TIDAL ENERGY

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INTRODUCTION

- Tidal energy is a form of hydropower that exploits the movement of water caused by tidal currents or the rise and fall in sea levels due to the tides.
- The tide moves a huge amount of water twice each day, and harnessing it could provide a great deal of energy.
- The tides are formed by the gravitational pull of the sun and moon on the oceans of the rotating earth.
- The moon exerts a larger gravitational force on the earth, though it is much smaller in mass, because it is a lot closer than the sun.
- This force of attraction causes the oceans, which make up 71% of the earth's surface, to bulge along an axis pointing towards the moon.
- The gravitational attraction of the sun also affects the tides similarly, but to a lesser degree.
- As well as bulging towards the moon, the oceans also bulge slightly towards the sun.

- The tides can be found with varying degrees of strength on any coastline, and sometimes even at sea, although these are better known as currents.
- The tidal power is reliable and predictable and can make a valuable contribution to electricity grid.
- For practical purposes, tidal energy can be considered a sustainable and renewable source of energy.
- Tidal electricity provides a good alternative to conventional methods of generating electricity, which would otherwise be generated by fossil fuels (coal, oil, natural gas) etc, thus reducing emissions of greenhouse and acid gases.


HISTORY OF TIDAL ENERGY

- Tidal energy is one of the oldest forms of energy used by human beings.
- During the Roman occupation of England, several tide mills were built in order to grind grain and corn. One such stone built tidal mill, dating back to 787 A.D., has been uncovered at the Nendrum Monastic Site on Mahee Island in Ireland.
- The Eling mill located near Southampton, England is an excellent tidal powered flour mill that has remained functional for over 900 years starting from 1086 A.D.

- Woodbridge tide mill in the Deben Estuary of Suffolk, England dates back to 1170 A.D.
- These tide mills consisted of a storage pond that was filled by the incoming flood tide through a sluice and emptied during the outgoing ebb tide through a water wheel.
- The tides turned waterwheels, producing mechanical power to mill grain.
- Large tidal water wheels were still in use for pumping sewage in Hamburg, Germany in 1880.
- The city of London used huge tidal wheels, installed under London Bridge in 1580, for 250 years to supply fresh water to the city.
- La Rance tidal power plant located in northern France is the world's first full scale tidal power plant running successfully since 1967, with 24 turbines, each capable of producing 10 MW of power.

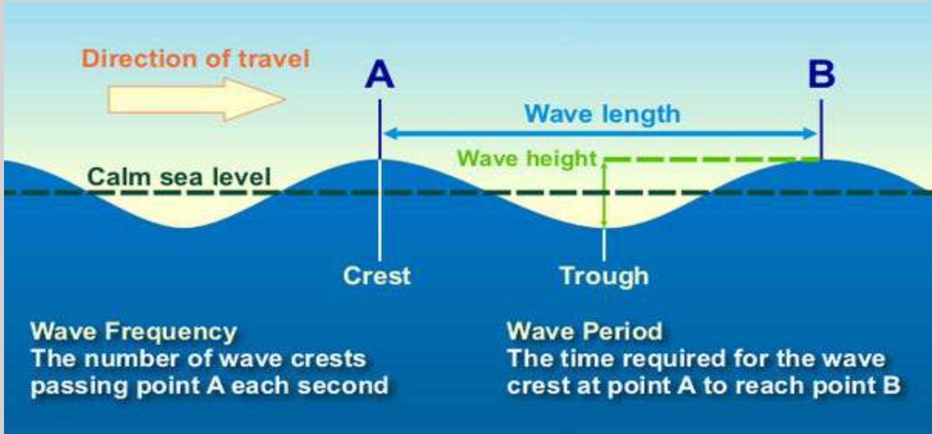


BASIC PRINCIPLES OF TIDES

- British physicist Issac Newton was the first to study the phenomenon of tides as follows:

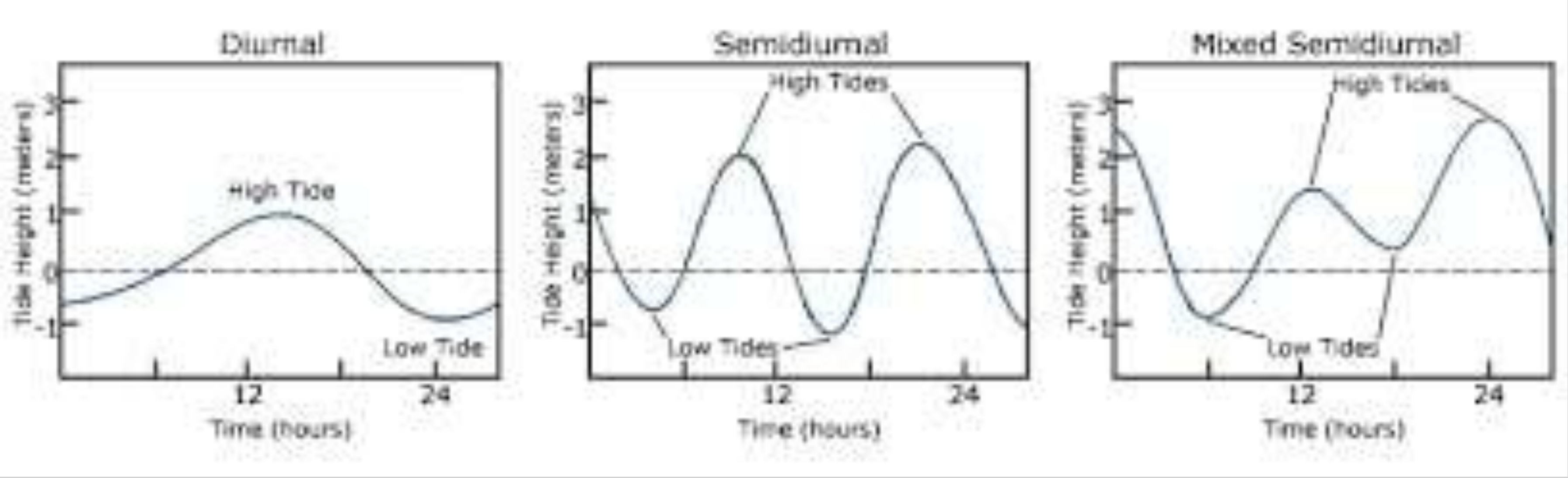
  The ocean must flow twice and ebb twice each day, and the highest water occurs at the third hour after the approach of the luminaries to the meridian of the place.

- Tides are very long-period waves that move through the oceans in response to the forces exerted by the moon and sun.
- Tides originate in the oceans and progress toward the coastlines where they appear as the regular rise and fall of the sea surface.
- When the highest part (crest) of the wave reaches a particular location, high tide occurs; low tide corresponds to the lowest part (trough) of the wave.
- The difference in height between the high tide and the low tide is called the tidal range.

