4-13-79

M O O N   P O W E R

In the fall of 1977 while traveling about the Gaspe, and the Maritime Provinces of Canada, we witnessed an incoming tide in the Bay of Fundy area, specifically in the town of Truro, Nova Scotia. At precisely the time posted, the tide moved in from around a bend in the stream. It was stimulating in that one wonders at the potential of this force, impressive in its precision, and then provoking which has prompted my further exploration for additional enlightenment of just how the tides are generated, what efforts ~~may be~~ ARE BEING made to harness the tides for electrical power purposes.

While we were in the Halifax area, which was possibly fifty miles from Truro, there was a newsppaer story of studies going on concerning the harnessing of the Bay of Fundy tides. As you may know the Bay of Fundy tides are one of the strongest in the world, with a range of 2 to 6 feet outside the Bay, and becoming 20 to 50 feet at the head. This pheonomenon is due largely to the shape and length of the Bay, which is about 165 miles from mouth to head.

The intentions of this paper are to provide you with some basics concerning the origin of tides, how they operate, and studies being currently made in the Maritime Provinces for the harnessing of tides for electrical power.

The rise and fall of the sea twice a day is such an obvious thing that it must have been well known to people living along the coasts of tidal seas from very early times. These people also must have noticed that the tides came later and later each day-- fifty minutes on the average, as did the rising of the Moon. And possibly there were some who associated this celestial event with the rhythmical rise and fall of the sea.

Most early written records of the tides were made by people living on the shores of the Mediterranean, but in nearly all parts of this sea tidal rise and fall is negligible. It was not until Phoenician, Greek, and Roman navigators ventured beyond the Mediterranean-- west into the Atlantic and east into the Indian Ocean-- that they saw impressively high tides, sometimes to their great surprise and fear. When the Army of Alexander the Great approached the mouth of the Indus from the north in 325 BC, his men were alarmed and confused by the effects of the tides on their moored ships. And, when Caesar's legions invaded Britain in 55 BC, his ships were left high and dry by a twenty-foot spring tide reinforced by a strong wind.

Much of our evidence of Greek and Roman knowledge of the tides comes from Strabo(born 63 BC), who in his "GEOGRAPHY", referred to the observations and writings of men before. him. Pytheas, who sailed to Britain and the North Sea around 325 BC, is credited with making the first systematic observations of the tides, and being the first to relate the alternation of spring and neap tides to phases of the moon. He also described the dangers of tidal bores which regularly and dramatically invade certain rivers.

Since Greek and Roman times men have known that the rhythm of the tides was somehow related to the apparent motion of the Moon and Sun, but it was not until Newton's time that we were given a rational explanation of the link. In his "Principia", published in 1687, Newton showed that the tides are one of the consequences of the law of gravitation. Every partical of matter on the Earth is attracted by the Moon, and the force of attraction is directed towards the Moon's center; also, the farther away from the Moon's center the particle is, the weaker the attracting force. So, the force varies slightly in both direction and in strength, depending on the position of the particle on the Earth. It is this variation in the attracting force that causes the ocean waters to move to and fro over the Earth's crust and so produce the tides. As we might expect, the tidal forces tend to cause the water on the side of the Earth facing the Moon to be heaped up, but a similar bulge also forms on the opposite side of the Earth.

Because the ocean waters on the far side of the Earth(most distant from the Moon) are the least affected by the moon's gravitational attraction, they tend, in a sense, to be left behind and so form a far-side bulge

We know that the Sun also exerts a tide-generating force on the Earth waters. It may seem surprising that the Sun, nearly twenty-five million times more massive than the Moon, does not have a greater pull. But mass is not the only key to the explanation. Although tidal force is directly proportional to the mass of the heavvnly body concerned, it is also inversely proportional to the cube of its distance. The Sun's greater distance from us, then, is the dominating fact, with the result that its ability to raise tides on Earth is less than half that of the Moon.

The Sun tides, though much smaller, are important because of the way they increase and reduce the lunar tides. The two most important situations are when the earth, sun,and moon are aligned(in phase), and when the three make a right angle(out of phase).

In the in-phase case the solar bulge rides on top of the lunar bulge to make spring tides. During spring tides, which have nothing to do with the spring season, but occur about every two weeks, the water level rises higher and falls lower than usual. This larger range of tide lastStwo or three days; then the two bulges get progressively further out of phase until, a week later, the high and low tides are about twenty percent less than average. These are <u>neap</u> tides, and in effect the sun's gravitational force reduces the moon's bulges.

