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SEDIMENTATION CHANGES DUE TO IN-STREAM TIDAL POWER GENERATING TURBINES IN THE MINAS PASSAGE

Power generation from one to three in-stream turbines in the Minas Passage equates to a proposed 0.004% to 0.013% reduction in tidal energy flow. This reduction in tidal flow equates to a reduction in tidal amplitude of 0.06 to 2mm respectively. Considering, that the rate of sedimentation is a function of tidal energy flow, the 14-16m tidal range and high flow velocity (~5 m/s) of the passage and the basin, the 2mm reduction in tidal amplitude will not have system-wide effects on tidal flow or sedimentation regime. An increase in local sedimentation in the near-field zone around the turbines is expected, but exact sedimentation concentration values have yet to be modeled. Eventually, the large-scale implementation of an array of turbines stretching across the passage could greatly reduce the tidal amplitude (%40 reduction results in a 2m elevation decrease) at Maximum Power Extraction (6.9GW). Proposed increases in sedimentation are expected in the Five Islands Provincial Park, Noel Bay, Truro area, Windsor Bay, Blomidon Bay, Parrsboro and Economy areas. Reduced Shad, Salmon and Sturgeon migrations; physical barriers for marine mammals, reduced invertebrate larval settlement and increased marshland biodiversity are proposed impacts from a probable large-scale turbine power array across the Minas Passage.

Acknowledgements

This report would not be possible without the help from Dr. David Greenberg (Department of Fisheries and Oceans (DFO) & Bedford Institute of Oceanography (BIO)) and Dr. Richard Karsten (Acadia University) with their help in modeling local sediment changes from the proposed three turbine power generation project and with understanding the technical nature of complex sediment models.

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Background

Tidal power generation in the Minas Passage and Basin have been topics of research for almost 100 years. Recent advances in tidal power extraction have lead the Minas Basin Pulp and Power Ltd. company and NS Power to design and implement a pilot project consisting of three in-stream turbines near Parrsboro, NS. Commercial scale numerical models have estimated power extraction across Minas Passage to be 6.9 Giga Watts (GW) which could potentially power 7.9 Million homes. The great potential of power extraction poses a substantial biological, ecological and socio-economic cost to the Minas Basin communities. The more power extracted, the greater the reduction in tidal flow; which equates to increased sedimentation through reduced tidal elevation, and changes in migration patterns of larvae, fishes and marine mammals. Not to mention a probable reduction in recreational fishing and possible smothering of Jurassic-Triassic aged fossils. The impacts of this project have been well investigated but lacked information on the change in sedimentation rates caused by reduced tidal flow rates due to the pilot project's in-stream turbines. This report identifies the proposed local sedimentation zones from the current pilot project while also presenting commercial scale predictions of sedimentation changes in the Minas Passage and Minas Basin.

Physiography, Geography, Bathymetry, Bedrock Geology, Oceanography, Sediment Characteristics, Biology and Ecology of the Minas Passage

Physiography

The Minas Passage and Basin are within the Appalachian Region in the Carboniferous-Triassic Lowlands also known as the Fundian Lowlands. The Appalachian Region began during the late Jurassic to early Cretaceous period and modifications of the landscape were driven by fluvial drainage. The Fundian Lowlands cover most of the Bay of Fundy and into the deeper parts of the Gulf of Maine. Subaerial erosion primarily developed the Fundian Lowlands and subsequent glacial erosion had a minor but regional influence on the physiography of the Minas Passage and Basin (Williams, Kennedy and Neale 1972).

Geography

The Minas Passage and Minas Basin are located in the Inner Bay of Fundy (Fig. 1). The Minas Passage is a rectangular shaped body of water that connects the Inner Bay of Fundy (east of Isle Haute) with the Minas Basin. *The Passage* is 14Km long and 5-10Km wide. *The Passage* is situated northwest-southeast and the four corners are shown in Figure 2. Black Rock is a small basalt island that lies in the northern corner of the Minas Passage (Fig. 3).

The southern shoreline of the Minas Passage is straight steep basalt cliffs. The northern coastline of the Minas Passage contains various bedrock lithologies. Partridge Island and Cape Sharp, within the Minas Passage, are high-relief basalt cliffs that have resisted erosion (Fig. 4). Adjacent to the cliffs are siltstone and shale that have been heavily eroded. Overlain by glacial and post glacial sedimentation from caving ice fronts and raised sea levels that produced terraced regions of glacial outwash, gravel barriers, till cliffs and exposed bedrock. These varieties of processes and materials have resulted in a highly irregular coastline with the occasional straight segments and a large embayment (Partridge Island area) (Welsted 1974). There are two bedrock types at the turbines installation sites; sandstone ridges and flat hummocky volcanic bedrock (Fig. 5) (Fader 2009).

Bathymetry and Bedrock Geology

The deeper parts of the Minas Passage range from 36m to 110m, Cape Split to Cape Sharp respectively (Fig. 4). Multibeam data at 1, 2 and 5m resolutions have been collected by the Canadian Hydrographic Service (CHS) and by the Geological Survey of Canada (GSC) around the proposed turbine installation sites (Fig. 4). Multibeam data provides detailed water depth and through data processing, backscatter (proxy for seabed hardness) and seabed slope can be generated. Sidescan Sonar at 0.25m resolution and bottom photographs at 1mm resolution have been taken to visualize the seabed geology (Fig. 5). Multibeam has identified a deep narrow linear depression (Minas Scour Trench) that runs throughout the Minas Passage, parallel to the southern shoreline. Multibeam also identified the volcanic bedrock ridge at 30-35m water depth with a 500m width. The multibeam imagery also shows that the volcanic bedrock ridge is 5-15m above the surrounding areas and some west flank scouring was visible as well. Multibeam imagery identified gravel waves east and west of Black Rock. Sub-bottom profilers (4 KHz Seistec and 0.3 to 3 KHz Huntec) were used to examine the sub-surface geology (up to 50m subsurface depth) for any irregularities within the exposed bedrock (engineering concerns for turbine installation) (Fig. 6). The seismic profiles from the turbine installation sites had strong reflections indicating solid bedrock. The seismic profiles indicate that *the Basin* sub-surface geology was influenced by pre-existing transverse faults (i.e. Glooscap Fault) (King and MacLean 1976). In the northwest region of Minas Passage the seabed is smoother in comparison to the rough bedrock ridged region in the central part. This suggests surficial sediments overlying the bedrock as *the Passage* gradually shallows to the northwest (Fader 2009).

Oceanography

The oceanographic conditions in the Minas Passage are comprised of well mixed Bay of Fundy (BoF) waters that are turbulent and form upwellings and gyre features in front and behind the Minas Passage (Fig. 7).

The seasonal temperatures within Minas Passage range from -1 to12°C (winter – summer) and the salinity in *the Passage* is ~31 PSU. In the Minas Basin and east towards the Cobequid Bay, mudflats can reach ~30°C in the summer at ~28 PSU (Oceans 2009).

The M_2 tide (semi-diurnal lunar tide that is typically 12.42 hours) in the Minas Passage, was calculated to have a period of 12.85 hours (Garrett and Cummins 2004, Karsten et al. 2008).

The volume of water through the Minas Passage was measured to be 1.0×10^6 m^3/s at a recorded flow rate of 3.28 m/s (Garrett and Cummins 2004). The velocity of the tidal flow varies by flow (advancing) or ebb (retreating) conditions and was measured by an Acoustic Doppler Current Profiler (ADCP) west of the proposed turbine installation sites (Karsten 2009). The ADCP recorded velocities ranged from 4.2 to 4.0 m/s (near surface) to 2.5 to 3 m/s (near bottom) at high tide (Fig. 8). The ADCP identified a velocity of ~0 m/s at low tide. The Minas Passage velocities were also by modeled Dr. Richard Karsten in the Finite-Volume Coastal Ocean Model (FVCOM 2.5) simulation environment for large scale power / flow dynamics and were estimated to be ~5 m/s (Fig. 9).

High tidal flow velocities continually keep fine-grained sediment in suspension; therefore, turbidity levels are high in the Minas Basin and slightly less in the center of the Minas Passage (Dadswell, Rulifson and Daborn 1986b). In the Minas Basin, the turbidity increases in concentration (20 to 800 mg/L) over the tidal flats. The Tidal flats are primarily silty-sand with < 20% clay; therefore, a noncohesive sediment.

