Floating Tidal Energy Site Assessment Techniques for Coastal and Island Communities

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Abstract — **Sustainable Marine Energy and SCHOTTEL Hydro have developed a taut-moored mid-water column tidal energy platform, PLAT-O, and a semi-catenary moored floating surface platform, PLAT-I, that each host between two and four turbines. The combined platform rated power is up to 280kW.**

Each platform is suitable for different environmental conditions, with PLAT-I intended for low wave climates and PLAT-O for more extreme offshore conditions. This provides the basis for site selection criteria for each system. Site criteria include flow velocity, wave conditions, water depth and bathymetry, power requirements, and station keeping requirements. These have been designated into a Site Classification System for identifying sites suitable for each of SME's platforms.

Site assessment must be conducted to find these sites. Whilst in developed and more easily accessible locations the equipment, vessels, and expertise used are readily available, in more remote areas and off-grid communities the traditional assessment techniques must be modified for the equipment available and for the cost associated with different survey methods.

SME have developed a site assessment technique for their platform systems which is divided into four stages: Desktop Study, Visual Survey, Initial Survey, and Detailed Survey. Each stage increases complexity and cost. This allows sites to be discounted at early stages if unsuitable for further development before unnecessary money is spent. This system leads to a cost saving of up to 47% when assessing two sites using SME's method rather than two ADP surveys, and discounting one for inadequate velocity, as an example. The assessment technique, relevance to SME's tidal energy platforms, cost implications, and suggested modifications for applicability to other systems is presented.

***Keywords*—Tidal energy; Site assessment; Resource characterisation; Floating**

NOMENCLATURE

ADP	Acoustic Doppler Profiler
EMEC	European Marine Energy Centre
FORCE	Fundy Ocean Research Center for Energy
GPS	Global Positioning System
PLAT-I	PLATform for Inshore Energy
PLAT-O	PLATform for Offshore Energy
RIB	Rigid Inflatable Boat
ROV	Remotely Operated Vehicle
SAMS	Scottish Association for Marine Science
SIT	SCHOTTEL Hydro Instream Turbine

I. INTRODUCTION

Tidal energy sites in the UK and Europe have been characterised extensively in order to fully understand the design basis for tidal energy platforms, and power and yield estimation. There are centres which have detailed survey and modelling information that has been gathered over several years, if not decades, such as at the European Marine Energy Centre (EMEC) [1]. When assessing sites away from these specialist centres, in the UK and Europe as well as other developed areas such as Canada, high specification vessels, personnel and survey equipment are readily available.

As tidal developers move to other more remote markets, such as South-East Asia, these survey and modelling results are no longer readily available and long time histories of information, such as flow speed and wave height, are rare. In order to assess whether a site is suitable information must be gathered up front, and in a cost- and data- effective manner. Additionally, the resources available at various locations must be considered since, for example, the vessels available at commercial sites in the UK would not be available at remote islands in the Philippines. A versatile and efficient methodology must be employed to enable data gathering at all potential deployment locations.

Sustainable Marine Energy [2] have developed a method of site characterisation for their tidal energy devices. The method, which will be presented here, is a process whereby information is acquired in a timely and cost-effective way, which streamlines the process of selecting, or discarding, potential sites.

II. PLAT-I AND PLAT-O

Whilst focus in the tidal and renewable energy business has been on a large scale in the developed world, an alternative is to target the technology as a diesel replacement technology or to form part of a cost-effective energy-mix addressing the energy trilemma. Sustainable Marine Energy (SME) and SCHOTTEL Hydro have designed technologies that address market needs in a smaller scale, for example 250kW to 5MW arrays, widely found in remote off-grid community scale applications in the developing world. The PLAT-I and PLAT-O platforms and SIT250 turbines are detailed here.

A. SIT

The SCHOTTEL Hydro Instream Turbines (SITs) are designed for deployment in arrays on a singular structure or multiple structures.

The turbines are smaller than traditional large diameter rotors e.g. Andritz Hydro Hammerfest [3]. The turbines are 4m or 6.3m in diameter, diameter selected depending on the site flow speeds, with a rated power of 70kW. The rotor diameter is selected depending on the flow speeds at site, [4].

The turbines can be operated upstream or downstream and the blades are interchangeable on the drivetrain. The turbines are hosted by SME's tidal platforms, which currently use SIT250s [5],[6].

