Hawaii National Marine Renewable Energy Center (HINMREC)

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2016 Annual Report of the Wave Energy Test Site at MCBH, Kāneʻohe

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ANNUAL REPORT OF THE WAVE ENERGY TEST SITE (WETS) AT MCBH, Kāneʻohe 2016

OAHU, HI

June 2017

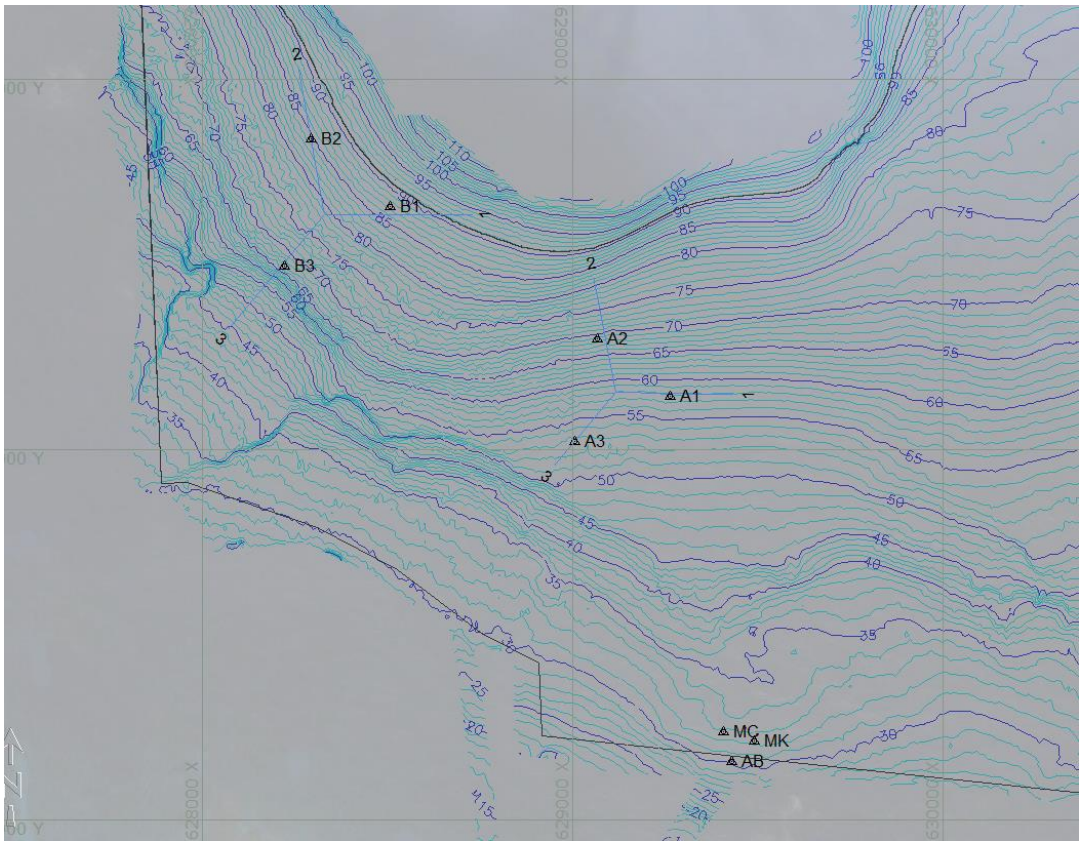

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The area north of the Mōkapu Peninsula, adjacent to Kāne‘ohe Marine Corps Base Hawai‘i (MCBH), has been utilized by the U.S. Navy for wave energy research since 2002. The Wave Energy Test Site (WETS) originated with Ocean Power Technologies (OPT) prototype wave energy converter (WEC) at the 30m water depth offshore of North Beach at the MCBH. The Hawai‘i National Marine Renewable Energy Center (HNMREC) at the University of Hawai‘i, under contract with Department of Energy and the U.S. Navy, has expanded the test site to water depths of 60m and 80m to allow for the testing of wave energy devices.

Sea Engineering has been contracted by the HNMREC to conduct site investigations and monitoring in support of the expanded test site, as well as installation, maintenance and removal of associated WECs.

The project location within the state of Hawai‘i is shown in Figure 1-1. The test site is 1600 to 2000 m wide and extends approximately 2600 m offshore from the 30m depth contour to the approximate 100m depth contour. An aerial image of the test site can also be seen in Figure 1-2

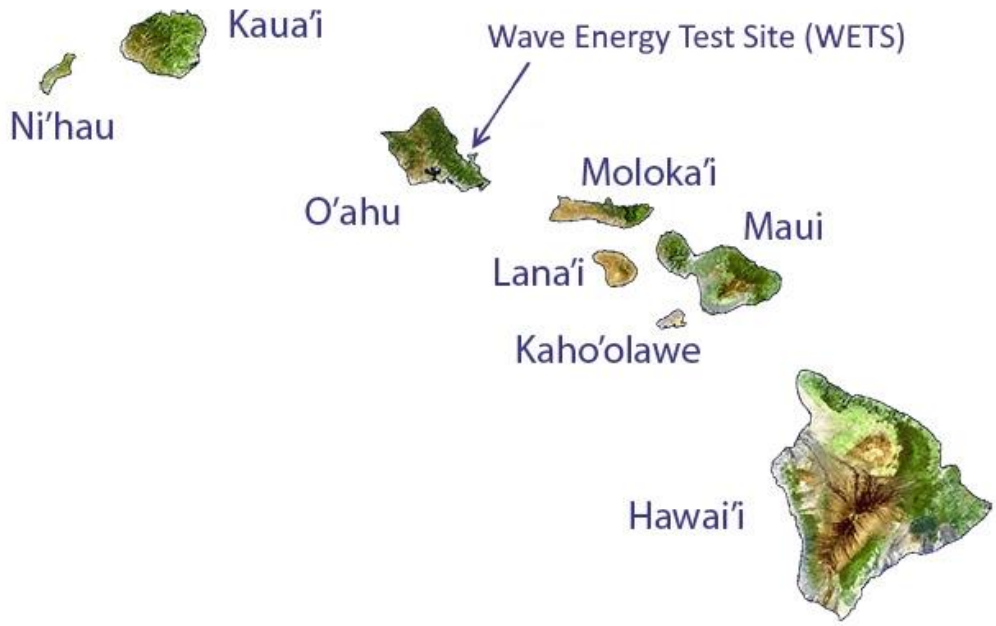

Figure 1-1 Project Location

Figure 1-2. Aerial image of project site (from Google Earth).

