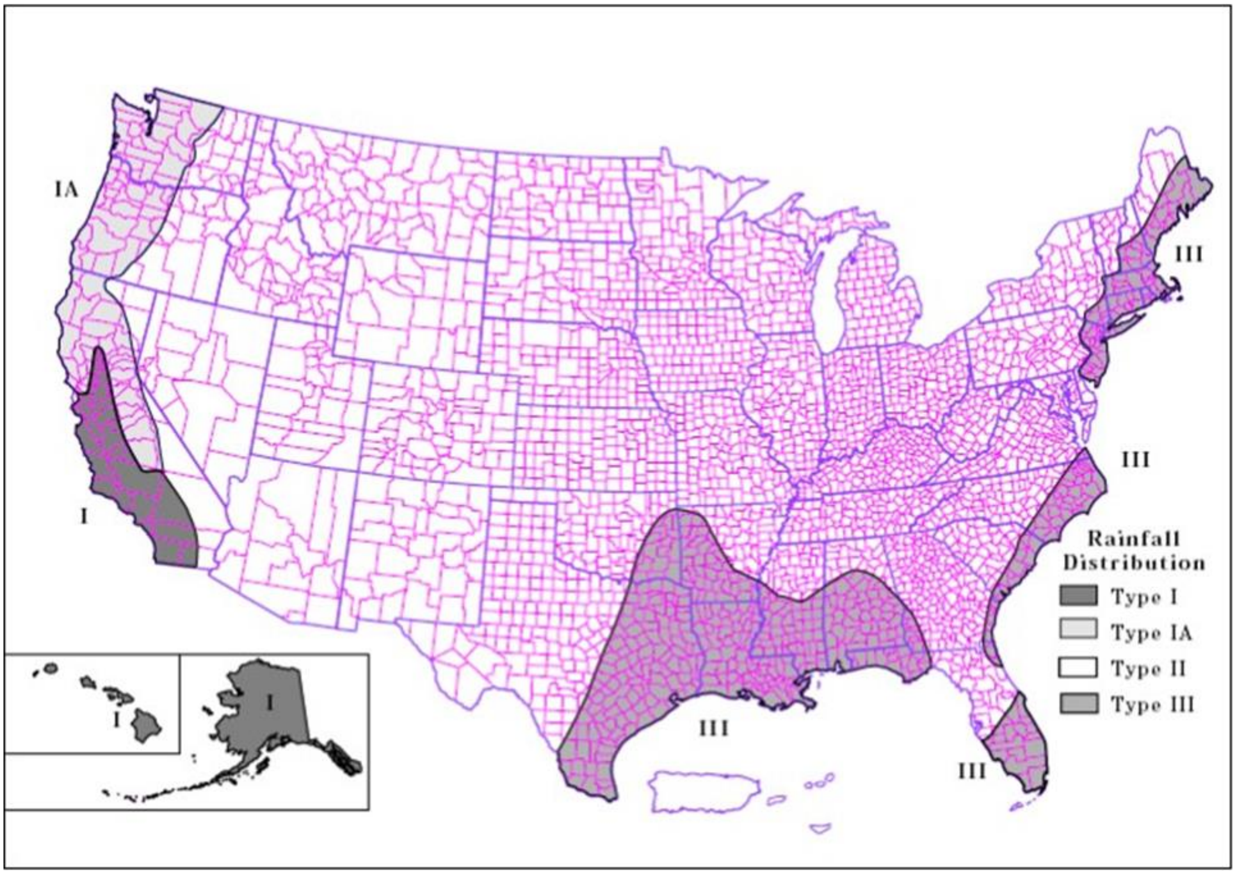
Attachments

A- Descriptive statistics of maximum 24 hours rain

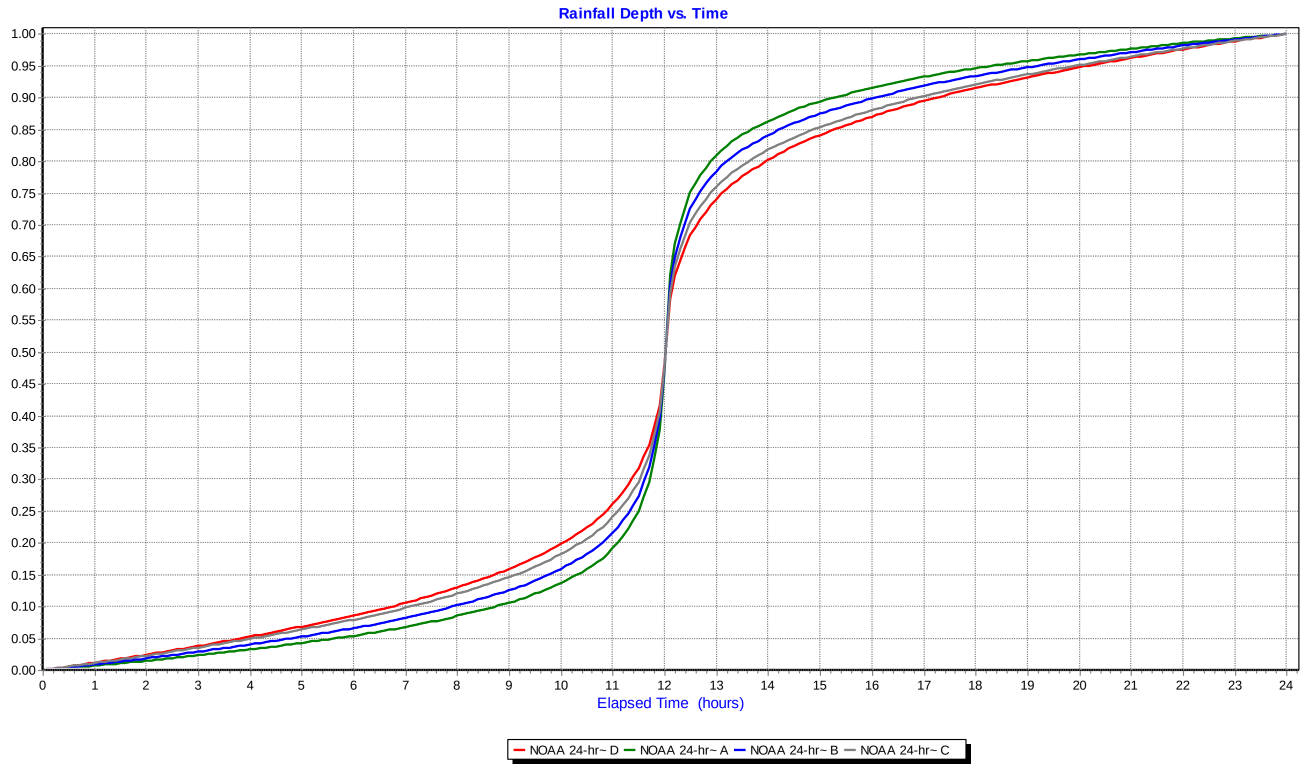
Descriptive statistics (Quantitative data):

Statistic	Intensity (mm/hr)
Number of observations	40
Minimum	3.217
Maximum	20.492
1st Quartile	5.749
Median	7.477
3rd Quartile	10.180
Mean	8.154
Variance (n-1)	11.723
Standard deviation (n-1)	3.424

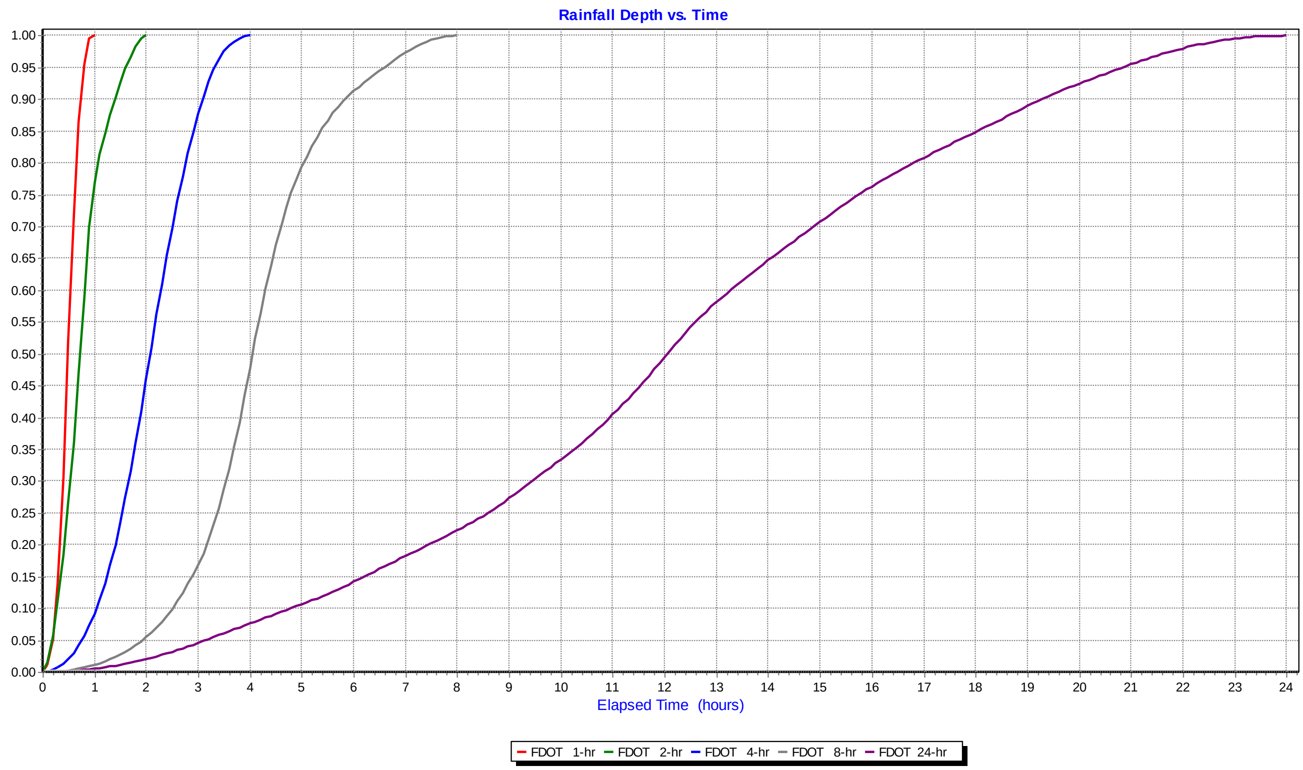
B- NRCS rainfall distribution across United States



C- NOAA rainfall distribution across United States



D- FDOT various rainfall distribution



Appendix J.2 –

Hydraulic and Hydrologic Studies of EWA, Memorandum 2 – Hydrology and Hydraulic Analysis – RVE

Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion

Memorandum 2- Hydrology and Hydraulic (H&H) Analysis

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

CI: Cayman Islands

USGS: United States Geographical Survey

Lidar: “**li**ght **d**etection **a**nd **r**anging" or "**l**aser **i**maging, **d**etection**,** **a**nd **r**anging”

NRA: National Roads Authority

WA: Water Authority

QGIS: Quantum Geographic Information System

HEC-HMS: Hydrologic Engineering Center Hydrologic Modeling System

HEC-RAS: Hydrologic Engineering Center River Analysis Program

2D Model: Two-Dimensional Model

Introduction

This hydraulic and hydrology analysis memorandum has been prepared under the pre-project hydraulic and hydrologic studies for the Cayman Islands Government National Roads Authority (NRA) proposed East-West (EW) Arterial Roadway Project on Grand Cayman Island. Remington & Vernick Engineers has been retained to prepare a Hydraulic and Hydrologic study for the proposed EW Arterial Expansion by NRA. This report employed the results of the Grand Cayman Island rainfall analysis report (Memorandum 1) and land data to perform a two-dimensional hydraulic model. The Hydraulic model was used to prepare inundation flood maps under various rainfall events or scenarios. This report was initially prepared for the only proposed East-West roadway option and the revised report has been prepared for several roadway alternatives. Inundation flood maps for a 2-year, 10-year, 25-year, 50-year, 100-year, and Hurricane Ivan of 2004 were prepared for a bigger drainage area. In general, the results showed that for the studied scenarios the depth of the floods from a 2-year to a 100- year event would be between 0.15 ft and 6 ft along the proposed inland roadways and the flood depth can be up to 10 feet for the roadway alternatives near the coastal area on the southwest of the site.

Grand Cayman Island Climate

In general, based on the Köppen- Geiger climate map, the climate of the Cayman Islands is a combination of tropical hot and humid throughout the year, with dry, relatively cold months from late November to mid-April [1]. The average amount of precipitation is almost 1,400 millimeters (55.10 inches) per year, and the wettest months are September and October.

Method

Three software packages including QGIS, HEC-HMS and HEC-RAS were used to perform this study. The results of the rainfall study along with GIS information (lidar, land use, and soil information) were input into the models. QGIS was used to extract an approximate general limit of the study area from the larger GIS information that was provided by the client (Figure 1). The US Army Corps of Engineer's Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), that is designed to simulate the precipitation-runoff processes of dendritic drainage basins, was used for hydrologic analysis. Using Lidar information from Cayman Lands and Survey website, a terrain model, in Grand Cayman datum, of the study area was built using QGIS for input into HEC-HMS [2]. HEC-HMS was used for delineating the drainage area and subcatchments from the terrain model and to define their characteristics for the model and rainfall-runoff studies (Figure 2 and Figure 3). Watershed and subcatchment boundaries are determined in the analysis at the accuracy of the terrain model. Refinement of the boundaries requires greater accuracy of the terrain model and local investigation, particularly along Frank Sound Road. From the model, the general runoff direction is from the east and west towards the north.

The groundwater lenses are generally situated under the high ground areas at the top of the watershed. There is an exfiltration of the lenses into the mangrove areas of a small amount that is not included in the analysis.

Future land development along with the roadway corridor without stormwater volume and rate reduction measures will increase runoff occurring at a faster time into the mangroves. With stormwater volume and rate reduction measures, such as the deep well injection methods currently utilized, is expected to reduce rates and volumes, but at an unknown amount due to the differences in the hydrologic methods utilized. Future development has not been addressed in this study.

The outputs from the HEC-HMS model, including the delineated drainage area and hydrographs, were input to the US Army Corps of Engineer's Hydrologic Engineering Center River Analysis Program (HEC-RAS) for preparing two-dimensional flood maps of the study area. A 2D area of almost 22 sq miles was defined over the study area (Figure 4). The 2D area mesh contained more than 427,733 computational cells. Additional information to run the HEC-RAS 2D model [3] including land use, infiltration, and manning's coefficients [3&4] were prepared from the GIS information received along with information from the Cayman Water Authority, Department of the Environment, and Department of Agriculture on the soils and land use shown in Figures 5 and 6. The assumed Manning's coefficient, percent impervious area, and soil infiltration information parameters are summarized in Table 1 and Table 2. USGS guidelines and the HEC-RAS 2D user manual were used for Manning's coefficient and soil parameters selection. The proposed roadway alignments were exported from AutoCAD into QGIS. The Proposed roadway shape files were generated in QGIS and then imported into HEC-RAS 2D for demonstration on the flood inundation maps. Figures 10 through 15 show the final developed flood inundation and depth maps.

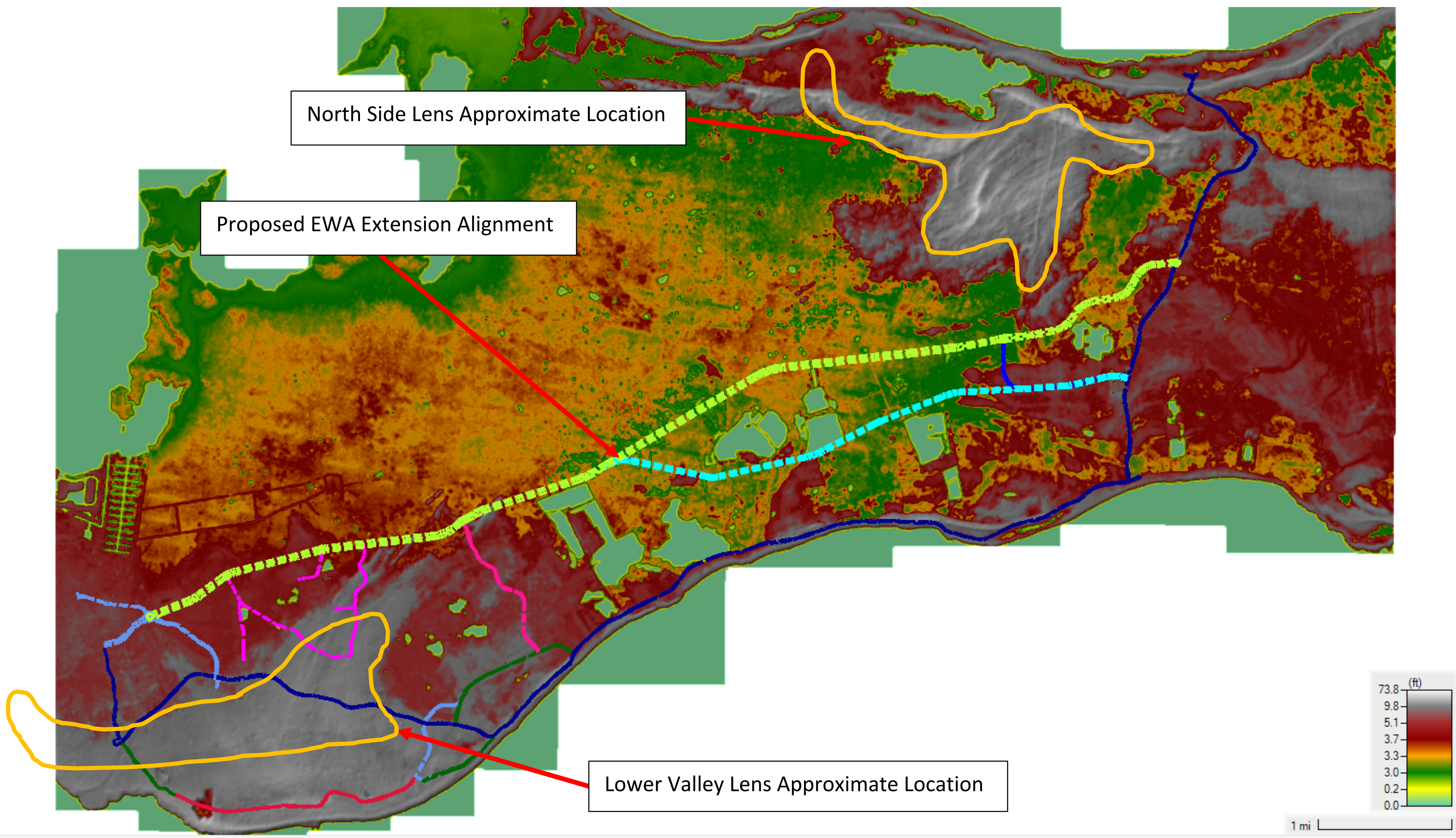

Figure 1 Study area boundary terrain model extracted by QGIS

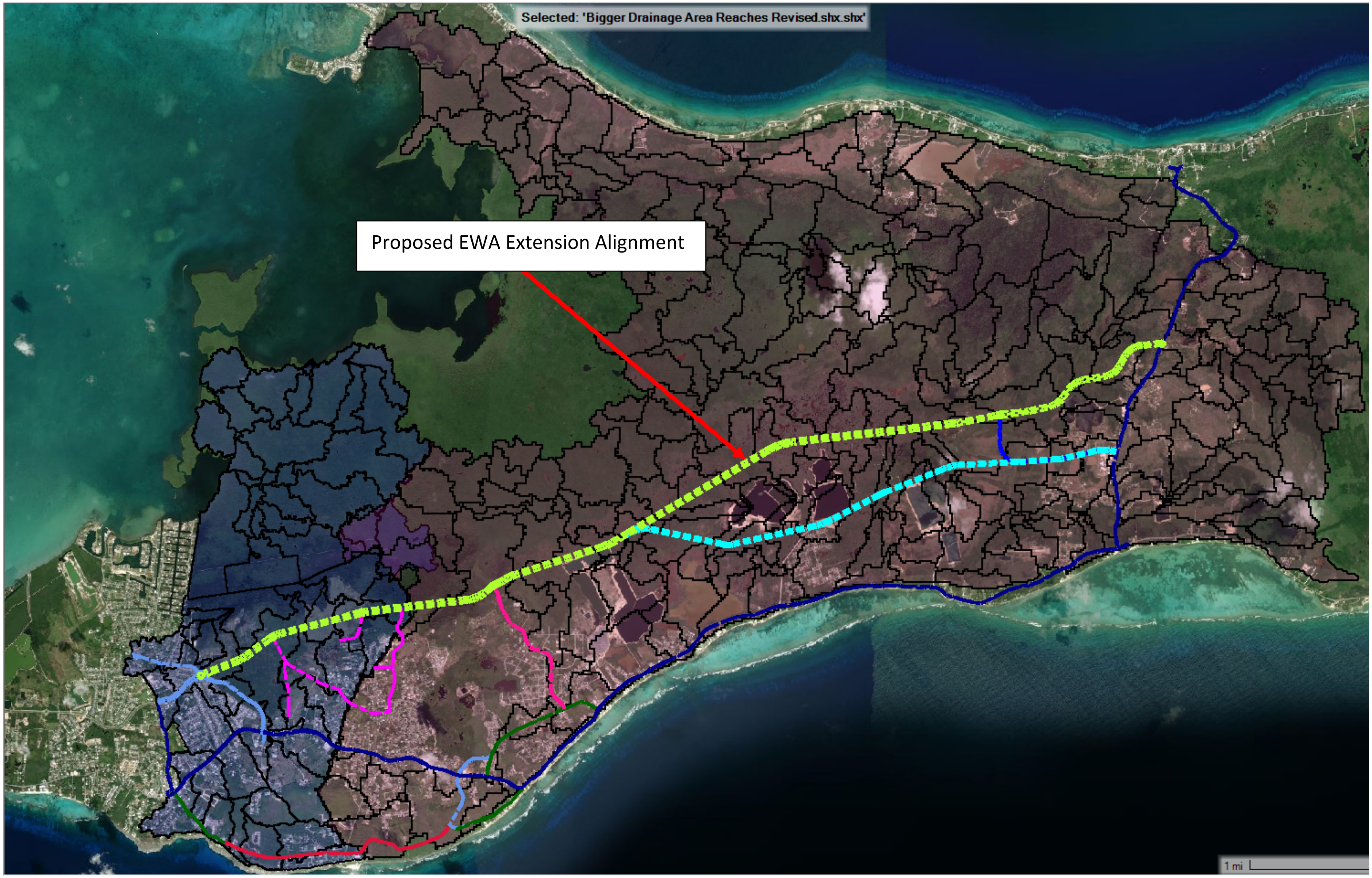

Figure 2 Delineated hydrological subcatchments for the study area

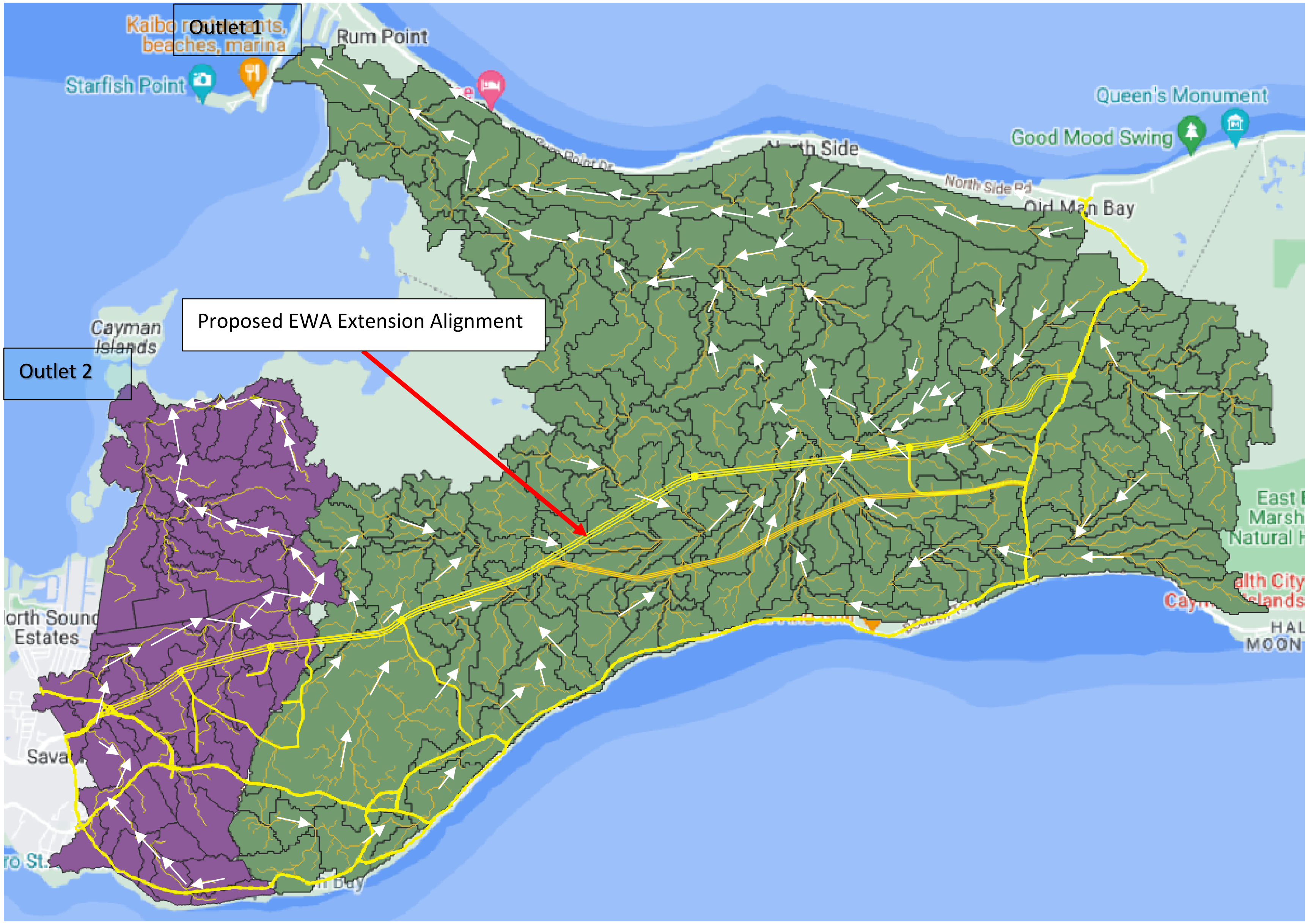

Figure 3 The delineated drainage area overlayed with a bigger Cayman Island map

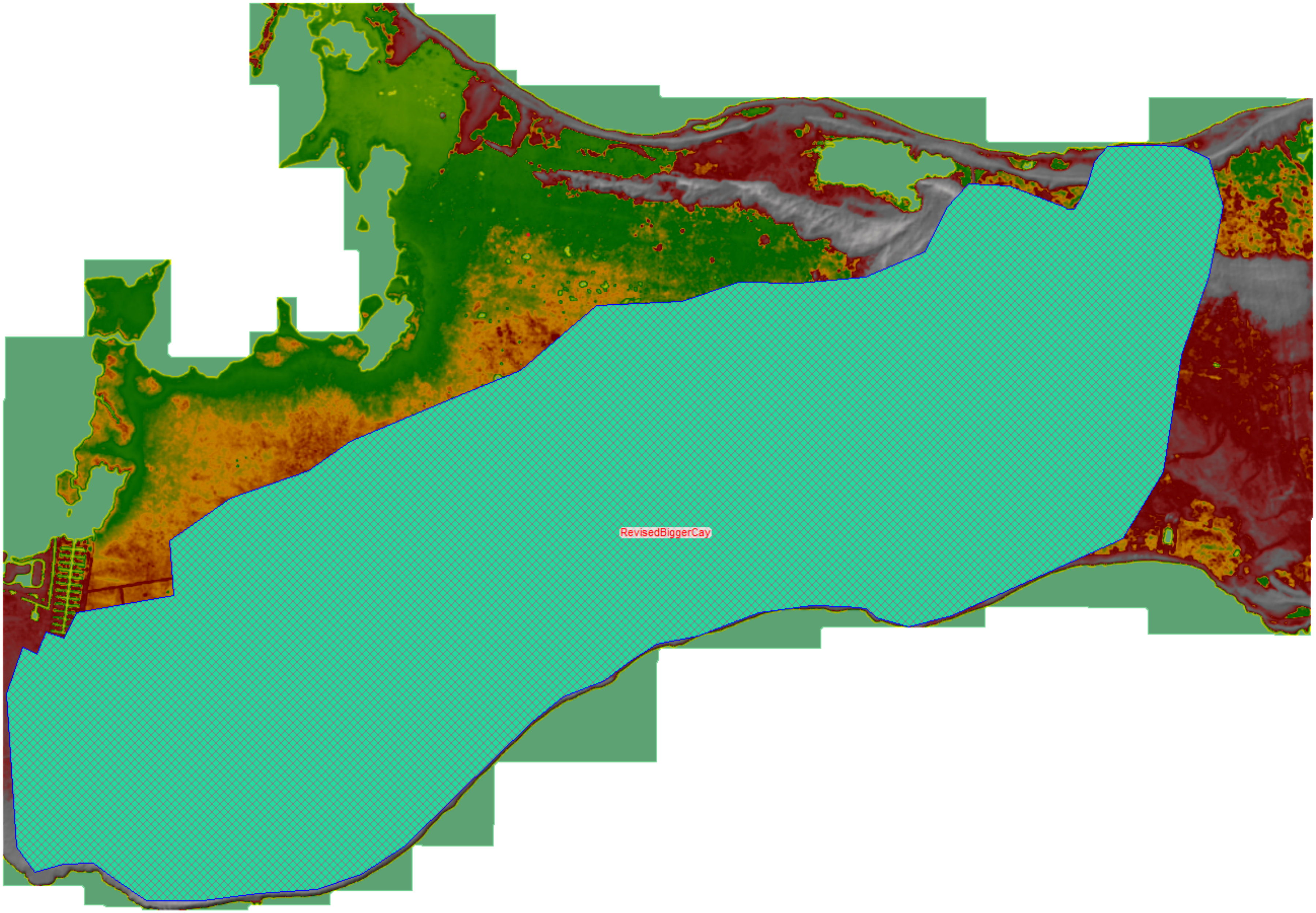

Figure 4 defined two dimentional flow area in HEC-RAS

Table 1 defined Manning's coefficient and percent impervious for Hec-2D model

ID	Name	Manning's' n	Percent Impervious
0	No Data	0.035	100
1	seasonally flooded mangrove forest and woodland	0.045	75
2	dry forest and woodland	0.10	60
3	seasonally flooded - saturated semi-deciduous forest	0.15	70
4	invasive species - casuarina	0.03	45
5	coastal shrubland	0.1	85
6	seasonally flooded mangrove shrubland	0.085	40
7	dry shrubland	0.07	60
8	ponds, pools, and mangrove lagoons	0.025	100
9	urban	0.03	80
10	man-modified without trees	0.025	90
11	man-modified with trees	0.15	60
12	semi-permanently flooded grasslands V.A.1.N.h [5]	0.1	100
13	salt tolerant succulents	0.11	30
14	tidally flooded mangrove forest and woodland	0.035	40
15	dwarf vegetation and vines	0.12	50

V.A.1.N.h as defined in Aicta, N. Ahmad (1996). Agricultural Land Capability of the Cayman Islands
Land use identifications from Department of the Environment [6].

Table 2 Selected curve numbers, abstraction ratio and minimum infiltration rate for HEC-2D Model

ID	Name	Curve Number	Abstraction Ratio	Minimum Infiltration Rate (in/hr)
0	No Data	0	0	0
1	4	60	0.15	0.3
2	3	70	0.1	0.35
3	6	40	0.25	0.4
4	1	95	0.05	0.1
5	2	85	0.08	0.2
6	5	45	0.2	0.35
7	Pond	100	0	0

Soil identifications from Aicta [5].

Studied Scenarios

The results of the Memorandum 1, Rainfall Studies, were used to develop several rainfall scenarios for 2-year, 10-year, 25-year, 50-year, 100-year, and the 2004 Hurricane Ivan. The diffusion wave equation was selected for the 2D studies. The model was run for the existing conditions with various 24-hours scenarios (Figures 7, 8, and 9) and the results are shown in Figures 10 through Figure 14. The result of simulated Hurricane Ivan is shown in Figure 15. Storm surge and wave flooding are being studied separately and are not included in this analysis.

Figure 18 shows the 100-year event with the general flow patterns. Of note is that the northern cut-off of the study area is in the mangroves where flow will be mixing into the North Sound. The area shown in red is an area where the flooding is slow moving multi-directional in nature. In this area, in the larger flooding events, the quarries and Meagre Bay Pond play a role in the flood flows. At the lesser magnitude 2-year and 10-year events, the flooding on each side of the East-West Arterial is more distinctly separated by high ground.

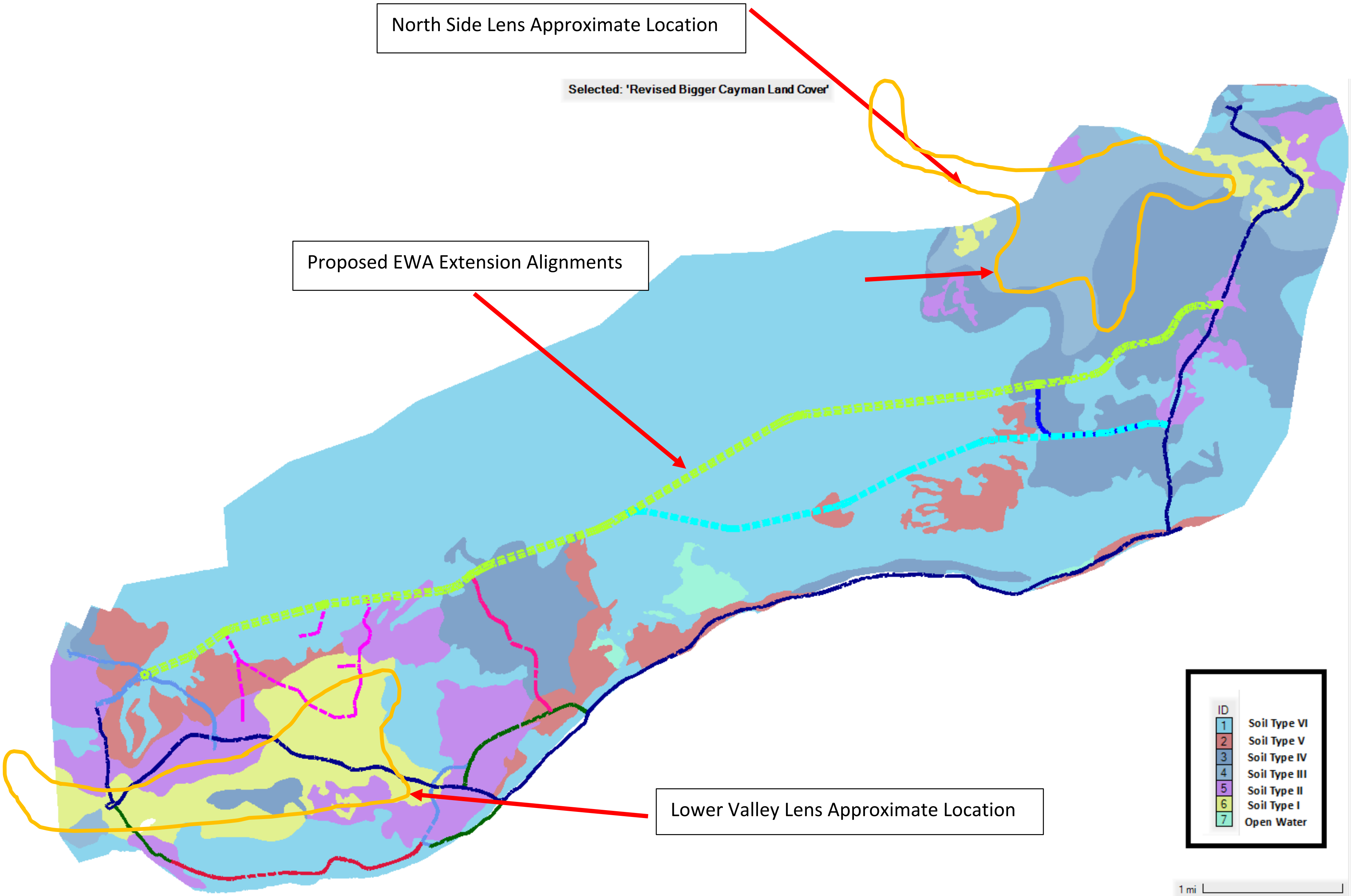

Figure 5 Soil types map of the study area, Aicta [5]

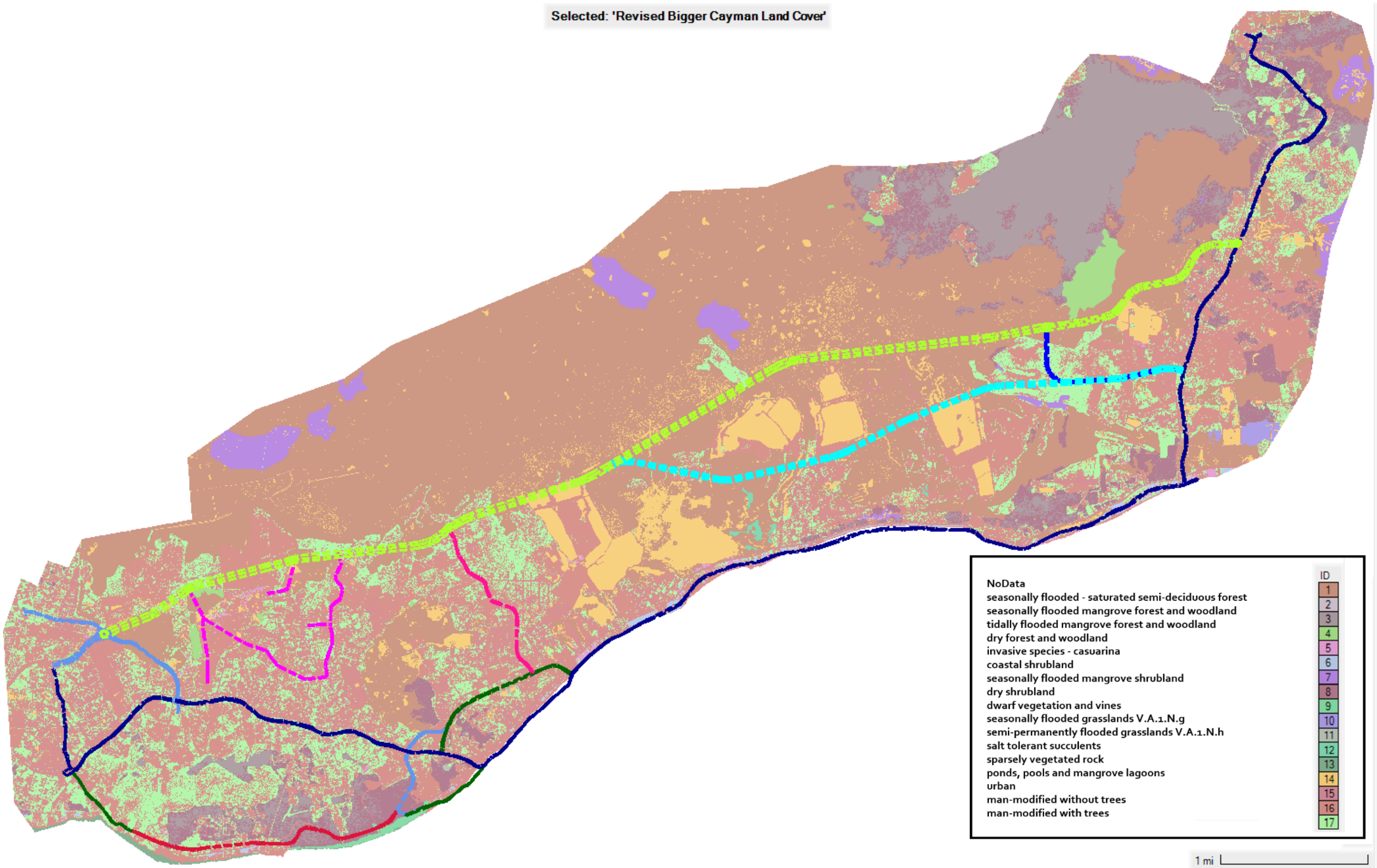

Figure 6 Land use map of the study area [6]

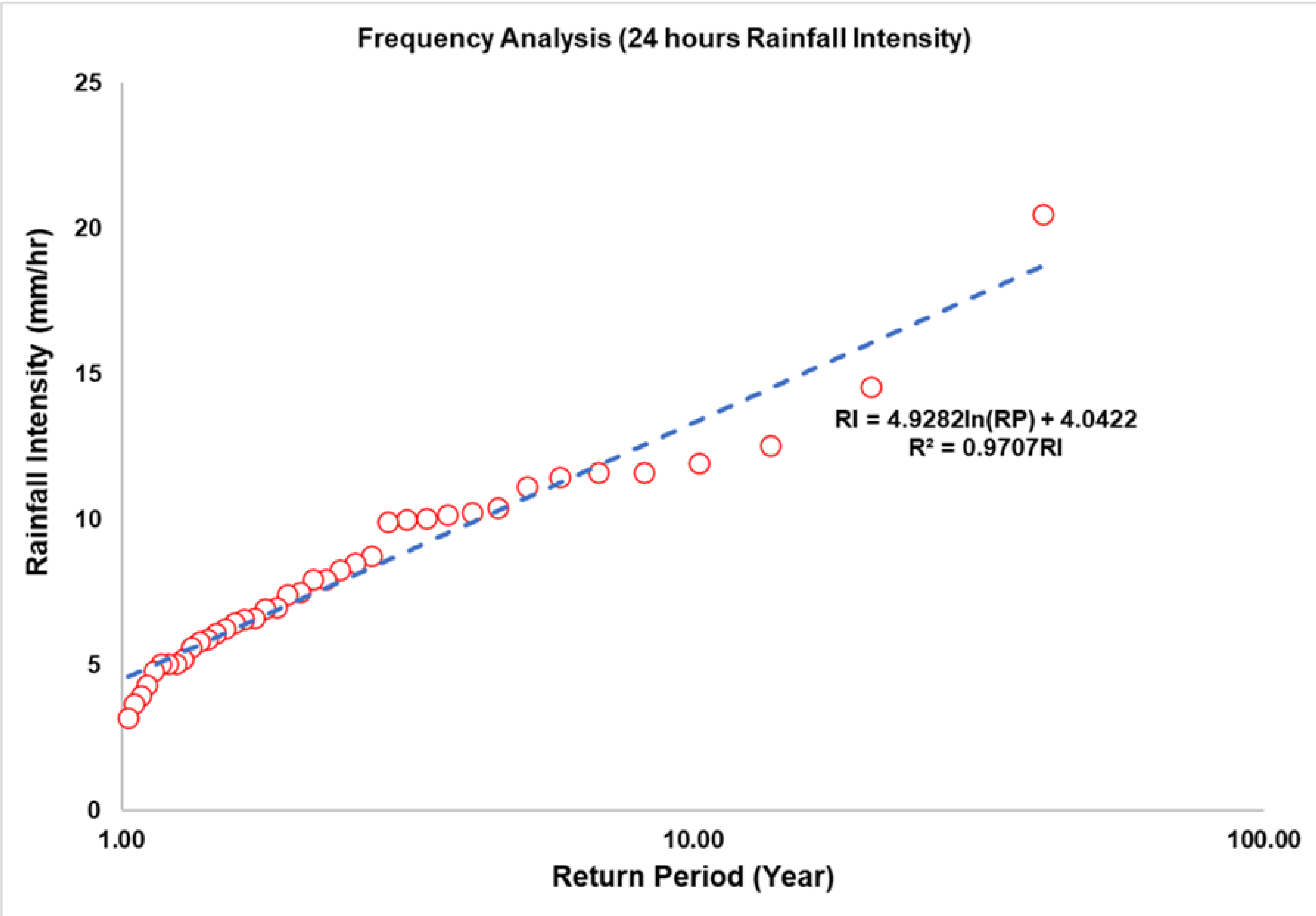

Figure 7 Rainfall intensity and return period relation for Cayman Island

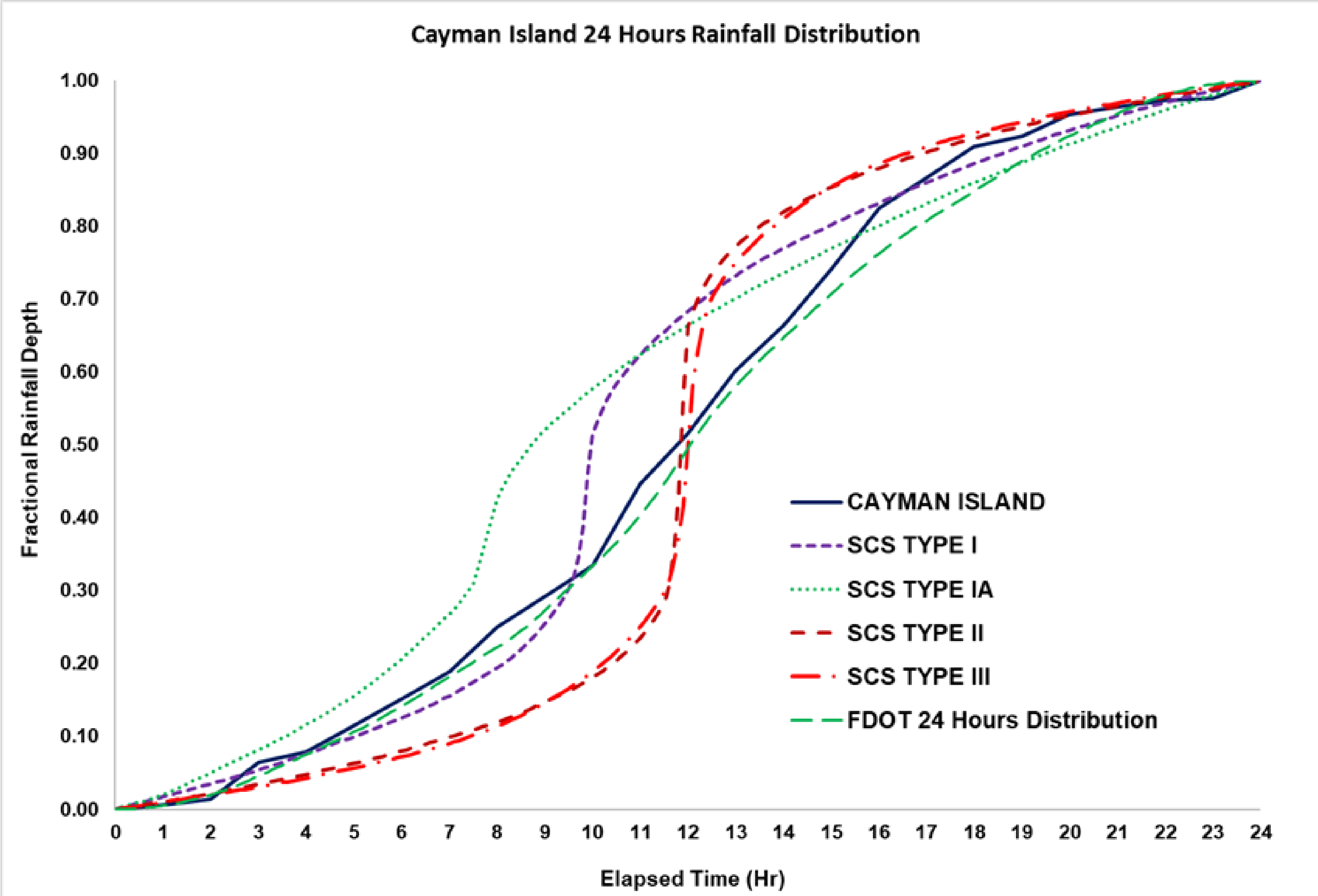

Figure 8 Cayman Island rainfall distibution with regards to various US distributions

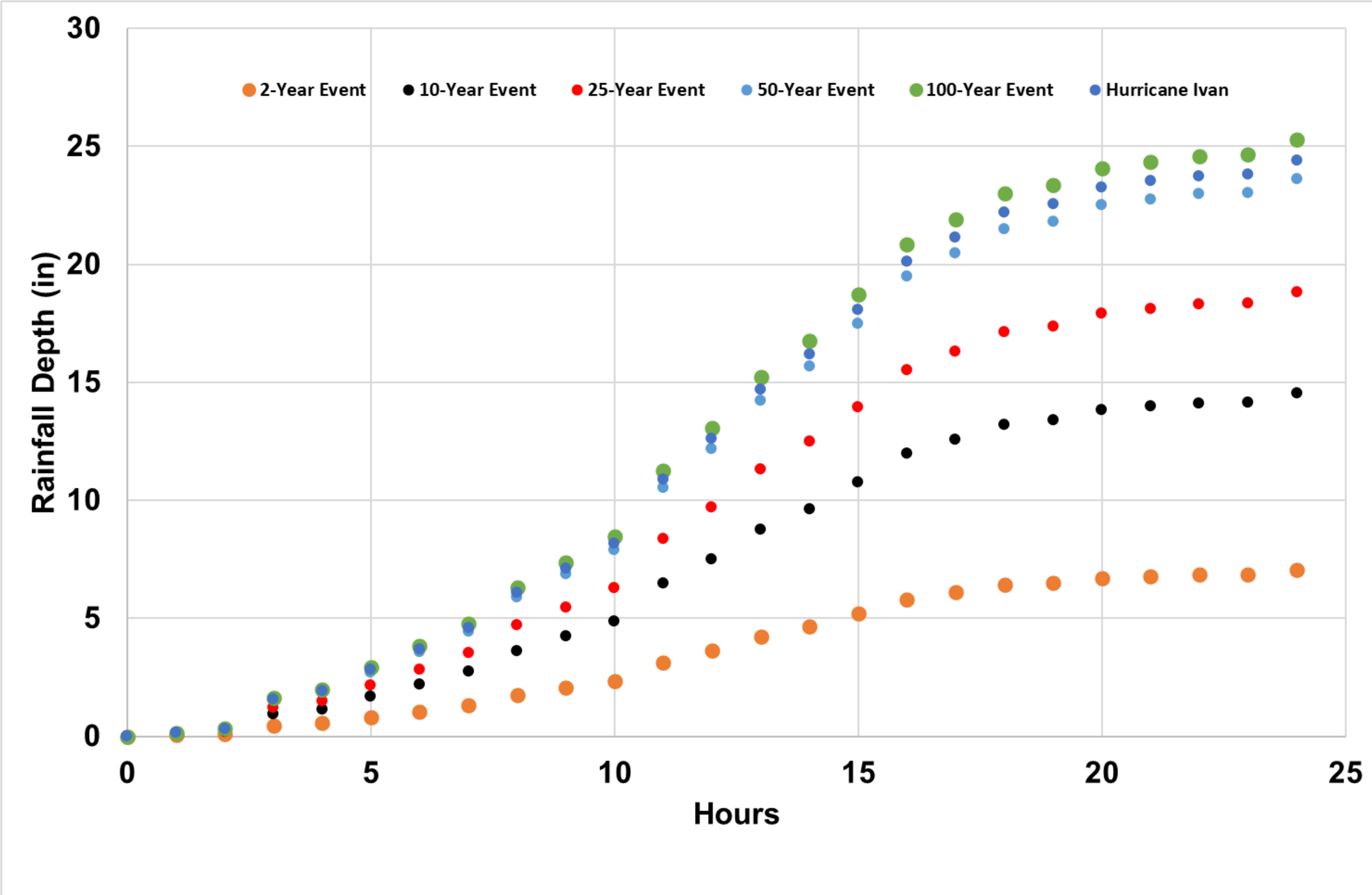

Figure 9 Developed various 24 hours rainfall distributions for Cayman Island

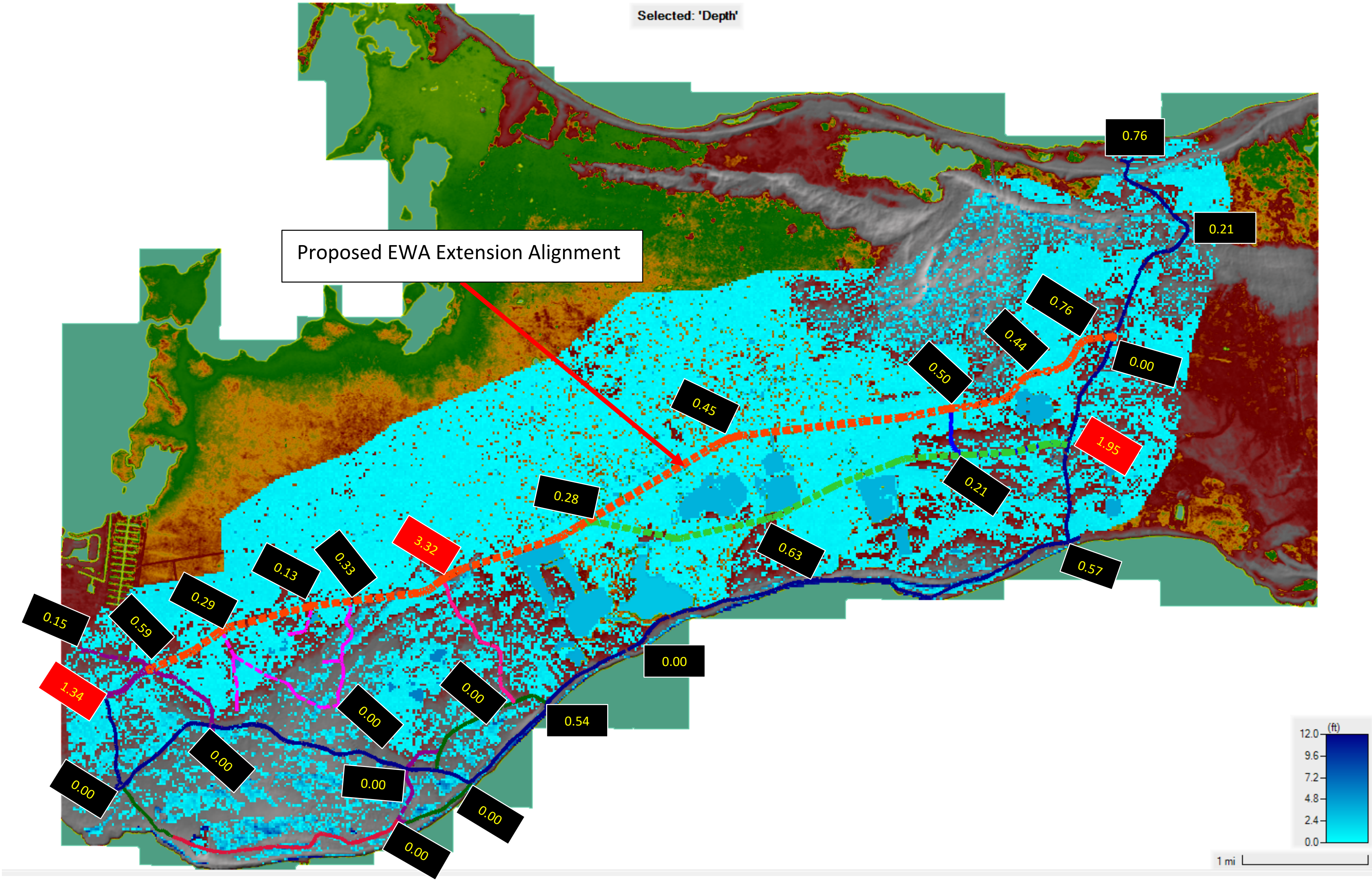

Figure 10 Maximum flood depth, in feet, for 24 hours event with a 2 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

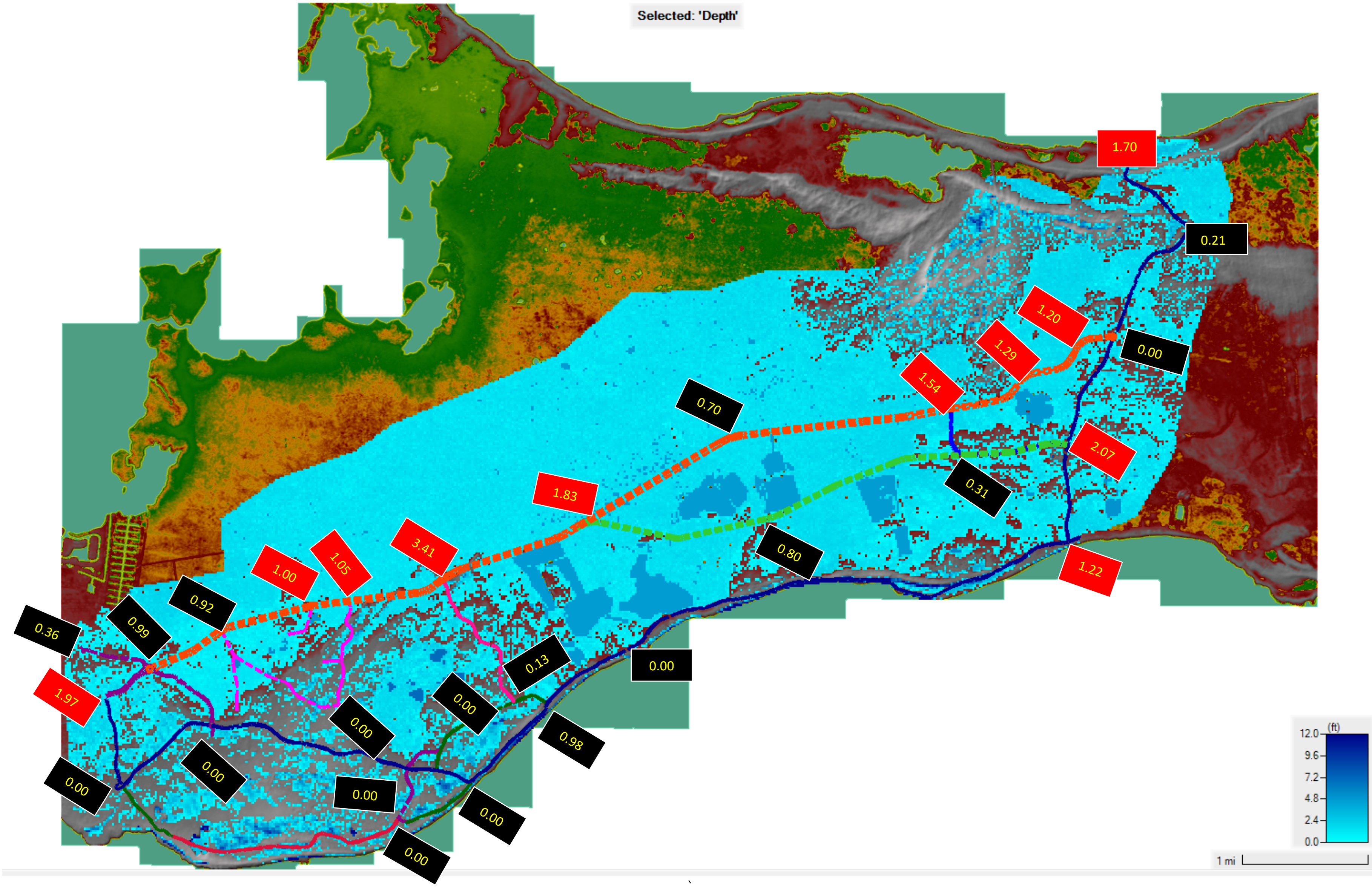

Figure 11 Maximum flood depth, in feet, for 24 hours event with a 10 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

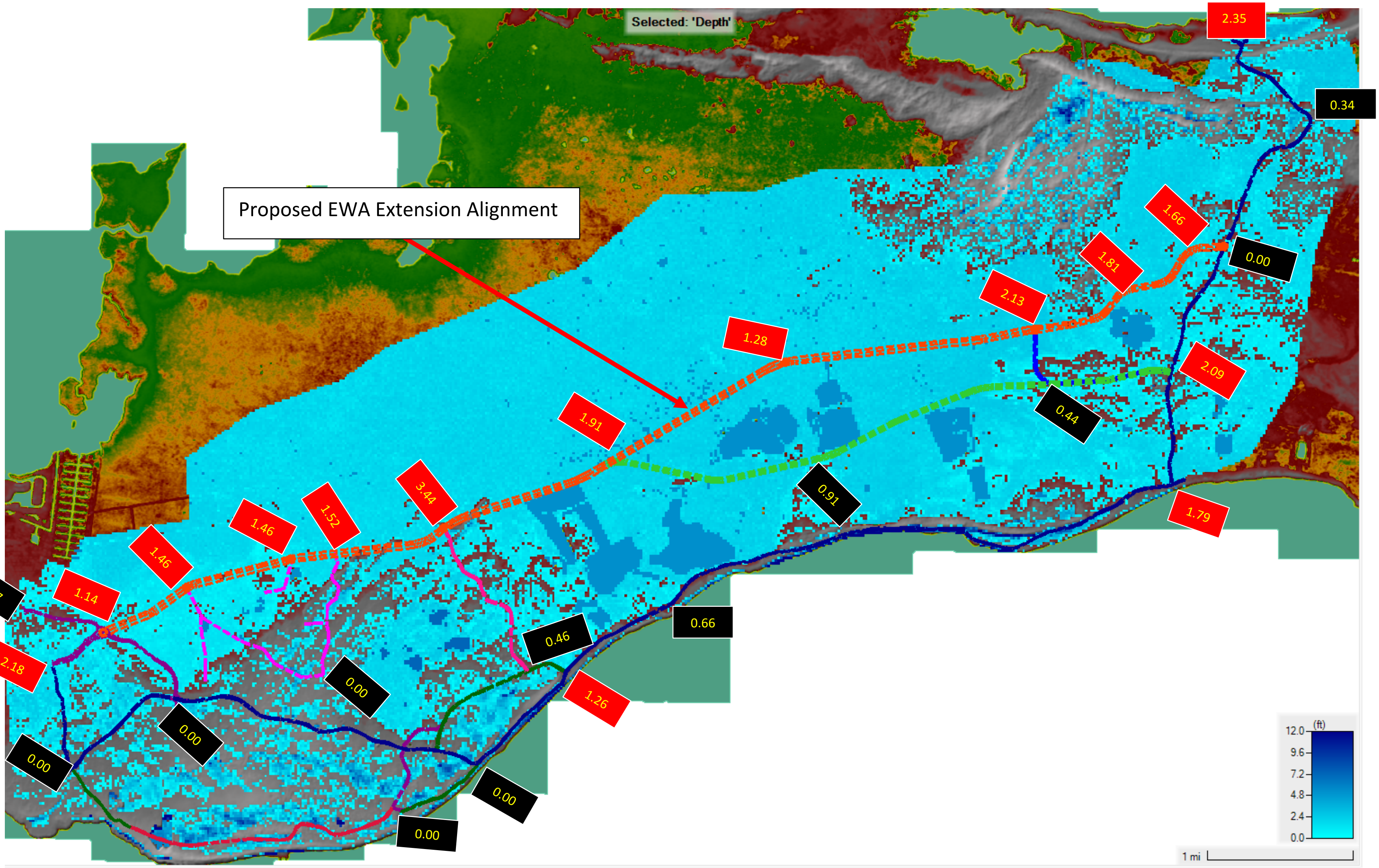

Figure 12 Maximum flood depth, in feet, for 24 hours event with a 25 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

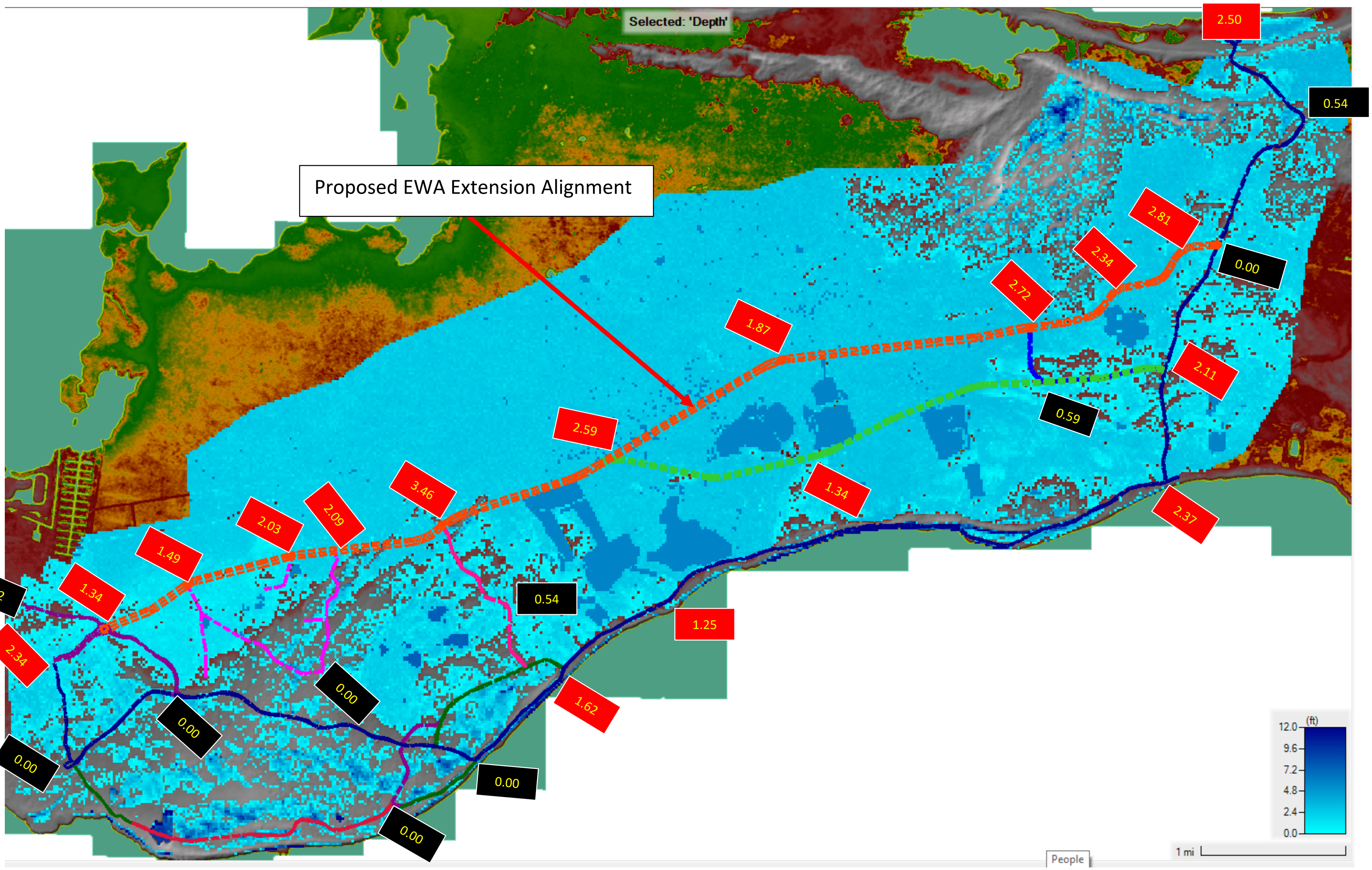

Figure 13 Maximum flood, in feet, depth for 24 hours event with a 50 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

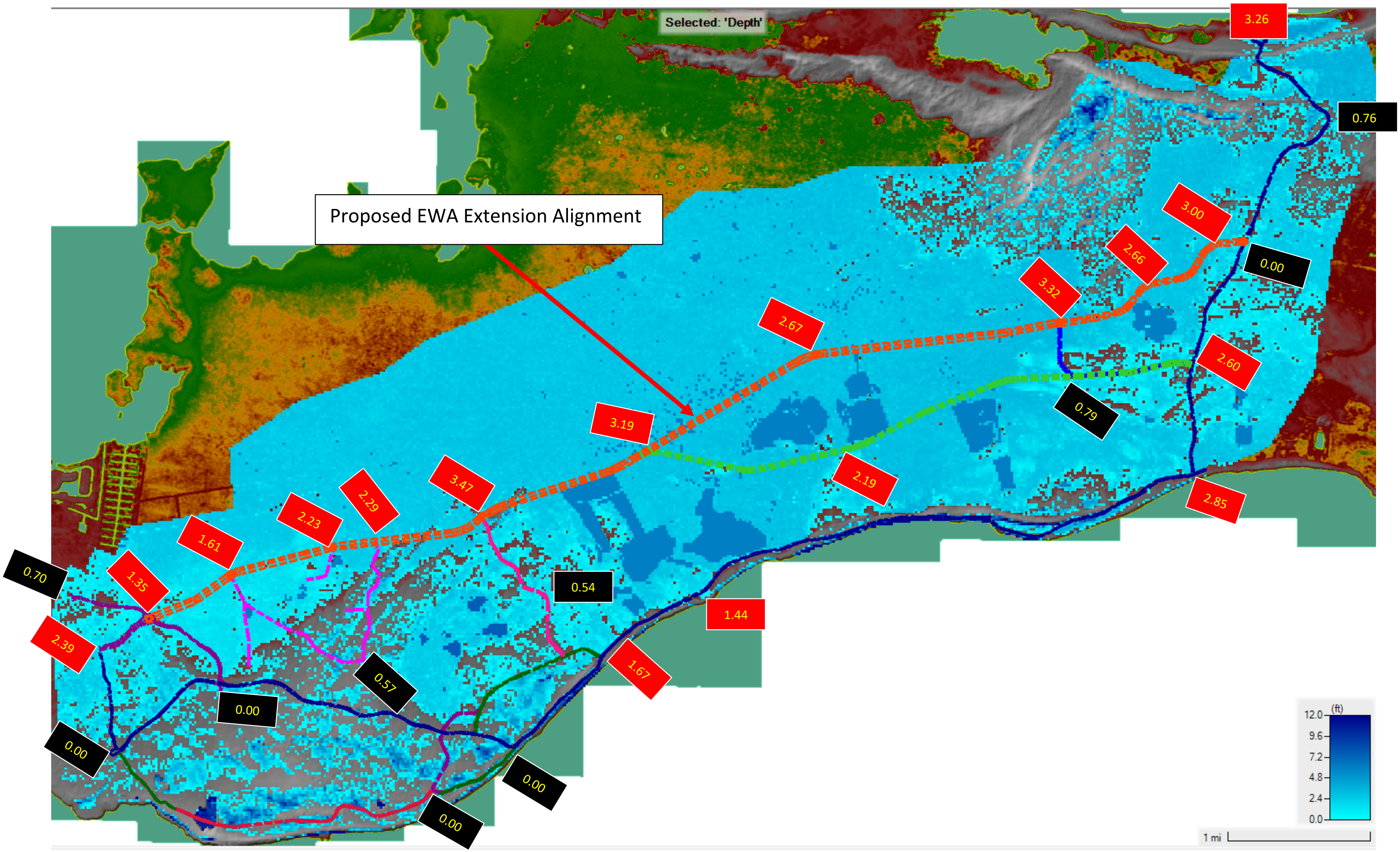

Figure 14 Maximum flood depth, in feet, for 24 hours event with a 100 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

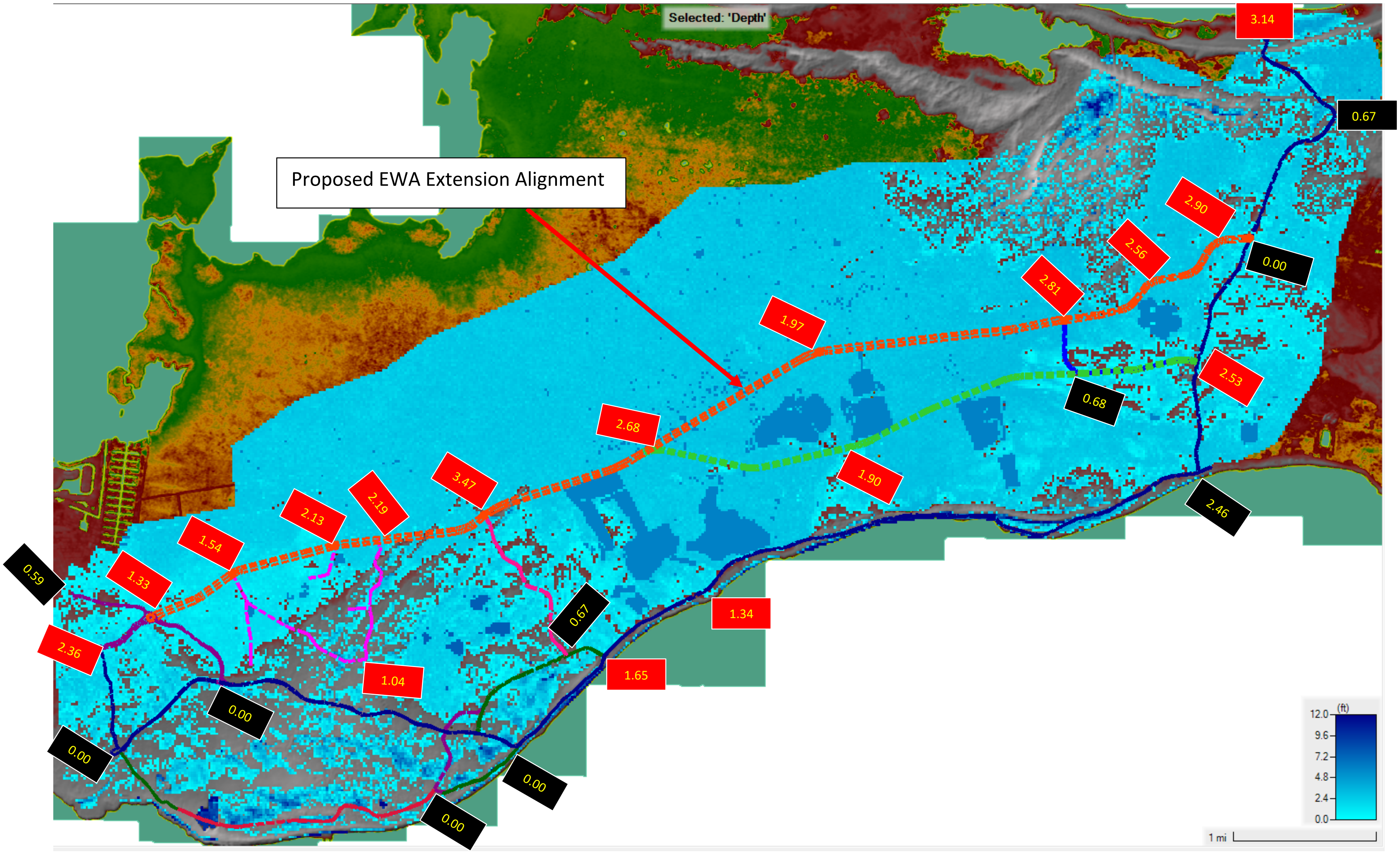

Figure 15 Maximum flood depth, in feet, for 24 hours event with Hurricane Ivan of 2004 (Black highlighted less than 1ft, Red highlighted more than 1ft)

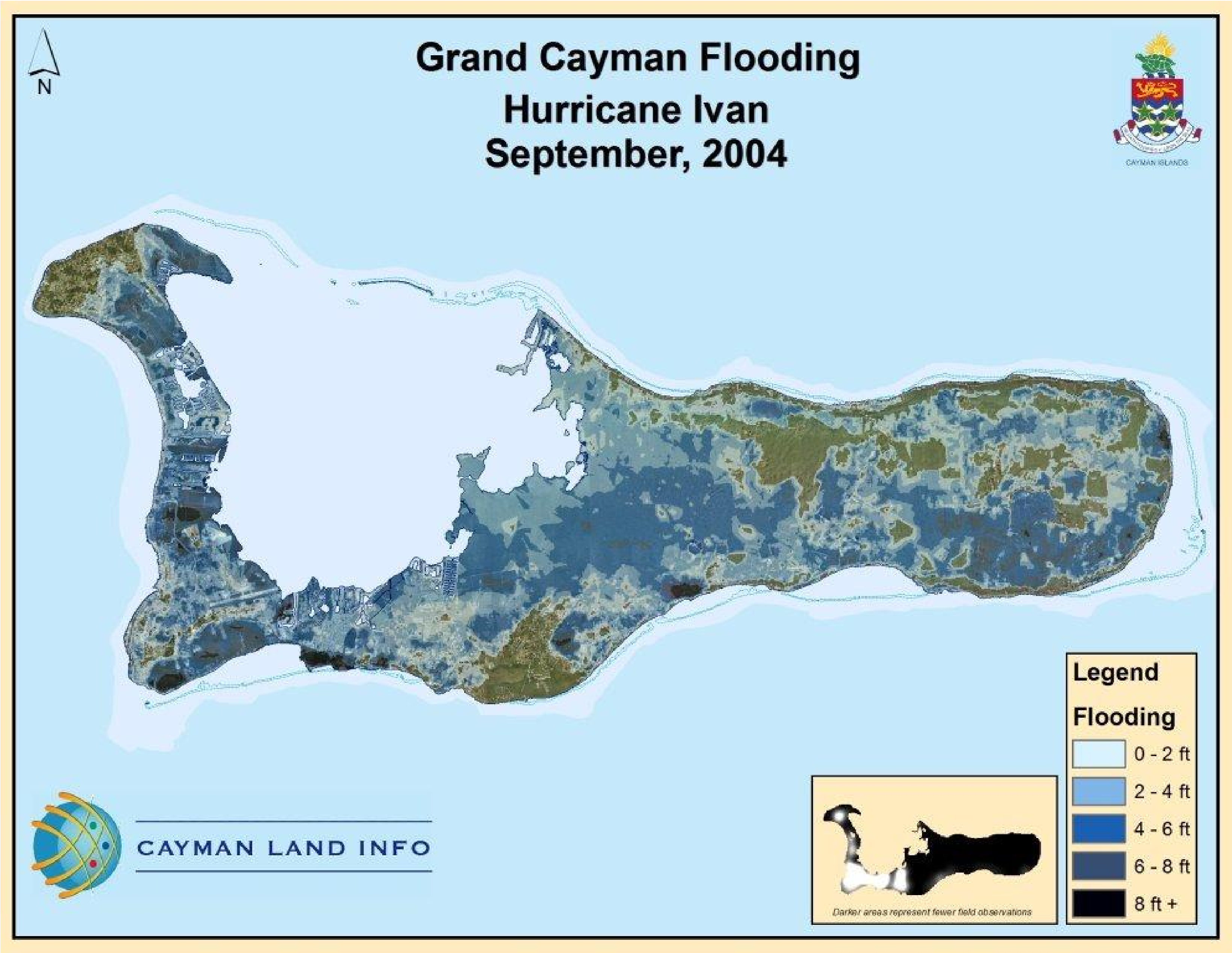

Figure 16 Grand Cayman Flood Map of 2004's Hurricane Ivan

Effects of various storm on the proposed roadway

Effects of various rainfall event scenarios on runoff generation and flooding across the project site were investigated. Each of the studied scenarios shows different inundation depths. In general, the lowest point of the area or the locations that are frequently flooded were inundated during the smaller events such as a 2-year event (Figure 10). For the larger events, the inundation flood pattern has been extended from the low points into the surrounding areas. The low points or the area that are immediately inundated and are the primary locations for conveyances such as a bridge to convey the runoff from the southern side of the site to the northern side of the site.

The product of approximate overlay of Figure 2 over Figure 3 has been shown in Figure 17. Locations (shown with blue lines) were identified as the places where the natural flood ways cross the proposed roadway. The conveyance/bridge locations are conceptually sited and will be revisited as the roadway design progresses.

Project design storm

To design roadways drainage and flooding infrastructure, design storms between 25 and 100 years have been considered. Corresponding to the greater the flooding magnitude are increasing costs for the roadway and bridges. A 50-year design storm is recommended to provide passage for large flooding events with roadway safety maintained. For comparison, the United States uses a 50-year design for major highways while Canada uses either a 50-year or 100-year design depending upon the bridge length.

Effect of unbuilt sections on the built sections of the roadway

The East-West Arterial is planned to be built in phases. During construction of each phase, the proposed roadway drainage infrastructure shall be built for those specific sections. It is expected that in the unbuilt sections, the site will follow its natural drainage pattern and is expected to have a small effect upon the built portions of the roadway. However, as depicted in Figure 18, the identified area shown in the dashed white line receives flow from both the north and south sides of the site and requires additional attention to the flow patterns.

Meagre Bay Pond and Quarries

Results show that the runoff flows north from the Meagre Bay Pond and quarries towards the North Sound. Proposed bridges and conveyances will alter flow patterns but provide for the normal direction of flow towards the North Sound. From the results, the roadway will alter the flows in the general area of the Meagre Bay Pond and quarries but also will have bridges and conveyances to maintain the overall flow movement. Otherwise, the salt intrusion and drawdown of the Meagre Bay Pond due to the nearby quarry is not expected to be impacted by the East-West Arterial.

Mastic Forest

Because the forest's location is on higher ground, the forest is a contributor to the runoff and not directly affected by the roadway. Both the northern and southern connection alternatives to Frank Sound Road are shown. The northern connection will cross the Mastic Trail constituting a direct impact to the trail.

Freshwater Lenses

Both the Lower Valley Lens and the North Side Lens are fed by infiltration from the lands above and are not expected to have their freshwater replenishment affected by the roadway, nor their exfiltration flow into the CMW affected by the roadway.

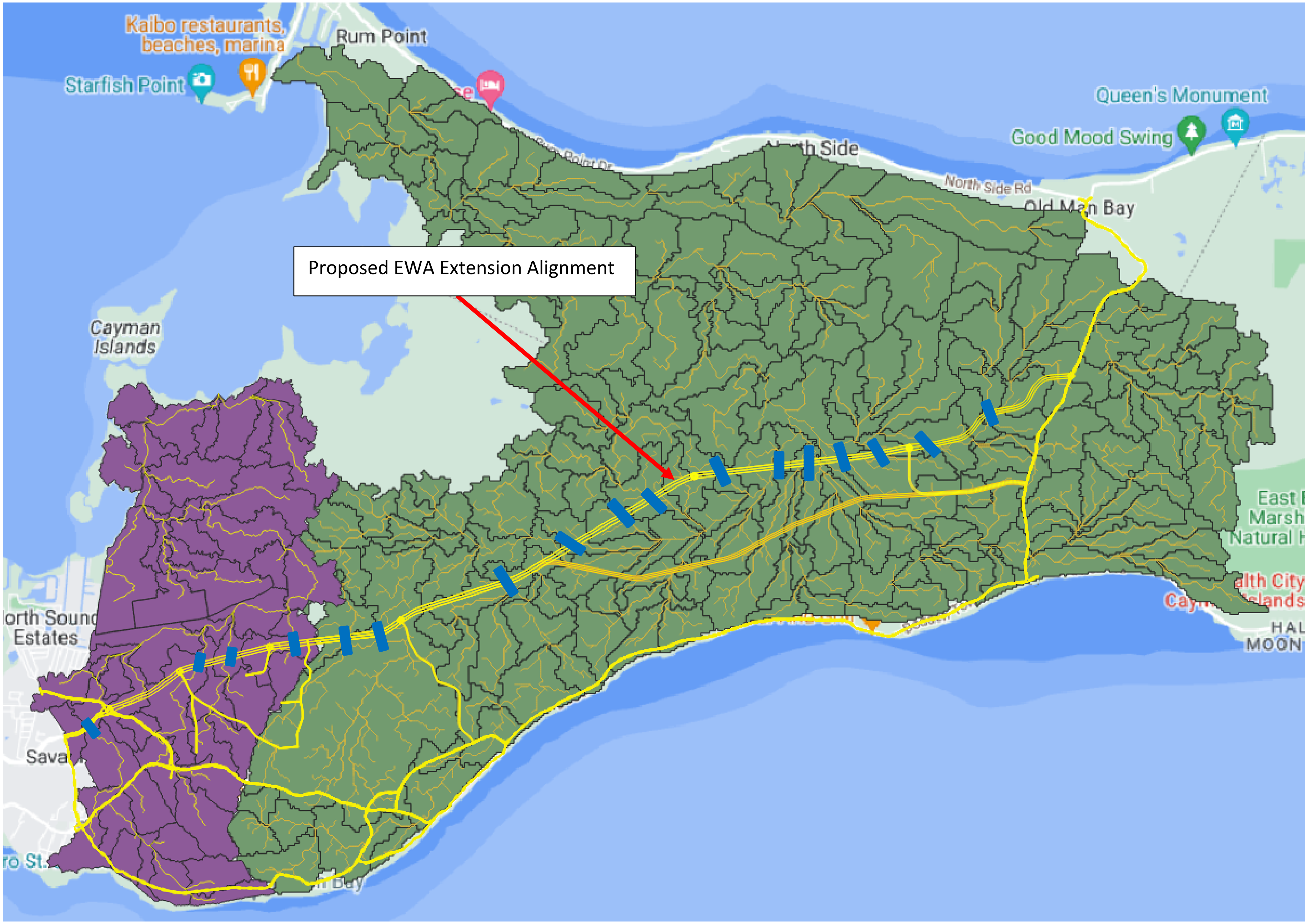

Figure 17 The location of natural runoff (Blue Lines) with the proposed roadway

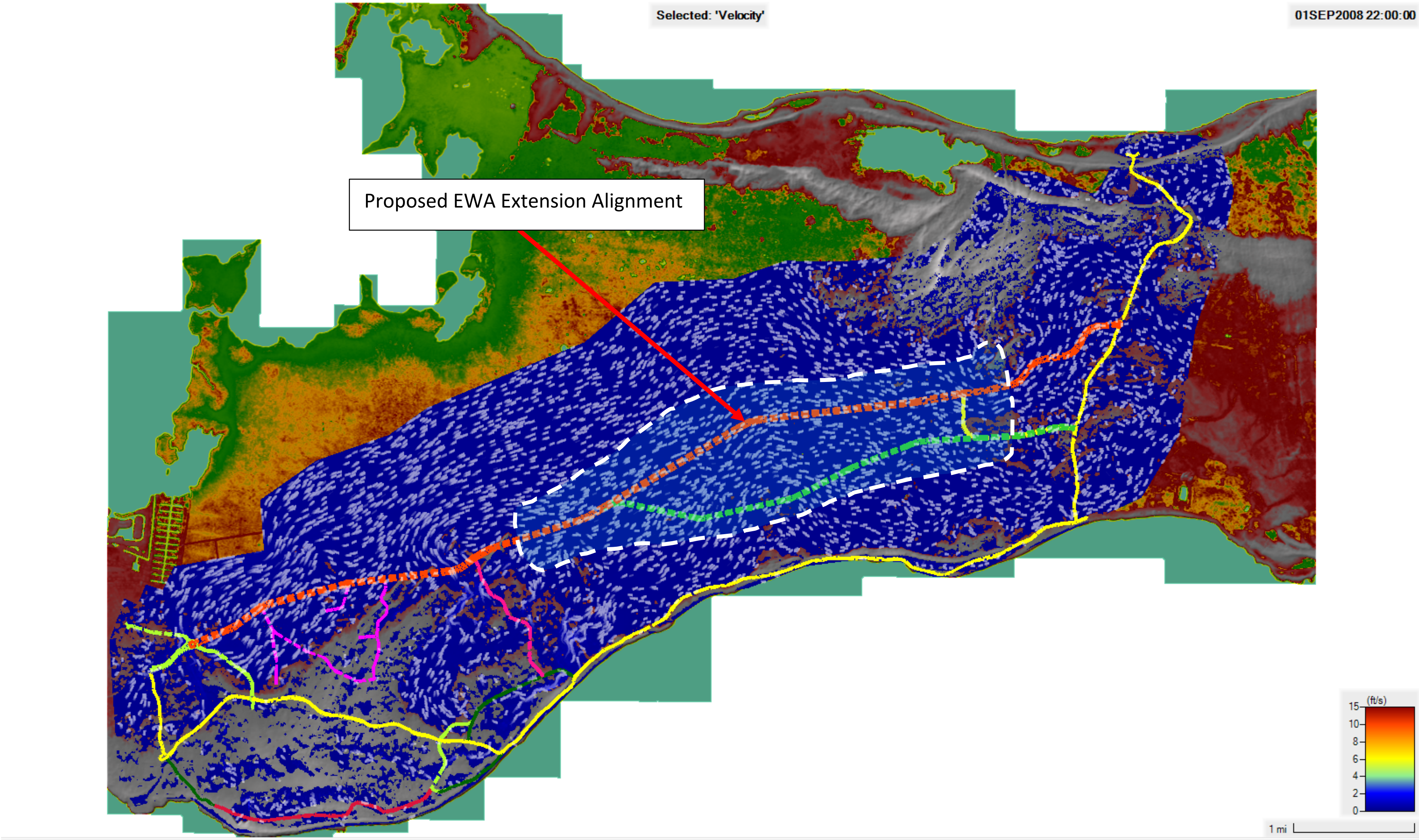

Figure 18 shows the static velocity arrows for a 100-year event

Conclusion

A two-dimensional hydraulic model was developed to prepare flooding information to design East-West Arterial Roadway and the associated alternatives on Grand Cayman Island. Various scenarios of rainfall events and the historic tropical Hurricane Ivan were studied. The rainfall events show that the project area will be inundated under most of the events. The results for a 2-year, show the simulated flood depth less than 1 foot and increasing to 5 feet to 6 feet for a 100-year simulated event along the inland roadway options, whereas the flood depth was simulated up to 10 feet for the options close to the coastal area on the southwest of the site. The simulated Hurricane Ivan event also showed a consistency with the Grand Cayman Hurricane Ivan Flooding map of September 2004. The locations for the proposed roadway drainage improvement have been proposed. Also, the results of the coastal and surge analysis, performed by others, shall be taken into consideration for the design with the simulated flood events, depths, and flows modelled in this study.

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2 USACE (2022). HEC-HMS User’s Manual. Version 4.10. https://www.hec.usace.army.mil/confluence/hmsdocs/hmsum/latest/release-notes/v-4-10-0-release-notes.

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4 Arcement, G. J., & Schneider, V. R. (1989). Guide for selecting Manning's roughness coefficients for natural channels and flood plains.

5 Aicta, N. Ahmad (1996). Agricultural Land Capacity of the Cayman Islands.

6 Cayman Islands Government, Department of the Environment, 2018 Landcover Habitat Mapping

Appendix J.3 – Hydraulic and Hydrologic Studies of EWA, Memorandum 3 – Water Budget Analysis – RVE

Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion

Memorandum 3 – Water Budget Analysis

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Date Prepared:
May 2023
Revised April 2024

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List of Abbreviations

NRA: National Roads Authority

EW: East-West

CMW: Central Mangrove Wetland

USDA: United States Department of Agriculture

NRCS: National Resources Conservation Service

QGIS: Quantum Geographic Information System

Introduction

This hydraulic and hydrology analysis memorandum for a water budget analysis has been prepared under the pre-project hydraulic and hydrologic studies for the Cayman Islands Government National Roads Authority (NRA) proposed East-West, EW, Arterial Roadway Project on Grand Cayman Island. Remington & Vernick Engineers has been retained to prepare a Hydraulic and Hydrologic study for the proposed EW Arterial expansion by NRA. This report employed the results of Razzaghmanesh & Gause (2022), Memorandum 1 - Preliminary Rainfall Analysis [1], land data, and data from the Hydrology and Hydraulic Analysis to perform a water budget for the Central Mangrove Wetland, CMW, area along the East-West Arterial alignment. The water budget analysis gives an assessment of the runoff, detained water, and soil moisture fluctuations for shorter precipitation time frames as opposed to extreme rainfall and flood events. This analysis uses monthly time intervals and the total rainfall per month to assess the CMW water fluctuations over a 10-year period and effects of the proposed EW Arterial upon the CMW.

Central Mangrove Wetlands Monthly Hydrology

According to Brundt "The Cayman Islands Natural History and Biography" [2] Chapter 15, Mangrove Swamps of the Cayman Islands, and the referenced maps at 1:25,000 prepared by Overseas Development Natural Resources Institute, 1987, saltwater movement into the central mangrove swamps appears to be limited, while the movement of rainwater flooding out to the sea is more common. The tidal range in the North Sound has a mean amplitude of 28 cm (11 inches) and a high-water elevation of 29 cm (11 inches) which is barely enough to cause significant mangrove inundation. Further, in the Avicenia Germinans, Black Mangrove, swamps surrounding the North Sound, the elevation for sea water inflow has been found to be close to 31 cm (12 inches). It is noted that Rhizophora Mangle, Red Mangrove, is along the CMW North Sound shoreline at elevations below 28 cm as a pioneer species. For purposes of the analysis, the CMW is assigned an elevation of 12 inches (31 cm).

Typically, the CMW is fully inundated during the wet season months of April through October with overflows into the North Sound. During the November to March dry season, drying can occur unless heavy or sustained rainfall or high sea water is received. The plant community has evolved over time to the freshwater inflows with salinity incursions into the CMW from the sea.

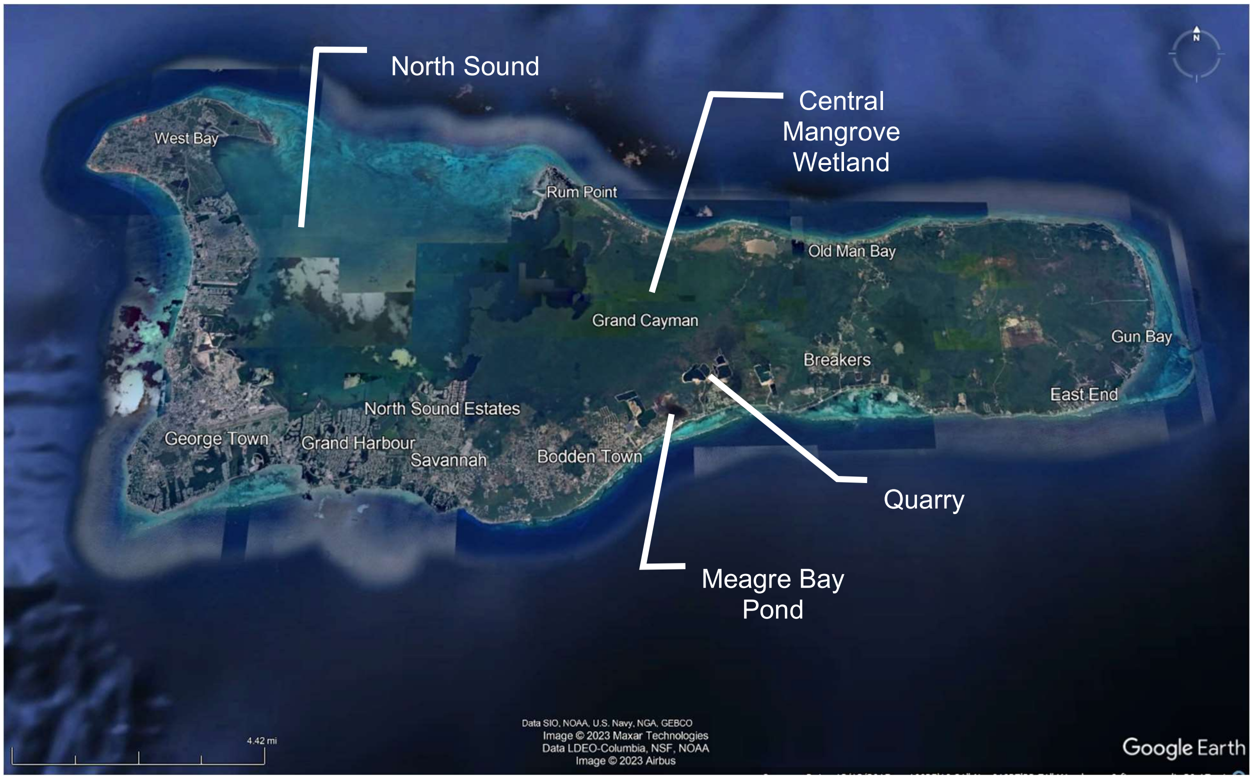

Figure 1 Grand Cayman Island

Method

The Thornthwaite and Mather method in "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance" [3] is used for the analysis performed using Microsoft Excel for the time frame from January 2011 to December 2021.

The water balance follows the general equation 1:

(Equation 1)   Wetland Inflow = Q + I – Adjusted PE + E

Where:

Wetland Inflow = Runoff into the CMW, inches

Q = Rainfall Runoff, inches

I = Infiltration from the Lower Valley Lens into the Central Mangrove Wetland, inches

Adjusted PE = Adjusted Potential Evapotranspiration, inches

E = Exfiltration out of the Central Mangrove Wetland into the Ground, inches

The Rainfall-Runoff method using the Soil Cover Complex Curve Numbers is utilized for determining the runoff into the CMW is computed using the USDA NRCS, United States Department of Agriculture National Resources Conservation Service, USDA NRCS Rainfall-Runoff methodology in the NRCS National Engineering Handbook [5]. A composite runoff curve number for the lands draining into the mangrove lands is utilized and computed from the runoff curve numbers (Table 1 and Table 2) determined in Razzaghmanesh & Gause (2022), Memorandum 2 – Hydrology and Hydraulic (H&H) Analysis [4].

The watershed area was determined using topography obtained from GIS data provided by the Cayman Islands Lands and Survey Department. The survey area covers the ridge lines for the areas contributing runoff into the lands along the EW Arterial, but does not extend to the CMW boundary at the North Sound and is a representative analysis for the CMW area. Additionally, the dense vegetation in the CMW precluded a detailed mapping of the CMW land area. For the analysis, the lands of the CMW area are assumed to be a constant 12 inches (31 centimeters) above sea level. As reported by Brunt [2], the CMW lands are generally sloping toward the North Sound. High water from the sea into the North Sound and overflowing into the CMW is not included in the analysis. Inundations from the sea are not included in the analysis due to lack of data when these inundations have occurred other that they coincide the greatest with hurricane season. Without the sea inundations, the total water inflow is lower than actual in the analysis.

Daily rainfall provided by the Cayman Islands Water Authority was summated for rain gauge stations PPGT-A, SBT-A, and PBBT-A from 2011 to 2021 which have proximity to the CMW watershed area (Figure 2). The averages of the three rain gauges summations were then used for the analyses. If the rain gauge had a partial or incomplete record for the month, a summation was not performed, and it was not included in the monthly average.

Infiltration from the Lower Valley Lens, an aquifer, into the Central Mangrove Wetland is as estimated to be 1950 cubic feet/year in Geraghty & Miller, Inc. "Investigation to Determine Effects of Canalization on Water Resources of Grand Cayman Island [6] and is applied as a constant value of 0.0037 ac-ft/month through the analysis as representative of Lower Valley Lens lands draining into the Central Mangrove Wetlands without adjustment for wet or dry soils The infiltration from the Lower Valley Lens into the Central Mangrove Wetlands is an insignificant amount compared to the runoff and evapotranspiration.

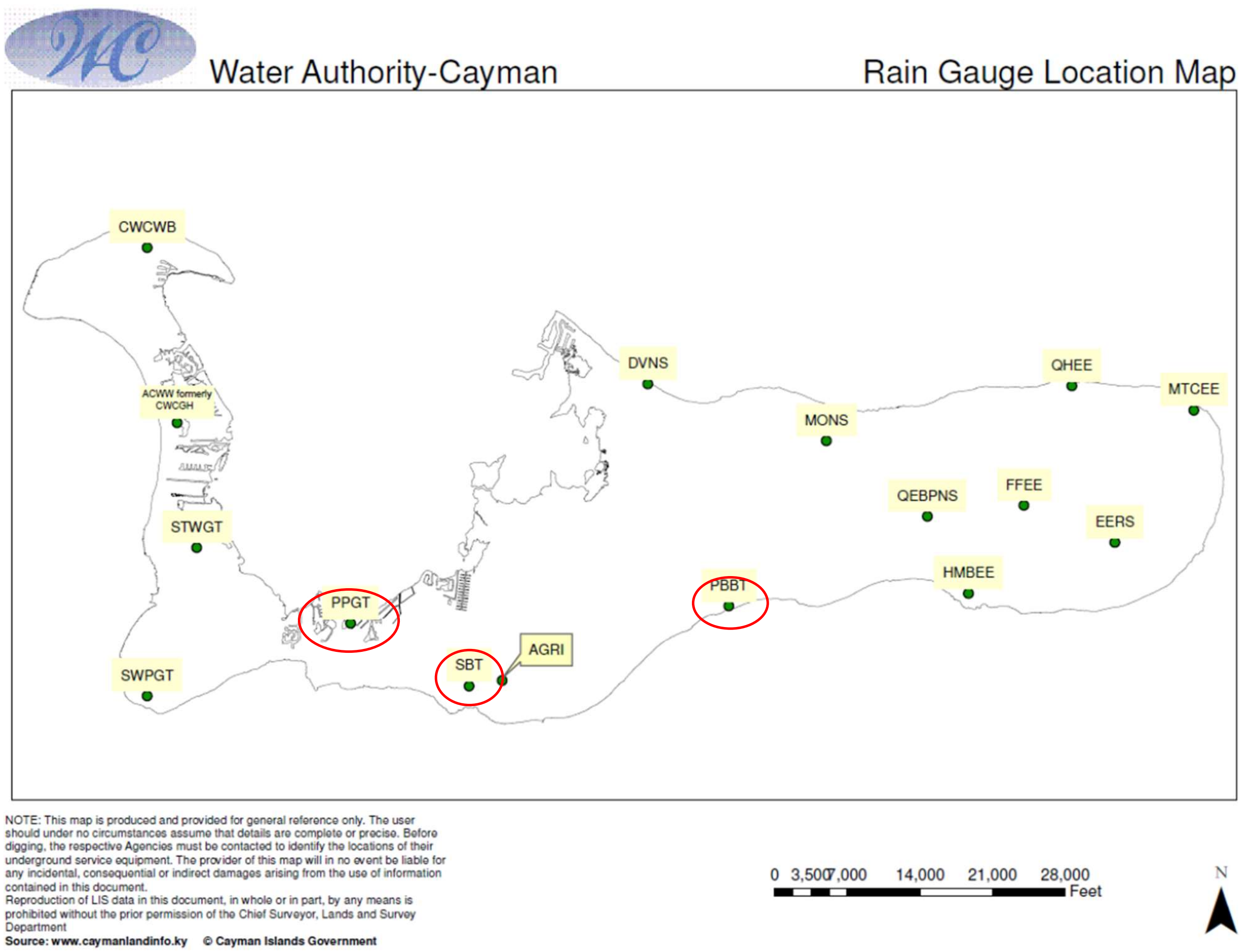

Figure 2 Rain Gauge Locations

Monthly temperature averages were obtained from the Cayman Islands National Weather Service for the time-period from January 2011 to December 2021.

The following water budget variables were taken from the tables presented in Thornthwaite [3]:

- Heat Index
- Unadjusted Potential Evaporation, and
- Mean Possible Duration of Sunlight

Adjusted Potential Evaporation, the product of Unadjusted Potential Evaporation and Mean Possible Duration of Sunlight is determined to model the full effects of evaporation of the CMW and uptake by the CMW vegetation.

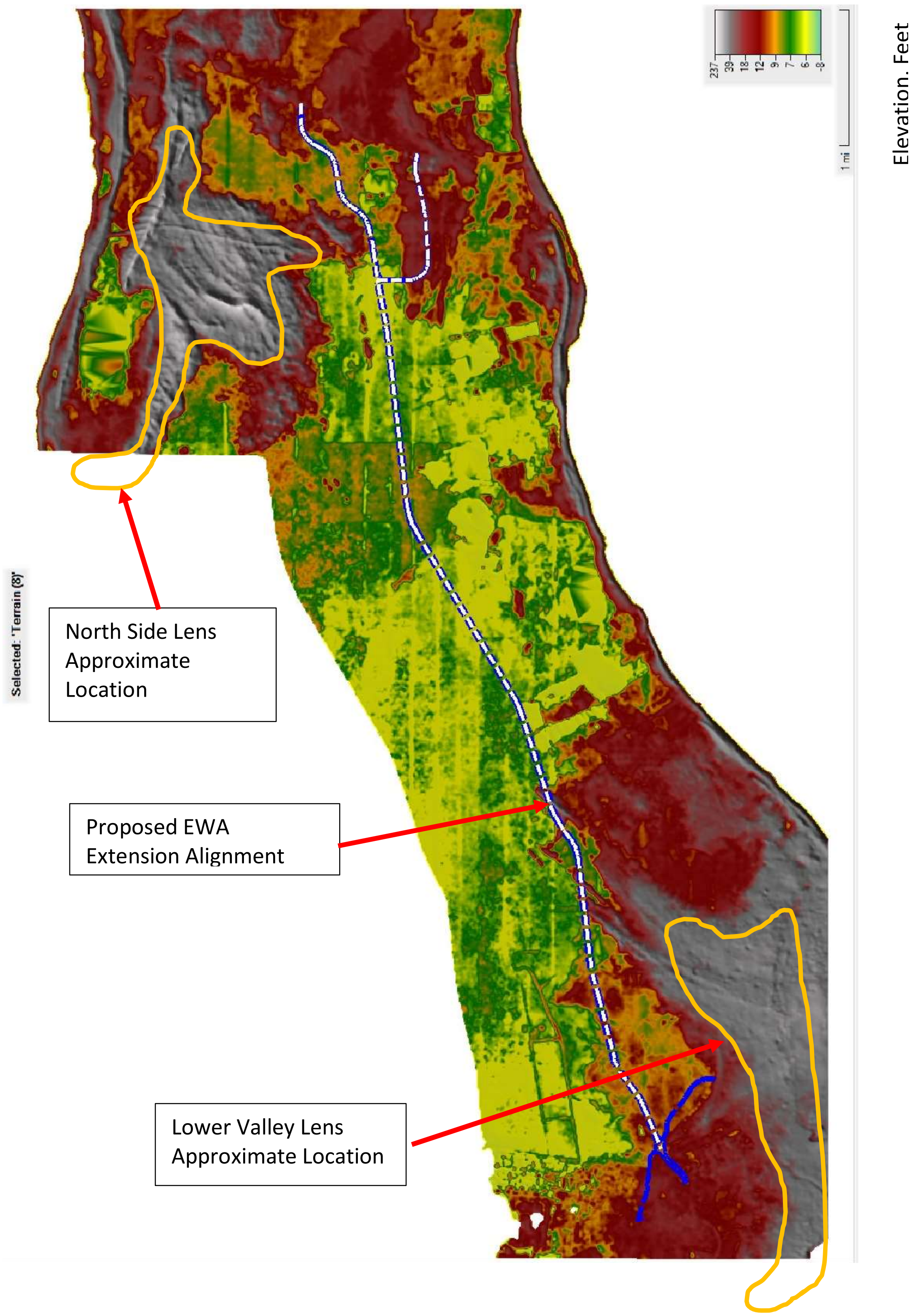

Figure 3 Study Area Boundary Terrain Model Extracted from QGIS

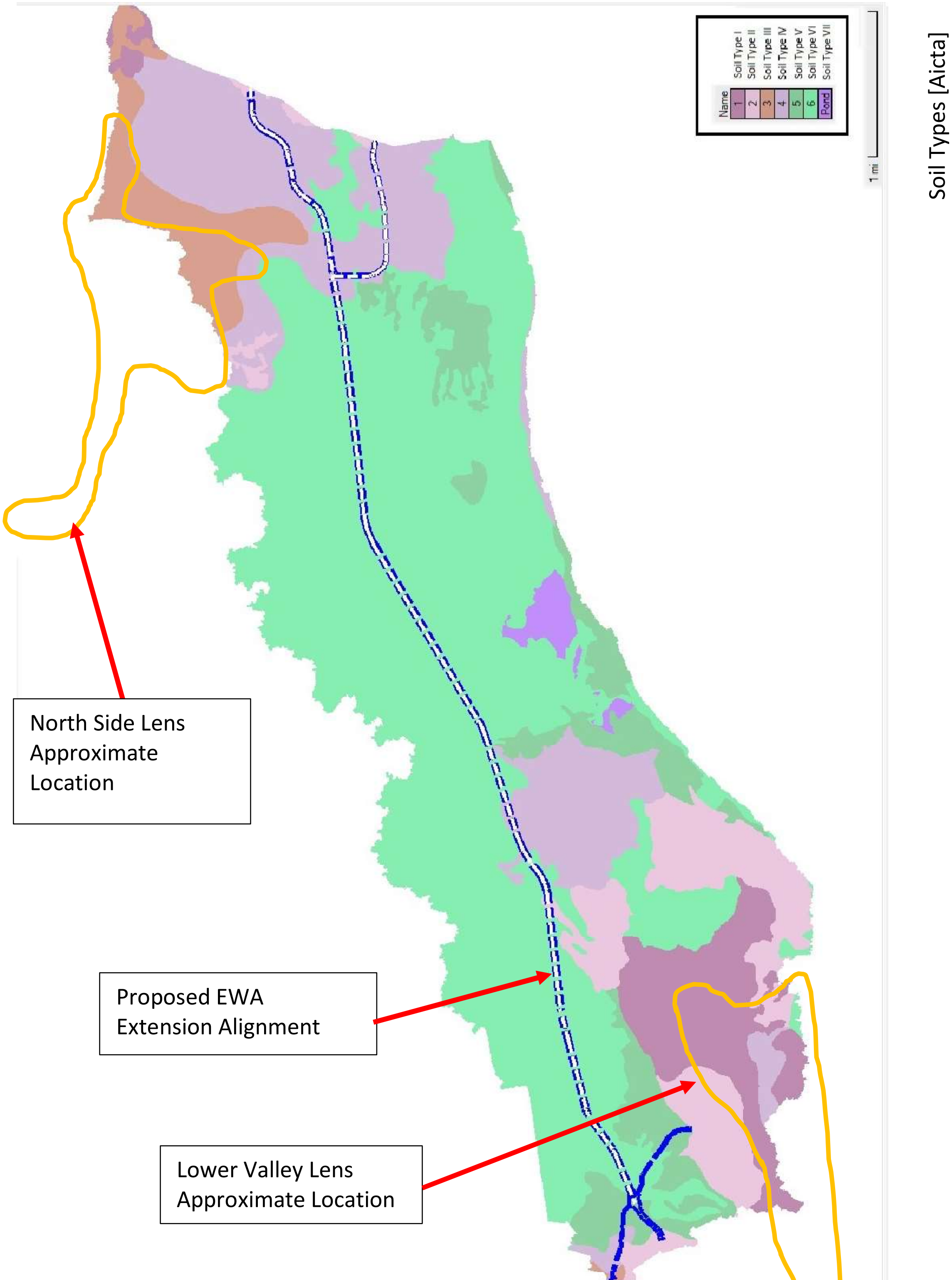

Figure 4 Infiltration, and Soil Map of the Study Area

Table 1 Soils Hydrologic Data

Soil Type	Runoff Curve Number	Abstraction Ratio
1	95	0.05
2	85	0.08
3	70	0.10
4	60	0.15
5	45	0.20
6	40	0.25
Pond	100	0

Soil moisture loss and determination of the wilting point are not considered in the analysis due to the limited data and near constant inundation of the mangrove wetland areas and underlying peat soils. The white mangroves and buttonwoods which generally grow on the upland areas of the wetlands will be affected first if there is a drawdown into the soil. Depending upon their roots systems, which can have a number of characteristics depending upon the inundation, anoxic peat soils, or the presence of rock, the white mangroves and button woods might be tapping into groundwater and be minimally affected by drought conditions or have more pronounced effects if the roots are shallow.

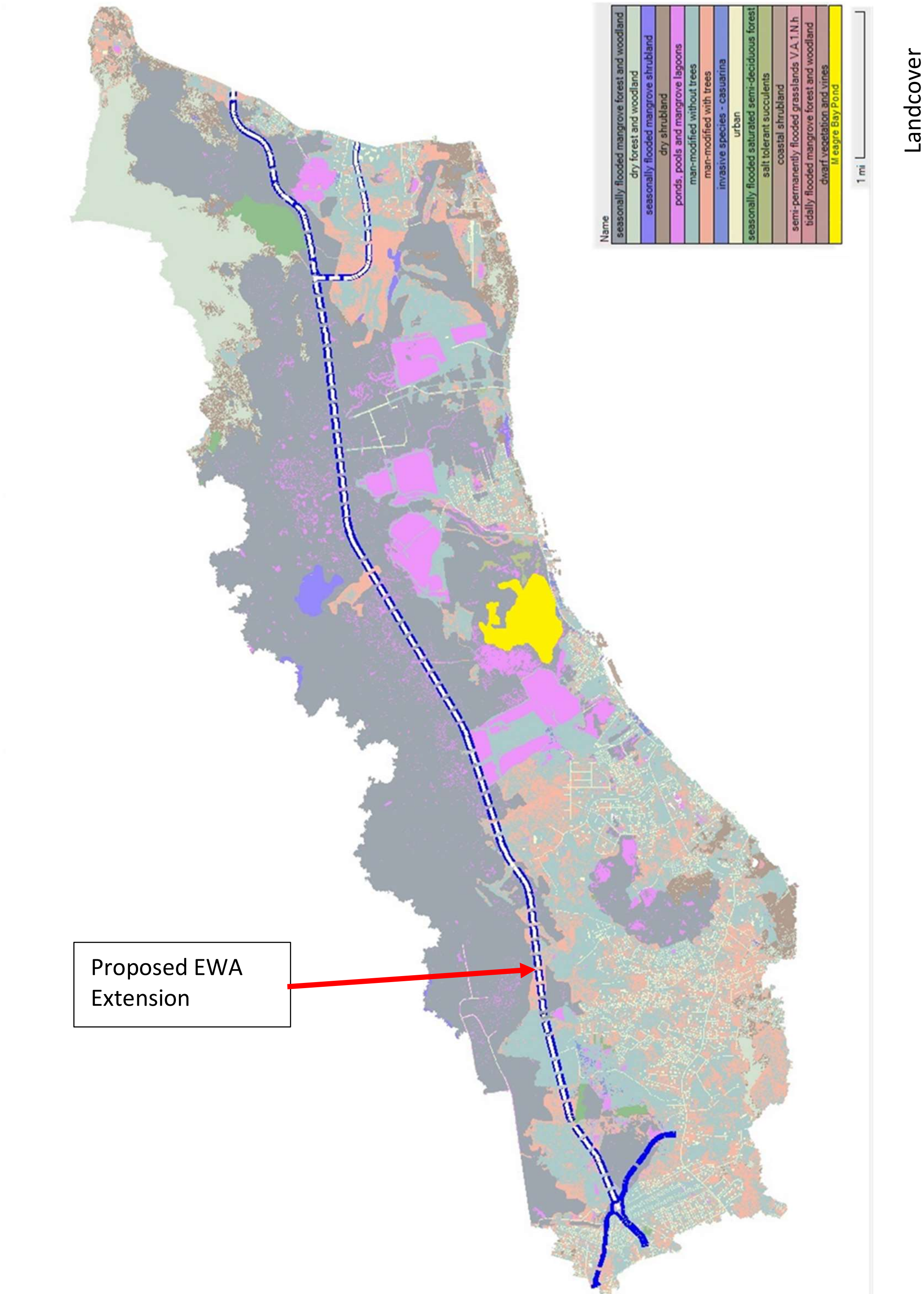

Figure 5 Land Use Map of the Study Area

Table 2 Defined Manning's Coefficient and Percent Impervious

	Name	Manning's' n	Percent Impervious
0	No Data	0.035	100
1	seasonally flooded mangrove forest and woodland	0.045	75
2	dry forest and woodland	0.10	60
3	seasonally flooded - saturated semi-deciduous forest	0.15	70
4	invasive species - casuarina	0.03	45
5	coastal shrubland	0.1	85
6	seasonally flooded mangrove shrubland	0.085	40
7	dry shrubland	0.07	60
8	ponds, pools, and mangrove lagoons	0.025	100
9	Urban	0.03	50
10	man-modified without trees	0.025	90
11	man-modified with trees	0.15	60
12	semi-permanently flooded grasslands V.A.1.N.h [7]	0.1	100
13	salt tolerant succulents	0.11	30
14	tidally flooded mangrove forest and woodland	0.035	40
15	dwarf vegetation and vines	0.12	50

V.A.1.N.h as defined in Burton (2007). Vegetation Classification for the Cayman Islands [7]

Existing Results

The water budget analysis demonstrates that the CMW can have a water deficit when there a few months of low precipitation, particularly in the dry season. Realistically, the CMW held moisture in the soils will evaporate or be taken by the vegetation unless additional inflow from rains occur or there are sea water additions from higher than normal seas, which is not included in the analysis.

There have been drought periods in the past that have caused extensive drawdowns in the Central Mangroves and the swamp habitat has evolved with these periods of dryness. But, like a large storm event bringing saltwater flooding and waves along with high winds, the wetlands sustain damages then recover. As in Figures 6 and 7, of the 33.9 inches of average annual rainfall, 11.4 inches becomes runoff, 0.0 inches is infiltrated from the Lower Valley Lens into the CMW, and 71.4 inches is consumed by evapotranspiration in the CMW study drainage area.

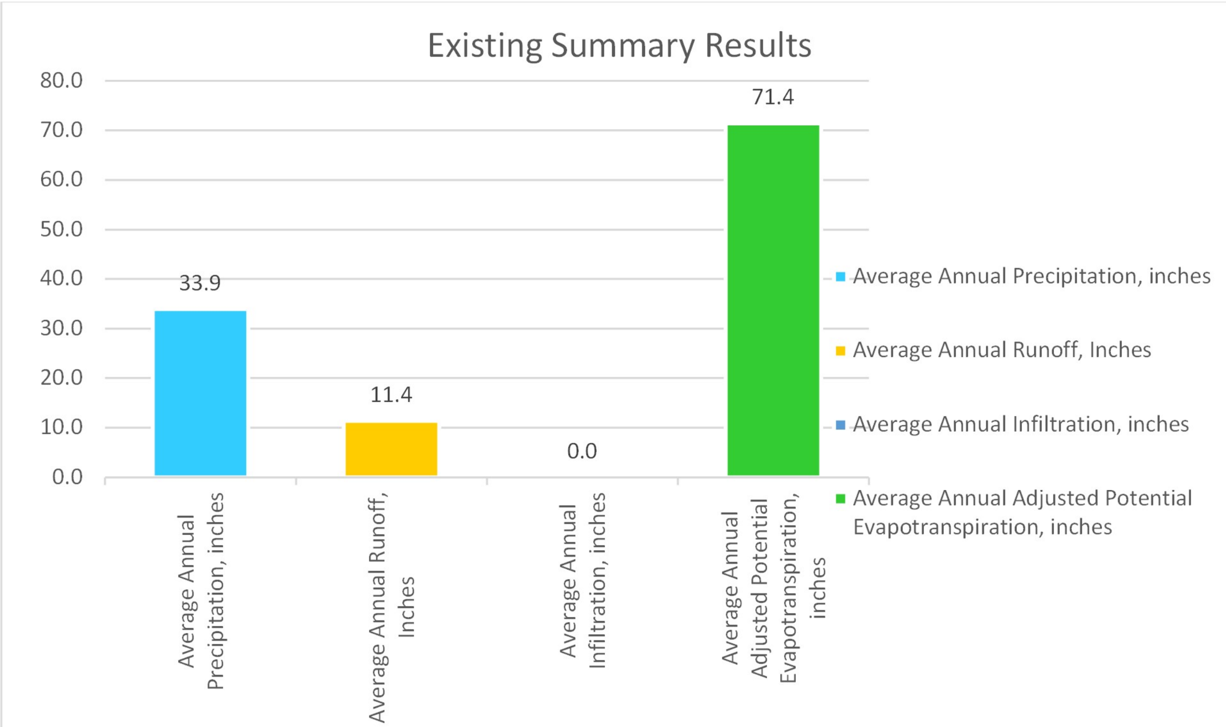

Figure 6 - Existing Summary Results

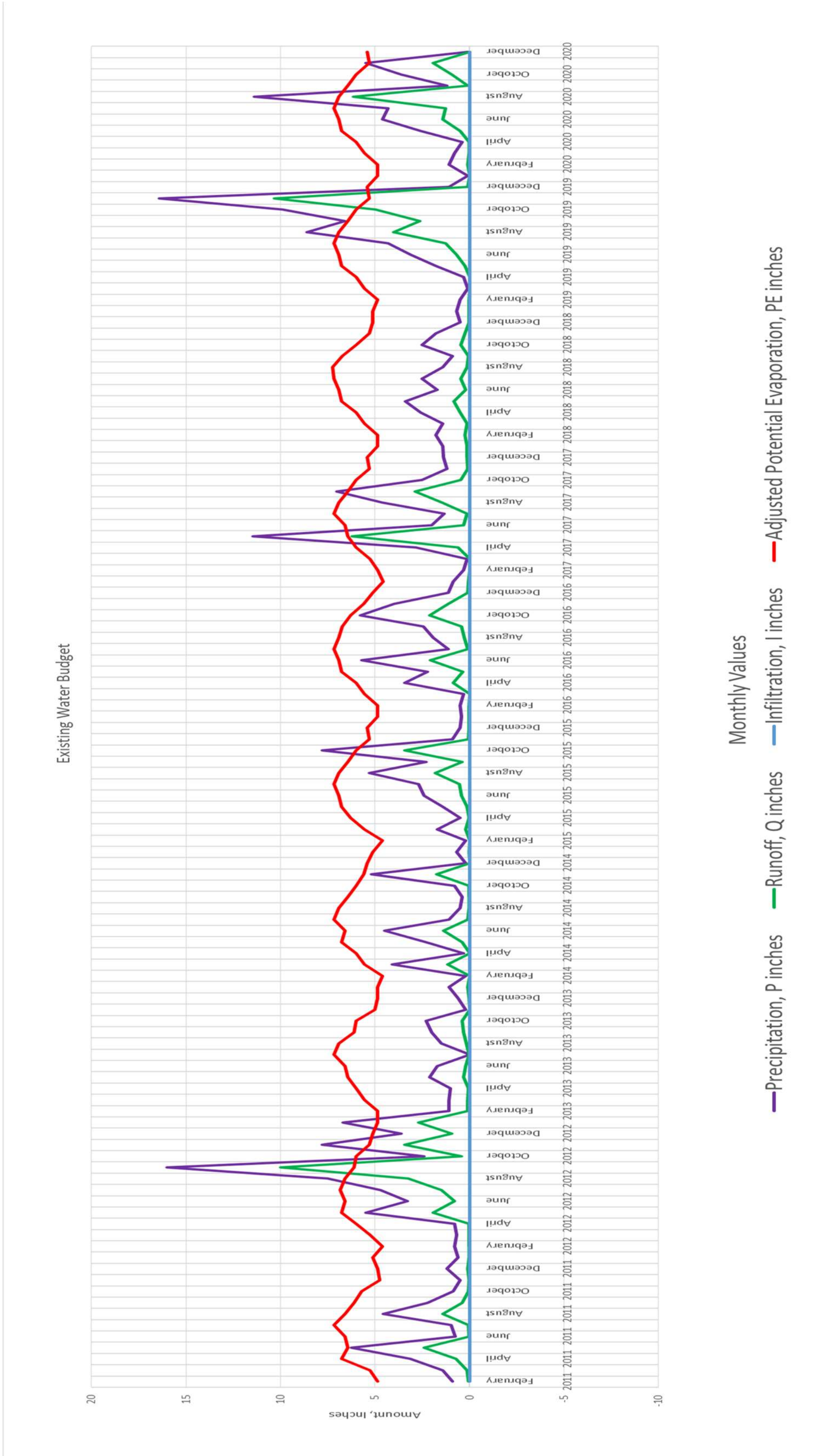

Figure 7- Existing Trends

Planned East-West Arterial

Proposed conditions were modelled by estimating the full build-out roadway cross section area and corresponding runoff curve number for the roadway and grass cross section equal to 86. The roadway was then added to the affected areas with a corresponding reduction in the existing land area resulting in an overall composite runoff curve number increase from 51.8 existing to 52.6 proposed.

Proposed Results

With the small increase in runoff curve number for the entire drainage area analyzed there is increased runoff into the CMW but the CMW water level is little affected (Figure 8 and Figure 9). The overall size of the watershed and the amount of watershed runoff is so great that the increase from the EW Arterial is not reflected within the accuracy of the analysis. Without inflow from the sea into the CMW, the results remain at 33.9 inches of average annual rainfall, with 11.4 inches becoming runoff, 0.0 inches infiltrated, and 71.4 inches consumed by evapotranspiration in the CMW study drainage area.

While the runoff from the proposed EW Arterial will increase the volume of water into the CMW, but at an amount too small for the analysis, the increase will provide an unknown amount of offset to the runoff directed deep underground by the current stormwater management requirements of new development. The land required for the arterial will decrease Central Mangrove Wetland area and vegetation which will lead to a decrease in the total evapotranspiration of the wetlands that is not reflected within the accuracy of the analysis. According to Bradley, the Central Mangrove Wetland evapotranspiration provides an estimated 40% of the rainfall in western districts and a decrease in area coupled with increased development will correspondingly decrease the rainfall in the western districts as assessed by Bradley.[8]

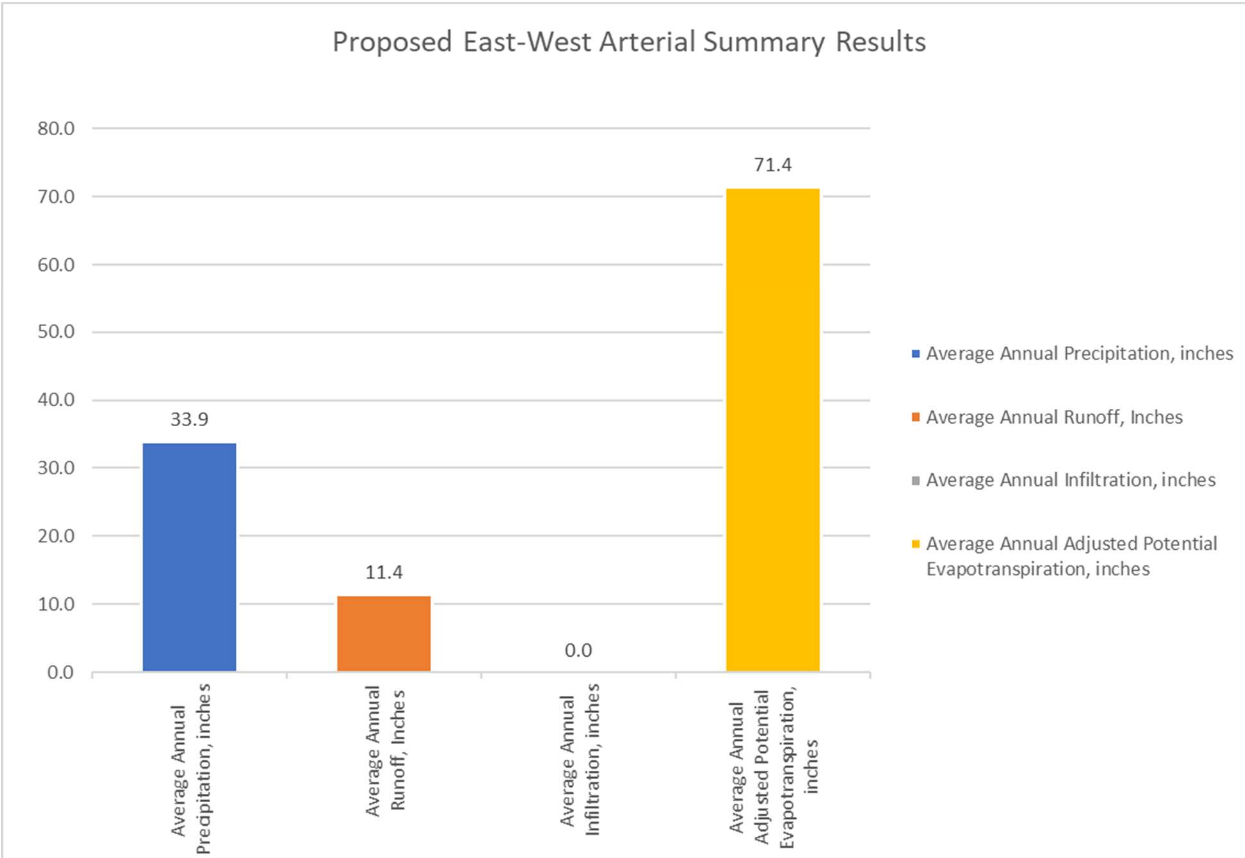

Figure 8 - Proposed Summary

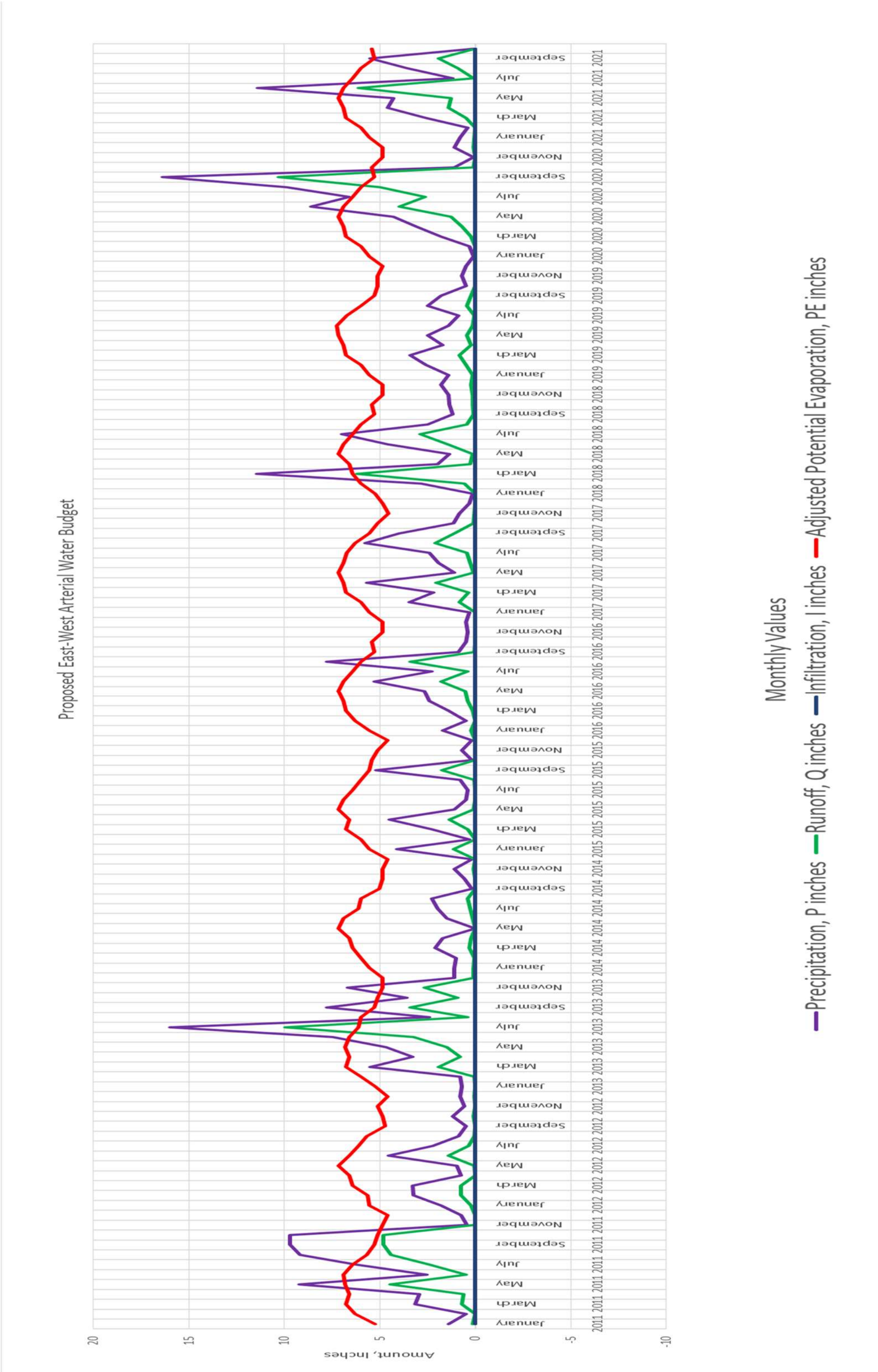

Figure 9 - Proposed Trends

Recommendations

It is recommended that runoff directly from the EW Arterial into the CMW be controlled for erosion and water quality and not for rate and volume. Runoff from the EW Arterial onto lands outside of the CMW will require evaluation for rate and runoff control along with erosion protection and water quality control.

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Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E
where: Infiltration as calculated by Bermes [6]
Exfiltration = 0
Wetland Inflow = Q - Adjusted PE
Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

	Cells	
Input		
Calculated		
Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

		2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0	-2362.31	-1622.93	-172.94	-3085.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.18	0.9	1.42	0.5	3.15	2.94	9.24	2.57	6.26	9.17	9.69	9.69
Runoff, Q	inches	0.0	0.1	0.1	0.0	0.7	0.6	4.5	0.5	2.4	4.4	4.8	4.8
Runoff, Q	ac-ft	0	895	2549	179	12650	11110	78810	8588	42364	77894	84755	84755
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	78	81	79	78	81	79	83.5	85.9	85	82.5	81.6	80
Adjusted Potential Evaporation, PE	inches	4.56	4.86	5.25	6.30	6.78	6.60	6.84	6.93	6.43	5.70	5.30	5.13
Adjusted PE	ac-ft	2362	2518	2721	3264	3513	3419	3544	3590	3329	2953	2746	2658
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.38	-0.26	-0.03	-0.50	1.47	1.24	12.11	0.80	6.28	12.05	13.19	13.21
Wetland Inflow	ac-ft	-2362	-1623	-173	-3085	9137	7691	75266	4998	39035	74941	82008	82097
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow
Accumulated Deficit	**inches**	-0.38	-0.64	-0.67	-1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-2362	-3985	-4158	-7244	0	0	0	0	0	0	0	0
Surplus	**inches**	0.00	0.00	0.00	0.00	0.30	1.24	12.11	0.80	6.28	12.05	13.19	13.21
Surplus	**ac-ft**	-2362	-1622.93	-172.94	-3085.33	1893.46	7691.12	75266.11	4997.98	39035.04	74940.71	82008.30	82096.90

Incursions of the sea into the Central Mangrove Wetlands are not included in the analyses

Volumes in acre-ft are calculated for another perspective on the water budget.

Monthly Average Temperature was obtained from the Cayman Islands National Weather Service

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw

Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E
where: Infiltration as ca
Exfiltration = 0
Wetland Inflow
Water Level = Ir

Wetland Inflow = Q + I - Adjusted PE + E
where: Infiltration as calculated by Bermes [6]
Exfiltration = 0
Wetland Inflow = Q - Adjusted PE
Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

		2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.46	0.76	1.79	3.23	3.27	0.75	0.97	4.57	2.24	0.87	0.5	1.2
Runoff, Q	inches	0.0	0.0	0.2	0.8	0.8	0.0	0.1	1.4	0.4	0.0	0.0	0.1
Runoff, Q	ac-ft	136	586	4163	13255	13562	566	1072	24801	6559	824	179	1756
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	78.4	79	79.8	80.4	82	84.3	85.4	84.7	84.6	81.9	79.7	79.7
Adjusted Potential Evaporation, PE	inches	4.85	4.59	5.56	5.67	6.44	6.60	7.18	6.60	6.12	5.70	4.74	4.85
Adjusted PE	ac-ft	2510	2378	2882	2938	3337	3419	3721	3419	3171	2953	2457	2510
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.38	-0.29	0.21	1.66	1.64	-0.46	-0.43	3.44	0.55	-0.34	-0.37	-0.12
Wetland Inflow	ac-ft	-2374	-1792	1282	10318	10225	-2854	-2649	21382	3389	-2130	-2279	-754
Monthly Deficit/Overflow		Deficit	Deficit	Overflow	Overflow	Overflow	Deficit	Deficit	Overflow	Overflow	Deficit	Deficit	Deficit
Accumulated Deficit	**inches**	0.00	-0.29	0.00	0.00	0.00	0.00	-0.43	0.00	0.00	0.00	-0.37	-0.12
Accumulated Deficit	**ac-ft**	-2374	-4166	-2885	0	0	-2854	-5502	0	0	-2130	-4408	-5162
Surplus	**inches**	0.00	0.00	0.00	1.66	1.64	0.00	0.00	3.01	0.55	0.00	0.00	0.00
Surplus	**ac-ft**	-2373.90	-1792.43	1281.55	7432.98	10225.08	-2853.52	-2648.64	15879.50	3388.63	-2129.53	-2278.68	-754.00

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

		2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.6	0.8	0.7	0.8	5.5	3.3	4.7	7.5	16	2.4	7.8	3.6
Runoff, Q	inches	0.0	0.0	0.0	0.0	1.9	0.8	1.5	3.2	10.0	0.4	3.4	0.9
Runoff, Q	ac-ft	309	668	472	668	34116	13794	26046	56831	175568	7516	60493	16189
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	80	79.5	77.9	82	83	84.3	84.5	84.5	84	84	82.7	81.3
Adjusted Potential Evaporation, PE	inches	5.13	4.59	5.25	5.99	6.78	6.60	6.84	6.60	6.12	6.00	5.30	5.13
Adjusted PE	ac-ft	2658	2378	2721	3101	3513	3419	3544	3419	3171	3109	2746	2658
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.38	-0.28	-0.36	-0.39	4.92	1.67	3.62	8.59	27.73	0.71	9.29	2.18
Wetland Inflow	ac-ft	-2349	-1710	-2250	-2433	30604	10374	22502	53412	172397	4407	57747	13531
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow
Accumulated Deficit	**inches**	-0.38	-0.28	-0.36	-0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-7511	-9222	-11471	-13904	0	0	0	0	0	0	0	0
Surplus	**inches**	0.00	0.00	0.00	0.00	4.53	1.67	3.62	8.59	27.73	0.71	9.29	2.18
Surplus	**ac-ft**	-2349.23	-1710.28	-2249.57	-2433.01	16699.42	10374.46	22502.18	53411.54	172396.97	4407.36	57746.91	13530.86

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EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Cayman Islands Government
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EAST-WEST ARTERIAL WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

		2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	6.7	1.1	1.1	1	2.1	1.7	0	1.5	2	2.3	0.2	0.6
Runoff, Q	inches	2.7	0.1	0.1	0.1	0.3	0.2	0.0	0.2	0.3	0.4	0.0	0.0
Runoff, Q	ac-ft	47365	1440	1440	1153	5766	3739	69	2869	5225	6912	0	309
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	78.6	80.4	81.1	82.2	82.9	84	86	85.4	84.2	84	81.1	79.3
Adjusted Potential Evaporation, PE	inches	4.85	4.86	5.56	5.99	6.44	6.60	7.18	6.93	6.12	6.00	5.02	4.85
Adjusted PE	ac-ft	2510	2518	2882	3101	3337	3419	3721	3590	3171	3109	2602	2510
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	7.21	-0.17	-0.23	-0.31	0.39	0.05	-0.59	-0.12	0.33	0.61	-0.42	-0.35
Wetland Inflow	ac-ft	44855	-1078	-1442	-1948	2429	320	-3652	-722	2055	3803	-2602	-2202
Monthly Deficit/Overflow		Overflow	Deficit	Deficit	Deficit	Overflow	Overflow	Deficit	Deficit	Overflow	Overflow	Deficit	Deficit
Accumulated Deficit	**inches**	0.00	0.00	-0.23	-0.31	0.00	0.00	-0.54	-0.12	0.00	0.00	0.00	-0.35
Accumulated Deficit	**ac-ft**	0	-1078	-2519	-4467	-2038	-1718	-5370	-6092	-4037	-234	-2835	-5037
Surplus	**inches**	7.21	0.00	0.00	0.00	0.08	0.05	0.00	0.00	0.21	0.61	0.00	0.00
Surplus	**ac-ft**	44855.09	-1077.84	-1441.54	-1948.03	2429.09	320.03	-3651.59	-721.77	2054.71	3803.37	-2601.57	-2201.58

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E

where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells	
Input	
Calculated	
Central Mangrove Wetland Area	6217 Acre
Land Area	11369 Acre

		2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015	2015
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	1.1	0.2	4.1	0.3	2.3	4.5	1.1	0.5	0.4	0.8	5.2	0.2
Runoff, Q	inches	0.1	0.0	1.2	0.0	0.4	1.4	0.1	0.0	0.0	0.0	1.8	0.0
Runoff, Q	ac-ft	1440	0	20472	23	6912	24139	1440	179	83	668	31011	0
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79.4	78.2	80.8	82.9	83	83.6	85.9	86	85.8	84.2	84.2	81.6
Adjusted Potential Evaporation, PE	inches	4.85	4.59	5.56	5.99	6.78	6.60	7.18	6.93	6.43	6.00	5.58	5.42
Adjusted PE	ac-ft	2510	2378	2882	3101	3513	3419	3721	3590	3329	3109	2891	2805
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.17	-0.38	2.83	-0.49	0.55	3.33	-0.37	-0.55	-0.52	-0.39	4.52	-0.45
Wetland Inflow	ac-ft	-1070	-2378	17591	-3077	3399	20720	-2281	-3412	-3246	-2441	28120	-2805
Monthly Deficit/Overflow		Deficit	Deficit	Overflow	Deficit	Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Overflow	Deficit
Accumulated Deficit	**inches**	-0.17	-0.38	0.00	0.00	0.00	0.00	0.00	-0.55	-0.52	-0.39	0.00	0.00
Accumulated Deficit	**ac-ft**	-6107	-8485	0	-3077	0	0	-2281	-5693	-8939	-11379	0	-2805
Surplus	**inches**	0.00	0.00	2.45	0.00	0.55	3.33	0.00	0.00	0.00	0.00	4.13	0.00
Surplus	**ac-ft**	-1070.07	-2377.76	9106.17	-3077.41	321.85	20719.65	-2280.83	-3411.73	-3246.05	-2440.78	16740.64	-2805.18

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

		2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.7	0.2	1.7	0.5	1.4	2.4	2.7	5.3	2.3	7.8	0.9	0.5
Runoff, Q	inches	0.0	0.0	0.2	0.0	0.1	0.4	0.5	1.8	0.4	3.4	0.1	0.0
Runoff, Q	ac-ft	472	0	3739	179	2471	7516	9446	32036	6912	60493	895	179
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79.8	78.7	81.3	82.8	84.3	85.1	85.6	86.1	86	84	81.6	81.7
Adjusted Potential Evaporation, PE	inches	5.13	4.59	5.56	6.30	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42
Adjusted PE	ac-ft	2658	2378	2882	3264	3513	3590	3721	3590	3329	3109	2746	2805
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.35	-0.38	0.14	-0.50	-0.17	0.63	0.92	4.58	0.58	9.23	-0.30	-0.42
Wetland Inflow	ac-ft	-2186	-2378	858	-3085	-1041	3926	5725	28446	3583	57385	-1851	-2627
Monthly Deficit/Overflow		Deficit	Deficit	Overflow	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow	Deficit	Deficit
Accumulated Deficit	**inches**	-0.35	-0.38	0.00	-0.50	-0.17	0.00	0.00	0.00	0.00	0.00	0.00	-0.42
Accumulated Deficit	**ac-ft**	-4991	-7369	-6511	-9596	-10638	-6712	-987	0	0	0	-1851	-4478
Surplus	**inches**	0.00	0.00	0.00	0.00	0.00	0.46	0.92	4.58	0.58	9.23	0.00	0.00
Surplus	**ac-ft**	-2185.85	-2377.76	857.80	-3085.33	-1041.45	3925.54	5724.97	28445.66	3582.67	57384.77	-1851.40	-2626.83

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EAST-WEST ARTERIAL WATER BUDGET | EAST-WEST ARTERIAL WATER BUDGET | Check: R. Razzaghmanesh
EXISTING CONDITIONS - WATER BUDGET

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Cells

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E

where: Infiltration as ca where: Infiltration as calculated by Bermes [6]

Exfiltration = 0 Exfiltration = 0

Wetland Inflow Wetland Inflow = Q - Adjusted PE

Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:

Precipitation, P

Runoff, Q

Adjusted Potential Evaporation, PE

Input

Calculated

Central Mangrove Wetland Area 6217 Acre

Land Area 11369 Acre

		2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.42	0.5	0.32	3.45	2.22	5.7	1.11	1.93	2.43	5.77	4	1.13
Runoff, Q	inches	0.0	0.0	0.0	0.9	0.4	2.1	0.1	0.3	0.4	2.1	1.1	0.1
Runoff, Q	ac-ft	99	179	32	14974	6443	36236	1470	4860	7701	36986	19588	1532
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79.2	80	80	81.6	83.8	84.8	86.1	85.7	86.5	85.4	83.4	80
Adjusted Potential Evaporation, PE	inches	4.85	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.73	6.30	5.58	5.13
Adjusted PE	ac-ft	2510	2518	2882	3101	3513	3590	3721	3590	3488	3264	2891	2658
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.39	-0.38	-0.46	1.91	0.47	5.25	-0.36	0.20	0.68	5.42	2.69	-0.18
Wetland Inflow	ac-ft	-2411	-2339	-2849	11873	2931	32645	-2251	1270	4213	33722	16697	-1126
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Deficit	Overflow	Overflow	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	-0.39	-0.38	-0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-6889	-9228	-12077	-204	0	0	-2251	-981	0	0	0	-1126
Surplus	**inches**	0.00	0.00	0.00	1.45	0.47	5.25	0.00	0.20	0.68	5.42	2.69	0.00
Surplus	**ac-ft**	-2410.69	-2339.29	-2849.20	11873.19	2930.83	32645.36	-2250.50	1269.79	4213.25	33722.44	16697.00	-1125.88

Cayman Islands Government Cayman Islands Government
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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated
Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

		2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.85	0.3	0.13	2.84	11.48	2	1.36	4.62	7.01	2.5	1.19	1.39
Runoff, Q	inches	0.0	0.0	0.0	0.6	6.2	0.3	0.1	1.4	2.9	0.5	0.1	0.1
Runoff, Q	ac-ft	777	23	7	10404	109257	5225	2320	25277	50979	8140	1723	2433
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	77.8	80.1	79.7	82.5	82.2	84	85.9	85.6	84.8	83.9	82.7	81.4
Adjusted Potential Evaporation, PE	inches	4.56	4.86	5.25	5.99	6.44	6.60	7.18	6.93	6.43	6.00	5.30	5.42
Adjusted PE	ac-ft	2362	2518	2721	3101	3337	3419	3721	3590	3329	3109	2746	2805
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.25	-0.40	-0.44	1.17	17.04	0.29	-0.23	3.49	7.66	0.81	-0.16	-0.06
Wetland Inflow	ac-ft	-1585	-2495	-2715	7304	105920	1806	-1401	21687	47650	5031	-1023	-373
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Deficit	Overflow	Overflow	Overflow	Deficit	Deficit
Accumulated Deficit	**inches**	-0.25	-0.40	-0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
Accumulated Deficit	**ac-ft**	-2711	-5205	-7920	-617	0	0	-1401	0	0	0	-1023	-1396
Surplus	**inches**	0.00	0.00	0.00	0.74	17.04	0.29	0.00	3.49	7.66	0.81	0.00	0.00
Surplus	**ac-ft**	-1584.99	-2494.57	-2714.88	7303.60	105919.90	1806.03	-1401.35	20285.80	47649.50	5031.36	-1023.12	-372.57

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw

Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E
where: Infiltration as ca
Exfiltration = 0
Wetland Inflow
Water Level = Ir

Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as calculated by Bermes [6]
Exfiltration = 0
Wetland Inflow = Q - Adjusted PE
Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells	
Input	
Calculated	
Central Mangrove Wetland Area	6217 Acre
Land Area	11369 Acre

		2019	2019	2019	2019	2019	2019	2019	2019	2019	2019	2019	2019
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	1.4	1.8	1.4	2.6	3.4	1.7	2.5	1.4	0.9	2.5	1.8	0.5
Runoff, Q	inches	0.1	0.2	0.1	0.5	0.8	0.2	0.5	0.1	0.1	0.5	0.2	0.0
Runoff, Q	ac-ft	2471	4211	2471	8783	14577	3739	8140	2471	895	8140	4211	179
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79.5	80.4	80.6	82.6	83.8	86	86.2	86.7	86.6	84.8	82.7	81
Adjusted Potential Evaporation, PE	inches	4.85	4.86	5.56	5.99	6.78	6.93	7.18	7.26	6.73	6.00	5.30	5.13
Adjusted PE	ac-ft	2510	2518	2882	3101	3513	3590	3721	3761	3488	3109	2746	2658
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.01	0.27	-0.07	0.91	1.78	0.02	0.71	-0.21	-0.42	0.81	0.24	-0.40
Wetland Inflow	ac-ft	-39	1694	-410	5683	11064	149	4419	-1290	-2593	5031	1465	-2479
Monthly Deficit/Overflow		Deficit	Overflow	Deficit	Overflow	Overflow	Overflow	Overflow	Deficit	Deficit	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.42	0.00	0.00	-0.16
Accumulated Deficit	**ac-ft**	-1435	0	-410	0	0	0	0	-1290	-3883	0	0	-2479
Surplus	**inches**	0.00	0.27	0.00	0.91	1.78	0.02	0.71	0.00	0.00	0.39	0.24	0.00
Surplus	**ac-ft**	-38.96	258.88	-410.42	5272.21	11064.04	149.06	4418.99	-1290.13	-2592.78	1148.46	1465.05	-2479.18

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells	
Input	
Calculated	
Central Mangrove Wetland Area	6217 Acre
Land Area	11369 Acre

		2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
	Unit	January	February	March	April	May	June	July	August	September	October	November	December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.7	0.5	0.1	0.3	1.8	3.1	4.3	8.6	6.6	9.9	16.4	1.1
Runoff, Q	inches	0.0	0.0	0.0	0.0	0.2	0.7	1.3	4.0	2.6	5.0	10.3	0.1
Runoff, Q	ac-ft	472	179	15	23	4211	12276	22280	70528	46215	87561	181661	1440
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79.9	80.6	80.8	82.5	83.8	84.8	85.7	85.4	86	84.7	81.4	81.4
Adjusted Potential Evaporation, PE	inches	5.13	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42
Adjusted PE	ac-ft	2658	2518	2882	3101	3513	3590	3721	3590	3329	3109	2746	2805
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.35	-0.38	-0.46	-0.49	0.11	1.40	2.99	10.77	6.90	13.58	28.78	-0.22
Wetland Inflow	ac-ft	-2186	-2339	-2866	-3077	699	8686	18560	66938	42886	84452	178915	-1365
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	-0.35	-0.38	-0.46	-0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-4665	-7004	-9871	-12948	-12249	-3563	0	0	0	0	0	-1365
Surplus	**inches**	0.00	0.00	0.00	0.00	0.00	1.40	2.99	10.77	6.90	13.58	28.78	0.00
Surplus	**ac-ft**	-2185.85	-2339.29	-2866.43	-3077.41	698.80	8686.04	18559.53	66937.57	42885.90	84452.45	178915.01	-1365.38

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - WATER BUDGET

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthw Calculations are done using the Thornthwaite and Mather Method

Wetland Inflow = Q + I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as ca where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflow Wetland Inflow = Q - Adjusted PE
Water Level = Ir Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells	
Input	
Calculated	
Central Mangrove Wetland Area	6217 Acre
Land Area	11369 Acre

	Unit	2021 January	2021 February	2021 March	2021 April	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October	2021 November	2021 December
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.1	1.1	0.8	0.4	2.6	4.6	4.3	11.4	1.2	3.6	5.5	0.1
Runoff, Q	inches	0.0	0.1	0.0	0.0	0.5	1.4	1.3	6.1	0.1	0.9	1.9	0.0
Runoff, Q	ac-ft	15	1440	668	83	8783	25087	22280	108136	1756	16189	34116	15
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79.7	80.6	80.8	82.5	83.8	84.8	85.7	85.4	86	84.7	81.4	81.4
Adjusted Potential Evaporation, PE	inches	4.85	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42
Adjusted PE	ac-ft	2510	2518	2882	3101	3513	3590	3721	3590	3329	3109	2746	2805
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.40	-0.17	-0.36	-0.49	0.85	3.46	2.99	16.82	-0.25	2.10	5.05	-0.45
Wetland Inflow	ac-ft	-2495	-1078	-2214	-3018	5271	21496	18560	104545	-1573	13080	31370	-2790
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Deficit	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	-0.40	-0.17	-0.36	-0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-3860	-4938	-7152	-10170	-4899	0	0	0	-1573	0	0	-2790
Surplus	**inches**	0.00	0.00	0.00	0.00	0.36	3.46	2.99	16.82	0.00	2.10	5.05	0.00
Surplus	**ac-ft**	-2494.97	-1077.84	-2213.86	-3017.58	5270.75	21496.21	18559.53	104545.40	-1573.09	11507.04	31369.97	-2790.27

Cayman Islands Government
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EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Cells	
Input	
Calculated	

Where $P > I_a$ and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in
S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and $I_a = 0.2S$

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

	Unit	2011 January	2011 February	2011 March	2011 April	2011 May	2011 June	2011 July	2011 August	2011 September	2011 October	2011 November	2011 December	2012 January
Precipitation, P	Inches	0.18	0.9	1.42	0.5	3.15	2.94	9.24	2.57	6.26	9.17	9.69	9.69	0.46
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.0	0.1	0.1	0.0	0.7	0.6	4.5	0.5	2.4	4.4	4.8	4.8	0.0
Volume	ac-ft	0	895	2549	179	12650	11110	78810	8588	42364	77894	84755	84755	136

Composite Curve Number Calculation		Soil - Curve Numbers [4]							
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6		
							Swamps		
Soil Type [4]		1	2	3	4	5	6	Total	Average
Area	square ft	30755320	38290920	20944681	76310110	58129171	270794034		
Area	Acre	756.0	947.0	491.0	1880.0	887.0	6094.0	11369	
CN [4]		95	85	70	60	45	40		51.8
Area * CN	Acre	67074	74718	33658	105110	60051	248663	589274	
Initial Abstraction Ia [4]		0.05	0.08	0.10	0.15	0.20	0.25	0.83	0.19
Area * Ia		38	76	49	282	177	1524	2146	

Soil Type taken from Memorandum 2 - Hydrology and Hydraulic (H&H) Analysis [4]
Calculations by the U.S. National Resources Conservation Service Part 630 Hydrology National Engineering Handbook [5]

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EAST-WEST ARTERIAL WATER BUDGETEAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCEXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodologCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_a}$ Runoff, Q (in) $Q = \frac{(P - I_a)^2}{(P - I_a) + S}$

Cells	
Input	
Calculated	

Where P>I_a and Ia as determined in MWhere P>I_a and Ia as determined in Memorandum 2 [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [!S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2012 February	2012 March	2012 April	2012 May	2012 June	2012 July	2012 August	2012 September	2012 October	2012 November	2012 December	2013 January	2013 February
Precipitation, P	Inches	0.76	1.79	3.23	3.27	0.75	0.97	4.57	2.24	0.87	0.5	1.2	0.6	0.8
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.0	0.2	0.8	0.8	0.0	0.1	1.4	0.4	0.0	0.0	0.1	0.0	0.0
Volume	ac-ft	586	4163	13255	13562	566	1072	24801	6559	824	179	1756	309	668

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET

EXISTING CONDITIONS - RUNOFF CALC EXISTING CONDITIONS - RUNOFF CALCULATION

Calculations following the methodolog Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers

By: S. Gause 15-May-23

Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P-I}{(P-I_a}$ Runoff, Q (in) $$Q = \frac{(P-I_a)^2}{(P-I_a)+S}$$

Cells	
Input	
Calculated	

Where P>I_a and Ia as determined in M Where P>I_a and Ia as determined in Memorandum 2 [4]

P - Monthly Precipitation, in P - Monthly Precipitation, in

S - Maximum Potential Retention, in [! S - Maximum Potential Retention, in [5]

I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2

and I_a = 0.2S

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2013 March	2013 April	2013 May	2013 June	2013 July	2013 August	2013 September	2013 October	2013 November	2013 December	2014 January	2014 February	2014 March
Precipitation, P	Inches	0.7	0.8	5.5	3.3	4.7	7.5	16	2.4	7.8	3.6	6.7	1.1	1.1
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.0	0.0	1.9	0.8	1.5	3.2	10.0	0.4	3.4	0.9	2.7	0.1	0.1
Volume	ac-ft	472	668	34116	13794	26046	56831	175568	7516	60493	16189	47365	1440	1440

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2

Calculations by the U.S. National Reso

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National Roads Authority	National Roads Authority
EAST-WEST ARTERIAL WATER BUDGETEAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCEXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodologCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_a}$ Runoff, Q (in) $Q = \frac{(P - I_a)^2}{(P - I_a) + S}$

Cells
Input
Calculated

Where P>I_a and Ia as determined in MWhere P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [!S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

	Unit	2014 April	2014 May	2014 June	2014 July	2014 August	2014 September	2014 October	2014 November	2014 December	2015 January	2015 February	2015 March	2015 April
Precipitation, P	Inches	1	2.1	1.7	0	1.5	2	2.3	0.2	0.6	1.1	0.2	4.1	0.3
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.1	0.3	0.2	0.0	0.2	0.3	0.4	0.0	0.0	0.1	0.0	1.2	0.0
Volume	ac-ft	1153	5766	3739	69	2869	5225	6912	0	309	1440	0	20472	23

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGETEAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCEXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodologCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_a.}$ Runoff, Q (in) $Q = \frac{(P - I_a)^2}{(P - I_a) + S}$

Cells
Input
Calculated

Where $P > I_a$ and Ia as determined in MWhere $P > I_a$ and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [!S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and $I_a = 0.2S$

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

	Unit	2015 May	2015 June	2015 July	2015 August	2015 September	2015 October	2015 November	2015 December	2016 January	2016 February	2016 March	2016 April	2016 May
Precipitation, P	Inches	2.3	4.5	1.1	0.5	0.4	0.8	5.2	0.2	0.7	0.2	1.7	0.5	1.4
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.4	1.4	0.1	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.2	0.0	0.1
Volume	ac-ft	6912	24139	1440	179	83	668	31011	0	472	0	3739	179	2471

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGETEAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCEXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodologCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_{a}}$ Runoff, Q (in)

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Cells
Input
Calculated

Where $P>I_a$ and Ia as determined in MWhere $P>I_a$ and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [5S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and $I_a = 0.2S$

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

	Unit	2016 June	2016 July	2016 August	2016 September	2016 October	2016 November	2016 December	2017 January	2017 February	2017 March	2017 April	2017 May	2017 June
Precipitation, P	Inches	2.4	2.7	5.3	2.3	7.8	0.9	0.5	0.42	0.5	0.32	3.45	2.22	5.7
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.4	0.5	1.8	0.4	3.4	0.1	0.0	0.0	0.0	0.0	0.9	0.4	2.1
Volume	ac-ft	7516	9446	32036	6912	60493	895	179	99	179	32	14974	6443	36236

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGETEAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCEXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodologCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
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Runoff, Q (in) $Q = \frac{(P-I}{(P-I_{a.}}$ Runoff, Q (in) $Q = \frac{(P-I_a)^2}{(P-I_a)+S}$

Where $P>I_a$ and Ia as determined in MWhere $P>I_a$ and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [!S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Cells	
Input	
Calculated	

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2017 July	2017 August	2017 September	2017 October	2017 November	2017 December	2018 January	2018 February	2018 March	2018 April	2018 May	2018 June	2018 July
Precipitation, P	Inches	1.11	1.93	2.43	5.77	4	1.13	0.85	0.3	0.13	2.84	11.48	2	1.36
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.1	0.3	0.4	2.1	1.1	0.1	0.0	0.0	0.0	0.6	6.2	0.3	0.1
Volume	ac-ft	1470	4860	7701	36986	19588	1532	777	23	7	10404	109257	5225	2320

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALC EXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodolog Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_a}$ Runoff, Q (in) $Q = \frac{(P - I_a)^2}{(P - I_a) + S}$

Where P>I_a and Ia as determined in M Where P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [! S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Cells	
Input	
Calculated	

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2018 August	2018 September	2018 October	2018 November	2018 December	2019 January	2019 February	2019 March	2019 April	2019 May	2019 June	2019 July	2019 August
Precipitation, P	Inches	4.62	7.01	2.5	1.19	1.39	1.4	1.8	1.4	2.6	3.4	1.7	2.5	1.4
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	1.4	2.9	0.5	0.1	0.1	0.1	0.2	0.1	0.5	0.8	0.2	0.5	0.1
Volume	ac-ft	25277	50979	8140	1723	2433	2471	4211	2471	8783	14577	3739	8140	2471

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGETEAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALCEXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodologCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_a.}$ Runoff, Q (in) $Q = \frac{(P - I_a)^2}{(P - I_a) + S}$

Cells	
Input	
Calculated	

Where P>I_a and Ia as determined in MWhere P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [!S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2019 September	2019 October	2019 November	2019 December	2020 January	2020 February	2020 March	2020 April	2020 May	2020 June	2020 July	2020 August	2020 September
Precipitation, P	Inches	0.9	2.5	1.8	0.5	0.7	0.5	0.1	0.3	1.8	3.1	4.3	8.6	6.6
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	0.1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.3	4.0	2.6
Volume	ac-ft	895	8140	4211	179	472	179	15	23	4211	12276	22280	70528	46215

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

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EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALC EXISTING CONDITIONS - RUNOFF CALCULATION
Calculations following the methodolog Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 15-May-23
Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P-I}{(P-I_a}$ Runoff, Q (in) $Q = \frac{(P-I_a)^2}{(P-I_a)+S}$

	Cells
Input	
Calculated	

Where P>I_a and Ia as determined in M Where P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in [! S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2020 October	2020 November	2020 December	2021 January	2021 February	2021 March	2021 April	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October
Precipitation, P	Inches	9.9	16.4	1.1	0.1	1.1	0.8	0.4	2.6	4.6	4.3	11.4	1.2	3.6
Runoff Curve Number, CN		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S	Inches	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Q	Inches	5.0	10.3	0.1	0.0	0.1	0.0	0.0	0.5	1.4	1.3	6.1	0.1	0.9
Volume	ac-ft	87561	181661	1440	15	1440	668	83	8783	25087	22280	108136	1756	16189

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

Cayman Islands Government
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EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - RUNOFF CALC
Calculations following the methodolog

Runoff, Q (in) $Q = \frac{(P - I}{(P - I_{a.}}$

Where $P>I_a$ and Ia as determined in M
P - Monthly Precipitation, in
S - Maximum Potential Retention, in [5
I_a - Initial Abstraction, in [4]

	Unit	2021 November	2021 December
Precipitation, P	Inches	5.5	0.1
Runoff Curve Number, CN		51.8	51.8
S	Inches	9.2	9.2
Q	Inches	1.9	0.0
Volume	ac-ft	34116	15

Composite Curve Number Calculation	
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum 2
Calculations by the U.S. National Reso

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - EVAPOTRANSPIRATION CALCULATION

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

	Units	2011 January	2011 February	2011 March	2011 April	2011 May	2011 June	2011 July	2011 August	2011 September	2011 October	2011 November	2011 December	2012 January	2012 February	2012 March
Avg Temp (^{O}F)	^{O}F	78	81	79	83.5	83.2	84.7	84.5	85.9	85	82.5	81.6	80	78.4	79	79.8
Heat Index, I		11.82	13.01	12.21	14.02	13.89	14.52	14.43	15.02	14.64	13.61	13.25	12.61	11.97	12.21	12.53
1 Year Heat Index Sum													163.03			
Unadjusted Daily PET (in)	inches	0.16	0.18	0.17	0.2	0.2	0.2	0.2	0.21	0.21	0.19	0.19	0.18	0.17	0.17	0.18
Lattitude 19.3^{o}																
Mean Possible Duration of Sunlight in Units of 12 Hours	twelve hours	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
Adjusted Potential Evapotranspiration, PET(in)	inches	4.56	4.86	5.25	6.30	6.78	6.60	6.84	6.93	6.43	5.70	5.30	5.13	4.85	4.59	5.56

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

EAST-WEST ARTERIAL WATER BUDGET
EXISTING CONDITIONS - EVAPOTRANSPIRATION CALCULATION
Calculations are done using the Thornthwaite and Mather Method

Adjusted PE = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2012 April	2012 May	2012 June	2012 July	2012 August	2012 September	2012 October	2012 November	2012 December	2013 January	2013 February	2013 March	2013 April	2013 May	2013 June	2013 July	2013 August	2013 September
80.4	82	84.3	85.4	84.7	84.6	81.9	79.7	79.7	80	79.5	77.9	82	83	84.3	84.5	84.5	84
12.77	13.41	14.35	14.81	14.52	14.47	13.37	12.49	12.49	12.61	12.41	11.78	13.41	13.81	14.31	14.43	14.43	14.22
								159.39									
0.18	0.19	0.2	0.21	0.2	0.2	0.19	0.17	0.17	0.18	0.17	0.17	0.19	0.2	0.2	0.2	0.2	0.2

31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6
5.67	6.44	6.60	7.18	6.60	6.12	5.70	4.74	4.85	5.13	4.59	5.25	5.99	6.78	6.60	6.84	6.60	6.12

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET - EVAPOTRANSPIRATION CALCULATION

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthwaite and Mather Method

Adjusted PE = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to $80^{O}F$ [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2013 October	2013 November	2013 December	2014 January	2014 February	2014 March	2014 April	2014 May	2014 June	2014 July	2014 August	2014 September	2014 October	2014 November	2014 December	2015 January	2015 February	2015 March
84	82.7	81.3	78.6	80.4	81.1	82.2	82.9	84	86	85.4	84.2	84	81.1	79.3	79.4	78.2	80.8
14.22	13.69	13.13	12.05	12.77	13.05	13.45	13.77	14.22	15.07	14.81	14.26	14.22	13.05	12.33	12.37	11.89	12.93
		162.45												163.05			
0.2	0.19	0.18	0.17	0.18	0.18	0.19	0.19	0.2	0.21	0.21	0.2	0.2	0.18	0.17	0.17	0.17	0.18

30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
6.00	5.30	5.13	4.85	4.86	5.56	5.99	6.44	6.60	7.18	6.93	6.12	6.00	5.02	4.85	4.85	4.59	5.56

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET - EVAPOTRANSPIRATION CALCULATION

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthwaite and Mather Method

Adjusted PE = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2015 April	2015 May	2015 June	2015 July	2015 August	2015 September	2015 October	2015 November	2015 December	2016 January	2016 February	2016 March	2016 April	2016 May	2016 June	2016 July	2016 August	2016 September
82.9	83	83.6	85.9	86	85.8	84.2	84.2	81.6	79.8	78.7	81.3	82.8	84.3	85.1	85.6	86.1	86
13.77	13.81	14.08	15.02	15.07	14.98	14.26	14.31	13.25	12.53	12.09	13.13	13.73	14.35	14.64	14.9	15.07	15.07
								165.74									
0.19	0.2	0.2	0.21	0.21	0.21	0.2	0.2	0.19	0.18	0.17	0.18	0.2	0.2	0.21	0.21	0.21	0.21

31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6
5.99	6.78	6.60	7.18	6.93	6.43	6.00	5.58	5.42	5.13	4.59	5.56	6.30	6.78	6.93	7.18	6.93	6.43

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET - EVAPOTRANSPIRATION CALCULATION

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthwaite and Mather Method

Adjusted PE = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2016	2016	2016	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2018	2018	2018
October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March
84	81.6	81.7	79.2	80	80	81.6	83.8	84.8	86.1	85.7	86.5	85.4	83.4	80	77.8	80.1	79.7
14.22	13.25	13.29	12.29	12.61	12.61	13.25	14.14	14.56	15.11	14.94	15.28	14.81	13.98	12.61	11.74	12.65	12.49
		166.27												166.19			
0.2	0.19	0.19	0.17	0.18	0.18	0.19	0.2	0.21	0.21	0.21	0.22	0.21	0.2	0.18	0.16	0.18	0.17

30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.73	6.30	5.58	5.13	4.56	4.86	5.25

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET - EVAPOTRANSPIRATION CALCULATION

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthwaite and Mather Method

Adjusted PE = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2018 April	2018 May	2018 June	2018 July	2018 August	2018 September	2018 October	2018 November	2018 December	2019 January	2019 February	2019 March	2019 April	2019 May	2019 June	2019 July	2019 August	2019 September
82.5	82.2	84	85.9	85.6	84.8	83.9	82.7	81.4	79.5	80.4	80.6	82.6	83.8	86	86.2	86.7	86.6
13.61	13.49	14.22	15.02	14.9	14.56	14.18	13.69	13.17	12.41	12.77	12.85	13.65	14.14	15.07	15.15	15.36	15.32
								163.72									
0.19	0.19	0.2	0.21	0.21	0.21	0.2	0.19	0.19	0.17	0.18	0.18	0.19	0.2	0.21	0.21	0.22	0.22

31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6
5.99	6.44	6.60	7.18	6.93	6.43	6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93	7.18	7.26	6.73

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET - EVAPOTRANSPIRATION CALCULATION

By: Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Calculations are done using the Thornthwaite and Mather Method

Adjusted PE = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2019 October	2019 November	2019 December	2020 January	2020 February	2020 March	2020 April	2020 May	2020 June	2020 July	2020 August	2020 September	2020 October	2020 November	2020 December	2021 January	2021 February	2021 March
84.8	82.7	81	79.9	80.6	80.8	82.5	83.8	84.8	85.7	85.4	86	84.7	81.4	81.4	79.7	80.6	80.8
14.56	13.69	13.01	12.57	12.85	12.93	13.61	14.14	14.56	14.94	14.81	15.07	14.52	13.17	13.17	12.49	12.85	12.93
		167.98												166.34			
0.2	0.19	0.18	0.18	0.18	0.18	0.19	0.2	0.21	0.21	0.21	0.21	0.2	0.19	0.19	0.17	0.18	0.18

30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
6.00	5.30	5.13	5.13	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42	4.85	4.86	5.56

2021 April	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October	2021 November	2021 December
82.5	83.8	84.8	85.7	85.4	86	84.7	81.4	81.4
13.61	14.14	14.56	14.94	14.81	15.07	14.52	13.17	13.17
								166.26
0.19	0.2	0.21	0.21	0.21	0.21	0.2	0.19	0.19
31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5
5.99	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUDGET
Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause
Check: R. Razzaghmanesh

17-Apr-24

Wetland Inflow = Q - I - Adjusted PE + E

where:
Infiltration as calculated by Bermes [6]
Exfiltration = 0
Wetland Inflow = Q - Adjusted PE
Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells	
Input	
Calculated	

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

Year Month		2011 January	2011 February	2011 March	2011 April	2011 May	2011 June	2011 July	2011 August	2011 September	2011 October	2011 November	2011 December	2012 January
Initial Water Level	inches	11	-0.38	-0.64	-0.67	-1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.18	0.9	1.42	0.5	3.15	2.94	9.24	2.57	6.26	9.17	9.69	9.69	0.46
Runoff, Q	inches	0.0	0.1	0.1	0.0	0.7	0.6	4.5	0.5	2.4	4.4	4.8	4.8	0.0
Runoff, Q	ac-ft	0	895	2549	179	12650	11110	78810	8588	42364	77894	84755	84755	136
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	78	81	79	78	81	79	83.5	85.9	85	82.5	81.6	80	78.4
Adjusted Potential Evaporation, PE	inches	4.56	4.86	5.25	6.30	6.78	6.60	6.84	6.93	6.43	5.70	5.30	5.13	4.85
Adjusted PE	ac-ft	2362	2518	2721	3264	3513	3419	3544	3590	3329	2953	2746	2658	2510
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.38	-0.26	-0.03	-0.50	1.47	1.24	12.11	0.80	6.28	12.05	13.19	13.21	-0.38
Wetland Inflow	ac-ft	-2362.41	-1622.93	-172.94	-3085.33	9136.97	7691.12	75266.11	4997.98	39035.04	74940.71	82008.30	82096.90	-2373.90
Monthly Deficit/Overflow		Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	-0.38	-0.64	-0.67	-1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-2362	-3985	-4158	-7244	0	0	0	0	0	0	0	0	-2374
Surplus	**inches**	0.00	0.00	0.00	0.00	0.30	1.24	12.11	0.80	6.28	12.05	13.19	13.21	0.00
Surplus	**ac-ft**	-2362	-1622.93	-172.94	-3085.33	1893.36	7691.12	75266.11	4997.98	39035.04	74940.71	82008.30	82096.90	-2373.90

Incursions of the sea into the Central Mangrove Wetlands are not included in the analyses

Volumes in acre-ft are calculated for another perspective on the water budget.

