LESSONS LEARNED

Marine Operations Minas Passage

OPERATIONAL EXCELLENCE
CONSULTING

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How to Use This Report

The report describes the marine service resources available for sea-going operations in the Bay of Fundy, including their operational advantages and limitations. It also describes the operational constraints of this complex, high energy marine environment and provides information to help address commonly encountered situations. The report provides contact information of the many vendors and service providers available to support marine operations in the Bay of Fundy. For additional information or more detail on the work described herein, please contact Jason Clarkson at Operational Excellence Consulting Inc or Andrew Lowery at the Fundy Ocean Centre for Research (FORCE) at.

Introduction

Fundy Ocean Research for Energy (FORCE), Offshore Energy Research Association (OERA) and Operational Excellence Consulting Inc. have teamed up to capture lessons learned from marine operations in the Minas Passage. The project involves information that is shared from developers and contractors who have been performing marine operations in the past number of years. The purpose is to help the tidal industry in Nova Scotia by sharing information about operations and experiences while operating in the conditions that are unique to the Minas Passage.

The report includes a detailed overview of the resources used while performing marine activities in the Minas Passage such as:

1. Types of Vessels
2. Types of equipment
3. Diving Operations
4. Challenges
5. Environmental limitations
6. Environmental Monitoring Equipment
7. Instrumentation Technology (SONAR etc.)
8. Vendors

Acronyms and Abbreviations

ADCP = Acoustic Doppler Current Profiler

ASD = Azimuth Stern Drive

ATL = Atlantic Towing Limited

BP = Bollard Pull

CLA = Crown Lease Area

DGPS = Differential Global Positioning Systems

DP(S) = Dynamic Positioning (System)

EMS = Environmental Management System

FAST = Fundy Advanced Sensor Technology

FORCE = Fundy Ocean Research for Energy

FRM – Float Release Mechanism

HP = Horse Power

Kts = Knots

Lbs = Pounds

MBR = Maximum Bend Radius

MW = Mega Watt

PPE = Personal Protective Equipment

RHIB = Rigid Hull Inflatable Boat

ROV = Remote Operated Vehicles

t = tonnes

VHF = Very High Frequency

Types of Vessels

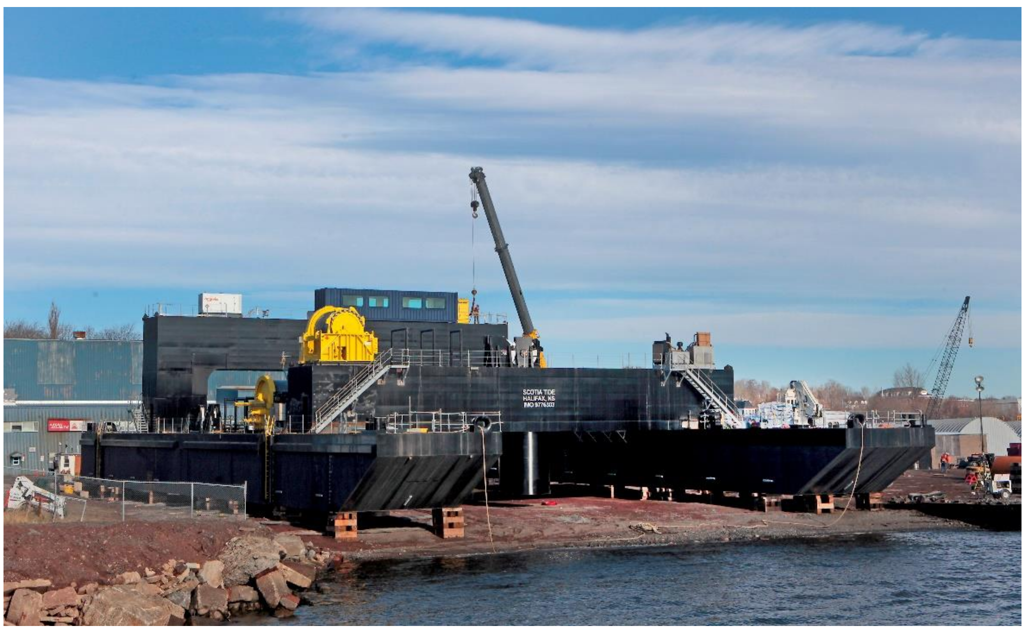
The following vessels are used during various marine operations in the Minas Passage:

- ***Scotia Tide:***

  OpenHydro's Lifting barge to deploy and recover turbines. Built in Pictou, Nova Scotia and launched in 2015 the *Scotia Tide* is a purpose-built installation barge for the 2MW (Mega Watt) turbines installed for Cape Sharp Tidal. Capable of lifting and lowering the 1000+ T (tons) turbine to and from the seabed. The vessel is not powered and needs to be towed to transport and install the turbines.

  Barge Specifications:

Length: 64 Meters	Width: 38 Meters	Draft Empty: 5 .8 Meters
Capacity: 1150 T	Keel Laid: 2015	Draft Loaded: 9.0 Meters
Design: Catamaran		



- **Atlantic Towing Ltd Anchor Handling Tug Supply Vessel (AHTS) (see datasheet in Appendix 1):**

  Two vessels of this type have been previously used for operations in the Minas Passage. The *Atlantic Kingfisher* and the *Atlantic Osprey* have 176.4t continuous bollard pull capability were used on different occasions in the Minas Passage by developer OpenHydro. A performance rating on this vessel including the limitations and it role in the operations are outlined by the developer below.

  - **Scope of Work:** Towing of *Scotia Tide*, Position of *Scotia Tide* in berth for turbine deployment.

    - **Performance:** Performed well. A high bollard pull is required due to the high drag of the turbine. At some point we did reach 100% of the engine thrust when deploying turbine (without consequences). We are reviewing our method statements to avoid this in the future. We have analyzed the data from the last deployment, we have lowered the window threshold, based on recorded data and calculations, and this will reduce the required BP and limit power.
    - **Limitations:** Effective bollard pull, is now a known factor, this was not fully understood prior to the last deployment; this ultimately feeds back to the design of the operations, especially in terms of timings.

  - **Remarks:** Captain's experience is the key in all operations.

    "We are requesting Atlantic Towing to provide the same captain that performed turbine deployment in 2016 for the next deployment." ***- Julien LeClerc – Naval Energies.***

- **Atlantic Towing Ltd harbour Azimuth Stern Drive (ASD) tugs (see datasheets in Appendix 1):**
  Atlantic Towing Ltd has a fleet of ASD tugs typically used for ship assist in ports as well as various other towing and marine operations. A number of these ASD tugs have been used for operations in the Minas Passage. A performance rating on this vessel type including the limitations and its role in the operations are outlined by the tidal turbine developer OpenHydro and are outlined below.

- ***Atlantic Fir:***
  - **Scope of Work:** Towing of Scotia Tide during turbine recovery and Motoring trials.
    - **Performance:** Performed well. 63 tons bollard pull, most powerful ASD tug to tow the *Scotia Tide*. It performed extremely well during the turbine recovery operation, very impressive position keeping throughout; these can only be used for a recovery operation they must start with low drag.
    - **Limitations:** Bollard pull: Note the ASD's seem to have better effective bollard pull than other propulsion types. Again, operations are always designed around bollard pull.
  - **Remarks:** Captain's experience is the key here. OpenHydro would request ATL to provide the same captain that already performed turbine recovery or cable operations for the next coming operations.

- ***Atlantic Hemlock:***
  - **Scope of Work:** Stern tug holding turbine tail during turbine deployment, Forward tug towing the Beaver barge during cable operations.
    - **Performance:** Performed Well. Fitted with bow winch to hook up onto a mooring and tow *Irving Beaver* barge at the same time. The *Atlantic Hemlock* is the most versatile ASD and one of the best performing in their fleet, also used for tail handling.
    - **Limitations:** Bollard pull. Not able to tow *Scotia Tide* for recovery or deployment operations, but acceptable for lesser operations such as motoring trials or such.
  - **Remarks:** Captain's experience is the key here.

