

Iona - Fionnphort Sedimentation Study

Draft Report

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Argyll and Bute Council



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Contract

This report describes work commissioned by Alex Leslie, on behalf of Argyll and Bute Council, by a letter dated 02 October 2019. Hannah Otton and Douglas Pender of JBA Consulting carried out this work.

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Purpose

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Acknowledgements

JBA would like to thank Argyll and Bute Council for provision of data and information to support this work.

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Executive summary

JBA Consulting were commissioned by Argyll & Bute Council (ABC) to undertake a morphodynamic modelling assessment to investigate the impact of new berthing facilities on sedimentation at Iona and Mull. The aim is to assess how the new berthing facilities will impact the morphodynamics in the Sound of Iona and determine areas where significant sedimentation or erosion will occur.

Three different scenarios were modelled, to understand the behaviour of the Sound under varying events.

- Annual Storm events (from SW, NW and NE)
- 200-year Extreme Event from SW
- 6-month winter period

A Delft3D nested and coupled model was used which includes wave transformation, tidal currents, winds and morphology.

Construction of the breakwaters reduces wave action in the lee of the structure, and therefore the risk of sediment deposition in the berthing areas and approach channels increases.

From the events tested, the duration over which high energy conditions occurred has more influence than the magnitude of the overall event. This is evident from the pronounced sediment movement trends from the winter period compared to the negligible trends seen from the 200-year extreme storm event.

The mechanism of sediment deposition is a result of a longshore transport gradient along the east of Iona from south to north. The deep channel offshore and the structure itself act as a sink for the transported sediment. This trend is backed up by anecdotal information collected by ABC.

During a winter period, up to 1m of sediment has the potential to build up in the approach channel at Iona, resulting in a bed level of -5mOD compared to -6mOD. However, sensitivity testing of the morphological acceleration factor shows this may contribute to 50% of this deposition.

Alternative breakwater arrangements have been modelled to attempt to mitigate this deposition however they result in similar erosion/deposition patterns and do not have much influence in mitigating the deposition of sediment.

Contents

1	Introduction	1
2	Background Information	2
2.1	Location	2
2.2	Proposed Berthing Facilities	2
2.3	Anecdotal information	3
3	Hydrodynamic Conditions	4
3.1	Water Levels	4
3.2	Waves	4
3.3	Model boundary conditions	4
3.3.1	1 in 200-year event	4
3.3.2	Average Annual Events	7
3.3.3	Winter period	9
4	Model Setup	12
4.1	Grids	12
4.2	Bathymetry	13
4.3	Model Boundaries	14
4.4	Additional Parameters	15
4.4.1	Sediment and morphology	15
4.4.2	Horizontal viscosity and diffusivity	16
4.4.3	Roughness	16
5	Results	17
5.1	Scenarios and outputs	17
5.2	200-year Event	17
5.2.1	Waves	17
5.2.2	Sediment	18
5.3	SW Event	20
5.3.1	Waves	20
5.3.2	Sediment	21
5.4	NW Event	22
5.4.1	Waves	22
5.4.2	Sediment	22
5.5	NE Event	23
5.5.1	Waves	23
5.5.2	Sediment	24
5.6	Winter Season	24
5.7	Sensitivity Testing	27
5.7.1	Sediment Diameter (D50)	27
5.7.2	Wave-related suspended transport and bed-load transport	27
5.7.3	Morfac	28
6	Mitigation measures	30
7	Conclusions and recommendations	33
7.1	Further work	34
A	Delft 3D Model Setup	I

List of Figures

Figure 2-1: Location of Iona and Fionnphort	2
Figure 2-2: Proposed breakwater locations	3
Figure 3-1: Wave and Wind Rose for Wave Watch WW3 Point 2469	4
Figure 3-2: 90th Percentile Threshold	5
Figure 3-3: Relationships with Hs: Tp and Windspeed	6
Figure 3-4: Relationship between peak Hs and duration above 1-year Hs threshold	7
Figure 3-5: The chosen annual average event from the southwest	8
Figure 3-6: The chosen annual average event from the northwest	8
Figure 3-7: The chosen annual average event from the northeast	9
Figure 3-8: Oct 2017 – March 2018 Wave Climate	10
Figure 3-9: Maximum Wave Height per winter (min value shown in orange, max in red, 2017 in yellow)	10
Figure 3-10: Threshold exceedances per winter (min value shown in orange, max in red, 2017 in yellow)	10
Figure 4-1: Coarse and Detailed Grid	13
Figure 4-2: Detailed model bathymetry	14
Figure 4-3: Tidal Boundaries for the Detailed Grid	15
Figure 5-1: Observation points within the model	17
Figure 5-2: Significant Wave Height at Mull_2	18
Figure 5-3: Significant Wave Height at Iona_2	18
Figure 5-4: Cumulative Sedimentation and Erosion at Iona (left) and Mull (right) for the 200-year extreme event	19
Figure 5-5: Cumulative Sedimentation and Erosion at Mull_2	19
Figure 5-6: Cumulative Sedimentation and Erosion at Iona_2	20
Figure 5-7: Significant Wave Height at Mull_2	20
Figure 5-8: Significant Wave Height at Iona_2	21
Figure 5-9: Cumulative Sedimentation and Erosion at Mull_2	21
Figure 5-10: Cumulative Sedimentation and Erosion at Iona_2	21
Figure 5-11: Significant Wave Height at Mull_2	22
Figure 5-12: Significant Wave Height at Iona_2	22
Figure 5-13: Cumulative Sedimentation and Erosion at Mull_2	23
Figure 5-14: Cumulative Sedimentation and Erosion at Iona_2	23
Figure 5-15: Significant Wave Height at Mull_2	24
Figure 5-16: Significant Wave Height at Iona_2	24
Figure 5-17: Cumulative Sedimentation and Erosion at Mull_2	25
Figure 5-18: Cumulative Sedimentation and Erosion at Iona_2	25
Figure 5-19: Sediment accumulation and erosion at Iona (left) and Mull (right) during winter season	26
Figure 5-20: Resulting Bed Level at Iona (left) and Mull (right)	26
Figure 5-21: Sediment diameter sensitivity testing at the sandbank (Point Middle_2).	27
Figure 5-22: SUSW and BEDW sensitivity testing. 1 (left) , 0.25 (right)	28
Figure 5-23: Sedimentation and Erosion differences (morfac on left, no morfac on right)	29
Figure 6-1: Alignment 2A	30
Figure 6-2: Alignment 2B	30
Figure 6-3: Sedimentation and Erosion differences (preferred breakwater alignment on left, alignment 2A on right)	31
Figure 6-4: Sedimentation and Erosion differences (preferred breakwater alignment on left, alignment 2B on right)	32
Figure A-1: Delft3D water level validation at Iona	I
Figure A-2: Delft3D tidal current validation at Iona	II
Figure A-3: Removal of sediment sink at Iona Harbour and defining of the channel offshore from Iona. Before (left), After (right).	III

Figure A-4: Bathymetric Smoothing at Fionnphort between area with sandbars and deeper channel to the north. Before (left), After (right).

III

List of Tables

Table 3-1: Extreme Wave Height (Hs) estimates	5
Table 3-2: Annual Events Summary	9

Abbreviations

ABC	Argyll and Bute Council
BEDW	Wave-related bed-load transport factor
CD	Chart Datum
DTM	Digital Terrain Model
EVA	Extreme Value Analysis
GPD	Generalised Pareto Distribution
Hs	Wave Height
OD	Ordnance Datum
RMSE	Root Mean Square Error (objective function)
SEPA	Scottish Environment Protection Agency
SUSW	Wave-related suspended transport factor
Tp	Wave Period
WW3	WaveWatch III

1 Introduction

JBA have been commissioned by Argyll and Bute Council (ABC) to undertake a morphodynamic modelling study to assess the sedimentation risk to new vessel berthing facilities at Fionnphort and Iona.

The aim of this study is therefore to understand how these new facilities will influence morphodynamics within the Sound of Iona and whether any negative impact will result through sedimentation or erosion.

Discussions with ABC highlighted the requirements to understand the morphodynamic behaviour of the study area under both, short-term extreme events, and longer-term scenarios, by answering the following key questions.

- How do the proposals influence morphodynamic behaviour within the Sound of Iona under extreme conditions?
- How do the proposals influence morphodynamic behaviour within the Sound of Iona throughout a typical winter season?

In response JBA developed a Method Statement¹ for review which outlined how the requirements would be met. Through consultation with ABC, it was agreed that understanding the morphodynamic response under the following scenarios would be required to meet the study objectives:

- An extreme 1 in 200-year (0.5% AP) wave event.
- Observed average annual extreme wave events from three main risk directions (SW, NW, NE).
- Long term “winter-period” from October to April – i.e. 6-months.

This report documents the methodology and findings of the study, as well as providing recommendations for future work that may be required to finalise the design and construction of the breakwaters.

¹ BYM-JBAU-00-00-MS-Z-0001-S3-P01-Method_Statement.pdf

2 Background Information

2.1 Location

Iona is located west of Mull, on the west coast of Scotland. As shown in the aerial imagery (Figure 2-1), there are multiple sand bars clearly visible in the Sound of Iona, which are known to shift after storm events, resulting in the ferry route changing somewhat to follow deeper water. The prevailing wind and wave conditions are from the SW.

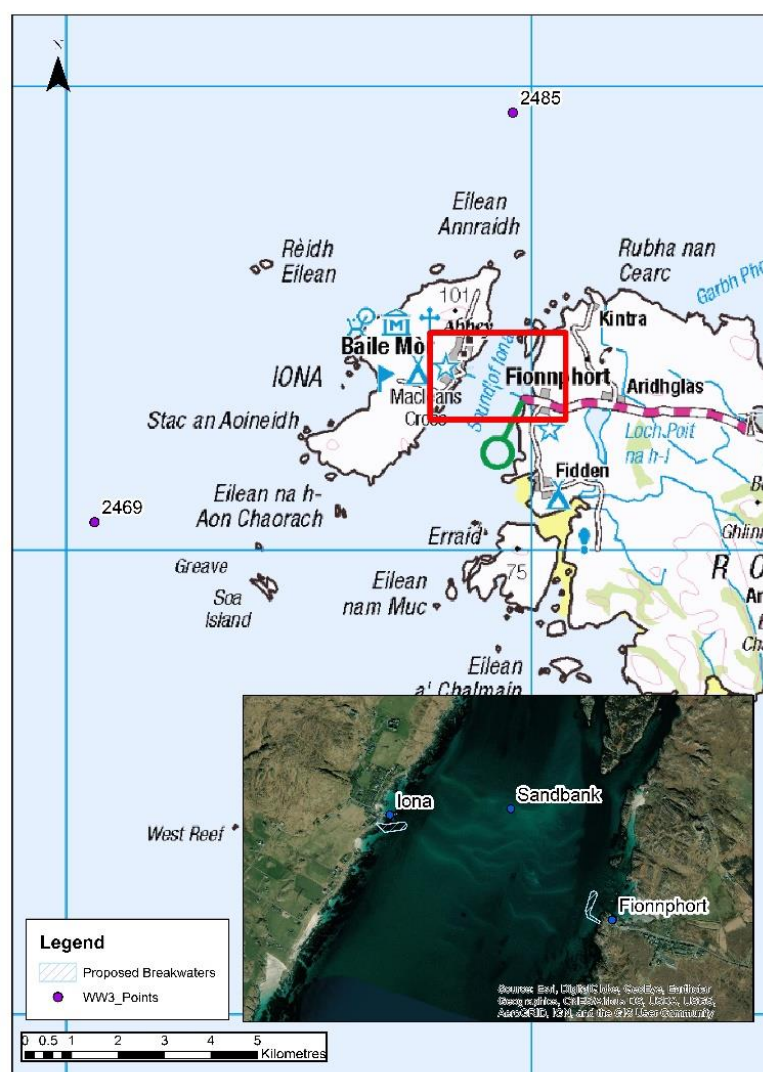


Figure 2-1: Location of Iona and Fionnphort

2.2 Proposed Berthing Facilities

The findings of the ABC feasibility study² recommended the construction of new rubble mound breakwater structures on both sides of the route, with an additional dredging requirement at Fionnphort to maintain adequate depth³.

² CM1052 MA R1801 01 Feasibility Study_FINAL. Byrne Looby. 2019

³ 00040-XX_007 Fionnphort Breakwater - Levels.pdf; 00040-XX_005 Fionnphort Breakwater - Proposed Outline

At Fionnphort a breakwater of 108m is proposed with a crest height of 7.83mOD (9.65mCD) and a width of 3.6m. A dredged area behind the breakwater is also proposed, to a depth of -4.82mOD (-3mCD).

At Iona, a 115m breakwater with a crest height of 7.83mOD (9.65mCD) is proposed.

These will provide shelter to the piers from the prevailing SW conditions when the ferries are operating in stormy conditions, as well as providing an overnight berth at Fionnphort.

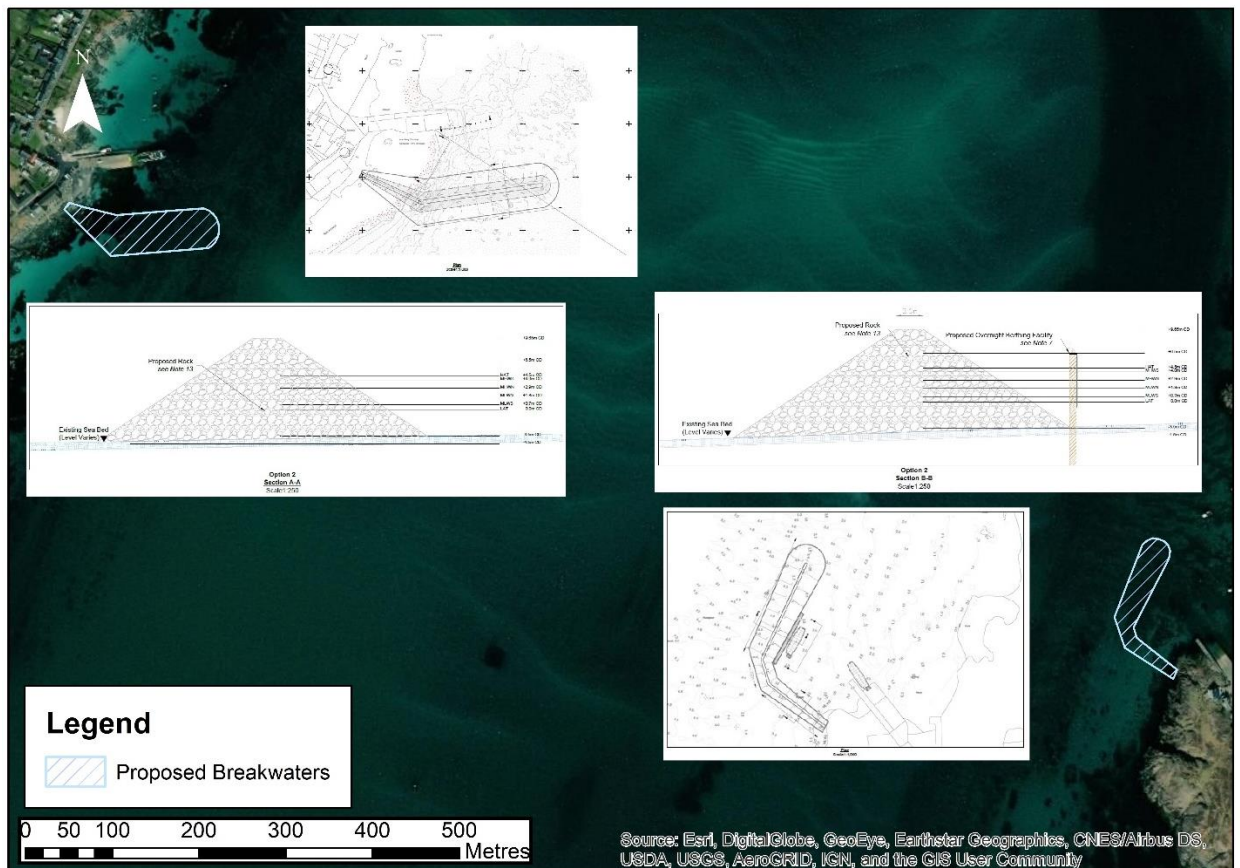


Figure 2-2: Proposed breakwater locations

2.3 Anecdotal information

Local boat operators provided useful information regarding sediment movement and tidal currents in the Sound of Iona to better calibrate the modelling as limited bathymetric information was available. The tidal currents are similar on both sides of the sound, however more sediment action (both erosion and deposition) is present on Iona compared to Mull. It was noted that there appears to be more sediment available on the Iona side, with several commenting on always seeing sand in the water column. Sediment is thought to be generally accreting within the beaches at Iona, and there has been a prominent increase in sediment within St Ronan's Bay since the current pier at Iona was built. However it is noted that weather events could reverse the accretive trend rapidly.

