Lubec Breakwater Project, USA
2D Physical model studies

Project report

July 2024

Prepared by:

Prepared for:

Lubec Breakwater Project, USA
2D Physical model studies

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Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

1.1. General

Lubec is part of the state of Maine in the United States of America (USA) and is located on a peninsula which lies adjacent to a narrow strait that forms the border between Canada and the USA. The Maine Department of Transportation (MaineDOT) is intending to construct a breakwater at Lubec to provide a safe harbour for fishing and recreational vessels. Jacobs Engineering Group Inc. was appointed by MaineDOT to fulfil the role of consulting engineers and was responsible for the planning and detailed design of the breakwater structure. The Council for Scientific and Industrial Research's Coastal Engineering and Ports Infrastructure group (CSIR) was contracted by Jacobs Engineering Group Inc. (Client) to commission a 2D physical model study to assess and verify the stability of key elements of the design.

The project site is located on the eastern shore of Johnson Bay, Maine, and the project will include the construction of a breakwater approximately 925 ft (282 m) in length. About 630 ft (192 m) of the structure will comprise a rubble mound structure and 295 ft (90 m) of a King Pile Sheet Pile Combi wall breakwater. The approximate location of site is indicated in **Figure 1**.

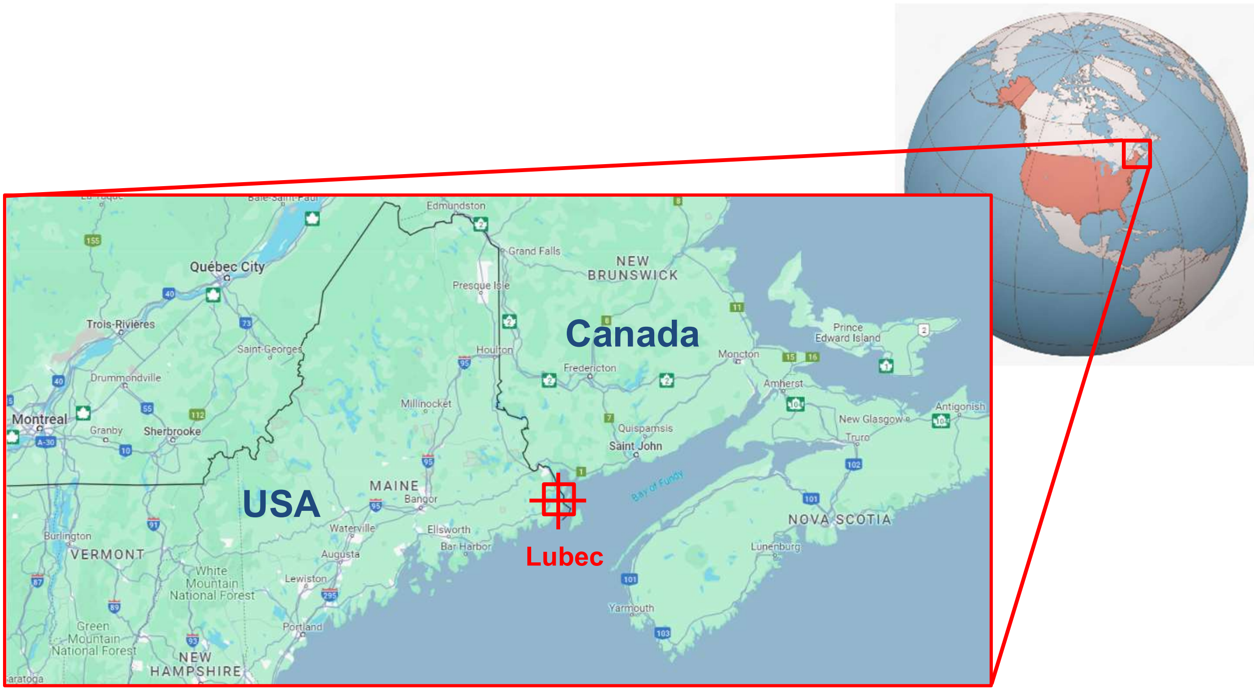


Figure 1: Project locality

The observations and results obtained during these physical model studies will be used to supplement the detailed design process by validating the performance of the proposed design options.

1.2. Study objectives

The objective of this 2D physical model study was to evaluate the performance and behaviour of key components of the Lubec breakwater design. This included verifying the stability of the rock armour layer and toe design, assessing potential interaction between the rubble mound and the combi wall structures, and measuring wave overtopping at a critical location on the trunk.

The study objectives included the following:

- Testing the breakwater design against of a range of wave scenarios, including moderate intensity events, the design wave conditions and extreme overload conditions. These also included different seawater level elevations for the various events.
- Measurements to identify damage to the design armour layer (seaward and harbour side slopes) and rock toe.
- The stability of the transition from the rubble mound structure to the King Pile Sheet Pile Combi wall structure.
- Measuring wave overtopping at the trunk section behind the parapet wall (STA_15+30).

To achieve the study objectives, a 2D model setup was commissioned inside a 4 m wide flume. The model coverage, test structure detail and test schedule for each model setup was confirmed by the Client prior to commissioning. All physical model testing was successfully conducted at the hydraulics laboratory of the CSIR in Stellenbosch, South Africa.

1.3. Report layout

This report summarises the construction and setup of the physical model, the test results obtained and the observations made during the study. The content of this document are as follows:

- Section 2 provides a description of the facility and equipment used to set up the physical model;
- Section 3 provides details on the test results; and
- Section 4 provides a testing summary and conclusions.

All parameters given in this report refer to prototype unless otherwise stated.

2. STUDY METHODOLOGY

This section provides details of the project, as well as of the physical model facilities and equipment used during this study.

2.1. General

A physical model study was required as input for the detailed design of the Lubec Breakwater Project. This study comprises a 2D physical model setup and the model scale was selected in cooperation with the Client. The model scale for this study was 1:20 and was based on a best fit of key components of the design to be included in the model setup.

The scope of this model study was defined by the Client and included verification of key design features of the Lubec Breakwater Project.

2.1.1. Rock armour layer stability

The Lubec breakwater design comprised a rock armour layer, where the rock size was defined by standard commercially available rock material. The same rock size was selected for the breakwater front and rear slopes (seaward side and harbour side), the roundhead, as well as the breakwater toe. The rock size for the breakwater was selected based on the design wave conditions near the structure toe.

During this study, the stability of two different armour rock sizes were investigated. This included 1-3 t rock (Series A) and 600-1900 kg rock (Series B). The underlayer rock was varied depending on the armour layer size and included 300-1000 kg and 60-300 kg rock for the two series respectively. The breakwater core comprised 5-40 kg material and was kept constant throughout this study.

2.1.2. Rock toe stability

The Lubec breakwater design included the same rock sizes for the structure toe as was used for the armour layer design. Filter material also extended beyond the toe, which comprised the same material used for the underlayer.

2.1.3. Overtopping

Wave overtopping was measured at a single location within the model. The measurement location was selected at the end of the trunk just before the transition to the combi wall. This location was considered the most critical since it will be located in deeper water depths. The breakwater trunk was orientated to be perpendicular to the direction of wave approach, which is commonly regarded as yielding a more conservative outcome.

2.2. Physical modelling

The methods and procedures described in this section were used during this physical model study.

2.2.1. Model bathymetry

The bathymetric detail used for this study was extracted from survey detail provided by the Client. The survey detail was provided in AutoCAD format, which allowed it to be easily scaled and transformed to a 1 m by 1 m grid in the x-y plane.

Grid lines for constructing the model floor were set out inside the flume using a Leica Total Station, where all points were referenced to a local coordinated grid system. Point elevations were adjusted and verified using a dumpy level surveying instrument. This combination allowed all x-y-z points to be staked out with millimetre precision.

Bulk filling sand was hauled into the flume, and then accurately shaped and compacted to form the correct contour detail of the model floor. All nodal points were fixed in place using construction templates and then covered with a 50 mm thick layer of cement-sand topping mix. Once the topping had dried and hardened, it was sufficiently strong to work on. This method of construction assumes a constant seabed roughness for the model and does not take minor seabed features into account, e.g. sand ripples and small outcrops.

Construction of the model bathymetry is shown in **Figure 2**. The cement-sand topping is constructed in 1 m wide strips, which span the length of the model flume. Every second line is constructed first and then once dry, the areas between lines are filled.

Figure 2: Construction and completion of the model bathymetry

The model floor for this setup included sufficient bathymetric cover in front of the test structure, which was equal to at least three times the longest wavelength (HYDRALAB III, 2007a). For this study, the longest wavelength was determined to be no more than 35 m, which is based on T_P = 4.71 s at 13.5 m water depth at the structure toe. A flat area was included in front of the wave generator to accommodate the maximum paddle stroke, and a gentle transition slope of 1:15 was constructed to link the flat area to the model bathymetry.

2.2.2. Model test structure

Once completed, the Lubec breakwater will be approximately 925 ft (282 m) in length, which includes a 630 ft (192 m) long rubble mound structure and a 295 ft (90 m) King Pile Sheet Pile combi wall breakwater. The model test structure only focused on the area closer to the rubble mound roundhead and included detail between stations STA_14+85 and STA_17+50. The coverage of the model test structure within the 4 m wide flume is shown in **Figure 3**.

The model test structure was constructed to the detail provided by the Client. The layout and positioning of the structure was determined from plan drawings (in AutoCAD format) and accurately staked out in the model flume using a Leica total station. Templates containing cross sectional detail were fabricated from hardboard and were accurately positioned and levelled in place. Rock material for the structure core, underlayer, main armour and toe were placed to the detail according to the templates, and once all material were in place, the templates were carefully removed. Surface indentations where templates were located were then filled and reshaped to match the adjacent structure detail.

The concrete roadway and combi wall breakwater was fabricated from wood in three main sections to accurately replicate the straight parts and complex corners. The vertical piles were replicated using Ø 48 mm PVC pipes. The top elevation of all parapet walls was accurately surveyed and then fixed in place to the top of the rubble mound structure. The combi wall breakwater was joined to the adjacent capping, as well as to the model floor via the PVC piles.

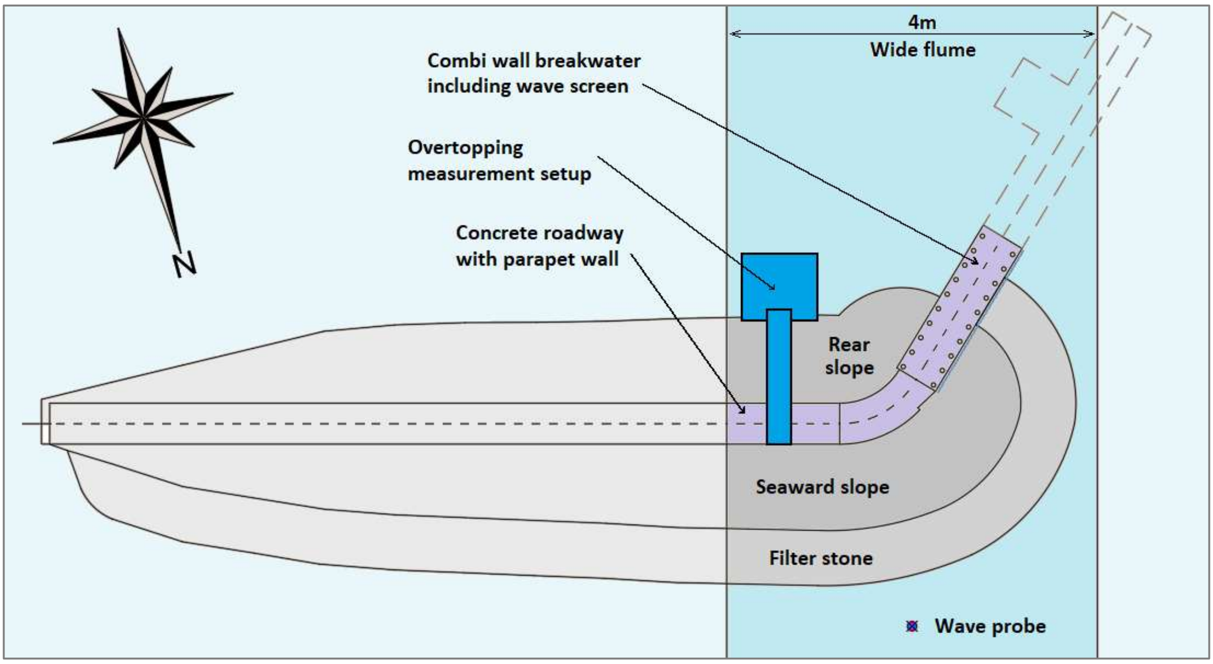


Figure 3: Coverage of the model test structure within the 4 m wide flume

Model rock for the toe, underlayer and armour layer were scaled according to Froude's law, whilst the core material was scaled in accordance with Burchardt (1999). Both methods take the difference between the specific density of seawater (prototype) and that of fresh water (model) into account.

During this study, the stability of two different armour rock sizes was investigated. This included 1-3 t rock (Series A) and 600-1900 kg rock (Series B). The underlayer rock was varied depending on the armour layer size and included 300-1000 kg and 60-300 kg rock for the two series respectively. The breakwater core comprised 5-40 kg material and was kept constant throughout this study. Apart from the different sized rock material, all structural dimensions and other cross-sectional detail for the two breakwaters remained the same.

The prototype material classification and corresponding model sizes are presented in **Table 1**.

