Saginaw Bay Restoration - Kawkawlin River Continued Reef Feasibility Study

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List of Acronyms and Abbreviations

°F	degree Fahrenheit
µg/m3	microgram per cubic meter
µg/kg	microgram per kilogram
µS/cm	microsiemens per centimeter
ACOE	U.S. Army Corps of Engineers
BOD	Biological oxygen demand
BUI	Beneficial Use Impairment
CDF	Confined Disposal Facility
DO	Dissolved oxygen
ECT	Environmental Consulting & Technology, Inc.
EGLE	Michigan Department of Environment, Great Lakes and Energy
EPA	U.S. Environmental Protection Agency
Ft	Foot
GSD	Geological Services Division
GSS	Geological Services Section
mg/L	milligram per liter
MDNR	Michigan Department of Natural Resources
ORP	Oxidation reduction potential
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated byphenyl
pg/g	picogram per gram
RRD	Remediation and Redevelopment Division
SWAN	Simulating Waves Nearshore (Computer Model)
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalency
WRD	Water Resource Division

1.0 Executive Summary

1.1 Introduction

The primary objective of the Saginaw Bay Habitat Restoration Continued Feasibility Study was to further evaluate the feasibility, cost-benefit analysis, and help answer questions from the community regarding a potential nearshore fish spawning reef near the mouth of the Kawkawlin River in Saginaw Bay. The proposed reef is intended to increase coastal resiliency by reducing the accretion of sediment near the river mouth and navigational channel, thereby reducing the need for dredging and associated cost to the community. The reef is also expected to provide suitable habitat for fish spawning. This work builds off the prior Feasibility Study conducted in 2021-22, and the community outreach workshop and feedback received in 2023.

Proposed Reef Goals include:

- Pursue opportunities that incorporate coastal resilience and fish habitat needs.
- Look to help shoreline communities with protection and buffering from the impacts of flooding, erosion, and coastal habitat loss.
- Improve habitats for fish and wildlife species for Saginaw Bay.
- Work with communities to generate shared vision, support, and buy-in.
- Potential to reduce sedimentation of the recreational navigation channel and reduce long-term dredging costs.

Project partners were hopeful to better understand sedimentation patterns and potential reef improvements for fisheries and avian habitat improvement areas in Saginaw Bay near the mouth of the Kawkawlin River. To investigate the potential impact of placing a reef near the mouth, ECT worked with LimnoTech to develop a set of complementary models to simulate how wind-driven waves would interact with the reef and surrounding areas. Utilizing historical dredging data and information generated by these models, a cost-benefit analysis was derived to better estimate cost savings.

A steady-state wind-driven offshore wave model (SWAN) was developed to simulate the potential energy of waves from offshore as they approach the shoreline and reef site, while a simplified one-dimensional sediment transport model (CSHORE) was developed to simulate the potential erosion and deposition of sediment from longshore transport near the site. This report summarizes the development and application of these models and provides a synthesis of outputs and results.

This report documents the need for this additional study, data collection and analysis available, and conclusions/findings agreed upon by project partners outlining questions around the proposed way forward. The study included several key aspects to best understand the feasibility and cost savings to the community of a potential reef system in Saginaw Bay near the mouth of the Kawkawlin River.

1.2 Background

This study builds upon the information contained in the 2022 Feasibility Study conducted by ECT utilizing National Fish and Wildlife (NFWF) Coastal Resiliency funding. In the lower Kawkawlin River, recreational boating provides access to Saginaw Bay for residents and the public. A boating channel was constructed and is maintained by Bangor Township, but sediment deposition within the channel and river mouth pose challenges and increases maintenance costs for dredging. The channel is maintained by Bangor Township with assistance from the Kawkawlin River Watershed Association. Though the majority of sediment comes from the Kawkawlin River watershed, part of the sediment that fills the channel comes from long-shore current transport along the shoreline of Saginaw Bay. Creating sustainable communities and recreation along the Great Lakes shorelines will require addressing impacts to recreational facilities like the recreational boating channel and reducing the cost of maintaining them. Several efforts are under way throughout the watershed to reduce sediment loading from the watershed.

A feasibility study was previously conducted (report finalized in 2022) to determine the optimal siting of a reef to reduce sediment transport into the boating channel and provide near-shore fish spawning habitat. **Figure 1-1** shows the reef location on the north side and offshore of the Kawkawlin River mouth in Saginaw Bay that was evaluated under this study. The 2022 analysis also confirmed that most sediment deposition at the mouth comes from the river watershed, however some is transported by long-shore currents within Saginaw Bay.

Figure 1-1. Site Vicinity Map – General Location of Proposed Reef System and Vicinity to Mouth of the Kawkawlin River

During a 2023 Workshop developed to share out results of the 2022 Feasibility Study, questions arose driving the need for this additional work to help better answer the following:

1. What is the projected impact of the proposed reef be on longshore drift and sediment deposition at the project site and in the general area?
2. What is the projected impact of the proposed reef on frequency, amount, and costs of dredging in the Kawkawlin River mouth recreational navigation channel?
3. What is the projected impact of the proposed reef on longshore current drift and erosion at various lake levels?
4. What is the projected impact of the proposed reef on potential flooding at the Kawkawlin River mouth and adjacent shoreline areas?

The goal of this continued feasibility study work is to collect necessary data, modeling, and analysis to better understand responses to these questions and share out with the project partners, stakeholders, and community.

1.3 Modeling

In a prior study assessing the feasibility of constructing a rock reef near the mouth of the Kawkawlin River, LimnoTech developed preliminary models to simulate the impacts of wind-driven waves on sediment bed stress (SWAN) and littoral zone transport (CSHORE) in the project vicinity. These models were relatively coarse in spatial resolution and parameterization; however, they provided valuable information on the optimal siting location and size of the potential reef. This phase of work involved refining and restructuring the models to allow for finer-scale resolution and a better assessment of the proposed reef's effect on wave energy and sediment transport. The sections below outline how the models were modified from the prior study.

1.4 Summary of Findings

Findings from this additional feasibility work support a better understanding of littoral sand drift into the Kawkawlin River Channel, potential impact to shoreline properties and a potential reduction in that material movement should a spawning reef of varying heights be implemented. This information then helped populate a cost-benefit analysis to ensure expectations around reduced cost burden to dredge the channel are aligned.

Reef Height Impact:

Proposed reef height was modeled at 3 proposed elevations for modeling and comparison purposes, as shown in **Figure 1-2** below:

1. Existing Conditions (no reef)
2. Proposed reef at 3ft below low water datum (LWD)
3. Proposed reef at mean water level (MWL), 580'

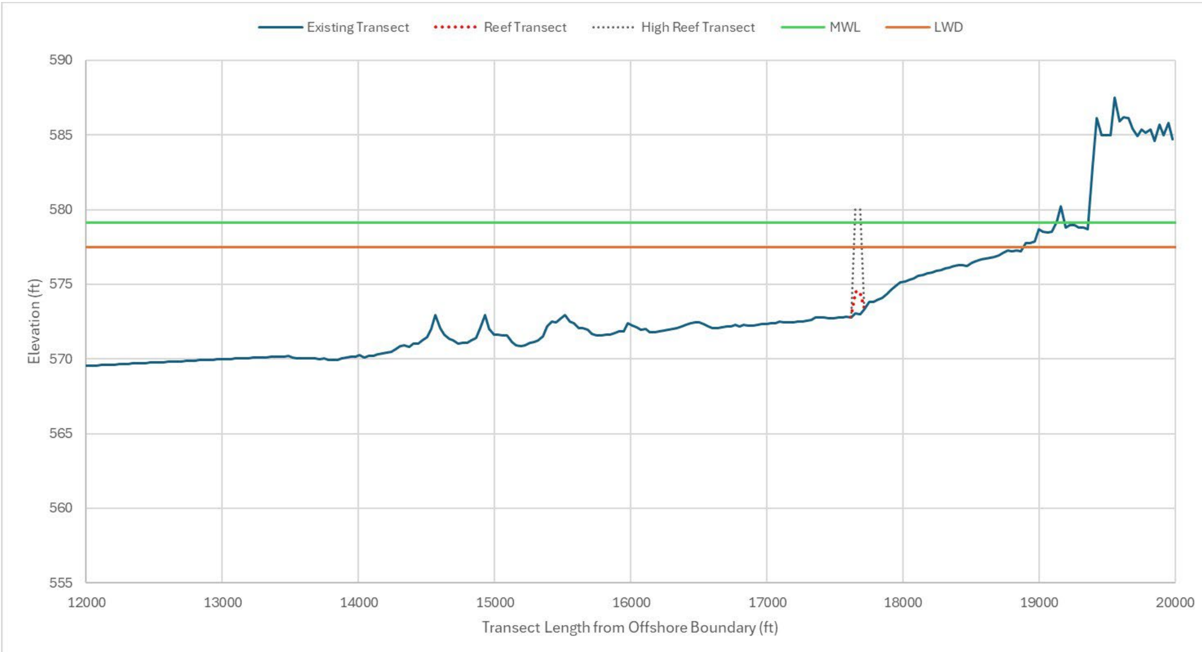


Figure 1-2. Bathymetry profile for CSHORE model transect. MWL and LWD water level elevations referenced

Conclusions:

1. What is the projected impact of the proposed reef on longshore drift and sediment deposition at the project site and in the general area?
    - The higher reef, exposed at LWD, had a more significant impact on longshore drift and sediment deposition, likely reducing transport by 58%.
    - A submerged reef would reduce sediment transport minimally, around 2.5%.
2. What is the projected impact of the proposed reef on frequency, amount, and costs of dredging in the Kawkawlin River mouth recreational navigation channel?
    - Potential Cost Savings Due to Reef Implementation – Range/Dredge Event:
        - Reef implementation is anticipated to reduce dredging needs by ~400 - ~1,600CY of sediment, or approximately ~$30k/cycle average.
        - Important note: the dredge frequency interval (in recent years) is not a direct correlation to when there was a dredging NEED, but when the funds became available.
3. What is the projected impact of the proposed reef on longshore current drift and erosion at various lake levels?

- The higher reef, exposed above the MWL, can significantly reduce the wave heights in the area, which would potentially lead to less shoreline erosion and/or flood potential under specific wind-wave circumstances.
- A submerged reef with a top elevation three feet below LWD shows only minor reductions in wave heights.

