Centre for Understanding Sustainability in Practice

Tidal Resource Mapping for the Territorial Waters of Guernsey

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Contents

Abstract

This paper demonstrates a methodology for assessing the tidal flows around the Island of Guernsey using readily available data and a matrix method for assembling velocity vectors (X,Y) within a Microsoft VB.NET graphical user interface (GUI). The data are taken from UKHO charts, Admiralty Tidal Stream Atlas and locally created anecdotal sketches provided by Guernsey Renewable Energy Team (GRET). The UKHO chart is scanned and depth contours/spot depths are converted to coloured lines and points. The GUI then scans the figure and converts each colour to a numerical value, interpolates between known values and creates a 3D mesh of the bathymetry. The mesh generates vertices at 50m intervals which is a considerable improvement on the 5-10km of many CFD models. Flow vector data are drawn in as lines directionally aligned and proportional to the flow speed, and tidal diamond data are provided as .csv files for use as look-up tables at the appropriate stage in the tidal cycle. The model then uses established numerical relaxation techniques to work from known point to known point until the desired relaxation accuracy ($^{+}/_{-}$ 0.01m/s) is achieved; this process takes around 2 hours to converge on a 32-bit MS Windows XP machine.

The subsequent outputs are plotted as coloured vectors indicating flow speed and direction for 13 x 1 hourly intervals. The resulting matrices are then used to plot the effectiveness of different existing tidal turbines based on their cut-in speed, rated output and depth installation limitations.

The model is validated against measured data taken by Guernsey Electricity Ltd (GEL) using Acoustic Doppler Current Profilers (ADCP) and produces a good fit with the shape and a reasonable fit with the magnitude, though its noted that the ADCP data disagrees with the tidal diamond data taken from the relevant chart.

The model gives a good general agreement with available printed and historical data.

Model Constraints

The model utilise input data from a variety of sources (see page 4) and is constrained by the accuracy of those sources. The limitations of the Admiralty Tidal Stream Atlas and Diamond data are discussed in [1] and the method for using anecdotal sketches is given on page 5. The model iterates to vertices of 50m using a relaxation technique, thus assuming conservation of mass flow and a linear rate of velocity change from one point to the next.

Introduction

The Channel Isles has long been recognised as a significant area for tidal current energy and attracts considerable developer interest. Due to their particular relationship with the UK, the individual island communities hold ownership of their territorial limits to 3 miles but not to the seabed, which allows each island to negotiate the use of its territorial resources according to its own systems of governance.

This idiosyncratic situation makes the region attractive for developers as there is the potential for faster, less complex licensing procedures than currently exist for the UK mainland. The difficulty that is faced by individual island communities, including Guernsey and Sark, is one of knowing where the best tidal current resource is and how to optimise the licensing procedure, whilst remaining attractive to incoming investment.

This report details the methodology employed in assessing the Guernsey tidal current resource location, magnitude, sensitivity to device depth and cut-in speeds, and possible landfall for power transmission. Some information on Sark is also offered though further work is required to fully detail Sark's resource.

The process is based on a completely rewritten and updated version of a software algorithm originally developed and used to quantify the tidal current resource for the Channel Isles region [1]. The software is provided with a range of data in numerical or graphical format, depending on the source, and maps the data to the area of interest on a 2D Cartesian grid. Utilising the existing data, realistic 'guess' values are generated for areas where no data is available and the software then employs a central differences relaxation method to solve the matrix.

Source materials

The full range of source materials for -6 hours to +6 hours relative to St Helier are given in appendices.

Appendix 1: Admiralty tidal stream atlas [2]
Appendix 2: Admiralty tidal diamond data
Appendix 3: Local anecdotal tidal vector sketches

Charts

The Channel Isles is a well charted area and considerable detail is available, though much of the bathymetry is based on very old sounding data. Assuming that the initial work was reasonably accurate, the soundings over clean rock can be assumed to be unchanged, but the charts show areas of mud, sand, gravel etc and these are often mobile, though cyclic in their movements.

Tidal chart atlas

The tidal chart atlas covers the area of the Channel Isles group, but offers little detail at the scale required. Tidal current vectors are referenced to HW at Dover with corrections given for HW at St Helier and it is these latter vectors that are used.

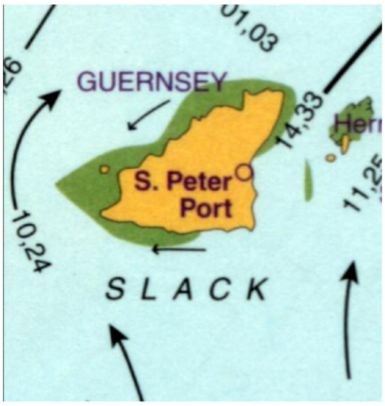


Figure 1: Excerpt from Admiralty Tidal Stream Atlas © 1993

Garmin

Garmin Mapsource ® software offers a digital chart system of the Guernsey area and is an excellent source of bathymetric data.

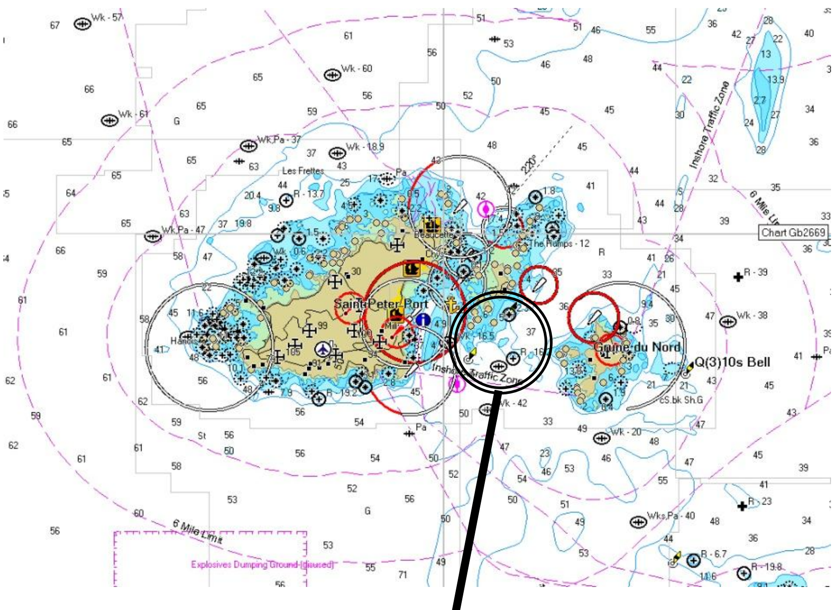


Figure 2: Area of interest from the Garmin Mapsource® software

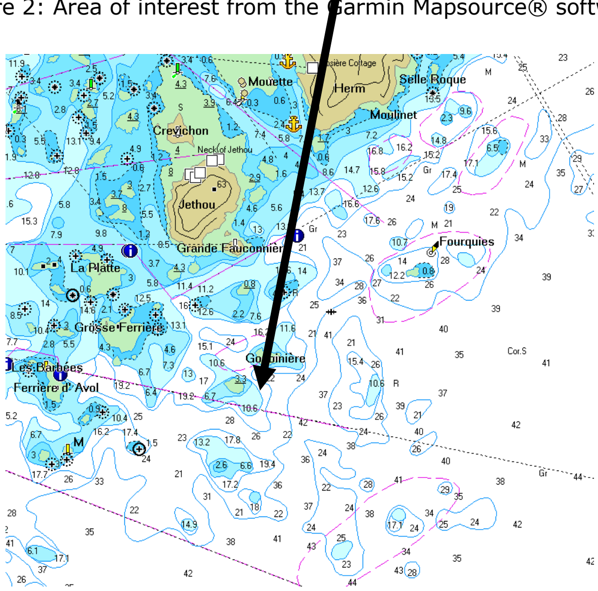


Figure 3: Detail of the Big Russel off the southern tip of Herm.

Admiralty Total Tide

The Admiralty TotalTide® software offers a digitised version of the tidal diamond data supplied on paper charts, in this case referenced to St Helier. Figure 4 shows the relevant area and the location of the 13 tidal diamonds used to provide data for this work. Interestingly, there are combinations of times and locations where the Admiralty tidal stream atlas offers significantly different values than the Admiralty TotalTide software package.

