10218

DOE/R4/10218--T1

DE84 000385

DOE/R4/10218--T1

SC-80-006

DEPARTMENT OF ENERGY

TIDAL POWER IN SOUTH CAROLINA

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CUBIT
ENGINEERING
LIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CUBIT ENGINEERING LIMITED

December 29, 1981

W. I. "Buck" Chapman, Jr.
Division of Energy Resources
1122 Lady Street, Room 400
Columbia SC 29201

Dear Mr. Chapman:

We are pleased to submit this report which summarizes our research of the application of tidal power in the South Carolina coastal region. This document culminates our study as authorized by the Appropriate Technology Small Grants Program under grant number DE-FG4480R410218.000.

Our report concludes that significant energy resources exist for small scale utilization. The report further recommends that more definitive study concerning the development of practical extraction devices be undertaken to fully determine the merit of the concept. We have appreciated the opportunity to participate in the Appropriate Technology Small Grants Program and we look forward to your review and comments on our report.

Very truly yours,

CUBIT ENGINEERING LIMITED

Ben L. Sill, Ph.D.
Vice President

jm

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FEASIBILITY STUDY
for
LOW-HEAD TIDAL POWER IN SOUTH CAROLINA

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

FR44-80 R4 10218

Cubit Engineering Limited
Clemson, South Carolina

December, 1981

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE.

It has been reproduced from the best available copy to permit the broadest possible availability.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

Title	Page
1.0 INTRODUCTION	1
2.0 POWER AVAILABILITY	3
3.0 POWER EXTRACTION	10
3.1 Low Head (Water Surface Elevation) Turbines	10
3.2 Run of the River Mechanisms	11
3.3 Type (a) Machines	15
4.0 CONCLUSIONS AND RECOMMENDATIONS	17

LIST OF TABLES

	Page
Table I. Hydraulic Characteristics of Candidate Tidal Power Sites at Mean Low Water; South Carolina-Georgia	7
Table II. Estimated Tidal Power Output for Candidate Sites Using Type (a) Machines	14

LIST OF FIGURES

	Page
Figure 1. Typical mean tidal ranges for a portion of the Atlantic Coast.	2
Figure 2. Average total tidal power available for a portion of the Atlantic Coast.	5
Figure 3. Candidate tidal power sites, South Carolina	8
Figure 4. Candidate tidal power sites, Georgia side of Savannah River mouth	9
Figure 5. Power (kw) produced by type (a) machines related to candidate site depth, surface area, and tidal range.	16

1.0 INTRODUCTION

In recent years, the production of power by low-head hydroelectric generation has received much renewed interest. One possible application of this technology is in coastal areas with tidal excursions large enough to power these generators. This requires that sufficient water be displaced during each tidal cycle to allow operation at relatively high system efficiencies. Adequate assessment of the opportunities for tidal power requires detailed analysis of the coastal and estuarine geography, tidal ranges, and the capability of low-head hydroelectric units. The present study investigates the feasibility of such installations for coastal South Carolina.

It is obvious that the greater the tidal range, the larger the amount of potential power available. The South Carolina coast experiences some of the higher tides in the southeast. In fact the highest values south of Maine occur on the South Carolina-Georgia border (7 ft mean tidal range), and the 200 miles of South Carolina shoreline experience an average mean tidal range of 5.5 ft. The average tidal range increases from about 4.5 ft on the North/South Carolina border to approximately 7 ft at the South Carolina-Georgia border at Savannah. Figure 1 depicts the mean tidal ranges from Virginia to Miami, Florida. Based on this observation if tidal power is not feasible in South Carolina then it is likely not feasible elsewhere in the southeastern United States.

A second important criteria essential to the production of tidal power is that of ample water storage. In other words, there should be estuaries or harbors which serve as reservoirs for the tidally influenced water. South

Figure 1. Typical mean tidal ranges for a portion of the Atlantic coast (Ref. 1).

