Draft Final Report

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Promoting Sustainable Energy in The Bahamas

FICHTNER

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FICHTNER

Sarweystraße 3
70191 Stuttgart • Germany
Phone: + 49 711 8995-0
Fax: + 49 711 8995-459

www.fichtner.de

Please contact: **Ole Langniss**
Extension: **584**
E-mail: **Ole.Langniss@fichtner.de**

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7. Ocean Energy

7.1 Introduction

This Section addresses the aspects related to the possibilities of power supply for the islands derived from ocean sources. The unique bathymetry of the seas around The Bahamas means that a number of different ocean energy resources are available in different parts of the archipelago. The location of the islands adjacent to the deep ocean in the sub-tropical region means that the investigation of ocean thermal resource is particularly appropriate. The existence of the north east trade winds on the eastern coasts of the Family Islands will result in significant wave energy resources. The tidal range is small but there are significant flows between many of the islands.

Ocean energy comprises a number of sources which represent the highest density energy sources of all of the natural renewable energies. The final report will outline the nature of these ocean resources as an information source for future reference.

Ocean Surface Waves represent a source of energy derived from the winds. Ocean waves are generated by winds passing across the sea surface and the energy contained in the waves is then transmitted over long distances in the ocean with very little loss. Wave energy is variable but also highly predictable as the wave conditions can be measured at a distance from the shore to give advanced information on future energy levels as the waves propagate and arrive onshore.

Ocean Thermal Energy – the surface layers of the ocean store the heat energy available from the incident solar insulation. The low thermal conductivity of the sea water results in a build-up of this energy near the surface with the deeper layers maintaining a relatively constant temperature of around 4^0C. The surface layer thickness increases over the summer period and the temperature rises to levels around 30^oC in the tropical regions. This difference in temperature provides a thermodynamic resource which can be used to drive heat engines.

Tidal Current Energy – the gravitational forces associated with the earth/moon/sun system result in the rise and fall of the ocean surface in the tides. This rise and fall causes large volumes of ocean water to flow into coastal embayments, shallow waters and through island cuts. This flow of water reverses every 6 hours and is highly predictable decades into the future. The flow of water can be utilized to drive submerged turbines to generate electricity.

Ocean Currents – the surface layers of the ocean have circulation patterns in the shape of large gyres driven by the surface wind fields. In the northern hemisphere these gyres rotate clockwise and are subject to intensification on the western boundaries of ocean basins. In some cases these surface layers can have velocities up to 2 m/sec. and these flows could be utilised to drive submerged turbines.

7.2 Potential for ocean power

7.2.1 Introduction to the ocean resources

The oceans are a large source of natural renewable energy. The primary sources are derived from the solar radiation onto the surface but there is also a significant contribution from the gravitational field of the earth/moon/sun system.

The resources which are relevant to the Bahamas are the energy available from ocean waves, the energy from tidal streams and the energy stored in the temperature differences between the water in the surface layers and that in the deep ocean.

Wave Energy
The variation in solar insolation into the atmosphere causes differential heating and the resulting pressure differences create the winds. These winds act on the surface of the ocean to generate waves. These waves are thus stored wind energy and this is transported across the surface to the downwind shorelines. Wave energy can therefore be available at the shoreline during times when the wind is zero as the waves are generated by distant storms. These types of waves are referred to as “swell waves” whereas the waves directly generated by the wind are called a “sea” or “wind sea”.

Figure 7-1: Wave Energy Propagation

The wave energy propagates long distances across the ocean and the energy transfer can be calculated from a relatively simple formula. The wave power, or rate of energy transfer, is given per meter width of the wave crests as shown in the above figure. All of the waves in the ocean have different heights and different wave periods and so representative statistics are used to characterize the sea state at any given time. The significant wave height is used along with the average or zero crossing wave period.

$P = 0.55\ Hs^2\ T_z$ kw/metre width

Or alternately where wave spectra are used the peak period parameter T_p.

In order to make an assessment of the energy resource available at any coastline it is necessary to have information about the occurrence of the different sea states over at least one year, data for longer periods is desirable as there can be significant inter annual variations in the resource. The statistical information regarding the occurrences of the different wave heights and corresponding wave periods are called the wave climate. Typically this is displayed as a joint probability diagram or scatter diagram as shown below.

British Met Office Data 51.32N 10.14W

Hs \ Tz	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5
10								1	0	0	0
9.5									1	0	0
9								1	0	0	0
8.5								1	1	0	0
8							5	5	1	0	0
7.5							8	2	0	0	0
7						3	9	2	0	0	0
6.5						8	9	1	1	1	0
6						20	7	1	0	1	0
5.5					7	18	5	2	0	0	0
5					16	24	5	0	0	0	0
4.5				1	34	22	9	2	0	1	0
4				8	32	17	7	3	1	0	0
3.5			1	28	21	20	6	2	0	0	0
3			3	55	24	14	8	2	1	0	0
2.5			29	48	26	16	7	7	1	1	0
2		7	33	32	24	14	7	2	3	1	0
1.5		16	32	30	23	18	5	3	1	1	0
1	6	11	16	23	18	13	3	0	1	0	1
0.5	1	4	13	1	4	1	1	0	0	0	0

Figure 7-2: Scatter Diagram – Wave Climate

The values in the scatter diagram represent the occurrences of particular combination in parts per thousand. In this example the wave height of 2m and wave period of 5.5 seconds occurs for 3.3% of the time in the year.

It is then possible to calculate the wave power for each of the wave height/period combinations and to work out the total energy available in the year and also the averaged power for the whole year.

The diagram below shows the distribution of averaged power for the world’s coastlines.

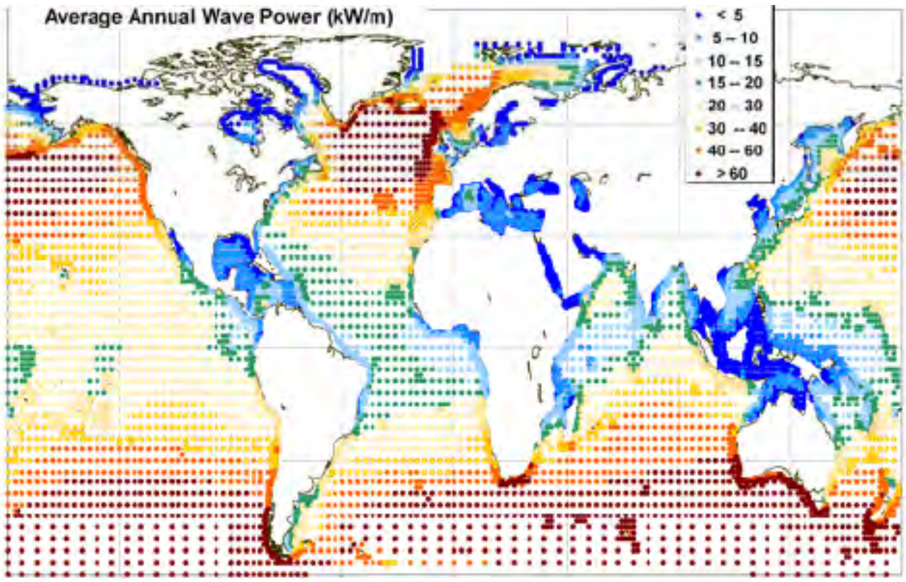

Figure 7-3: Average annual wave power

The level of wave power in the Bahamas region is relatively low. The Bahamas are however located in the Trade Wind Belt and the North East Trades may provide a more persistent wave climate on the eastern coastlines than in other regions of the world.

Tidal Energy

The tidal energy in the ocean is derived from the action of the gravitational field of the earth/moon/sun system on the water mass. This gravitational field causes the water levels to rise and fall in the ocean with different heights at different locations because of local bathymetric influences.

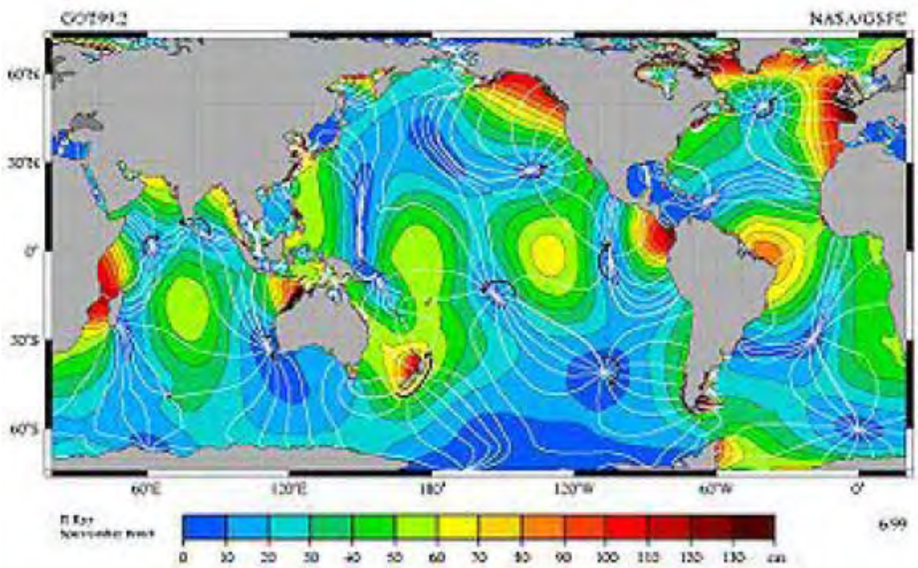

Figure 7-4: Tidal Energy Distribution

This map shows that the rise and fall of the tide around the Bahamas is relatively small. Interestingly however, even where the tidal range is small, there are locations because of inlets, narrows and other coastal features where the tidal stream flow velocity is large.

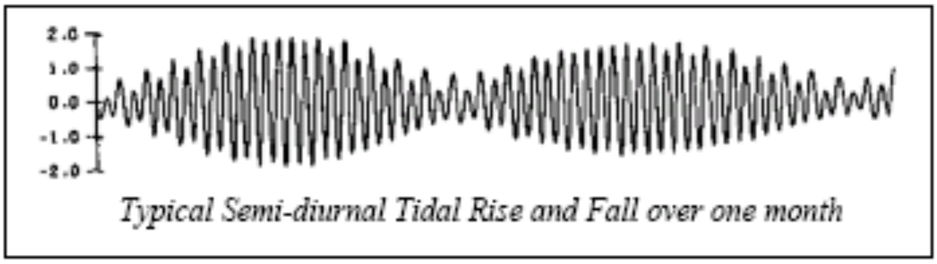

Figure 7-5: Typical semi-diurnal tidal rise and fall over nine months

Tidal levels are most commonly semi-diurnal with a periodicity of 12.42 hours although there are locations in the world where the tides are diurnal with a tidal period is 24.8 hours and other locations where the tides are mixed. It can be seen that the tidal range varies throughout a month with maximum ranges or spring tides and neap tides or minimum range occurring twice per month.

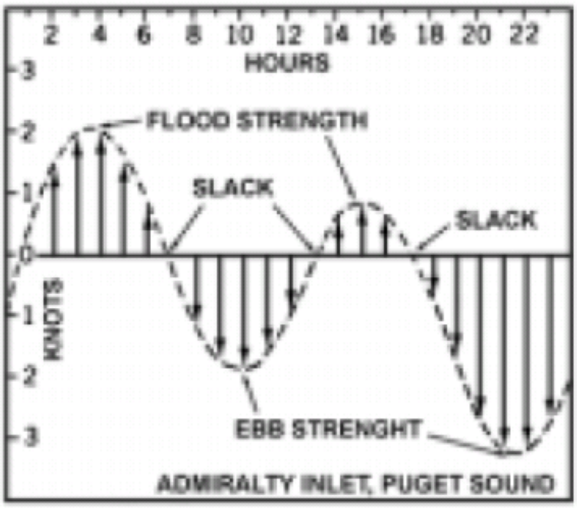

Figure 7-6: Tidal Currents in Puget Sound

Tidal streams are cyclical and normally follow the tidal rise and fall but out of phase by about 3 hours. The tidal velocity rises to a maximum and then returns to zero and reverses direction, again rising to a maximum, during this cycle. The velocity and hence the power production therefore varies on a 6.2 hour cycle. The maximum velocities of the tidal current also vary throughout the Springs/Neaps cycle and often the velocities are greater on the flood tide than on the ebb tide.

The tidal behavior is highly predictable with the astronomical tide capable of being predicted centuries into the future. This stream flow or tidal current can be used to drive an underwater turbine to generate electricity and this resource will be assessed for the Bahamas below.

Ocean Thermal Energy

The ocean surface waters are heated directly by the solar insolation and as the seawater is a poor conductor of heat the surface layers increase in temperature whereas the deep water layers remain at relatively low temperature.

