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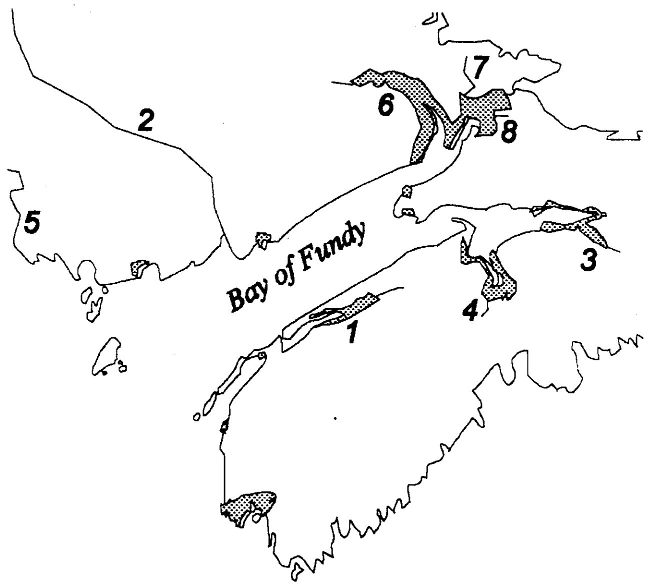
FUNDY ISSUES

DYKES, DAMS AND DYNAMOS

The Impacts of Coastal Structures

Maritime mudscapes

Most visitors to the upper Bay of Fundy are awed by the remarkable vistas of water-sculpted, shoals and flats of sticky, red mud that gradually rise from the sea on each ebbing tide. The ebb extends to several kilometres in some parts of Minas Basin, adding to the impression of an ochre wasteland of treacherous, oozing mud stretching almost to the horizon. These vast mudflats were created, and are continually being remolded, by the highest tides in the world. The swirling currents scour the soft shales and sandstones of the seafloor and shoreline, carrying off large quantities of fine sediments. At high tide, these silt-laden currents swirl across the low lying lands flanking riverbanks and estuaries. Here, among the marsh vegetation, their headlong rush is slowed, and slowly receding, they leave behind much of their sediment. A single tide may deposit 2 or 3 centimetres of soupy red mud over the whole of the flooded area. The silt has been slowly accumulating since the end of the last ice age, some 12,000 years ago, and in a few places the layers are 40 metres thick. Also since the ice age, the height of the sea relative to the land has been steadily rising by almost 40 centimetres every century; a result of both rising sea level and slow subsidence of the land. Thus, each year the sea has crept a little further up the gently sloping shore, depositing its sticky mud onto ever new areas of marsh.



Principal salt marshes around the Bay of Fundy, and the major rivers: 1. Annapolis, 2. St. John, 3. Shubenacadie, 4. Avon, 5. St. Croix, 6. Petitcodiac, 7. Tantramar, 8. Missaguash.

In lower intertidal areas that are underwater most of the time, the sediment layers form soft, sticky mudflats, that are rather bare, save for a thin film of microscopic marine algae growing on the surface. Higher up, in areas that are out of the water for longer periods, several species of tough land plants eventually manage to secure a foothold. These can tolerate regular immersion in salt water and soon spread widely over the mudflat, thrusting their roots deep into the sediment to exploit the abundant nutrients. These roots bind the sediments tightly in their tangled net and keep the swirling waters from washing it away. In addition, the protruding stems act like miniature snow fences in a blizzard, breaking the force of the currents and allowing the suspended sediments to accumulate in tiny "mud drifts". The marsh plants thus

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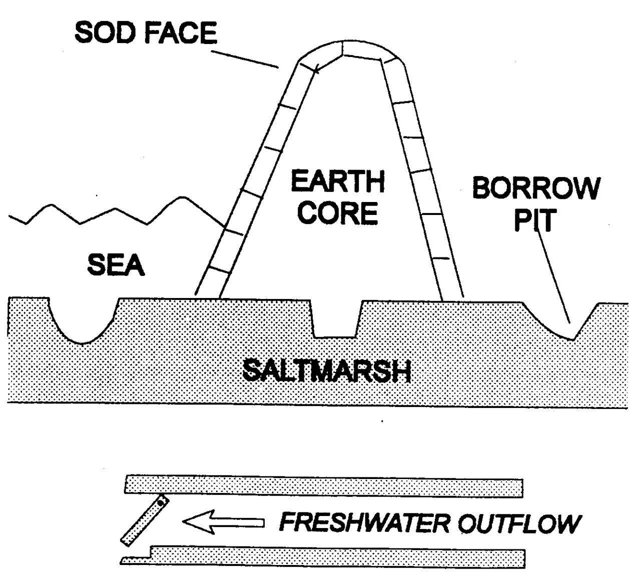
trap as well as hold the sediments, allowing the saltmarsh to slowly increase in size. The most abundant and effective of these plants is cord grass (*Spartina alterniflora),* which can survive long periods of submersion in salt water. Higher up the marsh, in areas that are submerged only occasionally, grow black grass, marsh sedge and glasswort; while spurrey, goose tongues and seaside goldenrod garnish the uppermost fringes. This rapidly growing marsh vegetation continually releases fragments of dead and decaying organic matter into the water. This provides food for large populations of intertidal invertebrates and fertilizes the nearshore waters with organic matter and nutrients. In fact, the saltmarshes contribute almost a third of the productivity of the marine ecosystem in the upper Bay.