4. What is the projected impact of the proposed reef on potential flooding at the Kawkawlin River mouth and adjacent shoreline areas?
    - The exposed reef that fully breaks the incoming waves would have a much more pronounced reduction in wave energy, under median water level conditions.
    - A higher reef will reduce wave heights by over 16% for nearshore properties, however this benefit it unlikely to have a significant impact further upstream in the Kawkawlin River on flooding

2.0 Modeling Approach and Refinement

2.1 Offshore Wind-Driven Wave Model (SWAN) Development

To simulate the bed stress and wave height from offshore wind-driven waves, the preliminary feasibility study SWAN model provided a coarse (500m x 500m cell size) estimation of wave energy in the project area (**Figure 2-1**). SWAN is a third-generation wind-wave model, developed at Delft University of Technology in the Netherlands, which computes random, short-crested wind-generated waves in coastal regions and inland waters (Booij et al. 1999). This model was used to estimate the overall wave energy near the mouth of the Kawkawlin River under existing, current conditions. However, it is not feasible to use this preliminary model configuration to simulate the wave energy with a reef included in the model domain. Figure 2 illustrates this, as the reef would cover 3 square model cells and only provide wave energy output at approximately nine model cells in the “shadow” of the reef between the reef and the shore.

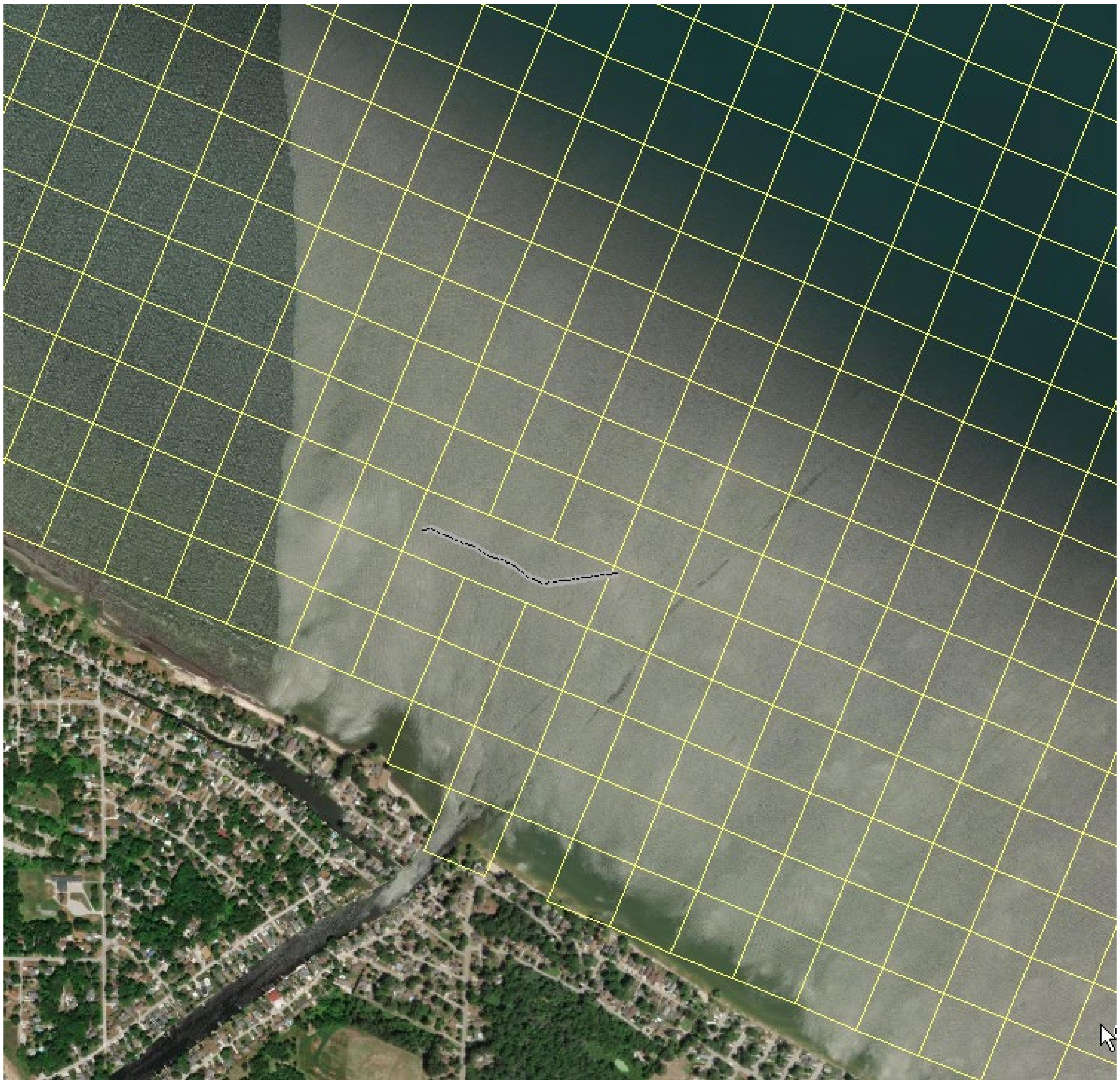


Figure 2-1. Spatial resolution of preliminary feasibility study SWAN model in the vicinity of the reef location (thin black line spanning three model grid cells).

The spatial resolution of the feasibility model was not sufficient to detail the impacts that a small offshore rock reef may have on wave energy in the project area. Therefore, the SWAN model was reconfigured to operate on an unstructured, flexible mesh with variable spatial resolution (**Figure 2-2**) and smaller triangular cells near the shore and the reef.

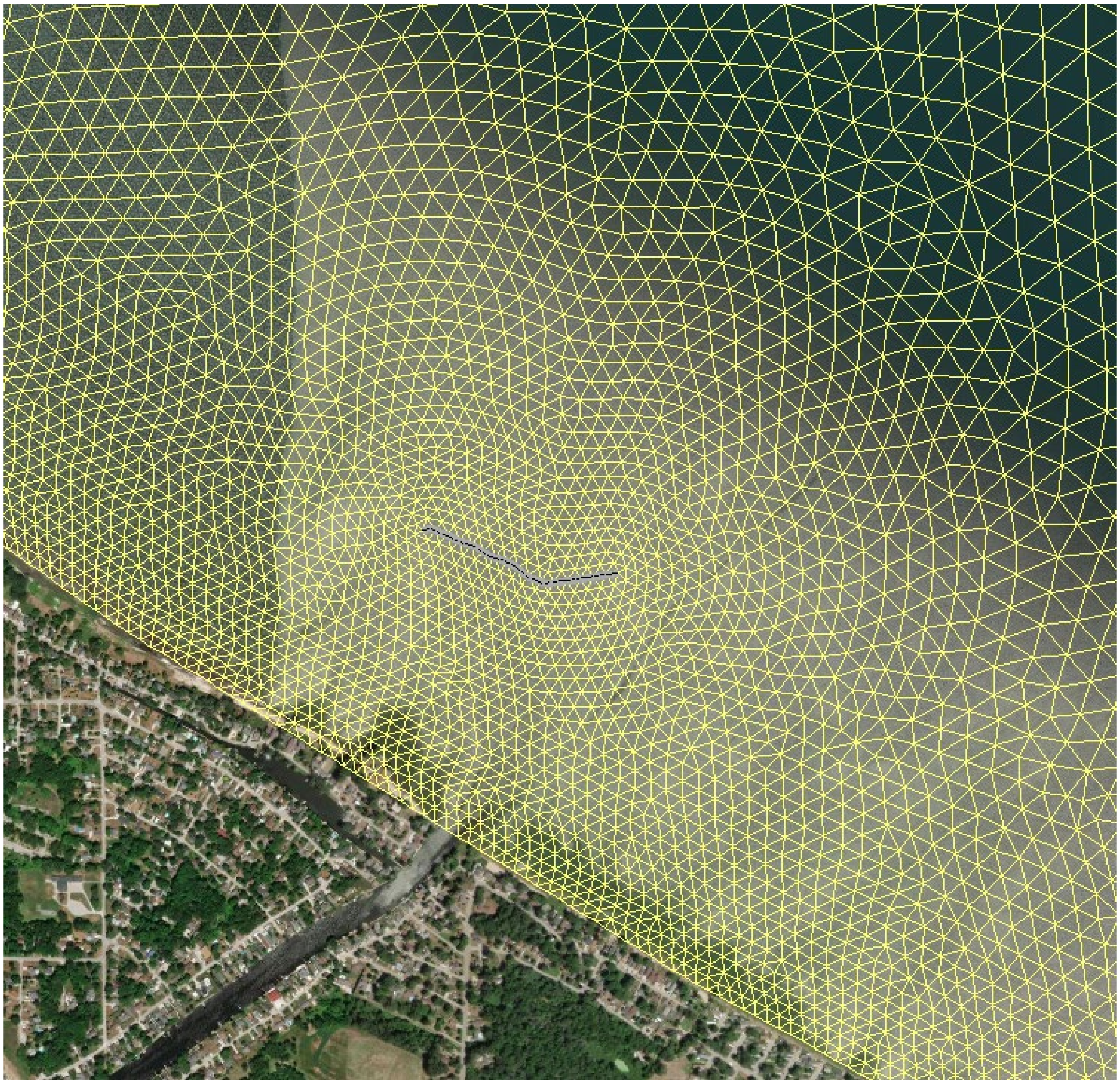


Figure 2-2. Spatial resolution of revised, flexible mesh SWAN model in the vicinity of the reef location, superimposed on the same aerial photo as used in Figure 2-1.

The existing data that defined the coarse model bathymetry were re-mapped onto the finer flexible mesh to represent the depths in the project area. All other model inputs remained the same as those used in the coarse preliminary feasibility model when simulating existing conditions. **Figure 2-3** shows the full domain of the flexible mesh model, with bathymetry data shown as the color scale (e.g., red = shallow water, and dark blue = deep). This figure further demonstrates how the resolution and refinement of the SWAN model is able to more clearly show how the proposed reef will impact sediment distribution etc.

