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Tidal Energy in the Bay of Fundy

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ABSTRACT

With increasing global energy demand, clean and renewable tidal energy is an appealing alternative energy source. The predictable and reliable nature of tides makes tidal energy an interesting option for electricity generation. The Bay of Fundy, Nova Scotia, has the world's highest tides, with a range of over 16 m vertically and 5 km horizontally. Specifically, the Minas Passage area of the Bay of Fundy has been selected for tidal energy research, where tidal energy may be harnessed without a great environmental impact. This area has straight flowing currents and a sediment-free bedrock sea floor, suitable features for in-stream tidal turbines. FORCE (Fundy Ocean Research Centre for Energy), a not-for-profit partnership, has been conducting the research in the Minas Passage area, along with Natural Resources Canada's CanmetENERGY and other collaborators.

The history of tidal energy activities in the Bay of Fundy is presented and the different in-stream technologies are described in this case study. A tidal barrage, (the Annapolis tidal generating station), has been operating for several years. In addition, various companies have begun testing in-stream turbines at the FORCE test site. Challenges are identified for both technologies. The tidal barrage has impacted marine life, as well as local erosion. In the case of the tidal turbine, the first turbine deployed did not withstand the Minas Passage flows.

1 INTRODUCTION

The Bay of Fundy is located between the provinces of New Brunswick and Nova Scotia. The ocean bay extends approximately 280 km, reaching the state of Maine as illustrated in Figure 1 [1]. The presence of exceptional rates and volumes of flow ensure this is an area of great interest for harnessing tidal energy. The Fundy Ocean Research Centre for Energy (FORCE) describes the 160 billion tonnes of water that flow into the bay on a flood tide as, "more than four times the estimated combined flow of all the world's freshwater rivers during the same 6-hour interval [2]." The tidal range is over 16 m

vertically and 5 km horizontally [2]. In addition, the tidal currents are up to 5.1 m/s (10 knots) at peak surface speed [2]. These tidal ranges and currents distinguish the bay from other areas around the world and people have been observing the energy potential for many years. Projects began as early as 1607, when a mill partially powered by tidal energy was built. Later, in 1935 the Passamaquoddy Bay tidal project began along the US-Canada border [3]. However, this project was abandoned in August of 1936 when further American government funding was not approved due to political challenges and opponents, such as, other power generation companies [4]. In more recent years, two tidal energy technologies have been tested in the Bay of Fundy. This case study describes the Annapolis Tidal Generating Station, and the in-stream tidal technology tested in the Minas Passage. The challenges associated with each are discussed.