Another important variation in the height of the tide is the result of the moon'e elliptical orbit about the earth. At perigee(221,463 miles) the nearest point in its orbit, the moon is fifteen thousand miles closer; at apogee(252,710 miles) it is that much farther away. This change in distance(and, therefore, in the attractive force)causes tides that are, respectively, twenty percent higher and lower than average. Perigee is reached once an orbit(once a month) and only rarely does this concide with the in=phase alignment of sun, earth, and moon. But, at least twice a year both effects exist at the same time-- that is, a full moon, or a new moon exists at perigee. Then the perigee tides add to the <u>spring</u> to produce the highest tides of the year. For a like reason, the tides will be increased by the sun's action when the earth is near its <u>perihelion</u> (HEL-YON), about the first of Jan., and decreased when near its <u>aphelion</u> (A PHEL-YON), about the first of July.

PERI - NEAREST
APH - FARTHEREST

<u>Neap</u> tides come when the moon is in the first and last quarter; <u>Spring</u> tides occur at new moon, and full moon.

The tides move with the apparent revolution of the moon around the earth. That is, the tide cycle has the same time interval as from one rising of the moon to the next, or about twenty-four hours and fifty minutes. The gravitation of the passing moon pulls the nearest water a little farther away from the solid earth beneath it, and at the same it pulls the whole earth a little away from the water on the fartherest side. Thus, the moon sets ~~about~~ up two tidal currents on opposite sides of the earth at the same time. These tides travel around the earth-- following the moon except where land stops them. They hit nearly every seacoast at intervals of about twelve hours and twenty-five minutes. Thus most seacoasts have two tides a day, and the tides occur fifty minutes later every day.From its lowest point, the water rises gradually for about six hours, until it reaches high water, or high tide. Then it begins to fall, continuing for about six hours until it reaches low water, or low tide. The difference between high and low water is called the range of the tide. The movement of the water is called the tidal current. When the water moves toward the coast or inlet, it is the flood current; when it flows seaward, it is called the ebb current.

The range of the tide differs from day to day according to the position of the sun and the moon. When the moon and sun are pulling along the same line, as they do at full and new moon, the tide rises higher than usual and is called a spring tide. When the sun and moon pull at right angles, as theydo when the moon is in its first and third quarters, the tides do not rise as high as usual and are called neap tides.

Furthermore, Spring tides have a greater range than others of the lunar month, and at such times the highest high tides as well as lowest low tides are experienced, the tidal range being then at its maximum. When neap tides occur, the tides are of minimum range, the high waters being lower ~~and low waters~~ and low waters higher than at other periods of the month. Since the horizontal motion of the water depends directly upon the rise and fall of the tides, it follows that the currents will be greatest at springs, and least at neaps.

The effect of the moon's being at full, or change is not felt at once in all parts of the world, and the greatest range of tides does not generally occur until one or two days thereafter; thus, on the Atlantic coast of Europe, two days afterward, though on the Pacific coast of North America they occur nearly at full and change.

The formation of the seacoast itself also makes a great difference in the range of the tide. In estuaries and bays, where the water pile up on itself, the range of the tide may be very high. The shape, size, and depth of seas or oceans make differences in the way the tide acts. For example, the Atlantic Ocean has tides that flow and ebb regularly, twice a day, But, some Pacific islands have mixed tides, such as two high tides daily, with only a little ebb between, and then a very low tide. At St. Michael, Alaska, and certain places along the Gulf of Mexico, there is only a daily tide. This is a slow, deliberate rise and fall of water with only one high tide and one low tide each twenty four hours. Tides in coastal seas, such as the English Channel, and the RedSea depend on oceanic tides; if these seas were cut off from the oceans, the tides in them would be almost imperceptible. Another observation shows that when we find a large vertical rise and fall of tidal water we know that enormous quantities of sea are also flowing horizontally from one place to another; in the Bay of Fundy tidal currents twice daily move 100,000,000 tons of water. In restricted passages and straits these tidal currents sometimes attain speeds of more than ten knots, as theydo in Discovery Passage and in Seymour Narrows, British Columbia. In coastal seas tidal currents frequently attain speeds of two or three knots, but in the open oceans they are rarely more than a quarter of a knot.