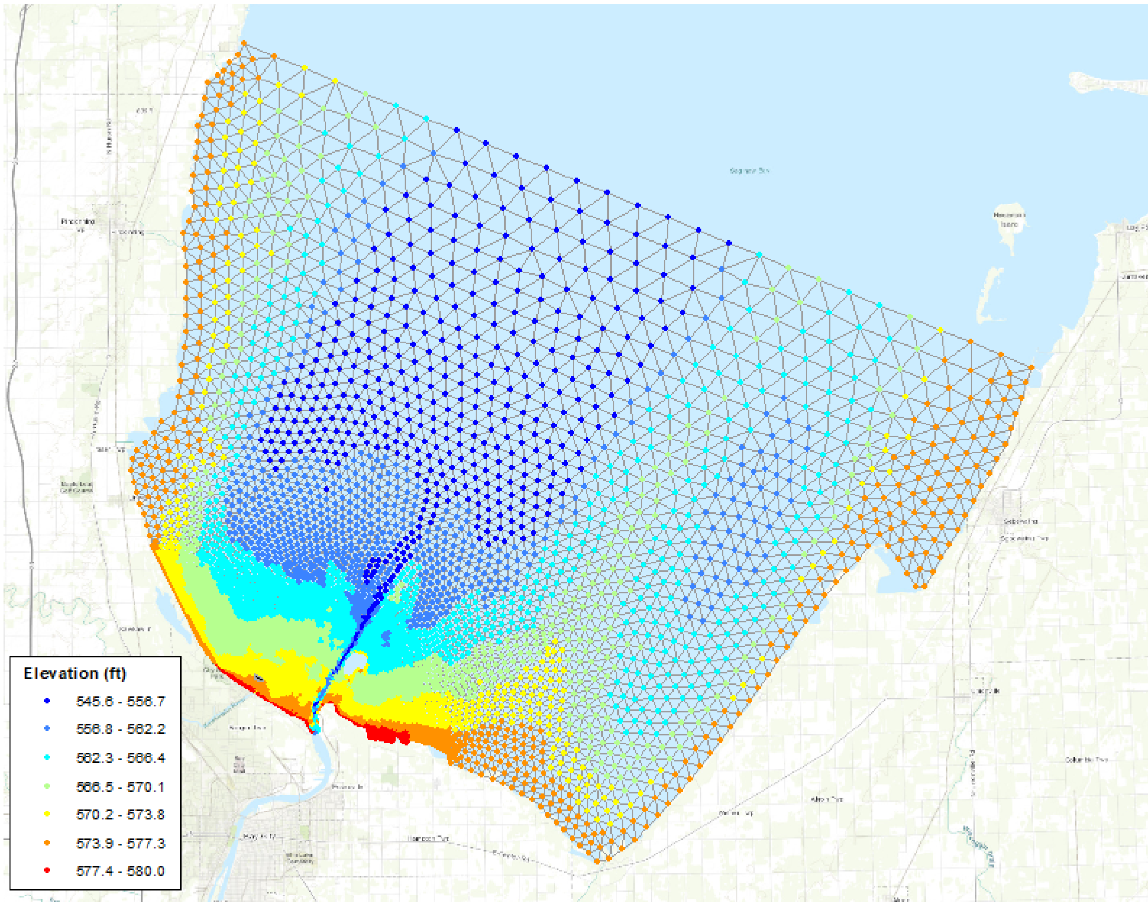


Figure 2-3. Full revised unstructured SWAN model domain. Bathymetry elevation data relative to sea level are shown with colored-binned dots at model nodes (see the legend). Grid cell sizes increase offshore; nearshore cells are too small to resolve in an image of this scale so the colors appear to be solid.

2.2 Simplified Littoral Transport Potential Model (CSHORE) Development

During the Feasibility Study, LimnoTech developed a preliminary sediment transport model based on the CSHORE model framework. CSHORE is a commonly applied one-dimensional coastal wave and sediment transport model used to predict sediment transport in the surf zone (Kobayashi, 2009). The prior study applied the model under existing bed conditions for a long-term time series of wave data obtained from the US Army Corps of Engineers Wave Information Studies (WIS) program (Halls et al. 2024).

Figure 2-4 shows the angle of incoming waves that the feasibility model determined would account for the majority of littoral transport that could deposit in the dredged recreational boating channel. Upstream of the river mouth, dredging is also intended to decrease flooding under high discharge conditions by increasing flow velocities in the lowermost reach of the Kawkawlin River.

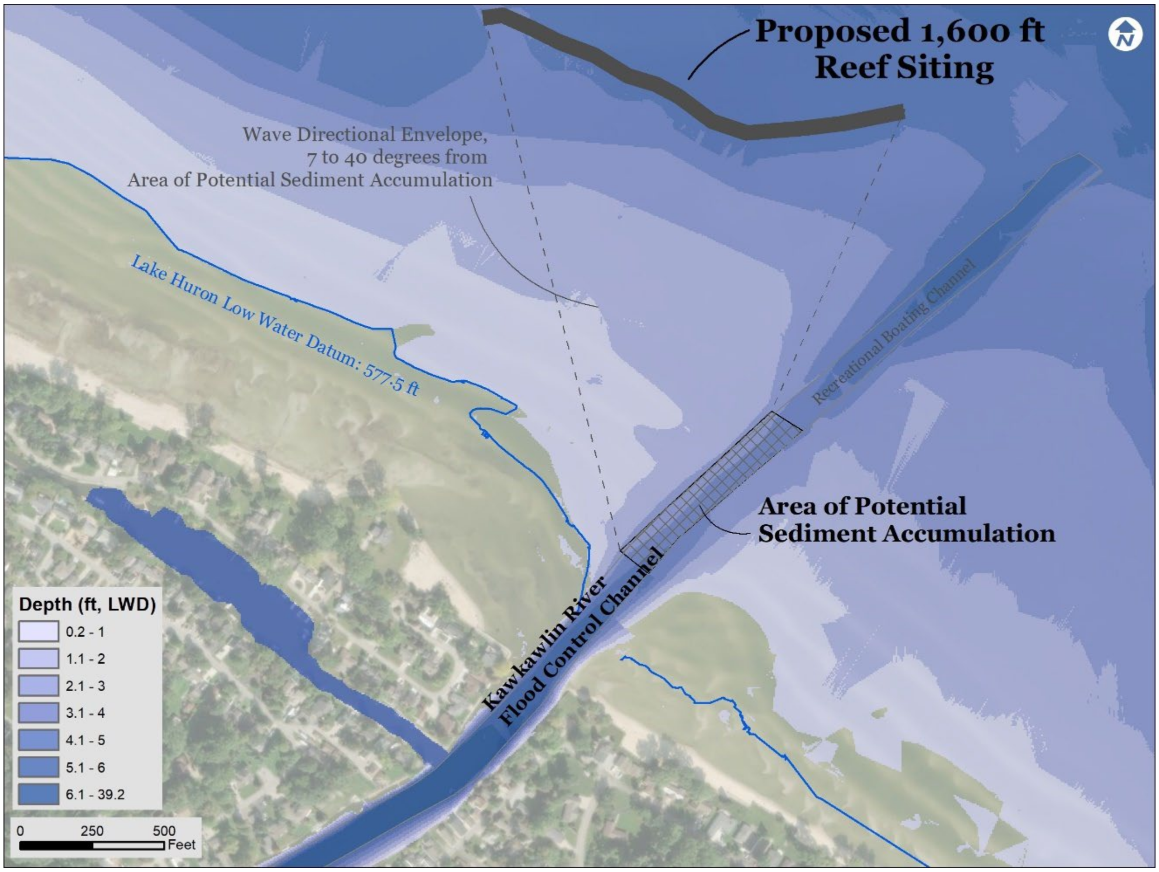


Figure 2-4. Incoming wave orientation for potential littoral sediment transport into the recreational boating channel

Essentially, CSHORE operates on a one-dimensional transect extending from an offshore location (e.g., where boundary condition data exists) to the shore and upland, if desired. The preliminary feasibility model was used to help determine the optimal location of the reef and was based on existing bathymetric data further to the northwest of the mouth of the Kawkawlin River. After the application of the preliminary feasibility model, the transect location was shifted to coincide with the proposed reef placement (**Figure 1-1**), and bathymetric data associated with this location were used for the one-dimensional transect. The same long-term wave data obtained from the USACE WIS were used in the updated model that was developed under the current phase of work

2.3 Model Application and Results

2.3.1 Refined SWAN Model Application

The refined SWAN model (**Figure 2-3**) was used to simulate the wave energy under both existing site conditions as well as with the proposed reef in place (**Figure 2-2**). Wind scenarios consisted of steady-state simulations with a constant 33.6 mph (15 m/s) wind heading in each of the eight cardinal and ordinal directions (N, NE, E, SE, etc) to represent conservative design conditions. These eight wind direction scenarios were applied under three water level conditions (25^{th} percentile of the historical record, median value, 99^{th} percentile) for a total of twenty-four scenarios using the existing bed elevations and twenty-four scenarios under the modified conditions including the proposed reef elevations.

To test for sensitivity to the elevation of the top of the reef, the bathymetry values at the model locations that coincide with the reef were adjusted for two reef elevation scenarios: (A) crest elevation of the reef at three feet below the low water datum (LWD; 577.5 ft), and (B) crest elevation of the reef exposed (580ft) above the median water level (579.1 ft). These two scenarios were chosen to bound potential effect on navigational channel sedimentation – one with the reef at an elevation that may be deemed safe for navigation and the other that would have maximum effect but resulting in an exposed reef above the median water level. Note that the sensitivity scenario with an exposed reef above the median water level was only simulated for median water level conditions and not for 25^{th} and 99^{th} percentile elevations, so seven bathymetric scenarios were simulated with eight wind directions each, in total. **Table 1** summarizes the scenarios evaluated with the refined SWAN model.

