GUIDE TO APPENDICES

Appendix 1 – Contribution to BV2004 Resource by Site

Appendix 2 – Comparison of BV2004 / 2005 Input Parameters

Appendix 3 – RGU Study – Channel Island Resource

Appendix 4 – RGU Tidal flow visualisation for the Channel Islands (.AVI video file)

Appendix 1 – Contribution to BV2004 Resource by Site

Appendix 1 - Contriubtion to BV 2004 Resource by Site

Phase 2 Rank	Phase 1 No.	Site Name	Grid Ref.	Width(m)	Depth(m)	Vsp(m/s)	Vnp(m/s)	Vsp/Vnp	Ratio 1st/ 2nd Tide	Rated V (m/s)	BV2004 Extractable & Available Annual Energy (GWh/site)	Cumulative Annual Energy (GWh/site)	Cumulative contribution to UK resource (%)	Individual Contribution to UK resource (%)
1	5	Pentland Skerries	58°40.5'N, 2°59W	3200	59	6.18	2.64	2.34	0.67	4.39	3901	3901	17.9%	17.9%
2	3	Stroma P. Firth	58°43'N, 3°8'W	2500	71	5.15	2.20	2.34	0.88	3.66	2774	6675	30.6%	12.7%
3	6	Duncansby Head	58°39'N, 2°59'W	2000	65	5.15	2.20	2.34	0.88	3.66	2031	8706	39.9%	9.3%
4	17	Casquets	49°47'N, 2°25W	8000	115	2.57	1.39	1.85	0.71	1.82	1651	10357	47.5%	7.6%
5	2	S. Ronaldsay P. Firth	58°44'N, 3°1'W	2300	58	4.89	2.05	2.39	0.77	3.47	1518	11875	54.4%	7.0%
6	1	Hoy, Pentland Firth	58°45.5'N, 3°15'W	2000	76	4.38	1.80	2.43	0.85	3.11	1377	13252	60.8%	6.3%
7	16b	Race of Alderney	49°41'N, 2°7'W	3324	33	4.38	2.41	1.82	0.96	3.11	1365	14617	67.0%	6.3%
8	4	S. Ronaldsay/ P.Skerries	58°42'N, 2°55'W	2300	63	4.38	1.79	2.45	0.75	3.11	1147	15764	72.3%	5.3%
9	9	Rathlin Island	55°10'N, 6°0'W	4000	80	2.57	1.44	1.78	1.00	1.82	866	16630	76.2%	4.0%
10	10a	Mull of Galloway	54°36'N, 4°55'W	4807	80	2.57	1.44	1.78	0.82	1.82	806	17436	79.9%	3.7%
11	18	North West Guernsey	49°33'N, 2°45'W	10000	57	2.06	1.11	1.85	0.65	1.46	492	17928	82.2%	2.3%
12	25a	Portland Bill	50°29'N, 2°27'W	1989	33	3.86	1.92	2.01	0.70	2.74	374	18302	83.9%	1.7%
13	13a	Foreland Point Bristol Channel	51°19'N, 3°48'W	5077	33	2.57	1.43	1.8	0.85	1.82	362	18663	85.6%	1.7%
14	16a	Race of Alderney	49°41'N, 2°7'W	677	39	4.38	2.41	1.82	0.96	3.11	328	18992	87.1%	1.5%
15	19a	Big Russel	49°27'N, 2°23W	2778	48	2.57	1.39	1.85	0.88	1.82	294	19286	88.4%	1.3%
16	37	Yell Sound - East Channel	60°30.5'N, 1°10'W	1500	35	3.45	1.72	2.01	0.84	2.45	251	19537	89.6%	1.2%
17	57	Irish Sea - Rathlin Sound	55°16'N, 6°16'W	2000	40	2.93	1.46	2.01	0.84	2.08	235	19772	90.6%	1.1%
18	54	Orkney - Papa Westray	59°23.5'N, 2°52'W	2500	30	2.93	1.46	2.01	0.84	2.08	221	19993	91.7%	1.0%
19	13b	Foreland Point Bristol Channel	51°19'N, 3°48'W	3923	22	2.57	1.43	1.8	0.85	1.82	186	20179	92.5%	0.9%
20	35	Westray Firth - Falls of Warness	59°8'N, 2°48'W	1500	25	3.45	1.72	2.01	0.84	2.45	180	20359	93.3%	0.8%
21	20	North East Jersey	49°16'N, 1°58'W	2500	22	3.09	1.72	1.8	0.65	2.19	164	20523	94.1%	0.8%
22	38	Yell Sound - West Channel	60°30'N, 1°12'W	1500	30	2.93	1.46	2.01	0.84	2.08	132	20655	94.7%	0.6%
23	7a	Inner Sound	58°39.5'N, 3°9.5W	688	33	3.35	1.44	2.32	1.00	2.38	116	20771	95.2%	0.5%
24	39	Bluemull Sound - North	60°42.5'N, 0°59'W	750	25	3.45	1.72	2.01	0.84	2.45	90	20861	95.6%	0.4%
