Worcester Polytechnic Institute

Cost Reduction
Of
Electrical Energy

An Analysis
On the Feasibility of Tidal Power in Massachusetts

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Table of Contents

Table of Figures

Table of Tables

1 Abstract

Our society faces impending issues concerning both availability and cost of electrical energy. Currently, large portions of electrical energy are based on costly nonrenewable and polluting sources such as oil, natural gas, and coal. Additionally, sources of these resources are dwindling at an increasing rate as worldwide consumption continues to grow. We propose to mitigate the adverse effects of these two major issues through the use of tidal power. Through the use of tidal power, we could reduce the general cost of electrical energy in Massachusetts by supplementing current costly nonrenewable power sources, and provide energy stability through a renewable source significantly more consistent than those of solar and wind. To determine if this power source is feasible in Massachusetts, we will analyze tidal data to estimate the power we could generate from tidal sources.

2 Tidal Power

In this section, tidal power theory is described and two major methods of generation are discussed. Using known tidal data around the Massachusetts coastline, calculations are performed with both methods of generation to estimate the potential power each system could offer to Massachusetts's power grid.

2.1 Introduction

Tidal power is a type of hydroelectric power that uses the energy of the oceans tides to generate electricity. It is a renewable energy source similar to that of solar or wind; however, dissimilar to the former sources, tidal power is a predictable and thus more reliable source of electricity. The tides are influenced by both the Earth's rotation and gravitational field of the sun and moon. There are three types of tides, semidiurnal, mixed, and diurnal. As shown in Figure 1-1, semidiurnal tides consist of two almost equal high and low tides a day. Diurnal tides consist of only one high and low tide a day while mixed tides can be a combination of both, typically consisting of two uneven high and low tides in a day.

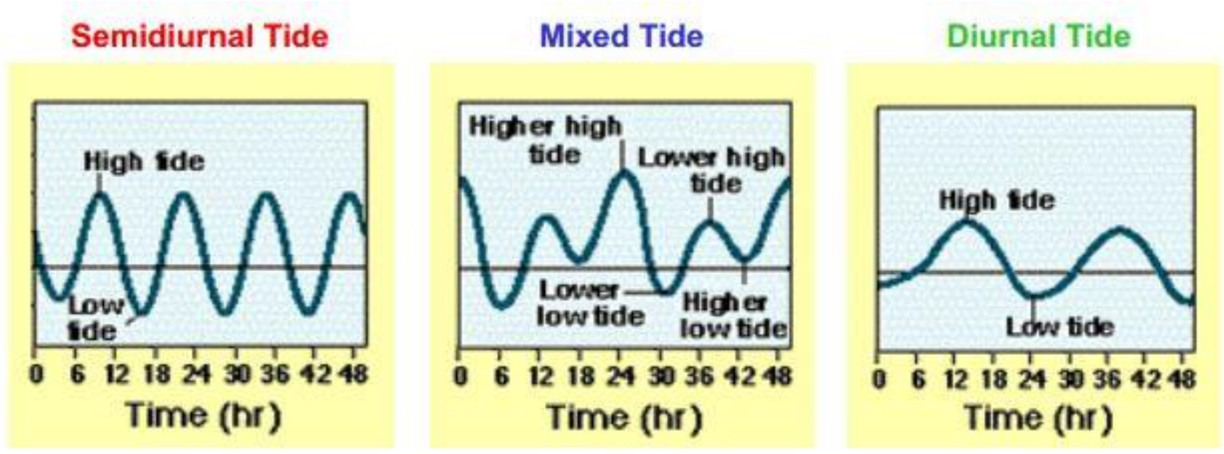

Figure 2-1: Different Types of Tides [1]

Since tidal power generation occurs as water currents flow between tide levels, semidiurnal tides are the most effective tidal pattern, assuming constant tide water levels, because they occur twice a day at the same peak levels. Figure 2-2 is a map of the world's tidal patterns. It can be observed that Massachusetts is in a semidiurnal tide zone.

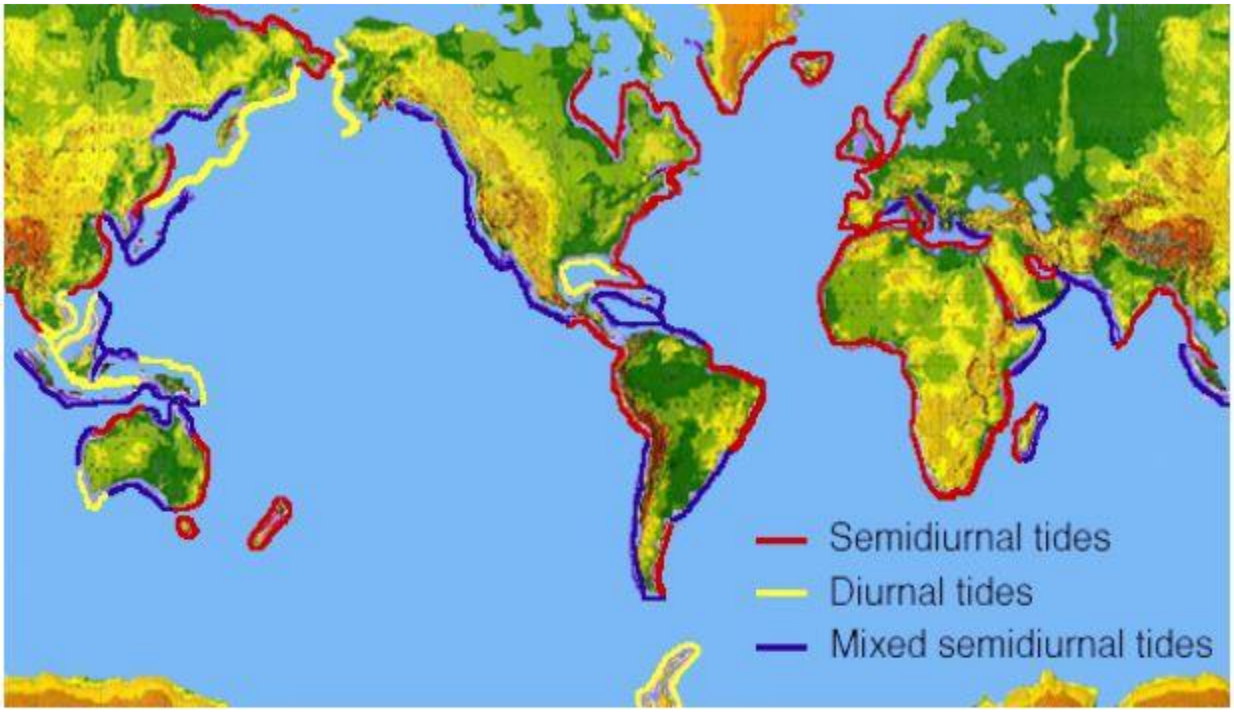

Figure 2-2: Global Tidal Distribution [1]

There are currently two primary technologies for tidal power generation, tidal barrage and tidal stream. To determine the most effective method of generation, the power output capabilities of both technologies will be analyzed in numerous locations along the coast of Massachusetts. Through the use of theoretical equations and tidal data the most effective method and location for a tidal power generation system will be determined. This data will then be used to predict the effect on the cost of electricity.

2.2 Tidal Barrage

Tidal barrage generation is an electricity generating method similar to that of hydroelectric dams. During high tide sluice gates are opened, allowing water to flow from the ocean into a holding basin. The water flows through a turbine, generating electrical current. At the peak of high tide the sluice gates are closed. When the tide recedes the gates are reopened allowing the water to travel through a turbine from basin to ocean, once again generating electrical current. Tidal barrage systems are best suited in areas where there is a relatively large tide differential.

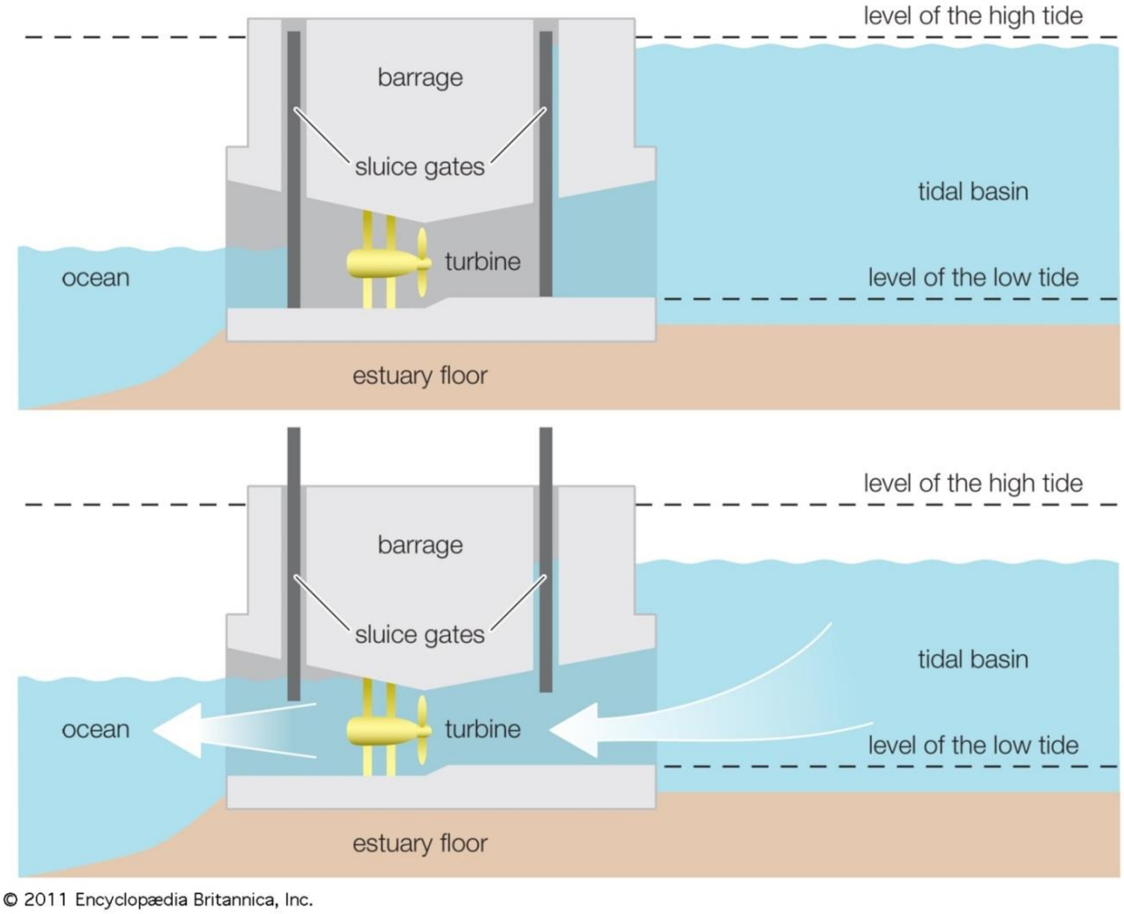

Figure 2-3: Tidal Barrage During Low Tide [2]