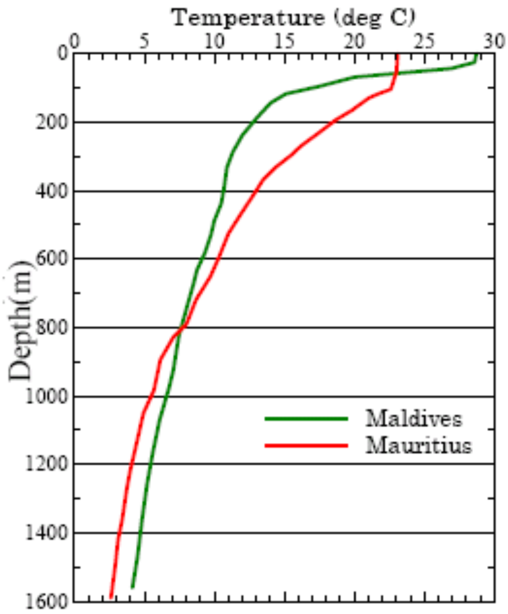

Figure 7-7: Typical Temperature Profile

It can be seen that the temperature gradient is high near the surface and up to around 100m depth there is an abrupt change in temperature called the thermocline. The surface water temperature increases and decreases over the year as the summer – winter cycle takes place but the deep water layers remain at a relatively constant temperature.

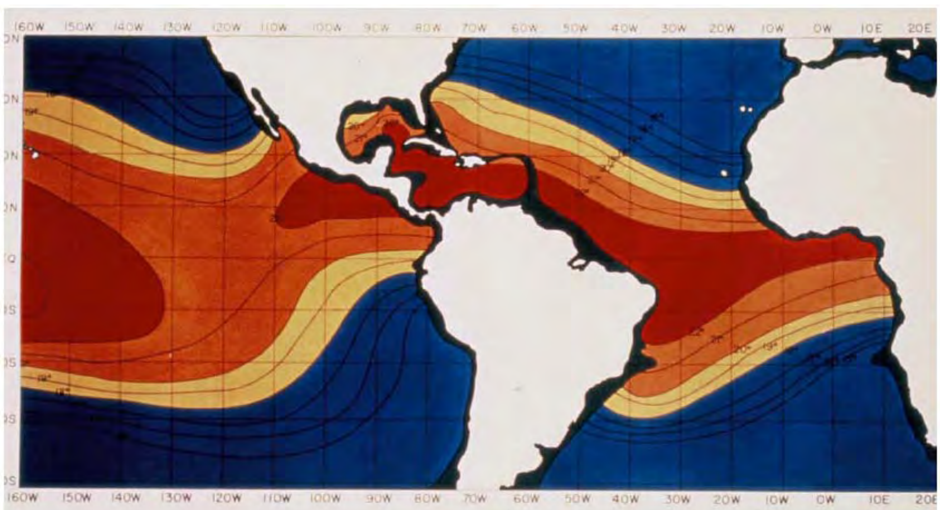

Figure 7-8: Ocean Surface/Deep Water Temperature Difference

This temperature difference can be used to drive a heat engine and generate useful power if the deep water is pumped to the surface. It can be seen that

the greatest temperature differences occur near the equator as would be expected. One prime advantage of the OTEC resource is that the power produced is base load and dispatchable and does not have the variability associated with other forms of renewable energy like wind and wave.
The Bahamas is located in the subtropical region where the temperature differences are still significant and has the unique situation where very deep water is located close to the shoreline.

7.2.2 Underlying data resources

Different data sources were used to assess the potential of ocean power on The Bahamas:

- *Bathymetry*

The bathymetric data for the Bahamas is available in the digitised ocean bathymetry model (GEBCO) which provides high resolution information on a global basis. Detailed charts have been obtained both in sheet format and in booklet form at a scale of 1:50,000. This information is sufficient to allow a detailed study of the ocean renewable resources to be carried out. The The GEBCO chart for the Bahamas with 30 second grid size is shown below.

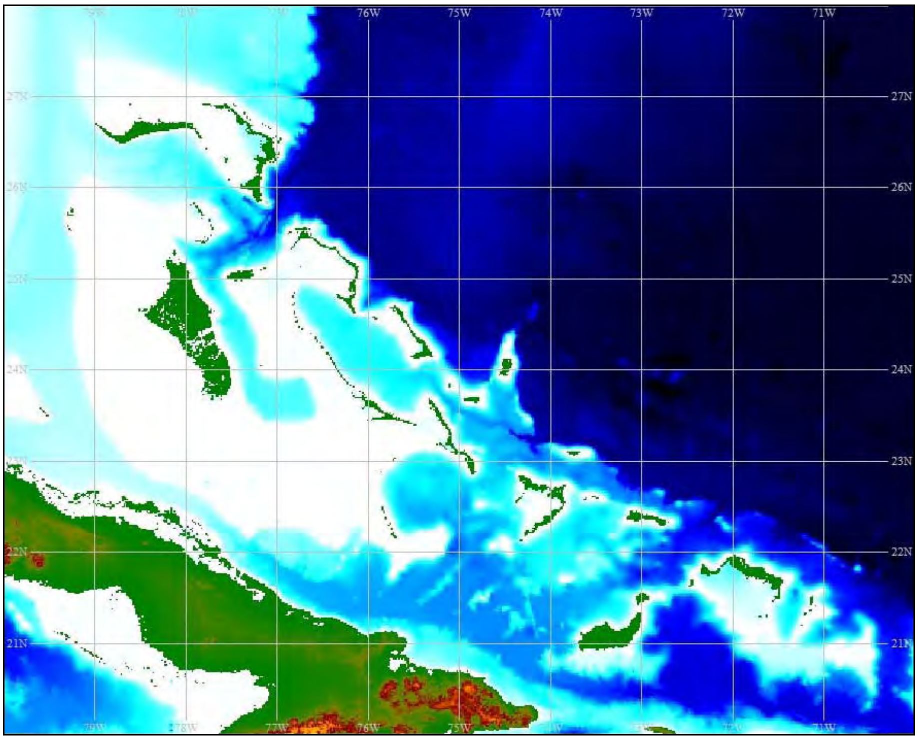

Figure 7-9: GEBCO Bathymetry Chart

- OTEC
  The existence of the deep water within a few kilometres of the shoreline in many locations means that OTEC is a promising option for the Bahamas. Sea surface temperature maps are available on a routine and archived basis from Rutgers University. The key to the assessment of the thermal gradient resource is the availability of temperature profile data. There is a long series of expendable bathythermograph (XBT) profiles taken in the Tongue of the Ocean by the US Navy and these are available in digital form. There does not appear to be any further source of temperature profile data and there will not be sufficient resources or time to make additional measurements so the resource assessment will be based on the sea surface data and the assumption that profiles in other locations have similar shape to the TOTO data. There are a series of published papers with information related to transects at 24.5^{o} N and 26^{o}N with oceanographic cruises monitoring the ocean circulation and the Gulf Stream. These will also be used where appropriate to reinforce data on temperature profiles.

- *Waves*
  There is no measured wave data available on a routine basis from the sea areas around Bahamas. There are a number of numerical modelling sources with archived data on wave conditions. The Norwegian company Oceanor provides an archive of data resulting from satellite measurements over the whole globe. Data is available for the eastern shores of the Family Islands.

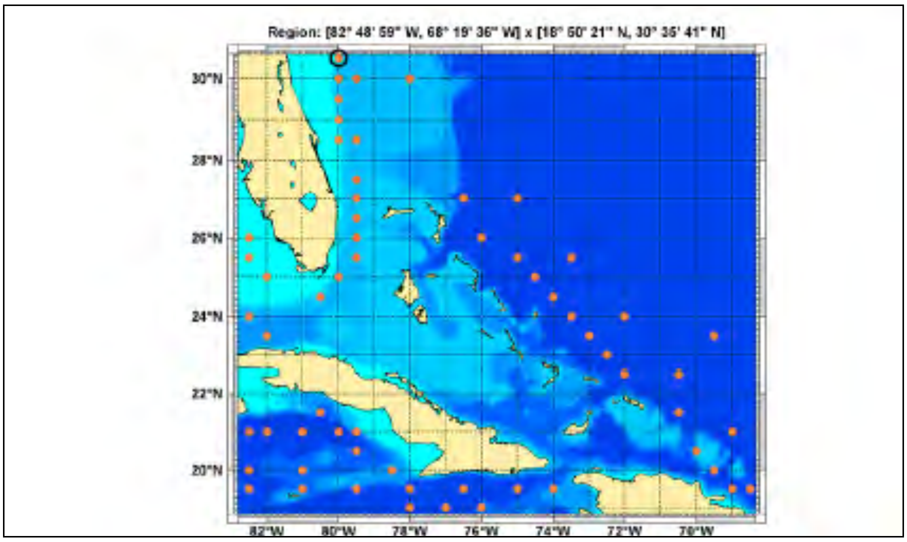

Figure 7-10: Picture from WorldWaves showing the offshore grid points

It was originally envisaged that a series of data from these satellite observations of the waves were to be used. Budget constraints have meant that this was not feasible and so alternate data sets have been sourced.

NOAA in U.S.A. run an operational forecast model for waves in the world's oceans. This WAVEWATCH data is archived and available for use.

This data has been obtained for a number of sites along the eastern boundary of the Bahamas Islands and the resource assessment has been completed using this data.

- *Tidal Currents*
  There is tidal level information available for nearly all of the islands in the Bahamas with some having more than one location. There are, however, no measurements of tidal flows available for the Bahamas. The detailed bathymetric chart books obtained from Bahamas give indications of the locations where tidal streams have high velocities in the cuts between islands. These have been investigated and a number of potential locations have been identified. Future work on detailed numerical tidal modelling cold be done when an assessment of the proximity of these locations to load centres has been established..

- *Ocean Currents*
  The ocean currents in the region to the east of the Bahamas have been extensively studied as it is the location of the Antilles Current. The region to the west of the Bahamas in the Florida Strait has a strong ocean current driven from the Gulf of Mexico but it is concentrated into the area up to 20km offshore from the Florida coast. Other ocean currents in the vicinity of the Bahamas seem to be too weak to warrant further investigation. The potential for these has not been assessed as the technology development is at an extremely early stage.

7.2.3 Ocean energy resource estimates

7.2.3.1 Wave energy resource

The wave energy resource of the Bahamas is not comparable to that of more exposed island chains, however at certain locations on the eastern seaboard the wave energy resource could be large enough to exploit for power production. This preliminary report identifies several such locations that merit further analysis. All the data for the wave resource analysis was obtained from WAVEWATCH III.

<u>WAVEWATCH III</u>

WAVEWATCH III was developed at the National Oceanic and Atmospheric Administration (NOAA).It is a wave model used by the NWS to predict a variety of wave characteristics including significant wave height, wave period, direction and frequency. The model resolves the balance equation, (1), for the spectrum N(k, θ; x ,t);

$$\frac{\partial N}{\partial t} + \frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\dot{\phi}N\cos\theta + \frac{\partial}{\partial\lambda}\dot{\lambda}N + \frac{\partial}{\partial k}\dot{k}N + \frac{\partial}{\partial\theta}\dot{\theta}_g N = \frac{S}{\sigma},$$

$$\dot{\phi} = \frac{c_g\cos\theta + U_\phi}{R},$$

$$\dot{\lambda} = \frac{c_g\sin\theta + U_\lambda}{R\cos\phi},$$

$$\dot{\theta}_g = \dot{\theta} - \frac{c_g\tan\phi\cos\theta}{R},$$

(1)

Where: R is the Radius of the Earth, λ is Longitude, Φ Latitude and U_λ and U_Φ are current components.

The model itself is FORTRAN based and uses a regularly spaced longitude-latitude grid. WAVEWATCH resolves in several grids of varying resolution and location, shown in Table 7-1. Using one-way nesting, grids are run as separate models consecutively. Output is provided in the form of ASCII or Binary. The output data files are available for download in Grib format. These Grib packages must be decoded before actual data analysis can be carried out.

Model	Type	Coverage (long., lat.)	Resolution	Min. depth (m)
NWW3	Global	77°S - 77°N 1.25°	1°	25
AKW	Regional	45°-75°N 160°E-123°W 0.5 °	0.25°	7.5
WNA	Regional	0°-50°N 98°-30°W	0.25°	7.5
NAH	Regional	0°-50°N 98°-30°W	0.25°	7.5
ENP	Regional	5°-60.25°N 170°-77.5°W	0.25°	7.5
NPH	Regional	5°-60.25°N 170°-77.5°W	0.25°	7.5

Table 7-1: WAVEWATCH III Grids

Validation of the model is carried out using both wave buoy data and satellite data. Figure 7-11 shows the agreement between model and field data.