B. PLAT-I

PLAT-I is a floating tidal energy platform, consisting of three hulls, that hosts four SIT250s [2]. The turbines are suspended from the cross-deck that spans the hulls. The turbines are mounted to a lifting support structure. This means that whilst the turbines are in the down configuration during normal operation they can be lifted clear of the water for maintenance, transport, or in the event of extreme inclement weather. This provides easy and safe access to the turbine drivetrains and blades whilst at site, a design feature particular to this type of platform.

The three-hulled platform is moored via a bow turret, which allows the system to pivot about its mooring to align with different flow direction, for example flood and ebb tides. The system is moored to the seabed using a mooring spread and point anchors. An example deployment configuration can be seen in Figure 2, with a four-point mooring spread and 4m rotors. This was used for recent Sea Acceptance Trials of PLAT-I at Connel, Oban, Scotland. The mooring system is dependent on the depth and range at a deployment site, whilst the anchoring system varies with bed rock and depth of deployment. Other factors contribute to the system design, such as temperature and light penetration which affect marine growth.

Since PLAT-I is a surface platform it is intended for deployments with low wave climates, or minimal extreme events [7]. For example, certain areas in the Philippines have generally low waves throughout the year, but with rare extreme events such as typhoons. The effect of these can be mitigated by design strategies such as lifting the turbines clear of the water to reduce loading.

Figure 1: PLAT-I installed in Scotland

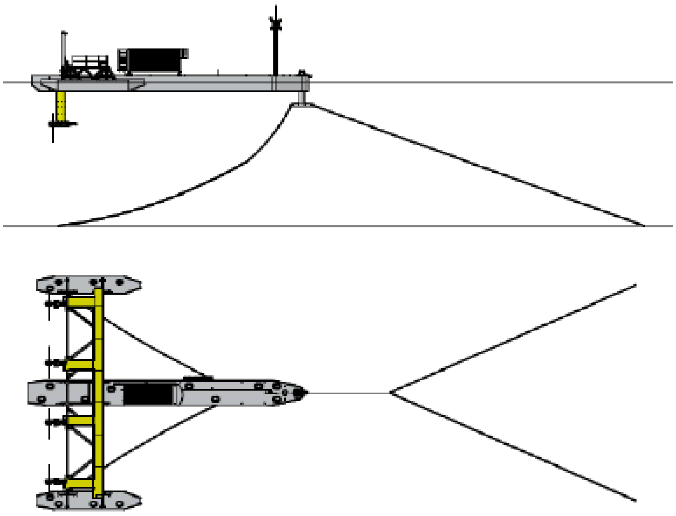

Figure 2: Schematic of PLAT-I and Mooring System

C. PLAT-O

In areas where the wave climate is high then a sub-surface platform must be used to reduce the loading impact of waves. PLAT-O [8] operates on the same principle as PLAT-I but is taut-moored below the water surface. The system therefore presents additional engineering challenges as all systems must be water-tight or designed for submarine environment, and all structures must be streamlined to minimise drag and thus mooring loading. PLAT-O is however designed to withstand stronger wave conditions typically found in the UK, for example at EMEC in the Orkney Islands [1]. The type of platform must therefore be assessed based on the site conditions and the economic price point for a region.

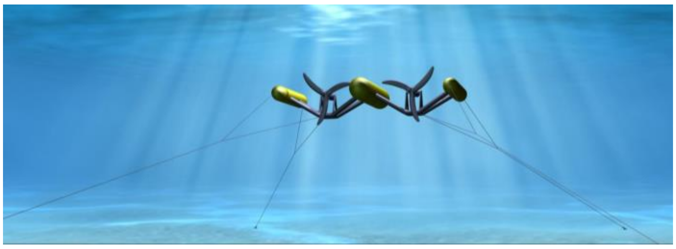

Figure 3: Model of PLAT-O#1 (first generation)

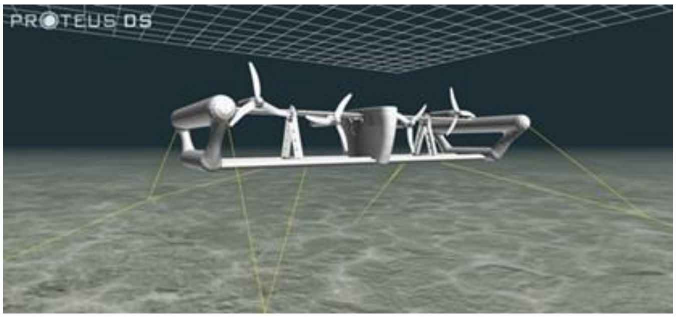

Figure 4: Model of PLAT-O#2 (second generation)

D. Tidal Site Criteria

Each part of the system requires different site information to inform design. These are summarised using SME's site classification criteria for their own technologies, Figure 5.

