ENV-2A36 Low Carbon Technologies 2010

Tidal Power

Churchill No 2 Barrier, Orkney. This barrier is 620 m long and was constructed during World War II. There is a difference in tides of 1 hour 40 minutes between the east and west sides of the barrier giving the potential for a tidal barrage without much of the capital costs associated with construction and without most of the environmental problems associated with such barrages.

A few of the diagrams may not reproduce very well in black and white.
This handout is available on the Internet at:

http://www2.env.uea.ac.uk/gmmc/env/energy.htm

- then follow links to ENV-2A36

17. TIDAL POWER

17.1 Tidal Power - Theory

Tides arise from the rotational motion of the earth and the differential gravitational field set up by the Earth, Moon, and Sun. The relative motions of these cause several different tidal cycles:-

1) a semi-diurnal cycle - period 12 hrs 25 mins

2) a semi-monthly cycle - (i.e. Spring - Neap Tides) corresponding with the position of the moon
3) a semi-annual cycle - period about 178 days which is associated with the inclination of the Moon's orbit. This causes the highest the highest Spring Tides to occur in March and September.
4) Other long term cycles - eg a nineteen year cycle of the Moon.

The Spring Tides have a range about twice that of neap tides, while the other cycles can cause further variations of up to 15%.

The Tidal range is amplified in estuaries, and in some situations, the shape of the estuary is such that near resonance occurs. This happens in the Severn Estuary where a tidal range at Cardiff is over twice that at the mouth of the estuary (see diagram on separate sheet).

A barrage placed across such an estuary can affect the resonance conditions, and either enhance further the potential range or suppress it. Careful modelling is therefore needed in the evaluation of any scheme.

Potential power is proportional to area impounded and the square of the tidal range. Thus about 4 times as much power can be generated at spring tides as at neap tides.

Historically most interest has been shown in Tidal Basin Schemes although in the last few years ineterst has also been shown into marine current deivces which operate in a similar manner to Wind Turbines. Such devices are described in section 17.7. There have also been ideas suggested for Tidal Lagoons which are in essence a derivative of the basin schemes. (section 17.8).

17.2 Tidal Power - Introduction to Basin Schemes

There have been tidal mills in operation for many centuries e.g. at Woodbridge in Suffolk, but only in the last 25 years have major new schemes been constructed to generate electricity.

Examples include the 240 MW Tidal Power Station at La Rance near St Malo in France, a scheme in northern USSR, and more recent schemes in China. All except La Rance are small schemes < 10 MW.

As early as 1925, consideration for a tidal barrage across the Severn Estuary was given by the Brabazon Committee. The proposal was for a barrage just seawards of the present Severn Bridge.

Subsequent schemes have favoured a more seaward barrage some as far seaward as Minehead.

Three Energy Papers on Tidal power have been written (Nos. 23, 27, and 46). The last of these is the so called Bondi Report (1981). There are also references to Tidal Power in the more recent Energy Papers 55 - 66.

Other estuaries in the UK under consideration include:-

1) Solway Firth
2) Morecombe Bay
3) The Wash
4) Humber
5) Dee
6) Mersey (recently this scheme has been promoted actively and could be the first scheme in the UK).
7) Strangford Lough

The total potential, if all sites were developed, would be to generate about 125 PJ of electricity per year, or about 16% of UK consumption.

About 147 PJ per annum (6%) could be generated by the favoured scheme for the Severn which has the second highest tidal range in the world (after the Bay of Fundy in Canada).

Tidal Basin Schmes fall into one of 5 categories.

1) schemes working on EBB flow only
2) schemes working on FLOOD flow only
3) schemes working on both EBB and FLOOD
4) Double Basin Schemes
5) Any of the the above schemes but incorporating pumping at high or low tide.

17.2.1 EBB schemes

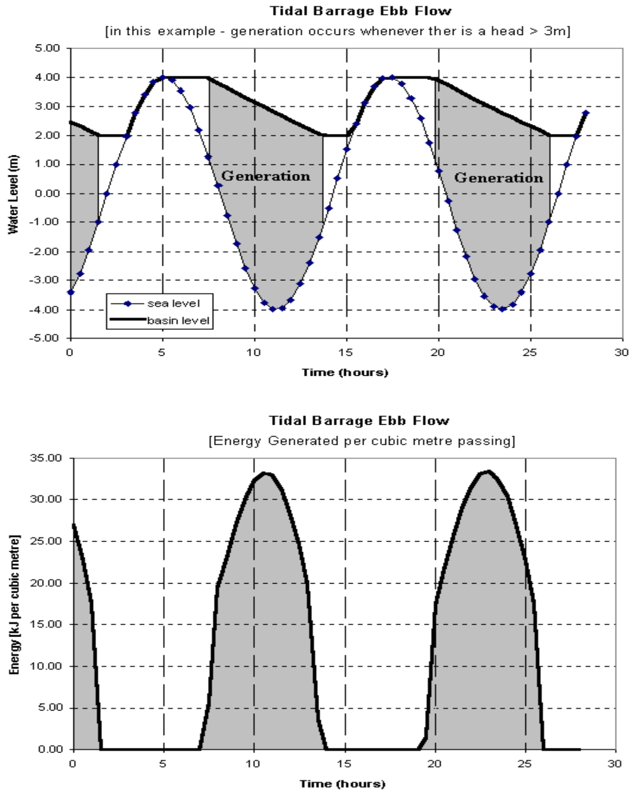


Fig. **17**.1 Generation from Tidal Power in the EBB Mode

Generation on **EBB** flow only (see Fig. 17.1) . The basin fills through sluice gates which are closed at high tide, and the water allowed to pass through the turbines as the tide ebbs.

Generation starts around 4 hours after high tide to ensure the head is large, and hence the output is greatest. Generation can be continued for up to 2 hours after low tide. Generation is possible for only one-third of time.

The water in the basin is always above mean sea level, and thus the mean water level in the basin is raised compared to conditions before the barrage is constructed..

17.2.2 FLOOD Schemes

Generation on **FLOOD** flow only. (Fig. 17.2) The basin is emptied rapidly through sluice gates which are then closed at low tide. Generation occurs as water flows in to flood the basin.

As with ebb flow schemes, generation is restricted to 4 hours in every 12 (2 hours either side of high tide).

The total energy generated would be less as less water would be able to pass through the turbines.

The mean water level in the basin would be below mean sea level, and hence would cause a hazard to shipping.

