

Tidal Research Center Framework

Svelvik TRC Project

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Tidal Research Center Framework

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Abstract

In order to achieve sustainable future, humanity needs renewable sources of energy. Tidal energy has the potential to complement wind and solar in renewable mix. Several ways exist to extract tidal energy. One of them is to use tidal in-stream energy converters. This requires building a research center. Construction and operation of tidal research center demands collaboration of numerous parties. Environmental surveys define the impact on the nature from almost every activity that takes place at research center. Prior to the construction preliminary research should be done. The focus areas will depend on the location of potential tidal center. In the case of Svelvik tidal research center one of the main focus areas is vessel traffic due to the confinement of the Drammensfjorden. This research found that 8 areas around Svelvik are potentially available with little or no interactions with shipping lanes. They can be considered for further assessment.

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Abbreviations

ADCP - Acoustic Doppler Current Profiler

AIS – Automatic Identification System

CAD – Canadian Dollar

EIA – Environmental Impact Assessment

EMEC – The European Marine Energy Centre

FORCE – Fundy Ocean Research Center for Energy

FOW – Fall Of Warness (full scale tidal test site in Orkney)

GBP – British Pound

GRT – Gross Register Tonnage – defines the moulded volume of all enclosed spaces of the ship in register tons. 1 register ton is equal to 100 feet³ or 2.83m³

GT – Gross Tonnage – defines the moulded volume of all enclosed spaces of the ship

IALA – International Association of Marine Aids and Lighthouse Authorities

ISEC – In stream Energy Converter

ISO – International Organization for Standardization

NCA - Norwegian Coastal Administration (Kystverket,-*nor.*)

NIVA – Norwegian Institute for Water Research (Norsk Institutt for Vannforskning,-*nor*)

NOK – Norwegian Krone

NV – High Voltage

RES – renewable energy resources (or sources)

ROV – Remotely Operated underwater Vehicle

SEA – Strategic Environmental Assessment

Summer DWT – maximum permissible deadweight tonnage at draft corresponding to the assigned summer freeboard of the vessel

TAP - Technology Assessment Process at EMEC

TISEC – Tidal In Stream Energy Converters

TOE – Tons of Oil Equivalent

TRC – Tidal Research Centre

Unit conversion

$$1 \text{ acre} = 4046.86 \text{ m}^2 = 0.00404686 \text{ km}^2$$

$$1 \text{ m/s} = 1.94384 \text{ knot} = 3.6 \text{ km/h}$$

$$1 \text{ MW} = 10^3 \text{ KW} = 10^6 \text{ W}$$

$$1 \text{ ft}^2 = 0.092903 \text{ m}^2$$

$$1 \text{ nm (nautical mile)} = 1852\text{m}$$

$$1 \text{ cable} = 0.1 \text{ nautical mile} = 185.2\text{m}$$

1 Introduction

Energy production is the main source of the anthropogenic emissions of CO₂ and other greenhouse gases. It is estimated that around 70% of all man made greenhouse gases derive from the energy sector. In the year 2008 emissions of CO₂ reached 30 billion ton. That is twice as much as in 1970. (Höök & Tang, 2013)

1.1 Importance of Renewable Energy and Sustainable Development

For the last two centuries fossil fuels act as an engine accelerating the economic growth of industrialized societies. Fossil energy production levels have grown to approximately 10 billion TOE since 1800 (Höök & Tang, 2013). As for the year 2010, oil production industry extracted 85 million barrel per day or 3.9 billion tons of oil equivalents (TOE) per year. Coal and natural gas production add up additional 3.7 billion TOE and 2.9 billion TOE respectively. As for 2011, around 80% of all primary energy was extracted from fossil fuels. Oil accounted for 32.8% while coal and natural gas stand for 27.2% and 20.9% respectively¹.

The shares of non-fossil fuels are much lower with combustible biomass and waste accounting for 10.2%, nuclear power – 5.8%, hydro energy (dams) – 2.3%. Renewable resources such as wind, solar, geothermal energy and tides account just for 0.8% of the total primary energy production¹.

The current system of energy extraction and distribution is highly centralized. Oil resources are spread across 50-70 thousand oil fields around the globe however around 60% of oil is extracted from 300 giant fields. Coal reserves are very unevenly distributed with about 90% concentrated in six countries¹.

It was found that in between the periods when the rate of global production of fossil energy doubles, mankind consumes more fossil fuels than during all previous periods combined. If

¹ (Höök & Tang, 2013)

the forecast for global production rate is valid, then the production should double in 2040. In this case in a period 2010-2040 the humanity will consume more hydrocarbons than during the last two centuries. It is expected that global energy demand will grow rapidly with an exponential increase by 2050. A higher level of life means increased demand for energy. Developed countries that account for around 25% of the total population tend to consume about 75% of the world's energy. (Dincer, 2000)

General public agrees that coal, oil, natural gas, and other fuels including uranium are finite while hydro-, wind- and solar power are renewable and as a result can be seen as sustainable. But despite alertness about fossil fuel depletion as well as understanding about the finite supply of oil, gas and coal, the issue of physical resource availability has not been widely discussed. The energy is often acknowledged as a limitless input to economic planning. This results in the fact that demand for energy is properly determined, but is not correlated with physical supply (Nel & Cooper, 2009).

According to Höök & Tang numerous studies show that transition to unconventional fuels or renewables will continue slowly. It is unlikely that renewable energy will be able to evenly fill the gap when hydrocarbons deplete. Rogner H. claims that there are enough fossil fuels physically available on Earth. It is theoretically possible to sustain production for an extended period of time. (Rogner, 1997) Höök & Tang argue that resources can only be relevant for human kind if they can be exploited. Factors that influence the rate of exploration depend on the demand and flow of resources rather than just availability.

To cope with energy demand and environmental issues mankind needs to take long term measures in order to achieve sustainable development. One of the most effective ways is to switch to renewable energy production. That is why there is a close connection between renewable energy and sustainable development. "Sustainable development is that meets the

needs of society today without compromising the ability of future generations to meet their own needs”, (Dincer, 2000).

Ideally sustainable development requires sustainable sources of energy that have no impact on the environment (no emissions) and society. Any energy production contributes to some degradation of the environment but the activities that lead to the *continuous* degradation of the environment cannot be seen as sustainable. (Dincer, 2000)

The utilization of renewable energy resources (RES) is a crucial component for sustainable development. There are three substantial arguments for this².

1. RES produce much smaller environmental footprint compared to other energy sources
2. RES can't be depleted compared to fossil fuels or uranium resources. When utilized appropriately and efficiently they can supply energy for many years to come.
3. Utilization of RES favors grid decentralization. This contributes to improved stability and flexibility of a grid as well as provides energy to remote and grid isolated regions.

(Lynn, 2013)

1.2 Tidal energy, its pros/cons; and its place in the renewable mix

Tidal energy conversion is a promising renewable source of energy that has a potential to complement existing renewables such as wind, solar and geothermal heat. (Lynn, 2013) As for today, one can find 3 ways of harvesting energy from the tides: by the means of barrages, tidal lagoons and in-stream energy converters.

1.2.1 Tidal Barrages

Tidal barrages use potential energy of the difference of the sea level as shown at Figure 1 and Figure 2. This difference occurs when gravitational pull from the moon or sun acts on the

² 1st and 2nd argument: (Höök & Tang, 2013)

water. The best place to construct barrages is across river estuaries or bays with high tides. When the difference between the sea level and the water level in a bay is sufficient, locks open and the water rushes through turbine blades generating electricity. The same process happens in reverse.

The construction of barrages is being criticized as environmentally unfriendly as it tends to block the whole estuary. Research connected to the possible construction of tidal barrage across Severn estuary in UK shows both negative and positive aspects of such construction. The area of mudflats exposed in the estuary would be reduced. That means a smaller area available for wading birds. However less turbidity of the water would mean that less sediments this water contains. Clean water can sustain more biological species. (Johnson & Veliotti, 2010)

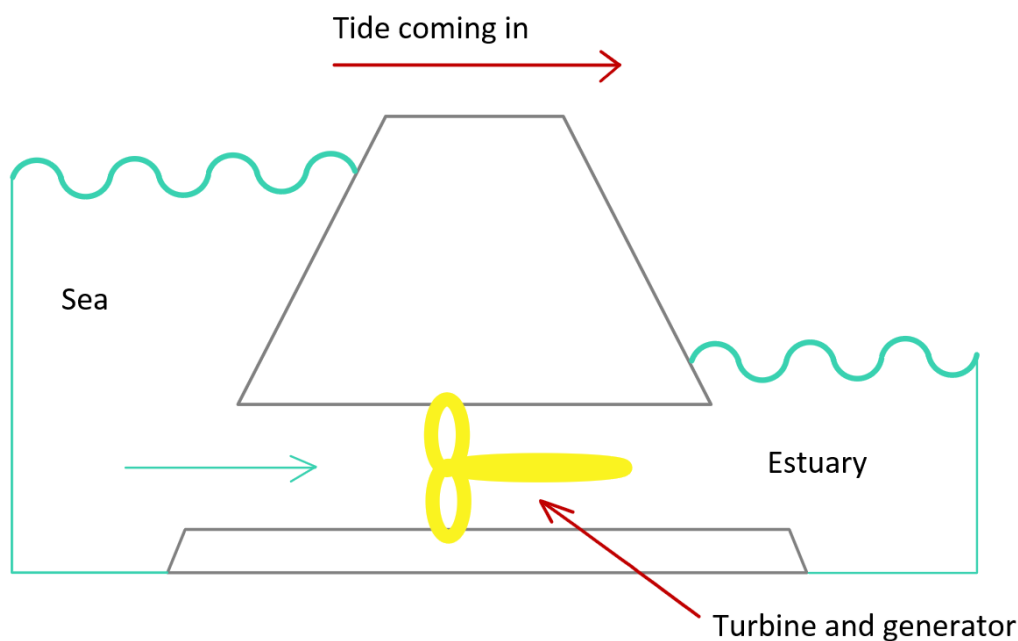


Figure 1: Tidal Barrages, tide coming in; Data: www.Tidalenergy.eu; Graphics: OneNote

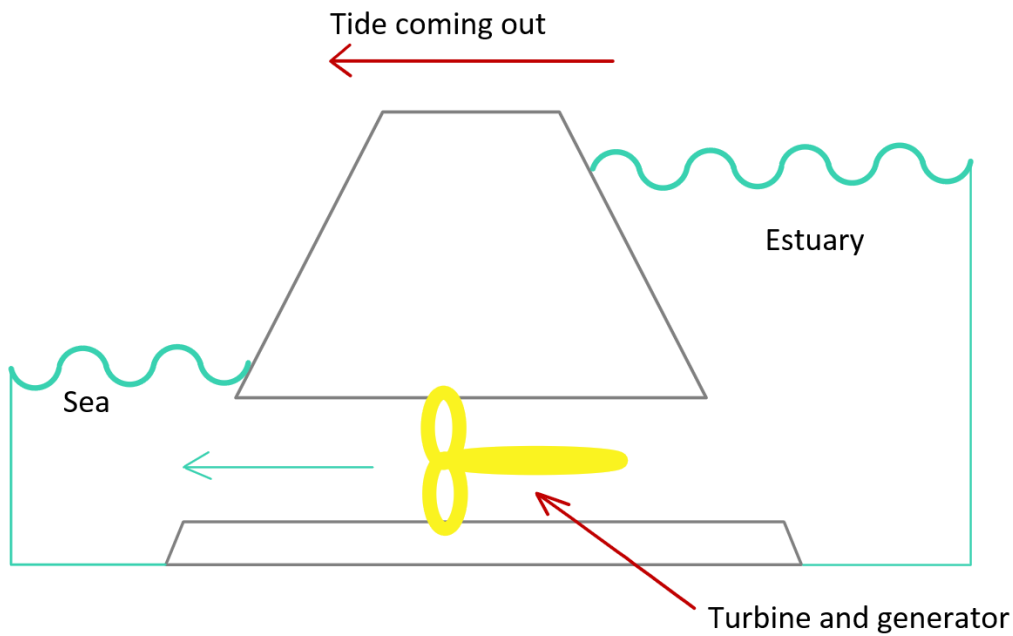


Figure 2: Tidal Barrages, tide coming out; Data: www.Tidalenergy.eu; Graphics:

OneNote

1.2.2 Tidal Lagoons

Tidal lagoons use the same method as barrages. The difference is that a certain part of the estuary is separated leaving a natural water flow in the rest of the estuary³.

³ (Tidal Lagoon (Swansea Bay) plc.)

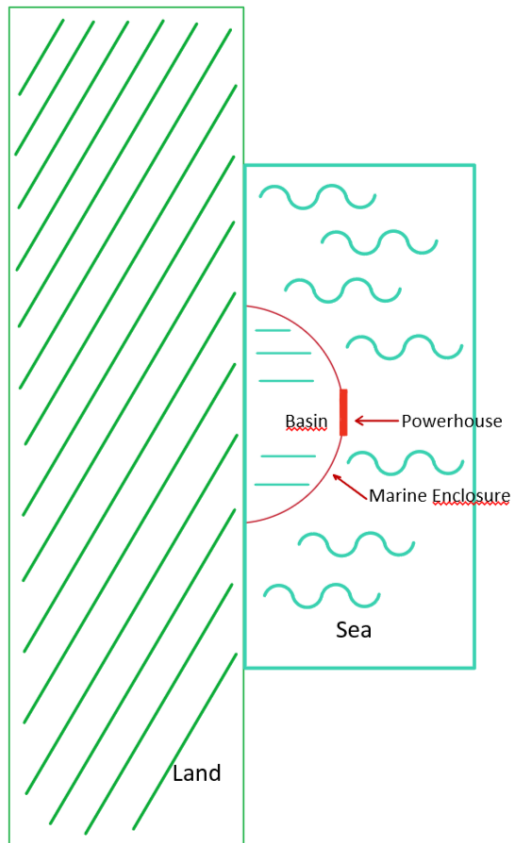


Figure 3: Tidal Lagoon; Data: Tidal Lagoon (Swansea Bay) plc. Graphics OneNote

1.2.3 Tidal In-stream Energy Converters

Energy converters or turbines work in a similar way to wind turbines. Like wind turbines they can be in a variety of shapes and sizes. While they are not able to catch as much energy as barrages or lagoons they have several advantages⁴:

- Turbines do not block the waterway or estuary
- Design is flexible and scalable. Various types are on the market today.
- TISECs can be gathered into an installation like a wind farm.
- Separate turbines of different size and type can be placed in different parts of estuary

⁴ (Johnson & Veliotti, 2010); (EMEC)

2 Framework for Tidal Research Center

The thesis researches a framework for development and operation of TRC. It is possible to divide the whole framework for TRC into two parts of vertical and horizontal integration⁵.

Figure 4 shows the framework as a block scheme. This idea was expressed by Nova Scotia Department of Energy⁶.

In this document the vertical part is called “Framework for development of Nova Scotia’s Marine Renewable Energy Industry” while the horizontal part is not clearly defined.

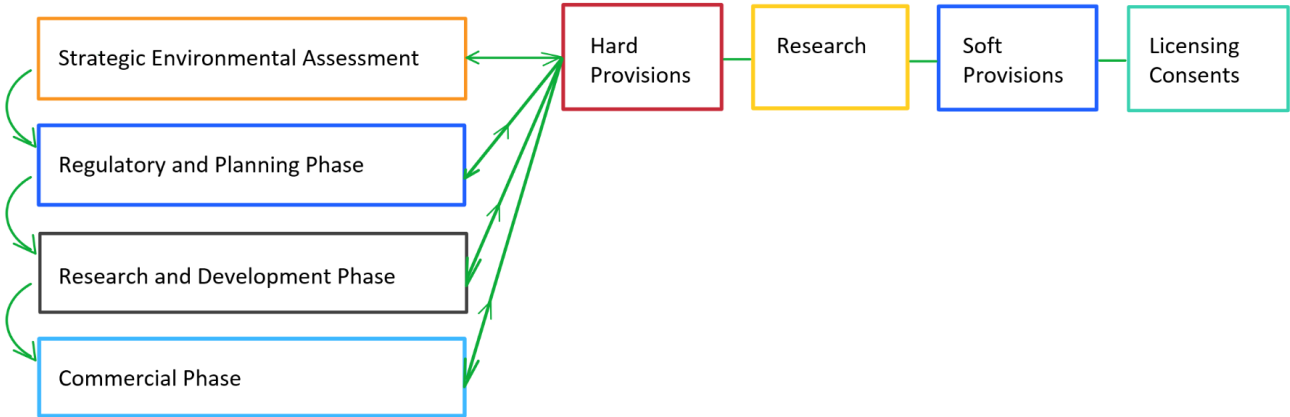


Figure 4: Vertical and horizontal integration in the framework for TRC. Data: Nova Scotia Department of Energy; FORCE; EMEC. Graphics: OneNote

This master thesis looks into the details of horizontal part of the framework and how those details apply to different stages of development of TRC.

The vertical part represents 4 phases progressing as the time goes. As the research has showed they can overlap each other but the order does not change.

Vertical part phases⁷:

⁵ Definitions of vertical and horizontal integration are given by the author based on how different parts and stages of the framework interact with each other.

⁶ (Nova Scotia Department of Energy, 2010)

⁷ (Nova Scotia Department of Energy, 2010)

1. Strategic Environmental Assessment – is the process prior to the decision to start a project of TRC research and development. At this stage interests of stakeholders are considered while the stakeholders can influence decisions on planning, management etc.
2. Regulatory and planning phase – during this phase the research is done to determine what environmental studies are required in order to comply with regulatory requirements and apply for the area leased.
3. Research and development phase is a phase when pre commercial prototypes are tested on the site, developed and tested again. According to FORCE and EMEC experience and the experience of their clients this can take from several months to several years⁸.
4. Commercial phase is a phase of commercial deployment.

The horizontal part of the framework like the vertical one can be divided into 4 main categories (**Figure 4**). These categories stick together, influence and complement each other at every stage.

1. Physical constructions or hard provisions include the main construction with the infrastructure and post construction installations.
2. Research – necessary research on the each stage of the project beginning with a preconstruction phase up to continuous monitoring of the facilities and prototypes under operation.

⁸ (FORCE); (EMEC, 2016b)

3. Services or soft provisions. This category includes services required before and after installation as well as services provided by the tidal research center to the developers in order to be competitive and to ensure safe and reliable operation.
4. Licensing Consents – licensing and legal documents required for operation.

2.1 Choosing Tidal Research Centers for analysis

To analyze the framework, two Tidal Research centers were chosen.

1. The Fundy Ocean Research Center for Energy or (FORCE) in Nova Scotia, Canada
2. The European Marine Energy Centre or (EMEC) in Orkney, Scotland, UK

These two centers were chosen for the following reasons:

- Established and operational tidal sites
- Several years of operational experience
- Comprehensive research covers most of the aspects of construction and operation
- Information Availability

Tidal Research Centers and projects that did not match the criteria and are not used in this thesis:

1. Tidal Testing Center in Netherlands is located at Den Oever in northern Holland. It provides testing at intermediate scale at sluice gates; water flow up to 5m/s; site is connected to the grid with capacity of 160kVA (Tidal Testing Center, 2012)
2. QUB - Portaferry Tidal Test Centre in Northern Island, UK (MARINET)

3. Pacific Marine Energy center⁹ in the United States of America unites several energy centers at the following locations:
 - Oregon, US¹⁰; Two test sites; North Energy Test Site for scaled prototypes up to 100KW with no grid connection; South Energy Test Site is a full scale grid connected site currently under development;
 - Washington, US¹⁰; Two test sites for scaled prototypes; available in period October to March
 - Alaska, US; Full name: Alaska Hydrokinetic Energy Research Center¹¹;
 - California, US; CalWave site is on the stage of strategic assessment¹².
4. Some interest was expressed in France in 2013¹³ but so far the research has found no evidence on new TRC projects in France.

General facts about FORCE and EMEC

FORCE:

- TRC is located on the northern coast of Minas Passage at the Bay of Fundy, around 10 km to the west of the town of Parrsboro
- The development of the site starts in 2008; FORCE is incorporated in 2009¹⁴; the first client – Open Hydro tests 1 megawatt turbine in 2009; main facility opens in 2011; four subsea cables are installed in 2014¹⁵

⁹ (Northwest National Marine Renewable Energy Center, 2014)

¹⁰ (Oregon State University, 2016)

¹¹ (Alaska Center for Energy and Power, 2016)

¹² Assessment area: (Esri & GEBCO)

Details: (California Polytechnic State University, 2014)

¹³ (Subsea World News, 2014); (PAYS DE LA LOIRE, 2015)

¹⁴ (FORCE; EMEC)

- The test site features 4 berth positions intended for full scale prototypes and commercial use with grid connection.

EMEC:

- EMEC main facility is located in Stromness; the full scale wave test site is located in Stromness; two sites for small scale tests and component testing located near Kirkwall on the same island; Fall of Warness full scale tidal test site is at the island of Eday (**Figure 17**).
- EMEC established in 2003; the first site to open is a wave test site in 2004; Fall of Warness becomes operational in 2006; the first client at FOW – Open hydro in 2008; Shapinsay Sound (tide) and Scapa Flow (wave) both are sites for scaled tests are open in 2011¹⁶.
- Fall of Warness features 8 berths with grid connection; Shapinsay Sound has no grid connection but a test buoy that dissipates excessive power (**Figure 42**) Fall of Warness testing site implies real sea conditions with spring tides of about 3.5 m/s in a south-easterly direction and about 3.3 m/s in a north-westerly direction, while neap tides occur to have around 1.5 and 1.3 m/s, respectively. Eight berth positions are provided at depths of between about 35 and 50 m, and there is also an underwater turbine test platform at a depth of about 10 m” (Lynn, 2013)

Two centers collaborate with each other under a strategic relationship sharing knowledge and experience¹⁴.

¹⁵ (FORCE, 2015)

¹⁶ (EMEC, 2016a)

2.2 Physical constructions or hard provisions

Schematically physical construction can be represented by five blocks and connections between them as in **Figure 5**

The blocks in **Figure 5** that stand for outside institutions and facilities, in stream energy converters and power grid are not within the scope of a tidal research facility construction. However they are of considerable importance as they represent some of the major stakeholders in a project building.

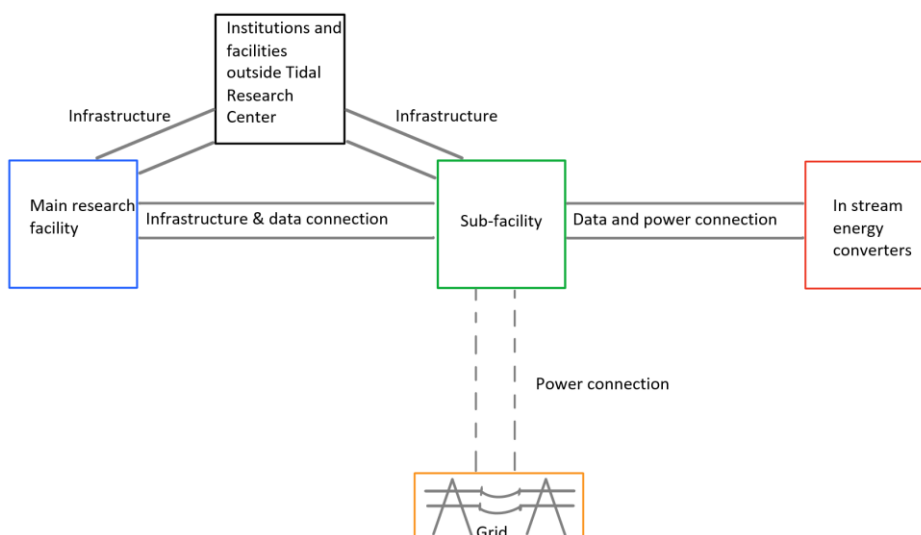


Figure 5: Block Scheme of Hard Provisions of TRC. Data: FORCE; EMEC.

Graphics: OneNote

2.2.1 Institutions and facilities outside Tidal Research Center

There are a number of institutions and organizations that can supply hard provisions required for construction and operation of TRC. Most of suppliers provide both hard provisions (materials, equipment, human resources) and services¹⁷ combined.

¹⁷ Data is from “Energy of Orkney” and companies listed on their home page.

In this section only types of companies are listed based on the experience from Orkney. For more detailed information and companies’ names see the list at: <http://www.orkneymarinerenewables.com/supply-chain.asp>

Regulatory and planning phase

- Agents; Brokers
- Regulators; Controllers
- Survey work
- Planning

Construction phase

- Cable laying
- Construction management
- Fabrication
- Assembly
- Lifting
- Underwater services

Operation phase

- Anchor handling
- Monitoring
- Maintenance
- Vessels

Decommissioning

- Scrap clearance
- Contamination clean-up
- Salvaging

2.2.2 Main Research facility

Main facility or headquarters is a facility that represents TRC. Depending on the scale of TRC and its primary goal, headquarters can be shaped in different ways. The area required for construction will also depend on the overall size of TRC. FORCE visitor center in Canada has an area of 3000 square feet or 278 square meters. It includes rooms for interpretive exhibits, a little theater or a community room, space for meetings and research work. On the other hand the main research facility of EMEC in Stromness includes offices for the developers. Each office is fully furnished and has SCADA PC workstation. This grants access to the data provided by EMEC as well as performance statistics from the correspondent prototype(s). As far as this research goes neither of the main facilities provides accommodations. According to the official data, developers working at FORCE can rent apartments in a town of Parrsboro that is 10,5 km away (FORCE). Those who are testing at EMEC can find a place in the town of Kirkwall which is around 25 km from the main facility (EMEC). However the research has found that one can rent accommodations very close to both centers. **(Figure 17)**

The center at the Bay of Fundy focuses on the visitors experience providing them with the view of the aquatory and the test site through large windows. According to Google Earth, the center's ground elevation at the Bay of Fundy is around 13m above the sea level. (FORCE, 2010) The EMEC building in Stromness has no observation opportunities of any of its test sites.

2.2.3 Sub-Facility

Sub-facilities are the link between the main center and sub-sea installations. Sub-facilities include connections to underwater cables, electrical sub-stations for transferring electricity generated by prototypes to the local power grid. Substations provide refining and purifying

electrical equipment to enhance the quality of produced electricity. This is required in order to reach the standards of the national grid. (EMEC) Data connection is provided, where the raw data from prototypes' sensors is collected, analyzed and sent further to the main facility or processed at substations by developers. **(Figure 14)**

European Marine Energy Center possesses two sub-facilities for full scale wave and tidal test sides. The initial project for the construction of a sub-facility at Fall of Warness (Name: Caldale EMEC onshore facility) together with a road system was estimated to last 3 months. Additional work on cable laying for onshore part and connection to the substation was expected to take two weeks. The size of the building is 165m² with dimensions 30x5.5 meters. External area counts for extra 300m² or 20x15 meters, making total area of 465m². The design reflects traditional buildings from the local area. (AURORA Environmental Ltd, 2005) The initial facility provided connection to four cables. Today eight cables are connected. One of them is temporary while seven others are permanently installed. (Appendix 4)

Inside the substation cables are connected to high voltage circuit breaker panels. From the switchgear a step-up transformer converts 11kV electricity from tidal devices into 33kV. Electricity passes through power factor correction equipment and is fed into the grid. It should be stepped up again at some point as the electricity transition network at Orkney operates at 132kV. (Scottish and Southern Energy, 2014); (Energy)

The substation has an uninterruptable power supply or UPS and generator in standby mode. This equipment is essential for uninterrupted data processing that comes from prototypes.

At FORCE sub-facility connects four permanently installed subsea cables to the grid. The design of a building is a steel construction. Voltage levels are unknown to the research. According to the equipment ordered for installation the voltage should be: 13.8kV intake,

138kV output. The station should have a UPS with a battery system and a low voltage circuit of 240/120V. (FORCE, 2011) According to the measurements made with the help of Google Earth Pro satellite imagery the area¹⁸ of sub-facility is around 75x65 meters or 4875m².

The system for data collection, transfer and analysis is called SCADA and installed at both EMEC and FORCE substations.

2.2.4 Tidal In Stream Energy Converters

Tidal in stream energy converters or tidal devices is equipment that converts tidal energy into electrical energy or kinetic energy of moving fluid.

Currently there are numerous prototypes at different stages of development¹⁹. It is possible to group them into several categories²⁰.

Horizontal axis turbines use the principle of extracting energy that is similar to that of a wind turbine. A rotor moves a generator through the reduction gearbox. In the most of the devices all three components are mounted in one compartment on the horizontal axis. Such design offers compatibility with different blade designs.

¹⁸ It includes just the area inside the perimeter of the facility. Measurements are not official data and can deviate. Deviation can occur due to insufficient accuracy of satellite imagery measurements. Some more area is occupied by road works on the north side and cable trench on the south side. This area is hard to estimate correctly with satellite imagery.

¹⁹ Data for this section is from: (EMEC)

²⁰ Category of Oscillating Hydrofoil is not included because no active companies were found developing this type. The design of Oscillating Hydrofoil can be compared to that of an onshore oil rig. Oscillating arm moves up and down in tidal current accelerated by hydrofoil.