1) Velocity: This criterion dictates which rotor diameter should be used, and where the design limits of the platform occur. At a V4 site a 6.3m rotor would be used, whereas at a V2 site a 4m rotor would be used. A V1 site however exceeds the design limit of the current designed PLAT-O and PLAT-I platforms.

2) Wave Height: The platform and mooring type will be defined based upon this. The return period will vary depending on the type of deployment, for example if a short-term or trial deployment then a return wave of 1-year will be used, whereas for commercial deployment it will be a 50-year wave. Based on the occurrence frequency the mitigation strategy will also change.

3) Depth: The depth is constrained by rotor clearance, and installation methods. This provides a window for deployments, between approximately 10 and 50m currently. The additional limiting factor for deployments is range. This can vary from ~5m at Connel, Oban, to 16m at FORCE in Canada [9].

4) Debris: This affects the rotor protection required and the extreme mitigation strategy. For example, at a site in the Philippines there may be surface debris of coconuts and small branches from typhoons which can be designed in to the loading requirement for structures and blades. Conversely at Canadian sites there may be significant ice during winter months which may require the turbines to be lifted clear of the water.

5) Grid Connection: The end user and requirement must be identified to determine what power requirements there are. For a remote fishing area, a singular PLAT-I with an onboard system to provide ice may be preferential to the requirements of another area which needs multiple platforms exporting to an island grid.

6) Cable Run: A significant cost and risk of these types of deployments is loss through cable run. The run and cable management must be defined for site classification.

7) Seabed: The anchor type and mooring connection is dependent on the seabed conditions. Though the criterion focuses primarily on seabed composition, it also includes structure and terrain, for example whether a smooth flat surface requiring rock anchors or significant vertical ridges which affect anchor deployment.

SME Platform Classification

Velocity (V)		Wave Height (Hs)		Depth (D)		Debris (Db)
V1	-	**Hs5**	-	**D3**	-	**Db1**

V1	3.0–5.4 m/s
V2	2.4–4.4 m/s
V3	2.0–3.8 m/s
V4	1.6–3.1 m/s
V5	0–1.5m/s
Ref	SCHOTTEL Hydro Rating (Scale Parameter - 50 yr)

Hs1	0–1m
Hs2	1–2m
Hs3	2–3m
Hs4	3–4m
Hs5	4m+
Ref	Wave data: longest return period e.g. 1yr or 50yr

D1	0–10m
D2	10–20m
D3	20–50m
D4	50–100m
D5	100m+
Ref	Bathymetric data or hydrographic chart

Db1	Negligible
Db2	Limited Surface
Db3	Limited All Water Column
Db4	Substantial
Db5	Excessive
Ref	

SME Balance of Plant Classification

Grid Connection		Cable Run (C)		Seabed (Sb)
G3	-	**C4**	-	**Sb1**

G1	Micro Grid - On Board Use
G2	Micro Grid - On Shore Use
G3	Local Grid Connection
Ref	

C1	0–100m
C2	101–500m
C3	501–1000m
C4	1001m–2000m
C5	2001m+
Ref	Distance to landfall for cable run

Sb1	Rock
Sb2	Clay
Sb3	Gravel/Sand
Sb4	Silt/Mud
Sb5	Complex Seabed
Ref	Geological charts, bore hole data, profile data

Example:-

EMEC Berth 7

Platform: **V1 - Hs5 - D3 - Db1**

BOP: **G3 - C4 - Sb1**

Figure 5: SME Site Classification Criteria

III. METHODOLOGY

All of the elements of the site classification must be investigated for a floating tidal energy system. Note that this list is not exhaustive but acts as a baseline for site identification and project assessment.

