Energy Resources and Policy
Handout:
Tidal barrage

1. The energy source

Around the coastlines of the world, sea levels rise and fall due to the gravitational attraction of the moon and the sun. The moon exerts the major influence: its rotational period about the earth is about 4 weeks and this, combined with the earth's own daily rotation results in a period for the tidal cycle of about 12.5 hours. The tidal range (the overall variation in water level during the cycle) is at its maximum when the gravitational pull of the moon is augmented by that of the sun: a Spring tide, coinciding with a new moon or full moon. The minimum range, when sun and moon are working against each other, is called a Neap tide. This cycle of spring and neap tides therefore has roughly a monthly period. Further variations in tidal range are caused by the fact that the orbits of the moon around the earth, and the earth around the sun, are elliptical and in slightly different planes. However, these motions are well determined and the timing and range of tidal movements around the world is predictable to a high level of accuracy - unusually for a renewable energy source. The only uncertainty concerns local weather patterns, which can produce abnormally high (or low) tides from time to time.

It is the gradient of the gravitational field which creates differences in sea level: Figure 1 shows this in an exaggerated form. The magnitude and direction of local gravitational forces are indicated by the large vectors. If the mean force is subtracted, local relative effects may be seen (the shorter, fainter vectors). The sea level responds accordingly.

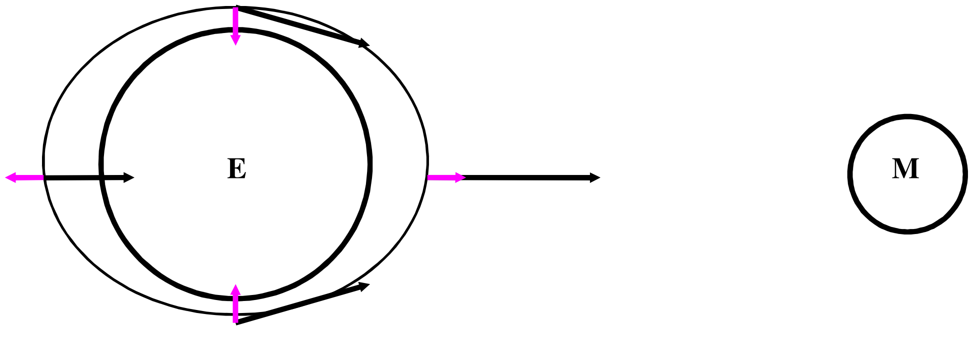

Figure 1: Gradient of moon's gravitational field, and its effect on the earth's oceans.

If the world were completely covered by water, tidal effects would be quite small, with a range of about 0.5m. It is the presence of land masses which channel the water movements and give rise to much larger local ranges. But promising sites (where the mean range exceeds say 5m) are not very numerous, and are unevenly distributed around the world (Figure 2). Enclosed areas of water, such as the Mediterranean, Baltic or Black Seas tend to have negligible tidal effects.

2. Exploitation: tidal barrage systems

An area of coastal water, previously open to the sea, is trapped by the construction of a dam or barrage. Gates are included in the barrage to allow free passage of water when required and other openings contain turbines for the generation of electrical power. The operating strategy for the system and the timing of the opening and closing of gates must be carefully planned to maximise energy capture.

Power generation may be during inflow to the basin, during outflow, or both. The most commonly adopted procedure is to generate on outflow (Figure 3), with the possibility of using pumping briefly at the end of the inflow period to increase the quantity of energy produced.

