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January 2011

Energy Calculations: Carryingplace Cove / Trescott, Maine

The area under consideration is illustrated below in Figure 1 (North direction is up along the vertical edge). The proposed location of the tidal barrage is at the western end of the entrance from Whiting Bay to Carryingplace Cove (see Figure 2).

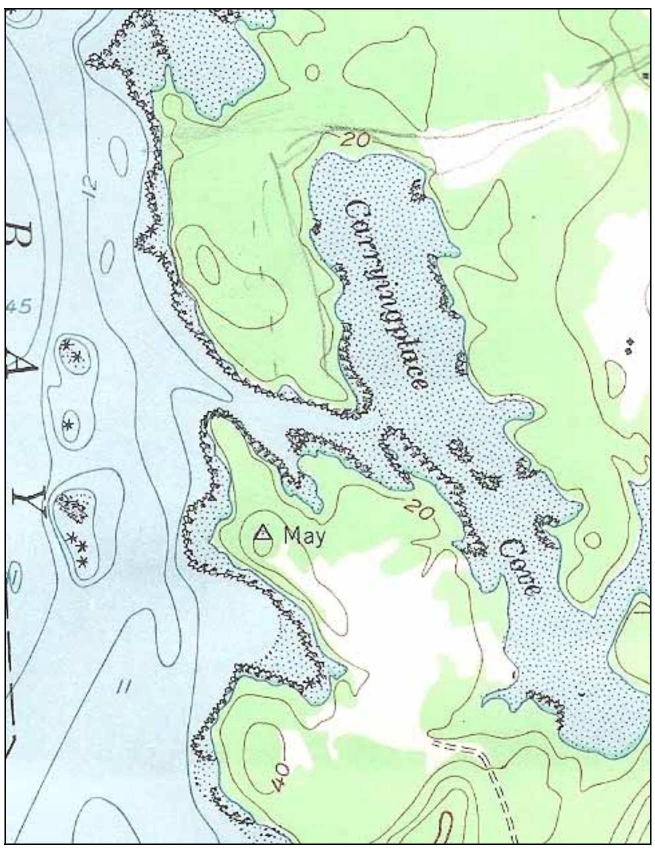

Figure 1: USGS (Whiting Quadrangle) / Unspecified Scale

The physical dimensions of Carryingplace Cove (CPC) are listed below in Table 1. In terms of the key parameters for determining the feasibility of a tidal barrage, the width (275') and the maximum depth (7' at lowest low tide) are extremely important in formulating project specifications.

NEAP TIDE AREA	5	ACRE
LOW TIDE AREA:	6.79	ACRE
HIGH TIDE AREA	97.32	ACRE
SPRING TIDE AREA	100	ACRE
LENGTH OPEN.	275	FT
MAX. DEPTH – Lowest Low Tide	7	FT
Volume (0' *-4')	23.58	acre-ft
Volume (4'-22')	936.99	acre-ft
Volume (22'-26')	394.64	acre-ft
* 0.0' Refers to Lowest Low Tide Level		
SPRING TIDE	26	FT
NEAP TIDE	12	FT
AVE. TIDE	18	FT

Table 1: Key Physical Parameters for Carryingplace Cove

The surface area of Carryingtplace Cove is approximately 100 acres for the highest tide levels. The tidal basin nearly drains out for the lowest low tides except for the entrance to Carryingplace Cove from Whiting Bay. In Table 1, the basin's volume is listed for three areas of interest as referenced to three corresponding water depth elevations. For an average tide, the basin level varies from 4.0' to 22' or a difference of 18' which is the average tidal range for Cobscook Bay. Under spring tide conditions, the water level varies from 0.0' to 26.0' where 0.0' designates the lowest low tide reference point. For neap tides, the water level ranges from approximately 7.0' to 19.0'. During a typical lunar cycle of approximately fourteen (14) days, the low tide level varies from 0.0' (spring tide) to 7.0' (neap tide) and the high tide level varies from 19.0' to 26.0'.