25	19b	Big Russel	49°27'N, 2°23W	1067	33	2.57	1.39	1.85	0.88	1.82	78	20938	96.0%	0.4%
26	25b	Portland Bill	50°29'N, 2°27'W	511	22	3.86	1.92	2.01	0.70	2.74	64	21002	96.3%	0.3%
27	40	Bluemull Sound - South	60°41'N, 0°59'W	500	25	3.45	1.72	2.01	0.84	2.45	60	21062	96.6%	0.3%
28	12a	Barry Bristol Channel	51°21'N, 3°16'W	721	33	2.57	1.41	1.82	0.92	1.82	56	21118	96.8%	0.3%
29	34	Eday Sound	59°13.5'N, 2°42'W	1000	18	2.93	1.46	2.01	0.84	2.08	53	21171	97.1%	0.2%
30	36	Westray Firth - Kili Hom/Fers Ness	52°12'N, 2°52.5'W	1000	25	2.59	1.29	2.01	0.84	1.84	50	21222	97.3%	0.2%
31	10b	Mull of Galloway	54°36'N, 4°55'W	693	33	2.57	1.44	1.78	0.82	1.82	48	21270	97.5%	0.2%
32	31	Dorus Mor	56°8'N, 5°38W	265	22	4.10	2.04	2.01	0.84	2.91	47	21317	97.7%	0.2%
33	12b	Barry Bristol Channel	51°21'N, 3°16'W	779	22	2.57	1.41	1.82	0.92	1.82	40	21357	97.9%	0.2%
34	50	Mizen Head	51°26.5'N, 9°49.5'W	1000	35	2.07	1.03	2.01	0.84	1.47	36	21393	98.1%	0.2%
35	55	Lundy North	51°13'N, 4°41'W	1000	35	2.07	1.03	2.01	0.84	1.47	36	21429	98.2%	0.2%
36	7b	Inner Sound	58°39.5'N, 3°9.5W	313	22	3.35	1.44	2.32	1.00	2.38	35	21464	98.4%	0.2%
37	56	Lundy South	51°9'N, 4°40'W	1000	45	2.07	1.03	2.01	0.84	1.47	32	21497	98.6%	0.1%
38	44	West Scotland - Loch Linne - Corran	56°42'N, 5°15'W	500	30	2.59	1.29	2.01	0.84	1.84	30	21527	98.7%	0.1%
39	32	Kyle Rhea	57°15'N, 5°37'W	153	22	4.10	2.04	2.01	0.84	2.91	27	21554	98.8%	0.1%
40	41	Cape Cornwall	50°10'N, 5°43'W	1500	35	1.55	0.77	2.01	0.84	1.10	23	21577	98.9%	0.1%
41	42	Land's End	50°2'N, 5°43'W	1500	35	1.55	0.77	2.01	0.84	1.10	23	21600	99.0%	0.1%
42	43	The Lizard	49°55'N, 5°15'W	1500	35	1.55	0.77	2.01	0.84	1.10	23	21623	99.1%	0.1%
43	27	Mull of Kintyre	55°17'N, 5°44'W	484	22	2.60	1.29	2.01	0.84	1.85	22	21645	99.2%	0.1%
44	28	Sanda Sound	55°18'N, 5°35'W	484	22	2.60	1.29	2.01	0.84	1.85	22	21666	99.3%	0.1%
45	29	Mull of OA	55°34'N, 6°18'W	484	22	2.60	1.29	2.01	0.84	1.85	22	21688	99.4%	0.1%
46	49	Dursey Head - The Cow	51°34.5'N, 10°16'W	1000	60	1.55	0.77	2.01	0.84	1.10	20	21709	99.5%	0.1%
47	52	Inishtooskert Island	52°7.5'N, 10°37'W	1000	38	1.55	0.77	2.01	0.84	1.10	17	21725	99.6%	0.1%
48	53	River Shannon - Scattery Island	52°35.5'N, 9°30.5'W	500	25	2.24	1.12	2.01	0.84	1.59	16	21742	99.7%	0.1%
49	26	Wigtown Bay	54°43'N, 4°17'W	684	22	2.10	1.05	2.01	0.84	1.49	16	21758	99.8%	0.1%
50	51	Gascanane Sound	51°27.5'N, 9°26.5'W	1000	35	1.55	0.77	2.01	0.84	1.10	15	21773	99.8%	0.1%
51	48	Dursey Head - The Calf	51°34.5'N, 10°14.5'W	750	60	1.72	0.86	2.01	0.84	1.22	14	21787	99.9%	0.1%
52	33	N. Ronaldsay Firth	59°19'N, 2°28'W	342	22	2.10	1.05	2.01	0.84	1.49	8	21795	99.9%	0.0%
53	19c	Big Russel	49°27'N, 2°23W	155	22	2.57	1.39	1.85	0.88	1.82	8	21803	100.0%	0.0%
54	30	Gulf of Corryvreckan	56°9'N, 5°44'W	153	22	2.60	1.29	2.01	0.84	1.85	7	21810	100.0%	0.0%
55	47	Dursey Sound	51°36.5'N, 10°9.5'W	100	20	2.07	1.03	2.01	0.84	1.47	2	21812	100.0%	0.0%
56	45	Menai Straits - Belan	53°8'N, 4°19'W	250	5	2.59	1.29	2.01	0.84	1.84	0	21812	100.0%	0.0%
57	46	Menai Straits - Menai Bridge	53°13'N, 4°10'W	250	5	2.07	1.03	2.01	0.84	1.47	0	21812	100.0%	0.0%

