Willis_Major Project. Feasibility study on tidal range power plant at UWTSD's SA1 waterfront campus

by Bruce Willis

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University of Wales Trinity Saint David

Faculty of Architecture, Computing and Engineering

School of Engineering

Energy and Environmental Engineering

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Bruce Willis

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A feasibility study on producing electricity from tidal flows at UWTSD's new SA1 campus

Declaration of Authenticity

'This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has lead to the award of a degree.'

Signed: Bruce Willis Date: 30th April 2019

Abstract

This report examines the feasibility of generating electricity at the tidal basin at UWTSD's purpose built SA1 waterfront campus. To guide this study, a description of how tides are generated, and an analysis of the existing tidal projects is presented to determine the benefits and shortcomings of existing production methods. Other equipment that could be used to harness the tides is assessed, as are optimisation techniques relating to energy and income optimisation.

The data pertaining to the tidal range over the past four years was processed using MATLAB, the dimensions of the tidal basin measured, and therefrom the potential electricity generation estimated. The land ownership at the project's site and the legal steps to be followed should the project be materialised are provided. The financial support for such a project is researched and the estimated savings in electricity costs are calculated, as are the project's cost of equipment, installation, operation, maintenance and civil works. These are used to calculate the payback period, levelised cost of electricity and return on investment, which are deciding factors on the project's feasibility. This report concludes that the small tidal basin on UWTSDs campus can produce enough energy to cover the University's base needs, or approximately 80 homes, with its 300MWh annual production. The tidal range project is further economically feasible, but is plagued by an extenuatingly long pay-back period (approximately 20 years for the UWTSD basin), after which returns of 5% can be expected.

This report conducts an assessment on the environmental impacts of such a project- which are minimal for this pre-existing basin- and estimates the pollution that this project would offset if it were to replace electricity generation from a fossil fuel power plant. The annual pollution that can be offset by implementing this project comes to 137.7tons of CO_2, 123.3kg SO_2 and 111.9kg NO_x.

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1 Introduction

1.1 Aims and objectives of project

This report assesses the feasibility of economically producing electricity at the tidal basin on UWTSD's new SA1 waterfront campus from the regular tidal flows. A report from 2015 suggests that "*the potential for smaller scale, local tidal power generation from shallow near-shore sites has not yet been investigated*" and could further "*have the potential to provide sustainable electricity for coastal homes and communities as part of a distributed generation strategy, and would benefit from easier installation and maintenance, lower cabling and infrastructure requirements and reduced capital costs when compared with larger scale projects*". (Roberts, et al., 2016)

This project aims to measure the exact size of the tidal basin, and to gather data on the variations of the tidal ranges to calculate the potential energy available to be harnessed. An analysis of the relevant methods to generate electrical energy will be conducted, with the respective costs and gains presented to decide the best choice of turbine. Moreover, research into the existing tidal projects will be conducted to guide this study. Considering the small size of the lagoon (when compared to industrial scale tidal projects) the electricity produced will ideally cover the base load at the Swansea Marina campus, or if gauged as more appropriate, exported to the grid.

The expected installation, maintenance and decommissioning costs, combined with the estimated savings from electricity production and governmental support, will be used to calculate the price of electricity per kWh. This will mark the financial feasibility of the project. If it is not deemed viable then an analysis of the minimum basin size needed for the project to be viable, assuming identical capital costs, will be done.

This project, if executed, will further diversify the energy mix and create a low-carbon, dependable electricity supply. The inspiration for this report arose from observations of the regular & pronounced sea-water level changes in the tidal basin, the energy from which is currently unutilised. The volume of water flowing through the sluice gate multiple times per day in both directions is sizable, and the author desires to harness this energy for human benefit.

1.2 Relevance of project

In the United Kingdom the current electrical peak demand is approximately 60GW, with power stations able to produce an estimated combined capacity of 90GW. Power stations scheduled to close by 2030 will create a loss of capacity by 35% in relation to 2010 levels- a loss of over 30GW. Since 2010, 26 power stations producing a combined 19GW have already closed. Simultaneously, the trend of electrifying transportation and heating will lead to a higher peak demand, creating an 'energy gap'. Furthermore, the UK has committed to ensuring that 15% (since increased to 20%) of its energy needs will be met by renewable sources by 2020 (EU Renewable Energy directive 2009), and has committed to reducing carbon emission levels in 2050 by 80% compared to its 1990 levels (Climate Change act 2008), leading to the need for low-carbon energy production. New low-carbon power stations must be built combined with an increase in efficiency so that the power generated reaches its end target, instead of being dissipated. A diverse energy mix, action on energy efficiency, demand management and smart grids are key to solving the power gap in the UK, as renewable energies such as wind and solar are characteristically intermittent. (EDF, 2018)

Guiding the discussion on energy are three key concepts: (MacKay, 2009)

- Mankind's reliance on fossil fuels must diminish, considering they are a finite resource. Inevitably, they will be replaced by sustainable energy sources.
- Electricity is the foundation of modern civilization and its supply (though taken for granted) must be secured. Dependence on energy imports and thus other countries' foreign policy is risky especially given the uncertain outcome of a Brexit deal (or no deal). Security of energy supply is crucial considering the sustained global increase in demand.
- Fossil fuel emissions, undoubtedly, have a negative effect on the environment and are a source of anthropogenic climate change. Low carbon energy solutions are needed to replace the existing polluting power plants.

If this report demonstrates that small scale tidal power plants can produce electricity at competitive rates, then this is an energy solution that can be implemented in coastal areas across the UK and will benefit society by reducing reliance on fossil fuels, securing electricity supply (tidal energy is predictable and dependable), and reducing fossil fuel emissions. Though the scale of this project is small, if deemed feasible, it could be replicated in coastal areas around the entire UK (and in other locations around the world), contributing a zero-emission, sustainable portion of energy supply.

1.3 Timing plan

In order to ensure that this study was completed prior to the academic deadlines set by the university, the author created a plan to guide his steps over the 7-month period that this project was being investigated. Initially, the author brainstormed the various areas this project examines and created a critical path to ensure that the areas on which other parts are dependent were started first (Figure 1). Next, the author estimated the time needed to conduct each part of the report and calculated the earliest and latest dates by which areas of the project would be started/completed. This helped to create the Gantt charts shown in the following two figures.

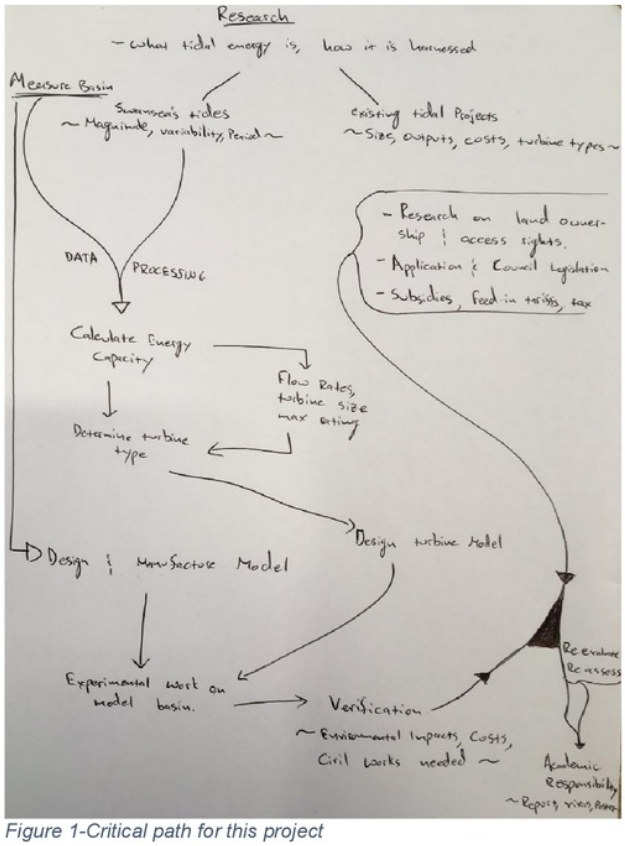


Figure 1-Critical path for this project

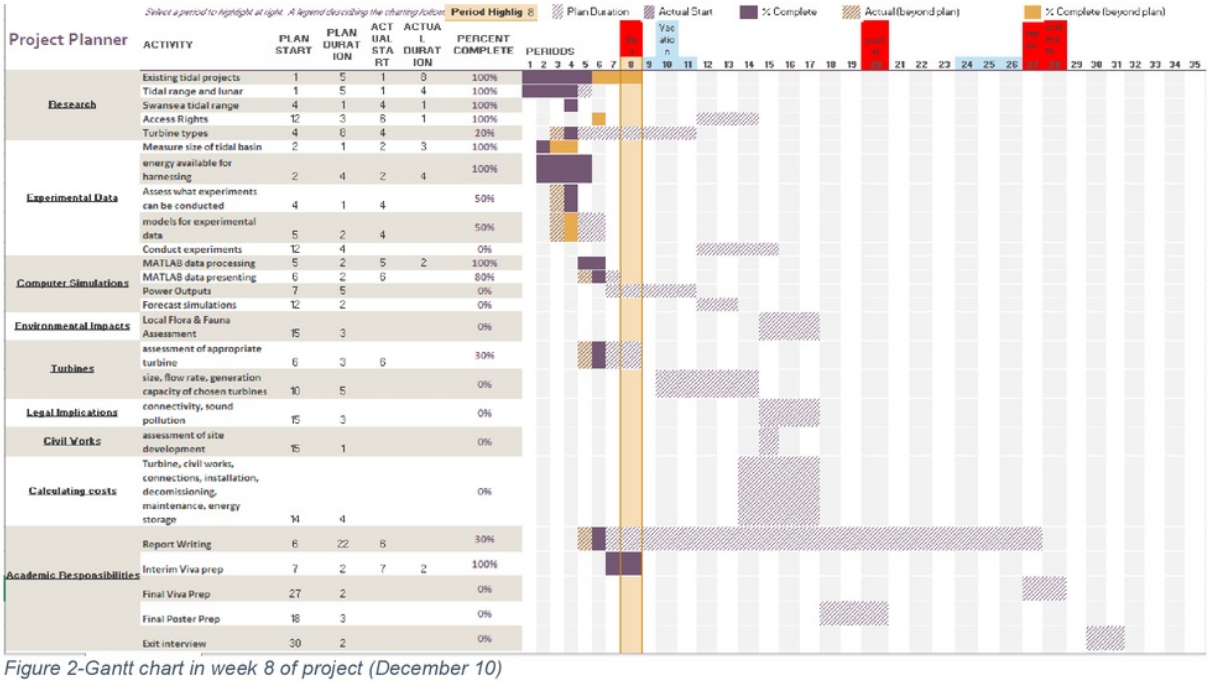


Figure 2-Gantt chart in week 8 of project (December 10)

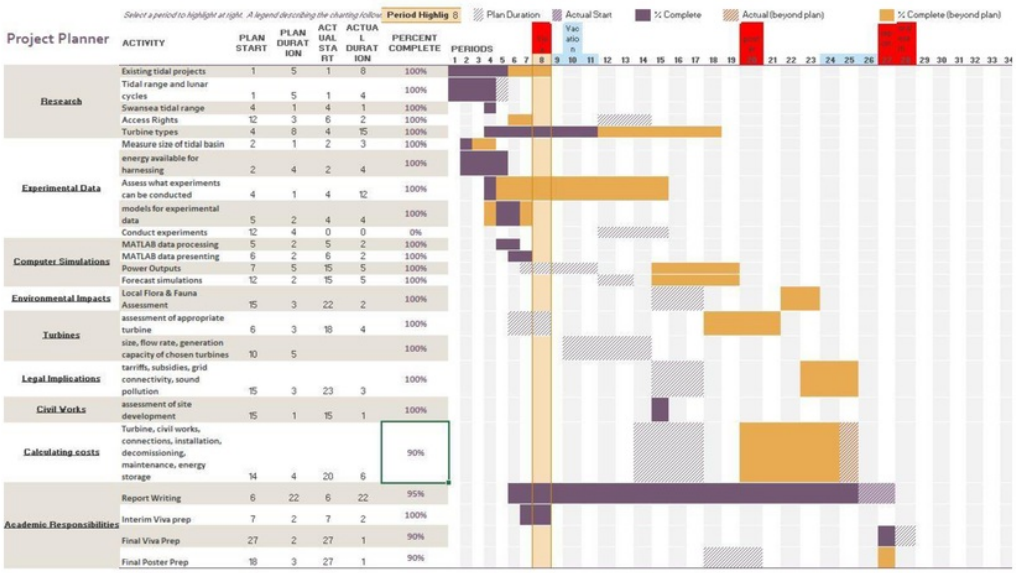


Figure 3- Gantt chart in April (week 26)

As is evident by Figure 3, the author did not uphold his own timing plan particularly well for a variety of reasons including:

- Underestimating the amount of time needed to complete a task,
- A weightier impact of the work-load from other modules and other obligations,
- Changes in circumstances surrounding specific topic areas,
- The unavailability of the university's CNC machine to manufacture a model,
- The time needed for external parties to get back to the author.

Despite not upholding the set plan, the author managed to complete some topics earlier than anticipated and managed to finish most subject areas prior to the Easter holidays. Furthermore, whilst not upholding the timings of the plan, it proved beneficial as it organised the author's thoughts and focus into specific topic areas. Moreover, the timing plan was aggressive in its targets, which encouraged the author to work harder once a milestone was missed- despite the milestone being an artificial one set by the author himself. The plan, finally, assisted the author's ability to maintain focus on the project, even at times when work was not actively done. With this mentality the author didn't need to 'restart' when he returned to the project, but instead picked up where he left off.

2 Research & Literature survey

2.1 The theory behind tidal power

The tides are caused by the gravitational attraction of the sun and moon on each water molecule, and the earth's rotation. Consequently, the sea water level and tidal range vary on a regular basis, with several factors affecting the magnitude of the tides: (Lynn, 2014) (Bernshtein, 1965)

- Coastal geography,
- Bathymetry (seabed geography),
- Earth's elliptical orbit around the sun,
- Moon's elliptical orbit around the earth,
- Sun's declination,
- Moon's declination
- Meteorology.

Newton's law of universal gravitation governs the magnitude of the forces incident on each water molecule in the Earth's oceans: (Kirk, 2007) (Frau, 1993)

Equation 1: $$F = G\frac{m_1 m_2}{r^2}$$

- F= value of attraction between two point masses
- G= $6.67*10^{-11}$ Nm^2kg^{-2} (gravitational constant)
- m_1 & m_2= magnitude of the two masses (celestial body & water molecule in ocean)
- r= the distance between the two masses.

Figure 4 and Figure 5 demonstrate the periodicity of the tides based on the relative location of the celestial bodies.

A spring tide (maximum tidal range) results from the gravitational forces of the moon and sun being aligned; this occurs briefly after the new moon and full moon.

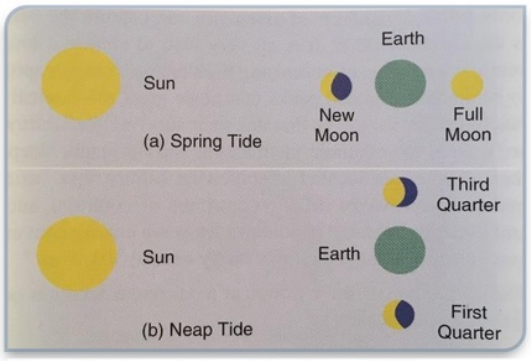


Figure 4-Spring and Neap Tides (Lynn, 2014)

A neap tide (minimum tidal range) results from the gravitational forces of the celestial bodies being perpendicular to each other; this occurs briefly after the first & third quarter of the lunar cycle.

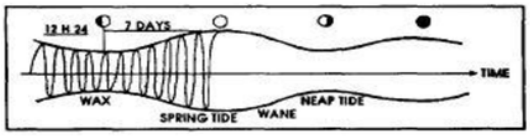


Figure 5-Tidal variation over a lunar month (Frau, 1993)

The moon's attraction is approximately double the sun's due to the square relationship for distance and the moon's proximity to the Earth. The distance between the sun, moon and earth are not constant, as seen in Table 1, due to elliptical orbits and the varying 'tilt' of the moon- termed the apogee (far) and perigee (near).

Table 1-Mass and Distance of Sun, Moon, Earth. (Williams, 2017) (Williams, 2018)

	Earth	Sun	Moon
Mass (kg)	$5.97*10^{24}$	$1.99*10^{30}$	$7.35*10^{22}$
Distance (m)	0	$(147\text{-}152)*10^{9}$	$(3.57 - 4.07)*10^{8}$

It is only every 18 years (233 lunar months) that the sun, moon and earth all return to the exact same position, termed the Chaldean period. The variation in tidal magnitude over this period is approximately 5%. Bernshtein concludes that a full study over 18 years is not needed to completely analyse the intra-monthly tidal inequality; rather, the design tidal period can be taken as equal to the lunar month. (Bernshtein, 1965)

The tides that result from the previous considerations, and some of the locations where they occur:

- Diurnal (one high and low tide each lunar day), [China sea, Tahiti]
- Semi-diurnal (two high and low tides each lunar day), [Bay of Fundy, Bristol Channel, French coast]
- Anomalistic (vary due to elliptical nature of moon's orbit),
- Mixed tide or no tide [Mediterranean, Saigon].

The lunar day is 50 minutes longer than the solar day so two tidal cycles to occur in a 24 hour and 50 minutes period.

The tides in Swansea are semi-diurnal, with the tide advancing (flood) for (on average) 6 hours and 12 minutes, followed by a retreat (ebb) for 6 hours and 12 minutes. The moon's angular offset (*declination*) in relation to the Earth's equatorial plane causes the two tides each day to be different in range. (Bernshtein, 1965) (MacKay, 2009) (Lynn, 2014)

The data for the tidal range in Swansea is available but needs to be purchased. The author collected data from the Swansea Marina instead, and processed it using a script he generated in MATLAB. The full process and resulting information can be found in Section 3.1.

2.2 Electricity Production from Tides

Many methods have been researched and tested to produce useful energy from oceans including: tidal range, tidal stream, wave energy, thermal energy and salinity gradient. Of these, only tidal range and tidal stream pertain to the tides and may provide useful insights guiding the discussion in this report. These are presented below.

2.2.1 Tidal Stream

This technology uses the kinetic energy of the colossal volumes of water that move during each tide. This technology is still novel and is predominantly in the theoretical, design or testing stages with the first large-scale project in Scotland providing electricity to the grid for the first time in 2016 (Embury-Dennis, 2016). Different methods of generating electricity from tidal streams include variations of: tidal turbines (axial and cross-flow), oscillating hydrofoils, tidal fences, and tidal kites. The power produced per square metre of the device's frontal area in a free stream flow can be mathematically derived using actuator disc theory (momentum theory): (Roberts, et al., 2016) (Rourke, et al., 2010)

Equation 2: $$Power\ Density\ (^{W}/_{m^2}) = 0.5 * \rho * C_p * v^3$$

Where ρ is the water density (1025 kg/m^3), C_p is the power coefficient of the turbine and v is the free stream flow speed of the water.

Many companies are utilising the knowledge generated from wind turbines, hence the similarities of many designs to wind turbines. Tidal stream technologies utilise slower flow rates than wind turbines and operate at lower rpm. The higher density of water than air (1025 kg/m^3 for sea water vs 1.25 kg/m^3 for air at standard temperature & pressure) allows tidal stream turbines to produce similar outputs with a lower blade diameter. Depending on the technology used the deployment depth differs, however for the following companies the deployment of tidal stream technology occurs at depths between 30-100meters.

The companies at the vanguard of this sector are:

SIMEC Atlantis Energy with the Maygen Project in Scotland that has already exported over 12GWh to the grid. (McPhee, 2019) Atlantis Energy uses a three bladed turbine resembling a wind turbine, as shown in Figure 6.

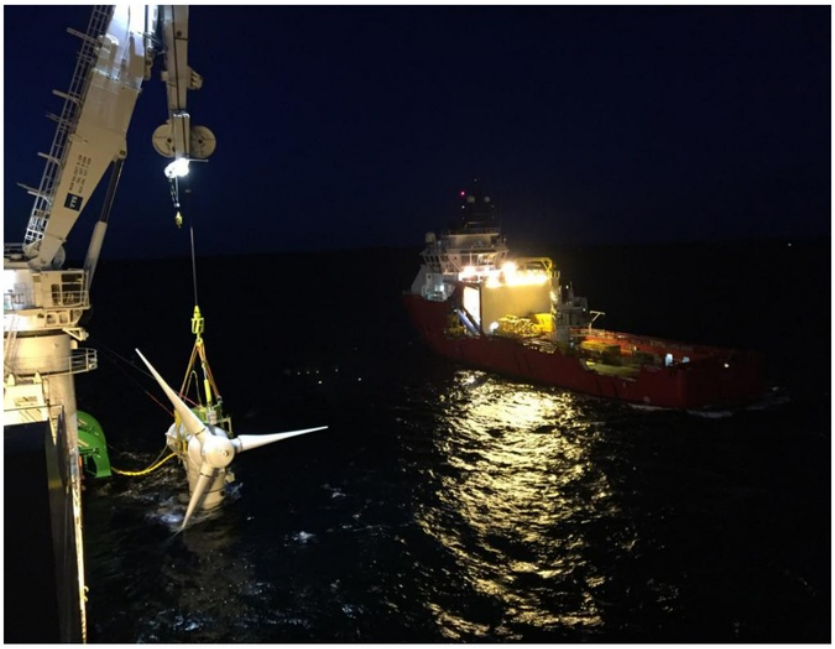


Figure 6-MeyGen Tidal Stream Turbine. (SIMEC ATLANTIS ENERGY, 2019)

Orbital Marine Power have developed floating technology equipped with two turbines for a combined output of 2MW, and which needs no specialist vessel for installation and maintenance (Figure 7). They recently (1st quarter of 2019) closed a debenture for 7 million GBP for further development of their prototype, and have rebranded from their original name of Scotrenewables. In less than one year of testing at EMEC in Orkney their SR2000 exported 3GWh of electricity to the grid; more than the energy produced from all other wave and tidal devices combined over the previous 12 years. (Keane, 2018)

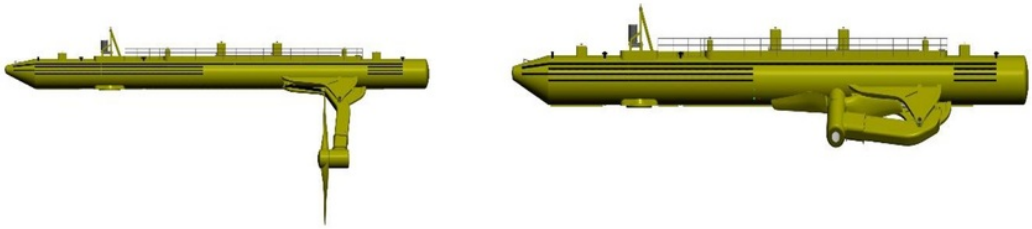


Figure 7-SR2000 in operation mode (left) and transport mode (right) (Orbital Marine Power, 2019)

Other companies and turbine manufacturers with tidal stream technology in various stages of development include: Andritz Hydro Hammerfest (Norway), OpenHydro (Ireland), Pulse Tidal [hydrofoils] (Sheffield), Tidal Energy Ltd (UK), Ocean Flow Energy (UK), Verdant Power Ltd (Canada), GCK Technology Inc. (USA), Lunar Energy Ltd (UK), Atlantis Resource Corporation Ltd (Singapore), Tidal Generation Limited (Nantes, France). Most of this cutting-edge technology is tested at the European Marine Energy Centre (EMEC) in Orkney with varying results. (Lynn, 2014) (Rourke, et al., 2010)

This section provides a useful insight into the technology currently being developed and deployed to generate electricity from the kinetic energy of the oceans' tidal movements. **It appears that tidal stream technology is not applicable for this project due to the typical deployment depth of 30-100 metres, and turbine diameters of 20 metres when compared to the shallow nature of Swansea's bay. Moreover, the variable loads that will act on the turbine blades in a tidal range setting where there is a variable head arising from the tidal basin filling and emptying will cause different stress concentrations which must be engineered into alternative designs**. Tidal stream technology has benefited from high levels of investment recently, and useful insights from this sector can be gained for tidal range power production such as managing the supply of electricity exported to the grid, generating electricity in offshore locations and the effects that predictable yet sporadic production will have on other power plants.

The following section researches the existing tidal range power plants.

2.2.2 Tidal Range

This technology generates electricity when there is a head difference between the two sides of a barrier that separates the sea from an enclosed basin. Typically, a barrage is used to separate the sea from the basin and electricity is generated on the ebb (from water captured in the basin towards the sea), the flood (water flowing into an empty basin) or bi-directionally as shown in Figure 8. Horizontal axis, low-head, variable-speed turbines are encased in the barrier, which operate when the hydrodynamic head is large enough (typically 1-1.5 metres), and cease producing when the two water levels are near equilibrium. This technology is mature and proven, though globally only 5 sites produce electricity from tidal range. This is because the capital investment is high to construct a barrage across an entire estuary. (Baker, 1991)

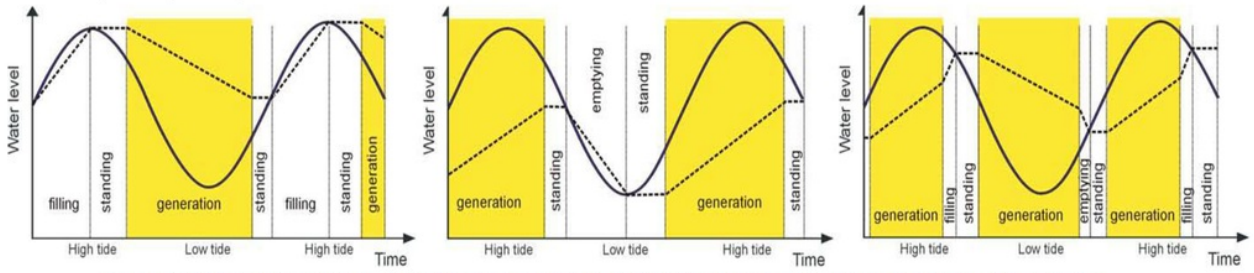


Figure 8--Ebb Production (left), Flow production (centre), Bidirectional production (right). Solid curve is sea water level, dotted line is basin water level. (Bae, et al., 2010)

Tidal lagoons have gained recent publicity, as they can be scaled to the desired size, have less environmental impacts than barrages and produce more energy per unit area of the basin's surface. Other designs have been developed, such as tidal reefs (similar to tidal fences mentioned in tidal stream section, but maintains a low (2m) head on either side of the barrier), but no plans exist to implement them. It is understandable why tidal stream technology has been given higher levels of investment when compared to tidal range schemes, as tidal stream projects have comparably minimal civil development costs. (Roberts, et al., 2016) (Waters & Aggidis, 2016)

The output of a tidal range scheme is temporally dependent on the times of high and low tide (Figure 8). To produce electricity on demand and export it to the grid at peak moments, multiple basin schemes have been suggested, where water is trapped in one basin at high tide and energy is produced when the water is allowed to flow into the second basin at the time of choice. These are not relevant to this report, as there is only one basin available at the UWTSD campus.

Furthermore, electricity production can be maximised by adding a pumping stage at high/low water, where additional water is pumped into and out of the basin accordingly. The generated energy surpasses the inputted energy (for pumping) due to the larger tidal range during the generating stage (pumping is done at high or low tide, whereas generation is between tides, once the head has reached the required value). This is one method of optimising a tidal range power plant, shown in Figure 9.

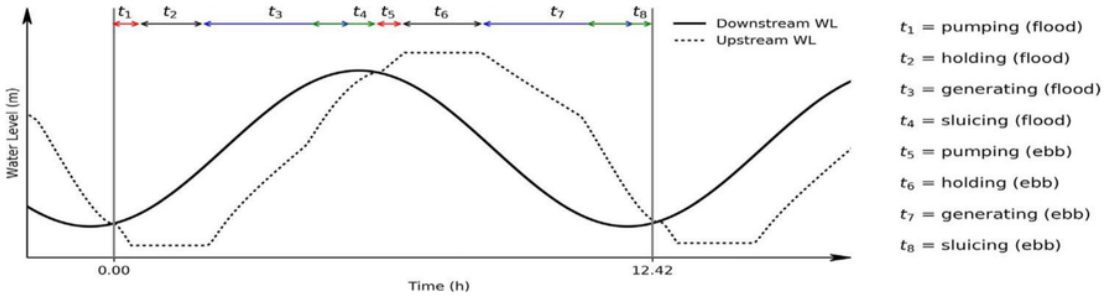


Figure 9-optimised generation output from tidal range scheme using pumping. (Angeloudis, et al., 2018)

2.3 Electricity generation from a Tidal Range Scheme

A crude estimate for calculating the potential energy within an impounded body of water is found from: (Waters & Aggidis, 2016) (Angeloudis, et al., 2018) (Xia, et al., 2012)

Equation 3: $$E_p = \frac{1}{2} A_b \rho g H^2$$

- A_b is the surface area of the basin,
- ρ is the density of the fluid,
- g is Earth's gravitational constant (9.81 m/s^2)
- H^2 is the available head (tidal range).

The following assumptions and simplifications are inherent in Equation 3:

- There is a linear reduction in hydraulic head as the basin fills/empties (causing the factor of 0.5),
- The area of the basin is considered constant over each tide and the lifetime of the project (basin walls are usually slanted, causing a variation in surface area),
- The basin dimensions (parallel to wave propagation) are equal or smaller than the tidal wave length (to avoid resonance and phase shifts),
- Maximum energy values are obtained assuming production occurs instantaneously when the head is largest.

To gain a more accurate approximation of the available energy from a tidal basin integrating over the tidal curve is suggested as opposed to averaging. (Roberts, et al., 2016) (Bernshtein, 1965)

Moreover, the annual generating capacity of the tidal power plant can be approximated using: (Xia, et al., 2012)

Equation 4: $$E_{year} = 0.987 * A_{basin} * H_{basin}^2 * \eta$$

Where η is the conversion efficiency of the machinery used. A typical range for conversion efficiency for tidal range projects is 20%-40%, with 33% often used. These equations have been compared to the existing tidal range power plants and provided similar results to the operational data proving their validity.

To guide the discussion on what the optimal choice of equipment, operating scheme, turbine type and turbine size is for the UWTSD tidal basin a presentation of the five operational tidal range power plants are presented below.

2.4 Existing Tidal Range Projects

2.4.1 La Rance, France (1967)

The 720 metre barrage in La Rance (Figure 10)was built behind cofferdams between 1961-1967, enclosing a basin of 22km^2, and has been operating successfully since then, though its total capacity was only available since June 1982. The mean tidal range is 7.85 metres and in 1988 fully automatic operation commenced. It uses 24 reversible 10MW bulb turbines that operate with a hydrostatic head of 5 metres. It is classed as a success having operated for over 30 years with less than a 6.5% downtime, the majority of which occurred during the large repairs of the generators between 1976-1982 (availability during this period varied between 71%-94%).

Generation is bidirectional, though predominantly done on the ebb phase with secondary production performed on the flood phase. Pumping from the sea to the basin increases the net generation on ebb production. The annual production is approximately 480 GWh.



Figure 10- La Rance Tidal Barrage in France. (Waters & Aggidis, 2016)

The environmental impacts of building the barrage were not well documented, however the consensus appears to suggest maximum impact was during the construction stage. During its operation it has created a new habitat for species that were not previously present around the barrage.

(Waters & Aggidis, 2016) (Frau, 1993) (Rourke, et al., 2010) (Baker, 1991) (Xia, et al., 2012)

2.4.2 Lake Sihwa, South Korea (2011)

Lake Sihwa in South Korea (Figure 11) was originally constructed as a dike in 1994 to hold fresh water for agriculture and irrigation, and to develop industrial and agricultural plots on the 173km^2 of reclaimed land. Due to severe water contamination the fresh water could no longer be used for its desired purpose, and for this reason the tidal power plant was retrofitted to the dam to improve the water quality by flooding the lake with sea water, and to provide a sustainable form of energy. The basin surface area was originally intended to be 43km^2 however, this figure has been reduced to 39km^2 due to freshwater dykes and land reclamation. The tidal power project was inaugurated in 2011 and cost $355.1 million.

This project annually produces approximately 550GWh from a rated capacity of 254 MW. The average tidal range is 5.6 metres (mean spring tidal range is 7.8metres), uses 10 bulb turbines each with a rated capacity of 25.4MW and runner diameters of 7.5 metres that rotate at 64.29rpm. The turbines operate and have been optimised for operation in the flood direction only. The result of operating during the flood phase is large intertidal areas constantly above water level, which is impossible using other generation methods. (Waters & Aggidis, 2016) (Bae, et al., 2010) (Roberts, et al., 2016) (Verdict Media Limited, 2014) (Xia, et al., 2012) (Kim, et al., 2012)



Figure 11- Lake Sihwa Tidal Power Plant. (Kim, et al., 2012)

2.4.3 Annapolis Royal, Canada (1985)

Constructed between 1980-1984 and inaugurated the year after, this tidal power plant (Figure 12) is blessed with the largest tidal range on the Earth (16m), though the average range is just under 7 metres. A governmental pilot project testing the waters for harnessing tidal energy, this 20 MW turbine operates for five hours during each tidal cycle with 400 m^3 of water flowing through the turbine each second. Annual generation reaches 50 GWh from a basin of 6km^2.



