Programme Area: Marine

Project: Tidal Modelling

Title: Executive Summary - Tidal Resource Characterisation

Abstract:

ETI has commissioned Black & Veatch (B&V), in collaboration with HR Wallingford (HRW) and the University of Edinburgh (UoE) to develop a Continental Shelf Model (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts. The objective of the project is to answer the following fundamental questions:

How will the interactions between tidal range and tidal current systems positioned around the UK's waters combine to form an overall effect?

Will the extraction of tidal energy resource in one area impact the tidal energy resouce at distant sites around the UK and Europe?

What constraints might these interactions place on the design, development and location of future systems?

Context:

Launched in October 2011 this project involved Black & Veatch, in collaboration with HR Wallingford and the University of Edinburgh to develop a model of the UK Continental Shelf and North European Waters, 100 times more accurate than existing marine data. This has been used to assess the tidal energy potential around the UK (tidal range and tidal streams), to inform the design of energy harnessing schemes, to assess their interactions, and to evaluate their impact on European coasts. It can also be used to renew and inform flood defences, coastal erosion and aggregate extraction. Now completed, the project has been launched to market under the brand of SMARTtide. This is available to the marine industry under licence from HR Wallingford.

ETI Executive Summary

Programme: Marine

Project: Tidal Modelling

Project ID: MA1009

Deliverable Title: D01**-** Tidal Resource Characterisation

1. Introduction

ETI has commissioned *Black & Veatch* (B&V), in collaboration with *HR Wallingford* (HRW) and the *University of Edinburgh* (UoE) to develop a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts.

The objective of the project is to answer the following fundamental questions:

- How will the interactions between tidal range and tidal current systems positioned around the UK's waters combine to form an overall effect?
- Will the extraction of tidal energy resource in one area impact the tidal energy resource at distant sites around the UK and Europe?
- What constraints might these interactions place on the design, development and location of future systems?

This will be achieved through a series of work packages and 10 deliverables:

D01 – Tidal resource characterisation

D02 – Continental Shelf Model (CSM) definition and requirements document

D03 – Scenarios modelling

D04 – Cost of Energy Model and supporting documentation

D05 – Interface specification for detailed tidal current modelling (via PerAWaT project) with CSM

D06 – CSM (coarse and detailed versions) with supporting documentation

D07 – Interactions (analysis and conclusions report)

D08 – Interface specification for detailed tidal range model and the CSM

D09 – Tidal Range model and supporting documentation

D10 – Project dissemination

This Executive Summary covers deliverable D01 – Tidal Resource Characterisation. The tidal resource has been characterised in two parts: Tidal Range and Tidal Current. The report is therefore split into Part A and Part B, respectively. It is noted that Tidal Fences have been considered as a variation of the Tidal Current technology instead of Tidal Range.

2. Part A: Tidal Range Resource Characterisation

The objective of the Tidal Range Resource Characterisation part of this report is to characterise the UK tidal range resource and identify potentially feasible schemes.

2.1 Approach

Traditional tidal range schemes can be split into three types of impoundment:

- Barrages;
- Coastal (land-connected) lagoons; and
- Offshore lagoons.

Offshore lagoons normally require longer lengths of embankment and deeper water than coastal lagoons that would generate similar power. For this reason, offshore lagoons have not been selected for scenario testing in the project.

Three possible modes of operation were considered for a tidal barrage or lagoon:

- Ebb-only generation;
- Flood-only generation; and
- Dual (ebb-flood) generation.

Pumping has not been included in the tidal range scenarios developed for this study as it adds considerable complexity to the operation of a scheme, whilst potentially delivering only a relatively small energy increase.

A requirement of the project is that schemes should maintain at least 80% of the natural tidal range. Previous studies of tidal range schemes have generally focussed on ebb-only generation. These ebb-only schemes have insufficient installed turbine and sluice capacity to maintain 80% of natural tidal range within the impounded basin. Despite this, ebb-only operation has been included for barrage schemes (but not lagoons) to enable direct comparison with previous tidal power studies.