Now that we have had a short course on the origin, characterists, and behavior of tides, I would like to spend the remainder of this paper on the developments which have occured in connection with the harnessing of the tides for electrical power purposes.

Tidal mills were built in Britain, France, and Spain as early as the twelfth century. In fact a mill powered partially by tidal energy was built at Port Royal in 1607, and two tidal grist mills were operated in

Passamaquoddy Bay prior to 1800. TIDAL POWER AT LAST, is the title of an article in the Literary Digest of Jan. 22, 1921, in which a plan is described for developing the tidal power in the Severn estuary in Great Britain. Yet only France and the U.S.S.R. have actually built stations which generate electricty from the tides, and these only recently. In 1966 Electricite de France offically inaugerated the world's first commercial tidal-electric generating station. It is located at La Rance, where the Cherbourg Peninsula, partially blocking the tidal flow into the Channel, causes an amplification of the tidal range to a maximum of about 45 feet. La Rance has a power installation of 240 megawatts and a net annual energy production of 544 gigawatt-hours. By comparison, the Mactaguac Dam o n the St. John River(New Brunswick) has an installed power capacity of 420 megawatts, and an annual energy output of approximately 1500 gigawatt-hours. In the USSR an experimental tidal power generating station was commissioned in 1968, with a capacity of less than one megawatt and a primary purpose of testing materials, equipment and new systems of construction in an artic marine environment.

61.5 meg. peak
92.5 capacity
40 for 10 yrs.

The only practical way of harnessing tidal energy is to close off an inlet, where there are very large tides, with a structure fitted with sluice-ways which permit the tidal basin to fill on the rising tide. At high tides the sluices are closed, and when the tide has dropped sufficiently to provide a significant operating head(the difference in elevation betwen the water levels in the tidal basin and the sea) the stored water is released through turbines which turn generators. The generating heads are low compare to those that occur, or can be created, in rivers, and the generating period is limited to between four and seven hours duration in each tidal cycle. However, an enormous volume of water is changed with each tide and is, therefore, available for generating electricity. In round figures, for every foot that an amount of 1500 tons of water falls in its journey through a turbine, one kilowatt-hour of energy is produced. As the energy production is proportional to the head, a tidal basin will store more potential energy during spring than neap tides.

A number of schemes have been put forward for improving the scheduling of tidal power. In the Single-Effect operation, the cycle begins with the opening of the sluice gates, which allows the incoming tide to fill the basin. The gates are then closed and there is a waiting period that lasts until the outgoing tide has created sufficient head, which occurs when the head is aboout half the tidal range. Generating then begins and continues until an hour or two past the turn of the tide, when the head has reduced to the point where operation is no longer practical. There is another short waiting period until the tide reaches basin level, then the gates are reopened and the cycle repeats. A little extra power can be obtained by pumping water into the basin while the tide is near the high, thus somewhat increasing the available head.

In the Single-Effect operation, the power potential is picked up on the ebb tide. However, in the Double=Effect operation, power may be generated on the rising tide as well. Although there is less energy available for generation-- the flood tide compared to the ebb, there are advantages. Double-Effect operation is the mode employed at La Rance, France. This has been made possible by the development of turbines which can operate in either direction,and thus can also be used as pumps. For the same installed capacity,the amount of energy produced from Double-Effect is not normally more than Single-Effect, but is available for more hours per day. In addition, a Double=Effect capability adds operating flexibility to a plant, because it can then also be used under a Single-Effect mode on either the emptying or filling phases of the cydle, and thus its usefullness for providing peak power is about doubled.