    "We are requesting Atlantic Towing to provide the same captain that already performed cable operations in 2016 for the next coming operations." **– Julien LeClerc – Naval Energies.**

- **Atlantic Bear:**
    - **Scope of Work:** Stern tug for *Irving Beaver* barge, pushing the barge while towed by *Atlantic Hemlock*. Positioning/stabilizing the *Irving Beaver* barge on berth D.
        - **Performance:** Performed well. Fitted with bow winch, useful for high capacity winch *on Irving Beaver* barge for cable operations. Very powerful ASD with 70t BP, but the Atlantic Bear's exceptional performance is largely attributed to its Captain Joey Mayalls.
        - **Limitations:** Cannot tow the Beaver barge. No stern winch.
    - **Remarks:** Captain's experience is the key here.

      "We are requesting ATL to provide the same captain that already performed cable operations for the next coming operations." – ***Julien LeClerc – Naval Energies.***

- ***Irving Beaver barge* (see datasheet attached):**

  The *Irving Beaver* is a flat deck unmanned barge operated by Atlantic Towing Ltd. A performance rating on this vessel type including the limitations and it role in the operations are outlined below by the tidal turbine developer OpenHydro.

  - **Scope of Work:** Turbine connection, mooring installation.

    - **Limitations:** A large barge difficult to control with ASD tugs in high currents during cable operations.

  - **Remarks:** A smaller barge must be investigated for better control with positioning on site. In addition, using a cargo barge such as the *Irving Beaver* barge requires the use of two tugs, one lead tug for towing and a stern tug to control the barge in strong current. The operation also requires the mobilization of a crane, winches, chutes, containers/control rooms, survey system, and other required equipment to be ready for cable operations. As consequence, mobilization/demobilization costs and vessels & equipment daily rates makes cable operations very expensive.

    " The ideal case would be to mobilize a large mutilcat (already fitted with cranes and winches) suitable for our operations (see specification in Appendix 1). It would lower our operational costs drastically. But such vessel (popular in Europe) is not available in North America."- ***Julien LeClerc – Naval Energies.***

- ***Nova Endeavour* (assistance vessel from Huntley Sub-Aqua Construction):**

  Huntley's Sub Aqua Construction is a vessel operator and commercial construction diving company used by developers and other operators in the Minas Passage. It operates two vessels the *Nova Endeav*or and a self-propelled barge called the *KIPAWO*. A performance rating on the *Nova Endeavor* including the limitations and it role in the operations are outlined by the tidal turbine developer OpenHydro and are outlined below.

  - **Scope of Work:** Assistance vessel used for line recovery and transfer to other vessels, survey operations, grappling ops, diving ops, inspection and maintenance of recovery line, safety boat during operations.

    - **Performance:** Performed well. Very versatile and useful tool on the water. The crew has good experienced and come highly recommended.
    - **Limitations:** Limited safe working load on A-frame/winch, cannot be used for heavy duty works,

  - **Remarks:** The Nova Endeavor is a work boat capable of deployment of FORCE's instrumentation FAST platforms and other monitoring equipment. This vessel has also been involved in every marine operation including the deployment and recovery oper of the Cape Sharp Turbine since 2015.

- ***Tidal Runner*** **(crew boat from RMI Marine):**

  RMI Marine is a vessel operator and professional dive company that has operated crew transfer and safety vessel services as well as platform installations in the Minas Passage with various companies including tidal turbine developers and instrument operators. One of the most commonly used vessels in the Minas Passage is the *Tidal Runner*. With a recent upgrade the this landing style craft with twin 300 horse power Yamaha outboard engines and mountable A-Frame provides a variety of options.

    - **Scope of Work:** Transfer of personnel (crew boat), safety boat during operations, assistance on site with pick-up lines.

      - **Performance:** Performed well for crew transfer and as a safety boat. Difficult to manage pick-up lines/buoys in berth D prior to upgrades being completed.
      - **Limitations:** Vessel is difficult to control/maneuver in high speed currents on berth D. Too difficult for *Tidal Runner* to pick-up a recovery line on Berth D as the vessel can lose control in high currents while pulling on a recovery line. I would like to note that this issue has been resolved with the addition of two new 300HP Yamaha outboard engines now installed on the Tidal Runner. Performance improved immensely, and maneuverability is no longer a concern.

  - **Remarks**: *"Looking back, we would suggest a minimum cruising speed of at least 20 knots, fully loaded. We took this very seriously and therefore repowered our Tidal Runner with twin 300 HP Yamaha outboards which cruise comfortably at 25 Knots."*

    - Mike Gregg RMI Marine

Dive Operations

RMI Marine has made several successful dives in the Minas Passage. Diving in the Minas is achievable when certain conditions are met, and good planning is employed.

- **Scope of Dives:**

  - Dive 1 – RMI divers were tasked to assist FORCE with the recovery of a sensor platform deployed in the Minas Passage. Dive video can be found in Appendix 3

  - Dive 2 – OpenHydro tasked RMI with performing several dives on the 16m diameter turbine located in berth d in the Crown Lease Area (CLA) in the Minas Passage.

- **Challenges:**

  The main concerns are tides, visibility, entanglement, and diver injury all of which can be safely controlled by good procedures and planning. A stable dive platform such as a barge or vessel is required and needs to be safely held in position. It should also have good egress means. Surface supplied diving gear should be the only equipment used as it can provide communications, rescue, and diver control. With surface supplied diving equipment an umbilical is attached to the top hat of the diver which allows constant communication with the diver while supply air to the diver during the dive.

> *"Looking back at some of the challenges, equipment redundancy is important as there are very limited resources in the immediate area."* ***Mike Gregg – RMI Marine***

  - A dive operator should be prepared to carry spare equipment and to make necessary repairs and should seek out local expertise and resources in the event of a break down.

  - Medical emergencies are always a factor so when the projects are greater in magnitude, so should be the availability of medical response. This may entail the need for a second standby safety vessel.

- Operating small vessels outside daylight hours presents risk of entanglement with fishing gear and collision with large floating debris which is always present, particularly during extreme tides. Small vessels are equipped with radar, but some low-profile floating objects cannot be detected when it is dark.

- Communications on the water are crucial. Any vessel involved in tidal operations should have at least two working VHF radios monitoring dedicated working channels. Cell phone coverage is not always reliable, and operators should limit the use of such unless prescribed.

- **Limitations:**
  - Due to the short durations to which diving can be performed, all diving operations should be kept within the no decompression limits. In reference to "short durations" we have experienced a safe dive window of approximately 20 minutes and possibly extending this by 5 – 10 minutes depending on the diver's comfort. The rapidity at which the tide turns is influenced by the moon phase, so the tide turn can be as brief as 15 minutes and as much as 30 minutes. The diver has to be deployed at least 15 minutes before the scheduled low tide turn and his recovery is dependent on when the tide gains to much force going the other way.

    *"The diver's recovery is paramount, so the diving window should be closely monitored. Bottom time is measured from the time the diver leaves the surface until the time the diver leaves the bottom. The diver's recovery time is not factored in, but his ascent rate should not exceed 60 feet/min. We use the DCIEM Diving Manual, January 1995, particularly Table 1: Standard Air Decompression (feet). As per Table 1 using a depth of 100 feet as an example, the diver would have 15 minutes of bottom time without having to do any decompression, i.e. in water decompression or recompression chamber. "**Mike Gregg – RMI Marine.***

- For all operations, a diving contractor should provide an approved recompression chamber and support equipment.

- A comprehensive safe diving plan complete with emergency arrangements and contingencies is mandatory and should be developed to include all parties but should not be so complex that it limits the intended scope of work.

- The diving operations conducted by RMI Marine pertaining specifically to the tidal projects involved input from several parties, so a diving contractor should expect to expend considerable resources in the development of an approved dive plan.

- **Key Lessons:**

  - A stable dive platform such as a barge or vessel that can be held on station in minimal currents is required.