2. PROJECT TASKS

SEI was contracted to perform a range of tasks in support of WETS program. These tasks are numbered and each have their own sub tasks which are assigned a letter following the task number. Table 2-2 lists the work tasks.

Table 2-1. WETS Tasks

Deliverable	Description
	(1) ACOUSTICS (HYDROPHONES)
1A	Field Report: Installation of Bottom-Mounted Hydrophone at 30m berth
1B/1C	Field Reports: Deploy, Monitor (over 4 days) and Retrieve UW Drifting Buoy Hydrophone (two separate activities)
1D/1E	Field Reports: Retrieve and Re-deploy Hydrophone at 30m (two separate quarterly activities)
1F	Field Report: Installation of two Bottom-Mounted Hydrophone at 60m and 80m berths
1G – 1H	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones at 60m (two separate quarterly activities)
1I	Field Report: Perform survey with floating SWIFT hydrophones (one activity)
1J	Field Report: Retrieve and Re-deploy SLOW Hydrophone at 60m
1K-1R	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)
1S-1W	Field Reports: Retrieve and Re-deploy SWIFT Hydrophones (five occurrences around Deep Berths)
	(2) EMF PROBE (Deliverable 2 Deleted)
	(3) SEDIMENT TRANSPORT (60M AND 80M BERTHS)
3A	Field Report: Installation of four Measurement Staffs
3B-3D	Field Reports: ROV Monitoring of Four Staffs (three separate quarterly activities)
	(4) ADCP-CURRENT METER
4A	Field Report: Install ADCP below Waverider (80m depth)
4B-4F	Field Reports: Retrieve (data chip) and Reinstall ADCP (five separate quarterly activities)
4G-4M	Field Reports: Retrieve (data chip) and Reinstall ADCP (seven separate quarterly activities at 60m berth)
	(5) ECOLOGICAL AND SEAWATER CHEMISTRY SURVEYS
5A-5F	Field Reports: Ecological Survey around 30m berth and Water Chemistry around all berths (six separate quarterly activities)

Deliverable	Description
	(6) HARDWARE DIVER INSPECTIONS
6A-6C	Field Reports: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (three separate monthly activities)
6D-6F	Field Reports: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (three separate quarterly activities)
6G-6J	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (four separate monthly inspections)
6K-6Q	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the Deep Berths (seven separate inspections)
	(7) ROV INSPECTIONS 60M AND 80M BERTHS
7A-7C	Field Reports: ROV inspections of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (three separate monthly activities)
7D-7E	Field Reports: ROV inspections at 60m and 80m berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (two separate activities)
7F-7I	Field Reports: ROV Deep Berth inspections of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (four separate activities)
	(8) PROGRESS REPORTS
8A/8B	Reports: Two separate reports documenting all activities and lessons learned to date

2.1 Task 1: Acoustics (Hydrophones)

Acoustic tasks included deploying and recovering University of Hawaii's bottom mounted hydrophones, deployment and recovery of hydrophones developed at the University of Washington (UW) attached to two different Sea Spiders instrument platforms, and conducting surface wave instrumentation float with tracking (SWIFT) hydrophone drifts accompanied by CTD casts to create a velocity profiles. Table 2-2 shows the subtasks completed under Task 1. The date the task was performed and the date of the report are also noted in Table 2-2. Table 2-3 shows the deployment schedule of the bottom mounted hydrophones.

Table 2-2. Acoustic Tasks

	TASK 1: Acoustics (Hydrophones)	Date Task Was Performed	Date of Report
1A	Field Report: Installation of Bottom-Mounted Hydrophone at 30m berth	11/10/2014-11/14/15	1/27/2015
1B	Field Report: Deploy, Monitor (over 4 days) and Retrieve UW Drifting Buoy Hydrophone (First Test)	3/24/2015-3/27/2015	4/6/2015
1C	Field Report: Deploy, Monitor (over 4 days) and Retrieve UW Drifting Buoy Hydrophone (Second Test)	7/6/2015-7/9/2015	7/20/2015
1D	Field Report: Retrieve and Re-deploy Hydrophone at 30m (1st Quarter/1st Year)	1/21/2015-2/20/2015	4/6/2015
1E	Field Report: Retrieve and Re-deploy Hydrophone at 30m (2nd Quarter/1st Year)	1/21/2015-2/20/2015	4/6/2015
1F	Field Report: Installation of two (2) Bottom-Mounted Hydrophone at 60m and 80m berths	1/12/2016-1/13/2016	3/3/2016
1G	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones at 60m (two separate quarterly activities)	8/18/2016 - 8/22/2016	8/25/2016
1H	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones at 60m (two separate quarterly activities)	8/3/2016	9/2/2016
1I	Field Report: Perform survey with floating SWIFT hydrophones (one activity)	3/18/2016	4/8/2016
1J	Field Report: Retrieve and Re-deploy SLOW Hydrophone at 60m	3/19/2016-3/22/2016	4/8/2016
1K	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	10/10/2016	11/21/2016
1L	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	3/8/2017	4/3/2017
1M	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	Prior to Azura install at 30m site	-
1N	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	Pending Lifesaver install at 30m site	-
1O	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	Pending Lifesaver install at 30m site	-

	TASK 1: Acoustics (Hydrophones)	Date Task Was Performed	Date of Report
1P	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	Pending Ocean Energy WEC install at deep-water berth	-
1Q	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	Pending Ocean Energy WEC install at deep-water berth	-
1R	Field Reports: Retrieve and Re-deploy SEASPIDER Hydrophones (eight occurrences at Deep Berths)	Task not scheduled	-
1S	Field Reports: Retrieve and Re-deploy SWIFT Hydrophones (five occurrences around Deep Berths)	12/1/2016 - 12/3/2016	1/31/2017
1T	Field Reports: Retrieve and Re-deploy SWIFT Hydrophones (five occurrences around Deep Berths)	1/23/2017 - 1/26/2017	1/31/2017
1U	Field Reports: Retrieve and Re-deploy SWIFT Hydrophones (five occurrences around Deep Berths)	Pending Azura install at 30m site	-
1V	Field Reports: Retrieve and Re-deploy SWIFT Hydrophones (five occurrences around Deep Berths)	Pending Lifesaver install at 30m site	-
1W	Field Reports: Retrieve and Re-deploy SWIFT Hydrophones (five occurrences around Deep Berths)	Pending Ocean Energy WEC install at deep-water berth	-