Sediment Characteristics

Sediment sources for Chignecto Bay are from the cliffs and the seabed. There was no identifiable sink because sediments are transport by storm events. Defined turbid ribbons meander unpredictably through the Chignecto Bay; therefore, sediment mass transport estimation would not be accurate (Amos 1987). The Minas Passage and Basin sediment transport regime is thought to be analogous to Chignecto Bay in that storm events are the principal sediment transport mechanism (Amos 1987). The sources of sediment for the Minas Passage are northwest of the Minas Passage and northeast of Black Rock while receiving some input from the Minas Basin mudflats (Amos and Zaitlin 1984, Amos 1978). Amos and Zaitlin 1984, Dadswell, Rullifson and Daborn 1986a identified that the Minas Passage is a conduit for the transfer of suspended sediment. Suspended sediment concentrations in 1983 were 5mg/L (Minas Passage) and 2mg/L (Bay of Fundy). The resident suspended sediment volume in the Minas Basin was calculated to be $30x10^6$ m^3 replenished annually with $1.6x10^6$ m^3 / year (Amos and Mosher 1985). The volume and flow rate of water that enabled sediment transport in the Minas Basin was recorded to be $1.9x10^5$ m^3/s (Pelletier and McMullen 1972).

Present day bedload movement in the Minas Passage occurs only within the northernmost intertidal zone of the Minas Basin. Radio-isotope tracer studies of this material shows a net eastward transport of $0.85x10^6$ m/year (Amos 1985). Bedload transport is therefore site dependent and depends on local flow patterns. FVCOM can create 2D and 3D local flow and current change models, but it requires several computers running at once, with multiple cores, to perform the calculations to make these models. The expertise to accurately input the variables and access to recent data is also not readily available. A Single turbine 3D flow and current change model using the bottom drag component relative to eight turbines (Fig. 10) shows the increase in current flow on either side of the turbine. Figure 10 also shows that an almost complete stop in flow occurs in the immediate (16-32m) range in the near-field environment. Based-on figure 10, and by reducing the flow effects by 8x, local sedimentation effects in the near-field environment are estimated to be 320m x 160m rectangular area (Fig. 11). Other prospective nearby sedimentation accretion zones were created based-off of the FVCOM 3D models made by Dr. Karsten and Dr. Amos's 2D sedimentation predictions from his power barrage models within the Minas Basin (Fig. 12).

Sedimentation in the Minas Basin due to bioturbation and ice rafting has been observed to be a source of sedimentation through resuspension, but hasn't been quantified in the Minas Basin or Passage and therefore, the present-day models are still lacking this source of sediment (van Proosdij and Townsend 2005, Daborn et al. 1993).

Biology and Ecology

Estuarine environments in the Minas Passage and Minas Basin, especially salt marshes are integral components of the riverine and estuarine ecosystems. Salt marshes are major zones of biodiversity, nutrient input from tidal action and nursing grounds for several species of fishes and invertebrates (Minello et al. 2003). Salt marshes are effective at decontaminating the affected wetland / marshes by adsorption of pollutants and heavy metals within the water column and through microbial degradation (Cundy et al. 1997, Zedler, Callaway and Sullivan 2001).

Small suspended particles in the Minas Passage, are found in the bedload, preventing growth on boulders, cobbles and pebbles <20cm off-bottom. This was evident by observing bottom photographs of boulders had almost no growth and hadn't been moved for thousands of years (Fig. 13).

Bioturbation and resuspension of sediment of wetland/ salt marsh mud in the Minas Basin are predominantly due to *Corophium volutator*, an amphipod that is a popular prey and predator species for wetland migratory birds and protists respectively (Daborn et al. 1993). Protists and bacteria within the fine-grained intertidal sediments bioturbate / resuspend sediment whilst feeding on diatoms, which produce polysaccharides (sugars) with increase sediment cohesion. When predation by the migratory birds increases, decreases in polysaccharide production occur due to increased predation on *C. Volutator* which consequently reduces its predation on protists, bacteria, filamentous algae and diatoms. This ecological cascade effect identifies that summer sediment strengthening is not only caused by atmospheric drying at low tide, but also by increased cohesive polysaccharide production by diatoms, bacteria and filamentous algae (Daborn et al. 1993, Shimeta et al. 2002).

Increased sedimentation rates and the ability for meiofaunal species to avoid suffocation appear to be variable by species, but studies have been done and models have been made to determine the resilience to 'undesirable disturbances' to marine ecosystems (Mitchell 2008). The results from these studies and models show that most intertidal benthic fauna will be able to adapt to the proposed sedimentation increase if the sediment nourishment remains constant and if the input of material / sediment doesn't happen to rapidly (large volumes > 25cm) (Mitchell 2008).

The Minas Passage and Basin are home to a variety of marine invertebrates, fishes and mammals. The Atlantic Sturgeon, Shad, Striped Bass, Atlantic Salmon, Herring, etc. are all recreationally and economically important species in the Minas Passage and Basin. Lobster, scallops, clams, mussels, crabs, worms, etc. are important benthic species to marine ecosystems. Seals, porpoises, pilot whales are just a few of the larger marine mammals that migrate through *the Passage*. Increased sedimentation and physical blockage through power turbine barrages threatens the biodiversity and socio-economic balance (e.g. tourism, recreation, archaeology, rock-hunting, etc.) that the Minas Basin communities presently enjoy. Currently used OpenHydro™ in-stream turbines are less detrimental to obstructing the tidal flow and the migration patterns associated fishes, invertebrates, mammals, etc. in and out of Minas Passage, than power barrages. As their lack of a center pivotal blade and incomplete blockage of the entire passage allows for the flow of water to go through and around the turbine, and therefore create less drag that power barrages (Fig. 14). The open turbine system still had blades and poses a threat for several species of fishes, primarily Shad, Atlantic Salmon and to a lesser extent Atlantic Sturgeon. This is because a few turbines will not significantly reduce the tidal flow and therefore the turbidity will remain high and the probability of aquatic species colliding with the turbines is expected to be high (Dadswell 2006, Dadswell and Rulifson 1994, Dadswell et al. 1986b, Gibson and Myers 2002).

Tidal Power Generation in Minas Passage and Basin

Engineering efforts to modify coastal zones for anthropogenic uses in the Minas Basin have records going back to ~400 years ago with the Acadian settlers. The creation of Barachois, coastal lagoons, trapped high tide water which was used for crop irrigation and other uses. The Barachois reduced the impact of the tidal bore and provided communities to live coastally. Several other engineering efforts in 1915, 1930, 1960's and 1970's to implement power barrages in the Minas Basin (near Economy, NS) to produce energy have been attempted. Due to inefficient power extraction technologies, high financial costs, minimal energy demands and low energy prices, these engineering projects never materialized.

Combined research efforts since the late 70's and new in-stream turbine technologies have lead the way for Minas Basin Pulp and Power Ltd. and NS Power to invest in a pilot project to examine the profitability and feasibility of future commercial scale tidal power extraction. The Minas Passage is fast flowing channel of water that has the potential to produce 6.9 Giga Watts (GW) of power per year using in-stream turbines (Karsten et al. 2008, McMillan and Lickley 2008). The three year pilot project has received approval (2009) from the Minister of the Environment, to examine the environmental sustainability of tidal power generation in the Minas Passage. The Environmental Impact Assessment (EIA) didn't address the potential change in tidal flow, sediment transport nor sedimentation rates in the Minas Basin or Passage caused by this pilot project because numerical models estimating these rates haven't been done / published, leaving this aspect of the environmental impact left unanswered.

Proposed Effects of Reduced Tidal Flow due to Tidal Power Extraction

Numerical models such as FVCOM and SedTrans05 are just a couple of the numerical models that help visualize complex tidal flow changes and sediment transport regimes in small to large scale water bodies (Amos and Mosher 1985, Karsten et al. 2008, McMillan and Lickley 2008, Neumeier et al. 2008, Quaresma, Bastos and Amos 2007, Wood and Widdows 2002). Numerical models require large amounts of data to be collected and large parallel computing networks. The degree of expertise in using and creating these models is very high and time consuming. The numerical models are limited in their complexity and cannot incorporate all aspects influencing tidal flow velocities and sedimentation. The importance of sediment transport models cannot be understated. Greenberg , 1979, modelled a blocked Minas Passage and *the Passage* sea level dropped while increasing in all other areas of the BoF (Greenberg and Amos 1983). Without numerical modelling, probable large-scale effects would not be known and proper power extraction estimates would also not be possible. From an economic point of view, knowing how much energy can be extracted with minimal environmental impacts is of great importance to investors and the environment.