Monthly Average Temperature was obtained from the Cayman Islands National Weather Service

Cayman Islands Government Cayman Islands Government
National Roads Authority National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUD(PROPOSED CONDITIONS - WATER BUDGET
Calculations are done using the Thorntl Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

Year / Month		2012 February	2012 March	2012 April	2012 May	2012 June	2012 July	2012 August	2012 September	2012 October	2012 November	2012 December	2013 January	2013 February
Initial Water Level	inches	0.00	-0.29	0.00	0.00	0.00	0.00	-0.43	0.00	0.00	0.00	-0.37	-0.12	-0.38
Precipitation, P	inches	0.76	1.79	3.23	3.27	0.75	0.97	4.57	2.24	0.87	0.5	1.2	0.6	0.8
Runoff, Q	inches	0.0	0.2	0.8	0.8	0.0	0.1	1.4	0.4	0.0	0.0	0.1	0.0	0.0
Runoff, Q	ac-ft	586	4163	13255	13562	566	1072	24801	6559	824	179	1756	309	668
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	79	79.8	80.4	82	84.3	85.4	84.7	84.6	81.9	79.7	79.7	80	79.5
Adjusted Potential Evaporation, PE	inches	4.59	5.56	5.67	6.44	6.60	7.18	6.60	6.12	5.70	4.74	4.85	5.13	4.59
Adjusted PE	ac-ft	2378	2882	2938	3337	3419	3721	3419	3171	2953	2457	2510	2658	2378
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.29	0.21	1.66	1.64	-0.46	-0.43	3.44	0.55	-0.34	-0.37	-0.12	-0.38	-0.28
Wetland Inflow	ac-ft	-1792.43	1281.55	10317.76	10225.08	-2853.52	-2648.64	21381.67	3388.63	-2129.53	-2278.68	-754.00	-2349.23	-1710.28
Monthly Deficit/Overflow		Deficit	Overflow	Overflow	Overflow	Deficit	Deficit	Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Deficit
Accumulated Deficit	**inches**	-0.29	0.00	0.00	0.00	0.00	-0.43	0.00	0.00	0.00	-0.37	-0.12	-0.38	-0.28
Accumulated Deficit	**ac-ft**	-4166	-2885	0	0	-2854	-5502	0	0	-2130	-4408	-5162	-7511	-9222
Surplus	**inches**	0.00	0.00	1.66	1.64	0.00	0.00	3.01	0.55	0.00	0.00	0.00	0.00	0.00
Surplus	**ac-ft**	-1792.43	1281.55	7432.98	10225.08	-2853.52	-2648.64	15879.50	3388.63	-2129.53	-2278.68	-754.00	-2349.23	-1710.28

Cayman Islands Government Cayman Islands Government
National Roads Authority National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUD(PROPOSED CONDITIONS - WATER BUDGET
Calculations are done using the Thorntl Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

Year Month		2013 March	2013 April	2013 May	2013 June	2013 July	2013 August	2013 September	2013 October	2013 November	2013 December	2014 January	2014 February	2014 March
Initial Water Level	inches	-0.28	-0.36	-0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.7	0.8	5.5	3.3	4.7	7.5	16	2.4	7.8	3.6	6.7	1.1	1.1
Runoff, Q	inches	0.0	0.0	1.9	0.8	1.5	3.2	10.0	0.4	3.4	0.9	2.7	0.1	0.1
Runoff, Q	ac-ft	472	668	34116	13794	26046	56831	175568	7516	60493	16189	47365	1440	1440
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	77.9	82	83	84.3	84.5	84.5	84	84	82.7	81.3	78.6	80.4	81.1
Adjusted Potential Evaporation, PE	inches	5.25	5.99	6.78	6.60	6.84	6.60	6.12	6.00	5.30	5.13	4.85	4.86	5.56
Adjusted PE	ac-ft	2721	3101	3513	3419	3544	3419	3171	3109	2746	2658	2510	2518	2882
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.36	-0.39	4.92	1.67	3.62	8.59	27.73	0.71	9.29	2.18	7.21	-0.17	-0.23
Wetland Inflow	ac-ft	-2249.57	-2433.01	30603.73	10374.46	22502.18	53411.54	172396.97	4407.36	57746.91	13530.86	44855.09	-1077.84	-1441.54
Monthly Deficit/Overflow		Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Overflow	Deficit	Deficit
Accumulated Deficit	**inches**	-0.36	-0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.23
Accumulated Deficit	**ac-ft**	-11471	-13904	0	0	0	0	0	0	0	0	0	-1078	-2519
Surplus	**inches**	0.00	0.00	4.53	1.67	3.62	8.59	27.73	0.71	9.29	2.18	7.21	0.00	0.00
Surplus	**ac-ft**	-2249.57	-2433.01	16699.42	10374.46	22502.18	53411.54	172396.97	4407.36	57746.91	13530.86	44855.09	-1077.84	-1441.54

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUD(
Calculations are done using the Thorntl

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUDGET
Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E

Wetland Inflow = Q - I - Adjusted PE + E

where: Infiltration as c
Exfiltration = 0
Wetland Inflov
Water Level = I

where: Infiltration as calculated by Bermes [6]
Exfiltration = 0
Wetland Inflow = Q - Adjusted PE
Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

	Cells	
Input		
Calculated		
Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

Year Month		2014 April	2014 May	2014 June	2014 July	2014 August	2014 September	2014 October	2014 November	2014 December	2015 January	2015 February	2015 March	2015 April
Initial Water Level	inches	-0.23	-0.31	0.00	0.00	-0.54	-0.12	0.00	0.00	0.00	-0.35	-0.17	-0.38	0.00
Precipitation, P	inches	1	2.1	1.7	0	1.5	2	2.3	0.2	0.6	1.1	0.2	4.1	0.3
Runoff, Q	inches	0.1	0.3	0.2	0.0	0.2	0.3	0.4	0.0	0.0	0.1	0.0	1.2	0.0
Runoff, Q	ac-ft	1153	5766	3739	69	2869	5225	6912	0	309	1440	0	20472	23
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	82.2	82.9	84	86	85.4	84.2	84	81.1	79.3	79.4	78.2	80.8	82.9
Adjusted Potential Evaporation, PE	inches	5.99	6.44	6.60	7.18	6.93	6.12	6.00	5.02	4.85	4.85	4.59	5.56	5.99
Adjusted PE	ac-ft	3101	3337	3419	3721	3590	3171	3109	2602	2510	2510	2378	2882	3101
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.31	0.39	0.05	-0.59	-0.12	0.33	0.61	-0.42	-0.35	-0.17	-0.38	2.83	-0.49
Wetland Inflow	ac-ft	-1948.03	2429.09	320.03	-3651.59	-721.77	2054.71	3803.37	-2601.57	-2201.58	-1070.07	-2377.76	17590.72	-3077.41
Monthly Deficit/Overflow		Deficit	Overflow	Overflow	Deficit	Deficit	Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Overflow	Deficit
Accumulated Deficit	**inches**	-0.31	0.00	0.00	-0.54	-0.12	0.00	0.00	0.00	-0.35	-0.17	-0.38	0.00	0.00
Accumulated Deficit	**ac-ft**	-4467	-2038	-1718	-5370	-6092	-4037	-234	-2835	-5037	-6107	-8485	0	-3077
Surplus	**inches**	0.00	0.08	0.05	0.00	0.00	0.21	0.61	0.00	0.00	0.00	0.00	2.45	0.00
Surplus	**ac-ft**	-1948.03	2429.09	320.03	-3651.59	-721.77	2054.71	3803.37	-2601.57	-2201.58	-1070.07	-2377.76	9106.17	-3077.41

Cayman Islands Government Cayman Islands Government
National Roads Authority National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUD(PROPOSED CONDITIONS - WATER BUDGET
Calculations are done using the Thorntl Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

Year Month		2015 May	2015 June	2015 July	2015 August	2015 September	2015 October	2015 November	2015 December	2016 January	2016 February	2016 March	2016 April	2016 May
Initial Water Level	inches	0.00	0.00	0.00	0.00	-0.55	-0.52	-0.39	0.00	0.00	-0.35	-0.38	0.00	-0.50
Precipitation, P	inches	2.3	4.5	1.1	0.5	0.4	0.8	5.2	0.2	0.7	0.2	1.7	0.5	1.4
Runoff, Q	inches	0.4	1.4	0.1	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.2	0.0	0.1
Runoff, Q	ac-ft	6912	24139	1440	179	83	668	31011	0	472	0	3739	179	2471
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	83	83.6	85.9	86	85.8	84.2	84.2	81.6	79.8	78.7	81.3	82.8	84.3
Adjusted Potential Evaporation, PE	inches	6.78	6.60	7.18	6.93	6.43	6.00	5.58	5.42	5.13	4.59	5.56	6.30	6.78
Adjusted PE	ac-ft	3513	3419	3721	3590	3329	3109	2891	2805	2658	2378	2882	3264	3513
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	0.55	3.33	-0.37	-0.55	-0.52	-0.39	4.52	-0.45	-0.35	-0.38	0.14	-0.50	-0.17
Wetland Inflow	ac-ft	3399.26	20719.65	-2280.83	-3411.73	-3246.05	-2440.78	28120.03	-2805.18	-2185.85	-2377.76	857.80	-3085.33	-1041.45
Monthly Deficit/Overflow		Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Overflow	Deficit	Deficit	Deficit	Overflow	Deficit	Deficit
Accumulated Deficit	**inches**	0.00	0.00	0.00	-0.55	-0.52	-0.39	0.00	0.00	-0.35	-0.38	0.00	-0.50	-0.17
Accumulated Deficit	**ac-ft**	0	0	-2281	-5693	-8939	-11379	0	-2805	-4991	-7369	-6511	-9596	-10638
Surplus	**inches**	0.55	3.33	0.00	0.00	0.00	0.00	4.13	0.00	0.00	0.00	0.00	0.00	0.00
Surplus	**ac-ft**	321.85	20719.65	-2280.83	-3411.73	-3246.05	-2440.78	16740.64	-2805.18	-2185.85	-2377.76	857.80	-3085.33	-1041.45

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Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

Year Month		2016 June	2016 July	2016 August	2016 September	2016 October	2016 November	2016 December	2017 January	2017 February	2017 March	2017 April	2017 May	2017 June
Initial Water Level	inches	-0.17	0.00	0.00	0.00	0.00	0.00	0.00	-0.42	-0.39	-0.38	-0.46	0.00	0.00
Precipitation, P	inches	2.4	2.7	5.3	2.3	7.8	0.9	0.5	0.42	0.5	0.32	3.45	2.22	5.7
Runoff, Q	inches	0.4	0.5	1.8	0.4	3.4	0.1	0.0	0.0	0.0	0.0	0.9	0.4	2.1
Runoff, Q	ac-ft	7516	9446	32036	6912	60493	895	179	99	179	32	14974	6443	36236
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	85.1	85.6	86.1	86	84	81.6	81.7	79.2	80	80	81.6	83.8	84.8
Adjusted Potential Evaporation, PE	inches	6.93	7.18	6.93	6.43	6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93
Adjusted PE	ac-ft	3590	3721	3590	3329	3109	2746	2805	2510	2518	2882	3101	3513	3590
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	0.63	0.92	4.58	0.58	9.23	-0.30	-0.42	-0.39	-0.38	-0.46	1.91	0.47	5.25
Wetland Inflow	ac-ft	3925.54	5724.97	28445.66	3582.67	57384.77	-1851.40	-2626.83	-2410.69	-2339.29	-2849.20	11873.19	2930.83	32645.36
Monthly Deficit/Overflow		Overflow	Overflow	Overflow	Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow
Accumulated Deficit	**inches**	0.00	0.00	0.00	0.00	0.00	0.00	-0.42	-0.39	-0.38	-0.46	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-6712	-987	0	0	0	-1851	-4478	-6889	-9228	-12077	-204	0	0
Surplus	**inches**	0.46	0.92	4.58	0.58	9.23	0.00	0.00	0.00	0.00	0.00	1.45	0.47	5.25
Surplus	**ac-ft**	3925.54	5724.97	28445.66	3582.67	57384.77	-1851.40	-2626.83	-2410.69	-2339.29	-2849.20	11873.19	2930.83	32645.36

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Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

	Cells	
Input		
Calculated		
Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

Year Month		2017 July	2017 August	2017 September	2017 October	2017 November	2017 December	2018 January	2018 February	2018 March	2018 April	2018 May	2018 June	2018 July
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.25	-0.40	-0.44	0.00	0.00	0.00
Precipitation, P	inches	1.11	1.93	2.43	5.77	4	1.13	0.85	0.3	0.13	2.84	11.48	2	1.36
Runoff, Q	inches	0.1	0.3	0.4	2.1	1.1	0.1	0.0	0.0	0.0	0.6	6.2	0.3	0.1
Runoff, Q	ac-ft	1470	4860	7701	36986	19588	1532	777	23	7	10404	109257	5225	2320
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	86.1	85.7	86.5	85.4	83.4	80	77.8	80.1	79.7	82.5	82.2	84	85.9
Adjusted Potential Evaporation, PE	inches	7.18	6.93	6.73	6.30	5.58	5.13	4.56	4.86	5.25	5.99	6.44	6.60	7.18
Adjusted PE	ac-ft	3721	3590	3488	3264	2891	2658	2362	2518	2721	3101	3337	3419	3721
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.36	0.20	0.68	5.42	2.69	-0.18	-0.25	-0.40	-0.44	1.17	17.04	0.29	-0.23
Wetland Inflow	ac-ft	-2250.50	1269.79	4213.25	33722.44	16697.00	-1125.88	-1584.99	-2494.57	-2714.88	7303.60	105919.90	1806.03	-1401.35
Monthly Deficit/Overflow		Deficit	Overflow	Overflow	Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	0.00	0.00	0.00	0.00	0.00	0.00	-0.25	-0.40	-0.44	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-2251	-981	0	0	0	-1126	-2711	-5205	-7920	-617	0	0	-1401
Surplus	**inches**	0.00	0.20	0.68	5.42	2.69	0.00	0.00	0.00	0.00	0.74	17.04	0.29	0.00
Surplus	**ac-ft**	-2250.50	1269.79	4213.25	33722.44	16697.00	-1125.88	-1584.99	-2494.57	-2714.88	7303.60	105919.90	1806.03	-1401.35

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Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

	Cells	
Input		
Calculated		
Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

Year Month		2018 August	2018 September	2018 October	2018 November	2018 December	2019 January	2019 February	2019 March	2019 April	2019 May	2019 June	2019 July	2019 August
Initial Water Level	inches	0.00	0.00	0.00	0.00	0.00	-0.06	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	4.62	7.01	2.5	1.19	1.39	1.4	1.8	1.4	2.6	3.4	1.7	2.5	1.4
Runoff, Q	inches	1.4	2.9	0.5	0.1	0.1	0.1	0.2	0.1	0.5	0.8	0.2	0.5	0.1
Runoff, Q	ac-ft	25277	50979	8140	1723	2433	2471	4211	2471	8783	14577	3739	8140	2471
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	85.6	84.8	83.9	82.7	81.4	79.5	80.4	80.6	82.6	83.8	86	86.2	86.7
Adjusted Potential Evaporation, PE	inches	6.93	6.43	6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93	7.18	7.26
Adjusted PE	ac-ft	3590	3329	3109	2746	2805	2510	2518	2882	3101	3513	3590	3721	3761
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	3.49	7.66	0.81	-0.16	-0.06	-0.01	0.27	-0.07	0.91	1.78	0.02	0.71	-0.21
Wetland Inflow	ac-ft	21687.15	47649.50	5031.36	-1023.12	-372.57	-38.96	1693.52	-410.42	5682.63	11064.04	149.06	4418.99	-1290.13
Monthly Deficit/Overflow		Overflow	Overflow	Overflow	Deficit	Deficit	Deficit	Overflow	Deficit	Overflow	Overflow	Overflow	Overflow	Deficit
Accumulated Deficit	**inches**	0.00	0.00	0.00	0.00	-0.06	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	0	0	0	-1023	-1396	-1435	0	-410	0	0	0	0	-1290
Surplus	**inches**	3.49	7.66	0.81	0.00	0.00	0.00	0.27	0.00	0.91	1.78	0.02	0.71	0.00
Surplus	**ac-ft**	20285.80	47649.50	5031.36	-1023.12	-372.57	-38.96	258.88	-410.42	5272.21	11064.04	149.06	4418.99	-1290.13

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Remington & Vernick Engineers
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Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + EWetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as cwhere: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

	Cells	
Input		
Calculated		
Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

Year Month		2019 September	2019 October	2019 November	2019 December	2020 January	2020 February	2020 March	2020 April	2020 May	2020 June	2020 July	2020 August	2020 September
Initial Water Level	inches	0.00	-0.42	0.00	0.00	-0.16	-0.35	-0.38	-0.46	-0.49	0.00	0.00	0.00	0.00
Precipitation, P	inches	0.9	2.5	1.8	0.5	0.7	0.5	0.1	0.3	1.8	3.1	4.3	8.6	6.6
Runoff, Q	inches	0.1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.3	4.0	2.6
Runoff, Q	ac-ft	895	8140	4211	179	472	179	15	23	4211	12276	22280	70528	46215
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	86.6	84.8	82.7	81	79.9	80.6	80.8	82.5	83.8	84.8	85.7	85.4	86
Adjusted Potential Evaporation, PE	inches	6.73	6.00	5.30	5.13	5.13	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.43
Adjusted PE	ac-ft	3488	3109	2746	2658	2658	2518	2882	3101	3513	3590	3721	3590	3329
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	-0.42	0.81	0.24	-0.40	-0.35	-0.38	-0.46	-0.49	0.11	1.40	2.99	10.77	6.90
Wetland Inflow	ac-ft	-2592.78	5031.36	1465.05	-2479.18	-2185.85	-2339.29	-2866.43	-3077.41	698.80	8686.04	18559.53	66937.57	42885.90
Monthly Deficit/Overflow		Deficit	Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Overflow
Accumulated Deficit	**inches**	-0.42	0.00	0.00	-0.16	-0.35	-0.38	-0.46	-0.49	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	-3883	0	0	-2479	-4665	-7004	-9871	-12948	-12249	-3563	0	0	0
Surplus	**inches**	0.00	0.39	0.24	0.00	0.00	0.00	0.00	0.00	0.00	1.40	2.99	10.77	6.90
Surplus	**ac-ft**	-2592.78	1148.46	1465.05	-2479.18	-2185.85	-2339.29	-2866.43	-3077.41	698.80	8686.04	18559.53	66937.57	42885.90

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Remington & Vernick Engineers
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Check: R. Razzaghmanesh

Wetland Inflow = Q - I - Adjusted PE + E Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c where: Infiltration as calculated by Bermes [6]
Exfiltration = 0 Exfiltration = 0
Wetland Inflov Wetland Inflow = Q - Adjusted PE
Water Level = I Water Level = Initial Water Level - Wetland Inflow

Calculated on Separate Worksheets:
Precipitation, P
Runoff, Q
Adjusted Potential Evaporation, PE

Cells
Input
Calculated

Central Mangrove Wetland Area 6217 Acre
Land Area 11369 Acre

Year Month		2020 October	2020 November	2020 December	2021 January	2021 February	2021 March	2021 April	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October
Initial Water Level	inches	0.00	0.00	0.00	0.00	-0.40	-0.17	-0.36	-0.49	0.00	0.00	0.00	0.00	0.00
Precipitation, P	inches	9.9	16.4	1.1	0.1	1.1	0.8	0.4	2.6	4.6	4.3	11.4	1.2	3.6
Runoff, Q	inches	5.0	10.3	0.1	0.0	0.1	0.0	0.0	0.5	1.4	1.3	6.1	0.1	0.9
Runoff, Q	ac-ft	87561	181661	1440	15	1440	668	83	8783	25087	22280	108136	1756	16189
Infiltration, I	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration, I	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Temp	Deg F	84.7	81.4	81.4	79.7	80.6	80.8	82.5	83.8	84.8	85.7	85.4	86	84.7
Adjusted Potential Evaporation, PE	inches	6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.43	6.00
Adjusted PE	ac-ft	3109	2746	2805	2510	2518	2882	3101	3513	3590	3721	3590	3329	3109
Exfiltration, E	inches	0	0	0	0	0	0	0	0	0	0	0	0	0
Exfiltration, E	ac-ft	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Inflow	inches	13.58	28.78	-0.22	-0.40	-0.17	-0.36	-0.49	0.85	3.46	2.99	16.82	-0.25	2.10
Wetland Inflow	ac-ft	84452.45	178915.01	-1365.38	-2494.97	-1077.84	-2213.86	-3017.58	5270.75	21496.21	18559.53	104545.40	-1573.09	13080.13
Monthly Deficit/Overflow		Overflow	Overflow	Deficit	Deficit	Deficit	Deficit	Deficit	Overflow	Overflow	Overflow	Overflow	Deficit	Overflow
Accumulated Deficit	**inches**	0.00	0.00	0.00	-0.40	-0.17	-0.36	-0.49	0.00	0.00	0.00	0.00	0.00	0.00
Accumulated Deficit	**ac-ft**	0	0	-1365	-3860	-4938	-7152	-10170	-4899	0	0	0	-1573	0
Surplus	**inches**	13.58	28.78	0.00	0.00	0.00	0.00	0.00	0.36	3.46	2.99	16.82	0.00	2.10
Surplus	**ac-ft**	84452.45	178915.01	-1365.38	-2494.97	-1077.84	-2213.86	-3017.58	5270.75	21496.21	18559.53	104545.40	-1573.09	11507.04

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EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - WATER BUD(
Calculations are done using the Thorntl

Wetland Inflow = Q - I - Adjusted PE + E
where: Infiltration as c
Exfiltration = 0
Wetland Inflov
Water Level = I

Year Month		2021 November	2021 December
Initial Water Level	inches	0.00	0.00
Precipitation, P	inches	5.5	0.1
Runoff, Q	inches	1.9	0.0
Runoff, Q	ac-ft	34116	15
Infiltration, I	inches	0	0
Infiltration, I	ac-ft	0	0
Avg Temp	Deg F	81.4	81.4
Adjusted Potential Evaporation, PE	inches	5.30	5.42
Adjusted PE	ac-ft	2746	2805
Exfiltration, E	inches	0	0
Exfiltration, E	ac-ft	0	0
Wetland Inflow	inches	5.05	-0.45
Wetland Inflow	ac-ft	31369.97	-2790.27
Monthly Deficit/Overflow		Overflow	Deficit
Accumulated Deficit	**inches**	0.00	0.00
Accumulated Deficit	**ac-ft**	0	-2790
Surplus	**inches**	5.05	0.00
Surplus	**ac-ft**	31369.97	-2790.27

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Runoff, Q (in)

$$Q=\frac{(P-I_a)^2}{(P-I_a)+S}$$

Where $P>I_a$ and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in
S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and $I_a = 0.2S$

Cells	
Input	
Calculated	

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2011 January	2011 February	2011 March	2011 April	2011 May	2011 June	2011 July	2011 August	2011 September	2011 October	2011 November	2011 December
Precipitation, P	Inches	0.18	0.9	1.42	0.5	3.15	2.94	9.24	2.57	6.26	9.17	9.69	9.69
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.0	0.1	0.1	0.0	0.7	0.6	4.6	0.5	2.5	4.5	4.9	4.9
Volume	ac-ft	0	76	217	15	1081	950	6690	734	3608	6613	7192	7192

Composite Curve Number Calculation		Soil - Curve Numbers [4]											
		Class 1	Class 1 Roadway	Class 2	Class 2 Roadway	Class 3	Class 3 Roadway	Class 4	Class 4 Roadway	Class 5	Class 5 Roadway	Class 6 swamps	Class 6 Roadway
Existing Soil Area	square ft	30755320		38290920		20944681		76310110		58129171		270794034	
Soil Type [4]		1	1	2		3		4		5		6	
Area	square ft	30755320	0	37967320	323600	20944681	0	74539510	1770600	57869771	259400	263997434	6796600
Area	Acre	706.0	0.0	871.6	7.4	480.8	0.0	1711.2	40.6	1328.5	6.0	6060.5	156.0
CN [4]		95	86	85	86	70	86	60	86	45	86	40	86.0
Area * CN	Acre	67074	0	74087	639	33658	0	102672	3496	59783	512	242422	13418
Initial Abstraction Ia [4]		0.05	0.05	0.08	0.08	0.10	0.10	0.15	0.15	0.20	0.20	0.25	0.25
Area * Ia		35.30	0.00	69.73	0.59	48.08	0.00	256.68	6.10	265.70	1.19	1515.14	39.01

Soil Type taken from Memorandum 2 - Hydrology and Hydraulic (H&H) Analysis [4]
Calculations by the U.S. National Resources Conservation Service Part 630 Hydrology National Engineering Handbook [5]

Soil - Curve Numbers [4]			
		Total	Average
Area	Acre	11369	
CN [4]			**52.6**
Area * CN	Acre	597760	
Initial Abstraction Ia [4]			**0.20**
Area * Ia		2238	

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PROPOSED CONDITIONS - RUNOFF
Calculations following the methodo

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PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodology in the US NRCS National Engineering Handbook

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By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Runoff, Q (in) $Q=\frac{(P-I_a}{(P-I_a)}$

Runoff, Q (in) $Q=\frac{(P-I_a)^2}{(P-I_a)+S}$

Where P>I_a and Ia as determined in

Where P>I_a and Ia as determined in Memorandum 2 [4]

P - Monthly Precipitation, in

P - Monthly Precipitation, in

S - Maximum Potential Retention, i

S - Maximum Potential Retention, in [5]

I_a - Initial Abstraction, in [4]

I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Cells	
Input	
Calculated	

Central Mangrove Wetland Area	6217	Acre
Land Area	11369	Acre

	Unit	2012 January	2012 February	2012 March	2012 April	2012 May	2012 June	2012 July	2012 August	2012 September	2012 October	2012 November	2012 December	2013 January
Precipitation, P	Inches	0.46	0.76	1.79	3.23	3.27	0.75	0.97	4.57	2.24	0.87	0.5	1.2	0.6
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.0	0.0	0.2	0.8	0.8	0.0	0.1	1.4	0.4	0.0	0.0	0.1	0.0
Volume	ac-ft	11	49	356	1133	1159	48	91	2116	561	70	15	149	26

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodoCalculations following the methodology in the US NRCS National Engineering Handbook

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Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P-I_a}{(P-I_a)}$ Runoff, Q (in) $Q = \frac{(P-I_a)^2}{(P-I_a)+S}$

Where P>I_a and Ia as determined inWhere P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, iS - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

		0
0		
0		
6217	Acre	0
11369	Acre	0

	Unit	2013 February	2013 March	2013 April	2013 May	2013 June	2013 July	2013 August	2013 September	2013 October	2013 November	2013 December	2014 January	2014 February
Precipitation, P	Inches	0.8	0.7	0.8	5.5	3.3	4.7	7.5	16	2.4	7.8	3.6	6.7	1.1
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.0	0.0	0.0	2.0	0.8	1.5	3.3	10.1	0.4	3.5	0.9	2.8	0.1
Volume	ac-ft	56	40	56	2908	1179	2222	4833	14834	642	5143	1383	4032	122

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodoCalculations following the methodology in the US NRCS National Engineering Handbook

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Runoff, Q (in) $Q=\frac{(P-I_a)^2}{(P-I_a)}$ Runoff, Q (in) $Q=\frac{(P-I_a)^2}{(P-I_a)+S}$

Where P>I_a and Ia as determined inWhere P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, inS - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

0
0
0
Acre 0 Wetland Inflow
Acre 0 Water Level = I

	Unit	2014 March	2014 April	2014 May	2014 June	2014 July	2014 August	2014 September	2014 October	2014 November	2014 December	2015 January	2015 February	2015 March
Precipitation, P	Inches	1.1	1	2.1	1.7	0	1.5	2	2.3	0.2	0.6	1.1	0.2	4.1
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.1	0.1	0.3	0.2	0.0	0.2	0.3	0.4	0.0	0.0	0.1	0.0	1.2
Volume	ac-ft	122	98	493	319	7	245	446	591	0	26	122	0	1748

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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EAST-WEST ARTERIAL WATER BUDGEAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodoCalculations following the methodology in the US NRCS National Engineering Handbook

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Check: R. Razzaghmanesh

Runoff, Q (in) $Q = \frac{(P-I_a)}{(P-I_a)}$ Runoff, Q (in) $$Q = \frac{(P-I_a)^2}{(P-I_a)+S}$$

0
Wetland Inflow = Q - I - Adjusted PE + E
where:

Where P>I_a and Ia as determined in Where P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

0 Inflow = Q - Ad 0
0 ial Water Level 0

	Unit	2015 April	2015 May	2015 June	2015 July	2015 August	2015 September	2015 October	2015 November	2015 December	2016 January	2016 February	2016 March	2016 April
Precipitation, P	Inches	0.3	2.3	4.5	1.1	0.5	0.4	0.8	5.2	0.2	0.7	0.2	1.7	0.5
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.0	0.4	1.4	0.1	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.2	0.0
Volume	ac-ft	2	591	2060	122	15	7	56	2644	0	40	0	319	15

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodo Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
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Check: R. Razzaghmanesh

Runoff, Q (in) $Q=\frac{(P-I_a}{(P-I_a)}$ Runoff, Q (in) $$Q=\frac{(P-I_a)^2}{(P-I_a)+S}$$

0
0
Infiltration as calculated by Bermes [6]

Where P>I_a and Ia as determined in Where P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, in S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

Wetland Inflow = Q - Adjusted PE | 0 | 0
Water Level = Initial Water Level - Wetland Inflow | 0 | 0

	Unit	2016 May	2016 June	2016 July	2016 August	2016 September	2016 October	2016 November	2016 December	2017 January	2017 February	2017 March	2017 April	2017 May
Precipitation, P	Inches	1.4	2.4	2.7	5.3	2.3	7.8	0.9	0.5	0.42	0.5	0.32	3.45	2.22
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.1	0.4	0.6	1.9	0.4	3.5	0.1	0.0	0.0	0.0	0.0	0.9	0.4
Volume	ac-ft	211	642	807	2731	591	5143	76	15	8	15	2	1279	551

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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National Roads Authority | National Roads Authority | By: S. Gause 17-Apr-24
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PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodoCalculations following the methodology in the US NRCS National Engineering Handbook

0

Runoff, Q (in) $Q=\frac{(P-I_a)}{(P-I_a)}$ Runoff, Q (in) $Q=\frac{(P-I_a)^2}{(P-I_a)+S}$

0
0

Where P>I_a and Ia as determined in Where P>I_a and Ia as determined in Memorandum 2 [4] — Calculations for Antecedent Moisture Condition = 2
P - Monthly Precipitation, in — P - Monthly Precipitation, in — and I_a = 0.2S — 0 | 0 | 0
S - Maximum Potential Retention, in S - Maximum Potential Retention, in [5] — 0 | 0 | 0
I_a - Initial Abstraction, in [4] — I_a - Initial Abstraction, in [4]

	Unit	2017 June	2017 July	2017 August	2017 September	2017 October	2017 November	2017 December	2018 January	2018 February	2018 March	2018 April	2018 May	2018 June
Precipitation, P	Inches	5.7	1.11	1.93	2.43	5.77	4	1.13	0.85	0.3	0.13	2.84	11.48	2
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	2.1	0.1	0.3	0.4	2.2	1.1	0.1	0.0	0.0	0.0	0.6	6.3	0.3
Volume	ac-ft	3088	125	415	658	3152	1673	130	66	2	1	889	9258	446

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodoCalculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Runoff, Q (in) $Q=\frac{(P-I_a}{(P-I_a)}$ Runoff, Q (in) $$Q=\frac{(P-I_a)^2}{(P-I_a)+S}$$

Where P>I_a and Ia as determined inWhere P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, inS - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

	0	
0		
0		
0	0	Adjusted Poter
0	0	0

	Unit	2018 July	2018 August	2018 September	2018 October	2018 November	2018 December	2019 January	2019 February	2019 March	2019 April	2019 May	2019 June	2019 July
Precipitation, P	Inches	1.36	4.62	7.01	2.5	1.19	1.39	1.4	1.8	1.4	2.6	3.4	1.7	2.5
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.1	1.5	3.0	0.5	0.1	0.1	0.1	0.2	0.1	0.5	0.8	0.2	0.5
Volume	ac-ft	198	2157	4338	696	147	207	211	360	211	751	1245	319	696

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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PROPOSED CONDITIONS - RUNOFF PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodoCalculations following the methodology in the US NRCS National Engineering Handbook

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By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Runoff, Q (in) $Q=\frac{(P-I_a}{(P-I_a)}$ Runoff, Q (in) $$Q=\frac{(P-I_a)^2}{(P-I_a)+S}$$

Where P>I_a and Ia as determined in Where P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in P - Monthly Precipitation, in
S - Maximum Potential Retention, i S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4] I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

0
0
0
0 Potential Evapo 0
0 0 0

	Unit	2019 August	2019 September	2019 October	2019 November	2019 December	2020 January	2020 February	2020 March	2020 April	2020 May	2020 June	2020 July	2020 August
Precipitation, P	Inches	1.4	0.9	2.5	1.8	0.5	0.7	0.5	0.1	0.3	1.8	3.1	4.3	8.6
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	0.1	0.1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.3	4.1
Volume	ac-ft	211	76	696	360	15	40	15	2	2	360	1049	1902	5991

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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PROPOSED CONDITIONS - RUNOFF
Calculations following the methodo

Cayman Islands Government
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EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - RUNOFF CALCULATION
Calculations following the methodology in the US NRCS National Engineering Handbook

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Runoff, Q (in) $Q=\frac{(P-I_a}{(P-I_a)}$

Runoff, Q (in) $Q=\frac{(P-I_a)^2}{(P-I_a)+S}$

Where P>I_a and Ia as determined in
P - Monthly Precipitation, in
S - Maximum Potential Retention, in
I_a - Initial Abstraction, in [4]

Where P>I_a and Ia as determined in Memorandum 2 [4]
P - Monthly Precipitation, in
S - Maximum Potential Retention, in [5]
I_a - Initial Abstraction, in [4]

Calculations for Antecedent Moisture Condition = 2
and I_a = 0.2S

0
Calculated on Separate Worksheets:
Precipitation, P
Adjusted Potential Evaporation, PE 0 0
0 0 0

	Unit	2020 September	2020 October	2020 November	2020 December	2021 January	2021 February	2021 March	2021 April	2021 May	2021 June	2021 July	2021 August	2021 September
Precipitation, P	Inches	6.6	9.9	16.4	1.1	0.1	1.1	0.8	0.4	2.6	4.6	4.3	11.4	1.2
Runoff Curve Number, CN		52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6
S	Inches	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Q	Inches	2.7	5.1	10.5	0.1	0.0	0.1	0.0	0.0	0.5	1.5	1.3	6.3	0.1
Volume	ac-ft	3934	7429	15345	122	2	122	56	7	751	2141	1902	9163	149

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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EAST-WEST ARTERIAL WATER BUDG
PROPOSED CONDITIONS - RUNOFF
Calculations following the methodo

Runoff, Q (in) $$Q=\frac{(P-I_a}{(P-I_a)}$$

Where $P>I_a$ and Ia as determined in
P - Monthly Precipitation, in
S - Maximum Potential Retention, in
I_a - Initial Abstraction, in [4]

	Unit	2021 October	2021 November	2021 December
Precipitation, P	Inches	3.6	5.5	0.1
Runoff Curve Number, CN		52.6	52.6	52.6
S	Inches	8.9	8.9	8.9
Q	Inches	0.9	2.0	0.0
Volume	ac-ft	1383	2908	2

Composite Curve Number Calculation	
Existing Soil Area	square ft
Soil Type [4]	
Area	square ft
Area	Acre
CN [4]	
Area * CN	Acre
Initial Abstraction Ia [4]	
Area * Ia	

Soil Type taken from Memorandum
Calculations by the U.S. National Re

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EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - EVAPOTRANSPIRATION CALCULATION
Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

	Units	2011 January	2011 February	2011 March	2011 April	2011 May	2011 June	2011 July	2011 August	2011 September	2011 October	2011 November	2011 December	2012 January	2012 February	2012 March
Avg Temp (^{O}F)	^{O}F	78	81	79	83.5	83.2	84.7	84.5	85.9	85	82.5	81.6	80	78.4	79	79.8
Heat Index, I		11.82	13.01	12.21	14.02	13.89	14.52	14.43	15.02	14.64	13.61	13.25	12.61	11.97	12.21	12.53
1 Year Heat Index Sum													163.03			
Unadjusted Daily PET (in)	inches	0.16	0.18	0.17	0.2	0.2	0.2	0.2	0.21	0.21	0.19	0.19	0.18	0.17	0.17	0.18
Lattitude 19.3^{O}																
Mean Possible Duration of Sunlight in Units of 12 Hours	twelve hours	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
Adjusted Potential Evapotranspiration, PET (in)	inches	4.56	4.86	5.25	6.30	6.78	6.60	6.84	6.93	6.43	5.70	5.30	5.13	4.85	4.59	5.56

Cayman Islands Government
National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - EVAPOTRANSPIRATION CALCULATION
Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2012 April	2012 May	2012 June	2012 July	2012 August	2012 September	2012 October	2012 November	2012 December	2013 January	2013 February	2013 March	2013 April	2013 May	2013 June	2013 July	2013 August	2013 September
80.4	82	84.3	85.4	84.7	84.6	81.9	79.7	79.7	80	79.5	77.9	82	83	84.3	84.5	84.5	84
12.77	13.41	14.35	14.81	14.52	14.47	13.37	12.49	12.49	12.61	12.41	11.78	13.41	13.81	14.31	14.43	14.43	14.22
								159.39									
0.18	0.19	0.2	0.21	0.2	0.2	0.19	0.17	0.17	0.18	0.17	0.17	0.19	0.2	0.2	0.2	0.2	0.2

31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6
5.67	6.44	6.60	7.18	6.60	6.12	5.70	4.74	4.85	5.13	4.59	5.25	5.99	6.78	6.60	6.84	6.60	6.12

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Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2013 October	2013 November	2013 December	2014 January	2014 February	2014 March	2014 April	2014 May	2014 June	2014 July	2014 August	2014 September	2014 October	2014 November	2014 December	2015 January	2015 February	2015 March
84	82.7	81.3	78.6	80.4	81.1	82.2	82.9	84	86	85.4	84.2	84	81.1	79.3	79.4	78.2	80.8
14.22	13.69	13.13	12.05	12.77	13.05	13.45	13.77	14.22	15.07	14.81	14.26	14.22	13.05	12.33	12.37	11.89	12.93
		162.45												163.05			
0.2	0.19	0.18	0.17	0.18	0.18	0.19	0.19	0.2	0.21	0.21	0.2	0.2	0.18	0.17	0.17	0.17	0.18

30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
6.00	5.30	5.13	4.85	4.86	5.56	5.99	6.44	6.60	7.18	6.93	6.12	6.00	5.02	4.85	4.85	4.59	5.56

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Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2015 April	2015 May	2015 June	2015 July	2015 August	2015 September	2015 October	2015 November	2015 December	2016 January	2016 February	2016 March	2016 April	2016 May	2016 June	2016 July	2016 August	2016 September
82.9	83	83.6	85.9	86	85.8	84.2	84.2	81.6	79.8	78.7	81.3	82.8	84.3	85.1	85.6	86.1	86
13.77	13.81	14.08	15.02	15.07	14.98	14.26	14.31	13.25	12.53	12.09	13.13	13.73	14.35	14.64	14.9	15.07	15.07
								165.74									
0.19	0.2	0.2	0.21	0.21	0.21	0.2	0.2	0.19	0.18	0.17	0.18	0.2	0.2	0.21	0.21	0.21	0.21

31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6
5.99	6.78	6.60	7.18	6.93	6.43	6.00	5.58	5.42	5.13	4.59	5.56	6.30	6.78	6.93	7.18	6.93	6.43

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Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2016 October	2016 November	2016 December	2017 January	2017 February	2017 March	2017 April	2017 May	2017 June	2017 July	2017 August	2017 September	2017 October	2017 November	2017 December	2018 January	2018 February	2018 March
84	81.6	81.7	79.2	80	80	81.6	83.8	84.8	86.1	85.7	86.5	85.4	83.4	80	77.8	80.1	79.7
14.22	13.25	13.29	12.29	12.61	12.61	13.25	14.14	14.56	15.11	14.94	15.28	14.81	13.98	12.61	11.74	12.65	12.49
		166.27												166.19			
0.2	0.19	0.19	0.17	0.18	0.18	0.19	0.2	0.21	0.21	0.21	0.22	0.21	0.2	0.18	0.16	0.18	0.17

30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.73	6.30	5.58	5.13	4.56	4.86	5.25

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Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to 80^{O}F [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2018	2018	2018	2018	2018	2018	2018	2018	2018	2019	2019	2019	2019	2019	2019	2019	2019	2019
April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September
82.5	82.2	84	85.9	85.6	84.8	83.9	82.7	81.4	79.5	80.4	80.6	82.6	83.8	86	86.2	86.7	86.6
13.61	13.49	14.22	15.02	14.9	14.56	14.18	13.69	13.17	12.41	12.77	12.85	13.65	14.14	15.07	15.15	15.36	15.32
								163.72									
0.19	0.19	0.2	0.21	0.21	0.21	0.2	0.19	0.19	0.17	0.18	0.18	0.19	0.2	0.21	0.21	0.22	0.22

31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6
5.99	6.44	6.60	7.18	6.93	6.43	6.00	5.30	5.42	4.85	4.86	5.56	5.99	6.78	6.93	7.18	7.26	6.73

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National Roads Authority
EAST-WEST ARTERIAL WATER BUDGET
PROPOSED CONDITIONS - EVAPOTRANSPIRATION CALCULATION
Calculations are done using the Thornthwaite and Mather Method

Remington & Vernick Engineers
By: S. Gause 17-Apr-24
Check: R. Razzaghmanesh

Adjusted PET = Unadjusted Daily PET * Mean Possible Duration of Sunlight in Units of 12 Hours

where: Heat Index, I, Table 1 [3]
Unadjusted Daily PET, inches, Table 3 or Table 5 when the Average Temperature, T, is greater than or equal to $80^{O}F$ [3]
Where the 1 Year Heat Index Summation exceeds the maximum in Table 3, the maximum value of Unadjusted Daily PET was utilized in Table 3
Mean Possible Duration of Sunlight in Units of 12 Hours, Table 6 [3]

2019 October	2019 November	2019 December	2020 January	2020 February	2020 March	2020 April	2020 May	2020 June	2020 July	2020 August	2020 September	2020 October	2020 November	2020 December	2021 January	2021 February	2021 March
84.8	82.7	81	79.9	80.6	80.8	82.5	83.8	84.8	85.7	85.4	86	84.7	81.4	81.4	79.7	80.6	80.8
14.56	13.69	13.01	12.57	12.85	12.93	13.61	14.14	14.56	14.94	14.81	15.07	14.52	13.17	13.17	12.49	12.85	12.93
		167.98												166.34			
0.2	0.19	0.18	0.18	0.18	0.18	0.19	0.2	0.21	0.21	0.21	0.21	0.2	0.19	0.19	0.17	0.18	0.18

30.0	27.9	28.5	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5	28.5	27.0	30.9
6.00	5.30	5.13	5.13	4.86	5.56	5.99	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42	4.85	4.86	5.56

2021 April	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October	2021 November	2021 December
82.5	83.8	84.8	85.7	85.4	86	84.7	81.4	81.4
13.61	14.14	14.56	14.94	14.81	15.07	14.52	13.17	13.17
								166.26
0.19	0.2	0.21	0.21	0.21	0.21	0.2	0.19	0.19
31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5
5.99	6.78	6.93	7.18	6.93	6.43	6.00	5.30	5.42

Heat Index

TABLE 1

MONTHLY VALUES OF i CORRESPONDING TO MONTHLY MEAN TEMPERATURES (°F)

T°F	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
32	.00	.00	.00	.01	.01	.01	.02	.02	.03	.03
33	.04	.04	.05	.05	.06	.06	.07	.08	.09	.09
34	.10	.10	.11	.12	.13	.14	.15	.16	.17	.18
35	.19	.20	.21	.22	.23	.24	.25	.26	.27	.28
36	.29	.30	.32	.33	.34	.35	.36	.37	.39	.40
37	.41	.42	.43	.44	.46	.47	.48	.50	.51	.52
38	.54	.55	.56	.58	.59	.60	.62	.63	.65	.66
39	.68	.70	.71	.73	.74	.76	.77	.79	.80	.82
40	.83	.85	.86	.88	.90	.91	.93	.95	.96	.98
41	1.00	1.01	1.03	1.05	1.07	1.08	1.10	1.12	1.14	1.16
42	1.17	1.19	1.21	1.23	1.24	1.26	1.28	1.30	1.32	1.33
43	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.50	1.52
44	1.54	1.56	1.58	1.60	1.62	1.64	1.66	1.68	1.70	1.72
45	1.74	1.76	1.78	1.80	1.82	1.85	1.87	1.89	1.91	1.93
46	1.95	1.97	2.00	2.02	2.04	2.06	2.08	2.10	2.13	2.15
47	2.17	2.19	2.21	2.23	2.26	2.28	2.30	2.32	2.34	2.37
48	2.39	2.41	2.43	2.46	2.48	2.50	2.53	2.55	2.57	2.60
49	2.62	2.64	2.67	2.69	2.71	2.74	2.76	2.79	2.81	2.84
50	2.86	2.89	2.91	2.93	2.96	2.98	3.01	3.03	3.06	3.08
51	3.11	3.13	3.16	3.18	3.21	3.23	3.25	3.28	3.30	3.33
52	3.35	3.38	3.40	3.43	3.45	3.48	3.50	3.53	3.55	3.58
53	3.60	3.63	3.65	3.68	3.71	3.73	3.76	3.79	3.81	3.84
54	3.87	3.89	3.92	3.95	3.97	4.00	4.03	4.06	4.08	4.11
55	4.14	4.16	4.19	4.22	4.25	4.27	4.30	4.33	4.35	4.38
56	4.41	4.44	4.47	4.50	4.52	4.55	4.57	4.60	4.63	4.66
57	4.69	4.72	4.75	4.77	4.80	4.83	4.86	4.89	4.92	4.95
58	4.98	5.01	5.04	5.07	5.10	5.13	5.16	5.19	5.22	5.25
59	5.28	5.31	5.34	5.37	5.40	5.43	5.46	5.49	5.52	5.55
60	5.58	5.61	5.64	5.67	5.70	5.73	5.76	5.79	5.82	5.85
61	5.88	5.91	5.94	5.97	6.00	6.03	6.06	6.10	6.13	6.16
62	6.19	6.22	6.25	6.28	6.31	6.34	6.38	6.41	6.44	6.47
63	6.50	6.53	6.56	6.59	6.62	6.66	6.69	6.72	6.75	6.79
64	6.82	6.85	6.88	6.92	6.95	6.98	7.02	7.05	7.08	7.12
65	7.15	7.18	7.22	7.25	7.28	7.32	7.35	7.38	7.42	7.45
66	7.48	7.52	7.55	7.58	7.62	7.65	7.68	7.72	7.75	7.78
67	7.82	7.85	7.89	7.92	7.95	7.99	8.02	8.05	8.09	8.12
68	8.16	8.19	8.23	8.26	8.30	8.33	8.37	8.40	8.44	8.47
69	8.51	8.54	8.57	8.61	8.64	8.68	8.71	8.75	8.78	8.82
70	8.85	8.89	8.92	8.96	8.99	9.03	9.06	9.10	9.13	9.17
71	9.20	9.24	9.27	9.31	9.34	9.38	9.42	9.45	9.49	9.53
72	9.57	9.60	9.64	9.67	9.71	9.75	9.78	9.82	9.85	9.89
73	9.93	9.97	10.01	10.04	10.08	10.12	10.15	10.19	10.22	10.26
74	10.30	10.34	10.37	10.41	10.45	10.48	10.52	10.56	10.60	10.64
75	10.67	10.71	10.75	10.78	10.82	10.86	10.89	10.93	10.97	11.01
76	11.05	11.09	11.13	11.17	11.20	11.24	11.28	11.31	11.35	11.39

MONTHLY VALUES OF i CORRESPONDING TO MONTHLY MEAN TEMPERATURES (°F)
(CONTINUED)

T°F	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
77	11.43	11.47	11.51	11.54	11.58	11.62	11.66	11.70	11.74	11.78
78	11.82	11.85	11.89	11.93	11.97	12.01	12.05	12.09	12.13	12.17
79	12.21	12.25	12.29	12.33	12.37	12.41	12.45	12.49	12.53	12.57
80	12.61	12.65	12.69	12.73	12.77	12.81	12.85	12.89	12.93	12.97
81	13.01	13.05	13.09	13.13	13.17	13.21	13.25	13.29	13.33	13.37
82	13.41	13.45	13.49	13.53	13.57	13.61	13.65	13.69	13.73	13.77
83	13.81	13.85	13.89	13.94	13.98	14.02	14.06	14.10	14.14	14.18
84	14.22	14.26	14.31	14.35	14.39	14.43	14.47	14.52	14.56	14.60
85	14.64	14.69	14.73	14.77	14.81	14.85	14.90	14.94	14.98	15.02
86	15.07	15.11	15.15	15.19	15.23	15.28	15.32	15.36	15.40	15.45
87	15.49	15.53	15.58	15.62	15.66	15.71	15.75	15.79	15.84	15.88
88	15.92	15.97	16.01	16.05	16.10	16.14	16.18	16.23	16.27	16.31
89	16.36	16.40	16.44	16.49	16.53	16.57	16.62	16.66	16.70	16.75
90	16.79	16.83	16.88	16.92	16.96	17.01	17.05	17.09	17.14	17.18
91	17.23	17.27	17.32	17.36	17.41	17.45	17.49	17.54	17.58	17.63
92	17.67	17.72	17.76	17.81	17.85	17.89	17.94	17.98	18.03	18.07
93	18.12	18.16	18.21	18.25	18.30	18.34	18.39	18.43	18.48	18.52
94	18.57	18.62	18.66	18.71	18.75	18.80	18.84	18.89	18.93	18.98
95	19.03	19.07	19.12	19.16	19.21	19.25	19.30	19.34	19.39	19.44
96	19.48	19.53	19.58	19.62	19.67	19.71	19.76	19.81	19.86	19.90
97	19.95	20.00	20.04	20.09	20.14	20.18	20.23	20.28	20.32	20.37
98	20.42	20.46	20.51	20.56	20.60	20.65	20.70	20.74	20.79	20.84
99	20.88	20.93	20.98	21.03	21.08	21.13	21.17	21.22	21.27	21.32
100	21.36	21.41	21.46	21.51	21.56	21.60	21.65	21.70	21.75	21.79
101	21.84	21.89	21.94	21.99	22.03	22.08	22.13	22.18	22.23	22.28
102	22.33	22.38	22.42	22.47	22.52	22.57	22.62	22.67	22.71	22.76
103	22.81	22.86	22.91	22.96	23.00	23.05	23.10	23.15	23.20	23.25
104	23.30									

Yearly sum of monthly I values

TABLE 3

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (IN.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

T°F	I 25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5	50.0	52.5
32.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.5	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.0	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00
34.5	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00
35.0	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
35.5	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
36.0	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01
36.5	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01
37.0	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01
37.5	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01
38.0	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01
38.5	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
39.0	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02
39.5	.04	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
40.0	.04	.04	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02
40.5	.04	.04	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
41.0	.04	.04	.04	.03	.03	.03	.03	.03	.02	.02	.02	.02
41.5	.04	.04	.04	.04	.03	.03	.03	.03	.03	.02	.02	.02
42.0	.04	.04	.04	.04	.04	.03	.03	.03	.03	.02	.02	.02
42.5	.05	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.02
43.0	.05	.05	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
43.5	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03
44.0	.05	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03	.03
44.5	.06	.05	.05	.04	.04	.04	.04	.04	.04	.04	.03	.03
45.0	.06	.06	.05	.05	.04	.04	.04	.04	.04	.04	.04	.03
45.5	.06	.06	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04
46.0	.06	.06	.06	.05	.05	.05	.04	.04	.04	.04	.04	.04
46.5	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04	.04	.04
47.0	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04	.04
47.5	.06	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04
48.0	.07	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05	.04
48.5	.07	.07	.06	.06	.06	.06	.06	.05	.05	.05	.05	.04
49.0	.07	.07	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05
49.5	.07	.07	.07	.06	.06	.06	.06	.06	.06	.05	.05	.05
50.0	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06	.05	.05
50.5	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06	.05
51.0	.08	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
51.5	.08	.08	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
52.0	.08	.08	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
52.5	.08	.08	.08	.07	.07	.07	.07	.07	.06	.06	.06	.06
53.0	.09	.08	.08	.07	.07	.07	.07	.07	.07	.06	.06	.06
53.5	.09	.09	.08	.08	.07	.07	.07	.07	.07	.07	.07	.06
54.0	.09	.09	.08	.08	.08	.07	.07	.07	.07	.07	.07	.06
54.5	.09	.09	.09	.08	.08	.08	.07	.07	.07	.07	.07	.07
55.0	.09	.09	.09	.08	.08	.08	.08	.07	.07	.07	.07	.07
55.5	.09	.09	.09	.09	.08	.08	.08	.08	.07	.07	.07	.07
56.0	.09	.09	.09	.09	.09	.08	.08	.08	.08	.07	.07	.07
56.5	.10	.09	.09	.09	.09	.09	.08	.08	.08	.08	.08	.07
57.0	.10	.10	.09	.09	.09	.09	.09	.08	.08	.08	.08	.07
57.5	.10	.10	.09	.09	.09	.09	.09	.09	.09	.08	.08	.08
58.0	.10	.10	.10	.09	.09	.09	.09	.09	.09	.08	.08	.08
58.5	.11	.10	.10	.10	.09	.09	.09	.09	.09	.09	.09	.08
59.0	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09	.08
59.5	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09
60.0	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09
60.5	.11	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09
61.0	.11	.11	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09
61.5	.12	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10	.09
62.0	.12	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10
62.5	.12	.12	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10
63.0	.12	.12	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10
63.5	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11	.11	.10
64.0	.13	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11	.11
64.5	.13	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11
65.0	.13	.13	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11
65.5	.13	.13	.13	.12	.12	.12	.12	.12	.12	.11	.11	.11
66.0	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12	.12	.11
66.5	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12	.12
67.0	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12
67.5	.14	.13	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12
68.0	.14	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13	.12
68.5	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13
69.0	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13
69.5	.15	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13	.13
70.0	.15	.14	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13
70.5	.15	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14	.13
71.0	.15	.15	.15	.15	.14	.14	.14	.14	.14	.14	.14	.14
71.5	.15	.15	.15	.15	.15	.15	.14	.14	.14	.14	.14	.14
72.0	.15	.15	.15	.15	.15	.15	.15	.15	.14	.14	.14	.14
72.5	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.14
73.0	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
73.5	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
74.0	.16	.16	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15
74.5	.16	.16	.16	.16	.16	.16	.15	.15	.15	.15	.15	.15
75.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.15
75.5	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
76.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
76.5	.17	.17	.17	.17	.17	.17	.17	.16	.16	.16	.16	.16
77.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
77.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
78.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
78.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.0	.18	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.5	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18
80.0	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18

T°F	115.0	117.5	120.0	122.5	125.0	127.5	130.0	132.5	135.0	137.5	140.0
32.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
36.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
36.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
37.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
37.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
38.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
38.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
39.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
39.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
40.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
40.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
41.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
41.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
43.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
43.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
44.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
44.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.0	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.5	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
46.0	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00
46.5	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00
47.0	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00
47.5	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00
48.0	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00
48.5	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00
49.0	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
49.5	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
50.0	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
50.5	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01
51.0	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01
51.5	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01
52.0	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01
52.5	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01
53.0	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01
53.5	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01
54.0	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01
54.5	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
55.0	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
55.5	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02

Yearly sum of monthly I values

T°F	115.0	117.5	120.0	122.5	125.0	127.5	130.0	132.5	135.0	137.5	140.0
56.0	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
56.5	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
57.0	.03	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02
57.5	.03	.03	.03	.03	.03	.03	.03	.03	.02	.02	.02
58.0	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02	.02
58.5	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02
59.0	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
59.5	.04	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03
60.0	.05	.04	.04	.04	.04	.04	.04	.04	.04	.03	.03
60.5	.05	.04	.04	.04	.04	.04	.04	.04	.04	.04	.03
61.0	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04	.04
61.5	.06	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04
62.0	.06	.05	.05	.05	.05	.05	.05	.04	.04	.04	.04
62.5	.06	.06	.05	.05	.05	.05	.05	.05	.04	.04	.04
63.0	.06	.06	.06	.05	.05	.05	.05	.05	.05	.05	.04
63.5	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05
64.0	.07	.06	.06	.06	.06	.06	.06	.06	.05	.05	.05
64.5	.07	.06	.06	.06	.06	.06	.06	.06	.06	.06	.05
65.0	.07	.07	.06	.06	.06	.06	.06	.06	.06	.06	.06
65.5	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
66.0	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
66.5	.08	.07	.07	.07	.07	.07	.07	.07	.07	.07	.06
67.0	.08	.08	.07	.07	.07	.07	.07	.07	.07	.07	.06
67.5	.09	.08	.08	.08	.08	.08	.07	.07	.07	.07	.07
68.0	.09	.08	.08	.08	.08	.08	.08	.07	.07	.07	.07
68.5	.09	.09	.08	.08	.08	.08	.08	.08	.08	.08	.07
69.0	.09	.09	.09	.09	.09	.09	.09	.08	.08	.08	.08
69.5	.10	.09	.09	.09	.09	.09	.09	.09	.09	.09	.08
70.0	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09	.09
70.5	.11	.10	.10	.10	.10	.10	.10	.10	.09	.09	.09
71.0	.11	.10	.10	.10	.10	.10	.10	.10	.10	.09	.09
71.5	.11	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10
72.0	.12	.11	.11	.11	.11	.11	.11	.11	.11	.10	.10
72.5	.12	.11	.11	.11	.11	.11	.11	.11	.11	.11	.11
73.0	.13	.12	.12	.12	.12	.12	.12	.12	.11	.11	.11
73.5	.13	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12
74.0	.13	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12
74.5	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
75.0	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
75.5	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
76.0	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
76.5	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
77.0	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
77.5	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
78.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
78.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
80.0	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18

TABLE 5

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION
FOR MEAN TEMPERATURES ABOVE 80°F OR 26.5°C

UNADJUSTED POTENTIAL EVAPOTRANSPIRATION IN MM

T°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
26						4.5	4.5	4.6	4.6	4.6
27	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.9	4.9
28	4.9	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.2
29	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.4	5.4
30	5.4	5.4	5.4	5.5	5.5	5.5	5.5	5.6	5.6	5.6
31	5.6	5.6	5.6	5.6	5.7	5.7	5.7	5.7	5.7	5.8
32	5.8	5.8	5.8	5.8	5.8	5.8	5.9	5.9	5.9	5.9
33	5.9	5.9	5.9	5.9	6.0	6.0	6.0	6.0	6.0	6.0
34	6.0	6.0	6.0	6.0	6.1	6.1	6.1	6.1	6.1	6.1
35	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
36	6.1	6.1	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
37	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
38	6.2									

UNADJUSTED POTENTIAL EVAPOTRANSPIRATION IN INCHES

T°F	0.0	0.5	T°F	0.0	0.5	T°F	0.0	0.5
80	.18	.18	87	.22	.22	94	.24	.24
81	.18	.19	88	.22	.22	95	.24	.24
82	.19	.19	89	.22	.23	96	.24	.24
83	.20	.20	90	.23	.23	97	.24	.24
84	.20	.20	91	.23	.23	98	.24	.24
85	.21	.21	92	.23	.24	99	.24	.24
86	.21	.22	93	.24	.24	100	.24	

SECTION III

To change the unadjusted daily values of potential evapotranspiration obtained from tables 3-5 into adjusted monthly potential evapotranspiration multiply by a factor giving the duration of sunlight for the particular month and latitude of the station whose record is being evaluated expressed in terms of a 12-hour day (table 6-7). Use the latitude nearest that of the station being considered.

To change the unadjusted daily values of potential evapotranspiration obtained from tables 3-5 into adjusted daily potential evapotranspiration multiply by a factor giving the duration of sunlight for the particular day and latitude of the station whose record is being evaluated expressed in terms of a standard 12-hour day (table 8). Select the table for the latitude nearest that of the station being considered.

Poleward from 50° use the duration of sunlight factors for 50°.

A table to convert from northern to southern latitudes is found on page 241 (table 9).

TABLE 6

MEAN POSSIBLE MONTHLY DURATION OF SUNLIGHT IN THE NORTHERN HEMISPHERE
EXPRESSED IN UNITS OF 12 HOURS

NORTHERN LATITUDES	J	F	M	A	M	J	J	A	S	O	N	D
0°	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	30.3	31.2
1	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	30.3	31.2
2	31.2	28.2	31.2	30.3	31.5	30.6	31.2	31.2	30.3	31.2	30.0	30.9
3	30.9	28.2	30.9	30.3	31.5	30.6	31.5	31.2	30.3	31.2	30.0	30.9
4	30.9	27.9	30.9	30.6	31.8	30.9	31.5	31.5	30.3	30.9	30.0	30.6
5	30.6	27.9	30.9	30.6	31.8	30.9	31.8	31.5	30.3	30.9	29.7	30.6
6	30.6	27.9	30.9	30.6	31.8	31.2	31.8	31.5	30.3	30.9	29.7	30.3
7	30.3	27.6	30.9	30.6	32.1	31.2	32.1	31.8	30.3	30.9	29.7	30.3
8	30.3	27.6	30.9	30.9	32.1	31.5	32.1	31.8	30.6	30.6	29.4	30.0
9	30.0	27.6	30.9	30.9	32.4	31.5	32.4	31.8	30.6	30.6	29.4	30.0
10	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7
11	29.7	27.3	30.9	30.9	32.7	31.8	32.7	32.1	30.6	30.6	29.1	29.7
12	29.7	27.3	30.9	31.2	32.7	32.1	33.0	32.1	30.6	30.3	29.1	29.4
13	29.4	27.3	30.9	31.2	33.0	32.1	33.0	32.4	30.6	30.3	28.8	29.4
14	29.4	27.3	30.9	31.2	33.0	32.4	33.3	32.4	30.6	30.3	28.8	29.1
15	29.1	27.3	30.9	31.2	33.3	32.4	33.6	32.4	30.6	30.3	28.5	29.1
16	29.1	27.3	30.9	31.2	33.3	32.7	33.6	32.7	30.6	30.3	28.5	28.8
17	28.8	27.3	30.9	31.5	33.6	32.7	33.9	32.7	30.6	30.0	28.2	28.8
18	28.8	27.0	30.9	31.5	33.6	33.0	33.9	33.0	30.6	30.0	28.2	28.5
19	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5
20	28.5	27.0	30.9	31.5	33.9	33.3	34.2	33.3	30.6	30.0	27.9	28.2
21	28.2	27.0	30.9	31.5	33.9	33.3	34.5	33.3	30.6	30.0	27.6	28.2
22	28.2	26.7	30.9	31.8	34.2	33.6	34.5	33.3	30.6	29.7	27.6	27.9
23	27.9	26.7	30.9	31.8	34.2	33.9	34.8	33.6	30.6	29.7	27.6	27.6
24	27.9	26.7	30.9	31.8	34.5	34.2	34.8	33.6	30.6	29.7	27.3	27.6
25	27.9	26.7	30.9	31.8	34.5	34.2	35.1	33.6	30.6	29.7	27.3	27.3
26	27.6	26.4	30.9	32.1	34.8	34.5	35.1	33.6	30.6	29.7	27.3	27.3
27	27.6	26.4	30.9	32.1	34.8	34.5	35.4	33.9	30.6	29.7	27.0	27.0
28	27.3	26.4	30.9	32.1	35.1	34.8	35.4	33.9	30.9	29.4	27.0	27.0
29	27.3	26.1	30.9	32.1	35.1	34.8	35.7	33.9	30.9	29.4	26.7	26.7
30	27.0	26.1	30.9	32.4	35.4	35.1	36.0	34.2	30.9	29.4	26.7	26.4
31	27.0	26.1	30.9	32.4	35.4	35.1	36.0	34.2	30.9	29.4	26.4	26.4
32	26.7	25.8	30.9	32.4	35.7	35.4	36.3	34.5	30.9	29.4	26.4	26.1
33	26.4	25.8	30.9	32.7	35.7	35.7	36.3	34.5	30.9	29.1	26.1	25.8
34	26.4	25.8	30.9	32.7	36.0	36.0	36.6	34.8	30.9	29.1	26.1	25.8
35	26.1	25.5	30.9	32.7	36.3	36.3	36.9	34.8	30.9	29.1	25.8	25.5
36	26.1	25.5	30.9	33.0	36.3	36.6	37.2	34.8	30.9	29.1	25.8	25.2
37	25.8	25.5	30.9	33.0	36.6	36.9	37.5	35.1	30.9	29.1	25.5	24.9
38	25.5	25.2	30.9	33.0	36.9	37.2	37.5	35.1	31.2	28.8	25.2	24.9
39	25.5	25.2	30.9	33.3	36.9	37.2	37.8	35.4	31.2	28.8	25.2	24.6
40	25.2	24.9	30.9	33.3	37.2	37.5	38.1	35.4	31.2	28.8	24.9	24.3
41	24.9	24.9	30.9	33.3	37.5	37.8	38.1	35.7	31.2	28.8	24.6	24.0
42	24.6	24.6	30.9	33.6	37.8	38.1	38.4	35.7	31.2	28.5	24.6	23.7
43	24.3	24.6	30.6	33.6	37.8	38.4	38.7	36.0	31.2	28.5	24.3	23.1
44	24.3	24.3	30.6	33.6	38.1	38.7	39.0	36.0	31.2	28.5	24.0	22.8
45	24.0	24.3	30.6	33.9	38.4	38.7	39.3	36.3	31.2	28.2	23.7	22.5
46	23.7	24.0	30.6	33.9	38.7	39.0	39.6	36.6	31.2	28.2	23.7	22.2
47	23.1	24.0	30.6	34.2	39.0	39.6	39.9	36.6	31.5	27.9	23.4	21.9
48	22.8	23.7	30.6	34.2	39.3	39.9	40.2	36.9	31.5	27.9	23.1	21.6
49	22.5	23.7	30.6	34.5	39.6	40.2	40.5	37.2	31.5	27.6	22.8	21.3
50	22.2	23.4	30.6	34.5	39.9	40.8	41.1	37.5	31.8	27.6	22.8	21.0

TABLE 7

MEAN POSSIBLE MONTHLY DURATION OF SUNLIGHT IN THE SOUTHERN HEMISPHERE
EXPRESSED IN UNITS OF 12 HOURS

SOUTHERN LATITUDES	J	F	M	A	M	J	J	A	S	O	N	D
0°	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	30.3	31.2
1	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	30.3	31.2
2	31.5	28.2	31.2	30.3	30.9	30.0	31.2	31.2	30.3	31.2	30.6	31.5
3	31.5	28.5	31.2	30.0	30.9	30.0	30.9	31.2	30.0	31.2	30.6	31.5
4	31.8	28.5	31.2	30.0	30.9	29.7	30.9	30.9	30.0	31.5	30.6	31.8
5	31.8	28.5	31.2	30.0	30.6	29.7	30.6	30.9	30.0	31.5	30.9	31.8
6	31.8	28.8	31.2	30.0	30.6	29.4	30.6	30.9	30.0	31.5	30.9	32.1
7	32.1	28.8	31.2	30.0	30.6	29.4	30.3	30.6	30.0	31.5	30.9	32.4
8	32.1	28.8	31.5	29.7	30.3	29.1	30.3	30.6	30.0	31.8	31.2	32.4
9	32.4	29.1	31.5	29.7	30.3	29.1	30.0	30.6	30.0	31.8	31.2	32.7
10	32.4	29.1	31.5	29.7	30.3	28.8	30.0	30.3	30.0	31.8	31.5	33.0
11	32.7	29.1	31.5	29.7	30.0	28.8	29.7	30.3	30.0	31.8	31.5	33.0
12	32.7	29.1	31.5	29.7	30.0	28.5	29.7	30.3	30.0	31.8	31.8	33.3
13	33.0	29.4	31.5	29.4	29.7	28.5	29.4	30.0	30.0	32.1	31.8	33.3
14	33.3	29.4	31.5	29.4	29.7	28.2	29.4	30.0	30.0	32.1	32.1	33.6
15	33.6	29.4	31.5	29.4	29.4	28.2	29.1	30.0	30.0	32.1	32.1	33.6
16	33.6	29.7	31.5	29.4	29.4	27.9	29.1	30.0	30.0	32.1	32.1	33.9
17	33.9	29.7	31.5	29.4	29.1	27.9	28.8	29.7	30.0	32.1	32.4	33.9
18	33.9	29.7	31.5	29.1	29.1	27.6	28.8	29.7	30.0	32.4	32.4	34.2
19	34.2	30.0	31.5	29.1	28.8	27.6	28.5	29.7	30.0	32.4	32.7	34.2
20	34.2	30.0	31.5	29.1	28.8	27.3	28.5	29.7	30.0	32.4	32.7	34.5
21	34.5	30.0	31.5	29.1	28.8	29.3	28.2	29.7	30.0	32.4	32.7	34.5
22	34.5	30.0	31.5	29.1	28.5	27.0	28.2	29.4	30.0	32.7	33.0	34.8
23	34.8	30.3	31.5	28.8	28.5	26.7	27.9	29.4	30.0	32.7	33.0	35.1
24	35.1	30.3	31.5	28.8	28.2	26.7	27.9	29.4	30.0	32.7	33.3	35.1
25	35.1	30.3	31.5	28.8	28.2	26.4	27.9	29.4	30.0	33.0	33.3	35.4
26	35.4	30.6	31.5	28.8	28.2	26.4	27.6	29.1	30.0	33.0	33.6	35.4
27	35.4	30.6	31.5	28.8	27.9	26.1	27.6	29.1	30.0	33.3	33.6	35.7
28	35.7	30.6	31.8	28.5	27.9	25.8	27.3	29.1	30.0	33.3	33.9	36.0
29	35.7	30.9	31.8	28.5	27.6	25.8	27.3	28.8	30.0	33.3	33.9	36.0
30	36.0	30.9	31.8	28.5	27.6	25.5	27.0	28.8	30.0	33.6	34.2	36.3
31	36.3	30.9	31.8	28.5	27.3	25.2	27.0	28.8	30.0	33.6	34.5	36.6
32	36.3	30.9	31.8	28.5	27.3	25.2	26.7	28.5	30.0	33.6	34.5	36.9
33	36.6	31.2	31.8	28.2	27.0	24.9	26.4	28.5	30.0	33.9	34.8	36.9
34	36.6	31.2	31.8	28.2	27.0	24.9	26.4	28.5	30.0	33.9	34.8	37.2
35	36.9	31.2	31.8	28.2	26.7	24.6	26.1	28.2	30.0	33.9	35.1	37.5
36	37.2	31.5	31.8	28.2	26.7	24.3	25.8	28.2	30.0	34.2	35.4	37.8
37	37.5	31.5	31.8	28.2	26.4	24.0	25.5	27.9	30.0	34.2	35.7	38.1
38	37.5	31.5	32.1	27.9	26.1	24.0	25.5	27.9	30.0	34.2	35.7	38.1
39	37.8	31.8	32.1	27.9	26.1	23.7	25.2	27.9	30.0	34.5	36.0	38.4
40	38.1	31.8	32.1	27.9	25.8	23.4	25.2	27.6	30.0	34.5	36.0	38.7
41	38.1	32.1	32.1	27.9	25.8	23.1	24.9	27.6	30.0	34.5	36.3	39.0
42	38.4	32.1	32.1	27.6	25.5	22.8	24.6	27.6	30.0	34.8	36.6	39.3
43	38.7	32.4	32.1	27.6	25.2	22.5	24.6	27.3	30.0	34.8	36.6	39.6
44	39.0	32.4	32.1	27.6	24.9	22.2	24.3	27.3	29.7	34.8	36.9	39.9
45	39.3	32.7	32.1	27.6	24.9	21.9	24.0	27.3	29.7	35.1	37.2	40.2
46	39.6	32.7	32.1	27.3	24.6	21.6	23.7	27.0	29.7	35.1	37.5	40.5
47	39.9	33.0	32.1	27.3	24.3	21.3	23.4	27.0	29.7	35.1	37.8	40.8
48	40.2	33.0	32.4	27.0	24.0	21.0	22.8	26.7	29.7	35.4	38.1	41.1
49	40.5	33.3	32.4	27.0	23.7	20.7	22.5	26.7	29.7	35.4	38.4	41.7
50	41.1	33.6	32.4	26.7	23.1	20.1	22.2	26.4	29.7	35.7	38.7	42.3

Appendix J.4 –

Reference: Pre-Project H&H Studies EWA Discussion of Roadway Openings - RVE and Baird

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January 29, 2024

Mr. Edward Howard, MSCE
Managing Director
National Roads Authority
Cayman Islands Government
P.O. Box 10426
Grand Cayman, KYI-1004, Cayman Islands

Reference: Pre-Project H&H Studies Related to the Proposed EW Arterial Expansion Project
Discussion of Roadway Openings Along the Proposed Alignment

Dear Mr. Howard:

Remington and Vernick Engineers, Inc. (RVE) and W. F. Baird & Associates Coastal Engineers, Ltd (Baird) were contracted by the National Roads Authority (NRA) to conduct Pre-Project Hydraulic and Hydrologic (H&H) analysis to support the Environmental Impact Assessment (EIA) of the proposed East-West Arterial Highway.

RVE was tasked with modeling rainfall events while Baird was tasked with modeling effects associated with hurricanes including storm surge and wave runup.

During the course of the modeling RVE and Baird analyzed different numbers and placements of proposed openings in the roadway. From these simulations, we developed a conceptual layout of the openings. Due to the preliminary nature of the analysis and the inaccuracies in the underlying data sources these openings were not optimized and fully coordinated.

These H&H models simulate discrete events and are not considered cumulative effects. The differences in the number and location of the roadway openings should not be considered contradictory between the analysis sets.

RVE and Baird recommend that the EIA team use the roadway openings and locations from the RVE H&H analysis as they present a more conservative approach to both cost and environmental impacts.

Please note the opening numbers and locations are considered proof-of-concept and will require significant development and detailed refinement by both engineering and H&H modeling during the future stages of project development.

Sincerely,

Remington & Vernick Engineers, Inc.

Steven B. Bolt, PE, PTOE
Regional Director

W. F. Baird & Associates Coastal Engineers, Ltd

Derek Williamson, MSc Peng
Principal

Appendix J.5 – Hydraulic and Hydrologic Studies EWA, Hydraulic Modelling – Alternatives Assessment - RVE

Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion

Hydraulic Modelling – Alternatives Assessment

Prepared For:

The National Roads Authority (NRA) of the Cayman Islands
370 North Sound Road (PWD Compound)
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Date Prepared:
Revised (March 2024)

Table of Contents

List of Figures and Tables

List of Abbreviations

RVE: Remington & Vernick Engineers

NRA: National Roads Authority

EIA: Environmental Impact Assessment

EWA: East-West Arterial

CMW: Central Mangrove Wetland

WRA: Whitman, Requardt & Associates

H&H: Hydraulic and Hydrologic

IDF: Intensity-Duration-Frequency

FDOT: Florida Department of Transportation

QGIS: Quantum Geographic Information System

HEC-HMS: Hydrologic Engineering Center – Hydrologic Modelling System

HEC-RAS: Hydrologic Engineering Center - River Analysis System

LiDAR: Light Detection and Ranging

2D: Two-Dimensional

Introduction

Remington & Vernick Engineers (RVE) was contracted by the National Roads Authority (NRA) to conduct Pre-Project Hydraulic and Hydrologic (H&H) analysis to support the Environmental Impact Assessment (EIA) of the proposed East-West Arterial Highway (EWA). This report focuses on the full extent of the EWA and the four shortlisted proposed alignments with an emphasis on the hydraulic analysis of the Central Mangrove Wetland (CMW) area on Grand Cayman Island in both existing condition and a near future potential sea rise scenario. This hydraulic and hydrologic study is the cumulative result of a multi-stage project preceded by three memorandums and coordination with many different organizations detailed further in the report. The four different shortlisted Phase II alignments of the EWA proposed for evaluation during the EIA can be seen in Figure 1.

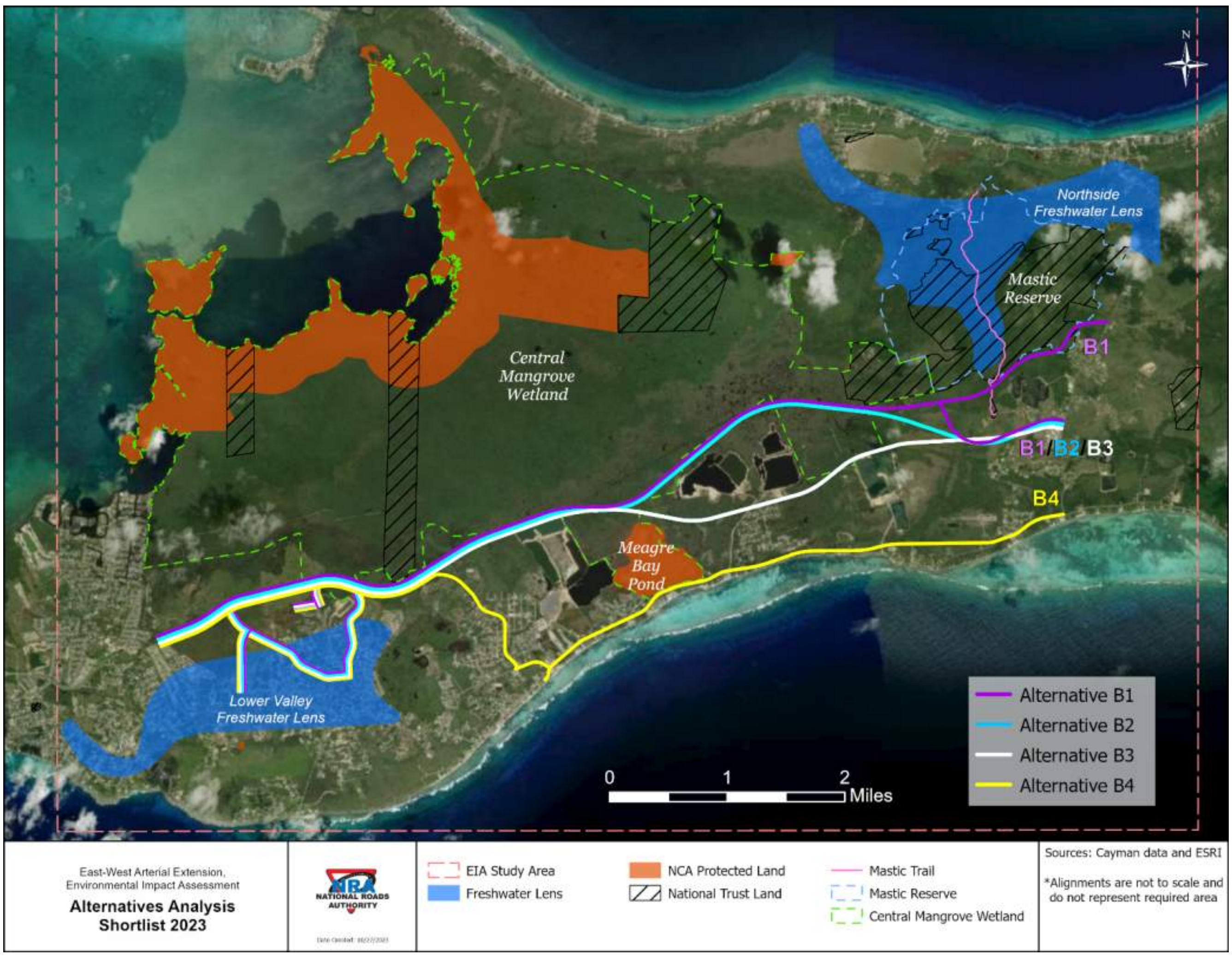

Figure 1. Alternative Proposed Shortlisted EWA Phase II Alternatives

Background

Project Scope

In addition to this hydraulic and hydrologic study, RVE's prior tasks included beginning the development of the hydrologic model utilizing the existing rainfall data for Grand Cayman, performing a statistical analysis of large and extreme rainfall events to determine design rainfall amounts for flooding assessments and roadway storm water designs. The data compiled for this, and previous reports' analyses included:

- Cayman National Weather Service rainfall data.
- 2004 Hurricane Ivan flood data.
- Vegetation distribution from the Department of Environment.
- Soils data from the Department of Agriculture.
- Vegetation, hydrogeology, and freshwater lens information from the Water Authority.
- Topographic and agricultural mapping from Lands and Survey.
- Discussions with Baird & Associates who have been performing concurrent hurricane analyses and the NRA.
- Information, alignments, and mapping of the shortlisted alternatives from Whitman, Requardt Associates (WRA).

RVE performed a distribution series to generate the different storm events utilized in this report. More details on the specifics of those findings can be found in Razzaghmanesh & Gause (2022), Memorandum 1 - Preliminary Rainfall Analysis [1] and Razzaghmanesh & Gause (2022), Memorandum 2 - Hydrology and Hydraulic (H&H) Analysis. Since the issue of these reports, there have been minor changes to the main model, including revising the energy grade line from 0.001 ft/ft (0.001 m/m) to 0.0005 ft/ft (0.0005 m/m). Flatter and steeper energy grade line slopes were run and 0.0005 ft/ft (0.0005 m/m) was determined to be most representative of the flow out of the study area into the North Sound.

Memorandum 1 Summary

Memorandum 1 analyzed the Grand Cayman Island rainfall data to determine the intensity-duration-frequency amounts for various rainfall events and the rainfall distribution. The daily (24 hours) recorded data was used for maximum daily rainfall intensity analysis. Daily data was available from year 1982 to year 2021 for the majority of the rain gauges under the jurisdiction of Water Authority across Grand Cayman Island. The peak 24 hours rainfall from the weather stations were identified and then the maximum daily (average 24-hours) intensity was calculated. The data was used for rainfall intensity analysis as well as extreme event identification. The available daily and hourly rainfall data was analyzed in Memorandum 1. There was missing information and a lack of long-term rainfall data in the study area that precluded identifying the Intensity-Duration-Frequency (IDF) curves precisely. Larger values for both the IDF curves and 25-years rainfall intensity were calculated. It was demonstrated that the overall rainfall distribution shows a good agreement with Florida Department of Transporation (FDOT) rainfall distribution pattern.

Memorandum 2 Summary

Three software packages including Quantum Geographic Information System (QGIS), Hydrologic Engineering Center – Hydrologic Modelling System (HEC-HMS) and Hydrologic Engineering Center – River Analysis System (HEC-RAS) were used to perform this study. A two-dimensional hydraulic model was developed to prepare flooding information to design East-West Arterial Roadway and the associated alternatives on Grand Cayman Island. Various scenarios of rainfall events and the historic tropical Hurricane Ivan were studied. The results of the Memorandum 1, Rainfall Studies, were used to develop several rainfall scenarios for 2-year, 10-year, 25-year, 50-year, 100-year, and the 2004 Hurricane Ivan. The rainfall events show that the project area will be inundated during most of the events. The results for a 2-year, showed the simulated flood depth less than 1 foot (0.3 m) and increasing to 5 feet to 6 feet (1.5 m to 1.8 m) for a 100-year simulated event along the inland roadway options, whereas the flood depth was simulated up to 10 feet (3.0 m) for the options close to the coastal area on the southwest of the site. The simulated Hurricane Ivan event also showed a consistency with the Grand Cayman Hurricane Ivan Flooding map of September 2004. The locations for the proposed roadway drainage improvement have been proposed.

Memorandum 3 Summary

A water budget was performed using the Thornthwaite and Mather method to assess the EWA impact upon the CMW in a monthly rainfall, runoff, and evaporation analysis over a 10-year period for an understanding of the water fluctuations in the CMW. Results determined that there will be an increase in runoff with the EWA at an amount too small for the CMW watershed size of the analysis. The water budget analysis in Memorandum 3 has no relationship with the large flood event hydraulic analyses in this report because of the different methods, time frames, and type of analysis.

Background Continued

The flow analyses for each storm event of this study utilizes a 200-foot (61 m) by 200-foot (61 m) computational mesh refined with breaklines along the roadway embankments and bridge openings through the embankments. Each Alternative, B1, B2, B3, and B4, has the outflow boundary set along the North Sound as a normal depth flow boundary with an energy grade line of 0.0005 ft/ft (0.00015 m/m). The energy grade line was selected to approximate a gradual drawdown of shallow flow from the CMW thick vegetation exiting into the North Sound. The model boundary, shown in Figure 2, which also comprises the outflow flow boundary along the North Sound, is set along the EWA study area. The study area includes the land east of Frank Sound Road as well as the southern shoreline. This boundary can be seen in Figure 4. Runoff flow computations are performed through an Unsteady Flow analysis of the 2D area.

Figure 2. Study Limits

Study Area Hydraulics

Figure 3. Grand Cayman Island

The terrain files utilized show overall decreasing elevation towards the North Sound with scattered pockets of higher and lower lands which vary in size. These areas depict ponds, quarries, and raised ground. It should be noted that the thick vegetation has the potential to obscure the ground surface elevations which causes artificially higher elevations than those of the actual ground surface. The terrain data indicates that the Meagre Bay Pond, other ponds, and quarries are 2 feet (0.6 m) to 3 feet (1.0 m) below the ground surface. As stated, this can be attributed to a combination of the Light Detection and Ranging (LiDAR) data collection picking up the water surface with the vegetation obscuring the ground in the study area, especially in the CMW.

Method

The analyses detailed in this report were performed using the US Army Corps of Engineers HEC-RAS 2-Dimensional (2D) software for each alternative. Terrain files, which included the proposed embankments for EWA Alternatives B1, B2, B3, and B4, were supplied by WRA for each analysis.

Each alternative model combines a Precipitation-Runoff analysis, which generates the runoff volumes, with the flow of the runoff volume in a 2D analysis. These two analyses combine forward-backward and side-to-side flows by time-step. The precipitation-runoff calculations utilize the 24-hour rainfall distributions for the 2-year, 10-year, 25-year, 50-year, and 100-year storms along with the land cover characteristics determined in Memorandum 2, Hydrology and Hydraulic (H&H) Analysis [2] performed for this project.

A 24-hour rainfall distribution was utilized for a large rainfall storm that can be considered somewhere between a fast-moving tropical storm or hurricane and a very slow to stalled hurricane, such as Hurricane Ivan in 2004.

Table 1. Boundary Condition Summary

Alternative B1	Outflow boundary set along North Sound
Alternative B2	Outflow boundary set along North Sound
Alternative B3	Outflow boundary set along North Sound
Alternative B4	Outflow boundary set along North Sound

Figure 4. Alternatives B1, B2, B3, and B4 Outflow Boundary

Proposed bridges with associated flow channels through the structures were placed at the approximate locations provided with the alternatives' terrain files by WRA. The initial structure locations were based on information provided by WRA. RVE slightly modified those locations to fit within the model parameters. Breaklines were added along the proposed embankments between the bridges to prevent the hydraulic model from calculating flow through the embankments by its algorithms.

The bridges are identified from west to east in each alternative using the following naming convention: Alternative name followed by the bridge number. For example, the westmost bridge in Alternative B1 is referred to as B1-1. Once the alignments diverge after B1-5, the prefix changes to reflect the specific Alternative and the suffix continues numerically from the diversion. For example, the first bridge after Alternative B2 diverges is B2-9. The first seven bridges in Alternatives B1, B2, and B3 are 330 feet (100 m) long divided into 30 feet (9.1 m) spans. In Alternative B4, the first six bridges are 330 feet (100 m) long. The remaining bridges in each alternative are 150 feet (45.7 m) long with 30 feet (9.1 m) spans, with an exception in Alternative B4 where the three eastern most bridges, along the southern ridge line, are 90 feet (27.4 m) long.

Bridge dimensions utilized for this study are consistently 1.5 feet (0.5 m) deep decks and beams with 3.5 feet (1.1 m) high parapets approximating 30 feet (9.1 m) long typical concrete spans. Actual bridge dimensions will be determined in future design.

The analysis run time is 3 days, in 5-minute computation intervals and 30 minutes mapping and output intervals. The 24-hour precipitation distribution is in 1-hour intervals. Peak runoff occurs between 12 and 18 hours from the start followed by slow drain downs of the area.

A second set of models is run with an initial elevation of 1.64 ft (0.5 m) at the outflow boundary to simulate future sea rise. The use of 1.64 ft (0.5 m) for sea rise was determined in discussions with Baird Associates and the NRA.

Results

The results of the analyses are displayed in a series of graphics located in Appendix B through E: Appendix B for Alternative B1, Appendix C for Alternative B2, and so on. There is a graphic representing the original terrain elevation, followed by graphics for each alternative of the storm conditions, 2-year, 10-year, 25-year, 50-year, and 100-year storms broken out by:

1. Maximum Depth with Model Terrain without and with Sea Rise.
2. Maximum Velocity and Model Terrain without and with Sea Rise.
3. Maximum Water Surface Elevation and Model Terrain without and with Sea Rise.

In general, the embankments with the bridge opening sizes as they are currently modeled cause a rise in the runoff on the uphill (southerly) sides of the embankment. There is little depth and water surface elevation difference in the 2-year event but there are noticeable differences of approximately 1 foot (0.3

m) to 2 feet (0.6 m) in the 50-year and 100-year events respectively. In each alternative, the runoff depths are generally shallow and slow moving with velocity increases at the bridges. Flow velocities range from nearly 0 feet (0 m) per second to 2 feet (0.6 m) per second indicative of flow in thick vegetation but can increase close to 3 feet (1.0 m) per second at the bridge openings as shown on the maximum velocity maps in the appendices.

Overall flows are generally from east to west with some meandering in the quarry areas along the south coast. North to south flows will occur through the alternative embankments from the CMW into the quarries and Meagre Bay Pond areas as the runoff increases, but then the accumulated runoff flows will slowly drain out.

It should be noted in Alternative B4 water running along the higher grounds toward the ridge line near the southern coast has the smallest effect upon the CMW due to its location, but it will still have local impacts along the south coast ridge line. These impacts are too small to be determined at the scale of this analysis but should be considered for future work. In addition, there are three locations of Alternative B4, shown in Figure 5 and Figure 6, that will be overtopped during the 50-year storm by inches due to the roadway's close elevation to the ground surface. The overtopping can be eliminated by modifying the currently proposed roadway profile and adding additional local drainage measures during the final design.

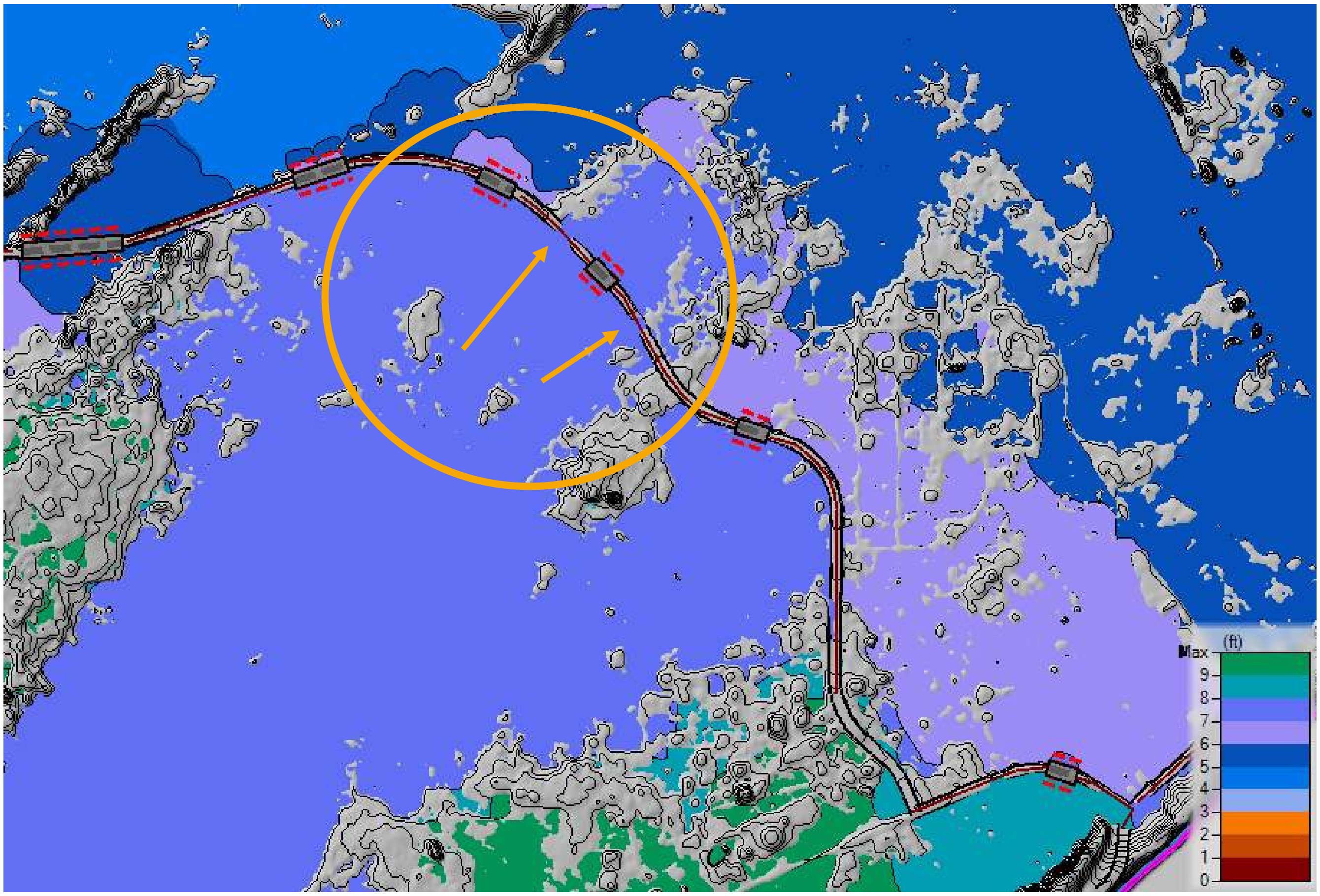

Figure 5. Alternative B4 Overtopping 50-Year Storm

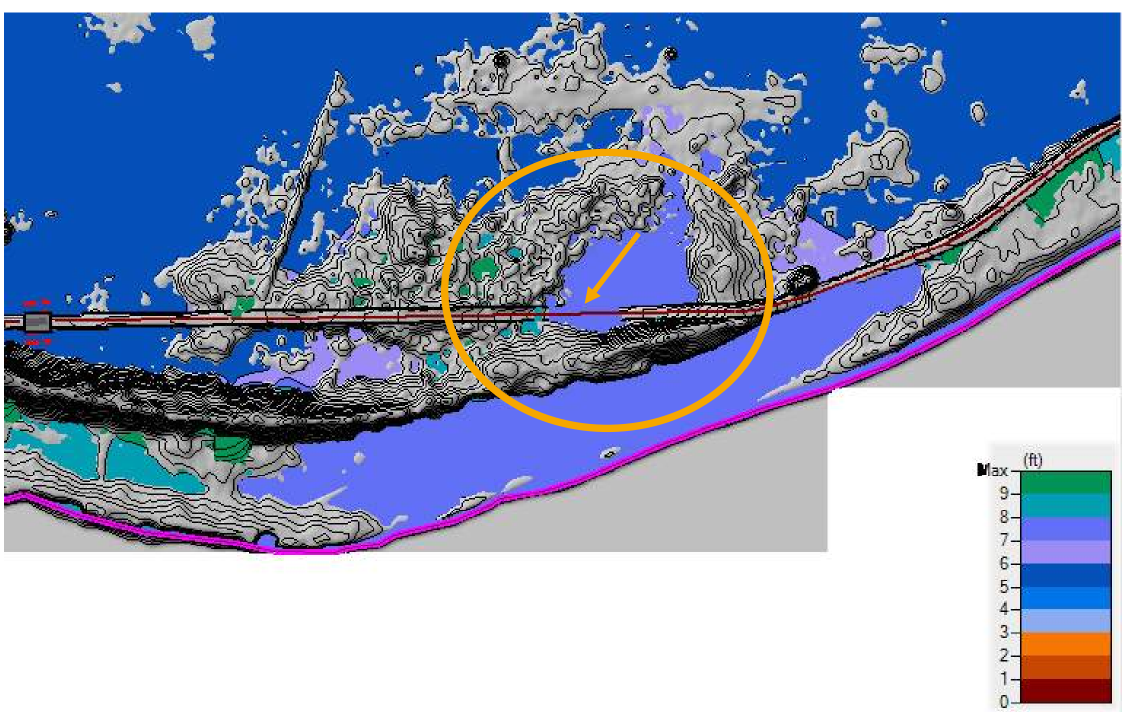

Figure 6. Alternative B4 Overtopping 50-Year Storm

Profiles across the terrain and through selected bridges show the storm events' water surface elevation over the ground. The profiles are through the bridge openings, but do not show the bridge structures. Being a precipitation to runoff model, the runoff is shown from the high grounds to the low areas and looks like a series of cascading pools on the profile when it is following over its courses to the North Sound. At many of the bridges, there is a high to low difference across the bridge showing that the alignments can act as a dam with the bridge dimensions modelled. The depth differences at the bridges and on each side of the alignments' embankments is an issue for the alignment chosen, bridge locations along the alignment, and the bridge dimensions in future design.

Profile B1-5 in Alternative B2 is a notable example of the bridge dimensions and the channels under the bridges. While the bridge configuration is the same as the other alternatives, the channel under the bridge is skewed which limits the flow capacity compared to other alternatives' profiles through Bridge B1-5 with channels that align more closely with the bridge.

Sea rise has little effect on the modelled water surface elevations and flow patterns due to the terrain elevation limitations of the model. It is anticipated that sea rise will flow into the CMW and will contribute to higher flooding depths and elevations that cannot be measured with the terrain limitations.

Water surface elevations for the flood events modelled at each bridge in each shortlisted alternative are presented in Table 2. Maximum flood elevations and minimum flood elevations for each shortlisted alternative are highlighted in the table. The differing elevations, particularly in the first 5 bridges, demonstrate the differences occurring due to the coarseness of the model, the overall impact of the shortlisted alternatives alignments upon the water elevations, and the differences in the input of the bridges and the channels under the bridges in each alternative. Each alternative required individual input of the bridges and channels under the bridges.

Table 2. Flood Elevations in Existing and Near Future Potential Sea Rise

Maximum water surface elevations are highlighted in pink and minimum water surface elevations are highlighted in orange.

Alternative	Bridge	2-yr	10-yr	25-yr	50-yr	100-yr		2-yr Sea	10-yr Sea	25-yr Sea	50-yr Sea	100-yr Sea
		FT	FT	FT	FT	FT		FT	FT	FT	FT	FT
B1	B1-1	5.30	5.79	5.96	6.15	6.23		5.33	5.80	5.70	6.13	6.23
B2	B1-1	5.45	5.88	6.18	6.51	6.62		5.47	5.88	6.18	6.50	6.60
B3	B1-1	5.60	6.20	6.60	7.03	7.16		5.62	6.22	6.61	6.13	7.12
B4	B1-1	5.34	5.66	5.82	6.13	6.27		5.35	5.66	5.82	6.13	6.27
B1	B1-2	5.32	5.79	6.00	6.15	6.26		5.33	5.80	5.98	6.17	6.23
B2	B1-2	5.40	5.82	6.17	6.48	6.60		5.31	5.82	6.23	6.48	6.61
B3	B1-2	5.58	6.20	6.58	6.99	7.16		5.62	6.21	6.61	7.02	7.12
B4	B1-2	5.35	5.69	5.84	6.14	6.28		5.36	5.69	5.84	6.15	6.27
B1	B1-3	5.36	5.85	6.02	6.22	6.30		5.38	5.86	6.02	6.22	6.30
B2	B1-3	5.38	5.86	6.25	6.50	6.58		5.38	5.86	6.15	6.47	6.55
B3	B1-3	5.59	6.16	6.60	7.02	7.16		5.57	6.17	6.60	7.03	7.07
B4	B1-3	5.10	5.31	5.52	6.01	6.20		5.05	5.30	5.52	6.02	6.16
B1	B1-4	5.30	5.77	5.94	6.16	6.21		5.34	5.84	5.97	6.13	6.27
B2	B1-4	4.72	5.60	6.07	6.50	6.60		7.74	5.62	6.23	6.49	6.57
B3	B1-4	5.54	6.19	6.60	6.97	7.10		5.57	6.16	6.62	7.05	7.04
B4	B1-4	4.48	5.07	5.31	5.97	6.18		4.51	5.08	5.31	5.98	6.18
B1	B1-5	4.61	5.05	5.22	5.45	5.51		4.57	5.07	5.22	5.43	5.53
B2	B1-5	7.64	8.48	8.62	8.80	8.77		7.61	8.56	8.64	8.75	8.80
B3	B1-5	4.92	5.54	6.01	6.42	5.68		4.93	5.54	6.04	6.51	5.46
B4	B1-5	4.90	5.38	5.59	5.85	5.92		4.90	5.41	5.59	5.83	5.93
B1	B1-6	4.47	5.51	5.65	6.11	6.23		4.55	5.17	5.64	6.15	6.02
B2	B1-6	5.60	4.48	6.73	5.95	7.02		5.68	6.46	6.72	6.97	7.00
B3	B1-6	4.40	5.14	5.87	5.59	5.53		4.50	5.15	5.92	6.44	6.31
B1	B1-7	4.03	4.57	5.09	5.69	5.90		4.02	4.74	5.11	5.85	6.00
B2	B1-7	4.21	4.66	5.73	5.66	5.82		4.11	4.81	5.26	5.78	5.94
B3	B1-7	4.18	4.61	5.05	5.59	5.80		4.18	4.75	5.19	5.75	5.88
B1	B1-8	3.70	4.60	5.10	5.72	5.89		3.89	4.74	5.12	5.84	6.00
B2	B1-8	3.71	4.65	5.12	5.66	5.82		3.92	4.80	5.25	5.76	5.92
B3	B1-8	3.72	4.61	5.06	5.60	5.80		3.90	4.73	5.20	5.75	5.90
B1	B1-9	3.69	4.61	5.11	5.72	5.90		3.89	4.79	5.12	5.84	6.02
B3	B1-9	3.72	4.62	5.07	5.60	5.83		3.90	4.74	5.19	5.75	5.90
B1	B1-10	3.68	4.63	5.13	5.70	5.91		3.90	4.80	5.14	5.85	6.04

Alternative	Bridge	2-yr	10-yr	25-yr	50-yr	100-yr	2-yr Sea	10-yr Sea	25-yr Sea	50-yr Sea	100-yr Sea
B3	B1-10	3.72	4.61	5.02	5.59	5.77	3.90	4.73	5.16	5.70	5.84
B1	B1-11	3.71	4.62	5.12	5.71	5.90	3.90	4.80	5.13	5.88	6.01
B3	B1-11	3.76	4.63	5.06	5.60	5.85	3.90	4.74	5.18	5.78	5.89
B1	B1-12	3.86	4.63	5.13	5.72	5.90	3.90	4.80	5.14	5.85	6.06
B3	B1-12	3.89	4.65	5.08	5.60	5.84	3.92	4.76	5.20	5.75	5.89
B1	B1-13	3.87	4.63	5.14	5.73	5.94	3.91	4.80	5.14	5.88	6.06
B3	B3-13	3.90	4.65	5.08	5.60	5.82	3.92	4.76	5.20	5.75	5.88
B1 North	B1-14	4.43	5.41	5.79	6.17	6.29	4.55	5.44	5.79	6.20	6.30
B1 North	B1-15	4.47	5.43	5.83	6.20	6.32	4.57	5.46	5.83	6.23	6.36
B1 South	B1-16	4.71	4.97	5.48	5.89	6.11	4.70	5.03	5.41	6.04	6.22
B1 South	B1-17	4.88	5.07	5.40	5.93	6.11	4.87	5.09	5.43	6.03	6.20
B3	B3-14	4.70	5.04	5.22	5.65	5.85	4.69	5.02	5.28	5.78	5.91
B3	B1-17	5.01	5.23	5.28	5.71	5.89	5.01	5.22	5.35	5.82	5.95
B2	B2-9	3.71	4.66	5.13	5.66	5.84	3.92	4.80	5.26	5.78	5.95
B2	B2-10	3.71	4.66	5.14	5.68	5.87	3.92	4.80	5.27	5.77	5.95
B2	B2-11	3.71	4.65	5.13	5.64	5.83	3.92	4.79	5.24	5.74	5.90
B2	B2-12	3.98	4.70	5.07	5.60	5.80	4.06	4.76	5.14	5.68	5.86
B2	B2-13	3.97	4.72	5.08	5.62	5.79	4.06	4.78	5.15	5.70	5.87
B2	B2-14	3.97	4.72	5.09	5.61	5.79	4.06	4.79	5.16	5.68	5.87
B2	B2-15	4.18	4.63	4.97	5.51	5.79	4.18	4.69	5.03	5.60	5.80
B2	B2-16	4.87	5.08	5.27	5.68	5.72	4.83	5.09	5.31	5.76	5.93
B2	B2-17	5.28	5.36	5.40	5.76	5.91	5.30	5.35	5.42	5.81	5.97
B4	B4-6	5.65	6.52	7.02	7.47	7.63	5.78	6.60	7.11	7.38	7.56
B4	B4-7	5.67	6.55	7.04	7.42	7.61	5.75	6.64	7.08	7.44	7.60
B4	B4-8	5.72	6.62	7.06	7.48	7.61	5.82	6.69	7.10	7.50	7.64
B4	B4-9	6.11	6.81	7.17	7.56	7.70	6.19	6.89	7.22	7.56	7.73
B4	B4-10	6.45	7.79	8.03	8.16	8.19	6.44	7.80	8.03	8.15	8.19
B4	B4-11	5.73	6.01	6.07	6.20	6.26	5.72	6.01	6.12	6.20	6.25
B4	B4-12	6.09	6.40	6.66	6.75	6.93	6.07	6.48	6.70	6.81	6.88
B4	B4-13	4.02	4.51	4.83	5.17	5.27	4.04	4.57	4.89	5.21	5.31

Areas of Concern

Results at the Areas of Concern shown in Figure 7 will change depending on the alternative chosen and as design progresses with respect to the conveyance openings through the embankment.

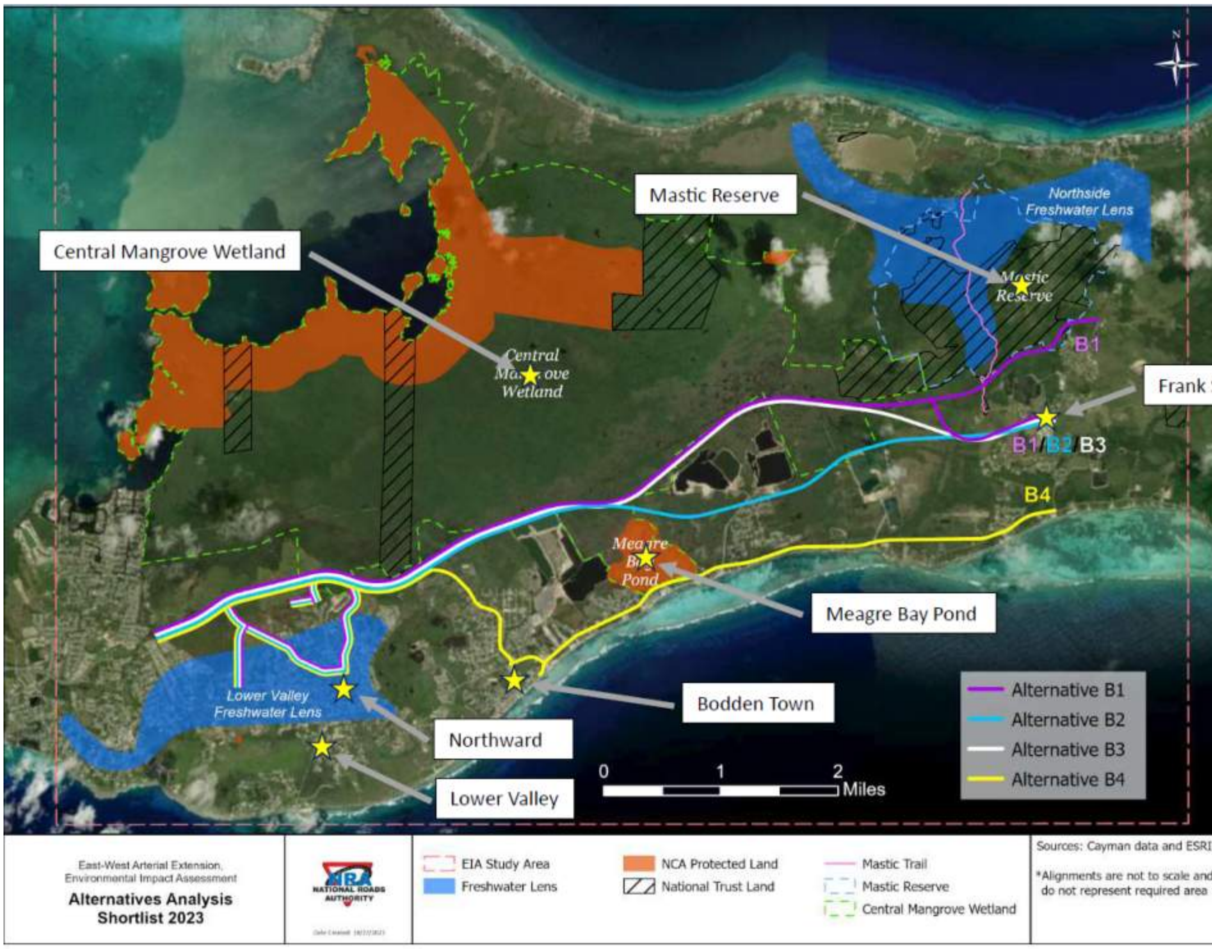

Figure 7. Areas of Concern

The Mastic Reserve, Mastic Trail, and Frank Sound Road are affected by the proximity of the embankment to the Mastic Reserve due to the embankment's channeling effect of the flow coming from the northeast. Flow is altered to a more channel like situation similar to a levee's effect on a wide area. The Alternative B1 Northern Connection option to Frank Sound Road causes the greatest effect to the area as currently modelled with the bridge openings.

Storm surge will continue to raise the Freshwater Lens' water mounds into the bedrock below. Large storm runoff accumulation in the CMW will have a short-term effect on the Lower Valley Freshwater Lens natural exfiltration into the CMW, which like the other Areas of Concern, will be dependent upon the alternative chosen and conveyance openings through the embankment. It is also important to keep the land data accuracy assumptions expressed in prior sections of this report in mind. These areas will require more detailed land data when undergoing further design to determine the full extent of the impacts.

At the communities of concern, it is anticipated that the low-lying areas will experience flooding that is comparable to current conditions with greater depths encroaching upon additional land, should the modelled scenario be constructed. Depending on the alternative chosen and the runoff conveyances through the embankment, the flooding frequency and depth could be increased or decreased from what has been studied.

Conclusions

The construction of the East-West Arterial will result in increases in runoff depths and elevations in each modelled alternative on the southern, upstream, side of the proposed roadway. The increases can be reduced through the use of bridge openings in the proposed roadways. The number and size of the openings can be manipulated through refined analysis to help lower the depths and velocities which will result in low erosion and scour potential. Any increase in the sizes and number of openings in the embankments will reduce the runoff depths, it will also decrease the already slow velocities. These velocities are indicative of flow through large vegetation dominated areas.

Due to the macroscopic nature of the study area local drainage features were not accounted for in the modeling of the flood depths. These features could aid in decreasing flood depths as well as the design project progresses and the H&H modelling refined.

With the knowledge of the increased runoff depths and elevations and the effects of the openings in the roadway it is expected that WRA will be able to complete their evaluation of each alternative alignment as part of the EIA process.

Limitations and Future Analyses

The accuracy of the model used for this analysis provides output data for conceptual analysis of the subject alternatives only. The limitations associated with the LiDAR data, terrain mapping and ground surface features, including the quarries' water levels, do not allow for a refined analysis of specific opening locations or sizes. Whichever alternative is selected and progressed to preliminary engineering design, the terrain mapping should be further refined at the ground surface with respect to the vegetation to provide more detailed and accurate results. As stated above, it is very likely that there are some areas where the LiDAR data registers the top of vegetation as the existing ground surface. The analysis time should also be further refined along with the outlet boundary energy grade line for a more detailed calibration of the HEC-RAS model. The outcome of refining these factors will indicate specific design choices that can be made to help minimize the runoff and flood elevations.

The location and size of the openings used in this model were selected as proof-of-concept that such openings would have a positive effect on the runoff depts and elevations. The opening numbers, locations and sizes will require significant development and detailed refinement by both engineering and H&H modelling during future stages of project development. Additionally, terrain model refinements, further calibration, and validation of the model will be necessary for the development of detailed design stages of the project.

References

1 Razzaghmanesh, M., & Gause, S. (2022), Hydraulic and Hydrologic Studies of Proposed East-West Arterial Highway Expansion, Memorandum 1 – Preliminary Rainfall Analysis, Remington & Vernick Engineers.

2 Razzaghmanesh, M., & Gause, S. (2022), Hydraulic and Hydrologic Studies of Proposed East-West Arterial Highway Expansion, Memorandum 2 – Hydrology and Hydraulic (H&H) Analysis, Remington & Vernick Engineers.

3 Gause, S., & Razzaghmanesh, M. (2023), Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion, Memorandum 3 – Water Budget Analysis, Remington & Vernick Engineers.

4 U.S. Army Corps of Engineers Hydrologic Engineering Center, HEC-RAS River Analysis System software and associated documentation.

Appendices

Appendix A – Areas of Concern

EWA Extension EIA Study – Interest for Potential Impoundment Areas During Heavy Rainfall Events
Locations of Concerns
Will T Analysis Points
Pre-Project H&H Studies Related to the Proposed EW Arterial Expansion Project Discussion of Roadway Openings Along the Proposed Alignment Letter
Razzaghmanesh & Gause (2022), Memorandum 1 - Preliminary Rainfall Analysis
Razzaghmanesh & Gause (2022), Memorandum 2 - Hydrology and Hydraulic (H&H) Analysis

Appendix B – Alternative B1

Appendix C – Alternative B2

Original Terrain
2-year storm - Maximum Depth with Model Terrain
2-year storm - Maximum Depth with Model Terrain with Sea Rise
2-year storm - Maximum Velocity and Model Terrain
2-year storm - Maximum Velocity and Model Terrain with Sea Rise
2-year storm - Maximum Water Surface Elevation and Model Terrain
2-Year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
10-year storm - Maximum Depth with Model Terrain
10-year storm - Maximum Depth with Model Terrain with Sea Rise
10-year storm - Maximum Velocity and Model Terrain
10-year storm – Maximum Velocity and Model Terrain with Sea Rise
10-year storm - Maximum Water Surface Elevation and Model Terrain
10-year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
25-year storm – Maximum Depth with Model Terrain
25-year storm – Maximum Depth with Model Terrain with Sea Rise
25-year storm - Maximum Velocity and Model Terrain
25-year storm – Maximum Velocity and Model Terrain with Sea Rise
25-year storm – Maximum Water Surface Elevation and Model Terrain
25-year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
50-year storm - Maximum Depth with Model Terrain
50-year storm - Maximum Depth with Model Terrain with Sea Rise
50-year storm – Maximum Velocity and Model Terrain
50-year storm – Maximum Velocity and Model Terrain with Sea Rise
50-year storm - Maximum Water Surface Elevation and Model Terrain
50-year storm - Maximum Water Surface Elevation and Model Terrain with Sea Rise
100-year storm – Maximum Depth with Model Terrain
100-year storm – Maximum Depth with Model Terrain with Sea Rise
100-year storm - Maximum Velocity and Model Terrain
100-year storm - Maximum Velocity and Model Terrain with Sea Rise
100-year storm - Maximum Water Surface Elevation and Model Terrain
100-year storm - Maximum Water Surface Elevation and Model Terrain with Sea Rise
Profiles
Bridges
Profile B1-2
Profile B1-2 with Sea Rise
Profile B1-5
Profile B1-5 with Sea Rise
Profile B1-7
Profile B1-7 with Sea Rise
Profile B2-11
Profile B2-11 with Sea Rise
Profile B2-13
Profile B2-13 with Sea Rise
Profile B2-14
Profile B2-14 with Sea Rise
Profile B2-17
Profile B2-17 with Sea Rise

Appendix D – Alternative B3

Original Terrain
2-year storm - Maximum Depth with Model Terrain
2-year storm - Maximum Depth with Model Terrain with Sea Rise
2-year storm - Maximum Velocity and Model Terrain
2-year storm - Maximum Velocity and Model Terrain with Sea Rise
2-year storm - Maximum Water Surface Elevation and Model Terrain
2-Year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
10-year storm - Maximum Depth with Model Terrain
10-year storm - Maximum Depth with Model Terrain with Sea Rise
10-year storm - Maximum Velocity and Model Terrain
10-year storm – Maximum Velocity and Model Terrain with Sea Rise
10-year storm - Maximum Water Surface Elevation and Model Terrain
10-year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
25-year storm – Maximum Depth with Model Terrain
25-year storm – Maximum Depth with Model Terrain with Sea Rise
25-year storm - Maximum Velocity and Model Terrain
25-year storm – Maximum Velocity and Model Terrain with Sea Rise
25-year storm – Maximum Water Surface Elevation and Model Terrain
25-year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
50-year storm - Maximum Depth with Model Terrain
50-year storm - Maximum Depth with Model Terrain with Sea Rise
50-year storm – Maximum Velocity and Model Terrain
50-year storm – Maximum Velocity and Model Terrain with Sea Rise
50-year storm - Maximum Water Surface Elevation and Model Terrain
50-year storm - Maximum Water Surface Elevation and Model Terrain with Sea Rise
100-year storm – Maximum Depth with Model Terrain
100-year storm – Maximum Depth with Model Terrain with Sea Rise
100-year storm - Maximum Velocity and Model Terrain
100-year storm - Maximum Velocity and Model Terrain with Sea Rise
100-year storm - Maximum Water Surface Elevation and Model Terrain
100-year storm - Maximum Water Surface Elevation and Model Terrain with Sea Rise
Profiles
Bridges
Profile B1-2
Profile B1-2 with Sea Rise
Profile B1-5
Profile B1-5 with Sea Rise
Profile B1-7
Profile B1-7 with Sea Rise
Profile B2-11
Profile B2-11 with Sea Rise
Profile B2-13
Profile B2-13 with Sea Rise
Profile B2-14
Profile B2-14 with Sea Rise
Profile B2-17
Profile B2-17 with Sea Rise

Appendix E – Alternative B4

Original Terrain
2-year storm - Maximum Depth with Model Terrain
2-year storm - Maximum Depth with Model Terrain with Sea Rise
2-year storm - Maximum Velocity and Model Terrain
2-year storm - Maximum Velocity and Model Terrain with Sea Rise
2-year storm - Maximum Water Surface Elevation and Model Terrain
2-Year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
10-year storm - Maximum Depth with Model Terrain
10-year storm - Maximum Depth with Model Terrain with Sea Rise
10-year storm - Maximum Velocity and Model Terrain
10-year storm – Maximum Velocity and Model Terrain with Sea Rise
10-year storm - Maximum Water Surface Elevation and Model Terrain
10-year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
25-year storm – Maximum Depth with Model Terrain
25-year storm – Maximum Depth with Model Terrain with Sea Rise
25-year storm - Maximum Velocity and Model Terrain
25-year storm – Maximum Velocity and Model Terrain with Sea Rise
25-year storm – Maximum Water Surface Elevation and Model Terrain
25-year storm – Maximum Water Surface Elevation and Model Terrain with Sea Rise
50-year storm - Maximum Depth with Model Terrain
50-year storm - Maximum Depth with Model Terrain with Sea Rise
50-year storm – Maximum Velocity and Model Terrain
50-year storm – Maximum Velocity and Model Terrain with Sea Rise
50-year storm - Maximum Water Surface Elevation and Model Terrain
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100-year storm – Maximum Depth with Model Terrain
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Profiles
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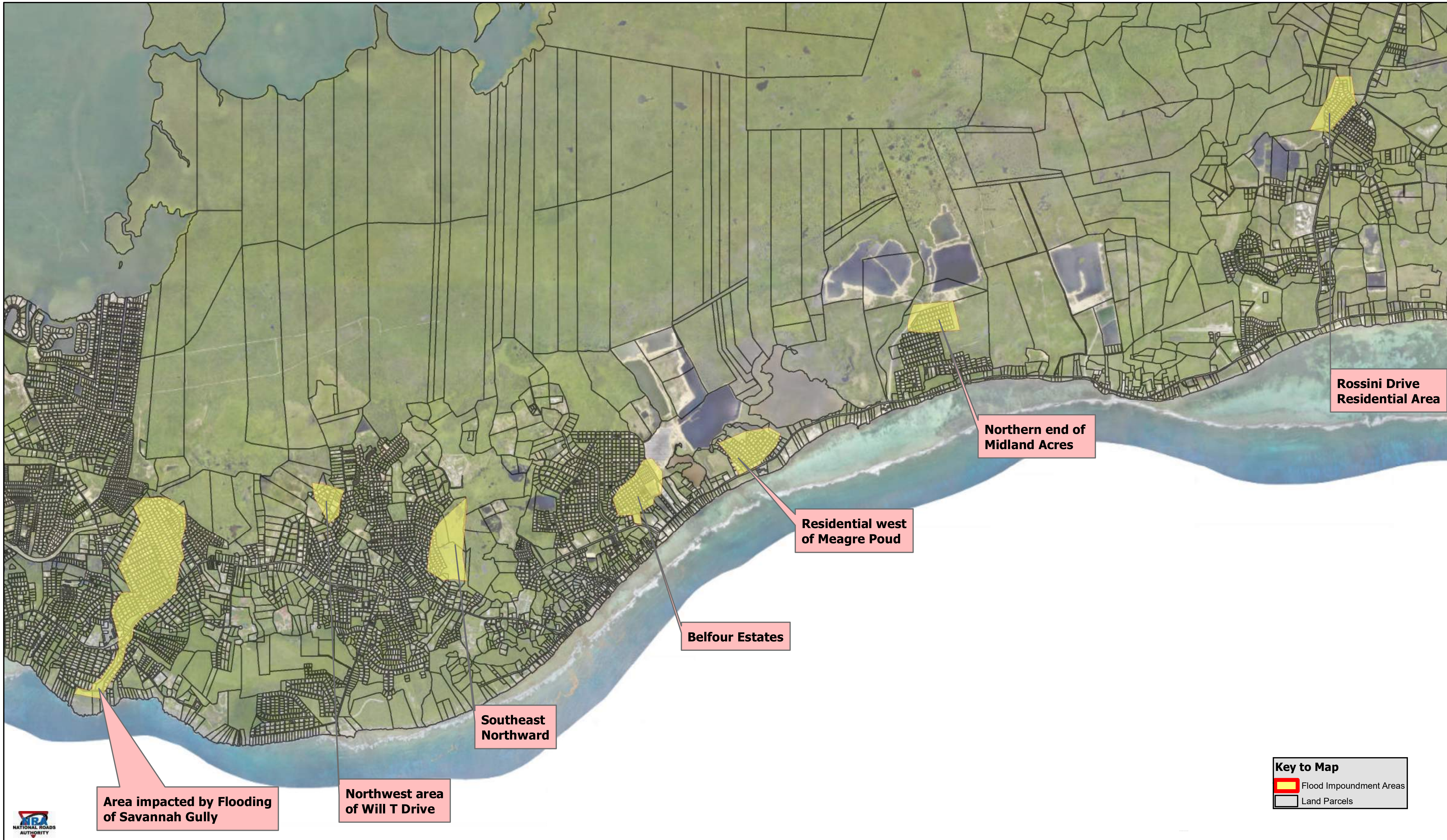
Profile B1-2
Profile B1-2 with Sea Rise
Profile B1-5
Profile B1-5 with Sea Rise
Profile B4-8
Profile B4-8 with Sea Rise
Profile B4-10
Profile B4-10 with Sea Rise
Profile B4-12
Profile B4-12 with Sea Rise
Profile B4-13
Profile B4-13 with Sea Rise

Appendix A – Areas of Concern

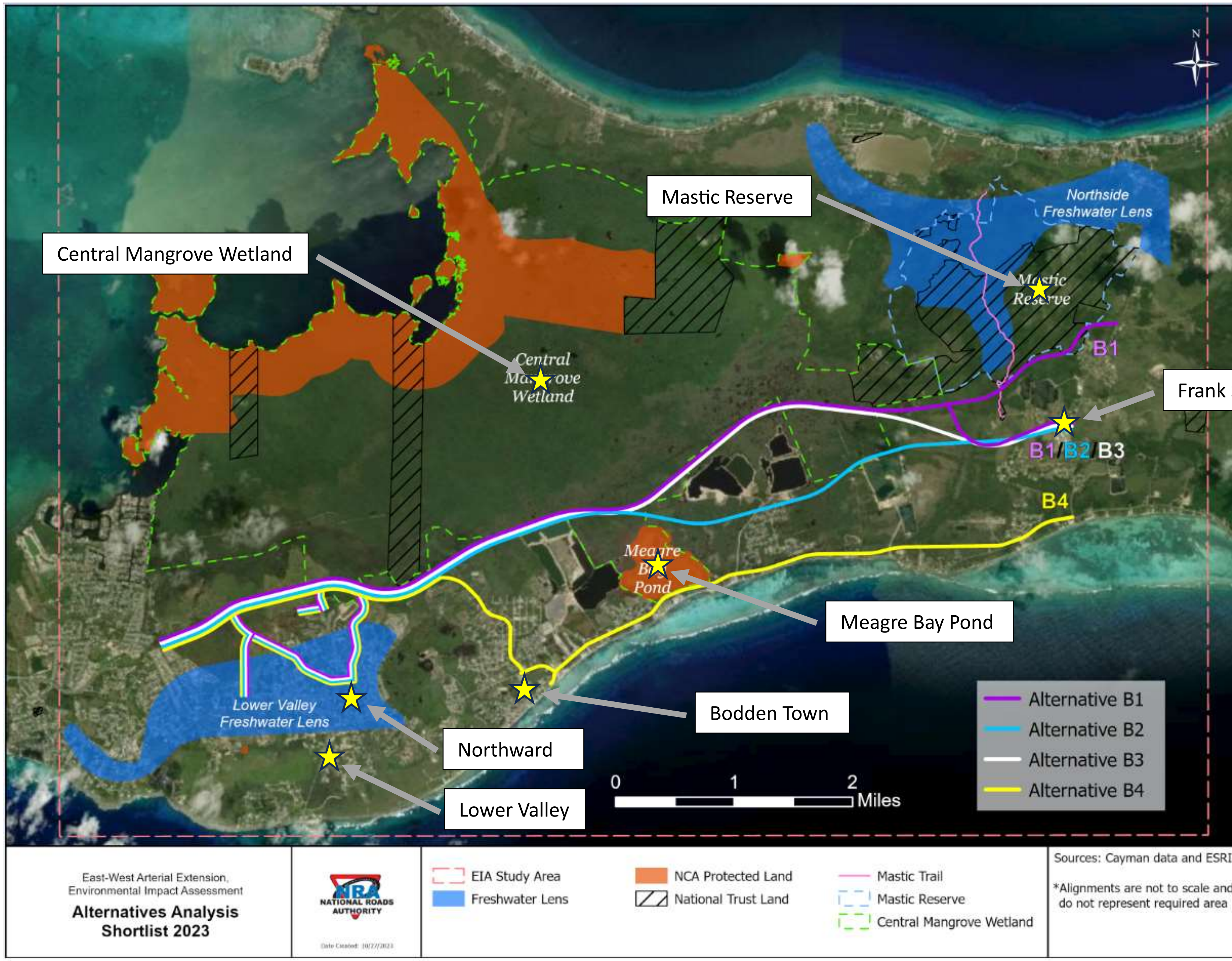
EWA Extension EIA Study - Interest for Potential Impoundment Areas During Heavy Rainfall Events



Base mapping data provided by the Lands & Survey Department - Map produced by Transportation & Planning Unit December 13, 2023

3,000 1,500 0 3,000 6,000 9,000 12,000 15,000 18,000 21,000 Feet

Locations of Concern



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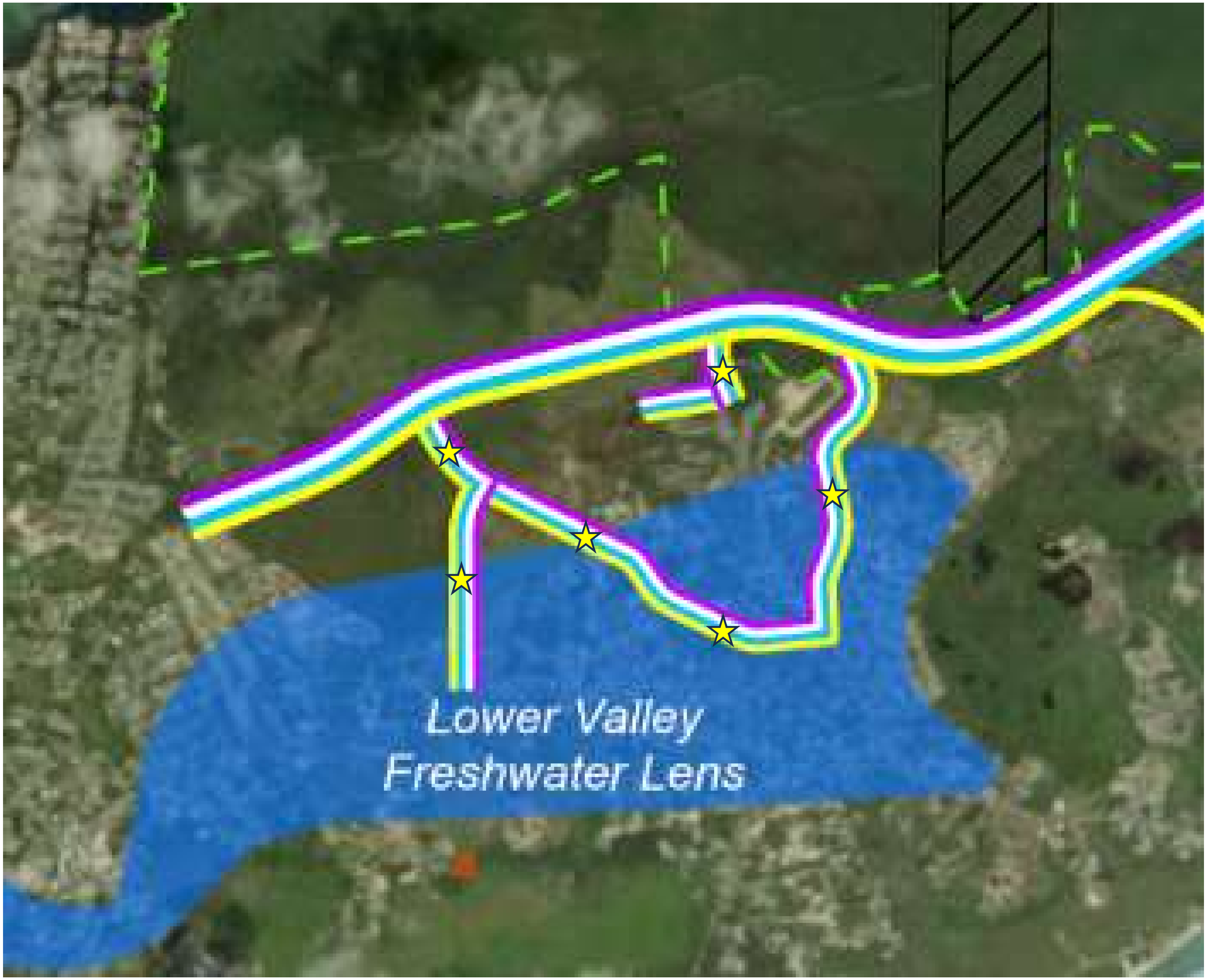

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January 29, 2024

Mr. Edward Howard, MSCE
Managing Director
National Roads Authority
Cayman Islands Government
P.O. Box 10426
Grand Cayman, KYI-1004, Cayman Islands

Reference: Pre-Project H&H Studies Related to the Proposed EW Arterial Expansion Project
Discussion of Roadway Openings Along the Proposed Alignment

Dear Mr. Howard:

Remington and Vernick Engineers, Inc. (RVE) and W. F. Baird & Associates Coastal Engineers, Ltd (Baird) were contracted by the National Roads Authority (NRA) to conduct Pre-Project Hydraulic and Hydrologic (H&H) analysis to support the Environmental Impact Assessment (EIA) of the proposed East-West Arterial Highway.

RVE was tasked with modeling rainfall events while Baird was tasked with modeling effects associated with hurricanes including storm surge and wave runup.

During the course of the modeling RVE and Baird analyzed different numbers and placements of proposed openings in the roadway. From these simulations, we developed a conceptual layout of the openings. Due to the preliminary nature of the analysis and the inaccuracies in the underlying data sources these openings were not optimized and fully coordinated.

These H&H models simulate discrete events and are not considered cumulative effects. The differences in the number and location of the roadway openings should not be considered contradictory between the analysis sets.

RVE and Baird recommend that the EIA team use the roadway openings and locations from the RVE H&H analysis as they present a more conservative approach to both cost and environmental impacts.

Please note the opening numbers and locations are considered proof-of-concept and will require significant development and detailed refinement by both engineering and H&H modeling during the future stages of project development.

Sincerely,

Remington & Vernick Engineers, Inc.

Steven B. Bolt, PE, PTOE
Regional Director

W. F. Baird & Associates Coastal Engineers, Ltd

Derek Williamson, MSc Peng
Principal

Hydraulic and Hydrologic Studies of Proposed East-West Arterial Highway Expansion

Prepared For:

The National Roads Authority (NRA) of the Cayman Islands
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Date Prepared:
August 11, 2022

Table of Contents

List of Tables

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List of Abbreviation

CI: Cayman Islands

FDOT: Florida Department of Transportation IDF:

Intensity-Duration-Frequency

NOAA: USA National Oceanic and Atmospheric Administration NRA:

National Roads Authority in Cayman

NRCS: USA National Resources and Conservation Service

WA: Water Authority - Cayman

Introduction

This rainfall analysis memorandum has been prepared under the pre-project hydraulic and hydrologic studies related to the National Roads Authority (NRA) proposed East-West (EW) Arterial Highway Expansion Project on Grand Cayman Island. Remington & Vernick Engineers has been retained to prepare a Hydraulic and Hydrologic study for the proposed EW Arterial Expansion by NRA. This report analyzes the Grand Cayman Island rainfall data to determine the intensity-duration-frequency amounts for various rainfall events and the rainfall distribution.

Various short term and long-term rainfall data in different time steps were provided by the client. Data was analyzed for quality control then used to determine the design storms to be used in the proposed highway drainage infrastructure of the study area. To better represent and understand the rainfall data, descriptive statistical parameters including maximum, minimum, average, median, and 1st Quartile and 3rd Quartile of the rainfall or calculated rainfall were calculated. Frequency analysis, correlation and regression methods were used to study of the similarity of the weather station as well as prediction of the events with various return periods.

Grand Cayman Island Climate

In general, based on the Köppen- Geiger climate map, the climate of the Cayman Islands is a combination of tropical hot and humid throughout the year, with a dry, relatively cold months from late November to mid-April [1]. The average amount of precipitation is almost 1,400 millimeters (55.10 inches) per year, and the wettest months are September and October.

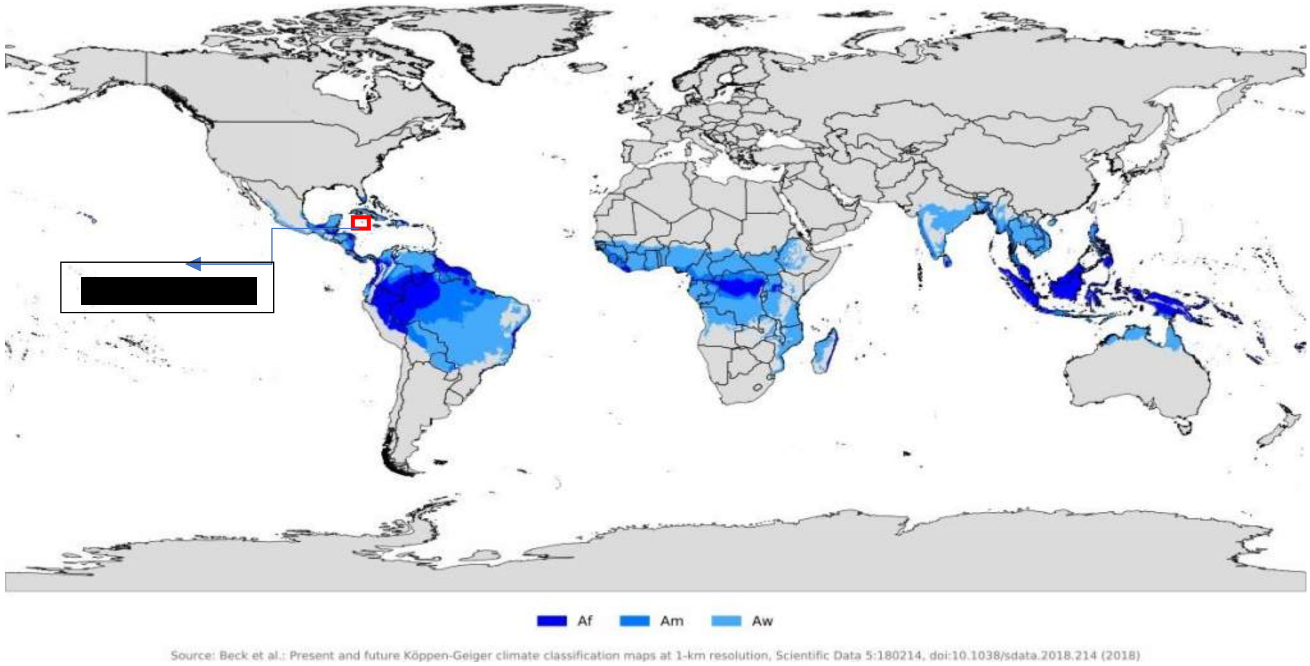


Figure 1 Köppen- Geiger classification of the study area

Rainfall Analysis

Three sets of rainfall data were received. The first two sets of data included a set of daily rainfall data of the Cayman Islands Water Authority rain gauges or weather stations data that includes, at minimum, 16 rainfall stations spanning from 1982 to 2021. The third set of data received was the hourly data of from 4 weather stations including ACWW, AGRI, CWCWB and DVNS (Figure 2). The second set of data spanned from 2009 to 2022. Table 1 shows the availability of the hourly data. HOBOware software was used for retrieving the logged data by HOBO onset data loggers. A spreadsheet of yearly totals at Grand Cayman containing the greatest 24-hour rainfall by month for years 1988 to 2022 was also received.

Method

The received data was checked for quality assurance. A correlation study was used to determine the correlation between the rain gauges. The stronger correlation shows the similarity of the recorded data between two weather stations and the missing data of one station can be estimated by the correlation relation.

The daily (24 hours) recorded data was used for maximum daily rainfall intensity analysis. Daily data is available from year 1982 to year 2021 for the majority of the rain gauges under the jurisdiction of Water Authority across Grand Cayman Island. The peak 24 hours rainfall from the weather stations were identified and then the maximum daily (average 24-hours) intensity was calculated. The data was used for rainfall intensity analysis as well as extreme event identification.

Hourly data of 4 weather stations (Figure 2) including ACWW, AGRI, CWCWB and DVNS was used for the rainfall distribution analysis. 1-minute logged rainfall data was created from the recorded data loggers information and then the 5 minutes, 10 minutes, 15 minutes, 30 minutes, hourly, 6 hours, 12 hours and 24 hours time series were generated. The developed time series were used for rainfall distribution analysis and creating Intensity-Duration-Frequency (IDF) curves. The Weibull equation (T=m/n+1) was used for return period calculation, if needed, whereas m is the rank of the event and n is the total number of the studied events.
Probability (P=1/T) also was calculated as the inverse of the return period.

Rainfall Intensity

The result of the statistical investigation for maximum 24-hours rainfall intensity is shown on Figure 1. The intensities calculated are between 3.22 mm/hr (0.13 in/hr) to 20.49 mm/hr (0.81 in/hr) with a mean of 8.15 mm/hr (0.32 in/hr). The analysis showed the value of 20.49 mm/hr (0.81 in/hr) is an extreme event that corresponds to Hurricane Ivan, 2004. A time series was generated for the 40 years data and the return period was calculated. The Figure 4 shows the graph that includes rainfall intensities versus the return periods.

The data followed a logarithmic distribution. A linear logarithmic relation with a goodness of fit of 0.97 was fitted. The regressed relation expected a 100-year return period maximum 24 hours rainfall intensity as 26.73 mm/hr (1.05 in/hr). From the calculated return periods, the probability of each event was calculated and then the cumulative probability calculated. The result of cumulative probability versus maximum 24-hours rainfall depths are shown on Figure 5. It can be concluded from Figure 5 that 50% of the events have a maximum 24 hours rainfall depth of less than 200 mm (7.87 in) corresponding to 8.33 mm/hr (0.33 in/hr) and 90% of the events have a maximum 24 hours rainfall depth less than 300 mm (11.81 in) corresponding to 12.50 mm/hr (0.49 in/hr).

Table 1 Available Hourly Data

[redacted]														
January	×	×	×	×	DA	DA	×	C	DA	DA	×	×	×	×
February	×	×	×	×	DA	DA	C	C	DA	DA	×	×	×	×
March	×	×	×	×	DA	DA	C	C	DA	DA	DA	×	×	×
April	×	×	×	×	DA	DA	C	×	DA	DA	×	×	×	×
May	×	×	×	×	DA	DA	C	×	DA	DA	×	×	×	×
June	×	×	×	×	DA	DA	C	C	DA	DA	DA	×	×	×
July	×	×	×	×	DA	DA	DA	×	DA	×	DA	×	×	×
August	×	×	×	×	DA	DA	DA	DA	DA	×	DA	×	×	×
September	×	×	×	×	DA	DA	DA	DA	DA	DA	DA	×	×	×
October	×	×	×	DA	DA	×	DA	DA	DA	DA	×	×	×	×
November	×	×	×	DA	×	DA	DA	DA	DA	×	×	×	×	×
December	×	×	×	×	DA	DA	×	DA	DA	DA	×	×	×	×
[redacted]														
January	×	DA	DA	×	×	DA	DA	C	×	×	DA	DA	×	×
February	×	DA	DA	×	×	DA	C	C	DA	DA	DA	DA	×	×
March	DA	DA	DA	×	×	DA	C	C	DA	DA	DA	DA	×	×
April	DA	DA	DA	×	×	DA	C	DA	DA	DA	DA	×	×	×
May	DA	DA	DA	×	×	DA	C	DA	DA	DA	DA	×	×	×
June	DA	×	DA	×	×	DA	C	C	×	DA	DA	×	×	×
July	DA	×	DA	×	×	×	×	DA	×	DA	DA	×	×	×
August	DA	×	×	×	×	DA	×	DA	×	DA	DA	×	×	×
September	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
October	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
November	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
December	DA	DA	×	×	×	DA	×	DA	×	DA	DA	×	×	×
[redacted]														
January	×	DA	DA	DA	×	×		C	DA	DA	DA	DA	×	×
February	×	DA	DA	×	×	×	C	C	DA	DA	DA	DA	×	×
March	DA	DA	×	×	×	×	C	C	DA	DA	DA	DA	×	×
April	DA	DA	×	×	×	DA	C	DA	DA	DA	DA	DA	×	×
May	DA	DA	×	×	×	DA	C	DA	DA	DA	DA	DA	×	×
June	DA	DA	×	×	×	DA	C	C	DA	DA	DA	DA	×	×
July	DA	DA	DA	×	×	DA	×	DA	DA	DA	DA	×	×	×
August	DA	DA	DA	×	×	DA	×	DA	DA	DA	DA	×	×	×
September	DA	DA	×	DA	×	×	×	DA	DA	DA	DA	×	×	×
October	DA	×	×	DA	×	×	DA	DA	×	DA	DA	×	×	×
November	DA	×	×	DA	×	×	DA	DA	×	DA	DA	×	×	×
December	DA	DA	×	DA	×	DA	DA	DA	×	DA	DA	×	×	×
[redacted]														
January	×	×	×	DA	×	×	DA	C	×	×	×	×	×	×
February	×	×	×	DA	×	DA	C	C	×	×	×	×	×	×
March	DA	×	DA	DA	×	DA	C	C	×	×	×	×	×	×
April	DA	×	×	DA	×	DA	C	DA	×	×	×	×	×	×
May	DA	×	×	DA	×	DA	C	DA	×	×	×	×	×	×
June	DA	DA	×	DA	×	DA	C	C	×	×	×	×	×	×
July	DA	DA	×	DA	×	DA	DA	DA	×	×	×	×	×	×
August	DA	DA	×	DA	×	DA	DA	×	×	×	×	×	×	×
September	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×
October	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×
November	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×
December	DA	DA	×	×	×	DA	DA	×	×	×	×	×	×	×

DA Data Available

× Data was not available

C Data Available Among all Four Weather Station

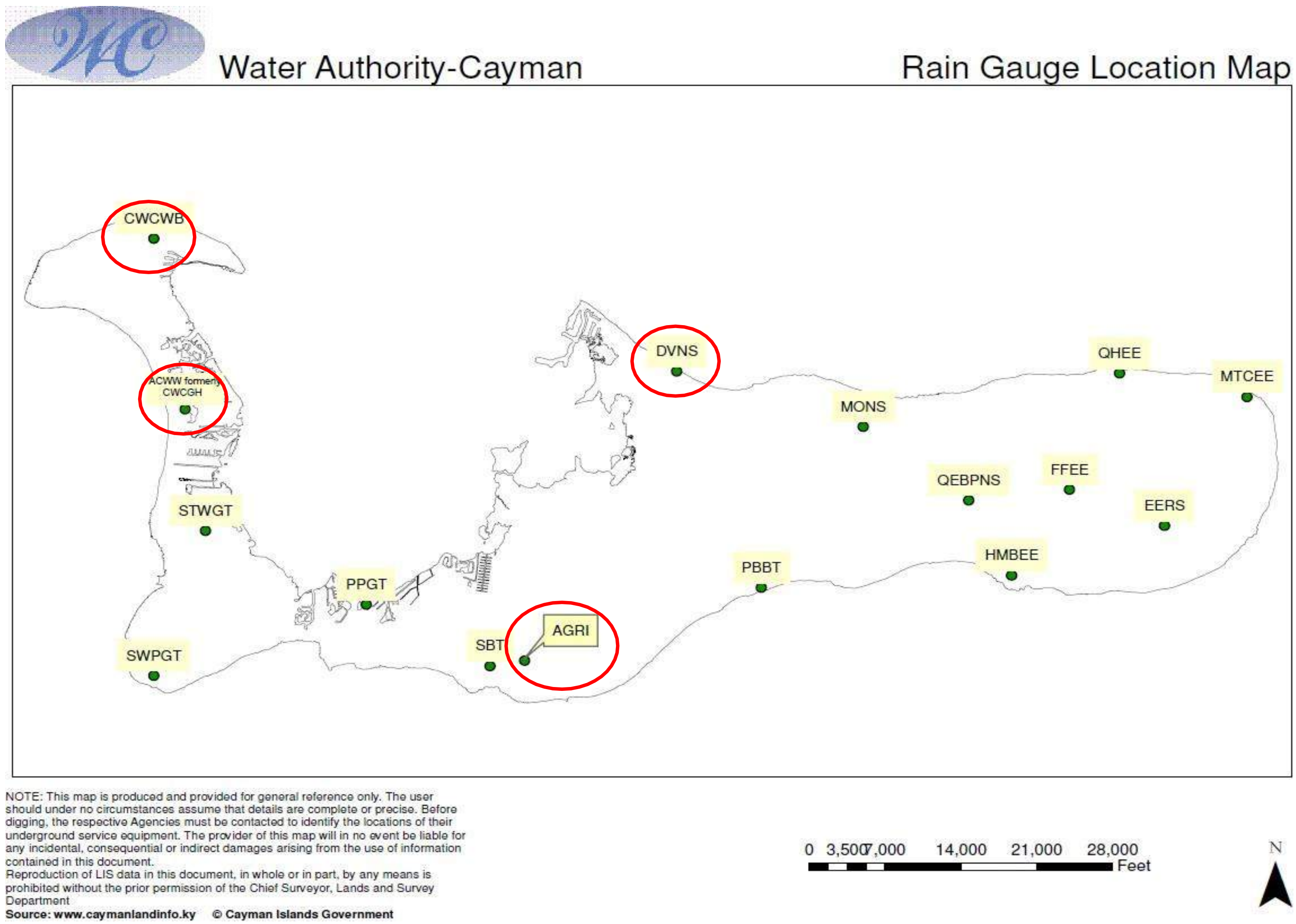


Figure 2 Map of the Cayman Island weather stations (red circled shows the station with hourly data)

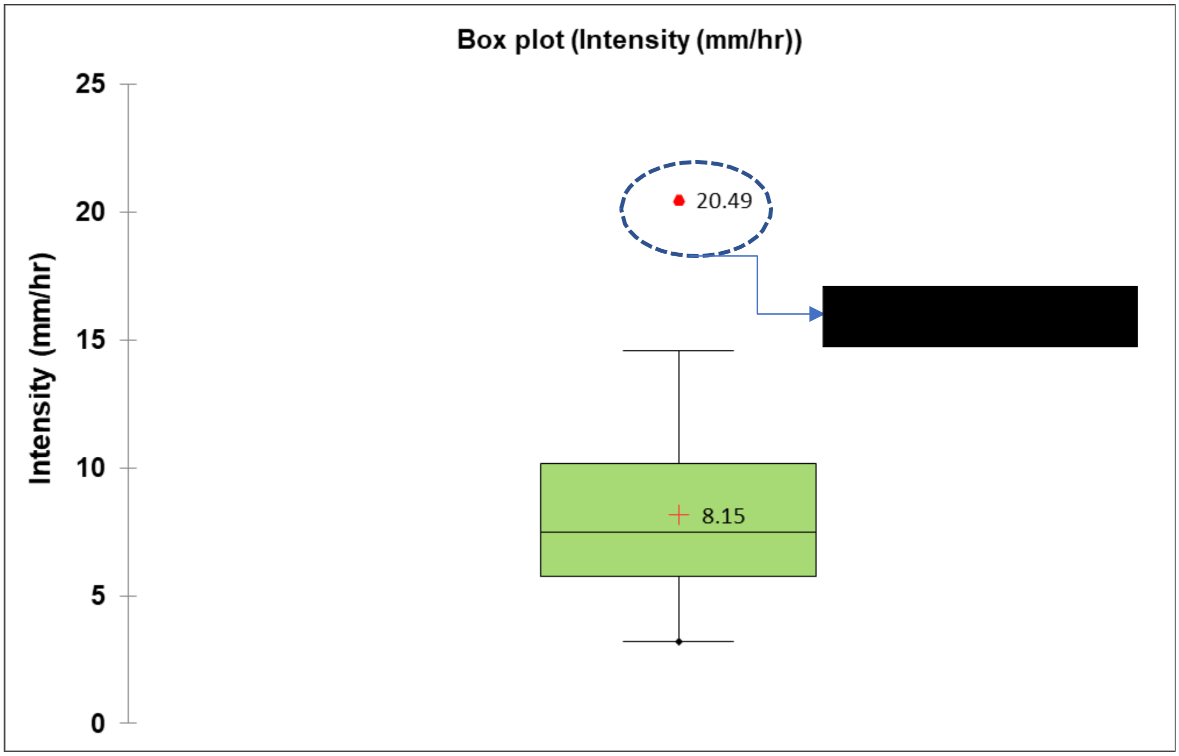


Figure 3 Maximum 24 hours rainfall intensity statistics

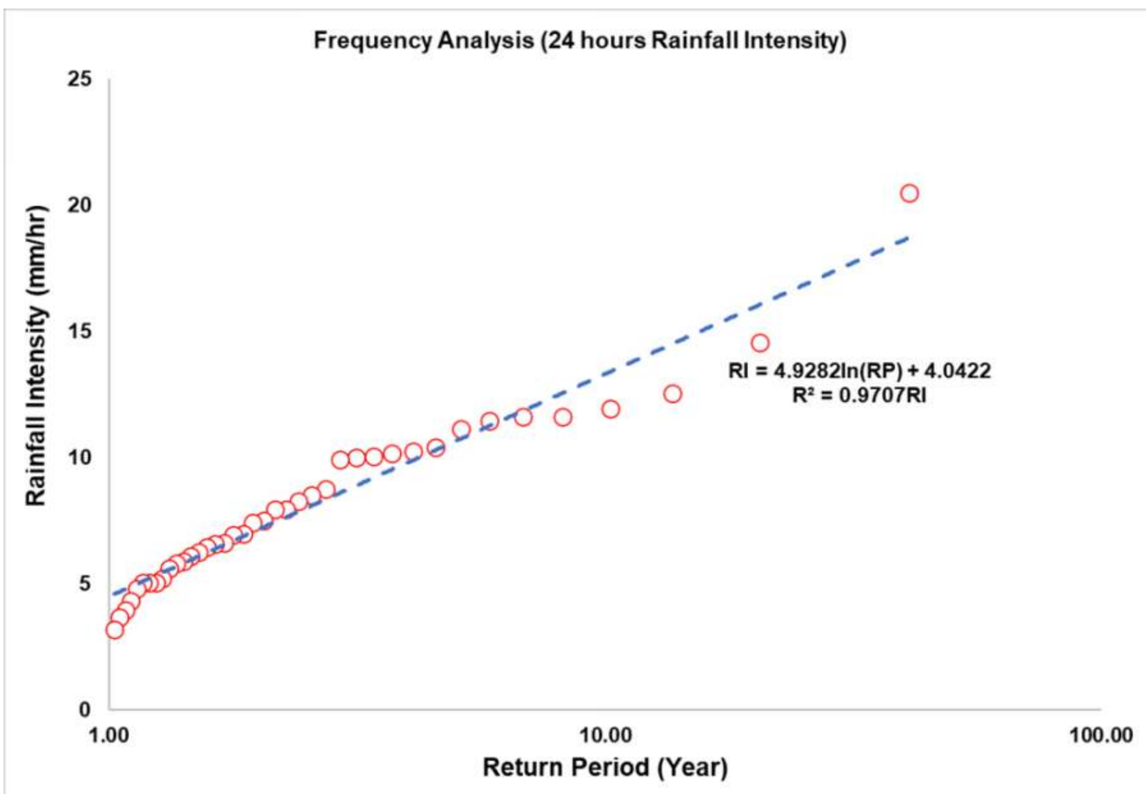


Figure 4 Maximum 24 hours rainfall intensities versus return period

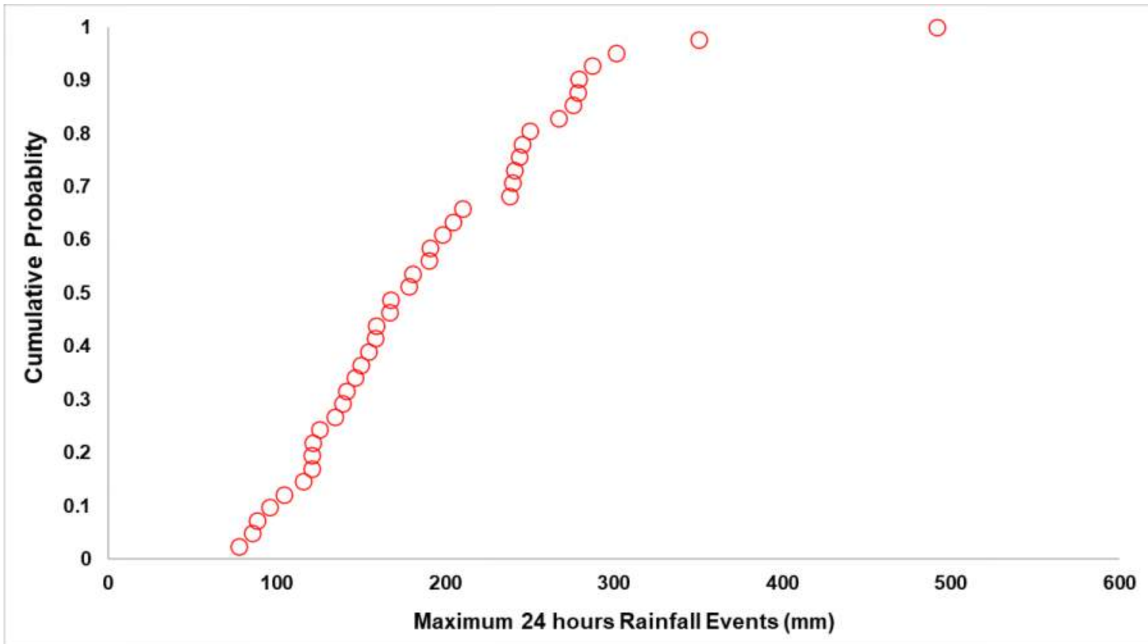


Figure 5 Cumulative probability versus maximum 24 hours rainfall depth

Hourly Rainfall Analysis

A correlation study among the rain gauges with hourly data was performed and the results are shown in the Table 2. Two periods, yellow highlighted in Table 1, in 2015 and 2016 when the data was available for all four rain gauges were selected for correlation study and the daily rainfall depths were used for analysis. CWCWB and DVNS showed the strongest correlation among the study rain gauges. The data from these two rain gauges can be used interchangeable and the missing data of one station can be estimated from the other one. The larger the correlation coefficient, the more accurate will be the predicted data.

Table 2 Correlation study among the rain gauges with hourly data

Year- Correlation (R^2)	Rain gauge	ACWW	AGRI	CWCWB	DVNS
2015	ACWW	1.0	0.24	0.39	0.17
	AGRI	0.24	1.0	0.4	0.33
	CWCWB	0.39	0.4	1.0	0.59
	DVNS	0.17	0.33	0.59	1.0
2016	ACWW	1.0	0.03	0.02	0.06
	AGRI	0.03	1.0	0.1	0.03
	CWCWB	0.02	0.1	1.0	0.4
	DVNS	0.06	0.03	0.4	1.0

Rainfall Distribution Analysis

Hourly data was used for distribution analysis. Each event was created from the rainfall data using a minimum of 25.4 mm (1 inch) and then 24 hours fractional rainfall depth calculated for each event. An average of the events was used for distribution analysis. Figure 6 shows the calculated distribution for the Water Authority rain gauges and its comparison with NRCS rainfall distribution and FDOT [4] in Figure 6 and the comparison with NOAA rainfall distributions and FDOT is depicted in Figure 7. While the expectation was that Grand Cayman Island follow the NRCS TYPE III rainfall distribution, the data mainly showed tendency towards the NRCS TYPE I distribution for hours 0 to 9 and the NRCS TYPE III distribution from hours 17 to 24 (Figure 6). Both the NRCS and NOAA types of distribution centered the events around mid-day and NRCS TYPE curves considered 50% of the event between hours 12 and 14 while NOAA considered 70% of the event between hours 12 and 14. FDOT uses a gradual type of distribution that centered around 12. Attachment B shows the NRCS type rainfalls across the United States. Attachments C & D shows the NOAA and FDOT rainfall distribution for various periods.

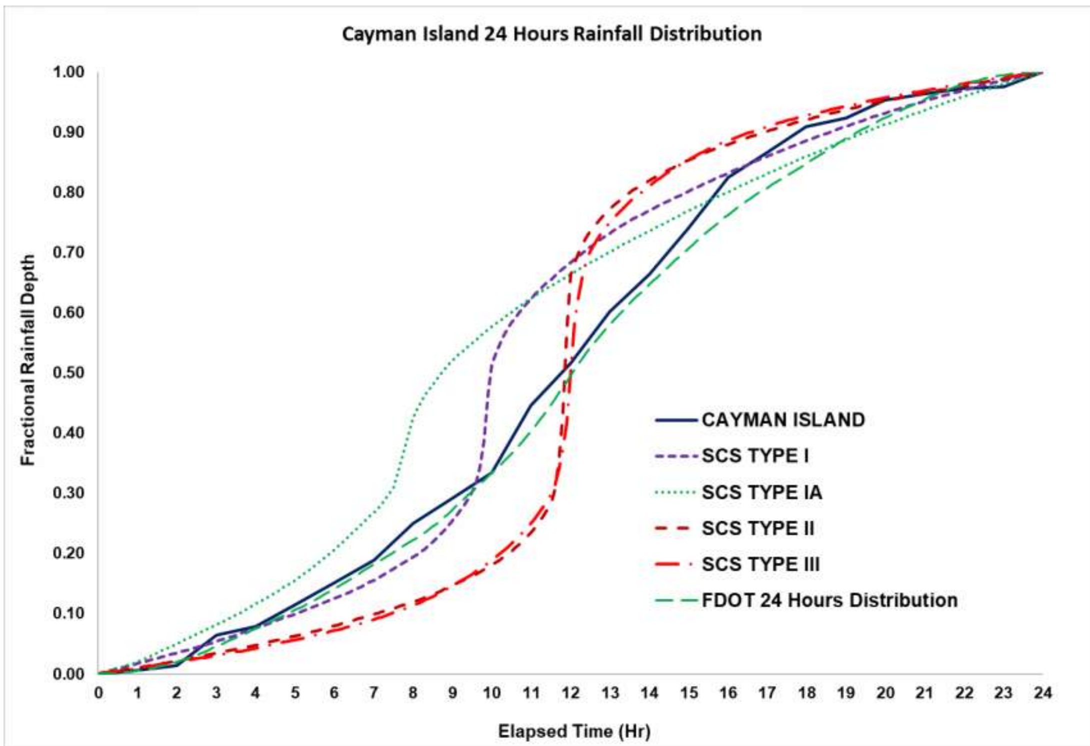


Figure 6 Estimated Grand Cayman Island rainfall distribution with regards to the NRCS distributions and the FDOT distribution

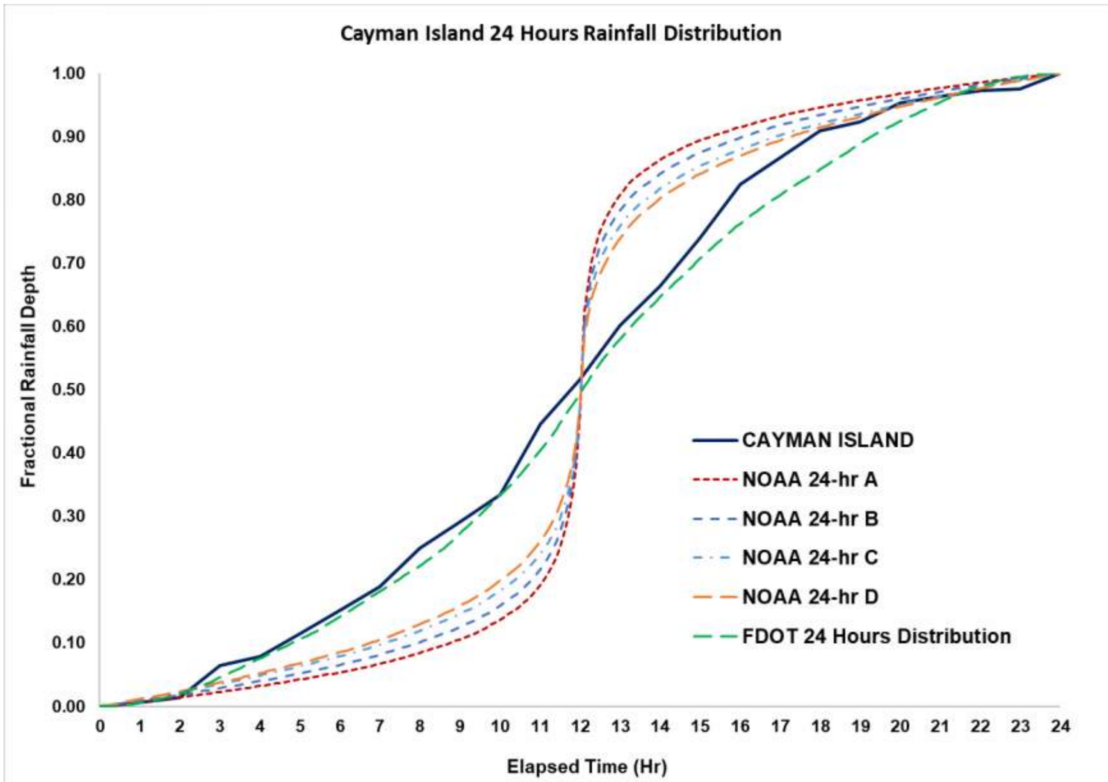


Figure 7 Estimated Grand Cayman Island rainfall distribution with regards to the NOAA distributions and the FDOT distribution

IDF Curves

For the generated time series with 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 6 hours, 12 hours, and 24 hours durations, associated rainfall intensities and return periods were calculated then the values were used for generating IDF curves. Initial IDF curves for the study area are shown in the Figure 8. As expected, the graph shows that the larger intensities are as the result of shorter duration rainfall events.