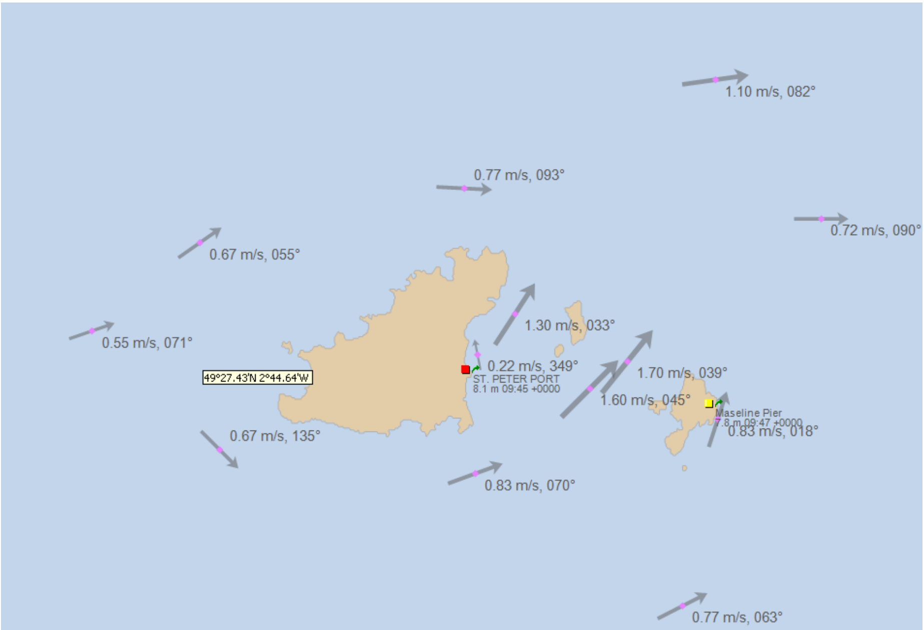


Figure 4: Area of interest from the Admiralty TotalTide® software

Anecdotal sketches

A set of locally produced vector sketches were provided and these introduce a level of detail not available from official publications covering the tidal currents in this region. Figure 5 shows the same time interval as Figure 1.

Figure 5: Anecdotal sketch of tidal current vectors around Guernsey

Assessment of source material

The level of detail required to give reasonable indications of flows at approximately 50m vertices challenges the interpretation of the source material. The Admiralty Tidal Stream Atlas is very general at this scale but can be used to form the foundations of the sense of the flow. The bathymetric data give reasonable framing of where the best flows are likely to be and the apparent scoured trench off the SE coast of Guernsey suggests that the flows are, or may have been, aggressive through this area. This appearance of a scoured trench is misleading; the deepest part of the 'trench' is no deeper than the seabed it relates to at its southern, northern and eastern edges. It is the presence of the Great Bank that is the anomalous feature.

Bathymetry

As well as dictating the depth of water available for installations, the bathymetry exercises considerable influence over the quality of the flow. Peaks and troughs will superimpose multidirectional flows onto the mean flow and may need to be taken into consideration in any assessment of power quality and equipment service life.

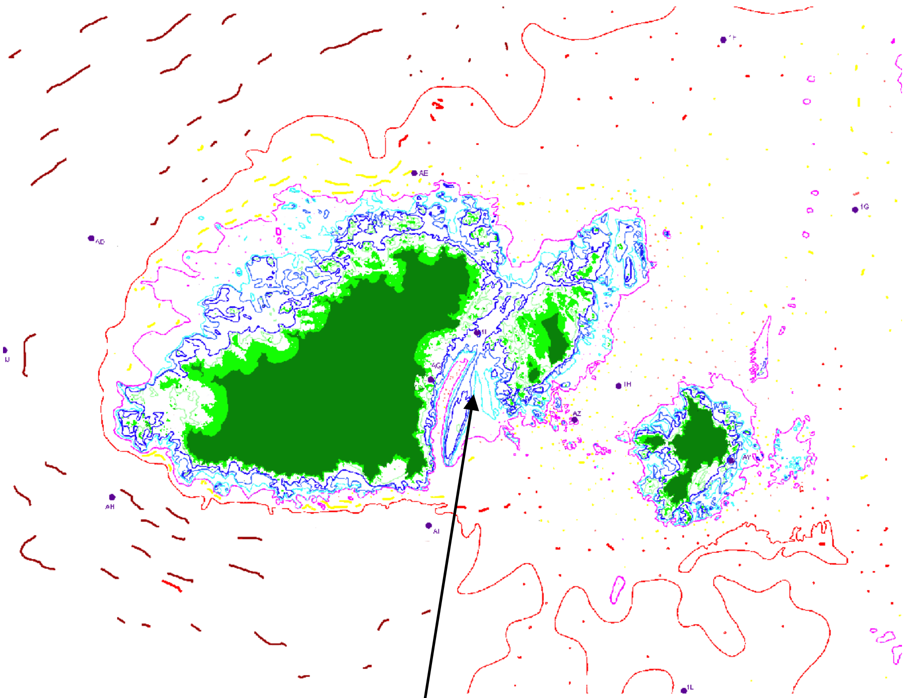


Figure 6: Bathymetric data in graphic format presented to the algorithm

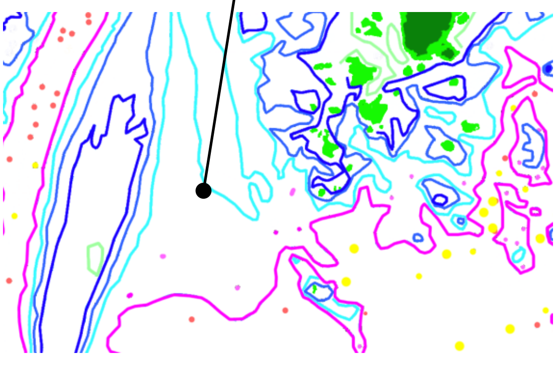


Figure 7: Detail section of main graphic

The bathymetric graphic is generated by hand from over 60 individual map segments and the original work is a 200MB file, which if printed a full scale would be 2.8m X 2.8m.

Incorporating the available chart data at this scale ensures that as much data as possible is included in the final graphic. The graphic is bicubicly re-sampled for subsequent processing by the algorithm, but still measures 870 x 680 pixels, giving a full scale grid resolution of 44.33m.

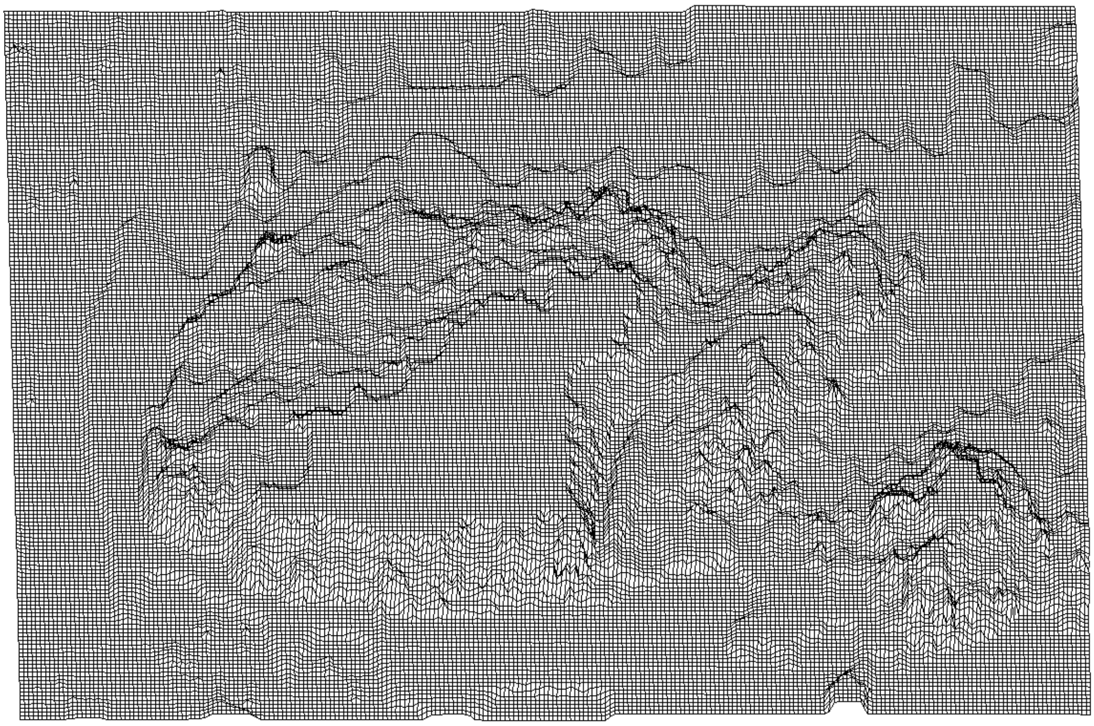


Figure 8: Bathymetric data as read and interpolated by the algorithm

To verify that the algorithm used is generating an acceptable solution, the X,Y,Z co-ordinates are input into a CAD programme and the resulting 3D mesh is checked against the 2D bathymetry on charts and other sources. Figure 8 shows the output, vertically exaggerated by 50% to highlight the principal shapes. The shape of Guernsey is easily visible along with the smaller islands of Herm and Sark. Of particular interest is the channel due east of Guernsey, thought to be created by the scouring effects of the flow between Guernsey and Herm. Additionally, the bathymetry to the north west of Guernsey is clearly very rough, whilst that between Herm and Sark is much flatter.