SME have developed a system for assessing sites specifically for PLAT-I and PLAT-O in the most cost- and data-efficient method. The methods for collecting this information is entirely dependent on the value of a project and the resources available. For this reason, the site assessment methodology utilised by SME is separated into four stages:

- A desktop study, which can be conducted anywhere and uses minimal resources
- A visual survey, using local resources and price at a level reflective of the project
- An initial survey, using local vessels and cheap resources to identify any major issues
- Detailed surveys of areas of most risk and also depending on what resources are available

A. Desktop Study

A desktop study can be conducted very simply and cheaply, and practically anywhere. There are many online resources available for identifying sites when reviewed by a marine expert who can assess material to interpret site characteristics. The example in Figure 6 is from navionics.com.

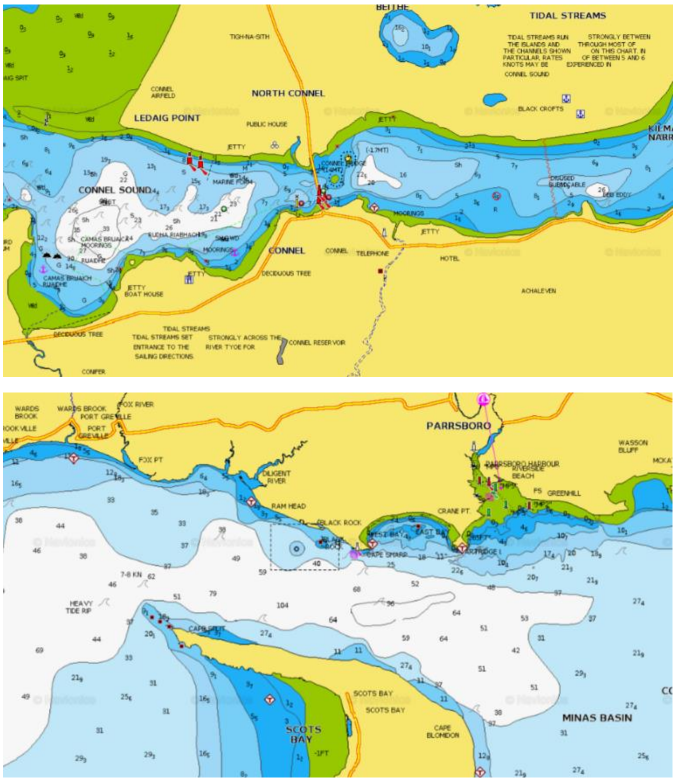

Figure 6: Navionics of Connel, Oban (top) and Minas Basin, Canada (bottom)

The areas were identified as good locations for PLAT-I or PLAT-O for the following reasons:

- They identify tidal rips, with 5 to 6 knots in Connel, and 7 to 8 knots in Minas Basin.
- The depths are within current targets, between 20 – 30m for Connel and 20 – 50m for areas of Minas Basin.
- Constrained channels limit the adverse wave conditions in most directions, limiting the weather systems which will affect the systems.

Differences in the sites occur, but affect different risks to potential projects:

- Connel is very small and so only suitable for a single platform, whereas there is space in Minas for an array.
- There is significant infrastructure at Connel, including seasonal moorings and fish farms further up the loch, meaning it would only be suitable as a temporary deployment for testing rather than a commercial investment.
- In Minas there are few ports for operational interventions, but there is the FORCE centre which makes it easier to negotiate with local bodies such as fishermen.

Each site has pros and cons depending on the intended deployment. An overview of sites' suitability can be conducted quickly and cheaply using this type of assessment.

Additionally, local knowledge is invaluable when conducting this assessment. Early stage discussion with local bodies, from fishermen and shipping, to research bodies or recreational users such as kayakers.

B. Visual Survey

The next stage of a site assessment is to conduct a visual survey. This removes any errors in information based on bias or incorrect recorded information. This can be as simple as a vessel trip to the site, or an aerial inspection over a region using helicopters or drones. A marine professional with the correct experience can identify areas suitable, or unacceptable, for deployment, by assessing certain criteria. Critical information gathered at this stage of assessment is:

- Is the information to date correct?
- How accessible is the site?
- Are there local vessels available, for both further surveys but also long-term project support?
- How exposed is the site?
- Who is the end user and what is the power requirement?
- What is the local infrastructure and facilities?