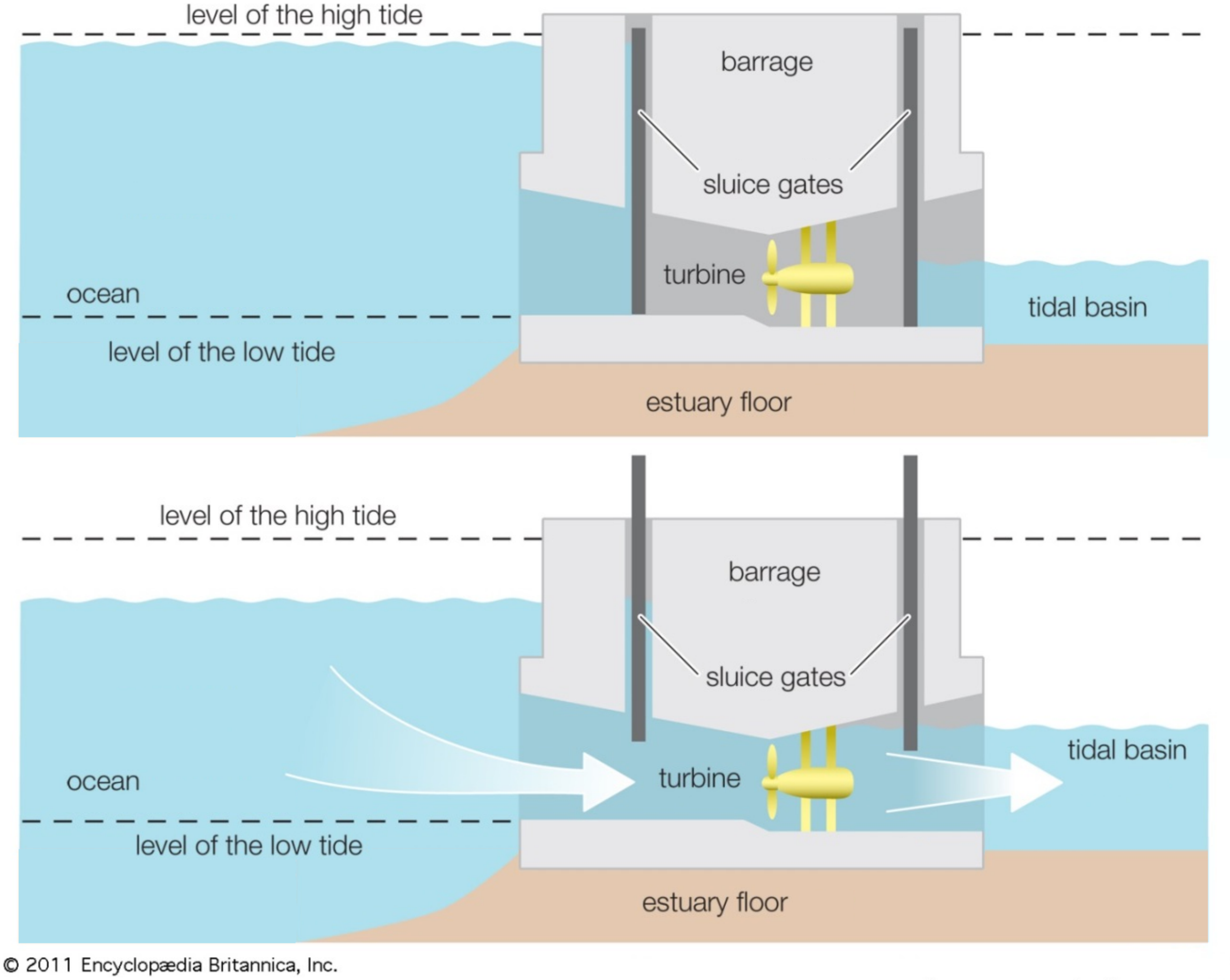

Figure 2-4: Tidal Barrage During High Tide

In the semidiurnal tides of Massachusetts, power would be generated twice a day, once at the high to low tide transition, and again at the low to high tide transition. This characteristic significantly limits the effect tidal barrage has on the price of electricity. Since power generation only can occur after tidal transitions, this method can only be used as a supplemental source. Other issues with tidal barrages include startup costs and effects on marine life, which will be discussed later.

2.2.1 Tidal Barrage Generation Analysis

To determine the amount of power generated through a tidal barrage we used the following theoretical Equation (1) to determine the potential energy contained in a body of water. [3]

$$E = \frac{1}{2} A\rho g h^2 \tag{1}$$

Where:
E = energy in joules
A = the horizontal area of the barrage basin in m
ρ = the density of water = 1025 kg/m^3
g = the acceleration due to Earth's gravity = 9.81 m/s
h = the vertical tidal range in m

Using this equation, we determined the amount of energy that could be gathered in a single tide transition. To determine the amount of power we could generate in a day, the energy given by this formula was multiplied by a factor of two to account for both tide transitions. We then divided the theoretical energy generation by 86400 seconds (1 day) to determine the mean power generation potential. Lastly, we multiplied the average daily power generated by a power conversion efficiency factor. For our calculations we assumed turbines with an efficiency of 30%. The resulting Equation (2) used to determine power generated was:

$$P = \frac{30\% * A\rho g h^2}{86400} \tag{2}$$

To determine the power potential in the surrounding waters of Massachusetts, we gathered tidal data from the National Oceanic and Atmospheric Administration, NOAA. The NOAA is a federal agency within the United States Department of Commerce that focuses research on the conditions of the oceans and atmosphere. For our tidal barrage analysis, we compiled high and low tide data of 43 of the NOAA sites over their entire year (See Appendix H for map of stations). For our calculations, we used the average of all high and low tide values over the course of the year. Table 1 summarizes the top 10 average tide differential results out of the 43 stations analyzed. For tables of stations analyzed sorted by relative area see Appendix A. For the full table of all 43 sites see Appendix B. An excerpt of the raw data used to calculate these values is listed in Appendix C.

Table 1: Top 10 Tide Differential Stations	
Station Name	**Tide Differential (m)**
Wellfleet	3.1378455
Sesuit Harbor, East Dennis	3.1113819
Boston	2.9879092
Hingham	2.9878243
Duxbury, Duxbury Harbor	2.9837136
Weymouth Fore River	2.9777462
Amelia Earhart Dam	2.9596314
Nantasket Beach, Weir River	2.9584124
Plymouth	2.9573774
Provincetown	2.9445499

Table 1: Top 10 Tide Differential Stations

Using this data and the derived power equation we estimated the total power we could generate at each site. For these calculations we assumed a 1kilometer long barrage. Using the tide differentials we calculated the average power that would be generated each day. The results are shown in Table 2.

Table 2: Top 10 Tide Differential Stations Estimated Average Power		
Station Name	**Average Daily Power (W)**	**Estimated Yearly Power (kW)**
Wellfleet	343.766456	125.4747565
Sesuit Harbor, East Dennis	337.992493	123.3672599
Boston	311.698850	113.7700804
Hingham	311.681106	113.7636039
Duxbury, Duxbury Harbor	310.824093	113.4507941
Weymouth Fore River	309.582046	112.9974468
Amelia Earhart Dam	305.826882	111.6268119
Nantasket Beach, Weir River	305.575010	111.5348787
Plymouth	305.361293	111.4568720
Provincetown	302.717997	110.4920689

Table 2: Top 10 Tide Differential Stations Estimated Average Power

The results from the possible tidal barrage sites show that theoretically, there could be at most 125kW of power extracted from the Wellfleet site a year.

2.3 Tidal Stream

Tidal stream generation extracts energy from moving water with a turbine that is rotated by the water current. This power generation method is similar to that of a wind will; however, tidal power has many more advantages. One advantage is the predictability of the tides versus that of wind. In addition water is a significantly more dense fluid than air, allowing for a greater power potential, given the same size turbine. Tidal stream systems are best suited where the natural water current is relatively fast.

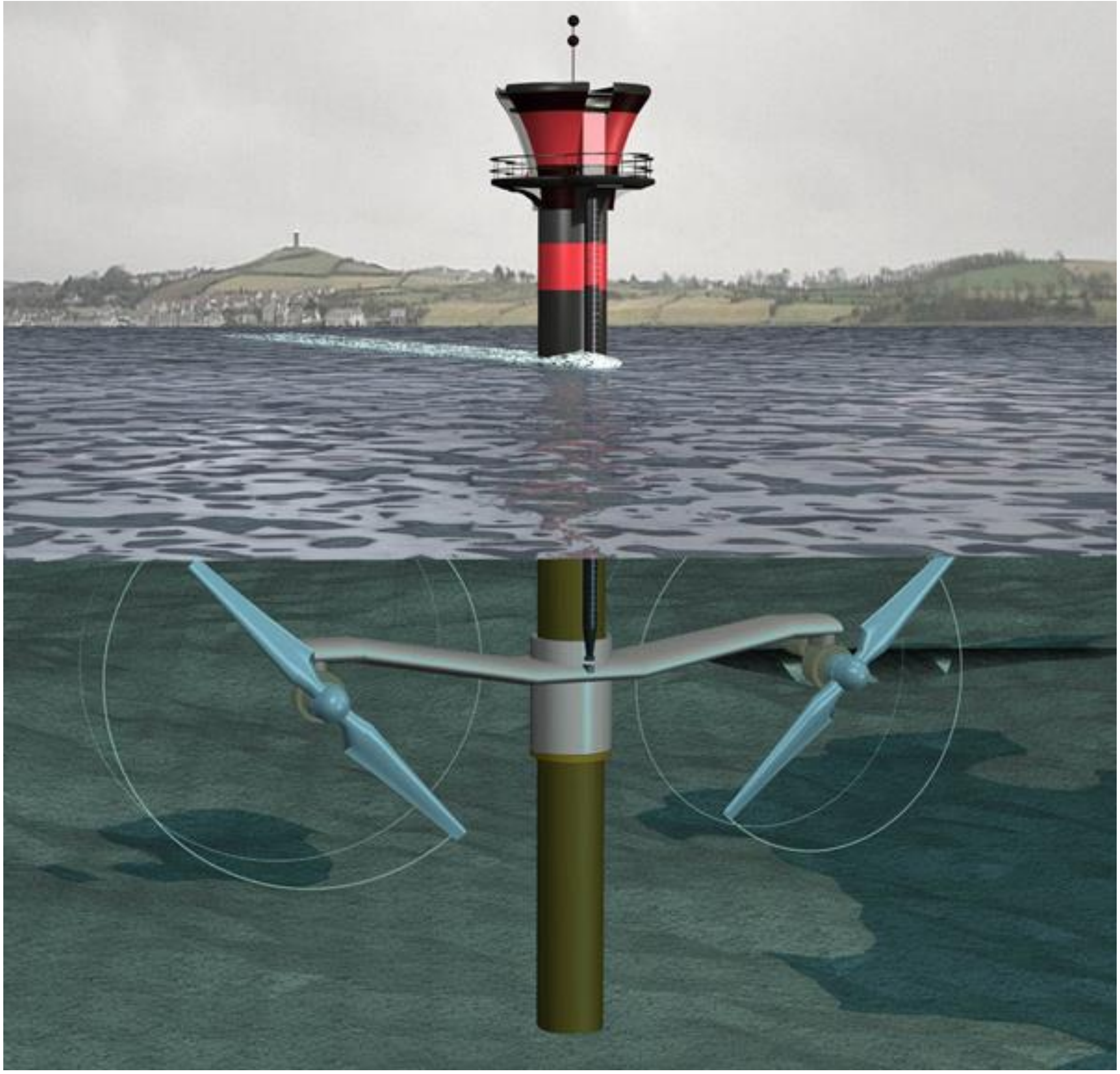

Figure 2-5: Tidal Stream [4]

2.3.1 Tidal Stream Generation Analysis

To determine the energy that could be gathered from the kinetic system of the turbine and water the following theoretical Equation (3) was used. [3]

$$P = \frac{1}{2}\xi\rho A V^3 \tag{3}$$

Where:
P = the power generated in watts
ξ = the turbine efficiency, assumed to be 30%
ρ = the density of water = 1025 kg/m^3
A = the sweep area of the turbine in m^2
V = the velocity of the water flow in m/s

By adding a shroud to a turbine, the power output could be increased by a factor of up to 4; however, this adds increased engineering and manufacturing costs. For our analysis we will be assuming no shroud. To determine the velocity of the water, we compiled historical current data sites from the NOAA. A total of 25 sites were used from the Boston and Cape Cod areas. See Appendix G for maps showing site locations on the coastline.