Carolina contains numerous estuaries ranging in size from several acres to major harbors (such as Charleston). These, coupled with the moderate tidal range comprise the necessary ingredients for successful utilization of tidal power.

Despite the desirable features mentioned above, other locations have more impressive qualifications. For instance, the well-known Bay of Fundy tides exceed fifty feet in range. Such sites are few in number however, so that investigation of areas with smaller tidal ranges is worthwhile simply because of their great number.

This report details the possibilities of extracting tidal power from sites with moderate tides and naturally occurring storage locations (estuaries). The important points covered include: available power, power extraction, and the best locations and techniques to utilize the tides in South Carolina.

2.0 POWER AVAILABILITY

There are several ways in which to discuss the power contained in the tidally influenced coastal waters. During a flood tide, water elevations increase to a maximum and energy is stored in the form of potential energy in bays and estuaries. The amount of this energy can be readily calculated since it may be extracted over about one half of a tidal cycle (approximately six hours). Alternately, the power contained in the flow can be computed based on the momentum flux of the flowing water. Both approaches yield the same results. If the average power is approximated by utilizing one half of the tidal range H , then the power available (in kw) per unit surface area (acres) is given by

$$\frac{P}{A_s} \begin{matrix} \text{(kw)} \\ \text{(acres)} \end{matrix} = 0.043 H^2 \quad (1)$$

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Figure 2. Average total tidal power available for a portion of the Atlantic Coast.

This minimum cross sectional area can be produced by modifying the banks into an hourglass shape (Venturi section). Finally Eq. (6) can be simplified to

$$A_{cs} \text{ (ft}^2\text{)}_{\min} = A_s \text{ (acres)} (0.35) H^{\frac{1}{2}} \quad (7)$$

by assuming $t = 6$ hours.

The above expressions are presented in simplified form but are useful for estimating the power available in tidal situations. Since a portion of the analysis will be to compare various sites along the South Carolina coast the comparison will be relative rather than absolute, thereby minimizing the errors introduced by using the simple equations.

A second step in investigating the availability of power is to examine the general characteristics of various locations in coastal South Carolina. Since Eq. (1) shows that the power produced depends on the square of the tidal range, areas having larger tides are preferred. This suggests (see Figs. 1 and 2) that the best sites will likely be located near the South Carolina-Georgia border. Table I is a list of pertinent estuary characteristics for twenty-two candidate sites in South Carolina and extending 15 miles along the Georgia coast; these sites were selected from navigation chart information and they represent the most likely areas where tidal power extraction could specifically be considered. Their locations are shown in Figs. 3 and 4.

By using Eq. (1) the power available from each of the sites in Table I can be calculated. This is given as the final column in Table I, and represents the total average power content of the tidal excursion. As would be expected, some of the larger values occur near the S.C.-Georgia border where tidal ranges are large. As shown in Eq. (1) the surface area of the bay or creek storing the water is important, i.e. more power is available when larger quantities of water are stored.