The assumptions of 3D unstructured, free-surface FVCOM numerical models include a sponge layer at the benthic boundary layer (to factor out the tidal reflections), constant water density and constant bottom drag factoring in the drag from the turbines, housing structure and the bottom frictional force. The FVCOM models accurately simulate simple nonlinear drag theory which increases confidence in numerical simulations and consequently, the associated potential for power extraction (Karsten et al. 2008, McMillan and Lickley 2008).

The maximum power and impact of extracting power on the tides were calculated using a fence of turbines that extended across *the Passage* extending from the bottom to the surface. This simulation environment is analogous to a power barrage with an adjustable drag. Therefore, using the kinetic flux equation$\left(P_{KE} = \frac{1}{2}\rho A_c \overline{U}^3\right)$, calculates the maximum power that can be extracted from the tidal flow through *the Passage*; where ρ is the density of water, A_c is the cross-sectional area of the channel and U is the depth-averaged, upstream current speed. In-stream turbines extract less tidal power than a power barrage / fence, but more energy would be collected by the turbines with less of a reduction in tidal flow energy. The impact on the environment can then be estimated by the amount of power extracted from the system. Numerical simulations support the theory that changes in the tides in Minas Basin and throughout the Bay of Fundy and Gulf of Maine will be a function of only how much power is extracted from the tidal flow and not necessarily their arrangement. The arrangement of the turbines will affect how efficiently the power extracted from the flow and the direct physical effects on the biology and ecology of Minas Passage and Basin.

Present-day Pilot Project

The theoretical impact on the tidal energy flow of the three 1 MW in-stream turbines, based-on large-scale FVCOM 3D flow models; assumes that these turbines are reasonably efficient and convert 30% of the power they remove from the tidal flow (i.e. 30% of all the power lost from the flow, including from the drag of the turbine frame/gravity base and the power lost in the wake, as well as the power that makes the turbine turn, is turned into electricity.) Therefore, 1MW of power produced actually accounts for ~3.3MW of tidal power reduction. Therefore, three 1MW turbines would actually remove 10MW of power from the tidal energy flow. Karsten et al., 2008 estimated that for small-scale power extraction, an estimated 770 MW of tidal power removal decreases the tidal elevation in the Minas Basin by 1%. Therefore, removing 10MW of power would reduce the tides by only 0.013%. For a tidal of range between 14-16 m, 0.013% equates to a 2 mm reduction in the tidal amplitude. A single turbine would only see a 0.004% reduction in tidal elevation, which equates to a 0.06mm reduction in tidal amplitude. Therefore, the flow reduction experienced in this pilot project is not expected to have any significant tidal elevation nor far-field sedimentation effects.

Dr. R. Karsten from Acadia University (Wolfville, NS), graciously ran FVCOM 3D flow models to determine the change in flow rates and power production yields from a three turbine array. The results show local sediment accretions in the near field around the turbine in a rectangular formation (320mx160m) (Fig. 11). This accounts for 10x the width and 20x the length of the turbine's physical footprint (16m). Exact sedimentation values could not be modeled at this time, but Dr. Greenberg and Dr. Karsten are in the process of creating these complex models.

Commercial Scale Turbine Barrages / Fences

Based-on previous sediment transport flow change predictions by (Amos 1979, Amos 1985, Amos 1987, Greenberg and Amos 1983, Neumeier et al. 2008) a 20%

decrease in Minas Basin flow would result in an increase in sedimentation rates that, on an annual scale, would be the equivalent of 10 years of normal (0% reduced flow) sedimentation. Sediment accretion zones were created based on the 2D sediment model by Amos, 1985 and the 3D FVCOM tidal energy flow models ran by Dr. Karsten (Acadia University) and by Dr. Greenberg (DFO-BIO) (Fig. 11). Due to the complex nature of the oceanography of the Minas Passage (i.e gyres west-east of *the Passage* and fast flow velocities ~5m/s) delineating accretion zones was influenced by Amos, 1985 and van Proosdij, 2005; whereby, their predictions of sedimentation caused by a power barrage and the Windsor Causeway would have similar effects to that of a 20-40% reduction in tidal energy flow. Therefore, increasing sedimentation patterns not unlike the resultant sedimentation experienced in Windsor Bay, due to the causeway installation, are predicted for the possible commercial-scale turbine array in the Minas Passage. Based-off of the delineated accretion zones in figure 11, the Five Islands Provincial Park, Noel Bay, Truro area, Windsor Bay, Blomidon Bay, Parrsboro and Economy areas are expected to see an increase in sedimentation, effectively seeing the migration of the intertidal zone move towards the center of the Minas Basin. The actual distance of the land migration is unknown, but based on the Windsor causeway sedimentation pattern (van Proosdij and Townsend 2005) since its installation, the delineated accretion zones in figure 11, could be accurate for a 20-40% reduction in tidal energy. The time scale of this proposed increased sedimentation is unknown, but Amos, 1985, predicted that visible effects of increased sedimentation could be seen in less than a year (Amos and Mosher 1985).

An estimated 40% reduction in tidal wave energy at a power generating target of 6.9 GW equates to a ~2m reduction in tidal elevation in the Minas Basin, conversely increasing the tidal amplitude in the Gulf of Maine by 25cm (Karsten et al. 2008, McMillan and Lickley 2008) (Fig. 15). This reduction in tidal energy flow is expected to result in an increase in sedimentation in the near and far fields from the turbine installation sites (Fig. 11). DFO and Acadia University are currently working on 3D sediment transport models in FVCOM (Karsten and Greenberg: personal communications).

Increased sedimentation in the Minas Basin will increase sedimentation within the wetland and estuarine systems (Amos 1985, van Proosdij and Townsend 2005). This increase in sedimentation could have negative effects on wetland / estuarine ecological dynamics, which could change migration patterns of birds, fishes and marine mammals (Dadswell, Rulifson and Daborn 1986a, Dadswell 2006, Dadswell and Rulifson 1994, Dadswell et al. 1986b, Shimeta et al. 2002, van Proosdij and Townsend 2005). The alteration of wetland and marine habitat of ecologically important species in highly productive coastal zones (estuaries and marshes) could also violate the *Canadian Environmental Protection Act*, *The Fisheries Act*, *The Oceans Act*, *and The Provincial Parks Act* whilst potentially disrupting delicate marsh / estuarine and benthic ecological dynamics (Benidickson 2002).

The socio-economic impacts of increased sedimentation would be seen in reduced tourism (i.e. semi-precious rock-hounds, fossil-finders, recreational fishing, etc.), commercial and recreational fisheries such as Shad, Atlantic Salmon, Stripped Sea Bass, lobster, scallop and possibly clam and mussel beds. The reduction in economic profits for local fishermen and tourism companies could be substantial; coinciding with a change in habitat and biodiversity both in *the Basin* and throughout the intertidal zone.

The Minas Basin Pulp and Power Ltd. company and NS Power can reduce the negative effects of increased sedimentation caused by the tidal power extraction by using in-stream turbine technologies compared to power barrages / fences. While, keeping their power extraction within environmentally sustainable levels (currently estimated to be 2.5 GW), equating to a 5% reduction in tidal elevation (Karsten et al. 2008). The real-time monitoring of power extraction, supporting of physical oceanographic modeling and biological and ecological research within the Minas Basin and Passage will keep the public and investors informed into the impacts and potential effects that the power extraction project is or may be creating.

Summary

Surficial sediment of Minas Passage is mainly bedrock (mudstone). The NW side has thicker surface sediment, glaciomarine sediment and strong current swept coarse deposits (linear furrows, ridges ad isolated scours). The installation site will be primarily on flat hummocky volcanic bedrock.

The Minas Basin is in equilibrium of sedimentation and depositional areas would see increased sedimentation by a 20-40% reduction in tidal flow (Amos and Mosher 1985, Karsten et al. 2008, McMillan and Lickley 2008). Current flow and sea level will be reduced with increasing distance from the turbines. The flushing rate of the bay will decrease and pollution concentrations will probably increase. With a tidal flow decrease, a decrease in mixing of water layers will result, causing extreme seasonal temperatures and a less turbid water column (Pelletier and McMullen 1972).

The strong currents in the Minas Passage make it a promising location for the installation of turbines. Though, if too many turbines are placed in the channel, the flow will be impeded, causing the power of the tidal flow to decrease; therefore, a theoretical maximum (6.9 GW) of tidal power can be harnessed from the Minas Passage (McMillan and Lickley 2008).