The largest tracts of salt marshes fringe the upper Bay, particularly the head of Chignecto Bay and the southern shore of Minas Basin. Large marshes also occur along the Annapolis Basin and River, around the Chebogue Meadow near Yarmouth and the Musquash Estuary South of Saint John, NB. When the Acadians first arrived in the early 1600's, there were more than 35,700 hectares (88,200 acres) of productive salt marshes scattered around the Bay. Most have long since been wrested from the sea, with seemingly far-reaching consequences for the marine ecosystem of the Bay of Fundy.



Cross section of an Acadian Dyke constructed with an earth core and a grass sod veneer. Below is a section through an "aboiteaux", showing the flapper valve to keep out seawater. These were placed at intervals along the base of the dyke to drain the protected dykelands.

Acadian agriculture

French colonists eagerly settled the shores of the Annapolis Basin in the decades following establishment of the fortified "Habitation" at Port Royal in 1605. They quickly recognized the rich agricultural potential of the large tracts of salt marsh, if only the sea could somehow be held at bay. Some among them were familiar with the dyking techniques used for reclaiming marshland in Europe, and they soon set about building comparable dykes to extend their newly acquired lowlands. The first such dyking was undertaken near Port Royal between 1635 and 1640. These were earthen structures about 1.5 metres high, veneered on both sides with sods of salt grass to hold the soil in place. Water inside could drain out through large wooden pipes ("aboiteaux") extending through the base of the dyke and usually placed in existing creek beds. These were fitted with a simple, ingenious wooden flap valve opening to seaward to allow water to drain out at low tide, but closing tightly as the tide rose, preventing intrusion of seawater. Within a few years rain and melting snow leached out most of the salt. The thick layers of fertile alluvial soil thus reclaimed were rich in inorganic and organic nutrients. One agricultural engineer termed these dykelands "a reserve of energy in the form of fertility". In fact, the Acadians found that their hard-won farmlands required no manure or other fertilizers for many generations, and yielded bountiful crops of wheat, vegetables, fruits and herbs. The natural marsh grasses in nearby undyked areas were also cut for winter fodder ("salt hay"). Having successfully mastered the dyking techniques on the Annapolis Basin, the Acadians soon extended similar settlements to the many other salt marsh areas fringing the head of the Bay of Fundy, such as the Missaguash, Shepody, Petitcodiac and Avon Rivers. The last large area of marshland settled by them was near Truro in the early 1700's. Little thought was given to the effects on the marine ecosystem of dyking all these marshes. The prevailing attitude was probably similar to that expressed in a 1760 provincial government document that concluded that "great quantities of marsh, meadows, and low ground .... in the Bay of Fundy .... are spoiled by overflowing of the sea .... which by industry may be greatly improved". Subsequent developments in the region suggest that this early antipathy towards Fundy's salt marshes has persisted through the sub-

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sequent two centuries.

Dykes to dams

New England settlers, who moved into the Fundy region following the expulsion of the Acadians in 1755, preferred to clear the wooded uplands for agricultural use, reserving the Acadian dykelands largely for hay and pasturage of cattle. Hay was becoming an increasingly valuable cash crop throughout eastern North America. It was in great demand as feed for the growing number of horses used in transportation, and for powering booming industries such as logging, mining and farming. Existing dykes were kept repaired, and as well many large new areas of saltmarsh, such as the Wellington Dyke in Kings County, were reclaimed between 1825 and 1860. However, by the 1920's the bubble burst, as the internal combustion engine replaced horses and the demand for hay plummeted. By the 1930's much of the dykeland lay unused and miles of dykes went unrepaired. The sea had already recaptured some marsh and increasingly threatened thousands more hectares of prime farmland. A period of exceptionally high tides was in the offing, and governments worried that "the region would lose tens of thousands of hectares of prime farmland that had taken three centuries to create". Thus, during the 1940's the federal and provincial governments launched a modest program (Maritimes Dykelands Rehabilitation Committee) to assist with dyke restoration. Modern, mechanized equipment, such as bulldozers, backhoes and draglines, rumbled to the defense of the dykes for the first time. However, it quickly became clear that a much larger coordinated effort would be needed to hold back the sea effectively. Thus the Maritime Marshland Reclamation Administration (MMRA) was launched in 1948. Over the next 20 years some 373 kilometres of dykes protecting over 33,000 hectares (81,500 acres) of farmland were repaired or constructed.