The sweep area of the turbine was calculated using the area of a circle. To estimate the ideal turbine size, we chose to have a radius equal to 45% of the depth of the station location. This value was used because it is the halfway point of ideally useable water flow. Only the upper 90% of the water depth is useful for tidal stream generation due to the low speed benthic boundary layer. Turbine size was limited to 10m radius. This value was chosen because it is the currently the largest turbine in use for tidal stream generation. The current data we analyzed was also at the 45% total depth point of the station. Turbine efficiency was once again assumed to be 30% as previously in tidal barrage analysis.

The dataset for our analysis of each station contained measured current data for the entire lifetime of the station. On average, each station was active for 41.6 days for the Boston sites, and 62.1 days for the Cape Cod sites. Current was measured at each site in 6 minute intervals, with a few stations, such as the Stellwagen Basin East End station, measuring every 2 minutes. Table 3 shows the timespan, average speed, estimated turbine size, and average power generation for the 10 best sites. For the full data listing see Appendix F. For an excerpt of the raw data gathered by the NOAA, see Appendix D.

Table 3: Top 10 Tidal Stream Generation Stations				
Station	**Timespan (days)**	**Average Speed (cm/s)**	**Estimated Turbine Radius (m)**	**Average Power Generation (W)**
Cape Cod Canal, Railroad Bridge	77.00	159.9278	4.41	57125.9865
Cape Cod Canal, Bournedale	47.00	115.1962	6.04	39976.7128
Hog Neck	48.00	105.5866	3.54	10859.9899
Woods Hole, The Strait	107.00	110.4358	2.90	7915.5299
Georges Island	40.00	47.2270	8.08	5992.8114
Quicks Hole, Middle	53.00	65.6249	5.24	5923.2678
Stellwagen Bank	42.00	34.9426	10.00	3241.2155
Deer Island (0.7mi.)	41.00	47.2242	5.00	2344.3403
Boston Harbor, Deer Island Light	88.00	37.7787	6.46	2314.8836
Abiels Ledge	47.00	49.8241	4.54	2077.0982

Table 3: Top 10 Tidal Stream Generation Stations

The results from the possible tidal stream sites show that theoretically, there could be at most 57.125kW of power extracted from the Cape Cod Canal, Railroad Bridge Site. The next best site, also in the canal, could yield 39.976kW.

3 Electrical Energy Cost Analysis

In this section, the potential values of tidal barrage and tidal stream are compared to each other. Additional analysis is done to determine the effect both methods could have on the cost of electrical energy in Massachusetts.

3.1 Tidal Power Effect on Electrical Power Generation

Based on the results of the theoretical power that would be generated from both tidal power sources, it appears that tidal stream is more effective at power generation in this area. To determine which system would be more effective, the energy that each system could give was calculated. The tidal barrage method only occurs twice a day. To calculate energy, it was assumed the generator would be able to run for 30 minutes each tide change, resulting in 1 hour of power generation a day. For tidal stream, it was assumed that turbine was running continuously year round. With these assumptions, the kWh/year was calculated for the best stations of each method, as shown in Table 4. Also shown is the number of households that could be powered by each method, based on the Massachusetts average energy consumption, 627kWh/month, according to the United States Energy Information Administration, EIA. [5]

Table 4: Comparison Between Tidal Barrage and Tidal Stream Generation

Station	Method	kWh/Year	Households Powered/Year
Cape Cod Canal, Railroad Bridge	Tidal Stream	500423.64	66.5103
Cape Cod Canal, Bournedale	Tidal Stream	350196.00	46.5439
Hog Neck	Tidal Stream	95133.51	12.6440
Woods Hole, The Strait	Tidal Stream	69340.04	9.2158
Georges Island	Tidal Stream	52497.03	6.9773
Quicks Hole, Middle	Tidal Stream	51887.83	6.8963
Stellwagen Bank	Tidal Stream	28393.05	3.7737
Deer Island (0.7mi.)	Tidal Stream	20536.42	2.7295
Boston Harbor, Deer Island Light	Tidal Stream	20278.38	2.6952
Abiels Ledge	Tidal Stream	18195.38	2.4183
Wellfleet	Tidal Barrage	125.47	0.0166
Sesuit Harbor, East Dennis	Tidal Barrage	123.37	0.0163
Boston	Tidal Barrage	113.77	0.0151
Hingham	Tidal Barrage	113.76	0.0151
Duxbury, Duxbury Harbor	Tidal Barrage	113.45	0.0150
Weymouth Fore River	Tidal Barrage	112.99	0.0150
Amelia Earhart Dam	Tidal Barrage	111.63	0.0148
Nantasket Beach, Weir River	Tidal Barrage	111.53	0.0148
Plymouth	Tidal Barrage	111.46	0.0148
Provincetown	Tidal Barrage	110.49	0.0146

Table 4: Comparison Between Tidal Barrage and Tidal Stream Generation

The calculated data shows that the most energy could be extracted from the Cape Cod Canal, Railroad Bridge, station, with 500MWh/year, enough to power about 66.5 household a year. The next best site would be Cape Cod Canal, Bournedale, with the ability to power about 46.5 household a year. Unfortunately, both of these sites are in the middle of a major shipping lane and therefore would be unusable. The third best site, Hogs Neck, could power about 12.6 houses a year. This data also shows that the least effective of the top 10 tidal stream sites is still better than the best tidal barrage site.

3.2 Tidal Power Cost Effectiveness

Tidal power systems have similar cost elements to most other power generators. Capital expenditures, or capex, consist of construction, electrical system infrastructure, and pre-developmental costs. Operational expenditures, or opex, consist of operating and maintenance costs, insurance, commissioning, and taxes. To estimate these costs for a Massachusetts tidal generator, a study by Black & Veatch was used. Black & Veatch is a global engineering, consulting, construction, and operations company that specializes in critical human infrastructure projects.

The Scottish government commissioned a study to assess tidal generation projects in the United Kingdom. Black & Veatch analyzed the financial aspects in this study, including but not limited to ROI analysis, installation estimation, and potential cost of electricity. The waters around Scotland have a faster current and larger tide differential than Massachusetts so this study would not fit perfectly; however, the study was chosen as a loose model because few tidal generation studies have been conducted recently.

This study included an analysis of tidal barrage and tidal stream in both shallow and deep waters. Table 5 shows the commercial project cost results of their study, converted to from British Pounds to United States Dollars. All estimates in this table were the mid-range values.

Table 5: Black & Veatch Scotland Cost Effectiveness of Tidal Power Study		
Technology	**Capex/MW**	**Opex/MW/year**
Tidal Barrage	$4.44 million	$0.05 million
Tidal Stream Shallow (<50m Depth)	$5.26 million	$0.25 million
Tidal Stream Deep (>50m Depth)	$5.42 million	$0.20 million

Table 5: Black & Veatch Scotland Cost Effectiveness of Tidal Power Study

For tidal barrage analysis, Black & Veatch combined four projects, the Mersey Tidal Power (700MW), Solway (150MW), Duddon (100MW), and Wyre (50MW) for 850MW capacity. In comparison, Massachusetts's best location for tidal barrage was Wellfleet, with an estimated 0.125MW capacity. By assuming that the projects would have similar costs per m of constructed barrage, it was determined that a project at Wellfleet would cost $30.384 billion in capital expenditure and $342.157 million/year in operational costs (see Appendix I for calculations). This project would be extremely financially unfeasible since the generator is estimated to only power 0.0166 households a year.

For tidal stream, Black & Veatch's calculations assumed a 3 m/s current speed for shallow water and a 3.2 m/s current speed for deep water. The best potential Massachusetts site for a tidal stream generator was Cape Cod Canal, Railroad Bridge, with a current speed of approximately 1.6 m/s. This turbine would fall into the shallow water category since it is in water with depth less than 50m. The current speeds in the Scotland study are double of those at the Cape Cod Canal, Railroad Bridge site, meaning there is a greater energy density in Scotland. Assuming that the tidal stream generators used at both sites were of comparable costs, the Massachusetts site would have costs of approximately $10.52 million/MW (Capex), and $0.50 million/MW/year (Opex). With an average power generation capability of 57.125kW a day, this project would cost around $219.349 million in capital expenditure and $10.425 million/year in operational costs. This project would also be financially unfeasibly since it is only estimated to be capable of powering 66.5 households a year.

3.3 Effect on Consumer Prices Due to Tidal Power

To further analyze the financial feasibility of tidal power the cost/kWh for both generation methods was calculated using the results from the previous section. Assuming the cheapest situation for the consumer, where the tidal power company broke even with a profit margin of $0, the cost of electricity generated from a Wellfleet tidal barrage would be $2.727 million/kwh. For a tidal stream generator at the Cape Cod Canal, Railroad Bridge site, the cost of electricity generated will be $20.832/kWh. To put this into perspective, electricity in Massachusetts currently costs around 15.63¢/kWh on average.

4 Social and Environmental Issues

This section addresses the potential social and ecological issues concerning the installation of a tidal barrage or tidal stream system.

4.1 Introduction

When planning any type of power installation, there are a few factors outside of the amount of energy produced that have to be considered. Any construction can cause damage to the environment around it, and property owners around the site may have further concerns about loud noises, increased pollution, and decreased property values. All of these concerns have to be taken into account when planning to construct either a tidal barrage or tidal stream turbines. While we do not have the means to conduct formal studies on the environmental impact tidal power would have there are several examples to compare our prospective proposals with.

For an energy method to be implemented, it requires for two groups to be satisfied. The first and more important group is the government. If the government does not approve the construction, it remains impossible. If the government does approve, as tidal power is an alternative source of energy, it can provide both funding and tax credits to aid in construction. The second group is the people around any proposed site. If the people are against our project they could also prevent construction through protests and legal challenges. In the past, Massachusetts has attempted to install alternative energy production on Cape Cod; the location we determined was the best for both types of tidal power. This project was called Cape Wind and despite clearing all legal requirements, it is still delayed by groups outside the government.

Figure 4-1: Cape Wind Project [7]

The Cape Wind project was proposed in the early 2000s and eventually backed by several environmental groups. These groups included the Massachusetts Audubon Society, which judged the primary environmental concern caused by wind turbines, their threat to birds, to not be “An ecologically significant threat” [9]. The project was predicted to eventually provide 75% of Cape Cod’s energy. However, the actual implementation of Cape Wind has proven to be difficult. It suffered from significant opposition from residents of the Cape. A group of several towns on the Cape and a coalition of wealthy landowners in the vicinity of the Cape Wind project site have led to a total stalemate in construction. The stalling tactic will lead to a significant withdrawal of funds from the project and my end up causing it to never be constructed. This demonstrates that although there may be support from some residents, or even most, as shown by a Civil Society Institute survey, construction is difficult to get approved in the Cape Cod area.