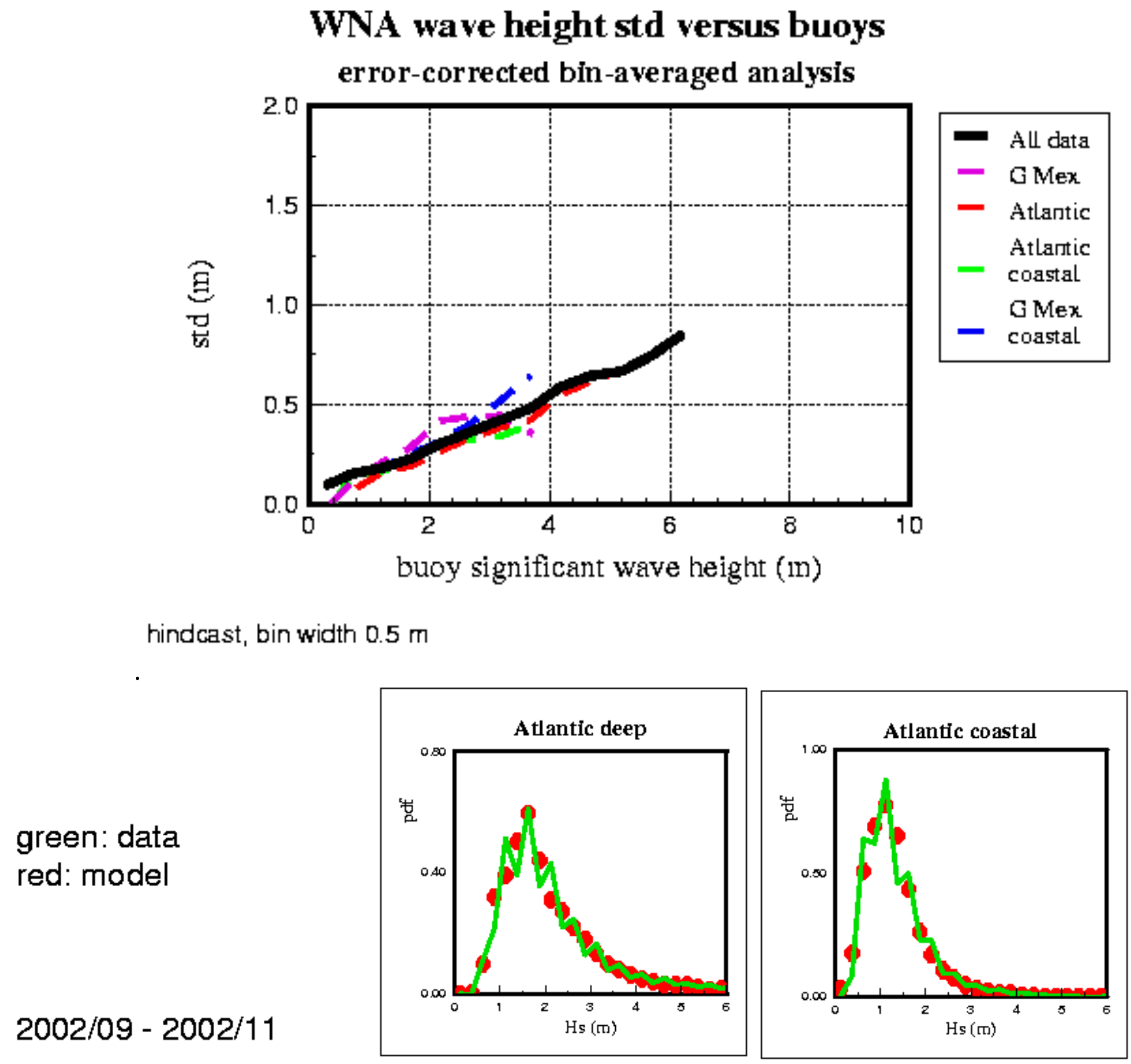

Figure 7-11: WAVEWATCH III Model validation

Data Acquisition
The Wave energy resource for the Islands was calculated from archived data from a NOAA Wave Watch III model. Peak period and significant wave heights generated by this model were used to calculate the power stored in the wave, using the formula (2);

$$Power = K*Hs^2*Tp \qquad (2)$$

Where; K is a constant (0.42) based on the BS Spectrum, Hs is the significant wave height, Tp is the peak period. The power is calculated in Kilowatts per meter width of wave front.

The data used in the analysis was from the WNA Grid Model, which represents the Western North Atlantic. The WNA model contains data from a grid running 0° to 50°North and 98° to 60° West. The Grid resolution is 0.25° i.e. parameters are calculated every 0.25°. Data from this model is stored every three hours. For each grid point a typical month's data is in the region of 249 entries, for both Significant wave height and Peak period.

The scope of this report did not require data from such a large region; therefore a smaller grid was extracted from the WNA Grid that encompassed the Bahamas. Running from 21° to 27° North and 79 to 72 West, this Bahaman grid contained 725 points of data. A years (2005) worth of data was obtained for this region.

The power calculated was then combined with a bathymetrical chart of the Bahamas.Ten locations primarily on the eastern front of the Islands were identified for further examination. These locations were selected based on their proximity to land/population and magnitude of resource available (Table 7-2).

Name	**Annual Average Power kW/m^2**	**Location**	**Grid Co-ordinates**	
			Latitude	Longitude
P1	6.18	SW of Freeport, GB	26° 30'	79° 00'
P2	8.24	NE of Little Abaco	26° 45'	77° 15'
P3	10.67	N of Grand Cay, GB	27° 00'	77° 30'
P4	8.74	NW of Eleuthra	25°30'	76° 30'
P5	10.61	N of San Salvador	24° 15'	74° 30'
P6	11.19	SE of San Salvador	24° 00'	74°15'
P7	11.07	Samana Cay	23° 00'	73° 30'
P8	8.39	Mayaguana Island	22° 15'	72° 45'
P9	8.34	E of Acklin Island	22° 45'	73°45'
P10	8.23	E of Cat Island	24° 30'	75° 30'

Table 7-2: Yearly average power for each location

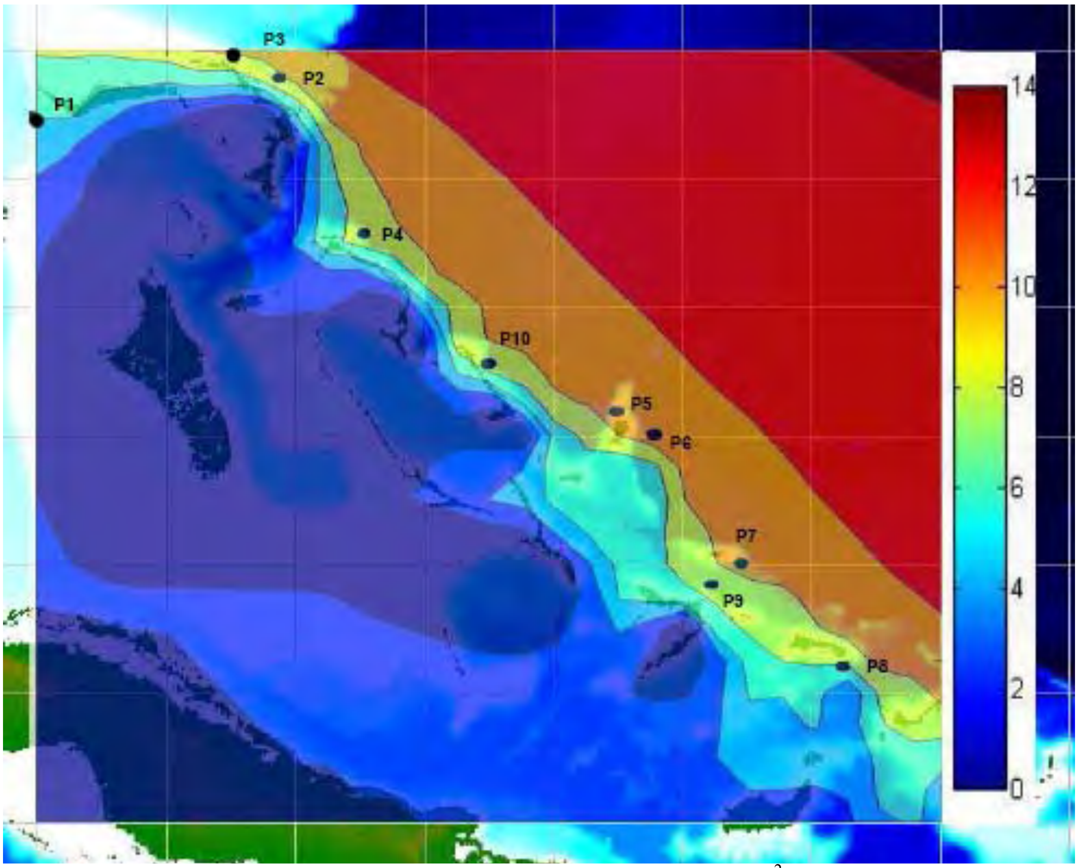

Figure 7-12 Average Wave Energy Resource 2005 in kW//M[2]

For each of these ten locations a wave scatter graph to quantify the frequency of a desirable wave climate a time series of monthly average power over a year was generated (Figure 7-13).

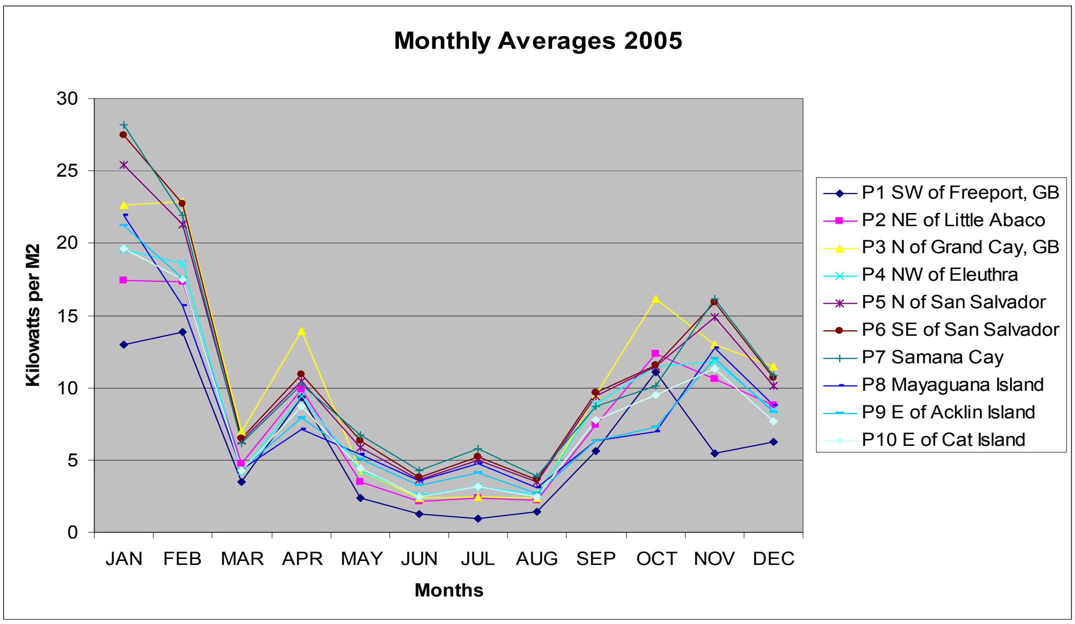

Figure 7-13: Monthly Average Wave Energy Resource

It is clear from initial examination of Figure 7-12, that the wave energy resource is greatest on the eastern boundary of the archipelago. The average near shore energy resource is within the 8-10 kW/m width range for the most suitable locations. The monthly time series, Figure 3, highlights the seasonality of the Bahamas wave climate, a relatively large resource is available during the winter months but during the summer months the resource is virtually non existent.

The yearly average wave power (Table 7-2) is quite low for wave energy extraction. Values in excess of 11 kW/m^2 were recorded for the more suitable locations around San Salvador and North of Gran Bahama Island. However the model results indicate an average wave power greater than 15 kW/M for several locations during the winter months; most notable are P7 located off Samana Cay, P5 & P6 off San Salvador and P3 Grand Cay on Gran Bahama Island. P1 South West of Gran Bahama displayed the lowest resource, although there were three months when the average power exceeded 11 kW/m^2.

The scatter diagrams, presented in the Annexe (example in Figure 7-14) indicate that the majority of waves are between 1 to 2 meters in height and the significant wave period lies within the range of 5 to 9 seconds. This is relatively low for a typical large scale wave energy generation.

An interesting feature of the scatter diagrams for the first three points P1,P2 & P3 is the presence of outlying large wave events. At P1, a wave of significant wave height greater than10m and peak period of 10s is recorded with similar larger waves present in P2 and P3. Initially it was thought these outliers were data errors and not representative of the wave climate, however, it was found that these extra large occurrences were on the 24th of October 2005. This date is significant because it is the same day Hurricane Wilma passed north of these points up through the Florida straits and between the Bahamas and the Florida coast. It is possible that this major storm event created waves in the vicinity of P1, P2 & P3 that may have been greater than 20m. This is an important finding as it has serious design implications for any wave energy device.