Table 2-3. Bottom Mounted Hydrophones Task Schedule

Deployment Date	**Task**	**Retrieval Date**	**Task**	**Comment**
11/10/2014	1A	11/14/2014	1A	UH Deployment Hydrophone
1/21/2015	1D-1E	2/20/2015	1D-1E	UH Deployment Hydrophone
3/24/2015	1B	7/6/2015	1C	UW Sea Spider
1/13/2016	1F	8/3/2016	1H	Deployed two Sea Spiders and recovered one Sea Spider
10/10/2016	1K	-		Deployment was canceled (instrument buoyancy to great)
12/6/2016	4E	3/8/2017	1L	
4/14/2017	4G	6/16/2017	-	Retrieval pending

The UH developed bottom mounted hydrophones experienced a range of technical issues included acoustic release failure, hydrophone power and operational issues. The UH developed

hydrophones were replaced by more conventional Loggerhead hydrophones u-bolted to Sea Spiders instrument platforms with commercially available acoustic releases for recovery.

The first SWIFT drifts used the original design, which is a vertically oriented tube with a float and GPS logger above water, and a hydrophone below water that is allowed to drift through the project area and collect acoustic data. As the trials progressed, the SWIFTs were modified to have a heave plate and a rubber tether to connect the surface float housing and GPS to the sub-surface hydrophone. This was done to reduce the noise from surface interactions with the float housing.

2.2 Task 2: EMF Probe

This project task was eliminated and funds reallocated.

2.3 Task 3: Sediment Transport (60m and 80m Berths)

The subtasks, completion dates, and dates of reports for Task 3 - Sediment Transport can be seen in Table 2-4. Sediment measurement staffs were deployed around the 60m and 80m berths and monitored quarterly with an ROV to determine if there is sediment movement at the site. The measurement staffs consisted of two graduated sediment staff platforms, each consisting of 4 measurement staffs, and two graduated scour cylinders.

Table 2-4. Sediment Transprt Tasks

	TASK 3: Sediment Transport (60m and 80m Berths)	Date Task Was Performed	Date of Report
3A	Field Report: Installation of Four (4) Measurement Staffs	10/29/2014	12/2/2014
3B	Field Report: ROV Monitoring of Four Staffs (1st Quarter/1st Year)	5/22/2015	7/1/2015
3C	Field Report: ROV Monitoring of Four Staffs (2nd Quarter/1st Year)	8/11/2015	10/1/2015
3D	Field Report: ROV Monitoring of Four Staffs (3rd Quarter/1st Year)	1/14/2016	Report in Progress

The sediment staffs and scour cylinders were deployed by lowering them on a slip line, and verifying position and orientation with an ROV. The ROV for deployment recorded video and still images of the sediment staffs and scour piles during initial conditions. The installation of the sediment staffs and scour cylinders was Task 3A.

Task 3B-3D entailed quarterly ROV monitoring of the sediment staffs. The first quarterly monitoring inspection was easily accomplished and without issue, but the second quarterly inspection revealed that marine growth had obscured the graduated markings, burrowing by benthic species had created holes and depression under the grate that caused the grate to tilt. This rendered measurements invalid. After the second inspection, marine growth and burrowing had hindered proper quantification to the point that the staffs and scour cylinders could no longer be used. Instead the WETS mooring blocks and anchors were scaled and used as reference for approximate measurement.

The Task 3 work showed little evidence of significant sediment transport. The work indicated that the marine growth at the WETS site is too rapid to allow for visual measurement of marked staffs or cylinders over long periods of time. Future deployments of sediment staffs must have heavily coated clear antifouling substance or paint. Burrowing may also move or undercut small platforms, rendering consistent measurement invalid. Scaling of the mooring blocks and anchor has been used for monitoring Task 3D; however, because they are part of the mooring system, the blocks, anchor and chain are susceptible to movement and degradation unlike the standalone staffs and cylinders. The mooring chains and sinker weights displace sediments in the form of trenches at the 60m site and depressions at the 80m site.

2.4 Task 4: ADCP-Current Meter

Table 2-5 shows the subtasks for Task 4 and the date that it was performed and the date of the report if applicable.

Table 2-5.ADCP Tasks

	TASK 4: ADCP-Current Meter	Date Task Was Performed	Date of Report
	Installation ADCP below Waverider (80m depth)	11/13/2014	12/2/2014
4A	Field Report: Retrieve (Data Chip) and Reinstall ADCP (1st Quarter/1st Year)	2/26/2015	4/6/2015 - Field Report 05/04/2015 - Comparison Report
4B	Field Report: Retrieve (Data Chip) and Reinstall ADCP (2nd Quarter/1st Year)	Retrieved: 6/4/2105 Redeployed: 7/6/2015	10/1/2015 - Field Report 10/2/2015 - Comparison Report
4C	Field Report: Retrieve (Data Chip) and Reinstall ADCP (3rd Quarter/1st Year)	Retrieved: 10/14/2015 Redeployed: 10/19/2015	10/20/2016
4D	Field Report: Retrieve (Data Chip) and Reinstall ADCP (4th Quarter/1st Year)	Retrieved: 1/13/2016 Redeployed: 1/14/2016	Report in Progress
4E	Field Report: Retrieve (Data Chip) and Reinstall ADCP (1st Quarter/2nd Year)	Retrieved:8/3/2016 Redeployed:12/6/2017	3/30/2017
4F	Field Report: Retrieve (Data Chip) and Reinstall ADCP (2st Quarter/2nd Year)	1/20/2017	4/3/2017
4G	Field Report: Retrieve (Data Chip) and Reinstall ADCP (Seven separate quarterly activities at 60m Berth)	Retrieved: 04/14/2017 Redeployed:04/15/2017	Report in Progress
4H	Field Report: Retrieve (Data Chip) and Reinstall ADCP (Seven separate quarterly activities at 60m Berth)	7/15/2017 Pending	-
4I	Field Report: Retrieve (Data Chip) and Reinstall ADCP (Seven separate quarterly activities at 60m Berth)	10/15/2017 Pending	-
4K	Field Report: Retrieve (Data Chip) and Reinstall ADCP (Seven separate quarterly activities at 60m Berth)	1/15/2018 Pending	-
4L	Field Report: Retrieve (Data Chip) and Reinstall ADCP (Seven separate quarterly activities at 60m Berth)	4/15/2018 Pending	-
4M	Field Report: Retrieve (Data Chip) and Reinstall ADCP (Seven separate quarterly activities at 60m Berth)	7/15/2018 Pending	-