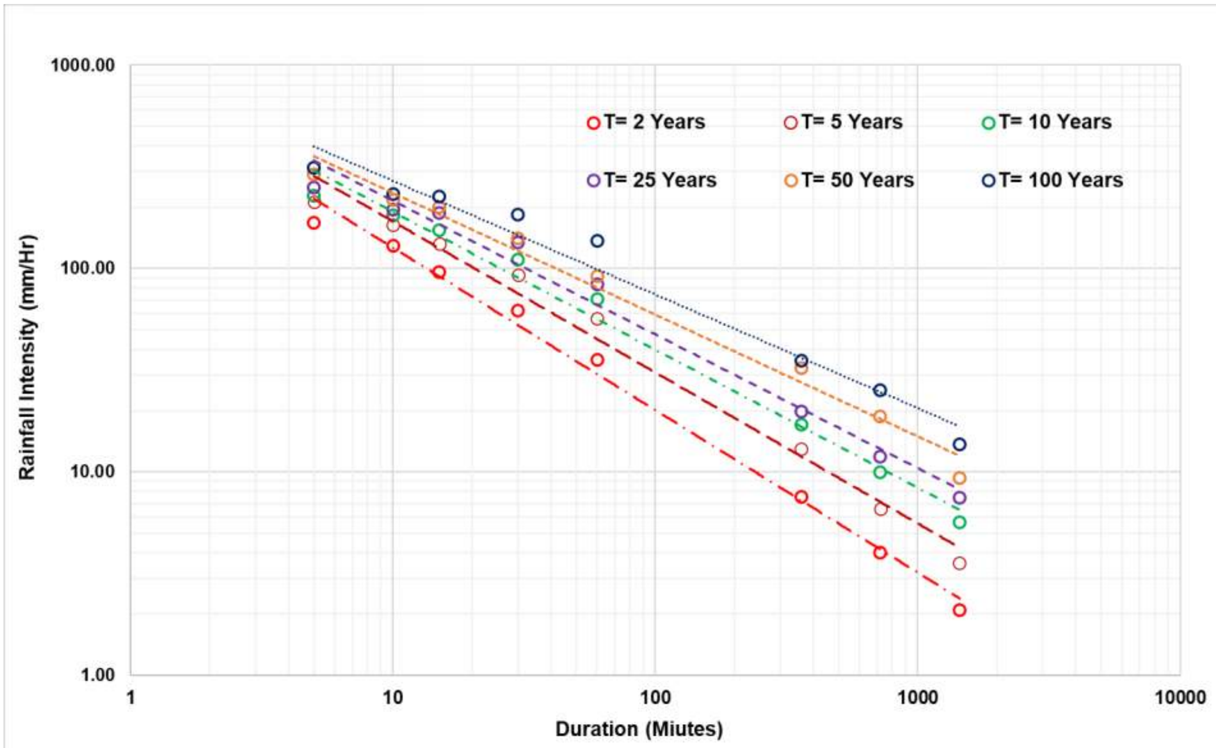


Figure 8 Calculated IDF curves for the study area

Conclusion

The available daily and hourly rainfall data was analyzed in this report. As it was discussed in earlier literature, there are a number of missing information and a lack of a long-term rainfall data in the study area that precludes identifying the IDF curves precisely [2]. The results of the IDF analysis correlate with the results presented by Baird and Associates [3] for the Cruise Berthing Facility (2015). Larger values for both the IDF curves and 25-years rainfall intensity were calculated. Additionally, it is demonstrated that the overall rainfall distribution shows a good agreement with FDOT rainfall distribution pattern.

References

1 Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences, 11(5), 1633-1644.

2 Lumbroso, D. M., et al. "The challenges of developing rainfall intensity–duration– frequency curves and national flood hazard maps for the Caribbean." Journal of Flood Risk Management 4.1 (2011): 42-52.

3 Baird and Associates (2015) Storm Water Master Plan Report for the Cayman Island Government Cruise Berthing Facility.

4 FDOT Drainage Design Guide (2019). State Of Florida Department of Transportation. Office Of Design, Drainage Section, Tallahassee, Florida

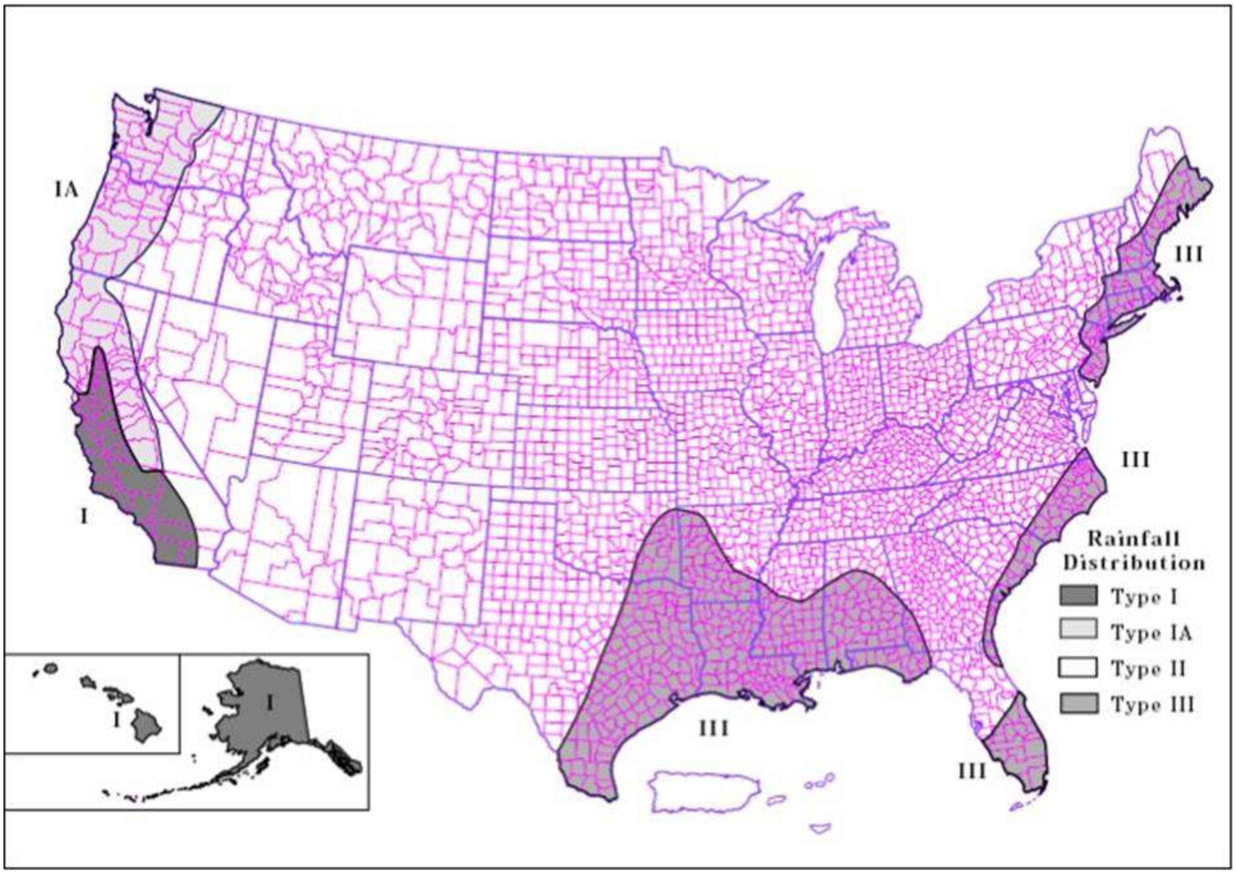
Attachments

A- Descriptive statistics of maximum 24 hours rain

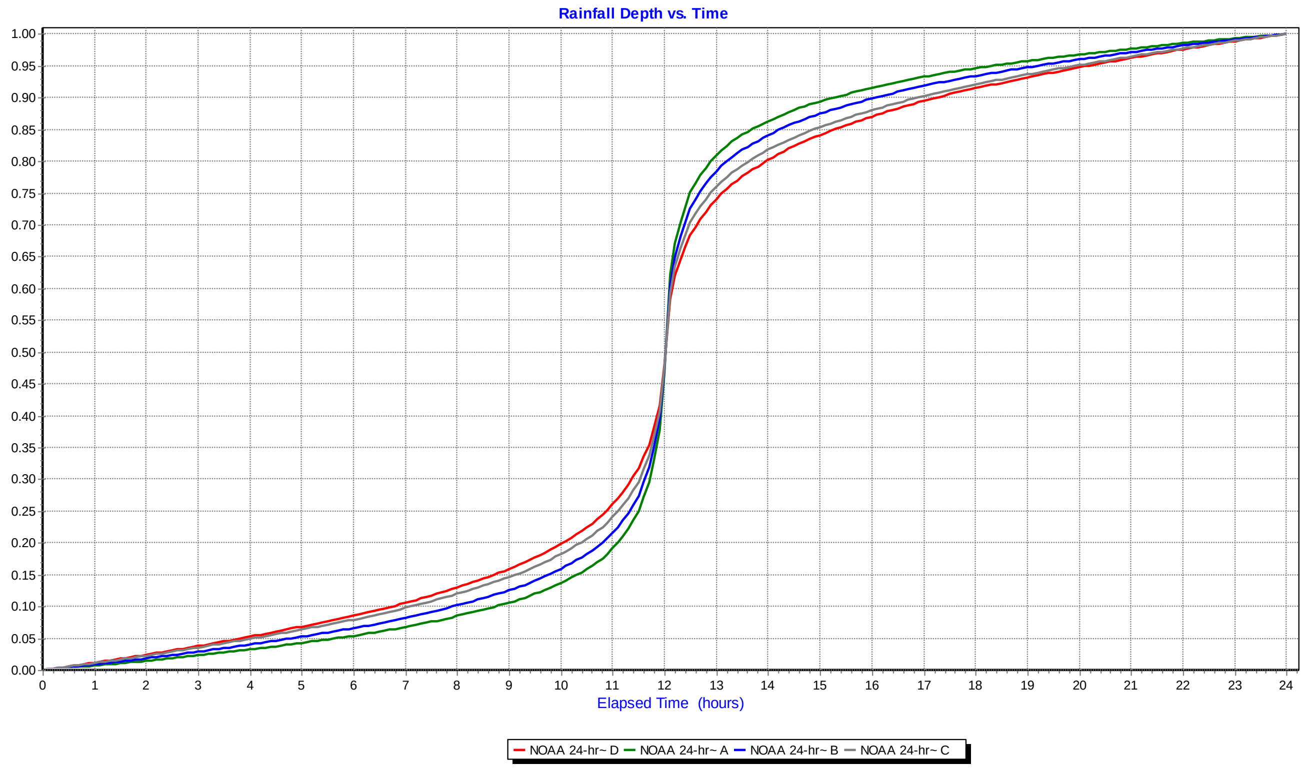
Descriptive statistics (Quantitative data):

Statistic	Intensity (mm/hr)
Number of observations	40
Minimum	3.217
Maximum	20.492
1st Quartile	5.749
Median	7.477
3rd Quartile	10.180
Mean	8.154
Variance (n-1)	11.723
Standard deviation (n-1)	3.424

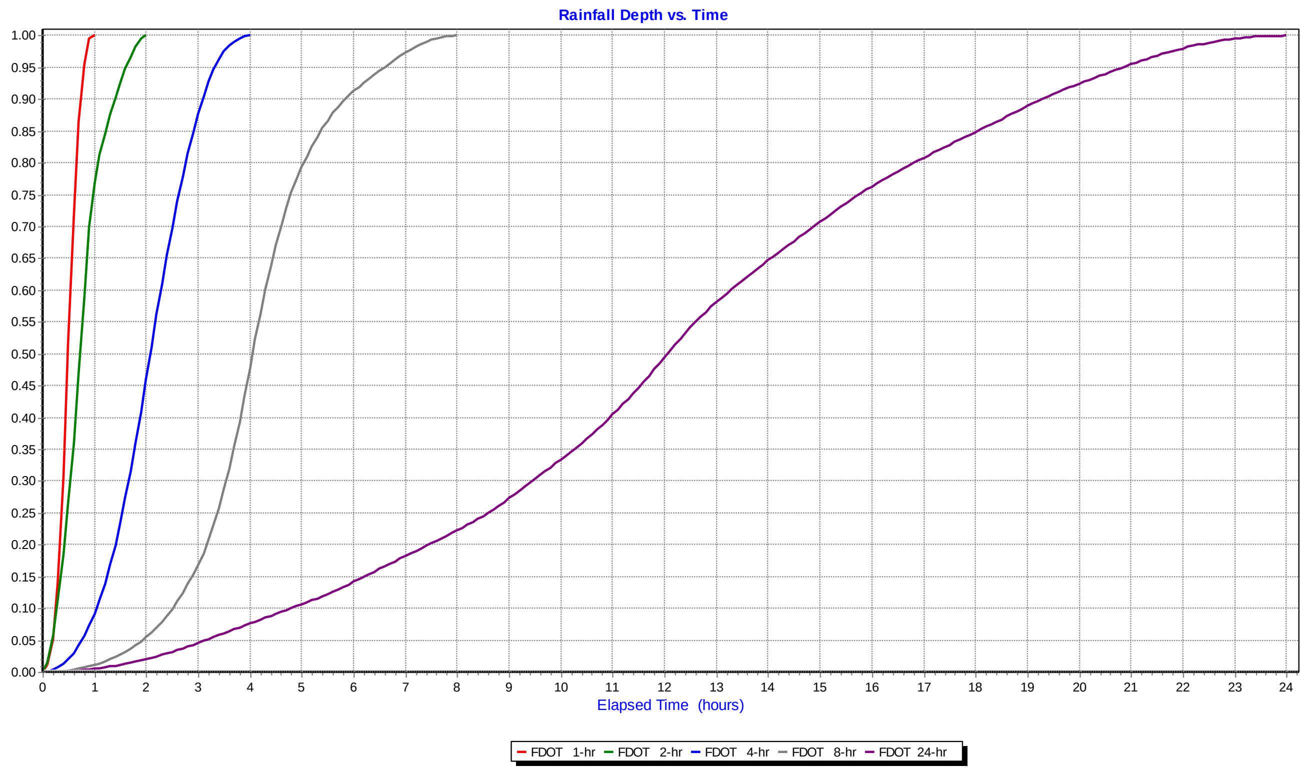
B- NRCS rainfall distribution across United States



C- NOAA rainfall distribution across United States



D- FDOT various rainfall distribution



Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion

Memorandum 2- Hydrology and Hydraulic (H&H) Analysis

Prepared For:

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370 North Sound Road (PWD Compound)
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Date Prepared:
Revised (March 2024)

Table of Contents

List of Tables

List of Figures

List of Abbreviations

CI: Cayman Islands

USGS: United States Geographical Survey

Lidar: “**li**ght **d**etection **a**nd **r**anging" or "**l**aser **i**maging, **d**etection**,** **a**nd **r**anging”

NRA: National Roads Authority

WA: Water Authority

QGIS: Quantum Geographic Information System

HEC-HMS: Hydrologic Engineering Center Hydrologic Modeling System

HEC-RAS: Hydrologic Engineering Center River Analysis Program

2D Model: Two-Dimensional Model

Introduction

This hydraulic and hydrology analysis memorandum has been prepared under the pre-project hydraulic and hydrologic studies for the Cayman Islands Government National Roads Authority (NRA) proposed East-West (EW) Arterial Roadway Project on Grand Cayman Island. Remington & Vernick Engineers has been retained to prepare a Hydraulic and Hydrologic study for the proposed EW Arterial Expansion by NRA. This report employed the results of the Grand Cayman Island rainfall analysis report (Memorandum 1) and land data to perform a two-dimensional hydraulic model. The Hydraulic model was used to prepare inundation flood maps under various rainfall events or scenarios. This report was initially prepared for the only proposed East-West roadway option and the revised report has been prepared for several roadway alternatives. Inundation flood maps for a 2-year, 10-year, 25-year, 50-year, 100-year, and Hurricane Ivan of 2004 were prepared for a bigger drainage area. In general, the results showed that for the studied scenarios the depth of the floods from a 2-year to a 100- year event would be between 0.15 ft and 6 ft along the proposed inland roadways and the flood depth can be up to 10 feet for the roadway alternatives near the coastal area on the southwest of the site.

Grand Cayman Island Climate

In general, based on the Köppen- Geiger climate map, the climate of the Cayman Islands is a combination of tropical hot and humid throughout the year, with dry, relatively cold months from late November to mid-April [1]. The average amount of precipitation is almost 1,400 millimeters (55.10 inches) per year, and the wettest months are September and October.

Method

Three software packages including QGIS, HEC-HMS and HEC-RAS were used to perform this study. The results of the rainfall study along with GIS information (lidar, land use, and soil information) were input into the models. QGIS was used to extract an approximate general limit of the study area from the larger GIS information that was provided by the client (Figure 1). The US Army Corps of Engineer's Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), that is designed to simulate the precipitation-runoff processes of dendritic drainage basins, was used for hydrologic analysis. Using Lidar information from Cayman Lands and Survey website, a terrain model, in Grand Cayman datum, of the study area was built using QGIS for input into HEC-HMS [2]. HEC-HMS was used for delineating the drainage area and subcatchments from the terrain model and to define their characteristics for the model and rainfall-runoff studies (Figure 2 and Figure 3). Watershed and subcatchment boundaries are determined in the analysis at the accuracy of the terrain model. Refinement of the boundaries requires greater accuracy of the terrain model and local investigation, particularly along Frank Sound Road. From the model, the general runoff direction is from the east and west towards the north.

The groundwater lenses are generally situated under the high ground areas at the top of the watershed. There is an exfiltration of the lenses into the mangrove areas of a small amount that is not included in the analysis.

Future land development along with the roadway corridor without stormwater volume and rate reduction measures will increase runoff occurring at a faster time into the mangroves. With stormwater volume and rate reduction measures, such as the deep well injection methods currently utilized, is expected to reduce rates and volumes, but at an unknown amount due to the differences in the hydrologic methods utilized. Future development has not been addressed in this study.

The outputs from the HEC-HMS model, including the delineated drainage area and hydrographs, were input to the US Army Corps of Engineer's Hydrologic Engineering Center River Analysis Program (HEC-RAS) for preparing two-dimensional flood maps of the study area. A 2D area of almost 22 sq miles was defined over the study area (Figure 4). The 2D area mesh contained more than 427,733 computational cells. Additional information to run the HEC-RAS 2D model [3] including land use, infiltration, and manning's coefficients [3&4] were prepared from the GIS information received along with information from the Cayman Water Authority, Department of the Environment, and Department of Agriculture on the soils and land use shown in Figures 5 and 6. The assumed Manning's coefficient, percent impervious area, and soil infiltration information parameters are summarized in Table 1 and Table 2. USGS guidelines and the HEC-RAS 2D user manual were used for Manning's coefficient and soil parameters selection. The proposed roadway alignments were exported from AutoCAD into QGIS. The Proposed roadway shape files were generated in QGIS and then imported into HEC-RAS 2D for demonstration on the flood inundation maps. Figures 10 through 15 show the final developed flood inundation and depth maps.

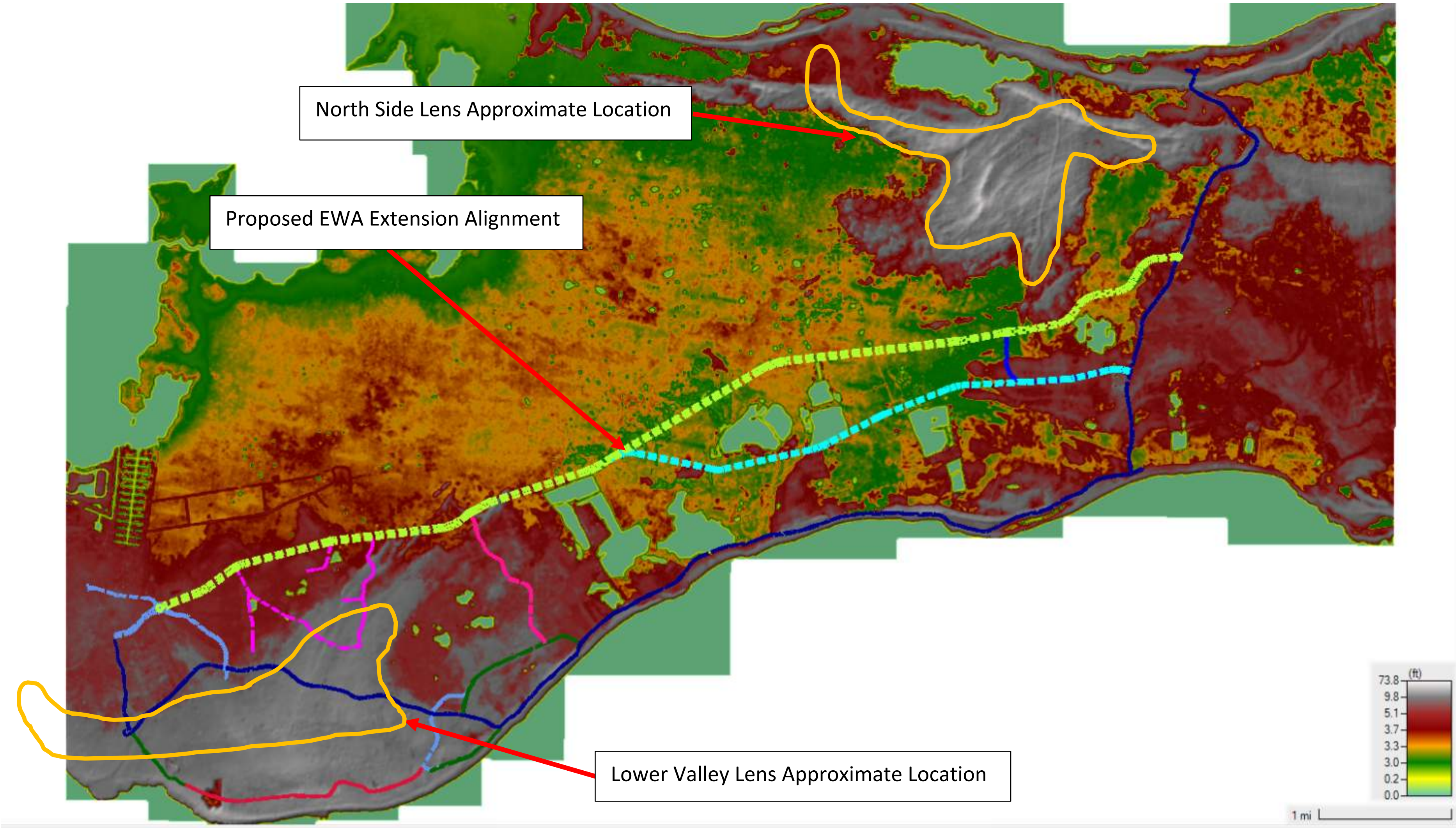


Figure 1 Study area boundary terrain model extracted by QGIS

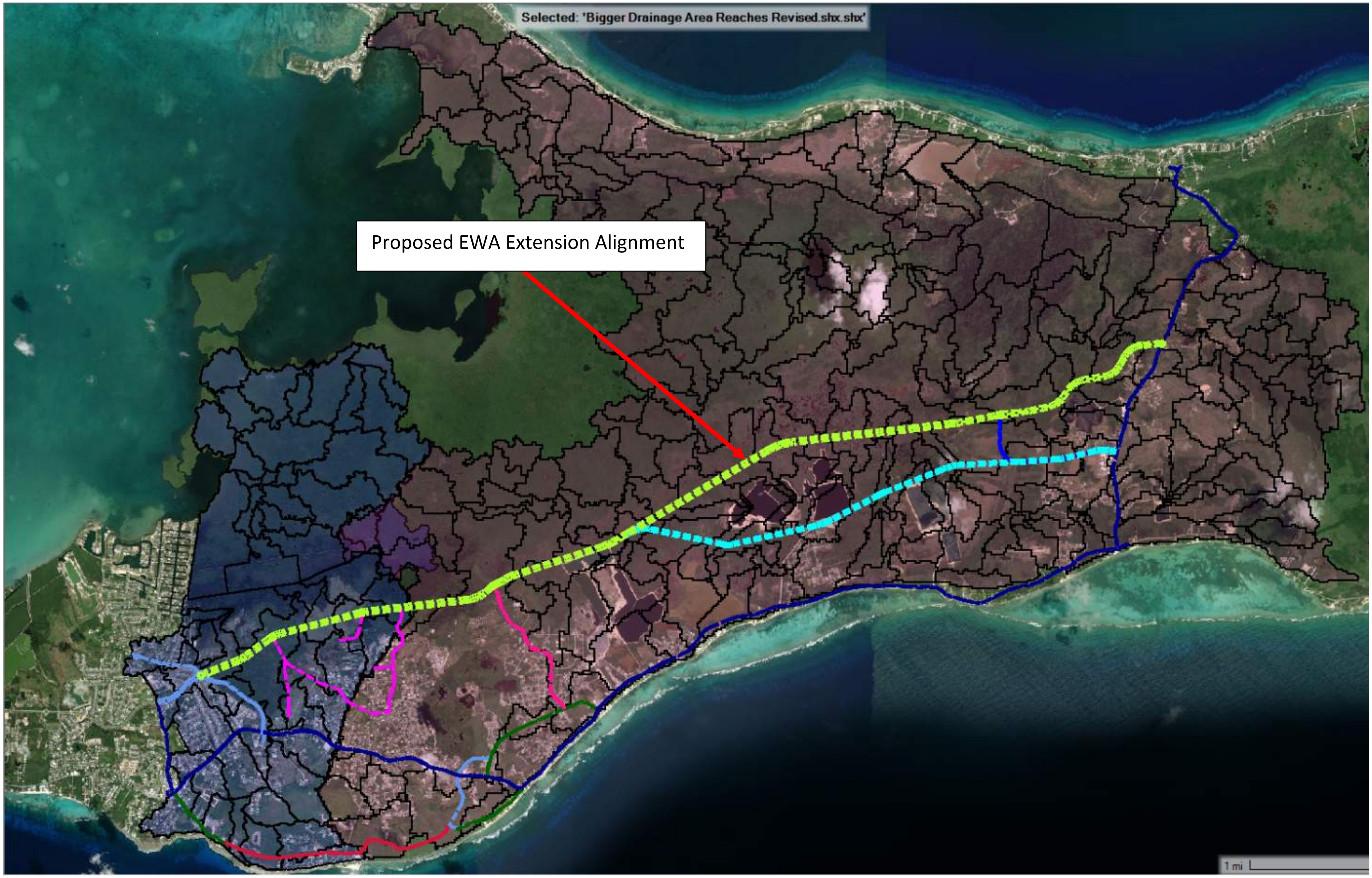


Figure 2 Delineated hydrological subcatchments for the study area

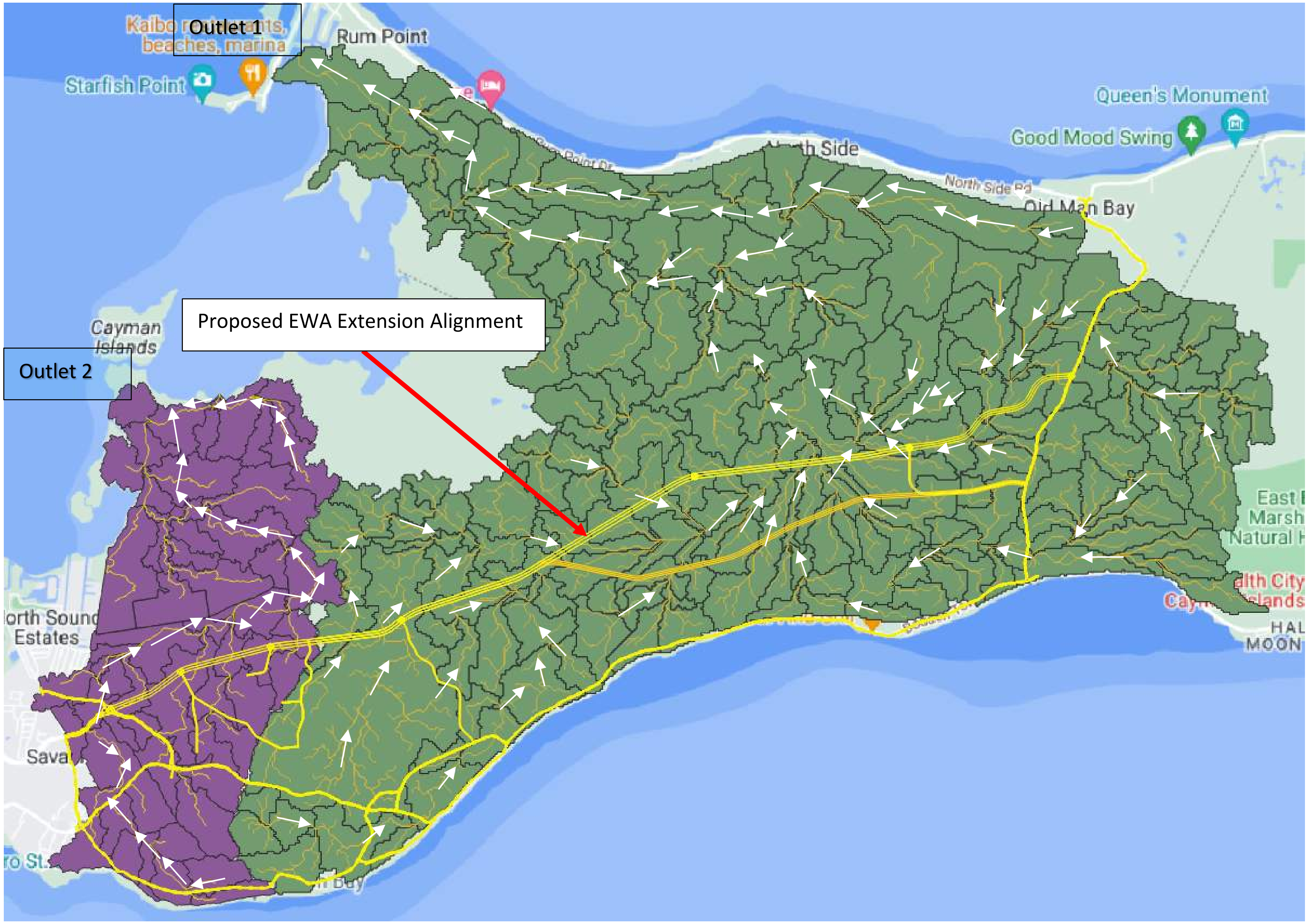


Figure 3 The delineated drainage area overlayed with a bigger Cayman Island map

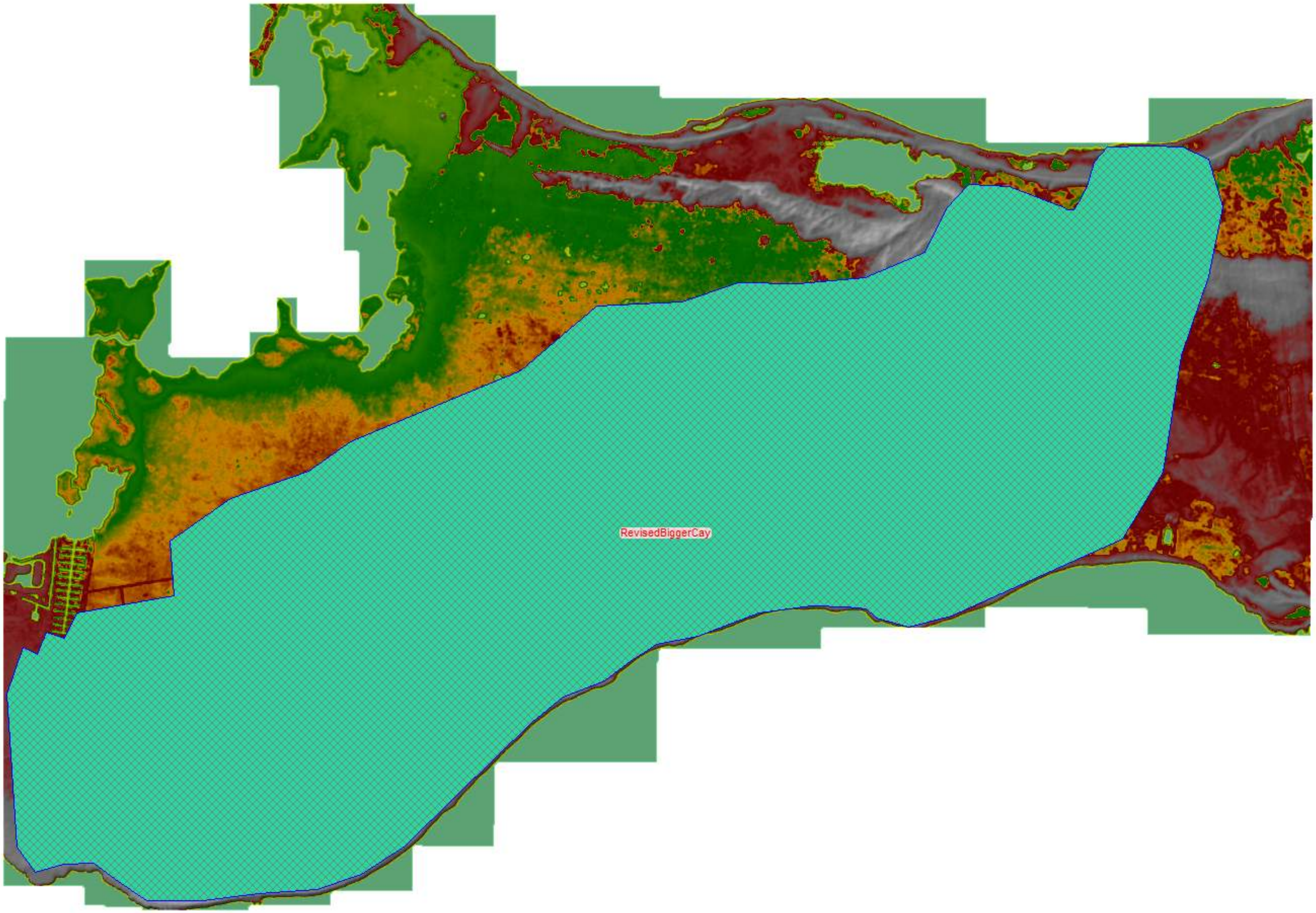


Figure 4 defined two dimentional flow area in HEC-RAS

Table 1 defined Manning's coefficient and percent impervious for Hec-2D model

ID	Name	Manning's' n	Percent Impervious
0	No Data	0.035	100
1	seasonally flooded mangrove forest and woodland	0.045	75
2	dry forest and woodland	0.10	60
3	seasonally flooded - saturated semi-deciduous forest	0.15	70
4	invasive species - casuarina	0.03	45
5	coastal shrubland	0.1	85
6	seasonally flooded mangrove shrubland	0.085	40
7	dry shrubland	0.07	60
8	ponds, pools, and mangrove lagoons	0.025	100
9	urban	0.03	80
10	man-modified without trees	0.025	90
11	man-modified with trees	0.15	60
12	semi-permanently flooded grasslands V.A.1.N.h [5]	0.1	100
13	salt tolerant succulents	0.11	30
14	tidally flooded mangrove forest and woodland	0.035	40
15	dwarf vegetation and vines	0.12	50

V.A.1.N.h as defined in Aicta, N. Ahmad (1996). Agricultural Land Capability of the Cayman Islands Land use identifications from Department of the Environment [6].

Table 2 Selected curve numbers, abstraction ratio and minimum infiltration rate for HEC-2D Model

ID	Name	Curve Number	Abstraction Ratio	Minimum Infiltration Rate (in/hr)
0	No Data	0	0	0
1	4	60	0.15	0.3
2	3	70	0.1	0.35
3	6	40	0.25	0.4
4	1	95	0.05	0.1
5	2	85	0.08	0.2
6	5	45	0.2	0.35
7	Pond	100	0	0

Soil identifications from Aicta [5].

Studied Scenarios

The results of the Memorandum 1, Rainfall Studies, were used to develop several rainfall scenarios for 2-year, 10-year, 25-year, 50-year, 100-year, and the 2004 Hurricane Ivan. The diffusion wave equation was selected for the 2D studies. The model was run for the existing conditions with various 24-hours scenarios (Figures 7, 8, and 9) and the results are shown in Figures 10 through Figure 14. The result of simulated Hurricane Ivan is shown in Figure 15. Storm surge and wave flooding are being studied separately and are not included in this analysis.

Figure 18 shows the 100-year event with the general flow patterns. Of note is that the northern cut-off of the study area is in the mangroves where flow will be mixing into the North Sound. The area shown in red is an area where the flooding is slow moving multi-directional in nature. In this area, in the larger flooding events, the quarries and Meagre Bay Pond play a role in the flood flows. At the lesser magnitude 2-year and 10-year events, the flooding on each side of the East-West Arterial is more distinctly separated by high ground.

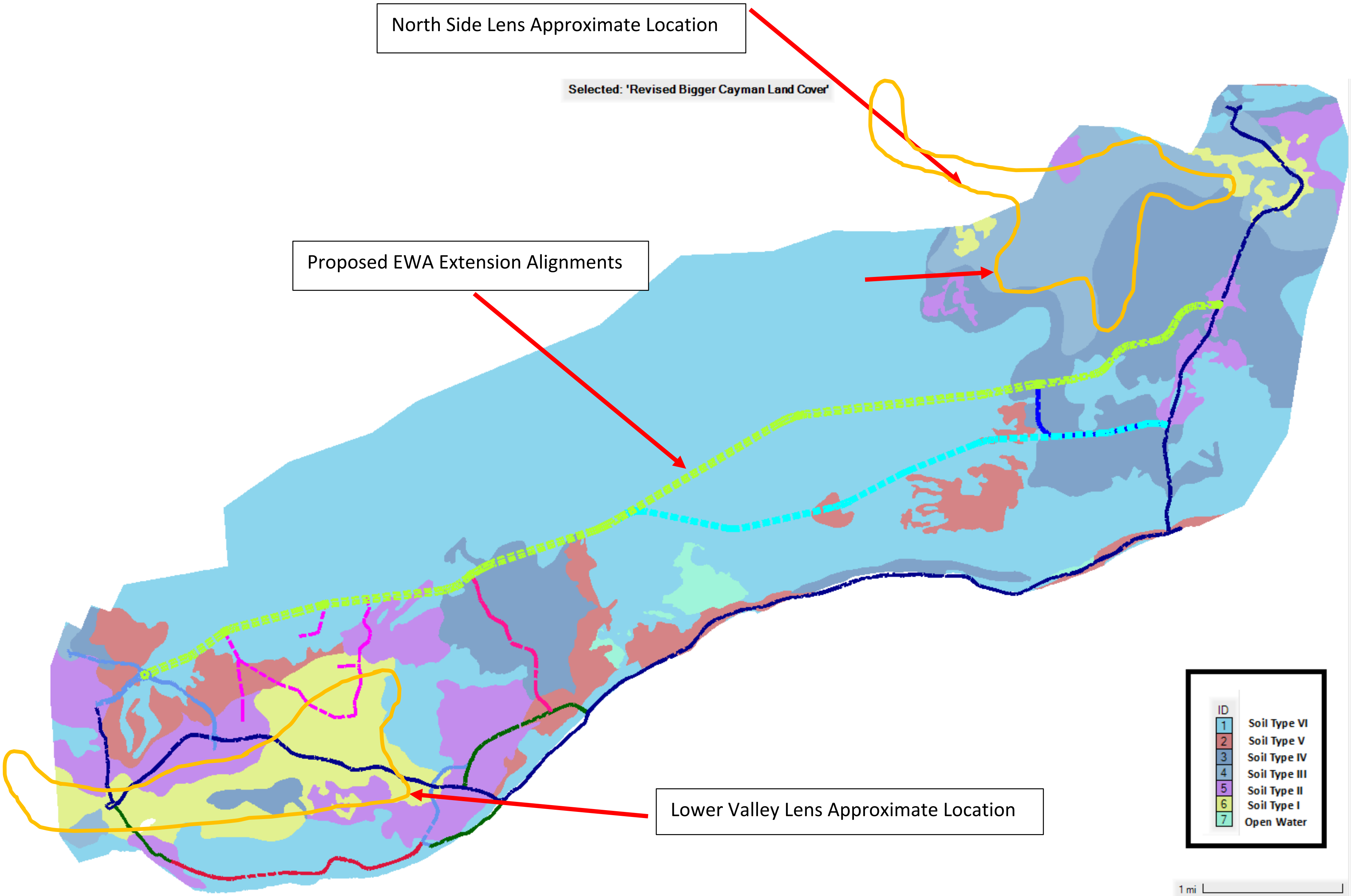


Figure 5 Soil types map of the study area, Aicta [5]

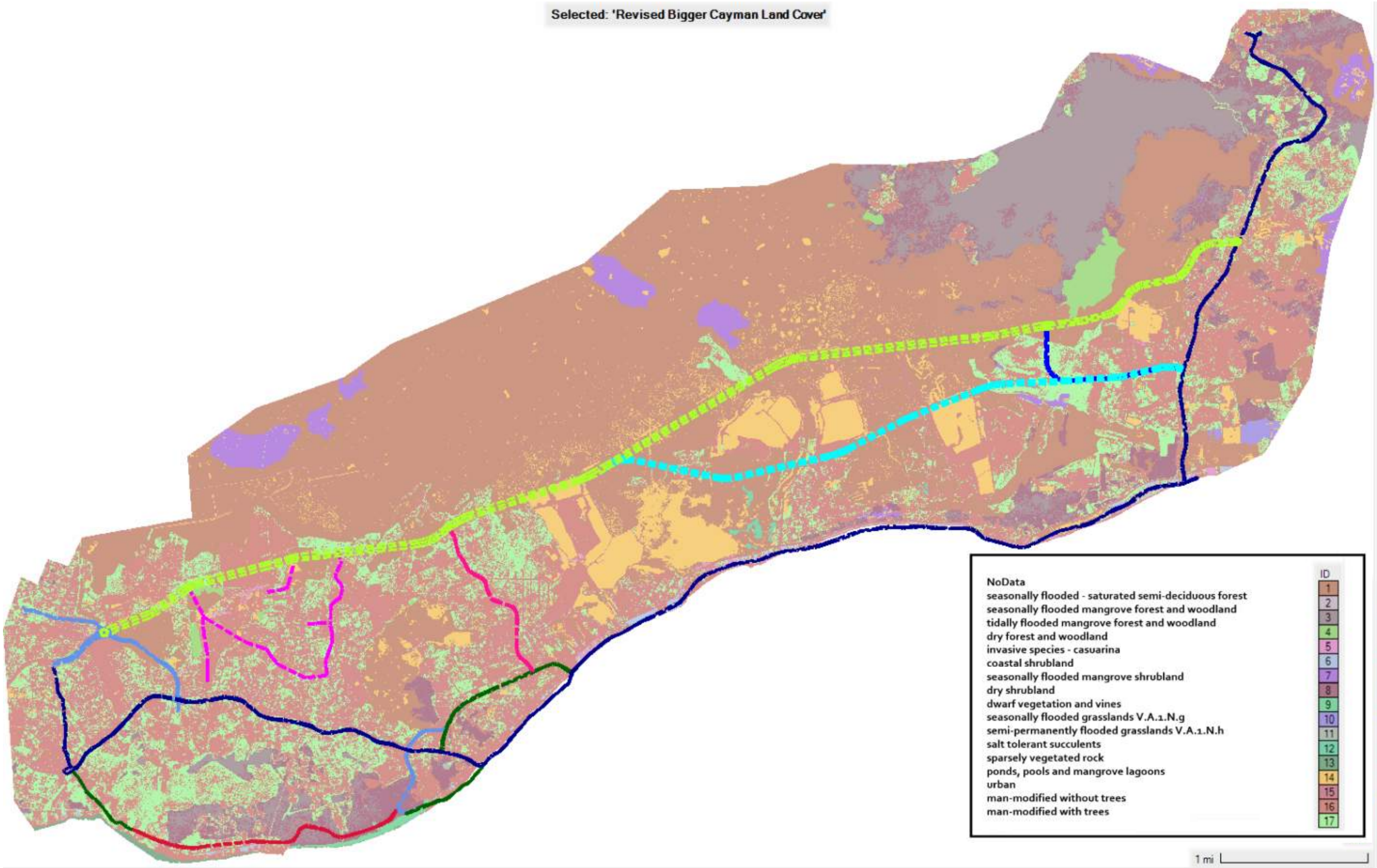


Figure 6 Land use map of the study area [6]

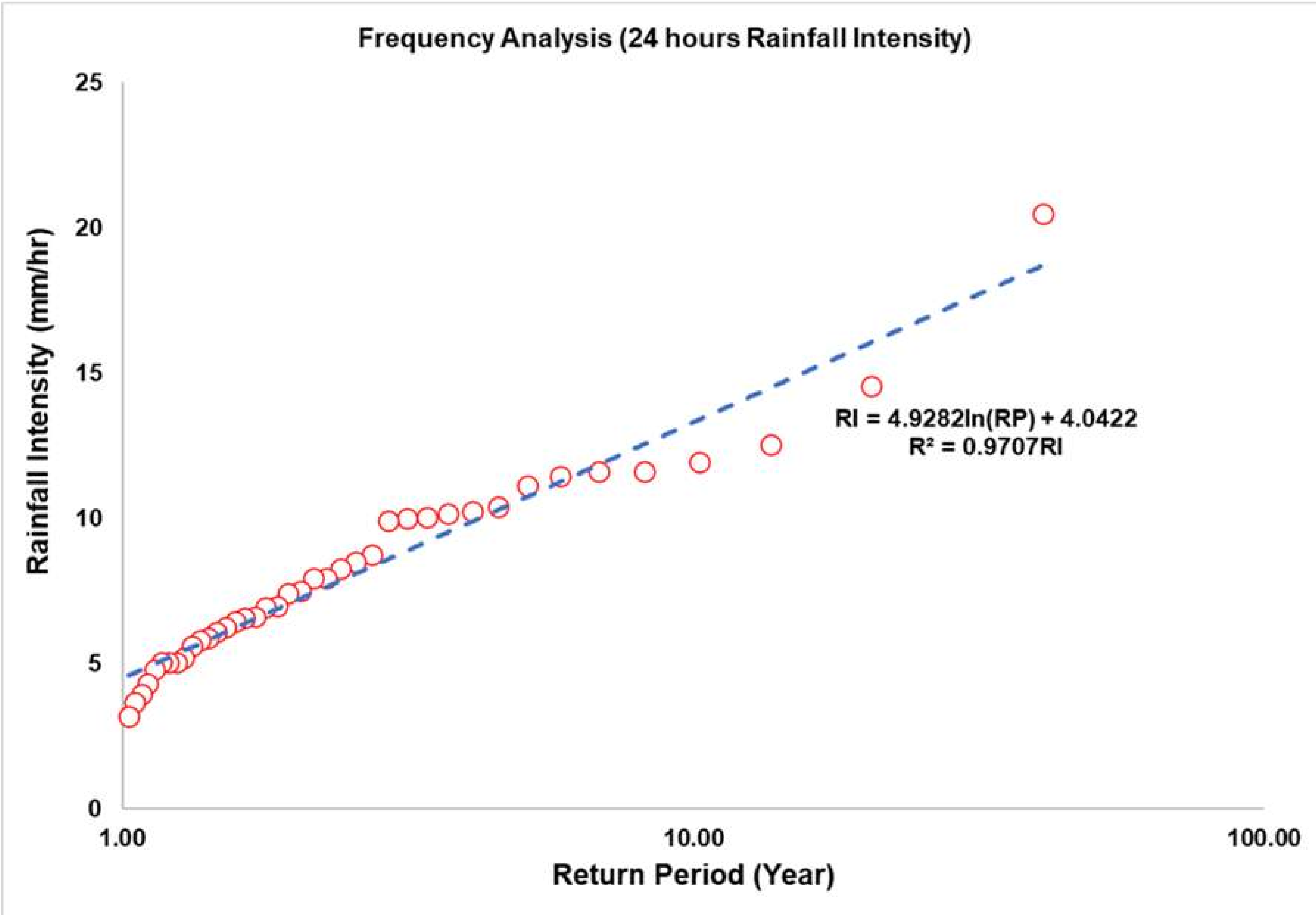


Figure 7 Rainfall intensity and return period relation for Cayman Island

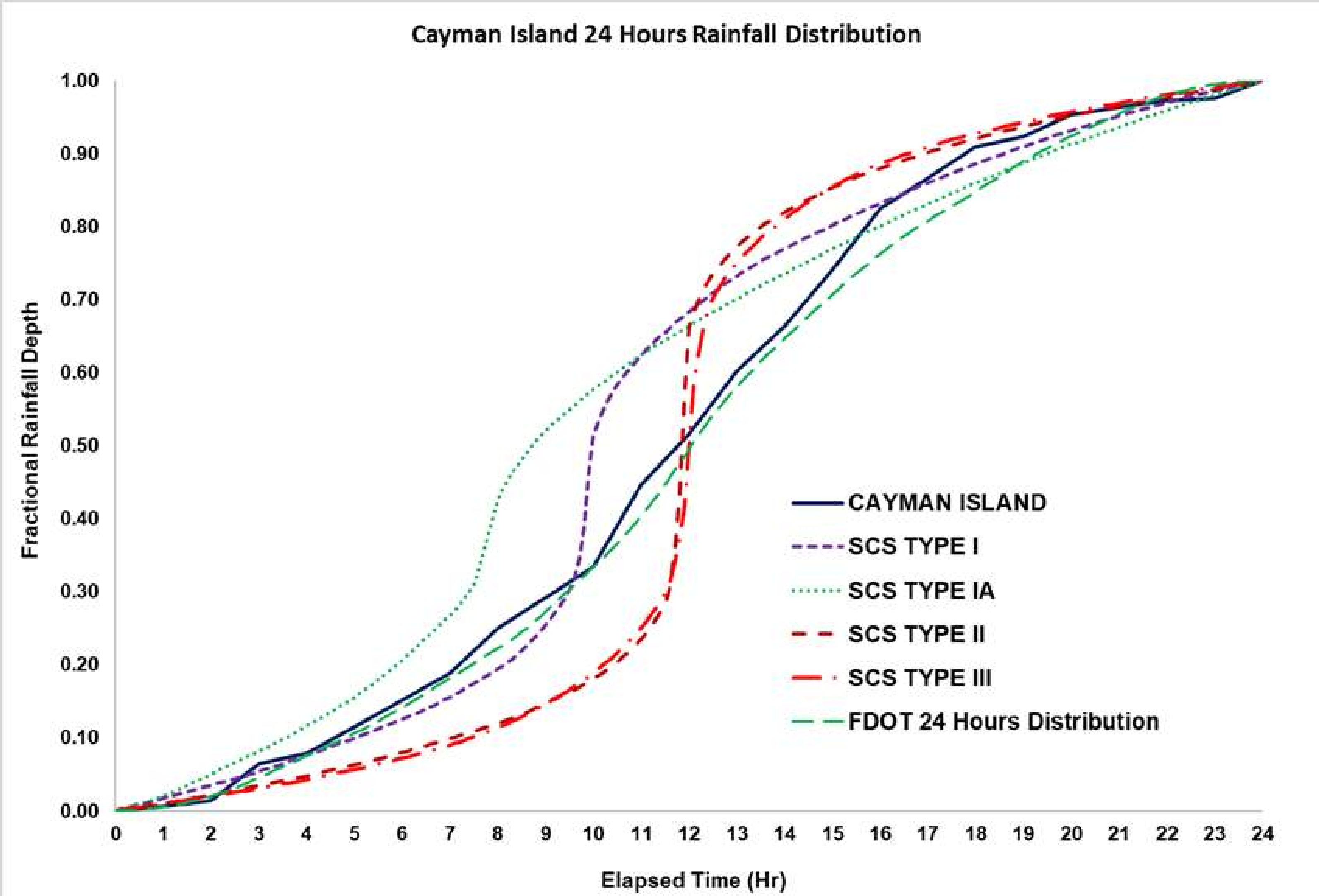


Figure 8 Cayman Island rainfall distibution with regards to various US distributions

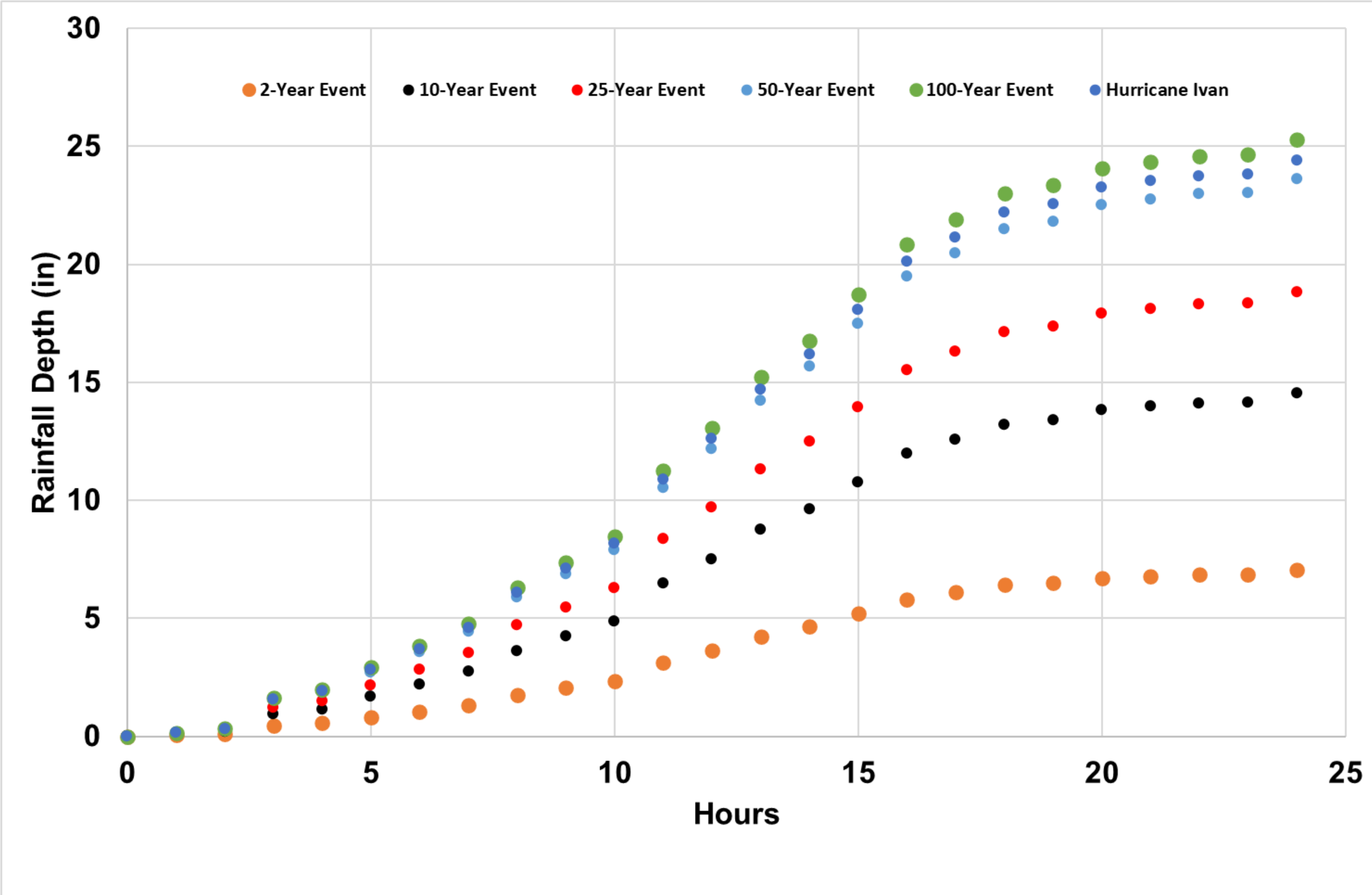


Figure 9 Developed various 24 hours rainfall distributions for Cayman Island

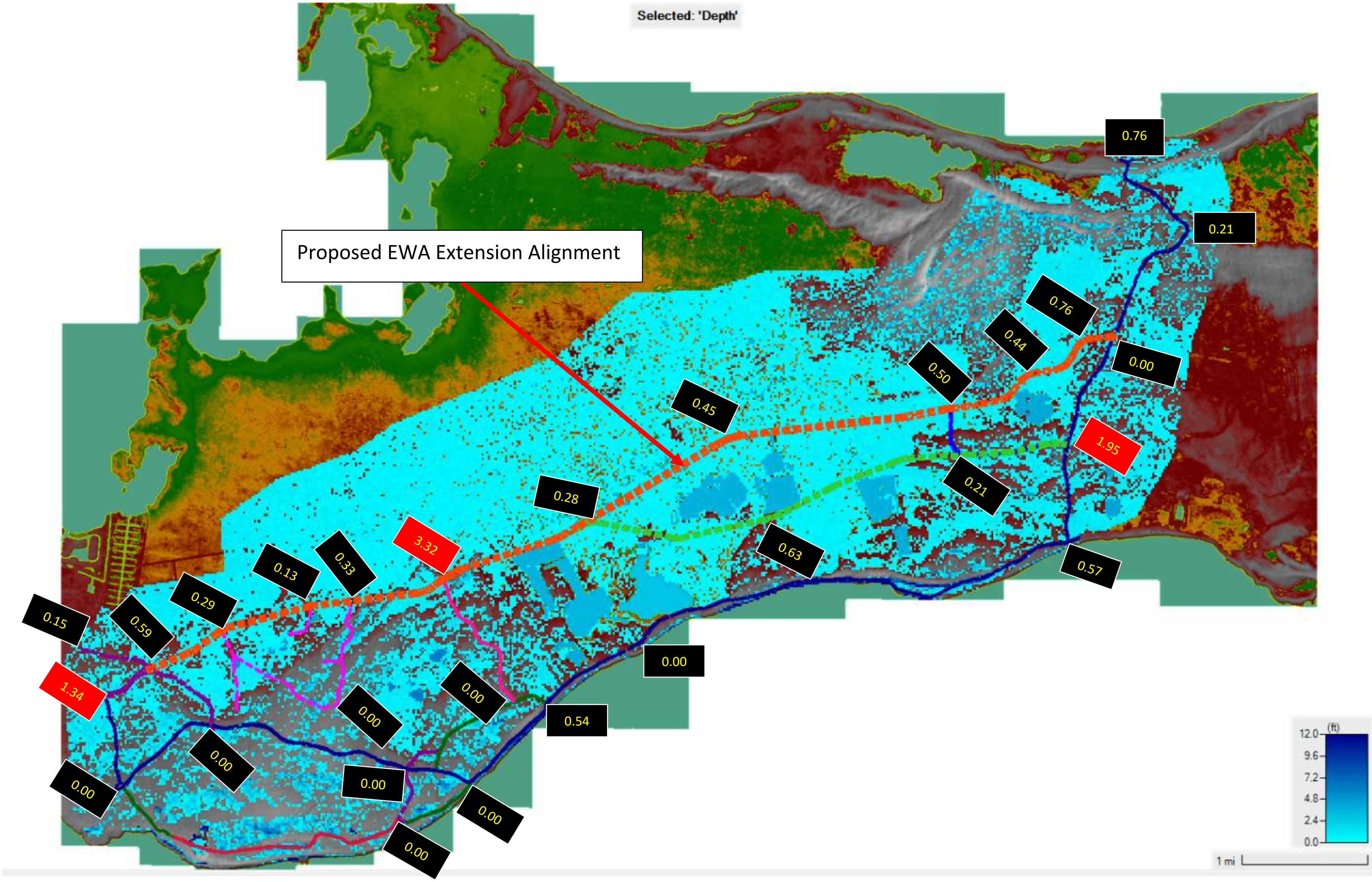


Figure 10 Maximum flood depth, in feet, for 24 hours event with a 2 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

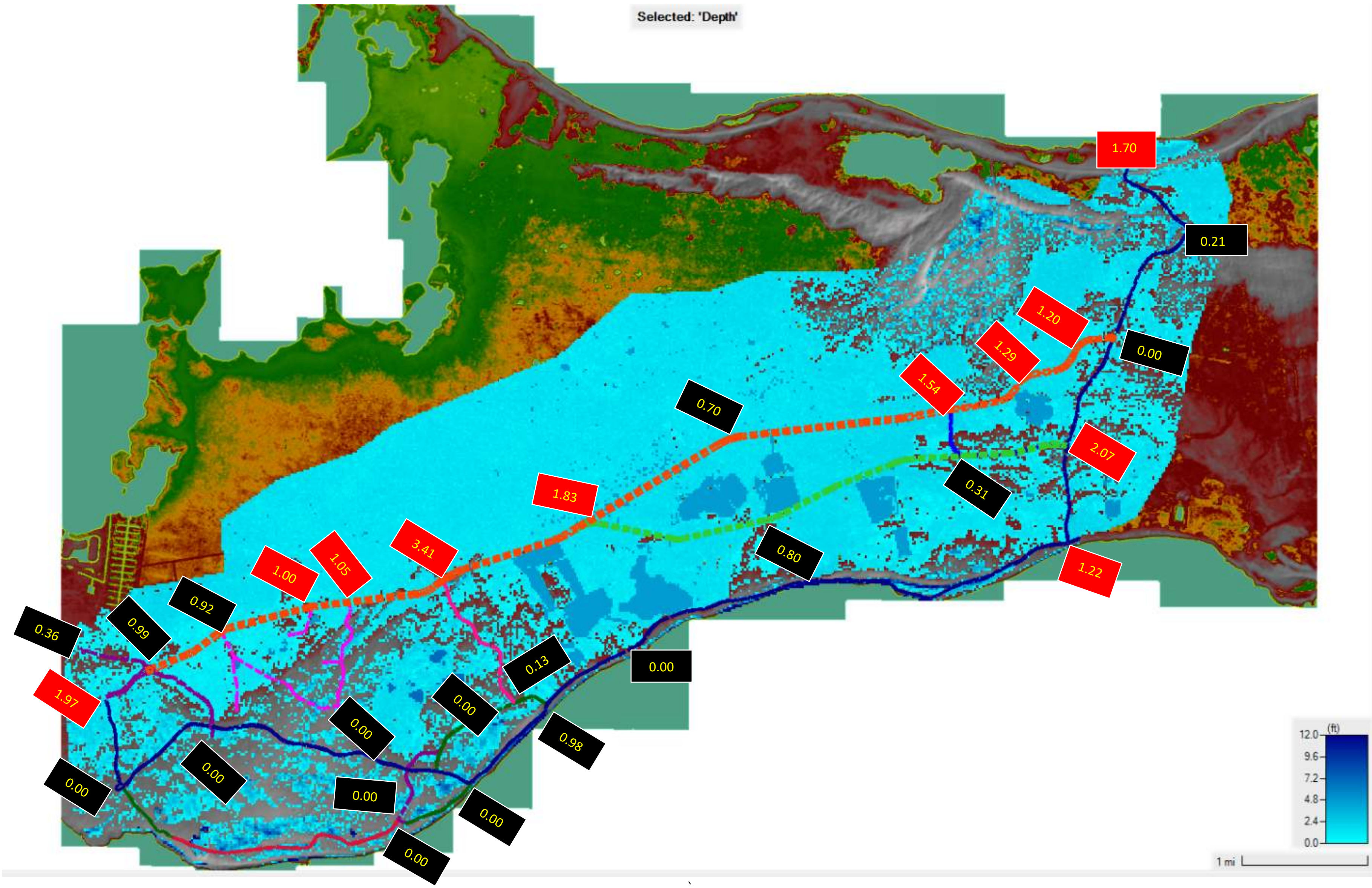


Figure 11 Maximum flood depth, in feet, for 24 hours event with a 10 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

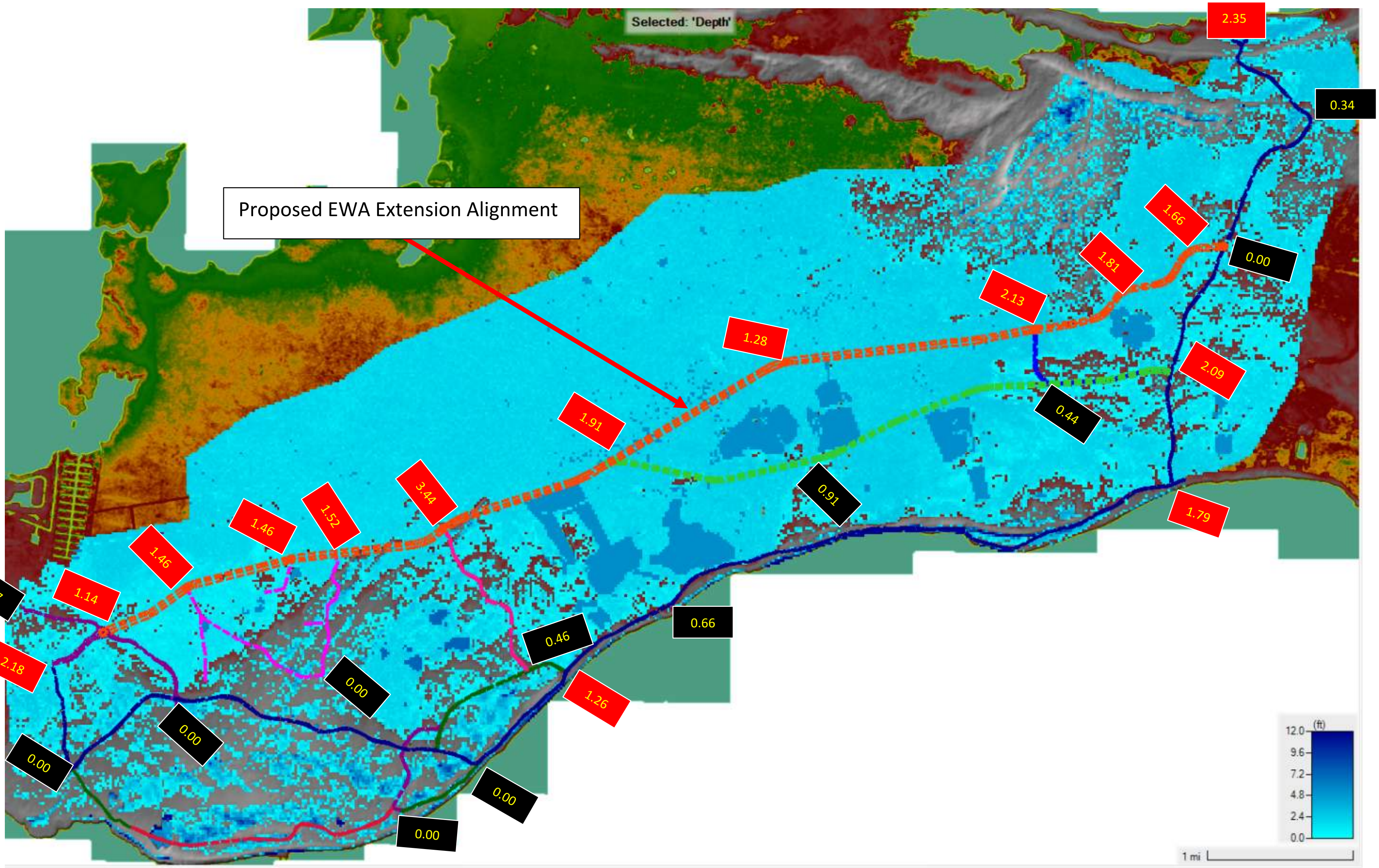


Figure 12 Maximum flood depth, in feet, for 24 hours event with a 25 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

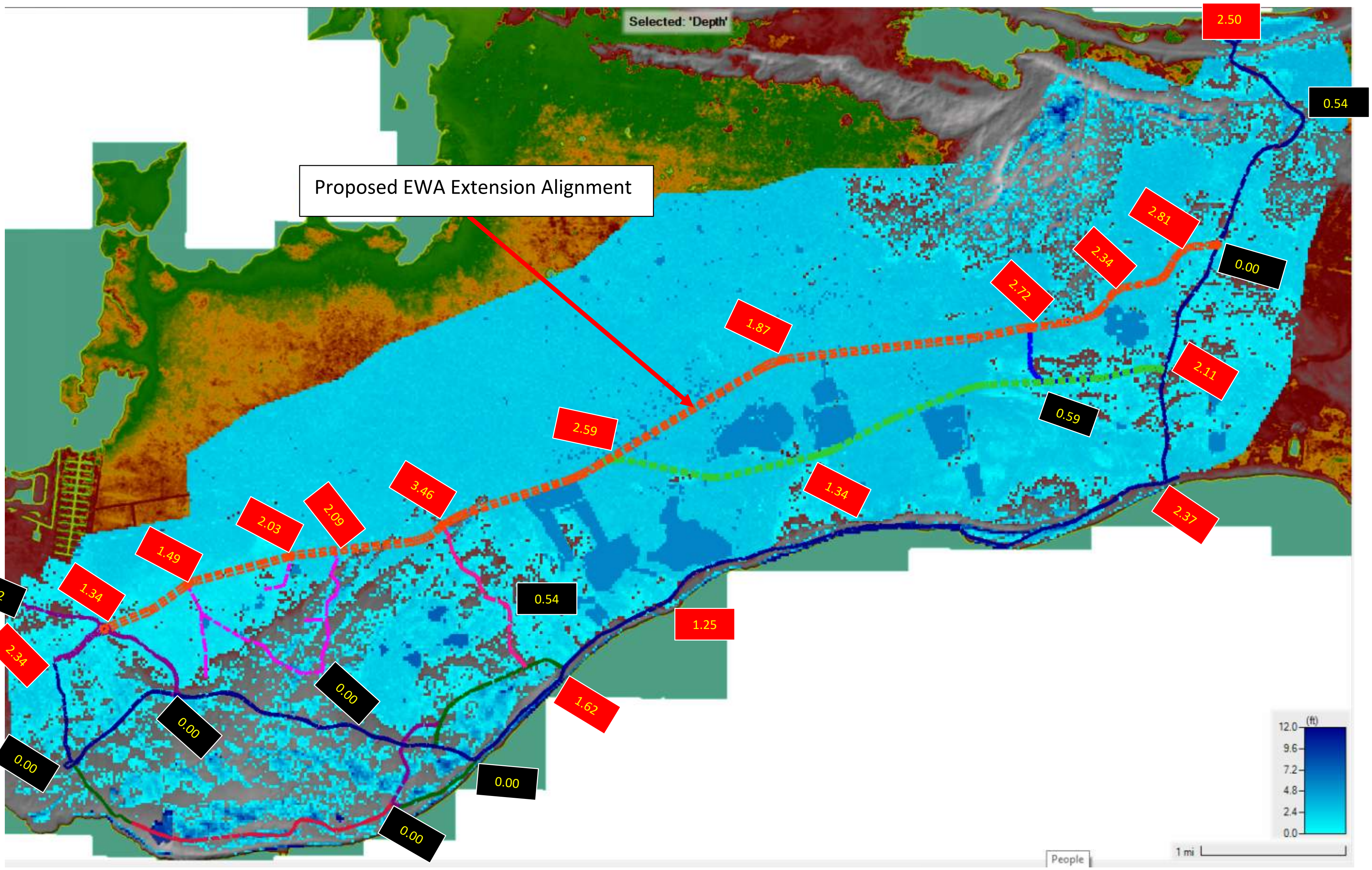


Figure 13 Maximum flood, in feet, depth for 24 hours event with a 50 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

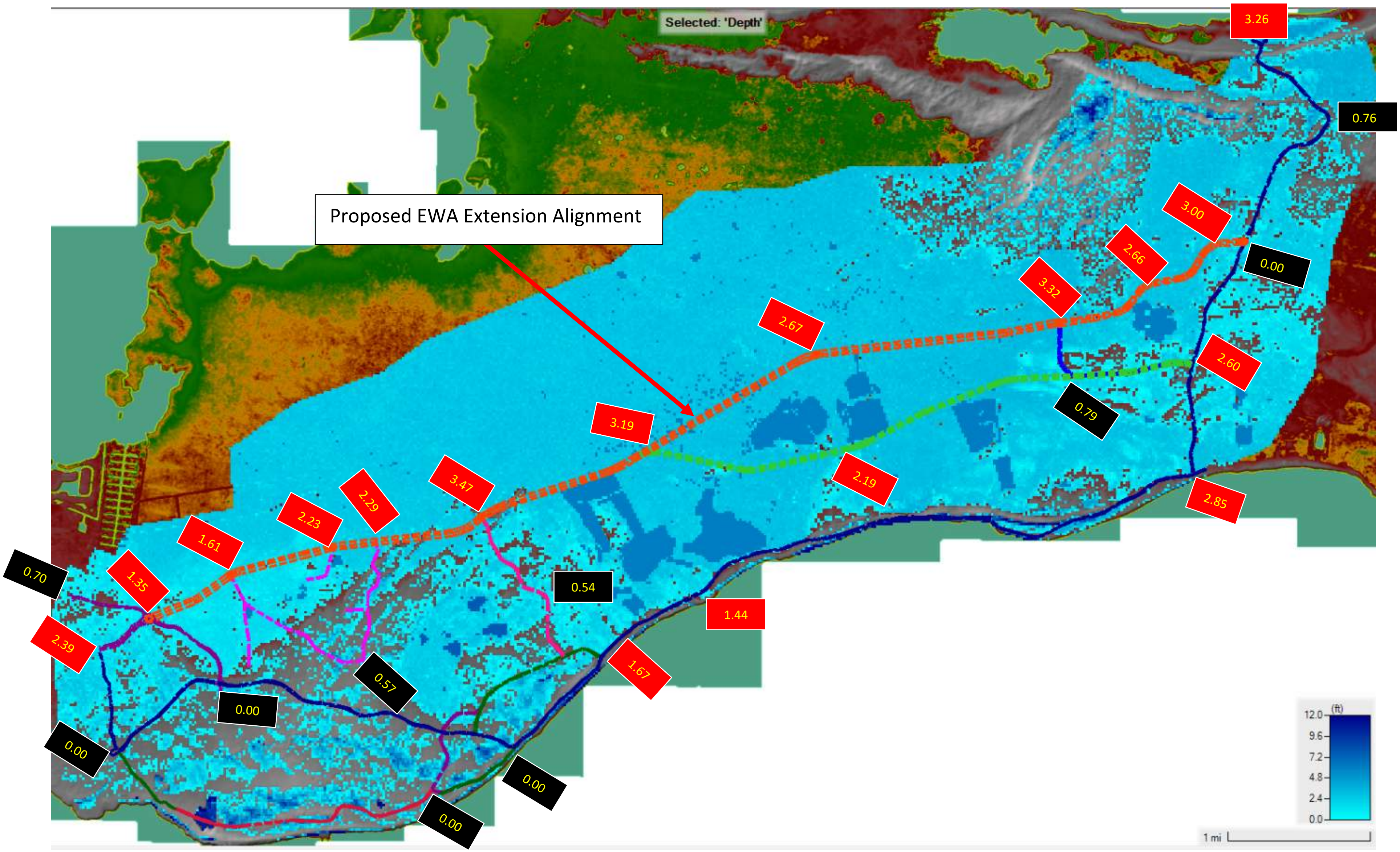


Figure 14 Maximum flood depth, in feet, for 24 hours event with a 100 years return period (Black highlighted less than 1ft, Red highlighted more than 1ft)

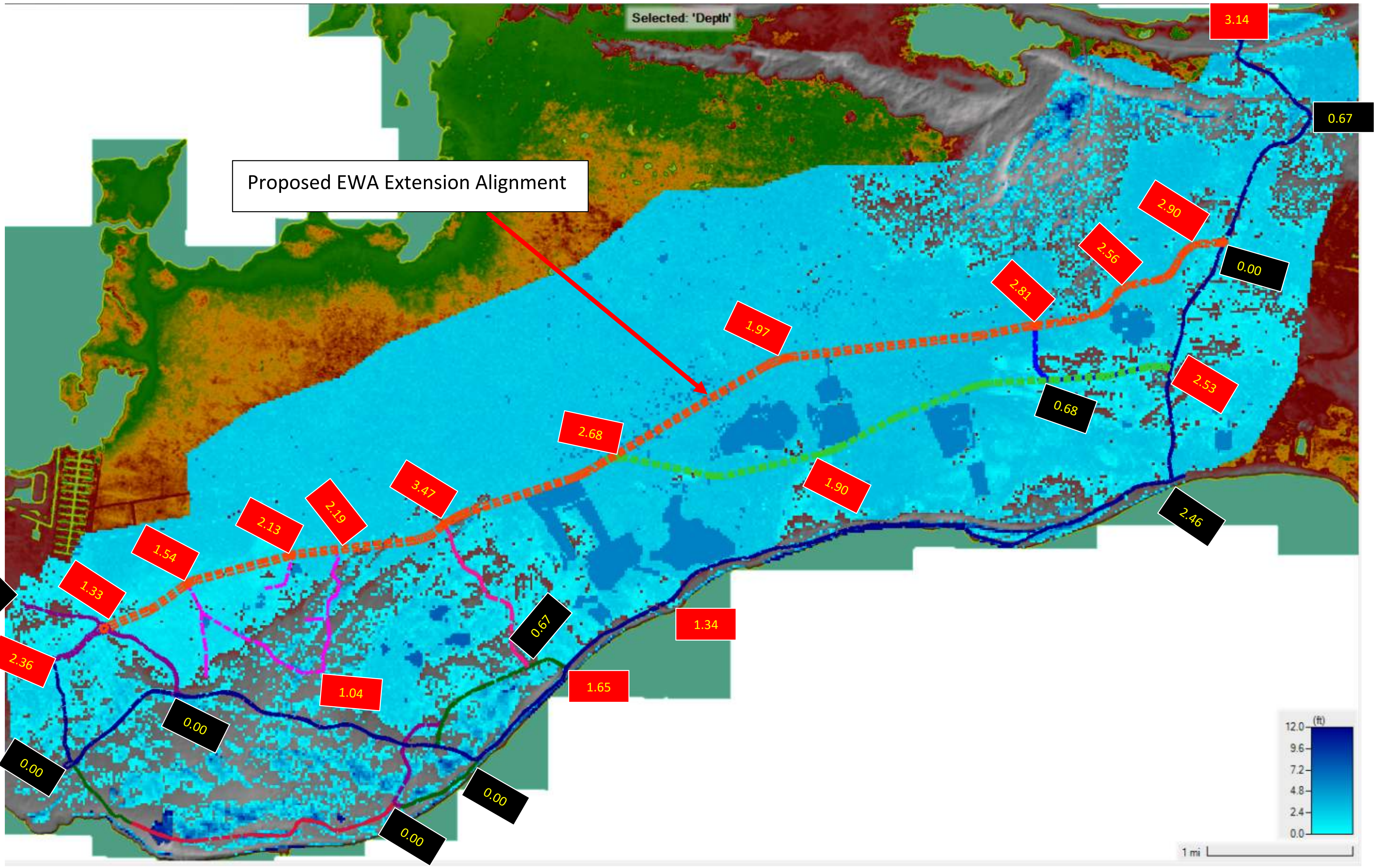


Figure 15 Maximum flood depth, in feet, for 24 hours event with Hurricane Ivan of 2004 (Black highlighted less than 1ft, Red highlighted more than 1ft)

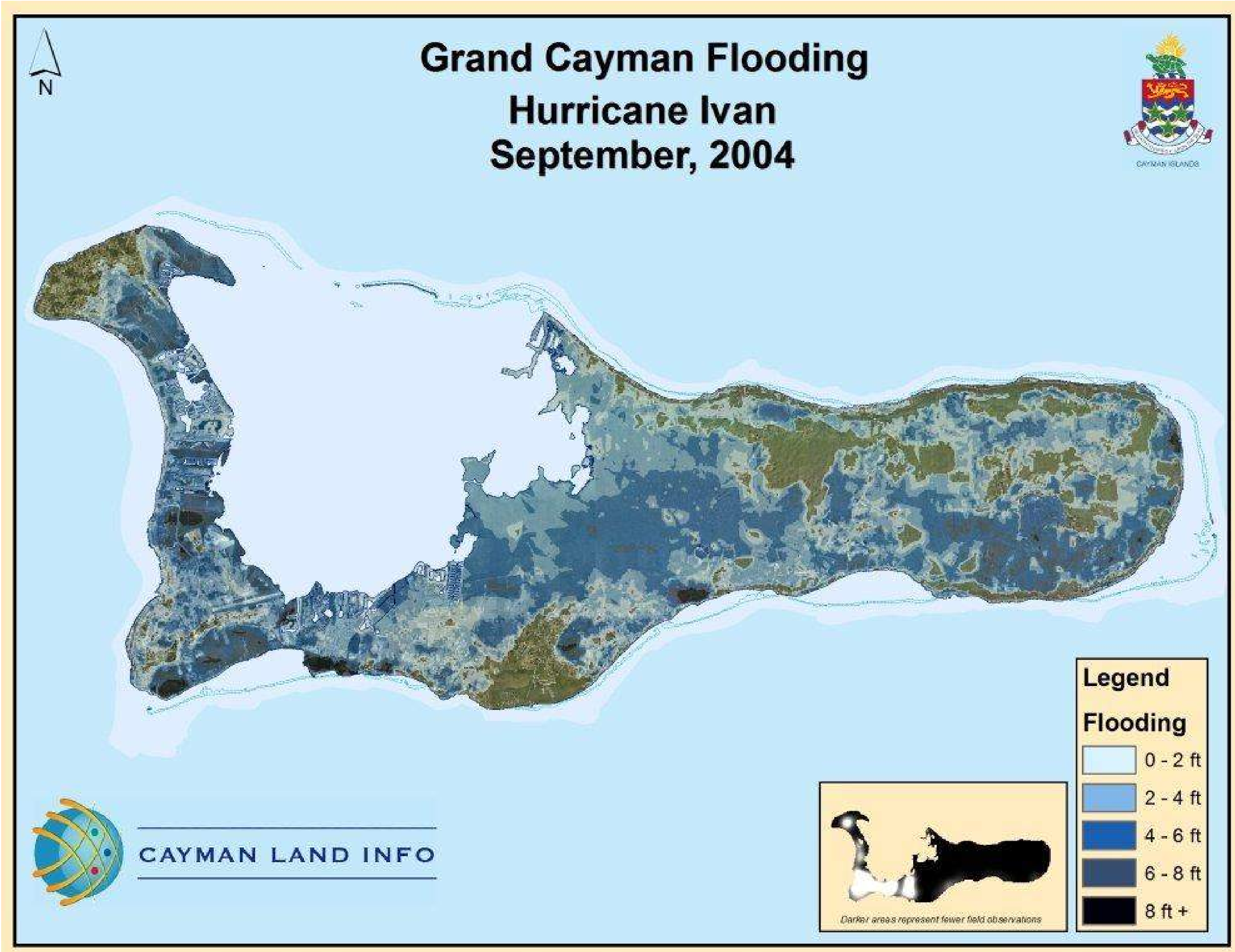


Figure 16 Grand Cayman Flood Map of 2004's Hurricane Ivan

Effects of various storm on the proposed roadway

Effects of various rainfall event scenarios on runoff generation and flooding across the project site were investigated. Each of the studied scenarios shows different inundation depths. In general, the lowest point of the area or the locations that are frequently flooded were inundated during the smaller events such as a 2-year event (Figure 10). For the larger events, the inundation flood pattern has been extended from the low points into the surrounding areas. The low points or the area that are immediately inundated and are the primary locations for conveyances such as a bridge to convey the runoff from the southern side of the site to the northern side of the site.

The product of approximate overlay of Figure 2 over Figure 3 has been shown in Figure 17. Locations (shown with blue lines) were identified as the places where the natural flood ways cross the proposed roadway. The conveyance/bridge locations are conceptually sited and will be revisited as the roadway design progresses.

Project design storm

To design roadways drainage and flooding infrastructure, design storms between 25 and 100 years have been considered. Corresponding to the greater the flooding magnitude are increasing costs for the roadway and bridges. A 50-year design storm is recommended to provide passage for large flooding events with roadway safety maintained. For comparison, the United States uses a 50-year design for major highways while Canada uses either a 50-year or 100-year design depending upon the bridge length.

Effect of unbuilt sections on the built sections of the roadway

The East-West Arterial is planned to be built in phases. During construction of each phase, the proposed roadway drainage infrastructure shall be built for those specific sections. It is expected that in the unbuilt sections, the site will follow its natural drainage pattern and is expected to have a small effect upon the built portions of the roadway. However, as depicted in Figure 18, the identified area shown in the dashed white line receives flow from both the north and south sides of the site and requires additional attention to the flow patterns.

Meagre Bay Pond and Quarries

Results show that the runoff flows north from the Meagre Bay Pond and quarries towards the North Sound. Proposed bridges and conveyances will alter flow patterns but provide for the normal direction of flow towards the North Sound. From the results, the roadway will alter the flows in the general area of the Meagre Bay Pond and quarries but also will have bridges and conveyances to maintain the overall flow movement. Otherwise, the salt intrusion and drawdown of the Meagre Bay Pond due to the nearby quarry is not expected to be impacted by the East-West Arterial.

Mastic Forest

Because the forest's location is on higher ground, the forest is a contributor to the runoff and not directly affected by the roadway. Both the northern and southern connection alternatives to Frank Sound Road are shown. The northern connection will cross the Mastic Trail constituting a direct impact to the trail.

Freshwater Lenses

Both the Lower Valley Lens and the North Side Lens are fed by infiltration from the lands above and are not expected to have their freshwater replenishment affected by the roadway, nor their exfiltration flow into the CMW affected by the roadway.

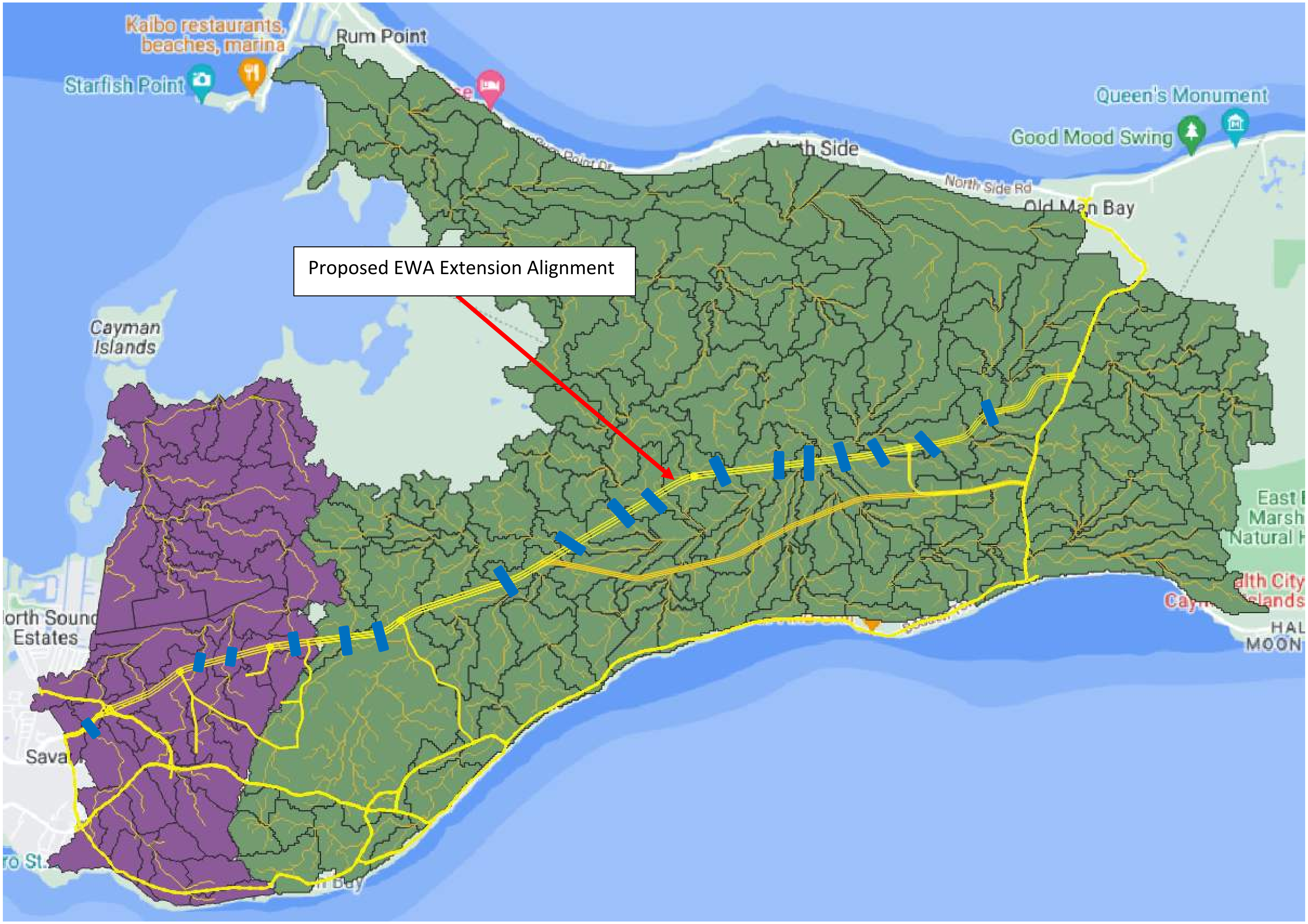


Figure 17 The location of natural runoff (Blue Lines) with the proposed roadway

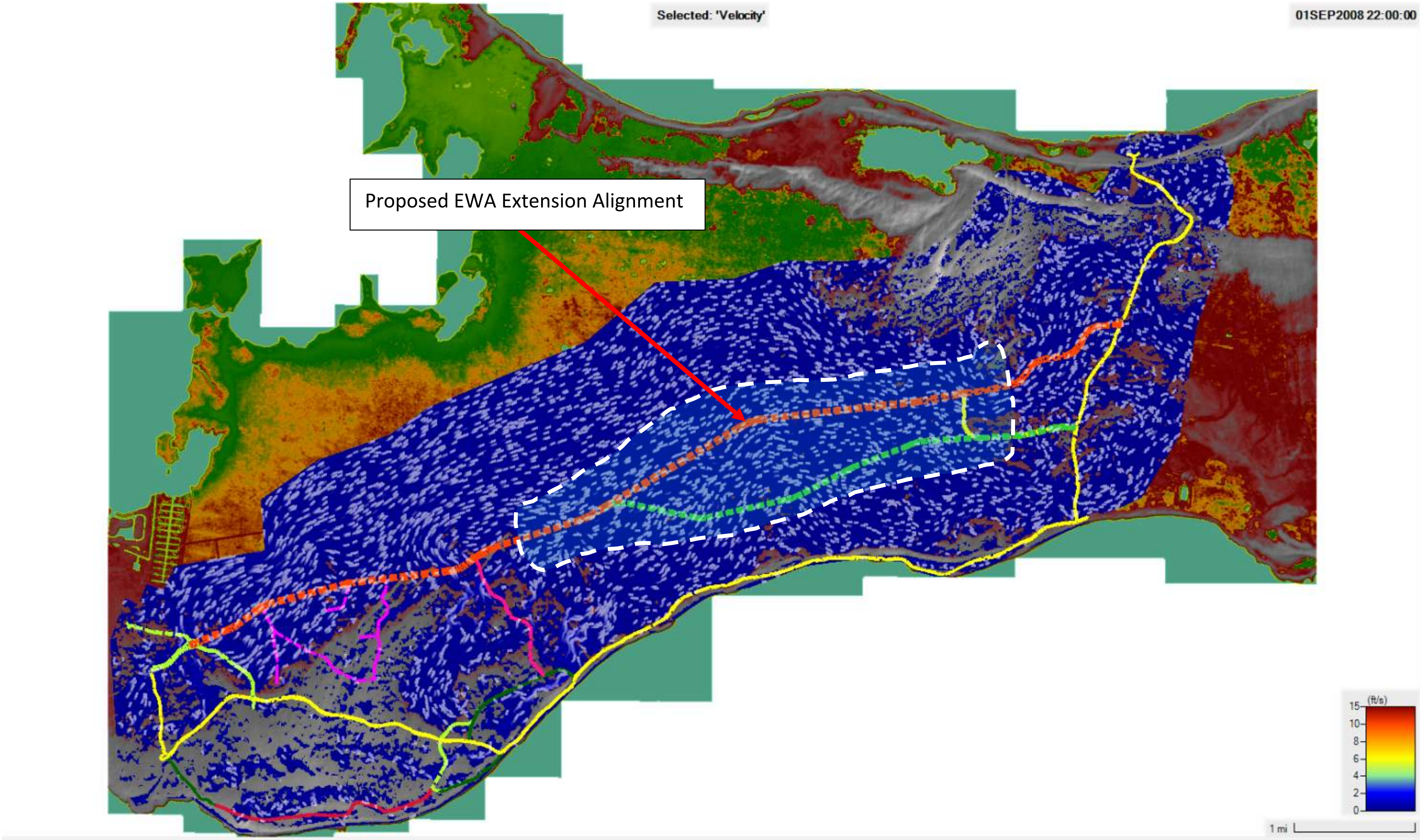


Figure 18 shows the static velocity arrows for a 100-year event

Conclusion

A two-dimensional hydraulic model was developed to prepare flooding information to design East-West Arterial Roadway and the associated alternatives on Grand Cayman Island. Various scenarios of rainfall events and the historic tropical Hurricane Ivan were studied. The rainfall events show that the project area will be inundated under most of the events. The results for a 2-year, show the simulated flood depth less than 1 foot and increasing to 5 feet to 6 feet for a 100-year simulated event along the inland roadway options, whereas the flood depth was simulated up to 10 feet for the options close to the coastal area on the southwest of the site. The simulated Hurricane Ivan event also showed a consistency with the Grand Cayman Hurricane Ivan Flooding map of September 2004. The locations for the proposed roadway drainage improvement have been proposed. Also, the results of the coastal and surge analysis, performed by others, shall be taken into consideration for the design with the simulated flood events, depths, and flows modelled in this study.

References

1 Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences, 11(5), 1633-1644.

2 USACE (2022). HEC-HMS User's Manual. Version 4.10. https://www.hec.usace.army.mil/confluence/hmsdocs/hmsum/latest/release-notes/v-4-10-0-release-notes.

3 USACE (2022). HEC-RAS River Analysis System. 2D Modeling User's Manual, Version 6.3. https://www.hec.usace.army.mil/confluence/rasdocs/r2dum/latest/introduction.

4 Arcement, G. J., & Schneider, V. R. (1989). Guide for selecting Manning's roughness coefficients for natural channels and flood plains.

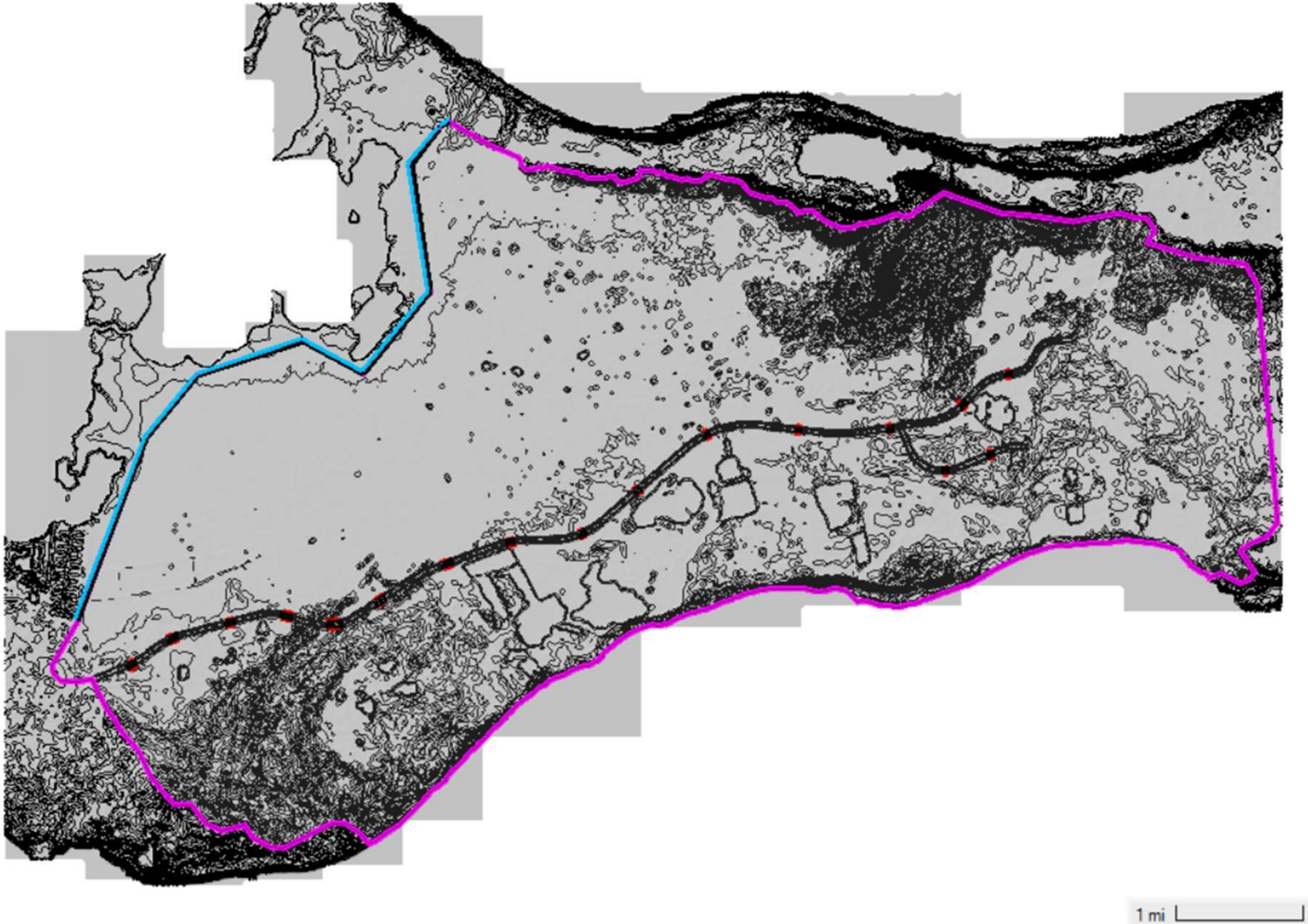
5 Aicta, N. Ahmad (1996). Agricultural Land Capacity of the Cayman Islands.

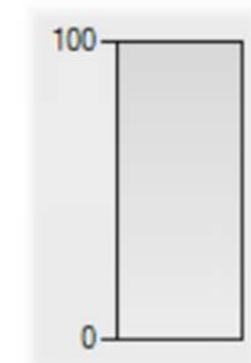
6 Cayman Islands Government, Department of the Environment, 2018 Landcover Habitat Mapping

Appendix B – Alternate B1

Alternative B1

Original Terrain





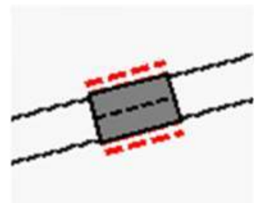
Alternative B1

Legend

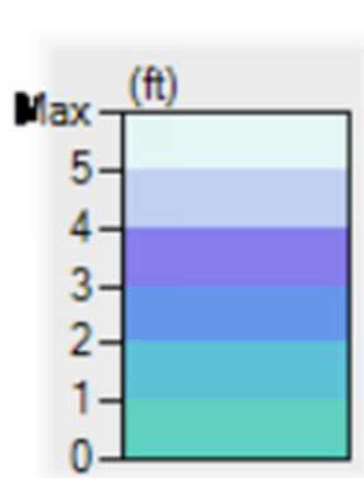
Terrain Elevation FT

Boundary Condition (Blue/Black) Perimeter (Magenta)

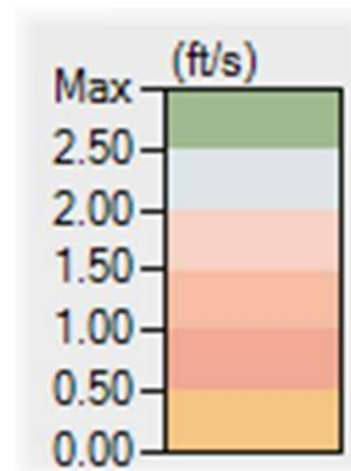
Bridge



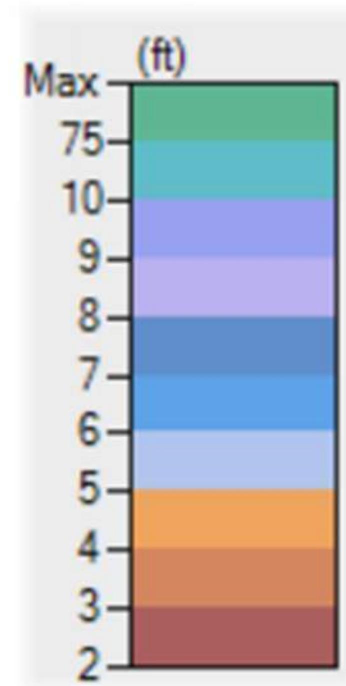
Runoff Depth FT

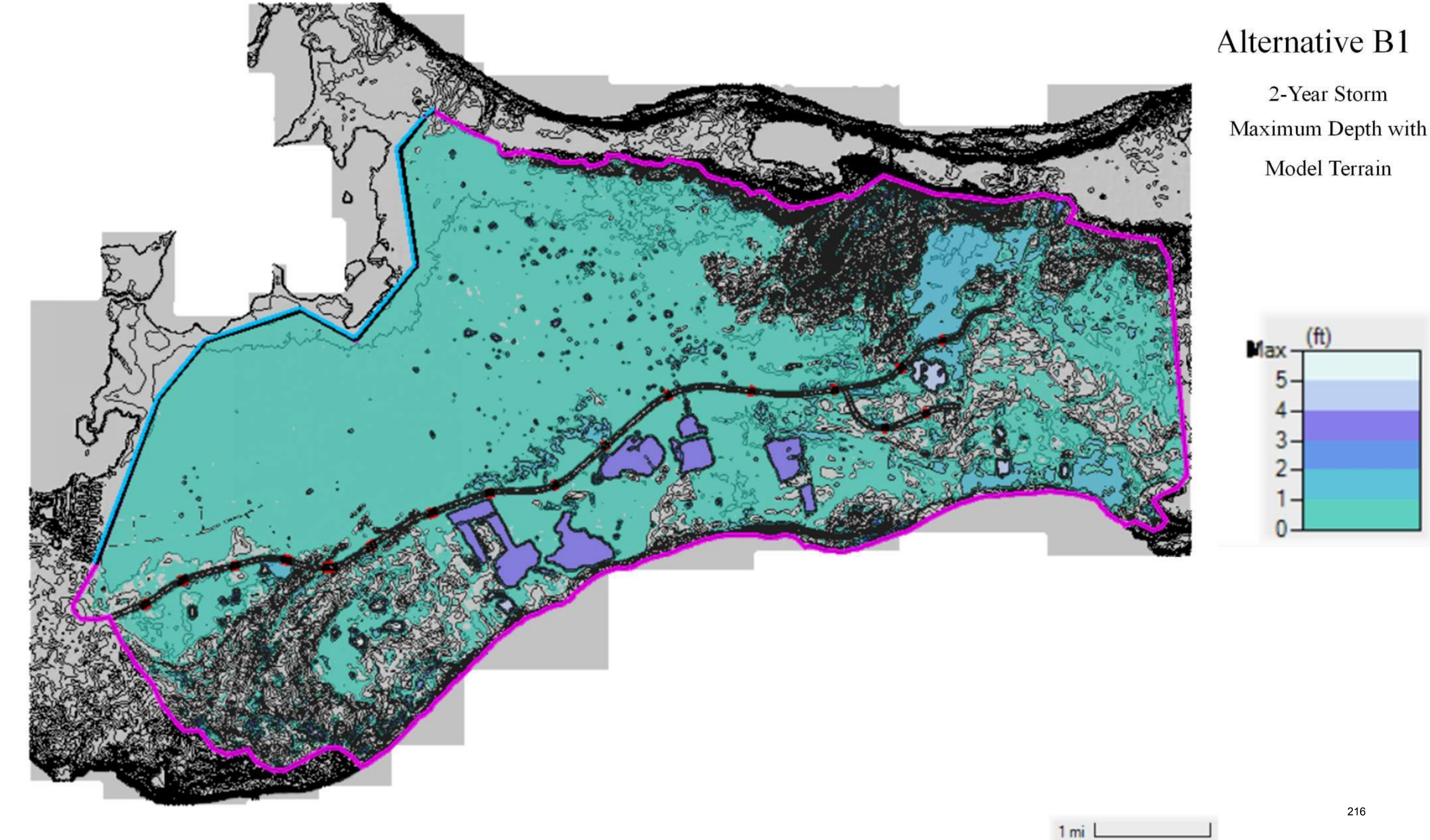


Velocity FT/SEC



Water Surface Elevation FT

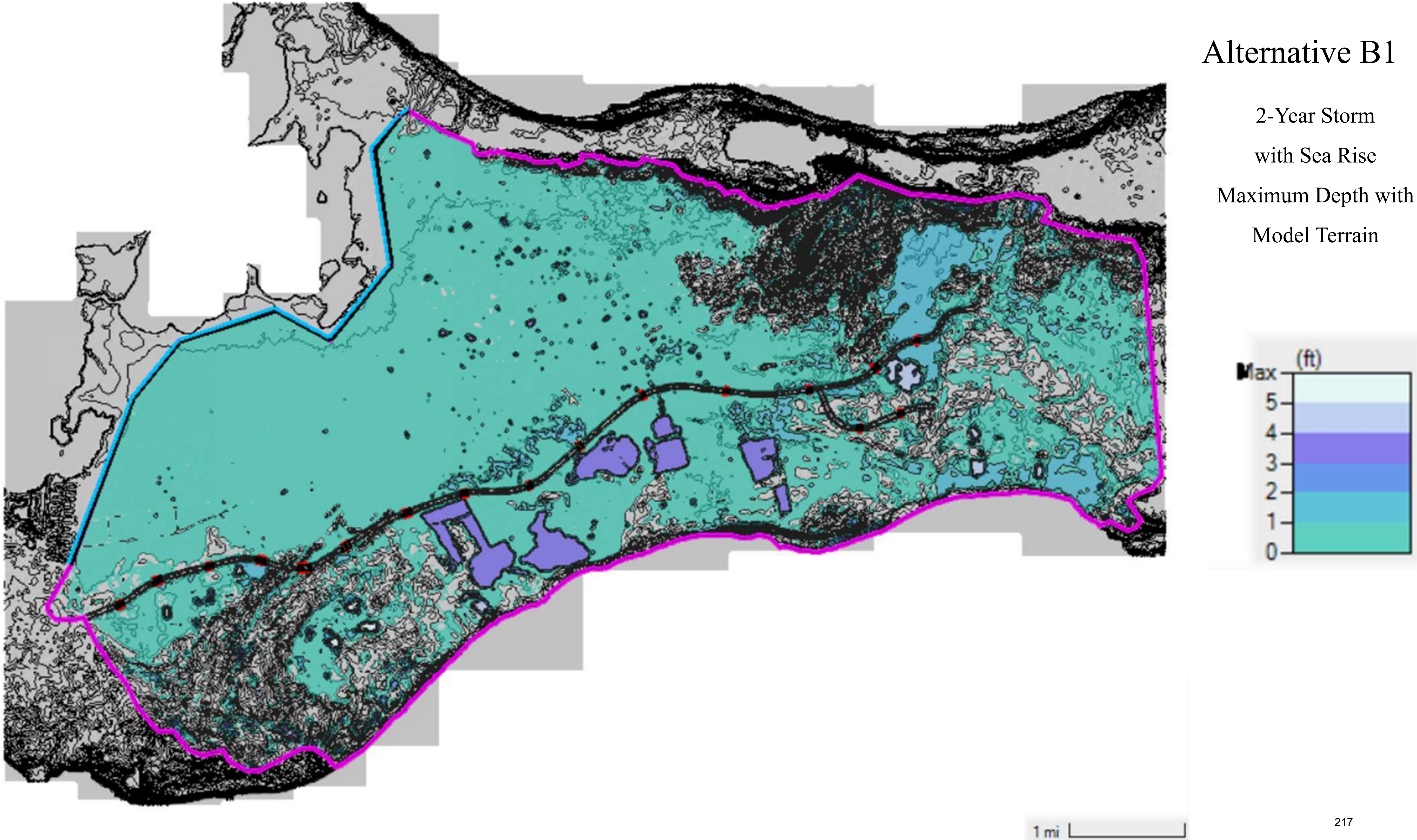


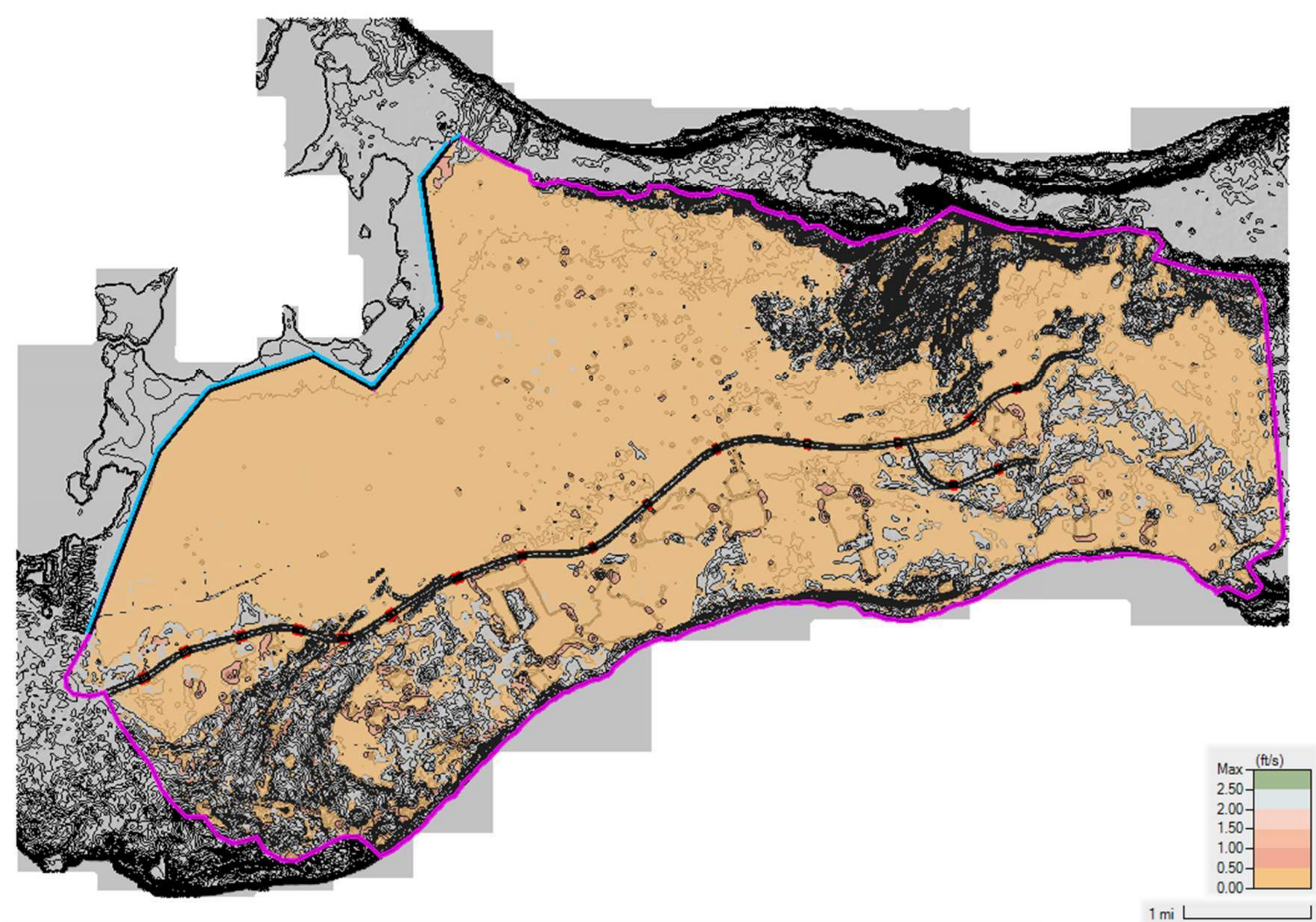


Alternative B1
2-Year Storm
Maximum Depth with
Model Terrain
(ft)
Max
5
4
3
2
1
0
1 mi

Alternative B1

2-Year Storm
with Sea Rise
Maximum Depth with
Model Terrain





Alternative B1

2-Year Storm

Maximum Velocity

And Model Terrain

(ft/s)

Max

2.50

2.00

1.50

1.00

0.50

0.00

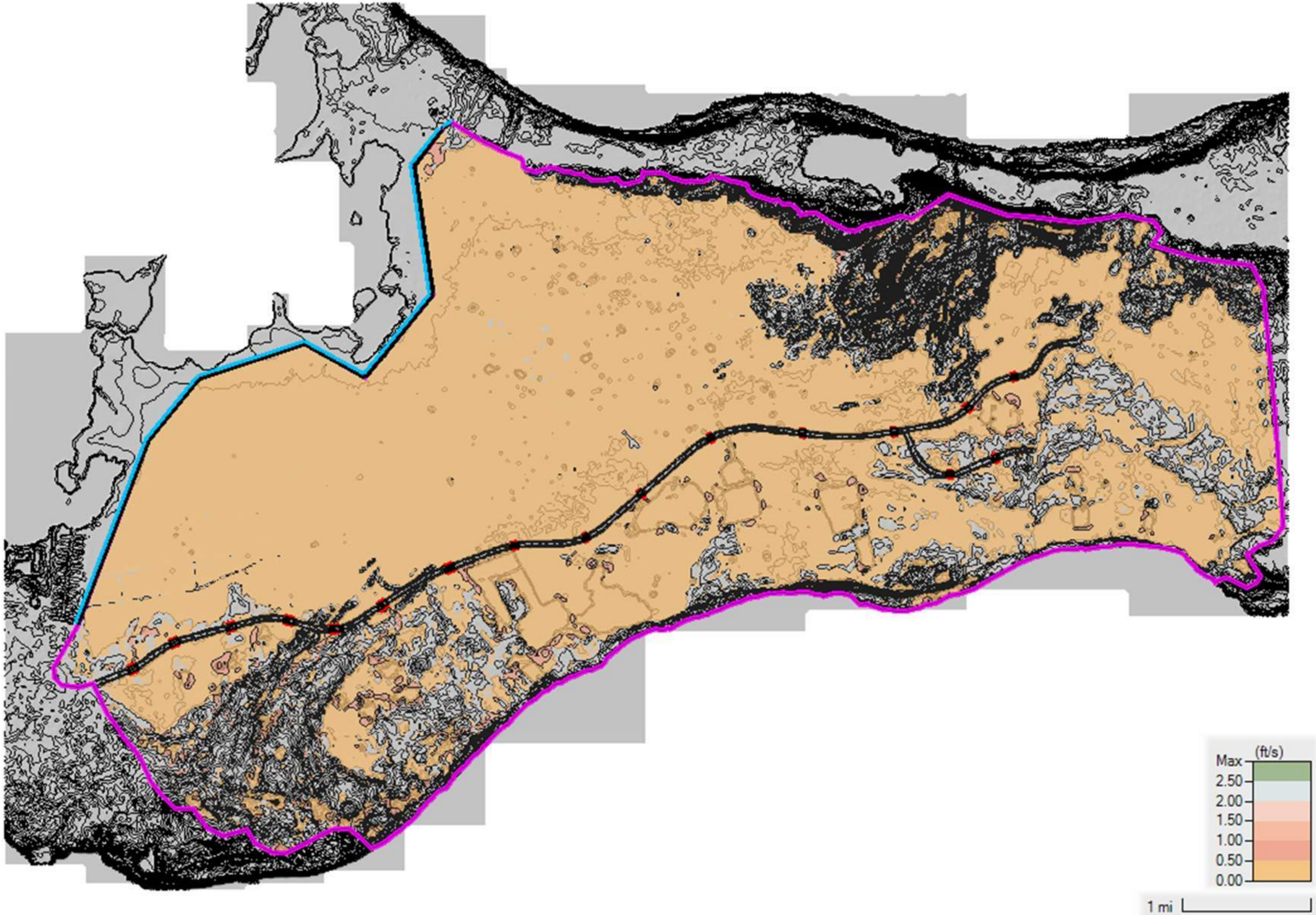
Alternative B1

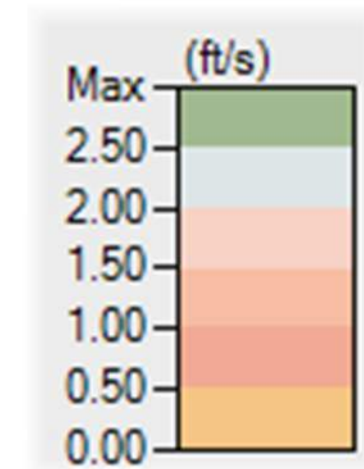
2-Year Storm

With Sea Rise

Maximum Velocity

And Model Terrain

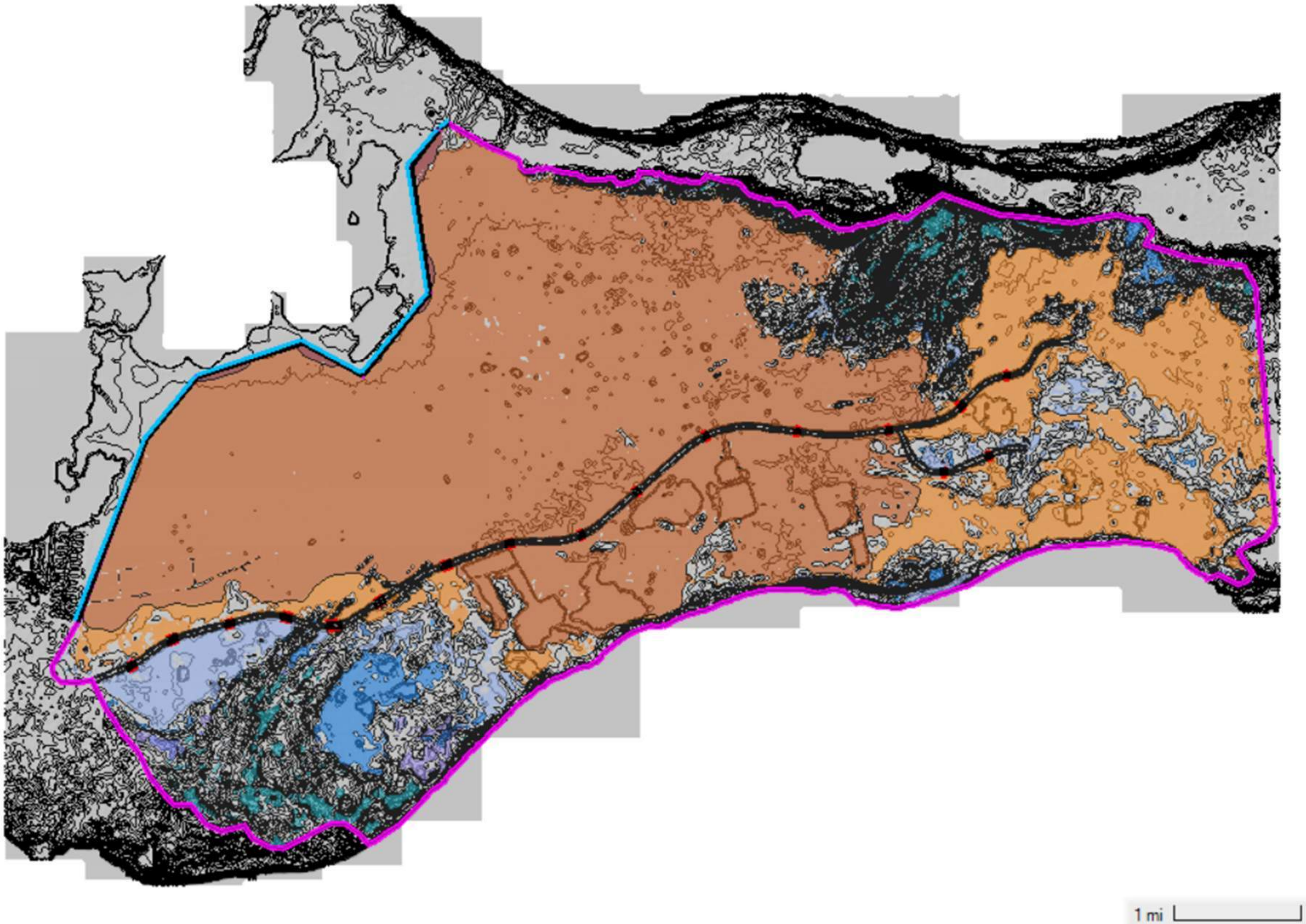


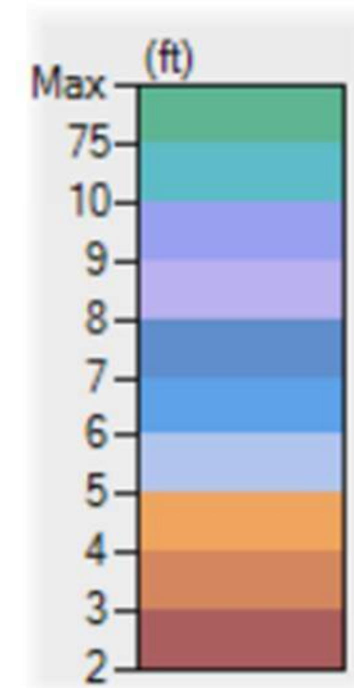


Alternative B1

2-Year Storm

Maximum Water Surface Elevation and Model Terrain





Alternative B1

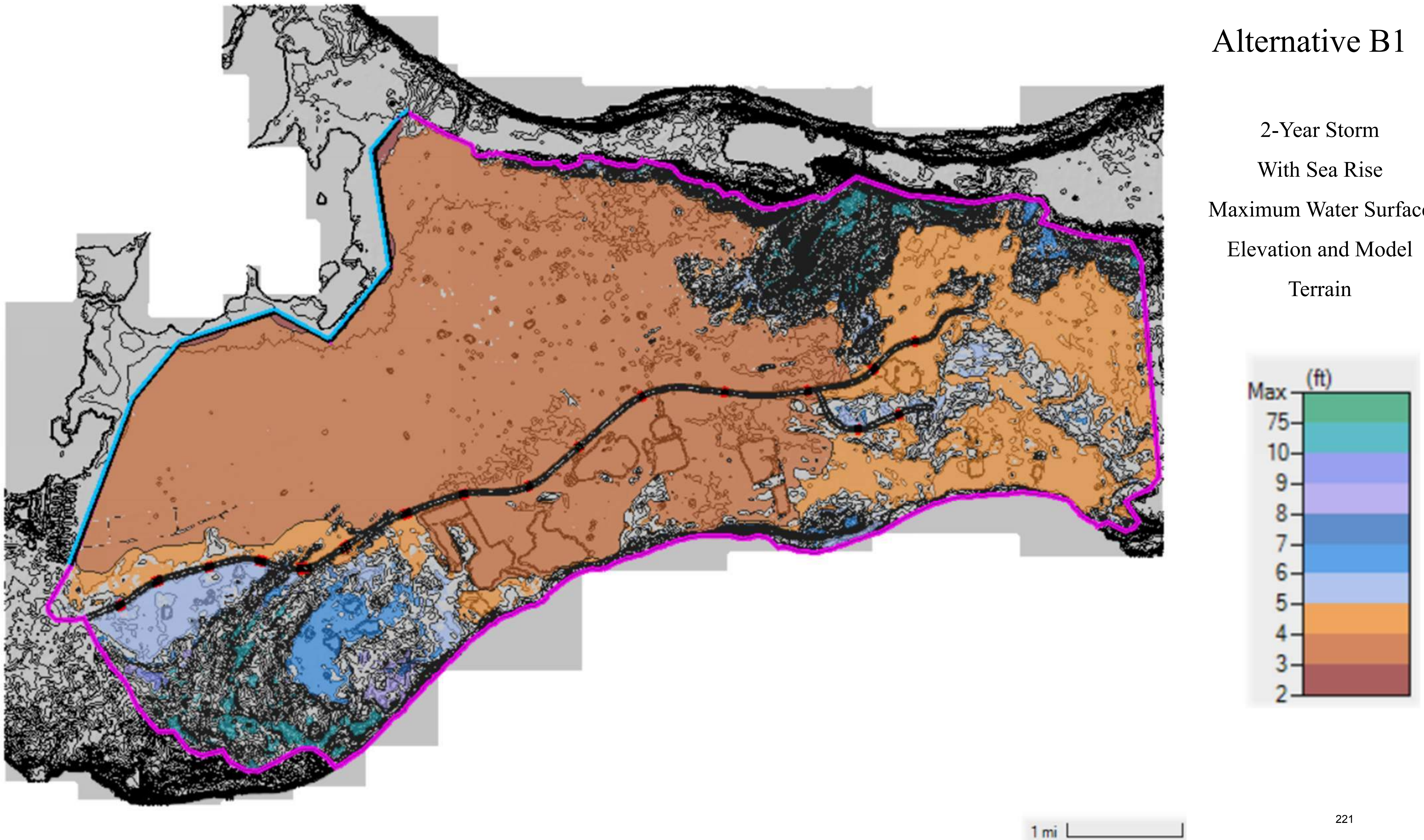
2-Year Storm

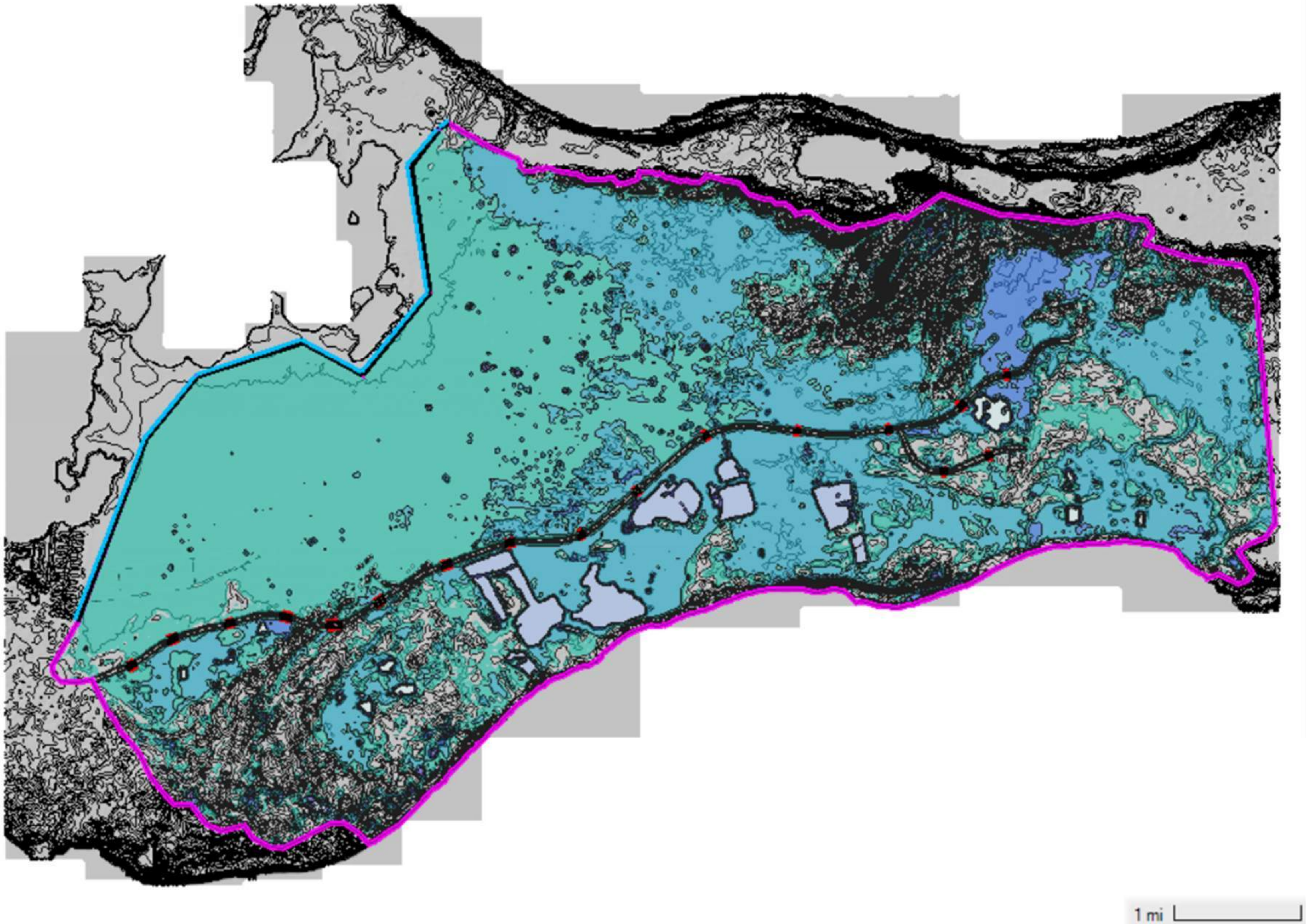
With Sea Rise

Maximum Water Surface

Elevation and Model

Terrain



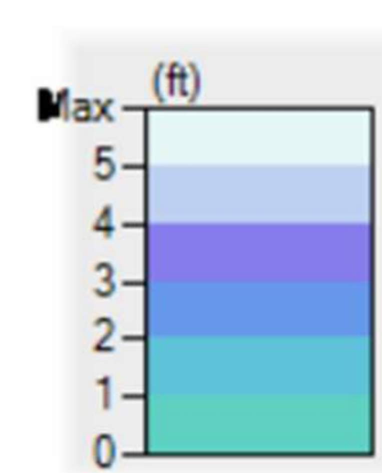


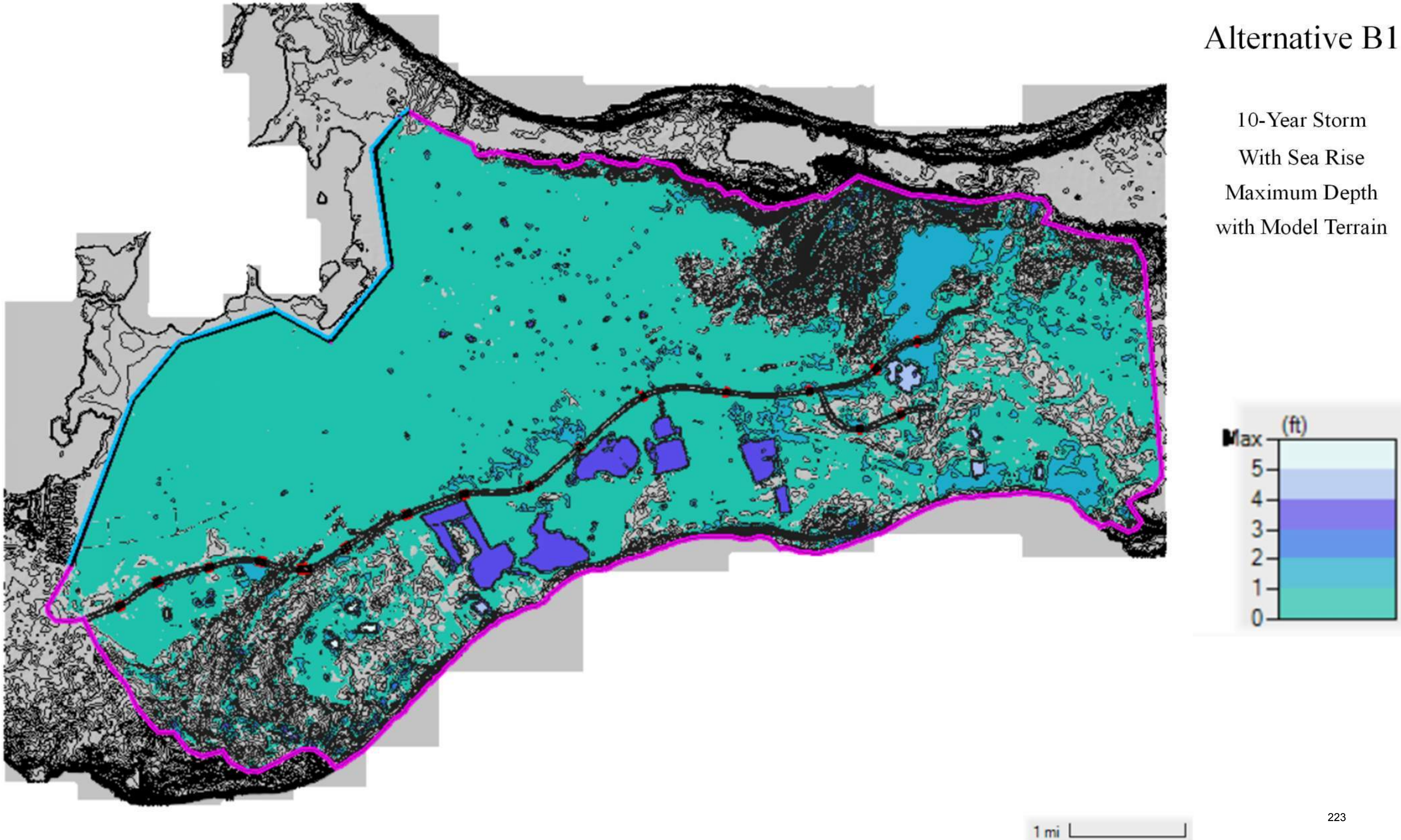
Alternative B1

10-Year Storm

Maximum Depth

with Model Terrain



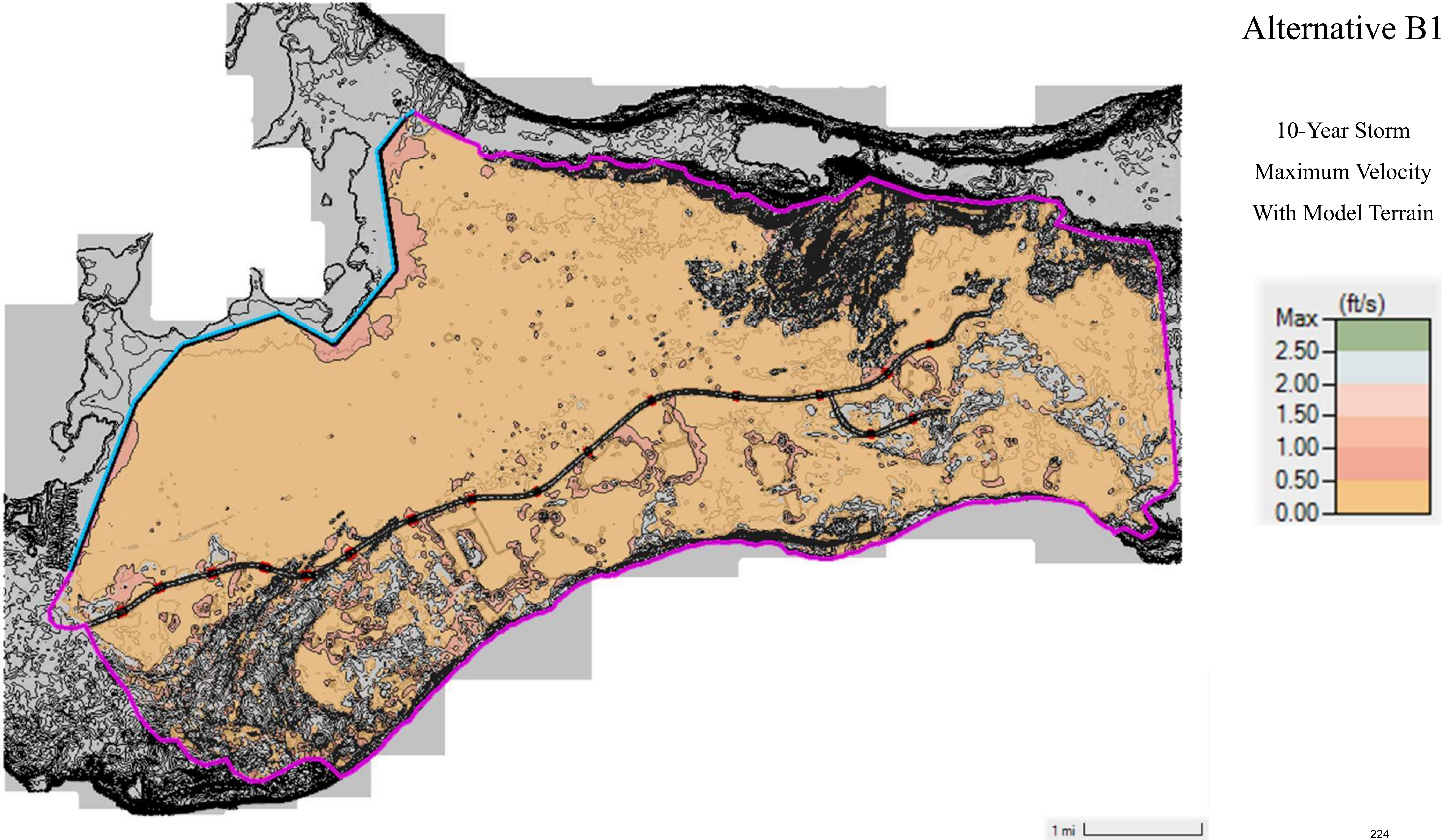

Alternative B1
10-Year Storm
With Sea Rise
Maximum Depth
with Model Terrain
(ft)
Max
5
4
3
2
1
0
1 mi