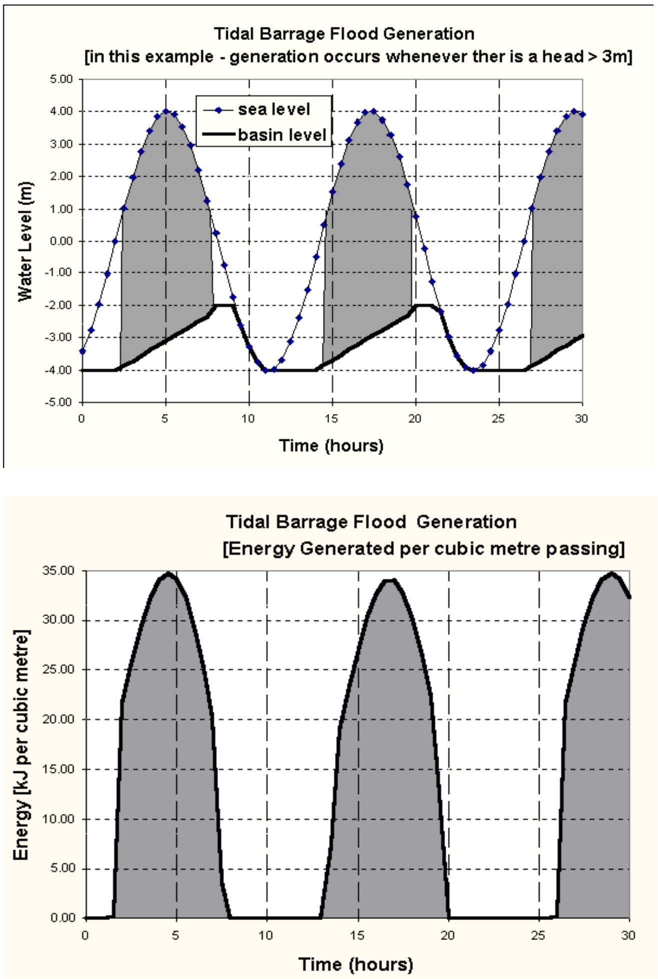


Fig. **17.2** Generation from Tidal Power in the FLOOD Generation Mode.

17.2.3 Two Way Generation Schemes

Two way generation on both **EBB and FLOOD**. This is a combination of the above methods (Fig. 17.3).

Generation is possible for more than 8 hours in any 12 hour cycle.

However, the total energy output is reduced as the mean height of the basin is at about mean sea level, and the effective head during generation is reduced. Also two way turbines are inherently less efficient.

Ports need relatively high water levels for shipping for at least part of the time and if, as with the Svern Barrage, there are several such ports, these would probably suffer.

The cost would be up to 20% greater than the equivalent single flow scheme.

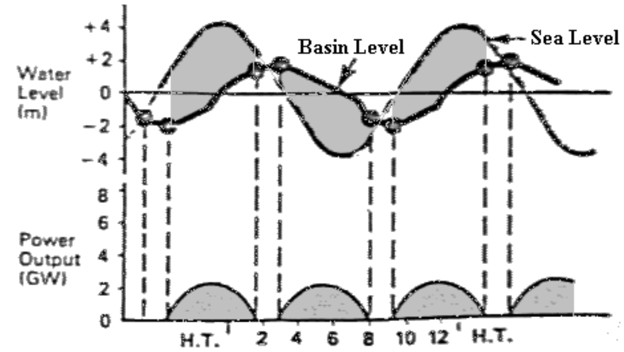


Fig. 17.3 Tidal Power - Generation on both flood and ebb. Although generation is available for a greater part of the diurnal cycle, the total amount generated is less than in EBB mode as the mean head difference during generation is lower.

17.2.4 Double Basin Schemes

In these there are two separate basins one which fills as the tide comes in, the other empties as the time goes out. Turbines connect the two pools, and can generate power at any time. Such a scheme was proposed as one variant for a Severn Barrage (see section 17.3). However the total output may be less than a single stage EBB scheme.

A variant is to incorporate additional pumps/turbines so that the schemes may also be used as a pumped storage scheme as well as generating electricity in their own right.

17.2.5 Tidal Barrages with Pumping

Pumping can be incorporated into any of the schemes so that the head may be artificially raised (or lowered) using energy imported from the grid. Thus in EBB generation, pumping could be done for about 1 hour after high tide through a relatively small head to increase the effective head during generation. It might be thought that such pumping does not make sense as any energy used for pumping will generally be more than that obtained from the extra head provided. But as will be seen in section 17.6 where discussing La Rance, such pumping can be particularly attractive and can lead to a net energy gain.

Pumping is usually always considered for double basin schemes.

17.2.6. Turbines used in barrage schemes.

All schemes involve low and variable heads with large flow rates. Kaplan or Bulb type turbines are thus the most suitable in all schemes.

17.3 Tidal Power - The Severn Barrage Schemes

Several schemes have been considered with a variety of locations for the barrage.

Generally the schemes that have been considered can be summarised as:-

- Fig. 17.4 a single basin scheme with EBB, FLOOD or two way generatiom with the barrier between Barry and Weston Super Mare
- A Double bais schemee (Fig. 17.5) with the lower basisn following the Somerset coast.
- A single, but larger seaward barrage between Minehead and a point west of Barry.

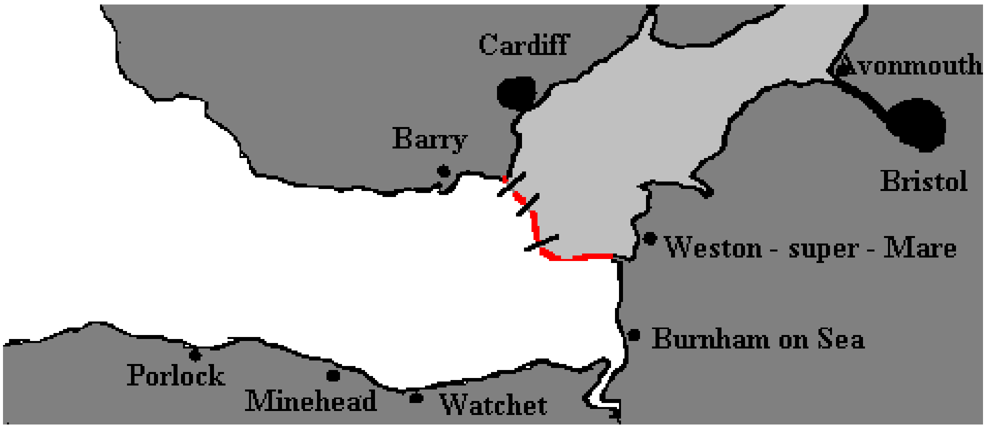


Fig. 17.4 A proposed single basin scheme

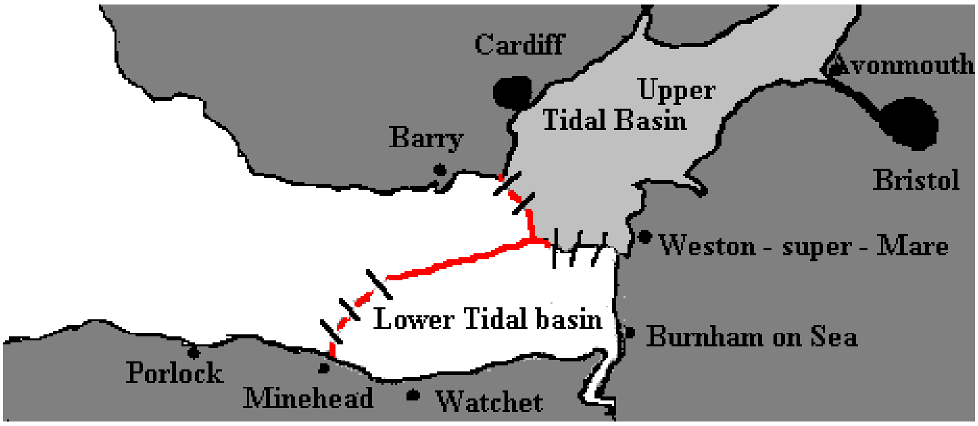


Fig. 17.5 A proposed double basin scheme. The upper basin would be filled at high tide, the lower one emptied at low tide.