C. Initial Survey

Once a site is identified to have sufficient resource and commercial justification to pursue further information then an initial survey is conducted. This uses cheap and simple in-house methods which can be easily modified to the local resources available.

1) Velocity: A simple technique is used to gain high level velocity information. SME have used drifters to measure the flow speed using on-board GPS trackers. These are deployed from a local vessel and record their GPS position with time. The drifters are deployed multiple times to build up a picture of flow speed, streamlines, and spatial variation, see Figure 7. The surface speeds recorded are suitable for determining the flow velocity likely to be experienced by the SITs suspended from PLAT-I.

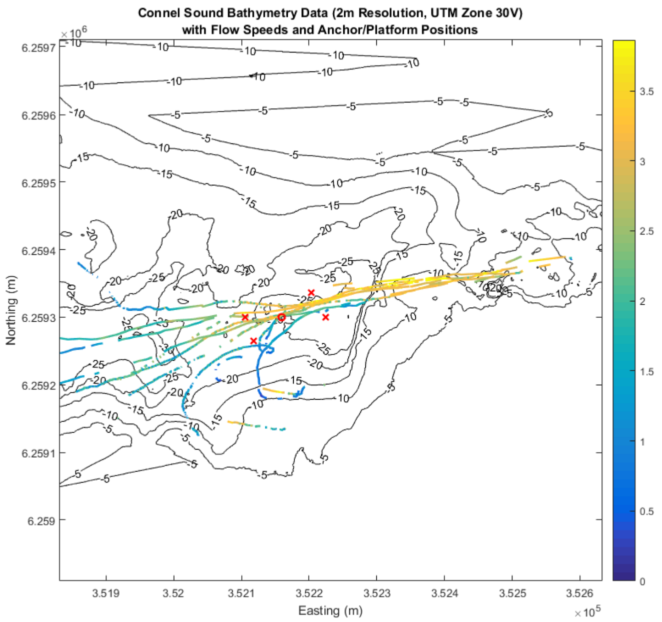

Figure 7: Drifter velocity results for Connel, Oban

The drifters are made from parts that can be broken down and easily shipped. All parts are very cheap and easy to obtain even in remote locations, Figure 8.

Figure 8: Drifters, made in Scotland (left) and Philippines (right)

Additionally, local vessels can be used for deployments, Figure 9. This means that local knowledge can be used to target surveys and understand local stakeholders, and also that any money spent goes to the local economy.

This process can be used to identify whether flow speeds are as high/low as expected, if there are any areas to target for better flow conditions, and also if there are areas to avoid, for example if there are strong recirculation zones.

Figure 9: Drifter vessels, RIB in Scotland (top) and bangka in Philippines (middle, bottom)

2) *Bathymetry:* Depth sounders can be used to estimate the depth in certain areas, and these are often mounted on modern boats. Sonars can be used to gather more detailed information but can be complex and expensive. A cheap and effective solution for this stage of the process is to use off-the-shelf fishfinders, such as Deeper Pro or FishHunter. These can be used to build up a map of the bathymetry, to estimate depth, bed steepness and spatial variation (Figure 10). At this stage this gives a good indication of bed suitability to PLAT-I or PLAT-Os mooring system, where a uniform bed and flat anchor points for the anchoring ROV are preferable.

The units can be deployed whilst running the drifter surveys, minimising vessel hire costs. Any sites from the desktop study that were identified with appropriate depth, but from bathymetric survey were discovered to have a steeply varying bathymetry, would be discarded prior to conducting a detailed bathymetric survey at high resolution, which is an expensive and time-consuming procedure.