Tasks 4A and 4B consisted of deploying a RDI Sentinel V100 Acoustic Doppler Current Profiler (ADCP) at the 80m test site for 90 days. The ADCP was set up to record wave parameters, spectra and currents for both background data and to compare observed values against the Waverider buoy's data. The Waverider buoy uses sensitive accelerometers to calculate wave statistics. These two systems measure the same wave statistics, but they use different methods which allows independent verification of the wave statistics.

Tasks 4C and consisted of shifting ADCP to the 30m test site for two 90 day periods. These deployments were conducted to measure the same wave parameters, spectra and currents, but at the 30m site. These new deployments helped define the wave climate at the 30m test site. The task schedule and completion dates for Task 4 can are listed in Table 2-6.

Task 4F was used to secure the B1 mooring float and chain which had broken free of the anchor. A tug towed the B1 surface float to a location near the B3 surface float, and the B1 surface float was secured to the B3 surface float.

Table 2-6. ADCP Task Schedule

Deployment Date	Task	Retrieval Date	Task
11/13/2014	Previous WETS Funding	2/26/2015	4A
2/26/2015	4A	6/4/2015	4B
7/6/2015	4B	10/14/2015	4C
10/19/2015	4C	1/13/2016	4D
1/14/2016	4D	8/3/2016	1H
12/6/2016	4E	4/14/2017	
B1 secured	4F	B1 secured	
4/15/17	4G		

Work conducted during Task revealed the following:

- High zinc content diaper rash cream proved to preventing marine growth than the previously used antifouling methods.
- A material failure in the plug connecting the external battery and the ADCP resulted in a truncated data record. The used of lithium batteries eliminates the need for the external battery.
- The comparison of the ADCP and Waverider buoy, Task 4A and Task 4B, showed that the significant wave height and peak period data from the ADCP compared well with the data form the Waverider; however, the peak direction shows less agreement.

2.5 Task 5: Ecological and Seawater Chemistry Surveys

The subtasks, completion dates, and dates of reports for Task 5 - Ecological and Seawater Chemistry Surveys are listed in Table 2-7.

Table 2-7. Ecological and Seawater Chemistry Task Schedule.

	TASK 5: Ecological and Seawater Chemistry Surveys	Date Task Was Performed	Date of Report
5A	Field Report: Ecological Survey around 30m Berth and Seawater Chemistry around all Berths (1st Quarter/1st Year)	Seawater Chemistry: 11/14/14 Ecological Diving: 1/15/2015	Seawater Chemistry: 12/02/2014 field measurements, 12/16/2014 lab results Ecological Diving: 3/4/15
5B	Field Report: Ecological Survey around 30m Berth and Seawater Chemistry around all Berths (2nd Quarter/1st Year)	4/3/2015	Ecological 04/16/2105 Seawater Chemistry 5/8/2015
5C	Field Report: Ecological Survey around 30m Berth and Seawater Chemistry around all Berths (3rd Quarter/1st Year)	Seawater Chemistry: 7/16/2015 Ecological Diving: 8/12/2015 10/09/2015	Seawater Chemistry: 10/2/2015 Ecological Diving: 11/6/2015
5D	Field Report: Ecological Survey around 30m Berth and Seawater Chemistry around all Berths (4th Quarter/1st Year)	1/26/2016	4/1/2016
5E	Field Report: Ecological Survey around 30m Berth and Seawater Chemistry around all Berths (1st Quarter/2nd Year)	5/6/2016	8/25/2016
5F	Field Report: Ecological Survey around 30m Berth and Seawater Chemistry around all Berths (2nd Quarter/2nd Year)	1/13/2017	3/27/2017

The ecological dive surveys consisted of diving on the chain box (mooring AB at the 30m site) to conduct a fish count, taking pictures of 4 quadrats located in the same place on the chain box for each survey, swimming two replicate transects along the high voltage cable recording video by divers and video recorded to observe marine species of interest, and to take photos of the cable and ocean floor every 10 meters. One 50 meter transect was completed from the shelf (~12 meters deep) along the cable towards shore, and the other transect started at the base of the shelf (~24 meters deep) and continued up the slope to the shelf.

The Seawater Chemistry Surveys consisted of taking water samples at the surface, mid water column and near bottom for all three mooring locations. A combination of field testing and laboratory testing were used analyze the samples. Laboratory testing was conducted by AECOS. Water samples were stored on ice, and taken to AECOS the same day as the sampling.

Task 5 was completed without difficulty. Quadrat marking and placement was improved by creating a static marking system on the quadrat frames to make sure that the quadrats were placed in the exact same location on the chain box or high voltage cable. This increased the accuracy of repeatability between surveys.

2.6 Task 6: Diver Inspections of Hardware

Diver visual inspections of hardware tasks and dates are listed in Table 2-8**Error! Reference source not found.**. Tasks ranged in scope based on necessity of inspecting or repairing different components, but generally consisted of visual inspections of the hardware with photo documentation of all inspected components at the 30m and 60m sites.