Appendix 2 – Comparison of BV2004 / 2005 Input Parameters

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	Width	Depth				Vsp			Vnp		
Site Name	2004	2004	2005	MEA	MEA	2004	2005	MEA	2004	2005	MEA
				Model	Calc						
Hoy, Pentland Firth	2000	76	72	56.0	68.0	4.38	3.70	3.60	1.80	1.59	1.65
S. Ronaldsay P. Firth	2300	58	63	55.3	40.7	4.89	4.24	2.65	2.05	1.88	1.34
Stroma P. Firth	2500	71	72	52.0	65.5	5.15	4.78	4.78	2.20	2.16	2.20
S. Ronaldsay/ P.Skerries	2300	63	61	62.0	47.5	4.38	4.17	4.24	1.79	1.80	2.08
Pentland Skerries	3200	59	65	57.0	68.0	6.18	6.43	4.65	2.64	2.73	2.16
Duncansby Head	2000	65	66	52.0	35.0	5.15	4.84	4.69	2.20	2.16	2.35
Rathlin Island	4000	80	100	115.5	106.5	2.57	2.42	2.31	1.44	1.59	1.14
Mull of Galloway	4807	80	57	47.0	45.3	2.57	2.31	2.69	1.44	1.90	1.32
Race of Alderney	3323.5	33	39	62.0	28.0	4.38	2.93	4.76	2.41	1.29	2.48
Casquets	8000	115	80	70.5	79.5	2.57	2.26	2.25	1.39	1.18	1.10

Notes

Width	For race of Alderney width increased as wider part of the site area falls closer to the Tidal stream data point
Depth	Differences in depth due to averaged depth values of whole site area taken from Ad. Charts. BV 2005 values show good likeness to MEA calculated depths.
Vsp and Vnp	Alderney value lower because different tidal stream atlas values used (point closer to site area). Differences in MEA values because of large grid size used.

Appendix 3 – RGU Study – Channel Island Resource

Tidal Stream Resource Assessment for The Channel Islands area

For Black & Veatch Consulting Limited

By Alan Owen, The Robert Gordon University, Aberdeen

THE
ROBERT GORDON
UNIVERSITY
ABERDEEN

30/03/05

Introduction

Black & Veatch Consulting Limited (B&V) has recently reviewed estimates of tidal stream resources and the techniques used therein. One particular report that considered UK sites in detail has been examined closely. The 1993 ETSU report [3] was generated using the tidal stream 'farm' methodology, which assumes that a grid of devices is installed and that the extractable energy is a function of the installed capacity. Whilst this method is broadly applicable to wind farms, it is not suitable for tidal stream energy exploitation due to the fact that it is possible for the calculated energy output to exceed the energy available.

An alternative method is being developed by The Robert Gordon University in which, the total energy flux through a site is calculated based on existing empirical data available in the public domain. Having defined the total energy flux available, the Significant Impact Factor (SIF) parameterises the exploitable energy, which seeks to determine the maximum energy that may be extracted without causing significant changes to the flow regime. The SIF has been tentatively set at 20% as an average figure, and it is considered that the figure will be site specific and dependent on flow drivers, bathymetry and other physical conditions. This report looks at the resource within the Channel Islands area and contrasts the results from the new flux methodology, with the 1993 report based on the farm methodology.

Methodology

The accuracy and cost effectiveness of the method depends on the ready availability of data, which has already been validated and is generally accepted as being reasonably accurate. Pictorial data can be found from a variety of publications including bathymetry from British Geological Survey maps and tidal stream vectors from the Admiralty Tidal Stream Atlas.

For the Channel Islands study, bathymetry data was used from BGS Sheet 49N 04W (Guernsey) [1], Admiralty Chart 2669, and tidal stream data was taken from Admiralty Tidal Stream Atlas NP264 (Channel Islands) [2]

Bathymetry

The bathymetry image is stripped of all information not required by the programme, leaving only contour lines and landmasses identified. The bathymetry is defined using individual colours for each of the bathymetric contours and for the landmasses, leaving the spaces in between as unknowns. The programme then scans the picture and generates an array of numerical contour values from the colour found at each vertex, using a linear interpolation algorithm to produce values for the vertices where no colour is identified.

Tidal stream data

In a tidal stream atlas the vectors are usually scaled in groups according to the strength of the flow that they represent and the programme allows for this by providing a vector scaling capability. For the Channel Islands however, this is not the case, and each vector has to be individually specified. The effects of flow momentum between the head of one vector and the tail of preceding vectors can also be modelled according to the strength of flow. The vector field (Fig.1) is input by overlaying the relevant tidal stream vector image over the bathymetric contour image and using the mouse click event to indicate the start and end points of each vector. These start and end points, along with variables indicating the strength of flow and momentum effects, are stored in a list box to be processed later in the programme. Outlines of landmasses are used to check the alignment of the vector map when overlaid onto the bathymetry graphic using the Visual Basic overlay command. Any land mass is given a zero vector value and boundary conditions for the graphics' edge are found by using an average value of the nearest available vectors.