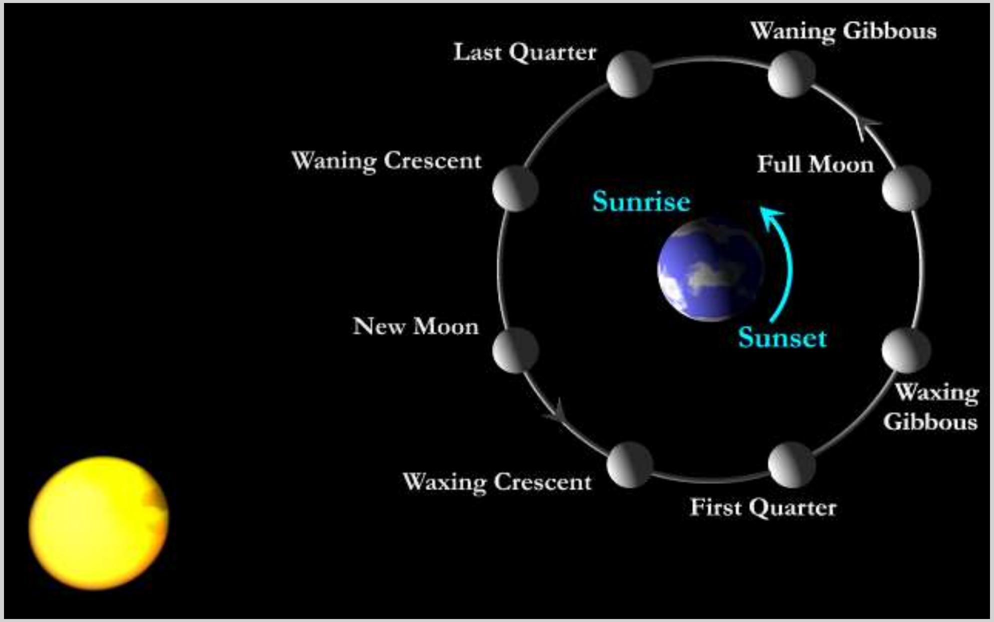


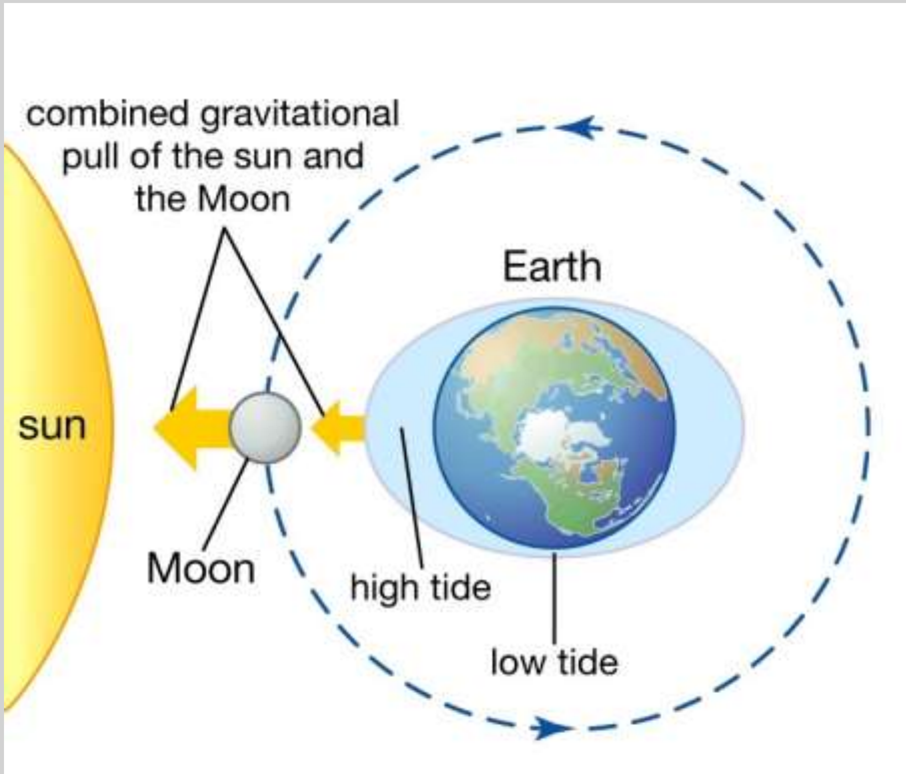
- A horizontal movement of water often accompanies the rising and falling of the tide. This is called the tidal current.
- The incoming tide along the coast and into the bays and estuaries is called a flood current; the outgoing tide is called an ebb current.
- The strongest flood and ebb currents usually occur before or near the time of the high and low tides.
- The weakest currents occur between the flood and ebb currents and are called slack tides.
- In the open ocean tidal currents are relatively weak.
- Near estuary entrances, narrow straits and inlets, the speed of tidal currents can reach up to several kilometers per hour.
- If the earth were a perfect sphere without large continents, all areas on the planet would experience two equally proportioned high and low tides every lunar day.
- The large continents on the planet, however, block the westward passage of the tidal bulges as the earth rotates.
- Unable to move freely around the globe, these tides establish complex patterns within each ocean basin that often differ greatly from tidal patterns of adjacent ocean basins or other regions of the same ocean basin.

- Three basic tidal patterns occur along the earth's major shorelines (**Fig. 1**).
- In general, most areas have two high tides and two low tides each day.
- When the two highs and the two lows are about the same height, the pattern is called a semi-daily or semidiurnal tide.
- If the high and low tides differ in height, the pattern is called a mixed semidiurnal tide.
- Some areas, such as the Gulf of Mexico, have only one high and one low tide each day. This is called a diurnal tide.
- The U.S. West Coast tends to have mixed semidiurnal tides, whereas a semidiurnal pattern is more typical of the East Coast.

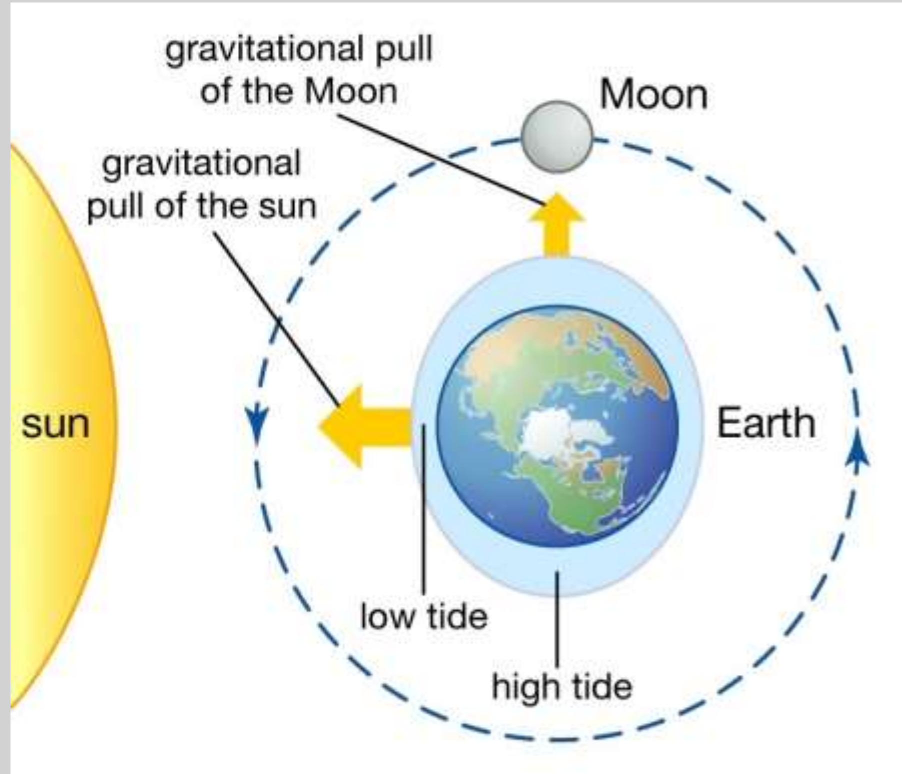


- As the moon completes one orbit around the earth in about 28 days, there are two times in each orbit when the earth, moon and sun are inline with each other and two times when the earth, moon and sun are at right angles.
- When all three are inline (around full and new moons), the combined effect of the moon's and sun's pull on the earth's water is at its greatest resulting in the greatest ranges between high and low tide.
- This is called a "**spring**" tide (from the water springing or rising up).
- Seven days after either full or new moon, the earth, moon and sun are at right angles to each other. At this time the pull of the moon and the pull of the sun partially cancel each other out.
- The resulting tide, a "**neap**" tide, has the smallest range between high and low tide.