"during the 50's and 60's the MMRA embarked on a major program to control most of the large rivers around the Bay with tidal barrages"

Just as the early Acadians drew heavily on European experiences in wresting the valuable dykelands from the sea, governments in the 1950's again turned to Europe for guidance in protecting them. Holland had recently experienced devastating floods and had fought back with a massive program of dam building to regulate tidal flows in almost all rivers and estuaries. A visiting delegation of Maritime government officials was impressed with what it saw there, and returned full of enthusiasm for a comparable approach to taming Fundy's unruly rivers. Thus, during the 50's and 60's the MMRA embarked on a major program to control most of the large rivers around the Bay with tidal barrages (see table). These served to protect upstream farmland from tidal flooding and did away with the need for frequent, costly repairs to miles of riverside dykes. At the time, little if any, consideration appears to have been given to the possible environmental consequences of blocking all these tidal rivers.

RIVER	DATE	PROTECTED (hectares)
Shepody	1955	2200
Annapolis	1960	1740
Tantramar	1960	1315
Petitcodiac	1968	7000
Avon	1971	595

Tidal barrages were constructed on many of the major rivers flowing into the Bay of Fundy to protect fertile dykelands from the sea.

Dams to dynamos

The causeway on the Annapolis River, was constructed in 1960 to protect the upstream dykelands from the tides and to replace a collapsed highway bridge. In recent years it has also assumed another unique role as the control structure for, and site of, the first successful tidal power generating station in North America. Engineers had long dreamed of harnessing the twice daily surges of Fundy's tides to produce cheap electricity. Since 1910 there have been periodic proposals for huge dams across different parts the Bay to trap large volumes of seawater and channel them through turbines. Perhaps the most ambitious of these tidal power projects was seriously contemplated in the late 1970's, in the wake of skyrocketing crude oil prices. Many sites for barrages were considered, and detailed assessments made of the likely economic and environmental consequences of such a massive undertaking. Although the full-size Fundy tidal project was eventually placed once again on the back burner, it was decided to proceed with the construction of a pilot-scale prototype tidal power plant, to test turbine design and to investigate possible environmental impacts. The causeway across the Annapolis River was selected as the site for this facility, which began operating in the summer of 1984. It produces electricity on the ebb tide, as water trapped in the upstream headpond passes through the 4-bladed 7.2 m diameter turbine on its way back into the Annapolis Basin. The station, with a capacity of 20 megaWatts, contributes sufficient electricity to the Nova Scotia Power grid to supply 4,500 homes. The associated tidal power interpretation centre is a perennial draw for some thirty five thousand tourists. Undoubtedly the shelved plans for the full-scale Fundy tidal project will one day be dusted off and seriously considered once again, hopefully taking into account many of the engineering and environmental lessons learned on the Annapolis River.

The environmental effects

For more than 350 years there has been an ongoing struggle to tame the unruly tides of Fundy, first with dykes and later dams, and more recently to harness them to generate electricity. All these activities have greatly altered the dynamics and distribution of sediments in the Bay, particularly in its upper reaches and larger estuaries. This has, in turn, caused great ecological adjustments, because, as Acadia University's Graham Daborn emphasises, in many parts of the Bay "it is the dynamics of the sediments that are the key to understanding the functioning of its ecosystems". Each of these engineering works has had its own distinctive effects on the erosion, transport and deposition of fine sediments. Each has resulted in changes in animal and plant populations and their habitats. However, the various impacts have been so closely intertwined, overlapping and long lasting that it is now very difficult to positively link any observed effects with a specific cause. For example, no one is quite sure whether the shoreline erosion now threatening the stability of the ancient ramparts of Fort Anne in Annapolis Royal is a long-delayed effect of nearby bridge abutments, the causeway across the Annapolis River, the tidal power plant, natural oceanographic processes or some combination of these. The fact that sea level and tidal amplitude have been rising steadily for the past several thousand years, only tends to further complicate the interpretation of ecological changes occurring here and elsewhere around the Bay. We can, however, describe some of the ways that each of these large engineering works could have contributed to the disruption of natural ecological processes and effected the marine populations of Fundy.