Table 1. Refined SWAN Model Scenarios

Water Level	Bathymetric Scenario	Wind Directions	Wind Speed (mph)	Notes
Median (579.1 ft)	Existing Conditions	N, NE, E, SE, S, SW, W, NW	33.6	
	Reef (3 ft below LWD)	N, NE, E, SE, S, SW, W, NW	33.6	
	Reef (exposed, 580 ft)	*N, NE, E, SE, S, SW, W, NW*	*33.6*	*Simulated for sensitivity testing*
25th Percentile (577.9 ft)	Existing Conditions	N, NE, E, SE, S, SW, W, NW	33.6	
	Reef (3 ft below LWD)	N, NE, E, SE, S, SW, W, NW	33.6	
	Reef (exposed, 580 ft)	-	-	*Not simulated*
99th Percentile (582.2 ft)	Existing Conditions	N, NE, E, SE, S, SW, W, NW	33.6	
	Reef (3 ft below LWD)	N, NE, E, SE, S, SW, W, NW	33.6	
	Reef (submerged, 580 ft)	-	-	*Not simulated*

2.3.2 Refined SWAN Model Results

Due to the large number of overall simulations performed with the SWAN model (n = 56), model output was aggregated to show the maximum simulated wave heights and wave-induced bed stress (i.e., sediment erosion power or resuspension potential) across the set of wind direction scenarios. That is, the maximum value of wave height or bed stress output was determined for each model output cell across the eight wind directions, resulting in a single spatially variable map of maximum wave height and bed stress output for each of the seven simulated rows shown in **Table 1**.

Figures 2-5 through 2-11 show the simulated maximum wave-induced bed stress for each water level and bathymetric combination. The maximum bed stress for median water level with existing (no reef) conditions (**Figure 2-5**) can be compared to simulations with the same water level with a reef either three feet below the low water datum (**Figure 2-6**), or with a reef exposed and above the median water level (**Figure 2-7**), to show the full range of effects the reef may have on wave energy and sediment transport. These maps illustrate that a lower elevation reef results in a minor reduction in wave energy in the reef's shadow, while an exposed reef that fully breaks the incoming waves would have a much more pronounced reduction in wave energy, under median water level conditions.

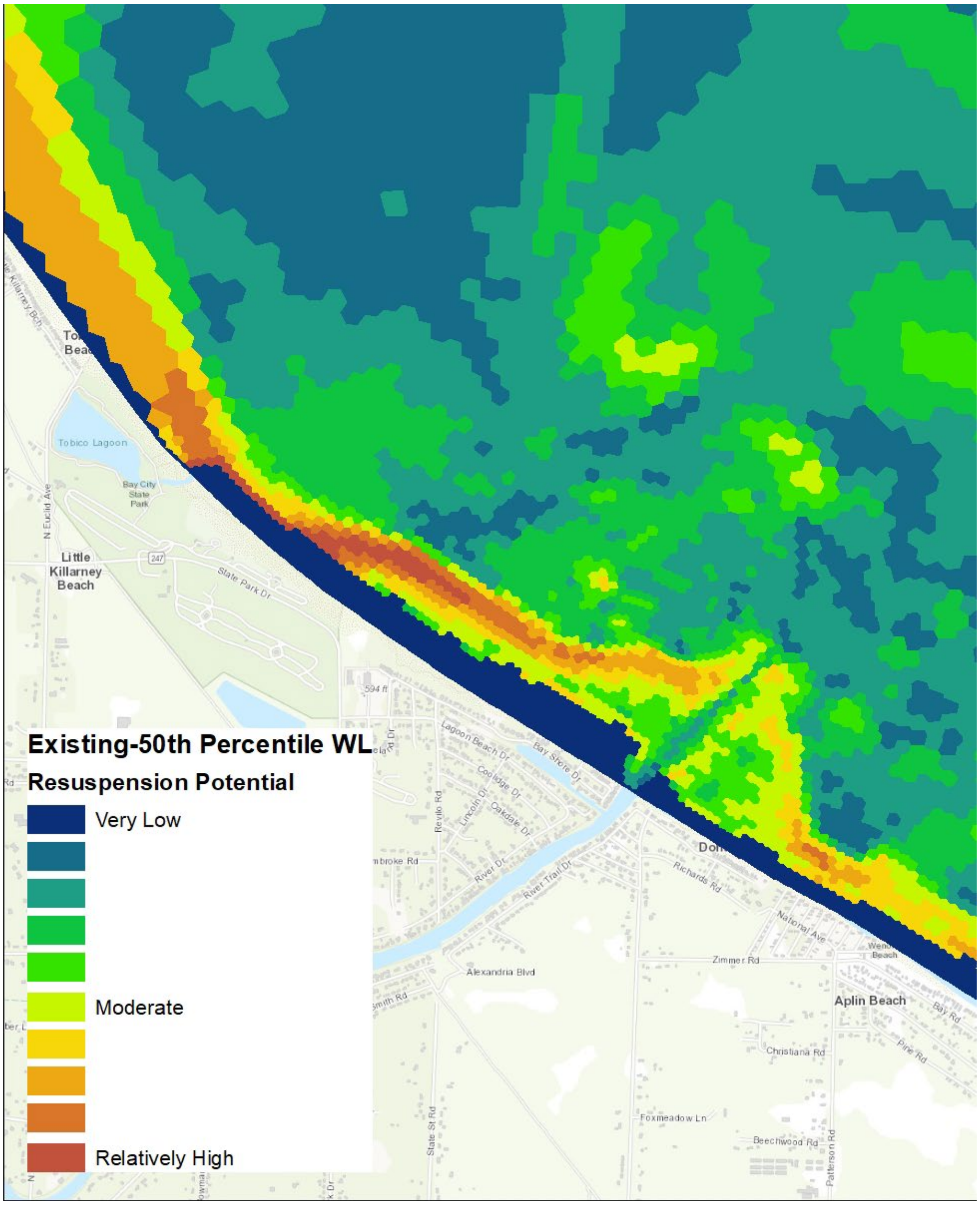


Figure 2-5. Aggregated maximum wave-induced bed stress across all eight wind directions for existing bathymetric conditions (no reef), with the median water level (50th percentile of the historical record of water levels)

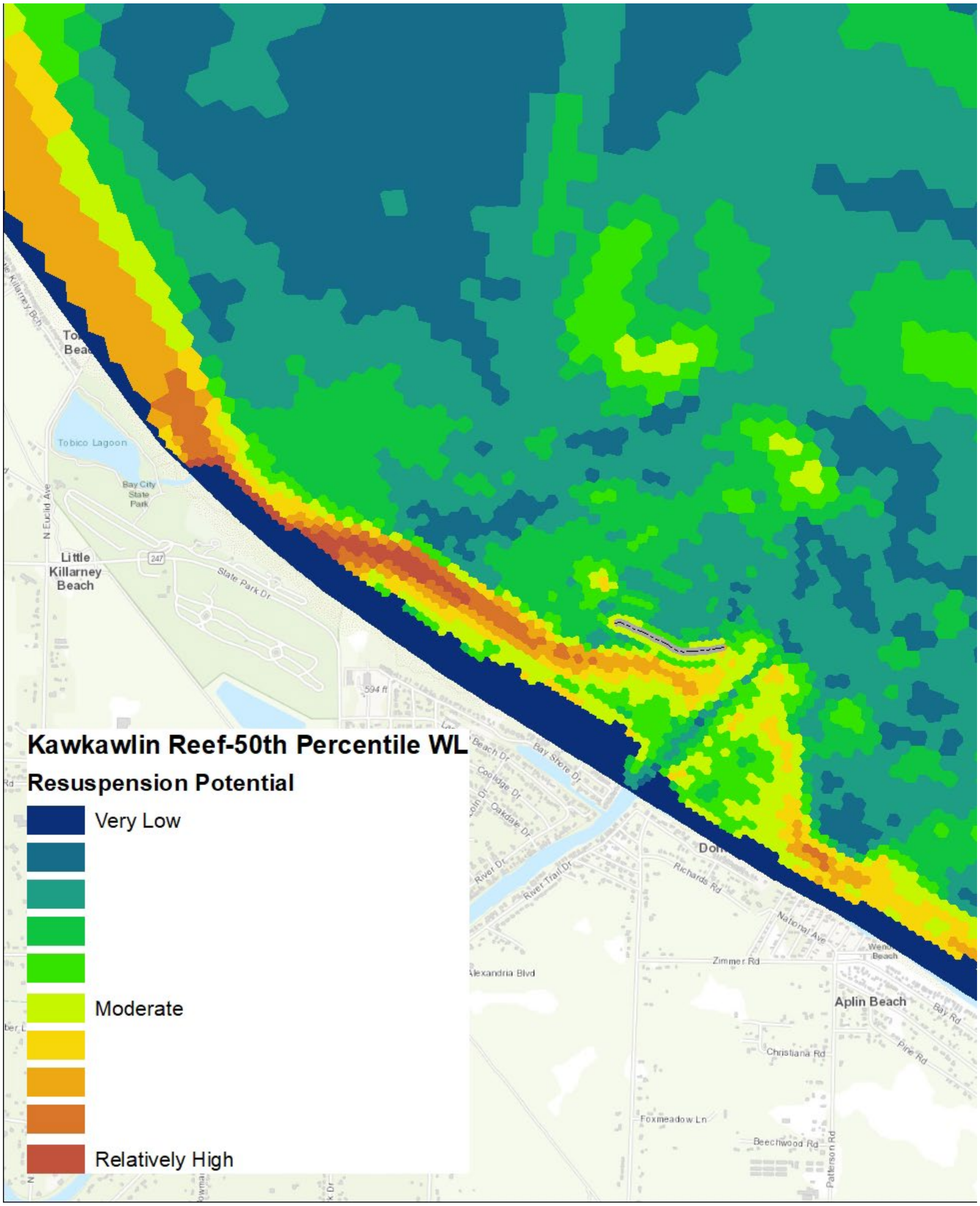


Figure 2-6. Aggregated maximum wave-induced bed stress across all eight wind directions for nearshore reef with crest height three feet below LWD, median water level. The dark blue area along the shore is not consistently submerged under these low water conditions