The technology options reviewed include conventional turbines (Bulb and Straflo), the Rolls-Royce turbine, the Spectral Marine Energy Converter from VerdErg and Tidal Reef. The latter two were not selected for scenario development because there is a lack of performance data with which to represent the technology. Therefore, at each location (except where constraints do not allow) there are three options for technology:

- Ebb-only generation with conventional bulb turbines;
- Dual (ebb-flood) generation with conventional bulb turbines; and
- Dual generation with Rolls-Royce very low head turbines

Scheme selections (number of turbines, size and capacity of turbines, number and size of sluices) were based on an appropriate previous study for barrages and simple 0-d modelling for lagoons. The 0-d modelling showed good correlation with previous literature.

2.2 Results

Potentially feasible locations for tidal range schemes that could give peak power output greater than 100MW have been identified giving:

- 10 barrage alignments – selected based on a literature review of previous studies; and
- 11 lagoon alignments – selected based on the tidal range, water depth and coastline shape.

The general locations are shown in the map in Annex A and the tables in Annex A summarise the three scheme selections for each location. These schemes will be considered for the scenario modelling (Deliverable D03).

2.3 Key Findings

Key Findings from the Tidal Range Characterisation are:

- Previous studies of UK tidal power have focussed on ebb-only generation, as this was generally believed to be likely to be the most economic in terms of Cost of Energy (CoE) and importantly minimises the absolute quantum of the capital costs . With this mode of operation, the tidal range within the impounded basin is generally around 50% of the natural range, which has in turn caused environmental issues to be a constraint on development. To increase the range inside the basin requires additional turbines and sluices. Often there is insufficient deep water in estuaries to achieve this using conventional bulb turbines (along the previously specified alignments). In some cases, it may be possible and worthwhile to dredge alignments to achieve such an approach. Alternatively, Rolls-Royce turbines do not require as much submergence as conventional turbines and so a lack of deep water (in the natural condition) is less of a constraint.

- If there is sufficient deep water to install enough turbines to achieve 80% of natural tidal range, the energy output from dual mode (ebb-flood) operation is likely to be significantly greater than for ebb-only operation. The optimisation of dual mode generation to achieve a particular tidal range constraint, particularly when using optimised starting heads, appears to be novel, and has not been considered for most existing schemes.

- Although dual mode operation can meet the specified tidal range constraints, and generally has a much greater energy output, the number of turbines required may mean that the economics are less attractive compared to the previously well-studied ebb-only schemes (although this does not appear to be the case for all schemes and it appears that the economics of some schemes may be improved when optimisation is fully implemented). However, the required number of turbines may be a constraint, although given enough incentives (and potentially a long-term roll out of the different sites) such manufacturing requirements should not be insurmountable. Perhaps more of an issue may be that the maximum power generated by such dual mode schemes using traditional bulb turbines is much greater, and therefore the grid reinforcement for such schemes may be prohibitive, although the Rolls-Royce turbines mitigate this to some extent by operating for longer at lower maximum output.

- In terms of energy output (relative to the cost of turbines, embankment and locks), the best location for a scheme is a large barrage on the Severn (either at the Cardiff-Weston or Outer alignment) followed by Bridgwater Bay lagoon, Solway Firth barrage, Morecambe Bay barrage and Dee barrage. The Severn schemes appear significantly more economic than others, which corresponds with previous literature.

- Some schemes are only possible with Rolls-Royce turbines, assuming that significant dredging is not undertaken and that the 80% tidal range constraint is fully imposed. These include Morecambe Bay, Severn Cardiff-Weston, Thames and the Humber. However, it could be that these alignments could be possible and similarly economic using conventional turbines and extensive dredging outside of the turbine caissons. The Rolls-Royce turbines appear to be most competitive (comparatively) at the Mersey.

- Lagoons are inevitably more costly than barrages in the same location because they need a longer embankment. Larger lagoons are more efficient than smaller ones, as expected.