Figure 12-Annapolis Royal Tidal Power Station (Rourke, et al., 2010)

It is the only tidal project using a straflo turbine, shown in Figure 13. The straflo turbine has the alternator mounted on the rim, as opposed to the centre, and has four fixed runner blades with a variable distributor. The Annapolis tidal power plant uses the largest straflo turbine in the world. Production occurs on the ebb flow with a minimum operating head of 1.6metres. The tidal power plant also functions as a flood defence system and transportation link. (Waters & Aggidis, 2016) (Rourke, et al., 2010) (Electrical Line Magazine, 2002) (Frau, 1993) (Xia, et al., 2012)



Figure 13-Straflo Turbine used in Annapolis TPP (Electrical Line Magazine, 2002)

2.4.4 Jiangxia, China (1985)

In China over 40 small tidal range power plants were constructed between 1958-1970s (Table 2). Poor site selection, operation inconvenience, flawed turbine designs, conflict of use between irrigation and navigation, the disrepair of generator sets, and comparatively high electricity prices to the large electricity grid caused the majority to cease functioning. Only three remained operating in 2011, Jiangxia, Baishakou, and Haishan. The information on the Haishan and Baishakou power plants is limited, and Baishakou has since stopped operating.

Table 2- Chinese Tidal Range Projects. (Waters & Aggidis, 2016) (Wang, et al., 2011) (Zhang, et al., 2014)

Chinese Tidal Range plants	Average Tidal Range (m)	Installed Capacity (kW)	Reservoir (km^2)	Operating Scheme	Operation Dates
Jiangxia	5.08	3900	137	Bidirectional. Single basin	1980-present
Haishan	4.91	2x125	0.25 & 0.03	One-way. Two Basin	1975-present
Xingfuyan	4.54	4x320	-	Ebb. Single Basin	1989-?
Baishakou	2.36-2.48	6x160	3.2	One-way. Single Basin	1978-?
Yuepu	3.6	4x75	0.02	Ebb. Single Basin	1971-1987
Liuhe	1.2	2x75	3.84	Bidirectional. Single basin	1976-1998
Shashan	5.08	40	0.05	Ebb. Single Basin	1959-1992
Guozishan	2	40	-	One-way. Single Basin	1977-1985
Shoudong	3.78	40	-	One-way. Single Basin	1959-1985

Construction on the Jiangxia project (Figure 14) started in 1974 with the first turbine of 500kW installed in 1980. The project was finished in 1985 with an additional four turbines installed (1x600kW, 3x700kW) and finally in 2007 another 700kW turbine was installed for a total installed capacity of 3.9MW. This tidal power plant has a basin size of 1.37km^2, the average tidal range is 5.1m and the annual output varies between 6-7GWh from bidirectional production.



Figure 14-Jiangxia Tidal Power Plant (Wang, et al., 2011)

This tidal power plant operates at a loss, however generates a net profit from optimising the use of the basin through aquaculture, shellfish farming and planting in reclaimed reservoir lands. (Xia, et al., 2012) (Wang, et al., 2011) (Zhang, et al., 2014) (Waters & Aggidis, 2016)

2.4.5 Kislaya Guba, Russia (1968)

This is the smallest operating tidal range power plant on the planet (Figure 15), with an installed capacity of 400kW in 1968. It was based off the La Rance project, using bidirectional bulb type turbines, however was adapted to meet the demands of the harsh arctic conditions and an average tidal range of 2.5 metres. The turbine runner diameter was 3.8 metres with a turbine/generator rotation speed of 69/600rpm respectively. Its construction in 1968 created a 2km^2 basin that was to function as a prototype for two other larger schemes each having a capacity between 6.8-15GW in the Mezen Bay and Tugar Bay, neither of which have been realised. (Frau, 1993) (Waters & Aggidis, 2016) (Rourke, et al., 2010) (Chaineux & Charlier, 2008)



Figure 15-Kislaya Guba Tidal Power Plant. (Unknown, 2019)

After funding was cut it ceased operation for 10 years until 2004 when a new 0.2MW turbine was installed, and in 2007 a 1.5MW turbine was installed, for a new combined capacity of 1.7MW. (Unknown, 2019)

For ease of the reader, the relevant information from this section has been accumulated into the following table:

Table 3- Operational Tidal Range Power Plants

Tidal Power Plants	Average Tidal Range (m)	Installed Capacity	Annual Production (GWh)	Reservoir (km^2)	Operating Scheme	Operation Dates
La Rance	7.85	24x10MW	480	22	Bidirectional	1967-Present
Lake Sihwa	5.6	10x25.4MW	550	39	Flood production	2011-Present
Annapolis Royal	6.4	20MW	50	6	Ebb Production	1985-Present
Jiangxia	5.08	3.9MW	6-7	137	Bidirectional	1980-Present
Kislaya Guba	2.5	1.7MW	Unknown	2	Bidirectional	1968-Present (not continuous)

The energy density of the tidal range projects was calculated using the average annual generation values, and are shown in the table below.

Table 4: Energy density of tidal range projects

Location	Energy Density (W/m^2)
La Rance	6.09
Lake Sihwa	3.92
Annapolis Royal	2.32
Jiangxia	1.42
Kislaya Guba	0.85

The variation in energy density for each site arises from the tidal range differences, production methods (ebb, flood or bidirectional), and turbine efficiency. Mackay suggests that with a tidal range of 4 metres $3W/m^2$ is a feasible production value if you generate electricity bi-directionally and the water is shallow. (MacKay, 2009)

2.5 Appropriate Technology for Tidal Range Power Generation

A 2015 study examined the possibility of using technology other than a Straflo or bulb turbine in tidal range schemes. A marking criterion was developed to evaluate the strengths of each turbine type, depending on the equipment costs, maintenance difficulty/costs, environmental impacts and generating efficiency (in two-way generation).

The new turbine types suggested include a modified bulb, counter rotating device, Archimedes screw and a gyro. The results of the study are presented in the table below (Waters & Aggidis, 2016)

Table 5- Evaluation of new turbine designs (Waters & Aggidis, 2016)

	Environment	Efficiency	Cost	Maintenance
Bulb	Acceptable	Good	Poor	Acceptable
Straflo	Acceptable	Acceptable	Acceptable	Poor
Modified bulb	Poor	Good	Poor	Poor
Archimedes Screw	Good	Acceptable	Good	Good
Gyro	Acceptable	Poor	Good	Good
Counter Rotating	Acceptable	Acceptable	Acceptable	Acceptable

It is important to note that in this study the values assigned to each turbine are relative to each other, and are not an indication of performance against an absolute measure. Moreover, the gyro, Archimedes screw and counter rotating turbines have never been tested in a tidal range environment, so the ratings of efficiency are estimates resulting from their use in other hydroelectric power generation settings. The gyro and counter rotating devices, are well established turbine designs, however using them in a variable head, variable speed, dual generation environment will affect output, and cannot be considered for this project. More research, both computational and with scale testing is required to assess the feasibility of using these turbines in a tidal range setting. The other turbines are presented in depth below.

2.5.1 Archimedes Screw

Lancaster University and the National Technical University of Athens are conducting research into the applicability of the Archimedes screw in tidal range settings. The author, moreover, contacted MannPower Consulting- the UK's first supplier of Archimedean Screw Hydropower Turbines- to discuss the possibility of using their devices in a tidal range environment. The engineer mentioned that the power output of an Archimedean screw is

dependent on the number of blades, the distance between them, the diameter of the screw, length of the screw, and inclination angle.

The inclination is of primary concern as the optimal operating range is for angles between 10°-45°. It moreover needs a minimum of 50cm operational head (for the size relevant to this project). These criteria cannot be met in a tidal range environment as the screw's top end requires a minimum height of between 0.87m and 3.54m (10° or 45° respectively, with a 5metre long screw). Combined with the minimum operational water head of 0.5m, the loss of range in the tidal basin is between 1.4m and 4m- almost half of the average range in Swansea.

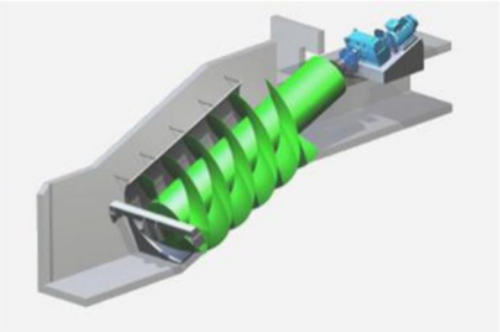


Figure 16-Archimedes Screw for Power Generation. (Waters & Aggidis, 2016)

If it were possible for the Archimedes screw to generate electricity while kept horizontal in the penstock leading from the sluice gate, then the screw would be an optimal design choice, arising from its low environmental impact on marine life, its low costs, ease of maintenance and decent efficiencies. Its symmetrical design would generate efficiently in bi-directional production, and the screw is effective when used as a pump. Moreover, water with a high silt content due to the low water depth will not adversely affect its operation, as it has been used as a dredging pump. The author anticipates the results from experimental work conducted by the universities of Athens and Lancaster in the generating efficiencies of a horizontal Archimedes screw.

An Archimedes screw is not currently an applicable turbine choice for this project, as it has not been proved in a tidal range environment.

2.5.2 Straflo Turbine

The only Straflo turbine in use for tidal range is at Annapolis, with its availability nearing 98%. This device has the generator's electromagnets around the runner's rim (Figure 13), outside of the flow and the resulting efficiency ranges between 79-89%. The fixed runner blades only allow generation in one direction, but the turbine costs are lower than that of a bulb turbine. In a couple of standard hydroelectric power plants in Germany straflo turbines have been replaced by bulb turbines for a higher generating efficiency. (Andritz Hydro, 2015) This indicates that they are not the optimum technology, especially as fish mortalities can be as high as 30% and there is extra turbulence created between the blades and the housing. (Waters & Aggidis, 2016)

2.5.3 Bulb (original and modified)

Of the various Kaplan turbine variations, the bulb turbine (Figure 17) has proven itself in the tidal range setting and is the most efficient turbine for variable low heads and slow flow rates. Guiding vanes direct the flow onto the blades in the optimum direction increasing output in comparison to a standard Kaplan turbine which has a similar blade design. The modified bulb has guiding vanes on both sides of the blades in order to increase output in the reverse direction. One test demonstrated a 10% efficiency gain in reverse production, however this resulted in a 2.6% decrease in efficiency during forward production. The generating gear is within the bulb resulting in minimal external electronic equipment needed. The downsides of the Kaplan bulb turbines are that the guide vanes and blades can injure marine life, by striking, turbulence, cavitation, grinding, shear stress or sudden pressure changes. These effects are even more prominent with the modified bulb, which will also be more expensive to manufacture and will suffer from higher maintenance costs as debris must be more thoroughly removed. (Waters & Aggidis, 2016)

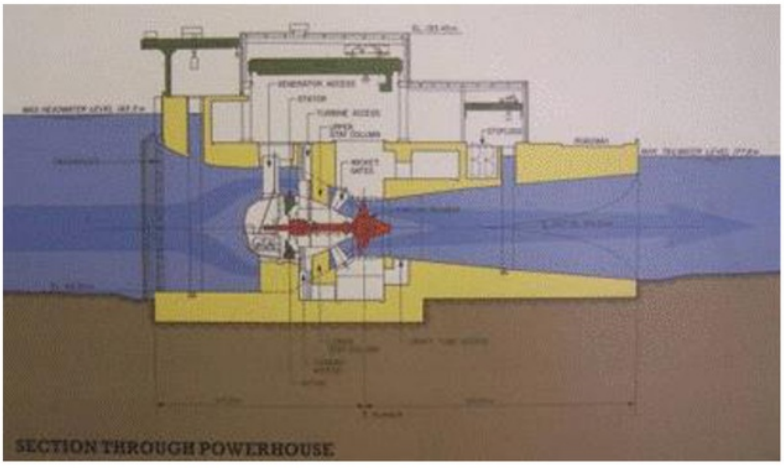
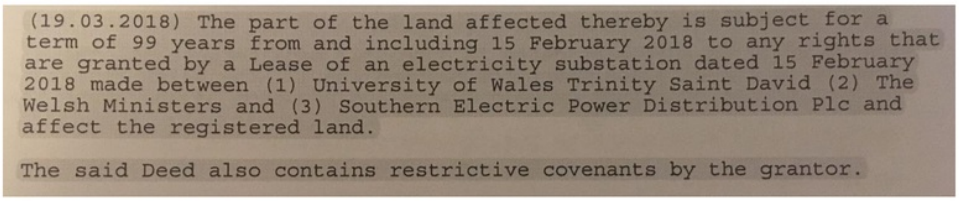


Figure 17- Kaplan Bulb turbine. (Renewables First, 2015)

The only technology readily usable at this time is either the straflo or bulb turbines, however the straflo turbine will only produce electricity in one direction, so the bulb is preferred for higher energy outputs. The modified bulb will increase net production values, however the author does not believe that for a project of this size it will be cost effective. The Archimedes screw has strong potential for future applications, however more testing is required to verify its applicability in a tidal range setting prior to manufacturing and using one.

2.6 Land Ownership, Access of Rights and Permitting

The author purchased from the Land registry the information relating to the deeds where the tidal basin is situated. The SA1 development area at the Swansea waterfront is under ownership of the national assembly for wales. The University of Wales Trinity Saint David has had the benefit of the rights from the Welsh Ministers reserved since September 25th 2013 (land access) and has leased the land for 99 years starting from and including the 15th of February 2018 (Figure 18). This project may thus be limited in the years it can produce, as it may need to be decommissioned in 2117.


(19.03.2018) The part of the land affected thereby is subject for a term of 99 years from and including 15 February 2018 to any rights that are granted by a Lease of an electricity substation dated 15 February 2018 made between (1) University of Wales Trinity Saint David (2) The Welsh Ministers and (3) Southern Electric Power Distribution Plc and affect the registered land.

The said Deed also contains restrictive covenants by the grantor.

Figure 18- Land registry information about tidal basin site

The project if executed will need licensing and compliance with all Welsh and EU legislation. Natural resources Wales advises early consultations with all interested parties (neighbours, environmental bodies, sea users [fishermen, marina & recreational boat users], regional electric company, local planning authorities) to address their concerns. Moreover, the following licences are needed:

- Planning permission from the Environmental Agency and local planning authority, which additionally require an environmental impact assessment & statement.
- Environmental Consenting including impoundment, fish pass and flood defence licences (an abstraction licence will only be needed should supplementary flow from the river Tawe be used (proposed in recommended further work)) (can take up to 12 months).
- Grid Connection Permission.
- A Natural Resources Wales (NRW) permit.

For more specific guidance on which application forms should be filled, the amount of time needed to process the various applications, which bodies they need to be submitted to, and how long in advance they can be submitted it is suggested to contact NRW in the earliest stages of project planning.

2.7 Available financial assistance for low renewable energy schemes

2.7.1 Feed in Tariffs

Starting in April 2010 Feed in Tariffs (FIT) were deployed by the UK government supporting small scale low-carbon & renewable electricity generating technologies (capacities under 5MW). Generators were rewarded with payments for electricity generation, export, and bill savings from consuming energy on-site.

The generation tariff rewards the owner of a green energy scheme based on:

- The size of the system,
- The technology installed,
- When the system was installed,
- How energy efficient the building it supplies is.

The export tariff is a measure of electricity exported into the grid. This is rewarded with 5.24p/kWh.

There is no indication of generation tariffs for tidal power, however for hydro electricity production the generation tariff is shown in Table 6:

Table 6: Feed in Generation Tariff in UK for hydro schemes 1 Jan 2019- 31 March 2019. (OFGEM, 2019)

Total Installed Capacity (kW)	Tariff (p/kWh)
0-100	8.03
100-500	6.46
500-2000	6.46
2000-5000	4.73

Unfortunately, as of 18 December 2018, the government decided to close the FIT scheme to new applicants effective 1 April 2019. For this reason, it appears that the University would not receive any support from the government in the form of tariffs, were this project to be developed, so the total savings would be reduced substantially. The incurred savings would be as a result of offsetting electricity consumption from the grid and for the first few years will be spent in paying back the project's capital costs.

2.7.2 Renewable & Non-Fossil Fuel Obligation Schemes

The renewable obligation (RO) scheme replaced the non-fossil fuel Obligation in April 2002 (when the RO began) and closed to new generating capacity on March 31st, 2017. Support is ongoing for existing stations and will continue for a 20 year period. The RO scheme was designed to incentivise large-scale renewable energy generation so the UK would meet its

targets of having 15% of electricity generated from renewables by 2020. It obliged electricity suppliers to source an increasing amount of their electricity from renewable sources by purchasing renewable obligation certificates (ROC) from renewable energy generators. Generators are awarded ROCs depending on the net production of the previous month and the generation methods (for example onshore wind is awarded 0.9ROCs/MWh, offshore wind 1.8ROCs/MWh, sewage gas receives 0.5ROCs/MWh). (Digest of UK Energy Statistics, 2018) Due to the FIT scheme (described above), hydro, wind PV & AD stations with a capacity under 50kW were not supported by the RO. Tidal lagoons and barrages post 2016 would be rewarded with 1.8 Renewable Obligation Certificates per MWh produced. (OFGEM, 2019) The ROCs that have been sold in auction the past five years have sold at £40-£50 per certificate. This scheme is no longer open to new generating capacity.

2.7.3 Contracts for Difference

Contracts for difference (CfD) were introduced in 2014 and replaced the Renewable Obligation (during overlap period, generators could only apply to one scheme). The Contract for Difference scheme focuses on promoting investment into low-carbon electricity by creating market mechanisms that guarantee a minimum buying price for renewable energy for a 15 year period despite the unpredictable and volatile UK energy market.

Eligible low-carbon electricity generators enter into an auction, which are expected to occur every two years, to receive funding from a fixed budget that is used to pay the difference between the strike price and the reference price once electricity production commences. The reference price reflects the cost of electricity in the UK while the strike price reflects the cost of investment in the generating technology. An example of this is shown in Figure 19. (Digest of UK Energy Statistics, 2018)

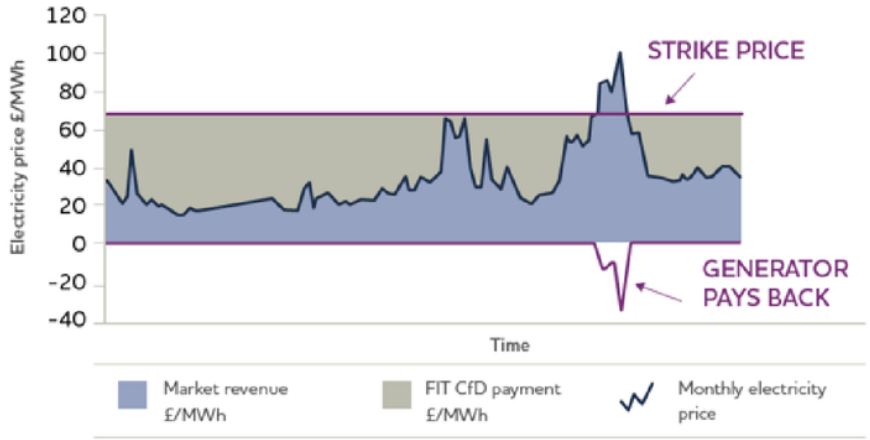


Figure 19-Contract for Difference explained. (EMR, 2011)

The payments are received from the Low Carbon Contracts Company, which the electricity generator enters into a private contract with. The 2015 auction supports onshore/offshore wind farms, solar PV, CHP, energy from waste and advanced conversion technologies, while the 2017 auction enabled generation from offshore wind, CHP, biomass and advanced conversion technologies, with a strike price as shown in Figure 20.

(A) Information on the successful applicants – strike prices are in 2012 prices.

Project Name	Developer	Technology Type	Capacity (MW)	Strike Price (£/MWh)	Delivery Year	Homes Powered	Region
Drakelow Renewable Energy Centre	Future Earth Energy (Drakelow) Limited	Advanced Conversion Technologies	15.00	74.75	2021/22	27,190	England
Station Yard CFD 1	DC2 Engineering Ltd	Advanced Conversion Technologies	0.05	74.75	2021/22	90	Wales
Northacre Renewable Energy Centre	Northacre Renewable Energy Limited	Advanced Conversion Technologies	25.50	74.75	2021/22	46,220	England
IPIF Fort Industrial REC	Legal and General Prop Partners (Ind Fund) Ltd	Advanced Conversion Technologies	10.20	74.75	2021/22	18,490	England
Blackbridge TGS 1 Limited	Think Greenergy TOPCO Limited	Advanced Conversion Technologies	5.56	74.75	2021/22	10,080	England
Redruth EfW	Redruth EFW Limited	Advanced Conversion Technologies	8.00	40.00	2022/23	14,500	England
Grangemouth Renewable Energy Plant	Grangemouth Renewable Energy Limited	Dedicated Biomass with CHP	85.00	74.75	2021/22	148,880	Scotland
Rebellion	Rebellion Biomass LLP	Dedicated Biomass with CHP	0.64	74.75	2021/22	1,120	England
Triton Knoll Offshore Wind Farm	Triton Knoll Offshore Wind Farm Limited	Offshore Wind	860.00	74.75	2021/22[1]	893,690	England
Hornsea Project 2	Breesea Limited	Offshore Wind	1,386.00	57.50	2022/23[2]	1,440,300	England
Moray Offshore Windfarm (East)	Moray Offshore Windfarm (East) Limited	Offshore Wind	950.00	57.50	2022/23[3]	987,220	Scotland

[1] Triton Knoll will be built in three phases; 2021/22 is the delivery year for phase 1
[2] Hornsea will be built in three phases; 2022/23 is the delivery year for phase 1
[3] Moray East will be built in 3 phases; 2022/23 is the delivery year for phase 1

Figure 20- Results of 2017 CfD auction. (Department for Business, Energy & Industrial Strategy, 2017)

The third round of CfD is due to open in May 2019 and is available for less established renewable technologies. According to the Contracts for Difference (Definition of Eligible Generator) Regulations 2014, regulation 3(5) tidal range projects are eligible for the scheme so long as the declared net capacity is below 1GW. Net capacity in this situation is the maximum generating capacity less the electricity consumed by the station whilst operating at maximum capacity. It is unknown what the strike price would be prior to entering the auction.

2.7.4 Enhanced Capital Allowance

This scheme incentivises companies to invest in energy efficient machinery by providing tax breaks. To be eligible the machinery must be within 25% of the most energy efficient items of the same category currently available on the market. It appears that energy production is not included in the list of eligible equipment, however could be included if implemented under R&D, and this project was used as a means of testing less-proven tidal range technologies, as described earlier (Archimedes screw, gyro, counter rotating device etc).

2.7.5 EU Support

The Horizon 2020 programme aids the creation and improvement of clean energy technologies, including tidal. If the project were implemented with a research & development mentality to improve the turbine tech, it is possible that it would be eligible to receive funding. The European Investment Bank, moreover, helps finance energy projects by providing loans and other financial instruments, though there are many other financing opportunities for local climate and energy actions. (European Commission, 2018)

3 Work carried out

3.1 Measuring the tidal range at Swansea

The location of the tidal basin is adjacent to the entrance of the Swansea Marina. Data was obtained from Swansea Marina Handbook relating to the water levels at high and low tide (Figure 21) and the respective times at which they occur. However, this data was not in a useful format for this study, nor did it provide all the information that was needed to evaluate the feasibility of the tidal power plant.

The author wrote a MATLAB script (transcribed in the appendixes) to process the data obtained from the Marina Handbook and calculate the tidal range values from 2016-2019. The processed data is presented graphically and in tables thereafter, with only the average, maximum and minimum values listed in the tables for ease of reading.

While processing this data, the author considered the meteorological effects that could impact the magnitude of the tides, and consequently on the generating capacity of a tidal range power plant. A study released in 2017 found that the mean annual resource estimate can be affected by 5% either positively or negatively. When the average was taken from the 9 sites examined over a 12-year period, the resource estimate was affected by a mere 1%, indicating that storm surges will affect a tidal power plant equally negatively as it will positively, and the long term effects are negligible. Dual-generation schemes were affected the least, while flood-only generation schemes were affected the most. The instantaneous power of the project would be affected most and caution must be shown during storms due to the impulse effects it can have the generating machinery. In the UK storm surges are routinely and accurately predicted by the early warning flood system, providing operators with a buffer to change plans of operation if deemed necessary. (Lewis, et al., 2017)

High & Low Waters to Datum for Swansea **2019**

Times adjusted for BST, heights in metres

January

	Time	m		Time	m
1 Tu	02:15	7.80	16 W	00:58	7.31
	08:25	2.65		07:15	3.14
	14:42	8.03		13:39	7.57
	21:06	2.51		19:57	2.87
2 W	03:23	8.03	17 Th	02:14	7.54
	09:29	2.43		08:31	2.83
	15:46	8.22		14:51	7.89
	22:06	2.25		21:06	2.50
3 Th	04:19	8.38	18 F	03:24	8.03
	10:23	2.13		09:36	2.34
	16:40	8.48		15:56	8.38
	22:54	1.96		22:06	2.00
4 F	05:06	8.72	19 Sa	04:24	8.62
	11:08	1.84		10:33	1.81
	17:26	8.71		16:54	8.90
	23:34	1.72		23:01	1.51
5 Sa	05:47	8.99	20 Su	05:18	9.18
	11:48	1.63		11:27	1.32
	18:06	8.87		17:46	9.34
				23:53	1.10
6 Su	00:11	1.55	21 M	06:08	9.62
	06:26	9.14		12:19	0.94
	12:27	1.50		18:37	9.67
	18:43	8.94			
7 M	00:46	1.48	22 Tu	00:43	0.80
	07:03	9.19		06:57	9.92
	13:03	1.46		13:10	0.69
	19:19	8.92		19:26	9.85
8 Tu	01:20	1.50	23 W	01:31	0.63
	07:38	9.12		07:45	10.06
	13:38	1.52		14:00	0.58
	19:53	8.81		20:14	9.88
9 W	01:52	1.62	24 Th	02:18	0.62
	08:12	8.96		08:32	10.04
	14:12	1.66		14:47	0.64
	20:26	8.64		21:00	9.73
10 Th	02:22	1.81	25 F	03:03	0.79
	08:45	8.73		09:19	9.84
	14:42	1.85		15:32	0.89
	20:59	8.42		21:45	9.42
11 F	02:50	2.04	26 Sa	03:46	1.13
	09:18	8.47		10:06	9.45
	15:14	2.08		16:16	1.32
	21:33	8.16		22:31	8.94
12 Sa	03:20	2.31	27 Su	04:31	1.61
	09:54	8.19		10:53	8.92
	15:49	2.34		17:03	1.87
	22:10	7.88		23:20	8.36
13 Su	03:57	2.60	28 M	05:21	2.18
	10:35	7.90		11:45	8.30
	16:32	2.62		17:56	2.46
	22:54	7.59			
14 M	04:45	2.91	29 Tu	00:15	7.79
	11:26	7.65		06:22	2.70
	17:28	2.88		12:45	7.75
	23:51	7.37		19:02	2.92
15 Tu	05:53	3.15	30 W	01:24	7.41
	12:28	7.50		07:36	3.00
	18:39	3.01		13:57	7.45
				20:21	3.06
			31 Th	02:43	7.41
				08:56	2.94
				15:15	7.52
				21:38	2.84

February

	Time	m		Time	m
1 F	03:54	7.76	17 Su	04:05	8.37
	10:02	2.60		10:19	1.84
	16:19	7.85		16:37	8.71
	22:34	2.43		22:46	1.54
2 Sa	04:47	8.22	18 M	05:03	9.06
	10:53	2.18		11:17	1.21
	17:09	8.25		17:32	9.30
	23:18	2.01		23:40	0.97
3 Su	05:30	8.65	19 Tu	05:54	9.64
	11:34	1.79		12:09	0.70
	17:49	8.58		18:23	9.74
	23:54	1.67			
4 M	06:09	8.96	20 W	00:30	0.55
	12:11	1.51		06:43	10.06
	18:27	8.81		13:00	0.36
				19:12	10.02
5 Tu	00:29	1.44	21 Th	01:18	0.29
	06:46	9.14		07:30	10.28
	12:46	1.35		13:46	0.20
	19:01	8.93		19:57	10.12
6 W	01:03	1.33	22 F	02:03	0.23
	07:21	9.18		08:15	10.30
	13:21	1.30		14:30	0.27
	19:34	8.94		20:40	10.01
7 Th	01:35	1.34	23 Sa	02:44	0.38
	07:53	9.11		08:58	10.10
	13:52	1.35		15:09	0.56
	20:06	8.88		21:21	9.69
8 F	02:03	1.45	24 Su	03:22	0.75
	08:24	8.98		09:39	9.66
	14:20	1.46		15:47	1.06
	20:36	8.75		22:01	9.16
9 Sa	02:29	1.61	25 M	04:00	1.30
	08:54	8.80		10:21	9.02
	14:47	1.63		16:24	1.72
	21:06	8.57		22:42	8.49
10 Su	02:54	1.80	26 Tu	04:40	1.98
	09:24	8.57		11:05	8.26
	15:15	1.84		17:07	2.45
	21:37	8.33		23:30	7.76
11 M	03:22	2.04	27 W	05:33	2.69
	09:57	8.29		11:58	7.51
	15:48	2.11		18:07	3.11
	22:12	8.03			
12 Tu	03:59	2.35	28 Th	00:33	7.15
	10:39	7.96		06:45	3.23
	16:31	2.48		13:12	6.98
	23:00	7.68		19:30	3.46
13 W	04:51	2.75			
	11:37	7.60			
	17:35	2.86			
14 Th	00:06	7.37			
	06:12	3.08			
	12:52	7.40			
	19:07	3.03			
15 F	01:27	7.32			
	07:52	3.00			
	14:16	7.55			
	20:36	2.75			
16 Sa	02:53	7.70			
	09:13	2.50			
	15:33	8.06			
	21:46	2.18			

March

	Time	m		Time	m
1 F	02:01	6.93	17 Su	02:32	7.56
	08:15	3.33		08:57	2.51
	14:40	6.94		15:18	7.91
	21:05	3.28		21:30	2.22
2 Sa	03:24	7.26	18 M	03:48	8.28
	09:38	2.94		10:07	1.77
	15:55	7.37		16:22	8.65
	22:12	2.75		22:31	1.48
3 Su	04:24	7.84	19 Tu	04:47	9.05
	10:33	2.38		11:04	1.07
	16:48	7.92		17:16	9.31
	22:56	2.19		23:24	0.85
4 M	05:09	8.41	20 W	05:38	9.67
	11:14	1.86		11:55	0.53
	17:28	8.41		18:06	9.80
	23:33	1.71			
5 Tu	05:48	8.84	21 Th	00:13	0.40
	11:51	1.47		06:26	10.10
	18:04	8.77		12:42	0.20
				18:51	10.09
6 W	00:07	1.37	22 F	00:59	0.16
	06:24	9.10		07:12	10.31
	12:24	1.22		13:26	0.09
	18:38	8.98		19:35	10.17
7 Th	00:40	1.18	23 Sa	01:41	0.12
	06:58	9.22		07:54	10.29
	12:57	1.11		14:06	0.22
	19:10	9.09		20:15	10.04
8 F	01:12	1.13	24 Su	02:20	0.31
	07:30	9.24		08:33	10.05
	13:27	1.10		14:42	0.56
	19:41	9.10		20:53	9.70
9 Sa	01:40	1.18	25 M	02:55	0.70
	08:00	9.18		09:12	9.59
	13:54	1.18		15:15	1.08
	20:11	9.04		21:30	9.18
10 Su	02:05	1.29	26 Tu	03:29	1.26
	08:29	9.06		09:48	8.93
	14:20	1.30		15:46	1.74
	20:40	8.91		22:07	8.51
11 M	02:30	1.43	27 W	04:04	1.93
	08:57	8.87		10:27	8.16
	14:45	1.48		16:22	2.46
	21:08	8.69		22:49	7.78
12 Tu	02:56	1.64	28 Th	04:50	2.65
	09:27	8.59		11:15	7.38
	15:15	1.76		17:15	3.15
	21:39	8.38		23:46	7.10
13 W	03:30	1.97	29 F	05:59	3.26
	10:04	8.19		12:23	6.77
	15:54	2.19		18:41	3.60
	22:23	7.94			
14 Th	04:17	2.45	30 Sa	01:16	6.75
	11:00	7.69		07:30	3.46
	16:53	2.73		14:00	6.64
	23:29	7.46		20:18	3.50
15 F	05:36	2.96	31 Su	03:47	7.00
	12:21	7.29		09:59	3.12
	18:34	3.09		16:21	7.08
				22:34	2.96
16 Sa	00:57	7.24			
	07:27	3.02			
	13:54	7.35			
	20:15	2.86			

19

Figure 21-Sample of the data from Swansea Marina Handbook

Figure 22 depicts how at spring tides the high tide is at its highest values and the low tide is at the lowest values, while during neap tides the high tide is at its lowest values and low tide is at its highest. The range is obtained by subtracting the low tide from the high tide, shown in **Error! Reference source not found.**.