The present work does not dynamically calculate the water depth above chart datum due to tidal range, but instead assumes the mid-range point as an average addition to chart datum depths. Admiralty and Chart data indicate this mean should be around 5.4m

Tidal Streams

The official data available do not illustrate the flows around Guernsey in sufficient detail to give any particular insights into the likely most energetic locations, other than general indications to the nearest 5-10km. The anecdotal sketches show a potentially very important level of detail, but are roughly drawn and the vectors are not scaled in terms of velocity.

It was necessary to establish what level of accuracy, if any, can be attributed to these sketches and a method was devised to attempt this.

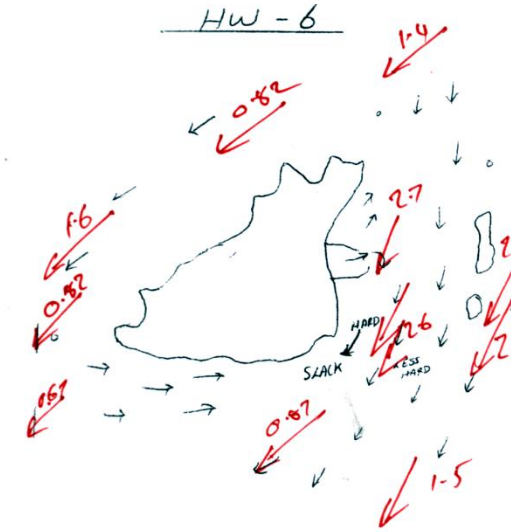


Figure 9: Comparison of sketch vectors with tidal diamond vectors (red)

The sketches cover an area that includes 12 of the 13 tidal diamonds used to calculate the flow vectors, and the hourly intervals noted on the sketches are assumed to refer to St Helier.
By sketching the data from the tidal diamond locations on to the sketch from the appropriate time, the information on the sketches is found to have a high level of compatibility with the official data. Of the 144 time/location combinations, only 6 are found to be at any significant level of disagreement in terms of direction, but there is little help in terms of flow speed.
The most comprehensive result will come from the combination of tidal atlas, tidal diamonds and anecdotal flow sketches; the difficulty is in combining them into a statistically meaningful whole. Since the sketches give good agreement directionally, it can be assumed that they are providing a useful input, but the challenge is how to use the direction without knowing the speed. The algorithm used to interpolate the vectors uses X and Y component vectors which require knowledge of both speed and direction to formulate; otherwise it is a zero vector.

Inputs

The algorithm has been largely rewritten using established texts ([3]) to accommodate the range of data sources and the type of vector information that can be deduced from them. The anecdotal sketches are accepted as being directionally consistent with known data at the tidal diamond locations, and the Admiralty Tidal Stream Atlas (ATSA) can be used to provide directional boundary conditions. However, at the scale desired, neither can be usefully relied upon to offer velocity magnitude data.
The tidal diamond data is read from a .csv file generated from Admiralty Total Tide software chronologically referenced (as is all data used in this report) to HW at St Helier. This data is assumed to be 'correct' and remains fixed throughout the finite differences routine. The anecdotal sketches and the ATSA data are stored as vector components assuming that these comprise a unit vector. This allows the vector direction to be fixed whilst allowing the finite differences approach to vary the vector magnitude to fit the known data. The resulting 850x650 matrix contains

about 15%-20% known data (including land). An interpolative approach[4], requiring at least two neighbouring point values, is taken to establish realistic guess values for the remaining unknown data points. A number of different computational molecules are used to check for and smooth out any unrealistic values present.

Data generation

A central differences algorithm ([5]) is used to relax the vector mesh across the areas that lack fixed information. The known velocities provided by tidal diamond data are used to seed the process and the directional data are used to maintain flow direction where applicable. The relaxation factor is adjusted according to the values of the four points around any given point. This adjustment affects the value of the next iteration. Once the relaxation factor is minimised and holds a reasonably steady state, it can be taken that the mesh is fully relaxed and a solution achieved.

Outputs

The outputs are in the form of coloured graphics with arrows indicating strength and direction of flows.

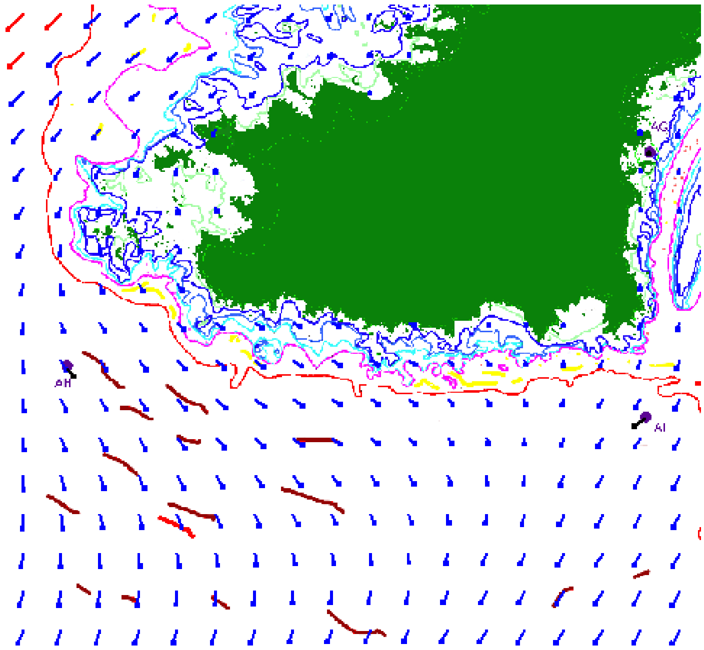


Figure 10: Vector graphic sample

It is easily seen where areas of contra flows and slow flows are present in what might be expected (from ATSA data) to be a fast moving stream.

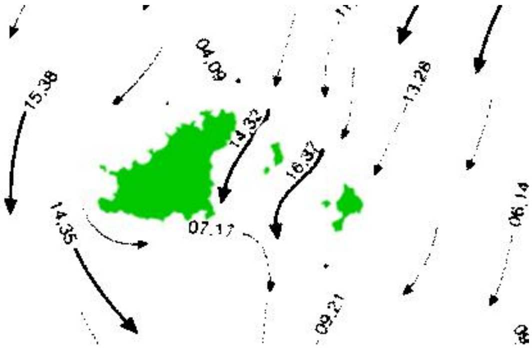


Figure 11: Corresponding ATSA data for Figure 10

Figure 11 shows the ATSA vectors suggesting that a strong flow is running southerly through the Little Russel, apparently being crossed by a weak flow heading east from south Guernsey

A further refinement (Figure 12) shows the use of colour to differentiate flow velocities, in this case, blue denotes flow below 1m/s, red denotes flows over 1m/s and the 13 black vectors denote the tidal diamond value at that point. This allows for the immediate visual check that the algorithm bears an appropriate relation to the source data.