- Effective turbine operation in dual mode with conventional turbines is sensitive to the starting heads that are used. The starting heads selected based on 0-d model results potentially may not operate as desired when implemented in the CSM because of hydrodynamic effects. This could cause the predicted energy output to fall significantly, without further optimisation within the CSM (which is beyond the scope of this entire project).

- Two-dimensional effects not represented in the 0-d model testing in this report may reduce the annual energy output for the selected schemes. These 2-d effects will be greatest where the flow of water away from the turbines is hampered by a shallow sea bed (such as the Dee estuary), a narrow deep water channel (such as the Mersey estuary or at Morecambe Bay), or in an estuary that has strong longitudinal gradients in tidal range (such as the Severn).

The 0-d model used to develop some of these schemes is presented as part of this report, and should be readily usable by any suitably experienced modeller. This 0-d model does not take account of hydrodynamic effects and therefore should always be confirmed in an appropriate hydrodynamic model.

3. Part B: Tidal Current Resource Characterisation

3.1 Approach

The objective of the Tidal Current Resource Characterisation was to review locations for tidal current farms based on the literature available, (primarily the Carbon Trust's June 2011 'UK Tidal Current Resource & Economics', referred to hereafter as the CT 2011 report), and identify potential areas, water depth, extent, and estimated power and energy output for tidal farms that are considered viable. The original scope was to identify farms over 100MWp. However, this criteria was relaxed (to 60MWp) to account for most potentially economic locations in UK waters.

The underlying hydrodynamic modelling used in the CT 2011 report is essentially based on the far-field response of the tidal system with regard to the economic and environmental implications of widespread, large-scale TEC (tidal [current] energy converter) deployment. The approach adopted was to consider ideal representations of each of the relevant hydrodynamic mechanisms which give rise to the tidal current conditions necessary for TEC deployment. The hydrodynamic mechanisms are: Hydraulic Current; Resonant Basin; and, Tidal Streaming. In all three tidal regimes, an upper theoretical limit was identified beyond which attempts to extract more energy from the system actually reduces the overall energy that is harvested. This indicates the existence of a theoretical extraction limit in a particular location using the TEC technology approach.

All the sites identified in the CT 2011 report were summarised and reviewed. The constraints applied to each of the locations in the CT 2011 report include the technical constraint assumptions: resource intensity, rotor diameter, rated velocity, turbine clearance and spacing, tidal range, structural drag, wake effects, water depth, and also the practical constraints. For the practical constraints, the CT 2011 report identified fishing, shipping and designated conservation sites and applies a probability that the site will be developed (or part developed). A number of potentially important additional constraints were considered:

- Grid connection/accessibility: This is considered an important constraint but, although an option for this was proposed, it is not included in the scope of work. Therefore, it should not be considered in any scenario modelling.
- Wave constraints: Some sites have relatively intense wave climates, which will make near-term deployment less likely. This should be considered in the scenario modelling timescales.
- Tidal range project interaction constraints: There may be interactions between tidal range and current project developments. This is not accounted for at this stage, as it is an output of the (later) work scope.
- Tidal range constraints: Some sites have relatively high tidal ranges, which may make near-term deployment less likely. This should be considered in the scenario modelling timescales.

The sites that have been selected from the CT 2011 report short-list are characterised by these generic criteria:

- Mean sea level (MSL) of greater than 15m;

- Mean annualised power density in excess of 1.5kW/m^2;
- Installed capacity: Farm rated power greater than 60MWp.

3.2 Results

The key sites identified were:

Pentland Firth Deep	North East Jersey	Mull of Kintyre
Carmel Head	Islay / Mull of OA	Isle of Wight
Race of Alderney	Westray Firth	Mull of Galloway
South Jersey	Bristol Channel - Minehead	South Minquiers (Jersey)
Pentland Firth Shallow	North of N. Ronaldsay Firth	N. Ronaldsay Firth
East Casquets	West Casquets	Rathlin Island
West Islay	Ramsey Island	

The CSM's proposed extensive coverage around the UK and surrounding waters, and its proposed open boundary location in deep water beyond the continental shelf, is (based on previous modelling experience of tidal current farms) sufficient to ensure that all significant impacts of these schemes are included in the model

3.3 Key Findings

Key Findings from the Tidal Current Resource Characterisation are.