3 Hydrodynamic Conditions

3.1 Water Levels

The geometry of the Sound means that relatively large tidal currents (0.5 m/s) are experienced at the centre as a result of the water level gradient to exist at the entrances to the sound at the north and south.

Various datasets of harmonic constituents are available to estimate the astronomical tidal predictions at the detailed model boundaries.

The appropriateness of these were tested by undertaking a validation exercise, outlined in Appendix A.1, and the European Shelf was shown to perform best.

3.2 Waves

The predominant direction of high energy waves is from the southwest, however smaller storms from the north and east may influence sediment transport in the Sound in different ways, potentially causing different sediment regimes within the proposed berthing facilities.

Two Wave Watch (WW3) points were selected to represent the range of wave conditions potentially influencing the Sound of Iona (Location 2469 and 2485) (Figure 2-1). The 38-year hindcast model results for each of these were obtained and have been used to develop the wave and wind forcing conditions for the scenarios to be tested.

Generally, these datasets show a similar climate in both locations with an average wave height (Hs) of 1.79m, and a maximum Hs of 12.7m.

The typical wave and wind climate is shown below (Figure 3-1).

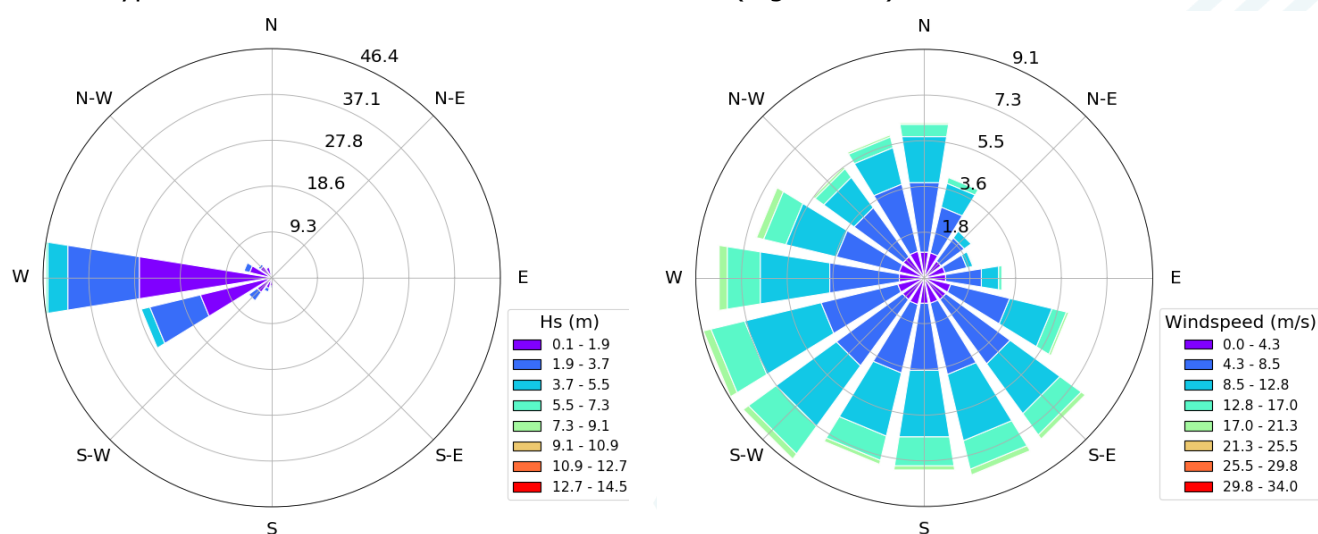


Figure 3-1: Wave and Wind Rose for Wave Watch WW3 Point 2469

3.3 Model boundary conditions

3.3.1 1 in 200-year event

To estimate the wave conditions for a 1 in 200-year event, an Extreme Value Analysis (EVA) was undertaken. The EVA fitted a Generalised Pareto Distribution (GPD) to the hindcast wave record of Point 2469.

A range of thresholds for the GPD were tested, with the most appropriate being determined using a visual fit against the observations, minimising the confidence

intervals, and having a sensible upper limit i.e. a finite tail as shown below in Figure 3-2.

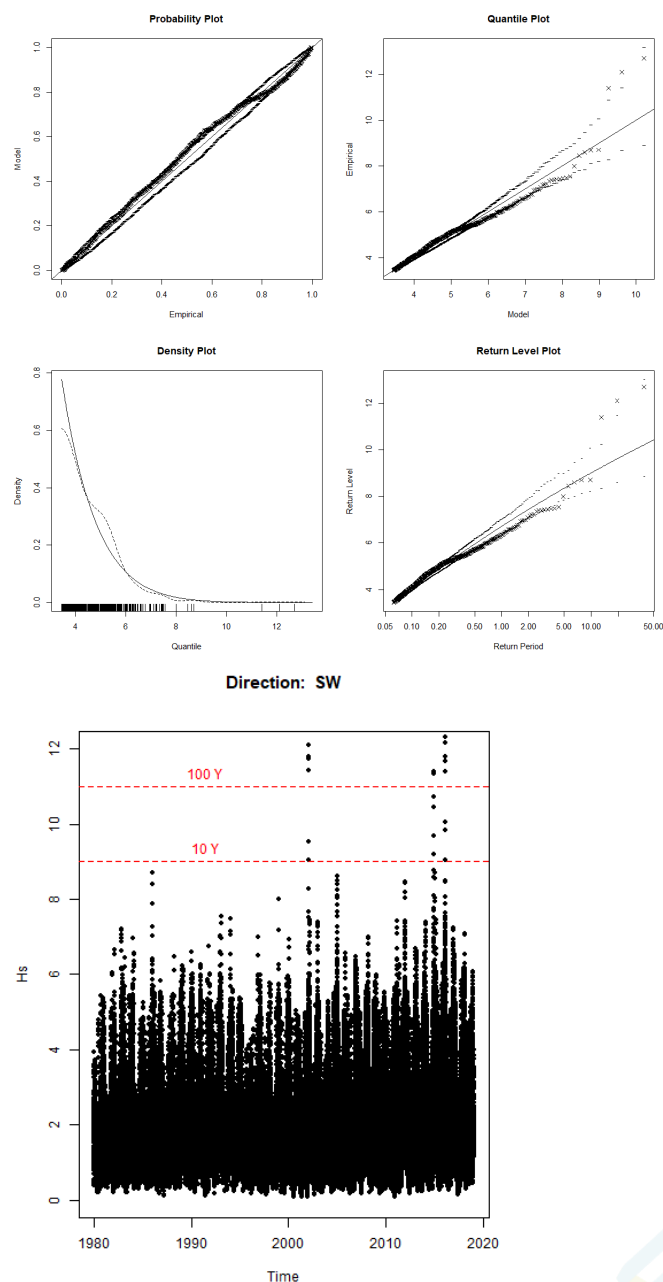


Figure 3-2: 90th Percentile Threshold

This resulted in a threshold of $H_s = 6\text{ m}$ being selected and produced the extreme return level estimates provided in Table 3-1.

Table 3-1: Extreme Significant Wave Height (H_s) estimates

Return Period	H_s (m)
1-year	6.71
5-year	8.35

10-year	9.01
100-year	10.98
200-year	11.52

Undertaking a univariate EVA means that the additional variables required to force the model have to be inferred from the empirical data. To achieve this, relationships between wave height (H_s), wave period (T_p) and wind speed were developed (Figure 3-3) and used. Wind direction was assumed equal to wave direction.

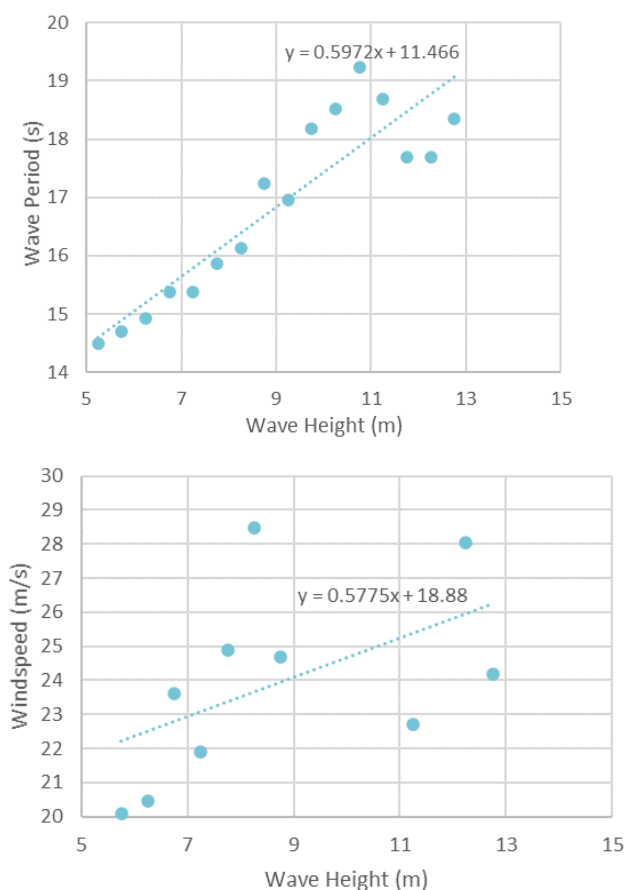


Figure 3-3: Relationships with H_s : T_p and Windspeed

For morphodynamic modelling, a duration over which the event is defined is critical. For a synthetic extreme condition this is extremely difficult to define as ideally the start and end point of the event would be under conditions that induced minimal morphological response.

To develop the time duration of the event, the WW3 dataset was analysed further to determine the relationship between H_s and duration above a threshold. It is this threshold that controls the duration, and here was assumed to be the 1-year wave height (H_s). An independence criterion of 24-hours was set to identify independent events.

Events that exceeded the 1-year H_s threshold were determined from the Point 2469 hindcast data and the duration of each calculated.

This resulted in the relationship between H_s and duration described by Figure 3-4, and showed that the larger energy events generally follow a regular shape.

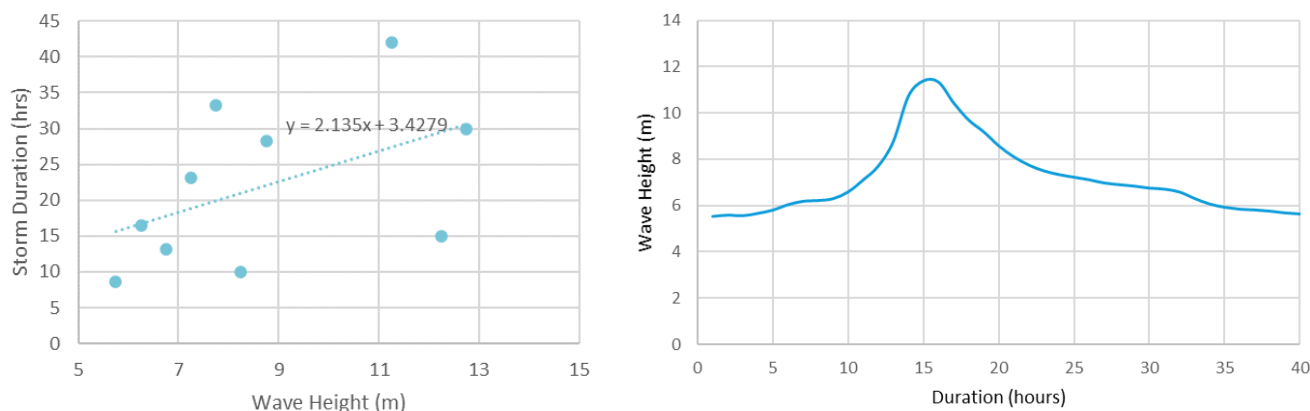


Figure 3-4: Relationship between peak Hs and duration above 1-year Hs threshold

The synthetic design event developed here therefore follows a triangular distribution of wave conditions over a 25-hour duration. The direction is set constant at 260 degrees, representing the average of events in the hindcast dataset.

3.3.2 Average Annual Events

A similar process to identify observed events was undertaken for the annual average events, with wave conditions grouped into relevant directional sectors. Southwest ($180^\circ - 270^\circ$) and East ($0^\circ - 90^\circ$) from point 2469 and North ($270^\circ - 0^\circ$) from point 2485.

From the identified events, annual average were extracted that represented a peak Hs between the 1 and 2-year return level from the EVA. For these lower return period events, a 48-hour duration was assumed, with 24 hours taken either side of the peak of the. All parameters (Hs, Tp, Dir, Spr, Wdsp, WdDir) were taken from the hindcast data for each of the three annual events.

Figure 3-5 - Figure 3-7 provide details of the events selected, with Table 3-2 summarising the key statistics.