4.2 Impact of Tidal Barrage

There is a real example of a working tidal barrage and the environmental impact can be used to determine how much of an impact tidal barrages have on the environment. In France, the La Rance tidal barrage has been in operation since 1966. This long period of time has allowed for researchers to obtain a thorough evaluation of La Rance's environmental effects.

Figure 4-2: La Rance Tidal Barrage [8]

The La Rance Barrage has led to several environmental changes in the Rance River, the river it holds the tides in. During construction in the 1960s, it prevented any flow of water from the sea into the Rance River and destroyed almost every ocean dwelling plant or animal. Currently, animals and plants have returned to the area, although their composition is different. The populations of sea bass and cuttlefish have grown, while sand eels and flatfish have suffered a reduction in population. There have also been changes in the populations of birds. The barrage has led to a far larger tidal basin upstream from its installation, which has in turn attracted more migratory birds and diving ducks. One population that the barrage has not disrupted is migratory fish, as they seem to be able to pass through the turbines without difficulty.

In addition to changes in the ecosystem, the land and river around the La Rance Barrage has been changed. The makeup of the seabed around the La Rance barrage has been greatly worn away. Before installation, it was made up of sediment, but after years of operation, it has become full of rocks and gravel. This may be the reason for declines in sand eel and flatfish population, as they rely on sand for hunting and shelter. The barrage has also led to an increase in salinity in the Range River, as the barrage causes water to be sent upstream during high tides. Another change is that the water of the river has warmed from the increased amount of ocean water upstream, leading to decreased populations of cold-water fish. One final discovery from the La Rance Barrage is that the operation must always be kept stable. If there is a significant change in the operations of the barrage, it causes significant damage to the local ecology so maintaining the barrage is required to avoid large scale animal and plant death.

The tidal barrage method of power generation would have a larger impact on the environment in Massachusetts compared to the effects of the La Rance Barrage. Most of this impact is caused by the large size required by the barrage to store tidal water here. Due to the lower high tides in Massachusetts that we discussed previously in the paper, any theoretical tidal barrage in Massachusetts would take up many kilometers of coastline. This would lead to a far greater ecological effect, and given the damage caused by the La Rance Barrage during construction, a larger structure would be far more difficult to justify to the government, environmental groups, and fishing industry of Massachusetts. Building a tidal barrage in Massachusetts would lead to many environmental issues.

This large use of coastline also makes any type of tidal barrage very unlikely to be approved socially, as the Massachusetts coastline is almost entirely already being used by various commercial, public, and private entities. Since the barrage would require a long contiguous area, it would cut off all access to the waterfront from the land it is parallel to. The water in this area could not contain any swimming, boating, or fishing as it would be drained or filled quickly through turbines to produce electricity.

Additionally, the same forces that opposed the Cape Wind project would likely oppose any sort of tidal barrage project. Cape Wind was opposed on the fact that it would decrease property values and be an eyesore. Cape Wind was 4.8 Miles or 7.7 Kilometers from the nearest shoreline and was only made of wind turbines. Any tidal barrage would have to be attached to the land and would look similar to a concrete dam. For these reasons, the public opposition would probably be far greater than the opposition to Cape Wind, which itself has been prevented from construction since 2001.

As a tidal barrage would be devastating to the environment of the Massachusetts shoreline in the short term, and potentially have permanent effects in the long term, tidal barrages would be very difficult to approve for construction. Additionally, as they require vast amounts of valuable coastline and would be unpopular for the residents of the coast, tidal barrages suffer from vast social challenges. With all of these concerns, a tidal barrage would likely have far too many issues to realistically be approved or constructed in Massachusetts.

4.3 Impact of Tidal Stream

Compared to tidal barrages, tidal stream has far less research. Because of the lack of research, the low age or the technology, and lesser popularity, tidal stream power's impact is harder to conclusively state. Additionally, since tidal stream generators are more popular in Europe, most existing studies were conducted on the fast moving waters of the United Kingdom's coastline, which may be more difficult to transfer to the slow streams of Massachusetts.

Figure 4-3: Turbine of a tidal stream generator [10]

There are problems caused by the construction and operation of a turbine. The main problem during construction is pollution from having to attach the turbine solidly to the seabed. This doesn't last too long since construction is only a temporary occurrence. The ecosystem may suffer, but it should be able to recover when construction is finished. During operation there are more problems. The turbine can change tides, waves, and reduces the velocity of the ocean currents it is placed in. The main environmental problem with running a tidal stream generator however, is the effects it would have on the surrounding sediment. Running a tidal stream generator can quickly remove an estimated 20% of sediment directly around the turbine. However, due to the way the various levels of sea currents travel, the stripping of sediment from the seabed is limited to this area close to the turbine. Additionally, as the turbine reduced the velocity of the water it is placed in, it reduces the erosion of the seabed from natural causes. While the sediment released by operating a turbine is not too much, it is has a constant presence in the water and changes the consistency. The environmental impact of a tidal stream turbine is low and localized to the area directly around the turbine. It would be minimally to moderately challenging to get such a project approved.

Compared to the social difficulties of a tidal barrage, the social requirements of a tidal stream generator are far less of a daunting obstacle. Unlike a barrage or a wind turbine, a tidal stream turbine is mostly hidden from view from land. The turbine would be mostly underwater, since that is where all of the actual working parts would have to be kept for it to produce any power. In fact, the only part of a tidal turbine that remains above water rests only a small distance above the surface and has the same appearance of a lighthouse or a large buoy. The biggest social problem of one of these generators is the amount of space underwater it takes up. It is dangerous for ships to travel over a turbine, so wherever a tidal stream turbine is constructed, ships may no longer pass through that area. Thus tidal stream generators would be difficult to obtain approval for a generator in any location used by commercial or private ships. Finding areas where the water moves fast enough to power a turbine and where there are no or few ships traveling through the waters is the main difficulty of placing a tidal stream generator. Unfortunately, finding a place like this would be very difficult in the modern world.

5 Alternative Solutions

In this section, a few other alternative hydroelectric sources that could be used in Massachusetts are discussed. These sources were considered for the initial study of electrical cost reducing technologies along with other energy sources such as nuclear. Nuclear power was not investigated further due to its poor public opinion and expense. In addition, despite its fuel being abundant, it is still a non-renewable source of power with extremely hazardous and dangerous waste materials.

5.1 Wave Power

Similar to tidal power, wave power uses the natural ocean currents to generate power. Two methods of wave energy generating technologies are through the use of buoys or oscillating water columns (OWCs).

Buoy type wave generators float on the ocean surface and generate electricity as the rising and falling motion drives hydraulic pumps. The first commercial wave power farm was built in the Atlantic coast of Portugal, where three Pelamis Wave Power machines were installed. The generators were able to generate energy close to speculated values; however the system was removed as the parent company that operated them went bankrupt. We chose not to investigate use of Pelamis generators in Massachusetts because of the currently limited use and failure of companies that attempted to utilize this technology.

Figure 5-1: Pelamis Buoy Type Wave Power Generator [26]

OWC type generators are similar to tidal barrage generators, however instead of requiring a basin to hold the water gating off by with sluices, it consists of a chamber filled with air. As the waves enter the chamber, air is pushed through a turbine to generate power.

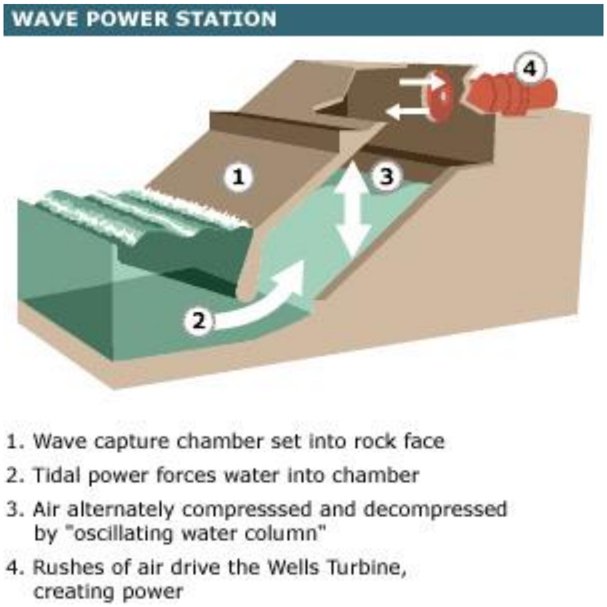

Figure 5-2: Oscillating Water Column Generator

OWC type wave power was not further investigated in our study due to the expense of electricity for current existing projects. Wave energy using this method is currently more expensive than wind power. In addition, previous studies have determined that the northeast coast in New England is far inferior to the potential power that could be harvested in the northwest. Areas such as Oregon and Alaska have been estimated to have at least four times more energy potential.

5.2 Pumped-Storage Hydroelectric

One alternative type of hydroelectric power that could be used is the pumped-storage generator. Pumped-storage hydroelectricity is generated by using electricity to pump water upward, storing the water, and releasing the water at a later time through turbines to generate power. It is mainly used as a storage method for electricity. Since the price of electricity varies over time by a predicable amount, the water is raised when electric costs are low, and released through the turbines when the costs are high. This process ends up producing money despite having a net loss of energy.

We did not choose to use this type of hydroelectric power for a few reasons. First, this type of power is not truly alternative energy because the raising of water up requires the use of electricity from the power grid. Since the majority of grid power in Massachusetts is from nonrenewable sources, such as natural gas, using this method would also be nonrenewable. Another difficulty with pumped-storage power is that it consumes more power than it can return back to the grid. This is counterproductive to the initial goal of using hydroelectricity of produce power.

6 Conclusion

The construction of either a tidal barrage or tidal stream generators is economically, environmentally, and socially unfeasible. Based on the analysis of Massachusetts tidal resources both tidal barrage and tidal stream are infeasible with current technology. A tidal barrage at the best site, Wellfleet, would cost approximately $30.384 billion to build and $342.157 million/year to operate and maintain. It would provide enough power for less than a single average Massachusetts household at an astronomical price of $2.727 million/kWh. A tidal stream generator in the best site, Cape Cod Canal, Railroad Bridge, would cost approximately $10.52 million to build and $10.425 million/year to operate and maintain. This system would be able to power approximately 67 households a year, but at a high price of $20.832/kWh. Tidal stream is significantly more feasible than tidal barrage cost wise; however, the energy prices to the consumer are two orders of magnitude larger with electricity in Massachusetts costing 15.63cents/kWh in October of 2013.

Additionally, the construction of either of these tidal power systems would face great social difficulty. Obtaining the valuable coastal land to construct a tidal barrage would require massive amounts of eminent domain or the use of public coastline. Constructing tidal stream generators would make sections of the ocean unusable by any other endeavor, and the best locations for these systems in Massachusetts are inside a canal specially dug to be a shipping lane. The next best location for a tidal stream generator would only have about 19% capacity as the former and is almost unavoidable when entering the Cape Cod Canal. As for environmental concerns, constructing a tidal stream generator would not be too taxing on the environment, but a tidal barrage would devastate all sea life around it or many years. Socially, a tidal barrage would have huge issues since many people prefer to live around a beach instead of a giant concrete barrier and would not want their property value to be decreased.