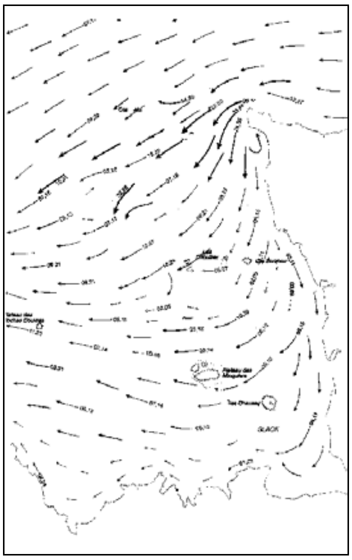

Figure 1 Tidal stream vectors for Channel Isles

The programme first identifies what information it has available to it by scanning the image, recognising any landmasses present, and imports the flow vectors from the listbox which holds the values defining the vector start and finish co-ordinates. The vector magnitude is then modified according to the user-defined variables describing the strength of flow and momentum effects. Before continuing, the known flow vectors and their associated momentum vectors, are drawn for approval and/or modification by the user. The programme then scans the picture, attaching known vector X and Y component values at each vertex, interpolating for any missing values and passing the results to an array, the coordinates of which coincides with the bathymetric coordinate system. The X and Y vector components are stored in separate arrays in order to reduce the number of string splitting and re-assembling operations. Once the interpolation process is complete, the vector components are smoothed by averaging over surrounding values to a maximum distance set by the user. Zero value vector components attached to landmasses are reasserted at this point to prevent the algorithmic erosion of the coastlines.

The vectors are assembled and their magnitude and direction (in degrees) are written to a final array for visual interpretation, printing to file etc. The image is then redrawn using the vector magnitude to govern the colour used in the image i.e. white (RGB(255,255,255)) indicates <0.05m/s flow and black(RGB(0,0,0)) indicates a flow speed in excess of 6m/s. (see fig.2 overleaf)

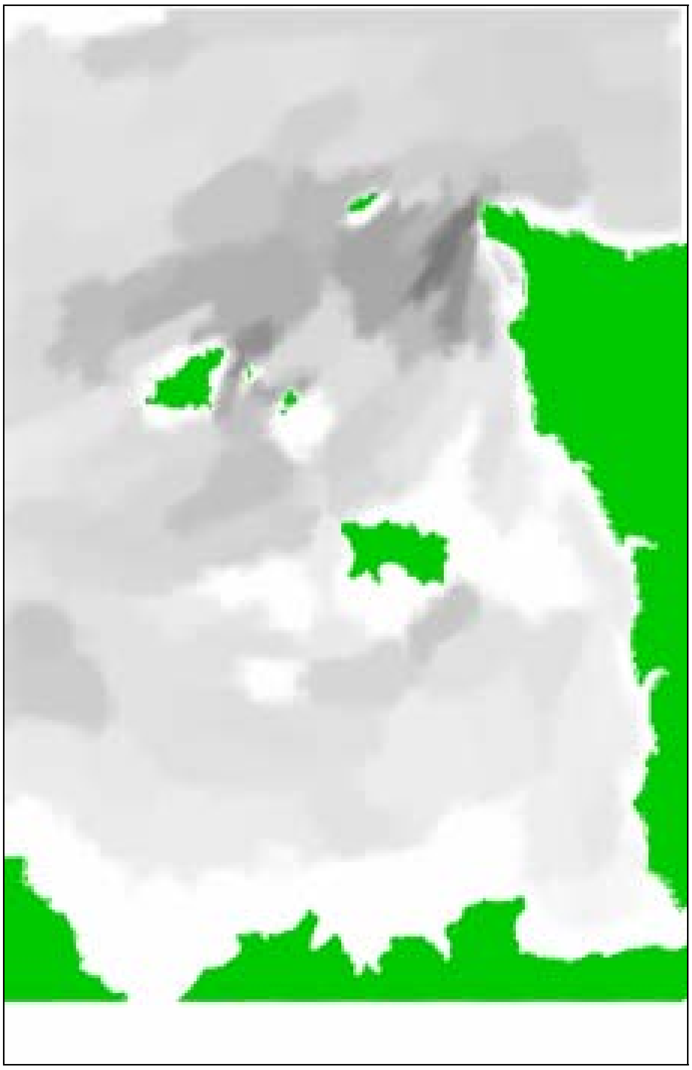

Figure 2 Greyscale flow map through Channel Isles

Combining Bathymetry and Flow Vectors

At this point, there exists a number of arrays holding information on flow speed and flow direction for each 1 hour period of the flow/ebb cycle as well as the bathymetry and land masses, all of which use the same X, Y co-ordinate system. Therefore at any given vertex (or vertices) linked information can be utilised. For example, if the surface velocity is known, and assuming that the surface flow is indicative of the flow profile, a reasonably representative flow profile can be obtained using the $1/7^{th}$ power law. Applying the power law to describe the flow profile with respect to depth, the programme creates a quasi-3D velocity matrix, which can be queried for a variety of data. For example, the data can provide information on the energy flux through any chosen cross section on the image or calculate the CSA of the flow at any point.

Time series interpolation

In this study, the data files for each one-hour interval are read into the program and assembled into a three-dimensional array. By extracting the data at any chosen section, a 13-point, approximately 1-hour interval, time series is found for the tidal stream velocities at that section, (in actual fact the flow/ebb cycle is generally taken as being 12.5 hours). Application of a second order Lagrange interpolating polynomial generates intermediate values at quarter hour intervals. Similarly, for the 14-day Spring/Neap cycle, tide tables provide twice daily high water and low water values for a nearby port that can be used to model the cyclical variation of the tidal stream velocities at the point. Taking the difference between the HW and LW heights and normalising for the Spring peak, gives a factor which, when applied to the Spring values used by the program, models the Spring/Neap cycle from Spring values only.
Between each vertex in the cross section, which on the scale used, represents a distance of 210m, the power is calculated as follows:-