Alternative B1

10-Year Storm

Maximum Velocity

With Model Terrain



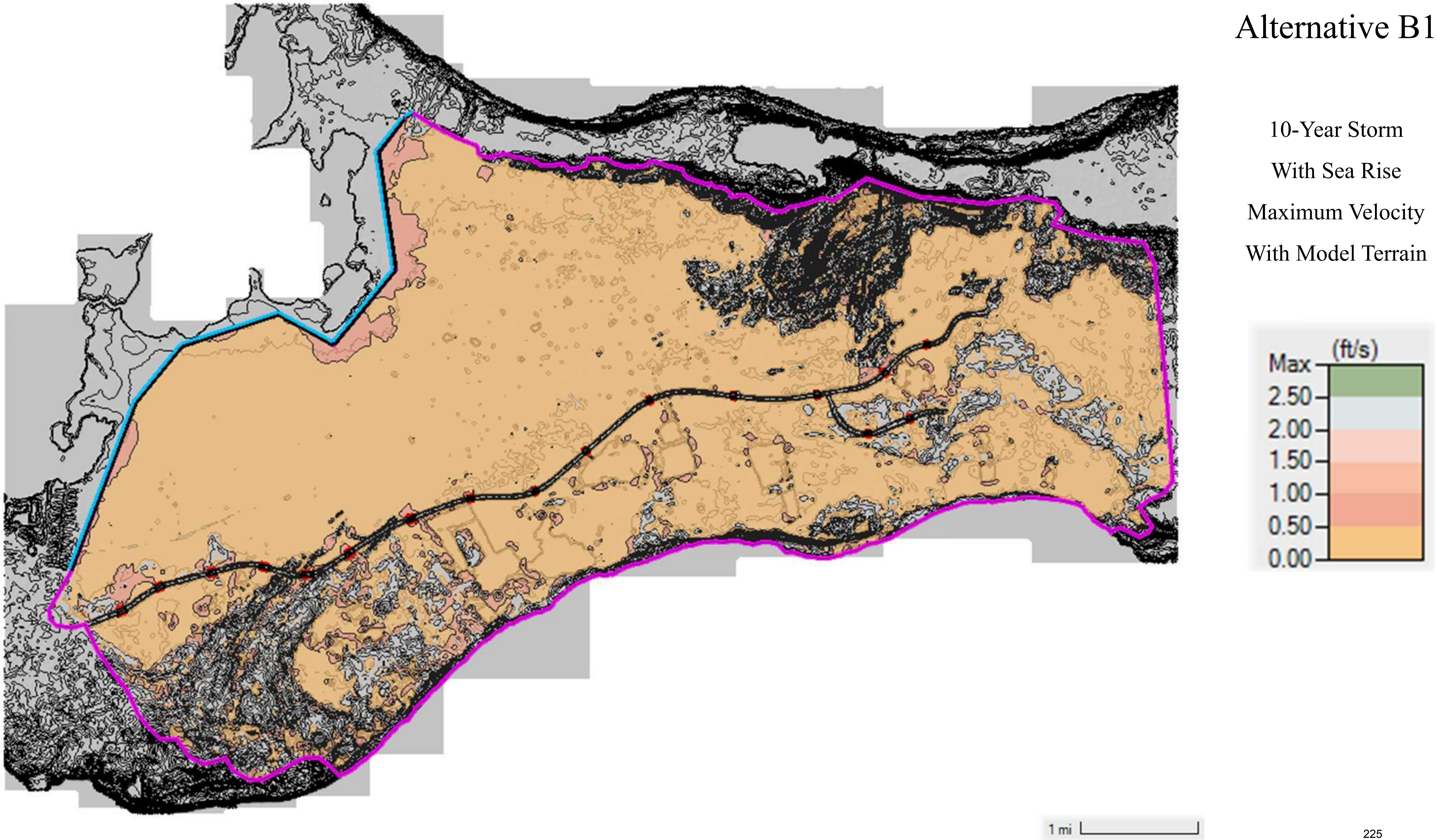
Alternative B1

10-Year Storm

With Sea Rise

Maximum Velocity

With Model Terrain



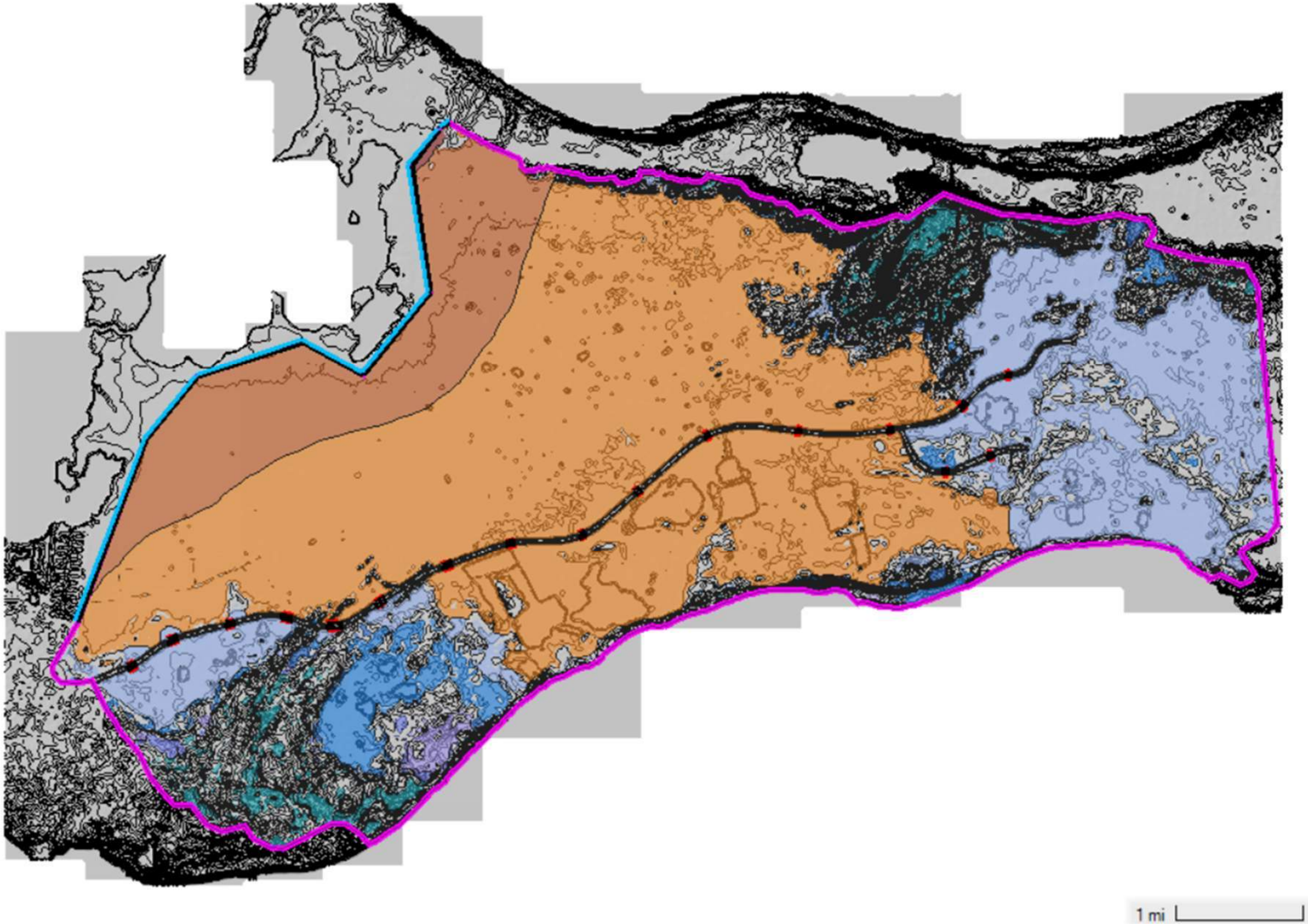
Alternative B1

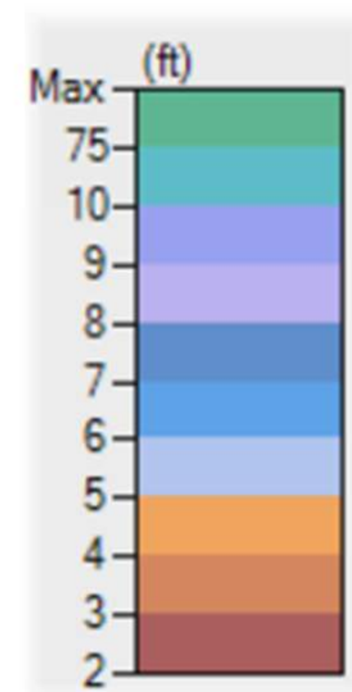
10-Year Storm

Maximum Water Surface

Elevations With Model

Terrain





Alternative B1

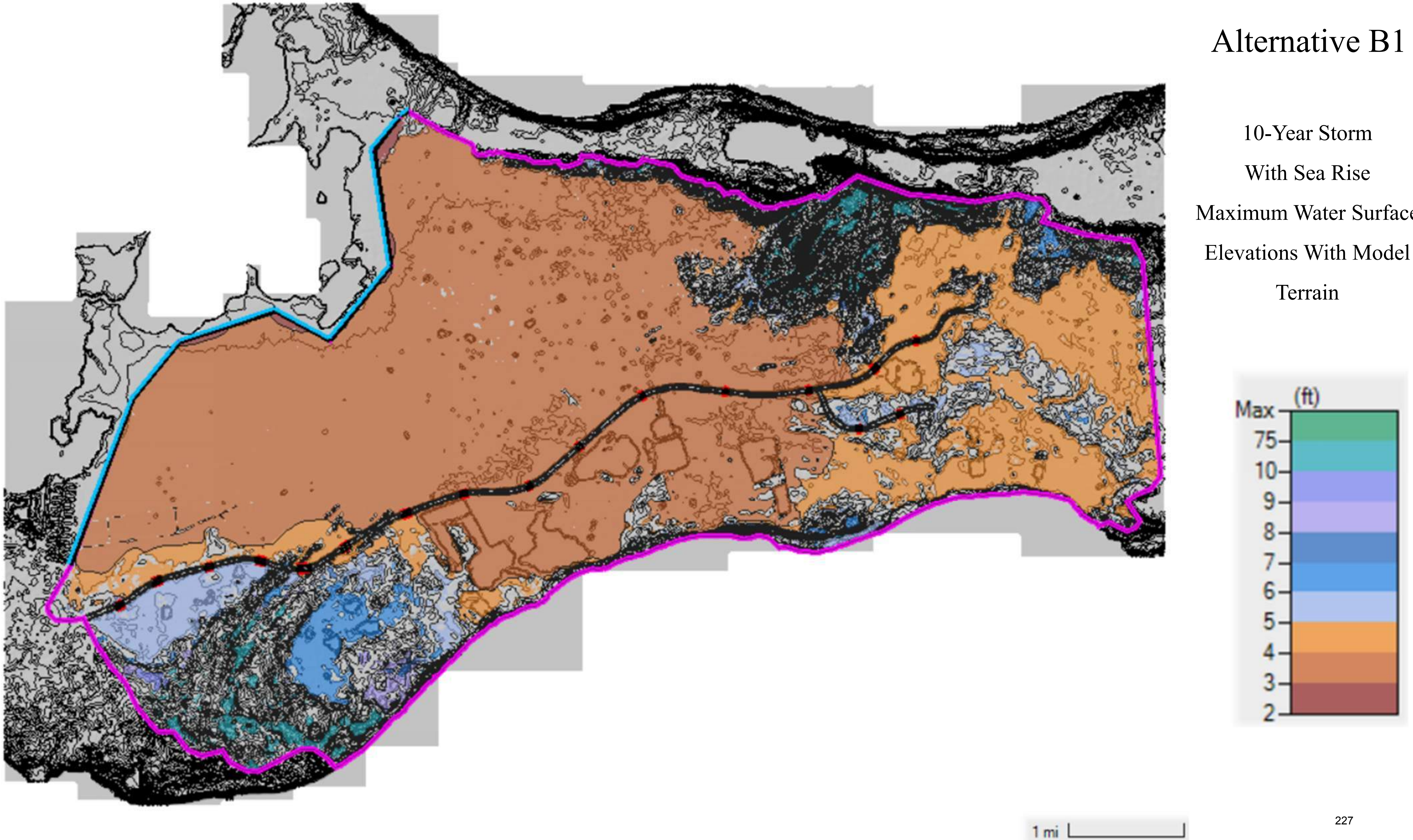
10-Year Storm

With Sea Rise

Maximum Water Surface

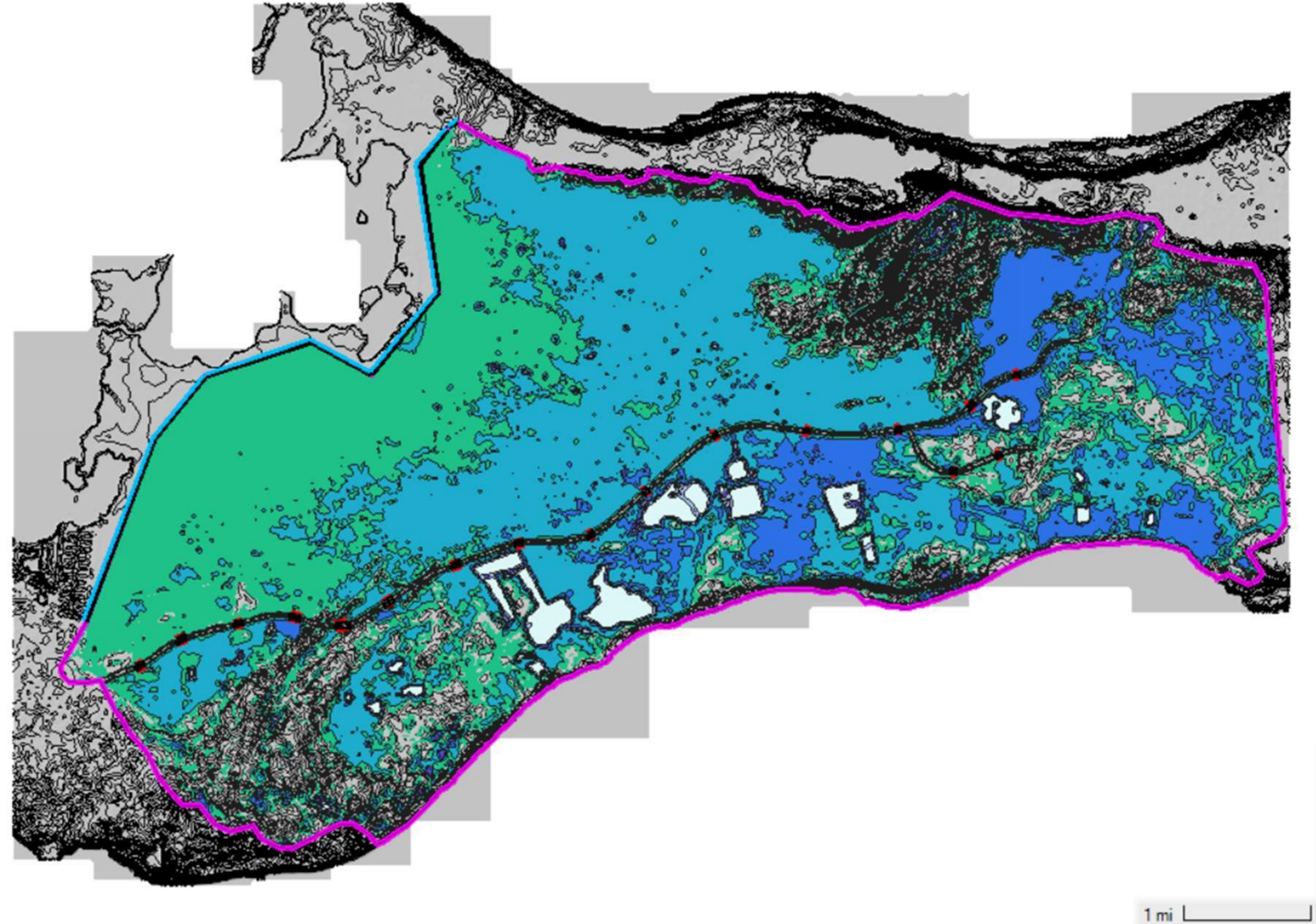
Elevations With Model

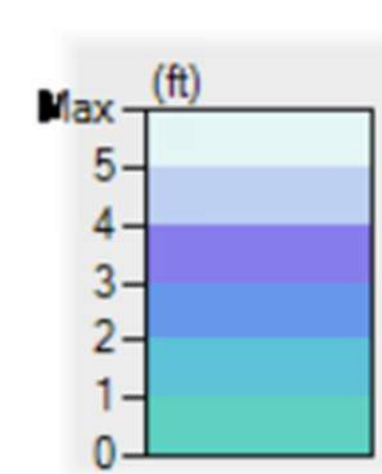
Terrain



Alternative B1

25-Year Storm
Maximum Depth with
Model Terrain





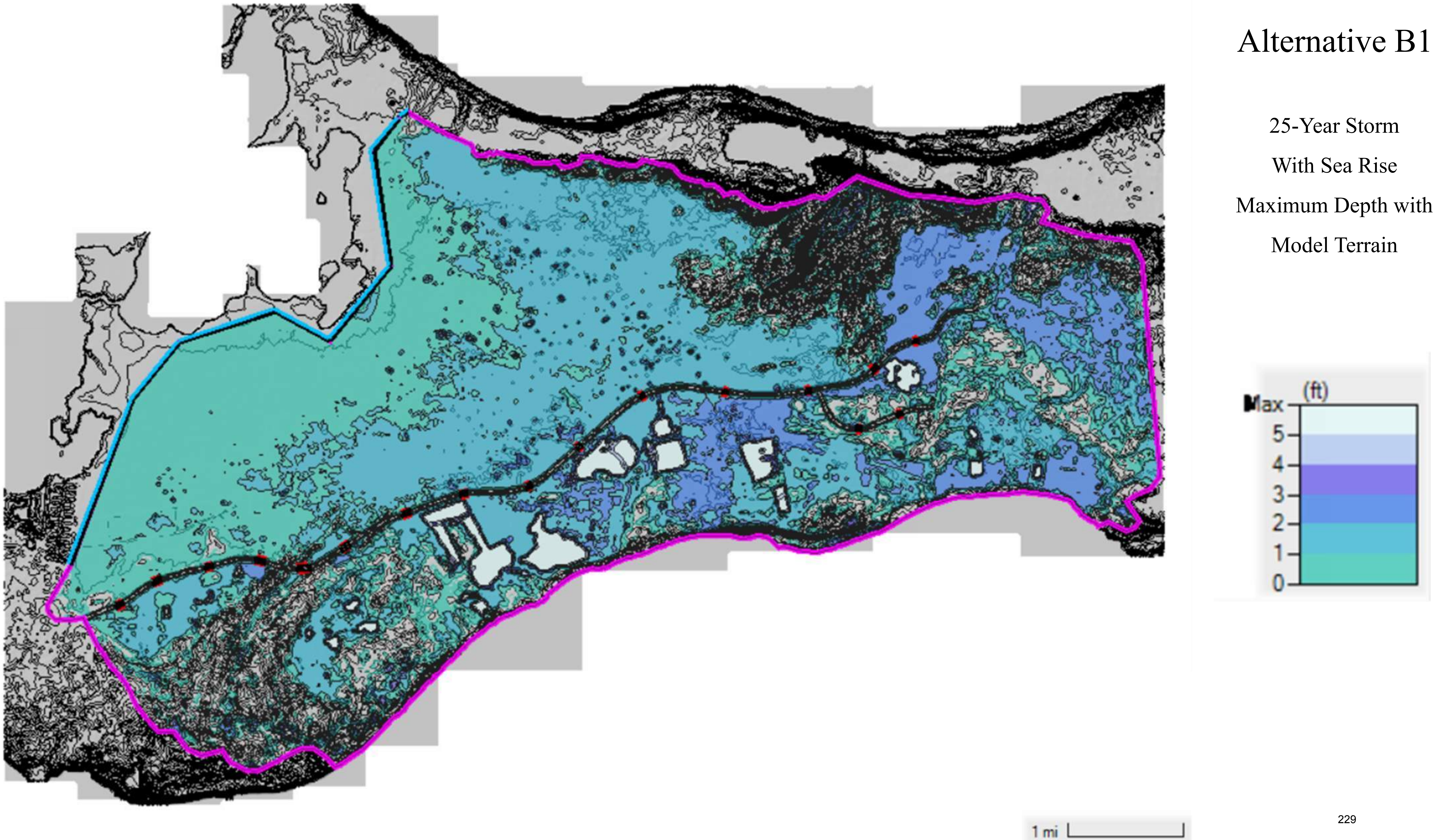
Alternative B1

25-Year Storm

With Sea Rise

Maximum Depth with

Model Terrain

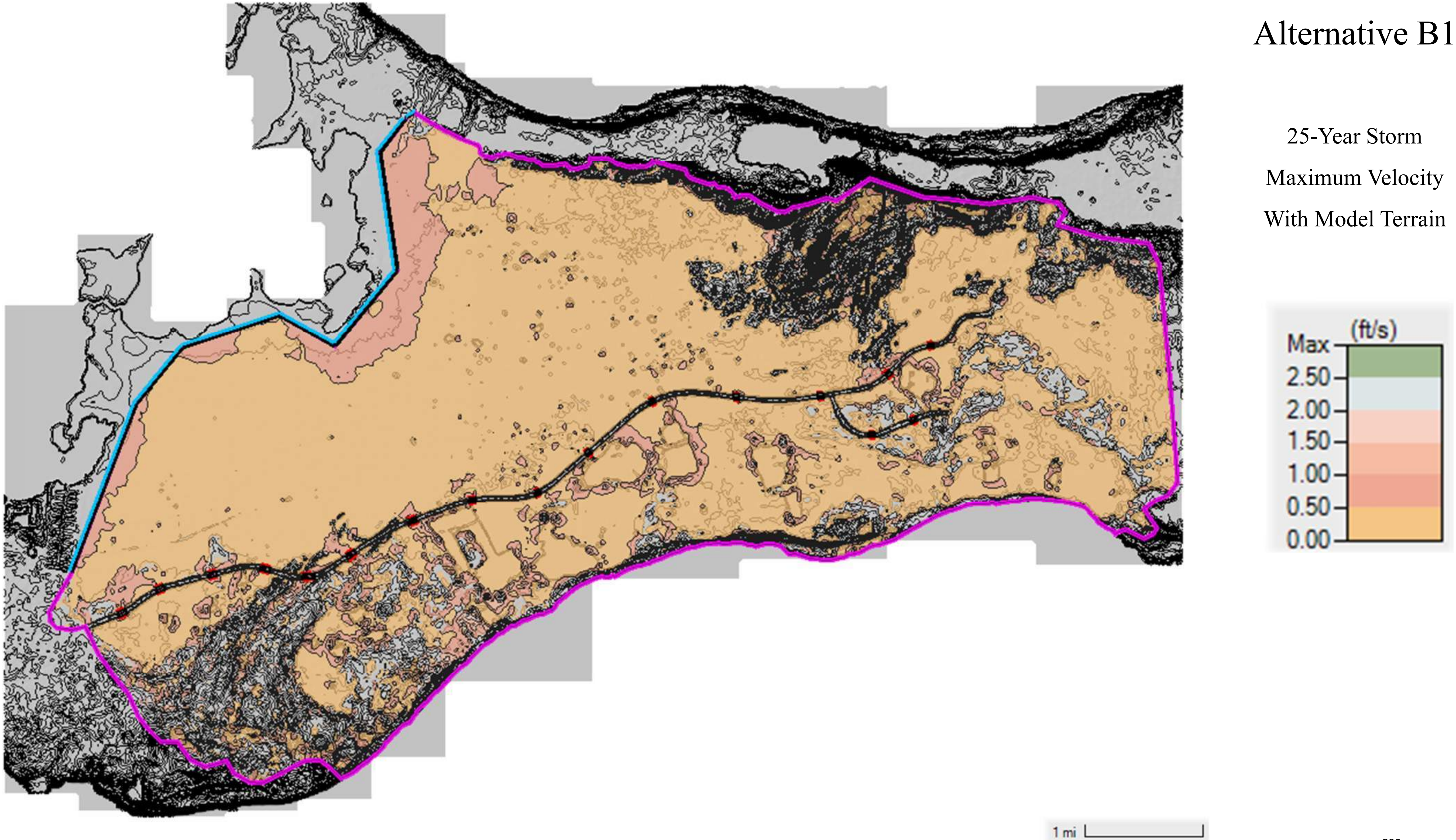


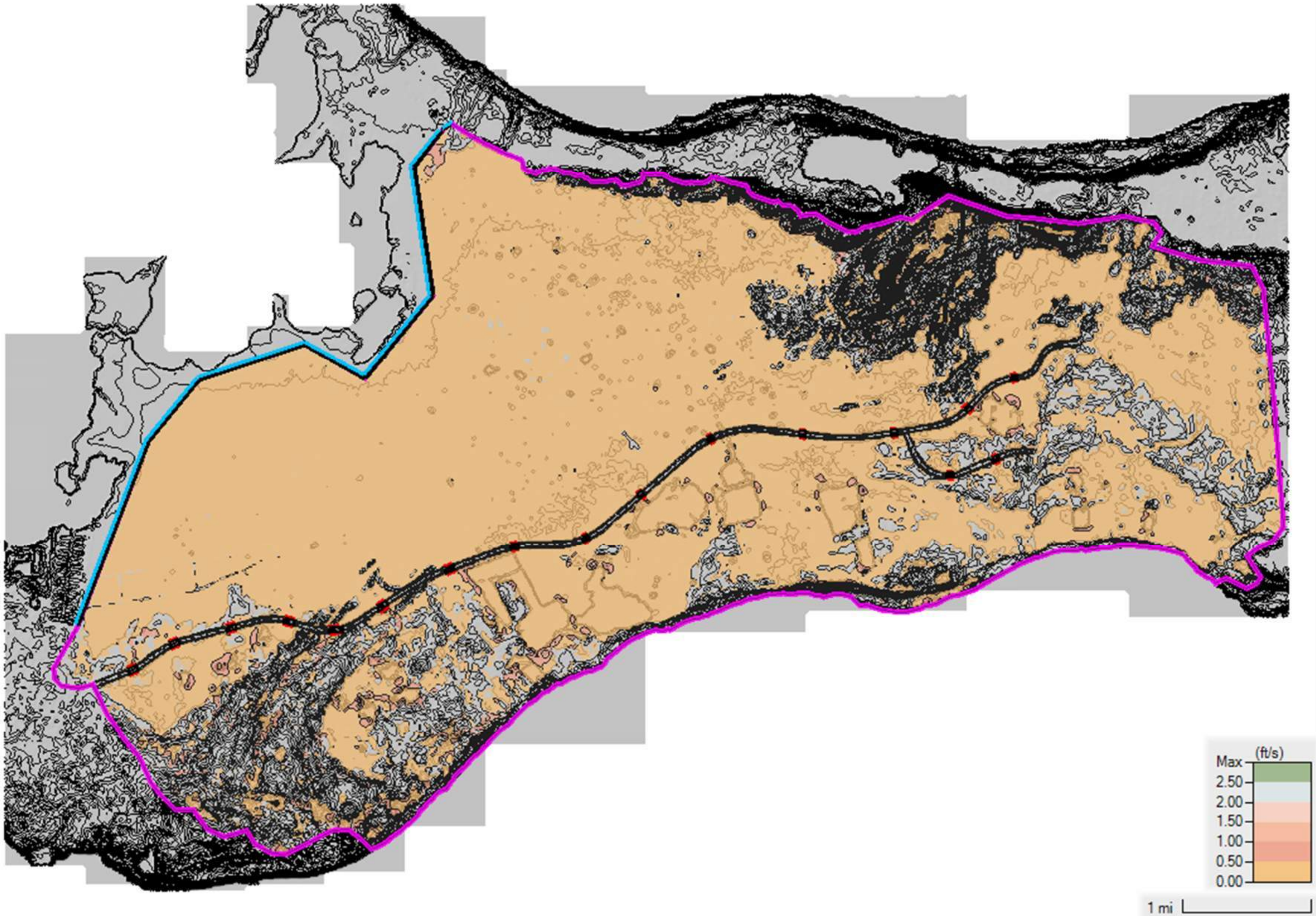
Alternative B1

25-Year Storm

Maximum Velocity

With Model Terrain





Alternative B1

25-Year Storm

With Sea Rise

Maximum Velocity

With Model Terrain

Max
(ft/s)
2.50
2.00
1.50
1.00
0.50
0.00

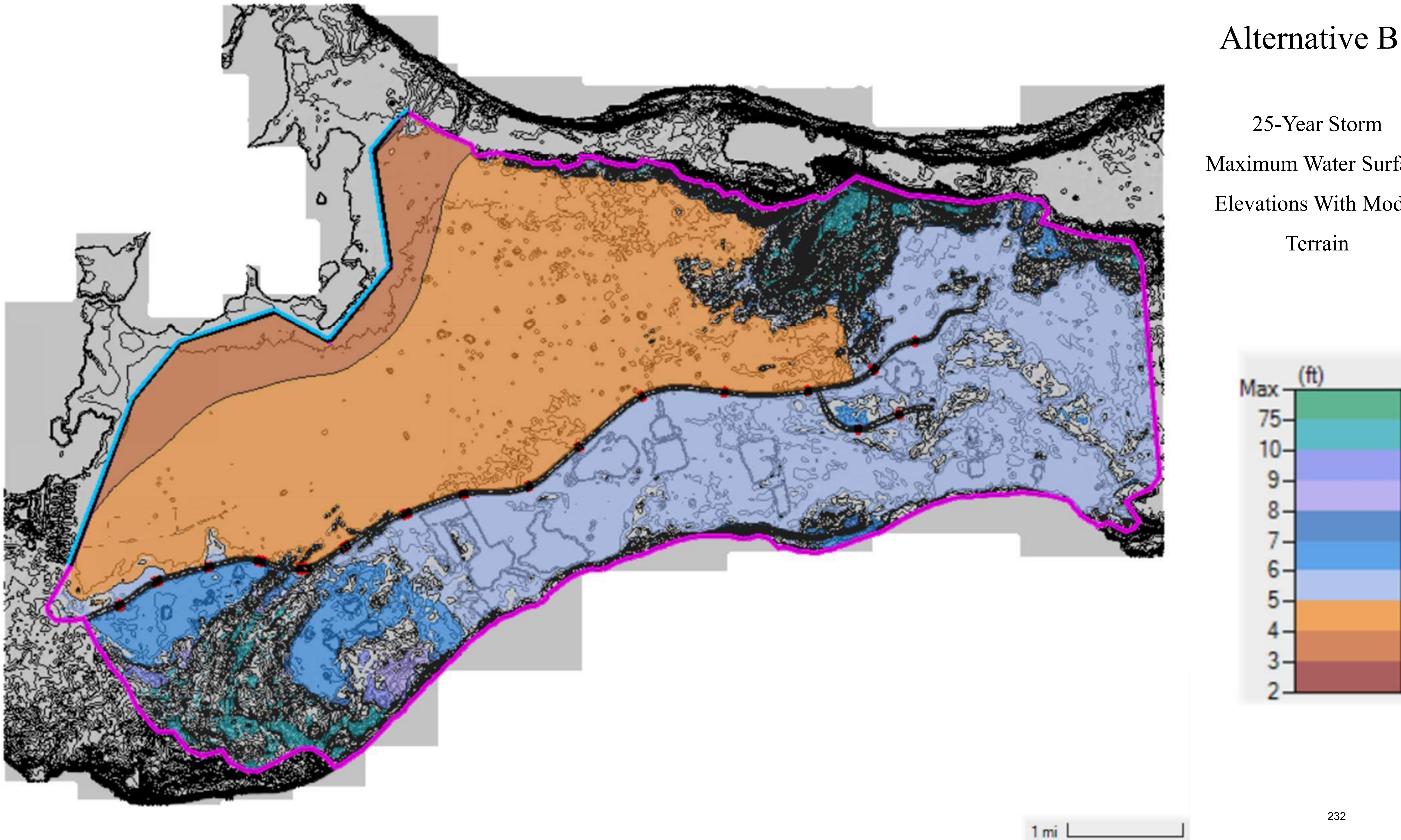
Alternative B1

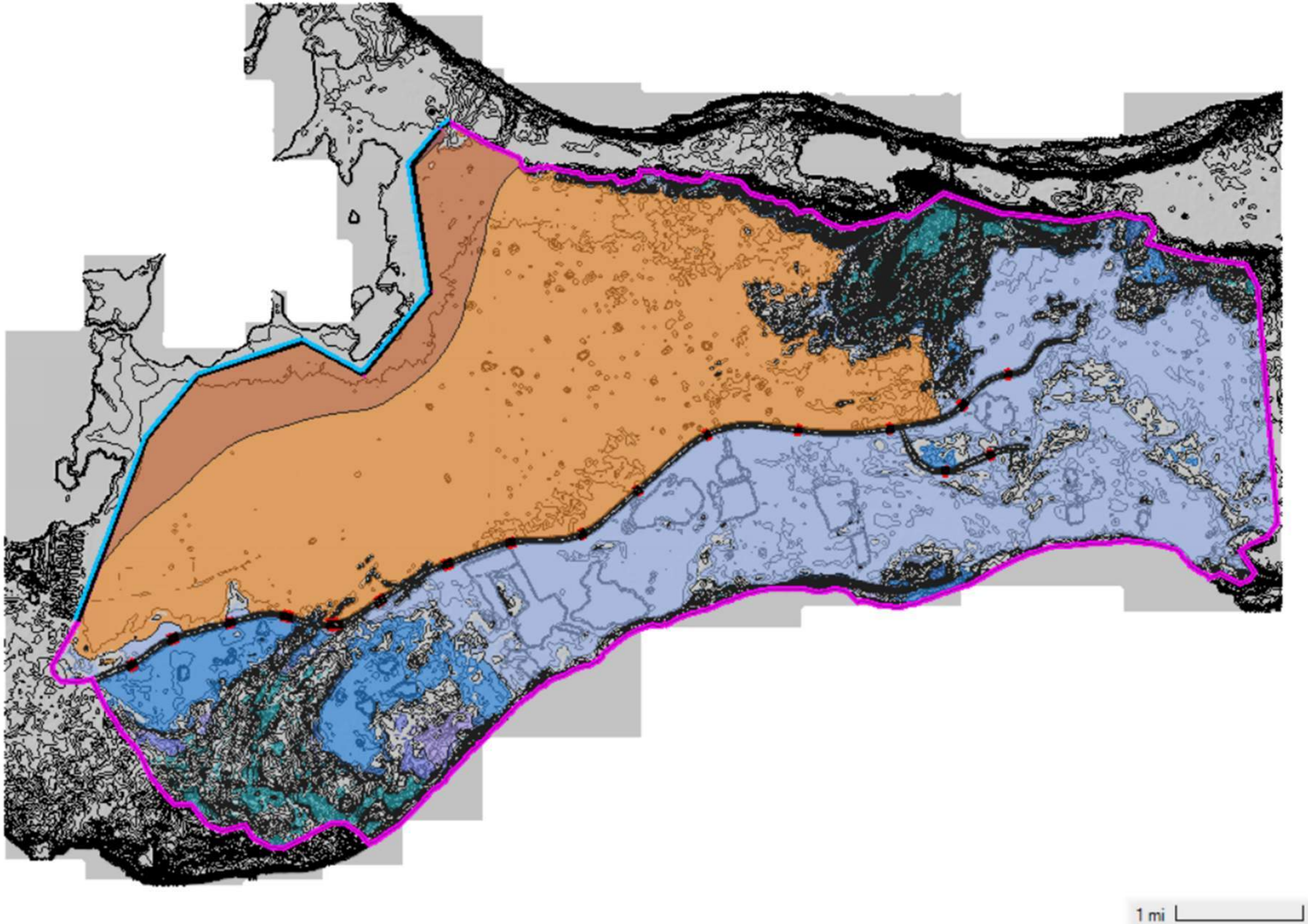
25-Year Storm

Maximum Water Surface

Elevations With Model

Terrain





Alternative B1

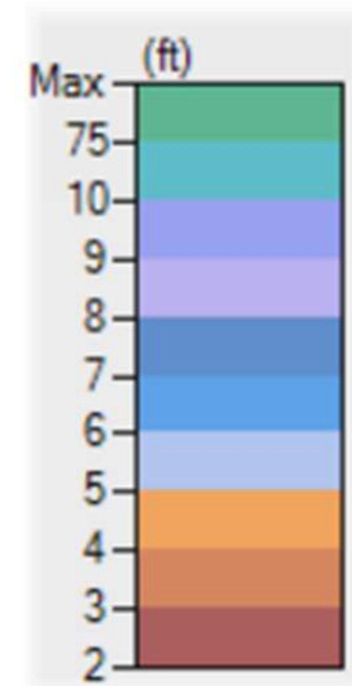
25-Year Storm

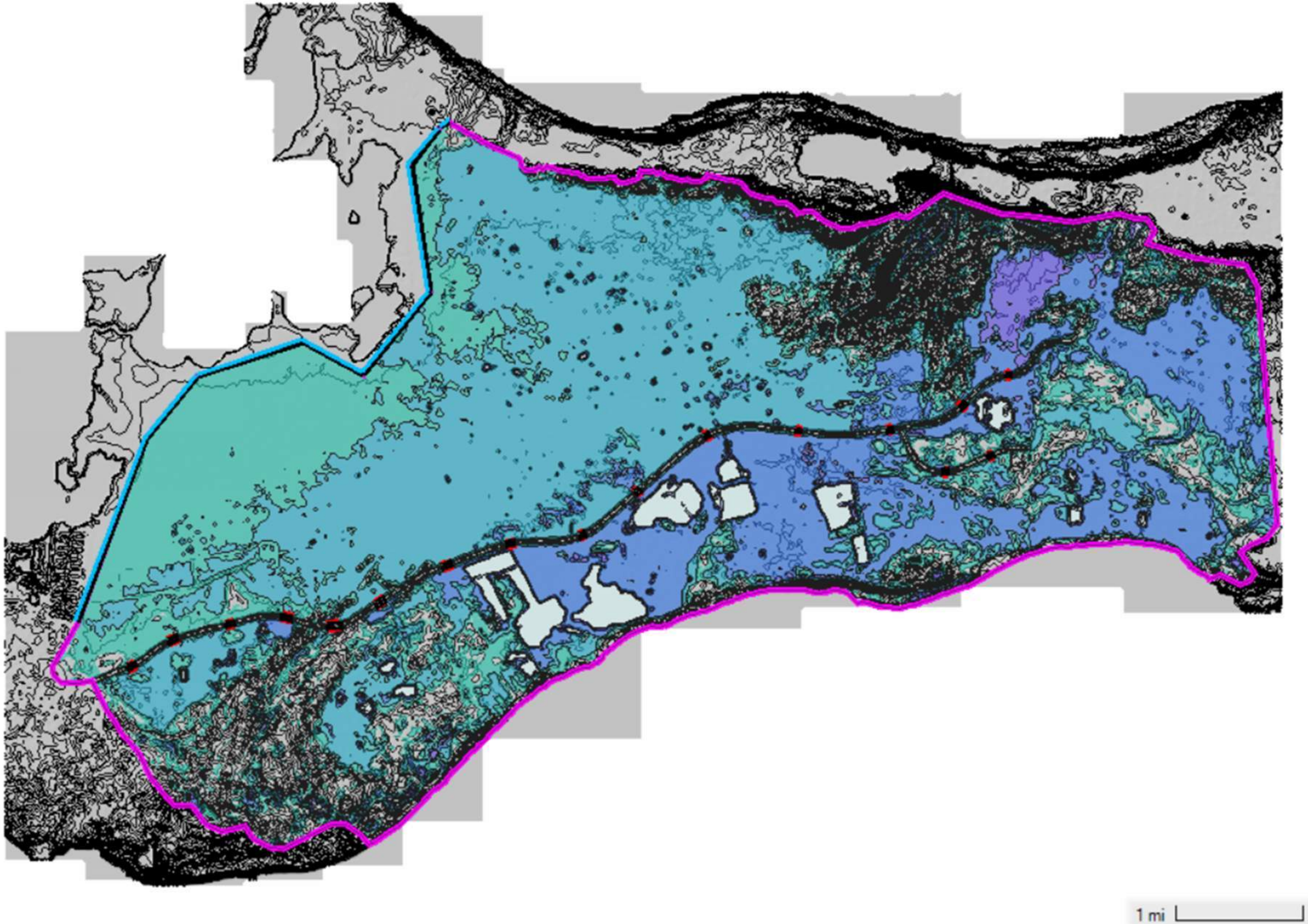
With Sea Rise

Maximum Water Surface

Elevations With Model

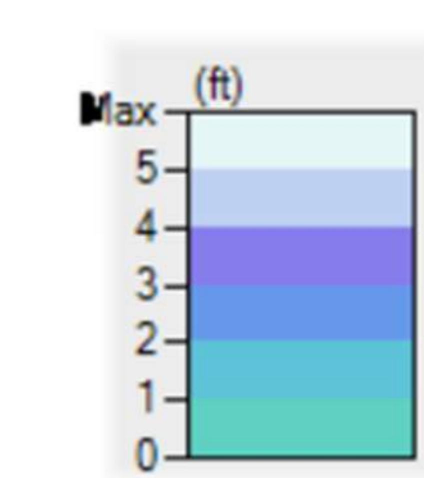
Terrain

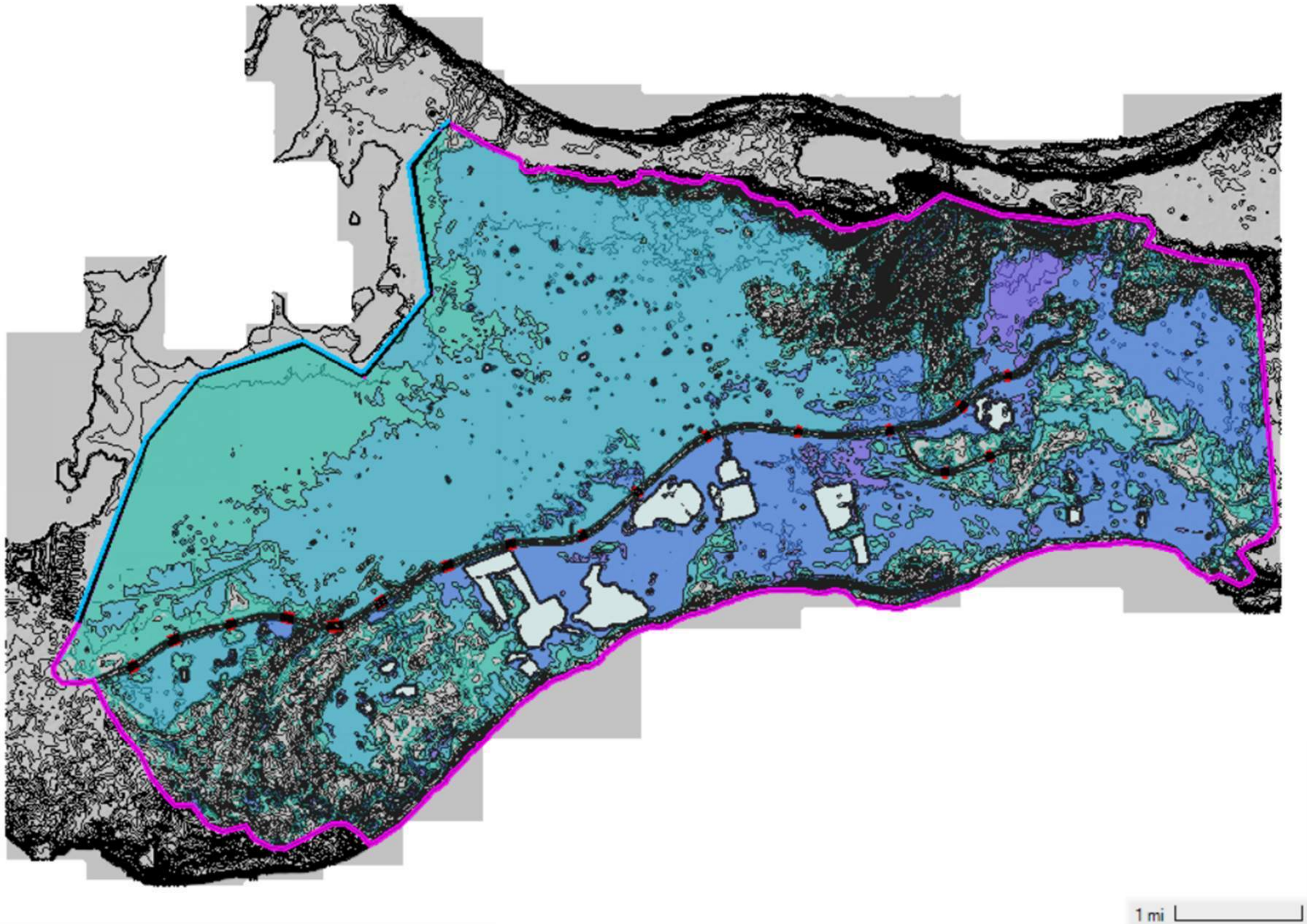




Alternative B1

50-Year Storm
Maximum Depths With
Model Terrain





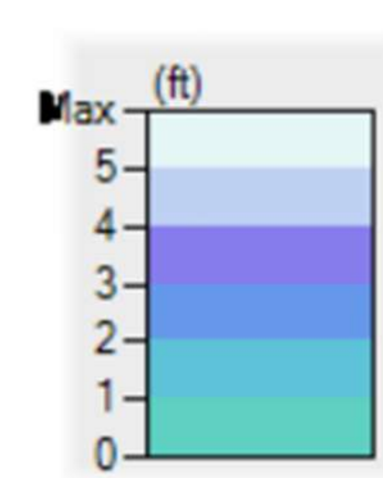
Alternative B1

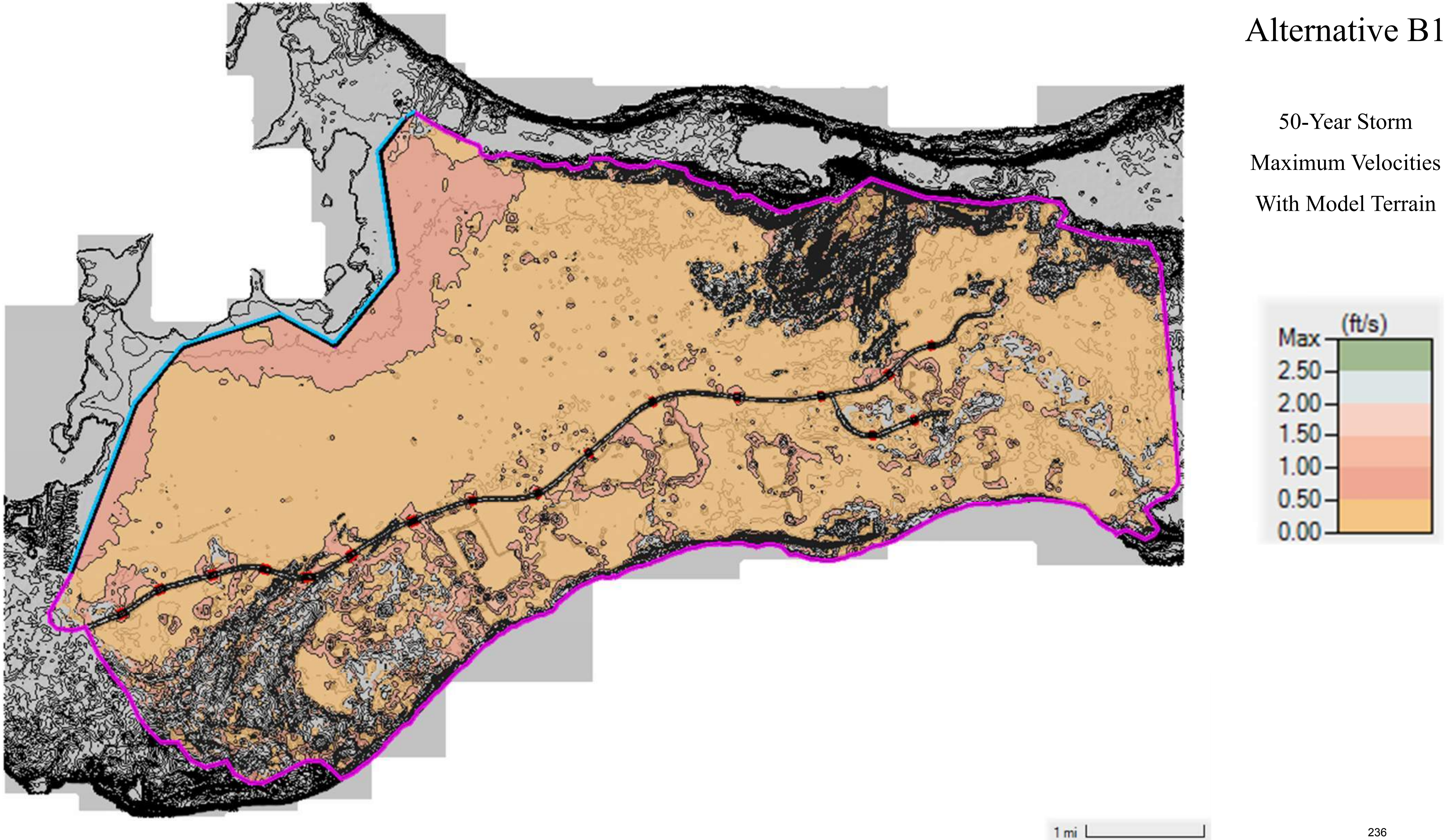
50-Year Storm

With Sea Rise

Maximum Depths With

Model Terrain





Alternative B1

50-Year Storm

Maximum Velocities

With Model Terrain

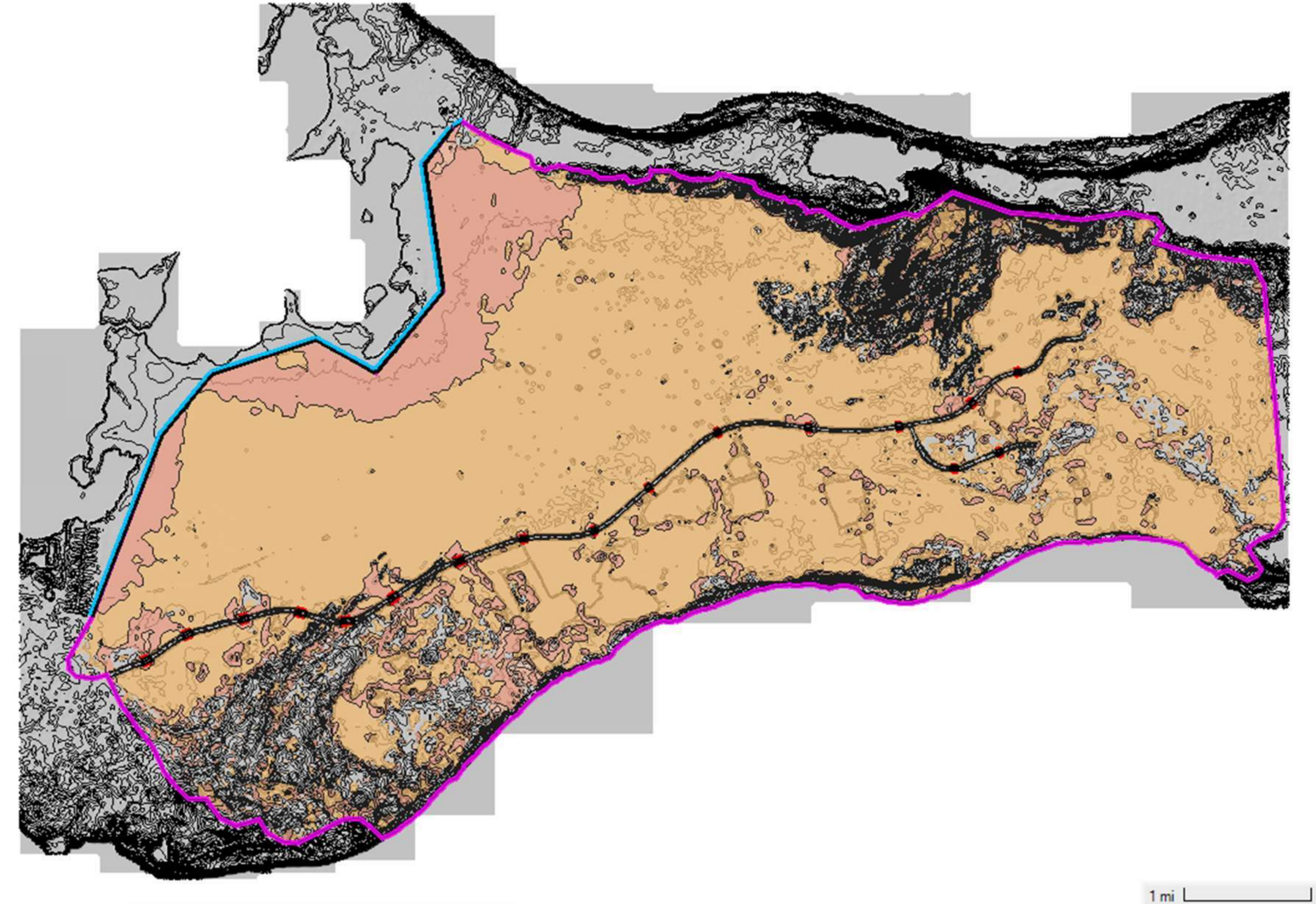
Alternative B1

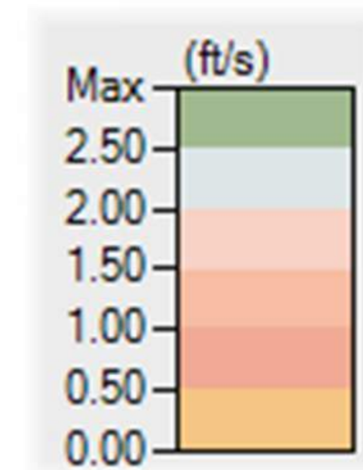
50-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain

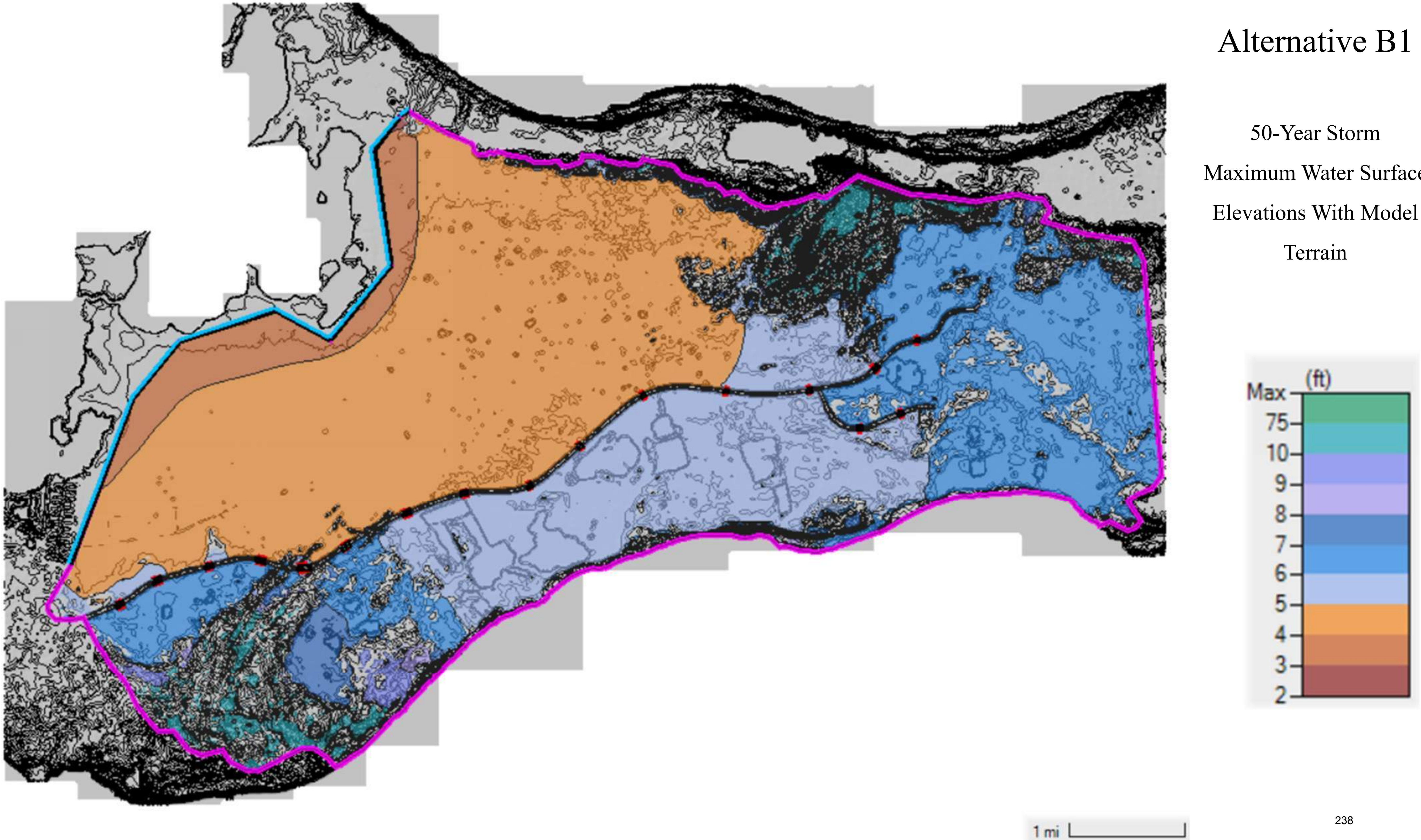


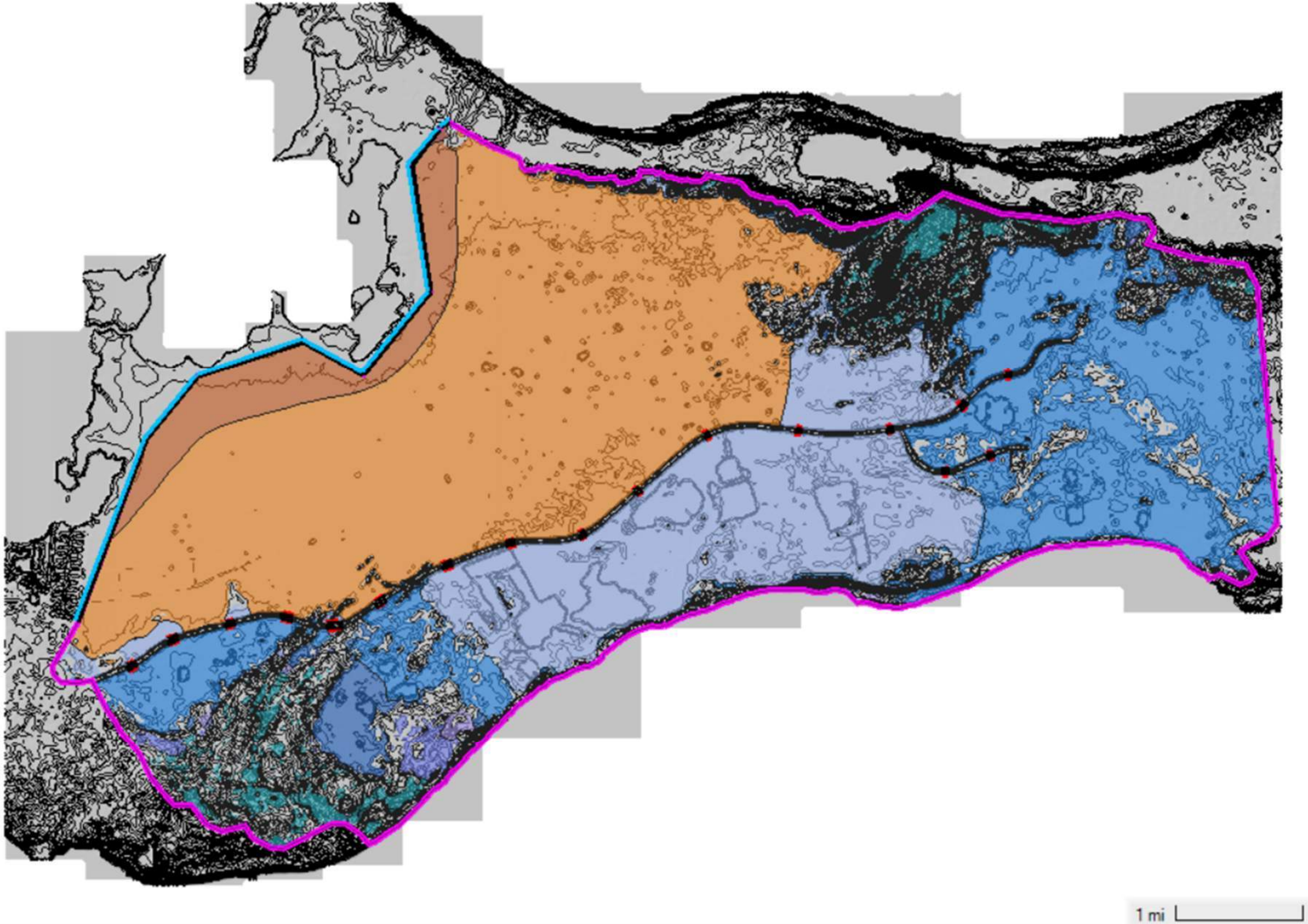


Alternative B1

50-Year Storm

Maximum Water Surface Elevations With Model Terrain





Alternative B1

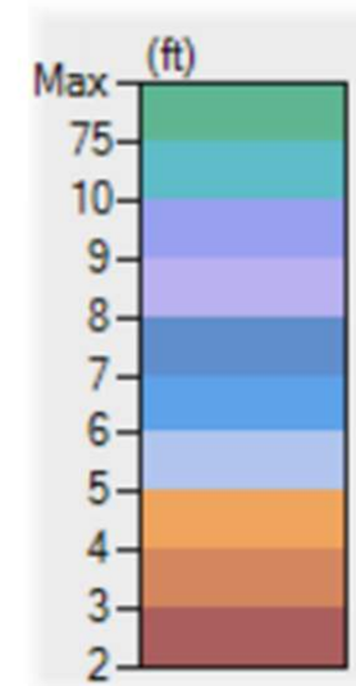
50-Year Storm

With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain

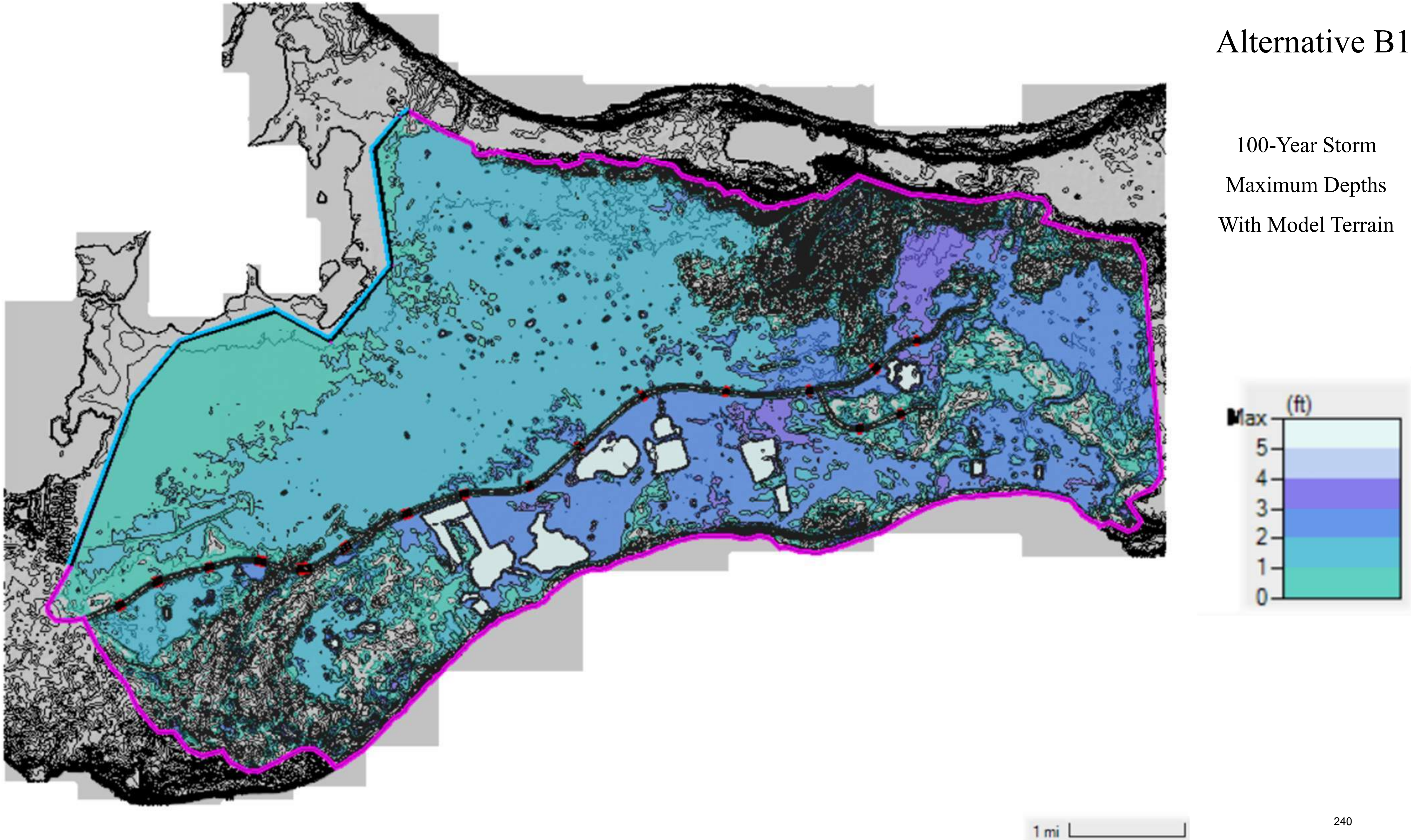


Alternative B1

100-Year Storm

Maximum Depths

With Model Terrain



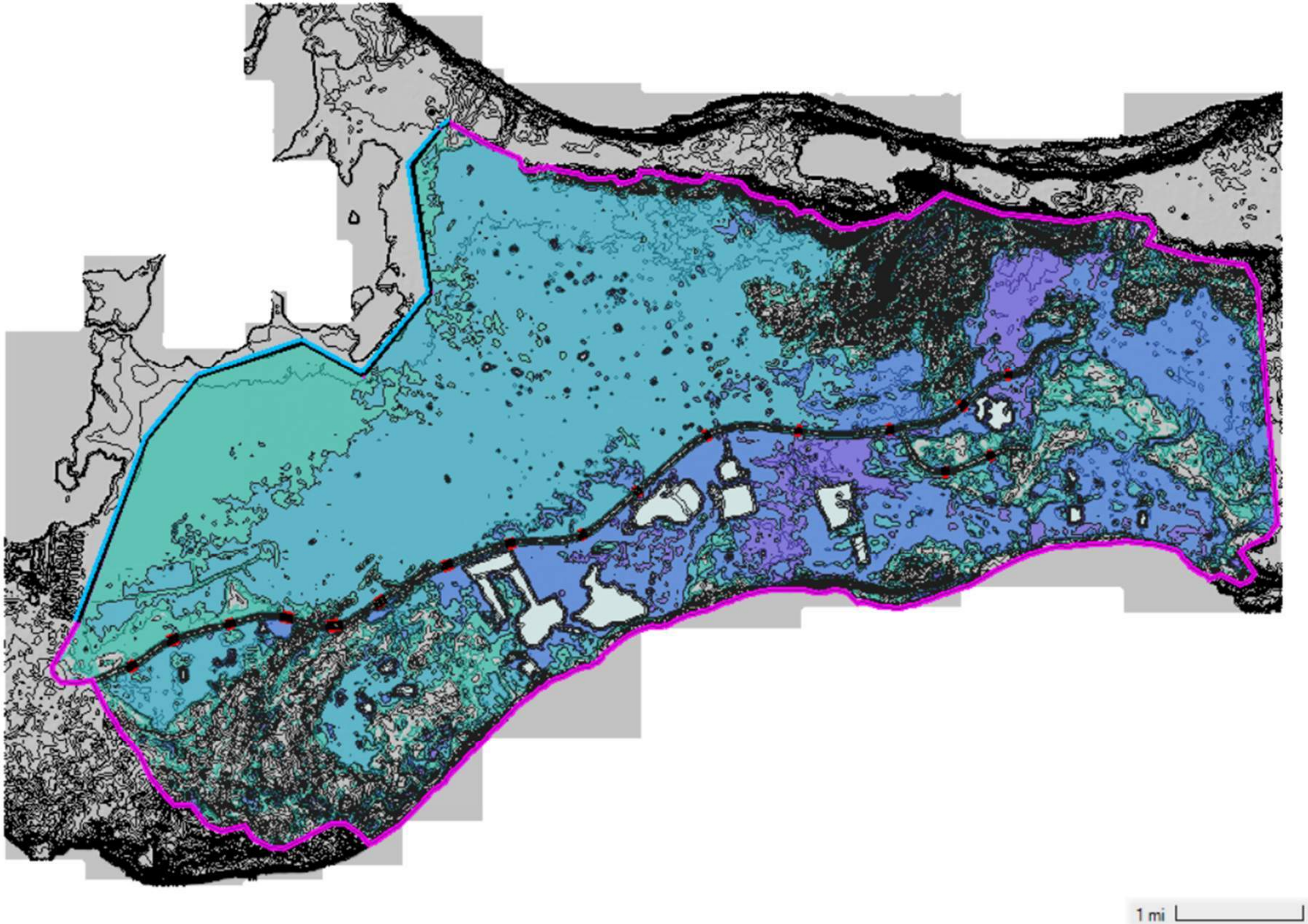
Alternative B1

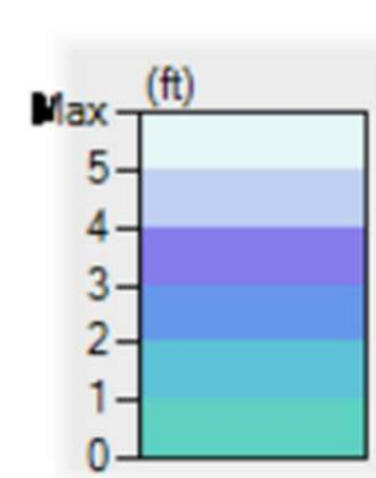
100-Year Storm

With Sea Rise

Maximum Depths

With Model Terrain



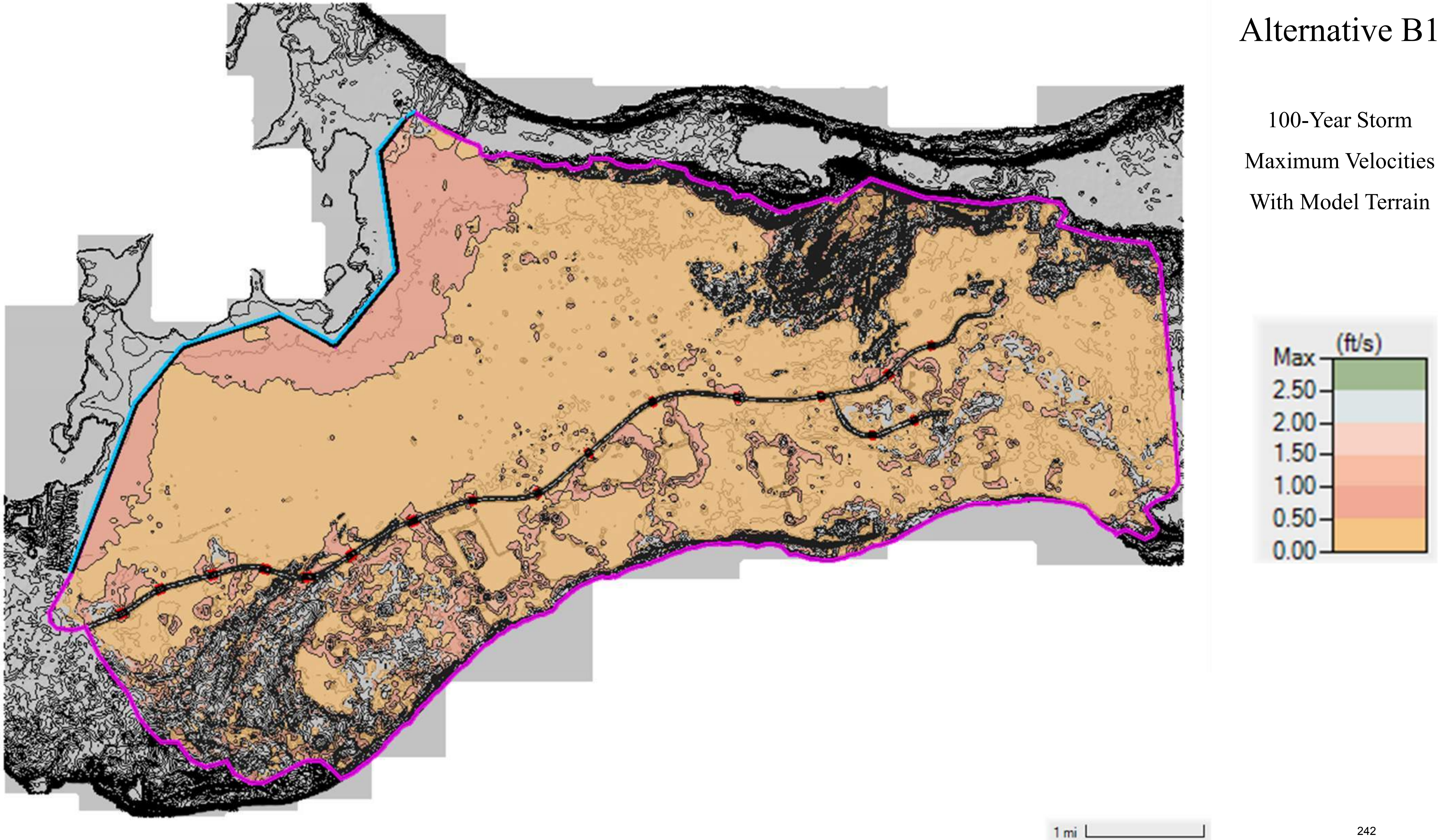


Alternative B1

100-Year Storm

Maximum Velocities

With Model Terrain



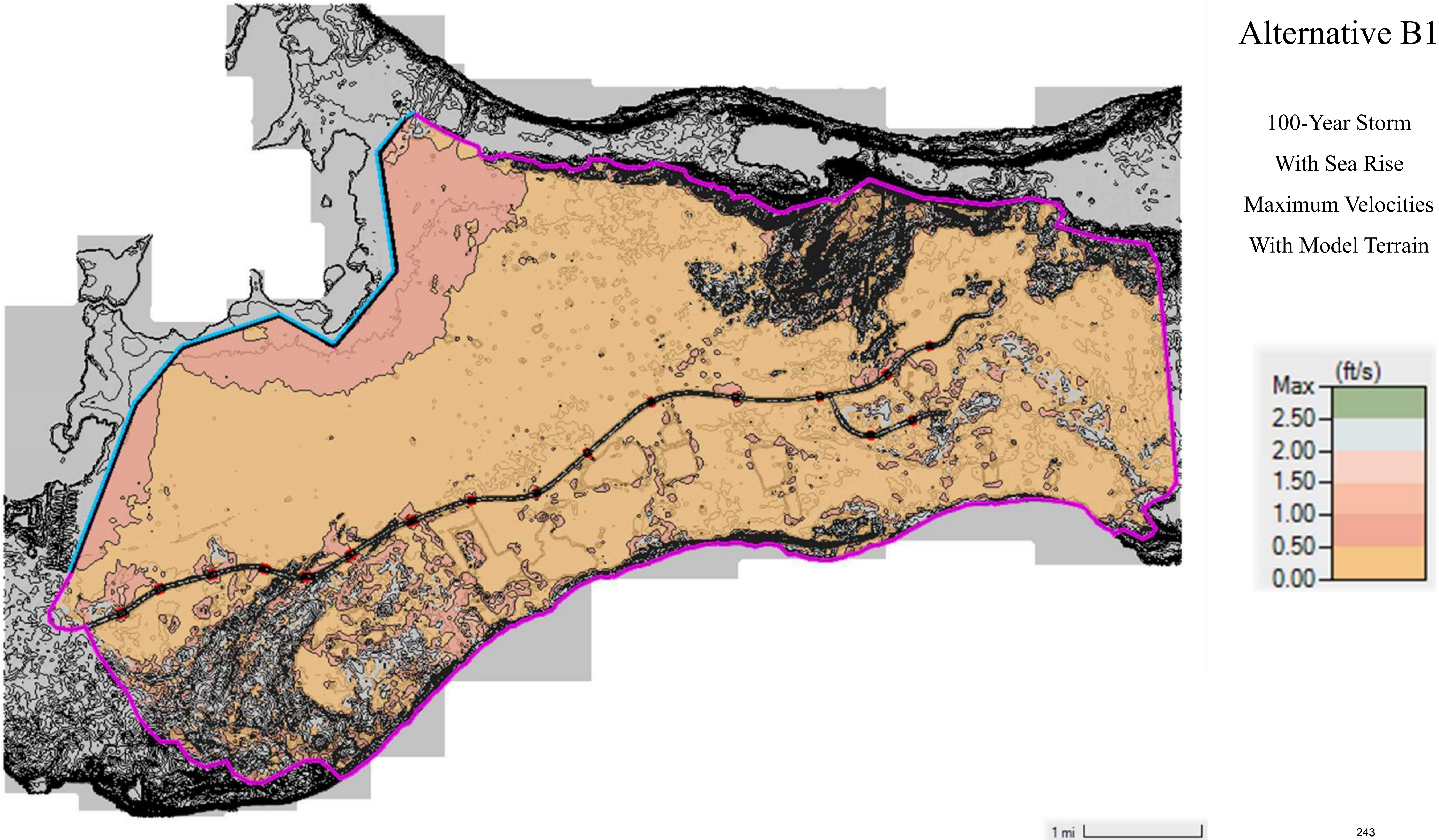
Alternative B1

100-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain



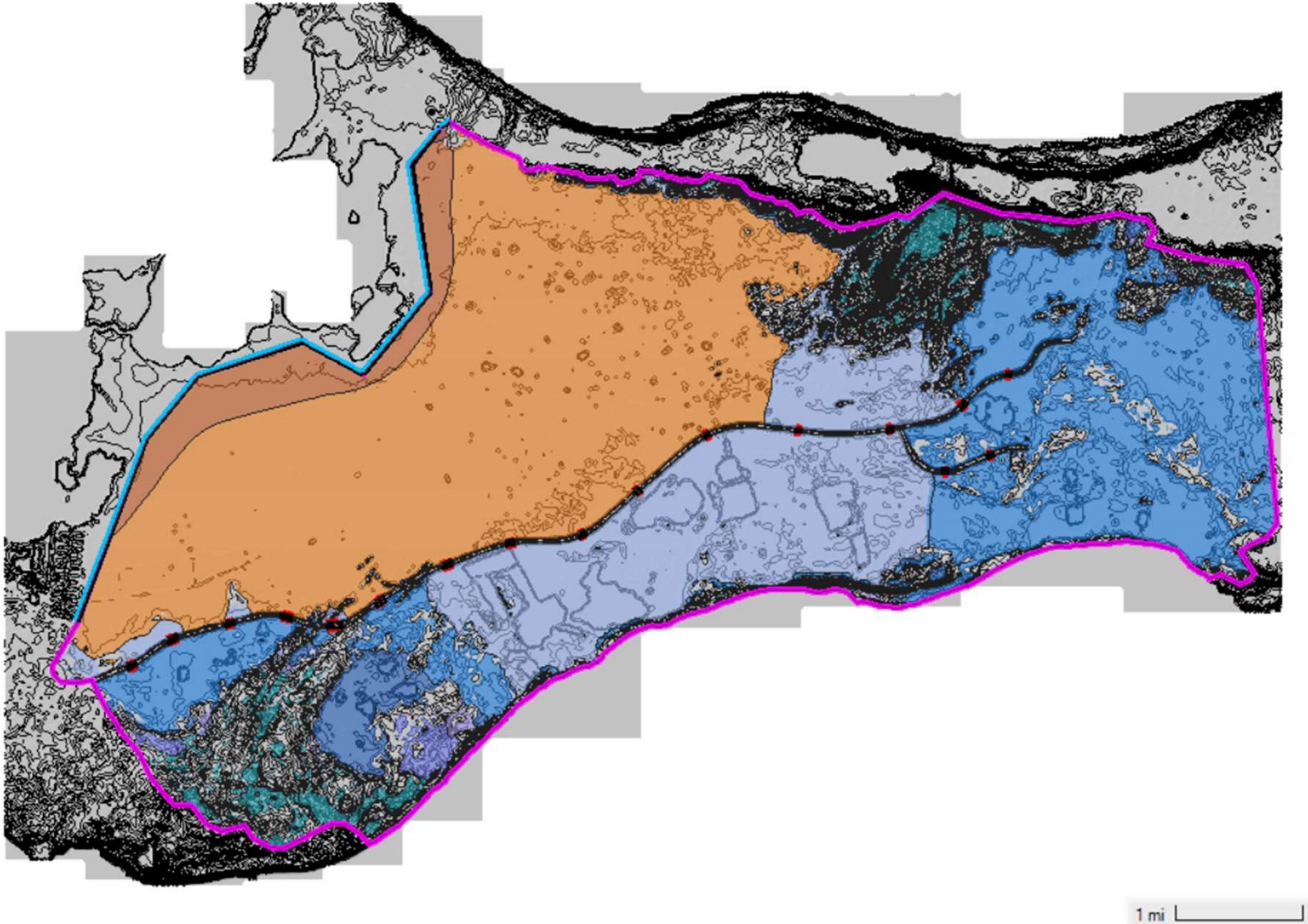
Alternative B1

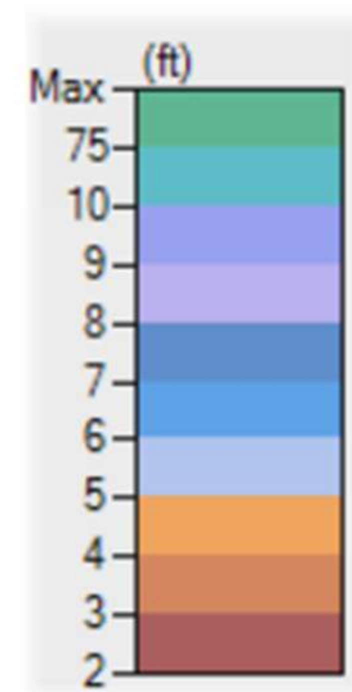
100-Year Storm

Maximum Water Surface

Elevations

With Model Terrain





Alternative B1

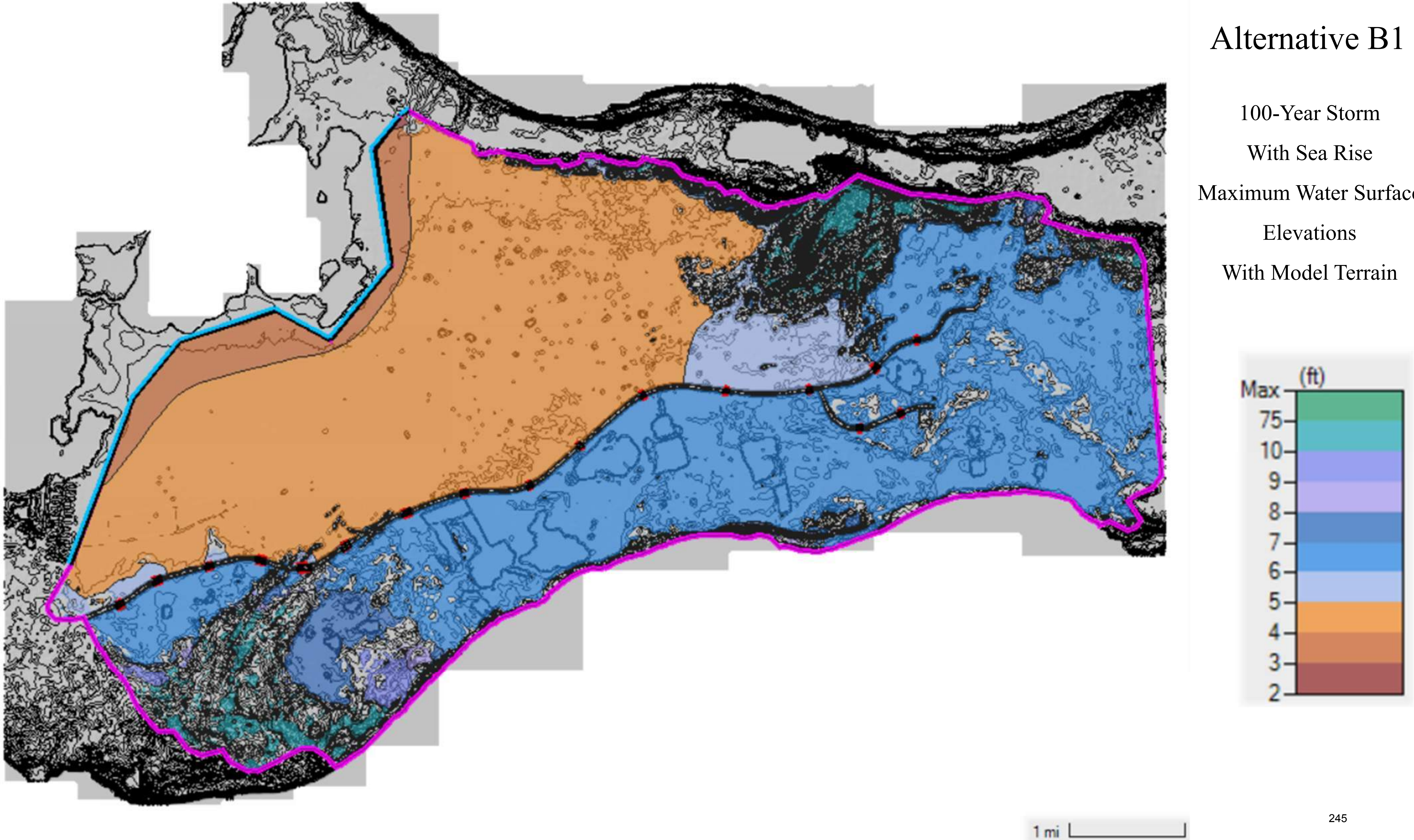
100-Year Storm

With Sea Rise

Maximum Water Surface

Elevations

With Model Terrain

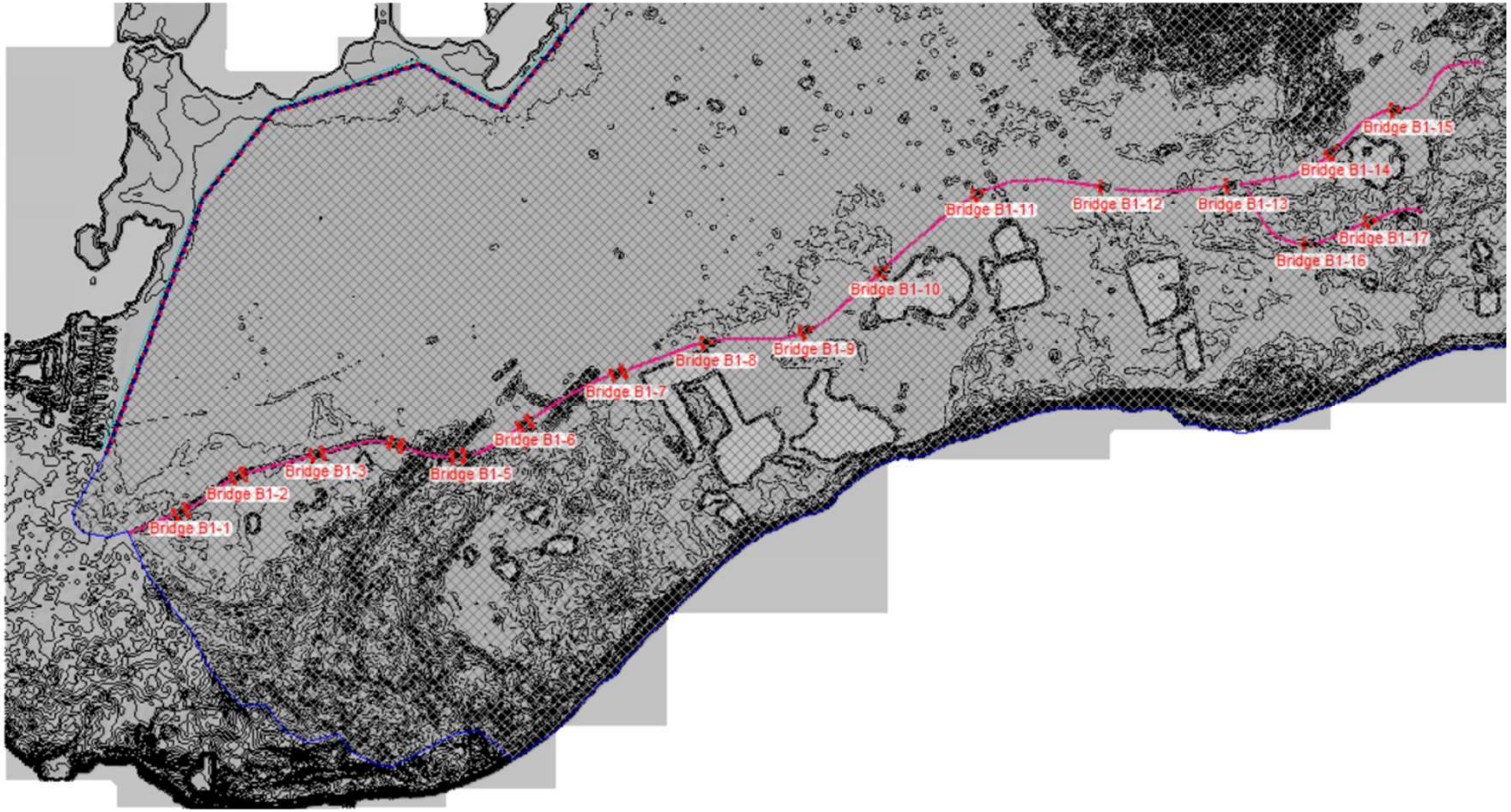


Alternative B1

Profiles

Alternative B1

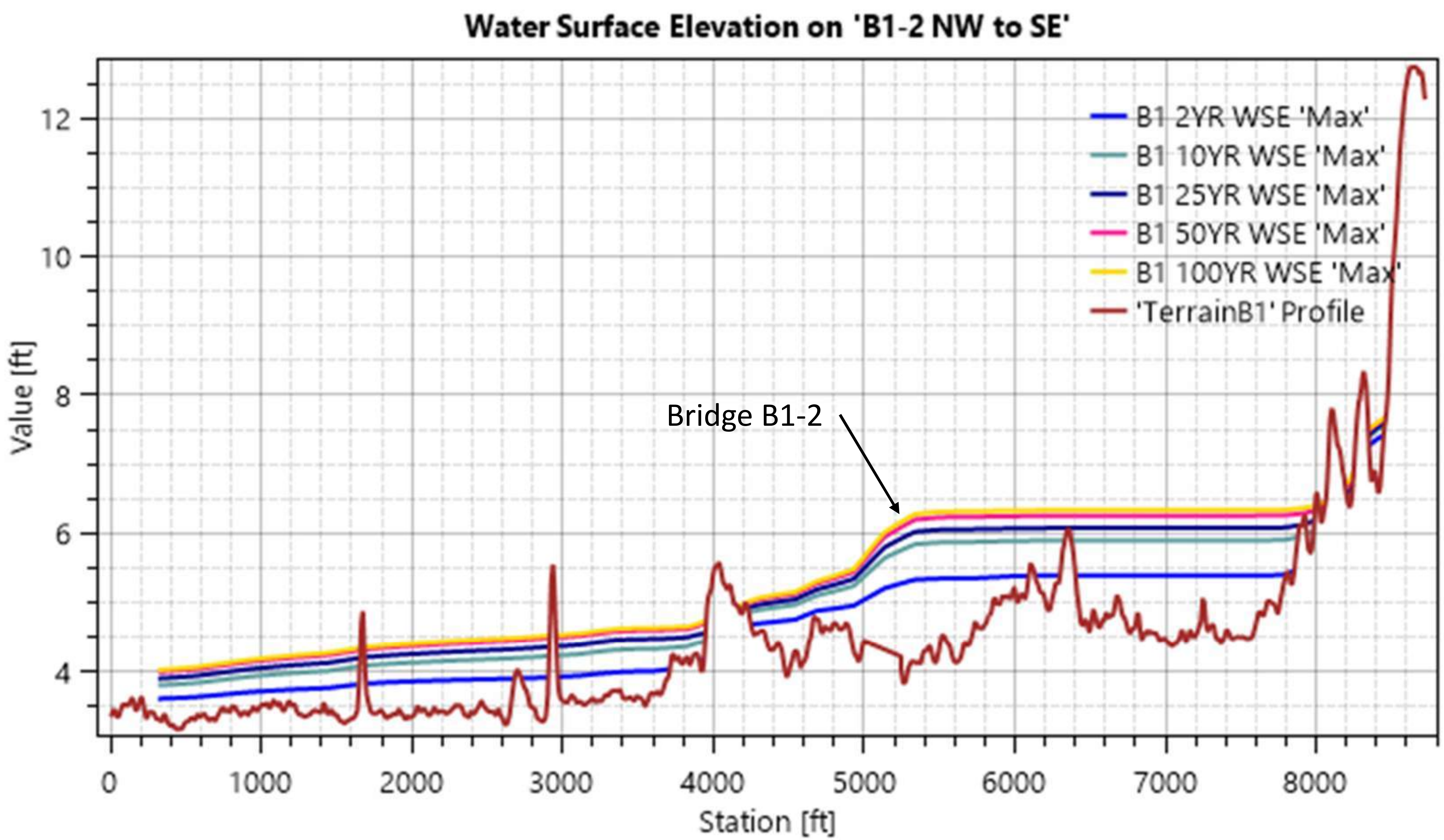
Bridges



Alternative B1

Profile B1-2

From NW to SE

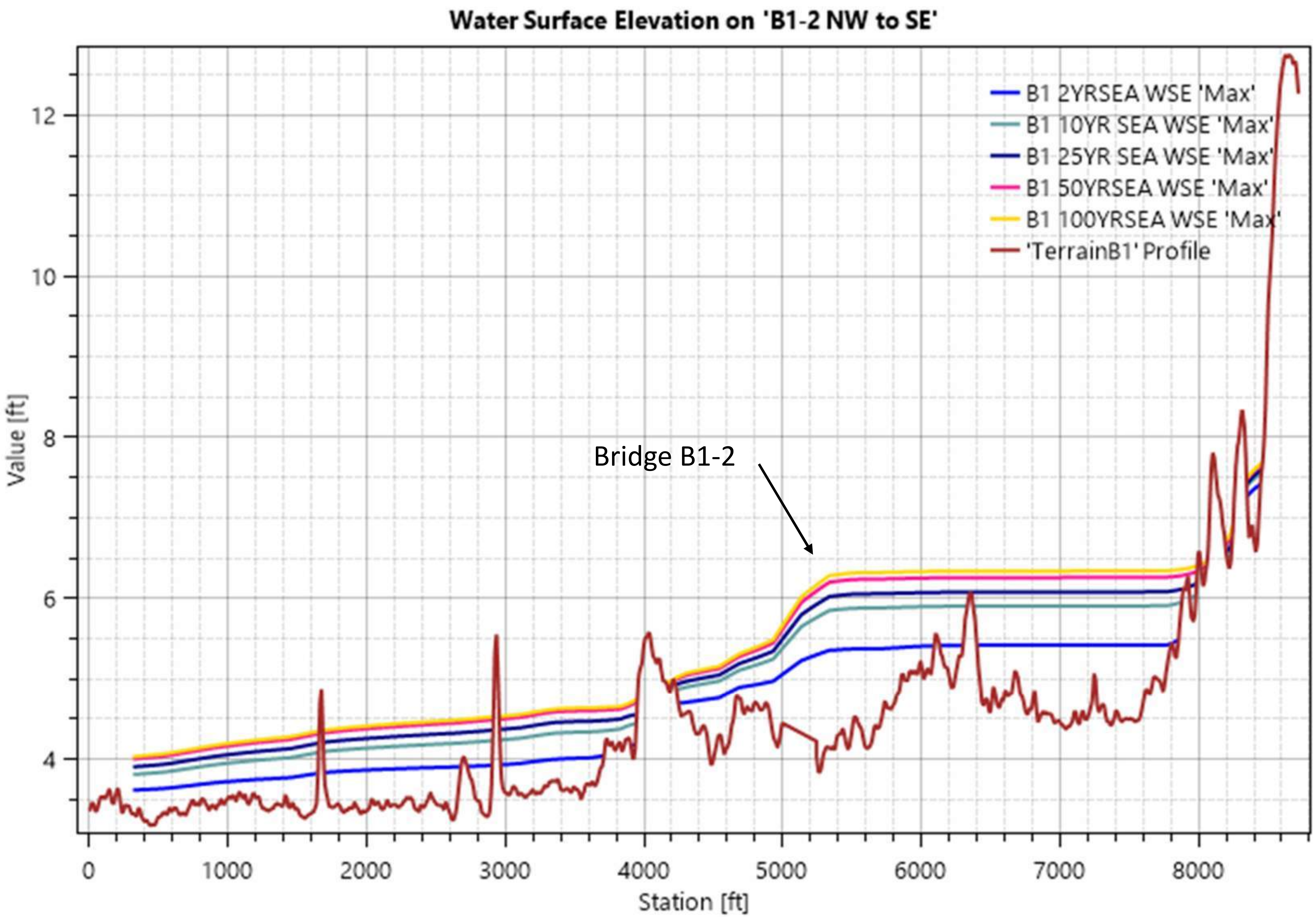


Alternative B1

Profile B1-2

With Sea Rise

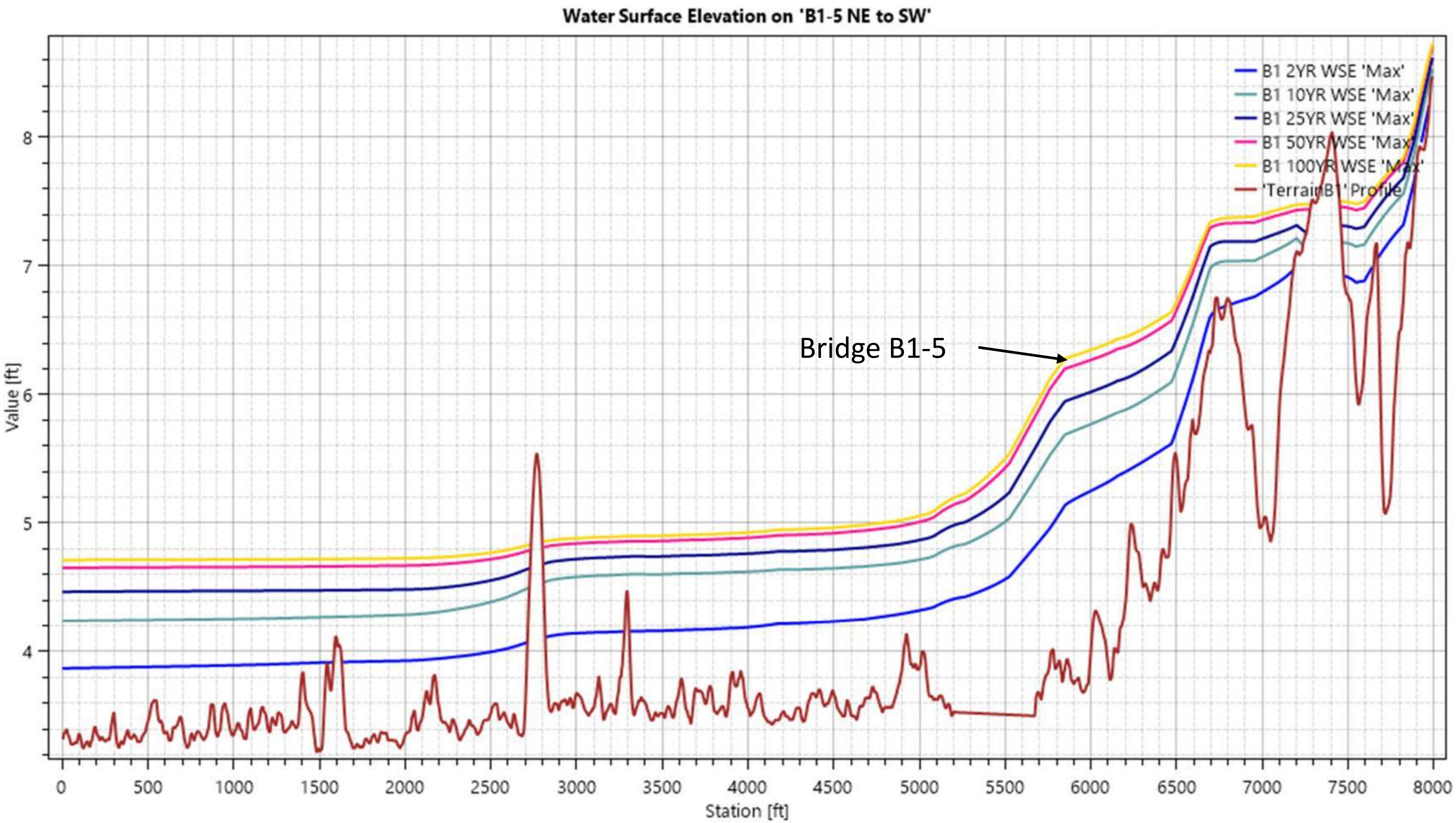
From NW to SE

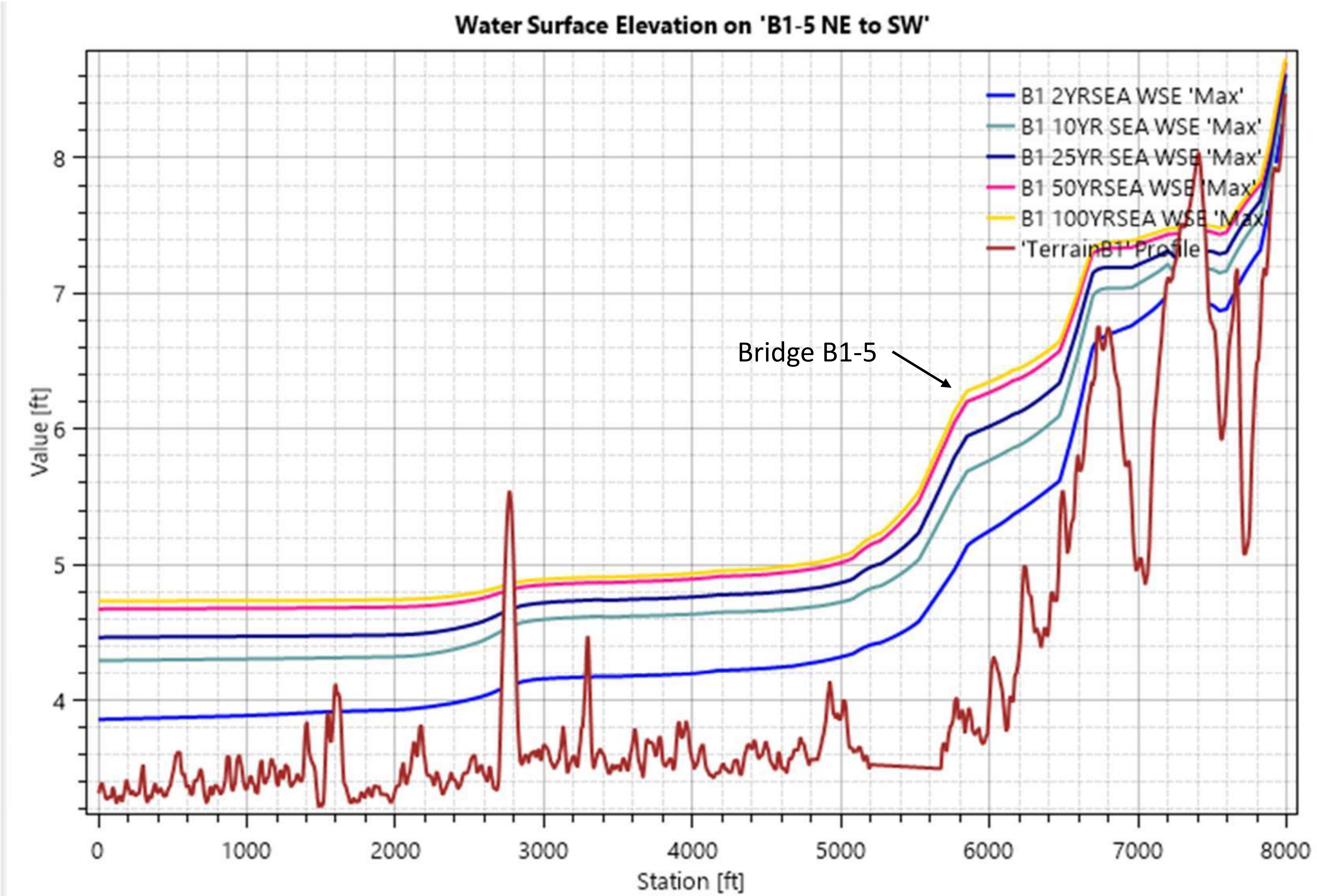


Alternative B1

Profile B1-5

From NE to SW



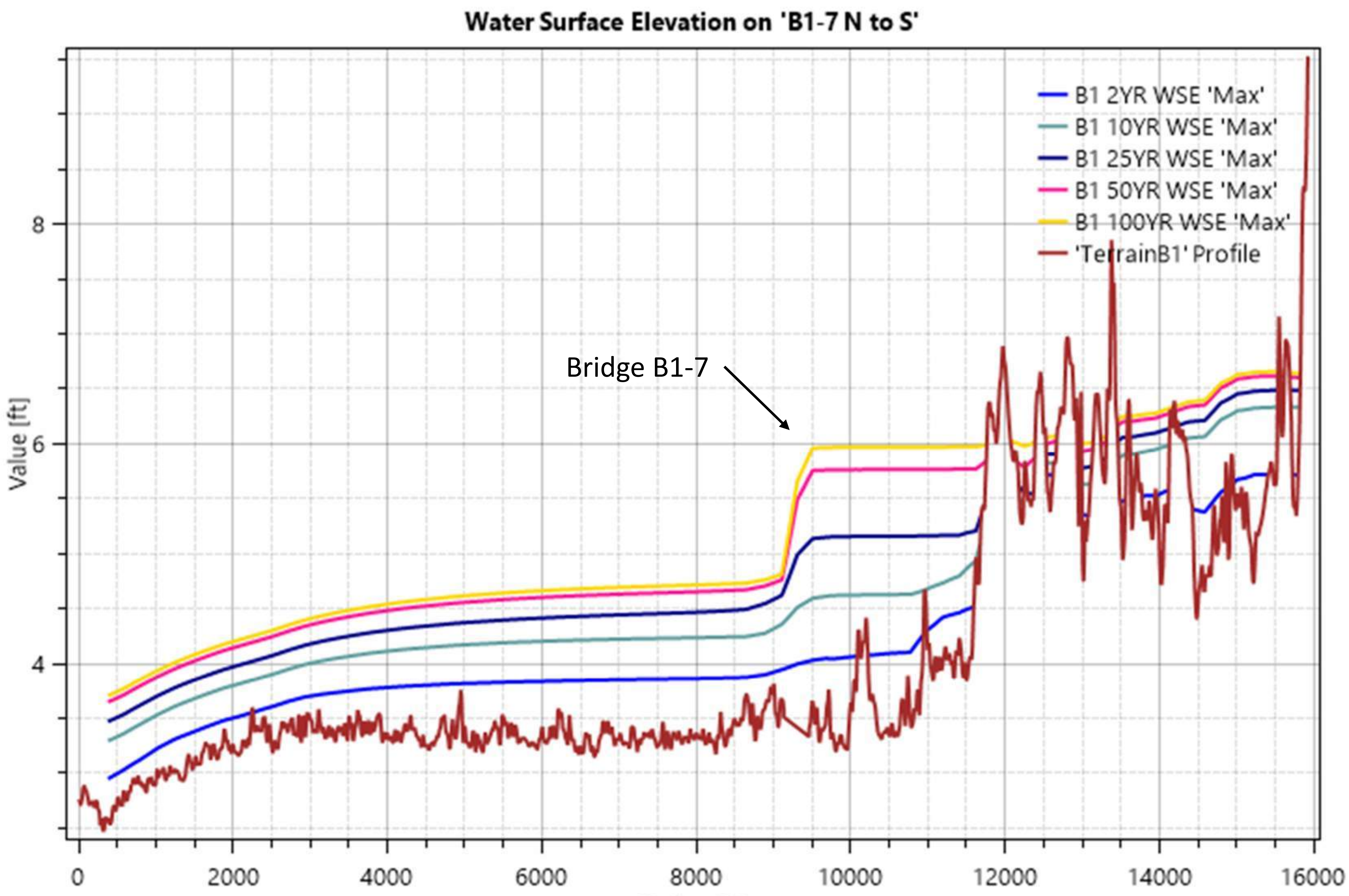


Alternative B1

Profile B1-5

With Sea Rise

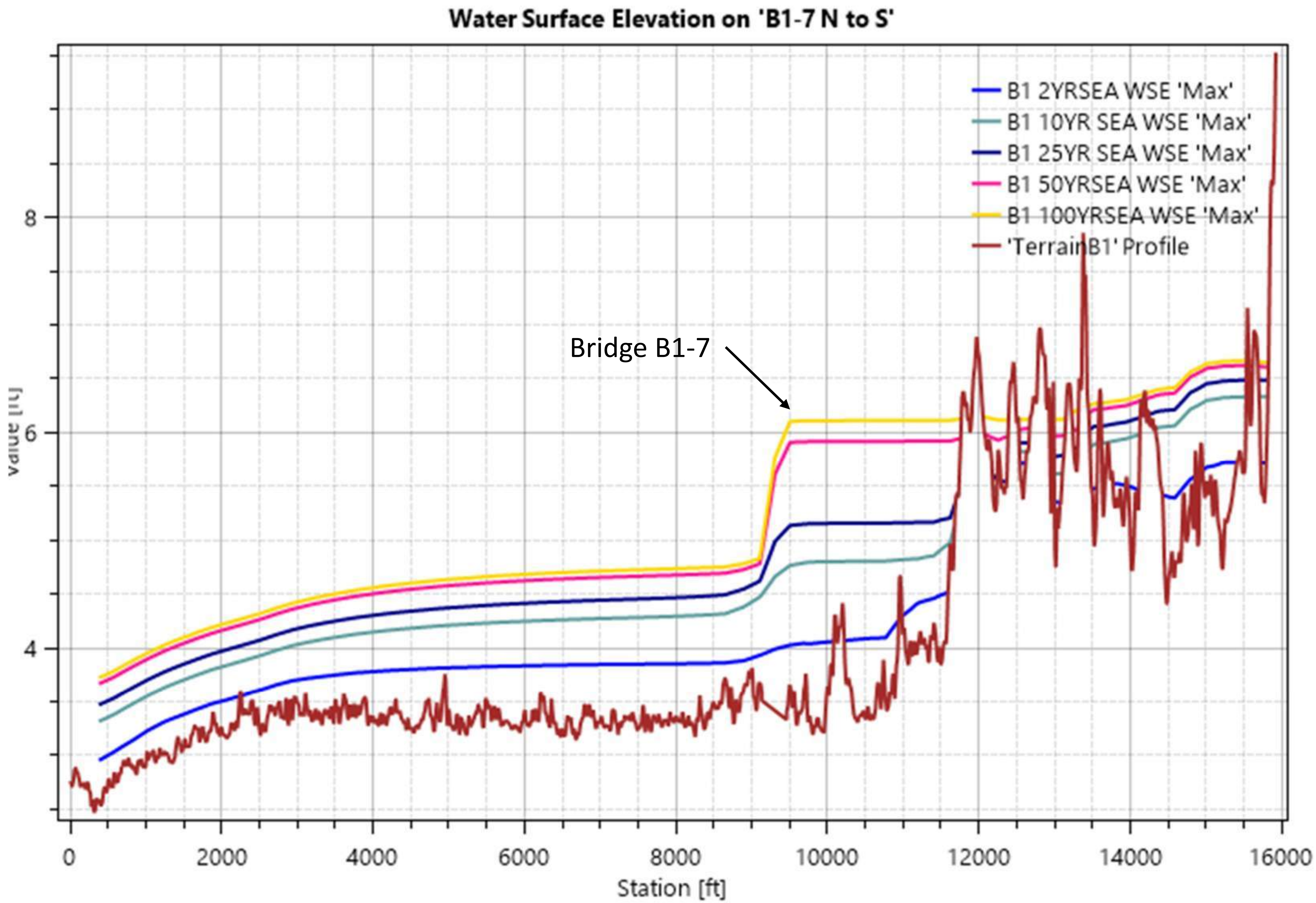
From NE to SW



Alternative B1

Profile B1-7

From N to S.



Alternative B1

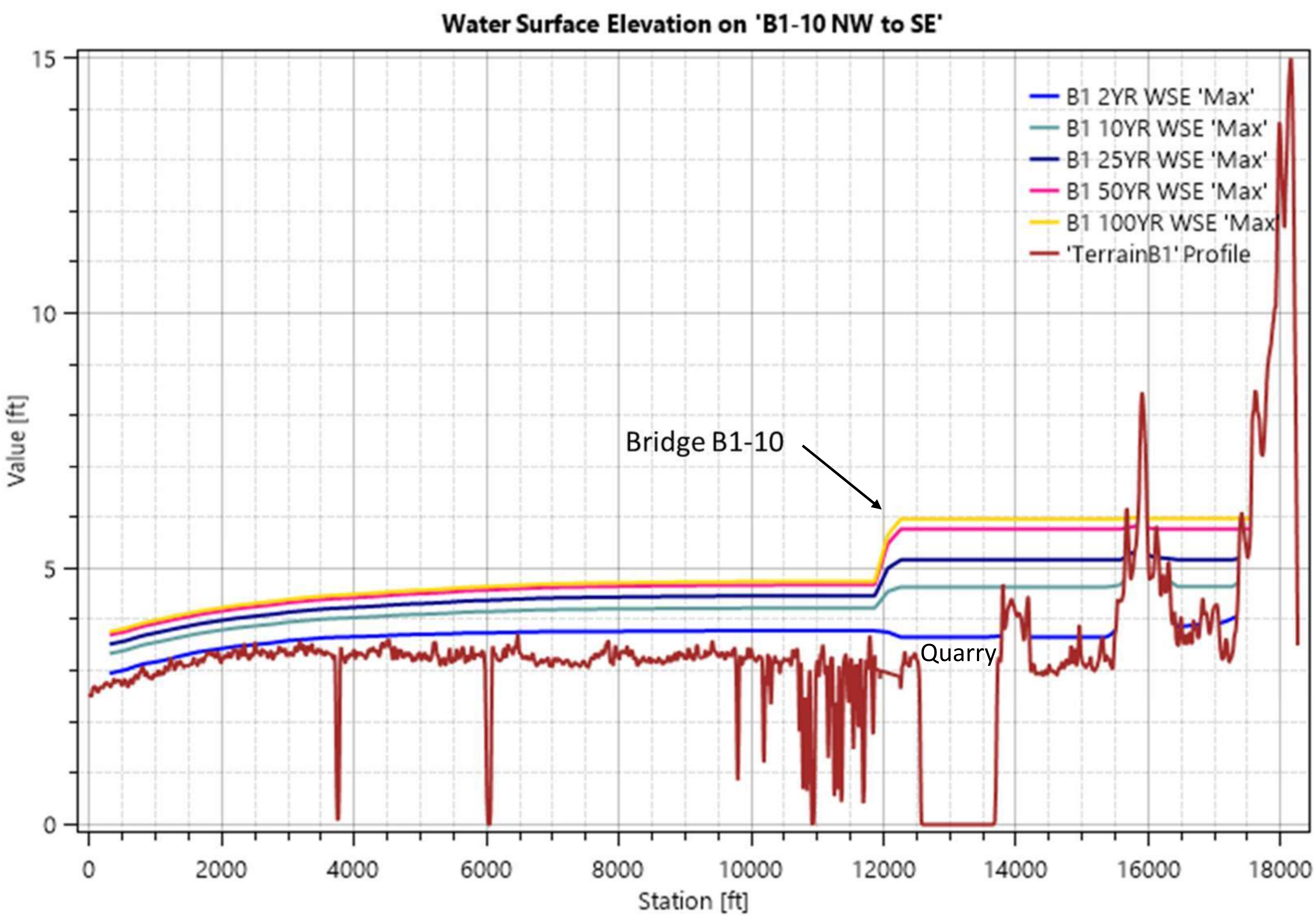
Profile B1-7

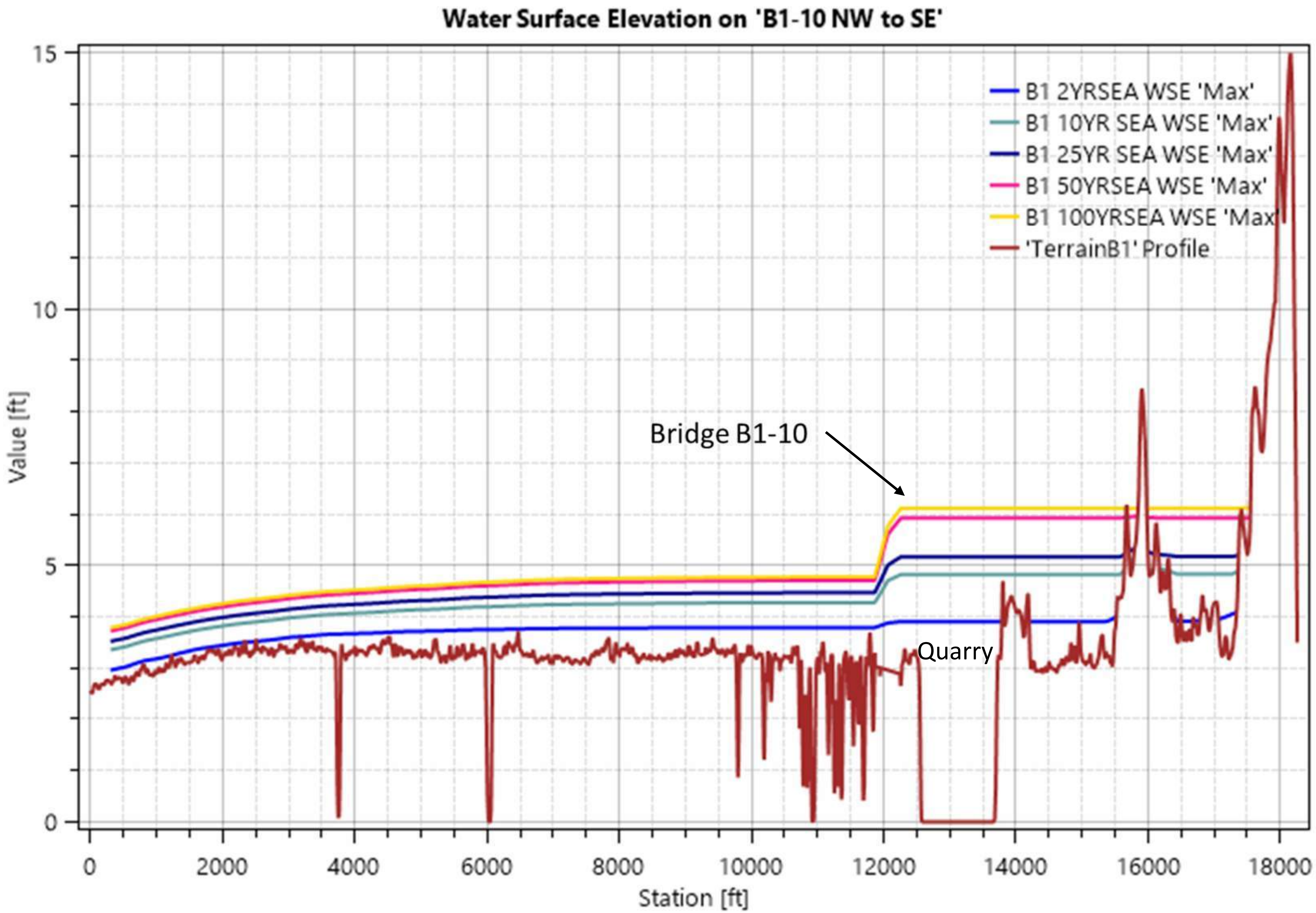
With Sea Rise

Alternative B1

Profile B1-10

From NW to SE





Alternative B1

Profile B1-10

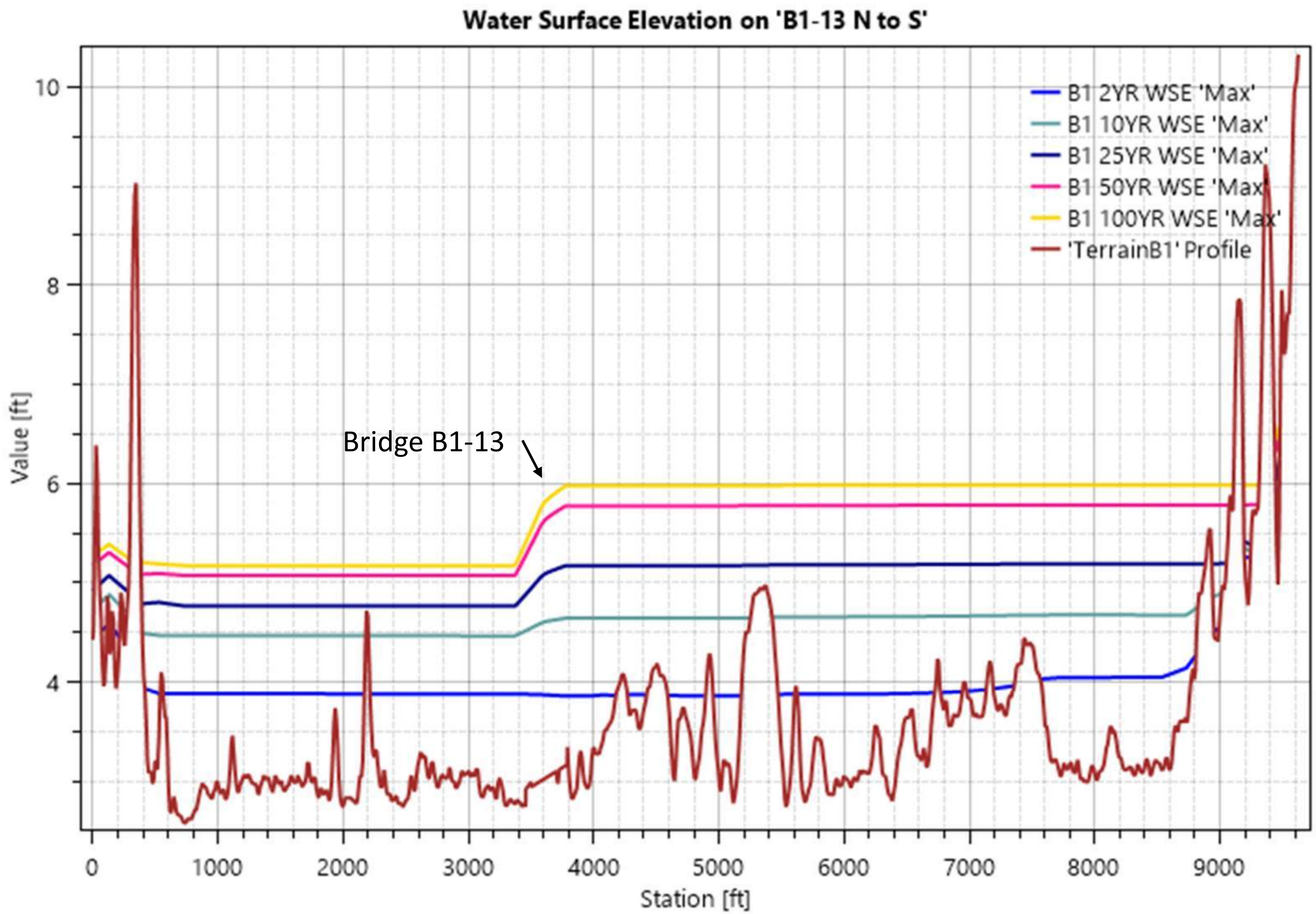
with Sea Rise

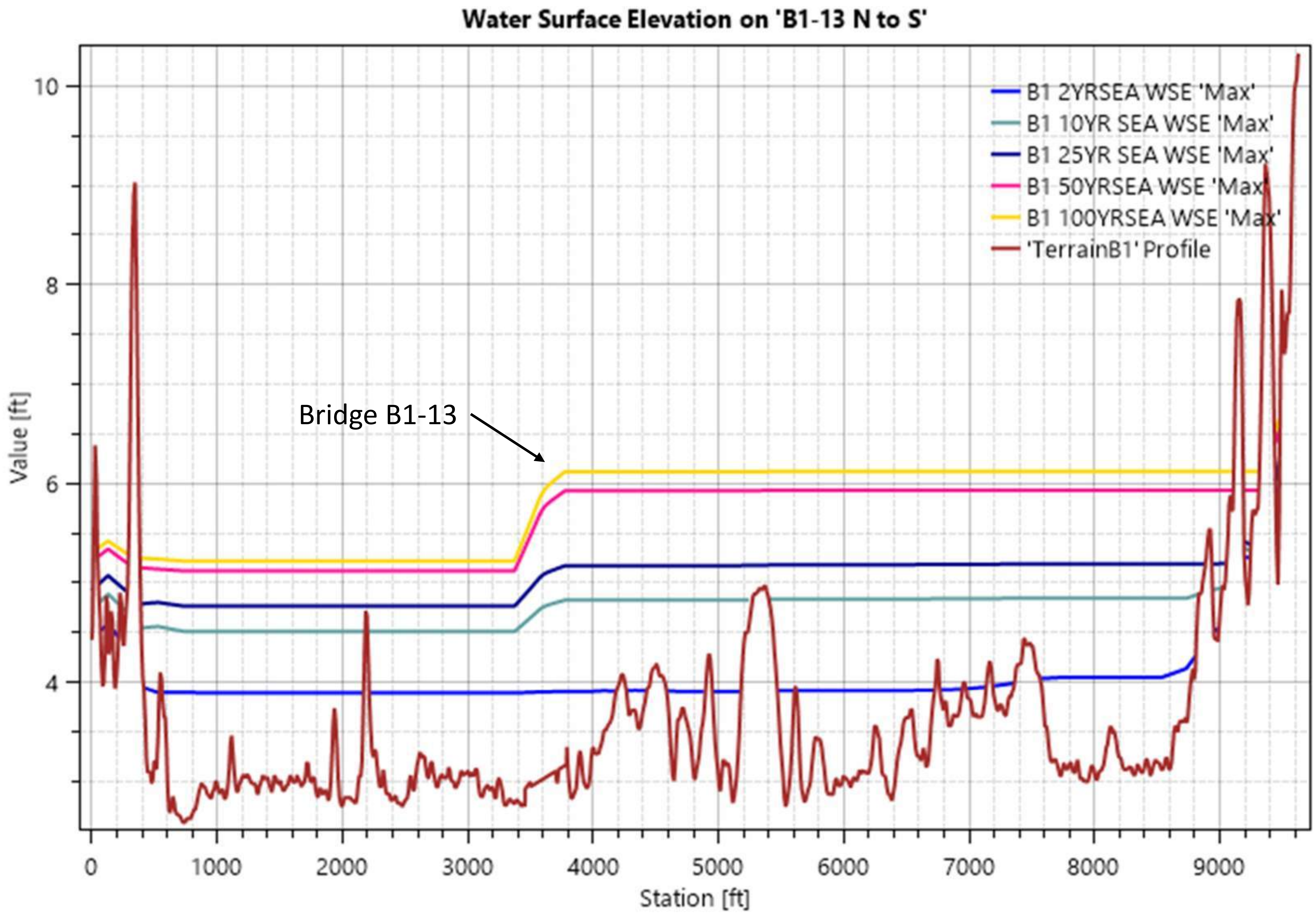
From NW to SE

Alternative B1

Profile B1-13

From N to S



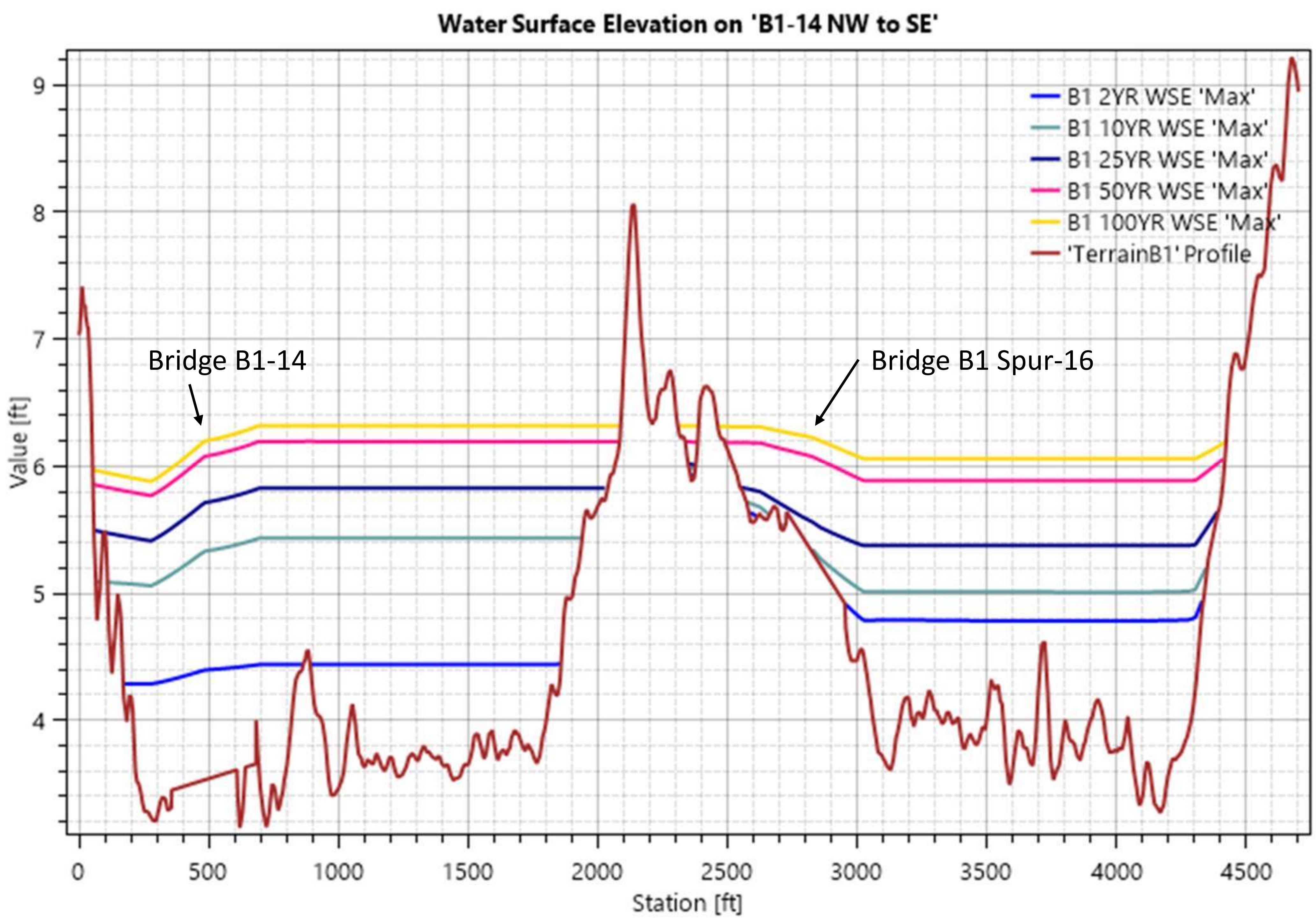


Alternative B1

Profile B1-13

With Sea Rise

From N to S



Alternative B1

Profile B1-14

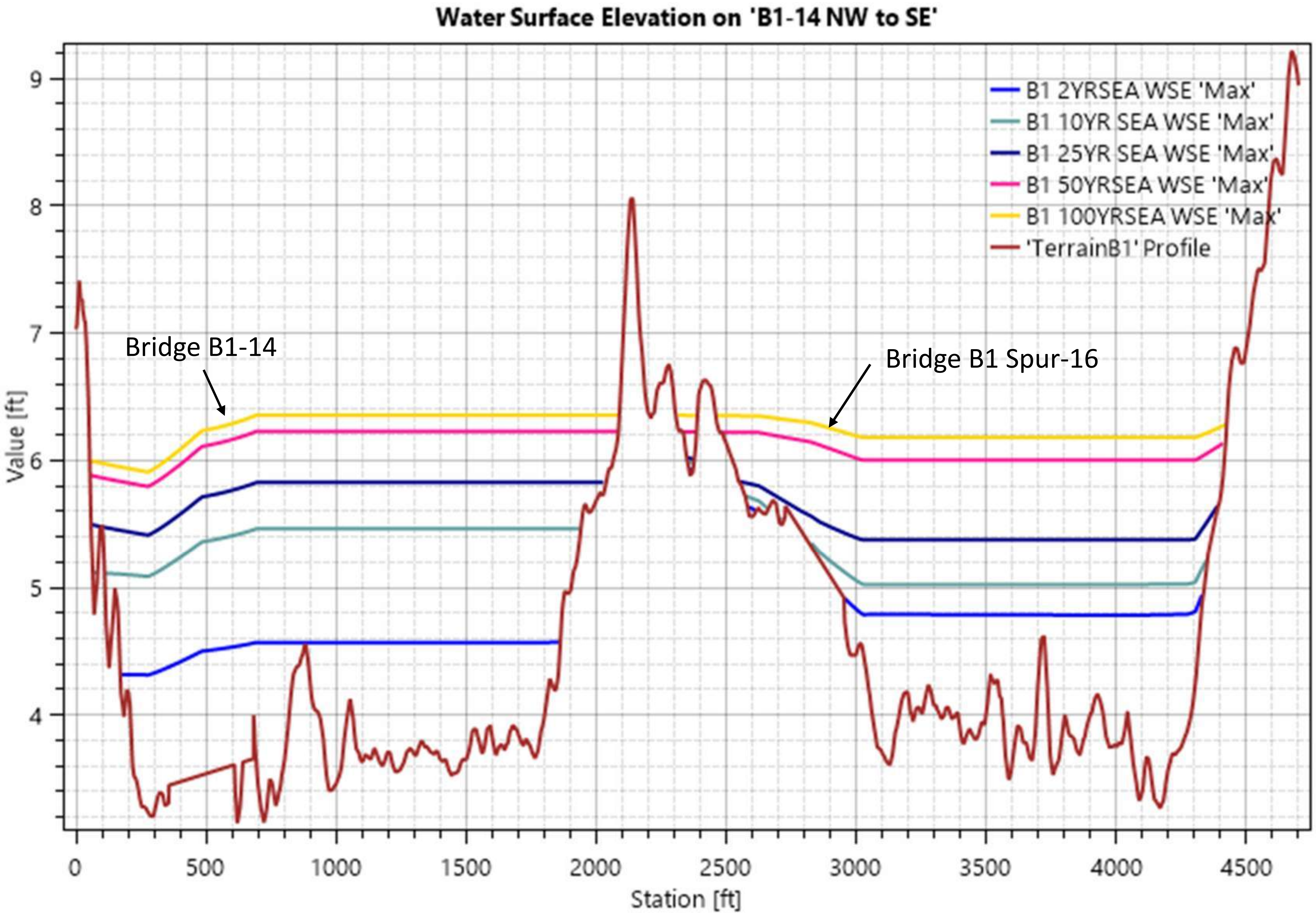
From NW to SE

Alternative B1

Profile B1-14

With Sea Rise

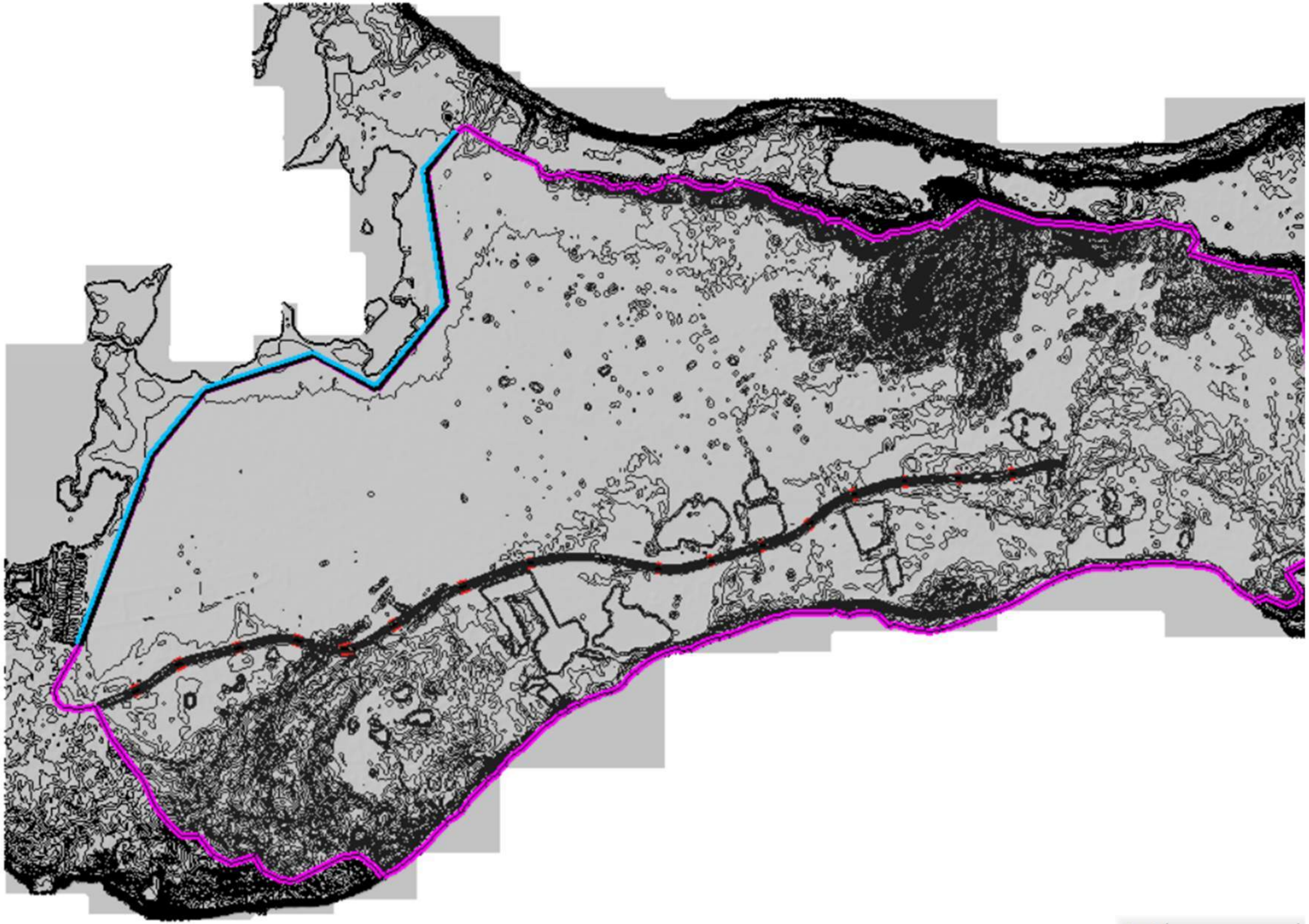
From NW to SE



Appendix C – Alternate B2

Alternate B2

Original Terrain



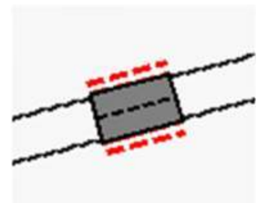
Alternate B2

Legend

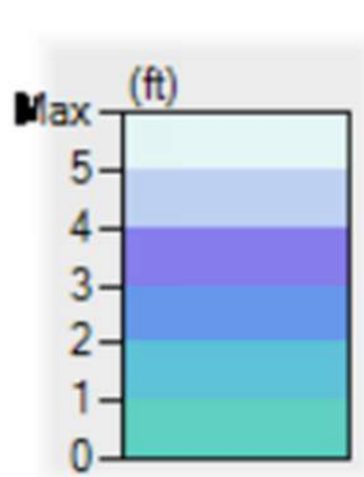
Terrain Elevation FT

Boundary Condition (Blue/Black) Perimeter (Magenta)

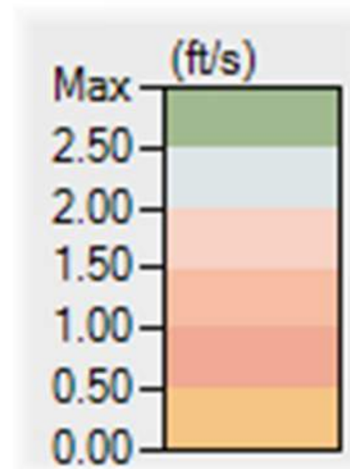
Bridge



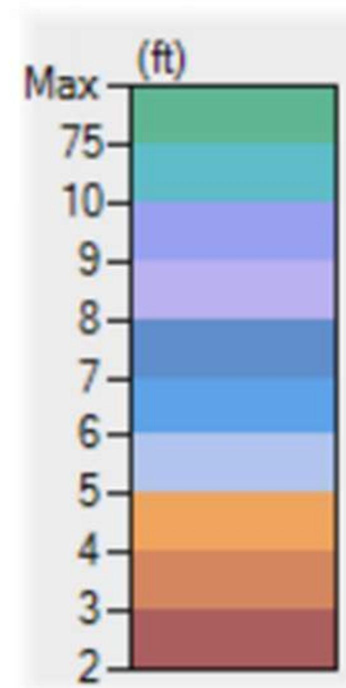
Runoff Depth FT

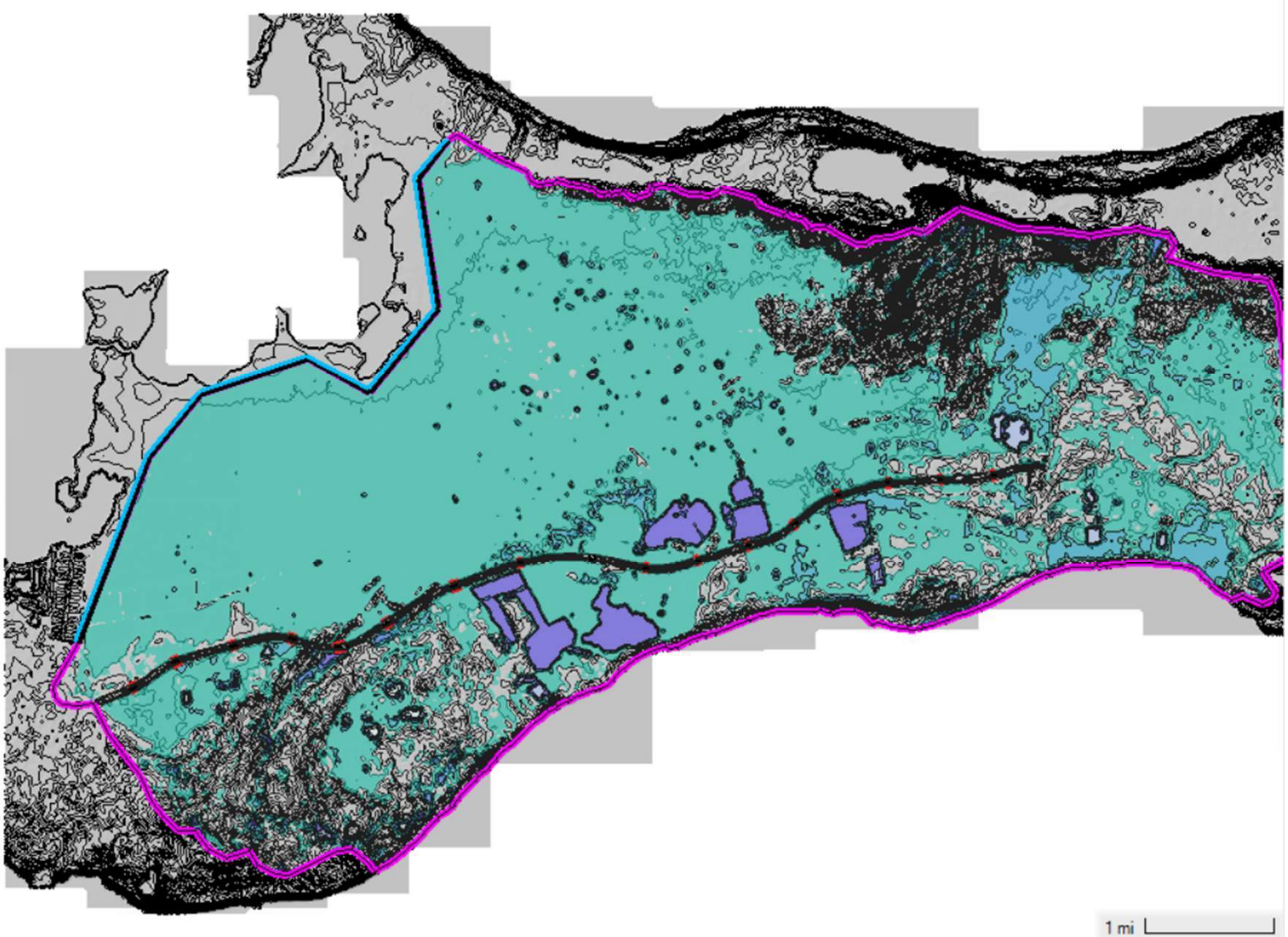


Velocity FT/SEC



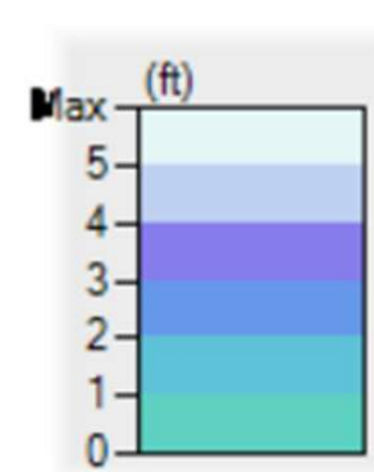
Water Surface Elevation FT

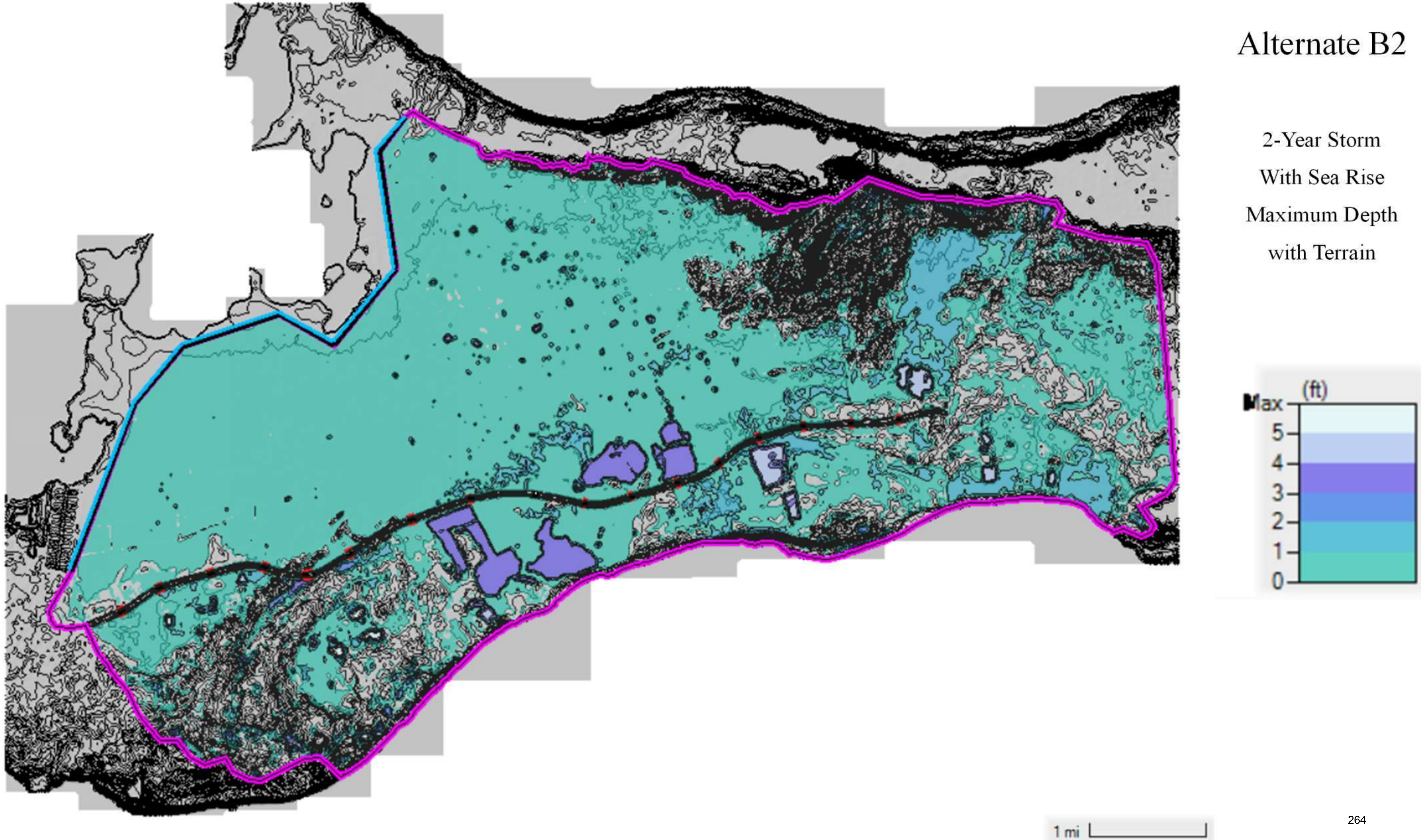




Alternate B2

2-Year Storm
Maximum Depth
with Terrain





Alternate B2

2-Year Storm

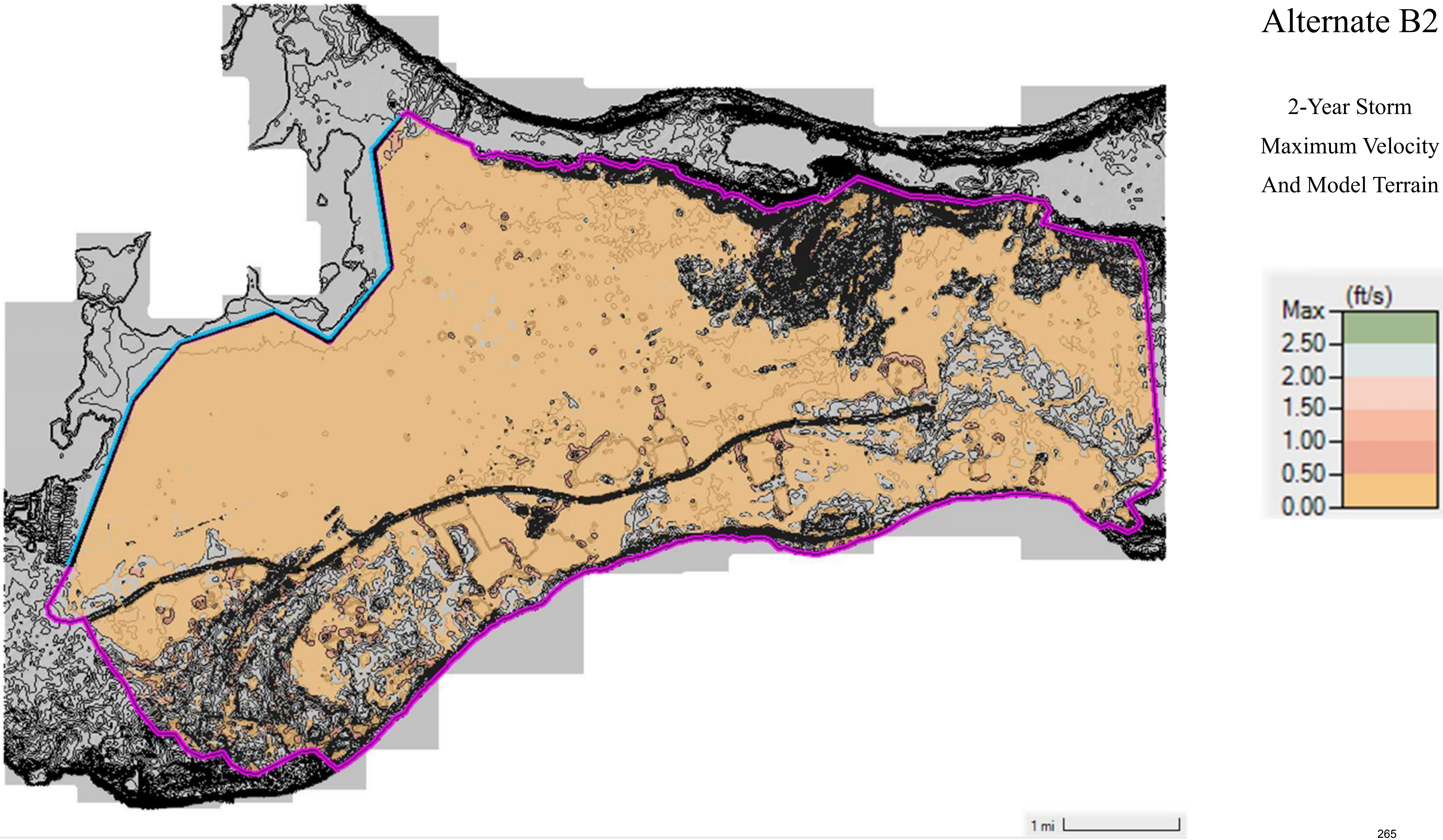
With Sea Rise

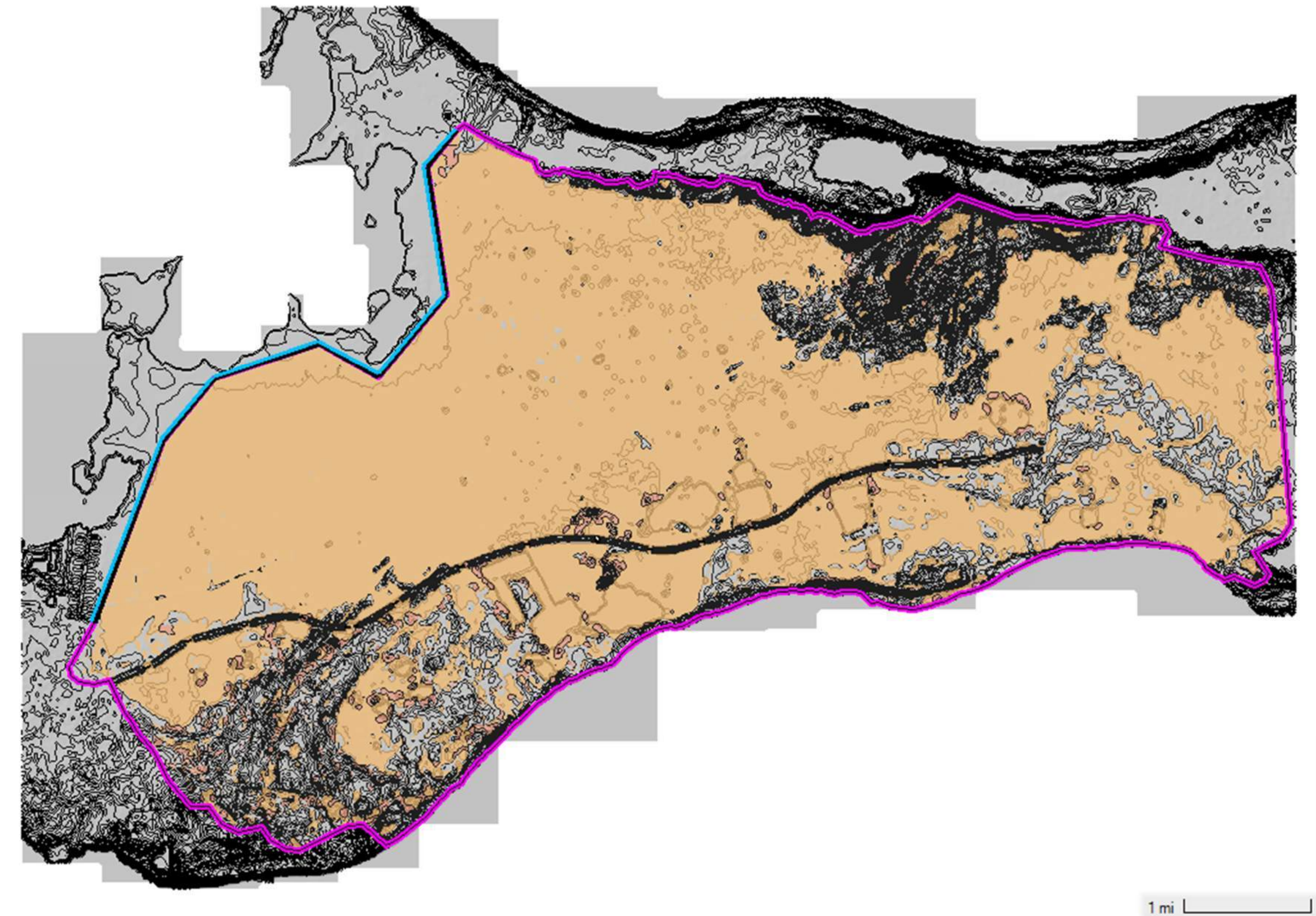
Maximum Depth

with Terrain

Alternate B2

2-Year Storm
Maximum Velocity
And Model Terrain





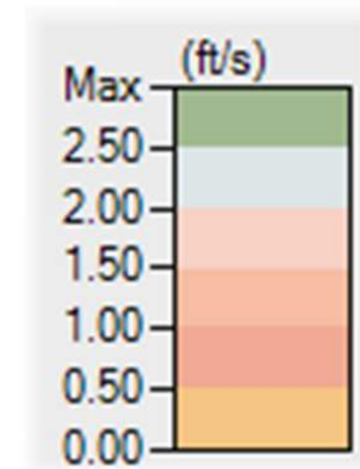
Alternate B2

2-Year Storm

With Sea Rise

Maximum Velocity

And Model Terrain

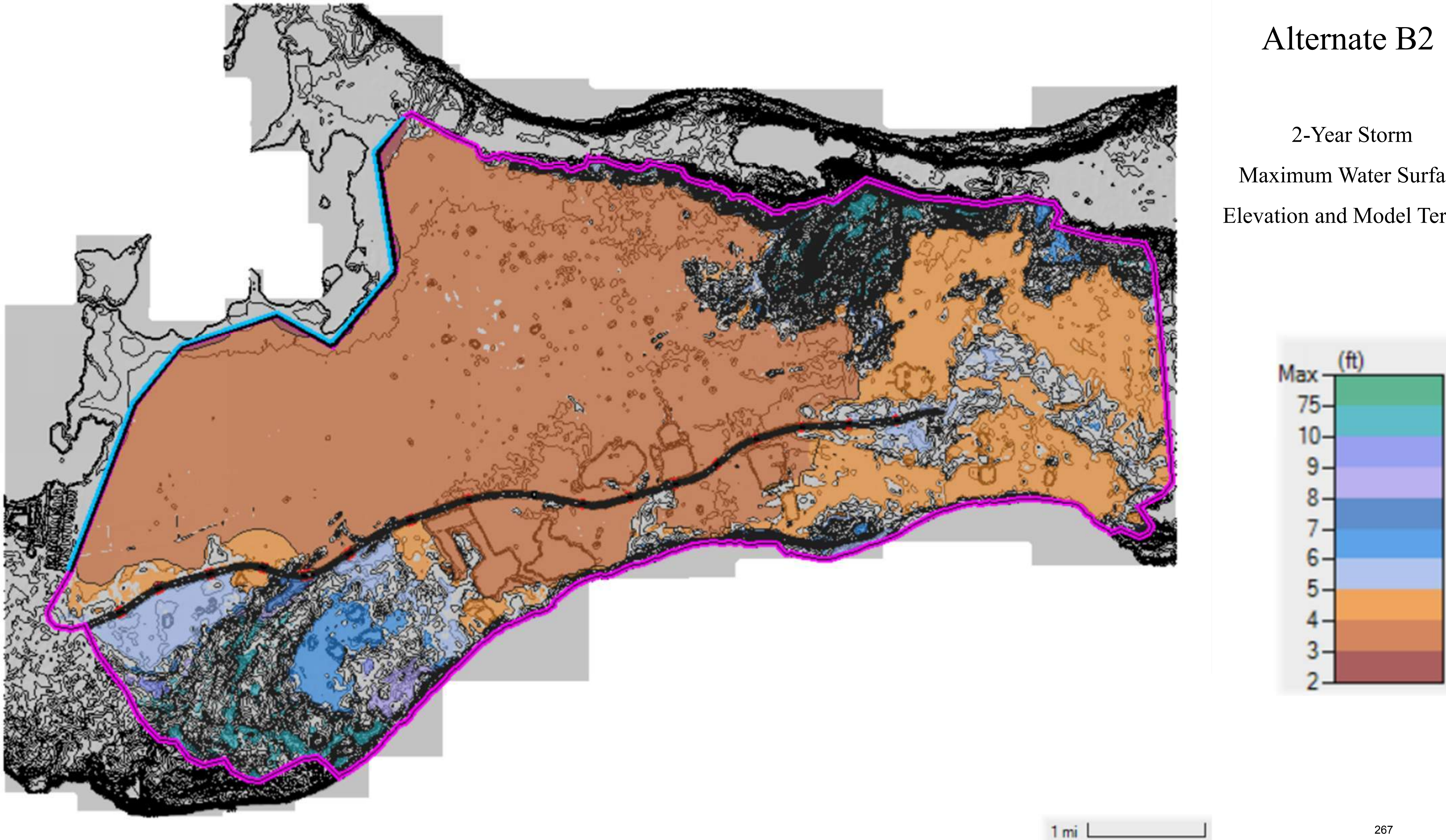


Alternate B2

2-Year Storm

Maximum Water Surface

Elevation and Model Terrain



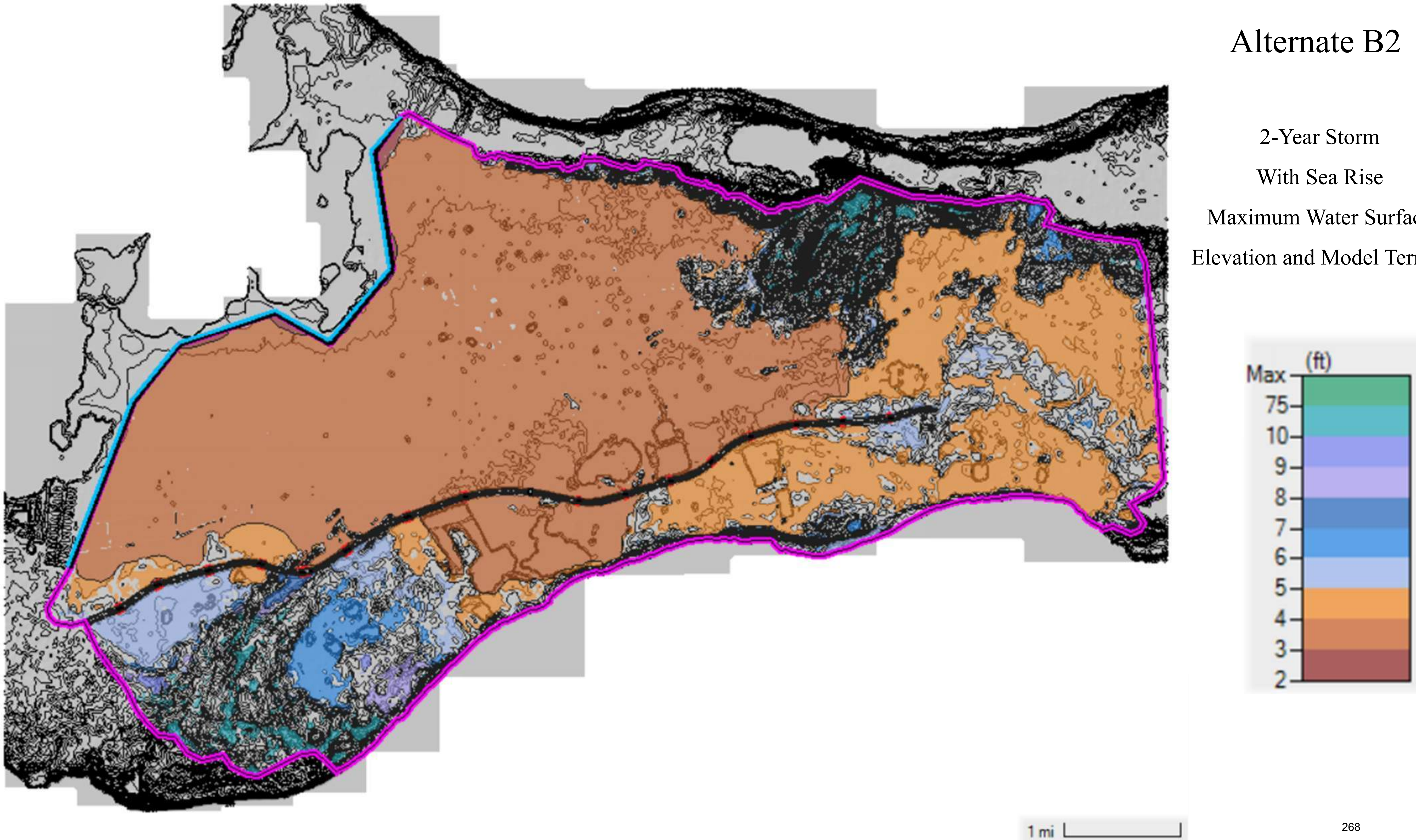
Alternate B2

2-Year Storm

With Sea Rise

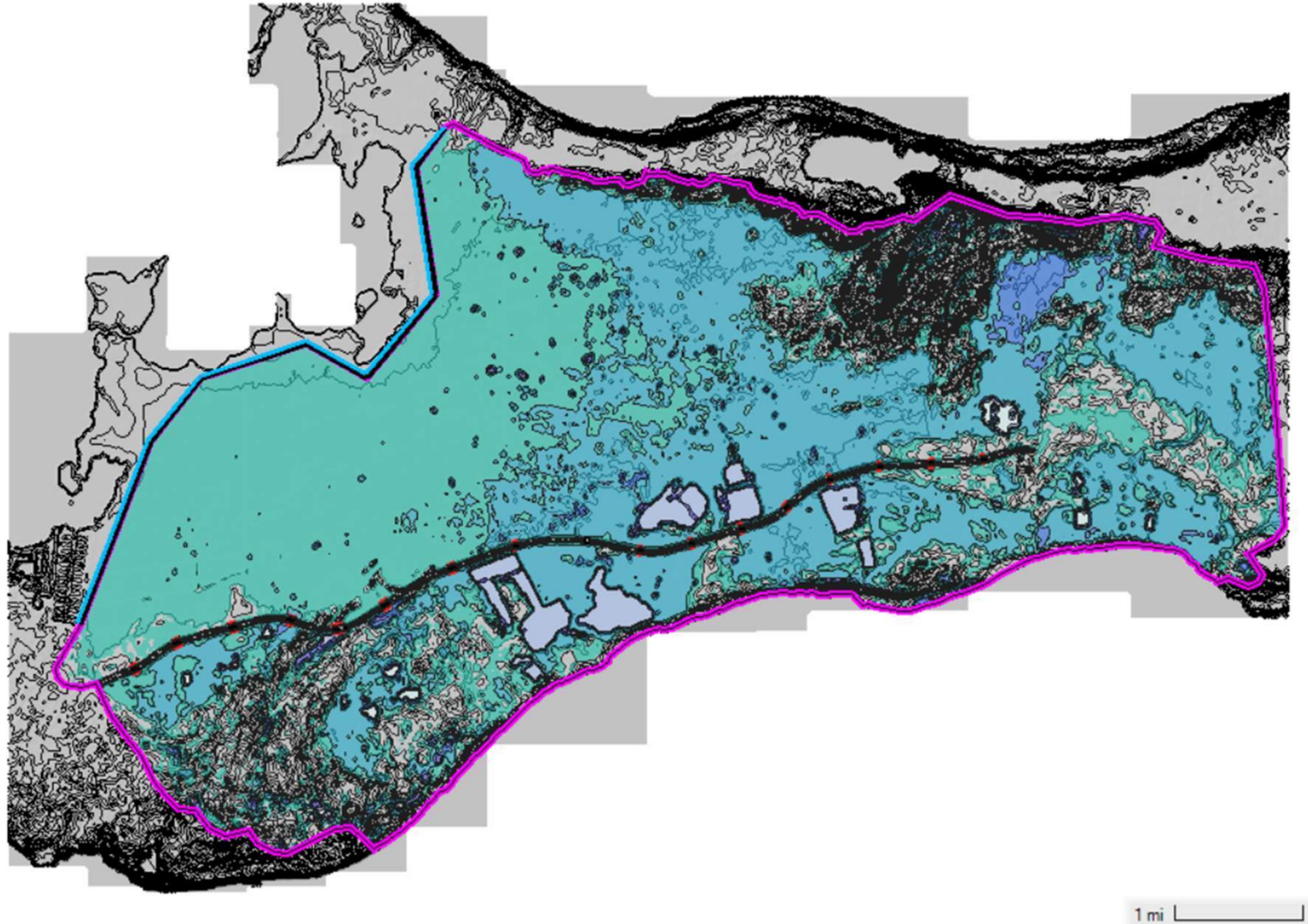
Maximum Water Surface

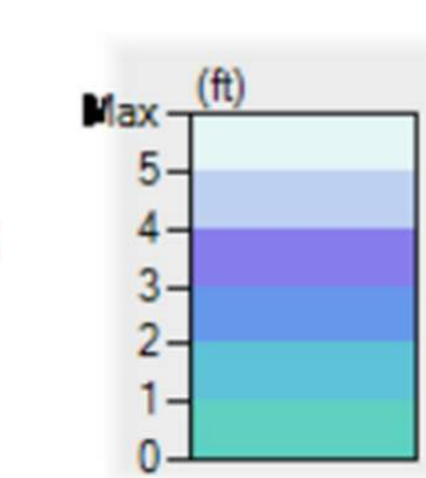
Elevation and Model Terrain



Alternate B2

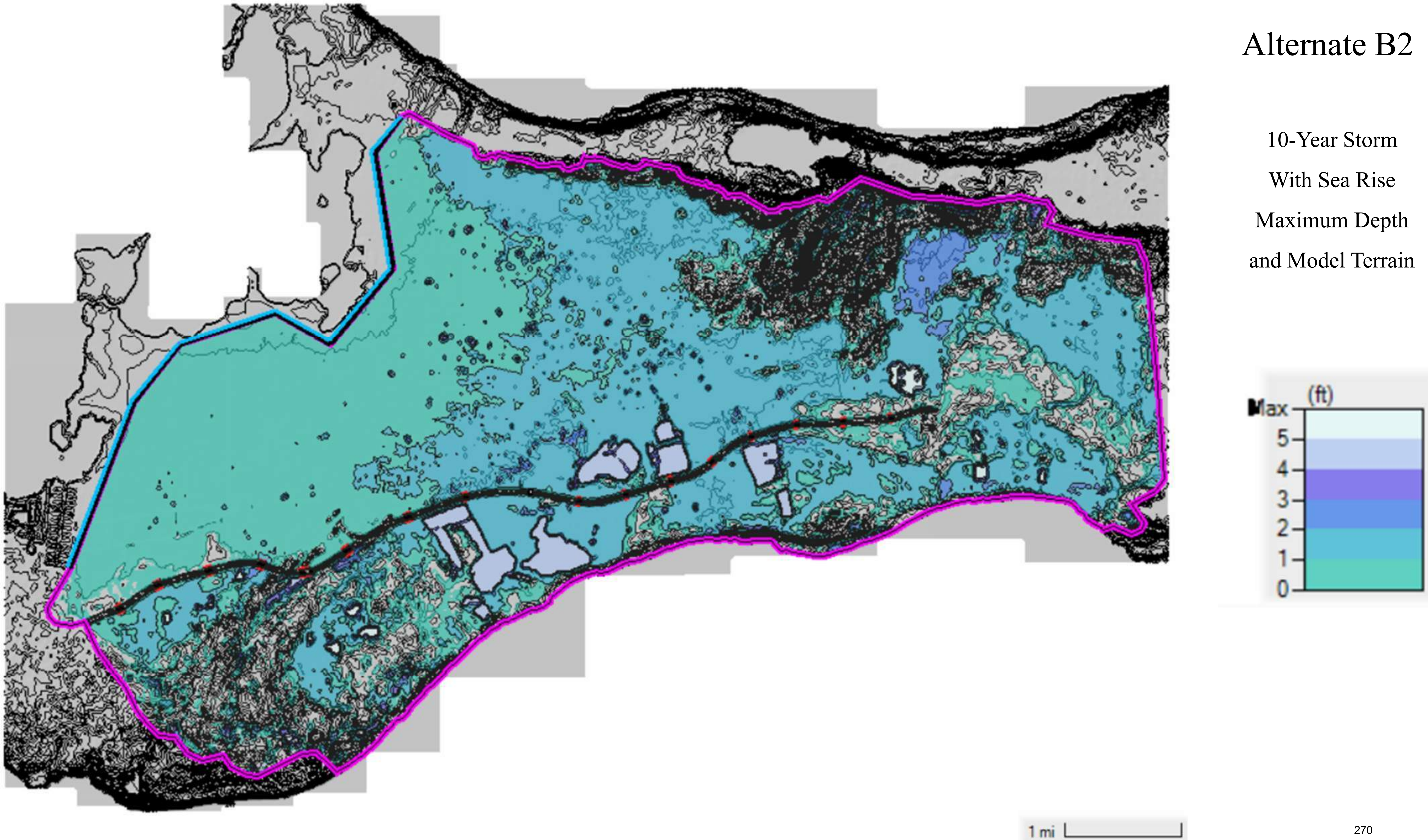
10-Year Storm
Maximum Depth
and Model Terrain





Alternate B2

10-Year Storm
With Sea Rise
Maximum Depth
and Model Terrain

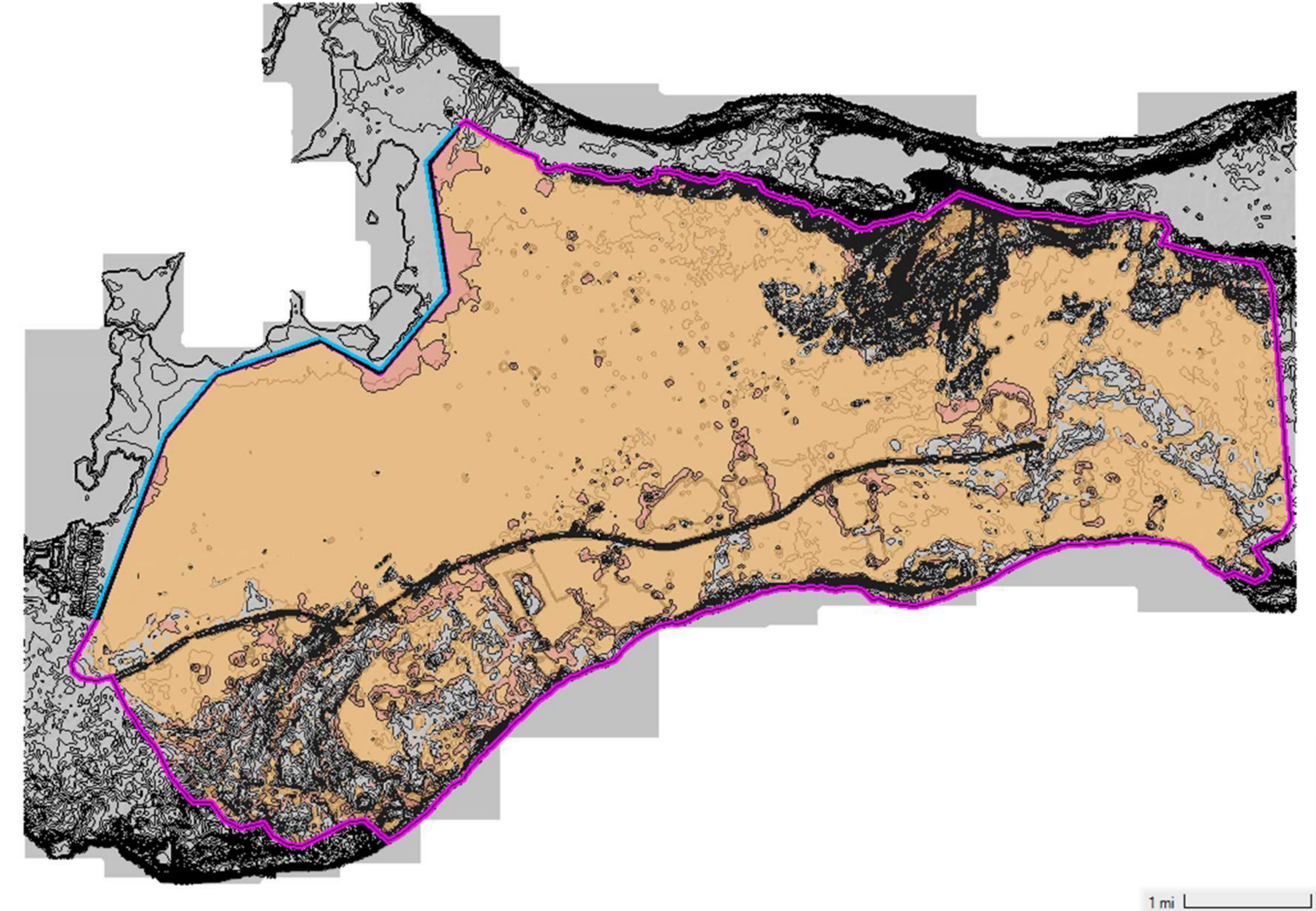


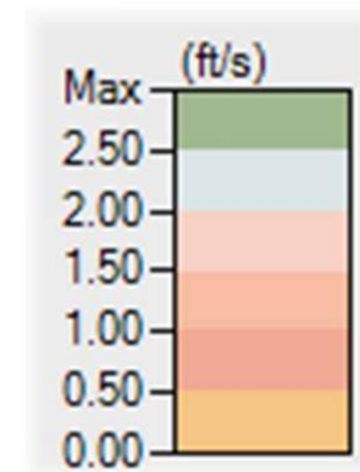
Alternate B2

10-Year Storm

Maximum Velocity

With Model Terrain





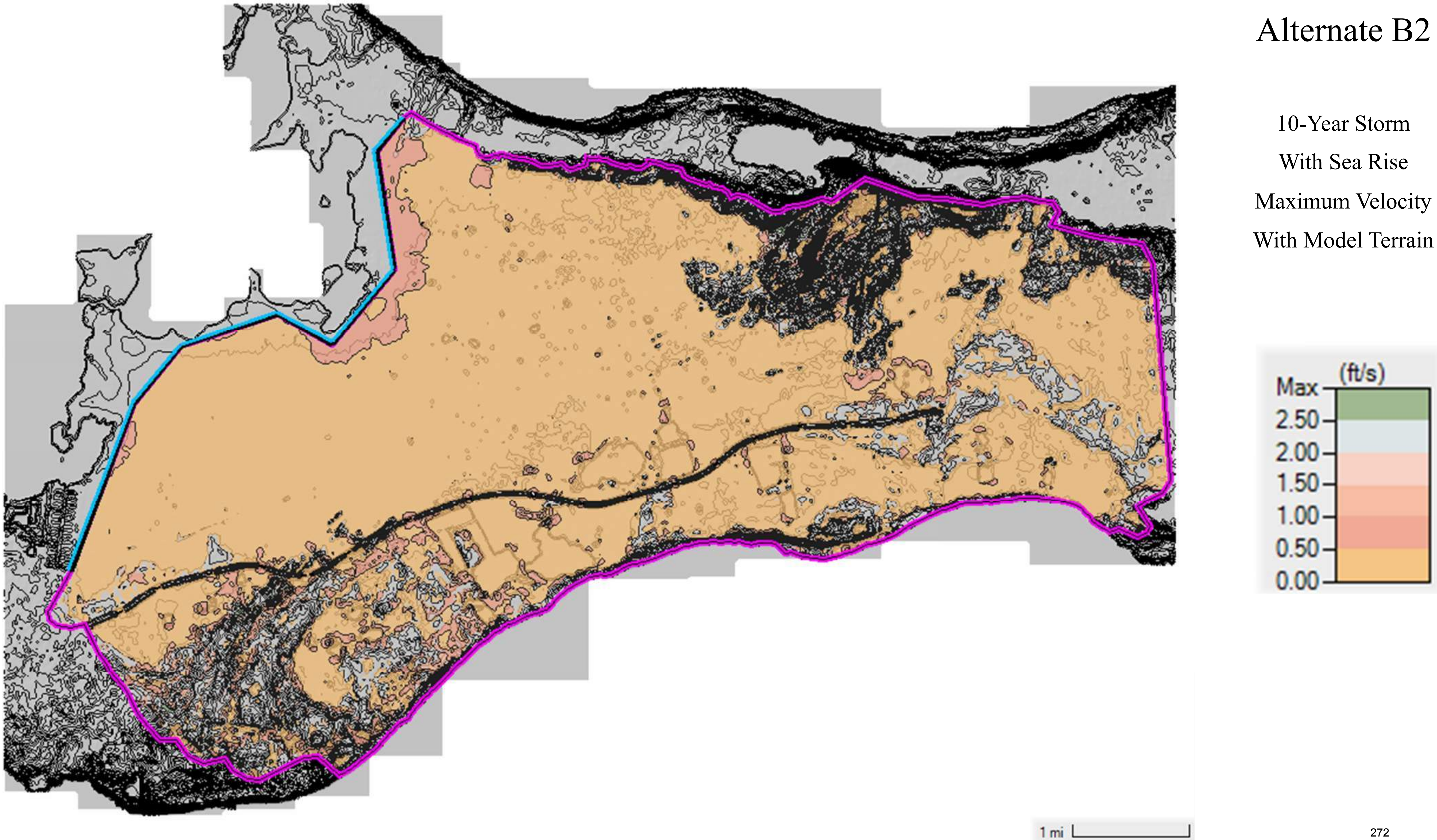
Alternate B2

10-Year Storm

With Sea Rise

Maximum Velocity

With Model Terrain



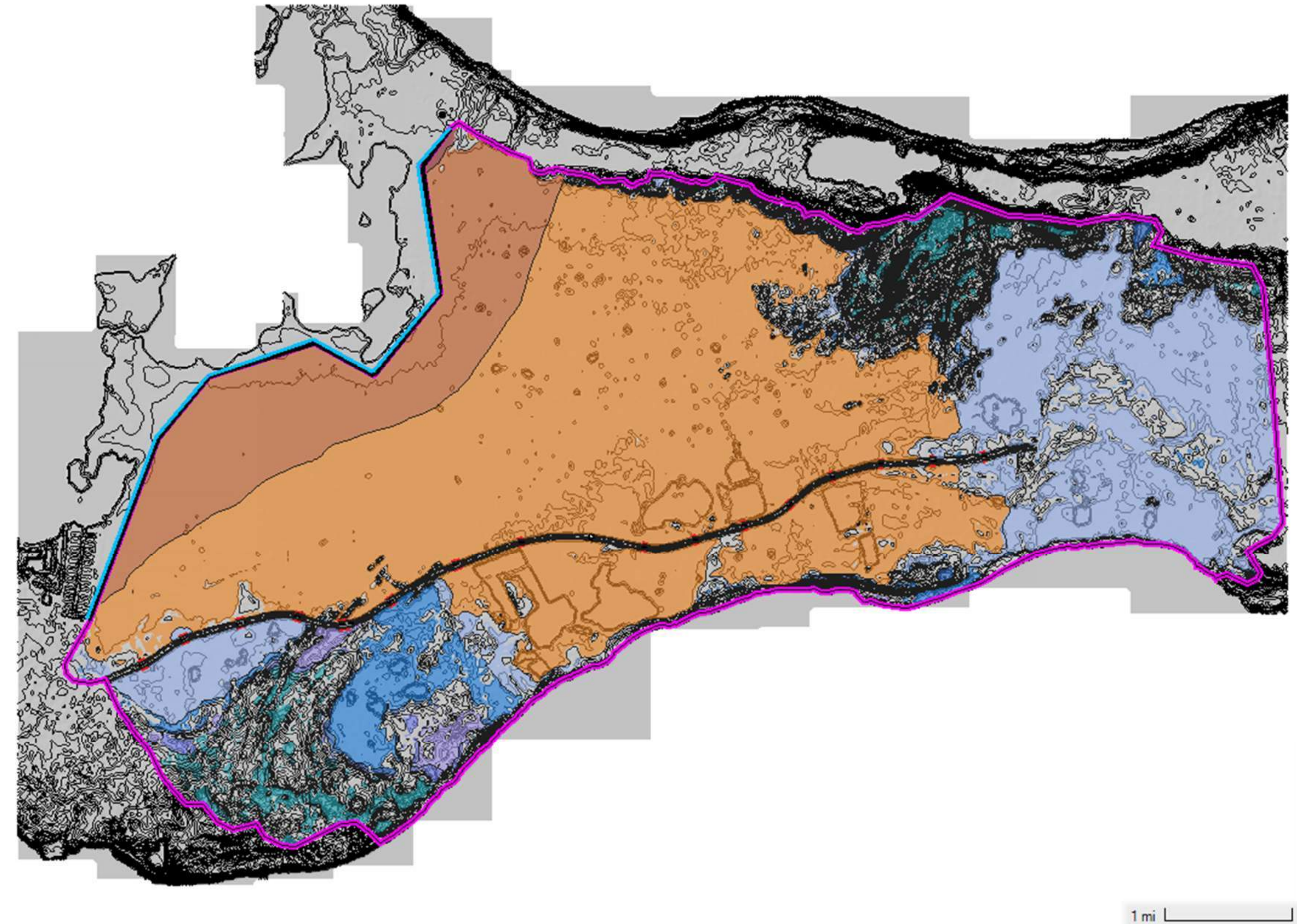
Alternate B2

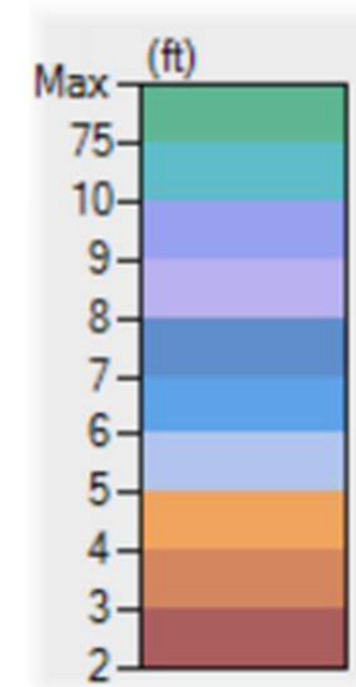
10-Year Storm

Maximum Water Surface

Elevations With Model

Terrain





Alternate B2

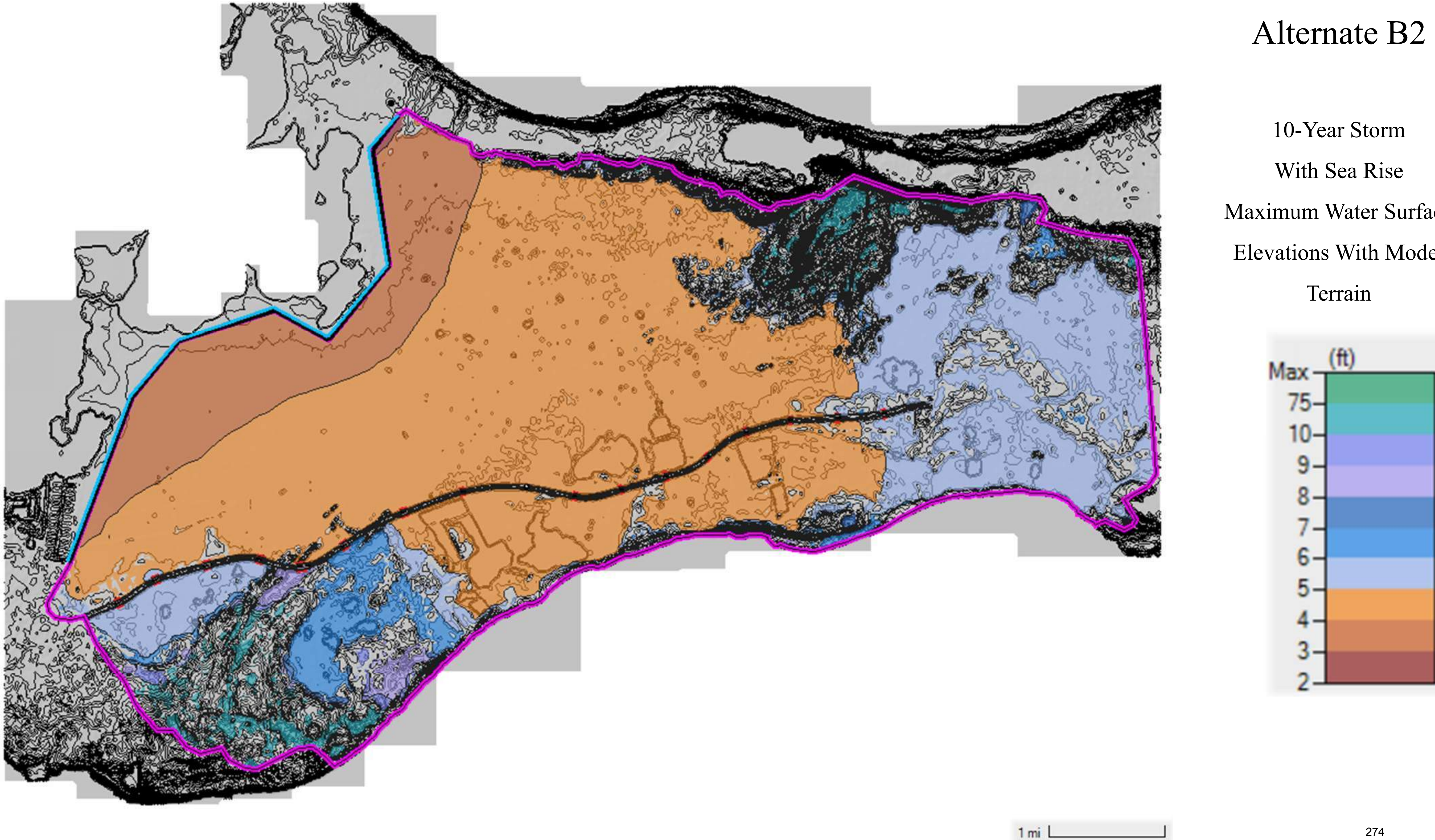
10-Year Storm

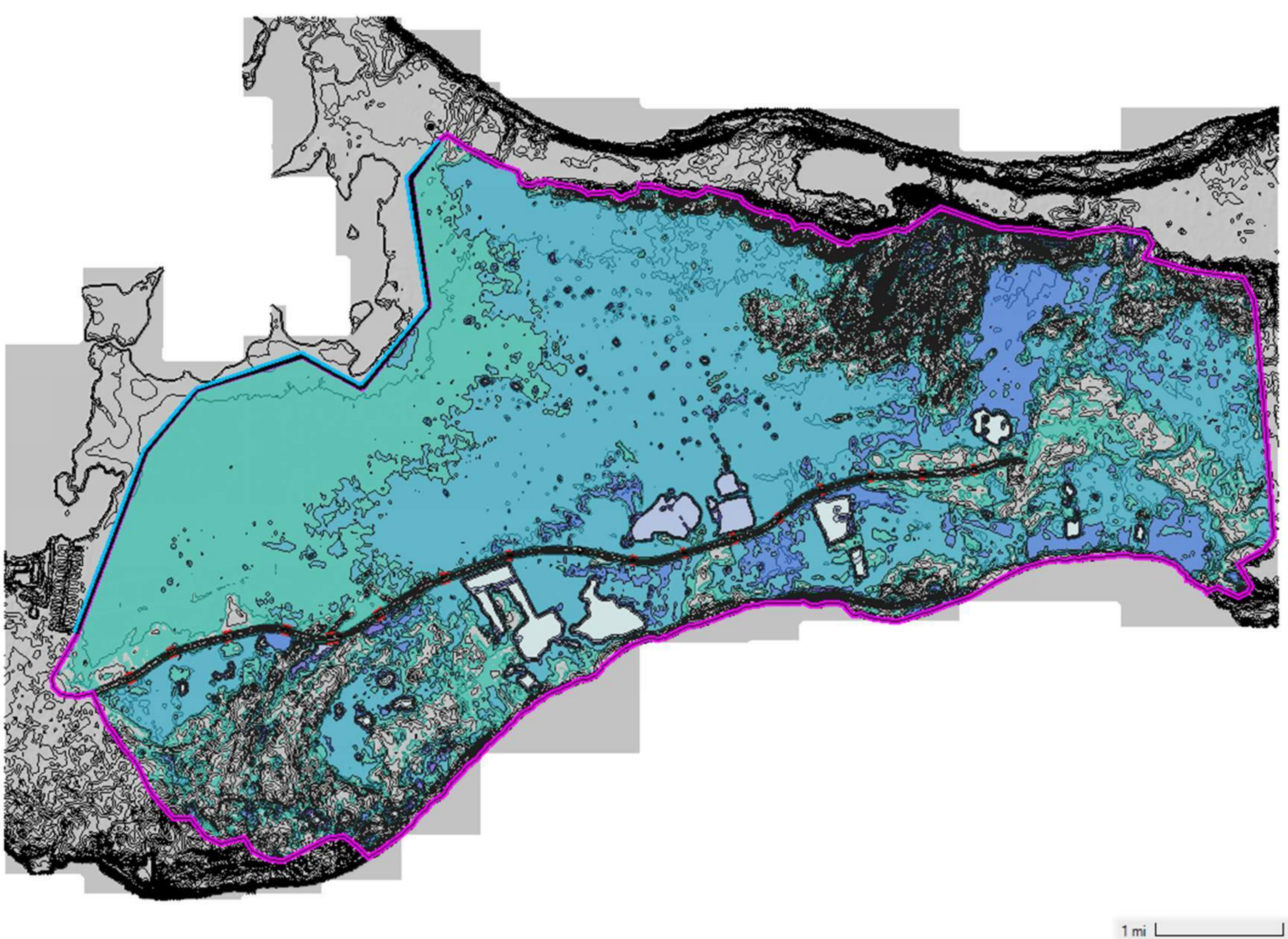
With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain