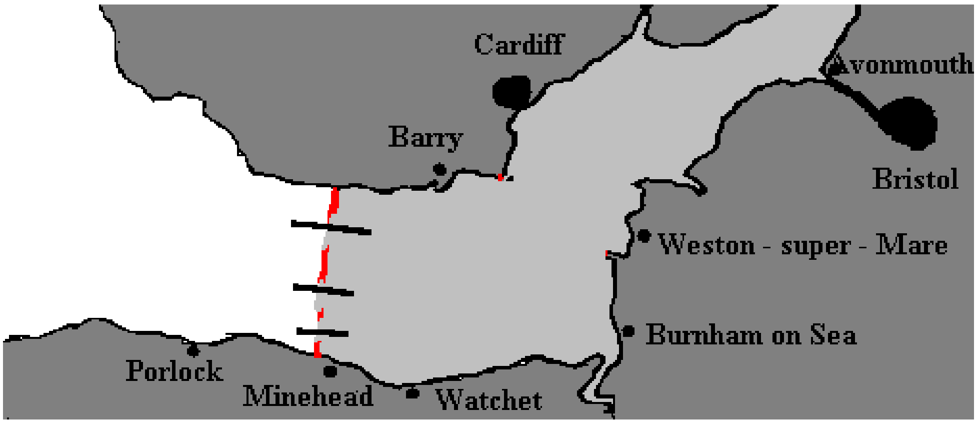


Fig. 17.6 A proposed single basis scheme. This is largest of all and would generate about 12000 MW.

After an extensive review, the Bondi Committee considered that the EBB only schemes without pumped storage were the most cost effective, and proposed three schemes:-

a) A seaward barrage near Minehead which would have an installed capacity of 12000 MW (i.e. 24% of current installed capacity, and would generated about 9% of the needs of England and Wales (Fig. 17.6).

b) An inner barrage just seaward of Cardiff which would have an installed capacity of 7200 MW (Fig. 17.4).

c) A staged scheme involving scheme (b) with the option to provide a second basin on the southern side of the estuary between Weston super Mare and Minehead.

The Bondi Committee favoured scheme (b).

Tidal Power from the Severn is predictable (unlike other renewables). However, there will be many occasions when the peak demand will occur when no power is available.

In the Bondi committee report it was estimated that an installed capacity of 7.2GW would only reduce the requirement for new fossil fuel / nuclear plant by about 1 GW because these plant would still be required to meet peak demand. Exepreince of La Rance scheme indicates that Load Factors of around 25% can be achieved – cf 20 – 40% for Wind turbines, depending on location. Tidal barrage schemes will save fossil fuel and reduce carbon emissions, but will not significantly reduce capacity requirement for new conventional stations unless pumped storage is incorporated [NKT's comment]..

17.4 Tidal Power - Some Environmental Considerations of Basin Schems.

There are several effects which such a scheme would have including:-

1) accessibility of shipping to existing Ports
2) employment - the Severn Barrage would provide jobs for about 21000 for up to 10 years.
3) large quantities of concrete will be needed and the materials for this and the earth fill barrage will have to be shipped to site.
4) water quality in the estuary might be affected if pollutants are not dispersed so readily.
5) recreation facilities could be provided in the basin.
6) extra pumping would be needed for land drainage.
7) sea defences would be less vulnerable to attack.
8) reduced sediment transport might lead to siltation behind barrage - however, by allowing flushing during summer (or periods of low demand), much of the impact of this can be reduced more easily than for hydro schemes,.
9) some species of birds would decline (especially wading birds), but other species would probably increase. However, with the double basin scheme it is likely that the habitat for wading birds would increase.

17.5 Tidal Power - other considerations of basin schemes.

EBB generation tidal schemes would NOT increase the requirement for pumped storage schemes unless there is a high proportion of nuclear plant or if the proportion of fossil fired stations is low, or the proportion of other renewables is high.

Fossil fired plant would be used to provide firm power at times of demand with no tidal power available. However, if these stations are displaced by large numbers of other renewable resources, then the need for extra storage would increase.

During the 1980s, the CEGB were interested in Private money being spent on Tidal Schemes as large sums of money would be required - four times the capital cost of Sizewell. However, the former CEGB would NOT give a guarantee that they will purchase all or even ANY of the power at a fixed price. This makes the economics difficult to evaluate. In the new regime following privatisation, it would be even more difficult to guarantee a a purchase price unless there was legislation.

The National Grid would argue that once sources of power are available (i.e. stations constructed) the decision to use power from that source is based solely on the marginal costs (including any subsidy (e.g. NFFO), and not the capital costs. Unless there is an agreed price (as there was originally for wind under NFFO) the viability for tidal is less certain if large schemes go ahead. On other hand smaller schemes such as the Mersey might well be more viable.

Double basin schemes have an advantage in that they can enhance the storage opportunity through additional pumped storage. This aspect is not taken into account in financial considerations. Since extensive renewable energy development would necessarily lead to an increase demand for pumped storage, such an additional facility could be an added benefit and should be treated as a net economic benefit for the whole Electricity Supply System. This needs central coordination and planning to achieve..

If a double basin scheme were built, there could be further advantages by combining wind turbine generation at the site with generation as an integrated package, rather than allowing renewables to compete one with another.

17.6 La Rance scheme

The "La Rance Tidal Barrage" is situated a few kilometres upstream from St Malo at a location where the tidal range is 13.5m during Spring Tides. The enclosed basin has an area of 2200 hectares and the barrage was completed in the late 1960s. the barrage itself is 750m long and the foundations are 13 m below mean French Ordnance Datum. The barrage incorporates shipping locks and provides a dual carriageway link between St Malo and Dinard.

There are 24 units each with a maximum generation of 10 MW generating at 3500 volts which is stepped up to 225 kV for the French SuperGrid. The turbines are 4-bladed Kaplan Bulb turbines with a diameter of 5.35 m with output as follows.

TABLE 17.1 Output Power per unit for different head differences at La Rance.

	Head			
	> 9m	**7m**	**5m**	**3m**
Ebb Flow	**10**	**10**	**8**	**3.2**
Flood Flow	**10**	**9.5**	**5.5**	**2**

The generation is thus greatest in the EBB generation mode.

The barrage can operate in a one way mode, although EBB flow generation is only normally considered, or on two way flow. Overall, the output in recent years indicates a load factor of around 25%, which is higher than the 16 - 17% several text book imply.

In one way operation the sluice gates are opened on the incoming tide to fill the basin and then closed at high tide. As the tidal cycle is sinusoidal, the fall in level from high tide is relatively small in the first 3 hours, and no generation takes place. Generation will continue beyond low water as the head will still be sufficient for generation for up to 90 minutes after low water (Fig. 18.7).