The series of studies of the Bay of Fundy proper started in earnest in 1944 with a Canada-New Brunswick examination of a two-basin concept for the Petitcodiac and Memramcook Rivers, linked by a canal with a power-house. This idea was found to be uneconomic. In 1966 a comprehensive analysis was financed by the Governments of Canada, New Brunswick, ar Nova Scotia. Responsibility was given to the Atlantic Tidal Power Pro= gramming Board whose report "Feasibility of Tidal Power Development in the Bay of Fundy" was published in 1969. Twenty-three potential sites were examined, and three sites were finally selected, namely in Shepody Bay, Cumberland Basin, and the one at the mouth of the Cobequid Bay(Truro) The Board examined the engineering, economics, and marketing aspects of these three sites and concluded that developing power from the tides was technically feasible, but at the time, not financially competitive with alternative energy sources such as oil and coal. Its recommendations were that the question would be re-evaluated-- if improvements in marine construction methods PROMISED lower capital costs, if interest rates declined, if imported fuel prices increased, or if the need for environmenta protection rendered fossil-fuel generation more costly. To monitor the changing situation , the participating Governments in 1972, appointed the "Bay of Fundy Tidal Power Review Board." By 1974, the introduction of long-overdue environmental safe=guards resulted in significant increases in the producers costs of generating electricity; but quadrupled oil prices not only improved the possibility of tidal power being competitive with thermal in price, and ALSO brought home the realization that oil is a depleting resource whereas tidal energy is eternally renewed-- twice a day, every day. Therefore, on Dec. 3, 1975, the Governments of Canada, New Brunswick, and Nova Scotia agreed to finance the ncessary investigation, with three members from Canada, and two each from New Brunswick, and Nova Scotia, making up the Management Committee.

A major portion of the energy displaced by tidal power would come from oil-fired generation.

As additional background, present energy demands, and inputs should be given. Primary energy demands for all purposes in the Atlantic Provinces are generated from 10% by hydro resources, 6% from coal, and imported oil 84%. Inputs to the Maritime Provinces only, come from oil 48%, coal 12%, and hydro 40%.

In summary, the Fundy Tidal Power Review Board determined that the exploitation of tidal energy is attractive for the following reasons:

1. It would provide for exploitation of an indigenous resource of renewable energy and through reduction of demand for dwindling fossil fuel supplies, conserve foreign exchange.
2. The characteristics of hydro-electric plants-- for example, long plant life and annual costs which are almost completely dependent upon the magniturde of investment cost, apply also to tidal power.
3. The costs of tidal energy can be expected to remain relatively stable throughout plant life, whereas costs of thermal energy can be expected to increase with the passage of time
4. It would lead to reduction of system generation costs in the Maritimes over the project life compared to those which would be incurred without tidal power.
5. It would provide some measure of security against unforeseen escalation of generation costs.
6. It would lead to lower envioronmental pollution loading compared to generation expansion programs without tidal power.
7. It would place Canada in the forefront of a technology of world wide interest and offer an opportunity to develop industrial capacity and technology applicable not only to tidal power, but also to low-head hydro-electric developments, which are increasing in interest and importance.

As mentioned previously, three sites were finally designated as the most desireable. Based on plannet plant capacity, cost, and projected in service costs, the middle figured site was found to be the most practical namely, the Cumberland Basin location. Because the minimum investment would be about $3 billion, and because this would result in an inordinate financial burden being placed upon utility customers in the early years, financial feasibility of a tidal power plant would be conditional upon substantial direct participation by governments involved. This was estimated to be at 33% of the capital cost for the proposed Cumberland Basin site.

COBEQUID # 9,290 MW

The Net Plant Capacity for the Cumberland Basin project would be 1085Megawatts(one MW is 1 million watts), and the Average Annual output of 3,423 Gigawatts(one GW is on billion watts). [The tidal plant and transmission Link costs would be 1.2 billion, and Projected in-service costs of$3.1 billion.] Projected in-service costs assume for purposes of the study, the commissioning by 1990, and include escalation and interest during construction; development would require about ~~would require about~~ seven years to complete. Taking all the benefits and costs into consideration, it was concluded that the break-even period is about 60 years. By the year 2010, comparing cost of serviee for the "with" and "without" tidal power, there appears to be about a 2% differential <u>decrease</u> in the level of electrical rates.

omit

As stated before, governmental financial involvment would be unavoidable. The Maritime Provinces would find it impossible to incur the debt required for a Maritime Integtated System and still maintain an "A" credit rating. Per capita debt, using Comberland Basin costs, would rise ~~to~~ FROM $611 in 1976 to $2,710 in 1990. The per capita debt, without tidal power, but adding to present generation facilities, would mean an increase from $611 in 1976 to $2,080 in 1990.

The Board therefore, recommende that funding be provided in 1978 to complete detailed investigations and definitive designs, including detailed specifications, for a singel=effect basin tidal power development at the Cumberland Basin site. Further recommended that instituational arrangements be established for execution of the detailed investigations and definitive designs. And finally, that immediate consideration be given to the resolution of the financial constraints to developing tidal power, which would identify governnment financial participation, and in turn facilitate the raising of necessary capital. The latter would then provide for maintaining the cost of services to utility customers in the Matitime region at levels which would not exceed, on an annual basis, the cost of service which would arise through an optimal expansion of generation facilities without tidal power.

letter > I trust this discussion will allow you to better appreciate the potential of tidal power, but also permit you to realize that there are many facets to what might have appeared to be a simple solution to the power problems of the Maritime Provinces.