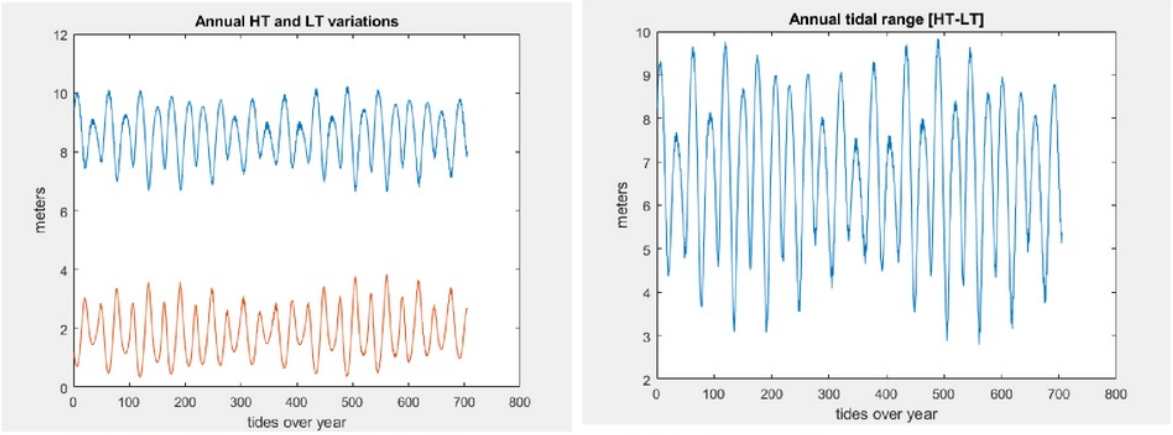


Figure 22- 2018 Variation in low tide and high tide from datum point & 2018 tidal range over entire year (HT-LT)

This process was repeated for each year to produce the figures of the tidal range for 2016-2019. It is interesting to note how the range varies similarly to a sin wave, and how large the effect of the spring & neap tides are. Figures 23-26 are in accordance with the theory presented in Section 2.1 of the Research and Literature Survey. **The tidal range varies from 3-10 metres, with an average annual tidal range of 6.78 metres. This value is used to estimate the energy and power outputs of the tidal basin.**

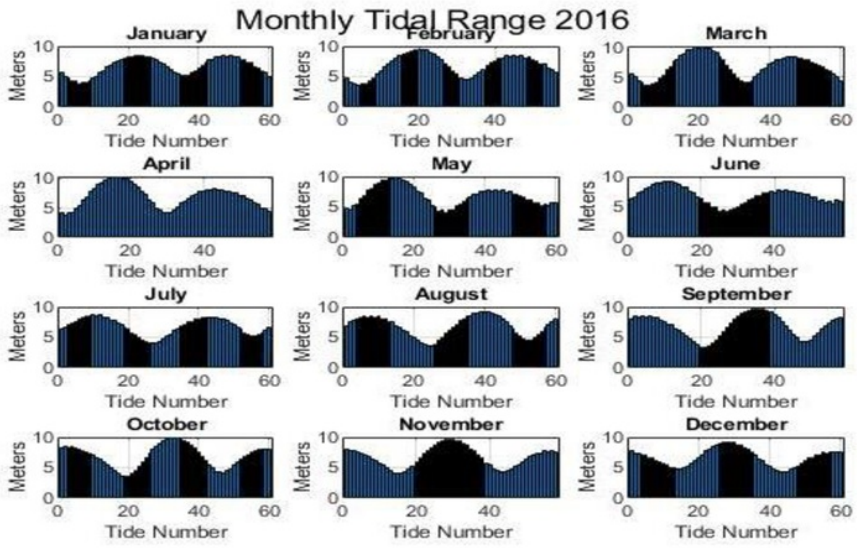


Figure 23-2016 Monthly Tidal Range

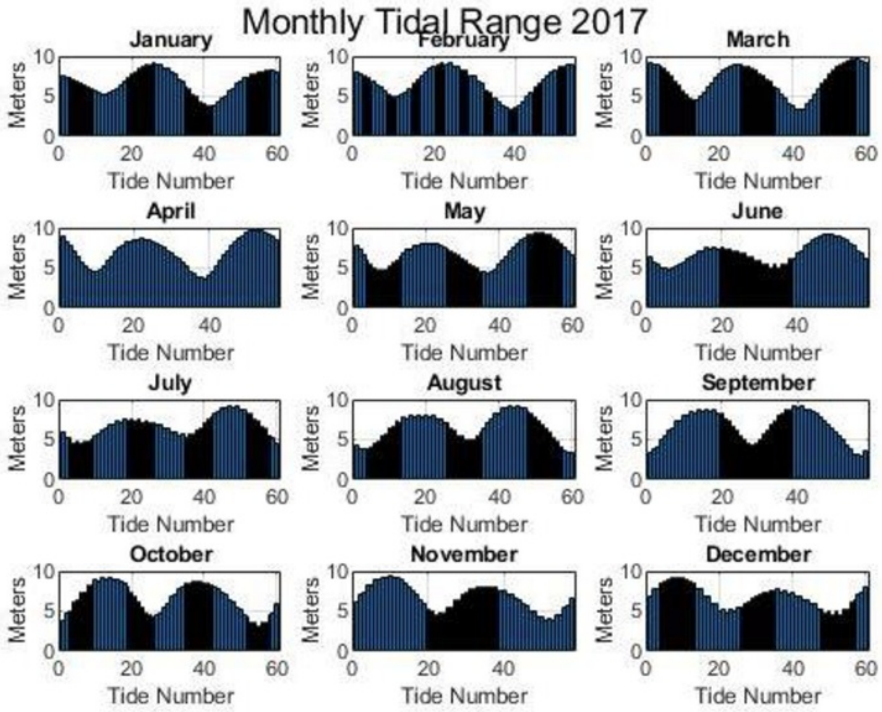


Figure 24-2017 Monthly Tidal Range

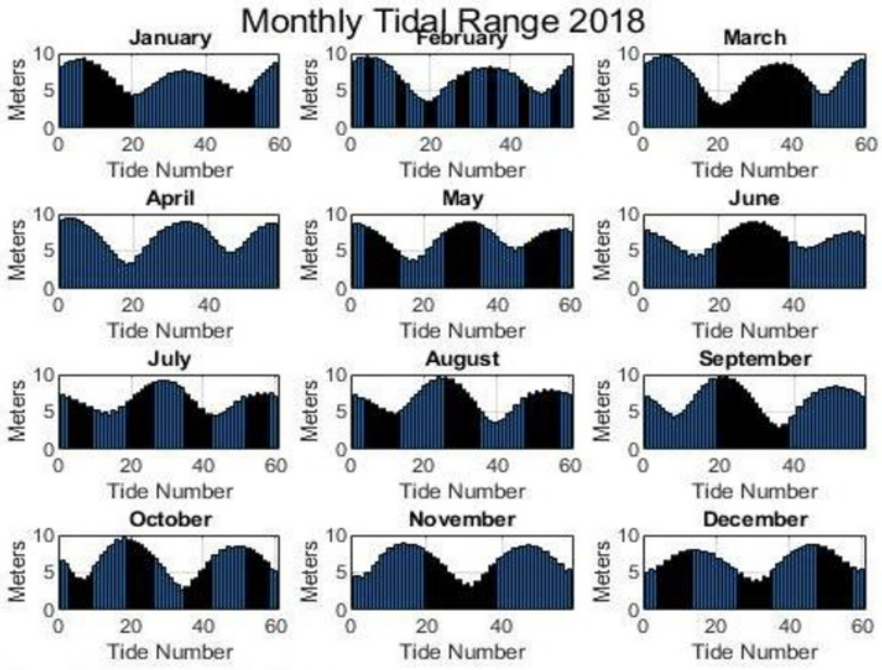


Figure 25-2018 Monthly Tidal Range

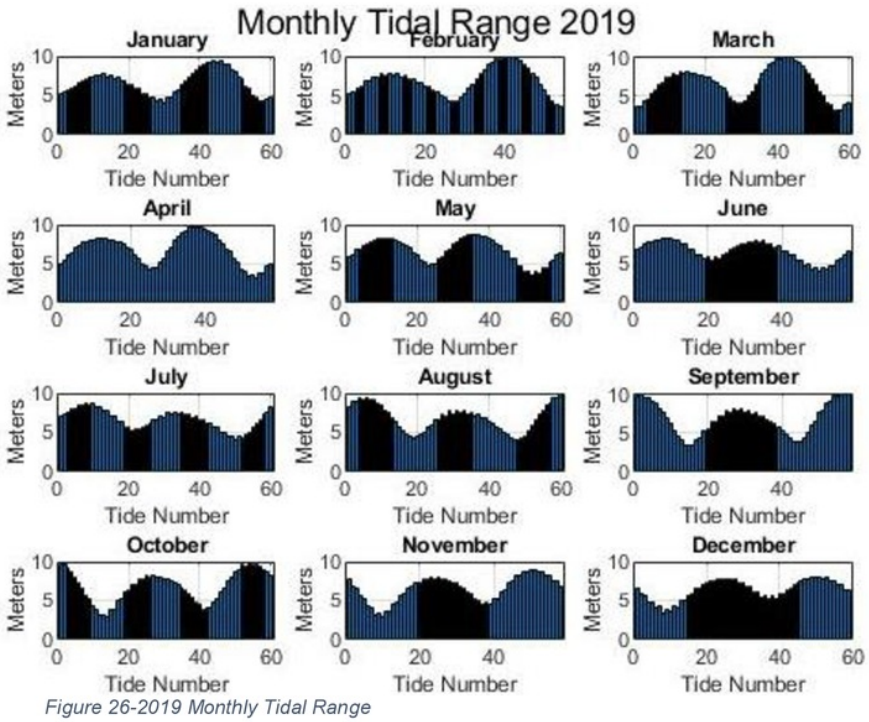


Figure 26-2019 Monthly Tidal Range

Table 7: Average Tidal Range Each Month (metres) 2016-2019

Table of average monthly tidal range (metres)				
	2016	2017	2018	2019
January	6.67	6.77	6.83	6.61
February	6.89	6.77	6.80	6.92
March	6.85	7.10	7.02	6.71
April	6.90	7.03	6.96	6.77
May	6.84	6.93	6.86	6.67
June	6.86	6.84	6.70	6.61
July	6.77	6.71	6.70	6.65
August	6.81	6.56	6.77	6.85
September	6.86	6.64	6.78	6.88
October	6.90	6.63	6.67	6.84
November	6.74	6.74	6.62	6.54
December	6.69	6.77	6.61	6.43
Annual Average	6.82	6.79	6.78	6.70

Table 8: Maximum Tidal Range Each Month (metres) 2016-2019

Table of monthly maximum tidal range (metres)				
	2016	2017	2018	2019
January	8.50	9.09	9.31	9.48
February	9.49	9.10	9.65	10.08
March	10.20	9.68	9.77	10.22
April	10.24	9.72	9.47	9.74
May	9.77	9.48	9.02	8.83
June	9.12	9.23	9.06	8.27
July	8.71	9.19	9.30	8.66
August	9.16	9.23	9.70	9.94
September	9.75	9.14	9.84	10.17
October	9.88	9.29	9.64	9.80
November	9.65	9.40	8.96	8.92
December	9.27	9.25	8.79	8.13
Average	9.48	9.32	9.38	9.35

Table 9: Minimum Tidal Range Each Month (metres) 2016-2019

Table of monthly minimum tidal range (metres)				
	2016	2017	2018	2019
January	3.88	3.79	4.37	4.17
February	3.63	3.29	3.66	3.52
March	3.58	3.32	3.09	3.14
April	3.81	3.69	3.07	3.14
May	4.16	4.33	3.56	3.59
June	4.28	4.73	4.09	4.03
July	4.04	4.45	4.48	4.15
August	3.56	3.26	3.54	3.96
September	3.37	2.94	2.88	3.45
October	3.49	3.09	2.79	2.92
November	3.99	3.73	3.16	2.91
December	4.23	4.44	3.74	3.44
Average	3.84	3.76	3.54	3.54

Table 10: Annual Maximum and Minimum Water Levels (metres)

Table of Sea Level height from datum point (metres)				
	2016	2017	2018	2019
Highest Water Level	10.37	10.12	10.22	10.41
Lowest Water Level	0.11	0.36	0.32	0.09

The mean tidal range over the past four years has been 6.78metres, with a mean maximum range of 9.38m and mean minimum range of 3.67m.

It is apparent that the annual average tidal range has varied by 15 centimetres in the past four years. The standard deviation of the monthly average is 0.13, and this small variation confirms the dependability of tidal energy, when compared to standard hydroelectric power stations, which suffer from seasonal and annual variations. However, during each month the tidal range varies on average by 3 metres from the mean, and by 6 metres from max range to min range- as is expected during the neap and spring tides. As indicated in Equation 3, the output will be affected by the square of the tidal range, so daily output over a tidal month can vary drastically. The benefit of tidal energy, however, is the predictability of the magnitude of each tide from beforehand.

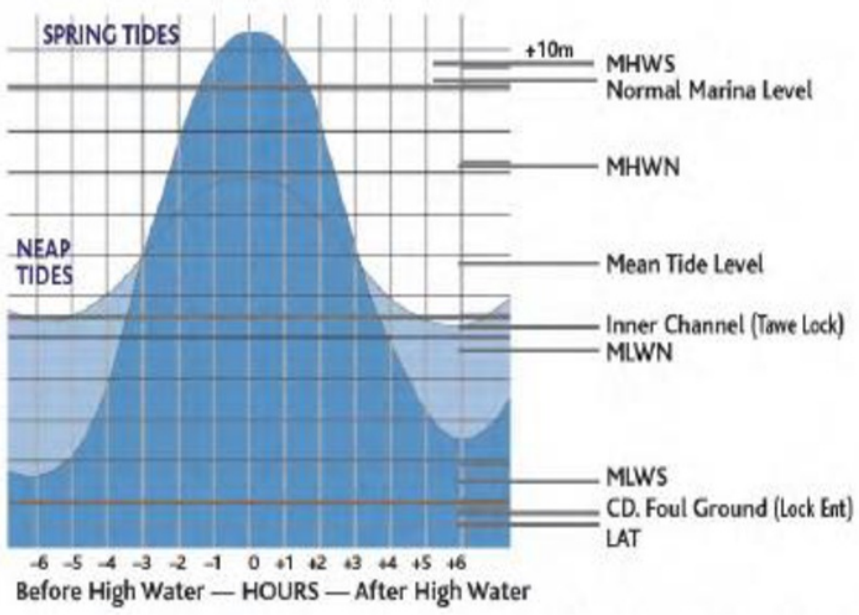


Figure 27- Datum Point is at LAT (Lowest Astronomical Tide). Swansea Marina Handbook 2015

It is important to note that the tidal data provided by Swansea Marina was generated at the beginning of the year for the entire year, and can vary from the real tidal range depending on meteorological effects.

The tidal range is an absolute term, however the water levels transcribed are relevant to a datum point. In this case the chart datum is the lowest astronomical tide (LAT) that occurs under normal meteorological conditions, seen in Figure 27. Table 10 shows the average sea level height for MHWS and MLWS from the past four years, that Figure 27 displays.

A concern arising from the long operating time of this project (until year 2117, and perhaps longer if the University's lease changes, or the renter of this land chooses to continue production- possibly with a change in turbines) is how sea level rise (SLR) will impact the operation and generation values of this tidal project. SLR occurs due to the melting of land ice (glaciers and ice sheets) and fluid expansion as the ocean temperatures increase. Average estimates of SLR is 1.8-2.5mm/year, with maximum estimates of 15-20mm/year. A SLR of 0.2-2meters estimated for the year 2100 will certainly affect the regional tides, and a 2017 study on how this impacts tidal stream generation predicted increases in energy output. (Chen & Liu, 2017) A similar increase would be expected in tidal range applications, as the volume of water passing through the turbine during each tide will be greater. The impact of this is that the tidal project's site will become more valuable over time. An increase in mean tidal range from 6.78metres to 8m by 2100 is possible, with an increase to 7m highly likely.

3.2 Calculating the area & volume of the tidal basin

The surface area of the tidal basin was calculated using two different online mapping tools: "daft logic"[1] and the built-in tool from Google Maps.

The walls in the lagoon are not perpendicular so the surface area is not constant over the entire tidal range. At high tide the area is larger than at low tide, which is beneficial for production considering the minimum operating head of the turbines and the larger output on ebb production.

A lower and higher estimate of the basin's surface area using the Daft Logic tool is demonstrated in Figure 28 and Figure 29. The surface area is 8,900 m^2 and 10,000m^2 respectively.



Output : Current Area

8903.41 m^2 | 0.01 km^2 | 2.20 acres | 0.89 hectares | 95835.50 $feet^2$ | 0.00 square miles | 0.00 square nautical miles

Current Perimeter

569.372m OR 1868.019feet

Output : Total Area(s)

8903.41 m^2 | 0.01 km^2 | 2.20 acres | 0.89 hectares | 95835.50 $feet^2$ | 0.00 square miles | 0.00 square nautical miles

Current Total Perimeter

569.372m OR 1868.019feet

Figure 28: Area of Tidal Basin Minimum Estimate

The Google Maps area tool was used to verify these estimates, shown in Figure 30.



Output : Current Area

10059.83 m^2 | 0.01 km^2 | 2.49 acres | 1.01 hectares | 108283.09 $feet^2$ | 0.00 square miles | 0.00 square nautical miles

Current Perimeter

603.830m OR 1981.069feet

Output : Total Area(s)

10059.83 m^2 | 0.01 km^2 | 2.49 acres | 1.01 hectares | 108283.09 $feet^2$ | 0.00 square miles | 0.00 square nautical miles

Current Total Perimeter

603.830m OR 1981.069feet

Figure 29: Surface Area of Tidal Basin Maximum Estimate

[1] <https://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm#>
Accessed 29/10/18

This area is found to be 9,011m^2. **The value of 9,000m^2 shall be used for the basin's surface area**, which is a prudent lower value, so as not to overexagerate the basin's production potential. This value is crucial to calculating the annual energy outputs and rated power outputs of the turbines that are needed for the tidal power plant.



Figure 30: Area of Tidal Basin using Google Maps Area Tool

The depth of the basin varies due to sludge and sediment accumulation, as is visible in the figure above, where the water is concentrated in the centre of the basin. The author used a weighted rope (Figure 31) to measure the depth of the basin at several locations around the circumference of the basin.

The depth varies by 1.5 metres around the circumference, with a minimum depth of 7 metres and a maximum depth of 8.5 metres. The ease with which the sludge that has accumulated around the edges can be removed prompted the author to use the value of 8.5 meters depth. **The height difference from the ground floor of the university to the basin's bottom (and the floor of the existing sluice gate/penstock) is thus taken to be 8.5 meters.**

The 8.5 metre depth of the basin differs significantly from the maximum sea water level of 10.41 metres obtained from Table 10. To measure the height between the basin's floor and the datum point, the sea water level was measured at a moment of high tide and compared to the literature value (Figure 32). The measurement was conducted at 7:12am on March 22nd, which is one of the highest tides of 2019. The reason this date was chosen was also to determine the safety of the basin in terms of flooding at periods of high tide. There was a 2.2 metre height difference between the university floor and the water level- a large margin of safety, even should the sea water level increase due to a storm surge.

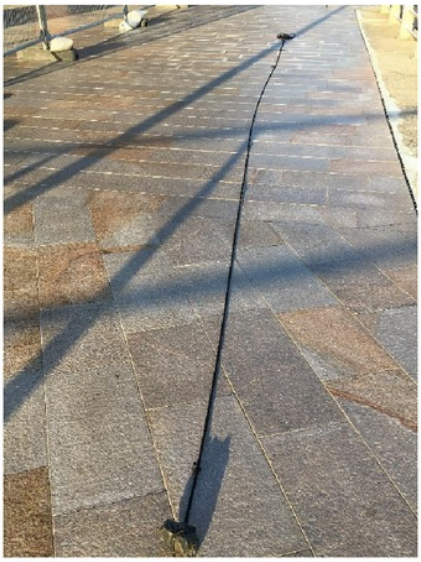
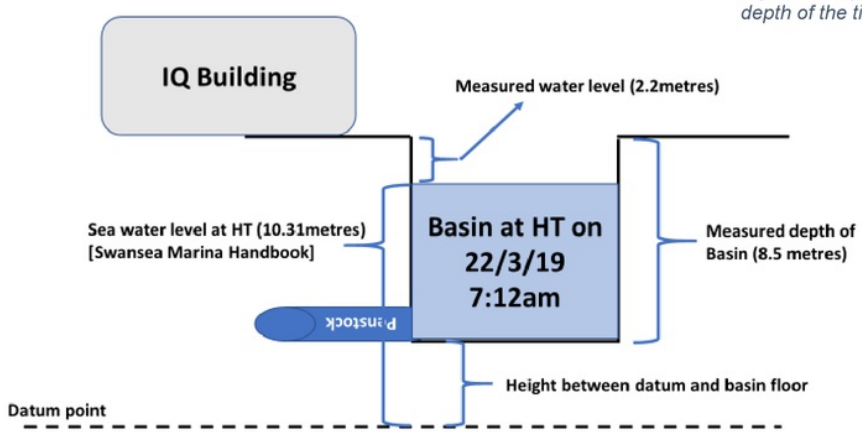


Figure 31- Apparatus used to measure the depth of the tidal basin



PROFILE VIEW OF TIDAL BASIN. IMAGE NOT TO SCALE

Figure 32-Measuring height between datum and basin floor

The basin floor is above the datum point by $(\mathbf{10.31} + \mathbf{2.2}) - \mathbf{8.5} = \mathbf{4.01}\ \boldsymbol{metres}$.

The repercussion of this is that the tidal basin cannot utilise the entire tidal range in producing energy, and must be dredged by a value of 4 meters with appropriate reinforcements added to the walls. Moreover, the penstock must be dug out and lowered so that the water can enter the basin starting from low tide. Unfortunately, the tidal basin is along the shoreline and consequently the water depth outside the basin is shallow (Figure 33).

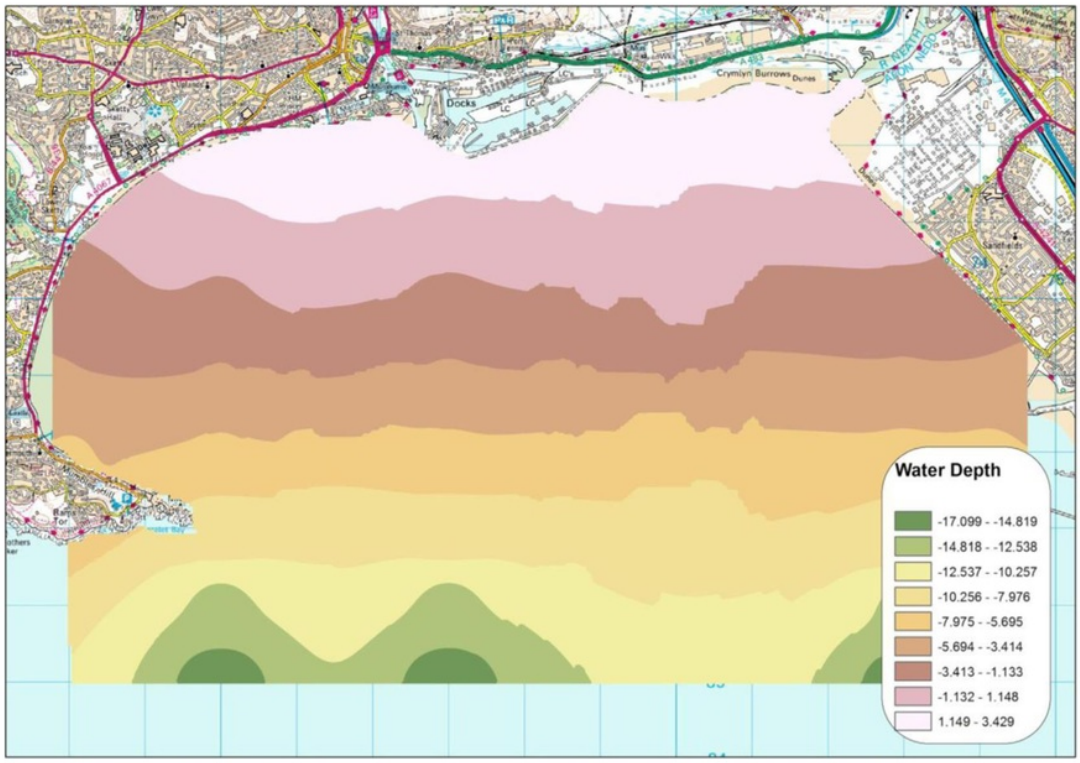


Figure 33- Inverse Distance Weighting surface at mean sea level (metres). (Petley & Aggidis, 2016)

The basin, penstock and sluice gate can only be lowered by approximately 2 meters before 'running aground', as shown in Figure 34.

This is an inevitable situation arising from the project's location (dredging that part of the bay regularly would not be feasible for this small a project). Figure 27 demonstrates how only the spring tides would be affected by an elevated basin, as the low water level during neap tides is near the basin's floor. The author further calculated how much of the tidal range would be lost during spring tides due to the elevated basin from the information gathered on the tidal range in the past four years.

The sea water level was plotted for the values obtained from the Swansea marina handbook, and a horizontal line plotted at y=2. Any water levels



Figure 34-Penstock emptying into bay (Low tide)

below this show that the effective tidal range is less than the actual range at that time. The impact of the elevated basin appears to be minimal. However, all hydroelectric turbines have a required minimum head to function (magnitude depending on turbine type and make, but typically between 1-1.5 metres), and this extra loss of head will impact production.

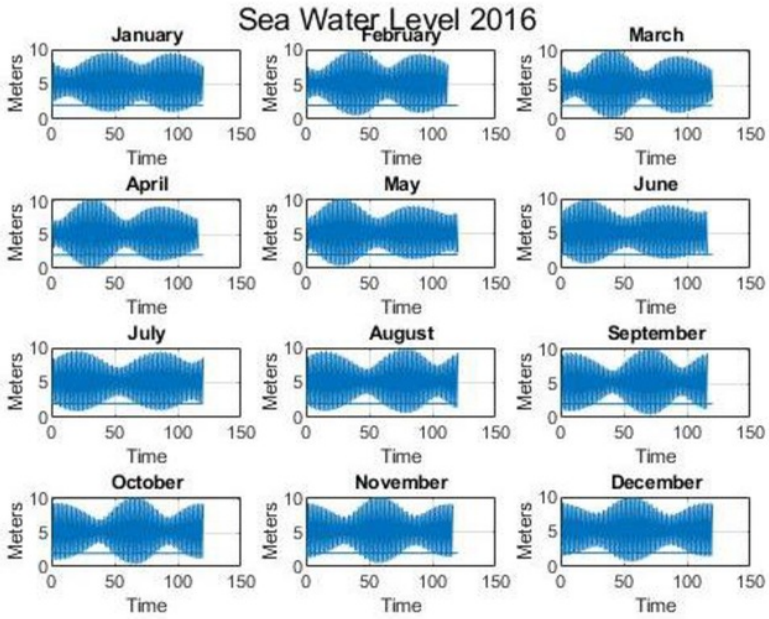


Figure 35-Sea Water Level 2016. Line at y=2 to show losses from elevated basin

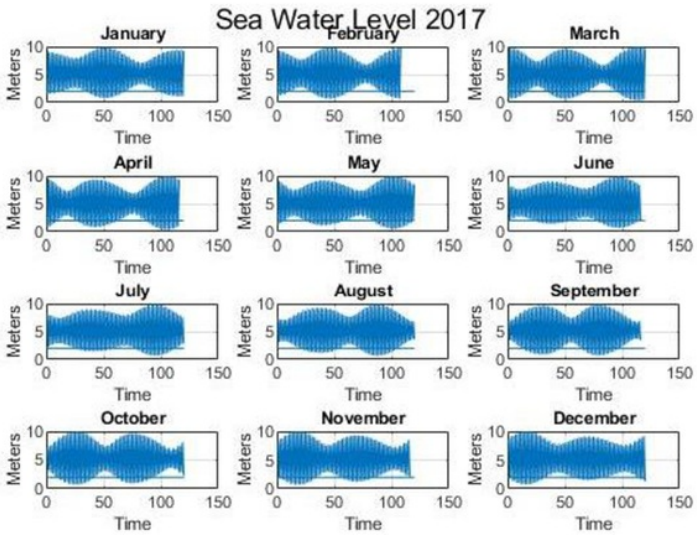


Figure 36-Sea Water Level 2017. Line at y=2 to show losses from elevated basin

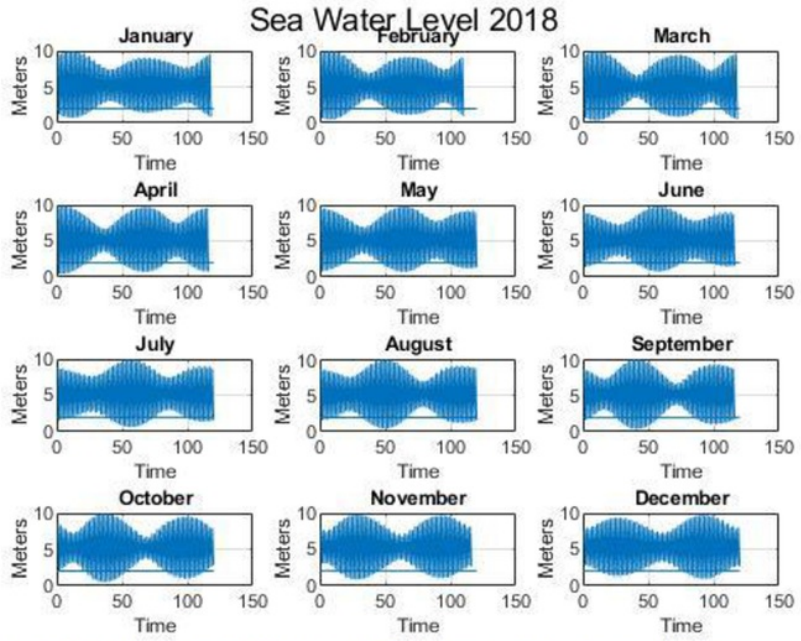


Figure 37-Sea Water Level 2018. Line at y=2 to show losses from elevated basin

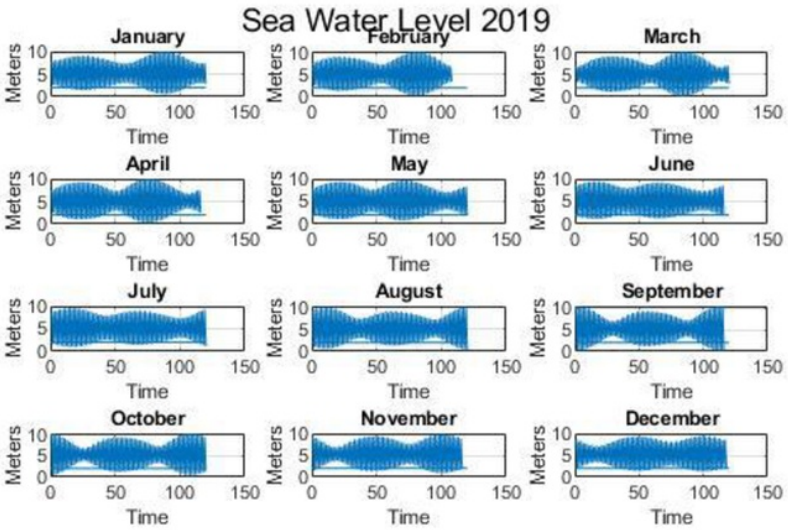


Figure 38-Sea Water Level 2019. Line at y=2 to show losses from elevated basin

These graphical images are supplemented by Table 11, which shows that on average the water levels at low tide are 1.8 metres above the datum point. **The elevated basin will incur an average loss of 20cm of head assuming that the basin's floor is 2 meters above the datum point. The average tidal range is thus amended from 6.78 metres to 6.58 metres.**

Table 11- Water level at high and low water 2016-2019 (Average)

Average high and low water levels (metres)				
	2016	2017	2018	2019
Average high water level	8.57	8.61	8.62	8.63
Average low water level	1.87	1.84	1.83	1.82

The basin's surface area and effective (average) tidal range which the past two sections have calculated are used to compute the flow rates, expected annual output and possible power ratings.

The tidal period last 12.42 hours, and the volume of water trapped in the basin from the average range is $Basin\ Area * Tidal\ Range = 9000 * 6.58 = 59220m^3$. Generation commences when the minimum functioning head for the turbine exists. If it is assumed that the flow through the penstock is constant and this minimum head is maintained until the basin is emptied/filled (water level on higher side passes minimum head requirement), then production can only occur for approximately 4 hours as the tide comes or recedes. The final meter of head will be lost, as it is the minimum head for the turbine to function. **The effective volume of water that will flow through the turbine is thus approximately 49,500 m^3 (average), with a maximum (at spring tides) of 75,500m^3, and minimum of 23,4000m^3.**

$$\frac{23400}{4 * 3600} = 1.63\frac{m^3}{sec}\ and\ \frac{49500}{4 * 3600} = 3.44\frac{m^3}{sec}\ \ and\ \ \frac{75500}{4 * 3600} = 5.24\frac{m^3}{sec},$$

Table 12: Approximate effective flow rates through the turbine

Minimum flow	Average flow	Maximum flow
1.63 m^3/sec	3.44 m^3/sec	5.24 m^3/sec

The minimum flow is disturbingly low, as the minimum flow required for micro-hydroelectric run-of-river schemes to be effective is an average of 2m^3/sec (Renewables First, 2015) . It is possible that at neap tides the range will be too low to generate for the full 4 hours, and would be restricted to a shorter period.