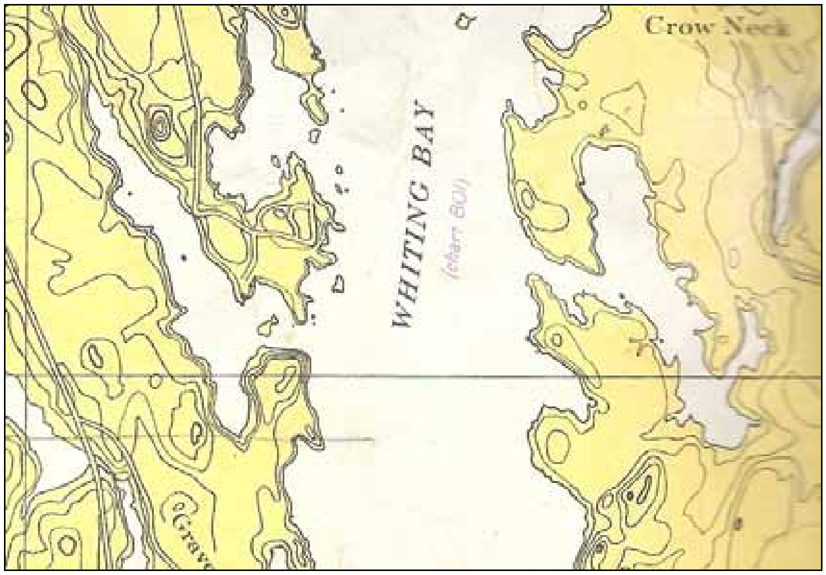

Figure 2: Location of Carryingplace Cove with Respect to Whiting Bay

Because of a periodic behavior in tide levels, certain areas of the intertidal zone in Carryingplace Cove are intermittently covered by tidal waters (upper end during a spring tide) and intermittently unexposed to tidal waters (upper end during a neap tide). A spring tide results in the greatest active area of intertidal zone as measured from lowest low tide level to highest high tide level. The periodic nature of the tides varying under spring to neap conditions defines an intertidal zone during a lunar cycle with less than steady-state environments. The only area in the intertidal zone which always experiences an exposed - unexposed regime within a 12 hour and 25 minute tide cycle is the area between highest low tide and lowest high tide; i.e., neap tide. For this reason, organisms and plants residing in the intertidal zone in the areas 0.0' – 7.0' and 19.0' – 26.0' are adaptable to a varying schedule of tidal action as represented by a high tide and low tide level which each vary by approximately seven (7) feet during a lunar cycle.

In designing a tidal barrage project for Carryingplace Cove, a decision was made to minimize the impacts on the tidal range within the impoundment. The reduction of tidal range within a barrage has been historically considered as the greatest environmental consequence of this type of development. Tidewalker Associates has addressed this concern by applying hydro-kinetic technology and incorporating an innovative mode of operation while attempting to maintain natural tidal flows. Figure 3 below is a plot of water level versus time for a natural function (Series #1) and a proposed basin level curve for this proposal (Series #2) where ∂ refers to an operational parameter controlling the amount of sluicing through the flexible dam to minimize the impacts on the intertidal zone. Details on ∂ appear later in this discussion.