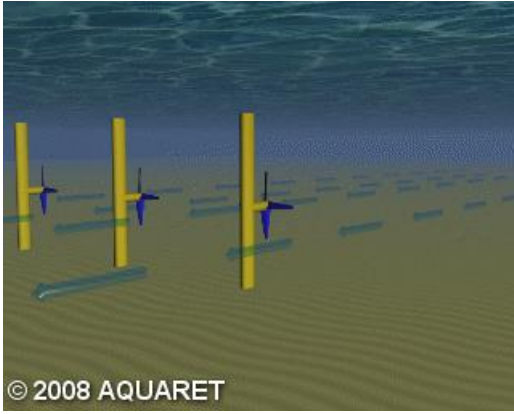


Figure 6: Horizontal axis turbines

Vertical axis turbines are similar to horizontal axis turbines in the way they use kinetic energy of the tide. A gearbox with a generator can be placed above or below the turbine. This offers greater flexibility.

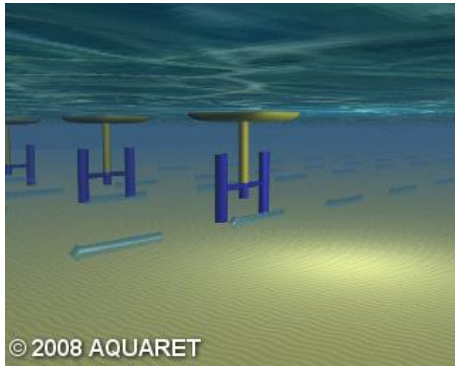


Figure 7: Vertical axis turbines

Enclosed tips represent a turbine mounted on the horizontal or vertical axis and enclosed in funnel-like structure. Such a structure concentrates a current flow onto the turbine.

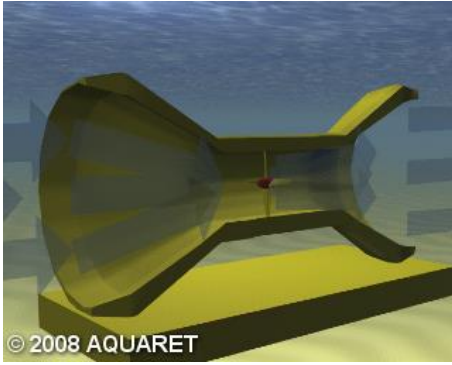


Figure 8: Enclosed tips

Archimedes Screw is a “helical corkscrew-shaped device”- Flumill AS. A rotor gets its rotation when water moves through the spiral of the screw. According to Flumill AS the device makes relatively small turbulence with little cross section. Because of this effect devices can be packed more compact when considering installation of several devices in a group.

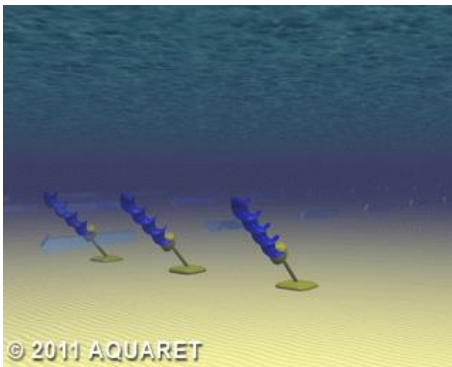


Figure 9: Archimedes Screw

Tidal kite is a device where the turbine is attached to the spoiler resulting in a kite-like shape. The whole body is connected to the seabed mooring point by the wire and moves in a figure-of-eight shape. The advantage of such design is high current flow through the turbine.

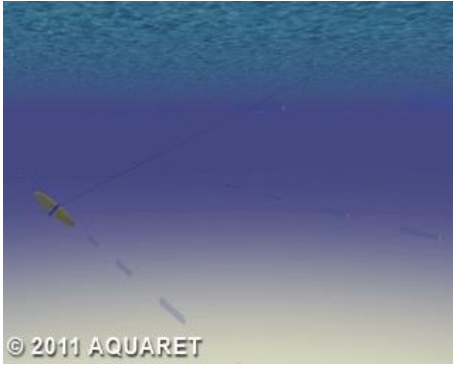


Figure 10: Tidal kite

Electrical power produced by a device in a steady fluid stream will not be equal to the power of the stream.

Electrical power can be estimated by the following formula:

$$P_e = 0.5 C_p * n * \rho * A * U^3 \quad (1)$$

In equation (1) 0.5 is a coefficient that shows a practical limit of how much energy can be extracted from the tidal flow. It is based on the Betz Limit which estimates the theoretical limit for the energy extraction to be 59% or 0.59. Practically we should expect the limit of approximately 50% or 0.5. Details on Betz Limit calculation and some important assumptions can be found in a book “Electricity from Wave and Tide: An Introduction to Marine Energy” by Lynn and Paul A. (2013) (page 93-96)

C_p – is a power factor or how efficient rotor blades convert kinetic tidal energy into mechanical energy

n – is efficiency of conversion of mechanical energy to electrical energy

ρ – stands for density of the fluid. For fresh water it is 1000 kg/m^3 where salt water has density up to 1030 kg/m^3 depending on salinity.

A – swept area of turbine blades

U – fluid velocity

Using this formula it is possible to roughly estimate the size of the TISEC according to the power output required and the area required for operation of this device. Alternatively one can estimate the power output from the device of a given size. One can choose different size of the devices for the areas with uneven tidal current conditions and depths. (Lynn, 2013)

Cubic dependency between velocity U and power output makes it possible that smaller devices in shallow waters with higher current velocities may produce as much power as devices with a larger swept area but at lower tidal speeds.

This cubic relationship requires TISEC to be very flexible to power input and reliable mechanically during large power variations. A tide with low velocity of 0.5 m/s and high velocity of 2.5 m/s represents ratio 1:5. At the same time the ratio of kinetic energy intercepting swept area is 1:125.

Developers consider mechanical reliability as an important factor in cutting maintenance costs. (Scotrenewables; Deep River AS; TideTec) In horizontal axis turbines blades, bearing and gearbox transfer forces from water movement to the turbine structure and generator. It is vital to keep balance between loads on turbine blades and bearings and torque applied to the gearbox. In transmission the higher the ratio between input and output speeds the more robust components should be available in order to cope with higher torque. So operating at slow speed but high torque will require more expensive durable elements. On the other hand high rotational speed with low torque will put more bending stress on turbine blades. (Lynn, 2013)

This relationship²¹ is illustrated in **Figure 11; Figure 12; Figure 13**

²¹ Vector numbers and forces that vectors represent in figures 12-13 correspond to those in **Figure 11**.

Figures 11-13 are just for a representation purpose and do not reflect mathematically calculated forces. Lengths of vectors 1; 2; 4; 5; were chosen such as to show distinctly the relationship between torque, axial force, current speed and speed of rotation. Lengths of vectors 4; 5; and as a result 6 were kept unchanged in figure 12-13.

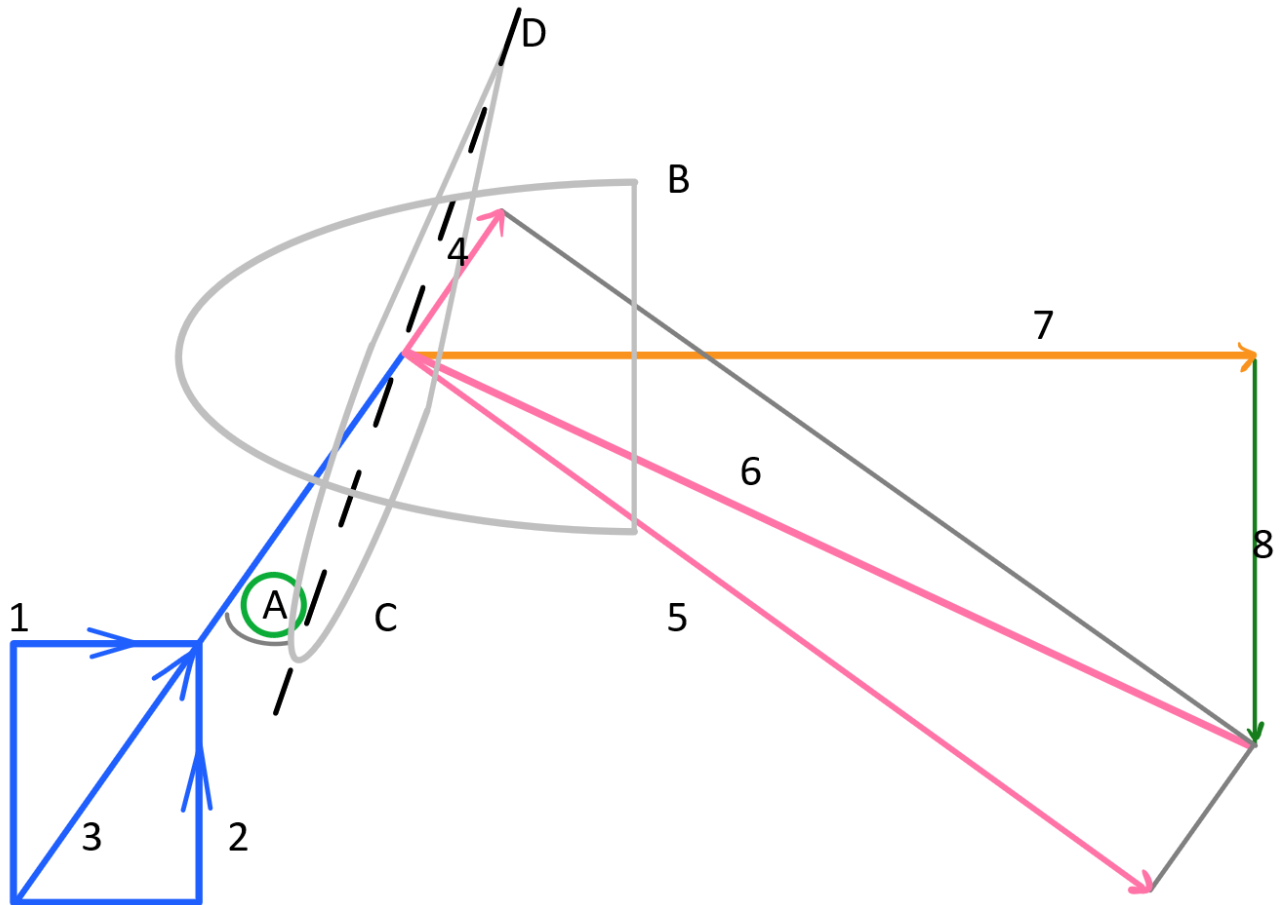


Figure 11 Data: (Lynn, 2013). Graphics: OneNote

Figure 11: 1 – tidal stream; 2 – stream caused by rotation; 3 – resulting vector shows the current influencing rotor blades; 4 – drag from hydrofoil; 5 – lift generated by blades is 90° to resulting current; 6 – net force blade generates; 7 – axial force; 8 – radial force that rotates turbine. A – angle of attack of the blade; B – turbine body; C – blade; D – vector in the middle of blade’s cross section.

In **Figure 11** tidal stream (1) is added to rotational stream (2). The faster blades rotate the more rotational stream is. Vector (7) represents force that tries to bend blades where vector (8) shows how much force is converted into torque.

If rotational speed is increased while tidal velocity, angle of attack and lift force are unchanged then torque decreases, while force on blades steps up. This allows for simpler solutions in gearbox construction. **Figure 12**

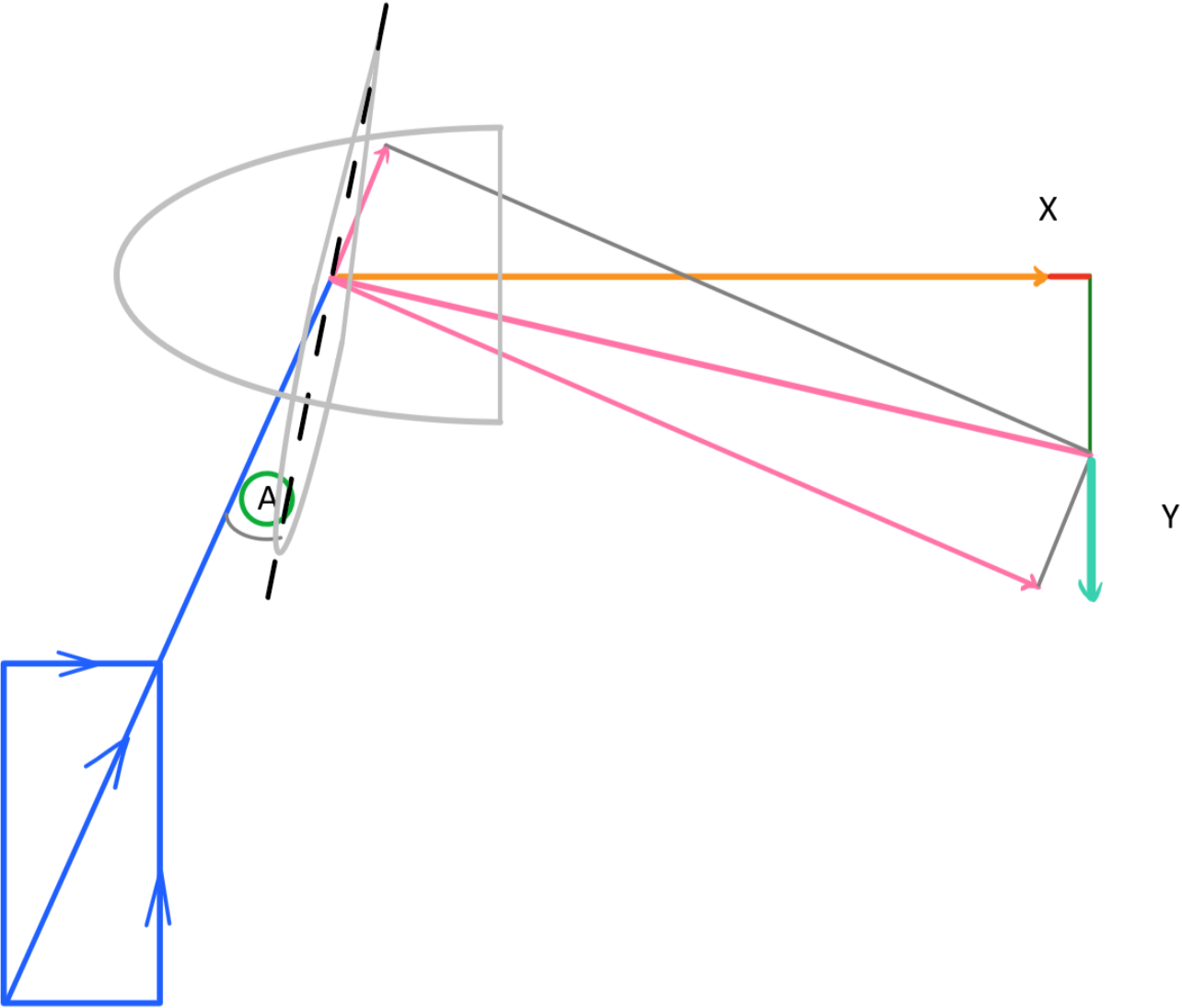


Figure 12 Data: (Lynn, 2013). Graphics: OneNote

At **Figure 12** X is for gain in axial force; Y is for loss in torque. If rotation decreases with tidal velocity, angle of attack and lift force are the same, then turbine experiences greater torque with less pressure on blades. (**Figure 13**)

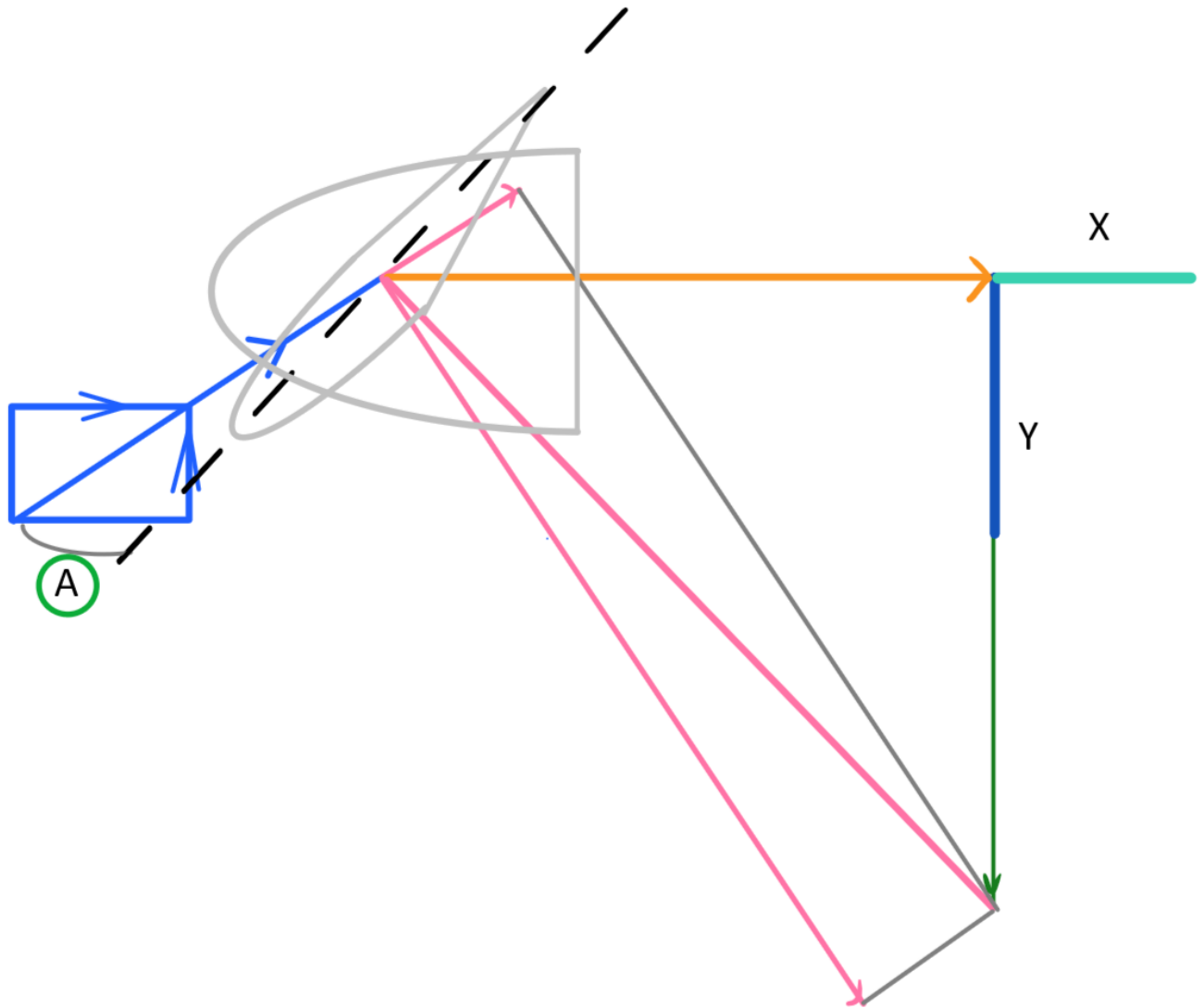


Figure 13 Data: (Lynn, 2013). Graphics: OneNote

At **Figure 13** X is loss in axial force; Y is gain in torque. To regulate torque and pressure on blades developers can use variable pitch propellers, rotate turbine along the vertical axis and other methods that are out of the scope of this thesis. The example above does not take into consideration variations in tidal speed, vortex formations, friction losses, interference with objects. Such complexity means it is hard to reach the level of 50% conversion of kinetic tidal energy into mechanical one. (Lynn, 2013)

Most of the tidal devices researched in this project have a generator installed in the turbine house and submerged in water except Deep River Turbine. This turbine pumps hydraulic fluid

to on-shore facility where the generator converts the energy stored in moving hydraulic fluid into electricity. The argument for such design is the ease of maintenance. (Deep River)

Several methods exist of fixing TISEC to the seabed²². (EMEC)

Gravity base device is held to the seafloor by the means of a massive weight.

Additional anchoring may be in place.

Pile mounted turbine is mounted to a pole that is stuck in the sea bottom. The device can yaw on a pole and in some designs can be taken out for maintenance.

Floating device floats on its own or mounted to a platform like a platform from Sustainable Marine Energy (Sustainable Marine Energy). Mooring can be flexible, allows relatively high freedom of movement; and rigid – for a minimum leeway.

2.2.5 Infrastructure between facilities at TRC and outside facilities

SCADA system

SCADA stands for Supervisory Control and Data Acquisition and is a real-time monitoring and analysis toolkit. According to SCADA the system is used by governmental institutions as well as small and large businesses. (B-Scada Inc, 2016)

Both FORCE and EMEC are using the system for data collection, storage and analysis. According to EMEC, historical data is used for environmental reports while live data is helpful for monitoring. Alarms and remote control provide safety and reliability. SCADA live feedback from devices informs developers about the status of the high voltage switch gear (HV), electrical performance and communication status. (EMEC) (AECOM, 2009)

²² Method when hydrofoil induces down force for holding device in place is not listed as no devices were found that implement this method.

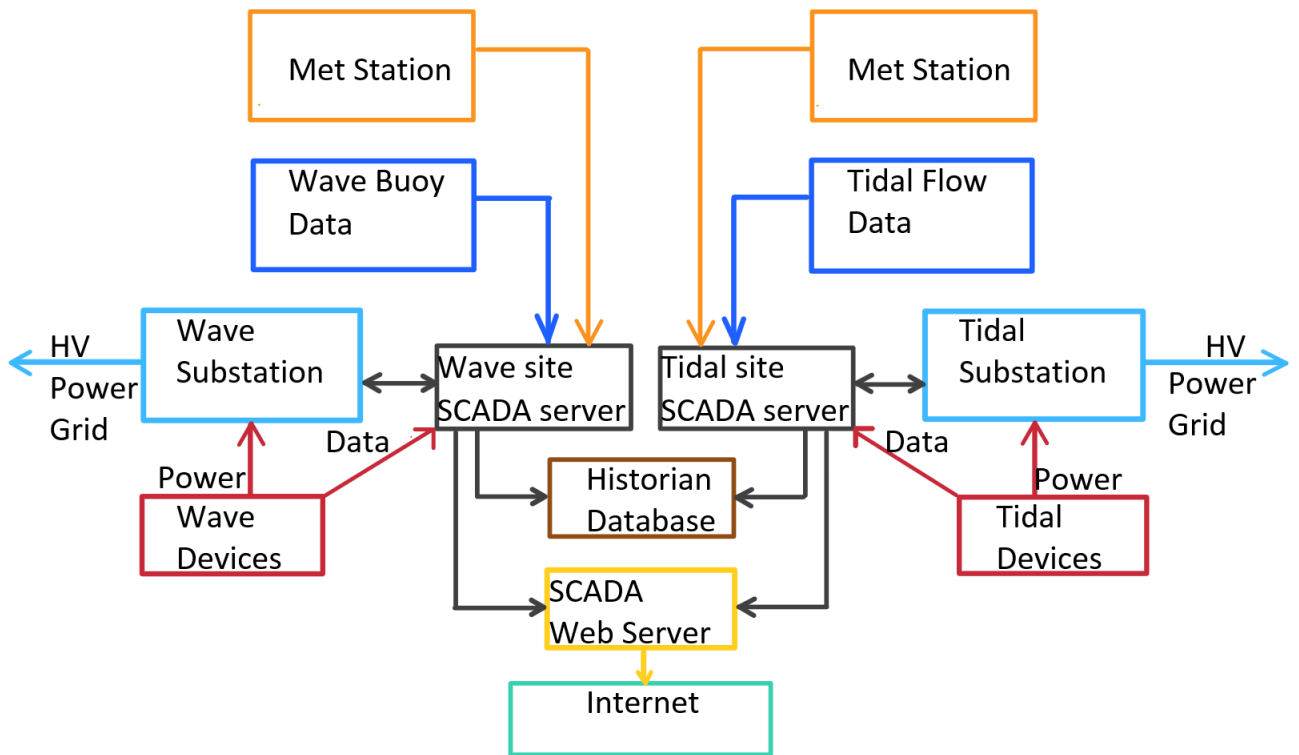


Figure 14: Flow of data at SCADA system and power transmission; Data: EMEC.

Graphics: OneNote

Figure 14 represents data flow between different components in SCADA system. Weather data is collected from meteorological stations at both tidal and wave test sites. At Billia Croo wave test site an array of wave riding buoys provide ocean data. Fall of Warness current profiler device feeds SCADA system with information about tidal current velocity. As it is ADCP device it shows velocity at many layers from the surface to the bottom. (Research Gate, 2016)

Status and performance information is collected from tidal and wave devices. SCADA is connected to substations at both test sites. That allows performance assessment and supervision.

The data is then recorded into historian database and to SCADA web server. It can be accessed from sub-facilities or via Internet at the main facility. According to EMEC and SCADA all connections are secured. (**Figure 14**)

Developed local infrastructure of TRC is one of the important factors for construction and operation of TRC. Wide enough roads are necessary for delivering of onshore modules under the construction. There is no evidence that TRC operation requires considerably wide roads to transport of large indivisible goods. However this might not be the case if sub-facilities are much bigger than those at Bay of Fundy and Orkney. The biggest single parts are TISECs and they come by sea (EMEC, 2012). During the construction of sub-facility at Fall of Warness site access tracks were built. They represent “hardcore access tracks” that follow UK’s forestry standard Type 1. (AURORA Environmental Ltd, 2005); (Forestry Commission UK, 2011) According to Google Earth Pro the average width of the access tracks is 4.34 meters²³. Measurements for FORCE sub-facility road show an average of 11.8 meters.

Subsea and marine infrastructure

The exact configuration of subsea and marine installations depends on the scale of the site and the purpose. Analyzing testing site at the Bay of Fundy and 4 sites at Orkney, it’s possible to say that all of them have foundations for anchorage or mooring and equipment for tidal current or wave profile monitoring.

At full scale test sites both FORCE and EMEC provide developers with connections to subsea cables for power and data transfer. According to the press release from FORCE²⁴, the TRC’s cables (**Figure 15 Power cables at FORCE**) at the Bay of Fundy are rated to 34.5 kilovolt and total capacity of 64 megawatts. According to quick stats at (FORCE) each cable is 200 amp-rated. Using formula $P=I*U$, where P – power (watt), I – current (amps), U – voltage (volts); total continuous power rating per cable is 6.9 megawatt. Subsea cables at Billia Croo (wave) and Fall of Warness (tidal) test sites have rated voltage of 11 kilovolt and

²³ It is problematically to estimate correctly such small distances with satellite imagery. The solution was to take 20 measurements along the length of the last 160 meters of the road that leads to sub-facility and then calculate mean value.

²⁴ (FORCE, 2014)

power rating of 2.2 and 5 megawatt correspondently. The latest 2 cables at Fall of Warness and 1 cable at Billia Croo that were installed in 2010 have a 4 core 4mm² auxiliary power cable inside²⁵. (EMEC); (The Crown Estate, 2015) At both EMEC test sites subsea cables have iron protectors upon the last 15m to the shore line. (**Figure 16 Power cables with iron protection EMEC**)It is unknown if cables at Bay of Fundy have similar protection.



Figure 15 Power cables at FORCE. Source: FORCE



Figure 16 Power cables with iron protection EMEC. Source: EMEC

FORCE has additional data cable. (Appendix 7) It is used for data transfer from equipment on subsea platforms to the shore. FORCE operates 3 custom designed platforms that can accommodate a number of instruments and are stable in high tidal currents. (FORCE)

Exact locations of cables and anchor points at Bay of Fundy and Fall of Warness with geographical coordinates can be found at Appendix 5, 6, 7.

²⁵ Draka from Norway provided cables. Older cables are from AEI (for Billia Croo) and Pirelli (for Fall of Warness)

Both centers in Canada and the UK have meteorological stations and marine RADARs. FORCE has hardware installed at visitor's center whereas EMEC has installations at sub-facilities²⁶.

Shapinsay Sound²⁷

European Marine Energy Centre opened two new test sites at Scapa Flow and Shapinsay Sound in 2011 (EMEC). Both sites are for small scale tests such as testing scaled prototypes, separate components, new tools, supply chain solutions, anchoring; ROV's testing, decommissioning trials; deployment/retrieval rehearsal and so on. Scapa Flow is intended for wave prototypes and Shapinsay Sound is for TISEC.

At Shapinsay Sound developers lease the area and are able to choose between 3 options of berth utilization:

- 1) Provide own moorings and power dissipation
- 2) Use EMEC moorings but own power dissipation
- 3) Utilize EMEC moorings and EMEC test support buoy that dissipates the power produced.

Power dissipation is required since the site is not connected to the grid. Test support buoy from EMEC integrates a resistor that dissipates excessive electricity as heat. The site does not have a dedicated meteorological station or RADAR. (EMEC, 2014)

²⁶ Just at the sub-facilities of full scale sites (Billia Croo and Fall of Warness)

²⁷ As far as this research goes, Shapinsay Sound is the only fully functional operating test site for small scale TISECs. As it is the only sample it's difficult to check if the practices applied at Shapinsay Sound while working with its hardware will work for other sites. The site is mentioned here for the purpose of further research.

2.3 Research

The following researches are part of the Environmental Impact Assessment (EIA)²⁸.

Besides EIA all the sites mentioned below take part in a number of surveys and studies on the subject of renewable tidal energy. (AURORA Environmental Ltd, 2005); (FORCE)

The scope of Environmental Impact Assessment covers almost all the aspects that concern TRC construction and operation. Because of such mightiness this research focuses just on some of EIA's aspects²⁹.