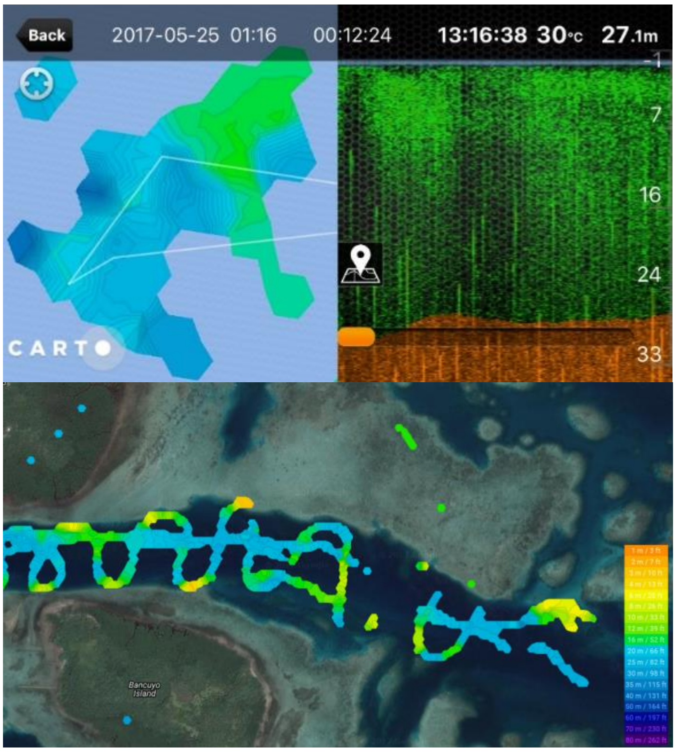

Figure 10: Bathymetry output from Deeper Pro, showing initial survey tracks

3) *Bed type:* To estimate the rock type at site and any issues with overburden or similar, rock samples in the surrounding vicinity can be collected. These can be used to estimate the bed type at site, though there are inherent issues with spatial variation with this method depending on the geological formation of the area. Identifying rock type gives information on drilling capability, rock holding capacity, and motion or degradation e.g. scour. The anchor type, size and design can be altered to best suit the site.

Additionally, remotely operated vehicle (ROV) surveys can be conducted to obtain seabed information at areas of the site. These can be focussed on specific locations, e.g. anchor positions based upon the velocity information from the drifter surveys.

These surveys are all conducted to obtain high level site information in a cost-effective, data-efficient manner to inform project viability based on the objectives of each individual project. The results also inform the selection of parts of the engineering system, e.g. anchors most suited to the site, and rotor size.

D. Detailed Survey

If a project warrants further information, and therefore cost, detailed information must be obtained to produce accurate performance predictions and operational constraints applicable to the type of installation (trial vs income generating). These will be focussed around the critical information based on project duration and requirements. For example, a trial deployment to test a new piece of equipment does not require detailed velocity measurement as the focus is not to find a commercially viable site, but a new deployment will require detailed bathymetry and geology information for anchor design and positioning, as these are critical for position keeping.

At site detailed surveys can include the following:

1) High resolution bathymetry: Anchor placement is accurate to 1m and the platforms' mooring systems are dependent on accurate elevation and inclusion angles, and so high-resolution bathymetry information is required to obtain good anchor positioning. Good quality data is dependent on higher specification vessels and equipment than those used in the initial survey process and so is more expensive to obtain. Additionally, for remote locations local vessels are not usually adequate and so specialist vessels must be obtained, and cost will include steaming time.

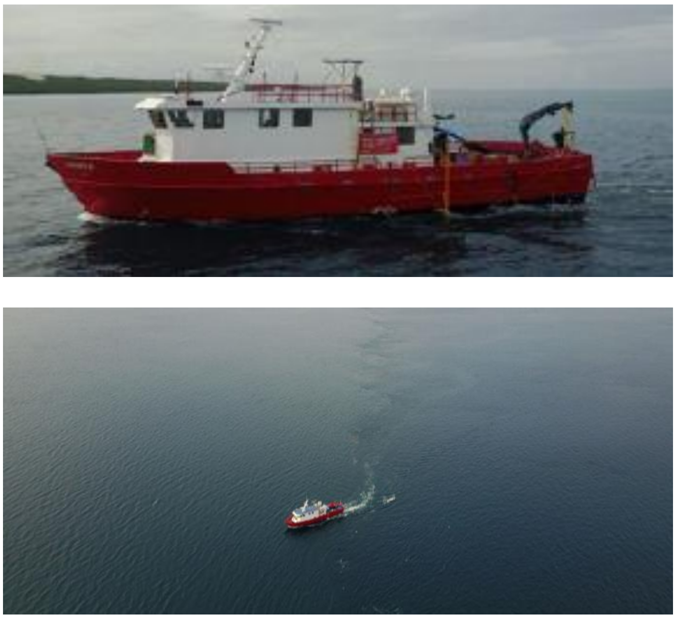

Figure 11: Example survey vessel, used by EGS, conducting bathymetry survey perpendicular to the flow direction

2) *Geology mapping:* Site mapping of the bed type allows refinement in positioning for platform and array. The optimum bed type for the Raptor anchors, or other mooring solutions, can be identified. It gives information of suitability of different areas in a single site. Local researchers or consultants can be used to gather this information; for example, SAMS [10] provided information for testing at Connel, as shown in Figure 12.