Based on the findings of this study, both tidal barrage and tidal stream generators are infeasible to be used in Massachusetts. Due to social, environmental, and economic issues, the construction of either of these systems could not decrease the cost of electricity, nor provide enough alternative energy to replace polluting nonrenewable sources like coal and natural gas.

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8 Appendices

Appendix A - Summary of Tide Differential Data By Location

Boston Harbor Sites	
Station	**Tidal Differential (m)**
StationName: BOSTON LIGHT	2.815620128
StationName: Deer Island (south end)	2.89924876
StationName: CHELSEA	2.942508859
StationName: Moon Head	2.958412473
StationName: AMELIA EARHART DAM	2.959631467
StationName: Charlestown, Charles River entrance	2.987824238
StationName: Neponset, Neponset River	2.987824238
StationName: BOSTON	2.987909284

Cohasset Harbor to Davis Bank	
Station	**Tidal Differential (m)**
StationName: Pleasant Bay	1.016371368
StationName: CHATHAM, STAGE HARBOR	1.197406095
StationName: Georges Shoal, Texas Tower	1.313550673
StationName: BOURNE BRIDGE, CAPE COD CANAL (STA. 320)	1.322664777
StationName: CHATHAM	1.773366407
StationName: BOURNEDALE, CAPE COD CANAL (STA. 200)	1.883004961
StationName: SAGAMORE, CAPE COD CANAL (STA. 115)	2.417207654
StationName: Damons Point, North River	2.659234585
StationName: SANDWICH	2.692955351
StationName: Cohasset Harbor (White Head)	2.748915663
StationName: SCITUATE, SCITUATE HARBOR	2.759759036
StationName: BRANT ROCK, GREEN HARBOR RIVER	2.788206945
StationName: PROVINCETOWN	2.944549965
StationName: PLYMOUTH	2.957377746
StationName: DUXBURY, DUXBURY HARBOR	2.983713678
StationName: Barnstable Harbor, Beach Point	2.987824238
StationName: SESUIT HARBOR, EAST DENNIS	3.111381999
StationName: Wellfleet	3.1378455

Hingam Bay	
Station	**Tidal Differential (m)**
StationName: Hull	2.89924876
StationName: NUT ISLAND	2.912147413
StationName: Crow Point, Hingham Harbor entrance	2.958412473
StationName: Nantasket Beach, Weir River	2.958412473
StationName: WEYMOUTH FORE RIVER	2.977746279
StationName: Hingham	2.987824238

Outer Coast	
Station	**Tidal Differential (m)**
StationName: RIVERSIDE	1.704096386
StationName: MERRIMACPORT	2.133579022
StationName: SALISBURY POINT	2.378639263
StationName: NEWBURYPORT	2.521389086
StationName: ROCKPORT	2.715832743
StationName: PLUM ISLAND SOUTH	2.733890858
StationName: SALEM, SALEM HARBOR	2.766435152
StationName: Annisquam, Lobster Cove	2.767484054
StationName: Gloucester Harbor	2.776895819
StationName: ESSEX	2.798398299
StationName: LYNN, LYNN HARBOR	2.865882353

Appendix B - Summary of All Tide Differential Data

All Sites Based on Tidal Differential (Smallest to Greatest)	
Station	**Tidal Differential (m)**
StationName: Pleasant Bay	1.016371368
StationName: CHATHAM, STAGE HARBOR	1.197406095
StationName: Georges Shoal, Texas Tower	1.313550673
StationName: BOURNE BRIDGE, CAPE COD CANAL (STA. 320)	1.322664777
StationName: RIVERSIDE	1.704096386
StationName: CHATHAM	1.773366407
StationName: BOURNEDALE, CAPE COD CANAL (STA. 200)	1.883004961
StationName: MERRIMACPORT	2.133579022
StationName: SALISBURY POINT	2.378639263
StationName: SAGAMORE, CAPE COD CANAL (STA. 115)	2.417207654
StationName: NEWBURYPORT	2.521389086
StationName: Damons Point, North River	2.659234585
StationName: SANDWICH	2.692955351
StationName: ROCKPORT	2.715832743
StationName: PLUM ISLAND SOUTH	2.733890858
StationName: Cohasset Harbor (White Head)	2.748915663
StationName: SCITUATE, SCITUATE HARBOR	2.759759036
StationName: SALEM, SALEM HARBOR	2.766435152
StationName: Annisquam, Lobster Cove	2.767484054
StationName: Gloucester Harbor	2.776895819
StationName: BRANT ROCK, GREEN HARBOR RIVER	2.788206945
StationName: ESSEX	2.798398299
StationName: BOSTON LIGHT	2.815620128
StationName: LYNN, LYNN HARBOR	2.865882353
StationName: Deer Island (south end)	2.89924876
StationName: Hull	2.89924876
StationName: NUT ISLAND	2.912147413
StationName: CHELSEA	2.942508859
StationName: PROVINCETOWN	2.944549965
StationName: PLYMOUTH	2.957377746
StationName: Moon Head	2.958412473
StationName: Crow Point, Hingham Harbor entrance	2.958412473
StationName: Nantasket Beach, Weir River	2.958412473
StationName: AMELIA EARHART DAM	2.959631467
StationName: WEYMOUTH FORE RIVER	2.977746279
StationName: DUXBURY, DUXBURY HARBOR	2.983713678
StationName: Charlestown, Charles River entrance	2.987824238
StationName: Neponset, Neponset River	2.987824238

StationName: Barnstable Harbor, Beach Point	2.987824238
StationName: Hingham	2.987824238
StationName: BOSTON	2.987909284
StationName: SESUIT HARBOR, EAST DENNIS	3.111381999
StationName: Wellfleet	3.1378455

Appendix C - Tidal Data Excerpt

*Due to the large size of data only 5 days are shown here. For full listing of data for all sites see the NOAA website at http://tidesandcurrents.noaa.gov/tide_predictions.html

<table>
<tr><td colspan="8">StationName: AMELIA EARHART DAM</td></tr>
<tr><td colspan="3">High (m)</td><td colspan="2">Low (m)</td><td colspan="2">Diff (m)</td><td></td></tr>
<tr><td colspan="3">3.0476967</td><td colspan="2">0.0880652</td><td colspan="2">2.9596315</td><td></td></tr>
<tr><td colspan="3">=AVERAGE(G5:G1415)*2/100</td><td colspan="2">=AVERAGE(H5:H1415)*2/100</td><td colspan="2">=A3-B3</td><td></td></tr>
<tr><td>Date</td><td>Day</td><td>Time</td><td>Pred(Ft)</td><td>Pred(cm)</td><td>High/Low</td><td>Only Highs</td><td>Only Lows</td></tr>
<tr><td>DATA</td><td>DATA</td><td>DATA</td><td>DATA</td><td>DATA</td><td>DATA</td><td>=IF(F5="H",E5,0)</td><td>=IF(F5="L",E5,0)</td></tr>
<tr><td>1/1/2013</td><td>Tue</td><td>1:23 AM</td><td>9.2</td><td>280</td><td>H</td><td>280</td><td>0</td></tr>
<tr><td>1/1/2013</td><td>Tue</td><td>7:31 AM</td><td>0.9</td><td>27</td><td>L</td><td>0</td><td>27</td></tr>
<tr><td>1/1/2013</td><td>Tue</td><td>1:33 PM</td><td>10.0</td><td>305</td><td>H</td><td>305</td><td>0</td></tr>
<tr><td>1/1/2013</td><td>Tue</td><td>7:58 PM</td><td>0.0</td><td>0</td><td>L</td><td>0</td><td>0</td></tr>
<tr><td>1/2/2013</td><td>Wed</td><td>2:04 AM</td><td>9.4</td><td>287</td><td>H</td><td>287</td><td>0</td></tr>
<tr><td>1/2/2013</td><td>Wed</td><td>8:17 AM</td><td>0.8</td><td>24</td><td>L</td><td>0</td><td>24</td></tr>
<tr><td>1/2/2013</td><td>Wed</td><td>2:18 PM</td><td>9.8</td><td>299</td><td>H</td><td>299</td><td>0</td></tr>
<tr><td>1/2/2013</td><td>Wed</td><td>8:43 PM</td><td>0.1</td><td>3</td><td>L</td><td>0</td><td>3</td></tr>
<tr><td>1/3/2013</td><td>Thu</td><td>2:50 AM</td><td>9.6</td><td>293</td><td>H</td><td>293</td><td>0</td></tr>
<tr><td>1/3/2013</td><td>Thu</td><td>9:06 AM</td><td>0.7</td><td>21</td><td>L</td><td>0</td><td>21</td></tr>
<tr><td>1/3/2013</td><td>Thu</td><td>3:07 PM</td><td>9.6</td><td>293</td><td>H</td><td>293</td><td>0</td></tr>
<tr><td>1/3/2013</td><td>Thu</td><td>9:31 PM</td><td>0.2</td><td>6</td><td>L</td><td>0</td><td>6</td></tr>
<tr><td colspan="8">…</td></tr>
<tr><td>12/30/2013</td><td>Mon</td><td>2:34 AM</td><td>0.4</td><td>12</td><td>L</td><td>0</td><td>12</td></tr>
<tr><td>12/30/2013</td><td>Mon</td><td>8:48 AM</td><td>11.0</td><td>335</td><td>H</td><td>335</td><td>0</td></tr>
<tr><td>12/30/2013</td><td>Mon</td><td>3:15 PM</td><td>-0.8</td><td>-24</td><td>L</td><td>0</td><td>-24</td></tr>
<tr><td>12/30/2013</td><td>Mon</td><td>9:26</td><td>9.6</td><td>293</td><td>H</td><td>293</td><td>0</td></tr>
</table>

		PM					
12/31/2013	Tue	3:27 AM	0.0	0	L	0	0
12/31/2013	Tue	9:41 AM	11.5	351	H	351	0
12/31/2013	Tue	4:08 PM	-1.3	-40	L	0	-40
12/31/2013	Tue	10:18 PM	10.0	305	H	305	0

Explanation of equations in spreadsheet:

The “Only Highs” and “Only Lows” columns were added to filter out the original data. To determine the “High (m)” value the average of the “Only Highs” column is taken, multiplied by 2 since every other value is 0 representing the low tide data. This is then divided by 100 to convert to meters. The “Low (m)” value was determined in the same way. Lastly, the “Diff (m)” value was determined by subtracting the “Low (m)” value from the “High (m)” value.