  - Surface supplied diving equipment complete with communications and lighting is required. *(Note: Surface-supplied diving is diving using equipment supplied with breathing gas using a diver's umbilical from the surface, either from the shore or from a platform such as a barge or diving support vessel.)*

  - A solid dive safety plan is mandatory as is an experienced dive team.

  - Diving depths should be verified, and bottom times should be conservative to avoid in water decompression.

  - The dive objective should be understood by all onboard to achieve success.

  - Through experience it was determined that a diver could be safely deployed at least one-half hour before the scheduled low tide and successfully dive for approximately 20 minutes. Even if there was an indication of surface flow, the bottom flow had already slackened.

- Diving should be conducted only at the low slack tide as the current flow changes too quickly at the high slack tide.

- Visibility is an issue so diving, if required, should be conducted at the appropriate daylight low tides. Good lighting on the diver's helmet is essential.

- Potential entanglement is always an issue, a good diver's knife, a standby diver, and a solid emergency plan with suitable rigging & deck equipment for emergency use is mandatory.

Equipment

- **Survey equipment for vessel positioning:**
  - **Dynamic Global Positioning System (DGPS) for vessel positioning (Seaforth Geosurveys):**
    - ✓ **Advantages:** Very accurate mean for positioning vessel on the surface over a subsea asset position on the seabed.
    - ✓ **Disadvantages:**
      - Requires accurate position of subsea assets on the seabed, which is difficult to attain.
      - Requires a subsea beacon on the load when the load is deployed/lowered.
      - Beacons cannot be left subsea (battery capacity, damage due to high current speed).
  - **3D Sonar (CODA) for subsea cable catenary monitoring (Seaforth Geosurveys):**
    - ✓ **Advantages:** Accurate means to control the shape of the tail/cable catenary during recovery of cable for connection or maintenance.
    - ✓ **Disadvantages**
      - Cannot survey or record the position of subsea assets on seabed (cables, anchor, etc....).
      - Expensive.
  - **Sonar (Klein 3000): Survey of subsea assets (Seaforth Geosurveys):**
    - ✓ **Advantages:** Compatible with DGPS positioning system,
    - ✓ **Disadvantages:** not able to survey cables on the seabed, expensive equipment and operations (multiple passes with survey vessels).
  - **Sonar (Klein 3500): Survey of subsea assets (Seaforth Geosurveys):**
    - ✓ **Advantages:** Compatible with DGPS positioning system; able to survey cables on seabed.
    - ✓ **Disadvantages:** expensive equipment and operations (multiple passes with survey vessels).

- **Work class Remotely Operated Vehicle (ROV) for subsea surveys (Oceaneering):**
  - ✓ **Advantages:** Provides video footage and has the ability to move subsea to survey specific locations on seabed.
  - ✓ **Disadvantages:** Difficult to deploy and recover in high current speeds (<.1.5 knots), very limited operational time subsea to perform survey (a total water time of approximately 2 hours 10 minutes), very difficult to control underwater with currents, not recommended for any subsea intervention in the berth D area. This would include surveys, mechanical work, free lines from entanglement, etc. Very expensive tool (high day rates for ROV + ROV support vessel). ROV footage from the Minas Passage can be found in Appendix 4.

- **Crawler Cranes:**

An LR1400 440 (t) Crawler crane was used onboard the Irving Beaver Barge. Various other crawler cranes have been used during operations in the Minas Passage for a variety of operations. The LR1400 440 (t) crawler was used for the Open Hydro turbine connection operation. An important thing to consider when selecting a crane is the derating of the cranes capacity when used on the deck of a barge.

For example; Irving Equipment Limited will only utilize a crane make & model that has been approved for use on a barge from the manufacturer. In this case, the manufacturer will provide a set of "Barge Charts" that will contain lift capacities for varying degrees of list, usually from 0 to 2 degrees.

> *"We always plan for the worst case and use the 2 degree-list charts. Barge chart capacities will be lower than a standard set of capacity charts, which is done not only to help account for barge list, but also the dynamic forces created from wave action or other barge movements."* ***– Ryan Long Branch Manager Irving Equipment Limited***

In the case of the LR1400 that was used on the Irving Beaver, the crane had a gross capacity of 102,238lbs using the 2-degree barge charts. In the exact same configuration on land, the standard charts indicate that it would have 126,000lbs capacity.

- **Winches:**

  10 (t) air powered winches, performed well, but slow pay-in speed. A slow pay-in speed will increase the time it takes for the winch to retrieve something that has been attached to it and lead to longer operational times in a tidal a tidal window. These were used onboard the Irving Beaver during multiple operations and were supplied by Oceanside Equipment in Halifax.

- **Over Boarding Chutes:**

  Customs built and designed for use with the Irving Beaver arrangement, they reportedly performed well. The chutes were designed for high currents, but required considerable welding work required to install them on the barge which was expensive.

- **Quadrant:**

  The quadrant allows connection of in-line connectors on turbine and hub tails while protecting the cable from exceeding the bend radius from excessive bending during the operation. It is a difficult operation to deploy or recover a quadrant, the heavy load is difficult to manage on the barge,

- **Cables**

The external wrapping that protects the electrical cables is vulnerable to damage from recurrent handling during installation and recovery phases. The export cable and tails are not designed to suffer multiple operations. Cable handling operations should be minimized, or the cable and tail design should be revised to permit multiple handling. It is also important to ensure that handling and storage equipment are fit for the cable:

- Maximum Bend Radius (MBR) is not exceeded in the reels used for storage
- Crush load applied on the cable during handling does not exceed maximum crush load allowed by the cable manufacturer.
- Tension on the cable does not exceed allowable values and cable is not compressed (fiber optic is very sensitive to compression).
- A layer of corrosion products and Molykote grease is observed on the outer ring of the connector flanges. During each disconnection/re-connection event, it is necessary to grind this part of the flange to ensure a proper connector seal.
- No issue is observed beyond the outer ring (i.e. between the O-rings), which confirms that the seal is effective and water tight.
- A half-liter 0f fresh water was recovered during connector disconnection. This was likely due to condensation.
- Multiple handling and equipment vibrations leads to fasteners un-tightening. A corrective mechanical system on the fasteners is recommended to prevent recurrence of this problem.

- **Cathodic Protection (Connectors):**

  In water connectors and associated fasteners are well protected by sacrificial anodes. No corrosion was observed on the fasteners or on areas where paint was removed.

  Cast iron bend restrictors were electrically connected to the hybrid connector and induced more anode consumption than expected (the anodes were initially designed to protect the connectors only).

  Additionally, it seems that the increases corrosion speed. In atmosphere, fasteners should be regularly protected by a layer of grease to avoid corrosion (cathodic protection does not work in air)

Challenges

- **Dealing with high current speed for subsea turbine and cable lifts:**
    - **Method:** The key here is the timing and sequence of the operation. The turbine is lowered as soon as current speed allows it typically on the ebb tide. The barge must be on position and stabilized for this operation. The same is true for cable operations.
    - **Equipment:** Various crawler cranes including a LR1400 440(t) Liebherr from Irving Equipment Limited have been used on the operations for subsea lifts as well as barges with large A-Frames. The Scotia Tide is always used for the turbine subsea lifts.

- **Operations possible during ebb only as current is too strong during flood:**

  "Agreement from the beginning of the project to avoid flood tides. Because of too strong current speeds and current speed profile over time. It has not been re-assessed since. New assessment not planned for the moment." ***– Julien LeClerc – Naval Energies.***

- **Short slack water duration between tides:**

  "Timing of the operation must be sufficiently detailed to be ready to lift turbine as soon as current speed reaches the allowable limit. This is same for cable operations." ***– Julien LeClerc – Naval Energies.***

- **Ccurrent direction changing rapidly when approaching slack:**

  Operations must be completed when approaching slack waters. The vessels become unstable and more difficult to hold position during the slack tide. Detailed sequence of operations must be in place keeping a sufficient safety margin. A timing sequence and constant verification of current speed is key to having success. Drift speed checks should be regularly conducted as an additional measurement to verify model data.