The program has generated X and Y vector components at each vertex (*Xvect, Yvect*), from which, the velocity vector (V_{vel}) may be defined.

$$V_{vel} = \sqrt{(X_{vect}^2 + Y_{vect}^2)} \qquad \text{eqn 1}$$

The length of the section can be found from the start and finish X,Y co-ordinates,

$$L_{section} = \sqrt{(X_{start}^2 - X_{end}^2) + (Y_{start}^2 - Y_{end}^2)} \qquad \text{eqn 2}$$

The CSA (*A*) is defined by the scale width (210), the length of the section in terms of the graphics X,Y co-ordinates and the section depth (*D*) at the vertex, ie

$$A = 210 * D * L_{section} \qquad \text{eqn 3}$$

To obtain hourly power (Whr) figures through the section from ¼ hour intervals, eqn 4 is used for each ¼ hour interval and the sum taken of four consecutive intervals.

$$P = 0.5 * \rho * A * V_{vel}^3 \qquad \text{eqn 4}$$

The resulting hourly figures are summed for the 13 hr flood/ebb cycle giving a total power flux through the section in Whr per flood/ebb cycle.

$$P_{FE} = \sum_1^{13} P \qquad \text{eqn 5}$$

These power totals are then transferred to a spreadsheet where the equivalent velocity that would be required to generate that power in that period is calculated from the total power flux, ie

$$V_{eq} = \sqrt[3]{(P_{FE} / (0.5 * \rho * A)} \qquad \textit{eqn 6}$$

The ratio of high water to low water for a nearby port eg St Helier, provides a reasonable model for the Spring/Neap cycle. Normalising the ratio to the Spring maximum gives a factor (γ), which may be applied to the 14 day cycle. Using St Helier as a pattern, this factor can be calculated for each site from the Spring/Neap values in the Tidal Stream Atlas

Data taken from Tide Table St Helier, Jersey, 49.1667N,2.1000W

Spring/Neap ratio for site	2.26	1.88	1.97
HW limit for site (m)	11.24	11.24	11.24
LW as proportion of HW	0.442478	0.531915	0.507614
Low water limit for site (m)	4.973451	5.978723	5.705584
HW/LW range for site (m)	6.266549	5.261277	5.534416

St Helier HW-LW (m)	Normalised	CSEC1 (HW-LW, (m))	Normalised(γ)	CSEC2 (HW-LW, (m))	Normalised(γ)	CSEC3 (HW-LW, (m))	Normalised (γ)
8.69	0.773132	9.10	0.81	9.44	0.84	9.35	0.83
8.28	0.736655	8.75	0.78	9.15	0.81	9.04	0.80
7.73	0.687722	8.29	0.74	8.76	0.78	8.64	0.77
7.19	0.63968	7.84	0.70	8.38	0.75	8.24	0.73
6.47	0.575623	7.23	0.64	7.88	0.70	7.70	0.69
5.81	0.516904	6.68	0.59	7.41	0.66	7.21	0.64
5.04	0.448399	6.03	0.54	6.87	0.61	6.64	0.59
4.59	0.408363	5.65	0.50	6.55	0.58	6.31	0.56
4.29	0.381673	5.40	0.48	6.34	0.56	6.08	0.54
3.78	0.336299	4.97	0.44	5.98	0.53	5.71	0.51
4.14	0.368327	5.28	0.47	6.23	0.55	5.97	0.53
4.31	0.383452	5.42	0.48	6.35	0.57	6.10	0.54
5.42	0.482206	6.35	0.57	7.14	0.63	6.92	0.62
5.91	0.525801	6.76	0.60	7.48	0.67	7.29	0.65
7.25	0.645018	7.89	0.70	8.43	0.75	8.28	0.74
7.68	0.683274	8.25	0.73	8.73	0.78	8.60	0.77
9	0.800712	9.36	0.83	9.66	0.86	9.58	0.85
9.2	0.818505	9.53	0.85	9.80	0.87	9.73	0.87
10.35	0.920819	10.49	0.93	10.61	0.94	10.58	0.94
10.24	0.911032	10.40	0.93	10.53	0.94	10.50	0.93
11.12	0.989324	11.14	0.99	11.16	0.99	11.15	0.99
10.7	0.951957	10.79	0.96	10.86	0.97	10.84	0.96
11.24	1	11.24	1.00	11.24	1.00	11.24	1.00
10.58	0.941281	10.69	0.95	10.77	0.96	10.75	0.96
10.73	0.954626	10.81	0.96	10.88	0.97	10.86	0.97
9.92	0.882562	10.13	0.90	10.31	0.92	10.26	0.91
9.68	0.86121	9.93	0.88	10.14	0.90	10.08	0.90
8.84	0.786477	9.22	0.82	9.55	0.85	9.46	0.84

Table 1 HW/LW difference, normalised to spring peak
Ref: http://www.mobilegeographics.com:81/calendar/month/5470.html

Since the equivalent velocity V_{eq} represents the velocity required to generate the calculated power through any given section at Spring peak over a period of 13 hrs, variation of this velocity in proportion to the difference between high water and low water (Combined Normalised (γ) in table 1 above), will permit a reasonable approximation of the velocity variation with the Spring/Neap cycle (eqn 7). The resulting total, (P_{cycle}) multiplied by 26 will give an annual power output, (P_{annual}), at the section, based on the Spring peak V_{eq} for that section. (eqn 8).

$$P_{cycle} = \sum_{1}^{28} 0.5 * \rho * A * (\gamma * V_{eq})^3 \qquad \textit{eqn 7}$$

$$P_{annual} = P_{cycle} * 26 \text{ (GWhr)} \qquad \textit{eqn 8}$$

Whilst the method is clearly an approximation, it does accommodate the variations both within the flood/ebb cycle and the Spring/Neap cycle, based on 15 minute intervals.