EIA covers construction of the site, installation of equipment and impact of the site in general as well as some general types of prototypes. The installation of certain prototypes and their operation is not covered. Developers should come up with Environmental Statement if the power of the devices is less or equal to 1 megawatt. If the power output is more than 1 megawatt they should carry out EIA. (AURORA Environmental Ltd, 2005)

There is no such restriction at FORCE. TRC in Canada does not require EIA as long as new device(s) occupy one of the four existing berths at Minas Passage or replaces previous TISEC; the device does not produce notably different impact from that of the previously tested prototypes. However, EIA may be required if the device is capable to produce 2 megawatt of power or more. (Nova Scotia Department of Energy, 2010)

2.3.1 Shapinsay Sound

Environmental studies at Shapinsay Sound were completed in October 2009. In 2010 EMEC completed two baseline studies together with Netsurvey Ltd³⁰:

²⁸ Environmental Impact Assessment (EIA) is the same document as Environmental Assessment (EA) for the studies about FORCE TRC

²⁹ EIA covers more or less all the aspects of the TRC framework discussed in this research. However the updated information is preferred when possible. Please refer to the original EIA documents from FORCE and EMEC if necessary. FORCE: <http://fundyforce.ca/environment/enviromental-assesment/> EMEC: <http://www.emec.org.uk/services/consents/>

- Study of physical environment by a geophysical survey method.
- Study of flora and fauna at the sea bottom (benthos) by the method of grab sampling.

Two monitoring programs took place:

- Benthic grab analysis. Researches sieved samples and analyzed them regarding number of species and their plentifulness. Completed in 2010.
- Wildlife monitoring of birds and mammals by observers from EMEC. The study was on-going when the original source was published in November 2014³¹. (Clements, 2014)

2.3.2 Fall of Warness

FOW was opened to the developers in 2006. Prior to that year EMEC conducted several surveys on the site.

Navigation risk assessment at FOW³² was conducted in 2005. The study was made by Anatec Limited, company that provides consultancy services for the offshore sector (Anatec Limited, 2016). The source of data for Anatec was shipping data from AIS (6 weeks summer data; 6 weeks winter data); vessel logs from Eday, an island near which FOW is located; fishing surveillance data from government and RYA UK Coastal Atlas Data.

The survey investigated shipping fishing and recreational vessel activity; historical incidents; SAR resources; under keel clearance; and as a result – navigational risk. The original navigational risk assessment by Anatec Ltd. Was published in May 2005 with an update in October 2005. The latest version that this research uses is from 16 November 2010.

³⁰ Results of these studies: (Clements, 2014)

³¹ Wildlife observations may still continue. No data on its termination was found.

³² Full report: (Anatec Limited, 2010)

Before the FOW test site opening, EMEC conducted several studies together with several different actors³³.

- A survey of coastal habitats. Together with Aurora environmental Ltd³⁴. This survey included flora and fauna near landfall site.
- A survey of coastal and seabed processes. In cooperation with HR Wallingford³⁵. Survey looked upon bathymetry of the FOW test site.
- A preliminary seabed survey with Aquatera Ltd.³⁶ And additional sea bottom survey with SULA Diving³⁷. The goal was to inspect the exact spots where TISEC developers would locate TISECs and where the cables should lay. Not all the spots were successfully inspected due to the strong current.
- A birds study – assessment of species onshore and offshore together with Mike Cockram³⁸. The goal of this study was to characterize birds located in the area of FOW and southwest coast of Eday island.
- A survey of cetaceans³⁹ and coastal wildlife with Chris Booth⁴⁰ and survey of otter populations in cooperation with Celtic Environmental Ltd⁴¹. The purpose of these two studies was to investigate the use of the area by cetaceans and otters.

³³ Results of these studies: (Clements, 2014)

³⁴ Consultancy company specializing on environmental science
<http://www.auroraenvironmental.com.au/>

³⁵ An independent organization that delivers solutions on civil engineering products and environmental hydraulics <http://www.hrwallingford.com/about/overview>

³⁶ <http://www.aquatera.co.uk/>

³⁷ <http://www.suladiving.com/>

³⁸ Mike Cockram is a local bird expert who lived at Eday and studied birdlife since 1974 (AURORA Environmental Ltd, 2005)

³⁹ Cetaceans are marine mammals like whales and dolphins (Britannica)

⁴⁰ Chris Booth has been a cetacean recorder at Orkney since 1990 (AURORA Environmental Ltd, 2005)

- Sea mammal study with SMRU⁴². This study focused on seals. The telemetry was used to determine the usage of the area by these marine mammals.

One on-going monitoring program takes place in FOW:

- Visual observations of birds and mammals. Carried out via land based visual observations.

A study on a life cycle of subsea cables is not included in the list above as it is dates from 2015. However EMEC considers decommissioning as an important part of the operation cycle of test sites (EMEC). The study was conducted by The Crown Estate and among all other factors highlights the interventions that took place with cables since installation (The Crown Estate, 2015).

2.3.3 Minas Passage⁴³ (Bay of Fundy)

All the research mentioned here was done not later than June 10, 2009 if no date is specified⁴⁴.

- Survey of marine birds and mammals⁴⁵. Survey took place during July 2008. It is followed by observations on October 1-3 2008⁴⁶. (AECOM, 2009e)
- Oceanographic survey. This study provided data on salinity, temperature and turbidity at Minas Passage. It dates from August 2008-March 2009. (AECOM, 2009d)

⁴¹ <http://celtic-ltd.com/>

⁴² SMRU is Sea Mammal Research Unit: <http://www.smru.st-andrews.ac.uk/>

⁴³ The area that is referred as "Minas Passage" is from Cape Split to Cape Blomidon. The name of the passage is local and is not identified on the charts. (AECOM, 2008a)

⁴⁴ Source: (AECOM, 2009g)

⁴⁵ By Patrick Stewart, M. Sc., EnviroSphere Consultants Ltd

⁴⁶ By S. Wehrel and R. Jeppesen

- Data and tide analysis at Minas Basin. From May 1, 2008 to March 29, 2009. Both moored and vessel mounted ADCP were used. The study describes current properties such as speed and direction on the time scale at different water layers; power density; temperature. (AECOM, 2009c)
- Oceanographic surveys of seabed biological communities in Minas Passage. The surveys took place during August 18-20 and September 23-24, 2008. Researchers used a survey vessel, video system of underwater still camera, rock and sediment sampling. The surveys geological characteristics and biological communities. (AECOM, 2009b)
- Geological report from April 27, 2009 by Atlantic Marine Geological Consulting Ltd. surveyed regional physiography; geography, bathymetry, bedrock of Minas Passage and inner Bay of Fundy; sediment transport; sea levels; seismic hazards. (AECOM, 2009a)
- Study of the main types of TISEC devices that were on the market before 2009. The exact date of the study is unknown. (AECOM)
- Terrestrial and intertidal biophysical survey. The survey looked upon plant and animal communities that inhabited area of the future construction of onshore facilities. (AECOM, 2009f)
- Marine transportation study from 2008. Assessed navigational risks connected with ship's navigation through the Minas Channel. (AECOM, 2008b) While installing a data cable, no anchor zone was defined. (FORCE, 2014)
- Other studies: archaeological assessment; botanical survey; survey of electromagnetic fields caused by subsea equipment.

2.3.4 Tidal Test Site Selection: Fall of Warness

The selection process for FOW test site began in 2004 or 2 years prior to the opening. The process was divided into two phases. Initially Highlands and Islands Enterprise located 8 potentially viable sites around the Orkney Isles, the Shetland Isles, the Western Isles, as well as some places along west coast of Scotland. Appendix 9 and 10

The main criteria were:

- Peak mean of spring tidal current 3.5 m/s
- Width of the area 1.5 km
- Depth 30-50 m

Only 3 sites could match those criteria: Yell Sound, Fall of Warness and Pentland Firth.

The additional criterion was the distance from EMEC's main facility to the site. For Yell Sound it is 205 km while the others are considerably closer – 35 km for FOW and 30 km for Pentland Firth.

In phase two 23 parameters were considered according to three categories⁴⁷:

- Physical resources
- Environmental sensitivity and constrains
- Cost differentials

Considerable advantage of FOW is that it is stated as an Area To Be Avoided by IMO. It concerns vessels larger than 5000 GRT. (AURORA Environmental Ltd, 2005)

⁴⁷ Appendix 10

2.4 Services

2.4.1 Services provided to TRC

Connections to local expertise

Researches and developers can benefit from the center's connections with a variety of relevant companies, contractors, consultants, institutions⁴⁸.

While the supply chain for FORCE is unknown, it is permissible to say that TRC in Nova Scotia has connections to local expertise. In 2011 Atlantis Resources Corporation won the bid to build 1 megawatt TISEC at Minas Passage. Corporation cooperates with Lockheed Martin and Irving Shipbuilding that have 130 and 1200 full time employees and ship yard workers correspondently in the area of Nova Scotia. (FORCE, 2011); (Atlantic Resources, 2016)

Life Cycle Support

Aquatera Limited – provides life cycle support for technology tested at EMEC. Aquatera Ltd was found in 2000, and specializes in offering environmental products and services. Those include but not limited to: technology and project development; marine and subsea surveying; marine operations; emergency planning and response; logistics; (Aquatera.co.uk)

Transportation

Public transportation services of personnel and goods to EMEC is conducted by air or by sea. (**Figure 17**) Airport at Orkney is 29 km away from the main facility. Public bus is available⁴⁹. Ferry lines from Scotland come directly to Stromness. It is unknown if any public transportation exists between the headquarters and tidal EMEC facilities. (Orkney

Renewables)

⁴⁸ For the full list of locally available companies and institutions associated with EMEC please visit: <http://www.orkneymarinerenewables.com/supply-chain.asp>

⁴⁹ According to Google Maps: <https://goo.gl/maps/nb5YYJajixk>

To come to FORCE one can link through Dartmouth, Halifax, Moncton or St. John airports and drive or take a taxi to the TRC. No information about public transport was obtained⁵⁰.

⁵⁰ Sources for obtaining data on public transport are not informative. No valuable data has been found on the sources associated with FORCE. Described data has been obtained through numerous trials to plot a trip to FORCE just by means of public transport on <http://www.rome2rio.com/>. All attempts failed. However there is no clear evidence of absence of public transport near FORCE.

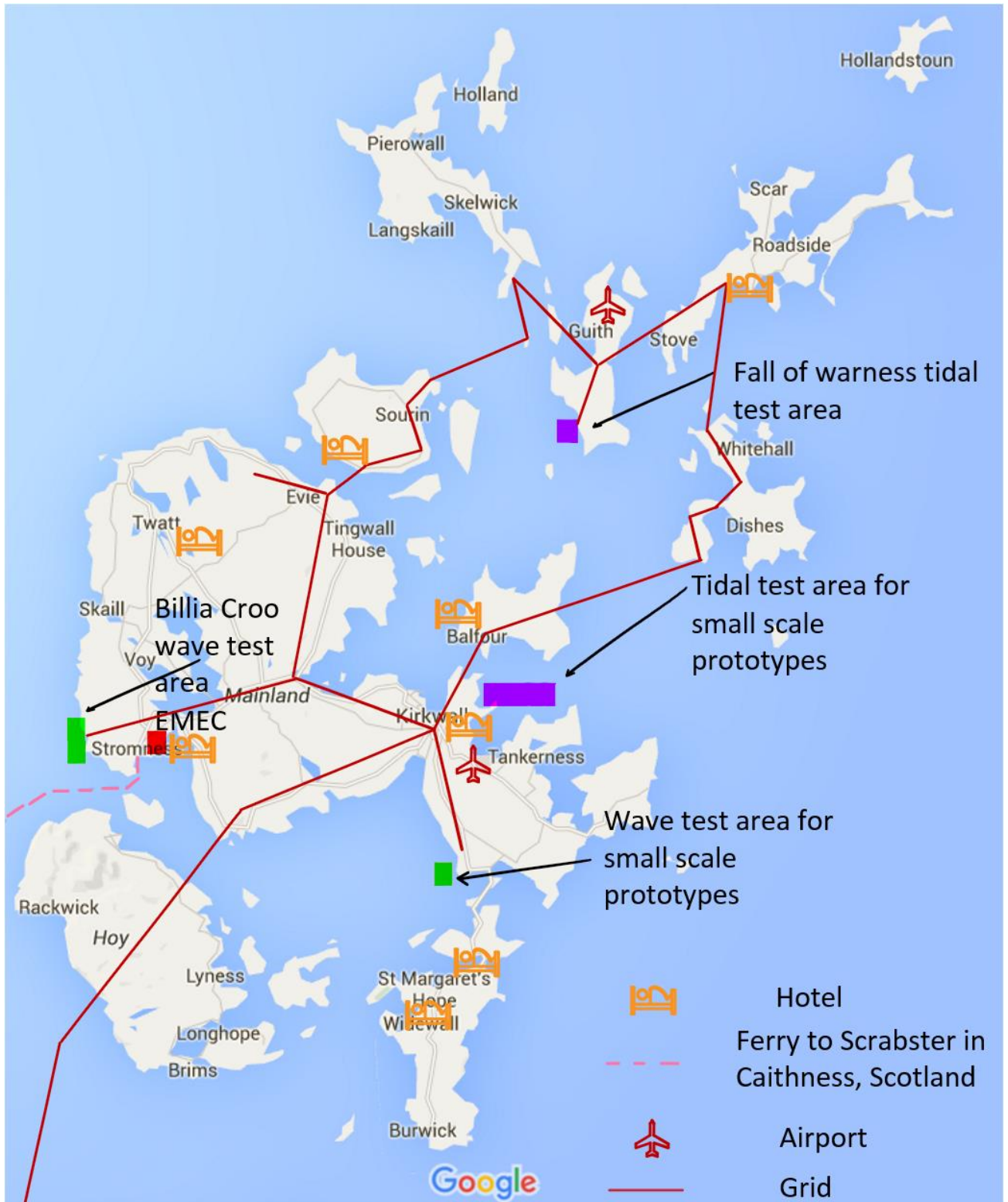


Figure 17: Air Transport; Accomodations and Power Grid at Orkney. Data: EMEC; Booking.com. Background: Google Maps. Graphics: OneNote

Accommodations

Additional analysis is required when deciding if the TRC should provide accommodations to developers.

The research has not found that either EMEC or FORCE provides accommodations for developers. Both areas offer a variety of lodging.

30 properties are found around Orkney. Some are marked at **Figure 17**. Some located on different islands than EMEC main facility. Prices range from 295 up to 3183 NOK. The average price is 1088 NOK⁵¹.

In Nova Scotia driving distances are longer than those at Orkney. Some of the properties are located on the South side of Minas Basin. 18 properties are found inside 50 km area⁵² from FORCE. Prices range from 479 to 1091 NOK. The average price is 787 NOK⁵³

2.4.2 Services provided by TRC

TRCs provide services to developers and other TRCs through collaboration, regulation, accreditation etc. Services provided to developers will depend on the facilities of the TRC and experience⁵⁴. TRCs facilitate with full scale testing (FORCE; EMEC) and small scale or component testing (EMEC) during the last stages of the development process (EMEC);

⁵¹ Data is from booking.com. Price is for 1 room; 2 persons; 1 night. Some properties did not have prices ready unless dates are specified those were discarded. The property from East Heddle was discarded because of the high price of 11,554 NOK that is uncommon for the area. Total sample size is 25. Prices provided by booking.com. Prices are subject to change as currency rate of GBP to NOK changes. At the moment of data acquisition currency rate was 1 GBP to 11.8 NOK.

⁵² 50 km roughly corresponds to the most remote accommodation at Orkney. Please take notice that in both cases type of terrain and transportation is not taken into account. Land and sea transport can have different speed and capacity.

⁵³ Data is from booking.com. Price is for 1 room; 2 persons; 1 night. Total sample size is 18. Prices provided by booking.com. Prices are subject to change as currency rate of CAD to NOK changes. At the moment of data acquisition currency rate was 1 CAD to 6.38 NOK.

⁵⁴ By comparing range of services from EMEC and FORCE

(Figure 17) The research has found no obvious obstacles for TRC to incorporate tank testing as well.



55

Figure 18: From Concept to Deployment. Data: EMEC. Graphics: OneNote

⁵⁵ Initial funding and research funding UK: <https://connect.innovateuk.org/web/energyktn/low-carbon-funding-navigator>

As a part of support and services EMEC provides an independent assessment of the generative performance of the prototypes. They call it “Technology Assessment Process” or TAP. For the development process TAP improves risk assessment/management and shows the aspects developers should focus on. TAP provides the documentation of competitive perspectives of the device. For investors TAP gives better opportunities to pick up best working solutions. (EMEC)

Besides TAP, EMEC provides independent verification of sea conditions; test management and verification for off-site deployments⁵⁶. (EMEC)

Both tidal research centers in Canada and the UK collaborate within and with other TRCs providing consultancy services. The agreement between FORCE and EMEC shows that some services can be provided free of charge (the receiving side still covers transport, insurance, labor and other expenses). Other services like access to intellectual property are provided on commercial basis⁵⁷. (FORCE; EMEC); (EMEC, 2015c); (EMEC, 2015d)

According to EMEC, it can provide support in the following aspects to new emerging TRCs:

- Business modeling – planning and cost estimation
- Construction – including design, development and delivery
- Collection of the necessary data for site operation
- Electrical systems installation and management
- Setting up infrastructure and deployment techniques

⁵⁶ The Latter is done in collaboration with UKAS – United Kingdom Accreditation Service <https://www.ukas.com/>

⁵⁷ It is reasonably to suggest that conditions will depend on the exact agreement between EMEC and new TRC. The decision making process of what services EMEC should provide free of charge and which are revenue generating activities is so far unknown to this research.

- Setting up operational procedures for site management (EMEC); (EMEC, 2013)

Meteorological data

Meteorological data is collected from stations and analyzed. It is then available to all the developers via SCADA system. (EMEC)

EMEC provides onsite developers with full time emergency response cover. It means EMEC will ensure that the latter are informed about the accident and take appropriate actions. However the developers and their contractors are fully responsible for the emergencies of their devices. (AURORA Environmental Ltd, 2005)

2.5 Licensing consents and Consent process⁵⁸

Tidal research center in Orkney complies with ISO/IEC 17025:2005 standard. This standard provides general prerequisites for the proficiency of testing and calibration laboratories. ISO 17025 covers testing and calibration activities and according to ISO, the standard applies to all laboratories that do those tasks⁵⁹. (ISO, 2005)

2.5.1 Shapinsay Sound

EMEC holds a generic marine license for this site. It means that if developers perform activities within the agreed scope or “envelope” they are entitled to a simplified consent process. Nevertheless they should provide two consents:

- Marine License

⁵⁸ For overview of regulations in some of the other countries regarding consent: <http://energy.novascotia.ca/sites/default/files/NS-MRE-Policy-Background-Final.pdf> and http://lawofficesofcarolynelefant.com/renewables/shore/wp-content/uploads/2010/04/CE_IEA_Rpt.pdf Sources are from 2009 and 2010 respectively and some data might be obsolete.

⁵⁹ However no evidence has been found that FORCE complies with this standard. More research required is

- Harbor works license

In addition developers should provide documentation of potential navigational and environmental risks associated with installation and operation of their devices as well as mitigation measures. When EMEC receives the documentation, the TRC updates its generic marine license for the site⁶⁰.

2.5.2 Fall of Warness

EMEC holds several licenses required for operation of this full scale site⁶¹. As with Shapinsay Sound, if developers act within the scope of these licenses the process is simplified⁶².

2.5.3 Minas Passage

For developers testing at FORCE more licensing may be required. However this will differ from case to case and depend on the properties of the exact devices. (FORCE); (Nova Scotia Department of Energy, 2010)

3 Svelvik Tidal Research Center

Svelvik commune is located on the west coast of the Drammensfjorden in southeast Norway, around 60km⁶³ from the capital Oslo. (**Figure 19**)

Commune is in possession of the west side of Svelvikstrømmen – a natural channel of 150-200m wide that was artificially dredged to 12m+ depths. Svelvikstrømmen is seen as a channel with one of the strongest tidal currents in Norway. The energy comes from tides and water mass of the rivers at inner Drammensfjorden. (FjordOs); (Secora)

⁶⁰ For detailed information about consenting process at Shapinsay Sound: (EMEC, 2012a)

⁶¹ Please refer to (Clements, 2014) for detailed information.

⁶² Please see the research section for EIA requirements; (EMEC, 2015b) for detailed framework for consenting process at FOW.

⁶³ Depends on the road and type of transport

An idea to develop the energy potential of Svelvikstrømmen and outer Drammensfjorden was born in 2014 at “Energy Exhibition” at Telenor arena when the commune leader Arvid Askø and TESS CEO Erik Jølberg discussed the potential for energy extraction in the area.

In spring 2015 Tine Wågønes, a managing director for Papirbredden Innovasjon in Drammen took the leadership of the project.

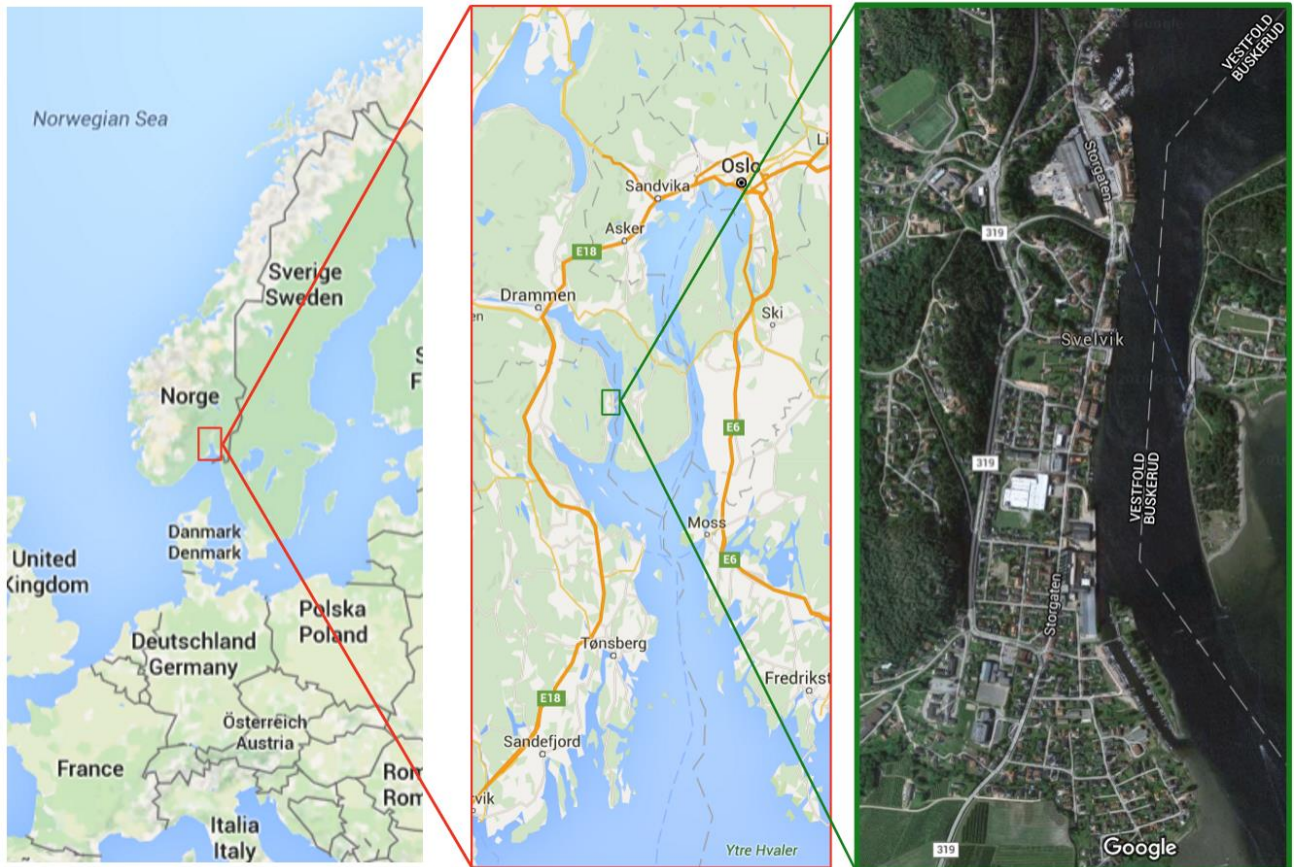


Figure 19: Svelvik on the map; Maps and satellite imagery: Google; Graphics:

OneNote

3.1 The vision of Svelvik commune for Tidal Research Centre

The vision of the Svelvik commune is to be on the edge of modern technology and innovation while being one of the leading players during the transition from offshore industry to renewable energy in Norway.

Creating TRC in Svelvik will bring competence in sustainable solutions for energy production to the region. Local suppliers and service providers will have new opportunities for business development. New businesses can emerge on demand. Educational institutions should benefit from dedicated research projects connected with TRC. Institutions of primary and secondary education will have better opportunities to raise the awareness about renewable energy solutions. Local infrastructure will develop according to the modern standards.

3.2 Research scope and method

This master thesis complements Svelvik TRC project during its first stage of the development (or Strategic Environmental Assessment according to the framework for TRCs) and touches upon further development of the project. It implements the knowledge obtained during the research on the framework in order to find potentially viable areas; points out difficulties and suggests improvements.

The thesis focuses on “research” section of horizontal framework (**Figure 20**). The main objective is to obtain clear and reliable data of vessel traffic in Svelvikstrømmen and outer Drammensfjorden. Additional data is provided about surface currents; sea bottom near Saltskjær; fauna at Grunnane Sanctuary; fish migrations⁶⁴. The thesis is positioned as the first step to determine further research on TRC in Svelvik.

⁶⁴ Suggestions for additional research in “Conclusion and Further Research” section

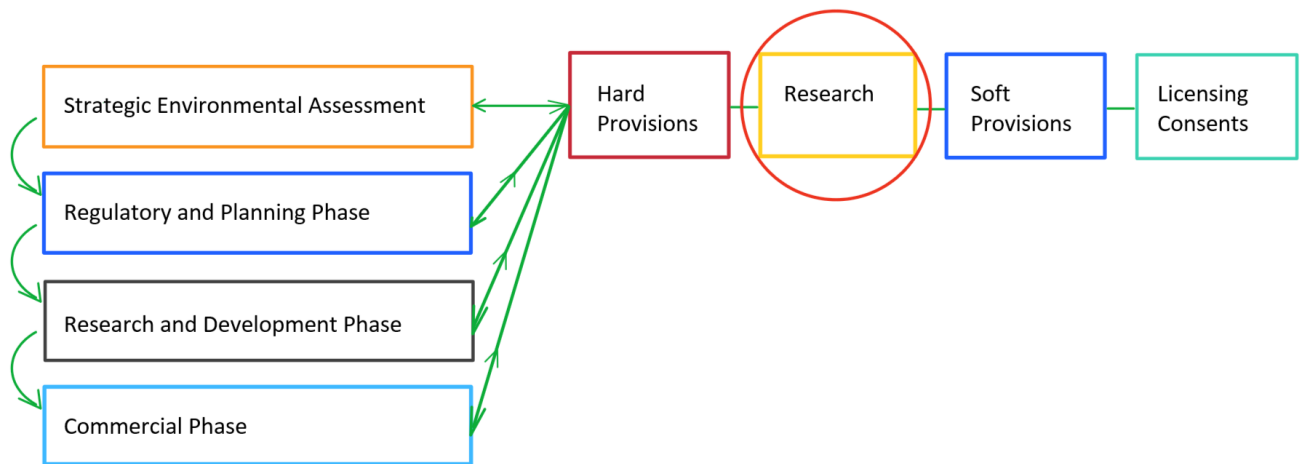


Figure 20: Research Scope, TRC Svelvik. Graphics: OneNote

The research includes:

- Consultations with several stakeholders. While some consultations took place during one-time meetings, others represent continuous data exchange between the researcher and a correspondent person.
- A trip with the research vessel “Trygve Braarud” from the University of Oslo when she was on the mission to deploy ADCP in outer Drammensfjorden.

3.3 Ship traffic in Svelvikstrømmen and outer Drammensfjorden

Waterways in the areas of Svelvik and Hurum are crucial for operation of the Port of Drammen since it is the only way to this port. The total number of the passages registered by the Norwegian Coastal Administration through Svelvikstrømmen in the year 2015 is 1770⁶⁵. Of that number 884 passages stretched northwards and 886 southwards⁶⁶.

⁶⁵ The initial source for the most of the data in this section is AIS. It means that water craft that does not have AIS on board are not accounted for.

⁶⁶ The difference in the number of passages to the north and to the south occurs because the data is limited to one year period. If a vessel came earlier prior to the sampling period or left later than the end of period, it would influence the data.

The Port of Drammen is known as the largest port for Ro-Ro cargo in Norway⁶⁷.

According to the NCA, 226 Ro-Ro vessels passed Svelvik on the way to the Port of Drammen in 2015. 180 of them were of 5000 to 24999 GT when passing Svelvikstrømmen northwards.

(Ошибка! Источник ссылки не найден.)

The next biggest group is general cargo vessels which passed Svelvik from 316 to 318 times in 2015. Of the total number of vessels, the size of 1000-4999 GT prevails with 286 passages to the north and 288 passages to the south.