- **Limited time during slack to lift/deploy:**

  Being on site well in advance and avoid loss of time by optimizing operations. This presents additional issues around vessel positioning. When vessels in tow around slack tide, holding vessels in line or in position can be difficult until there is enough current speed. Position of the vessels with respect to the current is important.

- **Limited operation windows with acceptable max current speed:**

  " *Dynamic positioning* (DP) trials with the installation vessel is under investigation. But it is an expensive test. Still to be confirmed if we will do it." **– Julien LeClerc Naval Energies** During the recent 2018 turbine deployment in the Minas Passage the *Atlantic Osprey* was the lead vessel in the installation operation. Having been on that vessel for the installation myself, I can tell you that the *Atlantic Osprey* did switch to DP nearing the last portion of the ebb tide during installation in order to be able to maintain position.

- **Barge positioning/stability/station keeping in high currents:**

  Different positioning methods between *Scotia Tide* and Irving *Beaver barge*, consequences are not the same. With the *Scotia Tide* barge during a turbine installation there is no use of an anchor or mooring systems to keep on station. The cable connection however uses a combination of mooring and movements by the tugs to keep position.

  - ***Irving Beaver barge:***
    - Use of mooring to position convoy,
    - Positioning is critical for *Irving Beaver barge* as barge linked to the subsea cables.
    - The use of the forward and stern tug as well as the mooring are required for any cable operations using the Irving Beaver barge
  - ***Scotia Tide:***
    - Scotia Tide position is made by the forward tug.
    - Post-deployment, station keeping with tugs is less critical for the *Scotia Tide* as it can be moored on the turbine once the turbine is landed on seabed.
    - "High turbine drag" requires high bollard pull to tow turbine on site. It is similar to a standard barge towing around 3 to 5 knots.

Limited or impossible subsea intervention for inspection or works due to high current (diving & ROV).

- Diving is the most efficient and most cost-effective solution, but it remains the highest risk (human intervention in high current speed) and difficult to conduct safely.
- Work Class ROV type was used Oceaneering Magnum Plus (see specification in Appendix 1):
- Only this ROV was used. It was believed that a Work Class ROV would be the most suitable for such strong currents. But it remains a very difficult and risky operation. Not recommended.

- **Multicat type vessel not available in North America for cable work:**

Multi-purpose workboat for offshore works, transport and dredging. Multicats are used for a variety of tasks in the offshore sector today. As a multifunctional all-purpose vessel, a multicat is typically equipped with powerful winches, one to two offshore cranes as well as a spacious flat deck. (specification in Appendix 1)

> *"A Multicat vessel would make our life much easier (technically speaking) for cable operations, it would replace the Beaver barge and the two tugs."* ***– Julien LeClerc Naval Energies***.

Recently Halifax based diving, salvage and ROV company Dominion Diving has purchased a Mulitcat and has had it delivered to Halifax.

- **Advantages:**
  - ✓ Large flat deck for cable works (like a propelled barge),
  - ✓ Fitted with cranes for over boarding and deck work purposes,
  - ✓ Can be fitted with a DP system,
  - ✓ Can deploy and recover a mooring line by itself,
  - ✓ Has considerable maneuverability, similar to a propelled cargo barge, eliminating the need for two tugs to position a cargo barge over the berth.

- **Rocky seabed limit mooring capability:**

  "There has been one incident with a significant slippage of anchor in the berth. The lesson learned here is that the holding capacity of anchors on such rocky seabed is not reliable. A new methodology was developed because of this slippage". – **Julien LeClerc Naval Energies.**

  More than one mooring is a potential solution. This solution is very complex to install and would also require multiple days to install which is very expensive.

  The mooring arrangement used in 2018 for the deployment of OpenHydro's turbine was an array of anchors and heavy chain. This combined with drag testing before and after the operation was an effective way to ensure there was no slippage in the mooring during the operation.

  Cleaning up the site after work is completed is another lesson learned. Lines left attached to anything on the seabed are a danger to fishers, boaters, other turbines and deployed instrument platforms. Companies should ensure they remove any floating lines and make sure any remaining are well marked to ensure they are visible. Coordinates should also be reported to Fundy Ocean Research Center for Energy (FORCE) and communicated to stake holders, especially local fishers.

- **Personnel Transfers**

  Ideal conditions for most deployments and recoveries of sensor platforms or other gear are the operational windows about the low tide slack. For operations that use vessels from dry ports (e.g., Parrsboro, Delhaven, Halls Harbour), the vessel needs to be on the water for approximately 8 to 10 hrs. for even the shortest operation at the FORCE site because the vessel is only able to access the wharf at high tide. While the vessel crew needs to be with the vessel at all times, the operational and / or scientific staff should use personnel transfers whenever possible to avoid prolonged time on the vessel.

  Small Rigid hull inflatable boat (RHIB) or dedicated transfer vessels for larger operations should be considered in all operational plans. Details should include personal protective equipment (PPE) specific to the transfer, transfer locations, transfer stations on each vessel, personnel transfer procedures, gear transfer procedures etc.

  FORCE beach below the FORCE Visitors Centre on West Bay Road is typically used as a primary transfer site, although when winds are in excess of 20 knots from the southwest the conditions at the beach can be rough and difficult for transfers. Alternatively, Ottawa House beach approximately 25 km east of the FORCE site is sheltered from southwest winds and can be used as a secondary spot for personnel transfers.

Environmental limitations

When planning operations in the Minas Passage the following limitations should be considered:

- **Wave height,**
- **Wind speed,**
- **Visibility,**
- **Maximum tide current speed for subsea lifts (turbine, tails and shore cables)**
- **Wave Height**

While producing this lesson learned report it was determined that do to the differences between operations that no one standard set of criteria here can be used as a *"one size fits all"*

Note: Companies will specify their own requirements and vessel operators will perform work based on the Captain's assessment during the operations should conditions change. This is normal protocol as the vessel Master is responsible for the crew and any equipment being attached to the vessel.

- **Weather**

    - **Wind Speed**

      The FORCE site is located in the Minas Passage, a natural bottle-neck in the Bay of Fundy. The site is relatively isolated from surrounding weather stations making it difficult to obtain a reliable and accurate wind forecast. Many vessels that work at the FORCE site come from dry ports where they must leave at high tide while the desirable operational conditions are at low tide. This means the go / no-go decision for weather must be made, at best, six (6) hours before the operation. Practically, the decision must be made closer to 12 – 24 hrs. before the operation.

- **Sources for wind forecasts:**
  - ✓ Government of Canada, Marine Weather for: Atlantic - Maritimes
  - ✓ Windy.com
  - ✓ FORCE Data (fundyforcelive.ca)

Winds in excess of 20 kts tend to be problematic for most operations, with more sensitive operations requiring 15 kts or less. The wind can affect the marine operation, as well as sensor data in some cases where vessel mounted gear or drifting sensors are used. Every operation should strive to identify comprehensive wind criteria from as many reliable sources as are available.

Both Government of Canada and Windy.com provide reasonably accurate forecasts for the region, however based on the season there are some differences:

- ✓ During summer, wind forecasts of 20 – 25 knots tend to be less severe or in reality are closer to 15 kts;
- ✓ During winter, wind forecasts of 20 – 25 kts tend to be more accurate, i.e. legitimately 20 – 25 kts as opposed to summer;

FORCE's wind data has never been corroborated, however anecdotally, the data appears to capture real time conditions, especially wind gusts, with sufficient accuracy to identify problematic data.

Winds from the south will cause more chop / waves on FORCE Beach. Operators should expect significant beach break waves with winds in excess of 20 kts coming from the south which could be problematic for beach landing vessels.