Table 1: Rock material classification and sizes

Description	Prototype classification	Model classification
Armour layer & toe (Series A)	1-3 ton	40 – 80 mm
Underlayer (Series A)	300 – 1000 kg	35 – 40 mm
Armour layer & toe (Series B)	600 – 1900 kg	36 - 60 mm
Underlayer (Series B)	60 – 300 kg	12 – 28 mm
Core	5 – 40 kg	12 – 19 mm

Rock samples were taken to ensure that the model rock was representative of the prototype material included in the design. Grading curves for the different rock material are included in **Appendix F**.

The setup and implementation of the model test structure is shown in **Figure 4**. Image A shows placement of the underlayer rock on top of the finer core. All underlayer rock was spraypainted a bright green colour for the purpose of aiding its positive identification if this material became exposed during testing. Similarly, as seen in Image B, the armour layer was also spraypainted in different colours to aid identifying and tracking of rock movement. The different colours conformed to different areas of the design, e.g. trunk, roundhead, etc., as well as separating the top and bottom halves. More images of the model setup and implementation are included in **Appendix E**.

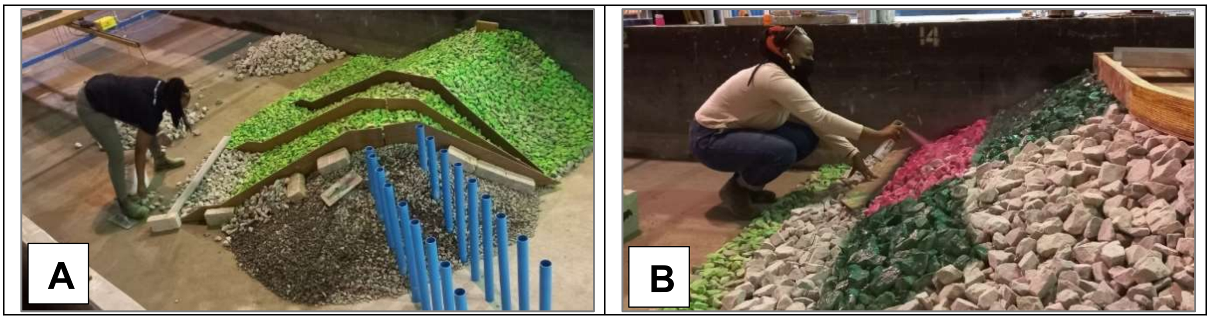


Figure 4: Set up of the model test structure

All design drawings for the test structures were provided by the Client in .dwg format. A typical cross-section of the rubble mound breakwater is included in **Appendix G**. The final rock placement for both test structures was inspected by the Client prior to the start of testing.

2.2.3. Wave generators

Waves inside the 4 m wide flume were generated using a multi-element wave generator manufactured by HR Wallingford, UK. The wave generator comprise a rack and pinion paddle system and waves are generated by synchronised pulsating movements of the paddles. A single wave module measuring 4 m wide was used for the Lubec study.

Wave conditions for this study were generated as irregular (random) long crested waves. Waves were defined by the standard JONSWAP spectral shape using a peak-enhancement factor (gamma) of 3.3. All waves were generated perpendicular to the wave generators.

2.2.4. Wave measurement

Wave measurements were taken using capacitance probes. These are twin wire gauges that measure the capacitance difference between the air-water interface as it fluctuates with passing waves. The output datasets captured from the probes were analysed using GEDAP analysis software developed by the Canadian Hydraulics Centre (Miles, 1997 and Miles & Funke, 2013) to provide usable outputs such as H_{mo}, T_P, etc. Before the start of each model test series, all probes were checked and calibrated to ensure that they functioned properly.

Four probe locations were identified for this study. This included a single probe close to the structure toe, as well as a three-probe reflection array that was used to measure wave reflection inside the flume. The data from this setup was analysed using the method developed by Mansard & Funke (1980) to separate the reflective waves from the incident waves.

All probe locations were verified by the Client.

2.2.5. Wave calibration

Wave calibration is required to validate the input parameters for wave generation and to achieve a desired wave condition at a specified calibration location. The calibration location for this study was selected at P-04 close to the structure toe.

Wave calibration was conducted without the presence of the test structures. An absorption beach was placed at the back of the flume, which comprised of large coarse rock. Absorption rock was placed at a slope of 1:12. The wave measurements recorded during calibration are included in **Appendix A**.

2.2.6. Test conditions

The test program for this study required each model setup to be subjected to multiple sea states. The intensity of the sea states ranged from a calmer shake down condition, to more sever design and overload conditions. The design waves were associated with a 100-year return period, while H_s for the overload conditions were 10% greater than that of the design conditions and included an additional storm surge. All water levels were referenced to NAVD88.

The test schedule is shown in **Table 2**. These include different conditions simulated for both Series A and Series B.

Table 2: Model test conditions

	Test ID	Return Period (yr)	Water Level (m NAVD88)	Hm0 (m)	Tp (s)	Duration (Hrs)	Design aspect verification
Series A							
	A1	1	4.57	0.90	3.69	10	Rock stability (slope and toe) Wave overtopping
	A2	10	4.83	1.44	4.10	10	
	A3	50	4.99	1.87	4.46	10	
	A4	100	2.03	2.07	4.71	10	
	A4B	100	-3.66	1.50	4.05	10	
	A5	100	5.05	2.07	4.71	10	
Series B							
	B1	1	4.57	0.90	3.69	10	Rock stability (slope and toe) Wave overtopping
	B5	100	5.05	2.07	4.71	10	
	B6	100*	5.55	2.28	4.71	10	

Note(*): Overload condition

The wave measurements recorded during testing are included in **Appendix A**. It should be noted that wave condition A4B was not calibrated prior to the start of testing.

2.2.7. Stability analysis

Rock displacements were tracked and quantified using the image-overlay flicker technique. This technique checks for displacements by comparing photographs taken before and after each test. To limit any shifts or changes between the before and after photos, each camera was set up on a tripod and triggered remotely to avoid any unnecessary handling. Four digital cameras were used to capture all areas of the test structure. Each camera was set up overlooking the structure at an angle that was nearly perpendicular to the test slope to achieve an orthogonal view of the structure slopes.

Rock movements are classified according to its magnitude. Only full displacements are considered as damage, which include those where rock was shifted a distance greater than D_{n50} regardless of whether it remained on the slope or not. Rocks that were dislodged from the slope were identified and its migration was tracked to prevent double counting of full displacements in subsequent tests. The classification used to quantify rock displacements is given in **Table 3**.

Table 3: Rock displacement (*X*) classification

Classification	Displacement	Damage description
1	$\frac{1}{4} D_{n50} < X < \frac{1}{2} D_{n50}$	Settlement
2	$\frac{1}{2} D_{n50} < X < D_{n50}$	Rocking / flipping over
3	$X > D_{n50}$	Full displacement (rock remains on slope or unit lost from slope)

By quantifying the rock displacement at the end of each test, it can then be defined as percentage damage (*D%*) sustained after a typical storm. This represents the number of rocks that were displaced from the armour layer (Class 3 displacements) divided by the total number of rocks in that section. The percentage damage is defined as shown in **Equation 1**.

Percentage damage: $$D\% = \frac{\textit{Number of stones displaced over a distance greater than } D_{n50}}{\textit{Total number of stones at that section}} \qquad (1)$$

The breakwater surface was split into multiple zones, which allows areas of interest to be identified based on the amount of damage observed. Separation lines were mainly drawn to identify the main slope, roundhead, rear slope and toe. The different zones are shown in **Figure 5**.

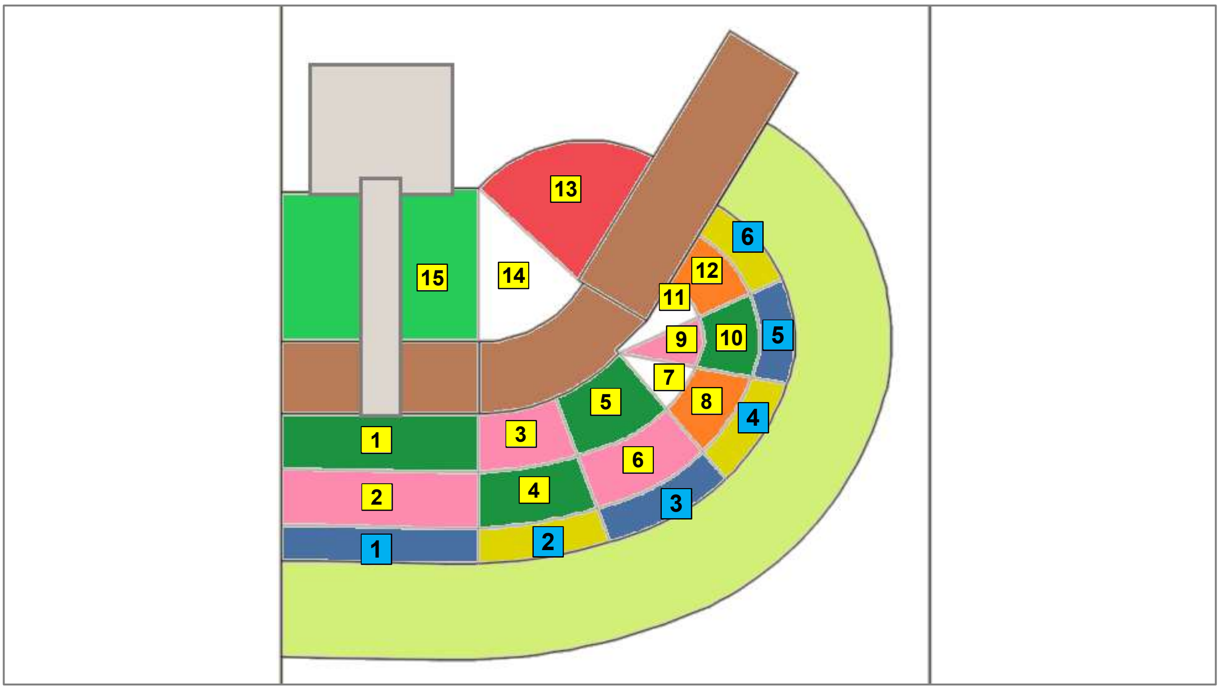


Figure 5: Structure separation zones

All test images are included in **Appendix B**, while the zones for each series defined during the post-test analysis are shown in **Appendix C**.

2.2.8. Wave overtopping

Wave overtopping was measured at the breakwater trunk section at STA_15+30, which is located immediately before the start of the breakwater bend. An overtopping chute, measuring 274 mm in width (5.48 m prototype), was fitted immediately behind the seaward parapet wall to collect wave overtopping.

The overtopping collection bin was placed at the rear of the breakwater and was fitted with a needle gauge to measure the total accumulated overtopping. A single wave probe was also placed inside the overtopping bin to collect data on individual wave overtopping events. The probe data would also allow the measurement and verification of the total overtopping per test. The location of the overtopping measurement setup is shown in **Figure 3**.

The data from the probe that was located inside the overtopping bin were analysed using the O/T-Track software, which was developed by the CSIR. This allowed the identification and quantification of individual overtopping events, as well as to determine its corresponding overtopping volumes. The total overtopping measurements for each test were converted to average overtopping rates in litre per second per metre (l/s/m). This was quantified for the full 134 minute (10-hour prototype) test duration.

3. MODEL TESTING AND RESULTS

On completion of this study, a total of two test series were successfully completed. This comprised verifying the stability of two different armour layer rock sizes for the same rubble mound structure. Each test series included different test conditions to verify the behaviour of the rock material.

3.1. Test Series A

3.1.1. Armour and toe rock stability

This section describes the stability and behaviour of the armour layer and toe at different parts of the model test structure. This included observations for the trunk and trunk transition, the roundhead and the rear slope. The before and after images of all tests are included in **Appendix B**.

Trunk and trunk transition

The trunk and trunk transition made up the largest portion of the seaward slope. This section was completely exposed to the approaching waves, where the trunk was also orientated perpendicular to the direction of wave approach. The design comprised 1-3 t rock for the main armour and the toe, while the underlayer comprised 300-1000 kg rock.

Rock displacements were mainly focussed near the still water level, thus movement on the armour layer varied as the water level was increased or decreased. Testing of the lowest water level of -3.66 m NAVD88, however, resulted in no observable rock displacements and the relative damage remained zero during this test. As can be expected, the greatest number of rock displacements were recorded during the high water 1:100 yr storm condition (Test A5).

The condition of the trunk and trunk transition before and after Test Series A is shown in **Figure 6** and **Figure 7**.