Define Area & sections

For the purposes of this study, the general area to be examined is outlined by the lat/long co-ordinates, 48.500°N, 1.500°W to 50.000° N, 3.000° W (fig.3 overleaf). Six sites are identified, five of which were previously assessed in [3]. This methodology generates comparative data for these five sites.

The cross sections considered to be of interest for this study are illustrated in fig 3 overleaf and listed below:-

CSEC1: Guernsey (49.416°N, 2.633°W) to Pte de l'Arcouest (48.816°N, 3.000°W)
Broad cross section of medium speed flow.

CSEC2: Race of Alderney, (49.720°N, 2.14°W) to (49.705°N, 2.067°W) , compared with Site 16 – Race of Alderney, [3]

CSEC3: Big Russel, Guernsey (49.460°N, 2.445°W) to (49.440°N, 2.390°W)
Compared with Site 19 – Big Russel

CSEC4: North East Jersey, (49.250°N, 2.060°W) to (49.273°N, 2.040°W)
Compared with Site 20 – North East Jersey

CSEC5: Casquets, Channel Islands, (49.748°N, 2.398°W) to (49.811°N, 2.472°W)
Compared with site 17 – Casquets

CSEC6: NW Guernsey (49.602°N, 2.791°W) to (49.517°N, 2.700°W)
Compared with Site 18 - North West Guernsey

The Lat/Long co-ordinates are converted to X,Y co-ordinates in relation to the graphic. Note that for ease of manipulation the X,Y coordinates are aligned with the Visual Basic system, which denotes the origin (0,0) as top left.

	X	Y	Lat	Long	X	Y	Lat	Long
CSEC1	113	273	49.416	2.633	3	553	48.816	3
CSEC2	264	131	49.72	2.14	287	138	49.705	2.067
CSEC3	171	252	49.46	2.445	187	262	49.44	2.39
CSEC4	289	350	49.25	2.06	295	340	49.273	2.04
CSEC5	185	118	49.748	2.398	162	88	49.811	2.472
CSEC6	64	186	49.602	2.791	92	226	49.517	2.7

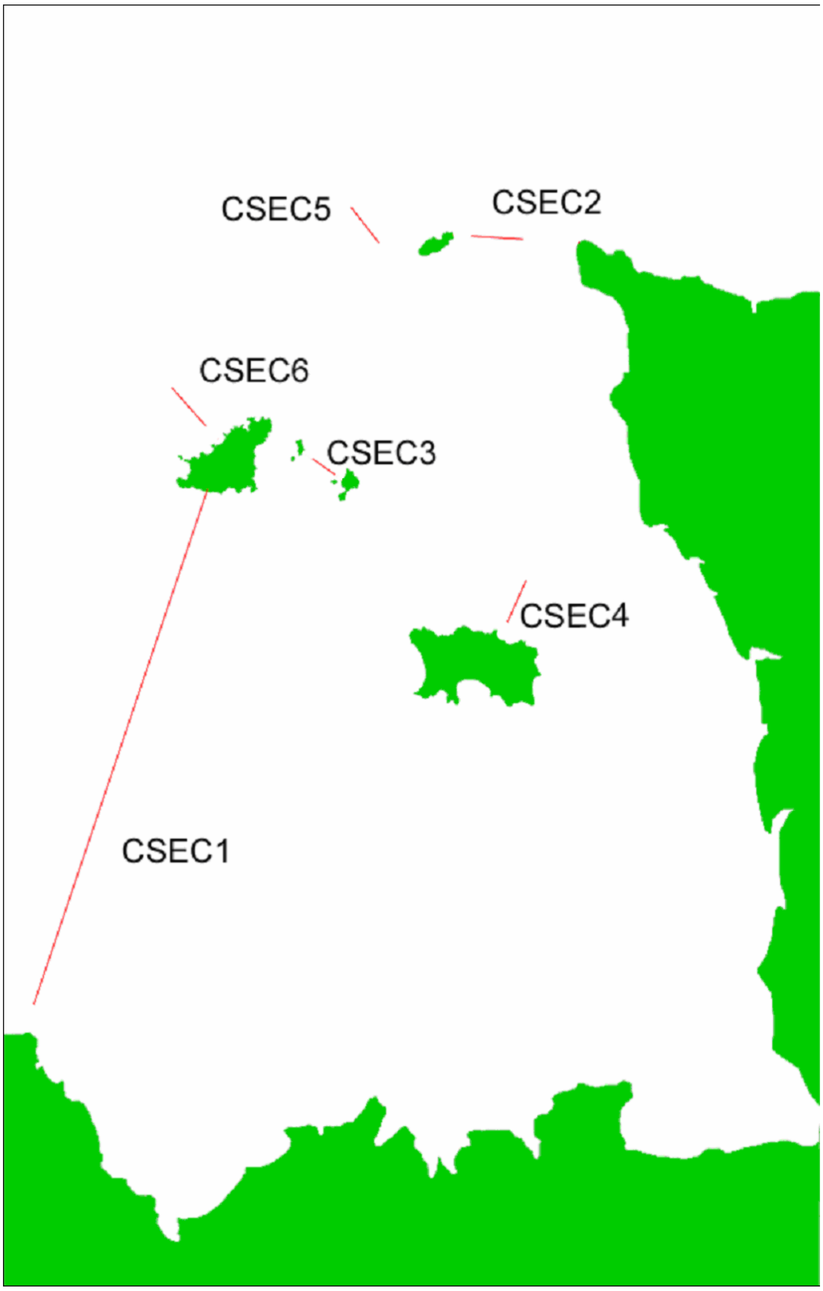

Figure 3
Approximate illustrative locations of the various sections.

