ENVIRONMENTAL IMPACTS OF BARRIERS ON RIVERS ENTERING THE BAY OF FUNDY:

Report of an *ad-hoc* Environment Canada Working Group

Peter G. Wells
Environmental Conservation Branch
Environment Canada, 45 Alderney Drive, Dartmouth, N.S. B2Y 2N6.

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Canadian Wildlife Service
Atlantic Region,
P.O. Box 1590,
Sackville, New Brunswick, Canada.
E0A 3C0

or

Dr. P.G.Wells
Environment Canada,
45 Alderney Drive,
Dartmouth, Nova Scotia.
B2Y 2N6

Tel. (902) 426-1426
Fax. (902) 426-4457
e-mail: Peter.Wells@ec.gc.ca

ABSTRACT

A wide range and number of barriers exist on rivers that drain into the Bay of Fundy, both upstream and on their estuaries. Barriers can be defined as any structure built into, through or over a waterway (stream, creek, river, estuary) that changes, possibly irreversibly, the physical (e.g. sedimentation, water circulation), chemical (e.g. salinity, oxygen, trace elements), biological (e.g. fish behavior) or ecological (e.g. production) characteristics of that waterway. Tidal barriers are obstructions constructed in or across a tidal water body that changes the tidal fluctuation in all or part of the water body above the obstruction. Barriers on Bay of Fundy rivers and their estuaries include dykes, aboiteau, causeways (with bridges, culverts and dams), dams and wharves. An ad-hoc Environment Canada working group was established in 1997; it convened to summarize what was known about the location, number, type, impacts and remediation potential associated with Fundy barriers. This report presents the working groups findings. Barriers exist on at least 25 of 44 major rivers around the Bay of Fundy. They have caused or are thought to have caused a wide range of ecological effects on the rivers themselves and their estuaries around the bay. These include: reduced lengths of tidal rivers, changed freshwater discharges, reduced movement of saltwater upstream, changed hydrodynamics, sedimentation (often severe), reduced open salt marsh, reduced nutrient transfer to the Bay, and interference with the movement of fish and invertebrates. However, the full scope of environmental impacts is not well understood at the present time; except for a few rivers and their estuaries, our data are largely anecdotal. It is recommended that federal agencies, provincial departments and other groups and interested parties consider strengthening the data and information base on barriers, update river flow information, model changes and cumulative effects, and determine the effects of rehabilitation or remediation efforts on selected river barriers.

RÉSUMÉ

Les rivières qui se jettent dans la baie de Fundy comportent un grand nombre d’obstacles divers, tant dans leurs cours supérieurs que dans leurs estuaires. Par obstacle, on entend ici toute structure aménagée au sein, en travers ou au-dessus d’un cours d’eau (fleuve, rivière, ruisseau ou estuaire) qui modifie, parfois irréversiblement, les caractéristiques physique (p. ex. sédimentation et circulation de l’eau), chimiques (p. ex. salinité, oxygène, éléments traces), biologiques (p. ex. comportement du poisson) ou écologiques (p. ex. production) du cours d’eau. Les obstacles à la marée qui modifient le flux de marée dans la totalité ou une partie des eaux en question, en amont de ces obstacles. Dans les rivières de la baie de Fundy et leurs estuaires, ces obstacles comprennent les digues, les aboiteaux, les chaussées (dotés de ponts, de buses et de barrages), les barrages et les quais. Un groupe de travail spécial a été mis sur pied par Environnement Canada en 1997; il a dressé un inventaire des données connues sur l’emplacement, le nombre et le type de ces obstacles, ainsi que sur leurs incidences et sur les mesures correctives possibles. Le présent rapport expose ses constations. Sur 44 grandes rivières de la baie de Fundy, au moins 25 comportent des obstacles. On sait ou on pense que ceux-ci ont eu des incidences biologiques nombreuses et variées sur les rivières elles-mêmes et sur leurs estuaires. Ils ont, notamment, diminué la longueur des rivières, modifié l’écoulement d’eau douce, réduit l’apport d’eau salée en amont, modifié l’hydrodynamique et la sédimentation (souvent gravement), rétréci les marais littoraux, réduit le transfert de matières nutritives vers la baie et gêné la migration des poissons et des invertébrés. Toutefois, on ne saisit pas très bien actuellement toute la portée des incidences environnementales; exception faite de quelques rivières et de leurs estuaires, nos renseignements; exception faite de quelques rivières et de leurs estuaires, nos renseignements sont très anecdotiques. On recommande que les organismes fédéraux, les ministères provinciaux, d’autres groupes et les parties intéressées envisagent d’accroître la base de données et de renseignements sur les obstacles, mettent à jour les données sur le débit des cours d’eau, modélisent les changements survenus et leur effets cumulés, et déterminent les effets des mesures ou de réparation dans certaines rivières obstruées.