Container ships add 152 and 149 passages to the north and to the south correspondingly. The most of the Container ships are of 5000-9999 GT capacity. There are 31/32 tracks of Oil Tankers; 29/30 of Bulk ships; 22/22 of Small Passenger ships; and 8/7 of Chemical Tankers.

Type	Direction	<1000 GT	1000- 4999 GT	5000- 9999 GT	10000- 24999 GT	25000- 49999 GT	TOTAL for Type
Bulk	S	1	26	1	2	0	30
Bulk	N	1	25	1	2	0	29
Chemical/product tankers	S	0	7	0	0	0	7
Chemical/product tankers	N	0	8	0	0	0	8
Container Ship	S	0	12	120	17	0	149

⁶⁷ (Drammen Havn, 2014)

Container Ship	N	0	12	122	18	0	152
General Cargo	S	12	288	12	6	0	318
General Cargo	N	12	286	12	6	0	316
Oil Tanker	S	0	20	12	0	0	32
Oil Tanker	N	0	19	12	0	0	31
Other Activities	S	97	3	1	0	0	101
Other Activities	N	96	3	1	0	0	100
Passenger Ship	S	22	0	0	0	0	22
Passenger Ship	N	22	0	0	0	0	22
Ro-Ro Cargo	S	0	21	83	98	25	227
Ro-Ro Cargo	N	0	21	80	100	25	226
TOTAL for GT:		263	751	457	249	50	All passages: 1770

Table 1: Ships sailed through Svelvikstrømmen in 2015 by Type and Gross Tonnage;

Data: Havbase, Norwegian Coastal Administration;

By gross tonnage the largest category by number is the ships of 1000-4999 GT that account for 751 crossings⁶⁸: Diagram 1: Ships sailed through Svelvikstrømmen both directions in 2015 by Gross Tonnage. Ships from 5000 GT to 9999 GT passed Svelvik 457 times; 10000-24999 GT – 249 times. The category of 25000-49999 GT consists only of Ro-

⁶⁸ Here total number of passages is shown: Northbound + Southbound

Ro vessels and accounts for 50 passages. Smaller boats of <1000 GT passed Svelvikstrømmen 263 times in 2015.

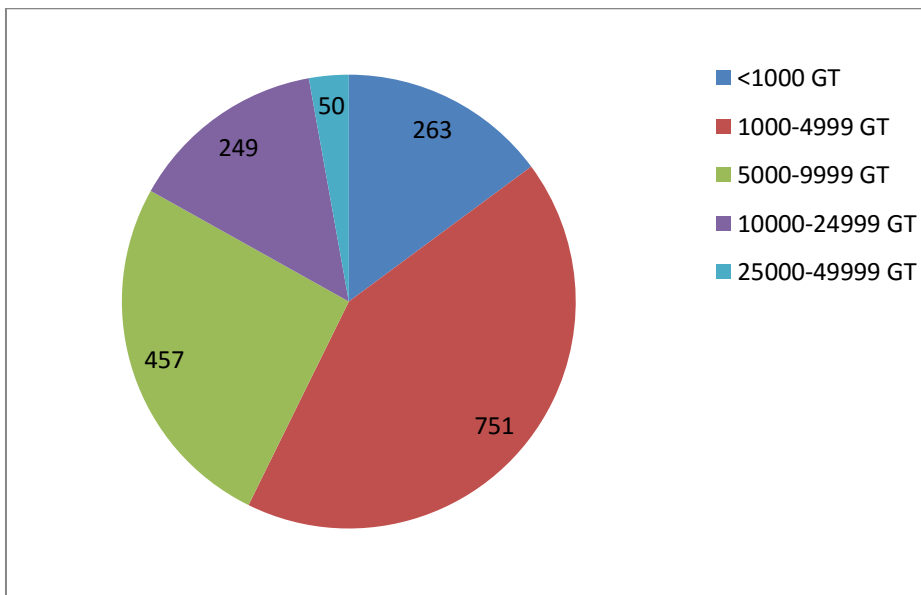


Diagram 1: Ships sailed through Svelvikstrømmen both directions in 2015 by Gross Tonnage

This data does not include General Cargo⁶⁹ Ships operating for Svelviksand – a local enterprise that transports sand⁷⁰. Analysis of the historical AIS data from MarineTraffic.com showed that in a period from February 17, 2016 to April 16, 2016 two General Cargo Vessels (MS Gullha and MS Zuzanna) made a total of about 120 voyages in total through outer Drammensfjorden to the loading area of Svelviksand there and back. Appendix 11 shows the list of vessels used during the research.

3.3.1 Method of analysis of AIS data

There are two main documents that are used as an example of the method of vessel traffic data analysis: “Marine Transportation Study” made in the scope of FORCE development and “Navigation Risk Assessment” made in the scope of FOW development.

⁶⁹ Type according to AIS

⁷⁰ <http://stangegruppen.no/svelviksand/>

Both studies are comprehensive and reveal that it is relatively safe to operate in both areas. One of the reasons is that Minas Passage in Nova Scotia has no shipping lanes or regularly routes passing through. At the same time the area where FOW is located is declared as a no go zone by IMO and absence of regular shipping routes was one of the main reasons in site selection process⁷¹.

This part of the research has found out that waters in Svelvikstrømmen and outer Drammensfjorden are more confined in terms of traffic than Minas Passage and FOW and therefore require another method. The solution is to estimate the navigational corridor as accurately as possible and areas free of vessel traffic. If vessel routes are known and they are logically and mathematically proven, then it is possible to estimate areas with little to none traffic. For those areas further research can estimate their sustainability for TISEC installations.

Both studies of vessels traffic in Nova Scotia and Orkney used AIS data. It has been found that there is little or none valuable AIS data exists in “free of charge” sources. Because of the limited financial resources dedicated to this thesis, the data from MarineTraffic.com was used. This resource allows a free one-month trial and provides historical AIS data with tracks of the vessels on nautical charts for two months previous to the acquisition date. It also provides logs from ports about vessels that called in.

The data was acquired on April 16, 2016 for 36 vessels that visited Port of Drammen from March 17, 2016 to April 16, 2016. In addition MS Gullha and MS Zuzanna were added. It makes a sample of 38 ships.

For each ship two months of historical AIS data was acquired and plotted. MarineTraffic.com allows plotting of 10 vessels simultaneously. Four charts with AIS tracks

⁷¹ Appendix 9; Appendix 10; (Anatec Limited, 2010)

were combined in Photoshop 2015 into a single chart. A background map was made of nautical charts from MarineTraffic.com.

All charts and tracks are at the same scale of 1:10000 that allows smooth combination process and transition between geo coordinates and Photoshop internal coordination system. In addition this provides an opportunity to draw visual nautical information such as leading lights and light sectors. A “line tool” was used to construct lines that correspond to nautical charts as this tool provides a user with angle in degrees and distance. Distance scale is 35 pixels per 100m or 2.857 pixels per 1 meter of the real distance.

Bearings to the objects are from Havbase.no. It has been found that all bearings taken from that source have deviation⁷² of +3.5° from true north. This is corrected by subtraction.

Position data from AIS is discrete. Discretization level varies from 2 to 6 minutes⁷³. It means that between two points of data input from AIS, the exact position of the ship is unknown. In this case it is more correct to talk about vessel's position between data acquisitions in terms of probability. It will not be correct to use interpolation between two points because a ship might not go in a straight line. Both Havbase.no⁷⁴ and MarineTraffic.com draw straight lines between AIS data inputs to visualize the past track.

Outer Drammensfjorden and Svelvikstrømmen are relatively narrow passages with the narrowest parts approaching 550m and 150m correspondently. If discretization is within 2-6 minutes and the speed of a vessel is 10 knots⁷⁵ it results in 130-390 meters of distance covered by ship between data inputs from AIS. In terms of this research such uncertainty in

⁷² This is not magnetic deviation but the deviation of the chart itself from true North that should be 0° in the charts with Mercator projection.

⁷³ From the sample used in this research

⁷⁴ Havbase provides users with notification at the very start about 6 minute's discretization applied save data traffic and process power.

⁷⁵ Speed will vary depending on the area. In Svelvikstrømmen the limit is 7 knots (Source: Havbase.no)

navigation tracks prevents from seeing the details that may be important in such narrow areas⁷⁶.

A three-stage approach is used to compensate for the discrepancy of AIS data and to reconstruct a clear pattern of navigation in outer Drammensfjorden.

Stage 1 – estimation and plotting a navigation corridor based on navigational rules and extreme positions of the vessels in those corridors.

Stage 2 – estimation and charting a navigation corridor where the sides represent a mathematical distribution of 95.4%

Stage 3 – combining both corridors

Stage 1

The primary goal of this stage is to understand why vessels follow the routes; what guides them and if this pattern will continue to exist in the future.

Navigational passage plotting is based on consultation with Thomas Førli, University College teacher of navigation and maritime subjects at University College of Southeast Norway; Sindre Holm, captain of “Trygve Braarud” and the author’s own navigational experience.

The passage follows navigational rules such as: steering towards the light sector; keeping vessels in a light sector; avoiding the light sector; steering towards the land mark; keeping a safe distance on port/starboard; etc.

When navigational rules are defined, the navigational corridor is plotted according to the extreme positions of the ships provided by AIS⁷⁷. **Figure 21** shows typical representation of

⁷⁶ This problem gets worse in areas where traffic turns. AIS tracks “cut” the trajectory of the inside circumference of the intended track while leaving the outside circumference empty making the impression that the ships tend to navigate closer to the inside circle.

AIS tracks when vessels navigating in confined waters make a turn⁷⁸. **Figure 22** shows the navigational passage constructed according to the extreme positions of the vessels.

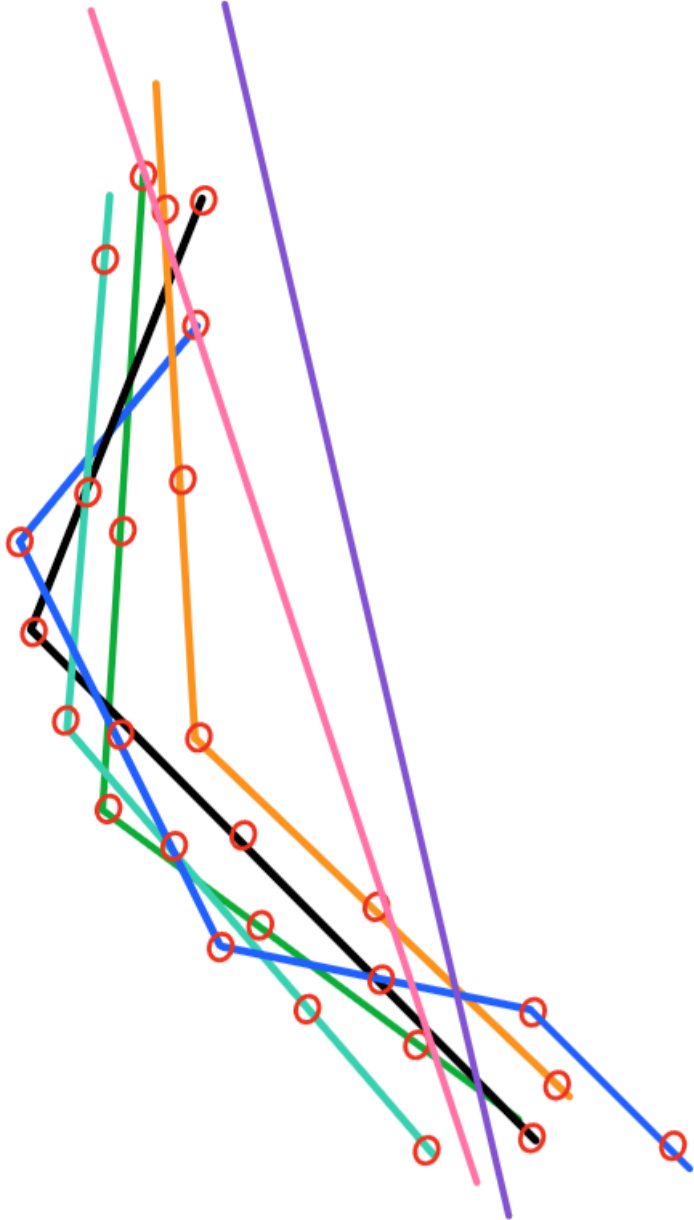


Figure 21: Simplified representation of AIS tracks. Red circles – ships’ positions provided by AIS; Tracks between positions – possible sail routes of vessels plotted by a

⁷⁷ As the navigational passage in Drammensfjorden goes in North-South direction than the extreme position of the vessels on that passage are westernmost and easternmost positions.

⁷⁸ This example follows the area to the North of Batterøya in Svelvik.

data provider. Pink and violet lines are bias tracks caused by low discretization of AIS inputs or high sailing speeds.

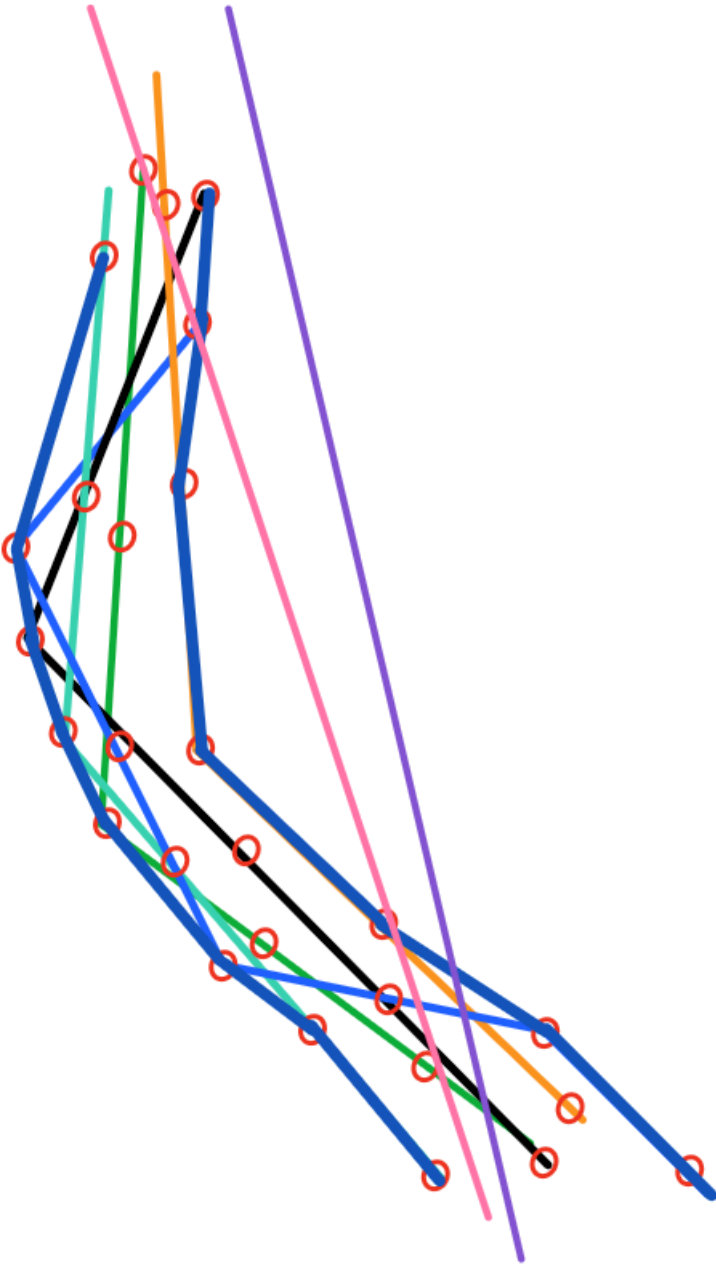


Figure 22: Simplified representation of AIS tracks with navigational passage plotted according to the extreme positions of the vessels.

Such plotting eliminates to some extent bias AIS tracks caused by low discretization or high speed of the craft and smoothens the edges of the corridor, as it is the case with outer circumference at **Figure 22**.

The research has found out that the more positions are used, the better the result is. If corridor lines are drawn on the base of a few inputs (inner circumference at **Figure 22**) they still keep the discretization pattern of the AIS tracks.

It is expected that these edges when based on significant number of inputs from different AIS tracks should provide more reliable results compared to AIS tracks from a data provider.

The plotted passage is then checked that it does not contradict with Pilot Book (Statens Kartverk Sjø, 2007); COLREG convention (Lloyd's Register, 2005) and its Norwegian version called “Sjøveisreglene” (Sjøfartsdirektoratet, 1975). Buoys and lights are checked if they match with IALA⁷⁹ Maritime Buoyage System. Areas from Blindsand to Svelvikstrømmen entrance are checked visually from the bridge of Trygve Braarud. Areas from Batteriøya to Sleavika are checked visually from the shore line.

Stage 2

It appears that for this thesis such plotting as described at stage 1 is not accurate enough on its own. The navigational corridor is still relatively wide with some few vessels offsetting the edges. It is noticeable in the following areas: from Blindsandodden to Kroksberget; from Selskjæret to Vollebukta; in between the main routes from Svelvikrenna SO to the sandbank in the North⁸⁰. (Appendix 1; area marked yellow)

A rough estimation showed that there are about from 5 to 1% of the bias tracks that offset the route width. They can't be erased randomly as it compromises the validity of data. It is possible to “cut off” 4.6% of the vessel distribution using the mean value and allowing for 2 standard deviations from the mean. In order to do this it is assumed that vessels inside the

⁷⁹ IALA buoyage system: <http://navlib.net/wp-content/uploads/2015/05/iala-bouya-system.pdf>

⁸⁰ 3.5 m depth contour

corridor are normally distributed⁸¹. It allows calculating the area where 95.4% of vessels navigate⁸² by calculating 2 standard deviations from the mean value.

The area inside the corridor from Stage 1 was divided into 139 pieces⁸³ from the North of Sleavika to Blindsandodden by parallel horizontal lines⁸⁴. Then the coordinates where AIS tracks meet the lines were recorded into Excel. Excel calculated the mean value and 2 standard deviations from the mean value in west and east direction. This resulted in 140 coordinate pairs⁸⁵ on each side of the “95.4% envelope” that were then connected together.

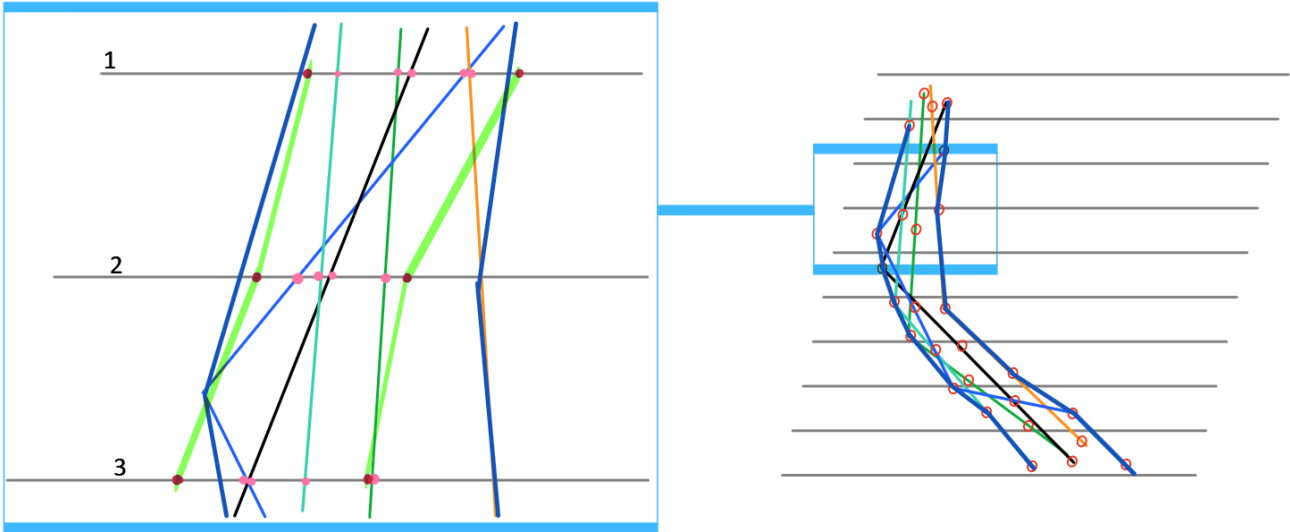


Figure 23: Simplified representation of Stage 2. Coordinates of each pink dot is measured; mean value is calculated (not on the picture); 2 standard deviations from the

⁸¹ It is not always the case. Because of this the current method cannot be applied on its own without stage 1.

⁸² More about normal distribution: (Krithikadatta, 2014)

⁸³ 139 pieces resulted in 140 blocks of measurements each block every 100 meters. The distance of 100m represents a compromise between accuracy and available resources for data analysis.

⁸⁴ As charts in Mercator projection horizontal lines on map result in 90° or West-East direction on the surface.

⁸⁵ X – is measured coordinate; Y – is a coordinate of the horizontal line.

mean are calculated and marked with red dots; red dots are connected with light green lines to represent 95.4% of vessels (if they are normally distributed)

Stage 2 makes it possible to plot a more accurate corridor and see where vessel tracks come together and where they are spread more wide. **Figure 23** shows that at line 2 most of the ships tend to sail closer to the left part and because they are not so much spread as at line 1 and 3, the width of the “envelope” is smaller.

Stage 2 represents simple mathematical calculations based the assumption about normal distribution for vessels. As a result it contradicts in some areas with stage 1⁸⁶.

Stage 3

Two corridors described above are merged as in **Figure 24**. The red area represents the area where 95.4% of the vessels sail (it is marked red in Appendix 1). The yellow area shows where 4.6% of the vessels navigate. The blue area shows where calculated distribution is wider in one or both directions. This area is disregarded as invalid. In Appendix 1 the blue area is left blank and only a limit representing 2 standard deviations is left. It is marked green.

⁸⁶ Example: Figure 23 on line 3 to the left from navigational corridor marked by dark blue.

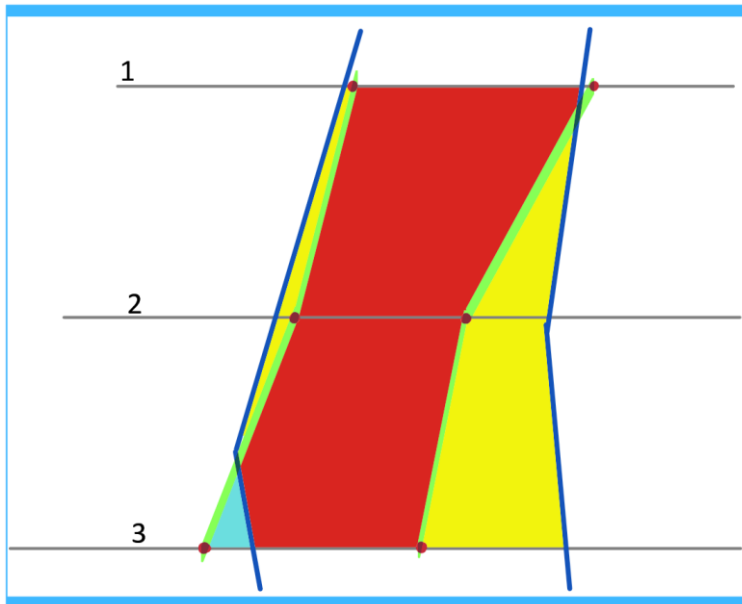


Figure 24: Simplified representation of Stage 3.

Conning Point

AIS position should be calibrated for a conning point on the ship that is usually in the center of the bridge. But the fact of calibration and point of calibration may vary for various vessels. If the conning position is in front then the stern of the vessel should come into the turn with a larger radius. If the conning position is closer to the stern then the bow should have a smaller radius in the same turn. **Figure 25.** More research is required on the topic of acquiring position coordinates, transmission via AIS and plotting of AIS tracks in case of operations in very close proximity to shipping lanes. This issue is mentioned to make all stakeholders aware of it.

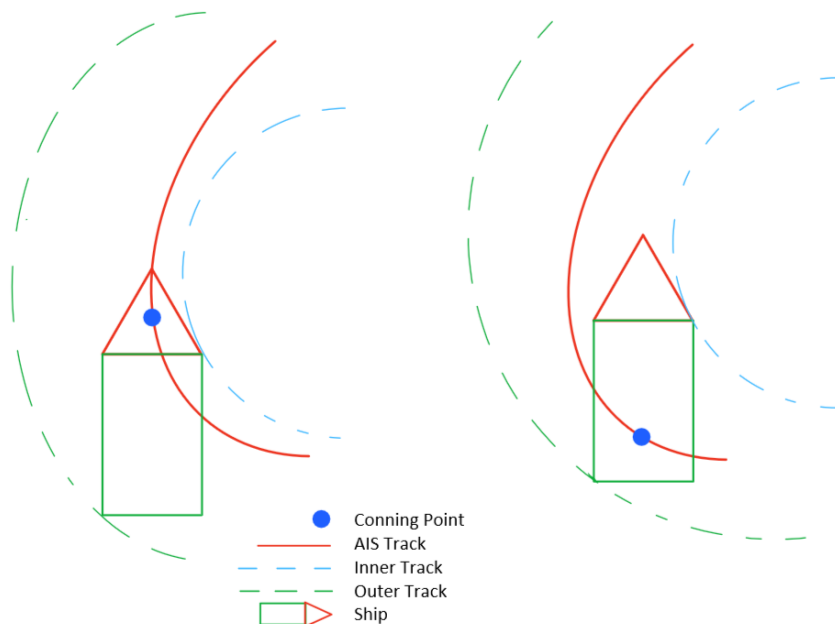


Figure 25: Conning Point; Representation model; Not intended for navigational use.

Graphics: OneNote

3.3.2 Results of Vessel Traffic Analysis

There are well established shipping lanes going through outer Drammensfjorden and Svelvikstrømmen. Ship patterns are identifiable and can be predicted to some extent.

From latitude North 59°32.2' to Holmsbusteinane

Vessels sail towards the white sector of Kroksberget light; tend to stay in the white sector or green sector of Kroksberget light. Few vessels enter the red sector. To the west from the red sector of Kroksberget there is little transit activity. At the narrow passage between Kroksberget and Holmsbusteinane most of the ships pass to the west from green lateral mark. Some small vessels sail in between the green mark and 4 meters contour at Holmsbusteinane but it is not what they are supposed to do. Vessels going southwards steer between the red lateral mark⁸⁷ at Blindsand and Rodtangen light. Free water that is on the west side from the

⁸⁷ Here basic names of buoys are used for the sake of simplicity. Full name of this buoy is: Lateral Port Hand Mark. Source: IALA

shipping corridor to: Bergerbukta 700m⁸⁸; Bergerasen 585m; Kjellerasen 612m. On the east side to: Holtnesstoa pontoon 114m; Trolebogen 540m; Arnestoa 525m; the east coast just south from Holmsbusteinane 588m.

From Holmsbusteinane to Bjørneskjær and Saltskjær

Vessels tend to stay within the white sector of Bjørneskjær; some cross the sector line into the red sector of Bjørneskjær for as much as 165m but to the north from N 59° 34,5' traffic returns into the white sector. The west border of the navigation corridor is limited by the red sector of Kroksberget and traffic tends to respect this limit from Kroksberget up to the green sector of Bjørneskjær. Vessels clear Bjørneskjær with 325m clearance⁸⁹. Free water on the west⁹⁰ side to: Kroksberget 122m; Krokåsen 348m; Solberg 1531m; Saltskjær 217m. Free water on the east side to: Holmsbu North 674m; Selskjæret 580m; Asskogen 382m;

From Saltskjær to Svelvikrenna SV/SO for vessels going through Svelvikstrømmen and from Saltskjær to Vollebukta for vessels operating for Svelviksand

Some northward traffic takes slightly to the east in order to make a wide and safe turn into Svelvikstrømmen. Ships going to Svelviksand follow Vestre Bogen ovre/nedre leading lights while holding course to the east from these lights. Sometimes vessels pass near Vollen as

⁸⁸ Distances here and further are estimated based on the methods described above and do not provide guaranty that ship traffic will avoid these areas in the future.

The author or/and any party associated with this project are not liable for any damage or loss of property cause by the usage of this data.

If the conning point of a vessel is amidships then one should subtract half of the breadth of the vessel from the distance. For large Ro-Ro vessels going through Svelvik it can be around 20 meters.

The distance is to the shore line. There are often shallow waters before the shore line. (Appendix 1)

⁸⁹ It should be expected that some vessels can come closer to Bjørneskjær in order to make a wide turn into Svelvikstrømmen. This can be a case if vessels have to give a way to those who sail in south direction.

⁹⁰ On the west side from Krokåsen up to Saltskjær Grunnane Sanctuary is located. Some activities are restricted.

close as 135m; but most of the time⁹¹ they leave Vollen 290m to the east. Vessels going to Svelvikstrømmen should change their course to 334.5⁰ that is according to Havbase.no is bearing to Svelvik ovre/nedre leading lights that mark the middle of the Svelvikstrømmen up to Batteriøya. Ships sailing from Svelvikstrømmen to the south after passing Svelvikrenna SV/SO start the turn to the south. Some vessels break the 9.5m depth contour to the south from Svelvikrenna SV. Free water on the west side to: Bokerøya 577m; Homannsbergbukta⁹² 1150m. Free water on the east side to: Knivsvika 430m; east coast between Knivsvika and Vollen 380-400m; Vollen 135m; Vollebukta (from South to North each 300m starting from Vollen) 135m; 348m; 382m; 374m; 514m.