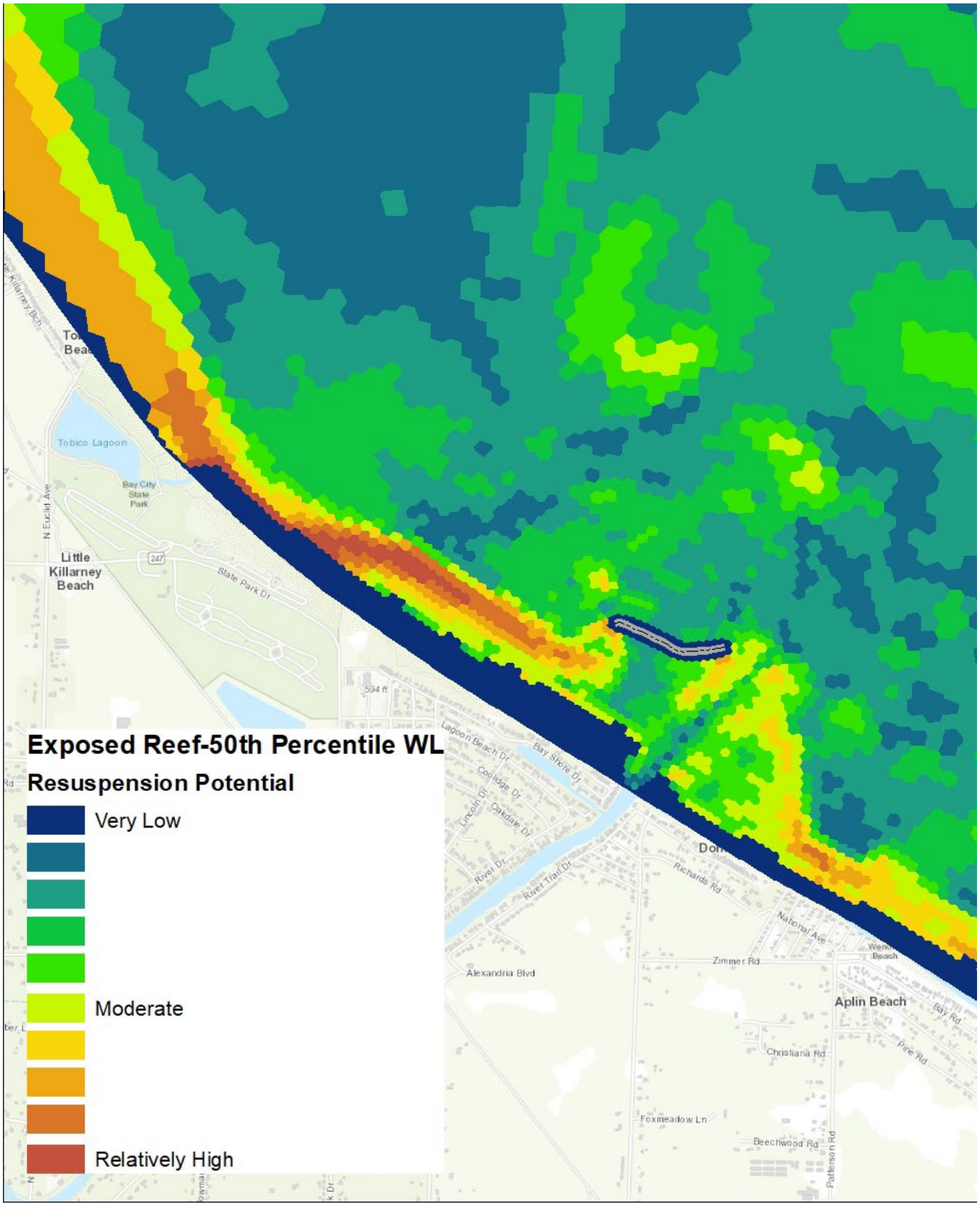


Figure 2-7. Aggregated maximum wave-induced bed stress across all eight wind directions for nearshore reef with crest above MWL, median water level. Note the low bed stress area between the reef and the shore

Similarly, the maximum wave-induced bed stress can be compared for low water level conditions (25th percentile). **Figure 2-8** shows the existing bathymetric configuration, while **Figure 2-9** shows the inclusion of the reef with a crest elevation set three feet below LWD. Under low water conditions, the proposed reef at this elevation shows a minor reduction in bed stress from wave energy in the shadow of the reef.

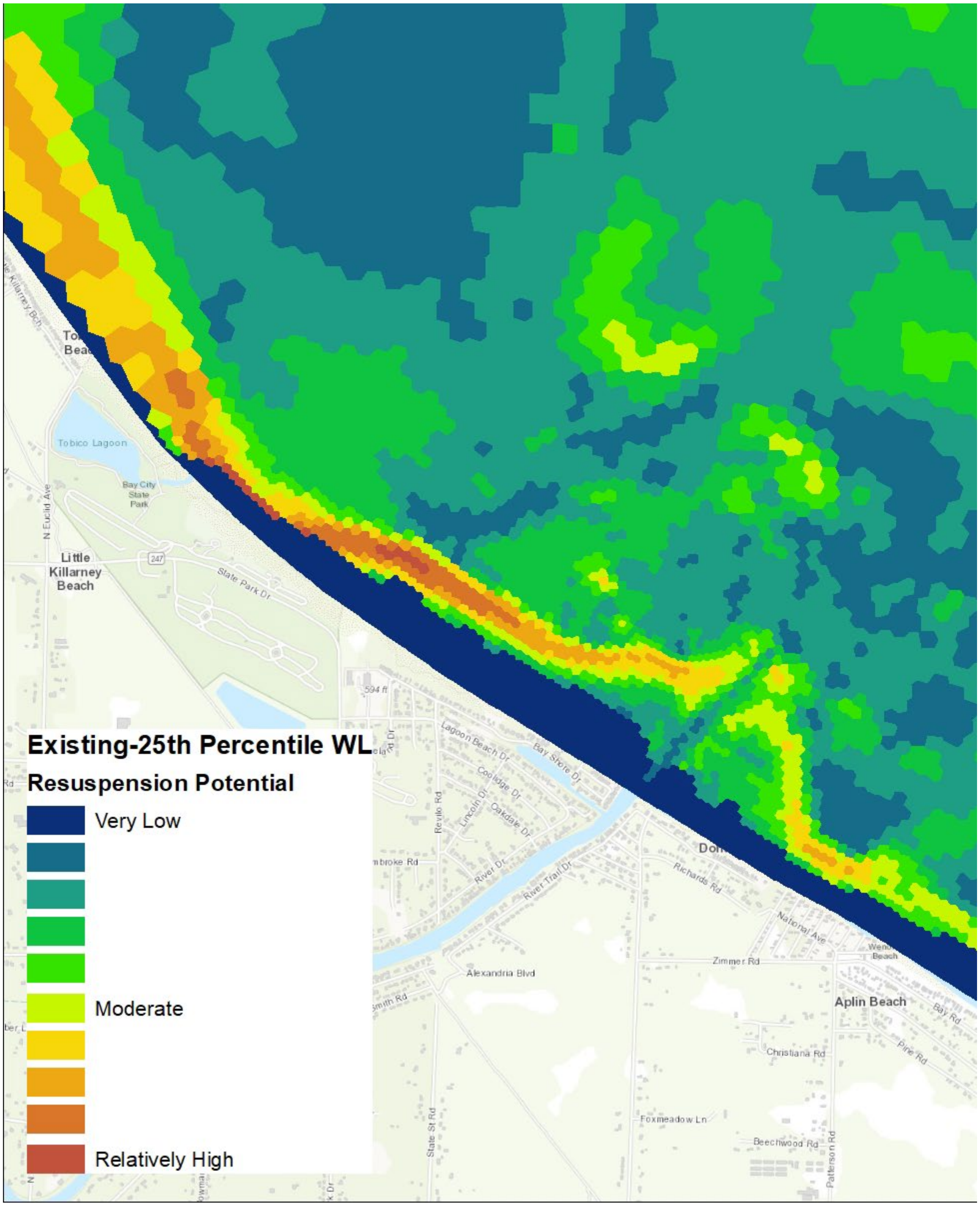


Figure 2-8. Aggregated maximum wave-induced bed stress across all eight wind directions for existing bathymetric conditions, 25th percentile water level

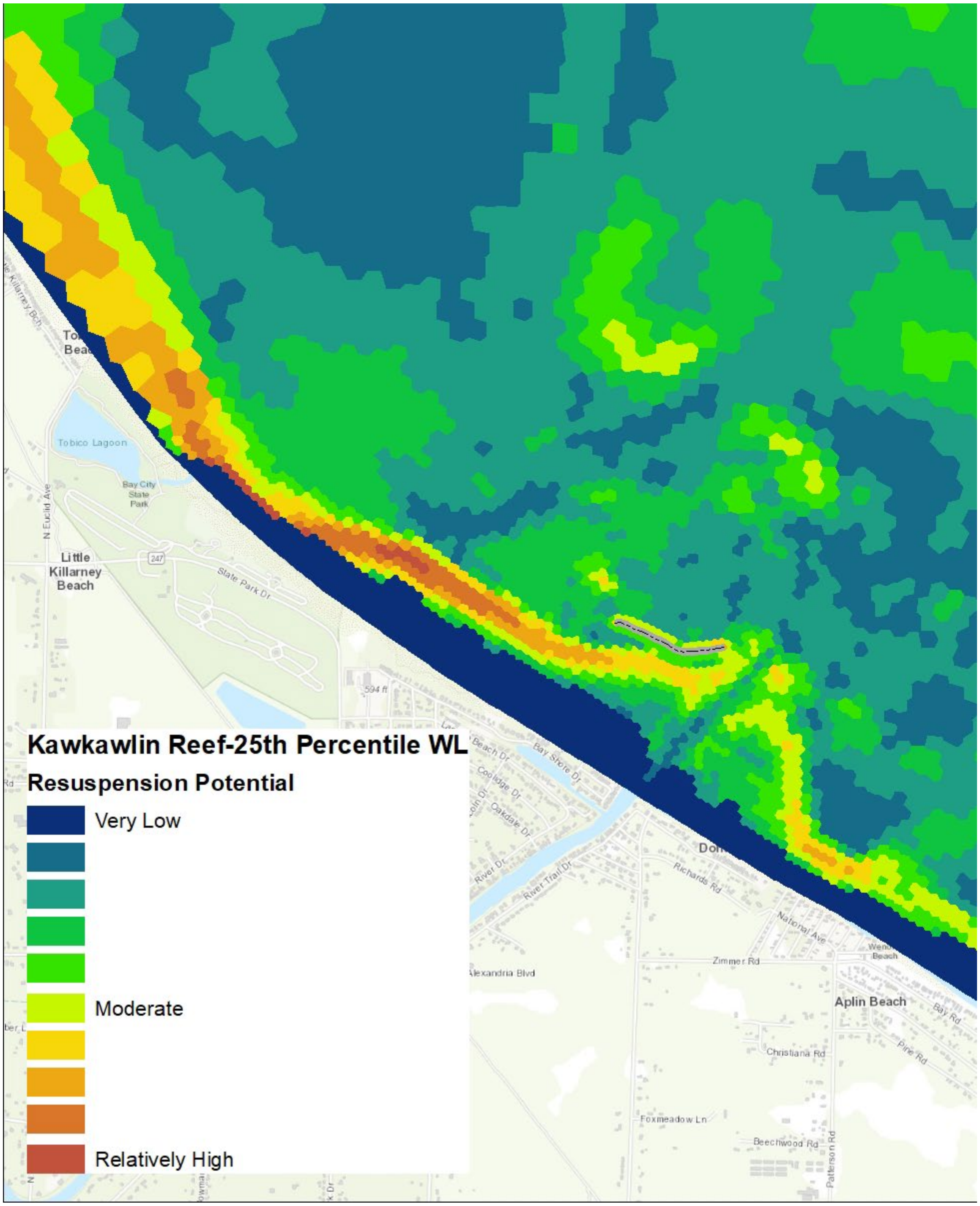


Figure 2-9. Aggregated maximum wave-induced bed stress across all eight wind directions for offshore reef with crest height three feet below LWD, 25th percentile water level