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This report was presented to the Coordinating Committee of the Federal Natural Resource Departments, in Fredericton, N.B., December 1998, and approved for distribution. On behalf of the ad-hoc working group, I thank members of this committee for their comments and support.

This report has gone through several revisions since the Workshop in June 1997. I (PGW) am responsible for any errors in content or interpretation, or any omissions, and welcome additional information, comments and suggestions from all readers as work on this important Bay of Fundy issue unfolds. The bay, its living resources and our coastal communities depend upon our collective efforts.

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“The complex links between land and sea may make the task of protecting oceans seem daunting, if not impossible. But it is precisely because of these links – because oceans touch the lives of all of us – that we cannot ignore the health of oceans if we are to protect our own place on the planet”.

[From Weber, P., 1994, Ch. 3, Safeguarding Oceans, State of the World 1994, Worldwatch Institute, Wash., D.C.]

“The environment was lost by increments. It can be saved by increments”

[Wendi Goldsmith, in Ghost Nets, Unraveling the Trap of the Familiar, an earth art project by Aviva Rahmani, at the International Landscape Conference on Site Technologies, Harvard Graduate School of Design, April 1998]

1. INTRODUCTION

It is important to study, assess, and if possible mitigate the environmental impacts of barriers[1] on rivers, their estuaries and nearby coastal waters in the Maritime Provinces. Although humans have been building some of these structures globally for millenia and in North America for almost 400 years, for flood control, acquisition of farmland, transportation and power generation, the issue of “environmental impacts of barriers” has gained much public and governmental attention in the Maritimes since the 1970’s. This is due in part to the large number of barriers constructed in the region since World War II, especially for roads, reconstructed dykelands and power generation, and the environmental concerns expressed vocally in specific cases (e.g. causeways across embayments in Prince Edward Island, the causeway at Annapolis Royal and the Annapolis Royal tidal generating station, the Canso Strait causeway to Cape Breton Island, and the causeway-dam crossing the Petitcodiac River between Moncton and Riverview, New Brunswick). Each of these cases raised it’s own set of environmental questions (see, for example, Harding et al. 1979). Some mitigation of negative effects has already taken place (e.g. some causeways on PEI have been opened, with rivers and marshlands restored). However, in the context of the Bay of Fundy, the concern remains about local effects on rivers and estuaries, as well as the larger concern of possible cumulative ecological effects of multiple barriers on the Bay of Fundy ecosystem as a whole.

In response to this issue, and with specific questions about the Petitcodiac causeway-dam looming, Environment Canada (Environmental Conservation Branch) set up an Ad Hoc Working Group on “Bay of Fundy Rivers” in May 1997. It met on June 16th, 1997. Its Terms of Reference were to conduct an internal discussion and overview:

a) To determine what we know about the extent and possible environmental impacts of the barriers, especially dams, aboiteaux and barrages, constructed on rivers that flow into the Bay of Fundy; and

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[1]Definitions relevant to the topic: **Aboiteau** – a small wooden tunnel with a hinged door inside, built into a dyke; the door swings open to let fresh water drain out and closes to keep out the tide; modern versions in reconstructed dykes use square logs or concrete, long sluices with multiple (often 3) waterways, and bronze, steel or Armco gates (adapted largely from Hustvedt 1987); **Barrier** – obstacle…that prevents communication, success, etc. (Sykes 1978); any physical structure built into, through or over a waterway (stream, creek, river, estuary) that changes, possibly irreversibly, the physical (e.g. sedimentation, water circulation), chemical (e.g. salinity, oxygen, trace elements), biological (e.g. fish behavior) or ecological (e.g. production) characteristics of that waterway (Wells, Bradford and Hubley); **Causeway** – raised road across low or wet place or piece of water (Sykes 1978); **Causeway-bridge structure** – a causeway with a bridge built into it, not always centrally; some are tidal barriers and some are not (modified from DFO 1999); **Causeway-culvert structure** – a causeway with a wooden, metal or concrete culvert; if coastal, it may be a tidal barrier (modified from DFO 1999); **Causeway-dam structure** – a causeway that functions as a dam, often with gates; if built in an estuary, it is a tidal barrier (modified from DFO 1999); **Dam** – barrier constructed to hold back water and raise its level, to form a reservoir, or to prevent flooding (Sykes 1978); **Dike, dyke** – embankment, , long ridge, dam, against flooding, especially one of those in Holland against sea; causeway; barrier, obstacle, defense (Sykes 1978); **Tidal barrier** – a physical obstruction constructed in or across a tidal water body that restricts the tidal fluctuation in all or part of the water body above and/or below the obstruction (adapted from DFO 1999 and D. Hache, pers. comm.); a causeway between the mainland and an island in an estuary is not a tidal barrier as it does not restrict tidal fluctuation, it only restricts water movement and shoreline sediment and sedimentation regimes (DFO 1999); a causeway-bridge structure constructed in an estuary that results in changes in tidal fluctuation upstream of the structure is a tidal barrier (DFO 1999); a dam is a tidal barrier if built in tidal waters (DFO 1999); a dyke constructed across a small cove to create a lobster pound is a tidal barrier in that it restricts tidal fluctuation (DFO 1999).