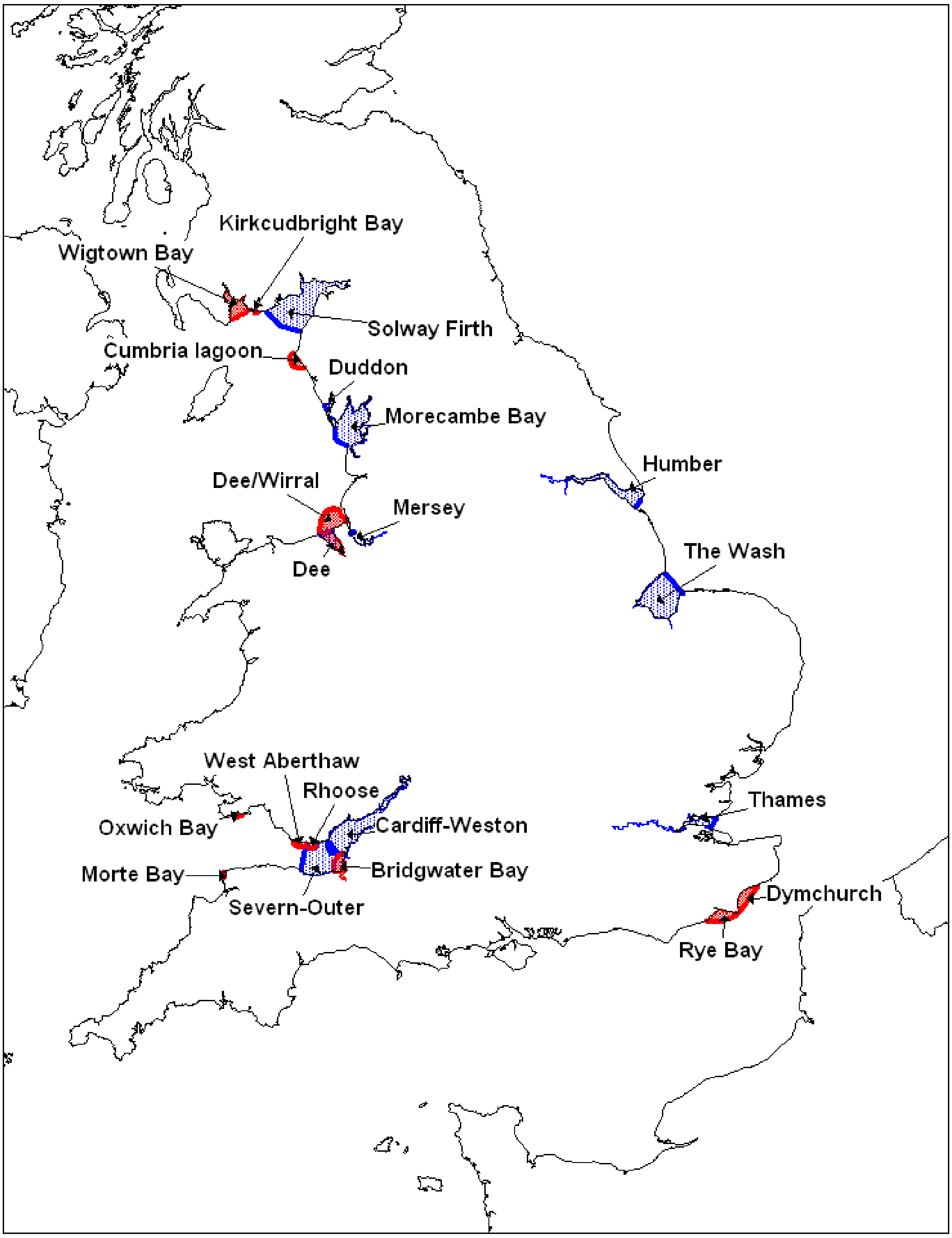
- No evidence was identified in the literature review which would suggest that the CT 2011 approach, and thus the proposed approach for this project, should be changed.
- Based on the agreed generic criteria, 20 known tidal current farm locations to be actively considered within future work packages were identified.