These flow rates can be used to identify the ideal turbine size by contacting manufacturers and using a hill-chart. Unfortunately, no technical data was received from the companies the author contacted, so a hill chart was not used to determine the ideal turbine size using the flow rates.

3.3 Energy and Revenue generated by the tidal power plant

Using the equations explained in the literature review, the energy production per tide can be calculated, as can the annual production from the scheme.

Equation 3: $$E_p = \frac{1}{2} A_b \rho g H^2$$

Equation 4: $$E_{year} = 0.987 * A_{basin} * H_{basin}^2 * \eta$$

3.3.1 Energy of the water impounded during each tide (Ebb production only)

Considering the magnitude of the values involved, instead of using SI units, the values were changed to km^2 for the surface area and tonnes/m^3 for the density for equation 3. The effective tidal range of 6.58m is used.

$$E = \frac{1}{2} * 0.009 km^2 * 1.025 \frac{tonnes}{m^3} * 9.81 \frac{m}{s^2} * (6.58m)^2$$

$$E = 1.96\ GJ\ per\ tide$$

$$E = \mathbf{1959\ MJ\ per\ tide}$$

Considering a 12.42 hour tidal period, the energy available to be harnessed each day is:

$$\frac{24}{12.42} * 1959 = \mathbf{3785.7\ MJ\ each\ day\ or\ 1051.6kWh\ each\ day}$$

The resulting annual energy from impounding sea water in the basin during each tide:

$$3785.7 * 365 = \mathbf{1.38TJ\ OR\ 383.8MWh\ each\ year}$$

This value is simplified due to the use of the average tidal range (6.58m) and will differ from generation values as it is impossible to harness 100% of the water's potential energy. The turbine's efficiency will further reduce the generated electricity when compared to these theoretical values. Using MATLAB, the author used equation 3 and calculated the energy production for each individual tidal range over the course of a year (after subtracting 20cm from each range value to amend for the elevated basin). The sum below provides a more accurate insight into the annual potential energy available to be harnessed (in ebb generation only). The MATLAB Script has been transcribed in the appendixes.

$$\sum_{i=1}^{705} (Tidal\ Range_i)^2 * 0.5 * 1025 * 9000 * 9.81 = \mathbf{1,437.5GJ} = \mathbf{399.3MWh\ each\ year}$$

Comparing these results to those found using Equation 4 (different source) to calculate the annual potential energy available to be harnessed provides a similar result:

$$E_{yr} = 0.987 * 0.009 * (6.58)^2 = \mathbf{384.6}\boldsymbol{MWh}$$

These calculations characterise the potential energy of water impounded behind a barrier. A 2018 study focusing on the optimisation of a tidal range power plant by analysing the proposed Swansea and Cardiff tidal lagoons advises controlled two-way production with pumping to achieve up to 46% of the potential energy to be harnessed. Figure 9 demonstrates what this controlled process entails. (Angeloudis, et al., 2018)

Using the MATLAB generated figures, this indicates that the annual electricity production will be 367.4MWh (assuming equal production of the flood as on the ebb, and utilising 46% of potential energy). A conservative estimate, which shall be used in the calculations of revenue and return on investment is a utilisation factor of 33% (as mentioned in Section 0 and advised by (Xia, et al., 2012) **&** (Roberts, et al., 2016)**), providing 263MWh of annual generation (daily generation of 722kWh).**

3.3.2 Power Ratings from calculations of potential energy

Generation occurs twice per tidal period but only for the portion of the flood and ebb flows when the minimum head is attained. Generation is thus restricted to roughly 4 hours in either direction, for a total of 4*2*(24/12.42)= 15.46hours each day. The power output for these periods, assuming generation begins and continues to operate when the head reaches its minimum operating value (dependent on the turbine), the flow is constant, and generation ceases when water level falls below the minimum head difference is calculated below. The production is on average (using the MATLAB values with a 33% efficiency):

$$\frac{263000kWh}{365 * 15.6h} = 46.2kW$$

It appears that a 50kW turbine is suitable for a tidal basin of this size.

3.3.3 Tidal Power Plant Revenues (including if awarded a CfD)

The cost of electricity for UWTSD is 14pence/kWh according to Tom Yearley- the head of sustainability delivery. Simply by offsetting the cost of importing electricity to campus by producing it on site, will produce an annual revenue of 263,000*0.14= £36,820, or a daily savings of £100 (using the 46% efficiency, these values are £51,436 and £140) respectively.

Assuming an average household consumption of 10kWh each day (this value is rounded up from the author's electricity bills from the past year, where average annual consumption was 8.8kWh per day, and the electricity was provided by SSE) the tidal basin can produce enough energy to supply 72 homes. **Should the generated electricity be exported to the grid instead of used on site, then the generated revenue would depend on the strike price agreed upon by the Contract for Difference, as indicated in Section 2.7.3 (if this project wins the auction). The typical strike price from the 2017 auction, as shown in Figure 20 was £74.75/MWh, thus the annual revenue from exporting the energy would be 74.75*263=£19,659. This value cannot be guaranteed, as the true strike price will only be known after the auction has been held.**

If the University's application is unsuccessful in winning a Contract for Difference, then the exported electricity revenue would be dependent on the going price of electricity, which in the UK can fluctuate as shown in Figure 19.

The university's savings are almost doubled by using the electricity on site as opposed to exporting it to the grid. This is clearly the preferable choice, if the University's base electricity usage is larger than the production rate.

3.3.3.1 How a feed-in-tariff would have affected revenues

Interesting to note is how the Feed in Tariff scheme described in Section 2.7.1 would have benefitted the University immensely, had it not closed to new generating capacity. The export tariff of 5.24p/kWh and generation tariff of 8.03p/kWh (for installed capacities of 0-100kW) would reward the University's annual generation of 263MWh with £34,899. £21,118 from the generation tariff and £13,781 from the export tariff were the electricity exported to the grid.

The optimum savings for the University would be to use electricity on site, while receiving the generation tariff of £21,118 accumulating a total savings of £57,938. Unfortunately as the FIT scheme closed these savings are no longer viable.

This report examines the ways of optimising energy output, however the possibility exists to maximise income by utilising the partial flexibility in generation timing. By selling electricity to the grid when the price of electricity is higher, a 23% increase in income can be generated

compared to standard operation, which is a 10% increase in income when compared to energy maximising operation. (Harcourt, et al., 2019) This demonstrates that the total savings by the university could be increased even further if the focus was on income maximisation instead of energy maximisation.

3.4 Experimental work using scale model

The author's desire was to manufacture a scaled basin at the university's workshop using the CNC machine, and to 3D print scaled turbines that were analysed in this study. These would be used to assimilate testing & project implementation as a proof of viability of this project. For example, testing an Archimedes screw in a horizontal orientation could indicate its viability (or otherwise) in a tidal setting.

Unfortunately, due to the university's recent move to the new waterfront campus the CNC machine is not yet operational. The operational CNC machine is too small to manufacture a model of the required minimum dimensions. For this reason, the development of this part of the project was limited to the development of a 3D CAD model using SolidWorks, shown in the figure below (UWTSD's IQ building included to demonstrate relative depth of basin to building's height).

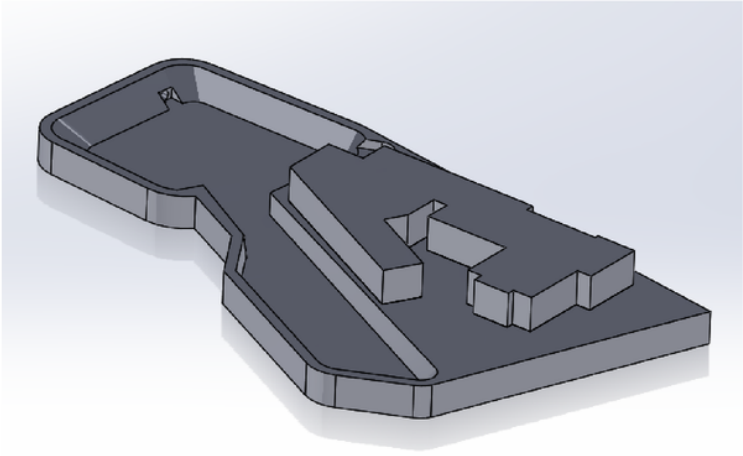


Figure 39- SolidWorks 3D model of tidal basin

3.5 Environmental impacts of using the tidal basin for electricity production

A small tidal range scheme with reduced power outputs compared to the existing tidal barrages will likely have lower environmental impacts. (Prandle, 2009) The environmental impacts of the existing tidal barrages were not well documented, though in La Rance the most visible damage to wildlife and the natural environment was during the construction phase that lasted 2-3 years. Once operational, the tidal scheme created new habitats for wildlife from the reduced inter-tidal areas, reduced variations in salinity and reduced currents favouring water-clarification phenomena. The largest impacts of tidal barrages are on the water movements within the basin, though there can be effects on silt deposition (within and outside the basin), variations in tidal range (when an entire estuary is developed), and a reduction in swell. (Frau, 1993) Bidirectional generation reduces many of these issues as the tidal range remains closest to its natural cycle. (Roberts, et al., 2016)

It appears that a smaller tidal range power plant will have minimal effects on the natural environment, and could in fact provide some benefits, such as a reduced inter-tidal area supporting wildlife and flood protection for the University by closing the sluice gate during storm surges. Moreover, the electricity that will be generated emits zero emissions, and the electricity it produces can offset the production from other polluting power plants. The next section analyses the current energy mix in the UK and USA to calculate how many pollutants could be offset by this project. Moreover, this study examines a pre-existing basin that needs alterations for its development as a power plant and the construction period is when the largest effects will occur on the natural environment. Over the past year that the author has been observing the tidal basin the only flora and fauna observed has been several birds and fish, neither of which would be adversely affected by civil works of a project this small. The author predicts that human interference will be the largest issue in project development, as local inhabitants will likely complain about the sound pollution during construction.

The Hendry report of 2016 on tidal lagoons confirms the role that tidal range power plants can play in the future of the UK's energy mix, and states that a limitation in tidal range projects concerning environmental impacts is the lack of documented data. The only way to change this, and what is suggested in the report, is to develop a new site and monitor the resulting effects. (Hendry, 2016)

3.6 Pollution Offset by tidal power generation plant

The UK has seen CO_2 emissions decrease by 43% since 1990- mostly a result of increased efficiency, lower energy consumption-11% decrease since 1990- (note that this value was increasing until 2001), and an evolving energy mix (with a pronounced decrease in use of coal and increase in renewables). In 2017, energy supply was the second largest sector contributing to CO_2 emissions (29%) after the transport sector (34%). Fossil fuels used for electricity production emitted an aggregate of 450 tonnes CO_2 per GWh, of which coal contributes 870 tonnes/GWh, while gas contributes 360 tonnes/GWh. (Department for Business, Energy & Industrial Strategy, 2018)

The following two figures show the generated electricity's fuel type with a total electricity generation of 338.65 TWh and 333.92TWh in 2017 and 2018 respectively. Wind & solar includes offshore and wave/tidal energy. (National Statistics UK, 2019)

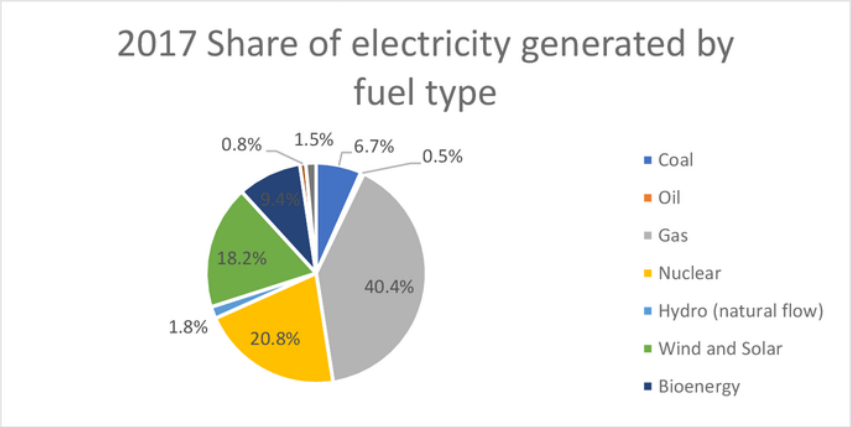


Figure 40- 2017 Electricity generation by source (National Statistics UK, 2019)

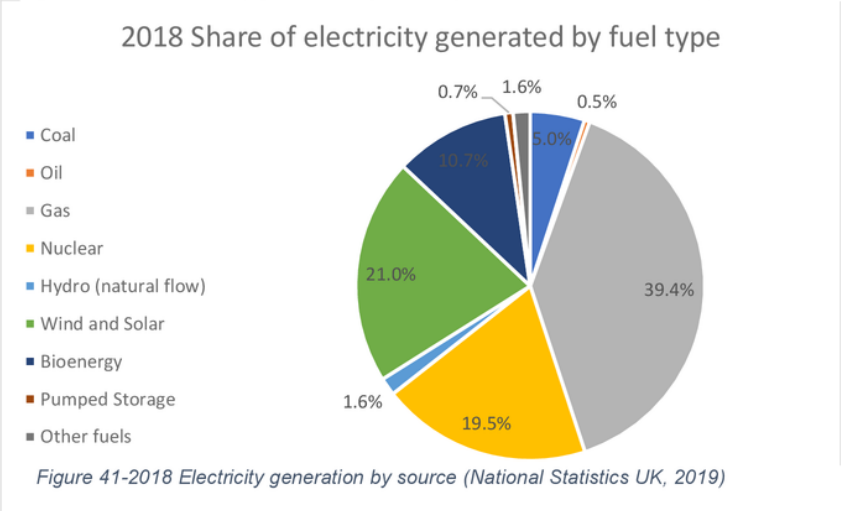


Figure 41-2018 Electricity generation by source (National Statistics UK, 2019)

The UK data for emissions from electricity generation is converted to the CO_2 equivalent, as shown in the figure below. The author could not find data pertaining to the specific pollutants, so data from the U.S. Energy Information Administration was found to complement this study.

	1990	1995	2000	2005	2010	2015	2016	2017 (p)
								$MtCO_2e$
Gas	146.1	188.5	241.5	235.4	228.2	172.9	187.3	183.0
Oil	197.8	187.1	174.5	175.6	154.9	148.7	150.4	150.9
Coal	219.2	152.2	117.0	124.9	100.9	73.0	33.6	25.5
Other solid fuels	14.1	13.3	11.5	10.1	8.9	7.3	6.5	6.5
Non-fuel[1]	16.8	15.5	9.2	7.3	-0.3	0.7	1.0	1.0
Total	**594.1**	**556.6**	**553.7**	**553.3**	**492.7**	**402.5**	**378.9**	**366.9**

Source: Table 2, Provisional UK greenhouse gas emissions national statistics 1990-2017 Excel data tables

Note: (p) 2017 estimates are provisional.

1. A negative number indicates that this sector was a net sink, with the total removals of carbon dioxide by the land use, land use change and forestry sector larger than the emissions from other non-fuel activities.

Figure 42- UK emissions (CO2 equivalent) by fuel type. (Department for Business, Energy & Industrial Strategy, 2018)

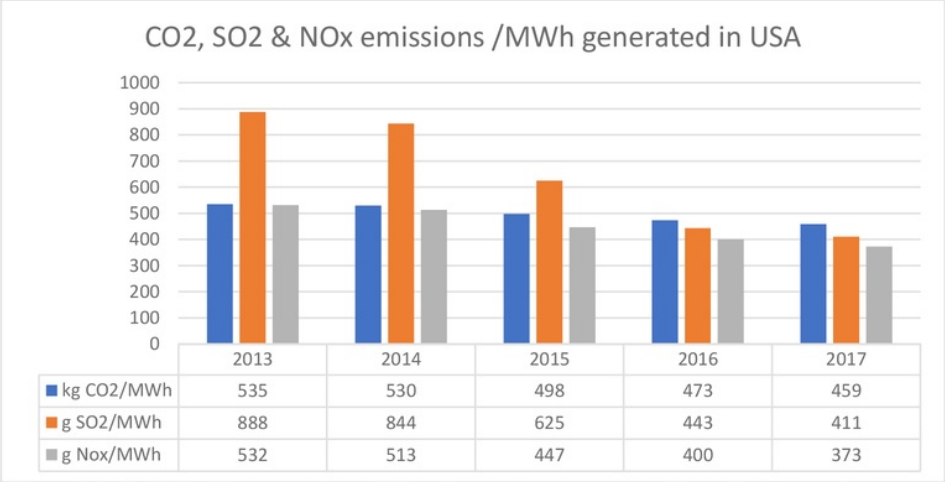


Figure 43-CO2, SO2, NOx emissions per MWh of electricity produced in USA. (U.S. Energy Information Administration, 2018)

These figures prove that greenhouse gas emissions are being reduced in the energy sector. Should a tidal power project like the one examined in this report be implemented, it will further offset 459kg CO_2, 411g SO_2 and 373 g NO_x for every MWh of electricity generated (assuming US fuel mix), or simply 450kg CO_2/MWh based on UK fuel mix.

3.7 UWTSDs Energy Consumption

Tom Yearley, the head of sustainability delivery at UWTSD provided data on the electricity consumption at the IQ building starting on June 8th, 2018 until January 28th, 2019. The author found that the data fluctuated unrealistically during the summer that the campus was still under construction. For this reason, the author only processed the data from October 1, 2018 (the first day of term) until January 28th 2019, shown in Figure 44. The average consumption for each 30 minute window that data is collected in was 51.4kWh, with a minimum of 31.5kWh and a maximum of 101.7kWh. The average daily consumption is 2467kWh with a standard deviation of 16.01. The 50kW turbine will produce 25kWh over 30 minutes- half of the University's base electricity needs.

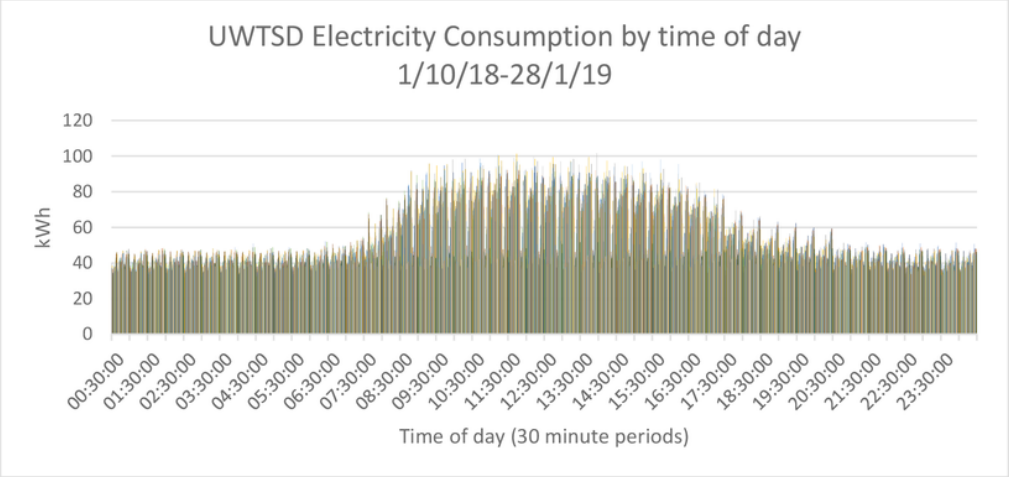


Figure 44-UWTSD electricity consumption by time of day

The total energy consumption over this four month period was 294MWh (though the last four days of January are missing, so the value would be slightly over 305MWh) costing a total of £41,186. The average cost of electricity per day is £345. It is interesting to see the highest daily cost in mid-December when students have more deadlines, and the dip in energy usage over the Christmas holidays (late December & early January).

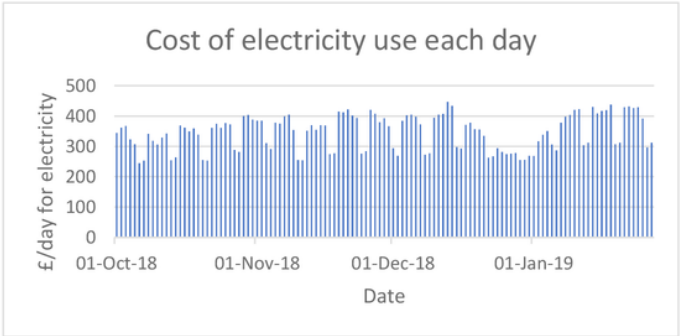


Figure 45- UWTSD electricity cost per day

4 Results

4.1 Feasibility of project based on costs & savings

4.1.1 Costs of Tidal Range Project

The typical breakdown of costs for a hydroelectric project is shown in Figure 46. Though this report examines tidal range, the site is pre-existing with minor modifications needed, is easily accessible and is on-shore creating more similarities with a run-of-river site than the existing tidal range power plants, which built barrages across entire bays. The largest civil works for this project involve digging out (and lowering) the sluice gate for the turbine installation and dredging the basin to lower the basin floor by 2 meters with the proper reinforcements added to the walls.

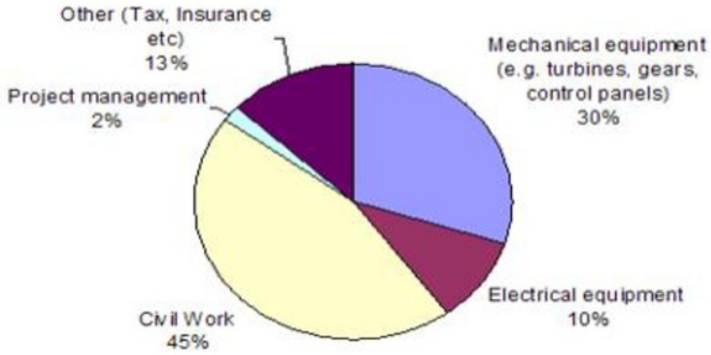


Figure 46-Break down of capital costs for small scale hydro (Aggidis, 2008)

Hydroelectricity facilities have large set costs arising from the civil works, grid connections, application fees, feasibility studies etc, and varying costs for electrical/mechanical equipment, installation, insurance, taxes depending on the magnitude of the power plant. Larger projects benefit from a lower cost per unit of electricity produced and are disproportionately cheaper to commission in the long term as depicted in Figure 47.

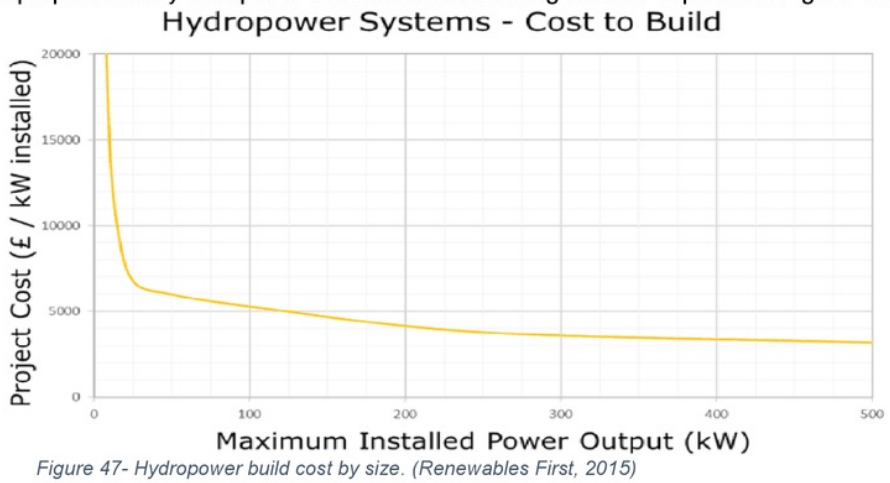


Figure 47- Hydropower build cost by size. (Renewables First, 2015)

Using the cost calculation tool created at Lancaster University (Aggidis, 2008) the suggested Kaplan turbine for a project this size costs £160,000. Knowing that a Kaplan bulb is more efficient in tidal range settings, the turbine cost would be higher- perhaps as much as £200,000. The bulb holds the electrical equipment so this value accounts for 35-40% of project costs (based on the previous figures), for a total project cost of £500,000-£575,000.

Renewables First, the company that supplied Figure 47, advise a minimum project size of 25-50kW for it to be financially feasible, and warn that their information is not accurate for all sites, as the work needed to prepare the site varies depending on the conditions. The calculated output for this project was 46kW- the threshold for cost-effective projects. Correlating this value with the project cost in the previous figure predicts £6,000 /kW, for a project cost of £276,000.

The author contacted several companies to verify what the cost of hydroelectric turbine technology is: HTE Engineering, Andritz Hydro Hammerfest & Renewables First, but did not learn the cost of the most suitable technology. For this reason, the estimates calculated previously will be used for the financial analysis that follows.

The operating costs post-commissioning will be for maintenance, monitoring, security, tax and upkeep. Monitoring, security and upkeep can be omitted as the project is located on the UWTSD campus, where faculty and staff members can perform these roles without a drastic increase in their daily responsibilities. Given the current levels of automation in power generation, it is possible the plant will operate marginally without interference. Regular maintenance will include cleaning screens of debris, kelp and rubbish, and lubricating the necessary mechanical parts. **For a project of this size, an approximate annual running cost would be £7,000.**

4.1.2 Levelised Cost of Energy

The levelised cost of energy (LCoE) is used to determine the minimum rate at which electricity can be sold in order for the project to be feasible over the course of its life time. Given that a loan will need to be taken and interest paid thereon, the revenue of the project must not only cover capital, operating and maintenance costs, but must also contribute to the returns of investors. The LCoE of a given project is given by (Neill, et al., 2018):

Equation 5: Levelised Cost of Energy

$$LCoE = \frac{C_1 + \sum_{n=1}^{N}(\frac{OM_n}{(1+r)^n})}{\sum_{n=1}^{N}(\frac{E_n}{(1+r)^n})}$$

Where C_1 is the capital investment, OM_n represents the operation and maintenance costs in the year '*n*', E_n is the energy yield in year '*n*' and r is the discount rate.

Using the highest cost (£575,000) and lowest energy outputs (263MWh), assuming that generation begins in 2030 and ceases in 2117, annual maintenance and operation costs are £7,000, and the discount rate is 4% this results in an LCoE of:

$$LCoE = \frac{575000 + \sum_{n=1}^{83}(\frac{7000}{(1+.04)^n})}{\sum_{n=1}^{83}(\frac{263000}{(1+.04)^n})}$$

$$LCoE = \frac{575000 + 168250}{6321412}$$

$$LCoE = £0.11757/kWh$$

The previous sections calculated the maximum savings for the university are derived from using the electricity on site and incurring savings from the reduced electricity bill. The cost of electricity for the university is £0.14/kWh, which demonstrates that the project costs over its lifetime are less than the current cost of electricity by £0.023/kWh. This is a narrow margin, but demonstrates that the project is financially viable, and similar small scale projects with a larger basin would incur larger savings (assuming a similar tidal range).

4.1.3 Payback period and return on investment

The payback period is a tool used to predict when the project will break even, after which the project begins to return a profit. Using conservative figures:

$$Payback\ period = \frac{capital\ costs}{annual\ revenue - annual\ costs}$$

$$payback\ period = \frac{575000}{36820 - 7000} = 19.3\ years$$

Using the 46% efficiency (51436GBP), the payback period is reduced to 13 years. The project costs have been exaggerated in this study, as exact figures were not available, so in reality it is possible that the payback period will be shorter.

The expected ROI will depend on how much electricity is consumed on site, and how much is exported to the grid. On average though, a small hydroelectric project could achieve 5%-10% if energy is exported, or 10-20% if the energy is used on site. This obviously depends on the total commissioning costs, the financial support from governmental schemes, availability of the installed technology and water to wire efficiency. (Renewables First, 2015) Using the numbers calculated above, the return on investment is:

$$ROI = \frac{Net\ profit}{Total\ investment} * 100$$

$$ROI = \frac{36820 - 7000}{575000} * 100 = 5.19\%$$

This is a meagre return on investment, but considering the value is positive, shows that this investment should provide 5% returns for the investor. Compared to other riskier investments on the market, this seems a beneficial investment, though investors will need to wait between 15-20 years before receiving their returns.

5 Discussion and Conclusions

Tidal energy is an underutilised energy resource, both globally and in the UK. Though tidal stream technology has seen vast investments and has benefitted from the wind power sector, tidal range has not benefitted in the same way, despite being a proven technology with the oldest tidal range plant celebrating its 52nd annum of operations this year. The recurring issue with tidal range schemes is the prohibitively high capital costs, the restricted operating periods and the environmental impacts of blocking entire estuaries. The benefits of tidal energy are its predictability and dependability, and if several tidal range power plants were developed across the UK, they could be used to cover 20% of England & Wales' energy usage. Moreover, as shown in Figure 48 there is a phase difference between the time of high tide in different coastal areas in the UK, which means net generation from many schemes will be spread over the day, despite each location being limited to specific generation periods. (Waters & Aggidis, 2016)

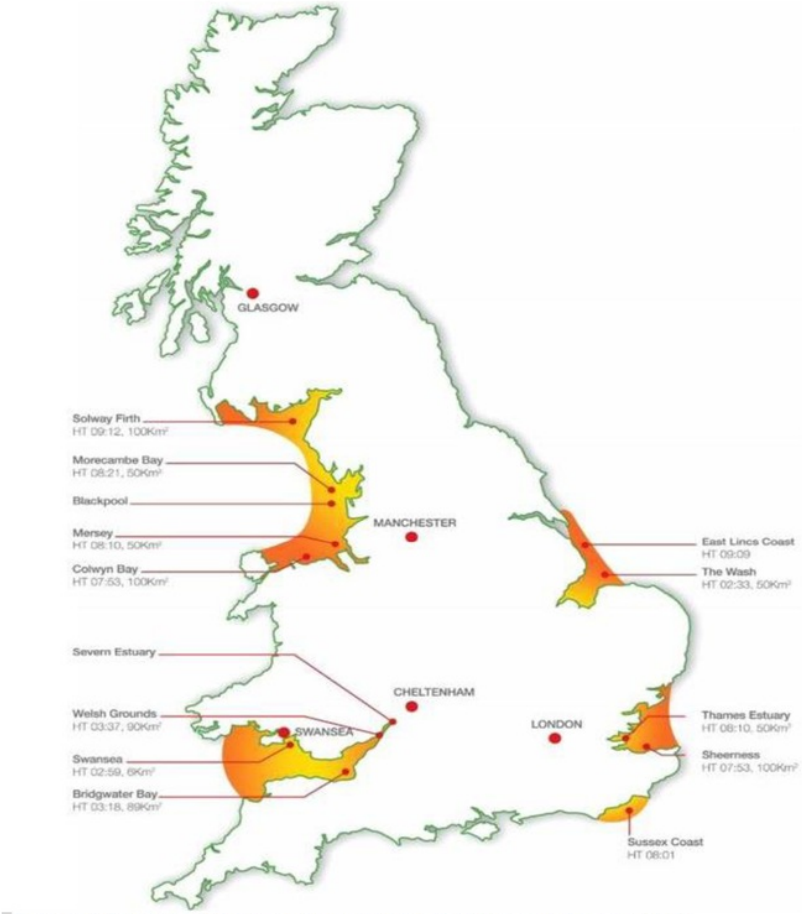


Figure 48-Proposed Tidal range projects in the UK (Waters & Aggidis, 2016)

This study examines the possibility of generating electricity in small tidal range power projects, ideally using pre-existing sites that are unutilised, such as dry docks or near shore sites with appropriate geometry to be adapted easily. By examining the case of the tidal basin at UWTSD's new waterfront campus in Swansea's SA1 development area, it was found that small tidal range projects are feasible, and can provide enough energy for a community near the project's site. For this specific location, the generated electricity can be used to cover the university's base energy needs. The limitation of a tidal range project of this size is the long-payback period, combined with high initial costs- possibly as long as 20 years and as much as £500,000 respectively. The environmental effects of a project this size are minimal, and would marginally be prevalent during site construction as civil works are carried out. Once operational, the largest environmental concern arises from fish being affected by the turbine blades & guiding vanes. The power plant would be mostly imperceptible to the public, with the largest interference to the surrounding environment coming from the sound of water flowing through the penstock (not an issue as the Swansea marina is adjacent to the project's site, which has a loud water flow from the river Tawe to the sea).

To guide the conversation on tidal range energy production, research was done and presented on the existing tidal range power plants, the technology and generation methods they use, as well as other turbines that could be used in lieu of the common Kaplan bulb. The bulb turbine was found to be the most appropriate choice, despite costing more, and having adverse effects on marine life passing through it. The next best choice was the Archimedes screw, however additional research is needed to verify its suitability in a tidal range setting.