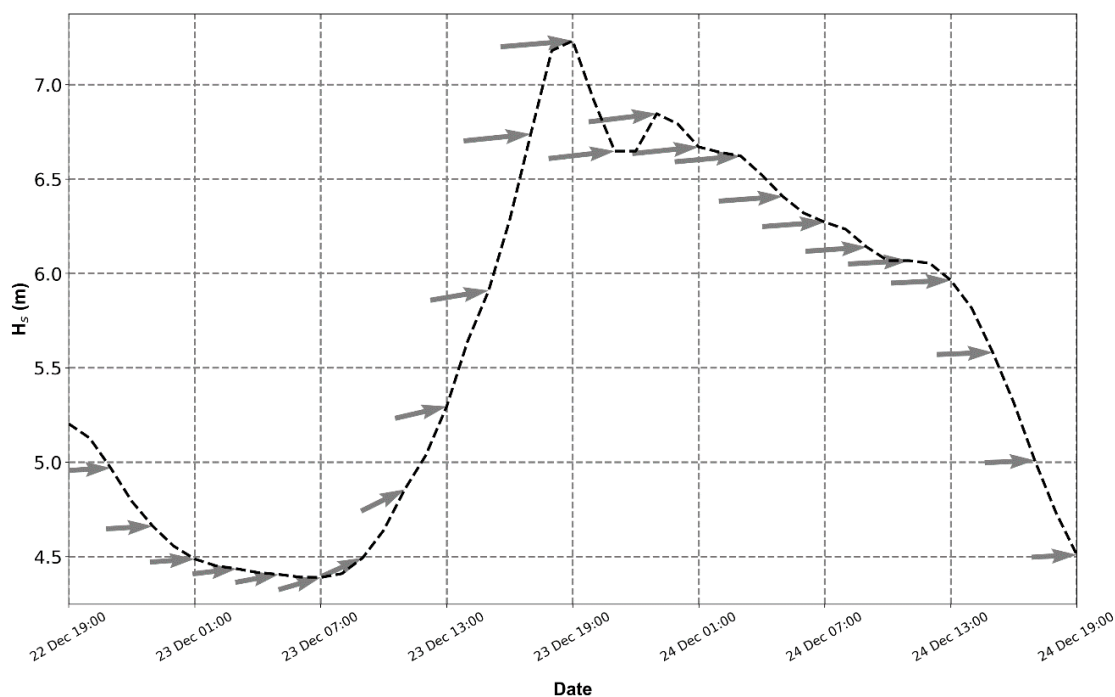


Figure 3-5: The chosen annual average event from the southwest

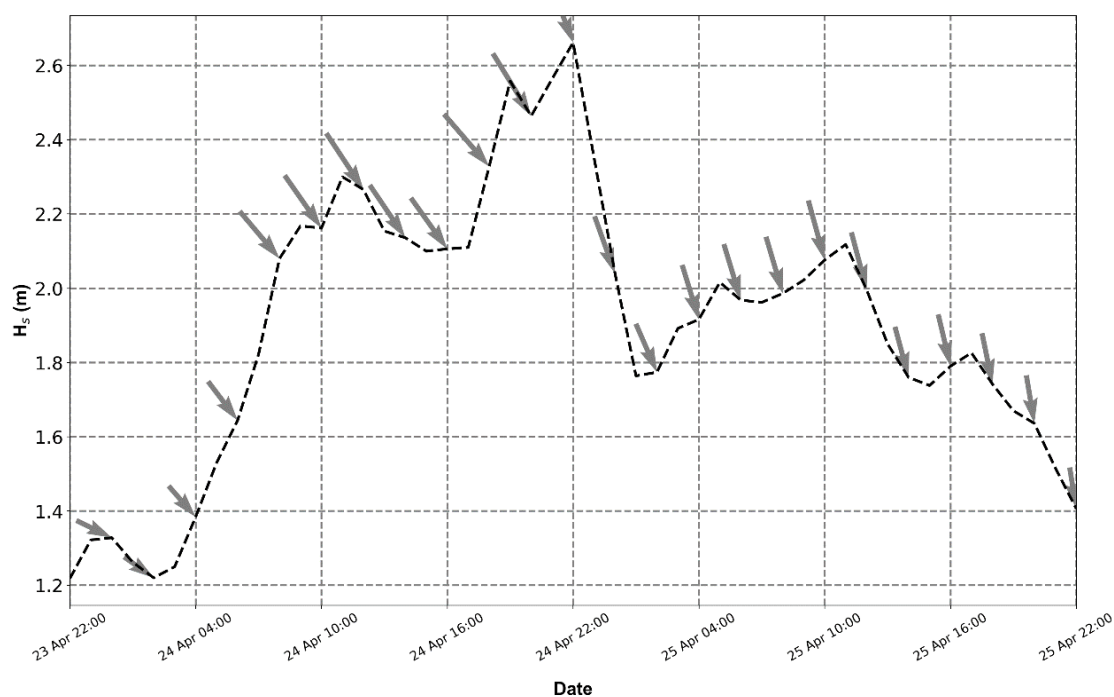


Figure 3-6: The chosen annual average event from the northwest

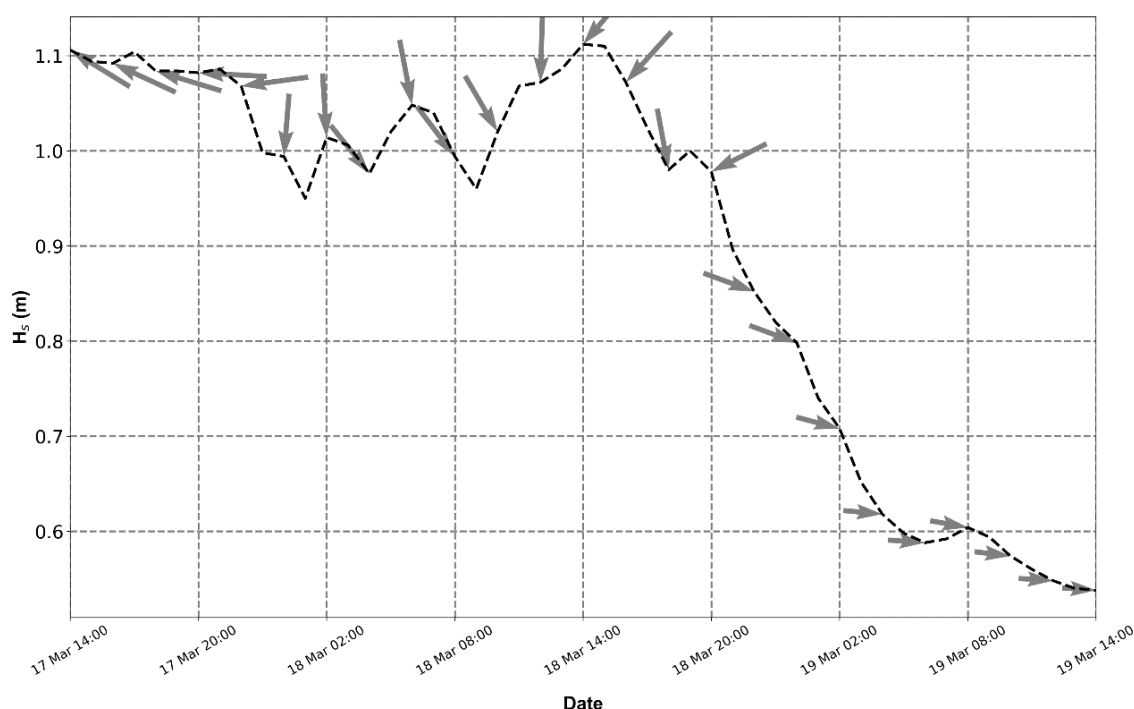


Figure 3-7: The chosen annual average event from the northeast

Table 3-2: Annual Events Summary

Return Period	Peak Wave Hs (m)	Peak Wave Dir (°)	Wind speed at Peak (m/s)
SW	7.23	265	19.1
NW	2.66	339	17.4
NE	1.11	40	10.8

3.3.3 Winter period

While the short-term extremes might result in significant localised erosion or deposition, sustained high energy conditions throughout a winter period are possibly more detrimental to the operability of the new berthing facilities.

For example, it could possibly be accepted that 1 in 200-year conditions would significantly alter the seabed, but if accumulation every winter was shown to occur then additional management options would need to be explored.

For this assessment, a single simulation has been undertaken. This uses annual average hindcast wave conditions between 1 October 2017 and 31 March 2018 (Figure 3-8).

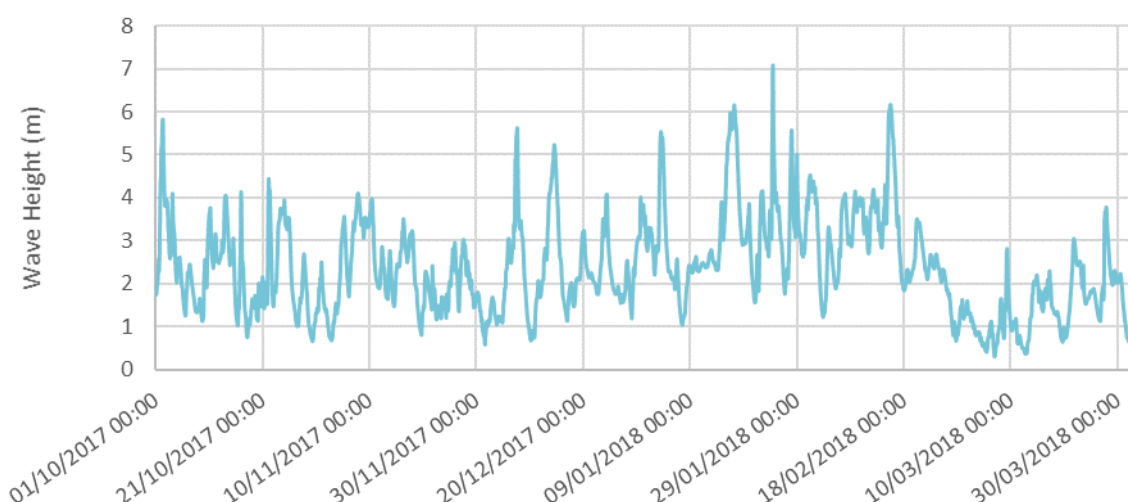


Figure 3-8: Oct 2017 – March 2018 Wave Climate

This winter period was considered a “typical” winter as the wave height for the 2017 winter (Oct ‘17 to Mar ‘18) was almost the same as the average wave height (Figure 3-9). The number of “events” that exceed wave heights greater or equal to 1m for a duration of 6 hours for the 2017 winter is only slightly higher than the average for the dataset (Figure 3-10). This makes 2017 a winter period suitable to represent the larger dataset.

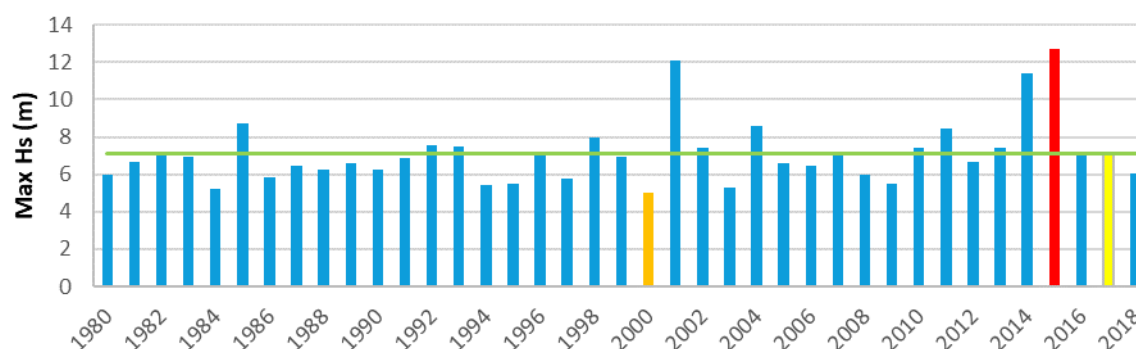


Figure 3-9: Maximum Wave Height per winter (min value shown in orange, max in red, 2017 in yellow)

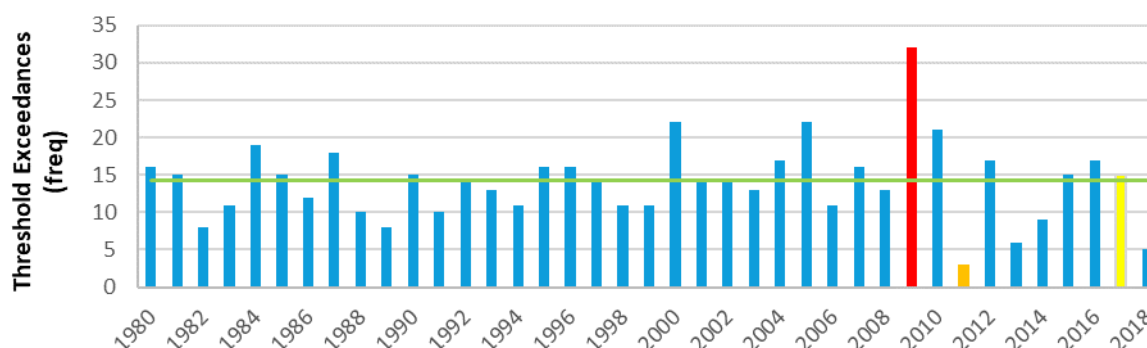


Figure 3-10: Threshold exceedances per winter (min value shown in orange, max in red, 2017 in yellow)

A morphological acceleration factor or *morfac* of 6 is applied to these simulations meaning wave conditions were compressed onto a monthly duration and bed change multiplied 6 times every model timestep. Such an approach is necessary to make the modelling computationally efficient and allow testing of multiple scenarios.

Each wave timeseries was applied to a monthly spring-neap tidal cycle between 1 October to 1 November 2017.

4 Model Setup

4.1 Grids

A coarse grid was set up to extend into the North Atlantic to include the relevant WaveWatchIII (WW3) data points at 2469 and 2485. This allows the offshore wave climate to be transformed into the Sound of Iona. The detailed grid covered the Sound of Iona at a resolution that better represents the sand bars and breakwaters which will allow for the morphodynamics to be modelled, at a resolution of 10x18m in the areas of interest.

These grids were nested (Figure 4-1) and coupled to allow for modelling of wave transformation from the North Atlantic, as well as tidal currents and sediment movement within the Sound of Iona. Further detail on the Delft 3D model is included in Appendix A.2.

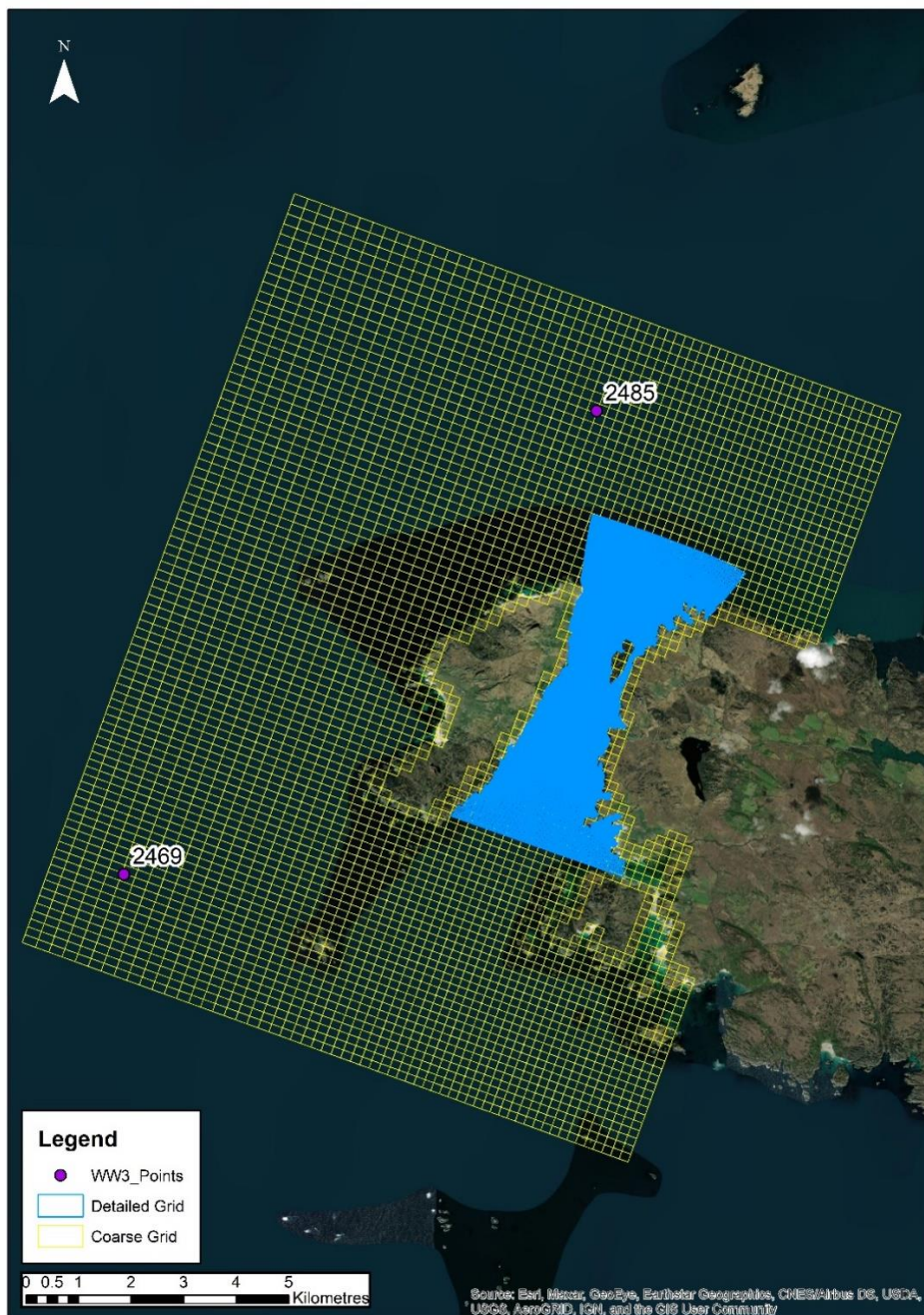


Figure 4-1: Coarse and Detailed Grid

4.2 Bathymetry

Model grid depth was generated from a mix of detailed survey at each harbour, undertaken by Aspect Chartered and Hydrographic Surveys, and Oceanwise Marine Themes DTM provided by SEPA.