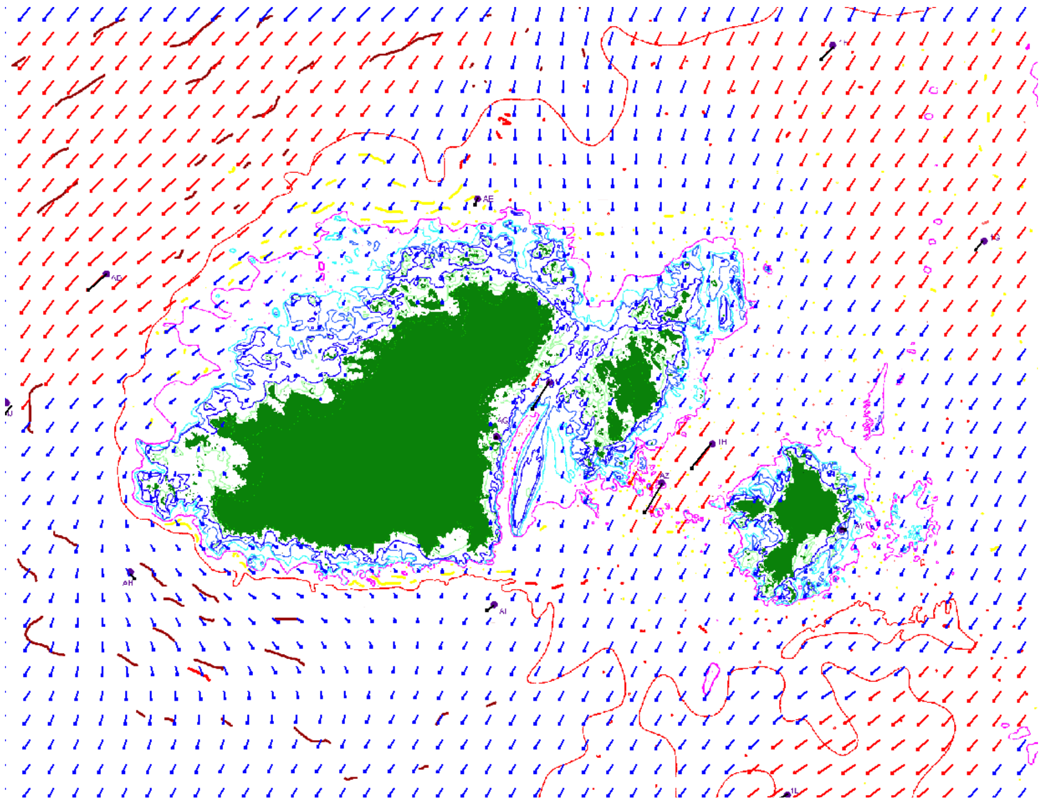


Figure 12: HW-6

The outputs are saved as .BMP files for visual examination and as vector components in .txt files for further automated analysis. Each 1hour dataset is expanded into 4 x ¼ hour datasets using a Lagrangian interpolation routine, giving 52 datasets for the 13 hours (approx) of the Spring HW/LW cycle. The average of the Spring/Neap HW/LW cycles across the area gives a two weekly variation of Neap tides being, on average, 32% of Spring tides.

Results

The raw results are in the form of .BMP graphics and very large .txt files and are therefore given in appendices. The highlights are utilised here for discussion purposes. For ease of classification the results will be discussed under three main headings;

- Raw Resource
- Technological Resource
- Economical Resource

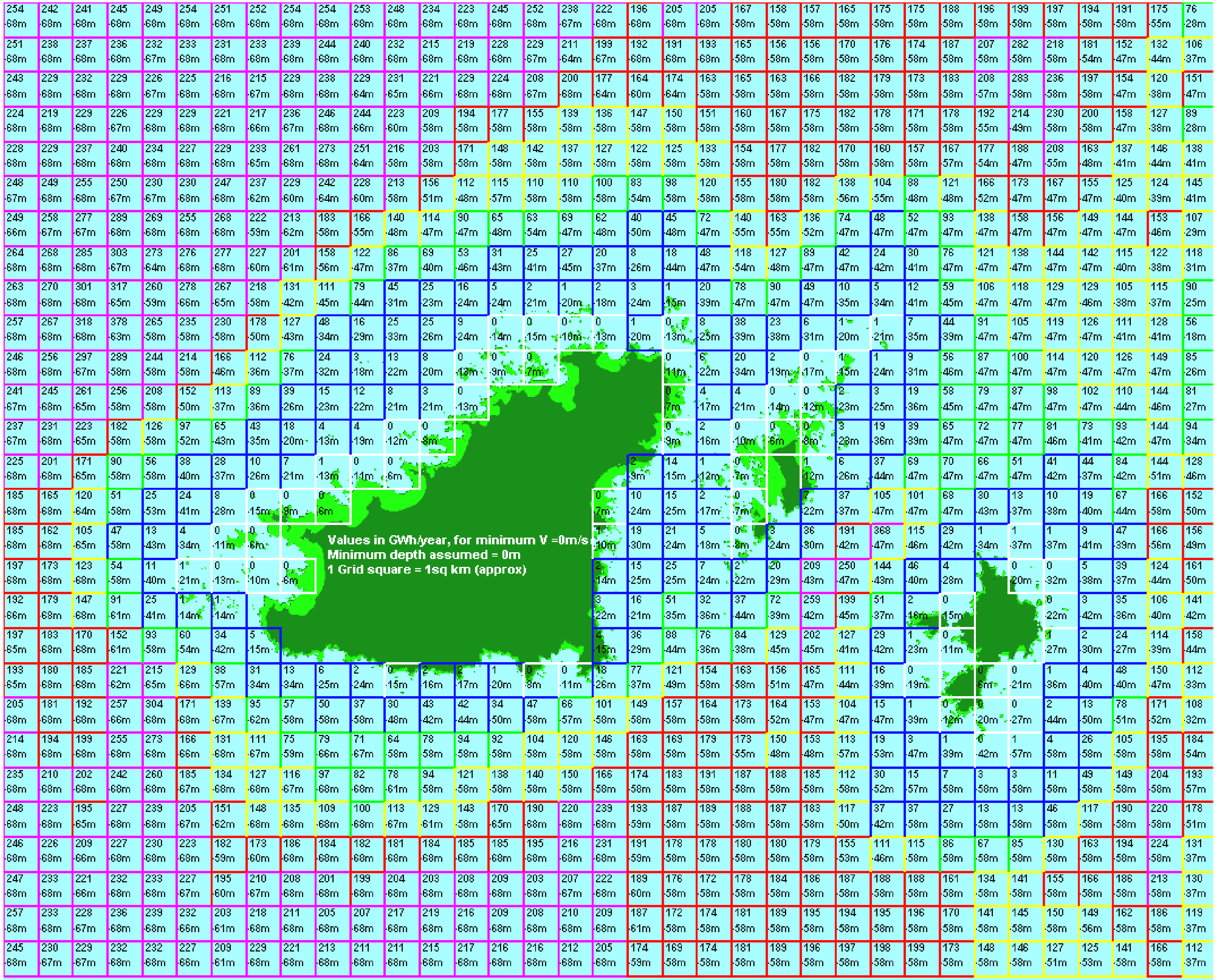
Raw resource

For the purposes of this report the raw resource is defined as any movement of water from which energy could potentially be taken regardless of whether or not that extraction is technologically or economically feasible either now or in the future. The raw resource per $1km^2$ is given in Figure 13. Each box represents $1km^2$ and shows the approximate raw annual energy passing through that volume in GWh per annum. The colour coding shows:-

- White- no resource of an significance
- Blue – < 50GWh/yr, some resource, usually close to land
- Green - < 100GWh/yr, usable but not substantial
- Yellow - < 150GWh/yr, substantial though not attractive for early consideration
- Red - < 200GWh/yr, very substantial
- Magenta- >200GWh/yr, very large, may not be first considerations

The raw resource passing through the Big Russel is around 700GWh/yr, which is of the same order of magnitude, though slightly more pessimistic than the 810GWh/yr given in (1).

Figure 13: Raw tidal current resource in Guernsey's waters



The area corresponding to CSEC6 (North West of Guernsey) in (1) shows a resource of approximately 2300 GWh/y compared to the earlier paper's estimate of 2530GWh/y

Technological Resource

The technological resource is that resource which can be exploited by existing or near-ready technologies within the constraints of flow velocities and installation depths applicable.