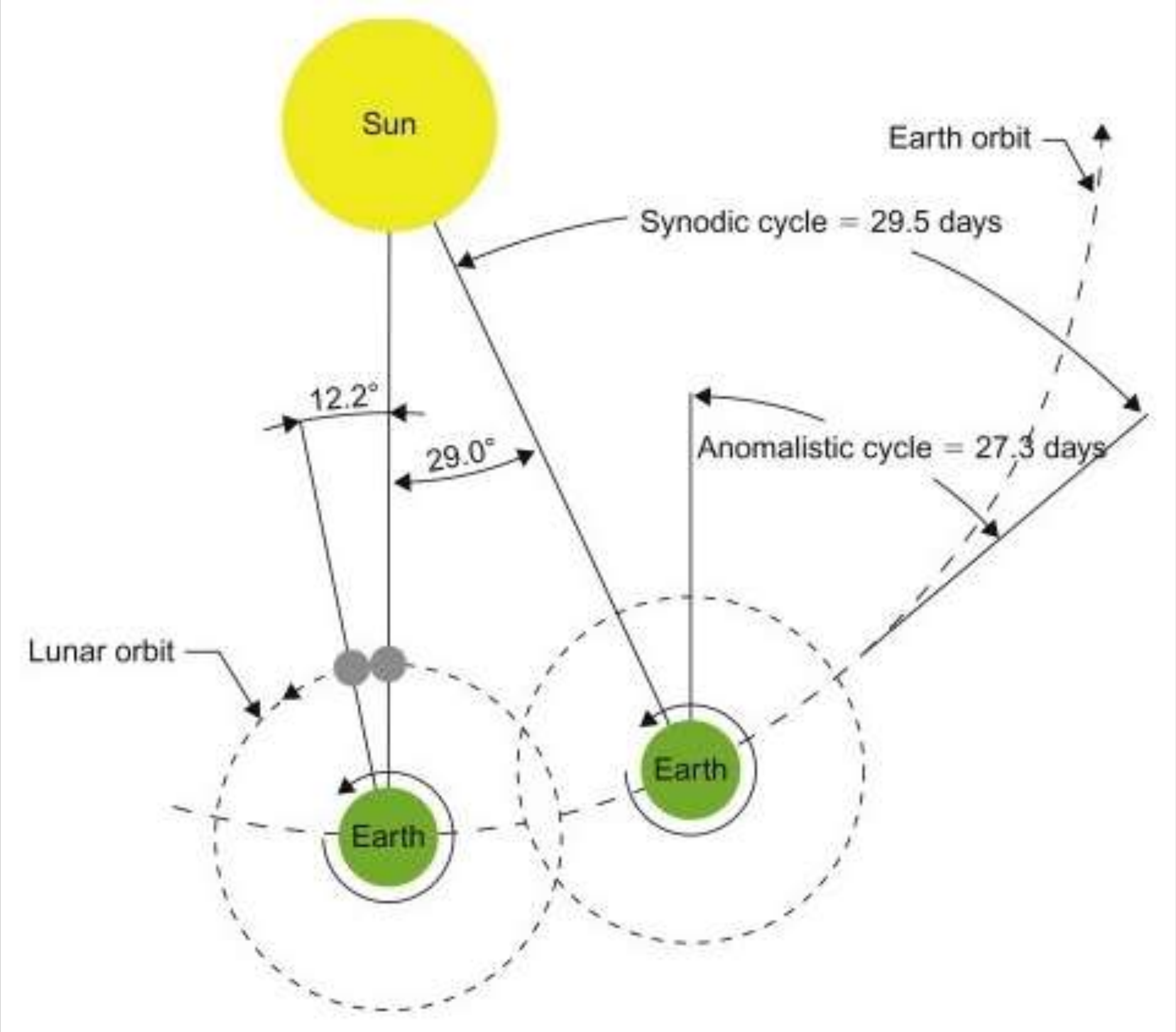
Spring tide



Neap tide

CREATION OF TIDES

- The fundamental lunar cycles in relation to the earth are: the Synodic cycle, which has a period of 29.5 days (new moon to new moon), and the Anomalistic cycle (perigee to perigee), which is 27.3 days (**Figure 2**).
- Solar gravitational influence is greatest at perihelion (when the earth is closest to the sun) in January, and least at aphelion in July.
- The plane of the earth's path around the sun is known as the ecliptic from which the earth's axis is inclined 66°30' and the moon's orbit is inclined 5°9', which in combination allow the moon's declination to reach 28°30' every 18.6 years.
- It is these offsets in combination with the superimposed rotational patterns of the earth/moon/sun system that create the complex forces which drive the earth's tides.
- The effects of masses of the earth, moon, and sun and their distances to each other play a critical role in affecting the earth's tides.
- In 1687, Sir Isaac Newton explained that ocean tides result from the gravitational attraction of the sun and moon on the oceans of the earth.



Sun
Earth orbit
Synodic cycle = 29.5 days
12.2°
29.0°
Anomalistic cycle = 27.3 days
Lunar orbit
Earth
Earth

- Newton’s law of universal gravitation states that the gravitational attraction between two bodies is directly proportional to their masses, and inversely proportional to the square of the distance between the bodies.
- Therefore, the greater the mass of the objects and the closer they are to each other, the greater the gravitational attraction between them.
- With regard to tidal forces on the earth, the distance between two objects usually is more critical than their masses.
- Tidal generating forces vary inversely as the cube of the distance from the tide generating object, while gravitational attractive forces only vary inversely to the square of the distance between the objects.
- The sun is 27 million times more massive than the moon.
- Based on its mass, the sun's gravitational attraction to the earth is 177 times greater than that of the moon to the earth.
- If tidal forces were based solely on comparative masses, the sun should have a tide-generating force that is 27 million times greater than that of the moon.
- However, the sun is 390 times further away from the earth than the moon.

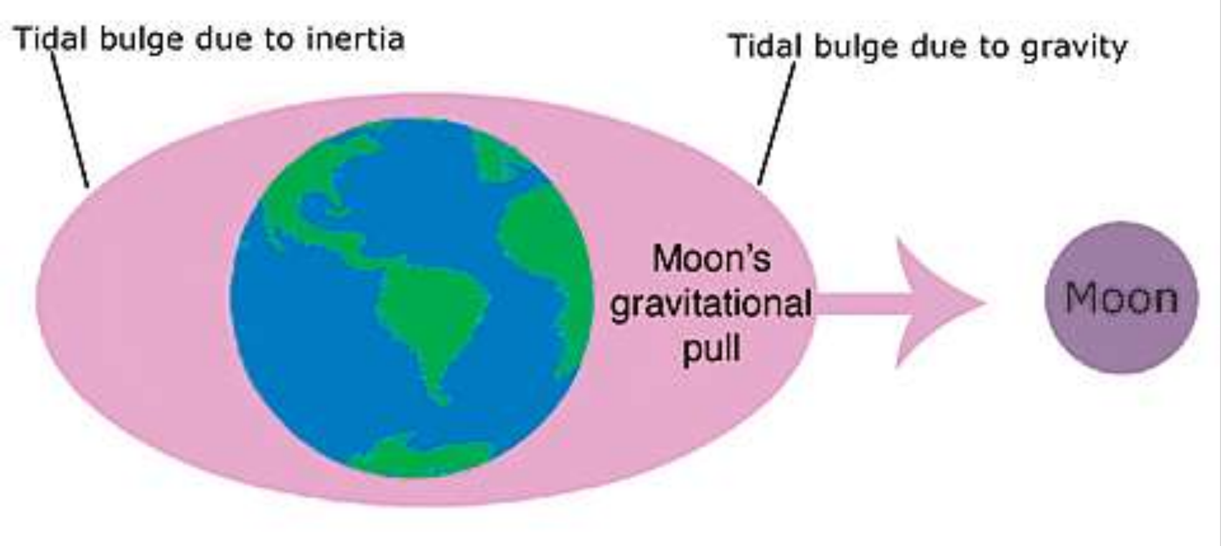
- Now since the tidal generating forces vary inversely as the cube of the distance from the tide-generating object. It means that the sun's tidal generating force is reduced by 390^3 (about 59 million times) compared to the tide-generating force of the moon.
- Therefore, the sun's tide-generating force is about half that of the moon, and the moon is the dominant force affecting the earth's tides.

The mass of moon	=	7.3×10^{19} metric tons
The mass of sun	=	22×10^{27} metric tons (27 million times the mass of moon)
The distance between earth and moon	=	384,835 kilometer
The distance between earth and sun	=	149,785,000 kilometer (390 times away from the earth than the moon)
Tide generating force	=	$\alpha \dfrac{\text{Mass}}{(Distance)^3}$
Tide generating force of the sun	=	$\alpha \dfrac{\text{Mass of sun}}{(Distance \text{ of sun to earth})^3}$
	=	$\dfrac{\text{27 million}}{(390)^3} = \dfrac{\text{27 million}}{\text{59 million}} = 0.46 \text{ or } 46\%$

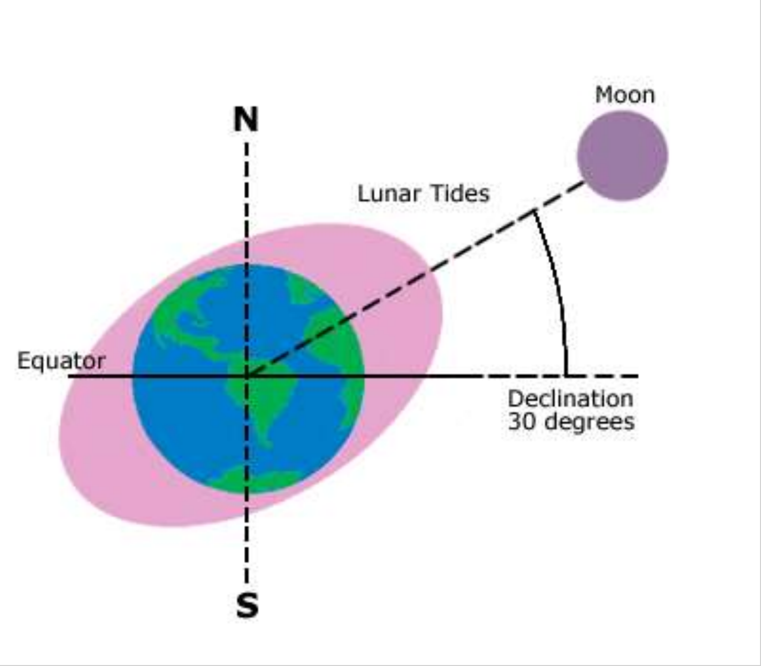
EFFECT OF GRAVITY AND INERTIA ON TIDAL BULGES

- Gravity is a major force responsible for creating tides, while the force of Inertia acts to counterbalance gravity.
- Together these forces are responsible for the creation of two major tidal bulges on the earth (**Figure 3**).
- The gravitational attraction between the earth and the moon is strongest on the side of the earth that happens to be facing the moon, simply because it is closer.
- This attraction causes the water on this “near side” of earth to be pulled toward the moon.
- As gravitational force acts to draw the water closer to the moon, inertia attempts to keep the water in place.
- But the gravitational force exceeds it and the water is pulled toward the moon, causing a “bulge” of water on the near side toward the moon.

- On the opposite side of the earth, or the “far side,” the gravitational attraction of the moon is less because it is farther away.
- Here, inertia exceeds the gravitational force, and the water tries to keep going in a straight line, moving away from the earth, also forming a bulge.
- In this way the combination of gravity and inertia create two bulges of water.
- One forms where the earth and moon are closest, and the other forms where they are furthest apart.
- Over the rest of the globe gravity and inertia are in relative balance.
- Because water is fluid, the two bulges stay aligned with the moon as the earth rotates.



- The changes in positions of the sun and moon relative to the earth's equator bring a direct effect on daily tidal heights and current intensity.
- As the moon revolves around the earth, its angle increases and decreases in relation to the equator. This is known as its declination (**Figure 4**).
- The two tidal bulges track the changes in lunar declination, also increasing or decreasing their angles to the equator.
- Similarly, the sun's relative position to the equator changes over the course of a year as the earth rotates around it.
- The sun's declination affects the seasons as well as the tides.
- During the vernal and autumnal equinoxes - March 21 and September 23, respectively, the sun is at its minimum declination because it is positioned directly above the equator.
- On June 21 and December 22 - the summer and winter solstices, respectively, the sun is at its maximum declination, *i.e.*, its largest angle to the equator.