From Svelvikrenna SV/SO to Ryggen

From Svelvikrenna north-going traffic navigates towards Svelvik ovre/nedre leading lights until it reaches the middle of Batteriøya, then vessels turn to the north following the curvature of Svelvikstrømmen. While some vessels may prefer to navigate using Tommeras ovre/nedre leading lights, for others navigation on the lights from astern (from the back) can be tricky. Vessels may prefer to navigate on Blindeskjær by steering towards its green and white sector. During the passage through Svelvikstrømmen the vessels will try to keep a safe distance. Safe distance varies on size of the ship, speed, tidal current; wind; crew preferences. Upon the research during this project it was agreed that comfortable distance for larger Ro-Ro boats going to Drammen should be approximate ½ of a cable or 93m on each side. As usually the distance to each coastal line in Svelvikstrømmen is closer than ½ of a cable, vessels will try to navigate in the middle of the passage keeping maximum distance from the shore and the objects along the coastal line. Svelvik-Hurum ferry route is established in the northern part of

⁹¹ Here it is more correct to say “most of the time” instead of “majority of the vessels” because there are just two vessels found that go to Svelviksand but they do operate on a regular basis: around 120 voyages in 60 days.

⁹² It is anchorage place in Homannsbergbukta

Svelvikstrømmen. Ferry does not go in a straight line. Area of navigation of the ferry is marked with magenta color at Appendix 1. The area between the ship passage to Svelvikstrømmen in the west, the ship passage to Svelviksand in the east, Svelvikrenna SO in the south and sandbank in the north is relatively calm. In a course of 2 months General Cargo ships from Svelviksand used this area few times as a shortcut on the way to inner Drammensfjorden. The area has different depths from 7.6m up to 1m where vessels from Svelviksand were seen navigating on the depths up to 3.8m. The width of the area in west-east direction is measured to be around 120m at 80m to the north from Svelvikrenna SO and 757m just on the edge of 2.8m depth contour.

More research is required about the width of Svelvikstrømmen. It is known that the channel was dredged in a period from 2003-2006 to at least 12m depth (Secora). However it is unknown how the width of the dredged channel was defined.

From Ryggen to Sleavika

To the north from Ryggen traffic spreads wider; ships keep routes to the east from Bjørneskjær holding to the green sector of Bjørneskjær light. A wide area to the east is free from commercial traffic. To the west it is 130m to the pier where small boats are moored.

3.4 Tidal current modeling and Samples of the Geometry of the seabed

A tidal current model that is being used to determine and predict water flow in outer Drammensfjorden is provided by FjordOs. The model calculates water flow velocity and direction for 40 horizontal layers. Examples⁹³ of FjordOs modeling are at **Figure 26** and **Figure 27**

⁹³ Figure 26 and 27 are representations of the model. Tidal current may vary depending on the time of the day, season and other factors. Contact FjordOs for details.

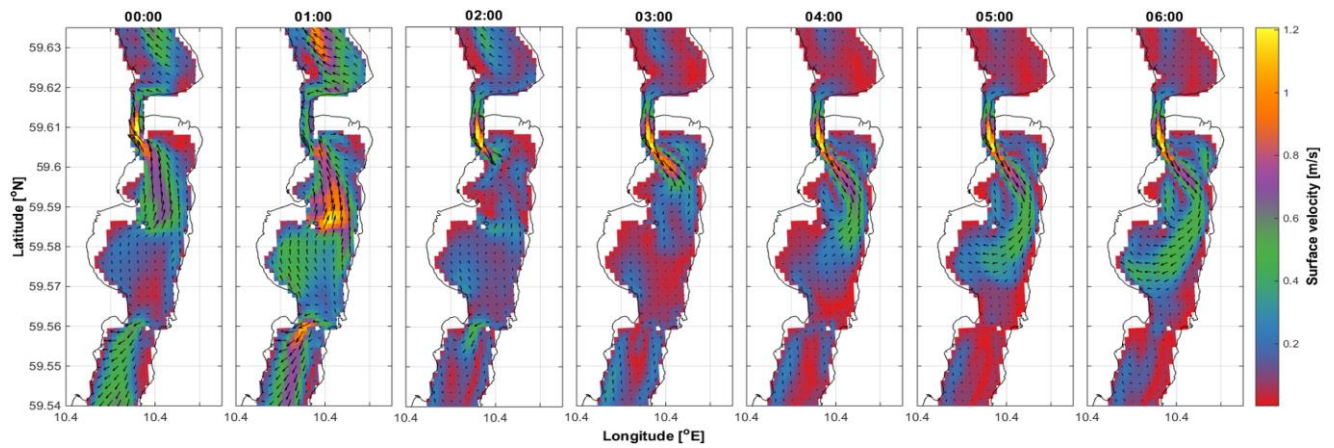


Figure 26: Example of surface current modeling at Svelvikstrømmen and outer

Drammensfjorden by FjordOs model. Source: (Lars Petter Røed, 2015)

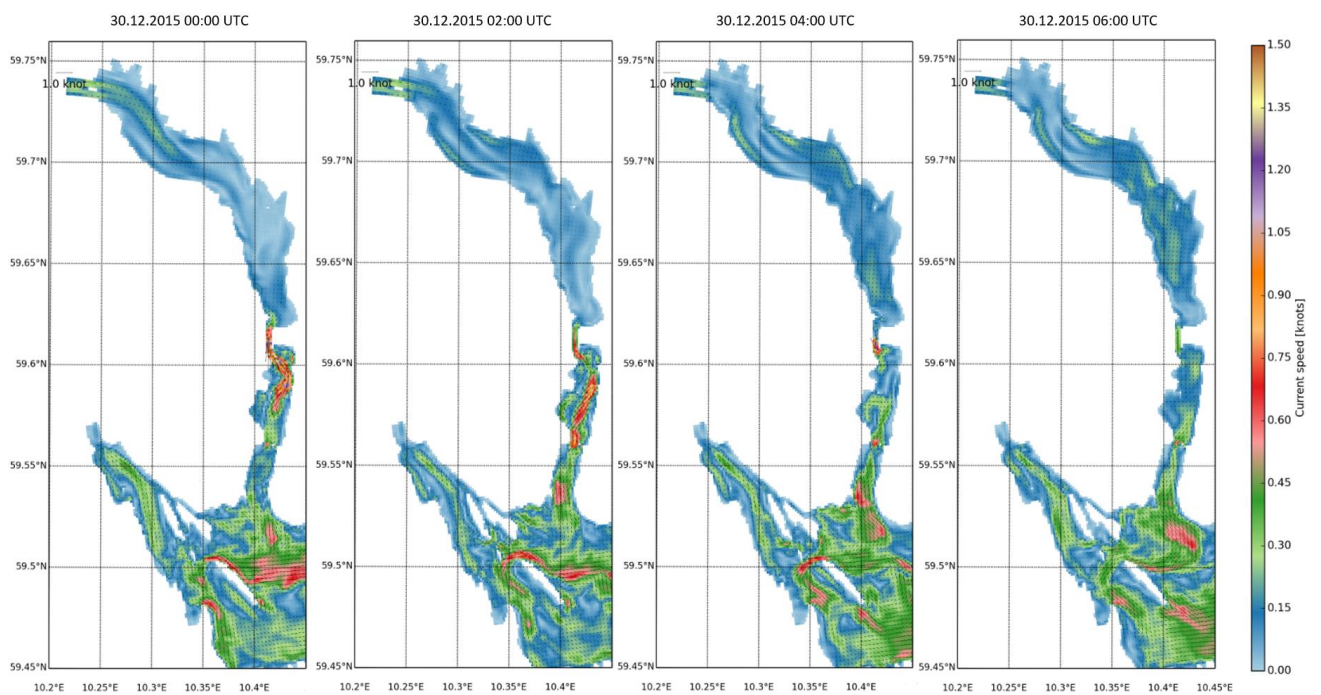


Figure 27: Example of current modeling at 2 meter depth in Drammensfjorden by

FjordOs model. Source: (FjordOs, 2015)

FjordOs model takes into consideration numerous factors such as topography of sea bottom; salinity of the water; atmospheric influence; tidal attraction; pressure from Skagerrak⁹⁴.

According to this model tidal current has the highest velocity in south part of Svelvikstrømmen and along the east coast near Vollen and Knivsvika as at **Figure 26** and **Figure 27**. According to FjordOs the model should be validated before using in the area. A stronger current is expected to the south from Svelvikstrømmen as the channel is narrower than that described in the model⁹⁵.

Acoustic Doppler Current Profiler was installed on the sea bottom by NIVA on April 26, 2016 and will be retreated in June 2016. When retreated it should validate FjordOs model for outer Drammensfjorden.

The initial position for installation was chosen by NIVA and FjordOs and after a quick bathymetry survey ADCP device was set down at the position shown at **Figure 28**

⁹⁴ More information on FjordOs model can be obtained from: <http://www.fjordos.no/>

⁹⁵ FjordOs used wider channel in calculations due to technical restrictions. For more information contact FjordOs.

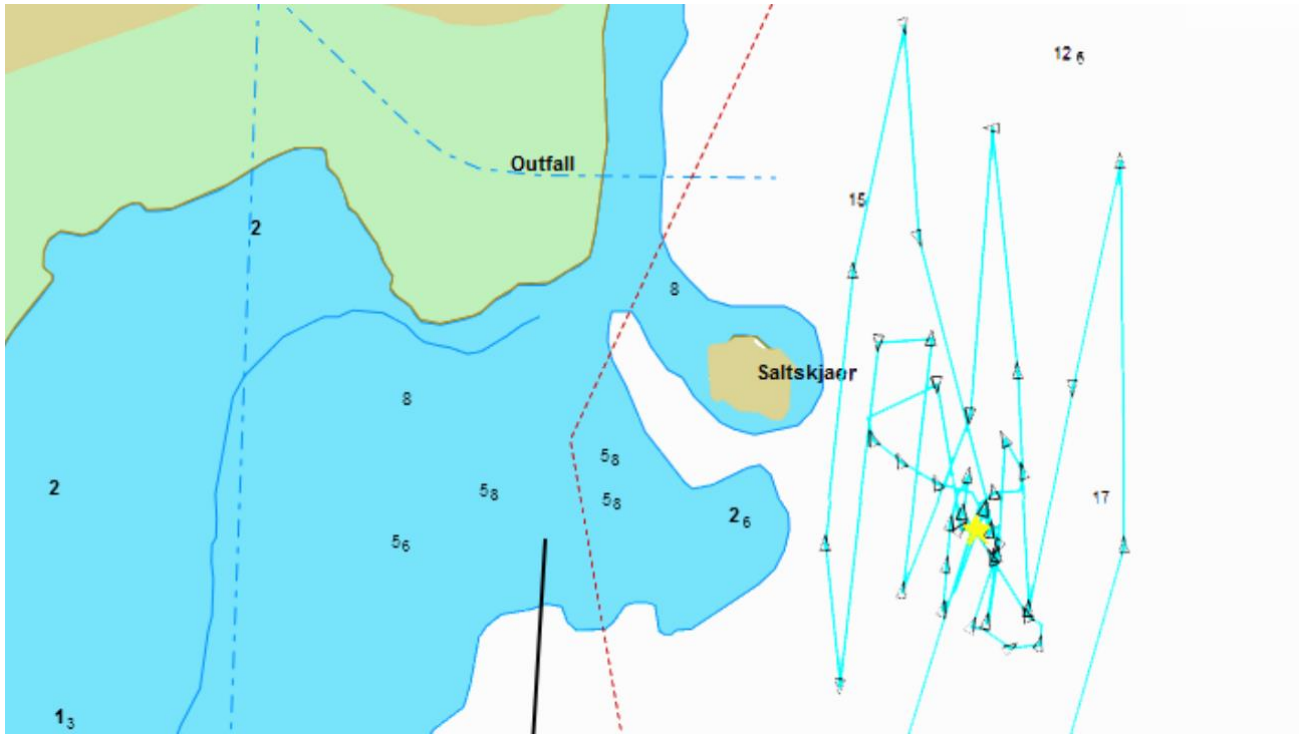


Figure 28: Deployment of ADCP with Trygve Braarud; Aquamarine – AIS track following bathymetry survey and ADCP deployment; A STAR – ADCP deployment position

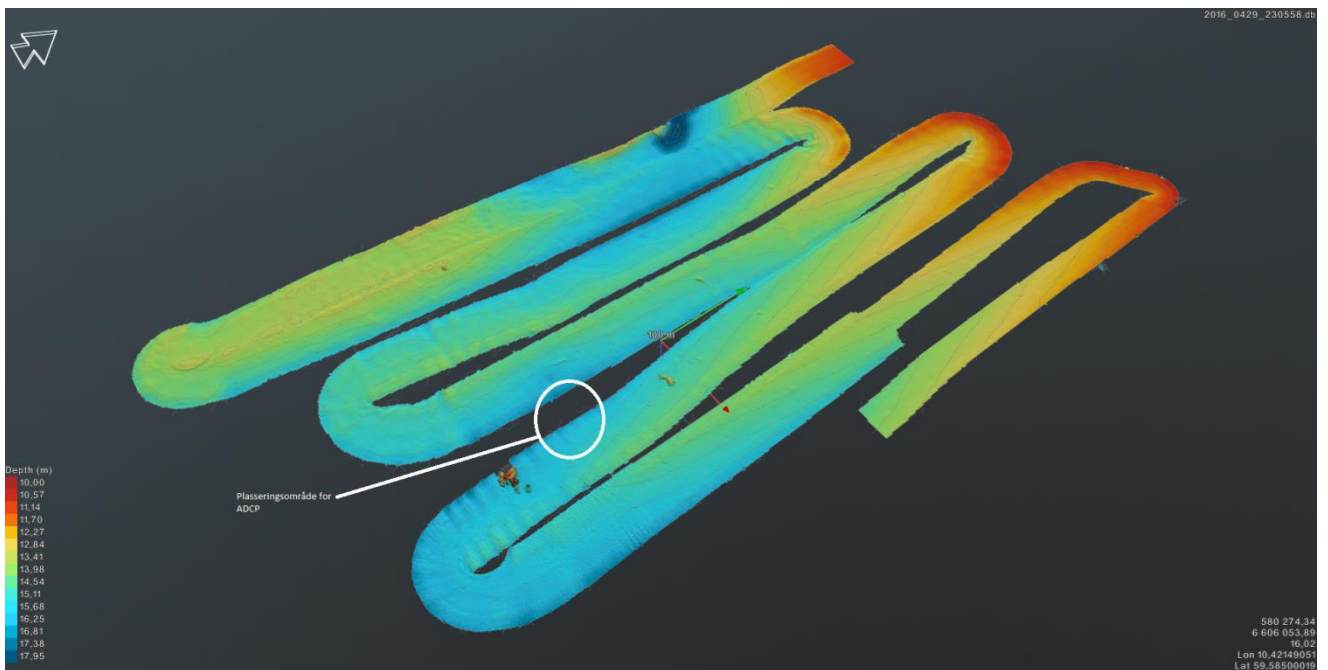


Figure 29: Bathymetry survey and ADCP deployment area; Source: Captain Sindre

Holm, Research Vessel Trygve Braarud, University in Oslo; Equipment – WASSP 160S multibeam echosounder.

Data from the bathymetry survey (**Figure 29**) shows a relatively flat bottom in the area deepening towards the south. Some objects were found on the bottom that might be of artificial origin. Depths vary from the mean depths marked in nautical charts. More research for potential sites is required.

Developers and those associated with subsea operations in Drammensfjorden should be aware of the possibility to encounter subsea mines from World War II. According to Secora AS during the dredging of Svelvikstrømmen in 2003-2006 they found 26 mines and “A number of these were removed during the dredging work” – Secora AS. (Secora) According to the commune leader Arvid Askø some mines were removed during cable works to the south from Svelvikstrømmen. Consultation on this topic with Secora AS and Arvid is advised.

3.5 Environment

3.5.1 Grunnane sanctuary

Grunnane nature sanctuary was founded in 1981 to preserve a wetland area in its natural state. Sanctuary covers 2937 acres (11.89 km²), where 2900 acres (11.74 km²) represent water area. In the past centuries the northern part of the area was filled with waste as a result of human activity in the region. Together with increased human activity these factors reduced life conditions for many species of birds. (Fylkesmannen i Vestfold, 2013)

This area is vital for birds because of its unique location and properties. Here salt water mixes with fresh water. In combination with a large mud surface it provides excellent conditions for algae, water plants, snails, crustaceans and worms that are food to 130 species of birds. (Vestfold, 2011)



Figure 30: Grunnane Sanctuary; Satellite imagery – Google; Nautical charts background – MarineTraffic.com; Data for graphics – Lovdata.no; Graphics – Photoshop.

Almost the whole area is located in Svelvik commune (Vestfold county) except the easternmost part next to Saltskjær that comes over the border with Hurum commune in Buskerud county. The sanctuary occupies mainly the water area with an exception of the north-western part of 37 acres (0.15 km²). The water border goes 600m to the east from Krokåsen then to the western part of Saltskjær and along the west coast of Saltskjær and to Bokerøya. On land the border follows the road Rv 319.

According to Lovdata.no the following restrictions are in place at Grunnane nature sanctuary:

- 1) New plant/animal species cannot be introduced
- 2) Hunt, fishing and use of weapons is prohibited
- 3) All the activity that leads to changing of the natural environment is prohibited. This includes: installation of cables in air or underground, sewage pipes, walls building, dragging or moving the soil, discharging concentrated contaminating substances.
- 4) Human presence is prohibited between April 15 and July 15

(Miljøverndepartement, 1981)

3.5.2 Fishing

During the research little data on subsea fauna in Drammensfjorden was found. Due to the lack of high quality data further research is required⁹⁶.

The data of fish species, their habitat and migration given further in this section is based on the consultation with Runar Larsen⁹⁷ who has long time experience of catching subsea fauna in Drammensfjorden.

According to Runar there are several main species of fish present in Drammensfjorden:

- Saithe
- Herring

⁹⁶ For examples of research and methods of subsea fauna please refer to Research section in the framework of TRC. Information about water quality and sediments in Drammensfjord: <http://prosjekt.fylkesmannen.no/rendrammensfjord/Om-prosjektet/>

⁹⁷ Runar can be the last commercial fisherman in Drammensfjorden . He has around 50 years of experience in the industry; works with NIVA on the project "Ren Drammensfjorden 2015" Source: (LIE, 2014); (AAS, 2010) and NIVA.

- Cod
- Salmon
- Pollack
- Flounder
- Eel

Because the water in Drammensfjorden is divided in horizontal layers by salinity and has tidal currents it provides a favorable habitat for fish.

Salmon migration up to Drammenselva starts in March and continues in April. During this period salmon fishing is prohibited. Newborn Salmon migrates down the fjord in September-October⁹⁸. This salmon because of its small size is not caught into the nets and does not take the bait. So there is no prohibition on fishing salmon during autumn migration. Some salmon won't go all the way up to Drammenselva as it was artificially released in outer Drammensfjorden and its offsprings use the same area for spawning⁹⁹.

Eel migrates to Drammensfjorden and stays in the area for many years (around a decade or more). Eel is a protected species and fishing eel is not allowed. The fish is around 6-9cm long when it comes to Drammensfjorden. Mature eel is 60-70cm long.

Cod migration takes place from February to March. Cod stops in the areas to the north from Holmsbu. This makes the area from Holmsbusteinane up to Bjørneskjær especially favorable in terms of fishing.

Conclusion on fishing section

⁹⁸ According to lovdata.no sport fishing in Drammenselva starts May 15 and continues until September 30 or October 31 depending on the area. It is allowed to fish all year round in Svelvik and to the south from it with fishing rod and hand fishing line registered at County Governor (Fylkesmannen (nor)). (Direktoratet for naturforvaltning (nå Miljødirektoratet), 2012)

⁹⁹ Runar did not specify any details about this case. It should be accounted as unproven until more evidence is gathered.

The source for the data in this section can be seen as genuine. But the lack of assured information from other sources takes place. If the data from Runar is confirmed it will mean that mitigation measures should be prepared to minimize the impact of TRC construction and operation on fish. If the area along the east coast from Holmsbu to Bjørneskjær is used for TRC's purposes it is expected to cause negative consequences for commercial fishing in Holmsbu. So far the effect on sport fishing in that area has been unknown.

4 Results

4.1 Tidal Research Center Framework

The process of establishing and operating Tidal Research Center is not a clear linear process. It is divided into four main sections (**Figure 4**). Each section includes interests of numerous stakeholders.

Tidal In-stream Energy Converter is a functional technology at prototype scale. There is not enough data to assess TISEC sustainability under commercial deployment and operation yet. The process of converting tidal energy into electricity differs among developers.

Tidal turbines design influences power output and reliability. Practically less than 50% of tidal energy will be converted into mechanical energy.

TRC's physical construction can represent several separate buildings, where office spaces may not have physical connections with substations. Data between facilities is transmitted wirelessly.

The main facility of TRC can incorporate visitor center with educational and business purposes.

Small scale sites may not have a grid connection.

Subsea cables can include auxiliary cables and data cables inside them for data transfer, control of the devices, and auxiliary power supply to device.

Construction of facilities does not require extra wide roads. Certain size will depend on the scale of TRC.

Meteorological equipment and marine RADAR can be installed in the area to monitor traffic and weather conditions in real time.

Environmental Impact Assessment is a vital document on the first stage of development. It covers most of the aspects that concern TRC construction and operation.

Environmental care is one of the top priorities.

TRC can have a general agreement with a grid operator that will let developers use a simplified process of connection to the grid.

Local expertise is very helpful for developers and a well-organized supply chain benefits TRC.

Organization of data into a functional system and its availability benefits developers and stakeholders. In addition TRC can provide some of the data as a part of commercial services.

TRCs in Orkney and Nova Scotia do not provide tank testing. The research has not found facts showing that tank testing cannot be implemented in other TRCs.

4.2 Tidal Research Center in Svelvik

Svelvikstrømmen is a busy waterway with 1770 passages in 2015. Most common vessels are General Cargo Vessels of 1000-4999 GT. The biggest vessels are of Ro-Ro type with capacity over 25000 GT.

The research has identified 8 areas for further assessment. (Appendix 1)

Area 1 is a water area on the west coast right on top of Svelvikstrømmen. The area is restricted by Svelvik Marina in the north; vessel traffic in the east. The widest area is around 70m. The depth gradually increases from 0m to 18m¹⁰⁰.

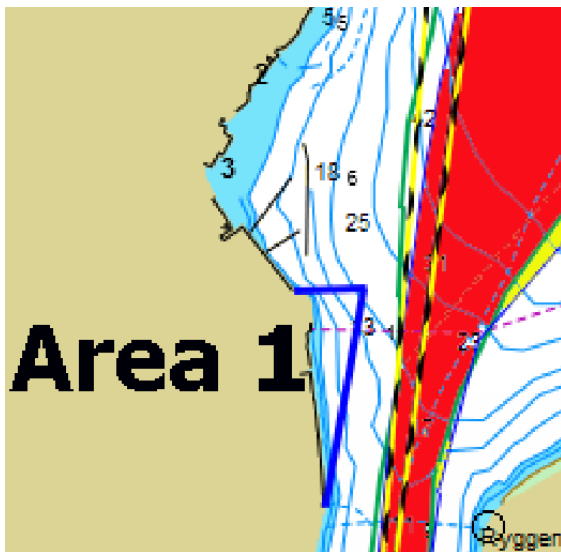


Figure 31

Area 2 starts at Ryggen on the opposite side of the channel from area 1. It covers the area up to the north of Dramstadbukta. There is little vessel traffic according to this research. Some small private boats can appear in Dramstadbukta and along the coast of Ryggen. A subsea power cable is stretching from Svelvik to Dramstadbukta. The depth gradually increases from the coast line up to 115m in the fjord center.

¹⁰⁰ All depths are according to nautical chart and may not represent correctly measured depths as at **Figure 29**.

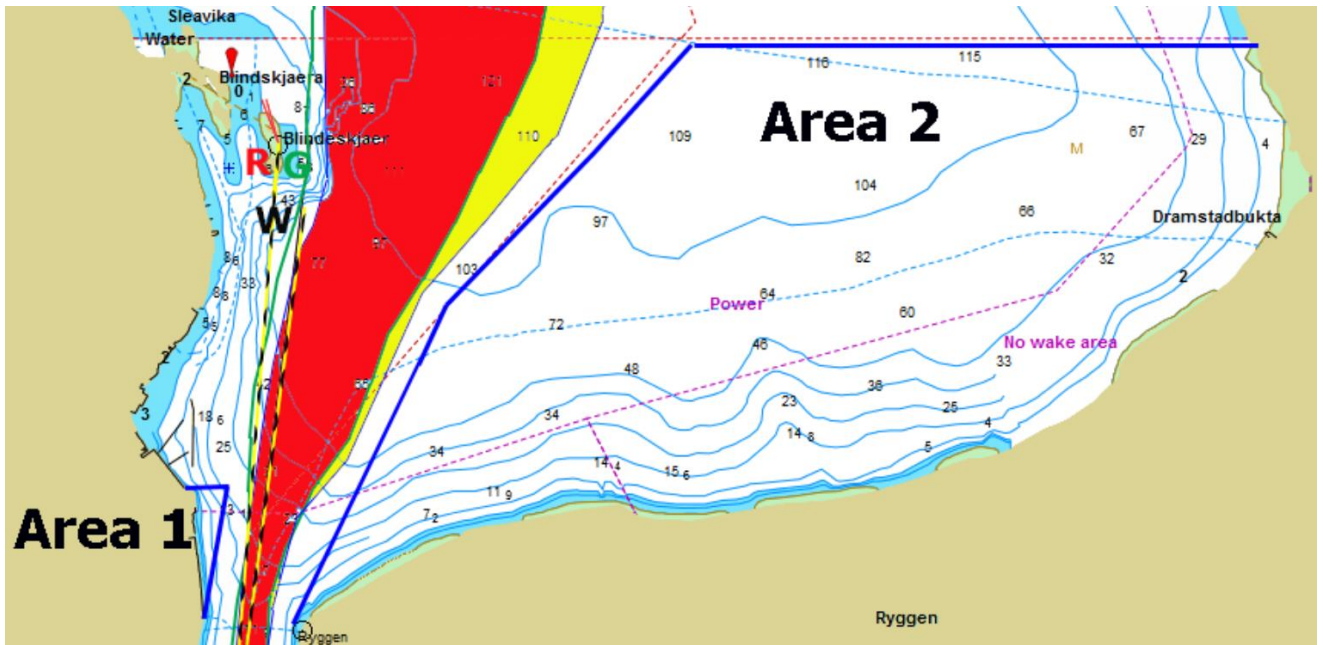


Figure 32

Area 3 is a zone right off the industry zone in Svelvik. It stretches for 200m from north to south; limited by shallow waters in the north, Batteriøya in the south, vessel traffic in the east (estimated width 48-70m). The depth is 4-4.3m

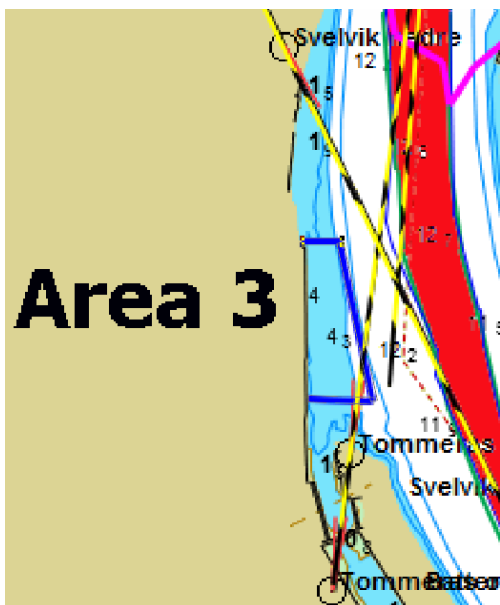


Figure 33

Area 4: This is an area lying between two shipping lanes. Some traffic with AIS onboard cross the south part while going from/to Svelviksand (marked yellow). In the middle stands the sandbank 1m deep. The depth contour is uneven.