3) Core samples: To get higher accuracy information at the anchor locations rather than at an adjacent area core samples should be taken, either at a site general location or at every specific anchor location. These should gain enough depth and detail of information to assist in anchor selection and design. This can also be an expensive process and hard to obtain in remote locations.

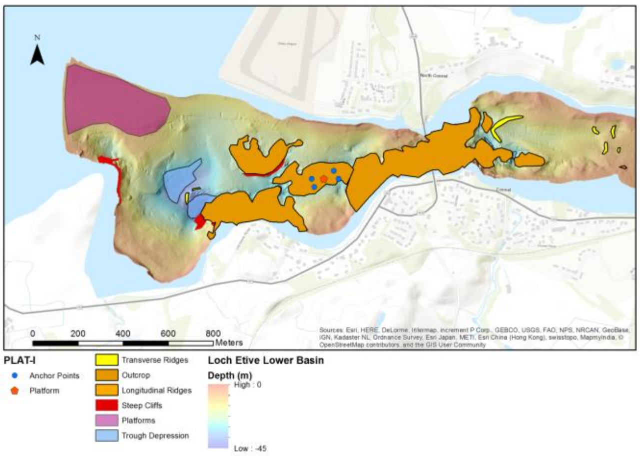

Figure 12: Geology mapping of Connel, conducted by SAMS

4) Bed mounted Acoustic Doppler Profiler (ADP): A bed ADP can be deployed to gather time varying velocity information throughout the water column for a long period of time. Typically, between one and two months information is gathered to cover the main lunar and solar tidal constituents to give an indication of the histogram of flow speeds expected for the year. This information can be used to estimate expected power generation, maximum structural and mooring line loads, flow directions, slack water periods for anchor installation, and operational windows for platform installation and interventions.

The vessel and equipment required for the bed mounted survey can be expensive and less available in remote locations as a frame is required to weight the unit to the bed in strong flows, and so therefore must have a lowering and lifting method.

5) Vessel mounted ADP: The spatial variation of a site can be measured using a vessel-mounted ADP survey. This gathers information throughout the depth across the site and can be used to identify areas where the flow speed or direction is reduced or worse than expected for the site. It may also identify areas of recirculation, or where strong shear is present. This improves array planning for multiple platforms at a commercial site. A vessel mounted survey can be conducted from a local vessel, though great care must be taken from information accuracy.

6) Flow modelling: Numerical modelling is also a very useful tool for identifying target areas within a site for array planning, and also obtaining longer period flow data for improved yield estimations. The models are entirely dependent on validation using field data, which can be the ADP data gathered. This has the advantage that it can be conducted remotely, if there is sufficient field data for model accuracy.

7) Wave and wind statistics: Though not directly related to output for a tidal device the local wind and wave conditions can significantly affect the device loading and the operational windows [7]. This also highlights areas where PLAT-O may be more suitable than PLAT-I, since it is sub-surface and thus further from the wave interaction zone. Historical wind and wave data can be obtained from weather stations and local government agencies. For more remote locations this information is harder to obtain but can be combined with modelling to produce statistical estimates.

8) *Wave and wind modelling:* Similarly, to the flow modelling wind and wave hindcast models can be used to estimate the statistical conditions at a site. These can also inform worst and/or prolific wave directions for a site. The advantage of modelling is that it can be conducted remotely, though accuracy is always an issue without sufficient real data.

Figure 13: Vessel mounted ADP survey from a bangka

IV. Cost Implications

The cost implications of these different survey techniques can be considerable, particularly when looking at remote sites. Being able to quickly discard a site through initial assessment prior to investing higher sums of money on detailed surveys makes site assessment more cost-efficient.