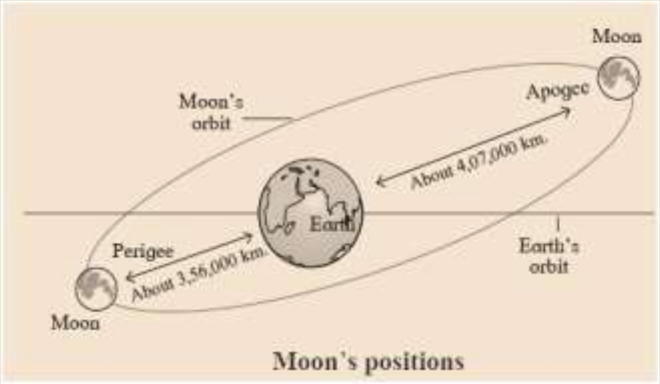


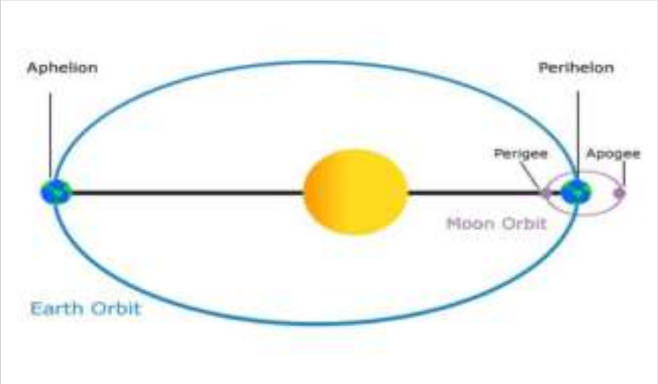
- Most coastal areas, with some exceptions, experience two high tides and two low tides every lunar day.
- A solar day (24-hour) is the time required for a specific site on the earth to rotate from an exact point under the sun to the same point under the sun.
- Similarly, a lunar day (24 hours 50 minutes) is the time taken for a specific site on the earth to rotate from an exact point under the moon to the same point under the moon.
- The lunar day is 50 minutes longer than a solar day because the moon revolves around the earth in the same direction that the earth rotates around its axis. So, it takes the earth an extra 50 minutes to “catch up” to the moon.
- Because the earth rotates through two tidal “bulges” every lunar day, coastal areas experience two high and two low tides every 24 hours and 50 minutes.
- High tides occur 12 hours and 25 minutes apart. It takes six hours and 12.5 minutes for the water at the shore to go from high to low, or from low to high.

VARIATIONS IN TIDES DUE TO POSITION AND DISTANCE OF SUN, MOON, AND EARTH

- The moon has a major influence on the earth's tides, but the sun also generates considerable tidal forces.
- Solar tides are about half as large as lunar tides and are expressed as a variation of lunar tidal patterns, not as a separate set of tides.
- When the sun, moon, and earth are in alignment (at the time of the new or full moon), the solar tide has an additive effect on the lunar tide, creating extra-high high tides, and very low, low tides—both commonly called spring tides.
- One week later, when the sun and moon are at right angles to each other, the solar tide partially cancels out the lunar tide and produces moderate tides known as neap tides.
- During each lunar month, two sets of spring tides and two sets of neap tides occur.
- Just as the angles of the sun, moon and earth affect tidal heights over the course of a lunar month, so do their distances to one another.

- The moon follows an elliptical path around the earth, the distance between them varies by about 31,000 kilometers over the course of a month.
- Once a month, when the moon is closest to the earth (at perigee), tide-generating forces are higher than usual, producing above-average ranges in the tides.
- About two weeks later, when the moon is farthest from the earth (at apogee), the lunar tide-raising force is smaller, and the tidal ranges are less than average.
- A similar situation occurs between the earth and the sun.
- When the earth is closest to the sun (perihelion), which occurs about January 2 of each calendar year, the tidal ranges are enhanced.
- When the earth is furthest from the sun (aphelion), around July 2, the tidal ranges are reduced (**Figure 5**).





Explanation for rising and receding tides along a shoreline area

- A low height tide wave, several hundred kilometers in diameter, runs on the ocean surface under the moon following its rotation around the earth until the wave hits a continental shore.
- The water mass moved by the moon’s gravitational pull fills narrow bays and river estuaries where it has no way to escape and spread over the ocean.
- This leads to interference of waves and accumulation of water inside these bays and estuaries, resulting in dramatic rise of the water level (tide cycle).
- The tide starts receding as the moon continues its travel further over the land, away from the ocean, reducing its gravitational influence on the ocean water (ebb cycle).
- This explanation is quite simplified due to consideration of moon’s gravitation only as the major factor influencing tide fluctuations.

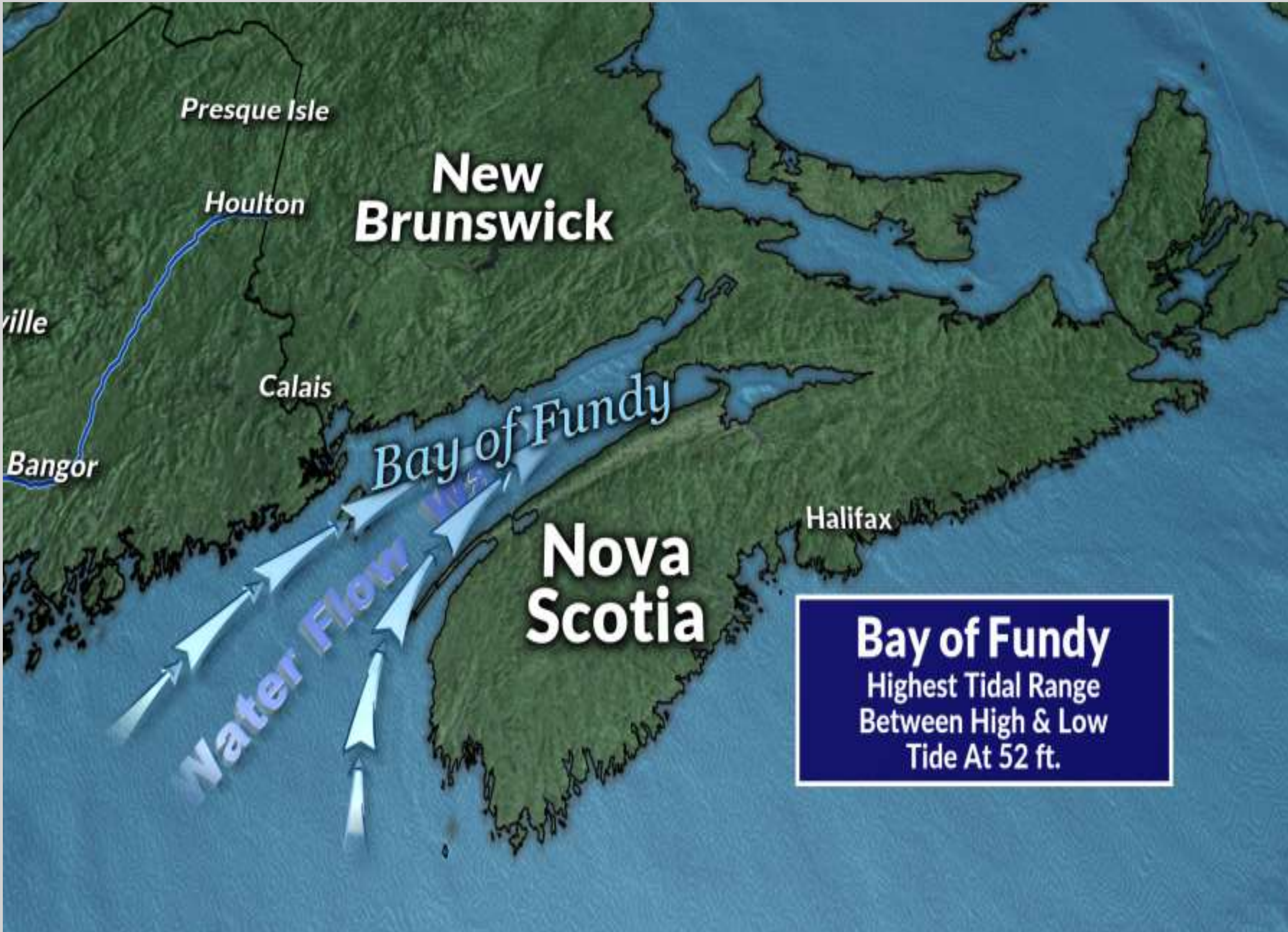
OTHER FACTORS AFFECTING TIDAL CHARACTERISTICS

- The height (amplitude) of the tide wave is of the order of few centimeters in the open ocean spread over several hundred kilometers.
- However, the tide can increase dramatically when it reaches continental shelves, bringing huge masses of water in to narrow bays and river estuaries along a coastline.
- The height of the coastline tide is known to be influenced by local topographical and bathymetrical features.

Table 1: Highest tides (tide ranges) of the global ocean

Country	Site	Tide range (m)
Canada	Bay of Fundy	16.2
England	Seven Estuary	14.5
France	Port of Ganville	14.7
France	La Rance	13.5
Argentina	Puerto Rio Gallegos	13.3
Russia	Penzhinskaya Guba	13.4
Russia	Bay of Mezen	10.0

- The relative distances and positions of the sun, moon and earth all affect the size and magnitude of the earth’s two tidal bulges.
- At a smaller scale, the magnitude of tides can be strongly influenced by the shape of the shoreline.
- When oceanic tidal bulges hit wide continental margins, the height of the tides can be magnified.
- Conversely, mid-oceanic islands not near continental margins typically experience very small tides of 1 meter or less.
- The shape of bays and estuaries also can magnify the intensity of tides.
- Funnel-shaped bays in particular can dramatically alter tidal magnitude.
- The Bay of Fundy in Nova Scotia is the classic example of this effect, and has the highest tides in the world—over 15 meters.
- Narrow inlets and shallow water also tend to dissipate incoming tides.
- Inland bays such as Laguna Madre (Texas) and Pamlico Sound (North Carolina) have areas classified as non-tidal, though they have ocean inlets.
- In estuaries with strong tidal rivers, such as the Delaware River and Columbia River, powerful seasonal river flows in the spring can severely alter or mask the incoming tide.