"it is a matter of conjecture how much more productive these waters would have been when the marshes were intact and six times as extensive."

Dykes - The Acadian dykes, and those constructed in the intervening years, have unquestionably had a significant effect on the dynamics of sediments in the Bay of Fundy. The massive quantities of sediments that are in the upper reaches of Fundy are in a constant state of change and movement. Accumulation as mudflats and marshes in certain places, and steady erosion in other places are indicative of continuous shifts in the balance of the oceanographic and other processes that deposit the sediments and those that erode them away. Even a relatively modest change in the direction or strength of a tidal current, can over time, cause drastic changes in the structure of the mudflats or marshes. Not all of these intricate balances are fully understood by the scientists who study such things. They are often hard pressed to predict what effect the construction of a breakwater or a causeway will have on the distribution and shape of nearby mudflats and marshlands. It is no wonder then, that it has been virtually impossible to say with any certainty what the Bay of Fundy would have been like if Acadian settlers had not engaged in their ambitious dyke building along its shores all those centuries ago. What is clear, however, is that the subsequent dyke building and barrage construction set up barriers to the huge quantities of fine grained sediments, which would normally have been deposited in slowly accumulating thin layers over thousands of hectares of productive salt marshes.

Studies in recent decades have shown that the coastal marshes were hardly "spoiled by the overflowing of the sea". They are not only highly productive ecosystems in their own right, but they are also an important part of a mutually beneficial association with coastal waters. The sea fertilizes the marshes with a continuous supply of nutrient rich sediments. The marshes in their turn supply abundant organic food and soluble nutrients to the coastal waters. The constant production of fragments of salt marsh vegetation adds huge amounts of organic matter to the surface layers of the mud in the saltmarshes and nearby mudflats. This provides ample food reserves for huge numbers of benthic invertebrates such as amphipods, worms and shellfish that sustain the large numbers of migrating shorebirds that stop over in the upper reaches of Fundy each year. A lot of the decaying vegetable matter is also swept into the shallow coastal waters, where it serves as food for a wide range of abundant marine invertebrates and fish. Scientists from Acadia University, Bedford Institute of Oceanography and elsewhere, who have studied present day rates of production of plant material (primary production) by the phytoplankton of the water column, the diatoms of the mudflats and the grasses of the saltmarshes have concluded that the marshes produce 25-30% of the total production of the inner Bay.

It is estimated that of the 35,700 hectares of salt marsh present at the time of European settlement, only 5-6,000 hectares remain today, a remnant 16%. According to Graham Daborn "it is a matter of conjecture how much more productive these waters would have been when the marshes were intact and six times as extensive." Unfortunately, we shall probably never know, because too many other things have changed over the centuries. But Daborn is confident that "in all likelihood, the progressive conversion of saltmarsh to dykeland, carried out in piecemeal fashion over time, has substantially reduced the productive potential of the tidal bays in favour of increasing agricultural land." Only we humans who dwell on Fundy's shores can judge whether the trade off has been worth it.

Dams - The many tidal rivers and their estuaries that flowed unimpeded into the Bay of Fundy were well known for the annual migrations of large numbers of fish such as salmon, striped bass, tom cod, sturgeon, eels and several species of herring. The construction of causeways across most of these rivers presented a formidable barrier to the migrating fish. Fishways were incorporated in some of these structures and early studies suggest that these permitted some of the fish to bypass the obstacles, but there can be little doubt that the barriers have severely disrupted spawning migrations. During the past few decades many of these prolific fish runs have been all but eliminated. However, it has proven difficult to directly link the decimation of the fish populations to the presence of the causeways because of a lack of adequate environmental studies prior to their construction. Also, even before this there had been a steady degradation of spawning habitat in most rivers and streams as a result of upstream hydroelectric and other dams, as well as a century or more of destructive forestry and agricultural practices.