An example cost comparison between the initial and detailed survey stages is the difference in cost between a drifter survey and a bed mounted ADP survey, for gathering initial velocity information. The costs are based on previous experience in the Philippines and the UK. The cost of a drifter survey in the

Philippines is 3.3% of that of an ADP survey for 30 days. In the UK the cost of a drifter survey is 9% of a bed ADP deployment. Note that it is understood that the information gathered from an ADP survey is significantly more valuable than a drifter survey, however when looking to determine whether several sites in an area could be worth pursuing further then the drifter level of detail is all that is required. For example, if two Philippine sites were investigated and only one identified as potential commercial project then the cost of two drifter surveys but only one ADP survey would be 47% cheaper than two ADP surveys.

V. Applicability to Other Technologies

Though this approach is specific for PLAT-I and PLAT-O, the same theory could be applied to other tidal technologies. For example, if a large rotor, bed mounted monopile device required a flat bed but only in a small area, then sites could be assessed focusing on high level bathymetry and depth measurements, with a local vessel mounted ADP to gather through column measurements.

For other industries, such as wave energy, a similar approach could be used. Sites can be targeted for the correct depth, distance to ports, and exposure to strong wind and wave, using some of these techniques.

VI. Conclusions

The site assessment process used by SME has been presented. This shows the four stages of assessment: Desktop, Visual, Initial, and Detailed; these steps are summarised in Figure 14.

The process aims to maximise cost- and data-efficiency. This is particularly important when operating in more remote locations, e.g. South East Asian island communities where distance to port and vessel availability are further limited. The cost comparisons show that significant savings can be made using this process to eliminate undesirable sites at an early stage, before excessive money is spent on high resolution, highly detailed surveys.

This process is presented specifically for SME and SCHOTTEL Hydro's PLAT-I and PLAT-O platforms which host SIT250 turbines but can be modified and applied to different technologies.

Acknowledgements

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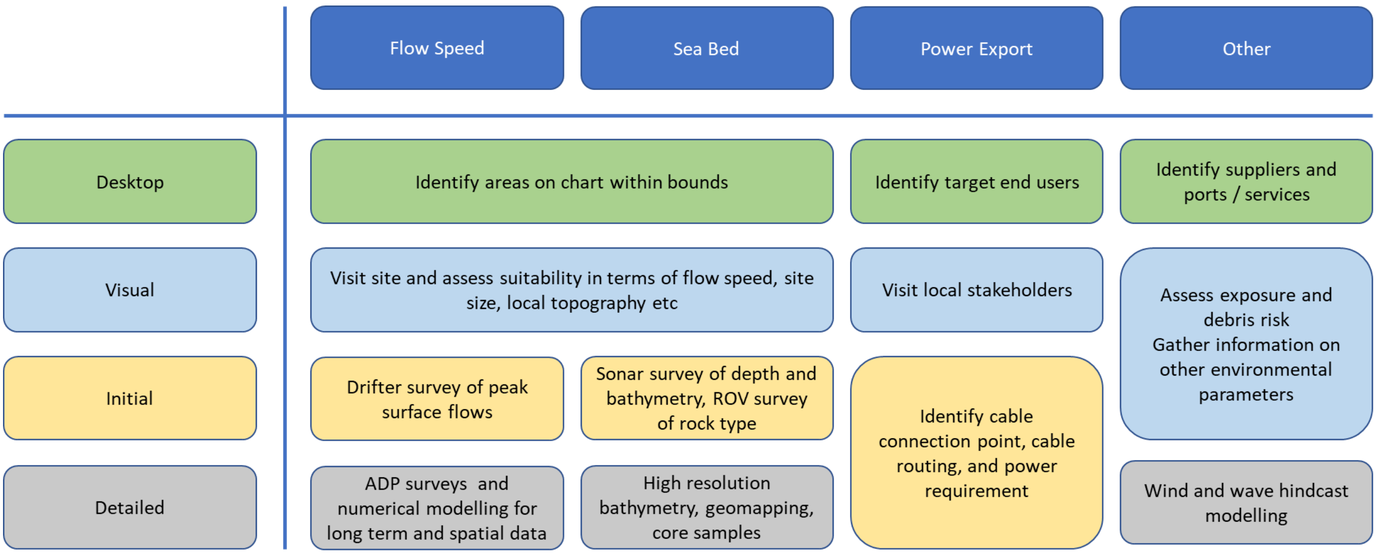

Figure 14: Site Selection Process Summary