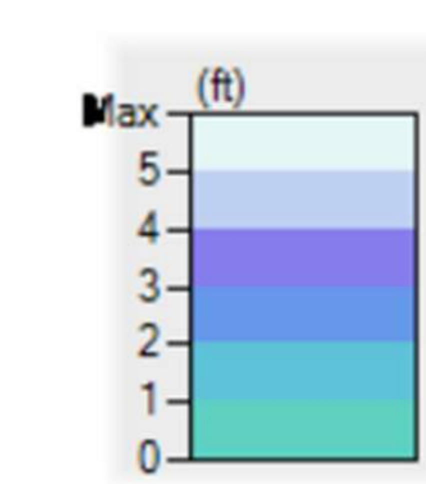


Alternate B2

25-Year Storm

Maximum Depth with

Model Terrain



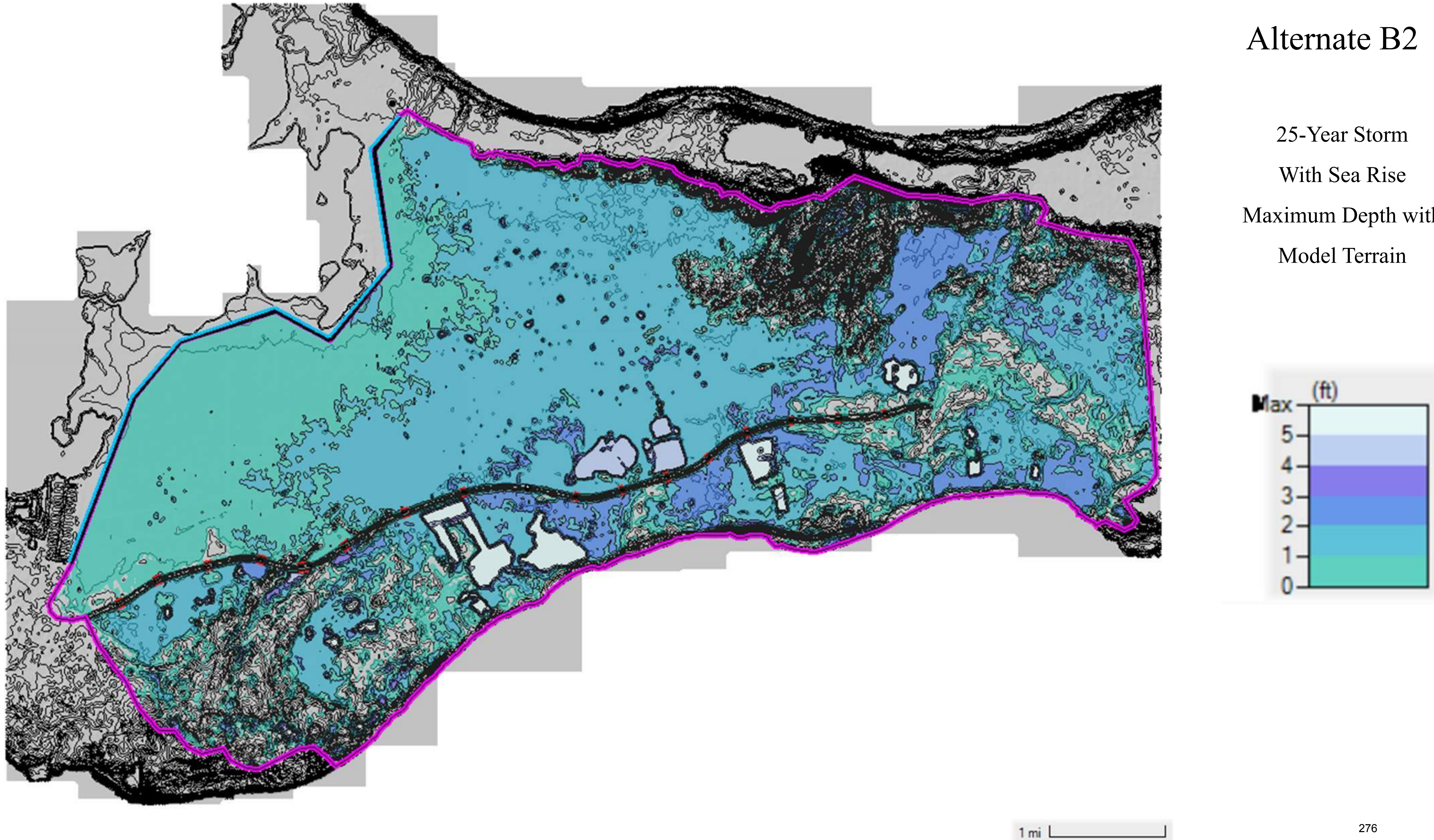
Alternate B2

25-Year Storm

With Sea Rise

Maximum Depth with

Model Terrain

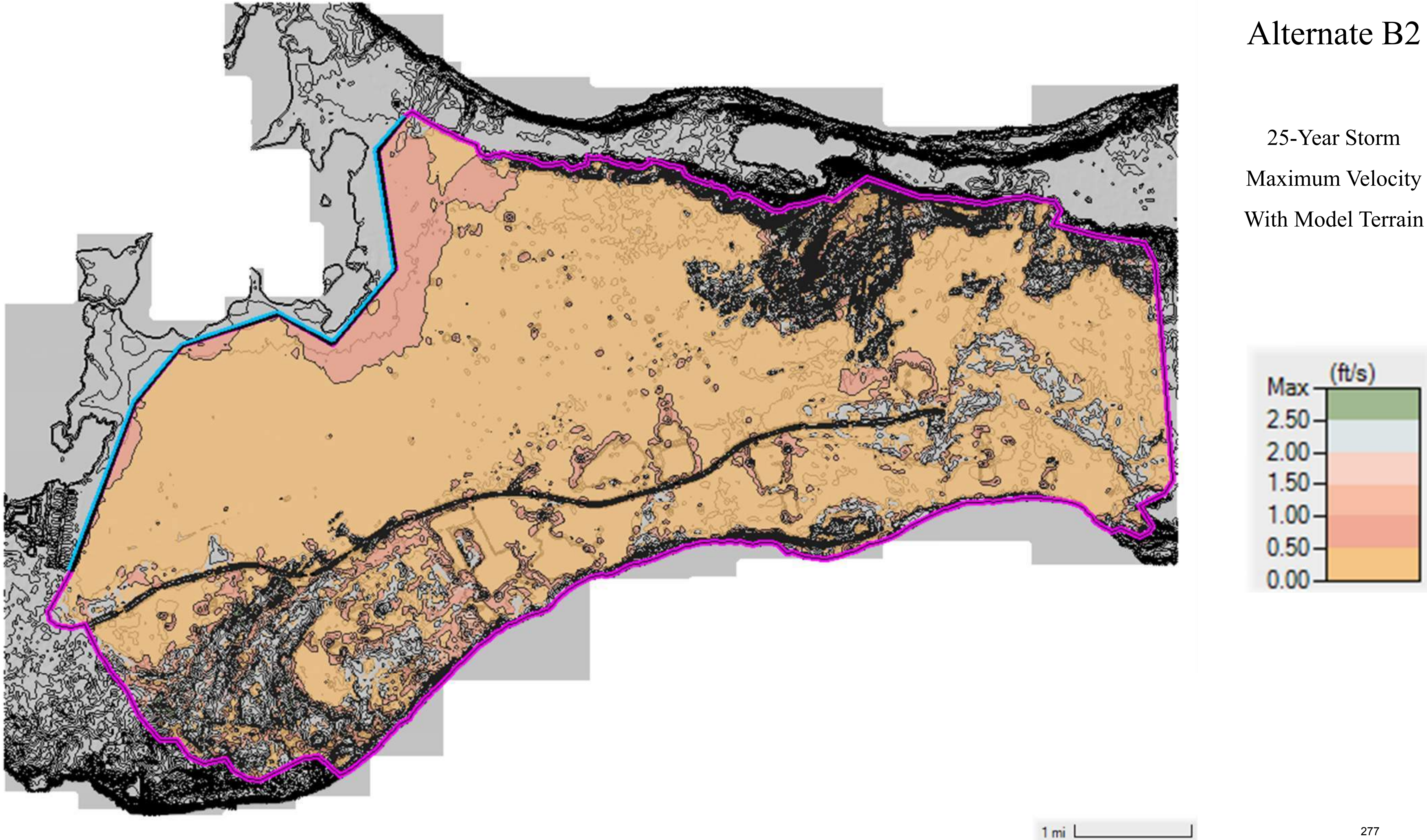


Alternate B2

25-Year Storm

Maximum Velocity

With Model Terrain



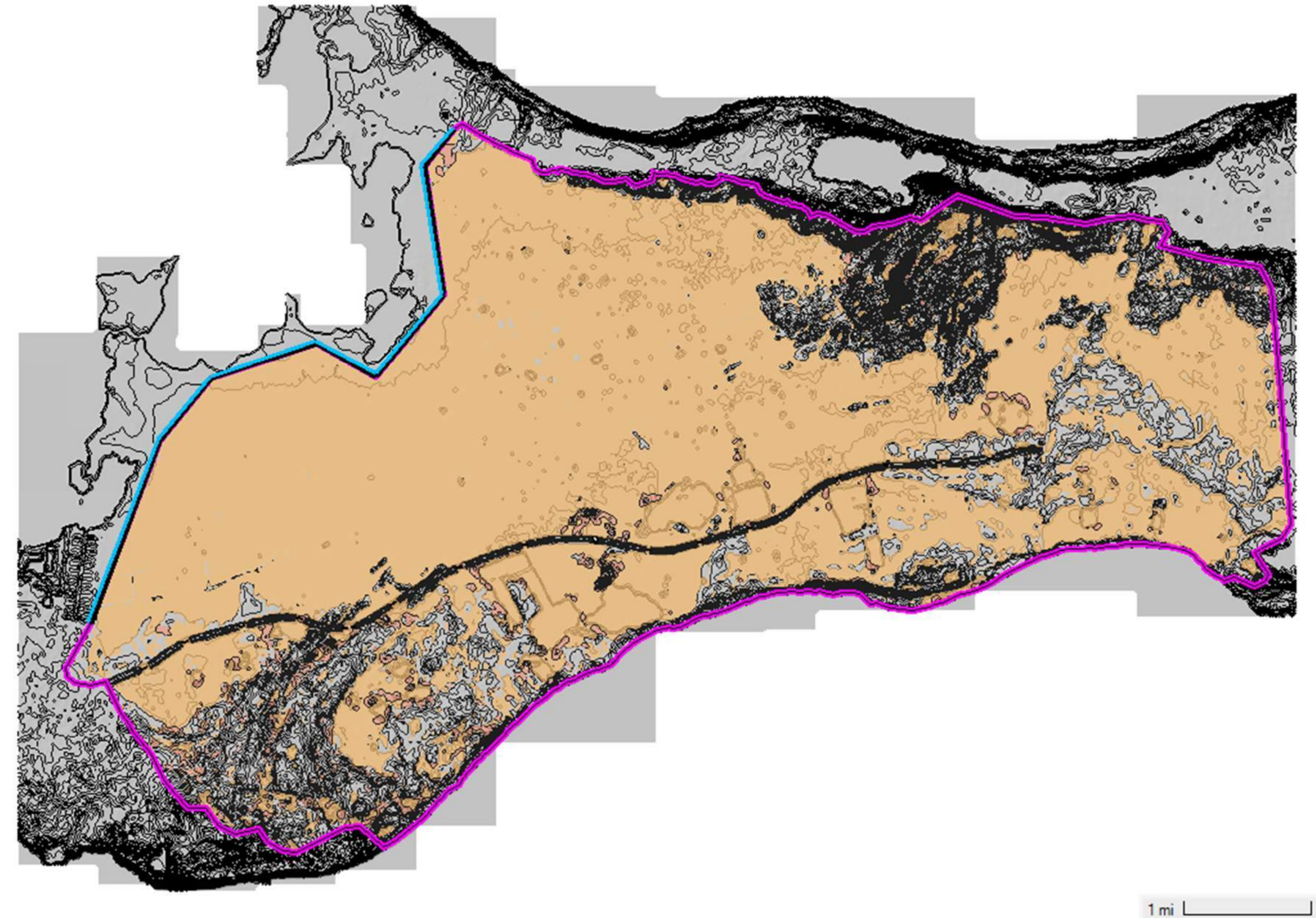
Alternate B2

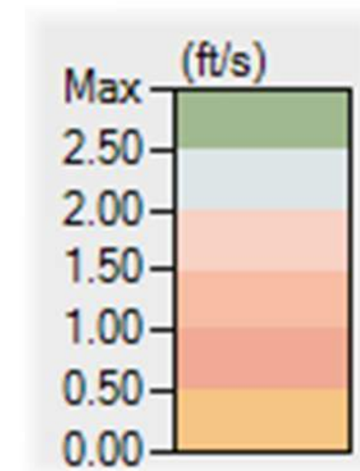
25-Year Storm

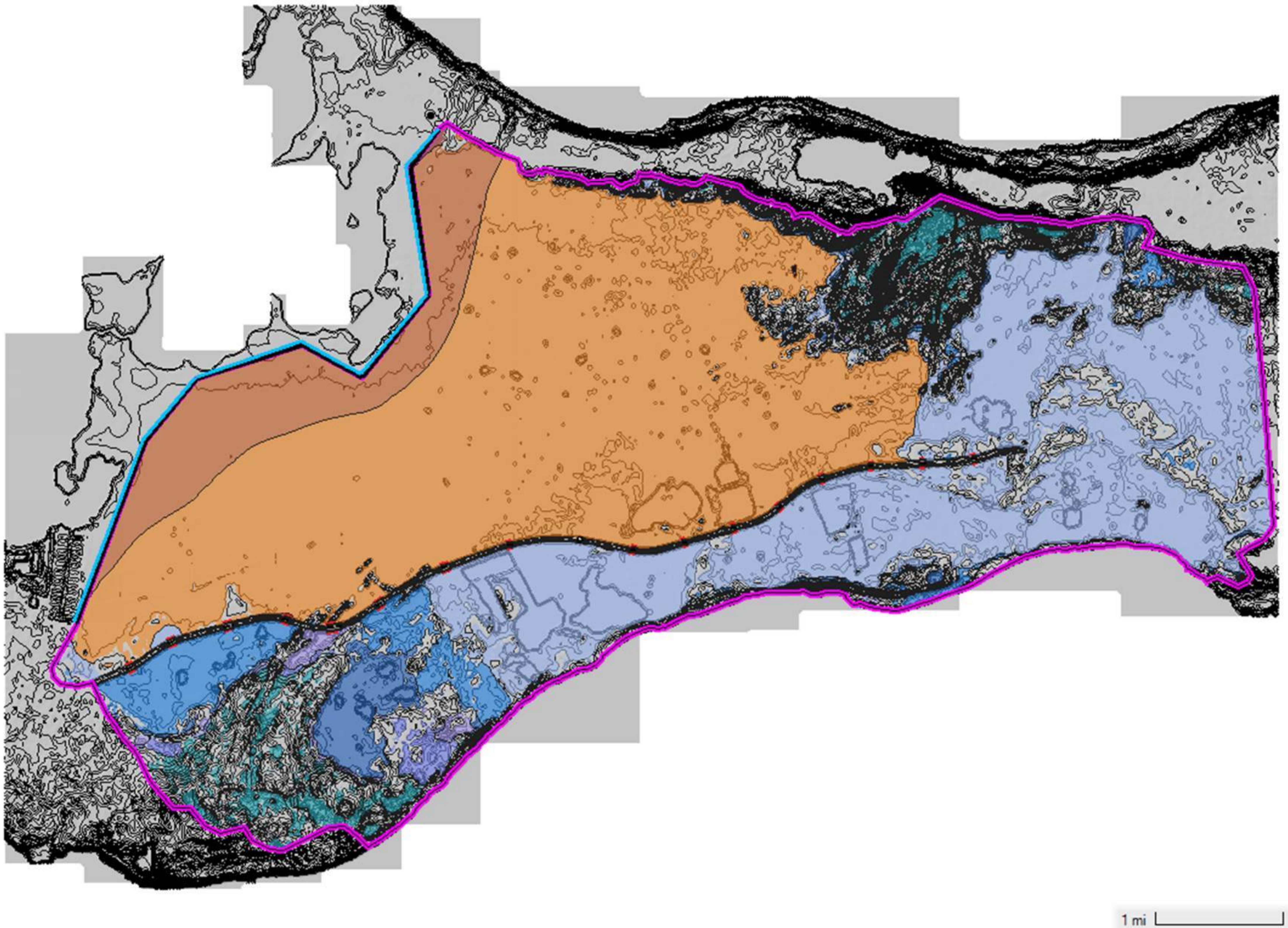
With Sea Rise

Maximum Velocity

With Model Terrain







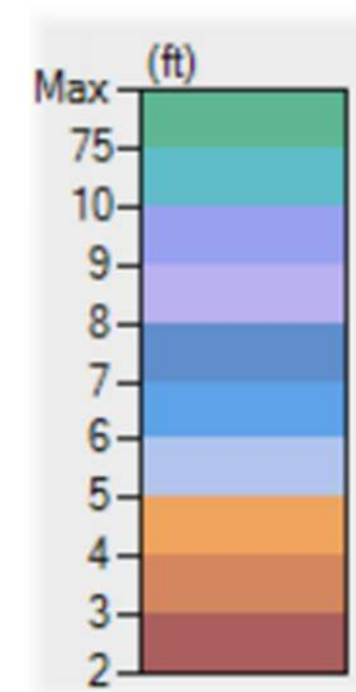
Alternate B2

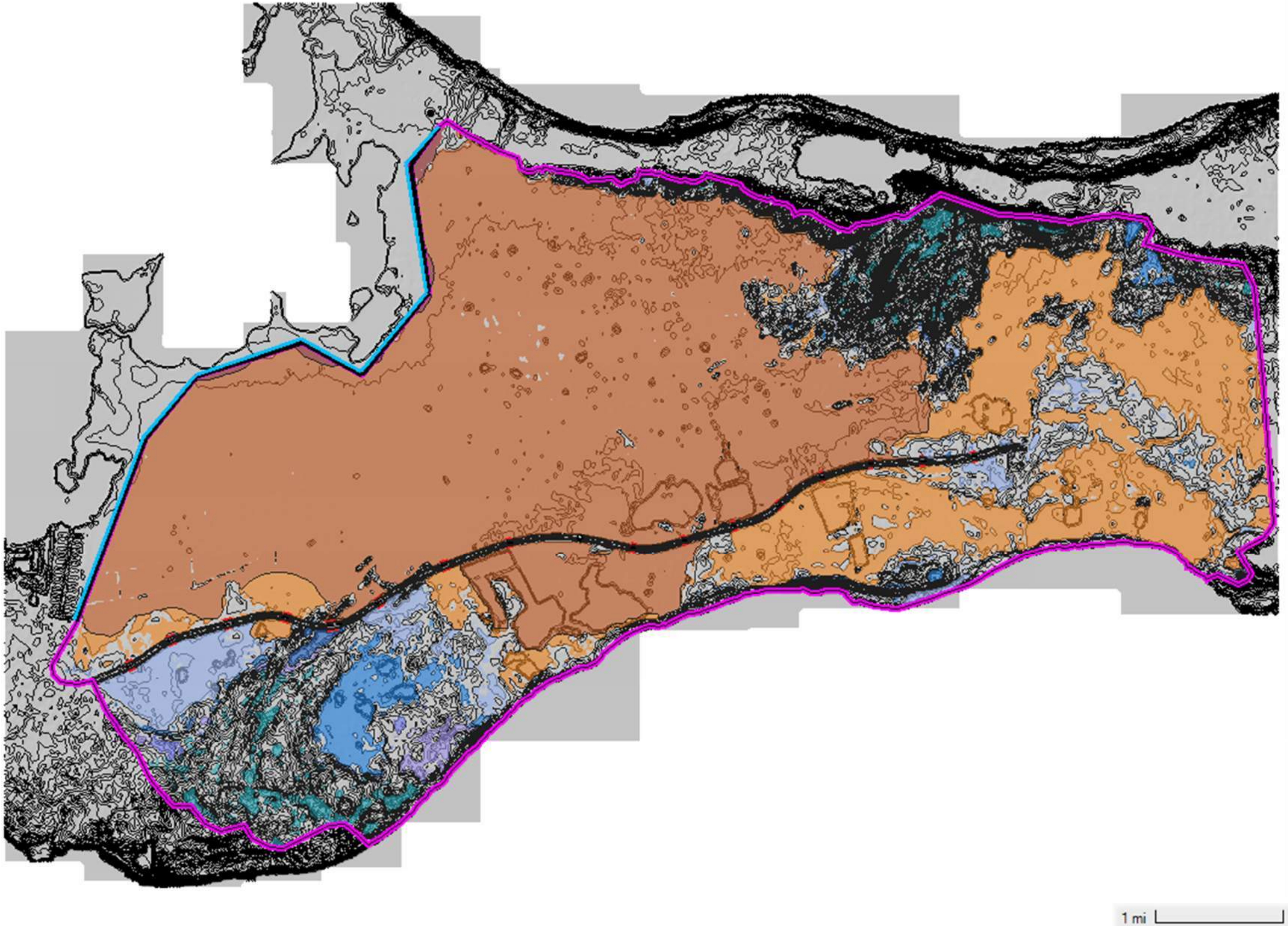
25-Year Storm

Maximum Water Surface

Elevations With Model

Terrain





Alternate B2

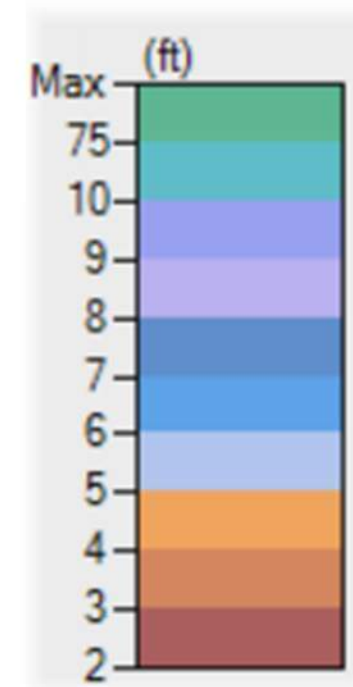
25-Year Storm

With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain

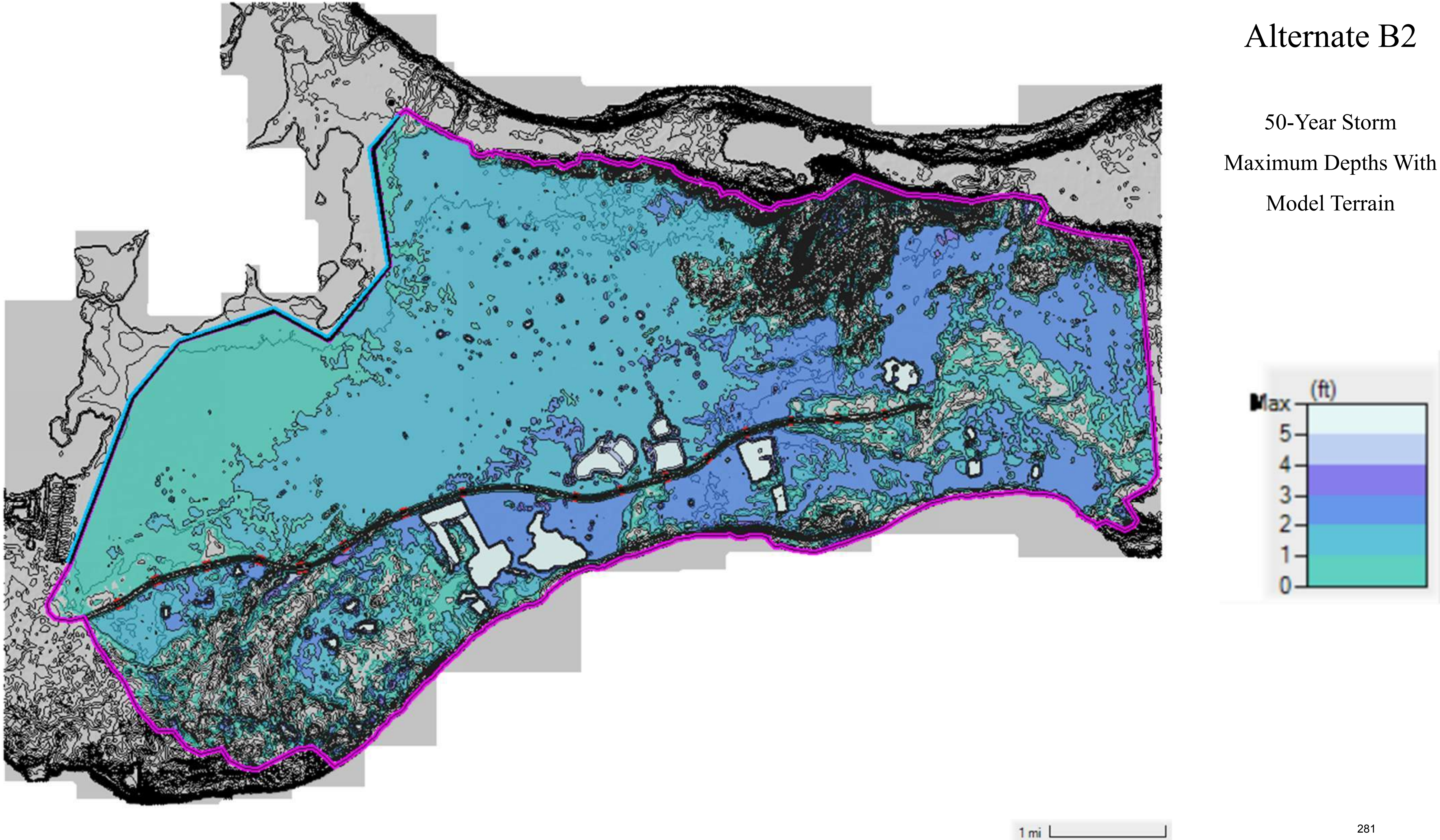


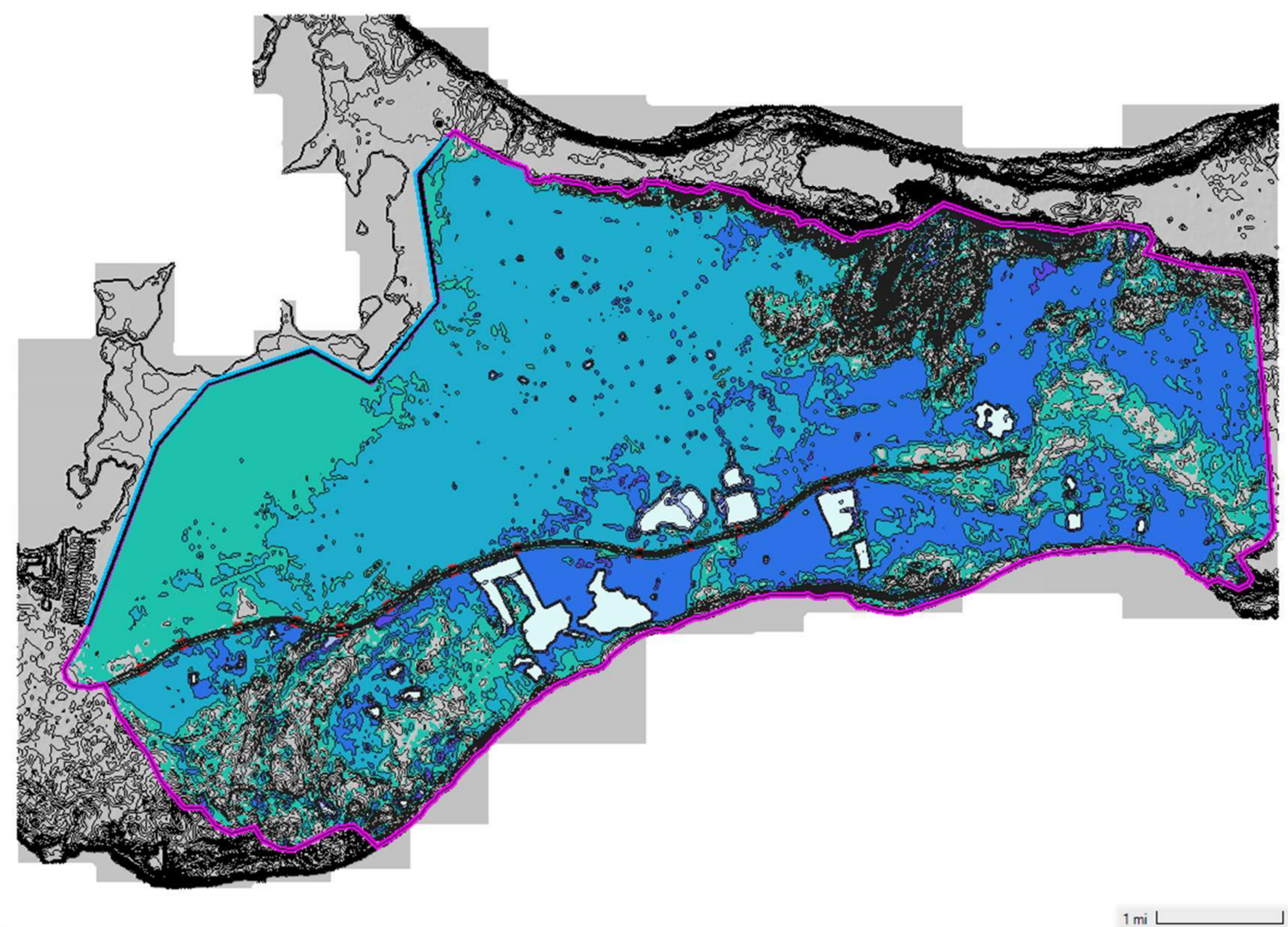
Alternate B2

50-Year Storm

Maximum Depths With

Model Terrain





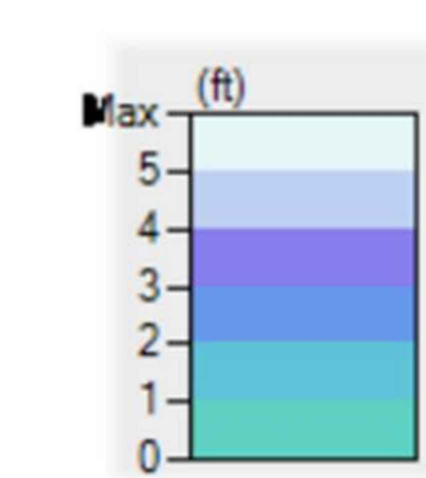
Alternate B2

50-Year Storm

With Sea Rise

Maximum Depths With

Model Terrain

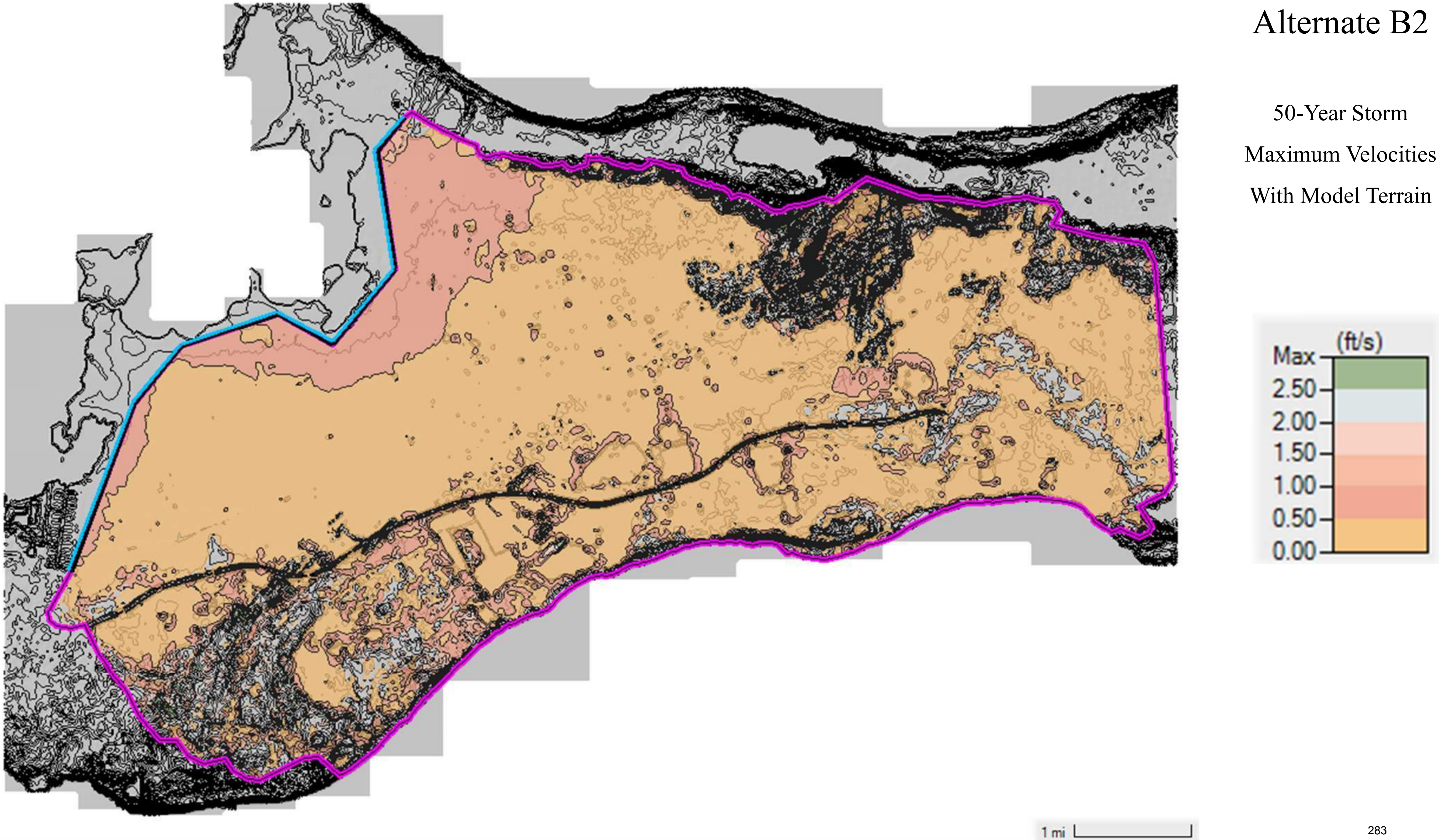


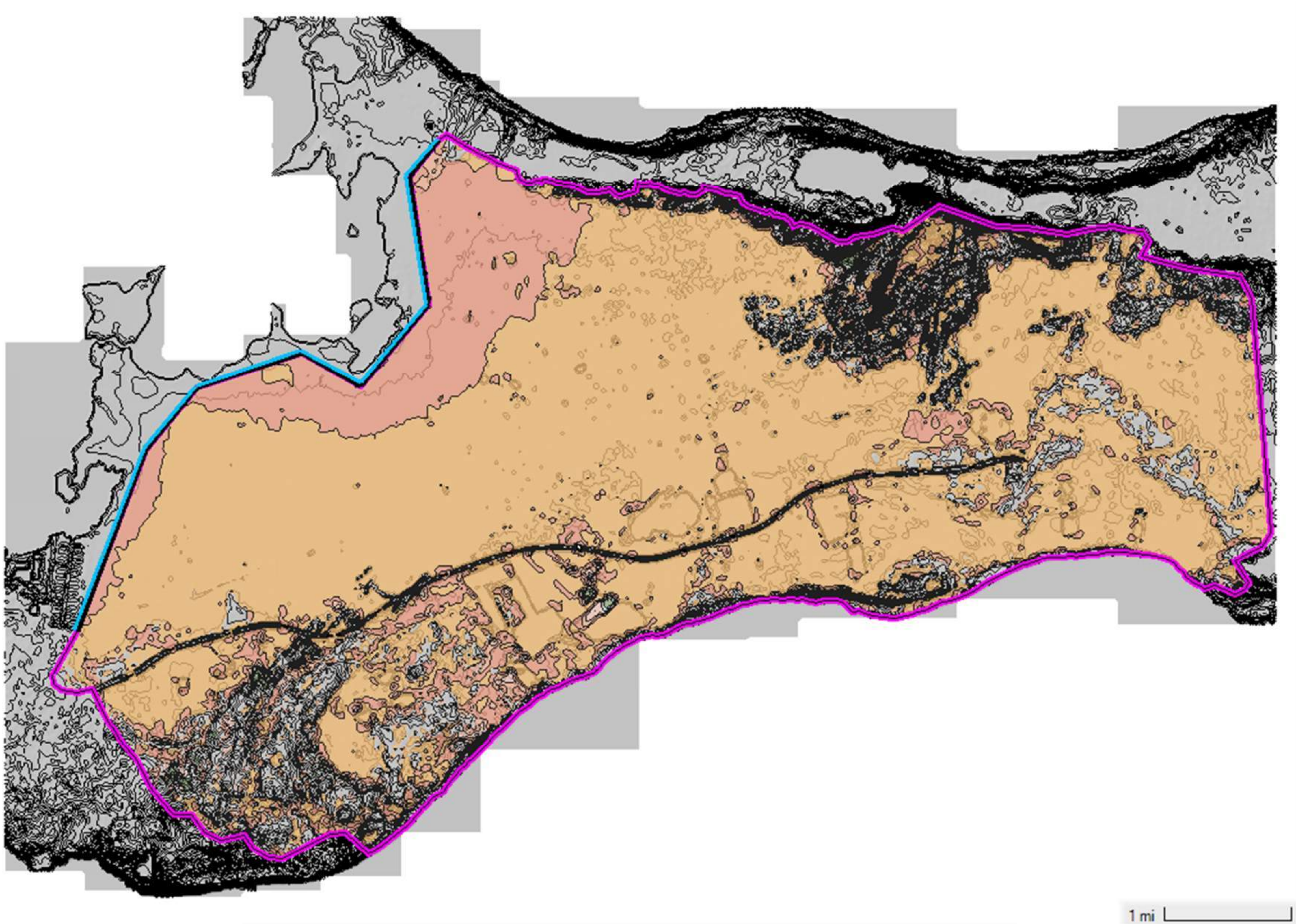
Alternate B2

50-Year Storm

Maximum Velocities

With Model Terrain





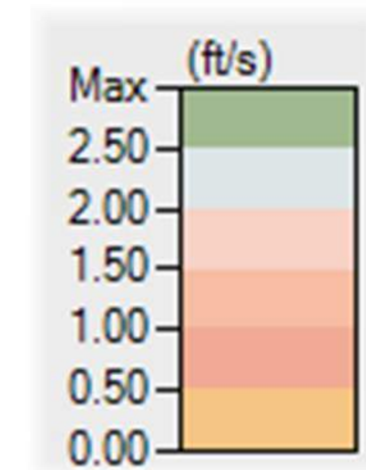
Alternate B2

50-Year Storm

With Sea Rise

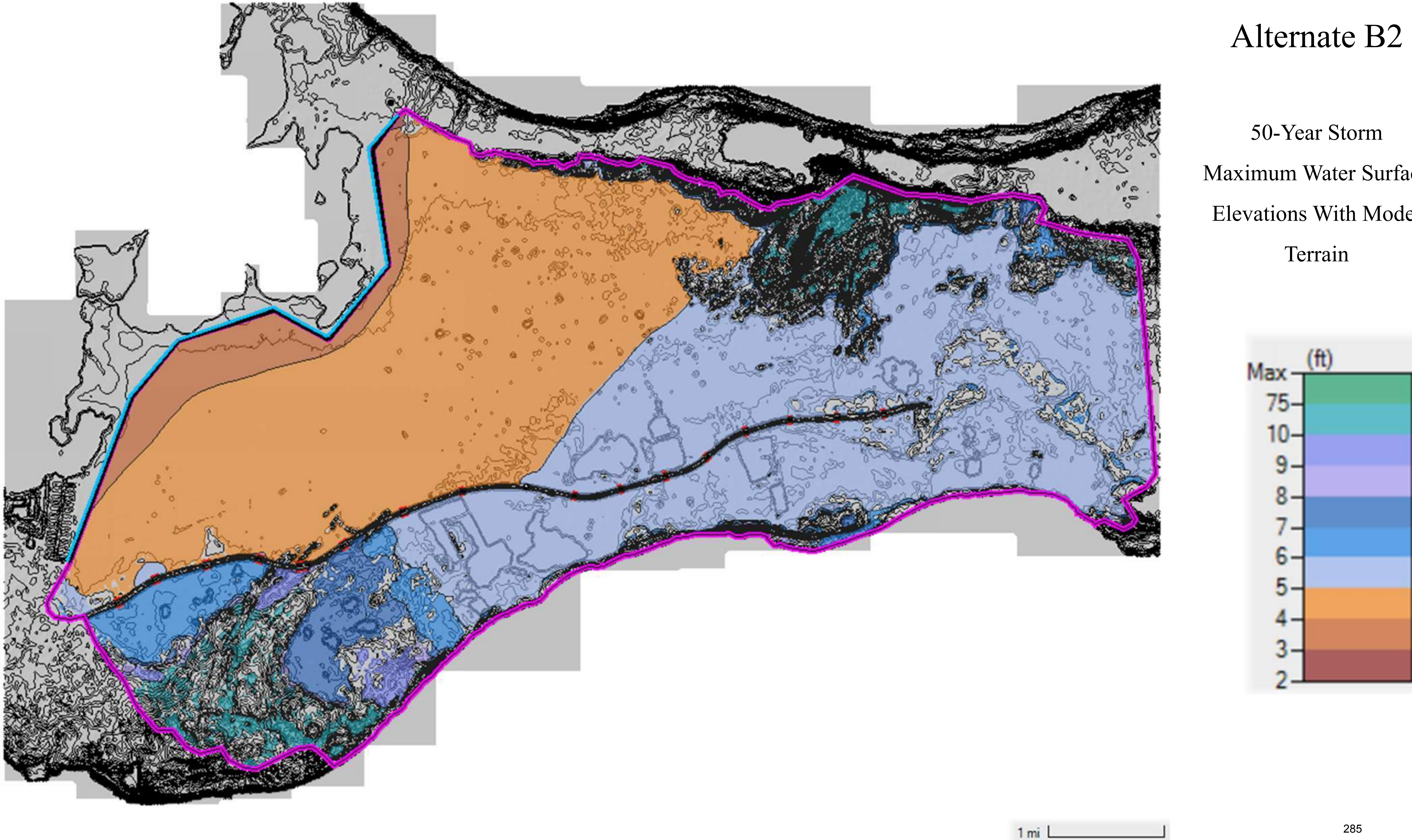
Maximum Velocities

With Model Terrain



Alternate B2

50-Year Storm
Maximum Water Surface
Elevations With Model
Terrain



Alternate B2

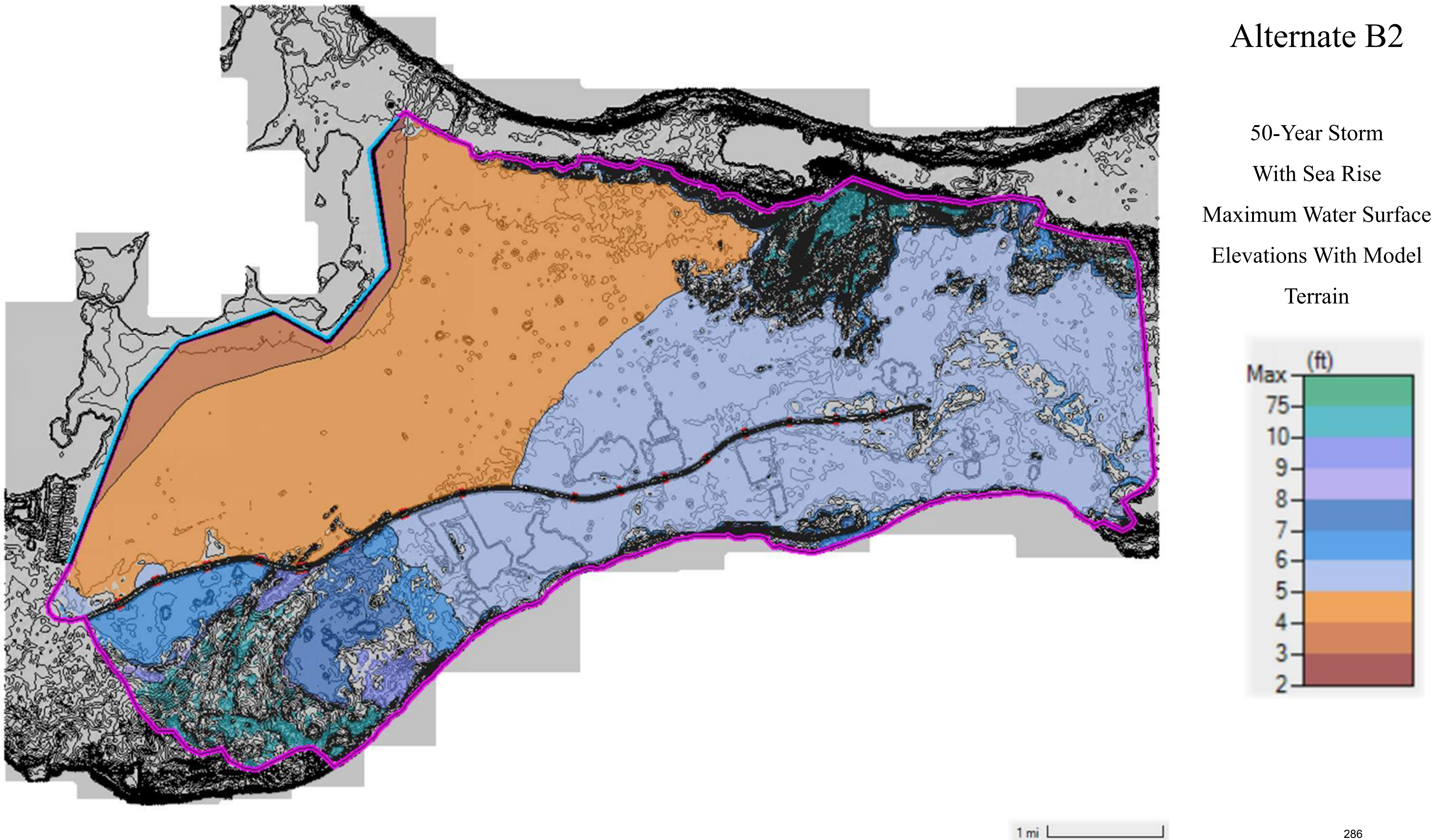
50-Year Storm

With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain

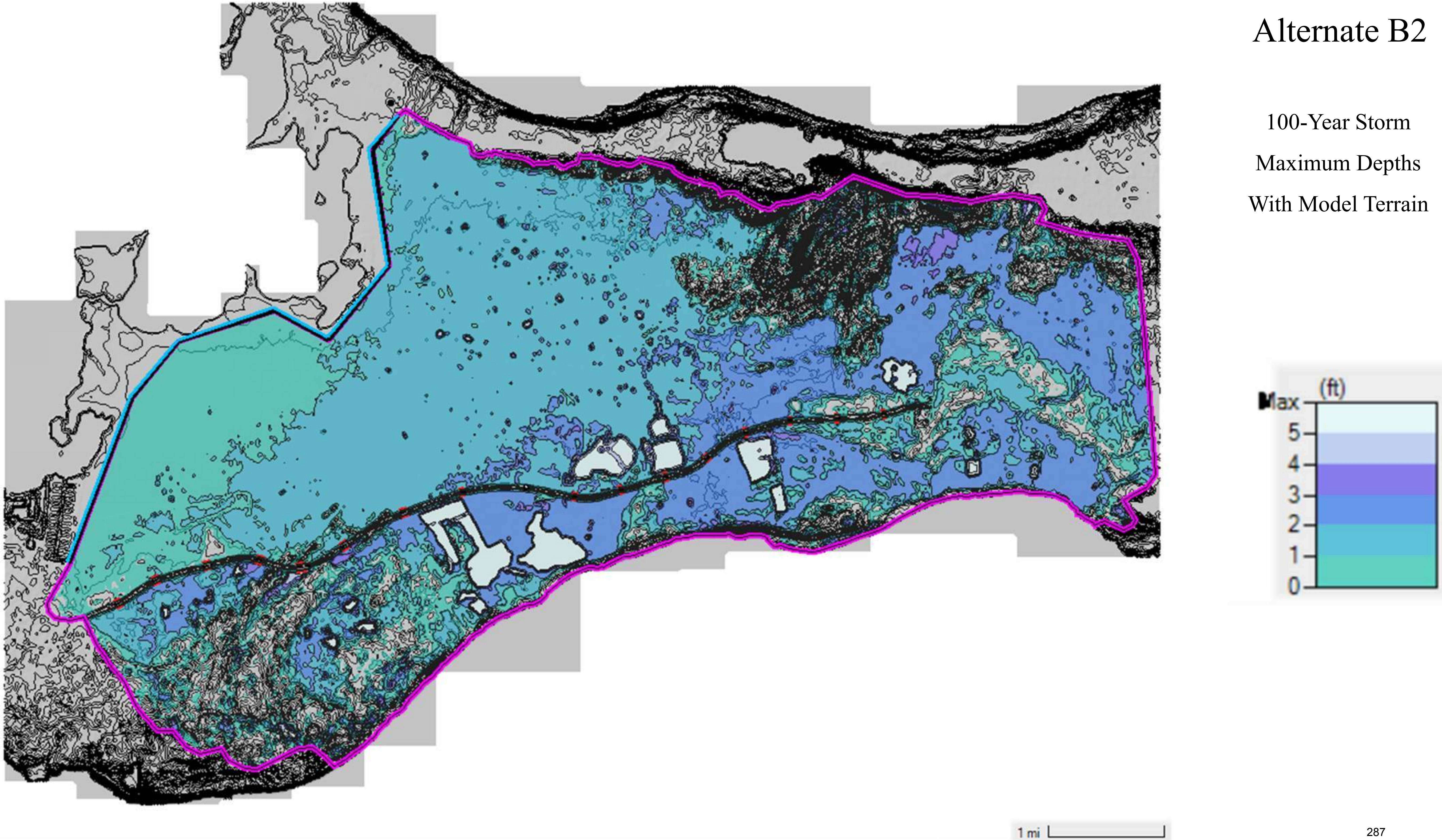


Alternate B2

100-Year Storm

Maximum Depths

With Model Terrain



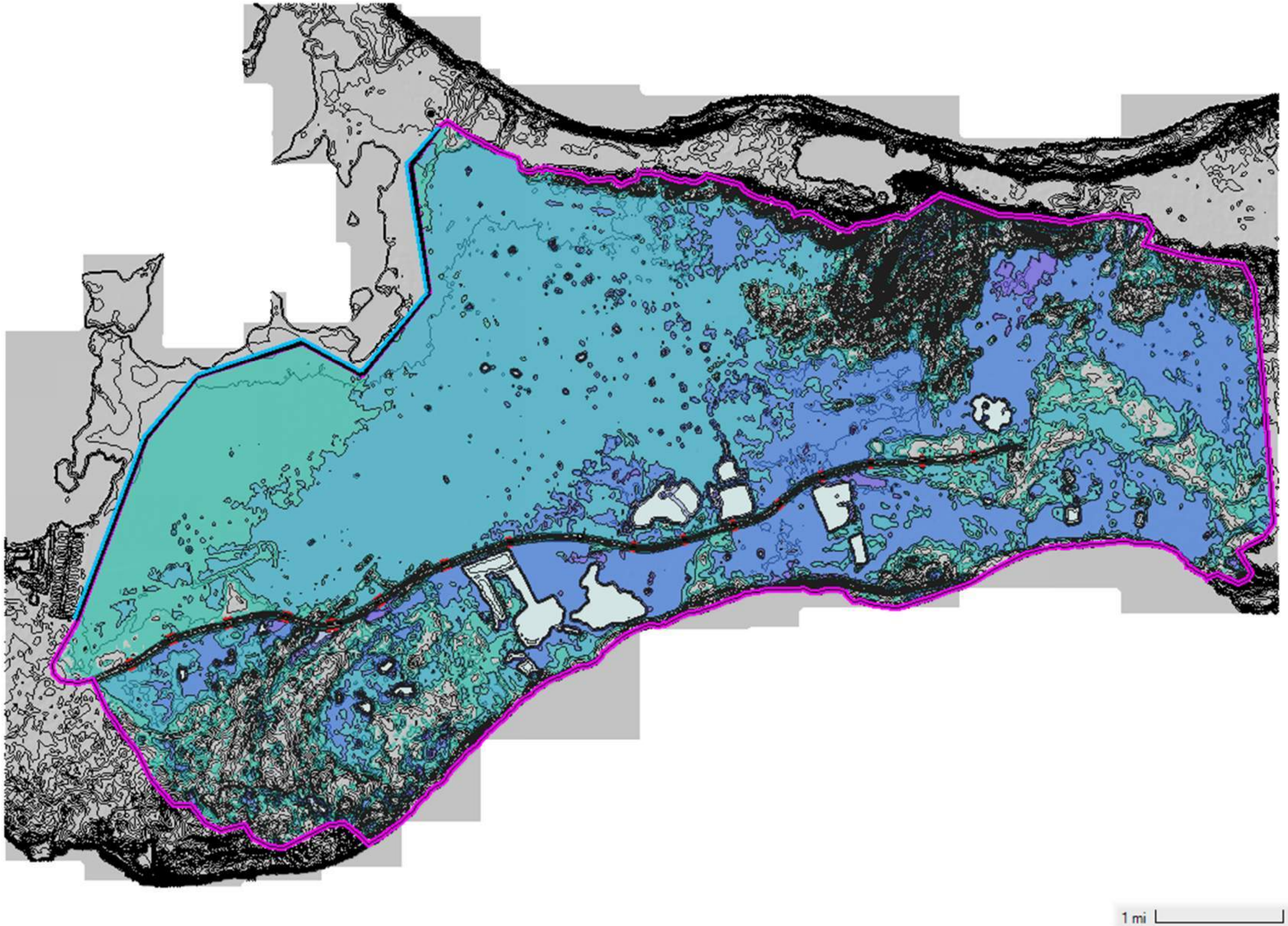
Alternate B2

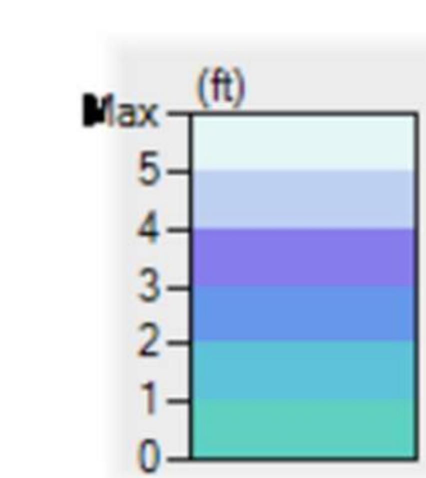
100-Year Storm

With Sea Rise

Maximum Depths

With Model Terrain



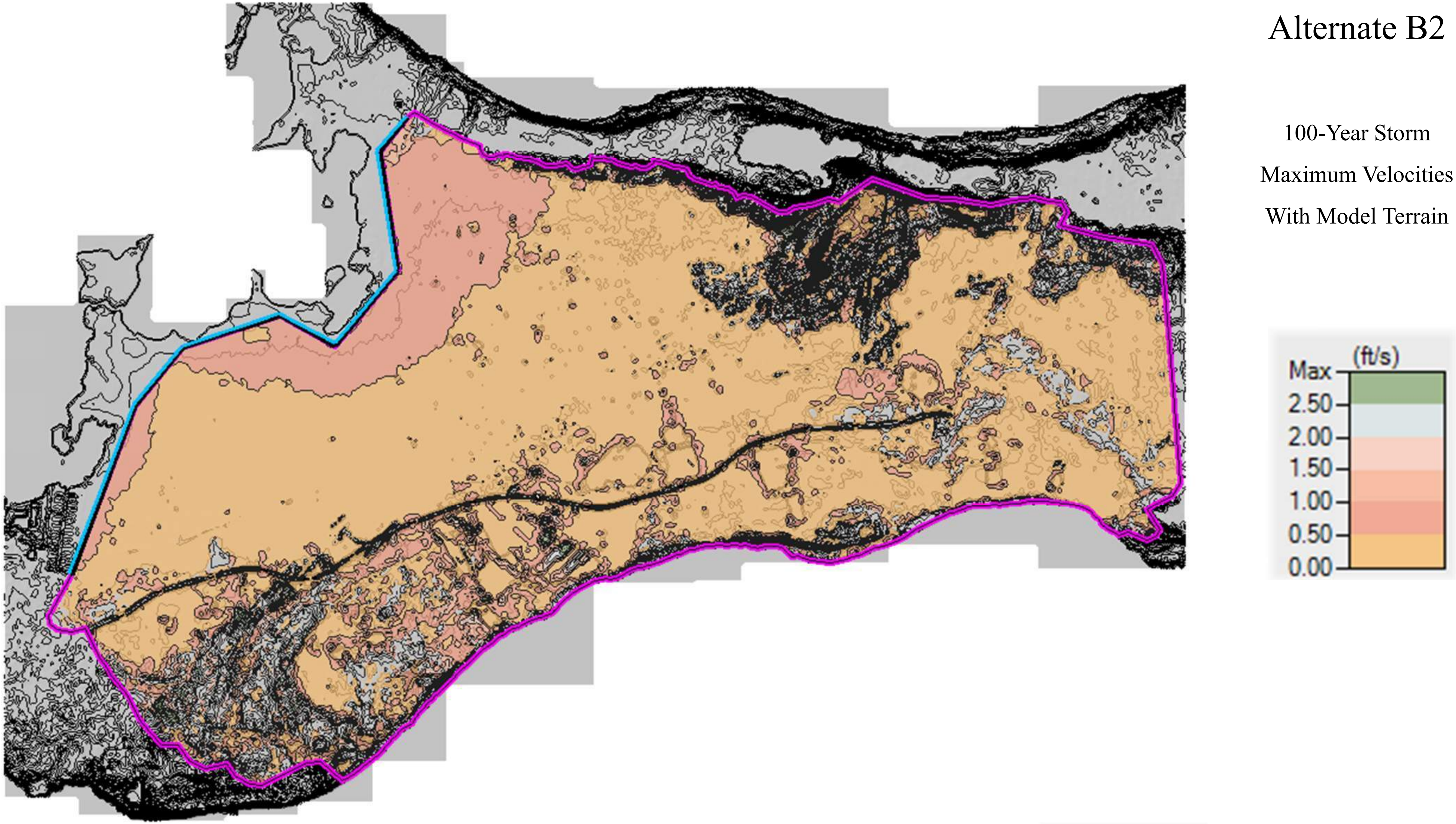


Alternate B2

100-Year Storm

Maximum Velocities

With Model Terrain



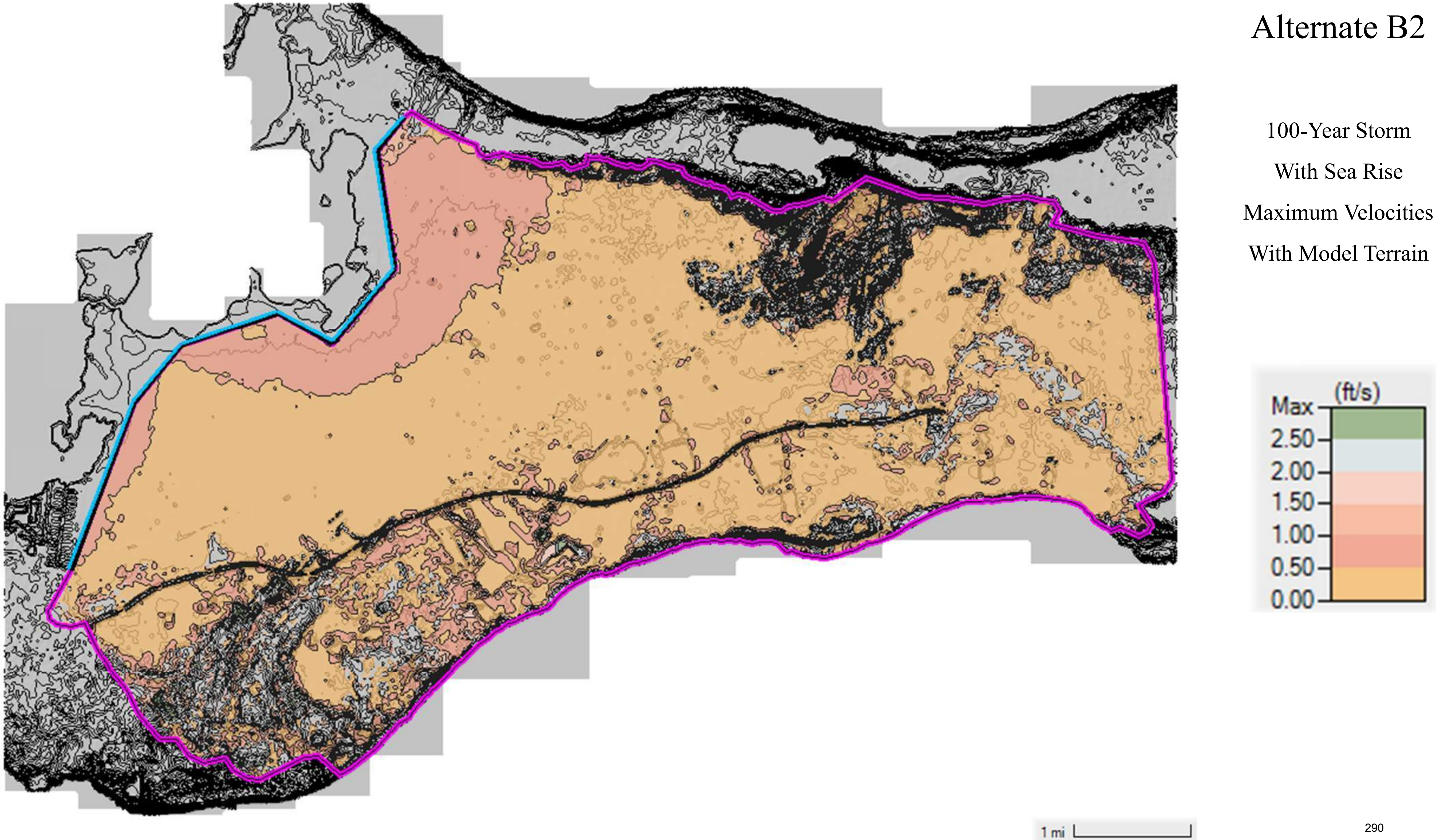
Alternate B2

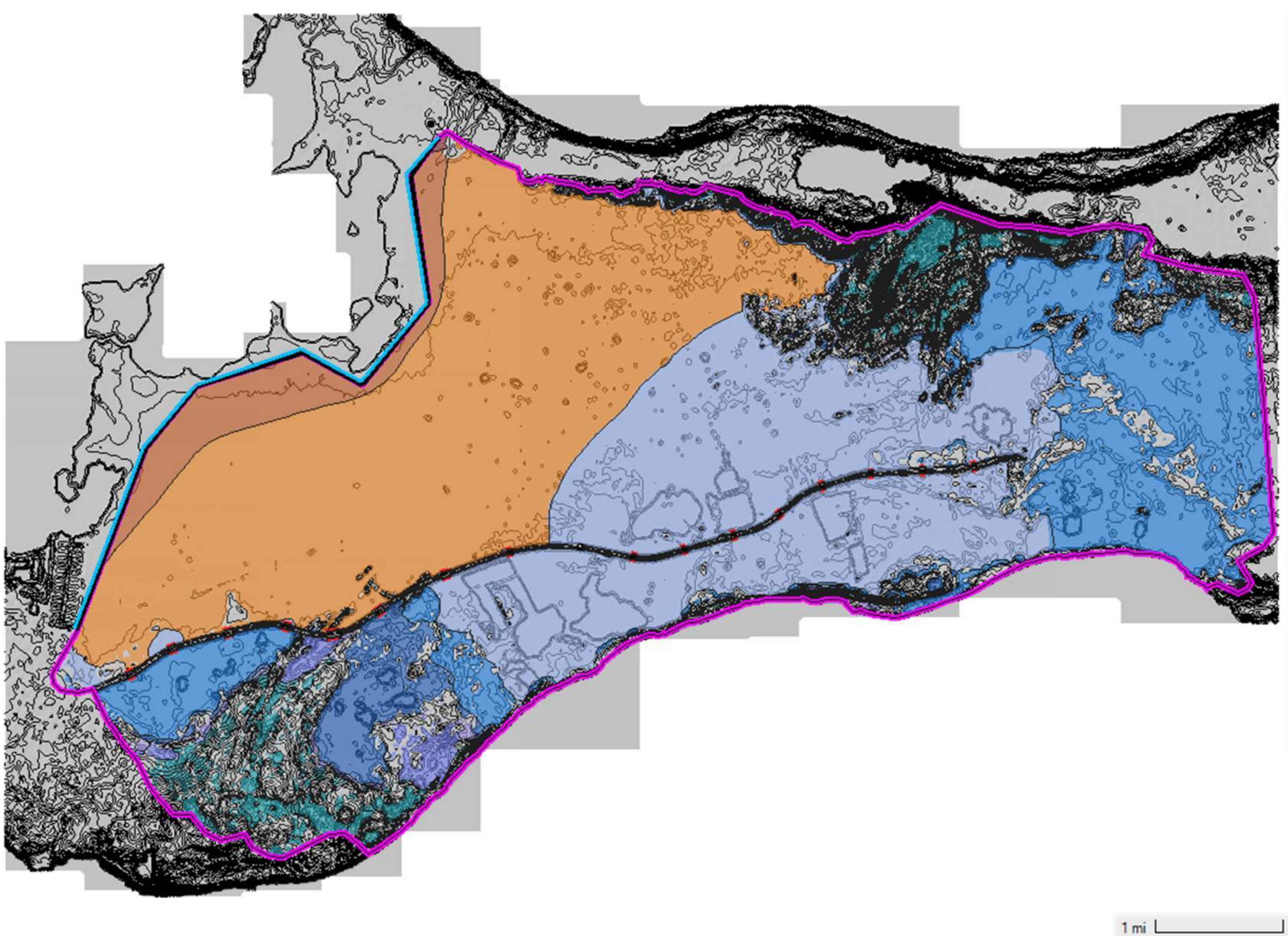
100-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain





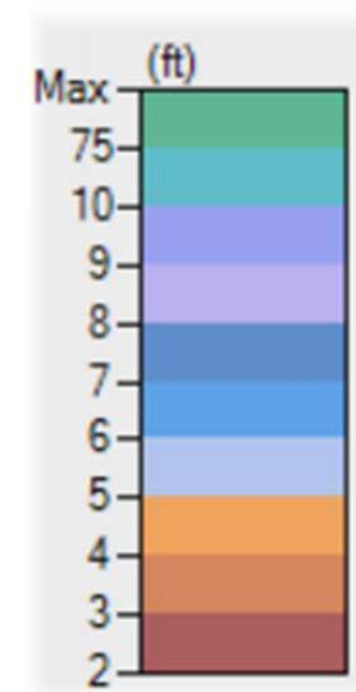
Alternate B2

100-Year Storm

Maximum Water Surface

Elevations

With Model Terrain



Alternate B2

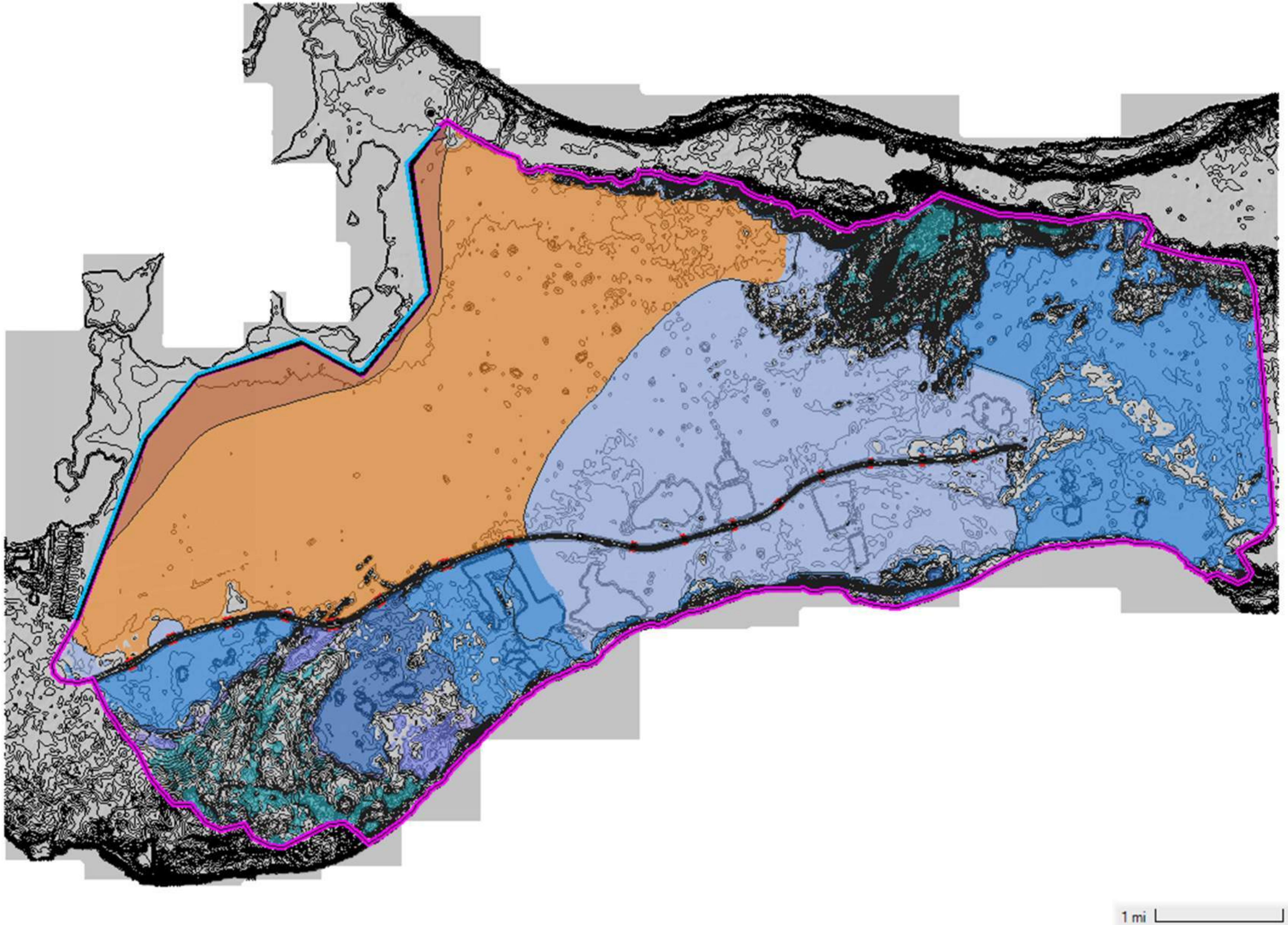
100-Year Storm

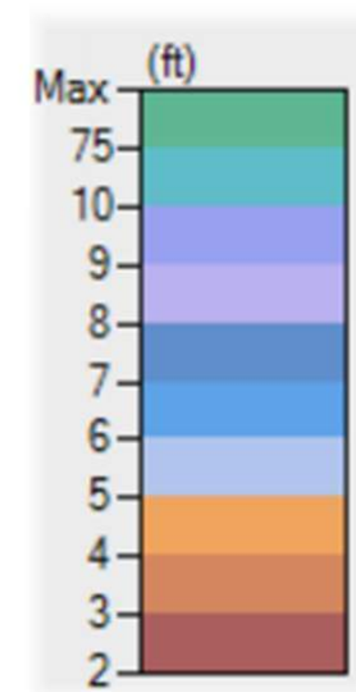
With Sea Rise

Maximum Water Surface

Elevations

With Model Terrain





Alternate B2

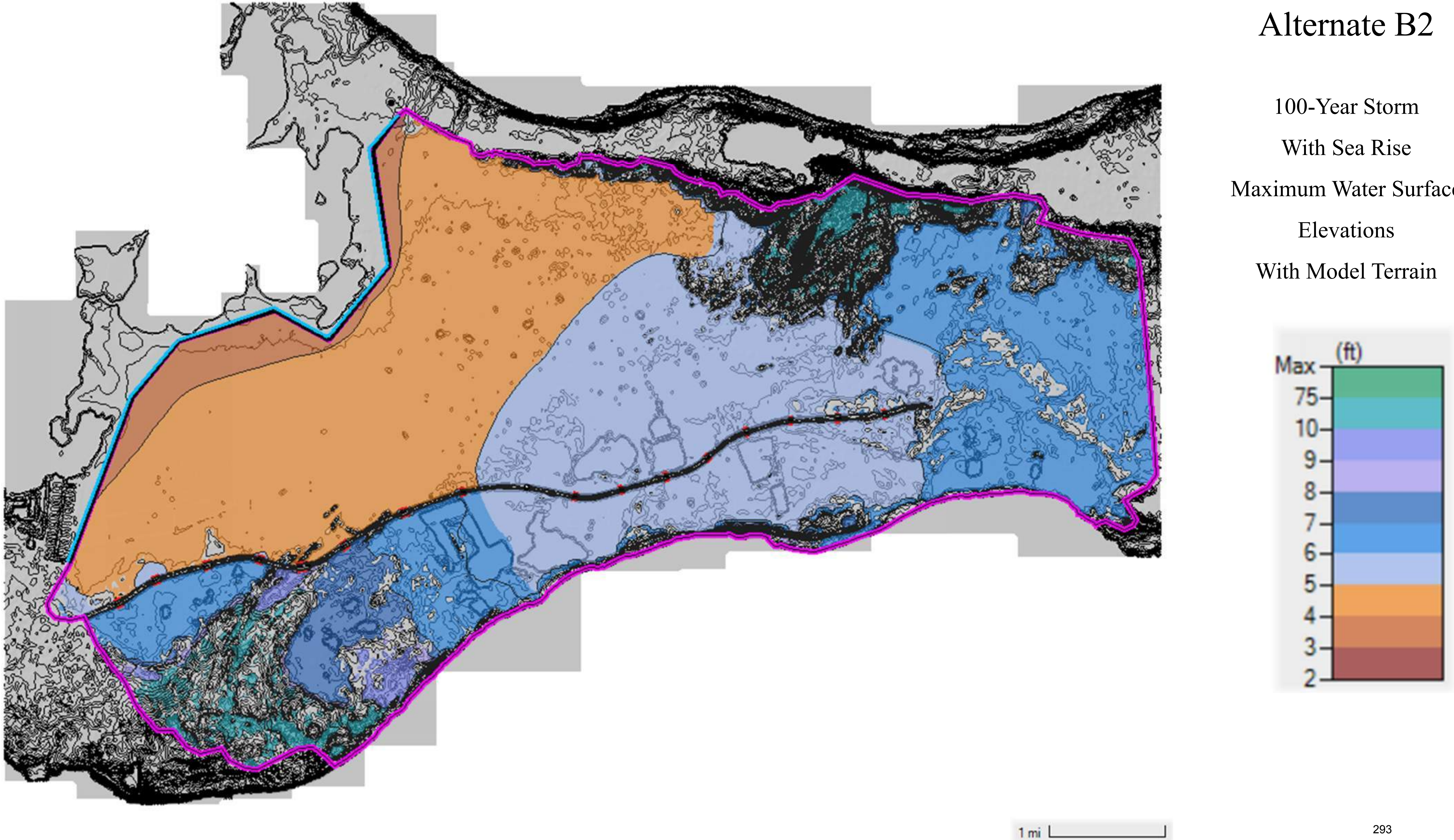
100-Year Storm

With Sea Rise

Maximum Water Surface

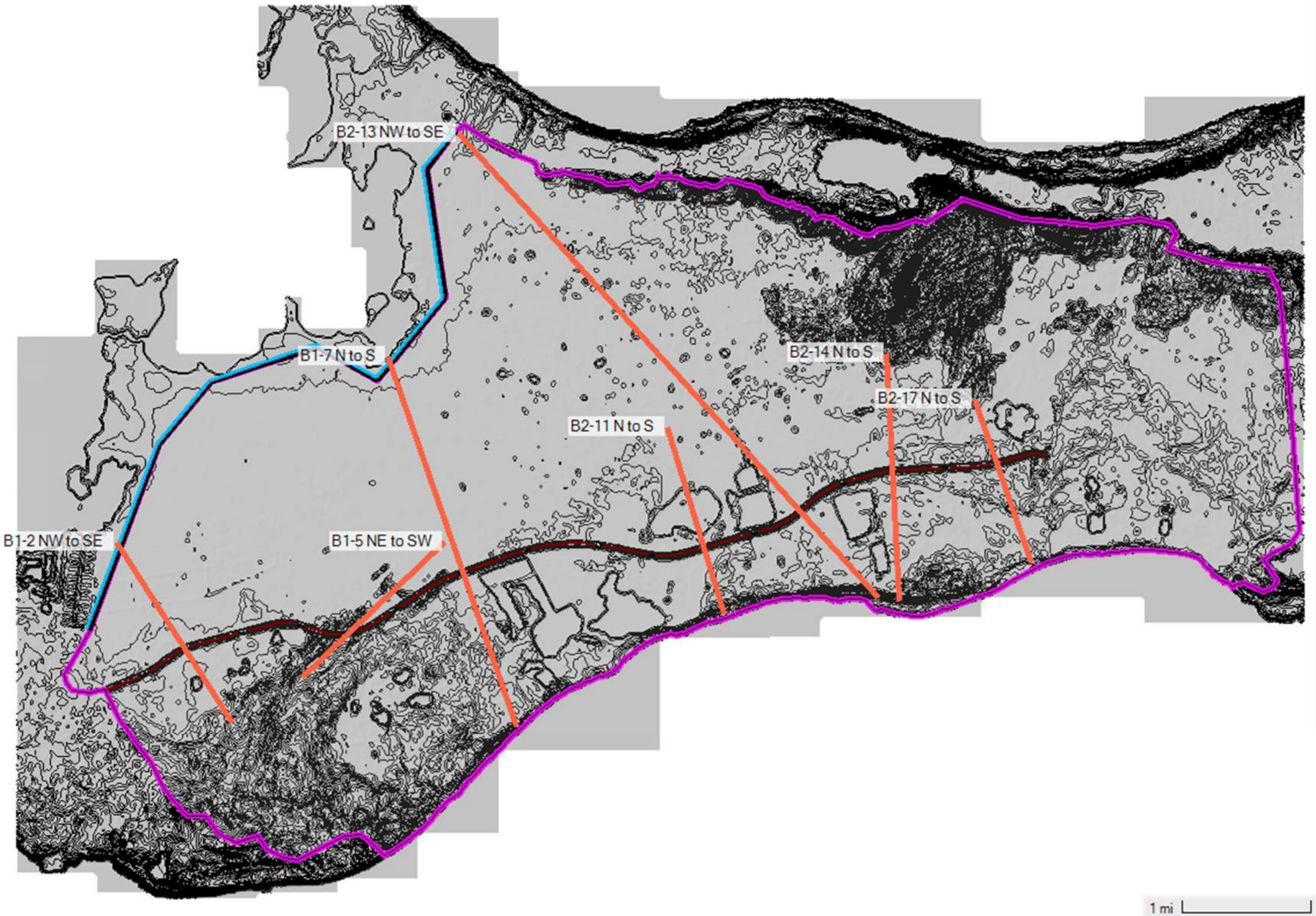
Elevations

With Model Terrain



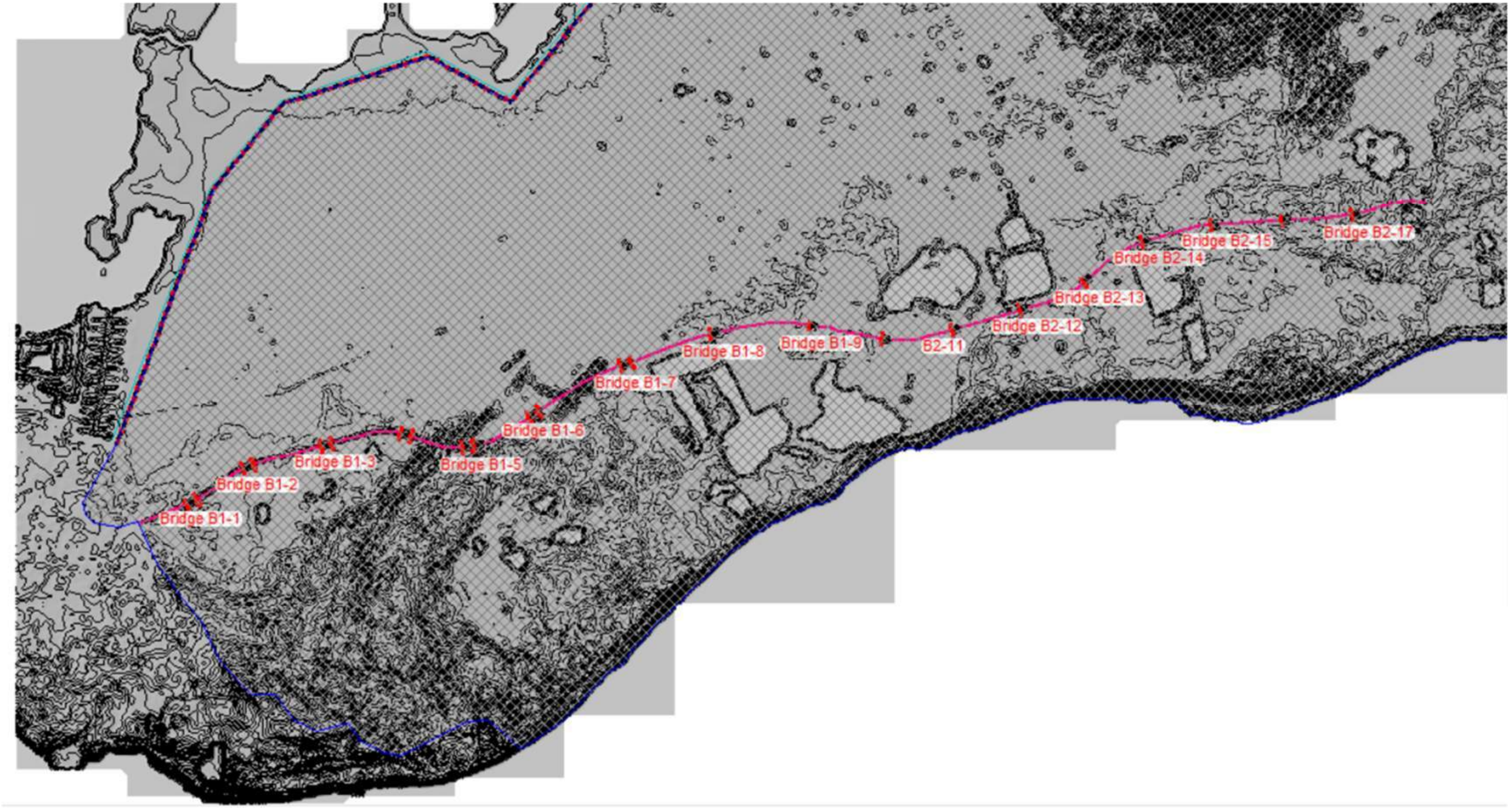
Alternative B2

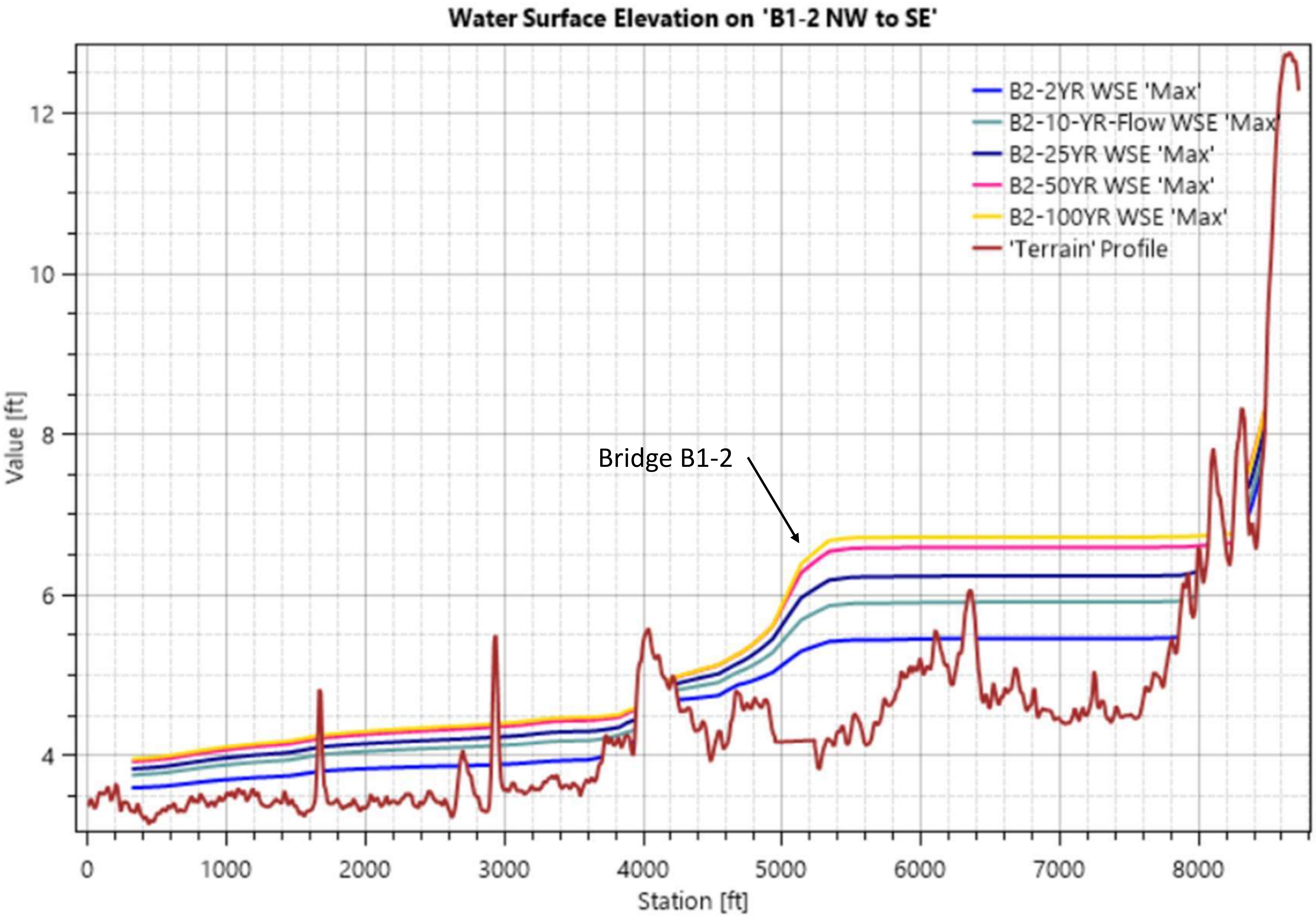
Profiles



Alternative B2

Bridges

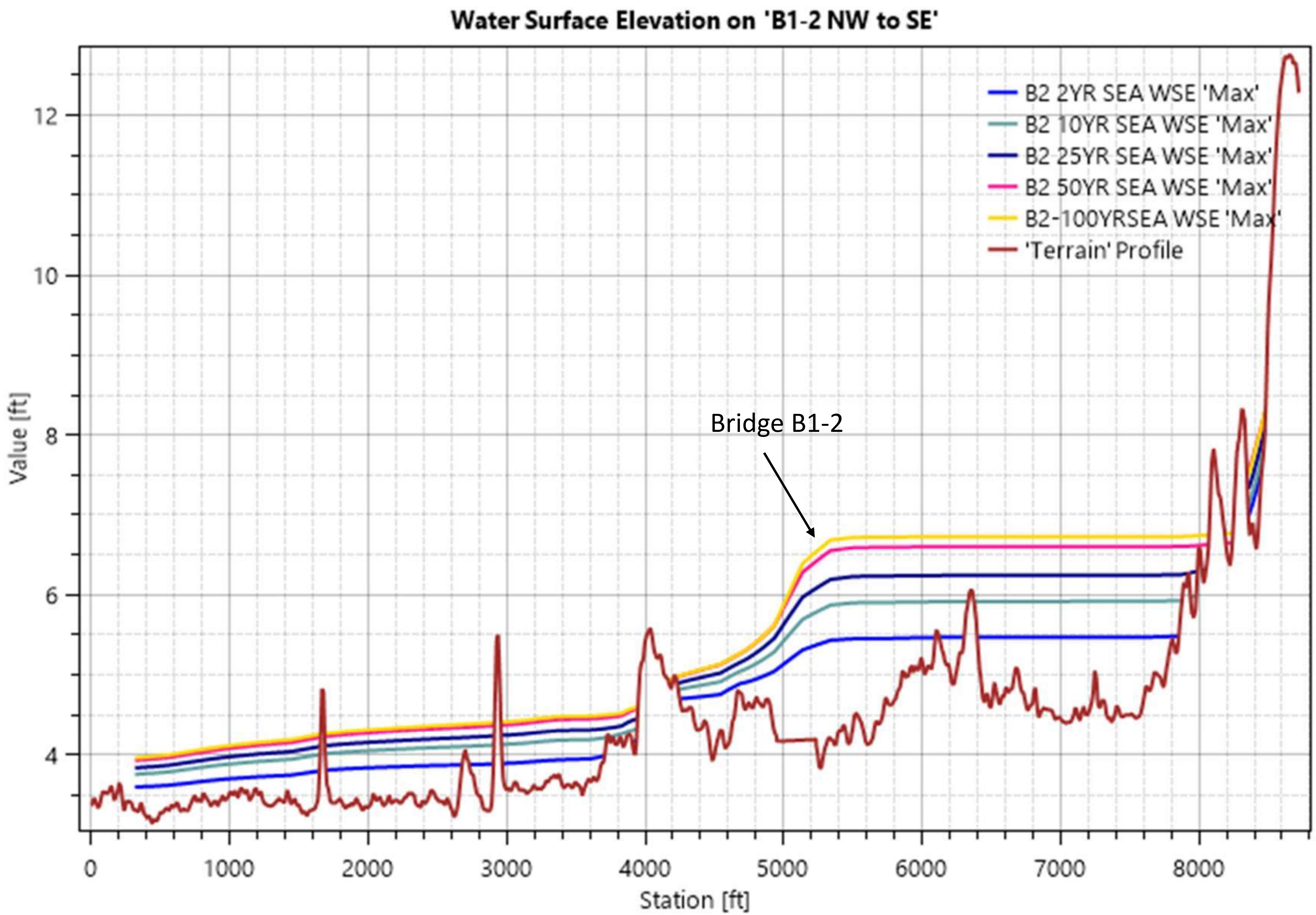




Alternative B2

Profile B1-2

From NW to SE



Alternative B2

Profile B1-2

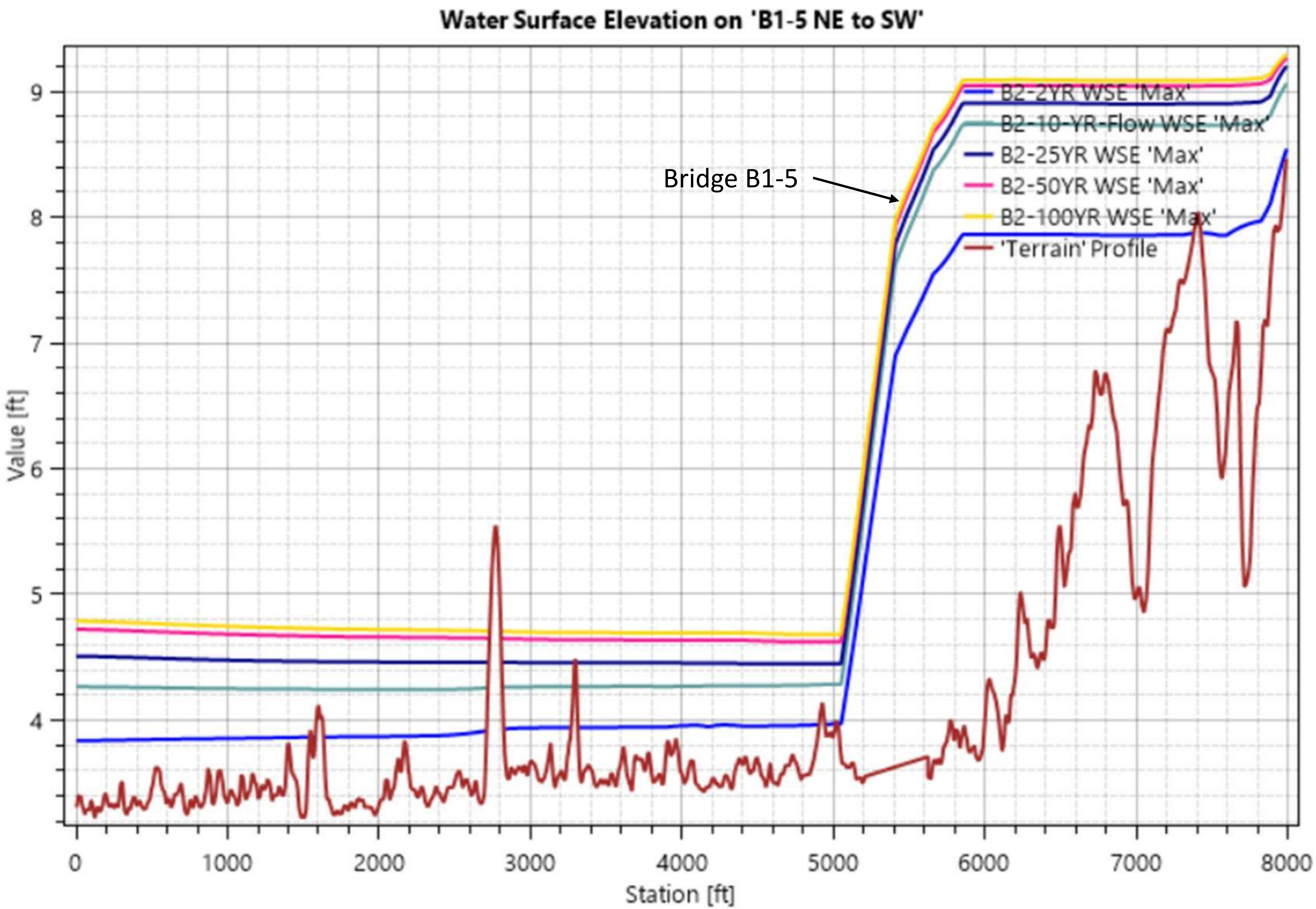
With Sea Rise

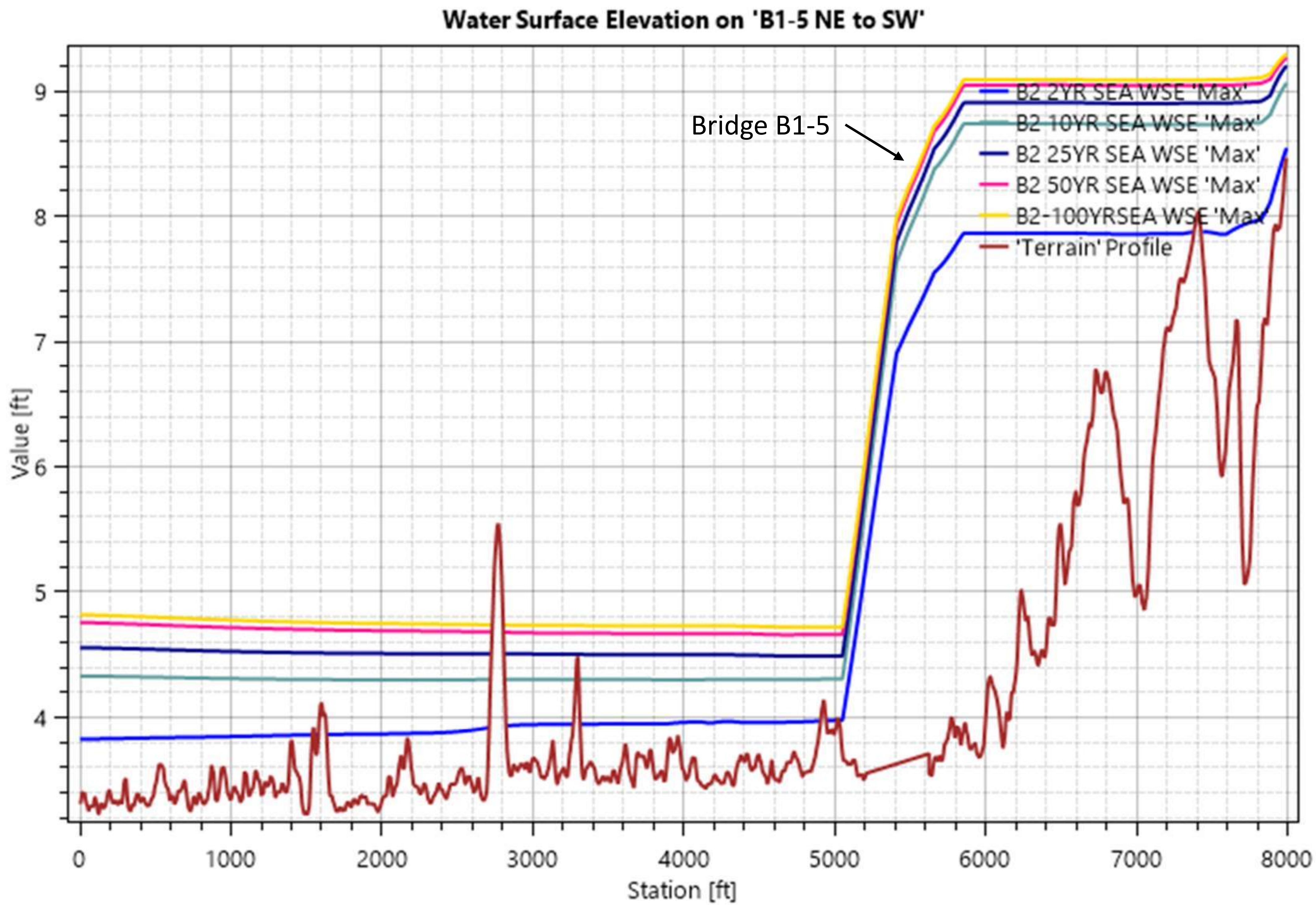
From NW to SE

Alternative B2

Profile B1-5

From NE to SW





Alternative B2

Profile B1-5

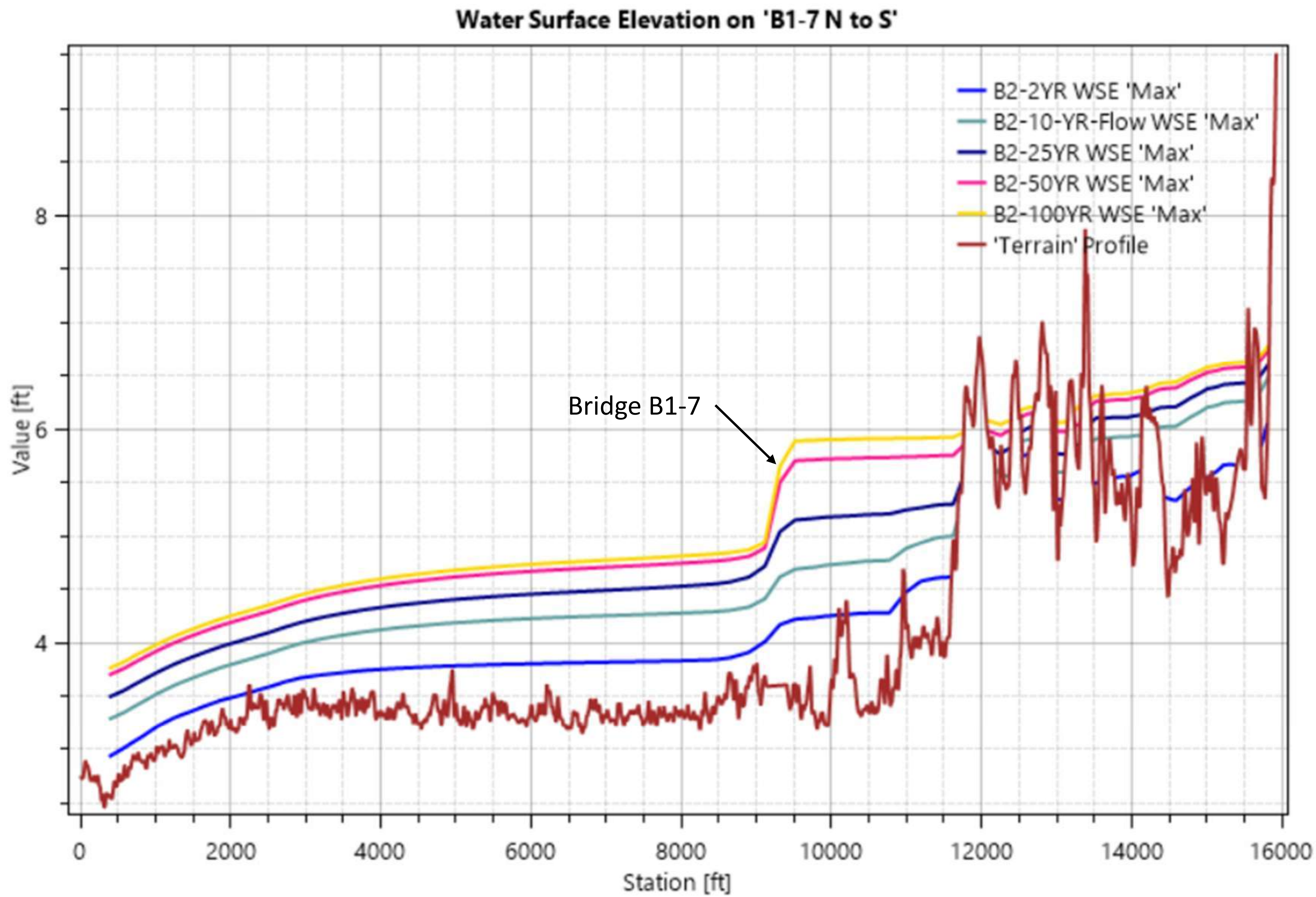
With Sea Rise

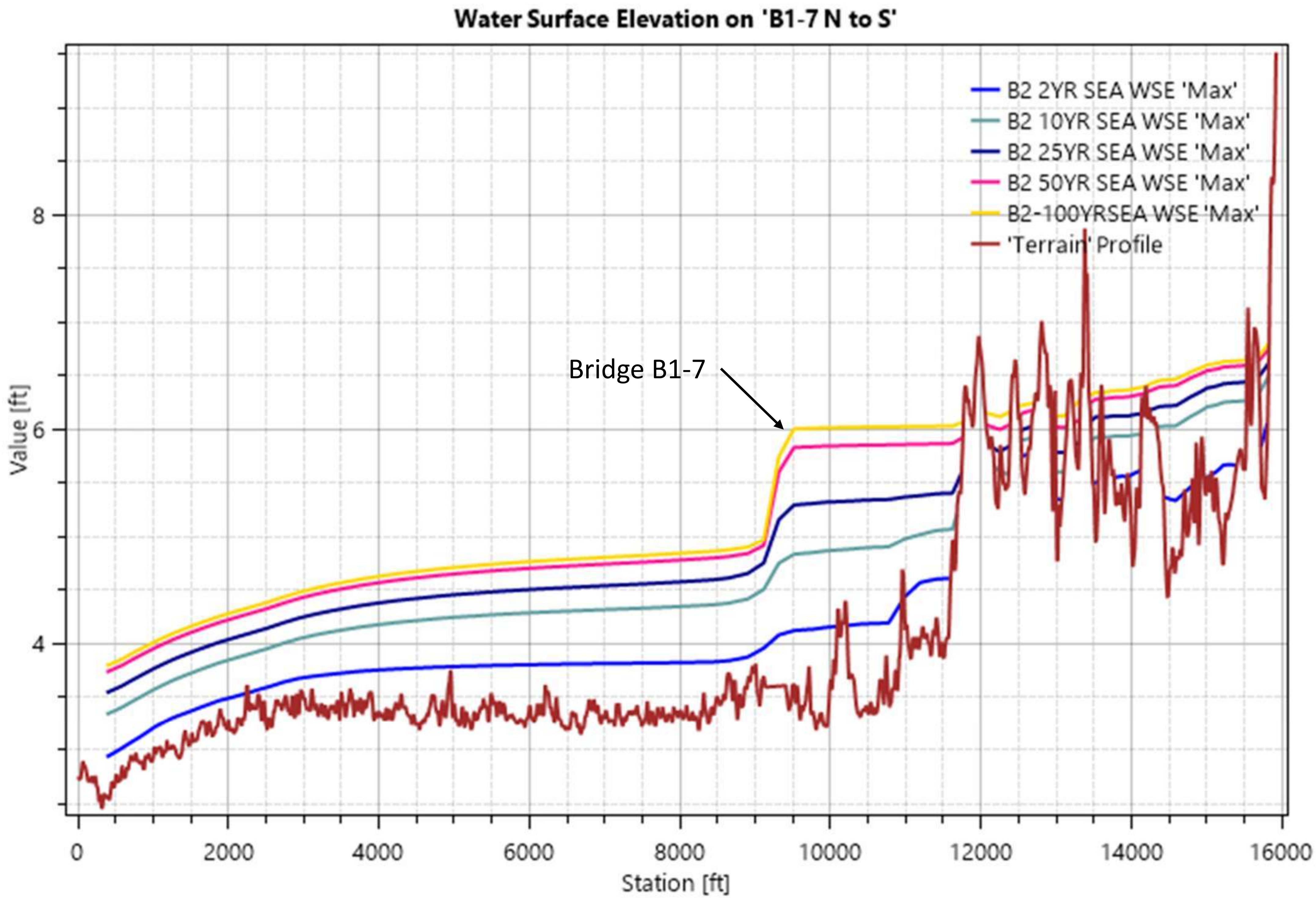
From NE to SW

Alternative B2

Profile B1-7

From N to S



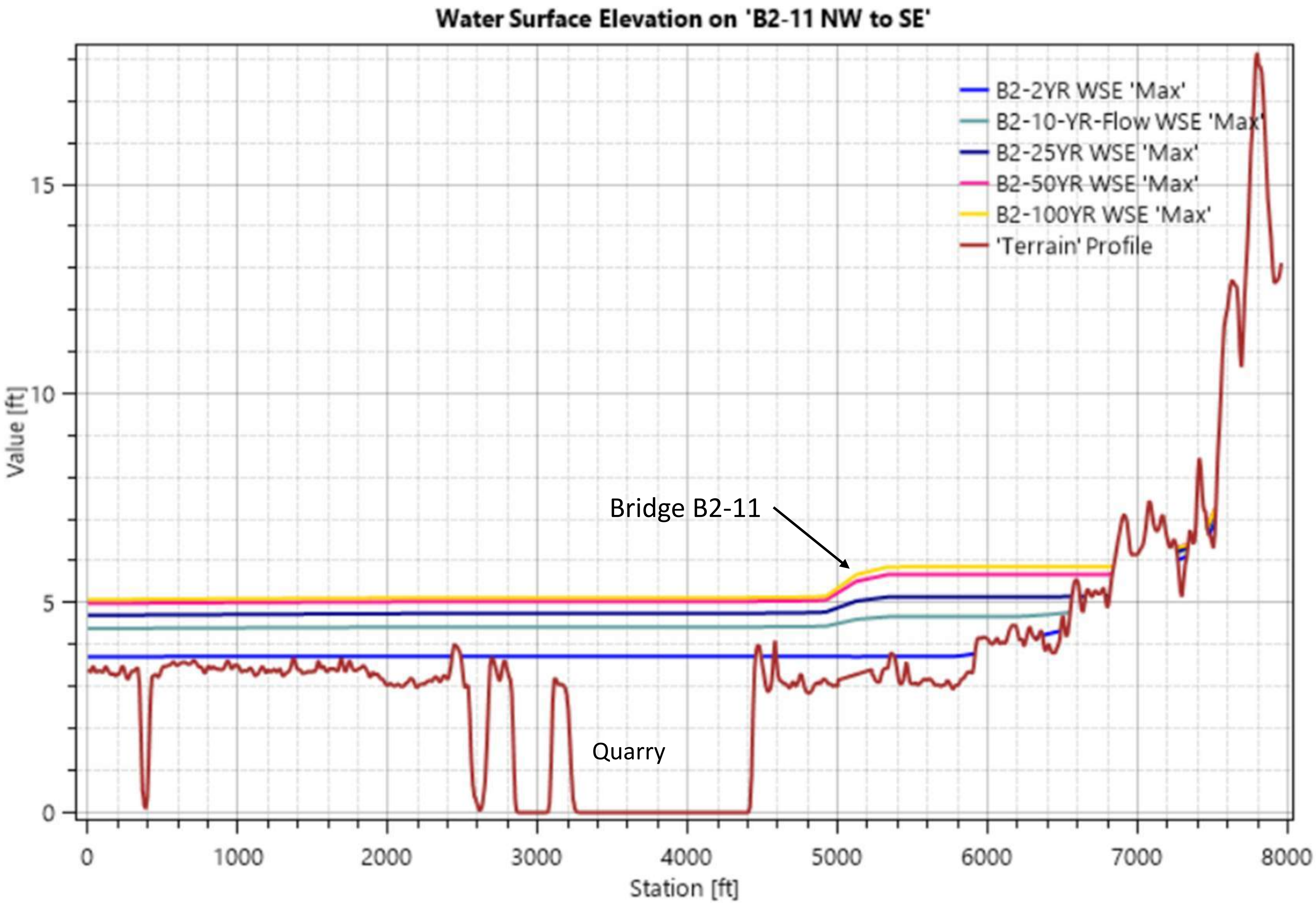


Alternative B2

Profile B1-7

With Sea Rise

From N to S



Alternative B2

Profile B2-11

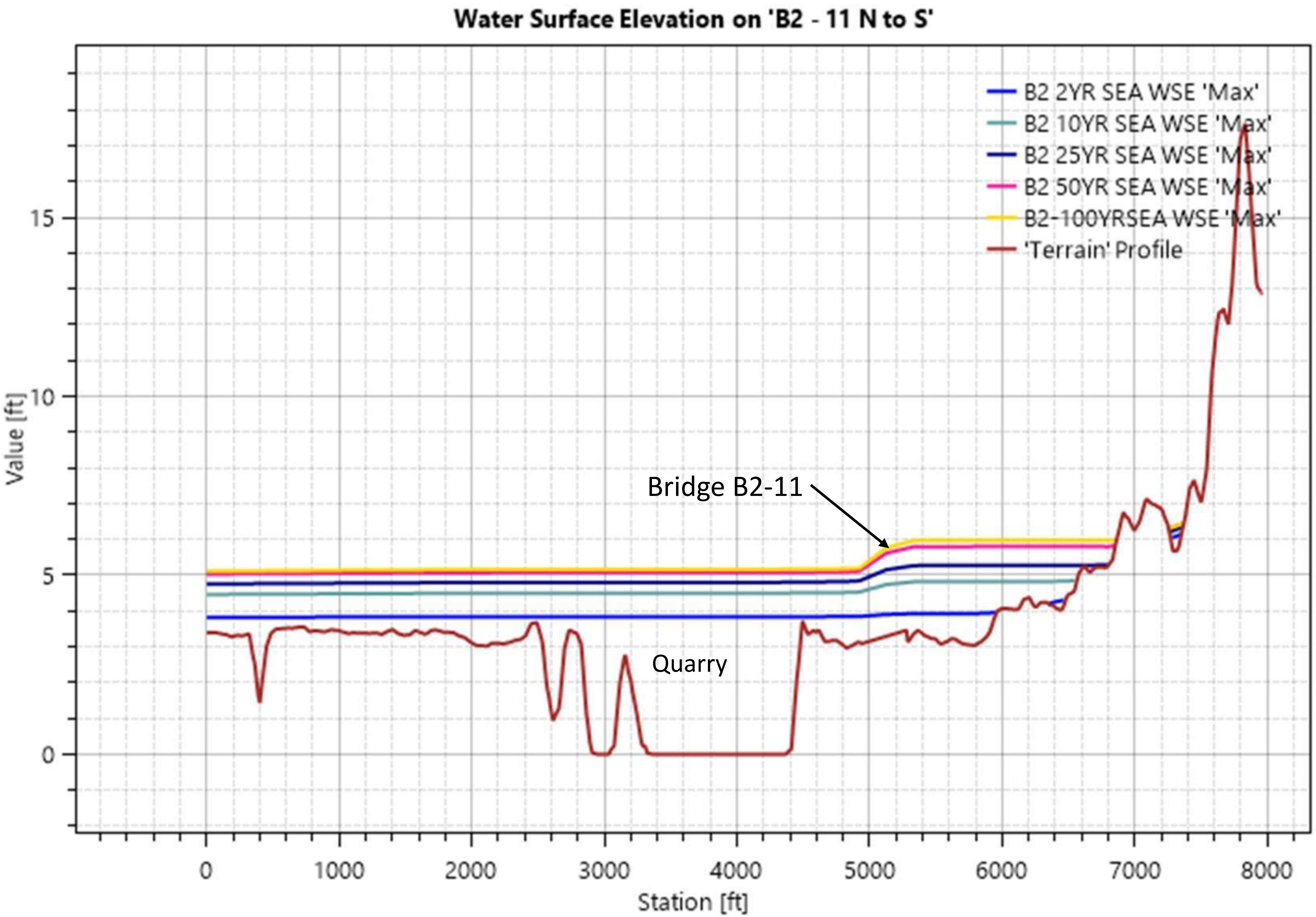
From NW to SE

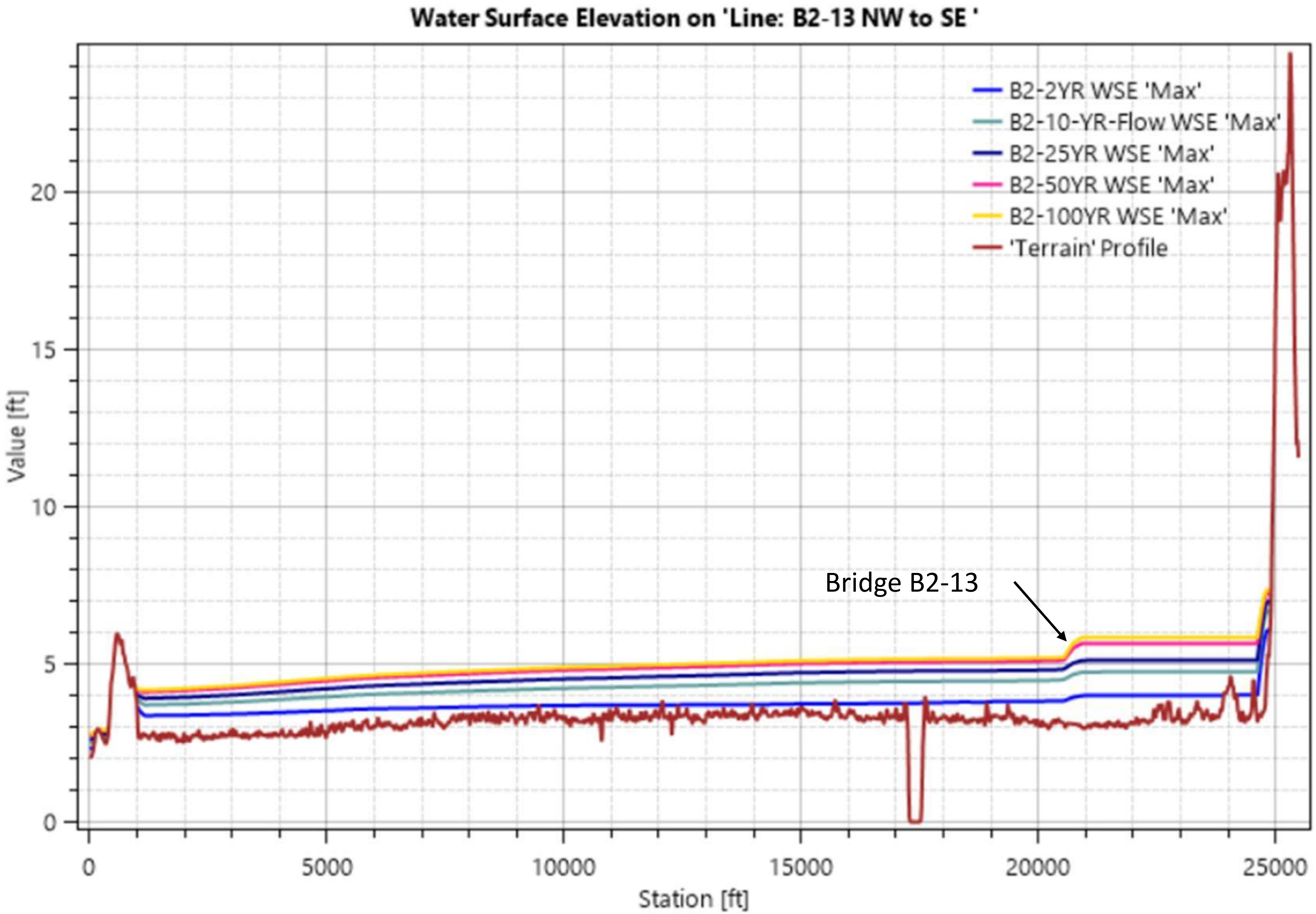
Alternative B2

Profile B2-11

with Sea Rise

From N to S

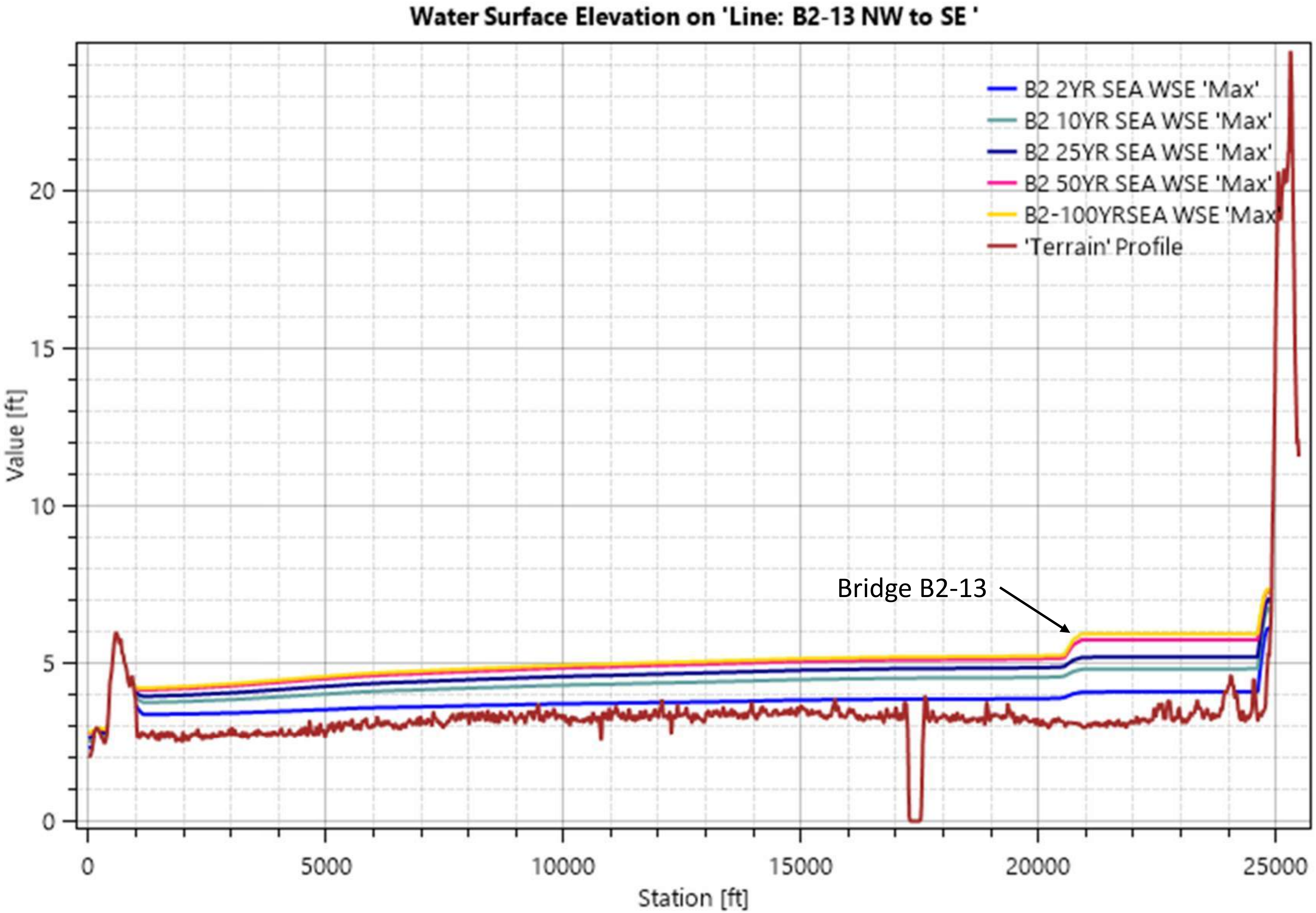




Alternative B2

Profile B2-13

From NW to SE

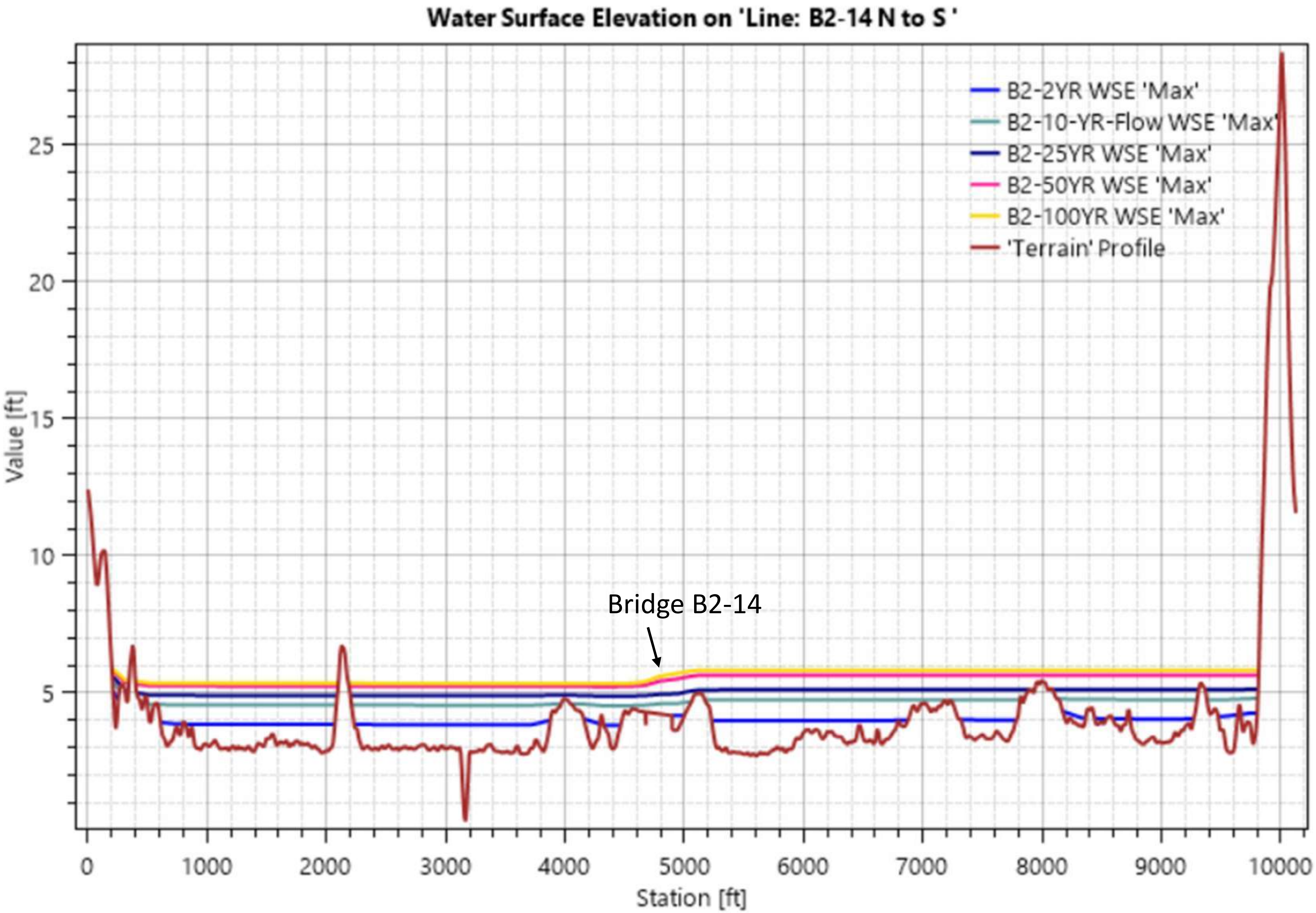


Alternative B2

Profile B2-13

With Sea Rise

From NW to SE



Alternative B2

Profile B2-14

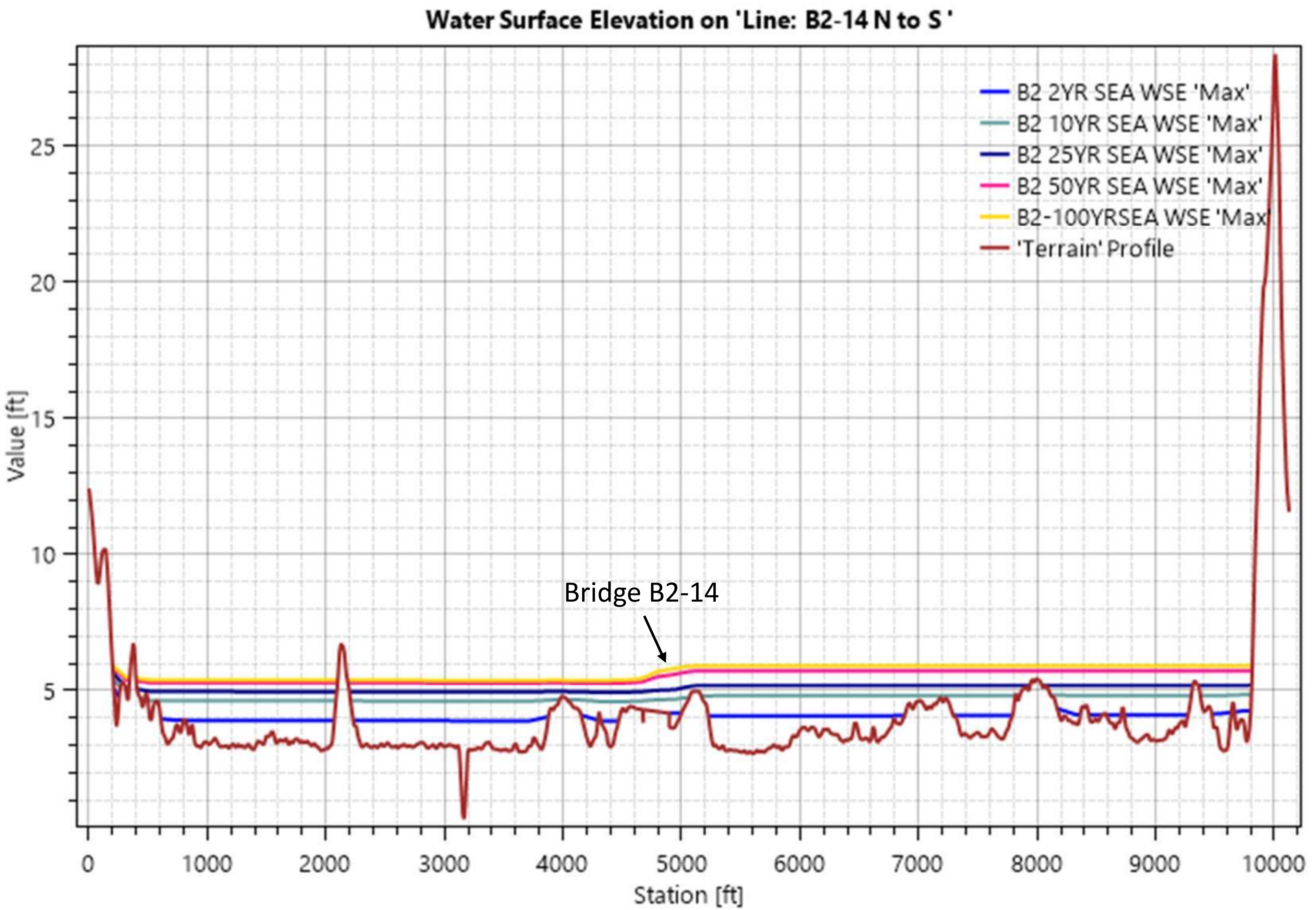
From NWto SE

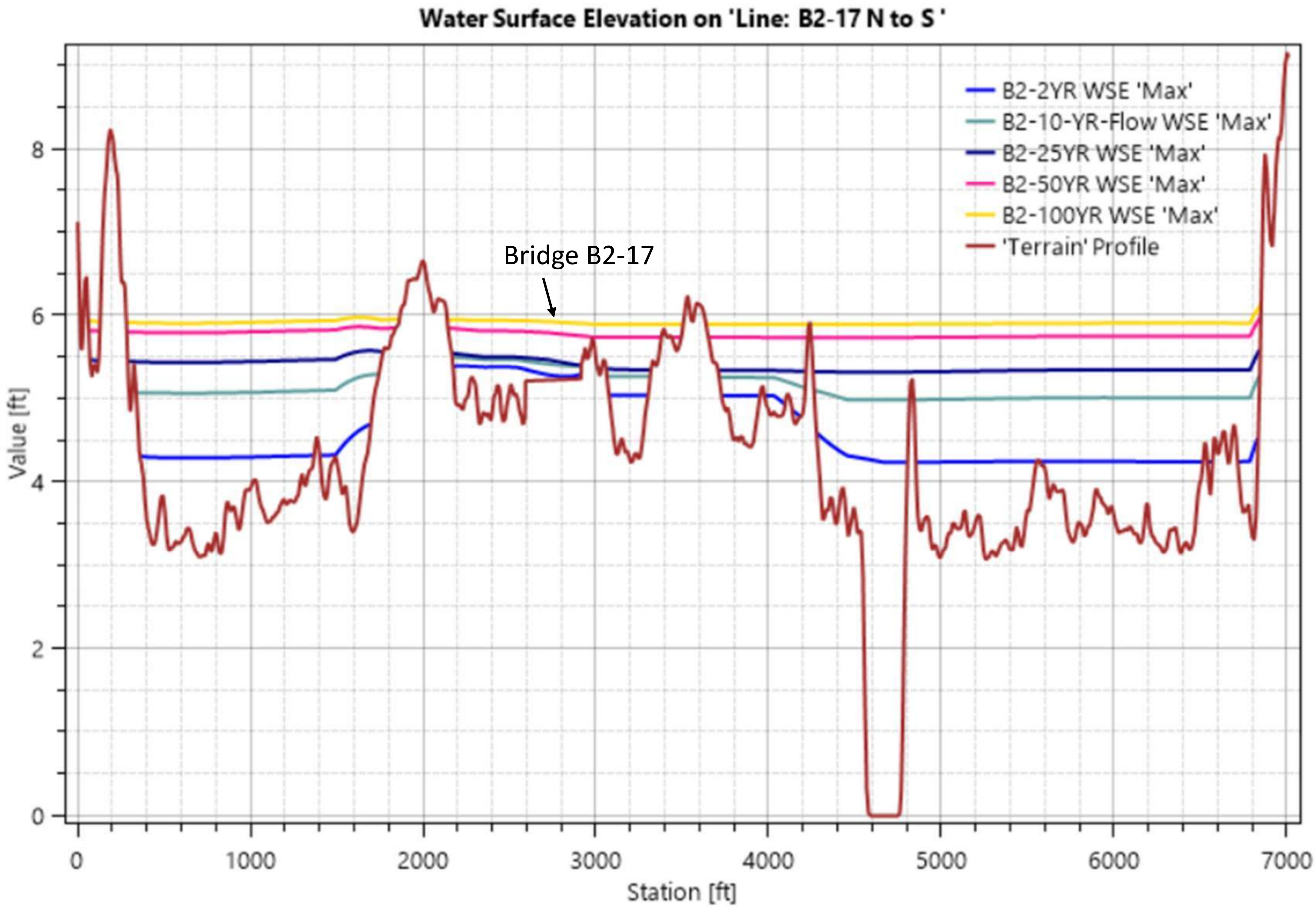
Alternative B2

Profile B2-14

With Sea Rise

From N to S





Alternative B2

Profile B2-17

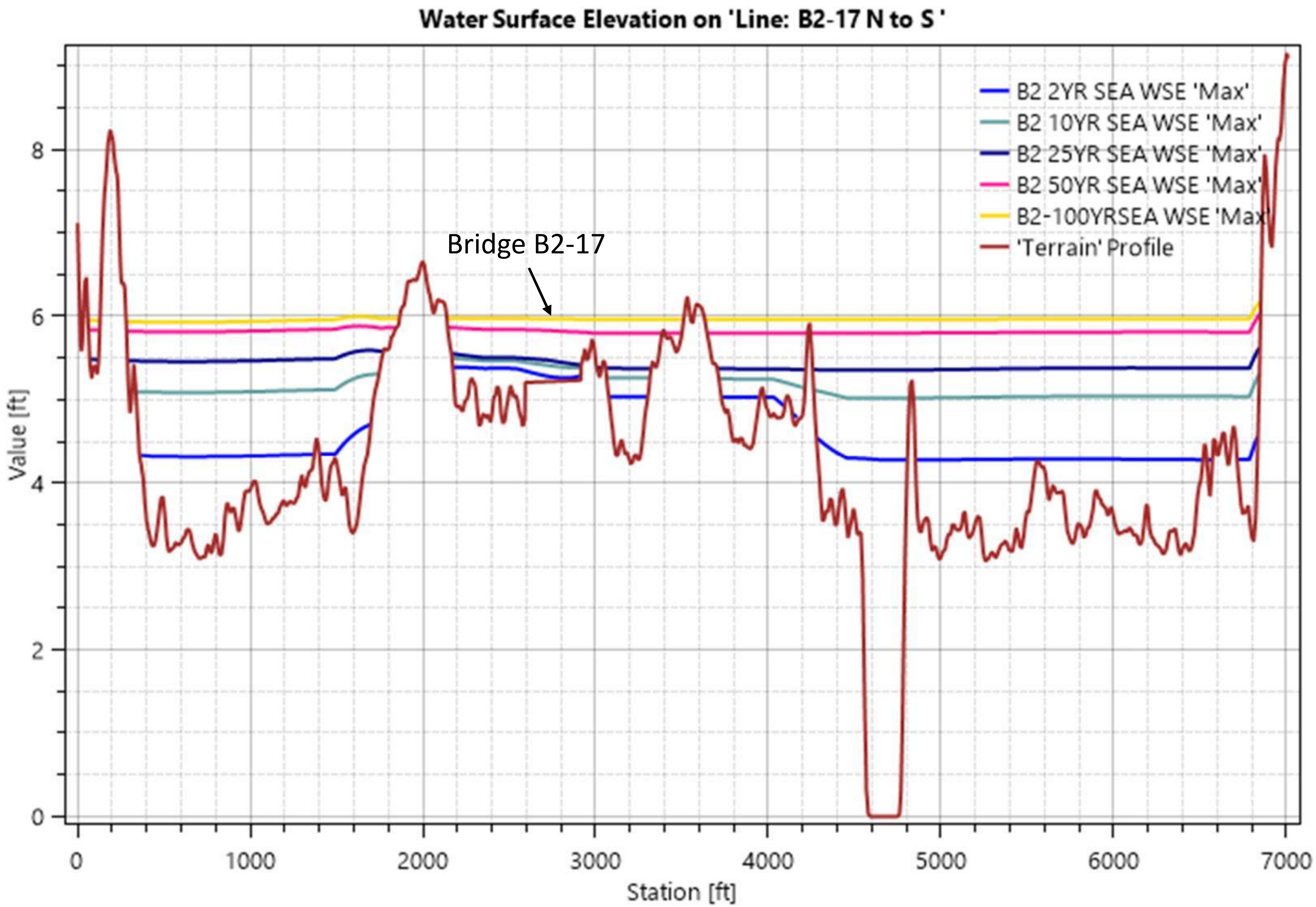
From N to S

Alternative B2

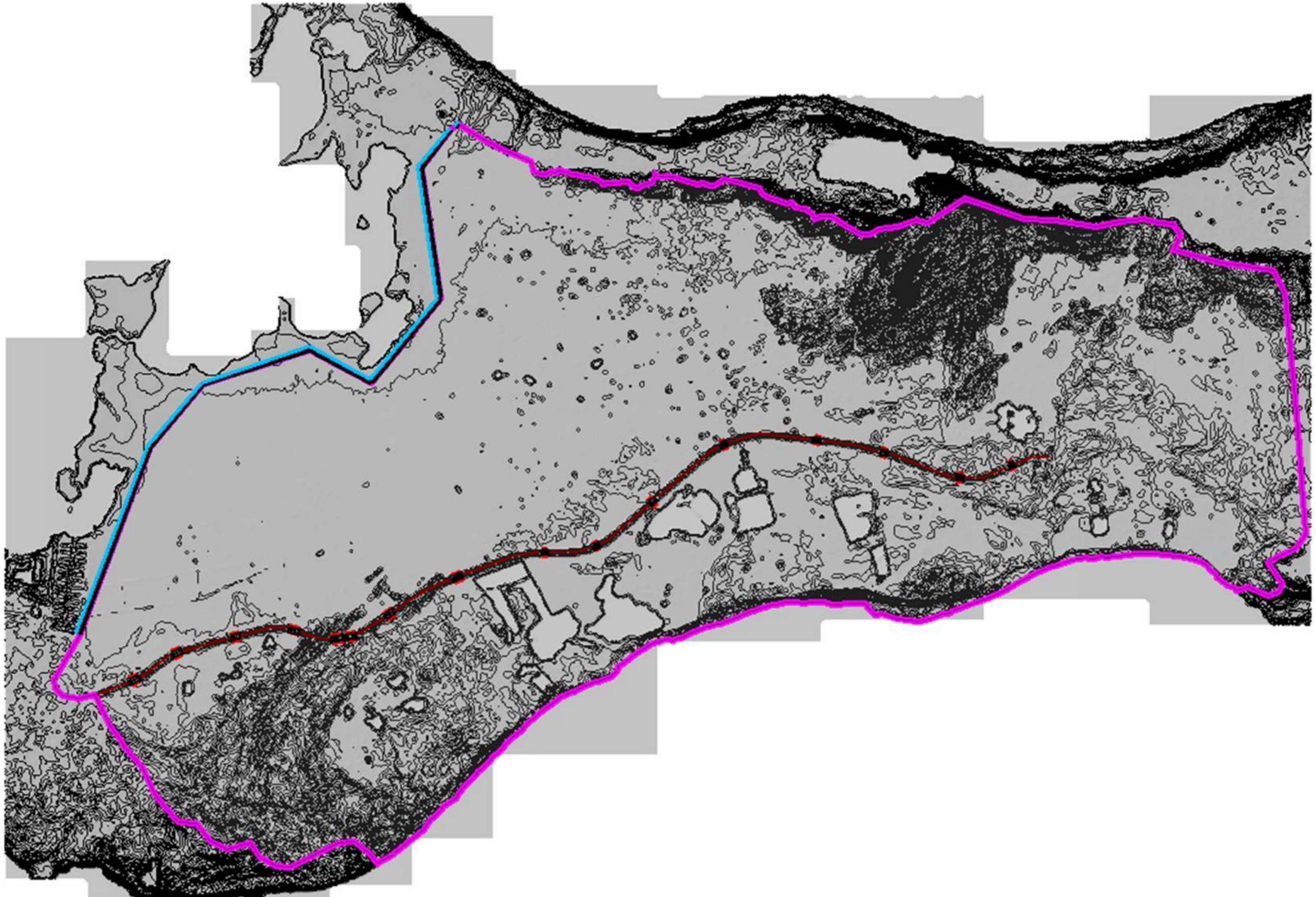
Profile B2-17

With Sea Rise

From N to S

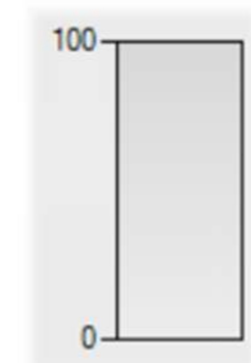


Appendix D – Alternate B3



Alternative B3

Original Terrain



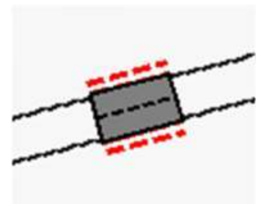
Alternate B1

Legend

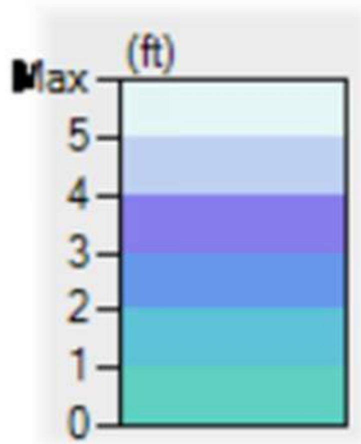
Terrain
Elevation
FT

Boundary
Condition
(Blue/Black)
Perimeter
(Magenta)

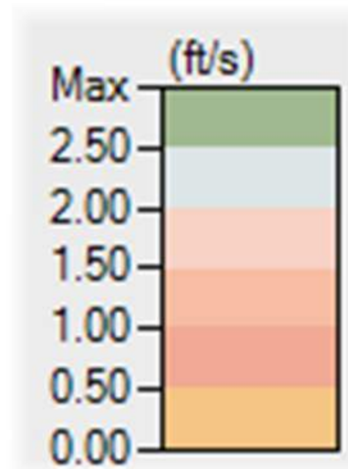
Bridge



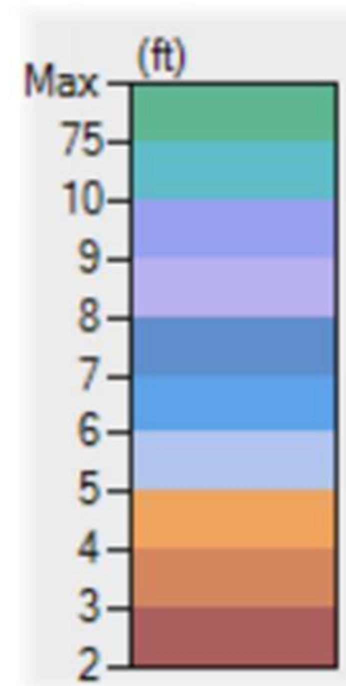
Runoff Depth
FT

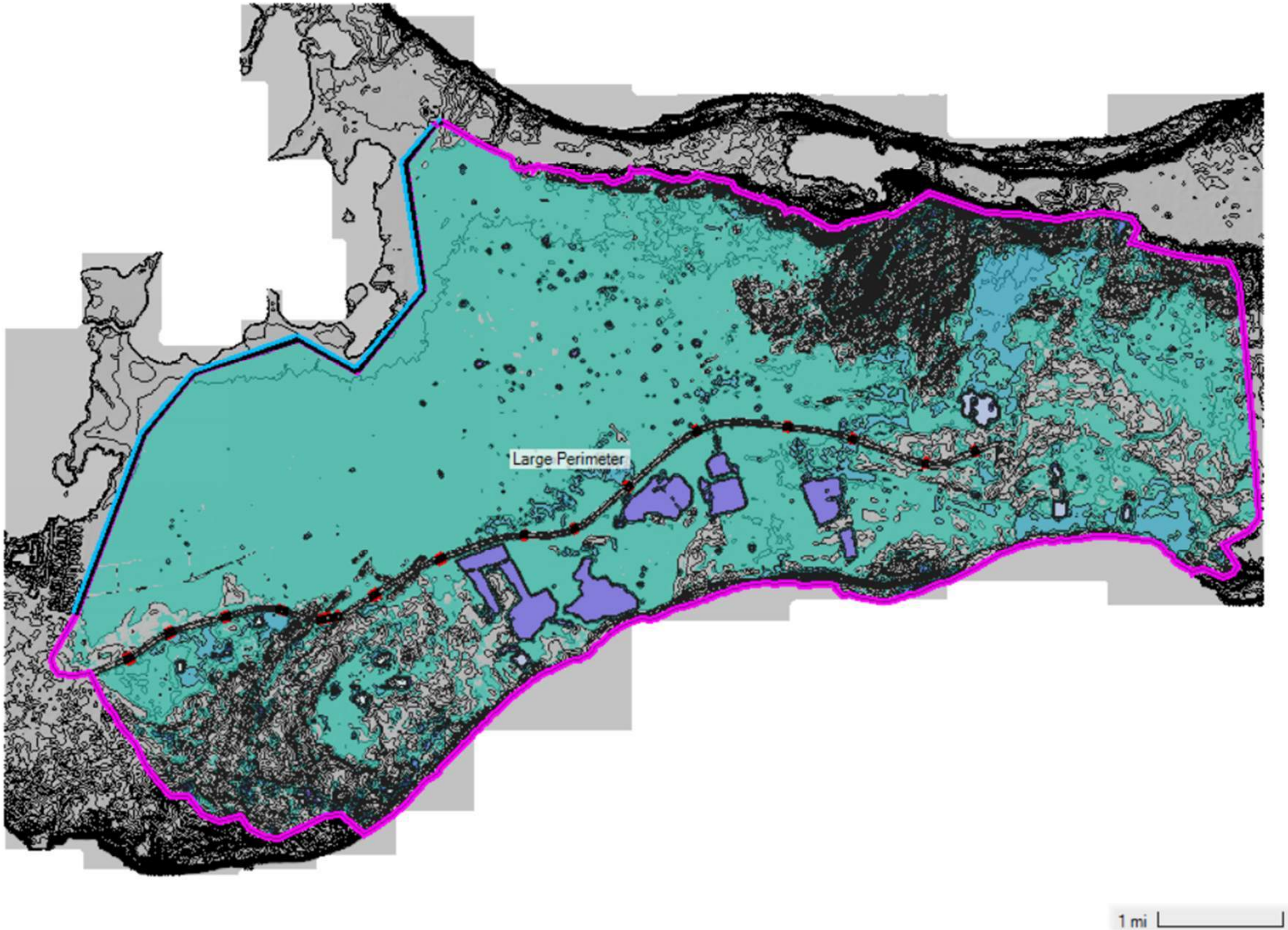


Velocity
FT/SEC



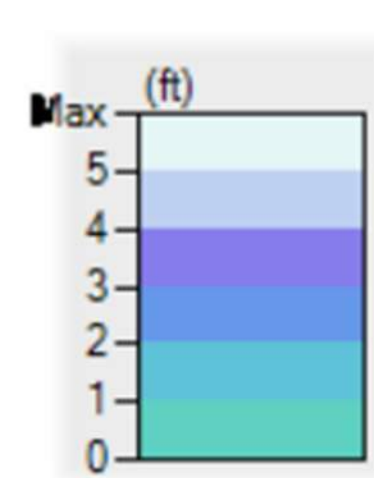
Water Surface
Elevation
FT





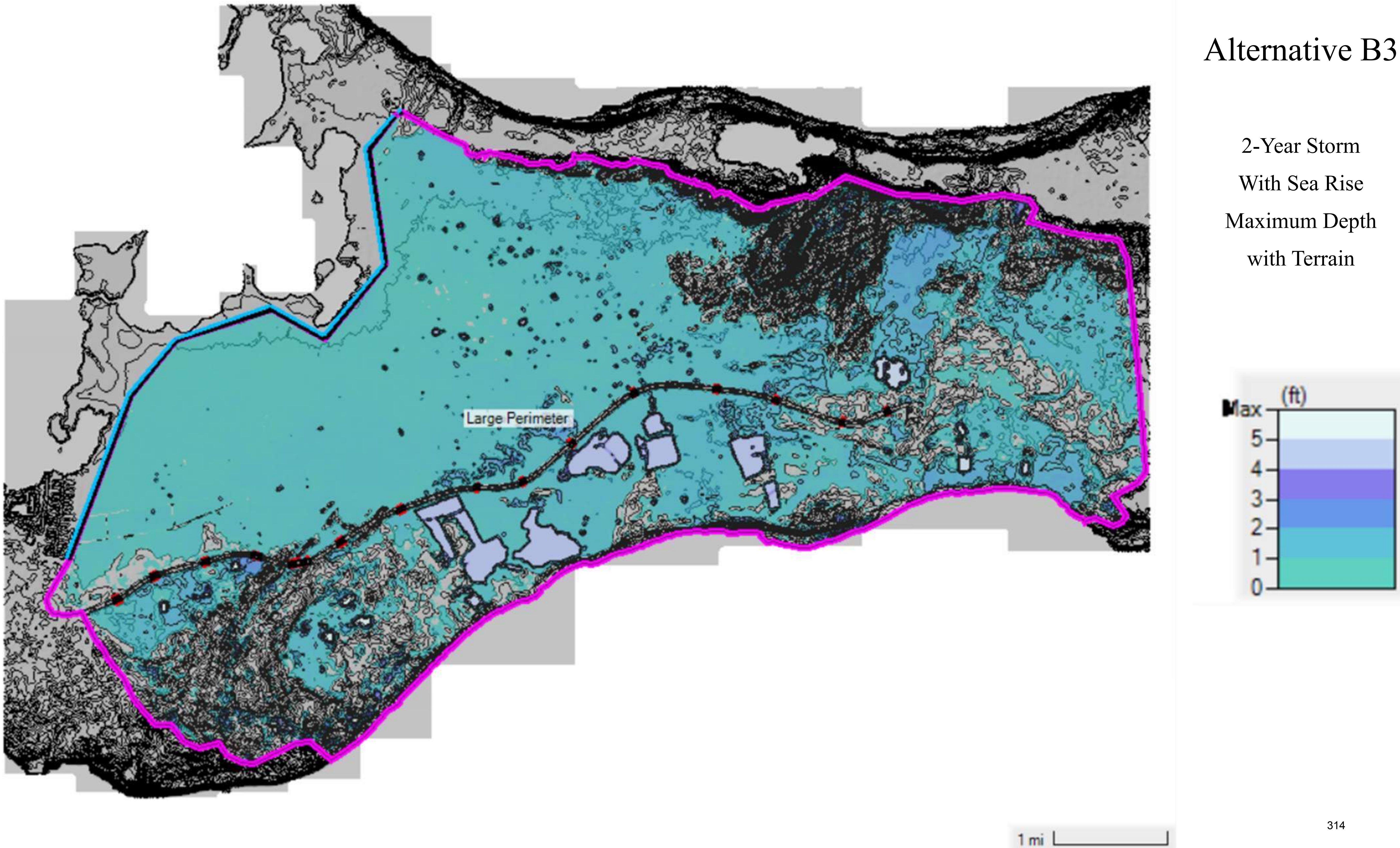
Alternative B3

2-Year Storm
Maximum Depth
with Terrain



Alternative B3

2-Year Storm
With Sea Rise
Maximum Depth
with Terrain

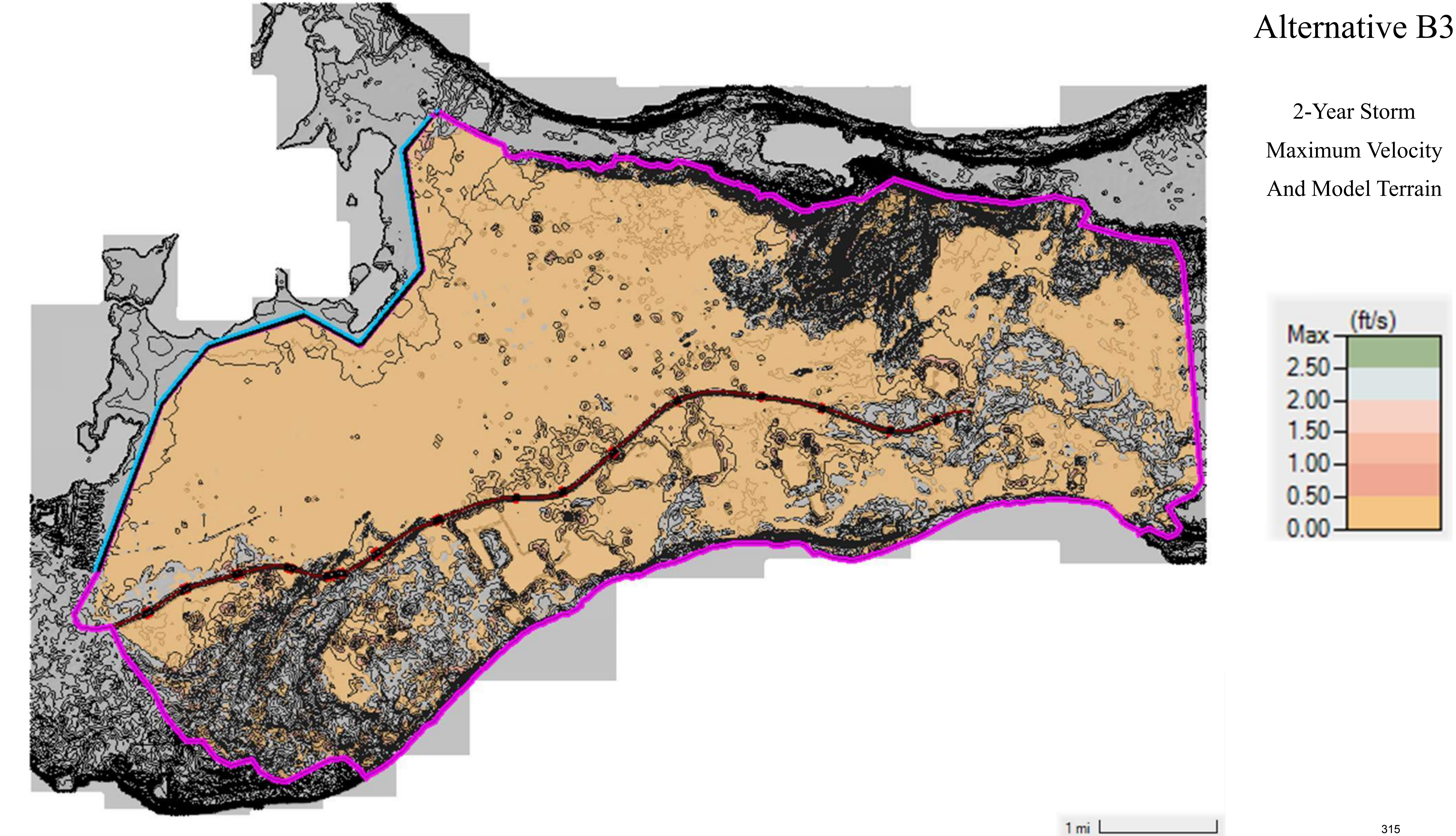


Alternative B3

2-Year Storm

Maximum Velocity

And Model Terrain



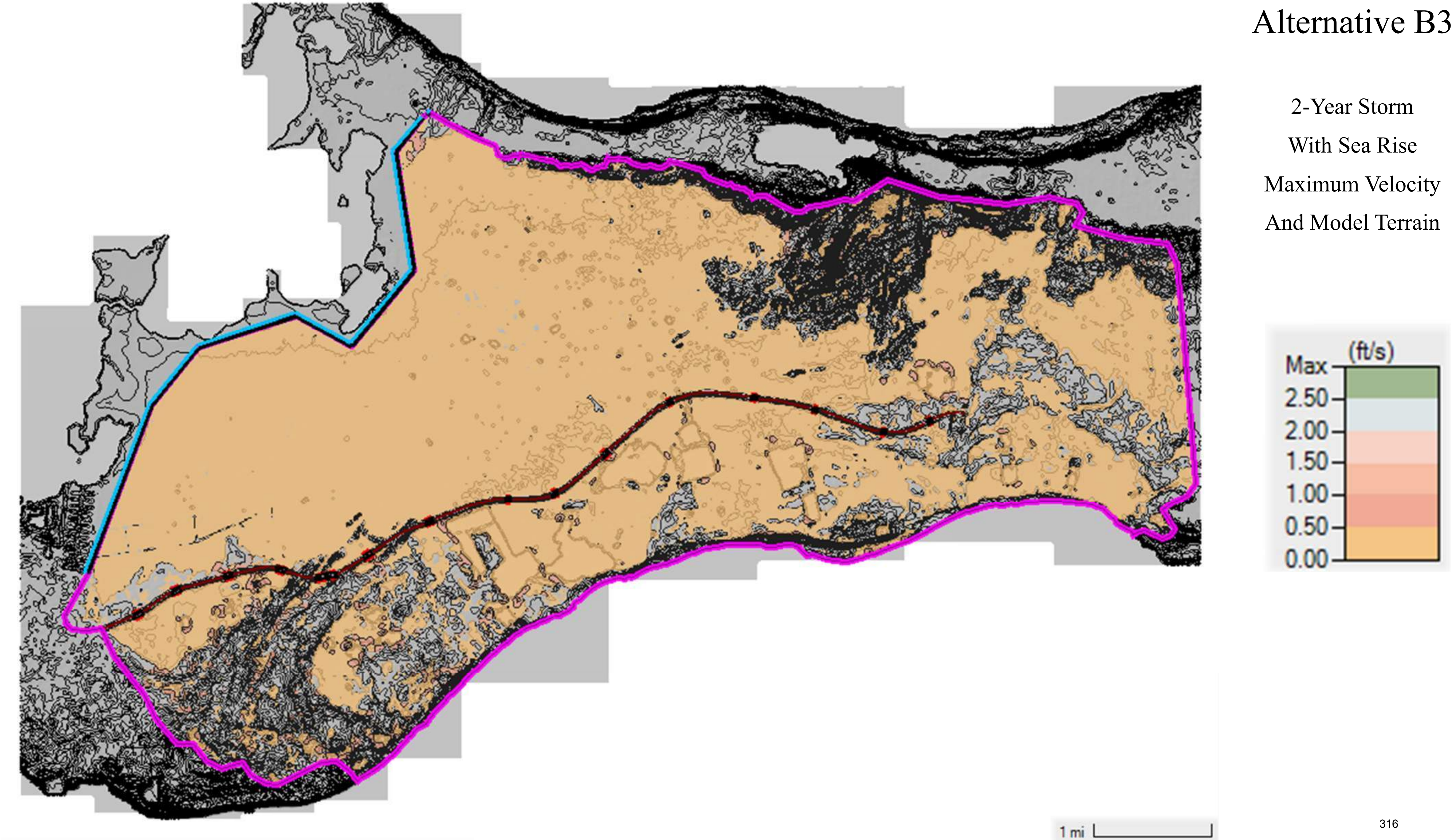
Alternative B3

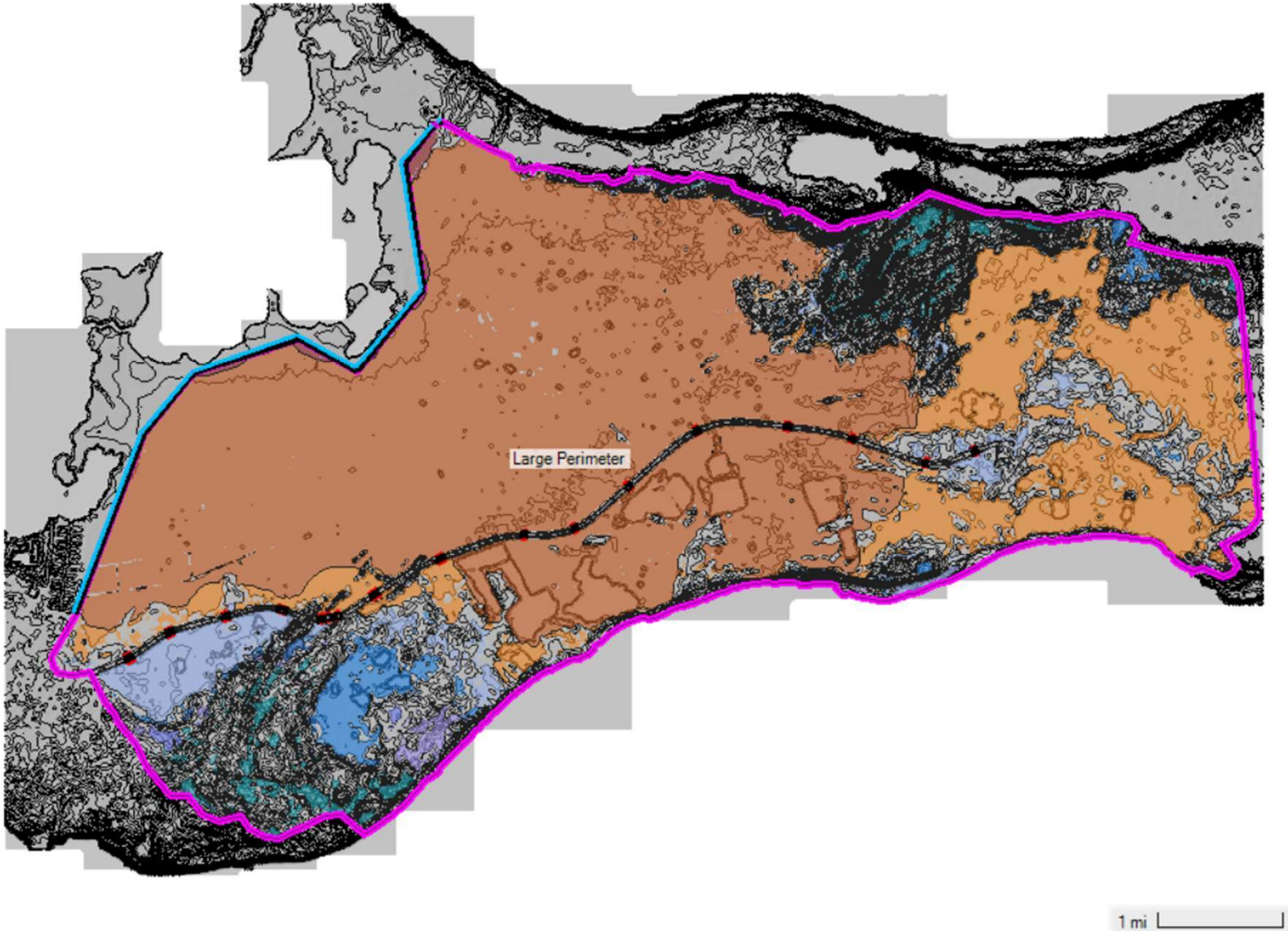
2-Year Storm

With Sea Rise

Maximum Velocity

And Model Terrain



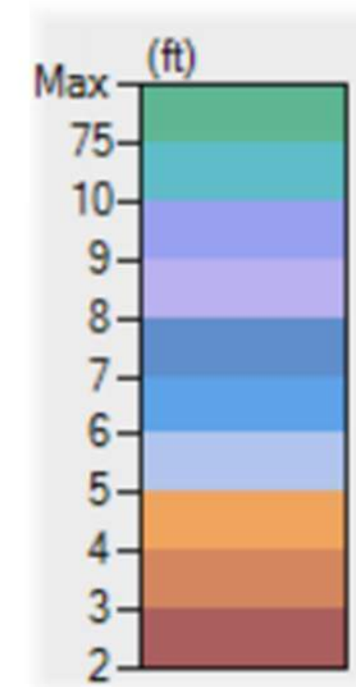


Alternative B3

2-Year Storm

Maximum Water Surface

Elevation and Model Terrain



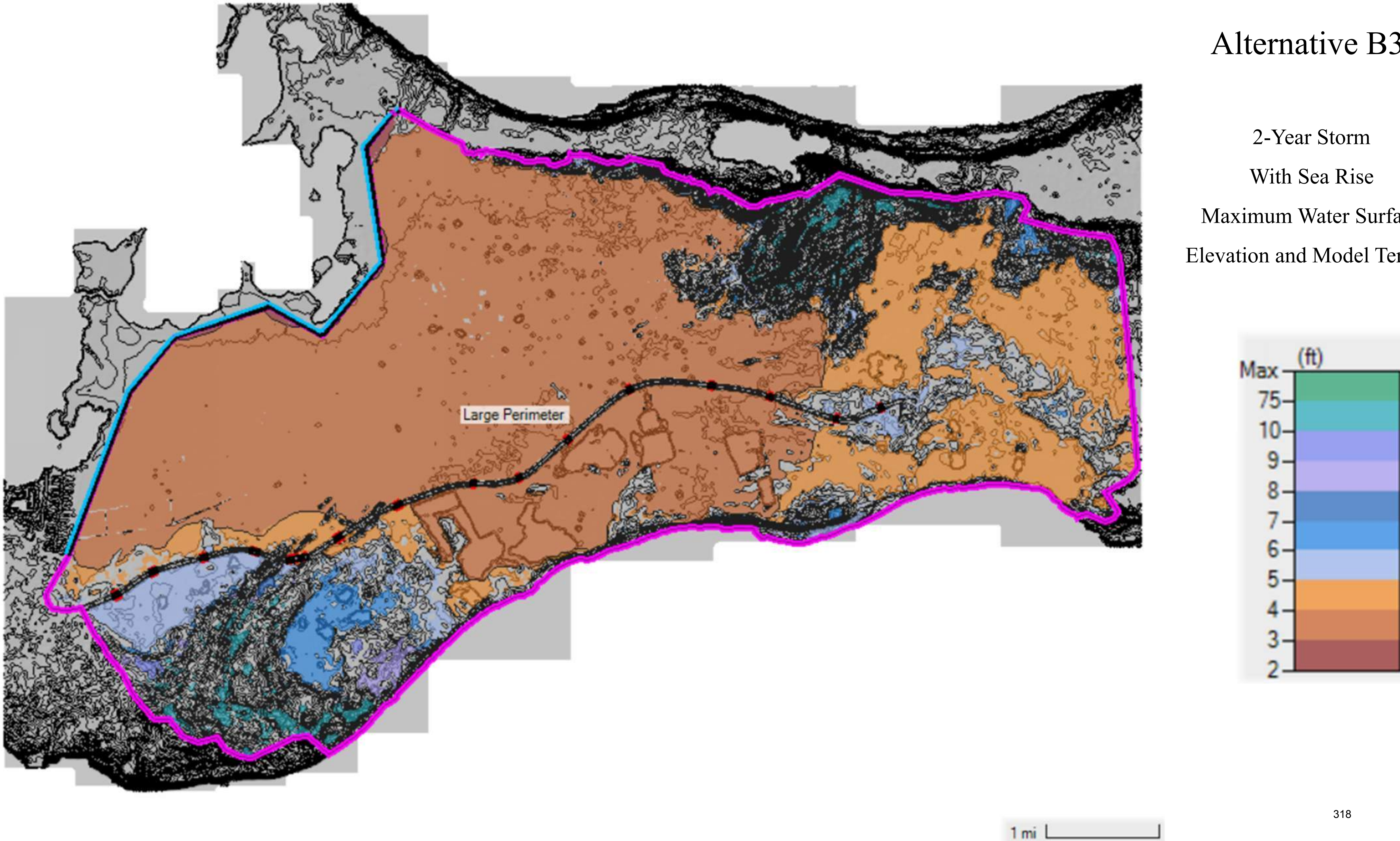
Alternative B3

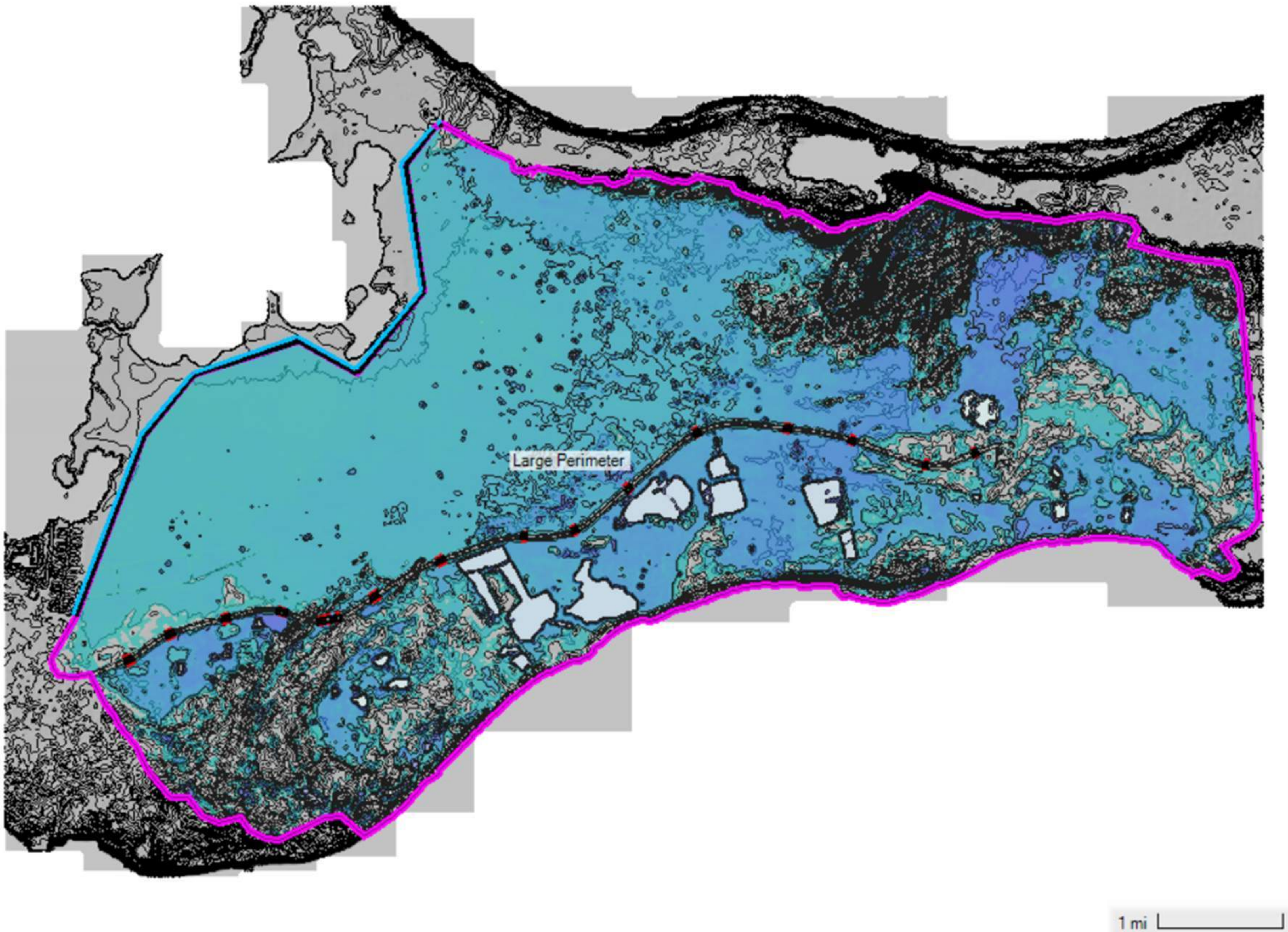
2-Year Storm

With Sea Rise

Maximum Water Surface

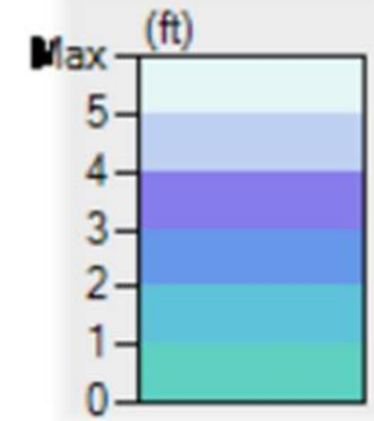
Elevation and Model Terrain

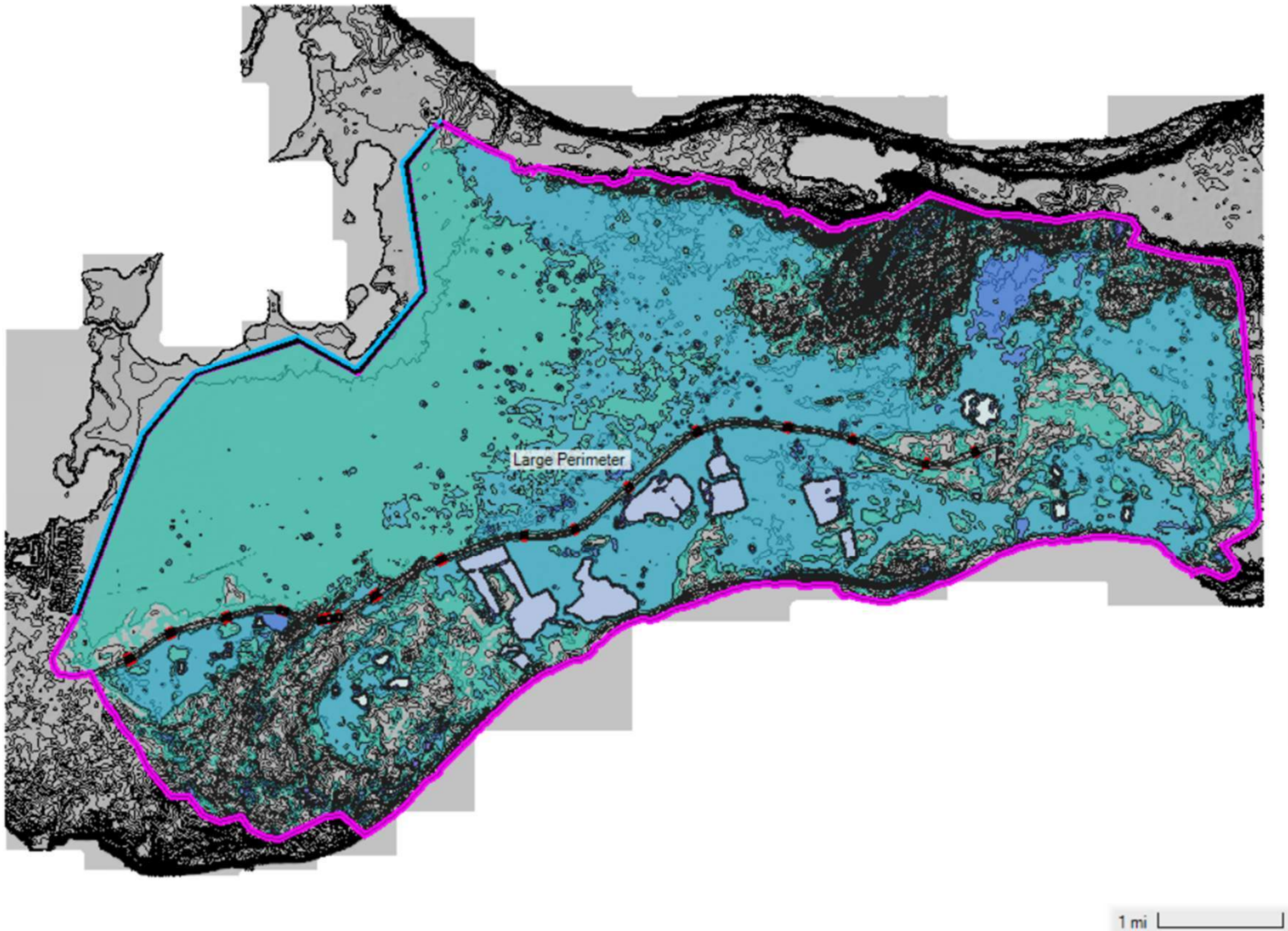




Alternative B3

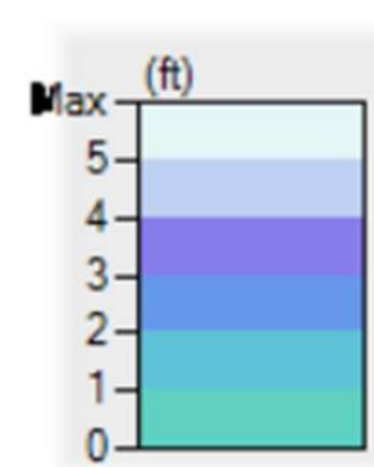
10-Year Storm
Maximum Depth
and Model Terrain