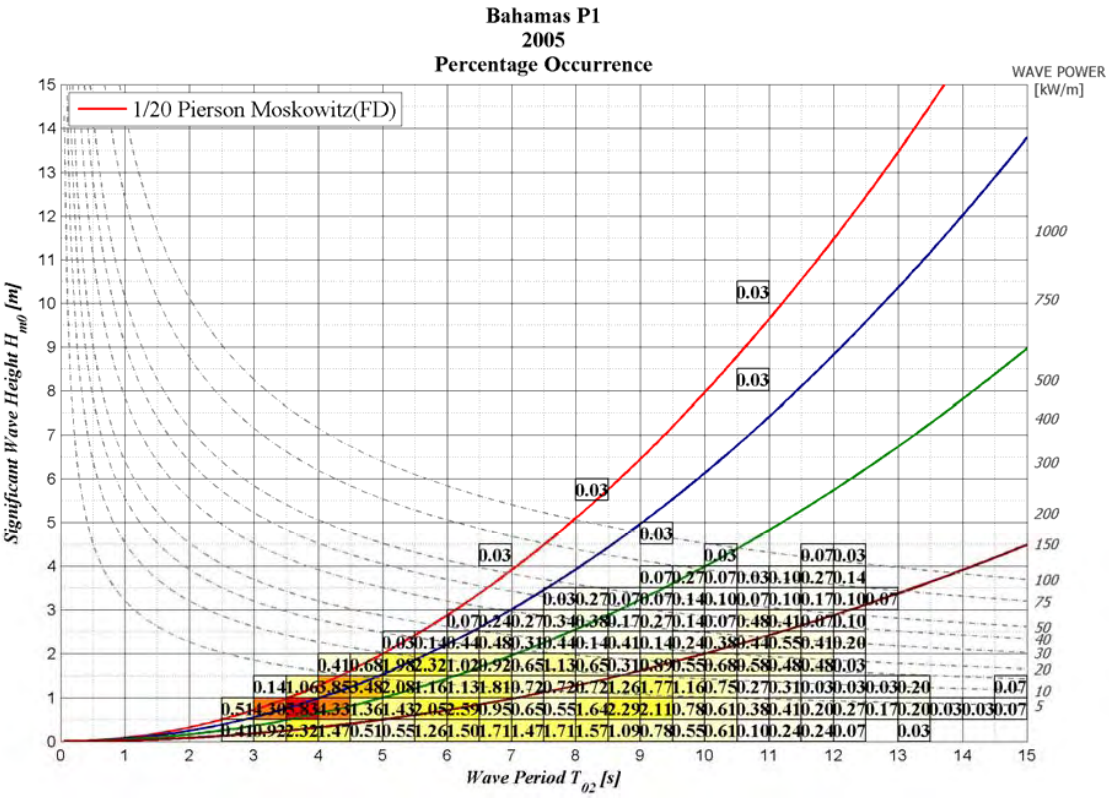

Figure 7-14: Scatter diagram for P1

7.2.3.2 Tital energy resource

Tidal Range

The tidal ranges for the Bahamas are small as can be seen from the tide curve for Nassau.

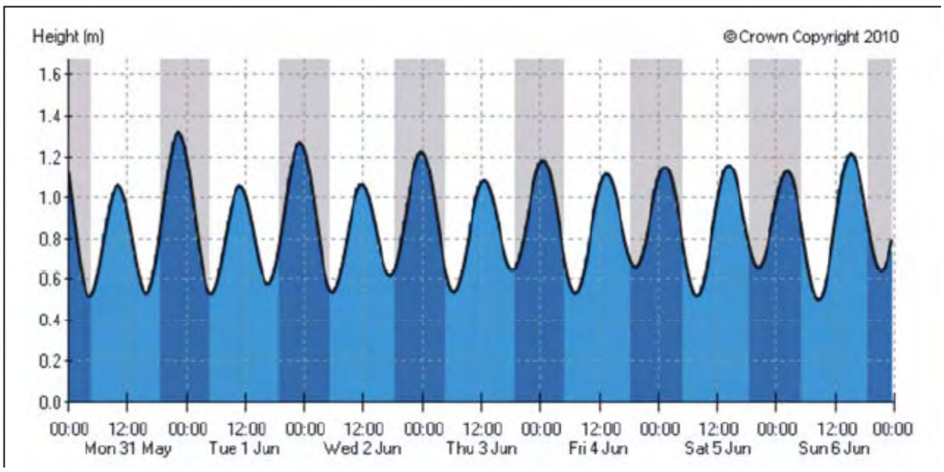

Figure 7-15: Tide Height Curve for Nassau – June 2010

The tidal range is around 0.8m maximum and the springs to neaps ratio is about 1.6. Given this low tidal range the Bahamas would not be suitable for tidal barrage type energy systems.

Tidal Streams
There are however, a number of narrow cuts between the Bahamas Islands where the tidal stream velocity is high.
Energy from fast moving tidal currents can be converted into electrical power by several different types of turbine driving a generator. Due to the lack of tidal velocity data, the tidal energy resource of the Bahamas Islands was very difficult to quantify within the scope of this study. In the place of tidal flow analysis, a geographic analysis of the Islands was conducted. Combining Admiralty charts, satellite imagery packages and anecdotal reports on tidal currents an outline assessment of the location of suitable areas for tidal energy extraction was undertaken. As a result of this analysis several locations with a potentially exploitable tidal current resource were identified. Further detailed computer modelling would be possible for these sites if a further phase of the examination of the potential is undertaken

Geographical Analysis
Table 7-3 documents the preliminary geographic analysis. This involved studying the bathymetry of each Island in the chain and identifying any suitable locations. The key parameters of this first pass were physical characteristics; where coastal features such as straits, tidal cuts and water depths greater than 4 m below SLW were identified. Population density was also considered when selecting the most suitable sites from the initial analysis.

Island	Location	Resource (if any)	Population
Great Inagua	Extreme South	None	1000
Little Inagua	Extreme South	None	0
Mayaguna	South East	None	318
Plana Cays	South East	None	0
Acklins	South East	Minimal	459
Samana Cay	South East	Minimal	0
Long Island	South	Minimal	3000
Conception Is	East	None	0
Rum Cay	East	Minimal	
San Salvador	Far East	None	1000
Great Exuma	Central South	Highbourne cay Normans cay Darby Island Staniels Cay Black point Little Farmers Cay Lee Stocking Island	Varies with Resort/Cay
Ragged Islands	Far west	Minimal	72
Cat Island	East	Minimal	1600
Eleuthra	Central	Current Island strong	11000
Rose Island	Central	None	0
New Providence	Central	Minimal	250000

Island	Location	Resource (if any)	Population
Abacos	North West	Double Breasted Cay Yankee Cay Man o war cay Elbow cay Lynyard cay Little Harbour	14,000
Andros	Central	Big wood cay	7800
Grand Bahamas	North	Indian cay	75000
Bimini	East	Gun cay Alice town	1600
Berry Islands	Extreme East	Bonds cay Frozen cay Devils cay	700

Table 7-3: Tital resource by island

After the initial survey of the entire archipelago several islands were identified for further research. The following islands had the greatest potential, Great Exuma, Eleuthra, The Abacos, Andros, Bimini and Grand Bahama Island.

Description of Selected Sites

Great Exuma

Great Exuma possesses several sites that merit further investigation. These sites are located on the Northern end of Great Exuma, where there are numerous tidal cuts that possess potential for development.

Location	**Description**
High Bourne Cay	Remote private marina with tidal channels to south
Normans Cay	Two tidal channels could be developed private bungalow development
Staniels Cay	Tidal cuts on Northern and Southern ends of the cay
Black Point	Deep cut to North of island of approx 200 population
Little Farmers Cay	Two tidal cuts approx 50 people
Darby Island	Private resort approx 50 -100people
Lee Stocking Island	Several tidal channels in the vicinity of Island. There is a marine research centre on the Island, The Perry Institute. The Institute is currently looking at Renewable energy technologies to replace or compliment existing power source in this centre and other similar Islands in The Caribbean.

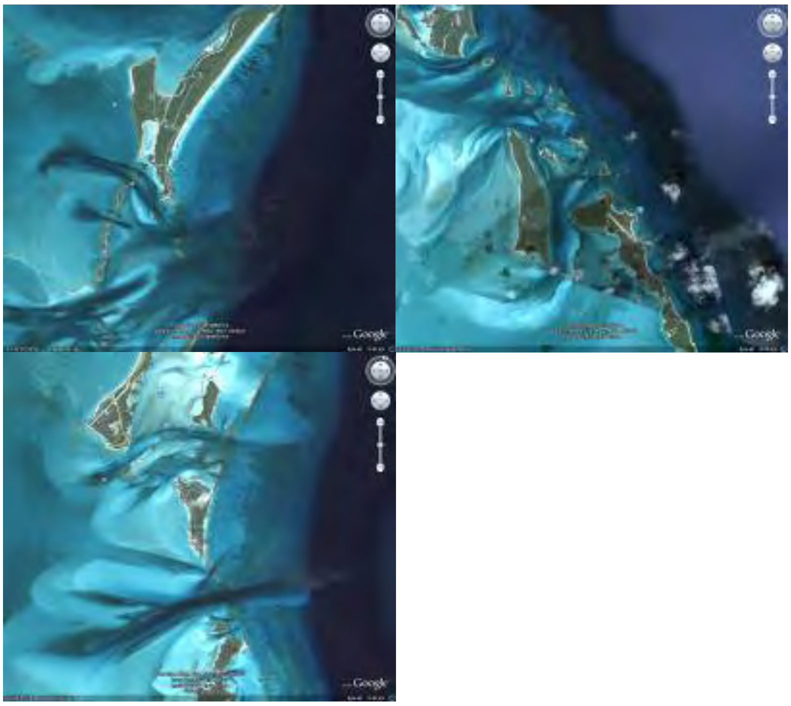

Figure 7-16: Highbourne Cay, Lee Stocking Island & Normans Cay

Eleuthra

The tidal cut between Eleuthra and Current Island, Figure 7-17, is a possible site for tidal energy extraction. The cut appears to have a large tidal flow and is close to a substantial population. The western end of Current Island may also be a viable tidal energy extraction site.

Figure 7-17: Tidal Cut between Eleuthra & Current Island

Abacos Islands

The outer lying cays running from the North West of Little Abaco to the South East of Great Abaco contain several tidal cuts. The following have been identified as possessing the greatest potential for tidal energy extraction; Double Breasted Cay, Yankee Cay, Man o war Cay, Elbow Cay and Lynyard Cay.

Double Breasted Cay and Yankee Cay are located off Little Abaco and are sparsely populated. A recent study of tidal flow interactions in the Bahamas by Reeder and Rankey, recorded flows greater than 1m/s in the tidal channels of Double Breasted Cay. This is an encouraging figure for tidal energy generation.

Elbow Cay, Man o War Cay and Lynard Cay are close to Marsh Harbour, while it has a substantial population and numerous tidal cuts that could be viable for energy extraction, the disadvantage of this is that most of the tidal cuts in the region are heavily trafficked seaways.

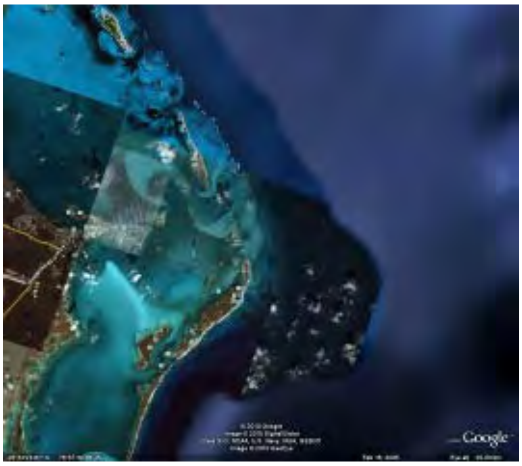

Figure 7-18: Man o War cay, Elbow Cay and Lynard Cay

Grand Bahama
There is a tidal channel between the western tip of grand Bahamas and Indian Cay. It appears to have a strong current but contains anchorage. The water depth at this location may also be too shallow with depths of under 3m SLW recorded in the channel.

Andros
There are several areas on Andros Island where tidal energy could be exploited but due to the remoteness and sparse population density, only one viable location was identified, the channel south of Big Wood Cay. This area may have significant flow and close to a population, but the area is a busy harbour and also may not have significant depth of water at low tide for installation of tidal energy extraction.

Bimini Islands
There are strong tidal currents in the passage between North and South Bimini; however this is the main access route to Alice Town harbour. There are also several tidal channels south of Nixon’s Harbour on South Bimini that merit more detailed study.

Figure 7-19: Bimini-Islands

7.2.4 Ocan thermal energy source

The assessment of the ocean thermal resource requires information about the temperature profiles down to at least 1000m over extended periods of time. The only data that was available came form the U.S. Navy Acoustic Test Range on Andros, Bahamas. Expendable Bathythermograph (XBT) casts have been made at a number of stations in the Tongue of the Ocean (TOTO). This data was available but required significant processing to load down from the website and formulate into useful data sets for analysis.

Data Acquisition

Ocean thermal energy conversion (OTEC) is a technology that exploits the oceans natural thermal gradient to produce electricity. The desired criteria for economically viable OTEC are a water temperature gradient of at least 20°C (36°F) between the sea surface and 1000 meters (3280 ft) depth. The unique bathymetrical character of the Bahamas, specifically the Tongue of the Ocean region, combined with year round warm sea surface temperatures makes the Bahamas an ideal location for OTEC development. With water depths of over 2000 meters occurring very close to the coastline and a large population base, the south west corner of New Providence appears to be the most suitable site to examine for OTEC development.

Two types of temperature data were obtained for analysis of the OTEC resource assessment, Expendable Bathythermograph (XBT) data and satellite sea surface temperature from Advanced Very High Resolution Radiometer (AVHRR). The former was sourced from the Atlantic Underwater Test and Evaluation Centre (AUTEC) and the latter from NOAA.