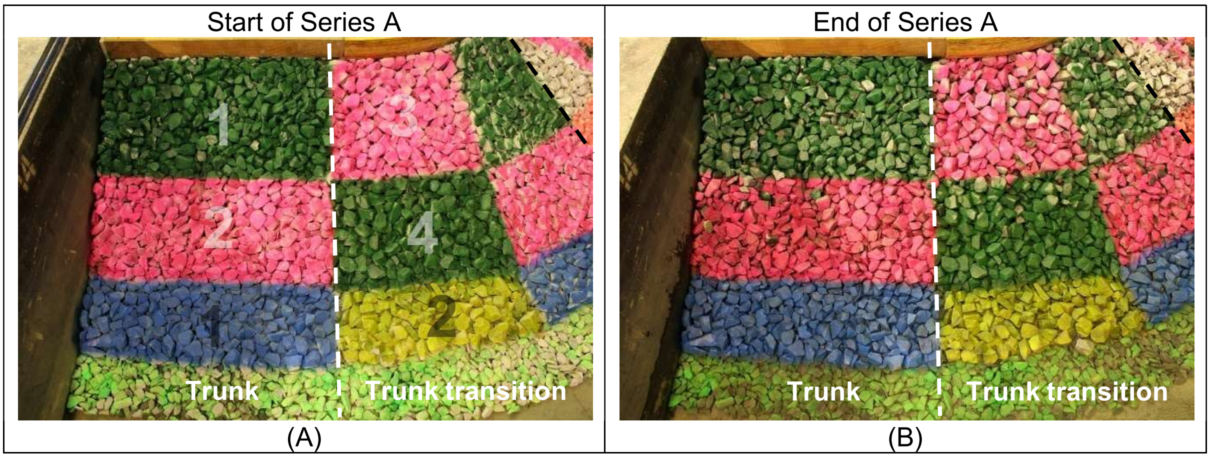


Figure 6: Series A - Trunk and trunk transition

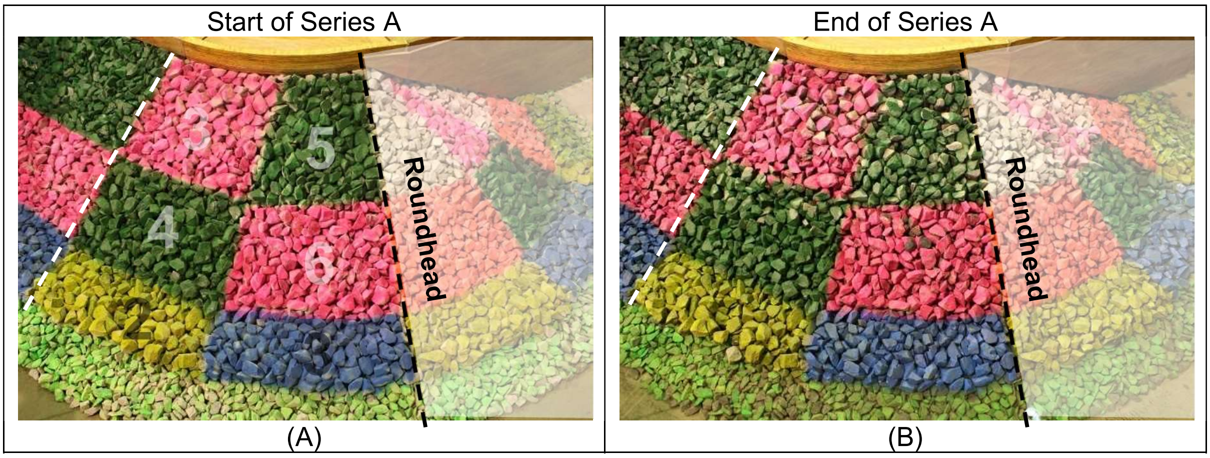


Figure 7: Series A - Trunk transition

By the end of the test series, the greatest number of rock displacements recorded for the armour layer were at Zone 5 (see **Figure 7**), where the cumulative damage was *D%* = 6.25%. The toe rock sustained negligible displacements, where the cumulative damage was *D%* = 0.57% for the most critically affected area (Zone 2).

The damage summary for the trunk sections is presented in **Table 4**.

Table 4: Series A – Damage summary for trunk sections

	Zone	Damage (*D%*) recorded after test						Cumulative
		A1	A2	A3	A4	A4B	A5	
Armour slope	1	0.38%	0.38%	0.76%	0.57%	0%	0.76%	2.85%
	2	0%	0%	0%	0.50%	0%	0%	0.50%
	3	0%	0.38%	0.38%	0%	0%	3.03%	3.79%
	4	0%	0%	0%	0.69%	0%	0%	0.69%
	5	0%	0.96%	0.96%	0.96%	0%	3.37%	6.25%
	6	0%	0%	0%	0.83%	0%	0%	0.83%
Toe	1	0%	0%	0%	0%	0%	0%	0%
	2	0%	0%	0%	0.57%	0%	0%	0.57%
	3	0%	0%	0%	0%	0%	0%	0%

The damage values shown in **Table 4** correspond to that of the Damage Tables for Camera 01 and 02 included in **Appendix D**.

Roundhead

Since the breakwater design included a combi wall with a wave screen that extended from the rubble mound roundhead, only about half of the rock on the roundhead was exposed to direct wave attack. The design comprised a continuation of 1-3 t rock for the roundhead armour layer and toe, while the same underlayer rock was also used as for the trunk sections.

Similar to the trunk sections, rock displacements were mainly focussed near the still water level, however for the roundhead, the greatest number of rock displacements were recorded during the low water 1:100 yr storm condition (Test A4). Test A4B comprising the lowest water level of -3.66 m NAVD88 resulted in no observable rock movements.

The condition of the roundhead before and after Test Series A is shown in **Figure 8**.

Start of Series A	End of Series A
(A)	(B)

Figure 8: Series A - Roundhead

By the end of the test series, the greatest number of rock displacements recorded for the armour layer were at zones 7 and 8, where the cumulative damage was *D%* = 2.11% and 4.44% respectively. The toe rock sustained no observable movements, thus *D%* remained zero.

The damage summary for the roundhead sections is presented in **Table 5**.

Table 5: Series A – Damage summary for roundhead sections

	Zone	Damage (*D%*) recorded after test						Cumulative
		A1	A2	A3	A4	A4B	A5	
Armour slope	7	0%	0%	0.7%	1.41%	0%	0%	2.11%
	8	0%	0%	0%	0%	0%	0%	0%
	9	0%	0%	0%	4.44%	0%	0%	4.44%
	10	0%	0%	0%	0%	0%	0%	0%
	11	0%	0%	0%	0%	0%	0%	0%
	12	0%	0%	0%	0%	0%	0%	0%
Toe	4	0%	0%	0%	0%	0%	0%	0%
	5	0%	0%	0%	0%	0%	0%	0%
	6	0%	0%	0%	0%	0%	0%	0%

The damage values presented in **Table 5** correspond to that of the Damage Tables for Camera 03 included in **Appendix D**.

Rear slope

The rear sections of the breakwater included part of the roundhead, the trunk and a transition section, and comprised a continuation of the same rock as used on the seaward slopes. Since the combi wall and wave screen protected the rear part of the roundhead, no portion of the rear slope was exposed to direct wave attack.

The rear slopes were well protected and nearly all rocks remained completely still. Some negligeable rock movements were observed at the top corner of the rear roundhead and transition, however these small shifts were noticed during the initial, less severe storm conditions (Test A2 and A3) and can thus be regarded as part of the initial settlement of the structure. This suggestion is further supported since no rock movements were observed at the rear slope during any of the more severe 1:100 yr storm conditions.

The condition of the rear slope before and after Test Series A is shown in **Figure 9**.

Start of Series A	End of Series A
	
(A)	(B)

Figure 9: Series A – Rear slope

No significant movements were recorded at the rear slopes, therefore *D%* for all areas remained zero. The damage summary for the rear sections is shown in **Table 6**.

Table 6: Series A – Damage summary for rear sections

	Zone	**Damage (*D%*) recorded after test**						**Cumulative**
		A1	**A2**	**A3**	**A4**	**A4B**	**A5**	
Slope	13	0%	0%	0%	0%	0%	0%	0%
	14	0%	0%	0%	0%	0%	0%	0%
	15	0%	0%	0%	0%	0%	0%	0%

The damage values shown in **Table 6** correspond to that of the Damage Tables for Camera 04 included in **Appendix D**.

3.1.2. Overtopping measurements

Wave overtopping was measured using the setup as described in **Section 2.2.8**. It is worth noting that during Test Series A, no significant wave overtopping events were observed visually. The wave overtopping collected was mainly as a result of wave splash, which merely caused a constant trickle of water into the overtopping collection bin. This was also confirmed from the data collected by the wave probe inside the bin, since no significant peaks in water level increase could be identified.

A summary of the average overtopping rates recorded during Series A is provided in **Table 7**.

Table 7: Series A - Wave overtopping measurements

Test ID	Water Level	Target H_s	Target T_p	Total overtopping (Litre)	Rate of overtopping (l/s/m)
A01	4.57	0.90	3.69	220	0.001
A02	4.83	1.44	4.10	10 117	0.051
A03	4.99	1.87	4.46	67 292	0.341
A04	2.03	2.07	4.71	174.4	0.001
A04B	-3.66	1.50	4.05	-	0.000
A05	5.05	2.07	4.71	114 616	0.581

No individual wave overtopping events were identified; therefore, no data could be presented on single events.

3.2. Test Series B

3.2.1. Armour and toe rock stability

Subsequent to the completion of Test Series A, the rock size for the breakwater armour and toe rock was reduced from 1-3 t to 600-1900 kg, while the underlayer rock size was reduced from 300-1000 kg to 60-300 kg. The breakwater core material remained unchanged at 5-40 kg.

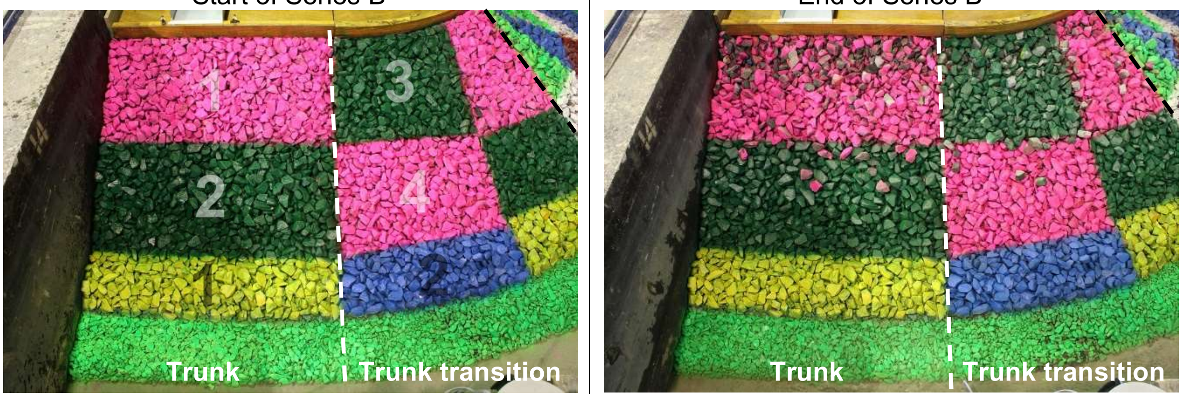
This section describes the stability and behaviour of the armour and toe rock at different parts of the model test structure. Similar to Test Series A, this mainly included observations for the trunk and trunk transition, the roundhead and the rear slope. The test images are included in **Appendix B**.

Trunk and trunk transition

Similar to Series A, rock displacements were mainly focussed near the still water level. For Series B, however, only high water conditions were tested, thus damage to the armour layer was mainly concentrated around the upper slopes. As can be expected, the greatest number of rock displacements were recorded during the hight water overload storm condition (Test B6).

The trunk and trunk transition before and after Test Series B is shown in **Figure 10** and **Figure 11**.

Start of Series B | End of Series B



(A) | (B)

Figure 10: Series B - Trunk and trunk transition

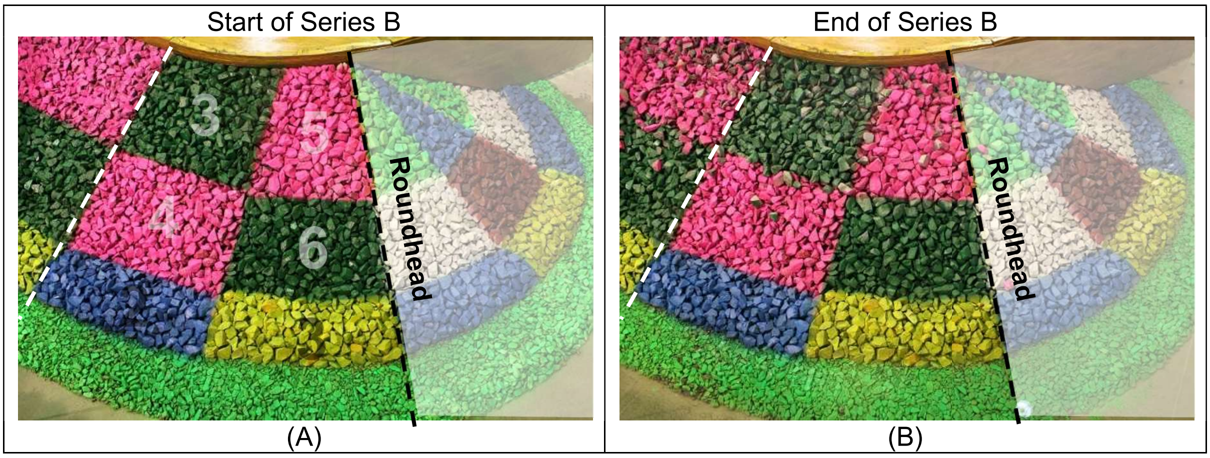


Figure 11: Series B - Trunk transition

The greatest number of armour rock displacements were recorded at Zone 1 (see **Figure** 10) and by the end of the test series, the cumulative damage to this section was *D%* = 10.63%. The rock toe had negligible displacements and thus the cumulative damage remained zero for all toe sections.

The damage summary for the trunk sections is presented in **Table 8**.