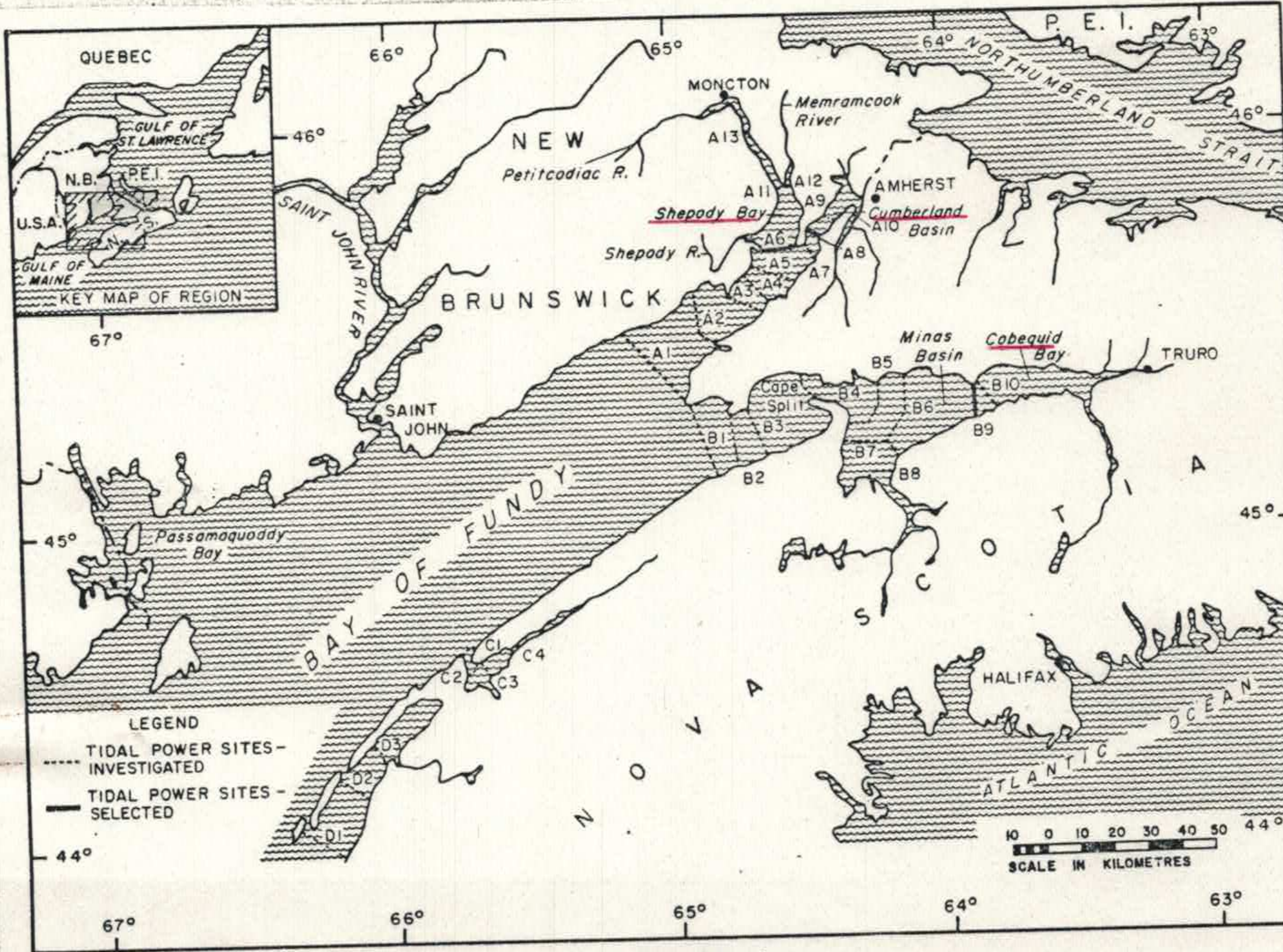

Fig. 3. Bay of Fundy.