Finally, comparing the wave energy under high water conditions (99th percentile water level) shows a similar overall impact of the reef. Compared to the existing conditions (**Figure 2-10**), a reef set three feet below LWD shows a minor reduction in wave energy between the reef and the shore.

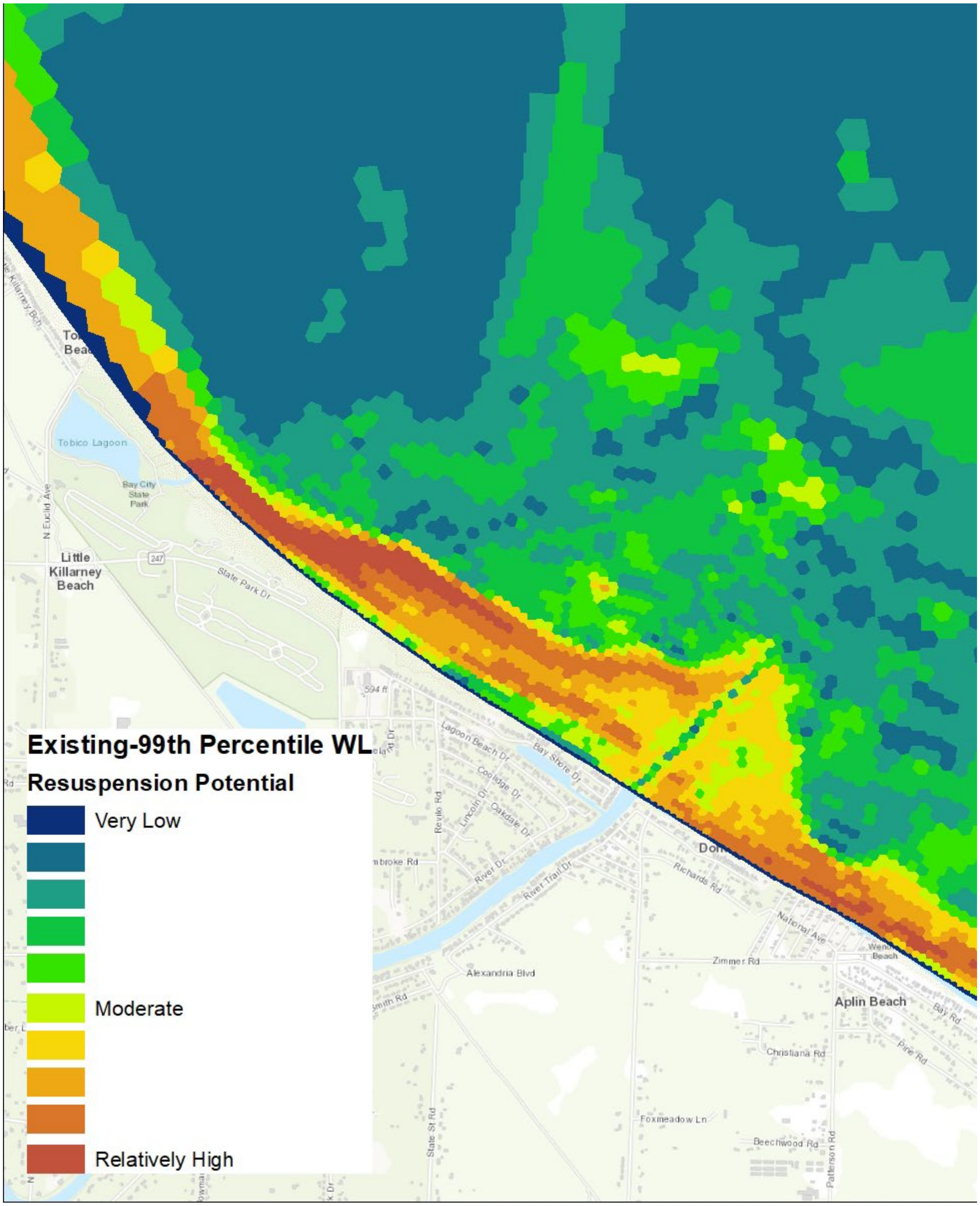


Figure 2-10. Aggregated maximum wave-induced bed stress across all eight wind directions for existing bathymetric conditions, 99th percentile water level. The dark blue area along the shore in earlier figures is submerged under these high water conditions, and two bands of high bed stress are present in the river mouth area due to the presence of a submerged offshore sand bar.

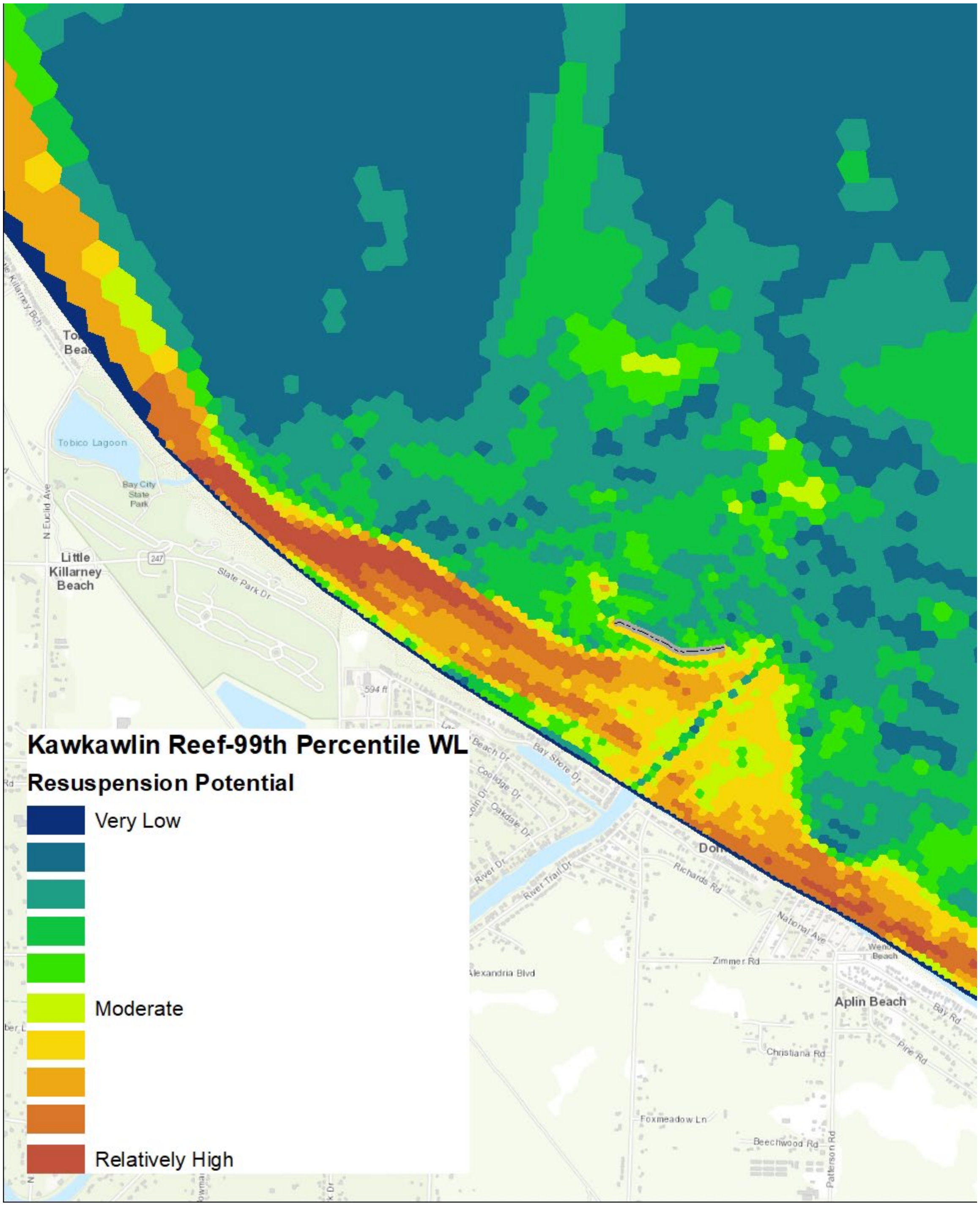


Figure 2-11. Aggregated maximum wave-induced bed stress across all eight wind directions for offshore reef with crest height three feet below LWD, 99th percentile water level

To further quantify the effect a near-shore reef could have on wave energy, a zone of influence of the reef was defined by grouping the model cells that fall within the shadow of the reef (between the reef and shore, including the recreational boating channel). The cells that comprise this zone are shown in **Figure 2-12**. Note, for consistency between water level and reef scenarios, very shallow cells near the shore are excluded from this aggregation zone as the stress output variable contains a threshold for effective depth that renders the output not applicable in low water simulations for these specific cells. Additionally, this zone of influence was delineated to be constant between all model scenarios to allow for direct comparison of the wave energy output, regardless of changes in water level.