Assuming that for any device to be considered existing or near-ready, it must have been tested at an appropriate scale and at sea, then referring to the attached Technology Update file, the following devices are potentially applicable:-

Technology update

Marine Current Turbines – max depth -30m
Scotrenewables – buoyant, not depth restricted
Openhydro – 30m depth
Verdant Power – 30m depth
Blue Energy – Tidal fence support structure, not applicable to Guernsey site
Sea Power International – 30m depth
HammerfestStrom turbine, max depth -70m
Clean Current , max depth -50m,
Open Hydro, max depth -50m
GCK Technology, depth unknown, assume 50m

Devices requiring flow speeds 2m/s >:

Since there are no locations within the Guernsey region that combine a flow velocity >2m/s and depths of <30m, then only the Scotrenewable device is applicable out of this selection. The sites exploitable by this device are shown in Figure 14, and suggest a maximum accessible raw resource of 200GWh/y .

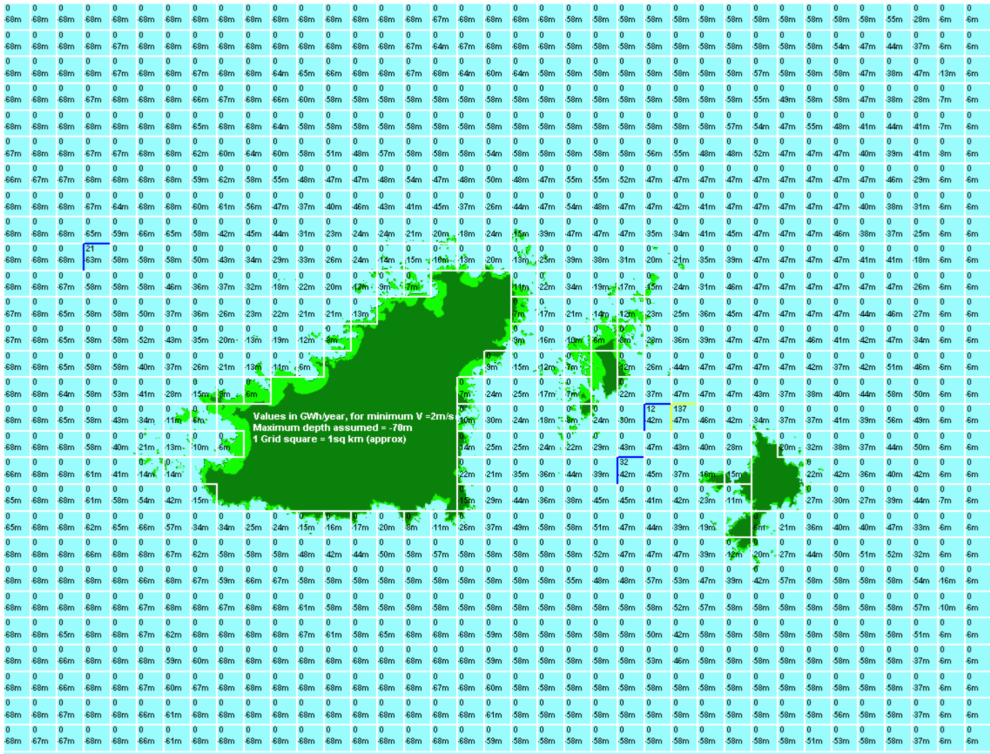


Figure 14: Sites available to Scotrenewables device.