Alternative B3

10-Year Storm
With Sea Rise
Maximum Depth
and Model Terrain

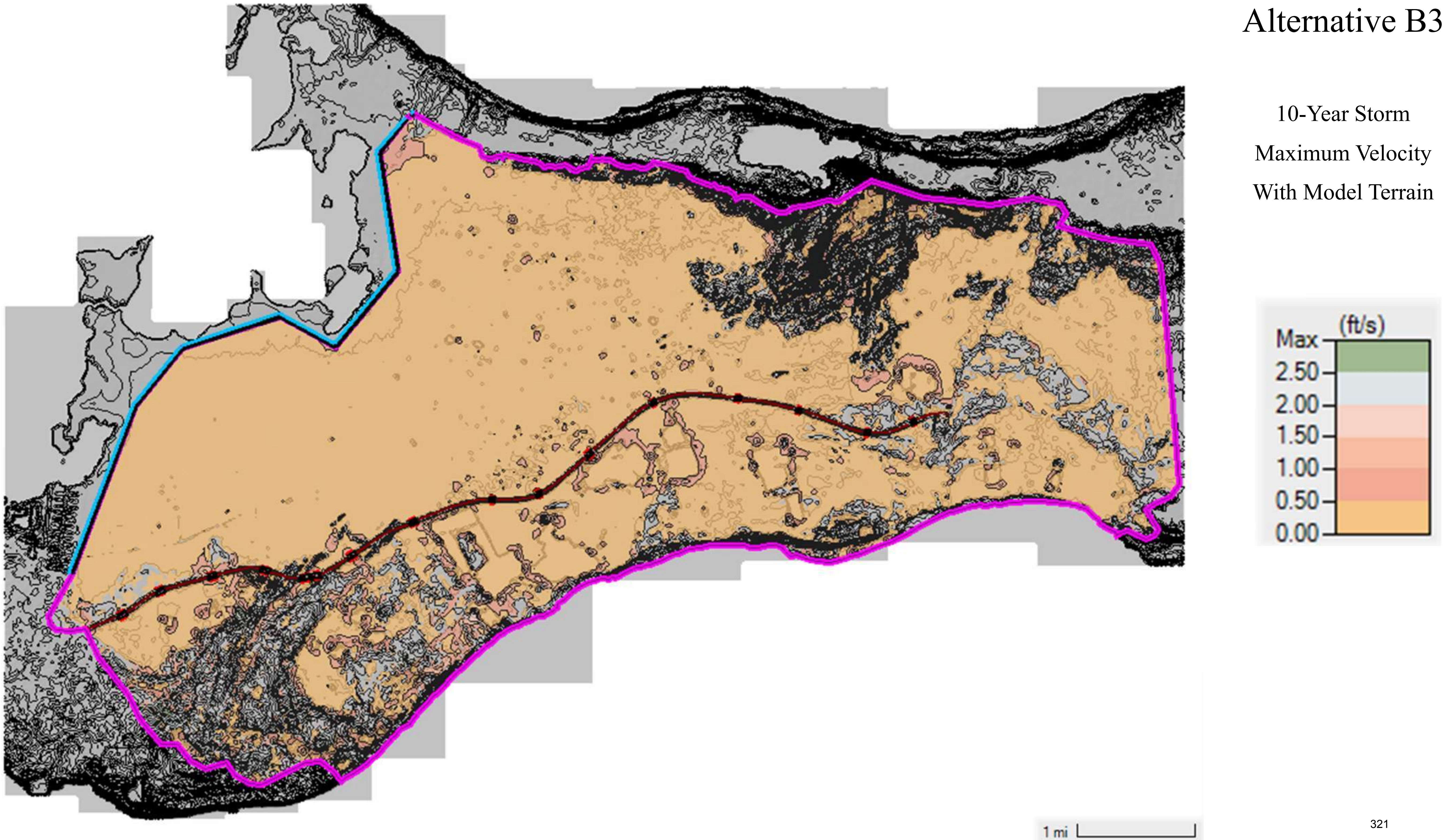


Alternative B3

10-Year Storm

Maximum Velocity

With Model Terrain



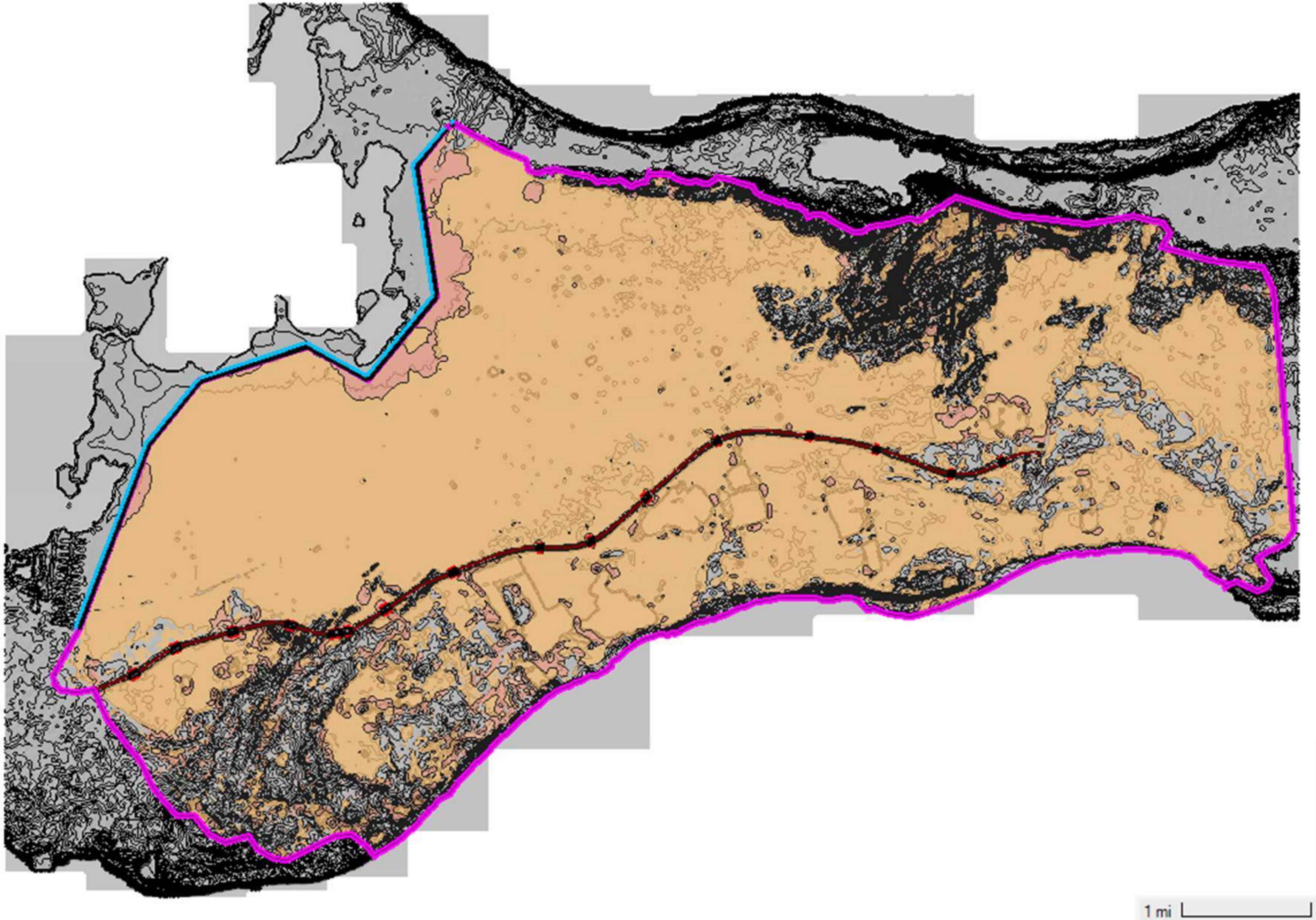
Alternative B3

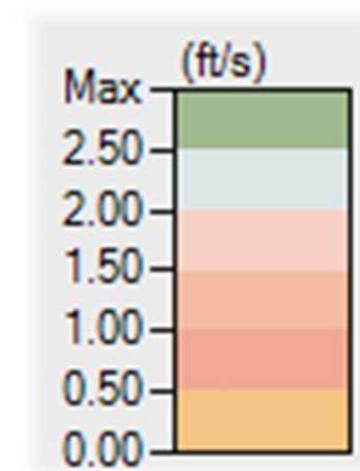
10-Year Storm

With Sea Rise

Maximum Velocity

With Model Terrain





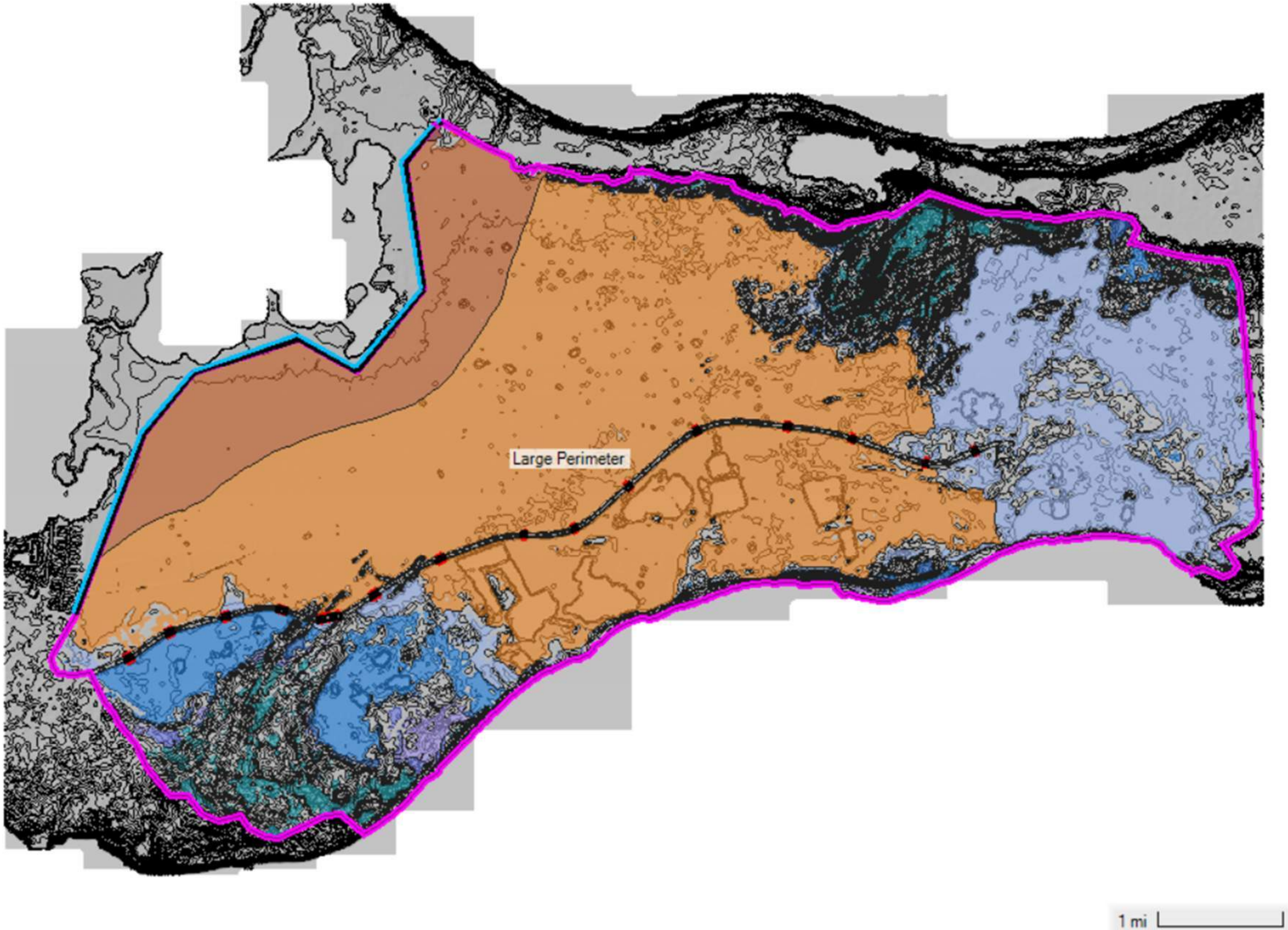
Alternative B3

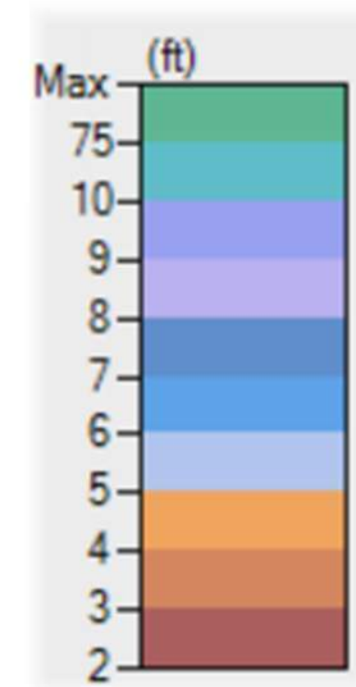
10-Year Storm

Maximum Water Surface

Elevations With Model

Terrain





Alternative B3

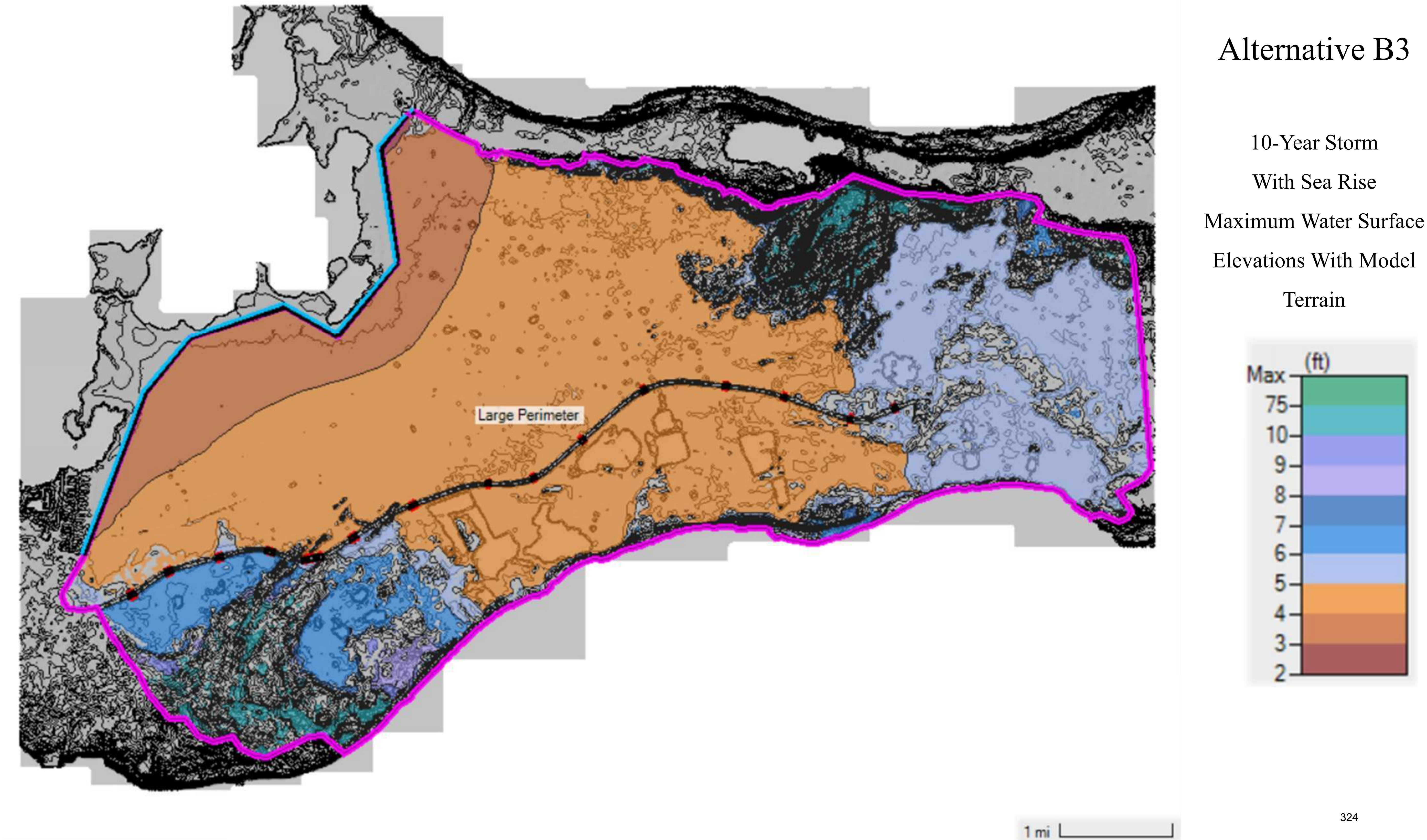
10-Year Storm

With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain

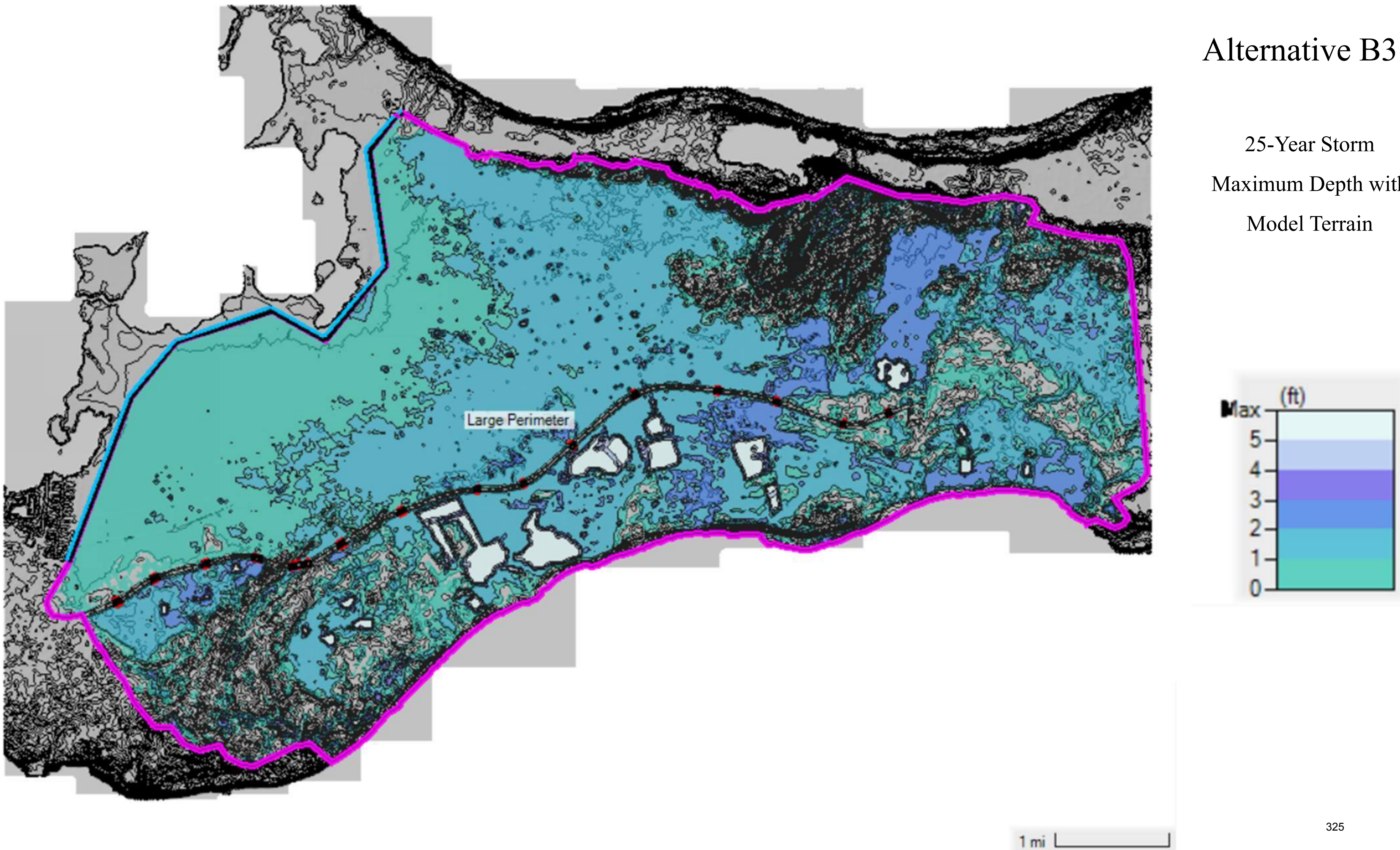


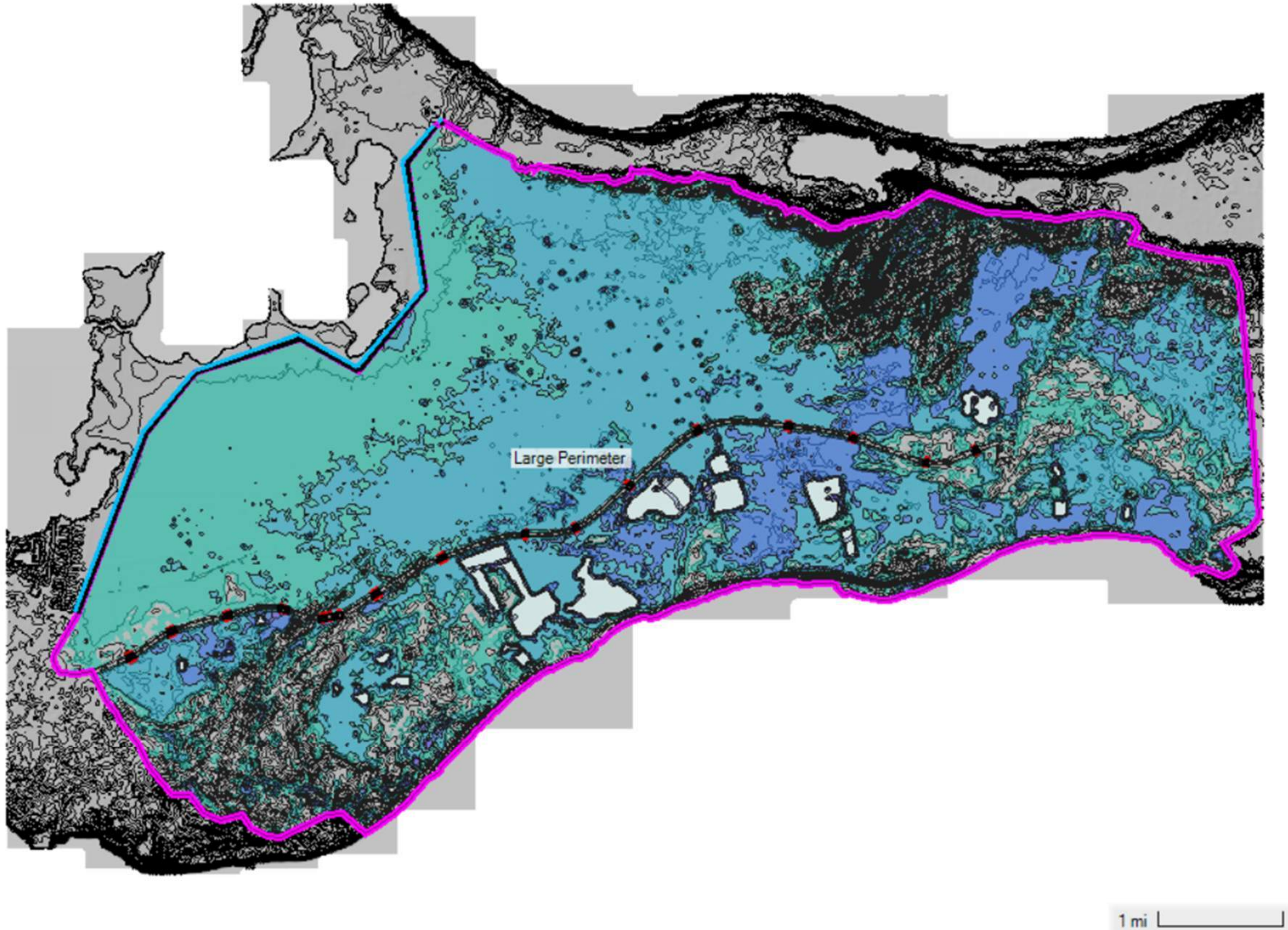
Alternative B3

25-Year Storm

Maximum Depth with

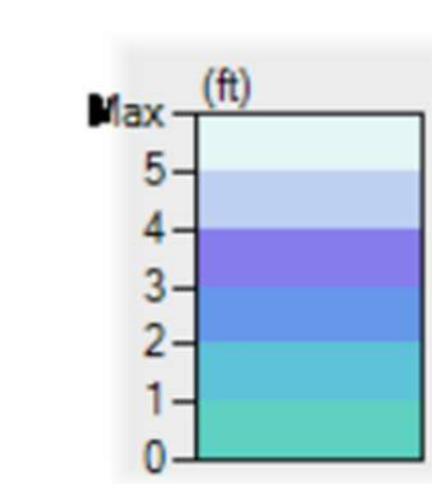
Model Terrain





Alternative B3

25-Year Storm
With Sea Rise
Maximum Depth with
Model Terrain

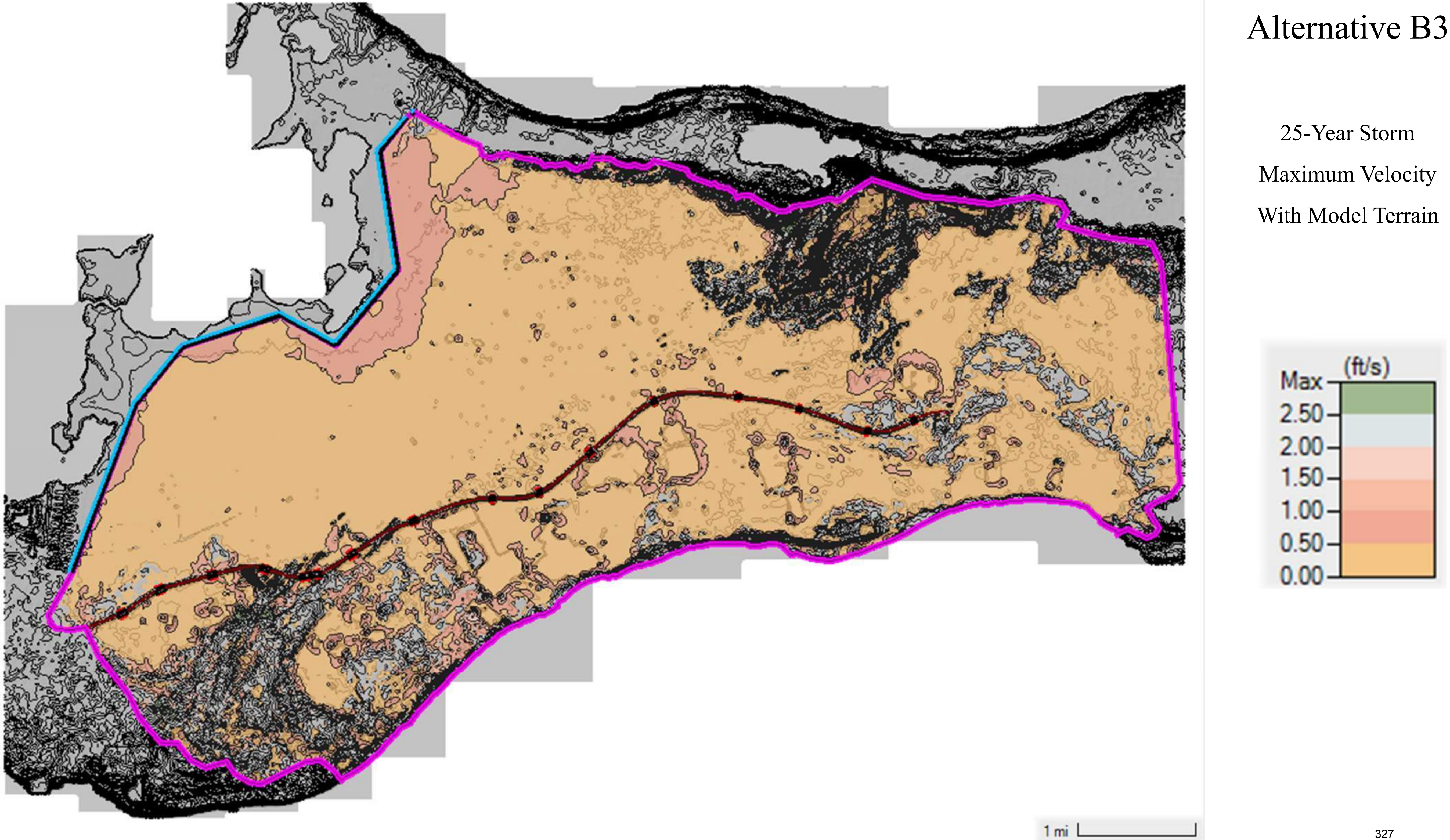


Alternative B3

25-Year Storm

Maximum Velocity

With Model Terrain



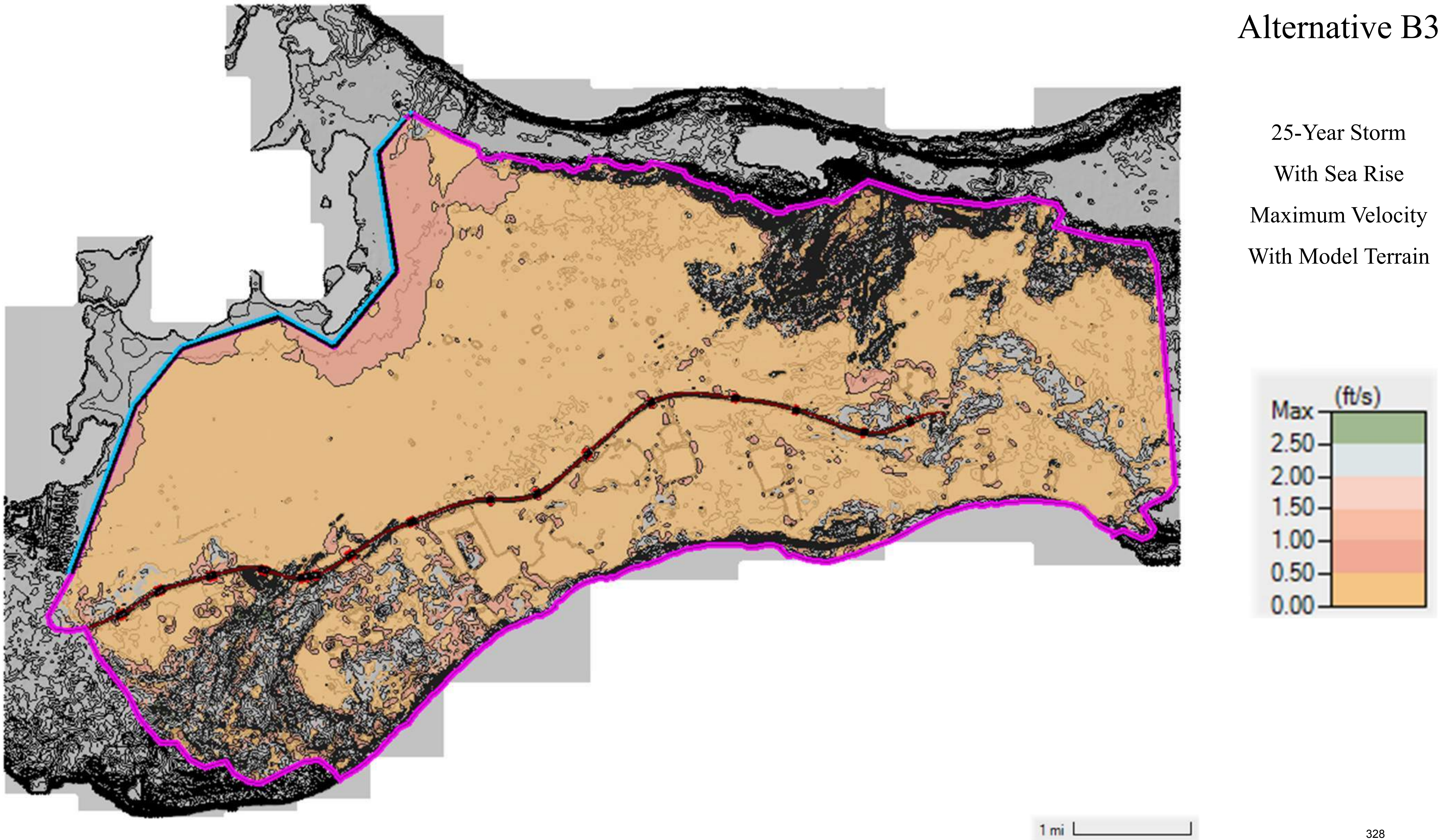
Alternative B3

25-Year Storm

With Sea Rise

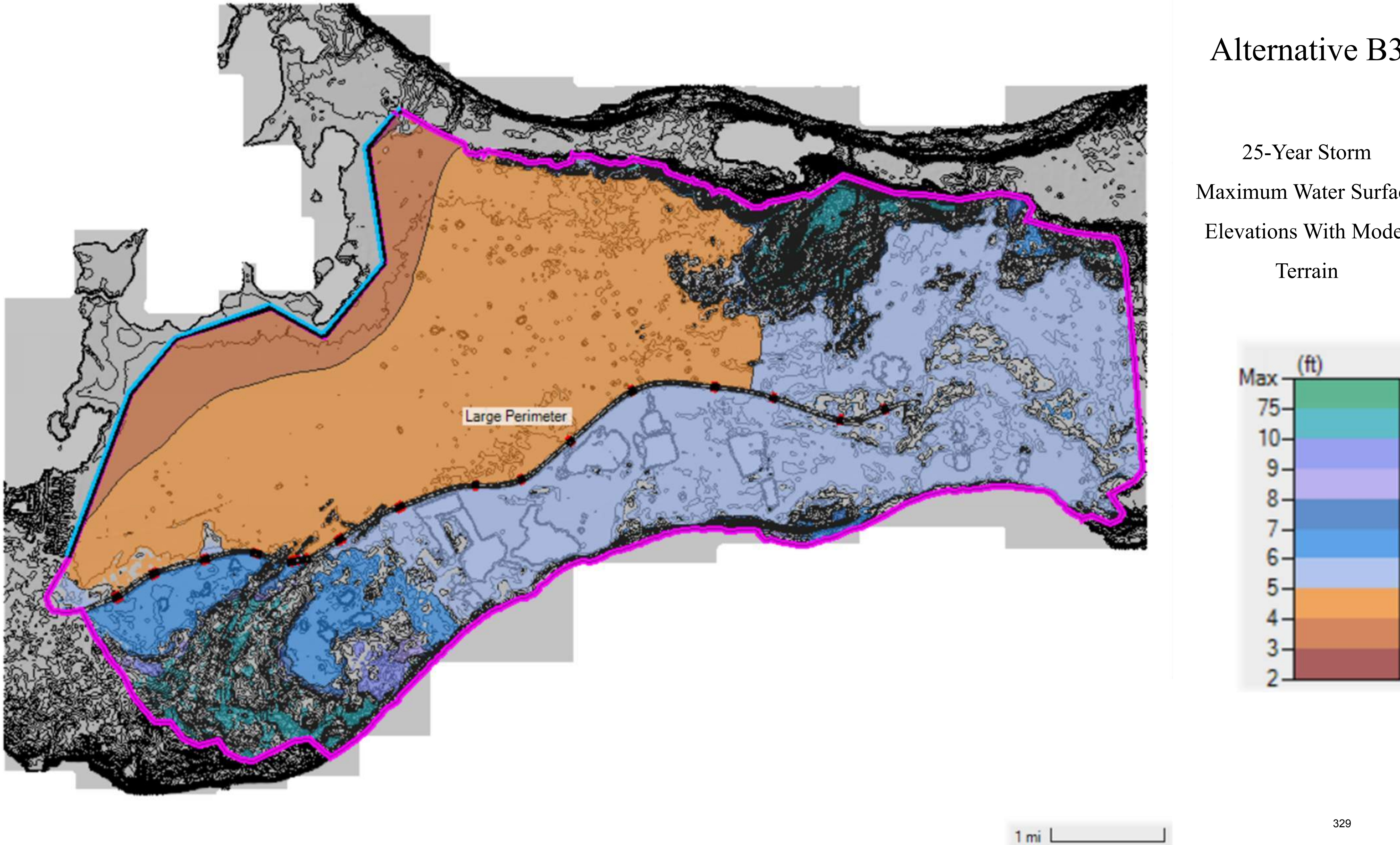
Maximum Velocity

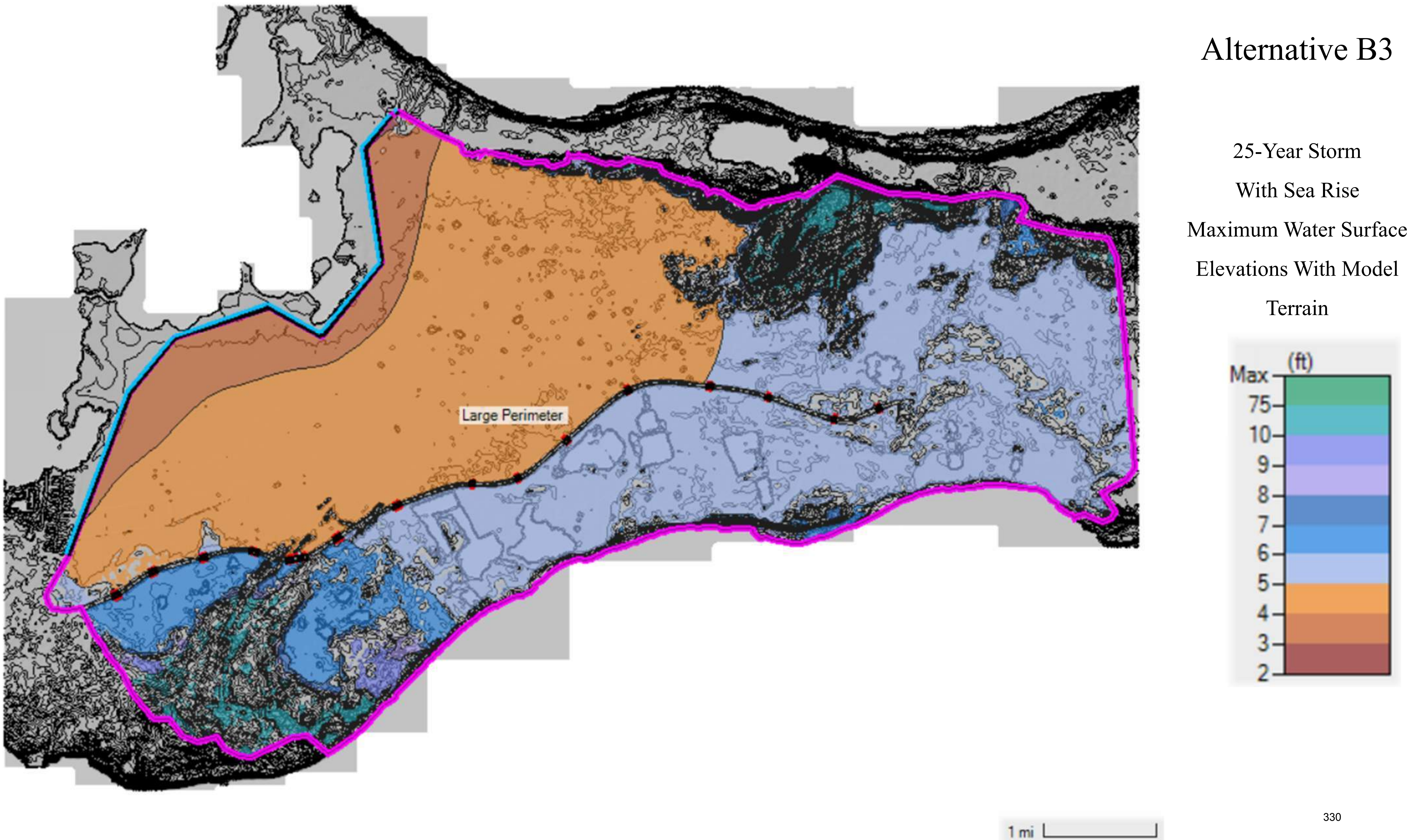
With Model Terrain



Alternative B3

25-Year Storm Maximum Water Surface Elevations With Model Terrain





Alternative B3

25-Year Storm

With Sea Rise

Maximum Water Surface

Elevations With Model

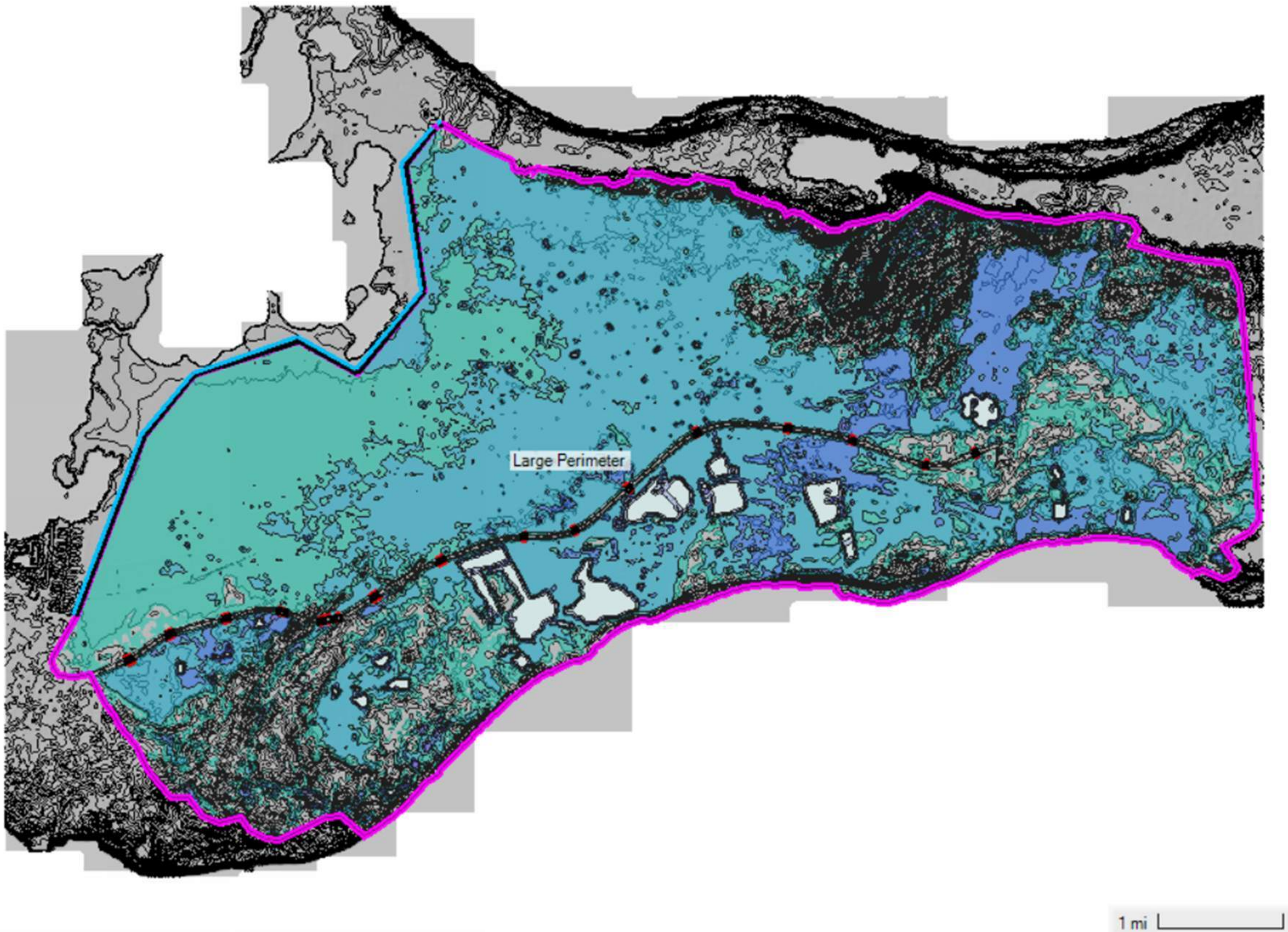
Terrain

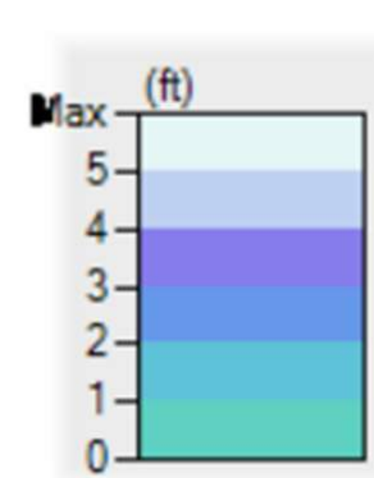
Alternative B3

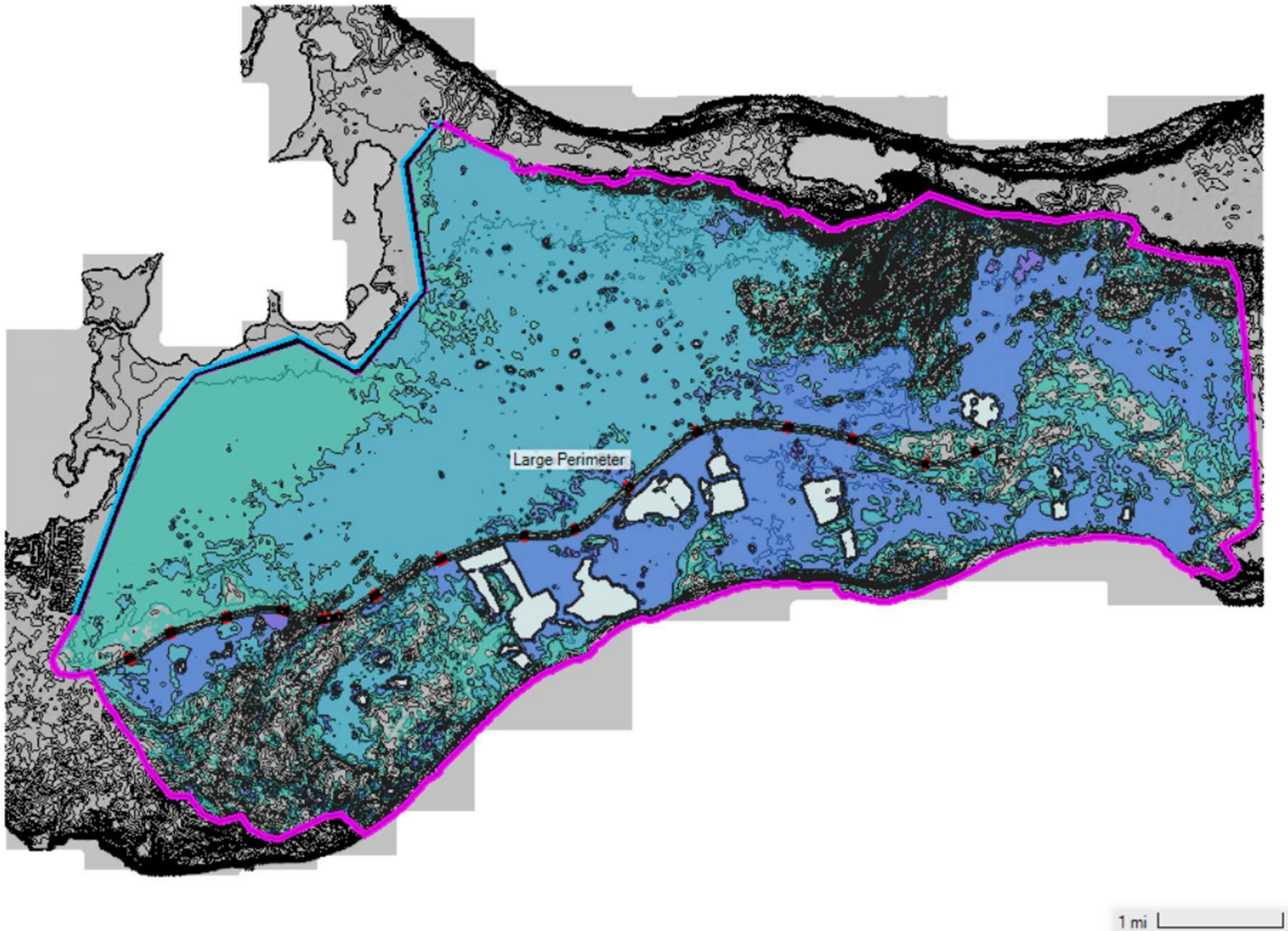
50-Year Storm

Maximum Depths With

Model Terrain







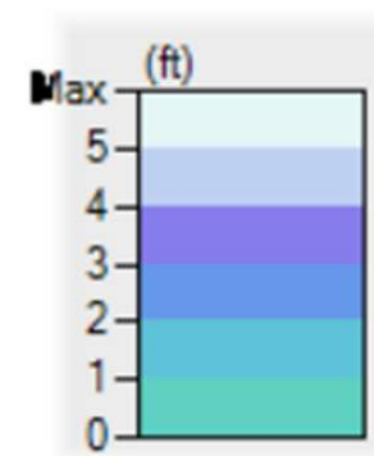
Alternative B3

50-Year Storm

With Sea Rise

Maximum Depths With

Model Terrain

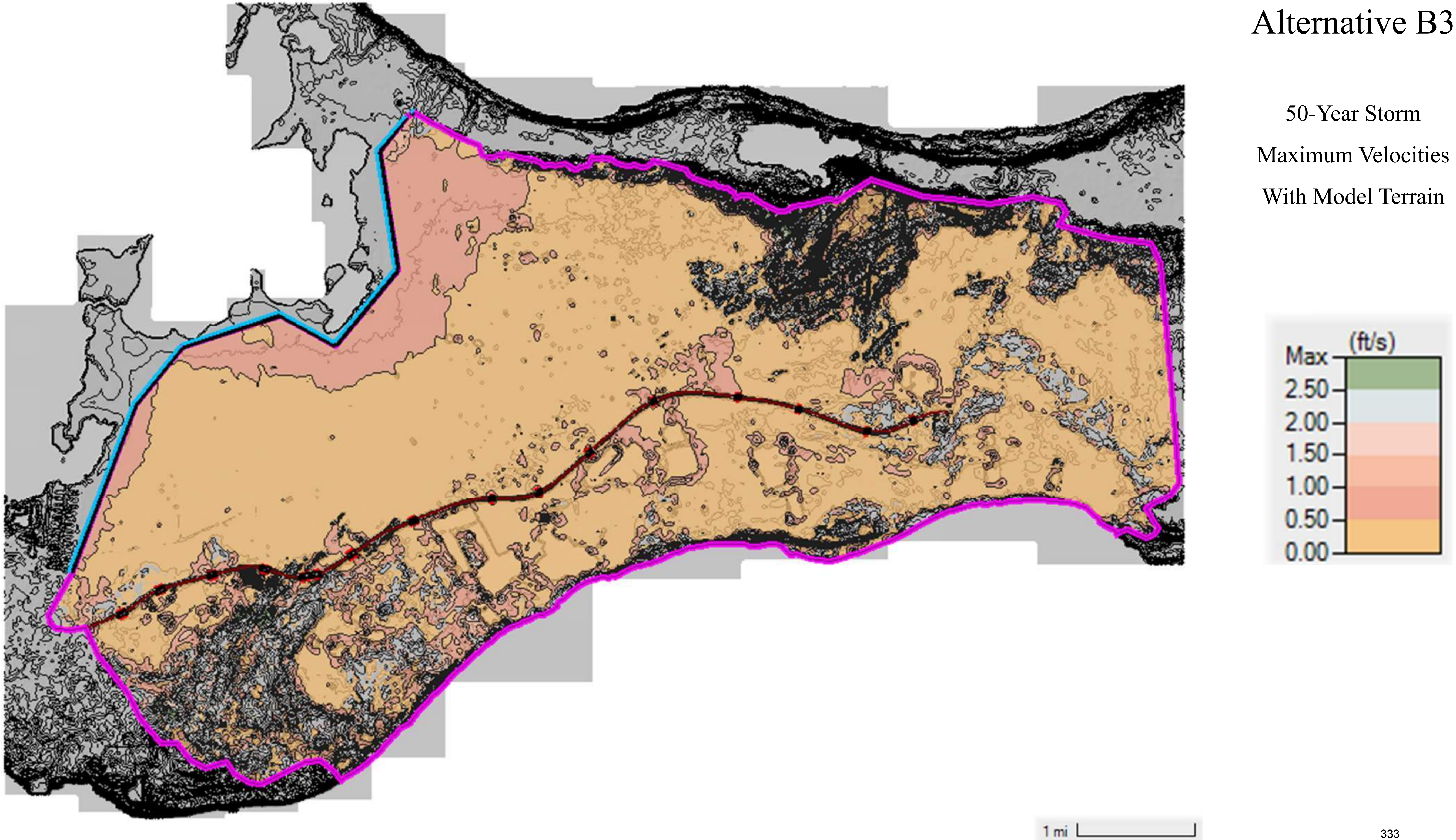


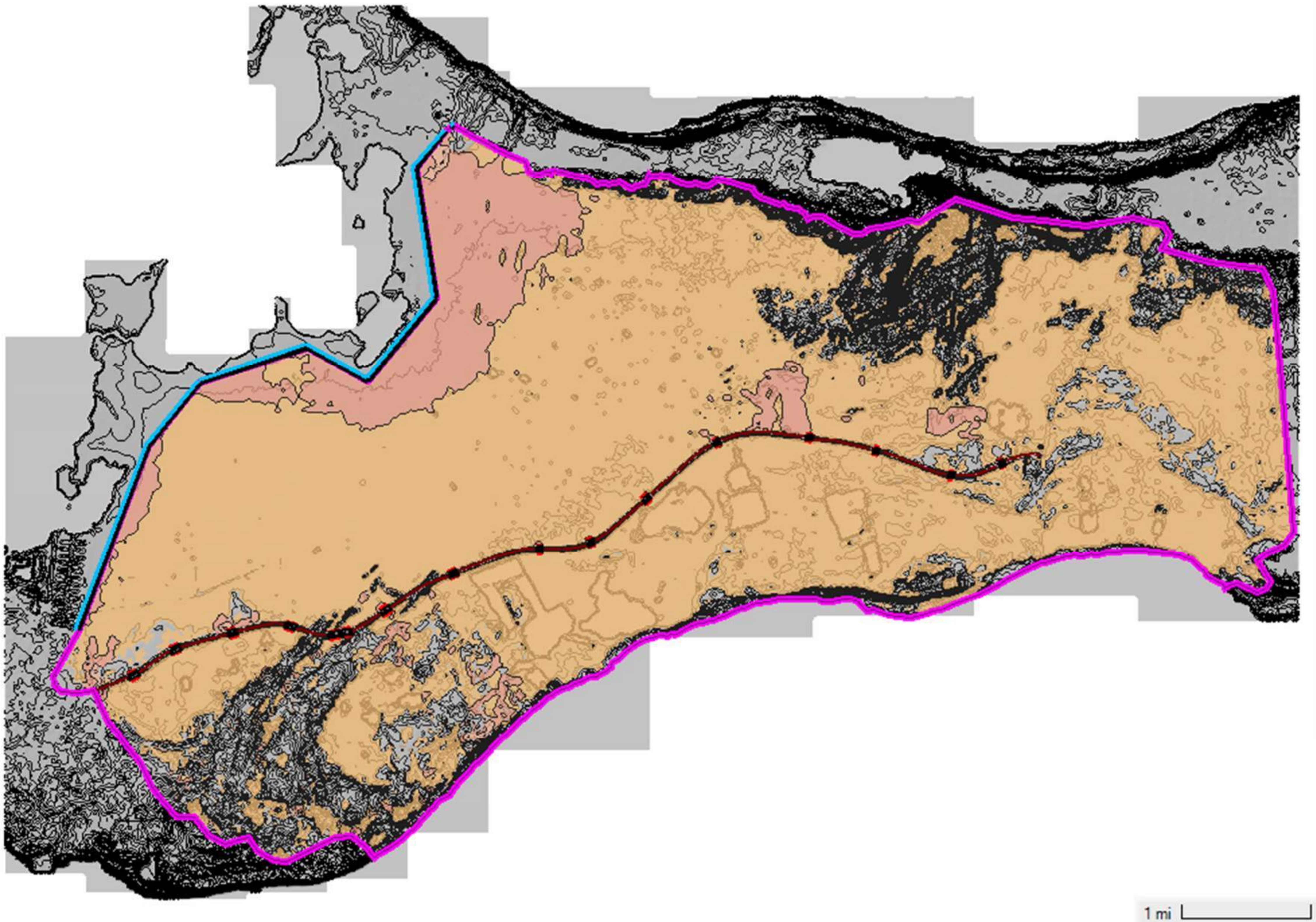
Alternative B3

50-Year Storm

Maximum Velocities

With Model Terrain





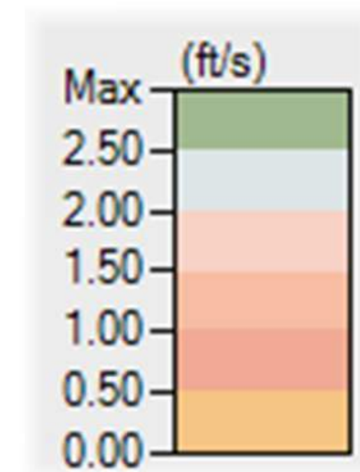
Alternative B3

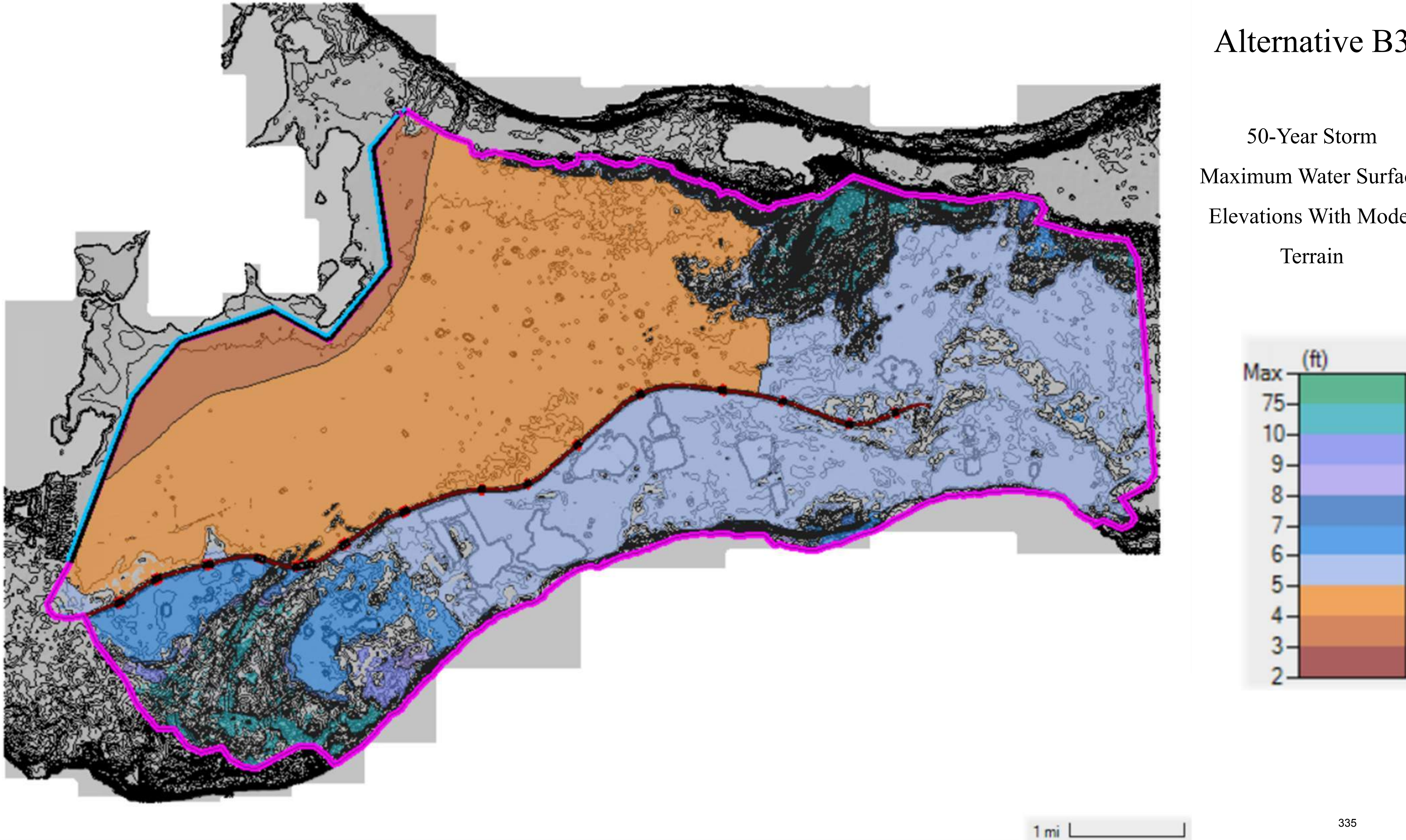
50-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain





Alternative B3

50-Year Storm

Maximum Water Surface Elevations With Model Terrain

Alternative B3

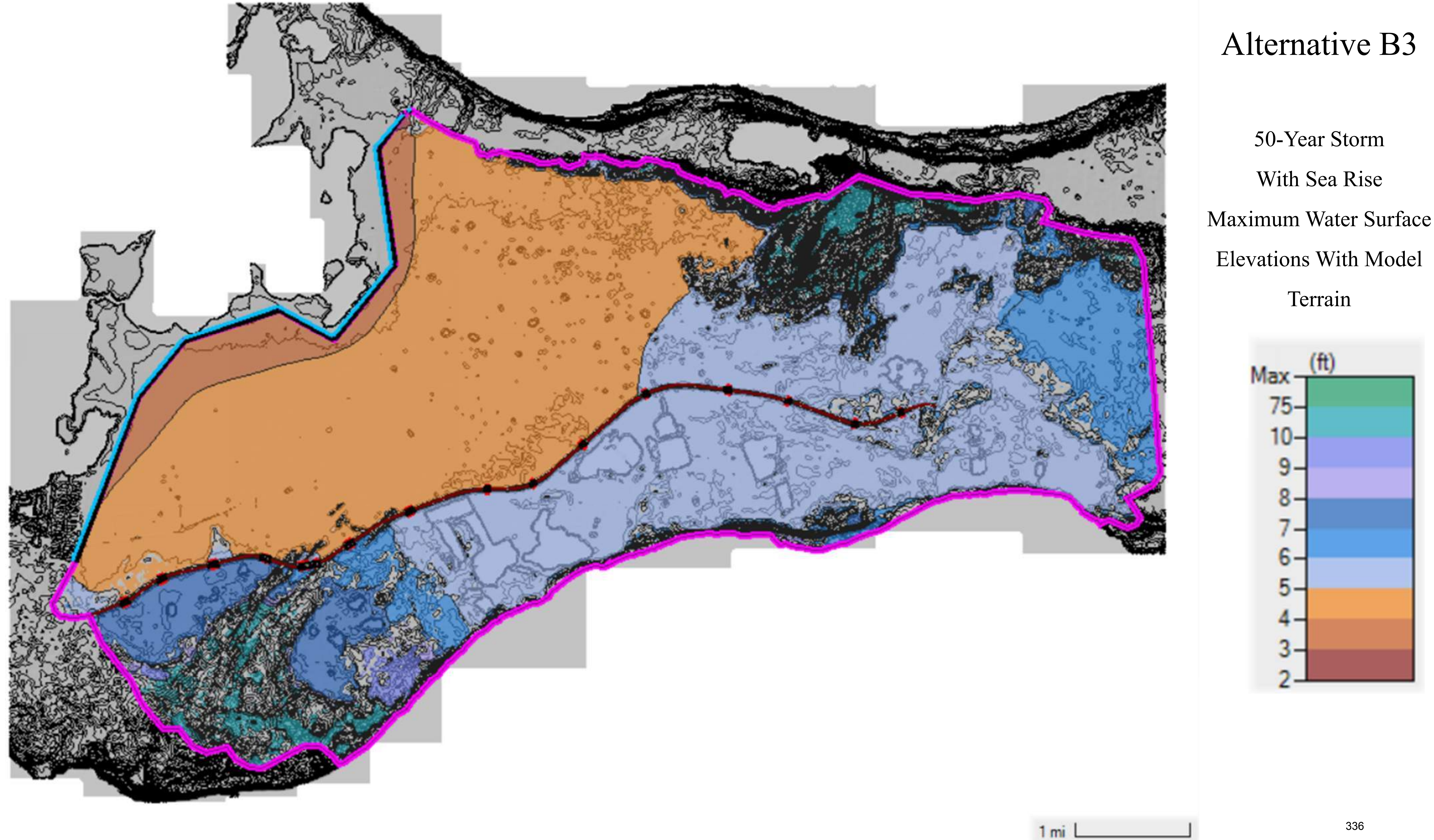
50-Year Storm

With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain

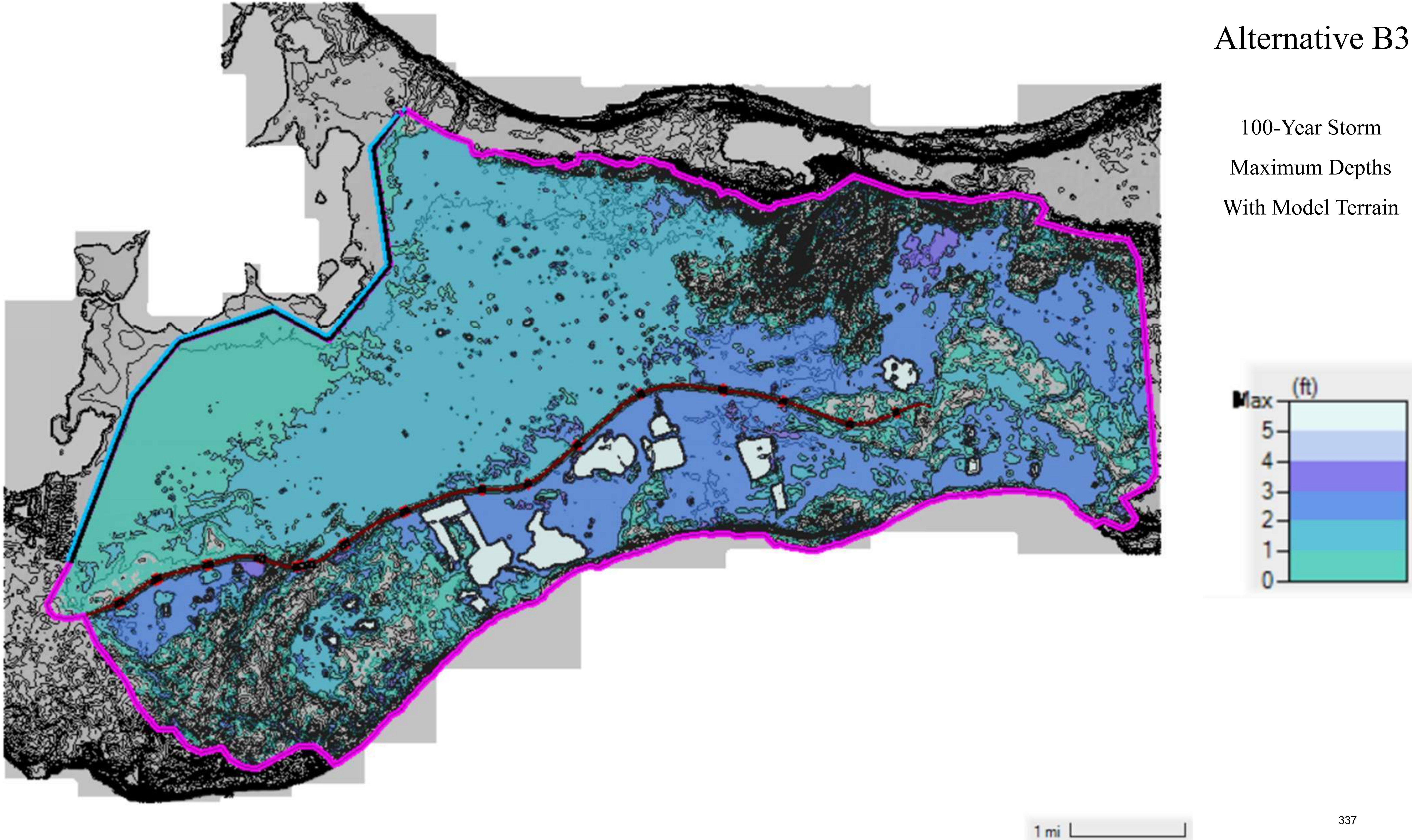


Alternative B3

100-Year Storm

Maximum Depths

With Model Terrain



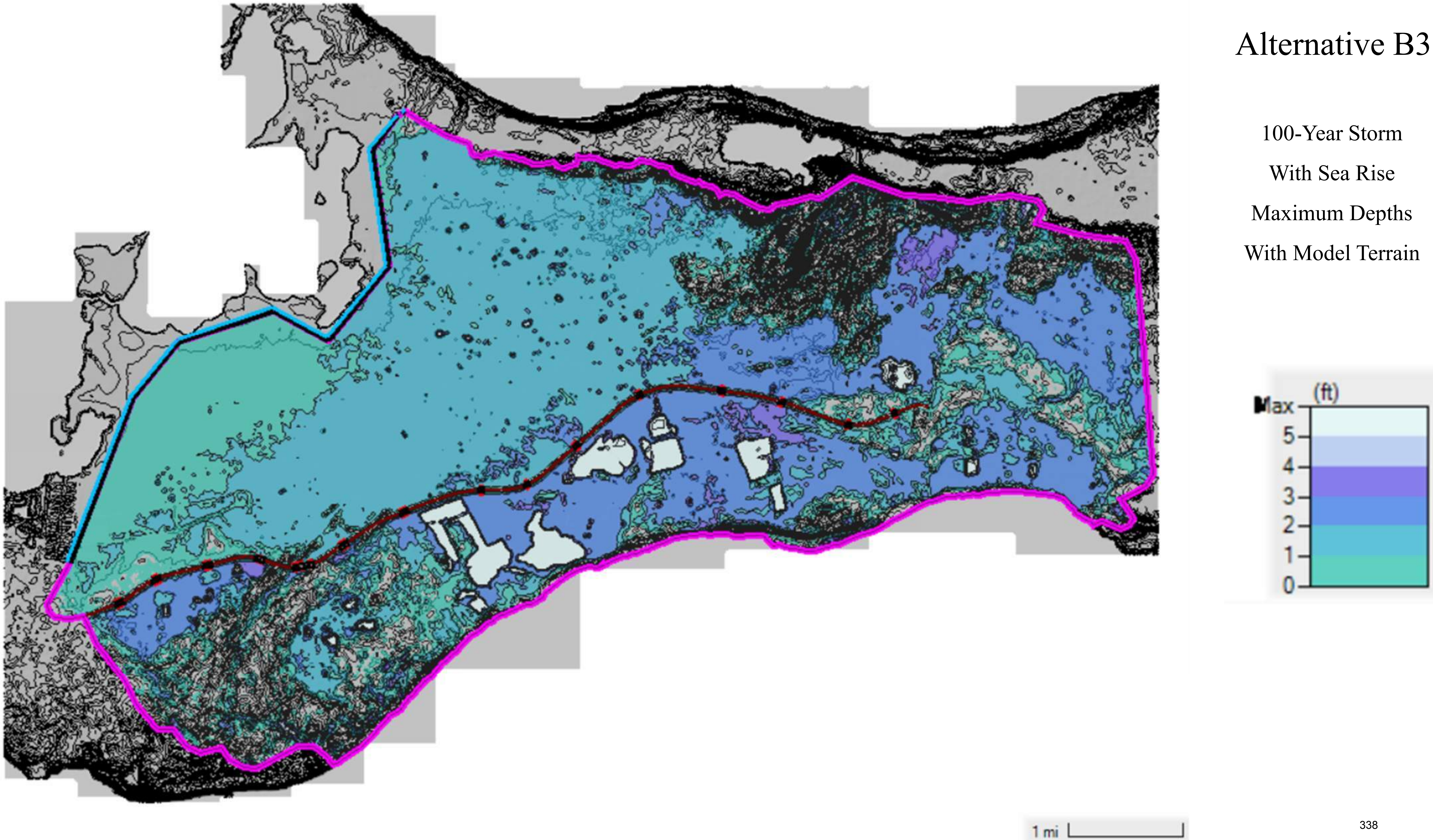
Alternative B3

100-Year Storm

With Sea Rise

Maximum Depths

With Model Terrain

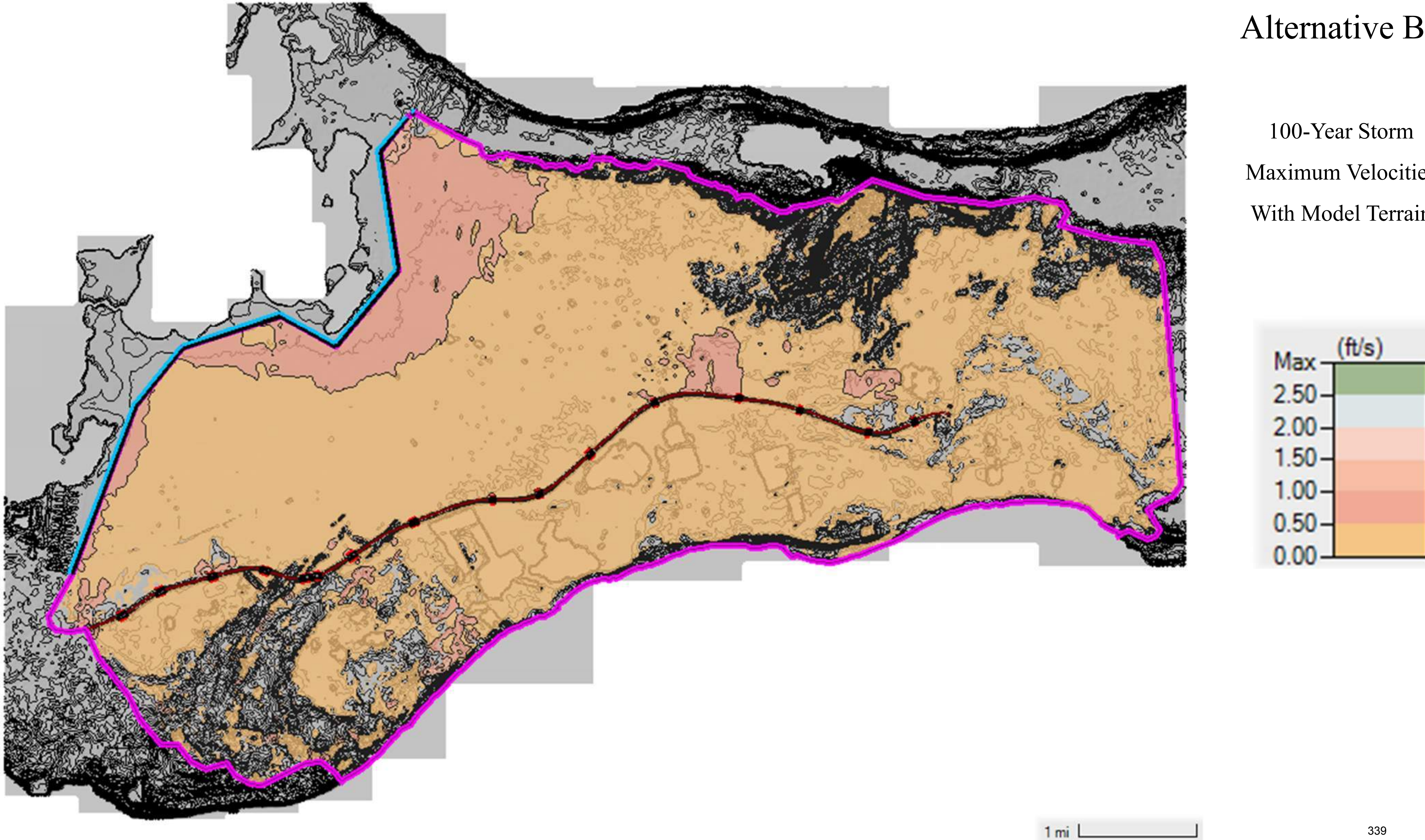


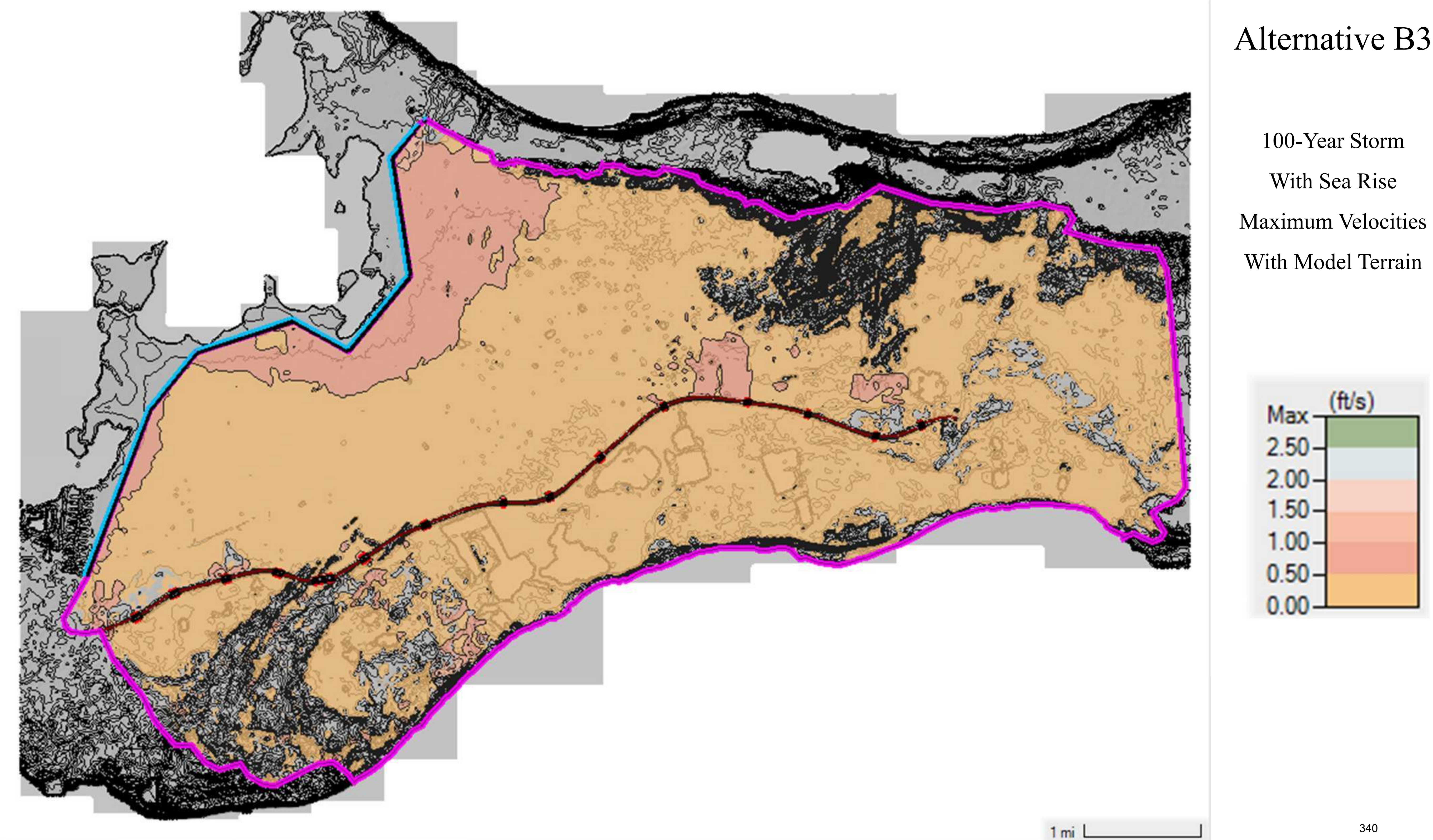
Alternative B3

100-Year Storm

Maximum Velocities

With Model Terrain





Alternative B3

100-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain

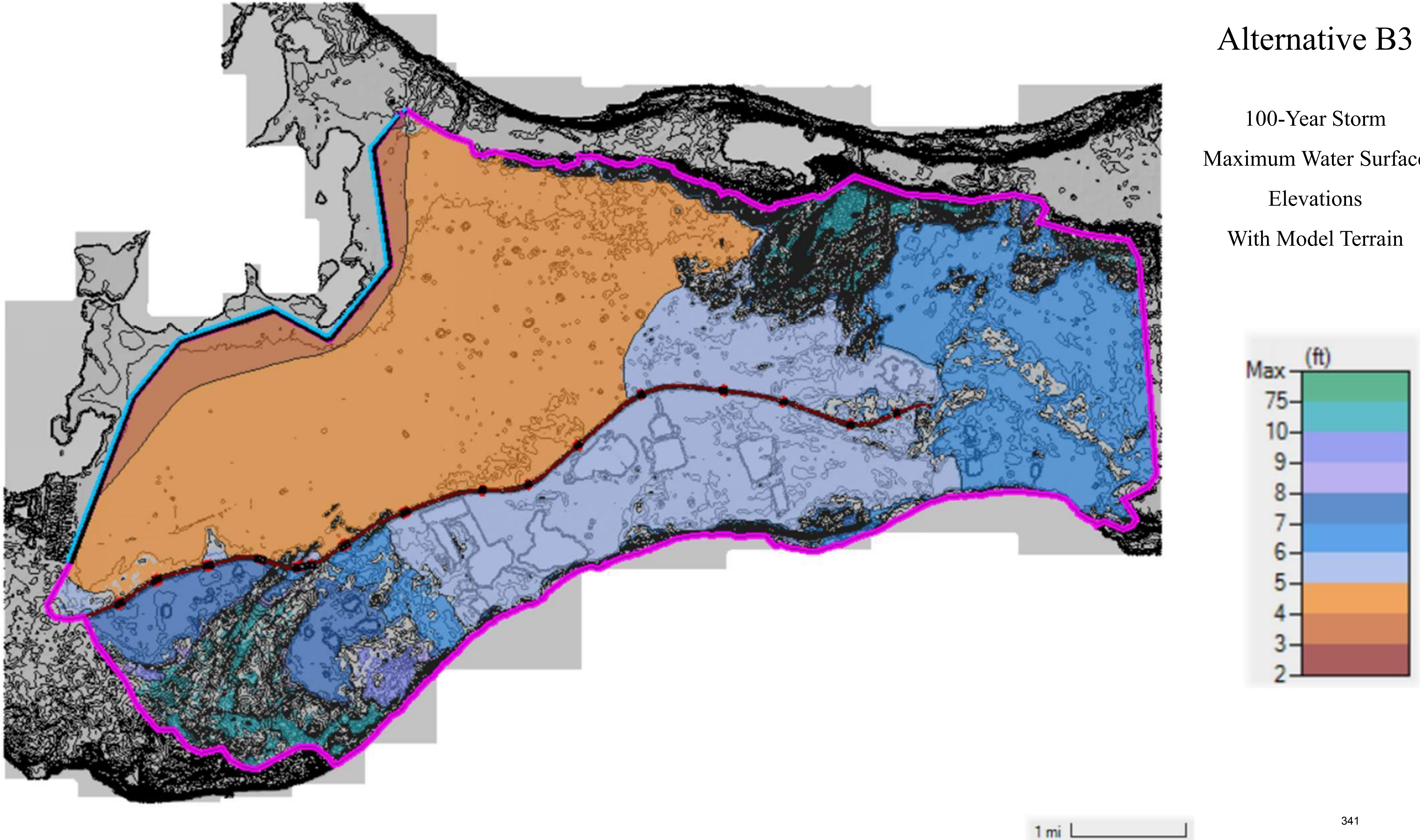
Alternative B3

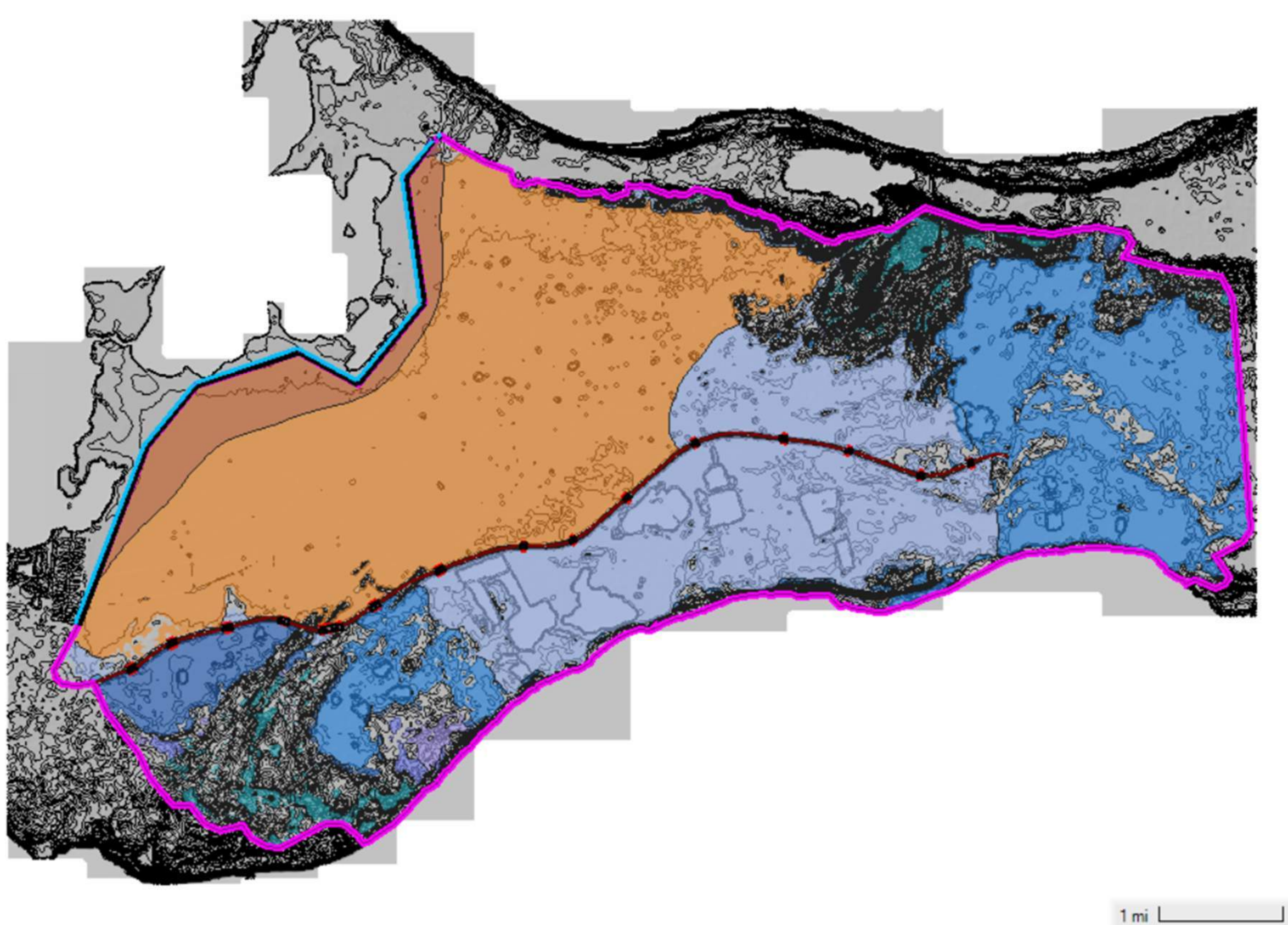
100-Year Storm

Maximum Water Surface

Elevations

With Model Terrain





Alternative B3

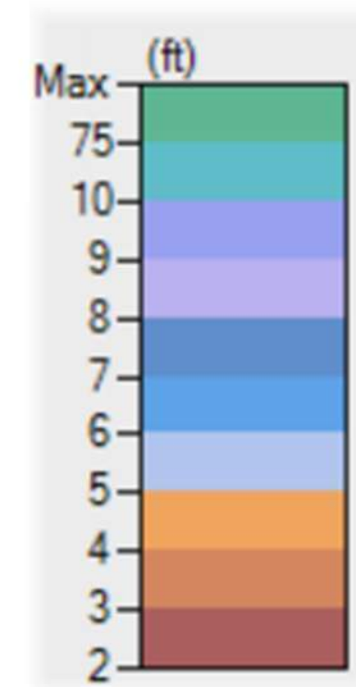
100-Year Storm

With Sea Rise

Maximum Water Surface

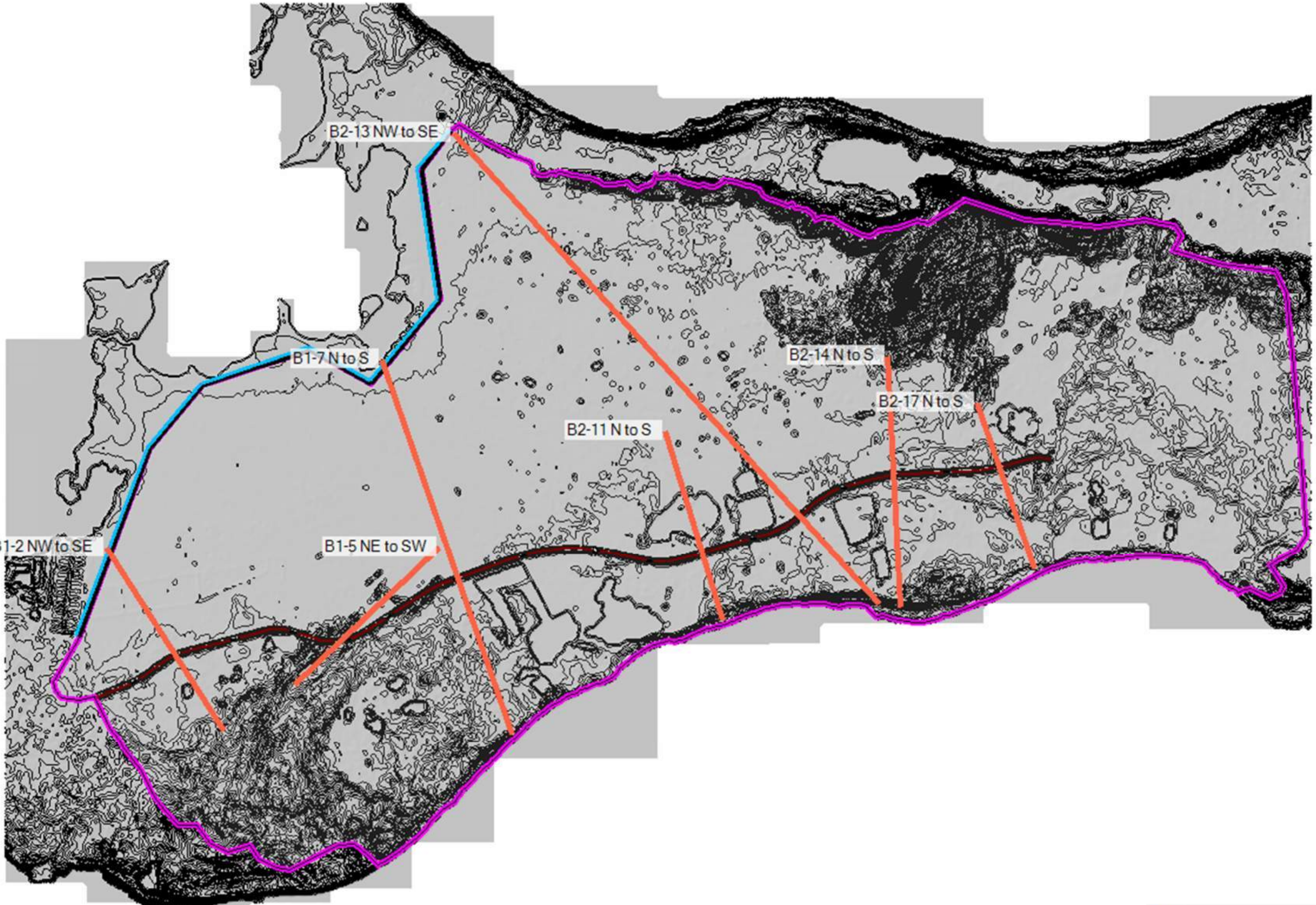
Elevations

With Model Terrain



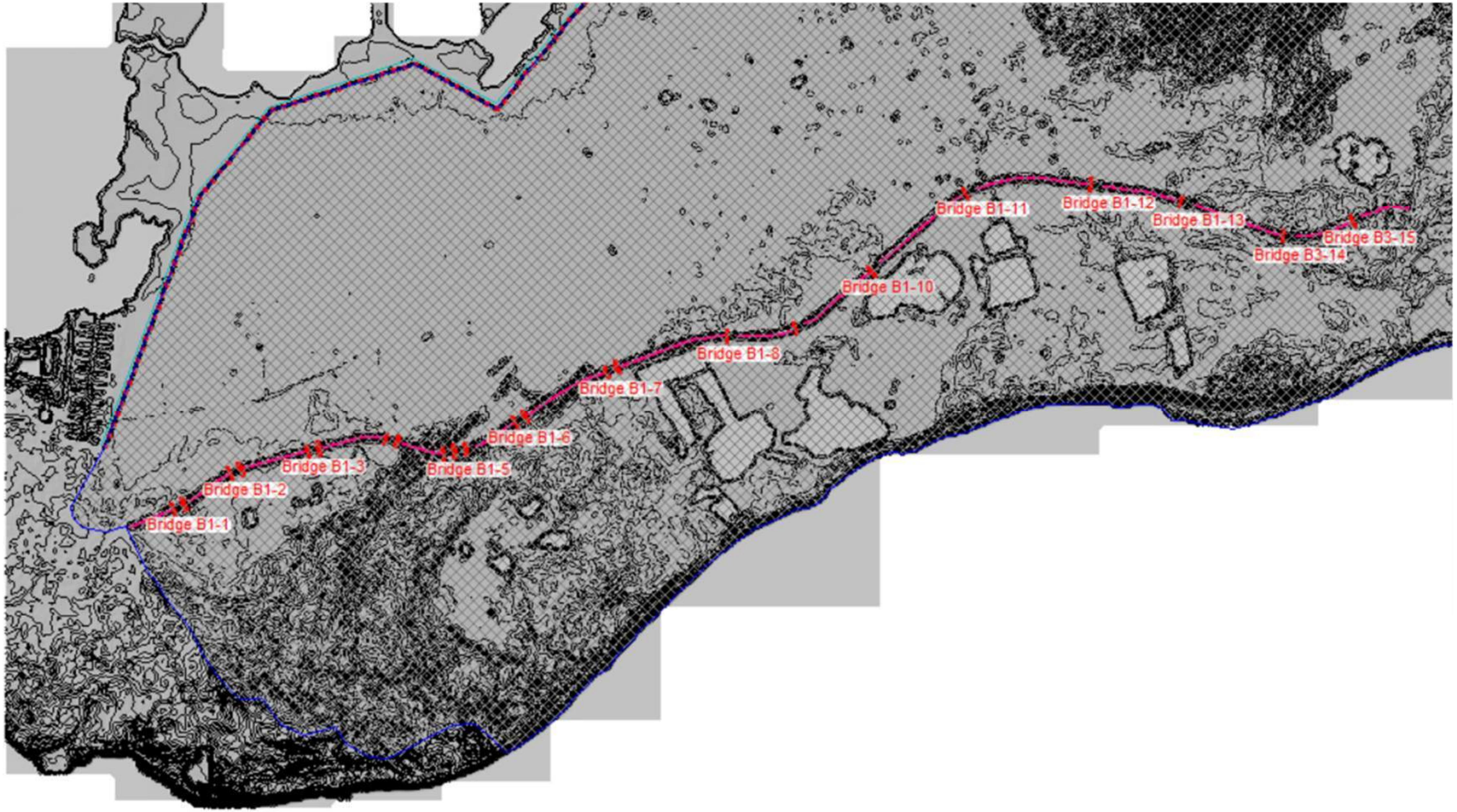
Alternative B3

Profiles



Alternative B3

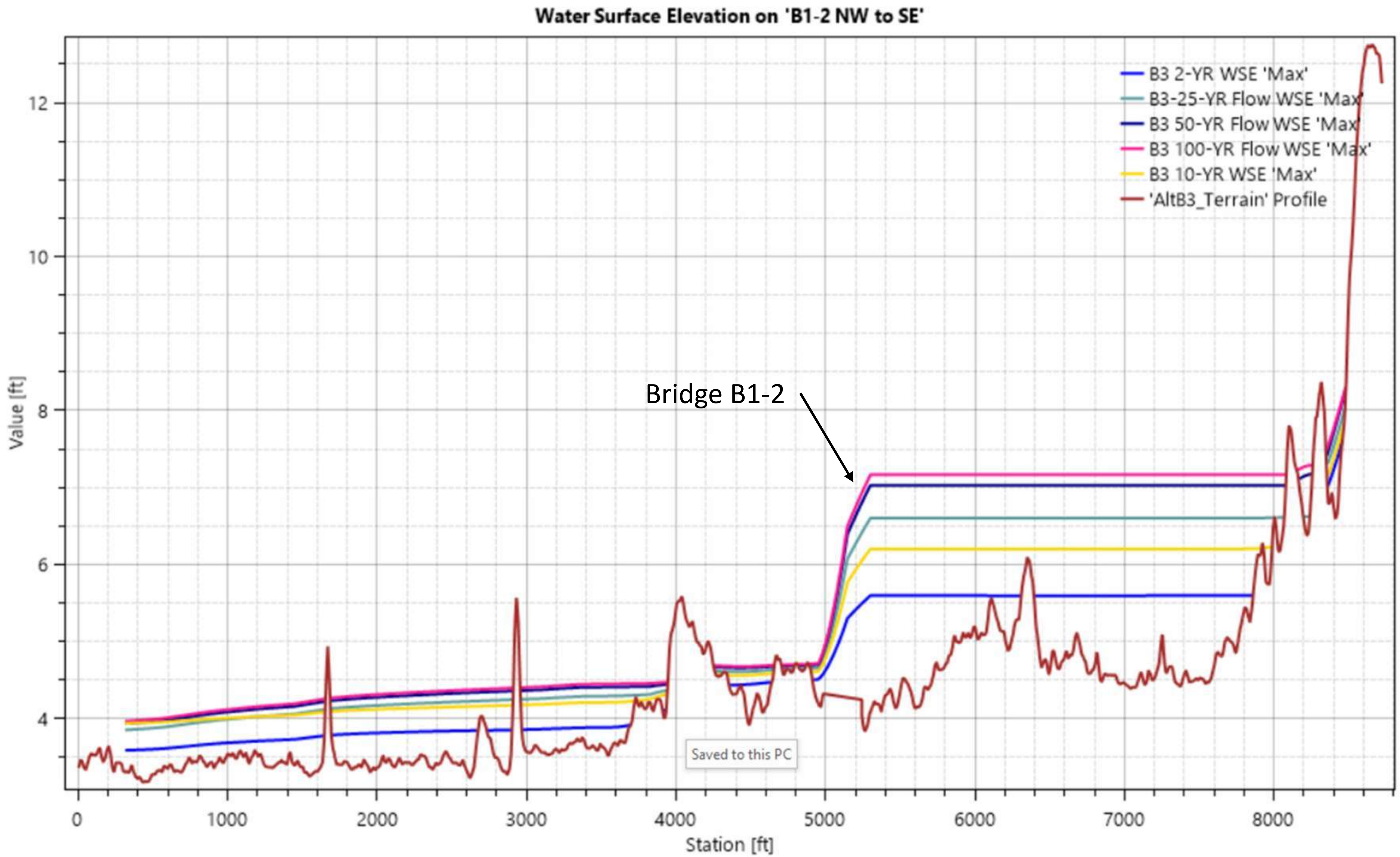
Bridges

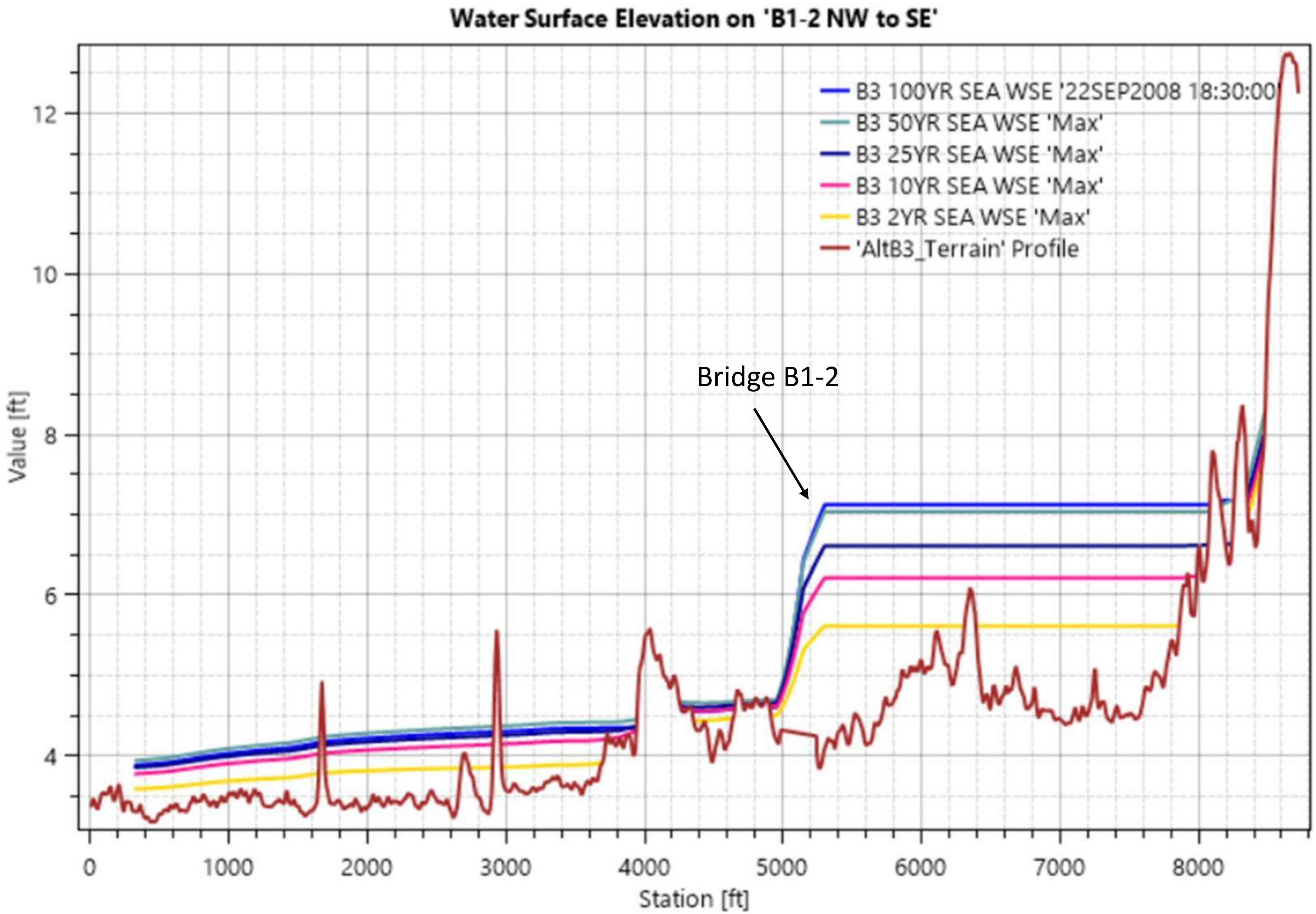


Alternative B3

Profile B1-2

From NW to SE





Alternative B3

Profile B1-2

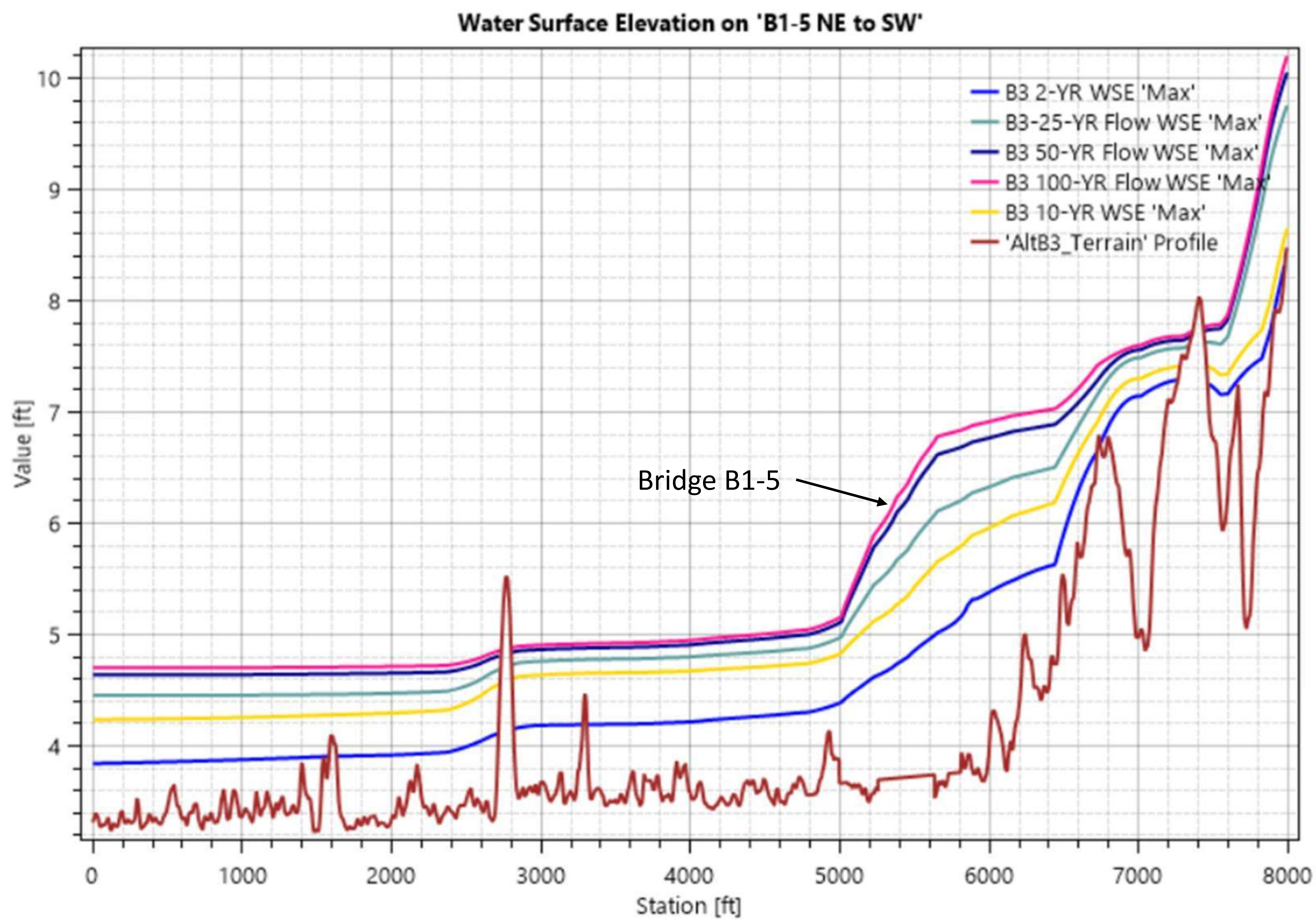
With Sea Rise

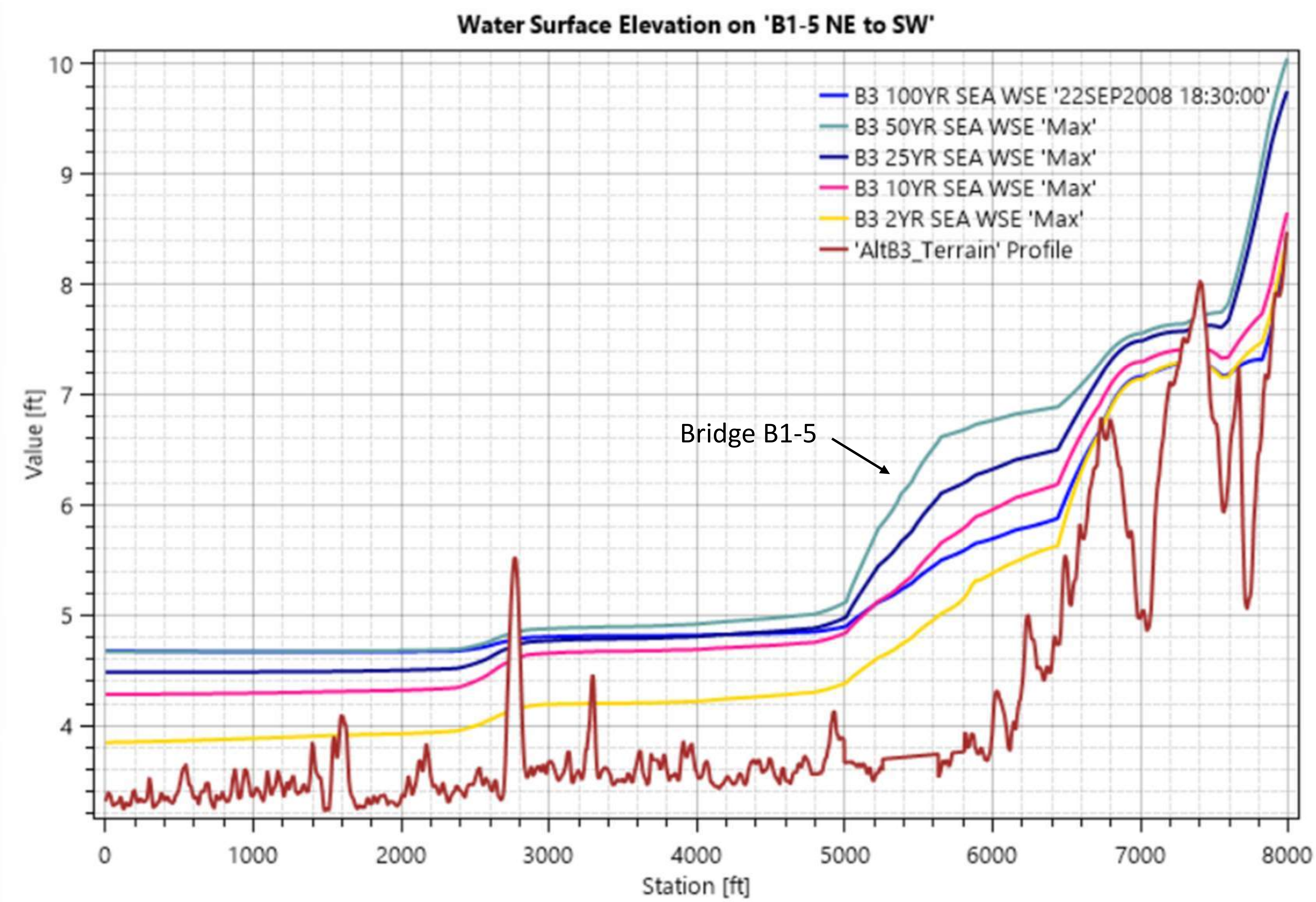
From NW to SE

Alternative B3

Profile B1-5

From NE to SW





Alternative B3

Profile B1-5

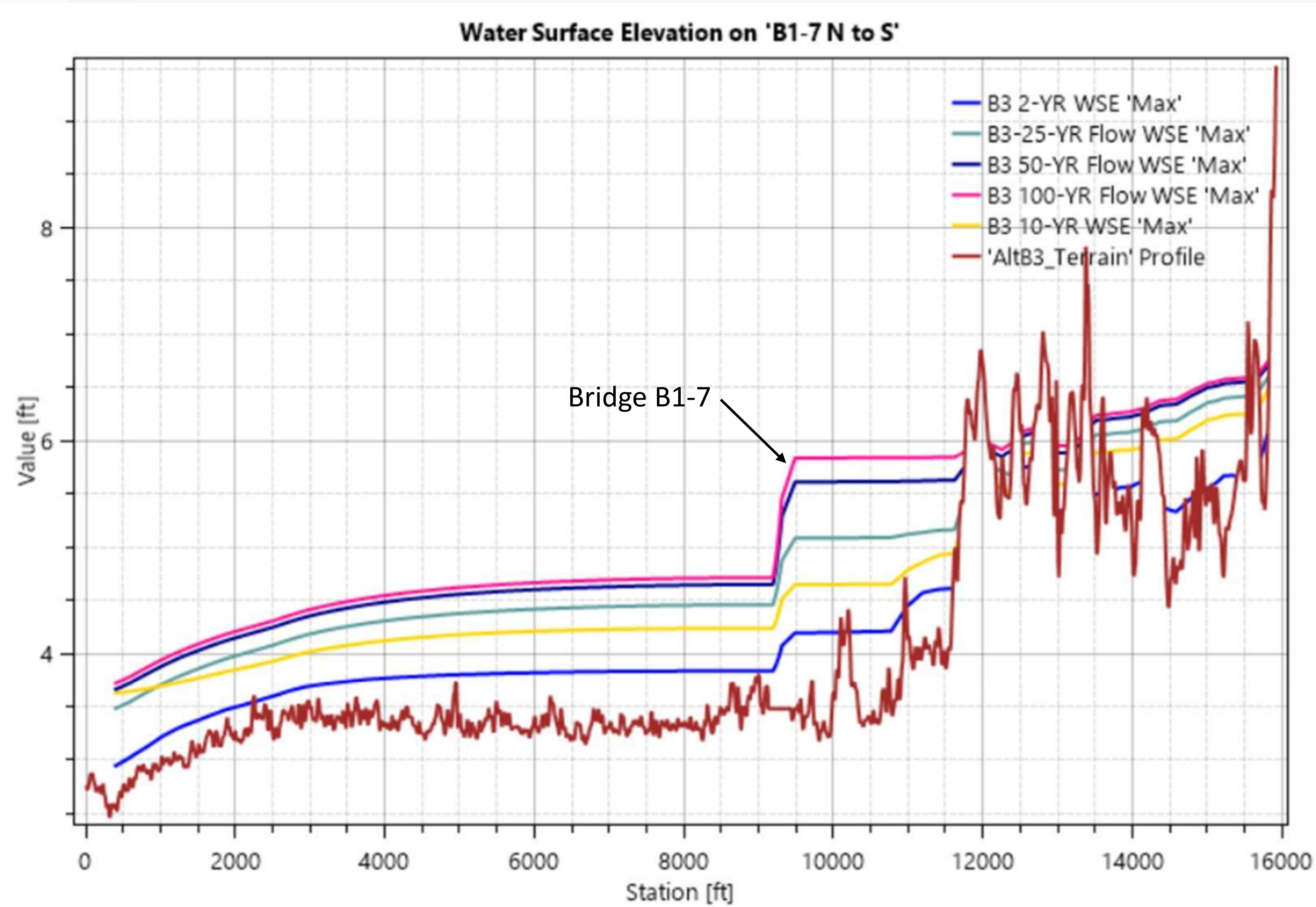
With Sea Rise

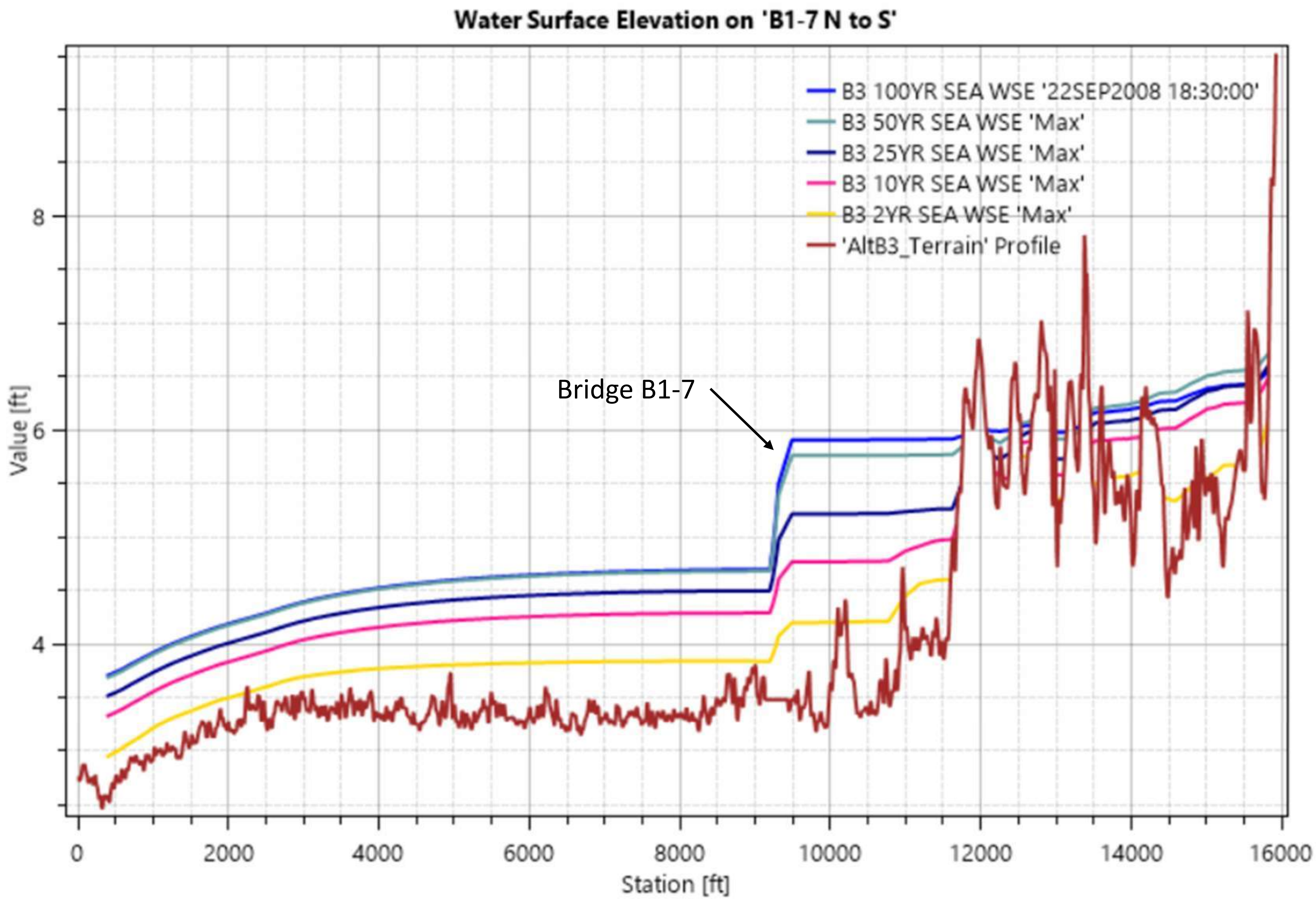
From NE to SWE

Alternative B3

Profile B1-7

From N to S





Alternative B3

Profile B1-7

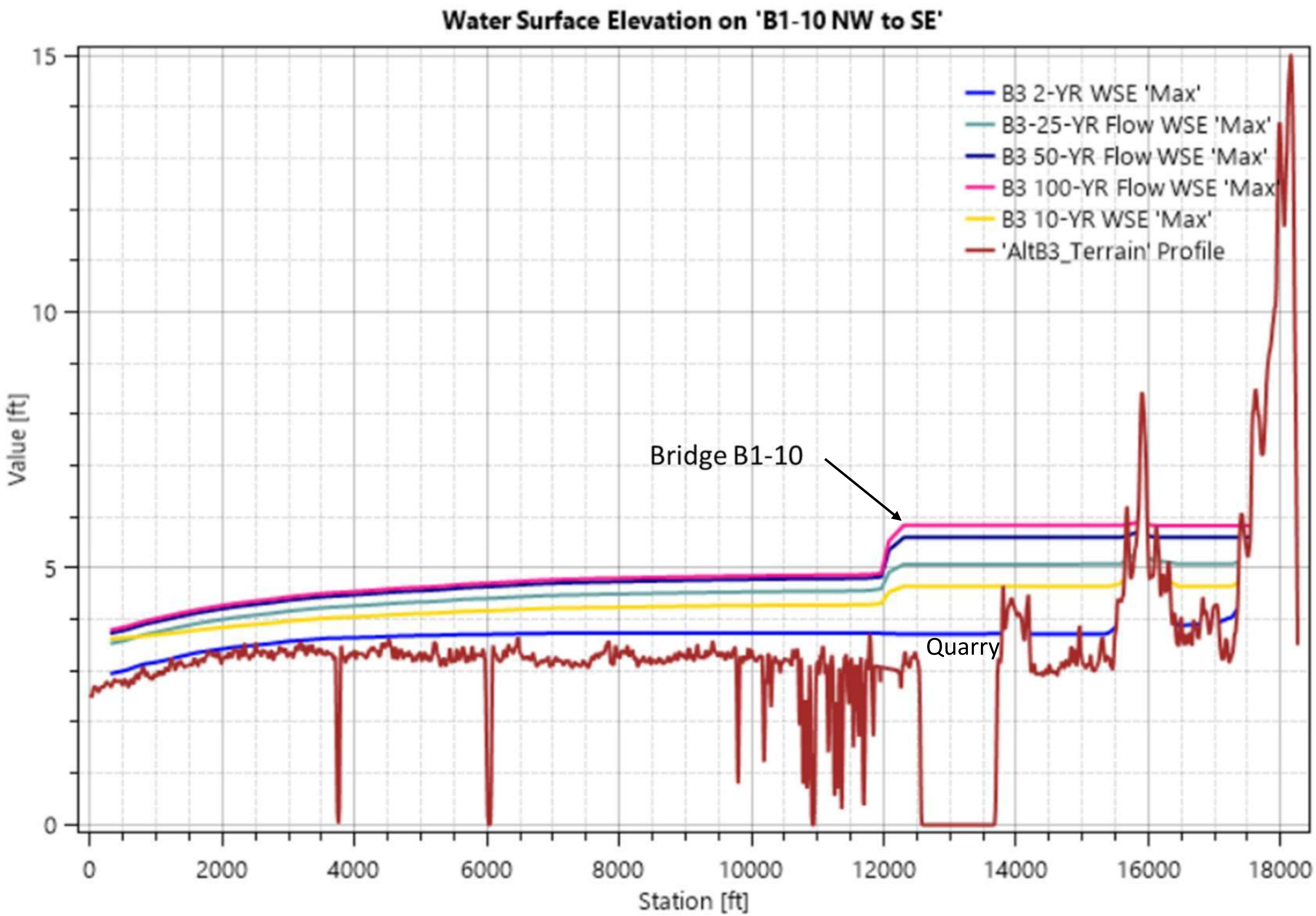
With Sea Rise

From N to S

Alternative B3

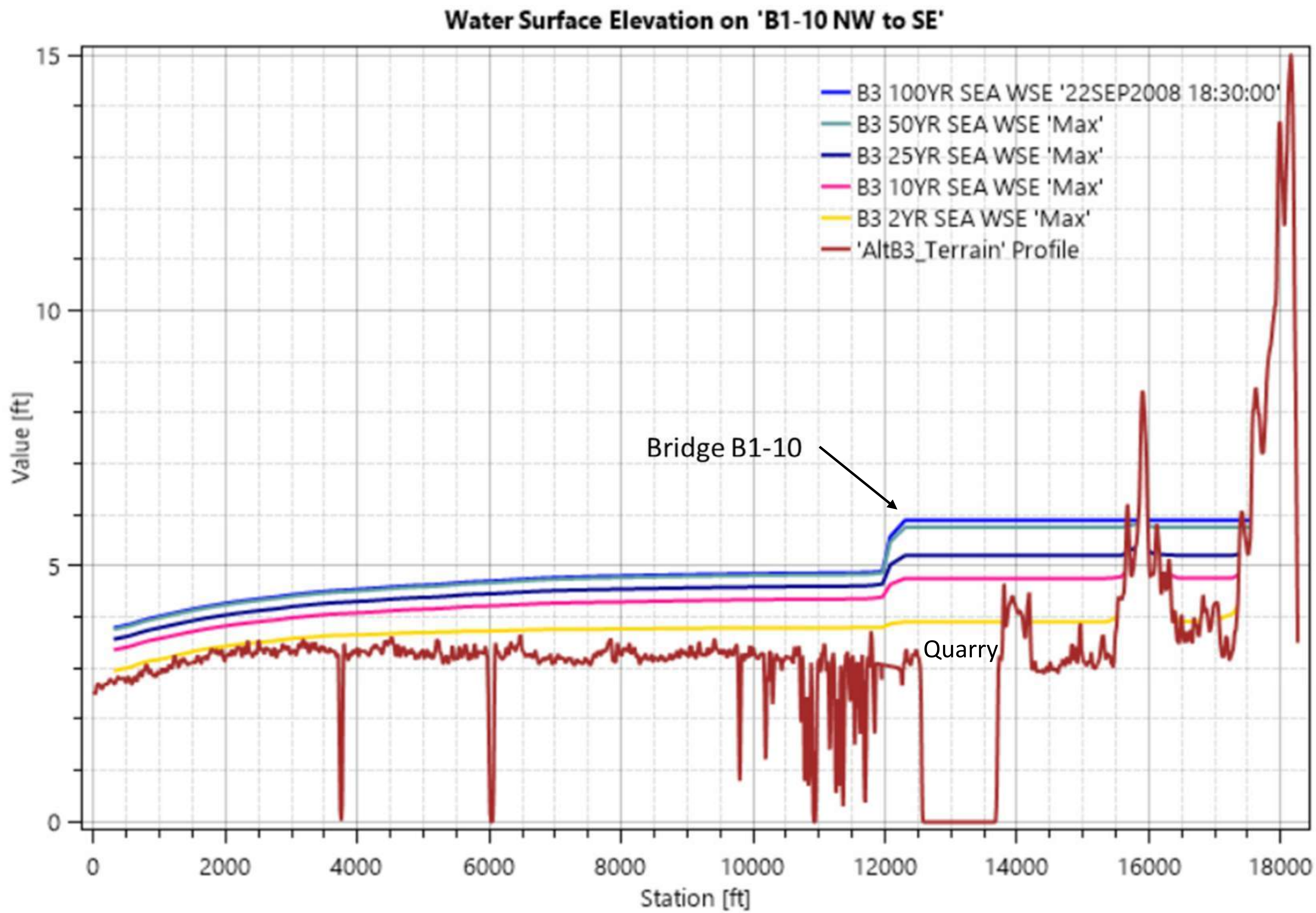
Profile B1-10

From NW to SE



Alternative B3

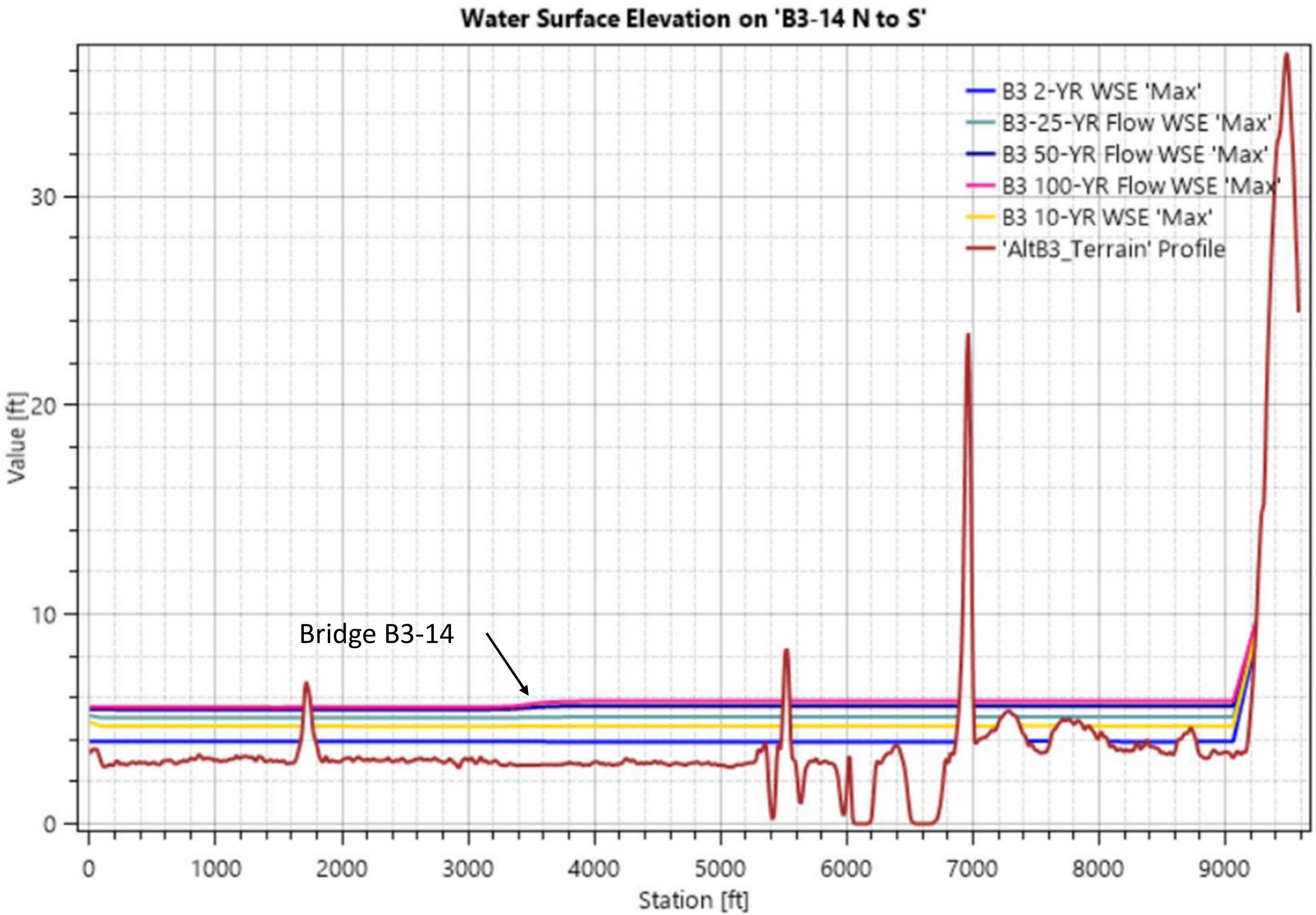
Profile B1-10
with Sea Rise
From NW to SE

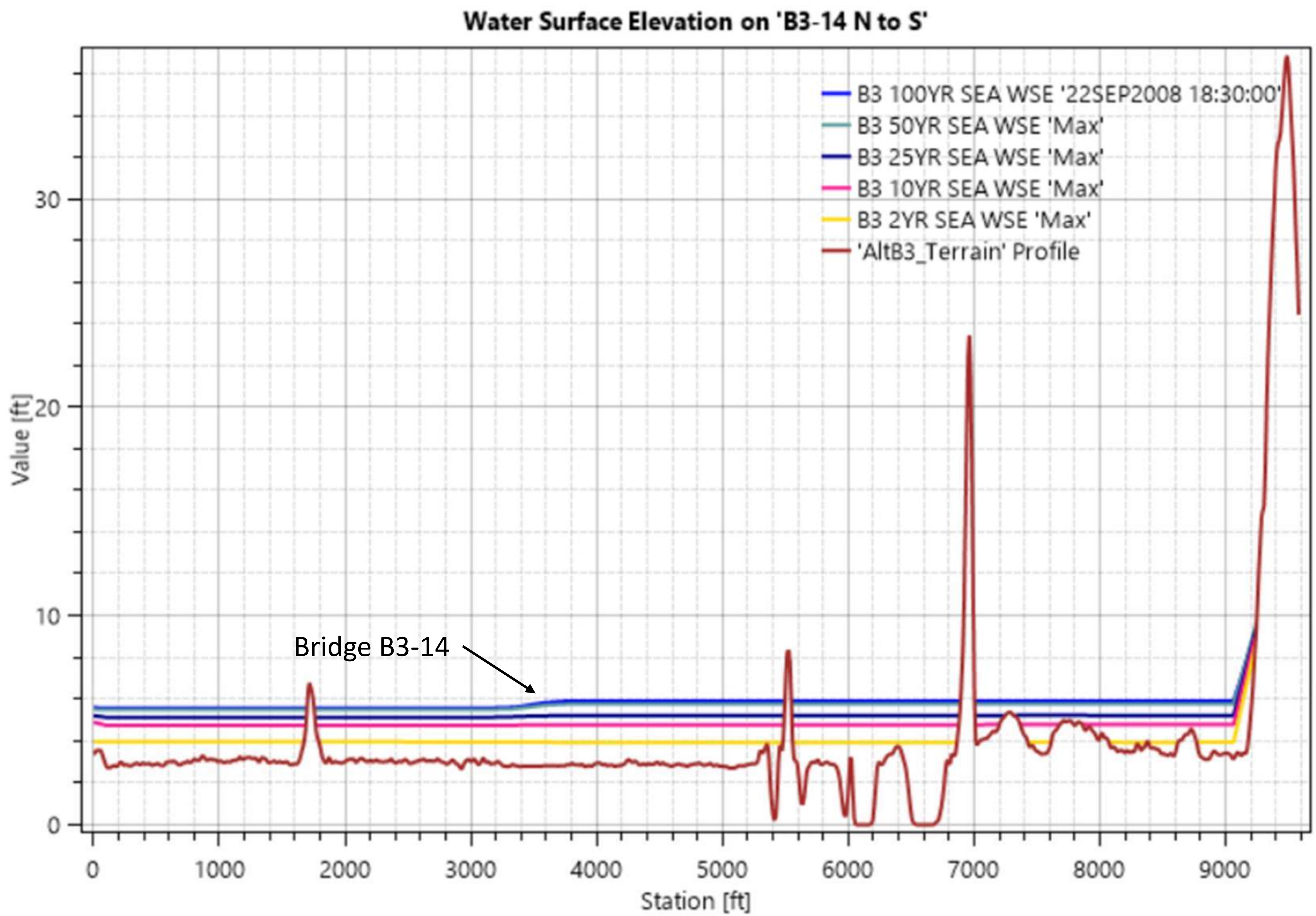


Alternative B3

Profile B3-14

From N to S



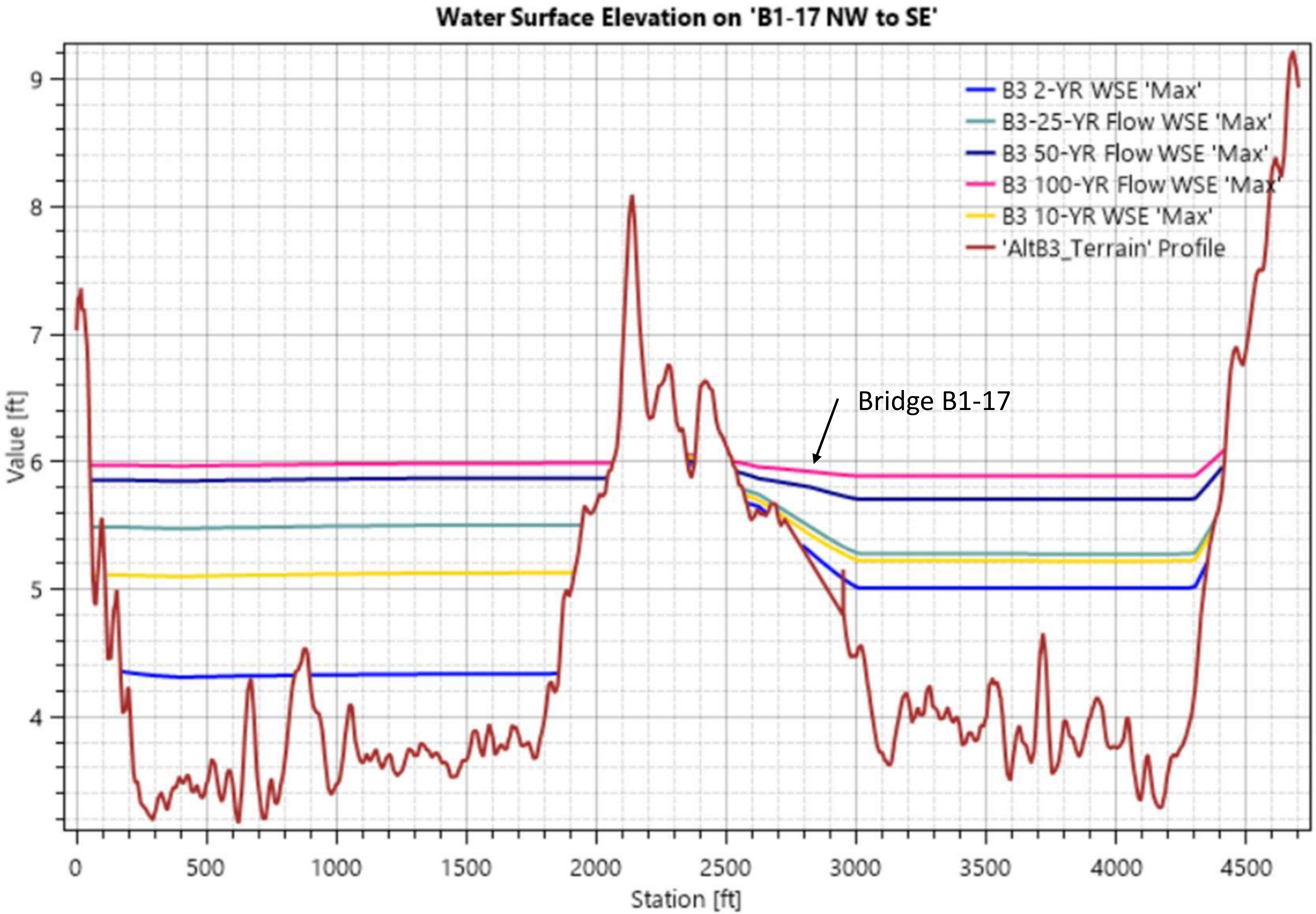


Alternative B3

Profile B3-14

With Sea Rise

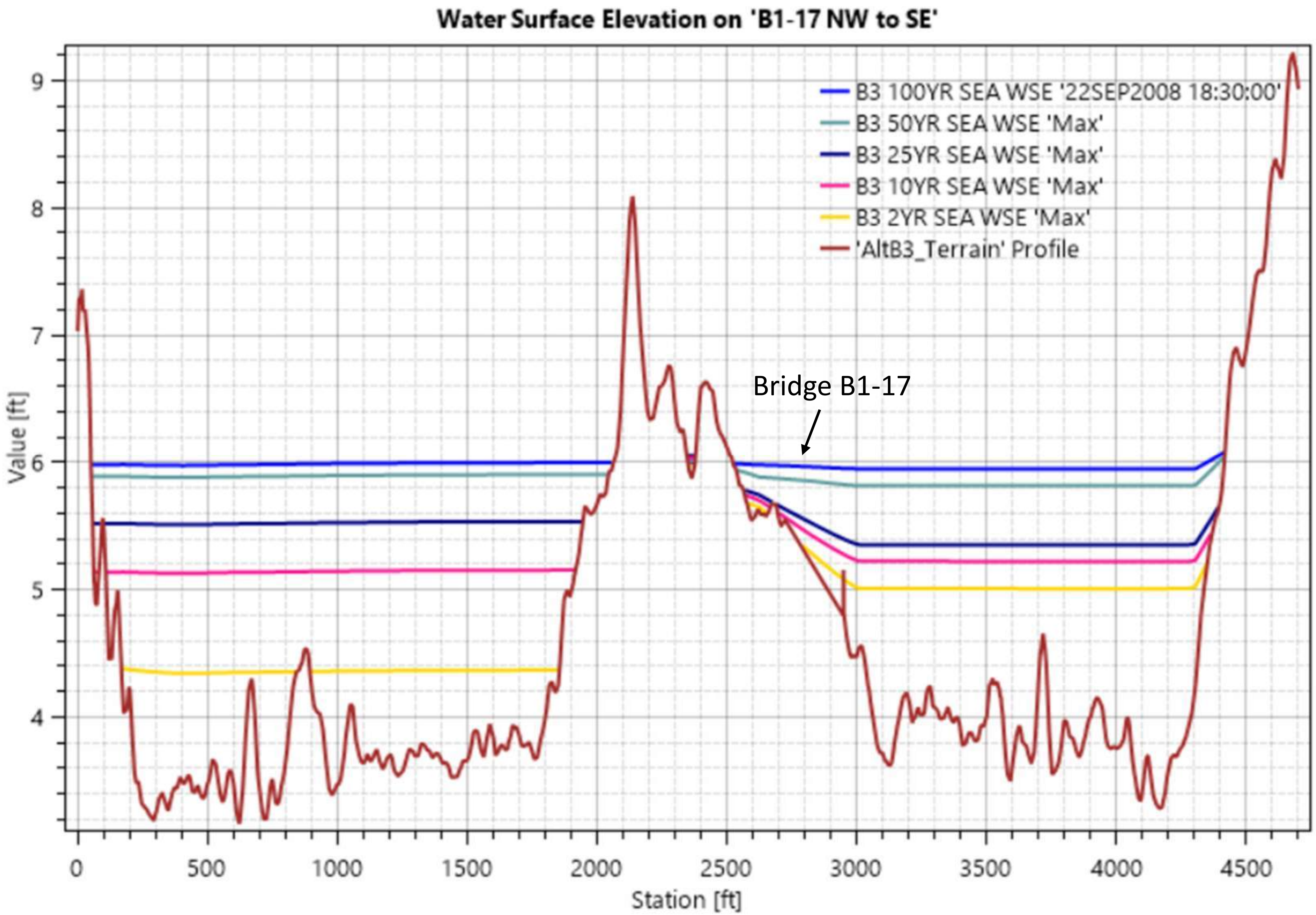
From N to S



Alternative B3

Profile B1-17

From N to S



Alternative B3

Profile B1-17

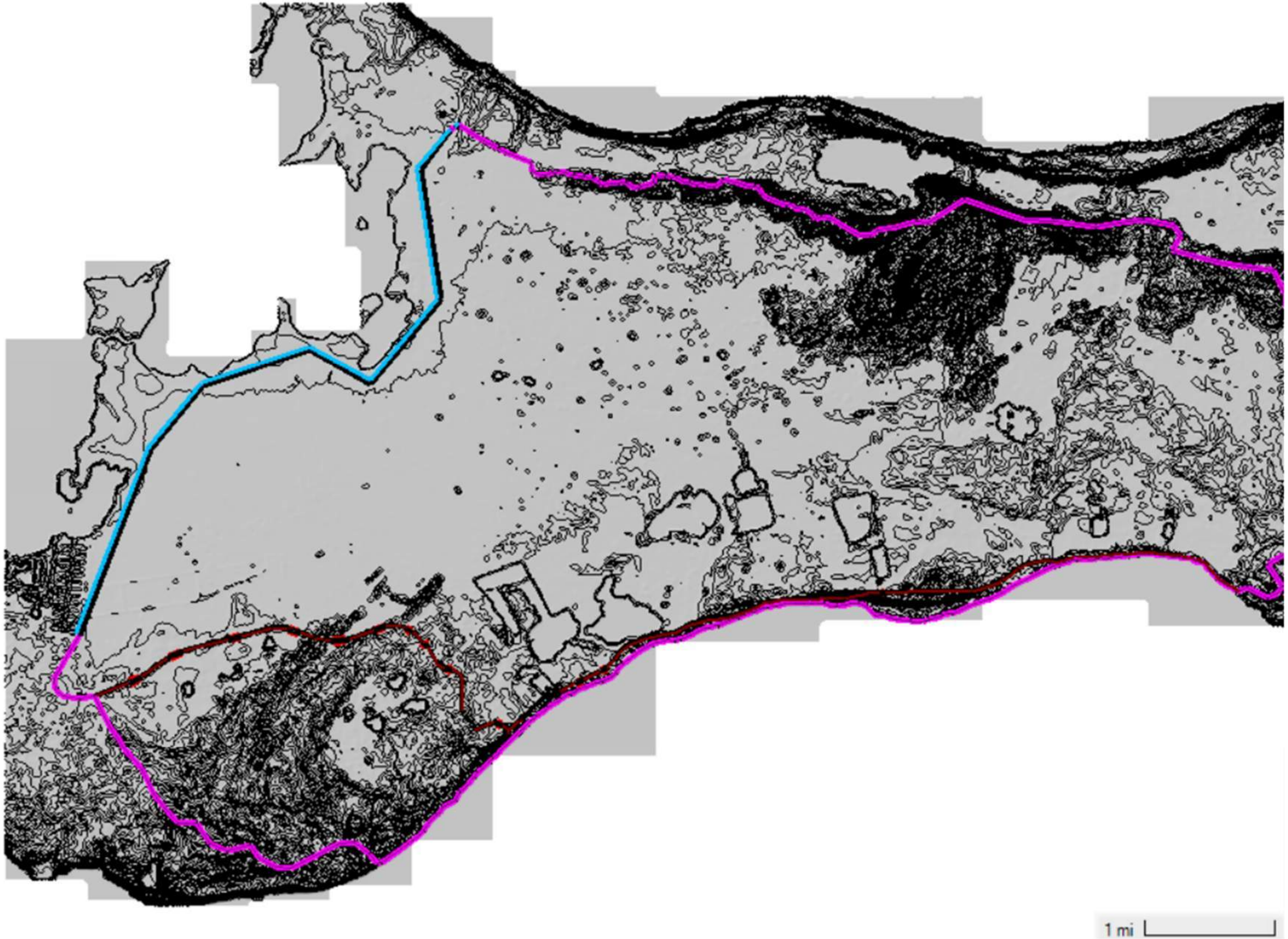
With Sea Rise

From NW to SE

Appendix E – Alternate B4

Alternative B4

Original Terrain

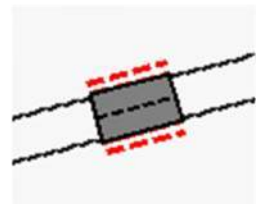


Alternate B1

Legend

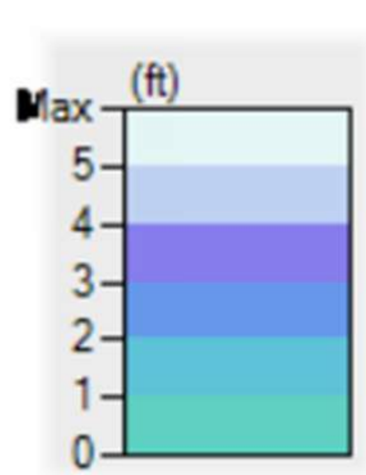
Terrain
Elevation
FT

Bridge

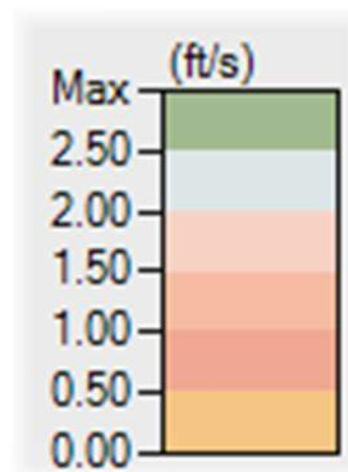


Boundary
Condition
(Blue/Black)
Perimeter
(Magenta)