4. Next Steps

The schemes outlined in the report will be used as the basis for the development of the scenario modelling (deliverable D03).

Annex A: Tidal Range Resource – Map & Tables

General locations of potentially feasible schemes



Summary of ebb-only conventional turbines scheme selection

	Location	Basin area (km^2)	Impound ment length (km)	Mean tidal range (m)	Turbine selection: Turbine dia. (m)	Turbine selection: Turbine unit capacity (MW)	Suggested installed capacity: No. of turbines	Suggested installed capacity: Total installed capacity (MW)	Suggested installed capacity: Indicative energy output (TWh/yr)	Sluices: No.	Sluices: Size	Min. tidal range inside basin	GWh/yr per turbine	GWh/yr per km impound ment
1	Solway Firth	814	28	5.6	9.0	29	200	5,800	12.1	226	12m x 12m	44%	61	426
2	Duddon	32	6	5.8	-	-	-	-	-	-	-	-		
3	Morecambe Bay	455	18	6.2	9.0	16	120	1,920	6.2	140	12m x 12m	39%	52	336
4	Mersey	56	2	6.5	8.0	25	28	700	1.3	18	12m x 12m	68%	45	700
5	Dee	103	8	5.9	8.0	21	40	840	1.6	40	8m x 12m	68%	39	189
6	Severn - outer	1060	20	7.0	9.0	40	370	14,800	28.9	320	12m x 12m	50%	78	1446
7	Severn - Cardiff-Weston	504	16	7.9	9.0	40	216	8,640	18.8	166	12m x 12m	49%	87	1177
8	Thames	160	8	4.2	9.0	20	32	640	1.1	32	12m x 12m	53%	35	138
9	Wash	650	19	4.8	9.0	23	120	2,760	5.1	140	12m x 12m	48%	42	264
10	Humber	292	7	4.3	9.0	20	60	1,200	2.2	80	12m x 12m	51%	37	307
11	Wigtown Bay lagoon	163	15	4.8										
12	Kirkcudbright Bay lagoon	16	4	5.1										
13	Cumbria lagoon	62	20	5.5										
14	Dee-Wirral lagoon	268	37	5.9										
15	Oxwich Bay lagoon	14	6	6.1										
16	West Aberthaw lagoon	30	13	7.5										
17	Rhoose lagoon	25	12	7.5										
18	Bridgwater Bay lagoon	90	16	8.3										
19	Morte Bay lagoon	12	5	5.5										
20	Rye Bay lagoon	103	25	5.2										
21	Dymchurch lagoon	103	23	5.2										