Devices requiring flowspeeds < 2m/s

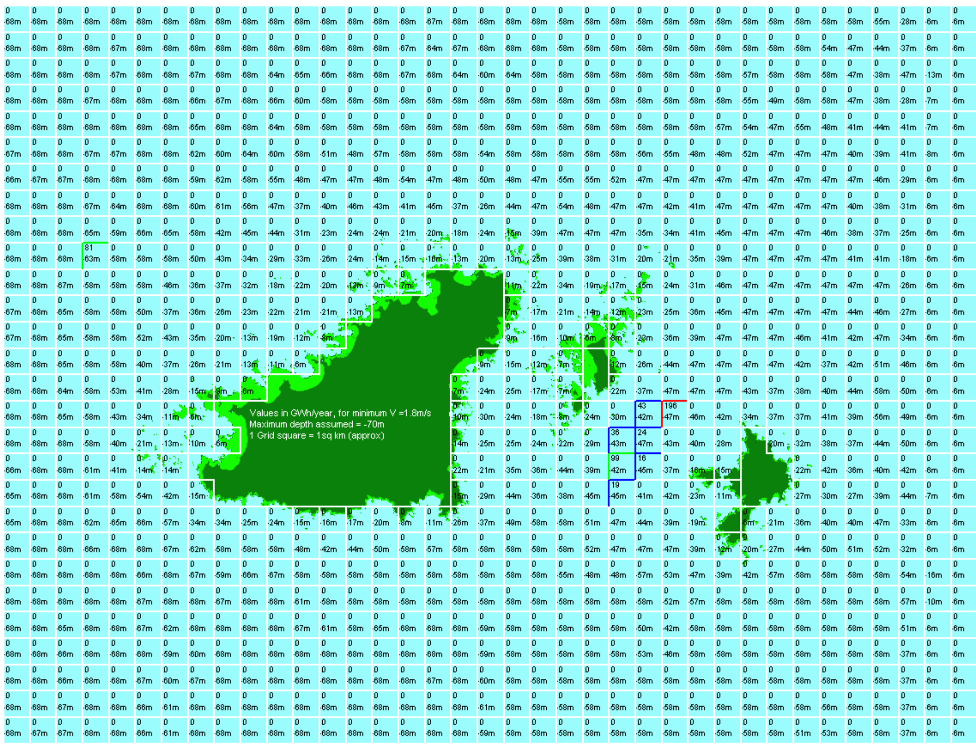


Figure 15: Areas likely to be applicable to Hammerfest Stroem device

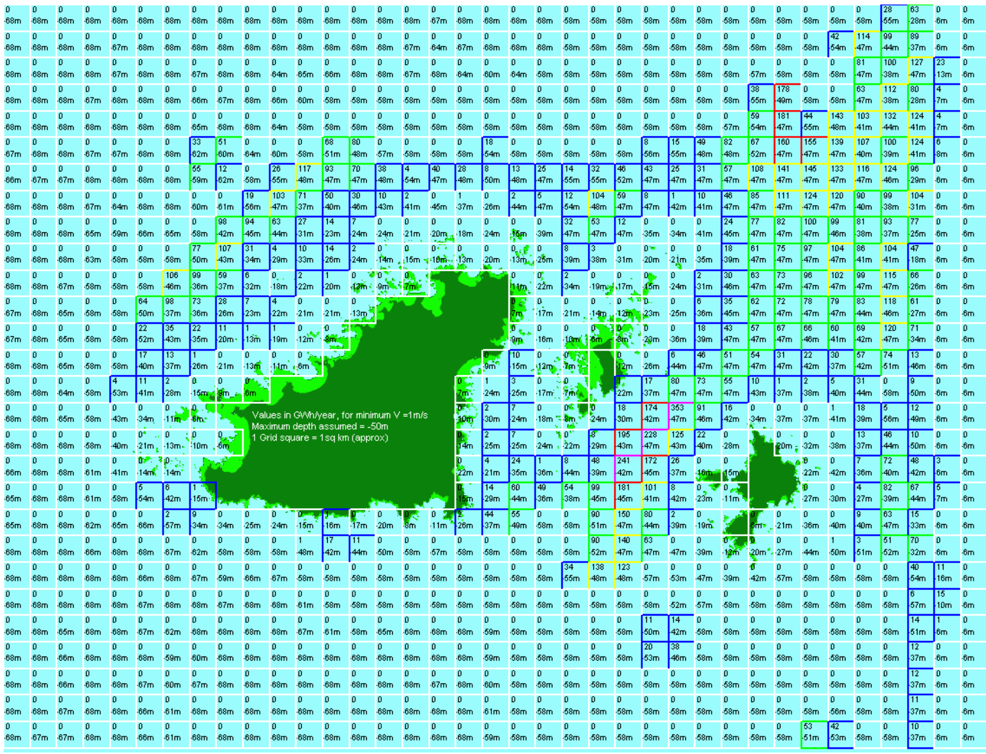


Figure 16: Areas likely to be applicable to a Clean Current device

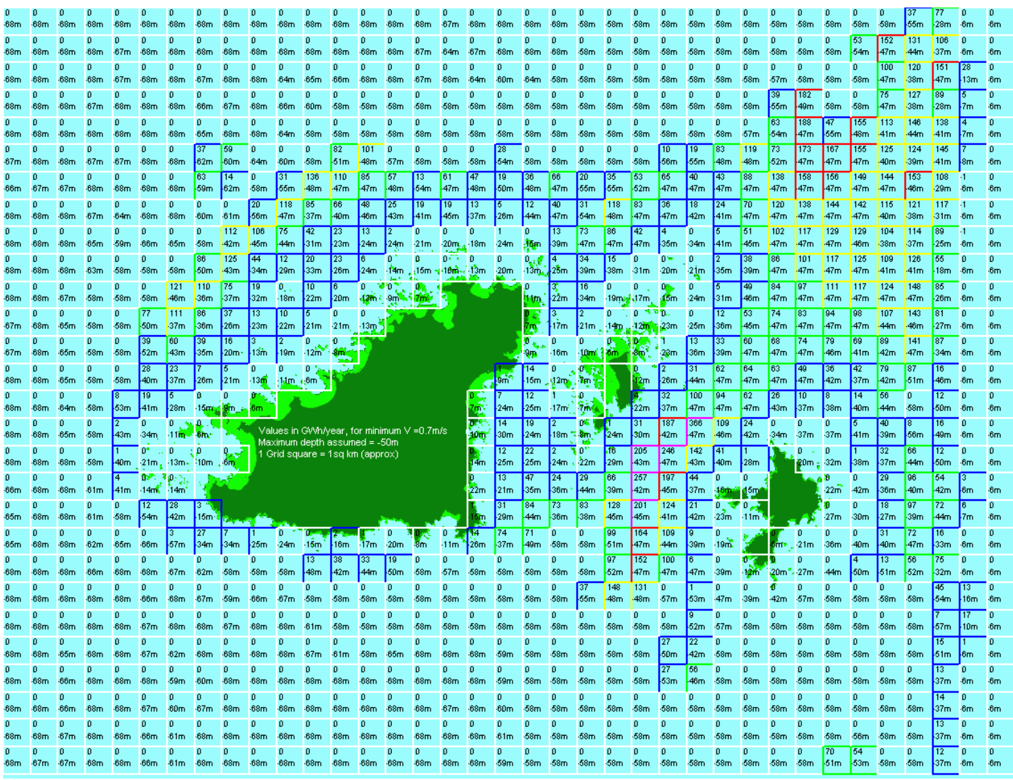


Figure 17: Areas likely to be applicable to a OpenHydro or GCK device

Clearly, the exploitable resource is highly technology sensitive and the sites in the Big Russel are the only ones available to certain devices, therefore making these sites more competitively valuable. Cut-in speed is more important than rated speed or rated output, and it is therefore necessary to obtain

- max/min installation depths,
- cut-in and rated generation speeds
- power curve

from each developer in order to be able to properly assess the technologically exploitable resource.

Economic Resource

The economic resource will require further developed knowledge of device cost, installation costs, servicing costs, cabling, feed-in-tarriffs, etc. Given the availability of further ADCP and other sampled data, it is anticipated that this work could contribute useful input into that process, by allowing the numerical assessment of the performance of different devices over a period of time. The model can accommodate, as has been shown, a variety of Cut-in and Cut-out speeds, installation depths etc and can therefore indicate the possible device deployment ranges.

Model Validation

Validation data for the model were made available in December 2011

Validation Data Sources

Validation data were provided by RET, sourced from ADCP measurement work commissioned by the Guernsey Electricity Limited. Two sites were given, identified as site 6 and site 9.

Site 6 –

Lat: 49-27-31, Long: 02-26-92, indicated by green arrow in Figure 18.

Figure 18: Site 6- Lat: 49 27.31, Long: 02 26.92

For this site the water depth from chart is given as 20m-30m, whilst the water depth from the ADCP deployment record is 35m and the water depth from the numerical model is 32m
According to the deployment log, the ADCP was deployed on 19th December 2009 at 1535 hours, (due south of Herm and to the west of the Fourquies buoy position) in 35m water and retrieved on 25th January 2010. The exact make and model is not given but it is believed to be an Aquadopp Profiler. The bin size is given as 2m, sample interval is 10 minutes and averaging interval is 60 seconds.

The 5414 lines of data for each velocity component of the 20 bins is imported into an Excel spreadsheet, representing just over 902 hours of continuous recording. Plotting the directionless velocity, the early phase of the ADCP operation appears to generate anomalous data for approximately 28 hours, as shown in Figure 19 centred around 2m/s +/- 0.5m/s. The reason for this is unknown, but this section of the data is removed for the purposes of subsequent analyses.

The data recorded after this initial phase follow the expected undulating pattern of tidal current flow velocities, driven by the Spring/Neap cycle and influenced by local topographical and bathymetric features.
For each bin at any given depth the ADCP generates flow components in the North, East and Up directions and the directionless velocity (U) is found using eqn. 1 below,

$$U = \sqrt{x^2+y^2+z^2} \qquad \text{eqn. 1}$$

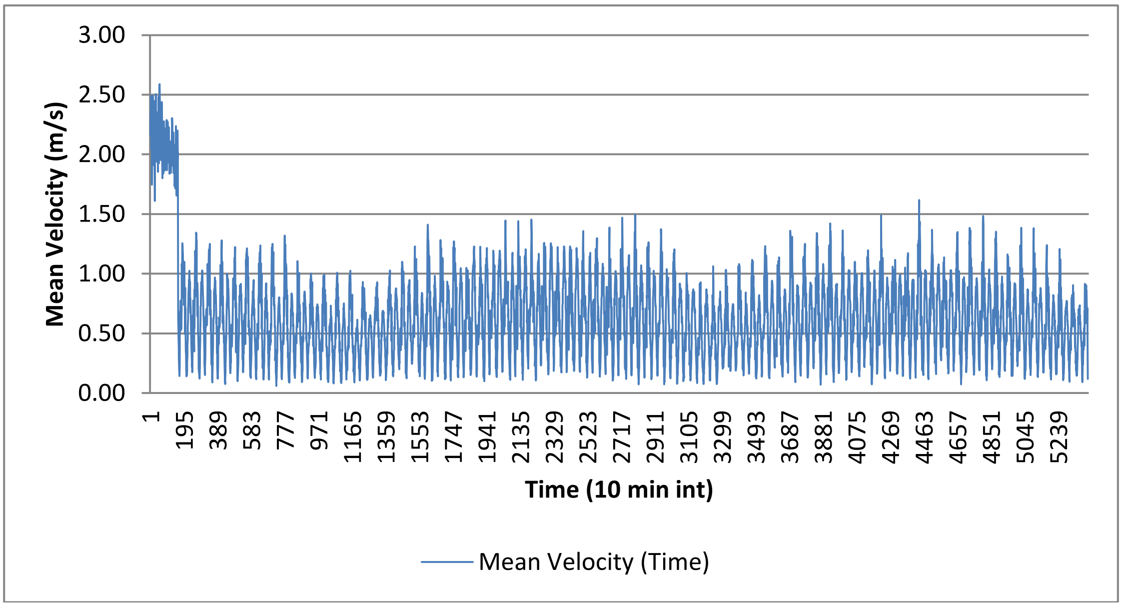


Figure 19: Directionless velocity data, Site 6

The time averaged velocity of all the data in each bin is used to generate the velocity profile for the site. The flows within 4m of the seabed are clearly less than half of the speed of the main body of the flow from 34m to 6m depth