Joining of relatively coarse bathymetry datasets (such as OceanWise) to the shoreline can be problematic and sometimes requires "blending" to remove step changes and instabilities. Here, the bathymetry dataset was compared with the depths outlined in the Admiralty Chart, and updated to better represent the steep transition between shoreline and the main channel of the Sound (Figure 4-2). This also removed a deep approach channel offshore from the pier at Iona.

More details about the required bathymetric changes are outlined in Appendix A.3.

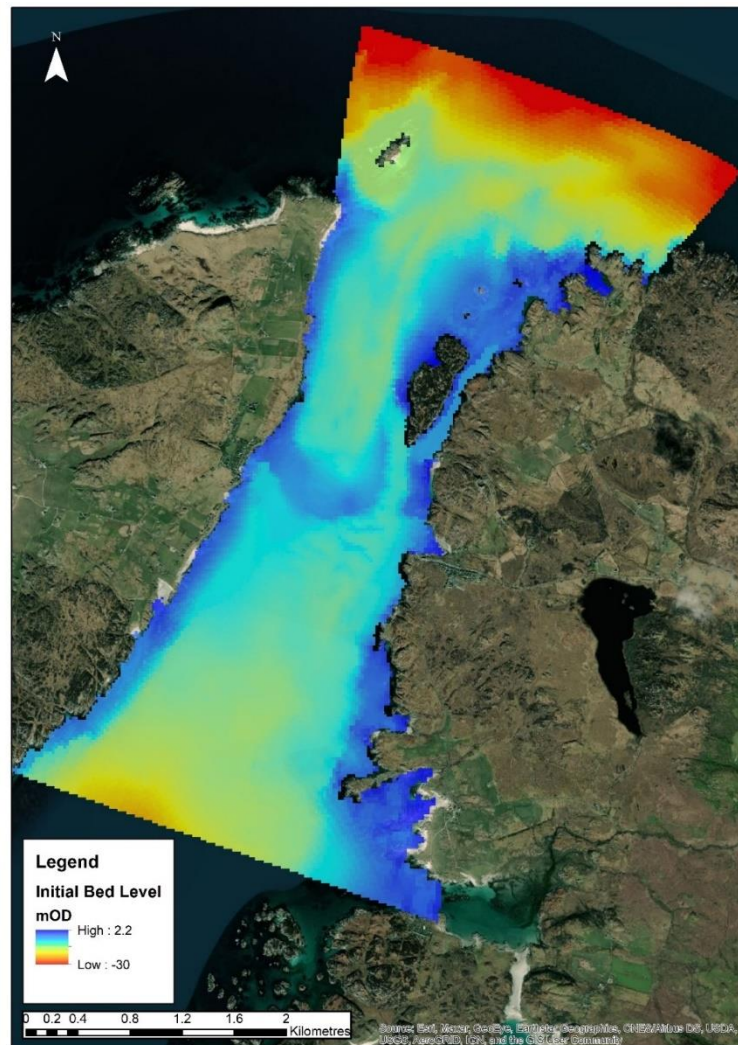


Figure 4-2: Detailed model bathymetry

Small islands have been removed from the bathymetry and instead represented as “dry points” which do not allow the flow of water between the neighbouring cells.

The breakwaters have been schematised as “dry points” within the FLOW model domain and “obstacles” within the wave model. This prevents flow of water across them and results in a reduced wave climate in the lee of the structure.

The footprint of the breakwaters have been taken from the Feasibility Study drawings (Figure 2-2).

4.3 Model Boundaries

The models are forced by wave and water levels. Water levels are applied along North, Northeast, Northwest and South of the Detailed Grid. Waves are applied along all relevant boundaries of the Coarse Grid.

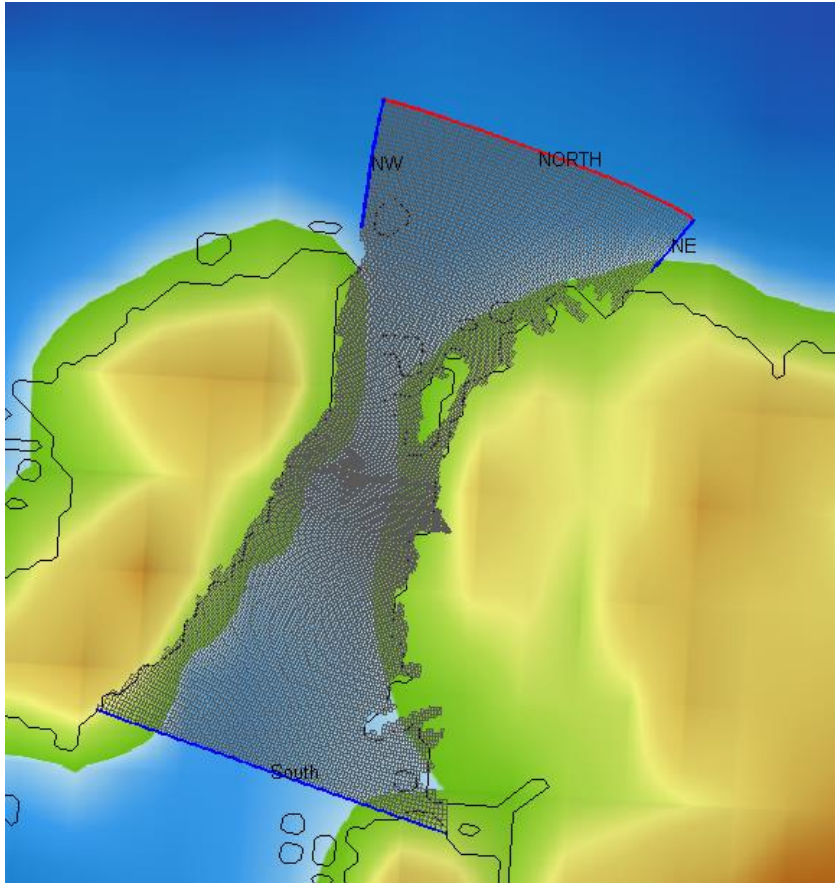


Figure 4-3: Tidal Boundaries for the Detailed Grid

4.4 Additional Parameters

4.4.1 Sediment and morphology

Information on sediment size and composition was taken from the Byrne Looby Iona & Fionnphort Marine Access Improvements Feasibility Study².

Six surface level sediment samples were taken each at Iona and Fionnphort at varying water depths. From the 12 samples undertaken, D50 varied between 0.17 – 3.00 mm, with an average of 0.85mm. This represents a coarse sand/fine gravel material.

The site visit undertaken by JBA in October 2019, showed that the majority of the sediment within the berthing locations was fine sand, and that a D50 of 0.85mm may be unrepresentative of the majority of the study area, making the sediment less mobile than in reality.

For the simulations undertaken and presented here a representative D50 of 0.2mm has been assumed.

For the extreme event simulations, no morphological acceleration (*morfac*) has been applied, but for efficiency a value of 6 is used for the winter period simulation meaning 6 months of wave conditions were compressed onto a monthly duration. This means that the bed is updated 6 times every hydrodynamic timestep.

The wave-related suspended transport factor (SUSW) and wave-related bed-load transport factor (BEDW) were set to 0.25 instead of the default 1.0. The default parameters were tested but tended to overestimate transport in shallow, wave-dominated areas.

4.4.2 Horizontal viscosity and diffusivity

The model horizontal eddy viscosity and the horizontal eddy diffusivity have been set to be $5\text{m}^2/\text{s}$ uniform over the computation grid. These represent the sub-grid scale losses through turbulence and eddy generation that cannot be represented in the model.

4.4.3 Roughness

The Chezy roughness formula was used, and a variable roughness layer was used across the domain. A default value of 55 was applied with localised areas of higher roughness near the boundaries as the model development phase showed the high energy 1 in 200-year waves resulted in unrealistic velocity patterns when coupled with the hydrodynamics.

5 Results

5.1 Scenarios and outputs

The model outlined and evaluated in previous sections was used to assess sediment response to the implementation of the breakwaters at Iona and Fionnphort. This assessment required the modelling of the scenarios listed:

- Baseline (no breakwaters)
 - Annual average storm from SW
 - Annual average storm from N
 - Annual average storm from E
 - 200-year storm from the SW
 - Winter period
- Developed (with proposed breakwaters in place)
 - Annual average storm from SW
 - Annual average storm from N
 - Annual average storm from E
 - 200-year storm from the SW
 - Winter period

These results are intended to evaluate the changes in sedimentation patterns within the Sound of Iona. For each model run, timeseries of waves and bed level changes were analysed at each of the observation points shown in Figure 5-1.

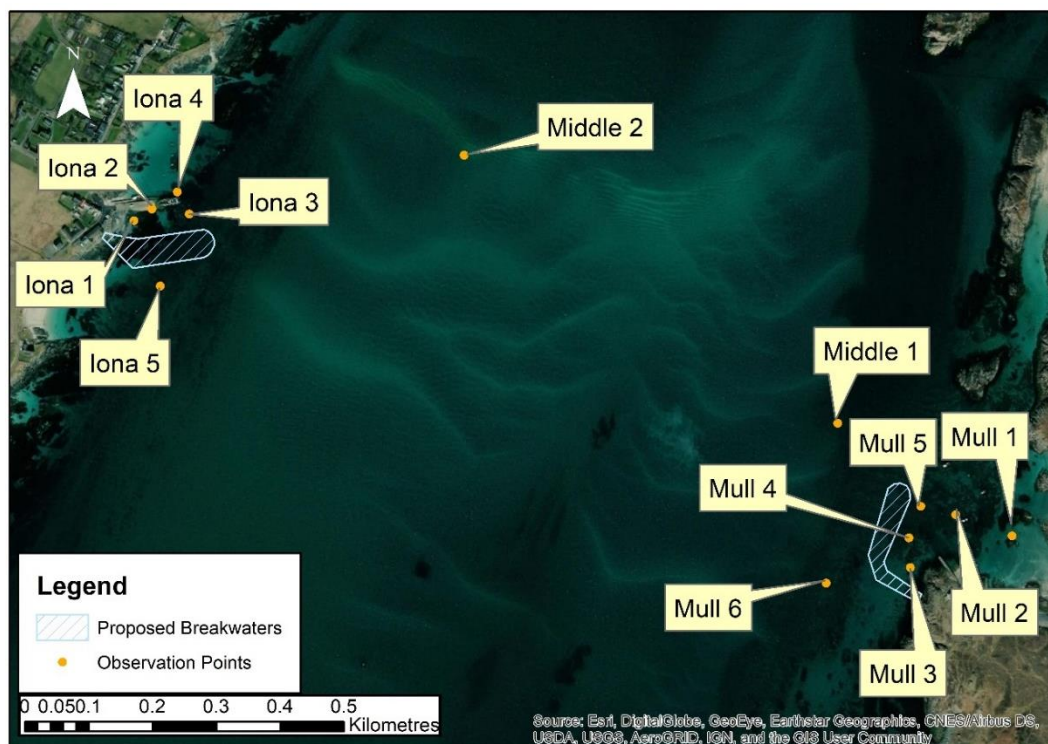


Figure 5-1: Observation points within the model

5.2 200-year Event

5.2.1 Waves

Figure 5-2 shows the difference in wave heights at Fionnphort with and without the breakwaters in place. A significant reduction in wave height occurs behind the breakwater with reductions of ca. 1.3m (at point Mull 2).

At Iona (Figure 5-3) a similar reduction is seen, from wave heights ca. 1.2m reducing to 0.3m with the breakwater in place (at point Iona 2).

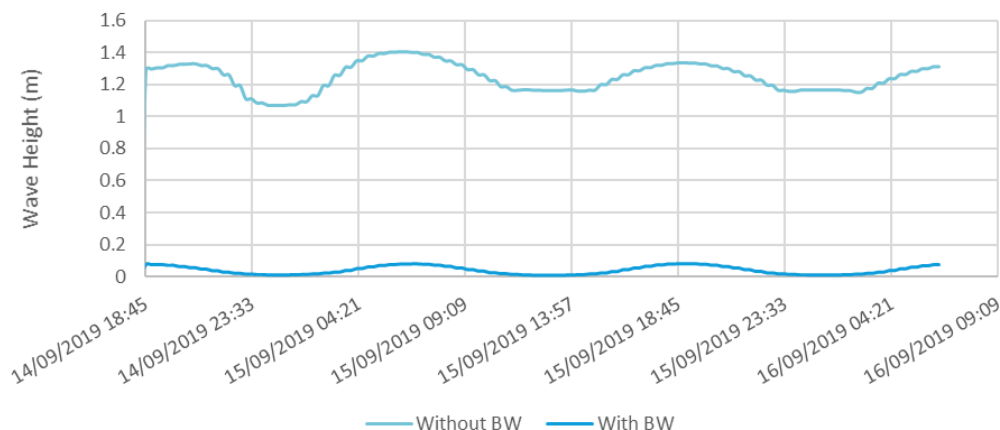


Figure 5-2: Significant Wave Height at Mull_2

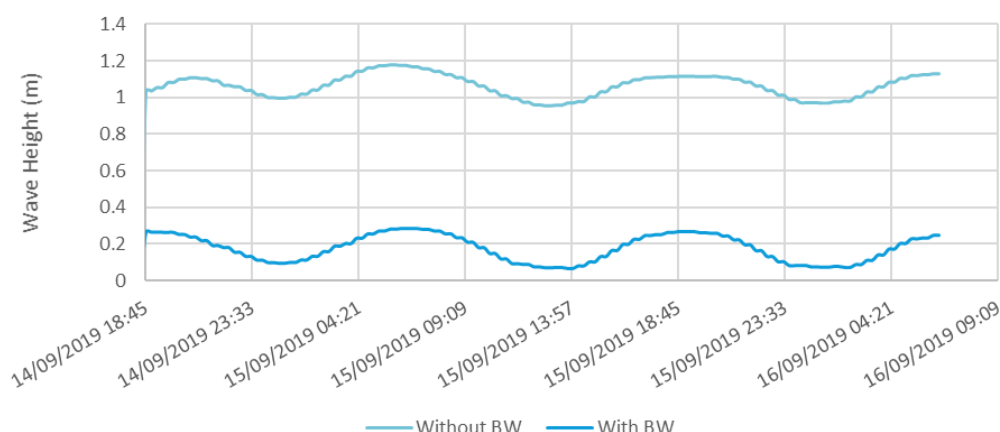


Figure 5-3: Significant Wave Height at Iona_2

5.2.2 Sediment

The model shows slight sediment accumulation on the south side of the breakwaters, and along the coastlines to the south of the berthing locations.