TABLE I. HYDRAULIC CHARACTERISTICS OF CANDIDATE TIDAL POWER SITES AT MEAN LOW WATER
SOUTH CAROLINA - GEORGIA

No.	Location	Dist from state line	Depth (ft)	Width (ft)	Λ_{cs} (ft ²) $\times 10^{-3}$	H (ft)	Λ_s (acres)	Vol stored (acre-ft)	Tot. power potential P(kw)
1	Crooked Creek	15.4	6.0	827	10.4	6.6	352	2324	659
2	Vernon River	14.7	7.5	1345	19.0	6.6	950	6272	1779
3	Delegat Creek	14.2	12.0	414	7.7	6.6	354	2336	663
4	Romerly Marsh	8.8	10.0	724	12.1	6.7	465	3119	898
5	Little Tybee River	6.0	2.5	517	4.4	6.8	278	1890	533
6	Herb River	5.3	8.5	414	6.3	6.8	284	1928	565
7	Tybee Creek	2.7	8.5	724	11.1	6.9	1210	8349	2477
(+) South Carolina - Georgia (+) Border									
8	New River	4.8	8.5	724	11.1	6.8	1467	9976	2917
9	Brcad Creek	9.0	10.0	1034	17.4	6.8	827	563	1644
10	Jarvis Creek	13.1	7.0	621	8.1	6.7	1284	8603	2478
11	Trenchard's Inlet	23.0	9.0	2793	43.6	6.6	2307	15226	4321
12	Battery Creek	26.2	9.0	1034	16.1	6.6	936	618	1753
13	Chowan Creek	26.6	8.0	1448	21.1	6.6	747	4932	1399
14	Boyc Creek	29.8	12.0	931	17.1	6.4	774	4952	1363
15	Albergattis Creek	29.9	1.0	517	3.8	6.4	227	1456	400
16	Haulover Creek	31.0	1.0	414	3.0	6.2	189	1170	312
17	Middle Creek	33.4	2.5	621	5.3	6.0	138	826	213
18	McCalley's Creek	34.4	3.0	827	7.4	5.9	662	3900	991
19	Jenkins Creek	34.6	10.5	827	13.4	5.7	976	5563	1363
20	Bass Creek	38.1	5.0	414	4.4	5.7	155	881	217
21	Bohicket Creek	54.2	9.9	931	13.6	5.6	968	5422	1309
22	Folly River	69.1	15.0	827	17.0	5.6	1440	8065	1942

Figure 3. Candidate tidal power sites, South Carolina.

Note: See Table I for list of sites by number.

Figure 4. Candidate tidal power sites, Georgia side of Savannah River mouth.

The values for power as given in Table I are a means by which to judge the relative capacities of various sites. As calculated, these powers represent the maximum possible (assuming all power is extracted from all the water) available during a single ebb tide. Calculation of the power during flood tide is much more complex and will not be done here. Instead it will be assumed that the power availability during rising and falling tides is the same.

3.0 POWER EXTRACTION

This section discusses actual extraction of power from the tides. It is this process which involves machine efficiencies and the problems associated with installation and operation of a power extraction device.

Two broad classes of power extractors will be considered: (1) low head turbines and (2) "run of the river" mechanisms. It is possible to examine most of the advantages and disadvantages of each class without the necessity of specifying a particular design. This discussion follows.

3.1 Low Head (Water Surface Elevation) Turbines

The criteria for low head with regard to turbines is often taken from ten to sixty feet. Based on the values given in Figure 1, the mean tidal range for the Atlantic coast south of Virginia is not sufficient to qualify as "low head". Some turbines can operate with less than ten feet of head but the efficiency drops. The efficiency of most turbines when utilizing adequate head is 60 to 90 percent. If a turbine were selected for tidal power use in South Carolina, the two primary problems would be:

- (1) low to insufficient head
- (2) short operating periods

The short periods of operation are a result of the installation requirements. To obtain maximum head, an impoundment would be constructed and allowed to fill on flood tide. Gates would be closed to store the water until near low tide to obtain maximum head (maximum difference in water level). The stored water would then be discharged through a turbine to generate power. As a result operating times would be limited to several hours centered on low tide. Based on the previous discussion, even the maximum head (five to seven feet) is barely enough to operate a turbine. A second problem with this type of installation is that power is generated only on a falling tide since during the rising tide, the impoundment fills. It is possible to install turbines for use with each flow direction; however, the capital investment is increased substantially. Lastly, the impoundment itself creates a problem from an ecological standpoint; a dam would restrict free exchange of water (and biota) in the estuary, and this may have undesirable biological consequences.

3.2 Run of the River Mechanisms

This class includes devices which turn when placed in a stream of water. They are effective regardless of flow direction; however, their efficiencies are typically substantially less than for turbines. Probably the best known example of this category is the "old-fashioned" undershot waterwheel. Before discussing specific types, it is helpful to enumerate some of the advantages and disadvantages of these mechanisms.