Appendix D - Current Data Excerpt

*Due to the large size of data only 5 days are shown here. For full listing of data for all sites see the NOAA website at http://tidesandcurrents.noaa.gov/cdata/StationList?type=Current+Data&filter=historic

	Start Date	**End Date**	
Little Misery Island	5/20/2011	6/25/2011	
Depth	6.37 m	DATA	
Average Speed	14.95519481 cm/s	=AVERAGE(B10:B8633)	
Average Power	133.5173383	=AVERAGE(D10:D8633)	
Timespan (days)	36	=C2-B2	
kWhr/year	1169.611883	=B5*8760/1000	
Date/Time	**Speed (cm/sec)**	**Dir (true)**	**Power**
DATA	DATA	DATA	=Constants!B$4*(B10/100)^3/2*B$3^2
5/20/2011 15:15	31.3	255	601.0033
5/20/2011 15:21	33.7	260	750.1249
5/20/2011 15:27	31.7	256	624.3407
5/20/2011 15:33	31.4	258	606.7822
5/20/2011 15:39	31.3	263	601.0033
5/20/2011 15:45	34.6	262	811.8432
5/20/2011 15:51	32.6	264	679.0420
…			
6/25/2011 12:51	4.5	234	1.7860
6/25/2011 12:57	4.8	205	2.1675
6/25/2011 13:03	4.1	217	1.3508
6/25/2011 13:09	3.3	206	0.7043
6/25/2011 13:15	3.3	224	0.7043
6/25/2011 13:21	3.2	233	0.6422
6/25/2011 13:27	2.3	220	0.2384
6/25/2011 13:33	3.2	197	0.6422
6/25/2011 13:39	4.6	146	1.9077

Explanation of equations in spreadsheet:

The “Power” was determined from Equation 3. The “Average Speed” was calculated by taking the average of the current speed data for a given station. The “Average Power” was calculated by taking the average of the calculated power data. The “Timespan (days)” was calculated by subtracting the “End Date” and “Start Date” values. The “kWhr/year” value was determined by assuming the turbine would be running 24 hours for 365 days.

Appendix E - Summary of Energy Provided by Tidal Stream

Code	**Station**	**kWh/year**	**Households Powered/Year**	**Households Powered/Year/Turbine Size**
DATA	DATA	DATA	=D3/J$3	=E3/C3
COD0904	Cape Cod Canal, Railroad Bridge	500423.64	66.5103	15.08170506
COD0903	Cape Cod Canal, Bournedale	350196.00	46.5439	7.705937114
COD0905	Hog Neck	95133.51	12.6440	3.571753518
COD0911	Woods Hole, The Strait	69340.04	9.2158	3.177878676
BOS1122	Georges Island	52497.03	6.9773	0.863524314
COD0914	Quicks Hole, Middle	51887.83	6.8963	1.316089425
BOS1131	Stellwagen Bank	28393.05	3.7737	0.377366397
BOS1110	Deer Island (0.7mi.)	20536.42	2.7295	0.545891059
BOS1111	Boston Harbor, Deer Island Light	20278.38	2.6952	0.417207364
COD0906	Abiels Ledge	18195.38	2.4183	0.532667856
BOS1133	Sanctuary 1	12662.15	1.6829	0.174213372
COD0912	Juniper Point	10893.40	1.4478	0.392363333
BOS1132	Traffic Scheme	8424.11	1.1196	0.111963246
BOS1128	Minots Light,3.3 mi north	3460.32	0.4599	0.045990417
BOS1129	Minots Light - 6.5 mi N	3297.17	0.4382	0.043822056
BOS1112	Spectacle Island	2944.36	0.3913	0.087939128
COD0910	Woods Hole, North End	2470.22	0.3283	0.147225125

BOS1130	Stellwagen Basin east end	2122.18	0.2821	0.028205519
BOS1135	Sanctuary 3	1835.89	0.2440	0.024400474
BOS1134	Sanctuary 2	1214.72	0.1614	0.016144543
COD0908	West Island, 1mi SE of	1179.82	0.1568	0.04249515
BOS1101	Little Misery Island	1169.61	0.1555	0.024403581
BOS1106	Northeast Grave	1001.94	0.1332	0.020238012
COD0907	Cleveland Ledge	249.01	0.0331	0.00743716
BOS1103	Abbot Rock	59.71	0.0079	0.002099393

Explanation of equations in spreadsheet:

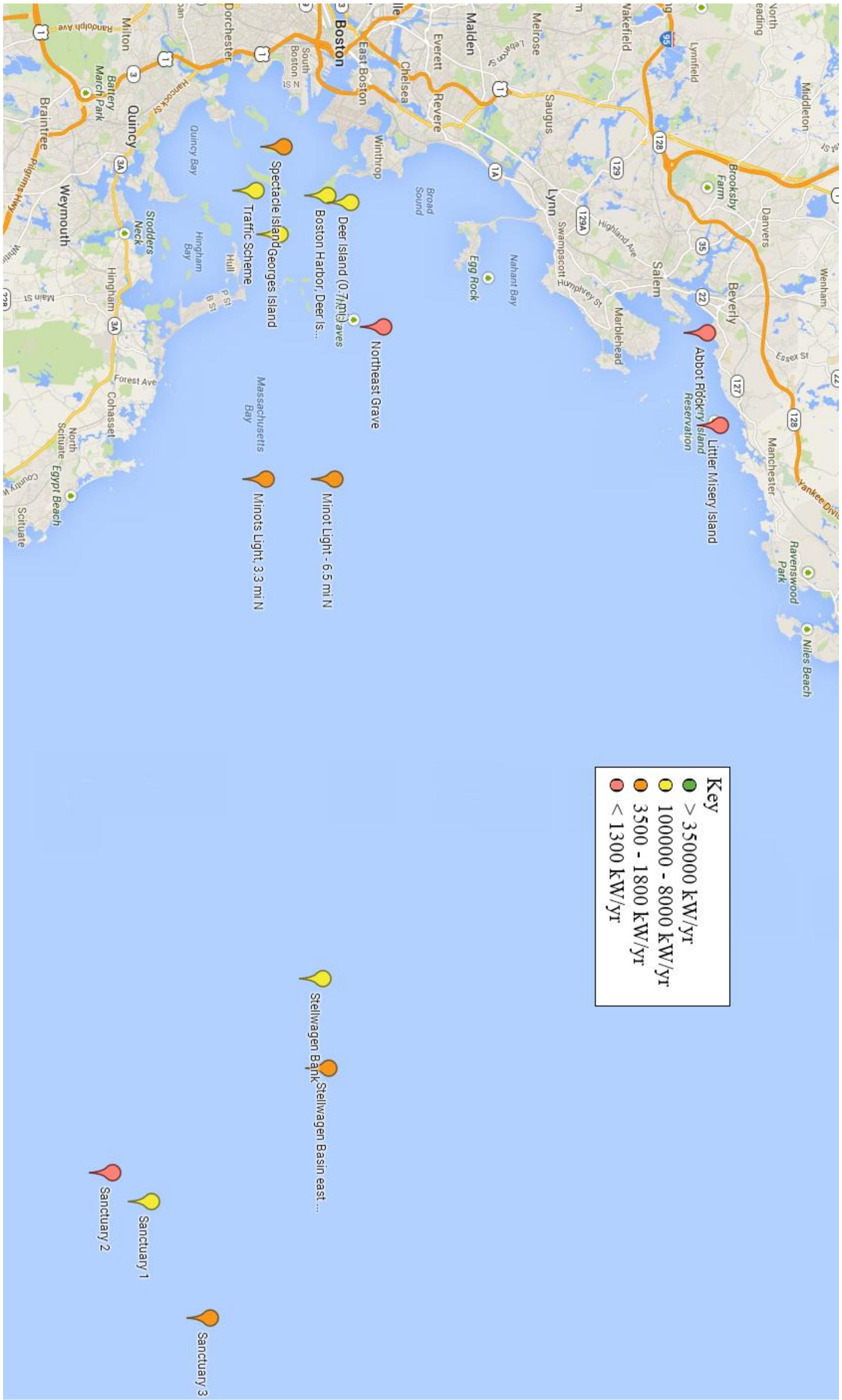
The “Households Powered/Year” value was calculated by dividing the kWh/year by the average kWh/year consumption in Massachusetts. The “Households Powered/Year/Turbine Size” was a calculated ratio of the households powered a year and the turbine size. This was a crude representation of value since larger turbines generally require greater capital investment.

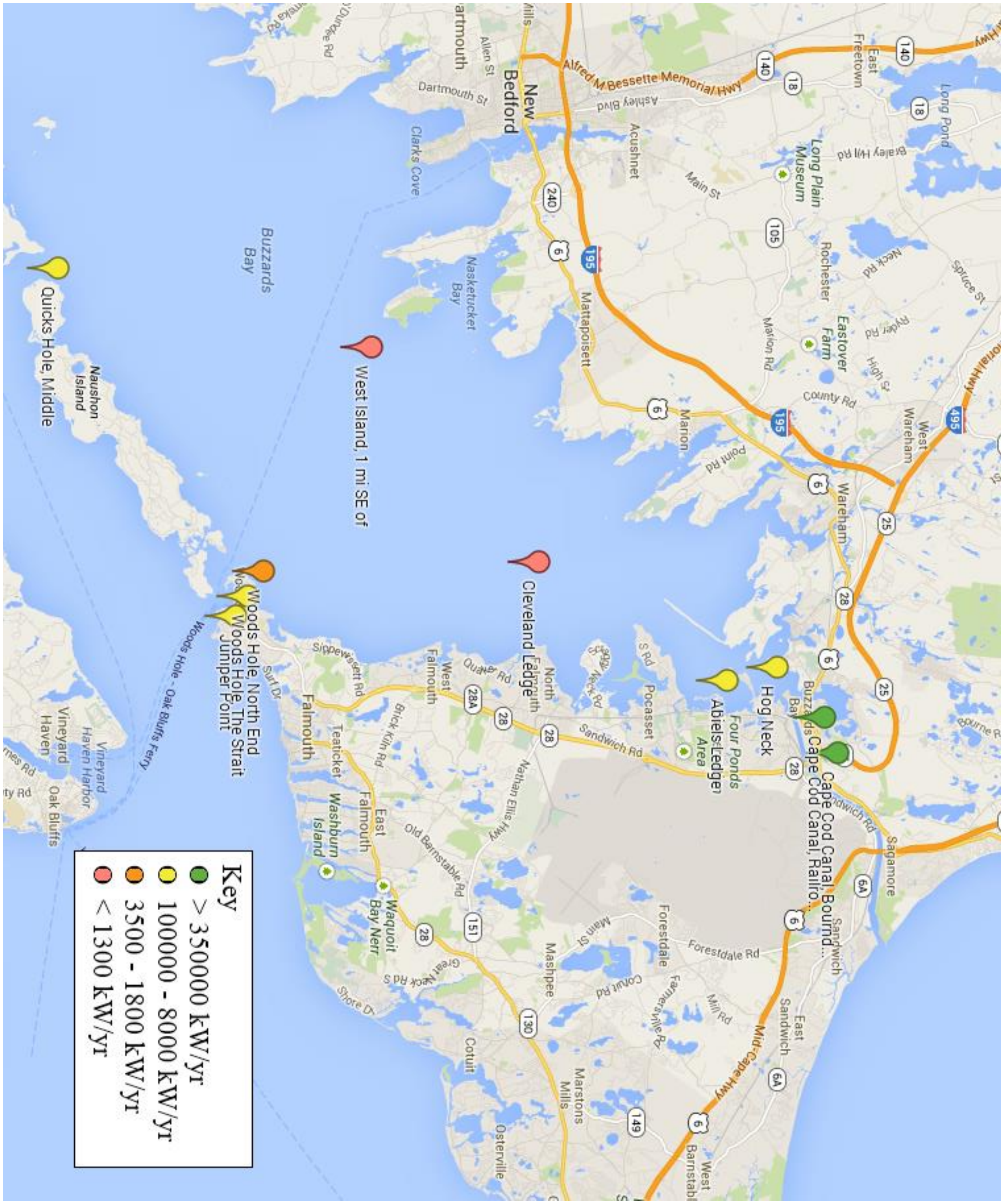
Appendix F - Summary of Tidal Current Data