Table 2-8. Diver Inspection of Hardware Schedule

	TASK 6: Diver Inspections of Hardware	Date Task Was Performed	Date of Report
6A	Field Report: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (1st Month/1st Year)	6/14/2015	7/21/2015
6B	Field Report: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (2nd Month/1st Year)	7/12/2015	8/3/2015
6C	Field Report: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (3rd Month/1st Year)	10/9/2015	12/14/2015
6D	Field Report: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (2nd Quarter/1st Year)	1/8/2016	3/3/2016
6E	Field Report: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (3rd Quarter/1st Year)	3/28/2016	5/11/2016
6F	Field Report: Diver visual inspections of submarine power cable, mooring components including anchor bases & WEC device at 30m berth (4th Quarter/1st Year)	12/9/2016	1/31/2017
6G	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (four separate monthly inspections)	3/28/2016	6/28/2016
6H	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (four separate monthly inspections)	5/26/2016	6/29/2016
6I	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (four separate monthly inspections)	10/8/2016	1/31/2017
6J	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (four separate monthly inspections)	12/12/2016	2/22/2017

	TASK 6: Diver Inspections of Hardware	Date Task Was Performed	Date of Report
6K	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	1/13/2017	3/31/32017
6L	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	3/4/2017	4/24/2017
6M	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	4/19/2017 5/2/2017	6/6/2017
6N	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	Pending Azura install at 30m site	-
6O	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	Pending Azura install at 30m site	-
6P	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	Pending Lifesaver install at 30m site	-
6Q	Field Reports: Diver visual inspections to 120 feet water depth of submarine power cables, mooring components & WEC device at the 60m berth (seven separate activities)	Pending Lifesaver install at 30m site	-

Table 2-9 shows a timeline of events for the 60m and 80m sites at WETS including the PTO functionality of the Lifesaver moored at the 60m site. Green shading indicates a that a PTO is operational and the mooring leg is intact and functional. Red shading indicates that a PTO is not operational and mooring leg is broken.

Table 2-9. Timeline of Events at Deepwater Berths

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
9/9/2014-9/13/2014	Installation of A & B Moorings	Healy Tibbits Barge and Tugs Installed the A and B Moorings									
6/27/2015-6/29/2015	Installation of Cable to A & B Moorings	Cable ship Intrepid Laid Cables to Moorings A and B									
2/4/2016	Emergency Inspection of B2 Deepwater Mooring	A kenter failed at about 15ft up the chain from the fist damper weight. Positions were taken for the chain weights, anchor, and end of the chain									
3/5/2016	ROV Inspection of Deepwater Mooring Inspection	ROV Inspection of deep water mooring site. Found that each mooring leg has stud link chain with the stud beaten out, the A3 mooring leg lost its first damper weight.									
3/23/2016	Fred Olsen Lifesaver Chain Basket Install	Healy Tibbitt's Builders installed the chain baskets and subsurface floats for each PTO with a crane barge at the 60m site.									
3/24/2016	B2 Mooring Float Removed	Healy Tibbitts removed the B2 float and upper chain from the 80m site.									
3/25/2016	Fred Olsen Lifesaver Install	SEI connected the three PTO bands to the sub-surface floats attached to the chain baskets on the seafloor. The sub-surface floats were attached to the riser line with a chain. The sub-surface float was attached in the middle of the chain to lower the floats so that the floats would not get pulled into the generators.									
3/30/2016	Additional Inspection and Repair of Lifesaver	Follow up to installation operations, bend cotter pins on shackles on the subsurface floats and finish inspection.									
4/10/2016	Repair of Communications Lifesaver	Communications repair for the Lifesaver (restarted the antenna/modem) and inspection of PTOs.									

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
5/14/2016	Lifesaver PTO Band Failure	On 5/14/2016 at 16:11:23. PTO3 band failed. Old style thinner band.									
5/19/2016	Repair and Inspection of Lifesaver	Repaired a lost communication connection with Lifesaver by resetting the antenna. Inspected the PTOs, bands, belts, coolant, etc.									
5/21/2016	Lifesaver A1 Hawser Failure	Communications issues lead to the discovery of the failed A1 mooring hawser.									
5/24/2016	Recon Survey of Mooring Line Failure	Snorkeled around the Lifesaver, found the A1 mooring hawser was parted at the thimble closest to the Lifesaver. The chain and thimble were still attached to Lifesaver however the line was not. Seems the line chaffed in the thimble or the splice pulled out.									
5/26/2016	Inspection of 60m Site Mooring Lines and Preparation for Hawser Repair	The inspection of the Lifesaver mooing lines showed that the A2 and A3 hawser lines were intact and free of major chaffing. The A1 mooring hawser was previously found to be broken at the Lifesaver end of the hawser in the thimble. The thimble at the surface float end of the hawser was cracked and the hawser line was chaffed around the thimble. Preparations were made for the installation of a new hawser line for A1, the chain on the WEC end of A1 was pulled on deck and the pigtail under the A1 surface float was pulled on top of the surface float									
5/27/2016	Replacement of A1 Mooring Line	The lifesaver was pulled in position using a snach block and the Healy Tibbitts Bill M. The new hawser was connected without any of the wire rope extensions. Current status is that all mooring lines are complete and intact and all PTO bands are broken due to being out of position.									
6/22/2016	Recon to Survey the Damage to A1 Hawser Line.	Survey of the damage caused by a passing sail boat that got caught on the A1 mooring line.									

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
7/19/2016	Replace Broken PTO Bands, Found Broken A3 Hawser.	The A3 hawser was broken, the line chaffed around the thimble closest the Lifesaver. A new hawser was delivered and spliced on site. The Huki Pau was used to pull the A3 surface float and the Lifesaver together with long piece of spectra and turnbuckle. The shackle was rendered 180 degrees the wrong way. The A3 hawser was not recoverable and was wrapped around the A3 anchor chain. PTO 2 band was reconnected, to the PTO 2 drum. It had just pulled out of clam on the drum because the Lifesaver was so out of position. PTO 1 and PTO 3 bands are still broken.									
7/26/2016	Replace Broken PTO Bands	Reconnected the PTO 1 and PTO 3 Bands. Attempted to render the A3 shackle, but the shackle was wedged onto the thimble. PTO 2 was making a loud noise and metal dust was found around one the shafts of belts in the PTO box. All bands and PTOs are functional.									
8/1/2016	PTO 2 Failure	PTO 2 band breaks at 8/1/2016 18:16:12									
9/1/2016	PTO 3 Overheating	Production stopped on PTO 3 for coolant issues.									
9/23/2016	Lifesaver Repair PTO 3 Loose Wiring Topside Work for PTO 2 Band Replacement	Repairs PTO3 coolant pump issues. Ended up being a lose wire. No pumps or hoses were replaced. Added shims to the PTO3 drum. Removed PTO2 broken band and installed the new band, Divers are needed to complete the installation of the band. Camera lens were cleaned. Distance from PTO2 band guide to the subsurface float is 42ft.									
10/8/2016	Lifesaver Repair Diver Connect PTO 2 Band	Connected to new band to PTO 2, subsurface float, removed water in PTO boxes with shop-vac, clean band guide cameras, gathered a sample of the residue in the PTO 2.									
10/14/2016	A2 Hawser Failure	A2 hawser failed on 10/14/2016 (load lost on load cell and angle encoder change)									