Table 8: Series B – Damage summary for trunk sections

	Zone	Damage (*D%*) recorded after test			Cumulative
		B1	B5	B6	
Armour slope	1	0.57%	3.59%	6.47%	10.63%
	2	0%	0%	0.14%	0.14%
	3	0%	0%	5.68%	5.68%
	4	0%	0%	0%	0%
	5	0%	1.45%	2.03%	3.49%
	6	0%	0%	0%	0%
Toe	1	0%	0%	0%	0%
	2	0%	0%	0%	0%
	3	0%	0%	0%	0%

The damage values presented in **Table 8** correspond to that of the Damage Tables for Camera 01 and 02 included in **Appendix D**.

Roundhead

Similar to the trunk sections, the only design changes that were made to the roundhead were the resizing of the rock material. The combi wall design remained unchanged and still provided protection to a large portion of the rubble mound roundhead.

As before, rock displacements were mainly focussed near the still water level, however since only high water conditions were tested, rock displacements were observed mainly on the upper slopes. The greatest number of displacements were recorded during the overload storm condition (Test B6).

The condition of the roundhead before and after Test Series B is shown in **Figure 12**.

Start of Series B | End of Series B

(A) | (B)

Figure 12: Series B - Roundhead

The greatest number of rock displacements were recorded at Section 11, where the cumulative damage was *D%* = 4.48%, closely followed by *D%* = 3.47% for the adjacent section. The rock toe sustained no observable movements, thus *D%* remained zero.

The damage summary for the roundhead sections is presented in **Table 9**.

Table 9: Series B – Damage summary for roundhead sections

	Zone	Damage (*D%*) recorded after test			Cumulative
		B1	B5	B6	
Armour slope	7	0%	0%	0%	0%
	8	0%	0%	0%	0%
	9	0.69%	0.68%	2.08%	3.47%
	10	0%	0%	0%	0%
	11	0%	2.99%	1.49%	4.48%
	12	0%	0%	0%	0%
Toe	4	0%	0%	0%	0%
	5	0%	0%	0%	0%
	6	0%	0%	0%	0%

The damage values presented in **Table 9** correspond to that of the Damage Tables for Camera 03 included in **Appendix D**.

Rear slope

Similar to Test Series A, the rear slopes remained mostly protected from direct wave attack and nearly all rocks remained completely still. Some negligeable rock movements were observed at the top of the slope, however these minor movements were too small to be considered as damage. *D%* for the rear slopes therefore remained zero for Series B.

The condition of the rear slope before and after Test Series B is shown in **Figure 13**.

Start of Series B	End of Series B
	
(A)	(B)

Figure 13: Series B – Rear slope

The lack of wave overtopping also aided the preservation of the rear slopes. The damage summary for the rear sections is presented in **Table 10**.

Table 10: Series B – Damage summary for rear sections

	Zone	Damage (*D%*) recorded after test			Cumulative
		B1	B5	B6	
Slope	1	0%	0%	0%	0%
	2	0%	0%	0%	0%
	3	0%	0%	0%	0%

The damage values presented in **Table 10** correspond to that of the Damage Tables for Camera 04 included in **Appendix D**.

3.2.2. Overtopping measurements

It is worth noting that, similar to Test Series A, no significant wave overtopping events were observed visually during Test Series B. The wave overtopping was mainly as a result of wave splash, which was also confirmed from the wave probe data since no significant peaks in water level increase could be identified.

A summary of the average overtopping rates recorded during Series B is provided in **Table 11**.

Table 11: Series B - Wave overtopping measurements

Test ID	Water Level	Target H_s	Target T_p	Total overtopping (Litre)	Rate of overtopping (l/s/m)
B01	4.57	0.90	3.69	2 535	0.013
B05	5.05	2.07	4.71	579 508	2.937
B06	5.55	2.28	4.71	1 064 380	5.395

No individual wave overtopping events were identified; therefore, no data could be presented on single events.

4. SUMMARY AND CONCLUSIONS

A 2D physical model study was commissioned at the CSIR to evaluate the performance and behaviour of key components of the new Lubec breakwater design. The objectives of this study included the verification of the rock armour stability, toe stability, assessing the interaction between the rubble mound and the combi wall structures, and quantifying the wave overtopping at the trunk.

Testing of two structures were successfully completed by the end of this study. The stability trends were similar for both structures, which indicated that damage occurred mainly around the still water level and that damage would increase as the wave heights were increased. The overall damage to Structure B were, however greater than that of structure A, where the maximum cumulative damage percentage (*D%*) recorded were 10.6% and 6.25% respectively. This was somewhat expected since the size of the armour rock for Structure B (M_{50} = 1.25 t) was about 40% lighter than that of Structure A (M_{50} = 2.0 t). A different combination of wave conditions was however simulated for each structure, which should be taken into consideration in the final engineering assessment.

No adverse interactions between the rubble mound and combi wall structures were observed, since the rock displacements adjacent to the wave screen were of the same magnitude as those recorded at the trunk. Other factors such as the water level, significant wave height and rock size had far greater effect on the overall stability.

The rear slopes on the harbour side of the breakwater remained completely protected from direct wave attack. This included a critical part of the breakwater roundhead, which was located in the lee of the combi wall and wave screen. As a result, the recorded damage to the rear slopes for both structures remained zero. This positive outcome does allow for some potential optimisation of the rear where, for instance, the rock size could be further reduced, or the design could include a steeper rear slope.

The wave overtopping results remained reasonably low for both structures, where the average rate of overtopping for the 1:100 yr high water design condition was 0.58 l/s/m and 2.94 l/s/m for structure A and B respectively. The higher overtopping rates for Structure B was anticipated, since the elevation of the seaward parapet wall was reduced by 2 ft (0.61 m). The highest overtopping rate of 5.4 l/s/m was recorded for Structure B during the 10% overload condition.

APPENDIX A – WAVE RESULTS

APPENDIX B – TEST IMAGES

APPENDIX C – ZONES FOR STABILITY ANALYSIS

APPENDIX D – DAMAGE TABLES

APPENDIX E – MODEL IMPLEMENTATION

APPENDIX F – ROCK GRADING CURVES

APPENDIX G – TYPICAL CROSS-SECTION

DRAFT
DATA REPORT

Lubec, ME Breakwater Current and Wave Collection
April 05 – May 04, 2023

Lubec Breakwater
Data Report
May 30, 2023

rpsgroup.com

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
V1	Data Report	Nathan West	Trap Puckette	Trap Puckette	5/30/2023

Approval for issue

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Contents

Figures (at end of text)

Pictures (at end of text)

Appendices

1 INTRODUCTION

RPS was contracted to install a bottom-mounted wave and current gage in support of a breakwater project in Lubec, ME. The target deployment duration was for 4 weeks at a depth of 35 ft. In addition, 6 sediment samples were taken in the area of the proposed breakwater for grain size analysis.

2 INSTRUMENTATION AND FIELD OPERATIONS

2.1 Instrumentation

A 1MHz Nortek AWAC was used to measure water column current profiles and waves. The AWAC was set to measure the water velocity profile in a series of 50-cm bins. The current profile begins at approximately 1.2 meters above bottom. Current profiles were collected at 10-minute intervals over a 2-minute period, and the average of the measurements is recorded. Each profile of recorded water velocity is referred to as an ensemble.

For wave measurements, the AWAC collects 2,048 samples at 2 Hz, over an approximately 17-minute period, once every hour. Concurrent with the water velocity and pressure measurements for wave data analysis, the AWAC also measures the water surface elevation at a rate of 4 Hz with a fourth acoustic beam oriented vertically. This feature is referred to as acoustic surface tracking (AST), and it provides improved resolution of small, high-frequency waves.

2.2 Field Operations

The AWAC was installed in an aluminum bottom mount equipped with an acoustic release system (Photograph 1). The acoustic release holds a buoy in place on the mount while the equipment is deployed. At recovery, the vessel is positioned near the deployment site and a topside deck box is used to send a coded acoustic signal to the release using a transducer lowered over the side of the vessel. Upon receiving the signal, the release opens, allowing the buoy to float to the surface bringing a recovery line with it. The recovery line is used to pull the mount up onto the vessel.

The equipment was mobilized on Wednesday April 5, 2023, and the instrument was deployed that afternoon. As part of the mobilization, the compass in the AWAC was calibrated, and the sampling parameters were uploaded into the instrument. The mount was loaded onto the vessel using the pier crane, and the vessel transited to the deployment location near Lubec. The vessel ran a series of lines across the proposed deployment location, and the data from depth sounder indicated that the bottom in the area was flat and there were no obvious obstructions. Once the conditions at the deployment site were confirmed, the mount was deployed using a slip line in 34 ft of water. Location for the instrument is 44.8584600°, -066.9984160° (State Plane 1811 769284.460mE, 114282.625mN).

Following the deployment of the bottom mount, a ponar style sampler was rigged to the winch cable on the vessel and used to collect six sediment grabs from the project area. The locations of the mount and sediment samples are provided in the table below and are shown in Figure 1.

Location	Latitude	Longitude	Date	Time UTC
AWAC	44.85846	-66.998416	04/05/2023	19:15:01
Sed 1	44.85498	-67.00078	04/05/2023	19:58:04
Sed 2	44.85589	-66.998521	04/05/2023	20:07:20
Sed 3	44.85486	-66.997284	04/05/2023	20:33:55
Sed 4	44.85714	-66.996477	04/05/2023	20:21:17
Sed 5	44.85610	-66.995059	04/05/2023	20:27:37
Sed 6	44.85767	-67.001127	04/05/2023	19:40:26

RPS returned to recover the mount on the morning of May 4, 2023. The vessel was prepped and departed the Eastport pier at 12:45 local time. The client had requested to have four personnel on the vessel for recovery operation. The team was picked up at the Lubec town pier and given a safety briefing by RPS and the captain. The vessel then proceeded to the bottom mount deployment location, and the acoustic signal was sent to the acoustic release on the mount. The recovery buoy surfaced immediately, and the mount was brought on board at 13:20 local time without incident. An inspection of the mount indicated that everything was in order, and it was confirmed that the instrument was still pinging. The team from Jacobs was dropped off in Lubec, and the vessel returned to the pier in Eastport. The vessel was demobilized, and equipment was palletized for shipping.

3 DATA PROCESSING

The recorded data was processed and reviewed to produce a standard set of data products, including plots and ASCII data files. The review of the data indicated the data set was complete and of good quality. All times provided in the data files are in UTC and a magnetic declination 15.99° west was applied to the direction, so they are all referenced to true North. A description of the parameters provided in the ASCII data files is provided in Appendix A. Additional information on the various parameters measured is provided below.

3.1 Current Data

The AWAC collects current measurements in 32 bins that are 50cm in length, which results in several bins being positioned above the water's surface. The instruments will record data for these bins even though they are out of the water, and often these data will appear reasonable. To cut the data above the water's surface, the spike in the backscatter amplitude was used to determine which bin should be considered the last good bin. In addition, the water depth measurements based on the AST were used to confirm that the correct cutoff point had been selected. Plots of the current data are provided in Appendix B. An ASCII text file of the current data (*Lubec AWAC_05Apr2023_04May2023_CurrentData_H.txt*) accompanies this report and the header of the file provides information on the data contained in the file. A second current data file (*Lubec AWAC_05Apr2023_04May2023_CurrentData_From WaveFigure.txt)* is also provided, and it includes the current data from a near surface bin, a mid-depth bin and a near bottom bin as plotted on the wave data figure discussed below. An additional thing to be noted is that the AWAC does not collect current data during the wave burst so there is no current data reported for the sample point at 10 minutes past the hour.

The current data indicate that currents at the site are tidally driven with daily maximum depth-averaged velocities typically around 35 cm/s. However, there were periods during the deployment where the current speeds varied rapidly from 10 to 20 cm/s to over 100 cm/s with rapid changes in direction during the same period. A review of the data indicates that these rapid variations in velocity and direction are related to the passage of an eddy over the instrument location. The boat captain confirmed that eddies were not uncommon in this area and that the current speed in the eddies could be quite significant.

3.2 Ancillary Data

In addition to the current and wave measurements, the instrument records additional ancillary information used in processing the data and providing an assessment of the instrument's performance. Plots of the ancillary data and data quality parameters are provided in Appendix C. As can be seen in the plots, the instrument measured significant downward vertical velocities in the near surface during the time periods when the horizontal velocities indicated that there were eddies at the site. This is consistent with what would be expected in an eddy as it would impart a downward motion in the water. The auxiliary data also indicates that the instrument orientation had no variation in pitch, roll and heading indicating that the mount was stable over the deployment. At the start of the deployment the water temperature was approximately 4.5° C and gradually increased over the deployment to 6.5° C. The backscatter data indicate that all the beams were functioning properly throughout the deployment period.

3.3 Water Level Data

For each current measurement burst, the AWAC reports the water level over the instrument based on the data from the pressure sensor. In order to adjust this water level to NAVD88, the first step was to remove any variations in the water level due to variations in the atmospheric pressure over the deployment period. This was accomplished using barometric data from the NOAA station 8410140 in Eastport approximately 2.5 miles from the site. Once the water level was corrected for barometric pressure, the average water level from the instrument was compared to the average water level measured by the tide station relative to NAVD88 to determine an offset between the AWAC water level and the tide station water level. This offset was then applied to the AWAC data to adjust the measured water level to NAVD 88. A plot of the AWAC adjusted water level relative to the NOAA station water level is provided in Appendix D. An excel file (*Lubec_WL_NAVD88 AWAC and NOAA_V1.xls*) containing the adjusted water level data from the instrument as well as NOAA tide data accompanies this report.