b) To comment on the issue's priority, the likely consequences of modifying or removing obstructions to permit freer flow of the rivers, and the level of effort needed to analyse this issue thoroughly and initiate action.

This report presents the results of an overview on barriers, rivers and the Bay of Fundy by the ad-hoc working group. It is based largely on the collective personal knowledge of these individuals, review of a limited literature, and information provided during the review process. Although the report has expanded well beyond the original workshop notes, and has benefited from some technical reviews, it still should be considered a preliminary assessment of the current situation regarding impacts of barriers on Bay of Fundy rivers. This report may serve as one basis for further review of this subject by interested parties.

2. BACKGROUND TO THE WORKING GROUP'S REVIEW OF THE ISSUE

2.1 Overview

Dykes (with aboiteaux), causeways, dams and other barrages have been constructed on, along or across many rivers in New Brunswick and Nova Scotia that flow into the Bay of Fundy. Most early structures were built by the first European settlers to create agricultural land protected behind extensive series of dykes; construction of such dykelands started in the 1630s and 1640s in the Bay of Fundy, and many, possibly most, have been restored and maintained during this century (Hustvedt 1987). However, since 1900, barriers have been built to meet several other needs, such as creation of headponds for the generation of hydro or tidal power, provision of road or highway crossings, provision of recreational or urban use areas, and the control of water levels and water flows for flood control, logging and other industrial activities.

The various structures have undoubtedly influenced patterns of water flow in the rivers themselves, their estuaries and possibly in the Bay itself, although these changes have rarely been quantitatively measured and documented. Other than the extensive system of dykes and other structures and their numerous aboiteaux (174 in New Brunswick, 280 in Nova Scotia, Anon (1993)), most of the larger structures, especially those built across the rivers, have been constructed since 1955. Most were built without prior environmental impact assessment as this was not a legal requirement at the time.

The various barriers or physical structures around the Bay of Fundy are known to affect or suspected to affect many ecological processes and components. These include current and tidal movements, water quality, sediment characteristics and dynamics, coastal and estuarine food webs, the passage of migratory marine fish, modification of nursery habitat for anadromous fish, and the habitat and food of migratory birds and other economically and ecologically important wildlife (see Sections 2.2 and 5). In most cases, reliable quantitative documentation of these effects or predicted effects is scarce or unavailable.

Concern over gradual, cumulative and potentially far-reaching impacts of barriers has led to discussions since 1996 of the costs and benefits of a longer opening of the gates in the causeway-dam across the Petitcodiac River at Moncton-Riverview, considering both environmental and social perspectives. It was proposed that the gates be partially opened for a seven-month experimental period in 1998 to assess the effects of small initial changes in flow patterns, with the possibility of eventually opening the gates on a more permanent basis; the current plan is for a trial opening during Spring 1999. Environment Canada has been involved in assessing some of the potential environmental effects of this pilot project.

The current report provides an initial overview of the present situation (circa 1997–98) concerning impacts of barriers around the Bay of Fundy, albeit with limited information. It provides a broad perspective in anticipation that assessments of ecological effects of other barriers i.e. in addition to the one at Moncton-Riverview, may be sought so as to consider restoring freer flow in other river systems of the Bay. The report should assist in developing departmental, federal, provincial and community approaches to “the issue of river barriers”, in identifying priority actions to better understand their effects, and in mitigating such effects or impacts if deemed environmentally beneficial and economically and socially feasible.

2.2 Literature Summary Pertaining to the Bay of Fundy

Effects (demonstrated or hypothesized) of physical barriers on rivers on estuaries and coastal waters have been addressed in numerous recent reports. Some of these are summarized below.