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
10/21/2016	Lifesaver Repair Restart Electronics	1. Reboot cRio controller 2. Replace Damp-Rid in and WECC housing 3. Take picture of fan setup in signal cabinet, network part of signal cabinet, encoder on rear of band guide 1. 4. Realign the bands on the PTO drums 5. Noticed that PTO 1 was damaged.	Reduced load								
11/9/2016	Lifesaver Repair Hawser Line Replacement	Replaced the Lifesaver Hawser lines with new nylon lines and thimble-less eyes. A2 hawser was broken. Also replaced the R6 and R7 relays in the control house cabinet. Left the cabinet door open to help with the cooling in the power cabinet. Noted that PTO 1 band was further damaged but not completely broken.	Reduced load								
11/16/2016	PTO 1 Stopped	PTO 1 was stopped due to overheating PTO. The initial thought was that the band broke because it was damaged.									
11/28/2016	PTO 2 Damage	PTO 2 Band damage was noted.		Reduced load							
12/9/2016	Repair of Lifesaver Bands	Started repairs on the Lifesaver, installed new PTO bands on each PTO, cleaned cameras, changed angle on PTO 3 camera, Inspected the inside of the PTO boxes.									
12/12/2016	Repair of Lifesaver Bands	Divers complete the PTO band connections and inspect the mooring hardware on Lifesaver. PTO 1 was found to not have any coolant in it, coolant was added, however the pump has failed.			Replaced band due to damage found on inspection						

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
12/19/2017	PTO 3 Chain Failure	The chain directly under the subsurface float on the PTO 3 failed. This was found to be the case on 1/5/2017 by swimmers.									
1/3/2017	PTO 2 Overheating	Production stopped on PTO 2 for overheating PTO.									
1/5/2017	Repair of Lifesaver Coolant System	Added two new pumps to the coolant system for PTO 1 and PTO 2. Filled the coolant reservoirs in each PTO. Replaced the Damp-rid in PTO 3. Inspected each PTO box and Control house. PTO 3 drum camera had no leaks and no LED lights. Swimmers found the PTO 3 band was intact. The chain broke at the first link under the subsurface float.									
1/11/2017	ROV Inspection of Deepwater Mooring Inspection Check 70m ADCP	Redeployed the ACDP at the 70m site. Continued the survey of the Deepwater moorings. Confirmed the B1 mooring chain is broken (pile of stud less chain found and the pile is too far away from the surface float. A moorings had lost the first sinker weight on each leg and A2 and A3 had lost the second sinker weight due to failure of the attachment hardware.									
1/13/2017	Ecological Diving and Water Sampling 60m Site mooring inspection	Conducted the Ecological diving, AB fish count, deep transect, and shallow transect. Conducted 60m site mooring inspection with diver on A1, A2, A3 mooring legs, and the A cable node float. Also dove on B1 and B3 and cable node B. Found that the pigtail thimble and line was bouncing against the shackle for the riser and completely worn through the thimble on the B1 and B3 pigtails. The B1 and B3 pigtails are damaged.									

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
1/20/2017	Secure the B1 Surface Float to the B3 Surface Float	The P&R Water Taxi JD Pringle II to tow the B1 surface float to the B3 surface location and secure.									
???		Communications were lost with the Lifesaver, PTOs were not operational									
3/4/2017	Diving mooring inspection	Dive on A and B Moorings with deck inspection of Lifesaver PTO 3 subsurface float has lost its foam. PTO 1 band has a break/crack in the area of the band guide.									
4/19/2017	Lifesaver Removal 12552	Lifesaver Removal: Bands disconnected, WEC Cleaned, Mooring Inspection, Electrical disconnect. PTO1-6 and PTO1-8 lost cotter pins, PTO2-8 lost pin and cotter pin.									
4/20/2017	Lifesaver Removal 12552	Lifesaver Removal: Final Electrical Disconnect, Disconnected the Hawsers.									
4/28/2017	Lifesaver Removal 12552	Removal of the B1 mooring float and the PTO 1 chain box. Picked the PTO 1 chain box up with the deck wench (air tugger) of the barge. The Carolyn was used to tow the barge and PTO 1 chain box to the fuel pier. The barge was secured and chain box lifted on deck with a Grove crane on the barge.									
5/1/2017	Lifesaver Removal 12552	Removal of the PTO 2 chain basket. Recovered the chain basket to the stern of the barge and towed it in to the fuel pier. ROV was used to confirm the loop of PTO 3 riser line was not going to be caught in the recovery of the chain basket.									

Date	Item	Description / Notes	PTO1	PTO2	PTO3	A1	A2	A3	B1	B2	B3
5/2/2007	Lifesaver Removal 12552	Removal of the PTO 3 chain basket. ROV was used to help spot the hook for the recovery of the riser line. The ROV tether was damaged during the placement of the hook in the water. ROV operations were canceled and the ROV recovered. The barge camera was used to spot the hook in to the loop of the riser.									
5/3/2017	Lifesaver Removal 12552	The final connection to connect the A3 hawser to the center master link was completed using both the Bill M and the Carolyn pulling on a single parted line attached to A3 and the center master link. Once connected all the Norwegian float were removed and the final inspection was completed.									