Measurements of the tidal basin were made (surface area of 9000m^2), data on the tidal range for the years 2016-2019 were processed using a MATLAB script (effective average range is 6.57m) and the effective volume of water passing through a turbine calculated (on average 3.4m^3/s). The civil works that must happen for this project to move forward involve dredging and lowering the basin floor by 2 meters, reinforcing the walls appropriately and lowering the penstock by an equal amount for the turbine to be installed. A small station regulating the generated electricity would also be required with a charge controller, power regulator and other electrical safety equipment.

The discourse on tidal range energy production is producing vast amounts of knowledge on the topic. The viability of tidal range projects increase as different optimisation strategies are conceived and presented, such as maximising energy output or maximising income by

varying the modes of operation. Increases in income by 26% have been estimated by maximising income when compared to a standard mode of operation.

The tidal basin at UWTSD annually has 1,437.5GJ (399.3MWh) of energy flowing out of it, and double that amount if the flow of water into the basin is also considered. This potential energy is currently unutilised. If a turbine were used to harness this energy (the author suggests a power rating of 50kW) and produce electricity between 33%-46% of the potential energy would be transformed into useful electricity- an annual production between 263MWh and 367.4MWh. This is enough electricity to cover half of the university's minimum consumption (ie electricity would always be used on site), which would provide the university with annual savings on its electricity bill of between £36,820 and £51,436 respectively.

If an annual generation of 300MWh is assumed, this project could potentially offset electricity generation from a fossil-fuel based power plant. The annual pollution that is offset by implementing this project comes to 137.7tons of CO_2, 123.3kg SO_2 and 111.9kg NO_x.

Financial support for a project like this would come from a Contract for Difference, in which the generator enters into an auction for a set amount of money that will reward the generator with a fixed price that their electricity will be purchased at for a 15 year period. The University achieves maximum savings by using the electricity on-site and offsetting their electricity bill so it is possible that a CfD is not beneficial for this project. A feed in tariff would have been the most lucrative option for the University, but unfortunately, the FIT scheme closed this year to new generating capacity.

The long payback period of 20 years indicates that investors must be patient with returns. The project can provide a return on investment of 5%, which means that for a projected life of 80 years, the last 60 years of the project will provide a consistent 5% return. The LCoE of £0.12/kWh further proves this, which is below the current costs of electricity by £0.023kWh. These estimates must be recalculated with more accurate information on capital, operational and maintenance costs. Once this information is obtained from equipment suppliers, quotes have been received for the required civil works and a further assessment of total costs is conducted, a more accurate indication of the payback period, return on investment and levelised cost of energy can be gained. The author used higher estimates in this study than are expected from industry, so newer information should make this project more compelling.

The energy outputs from a tidal basin are proportional to the basin's surface area, and the square of the tidal range. The Severn estuary is blessed with some of the largest global tidal ranges, which was one of the factors that inspired this research project. Other areas that can benefit therefrom, and could feasibly produce electricity from small scale tidal schemes are in the Bay of Fundy in Canada-19.6m range, Granville in France 14.7m range, Puerto

Gallegos in Argentina-13.3m range, Fitzroy River in Australia-11.5m range, Gulf of Mezen in the white sea -10m range. (Bernshtein, 1965) Some other sites that have proven technically feasible for tidal range are shown in the figure below.

The author was hoping to manufacture a scaled basin and turbines to demonstrate the projects operating methods, and available technology to be used, however this was not possible due to the unavailability of the university's CNC machine. Despite this, the workshop technicians provided constructive criticism on the authors CAD models and suggested improvements for ease of manufacturing, which benefited the author's knowledge on the topic for future use.

Country	Site	Type	Mean tidal range (m)
Argentina	San Jose	Barrage	5.9
Australia	Secure Bay 1	Barrage	10.9
	Secure Bay 2	Barrage	10.9
Canada	Cobequid	Barrage	12.4
	Cumberland	Barrage	10.9
	Shepody	Barrage	10
India	Gulf of Kutch	Barrage	5.3
	Gulf of Cambay	Barrage	6.8
South Korea	Garorim	Barrage	4.7
	Cheonsu	Barrage	4.5
Mexico	Rio Colorado	Barrage	6–7
	Tiburon	Barrage	–
UK	Severn	Barrage	7.0
	Mersey	Barrage	6.5
	Wyre	Barrage	6.0
	Conwy	Barrage	5.2
	Swansea	Lagoon	–
	Newport	Lagoon	–
	Bridgewater	Lagoon	–
	Cardiff	Lagoon	–
	Colwyn Bay	Lagoon	–
	Blackpool	Lagoon	–
US	Passamquoddy	Barrage	5.5
	Knik Arm	Barrage	7.5
	Turnagain Arm	Barrage	7.5
Former Soviet Union	Mezen	Barrage	9.1
	Tugur	Barrage	–
	Penzhinskaya	Barrage	6.0
	Cauba	Barrage	–

Figure 49- Sites that have been identified as technically feasible for tidal range (Neill, et al., 2018)

6 Recommended Further Work

The project site is within 200 meters of the river Tawe and the author believes that the water flow from the river could be used to supplement energy outputs during ebb generation. The river suffers from variations in flow depending on the rainfall resulting in fluctuations by season and year. The predictability of tidal power provides a guaranteed amount of energy, and increasing this value- even by an unpredictable amount- will create a shorter payback period and a higher return of investment. The rate of return will also be increased, however a further study on the flow rates of the river Tawe must be first conducted. Subsequently, the optimisation of the power plant must be recalculated using the new fresh-water flow, so that the sluice gate bringing water from the river Tawe can be operated automatically (opened and closed depending on when extra flow is needed in the tidal basin). Finally, an estimate of the costs of installing/maintaining & operating new pipework and a sluice gate must be compared to the revenues generated from the supplementary power the new flow will produce.

Other turbine types than the bulb can be suitable in a tidal range setting, however more research is needed in this area to prove or disprove the suitability of a specific turbine in a tidal range setting. The turbines presented that could be appropriate include a gyro, counter rotating device and Archimedes screw. There is the possibility of receiving governmental funding for researching new designs for low-carbon electricity production. Testing could happen at UWTSDs tidal basin.

The exact environmental effects of tidal range schemes have not been documented, though observations have been made surrounding the existing tidal range schemes and tentative conclusions made. The Hendry report advises that a tidal range project must be constructed and operated for several years with strict monitoring to determine the implications of tidal range schemes on the natural environment. A further study on this site, and other sites in the regions shown in Figure 49 should be done to confirm the findings of this report, perhaps with more technical data from equipment suppliers to guide the findings.

This project examines the feasibility of a small scale tidal range project in the UK. It is possible that in other regions of the world financial support for such a scheme is more readily available. Those regions could develop such a project sooner with larger financial gains, and the results of this study indicate that this is worth being researched further.

The largest limitation in this report arises from the estimates of costs for grid connectivity, maintenance, operations, machinery, civil works, financing charges, site access, permitting, decommissioning, site remediation, and the possibility of changing the turbine halfway

through the projects life. The author would like to collaborate closer with industrial partners in the future to calculate precise costs of the aforementioned topics. This will provide a deeper insight into the feasibility of such a project by recalculating the return on investment and payback period using more accurate data. Specifically, more research is needed in grid connectivity and whether the electrical connection should be isolated from the grid, passed through the university's supply, or linked directly to the grid. It is the author's understanding that using the electricity on site provides the largest savings, but needs to further research how the projects electricity can supply the University's base load. If this project moves forward, the company manufacturing and installing the turbine will provide the relevant information on this topic.

Lastly, the decommissioning costs were not considered in this report. Primarily, this was because the site already exists, and the civil works to adapt it would be minimal. It is possible that decommissioning would only involve removing the turbine and powerhouse, and leaving the penstock as it is. In this way the tidal flows will continue passing through the sluice gate as they currently are.