A variant of the scheme is to pump water for a period of about 1 hour after high water into the basin. Though this introduces inefficiency (~85% efficient) the head difference is small and generation can later take place over a greater head and hence this pumping arrangement is a net energy producer. Electricity for pumping is drawn from the grid, and clearly if this coincides with peak demand, no pumping will be done on that tidal cycle (Fig. 17.7).

The Two way operation which is used from time to time starts with the basin emptied with the sluice gates closed. When the tide has risen sufficiently (usually about 4 hours after low water, generation in the flood mode can occur for up to 1.75 hours. The turbines are stopped and the sluice gates opened to allow the basin to fill - with pumping if relevant. The sluice gates are closed at high tide, and generation on the Ebb tide then takes place as before except that generations ceases at low tie to allow the sluice gates to be opened to empty the basin. In theory pumping to empty the basin is possible, but cavitation problems may prevent this as the turbines must always be completely covered with water. The cycle then resumes.

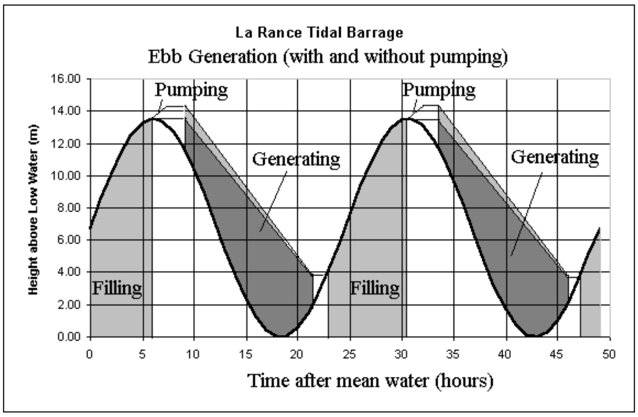


Fig. 17.7 One way operation of La Rance – incorporating optional pumping. Additional output can be obtained by overfilling basin at high tide. The head difference during pumping is less than that in generation, and hence there is a net gain in the system.

In two way operation, the basin does not rise to the same level as in single way operation as the turbines form a restriction to the incoming tide. As a result, the two way generation usually provides less electricity, but the generation period is more uniformly spread over the diurnal cycle. Assume that the tidal cycle is exactly 12 hours.

17.7 Marine Current Devices

There are several regions around the coast of the UK where significant currents exists. Often these occur in narrow straits between islands – e.g. Eynhallow Sound between Mainland Orkney and Rousay, in the Fall of Warness near Eday (Orkney), the Pentland Firth, and between Cap de la Hague and Aldernay. Barrages are costly to build and several people believe they are environmentally undesirable. It is possible, in theory to construct marine current turbines which are like underwater wind turbines to harness power from the currents. Typical sizes will be 0.5 – 2MW and individual or clusters of devices can be installed. The strong currents and corrosion do mean that technical developments are still needed and the technology is probably 20 years + behind that of wind. A further issue is that there are already significant problems in gaining access to offshore wind turbines for maintenance and at Scroby Sands for instance – access is only possible on 60% of days. For underwater turbines – the maintenan ce issues will be increased although it is usually planned that the turbine can be jacked up above water level for maintenance.. A single demosntration scheme of 750 kW has been operating off Cornwall. Fig 17.8 is an illustration of what a tidal turbine device might look like.

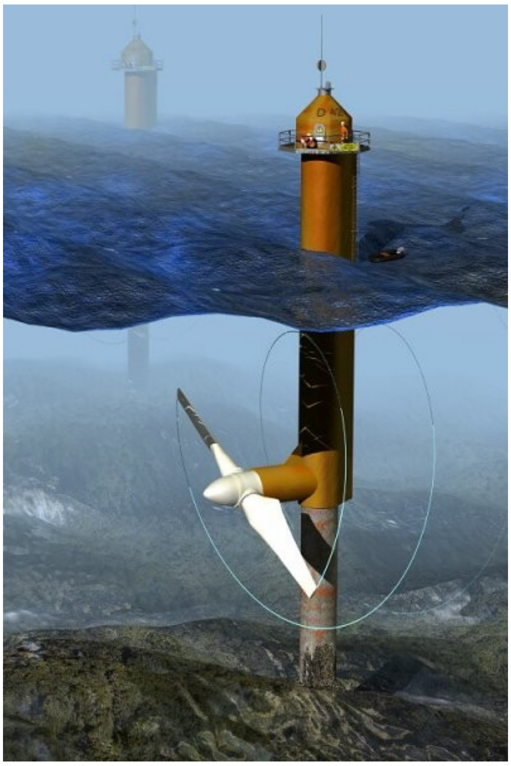


Fig. 17.8 Underwater Marine Current Turbine

Fig. 17.9 Open Hydro Marine Current device – the first grid connected tidal stream device at time of installation in Fall of Warness, Orkney

The EMEC Centre in Orkney has a test site at the Fall of Warness, and it is hoped to fully commission this in mid – late 2007 with direct Grid connection (Fig. 17.9).. All tidal turbines are very much experimental at the present time and if successful, and if the costs could be brought down, then full scale commercial exploitation might be possible in around 10 years time or so – i.e around 2020, although several small pre-commerical sites might be in operation by 2015..

Other devices are being tested in wave tanks such as the floating Scot-Renewables device (Fig. 17.10) prior to testing in actual sea condition. .A further conceptual idea is to mount turbines on the sea bed in strong current areas such as the Pentland Firth, (Fig. 17.11), but such devices will face severe anchoring problems.

Fig. 17.10. Scot-Renewables floating tidal device – shown in operation mode and also survival mode.

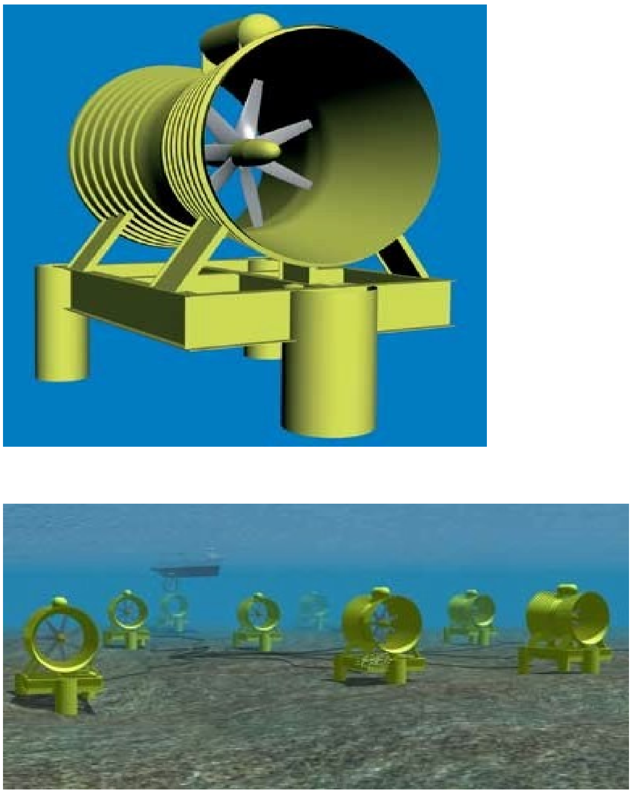


Fig. 17.11 Concept of a sea bed maounted device

The formula to estimate the power from a marine turbine will be exactly the same as for a wind turbine:-

$$\frac{1}{2}\eta\pi\rho\mathbf{R}^2\mathbf{V}^3$$

where η is the efficiency (typically around 40% for the best machines)

ρ is the density of sea water which may be taken as 1070 kg m-3

R is the radius of the area swept

V is the wind velocity.