The sedimentation accretion zones identify probable areas of increased sedimentation within the Minas Passage and Basin. The accretion zones were created based-on previous research by Amos, 1985 and van Proosdij, 2005. If the Minas Passage tidal energy flow is reduced by 40% then the Five Islands Provincial Park, Noel Bay, Truro area, Windsor Bay, Blomidon Bay, Parrsboro and Economy areas are expected to see an increase in sedimentation, effectively seeing the migration of the intertidal zone move towards the center of the Minas Basin.

The current three turbine pilot project will not significantly reduce the tidal energy flow (reduction of 0.013%) and therefore only small-scale local sedimentation in the near-field in relation to the turbines is expected. In the future when a commercial-scale turbine array is installed the operators of the power extraction process should not reduce the flow rate by more than 5% as negative system-wide effects are expected with greater tidal power extraction. Sustainable power extraction from the Minas Passage is possible with proper monitoring and continual research into the biological, ecological and oceanographic impacts.

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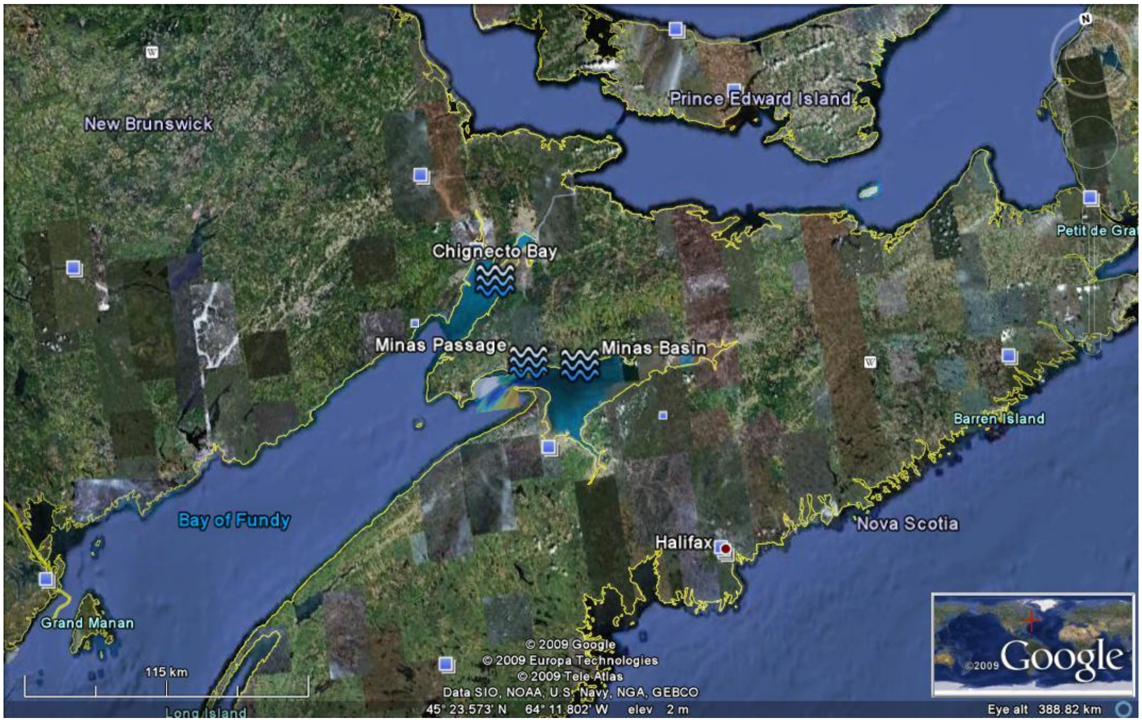

Figure 1. Geographic Location of The Minas Passage

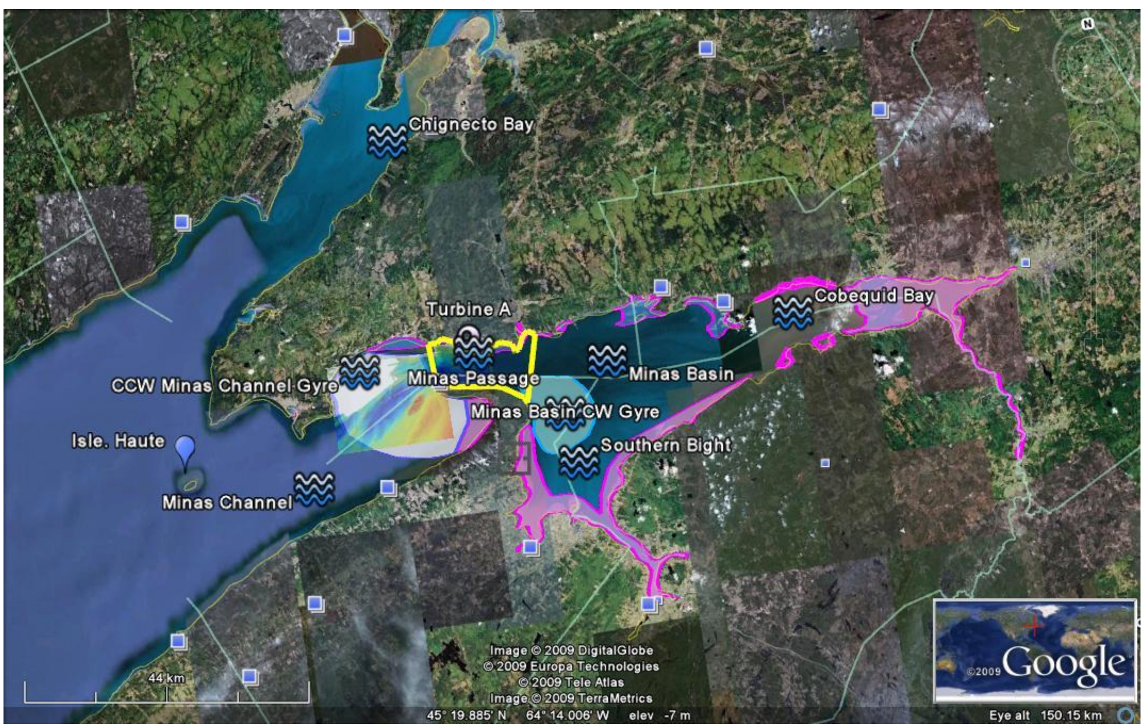

Figure 2. Minas Passage, Minas Basin, Cobequid Bay; Yelllow outline identifies Minas Passage; Minas Passage Multibeam is visible; pink outlines identify Large-Scale Power Extraction Sediment Accretion Zones

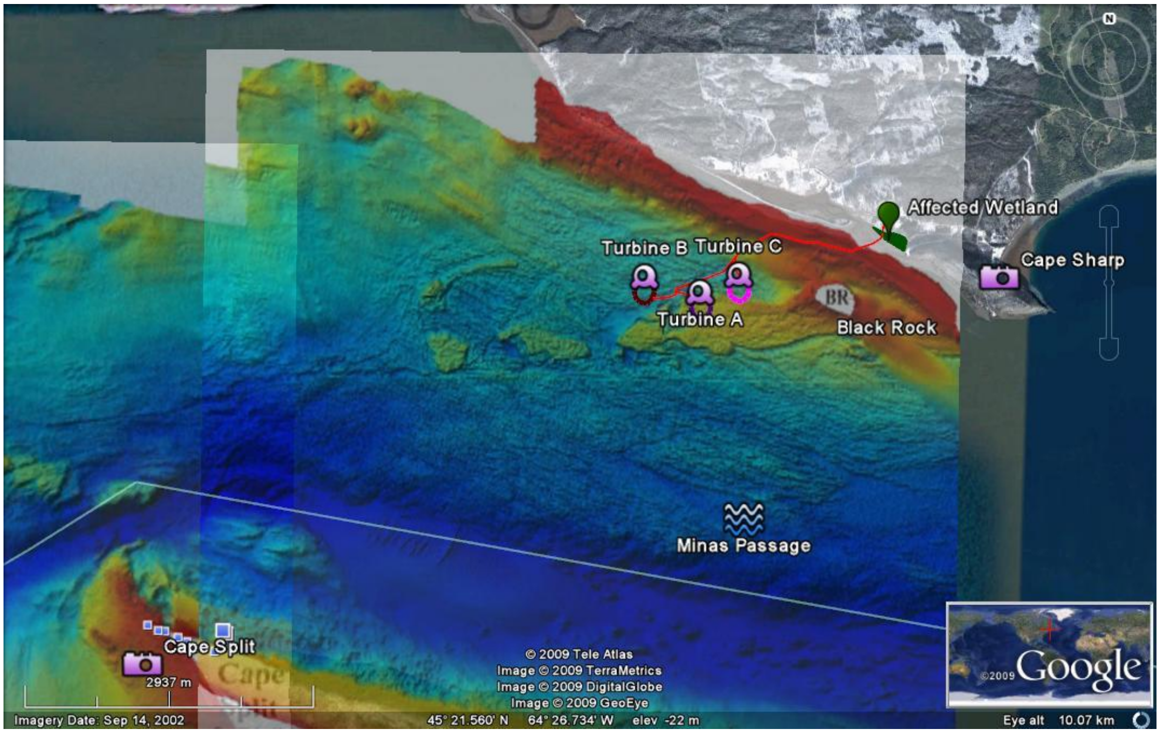

Figure 3. Location of In-stream Turbine Installtion Sites with associated power cabling delineation