Station	Estimated Turbine Radius (m)	Timespan (days)	Average Speed (cm/s)	Average Power Generation (W)
Cape Cod Canal, Railroad Bridge	4.41	77	159.927793	57125.986590
Cape Cod Canal, Bournedale	6.04	47	115.196209	39976.712770
Hog Neck	3.54	48	105.586572	10859.989960
Woods Hole, The Strait	2.90	107	110.435837	7915.529860
Georges Island	8.08	40	47.227020	5992.811425
Quicks Hole, Middle	5.24	53	65.624894	5923.267787
Stellwagen Bank	10.00	42	34.942566	3241.215488
Deer Island (0.7mi.)	5.00	41	47.224237	2344.340369
Boston Harbor, Deer Island Light	6.46	88	37.778745	2314.883630
Abiels Ledge	4.54	47	49.824144	2077.098173
Sanctuary 1	9.66	32	20.858724	1445.450731
Juniper Point	3.69	48	50.981183	1243.539149
Traffic Scheme	10.00	42	22.385009	961.656917
Minots Light,3.3 mi north	10.00	39	14.992375	395.013578
Minots Light - 6.5 mi N	10.00	38	15.886563	376.389437
Spectacle Island	4.45	37	26.705132	336.114189
Woods Hole, North End	2.23	54	42.307341	281.988550
Stellwagen Basin east end	10.00	30	13.621467	242.258362
Sanctuary 3	10.00	42	12.240219	209.576677
Sanctuary 2	10.00	42	10.822032	138.666140
West Island, 1mi SE of	3.69	93	21.163939	134.682266
Little Misery Island	6.37	36	14.955194	133.517338
Northeast Grave	6.58	39	13.915203	114.376929
Cleveland Ledge	4.45	47	11.397835	28.425741
Abbot Rock	3.78	36	8.068590	6.816011

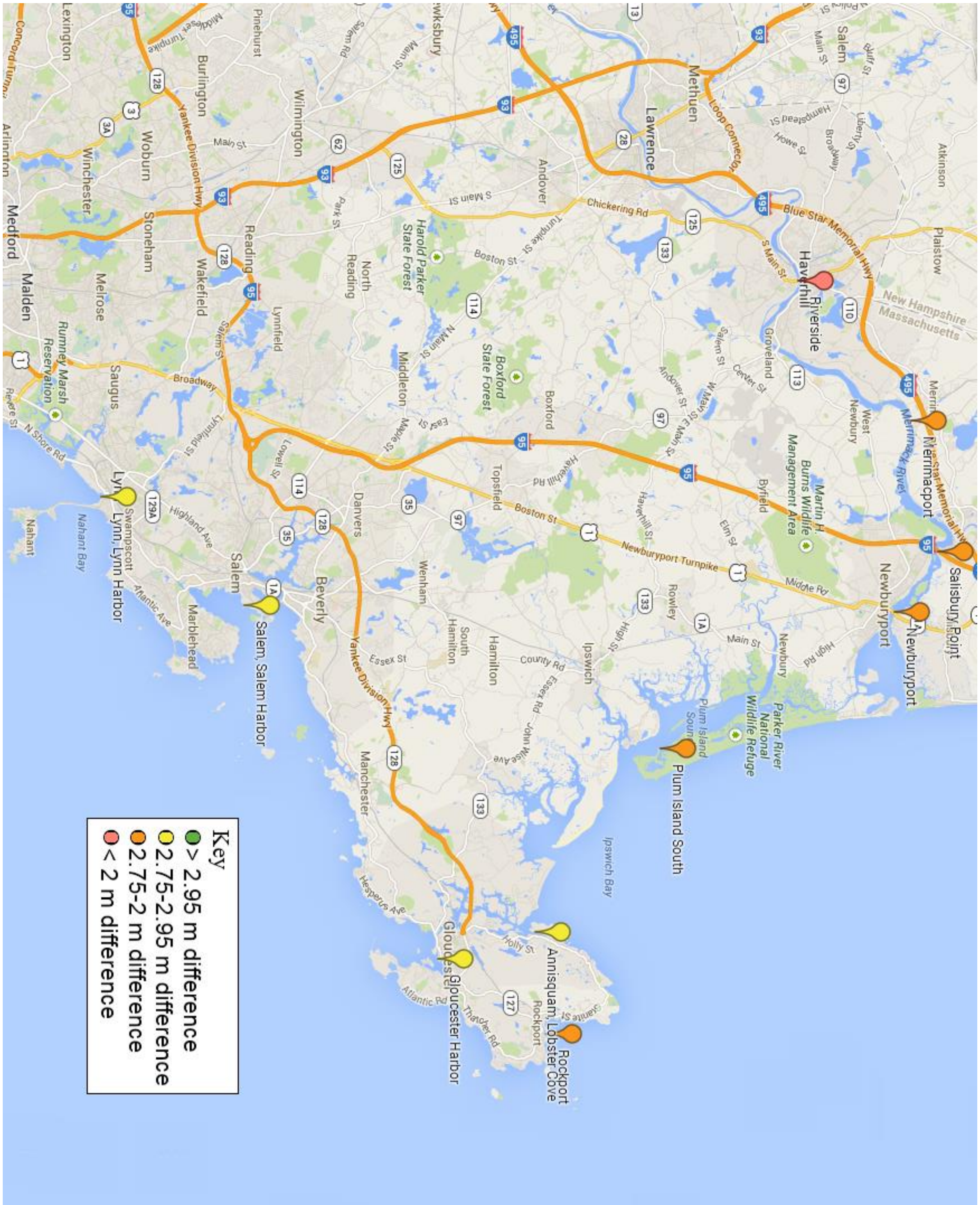
Estimated Turbine Radius is 85% of total water depth. All other values in this spreadsheet were values pulled from current data for sites as shown in Appendix D.

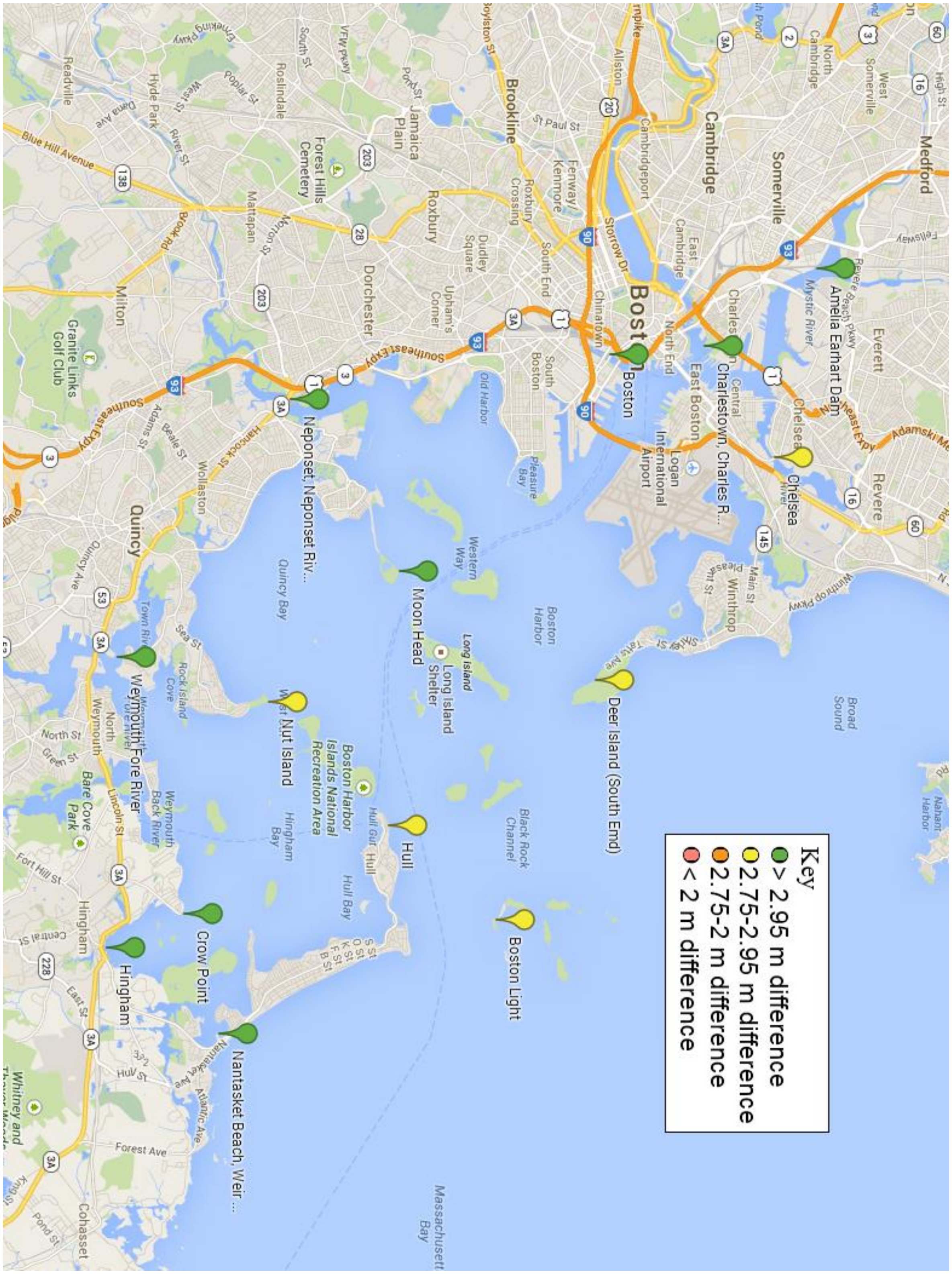
Appendix G – Current Data Site Location Maps for BOS and COD