The XBT is a probe launched from a ship and allowed to freefall until the end of its reel upon which it disconnects from the ship. The probe is grounded by seawater so as soon as it hits the water surface it is activated and begins relaying data to the onboard processor. The parameters recorded include depth, measured by rate of descent to an accuracy of ± 2% and temperature, measured by a thermistor at the nose on the probe to an accuracy of ± 0.1C°.

The AVHRR measures surface temperature by radiation detection. Relying on 6 different detectors, it collects varying bands of radiation emitted from the earth's surface. Sea surface temperature is collected at resolution of 1km^2. One disadvantage of this type of data is that cloud interference can be quite significant it can be seen on the sea surface graphs as bright purple and blue patches.

Annual Temperature Variation

The Temperature vs Depth curves, Figure 7-20, Figure 7-21 and Figure 7-22 clearly show that temperature change through out the year occurs primarily at the upper 500ft of the water column. There is minimal variation between the samples analysed below this depth with the exception of the 20th July 2002 sample which appears to be approximately two degrees Celsius warmer between depths of 2000ft and 4500ft than the other samples.

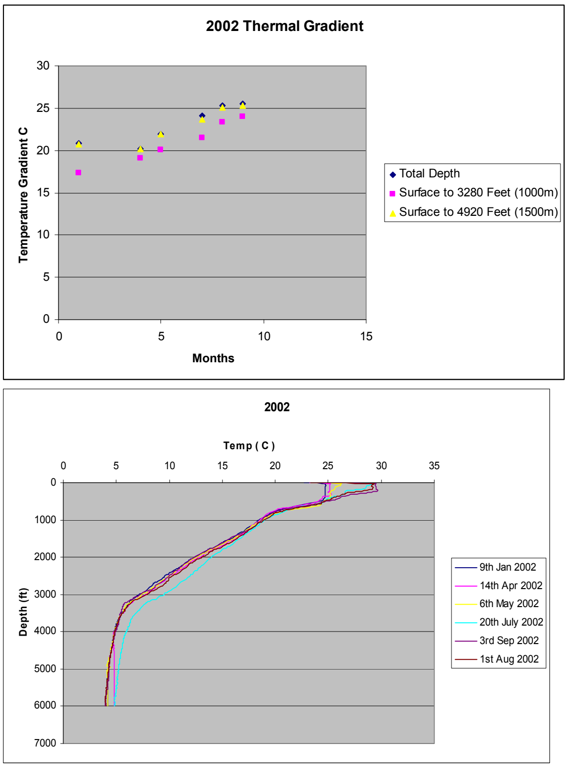

Figure 7-20: Temperature Gradient Profile for 2002

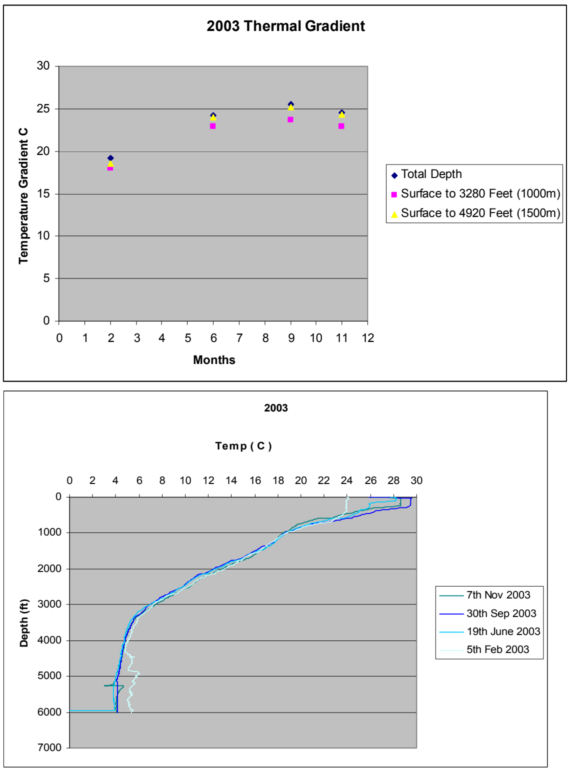

Figure 7-21: Temperature Gradient Profile for 2003

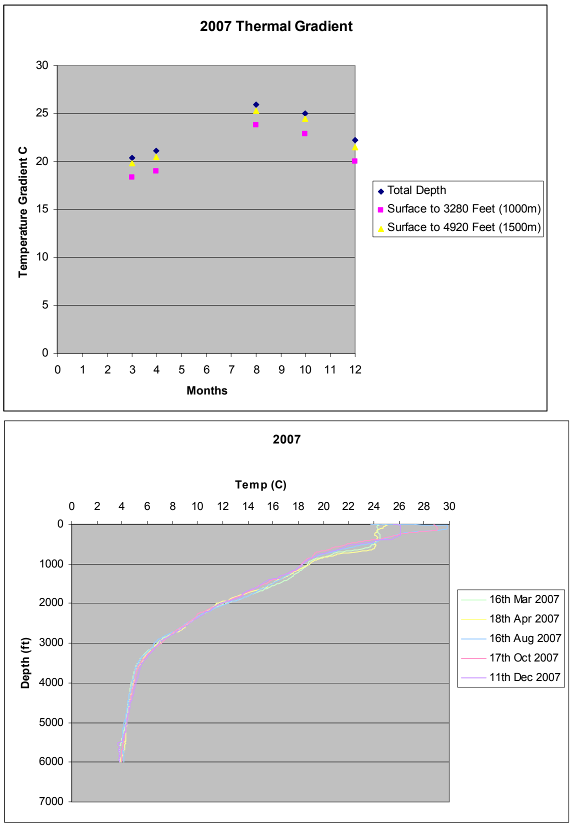

Figure 7-22: Temperature Gradient Profile for 2007

Figure 7-23: Locations of XBT measurements 2007

On initial observation of Table 7-4, the temperature difference between surface and sea bed appears to be above the required 20 Degrees C for feasible Ocean Thermal energy conversion (OTEC) for most of the year. However it has been recommended that for optimum operation of OTEC systems the deepest they should be employed is to 3280 feet (1000m) from the surface. This reduces the temperature difference by several degrees and significantly reduces the percentage of the year when the gradient is greater than required 20 degrees.

	2007	2003	2002
Depths of XBT	6000ft (1830 M)	6000ft (1830 M)	6000ft (1830 M)
Monthly Avg	Temp Difference C	Temp Difference C	Temp Difference C
January			20.09
February		19.28	
March	20.54	21.85*	
April	21.26	21.66	20.38*
May			25.94
June		24.47*	
July			24.01
August	25.70		25.3*
September		26.40	25.60
October	24.06	25.17	
November		24.58*	
December	22.11	22.6*	

*denotes a single survey reading in that month.

Table 7-4: Temperature gradient in Degrees Celsisus for depths of 6000 ft (1830m)

Sea Surface Temperature

Considering that the variation of temperature occurs close to the surface and below this temperature gradient between samples is relatively constant. The thermal resource fluctuates with seasonal temperature change i.e. the resource (thermal gradient) is greatest between the months July to November, with the lowest resource recorded in February.

A factor critical to establishing an economically viable OTEC plant in the Bahamas is its proximity to a large population base. A plant located in an area of optimal resource but in a sparsely populated area is not feasible. Ideally any OTEC plant would be located close to the capital city Nassau on the Island New Providence.

XBT data is not currently available for the Nassau coastal area or for the other large population centres on Gran Bahamas and Abaco. The data analysed in this report between 40km and 80km from Nassau. However, using sea surface temperature maps, it is possible to approximate the resource available in the vicinity of Nassau. These maps are reproduced in the Annexe to this report. An example is shown in Figure 7-24.

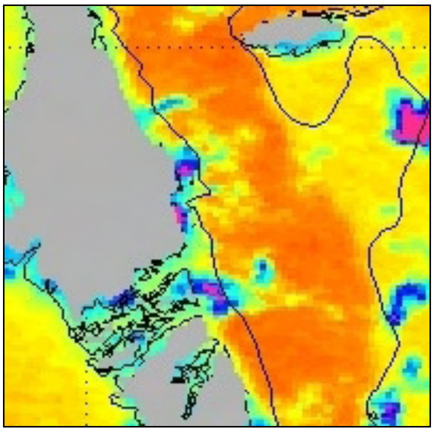

Figure 7-24: December 2007

Comparing the sea surface temperature around Nassau and at the recorded locations, only small variations are observed. However, there are localised cooler patches visible on some of surface temperature maps, for example the cooler areas around the south west of New Providence on 17th October 2007. These cooler patches are up to 5 Degrees cooler than the average surface temperature of the surrounding water body could be due to cloud interference with the satellite imagery.

It is difficult to assess the difference year on year as the availability of data is limited. For this averaged data, Table 1, the maximum difference between corresponding months in the years analysed (2002, 2003 & 2007) is 1.28 Degrees C.

Comparing the sea surface temperature maps from the 14th April 2002 and the 18th April 2007, it can be seen that there are only slight differences in the surface temperature. On both dates the recorded sea surface temperature off south west of New Providence was cooler compared with the surrounding area.

7.3 Technologies for ocean power

All of the technologies for the exploitation of the ocean energy resource are still at a development stage. Some of these technologies are close to commercial realization whereas others are still at the research and demonstration stage. No commercial plant for ocean energy conversion is available at present. It is expected that commercial devices will become available around 2014 and so it is prudent to consider these resources in any long term energy strategy study.

7.3.1 Wave energy technology

Wave energy has the highest density of any of the natural renewable energy sources. It also has large extreme forces compared to the normal which poses an engineering challenge. There is no single system concept for wave energy conversion and many different device types are under development. The devices being proposed fall into three main categories:- (i) Oscillating water column systems, (ii) Mechanical float based systems and (iii) overtopping systems. These devices can be mounted in the seabed at or near the shoreline or alternatively be floating and located away from the shoreline. All of the devices are modular with unit sizes of around 1 to 2 MW and so, like wind turbines, these must be deployed in farms to produce power plant scale installations.
The principles of operation for the different types are outlined below with examples given of the more advanced prototypes under development.

Oscillating Water Column Devices
The principle of operation is that the device consists of a large chamber which has a submerged opening acted upon by the wave motion. The large chamber houses a trapped air volume which is alternately compressed and expanded by the wave pressures. The air is then forced into and out of this plenum chamber to the atmosphere through an air turbine. This air turbine rotates in the same direction irrespective of whether the air flow is into or out of the air chamber. The turbine runs at high speed and is connected to a generator directly producing electricity.

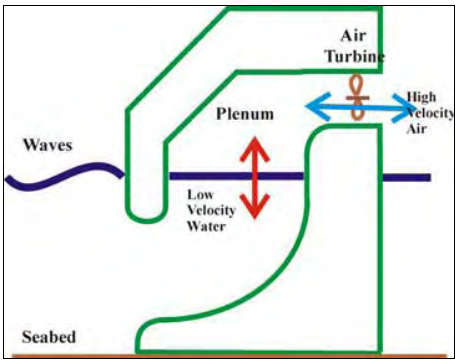

Figure 7-25: O.W.C. Principle of Operation

The Limpet Pilot Plant in Scotland (see Figure 7-26) and the Mutriku breakwater OWC (see Figure 7-27) have both been developed by Wavegen Ltd. (www.wavegen.com) and they expect to construct a new 4MW system at an offshore island in Scotland soon. The shoreline fixed units or breakwater systems must be constructed in situ but they can benefit from co-financing from the construction of the infrastructure. The Limpet plant has been operating for 80,000 hours.

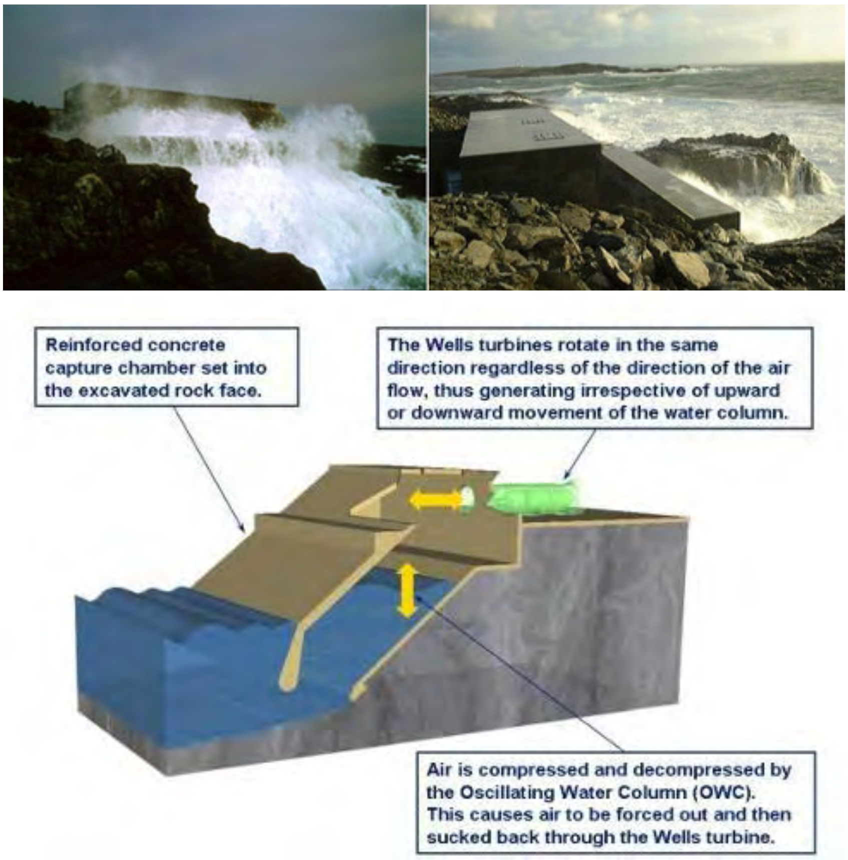

Figure 7-26: Limpet 500 kW Islay-Scotland

Figure 7-27: Mutriku OWC Breakwater – Bilbao, Spain

The Ocean Energy Buoy, which is under development by OE Ltd (www.oceanenergy.ie), is a floating OWC which can be constructed in a shipyard and towed to site for installation (Figure 7-28). They are constructing a 1MW prototype for testing and expect to produce 2MW commercial units in 2013.