Due to the reduction in wave action, there is limited sediment movement within each berthing area. Greater accumulation of sediment on the outside of the breakwater occurs at Iona, where changes in bed level of up to 0.25m are estimated by the model.

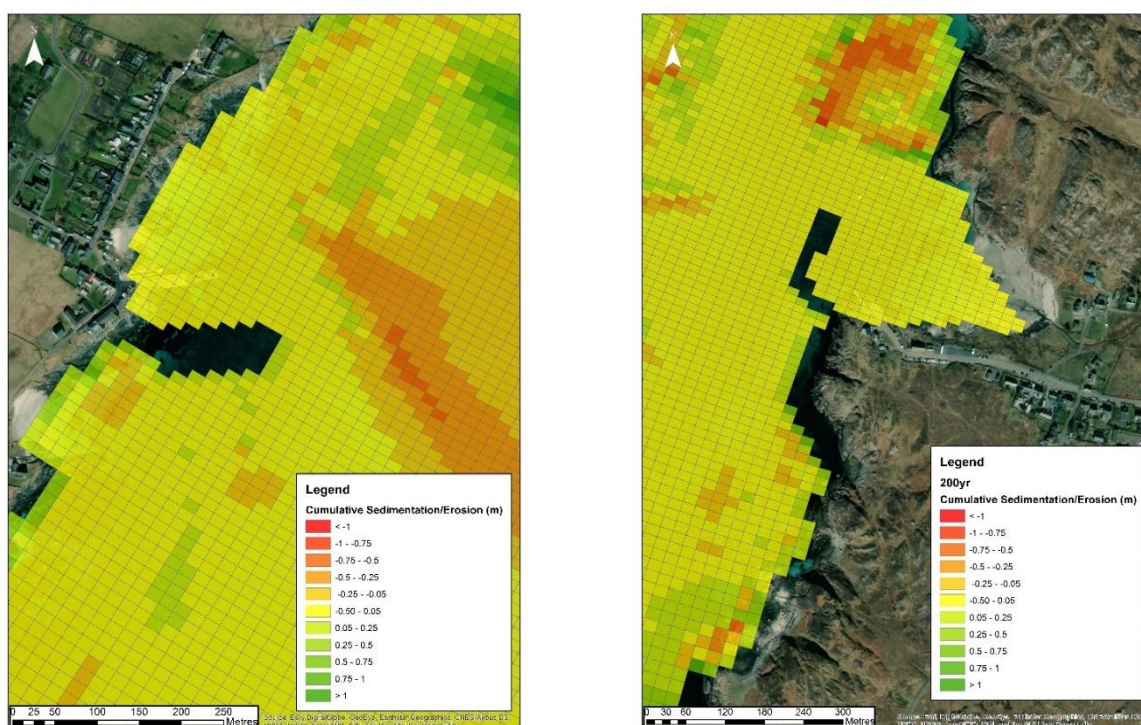


Figure 5-4: Cumulative Sedimentation and Erosion at Iona (left) and Mull (right) for the 200-year extreme event

Evaluating the response through time show how the breakwaters provide shelter and reduce sediment movement (Figure 5-6 and Figure 5-5).

At both sides, the baseline scenario estimates a small degree of erosion within the area. Compared to this, the model estimates that, after construction of the breakwater the berthing area will become more susceptible to deposition of sediment. However, the results from the modelling estimate bed level change within the berthing areas to be small.

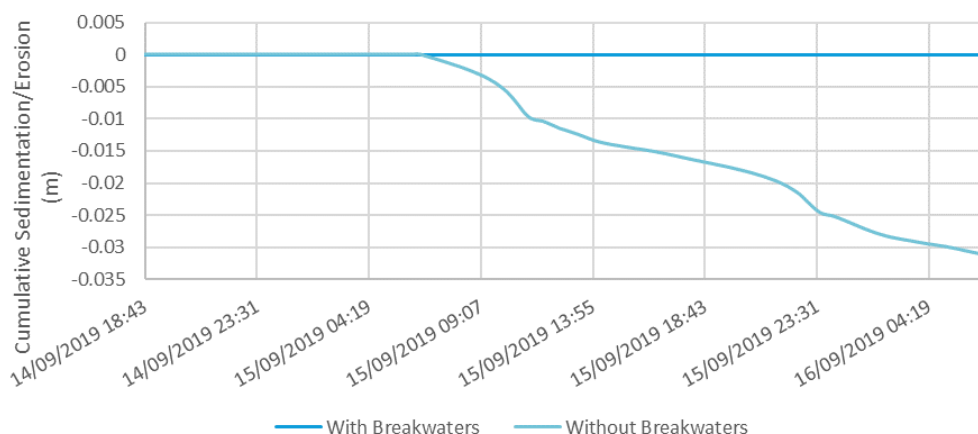


Figure 5-5: Cumulative Sedimentation and Erosion at Mull_2

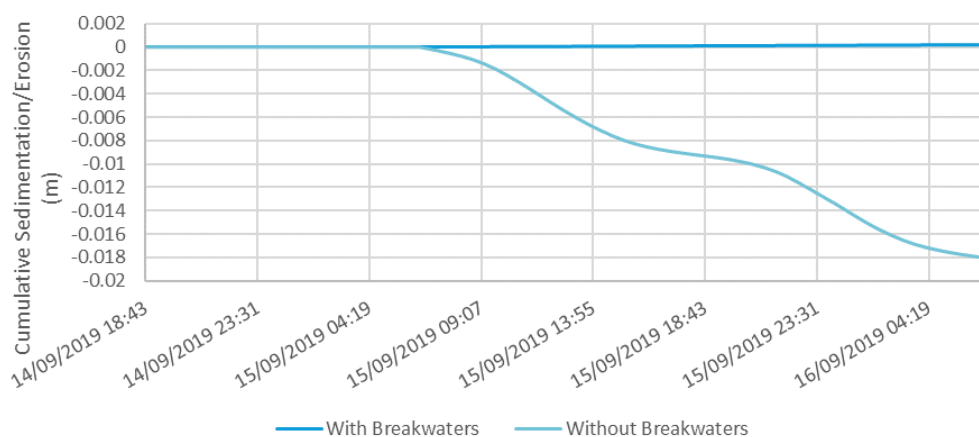


Figure 5-6: Cumulative Sedimentation and Erosion at Iona_2

5.3 SW Event

5.3.1 Waves

Figure 5-7 shows the difference in wave heights at Fionnphort with and without the breakwaters in place. A significant reduction in wave height occurs behind the breakwater with reductions of ca. 0.15m (at point Mull 2).

At Iona (Figure 5-8) a smaller reduction is seen, from wave heights ca. 0.2m reducing to 0.18m with the breakwater in place (at point Iona 2).

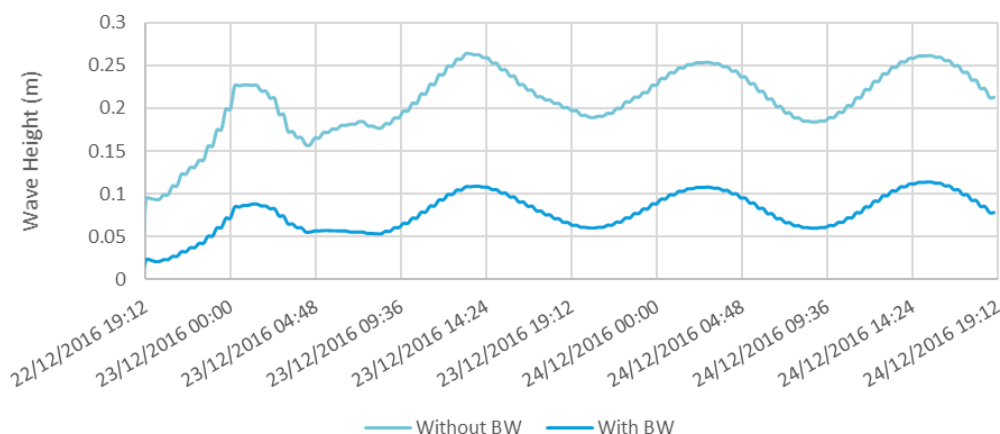


Figure 5-7: Significant Wave Height at Mull_2

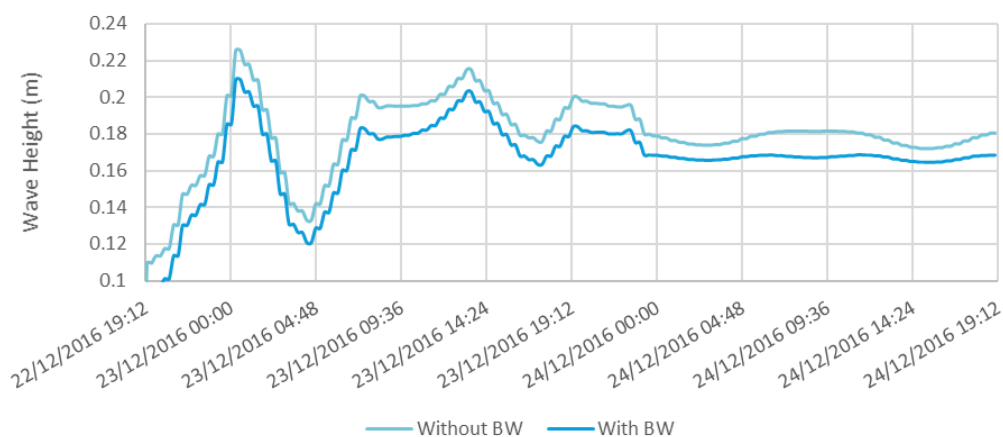


Figure 5-8: Significant Wave Height at Iona_2

5.3.2 Sediment

The breakwaters reduce wave action, and therefore sediment movement is less. Compared to the baseline case, the model estimates reduced sediment movement within the harbours after construction of the breakwaters (Figure 5-9 and Figure 5-10). Overall sediment movement is low throughout this event.

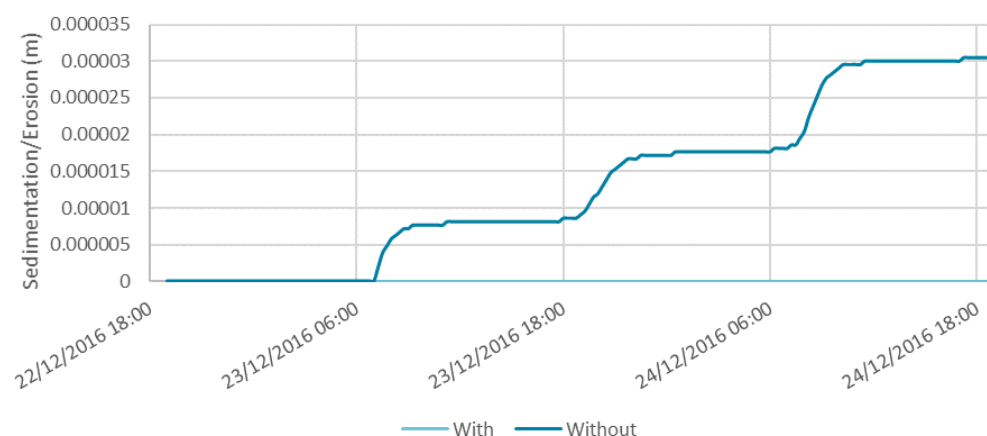


Figure 5-9: Cumulative Sedimentation and Erosion at Mull_2

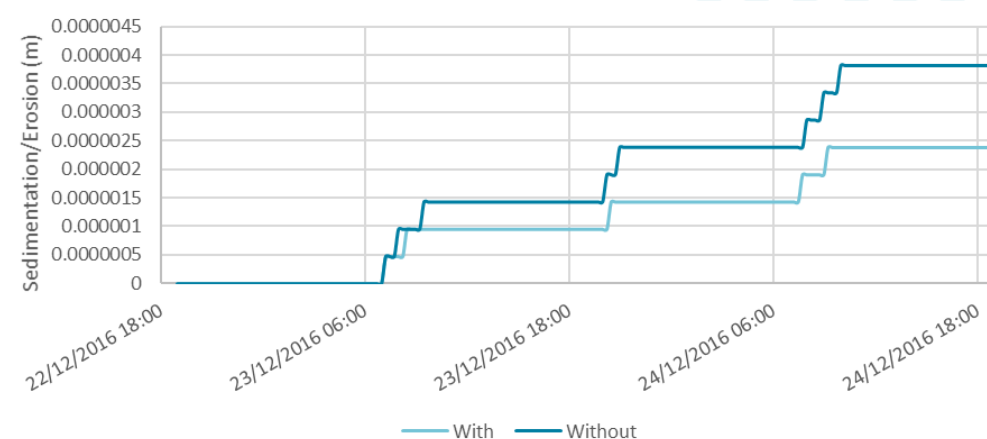


Figure 5-10: Cumulative Sedimentation and Erosion at Iona_2

5.4 NW Event

5.4.1 Waves

Figure 5-11 shows the difference in wave height at Fionnphort with and without the breakwaters in place. A reduction in wave height occurs behind the breakwater with reductions of ca. 0.15m (at point Mull 2).

At Iona (Figure 5-12) a smaller reduction of 0.05m is seen (at point Iona 2).

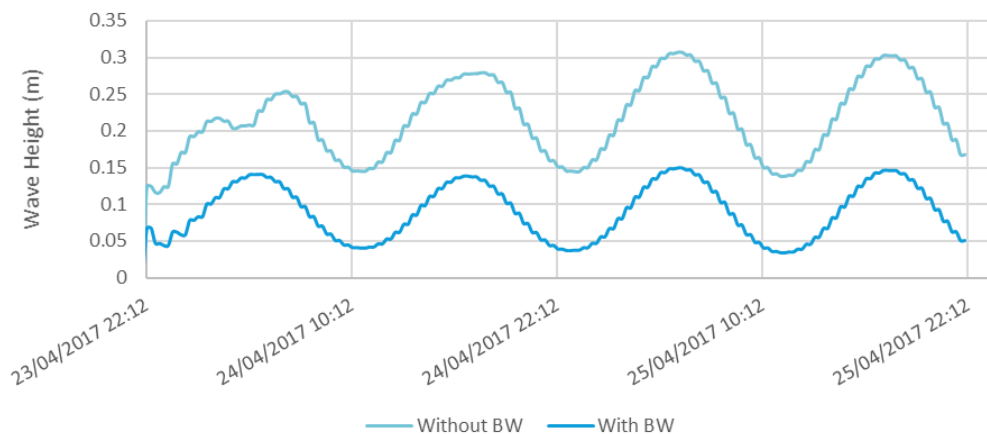


Figure 5-11: Significant Wave Height at Mull_2

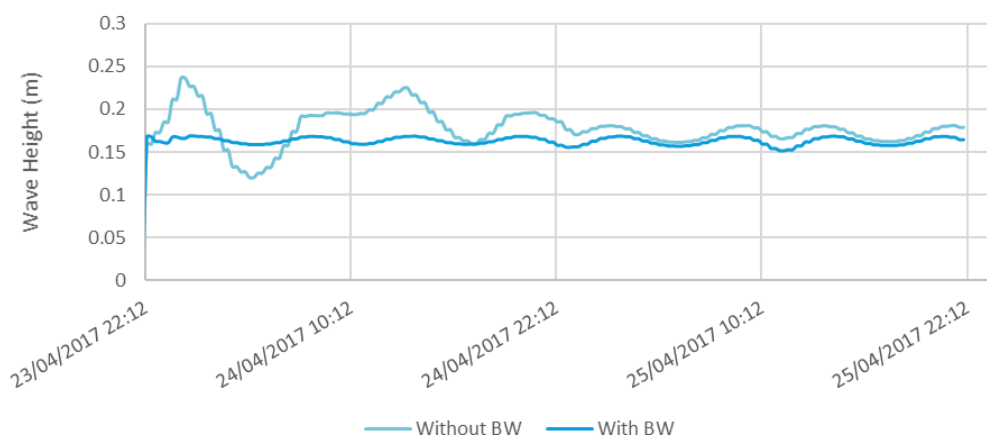


Figure 5-12: Significant Wave Height at Iona_2

5.4.2 Sediment

Sediment deposition during this event is low, with the model estimating this to decrease when breakwaters are in place (Figure 5-13 and Figure 5-14).