2.21 From Gordon (1989) in Gulf of Maine Conference Proceedings

On dams, Gordon wrote: “ Early industrial development in the Gulf Region was based on water power. While some power was obtained from tidal mills, most came from rivers. Towns developed on rivers, and a large number of dams were built to impound water for power generation. Unfortunately, the dams served as a barrier to anadromous fish which prevented them from reaching their spawning beds. This, coupled with pollution from domestic and industrial (such as pulp and paper) wastes, led to the decline of important fisheries. All areas around the Gulf were affected, but loss was greatest in the southern area where population is greatest.

Fortunately, the problems caused by dam construction have been recognized and action is being taken to correct them. Not all damage can be corrected, however, because unique genetic stocks have been lost forever. Abandoned dams are being removed and fish-passage structures are being installed. For example, a major international effort is underway to restore anadromous fish to the St. Croix River between Maine and New Brunswick. Stocks of both alewife and salmon are already showing signs of increasing.”

On alteration of wetlands, Gordon wrote: “ The Acadians who settled in the Bay of Fundy region brought with them a knowledge of diking. Therefore, instead of clearing the forest they created their agricultural land by diking saltmarsh. The impact was substantial. It is estimated that approximately 75% (or 216 sq. km.) of the original saltmarsh area in the Bay of Fundy was diked. This loss certainly affected wildlife, but the impact on fisheries is not clear.”

2.2.2 From Health of Our Oceans (Wells and Rolston (1991), Wells et al., Chapter Five, p. 92–93):

“Dams, wharves, dikes, causeways and tidal power projects individually or collectively influence the quality of estuaries and coastal waters. Dams on rivers in southern Quebec have reduced the amounts of freshwater entering the St. Lawrence River Estuary and Gulf with negative effects on the salinity regimes and biological production in some river mouths (Drinkwater 1985). Wharves (though greatly reduced in numbers compared to the 1800s and 1900s) influence water and sediment flows in many locations, changing the structure of beaches and other shorelines. This is a problem in Prince Edward Island in particular.

The past four hundred years of European settlement (in Atlantic Canada) have reduced coastal marine habitats. For example, the Acadians diked approximately seventy-five percent (216 sq. km.) of the original salt marshes of the Bay of Fundy for farming (Gordon 1990). In-filling, “land reclamation”, and other coastal developments continue to remove productive and critical habitat from the marine environment, especially areas used by migratory birds. Although not well documented, habitat loss in open waters and from the ocean floor has also occurred (Gordon 1989).

Causeways have been built throughout the Atlantic Provinces. Some have disrupted the natural flow and accumulation of sediments (e.g. Petitcodiac River at Moncton, N.B., the Avon River at Windsor, N.S., numerous highways) (Daborn and Dadswell 1988; P. Lane, pers. comm.). Others have prevented the flow of estuarine waters and the dilution of industrial discharges (L’Etang Inlet, N.B.), or the natural distribution of critical life stages of commercial fish species, such as at Canso Causeway, N.S. (Harding et al. 1979, 1983). The problems with causeways are now well recognized, and some are being removed or modified. The proposed bridge to Prince Edward Island (the so-called fixed link crossing) recently underwent an environmental impact assessment and was rejected due to serious concerns for local fisheries and their habitat (Note: this bridge was completed in May 1997 and its environmental effects are being monitored and assessed by provincial and federal authorities).

Harnessing tidal power in the Bay of Fundy has been considered for many decades, and is documented in numerous studies (D. Wilson, pers. comm.). Numerous recent studies intensively evaluated its environmental consequences to the Bay’s unique ecology (Daborn 1977; Gordon 1984; Gordon and Dadswell 1984; Plant 1985). Primary concern centered on sediment transport which is so vital to the productive mudflats, the movement of fish, and the food supplies of migratory birds in the upper Bay. The recent, pilot-size Annapolis Tidal Power Station on the Annapolis River, N.S., is attributed with killing fish and changing current patterns, causing additional river bank erosion upstream, and changing the deposition of natural muds in the Annapolis Basin (Daborn and Dadswell 1988; Prouse et al. 1988). Such coastal construction and developments cause cumulative effects along a coastline (Simon 1978). They can substantially influence its continued natural functioning (water flow, sediment deposition, productivity, condition of habitats) and appearance.”