Presque Isle
New Brunswick
Houlton
ville
Calais
Bangor
Bay of Fundy
Water Flow
Halifax
Nova Scotia
Bay of Fundy
Highest Tidal Range
Between High & Low
Tide At 52 ft.

- Local wind and weather patterns also can affect tides.
- Strong offshore winds can move water away from coastlines, exaggerating low tide exposures.
- Onshore winds may act to pile up water onto the shoreline, virtually eliminating low tide exposures.
- High-pressure systems can depress sea levels, leading to clear sunny days with exceptionally low tides.
- Conversely, low-pressure systems that contribute to cloudy, rainy conditions typically are associated with tides than are much higher than predicted.

CORIOLIS FORCES

- Although named after Coriolis (1835), the actual concept was given by Laplace in 1775 in his original study on tides.
- If a particle is considered to be at the earth's equator, it will experience acceleration due to the curvature of earth and have an angular momentum given by $r\omega^2$, where r is the radius of motion and it is equivalent to the radius of earth at equator.

$$\text{Angular velocity } \omega = \frac{2\pi}{24 \times 3600} \frac{rad}{s}$$

- If the particle now travels northward, the radius of motion will shrink with the cosine of the latitude, until it reaches a theoretical singularity at the North Pole.
- In order for angular momentum ($r\omega^2$) to be conserved the particle must accelerate, and this acceleration is observed to be eastward in the northern hemisphere and westward in the southern hemisphere.
- A movement by the particle back towards the equator would render the opposite effects to be observed.
- The action of the Coriolis force is to modify tidal flows, particularly in estuaries and other partially enclosed areas such as sea lochs.

ENERGY OF TIDES

- The energy of the tide wave contains two components, namely, potential and kinetic.
- The potential energy is the work done in lifting the mass of water above the ocean surface and can be calculated by following equation.

$$\text{Potential energy } P.E. = g\rho A \int z\,dz = 0.5 g\rho A h^2$$

- Here ***g*** is acceleration of gravity, and ***A*** is the sea area under consideration.
- Taking an average ***gρ = 10.15 kN/m³*** for sea water, the energy for a tidal cycle / m^2 of ocean surface area can be calculated.

$$P.E. = 1.4h^2 watt.hr = 5.04h^2 kJ$$

- The kinetic energy *K.E.* of the water mass ***m*** is its capacity to do work by virtue of its velocity ***U***. It is defined by ***K.E.* = 0.5*mU*²**. The total energy of tide equals the sum of its potential and kinetic energy components.

- Knowledge of the potential energy of the tide is important for designing conventional tidal power plants using water dams for creating artificial upstream water heads.
- Such power plants exploit the potential energy of vertical rise and fall of the water.
- In contrast, the kinetic energy of the tide has to be known in order to design floating or other types of tidal power plants which harness energy from tidal currents or horizontal water flows induced by tides. They do not involve installation of water dams.
- The power output ***P*** of a conventional hydropower plant can be expressed as a function of the volumetric flow rate of water ***Q*** through the turbines and the difference between upstream and downstream water levels ***h***.

$$P = \rho g h Q \text{ kW}$$

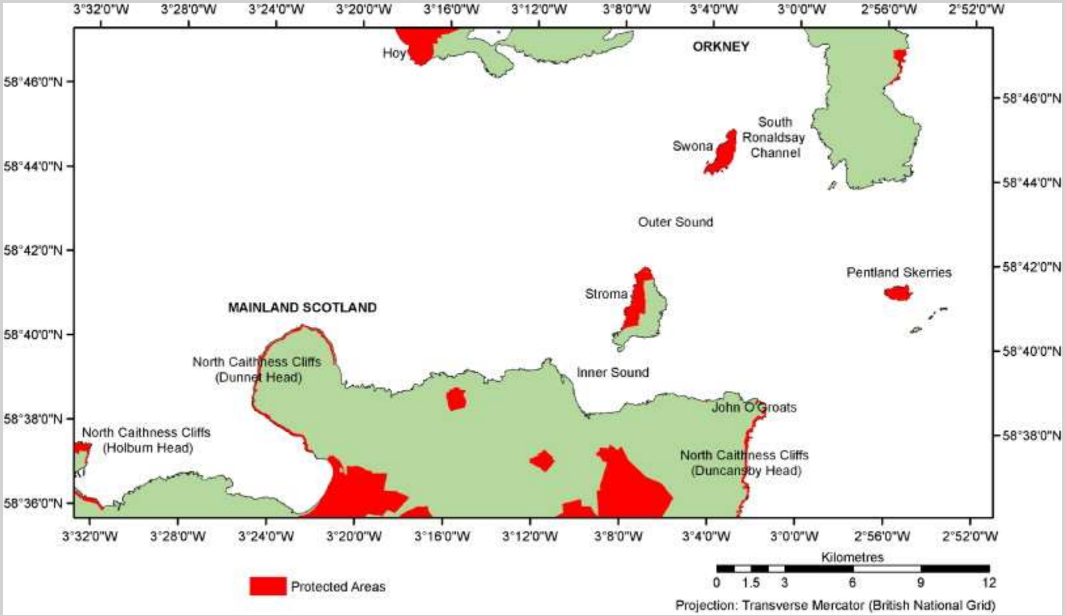
- The average annual power production of a conventional tidal power plant with dams can be calculated by taking into account some other geographical and hydraulic factors, such as the effective basin area, tidal fluctuations, etc.

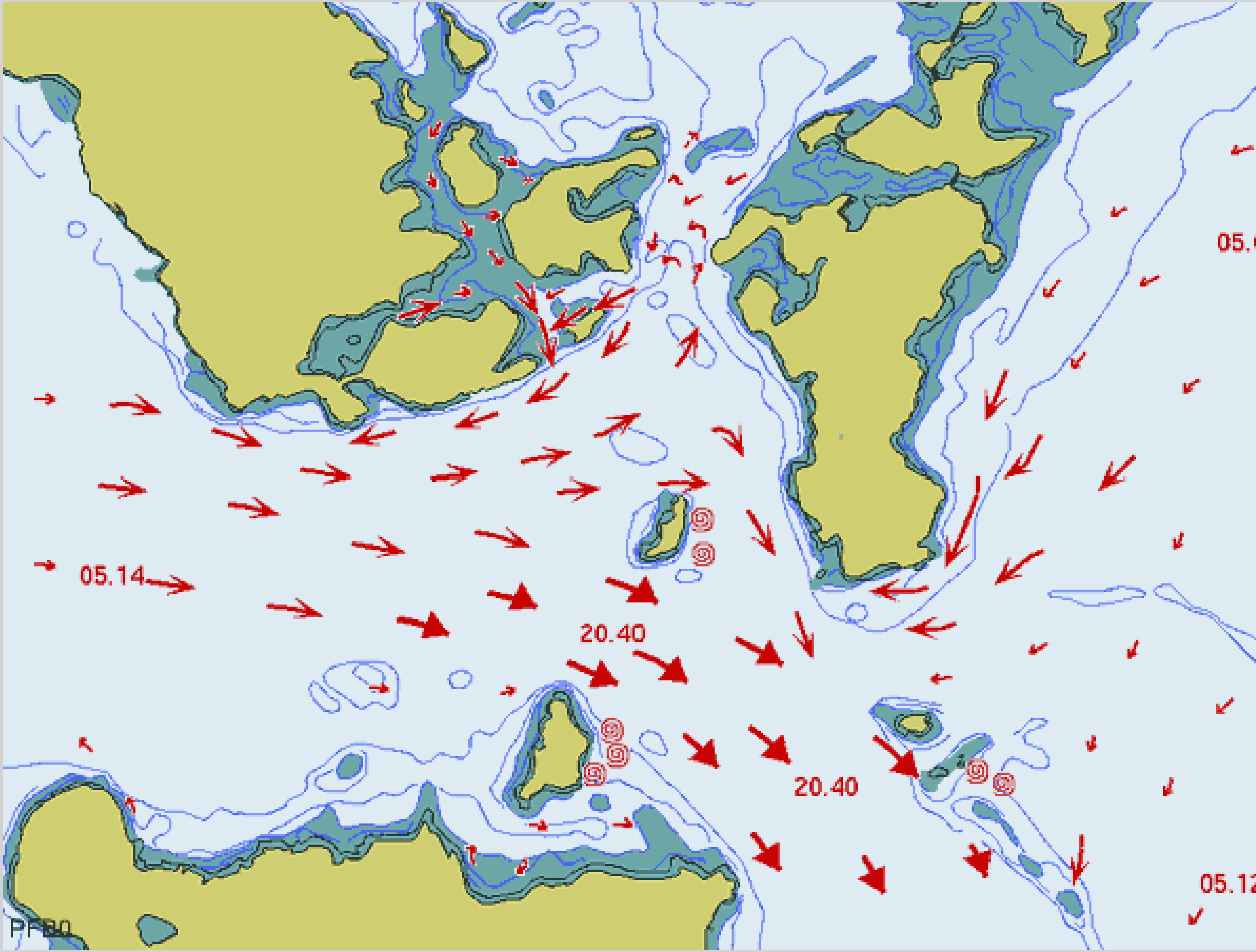
TIDAL CURRENT VELOCITY

- The tidal waves created by the earth/moon/sun system propagate as long waves, and their speed is dependent on water depth.
- A typical wave in an average ocean of 4000 m depth would travel at about 200 m/s.
- These tidal waves, being of astronomical origin, have no connection with a tsunami, an event that is often erroneously referred to as a tidal wave.