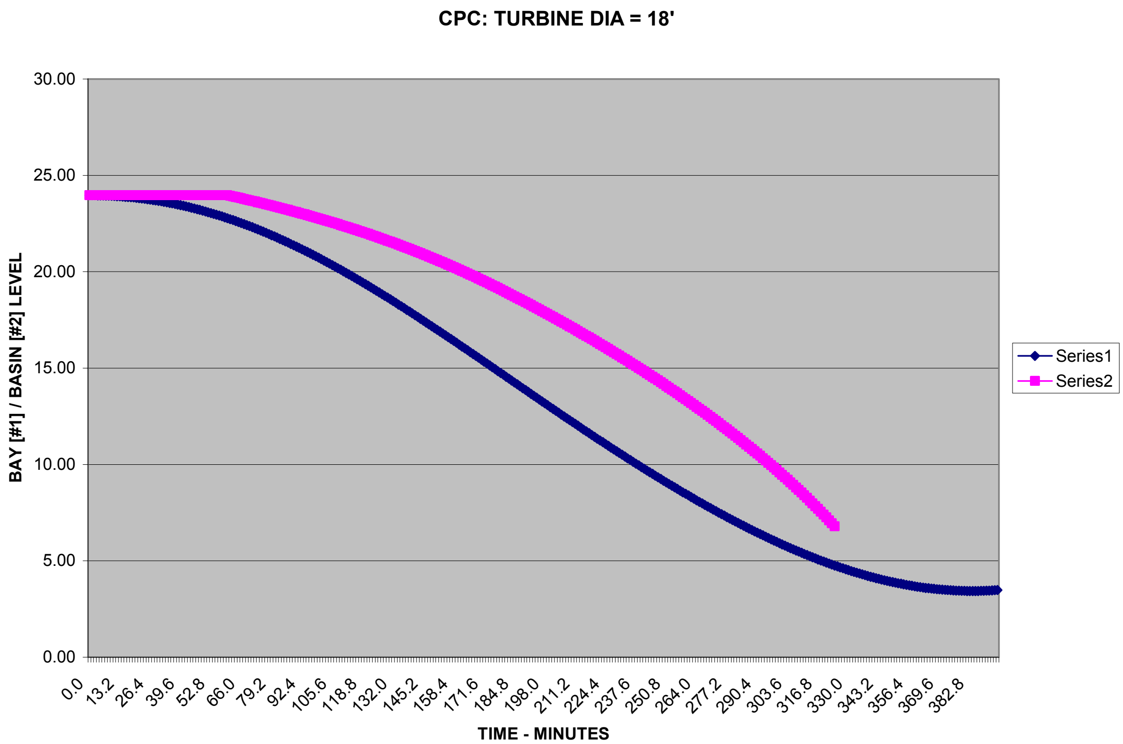

Figure 3: Water Level versus Time (Sluice Factor, ∂ = 0.75)

For this conceptual mode of operation, generation of electricity starts one hour after high tide and continues until one hour before low tide. Series #1 depicts a natural tide function with a vertical range of approximately twenty (20) feet. Series #2 depicts the basin level from high tide until the end of ebb tide production. For this example, the end point of production results in an elevation difference of 2.03 feet between the basin and receding level of Cobscook Bay. In theory, the generation of electricity will continue until a head of approximately one foot exists between water levels in the impoundment and Cobscook Bay. The design will also include a mechanism to release additional tidal waters from Carryingplace Cove in order to minimize the difference in elevation with Whiting Bay and, thereby, minimize impacts on the intertidal zone. A possibility also exists to use the reversible turbine to power a pump starting one hour before low tide and while the head reduces from 2.03’ to around 0.5’.

At low tide, the procedure is repeated for the flood tide but in a different direction. Gates are closed for one hour after low tide and generation continues until one hour before high tide. An equalization process in the respective water levels will occur up to high tide with the potential for the turbine to power a pump. Flexible gates also provide a mechanism to increase tidal flow between the two adjacent bodies of water as part of sluicing without reducing flow through the turbine(s).

An analysis was performed to determine the pertinent operational factors for a tidal barrage placed at the entrance to Carryingplace Cove. Details of the calculations appear later; however, end results are listed in Tables 2 and 3.

EQUIVL. CIRCULAR TURBINE DIAMETER [FT]	TURBINE AREA FT^2	AVERAGE POWER KW	TOTAL EBB ENERGY [KW-HR]	AVERAGE HEAD [FT]	BASIN / SEA ELEVATION DIFF. [FT] @ 1 HR BEFORE LOW TIDE
12	113	607	2685	7.03	11.44
14	154	495	2189	5.98	8.71
16	201	383	1696	4.82	5.55
18	254	280	1241	3.62	2.03
20	314	195	862	2.52	0.03

Table 2: Results of Energy Calculations for Different Turbine Specifications: Ebb Tide Production (∂ = .75)

Table 2 ($\partial = 0.75$) summarizes the analysis of plant simulations for various turbine options under the same mode of operation illustrated in Figure 3; i.e., operation one hour after high tide to one hour before low tide. Energy generation decreases with an increase in turbine diameter along with a more desirable equalization of basin and Cobscook Bay levels. This analysis has not included an economic evaluation to determine the actual cost of producing electricity and has not included the energy possible of being generated with flood tide operation which is only possible when the turbine diameter is greater than or greater than 18' as a way to minimize intertidal impacts.

Flood tide production is only possible when the impoundment approaches natural low tide conditions. As a rough estimate, flood tide production is approximately 75% - 85% of ebb tide production. Under this scenario, a tidal barrage with a cross-sectional area of 254 ft^2 (18' diameter) will generate nearly the same amount of energy as a turbine with an equivalent diameter of 14' by adding flood tide production into Table 2 estimates. The other major environmental difference between a 14' and 18' diameter is presented in the right-most column of Table 2; i.e., basin / sea elevation difference. In our opinion, the prospect for permit / license approval are much greater for the 18' diameter design than the option with a 14' diameter turbine.