3.4 Wave Data

The wave data were processed using Nortek's QuickWave software using cutoff frequencies of 0.02Hz and 0.99Hz, and a step frequency of 0.01Hz. A magnetic declination of 15.99 degrees west was applied to the data to adjust the direction to True North. Plots of the time series wave data results are shown in the figures in Appendix E. An ASCII text file of the wave data (*Lubec AWAC_Apr2023_May2023_CleanWaveData_m*) accompanies this report and the header of the file provides information on the data contained in the file.

Overall, the quality of the wave data is good, and the instrument was functioning properly during the deployment. The wave data from the deployment indicates that wave conditions at the site are typically very low with only a few periods during which the wave heights exceeded 0.25 m and several periods where the wave height went to zero. These results are consistent with what would be expected given that the location where the wave gage was deployed is a confined bay with the only a limited area of open water to the north and northeast. There are periods in the time series where wave conditions were so low in amplitude that the sensor was unable to measure them due to the physical limitations of the sensor. In other instances, the sensor was able to measure a wave height, but could not resolve their direction due to their high frequency. The analysis routine for processing the data identifies wave bursts where there are issues such as the ones described above and flags the results of the analysis for that wave bursts based on the issue encountered. The flag indicator is referred to as an error code, and it is reported with the results for each burst and is included in the ASCII files for the wave data.

A description of the various error codes reported for this data set are provided below. Note that an error code can have more than one error associated with it.

The descriptions of the data flags in the data set are as follows:

Error 0 Data Good

Error 16 (Unreasonable Estimate): *If it appears that there is an unreasonable wave parameter estimate, then the burst is flagged as bad. Such estimates that would be considered unreasonable are:*

Hs > 20 meters
Tm02 > 35 seconds or Tm02 < 0.5 seconds
Tp > 50 seconds or Tp < 0.5 seconds

Error 66 (Low Pressure): *This flag indicates that there was no dynamic pressure detected in the time series, and suggests that the waves were not measurable (i.e. a constant pressure). This would occur if the instrument was deployed at a depth that is too deep to measure the waves or simply that there were no measurable waves.*

(AST Out of Bounds): *Since many of the AST estimates are based on the zero-crossing, there is a check to make certain none of these estimates are unreasonable. Estimates are limited as follows:*

H3 < 20.0 meters
H10 < 25.0 meters
Hmax < 35.0 meters
0.5 seconds < Tmean < 35.0 seconds
Tpeak < 30 seconds

Error 128 (Direction for Peak Period Out of Bounds): *This limit is applicable for directional estimation using the Maximum Likelihood Method. As the wave frequency increases, the wavelength decreases and at some wavelength there is a limit associated with the array separation distance that can unambiguously resolve wave directions. This limit is dependent on water depth and will vary as the water level varies. A check is performed to see if the wavelength associated with the peak period is too small to resolve the wave direction at this frequency. If the wavelength is too small this error code is reported.*

This is the most common error code and indicates that the directional wave information for the peak period should be disregarded. Data for the other parameters is unaffected.

Error 132 *Low signal amplitude and flag 128*

Error 144 *Both flag 16 and 128*

Error 1168 *Flag 16 and 128 and high AST data loss*

3.5 Meteorological DATA

To aid in the interpretation of the wave data, wind data for vicinity over the deployment periods has been compiled. These data include mean wind speed, peak gust speeds, wind direction, atmospheric pressure, barometric pressure, and relative humidity. These data came from NOAA Station 8410140 which is in Eastport, ME approximately 2.5 miles North of the deployment site and are provided in ASCII format along with the report (*CO-OPS_8410140_met.txt*).

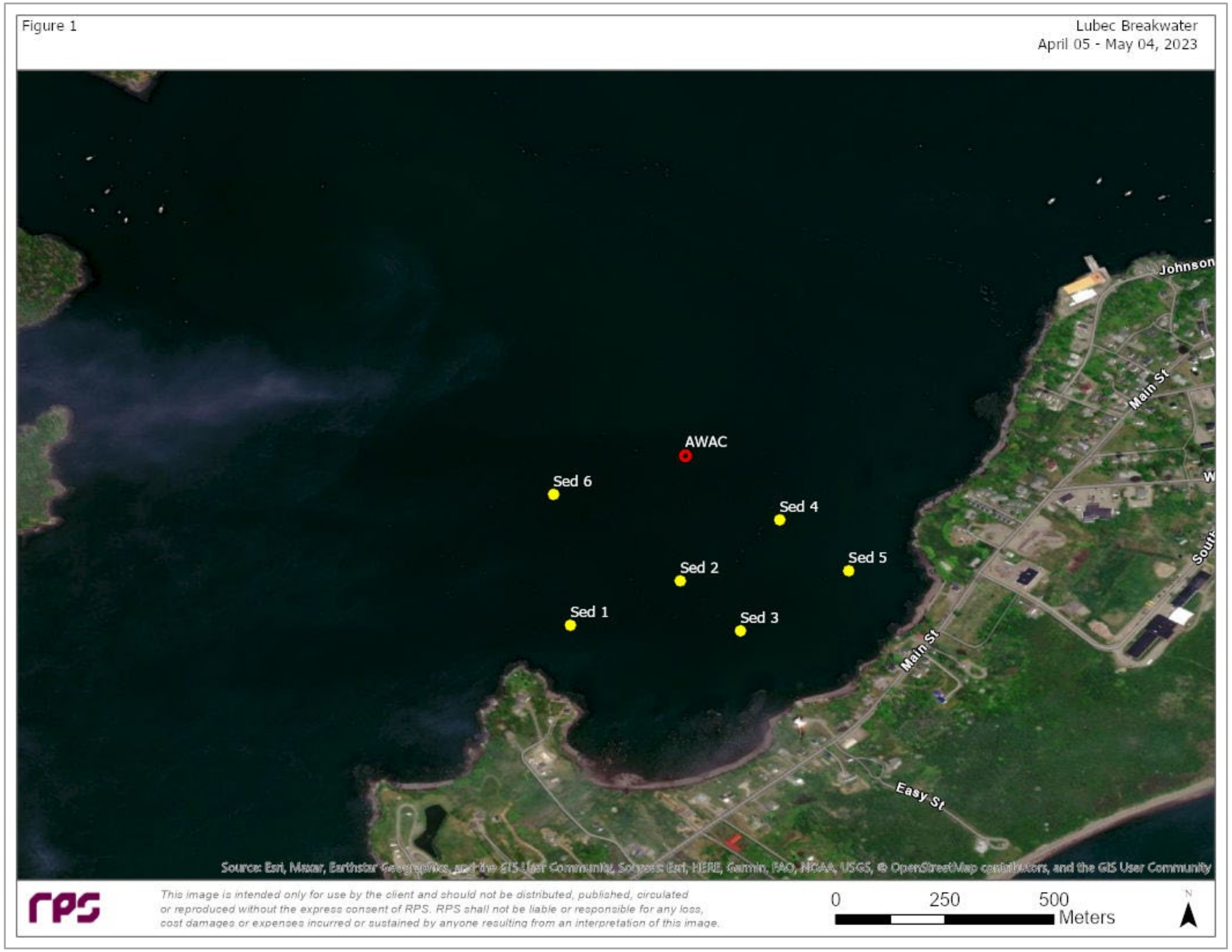
3.6 Sediment Analysis

Sediment sampling results are given in Appendix F, and a picture of each sample precedes the test results. The grain size analysis results indicate that the sediments at the site are primarily fine grain with approximately 1-2 inches of a silty fluff at the surface with the underlying sediments being a more consolidated fine grain material. The breakdown of the fines versus coarse fractions of the samples are summarized in the table below:

Location	Silts & Clays	Sand & Gravel
Sed 1	68.5%	31.5%
Sed 2	84.8%	15.2%
Sed 3	94.3%	5.7%
Sed 4	94.1%	5.9%
Sed 5	92.3%	7.7%
Sed 6	98.3%	1.7%

Figures

Figure 1: AWAC Mount and Sediment Locations



Photographs

Picture 1: AWAC in bottom mount prior to deployment

Picture 2: Ponar Style Sediment Sampler

Appendix A

Description of ASCII Data

WAVE DATA FILES

ASCII File reference	Acronym	Units	Description	Comment
Significant Wave Height	Hsig or Hm0	m	Calculated from energy spectrum. Known as Significant Wave Height, defined as the mean f the highest 1/3 of all waves in the record's ranking.	
Mean 1/3 Height	H3	m	Time series based estimate. Mean of the 1/3 largest waves in a record	Calculated using zero crossing up approach
Mean 1/10 Height	H10	m	Time series based estimate. Mean of the 1/10 largest waves in a record	Calculated using zero crossing up approach
Max Height	Hmax	m	Time series based estimate. Largest wave in a record	Calculated using zero crossing up approach
Mean Period	Tm02	s	Calculated from energy spectrum. Mean period	
Peak Period	Tp	s	Calculated from energy spectrum. Peak period of the waves corresponding to the peak frequency	
Mean Zero crossing Period	Tz	s	Time series based estimate. Mean period. This is a direct measurement unlike the spectral equivalent, Tm02	Calculated using zero crossing up approach
Peak Direction	TpDir	Deg	Calculated from energy spectrum. Peak direction is the wave direction at the frequency at which a wave energy spectrum reaches its maximum.	Adjusted to True north; direction from
Directional Spread	Spr1	Deg	Calculated from energy spectrum. Measure of the directional variance at peak frequency.	
Mean Direction	Mdir	Deg	Calculated from energy spectrum. Mean direction. Weighted average of all the directions in the wave spectrum	Adjusted to True north; direction from
Unidirectivity Index			Calculated from energy spectrum. Measure of how much of the wave energy over the full spectrum is from a single direction. Value of 1.0 indicates the energy is from one primary direction	

Mean Pressure		dbar	Mean pressure recorded over the wave burst measurement	
Water level		m unref	Water level over the wave measurement burst relative to the top of the instrument based on the pressure sensor	Referenced to the top transducer on the instrument only – no datum
No detects			Number of AST pings in a wave burst where water surface was not detected	
Bad detects			Number of AST pings in a wave burst where reported water surface distance is unrealistic.	
Current Speed (wave cell)		m/s	The current magnitude in the cell used for the wave measurement calculations	
Current Direction (wave cell)		deg	The current magnitude direction in the cell used for the wave measurement calculations	Referenced to True north; direction towards
Error Code			Numeric flag generated by the wave analysis routine to indicate any issues or limitations of the results. Listing of error codes attached.	

CURRENT DATA FILES

ASCII File reference	Acronym	Units	Description	Comment
Depth Avg Current Speed		cm/s	Current speed averaged over all good depth bins for a particular ensemble. Averaging done using vector components from each bin and then converted back to a magnitude.	
Depth Avg Current Dir		deg	Current direction averaged over all good depth bins for a particular ensemble. Averaging done using vector components from each bin and then converted back to direction in degrees	Direction referenced to True north and indicate direction current is going
Current Speed		cm/s		
Current Direction		deg		Direction referenced to True north and indicate direction current is going
Vertical Velocity		cm/s	Vertical component of current velocity	
Temperature		deg C	Water temperature as measured by the instrument	
Pressure		m	Meters of water over the instrument based on the pressure sensor. Unreferenced to a datum	This parameter actually represents the meters of water over the instrument instead of pressure but that is the nomenclature used to be consistent with other sensor systems.

FIGURES

ASCII File reference	Acronym	Units	Description	Comment
Signal Amplitude		counts	Raw backscattered signal amplitude recorded by the instrument during the current measurements	
Average vertical velocity		cm/s	Vertical component of the measured current velocity averaged over all good bins in an ensemble	
Instrument Pitch & Roll		deg	The pitch and roll of the instrument as measure by an internal sensor. Data is used to correct the beam orientation during data processing if the instrument is tilted	Instrument can correct for pitch and roll of up to 15 deg
Instrument heading		deg	Heading of the sensor based on compass in the instrument. Used to convert measurements to earth referenced values (ie to True north)	
Current magnitude at average depth		cm/s	Current measurements at different bins intended to provide a snapshot of water velocity near the surface, near mid-depth and near the bottom. Depths referenced in the plot are the average distance of the bin over the deployment below the average water level surface	
Current direction at average depth		deg	Current direction at different bins intended to provide a snapshot of water direction near the surface, near mid-depth and near the bottom. Depths referenced in the plot are the average distance of the bin over the deployment below the average water level surface	Direction is relative to True north and represents the direction towards which the current is going.