2.7 Task 7: ROV Inspections (60m and 80m Berths)

Tasks 7A, 7B, and 7C consisted of a Remotely Operated Vehicle (ROV) inspection of the mooring components for the 60m and 80m test site. A ROV was deployed at each of the surface mooring floats, and was used to visually record and observe the condition of the various deep water mooring site components. Table 2-10 shows the dates when each subtask was completed for at Task 7. Mooring site conditions can be seen for Task 7E and 7D in Table 2-11 and Table 2-12 respectively.

Table 2-10. ROV Inspection Schedule

	TASK 7: ROV Inspections (60m and 80m Berths)	Date Task Was Performed	Date of Report
7A	Field Report: ROV inspections of submarine power cable, mooring components including anchor bases & WEC device at depths below diver depth (1st Month/2nd Year)	11/13/2014 visual survey; 1/21/2015 anchor location w USBL	12/16/2014; updated 1/27/2015
7B	Field Report: ROV inspections of submarine power cable, mooring components including anchor bases & WEC device at depths below diver depth (2nd Month/2nd Year)	2/4/2016	3/3/2016
7C	Field Report: ROV inspections of submarine power cable, mooring components including anchor bases & WEC device at depths below diver depth (3rdMonth/2nd Year)	3/5/2016	4/8/2016
7D	Field Reports: ROV inspections at 60m and 80m berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (two separate activities)	1/11/2017	1/25/2017
7E	Field Reports: ROV inspections at 60m and 80m berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (two separate activities)	3/7/2017	3/31/2017
7F	Field Reports: ROV Deep Berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (four separate activities)	Completion pending directive	-
7G	Field Reports: ROV Deep Berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (four separate activities)	Completion pending directive	-
7H	Field Reports: ROV Deep Berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (four separate activities)	Completion pending directive	-
7I	Field Reports: ROV Deep Berths of all submarine power cables, mooring components including anchor bases & WEC devices at depths below diver depth (four separate activities)	Completion pending directive	

Table 2-11. Deep-water Mooring Site Inspection Results 3/7/2017

Site	Leg	Anchor (ML-1)	Sinker Weight 1 (SW1)	Sinker Weight 2 (SW2)	Sinker Weight 3 (SW3)	Sinker Weight 4 (SW4)	Sinker Weight 5 (SW5)	Dip section (ML-4)	Additional Comments
60 Mooring Site (Lifesaver)	A1	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 2ft scour around block	Attached to ML-4 Dense marine growth with some voids near the chain attachment Block tilted on seafloor	Attached to ML-4 Rounded corners and wear due to ML-4 movement On edge of trench partial buried	Detached from ML-4 Block not found, Task 7D found SW5-1 parts on seafloor	Trench formed due to the movement of the ML-4 chain. Dip section starts at SW3 and continues to SW4.	Kenter link the section of chain (ML-4) with studs missing has a gap, looks abnormal.
	A2	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth with some voids near the chain attachment 1ft scour around block	Detached form ML-4 limited marine growth on WEC side of block, rounded corners and grooves from chain wear on top of block, block in the middle of trench	Detached form ML-4 Block has rounded corners and 20% loss of mass, sits in the center of the trench, Light marine growth	Detached form ML-4 Block has rounded corners, sits in the center of the trench with the ML-4 chain well above it Light marine growth	Trench formed due to the movement of the ML-4 chain extends from SW5 to SW2. Dip section starts at the third sinker weight (SW3),	Two loops of line are near the dip section of the A2 mooring chain. They are connected and have floatation (lift bag or crushed Norwegian Floats).
	A3	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 light marine growth, rounded corners and grooves from chain wear, Block in middle in of the trench	Detached form ML-4 Block has rounded corners and 25% loss of mass, block is buried on the outer edge of the trench	Detached form ML-4 Block has rounded corners and 50% loss of mass with exposed rebar, sits in the center of the trench	Trench formed due to the movement of the ML-4 chain, deepest part is between SW3 and SW4. Dip section starts at SW3. Chain (ML-4) lands on top of the block.	-
80m Mooring Site (vacant)	B1	Both Flukes Buried 0.5 ft scour on south side of exposed anchor	Attached to ML-4 Dense marine growth chain on top of block 1.0 ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block, void space under one corner of block	Attached to ML-4 Dense marine growth 1ft scour around block, void space under one corner of block	Attached to ML-4 Dense marine growth 1ft scour around block Block on its side	Detached form ML-4 Block not found, there is a hole in the area of where it should be and could be buried	Dip section is directly under the surface float. Chain (ML-4) ends with a single link missing a stud.	The B1 mooring chain is broken between SW4 and the section of chain that is missing it studs.
	B2	Both Flukes Buried	Attached to ML-4 Density marine growth 1.5ft scour around block	Attached to ML-4 Dense marine growth 1.5ft scour around block edge of block on chain (ML-4)	Attached to ML-4 Dense marine growth 1.5ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block Block on the edge of a hole	Chain (ML-4) is broken at a kenter link on the approximately 20-25ft past the fifth sinker weight (SW5). B2 surface float was removed by Healy Tibbits Builders.	The end of the B2 mooring chain was a previously found to have a failed kenter link. This was not visible on this inspection.
	B3	Both Flukes Buried	Attached to ML-4 Density marine growth 1ft scour around block Chain (ML-4) on top of block	Attached to ML-4 Dense marine growth 2.0ft scour around block Chain (ML-4) on top of block	Attached to ML-4 Dense marine growth 1.0ft scour around block	Attached to ML-4 Dense marine growth 1.0ft scour around block	Attached to ML-4 Rounded corners on block Block in the hole under the subsurface float	Hole/sink is formed under the subsurface float.	-

All distances and mass percentages are visually estimated, green cells indicate functional components, red cells indicate failed components.