テレトラック
MIYAKO

- Two basic types of tidal currents: **bidirectional** and **rotational**.
- The bidirectional type (hydraulic currents) is generally tightly constrained by topographical features into operating as a conduit between two bodies of water, for example, the Pentland Firth where the flow is generally east south-easterly or west north-westerly.
- **Pentland Firth**, between the Scottish mainland and the Orkney isles, is the best site in the world for tidal power generation.
- This is a 60–90 m deep channel that carries water from the Atlantic Ocean to help fill and drain the North Sea and the Baltic twice a day with current flows up to 16 knots.
- Around 3 million tons/sec of water flows through this channel at peak times.
- East end of the Firth is most suitable, where the channel is narrowest (especially between the islands of Stroma and Swona), the two islands straddling the main flow.




05.0
05.14
20.40
20.40
05.12

- **Rotational flows** are found in more open areas such as the North Sea and the Channel Isles.
- The rotational currents reflect the nature of the governing amphidrome(s) and are generally circular or large symmetrical ellipsoids in offshore areas, but tend to become tight, asymmetrical ellipsoids closer to shore.
- At present, the development of tidal energy devices is focused on the bidirectional model, which also exists at the entrance to sea lochs, fjords and bays, generally restricted by width and/or depth.
- These channels are very short in comparison with the tidal wavelength, and are a balance of forces between pressure head and friction.
- The bottom friction or drag force, for a channel of length L and width W, is given by:

$$\mathbf{Drag = C_D\, L\, W\, \rho\, U^2}$$

- Here C_D is the dimensionless drag coefficient, typically 0.002 at 1 m above the seabed, ρ is the density of sea water and U is the freestream velocity.

- The force applied by the pressure head (F_P) for a channel of width W and depth z is given by:

$$\mathbf{F_P = \rho g h W z}$$

- Here h represents the head difference across the channel.
- Equating the two force equations and solving for U:

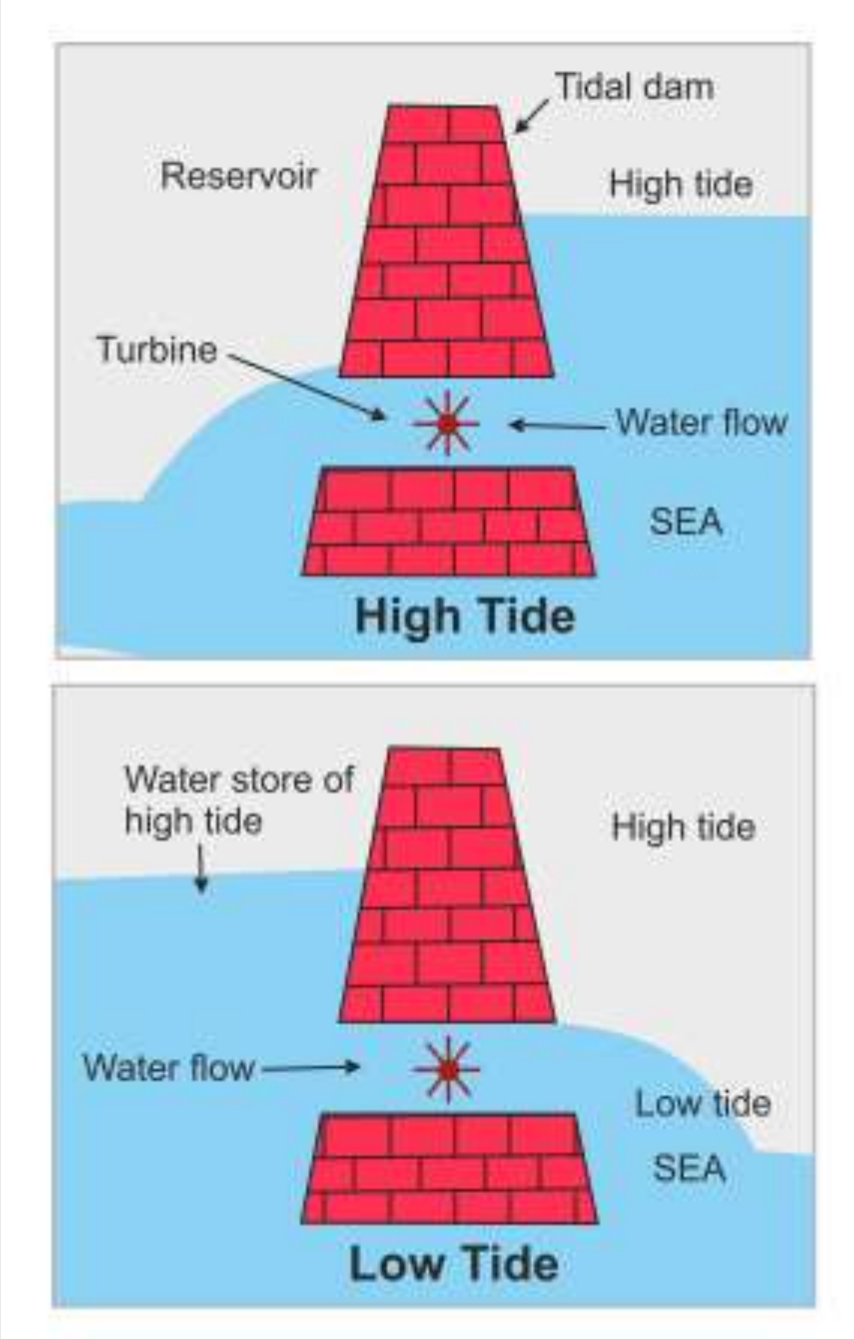
$$U = \sqrt{\frac{zgh}{C_D L}}$$

- If h is found from the tide heights at each end of the channel, then the flow velocity U can be found, after allowing sufficient time for the flow to develop.
- However, this is a very simplistic analysis, and realistic modelling requires much greater detail and substantial computing power.

EXTRACTION OF TIDAL ENERGY

- All existing tidal power plants use the conventional barrage technique used for river hydropower stations.
- A large barrage with gates is built at the opening of a bay to create an artificial water basin or estuary, and a number of hydraulic turbines coupled with electric generators are installed at the lowest point of the barrage.
- The function of hydraulic gates is to control the water flow in and out of the water basin behind the barrage.
- As the tide shifts from high to low, there exists a pressure difference between the water levels on the two sides of the barrage.
- Increased water level in the estuary results in increased potential energy.
- When the ocean water reaches a very low level due to the low tide, the gates are opened and the high potential energy water within the barrage is released through specially made outlets equipped with turbines.
- The force of the rushing water spins the turbines, which turn electric generators to produce electricity.

- The tidal power plants can be designed for operation either by double or single action.
- Double action means that the turbine work in both water flows - during the high tide (flood) when the water flows in to the barrage, and then low tide (ebb) when the water flows out to the ocean.
- Single action systems are those where the turbines work only during the ebb cycle.
- Here the water gates are kept open during the flood allowing the water to fill the estuary.
- When the tide falls, the receding water retreats back to the ocean by passing through turbines, thus generating electricity.



- Advantages of the double action method are that it closely models the natural phenomenon of the tide, has least effect on the environment and has higher power efficiency. However, this method requires more complicated and expensive reversible turbines and electrical equipment.
- The single action method is simpler, and requires less expensive turbines. The negative aspects of the single action method are its greater potential for harm to the environment by developing a higher water head and causing accumulation of sediments in the basin.
- Nevertheless, both methods have been used in practice. For example, the La Rance and the Kislaya Guba tidal power plants operate under the double action scheme, whereas the Annapolis plant uses a single action system.
- The barrage technology is very well established, but building a barrage is expensive and the best sites are those where a bay has a narrow opening, thus reducing the length of barrage required.

ADVANTAGES OF TIDAL ENERGY

- The chief advantage of tidal energy is its economical benefit. Once you have built a tidal power plant, power is free as it does not require any fuel.
- Although tidal barrage power schemes have a high capital cost, but they also have a very low running cost, it is not expensive to maintain them.
- A tidal power plant may not produce returns for many years, but once it moves into surplus, it is likely to provide profit for an indefinite period.
- The economic life of a tidal plant is very high. A plant is expected to be in production for 75-100 years, compared to 35 years for a conventional fossil fuel plant.
- Besides the economical factors, tidal energy is renewable and non-polluting producing no greenhouse gases or other waste.
- Tides rise and fall every day in a very consistent pattern and are absolutely reliable and predictable, so that one can plan to have other power stations generating electricity at times when the tidal station is out of action.

- Tidal electricity can be used to displace electricity which would otherwise be generated by fossil fuel (coal, oil, natural gas) fired power plants, thus reducing emissions of greenhouse and acid gases, and simultaneously offering a substitute for hydrocarbon and fossil fuels.
- A tidal barrage can prevent approximately one million tons of CO_2 per TWh power generated.
- A barrage can also protect a large stretch of coastline against damage from high storm tides.