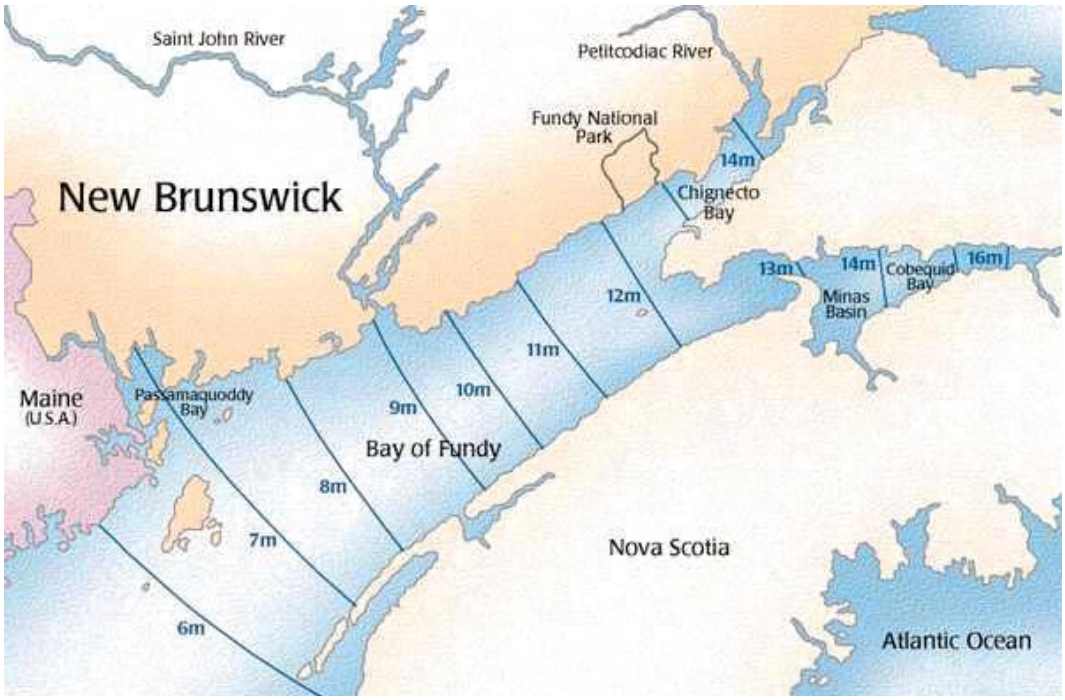

Figure 1: Tidal Ranges in the Bay of Fundy [5]

2 BARRAGE PLANT TECHNOLOGY

Barrage plant (or barrier plant) technology works similarly to conventional hydroelectric dams. The potential energy of the water height is converted to electricity through a generator. In addition to the Annapolis tidal station, there is a 240 MW plant in France, a 0.5 MW plant in Russia, and a 254 MW tidal barrage in South Korea [6], [7].

2.1 The Annapolis Tidal Generating Station

The Annapolis (Nova Scotia) tidal generating station is a 20 MW plant that has been operating in Annapolis Royal, NS, since 1984 [8]. The capacity is enough energy to power about 6000 homes [9]. The station is operated by Nova Scotia Power and it is pictured in Figure 2 [9].

Figure 2: The Annapolis Tidal Generating Station [10]

2.2 Challenges for the Tidal Generating Station

In the case of the Annapolis tidal generating station, two of the impacts observed are the effect on marine life, and increased erosion. There have been cases of marine life becoming trapped behind the barrier. "In August of 2004 a mature humpback whale (nicknamed sluice) swam through the open sluice gate and ended up trapped for several days in the basin [11]." As well, an increased rate of erosion has been observed on the upstream and downstream banks of the Annapolis River since the installation of the plant [11].

Other environmental impacts that tidal barriers may have are the effect on fish population and silting due to the reduction in tide force and speed [11]. Although some sedimentation in the basin takes place, from the start of operations until 2003, it has not been necessary to dredge the basin of the Annapolis tidal generating station [12].

3 IN-STREAM TIDAL ENERGY

In contrast with barrage technology, in-stream tidal technology does not require a dam or impoundment [6]. Turbines are placed in the tidal stream and harness the kinetic energy of the moving water [6]. The turbines rotate electricity generators. In-stream tidal energy technology is of greatest interest today because it has a smaller environmental footprint than tidal barrages [7]. With the devices installed offshore, there is minimal effect on the coastline [7]. However, installed in-stream tidal projects do not produce such great amounts of power as the barrage plants [7].

3.1 The Minas Passage

The "North America Tidal In-Stream Energy Conversion Technology Feasibility Study" conducted by the Electric Power Research Institute (EPRI) evaluated potential energy supply sources in North America as part of their techno-economics investigation of in-stream tidal energy conversion. Through this study, the Minas Passage in the Bay of Fundy was identified as a favourable site. There is a tidal energy potential of over 1 GW, and assuming that 15% could be harnessed, the technology would generate enough electricity to power about 120,000 homes. The Minas Passage has the most available power out of the seven states and provinces that were part of the study. [6]

The available power comes from the significant tidal range. The EPRI describes how the tidal range starts at about 5 m at the mouth of the Bay of Fundy and is amplified toward the smaller basins at the head of the Bay. The amplification of the tidal range is, firstly, "because the natural period of the semi-enclosed basin that encompasses the Gulf of Maine and Bay of Fundy is about 13 hours, which is very close to the principal lunar semi-diurnal tidal forcing period of 12.4 hours." Secondly, shoaling and funnelling within the Bay of Fundy results in the highest tidal ranges in the world. Figure 1 illustrates the tidal ranges. [5]

Through the EPRI "Survey and Characterization of Potential Project Sites", eight sites that have tidal current velocities of at least 1.5 m/s (3 knots) were selected. These sites are shown in Figure 3. Through the study it was found that The Minas Passage and the Minas channel were the only locations to have sufficient potential for central generation. The Minas Passage was identified to have the highest potential installed tidal in-stream energy conversion capacity of 333 MW. The Minas Passage also satisfied criteria including, suitable site bathymetry and seafloor geology, availability of suitable onshore grid interconnection, nearby regional shipyard labour and infrastructure, and minimal conflict with competing use of sea space. [5]

In addition to the water speed, the beneficial characteristics of the Minas Passage site include a sediment-free bedrock sea floor, straight flowing currents, and water depths of up to 45 m at low tide [13]. Figure 4 shows the bedrock exposure area.