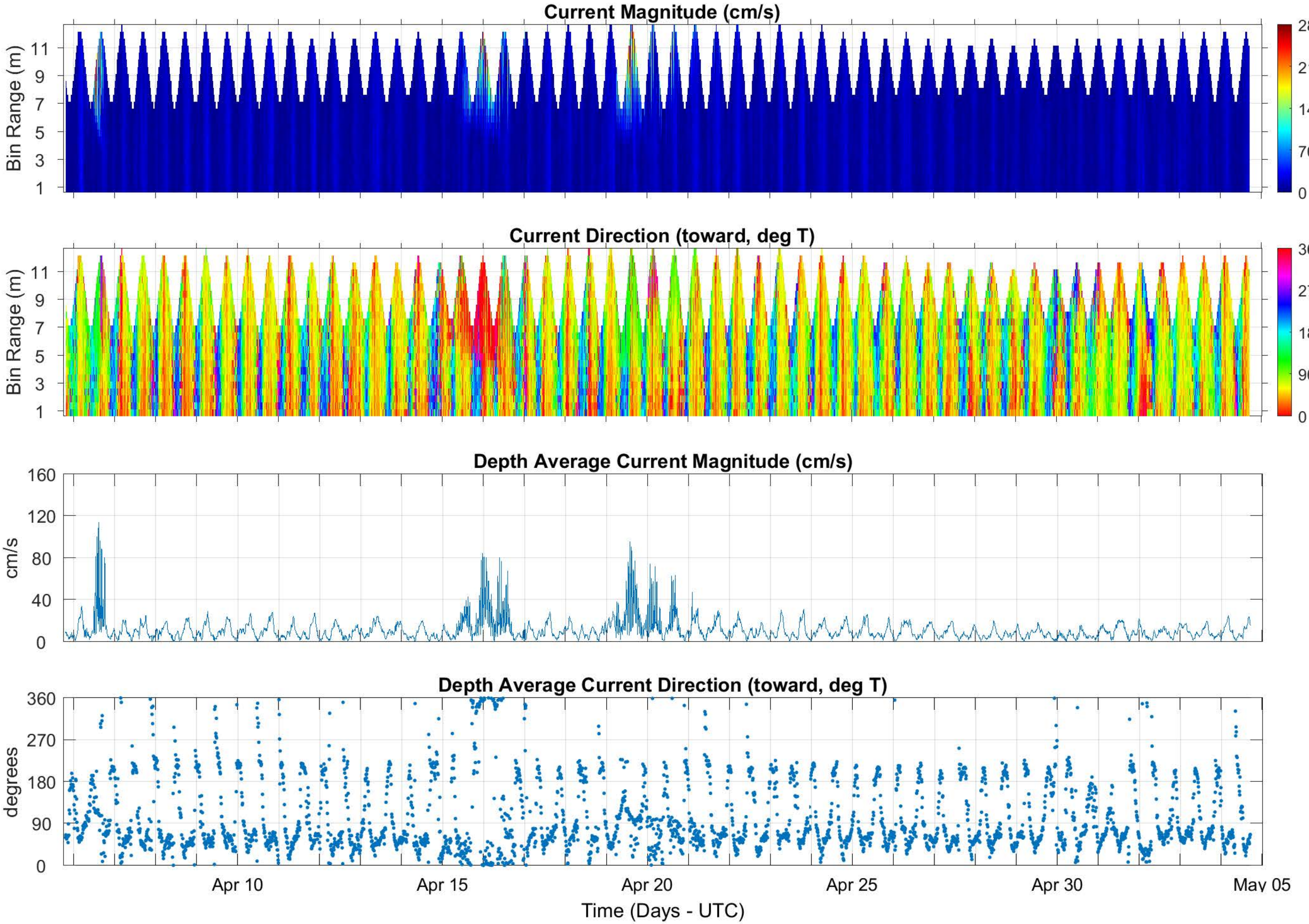
LIST OF FLAGS/ CODES FOR WAVE DATA ANALYSIS

Code 0	Good Data
Code 16	Unreasonable estimate: Hs > 20 m, Tm02 > 30 or Tm02 < 0.5 sec, Tp > 30 or TP < 0.5 sec
Code 66	AST out of bounds -AND- Low Pressure change
Code 128	Directional ambiguity (cannot resolve direction at peak period
Code 132	Directional ambiguity -AND- Low amplitude
Code 144	Directional ambiguity -AND- Unreasonable estimate
Code 1168	High AST Data Loss -AND- directional ambiguity -AND- unreasonable estimate