The site graphic as used by the program measures 461(W) x 724(H), producing data at 333764 vertices with depths varying from 0m to 80m, in increments of 1m.
CSEC1 was chosen for its approximate perpendicularity to the average flow for the majority of the tidal cycle and because initial visual inspection suggested a phase difference would be found between this and CSEC2. The remaining sections were taken for the purposes of comparison with the 1993 report. [3]

Results

Model Validation

The model is run for each image combination representing 13 x 1hour (approx) intervals of the tidal cycle. The resulting greyscale image is then checked for correlation with the known values as given in the Tidal Stream Atlas. By clicking on the image, a text box shows the X,Y co-ordinates at the point and displays the vector speed and direction at that point. In previous work, (Pentland Firth and The Orkney Islands), the vectors are scaled to a reasonable level of accuracy. In the case of the Channel Islands, no scaling was inherent within the vector images and each image was tuned individually to a variation of +/- 5%. The section between Guernsey and Alderney was not included since, when viewed with the direction of flow, the CSA available for most of the tidal cycle is minimal. Also, in its present configuration, the methodology is not yet comparing flow direction with the relative direction of the chosen section, although this will be available in future versions. The methodology examines the flux at the boundary, regardless of direction, and assumes that any energy extraction method would be capable of aligning itself with the prevailing flow.

The AVI file below shows the flux represented in greyscale over the 13 hour period at 1 hour intervals.

Results

The output from the software is collated into tables (see appendix), which provides numerical values for the Channel Islands tidal resource. Figures shown in brackets refer to those available in the 1993 report.

CSEC1: Guernsey (49.416°N, 2.633°W) to Pte de l'Arcouest (48.816°N, 3.000°W)

The site covers a broad spread of variable speed flow between the north coast of France and the south coast of Guernsey, and is primarily driven by the head difference between the Baie du Mont Saint Michel and the English Channel.

Bathymetry

The maximum depth is found as 60m, which correlates well with Chart 2669. Average depth is 53m and the width of the section is 63210m

Velocities

Peak flow speed across this section is given as 2.09m/s at +4hrs(HW, Dover) by the program, which compares with 2.15m/s at +4hrs(HW, Dover) shown in the Tidal Stream Atlas. Peak spring/neap ratio is 2.26.

Resource

Total flux across the section is 8491 GWhr/yr. If a 20% SIF is assumed, this suggests an available resource of 1698 GWhr/yr. Annual power as a function of CSA is 2.75 $MWhr/m^2$

CSEC2: Race of Alderney, (49.720°N, 2.14°W) to (49.705°N, 2.067°W) , compared with Site 16 – Race of Alderney, [3]

Bathymetry

The maximum depth is found as 46m, which correlates reasonably well with Chart 2669 giving a spot depth of 42m. Average depth is 40.1m and the width of the section is 4936m

Velocities

Peak flow speed across this section is given as 4.5 m/s (4.4m/s) at -3hrs(HW, Dover) by the program, which compares with 4.4 m/s at -3hrs(HW, Dover) or 4.8 m/s at -4hrs (HW, Dover) shown in the Tidal Stream Atlas. Peak spring/neap ratio is 1.88 (1.82).

Resource

Total flux across the section is 3628 GWhr/yr. If a 20% SIF is assumed, this suggests an available resource of 726 Whr/yr (5187 GWhr/yr). Annual power as a function of CSA is 18.3 $MWhr/m^2$

CSEC3: Big Russel, Guernsey (49.460°N, 2.445°W) to (49.440°N, 2.390°W)

Compared with Site 19 – Big Russel

Bathymetry

The maximum depth is found as 36.6m, which correlates well with Chart 2669 giving a maximum spot depth of 37m. Average depth is 24.5m and the width of the section is 4056m

Velocities

Peak flow speed across this section is given as 2.6 m/s (2.8m/s) at -5hrs(HW, Dover) by the program, which compares with 2.6 m/s at -5hrs(HW, Dover) shown in the Tidal Stream Atlas. Peak spring/neap ratio is 1.97 (n/a).

Resource

Total flux across the section is 822 GWhr/yr. If a 20% SIF is assumed, this suggests an available resource of 164 GWhr/yr (2000 GWhr/yr). Annual power as a function of CSA is 8.3 $MWhr/m^2$

CSEC4: North East Jersey, (49.250°N, 2.060°W) to (49.273°N, 2.040°W)

Compared with Site 20 – North East Jersey

Bathymetry

The maximum depth is found as 20m, which correlates well with Chart 2669 giving a maximum spot depth of 23m. Average depth is 20m and the width of the section is 2599m

Velocities

Peak flow speed across this section is given as 2.6 m/s (3.1m/s) at +4hrs(HW, Dover) by the program, which compares with 2.6 m/s at +4hrs(HW, Dover) shown in the Tidal Stream Atlas. Peak spring/neap ratio is 1.8. (1.8)

Resource

Total flux across the section is 282 GWhr/yr . If a 20% SIF is assumed, this suggests an available resource of 56 GWhr/yr (1403 GWhr/yr). Annual power as a function of CSA is 5.43 $MWhr/m^2$

CSEC5: Casquets, Channel Islands, (49.748°N, 2.398°W) to (49.811°N, 2.472°W)

Compared with site 17 – Casquets

Bathymetry

The maximum depth is found as 71.6m, which correlates reasonably well with Chart 2669 giving a maximum spot depth of 79m. Average depth is 70.1m and the width of the section is 7810m.