Figure 3: Eight Potential Project Sites [5]

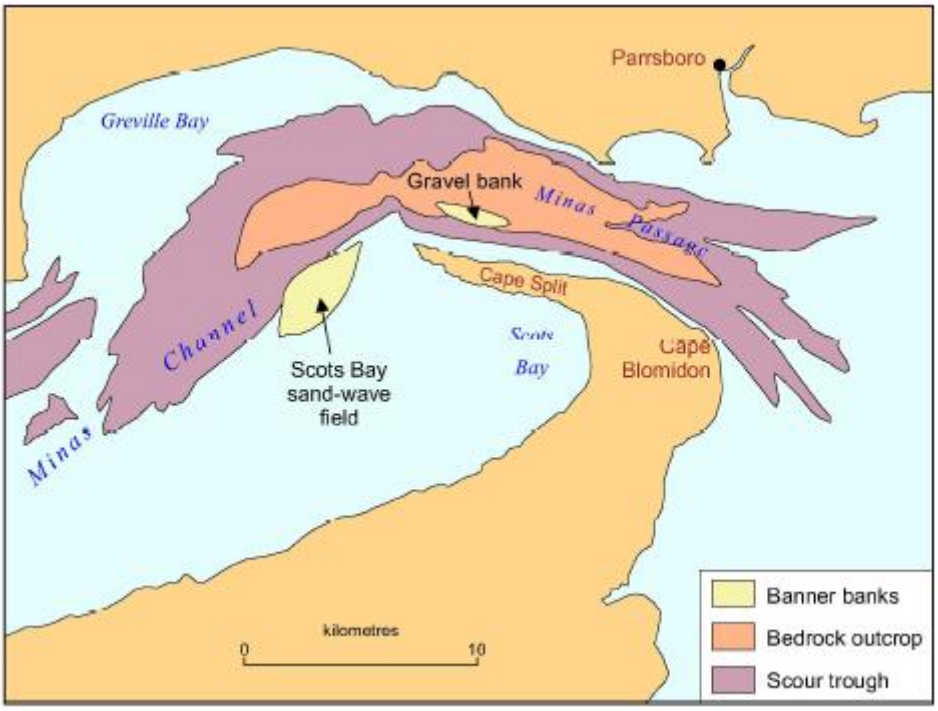

Figure 2. Geomorphological interpretation of Minas Channel and Minas Passage.

Figure 4: Exposed Bedrock Area in the Minas Passage [14]

3.2 The Fundy Ocean Research Centre for Energy

FORCE is an in-stream tidal energy technology test centre that is funded through the Province of Nova Scotia, the Government of Canada, Encana Corporation and participating developers. They provide an in-stream technology test site that can facilitate up to four different participants who currently include, Nova Scotia Power (with OpenHydro), ALSTOM (using Clean Current design), Minas Basin Pulp and Power (with Marine Current Turbines), and Atlantis Resources Corporation (in partnership with Lockheed Martin and Irving Shipbuilding) [13]. FORCE provides an observation facility, submarine cables, grid connection, and environmental monitoring at the site [13] Notable objectives of the project include accelerating the development and deployment of tidal in-stream energy conversion technology in Canada, monitoring the performance of the technology and the interaction with the environment, and establishing markets in Canada, as well as creating international market opportunities [13].

3.3 Nova Scotia Power and OpenHydro Commercial Test Turbine

Nova Scotia Power, the company that provides more than 95% of the generation, transmission and distribution of electrical power in Nova Scotia, and OpenHydro, a company that specialises in the design, manufacture, installation and maintenance of in-stream tidal energy turbines, are working together as a developer at the FORCE test site [15]. They designed a 10 m diameter, 1 MW capacity commercial tidal turbine that is shown in Figure 5 [16].