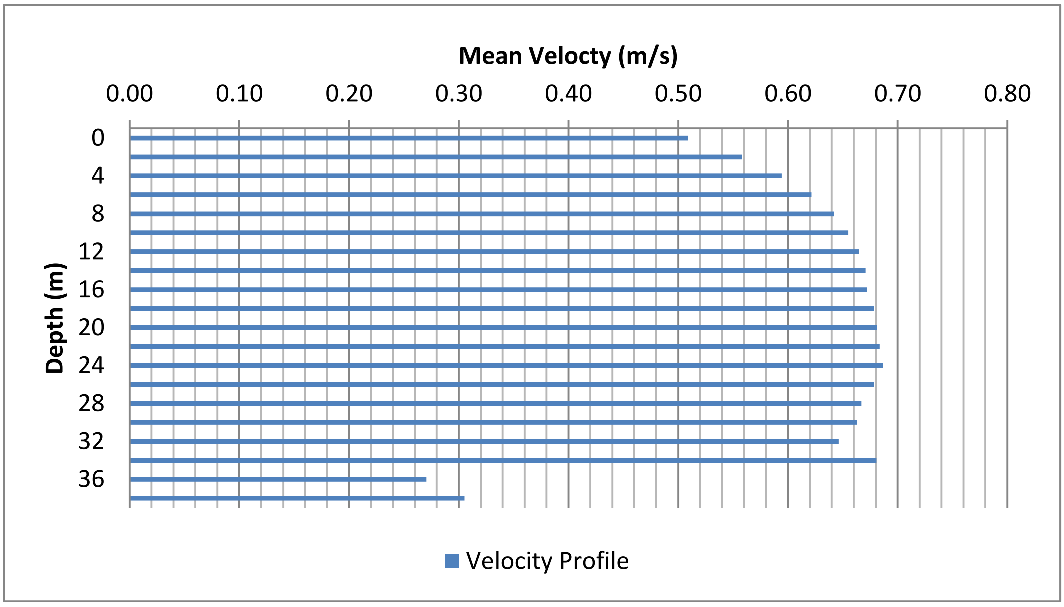


Figure 20: Velocity profile, Site 6

Averaging the data across all bins at any given time interval generates a depth averaged ensemble for each 10 minute interval. Further averaging three consecutive 10 minute depth averaged ensembles gives an average flow at the location for any 30 minute interval. Identifying the maximum 30 minute average flow velocity indicates the point in the data that represents the strongest Spring tidal currents and therefore the point at which there should be a strong correlation between the ADCP data and the model which uses the Admiralty Spring tide data as seeding values.

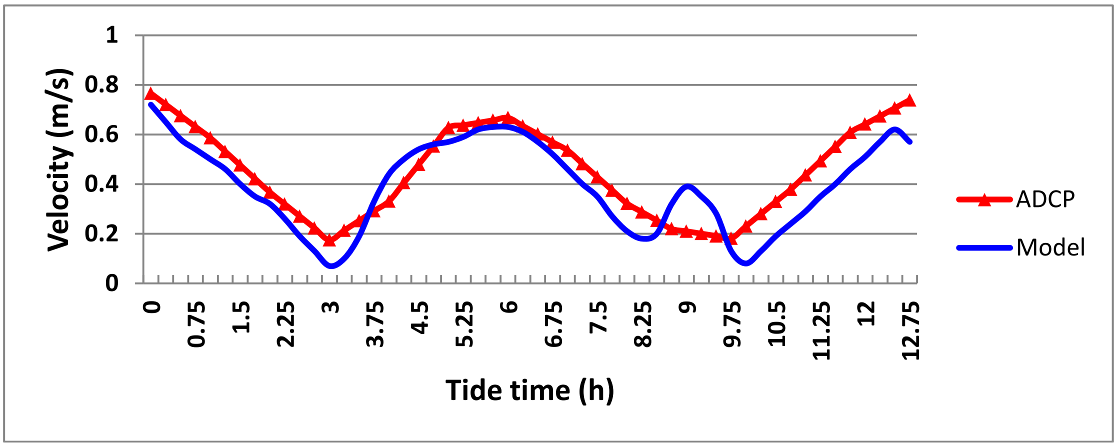


Figure 21: Comparison of Model and ADCP data

Figure 21 shows a very strong correlation between the model output and the measured data from the ADCP deployment, though the small peak at hour 9 is, at present unexplained.

Site 9

Site 9, Lat: 49-26-25, Long: 02-25-99, indicated by green arrow in Figure 22 . is situated within the Big Russel, very close to an existing tidal diamond on the navigational chart Sheet 3654

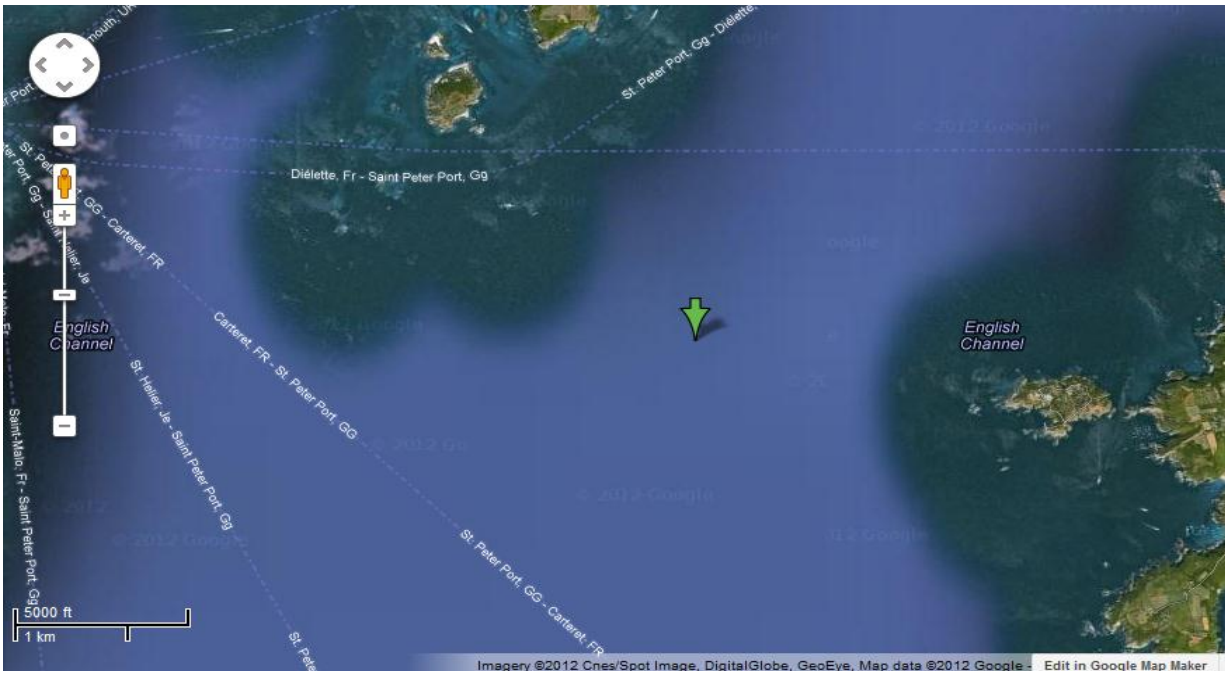


Figure 22: Site 9, Lat: 49-26-25, Long: 02-25-99

For this site the water depth from chart is given as a spot depth of 42m, whilst the water depth from the ADCP deployment record is 48m and the water depth from the numerical model is 39m

According to the deployment log, the ADCP was deployed on 1st June 2010 at 1130 hours, (approximately 500m south east of tidal diamond “G” on Admiralty Sheet 3654) in 48m water and retrieved on 7th July 2010. The exact make and model is not given but it is believed to be an Aquadopp Profiler. The bin size is given as 2m, sample interval is 10 minutes and averaging interval is 60 seconds.

The 5414 lines of data for each velocity component of the 20 bins is imported into an Excel spreadsheet, representing just over 902 hours of continuous recording. Plotting the directionless velocity, the early phase of the ADCP operation again appears to generate anomalous data for approximately 100 hours, as shown in Figure 23, centred around 2m/s +/- 0.75m/s. The reason for this is unknown, but this section of the data is removed for the purposes of subsequent analyses.

The data recorded after this initial phase follow the expected undulating pattern of tidal current flow velocities, driven by the Spring/Neap cycle and influenced by local topographical and bathymetric features.