DISADVANTAGES OF TIDAL ENERGY

- The biggest drawback of tidal power is the alterations in the ecosystem at the bay. A barrage across an estuary affects a very wide area - the environment is changed for many miles upstream and downstream.
- Damages like reduced flushing, winter icing and erosion can change the vegetation of the area and disrupt the balance.
- The alteration of tidal currents affects the habitat of the seabirds as many of them rely on the tide uncovering the mud flats so that they can feed.
- Another drawback of tidal power stations is that they can only generate power for around 10 hours each day, when the tide is actually moving in or out.
- Tidal power plant has several prerequisites that make it only available in a small number of regions. The major consideration has to be given to see whether the tides are high enough or not.

- For a tidal power plant to produce electricity effectively at about 85% efficiency, a basin or a gulf with mean tidal amplitude (the differences between spring and neap tide) of 7 m or above is required. It is also desirable to have semi-diurnal tides where there are two high and low tides everyday. Tides out in the ocean have maximum amplitude of about one meter, but close to shore this can increase to more than 12 m high depending on local features such as shelving or funneling meaning the tidal range can vary considerably along any given coastline. This can mean that a lot of places just aren't suitable for tidal barrages.
- A tidal barrage is very expensive to build.

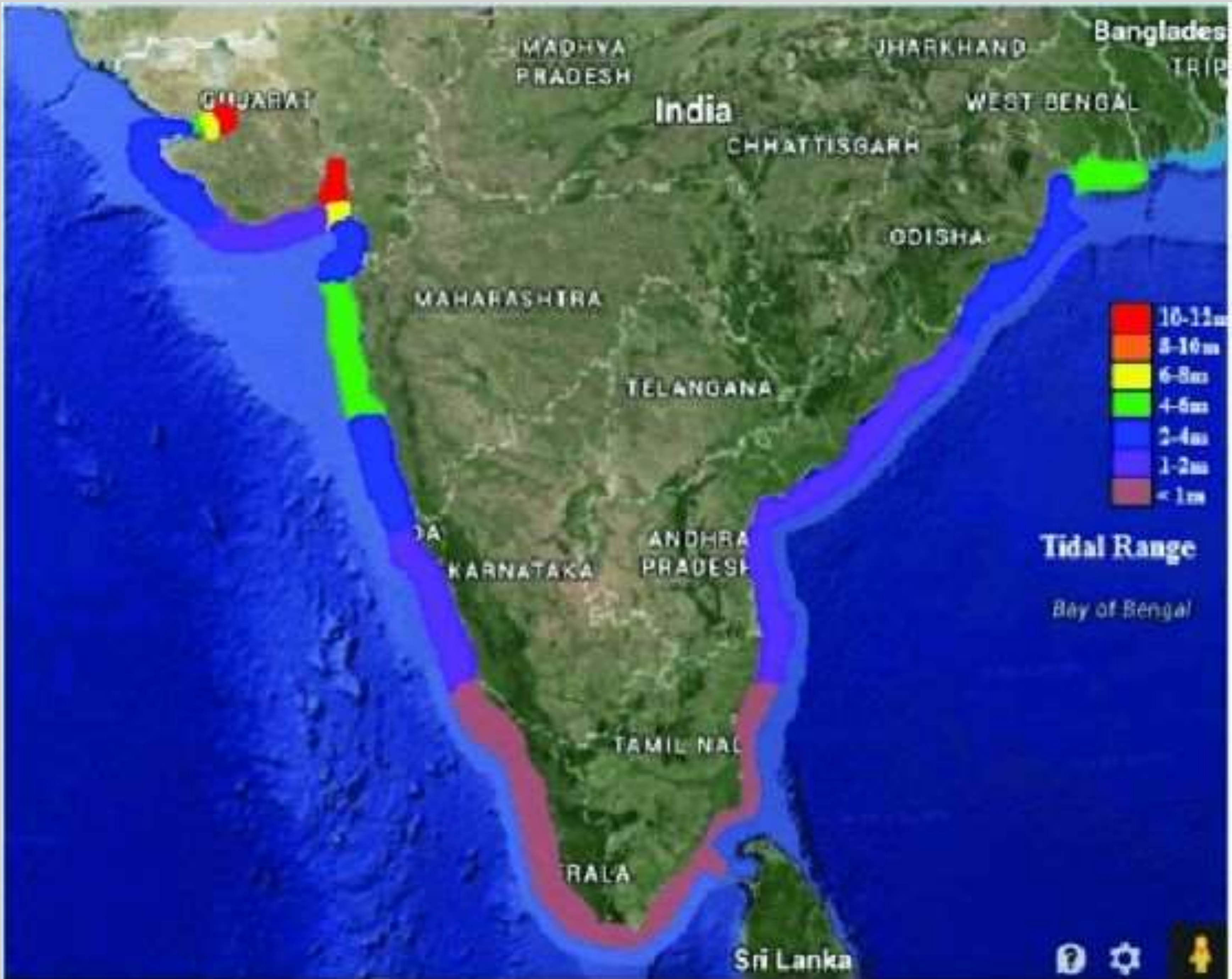
FUTURE OPTIONS

- A serious issue that must be addressed is how and where to use the electric power generated by extracting energy from the tides.
- Tides are cyclical by their nature, and the corresponding power output of a tidal power plant does not always coincide with the peak of human activity.
- In countries with a well-developed power industry, tidal power plant can be a part of the general power distribution system.
- However, power from a tidal plant would have to be transmitted a long distance because locations of high tides are usually far away from industrial and urban centers.
- An attractive future option is to utilize the tidal power *in situ* for year round production of hydrogen fuel by electrolysis of the water.
- The hydrogen, liquefied or stored by another method, can be transported anywhere to be used either as a fuel instead of oil or gasoline or in various fuel cell energy system.

- Fuel cells convert hydrogen energy directly into electricity without combustion or moving part, which is then used, for instance, in electric cars.
- Many scientists and engineers consider such a development as a future new industrial revolution.
- However, in order to realize this idea worldwide, clean hydrogen fuel need to be also available everywhere.
- At present most hydrogen is produced from natural gases and fossil fuels, which emit greenhouse gases into the atmosphere and harm the global echo system.
- From this point of view, production of hydrogen by water electrolysis using tidal energy is the one of the best ways to use development clean hydrogen fuel by a clean method.
- Thus, tidal energy can be used in the future to help develop a new era of clean industries, for example, to clean up the automotive industry, as well as other energy consuming areas of human activity.

TIDAL ENERGY IN INDIA

- India has a vast potential of about 8000 – 9000 MW electricity generation using tidal power plants as it is surrounded by sea on three sides with a long coastline of 7517 km.
- But tidal energy is extremely site specific and requires mean tidal differences greater than 4 m along with favorable topographical conditions such as estuaries or certain types of bays in order to bring down costs of dams, etc.
- Some potential sites identified by Indian government for tapping tidal energy are in the Gulf of Kutch (1200 MW), Gulf of Cambay (7000 MW), Gulf of Mannar, and the Ganges Delta in the Sunderbans region (less than 100 MW) in West Bengal.
- The Gulf of Kutch and the Gulf of Cambay on the west coast are the most attractive locations where the maximum tidal range is 8 m and 11 m with average tidal range of 5.23 m and 6.77 m, respectively.



MADHYA PRADESH
JHARKHAND
India
GUJARAT
WEST BENGAL
CHHATTISGARH
ODISHA
MAHARASHTRA
TELANGANA
KARNATAKA
ANDHRA PRADESH
TAMIL NAD
RALA
Sri Lanka
10-12m
8-10m
6-8m
4-6m
2-4m
1-2m
< 1m
Tidal Range
Bay of Bengal

- The Ganges Delta in the Sunderbans in West Bengal also has good locations for small scale tidal power development.
- The maximum tidal range in Sunderbans is approximately 5 m with an average tidal range of 2.97 m.
- The Kutch Tidal Power Project with an installed capacity of about 900 MW is estimated to cost about Rs. 1460 Crore generating electricity at about 0.90 Rs. per unit.
- The West Bengal Renewable Energy Development Authority has set up a 3.65 MW mini tidal power plant at Durgaduani (Sunderbans, West Bengal) in a joint collaboration with National Hydroelectric Power Corporation, Indian Institute of Technology Madras, and National Institute of Ocean Technology.
- The plant has been made operational and is providing electricity to nearly 15000 homes.

WORLD TIDAL ENERGY OUTLOOK

- The world tidal energy potential has been estimated at 3,000 GW, however, the exploitable potential available for electricity generation is only about 2% (= 60 GW = 60,000 MW).
- To produce enough amounts of electricity for practical use, a difference of at least 5 m between high and low tides is required.
- The higher the tide, the greater is the amount of electricity that can be generated from a given site.
- The presence of geographical features such as bays and inlets result in higher tides.
- There are about 40 suitable sites around the world with this kind of tidal range.
- **Tables 2** and **3** give the main characteristics of world's largest existing tidal power plants, and of few potential sites for the development of tidal power plants, respectively.