Appendix B

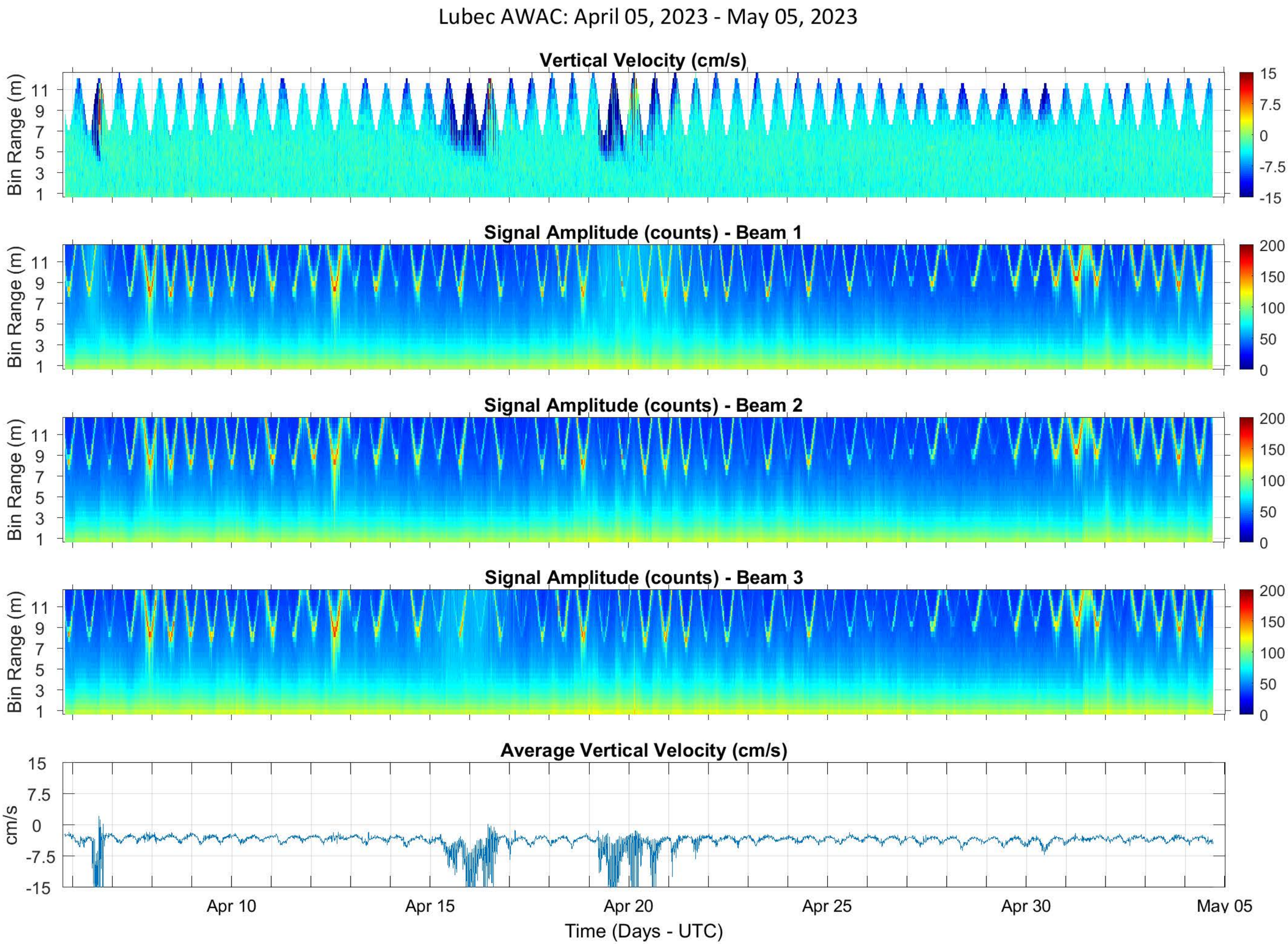
Plots of Current Data

Lubec AWAC: April 05, 2023 - May 05, 2023



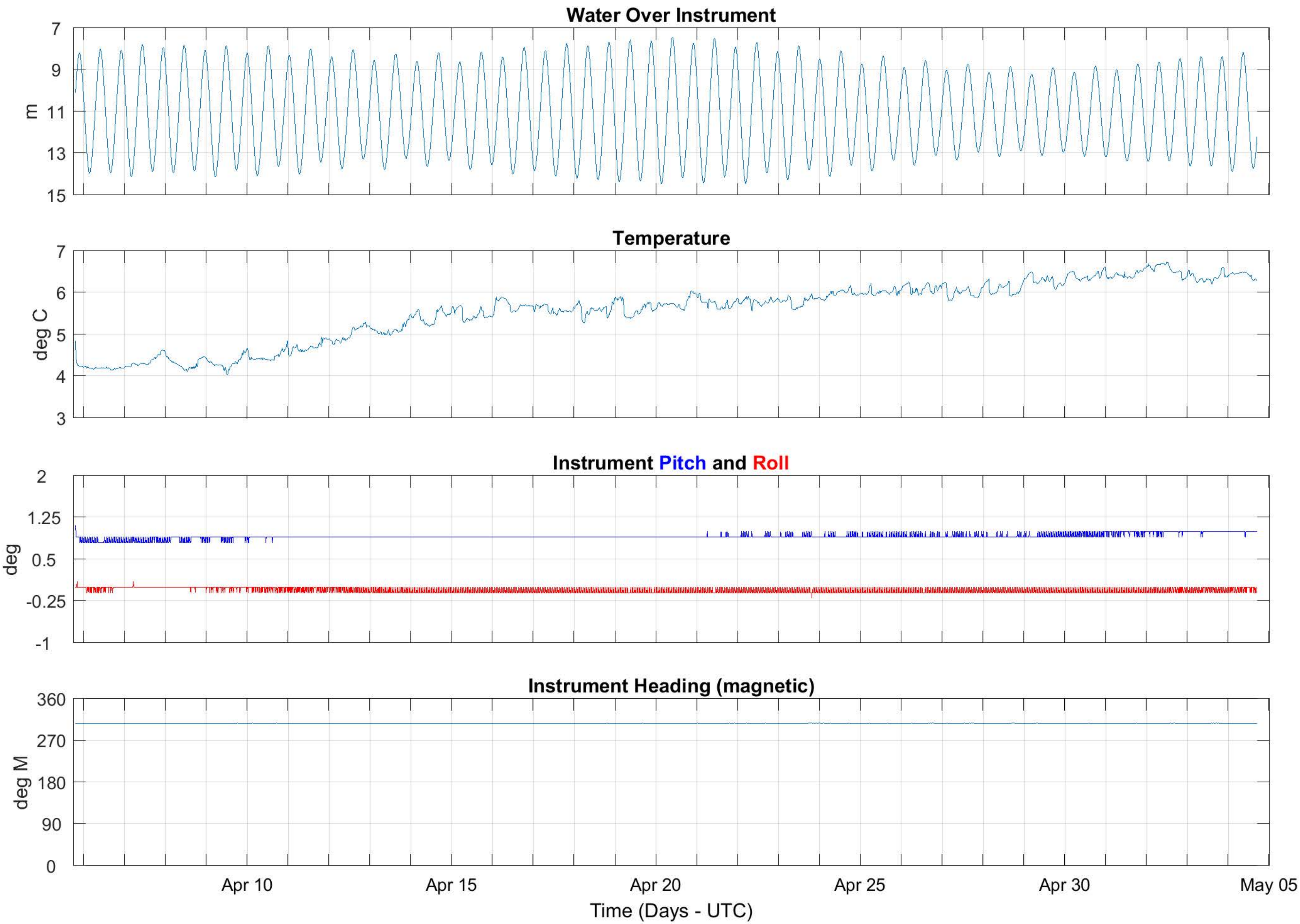
Appendix C

Plots of Data Quality Parameters and Ancillary Data



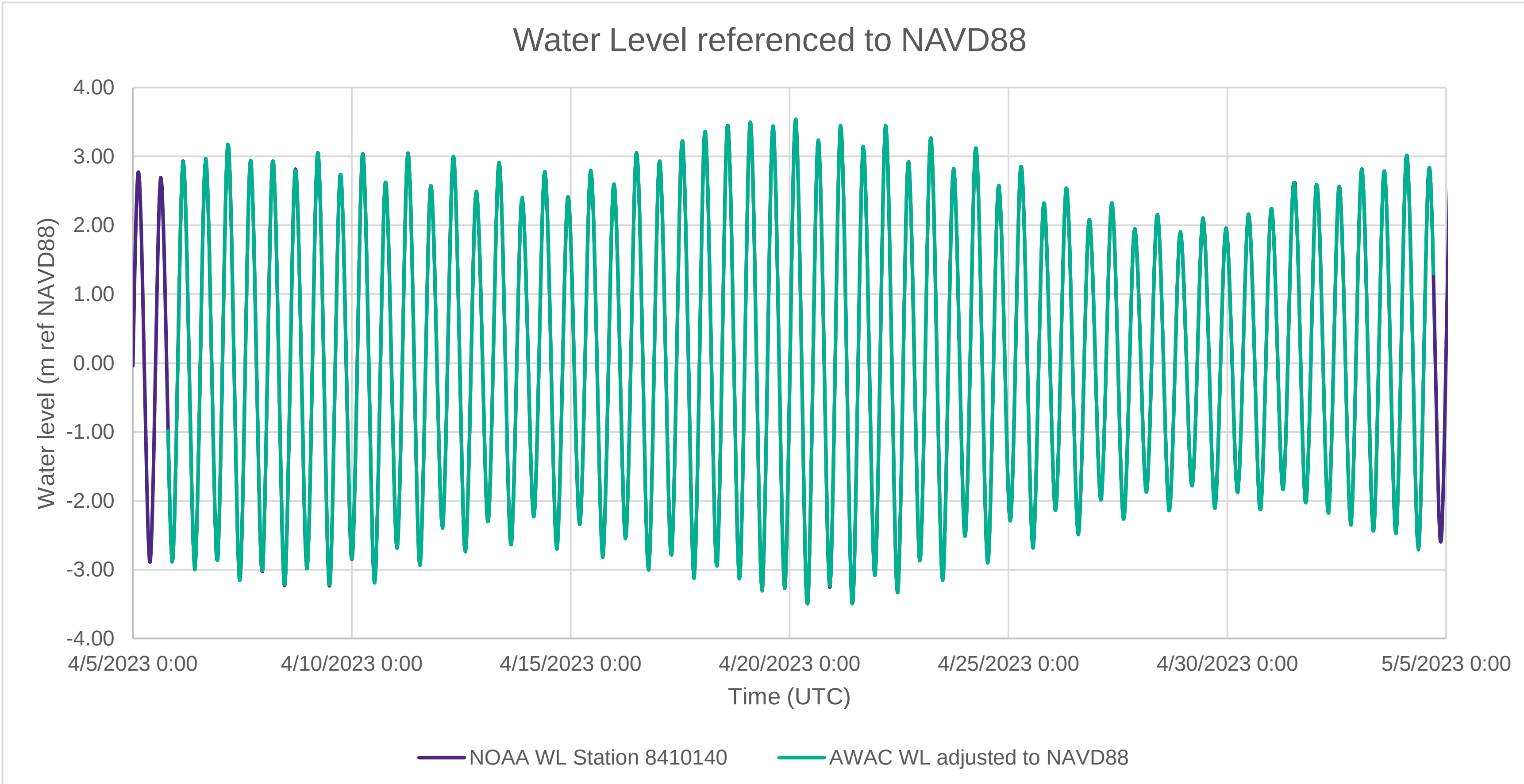
Lubec AWAC: April 05, 2023 - May 05, 2023
Vertical Velocity (cm/s)
Signal Amplitude (counts) - Beam 1
Signal Amplitude (counts) - Beam 2
Signal Amplitude (counts) - Beam 3
Average Vertical Velocity (cm/s)
Bin Range (m)
cm/s
1
3
5
7
9
11
15
7.5
0
-7.5
-15
200
150
100
50
Apr 10
Apr 15
Apr 20
Apr 25
Apr 30
May 05
Time (Days - UTC)

Lubec AWAC: April 05, 2023 - May 05, 2023



Appendix D

Plots of Water Level Data

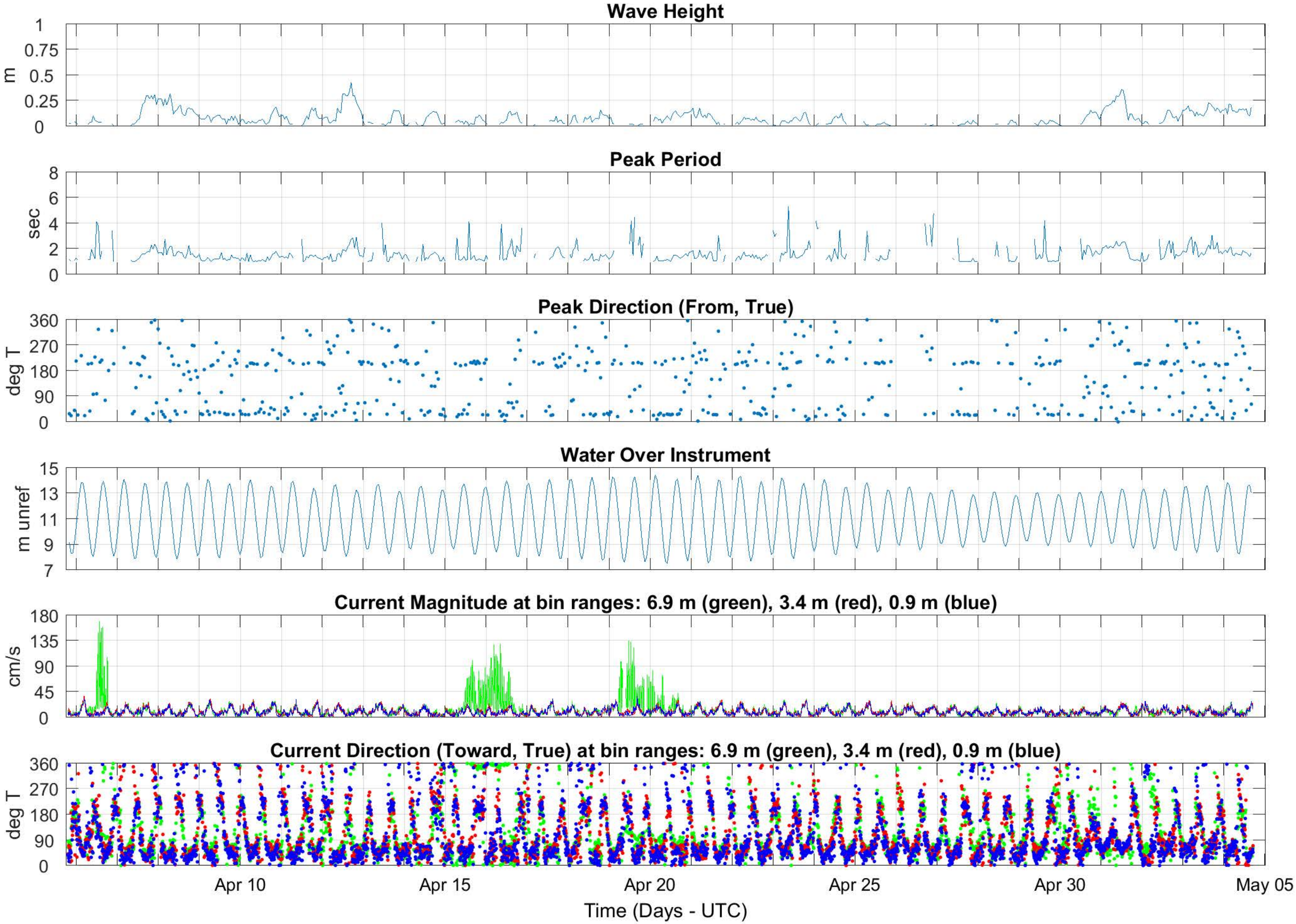


Water Level referenced to NAVD88
Water level (m ref NAVD88)
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
4/5/2023 0:00
4/10/2023 0:00
4/15/2023 0:00
4/20/2023 0:00
4/25/2023 0:00
4/30/2023 0:00
5/5/2023 0:00
Time (UTC)
NOAA WL Station 8410140
AWAC WL adjusted to NAVD88

Appendix E

Plots of Wave Data

Lubec AWAC: April 5, 2023 - May 4, 2023



Appendix F

Sediment Results and Grab Images

Sample 1

SCI
SOIL CONSULTANTS, INC.
Engineering and Testing
Since 1951

PO Drawer 698
Charleston, South Carolina 29402
P: 843.723.4539 F: 843.723.3648
www.SoilConsultantsInc.com

Construction Materials | Geotechnical | Nondestructive | Special Inspections

Acct. No: RP004 **Project No:** 221192 **Date Sampled:** 04/05/2023
Report Date: 05/01/2023 **Sampled By:** Client
Project: Lubec ME **By Order Of:** Client

Location: 04051558-SED-1 **Order Number:**

Client: RPS EVANS-HAMILTON

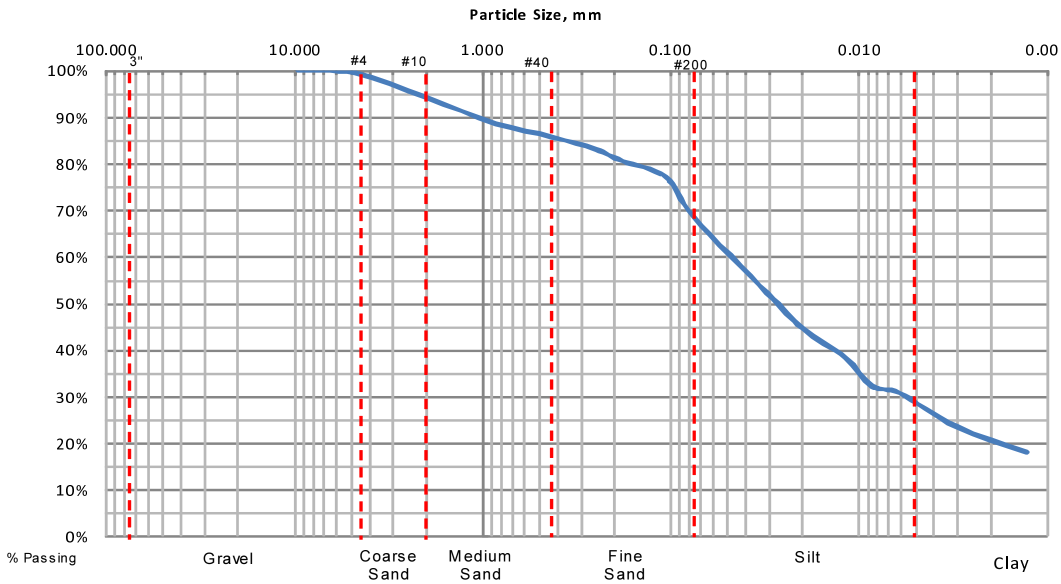
REPORT: Particle Size Distribution **LAB NO:** 82162-1

TEST RESULTS **Report No:** 82162-1
Page 1 of 1

Sample Identification		
SED-1		
Sieve	Size, mm	% Passing
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.	9.5	100
No. 4	4.75	99
No. 10	2.00	94
No. 20	0.85	89
No. 40	0.425	86
No. 60	0.25	83
No. 80	0.18	81
No. 140	0.106	77
No. 200	0.075	68.5

Material	%
Gravel	0.5
Total Sand	31.0
Coarse Sand	5.3
Medium Sand	8.5
Fine Sand	17.2
Silt and Clay	68.5
Silt size	40.3
Clay	11.2
Colloids	17.0

Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)



Max Particle Size, mm	4.75
Dispersion	Mechanical stirrer /1 min
Specfic Gravity	2.68 (estimated)

Visual Classification	
	Sandy Lean Clay

Test Method (As Applicable): ASTM D422

Orig: RPS EVANS-HAMILTON Attn: Mr. Trap Puckette
E-Mail: trap.puckette@rpsgroup.com
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Respectfully Submitted,
SOIL CONSULTANTS, INC.

AASHTO ACCREDITED

Audrey D. Chubb
Audrey Chubb
CMT Manager

Sample 2

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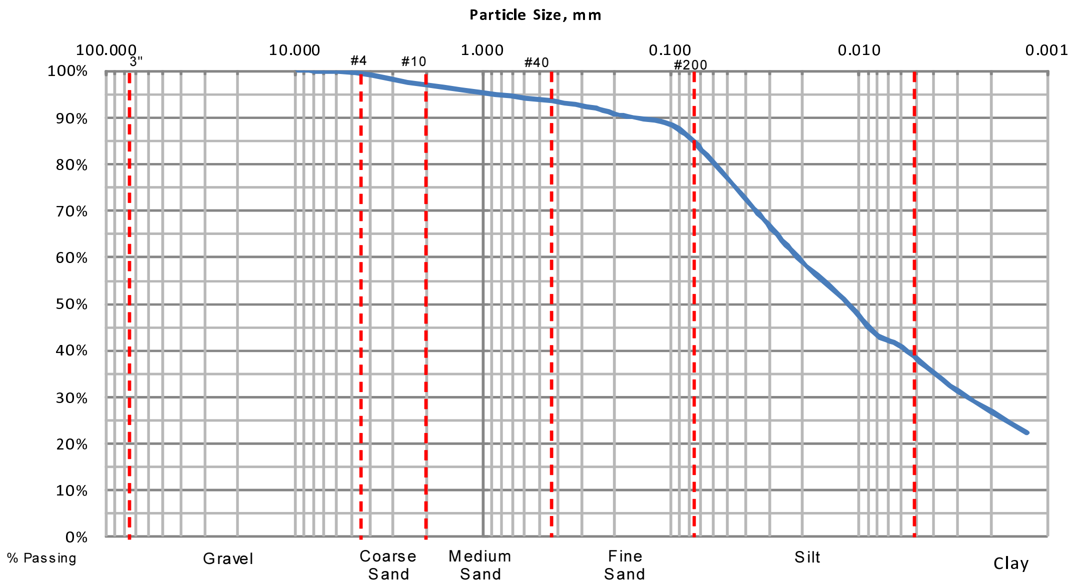
Acct. No:	**RP004**	**Project No: 221192**	**Date Sampled:** **04/05/2023**
Report Date:	**05/01/2023**		**Sampled By:** **Client**
Project:	**Lubec ME**		**By Order Of:** **Client**
Location:	**04051607-SED-2**		**Order Number:**
Client:	**RPS EVANS-HAMILTON**		
REPORT:	**Particle Size Distribution**		**LAB NO:** **82162-2**

TEST RESULTS

Report No: **82162-2**

Sample Identification		
SED-2		
Sieve	**Size, mm**	**% Passing**
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.	9.5	100
No. 4	4.75	100
No. 10	2.00	97
No. 20	0.85	95
No. 40	0.425	93
No. 60	0.25	92
No. 80	0.18	90
No. 140	0.106	89
No. 200	0.075	84.8