Summary of dual mode, conventional turbines scheme selection

	Location	Basin area (km^2)	Impound ment length (km)	Mean tidal range (m)	Turbine selection: Turbine dia. (m)	Turbine selection: Turbine unit capacity (MW)	Suggested installed capacity: No. of turbines	Suggested installed capacity: Total installed capacity (MW)	Suggested installed capacity: Indicative energy output (TWh/yr)	Min. tidal range inside basin	GWh/yr per turbine	GWh/yr per km impound ment
1	Solway Firth	814	28	5.6	9.0	18	1100	19,800	31.0	83%	28	1092
2	Duddon	32	6	5.8	-	-	-	-	-	-		
3	Morecambe Bay	455	18	6.2	-	-	-	-	-	-		
4	Mersey	56	2	6.5	9.0	18	25	450	0.9	80%	34	478
5	Dee	103	8	5.9	9.0	18	60	1,080	2.2	80%	36	259
6	Severn - outer	1060	20	7.0	9.0	18	875	15,750	45.0	80%	51	2250
7	Severn - Cardiff-Weston	504	16	7.9	-	-	-	-	-	-		
8	Thames	160	8	4.2	-	-	-	-	-	-		
9	Wash	650	19	4.8	9.0	14	350	4,900	8.5	80%	24	440
10	Humber	292	7	4.3	-	-	-	-	-	-		
11	Wigtown Bay lagoon	163	15	4.8	9.0	14	160	2,240	3.8	80%	24	261
12	Kirkcudbright Bay lagoon	16	4	5.1	9.0	18	14	252	0.4	80%	27	95
13	Cumbria lagoon	62	20	5.5	9.0	18	70	1,260	2.2	82%	31	108
14	Dee-Wirral lagoon	268	37	5.9	9.0	18	250	4,500	9.0	80%	36	244
15	Oxwich Bay lagoon	14	6	6.1	9.0	22	16	352	0.6	80%	39	102
16	West Aberthaw lagoon	30	13	7.5	9.0	27	45	1,215	2.3	82%	52	174
17	Rhoose lagoon	25	12	7.5	9.0	27	40	1,080	2.0	82%	49	158
18	Bridgwater Bay lagoon	90	16	8.3	9.0	30	120	3,600	6.9	81%	58	435
19	Morte Bay lagoon	12	5	5.5	9.0	18	14	252	0.4	83%	31	88
20	Rye Bay lagoon	103	25	5.2	9.0	18	110	1,980	3.2	80%	29	126
21	Dymchurch lagoon	103	23	5.2	9.0	18	110	1,980	3.2	80%	29	137

Summary of dual mode, Rolls-Royce turbines scheme selection

	Location	Basin area (km^2)	Impoundment length (km)	Mean tidal range (m)	Suggested installed capacity: No. of 14m dia. turbines	No. of 9m dia. turbines	Indicative max. output (MW)	Indicative energy output (TWh/yr)	Min. tidal range inside basin	GWh/yr per turbine	GWh/yr per km impoundment
1	Solway Firth	814	28	5.6	750	0	6,790	20.8	80%	28	732
2	Duddon	32	6	5.8	-	-	-	-	-		
3	Morecambe Bay	455	18	6.2	320	0	3,670	10.5	80%	33	568
4	Mersey	56	2	6.5	40	0	570	1.4	80%	35	767
5	Dee	103	8	5.9	55	0	740	1.7	81%	31	206
6	Severn - outer	1060	20	7.0	800	352	7,540	24.1	75%	21	1207
7	Severn - Cardiff-Weston	504	19	7.9	165	900	5,130	17.0	80%	16	912
8	Thames	160	8	4.2	90	20	530	1.8	80%	16	216
9	Wash	650	19	4.8	400	0	3,150	8.3	80%	21	431
10	Humber	292	7	4.3	200	0	1,340	3.7	80%	18	507
11	Wigtown Bay lagoon	163	15	4.8	140	0	1,160	3.2	80%	23	221
12	Kirkcudbright Bay lagoon	16	4	5.1	12	0	110	0.3	80%	25	75
13	Cumbria lagoon	62	20	5.5	60	0	450	1.6	80%	27	80
14	Dee-Wirral lagoon	268	37	5.9	220	0	2,360	6.9	80%	32	187
15	Oxwich Bay lagoon	14	6	6.1	16	0	190	0.5	82%	33	84
16	West Aberthaw lagoon	30	13	7.5	40	0	580	1.7	82%	42	124
17	Rhoose lagoon	25	12	7.5	30	0	410	1.3	80%	42	101
18	Bridgwater Bay lagoon	90	16	8.3	110	0	1,500	4.1	90%	37	257
19	Morte Bay lagoon	12	5	5.5	14	0	140	0.4	84%	27	76
20	Rye Bay lagoon	103	25	5.2	100	0	780	2.5	80%	25	102
21	Dymchurch lagoon	103	23	5.2	100	0	780	2.5	80%	25	110