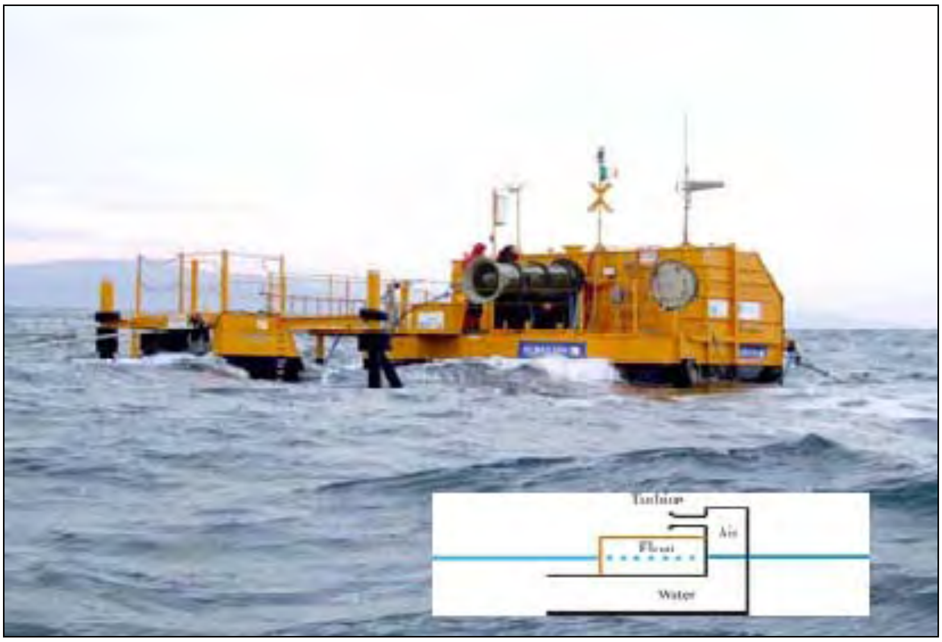

Figure 7-28: OE Buoy Floating OWC, Ireland

Mechanical Float Systems

The mechanical float systems work on the principle of utilizing the relative motion between a number of floats or between the float and a seabed connection. The power conversion system consists of either a closed loop hydraulic system where rams drive oil through a hydraulic motor coupled to an electrical generator or a direct drive electrical linear generator. The free floating systems can have all surface floats like the Pelamis or surface and submerged floats like the Wavebob or OPT devices. The systems which are connected to the seabed either react vertically against a seabed anchor like the SeaBased system or surge horizontally around a bottom mounted hinge like the Oyster.

The Pelamis (sea snake) (www.pelamiswave.com) device consists of a number of horizontal cylindrical floats hinged together (see Figure 7-29). Each float is about the size of a railway carriage and there are hydraulic rams attached to the hinges. Relative movement at the hinges causes oil to be pumped in a circuit where a hydraulic motor/generator produces electricity. The test machines deployed in Portugal had operational and financial difficulties and so were recovered after only a short duration test. Three new demonstration machines have been purchased by E-ON for testing in Scotland and the company can be expected to produce 1 MW commercial devices in 2013.

Figure 7-29: Pelamis – Three 750 kW machines in Portugal

The Wavebob (www.wavebob.com) device consists of a large submerged float which remains relatively stationary and the surface toroid (donut) float moves vertically under wave action (see figure Figure 7-30). There are hydraulic cylinders connecting the two floats and the relative motion pumps oil in a closed circuit with a hydraulic motor/generator producing electricity. A grid connected pre-commercial demonstration unit with an output of around 500kW is to be constructed in Portugal by 2011.

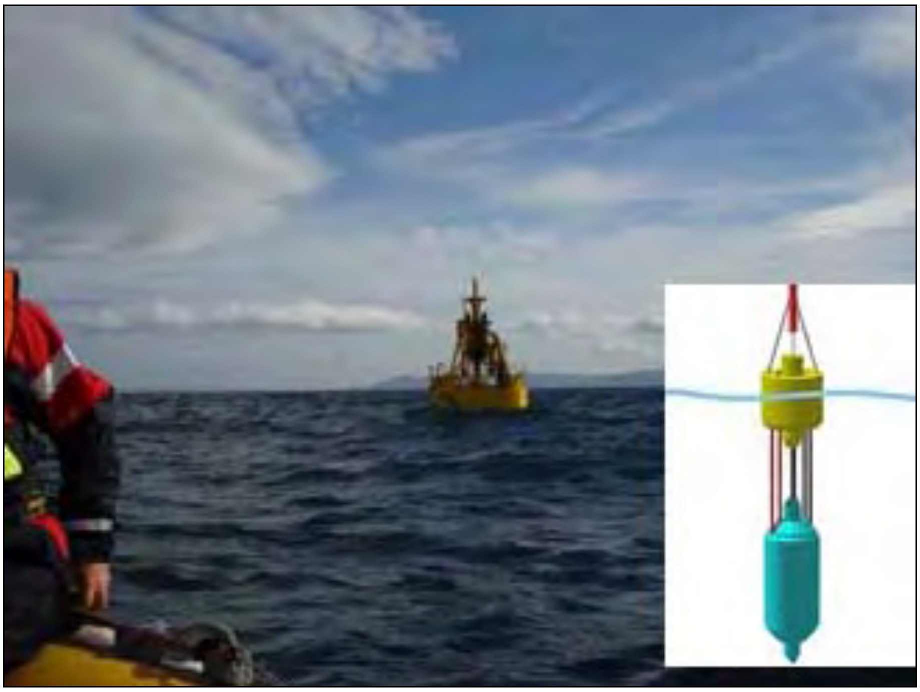

Figure 7-30: Wavebob - Ireland

The OPT (www.oceanpowertechnologies.com) device is similar to the Wavebob in operating principle except that the submerged float is also restrained by a damping plate (see Figure 7-31). They have been testing the PB40 a 40kW device in New Jersey, U.S.A. for some time and recently deployed a similar unit in Hawaii. They are in the process of constructing further PB40 devices in Scotland and are seeking permits for a PB150 device in Oregon State, U.S.A. A fully commercial device cannot be expected before 2013.

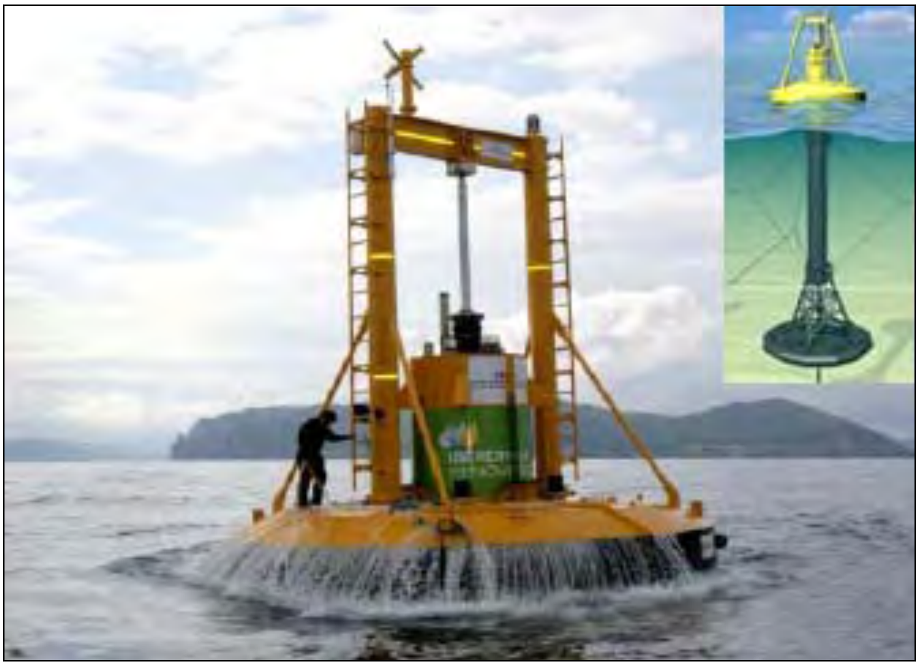

Figure 7-31: OPT Device deployed in Spain

The Oyster Device (www.aquamarinepower.com) has been developed by Aquamarine Power Ltd. This is a seabed mounted flap which moves horizontally as the waves act on it. The flapping motion then pumps sea water through a series of pipes to a hydro-generator onshore where electricity is produced (see Figure 7-32). There are no electrical components placed offshore and the device can be laid flat on the seabed in survival mode. They have deployed a 200kW unit at the Orkney Islands, Scotland and are working on the production of a larger scaled up unit to be installed in 2011.

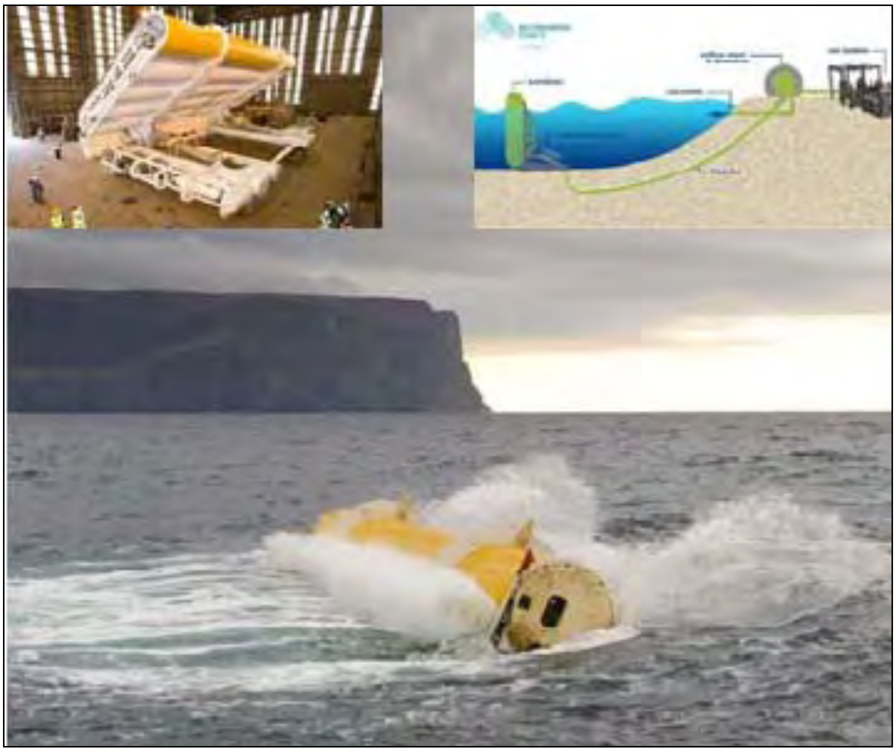

Figure 7-32: Oyster 200 kW device in Orkney, Scotland

The Seabased (www.seabased.com) device has been developed from research at Uppsala University, Sweden. It consists of a simple float connected to a seabed mounted generator (see Figure 7-33). This generator is a direct drive linear generator which produces electricity from the vertical mechanical motion of the float. The device can produce 10kW and ten of these have been deployed at a test site in Lysekil, Sweden, There are plans to install about 200 larger units to create a power station of 5MW in 2012.