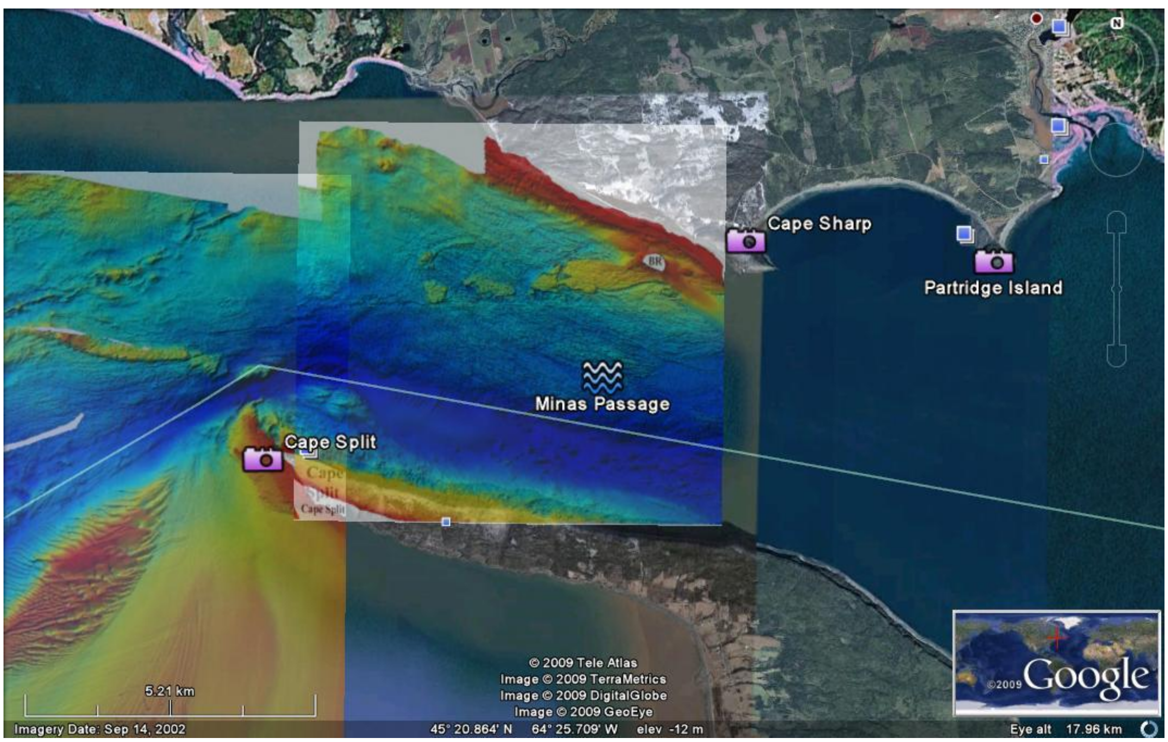

Figure 4. Cape Split to Partridge Island Geographic Locations with underlain 2m Resolution Multibeam Imagery for the Minas Passage

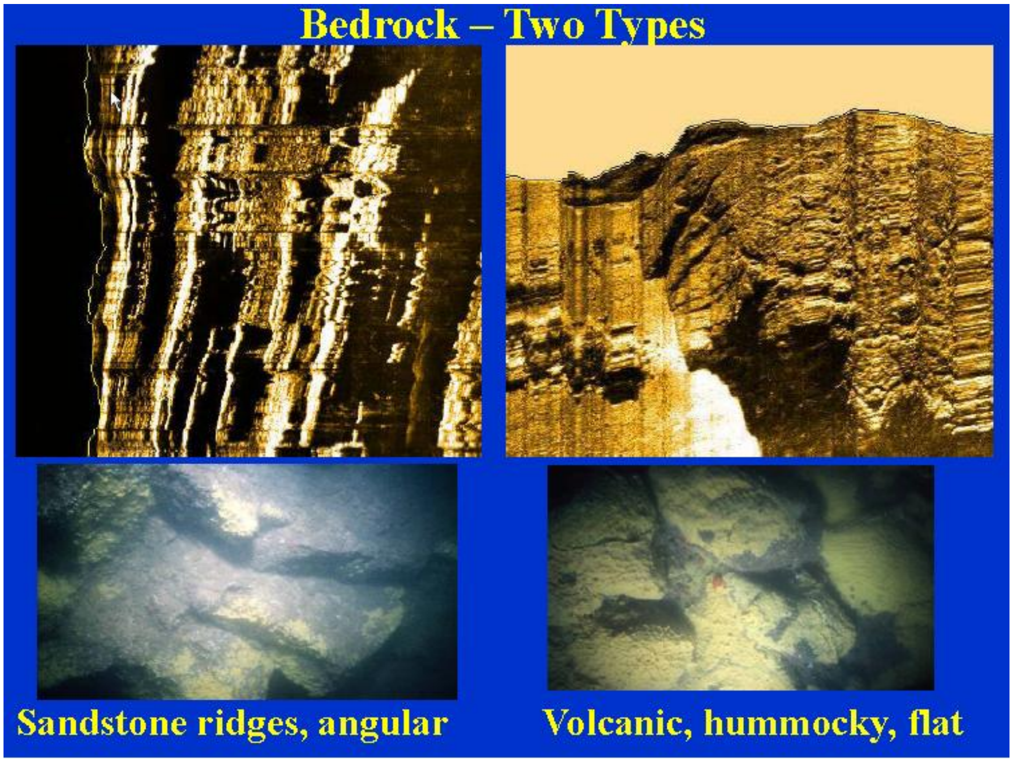

Figure 5. Sidescan and Bottom photographs taken of the bedrock types in the Minas Passage (Fader 2009)

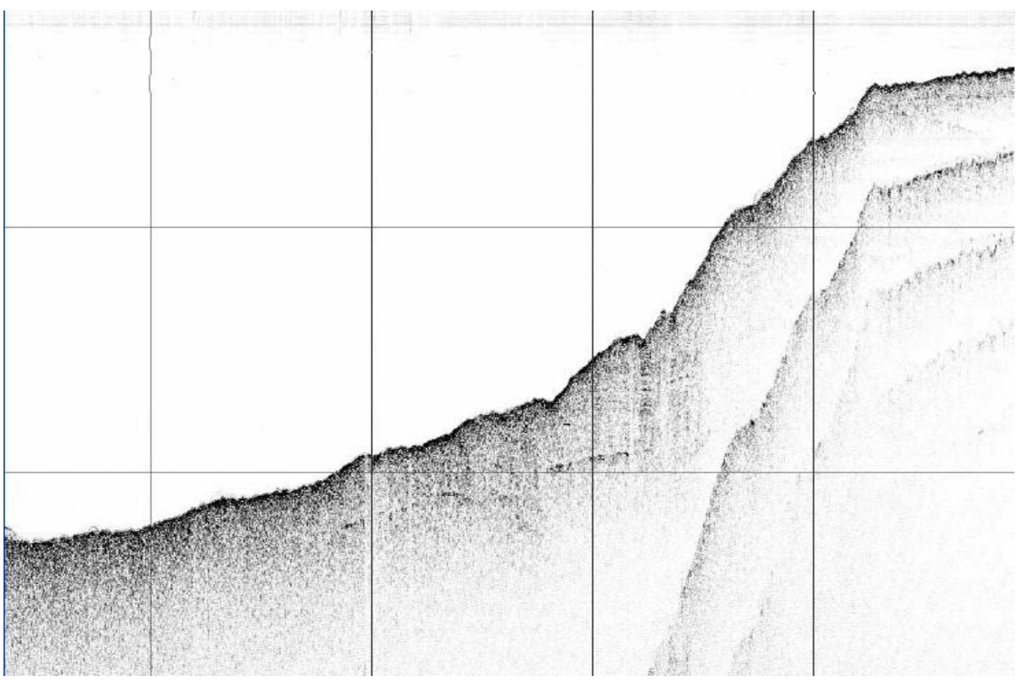

Figure 6. Seistec Seismic Reflection Profile from the Minas Passage identifying a bedrock bottom (Fader 2009)