Advantages:

- (1) They require a very low head (typically just flowing water);
- (2) they operate for both flood and ebb flows; and
- (3) they require no impoundment.

Disadvantages:

- (1) Low efficiency (20 to 40 percent):
- (2) they only intercept a portion of the flowing water; and
- (3) their rotation rate and power depends on the water velocity.

Despite these drawbacks, the advantages are sufficiently compelling to further explore the use of the run of the river mechanisms. This will be done by estimating the efficiencies of typical units and the percentage of the cross sectional channel area which can be effectively intercepted.

The theory for these devices is essentially identical to that for windmills, anemometers or other typical wind-driven systems. A good description of these is given in Golding and Harris, 1976, from which some expressions given below were excerpted.

There are two basic types of systems which operate in a run of the river mode:

- (a) machines whose rotors move in a plane perpendicular to the direction of water flow
- (b) machines whose moving surfaces rotate parallel to the direction of water flow

Power output is given by a generalized form of Eq. (2), or

$$P = C_p \rho \frac{A_s V_u^3}{2} \quad (8)$$

with V_u the upstream water velocity, and C_p a "power coefficient" with values from zero to one. In this expression, A_s is the area intercepted or swept out by the device.

It can be shown that maximum power of a windmill or type (a) machine is produced when the water velocity downstream (V_d) of the device is one-third that upstream ($R = V_d/V_u = 1/3$). Since C_p is expressed as

$$C_p = 1/2 (1+R) (1-R^2)$$

a maximum value for C_p of 8/27 results. Since the energy content of the water is given by Eq. (1) it follows that 16/27 or 59.3 percent is the maximum efficiency of such a system.

In a similar manner it can be shown that the maximum efficiency of a type (b) machine (with moving surfaces rotating parallel to the flow) is 33 percent although in practice it is usually considerably less than this. The well known anemometer used for measurement of wind speeds is an example of such a device. It is obvious that one of the primary drawbacks of such a design is that while the capture surface moves with the water during one half of their rotation, it moves against the flow during the other half. This causes a considerable loss of power. Although both type (a) and type (b) can be used, only the type (a) will be discussed since efficiencies of this type are nearly twice that of type (b).

Of the two types of machines, the consensus is that the type (a) or "windmill" configuration is the best for large scale installations. Since, however, the present tidal application must be installed in cross sections which are relatively wide and shallow, it may be that a type (b) machine would be most appropriate once a specific design was developed.

In order to evaluate the actual power availability of the South Carolina coast, the maximum possible values given in Table I can be rendered realistic through the use of appropriate efficiencies. This is done by including (1) the machine efficiency and (2) the effective flow cross sectional area utilized. This may be expressed by:

$$P_{\text{actual}} = (\text{Efficiency}) \left(\frac{A_{\text{used}}}{A_{\text{total}}} \right) P_{\text{maximum}} \quad (10)$$

for an estimate of the actual power available. Table II summarizes the available output for the candidate sites considered for type (a) machines.

TABLE II. ESTIMATED TIDAL POWER OUTPUT FOR CANDIDATE SITES USING TYPE (a) MACHINES

Location	(A _{cs}) _{min} (ft ²)	L (ft)	N	Fraction of area used	P (kw)	P x eff. (kw)
Crooked Creek	317	53	6	0.06	39	15
Vernon River	854	114	11	0.12	213	85
Delegal Creek	318	26	1	0.16	106	42
Remerly Marsh	421	42	3	0.20	180	72
Little Tybee River	254	102	23	0.16	88	35
Herb River	259	30	2	0.12	68	27
Tybee Creek	1112	131	12	0.17	421	168