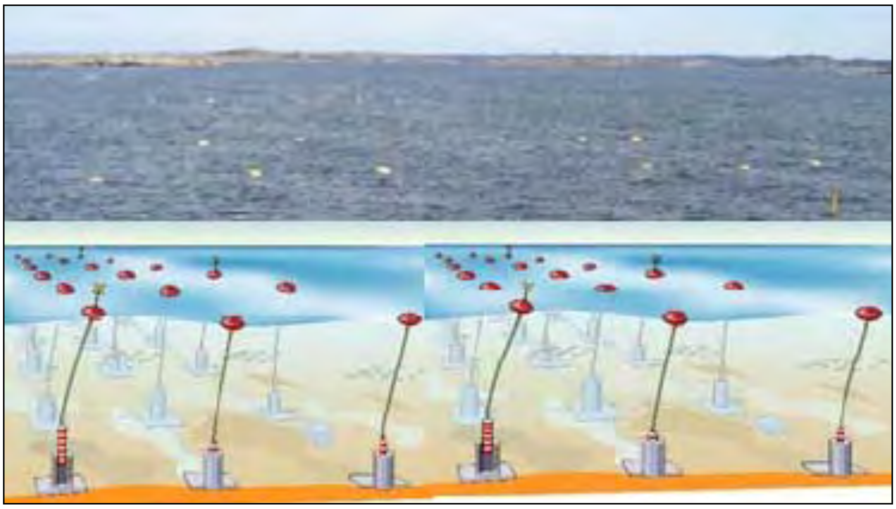

Figure 7-33: Seabased -10 kW units, Lysekil, Sweden

Overtopping Systems

The overtopping systems work on the principle of the waves driving water directly up a sloping beach into a large reservoir. This reservoir is above the mean sea level and the stored water then returns through a conventional low head hydro-turbine to generate electricity. The reservoir can be formed at the seashore or be contained in a floating system. One of the advantages of this type of system is that it incorporates a short term smoothing of the power output by storing water in the reservoir. The disadvantage is that the volume of the reservoir has to be large to yield significant power output.

The shore based overtopping system Tapchan was installed in Toftestallen, Norway in the 1980s (see Figure 7-34). The construction of such shore based systems is difficult and is limited to locations with suitable topography and small tidal ranges. The device operated for over three years generating electricity to the grid. Further systems were planned to be constructed in Pacific Islands but none were completed because of high capital cost.

Figure 7-34: 500 kW Tapchan, Toftestallen, Norway

In 1983 an overtopping system was proposed for Mauritius where an offshore coral reef exists forming a series of lagoons. The concept was to construct concrete ramps on the coral reef and to block exits from the lagoon to store the overtopping water. The stored water would then be returned to the sea through a series of low head hydro-turbines. This system was not constructed again because of high capital cost and potential environmental impacts. Similar schemes were proposed for the French Polynesian Islands of Maree and Tahiti but were also never constructed.

The Wavedragon (www.wavedragon.net) device consists of a floating reservoir with a curved beach contained between two arms designed to channel waves into the centre (see Figure 7-35). The waves push water up the beach to fill the reservoir and a number of low head hydro-turbines produce the electricity. A quarter scale prototype has been deployed at the Nissum Bredning test site in Denmark since 2003 and a full size pre-commercial demonstration project with a 5MW device is planned for Milford Haven, Wales in 2011.

Figure 7-35: The Wave Dragon Nissum Bredning Prototype

Figure 7-36: The basic principle of the Wave Dragon

7.3.2 Tidal stream technology

Tidal streams exist in a number of locations, even though the tidal rise and fall may be small. There are instances where the amphidromes exist but primarily they are generated by topographic features such as around headlands and in narrow channels between land masses. The tidal streams change direction during the tidal cycle and so conversion devices must be capable of dealing with this reversing flow.

The most common technologies for converting this flow into useful energy consist of devices similar to wind turbines. Propeller type turbines rotate when submerged and subject to the flow. The turbine must have some method to deal with the reversing flow but this only occurs about once every 6 hours.

There are two main types of turbine: (i) horizontal axis turbines, (ii) those with a vertical axes. The turbine can also operate in the free stream or be housed inside a duct.

Horizontal Axis Turbines

These turbines are similar to wind turbines in design except the speed of rotation is slower (about 10 rpm) and the diameter for a given power output is much less. A typical wind turbine will have a power density of around 500W per square meter whereas a typical tidal turbine will have an energy density of 4 kW per square meter of swept area. Some of the designs have blades with variable pitch to optimize the flow conversion whereas others simply reverse direction every 6 hours.

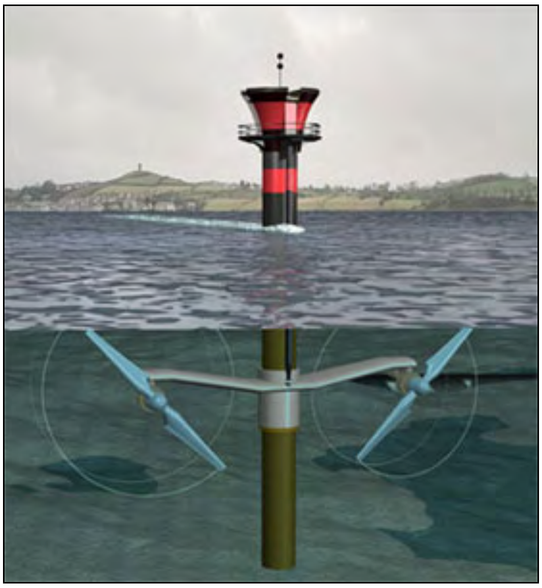

Figure 7-37: Seagen 1.2 MW device Strangford , Northern Ireland

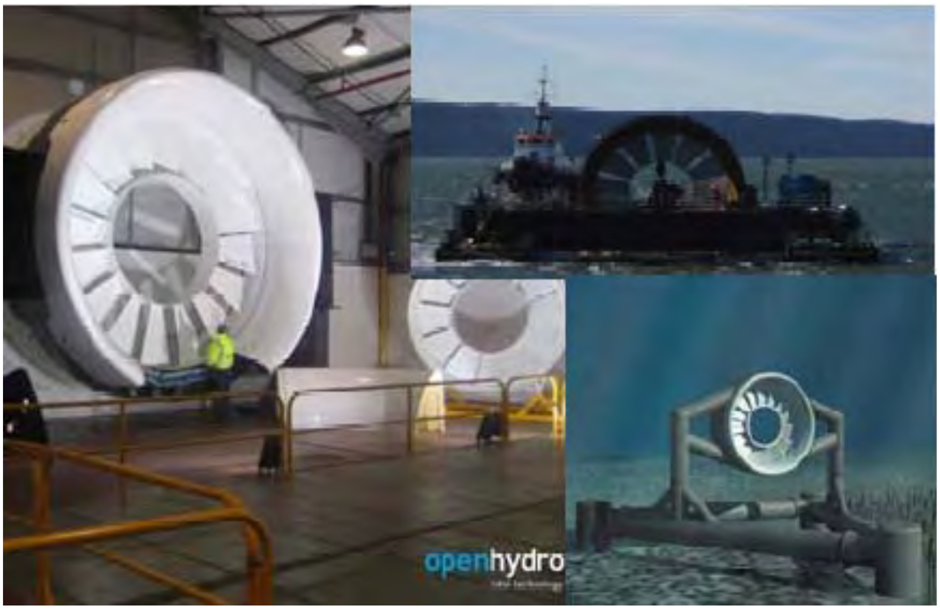

Figure 7-38: Open Hydro – 1 MW device, Bay of Fundy, Canada

The Seagen device (www.mct.com) has been developed by Marine Current Turbines Ltd and is the first large scale tidal turbine to be connected to the electricity grid. The device has two 16m diameter rotors each rated at 600kW. Each rotor is fitted with a gearbox and connected directly to an electrical generator. The turbine blades are fitted with the pitching mechanism which are altered every 6 hours to accommodate the reversing flow and allow the generators to run in the same direction all of the time. The whole assembly is mounted on an aerofoil shaped beam which can be raised above the water level for maintenance. MCT are in the process of seeking permits for a 10MW array of similar turbines to be deployed in Wales during 2011.

The Open Centre Turbine device (www.openhydro.com) has been developed by Open Hydro Ltd. This turbine has fixed blades and is fitted with a permanent magnet generator around the rim which removes the need for a gearbox. The turbine therefore changes direction every 6 hours and this is accommodated electrically. They have successfully completed a test program of a 60kW device in Scotland and proved the installation methods for their commercial support structure. The first 16m diameter 1MW machine was recently installed in Nova Scotia, Canada and a total of 4 machines will be installed at this site. Further commercial developments are under way in Scotland and France.

Vertical Axis Turbines

The vertical axis turbines can operate with fixed blades as they turn in the same direction whatever the direction of the flow. These turbines can have all of the mechanical and electrical generation equipment above the water level in the support structure. The support structure can be a fixed platform or can be a float. Power levels can be increased by increasing the diameter and also the depth of the turbine.

Figure 7-39: Enemar 40 kW turbine – Messina, Italy

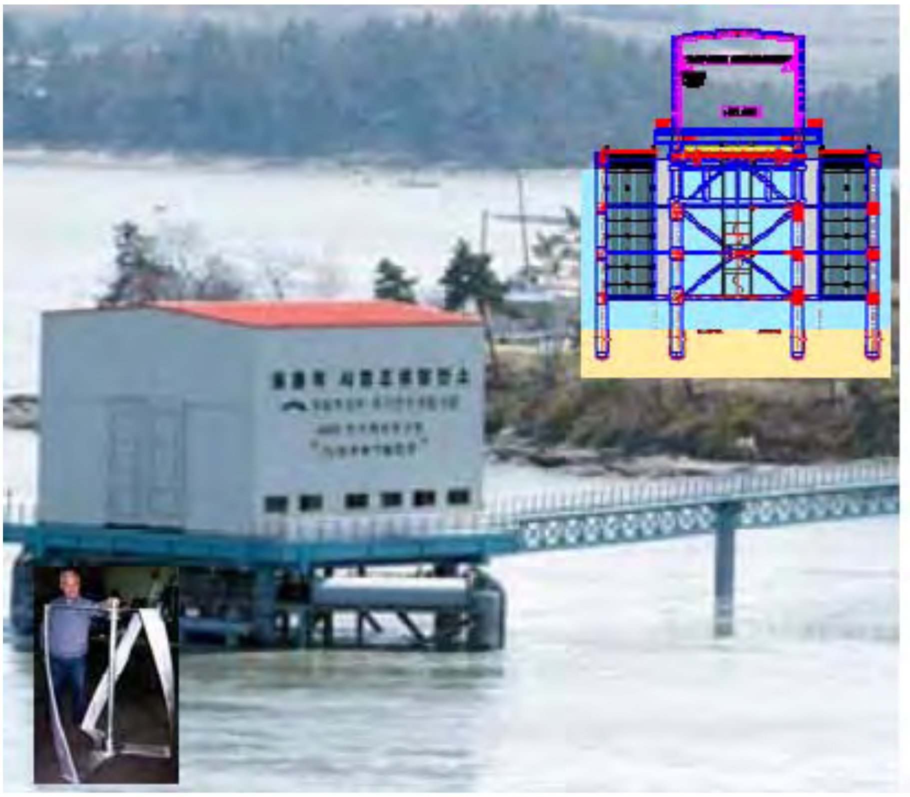

Figure 7-40: Gorlov 1 MW turbine – Uldolmok, Korea

Ponte di Archimede (www.pontediarchimede.it) have deployed a floating vertical axis turbine in the Straits of Messina. This device utilizes the Kobold rotor which has three vertical aerofoil blades which can feather during rotation and increase efficiency. The gearbox and generator are housed inside the float and the system is connected to the electrical grid. Contracts have recently been signed with Indonesia to construct a pilot plant funded by the UNIDO program.

The Korean Government has constructed a vertical axis tidal power plant in the Uldolmok Strait, Korea. This system is based on the Gorlov turbine which has vertical helical aerofoil blades which is a more efficient configuration than the conventional straight blades. The first installation is a large steel support structure which contains a number of rotors with an installed capacity of 1MW. There are ambitious plans to add further installations up to a total of 90 MW by 2013.

7.3.3 Ocean Thermal Energy Conversion (OTEC) Technology

The technology for converting the temperature difference between the deep ocean and the surface waters consists of a system to pump to cold deep water to the surface and utilize this in a heat engine together with the hot surface water. The principle has been well understood for many years but as the temperature difference is only 20^{o}C this low grade heat needs innovative heat engines to be economic.

In order to attain the temperature difference required, the cold water must be pumped from at least 1000m depth. The pumping energy for this is not so large as the hydrostatics means that only a few meters of head must be provided. The more important consideration is the construction of the deep water feed pipe which must be several meters in diameter as the volumes required for the system to operate are extremely large.
The OTEC power conversion system can consist of two main configurations – open cycle and closed cycle. In the open cycle system, sea water is flash evaporated by the warm seawater and the steam produced used to drive a turbine to generate electricity. The steam is then condensed by the cold seawater and the condensate is fresh water. This system has the advantage of producing potable water as well as electricity.

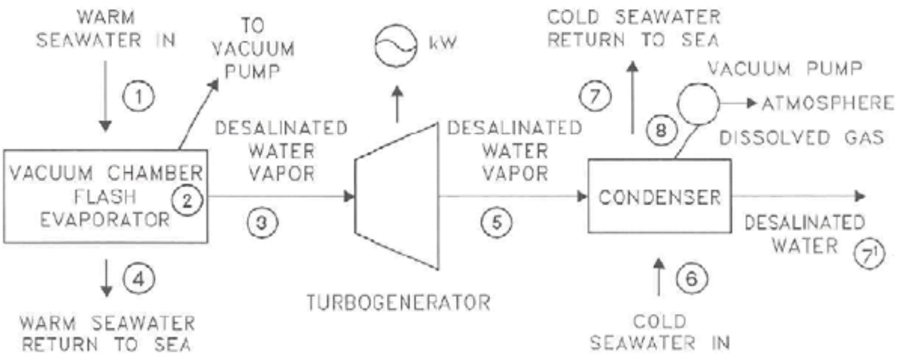

Figure 7-41: Open Cycle OTEC System

In the closed cycle a special working fluid is evaporated and condensed with the vapor being used to drive a turbine generator system. The warm surface water evaporates the ammonia or similar fluid which is then used to drive the turbine to generate electricity. The exhaust vapor is then condensed by the cold seawater for reuse in the evaporator.