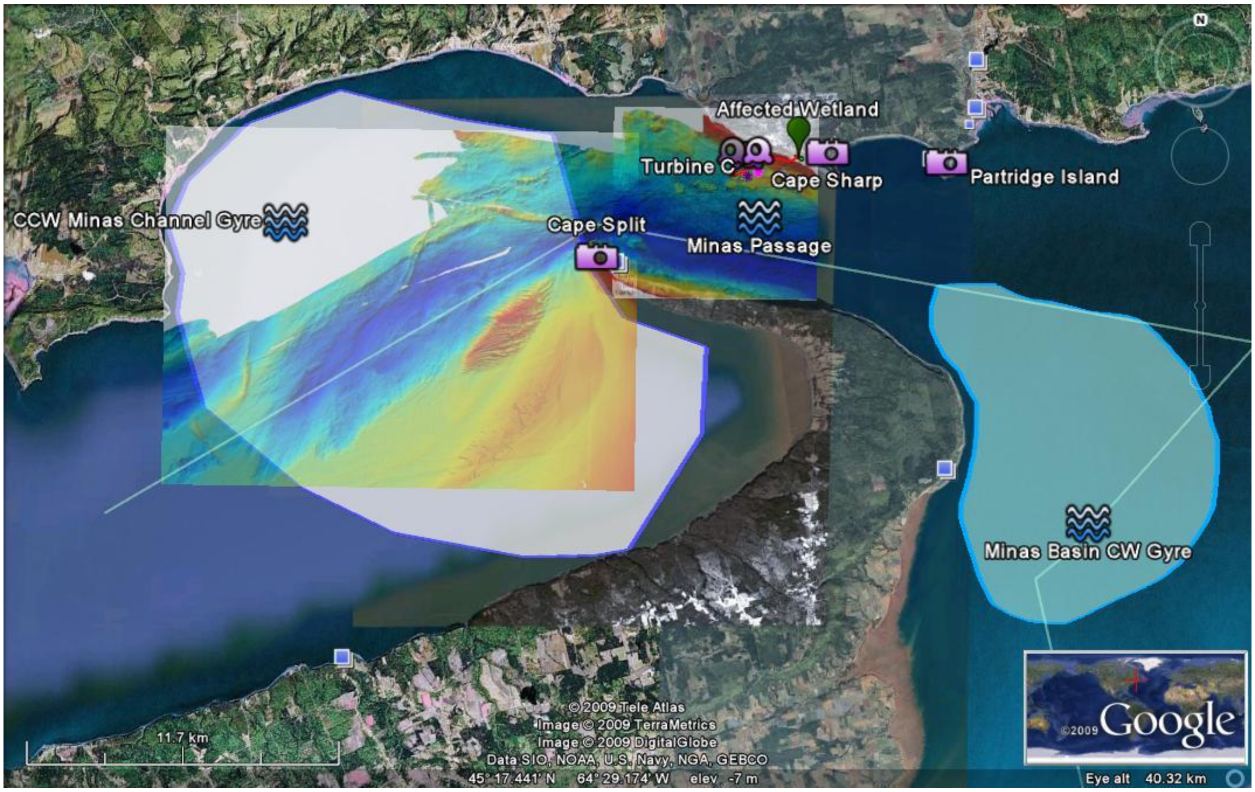

Figure 7. Minas Channel and Minas Basin Gyres with underlying 2m resolution Multibeam imagery in relation to in-stream turbine locations

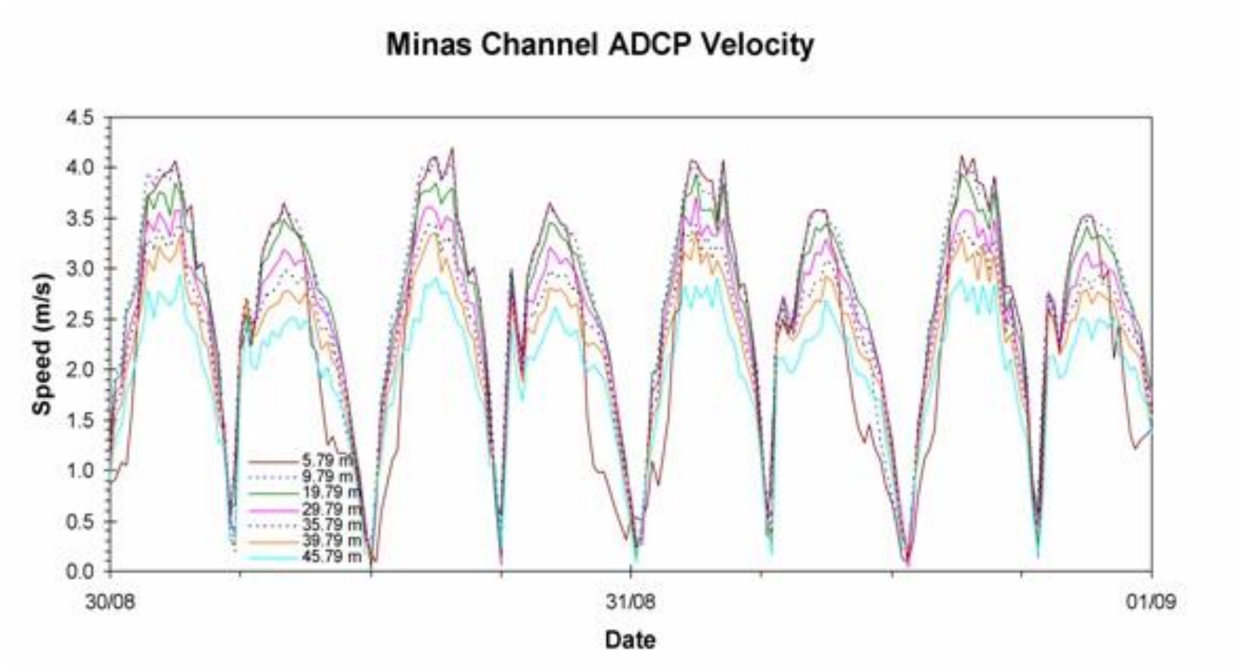

Figure 8. Acoustic Doppler Current Profiler (ADCP) current velocities in the Minas Channel over a 2 day time period (Karsten 2009)