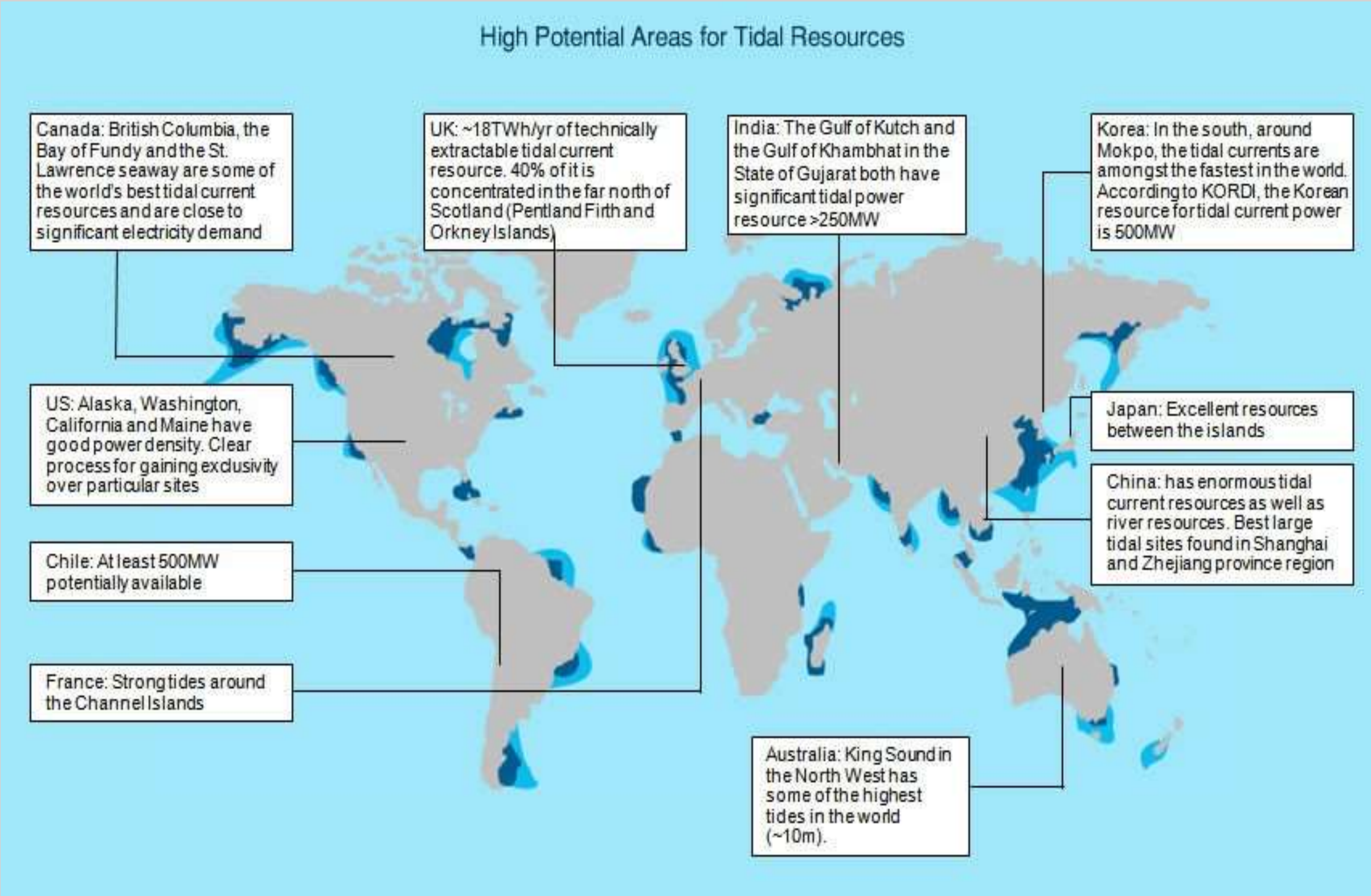

High Potential Areas for Tidal Resources
Canada: British Columbia, the Bay of Fundy and the St. Lawrence seaway are some of the world's best tidal current resources and are close to significant electricity demand
UK: ~18TWh/yr of technically extractable tidal current resource. 40% of it is concentrated in the far north of Scotland (Pentland Firth and Orkney Islands)
India: The Gulf of Kutch and the Gulf of Khambhat in the State of Gujarat both have significant tidal power resource >250MW
Korea: In the south, around Mokpo, the tidal currents are amongst the fastest in the world. According to KORDI, the Korean resource for tidal current power is 500MW
US: Alaska, Washington, California and Maine have good power density. Clear process for gaining exclusivity over particular sites
Japan: Excellent resources between the islands
China: has enormous tidal current resources as well as river resources. Best large tidal sites found in Shanghai and Zhejiang province region
Chile: At least 500MW potentially available
France: Strong tides around the Channel Islands
Australia: King Sound in the North West has some of the highest tides in the world (~10m).

Table 2: Existing large tidal power plants

Plant	Installed power (MW)	Basin area (km^2)	Mean tide (m)
La Rance, France (1967)	240	22	8.55
Kislaya Guba, Russia (1968)	0.4	1.1	2.3
Annapolis, Canada (1984)	18	15	6.4
Jiangxia, China (1985)	3.9	1.4	5.08

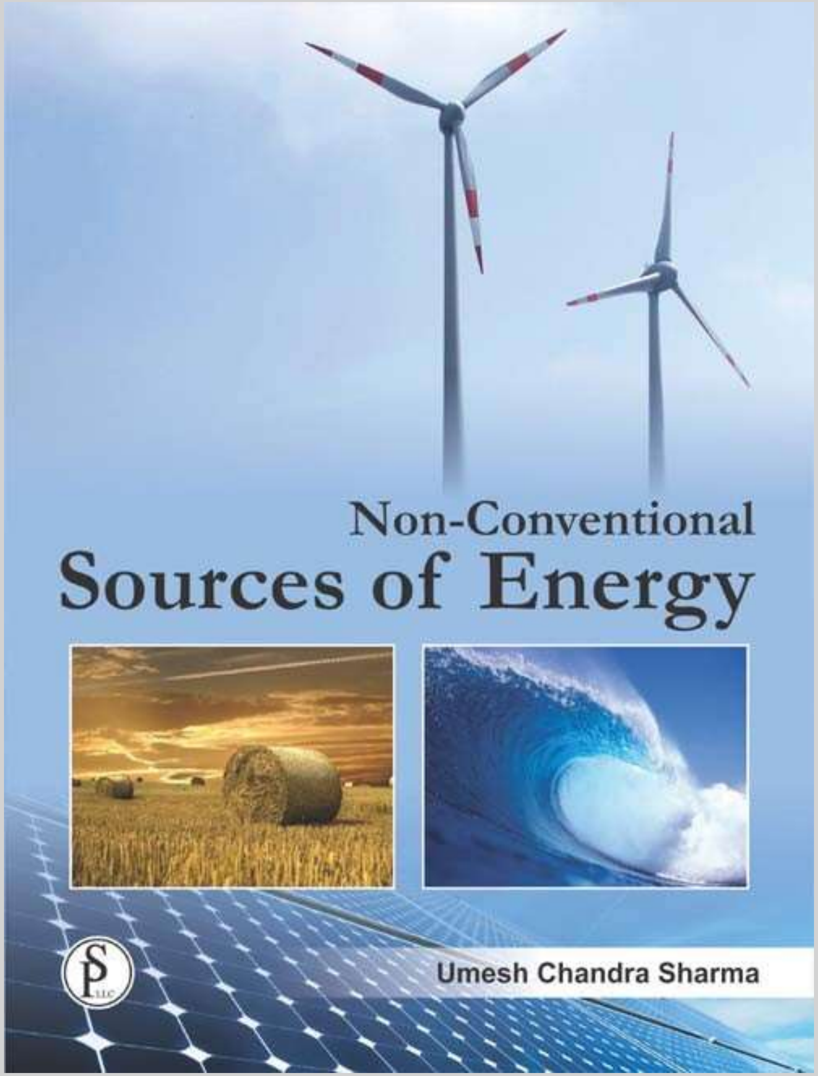
Table 3: Some potential sites for the development of tidal power plants

Site	Potential power (MW)	Basin area (km^2)	Mean tide (m)
Walcott, Australia	1750	260	8.4
Secure, Australia	570	130	8.4
Mersey, UK	700	60	8.4
Severn, UK	6000	490	8.3
San Jose, Argentina	7000	780	6.0
Mezen, Russia	15000	2640	5.66
Passamaquoddy, USA	400	300	5.5
Tugursk, Russia	6790	1080	5.38
Garolim, Korea	480	90	4.8
Cook, USA	18000	3100	4.35

ECONOMICS OF TIDAL POWER

- The economics of tidal energy depend primarily on site-specific factors, such as tidal range, basin area, and the required barrage length and height.
- These factors are expressed in terms of **Gibrat ratio**. The **Gibrat ratio** is the ratio of the length of the barrage in metres to the annual energy production in kilowatt hours.
- The smaller the Gibrat ratio for a site, the more desirable the site will be.
- The Gibrat ratios for few sites are: La Rance (0.36), Severn (0.87), and Passamaquoddy in the Bay of Fundy (0.92).
- The technology required for tidal power is well developed, but the main barrier to increased use of the tidal energy is the construction costs.
- The civil work amounts to about 55-60% of the capital cost of a project, the electromechanical components including the transmission facilities to shore approximates 35% of the capital cost, with the remainder for feasibility studies, engineering and management, and miscellaneous costs.
- The construction time is currently in the order of 10-years or more, which is a potential area for cost reduction by shortening the construction time.

REFERENCE



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Thank You