Material		**%**
Gravel		0.4
Total Sand		14.8
Coarse Sand		2.7
Medium Sand		3.4
Fine Sand		8.7
Silt and Clay		84.8
Silt size		46.8
Clay		16.2
Colloids		21.8
Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)



Max Particle Size, mm	4.75
Dispersion	Mechanical stirrer /1 min
Specfic Gravity	2.68 (estimated)

Visual Classification	
	Lean Clay with Sand

Test Method (As Applicable): ASTM D422

Orig: RPS EVANS-HAMILTON Attn: Mr. Trap Puckette
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CMT Manager

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Acct. No: RP004 **Project No:** 221192 **Date Sampled:** 04/05/2023
Report Date: 05/01/2023 **Sampled By:** Client
Project: Lubec ME **By Order Of:** Client

Location: 04051634-SED-3 **Order Number:**

Client: RPS EVANS-HAMILTON

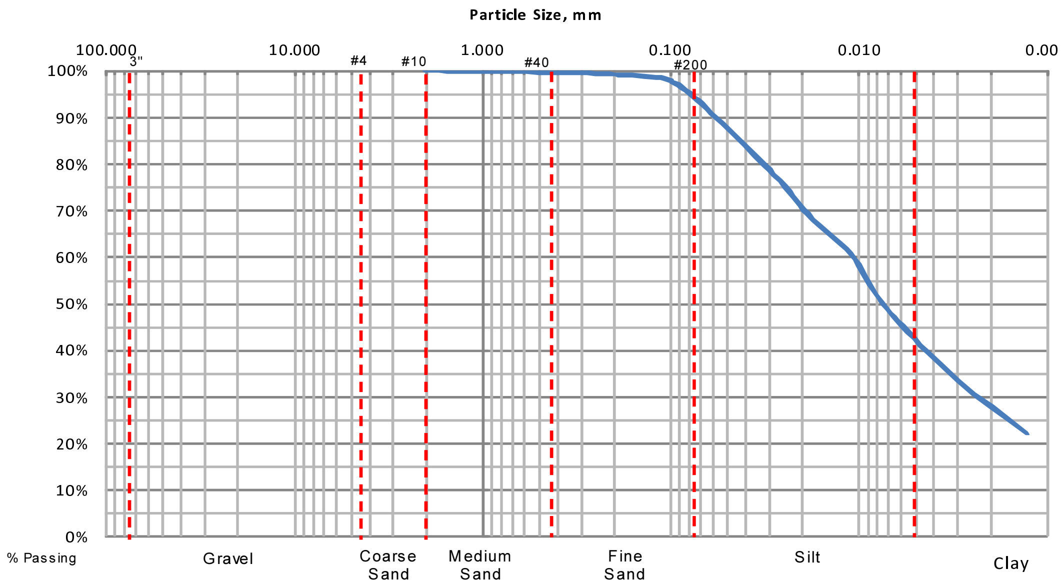
REPORT: Particle Size Distribution **LAB NO:** 82162-3

TEST RESULTS **Report No:** 82162-3
Page 1 of 1

Sample Identification		
SED-3		
Sieve	**Size, mm**	**% Passing**
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.		
No. 4		
No. 10	2.00	100
No. 20	0.85	100
No. 40	0.425	100
No. 60	0.25	99
No. 80	0.18	99
No. 140	0.106	98
No. 200	0.075	94.3

Material	%
Gravel	0.0
Total Sand	5.7
Coarse Sand	0.0
Medium Sand	0.4
Fine Sand	5.3
Silt and Clay	94.3
Silt size	52.3
Clay	22.0
Colloids	20.0

Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)



Max Particle Size, mm	0.85
Dispersion	Mechanical stirrer /1 min
Specfic Gravity	2.68 (estimated)

Visual Classification	
	Fat Clay

Test Method (As Applicable): ASTM D422

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CMT Manager

Sample 4

SCI

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Acct. No: RP004 **Project No:** 221192 **Date Sampled:** 04/05/2023
Report Date: 05/02/2023 **Sampled By:** Client
Project: Lubec ME **By Order Of:** Client

Location: 04051620-SED-4 **Order Number:**

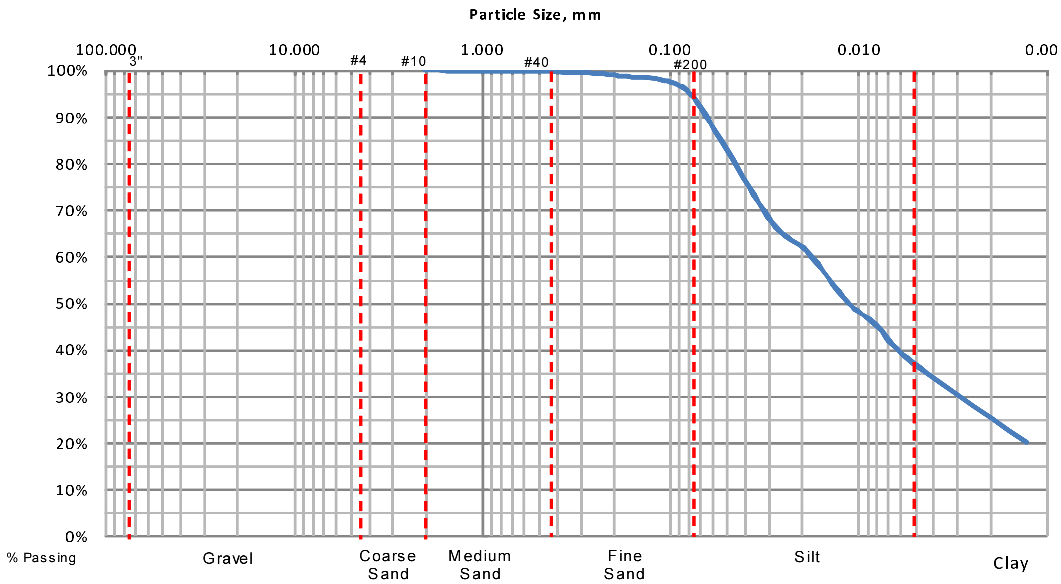
Client: RPS EVANS-HAMILTON

REPORT: Particle Size Distribution **LAB NO:** 82162-4

TEST RESULTS

Report No: 82162-4

Sample Identification		
SED-4		
Sieve	**Size, mm**	**% Passing**
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.		
No. 4		
No. 10	2.00	100
No. 20	0.85	100
No. 40	0.425	100
No. 60	0.25	99
No. 80	0.18	99
No. 140	0.106	98
No. 200	0.075	94.1



Material	%
Gravel	0.0
Total Sand	5.9
Coarse Sand	0.0
Medium Sand	0.3
Fine Sand	5.6
Silt and Clay	94.1
Silt size	57.6
Clay	17.5
Colloids	19.0

Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)

Max Particle Size, mm	0.85
Dispersion	Mechanical stirrer /1 min
Specfic Gravity	2.68 (estimated)

Visual Classification	
	Fat Clay

Test Method (As Applicable): ASTM D422

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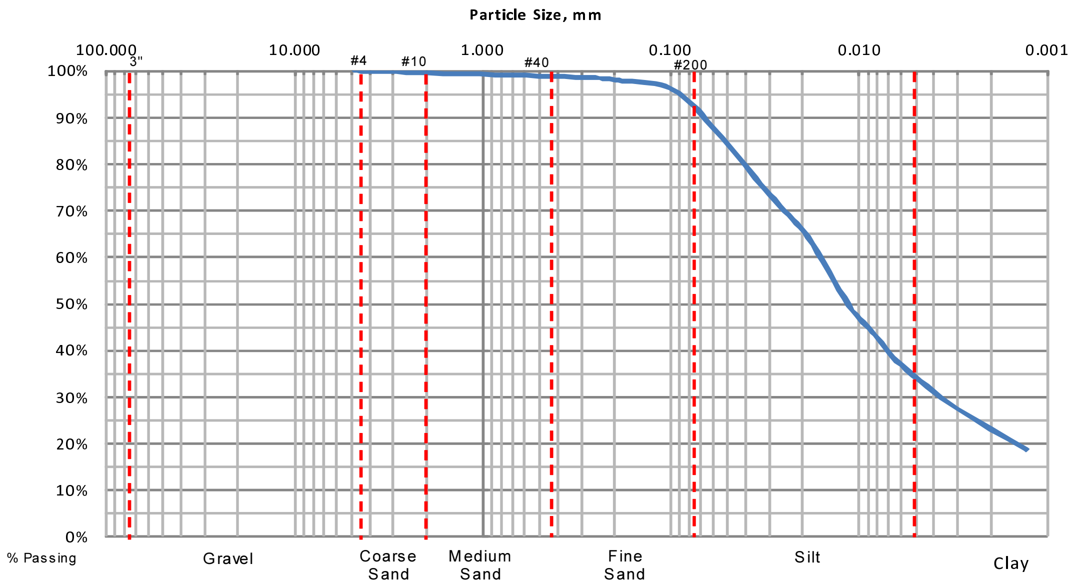
Acct. No:	RP004	Project No: 221192	Date Sampled: 04/05/2023
Report Date:	05/01/2023		Sampled By: Client
Project:	Lubec ME		By Order Of: Client
Location:	04051627-SED-5		Order Number:
Client:	RPS EVANS-HAMILTON		
REPORT:	Particle Size Distribution		LAB NO: 82162-5

TEST RESULTS

Report No: 82162-5
Page 1 of 1

Sample Identification		
SED-5		
Sieve	Size, mm	% Passing
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.		
No. 4	4.75	100
No. 10	2.00	100
No. 20	0.85	99
No. 40	0.425	99
No. 60	0.25	98
No. 80	0.18	98
No. 140	0.106	97
No. 200	0.075	92.3



Material	%
Gravel	0.0
Total Sand	7.7
Coarse Sand	0.5
Medium Sand	0.7
Fine Sand	6.5
Silt and Clay	92.3
Silt size	57.8
Clay	16.5
Colloids	18.0

Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)

Max Particle Size, mm	2
Dispersion	Mechanical stirrer /1 min
Specfic Gravity	2.68 (estimated)

Visual Classification	
	Fat Clay

Test Method (As Applicable): ASTM D422

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Acct. No: RP004 **Project No:** 221192 **Date Sampled:** 04/05/2023
Report Date: 05/01/2023 **Sampled By:** Client
Project: Lubec ME **By Order Of:** Client

Location: 451540-SED-6 **Order Number:**

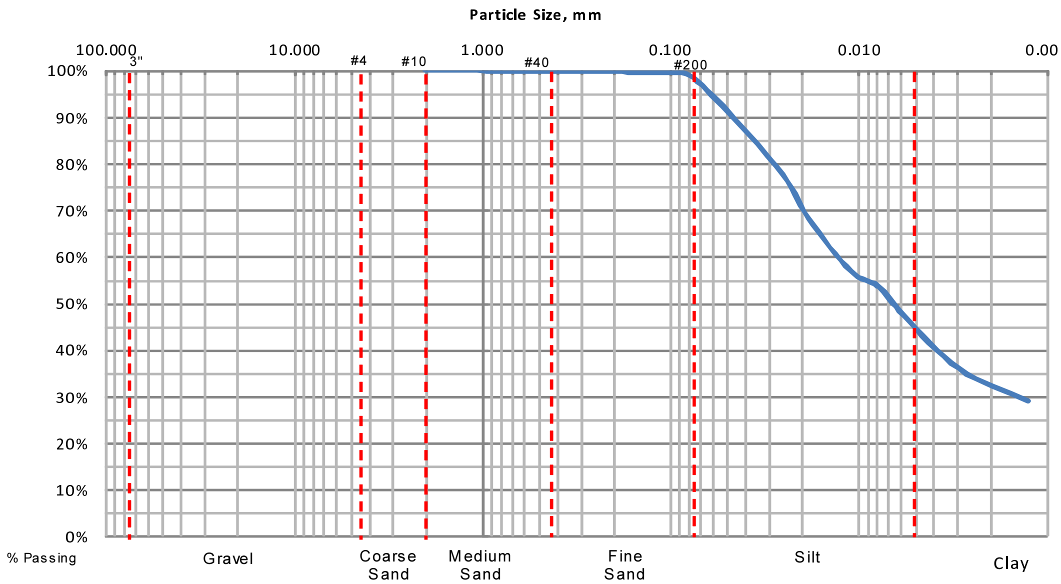
Client: RPS EVANS-HAMILTON

REPORT: Particle Size Distribution **LAB NO:** 82162-6

TEST RESULTS **Report No:** 85162-6
Page 1 of 1

Sample Identification		
SED-6		
Sieve	**Size, mm**	**% Passing**
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.		
No. 4		
No. 10	2.00	100
No. 20	0.85	100
No. 40	0.425	100
No. 60	0.25	100
No. 80	0.18	100
No. 140	0.106	100
No. 200	0.075	98.3

Material	%	
Gravel	0.0	
Total Sand	1.7	
Coarse Sand	0.0	
Medium Sand	0.1	
Fine Sand	1.6	
Silt and Clay	98.3	
Silt size	54.3	
Clay	16.0	
Colloids	28.0	
Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)



Max Particle Size, mm	0.85
Dispersion	Mechanical stirrer /1 min
Specfic Gravity	2.68 (estimated)

Visual Classification	
	Fat Clay

Test Method (As Applicable): ASTM D422

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