- **Visibility**

During personnel transfers with reduced visibility due to fog, no transfer vessel should be used without sufficient navigation or safety equipment. i.e., losing sight of shore and / or the destination vessel is a serious risk to crew and vessel safety. Based on the vessel(s) involved in the operation, the risk mitigation steps for personnel transfers should cover actions to be taken in situation with the risk of fog.

During buoy recovery, it is important to take the pre-emptive step of labelling any deployed equipment so that it is immediately identifiable when found on the surface. For example, two adjacent and similar surface floats with no markings will be indistinguishable without visual cues.

Recovering buoys or other assets by means of acoustic release that aren't tethered should follow the same labelling protocol, and further, whenever possible they should be triggered and recovered one at a time if there is any compromise to visibility. Generally, extreme caution should be exercised when releasing untethered gear in fog.

- **Tides**

  On a flood tide, 160 billion tonnes of seawater flows into the Bay of Fundy — more than four times the estimated combined flow of all the world's freshwater rivers during the same 6-hour interval.

  The vertical tidal range can be over 16 meters — giving the Bay of Fundy the highest tides in the world. The horizontal range can be as much as 5 kilometers, exposing vast areas of ocean floor.

  The tidal currents in the Bay of Fundy are fast, exceeding 10 knots (5 m/s, or 18 km/hr) at peak surface speed.

  When operating in the Minas passage it is important to consider the speeds at which everything can move. Special precautions for "man overboard" (MOB) should taken to ensure the ability to track a person in the even they fall into the water. Using a device such as an Automatic Identification System (AIS) Man Overboard Beacon (MOB) is recommended for operations in the Minas Passage.

Fundy Advanced System Technology (FAST)

The tidal flow through the Minas Passage comprises 14 billion tonnes of water, moving at speeds in excess of five meters per second. Understanding this powerful environment is critical to successful turbine design, environmental effects monitoring, and related marine operations.

FORCE created the Fundy Advanced Sensor Technology (FAST) program to advance efforts to monitor and characterize the FORCE site.

FAST combines both onshore and offshore monitoring assets. A focus of FAST has been the development of two underwater monitoring platforms. The platforms use a variety of onboard sensing equipment to capture data from the Minas Passage, including:

- Currents and turbulence
- Marine life activity
- Noise levels
- Seabed stability

The entire FAST program includes subsea data collection, subsea data cable installation, shore-based radar and meteorological equipment, as well as platform fabrication, instrumentation, and deployment. FAST is supported by Encana Corporation, Natural Resources Canada, and FORCE turbine developer members.

- **Sensor Platform Deployment**

  If possible, a slip line deployment is preferable to a winch and acoustic release deployment. Smaller sensor platforms like the FAST-2, FAST-3, FAST-EMS, FAST-ADCP and FAST-RRP units, all typically 1,500 lbs., can be deployed by slip line. The drawback to a slip line deployment is that it is irreversible.

  Heavier platforms like FAST-1 require a winch to lower them and an acoustic release to let go once the platform is on the bottom.

  With a large platform, there is little risk of the deploying vessel dragging the platform while waiting for the acoustic communication to release the platform. With the smaller platforms, there is a risk that they could be dragged by the vessel while waiting for the acoustic release to trigger.

  Deployment options for any sensor platform should be thoroughly vetted with the vessel crew and confirmed with the vessel's gear.

- **Typical Slip Line Deployment Procedure**

The deck layout should be as below, or equivalent:

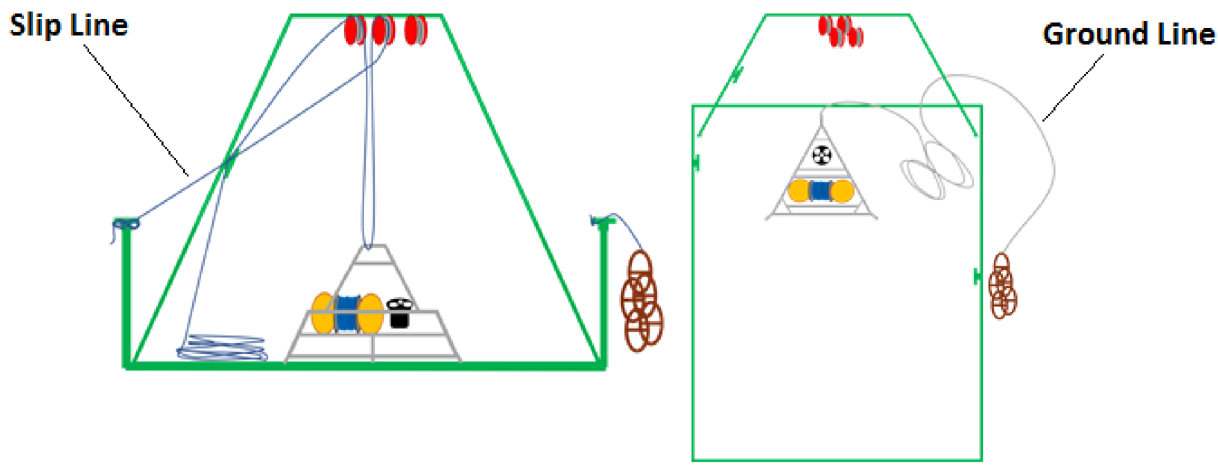


FIGURE 1 DECK LAYOUT

The slip line should be fastened to the a-frame or somewhere else out of the way of operators, run through a pulley on the a-frame, through the lifting point on the platform, back through another pulley on the a-frame and then back to deck where an operator can handle the line during slipping through a cleat. The operator and slip line should be on the opposite side of the platform than the ground line (if used) to avoid entanglement.

The following is for a deployment using the Nova Endeavor that has a winch on deck.

Deployment Procedure		
Item No.	**Condition**	**Task**
1.	On location, Captain able to hold station	Platform lifted from the deck and hung over the stern using the winch. Weight of platform transferred to slip line and winch wire disconnected.
3.	When on location, and when Person in Charge gives go ahead	Platform slipped away and lowered to seafloor.
4.	While lowering platform	Deckhand to manage the ground line and pay out what is required while maintaining some tension.
5.	While lowering platform	ENSURE NO PERSONNEL ARE IN THE BITE AND IF SOMETHING GOES WRONG THE GROUND LINE CAN FREE RUN OVER THE RAIL
6.	Platform touches down on seafloor	Vessel position recorded
7.	Platform touches down on seafloor	Slip rope recovered to the deck;
8.	Post Platform Touchdown	Vessel moved into desired direction of ground line layout. Ground line managed over side
9.	Ground line being payed out	Clump weight ready and prep to cut sacrificial rope for deployment
10.	Just prior to all Ground Line being payed out	Vessel will stop
11.	After vessel has stopped	Sacrificial rope holding clump over side of vessel is cut
12.	Clump touches down	Vessel position recorded

- **Sensor Platform Recovery / Configuration**

  In a high flow tidal site, especially one with significant vessel traffic, there is appreciable risk of a float line being entangled, lost or cut, thus complicating recovery of a sensor platform. The primary method of sensor platform recovery should be a float release mechanism.

  Redundancy is critical for any recovery operation, reliance on a single recovery method should be a last resort. FORCE uses a ground line connected to a clump weight complete with recovery line and float whenever possible.

  A typical FORCE sensor platform configuration is shown below.