For each bin at any given depth the ADCP generates flow components in the North, East and Up directions and the directionless velocity (U) is found using eqn. 1 as before,

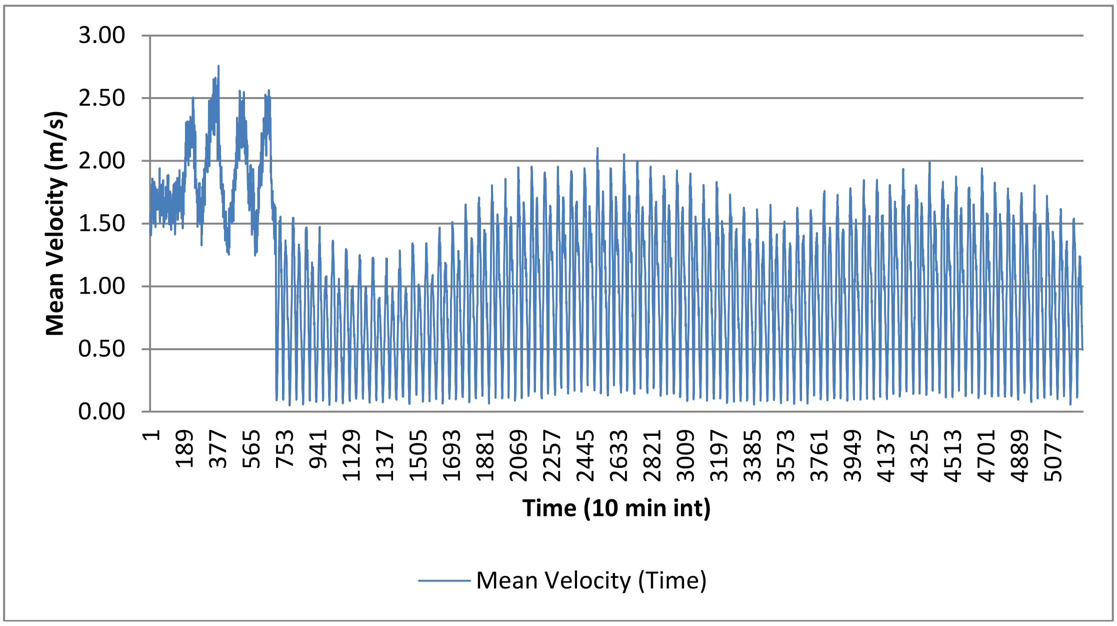


Figure 23: Directionless velocity data, Site 9

The time averaged velocity of all the data in each bin is used to generate the velocity profile for the site. Again, the flow speeds within 6m of the seabed are clearly much reduced relative to the main body of the flow.

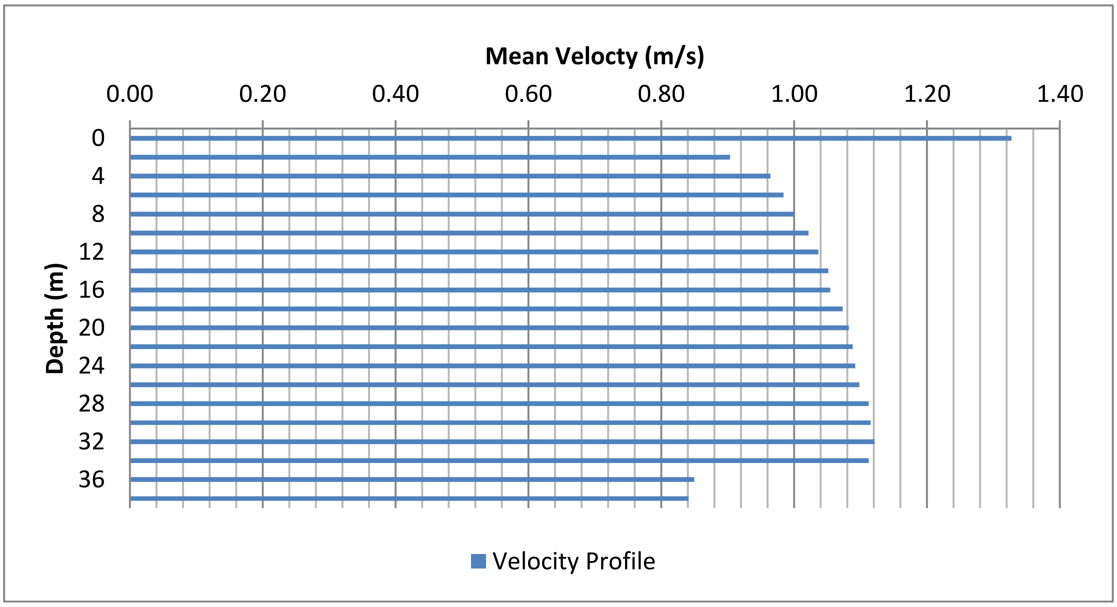


Figure 24: Velocity profile, Site 9

However, this site exhibits a very strong surface current measurement.

Again, depth averaging the data, normalising to Spring Peak flow and comparing with the model output, and, in this instance, the tidal diamond data, gives the plots shown in Figure 25.

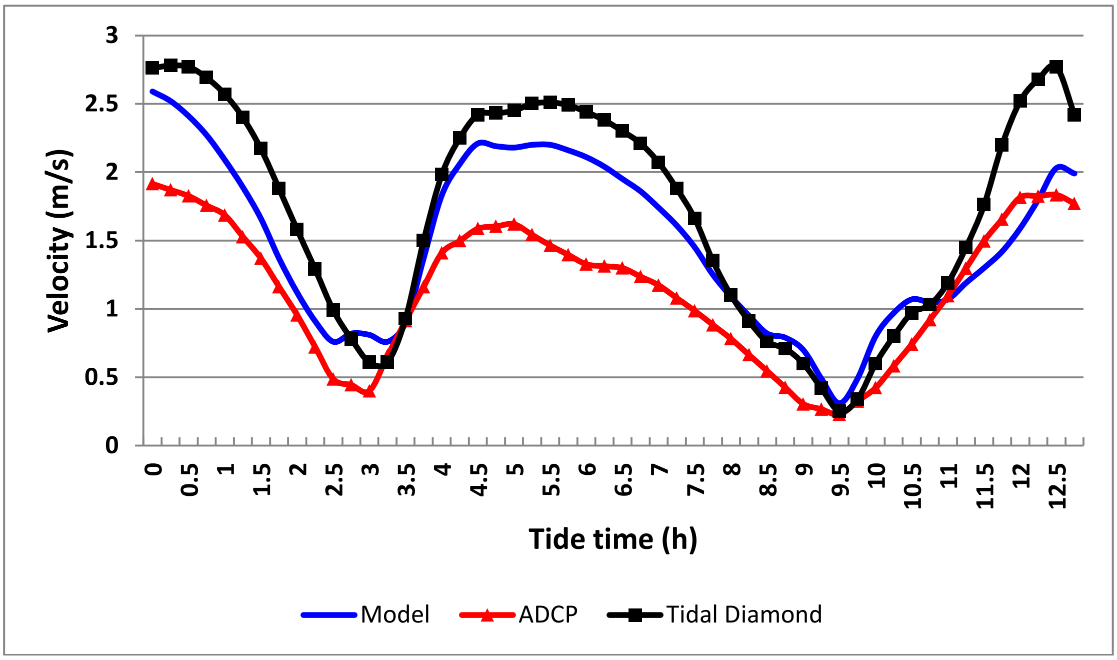


Figure 25: Comparison of Model and ADCP data for Site 9

Figure 21 shows a very strong timing correlation between the model output, the tidal diamond data, and the measured data from the ADCP deployment, but the magnitude of each is different. The overall significance, from this single validation point is that the peak UKHO values are 1.56 times greater than the ADCP measured peak velocity data at this spatial and temporal point, and that the model is around 1.37 times greater. Further validation data would need to be acquired for this to be analysed to a general factor. Additionally, it must be considered that ADCP's are not in themselves 100% accurate, but output data as a function of their internal algorithms, sampling and averaging intervals. More ADCP data would help to improve the model correlation with reality, but it is estimated that statistical analysis would require 15-20 sets of disparate monthly data to indicate the mean variance between the UKHO data, the model and the real flows.

Conclusions

1. Tidal diamond data are not necessarily an accurate indicator of local tidal current speeds.
2. The Model, as developed, accurately reflects the shape of the ADCP tidal data
3. The Model reflects the pattern of the seed data with a good level of consistency
4. Seeding the model with more ADCP data should improve the accuracy of the overall Model environment.
5. The energy available at any site is a function of the chosen technology, its cut-in speed and installation depth limitations.
6. The Big Russel has a raw resource of around 700GWh/y.

[1] Owen A, Bryden IG, A novel graphical approach for assessing tidal stream energy flux in the Channel Isles, Journal of Marine Science and Environment, IMarEST, 2006

[2] UK Hydrographic Office, "Admiralty Tidal Stream atlas NP264", Crown Copyright, Taunton 1993

[3] Gallagher R.H., et al (ed) "Finite Elements in Fluids", John Wiley & Sons, Bristol, 1978

[4] Gerald C.F. "Applied Numerical Analysis", 2nd Ed, Addison-Wesley, Massachusetts, 1978

[5] Dyke P, "Modelling Marine Processes", Prentice Hall, London 1996,