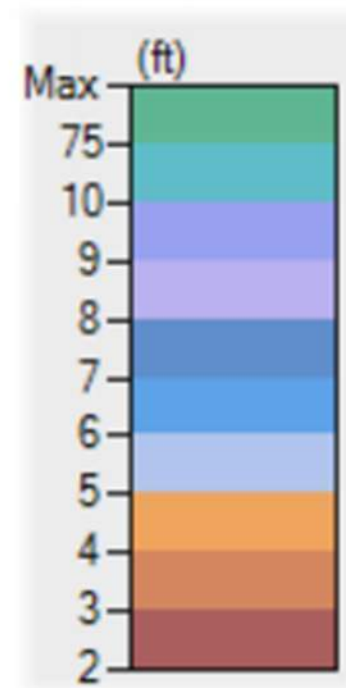
Runoff Depth
FT



Velocity
FT/SEC

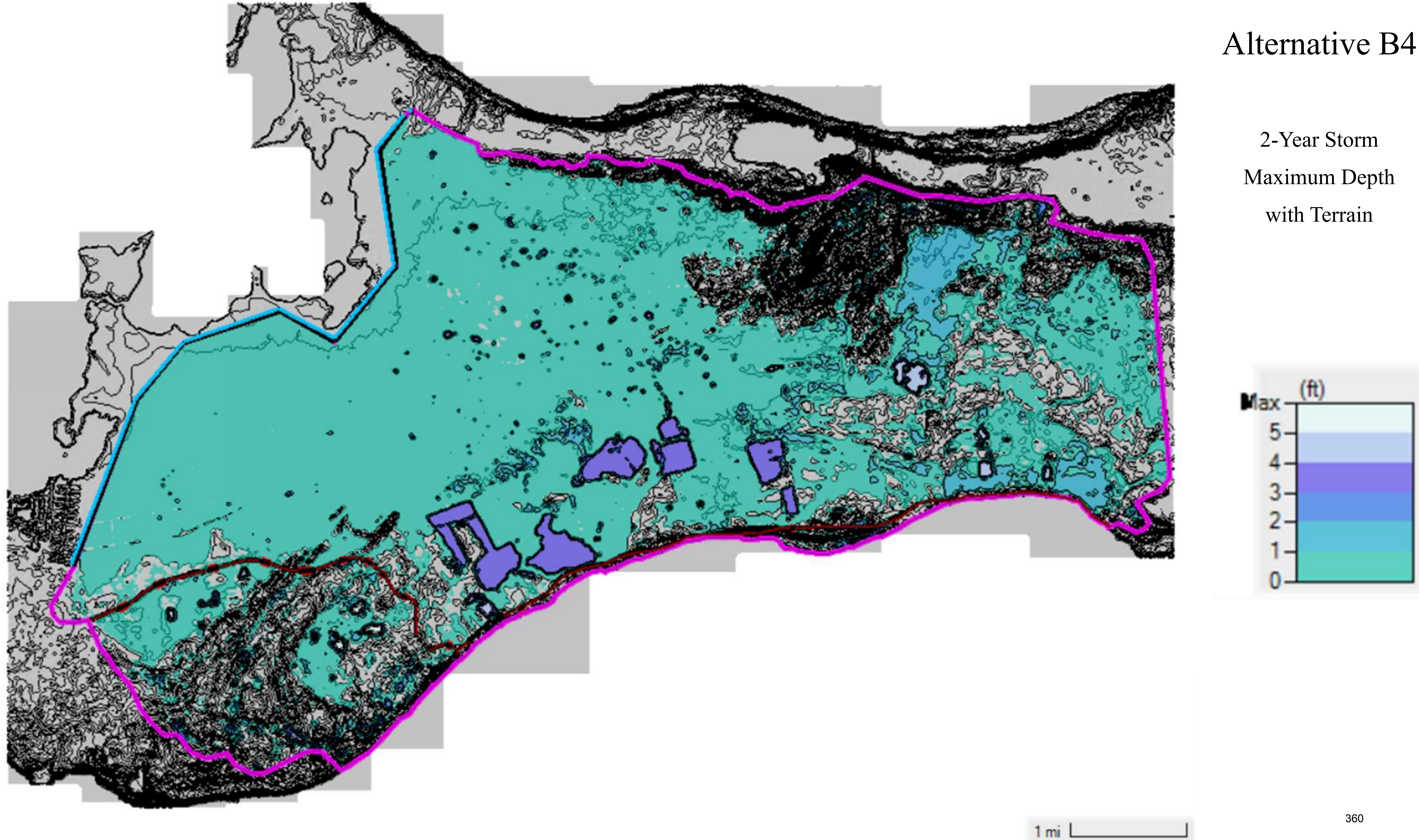


Water Surface
Elevation
FT



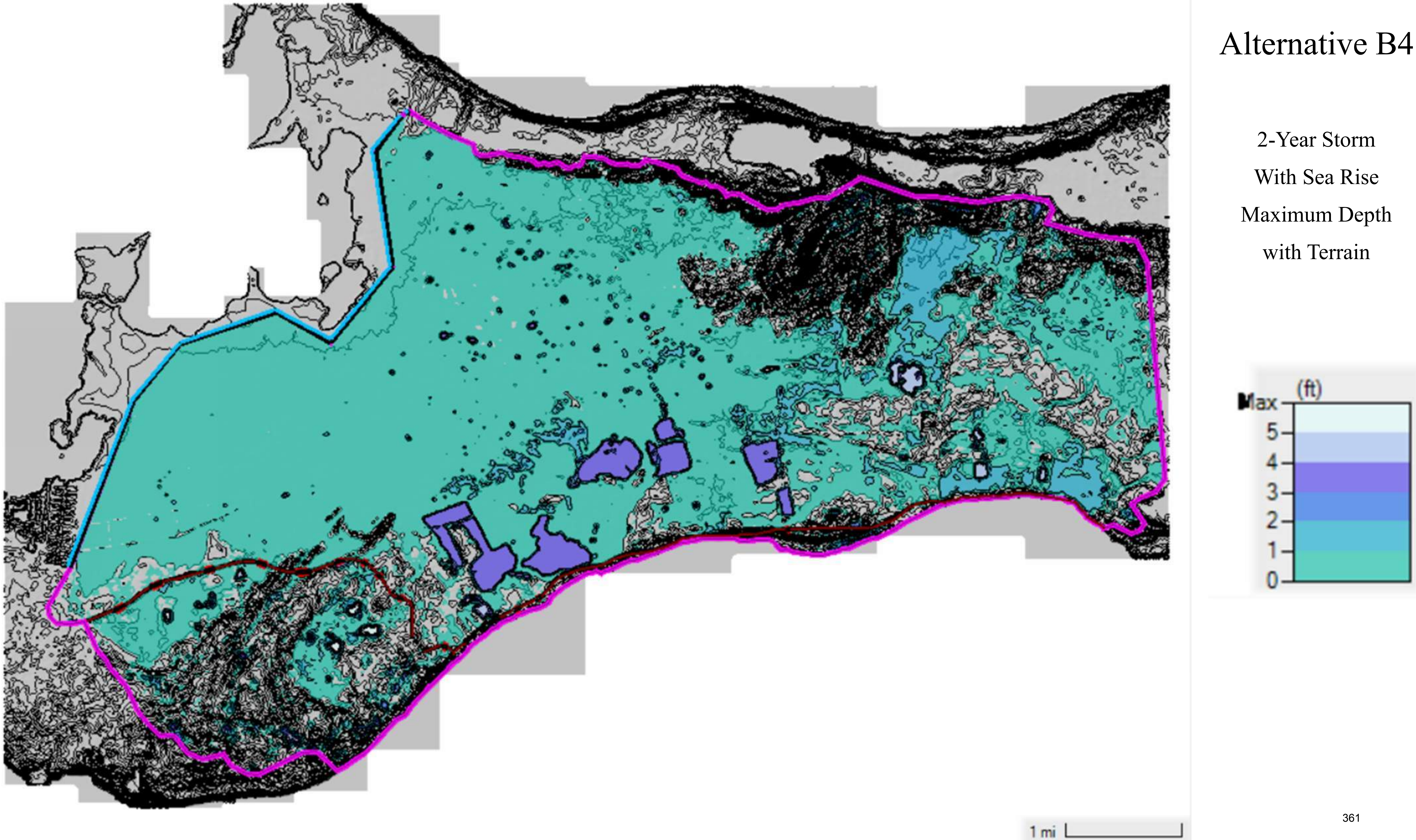
Alternative B4

2-Year Storm
Maximum Depth
with Terrain



Alternative B4

2-Year Storm
With Sea Rise
Maximum Depth
with Terrain

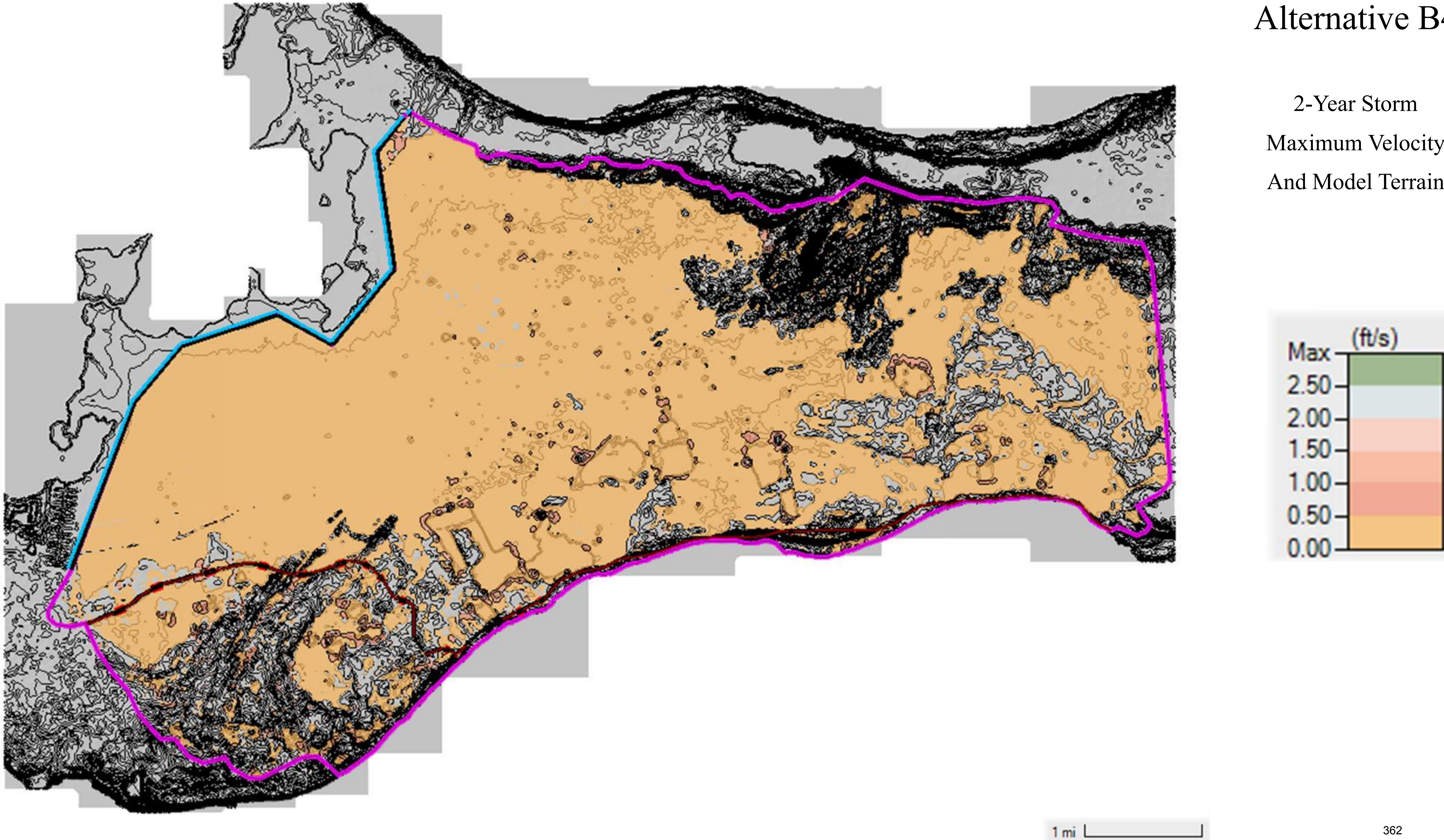


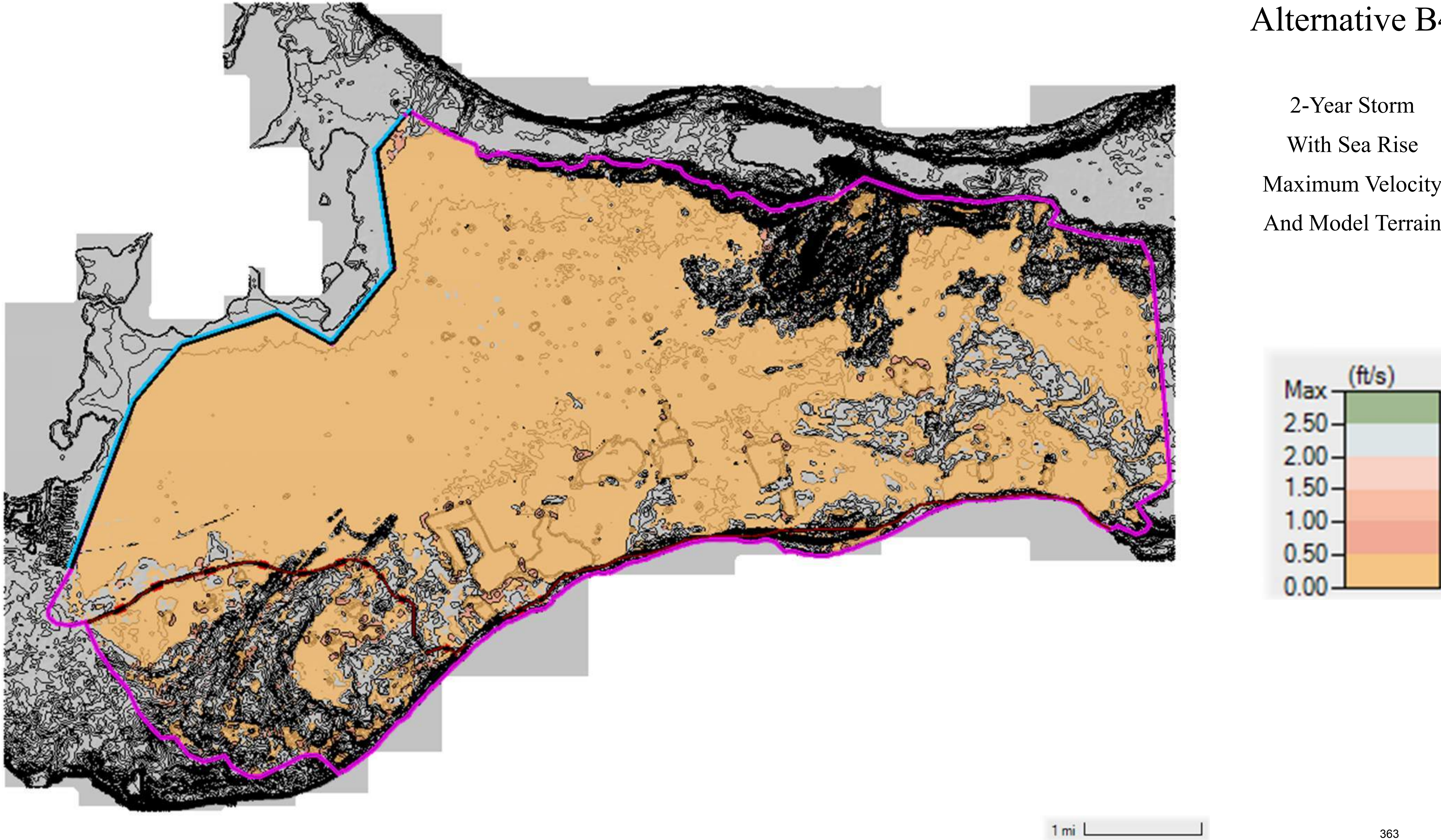
Alternative B4

2-Year Storm

Maximum Velocity

And Model Terrain





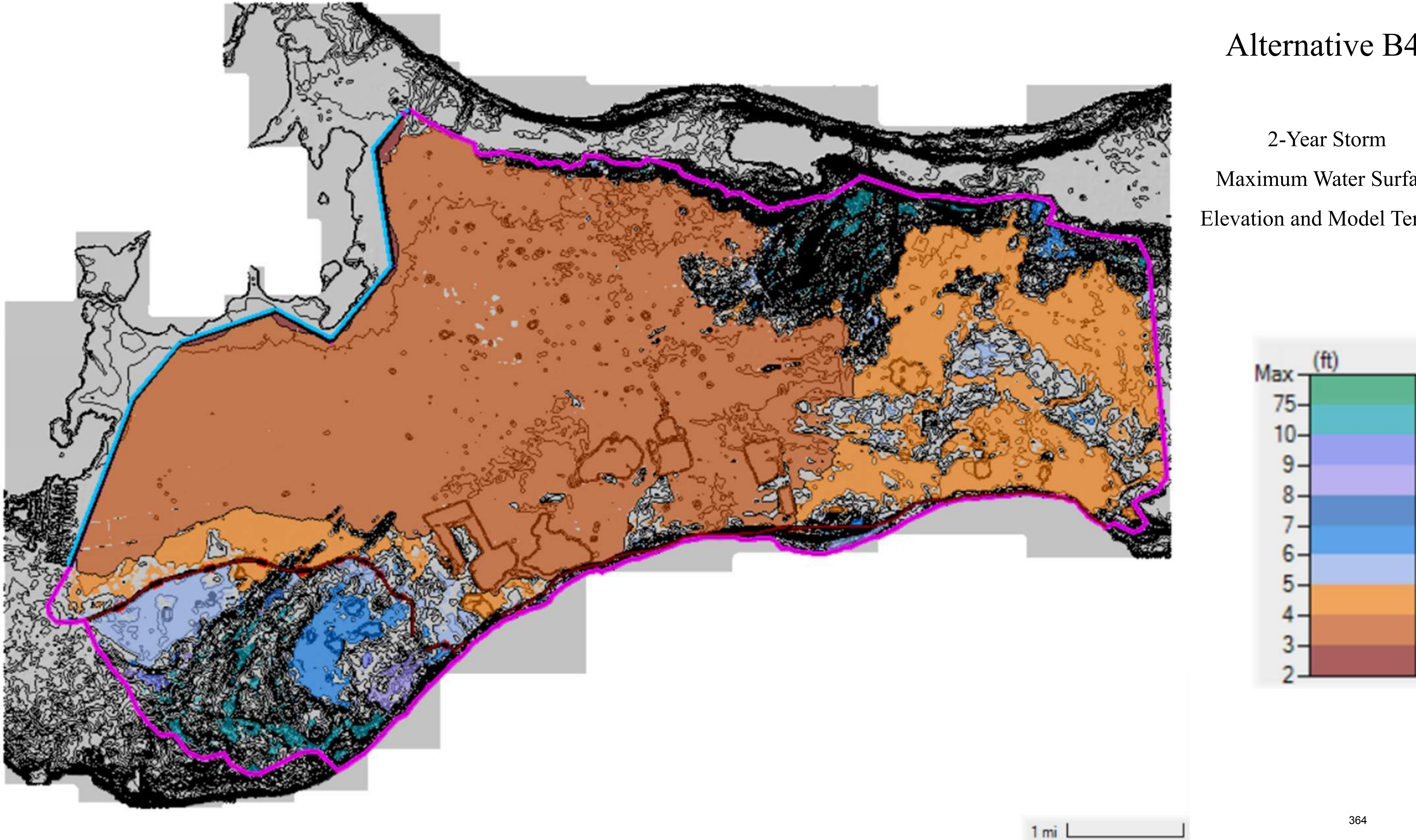
Alternative B4

2-Year Storm

With Sea Rise

Maximum Velocity

And Model Terrain



Alternative B4

2-Year Storm

Maximum Water Surface

Elevation and Model Terrain

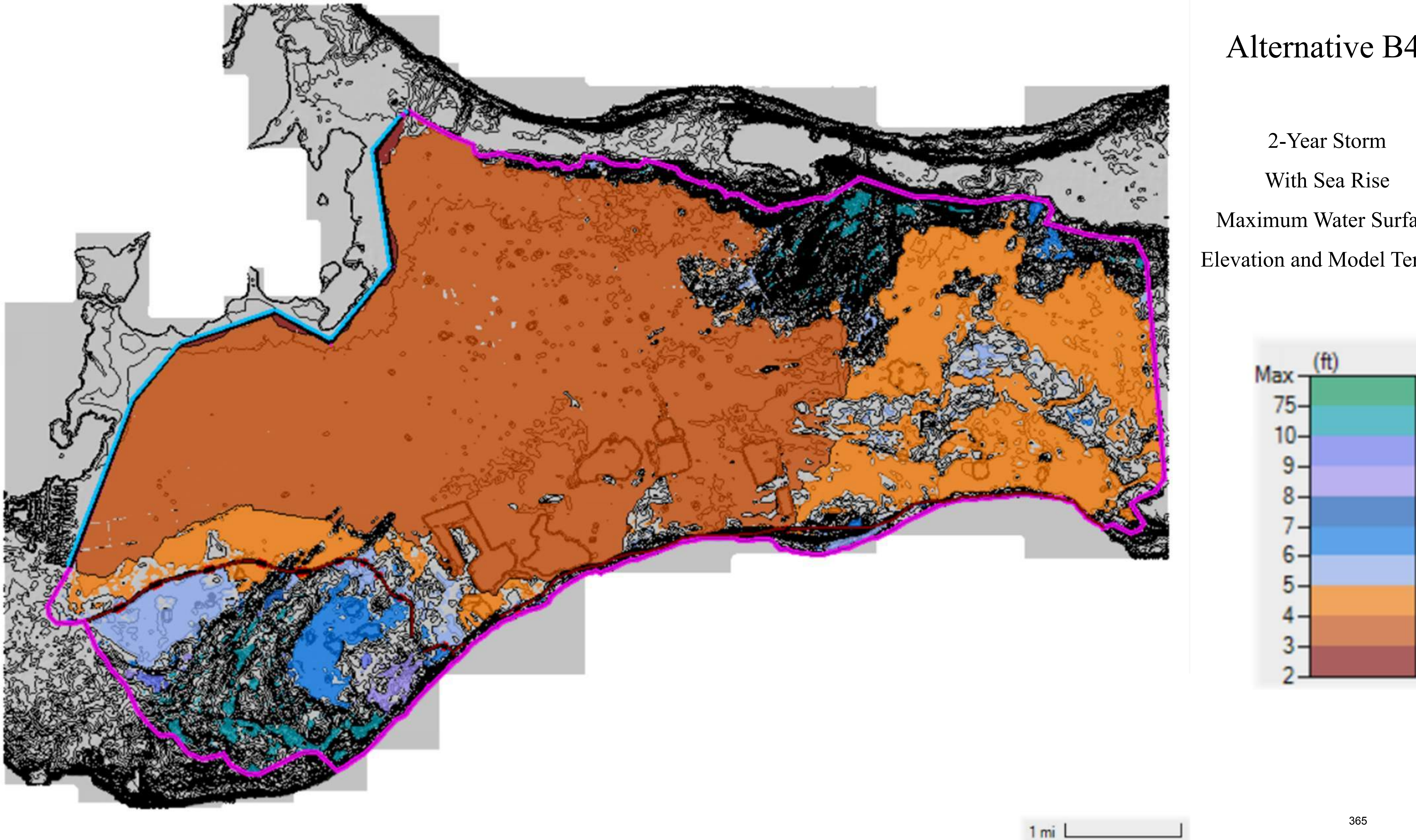
Alternative B4

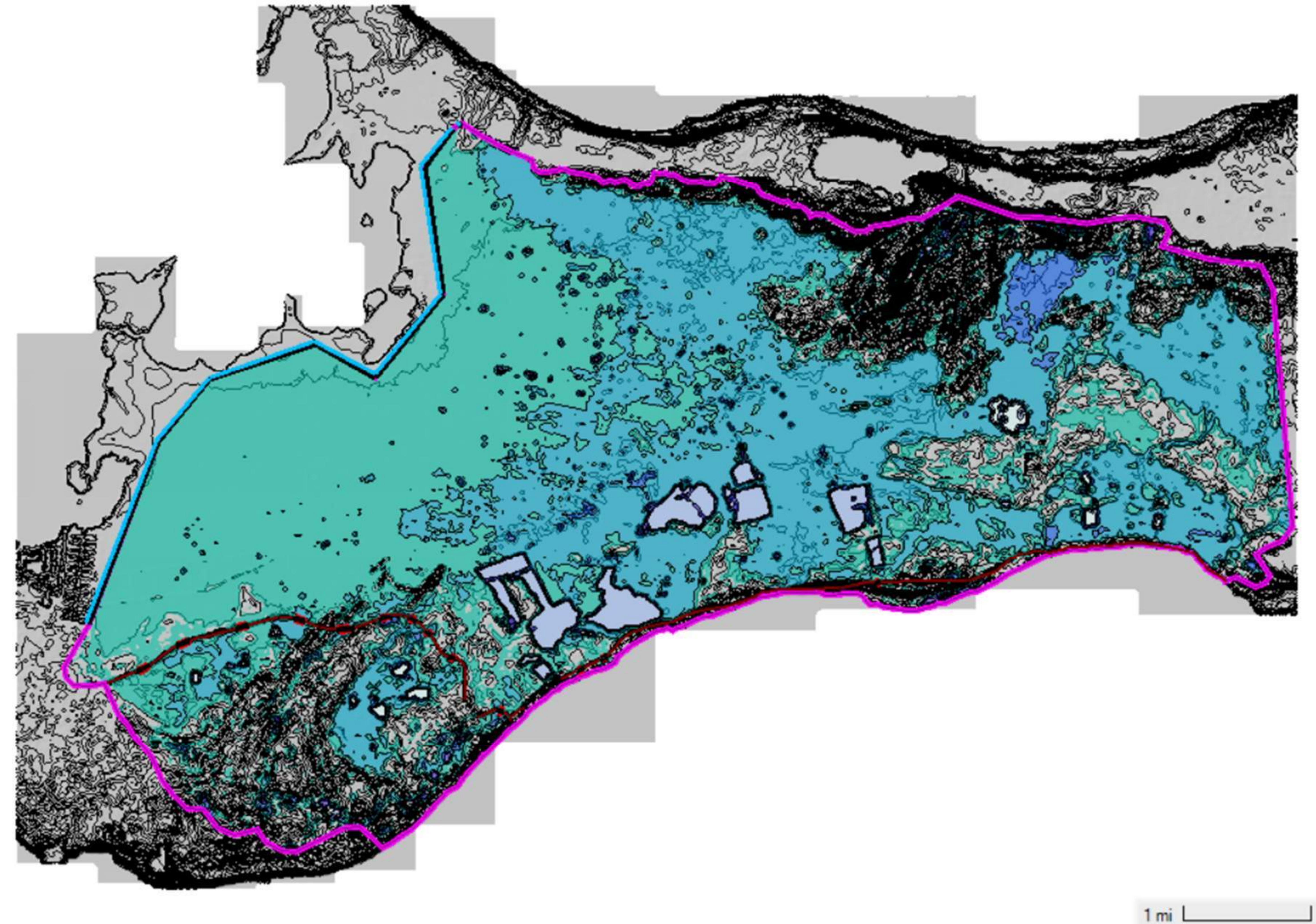
2-Year Storm

With Sea Rise

Maximum Water Surface

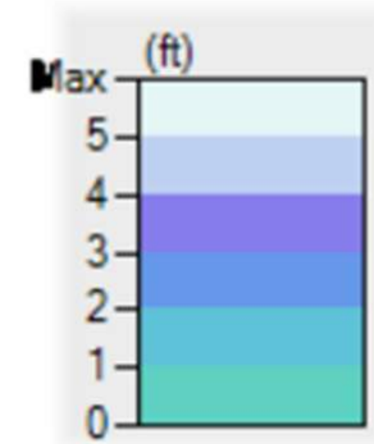
Elevation and Model Terrain

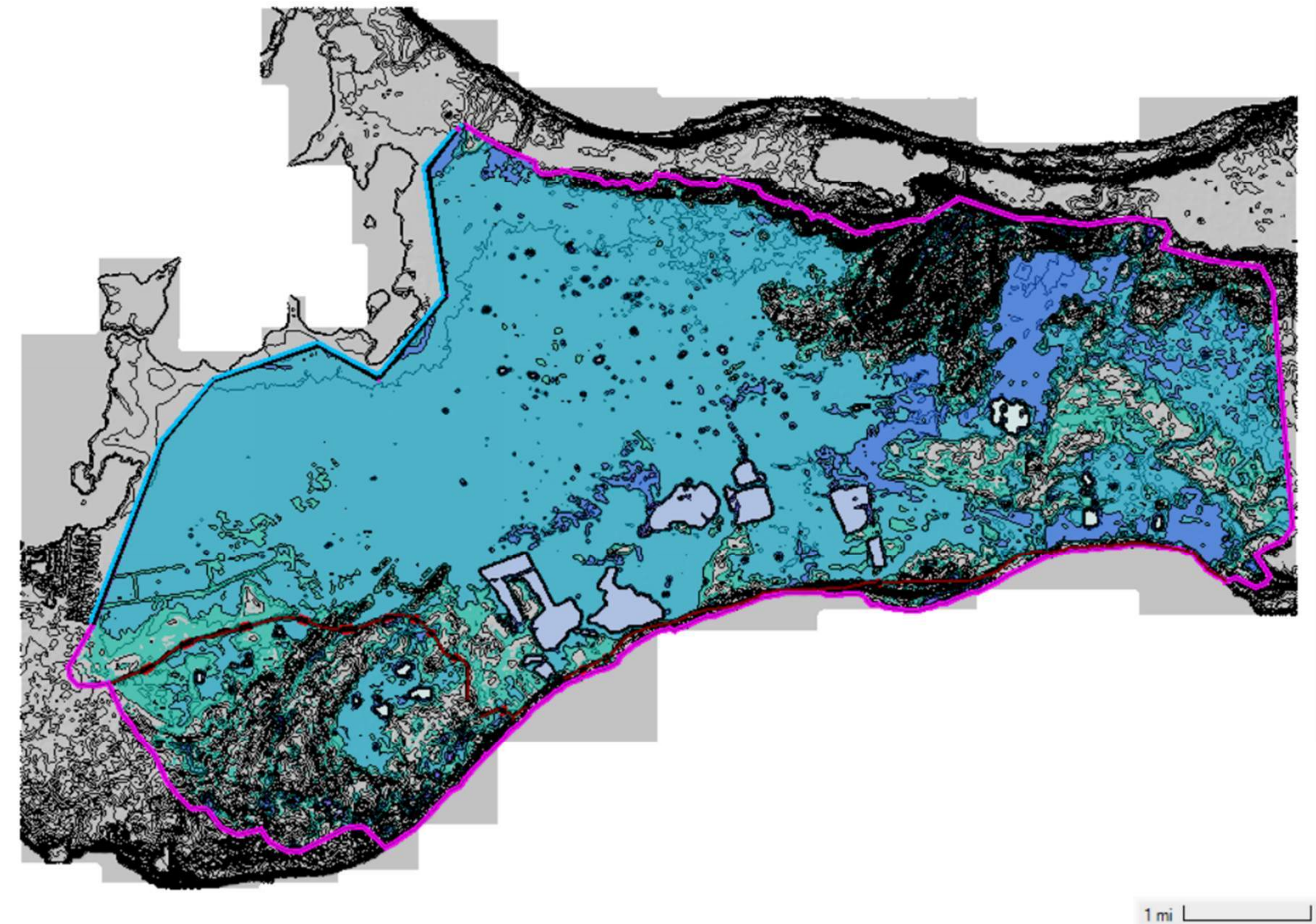




Alternative B4

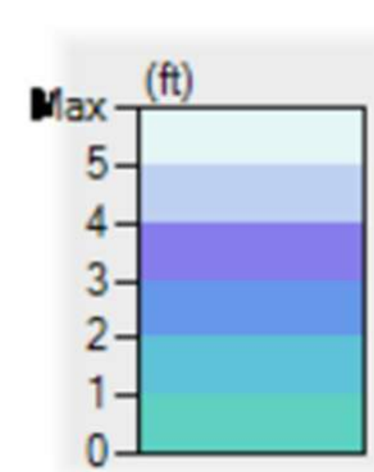
10-Year Storm
Maximum Depth
and Model Terrain





Alternative B4

10-Year Storm
With Sea Rise
Maximum Depth
and Model Terrain

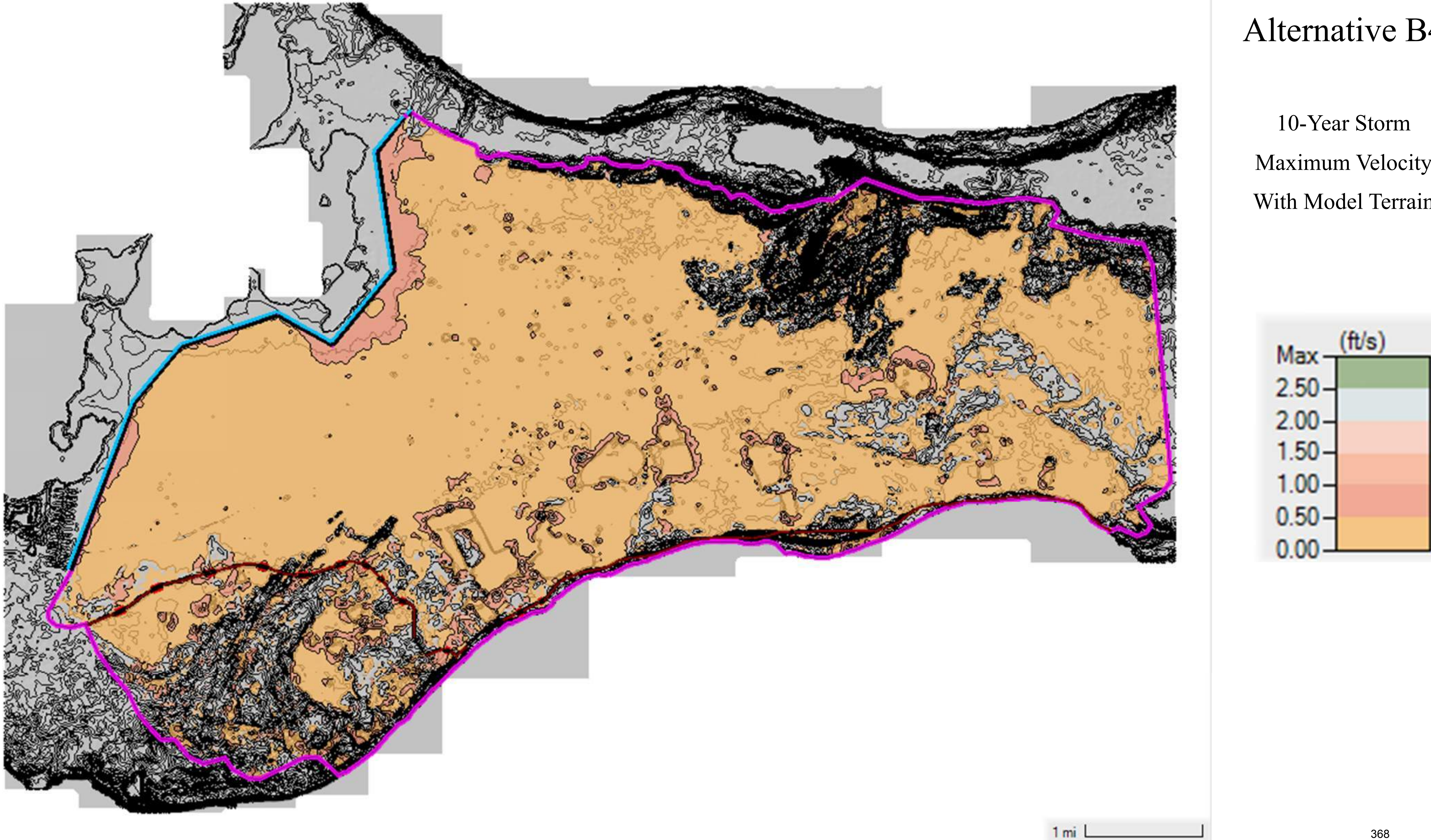


Alternative B4

10-Year Storm

Maximum Velocity

With Model Terrain



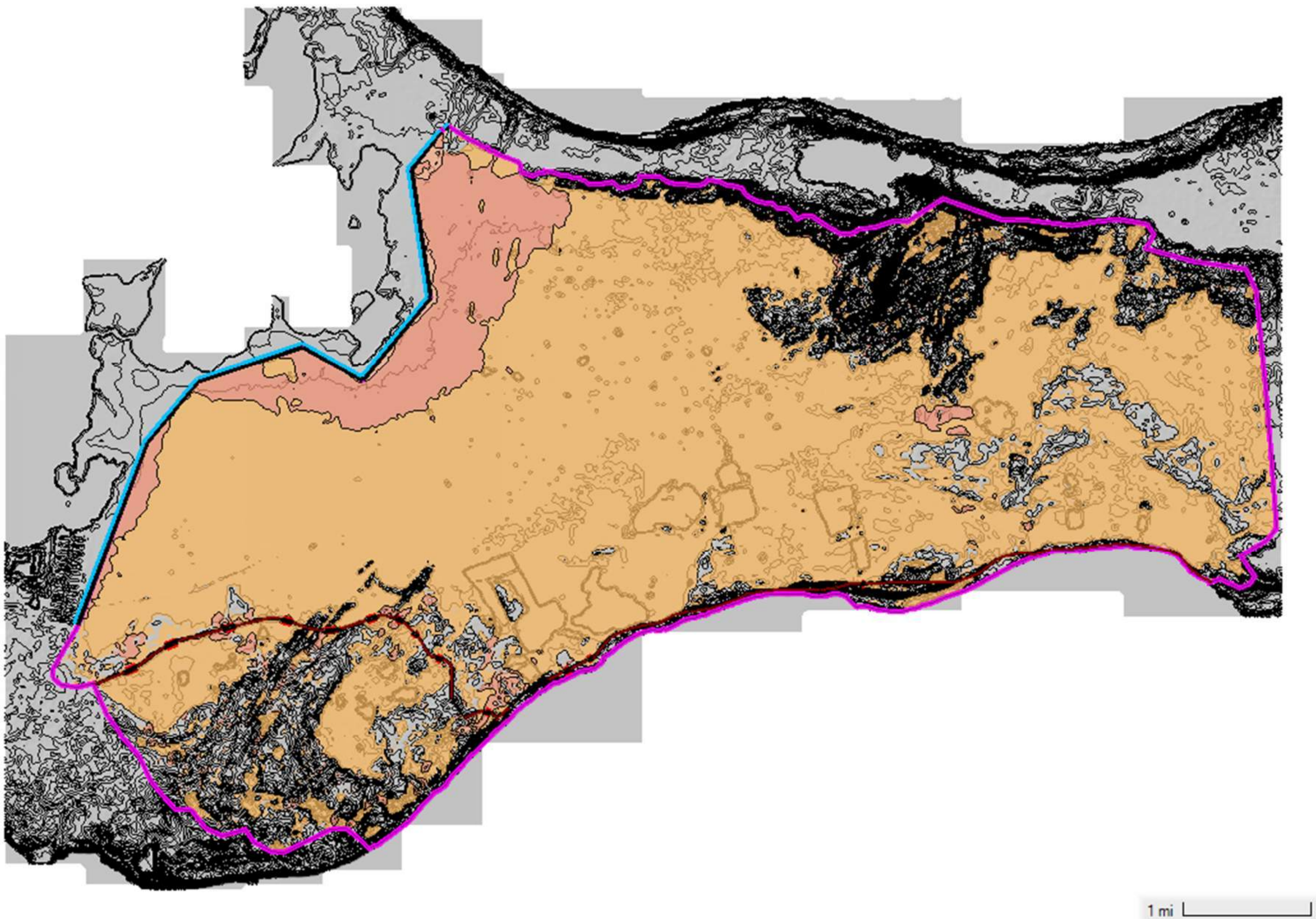
Alternative B4

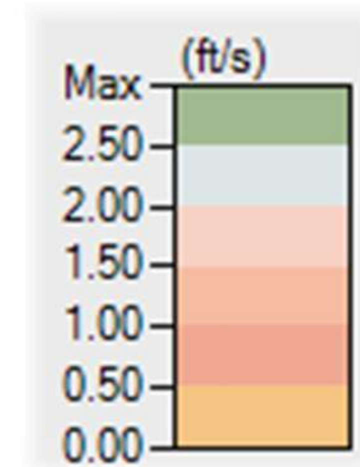
10-Year Storm

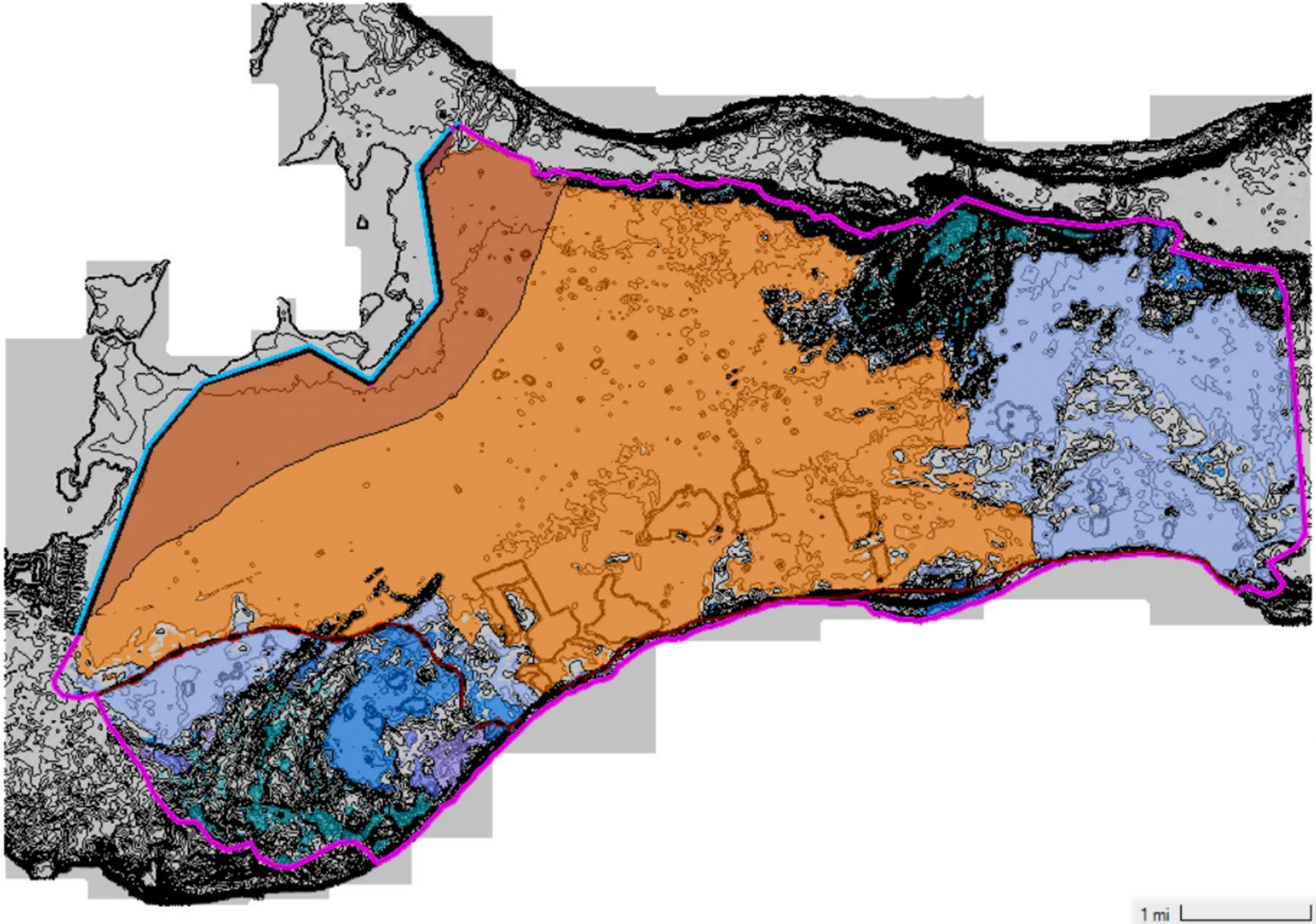
With Sea Rise

Maximum Velocity

With Model Terrain

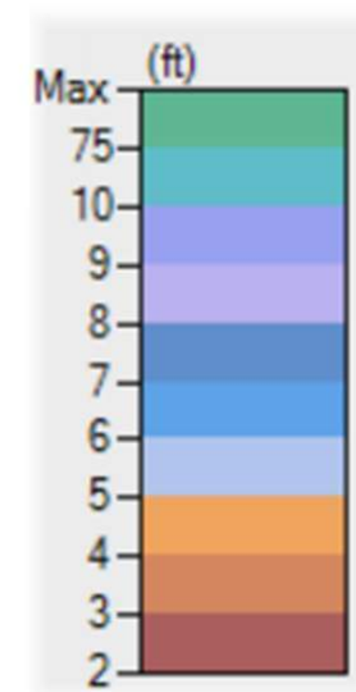






Alternative B4

10-Year Storm
Maximum Water Surface
Elevations With Model
Terrain



Alternative B4

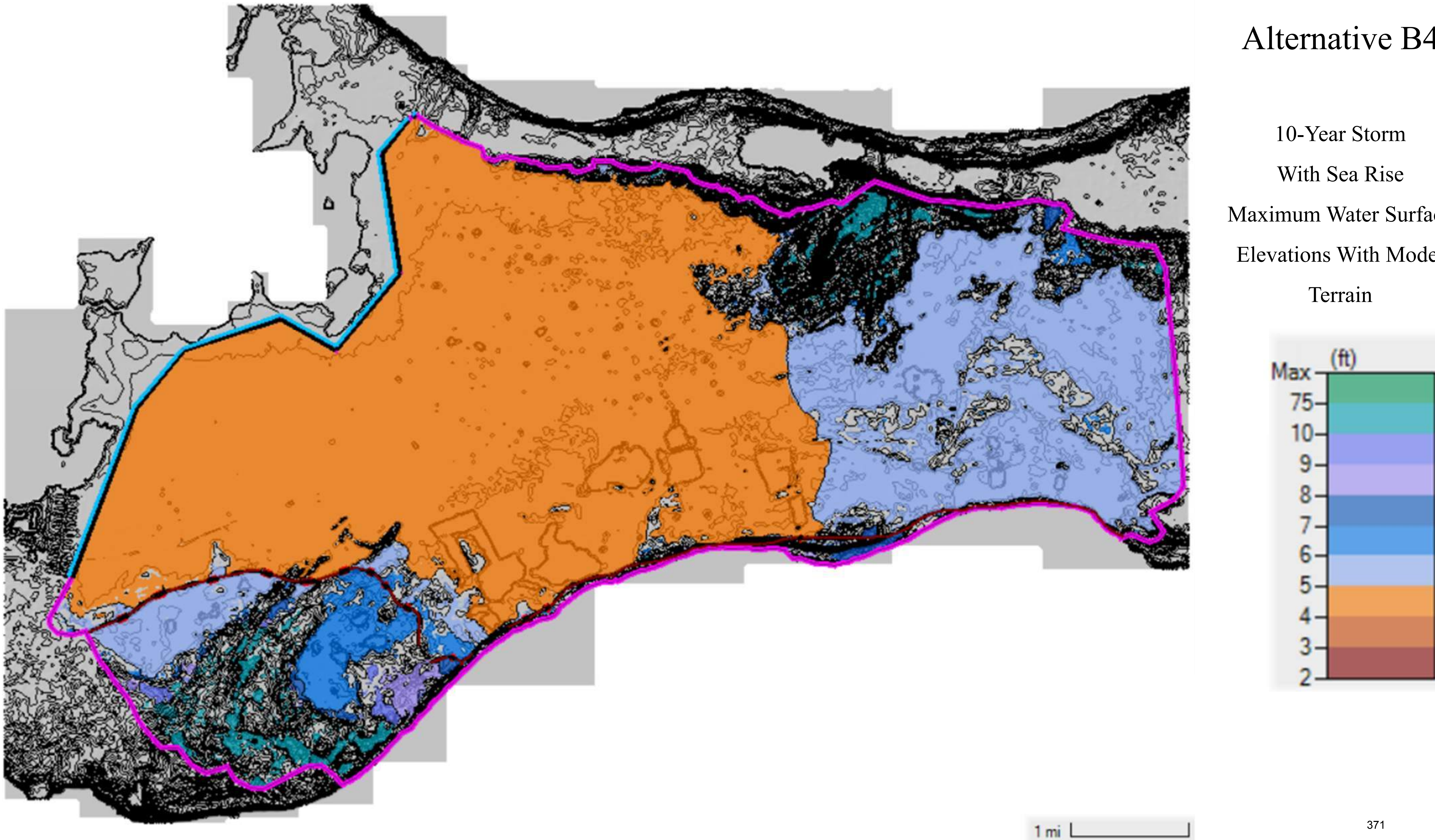
10-Year Storm

With Sea Rise

Maximum Water Surface

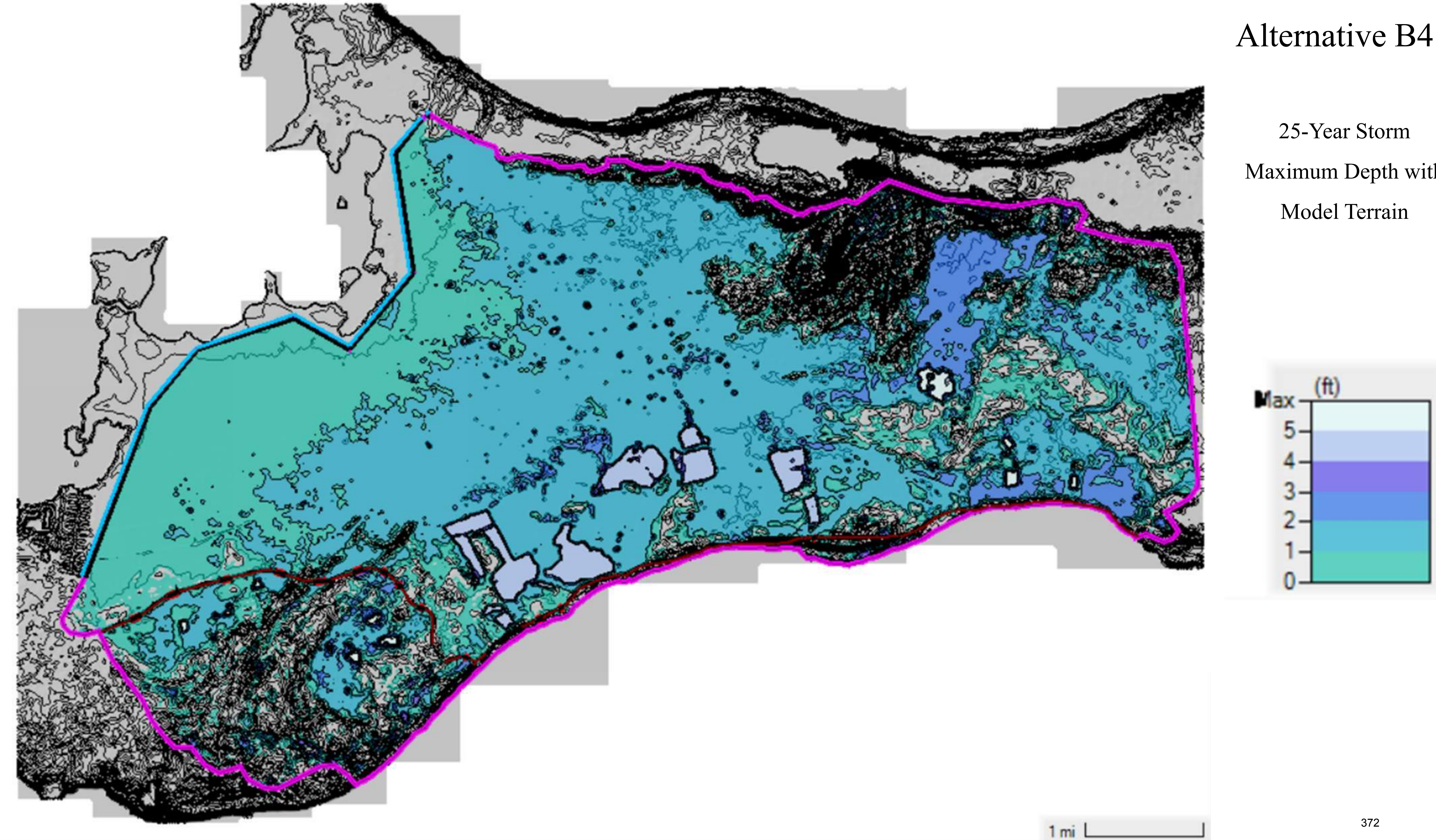
Elevations With Model

Terrain



Alternative B4

25-Year Storm
Maximum Depth with
Model Terrain



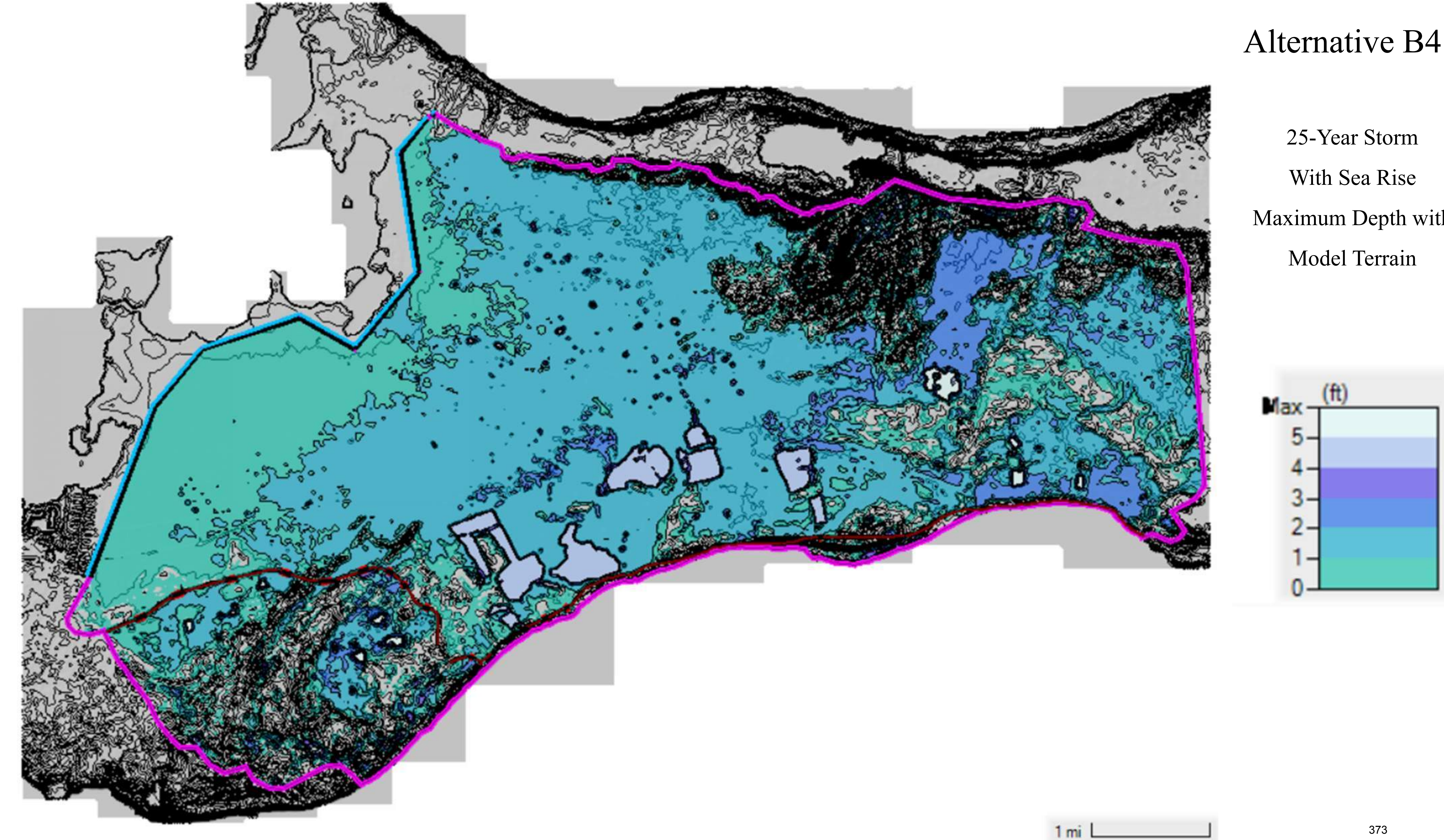
Alternative B4

25-Year Storm

With Sea Rise

Maximum Depth with

Model Terrain

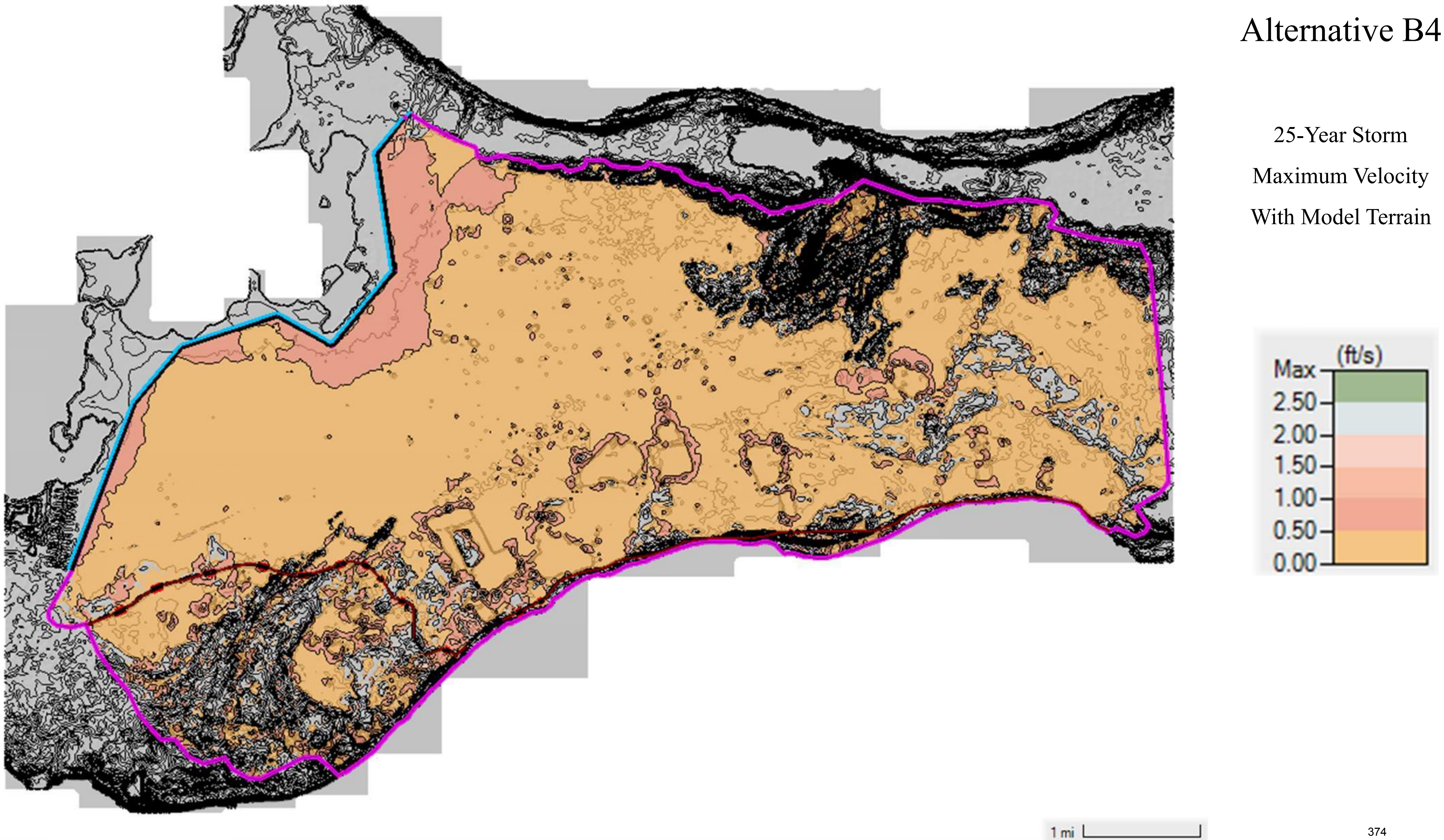


Alternative B4

25-Year Storm

Maximum Velocity

With Model Terrain



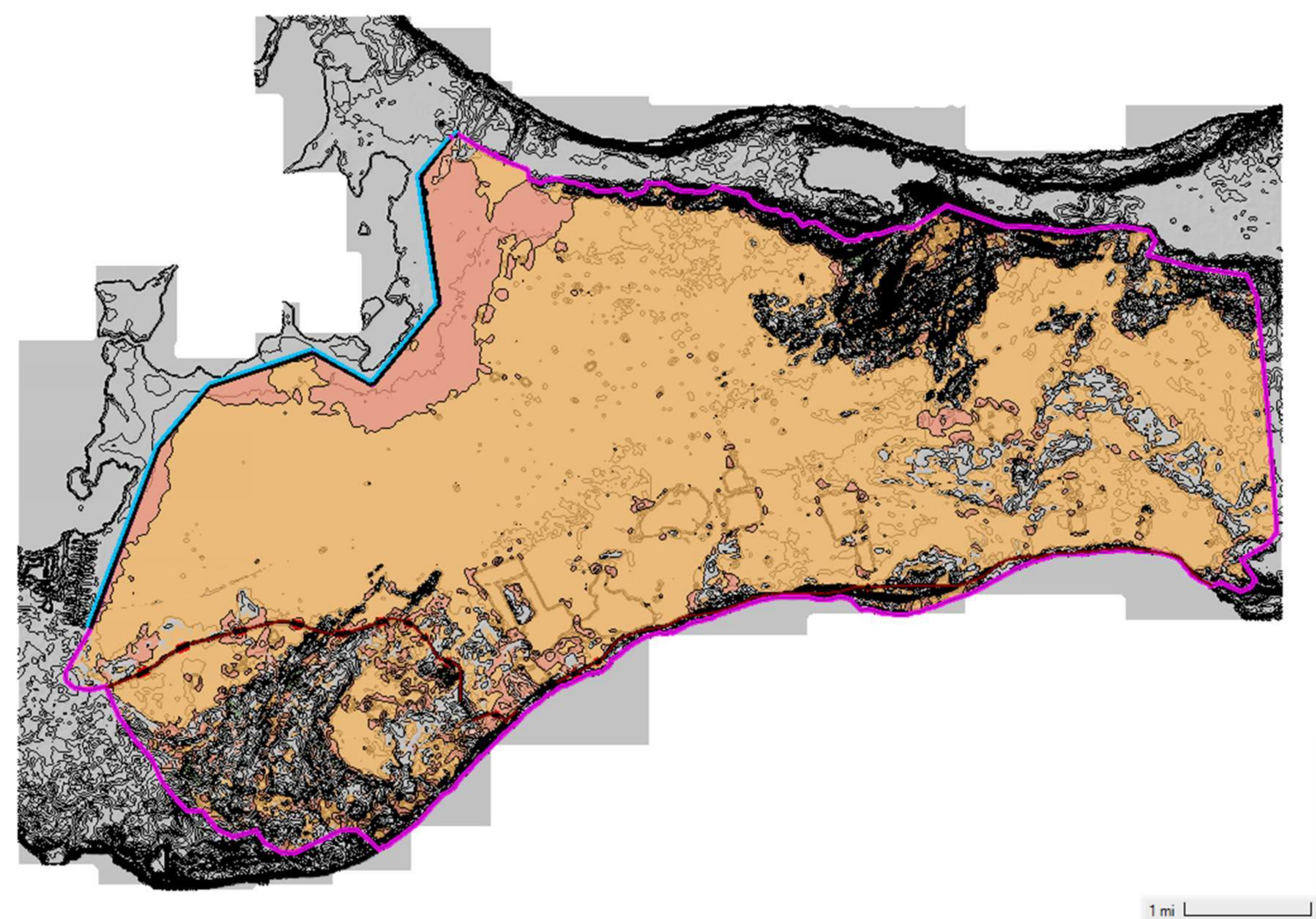
Alternative B4

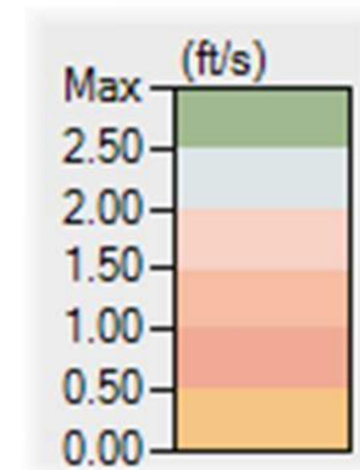
25-Year Storm

With Sea Rise

Maximum Velocity

With Model Terrain

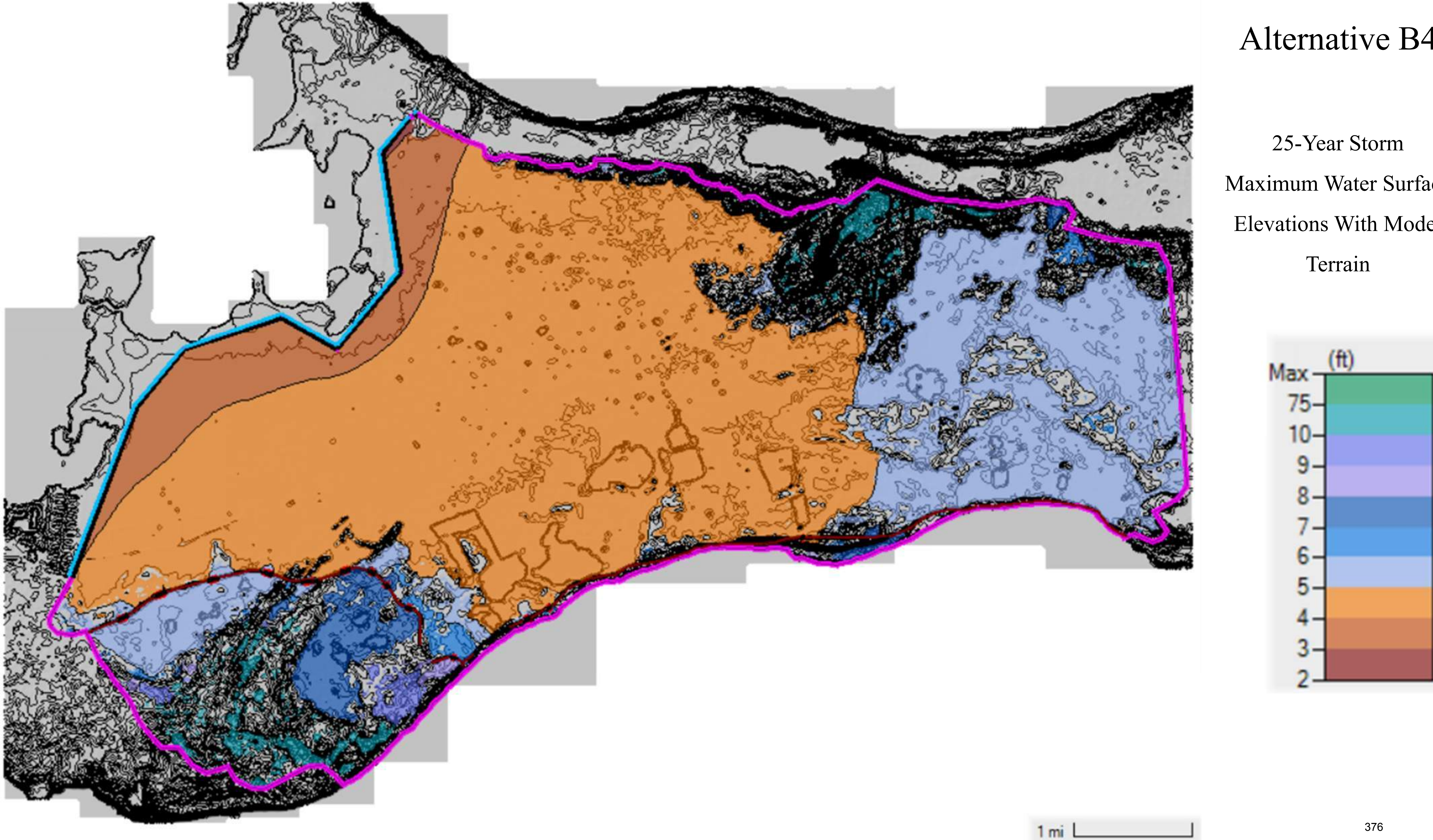




Alternative B4

25-Year Storm

Maximum Water Surface Elevations With Model Terrain



Alternative B4

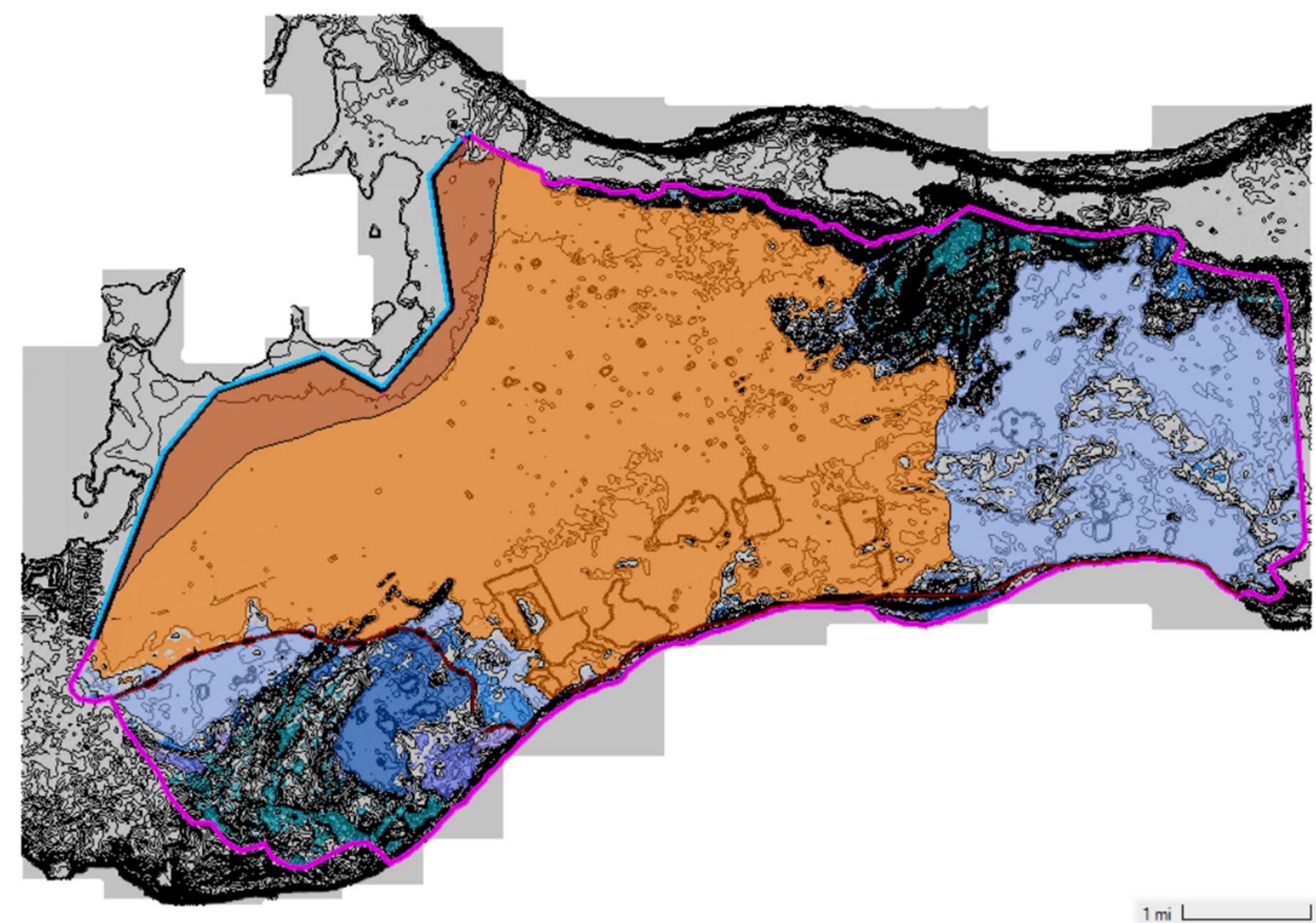
25-Year Storm

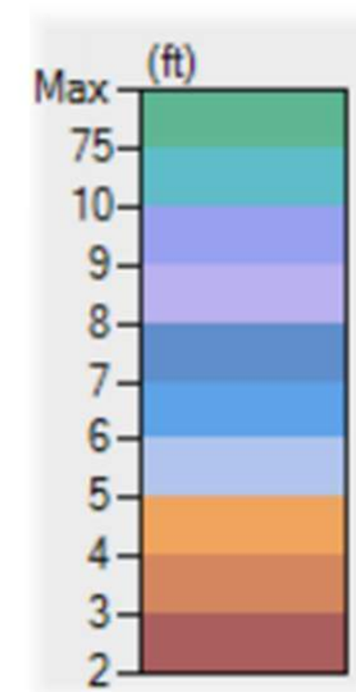
With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain



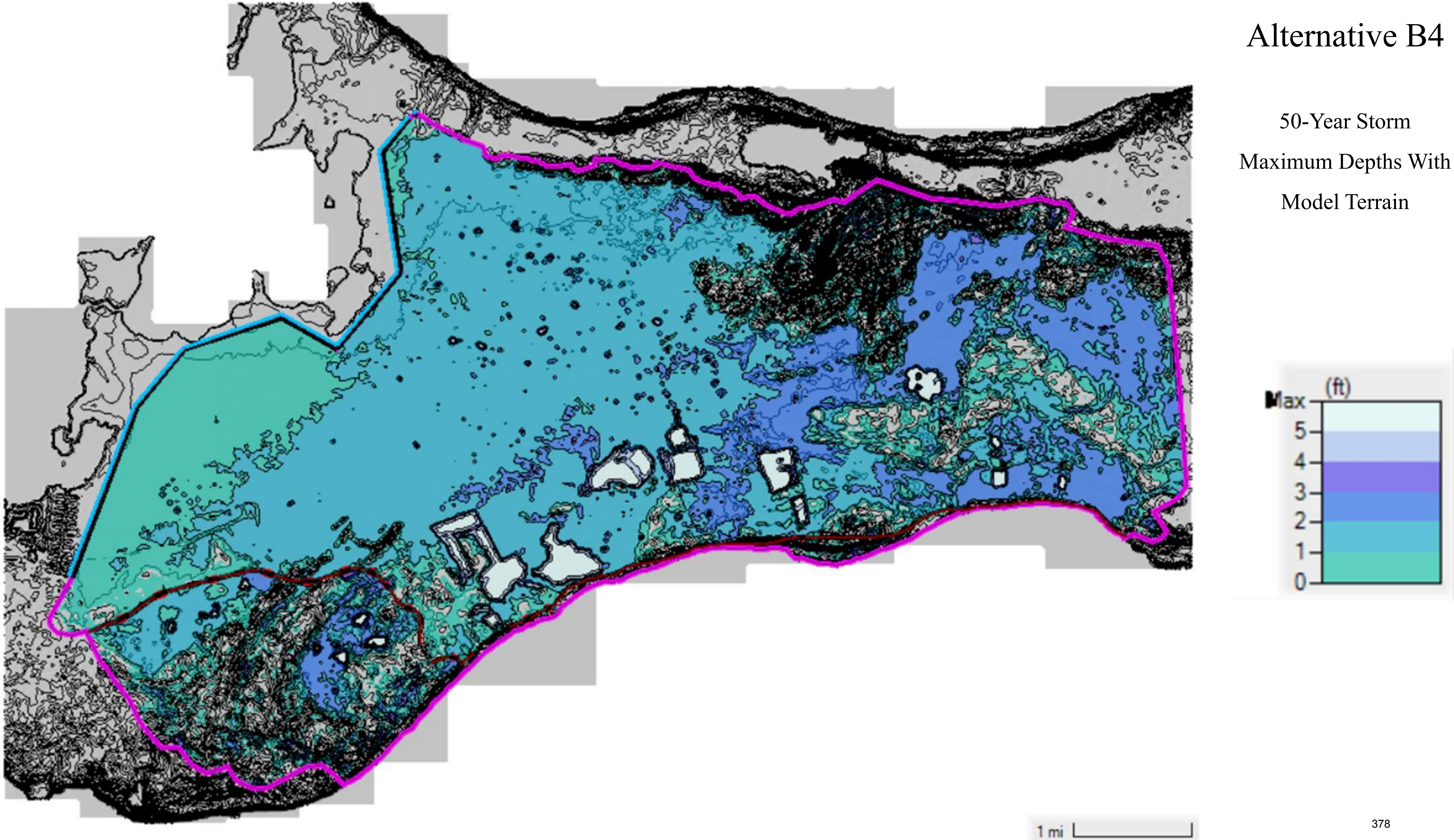


Alternative B4

50-Year Storm

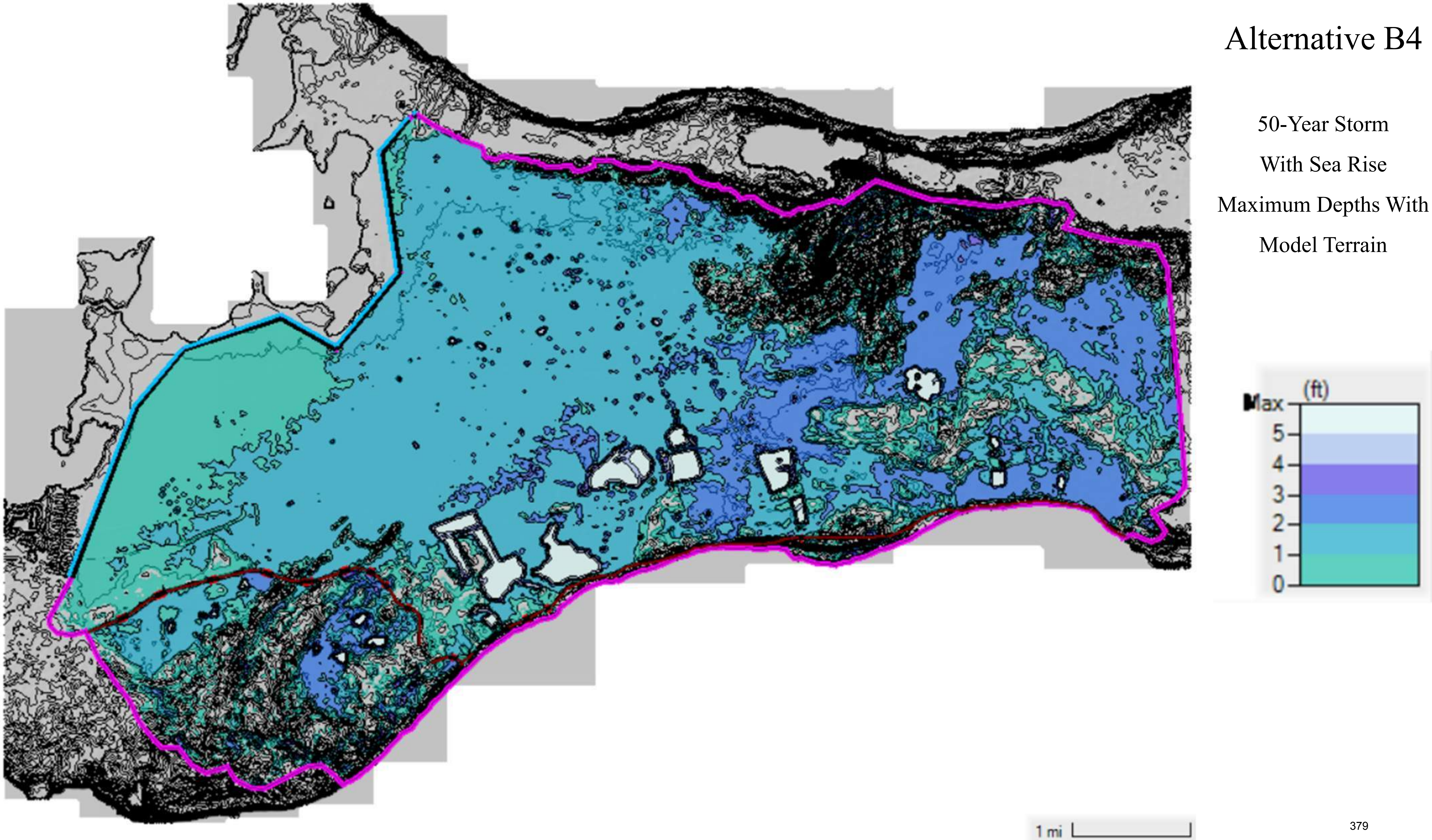
Maximum Depths With

Model Terrain



Alternative B4

50-Year Storm
With Sea Rise
Maximum Depths With
Model Terrain

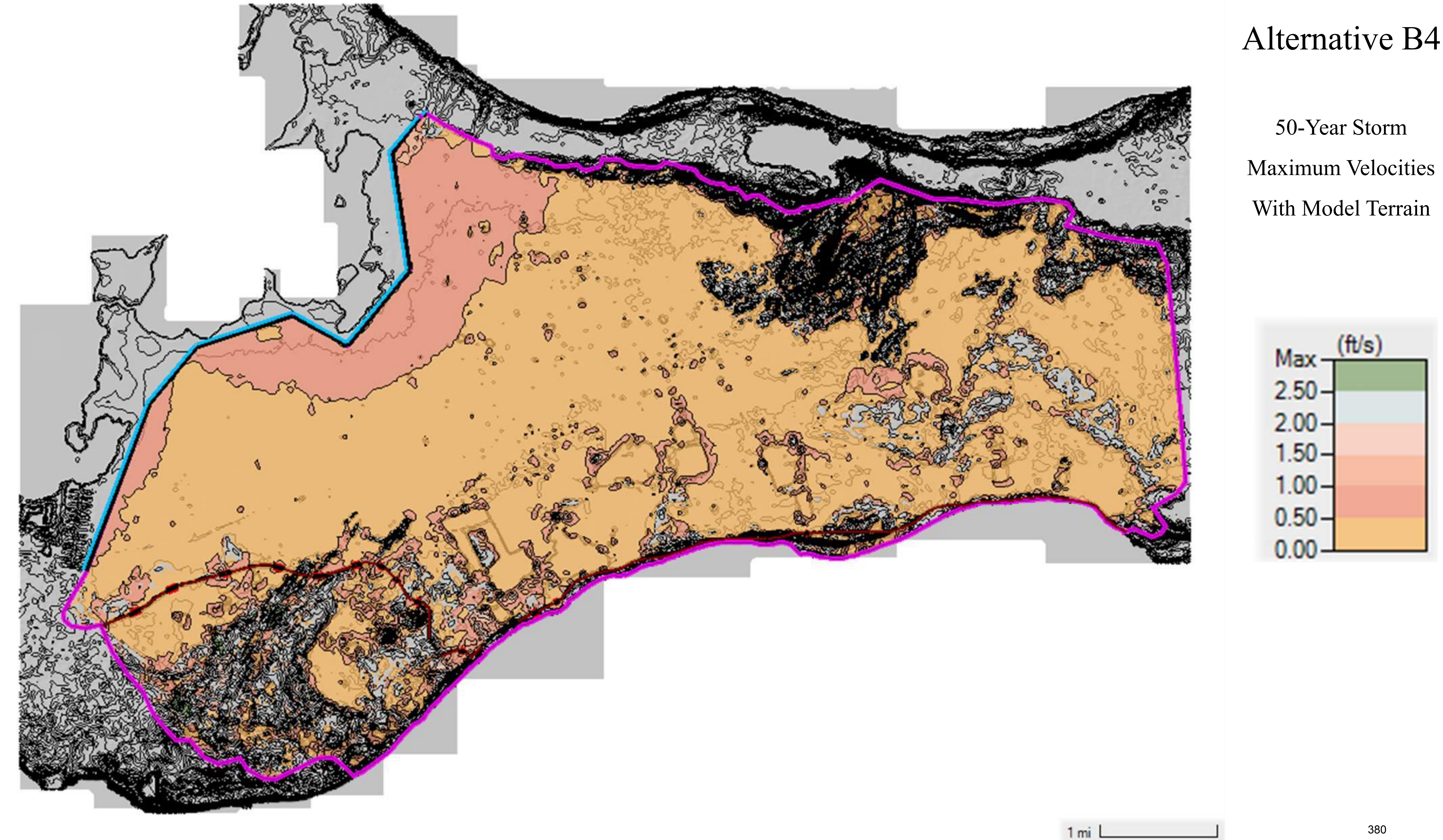


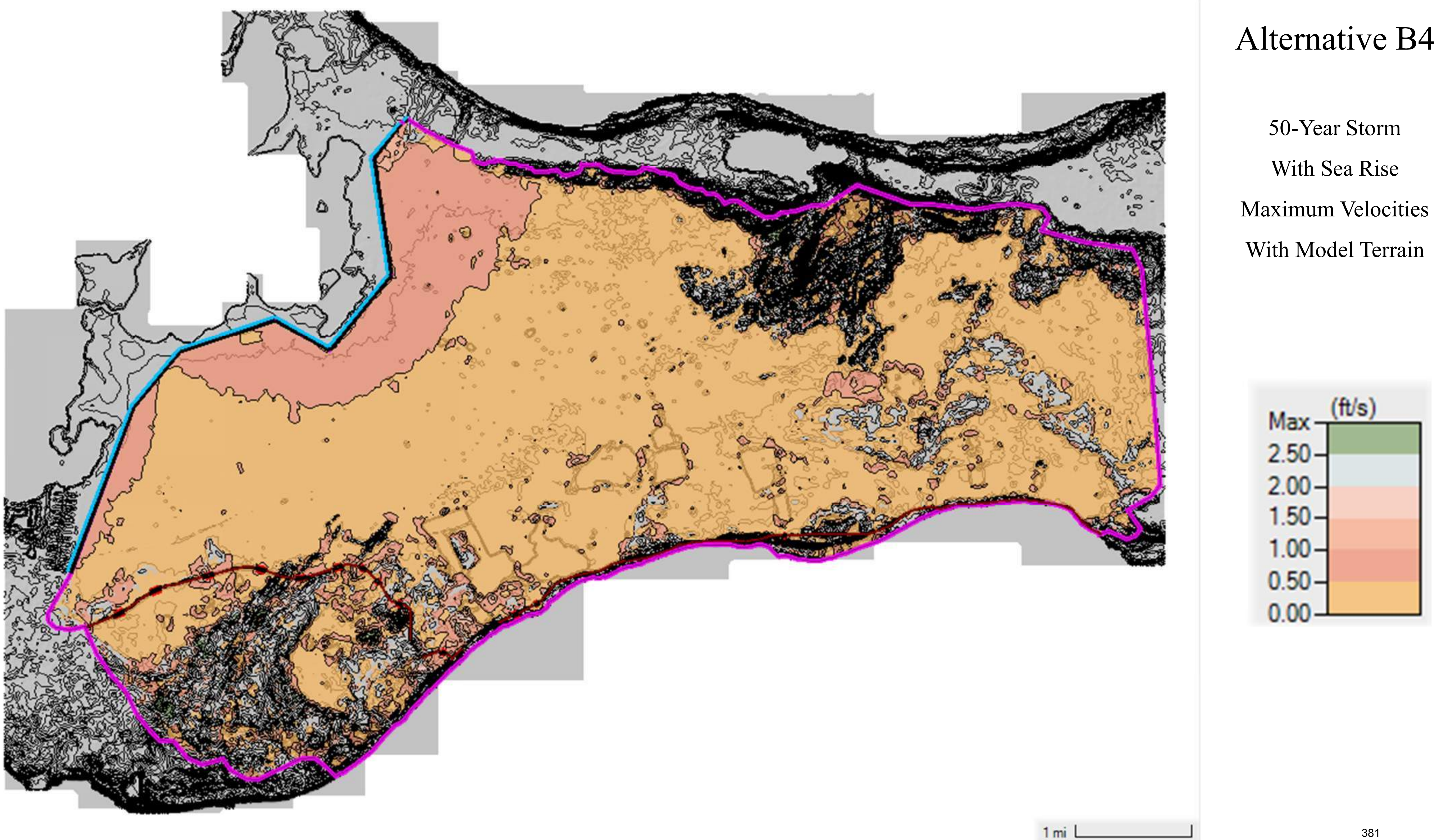
Alternative B4

50-Year Storm

Maximum Velocities

With Model Terrain





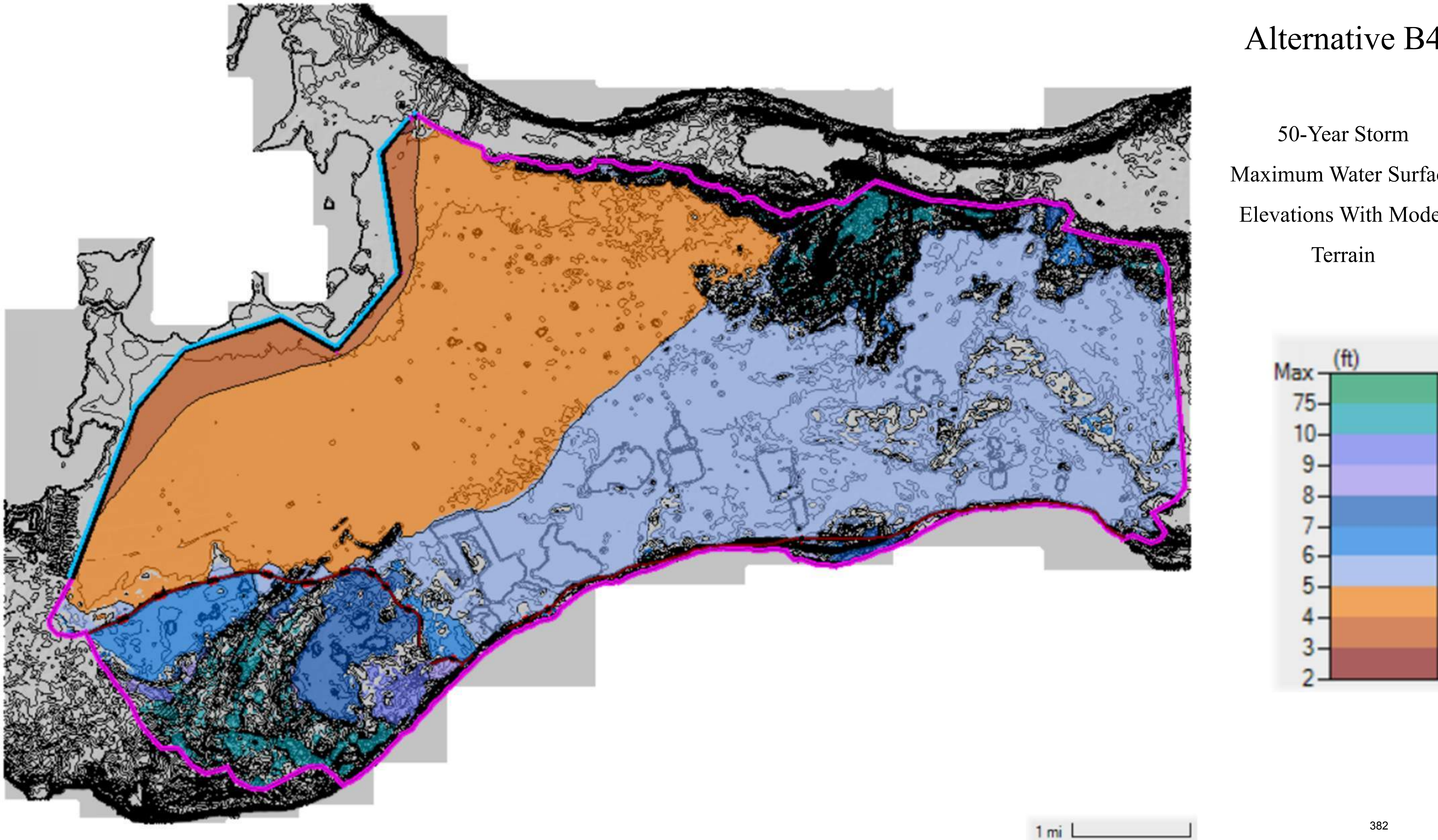
Alternative B4

50-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain



Alternative B4

50-Year Storm
Maximum Water Surface Elevations With Model Terrain

Alternative B4

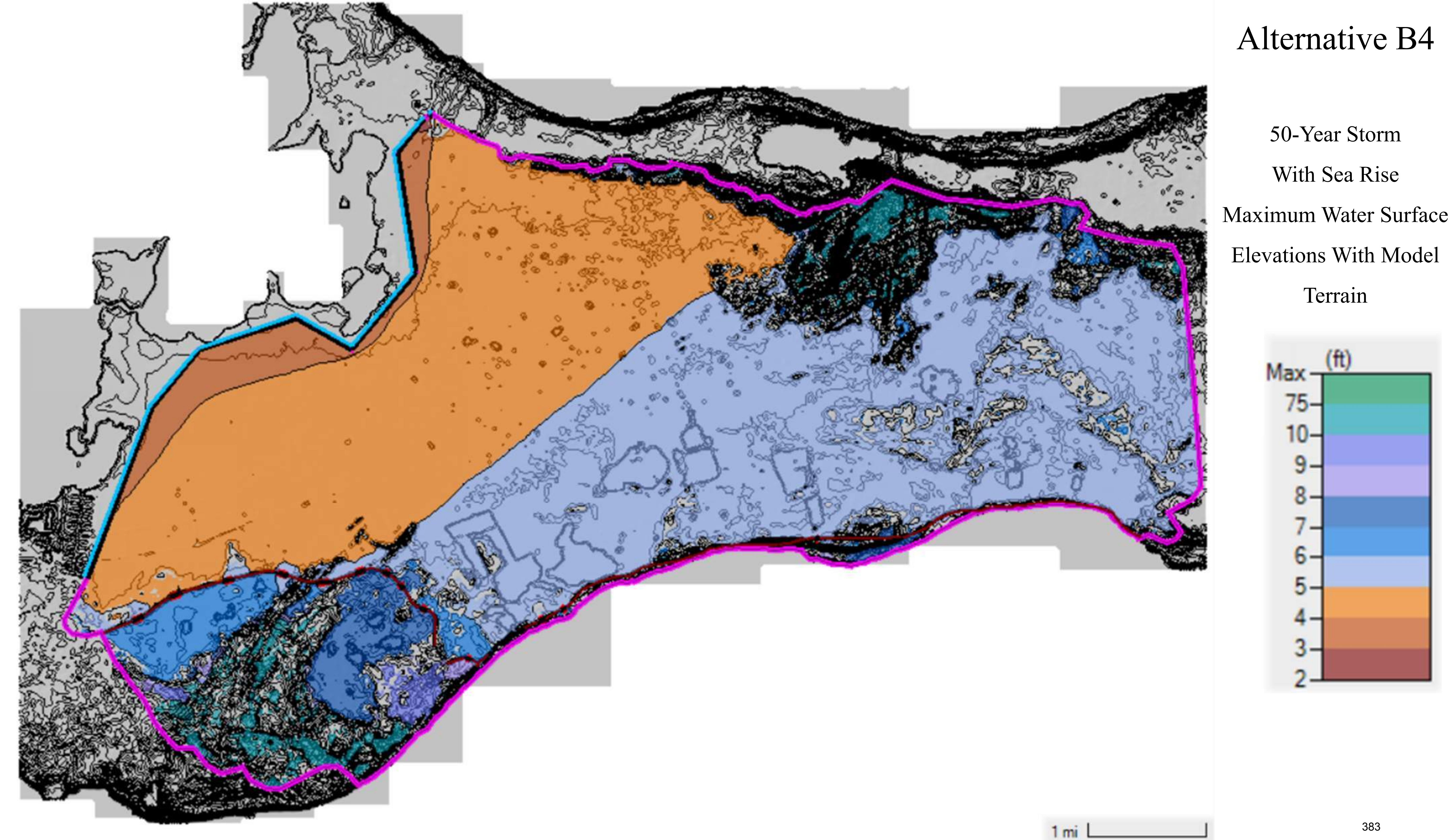
50-Year Storm

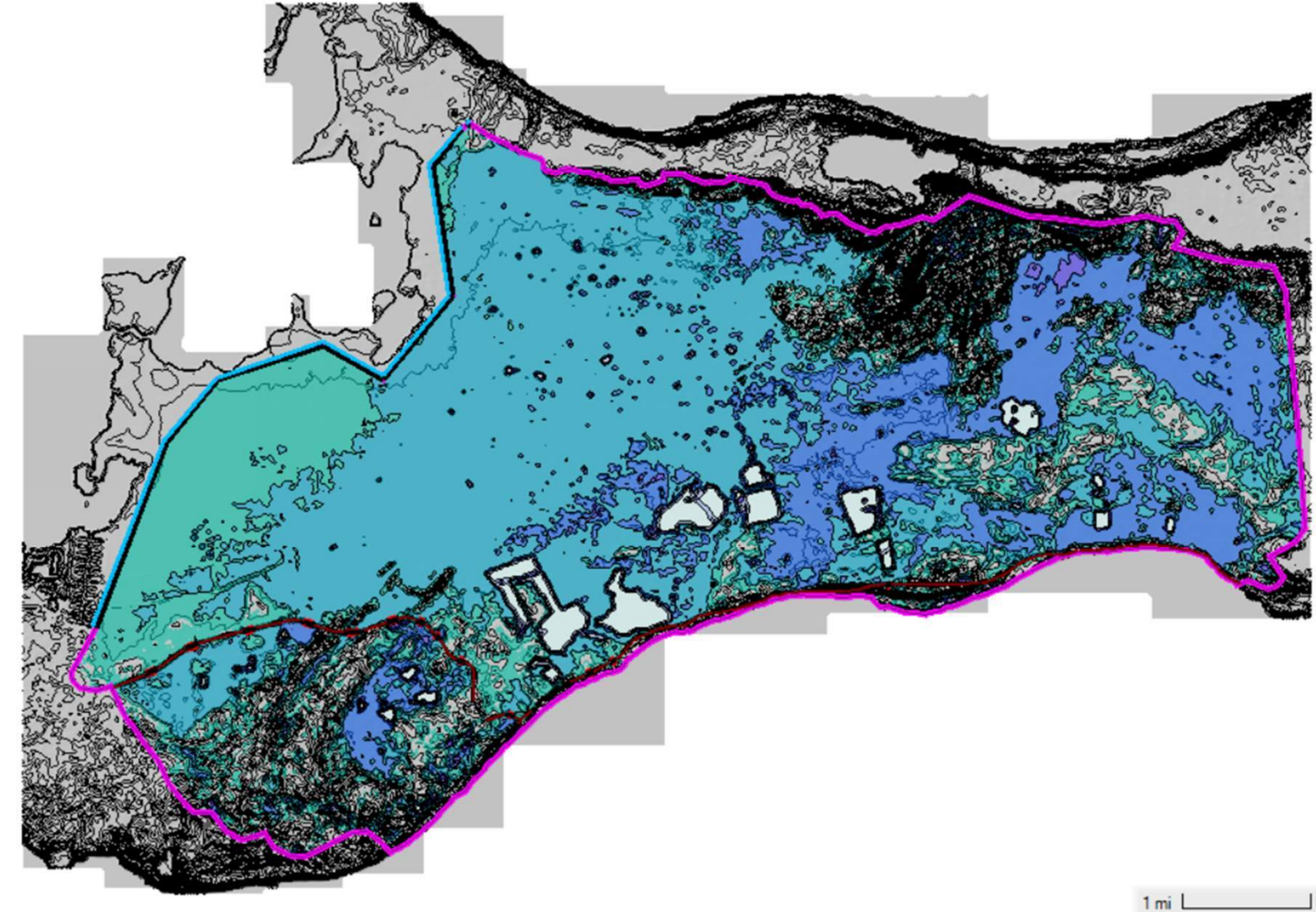
With Sea Rise

Maximum Water Surface

Elevations With Model

Terrain



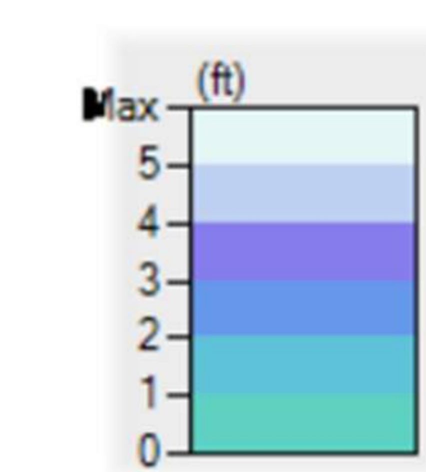


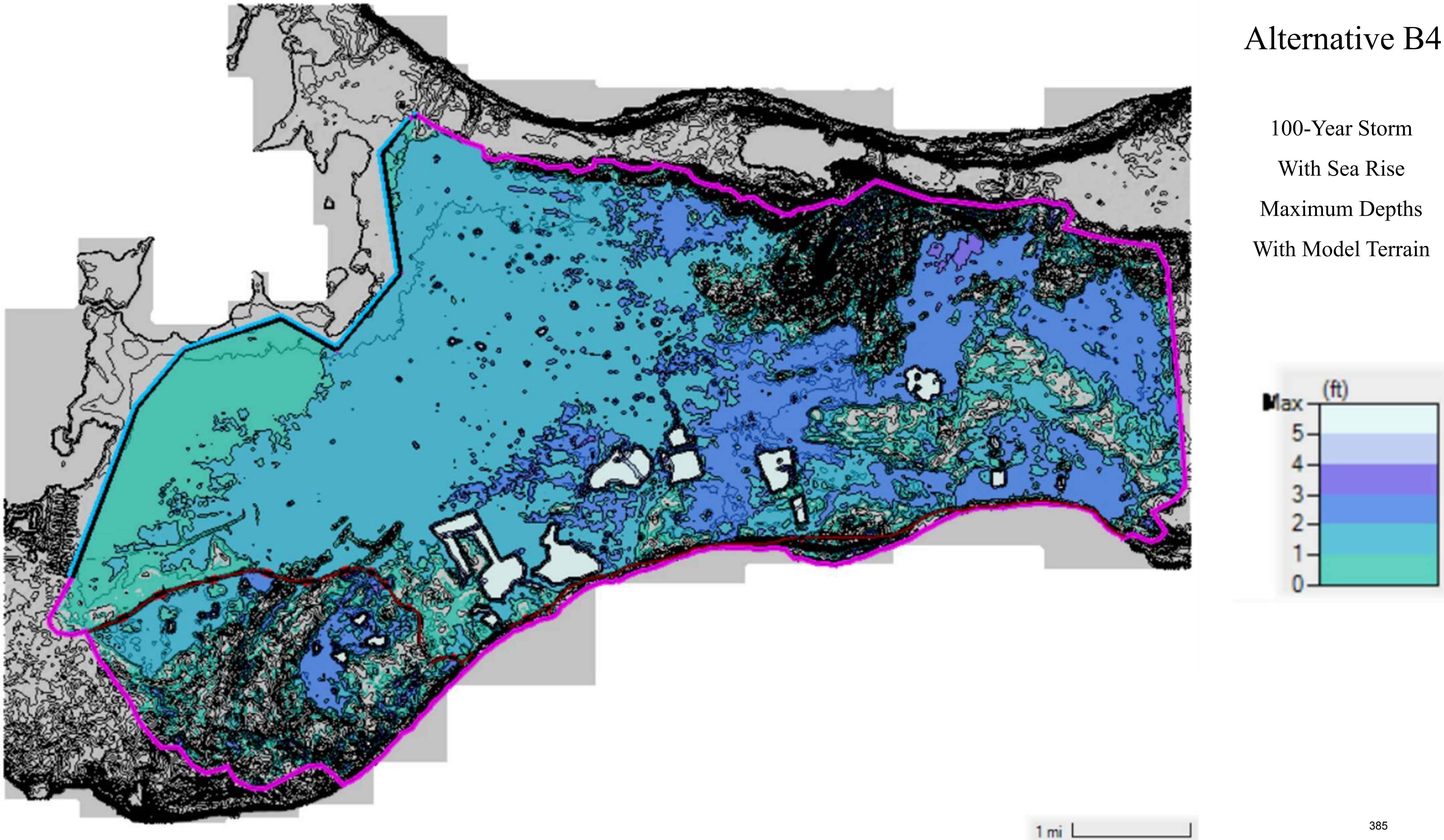
Alternative B4

100-Year Storm

Maximum Depths

With Model Terrain



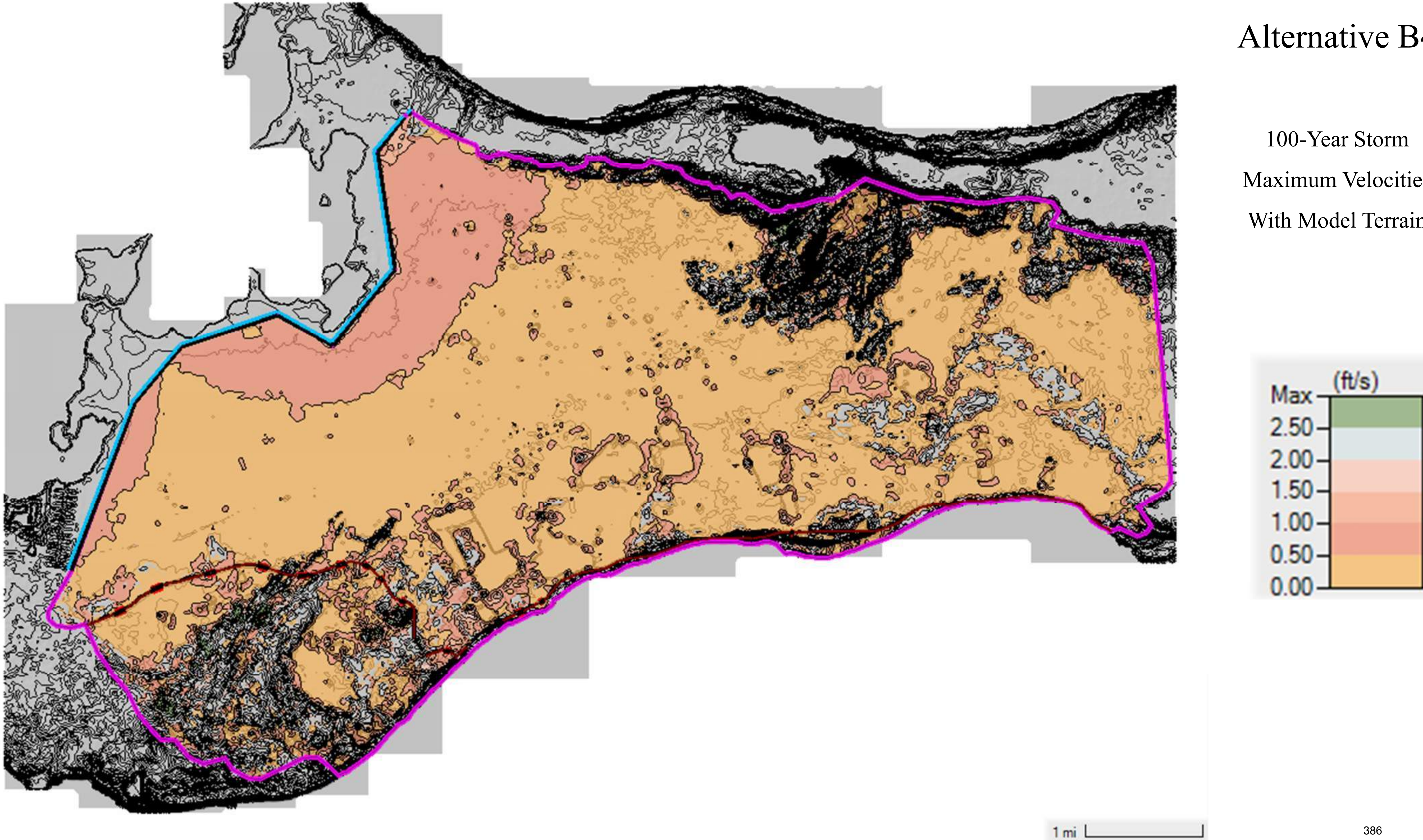

Alternative B4
100-Year Storm
With Sea Rise
Maximum Depths
With Model Terrain
(ft)
Max
5
4
3
2
1
0
1 mi

Alternative B4

100-Year Storm

Maximum Velocities

With Model Terrain



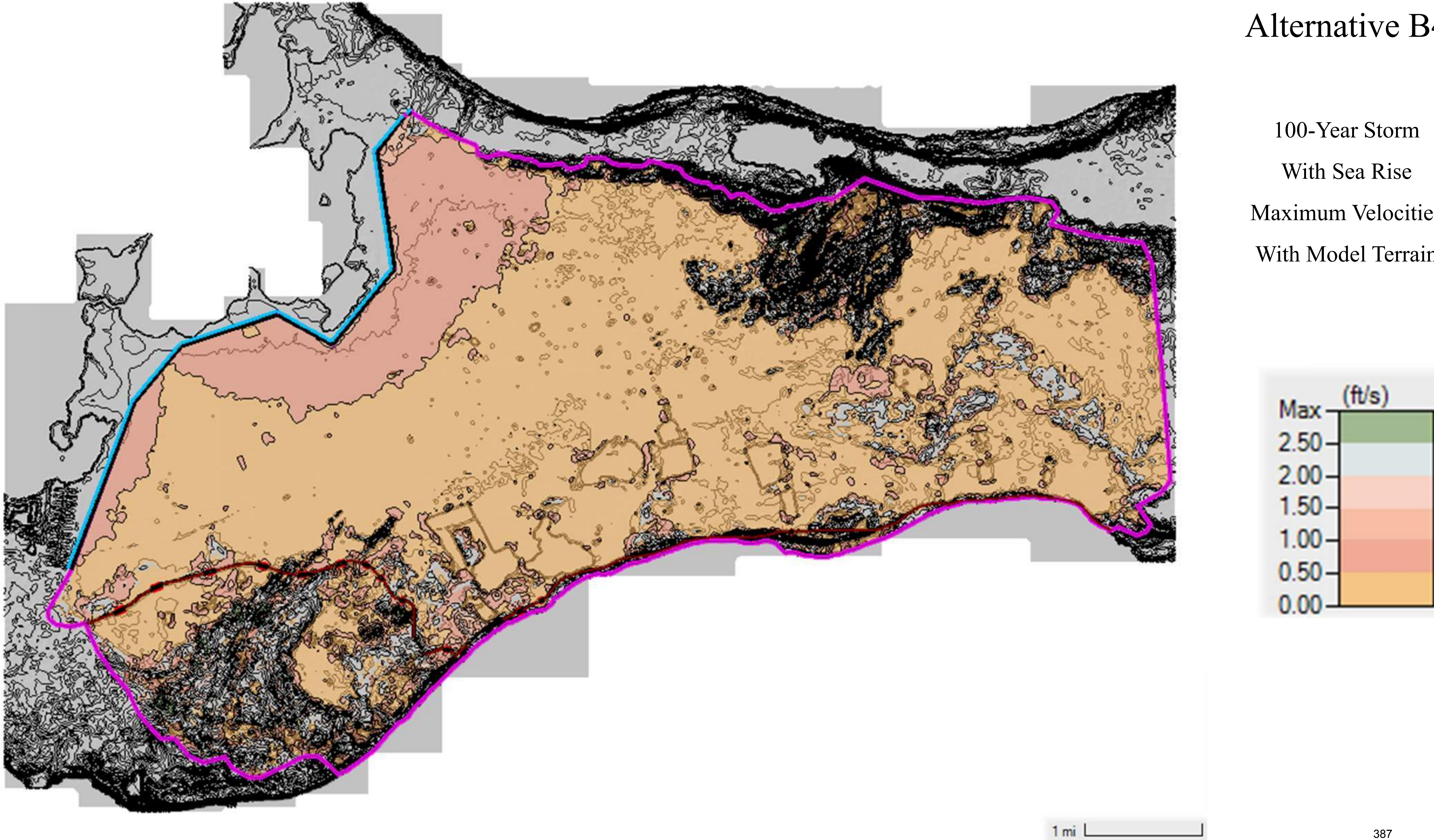
Alternative B4

100-Year Storm

With Sea Rise

Maximum Velocities

With Model Terrain



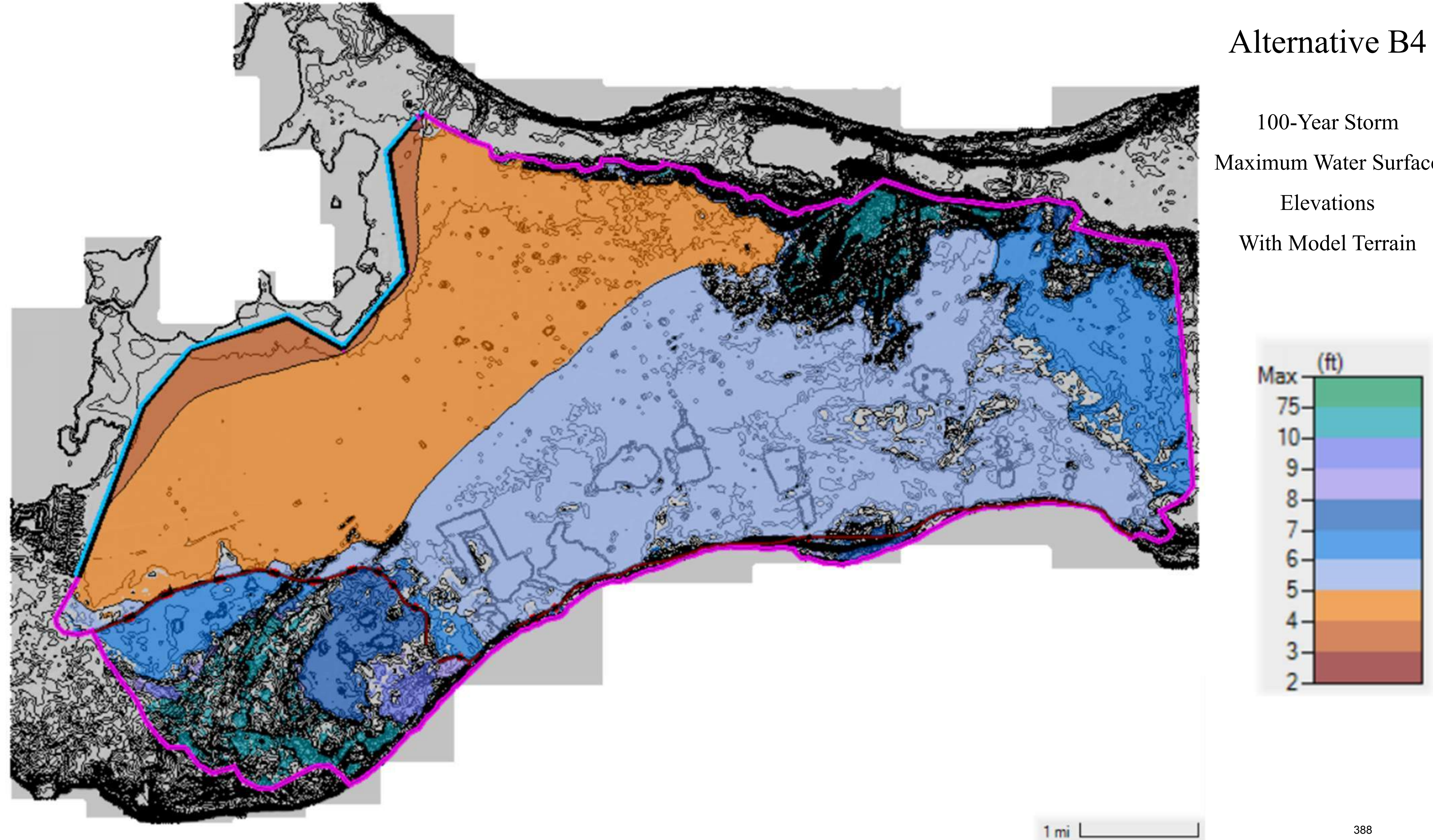
Alternative B4

100-Year Storm

Maximum Water Surface

Elevations

With Model Terrain



Alternative B4

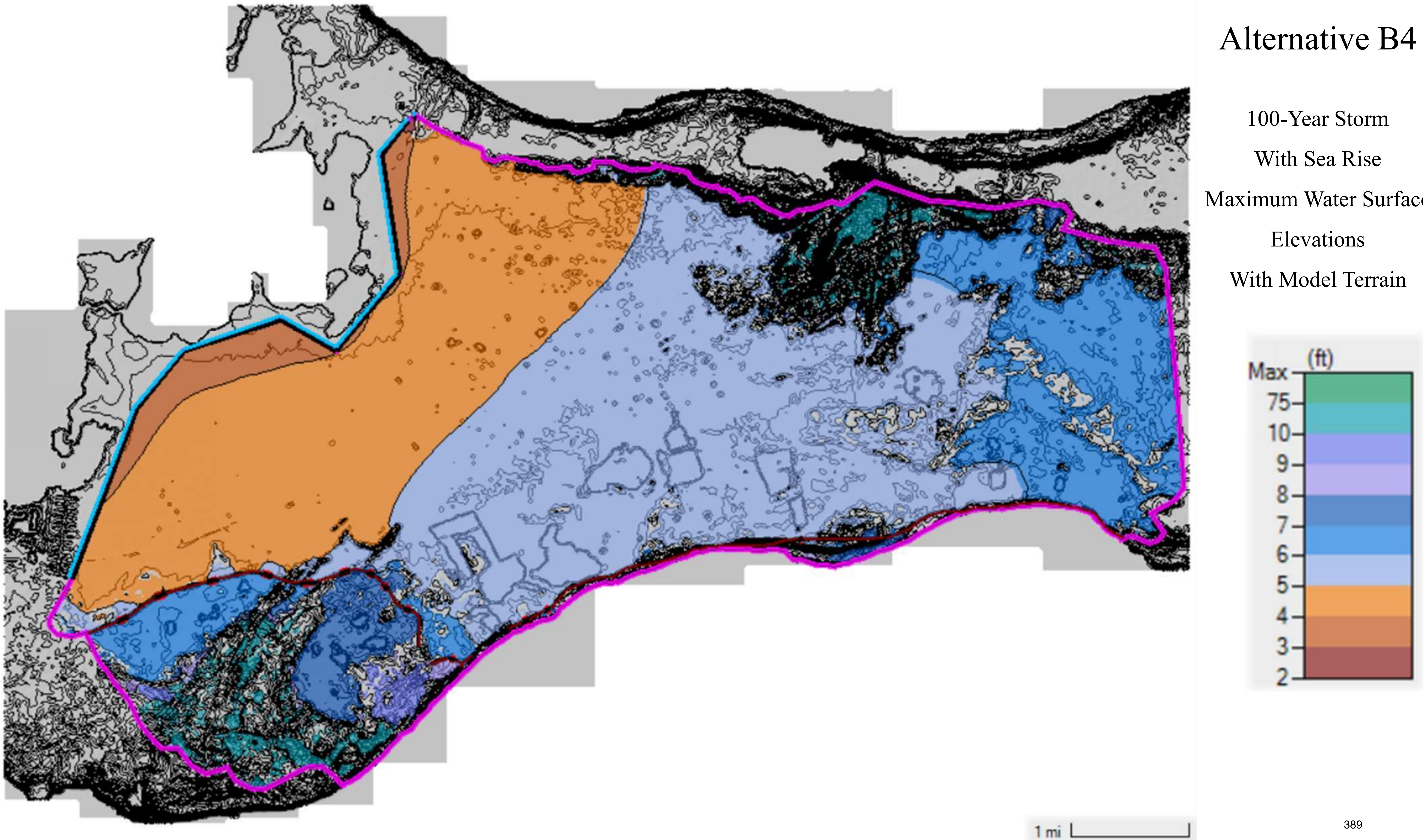
100-Year Storm

With Sea Rise

Maximum Water Surface

Elevations

With Model Terrain

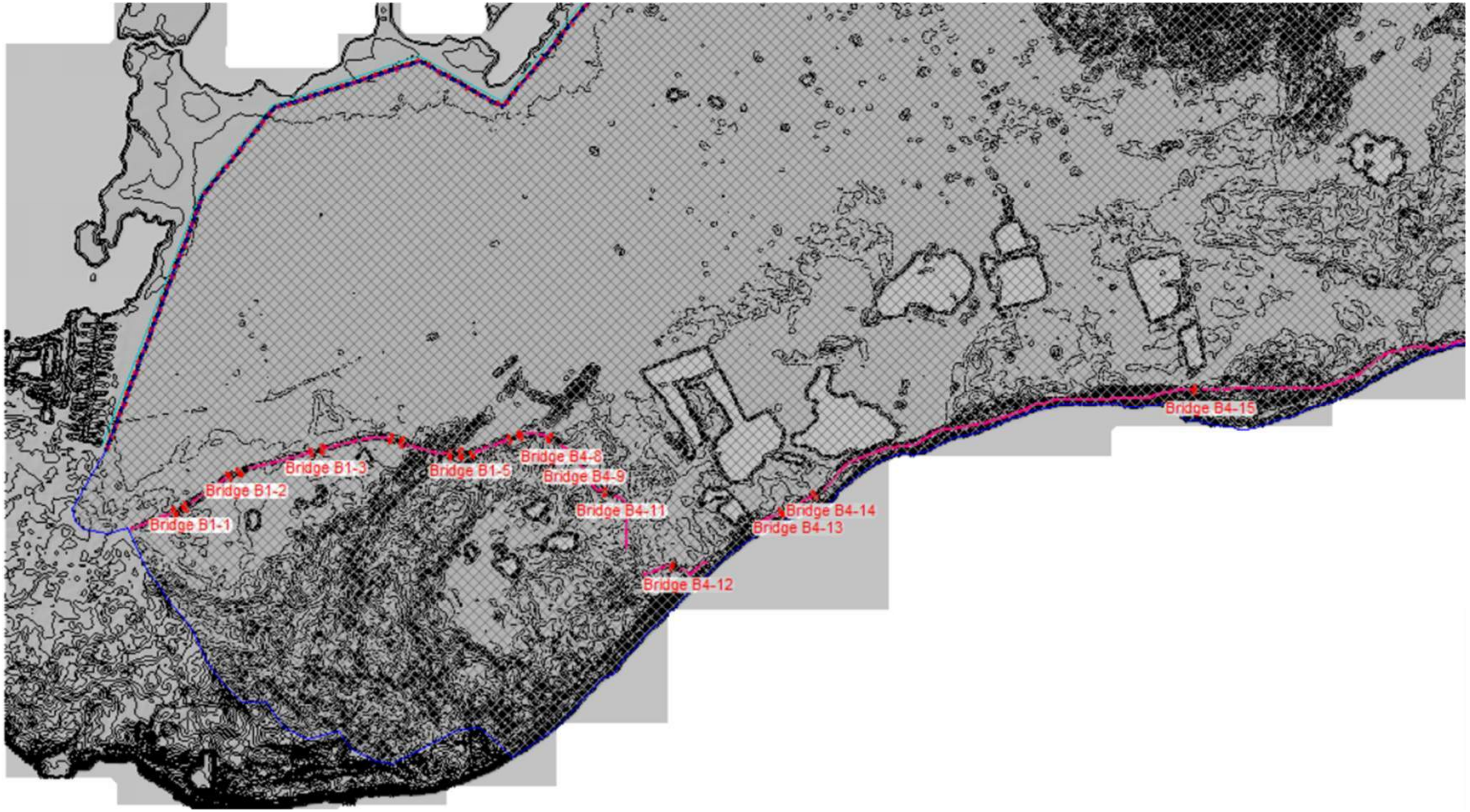


Alternative B4

Profiles

Alternative B4

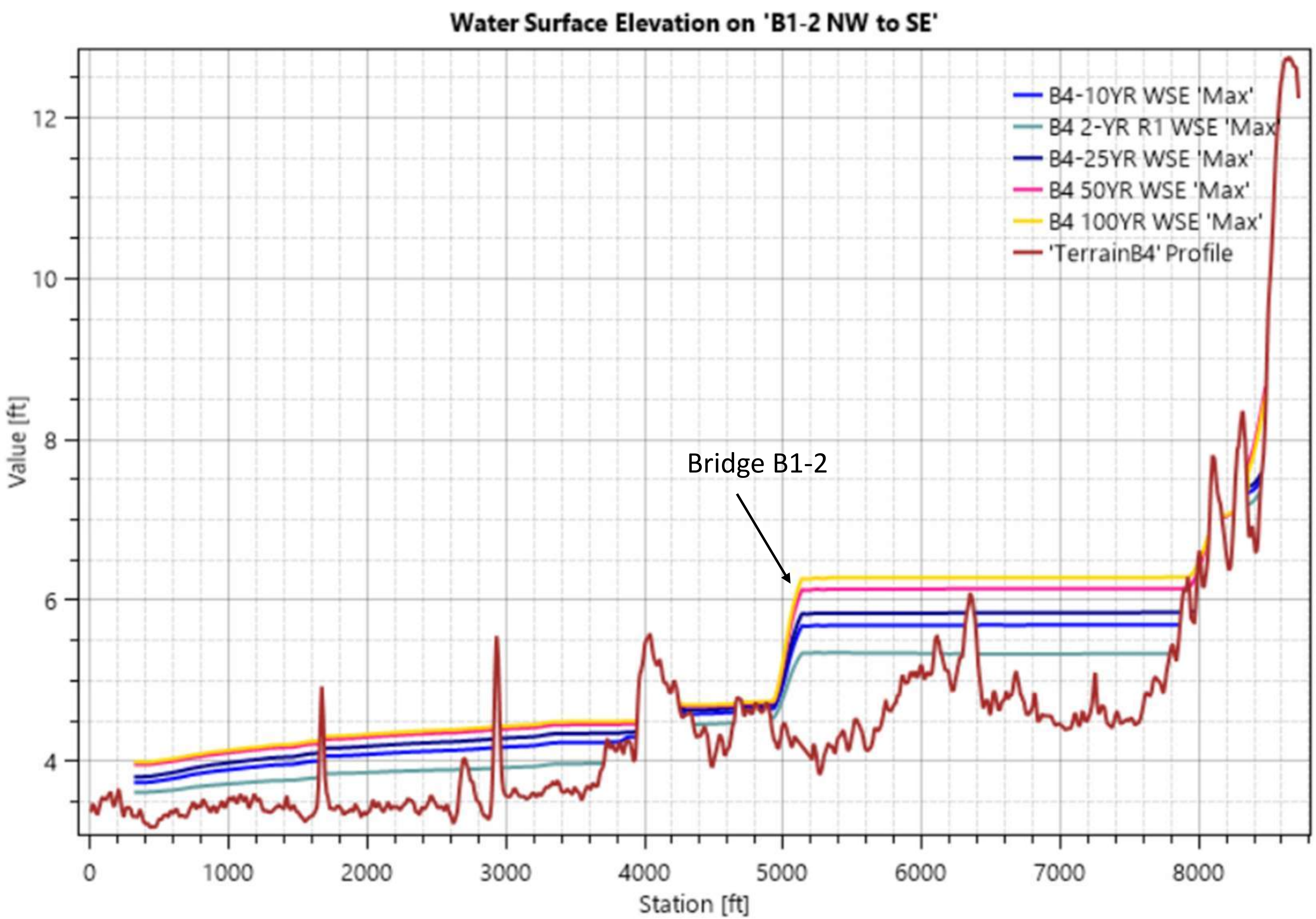
Bridges



Alternative B4

Profile B1-2

From NW to SE

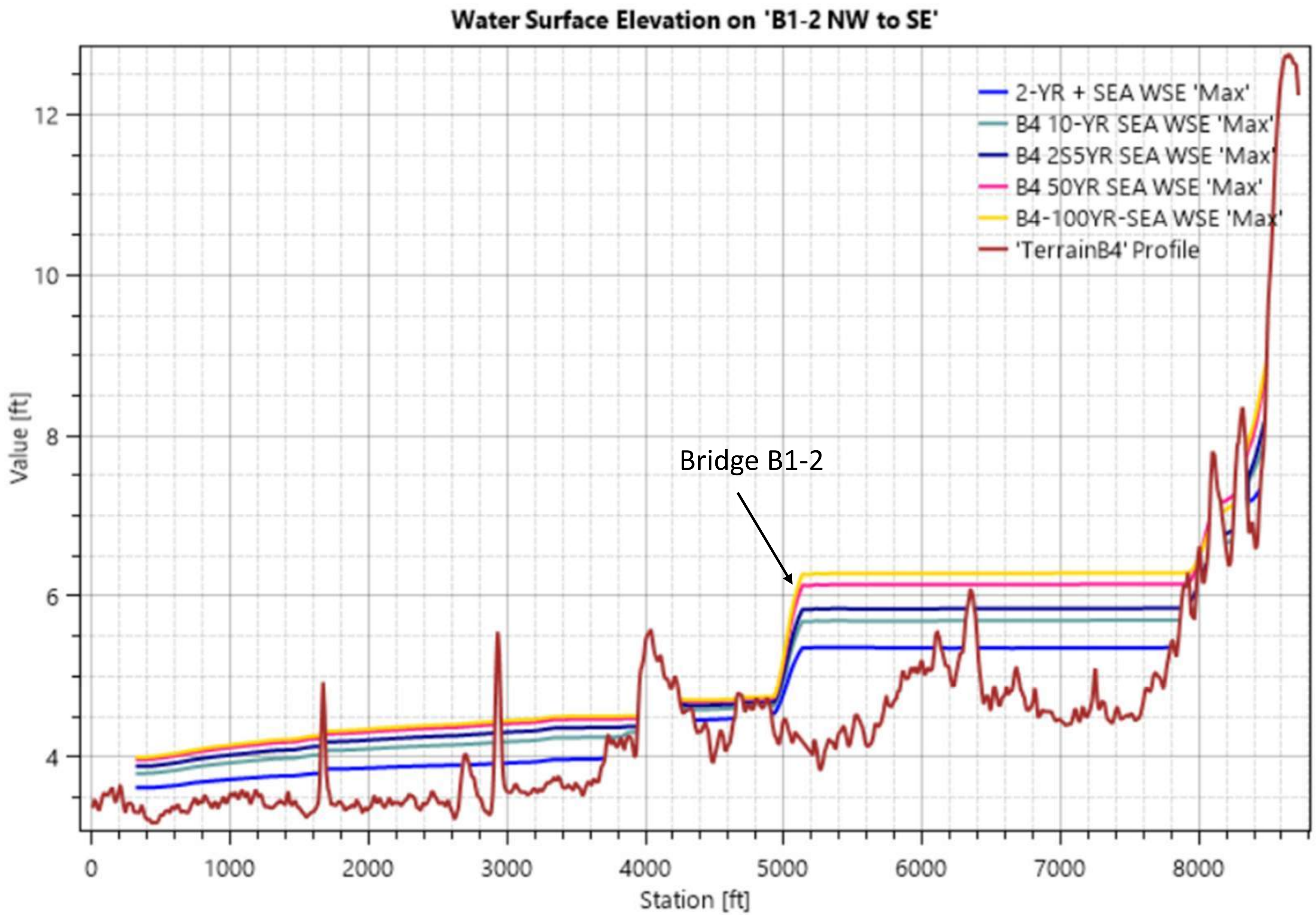


Alternative B4

Profile B1-2

With Sea Rise

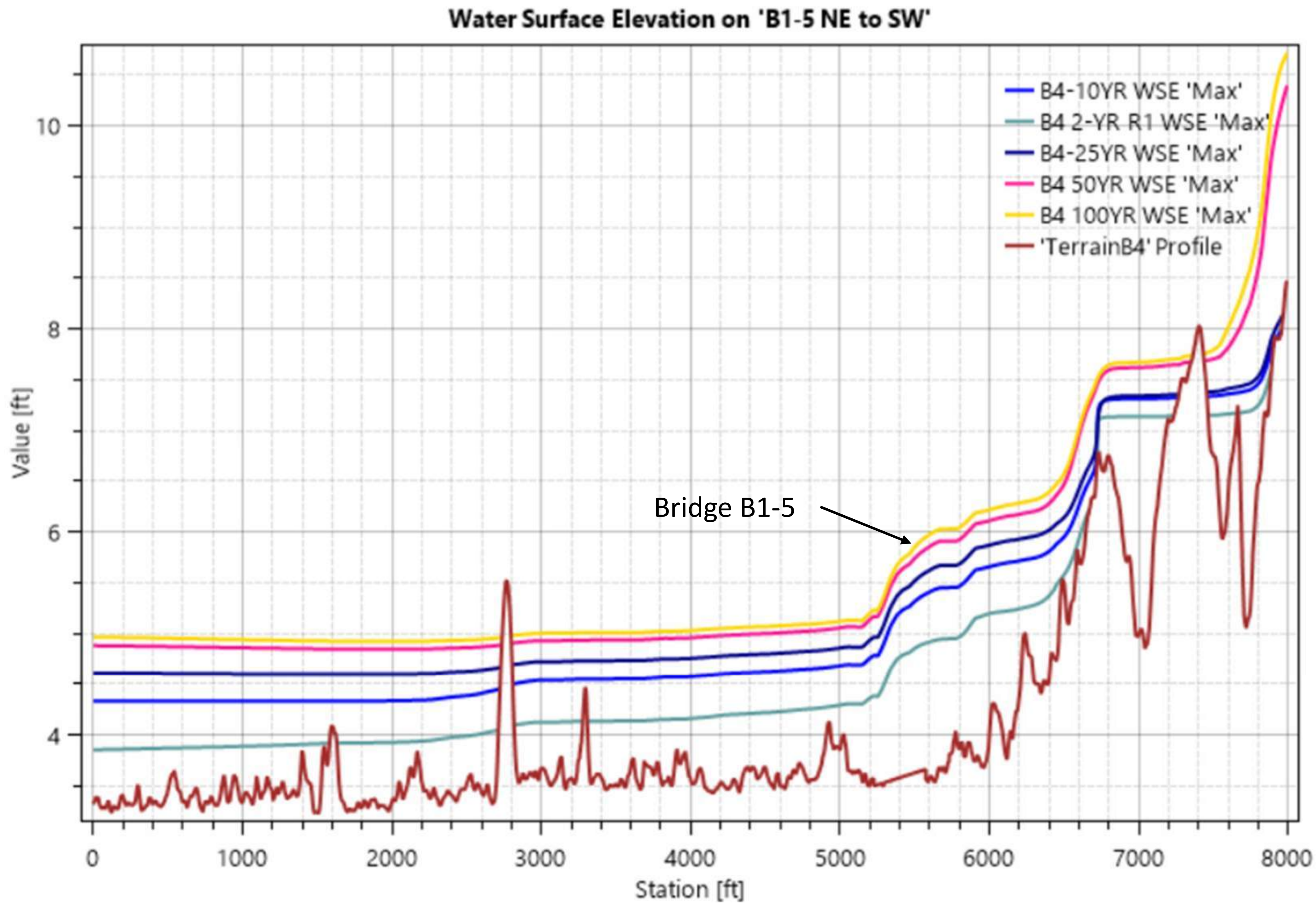
From NW to SE

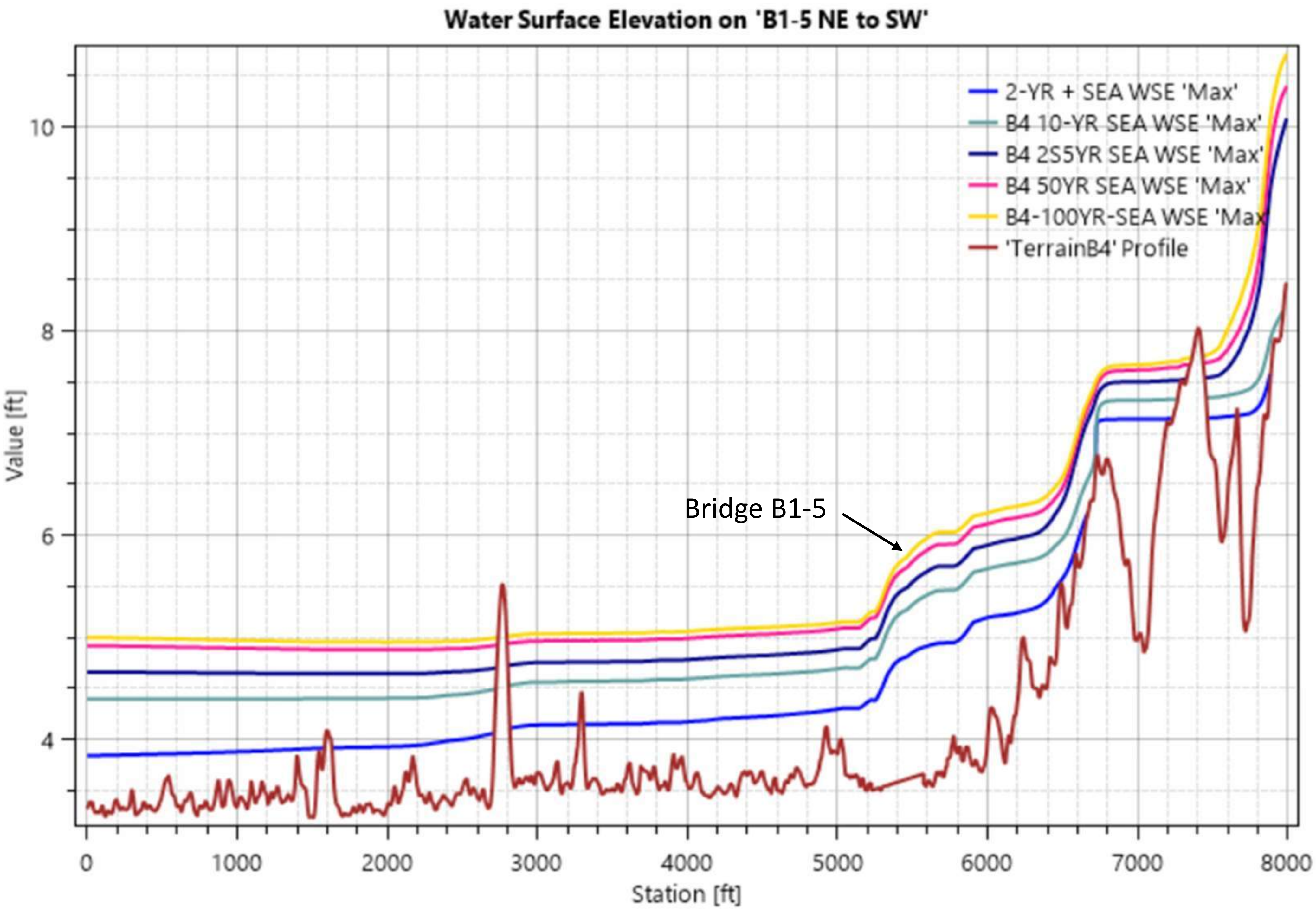


Alternative B4

Profile B1-5

From NE to SW





Alternative B4

Profile B1-5

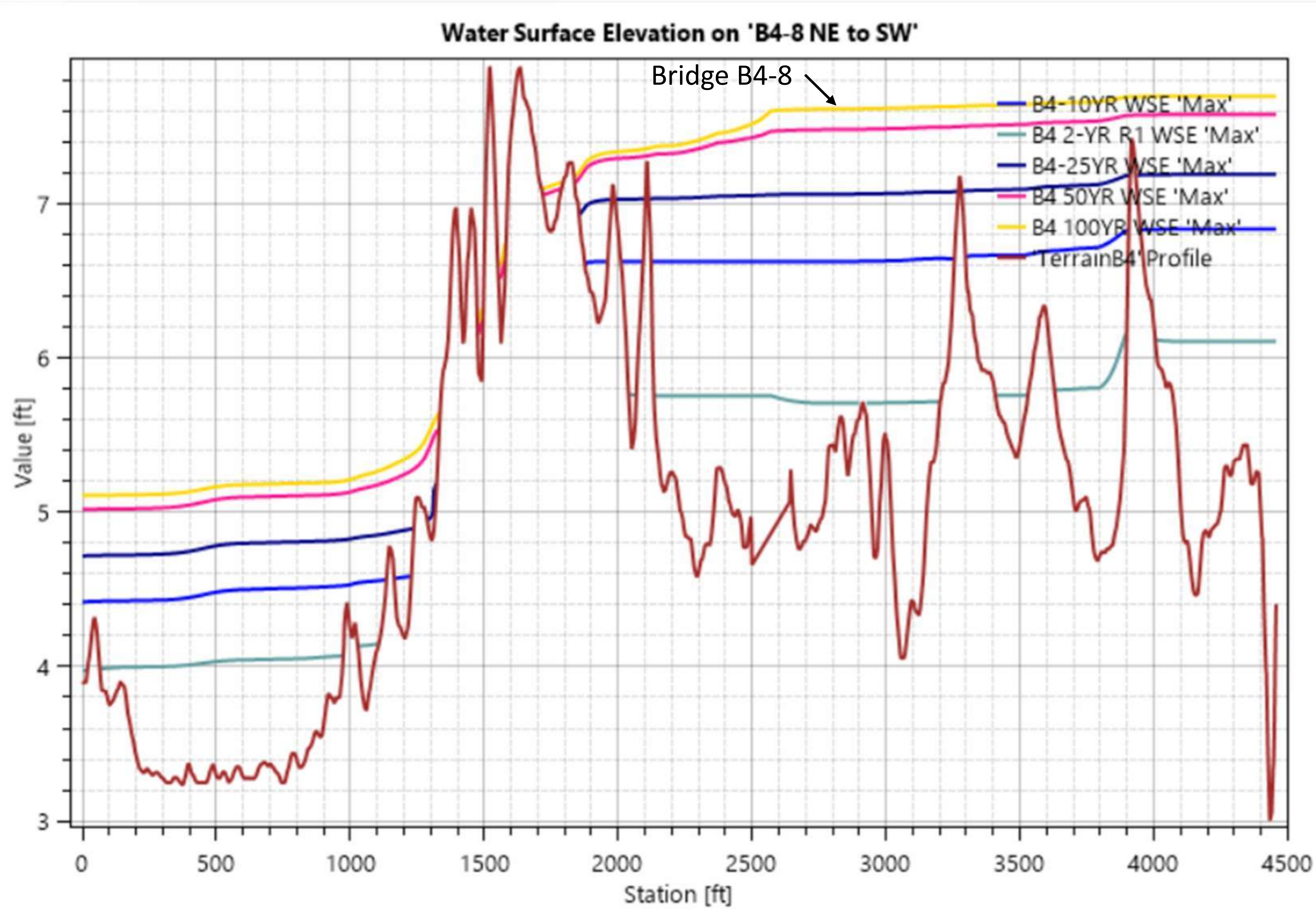
With Sea Rise

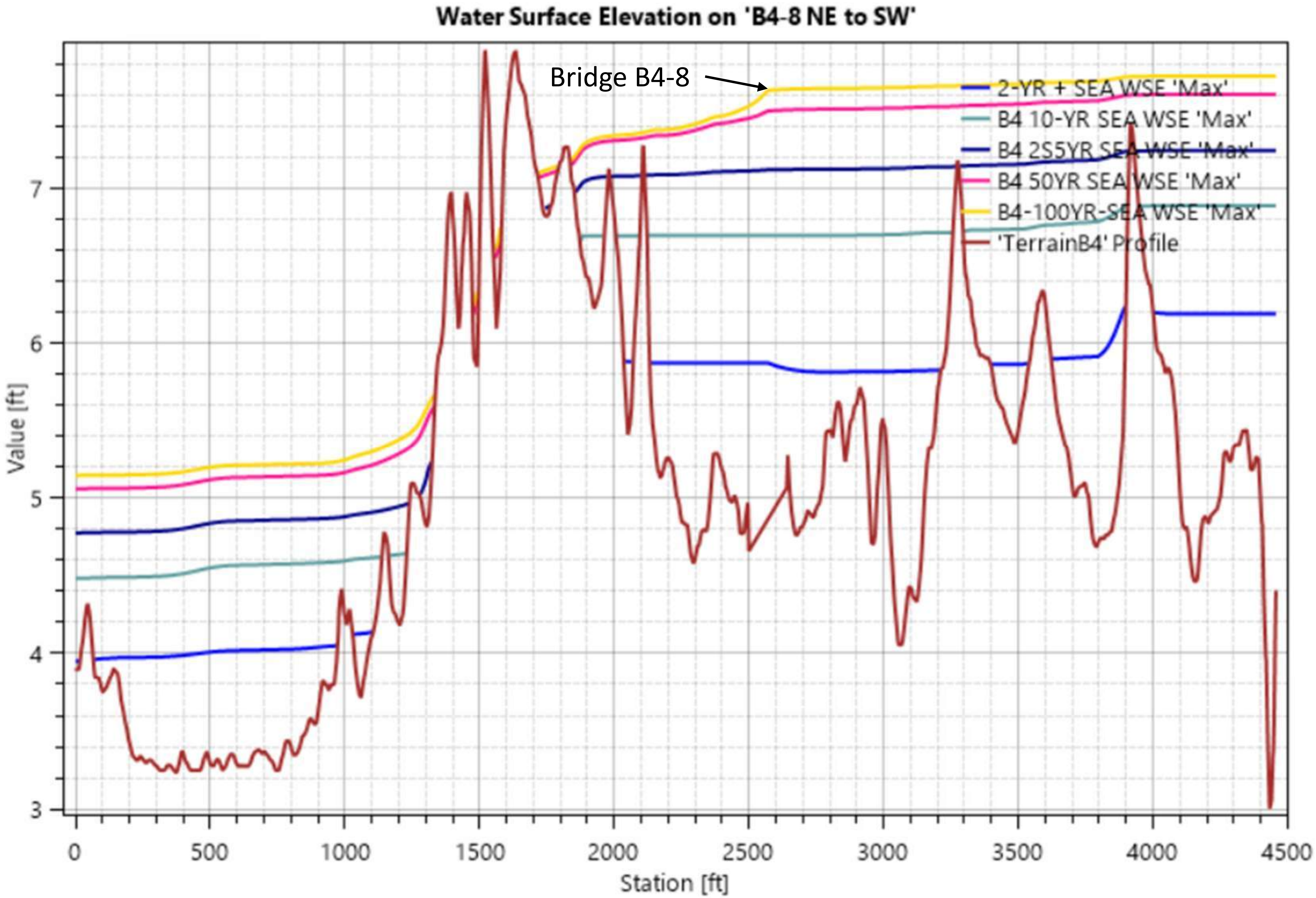
From NE to SWE

Alternative B4

Profile B4-8

From NE to SW





Alternative B4

Profile B4-8

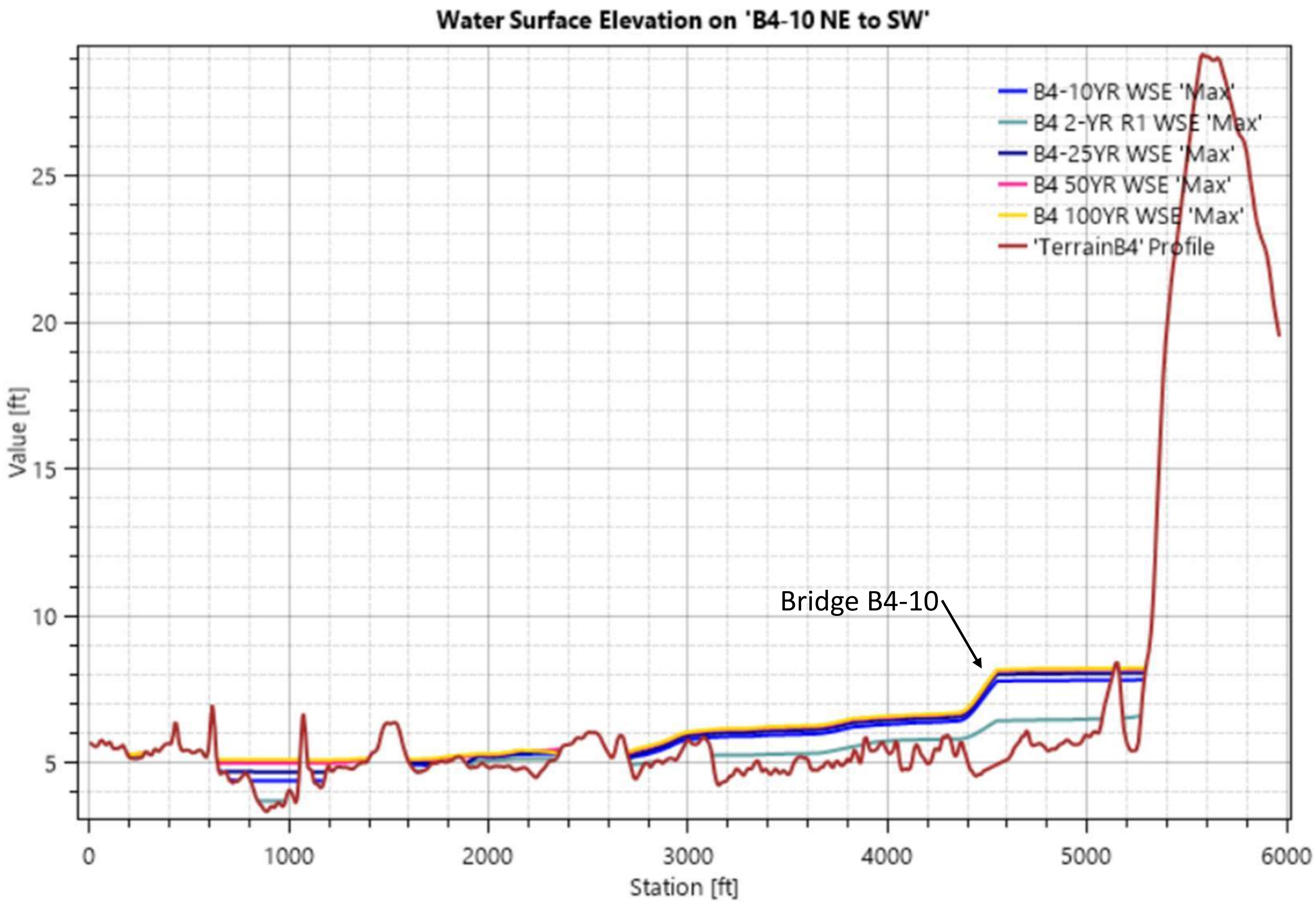
With Sea Rise

From NE to SW

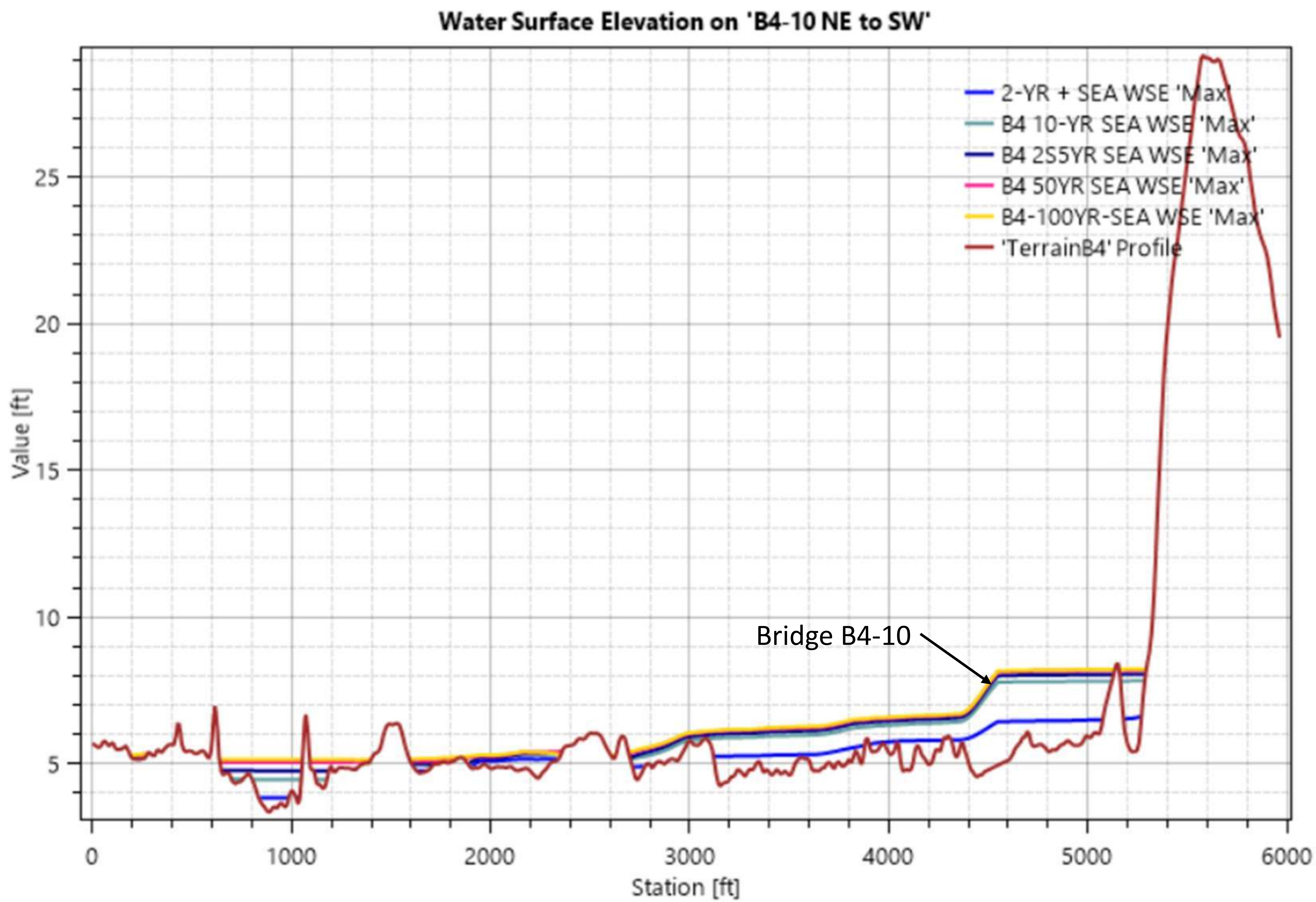
Alternative B4

Profile B4-10

From NE to SW



Alternative B4



Profile B4-10

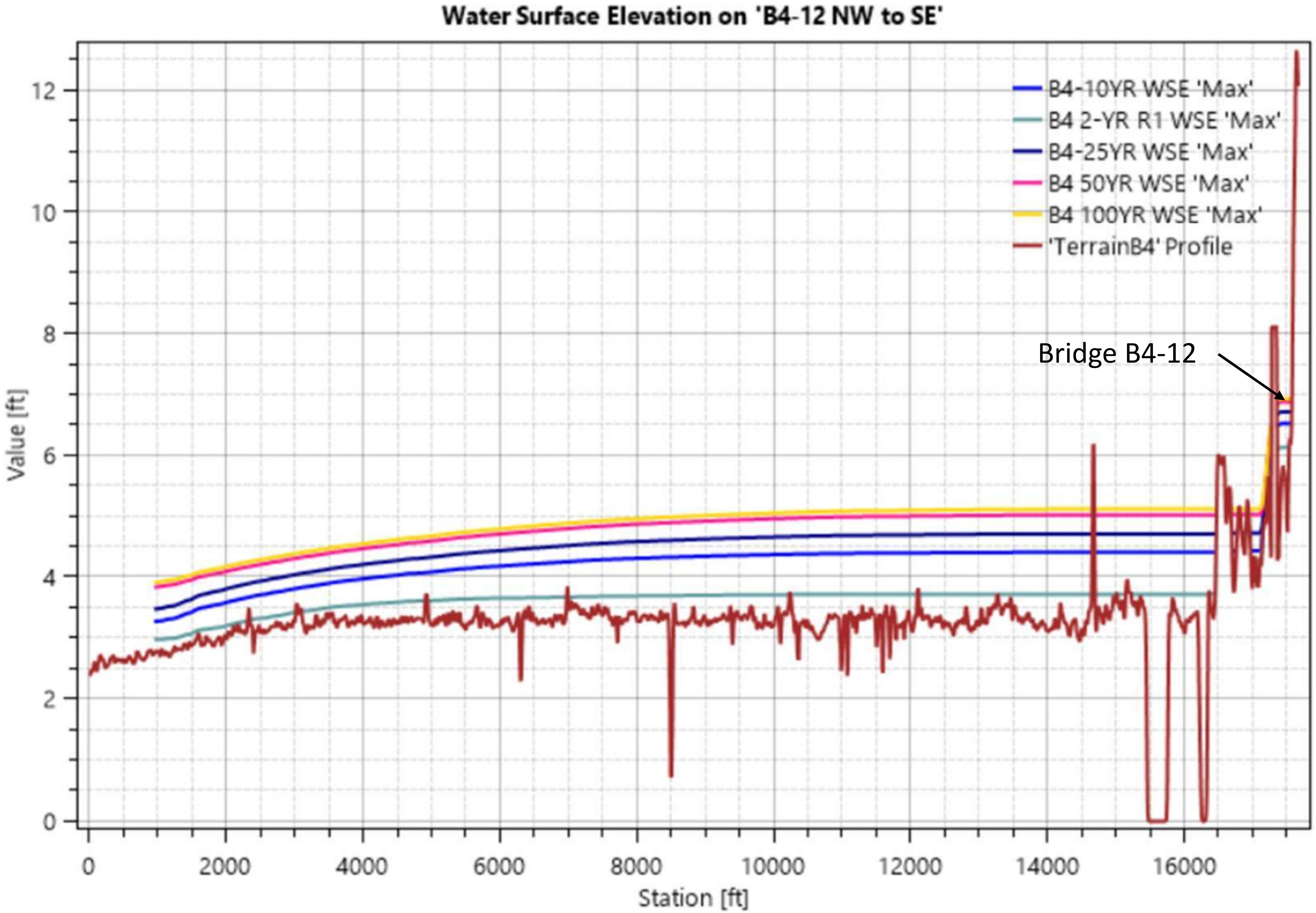
with Sea Rise

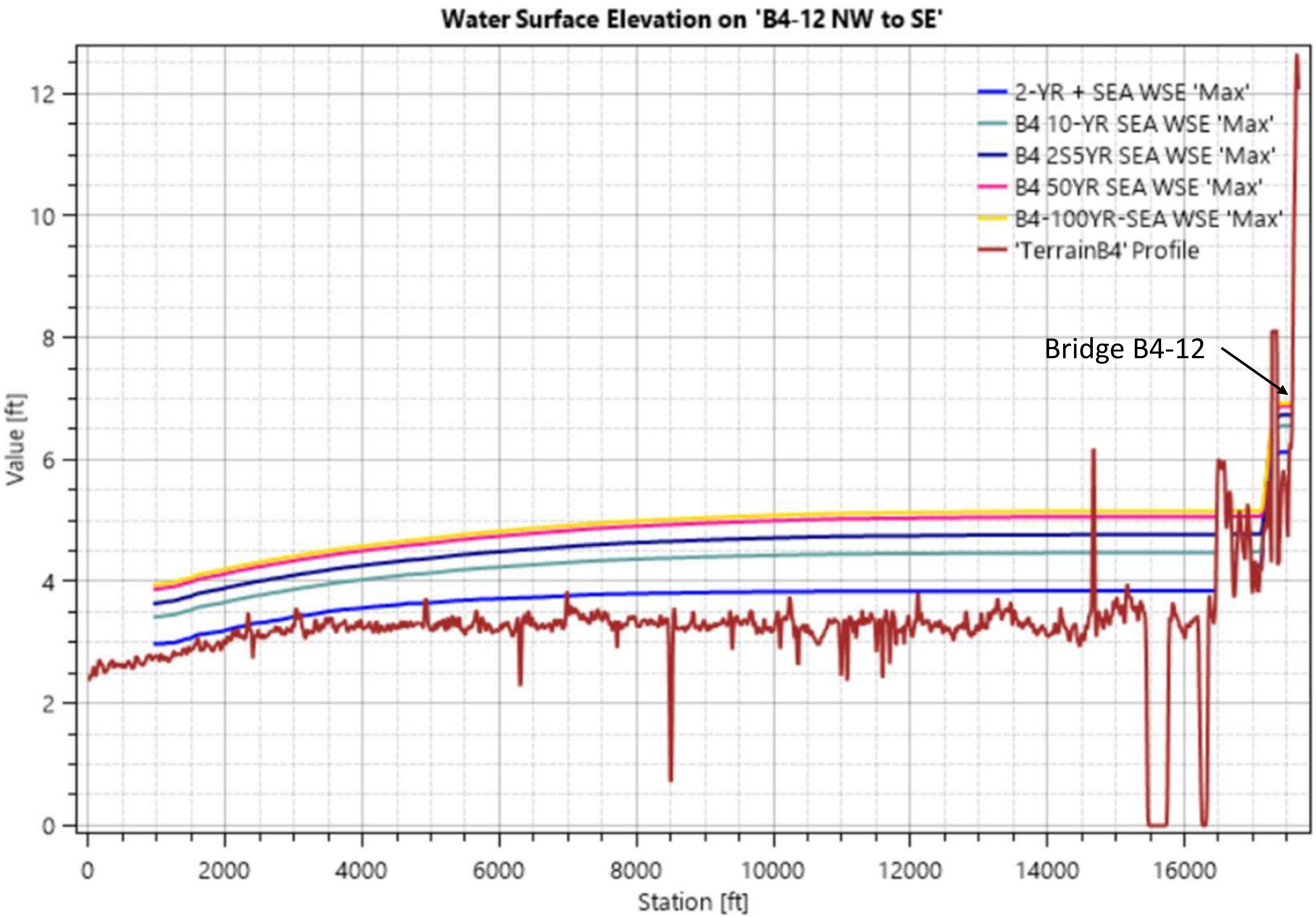
From NE to SW

Alternative B4

Profile B4-12

From NW to SE



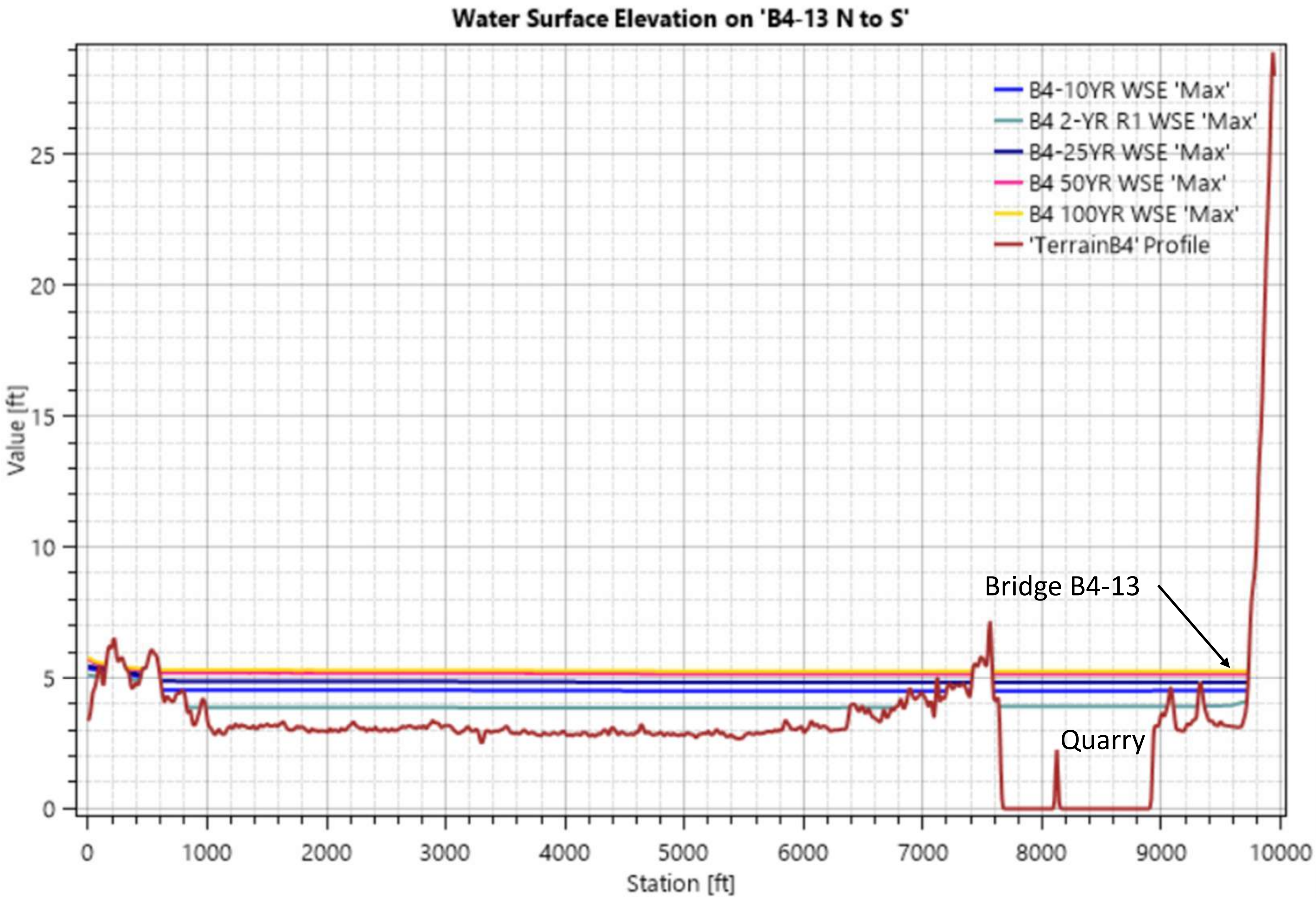


Alternative B4

Profile B4-12

With Sea Rise

From NW to SE



Alternative B4

Profile B4-13

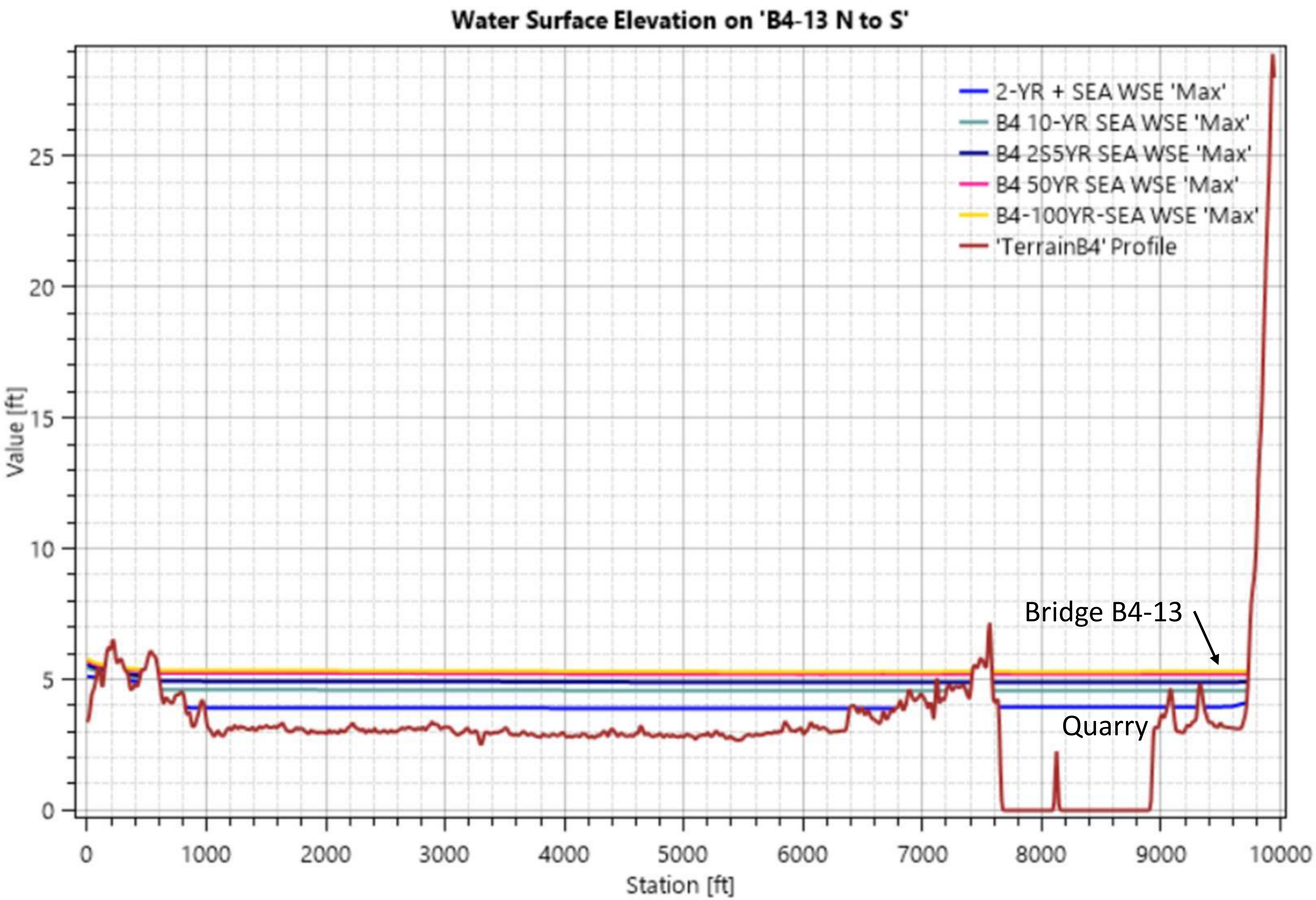
From N to S

Alternative B4

Profile B4-13

With Sea Rise

From N to S



Appendix J.6 –

Cayman EWA Extension, Flood Modeling and Roadway Drainage Openings – Final Report - Baird

Cayman East-West Arterial Extension

Flood Modeling and Roadway Drainage Openings - Final Report

April 3, 2024 | 13798.103.R1.Rev1

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Cayman East-West Arterial Extension

Flood Modeling and Roadway Drainage Openings - Final Report

Prepared for:	Prepared by:
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13798.103.R1.Rev1

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Revision	Date	Status	Comments	Prepared	Reviewed	Approved
RevA	Dec 20, 2023	Draft	Draft for review	DCW	OK	DCW
Rev0	Jan 5, 2024	Final	Comments from NRA addressed	DCW	OK	DCW
Rev1	April 3, 2024	Final	Comments from NRA, WRA & EAB	DCW	KJR	DCW

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Figures

1. Introduction

The Cayman E/W Arterial Extension is intended to improve traffic flow in the region and a number of different routing options are being considered. These options are all influenced by the potential for flooding to approach from the region of North Sound during a large surge event. Southern nearshore options are also potentially at risk from wave runup and overtopping along the south coast. Choosing an appropriate route for the road must consider these flooding parameters, as well as numerous other factors. Figure 1.1 shows the road alignments that were considered during this flooding assessment.

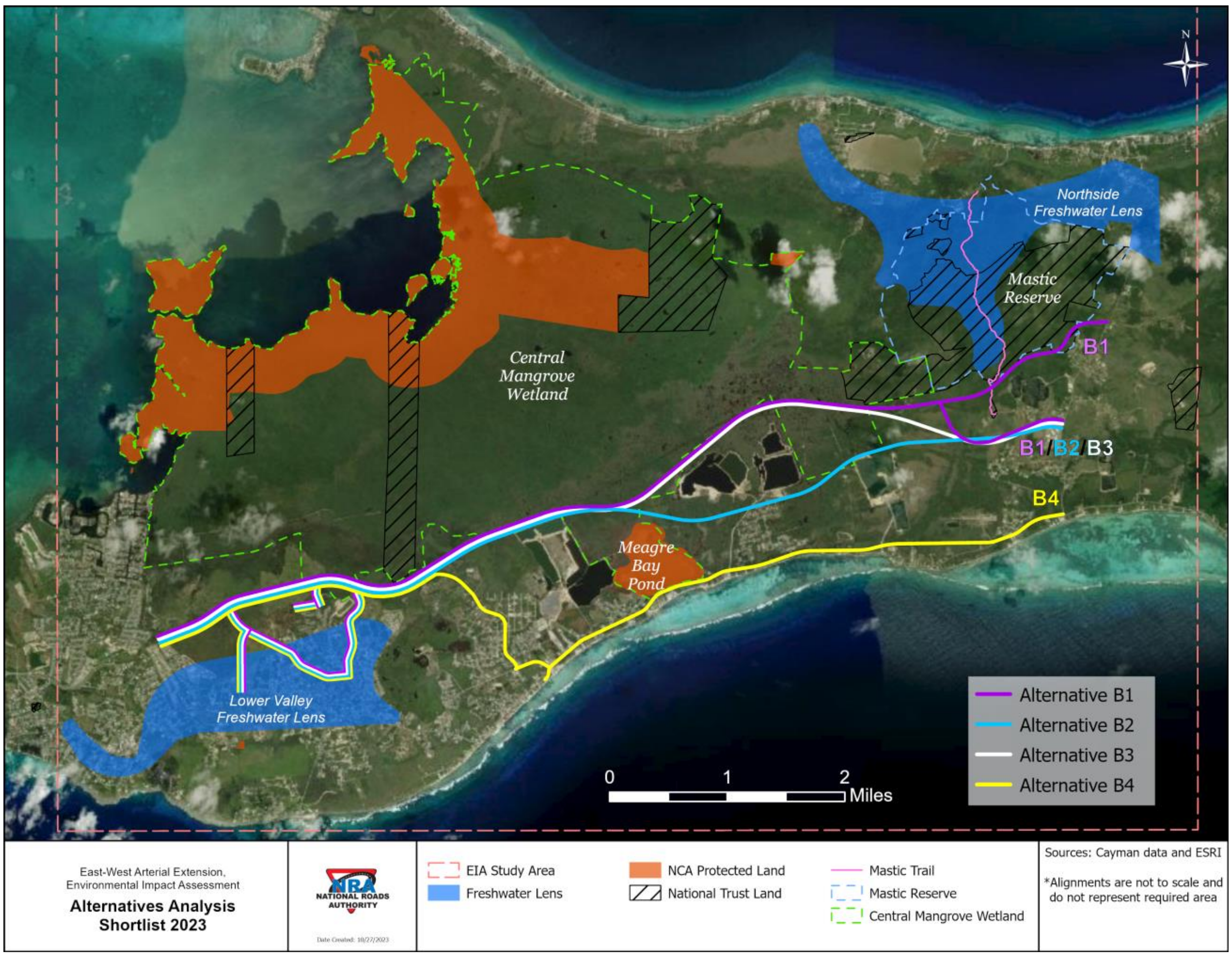

Figure 1.1: Overview of Road Alignments Under Consideration

Baird was retained by the National Roads Authority (NRA) to assess the hurricane-induced flooding along the road alignments that were being considered. Flooding in this area could be due to heavy rains, or a combination of rainfall and storm surge during the passing of a tropical storm or hurricane. Remington & Vernick Engineers (RVE) are assessing the general hydrologic impacts from the proposed alignments and the impacts of non-hurricane rainfall events.

Storm surge is generally described as the increase in the mean water level as a result of onshore winds and low atmospheric pressures. Storm surges are most pronounced and destructive in low lying areas that are fronted by broad regions of shallow water; North Sound is a good example of where significant storm surges may occur. Wave runup and overtopping can also cause severe damage, especially in regions with deeper nearshore regions or where infrastructure is very close to the shoreline.

The first phase of numerical modeling work involved existing conditions modeling and simulations of one road alignment for wind and pressure driven surge. These simulations were completed in a more systematic manner to provide more reliable estimates of return period water levels. The second round of simulations were completed for a subset of storms, with details extracted along all four of the B1 to B4 road alignments. In this second round, the roadway alignments were elevated according to the data received from WRA.

The B4 alignment is unique among the four under consideration in that it is also threatened by wave runup and overtopping during severe storm conditions that approach from the south. Additional analyses were completed for B4 and are described in this report.

2. Modeling Approach

2.1 Synthetic Hurricane Approach

Simulating hurricanes can generally be completed using two different methods: historical storms or synthetic storms.

Simulations of historical storms are faced with two problems: the storms are often poorly defined and there are also a limited number of storms for which there is adequate data. To remedy this problem a more reliable approach is to simulate synthetic storms, which are developed based on regional statistics.

Synthetic storms can be generated in any number, with a wide variation in tracks, forward speed, radius to maximum winds, shape parameters (wide versus narrow), etc. The regional data provide the statistics on these storm parameters so that all of the storms that are generated are plausible storms and exist in a similar distribution (for example more weak to moderate storms and fewer extremely strong storms) as the historical record. Any number of storms can be generated, and these would then be assumed to represent an appropriate length of time. In the Cayman region, the number of storms passing near the site is about one per year. Therefore, a set of 500 storms could be assumed to represent a 500 year period, or it could be split up to represent (for example) ten realizations of a 50 year period (484 storms were simulated; round numbers were used for this illustration). From this set of data, more robust statistics can be developed than relying on historical events.

The methodology to generate wind/pressure/rainfall fields for synthetic tracks is described below and the validation figures are attached in Appendix A.

2.2 Hurricane Wind Field Modeling

Hurricane wind fields were developed for the synthetic storms using a parametric wind profile model. Specifically, a modified version of the Holland et al. (2010) wind profile, implemented within Baird's in-house *CycWind* toolbox, was applied to generate the 2D cyclonic vortex. The single vortex cyclonic pressure and wind profile model of Holland et al. (2010) provides an update to the Holland (1980) model by allowing spatial 'stretching' of the wind field to match wind speed observations at fixed points. This wind model is applied to the surface wind directly with use of a scaling factor, *Bs*, and requires iterative estimation of the exponent term. It has advantages in replicating the observed thickening of the tails of the wind speed profile in comparison with the Holland (1980) model and reduces the sensitivity of the outer wind profile to Radius to Maximum Winds RMW.

To account for the asymmetric nature of cyclones where the forward speed of the system increases the wind speed on one side, the forward speed correction, α, of Sobey (1977) was made to the gradient wind speed. θ_{max}, being the angle of the maximum wind speed in the cyclone relative to the forward direction, θf, is typically chosen in the range of 45° to 135°, with a value of 65° applied by Baird on the North-West Shelf. Also, an inflow angle correction, β, was made to represent the cross-isobaric flow due to surface friction.

2.3 Rainfall Modeling

Utilizing Bader's 2019 framework, spatially and temporally variable rainfall rates were modeled for each synthetic tropical cyclone. The methodology correlates observed peak rainfall rates to maximum sustained winds of tropical cyclones via a Frank Copula. Given a synthetic hurricane's simulated maximum sustained wind speed, the peak rainfall rate is estimated by querying the fitted Copula. The predicted peak rainfall rate is then fitted to an exponential decay function (e.g., a “Holland” profile) with respect to distance from the cyclone's center, peaking near the radius of maximum winds and terminating nearby the radius to gales. This results in an axisymmetric rainfall field about the center of the cyclone and is applicable for numerical simulation using our hydrodynamic model. Rainfall is applied to all nodes (i.e., both wet & dry) of the mesh leading to both infiltration and runoff along the surface of the model. Validation of the parametric rainfall model against several U.S. east coast landfalling hurricanes was provided in Bader (2019) and asserts the model's realism in a climatological sense to model rainfall associated with tropical cyclones (Bader 2019). While the parametric approach is incapable of resolving complex precipitation banding and convection structures, it provides a conservative estimate of the contribution of rainfall runoff on total water levels during significant tropical cyclones.

An example of modeled rainfall for a significant surge event on the island is shown in Figure 2.1.