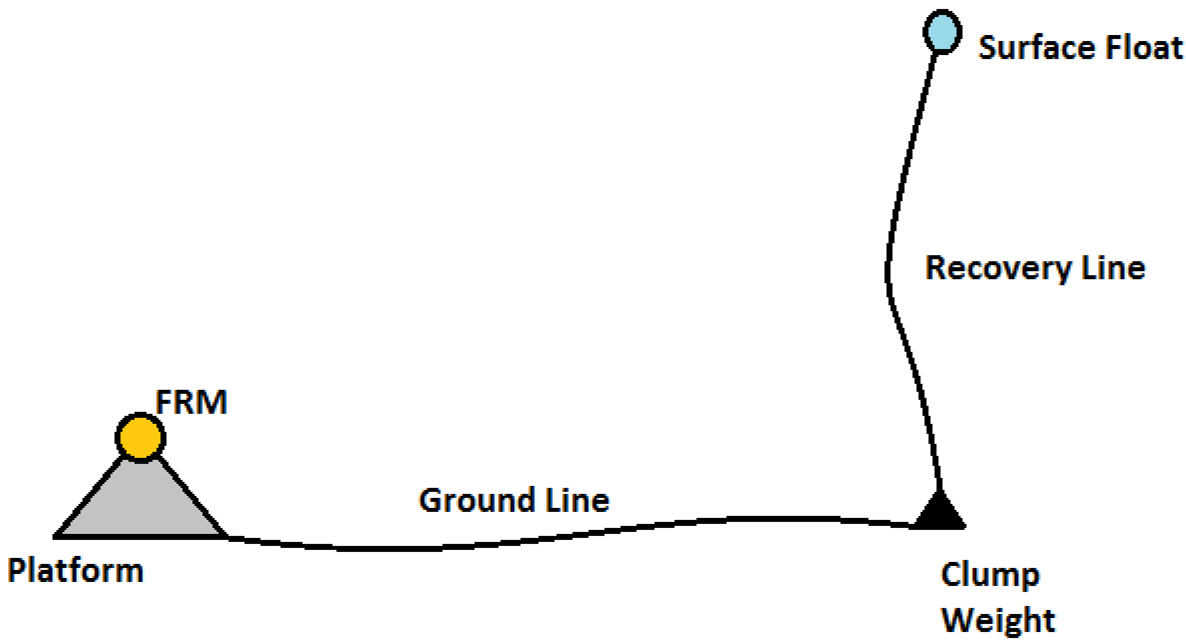


FIGURE 2 GENERAL PLATFORM ARRANGEMENT

It is important to source the ground line and recovery line appropriately for the sensor platform. For FAST-2, FAST-3, FAST-EMS, FAST-ADCP and FAST-RRP, FORCE typically uses 1/2 in or 5/8 in wire rope for the ground line, plastic coated or impregnated seems to offer more hysteresis which could enhance and grappling capabilities.

Recovery lines should be at least 1/2 in poly, but FORCE has experienced significant wear on 1/2 in poly. A measure to help prevent wear is to attach a second float to the recovery line just above the recovery line just above the clump weight to keep the recovery line off of the bottom during peak tides. The drawback of using thicker recovery line is that there is more hydrodynamic drag and the surface float will be under water longer.

Surface floats should be foam. Inflatable rubber floats can collapse at depth, and hard plastic floats can be broken from impacts to the bottom. A typical surface float and 1/2 in poly recovery line used by FORCE is shown below.

FIGURE 3 TYPICAL SURFACE FLOAT

Ground line length should be a function of your recovery method. For grappling, a minimum of 80 m should be used. The longer the ground line, the more capacity required on the winch. IN the event that you run out of room, some sort of cable grip system is needed to advance the recovery line, which is time consuming and time is valuable during a slack tide recovery. Ground line length should be thoroughly vetted with the vessel crew.

Surface float line length should be approximately twice the depth at the location of deployment. If it is known without doubt that the platform will be recovered at low tide slack, use the low tide depth; else, use the mean depth. Longer recovery lines are on the surface longer and also surface further away from the clump which could cause confusion in high traffic areas. Longer float lines also run a greater risk of entanglement.

FORCE typically uses a ~500 lbs clump weight, though ~100 lbs clumps have been used when necessary.

In circumstances where a platform is to be deployed near an asset such as a turbine, it may be too risky to have a float release mechanism (FRM) on the platform. To offer redundancy, FORCE has successfully deployed platforms with two ground lines deployed in-line as shown below.

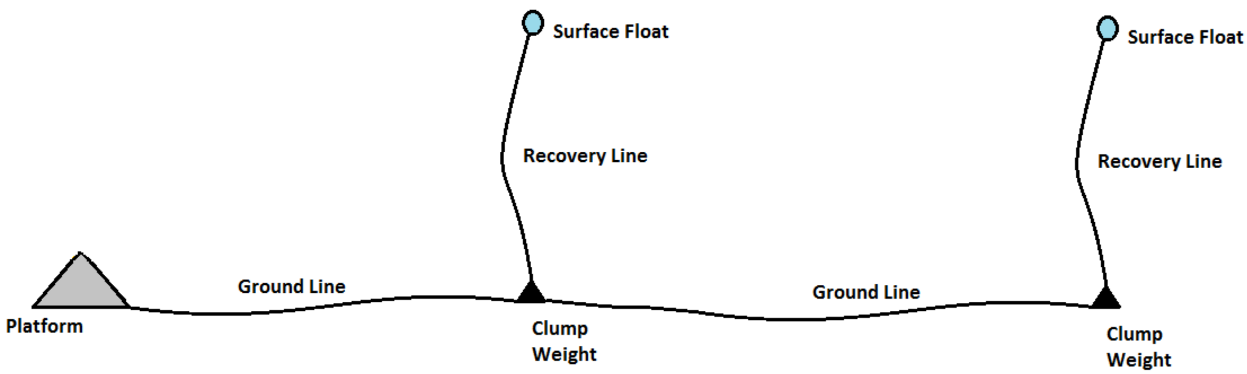


FIGURE 4 DOUBLE GROUND LINE CONFIGURATION

The following is a for a recovery with the Nova Endeavor:

Recovery Procedure	
Item No.	**Task**
1.	Approximately one hour before low water slack, the acoustic release securing the FRM on the platform will be interrogated. Ranging on the acoustic release will determine if the platform is still at the deployed position.
2.	When the Person in Charge determines that the tide conditions are favorable the acoustic release will be actuated and the recovery floats and rope will surface.
3.	On the Person in Charge's command, the vessel will maneuver to recover the floats to the deck. Enough slack will be gathered on deck to take a few wraps around the cleat. The deckhand (under supervision of Deck Supervisor) will remove the floats from the recovery rope and attach it to the line from the capstan that is fed through the block on the A-frame.
4.	Slack rope will be pulled in by hand by the deckhand and coiled near the capstan. Once the recovery rope becomes tight, several turns will be wound on the capstan and pulled in to maintain tension on the rope.
5.	As the capstan recovers the rope, the Nova Endeavor E maneuvers over the platform to keep the recovery rope as vertical as possible.
6.	Once on the surface the winch wire will be attached to the lifting point by the deckhand and the sensor platform landed on deck using the winch.
7.	If the ground line surface buoy is still visible, the ground line end attached to the platform will be disconnected and tossed overboard. Contingency step: If the ground line surface buoy is not visible, the ground line slack will be recovered to the vessel by hand by the deckhand. Once as much ground line slack as possible is recovered, the deckhand will use the wire stoppers and winch will be used to recover the last of the ground line and the anchor. The anchor will then be brought onto the deck.
8.	Once the sensor platform is secured the Person in Charge will notify the Captain to will maneuver to recover the ground line buoy and attached rope.
9.	The rope will be attached to the capstan by the deckhand and the ground line anchor weight lifted to the surface.
10.	With the ground line anchor on board the ground line can be recovered by hand or with assistance from the winch at the deckhand's discretion.

In the event of an Float Release Mechanism (FRM) failure, the recovery starts at the surface float. If the surface float has also been compromised, the recovery must be made by means of grappling for the ground line.

- **Grappling Recovery Procedure**

Vessels should be equipped with purpose build grapnels for grappling small gauge ground lines:

FIGURE 5 TYPICAL STYLE OF GRAPNELS

The following is a for a grappling recovery with the Nova Endeavor:

Grappling Recovery Procedure	
Item No.	**Task**
1.	On slack tide, the vessel will approach the ground line at the middle and drag the grapnel for recovery; attempts will be made at the Nova Endeavor's Deck Boss' discretion.
2.	If mid-point grappling is unsuccessful, the Nova Endeavor will take additional runs for the ground line while incrementally proceeding toward the clump.
3.	If progression toward the clump is unsuccessful, the vessel will take additional runs for the ground line while incrementally proceeding toward the platform.
4.	Once grappling is successful, the ground will be brought to the surface and at the vessel's Deck Boss' discretion, progress will be made toward the clump or the platform, depending on where and how the ground line was collected.
5.	Recovery will be done using the same winch / wire stopper method described above.