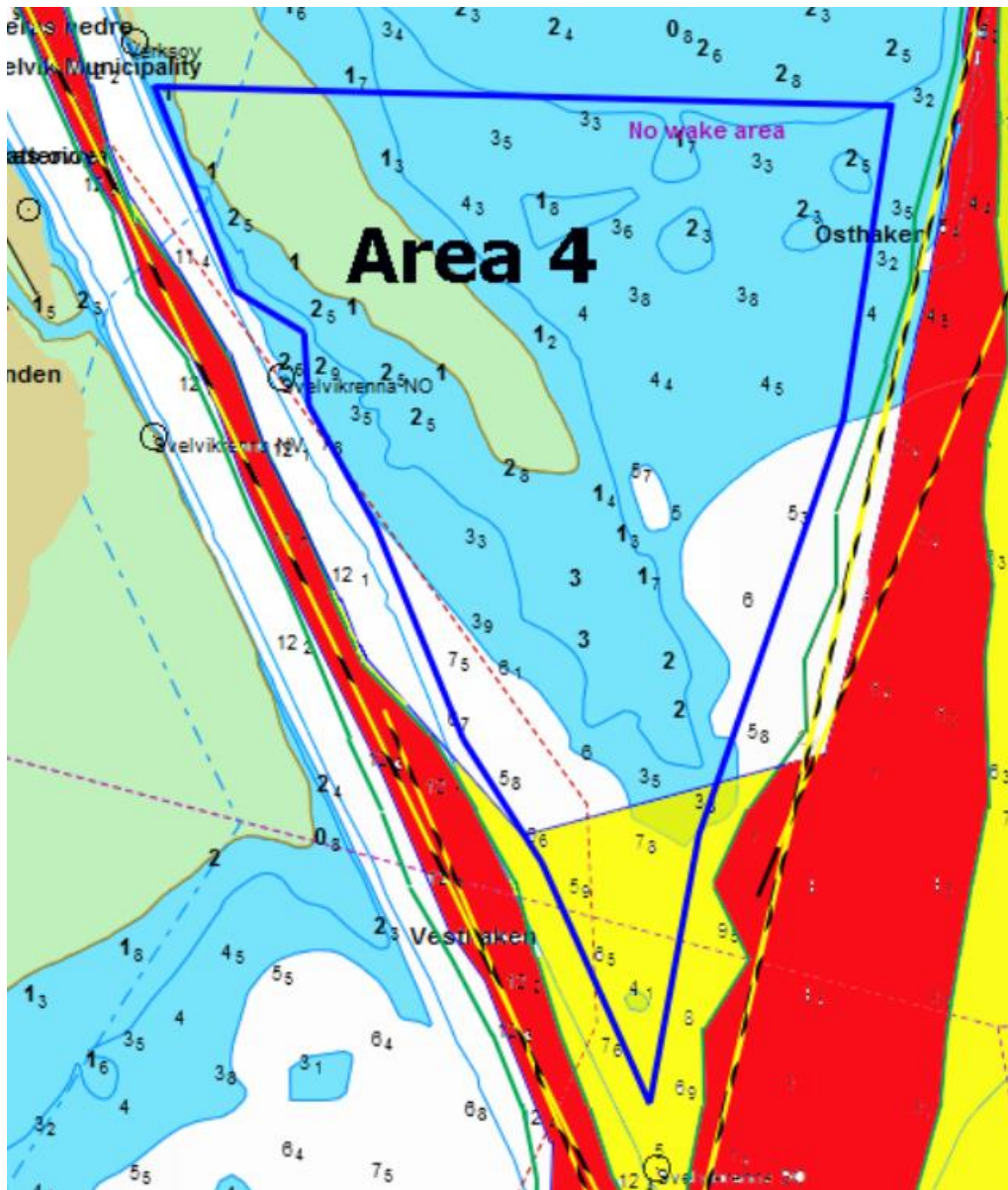


Figure 34

Area 5 stretches along the east coast line from Vollen in the north to Bjørneskjær in the south. It is limited by an anchorage zone at Vollebukta in the north; vessel traffic in the west. In the south it merges with area 6. Commercial fishing activity takes place in this area.

Contour along the coast shows 2-6m depths, then the depth increases until 10.5-12m and stays within this limit until the western border.

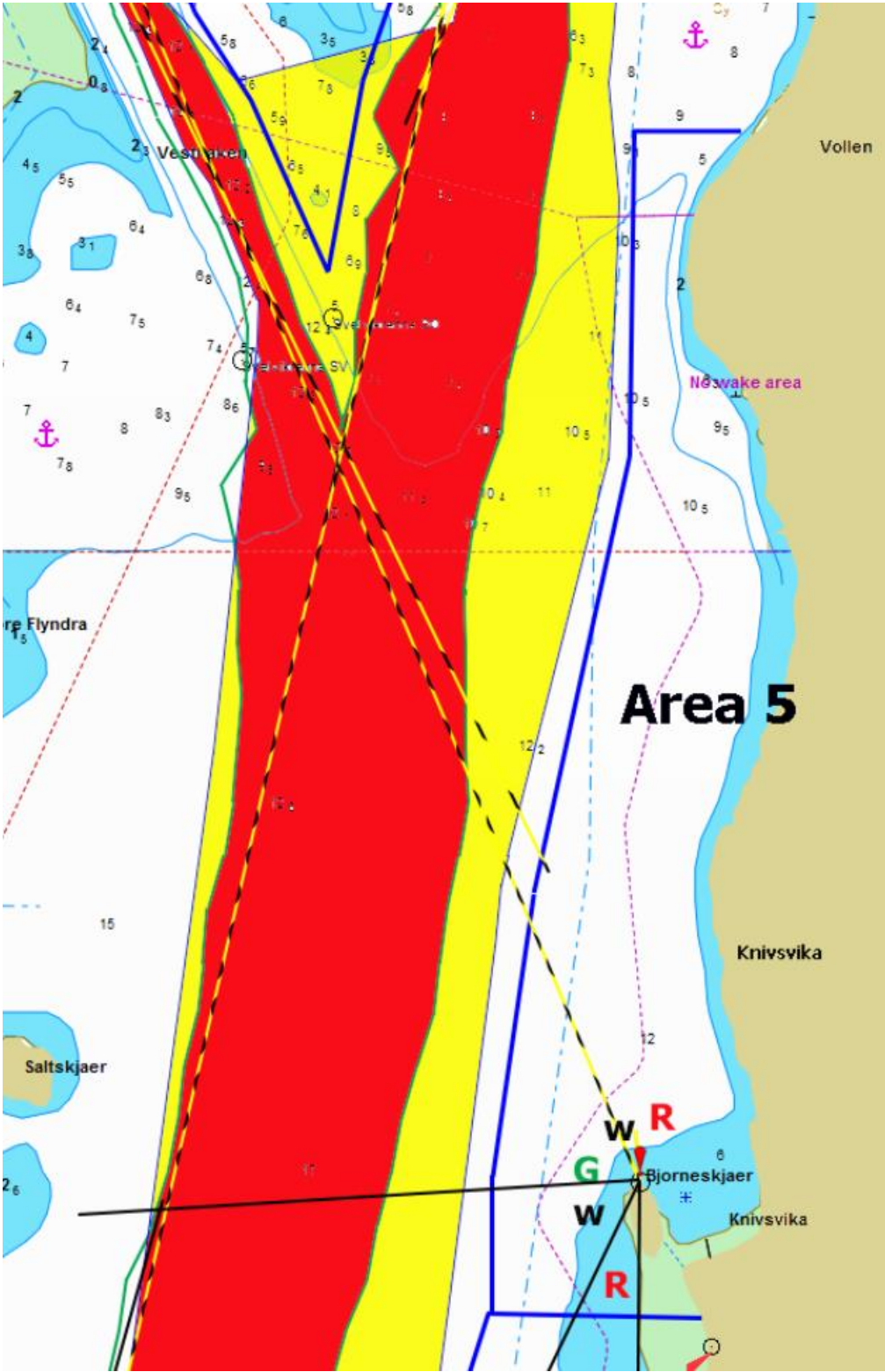


Figure 35

Area 6 is located along the eastern coast from Knivsvika to Holmsbu; almost completely in the red sector of Bjørneskjær; little deviation in depth; small contour of shallow water along the coast that widens in the northern part. This is the area where fishermen from Holmsbu and others tend to fish. Cod migrates to this area. There are many recreational boats at Holmsbu marina. To the south from Holmsbu a shallow area called Holmsbusteinane is located. Small rock formation separated from the mainland by 3.8m deep water; to the west from the rocks are shallow waters of 4m deep that end with the green lateral mark. Ships should pass this mark on the west side. It was found that some smaller vessels can sail to the east from the mark. For bigger vessels it is not safe.

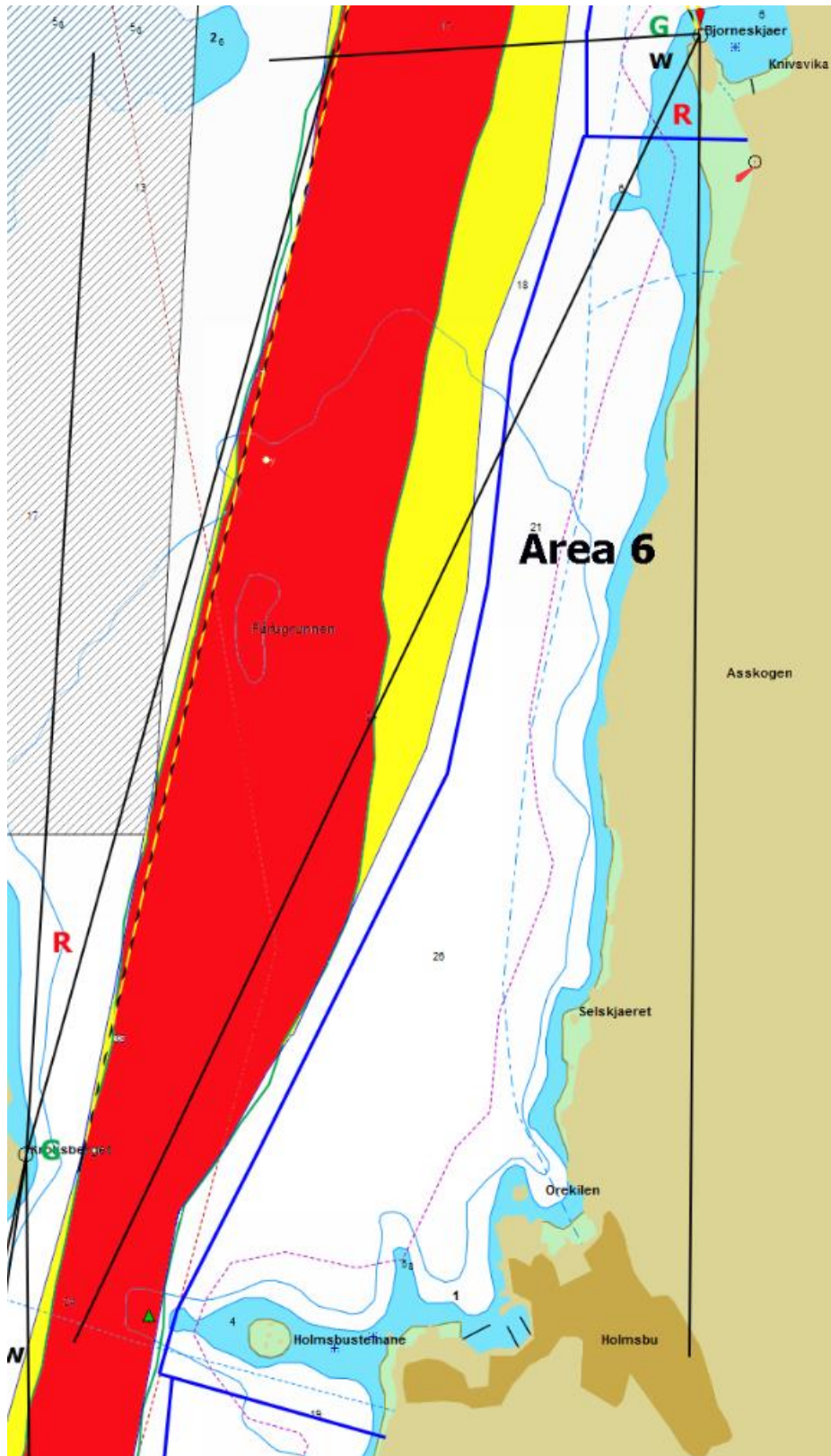


Figure 36

Area 7 is from Kroksbukta to Blindsandodden; located beyond the red sector of Kroksberget light. Because of shallow waters at Blindsand in the south and Krokåsen in the

north vessel traffic do not tend to enter the area. Some recreational boats are located in Kjelleråsen and Sand. Main depth is 15-28m.

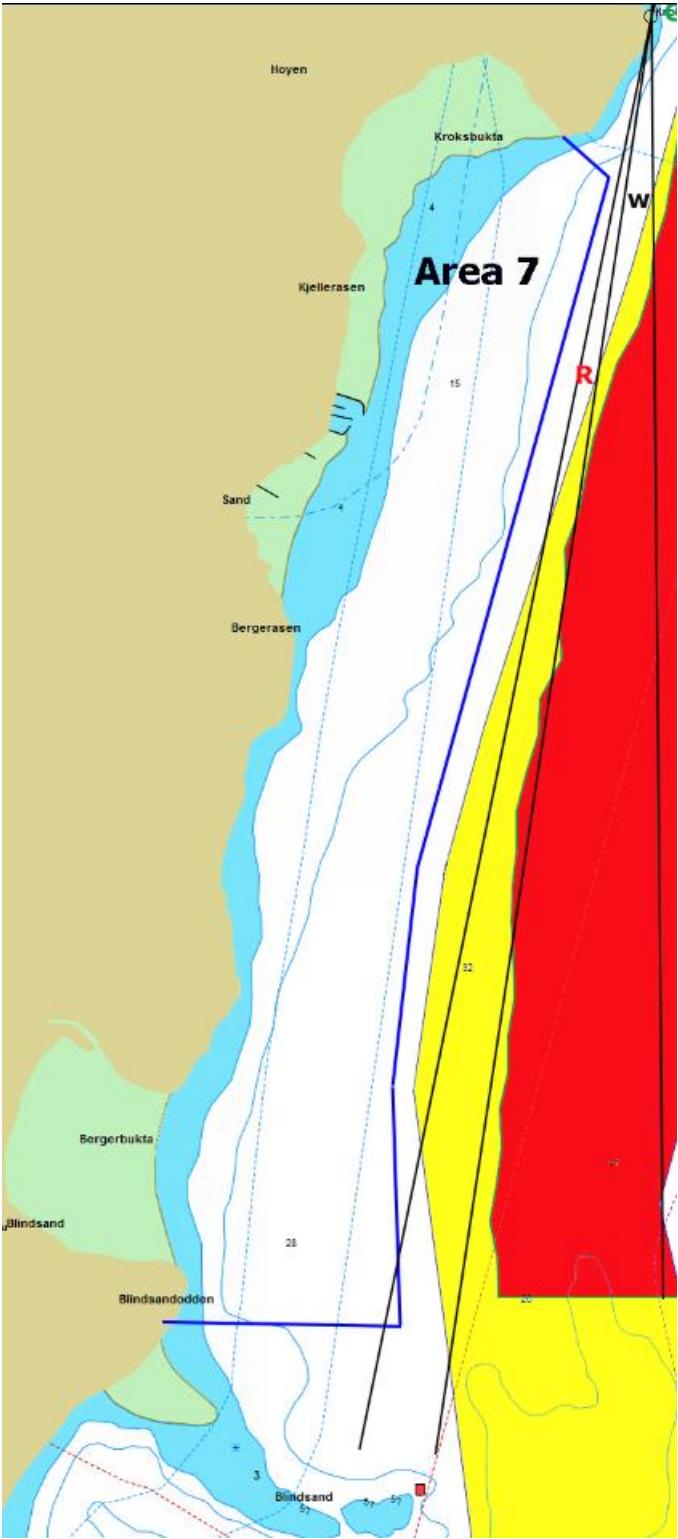


Figure 37

Area 8 is on the eastern coast to the south from Holmsbusteinane. The anchorage place for small boats is to the north from Arnestoa. In the south the area is limited by vessel traffic and marina at Holtnesstoa. Main depth is 19-29m

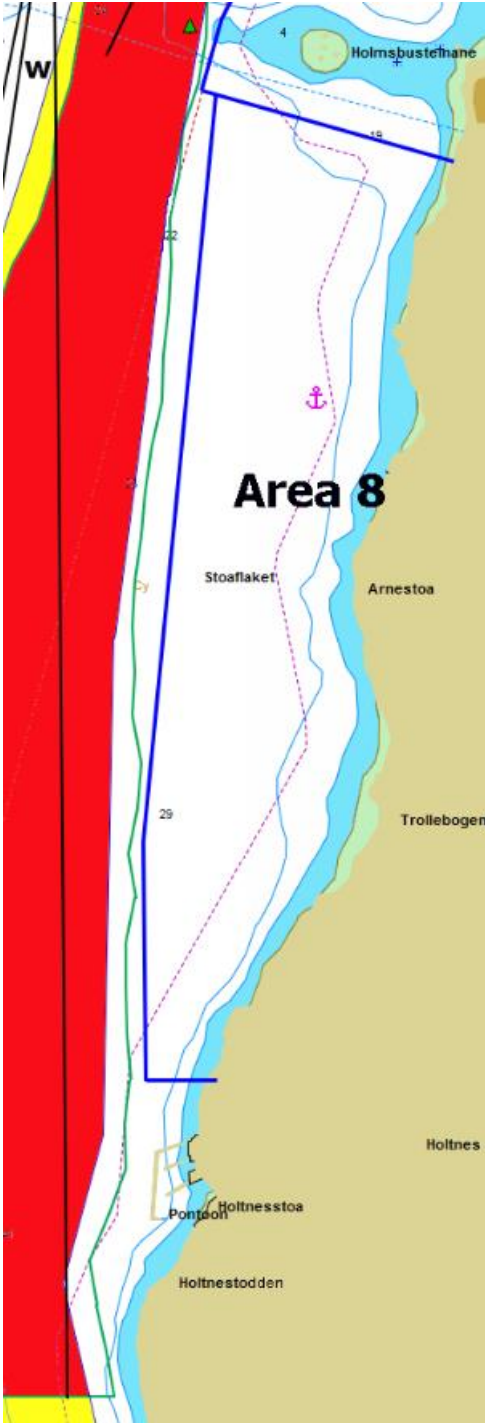


Figure 38

5 Discussion

The research of the framework of TRC has revealed that in order to determine an area for installation of tidal turbines a complex of surveys should take place. To estimate the direction and scope of surveys it is important to identify the areas of concern. According to the results produced by this thesis, the areas of concern for the project of Svelvik TRC are the following:

1. Ship Traffic: established shipping lanes with regular passages and leisure boat traffic; interaction with TISECs.
2. Confined waters: assessment of possible interactions and consequences of incidents (risk analysis).
3. Fishing: areas for fishing industry and sport fishing in Drammensfjorden; possible consequences when TISECs encounter fishing equipment and vice versa.
4. Fish: estimation of consequences for fish species from TRC installations.
5. Subsea flora and fauna: environmental impact of TRC installations and operation on biological communities on the seabed
6. Birds study: assessment of TRC impact on wild birds in Grunnane sanctuary and along the designated areas.
7. Marine mammals and other species: outlining other species of wild life that is not mentioned in section 3-6.
8. Bathymetry: mapping sea bottom and depths in designated areas to confirm the possibility of subsea installations.
9. Social Impact: Impact of Svelvik TRC on societies along the coast of Drammensfjorden.

The complete list of the studies and surveys as well as the scope can change after the input from all stakeholders. Studies should meet regulatory requirements and satisfy them. When requirements are met, the project of Svelvik TRC can apply for lease of the designated areas.

An additional survey is advised to determine which authorities govern installation and operation of TRC. The waters of the Svelvikstrømmen and Drammensfjorden are divided between Vestfold and Buskerud counties. Svelvik commune borders on Hurum commune (marked with red on **Figure 39**). It is also likely that cooperation on the commune level as well as cooperation on the county level will be required in order to proceed with a TRC project.

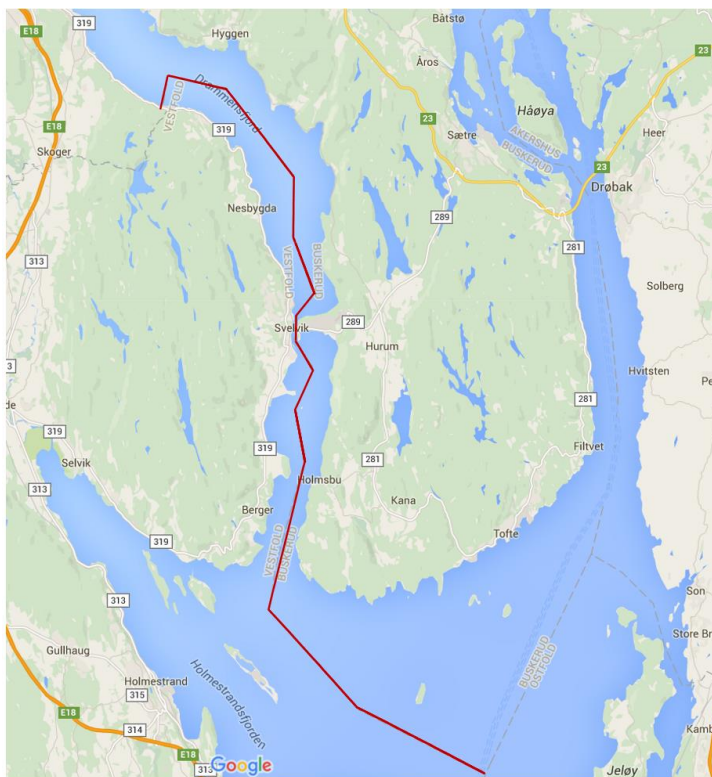


Figure 39: County and commune border between Vestfold and Buskerud. Data:

Lovdata.no; Background map: Google; Graphics: OneNote

Each project of TRC is unique. Methods used during the development of some TRCs may not be applicable to others. In Drammensfjorden ship traffic represents such an issue. So far during the research no clear method in literature how to represent correctly AIS data on the map in confined waters has been found. As a result this research has to combine the navigational assessment with the distribution analysis. To validate the method and navigational corridor, AIS data chart from Havbase.no is taken. The scale is corrected to 1:10000 and the chart is rotated 3.5° counter clockwise. The period for AIS data is March 2015; vessel types that navigated in that period and chosen: Chemical Tankers; Bulk Ship; General Cargo Ships; Container Ships; Ro-Ro; Passenger Ships; Offshore/Supply; Other Vessels. It has been found out that vessels move inside the marked corridor except two cases showed at **Figure 40** and **Figure 41**:

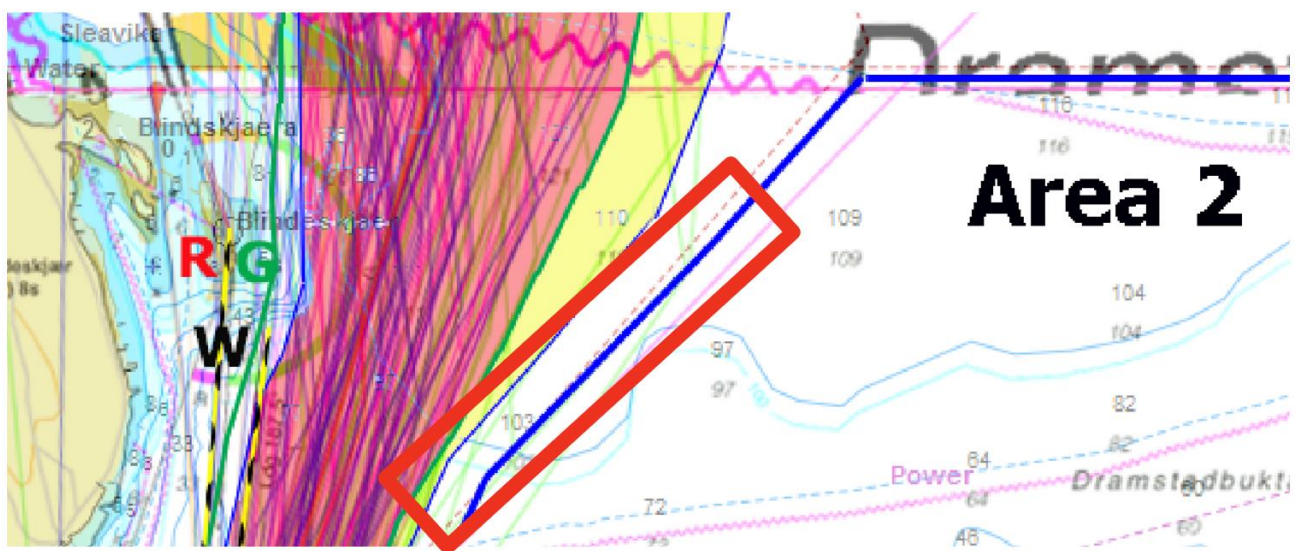


Figure 40: Combination of nautical charts from MarineTraffic.com and Havbase.no.

At **Figure 40** several container ships marked light green sailed around 80m to the east from the estimated navigational corridor into the area marked inside the red figure.



Figure 41: Combination of nautical charts from MarineTraffic.com and Havbase.no.

At **Figure 41** two Ro-Ro ships left the corridor (pink tracks). This is expected as larger ships can come closer to Bjørneskjær in order to take a wide safe turn. One General Cargo Ship navigated 157m closer to the shore than expected. The motives to choose this route are unknown.

It is concluded that such method can be used in Drammensfjorden. To increase the validity the method can be applied to different periods. High quality AIS data with discretization of 1 minute or less would improve the output. The method is time consuming. For frequent use or use in various periods programming is desirable.

For a proper assessment of fishing activity more research is required. The method used consultation with industry as a source of data. The research has found that Runar Larsen may be the only representative for commercial fishing industry in outer Drammensfjorden. So far no other fishing companies have been found. Other research method is required.

FORCE, EMEC and other TRCs use produced electricity in different ways. This section is to discuss some of the ideas about possible applications of energy produced by TRC in

Svelvik. Implementation of the ideas mentioned below will depend on numerous factors such as power output of TISECs, infrastructure development, financing etc¹⁰¹.

Dissipation

Dissipation looks as the simplest way as little infrastructure is required. Dissipation occurs by connecting a resistor that turns produced electricity into heat. A test support buoy at Shapinsay Sound in Orkney is an example of such a technology. The buoy is anchored at the site.



Figure 42: Test support buoy at Shapinsay Sound. Source: EMEC

Grid connection

Grid connection with power purchase agreement gives developers an opportunity to receive income from the produced electricity. This will depend on the grid requirements for generating capacity of tidal turbines, quality of electricity etc.

Storage and use for internal purposes

It may be possible to store and use the energy produced by tidal turbines for the internal usage at TRC. The energy can be used directly for powering TRC operations or can be stored in batteries which can be a solution to even the power output of TISECs. During peak production the excessive power is transformed to charge batteries which then will power the

¹⁰¹ Based on the experience from FORCE and EMEC

facility when the tidal current is insufficient. Lithium-ion technology can be a solution. An example of this technology is a Powerwall from Tesla Motors¹⁰².



Figure 43: Powerwall from Tesla; Source: Tesla Motors

One battery is 130cm high, 86cm wide, 18cm deep; capacity 6.4kw; peak power output 3.3kw; can be placed outside or inside; operating temperature from -20°C to 50°C; multiply batteries can be installed together

Storage and use for external purposes

The same principle as described above can be used on a larger scale to power consumers outside the TRC. Two promising solutions are batteries and hydrogen storage.

A Powerpack can be described as scaled up Powerwall. Capacity starts from 95kw AC current with a peak power of 50kw. According to Tesla the technology is infinitely scalable for industrial use¹⁰³. It can provide an opportunity to create a micro grid with continuous and reliable power supply to external facilities between the peaks of power production.

¹⁰² <https://www.teslamotors.com>

¹⁰³ <https://www.teslamotors.com/powerpack>



Figure 44: Powerpack installation from Tesla; Source: Tesla Motors

Integrated hydrogen system is an alternative to batteries. The system is piloted at Orkney by EMEC. An electrolyser uses excessive energy for hydrogen production that than can be transported and used in fuel cells. (EMEC, 2015b); (EMEC, 2015a)

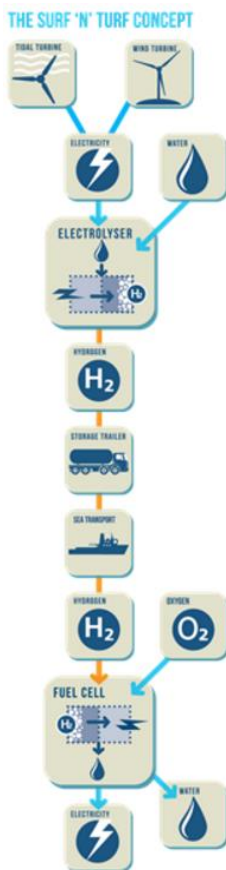


Figure 45: Block scheme of planned hydrogen production-consumption chain in Orkney. Source: EMEC

The electrolyser is shipped in two containers; has 500kg hydrogen storage capacity; production rate is 220kg/24h; energy consumption is 0.5 megawatt.

Special applications

Special applications may include powering:

- Charging stations for electric cars.
- Light power towers across Svelvikstrømmen¹⁰⁴

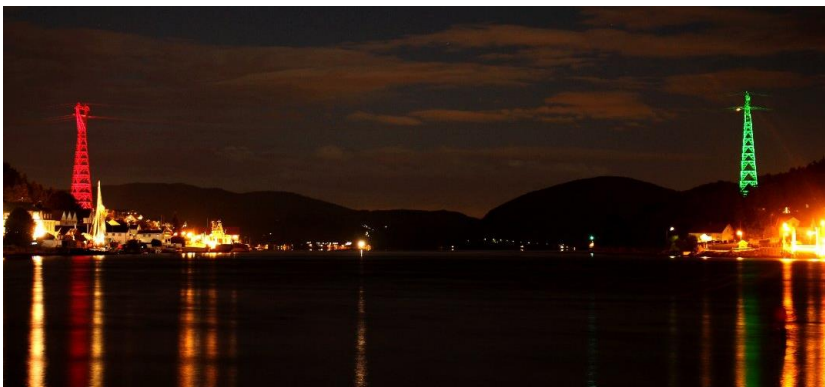


Figure 46: Light towers in Svelvik and Hurum; Source: Drammens Tidende¹⁰⁵

- Electrical ferry;

6 Conclusion and further studies

Energy production contributes around 70% to global amount of man-made greenhouse gases. On another hand, energy production uses non-renewable fossil resources. The energy distribution system is centralized. This model cannot be seen as sustainable. To achieve sustainable development the mankind should alter this model. Renewable energy resources represent a healthy opportunity for changing the existing system.