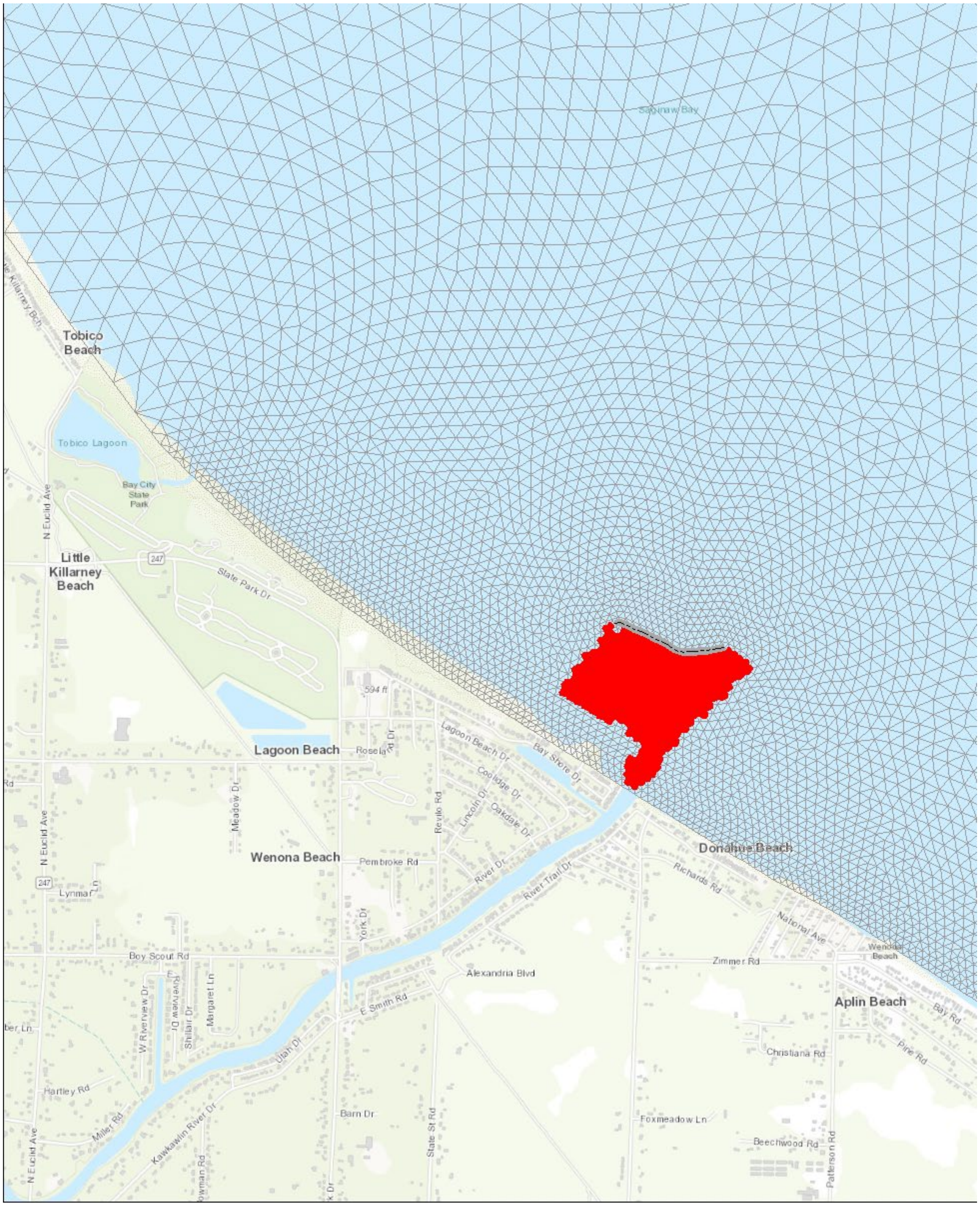


Figure 2-12. Assessed zone of influence of the simulated nearshore reef, between the reef site and the existing shoreline, shown in red

Table 2 shows the summarized wave-induced bed stress within this zone for each scenario, along with the percent reduction in wave energy from the existing condition for the specified water level. This table indicates that maximum wave energy can be reduced by approximately 15% near the reef if the crest elevation of the reef is exposed (above MLW, reef elevation of 580ft). However, with a submerged reef placed three feet below LWD, the reduction in wave energy is on the order of 3%, indicating a much smaller effect. Any cell in the red polygon of Figure 12 that shows a reduction in bed shear stress could have sediment accumulation on the bed to an unknown thickness.

Table 2. Summary of Wave-Induced Bed Stress in the Reef Zone of Influence for each SWAN Model Scenario.

Water Level	Scenario	Max Bed Stress (dynes/cm^2)	Avg Bed Stress (dynes/cm^2)	Reduction in Max Bed Stress	Reduction in Avg Bed Stress
Median (579.1 ft)	Existing Conditions	14.7	6.1	-	-
	Reef (3ft below LWD)	14.3	5.7	2.9%	6.9%
	Reef (exposed, 580ft)	12.5	4.0	15.4%	34.9%
25th Percentile (577.9 ft)	Existing Conditions	12.7	4.8	-	-
	Reef (3 ft below LWD)	12.2	4.2	3.9%	12.8%
	Reef (exposed, 580ft)	-	-	-	-
99th Percentile (582.2 ft)	Existing Conditions	17.7	9.0	-	-
	Reef (3 ft below LWD)	17.1	8.9	3.6%	1.3%
	Reef (submerged, 580ft)	-	-	-	-

The refined SWAN model also generates companion spatially variable outputs for significant wave height. The maps of these outputs are not presented in this documentation, as they follow a similar pattern to the bed stress maps. However, a companion table comparing the reduction in wave heights in the reef zone of influence is shown in Table 3. The maximum wave heights are depth-limited in the SWAN model, and therefore very similar between each bathymetric scenario. However, the average wave height within this zone of influence is more directly influenced by the reef. Similar to the results for bed stress, a reef that is exposed above the MWL can significantly reduce the wave heights in the area, while a submerged reef with a top elevation three feet below LWD shows only minor reductions in wave heights. Based on **Figures 2-5 through 2-12** and **Tables 2 and 3**, a submerged reef would allow for a minor depositional zone directly behind and shoreward of the reef that may allow a small amount of sand to deposit that would continue to move along the shore in the absence of the reef.

Table 3. Summary of Significant Wave Heights in the Reef Zone of Influence for each SWAN Model Scenario.

Water Level	Scenario	Maximum Wave Height (ft)	Average Wave Height (ft)	Reduction in Max Wave Height	Reduction in Avg Wave Height
Median (579.1 ft)	Existing Conditions	2.3	1.5	-	-
	Reef (3 ft below LWD)	2.3	1.5	0.02%	1.38%
	Reef (exposed, 580ft)	2.3	1.2	0.02%	16.42%
25th Percentile (577.9 ft)	Existing Conditions	1.8	1.0	-	-
	Reef (3 ft below LWD)	1.8	1.0	0.12%	2.30%
	Reef (exposed, 580ft)	-	-	-	-
99th Percentile (582.2 ft)	Existing Conditions	3.3	2.6	-	-
	Reef (3 ft below LWD)	3.3	2.6	0.01%	0.60%
	Reef (submerged, 580ft)	-	-	-	-

2.3.3 Refined CSHORE Model Application and Output

The CSHORE model that was developed as part of the preliminary feasibility study was based on a one-dimensional transect extending from the shore approximately 5,000 ft northeast of the mouth of Kawkawlin River to 20,000 ft perpendicular offshore. The revised CSHORE transect was shifted to intersect with the proposed reef location, aligning approximately 500 ft northwest of the mouth of the Kawkawlin River, while also extending out to 20,000 ft perpendicular to the shore. The offshore extent was determined to coincide with USACE WIS boundary condition wave data. **Figure 2-13** shows the location of the revised transect. The bathymetry data were modified from the feasibility model to represent the bed elevations associated with the shifted transect.

Figure 2-13. Modified CSHORE model transect

The bathymetric profile for this transect is shown in **Figure 2-14**. The x-axis in **Figure 2-14** shows the distance along the transect, with 0 ft representing the offshore extent and 20,000 ft representing the upland shore extent. The bathymetry is relatively flat from the offshore extent to the 12,000-ft station. The proposed reef is also shown in Figure 15 as a dashed red line, indicating a small vertical increase in bed elevation at approximately the 17,500-ft station, extending vertically to three feet below the low water datum. This demonstrates the minor adjustment to the bed elevation that such a reef would produce. CSHORE model simulations were performed using both the exiting transect and the proposed reef transect shown in **Figure 2-14**. An additional sensitivity simulation was produced with the reef elevation extending above the MWL line. All wave forcings from the WIS boundary condition data were set to be consistent among all simulations. The bottom friction factors (default value of 0.015) were held constant for the entire transect, except where the reef was located, which used a scaled friction factor of 0.05 to limit erosion of the reef itself.