To mitigate the risk of grappling procedures, the minimum distance between parallel ground line arrangements in any deployment area should be 50 m. Ideal distance between ground line arrangements is 150 m or more.

- **Post Deployment Condition Report for the Fundy Advanced Sensor Technology (FAST) Platform - September 2017 Deployment** -Source: *POST- DEPLOYMENT CONDITION REPORT FOR THE FUNDY ADVANCED SENSOR TECHNOLOGY (FAST 3) PLATFORM SEPTEMBER 2017 DEPLOYMENT – T. Windeyer with Tyler Boucher and Haley Viehman. Full report in appendix 2.*

The FAST 3 Small Autonomous Sensor Platform has been developed to provide oceanographic and environmental data for design engineering purposes and environmental monitoring. It is equipped with instrumentation to provide data on fish and marine life as well as tidal currents and water quality in the water column near the tidal energy site. This is the third stage of the oceanographic data acquisition program implemented by FORCE.

- **Platform Description**

Photo below shows the platform and instruments setup and ready in the workshop prior to deployment. Table 1.1 lists the instrument mounted on the platform and their functions.

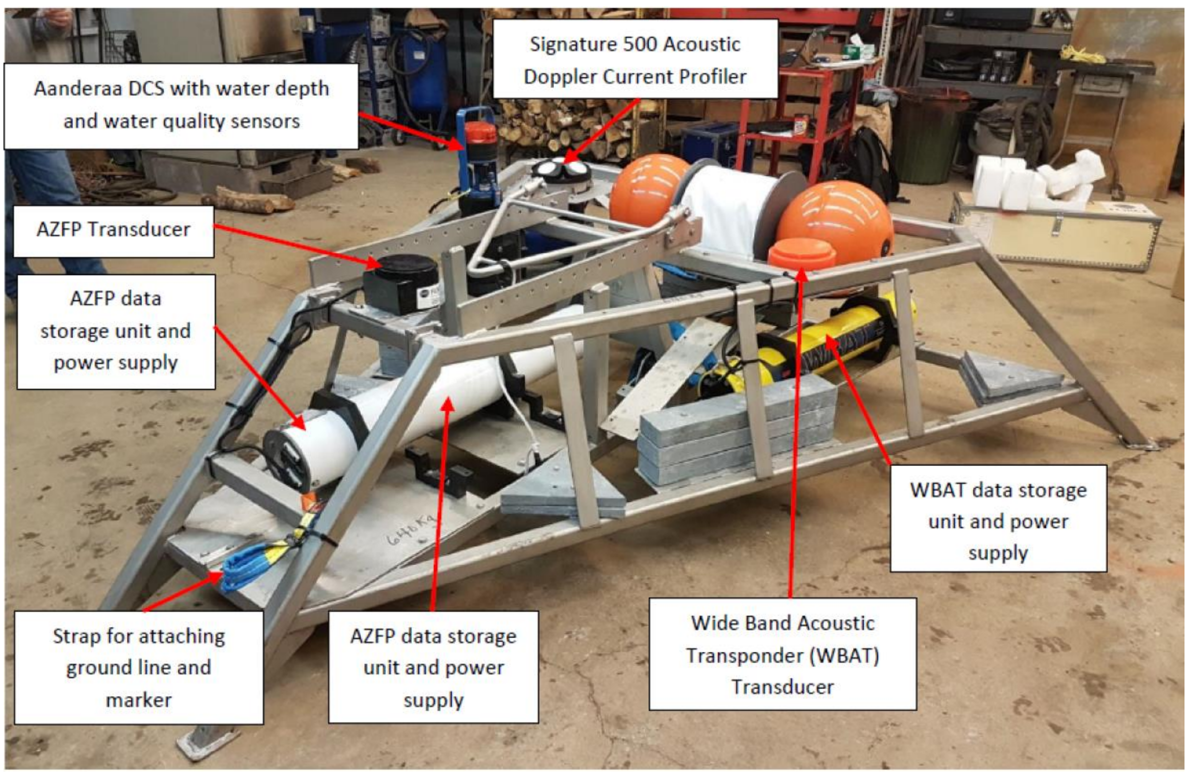


FIGURE 6 PHOTO HALEY VIEHMAN – FAST PLATFORM

- **FAST 3 Measurement Parameters, Instrument Array and Units**

Measurement	Source	Range and Units
Current speed and direction by depth	Signature 500 ADCP	cm/s, degrees true, metres and tenths.
Current Speed and Direction	Aanderaa Seaguard DCS	cm/s, degrees true, metres and tenths.
Conductivity	Aanderaa Sensor 4319A	0-7.5M/s ±0.005 S/m, seimens per meter
Water Temperature	Aanderaa Sensor 4060	-4-+36°C ±0.03°C degrees, tenths and hundredths C
Turbidity	Aanderaa Sensor 4112B	0-500 turbidity units
Instrument Depth/Water Level	Aanderaa Sensor 52177	0 - 1000kPa, ±0.04° FSO
Fish and objects in the water column	ASL Acoustic Zooplankton and Fish Profiler (AZFP)	Echo return and depth
Fish and objects in the water column	Simrad Wide Band Acoustic Transceiver (WBAT)	Echo return and depth

- **Environmental Design Criteria**

The extreme environmental conditions of the project site place significant demands on instruments and the physical integrity of the platforms on which they are mounted during deployment. The design and construction of FAST 3 platform is based on the following design considerations:

  - High current speeds and rapid changes in direction which affect the stability and survivability of the platform and create drag on the structure, connecting cables and instruments;
  - Wave and tide conditions which limit the timing of safe deployment/recovery operations;
  - Turbulence in the water column which affects stress loads and sensor mounts;
  - Water velocity and salinity which exacerbate the metal corrosion;
  - Suspended sediment in the water column which causes abrasion to subsea component and potential damage due to impacts and accretion on instruments and fittings. (High current speeds (> 500 cm/s) can mobilize large obstacles such as rocks and boulders);
  - Accretion of fouling containing sediment and marine organisms which can exacerbate corrosion of components and cause instrument failure;
  - Water level fluctuations (tides) vary the water pressure on instrument housings and watertight components which may induce stress and fatigue;
  - Debris and ice can be carried long distances in the water column and may pose impact hazards to the structure.

- **Deployment/Recovery Features:**

  The following features have been incorporated into the platform design to facilitate deployment and recovery of the platform:

  - There is a lifting bracket on the top of the platform to facilitate adjusting the platform to a level attitude when lifting.
  - A "pop-up" buoy has been installed for recovery. The pop-up buoy is released by an acoustic release on the platform which is operator activated from the surface using a command unit and hydrophone. When released, a buoy floats to the surface on a retrieval line attached to the platform.
  - As a secondary recovery system, a 75 meter, ½" diameter vinyl coated wire cable ground line is attached to the front cross member of the platform and to a chain clump anchor to which a surface buoy is attached. Photo below shows the marker line and buoy readied for deployment. The ground line is payed out during deployment and lies on the seabed between the platform and the clump anchor. This provides two additional recovery methods in case of failure of the pop-up buoy: 1; the marker buoy can be retrieved to recover the ground line cable which will lift the Platform to the vessel; or. 2; in case the marker buoy is lost, the ground line can be recovered by dragging a grapnel along the seabed to snag and lift the ground line aboard the recovery vessel.