¹⁰⁴ Ideas of powering lighting towers and electrical ferry in Svelvik came from Arvid Askø

¹⁰⁵ (SHETELIG, 2012)

RES are referred to as infinite; they have lower carbon footprint and optimized for decentralized energy distribution.

Tidal energy has a potential to contribute to the mix of renewable technologies. Three main concepts of harvesting tidal energy dominate today: tidal barrages, tidal lagoons and tidal in-stream energy converters. Tidal Barrage method is the oldest method used for decades. But it is the least environmentally friendly technology. Technology of TISECs is scalable and turbines do not block waterways.

Technology of TISEC is under development that is why it is favorable to construct a tidal research center to develop prototypes and choose the ones that suit best for permanent installation on the site.

In order to succeed with construction and operation of TRC, the project should have several components in place on each stage of the development. Those are: hard provisions; research; soft provisions; licensing consents.

Svelvik TRC project is currently on the first stage of the development called Strategic Environmental Assessment. The main task is to define the course for further research according to the framework of TRC and estimate possible water areas for further assessment. As Drammensfjorden is known for its vessel traffic it is essential to estimate navigational corridors and free areas.

As the result of research Svelvik TRC project can proceed with assessment of eight proposed areas.

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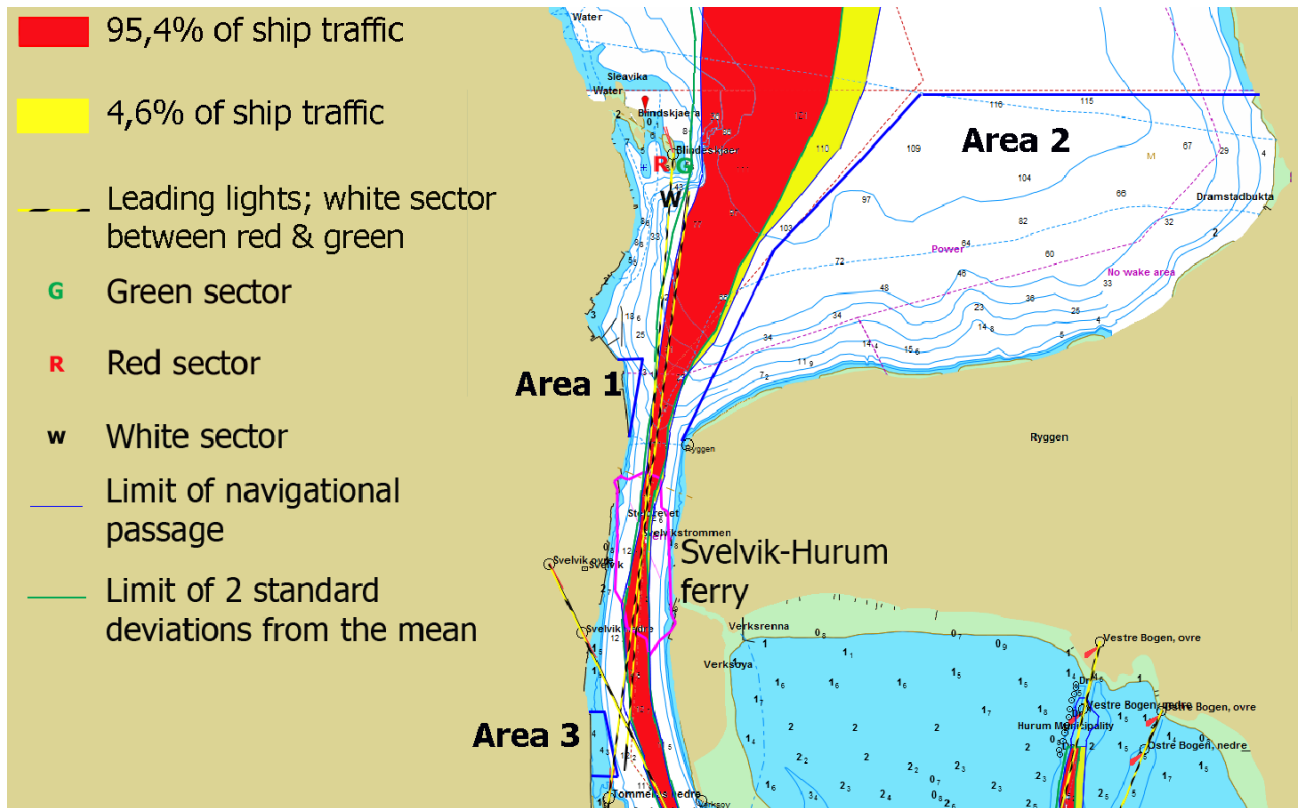
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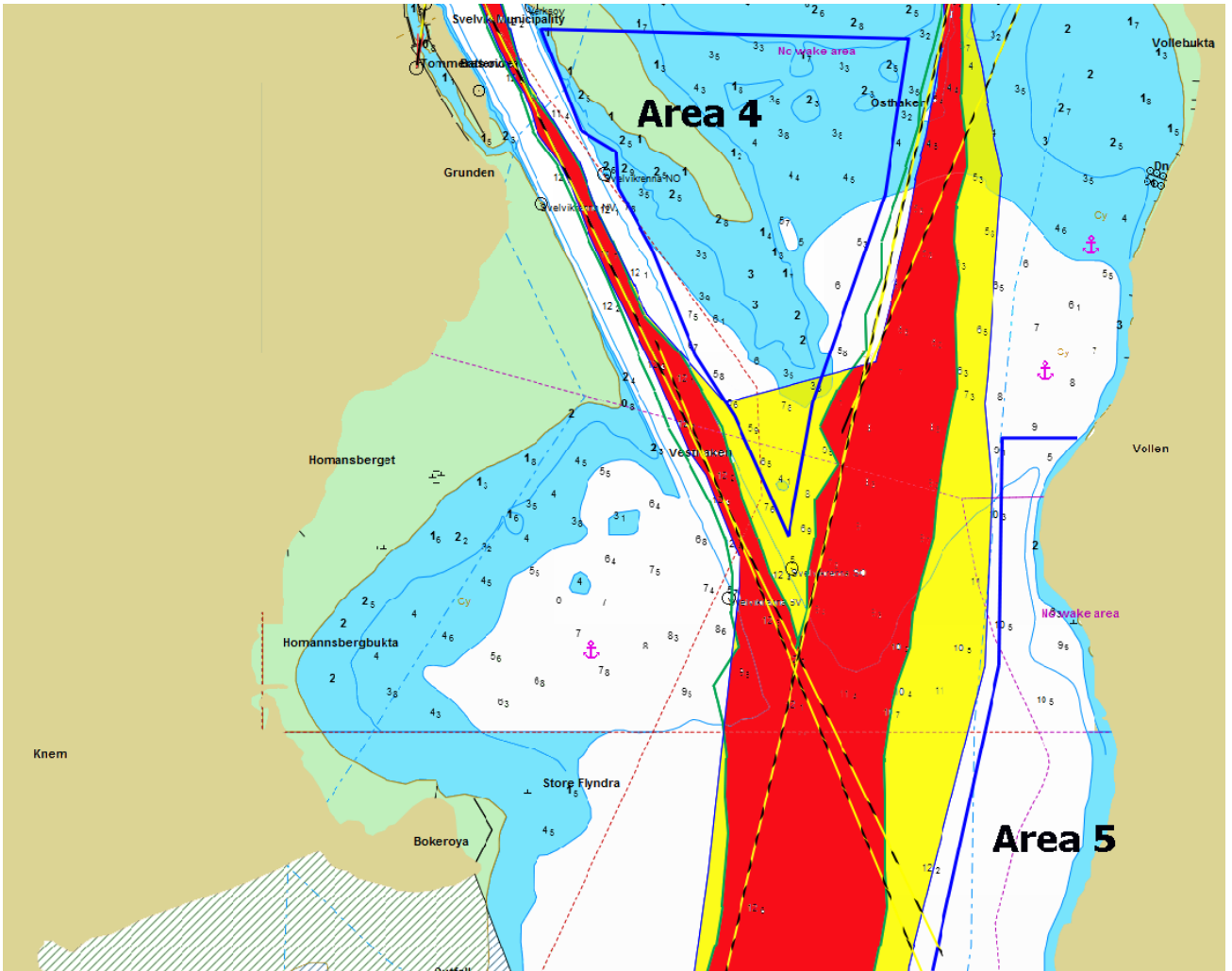
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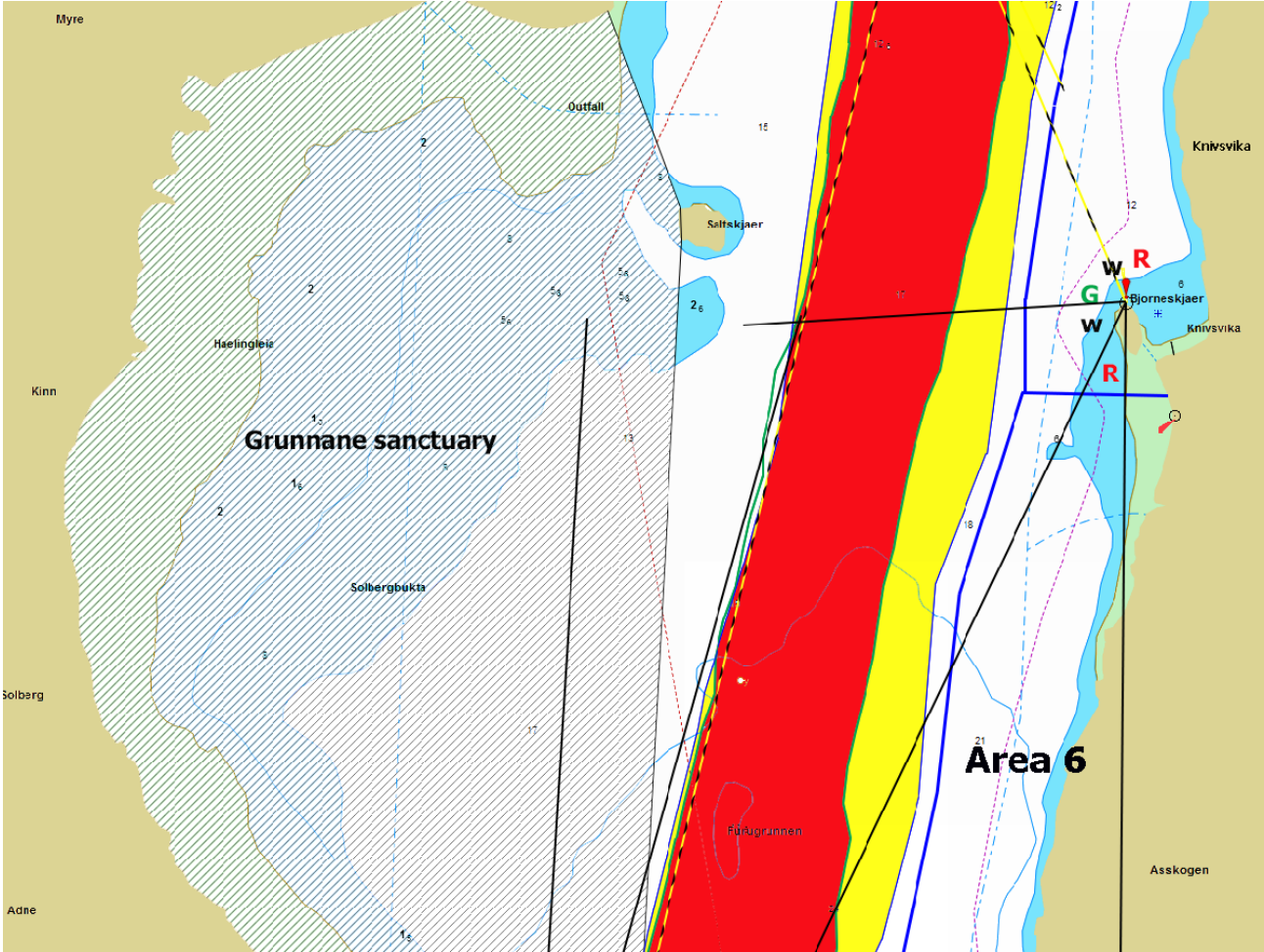
Appendix 1

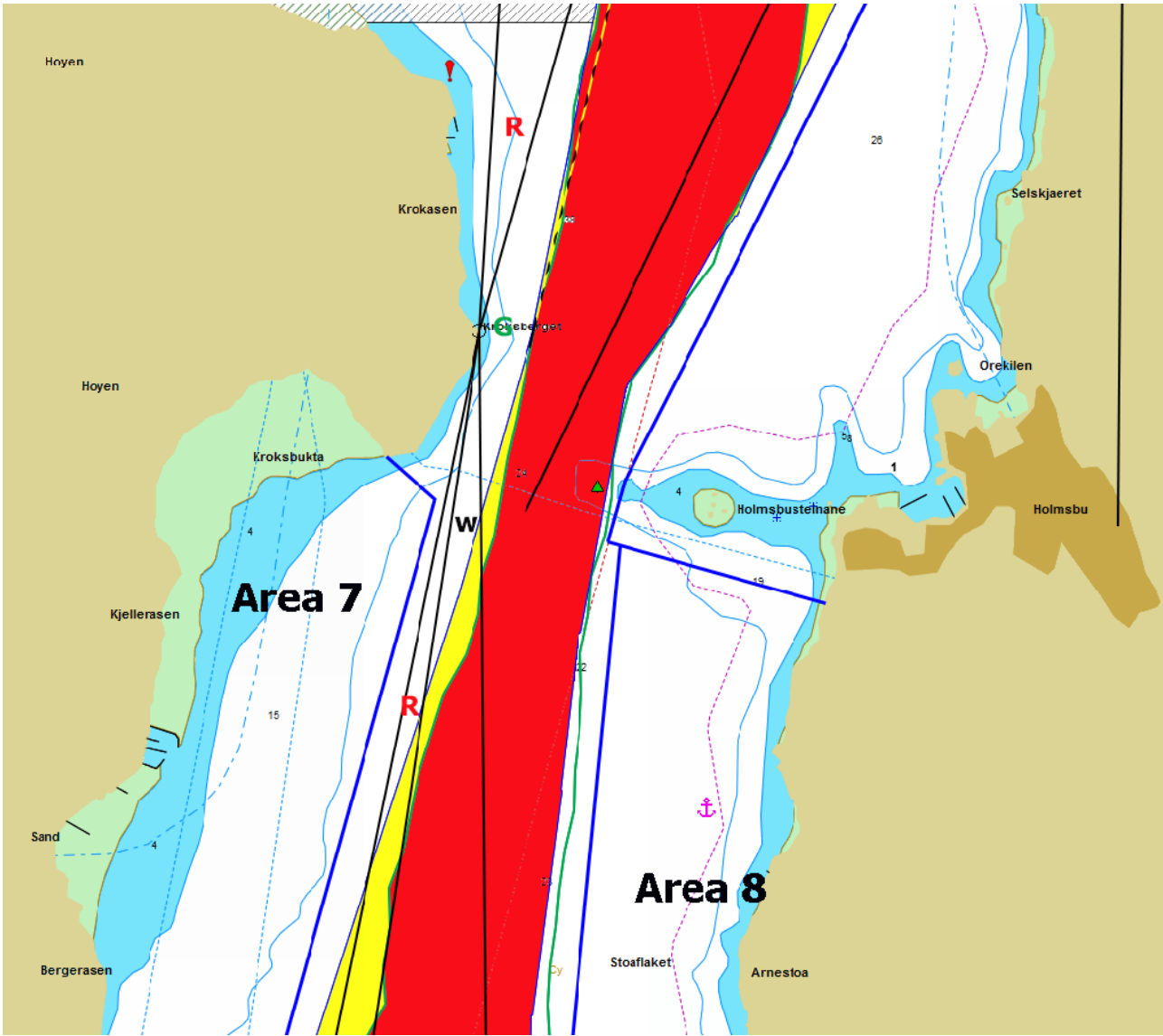
Map of area divided into several parts. High resolution complete map:

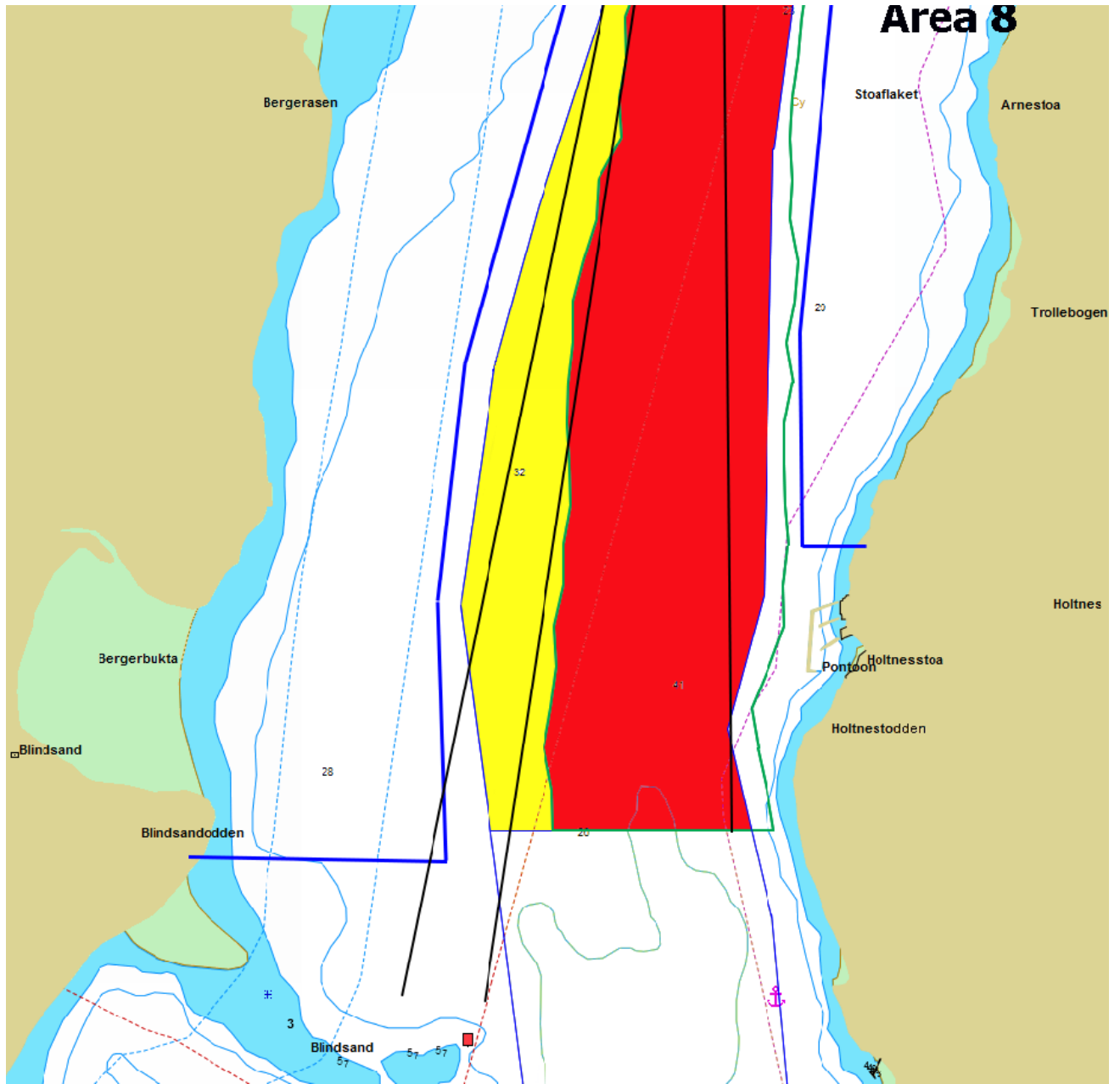
https://drive.google.com/open?id=0B9oTYdjgR3m_Zmt0aFlnLUJPLU0











Appendix 2

Scapa Flow Small Scale Test Site (EMEC, 2014)

ACCESSIBLE, FLEXIBLE OPEN WATER SITES

SCAPA FLOW WAVE TEST SITE

SHAPINSAY SOUND TIDAL TEST SITE

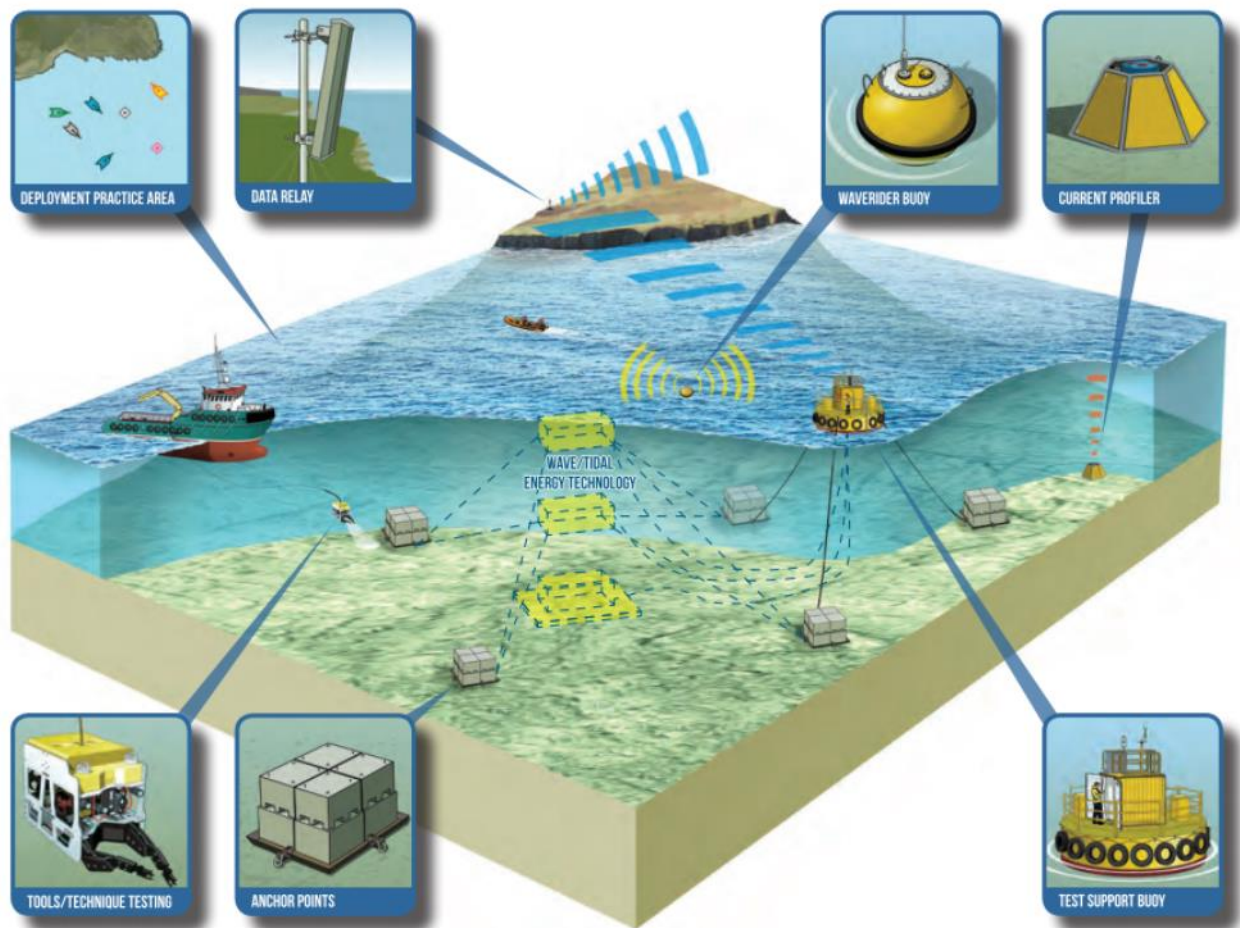
In **less challenging conditions**, reducing the need for big vessels or large plant, the **non-grid connected** sites provide a more **flexible sea space** helping close the gap from tank testing, and acting as a stepping stone towards larger scale projects.

Accessible real sea testing enables marine energy developers and suppliers to learn lessons more cheaply.

- Bespoke **test support buoys** can be provided, allowing developers to dissipate electricity generated by their devices and record data.

- Pre-installed **anchor points** provide mooring options, and an **area of seabed** is available for rehearsal or deployment of other tools and techniques.

- EMEC holds an **overarching site licence**, simplifying the consent process within an agreed envelope of activity.



SITES SUITABLE FOR, BUT NOT LIMITED TO, THE FOLLOWING ACTIVITIES:

- Device testing
- Component testing
- New tools, techniques & supply chain solutions
- Monitoring corrosion, biofouling & acoustic instrument packages
- Anchoring, cabling, subsea hub & wet-mate connectors
- Installation tests
- Rehearsal activities
- Testing ROV's & vessel activities
- Operation & maintenance tests
- Training
- Health & safety procedures
- Decommissioning trials
- Research projects

Appendix 3

Fall of Warness Full Scale Tidal Testing Site (EMEC, 2014)

ACCREDITED, GRID CONNECTED PERFORMANCE TESTING

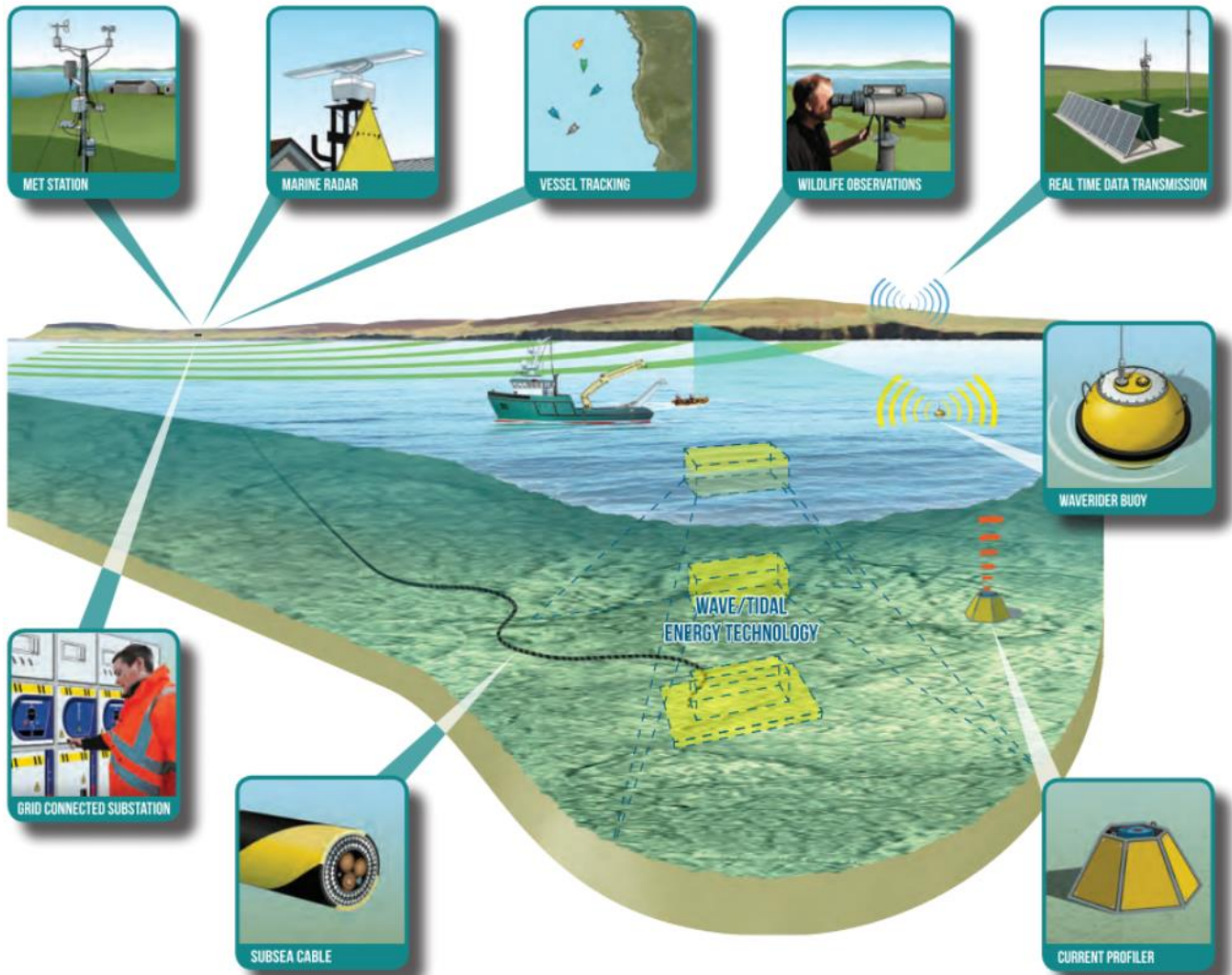
BILLIA CROO WAVE TEST SITE

FALL OF WARNESS TIDAL TEST SITE

EMEC is the only accredited test centre in the world, suitable for testing **multiple devices simultaneously** while producing electricity to the **national grid**. All **income generated** by the sale of electricity is returned to the developers, increasing the funds for future industry investment.