By shutting out the normal tidal flow, the causeways also significantly changed the ecology of the rivers for a considerable distance upstream. Researchers from Acadia University found that the "biological communities, which remained rich and abundant in the tidal regime below the dam, were impoverished upstream". Strict control of water height at much higher mean levels also eliminated much of the intertidal zone and converted well mixed water masses into highly stratified (layered) ones. Increased streambank erosion occurred in many places and silt began to settle in the impoundments, instead of being swept out into the estuary. The barriers have also had profound effects on the distribution of mudflats and saltmarshes downstream in nearby coastal areas. An example of their dramatic effect on estuaries is clearly visible from the highway on the causeway across the Avon River near Windsor, Nova Scotia. In the 27 years since its construction, a large bank of reddish-brown mud has formed downstream. This has steadily expanded down the river, until its effects are now evident in the form of a pronounced shallowing of the estuary at Hantsport, 8 kilometres away. In the past few years, spreading patches of marine grasses indicate that the mudflat is slowly evolving into a new saltmarsh. A similar phenomenon occurred following construction of a causeway across the Petitcodiac River at Moncton, NB. In the Annapolis Basin there are strong suspicions that the construction of the causeway across the river, or the subsequent installation of the tidal power plant, caused marked changes in the nature of surface sediments around much of the Basin, with disastrous effects on the clam fishery.

Dynamos - The huge spinning blades of the tidal power turbines have proven to be a particular hazard for migrating fish, in spite of the presence of nearby fishways offering safe passage. Studies on shad suggested that the majority pass through the turbines on their way downstream; less than 1% used the fishways. Over half of those passing through the turbines were killed. Two thirds of them were killed as a result of sudden changes in water pressure during the passage, while a third of them had been hit by the large spinning blades. Surveys by scuba divers in the Basin below the plant revealed large numbers of dead and dismembered fish littering the bottom. As a result the area has become a popular hang out for seals and seagulls in search of a quick and easy ready-processed fish dinner. Researchers concluded that "the mortality rates of both adult and juvenile fish are far higher than originally expected" and that the tidal power plant imposes "a continuing steady mortality on already stressed populations during their migration". A wide range of fish species, including salmon, herring, striped bass and sturgeon appear to be effected to varying degrees. Unfortunately, the spinning

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turbines are only one of many environmental stresses that have contributed to the gradual destruction of most fish stocks in the Annapolis, and nearly all other Fundy rivers. Researchers have been hard pressed to determine with any confidence, the importance any one stress factor by itself in reducing the fish populations.

Reducing repercussions

For more than 350 years we humans have been creating large coastal structures and steadily modifying much of the Fundy coastline to better suit our needs. It is clear that we do not yet fully understand the consequences of such large scale engineering on the ecosystem of the Bay, particularly on its economically valuable living resources. Graham Daborn worries that " man's increasing ability to modify natural systems, particularly through engineering works, has far outstripped his ability to forecast the changes in complex ecosystems". There is evidence that these "engineering works" around the Bay have contributed to the severe depletion of several once abundant fish and shellfish stocks in many estuaries. Before embarking on further coastal modifications, particularly in connection with large scale tidal power projects, we must come to terms with what we have done to the Bay thus far. We must also determine if and how we can remedy some of the more undesirable side effects. Some scientists and others are even suggesting that there may be merit in returning much of the now unused dykelands to the sea. For example, there is a proposal to slowly allow the Petitcodiac River to once again become a tidal river, and to carefully monitor the subsequent environmental changes that occur. Other scientists warn that it is only a matter of time before the sea forcefully reclaims some of the dykelands. They warn that rising sea level, increasing tidal amplitude and long-term tidal cycles mean that eventually a very high tide and a severe storm surge will coincide and overwhelm many dykes. This will not only result in a loss of agricultural land, but may devastate areas where urban development has spread onto vulnerable dykelands. In the long run, however, it may indeed be in our best interest to allow some of these coastal marshlands to once again **"be spoiled ....by the overflowing of the sea".**

Further Reading

Potential impacts of hydro and tidal power developments on the ecology of bays and estuaries. G.R. Daborn. Pages 334 -348 In: Environmental Consequences of Energy Production: Problems and Prospects. Edited by S.K. Majumdar, F.J. Brenner and E.W. Miller. The Pennsylvania Academy of Science. 1987.

Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Edited by D.C. Gordon, Jr. and M.J. Dadswell. Canadian Journal of Fisheries and Aquatic Sciences. Volume 1256. 1984.

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Cause and Effect. M.Higgins and D. Jeffery. Nature Canada. Volume 25 Number 4 pages 25-28. Autumn 1996.

The Fundy Issues Series is an initiative of the Bay of Fundy Ecosystem Project. These publications describe our present scientific understanding of some of the environmental issues confronting the Bay. We hope that they will enhance your understanding of the biological richness and complexity of this unique marine area. Such awareness may encourage you to help in protecting it for the use and enjoyment of all, particularly future generations who may also come to rely on its bounty and rare beauty.

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