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8 Appendixes

8.1 Appendix A- MATLAB Script used to process tidal range data

```
clc
close all
clear all
format compact
%Subtracted the final value and made it first value of next month so that the arrays have same number of
elements

                        %2019
Jan2019=[0215 7.80 0825 2.65 1442 8.03 2106 2.51 0323 8.03 0929 2.43 1546 8.22 2206 2.25 0419 8.38 1023
2.13 1640 8.48 2254 1.96 0506 8.72 1108 1.84 1726 8.71 2334 1.72 0547 8.99 1148 1.63 1806 8.87 0011 1.55
0626 9.14 1227 1.50 1843 8.94 0046 1.48 0703 9.19 1303 1.46 1919 8.92 0120 1.50 0738 9.12 1338 1.52 1953
8.81 0152 1.62 0812 8.96 1412 1.66 2026 8.64 0222 1.81 0845 8.73 1442 1.85 2059 8.42 0250 2.04 0918 8.47
1514 2.08 2133 8.16 0320 2.31 0954 8.19 1549 2.34 2210 7.88 0357 2.60 1035 7.90 1632 2.62 2254 7.59 0445
2.91 1126 7.65 1728 2.88 2351 7.37 0553 3.15 1228 7.50 1839 3.01 0058 7.31 0715 3.14 1339 7.57 1957 2.87
0214 7.54 0831 2.83 1451 7.89 2106 2.50 0324 8.03 0936 2.34 1556 8.38 2206 2.00 0424 8.62 1033 1.81 1654
8.90 2301 1.51 0518 9.18 1127 1.32 1746 9.34 2353 1.10 0608 9.62 1219 0.94 1837 9.67 0043 0.80 0657 9.92
1310 0.69 1926 9.85 0131 0.63 0745 10.06 1400 0.58 2014 9.88 0218 0.62 0832 10.04 1447 0.64 2100 9.73
0303 0.79 0919 9.84 1532 0.89 2145 9.42 0346 1.13 1006 9.45 1616 1.32 2231 8.94 0431 1.61 1053 8.92 1703
1.87 2320 8.36 0521 2.18 1145 8.30 1756 2.46 0015 7.79 0622 2.70 1245 7.75 1902 2.92 0124 7.41 0736 3.00
1357 7.45 2021 3.06 0243 7.41 0856 2.94 1515 7.52 2138 2.84];
HTJan19=Jan2019(2:4:end);
LTJan19=Jan2019(4:4:end);
RangeJan19=(HTJan19-LTJan19);
RJan19=mean(RangeJan19)
figure(1)
suptitle('Monthly Tidal Range 2019')
subplot(4,3,1)
bar(RangeJan19)
title('January')
grid on
xlabel('Tide Number')
ylabel('Meters')

Feb2019=[0354 7.76 1002 2.60 1619 7.85 2234 2.43 0447 8.22 1053 2.18 1709 8.25 2318 2.01 0530 8.65 1134
1.79 1749 8.58 2354 1.67 0609 8.96 1211 1.51 1827 8.81 0029 1.44 0646 9.14 1246 1.35 1901 8.93 0103 1.33
0721 9.18 1321 1.30 1934 8.94 0135 1.34 0753 9.11 1352 1.35 2006 8.88 0203 1.45 0824 8.98 1420 1.46 2036
8.75 0229 1.61 0854 8.80 1447 1.63 2106 8.57 0254 1.80 0924 8.57 1515 1.84 2137 8.33 0322 2.04 0957 8.29
1548 2.11 2212 8.03 0359 2.35 1039 7.96 1631 2.48 2300 7.68 0451 2.75 1137 7.60 1735 2.86 0006 7.37 0612
3.08 1252 7.40 1907 3.03 0127 7.32 0752 3.00 1416 7.55 2036 2.75 0253 7.70 0913 2.50 1533 8.06 2146 2.18
0405 8.37 1019 1.84 1637 8.71 2246 1.54 0503 9.06 1117 1.21 1732 9.30 2340 0.97 0554 9.64 1209 0.70 1823
9.74 0030 0.55 0643 10.06 1300 0.36 1912 10.02 0118 0.29 0730 10.28 1346 0.20 1957 10.12 0203 0.23 0815
10.30 1430 0.27 2040 10.01 0244 0.38 0858 10.10 1509 0.56 2121 9.69 0322 0.75 0939 9.66 1547 1.06 2201
9.16 0400 1.30 1021 9.02 1624 1.72 2242 8.49 0440 1.98 1105 8.26 1707 2.45 2330 7.76 0533 2.69 1158 7.51
1807 3.11 0033 7.15 0645 3.23 1312 6.98 1930 3.46];
HTFeb19=Feb2019(2:4:end);
LTFeb19=Feb2019(4:4:end);
RangeFeb19=(HTFeb19-LTFeb19);
RFeb19=mean(RangeFeb19)
subplot(4,3,2)
bar(RangeFeb19)
title('February')
grid on
xlabel('Tide Number')
ylabel('Meters')

Mar2019=[0201 6.93 0815 3.33 1440 6.94 2105 3.28 0324 7.26 0938 2.94 1555 7.37 2212 2.75 0424 7.84 1033
2.38 1648 7.92 2256 2.19 0509 8.41 1114 1.86 1728 8.41 2333 1.71 0548 8.84 1151 1.47 1804 8.77 0007 1.37
0624 9.10 1224 1.22 1838 8.98 0040 1.18 0658 9.22 1257 1.11 1910 9.09 0112 1.13 0730 9.24 1327 1.10 1941
9.10 0140 1.18 0800 9.18 1354 1.18 2011 9.04 0205 1.29 0829 9.06 1420 1.30 2040 8.91 0230 1.43 0857 8.87
1445 1.48 2108 8.69 0256 1.64 0927 8.59 1515 1.76 2139 8.38 0330 1.97 1004 8.19 1554 2.19 2223 7.94 0417
2.45 1100 7.69 1653 2.73 2329 7.46 0536 2.96 1221 7.29 1834 3.09 0057 7.24 0727 3.02 1354 7.35 2015 2.86
```

```
0232 7.56 0857 2.51 1518 7.91 2130 2.22 0348 8.28 1007 1.77 1622 8.65 2231 1.48 0447 9.05 1104 1.07 1716
9.31 2324 0.85 0538 9.67 1155 0.53 1806 9.80 0013 0.40 0626 10.10 1242 0.20 1851 10.09 0059 0.16 0712
10.31 1326 0.09 1935 10.17 0141 0.12 0754 10.29 1406 0.22 2015 10.04 0220 0.31 0833 10.05 1442 0.56 2053
9.70 0255 0.70 0912 9.59 1515 1.08 2130 9.18 0329 1.26 0948 8.93 1546 1.74 2207 8.51 0404 1.93 1027 8.16
1622 2.46 2249 7.78 0450 2.65 1115 7.38 1715 3.15 2346 7.10 0559 3.26 1223 6.77 1841 3.60 0116 6.75 0730
3.46 1400 6.64 2018 3.50 0347 7.00 0959 3.12 1621 7.08 2234 2.96];
HTMar19=Mar2019(2:4:end);
LTMar19=Mar2019(4:4:end);
RangeMar19=(HTMar19-LTMar19);
RMar19=mean(RangeMar19)
subplot(4,3,3)
bar(RangeMar19)
title('March')
grid on
xlabel('Tide Number')
ylabel('Meters')

Apr2019=[0451 7.60 1100 2.53 1717 7.70 2322 2.34 0539 8.20 1143 1.96 1759 8.27 0001 1.80 0620 8.69 1221
1.51 1835 8.71 0037 1.42 0656 9.01 1256 1.22 1909 9.00 0112 1.19 0730 9.20 1329 1.07 1942 9.17 0144 1.09
0802 9.28 1400 1.02 2014 9.25 0213 1.08 0833 9.29 1428 1.05 2045 9.24 0241 1.14 0905 9.22 1456 1.15 2115
9.14 0309 1.25 0936 9.04 1524 1.33 2145 8.92 0339 1.47 1008 8.74 1554 1.63 2220 8.58 0415 1.83 1048 8.30
1636 2.10 2306 8.09 0505 2.34 1146 7.75 1737 2.67 0014 7.58 0629 2.83 1308 7.33 1921 3.03 0144 7.34 0812
2.87 1439 7.38 2057 2.79 0315 7.66 0941 2.39 1600 7.93 2212 2.16 0428 8.34 1050 1.69 1704 8.65 2312 1.46
0527 9.04 1145 1.06 1757 9.27 0003 0.89 0618 9.59 1234 0.60 1844 9.71 0051 0.52 0704 9.93 1319 0.35 1928
9.94 0134 0.34 0748 10.06 1401 0.32 2010 9.98 0215 0.36 0830 9.99 1439 0.48 2048 9.84 0253 0.56 0908 9.73
1513 0.81 2125 9.53 0327 0.91 0944 9.31 1544 1.28 2201 9.06 0401 1.40 1020 8.74 1614 1.83 2237 8.49 0435
1.97 1057 8.09 1646 2.43 2317 7.86 0517 2.57 1140 7.42 1733 3.03 0009 7.26 0619 3.10 1239 6.87 1851 3.48
0127 6.88 0742 3.35 1407 6.65 2025 3.51 0257 6.97 0906 3.15 1533 6.94 2143 3.09 0406 7.43 1012 2.67 1634
7.51 2238 2.53];
HTApr19=Apr2019(2:4:end);
LTApr19=Apr2019(4:4:end);
RangeApr19=(HTApr19-LTApr19);
RApr19=mean(RangeApr19)
subplot(4,3,4)
bar(RangeApr19)
title('April')
grid on
xlabel('Tide Number')
ylabel('Meters')

May2019=[0459 7.98 1102 2.15 1720 8.09 2322 2.02 0542 8.46 1142 1.71 1759 8.57 0000 1.62 0621 8.82 1220
1.39 1836 8.92 0037 1.36 0657 9.07 1255 1.19 1911 9.16 0112 1.20 0733 9.23 1330 1.08 1946 9.31 0145 1.13
0809 9.30 1403 1.06 2021 9.35 0219 1.13 0844 9.27 1436 1.12 2055 9.28 0254 1.22 0920 9.12 1510 1.30 2131
9.08 0330 1.42 1000 8.83 1547 1.60 2212 8.74 0414 1.76 1046 8.41 1634 2.04 2304 8.29 0512 2.19 1145 7.93
1741 2.52 0012 7.86 0630 2.54 1300 7.59 1909 2.78 0133 7.68 0755 2.57 1421 7.61 2035 2.61 0253 7.90 0917
2.25 1536 8.01 2148 2.14 0403 8.39 1024 1.75 1640 8.57 2248 1.60 0502 8.90 1121 1.28 1733 9.07 2339 1.17
0554 9.30 1209 0.95 1821 9.42 0025 0.89 0641 9.52 1254 0.79 1904 9.60 0109 0.77 0724 9.59 1335 0.78 1945
9.63 0149 0.80 0806 9.51 1412 0.92 2024 9.52 0227 0.96 0844 9.30 1446 1.16 2101 9.28 0303 1.22 0921 8.98
1518 1.49 2138 8.93 0337 1.57 0957 8.56 1548 1.89 2214 8.50 0412 1.97 1033 8.09 1621 2.32 2254 8.03 0453
2.40 1114 7.61 1703 2.77 2340 7.57 0545 2.79 1204 7.19 1803 3.17 0041 7.22 0651 3.05 1309 6.93 1924 3.34
0156 7.13 0804 3.05 1427 6.98 2042 3.18 0308 7.33 0912 2.80 1538 7.33 2145 2.79 0407 7.73 1009 2.41 1633
7.83 2235 2.34 0457 8.16 1056 2.01 1718 8.32 2318 1.94];
HTMay19=May2019(2:4:end);
LTMay19=May2019(4:4:end);
RangeMay19=(HTMay19-LTMay19);
RMay19=mean(RangeMay19)
subplot(4,3,5)
bar(RangeMay19)
title('May')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jun2019=[0540 8.55 1139 1.67 1800 8.74 0000 1.62 0622 8.87 1221 1.41 1841 9.06 0039 1.38 0704 9.11 1302
1.22 1920 9.29 0121 1.22 0745 9.25 1342 1.12 2000 9.41 0201 1.14 0827 9.30 1422 1.11 2041 9.41 0244 1.16
0910 9.22 1503 1.22 2124 9.28 0328 1.30 0955 9.01 1548 1.45 2211 9.02 0418 1.53 1045 8.69 1638 1.78 2305
```

```
8.67 0515 1.83 1142 8.33 1739 2.14 0006 8.34 0621 2.11 1245 8.02 1850 2.40 0114 8.12 0731 2.26 1354 7.89
2005 2.44 0224 8.11 0844 2.22 1505 8.00 2116 2.26 0332 8.28 0953 2.02 1611 8.31 2219 1.95 0433 8.55 1053
1.75 1708 8.66 2313 1.64 0528 8.80 1145 1.51 1757 8.97 0001 1.41 0618 8.97 1230 1.35 1842 9.16 0045 1.28
0703 9.05 1312 1.29 1924 9.25 0127 1.25 0745 9.03 1348 1.31 2003 9.23 0205 1.30 0824 8.93 1424 1.42 2041
9.10 0242 1.43 0901 8.75 1457 1.59 2118 8.89 0318 1.62 0937 8.51 1529 1.83 2155 8.60 0352 1.86 1012 8.22
1602 2.11 2231 8.27 0429 2.14 1049 7.91 1637 2.43 2311 7.93 0511 2.43 1130 7.60 1721 2.75 2357 7.62 0600
2.69 1218 7.34 1818 3.04 0052 7.40 0700 2.86 1317 7.19 1929 3.16 0156 7.35 0805 2.87 1425 7.25 2041 3.03
0303 7.51 0909 2.68 1535 7.54 2144 2.70 0406 7.84 1009 2.36 1634 8.00 2238 2.29 0500 8.25 1101 1.99 1726
8.49 2327 1.87];
HTJun19=Jun2019(2:4:end);
LTJun19=Jun2019(4:4:end);
RangeJun19=(HTJun19-LTJun19);
RJun19=mean(RangeJun19)
subplot(4,3,6)
bar(RangeJun19)
title('June')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jul2019=[0551 8.65 1151 1.63 1813 8.93 0015 1.52 0639 8.99 1239 1.33 1858 9.27 0102 1.24 0726 9.24 1326
1.11 1944 9.51 0149 1.05 0813 9.39 1412 0.99 2030 9.62 0237 0.96 0901 9.43 1458 0.98 2117 9.60 0326 0.99
0949 9.35 1545 1.09 2206 9.45 0415 1.13 1038 9.14 1633 1.33 2257 9.19 0506 1.38 1128 8.82 1724 1.66 2351
8.84 0600 1.73 1222 8.44 1821 2.05 0048 8.45 0659 2.09 1321 8.08 1927 2.38 0150 8.13 0805 2.38 1427 7.85
2039 2.54 0257 7.96 0917 2.48 1538 7.88 2150 2.46 0406 8.01 1026 2.36 1644 8.13 2253 2.22 0507 8.20 1125
2.12 1739 8.46 2345 1.93 0600 8.43 1213 1.86 1825 8.76 0030 1.69 0646 8.62 1254 1.66 1907 8.98 0110 1.52
0727 8.74 1330 1.53 1946 9.08 0147 1.44 0806 8.77 1404 1.48 2024 9.07 0223 1.44 0842 8.73 1438 1.52 2100
8.96 0257 1.52 0916 8.62 1509 1.65 2134 8.78 0330 1.66 0949 8.46 1539 1.84 2206 8.54 0402 1.85 1021 8.25
1609 2.07 2239 8.28 0435 2.09 1056 8.01 1642 2.35 2315 7.99 0512 2.35 1134 7.75 1722 2.66 2359 7.70 0559
2.64 1221 7.49 1817 2.98 0054 7.46 0700 2.88 1321 7.31 1932 3.16 0201 7.38 0814 2.93 1433 7.35 2054 3.02
0315 7.55 0927 2.70 1550 7.69 2205 2.60 0426 7.96 1032 2.28 1657 8.25 2304 2.07 0526 8.48 1130 1.79 1751
8.83 2357 1.56 0620 8.96 1222 1.34 1842 9.33 0049 1.13];
HTJul19=Jul2019(2:4:end);
LTJul19=Jul2019(4:4:end);
RangeJul19=(HTJul19-LTJul19);
RJul19=mean(RangeJul19)
subplot(4,3,7)
bar(RangeJul19)
title('July')
grid on
xlabel('Tide Number')
ylabel('Meters')

Aug2019=[0711 9.35 1313 0.98 1930 9.71 0139 0.81 0800 9.62 1402 0.73 2018 9.94 0229 0.63 0848 9.76 1448
0.62 2106 10.01 0317 0.59 0936 9.75 1533 0.67 2152 9.91 0403 0.73 1021 9.57 1618 0.90 2239 9.63 0447 1.05
1106 9.21 1702 1.31 2327 9.16 0532 1.54 1153 8.69 1749 1.86 0016 8.56 0621 2.13 1245 8.11 1845 2.46 0114
7.94 0721 2.70 1347 7.60 1957 2.92 0222 7.49 0838 3.04 1504 7.39 2122 3.02 0341 7.40 1005 2.98 1623 7.60
2240 2.75 0452 7.66 1112 2.62 1724 8.06 2336 2.32 0548 8.05 1201 2.20 1812 8.52 0019 1.91 0632 8.41 1239
1.83 1851 8.88 0055 1.60 0710 8.67 1312 1.56 1929 9.09 0130 1.40 0746 8.82 1345 1.40 2005 9.17 0203 1.32
0820 8.87 1417 1.37 2038 9.13 0235 1.34 0852 8.84 1448 1.44 2109 9.00 0305 1.44 0922 8.74 1515 1.59 2138
8.82 0332 1.61 0951 8.59 1540 1.79 2206 8.58 0359 1.82 1021 8.37 1607 2.03 2236 8.30 0429 2.09 1054 8.10
1639 2.35 2312 7.96 0506 2.44 1134 7.76 1723 2.76 0003 7.57 0600 2.86 1231 7.41 1831 3.17 0115 7.27 0724
3.15 1348 7.23 2014 3.27 0241 7.29 0858 3.02 1518 7.47 2143 2.84 0404 7.74 1013 2.50 1636 8.11 2251 2.16
0510 8.41 1115 1.86 1736 8.85 2348 1.48 0605 9.05 1209 1.25 1827 9.49 0039 0.91 0655 9.56 1300 0.77 1915
9.97 0128 0.52 0744 9.90 1348 0.46 2003 10.25 0215 0.31];
HTAug19=Aug2019(2:4:end);
LTAug19=Aug2019(4:4:end);
RangeAug19=(HTAug19-LTAug19);
RAug19=mean(RangeAug19)
subplot(4,3,8)
bar(RangeAug19)
title('August')
grid on
xlabel('Tide Number')
ylabel('Meters')
```

```
Sept2019=[0830 10.07 1433 0.33 2048 10.34 0300 0.31 0915 10.05 1516 0.40 2133 10.20 0342 0.53 0958 9.83
1557 0.69 2215 9.82 0421 0.97 1039 9.39 1636 1.20 2257 9.23 0500 1.59 1121 8.76 1717 1.87 2342 8.47 0543
2.32 1208 8.04 1807 2.62 0035 7.67 0639 3.04 1308 7.36 1916 3.27 0147 7.04 0758 3.52 1433 7.02 2052 3.48
0318 6.91 0945 3.46 1603 7.25 2228 3.12 0438 7.29 1059 2.96 1708 7.83 2324 2.53 0533 7.85 1145 2.38 1754
8.42 0003 1.99 0613 8.36 1218 1.89 1832 8.88 0036 1.58 0648 8.74 1250 1.53 1908 9.17 0108 1.31 0722 8.97
1321 1.32 1942 9.30 0139 1.19 0754 9.08 1354 1.25 2013 9.30 0210 1.19 0825 9.08 1423 1.31 2042 9.20 0238
1.29 0854 9.01 1450 1.45 2110 9.04 0304 1.46 0923 8.87 1514 1.63 2137 8.82 0328 1.67 0951 8.66 1539 1.87
2204 8.53 0354 1.95 1019 8.37 1608 2.19 2236 8.15 0428 2.34 1057 7.97 1648 2.65 2324 7.65 0518 2.87 1155
7.50 1754 3.19 0042 7.18 0650 3.33 1320 7.20 1952 3.39 0221 7.13 0840 3.21 1459 7.41 2130 2.92 0351 7.66
0959 2.60 1620 8.13 2240 2.13 0457 8.45 1101 1.84 1720 8.96 2336 1.36 0550 9.18 1154 1.16 1811 9.65 0025
0.75 0638 9.74 1242 0.66 1858 10.14 0112 0.37 0724 10.08 1329 0.37 1944 10.39 0157 0.22 0809 10.22 1413
0.28 2027 10.41 0239 0.30];
HTSept19=Sept2019(2:4:end);
LTSept19=Sept2019(4:4:end);
RangeSept19=(HTSept19-LTSept19);
RSept19=mean(RangeSept19)
subplot(4,3,9)
bar(RangeSept19)
title('September')
grid on
xlabel('Tide Number')
ylabel('Meters')

Oct2019=[0851 10.14 1454 0.42 2109 10.20 0318 0.61 0932 9.86 1533 0.78 2149 9.75 0354 1.11 1010 9.38
1609 1.32 2228 9.10 0428 1.77 1050 8.73 1648 2.01 2309 8.31 0506 2.52 1133 7.99 1734 2.77 2357 7.48 0600
3.25 1231 7.29 1842 3.43 0109 6.81 0720 3.76 1358 6.90 2015 3.69 0247 6.65 0906 3.73 1531 7.10 2158 3.33
0412 7.08 1030 3.19 1639 7.70 2257 2.70 0506 7.73 1115 2.55 1726 8.33 2335 2.11 0546 8.32 1148 2.01 1805
8.84 0009 1.64 0621 8.77 1221 1.60 1841 9.16 0041 1.34 0654 9.06 1254 1.37 1914 9.33 0112 1.19 0727 9.21
1327 1.28 1945 9.36 0144 1.17 0757 9.26 1357 1.32 2016 9.31 0212 1.26 0828 9.21 1425 1.43 2045 9.18 0239
1.41 0857 9.09 1452 1.60 2115 8.97 0306 1.63 0927 8.87 1519 1.84 2144 8.66 0333 1.93 0958 8.55 1551 2.17
2219 8.24 0407 2.35 1039 8.12 1634 2.64 2310 7.70 0500 2.90 1141 7.62 1748 3.16 0030 7.22 0640 3.35 1307
7.34 1940 3.29 0206 7.19 0824 3.20 1442 7.57 2112 2.83 0333 7.73 0942 2.59 1600 8.26 2224 2.08 0439 8.50
1043 1.86 1700 9.02 2318 1.36 0531 9.21 1135 1.22 1751 9.65 0006 0.82 0518 9.73 1122 0.78 1738 10.06 2352
0.51 0603 10.03 1207 0.55 1823 10.23 0035 0.43 0646 10.12 1251 0.53 1906 10.19 0115 0.56 0727 10.01 1331
0.69 1946 9.94 0153 0.88 0806 9.73 1409 1.04 2024 9.50 0228 1.35];
HTOct19=Oct2019(2:4:end);
LTOct19=Oct2019(4:4:end);
RangeOct19=(HTOct19-LTOct19);
ROct19=mean(RangeOct19)
subplot(4,3,10)
bar(RangeOct19)
title('October')
grid on
xlabel('Tide Number')
ylabel('Meters')

Nov2019=[0845 9.28 1446 1.53 2102 8.90 0301 1.94 0924 8.70 1524 2.13 2142 8.21 0337 2.58 1006 8.06 1609
2.76 2227 7.50 0425 3.20 1100 7.46 1709 3.32 2329 6.90 0539 3.68 1217 7.06 1830 3.59 0058 6.66 0709 3.75
1343 7.12 1959 3.41 0224 6.96 0833 3.36 1454 7.56 2107 2.91 0326 7.53 0929 2.80 1547 8.11 2154 2.36 0411
8.12 1011 2.27 1630 8.60 2233 1.89 0449 8.61 1048 1.86 1709 8.95 2309 1.57 0524 8.96 1124 1.60 1744 9.17
2344 1.37 0558 9.19 1159 1.47 1818 9.28 0017 1.30 0631 9.29 1232 1.44 1851 9.29 0049 1.33 0705 9.31 1304
1.48 1925 9.22 0121 1.43 0738 9.22 1336 1.60 1959 9.05 0152 1.62 0812 9.04 1411 1.80 2035 8.77 0225 1.90
0850 8.74 1450 2.10 2118 8.37 0306 2.29 0937 8.34 1541 2.49 2212 7.91 0405 2.75 1039 7.94 1655 2.85 2324
7.53 0533 3.06 1157 7.72 1822 2.94 0046 7.48 0700 2.98 1318 7.86 1945 2.66 0206 7.84 0815 2.56 1432 8.32
2056 2.14 0313 8.42 0918 2.00 1534 8.88 2154 1.59 0409 9.00 1012 1.50 1627 9.36 2245 1.17 0457 9.44 1100
1.14 1716 9.66 2330 0.93 0542 9.71 1145 0.95 1803 9.78 0014 0.86 0625 9.80 1230 0.93 1845 9.74 0054 0.96
0706 9.73 1311 1.05 1926 9.53 0132 1.19 0745 9.52 1350 1.29 2005 9.20 0207 1.53 0824 9.19 1428 1.64 2043
8.77 0241 1.94];
HTNov19=Nov2019(2:4:end);
LTNov19=Nov2019(4:4:end);
RangeNov19=(HTNov19-LTNov19);
RNov19=mean(RangeNov19)
subplot(4,3,11)
bar(RangeNov19)
title('November')
grid on
```

```
xlabel('Tide Number')
ylabel('Meters')

Dec2019=[0904 8.75 1506 2.07 2121 8.25 0317 2.41 0945 8.27 1548 2.52 2203 7.74 0359 2.88 1033 7.80 1638
2.94 2253 7.27 0455 3.30 1131 7.43 1741 3.24 2357 6.96 0609 3.52 1242 7.26 1853 3.31 0115 6.94 0727 3.44
1354 7.39 2003 3.11 0228 7.25 0833 3.11 1457 7.73 2103 2.74 0325 7.73 0927 2.68 1548 8.14 2151 2.33 0412
8.22 1012 2.28 1633 8.53 2233 1.97 0452 8.64 1052 1.95 1713 8.83 2313 1.69 0530 8.97 1131 1.71 1752 9.06
2352 1.50 0608 9.20 1209 1.55 1830 9.19 0030 1.40 0645 9.32 1248 1.47 1909 9.23 0108 1.39 0724 9.34 1328
1.47 1949 9.17 0146 1.47 0804 9.26 1409 1.56 2031 9.00 0227 1.64 0848 9.07 1454 1.74 2118 8.73 0312 1.91
0937 8.79 1546 2.00 2210 8.39 0407 2.23 1034 8.49 1647 2.27 2310 8.07 0514 2.52 1138 8.24 1755 2.47 0017
7.87 0627 2.65 1246 8.14 1908 2.51 0128 7.89 0739 2.56 1356 8.23 2020 2.35 0239 8.14 0848 2.29 1503 8.48
2125 2.06 0342 8.53 0948 1.95 1604 8.78 2222 1.74 0436 8.91 1041 1.64 1657 9.04 2312 1.49 0525 9.20 1129
1.42 1746 9.20 2357 1.34 0609 9.37 1213 1.30 1830 9.24 0038 1.30 0650 9.42 1255 1.29 1911 9.18 0115 1.36
0730 9.35 1334 1.38 1949 9.01 0151 1.52 0809 9.17 1412 1.55 2027 8.77 0224 1.75 0847 8.91 1448 1.80 2103
8.46 0258 2.05 0924 8.58 1524 2.10];
HTDec19=Dec2019(2:4:end);
LTDec19=Dec2019(4:4:end);
RangeDec19=(HTDec19-LTDec19);
RDec19=mean(RangeDec19)
subplot(4,3,12)
bar(RangeDec19)
title('December')
grid on
xlabel('Tide Number')
ylabel('Meters')

AnnualHT19=[HTJan19 HTFeb19 HTMar19 HTApr19 HTMay19 HTJun19 HTJul19 HTAug19 HTSept19
HTOct19 HTNov19 HTDec19];
AnnualLT19=[LTJan19 LTFeb19 LTMar19 LTApr19 LTMay19 LTJun19 LTJul19 LTAug19 LTSept19 LTOct19
LTNov19 LTDec19];

AnnualHTMax19=max(AnnualHT19)
AnnualHTMin19=min(AnnualHT19)
AnnualLTMax19=max(AnnualLT19)
AnnualLTMin19=min(AnnualLT19)

aveRange19=(RJan19+RFeb19+RMar19+RApr19+RMay19+RJun19+RJul19+RAug19+RSept19+ROct19+RNov
19+RDec19)/12
AnnualRange19=(AnnualHT19-AnnualLT19);
[r,c]=min(AnnualRange19);
[r2,c2]=max(AnnualRange19);

figure(2)
plot(AnnualHT19)
hold
plot(AnnualLT19)
title('Annual HT and LT variations 2019')
xlabel('tides over year')
ylabel('meters')

hold off
figure(3)
plot(AnnualRange19)
title('Annual tidal range [HT-LT] 2019')
xlabel('tides over year')
ylabel('meters')

figure(4)
suptitle('Monthly Tidal Range 2019')
subplot(4,3,1)
plot(RangeJan19)
subplot(4,3,2)
plot(RangeFeb19)
subplot(4,3,3)
plot(RangeMar19)
```

```
subplot(4,3,4)
plot(RangeApr19)
subplot(4,3,5)
plot(RangeMay19)
subplot(4,3,6)
plot(RangeJun19)
subplot(4,3,7)
plot(RangeJul19)
subplot(4,3,8)
plot(RangeAug19)
subplot(4,3,9)
plot(RangeSept19)
subplot(4,3,10)
plot(RangeOct19)
subplot(4,3,11)
plot(RangeNov19)
subplot(4,3,12)
plot(RangeDec19)
                    %2018
Jan2018=[0513 9.42 1123 1.19 1742 9.59 2351 0.96 0604 9.78 1216 0.89 1834 9.82 0041 0.76 0654 9.98 1309
0.73 1924 9.90 0130 0.70 0742 10.03 1358 0.72 2013 9.82 0216 0.80 0830 9.91 1446 0.86 2100 9.58 0301 1.05
0918 9.64 1533 1.16 2146 9.19 0345 1.43 1005 9.23 1618 1.59 2233 8.70 0430 1.91 1054 8.72 1705 2.10 2322
8.17 0521 2.41 1145 8.19 1758 2.59 0018 7.69 0621 2.83 1245 7.75 1901 2.94 0124 7.41 0730 3.04 1352 7.53
2014 3.03 0237 7.45 0842 2.95 1503 7.62 2123 2.82 0342 7.78 0944 2.64 1603 7.91 2217 2.46 0433 8.22 1033
2.26 1652 8.27 2300 2.08 0517 8.63 1116 1.90 1735 8.58 2339 1.77 0557 8.92 1155 1.64 1813 8.80 0015 1.56
0633 9.09 1232 1.49 1848 8.91 0050 1.46 0708 9.13 1307 1.44 1922 8.93 0122 1.47 0741 9.09 1339 1.47 1955
8.88 0153 1.55 0813 8.99 1411 1.55 2028 8.78 0221 1.68 0846 8.85 1442 1.66 2102 8.63 0251 1.83 0921 8.67
1515 1.82 2137 8.43 0324 2.03 0959 8.44 1553 2.05 2218 8.17 0406 2.31 1046 8.17 1642 2.34 2309 7.88 0503
2.63 1146 7.90 1748 2.63 0015 7.64 0624 2.86 1257 7.77 1912 2.72 0131 7.64 0753 2.76 1414 7.92 2032 2.50
0250 7.97 0909 2.35 1528 8.33 2142 2.03 0401 8.54 1015 1.79 1633 8.86 2245 1.50 0500 9.13 1115 1.26 1730
9.34 2340 1.03 0554 9.62 1209 0.83];
HTJan18=Jan2018(2:4:end);
LTJan18=Jan2018(4:4:end);
RangeJan18=(HTJan18-LTJan18);
RJan18=mean(RangeJan18)
figure(5)
suptitle('Monthly Tidal Range 2018')
subplot(4,3,1)
bar(RangeJan18)
title('January')
grid on
xlabel('Tide Number')
ylabel('Meters')

Feb2018=[1823 9.70 0031 0.68 0643 9.95 1300 0.56 1912 9.89 0118 0.51 0730 10.10 1348 0.45 1958 9.92 0203
0.50 0815 10.07 1431 0.54 2042 9.77 0243 0.68 0857 9.86 1511 0.82 2122 9.45 0321 1.02 0939 9.47 1547 1.26
2201 8.98 0357 1.50 1019 8.93 1623 1.81 2241 8.40 0436 2.08 1101 8.29 1703 2.43 2324 7.78 0524 2.68 1150
7.65 1757 3.00 0021 7.24 0629 3.16 1254 7.15 1909 3.36 0140 6.98 0749 3.32 1415 7.02 2033 3.31 0303 7.19
0907 3.07 1530 7.32 2144 2.91 0406 7.70 1008 2.58 1627 7.81 2236 2.39 0454 8.25 1055 2.08 1713 8.29 2317
1.91 0536 8.70 1135 1.67 1752 8.66 2354 1.55 0613 9.01 1212 1.39 1827 8.92 0030 1.33 0648 9.19 1247 1.22
1902 9.07 0103 1.22 0721 9.27 1320 1.14 1935 9.14 0134 1.19 0754 9.28 1351 1.14 2009 9.14 0203 1.23 0827
9.23 1421 1.20 2041 9.07 0233 1.32 0900 9.10 1452 1.33 2114 8.89 0303 1.50 0936 8.85 1527 1.58 2151 8.60
0340 1.82 1017 8.48 1609 1.98 2236 8.18 0430 2.27 1113 8.02 1709 2.47 2339 7.72 0546 2.75 1227 7.63 1837
2.84 0100 7.46 0726 2.88 1351 7.58 2011 2.75 0230 7.65 0856 2.52 1515 7.98 2130 2.24 0348 8.25 1009 1.88
1623 8.60 2235 1.60 0450 8.94 1108 1.24 1719 9.19 2329 1.02];
HTFeb18=Feb2018(2:4:end);
LTFeb18=Feb2018(4:4:end);
RangeFeb18=(HTFeb18-LTFeb18);
RFeb18=mean(RangeFeb18)
subplot(4,3,2)
bar(RangeFeb18)
title('February')
grid on
xlabel('Tide Number')
ylabel('Meters')
```

```
Mar2018=[0542 9.51 1200 0.73 1809 9.63 0018 0.60 0630 9.90 1246 0.42 1856 9.88 0102 0.38 0714 10.09 1329
0.32 1938 9.94 0142 0.35 0754 10.08 1408 0.41 2017 9.82 0218 0.50 0833 9.88 1442 0.69 2053 9.53 0252 0.82
0909 9.50 1512 1.13 2127 9.09 0323 1.29 0943 8.96 1541 1.67 2200 8.53 0354 1.86 1018 8.32 1611 2.28 2236
7.91 0430 2.49 1057 7.64 1651 2.91 2320 7.28 0526 3.11 1151 7.01 1803 3.45 0030 6.80 0654 3.47 1316 6.67
1941 3.58 0217 6.80 0825 3.33 1452 6.89 2104 3.20 0333 7.31 0936 2.80 1557 7.47 2203 2.60 0426 7.95 1027
2.21 1645 8.07 2248 2.02 0508 8.51 1108 1.69 1724 8.58 2327 1.56 0546 8.94 1146 1.30 1800 8.96 0003 1.23
0621 9.23 1221 1.05 1836 9.22 0038 1.02 0656 9.43 1256 0.89 1910 9.39 0111 0.91 0731 9.54 1328 0.83 1945
9.47 0143 0.89 0806 9.54 1400 0.87 2019 9.42 0215 0.97 0841 9.42 1433 1.02 2054 9.24 0248 1.17 0917 9.13
1506 1.33 2131 8.89 0325 1.55 0959 8.66 1548 1.82 2217 8.37 0415 2.10 1054 8.06 1648 2.44 2319 7.78 0631
2.68 1309 7.53 1920 2.90 0142 7.40 0812 2.89 1438 7.41 2057 2.84 0316 7.55 0946 2.54 1603 7.82 2219 2.31
0436 8.15 1100 1.88 1711 8.48 2322 1.63 0536 8.85 1155 1.23 1805 9.09 0013 1.06 0626 9.40 1243 0.76 1851
9.52 0058 0.66 0711 9.75 1326 0.49];
HTMar18=Mar2018(2:4:end);
LTMar18=Mar2018(4:4:end);
RangeMar18=(HTMar18-LTMar18);
RMar18=mean(RangeMar18)
subplot(4,3,3)
bar(RangeMar18)
title('March')
grid on
xlabel('Tide Number')
ylabel('Meters')

Apr2018=[1934 9.75 0139 0.47 0751 9.90 1404 0.43 2012 9.81 0216 0.46 0830 9.87 1439 0.54 2048 9.70 0251
0.60 0905 9.68 1511 0.81 2122 9.45 0322 0.89 0938 9.34 1539 1.19 2154 9.07 0351 1.30 1009 8.87 1603 1.66
2225 8.59 0418 1.79 1042 8.31 1627 2.18 2257 8.03 0450 2.34 1118 7.70 1702 2.74 2338 7.45 0537 2.92 1205
7.10 1759 3.31 0037 6.93 0657 3.37 1317 6.67 1945 3.60 0214 6.73 0835 3.36 1458 6.72 2117 3.34 0346 7.11
0951 2.92 1615 7.26 2222 2.76 0445 7.73 1048 2.32 1707 7.91 2310 2.16 0531 8.34 1132 1.77 1749 8.49 2351
1.64 0611 8.84 1212 1.33 1827 8.97 0030 1.25 0649 9.23 1250 1.00 1906 9.32 0108 0.97 0727 9.51 1327 0.80
1944 9.56 0145 0.80 0806 9.68 1405 0.70 2021 9.68 0221 0.74 0845 9.72 1441 0.73 2059 9.65 0258 0.82 0924
9.58 1517 0.91 2137 9.45 0336 1.05 1004 9.26 1555 1.26 2218 9.06 0419 1.46 1051 8.75 1641 1.78 2309 8.51
0515 2.01 1148 8.13 1744 2.39 0012 7.93 0630 2.53 1300 7.61 1909 2.81 0133 7.57 0759 2.72 1424 7.48 2041
2.78 0259 7.67 0930 2.45 1545 7.82 2201 2.32 0415 8.16 1040 1.91 1651 8.39 2301 1.74 0515 8.72 1134 1.39
1744 8.92 2350 1.26 0604 9.17 1219 1.01 1828 9.30 0033 0.94 0647 9.43 1300 0.81 1908 9.50 0111 0.79 0726
9.53 1336 0.78];
HTApr18=Apr2018(2:4:end);
LTApr18=Apr2018(4:4:end);
RangeApr18=(HTApr18-LTApr18);
RApr18=mean(RangeApr18)
subplot(4,3,4)
bar(RangeApr18)
title('April')
grid on
xlabel('Tide Number')
ylabel('Meters')

May2018=[1945 9.55 0147 0.79 0803 9.50 1409 0.87 2021 9.47 0221 0.90 0837 9.34 1440 1.07 2054 9.28 0254
1.12 0910 9.08 1508 1.36 2126 8.98 0323 1.43 0942 8.72 1533 1.71 2157 8.60 0351 1.81 1014 8.29 1559 2.11
2230 8.15 0424 2.23 1050 7.81 1633 2.57 2309 7.67 0509 2.69 1135 7.33 1723 3.05 0003 7.23 0614 3.07 1236
6.95 1845 3.39 0117 6.99 0737 3.18 1356 6.87 2018 3.31 0243 7.15 0855 2.91 1518 7.20 2130 2.88 0352 7.62
0957 2.43 1620 7.78 2224 2.33 0445 8.19 1047 1.91 1709 8.38 2310 1.81 0531 8.72 1133 1.45 1752 8.90 2353
1.38 0615 9.15 1216 1.10 1835 9.32 0036 1.05 0659 9.48 1300 0.85 1917 9.61 0119 0.84 0742 9.68 1342 0.72
1959 9.77 0202 0.75 0826 9.74 1424 0.73 2041 9.77 0246 0.80 0910 9.63 1506 0.89 2125 9.59 0331 1.00 0957
9.34 1550 1.21 2212 9.23 0420 1.36 1046 8.89 1640 1.67 2305 8.75 0517 1.80 1143 8.36 1741 2.17 0007 8.26
0624 2.22 1248 7.91 1854 2.55 0118 7.93 0739 2.45 1401 7.70 2015 2.63 0233 7.88 0859 2.39 1516 7.83 2130
2.40 0344 8.11 1009 2.10 1623 8.20 2232 2.02 0445 8.46 1105 1.76 1716 8.60 2321 1.66 0536 8.76 1151 1.48
1801 8.92 0003 1.40 0620 8.97 1231 1.30 1842 9.13 0042 1.25 0700 9.07 1307 1.23 1919 9.23 0119 1.19 0737
9.08 1341 1.24 1956 9.22 0155 1.24 0813 8.99 1413 1.34];
HTMay18=May2018(2:4:end);
LTMay18=May2018(4:4:end);
RangeMay18=(HTMay18-LTMay18);
RMay18=mean(RangeMay18)
subplot(4,3,5)
bar(RangeMay18)
title('May')
grid on
```

```
xlabel('Tide Number')
ylabel('Meters')

Jun2018=[2030 9.11 0229 1.36 0848 8.83 1443 1.52 2103 8.90 0300 1.56 0921 8.60 1512 1.75 2136 8.62 0332
1.81 0954 8.31 1541 2.03 2209 8.29 0406 2.10 1029 7.99 1614 2.36 2248 7.94 0447 2.40 1110 7.65 1657 2.71
2334 7.62 0539 2.68 1201 7.36 1757 3.01 0033 7.40 0645 2.84 1303 7.21 1914 3.12 0142 7.39 0754 2.78 1415
7.32 2030 2.93 0251 7.63 0901 2.50 1524 7.69 2133 2.51 0354 8.06 1000 2.10 1624 8.21 2228 2.03 0450 8.55
1054 1.67 1717 8.75 2319 1.57 0542 9.00 1145 1.29 1806 9.21 0009 1.21 0632 9.35 1235 1.00 1853 9.56 0057
0.94 0721 9.59 1324 0.82 1940 9.77 0148 0.80 0811 9.70 1412 0.76 2027 9.83 0237 0.77 0900 9.66 1458 0.83
2115 9.74 0327 0.88 0949 9.47 1545 1.05 2206 9.49 0418 1.13 1039 9.15 1635 1.39 2258 9.12 0511 1.47 1132
8.72 1728 1.81 2354 8.69 0607 1.87 1227 8.28 1828 2.22 0053 8.29 0709 2.23 1328 7.92 1935 2.52 0157 8.01
0816 2.45 1436 7.76 2047 2.59 0303 7.92 0927 2.46 1544 7.85 2154 2.45 0408 8.02 1029 2.30 1644 8.12 2250
2.19 0504 8.23 1121 2.06 1734 8.45 2336 1.92 0553 8.45 1203 1.83 1818 8.73 0018 1.69 0636 8.63 1242 1.65
1857 8.93 0056 1.54 0715 8.74 1317 1.53 1935 9.03 0133 1.47 0753 8.76 1351 1.50 2012 9.02 0208 1.48 0828
8.72 1424 1.55];
HTJun18=Jun2018(2:4:end);
LTJun18=Jun2018(4:4:end);
RangeJun18=(HTJun18-LTJun18);
RJun18=mean(RangeJun18)
subplot(4,3,6)
bar(RangeJun18)
title('June')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jul2018=[2045 8.91 0242 1.57 0902 8.60 1455 1.69 2118 8.73 0315 1.71 0935 8.44 1524 1.86 2151 8.51 0348
1.87 1009 8.25 1556 2.07 2226 8.28 0423 2.06 1045 8.04 1631 2.31 2305 8.04 0505 2.27 1127 7.81 1715 2.57
2354 7.82 0556 2.48 1218 7.62 1815 2.80 0051 7.68 0659 2.61 1320 7.53 1930 2.88 0158 7.69 0809 2.57 1430
7.64 2046 2.70 0308 7.92 0918 2.33 1542 8.00 2154 2.30 0415 8.31 1022 1.95 1646 8.51 2254 1.82 0515 8.77
1121 1.54 1743 9.03 2350 1.37 0612 9.18 1217 1.16 1836 9.47 0044 1.01 0706 9.50 1310 0.87 1927 9.78 0137
0.76 0758 9.70 1401 0.70 2016 9.94 0230 0.64 0848 9.76 1450 0.67 2106 9.95 0320 0.66 0938 9.68 1536 0.78
2154 9.79 0408 0.84 1025 9.44 1621 1.05 2242 9.48 0454 1.17 1112 9.06 1706 1.46 2330 9.03 0539 1.62 1159
8.57 1754 1.96 0021 8.49 0628 2.14 1250 8.04 1848 2.47 0116 7.97 0724 2.62 1349 7.61 1954 2.85 0219 7.59
0833 2.91 1459 7.43 2109 2.95 0329 7.49 0948 2.90 1609 7.59 2219 2.75 0435 7.66 1051 2.64 1709 7.97 2315
2.40 0530 7.98 1141 2.28 1757 8.38 2358 2.04 0615 8.30 1221 1.94 1839 8.73 0037 1.73 0656 8.56 1257 1.67
1917 8.95 0114 1.53 0733 8.71 1332 1.52 1953 9.05 0149 1.44 0809 8.78 1405 1.46 2027 9.03 0223 1.43 0842
8.77 1437 1.50 2059 8.94 0254 1.49 0915 8.71 1506 1.60];
HTJul18=Jul2018(2:4:end);
LTJul18=Jul2018(4:4:end);
RangeJul18=(HTJul18-LTJul18);
RJul18=mean(RangeJul18)
subplot(4,3,7)
bar(RangeJul18)
title('July')
grid on
xlabel('Tide Number')
ylabel('Meters')

Aug2018=[2130 8.82 326 1.58 947 8.60 1536 1.74 2202 8.65 0357 1.72 1020 8.45 1606 1.92 2236 8.45 0432
1.91 1055 8.24 1642 2.16 2316 8.19 0513 2.17 1139 7.98 1729 2.48 0009 7.91 0609 2.48 1236 7.72 1836 2.81
0116 7.68 0723 2.71 1348 7.58 2006 2.90 0233 7.69 0847 2.65 1508 7.75 2130 2.60 0351 8.01 1002 2.28 1625
8.25 2240 2.06 0500 8.53 1108 1.76 1729 8.87 2341 1.47 0600 9.07 1206 1.25 1824 9.44 0037 0.98 0654 9.50
1300 0.84 1915 9.86 0130 0.63 0745 9.78 1350 0.57 2004 10.10 0219 0.45 0834 9.91 1436 0.47 2051 10.15
0306 0.45 0920 9.87 1520 0.56 2136 10.02 0348 0.65 1003 9.65 1600 0.83 2218 9.68 0427 1.03 1043 9.25 1637
1.27 2300 9.1 504 1.56 1124 8.70 1716 1.84 2342 8.52 0543 2.19 1206 8.07 1801 2.49 0030 7.83 0632 2.82
1259 7.47 1900 3.08 0130 7.24 0737 3.30 1411 7.07 2019 3.40 0249 6.97 0900 3.43 1535 7.12 2148 3.25 0408
7.16 1023 3.11 1645 7.58 2254 2.77 0509 7.63 1118 2.60 1736 8.14 2341 2.25 0555 8.13 1200 2.10 1818 8.64
0019 1.80 0635 8.53 1236 1.71 1857 8.98 0054 1.48 0712 8.81 1310 1.44 1932 9.17 0128 1.30 0745 8.97 1344
1.32 2005 9.23 0201 1.23 0818 9.04 1416 1.29 2036 9.22 0233 1.24 0851 9.04 1445 1.34 2107 9.15 0303 1.31
0922 8.97 1514 1.45 2138 9.01 0332 1.45 0954 8.84 1543 1.62];
HTAug18=Aug2018(2:4:end);
LTAug18=Aug2018(4:4:end);
RangeAug18=(HTAug18-LTAug18);
RAug18=mean(RangeAug18)
subplot(4,3,8)
```

```
bar(RangeAug18)
title('August')
grid on
xlabel('Tide Number')
ylabel('Meters')

Sept2018=[2209 8.8 403 1.66 1026 8.60 1615 1.89 2245 8.47 0439 2.00 1106 8.25 1657 2.31 2334 8.03 0530
2.47 1202 7.82 1800 2.81 0045 7.58 0650 2.92 1318 7.48 1941 3.11 0212 7.42 0828 2.97 1449 7.53 2118 2.84
0340 7.75 0952 2.55 1615 8.09 2236 2.19 0452 8.40 1100 1.89 1720 8.83 2337 1.47 0550 9.06 1157 1.26 1813
9.48 0030 0.89 0642 9.57 1248 0.78 1902 9.95 0118 0.51 0729 9.89 1334 0.49 1948 10.19 0203 0.35 0814
10.01 1417 0.41 2031 10.22 0244 0.41 0856 9.94 1457 0.52 2112 10.05 0321 0.66 0935 9.70 1533 0.82 2149
9.68 0354 1.09 1012 9.29 1606 1.28 2226 9.13 0427 1.64 1047 8.73 1640 1.87 2302 8.46 0459 2.29 1123 8.09
1717 2.54 2342 7.73 539 2.95 1207 7.44 1809 3.20 0034 7.04 0643 3.54 1315 6.91 1933 3.65 0201 6.64 0815
3.76 1457 6.85 2109 3.57 0337 6.82 0947 3.44 1615 7.33 2227 3.03 0443 7.40 1050 2.84 1710 7.99 2316 2.39
0530 8.03 1133 2.23 1753 8.57 2354 1.84 0609 8.55 1209 1.75 1831 9.00 0030 1.44 0645 8.93 1245 1.42 1906
9.28 0103 1.19 0719 9.17 1319 1.23 1939 9.42 0136 1.08 0752 9.31 1351 1.16 2011 9.47 0209 1.06 0826 9.35
1424 1.18 2044 9.44 0240 1.13 0858 9.31 1454 1.28 2116 9.31 0310 1.29 0930 9.16 1524 1.47 2149 9.04 0341
1.56 1005 8.87 1558 1.80];
HTSept18=Sept2018(2:4:end);
LTSept18=Sept2018(4:4:end);
RangeSept18=(HTSept18-LTSept18);
RSept18=mean(RangeSept18)
subplot(4,3,9)
bar(RangeSept18)
title('September')
grid on
xlabel('Tide Number')
ylabel('Meters')

Oct2018=[2227 8.63 0418 1.99 1046 8.42 1641 2.30 2317 8.06 0509 2.57 1144 7.88 1748 2.89 0030 7.50 0636
3.10 1304 7.46 1933 3.20 0203 7.29 0819 3.15 1440 7.51 2112 2.90 0333 7.67 0945 2.66 1605 8.11 2232 2.19
0443 8.38 1052 1.95 1708 8.86 2330 1.46 0538 9.08 1145 1.31 1800 9.50 0017 0.90 0626 9.59 1231 0.85 1845
9.92 0100 0.57 0710 9.88 1314 0.61 1928 10.11 0141 0.47 0751 9.96 1353 0.57 2008 10.08 0218 0.58 0830
9.87 1430 0.71 2045 9.88 0252 0.85 0906 9.62 1505 1.00 2120 9.51 0323 1.26 0939 9.24 1537 1.43 2154 9.00
0352 1.77 1012 8.74 1608 1.96 2227 8.40 0419 2.34 1047 8.17 1642 2.55 2303 7.74 0452 2.94 1127 7.57 1728
3.16 2350 7.10 0548 3.52 1226 7.04 1847 3.64 0103 6.63 0729 3.84 1405 6.83 2022 3.66 0251 6.68 0901 3.61
1535 7.20 2144 3.20 0407 7.23 1009 3.04 1634 7.82 2239 2.56 0457 7.90 1057 2.43 1720 8.43 2322 1.98 0538
8.49 1137 1.91 1759 8.92 2359 1.54 0615 8.95 1215 1.53 1835 9.27 0035 1.23 0650 9.27 1251 1.28 1910 9.50
0110 1.06 0726 9.48 1326 1.16 1946 9.61 0145 1.01 0801 9.57 1402 1.13 2022 9.61 0220 1.06 0837 9.55 1437
1.21 2058 9.48 0154 1.23 0813 9.39 1413 1.42 2036 9.19 0230 1.54 0852 9.07 1452 1.78 2119 8.73 0311 2.01
0939 8.59 1542 2.28 2213 8.15 0408 2.58 1039 8.05 1655 2.79];
HTOct18=Oct2018(2:4:end);
LTOct18=Oct2018(4:4:end);
RangeOct18=(HTOct18-LTOct18);
ROct18=mean(RangeOct18)
subplot(4,3,10)
bar(RangeOct18)
title('October')
grid on
xlabel('Tide Number')
ylabel('Meters')

Nov2018=[2325 7.61 533 3.04 1158 7.67 1825 3.03 0051 7.42 0706 3.08 1326 7.72 1958 2.79 0217 7.74 0829
2.67 1446 8.19 2115 2.21 0326 8.36 0934 2.06 1549 8.81 2211 1.60 0420 8.96 1025 1.51 1640 9.33 2257 1.14
0506 9.41 1109 1.13 1725 9.65 2339 0.89 0548 9.66 1150 0.94 1806 9.78 0016 0.82 0627 9.74 1228 0.92 1844
9.74 0052 0.92 0704 9.67 1305 1.03 1920 9.56 0125 1.13 0739 9.47 1339 1.26 1954 9.26 0156 1.46 0813 9.17
1412 1.59 2027 8.86 0225 1.85 0846 8.77 1445 2.00 2100 8.38 0253 2.30 0921 8.30 1518 2.46 2136 7.86 0325
2.78 1001 7.81 1601 2.94 2221 7.34 0412 3.27 1053 7.35 1705 3.35 2320 6.92 0533 3.64 1205 7.08 1827 3.5
0042 6.78 0705 3.62 1333 7.18 1947 3.27 0210 7.09 0818 3.24 1443 7.62 2051 2.79 0312 7.66 0914 2.71 1536
8.16 2140 2.26 0400 8.25 0959 2.20 1620 8.67 2223 1.80 0441 8.78 1040 1.77 1701 9.09 2303 1.43 0520 9.19
1121 1.45 1742 9.40 2344 1.19 0600 9.49 1202 1.24 1822 9.59 0024 1.06 0639 9.66 1243 1.14 1903 9.66 0104
1.05 0720 9.69 1324 1.16 1945 9.58 0145 1.17 0801 9.58 1408 1.31 2030 9.33 0227 1.43 0847 9.30 1454 1.60
2118 8.94 0314 1.82 0938 8.90 1549 1.99 2212 8.45 0412 2.28 1037 8.46 1654 2.38 2316 8.00 0522 2.67 1145
8.11 1807 2.64];
HTNov18=Nov2018(2:4:end);
LTNov18=Nov2018(4:4:end);
```

```
RangeNov18=(HTNov18-LTNov18);
RNov18=mean(RangeNov18)
subplot(4,3,11)
bar(RangeNov18)
title('November')
grid on
xlabel('Tide Number')
ylabel('Meters')

Dec2018=[0029 7.74 0640 2.82 1300 8.00 1927 2.63 0146 7.81 0757 2.66 1415 8.18 2042 2.36 0257 8.16 0905
2.30 1520 8.53 2143 1.98 0355 8.60 1000 1.91 1615 8.88 2233 1.63 0444 8.98 1045 1.60 1702 9.14 2315 1.40
0526 9.25 1127 1.40 1745 9.27 2354 1.29 0606 9.38 1206 1.31 1823 9.29 0029 1.28 0642 9.40 1243 1.33 1900
9.20 0103 1.37 0718 9.30 1319 1.44 1935 9.03 0136 1.55 0754 9.11 1354 1.64 2009 8.78 0207 1.81 0828 8.83
1427 1.90 2042 8.46 0236 2.12 0903 8.49 1501 2.22 2118 8.10 0308 2.47 0940 8.13 1539 2.55 2157 7.72 0346
2.84 1024 7.77 1627 2.88 2245 7.38 0439 3.19 1117 7.48 1727 3.13 2343 7.14 0553 3.40 1221 7.35 1839 3.18
053 7.12 0712 3.33 1332 7.47 1948 2.98 0207 7.40 0820 3.00 1439 7.82 2050 2.60 0311 7.89 0916 2.54 1536
8.29 2143 2.15 0403 8.44 1006 2.07 1627 8.76 2233 1.73 0451 8.95 1054 1.65 1715 9.17 2320 1.37 0536 9.36
1141 1.33 1802 9.47 0006 1.12 0621 9.65 1229 1.10 1849 9.64 0053 0.98 0707 9.79 1317 1.00 1936 9.68 0139
0.98 0754 9.80 1406 1.02 2024 9.57 0224 1.10 0842 9.65 1454 1.17 2112 9.31 0312 1.36 0933 9.37 1546 1.45
2203 8.94 0403 1.72 1026 9.00 1640 1.82 2257 8.51 0500 2.13 1123 8.58 1739 2.21 2357 8.09 0603 2.49 1224
8.22 1844 2.52 0103 7.82 0713 2.69 1331 8.01 1956 2.63];
HTDec18=Dec2018(2:4:end);
LTDec18=Dec2018(4:4:end);
RangeDec18=(HTDec18-LTDec18);
RDec18=mean(RangeDec18)
subplot(4,3,12)
bar(RangeDec18)
title('December')
grid on
xlabel('Tide Number')
ylabel('Meters')

AnnualHT18=[HTJan18 HTFeb18 HTMar18 HTApr18 HTMay18 HTJun18 HTJul18 HTAug18 HTSept18
HTOct18 HTNov18 HTDec18];
AnnualLT18=[LTJan18 LTFeb18 LTMar18 LTApr18 LTMay18 LTJun18 LTJul18 LTAug18 LTSept18 LTOct18
LTNov18 LTDec18];

AnnualHTMax18=max(AnnualHT18)
AnnualHTMin18=min(AnnualHT18)
AnnualLTMax18=max(AnnualLT18)
AnnualLTMin18=min(AnnualLT18)

aveRange18=(RJan18+RFeb18+RMar18+RApr18+RMay18+RJun18+RJul18+RAug18+RSept18+ROct18+RNov
18+RDec18)/12
AnnualRange18=(AnnualHT18-AnnualLT18);
[r,c]=min(AnnualRange18);
[r2,c2]=max(AnnualRange18);

figure(6)
plot(AnnualHT18)
hold
plot(AnnualLT18)
title('Annual HT and LT variations 2018')
xlabel('tides over year')
ylabel('meters')

hold off

figure(7)
plot(AnnualRange18)
title('Annual tidal range [HT-LT] 2018')
xlabel('tides over year')
ylabel('meters')

figure(8)
```

```
suptitle('Monthly Tidal Range 2018')
subplot(4,3,1)
plot(RangeJan18)
subplot(4,3,2)
plot(RangeFeb18)
subplot(4,3,3)
plot(RangeMar18)
subplot(4,3,4)
plot(RangeApr18)
subplot(4,3,5)
plot(RangeMay18)
subplot(4,3,6)
plot(RangeJun18)
subplot(4,3,7)
plot(RangeJul18)
subplot(4,3,8)
plot(RangeAug18)
subplot(4,3,9)
plot(RangeSept18)
subplot(4,3,10)
plot(RangeOct18)
subplot(4,3,11)
plot(RangeNov18)
subplot(4,3,12)
plot(RangeDec18)
                    %2017
Jan2017=[0142 1.57 0803 9.09 1402 1.55 2020 8.88 0214 1.68 0839 8.96 1437 1.66 2057 8.73 0248 1.84 0918
8.79 1516 1.81 2138 8.52 0327 2.05 1003 8.56 1602 2.03 2225 8.26 0417 2.33 1057 8.31 1658 2.29 2322 7.99
0523 2.61 1159 8.10 1807 2.50 0029 7.82 0644 2.73 1309 8.04 1924 2.51 0142 7.88 0803 2.58 1421 8.21 2038
2.28 0257 8.21 0914 2.20 1531 8.57 2145 1.88 0403 8.71 1017 1.73 1634 9.00 2245 1.45 0501 9.19 1115 1.31
1730 9.37 2339 1.08 0553 9.57 1207 0.99 1822 9.62 0029 0.85 0641 9.80 1257 0.81 1909 9.72 0114 0.77 0726
9.86 1342 0.79 1954 9.66 0156 0.83 0809 9.78 1424 0.91 2036 9.47 0234 1.03 0850 9.55 1502 1.17 2115 9.15
0311 1.35 0930 9.20 1538 1.55 2153 8.73 0347 1.77 1010 8.74 1614 2.00 2232 8.24 0425 2.24 1051 8.22 1654
2.50 2314 7.74 0512 2.74 1138 7.71 1744 2.96 0006 7.30 0613 3.14 1236 7.30 1852 3.27 0118 7.06 0729 3.30
1351 7.15 2009 3.27 0242 7.20 0843 3.11 1507 7.36 2119 2.96 0347 7.65 0945 2.70 1607 7.79 2215 2.50 0438
8.17 1035 2.23 1655 8.24 2300 2.05 0521 8.63 1118 1.82 1736 8.63 2339 1.69 0559 8.98 1157 1.51 1815 8.92
0018 1.43 0635 9.21 1235 1.29 1851 9.12 0054 1.26 0711 9.36 1312 1.15 1928 9.25 0129 1.18 0748 9.43 1348
1.09 2005 9.29 0203 1.17 0825 9.42 1424 1.11 2042 9.24];
HTJan17=Jan2017(4:4:end);
LTJan17=Jan2017(2:4:end);
RangeJan17=(HTJan17-LTJan17);
RJan17=mean(RangeJan17)
figure(9)
suptitle('Monthly Tidal Range 2017')
subplot(4,3,1)
bar(RangeJan17)
title('January')
grid on
xlabel('Tide Number')
ylabel('Meters')

Feb2017=[0238 1.25 0904 9.31 1501 1.23 2121 9.06 0315 1.44 0945 9.07 1541 1.48 2204 8.76 0357 1.77 1033
8.70 1629 1.87 2254 8.35 0451 2.21 1130 8.26 1730 2.32 2354 7.91 0606 2.63 1238 7.89 1849 2.65 0109 7.65
0734 2.77 1356 7.79 2015 2.63 0233 7.77 0858 2.50 1516 8.07 2132 2.25 0351 8.26 1010 1.99 1624 8.56 2236
1.72 0452 8.84 1109 1.45 1721 9.05 2330 1.23 0543 9.32 1200 1.02 1810 9.41 0017 0.89 0629 9.64 1245 0.76
1855 9.60 0059 0.70 0710 9.79 1325 0.67 1935 9.64 0136 0.68 0749 9.78 1402 0.74 2012 9.53 0211 0.80 0826
9.62 1435 0.96 2047 9.30 0244 1.05 0901 9.32 1505 1.29 2120 8.95 0314 1.42 0935 8.91 1533 1.71 2151 8.51
0343 1.87 1007 8.40 1600 2.19 2224 8.00 0415 2.39 1044 7.84 1635 2.72 2304 7.47 0500 2.94 1130 7.30 1730
3.23 0000 7.00 0617 3.37 1237 6.89 1905 3.51 0128 6.80 0753 3.40 1412 6.89 2033 3.31 0306 7.14 0909 2.99
1531 7.34 2140 2.80 0406 7.76 1006 2.42 1626 7.93 2230 2.21 0453 8.37 1052 1.86 1709 8.49 2314 1.69 0533
8.89 1133 1.39 1749 8.95 2354 1.28 0611 9.30 1213 1.04 1828 9.31 0033 0.98 0650 9.59 1251 0.79 1907 9.55
0110 0.78 0729 9.78 1330 0.65 1946 9.69];
HTFeb17=Feb2017(4:4:end);
LTFeb17=Feb2017(2:4:end);
RangeFeb17=(HTFeb17-LTFeb17);
RFeb17=mean(RangeFeb17)
subplot(4,3,2)
```

```
bar(RangeFeb17)
title('February')
grid on
xlabel('Tide Number')
ylabel('Meters')

Mar2017=[0147 0.70 0808 9.84 1407 0.64 2024 9.68 0224 0.75 0847 9.74 1444 0.79 2103 9.50 0300 0.97 0928
9.44 1522 1.11 2144 9.12 0340 1.38 1012 8.95 1606 1.63 2231 8.58 0430 1.96 1106 8.32 1704 2.26 2330 7.95
0541 2.57 1215 7.73 1824 2.78 0045 7.48 0713 2.89 1338 7.46 1957 2.88 0216 7.48 0849 2.68 1504 7.72 2122
2.48 0340 7.97 1005 2.10 1615 8.28 2227 1.87 0442 8.61 1100 1.50 1709 8.85 2318 1.32 0530 9.14 1146 1.05
1754 9.26 0000 0.93 0612 9.49 1226 0.77 1834 9.49 0037 0.71 0650 9.66 1302 0.67 1911 9.56 0112 0.66 0725
9.67 1335 0.73 1945 9.51 0144 0.74 0759 9.54 1405 0.91 2017 9.33 0215 0.95 0831 9.30 1431 1.20 2047 9.04
0242 1.27 0901 8.94 1454 1.56 2115 8.66 0306 1.66 0930 8.49 1516 1.97 2145 8.20 0333 2.12 1003 7.98 1546
2.45 2221 7.68 0411 2.65 1044 7.42 1630 3.00 2311 7.16 0512 3.19 1144 6.93 1751 3.48 0024 6.80 0653 3.42
1309 6.74 1943 3.46 0207 6.92 0824 3.11 1445 7.10 2100 2.95 0324 7.52 0929 2.50 1548 7.76 2155 2.30 0417
8.22 1019 1.86 1636 8.44 2242 1.68 0600 8.86 1203 1.29 1820 9.02 0024 1.17 0642 9.38 1246 0.86 1901 9.47
0106 0.79 0724 9.77 1328 0.55 1943 9.80 0148 0.53 0806 10.02 1409 0.39 2024 9.97 0228 0.42 0848 10.10
1448 0.38 2104 9.97 0307 0.48 0930 9.98 1527 0.57 2145 9.76];
HTMar17=Mar2017(4:4:end);
LTMar17=Mar2017(2:4:end);
RangeMar17=(HTMar17-LTMar17);
RMar17=mean(RangeMar17)
subplot(4,3,3)
bar(RangeMar17)
title('March')
grid on
xlabel('Tide Number')
ylabel('Meters')

Apr2017=[0347 0.74 1012 9.62 1607 0.97 2227 9.32 0429 1.22 1057 9.05 1651 1.56 2315 8.70 0520 1.85 1151
8.33 1748 2.25 0014 8.01 0628 2.50 1258 7.66 1906 2.82 0129 7.48 0757 2.87 1421 7.34 2039 2.96 0259 7.42
0934 2.71 1548 7.57 2206 2.58 0422 7.86 1049 2.18 1658 8.12 2309 2.00 0523 8.45 1142 1.63 1749 8.67 2356
1.48 0609 8.94 1224 1.21 1832 9.07 0034 1.11 0648 9.25 1300 0.96 1909 9.32 0109 0.90 0724 9.41 1333 0.86
1943 9.42 0142 0.83 0759 9.44 1405 0.89 2016 9.39 0215 0.88 0831 9.34 1434 1.03 2048 9.26 0246 1.05 0903
9.15 1500 1.26 2117 9.03 0312 1.31 0932 8.87 1522 1.55 2145 8.72 0336 1.62 1001 8.51 1545 1.88 2215 8.33
0405 2.00 1033 8.07 1615 2.28 2250 7.87 0442 2.44 1112 7.60 1655 2.77 2336 7.40 0537 2.91 1208 7.14 1803
3.24 0044 7.05 0703 3.18 1324 6.91 1948 3.36 0211 7.05 0833 3.01 1453 7.13 2112 2.97 0333 7.52 0943 2.48
1605 7.73 2214 2.34 0434 8.19 1039 1.86 1700 8.43 2305 1.71 0524 8.85 1129 1.28 1748 9.05 2351 1.17 0612
9.40 1216 0.83 1833 9.55 0037 0.76 0657 9.81 1302 0.52 1918 9.89 0123 0.50 0743 10.05 1347 0.36 2001
10.07 0208 0.40 0828 10.12 1430 0.38 2045 10.06 0252 0.47 0913 9.99 1512 0.58 2128 9.84 0336 0.73 0958
9.63 1555 0.98 2214 9.41];
HTApr17=Apr2017(4:4:end);
LTApr17=Apr2017(2:4:end);
RangeApr17=(HTApr17-LTApr17);
RApr17=mean(RangeApr17)
subplot(4,3,4)
bar(RangeApr17)
title('April')
grid on
xlabel('Tide Number')
ylabel('Meters')

May2017=[0422 1.18 1046 9.07 1642 1.54 2304 8.82 0515 1.76 1140 8.40 1737 2.17 0003 8.19 0618 2.33 1243
7.79 1848 2.70 0112 7.70 0736 2.70 1358 7.44 2012 2.89 0232 7.56 0903 2.68 1519 7.53 2135 2.67 0349 7.81
1017 2.33 1628 7.94 2237 2.22 0451 8.23 1110 1.92 1720 8.41 2324 1.79 0538 8.62 1152 1.57 1802 8.79 0002
1.46 0618 8.90 1229 1.33 1839 9.05 0038 1.24 0656 9.07 1303 1.20 1915 9.20 0113 1.14 0731 9.12 1335 1.17
1949 9.23 0147 1.15 0805 9.08 1406 1.24 2021 9.15 0219 1.25 0837 8.95 1433 1.40 2052 8.98 0248 1.43 0908
8.75 1458 1.61 2122 8.73 0316 1.66 0939 8.49 1524 1.86 253 8.43 0347 1.93 1012 8.18 1555 2.17 2228 8.08
0424 2.25 1051 7.82 1634 2.53 2313 7.73 0515 2.58 1142 7.48 1732 2.90 0014 7.45 0626 2.80 1248 7.28 1859
3.08 0128 7.41 0745 2.75 1406 7.36 2023 2.87 0245 7.69 0856 2.40 1519 7.79 2130 2.38 0351 8.21 0958 1.90
1621 8.38 2227 1.81 0448 8.79 1054 1.40 1715 8.98 2320 1.30 0541 9.29 1146 0.98 1805 9.47 0010 0.91 0632
9.67 1237 0.68 1854 9.81 0100 0.66 0721 9.90 1327 0.53 1941 9.99 0150 0.54 0811 9.97 1414 0.52 2028 10.00
0239 0.58 0900 9.86 1500 0.68 2115 9.83 0327 0.78 0948 9.57 1545 0.99 2203 9.49 0415 1.13 1036 9.13 1631
1.44 2254 9.02 0506 1.59 1127 8.59 1722 1.96 2348 8.49];
HTMay17=May2017(4:4:end);
LTMay17=May2017(2:4:end);
```

```
RangeMay17=(HTMay17-LTMay17);
RMay17=mean(RangeMay17)
subplot(4,3,5)
bar(RangeMay17)
title('May')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jun2017=[2348 8.49 0602 2.07 1223 8.05 1821 2.44 0048 8.02 0705 2.47 1326 7.65 1930 2.76 0154 7.74 0815
2.66 1435 7.52 2045 2.79 0303 7.71 0927 2.60 1543 7.68 2151 2.56 0406 7.91 1027 2.35 1641 8.02 2244 2.23
0500 8.19 1114 2.06 1728 8.39 2327 1.91 0545 8.46 1155 1.79 1810 8.71 0007 1.65 0627 8.67 1232 1.59 1848
8.93 0045 1.48 0705 8.79 1307 1.48 1925 9.04 0121 1.41 0742 8.83 1340 1.45 2000 9.04 0156 1.43 0816 8.80
1412 1.51 2033 8.95 0228 1.51 0849 8.70 1442 1.62 2104 8.79 0300 1.64 0922 8.55 1511 1.78 2137 8.60 0333
1.79 0957 8.37 1543 1.98 2212 8.37 0411 1.98 1035 8.15 1620 2.21 2255 8.13 0456 2.18 1121 7.92 1709 2.48
2348 7.92 0553 2.37 1217 7.73 1815 2.69 0051 7.81 0701 2.44 1323 7.67 1934 2.70 0201 7.89 0812 2.33 1434
7.85 2048 2.45 0310 8.18 0920 2.04 1543 8.25 2154 2.03 0415 8.61 1023 1.66 1645 8.75 2254 1.57 0514 9.04
1121 1.27 1742 9.23 2350 1.17 0610 9.40 1218 0.96 1834 9.60 0044 0.88 0704 9.64 1310 0.75 1925 9.84 0137
0.72 0757 9.76 1400 0.67 2015 9.91 0228 0.68 0847 9.73 1448 0.73 2103 9.83 0318 0.78 0935 9.56 1533 0.93
2150 9.61 0405 1.02 1021 9.25 1616 1.26 2237 9.25 0449 1.38 1107 8.82 1700 1.68 2325 8.79 0534 1.82 1154
8.34 1746 2.15];
HTJun17=Jun2017(2:4:end);
LTJun17=Jun2017(4:4:end);
RangeJun17=(HTJun17-LTJun17);
RJun17=mean(RangeJun17)
subplot(4,3,6)
bar(RangeJun17)
title('June')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jul2017=[0015 8.30 0623 2.28 1245 7.86 1841 2.59 0110 7.85 0718 2.66 1343 7.51 1944 2.89 0212 7.56 0823
2.88 1450 7.39 2054 2.94 0317 7.51 0932 2.84 1557 7.56 2200 2.74 0420 7.68 1033 2.60 1654 7.92 2254 2.40
0513 7.98 1121 2.27 1742 8.32 2340 2.06 0600 8.29 1204 1.96 1825 8.66 0021 1.77 0642 8.54 1242 1.71 1903
8.89 0059 1.58 0720 8.70 1318 1.56 1940 9.00 0135 1.48 0756 8.78 1353 1.50 2014 9.02 0210 1.45 0831 8.80
1426 1.50 2048 8.98 0244 1.47 0906 8.76 1458 1.56 2122 8.89 0318 1.52 0941 8.69 1531 1.66 2157 8.76 0355
1.62 1018 8.56 1606 1.81 2236 8.59 0435 1.77 1059 8.38 1647 2.03 2322 8.37 0522 1.98 1147 8.15 1740 2.31
0018 8.14 0621 2.22 1246 7.93 1850 2.56 0125 7.98 0733 2.38 1356 7.84 2012 2.60 0238 8.01 0848 2.32 1511
8.00 2129 2.34 0350 8.27 1000 2.04 1624 8.41 2238 1.91 0457 8.68 1106 1.64 1727 8.93 2339 1.44 0557 9.10
1206 1.23 1822 9.38 0036 1.05 0652 9.43 1300 0.92 1914 9.71 0128 0.79 0744 9.62 1349 0.74 2002 9.87 0218
0.68 0833 9.68 1434 0.70 2048 9.87 0303 0.72 0918 9.59 1515 0.82 2132 9.72 0345 0.91 1000 9.36 1554 1.07
2214 9.42 0422 1.23 1040 9.00 1630 1.45 2255 8.98 0458 1.67 1119 8.54 1708 1.92 2336 8.45 0536 2.17 1200
8.02 1751 2.45 0020 7.89 0621 2.68 1246 7.52 1845 2.94];
HTJul17=Jul2017(2:4:end);
LTJul17=Jul2017(4:4:end);
RangeJul17=(HTJul17-LTJul17);
RJul17=mean(RangeJul17)
subplot(4,3,7)
bar(RangeJul17)
title('July')
grid on
xlabel('Tide Number')
ylabel('Meters')

Aug2017=[0114 7.39 0719 3.09 1349 7.15 1955 3.25 0224 7.11 0833 3.27 1510 7.11 2114 3.22 0340 7.18 0948
3.10 1621 7.45 2223 2.86 0445 7.54 1050 2.69 1717 7.96 2315 2.39 0536 7.99 1138 2.24 1803 8.45 2359 1.95
0619 8.39 1219 1.84 1842 8.82 0038 1.61 0657 8.70 1257 1.55 1919 9.07 0115 1.38 0734 8.91 1333 1.36 1954
9.22 0151 1.24 0810 9.04 1408 1.27 2029 9.29 0227 1.17 0846 9.11 1442 1.24 2104 9.28 0301 1.17 0922 9.10
1515 1.29 2140 9.21 0336 1.25 0958 9.01 1550 1.42 2217 9.03 0414 1.43 1036 8.81 1627 1.68 2259 8.73 0456
1.74 1121 8.48 1713 2.07 2351 8.33 0549 2.16 1216 8.07 1817 2.53 0057 7.92 0701 2.56 1326 7.73 1945 2.83
0215 7.71 0827 2.70 1449 7.70 2115 2.70 0336 7.89 0949 2.44 1612 8.09 2234 2.21 0449 8.37 1100 1.94 1719
8.70 2338 1.61 0550 8.90 1159 1.41 1815 9.26 0031 1.11 0642 9.33 1250 0.99 1903 9.66 0119 0.78 0730 9.59
1335 0.74 1948 9.87 0203 0.64 0815 9.69 1415 0.67 2030 9.90 0242 0.68 0855 9.63 1452 0.75 2109 9.76 0318
0.87 0933 9.43 1527 0.98 2145 9.47 0350 1.19 1007 9.10 1559 1.34 2220 9.05 0420 1.62 1040 8.67 1630 1.80
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2254 8.52 0449 2.12 1112 8.16 1703 2.34 2328 7.93 0522 2.67 1150 7.62 1744 2.92 0012 7.34 0612 3.21 1240
7.11 1853 3.43 0115 6.87 0735 3.57 1404 6.83 2027 3.57];
HTAug17=Aug2017(2:4:end);
LTAug17=Aug2017(4:4:end);
RangeAug17=(HTAug17-LTAug17);
RAug17=mean(RangeAug17)
subplot(4,3,8)
bar(RangeAug17)
title('August')
grid on
xlabel('Tide Number')
ylabel('Meters')

Sept2017=[0254 6.78 0906 3.49 1546 7.08 2150 3.21 0415 7.19 1018 3.02 1650 7.68 2251 2.63 0510 7.79 1111
2.43 1737 8.31 2336 2.04 0554 8.35 1154 1.90 1817 8.83 0015 1.56 0633 8.81 1233 1.49 1854 9.21 0052 1.22
0710 9.14 1310 1.20 1930 9.48 0130 0.99 0747 9.37 1347 1.02 2007 9.64 0206 0.87 0824 9.50 1423 0.95 2044
9.69 0242 0.86 0901 9.52 1459 0.98 2121 9.62 0318 0.97 0938 9.41 1534 1.15 2159 9.38 0354 1.24 1017 9.14
1612 1.49 2240 8.96 0435 1.67 1100 8.69 1657 2.00 2330 8.39 0527 2.25 1155 8.12 1800 2.62 0037 7.78 0642
2.81 1307 7.62 1931 3.04 0201 7.44 0814 3.03 1438 7.50 2111 2.93 0330 7.63 0945 2.72 1606 7.94 2236 2.34
0445 8.20 1057 2.11 1713 8.62 2336 1.67 0542 8.83 1151 1.51 1805 9.22 0023 1.13 0630 9.30 1236 1.07 1849
9.63 0104 0.81 0712 9.58 1315 0.82 1929 9.83 0142 0.69 0751 9.67 1351 0.74 2006 9.84 0215 0.75 0828 9.62
1425 0.82 2042 9.70 0247 0.94 0902 9.44 1458 1.03 2115 9.42 0317 1.25 0933 9.15 1528 1.36 2145 9.03 0343
1.64 1003 8.76 1556 1.79 2215 8.55 0406 2.10 1033 8.30 1623 2.29 2247 8.01 0433 2.60 1108 7.78 1658 2.84
2327 7.42 0515 3.16 1155 7.25 1756 3.41 0024 6.89 0631 3.66 1305 6.86 1938 3.70 0151 6.64 0823 3.70 1456
6.92 2112 3.41];
HTSept17=Sept2017(2:4:end);
LTSept17=Sept2017(4:4:end);
RangeSept17=(HTSept17-LTSept17);
RSept17=mean(RangeSept17)
subplot(4,3,9)
bar(RangeSept17)
title('September')
grid on
xlabel('Tide Number')
ylabel('Meters')

Oct2017=[0336 6.99 0942 3.24 1614 7.51 2218 2.79 0438 7.65 1039 2.60 1705 8.21 2306 2.12 0524 8.33 1124
1.98 1746 8.83 2348 1.55 0603 8.91 1204 1.48 1825 9.33 0027 1.12 0642 9.34 1244 1.12 1904 9.69 0106 0.84
0721 9.65 1324 0.88 1943 9.91 0145 0.69 0801 9.82 1403 0.78 2023 9.98 0224 0.69 0840 9.85 1442 0.83 2103
9.88 0301 0.85 0919 9.70 1521 1.04 2143 9.58 0339 1.18 1000 9.36 1601 1.44 2227 9.08 0422 1.70 1046 8.83
1650 2.02 2319 8.41 0516 2.34 1143 8.20 1756 2.65 0026 7.75 0633 2.93 1257 7.66 1923 3.07 0151 7.38 0803
3.15 1427 7.54 2104 2.96 0320 7.57 0936 2.84 1554 7.95 2227 2.40 0433 8.14 1045 2.24 1659 8.58 2322 1.77
0527 8.75 1135 1.68 1748 9.12 0006 1.30 0612 9.20 1215 1.27 1829 9.47 0042 1.01 0651 9.47 1251 1.04 1906
9.64 0116 0.91 0727 9.58 1324 0.97 1941 9.65 0148 0.95 0800 9.54 1358 1.03 2015 9.53 0218 1.11 0833 9.40
1431 1.20 2046 9.29 0248 1.37 0904 9.16 1501 1.48 2117 8.97 0313 1.70 0933 8.83 1528 1.84 2146 8.57 0336
2.09 1003 8.43 1556 2.26 2218 8.10 0403 2.52 1038 7.96 1630 2.73 2256 7.58 0441 3.01 1124 7.48 1723 3.23
2349 7.09 0544 3.52 1227 7.10 1848 3.55 0105 6.79 0631 3.70 1254 7.04 1921 3.42 0139 6.96 0757 3.36 1421
7.45 2034 2.90 0254 7.55 0900 2.76 1522 8.11 2128 2.25];
HTOct17=Oct2017(2:4:end);
LTOct17=Oct2017(4:4:end);
RangeOct17=(HTOct17-LTOct17);
ROct17=mean(RangeOct17)
subplot(4,3,10)
bar(RangeOct17)
title('October')
grid on
xlabel('Tide Number')
ylabel('Meters')

Nov2017=[0347 8.26 0948 2.13 1610 8.76 2215 1.66 0432 8.89 1033 1.59 1654 9.32 2258 1.18 0514 9.40 1116
1.18 1736 9.73 2341 0.85 0556 9.76 1200 0.90 1820 9.98 0024 0.68 0638 9.97 1243 0.78 1903 10.07 0106 0.67
0721 10.01 1327 0.81 1946 9.97 0148 0.83 0803 9.86 1411 1.01 2031 9.66 0230 1.17 0848 9.52 1457 1.39 2118
9.17 0316 1.67 0938 9.02 1549 1.91 2212 8.54 0412 2.26 1036 8.44 1652 2.46 2316 7.93 0521 2.79 1145 7.95
1808 2.85 0032 7.56 0642 3.04 1304 7.76 1937 2.88 0154 7.60 0808 2.89 1425 7.96 2058 2.53 0307 8.00 0918
2.46 1531 8.39 2155 2.07 0403 8.49 1008 2.00 1621 8.81 2239 1.68 0447 8.91 1048 1.65 1703 9.11 2316 1.41
0525 9.20 1124 1.41 1742 9.28 2349 1.27 0601 9.35 1159 1.29 1817 9.33 0021 1.24 0636 9.39 1233 1.29 1851
```