- Accredited by the United Kingdom Accreditation Service (UKAS), EMEC operates to **laboratory standards** (ISO17025), providing a unique service - **independently verified performance reports**.

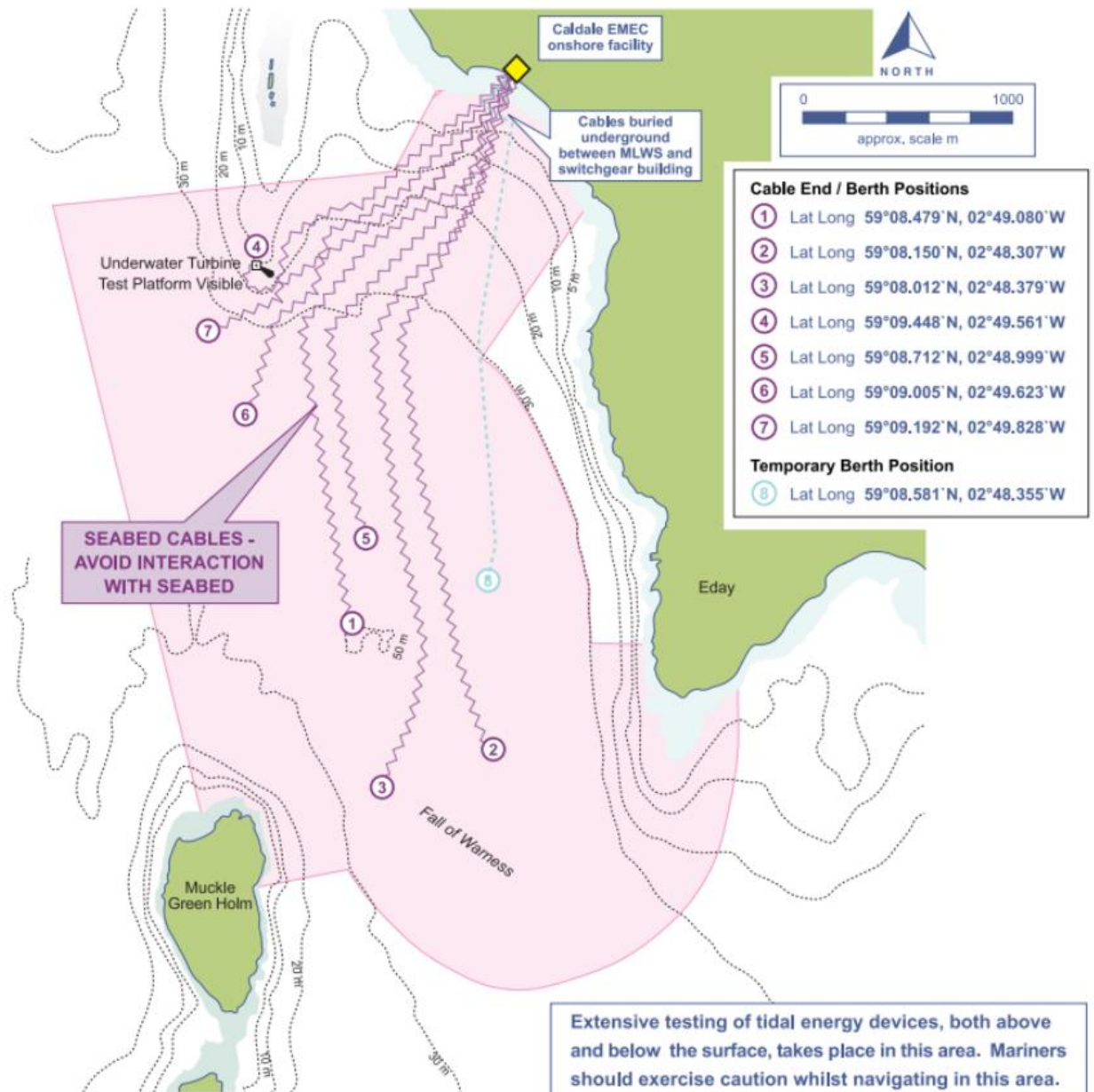
- EMEC works closely with regulators to streamline **consenting** and facilitate **environmental monitoring**. Research and Operational Forums give EMEC clients an exclusive platform to **share learning** and collaborative opportunities.



Appendix 4

Fall of Warness Cable Layout Source: (EMEC, 2012)

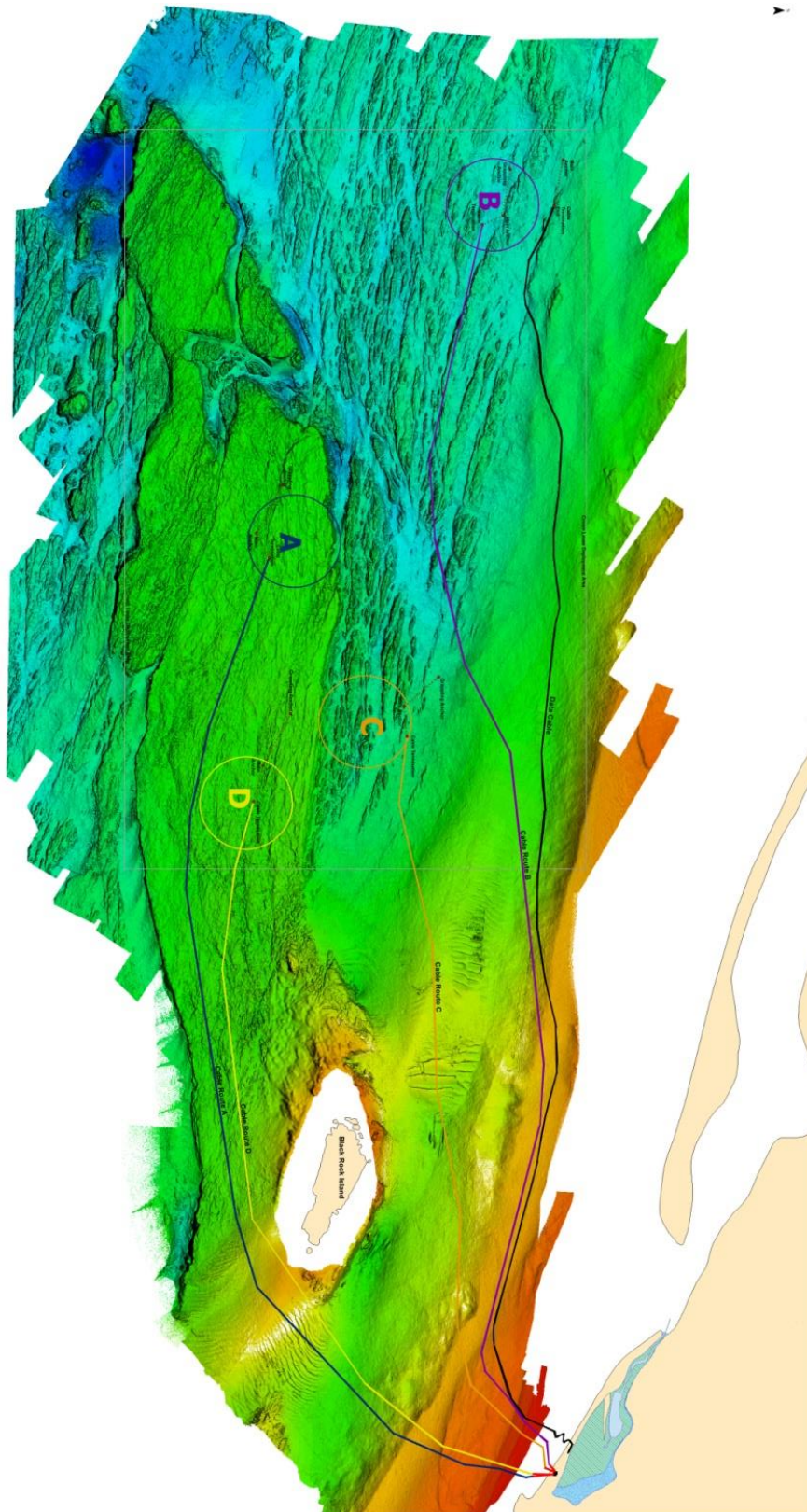
TIDAL TEST SITE

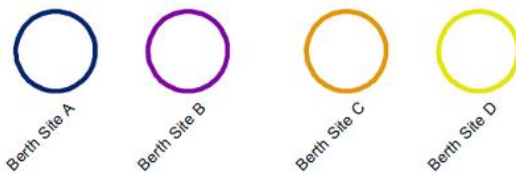
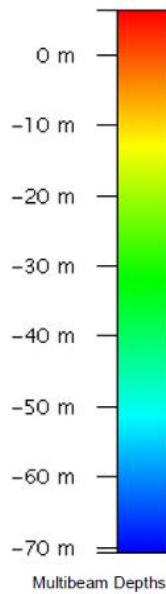
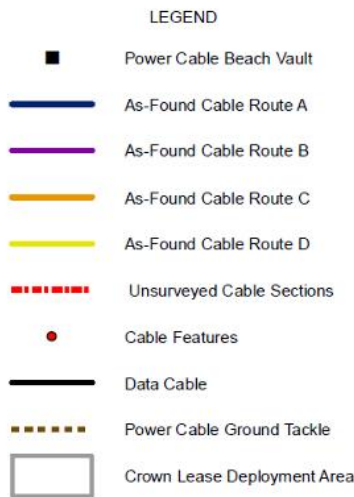


Not to be used for navigation

Appendix 5

FORCE cables and bathymetry: map and legend (SEAFORTH GEOSURVEYS, 2015)





Notes:

- 1) North up plan showing the FORCE Power Cable As-Found Positions.
- 2) The power cables were laid between October 16, 2014 and October 28th.
- 3) Post cable lay surveys were conducted aboard the MV Point Vim using an R2Sonic 2024 multibeam echosounder.
- 4) Positioning during cable lay and post lay survey operations consisted of differential GPS supplied by the shore-based Coast Guard station 326 located on Partridge Island (295 KHz).
- 5) Coastline data downloaded from the NS Geomatics Centre GEONOVA web portal.
- 6) Black Rock Island coastline digitized from Google Earth.
- 7) All measurement units in metres unless otherwise noted.
- 8) Displayed bathymetric image combines Seaforth data with 2m grid data from the Canadian Hydrographic Service, strictly for the area surrounding Black Rock Island.
- 9) Main anchor and cable termination positions displayed on chart are sea surface position referenced to the chute position during cable laying operations.
- 10) Grappling anchor position displayed on chart is a sea surface position obtained during repositioning operations of the grappling anchor post cable deployment.

GEODETTIC PARAMETERS:

Ellipsoidal Parameters

Ellipsoid: WGS84
Semi-Major Axis (a) (m): 6378137.000
Inverse Flattening (1/f): 298.257223563

Projection Parameters

Projection: UTM
Zone: 20 North
Central Meridian: 63° W
Scale Factor: 0.9996
False Easting: 500000
False Northing: 0

Vertical Datum: Chart Datum



Job / Proposal #: 703

Doc #: SGI-703-006-2

Prepared By:

SEAFORTH
GEOSURVEYS
Seaforth Geosurveys Inc.
300 Prince Albert Road, Suite 200
Dartmouth, Nova Scotia
Canada B2Y 4J2
Phone: (902)468-3579
Fax: (902)468-6865

Rev	Date	Prepared By	Approved By	Comment	Filename
2	27/03/15	AA	GJC	REMOVAL OF CROWN LEASE CABLE CORRIDOR	SGI-703-006-2-PUBLIC
1	09/01/15	AA	AC	ISSUED FOR USE	.mxd

Project: Fundy Tidal Energy Demonstration Project

Client: **FORCE**
PO Box 2573
Halifax, NS, Canada
B3J-3N5
Phone: (902) 406-1166



Appendix 6

FORCE Power Cable Position List

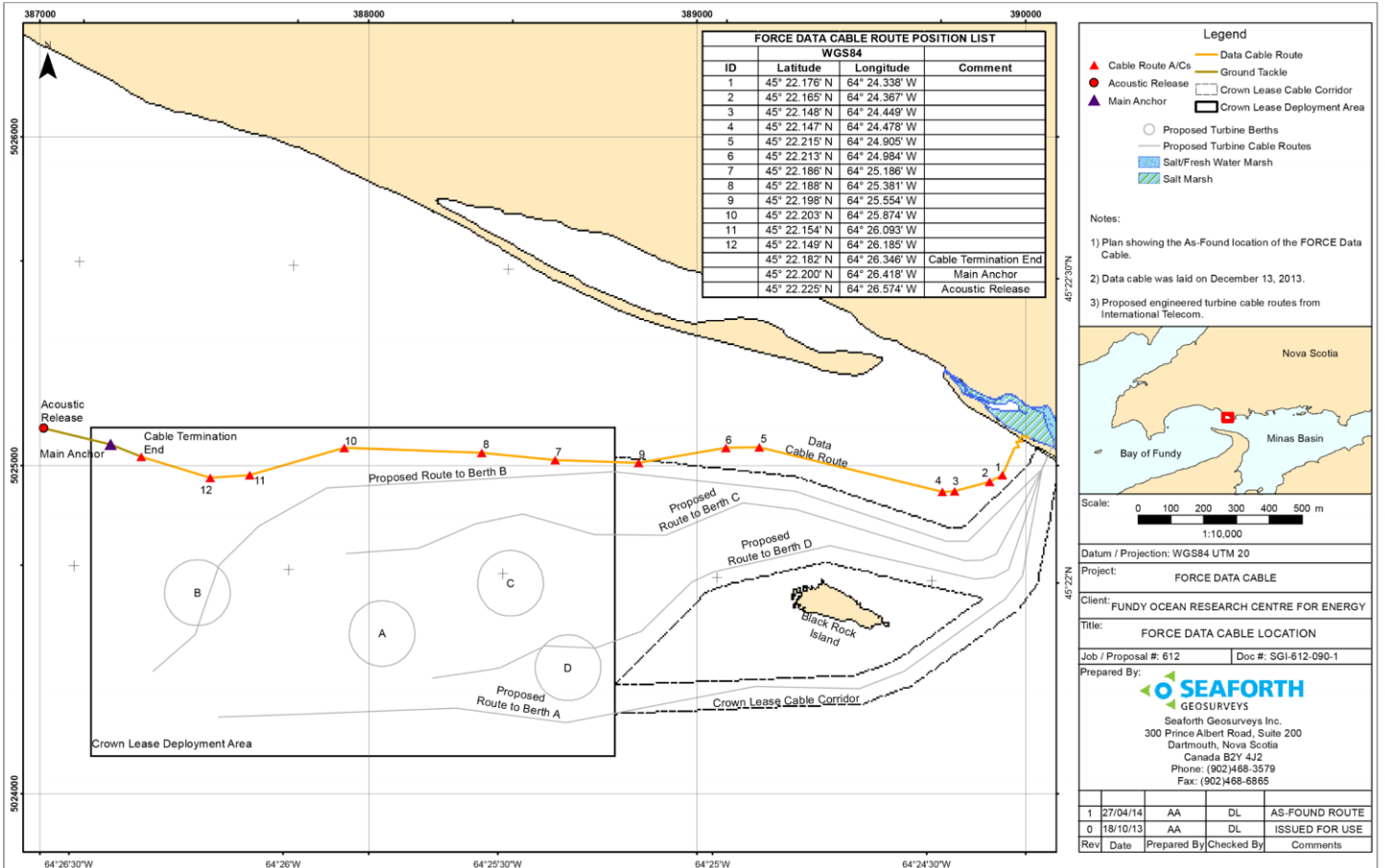
Id	Cable	Latitude	Longitude	Note		Id	Cable	Latitude	Longitude	Note
0	A	45.364 714	- 64.431162	Grappli ng Anchor		0	B	45.369 041	- 64.440000	Grappling Anchor
1		45.364 227	- 64.429836	Main Anchor		1		45.368 917	- 64.438725	Main Anchor
2		45.364 482	- 64.429158	Cable terminatio n		2		45.368 522	- 64.438459	Cable termination
3		45.363 370	- 64.424446			3		45.367 575	- 64.431986	
4		45.363 032	- 64.422037			4		45.367 708	- 64.429810	
5		45.362 966	- 64.419991			5		45.368 332	- 64.426334	
6		45.363 527	- 64.415485			6		45.369 261	- 64.423897	
7		45.364 065	- 64.410931			7		45.370 016	- 64.415316	
8		45.364 508	- 64.409006			8		45.369 956	- 64.413607	

9		45.367 219	- 64.405030		9		45.368 901	- 64.407312	
10		45.368 618	- 64.404202		10		45.368 959	- 64.406822	
11		45.369 272	- 64.404129		11		45.369 491	- 64.405990	
12		45.369 814	- 64.403891		12		45.369 759	- 64.405429	
13		45.370 359	- 64.403989	Beach Vault	13		45.370 185	- 64.404866	
					14		45.370 242	- 64.404247	
					15		45.370 379	- 64.404024	Beach Vault
Id	Cable	Latitude	Longitude	Note	Id	Cable	Latitude	Longitude	Note
0	C	45.367 823	- 64.425955	Grappli ng Anchor	0	D	45.364 952	- 64.424857	Grappling Anchor
1		45.367 162	- 64.425115	Main Anchor	1		45.364 432	- 64.423412	Main Anchor
2		45.367 228	- 64.424290	Cable terminatio	2		45.364 262	- 64.422420	Cable termination

				n						
3		45.367 098	- 64.422450			3		45.363 932	- 64.420551	
4		45.367 784	- 64.418623			4		45.363 708	- 64.417763	
5		45.367 928	- 64.414581			5		45.364 377	- 64.410902	
6		45.368 427	- 64.411143			6		45.366 633	- 64.406392	
7		45.368 400	- 64.408129			7		45.368 199	- 64.404699	
8		45.368 698	- 64.406424			8		45.369 386	- 64.404213	
9		45.369 729	- 64.405073			9		45.369 858	- 64.403989	
10		45.370 117	- 64.404742			10		45.370 359	- 64.403989	Beach Vault
11		45.370 158	- 64.404181							
12		45.370 379	- 64.404024	Beach Vault						

Appendix 7

FORCE data cable map and position list (on the map) (GEOSURVEYS, 2014)



Appendix 8

Wildlife sensitivities from (EMEC, 2009)¹⁰⁶

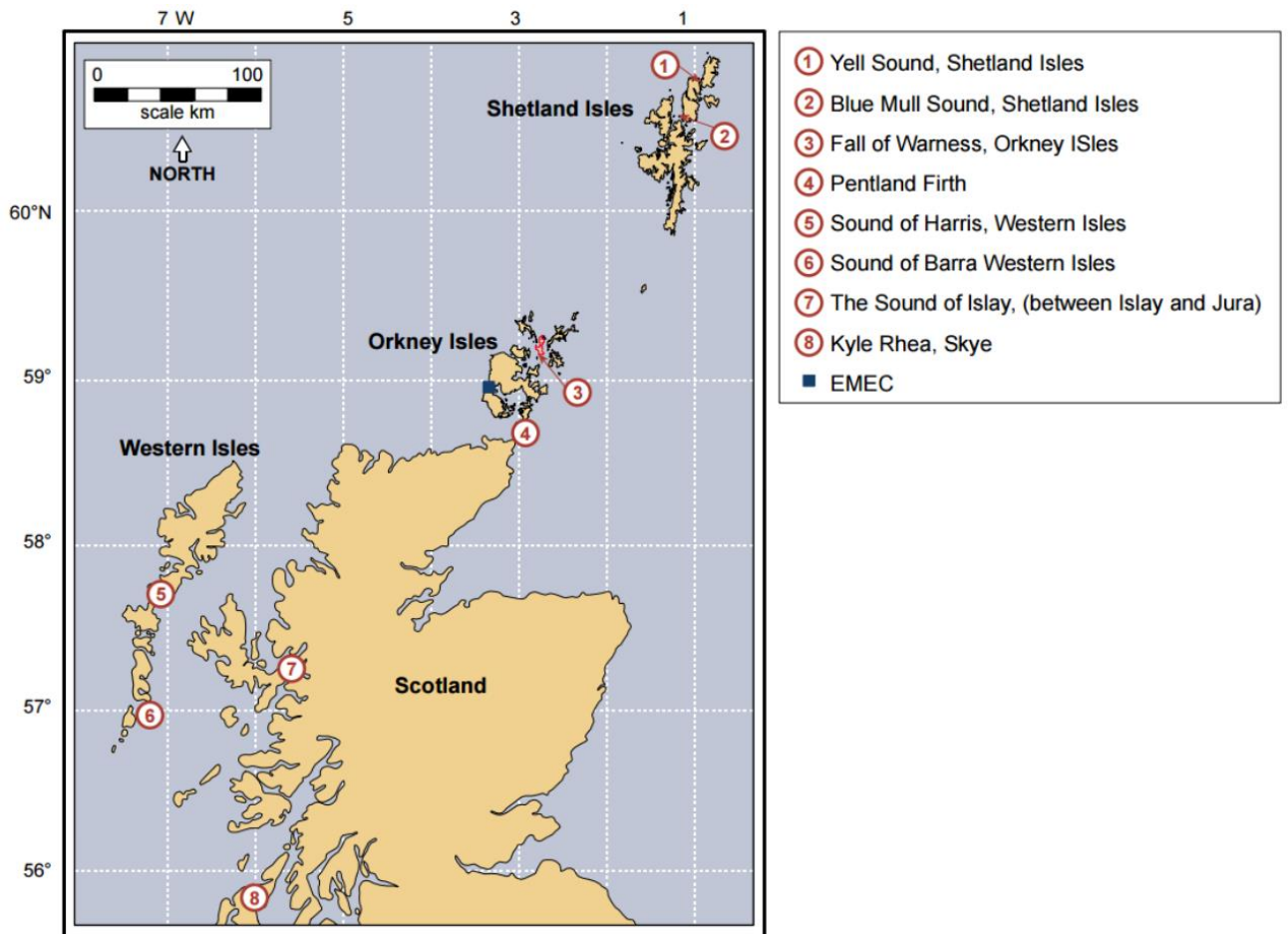
Common Seals	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Common seals pup in early June and July, and this is followed by a moulting period in late July and early August. The closest haulout sites are at Seal Skerry, The Graand (on the south coast of Eday) and on Muckle and Little Green Holms, with a European protected population on the near by island of Sanday. The key issues to consider are collision risk and construction/operation/decommissioning disturbance.													
Grey Seals	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
The grey seal breeding season is from early October to late November. The moulting period follows in January to March (females), and March to May (males). Grey seal breeding colonies are located adjacent to the site on Muckle and Little Green Holms, with a European Protected SAC to the north on the islands of Faray and Holm of Faray. The key issues to consider are collision risk and construction/operation/decommissioning disturbance.													
Harbour Porpoise	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
There are no resident populations of Harbour Porpoise, however from observations a moderate number of sightings have been made in the months from July to September. This species has a large ranging nature and it has been suggested that they move offshore during the winter. They are also a European Protected Species. The key issues to consider are collision risk and construction/operation/decommissioning disturbance.													
Cetaceans	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Minke whale, Risso, Orca and White-beaked dolphins have been recorded in the Fall of Warness during the summer months. They carry a high European Protective Species status, but are present in extremely low numbers with a sporadic occurrence. The key issues to consider are collision risk and construction/operation/decommissioning disturbance.													
Birds	<i>See Note</i>	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bird species are present all year round and of note there is a cormorant breeding colony on Little Green Holm (April-June) adjacent to the test site. The key issue to consider is collision risk.													
Plankton	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
The main components of the zooplankton are copepods, which form an important link in the food chain.													
Finfish & Shellfish	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
The site (and Orkney as a whole) is located within spawning and nursery areas of a number of fish species.													
Basking Sharks	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
From the wildlife observations, low numbers of basking sharks have been sighted in late summer and a regularly spotted in Orkney waters during the summer. They are usually seen along the tidal fronts where mixing water generates the zooplankton on which they feed and are a UK BAP priority species. The key issues to consider are collision risk and construction/operation/decommissioning disturbance.													
Otters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
A few otter sightings have been recorded adjacent to the test site over the past few years. Otters normally cub in the winter months in Orkney, although they can breed at any time of the year. Due to low number of observations and lack of evidence it is not possible to identify a seasonal sensitivity for the otter. The key issue to consider is and disruption from shore based works.													
Coastal & seabed habitats	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
From baseline EIA studies there is no evidence to indicate any particular sensitivity.													
Key:	High	Moderate	Low	Minor interaction	Unclear due to lack of data								

Note: All birds are protected, so any potential effects must be considered, with particular attention given to diving species.

¹⁰⁶ To see the older version from 2005 please check (AURORA Environmental Ltd, 2005)

Appendix 9

Site selection process (EMEC)



Appendix 10

Phase 2 site evaluation. The less the score the better (EMEC)

	Issue	Shetland Yell Sound	Orkney Fall of Warness	Orkney Pentland Firth
Resource/ physical	Tidal stream energy resource	1	1	1
	Channel width	3	2	1
	Range of channel depths	2	1	3
	Shelter from wave exposure	1	2	3
	Geology/seabed conditions *	-	-	-
	Sub total	7	6	8
Environmental sensitivity and constraints	Designated areas	1	1	1
	Benthic ecology	1	1	1
	Marine mammals	2	2	1
	Shellfish	2	2	1
	Fish spawning and nursery areas	2	2	1
	Birds	1	1	3
	Commercial fisheries and shellfisheries	2	1	2
	Human infrastructure & activities	2	1	2
	Wrecks and archaeology *	-	-	-
Sub total	15	12	15	
Cost differentials	Offshore pile installation (mob / demob)	3	2	1
	Marine cable installation	2	1	3
	Waiting on weather	2	1	2
	Logistics	3	2	1
	Labour	3	1	2
	Grid connection capacity (short-term)	3	1	2
	Grid connection cost (long term)	3	2	1
	Data communications	3	1	2
	Integration with EMEC	3	1	2
	Sub total	25	12	16
Grand total	47	30	39	

Appendix 11

List of vessels called into Drammen port from 17.03.2016 to 16.04.2016¹⁰⁷ and used for analysis of ship traffic. MS Gullha and MS Zuzanna are loaded at Svelviksand not in Drammen.

Flag	Imo	MMSI	Vessel Name	Type
NL	9133599	244700000	BITLAND	Asphalt/Bitumen Tanker
MH	8221363	538002019	DANAVIK	Cement Carrier
DE	9354454	218031000	ANNA SIRKKA	Container Ship
AG	9242560	305886000	NATHALIE EHLER	Container Ship
CY	9483671	209467000	NORDI	Container Ship
AG	9344253	304824000	PACHUCA	Container Ship
NO	7805021	257191400	EIDE LIFT 6	Crane Ship
GI	9247106	236598000	AASHEIM	General Cargo
BS	9473250	311063500	CLIPPER NEW YORK	General Cargo
BS	8100636	311257000	FRI STAR	General Cargo
CK	7311769	518631000	GULLHA	General Cargo
FO	8719097	231099000	HAV NES	General Cargo
BS	9063885	308542000	KAAMI	General Cargo

¹⁰⁷ Data: MarineTraffic.com; Original data: AIS

AG	9325130	305981000	LISA LEHMANN	General Cargo
SE	8805597	265735000	MINI STAR	General Cargo
BS	8922266	308874000	ROMI	General Cargo
AG	9325142	305982000	SIEGFRIED LEHMANN	General Cargo
AG	9429273	305838000	SYLT	General Cargo
AG	9229130	304867000	WILSON HOLLA	General Cargo
CK	8203555	518730000	ZUZANNA	General Cargo
NO	0	258194720	MARIBETT II	Pleasure Craft
SG	8202381	564994000	8ASIAN BREEZE	Ro-Ro Cargo
SG	8202355	563373000	ARABIAN BREEZE	Ro-Ro Cargo
PT	9190157	255801580	AUTOPRESTIGE	Ro-Ro Cargo
GB	9174763	232079000	CITY OF ROME	Ro-Ro Cargo
PA	9473456	353083000	CITY OF ST.PETERSBURG	Ro-Ro Cargo
GB	9046356	233150000	CITY OF SUNDERLAND	Ro-Ro Cargo
NO	6930520	258208000	ELEKTRON II	Ro-Ro Cargo

NO	0	258226500	NJORD	SAR
NO	0	257165800	RESCUE BERGESEN D.Y	SAR
NO	7406930	257369500	BALDER	Tug
NO	9706011	257369000	BAUS	Tug
SE	8003072	265531370	BRUSE	Tug
NO	7392816	259532000	EIDE REX	Tug
NO	5362219	257269500	SKILSO	Tug
PT	9131967	255801570	AUTOPROGRES S	Vehicles Carrier
US	9070448	367318000	INDEPENDENC E II	Vehicles Carrier
BS	9386225	309586000	NORDIC ACE	Vehicles Carrier