Figure 4 below illustrates turbine efficiency as a function of hydraulic head for a hydro-kinetic turbine with a circular diameter of eighteen (18) feet. In order to have an equivalent circular area of 254 sq. ft., three (3) rectangular turbine cross sections with dimensions of 7' x 12' will provide the same opening for the transfer of tidal waters through the power house. In this case, the rectangular units will be well suited for the actual dimensions of the entrance to Carryingplace Cove; i.e., seven (7) foot depth at lowest low tide. The Gorlov Helical Turbine (GHT) has the appropriate characteristics for this type of installation which includes the installation of a float-in power house and use of a flexible dam design.

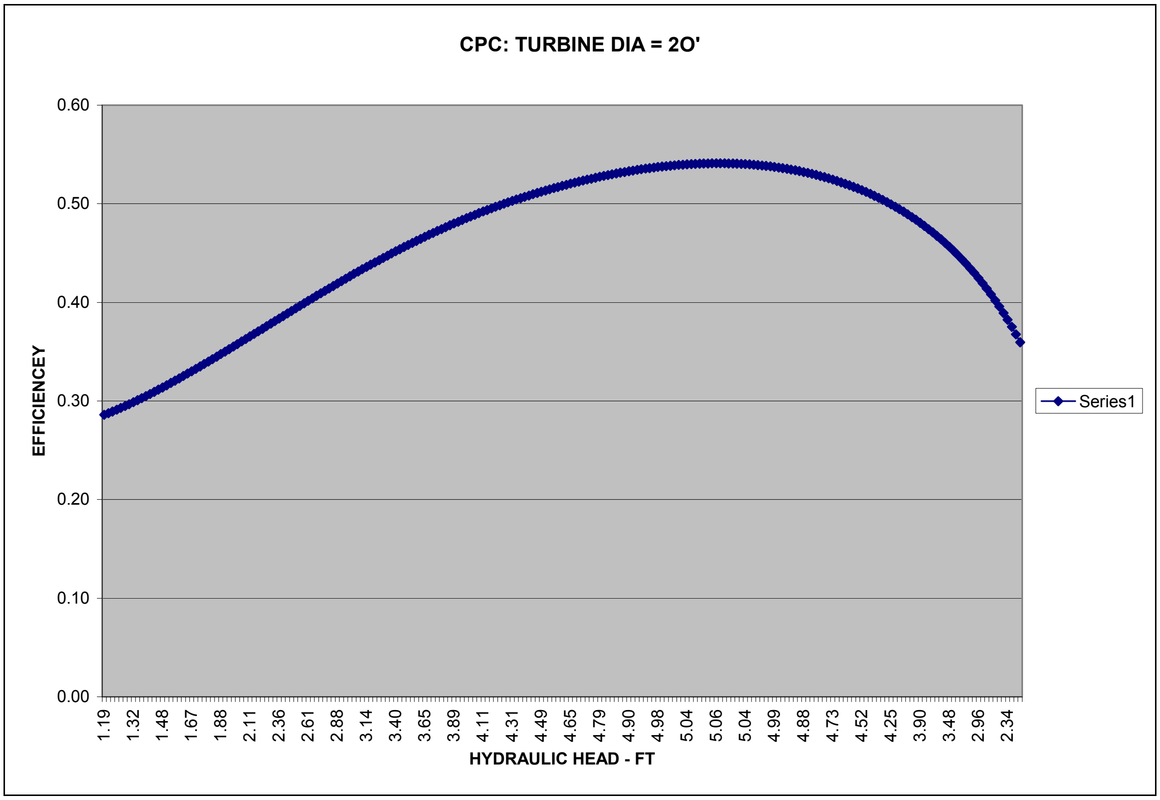

Figure 4: Theoretical Efficiency as Function of Hydraulic Head (ft)
TIDAL RANGE = 20' / ∂ = 0.75

The preliminary analysis of tidal barrage options for Carryingplace Cove also provided information on other relevant factors as listed in Table 3. Once again, the importance of being able to minimize the impacts on the tidal range within the impoundment has to be stressed in terms of being able to obtain regulatory approval for the project's construction and operation. The fact that capacity factor does not vary substantially for the different options listed in Table 3 is an artifact of the calculation algorithm. As expected, the velocity through the turbines is greater for the smaller diameter unit which results in the highest theoretical efficiency. Another environmental concern refers to the ability of fish to pass through turbines without an abnormally high mortality rate. Less fish mortality is expected with lower rotational rates for the turbines which is directly related to the maximum velocity of tidal waters through the turbine(s).