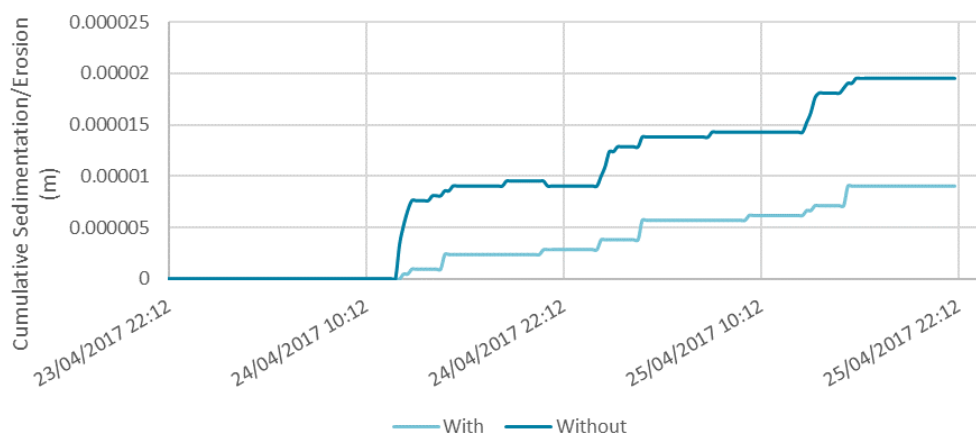


Figure 5-13: Cumulative Sedimentation and Erosion at Mull_2

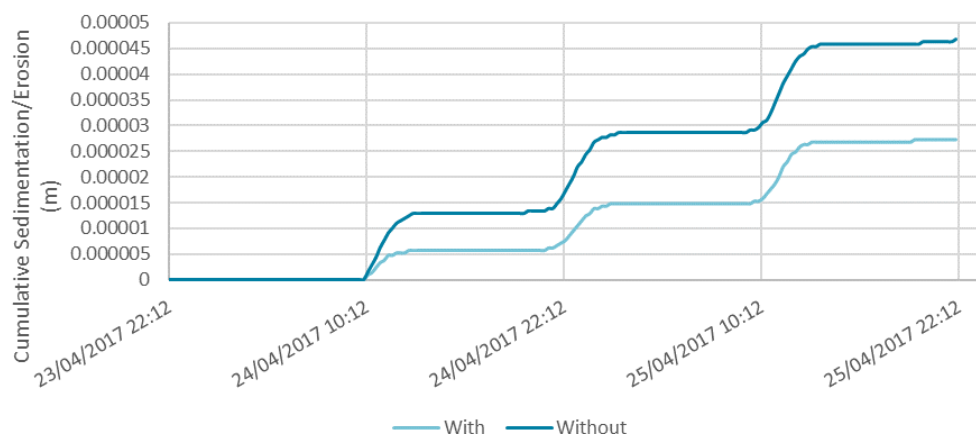


Figure 5-14: Cumulative Sedimentation and Erosion at Iona_2

5.5 NE Event

5.5.1 Waves

Figure 5-15 shows the difference in wave heights at Fionnphort with and without the breakwaters in place. A small reduction in wave height occurs behind the breakwater with reductions of ca. 0.1m (at point Mull 2).

At Iona (Figure 5-16) a similar reduction is seen, from wave heights ca. 0.15m reducing to 0.05m with the breakwater in place (at point Iona 2).

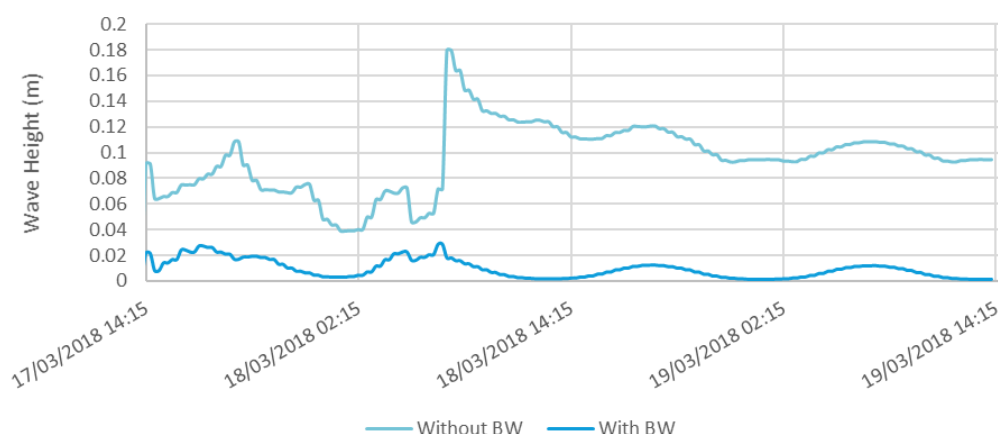


Figure 5-15: Significant Wave Height at Mull_2

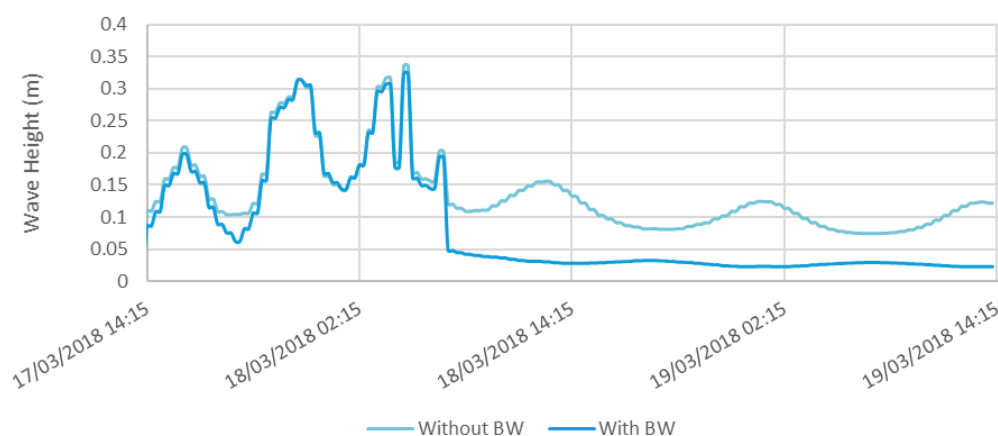


Figure 5-16: Significant Wave Height at Iona_2

5.5.2 Sediment

Due to the small wave heights and direction of this annual event, the model estimates the resulting sediment movement to be minimal with and without the breakwaters.

5.6 Winter Season

The modelling shows the longer-term winter scenario experiences a higher magnitude of sediment movement across the whole model domain compared to any of the individual extreme events tested.

Evaluating the response through time show how the breakwaters provide shelter and reduce sediment movement (Figure 5-17 and Figure 5-18).

At both sides, the baseline scenario estimates erosion within the berthing area, however the model estimates that during a winter period, the breakwaters will provide shelter to the harbour area and less sediment movement will take place.

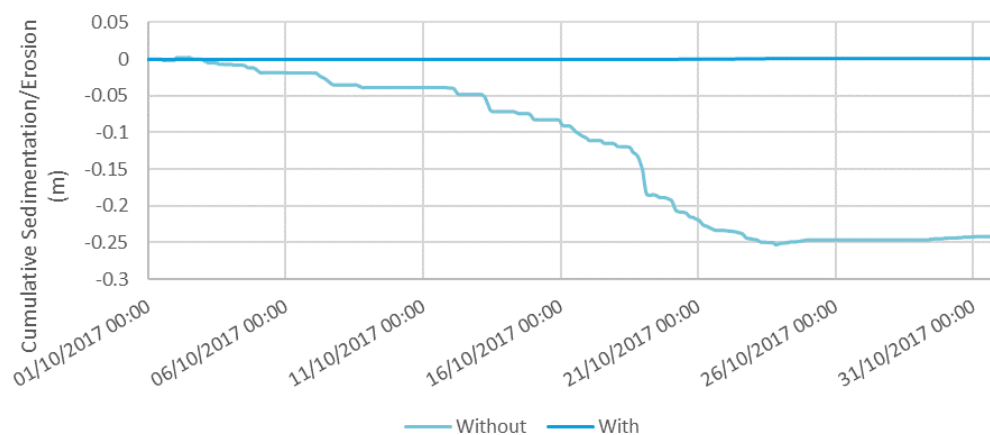


Figure 5-17: Cumulative Sedimentation and Erosion at Mull_2

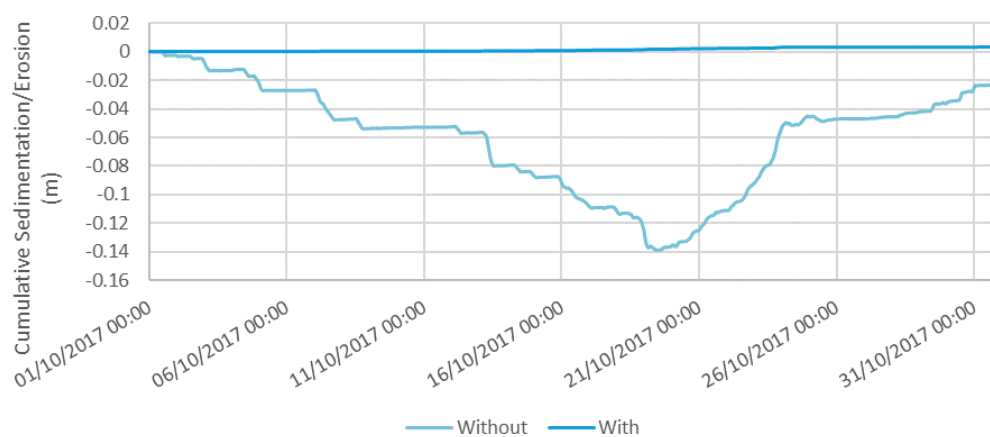


Figure 5-18: Cumulative Sedimentation and Erosion at Iona_2

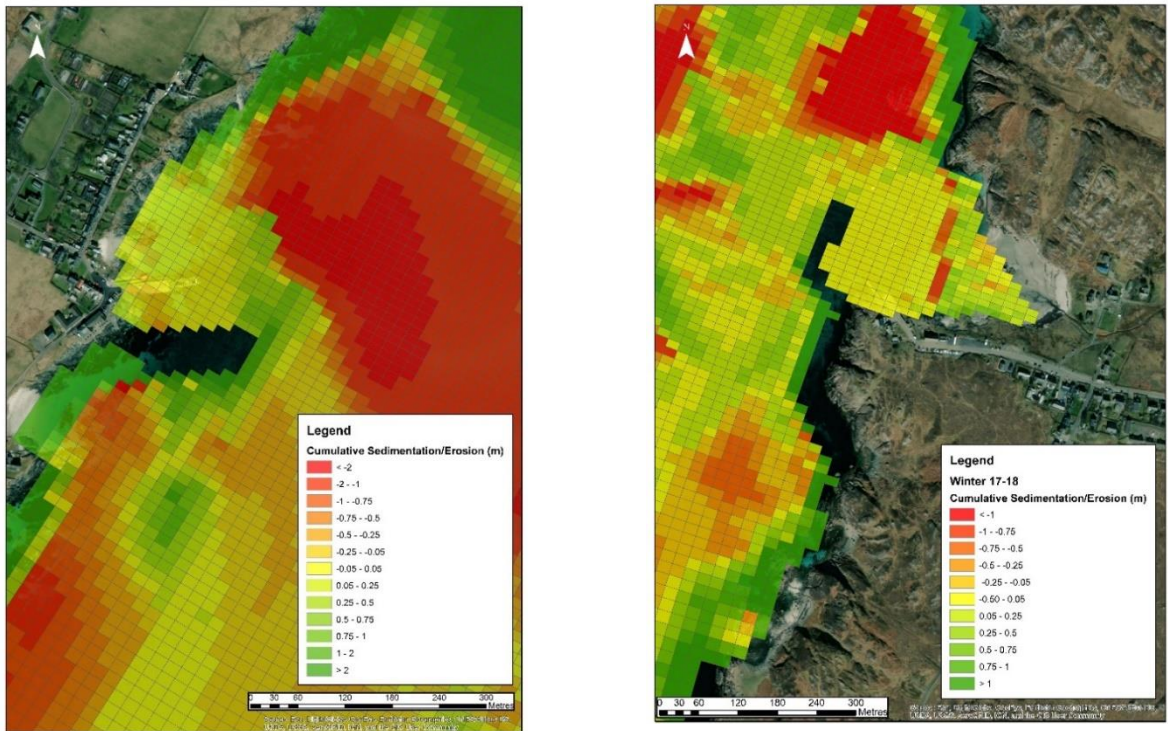


Figure 5-19: Sediment accumulation and erosion at Iona (left) and Mull (right) during winter season

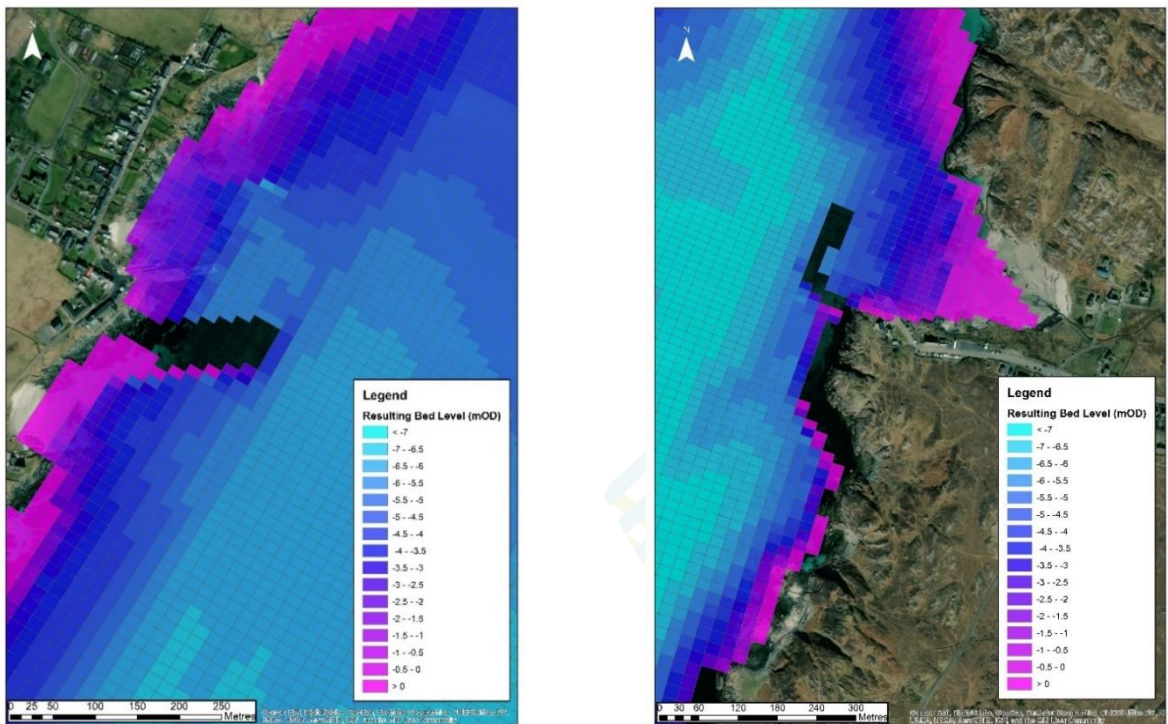


Figure 5-20: Resulting Bed Level at Iona (left) and Mull (right)

The sediment transport rates and patterns were discussed with ABC and were considered higher than the sediment trends experienced throughout a typical winter at Iona and Mull. The model results were compared to bathymetric surveys from 2014 and 2017. There were no overall erosion or deposition trends but

localised pockets of erosion and deposition in the nearshore at Iona, up to 1m, were present during this time period. This suggests the bed has been relatively stable between 2014 and 2017.