(+) Georgia South Carolina (+) Border

New River	1339	157	14	0.17	496	198
Broad Creek	755	75	6	0.22	362	145
Jarvis Creek	1163	166	18	0.11	273	109
Trenchards's Inlet	2074	230	20	0.19	821	328
Battery Creek	842	94	8	0.19	333	133
Chowan Creek	672	84	8	0.15	210	84
Boyd Creek	685	57	3	0.22	300	120
Albergattis Creek*	201	201	66	----	---	---
Haulover Creek*	165	165	54	----	---	---
Middle Creek	118	47	10	0.15	32	13
McCalley's Creek	512	171	33	0.05	45	18
Jenkins Creek	816	78	6	0.24	327	131
Bass Creek	129	26	3	0.02	4	1
Bohicket Creek	802	89	7	0.17	222	89
Folly Creek	1193	79	4	0.32	621	248

*MLW depth must be at least four feet.

3.3 Type (a) Machines

Based on the discussion above, the efficiency of the type (a) machine will be taken as 40 percent. This value will be used as a constant regardless of water velocity.

Since the cross sections of each tidal creek or estuary vary, it is more difficult to estimate the amount of area which can be utilized. A simple expression for the area ratio is given by

$$\frac{A_{\text{used}}}{A_{\text{total}}} = \frac{0.785 N}{dL} \quad (11)$$

In this equation, N is the total number of units each of diameter D . Their spacing is assumed to be continuous over the channel width, and the channel cross section is assumed rectangular (width L and depth d). The decision on the clearance, W , needed between units and at the surface and bottom is somewhat arbitrary, however it should be at least two feet. The number of machines which can be installed is determined from

$$N = \frac{L-W}{D+W} \quad (12)$$

where N is an integer. The number of units allowable for $W = 2$ ft is given in Table II. The area fraction and actual power output for type (a) machines is also given.

In order to develop a technique for estimating the performance of this type of system, Eq. (10) can be combined with (1), (7), (11), and (12) to obtain

$$\frac{P/A_s}{(H/d)^2} = f(d) \quad (13)$$

This expression is plotted in Figure 5 with a spacing value of $W = 2$ ft. For this case, the depth at MLW must be at least 5 ft before any measurable power is produced.

Figure 5. Power (kw) produced by type (a) machines related to candidate site depth (feet), surface area (acres), and tidal range (feet).

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study has demonstrated that significant amounts of tidal power are available in South Carolina to provide energy to a single or small circuit group of domestic users. However, the methodology to convert the resource to a usable product presents some drawbacks. It has been shown that submerged propeller type machines are among the most promising devices to capture tidal power directly. The submergence requirement creates two production problems:

- 1) structure maintenance
- 2) direct conversion to electric power

Submerged turbines are not considered practical and gearing necessary to transfer electrical power (with appropriate 60 cycle frequency) to above water machines would impair efficiencies detrimentally. Indirect energy conversion is possible via connection of a submersible pump to the tidal power installation. The pump would charge an elevated storage tank which in turn would service a vertical penstock/turbine assembly. The concept has cost drawbacks in terms of the elevated tank size required to store enough water to generate electricity continuously through slack water periods. At this time, the method seems suitable for continuous power generation at low levels and interrupted service at higher outputs.

In conclusion, the principal difficulty with utilization of tidal power lies in the detailed mechanics of the conversion system which is beyond the scope of the present study. This report has demonstrated that adequate tidal power resources for individual energy consumption are available. The next phase of study should address the candidate power generation systems and their economics. Before the merits of the concept can be conclusively judged, more definitive information on design details, construction costs, and maintenance

expenses must be obtained. It is therefore recommended that a study concerned with developing a detailed, feasible design be undertaken.

REFERENCES

1. US Department of Commerce, National Ocean Survey, "Tide Tables East Coast of North and South America, 1981," issued 1980.
2. Vennard, J. K., "Elementary Fluid Mechanics," John Wiley & Sons, Inc., 1961.
3. Golding, E. W. and R. I. Harris, "The Generation of Electricity by Wind Power," E. & F. N. Spon Ltd., 1976.