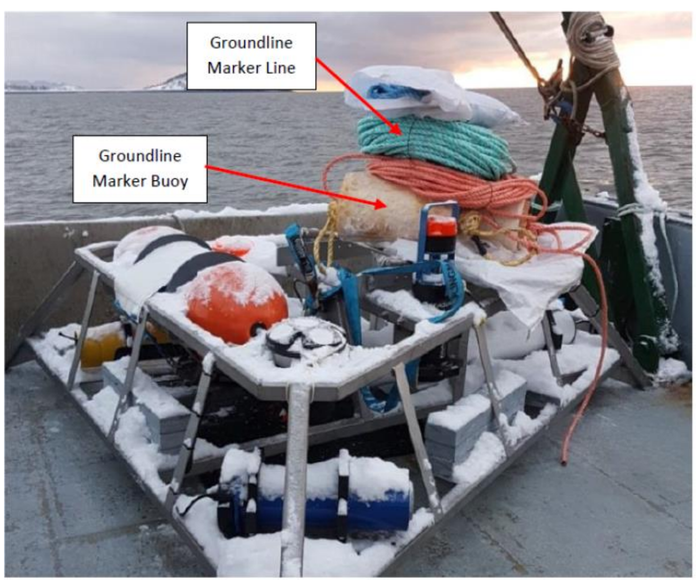


FIGURE 7 PHOTO COURTESY OF HALEY VIEHMA

- **MOORING TRIALS AND DATA CABLE RECOVERY**

  Source: Prepared by - R.J. MacIsaac Construction Ltd. / Seaforth Geosurveys Inc. for FORCE.

Station-keeping and cable recovery trials were conducted using RJ MacIsaac's TKL5 barge in the Bay of Fundy. The following document contains a detailed report of the objectives, approach, and results of trial operations over the duration of the project, from June 2014 to December 2015. Through strategic, detailed planning and constant risk management, project operations were executed safely and effectively. The experience and site knowledge gained throughout project operations provided valuable information for future project planning.

- The project objectives were two-fold:

  1. To develop and demonstrate a method of maintaining a work vessel on station, within a limited range of movement, for a defined period of time, and

  2. to apply this method to recovery of the subsea data cable at FORCE. Specific criteria for movement range and timeframe were established to evaluate demonstrated station-keeping ability.

The suite of marine assets and equipment used in the trials included the TKL5, two tugs (primary tug and support tug), a safety vessel, and several winches and specialized lifting and anchor equipment. Procedures to deploy and recover the anchors were developed and tested in both low-flow and high-flow test sites; procedures and equipment were revised throughout the project, to improve safety, capacity and efficiency.

Trials were conducted over 4 phases, primarily in neap tide conditions with the exception of one set of spring tide trials. Precise position-monitoring was used to track barge movement. Three different anchor types were tested, with two deemed suitable to safely hold the barge at anchor in various seabed types for the duration of a half tidal cycle (flood or ebb). A final anchor assembly was designed that incorporated different anchor holding mechanisms, adding redundancy to the mooring. A stern anchor was added in the final demonstration, and initially resulted in reduced barge movement before losing hold of the seabed.

A test tackle assembly was used to test the procedures developed for cable recovery. During the final trial phase, a station-keeping and test tackle recovery demonstration was executed; while the performance did not meet the full requirements, the results were deemed sufficiently accurate to proceed to cable recovery. Data cable recovery was initiated but was aborted due to failure of the cable mooring.

Safety, hazard assessment, and risk management were major considerations throughout the project, and safety considerations were integrated into all project decisions. Detailed project safety plans were developed and communicated to maintain safe working conditions.

The station-keeping and cable recovery trials successfully demonstrated a method of establishing and maintaining station with the equipment and configuration used in these trials. However, the trials did not meet the original criteria, indicating that there may be a limit to the minimum movement range that can be feasibly achieved with this approach.

The following recommendations are presented based on trial outcomes:

1. A three-point anchor system, using a primary bow anchor and two positioning anchors, is likely the most effective approach for maintaining station with minimal movement. This approach would be recommended for cases where the primary anchor can be deployed directly from the bow, thus reducing deployment time and eliminating the need for a preestablished mooring.
2. A detailed analysis should be conducted to determine the minimum capacity of the primary tug. Limitations in tug capabilities can significantly hinder project operations and can introduce additional risks.
3. Detailed project planning, that addresses safety, risk management, weather conditions, and coordination/communication, and strategic scheduling, that accounts for tidal cycle, flow conditions, daylight hours, and transit times, are crucial for successful station keeping operations. Knowledge of unique site conditions, including variation in flow speeds, water depth range, and seabed characteristics, should be incorporated into project plans. Full Report can be found in Appendix 4 Station keeping and mooring trials.

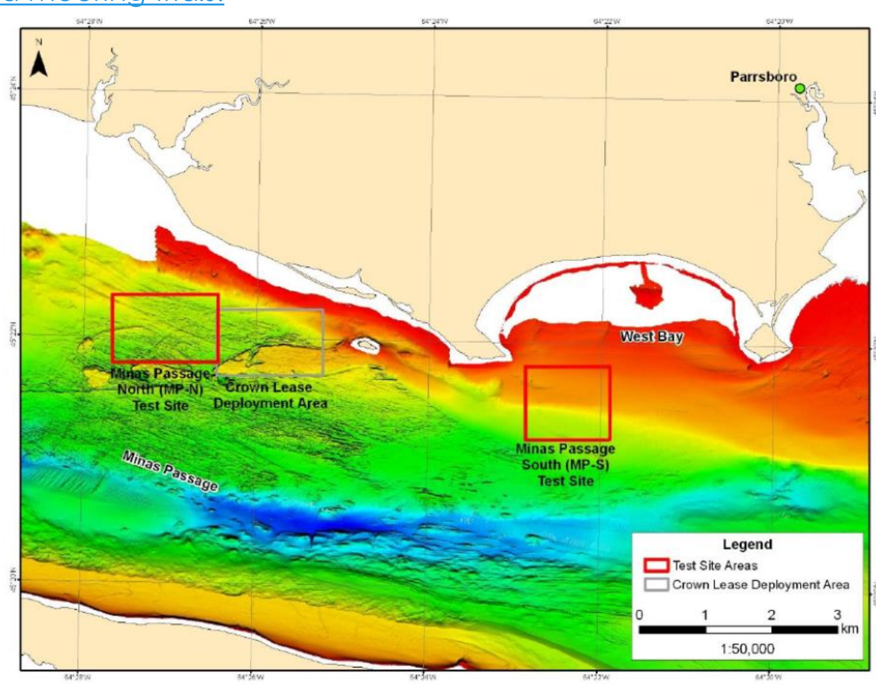


FIGURE 8 TEST LOCATIONS

This document touches a bit on the FAST program and more detailed information about FAST can be found in Appendix 2.

Vendors

A wide variety if vendors are used and have contributed to the marine operations in support of the tidal industry in Nova Scotia. Many of these have been compiled by Marine Renewables Canada and are listed in their Supply Chain database.

Marine Renewables Canada developed Canada's first database solely focused on the supplier capabilities for marine renewable energy projects. Through a publicly accessible online platform, the database assists in identifying, assessing, and engaging businesses and organizations with capabilities that can aid in the advancement of the marine renewable energy sector. It also helps to ensure that Canada's supplier strengths are profiled amongst other jurisdictions that are putting significant investment and resources into building their marine renewable energy supply chain and have developed similar tools.

Appendix 1: Vessel Information

Appendix 2: FAST Reports

Appendix 3: Diving

Appendix 4: Station Keeping / Mooring Trials

Appendix 5: Video

- Oceaneering ROV Video

    - ROV Video 1
    - ROV Video 2
    - ROV Video 3

- Dive Operations Video

    - FAST Platform Dive Video

Acknowledgments:

This report was made possible through the cooperation of the companies mentioned below. Further updating of this document will be required as this is essentially a "Live" document. As activity in the Minas Passage and the surrounding Bay of Fundy increase it is the hope that this information will expand, and a yearly update can be released with the assistance a cooperation of all involved in activities in the Bay of Fundy.

I thank all that have provided input to this report and look forward to working with you all in the future.