Whilst the magnitude of sediment transport is higher than expected, the sediment behaviour and trends are at least representing the anecdotal information provided by ABC from locals in the area (Section 2.3). The mean transport rates are higher along the Iona coastline compared to the rates along the Mull coastline which was highlighted in the anecdotal information as the sediment transport regime is much more dynamic at Iona compared to Fionnphort. Also the availability of sediment on the Iona side is much greater which is in line with local evidence.

5.7 Sensitivity Testing

5.7.1 Sediment Diameter (D50)

Sediment diameter was tested on the 200-year model, comparing the survey D50 of 0.85mm, to the estimated D50 of 0.2mm, to determine the impact it has on sediment movement. Overall, the magnitude of erosion and deposition reduced with the larger sediment size. At Iona_2 and Mull_2, behind the breakwaters, there was no sediment movement, which seems unrealistic given the nature of the sediment observed in the site visit. On the sandbank in between the two berthing locations (point Middle_2), sediment accumulation is reduced by more than 50% (Figure 5-21).

The sediment movement patterns are similar but minimised when a larger D50 of 0.85mm is used. The reduction in sediment mobility does not align with the anecdotal evidence about sediment patterns in this area.

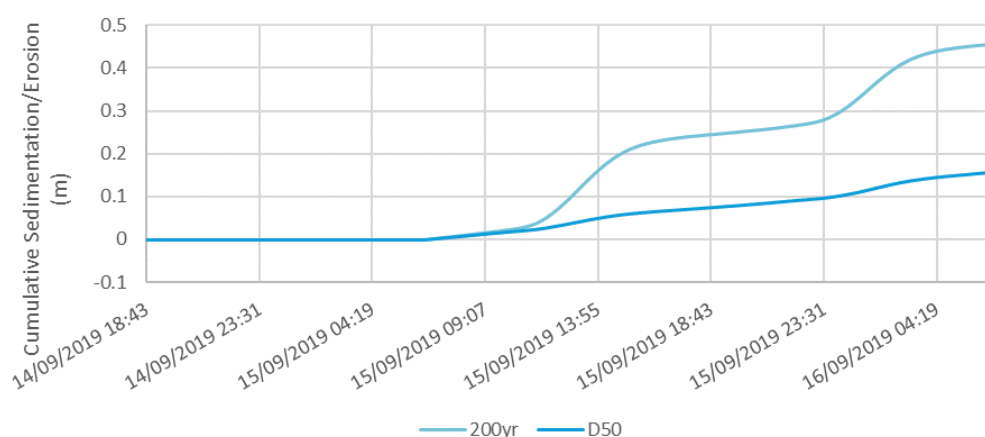


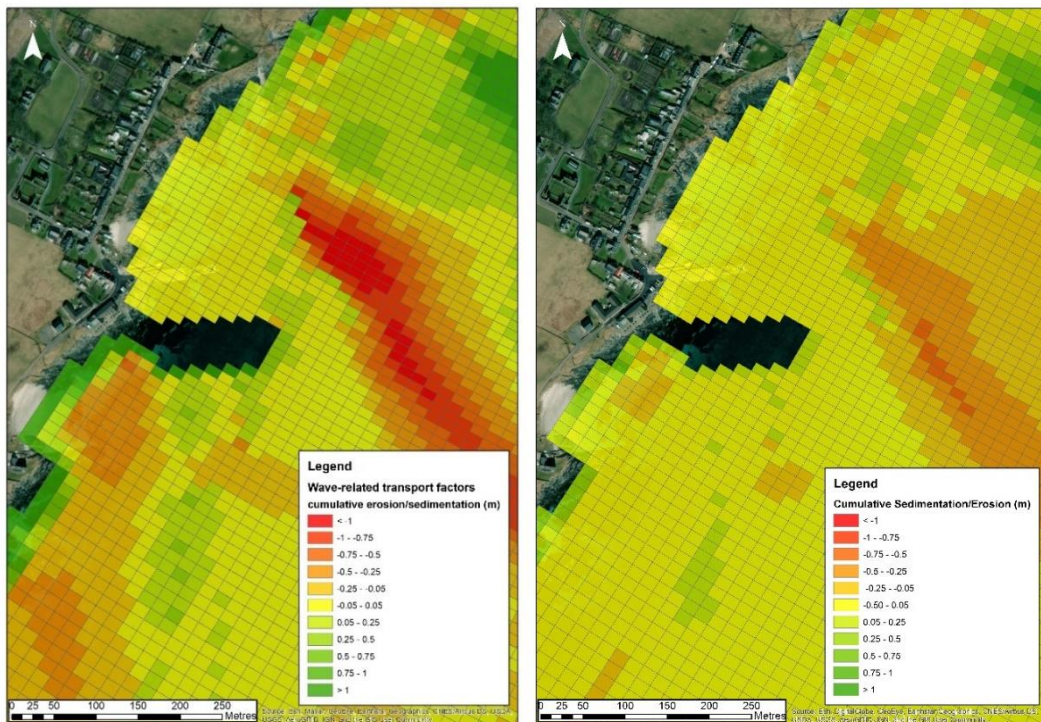
Figure 5-21: Sediment diameter sensitivity testing at the sandbank (Point Middle_2).

5.7.2 Wave-related suspended transport and bed-load transport

SUSW and BEDW were tested on the 200-year model, using the default value of 1 and comparing it to the value of 0.25 used in the model. Deposition south of the Iona harbour along the coast is up to 2.8m, compared to 0.5m in the baseline model, and the maximum erosion of the sandbank up to -1.4m, compared to -0.7m (Figure 5-22).

The resulting sediment transport patterns from the sensitivity modelling are the same as the baseline scenario, but on a much larger scale when the wave-related transport factor of 1 was used compared to the value of 0.25. This magnitude of

sediment movement does not align with the anecdotal evidence about sediment movement in this area.



5.7.3 Morfac

To make the long term simulations computationally efficient, a morphological acceleration factor was applied. This led to the six months of morphological changes being represented by the one month of hydrodynamic conditions (i.e. morfac = 6). This means that the bed is updated 6x every hydrodynamic timestep. In high energy, wave dominated environments, model results can be sensitive to the selection and application of morfac.

A sensitivity test was therefore carried out without a morphological acceleration factor to determine the effect it had on sediment transport and overall deposition. This puts the results in a more comparable context with the storm event simulations in the initial Interim Modelling Results Technical Note.

Overall, the results show the sediment trends to be the same, however, the magnitude of sediment accumulation and erosion was reduced without morfac. The sediment deposition on the south of the breakwater is reduced by up to 50% in some cells, and the sediment deposition at the end of the breakwater reduces between 20%-50% from the baseline scenario with breakwaters (Figure 5-23).

It should be noted that running the model without morfac for a six month simulation takes seven days, making it prohibitive for the number of simulations required here.

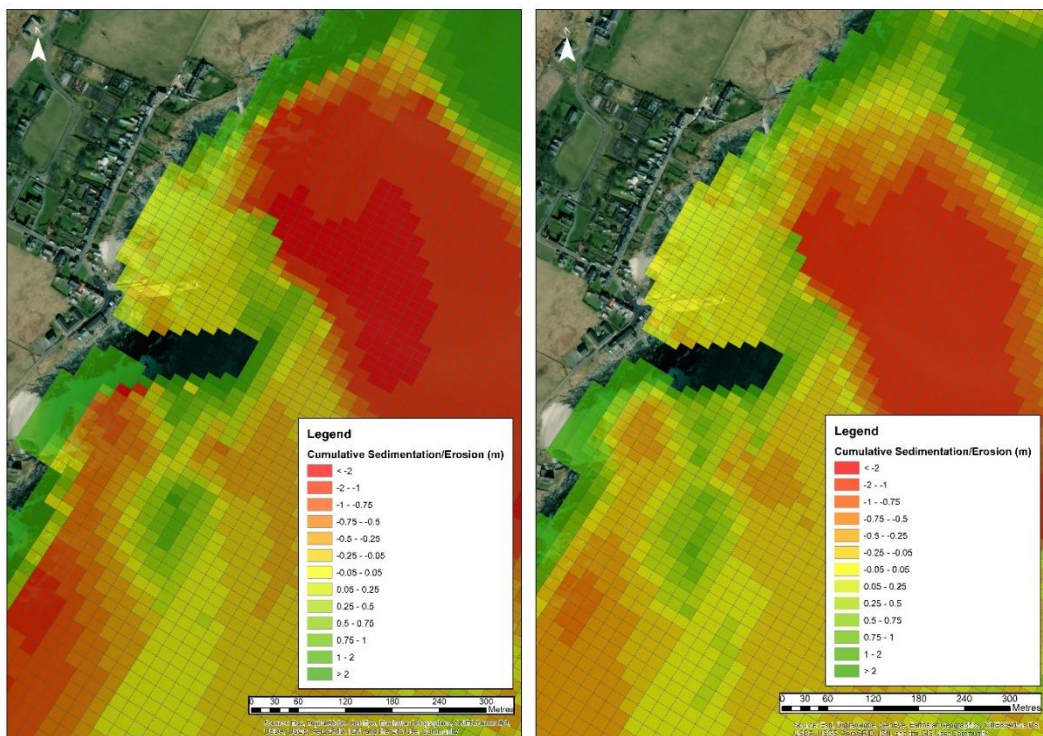


Figure 5-23: Sedimentation and Erosion differences (morfac on left, no morfac on right)

6 Mitigation measures

The initial long term results caused concern as regular dredging may be required. In an attempt to mitigate that, additional breakwater alignments were tested. The alignments were tested in the model for a winter period to determine the long term sediment impact, which appears to be the most influential to berthing of vessels. Alignment 2A consists of a breakwater situated 210m south of the current slipway, with a 140m crest. 2B starts at the same location as 2A however the crest is 235m long.



Figure 6-1: Alignment 2A



Figure 6-2: Alignment 2B

Sediment accumulates on the south side of the breakwater in this alignment and between 0.5-1.0m of accumulation is seen in the approach channel offshore from the current pier location (Figure 6-3).

Overall transport rates are similar between scenario 2A and the preferred arrangement, with minimal changes in the deposition of sediment in areas that are unlikely to influence ferry operations.

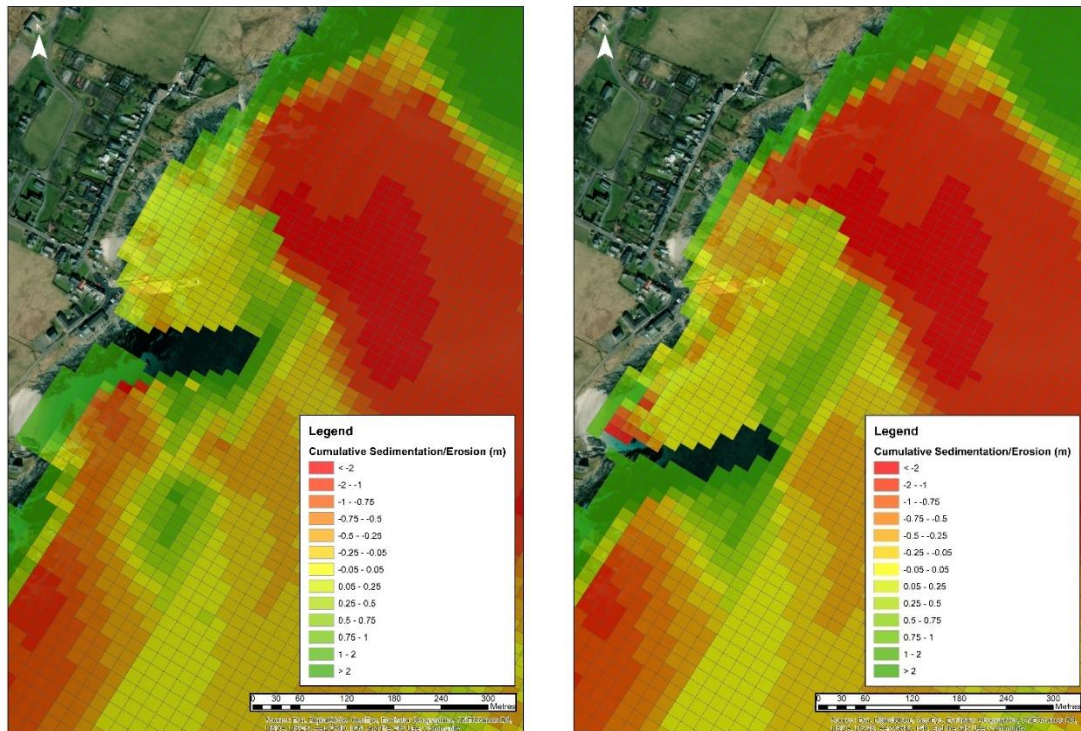


Figure 6-3: Sedimentation and Erosion differences (preferred breakwater alignment on left, alignment 2A on right)

The length of alignment 2B encourages sediment deposition along the south of it (Figure 6-4). The approach channel offshore from the pier at Iona experiences sediment accumulation of 0.5-1.0m which will have a negligible effect on boat operations. Sediment transport rates are similar to the baseline scenario and alignment 2A.