Typically the diameter of the blades should not be more than 50% of the water depth and it makes sense to have all turbines in an area of the same diameter. That means the size will be dictated by the minimum depth of water where the turbines are to be installed. The density of sea water is nearly 1000 times that of air, and so even though the velocity is much less, significant output is potentially obtainable from devices with blade diameters from about 10 m upwards. For a 0.5 MW device a blade diameter of around 20m is required in a current of 2 m s^{-1}, whereas for a windturbine of equivalent output a 40 m blade diameter with a wind speed of 12 m $^{s-1}$ is required.

Because the current speeds are relatively low (in normal generation terms), it would not make sense to attempt to generated in synchronism with the mains. Instead consideration is likely to be given to generating with DC and then inverting to AC when the power comes ashore.

Marine Current Turbines will have to work in a harsh environment and technical problems such as offshore and underwater maintenance still need to be addressed.

17.8 Tidal Lagoons.

A relatively recent development in Tidal Power has been the development of the Tidal Lagoon principle. Unlike the Tidal barrage, for which there is already a full scale operational device at La Rance, and several individual tidal stream devices, there is no operating Tidal Lagoon scheme. Whi8le the Tidal Lagoon does offer a considerable potential it has yet to be tested, and unlike the tidal stream devices which can be constructed in modular form, the lagoon requires the construction of very large devices which will not only be a long time in construction, but also have significant initial investments in embodied energy and associate carbon in the construction phase. While in the long term there will be a significant saving tin carbon, the initial heavy carbon outlay is an issue which must be addressed, and may require a significant phasing (and consequential limit on the rate of deployment) of such schemes if there is not to be a significant increase and overshoot in carbon emissions in the criticval period between now ond 2025.

A tidal lagoon requires the construction of a large barrier to enclose a large tidal area. Unlike a barrage this is not connected to land, and is located in relatively shallow areas in tidal esturaries such as in Swansea Bay in the Severn Esturary.

A barrier some 90 miles long would be constructed with the requirement of some 200 million tonnes of aggregate. This would create an artifical basin from which both flood and ebb generation is possible (probably supported by pumping).

It is probable that the lagoon wmight be built in stages, but until a complete section is isolated from the main estuary, no generation can take place and this is a disadvantage compared to tidal stream edevices. A normal tidal barrage would require only around 7 – 10% of the amount of aggregate, and this should be somewhat quicker to construct and start recover the benefits.

It is claimed that a laod factor of 61% might be achieved, which is high for renewable generation, although experience with other technologies suggests that such levels are unlikely to be achieved in the early schemes. However, if it does then there could be significant advantages.

Perhaps the best aspects of such lagoons is, like the double basin scheme for barriers the potential ability to provide a level of pumped storage, particularly if multiple basins schemes are used.

17.10 Consultation on Severn Tidal Schemes January – April 2009

In January 2009, the new Department of Energy and Climate Change launched an extensive public consultation relating to several different proposed schemes for extracting energy from the tides in the Severn Estuary. The consultation may be consulated at:

http://severntidalpowerconsultation.decc.gov.uk/

Essentially there are 5 separate barrage schemes, several lagoons, some of which are connected to land, and two tidal fence schemes. These are summarised in the following:

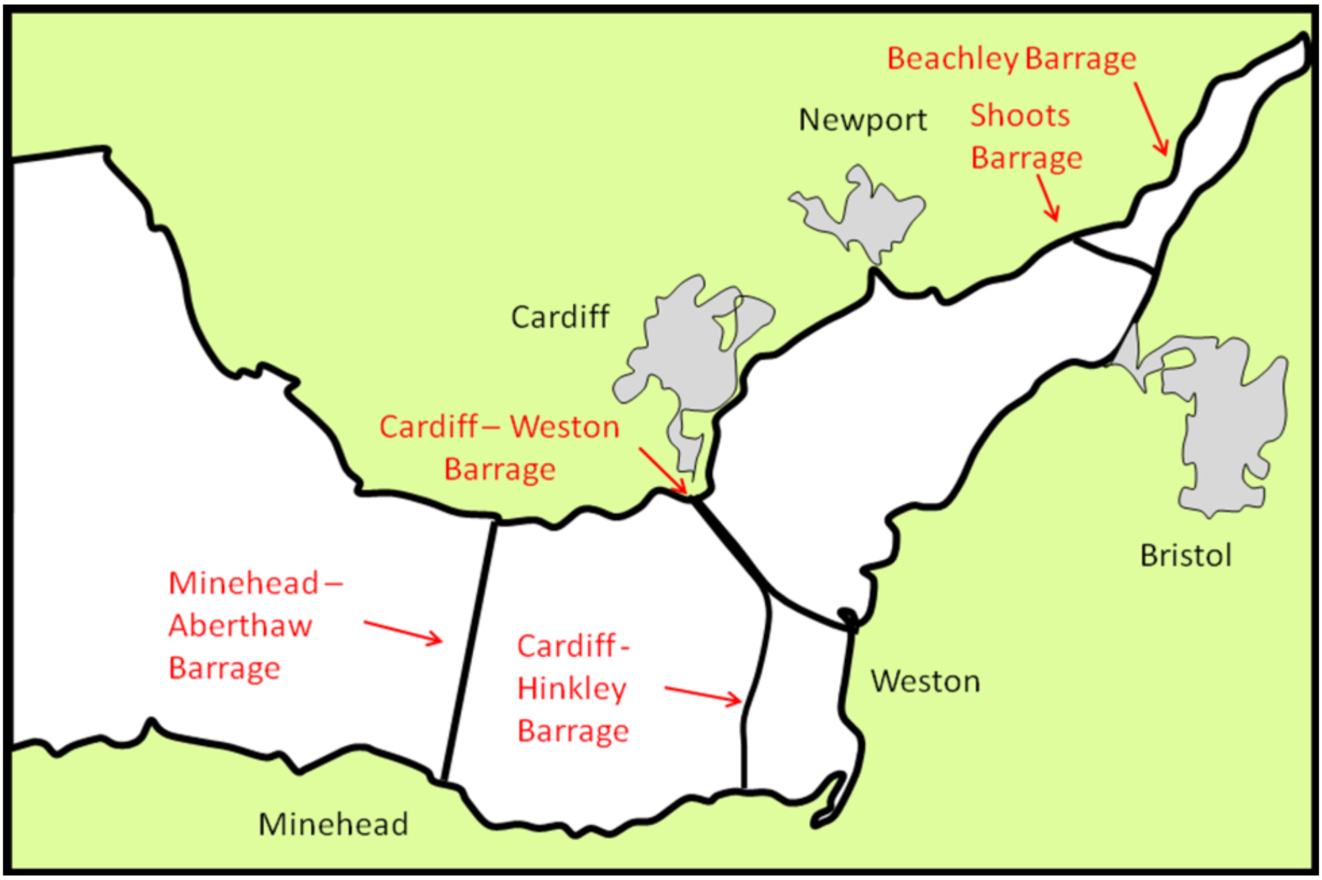


Fig. 17.8 Proposed Barrier schemes in the 2009 consultation

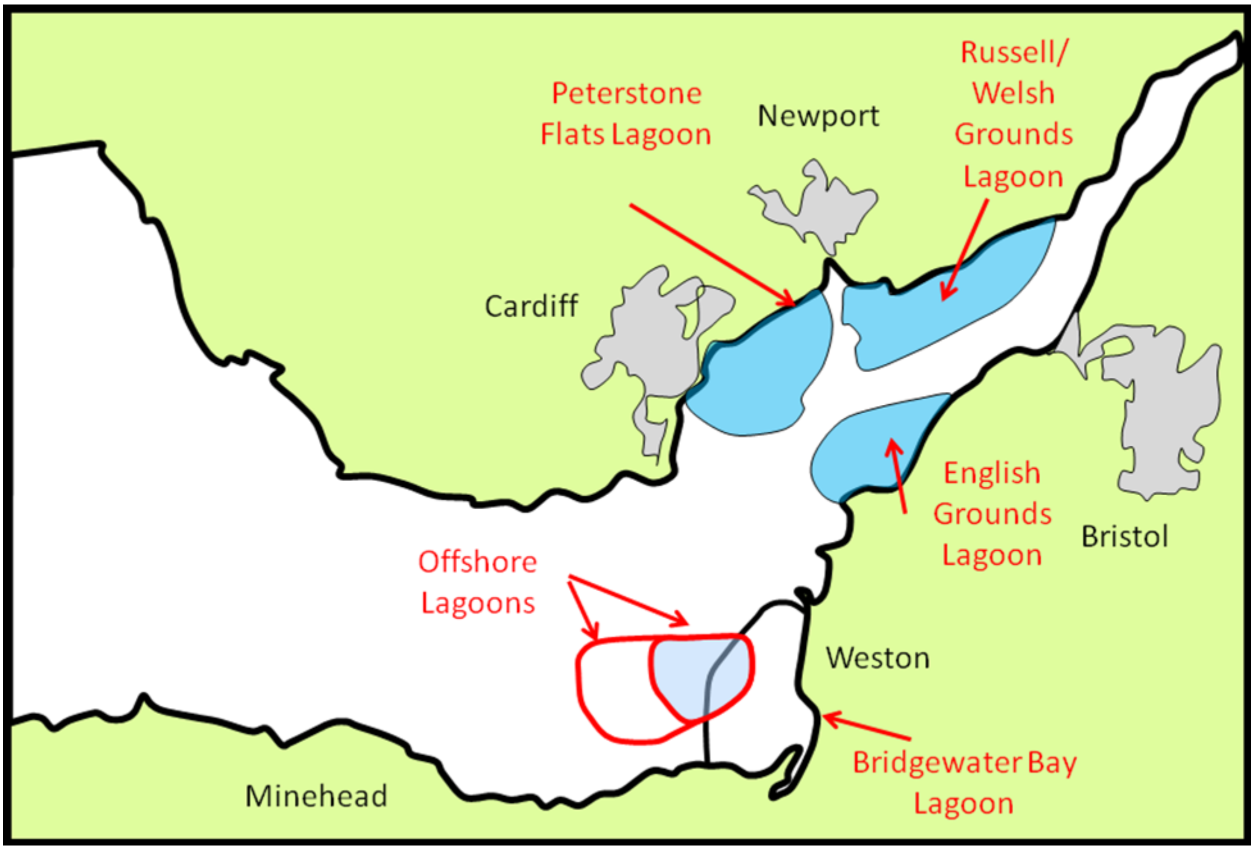


Fig. 17.9 Proposed Lagoon schemes in the 2009 consultation

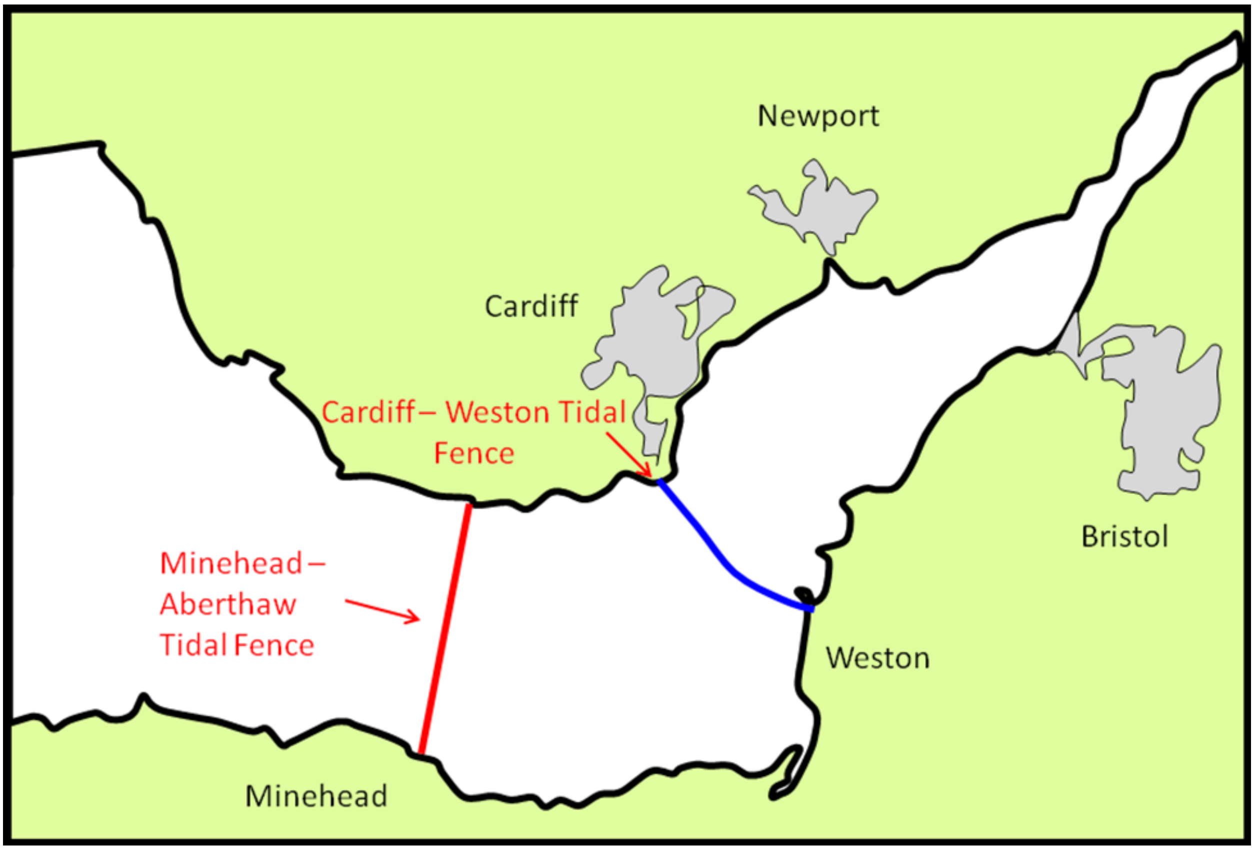


Fig. 7.10 Proposed Tidal Fence Schemes in the 2009 consultations.