Figure 5: Nova Scotia Power and OpenHydro In-Stream Tidal Turbine [9]

The turbine is designed for open-centre axial flow [9]. The rotor blades are within an outer housing in order to minimize environmental impact [17]. The large opening in the centre provides an exit route for marine life [17]. In addition, the design of the turbine is such that no potentially toxic oils or lubricants are required [17]. The materials used in the manufacturing of the turbine are glass reinforced composite materials and steel [17]. The turbine was manufactured by OpenHydro in Ireland and the gravity base of the turbine was built by Cherubini Metal Works in Dartmouth, NS [16].

The turbine was transported to the Minas Passage and arrived at the FORCE deployment site November 11, 2009. On November 12, 2009 the "OpenHydro Installer", a specialized barge, lowered the turbine to the seabed within one hour [18]. The Nova Scotia Power and OpenHydro turbine was the first commercial scale technology to be successfully deployed and tested in the Bay of Fundy [18]. The testing was focused on evaluating the robustness of the turbine for the harsh Minas Passage environment, monitoring of environmental impacts and evaluating energy production capacity [16].

In June of 2010, Nova Scotia Power and OpenHydro released a project update describing that an acoustic modem that recovered data from the turbine was no longer functioning. OpenHydro used video footage to observe the location and condition of the turbine, and concluded that the turbine rotor may be damaged. Therefore, it was planned to recover the turbine in the fall of 2010 with a plan to conduct detailed engineering analysis of the turbine upon recovery. The examination of the unit would provide information on the condition of the turbine [19]. At the time it was planned to review the turbine design and redeploy in 2011 [19].

On December 16, 2010, Nova Scotia Power and OpenHydro successfully recovered the 400 tonne turbine, and the gravity base, from the Minas Passage [9]. Later, in 2012, Nova Scotia Power turned over the in-stream tidal energy responsibility to its parent company Emera Inc. [20]

3.4 In-Stream Tidal Energy Challenges

For Nova Scotia Power and OpenHydro the most evident challenge in harnessing tidal energy is in the turbine design. Based on the initial assessment of the turbine upon recovery, the structure remained intact but the turbine blades were all missing [15]. This indicated that the tidal flows experienced at the Minas Passage test site were much stronger than the design flows [15]. No specifics on the revised estimation of the tidal flow rates were provided by Nova Scotia Power but, according to CBC news, "all 12 rotor blades were destroyed by tidal flows that were two and a half times stronger than what the turbine was designed to withstand [20]."

3.5 Future In-Stream Tidal Technology Testing

As mentioned earlier, there are three other participants at the FORCE test site. Firstly, Minas Basin Pulp and Paper, and Marine Current Turbines plan to install three 1 MW "SeaGen U" tidal generators in 2015. Secondly, Alstom plans to install a 1 MW TGL Turbine in the spring of 2015 [21]. They will be studying results from a turbine demonstration off the Orkney Islands before deployment in the Bay of Fundy [20] Thirdly, Atlantis Resources Corporation, in partnership with Lockheed Martin and Irving Shipbuilding plans to deploy a 1 MW turbine in the summer of 2015 [21].

4 CONCLUSION

For years people have been using technology to harness the energy in the Bay of Fundy, through the Annapolis tidal generating station, as well as, exploring new in-stream tidal technology at the FORCE test site in the Minas Passage. The Annapolis tidal generating station, a barrage plant, has been operating well economically, however, there are some associated environmental challenges including trapped marine life within the basin, and locally increased erosion. These environmental impacts have led to a research and development focus on in-stream tidal energy technology, which is thought to have a lesser environmental impact. An EPRI study identified the Minas Passage in the Bay of Fundy as having the greatest potential for in-stream tidal energy technology in North America, and FORCE was created to facilitate technology testing and environmental monitoring. The main challenge experienced by Nova Scotia Power and OpenHydro, with their in-stream turbine was the power of the tides in the Minas Passage and the robustness the turbine design.

As the remaining three participants deploy various in-stream turbine designs, we will learn more about the conditions at the Minas Passage site and how the designs succeed or fail. It is important that environmental monitoring continues during testing because the effects will be dependent on different turbine designs and the specific site characteristics. The in-stream tidal turbine is a promising technology and it is important to continue research and tests, as the world's energy demand and the importance of environmental sustainability continue to grow.

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