EQUIVL. CIRCULAR TURBINE DIAMETER [FT]	BASIN / SEA ELEVATION DIFF. [FT] @ 1 HR BEFORE LOW TIDE	CAPACITY FACTOR	MAXIMUM EFFICIENCY	MAXIMUM VELOCITY [FT/SEC]	AVE. HEAD [FT]
12	11.44	0.44	0.79	23.08	7.03
14	8.71	0.44	0.71	20.43	5.98
16	5.55	0.44	0.62	17.79	4.82
18	2.03	0.44	0.54	15.34	3.62
20	0.03	0.44	0.47	13.21	2.52

Table 3: Other Tidal Barrage Parameters for Turbines with Different Cross-sectional Areas [∂= .75)

The hydrological model for turbine selection has to be refined to include the consideration of spring and neap tides. With the use of a flexible dam, Tidewalker is confident that natural high tide levels are attainable in Carryingplace Cove under this mode of operation for tides varying from neap to spring conditions.

For energy calculations, the following assumptions were made on: (1) efficiency (μ) of the turbine to generate electricity; (2) draft tube coefficient (Ω_d); (3) sluicing (emptying / filling gates) factor (∂); and, (4) coefficient (solidity) of turbine (Ω_t) to transform kinetic energy into rotational (generator) power. Tidewalker assumed an efficiency of 0.7 and 0.1 for water velocities of 20.27 fps (12 knots) and 1.69 fps (1 knot). A coefficient of 0.85 was assumed for draft tube efficiency. Based on GHT specifications, a solidity coefficient of 0.85 was assumed for the calculation of energy over a constant time interval of 1.2 minutes. The sluicing factor was varied to optimize environmental conditions.

The method used for calculating energy and other relevant parameters is outlined below:

- NOAA power series for Cobscook Bay was used to calculate Whiting Bay levels for a representative tide in 1.2 minute intervals

- For ebb production, basin level was assumed to remain level for one hour after high tide and low tide and to then vary in accordance with basin volume passing through the turbine(s)
- Dimensions of Carryingplace Cove were used to determine basin volume as a function of tide elevation; three (3) zones were delineated from (i) 0.00' to 4.00', (ii) 4.00' to 22.0', and (iii) 22.0' to 26.0' to represent the range of spring tide to neap tide conditions; range of neap variation was included in the second zone from 7.00' to 19.0'; straight line extrapolation was used to determine volume elements in respective zones
- At the start of production, head (H) was defined as the difference between Whiting Bay level and basin level; velocity was then calculated as the product of: $(\Omega_d)(2*g*H)^{0.5}$
- From the assumed cross-sectional area, turbine discharge (cfs) was calculated as the product of: (Area)(Velocity)(Time [sec])
- Linear function for efficiency (μ) was dependent on water velocity as previously described
- Energy (lb_f ft) for time interval was calculated as Kinetic Energy: $(0.5)(\mu)(\text{Vol Incr.})\ (\Omega_t)\ (\text{Density} - 64\ lb_m\ /\ ft^3)(\text{Vel})^2/(32.2\ lb_m\ ft\ /\ sec^2)$
- Basin control factor was included in the energy algorithm to incorporate the ability to discharge excess volume when the discharge capacity of the turbine exceeded the natural volume decrease of Whiting Bay for discrete time increments; by taking these measures, the head was lowered and the sluicing capacity increased to result in an acceptable final basin elevation at the end of ebb tide operation; the factor, (∂), was varied in order to determine the optimum sluicing rate to control the basin level; Table 4 below illustrates the effect of a varying "∂", sluice factor, for a constant turbine diameter
- Power for each time increment was calculated from the division of energy by time
- Capacity factor which is a questionable parameter for a tidal barrage was calculated by dividing the annual energy output by the product of capacity and number of hours in a year
- Elevation of basin was determined by using the volume equation to solve for the corresponding elevation

∂, SLUICE FACTOR	TOTAL ENERG Y [KW-HR]	AVE. POWER [KW]	AVE. HEAD [FT]	AVERAGE EFFICIENCY	SLUICE VOLUME [ACRE-FT]	ELEV. DIFF. AT END OF PROD. [FT]
0.00	1481.00	335.00	4.79	0.51	0.00	9.12
0.25	1391.00	314.00	4.39	0.50	119.00	6.79
0.50	1311.00	297.00	4.00	0.48	213.00	4.40
0.75	1241.00	280.00	3.62	0.46	276.00	2.03
0.90	1205.00	273.00	3.42	0.44	297.00	0.81
1.00	1183.00	267.00	3.29	0.44	303.00	0.26

Table 4: Operational Parameters for Turbine Diameter = 18.0 Ft

The behavior demonstrated in Table 4 emphasizes the importance of having sufficient sluicing capacity besides the actual turbine discharge to control the level of the basin to minimize the impact on the intertidal zone at the end of ebb and flood production. In comparing the results in Table 4 for a sluice factor of 0.75 and 0.90 for a turbine with a net effective diameter of 18 feet, the major difference refers to the elevation different at the end of production; i.e., 2.03' and 0.81', respectively. The capacity factor for all the options listed in Table 4 is virtually equal to 0.44 which is representative of a "run-of-tide" mode of operation.