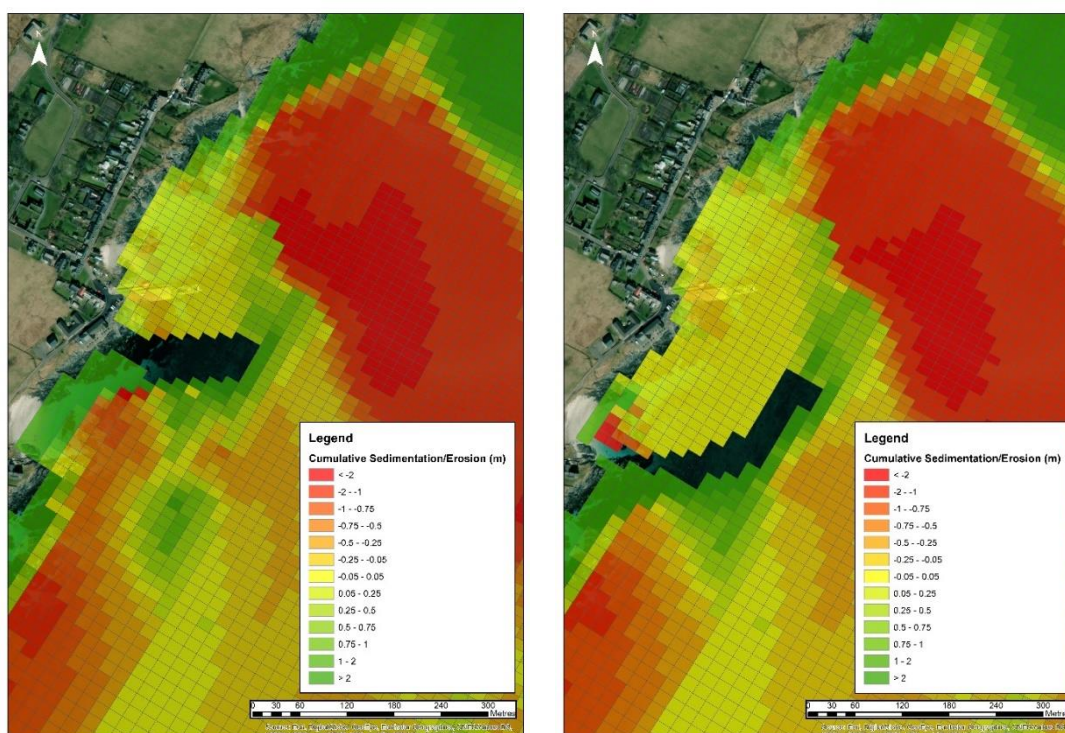


Figure 6-4: Sedimentation and Erosion differences (preferred breakwater alignment on left, alignment 2B on right)

7 Conclusions and recommendations

This study has undertaken a morphodynamic modelling exercise to understand the sediment transport regime of the Sound of Iona and assess how this may be affected by the construction of new berthing facilities at Iona and Fionnphort.

The modelling was developed to understand:

- How the proposals influence morphodynamic behaviour within the Sound of Iona under extreme conditions.
- How the proposals influence morphodynamic behaviour within the Sound of Iona throughout a typical winter season.

Based on the modelling conducted and results presented the following conclusions can be drawn:

- Construction of the breakwaters will result in reduced wave action in the lee of the structure.
- The addition of breakwaters increases the risk of deposition within the berthing facilities and approach channels.
- Generally, this occurs for all events testing in both Iona and Fionnphort. The one exception is under northeasterly conditions, where the waves are too small to impact sediment movement to any large extent.
- Accumulation of sediment along the south sides of the breakwaters increases in all of the event tests conducted. This deposition is predicted to be localised and unlikely to affect navigation and berthing of vessels in the locations estimated by the model.
- The duration over which high energy conditions occur are shown to have more influence than the overall magnitude of the event: the winter period model shows that the cumulative changes in the bed become much more pronounced compared to the 200-year extreme event.
- The mechanism of this deposition has been shown to be the result of a longshore generated current on the eastern side of Iona which results in a predominant south to north transport gradient close to the island. The structure and deeper navigation channel here act as a sink for this transported sediment. This is supported by the anecdotal information collected by ABC.
- The model estimates sediment deposition during the winter period of up to 2m along the south of the breakwater at Iona, and up to 1m along the south of the breakwater at Fionnphort.
- At Iona, the modelling estimates there is the potential for up to 1m of sediment to be deposited in the approach channel over a winter period. This would result in the approach channel being at a depth of -5mOD, rather than -6mOD. However, sensitivity testing of the *morfac* shows this may contribute to 50% of this deposition.
- Attempts to mitigate this deposition through alternative breakwater arrangements result in similar erosion/deposition patterns and do not have much influence in mitigating the deposition of sediment.

To support the design of the structures, the above results require careful consideration and should be interpreted within the context of the limitations and assumptions of the modelling. Morphodynamic modelling of any form is

inherently uncertain but the conditions within the Sound of Iona make this an extremely challenging environment.

The lack of available recorded data to calibrate and validate the model performance results in high uncertainty in the predicted morphodynamic behaviour. While efforts have been made to calibrate the tidal flow, this cannot be achieved with the wave climate and associated sediment transport.

Tests on the model have shown that it is waves that are the predominant control on sediment transport within the sound, meaning that the model predictions are sensitive to the parameterisation of this component. Testing the wave-related transport factors (SUSW and BEDW) shows that using the default value of 1 may overestimate sediment movement in shallow wave-dominated areas such as the Sound of Iona.

Previous discussions with ABC and Cal Mac representatives indicated that, generally, there are little sedimentation issues at the existing slipways. While there is anecdotal evidence that the shoreline position and level can vary considerably during high-energy conditions, the changes below low water are thought to be minimal.

Of the model results presented, confidence in the behaviour of the winter period simulation is most critical as the results here demonstrate that there is potential for the navigation and berthing to be affected.

The model uses a bathymetry representation that combines datasets and has required manual manipulation to transition between the two and better align with chart information. The bathymetry within the model will control the sediment transport predictions which, if this changes, will influence the results.

It should be noted that while three output points analysed at each location all show similar trends of sediment accumulation behind the breakwater, there may also be localised areas of higher deposition and erosion nearer the shoreline which cannot be appropriately represented by this type of modelling.

The results presented here should therefore be considered as providing an indication of the overall morphodynamic trends in the study area.

7.1 Further work

Prior to the finalisation of the designs, and construction, the following activities are recommended to support the design process.

1. Bathymetric survey of berthing areas, including extending into deeper water to better capture the transition to the coarser datasets. This is particularly important in the approach channel to Iona.
2. This survey should be carried out at least bi-annually (e.g. before and after the winter period) to establish the critical seasonal variation.
3. Upon completion of two additional surveys an assessment of the change should be undertaken, including a correlation exercise with the offshore wave conditions.
4. Additional sediment samples from multiple locations inside harbour areas and around proposed breakwater locations on both sides of the Sound, but on the Iona side as a minimum. Areas sampled during the feasibility study should be resampled to provide details of bed composition changes that could help inform sediment transport patterns.
5. Should further modelling be required, collection of hydrodynamic and sediment transport conditions should be considered to support calibration validation. This would include – waves in the sound, tidal currents in the sound and suspended sediment transport. This would be desirable at

several locations but should focus on the Iona side as a minimum, as the modelling here has shown this to be critical.

Appendices

A Delft 3D Model Setup

A.1 Tidal Validation

Predicted water levels in the centre of the sound were compared to available data sources.

Within the DelftDashboard⁴ software, four different tidal models exist for which astronomic constituents are available.

The validation exercise tested each of these against a seven day spring tidal cycle (September 2019) and compared model results to estimates from the Admiralty TotalTide software at the Iona station.

Of these, the European Shelf was shown to perform best resulting in an RMSE of 0.15m for the seven day period. On average the model peaks ca. 0.01m higher than the ATT predictions, while the troughs are 0.02m higher (Figure A-1).

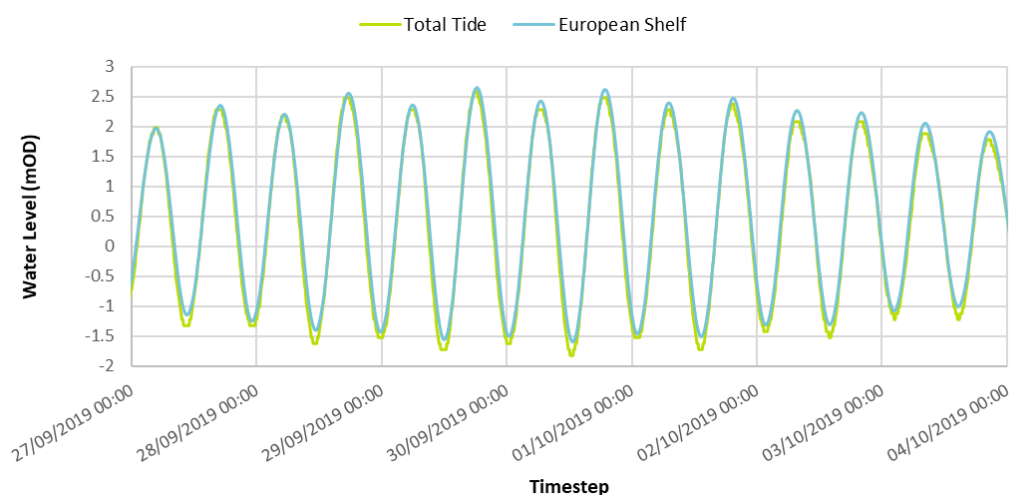


Figure A-1: Delft3D water level validation at Iona

No data exist to calibrate the tidal velocities within the channel. Therefore an anecdotal validation was undertaken using information in available literature.

This indicated a spring rate of 1.29 m/s (2.5 knots)⁵ which is comparable to the rates produced by the spring cycle tested here (Figure A-2).

⁴ <https://publicwiki.deltares.nl/pages/viewpage.action?pageId=42401894>

⁵ Scottish Sea Kayaking. D. Cooper and G. Reid

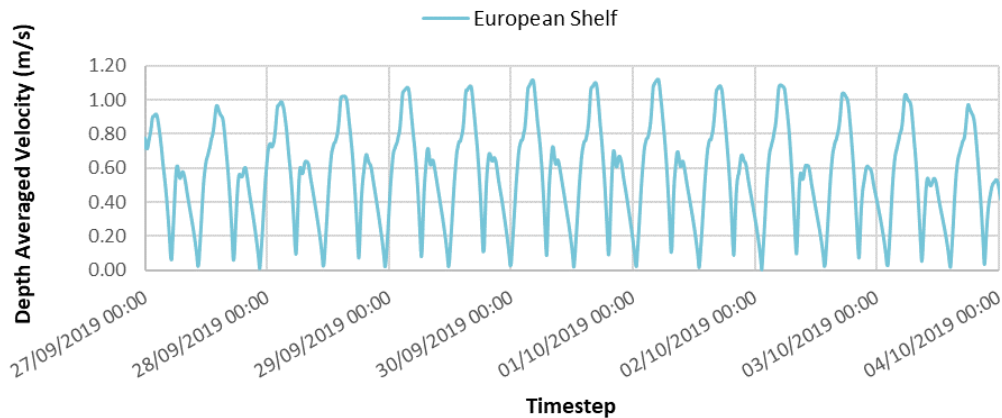


Figure A-2: Delft3D tidal current validation at Iona

A.2 Model Set Up Validation

To transform the waves into the nearshore of the Sound of Iona, a nested D-WAVE model was set up and tested independently to check performance.

Next, a FLOW model was setup to assess tidal currents through the sound. Initially, both the coarse grid, and detailed grid were modelled to establish the difference in tidal currents. These tests showed resulting tidal levels were similar across both grids and it was decided that a FLOW boundary would only be applied in the detailed grid to reduce model run time.

Following the tests, a nested (Detailed and Coarse) and coupled (FLOW and WAVE) model was set up. The model was tested with and without the morphodynamics to assess the impact that sediment movement had on model stability and allowed necessary refinements.

A.3 Bathymetric Alterations

Two varying resolutions of bathymetric data were merged together. The "smoothing" tool within QUICKIN was used for specific small areas to reduce large step changes, in particular around the areas of interest.

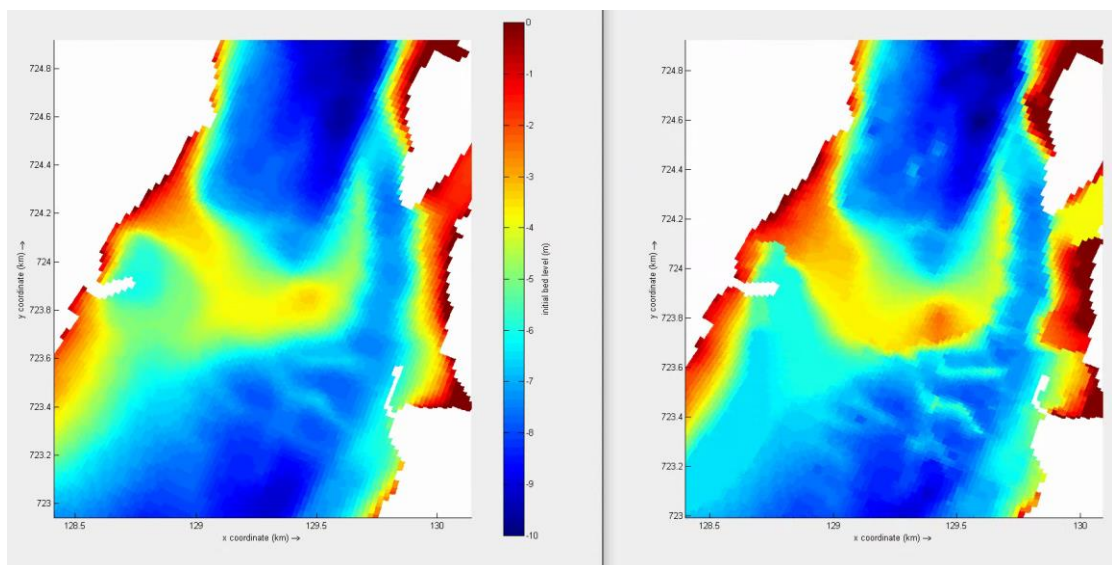


Figure A-3: Removal of sediment sink at Iona Harbour and defining of the channel offshore from Iona. Before (left), After (right).

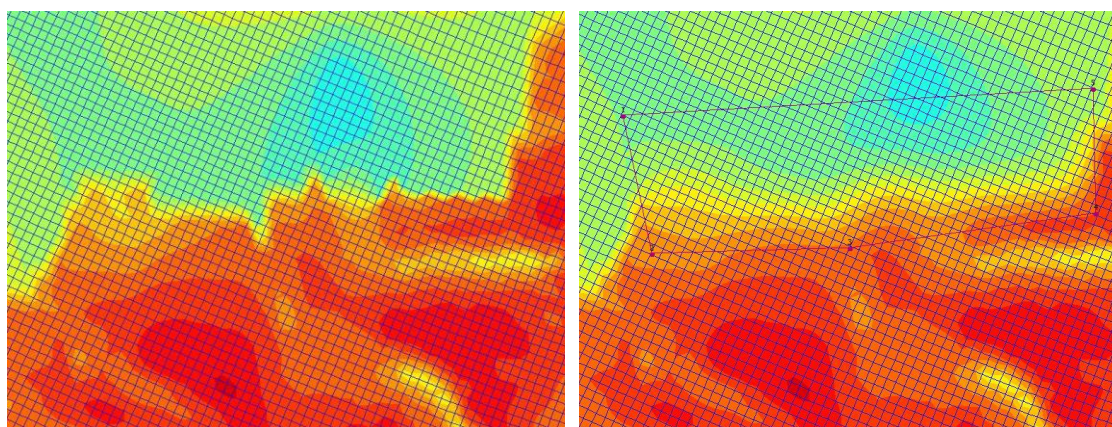


Figure A-4: Bathymetric Smoothing at Fionnphort between area with sandbars and deeper channel to the north. Before (left), After (right).

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