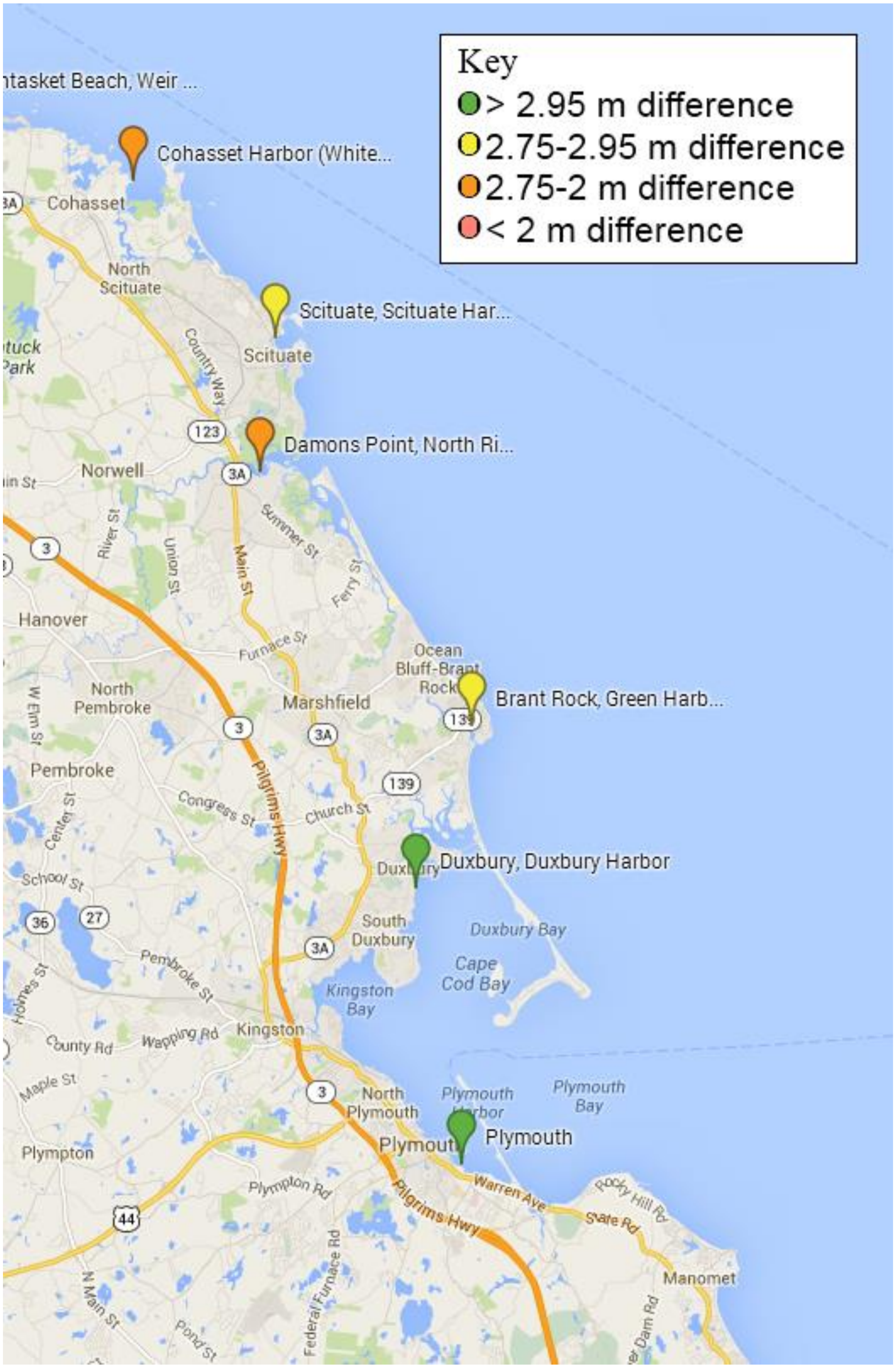



Key
● > 350000 kW/yr
● 100000 - 8000 kW/yr
● 3500 - 1800 kW/yr
● < 1300 kW/yr
Quicks Hole, Middle
West Island, 1 mi SE of
Cleveland Ledge
Woods Hole, North End
Woods Hole The Strait
Juniper Point
Hog Neck
Abiels Ledge
Cape Cod Canal, Bournd...
Cape Cod Canal, Railro...
Buzzards Bay
Buzzards Bay
New Bedford
Dartmouth
Clarks Cove
Nasketucket Bay
Mattapoisett
Marion
Wareham
West Wareham
Rochester
Acushnet
Long Plain Museum
Eastover Farm
East Freetown
Naushon Island
Woods Hole - Oak Bluffs Ferry
Vineyard Haven
Vineyard Haven Harbor
Oak Bluffs
Falmouth
West Falmouth
North Falmouth
East Falmouth
Teaticket
Pocasset
Four Ponds Area
Washburn Island
Waquoit Bay Nerr
Mashpee
Forestdale
Sandwich
East Sandwich
Sagamore
Cotuit
Osterville
Marstons Mills
West Barnstable
Mid-Cape Hwy

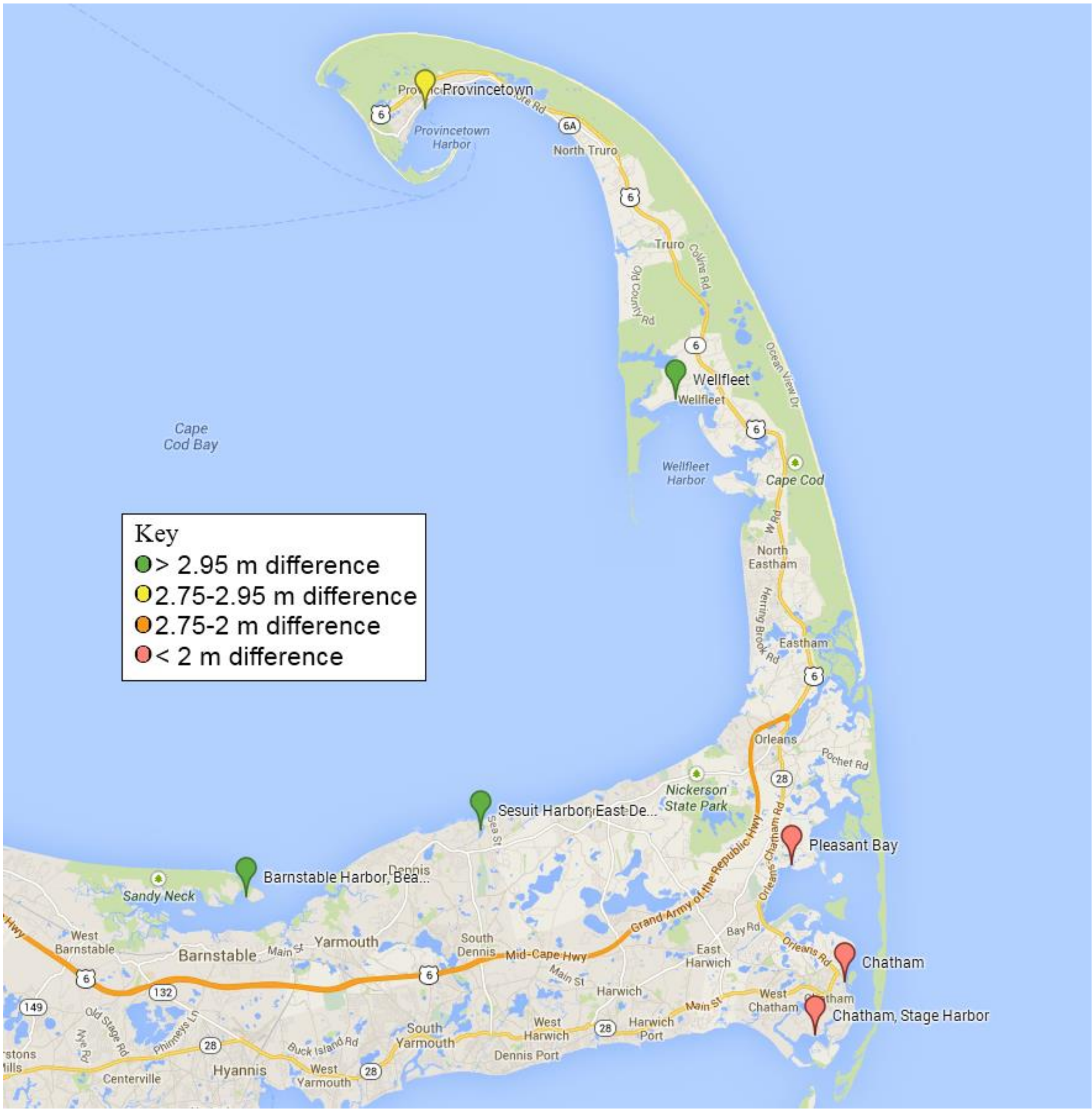
Appendix H – Tidal Barrage Analysis Station Maps




Key
🟢 > 2.95 m difference
🟡 2.75-2.95 m difference
🟠 2.75-2 m difference
🔴 < 2 m difference
Amelia Earhart Dam
Charlestown, Charles R...
Boston
Chelsea
Neponset, Neponset Riv...
Moon Head
Deer Island (South End)
Weymouth Fore River
Nut Island
Hull
Boston Light
Crow Point
Hingham
Nantasket Beach, Weir ...


Key
🟢> 2.95 m difference
🟡2.75-2.95 m difference
🟠2.75-2 m difference
🔴< 2 m difference
ntasket Beach, Weir ...
Cohasset Harbor (White...
Cohasset
North Scituate
Scituate, Scituate Har...
Scituate
Damons Point, North Ri...
Norwell
Hanover
North Pembroke
Pembroke
Marshfield
Ocean Bluff-Brant Rock
Brant Rock, Green Harb...
Duxbury, Duxbury Harbor
South Duxbury
Duxbury Bay
Cape Cod Bay
Kingston Bay
Kingston
North Plymouth
Plymouth Harbor
Plymouth Bay
Plymouth
Plympton
Manomet
Pilgrims Hwy
Warren Ave
State Rd


Key
🟢> 2.95 m difference
🟡2.75-2.95 m difference
🟠2.75-2 m difference
🔴< 2 m difference
Bourne Bridge-Cape Co...
Bournedale, Cape Cod C...
Sagamore, Cape Code Ca...
Sandwich
Cape Cod Bay
Buzzards Bay
Great Herring Pond
Sagamore
Sagamore Beach
State Reservation
Shawme-Crowell State Forest
Heritage Museums & Gardens
East Sandwich
Bourne


Key
> 2.95 m difference
2.75-2.95 m difference
2.75-2 m difference
< 2 m difference
Provincetown
Provincetown Harbor
North Truro
Truro
Collins Rd
Old County Rd
Ocean View Dr
Wellfleet
Wellfleet Harbor
Cape Cod
Cape Cod Bay
North Eastham
Herring Brook Rd
Eastham
Orleans
Pochet Rd
Nickerson State Park
Sesuit Harbor, East De...
Pleasant Bay
Barnstable Harbor, Bea...
Sandy Neck
Dennis
Grand Army of the Republic Hwy
Orleans Chatham Rd
West Barnstable
Barnstable
Yarmouth
South Dennis
Mid-Cape Hwy
East Harwich
Bay Rd
Orleans Rd
Chatham
Harwich
West Chatham
Chatham, Stage Harbor
West Harwich
Harwich Port
South Yarmouth
Dennis Port
Hyannis
West Yarmouth
Centerville
Buck Island Rd
Phinneys Ln
Old Stage Rd
Nye Rd

Appendix I – Tidal Barrage Cost Analysis Calculations

For the 850MW capacity system, cost estimates were \$4.44m startup and \$0.05m operating per MW. Tide differentials in the Severn project are around 14m.

(\$4.44m/MW)*850MW = \$3.774 billion

(\$0.05m/MW)*850MW/year = \$42.5 million/year

$$P = \frac{30\% * A\rho g h^2}{86400} \quad (2)$$

Where:
E = energy in joules
A = the horizontal area of the barrage basin in m
ρ = the density of water = 1025 kg/m^3
g = the acceleration due to Earth's gravity = 9.81 m/s
h = the vertical tidal range in m

$$850 = \frac{30\% * A * 1025 * 9.81 * 14^2}{86400}$$

A = 124.212 m

Assuming that the projects would be similar in cost per m of barrage the following ratio is used to estimate the costs for the Massachusetts project.

X = cost in billions of dollars (capex)

$$\frac{\$3.774\ billion}{124.212\ m} = \frac{X}{1000m}$$

X = \$30.384 billion

Y = cost in billions of dollars (opex)

$$\frac{\$42.5\ million}{124.212\ m} = \frac{X}{1000m}$$

Y = \$342.157 million