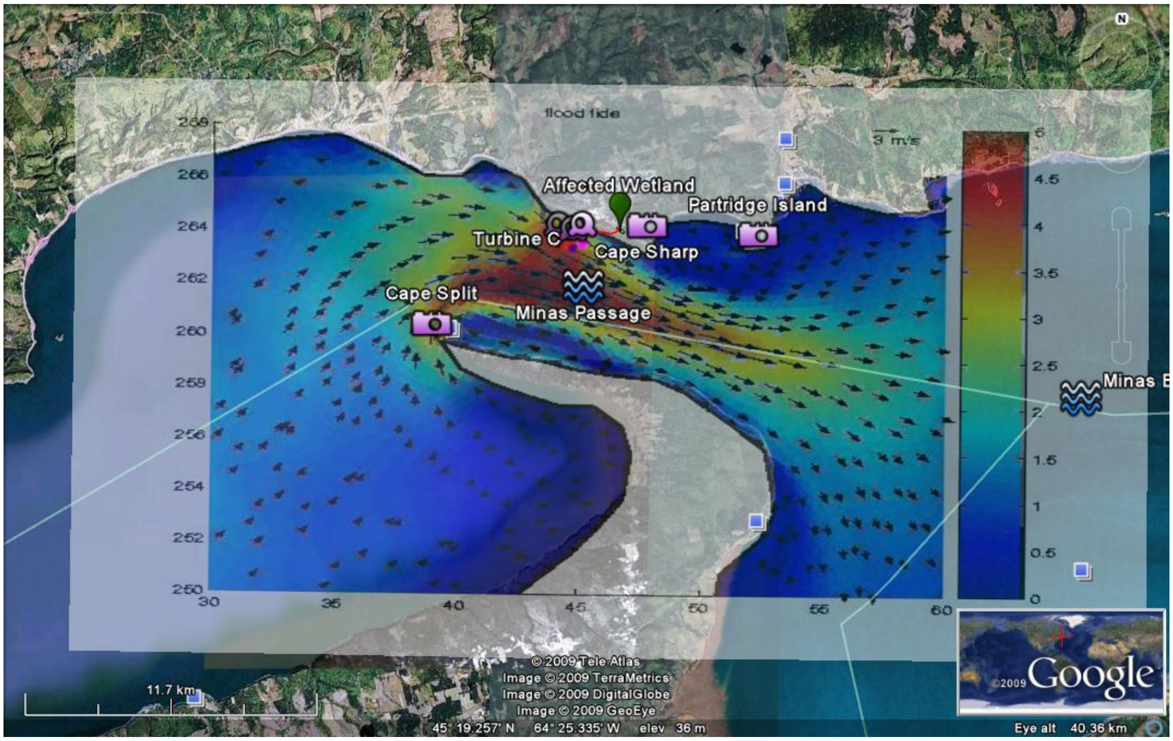

Figure 9. Tidal Flow Velocities (m/s) in the Minas Passage, modeled by FVCOM 2.5 software (Karsten 2009)

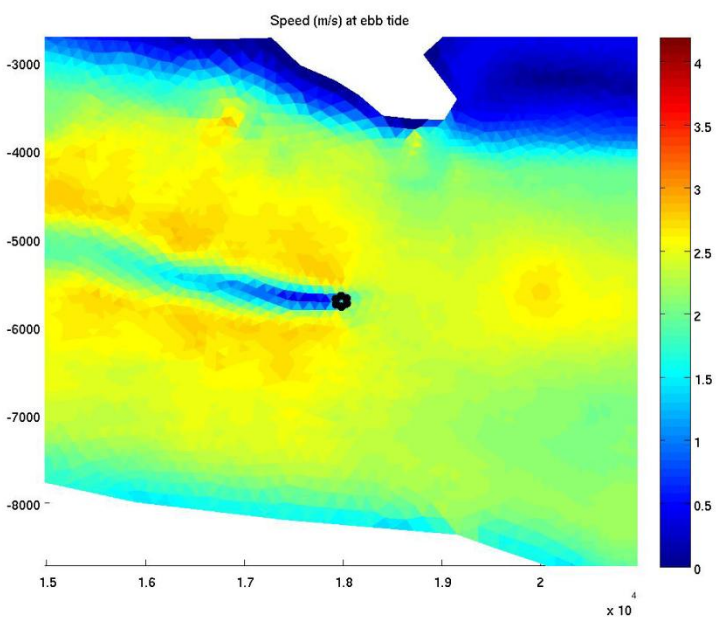

Figure 10. 3D Flow Velocity change model of single turbine (8x the size of an OpenHydro in-stream turbine) in the Minas Passage, modeled by FVCOM software (Karsten 2009).

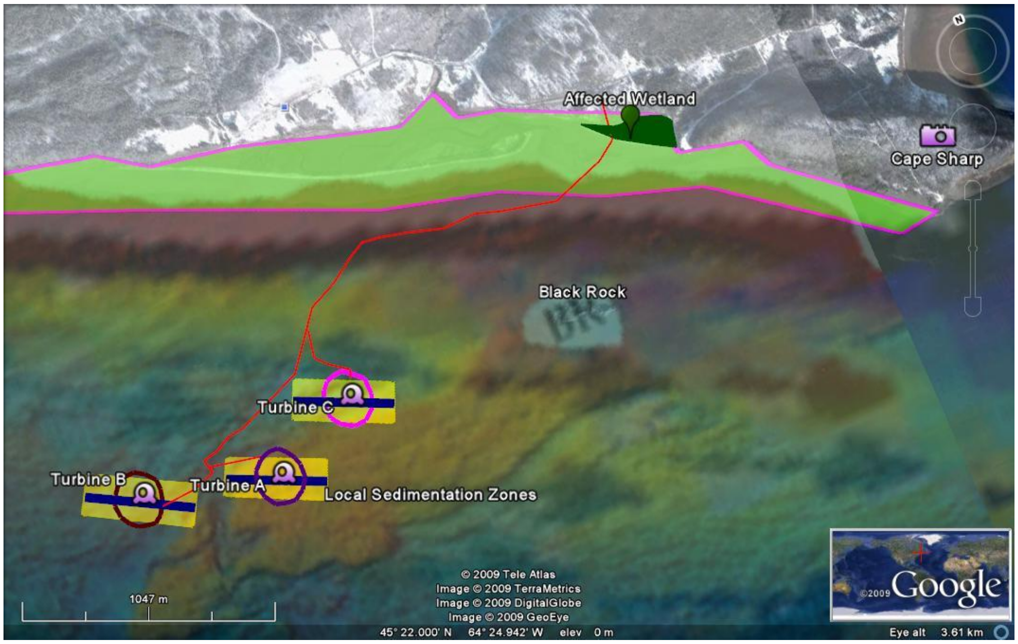

Figure 11. Local sedimentation Zones at In-stream Turbine sites in Minas Passage with possible north shore deposition underlain by tidal flow direction imagery

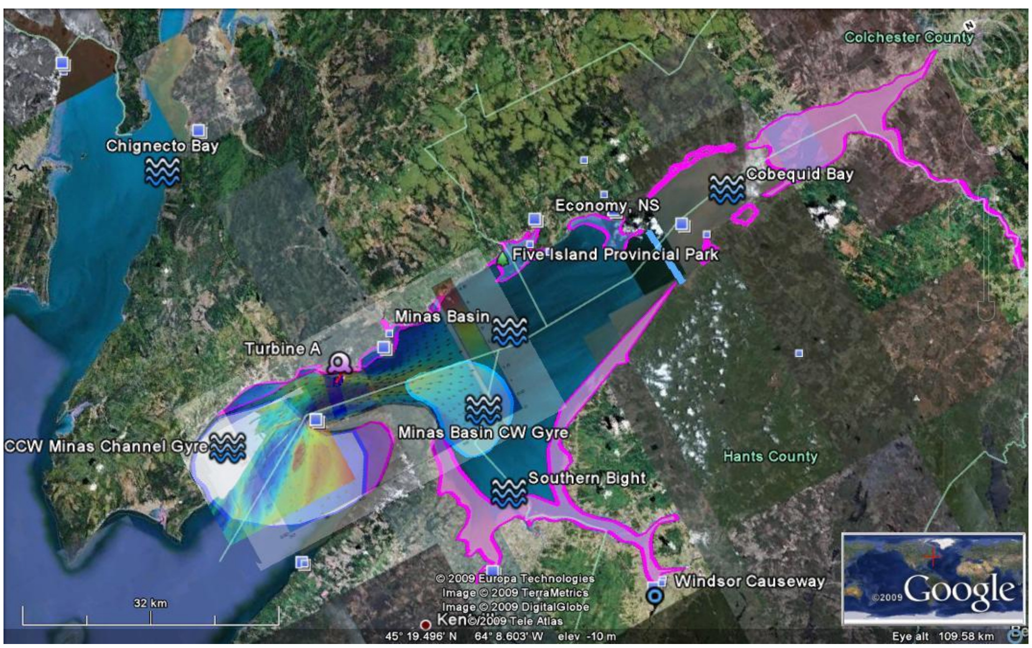

Figure 12. Sedimentation Zones proposed by 3D modeling of power barrages across the Minas Passage (Blue Band) and Minas Basin (Teal Band near Economy, NS).

The Pink outlines identify the accretion zones while the filled-in pink colored zones are zones based-off of predictions by Amos, 1985. The pale Blue filled-in accretion zones are zones identified by 3D flow velocities based-on FVCOM simulations (Karsten 2009). The Minas Channel and Minas Basin gyres are indicated by blue outlines filled-in with white. Underlain flow velocity imagery for the Minas Passage is also included.