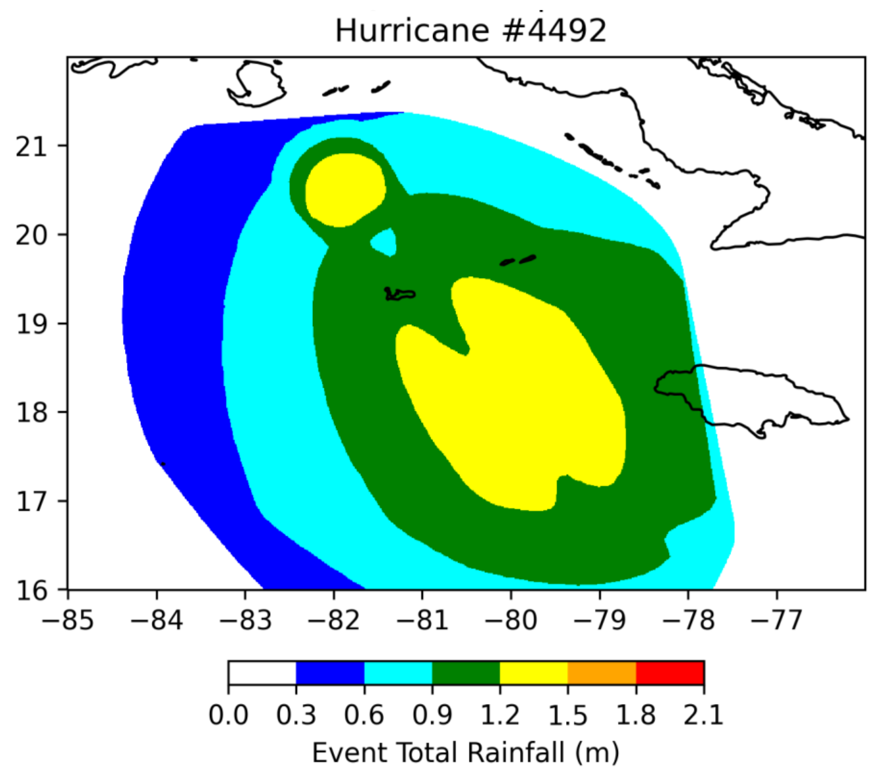

Figure 2.1: Example of modeled event total rainfall for a synthetic hurricane.

2.4 Hydrodynamic Modeling of Surge and Rainfall

A numerical model grid was developed that included a detailed depiction of Grand Cayman, as well as a wide area surrounding the site. The extent of the model domain was defined such that hurricanes could develop over open water and then pass near Grand Cayman. Offshore areas were defined from regional bathymetric data, while elevations at Grand Cayman were defined based on LiDAR that was supplied by the Cayman Islands Lands and Surveys. The survey was flown from November 10, 2021 to November 28, 2021. The water level in the mangroves is uncertain during this time period, although with the survey taking place the month after the wettest month of the year (on average), it is possible that there was considerable standing water in the mangroves.

One of the challenges that was faced with the topographic data was the poor definition of elevations in the mangrove areas. Topographic LiDAR will penetrate through gaps in the foliage and will ideally define the ground elevation in vegetated areas. However, extremely dense foliage can limit this and then reports a ground that is too high. In areas where there is standing water, topographic LiDAR will report back the water surface elevation, rather than the bed under the surface. Both of these issues will lead to a condition where the topographic LiDAR reports back a surface that is unrealistically high.

Significant effort was spent trying to better understand the LiDAR data in the mangrove region. The dataset had a discontinuity in the data at the seaward extent of the mangroves, suggesting that penetration into the mangroves was not adequate. The was also a misalignment between the apparent extent of high tide penetration into the mangroves, and the reported penetration.

The originally provided data included features such as buildings and vehicles on the road. Baird was subsequently provided the classified LAS files and we developed our own DEM of the ground in the area. However, we did not reclassify the points and believe that many of the points classified as “ground” did not fully penetrate to the ground. To remedy this issue, the regions of Grand Cayman that were defined as mangrove through government datasets were reduced by 0.75 m in elevation. This adjustment needs to be validated in future phases of analysis.

Simulations were completed using the Telemac model. Outer boundaries were defined using tidal constituents and winds/pressures were applied to the surface of the model. The winds and pressure are vital for developing storm surge in the model. The extent of the numerical model mesh is shown in Figure 2.2, while a close up of the model domain at the project site is shown in Figure 2.3.

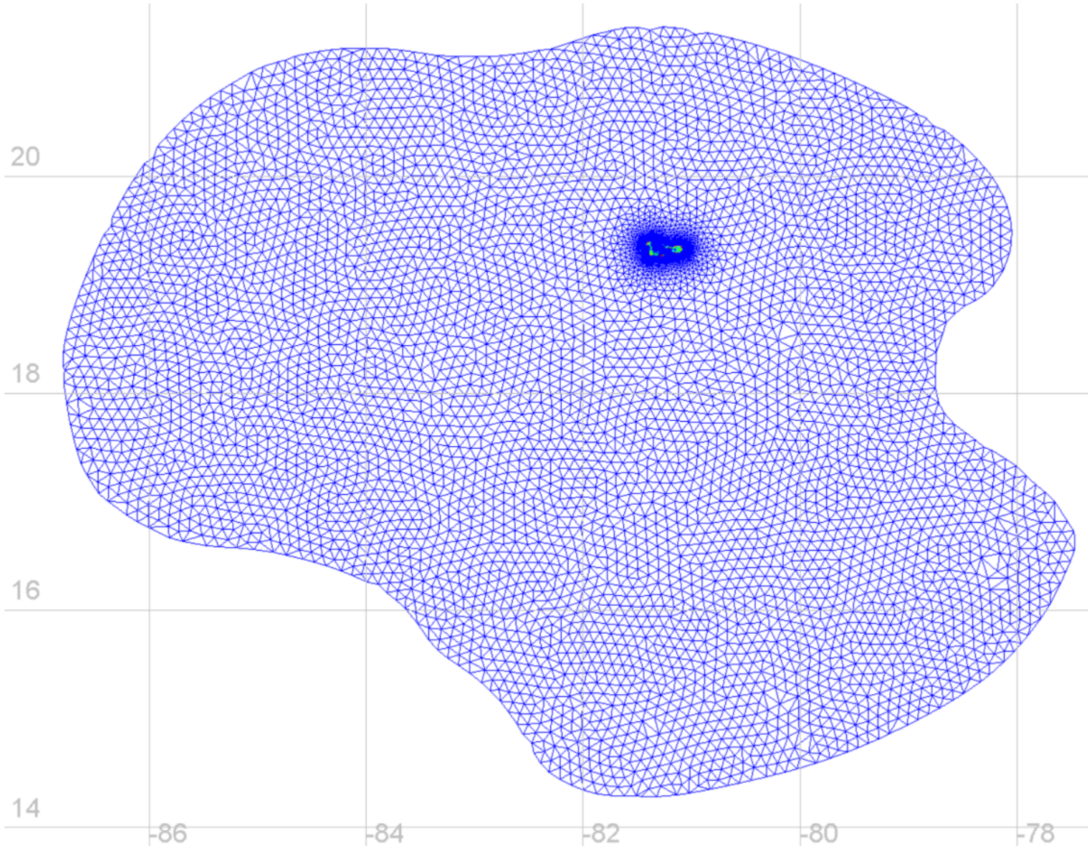

Figure 2.2: Model Domain for Telemac Simulations of Grand Cayman

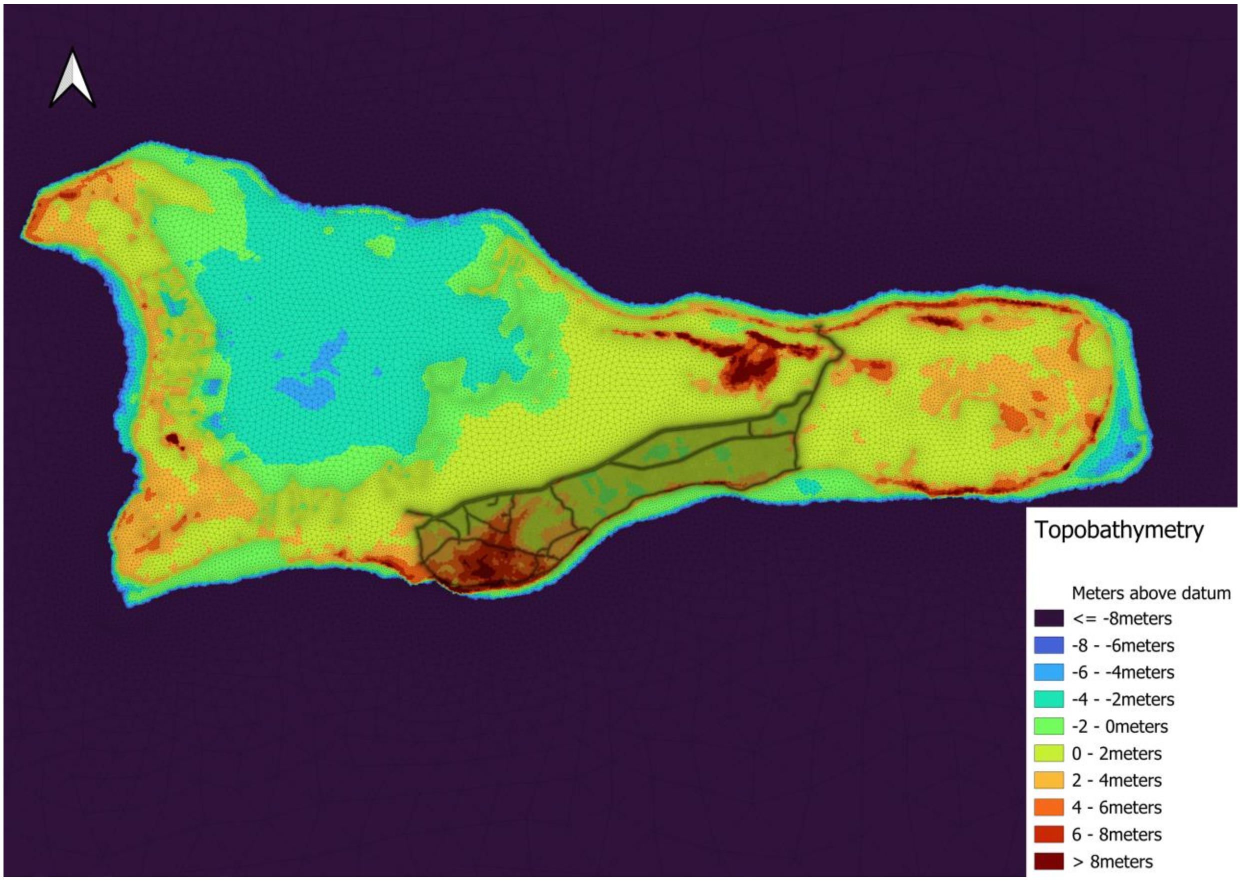

Figure 2.3: Close-up of Grand Cayman Model Domain showing topo-bathymetry on the mesh nodes.

Some simulations were also completed with a wave model to investigate the impact of waves on the overall surge patterns in the area. The wave model generates a map of radiation stresses, which defines how varying wave heights will impact water levels. An example of this process would be waves breaking over a reef that result in a shoreward push of water, which can raise the water level near the shore. The map of radiation stresses is then applied to the Telemac model and the model defines how the water level may react. With the gradually varied water depths in the North Sound region, radiation stresses were found to have limited impact (typically less than 5 or 10 cm) on the surge levels in the area. Most of the runs were therefore completed without including the impacts of waves.

Infiltration of rainfall (or surge water) into the ground was simulated using the curve number method for infiltration. The curve number was applied spatially with soil group raster and landcover data, assuming soil group class D for high water table conditions. The curve numbers are detailed at Purdue Engineering https://shorturl.at/jmt09 . Infiltration will play an extremely minor role in attenuating flooding given that much of the area is mangroves (very wet ground or ponding in many areas) and that surges can exceed several feet in height. The amount of water absorbed into the ground is small relative to the magnitude of the surge and the error bars that surround many of the surge processes.

3. Flooding from North Sound

3.1 Flood Generation Components

Flooding along the road is a complex process that can involve influences from many sources. The underlying water level in the form of tide and future sea level rise will impact the baseline upon which the storm impacts will develop upon.

Storm surge is a combination of three different generation mechanisms:

- Pressure setup: Pressure setup occurs in the more central parts of the storm where the atmospheric pressure is reduced, and the seawater is allowed to rise to account for the difference in pressure from the surrounding area. A rise in water level of about 1 cm per 1 mb reduction in pressure is expected in deepwater regions, or in shallow regions with a narrow continental shelf (such as Grand Cayman).
- Wind setup: Wind setup is caused by strong winds pushing water shoreward; it is particularly important in areas such as North Sound where shallow water makes wave setup more severe. Wind setup occurs in the bands of the storm where the wind is strongest; it is negligible in the center of the storm where the wind is weak (and pressure setup is strongest).
- Wave setup: Wave setup is generated by large waves breaking in depth limited water and causing a landward flux of energy (this can be conceptualized as the white-water in breaking waves moving shoreward). Wave setup is the increase in water level near the shoreline that is required to create seaward currents to remove this water. In a broad shallow area such as North Sound, wave setup is not a major contributor to flooding; it was generally found to influence flood levels by about 5 cm or less. Therefore, wave setup from North Sound was not included in this study, while it was included for the B4 alignment along the south coast

Flooding can occur due to surge alone. Wind setup is the greatest contributor to large surge events with winds from the NW quadrant pushing water into and across North Sound. A north wind is likely to more severely impact the west end of the road, since surge is concentrated close to North Sound. For a large surge to reach further inland (to the east) the winds must be more northwesterly in direction.

Rainfall is also a vital part of understanding hurricane effects. Rainfall was included in the Telemac simulations and is modeled following the approach outlined in Section 2.3.

Tide levels were included in the model by randomly selecting a start time for each of the storms. This meant that tides would be rising and falling at the model boundaries (and hence throughout the domain) in a manner that was independent of the storm. In other words, there was no single tide level that was selected for simulating these storms; levels varied naturally throughout the simulations.

Sea level rise is also a consideration for the design of the road. As a general rule, a rise in sea level of a given amount will result in flood levels increasing by a similar amount in the project area. Given the uncertainty in future sea level rise, this is a reasonable assumption at this stage of the design. In earlier phases of this study, a 0.5 m increase in mean sea level was selected as an appropriate value for the proposed road. The synthetic storms described in this report used today's mean sea level, with zero future adjustment for sea level rise. During the final design process, a value for sea level rise should be included, as part of a general review of uncertainty in modeling results, construction cost implications and ability to adapt levels in future decades if required.

3.2 Return Periods of Selected Synthetic Events

Investigation of the impacts of various storms took place through simulation of seven selected synthetic storm events, as outlined in Table 3.1. These storms are approximately ranked by surge severity; however, the severity is variable by location. The storm severity was gauged by documenting the surge level in the existing conditions simulated at three locations in the project area (west, middle and east). The rank of the storm at each of these locations is provided in the table. Storm 1115 was first or second worst storm at the three locations, while a storm such as 4184 was the fourth worst at the east end, but only ranked 16th worst at the west end. Rainfall parameters are provided as well as a general description of the path of the storm.

Table 3.1: Selected Storms for Simulation of Alternatives

Event	Location	Surge (m)	Rank	Return Period (yr)	Rainfall Parameters	Path
1115	West	3.6	1	485	Total 1226 mm	N of site, moving to WNW
	Middle	4.1	2	243	Peak rate 39 mm/hr	
	East	4.3	1	485	Hrs>2.5mm: 45	
2848	West	2.2	4	121	Total 2135 mm	N of site, moving to WNW
	Middle	3.0	5	97	Peak rate 39 mm/hr	
	East	3.7	3	162	Hrs>2.5mm: 74	
4492	West	2.1	6	81	Total 1106 mm	N of site, moving to WNW, weaker & closer to site than 1115 & 2848
	Middle	2.7	8	61	Peak rate 38 mm/hr	
	East	2.3	7	69	Hrs>2.5mm: 42	
4184	West	0.8	16	30	Total 1496 mm	N of site, moving to WNW, further away than 1115 & 2848
	Middle	1.8	14	35	Peak rate 39 mm/hr	
	East	2.8	4	121	Hrs>2.5mm: 58	
5031	West	1.5	9	54	Total 1051 mm	S of site, moving to WNW, but passing close-by
	Middle	2.3	9	54	Peak rate 38 mm/hr	
	East	1.2	32	15	Hrs>2.5mm: 45	
5005	West	1.0	14	35	Total 1224 mm	NE of site, moving to NW, closer but weaker storm
	Middle	1.9	13	37	Peak rate 35 mm/hr	
	East	2.0	11	44	Hrs>2.5mm: 54	
2977	West	0.7	17	29	Total 1226 mm	Almost directly over site, moving to WNW
	Middle	1.4	35	14	Peak rate 37 mm/hr	
	East	1.0	67	7	Hrs>2.5mm: 52	

The values presented in this table are intended to provide general guidance on the relative severity of the different storms in different regions of the study area. There is no clear transition of what might be considered west, middle and east; these are general areas and there will be variability throughout the area. All of these storms are example storms and actual events may be quite similar or quite different from these events. It is for this reason that more detailed statistical analysis relies on hundreds of storm events.

Rainfall in these storms synthetic is very high, although the heaviest rainfall of 2135 mm (Storm 2848) is well below recorded maximum levels in Cuba (2550 mm in Flora 1963) and Jamaica (3429 mm in 1909 Hurricane). A more detailed assessment of rainfall flooding was completed by RVE in a separate report for NRA.

3.3 Local Flood Processes – General Observations

3.3.1 General Flood Processes

The site is most prone to severe flooding during a major hurricane event, particularly one that produces sustained and strong winds from the NW. NW winds cause a large wind setup to occur in North Sound. When this is added to pressure setup within the storm (wind and pressure setup are the primary components of storm surge), along with a higher tide level and the potential for future sea level rise, the flooding along the roadway alignment can reach elevations of several feet in height. It is highly likely that the roadway will be built at a level such that extreme storm surges inundate the roadway. This would be a cost saving measure to reduce the amount of fill that would be required.

The effectiveness of openings in the road were quantified by their impact on flood duration. This was assessed by documenting the flood levels at 12 locations along the B1 alignment (Figure 3.1). The B1 alignment was used as a representative roadway and the fundamentals derived for B1 are generally applicable to the other alignments which are relatively close by. The road was considered to be flooded when some minimum level of freeboard (0.2 m) was not present. Freeboard is required so that the road is more than just at the water level; the width of the lanes should be dry. Arguably, a freeboard of over 0.2 m will be required in some areas, such as where there is superelevation; however, there will also be other vertical profile variation in the section that would be included in the final vertical alignment. This initial assessment is intended to provide a preliminary indication of the opening sizes.

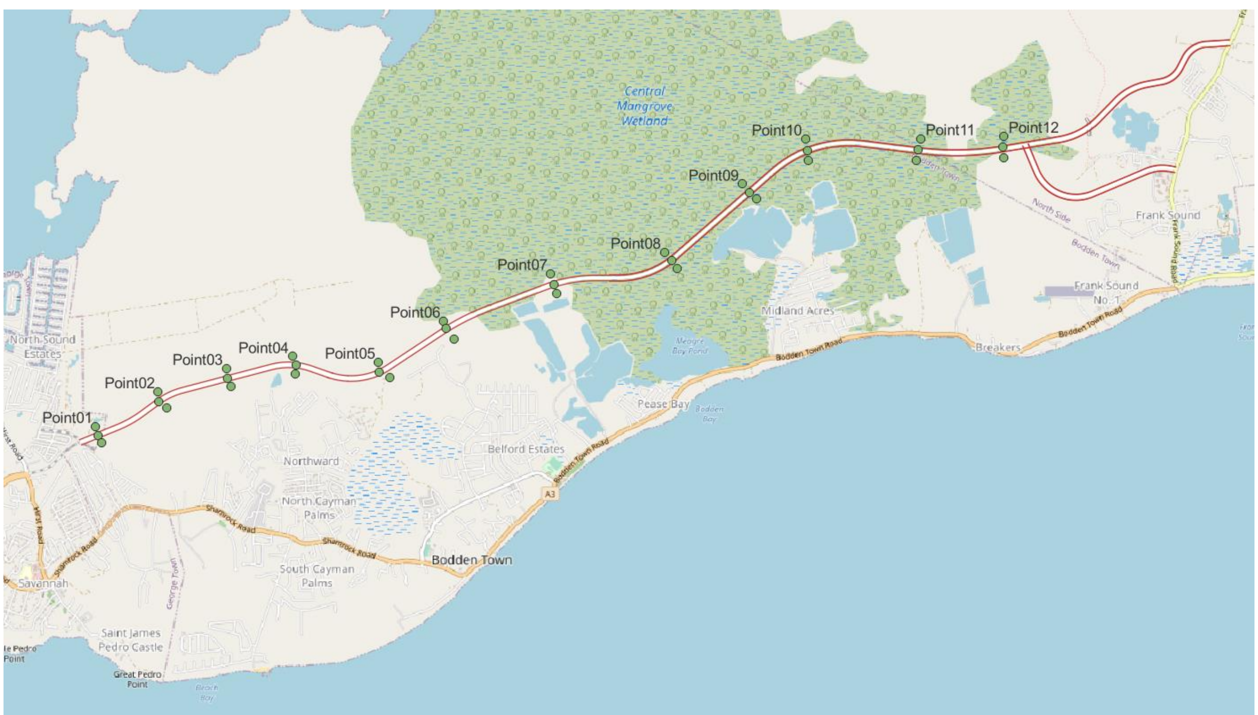

Figure 3.1: Twelve Locations for Assessing Opening Effectiveness

An example of the flooding of the road is shown in Figure 3.2, which shows the water levels near mile 1.25 (alignment B1) for synthetic storm 4492. This is a major flood that starts with rain causing an increase in water level, after which there is an abrupt rise in the water level starting on the north side (front) of the structure. The road floods within about one hour of the storm surge arriving and the road is eventually covered by about 1.5 m of water. At the peak of the flood, the water level is higher on the back as the rainwater needs to drain from south to north across the road. The water level drops below the level of the road on the north (front) side of the road after about nine hours. However, an extended period at the end of the storm with high water levels on the south (back) of the structure prolongs the flooding by about six hours at this location (possibly longer depending on required freeboard). This example shows the road level at an elevation of 2.25 m, although this area has been recommended for a higher road level following review of these simulations.

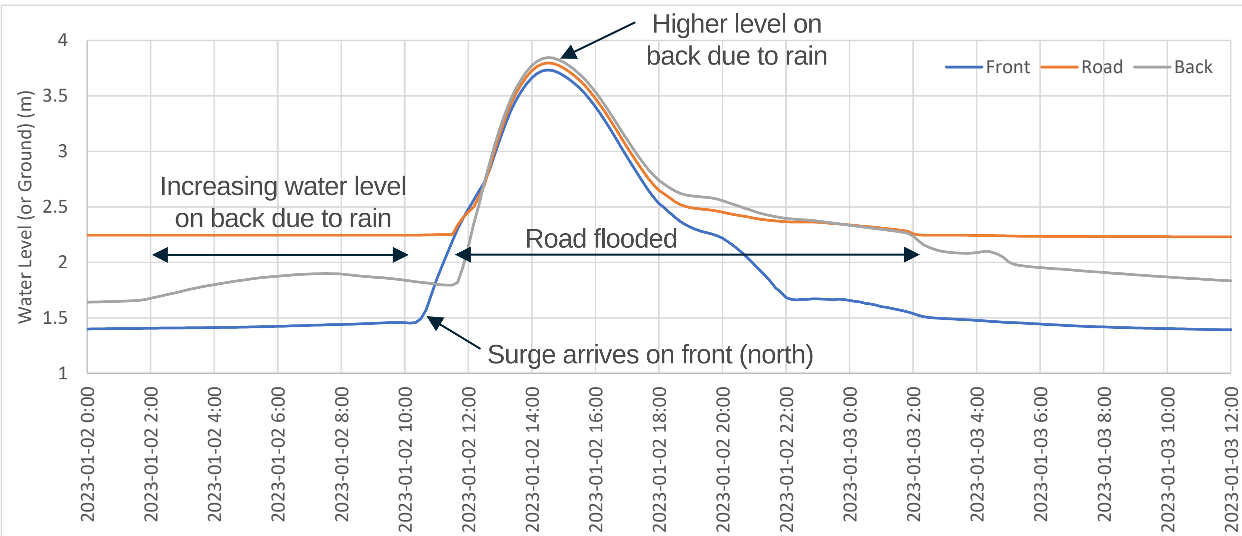

Figure 3.2: Example of Road Flooding Time Series

Many different storms were simulated and many combinations of roadway openings were tested. From the 500 storms that were initially simulated, the focus was on simulating the storms that had the potential to flood the road. Some of these storms inundated the entire area, while others may have only flooded a specific location.

During a storm surge that approaches from North Sound, the rate of increase of the water level can be very rapid. For example, some tests show an initial increase in the water level of about three feet over 10 minutes. This rapid rise in the water level will not pass through limited openings in the roadway; only a roadway that is almost entirely elevated would pass such a flow. With intermittent openings, the flows that reach the road must then redirect towards an opening, which is not feasible on a rapidly rising water level.

Flooding can approach the study area from either a more northly wind or a northwesterly wind. North winds will have a greater impact on the west end but will not propagate as far inland to the east. Many of the northerly events only flood the west end of the road. These ones can be brief in duration, but rainfall can prolong them. In some instances, there was flooding for 10 to 15 hours where the back water level was very close to the road as it slowly drained. There are also some very large events that flood the entire road along its length.

In some of the tests that compared rainfall plus surge, versus surge alone, the road closure duration was greatly extended by the inclusion of rain. This was particularly the case for situations with narrower openings (e.g., 30 m versus 100 m). An example of this is shown in Figure 3.3 for storm 4184 for simulations with thirteen 30 m wide openings distributed along its length. In this example the flood duration increased dramatically (up to 50 hours) with the inclusion of rainfall; non-rain simulations had a closure of about 5 hours in length. Storm 4184 exhibited an extraordinary total rainfall of ~1.5 meters at the center of Grand Cayman, with a peak intensity reaching 39 mm/hr. The event persisted for 57 hours, during which the rainfall rate consistently exceeded 10 mm/hour. This rainfall total is comparable to Hurricane Harvey from 2017, which dropped about 1539 mm of rain over Texas.

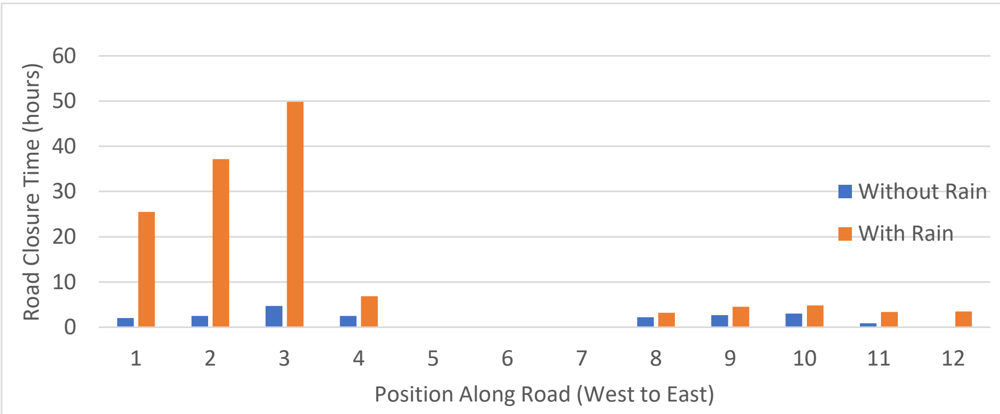

Figure 3.3: Example of Road Closure Time – With and Without Rainfall

An example of the variability between storms is shown in Figure 3.4 for five of the storms that were simulated. In these simulations there were 23 openings at 50 m in width, and the central part of the road had the highest elevation (as per original suggestion). Storm 2848 flooded the entire length and was one of the more severe storms in the 500 storm set; storm 1115 was similar in that it flooded the full length but less severe. Other less severe storms had flooding that was shorter in duration but more localized. In these examples, rainfall was turned off in order to better understand the dynamics of the surge process.

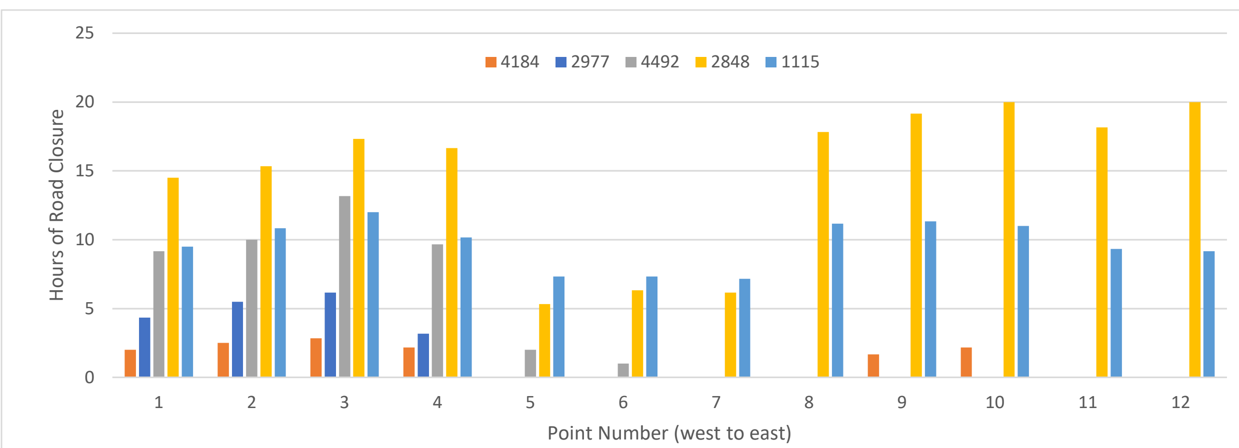

Figure 3.4: Variation in Closure Time for Different Storms (no rain included)

In some of the sample storms, flooding at east end of the road can last longer due to the distance for water to flow-back to the sound. If that area gets flooded then the mean water level slope back to the sound is very gentle and through significant mangrove areas, resulting in slower flood-recovery times.

Another important observation is that assessing overtopping and flooding in a two-dimensional sense (such as a slice through the road) can miss some important processes. When water overtops the road in a big event it can sometimes recede quickly on the back. This can be due to lateral flow as floodwater spreads into surrounding areas that may not be flooded to the same level.

Comparing existing conditions to simulations with the road in place we find that if the road overtops there is no difference in the peak level. If the road does not overtop, then the levels are slightly higher north of the road (assuming no/minimal rain) because the surge cannot spread as far inland. This also results in slight lower levels south of the road.

3.3.2 Opening Size Impacts

The simulations of the road involved a range of opening sizes through the roadbed, with the largest ones being about 100 m in width. These openings would likely be pile-supported bridge spans; however, piles were not included in the simulations. The openings had no controls and allowed floodwater to pass from north to south during the flood phase and from south to north during the ebb phase.

If there is overtopping of the road by floodwater it flows in and flows out at a significant flow rate while the entire road is flooded. The size of the openings (100 m vs 30 m) has little impact on closure time when rainfall is not considered, for the following reasons:

1. The floodwater only has to recede a small amount for the road to be open
2. Some lateral distribution of the water occurs. This means that some areas that may not be as severely flooded will receive water from the more flooded areas.
3. If there is no rainfall, then there is no additional water flowing into the flooded area

However, if there is heavy rainfall, then the capacity of the openings must be large enough to allow the overtopped floodwater to escape, as well as any incoming rainfall floodwater. In this situation, having additional opening width is beneficial as it can convey the combined overtopped and rainfall floodwater. Without additional capacity, the rainfall runoff can significantly extend the closure time.

3.4 Road Elevations Based on Existing Conditions Simulations

A total of 484 synthetic hurricane simulations were completed during phase 1 of this study. These storms were simulated on an existing conditions grid, meaning that the raised roadbeds were not included in the model mesh. The inclusion of a raised roadbed will have some impact on flood levels; however, existing conditions simulations do provide useful guidance on approximate flood levels in the area. Based on a storm frequency of about 1.0 storms per year (within 300 km of Grand Cayman), it is possible to use this wide range of storm conditions to define the return period levels within the model domain.

Elevations were extracted along each of the road alignments, and model results were processed to define the maximum flood level during each of the storms, for each selected position along the alignments. The water levels in these simulations represent the flood level from rainfall and storm surge. The result of this is a data set that appears to have very distinct zones. Figure 3.5 shows the maximum water level at a location along alignment B4, where the ground is at an elevation of about +1.8 m. For the most extreme surges, the highest water level reached +4.4 m, while the next 13 events also peak at over +2.0 m. The remaining 470 events (from 15 to 484) have much lower flooding, resulting only from rainfall runoff, rather than wind-driven surge.

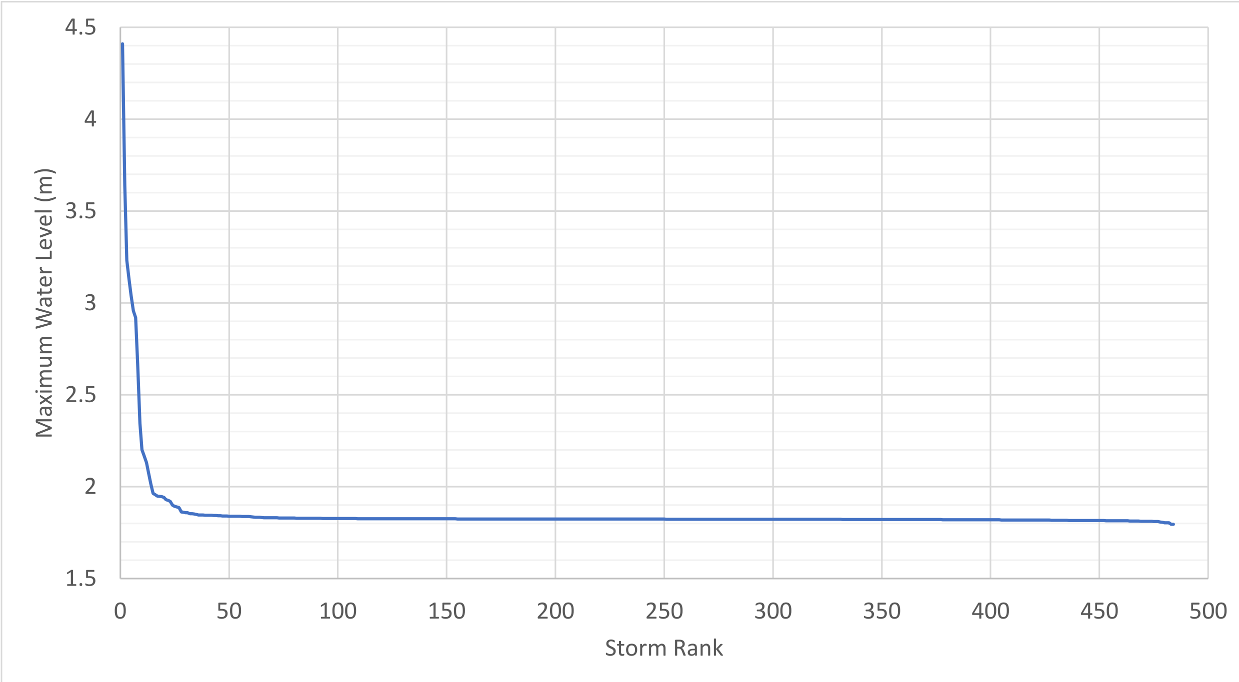

Figure 3.5: Maximum Storm Water Level at Higher Ground Elevation

The data in this plot represent all 484 storms, which are formed from two different populations of data: rainfall only (if there is no surge reaching the area of interest), and surge plus rainfall (typically the larger flooding events). When extracting results from these data, it is important to consider that large rainfall events often occur separate from a tropical storm or hurricane. Therefore, return period information should be treated cautiously for lower return period events and/or at higher elevations where rainfall will dominate until the surge is sufficiently large to flood the area.

A summary of the return period levels along alignment B1 is shown in Figure 3.6. Flood levels at the west end are higher due to the proximity to North Sound and the potential to experience flooding from both northerly winds and NW winds. The rainfall runoff from adjacent higher elevation areas is likely also a contributing factor. During a very extreme event (for example 100 year plus event) the entire area is flooded; however, the flooding is more frequent at the west end. In the middle of the alignment, the ground is lower and the flood levels are also lower. The plot also shows an increase in the water levels at the east end. This is due to the higher ground, which effectively acts as a ramp for the surge to ascend, while heavy rainfall in will also cause more flooding further away from North Sound.

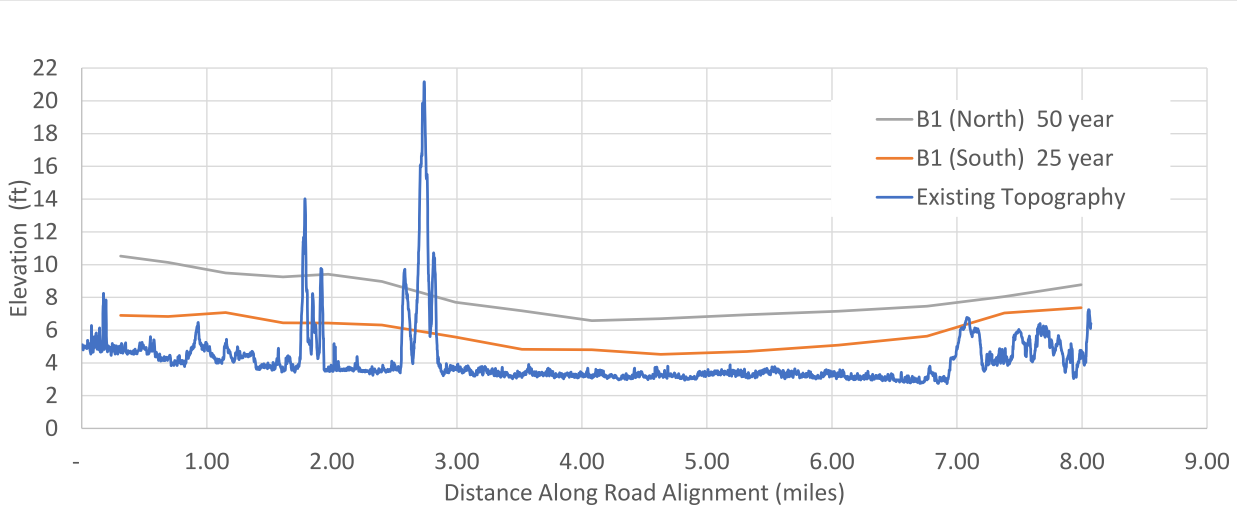

Figure 3.6: Return Period Levels Along B1 Alignment

The flood levels were produced at locations along the B2, B3 and B4 alignments. Note that all of these alignments have a common path at the west end, resulting in some repetition of values. Data are provided for return periods of 20, 25, 30, 40, 50, 75 and 100 years in Appendix B. The 25 and 50 year return periods are shown in Figure 3.7 and Figure 3.8 for alignments B2 and B3.

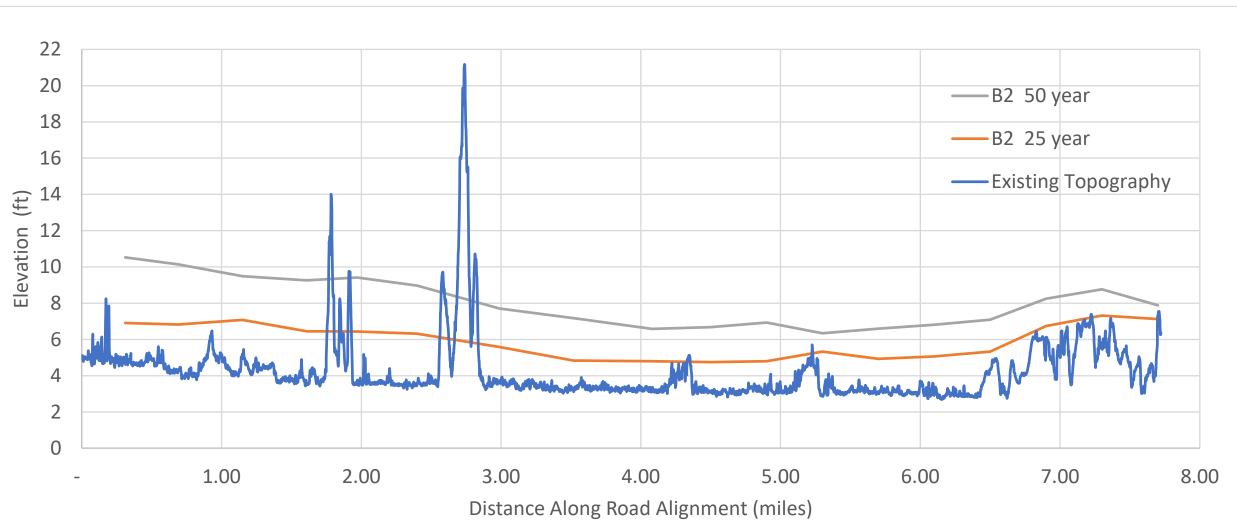

Figure 3.7: Return Period Levels Along B2 Alignment (Splits from B1 at mile 4.04)

The flood levels along alignment B4 have an added level of complexity due to the proximity to the south coast and the threat of wave overtopping. The topography in the area often features a higher ridge along the south coast, with the road on the ridge or on the north side of the ridge. This means that the existing ground along the road alignment may be higher than some of the other alignments; however, there is still the threat of flooding from the surge that can inundate the mangrove areas to the north. Figure 3.9 shows the ground levels and the return period alignments along alignment B4. Note that mile 0 to 2 is along B1, after which the road heads south towards the coast from mile 2 to 3.8. The road is close to the south coast from mile 3.8 to 8.3, but slightly inland around mile 7.

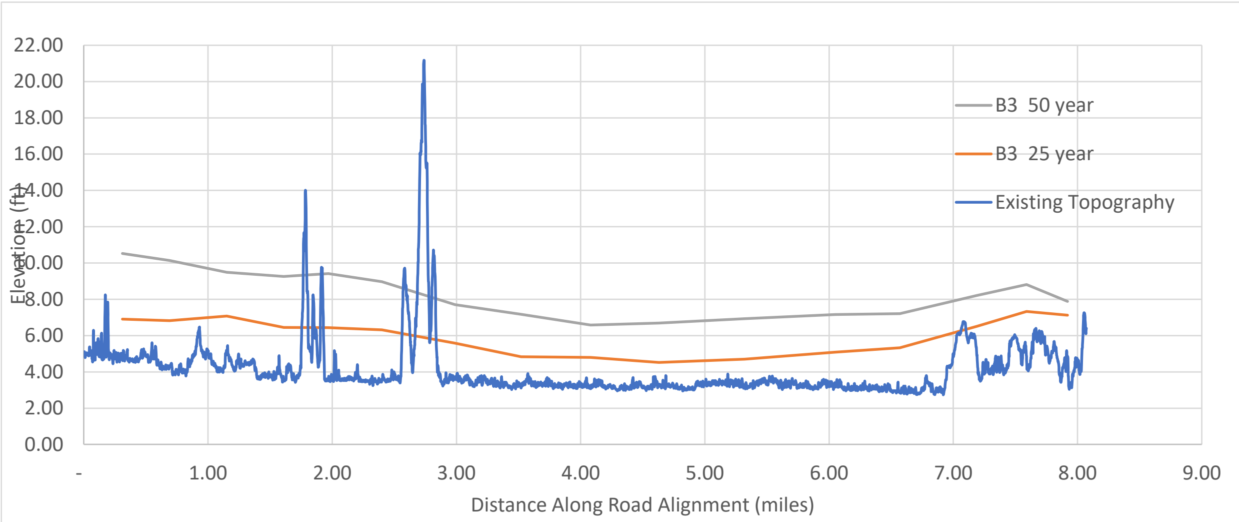

Figure 3.8: Return Period Levels Along B3 Alignment

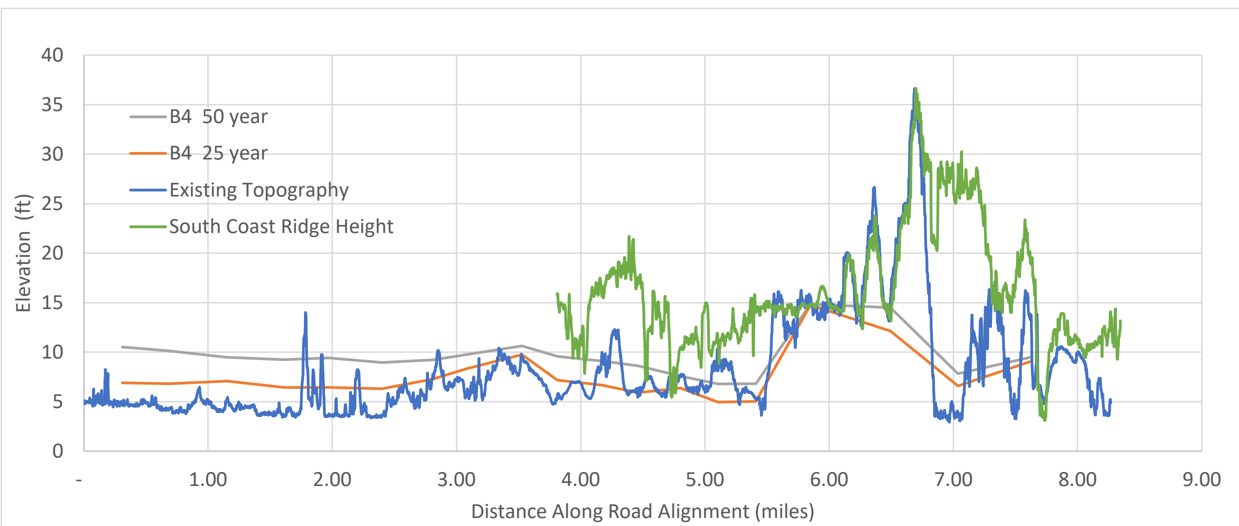

Figure 3.9: Return Period Levels Along Alignment B4

The 25 and 50 year flood levels become much higher in the region of mile 6; however, this is not due to surge, this is due to ponded rainfall in the higher regions. It is likely that the road would be cut through the higher regions (for example if crossing a ridge) and rainfall flooding would be mitigated through ditches along the side of the road that would move water from these higher areas.

4. South Coast Wave Overtopping

4.1 Overview of Bathymetry and Topography

Wave overtopping along the south coast occurs in storms that have strong wind and waves approaching from a southerly direction. The offshore reef results in a major reduction in the approaching wave heights through depth limited breaking. The waves then travel across the shallow nearshore area and will runup the beach that fronts the B4 road alignment from about mile 3.8 to 8.3. Figure 4.1 shows the shallow offshore reef as a red band about 300 to 1000 m from the shore; the elevation of the crest of the reef is at about -0.15 m. The alignment of the reef approaches the shore near the community of Breakers; the proposed B4 road alignment (shown as a blue line) is further inland near Breakers where there is less offshore protection.

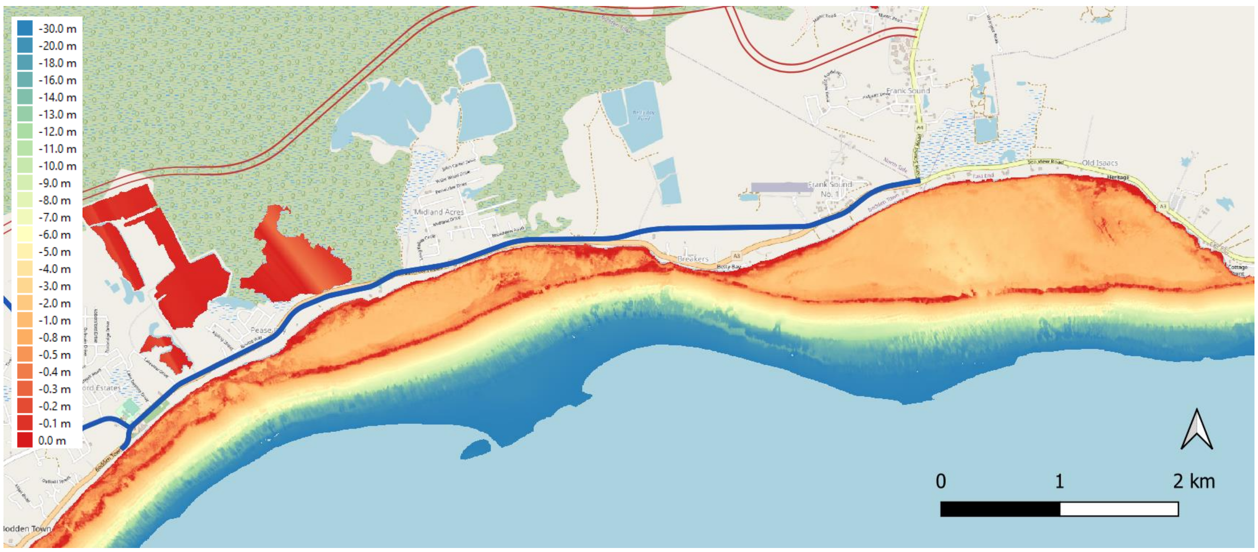

Figure 4.1: Nearshore Bathymetric Conditions Along B4 Alignment

Topography in the area includes a ridge (likely formed by wave runup) along the shoreline that reaches an elevation typically in the range of +10 to +20 ft. The B4 alignment is generally positioned on or north of this ridge, as shown in Figure 4.2. The B4 alignment is generally consistent with the position of the existing road, although in some areas the proposed alignment is further north.

Figure 4.2: Topography Along South Coast

Hurricane Ivan resulted in significant wave runup and overtopping of the south coast in September 2004. Google Earth has imagery from September 21, 2004, which clearly shows the impacts of wave runup and overtopping of the berm along the south coast. An example is shown in Figure 6.3, where there is visible deposition of sand on the road and in areas north of the road.

Figure 4.3: September 2004 Post-Ivan Imagery (Google Earth)

The overall pattern of overtopping was documented from the Google Earth image, to provide guidance on the severity of overtopping from Hurricane Ivan, which is generally described as being a 75 year event. In areas where there were large patches of sand visible north of the road, the overtopping was estimated to be severe and assigned the value 3 in Figure 4.4. Areas with no apparent overtopping were assigned a zero. Also shown in this figure are the ground elevations along the road or along the ridge height at or south of the road.

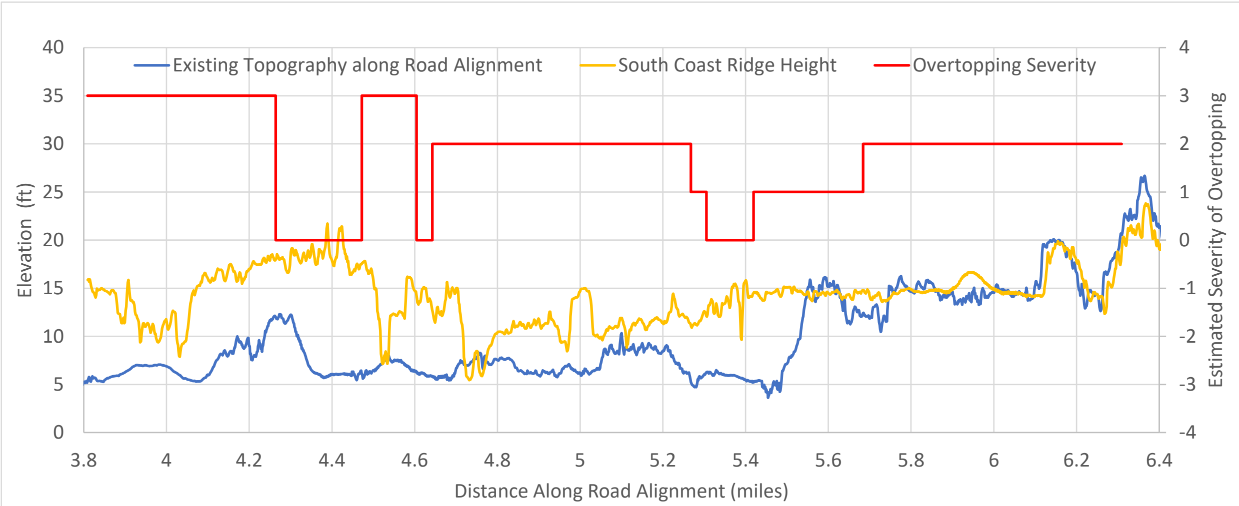

Figure 4.4: Overtopping Severity from Post Hurricane Ivan Imagery

The conclusion from these observations is that during Hurricane Ivan, severe overtopping appears to have occurred in regions with a ridge elevation of up to 18 ft. There are also some areas where there was no observed overtopping where the elevation reached 15 ft. In some areas, thick bands of vegetation appear to have reduced the overtopping so that there was no sand on the road, despite being at 13 to 15 ft.

Hurricane Ivan passed approximately 50 km south of Grand Cayman with maximum winds in the range of 130 knots. With a track just south of Grand Cayman, this storm appears to have produced waves in excess of 10 m, and possibly over 11 m in height. Baird's previous work (2017) on the cruise ship terminal for the Cayman Islands Government was leveraged to obtain the wave height return periods outline in Table 4.1. The wave heights are defined in deep water, and we have conservatively assumed that the waves are traveling directly towards the shore (i.e., refraction has been ignored) for the south coast assessment.

This means that the waves produced by Ivan (and therefore the runup and overtopping) were likely in excess of the 100 year event, possibly at the 200+ year level. The runup and overtopping observed in photos along the south coast needs to be considered in this context.

Table 4.1: Approximate Wave Return Periods in Deep Water on South Coast

Return Period (years)	Hm0 (m)	Hm0 (ft)	Tp range (s)
5	4.5	14.8	8 to 13
10	5.9	19.4	9 to 14
25	7.5	24.6	9 to 14
50	8.5	27.9	10 to 15
75	9.0	29.5	11 to 15
100	9.5	31.2	11 to 15

4.2 Numerical Modeling of Runup

Wave runup was assessed in three different numerical models: CSHORE, XBEACH, and IH2VOF. These models included the wave breaking processes from about 30 m water depth, across the reef to the shore. The models also include wave setup (an increase in the mean water level near the shore due to the wave action) and the wave runup processes on the face of the beach. The models CSHORE and XBEACH included the impacts of wind since there is some wind setup in the shallow waters inside the reef. However, the third numerical model, IH2VOF, did not include the impacts of wind setup inside the reef.

Wave runup is a highly irregular process, and it is not unusual to have significantly varied results when using different methods. The overtopping flow rate is even more variable and in physical model tests (not completed for this study) it is common to have significant variation between repeated identical tests. As such, we expect results from this modeling to be indicative, but still with significant uncertainty.

To have improved confidence in the results, comparisons were made between the model results and the observations from Hurricane Ivan. This serves as only a single point of comparison for the runup and overtopping results; however, a valid observation at this extreme level is very useful.

The focus of this modeling was therefore to establish a wave height versus overtopping relationship that was validated based on field observations. Consequently, the data from this model can be used to define an expected wave runup level for varied offshore wave conditions. During the modeling study, IH2VOF had challenges with the large model domain, and it was only possible to simulate the processes using a 0.5 m grid resolution, which is considered coarse for IH2VOF. Given that the beach and reef represented with 0.5 m grid cells, it is expected that runup results may be slightly under-estimated in IH2VOF.

XBEACH was tested and provided similar results to IH2VOF. However, comparison of these two models to the observations from Hurricane Ivan suggested that these two models were under-estimates. CSHORE provided higher results than the other two models, and perhaps over-estimates based on observations from Hurricane Ivan.

The final approach used a blend between CSHORE results and XBEACH result. Numerous conditions were simulated in CSHORE for a range of wave heights and wave periods; the results are shown in Figure 4.5. The multiple dots for the same offshore wave heights represents a typical range of periods that might be expected for that wave height; the longer periods produced a higher runup level. The unadjusted values in this figure suggest that the berm should have been overtopped for elevations up to about 25 to 30 ft or more. However, from observations, this appears to be too high. The adjusted values reduce the upper end of the runup predictions, while not lowering the estimates at lower levels (below 10 ft).

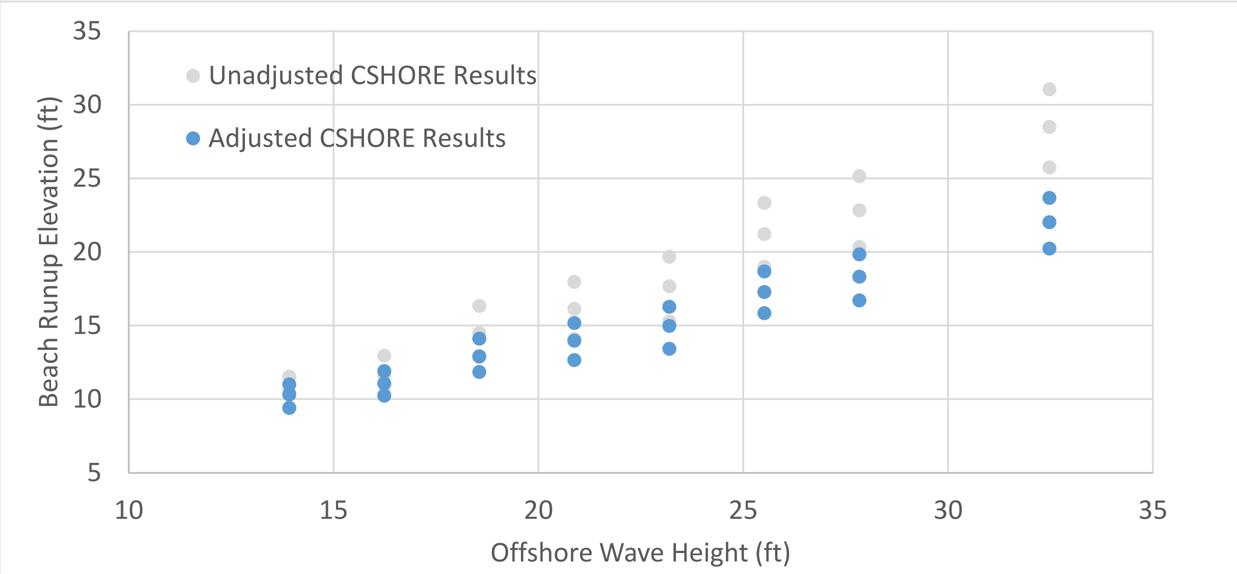

Figure 4.5: Unadjusted and Adjusted CSHORE Runup Estimates

4.3 Acceptable Levels of Overtopping

For the case of simple road flooding (not considering waves on a beach), a road that is raised to a 50 year flood level would be inundated during the 100 year flood event, but would be expected to be passable again as the storm abated. On the other hand, a road on a beach ridge that is being overtopped by waves could be buried in sand and unusable for typical vehicles until significant clearing efforts had taken place. Therefore, we cannot allow low return period events to briefly impair use of the road, since the timing may not be brief. In this context, a road level that corresponds to a higher wave overtopping return period would be appropriate in order to avoid long closures of the road.

To be mostly clear from wave overtopping and deposition of sand in a storm such as Ivan, it appears that an elevation in the range of 20 ft would be required. Alternatively, if a slight lower return period was selected, such as the 100 year return period, then an elevation of about 18 ft could be appropriate.

With all of the uncertainty associated with wave overtopping predictions, some additional security might be advisable. Options for this include an additional 3 to 5 ft of elevation for the beach ridge, or the use of a wider or more heavily vegetated beach ridge. This implies that the beach ridge would need to be raised along almost all of the 4.5 miles of nearshore road along the B4 alignment. Figure 4.7 shows the elevations along the south coast section of B4, with fill required to bring the level of the blue line up to the level of the orange line at +22 ft. It is important to note that this assessment does not consider the additional elevation that might be required in the vicinity of Breakers, where there is not an offshore reef protecting the area. However, this is also a rocky section of shoreline that would require a different assessment approach.

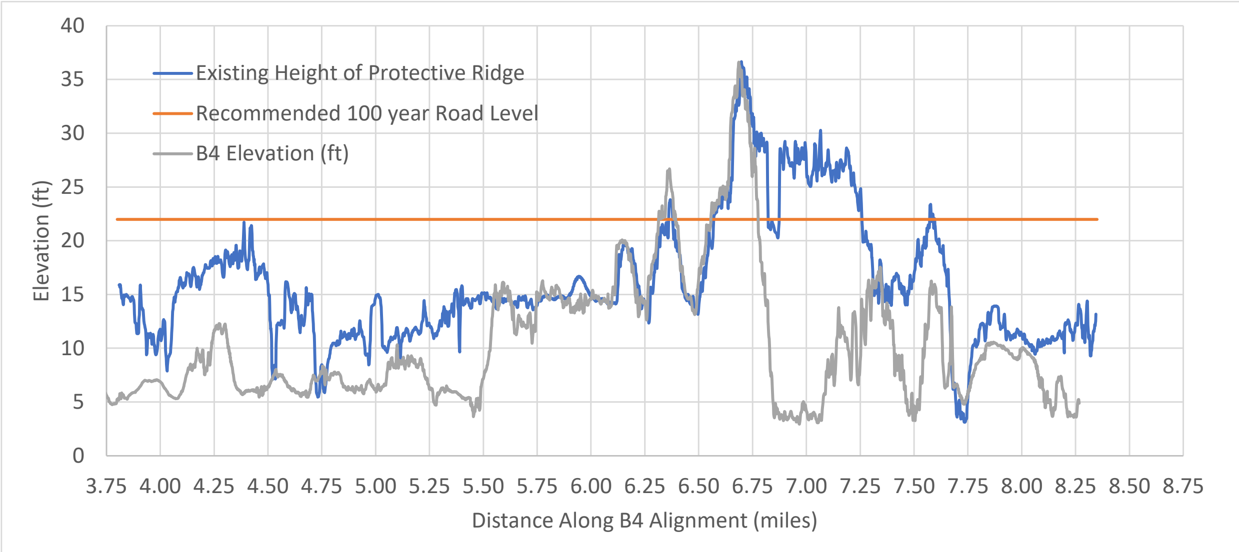

Figure 4.6: B4 Alignment Existing Elevation and Elevation of Protective Ridge

Figure 4.7 shows the length that would need to be raised for different crest levels. For example, elevating the road by between 10 and 15 ft would need to take place over about 10 000 ft (from 2000 to 12000 on the x-axis). The filling could take place along the beach ridge to the south of the road, or it could be a raised road.

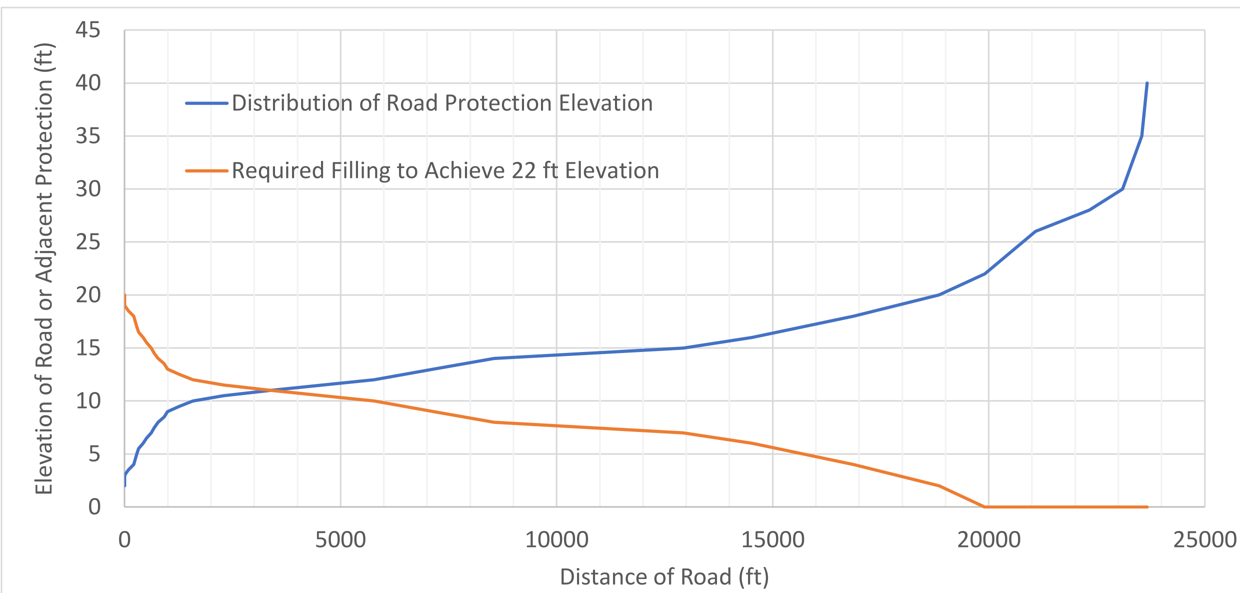

Figure 4.7: Distance Required to Raise the Protection Along Alternative B4

There are significant practical implications for raising a road or a near-road beach ridge by (for example) 15 ft in a confined area. This would need to be achieved either with steeper side slopes (some sort of structure) or the fill would require a significant width. Typical beach slopes might be 10:1 on the front, but steeper on the back. Using our 15 ft example as a basis, this would require an additional width of over 200 ft, plus whatever was required for the road itself. In most areas this space is simply not available. Moreover, structures along the beach would need to be considered in the design and installation of the berm, either by removing them, raising them, or working around them. All these options entail considerable implications.

In summary, the wave overtopping issue along the B4 alignment is a serious problem that would require significant works to overcome. Unlike a floodwater issue, wave overtopping along this alignment would be expected to result in damage or sand deposition that could take days to clear or repair. The issues related to properties and waterfront concerns would need to be addressed but are outside the scope of this report.

5. Floodwater Reduction or Impoundment

5.1 Overview

Elevated roadways have the potential to impact the overall flooding and drainage patterns in the area. For example, an adequately high roadway could prevent surge passing from North Sound to the area south of the road; however, it would also prevent drainage of rainfall runoff. It is therefore important to maintain an appropriate level of hydraulic connectivity between the north and the south sides of the selected roadway. Mechanical gates and/or pumping systems are not being consider at this time; drainage will take place through non-mechanical hydraulic pathways.

Extremely severe storms (100+ year return period) will have surges in the range of 11 to 14 ft or more in some areas and present plans are to not raise the road above all conceivable flood events. We therefore know that the road will be overtopped and will not act as a complete dam. The impacts of the raised road could be of two types:

- Reduction of flooding: If the road reduces the extent to which a surge extends inland, then it could reduce the extent of the flooding in areas typically to the south of the road.
- Increased flooding: An increase in flooding could take place through two mechanisms. If floodwater is reduced in one area then it could build up higher in other flooded areas through this loss of additional flood storage. Alternatively, if water's ability to drain away is slowed, this could prolong the extent of the flooding.

The potential for an increase in flooding in the region was assessed by examining the details of the flooding on seven synthetic storms, as outlined in Table 3.1.

The flood level impacts were documented at 11 locations in the model, as shown in Figure 5.1. These locations were suggested to Baird as approximate areas of interest. The shading in the figure depicts the elevation, with Lower Valley and Northward being at much higher elevations (over 20 ft). Bodden Town is at +8 ft, while Central Mangrove and Mastic Reserve are below 1 ft. All of the other locations are between 4.1 and 6.0 ft.

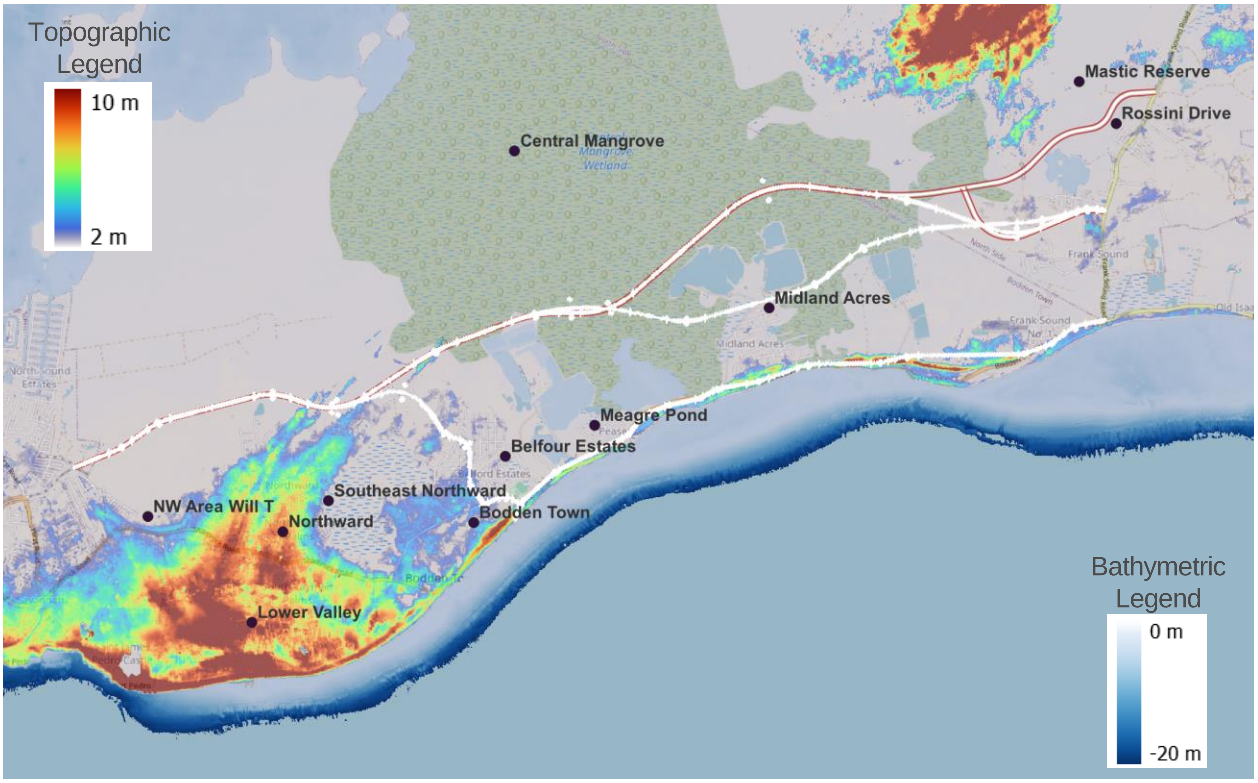

Figure 5.1: Locations for Flooding and Impoundment Comparisons

Comparing flood levels between different runs has some complications since different meshing arrangements have slightly different representations of the topography. This is largely irrelevant in areas such as Central Mangrove, where the floodwater can be deep, and the ground is relatively flat. In areas where there is shallow water and irregular topography, slight changes in the meshing of the topography can change whether a grid node aligns into the base of a natural flow path, or very close to that but a few inches different in elevation.

The most straight forward approach for assessing potential impacts on the flood level, is to compare the maximum flood levels from the storm simulations. This approach provides consistent results since it is based on a single value from each run.

Comparing the impoundment is completed by assessing the water level every 10 minutes during the run and comparing the difference between the proposed alignment and the existing conditions. An example of the impact can be seen in Figure 5.2, which shows the impact of the B2 alignment at Meagre Pond for storm 1115 (extremely severe storm). In this example, the overall maximum flood level is almost identical for the existing and B2 alignments, but there are some differences in the timing of the approaching and receding floodwater. The proposed condition is delaying the initial flooding process, likely until the flood overtops the road. In this case the peak level is almost identical. During the draining process, the outflow is slightly delayed later in the process so that the difference in elevation between the two runs is about 0.1 m for close to a day as the water is receding. In this example, the ground is flooded for about one more additional hour (23 vs 24 hours) for the case with the B2 alignment compared to the existing condition.

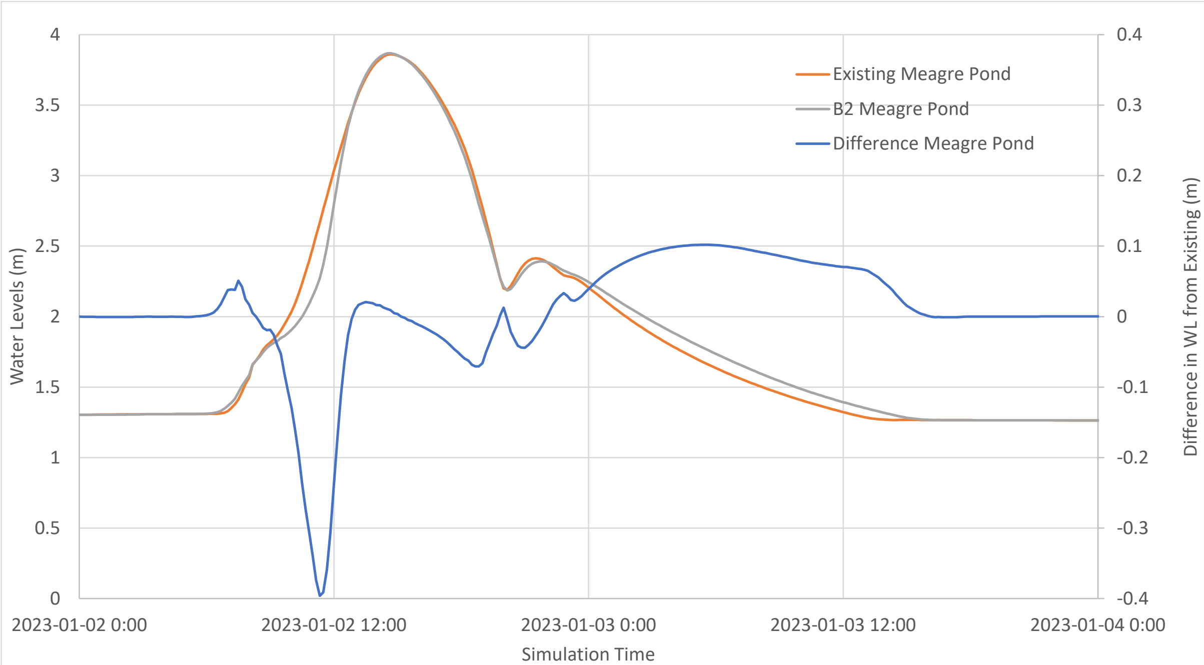

Figure 5.2: Flooding and Impoundment Impacts at Meagre Pond, Storm 1115

In this example, the conclusion might be that the roadway causes more flooding (longer duration) so this is unacceptable. However, in another storm that does not overtop the road, the flooding maximum may be less. For example, in storm 2977, the maximum flood level was reduced by 0.13 m at Meagre Pond for B2, and the duration was not significantly impacted. In this case the new roadway would be beneficial for flooding.

Assessing hurricane storm surge impacts is much more complicated than (for example) assessing the flooding impact of a bridge that crosses a river. In the case of storm surge:

- There are multiple processes driving the flooding (wind setup, pressure setup, rainfall, wave overtopping, tides, etc.).
- The direction of approach may be varied in space and in time.
- These process may all interact with different timing and overlap in different storms.
- These process may all interact non-linearly for different storms.

For these reasons, it is necessary to consider many events and look for broad trends in the data, rather than focusing on individual events and very specific locations. Furthermore, at this stage of the design, very localized issues can likely be mitigated through changes to openings through the road or improvements to localized drainage pathways.

5.2 Impacts on Maximum Flood Height

The peak flood level that was reached at each of the 11 comparison points is provided in Table 5.1 for alignments B1 and B3 (there was essentially no difference between the two sets of data). A summary of the positions of the openings and their widths from these simulations is provided in Table 6.1.

Table 5.1: Impact on Maximum Flood Level – Alignments B1 & B3

Location	Impact on Peak Flood Level (in metres) by Storm Number							Ave Change in Peak Level	
	1115	2848	2977	4184	4492	5005	5031	(m)	(ft)
NW Area Will T	0.00	0.00	-0.01	-0.14	0.02	0.03	0.02	-0.01	0.0
Lower Valley	-0.08	-0.07	-0.08	-0.06	-0.05	-0.08	-0.05	-0.07	-0.2
Northward	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.0
Southeast Northward	0.04	0.00	-0.01	-0.01	-0.15	-0.01	-0.01	-0.02	-0.1
Bodden Town	0.05	-0.04	-0.01	-0.03	-0.18	-0.01	0.00	-0.03	-0.1
Belfour Estates	0.05	-0.19	0.00	-0.04	-0.22	-0.01	0.00	-0.06	-0.2
Central Mangrove	0.05	0.11	0.02	0.14	0.11	0.03	0.02	0.07	0.2
Meagre Pond	0.03	-0.09	-0.11	-0.33	-0.16	-0.11	0.01	-0.11	-0.4
Midland Acres	0.04	-0.01	0.00	-0.22	0.00	-0.01	0.00	-0.03	-0.1
Mastic Reserve	-0.01	-0.03	0.02	-0.11	-0.11	-0.06	0.02	-0.04	-0.1
Rossini Drive	-0.01	-0.03	0.02	-0.12	-0.11	-0.07	0.02	-0.04	-0.1

Table 5.2 presents the data for alignment B2, while the positions of the B2 openings are shown in Figure 5.3. For all of these locations (except Central Mangrove) the proposed alignments have flood levels that are the same or slightly lower than the existing conditions. The only exception to this is at Central Mangrove where there was a slight increase in the flood level. This is presumably due to slightly limiting the floodwater's inland movement, which results in higher elevations on the north side of the alignments.

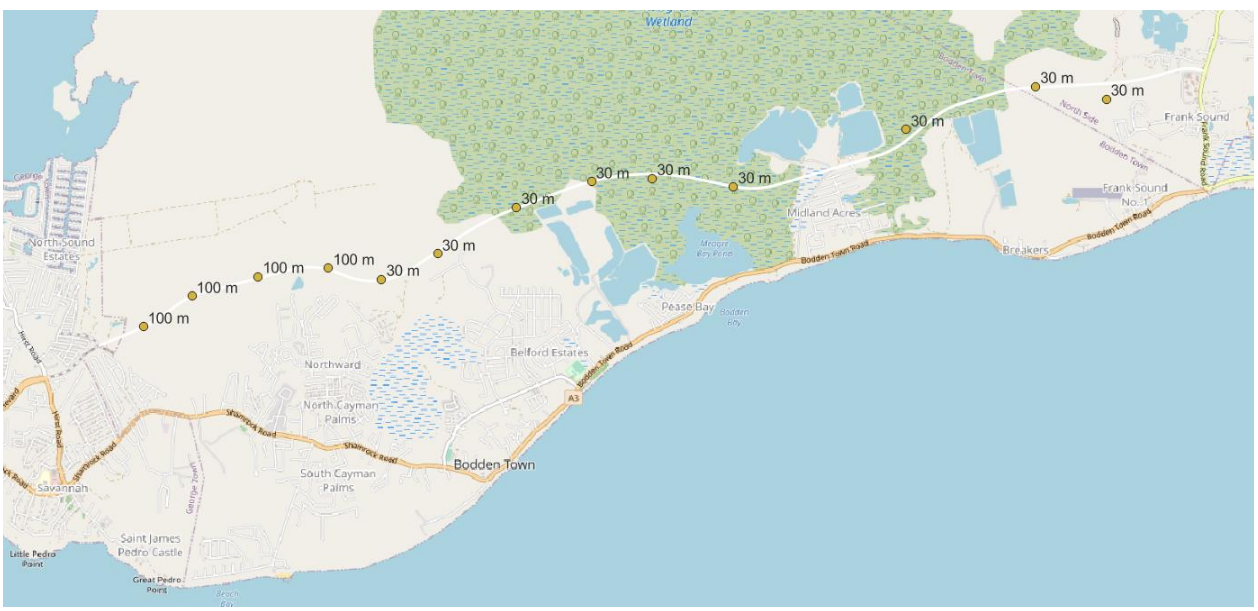

Figure 5.3: Location and Width of Openings in B2 Alignment

Table 5.2: Impact on Maximum Flood Level – Alignments B2

Location	Impact on Peak Flood Level (in metres) by Storm Number							Ave Change in Peak Level	
	1115	(m)	(m)	4184	4492	5005	5031	(m)	(ft)
NW Area Will T	-0.01	0.01	0.02	-0.10	0.01	0.04	0.02	0.00	0.0
Lower Valley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Northward	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Southeast Northward	0.04	0.00	0.00	0.00	-0.18	0.00	0.00	-0.02	-0.1
Bodden Town	0.03	-0.01	0.00	0.00	-0.20	0.00	0.00	-0.03	-0.1
Belfour Estates	0.02	-0.24	0.00	-0.05	-0.22	-0.01	0.00	-0.07	-0.2
Central Mangrove	0.04	0.08	0.03	0.08	0.08	0.02	0.01	0.05	0.2
Meagre Pond	0.01	-0.13	-0.11	-0.37	-0.13	-0.01	0.00	-0.11	-0.3
Midland Acres	0.02	-0.02	0.09	-0.14	-0.01	0.19	0.00	0.02	0.1
Mastic Reserve	0.00	-0.02	0.01	-0.05	-0.07	-0.05	0.01	-0.02	-0.1
Rossini Drive	0.00	-0.02	0.01	-0.05	-0.07	-0.05	0.01	-0.02	-0.1

5.3 Impacts on Flood Duration

The impacts on flood duration are more complex to consider since we are comparing the entire time series rather than just a maximum value from the event. The difference in flood level was compared at each time step and the number of hours when the flood level was higher than the existing conditions was documented for elevation differences of 0.05, 0.10, 0.20, 0.30 metres. In the example of Figure 5.2, the time starting at about 00:00 on Jan 3rd represents about 12 hours when there was a deeper (and longer) impoundment of water as the flood receded. In this calculation there was no offset for delays in the flooding, only a count of the number of hours when the difference was higher.

In some instances, documenting the 0.05 m difference was problematic as it showed differences that could be described as localized puddling. In other words, a difference of 0.05 m may have occurred for days after the peak of the event due to differences in how the mesh represents the topography, and the inability of one of the mesh systems (either the existing or proposed alignments) to drain a puddle. Figure 5.4 shows an example of how flood differences appeared in some instances when the water became very shallow. In this example there is about 0.06 m of water that persists at the site.

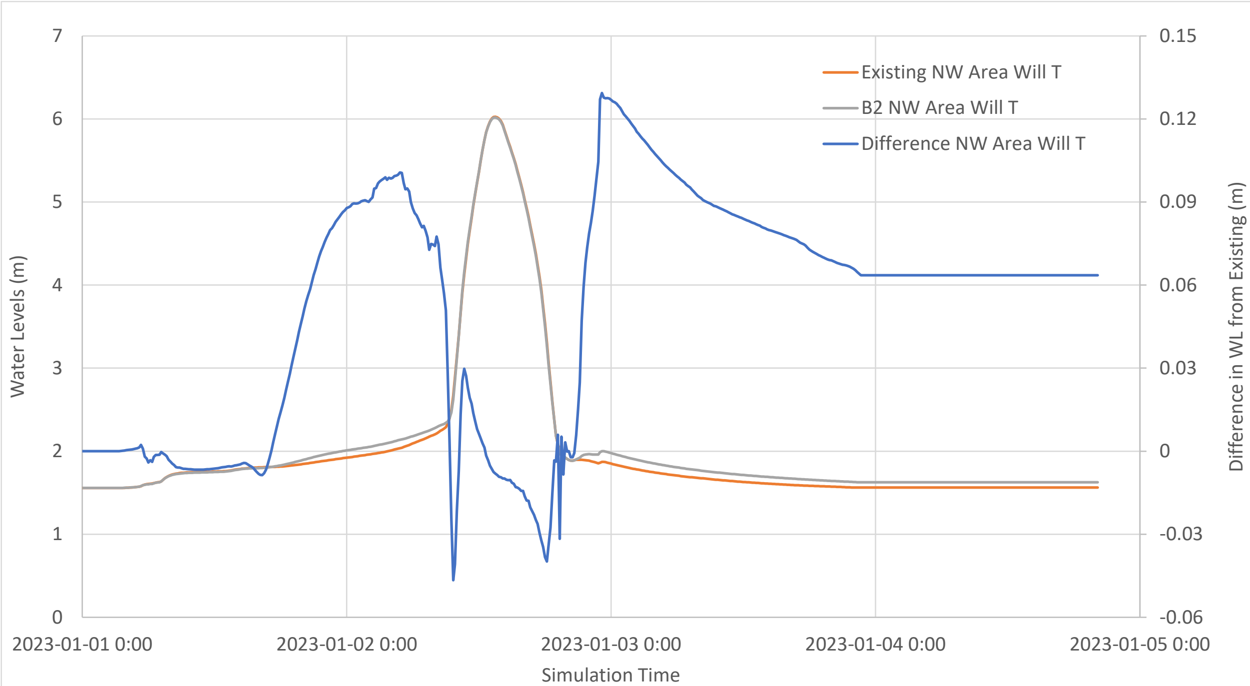

Figure 5.4: Example of Ponding Issue in Shallow Regions

Table 5.3 shows the difference in flood duration for a level difference of >0.10 m. The longer flood durations at NW Area Will T and Rossini Drive are attributed to slight local differences in shallow drainage, rather than any broad impoundment of water in the area. A flood depth difference of more than 0.20 m only occurred for 10 minutes at NW Area Will T in one storm, and never occurred anywhere else.

The results for Alignment B2 are provided in Table 5.4. These data show similar trends to those for Alignments B1 and B3, with slightly higher values at the west end (mostly local ponding), but also some differences at Midland Acres. The data point at Midland Acres was located about 0.6 miles away from the nearest opening through the roadway. This has resulted in a few events where there was some impoundment of about 0.10 m above the existing as the stormwater drained away through a longer drainage path. However, the peak of the flood was reduced at this location as shown in Table 5.2.

It is likely possible to mitigate the increase in flood duration at a site such as Midland Acres by adding an opening through the roadway that is closer to the area of interest. This may result in loss of the slight reduction in the peak water level as the area of Midland Acres would then be more similar in water level to the condition on the north side of B2. Adjustments to the drainage positioning and size to mitigate these impacts is something that can be completed at a subsequent design phase.

Table 5.3: Impact on Flood Duration – Alignments B1 & B3

Location	Hours with >0.10 m Additional Flood Depth by Storm Number							Ave (hrs)
	1115	2848	2977	4184	4492	5005	5031	
NW Area Will T	10	0	16	13	0	6	24	10
Lower Valley	0	0	0	0	0	0	0	0
Northward	0	0	0	0	0	0	0	0
Southeast Northward	1	0	0	0	0	0	0	0
Bodden Town	0	0	0	0	0	0	0	0
Belfour Estates	4	0	0	0	0	0	0	1
Central Mangrove	3	5	0	2	2	0	0	2
Meagre Pond	14	5	0	21	9	7	0	8
Midland Acres	0	0	0	0	0	0	0	0
Mastic Reserve	4	0	0	0	0	0	0	1
Rossini Drive	5	0	0	13	0	0	23	6

Table 5.4: Impact on Flood Duration – Alignments B2

Location	Hours with >0.10 m Additional Flood Depth by Storm Number							Ave (hrs)
	1115	2848	2977	4184	4492	5005	5031	
NW Area Will T	7	0	3	0	8	6	15	6
Lower Valley	0	0	0	0	0	0	0	0
Northward	0	0	0	0	0	0	0	0
Southeast Northward	1	0	0	0	0	0	0	0
Bodden Town	0	0	0	0	0	0	0	0
Belfour Estates	0	0	0	0	0	0	0	0
Central Mangrove	2	4	0	0	2	0	0	1
Meagre Pond	2	0	0	14	2	4	0	3
Midland Acres	6	0	0	20	9	19	0	8
Mastic Reserve	4	2	0	0	0	0	0	1
Rossini Drive	3	1	0	0	0	0	0	0

The overall conclusion on the duration of the flooding is that during some storms there is some slight additional impoundment as the storm recedes. This rarely exceeds 0.10 m and may last for a few hours and prolong the overall flooding by perhaps one or two hours. However, this is a trade off against a reduction in the maximum flood level that can sometimes occur during moderate storm events. In areas where there is shallow floodwater, localized adjustments to drainage infrastructure should mitigate the small impacts (slightly longer flood duration) that were observed in the modeling.

5.4 Alignment B4

The impact of Alignment B4 on the flood level and impoundment in the area was not assessed in this study. Much of the B4 alignment is along the coast and would be built on a higher ridge (or adjacent to or on the back-slope of a higher ridge) and would not change the drainage patterns in the area. There are a small number of locations where there are natural drainage paths along the south coast (lower sections of the coastal ridge) and the width and elevation of these openings would need to be mimicked by the roadway berm to allow sufficient drainage.

The western section of the B4 alignment that approaches the coast from the north (towards Bodden Town) would need to travel through a developed area from about mile 2.0 to mile 3.8. This area is higher than the flood-prone mangrove areas (hence the existing development) and the road would need to be raised in this area if additional flood resistance was desired.

Raising a road in a developed area will have significant implications on grading of adjacent roads, grading near existing homes, drainage under the road, sight lines, property issues, etc. There is a level of detail that would need to be included in the model that does not exist at this time.

The storm surge model that we are using to simulate process on Grand Cayman covers a region of about half a million square kilometers with mesh dimensions ranging from about 15 km down to 5 m. However, it does not include urban drainage features such as swales, ditches, concrete channels, culverts, etc. that would be required to do simulate street-level drainage accurately. It is not appropriate, and potentially misleading, to extract street-level flood information from this broad storm surge model. Street-level adjustments can be undertaken at the final design stage.

For the north/south section of the B4 alignment, it is likely that this road would only be raised by a small amount due to the aforementioned implications, as well as the higher existing grade in the area. Increases in the grade would be small and future phases of design would need to consider this. Based on the data observed for the other road alignments we expect that small changes in drainage would be observed in this area.

Based on modeling in the surrounding area, we can conclude that in the event of a major surge approaching from North Sound, a slight reduction of the peak on the SW side of the road would be expected, with possible slight delays in the drainage of water following a storm. If the surge was strong enough, then there would be no impact on the peak surge level and there would be a slight delay in the drainage of the area due to the increased road elevation. However, these issues could be mitigated through improved drainage paths that are not included in the scale of this model.

6. Preliminary Recommendations

6.1 Variables Impacting Road Flooding

There are numerous variables that impact the extent and duration of flooding. A summary of these is provided below:

- Height of road: Simply raising the road will reduce closure times and severity; however, it comes at significant expense. For this reason, road elevation should be adjusted as appropriate along the length of the road. Note that the most recent simulations that were completed used a recommended value; no variation of road elevation was tested.
- Width of openings: Wider openings can move more water; however, there are additional factors to consider. For example, an opening that is twice as wide will not move twice as much water as there are frictional losses as the water flows radially towards or away from the opening. If the basins on either side of the road were extremely deep then there would be plentiful supply of water to pass through the channel. However, this is not the case.
- Spacing between openings: This is essentially the same process as the “width of openings” parameter. It is more effective to have lesser distance between large openings. For example, openings 100 m wide spaced at 2000 m will move less water than 50 m wide openings spaced at 1000 m, despite the nominally identical opening percentage. However, there may be cost implications of having many narrower openings (e.g. abutment protection and approach ramps).
- East/west position & proximity to North Sound: The west end of the road appears to see flooding more frequently from surges. There are some events that flood the road at the west end and then the surge dissipates further to the east. These are typically brief events and can be associated with winds from the north (perhaps an E/W track that passes right over the site with north winds as the storm approaches). Longer duration events often have a more NW or even WNW wind field and can push water well inland to the east. These flood scenarios can take a long time to drain at the west end.
- Proximity to higher elevations that drain towards the road: When rainfall is significant, the additional water depth is related to the upland watershed area. In regions where it is very flat, there is minimal concentration of water into low-lying areas. However, in some regions (such as the west end of the site) there are upland areas that drain towards the road. This can greatly increase the water depths in the lower areas adjacent to the road. This can also prolong the time of closure as water is continuously delivered to the low areas at a rate comparable to its ability to pass the water through the road.
- Adjacent flooded or dry areas: In some instances, water passes through gaps or over the road and floods an area to the south. The water may then be able to move to the east if that region is not flooded. In areas where the road is further south and there is some higher topography close to the road, the flood plain can be cutoff (or partially cutoff) from adjacent areas. This can result in higher flood levels in some areas compared to adjacent areas. If there is a cut in the topography for the road to pass through, this can result in flow along the length of the road as the flow tries to “link” adjacent areas

6.2 Opening Sizes

The widths of the openings are described later in this section, with other recommendations provided in the following sections. The definition of openings should be considered preliminary, with additional simulations recommended prior to final design.

The simulations were completed with openings that had a base (invert) elevation of +0.5 m (+1.6 ft). If possible, a lower elevation could be used as it will provide a greater conveyance. However, if there is a desire to limit ponding of water, then an opening that is as close as possible to the typical water table, but slightly above it, is recommended.

Strong flows will pass in both directions through the channels and therefore both ends of the channels should be considered to be both an inlet and an exit. Gradually flared ends will provide lesser entrance/exit losses. The details will need to be determined; however, abrupt square ends to the channel should be avoided.

Scour protection will need to be provided in the channels. There should be consideration of having a smooth base to the channel (versus very rough or large diameter riprap) in order to increase the conveyance of the section. Numerical model simulations show that velocities can be in the range of 4 m/s or possibly more. For design purposes a significant factor of safety should be considered

The openings will have pile-supported bridge decks passing over them. Ideally, the underside of the bridge deck will be raised at or above the level of the road on either side of the bridge. During a large flood, the road will act as a weir and allow large volumes of water to pass over it. As the water level recedes closer to the elevation of the road, the weir will become much less effective at eliminating floodwater. At this point in the drainage process, having a bridge deck that significantly impedes flow should be avoided; a higher bridge deck will increase the flow rate as the road becomes dry. Therefore, the vertical alignment of the road will rise and fall, with higher sections at the bridges and lower sections between. The elevations that are called out in the following section are for the mid-segment (between bridges) part of the roadway.

6.3 Road Elevations and Opening Parameters

The combination of the road elevations and the opening sizes will determine the flood parameters along the road. Road closure parameters were assessed in the numerical model and recommendations have been developed to try to attain some spatial equivalence between closure times for large events. The goal is to build the road so that there are no regular flood-prone areas, or in other words the flood parameters are similar along the length of the road. For example, in a small event a particular region of the road may be flooded for 2 to 4 hours. This is seen as acceptable as there is rarely significant traffic movement during the peak of a storm. The greater concern is during the most extreme events where the simulations showed some areas being closed for 24 hours or more. If the rest of the road is clear after six hours, but one area is still flooded for much longer then that area should be raised, or other drainage parameters should be altered.

The elevation of the roadway was stipulated by others for the simulations that were completed. The higher elevations were in the middle section of the road, while the east and west ends were slightly lower. The simulations completed by Baird did not specifically investigate changing the road elevations; the simulations mainly focused on understanding the openings. The elevation of the floodwater in the simulation provides guidance on how the elevations should be modified.

6.3.1 West End (0 to 2.2)

The west end of the road was simulated at +2.2 m over the western 1.9 miles. At about 1.9 miles, a higher section of topography creates a break in the southern floodplain, which isolates the west floodplain from the region further to the east. With significant rainfall runoff entering this area from the south, this area is prone to flood both from heavy rainfall and from surges that approach during N to NW winds. A higher road elevation is recommended for this area, with a target level at +2.75 m. A total opening width of 300 to 400 m should be included; these should be distributed into a minimum of four openings, but preferably more. The openings should be relatively evenly spaced, but adjusted to fit in with local infrastructure.

Figure 6.1 shows the region of interest, with a dashed black line that outlines the region where rainfall is expected to drain towards the roadway. The dashed red line shows a narrow catchment that produced strong flows, with a recommended opening in the roadway at the position of the red arrow (approximately mile 2.0). This opening could be narrower due to the limited width of the contribution area; 30 m should be adequate.

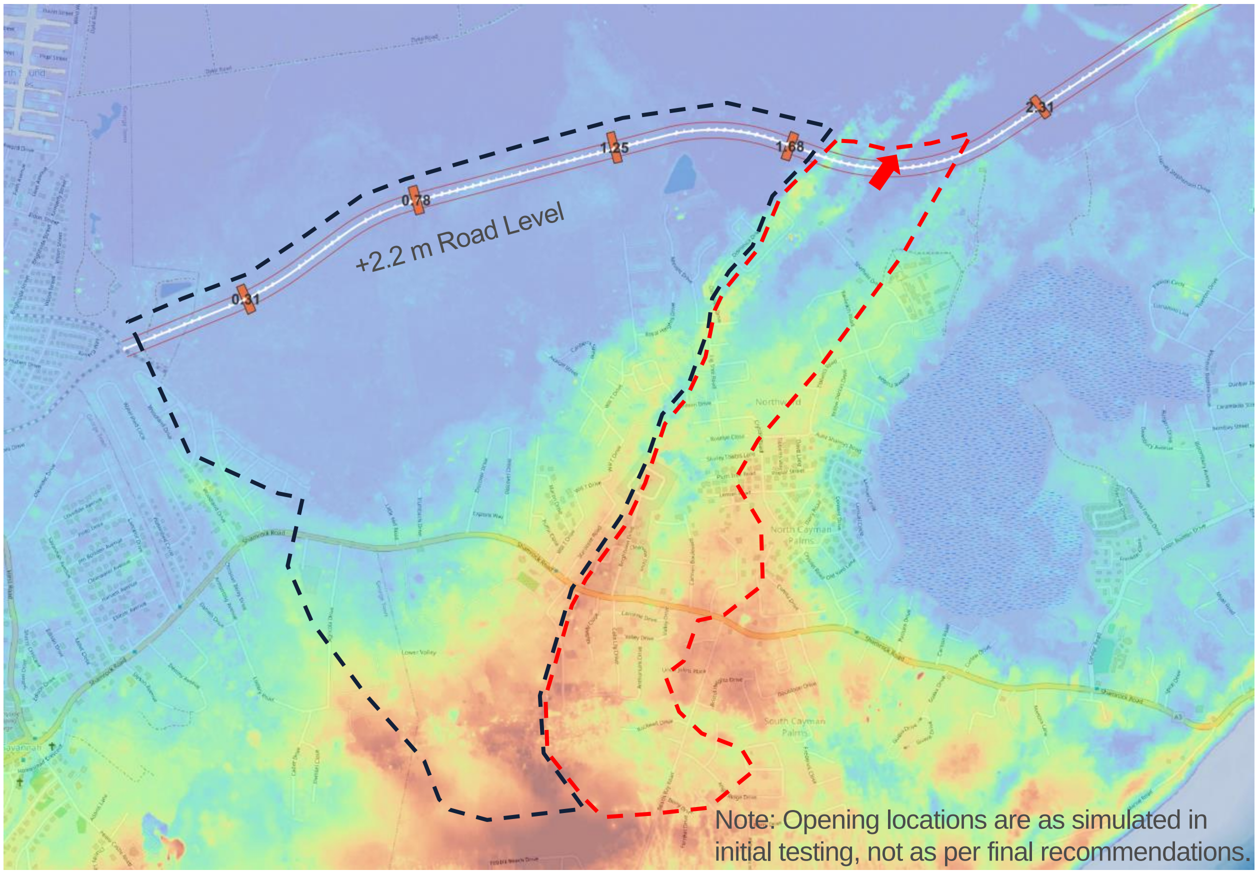

Figure 6.1: Simulated Openings in Western Sector (Miles 0 to 1.8)

6.3.2 B1 Central Section (Mile 2.2 to 6.0)

This region has a wide floodplain south of the roadway that includes the mangrove area. At the west end of this central area (mile 2.2 to 3), there is some development and the ground is slightly higher.

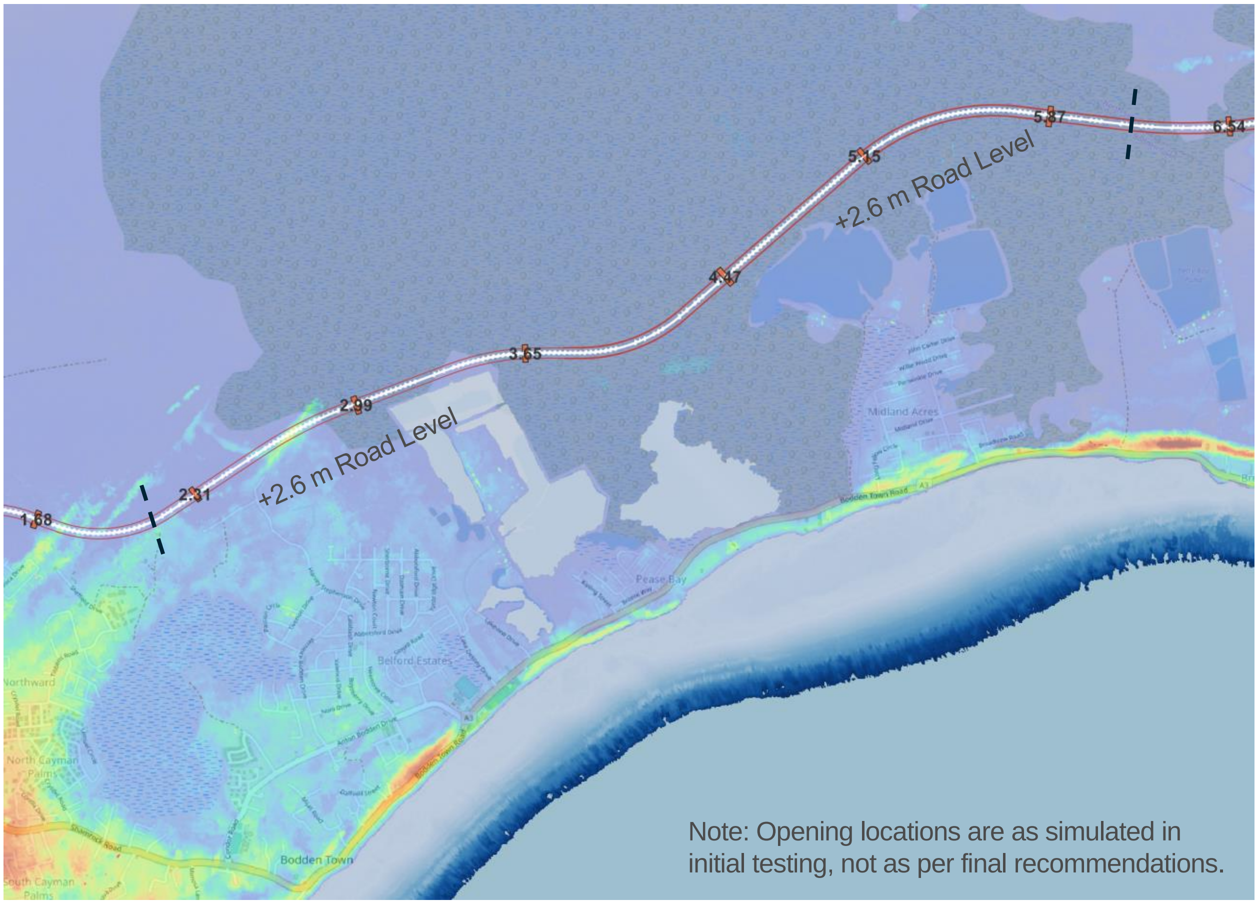

Figure 6.2: Elevations and Simulated Openings for Middle Section

Floodwater that passes south of the roadway in the central area can move laterally, especially in excavated pond areas. This area is slightly less prone to storm surge than the west end because it is further from North Sound. When a surge does occur, it is slower to drain than the west end, yet faster draining than the east end.

During a major surge and rainfall event, the additional water from rain will increase the flood depth; however, we do not have a condition where higher ground significantly contributes to greater flooding in the low lying areas. In a major event, the area that is flooded is relatively close to the total area of the catchment, meaning that (for example) 100 mm of rain would increase the water levels by about 100 mm.

Altering the size of the openings in this area had a lesser impact than in the western section. With the absence of rainfall, smaller openings meant slightly less water passing to the south of the road. The result of this was less water to drain back from the south side. When rain is included, the water level is deeper on both sides but the increase in water level is not that extreme.

In a very large surge, the road overtops and acts as a weir, both during flow to the south and to the north as the flood recedes. Once the water level is close to the road level (when it stops acting as a weir), the level typically continued to decline at an acceptable rate so that the road opened soon after. The dropping of water on the south side was due to a combination of water draining back under the road, and water spreading laterally into possibly less flooded areas.

During earlier simulations, the crest of the road was higher (elevation +3.2 m) from about mile 2.0 to 3.8. The added elevation in this area did provide less closure of the road in this isolated area, although this central section of road is probably not accessible from each side.

The recommended elevation in this region would is lightly lower than adjacent areas, at about +2.6 m for mile 2.0 to 6.0. This corresponds to lower return period levels that are shown in Figure 3.6.

Openings throughout this area can be smaller than in the western section since the catchment does not have significant upland areas that deliver large volumes of water to the area near the road. Five openings in the range of 30 m wide appear to provide adequate drainage of the floodwater.

6.3.3 Eastern Section (Mile 6.0 to 8.0)

The eastern section of the site has the disadvantage of being a long way upstream from North Sound when floodwater needs to be drained. A strong surge from a storm passing north of the site will push the surge a long way inland to the east. In a large event the surge will pass over the road and there will be flooding both north and south of the road. The floodwater recedes much more slowly in these areas due the distance (and therefore gentle slope of the water surface) back to North Sound.

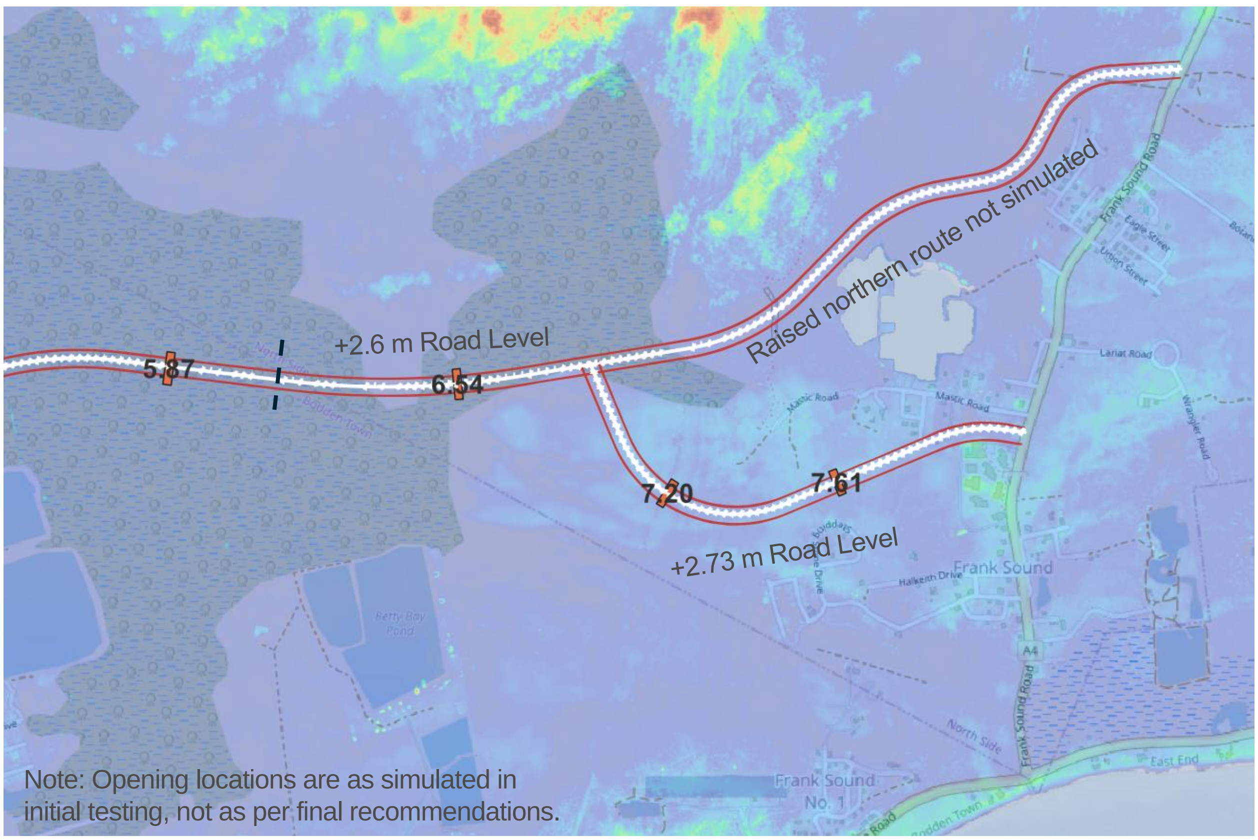

Figure 6.3: Elevations and Simulated Openings for Eastern Section

During these conditions, even the largest opening in the roadway will do little to promote drainage since there is floodwater on both sides of the road at a similar elevation. There needs to be adequate openings so that the water on the south side can equalize with the water level on the north side, rather than flowing only to the west.

Our recommendation in this area is a 30 m opening; however, with further testing it is likely that openings in the range of 20 m wide should be adequate, with four required. Depending on the final alignment of the road at the west end, there may be limited need for having openings after mile 7.3.

With such slow drainage times in this area, we recommend that the elevation of this section be higher than the adjacent section, and slightly higher than the value in the model (2.73 m) at +2.9 m

6.3.4 Summary of Elevations and Openings

A summary of the preliminary recommended opening parameters is provided in Table 6.1. These parameters define a roadway that will have brief localized flooding in a strong event (25 year), but possibly complete flooding in an extreme event (over 100 year).

Table 6.1: Summary of Road Flooding/Drainage Parameters

Mile Range	Length ft (m)	Road Level	Opening Width	Number of Openings	% Open
0.0 to 2.0	10560 (3220)	+2.75 m	100 m (330 ft)	4	12%
2.0 to 2.2	1056 (322)	+2.75 m	30 m (100 ft)	1	9%
2.2 to 6.0	20064 (6116)	+2.6 m	30 m (100 ft)	5	2.5%
6.0 to 8.0	10560 (3219)	+2.9 m	30 m (100 ft)	4	3.7%
0.0 to 8.0	42240 (12874)	Varies	Varies	14	5.4%

The final values that are selected for road elevations may be adjusted in response to cost factors. The fill required to build this road is substantial and downward adjustment may be necessary. We would anticipate that adjustment of the road elevation would be completed similarly along the length of the road

6.4 Overtopping of the Road

During the simulations, all parts of the road were overtopped during both the flood and the ebb of the surge process. Overtopping of the road is not a problem if the currents are mild enough and if there is not such a large water level change that the downstream side of the road is subject to erosion. During the flood of the surge, a water level increase in the range of 1 m in 15 minutes was observed. This rapid change in water level will not redirect through openings in the roadway with such a rapid water level change taking place. It would probably be necessary to have frequent and wide openings in the roadway to limit the water level drop as water flowed off the road onto the back of structure. Some sort of erosion control would be required to limited development of down-slope erosion on the back of the structure.

Given the rapid changes in water level that were seen in the model, it appears likely that erosive forces on the road would need to be considered in the design. For example, it was not unusual to have a water elevation change of 1.5 m or more as the water crested the road. This suggests that armouring of the road shoulder and adjacent slope may be required to prevent erosion damage along the road. This armouring could include riprap, gabion baskets or possibly other approaches. Locally, the longitudinal profile of the road will impact what areas may be most prone to erosion due to overtopping.

6.5 Simulations of Recommended Arrangement

A final series of simulations were completed with the recommended arrangement of openings and road elevations (Table 6.1), as shown in Figure 6.4. In this arrangement the first four openings (west end) are 100 m wide, while the remaining openings are 30 m wide.

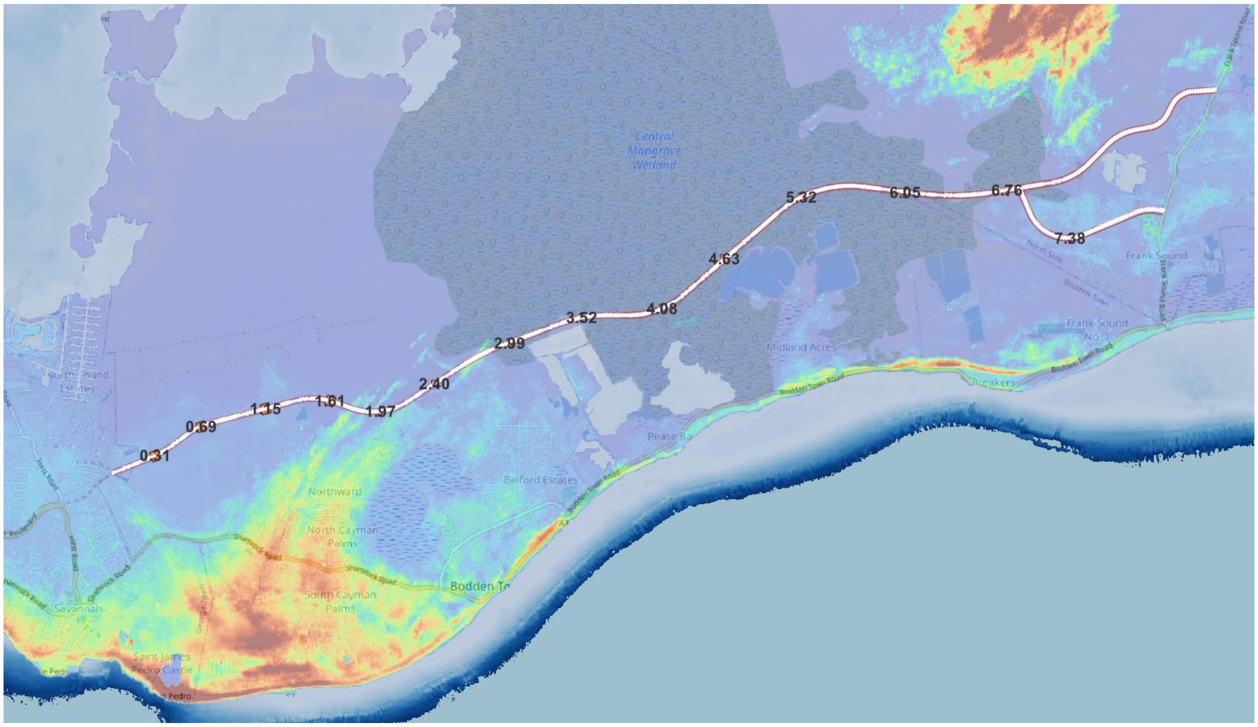

Figure 6.4: Road Alignment with Recommended Openings

6.6 Details Of Openings

The openings could be box culverts (many side by side) or they could be pile-supported spans. Using pile supported spans is probably going to result in fewer obstructions to flow as a result of the wider bridge spans. This makes then less likely to become clogged by debris in the event that there is significant mangrove damage or other debris during a flood event.

The functionality of the openings is most critical at the time when the water level is very close to the roadway elevation. The ability of the road to remain unflooded and open, or the rate at which the water drops back below the road will be improved by having the bridge deck high enough that it is not reducing the rate of flow at this critical time. We therefore recommend that the lower chord of the bridge be above the nominal road height in the area. This will require a transition in elevation up to the bridge deck, which is common for most bridge structures. This higher bridge deck will make the openings as effective as possible at this critical time.

There is limited value in having the opening significantly higher than the nearby road elevation. Once the road is significantly submerged (e.g. 1 ft depth), there is a large amount of flow passing over the road, such that the effectiveness of the openings becomes less critical. For example, 1000 ft (305 m) of road that is submerged by 1 ft (0.3 m) could pass up to 2800 ft^3/s (80 m^3/s) of floodwater over the road. This value becomes much larger with more water depth.

Assuming that the bridge is supported using piles and that there is a transverse pile cap, this pile cap does not need to be considered when defining the lower chord of the bridge. The pile cap will be largely aligned with the flow through the piles and is small relative to the opening size. Therefore, the impact of a lower pile cap below the primary beams is minimal.

The base of the opening should be as low as possible, while also considering issues such as standing water. This will improve the conveyance of the opening and could allow for a reduction in the width of the openings. The modeling thus far has assumed an elevation of 1.5 ft (0.5 m) for the base of the openings.

Opening abutments will need to be armoured either with riprap or some other approach to reduce the potential for erosion of the abutment. Similarly, the base of the opening may need to be armoured, depending on the velocities, the bed material and the construction approach (box culverts, versus piles and depth of penetration).

7. Conclusions

Numerical modeling of hurricane induced storm surge was undertaken to assess different parameters related to the design of the proposed east/west arterial on Grand Cayman. Four road alignments, named B1 through B4 were provided to Baird for assessment. The goal of this study was to evaluate the hurricane surge flood parameters along these routes including:

- The return period of different flood levels along the routes.
- The implications of different road heights relative to road closures and nearby flood impacts
- The required opening sizes to pass the floodwater

The model focused on hurricane surge events, and included rainfall in the model. However, the assessment did not include rainfall-only events that might occur during something less severe than a tropical storm. Rainfall impacts were assessed in a separate study by RVE. Lower return period flooding events are likely defined by rainfall only, while events of 10 or 20 years or longer are probably combined flooding from hurricane induced rainfall and surge.

The modeling completed for this study is intended to support the ongoing EIA; it is not intended to provide final design guidance and is not intended to represent the details of street-level flooding. The guidance from this modeling supports broad scale comparisons of the different routes and provides a starting point for detailed modeling at the preliminary and final design stages.

Alignments B1, B2 and B3 are similar in character and have some common sections. They pass through regions that are extremely similar from a flooding perspective as can be seen by the similarity in Figure 3.6 through Figure 3.8. They should be elevated to a level that keeps them above a moderate return period level (perhaps 25 years or more) but will be inundated during the most severe surge events. These surge events initially recede quite quickly, although regions further to the east experience slower recession of the water due to the long drainage path back to North Sound. Additional height along the road alignment could keep them above a future surge event, but also provides the advantage of emerging sooner after the storm recedes. Recommended road elevations are provided for Alternative B1; these elevations are equally valid for Alternatives B2 and B3 (applied to a similar easting along the path).

Openings under the roadway need to be sized differently in the western two miles of the proposed alignment due to the rainfall runoff in this area. Higher ground to the south results in considerable additional rainfall runoff into this area and requires wider or more closely spaced openings. The openings in the central and eastern part of the road alignments can be narrower due to less rapid rainfall runoff in the area, as well as the overall drainage direction. With no broad elevated areas to the south of the road alignments we do not have the rapid rainfall runoff that is experienced in the first two miles. Also, runoff in the eastern section of the project area needs to drain in a generally westward direction back towards North Sound. This means that drainage patterns are more aligned with the road alignment and will recede more slowly. This alleviates the need for large and closely spaced openings that we see at the west end.

The proposed roadway alignments (B1 to B3) were found to have minor impacts on flooding in adjacent areas, provided adequate openings are included. For smaller events that pass from North Sound, regions south the road alignments can see a very minor reduction in the peak flood level for moderate events. For very large events (e.g. 100 years or more) there is no difference in the peak flood level as the road is likely completely submerged by the floodwater. In some areas there was a minor increase in the time that the flooding persisted after the storm due to impoundment by the roadway. However, the difference in the flood level was generally only a few centimetres and only reached a maximum of 0.20 m for 10 minutes during one of the storm events.

A flood depth difference of about 0.10 m was only experienced in some events, briefly, and in selected areas. Overall, the implications of the roadway on flooding can be described as a possible reduction in the peak of the event, but a slight extension of the event by an hour or two is also possible. Fine tuning of this trade-off between additional protection and a slight longer impoundment can be completed at a final design stage, with all of the differences being quite minor.

The flooding issues experienced along alignments B1, B2 and B3 are generally similar and can be mitigated using similar approaches. The B4 alignment was assessed in a different manner as a result of its extremely different path and exposure.

The B4 alignment initially follows the B1 path before turning towards the south coast. On its southward transition it passes through a developed area that was not considered in our flood modeling. As previously mentioned, street-level modeling cannot be extracted from this model without significantly different information and methods. Furthermore, the change in grade for the road is likely to be subtle in this area and would be addressed with a detailed flood assessment.

The section of B4 that passes along the south coast is at high risk of being blocked by sand in a severe event. Imagery from after Hurricane Ivan in 2004 provides guidance on how severe wave overtopping can be and the extent to which the road can be blocked. Numerical modeling, validated against this imagery suggests that a beach berm in the range of +20 ft in elevation would be required to remain clear in a 100 year event. Designing for a 25 year event is not recommended since this is more likely to be exceeded and could remain blocked by sand for days afterwards.

There are significant challenges related to how such a high beach berm, or alternatively a coastal structure could be implemented along this coast without very large impacts on the ownership, usage and value (environmental, economic and social) of this shoreline.

The elevations for floodwater and roadways presented in this report do not include an allowance for future sea level rise. Previous work on this project suggested that a 0.5 m allowance be included for sea level rise. We recommend that this adjustment, and any other adjustments that may be required related to uncertainty and cost issues, be considered at a future design stage.

8. References

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Appendix A

Validation of Wind/Pressure/Track Models

A.1 Validation of Wind/Pressure/Track Models

A synthetic hurricane model was used to define potential storm events that could impact Grand Cayman. This is a preferred method to using only historical storms as the historical storms are often sparse in terms of the data surrounding them. Furthermore, better defined storms are limited to the past few decades and the small number of these storms is insufficient for defining longer return periods.

The synthetic hurricane model can be validated based on two primary processes:

- The ability of the model to produce reasonable wind fields for a known hurricane. These wind fields can be compared to recorded wind conditions and show that the process used to characterize the wind field in the storm is acceptable.
- The ability of the storm generation approach to develop storms in the appropriate region of the tropical Atlantic and the ability to create realistic track patterns near the site.

These two types of validation are provided below.

A.1.1 Hurricane Wind and Pressure Model Validation

The validation of hurricane wind model has focused on significant events that have passed within a 300 km radius of the Grand Cayman Island and during times when there were available surface wind measurements. This Caribbean basin has a total of three NDBC buoys with publicly available observations. A total of four historical events were identified:

- Hurricane Emily – 2005
- Hurricane Wilma – 2005
- Hurricane Dean – 2007
- Hurricane Grace – 2021

Of the above events, Wilma has reached the highest recorded intensity in the Atlantic basin with sustained surface winds of 183 mph. Figure 1 presents a spatial plot of the Hurricane Wilma wind and wave fields at the time of peak winds nearby the island of Grand Cayman.

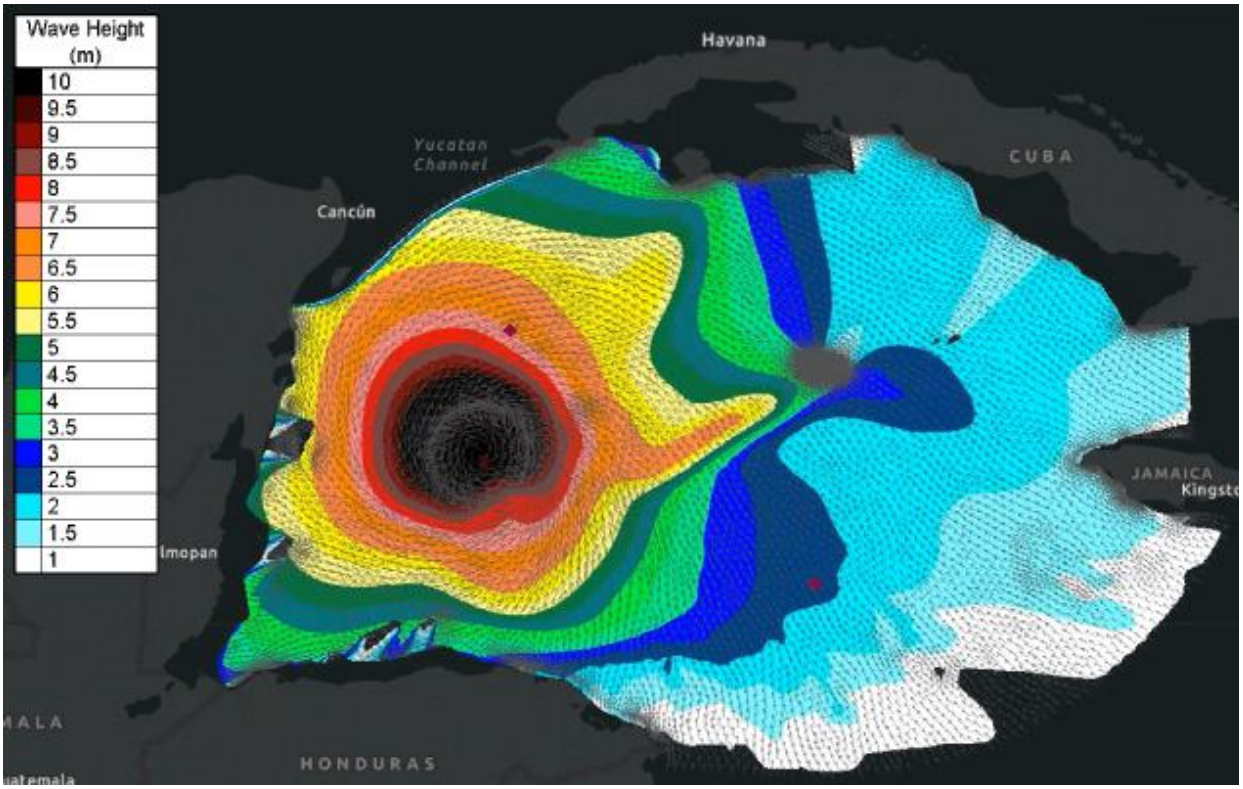

Figure 1: A spatial map of modeled 10-meter wind vectors and wave height during Hurricane Wilma.

Figure 2 and Figure 3 show a comparison between the modeled and measured wind speed and direction at NDBC Buoy 42056. The hurricane passed in a NW direction, while to the SW of buoy 42056, resulting in the strongest winds approaching from the SE.

The plots confirm the model's ability to accurately reproduce the wind field of the hurricane, including both wind speed and direction relative to the cyclone's center. They show that the model effectively captures the intensity and rotational pattern of the winds, indicating its reliability in simulating the dynamics of the hurricane's wind field. The scarcity of data in the Caribbean complicates the validation of wind field models, making it challenging to assess their accuracy in this region. For this reason, a well proven and robust cyclone wind field model with calibration in other geographic areas was used for this study.

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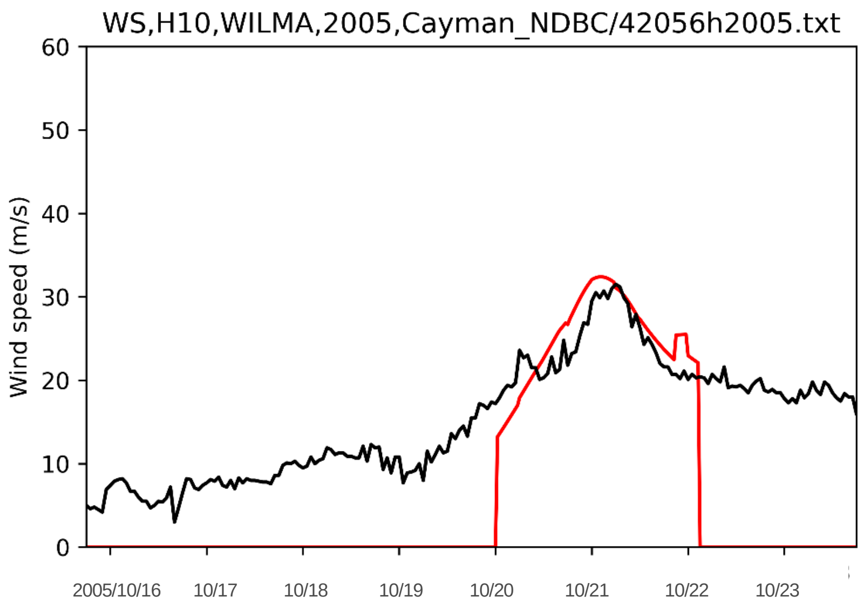


Figure 2: Time series comparison of modelled and measured winds at NDBC buoy 42056 during Hurricane Wilma.

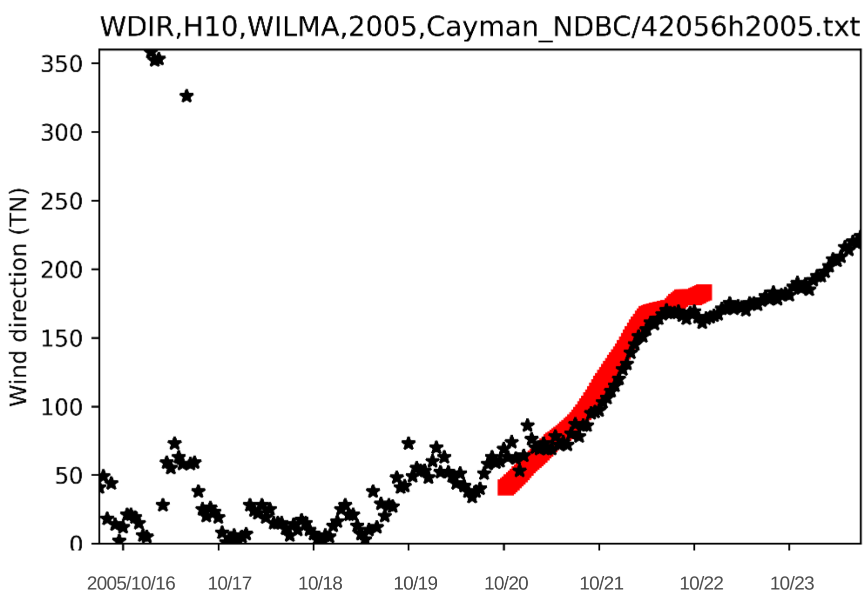


Figure 3: Time series comparison of modelled and measured wind directions at NDBC buoy 42056 during Hurricane Wilma

A.1.2 Monte Carlo Hurricane Track Model Validation

In order to generate synthetic storm tracks, it is first necessary to develop statistics for a broad area that depicts the development (cyclogenesis) of the storm and how the storm strengths/weakens and travels. Statistics are also derived to represent the overall shape of the storm (narrow versus broad). The value of doing this for a broad area is that far more data can be assessed and then developed into smooth representations of the statistical patterns. This helps to alleviate the variability that can occur from reviewing only an isolated area.

The Monte Carlo track model applied to define storms over the Caribbean region based on statistics derived from the HURDAT/HURDAT2 dataset. The model domain for synthetic track generation consists of the entire Atlantic region and is summarized below:

- Longitude range: -99 W to -65 W
- Latitude range: 15 N to 35 N.

It is important to note that by selecting a domain that encompasses the entire Atlantic basin, we sidestep problems associated with missing the location of important cyclogenesis regions.

A summary of key model validation is presented below. Figure 4 presents a comparison of measure and model cyclogenesis points. Cyclogenesis is defined as the first track observation when maximum sustained winds exceed gale force. Figure 4 represents the spatial distribution of storms reaching hurricane intensity throughout the Atlantic Basin and in the vicinity of the project site. The general pattern of the historical and synthetic storms suggest that the model is providing a good representation of the historical data, noting that the time frames are 147 years (historical) versus 1000 years (model).

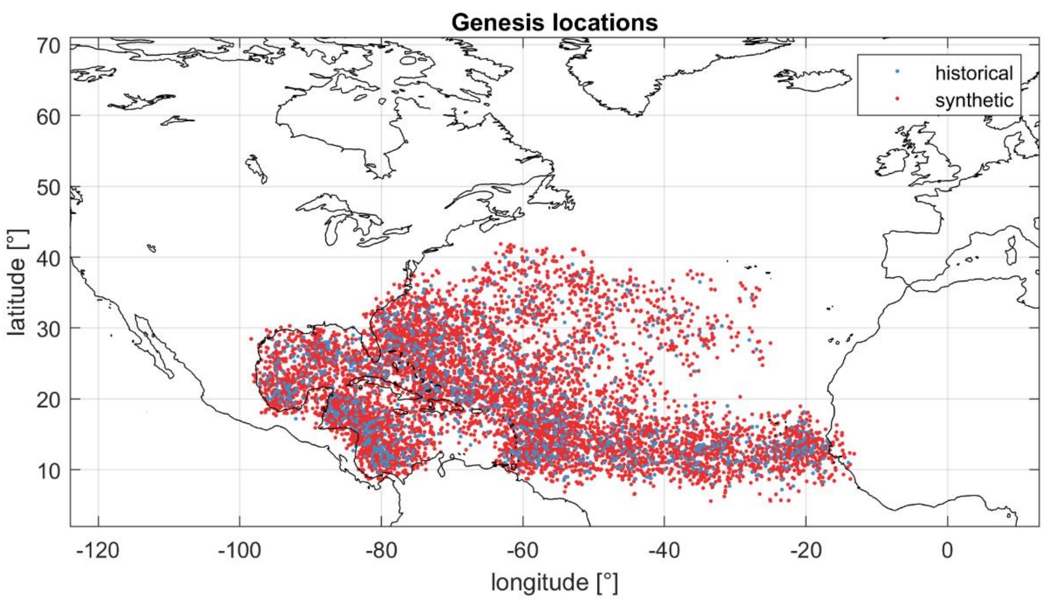


Figure 4: Comparison of modelled (N=1,000 y) and measured (N=147 y) cyclogenesis positions.

The storm tracks shown in Figure 5 show the 41 years of recent tracks in the vicinity of Grand Cayman. The synthetic storms are not expected to reproduce the historical storms, but instead the patterns should be similar. In these plots we see a similar number of tracks and a general pattern of tracks moving towards a WNW direction. There are also a much lower number of tracks that turn and head to the north. Overall, these track patterns support the qualitative statement that the synthetic tracks are reasonably representing the observed tracks. Note that another realization of storms from the model would provide a different set of tracks, with generally similar properties.

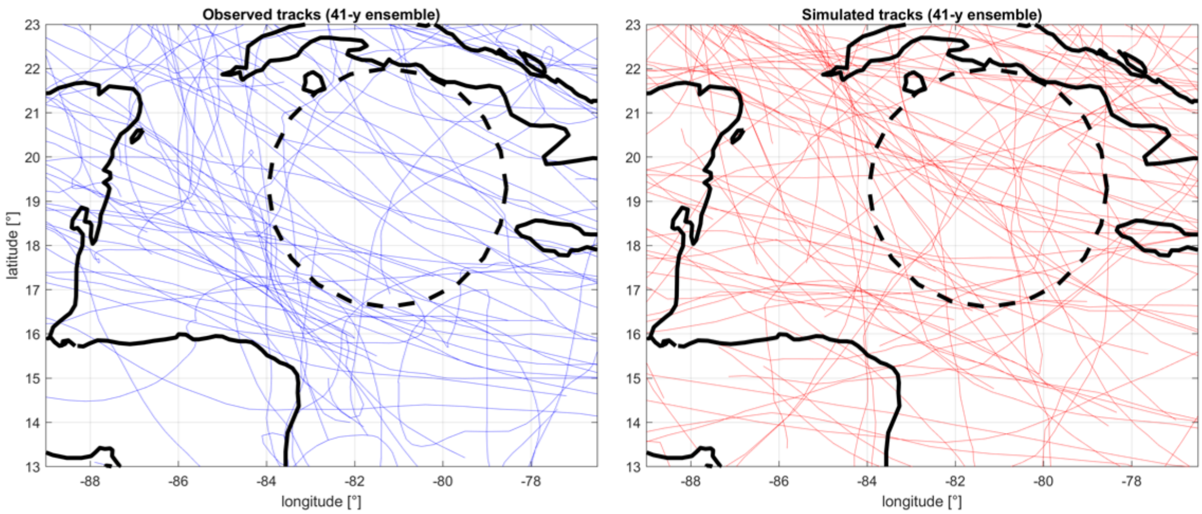


Figure 5: Comparison of modelled and measured hurricane tracks – 41-year period (measured 1979-2020).

Figure 6 shows the density of cyclogenesis in the region, with very similar patterns observed. This plot further supports the validity of the synthetic storm model. Note that with 1000 years of modeled storms versus 147 years of recorded storms, the color scales are different by a factor of 10, and the trends are smoother.

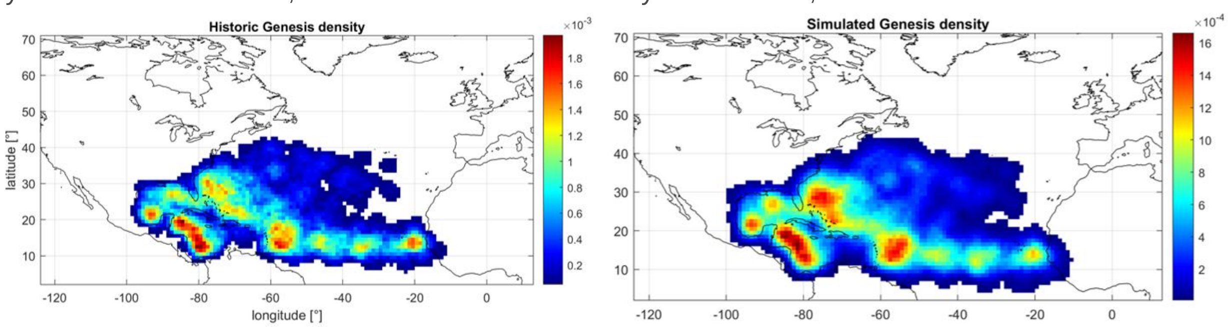


Figure 6: Comparison of cyclogenesis rates per 1 x 1 degree grid cell.

Figure 6 shows the observed and simulated number of storms per year within 300 km of Grand Cayman. The number of storms varies between zero and five (only once), but a better comparison is shown in the lower half of the plot where the cumulative number of storms is shown. The modeled and historical numbers track fairly closely until the mid-1970s to the mid-1990s where there is a lessening of the observed rate (a slightly flatter line). The model provides more of a long-term average value throughout this period, which is believed to be an appropriate, but only slightly conservative approach for assessing the present day frequency. Overall, these plots show good comparisons in the total number of storms and provide confidence in the modeling approach.

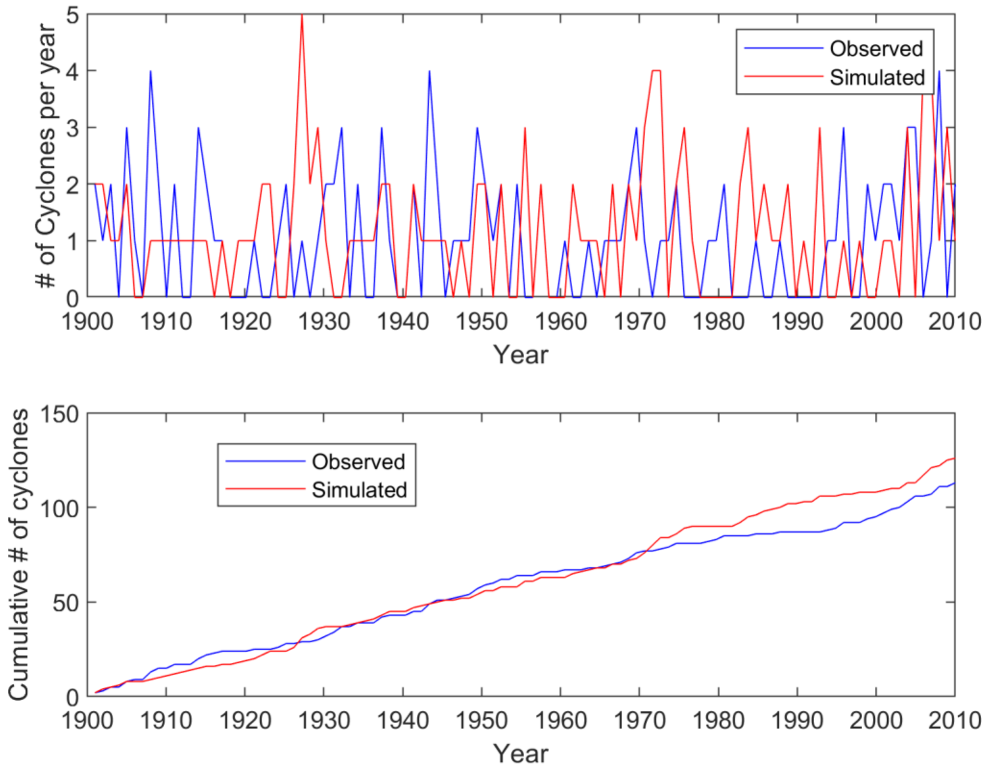


Figure 7: Comparison of cyclone frequency within a 300 km radius of Grand Cayman. Top panel – Number of cyclones per year. Bottom panel – Cumulative number of cyclones

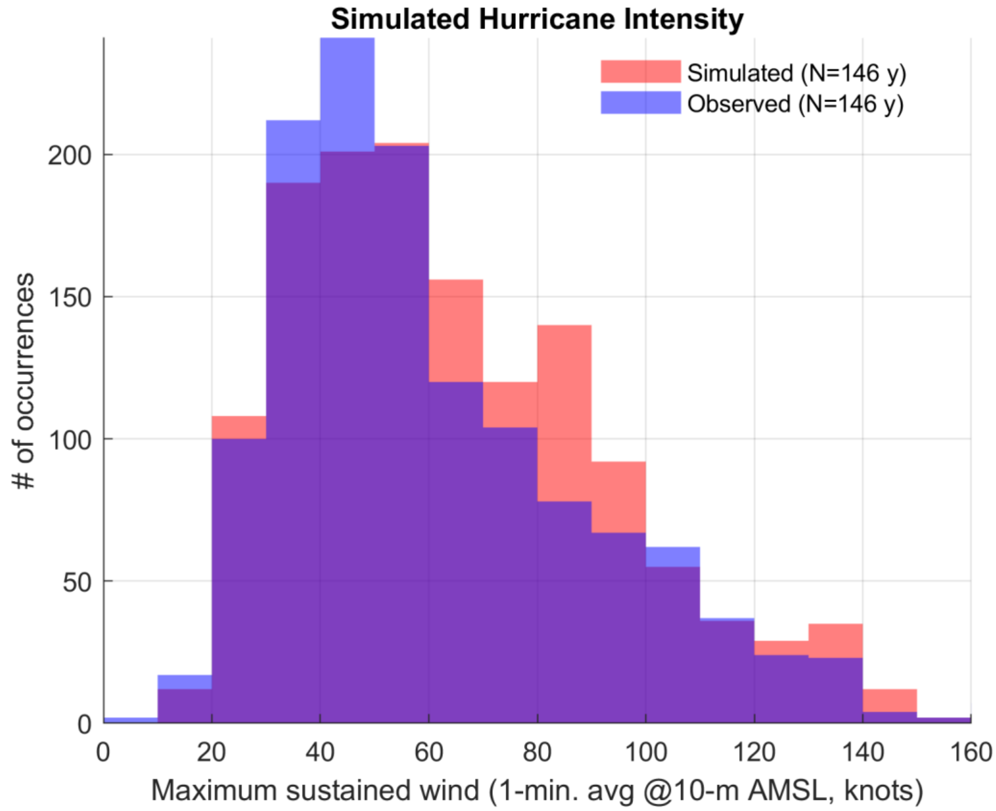


Figure 8: Comparison of simulated maximum sustained winds observations within a 300 km radius of Grand Cayman for a 146-y period randomly selected from the 1,000 years of simulated tracks.

The modeled rainfall for the selected synthetic tropical cyclones (TC), detailing total rainfall (in mm), peak rainfall (in mm/hr), and the duration of rainfall exceeding 2.5 mm/hr (in hours) is shown in Table 8.1. For instance, TC #0149 had a total rainfall of 356 mm, a peak rainfall intensity of 30.71 mm/hr, and experienced rainfall above 2.5 mm/hr for 20 hours. In contrast, TC #2848, with the highest total rainfall in the dataset, recorded 2135 mm, a peak intensity of 38.8 mm/hr, and had rainfall above 2.5 mm/hr for 74 hours. This summary reflects realistic variability in intensity and duration of rainfall across different synthetic tropical cyclones using the approach described in Section 2.3.

Table 1: A summary of modeled rainfall statistics at (-81.265 W, 19.2985 N) for select events.

Event	Peak Rainfall (mm/hr)	Duration over 2.5 mm/hr	Total Rainfall (mm)
TC_0149	30.7	20	356
TC_1115	38.9	45	1226
TC_1855	20.7	21	376
TC_2134	35.4	30	707
TC_2848	38.8	74	2135
TC_2977	36.9	52	1051
TC_4184	39.1	58	1496
TC_4492	38.1	42	1106
TC_5005	35.3	54	1224

Appendix J.7 –
Hydrology and Drainage Field Assessment

1 Field Assessment Method

Hydrology and drainage field assessment efforts in July 2023 and May 2024 included observation and collection of information regarding existing drainage conveyance structures (pipes, inlets, manholes, etc.) within the Proposed Project study area, observations of the existing on-island bridge, field views of the natural resources and mosquito canals, and visits to four active quarries. The existing roadways and Proposed Project corridor, when possible, were viewed to assess existing conditions and observe drainage patterns. The existing inlets and drainage systems were measured, mapped, and photographed. A rainfall event was observed and photographed. Observations of the event including localized temporary flooding along Bodden Town Road. An existing bridge in the Seven Mile Beach area was also observed. Flow patterns along the Savannah Gully were also assessed. Field views of natural resources, including the Central Mangrove Wetland, Meagre Bay Pond, and Mastic Trail were conducted. The mosquito canals were walked and periodically measured. Drainage pipes and structures were mapped, characterized, and photographed. Exposed bedrock was mapped and photographed.

2 Existing Roadways, Inlets, and Bridges

During the field assessment, several existing roadways were traversed including Lookout Road, Bodden Town Road, Shamrock Road, and Hirst Road. The existing roadways along and adjacent to the proposed Will T Extension were viewed, including Trumbach Drive, Plum Tree Road, Northward Road, Crysdel Road, Thatch Tree Lane, Dominica Drive, Minzett Road, Will T Road, Canberra Street, and Avalon Street. Pictures were taken to document the existing conditions of the roads. Generally, the existing roads were two lane roads with housing developments, businesses, and government buildings in close proximity to the road. There were some locations, particularly along Shamrock and Bodden Town Roads, with small (approximately 3 to 4 ft (0.9 to 1.2 m) tall) decorative walls that were only a few feet from the edge of the roadway on either side of the road (**Photo 1**). Bodden Town Road was at times close to the ocean (**Photo 2**). Bodden Town Road is also in close proximity to Meagre Bay Pond. The roads follow the existing topography with Hirst and Shamrock Roads rising along the ridge located in the Bodden Town Area and Bodden Town Road following the coastline. Bodden Town Road is located several feet above sea level for a majority of the EIA study area with only a few locations, particularly at Meagre Bay Pond, dropping closer to sea level. Many streets along the proposed Will T Extension were unlined (**Photo 3**). In addition, Trumbach Drive was gravel (**Photo 4**) while other roadways had gravel roads extending past the pavement.

Photo 1: Two-lane road in residential area with relatively short decorative walls (July 2023)

Photo 2: Bodden Town Road in close proximity to the ocean (July 2023)

Photo 3: Unlined roadway in the proposed Will T Extension area (May 2024)

Photo 4: Trumbach Drive is gravel (May 2024)

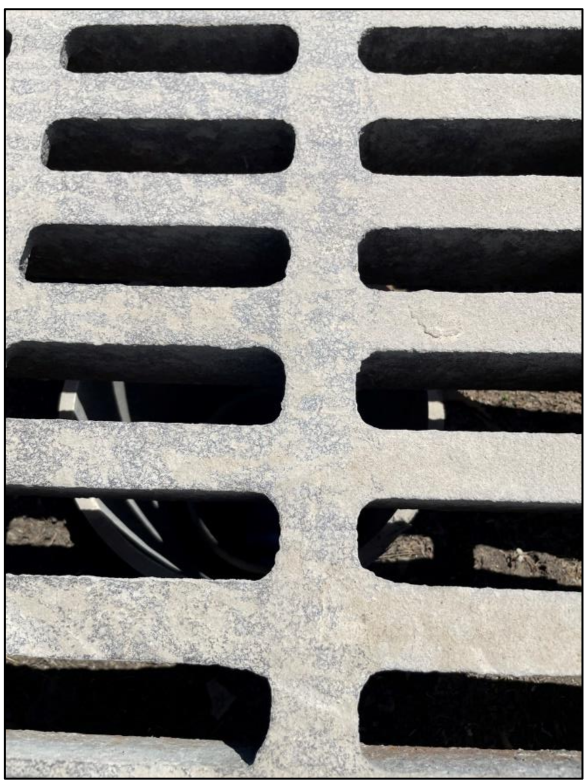
The existing inlets and drainage systems in the roadways were also observed during the field view. Inlets were observed along Lookout Road, Bodden Town Road, Shamrock Road, and Hirst Road. Along the proposed Will T Extension, one inlet along Plum Tree Road was noted. The observed drainage systems consisted of shallow inlets located on the roadside in between the edge of the roadway and the adjacent properties (**Photo 5**). Several locations contained multiple inlets that were connected with small pipes (approximately 15-inches in diameter, maximum) (**Photo 6**). There were also several locations of kerb and gutter that contained combination kerb opening/grate inlets with grates that indicated they were manufactured in the USA (**Photo 7**). All the inlets either drained to or contained a drainage well standpipe (**Photo 8**). Most of the well standpipes were observed to be approximately 8-inches in diameter and were fabricated from Polyvinyl Chloride (PVC) pipe. The ends of the PVC standpipes were generally oriented upward with no trash racks or other screening devices. Several of the wells observed contained perforations along the raised portion of the standpipe. Water was visible within most drainage/well standpipe inlets with a few of the standpipes appearing clogged with debris (**Photo 9**). Conversation with NRA field personnel in July 2023 verified that the water table is close to the surface in most locations and that the well standpipes are cleaned out periodically to ensure they will function properly during the hurricane season.

Photo 5: Typical inlet location (July 2023)

Photo 6: Inlet on shoulder drains to inlet in centre of roadway (July 2023)

Photo 7: Made in USA inlet (July 2023)

Photo 8: Typical well- 8inch diameter PVC standpipe (July 2023)



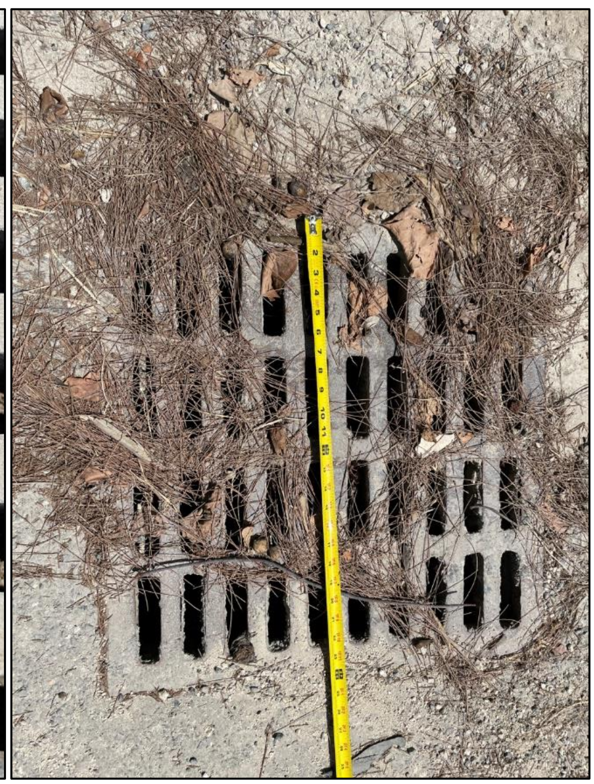


Photo 9: Inlet clogged with sediment (top) and debris (bottom) (July 2023)

A rainfall event was observed during the field view. During the rainfall event, the water drained from the roadway to the roadside and ponded above the inlets. The water ponded on to the roadway surface in several locations with the worst of these locations having the water almost reach the centerline of the road (**Photos 10 and 11**). These locations were also observed approximately 1.5 hours after the rainfall stopped and the drainage wells in the inlets had drained runoff from the roadside.

Photo 10: Flooding on Bodden Town Road during rainfall event (July 2023)

Photo 11: Flooding on Bodden Town Road after rainfall event (July 2023)

Research prior to the field review identified the location of only one existing bridge on Grand Cayman in the Seven Mile Beach area. Observations during the field review indicate that the bridge was raised with a 17-foot (5-meter) clearance under the bridge. The bridge appeared to be constructed of concrete girders with embankment and retaining walls used to raise roadway approaches to the elevation of the bridge deck (**Photo 12**). No areas of erosion or stream instability were noted on the watercourse spanned by the bridge.

Photo 12: Existing Bridge in the Seven Mile Beach area (July 2023)

3 Savannah Gully

The Savannah Gully is an area of geographic relief along the south shore of Grand Cayman in the Savannah area that has been documented as a historical area of storm surge inundation and conveyance. In 2006, the Savannah Gully was flooded and a wall was designed to prevent subsequent surges from being conveyed over the gully and to the north; however, the wall was not constructed. The Savanah Gully has not been reported to have flooded since the 2006 storm event. Several photos were taken along Sandy Ground Drive in the vicinity of the gully to document the existing conditions. The relief area is easily observable along the shoreline and appears to run back along Sandy Ground Drive into the vicinity of Shamrock Road. There was an obvious increase in dense vegetation in the vicinity of the gully as well as an accumulation of plant and trash debris. **Photos 13 to 16** show the general direction of flow with red arrows.

Photo 13: Savannah Gully, facing south from Sandy Ground Drive toward ocean (July 2023)

Photo 14: Savannah Gully, facing east along Sandy Ground Drive (July 2023)

Photo 15: Savannah Gully, facing north from Sandy Ground Drive (July 2023)

Photo 16: Savannah Gully, facing west from Sandy Ground Dr. Downslope extent (July 2023)

4 Central Mangrove Wetland

The Central Mangrove Wetland is densely vegetated and was only accessible during the field reviews via the roads along the active quarries (**Photos 17, 18 and 19**) and the mosquito canals, or ditches, on the west side of the wetland located off the Windward Road near Nadine Street, just south of the North Sound (**Photo 20**). There were also multiple locations of exposed rock surface located throughout the wetland (**Photo 21**).

The ditches along the side of the road contained two observable reinforced concrete pipes (RCP) connecting the ditches underneath the roadway; however, there did not appear to be any flow in the ditches (**Photo 22**). The RCP were round with a 42-inch (1.1 m) diameter and a 2-inch (5.1 cm) wall thickness. At the western RCP, the observed water depth was 2.5-feet (0.8 m) from the pipe crown and 1.5-feet (0.5 m) from the ditch bottom. At the eastern RCP, water depth was 2.75-feet (0.84 m) from the pipe crown and 1.75-feet (0.53 m) from the ditch bottom.

The ditches were, on average, approximately 10 feet to 15 feet (3 to 4.6 m) wide with 1.5 to 2 feet (0.5 to 0.6 m) water depth (**Photo 23**). The density and species of mangrove trees appeared to vary with proximity to the centre of the wetland. The amount of water inundating the wetland also appeared to increase towards the centre of the wetland with obvious signs of water level fluctuation visible on the vegetation.

Photo 17: View of CMW from active quarry west of Meagre Bay Pond (May 2024)

Photo 18: View of CMW from active quarry east of Meagre Bay Pond (May 2024)

Photo 19: View of CMW from active quarry north of Betty Bay Pond (May 2024)

Photo 20: Access road with adjacent mosquito ditches (July 2023)

Photo 21: Bedrock outcrop in the Central Mangrove Wetland (May 2024)

Photo 22: RCP drainage pipe (July 2023)

Photo 23: Drainage Canal (July 2023)

5 Meagre Bay Pond

Meagre Bay Pond was accessed by a short trail off Bodden Town Road (**Photo 24**). The distance between the edge of the pond water and the edge of the roadway stripe was roughly measured to be 90 feet (27 meters). Quarry equipment was observed on the far side of the pond. The pond bottom as viewed from the bank consists mainly of sand with scattered rock outcrops and woody debris (**Photos 25, 27, and 29**). The water surface elevation of the pond was visually lower during the May 2024 field visit than the July 2023 field visit (**Photos 26, 28, and 30**).

Photo 24: Access Trail to Meagre Bay Pond from Bodden Town Road (July 2023)

Photo 25: Meagre Bay Pond, facing Northwest. Bird in water. (July 2023)

Photo 26: Meagre Bay Pond, facing Northwest. Lower water surface elevation (May 2024)

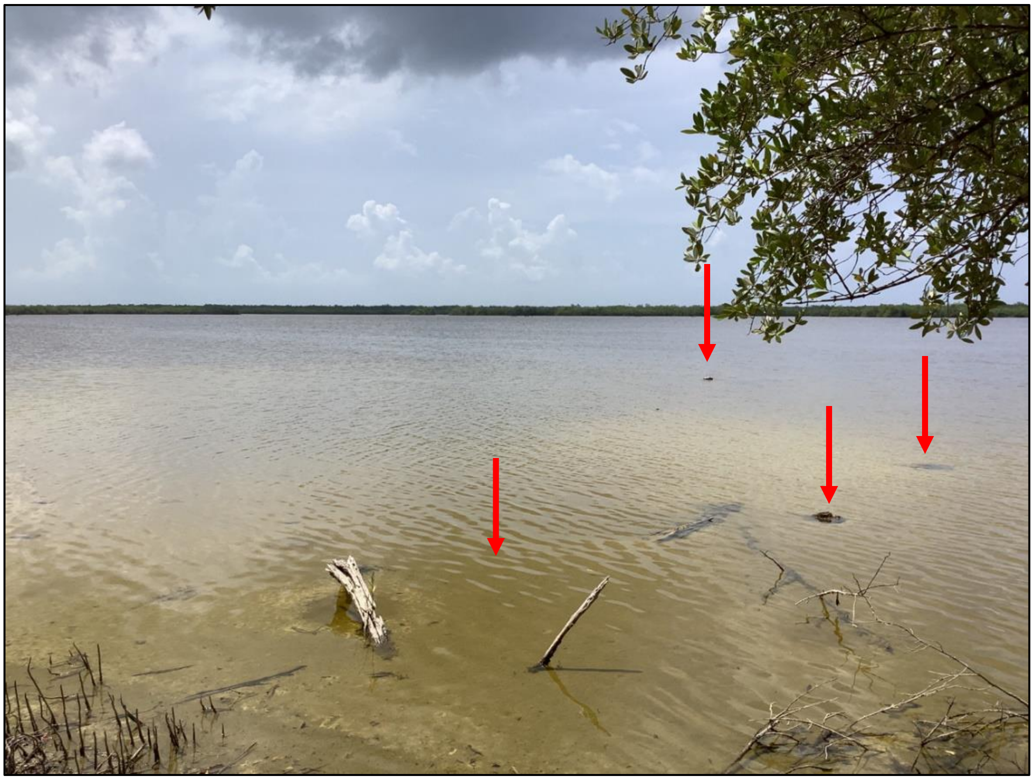


Photo 27: Meagre Bay Pond, facing North. Sandy substrate and rock outcrops (July 2023)

Photo 28: Meagre Bay Pond, facing North. Lower water surface elevation (May 2024)

Photo 29: Meagre Bay Pond, facing Northeast. Woody debris (July 2023)

Photo 30: Meagre Bay Pond, facing Northeast. Lower water surface elevation (May 2024)

6 Mastic Trail

The Mastic Trail is located on the eastern side of the island and 2.3-mile (3.7 kilometre) trail was traversed from the southern trailhead to the northern trailhead. The trail width varied with an approximate average width of 5 feet (1.5 m). Dense vegetation was noted immediately adjacent to either side of the trail. The trail transitioned from a dirt path in the south to a rocky path in the north with several wooden boardwalks located in between. The area was mostly dry with a few puddles located adjacent to the boardwalk and in the bottom of pits in the rock surface. The vegetation varied along the trail but remained dense along the length of the trail. The elevation of the trail also varied, particularly along the rock formations encountered towards the north end of the trail, with some locations climbing over approximately 6-foot-high (1.5 meter) rock outcroppings.

The two elevated boardwalks were measured. The southern boardwalk was 3 feet (0.9 m) wide, consisted of 2 inches by 6 inches (5 cm by 15 cm) wooden planks and was elevated up to 2 feet (0.6 m) above existing grade (**Photo 31**). The depth of existing standing water adjacent to the bridge was approximately 1.5 feet (0.5 m) in the deepest spot (**Photo 32**). The northern boardwalk was 4-feet wide, consisted of 2 inches by 6 inches (5 cm by 15 cm) wooden planks, and was elevated up to 29 inches (74 centimetres) above existing grade by PVC pipe posts (**Photo 33**). There was no standing water under or adjacent to the bridge. It appears that the existing bridge had replaced an earlier bridge.

Photo 31: Southern Boardwalk (July 2023)

Photo 32:Standing water adjacent to southern boardwalk. (July 2023)

Photo 33: Northern Boardwalk, no standing water (July 2023)

7 Bedrock and Peat

Exposed bedrock formations and peat were assessed during the field effort. Bedrock formations were found in the Central Mangrove Wetland area (**Photo 34**), near the existing EWA (**Photo 35**), Savannah Gully and Mastic Trail (**Photos 36 to 39**). Access was provided by the NRA to the quarry just east of the Meagre Bay Pond during the July 2023 field effort. Observations were made around the perimeter of the quarry up to the northern most point of the quarry where it borders the Central Mangrove Wetland. The quarry contained large excavators that were actively being used for excavation in the quarries (**Photo 40**). The NRA personnel also indicated that blasting was being used in the excavation process. Limestone is being excavated from the quarry (**Photo 41**) with fossilized shells embedded in some of the rocks, as observed at the quarries visited during the May 2024 field effort (**Photo 42**). The excavation areas at the quarries visited during the May 2024 field effort were filled with groundwater almost up to the existing ground level (**Photo 43**). The NRA personnel mentioned that the quarries are approaching 60-feet (18.3 m) in depth. Excess material was observed piled up around the perimeter of the quarry visited during the July 2023 field effort, including piles of an unknown dark material on the north end of the quarry. The portion of the Central Mangrove Wetland that could be observed from the north end of the quarry was mostly covered with pools of water at the surface level and was populated with mangrove trees, similar to the portion of the wetland along the mosquito ditches. Peat was found in conjunction with the mangroves (**Photo 44**).

Photo 34: Bedrock outcrop in the Central Mangrove Wetland area (May 2024)

Photo 35: Bedrock outcrop near the existing EWA (July 2023)

Photo 36: Limestone Pit along the Mastic Trail (July 2023)

Photo 37: Exposed bedrock along Mastic Trail (July 2023)

Photo 38: Large bedrock outcrop along the Mastic Trail (July 2023)

Photo 39: Crevice in the bedrock along the Mastic Trail (July 2023)

Photo 40: Active Quarry (July 2023)

Photo 41: Quarried rock (July 2023)

Photo 42: Fossilized shells in quarried rock (May 2024)

Photo 43: Water surface level of pond at quarry (May 2024)

Photo 44: Peat in mangroves north of quarry (July 2023)

Appendix J.8 –

L&S Elevation Data Shared for the East-West Arterial Extension EIA

Thibeault, Denis

From: Kelly, Darren
Sent: Wednesday, April 3, 2024 7:45 PM
To: Thibeault, Denis; Whiteman, Michael; Edwards, Andrew
Cc: Howard, Edward; Obi, Uche; Comsa, Irina; Matheka, James
Subject: RE: L&S Elevation Data shared for the East-West Arterial Extension EIA

Good afternoon Denis,

Thank you for providing an update as it relates to the outcomes shared by the consultants working on the EWA extension project. L&S are happy to assist the NRA with their review by validating the findings of the consultants, and by providing advice on the application of geospatial data for the next phase of the project.

In regards to the low points classified as noise, it's worth noting that Topographic LiDAR will not penetrate water, hence the null values and noise in the areas covered with mangroves; I presume that underlying water bodies or settled water are present in these areas. This is an expected limitation when interrogating wetlands. The quality of the data will be poor (especially during the rainy season), and will therefore vastly reduce the user's confidence in the returns beneath the vegetation. For the purpose of sharing information, please note that two LiDAR sensors were used to undertake the 2021 project. The Bathy LiDAR, which can penetrate relatively clear water, was used for near and offshore soundings. The Topographic LiDAR was used to acquire elevation data over land.

We are aware that users of the data are having difficulty transforming the elevation observations to align with our local vertical datums. In an effort to obtain further information and clarity on the matter, the issue has been raised with the UKHO's Head of Tides, who has proceeded to instruct his team to determine the relationship between EGM08 and the Cayman Islands vertical datums. Once we are in possession of this information, It will be shared with the NRA and the other data users.

An alternate solution would be to use L&S' most recent LiDAR data set acquired in 2018. Although it's approximately 6 years old, there's been minimal changes (if any) in the proposed EWA extension area, and the elevations are tied to our local vertical datum. We're confident in the positioning and accuracy of this data, as checks on the ground have been undertaken. Also, this data set was delivered at a much higher resolution of 1.5ft., in stark contrast to the 2021 Topographic LiDAR data which was delivered at 2m (or 6.6ft.). The 2018 data will result if more ground returns, notably in mangrove areas, and provide your consultants with a much better DTM definition.

Please let me know if you have any questions, and how we can further assist.

Kind regards,

Darren Kelly, MRICS
Chief Surveyor
Lands & Survey Department

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From: Thibeault, Denis <Denis.Thibeault@nra.ky>
Sent: Tuesday, April 2, 2024 3:59 PM
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Cc: Howard, Edward <Edward.Howard@nra.ky>; Obi, Uche <Uche.Obi@gov.ky>; Comsa, Irina <Irina.Comsa@nra.ky>
Subject: L&S Elevation Data shared for the East-West Arterial Extension EIA
Importance: High

Good afternoon gentlemen,

The NRA currently undertaken a brief review of the information provided by Land & Survey Department (L&S) to the consultants retained to undertake the Environmental Impact Assessment (EIA) of the Proposed Phase 2 Extension of East-West Arterial (EWA) multi-purpose transportation corridor between Woodland Drive to Frank Sound Road. The consultants associated with the EIA project and which all signed an agreement with L&S were Remington & Vernick Engineers (RVE) for Hydraulic and Hydrology modelling, W.F. Baird & Associates Coastal Engineers Ltd. (Baird) for Coastal Engineering Risk Assessment, and Whitman, Requardt & Associates, LLP (WRA) – prime consultant for the EIA.

The purpose of this review is to identify what additional data requirements will be required for the next stage of the EWA extension project – the final detailed design fit for construction and to obtain a confirmation on the quality of data used to date as part of this project.

Our consultants encountered some issues with the accuracy of the 2021 LIDAR data; we list the main points raised by them with regards to the data quality as follows:

- The DTM provided was missing the many areas, including areas like roads – this issue was rectified by using the LAS files provided extracting the data under the ground (2) and road (11) and a new DTM was created.
- In the LAS file provided, significant number of low points were classified as noise, although those points were fitting better with the surrounding areas – suggesting thus that a true land elevation might be lower than the provided level.
- In some circumstances to align various sources like the GEBCO (Offshore bathymetry), the UKHO nearshore Bathymetric survey and the LAS files provided – a digital elevation model was created but this required for some of the land elevations in the mangroves to be lowered by 0.75m.
- Vertical datum issues which will need to be addressed.

To summarise, the main concern was about the classifications of the data contained in the LAS files and the challenges encountered in realistically interpreting and processing the data, especially in mangrove areas where the true ground level was difficult to confirm. This issue has led to a lack of confidence in the current available data which cast shadows especially the hydraulic and hydraulics studies undertaken as part of the Environmental Impact Assessment.

Consequently, the NRA would firstly like to ask your opinion on any identified shortcomings of the data provided. Could you please let us know if the above consultants' statements are correct based on your knowledge and understanding of the data, and whether there are also other issues which have been noticed by Land& Survey team when processing the data? Please refer to the package shared with NRA and consultants in 2022.

As we are approaching the end of the EIA study, we just need to confirm and understand the limitations of the data, in order to improve it for the next stages of the project. It is very important at detailed design/construction stage to have accurate information.

And secondly, although the 2021 LIDAR survey data, which was provided back in 2022, might have been the most relevant and accurate at that time, could you please let us know whether there is a more recent package of data that we could use as part of the detailed design phase? Perhaps more data processing was undertaken in-house and better DTM/DEM data is available.

The NRA counts on the L&S support on this matter by clarifying the aspects highlighted above and identifying potential solutions for the next stages. You department's support on this important project will be much appreciated.

Kind regards,
Denis

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