Figure 3 provides an illustration of the mode of operation for a sluice factor of 0.75. One hour is available before low tide for the basin level to equalize to the level of Cobscook Bay which represents an elevation difference of 2.03' for a turbine(s) with an equivalent diameter of 18 feet. During this period before low tide, the turbine is still able to generate electricity under a head of 2.0' down to as low as 0.5'. The turbine output can be fed into the grid or can be used, as previously mentioned, to power a pump to supplement the sluicing capacity of the flexible dam. Under this scenario, Tidewalker estimates in a basin level which is less than 0.5' higher at low tide than natural Whiting Bay conditions.

The process is repeated for the flood tide under the same mode of operation. The ability to raise the basin level to normal high tide level is a critical factor which will require an adjustment to the sluicing factor (∂). The final mode of operation will require a more refined hydraulic model in order to optimize energy production while still ensuring acceptable environmental conditions. A flexible dam combined with an appropriately sized turbine will assist in finalizing production factors under a predictable schedule for neap and spring tides.

The average power value has been used to calculate capacity factor, a term which is more appropriate for typical "run-of-river" projects. A common definition for installed or nameplate capacity for a hydro-electric facility is the power value available for 95% of the time. Since a tidal barrage does not have any production for approximately four hours in a 12 hr and 25 min cycle, the use of the 95% criteria results in an installed capacity of zero. For a tidal barrage, the 95% criteria applied for the periods of actual production will result in an installed capacity less than the average power level which results in a higher capacity factor. The key parameter for a tidal plant is the actual cost of production which requires a consideration of economic and financing assumptions. Based on preliminary data, the cost of production at CPC is expected to be less than eight cents per kw-hr.

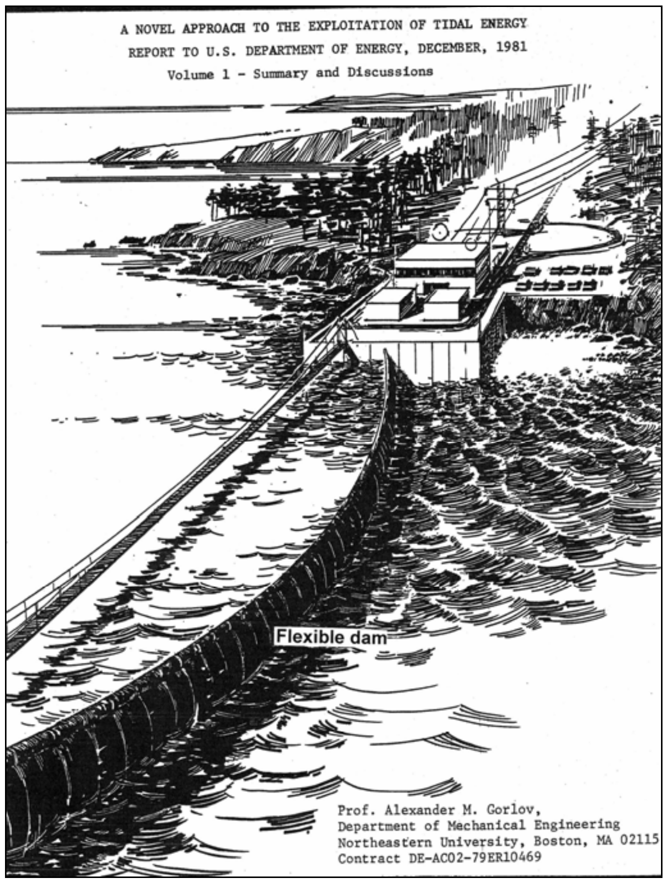

Figure 5: Conceptual View of Tidal Barrage with Flexible Dam (Gorlov)

Except for the power house on shore, Figure 5 closely resembles the tidal barrage envisioned for the opening to Carryingplace Cove (Trescott).