Velocities

Peak flow speed across this section is given as 2.4 m/s (2.6m/s) at -4hrs(HW, Dover) by the program, though there is no immediate figure shown in the Tidal Stream Atlas, the closest suggests 1.95m/s at –3hrs(HW, Dover). Likewise, peak spring/neap ratio is approximately 1.8. (1.85)

Resource

Total flux across the section is 2933 GWhr/yr. If a 20% SIF is assumed, this suggests an available resource of 587 GWhr/yr (2943 GWhr/yr). Annual power as a function of CSA is 5.36 $MWhr/m^2$

CSEC6: NW Guernsey (49.602°N, 2.791°W) to (49.517°N, 2.700°W)

Compared with Site 18 - North West Guernsey

Bathymetry

The maximum depth is found as 70m, which correlates well with Chart 2669 giving a maximum spot depth of 65m. Average depth is 69.7m and the width of the section is 10199m.

Velocities

Peak flow speed across this section is given as 2.1 m/s (2.1m/s) at +2hrs(HW, Dover) by the program, which compares with 2.05 m/s at +2hrs(HW, Dover) shown in the Tidal Stream Atlas. Peak spring/neap ratio is 2.6. (1.85)

Resource

Total flux across the section is 2530 GWhr/yr. If a 20% SIF is assumed, this suggests an available resource of 506 GWhr/yr (4402 GWhr/yr). Annual power as a function of CSA is 3.56 $MWhr/m^2$

Discussion

The program output generally achieves a high degree of correlation with the Tidal Stream Atlas, and the bathymetry and flow dimensions of the 1993 report. Whilst the 1993 report mentions installed capacity and resulting output, it is likely that the 1993 report assumed a much higher level of installed capacity than would be considered now.

It is apparent from the Tidal Stream Atlas that the Channel Islands area partially behaves in a manner analogous to a sea loch, in that the flow is forced towards the Baie du Mont Saint Michel where it is held by the tide rising in the English Channel. Some of the flow which passes through CSEC2 is from the periphery of the English Channel flow at +6,–6,-5, +1,+2,(hrs relative to HW @ Dover) whilst at –4,-3,-2,-1,HW,+3,+4,+5,+6, the site is filling and draining with a change in head, rather than running as a channelled flow. It is therefore very likely that the proposed SIF of approximately 20% may be different for the sites within this area. Extraction of energy from this area would impact on the performance of the barrage at La Rance, since energy extraction would change the head available at the barrage site.

The overall spring/neap ratio is not constant for the sites within the area, varying from 2.94 at HW Dover, to 1.76 at +5Hrs(HW, Dover). The Race of Alderney (CSEC2) provides the best power availability per m^2, with an annual average of 18.31 $MWhr/m^2$.

This study models the power available at each site when considered individually, but CSEC2 and CSEC3 are interdependent as are CSEC5 and CSEC6. Their interdependency varies through the flood/ebb cycle, i.e. for both pairs of sites, no interdependency exists at HW-2 and HW-1, when there is little flow present through either, but major interdependency exists at HW-5 and HW-4, when there are large flows through both.

Further modelling is required to establish the true power resource for the Channel Islands, but a reasonable approximation is of the order of 1.5 – 2.5 TWhr/yr, assuming an SIF of 20%. The model itself appears to obtain reasonably accurate flow velocities but requires a more flexible algorithm for interpolating the bathymetry.

Conclusions

The graphical flux method is relatively quick to produce results but relies entirely on the accuracy of the original data. However, the data employed is as measured by the Hydrographic Office rather than produced by theoretical equations as used in more sophisticated CFD packages. The correlation with the measured data on the vector graphics is generally of the order of +/- 5% and therefore is considered to be a reasonable reflection of the flow as mapped. It is not possible to take into account any shear flows at depth, and these would need to be determined by site measurements.

The Channel Islands area appears to offer a usable resource of 1.5 – 2.5 TWhr/yr based on the proposed SIF of 20%, but exploitation at one site will have an effect on neighbouring or downstream sites. Exploitation on any commercial scale will affect the HW/LW cycle at the existing tidal barrage site at La Rance. More accurate modelling of the effects of energy extraction on the head is required to quantify this effect. This study has excluded the area between Alderney and Guernsey, since the energy extracted at this point would largely be available at the other sites.

References

1. BGS Map, Guernsey Sheet 49N 04W, Scale 1:250000, NERC
2. Admiralty Tidal Stream Atlas NP264 (Channel Islands) 1993, ISBN 0707712645
3. ETSU Tidal Stream Energy Review, Report T/05/00155/REP, 1993

Appendix 4 – RGU Tidal flow visualisation for the Channel Islands

This is a video file (.avi) and has been delivered separately.