Comparison of different schmes

		Installed capacity	Annual Generation	Earliest operation	capital cost	Cost per unit
		MW	TWh		£bn	p/kWh
B1	**Outer Barrage from Minehead to Aberthaw**	**14800**	**25.3**	**2022**	**29**	**7.3**
B2	**Middle Barrage from Hinkley to Lavernock Point**	**~9950**	**19.3**	**2021**	**21.9**	**7.82**
B3	**Middle Barrage (Cardiff - Weston)**	**8640**	**16.8**	**2020**	**18.3**	**7.39**
B4	**Inner Barrage (Shoots Barrage)**	**1050**	**2.77**	**2019**	**2.6**	**6.69**
B5	**Beachley Barrage**	**625**	**1.59**	**2018**	**1.8**	**8.21**
F1a	**Tidal Fence (Cardiff - Weston)**		**0.7**	**?**	**4.4**	**40.47**
F1b	**Tidal Fence (Minehead -Aberthaw)**		**3.3**		**6.3**	**14.33**
L3a	**English Grounds Tidal Lagoon**		**1.41**	**2018**	**3.1**	**11.35**
L3b	**Welsh Grounds Tidal Lagoon**	**1360**	**2.31**	**2019**	**2.6**	**11.27**
L3c	**Peterstone Flats**	**1120**	**2.33**	**2019**	**3.3**	**9.03**
L3d	**Bridgewater Bay**	**1360**	**2.64**	**2020**	**3**	**8.29**
L3e(i)	**Offshore Tidal Lagoon 1**	**1360**	**2.6**	**2020**	**5.8**	**12.86**
L3e(ii)	**Offshore Tidal Lagoon 2**	**760**	**1.32**	**2019**	**3.5**	**15.05**

- **Tidal Fences are unknown technology so uncertainty over operation date.**
- **For comparison Sizewell B generates ~8.0 TWh per annum.**
- **Data do not consider potential advantages of double barrier scheme with pumped storage – something which will be needed with more renewables**

NOTES:

- **In 1979, construction of Dinorwig Pumped Storage Power station (1800 MW) was started and cost £0.45bn**
- **Compared to January 1979, the RPI in Jan 2009 was 399.89, i.e. prices were 4 times those in 1979. Thus the cost of similar station today would be £1.8bn or £1m per installed MW.**
- **If 50% of capacity were available as pumped storage, the Minehead – Aberthaw basin if made a double basin would provide same capabilities as spending £7bn elsewhere on alternative pumped storage and is thus a net benefit to the scheme.**
- **Such additional spending will be needed in future with increased renewable generation such as wind**
- **A holistic approach is needed**

See http://www.independent.co.uk/opinion/letters/letters-tidal-power-1517932.html

- **Public Consultation on Severn Tidal Schemes is currently open – until 23rd April 2009.**
-
- **Have your say!**
- **See http://severntidalpowerconsultation.decc.gov.uk/ Where more details of schemes may be found**

17.10 Numeric Example of a Tidal Barriers.

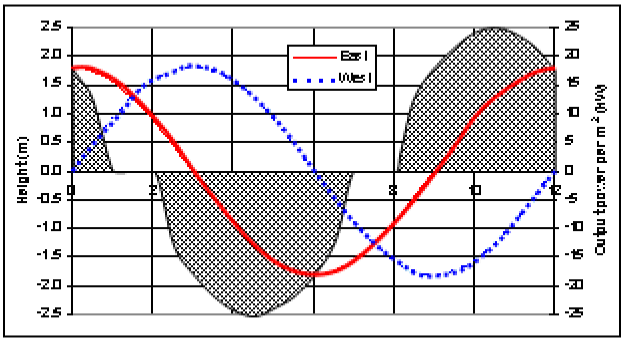
Three numeric questions have been set in examinations relating to Tidal Barriers, and in addition the Field Courses in 1999, 2001 had exercises relating to tidal stream generation in the Race of Aldernay, while in 2005, and 2007, barrier and tidal streams in Orkney wefre examined.

17.11 Example of a Tidal Barrage – e.g. Churchill Barrier.

A man made causeway is built joining two islands. After construction it is found that there high tide on the east is 3 hours before high tide on the west.

The tidal heights are shown in the following table and graph

Time relative to east side (hrs)	*Height on east side (m)*	*Height on west side (mj)*
0	*1.80*	*0.00*
1	*1.56*	*0.90*
2	*0.90*	*1.56*
3	*0.00*	*1.80*
4	*-0.90*	*1.56*
5	*-1.56*	*0.90*
6	*-1.80*	*0.00*
7	*-1.56*	*-0.90*
8	*-0.90*	*-1.56*
9	*0.00*	*-1.80*
10	*0.90*	*-1.56*
11	*1.56*	*-0.90*
12	*1.80*	*0.00*
13	*1.56*	*0.90*



. The shaded area shows the output for each cubic metre flowing through the turbine [thisshaded area is shown for information only]..

Estimate the daily electricity production and the mean power produced if a turbine with a diameter of 4047mm is inserted into the causeway. Power can be extracted whenever the height difference between the two sides of the barrier exceeds 0.9mThe density of sea water is 1070 kg m^{-3}, and the efficiency of the turbines is 80%.

First work out the height difference in column 4 and then the effective height in column 5. Whenever the height is less than the critical 0.9m there is no generation available. The shaded columns are direct copies from the data. Notice the data are symmetric and many values are the same value (or same value but opposite sign)

Time relative to east	Height east	Height west	Height differ-ence	Effective Height	Velocity	Cube of velocity
	(m)	(m)	(m)	(m)	(m/s)	
0	1.80	0.00	1.80	1.80	5.94	209.87
1	1.56	0.90	0.66	0.00	0.00	0.00
2	0.90	1.56	-0.66	0.00	0.00	0.00
3	0.00	1.80	-1.80	-1.80	5.94	209.87
4	-0.90	1.56	-2.46	-2.46	6.95	335.08
5	-1.56	0.90	-2.46	-2.46	6.95	335.08
6	-1.80	0.00	-1.80	-1.80	5.94	209.87
7	-1.56	-0.90	-0.66	0.00	0.00	0.00
8	-0.90	-1.56	0.66	0.00	0.00	0.00
9	0.00	-1.80	1.80	1.80	5.94	209.87
10	0.90	-1.56	2.46	2.46	6.95	335.08
11	1.56	-0.90	2.46	2.46	6.95	335.08
12	1.80	0.00	1.80	1.80	5.94	209.87
					Σ	**2179.8**

Now water flowing through turbine, must be consistent.

i.e potential energy of head difference = kinetic energy flowing thorugh turbines

i.e. mgh = 0.5 m V^2

or V = sqrt(2 g h)

where g is the acceleration due to gravity = 9.81 m s^{-1}

Hence enter the values of velocity as computed in the manner outlined above in column 6. Notice you should disregard the –ve sign in these calculation as this merely implies two way flow. This will be the velocity of the water through the turbine.