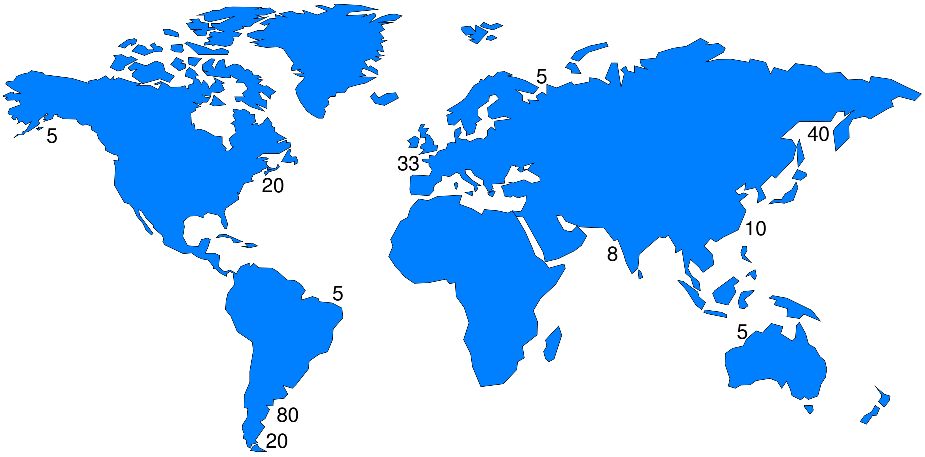

Figure 2: World tidal energy resources, exploitable at reasonable cost, in GW.

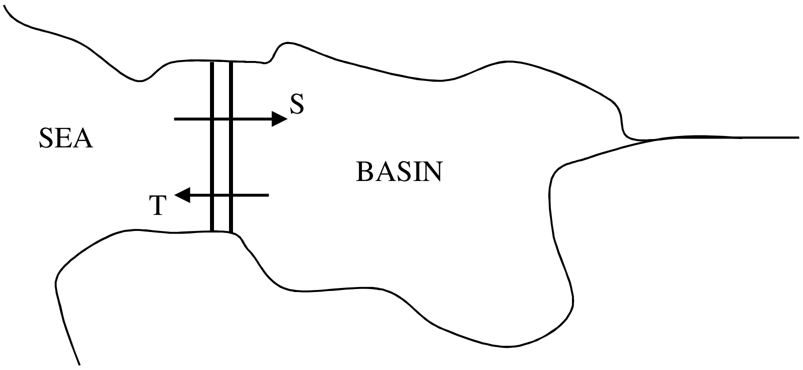

Figure 3: Single-effect tidal barrage scheme with sluice gates (S) and turbines (T).

A typical cycle of this type is shown in Figure 4. The rise and fall of the sea level outside the barrage is assumed to be sinusoidal. The basin level is initially held constant, and then allowed to fill. At high tide, the gates are closed, and the basin is isolated (solid line). The sea level falls, and when there is sufficient head differential, water is allowed to leave the basin through the turbines. After a time, the head differential becomes too small and power generation is terminated. All gates are closed, the basin level remains static and the cycle begins once more.

Pumping may be performed for a short time (dotted line), using electricity from the grid, to raise the level of the basin and increase the energy output during the power generation phase. The rise in head during pumping is small compared to the differential head during power generation, and so there is a net gain in energy capture despite the electrical, mechanical and hydraulic losses. The duration of pumping must be limited to avoid flooding in the basin region.

It will be seen that power is produced for less than 50% of the time, which may pose problems for the integration of large schemes into electrical networks. The construction of two or more basins linked together may produce a more uniform power flow, at the cost of some complexity.

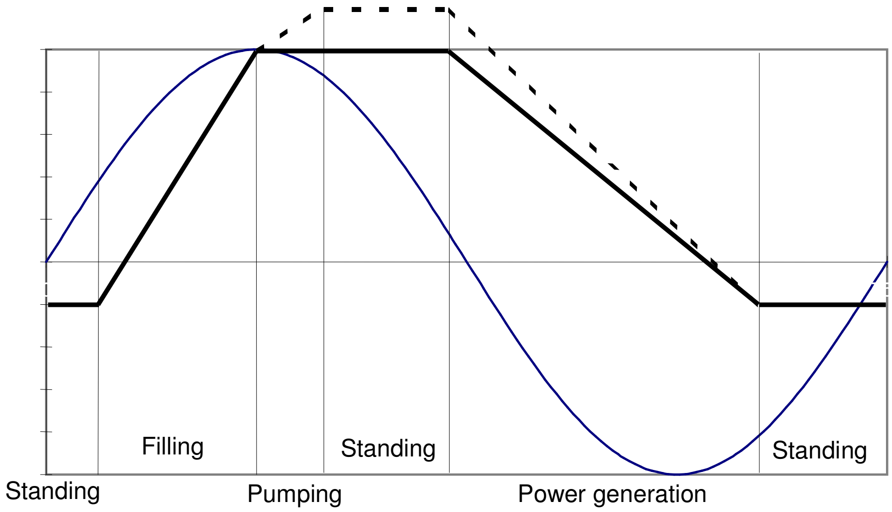

Figure 4: Variation with time of sea and basin levels for single-effect tidal barrage (power generation on outflow), with and without pumping.