Table 2-12. WETS Deepwater Mooring Inspection Results 1/11/2017

Mooring Site	Mooring Leg	Anchor (ML-1)	Sinker Weight 1 (SW1)	Sinker Weight 2 (SW2)	Sinker Weight 3 (SW3)	Sinker Weight 4 (SW4)	Sinker Weight 5 (SW5)	Dip section (ML-4)
60 Mooring Site (Lifesaver)	**A1**	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 2ft scour around block	Attached to ML-4 Dense marine growth Block tilted on seafloor	Attached to ML-4 Rounded corners and wear due to ML-4 On edge of trench	Detached form ML-4 Block not found, buried Parts on seafloor	Trench formed due to the movement of the ML-4 chain. Dip section starts at the between SW3 and SW4.
	A2	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 light marine growth, rounded corners and grooves from chain wear, Block in the edge of trench	Detached form ML-4 Block has rounded corners and 10% loss of mass, sits in the center of the trench	Detached form ML-4 Block has rounded corners, sits in the center of the trench	Trench formed due to the movement of the ML-4 chain. Dip section starts at the third sinker weight (SW3), Chain lays on side of the block.
	A3	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 light marine growth, rounded corners and grooves from chain wear, Block in the edge of trench	Detached form ML-4 Block has rounded corners and 25% loss of mass, block is buried on the outer edge of the trench	Detached form ML-4 Block has rounded corners and 50% loss of mass with exposed rebar, sits in the center of the trench	Trench formed due to the movement of the ML-4 chain. Dip section starts at the third sinker weight (SW3). Chain (ML-4) lands on top of the block.
80m Mooring Site (vacant)	**B1**	Both Flukes Buried	Attached to ML-4 Dense marine growth Chain on top of block 1.5 ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Detached form ML-4 Block not found, there is a hole in the area of where it should be and could be buried	Dip section is directly under the surface float. Chain (ML-4) is broken in the dip section.
	B2	Both Flukes Buried	Attached to ML-4 Density marine growth 2ft scour around block	Attached to ML-4 Dense marine growth 2ft scour around block edge of block on chain (ML-4)	Attached to ML-4 Dense marine growth 1.5ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block Block on the edge of a hole	Chain (ML-4) is broken at a kenter link on the approximately 20 ft past the fifth sinker weight (SW5). B2 surface float was remove by Healy Tibbits Builders.
	B3	Both Flukes Buried	Attached to ML-4 Density marine growth 1ft scour around block Chain (ML-4) on top of block	Attached to ML-4 Dense marine growth 2.5ft scour around block Chain (ML-4) on top of block	Attached to ML-4 Dense marine growth 1.5ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Rounded corners on block Block in the hole under the subsurface float	Hole is formed under the subsurface float.

ROV surveys proved to be particularly useful for inspecting mooring leg components at depths beyond diver access. Video footage provides conclusive documentation of current conditions as well as damage, and causes of the damage. The ROV was mobilized quickly on several occasions and verified potential failures that needed attention before buoys or equipment broke free and drifted out of the site or washed up on shore. The ROV has also been used to search for missing objects or parts in deeper water and not only visually document their location, but provide depth and GPS position if equipped with the USBL. The ROV was used to document the actual locations at which the anchors were located on the bottom.

Failures of the hawsers at the 60m site led to the complete replacement of the hawser with lines of similar material but terminated with soft eyes and wide body shackles. Chaffing in the eye of the hawser is what led to the failure of each of the hawsers. In one case the thimble was cracked. Additional failures of the attachment points of the sinker weights closest to the WEC have not yet been repaired. The failure of the B1 mooring chains at the 80m site was attributed to a separated kenter link. There is was no conclusive evidence that the same thing happens at the B2 mooring: however, the failure occurred in a similar location. These failures have yet to be repaired as well.

2.8 Task 8: Annual Reports

The present report represents the first annual report Task 8A. The monitoring and inspection work and operations conducted at the WETS site to-date have revealed numerous modes of failures and difficult associated with WEC operations. This prompted, as part of the Task 8A the contracting of Noble Denton Ltd. to produce a Mooring Analysis Report. This report listed numerous conclusions and recommendations including the following:

- Modeling the mooring for vacant berths was not conducted.
- No corrosion allowance or wear allowance was used.
- No fatigue analysis was conducted.
- Most of the equipment employed are not suitable for long term mooring.

The report is attached in Appendix A. Table 2-13 lists the Task 8 schedule.

Table 2-13. Annual Report Schedule

	TASK 8: Annual Reports	Date Task Was Performed	Date of Report
8A	Report: Summarizing activities and lessons learned during Year 1 at WETS in support of HINMREC	6/9/2017	6/9/2017
8B	Report: Summarizing activities and lessons learned during Year 2 at WETS in support of HINMREC		Report in Progress

3. SUMMARY (LESSONS LEARNED)

The mooring failures have had a significant impact to operations at WETS. The AB subsurface float broke free which prompted the replacement of the AB riser with a shorter line. Fortunately, Azura operation was not affected. The failure of the B1 mooring forced the relocation of the deployment of the Lifesaver from the B moorings (80m) to the A moorings (60m) site. The B moorings have not yet been repaired. Hawser failures at the 60m site resulted in PTO band failures on the Lifesaver. Additionally, the detachment of the sinker weights at the 60m site increased the watch circle of the Lifesaver, potentially further straining the PTO bands due to misalignment of the chain boxes and Lifesaver. These events underscore the importance of proper material and design of mooring components. The WETS site cannot house buoys or function properly without an intact and properly functioning mooring system. Inspections of the hardware can easily be performed satisfactorily, but if improper design or materials are used, components can fail rapidly or instantaneously without any prior indications. The mooring analysis report from Noble Denton Consultants Ltd. presents a detailed analysis of mooring performance and suggestion for improvement (Appendix A).

Rapid marine fouling of all submarine components presents numerous challenges for environmental monitoring and WEC operations. Some that have affected WETS are:

- Algae grew on the deck of the Lifesaver resulting in a significant slip hazard. Any operation to repair the Lifesaver had to account for the removal of the algae to reduce the risk slipping.
- Marine growth on mooring components hindered measurements of wear during the 30m site mooring inspections.
- The sediment staffs and scour cylinders were eventually overcome with marine growth that measurements could not be recorded accurately.

Marine growth can be easily overcome by use of antifouling paints or compounds, or by regular cleaning or replacement.

The ability of the vessels available in Hawai‘i is a limiting factor for larger WECs installed at WETS. The Site Dedicated Vessel being developed, with it’s A-frame and crane, will help minimize this. The vessel will provide greater lift capabilities with the heave compensated winch. With the addition of the Super Mohawk ROV repairs will be possible at depths greater than diver depths with on limits on bottom duration.

4. APPENDIX A

4.1 Mooring Analysis Report from Noble Denton Consultants Ltd.