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9.27 0054 1.32 0709 9.31 1308 1.39 1924 9.12 0124 1.49 0741 9.14 1339 1.59 1955 8.89 0152 1.74 0812 8.88
1409 1.86 2026 8.59 0218 2.04 0843 8.56 1439 2.17 2059 8.23 0245 2.38 0918 8.19 1514 2.52 2136 7.83 0321
2.77 1001 7.81 1600 2.88 2224 7.44 0412 3.16 1056 7.48 1706 3.17 2326 7.16 0533 3.43 1205 7.36 1826 3.21
0041 7.15 0701 3.33 1321 7.54 1940 2.92 0158 7.49 0812 2.90 1430 8.00 2043 2.43 0303 8.08 0909 2.35 1529
8.58 2138 1.88];
HTNov17=Nov2017(2:4:end);
LTNov17=Nov2017(4:4:end);
RangeNov17=(HTNov17-LTNov17);
RNov17=mean(RangeNov17)
subplot(4,3,11)
bar(RangeNov17)
title('November')
grid on
xlabel('Tide Number')
ylabel('Meters')

Dec2017=[0357 8.71 1000 1.81 1621 9.12 2229 1.40 0445 9.25 1050 1.36 1710 9.56 2317 1.03 0533 9.67 1139
1.03 1758 9.85 0005 0.81 0618 9.93 1227 0.85 1846 9.98 0052 0.73 0705 10.03 1316 0.81 1934 9.94 0138 0.82
0752 9.95 1405 0.93 2022 9.72 0224 1.06 0840 9.70 1454 1.20 2112 9.34 0312 1.44 0930 9.31 1545 1.59 2203
8.84 0403 1.91 1024 8.83 1640 2.05 2259 8.31 0500 2.40 1124 8.36 1742 2.48 0000 7.86 0606 2.77 1228 8.00
1851 2.75 0110 7.63 0718 2.9 1338 7.88 2006 2.76 0223 7.71 0830 2.77 1447 8.00 2112 2.54 0326 8.02 0930
2.47 1546 8.27 2204 2.23 0416 8.41 1017 2.14 1634 8.56 2247 1.93 0459 8.76 1057 1.84 1716 8.79 2324 1.69
0538 9.02 1136 1.63 1755 8.95 2359 1.54 0615 9.17 1213 1.52 1831 9.01 0033 1.48 0651 9.20 1248 1.50 1906
8.97 0106 1.53 0724 9.12 1323 1.58 1939 8.86 0137 1.67 0757 8.96 1355 1.73 2011 8.68 0206 1.87 0829 8.74
1427 1.93 2045 8.45 0234 2.10 0903 8.48 1500 2.15 2120 8.19 0306 2.36 0941 8.21 1539 2.38 2200 7.91 0346
2.64 1027 7.96 1627 2.63 2250 7.66 0442 2.91 1124 7.76 1730 2.81 2351 7.50 0558 3.06 1230 7.72 1844 2.82
0102 7.54 0718 2.94 1339 7.89 1957 2.59 0215 7.85 0829 2.57 1448 8.28 2103 2.18 0321 8.37 0931 2.08 1551
8.76 2202 1.72 0420 8.93 1028 1.59 1648 9.22 2257 1.29];
HTDec17=Dec2017(2:4:end);
LTDec17=Dec2017(4:4:end);
RangeDec17=(HTDec17-LTDec17);
RDec17=mean(RangeDec17)
subplot(4,3,12)
bar(RangeDec17)
title('December')
grid on
xlabel('Tide Number')
ylabel('Meters')

AnnualHT17=[HTJan17 HTFeb17 HTMar17 HTApr17 HTMay17 HTJun17 HTJul17 HTAug17 HTSept17
HTOct17 HTNov17 HTDec17];
AnnualLT17=[LTJan17 LTFeb17 LTMar17 LTApr17 LTMay17 LTJun17 LTJul17 LTAug17 LTSept17 LTOct17
LTNov17 LTDec17];

AnnualHTMax17=max(AnnualHT17)
AnnualHTMin17=min(AnnualHT17)
AnnualLTMax17=max(AnnualLT17)
AnnualLTMin17=min(AnnualLT17)

aveRange17=(RJan17+RFeb17+RMar17+RApr17+RMay17+RJun17+RJul17+RAug17+RSept17+ROct17+RNov
17+RDec17)/12
AnnualRange17=(AnnualHT17-AnnualLT17);
[r,c]=min(AnnualRange17);
[r2,c2]=max(AnnualRange17);

figure(10)
plot(AnnualHT17)
hold
plot(AnnualLT17)
title('Annual HT and LT variations 2017')
xlabel('tides over year')
ylabel('meters')

hold off
```

```
figure(11)
plot(AnnualRange17)
title('Annual tidal range [HT-LT] 2017')
xlabel('tides over year')
ylabel('meters')

figure(12)
suptitle('Monthly Tidal Range 2017')
subplot(4,3,1)
plot(RangeJan17)
subplot(4,3,2)
plot(RangeFeb17)
subplot(4,3,3)
plot(RangeMar17)
subplot(4,3,4)
plot(RangeApr17)
subplot(4,3,5)
plot(RangeMay17)
subplot(4,3,6)
plot(RangeJun17)
subplot(4,3,7)
plot(RangeJul17)
subplot(4,3,8)
plot(RangeAug17)
subplot(4,3,9)
plot(RangeSept17)
subplot(4,3,10)
plot(RangeOct17)
subplot(4,3,11)
plot(RangeNov17)
subplot(4,3,12)
plot(RangeDec17)
                    %2016
Jan2016=[0409 2.42 1036 8.12 1638 2.61 2258 7.66 0454 2.84 1122 7.71 1729 2.99 2349 7.31 0556 3.17 1218
7.39 1835 3.23 0057 7.11 0710 3.29 1328 7.28 1950 3.22 0218 7.24 0822 3.12 1442 7.46 2057 2.95 0326 7.65
0923 2.74 1544 7.85 2154 2.53 0418 8.15 1014 2.29 1634 8.29 2241 2.10 0502 8.63 1059 1.88 1718 8.69 2324
1.73 0542 9.03 1141 1.54 1800 9.02 0004 1.43 0622 9.33 1222 1.28 1840 9.26 0044 1.23 0702 9.52 1303 1.10
1921 9.41 0124 1.13 0742 9.62 1345 1.01 2003 9.46 0203 1.11 0824 9.61 1427 1.03 2045 9.39 0244 1.21 0909
9.49 1510 1.17 2129 9.19 0326 1.44 0955 9.23 1557 1.44 2215 8.85 0414 1.79 1046 8.85 1648 1.83 2308 8.43
0512 2.22 1143 8.42 1750 2.25 0009 8.01 0624 2.58 1249 8.07 1902 2.55 0121 7.77 0745 2.71 1403 7.96 2021
2.56 0241 7.87 0903 2.50 1519 8.15 2135 2.27 0354 8.27 1012 2.09 1625 8.53 2236 1.85 0452 8.74 1108 1.66
1720 8.91 2327 1.46 0541 9.14 1155 1.32 1807 9.19 0011 1.18 0623 9.40 1236 1.12 1848 9.33 0049 1.03 0703
9.51 1315 1.04 1927 9.35 0125 1.01 0740 9.50 1350 1.09 2003 9.25 0159 1.10 0816 9.37 1423 1.25 2036 9.07
0232 1.30 0851 9.13 1453 1.49 2109 8.79 0302 1.59 0923 8.81 1521 1.81 2140 8.45 0330 1.95 0956 8.42 1548
2.19 2213 8.04 0401 2.37 1032 7.98 1624 2.61 2253 7.61];
HTJan16=Jan2016(4:4:end);
LTJan16=Jan2016(2:4:end);
RangeJan16=(HTJan16-LTJan16);
RJan16=mean(RangeJan16)
figure(13)
suptitle('Monthly Tidal Range 2016')
subplot(4,3,1)
bar(RangeJan16)
title('January')
grid on
xlabel('Tide Number')
ylabel('Meters')