The long period of the cycle permits the use of conventional low-head hydro-electric plant, typically horizontal-axis machines with bulb or rim generators. For local, low-output schemes more unusual designs have been proposed, but have not yet progressed beyond the laboratory stage.

Exploitation worldwide has been very limited: the most significant site is at La Rance on the French coast, with ten 24MW bulb turbines, which was built in the 1960's. A single 20MW unit is operating in Newfoundland, and there are a few much smaller demonstration plants around the world. A major difficulty appears to be the raising of capital for such large civil engineering projects, with several years of construction time before money begins to return to the investors.

3. Environmental aspects

Environmental impact is localised, but may be severe. At La Rance, the river estuary had to be blocked during part of the construction phase, and the ecosystem in the basin area collapsed, to recover to some extent once flow had resumed. Wildlife and ecology are the main concerns, with the possibility of silt and pollutants collecting in the basin. Interference with shipping is a problem for many schemes, and provision for passage through the barrage must be made. On the positive side, the barrage will create a sheltered area for leisure activities, and can be used as a road or rail link.

4. Analysis

If the rise and fall of the surface of the sea is assumed to be sinusoidal, then $z_1 = Z + a.\sin \omega t$ (see Figure 5). The motion of the free surface is deter-mined by

$$\frac{d z_2}{d t} = \frac{C_d A}{B} \sqrt{2 g (z_1 - z_2)}$$

where A and C_d are the cross-sectional area and discharge coefficient of the flow passage through the barrier and B is the basin surface area. When the flow is directed through a turbine, the power theoretically available at any given instant is

$$P = \rho g C_d A \sqrt{2 g (z_1 - z_2)}^3$$

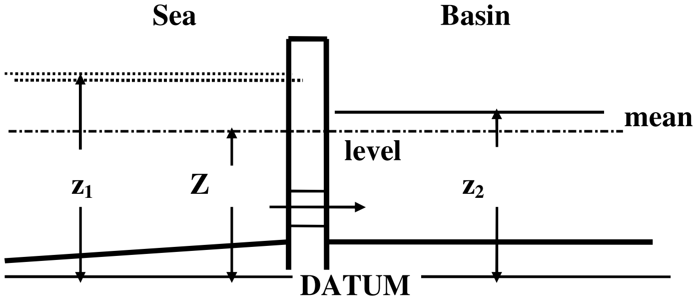

Figure 5: Cross-section through tidal barrage.

For any system, the energy extracted per cycle, E, depends upon the tidal range (2a), the basin area B and also ρ and g. Dimensional analysis produces an energy coefficient

$$\Phi_E = \frac{E}{(2a)^2 B \rho g}$$

for which the maximum achievable value seems to be about 0.2 with E measured in Joules.

Actual* and proposed tidal barrage schemes

Location	Mean tidal range (m)	Barrage length (km)	Basin area (km^2)	Turbines (no., dia.)	Capacity (MW)
*La Rance (France)	8.0	0.75	22	24, 5.4m	240
River Severn (UK)	7.2	16.3	1000	192, 9m	12000
Solway Firth (UK)	5.6	30	860	180, 9m	5580
Bay of Fundy (Newfoundland)	11.7	8	282	128, 8m	4865
Golfo San Jose (Argentina)	5.8	7	788	270, 8m	6000

5. Conclusions

On a global scale, tidal power can make only a small contribution to our needs, but locally, it can provide a large resource. It is unusual among renewable energy sources in being highly predictable. Barrage schemes use established technology and in a number of locations, costs compare favourably with conventional energy sources. However, the scale of investment required is very large (comparable with large hydro-electric schemes), and little progress is likely without government support. Environmental impact is localised but may be severe, and needs careful consideration.