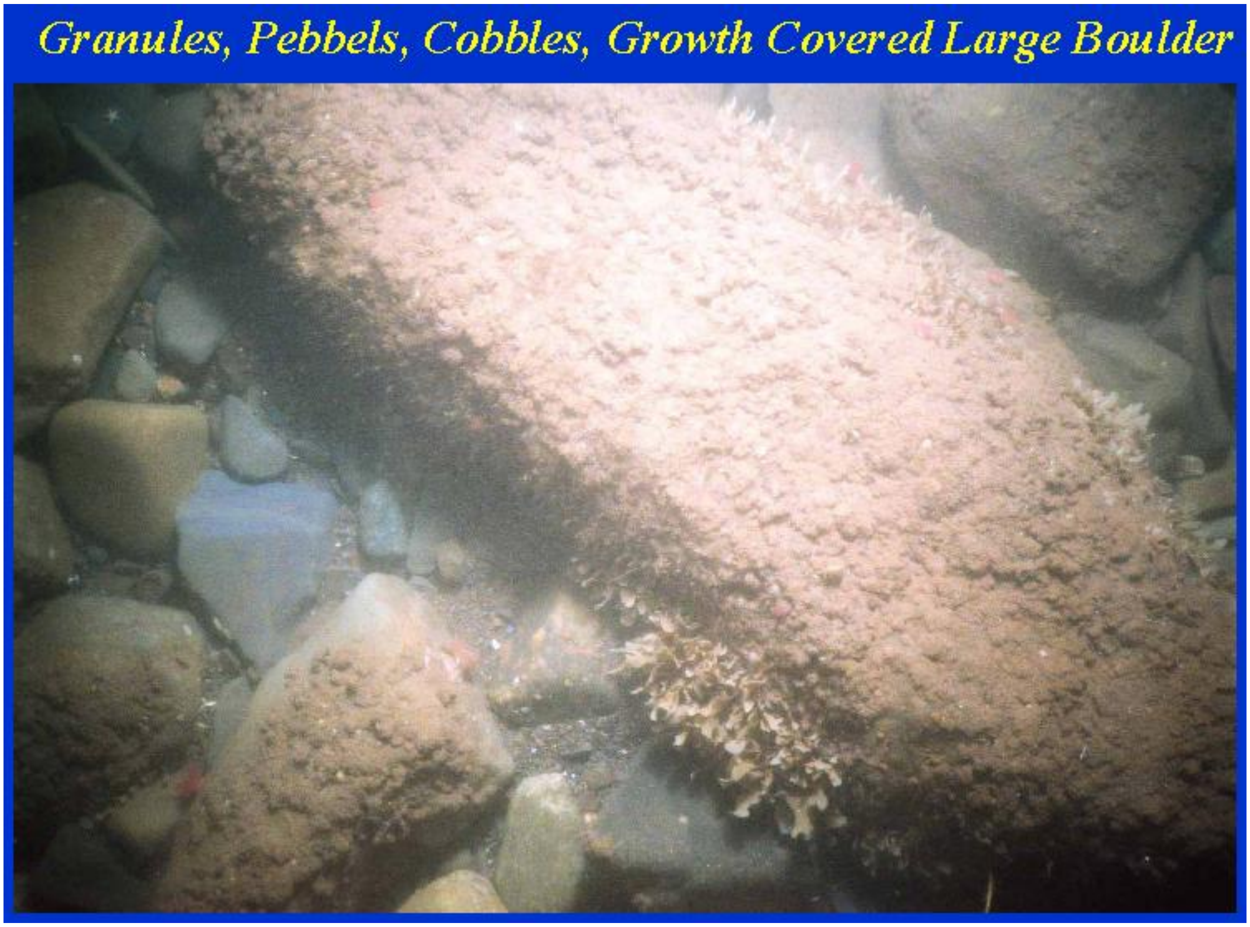

Figure 13. Benthic Imagery of Minas Passage identifying minimal growth on a large boulder while showing granules, pebbles and cobbles on the sea floor (Fader 2009)

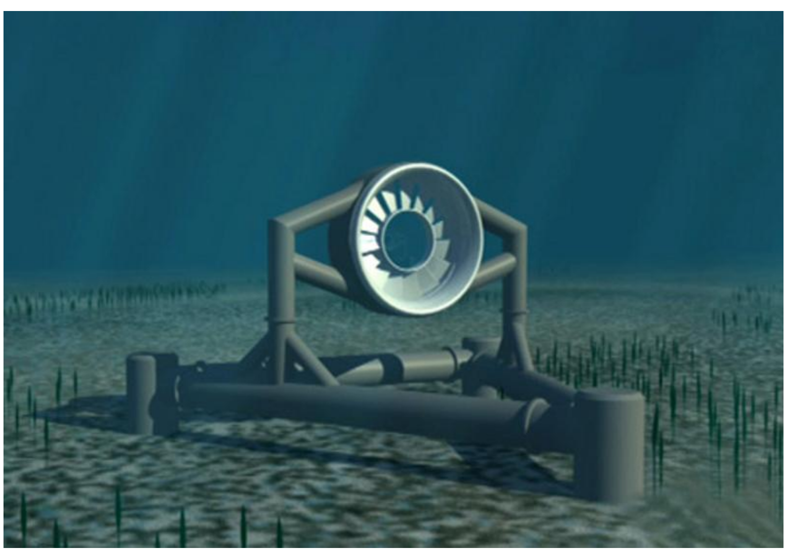

Figure 14. OpenHydro In-stream Turbine (http://www.openhydro.com/images.html)

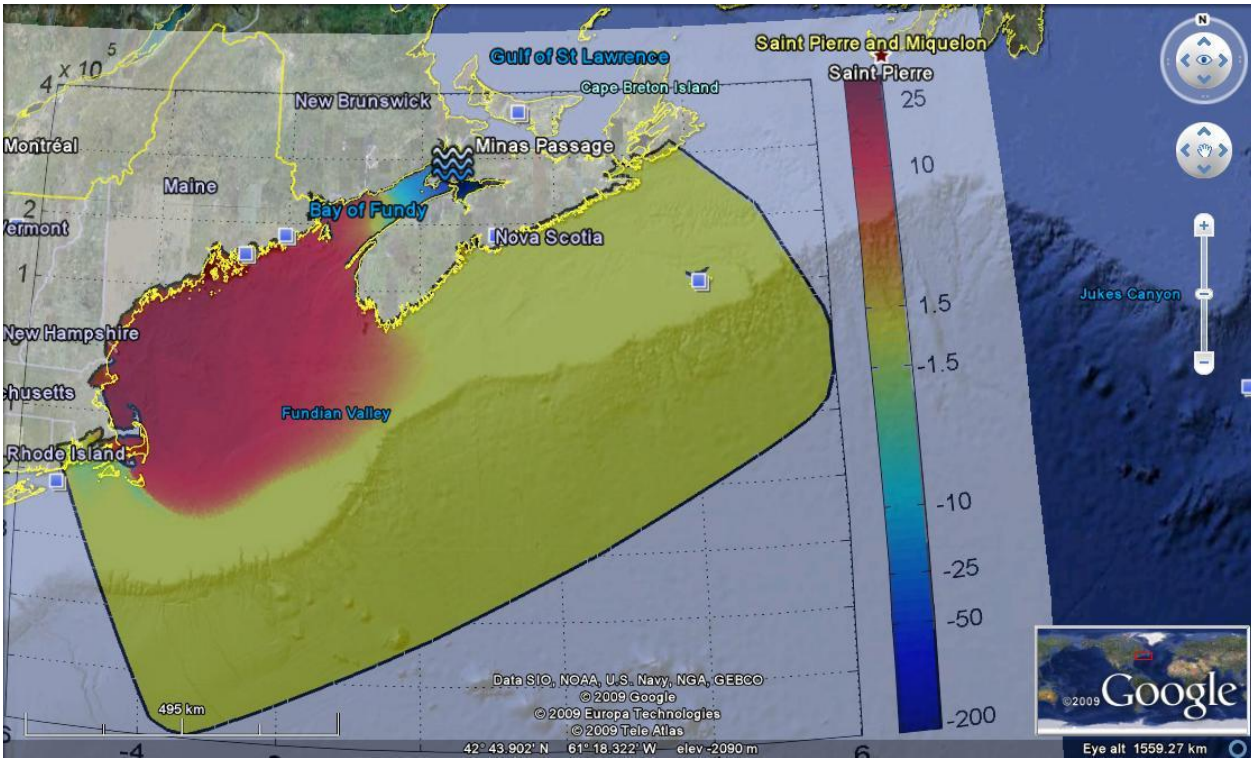

Figure 15. FVCOM model of tidal elevation change (cm) in the Bay of Fundy and Gulf of Maine (Karsten 2009)

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Acronyms