Now by continuity

the mass passing per second = density x volume
= density x velocity x cross section area
= ρ V πR^2

and kinetic energy = 0.5 m V^2 multiplied by efficiency

so energy available = 0.5 η ρ V $\pi R^2 V^2$ = 0.5 $\eta \rho \pi R^2 V^3$

substituting values for η, ρ, and R

gives the theoretical energy at any instant = 5505.09 V^3

(remember that density of SEA water is 1070 kg m^{-3}).

Alternatively the energy available in a day will be
2 x 5505.09 x ΣV^3
[the factor 2 comes from two tidal cycles per day)

Thus to find total energy work out V^3 and enter values in column 7 and sum

total energy will thus be 2 * 5505.1 *2179.8 /1000/1000 MWh per day.

= 24.00 MWh per day

and the rated output of the turbine will be 24.00/24 = **1MW**

17.12 Tidal Power Example: based on Question 8, ENV 258 (1991).

Several different schemes have been suggested for the extraction of energy from tides in the Severn Estuary. Briefly describe them giving the advantages and disadvantages of each.

The height (h) of the water level above mean sea level in the Rance Estuary in Northern France may be approximately found from the relationship:-

$$\mathbf{h = 0.5\,d}\cos\left(\frac{\mathbf{360\,t}}{\mathbf{p}}\right)$$

where t is the time in hours after high tide,
d is the range (maximum-minimum) of the tide = 9m,
and p is the period between high tides (12.5 hours in this case).

Generation of electricity takes place whenever there is a head difference of 2.089m or more, and continues until the level of water in the basin falls to 0.779m below mean sea level. The turbines have an efficiency of 60%. You may assume that the density of water is 1000 kg/m^3.

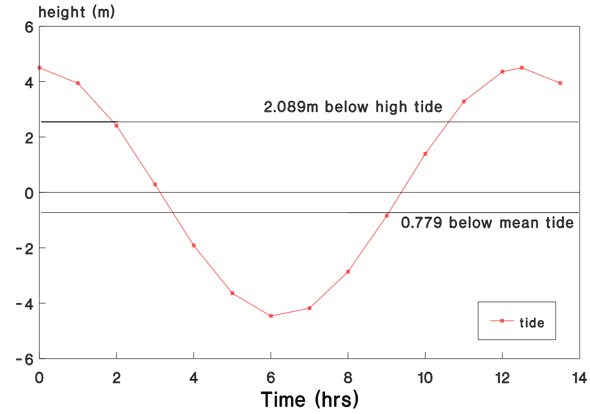
Estimate how long generation can continue during each tidal cycle. Estimate also the mean output from the power station if a total of 108.73 x 10^6 m^3 of water pass through the turbines during generation.

SOLUTION:

First use the equation to work out the height of the tide at each hour from 0 up to 12.5 hours. It is only necessary to do this once an hour:

HOUR	HEIGHT (m)	HOUR	HEIGHT (m)
0	4.500	7	-4.184
1	3.943	9	-0.843
2	2.411	10	1.391
3	0.283	11	3.280
4	-1.916	12	4.359
5	-3.641	13	4.359
6	-4.465		

Now plot a graph with the time as the x-axis.



ENV 258 Question 8 (1991)

Now draw on lines which are 2.089m below high tide (representing start of generation), and 0.779m below mean tide (representing the end of generation.

The start coincides exactly with the 2 hour point. This can be checked as at two hours the difference from high tide is 4.5 - 2.411 = 2.089m).

Similarly the generation ceases when the level is 0.779m below mean tide, but the head of 2.089 must still be maintained. So the level of the tide when generation ceases will be:-

-0.779 - 2.089 = - 2.868 i.e. exactly the height after 8 hours.

So generation will occur for 8 - 2 = 6 hours (answer to first part).

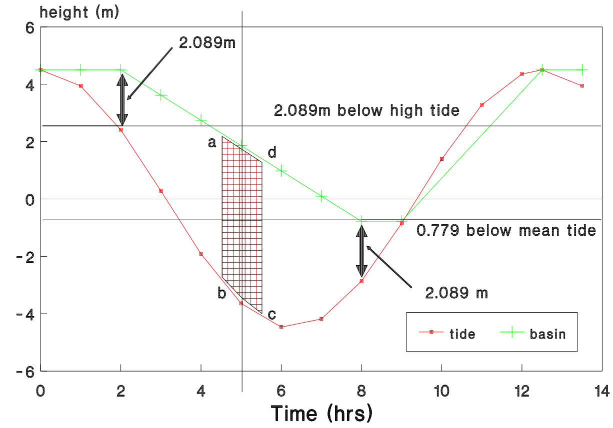
======

There are now two ways to proceed for the second part:-

Method 1: Graphical Method

Plot on the basin level assuming a linear decline from the start to the end of generation.

Then measure off at each hour the height difference between the basin level and the tide as shown in the following table:-



ENV 258 Question 8 (1991)

HOUR	HEIGHT	HEAD
0	4.500	no generation
1	3.943	no generation
2	2.411	2.089
3	0.283	3.337
4	-1.916	4.656
5	-3.641	5.502
6	-4.465	5.446
7	-4.184	4.285
8	-2.868	2.089
9	-0.843	no generation
10	1.391	no generation
11	3.280	no generation
12	4.359	no generation
13	4.359	no generation

This method continues after the Numeric Method

NUMERIC METHOD

It is not difficult to linearly interpolate to get the height of the basin at any hour between the start and end of generation as shown in the table below. Once this has been found it is a simple matter to subtract the tide level from the basin level to get the effective head.

HOUR	HEIGHT	BASIN	HEAD
0	4.500	4.500	no generation
1	3.943	4.500	no generation
2	2.411	2.089	2.089
3	0.283	3.620	3.337
4	-1.916	2.740	4.656
5	-3.641	1.861	5.502
6	-4.465	0.981	5.446
7	-4.184	0.101	4.285
8	-2.868	-0.779	2.089
9	-0.843		no generation
10	1.391		no generation
11	3.280		no generation
12	4.359		no generation
13	4.359		no generation

BOTH METHODS

The figures in the final columns for both methods are the same.

The energy generated at any one instant is ...... m.g.h

To find out the MEAN OUTPUT we need to find the mean head over the period.

There is a small catch here:-

For the shaded area we can take the approximation that the head is that for 5 hours, similarly for 4 hours and 6 hours etc. But for both 2 hours and 8 hours, the generation is for only half the time, so the mean generation height is given by:-

$$= \frac{0.5 \times 2.089 + 3.337 + 4.656 + 5.502 + 5.446 + 4.285 + 0.5 \times 2.089}{6}$$

$$= 4.219 \text{ m}$$

The time interval is 6 x 3600 seconds

$$\textbf{So mean output} = \frac{\overset{\text{volume}}{108.73 \times 10^{6}} \times \overset{\text{density of water}}{1000} \times 9.81 \times 4.219}{6 \times 3600}$$

$$= \underline{\underline{125 \text{ MW}}}$$

So mean output is 125 MW