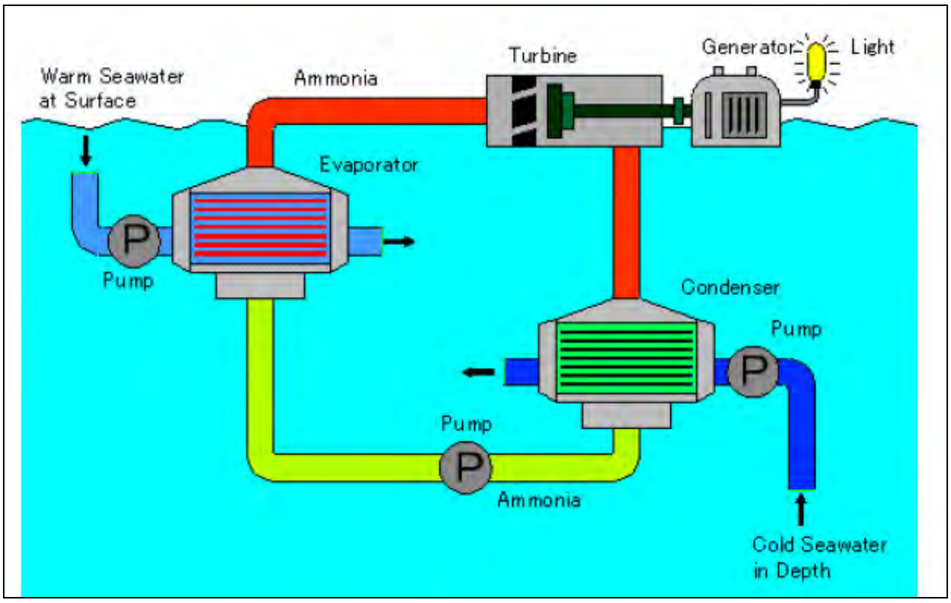

Figure 7-42: Closed Cycle OTEC System

The potential for harnessing this resource has been recognized for many years with the first attempts made in Cuba in the 1930's. Experiments were undertaken in Hawaii in the 1980's both with floating plant and land based units. These were abandoned because of the low oil price at the time.

Interest in OTEC has been renewed in recent years. India and Japan are now active in developing systems.

India

Figure 7-43: India 1 MW Floating OTEC Pilot Plant

A 1MW floating pilot plant has been constructed at a site in Tuticorin in South East India and placed 30km from the shore. This system produces a net power output of 500kW as the balance is used in pumping the hot and cold seawater. A total of 5000 tons per hour of cold water and a total of 7,500 tons of warm water per hour are required for the system. The cold water pipe is 100m long and has a diameter of 0.9m.

Japan

A new research centre has been established at Saga University Japan to study OTEC processes.

Figure 7-44: Saga University OTEC Research Centre

The researchers of Saga University are investigating more efficient heat conversion cycles such as the Kalina and Uehara Cycles as well as hydrid plant which are closed cycle with fresh water production. Japan has signed memoranda with a number of Pacific Islands as well as Mauritius to develop OTEC concepts for use.

U.S.A.

Lockheed Martin were involved in the technology development for OTEC in the 1980's. With the renewed interest in renewable energy and the increased oil prices they have re-entered the development activity. In 2008 they were awarded support from the U.S. Department of Energy to investigate new methods for construction of the OTEC systems

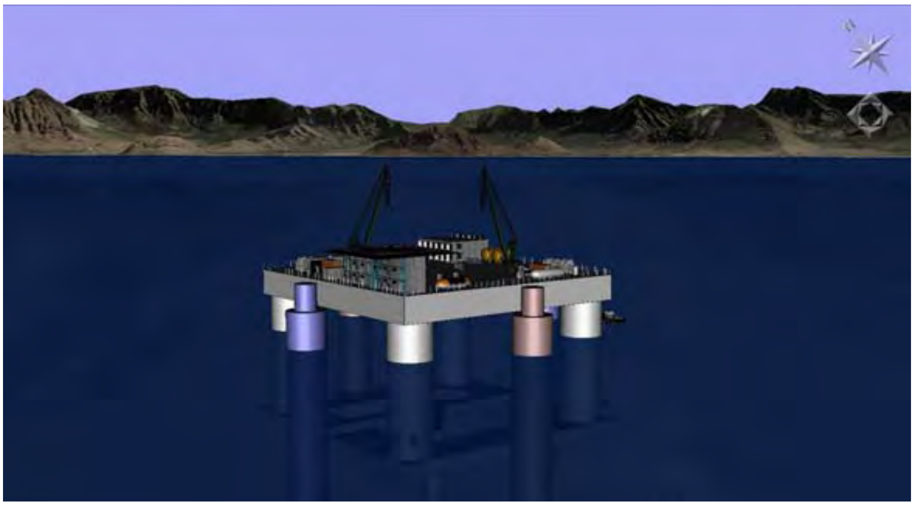

Figure 7-45: Lockhead proposed 10MW floating OTEC

7.4 Potential Sites

Wave Energy
The wave energy was studied at 10 sites extending along the coastlines from west of Freeport in Grand Bahama to Mayaguana Island. The sites are

located along the eastern boundary of the Bahamas and face the predominant wave approach directions.

There were four sites where the resource level was estimated at 10 kW per metre with the others being at around 8 kW/m.

This is about the same level as in the Southern North Sea in Europe where a number of development trials are ongoing.

Tidal Stream Energy
There were no available current speed data available for any of the sites identified in the Bahamas. A number of potential sites were identified in islands with significant populations to justify development.

These were – Eleuthra, Abacos and Great Exuma.

Ocean Thermal Energy (OTEC)
There were two main potential locations for the development of an OTEC plant - Gran Bahama and New Providence.

At both of these sites there was a temperature difference of more than 20 degrees C and for about 7 months the difference was above 24 degrees.

This makes these sites suitable for the development of OTEC power plants.

7.5 Initial environmental examination

The initial environmental examination should provide a first overview of the potential environmental impacts. These are in general difficult to quantify because such energy conversion plants have not been operated for extended periods of time. An additional gap with respect to the environmental impact evaluation is the fact that no dedicated locations have been chosen. This outstanding information are normally needed to identify possible environmental impacts because impacts are related to the surrounding environment. A less sensitive environment will cause normally no major impacts, on the other hand site, an environment with a high ecological value reacts much more sensitive regarding any disturbances to be caused be project to be implemented. In the following a first rough picture about possible environmental impacts expected from the operation of ocean energy plants is drawn.

Major general environmental concerns are expected from two aspects. The first aspect is the construction of the plants in the ocean. A specific work procedure is not available at the moment but it should be considered that the area where the plants will be fixed for permanent location should be as small as possible. Furthermore, it should be considered that no sea fauna or flora with a high ecological value should be effected, such as coral reefs which needs hundreds or thousands of years for growing. This should be a mandatory requirement for the construction phase and it should be supported by a baseline marine investigation considering the sea bed flora and fauna.

A much more interesting question is the subject if fishes, turtles or any other sea fauna could be affected be the ocean energy plants? Will it be possible that fishes, sea snakes or turtles will get effected be the turbines? If yes, no answer could be provided if this will effect only a small and limited number of species or if plenty of individuals will get lost.

In the following an environmental examination will be done with respect to the different possible technologies.

- Wave energy technology with the following possible types: (i) Oscillating water column systems, (ii) Mechanical float based systems and (iii) overtopping systems. These devices can be mounted in the seabed at or near the shoreline or alternatively be floating and located away from the shoreline.

  The most important environmental concern will result from the anchoring of the devices. Depending from the value and quality of the sea bed, the potential of an environmental concern will have a type specific significance.

- Tidal energy generation system with a difference regarding the location. One type of system will float on the surface of the sea and will fixed by an anchoring system on the sea bed and the second type where the system will directly fixed on the sea bed. The second type could cause in a higher environmental impact because the seabed will be more effected as in comparison to the one fixed only by anchors.

- A third technology is OTEC. The technology for converting the temperature difference between the deep ocean and the surface waters consists of a system to pump to cold deep water to the surface and utilise this in a heat engine together with the hot surface water. In order to attain the temperature difference required, the cold water must be pumped from at least 1000m depth. This system requires a kind of pipeline placed on the seabed. This is the most important difference in comparison to the other systems. The “pipeline” needs a corridor which must be cleared from obstacles prior to the construction. Depending from the environmental conditions the site preparation works could increase the amount of suspended solids which will effect the sea fauna and flora, e.g. corals. A second impact resulting from this technology is the effect that cold water will be discharged in an area of higher temperature. Marine fauna and flora with a high sensitivity regarding temperature differences could be affected but this is depending from the amount of discharge of cold water.

The only possibility to evaluate the sources of environmental concerns is to discuss all possible mechanical injuries with the supplier and to evaluate which measures are foreseen to limit such injuries or to avoid them. This discussion should involve not only the supplier and the technical consultant, even a marine biological expert should be asked to participate in this discussion and the prior mentioned marine baseline investigation shall form an integral part within this discussion.

The results this expert round is assumed to be a decision board for the development of the scope of work for the needed environmental impact assessment. Even if it possibly not foreseen or considered by law to execute an EIA for the ocean energy plants, it is recommended to undertake these studies because they are not common project used since many years.

7.6 Summary

The data sources for this study were considered adequate for an initial assessment but the accompanying data report (to follow) highlights certain areas where further data would be helpful before any development decisions were made. In particular some confirmation of the sea surface temperature data near New Providence and some tidal flow measurements in Eleuthra and Abacos would be required,

Resource Assessment
The sections above highlight the sources and analysis of the ocean data.

Wave Energy

The wave energy was studied at 10 sites extending along the coastlines from west of Freeport in Grand Bahama to Mayaguana Island. The sites are located along the eastern boundary of the Bahamas and face the predominant wave approach directions.

There were four sites where the resource level was estimated at 10 kW per metre with the others being at around 8 kW/m.

This is about the same level as in the Southern North Sea in Europe where a number of development trials are ongoing.

Tidal Stream Energy

There were no available current speed data available for any of the sites identified in the Bahamas. A number of potential sites were identified in islands with significant populations to justify development.

These were – Eleuthra, Abacos and Great Exuma.

Ocean Thermal Energy (OTEC)

There were two main potential locations for the development of an OTEC plant - Gran Bahama and New Providence.

At both of these sites there was a temperature difference of more than 20 degrees C and for about 7 months the difference was above 24 degrees.

This makes these sites suitable for the development of OTEC power plants.

Potential for technologies

Wave Energy

Given that the level of the wave energy resource is around 10kW/m it would be expected that the economic costs of the electricity produced by wave energy convertors would be high. There is no limit to the level of the theoretical resource as it occurs extensively along the eastern coast. It would be important to match the electricity demand centres to the resource and so it would be expected that small scale installations relevant to the outer islands would be most appropriate. The practical resource would therefore be limited.

Devices like the Seabased machines with unit sizes of around 15kW could be relevant here, the devices designed to produce large power units would probably be located too far from the load centres to be economic as the sites are remote from the main population centres. The expected cost of electricity from these devices after the development has been completed is around the same as that of offshore wind turbines. The costs at this time are highly speculative as no commercial machines have been produced. Estimates of the CAPEX come out at up to $5,000 per MW and the LCOE estimates vary from $0.13 to $0.30 per kWh when large scale deployments have taken place worldwide.

The timescale for first availability of commercial machines is estimated to be after 2015.

Tidal Streams

It is difficult to estimate the potential for the development of tidal stream resources in Bahamas as there are few sites with high flow velocities. The sites that do exist may be restricted by needs of navigation and other constraints. The costs of tidal stream generators will come in at about the same value as that of wave energy convertors. Again the devices will not become commercially available until around 2012/2013. The advantage of the tidal stream resource is that it is highly predictable and small scale deployments may be suitable to remote communities.

OTEC

There are two sites where there could be development of OTEC systems. These are located near large population centres. One is west of New Providence and the other is west of Grand Bahama, The temperature differences measured were above 20 degrees centigrade which suggest that multi megawatt installations could be feasible. The electricity produced by an OTEC plant is base load and so the installation must be sized to fit into the island grid receiving the power. In the case of New Providence a maximum plant size of around 50 MW could probably be considered.

The development of OTEC technology is ongoing and there are no commercial systems operational at present. The current estimates for CAPEX are in the region of $ 8,000 per MW with LCOE estimates between $0.16 and $0.20 per kWh. Commercial power plant development is ongoing in U.S. at present in particular by Lockheed Martin. They expect power plants to be available commercially within the next 5 years.

Conclusion

It is concluded that the most suitable technology for large scale power supply from the ocean in Bahamas is OTEC with a potential installed capacity of several 10's of MW. There could be opportunities to provide power for some of the Family Islands from wave and tidal streams but more detailed matching of the resource to the electricity demands would be necessary.