Feb2016=[0443 2.82 1117 7.54 1714 3.05 2345 7.21 0548 3.23 1216 7.18 1831 3.36 0054 6.99 0719 3.35 1332
7.08 2003 3.29 0227 7.15 0839 3.06 1457 7.37 2115 2.88 0341 7.69 0942 2.53 1601 7.92 2211 2.32 0433 8.33
1033 1.96 1651 8.50 2259 1.77 0518 8.92 1120 1.44 1737 9.01 2344 1.30 0601 9.40 1204 1.02 1821 9.42 0027
0.93 0644 9.76 1248 0.71 1904 9.71 0110 0.69 0727 9.99 1332 0.53 1947 9.86 0152 0.58 0810 10.07 1415 0.49
2030 9.86 0233 0.64 0854 9.97 1456 0.64 2112 9.67 0313 0.88 0937 9.66 1538 0.99 2155 9.27 0356 1.31 1024
9.15 1623 1.52 2243 8.70 0445 1.90 1116 8.51 1718 2.15 2339 8.06 0551 2.52 1220 7.88 1828 2.71 0048 7.54
0715 2.91 1337 7.52 1954 2.92 0215 7.43 0848 2.82 1503 7.63 2121 2.66 0340 7.81 1004 2.36 1614 8.09 2227
2.14 0441 8.38 1100 1.82 1708 8.59 2315 1.63 0528 8.87 1143 1.39 1751 8.97 2354 1.24 0607 9.22 1220 1.11
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1830 9.22 0030 1.00 0644 9.41 1254 0.97 1905 9.32 0103 0.90 0718 9.47 1326 0.96 1938 9.31 0136 0.92 0751
9.39 1356 1.06 2009 9.19 0206 1.07 0823 9.22 1423 1.27 2039 8.98 0233 1.31 0852 8.95 1445 1.54 2107 8.69
0255 1.62 0921 8.61 1508 1.86 2136 8.33 0321 1.99 0951 8.20 1536 2.25 2209 7.89];
HTFeb16=Feb2016(4:4:end);
LTFeb16=Feb2016(2:4:end);
RangeFeb16=(HTFeb16-LTFeb16);
RFeb16=mean(RangeFeb16)
subplot(4,3,2)
bar(RangeFeb16)
title('February')
grid on
xlabel('Tide Number')
ylabel('Meters')

Mar2016=[2209 7.89 0356 2.43 1030 7.73 1616 2.72 2254 7.42 0447 2.93 1124 7.26 1718 3.21 2359 7.03 0612
3.29 1239 6.98 1903 3.40 0126 6.98 0753 3.17 1409 7.14 2035 3.04 0257 7.44 0908 2.61 1527 7.72 2139 2.39
0401 8.17 1006 1.93 1624 8.43 2233 1.72 0451 8.89 1056 1.28 1712 9.08 2321 1.13 0538 9.50 1143 0.76 1759
9.59 0007 0.67 0624 9.96 1230 0.39 1844 9.96 0052 0.36 0708 10.26 1315 0.18 1927 10.16 0136 0.22 0752
10.36 1357 0.16 2010 10.16 0217 0.28 0836 10.23 1439 0.36 2052 9.94 0257 0.57 0918 9.86 1518 0.78 2135
9.48 0338 1.07 1003 9.26 1600 1.40 2220 8.83 0424 1.75 1053 8.49 1651 2.14 2313 8.07 0525 2.48 1154 7.72
1759 2.81 0022 7.43 0647 2.99 1312 7.24 1927 3.13 0150 7.20 0827 2.99 1442 7.31 2101 2.89 0319 7.54 0948
2.52 1556 7.80 2207 2.33 0422 8.13 1041 1.96 1648 8.36 2254 1.78 0507 8.66 1121 1.50 1729 8.81 2330 1.35
0545 9.04 1155 1.18 1805 9.11 0003 1.06 0619 9.27 1227 1.01 1838 9.27 0036 0.92 0653 9.35 1258 0.97 1910
9.31 0109 0.91 0725 9.32 1327 1.04 1941 9.23 0139 1.03 0755 9.19 1353 1.21 2010 9.07 0304 1.23 0924 8.98
1515 1.43 2138 8.82 0327 1.48 0951 8.69 1536 1.69 2206 8.50 0353 1.78 1020 8.34 1603 2.02 2236 8.11 0425
2.16 1055 7.91 1639 2.45 2317 7.66 0512 2.63 1146 7.44 1733 2.96];
HTMar16=Mar2016(2:4:end);
LTMar16=Mar2016(4:4:end);
RangeMar16=(HTMar16-LTMar16);
RMar16=mean(RangeMar16)
subplot(4,3,3)
bar(RangeMar16)
title('March')
grid on
xlabel('Tide Number')
ylabel('Meters')

Apr2016=[0021 7.24 0629 3.04 1302 7.09 1915 3.28 0146 7.10 0810 3.03 1431 7.16 2056 3.01 0316 7.46 0932
2.54 1552 7.71 2207 2.37 0427 8.17 1035 1.85 1654 8.45 2303 1.66 0522 8.92 1129 1.19 1746 9.14 2354 1.04
0612 9.56 1219 0.66 1834 9.68 0042 0.57 0700 10.02 1307 0.29 1921 10.05 0130 0.28 0747 10.30 1354 0.11
2006 10.24 0215 0.16 0833 10.37 1438 0.13 2049 10.22 0300 0.25 0917 10.21 1520 0.37 2132 9.97 0341 0.55
1000 9.81 1600 0.81 2215 9.51 0423 1.06 1045 9.20 1641 1.43 2300 8.86 0509 1.71 1133 8.44 1730 2.14 2353
8.14 0605 2.40 1231 7.70 1832 2.79 0058 7.50 0718 2.92 1345 7.20 1954 3.15 0218 7.22 0851 3.03 1509 7.18
2124 3.01 0342 7.43 1012 2.68 1623 7.59 2232 2.53 0447 7.91 1107 2.19 1716 8.12 2319 2.02 0534 8.40 1148
1.74 1757 8.59 2357 1.58 0614 8.78 1223 1.42 1834 8.94 0032 1.28 0651 9.02 1257 1.21 1909 9.14 0106 1.11
0725 9.14 1329 1.14 1942 9.22 0140 1.08 0758 9.15 1359 1.17 2014 9.19 0211 1.15 0829 9.07 1425 1.28 2044
9.08 0239 1.29 0859 8.93 1450 1.45 2114 8.88 0305 1.47 0929 8.71 1515 1.66 2142 8.62 0334 1.70 1000 8.43
1543 1.92 2215 8.30 0409 2.00 1036 8.08 1619 2.28 2257 7.92 0456 2.37 1127 7.69 1712 2.71 2358 7.57 0608
2.70 1236 7.38 1844 3.01];
HTApr16=Apr2016(2:4:end);
LTApr16=Apr2016(4:4:end);
RangeApr16=(HTApr16-LTApr16);
RApr16=mean(RangeApr16)
subplot(4,3,4)
bar(RangeApr16)
title('April')
grid on
xlabel('Tide Number')
ylabel('Meters')

May2016=[0118 7.43 0736 2.73 1359 7.40 2018 2.84 0241 7.69 0855 2.37 1518 7.82 2133 2.32 0351 8.27 1002
1.81 1623 8.47 2233 1.69 0451 8.92 1100 1.23 1718 9.10 2327 1.13 0545 9.47 1153 0.77 1809 9.61 0018 0.71
0636 9.87 1244 0.46 1857 9.94 0107 0.45 0725 10.09 1332 0.32 1944 10.10 0155 0.37 0813 10.13 1418 0.36
2030 10.07 0242 0.46 0859 9.97 1501 0.57 2114 9.85 0326 0.73 0944 9.61 1542 0.96 2158 9.45 0409 1.15 1028
9.09 1623 1.47 2244 8.91 0454 1.69 1115 8.47 1709 2.06 2334 8.30 0544 2.25 1208 7.84 1803 2.62 0032 7.76
0645 2.72 1311 7.37 1912 2.99 0140 7.42 0800 2.94 1423 7.20 2029 3.04 0252 7.41 0916 2.84 1535 7.41 2140
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2.77 0358 7.68 1018 2.51 1633 7.83 2234 2.35 0452 8.07 1106 2.12 1721 8.28 2318 1.95 0537 8.42 1146 1.79
1802 8.66 2358 1.63 0618 8.69 1223 1.55 1839 8.92 0036 1.42 0656 8.86 1258 1.41 1915 9.07 0112 1.33 0731
8.94 1330 1.36 1949 9.11 0145 1.32 0805 8.94 1401 1.40 2021 9.07 0217 1.38 0839 8.88 1431 1.48 2054 8.95
0248 1.47 0912 8.76 1501 1.62 2127 8.77 0323 1.62 0947 8.57 1533 1.81 2203 8.55 0401 1.81 1027 8.33 1612
2.07 2248 8.27 0449 2.06 1115 8.04 1704 2.38 2345 8.01 0551 2.29 1217 7.80 1818 2.63 0054 7.87 0706 2.37
1328 7.74 1942 2.62 0208 7.97 0819 2.22 1442 7.95 2057 2.31];
HTMay16=May2016(2:4:end);
LTMay16=May2016(4:4:end);
RangeMay16=(HTMay16-LTMay16);
RMay16=mean(RangeMay16)
subplot(4,3,5)
bar(RangeMay16)
title('May')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jun2016=[0318 8.32 0928 1.88 1551 8.38 2203 1.86 0421 8.77 1031 1.47 1651 8.89 2301 1.40 0519 9.20 1128
1.09 1745 9.34 2355 1.03 0614 9.53 1222 0.82 1837 9.66 0048 0.79 0706 9.72 1312 0.68 1925 9.82 0138 0.70
0756 9.76 1400 0.67 2012 9.83 0226 0.74 0843 9.65 1444 0.81 2057 9.68 0311 0.92 0928 9.41 1524 1.07 2142
9.40 0354 1.21 1012 9.04 1604 1.44 2226 9.01 0435 1.60 1055 8.58 1645 1.88 2312 8.54 0518 2.03 1140 8.09
1730 2.33 0000 8.07 0606 2.45 1230 7.65 1824 2.74 0056 7.67 0703 2.78 1329 7.33 1929 2.99 0158 7.44 0808
2.93 1437 7.27 2039 2.99 0304 7.45 0916 2.84 1543 7.48 2144 2.75 0406 7.67 1016 2.57 1641 7.87 2238 2.39
0459 7.99 1106 2.24 1729 8.28 2324 2.04 0545 8.31 1148 1.93 1811 8.64 0006 1.75 0627 8.57 1228 1.69 1850
8.89 0044 1.55 0706 8.76 1305 1.53 1926 9.05 0121 1.42 0743 8.88 1340 1.44 2002 9.12 0158 1.36 0820 8.93
1415 1.41 2038 9.12 0235 1.35 0857 8.93 1451 1.45 2115 9.05 0313 1.39 0936 8.86 1527 1.54 2154 8.92 0354
1.48 1018 8.71 1607 1.71 2239 8.73 0439 1.65 1103 8.51 1654 1.95 2330 8.50 0533 1.87 1157 8.26 1754 2.23
0030 8.28 0636 2.08 1259 8.05 1906 2.43 0137 8.15 0745 2.19 1408 7.99 2024 2.41 0247 8.21 0857 2.12 1520
8.16 2136 2.17];
HTJun16=Jun2016(2:4:end);
LTJun16=Jun2016(4:4:end);
RangeJun16=(HTJun16-LTJun16);
RJun16=mean(RangeJun16)
subplot(4,3,6)
bar(RangeJun16)
title('June')
grid on
xlabel('Tide Number')
ylabel('Meters')

Jul2016=[2136 2.17 0356 8.45 1006 1.87 1628 8.52 2242 1.80 0500 8.78 1110 1.55 1728 8.94 2342 1.43 0558
9.10 1207 1.24 1822 9.30 0036 1.14 0651 9.33 1258 1.02 1912 9.53 0125 0.97 0742 9.44 1345 0.92 1957 9.63
0212 0.92 0827 9.43 1427 0.94 2041 9.58 0254 1.00 0910 9.30 1506 1.08 2123 9.41 0333 1.19 0951 9.07 1542
1.32 2203 9.13 0409 1.47 1029 8.74 1618 1.64 2243 8.76 0445 1.82 1107 8.35 1654 2.03 2323 8.33 0522 2.21
1146 7.93 1736 2.45 0006 7.88 0606 2.61 1230 7.53 1827 2.86 0055 7.49 0700 2.95 1326 7.23 1933 3.13 0158
7.24 0809 3.11 1442 7.15 2048 3.13 0312 7.25 0921 3.01 1557 7.41 2156 2.85 0419 7.54 1024 2.68 1656 7.86
2251 2.44 0513 7.95 1116 2.28 1743 8.34 2338 2.01 0600 8.35 1200 1.89 1825 8.76 0020 1.65 0642 8.69 1242
1.58 1904 9.07 0100 1.38 0722 8.95 1321 1.34 1943 9.29 0140 1.18 0802 9.14 1400 1.19 2021 9.42 0221 1.06
0842 9.25 1439 1.12 2102 9.46 0301 1.02 0923 9.27 1518 1.14 2142 9.41 0342 1.07 1004 9.19 1557 1.27 2226
9.24 0425 1.24 1048 8.98 1641 1.53 2313 8.94 0512 1.55 1136 8.64 1732 1.92 0007 8.55 0608 1.94 1231 8.24
1836 2.35 0109 8.16 0715 2.32 1337 7.90 1954 2.63 0221 7.93 0830 2.50 1454 7.82 2118 2.58 0338 8.00 0950
2.36 1612 8.10 2235 2.22 0448 8.33 1100 1.99 1719 8.57];
HTJul16=Jul2016(4:4:end);
LTJul16=Jul2016(2:4:end);
RangeJul16=(HTJul16-LTJul16);
RJul16=mean(RangeJul16)
subplot(4,3,7)
bar(RangeJul16)
title('July')
grid on
xlabel('Tide Number')
ylabel('Meters')

Aug2016=[2338 1.76 0549 8.73 1159 1.57 1813 9.02 0030 1.36 0641 9.06 1248 1.24 1900 9.35 0115 1.09 0727
9.27 1330 1.03 1943 9.53 0157 0.98 0809 9.34 1408 0.96 2023 9.56 0233 0.99 0848 9.29 1443 1.01 2100 9.46
0308 1.12 0924 9.14 1516 1.17 2136 9.24 0339 1.35 0959 8.90 1548 1.44 2210 8.92 0409 1.66 1030 8.57 1619
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1.79 2242 8.52 0438 2.03 1102 8.19 1649 2.21 2316 8.07 0510 2.44 1137 7.76 1727 2.68 2357 7.60 0554 2.89
1223 7.34 1822 3.15 0051 7.18 0659 3.27 1325 7.03 1948 3.41 0204 6.97 0827 3.36 1457 7.04 2114 3.24 0334
7.16 0945 3.05 1621 7.51 2221 2.74 0442 7.67 1046 2.53 1715 8.13 2313 2.17 0533 8.24 1135 1.99 1800 8.71
2358 1.64 0617 8.75 1219 1.52 1842 9.20 0040 1.21 0700 9.16 1301 1.15 1922 9.56 0122 0.90 0742 9.46 1343
0.89 2003 9.80 0204 0.71 0824 9.65 1424 0.75 2045 9.91 0246 0.64 0905 9.72 1504 0.75 2127 9.87 0327 0.72
0946 9.63 1544 0.91 2209 9.65 0408 0.97 1028 9.35 1625 1.25 2254 9.23 0452 1.40 1114 8.89 1712 1.77 2345
8.65 0543 1.98 1206 8.31 1812 2.39 0045 8.03 0649 2.57 1312 7.76 1931 2.89 0201 7.59 0811 2.91 1436 7.51
2108 2.94 0327 7.59 0942 2.79 1603 7.77 2236 2.51 0442 8.00 1057 2.31 1713 8.34 2336 1.94 0541 8.52 1152
1.77 1804 8.89 0023 1.45 0629 8.96 1235 1.36 1847 9.28];
HTAug16=Aug2016(4:4:end);
LTAug16=Aug2016(2:4:end);
RangeAug16=(HTAug16-LTAug16);
RAug16=mean(RangeAug16)
subplot(4,3,8)
bar(RangeAug16)
title('August')
grid on
xlabel('Tide Number')
ylabel('Meters')

Sept2016=[0102 1.14 0710 9.23 1312 1.09 1925 9.50 0136 0.99 0748 9.35 1345 0.97 2001 9.56 0209 0.98 0823
9.35 1418 0.98 2035 9.49 0239 1.08 0856 9.24 1449 1.11 2108 9.30 0308 1.29 0926 9.03 1519 1.35 2137 9.02
0334 1.57 0955 8.75 1545 1.67 2206 8.66 0357 1.91 1024 8.40 1610 2.06 2236 8.23 0424 2.30 1056 7.98 1642
2.52 2311 7.74 0500 2.78 1137 7.51 1728 3.04 0001 7.24 0556 3.28 1236 7.09 1845 3.48 0113 6.89 0735 3.57
1358 6.94 2032 3.45 0247 6.95 0909 3.30 1539 7.32 2150 2.93 0409 7.51 1017 2.70 1644 8.03 2248 2.23 0506
8.23 1109 2.03 1733 8.76 2335 1.57 0552 8.88 1155 1.44 1816 9.37 0019 1.03 0636 9.41 1239 0.98 1900 9.83
0103 0.66 0719 9.78 1323 0.67 1942 10.13 0146 0.44 0802 10.00 1406 0.51 2025 10.26 0228 0.39 0845 10.06
1448 0.52 2108 10.18 0310 0.53 0927 9.92 1530 0.74 2151 9.88 0351 0.88 1009 9.57 1611 1.16 2236 9.35 0433
1.42 1054 9.02 1657 1.78 2325 8.64 0524 2.11 1147 8.33 1755 2.49 0026 7.89 0629 2.79 1253 7.68 1915 3.06
0145 7.36 0753 3.19 1419 7.38 2059 3.15 0315 7.36 0933 3.05 1551 7.64 2229 2.67 0432 7.83 1048 2.51 1700
8.23 2324 2.07 0527 8.41 1137 1.94 1748 8.79 0006 1.57 0611 8.89 1215 1.50 1827 9.20 0041 1.24 0648 9.20
1246 1.22 1903 9.43];
HTSept16=Sept2016(4:4:end);
LTSept16=Sept2016(2:4:end);
RangeSept16=(HTSept16-LTSept16);
RSept16=mean(RangeSept16)
subplot(4,3,9)
bar(RangeSept16)
title('September')
grid on
xlabel('Tide Number')
ylabel('Meters')

Oct2016=[0111 1.08 0722 9.36 1318 1.06 1936 9.51 0141 1.04 0755 9.39 1351 1.05 2009 9.45 0211 1.12 0827
9.31 1423 1.16 2039 9.29 0239 1.31 0856 9.14 1451 1.38 2108 9.05 0303 1.57 0924 8.88 1517 1.67 2136 8.73
0325 1.88 0953 8.56 1542 2.02 2204 8.35 0351 2.23 1024 8.16 1612 2.43 2237 7.89 0423 2.67 1103 7.71 1654
2.92 2324 7.39 0512 3.19 1200 7.27 1805 3.38 0036 6.98 0648 3.58 1321 7.07 1951 3.44 0206 6.97 0833 3.39
1454 7.35 2115 2.97 0333 7.49 0945 2.79 1608 8.04 2217 2.26 0436 8.24 1040 2.08 1702 8.81 2309 1.56 0525
8.97 1129 1.44 1749 9.47 2355 0.98 0611 9.55 1215 0.95 1835 9.96 0041 0.59 0656 9.96 1302 0.62 1921 10.26
0126 0.38 0740 10.18 1347 0.48 2006 10.36 0210 0.36 0824 10.21 1432 0.52 2050 10.25 0253 0.55 0907 10.04
1515 0.76 2134 9.91 0335 0.93 0951 9.66 1559 1.20 2220 9.35 0418 1.50 1038 9.09 1646 1.81 2309 8.63 0508
2.18 1131 8.42 1743 2.48 0009 7.89 0610 2.83 1236 7.79 1856 3.03 0124 7.36 0729 3.24 1356 7.47 2031 3.18
0249 7.29 0903 3.19 1522 7.62 2201 2.83 0406 7.68 1019 2.73 1632 8.09 2257 2.31 0502 8.22 1108 2.22 1721
8.59 2339 1.85 0544 8.70 1145 1.78 1800 8.98 0012 1.51 0621 9.06 1218 1.47 1836 9.22 0043 1.31 0555 9.27
1151 1.29 1810 9.33 0014 1.22 0629 9.35 1225 1.24 1843 9.32];
HTOct16=Oct2016(4:4:end);
LTOct16=Oct2016(2:4:end);
RangeOct16=(HTOct16-LTOct16);
ROct16=mean(RangeOct16)
subplot(4,3,10)
bar(RangeOct16)
title('October')
grid on
xlabel('Tide Number')
ylabel('Meters')
```

```
Nov2016=[0045 1.26 0701 9.32 1258 1.31 1914 9.21 0115 1.40 0731 9.18 1328 1.48 1944 9.02 0140 1.62 0800
8.97 1356 1.72 2013 8.76 0204 1.88 0830 8.68 1423 2.01 2044 8.44 0230 2.19 0902 8.34 1454 2.34 2118 8.05
0302 2.55 0942 7.96 1536 2.72 2203 7.63 0348 2.99 1036 7.58 1641 3.09 2308 7.27 0509 3.36 1150 7.39 1812
3.20 0030 7.19 0651 3.30 1312 7.56 1934 2.89 0153 7.55 0808 2.83 1427 8.09 2042 2.31 0301 8.20 0909 2.20
1528 8.76 2139 1.68 0357 8.90 1002 1.58 1621 9.38 2230 1.13 0446 9.48 1052 1.10 1711 9.85 2319 0.75 0533
9.89 1141 0.78 1800 10.13 0007 0.54 0620 10.12 1230 0.63 1847 10.22 0054 0.51 0706 10.16 1317 0.66 1934
10.12 0139 0.67 0751 10.02 1403 0.86 2020 9.81 0222 1.01 0837 9.69 1449 1.22 2106 9.33 0306 1.48 0924
9.21 1536 1.72 2155 8.73 0353 2.06 1015 8.64 1629 2.28 2249 8.09 0448 2.63 1114 8.09 1730 2.78 2352 7.57
0553 3.06 1220 7.70 1842 3.06 0105 7.34 0709 3.20 1333 7.61 2003 3.02 0220 7.48 0825 3.00 1444 7.82 2111
2.70 0322 7.87 0924 2.61 1540 8.19 2159 2.30 0410 8.33 1008 2.19 1627 8.56 2239 1.94 0451 8.73 1047 1.85
1707 8.85 2314 1.67 0529 9.03 1124 1.61 1745 9.03 2348 1.50 0605 9.19 1201 1.48 1820 9.10 0022 1.44 0639
9.24 1236 1.47 1854 9.08];
HTNov16=Nov2016(4:4:end);
LTNov16=Nov2016(2:4:end);
RangeNov16=(HTNov16-LTNov16);
RNov16=mean(RangeNov16)
subplot(4,3,11)
bar(RangeNov16)
title('November')
grid on
xlabel('Tide Number')
ylabel('Meters')

Dec2016=[0054 1.50 0711 9.18 1309 1.55 1925 8.98 0124 1.63 0743 9.04 1340 1.69 1957 8.82 0152 1.81 0815
8.84 1412 1.88 2031 8.59 0221 2.04 0850 8.59 1446 2.10 2107 8.32 0254 2.30 0929 8.31 1527 2.36 2151 8.01
0337 2.61 1019 8.03 1622 2.62 2246 7.72 0441 2.92 1123 7.83 1733 2.79 2354 7.57 0607 3.03 1234 7.84 1851
2.72 0109 7.68 0727 2.81 1346 8.10 2003 2.40 0222 8.08 0836 2.37 1454 8.56 2107 1.93 0326 8.63 0936 1.86
1554 9.06 2206 1.46 0422 9.17 1031 1.40 1650 9.49 2300 1.08 0515 9.60 1124 1.05 1742 9.79 2351 0.82 0604
9.88 1216 0.85 1833 9.92 0039 0.72 0651 9.99 1306 0.79 1921 9.90 0126 0.77 0738 9.94 1353 0.88 2008 9.71
0210 0.98 0824 9.73 1439 1.12 2054 9.38 0252 1.31 0909 9.39 1523 1.48 2138 8.93 0334 1.74 0956 8.94 1607
1.92 2224 8.42 0419 2.22 1044 8.45 1654 2.39 2313 7.91 0510 2.68 1137 7.98 1748 2.81 0010 7.49 0611 3.03
1237 7.63 1853 3.07 0118 7.30 0720 3.16 1344 7.52 2003 3.07 0228 7.42 0829 3.00 1451 7.66 2109 2.83 0330
7.79 0927 2.67 1549 7.98 2201 2.46 0420 8.23 1016 2.28 1638 8.33 2245 2.10 0504 8.63 1100 1.94 1720 8.64
2324 1.80 0543 8.93 1139 1.69 1759 8.85 0001 1.61 0620 9.11 1217 1.55 1835 8.97 0036 1.51 0654 9.18 1253
1.49 1909 9.00 0109 1.51 0728 9.16 1327 1.50 1945 8.97];
HTDec16=Dec2016(4:4:end);
LTDec16=Dec2016(2:4:end);
RangeDec16=(HTDec16-LTDec16);
RDec16=mean(RangeDec16)
subplot(4,3,12)
bar(RangeDec16)
title('December')
grid on
xlabel('Tide Number')
ylabel('Meters')

AnnualHT16=[HTJan16 HTFeb16 HTMar16
HTApr16 HTMay16 HTJun16 HTJul16 HTAug16
HTSept16 HTOct16 HTNov16 HTDec16];
AnnualLT16=[LTJan16 LTFeb16 LTMar16 LTApr16
LTMay16 LTJun16 LTJul16 LTAug16 LTSept16
LTOct16 LTNov16 LTDec16];

AnnualHTMax16=max(AnnualHT16)
AnnualHTMin16=min(AnnualHT16)
AnnualLTMax16=max(AnnualLT16)
AnnualLTMin16=min(AnnualLT16)

aveRange16=(RJan16+RFeb16+RMar16+RApr16+
RMay16+RJun16+RJul16+RAug16+RSept16+ROct
16+RNov16+RDec16)/12
AnnualRange16=(AnnualHT16-AnnualLT16);
[r,c]=min(AnnualRange16);
[r2,c2]=max(AnnualRange16);

figure(14)
plot(AnnualHT16)
hold
plot(AnnualLT16)
title('Annual HT and LT variations 2016')
xlabel('tides over year')
ylabel('meters')
hold off

figure(15)
plot(AnnualRange16)
title('Annual tidal range 2016 [HT-LT]')
xlabel('tides over year')
ylabel('meters')

figure(16)
suptitle('Monthly Tidal Range 2016')
subplot(4,3,1)
plot(RangeJan16)
subplot(4,3,2)
plot(RangeFeb16)
```

```
subplot(4,3,3)
plot(RangeMar16)
subplot(4,3,4)
plot(RangeApr16)
subplot(4,3,5)
plot(RangeMay16)
subplot(4,3,6)
plot(RangeJun16)
subplot(4,3,7)
plot(RangeJul16)
subplot(4,3,8)
plot(RangeAug16)
subplot(4,3,9)
plot(RangeSept16)
subplot(4,3,10)
plot(RangeOct16)
subplot(4,3,11)
plot(RangeNov16)
subplot(4,3,12)
plot(RangeDec16)
%Max & Min Monthly Range
MaxJan19=max(RangeJan19);
MaxFeb19=max(RangeFeb19);
MaxMar19=max(RangeMar19);
MaxApr19=max(RangeApr19);
MaxMay19=max(RangeMay19);
MaxJun19=max(RangeJun19);
MaxJul19=max(RangeJul19);
MaxAug19=max(RangeAug19);
MaxSept19=max(RangeSept19);
MaxOct19=max(RangeOct19);
MaxNov19=max(RangeNov19);
MaxDec19=max(RangeDec19);

MinJan19=min(RangeJan19);
MinFeb19=min(RangeFeb19);
MinMar19=min(RangeMar19);
MinApr19=min(RangeApr19);
MinMay19=min(RangeMay19);
MinJun19=min(RangeJun19);
MinJul19=min(RangeJul19);
MinAug19=min(RangeAug19);
MinSept19=min(RangeSept19);
MinOct19=min(RangeOct19);
MinNov19=min(RangeNov19);
MinDec19=min(RangeDec19);

MaxJan18=max(RangeJan18);
MaxFeb18=max(RangeFeb18);
MaxMar18=max(RangeMar18);
MaxApr18=max(RangeApr18);
MaxMay18=max(RangeMay18);
MaxJun18=max(RangeJun18);
MaxJul18=max(RangeJul18);
MaxAug18=max(RangeAug18);
MaxSept18=max(RangeSept18);
MaxOct18=max(RangeOct18);
MaxNov18=max(RangeNov18);
MaxDec18=max(RangeDec18);
MinJan18=min(RangeJan18);
MinFeb18=min(RangeFeb18);
MinMar18=min(RangeMar18);
MinApr18=min(RangeApr18);
MinMay18=min(RangeMay18);
MinJun18=min(RangeJun18);
MinJul18=min(RangeJul18);
MinAug18=min(RangeAug18);
MinSept18=min(RangeSept18);
MinOct18=min(RangeOct18);
MinNov18=min(RangeNov18);
MinDec18=min(RangeDec18);

MaxJan17=max(RangeJan17);
MaxFeb17=max(RangeFeb17);
MaxMar17=max(RangeMar17);
MaxApr17=max(RangeApr17);
MaxMay17=max(RangeMay17);
MaxJun17=max(RangeJun17);
MaxJul17=max(RangeJul17);
MaxAug17=max(RangeAug17);
MaxSept17=max(RangeSept17);
MaxOct17=max(RangeOct17);
MaxNov17=max(RangeNov17);
MaxDec17=max(RangeDec17);

MinJan17=min(RangeJan17);
MinFeb17=min(RangeFeb17);
MinMar17=min(RangeMar17);
MinApr17=min(RangeApr17);
MinMay17=min(RangeMay17);
MinJun17=min(RangeJun17);
MinJul17=min(RangeJul17);
MinAug17=min(RangeAug17);
MinSept17=min(RangeSept17);
MinOct17=min(RangeOct17);
MinNov17=min(RangeNov17);
MinDec17=min(RangeDec17);

MaxJan16=max(RangeJan16);
MaxFeb16=max(RangeFeb16);
MaxMar16=max(RangeMar16);
MaxApr16=max(RangeApr16);
MaxMay16=max(RangeMay16);
MaxJun16=max(RangeJun16);
MaxJul16=max(RangeJul16);
MaxAug16=max(RangeAug16);
MaxSept16=max(RangeSept16);
MaxOct16=max(RangeOct16);
MaxNov16=max(RangeNov16);
MaxDec16=max(RangeDec16);

MinJan16=min(RangeJan16);
MinFeb16=min(RangeFeb16);
MinMar16=min(RangeMar16);
MinApr16=min(RangeApr16);
MinMay16=min(RangeMay16);
MinJun16=min(RangeJun16);
MinJul16=min(RangeJul16);
MinAug16=min(RangeAug16);
MinSept16=min(RangeSept16);
MinOct16=min(RangeOct16);
MinNov16=min(RangeNov16);
MinDec16=min(RangeDec16);

AnnualHTAve19=mean(AnnualHT19)
AnnualLTAve19=mean(AnnualLT19)
AnnualHTAve18=mean(AnnualHT18)
AnnualLTAve18=mean(AnnualLT18)
AnnualHTAve17=mean(AnnualHT17)
AnnualLTAve17=mean(AnnualLT17)
AnnualHTAve16=mean(AnnualHT16)
AnnualLTAve16=mean(AnnualLT16)
```

8.2 Calculating Energy and power from tidal range

```
%You must run this script after Bruce_Matlab, as it uses the arrays from
%that script. Calculating the Energy & power that the tidal basin will generate
AnnualRange19=AnnualRange19-0.2;
%Energy 19 in *10^9 J here
Energy19=(AnnualRange19.^2)*0.5*1025*9.81*9000;

[r,c]=size(Energy19);
Etotal19=0;
for i=1:c
Etotal19=Energy19(1,i)+Etotal19;
end
%This is in J
Etotal19
%This is in kWh
Etotal19kWh=Etotal19*(1/3600000)
%Ability to harness this is 33%, and in 2-way generation
ElectricityGen19kWh=Etotal19kWh*2*0.33
DailyElectricityGen19kWh=ElectricityGen19kWh/365

PowerRating=(DailyElectricityGen19kWh)/15.6
```