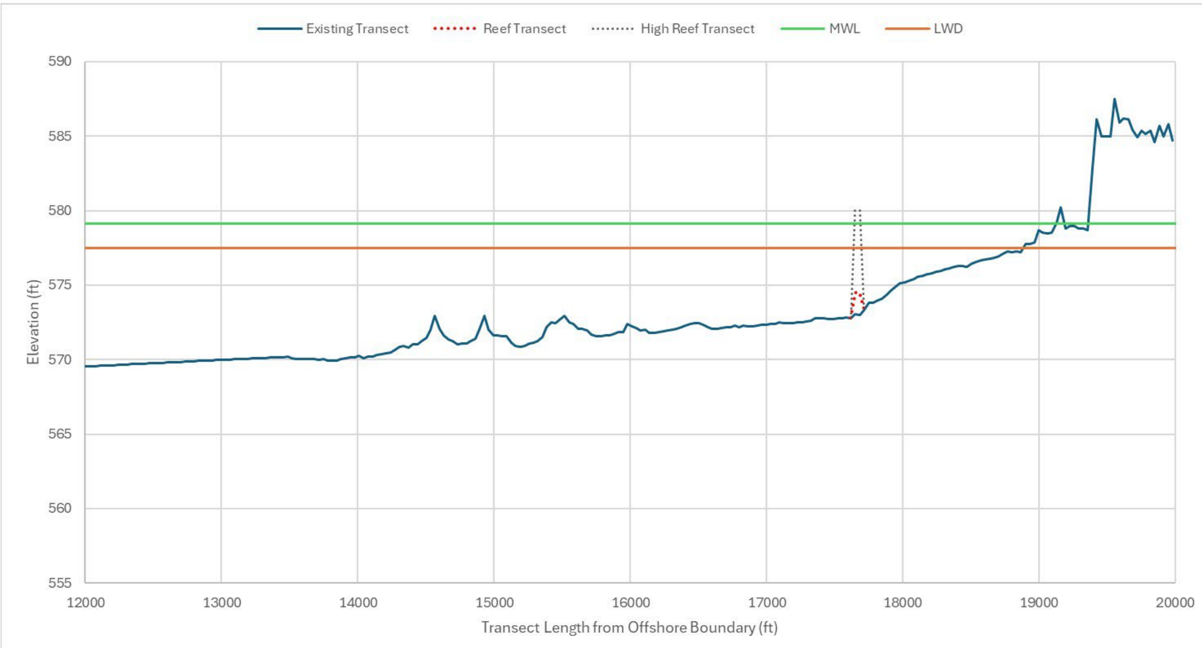


Figure 2-14. Bathymetry profile for CSHORE model transect. MWL and LWD water level elevations shown for reference. Red dashed line indicates the location and elevation of the proposed reef, with a crest height three feet below the LWD. Black dashed line indicates the location and elevation of a proposed reef above the MWL, with an elevation of 580 ft.

The revised CSHORE model was used to simulate littoral transport of sands during moderate to high wave periods within a 36-year interval from 1979-2014, based on USACE WIS wave data at the offshore extent of the transect. This analysis produced hourly estimates of sand transport in the direction of the Kawkawlin River channel. These data were then analyzed to describe how waves from varying directions contributed to total transport (**Figure 2-15**). Waves at approximately a 15-degree angle relative to the shoreline produce the most transport toward the Kawkawlin River channel, in part because this angle is associated with a relatively long fetch length. Consistent with the preliminary feasibility model results (**Figure 2-4**), waves within an envelope of 7-40 degrees from the recreational channel tend to produce the majority of the littoral transport toward the channel, for all three simulations. The simulation with the reef elevation set to three feet below the LWD (orange) shows a very minor reduction in the overall littoral transport, while an exposed reef (green) shows a more significant reduction in littoral transport. The model outputs for the three scenarios are also summarized in **Table 4**, further showing a minimal impact of the submerged reef.

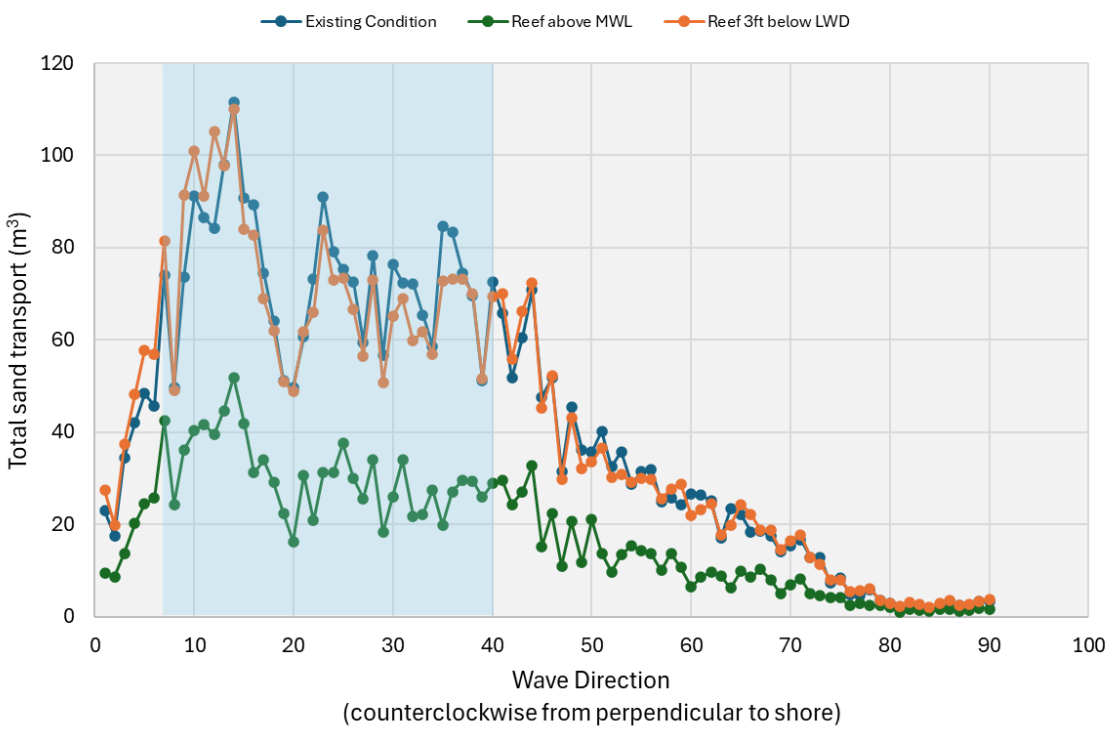


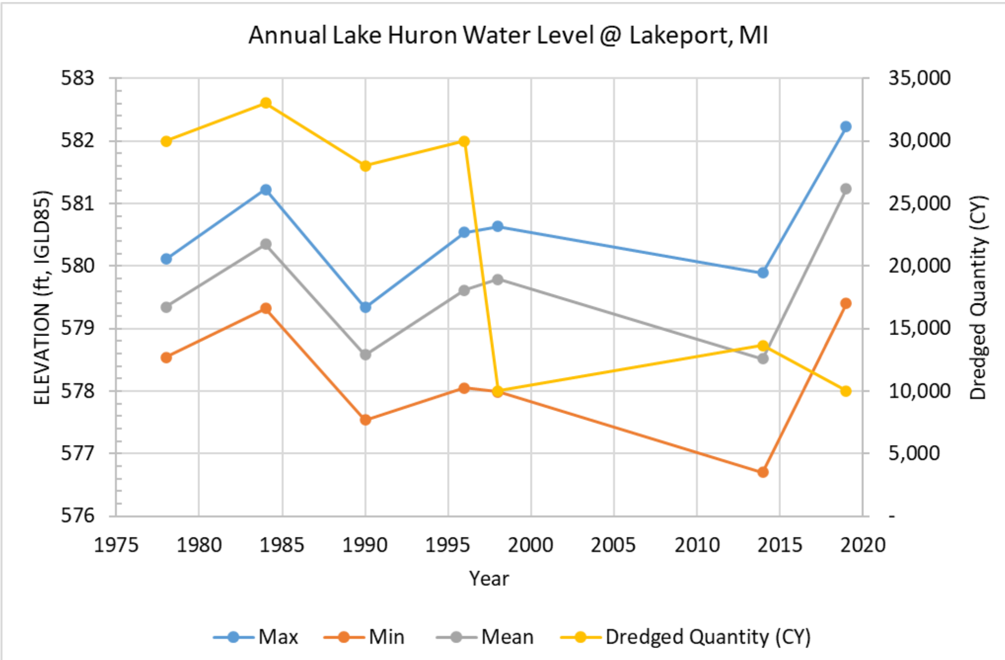
Figure 2-15. Distribution of littoral sand transport potential from incoming wave angles based on revised CSHORE model analysis

Table 4. Summary of Littoral Sand Transport for each CSHORE Model Scenario.

	Total Sand Transport (yd^3/yr)	7-40 deg Sand Transport (yd^3/yr)	Total Transport Reduction	7-40 deg Transport Reduction
Existing Conditions	209	137	-	-
Reef 3ft below LWD	207	134	0.7%	2.5%
Reef above MWL (580ft)	88	57	57.7%	58.4%

3.0 Recommendations and Conclusions

3.1 Cost-Benefit Analysis Preliminary Results



Preliminary Take Aways

- **Average Dredge Frequency**: Range ~ 4 - 8 years
  - Important note: this frequency interval (in recent years) is not a direct correlation to when there was a dredging NEED, but when the funds became available.
- **Average Dredged Volume/Event**: Range ~18,000 – 25,000 CY
  - Of which approximately 4-8% is from littoral transport, the remaining from the river.
  - Important note: this dredge volume (in recent years) is not a direct correlation to the total dredging volume NEEDED, but instead the volume of sediment that could be dredged with the available funds.
- **Potential Cost Savings Due to Reef Implementation – Range/Dredge Event:**
  - Assumes a ~58% reduction in littoral sediment transport and drift into the channel, or approximately 3% of the overall channel dredging needs.
  - This reduction will reduce dredging by ~700CY of sediment, or save ~$30k/cycle.
  - The team recognizes that the majority of the sediment is coming from the Kawkawlin River out the mouth.

Based on the data collection, modeling, and evaluations performed and discussed above, the following recommendations are made for further consideration in final design.

3.2 Summary of Findings to Date

A reef constructed at a higher elevation will have a more substantial impact on coastal resiliency including dredging and wind-wave action around the mouth of the Kawkawlin River. The reef, no matter which height, will need to be marked as a navigational hazard for the recreational boaters.

The reefs impact is primarily localized to the areas surrounding the mouth of the Kawkawlin River and is not likely to have a significant impact on longshore sediment transport impact downshore beachfronts (impacts are quite localized). At the higher reef elevation, material diverted by the reef is anticipated to deposit in the bay depending on water depth fluctuations. Based on wind-wave models, and understanding the importance water levels will have, the material is expected to be blown out and redeposited throughout the bay regularly. Similar to existing conditions, there is a likely impact between the reef and shoreline during low water levels.

Current models indicate a reef constructed above MWL has the potential to reduce channel sedimentation from littoral inputs by 58%, or 3% of the overall sedimentation inputs. Rough current day estimate suggest this can reduce dredging needs by ~700CY, or $30,000/cycle.

A higher reef will reduce wave heights by over 16% for nearshore properties adjacent to the mouth of the Kawkawlin River, however there were no modeled impacts evident on flooding upriver. Modeling results indicate there may be some reduction in shoreline erosion in locations directly adjacent to reef due to higher sand deposition, lower flooding and erosion risks in the shadow of the reef.

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