2.2.3 From Daborn 1997, p. 7 (in Bay of Fundy Issues: A Scientific Overview):

" In recent years, the potential long-term effects of modifications to rivers and estuaries has become an issue in itself. The Windsor Causeway in Nova Scotia was a focus of early sedimentological work (Greenberg and Amos 1983). Following its construction in 1970, a large tidal flat developed on the seaward side that has grown steadily down the estuary, resulting in significant shoaling in the region of Hantsport, some 9 km away. Because the initial deposits were fluid and unconsolidated, it took 17 years before the first signs of a saltmarsh became visible on high points on the flat. Since then the rapid growth of the marsh and stabilization of the sediment are producing a productive habitat that attracts fish, piscivorous birds, and migratory shorebirds. Similar long-term changes appear to have been induced by causeways on the Petitcodiac and the Annapolis Estuary. In the latter case, the causeway and power project have resulted in rapid erosion of a bordering saltmarsh at Fort Anne National Historic Site (Daborn et al. 1995). Many of these long-term consequences are only obvious in retrospect, indicating that our predictive understanding of impacts of modifications to the ecosystem is inadequate".

2.2.4 From Percy and Wells (Section 6.2.10 Physical stresses in rivers and estuaries) in Percy et al. (1997), p. 145:

"The anthropogenic stresses on most diadromous fish in Fundy region rivers and estuaries have been severe for many decades and have had devastating impacts on their populations. In certain areas, some species, such as the Tomcod in Frost Fish Creek and the Sturgeon in the Avon River, appear to have been completely extirpated. In almost all cases, the environmental insults are multiple and insidious, making it virtually impossible to completely unravel causes and effects. At best we can simply tally those anthropogenic factors that appear to be most serious. Agriculture, forestry and construction in the riparian zone have resulted in extensive erosion and siltation in most river systems, destroying large areas of critical spawning habitat for many species. Construction of causeways, barrages and other obstructions in virtually all rivers emptying into the Bay of Fundy, without adequate provision for fish passage, has severely disrupted fish spawning migrations. The installation of power generating turbines in some of these structures, such as the Annapolis Tidal Power Station, exacerbates the situation by imposing a continuing steady mortality on already stressed fish populations during their migrations."

2.2.5 From Percy 1996 (Dykes, Dams and Dynamos. The Impacts of Coastal Structures):

Percy describes "some of the ways in which each of these engineering works (i.e. dykes, dams, dynamos) could have contributed to the disruption of natural ecological processes and affected the marine populations of Fundy".

It is important to note that relatively little research in the Bay of Fundy is being conducted currently (circa Oct. 1998) to test the hypotheses of effects of barriers. Exceptions are: (1) studies at the tidal power project at Annapolis Royal where fish are still killed by the turbine blades, downstream intertidal erosion has occurred at Fort Anne, and sedimentation patterns have changed on mudflats in parts of the lower Annapolis Basin (Daborn, pers, comm.); (2) studies at the Windsor causeway where the mudflat and its inhabitants are being observed and studied (Daborn and Partridge, pers. comm., Wells, pers. observ.); (3) studies on the Petitcodiac River above and below the causeway on contaminants and sediments (H.O'Neill and K.G.Doe, pers. comm.); and (4) studies on fish and invertebrates in systems such as the L'Etang estuary (P. Keizer, pers. comm.).

3. EARLY CHANGES TO RIVERS AND LAND AROUND THE BAY OF FUNDY (1600S TO 1950S)

3.1 Dykes and Dykelands

There was extensive dyking by the early Acadian settlers on both sides of the upper Bay of Fundy in the 1600s (from approx. 1630) and 1700s (Hustvedt 1987), producing dykeland or dyked saltmarsh. The dykes were maintained and improved upon by English colonists after 1763, and many have been maintained to this day for agricultural use, with significant expensive modifications through land forming (Environment Canada 1991; D. Wilson, pers. comm.). A number of dykes, such as in parts of Shepody Bay, Minas Basin, and Annapolis Basin below the Annapolis causeway (pers. observ.), have not been maintained and the land has reverted to natural marshlands. However, most still are maintained, in places such as the Southern Bight of the Minas Basin, inner part of Cobequid Bay, most of Shepody Bay and Cumberland Basin, especially the Tantramar Marsh (Environment Canada 1991). Hence, much productive saltmarsh (estimates ranging from 75–90%, in Gordon (1989) and Hustvedt (1987), respectively) has been removed from the Bay of Fundy coastal ecosystem.

“Dykeland makes up, on average, about 40% of the cultivated land around the Bay” (Hustvelt 1987). This has had various detrimental ecological effects as the marshes previously functioned as undisturbed wetlands, fish and invertebrate nurseries, sources of detritus and carbon for the subtidal coastal environment, and traps for sediments and particles originating from coastal erosion and riverine discharges. In some cases, less productive dykeland has been reverted to freshwater impoundments, enhancing avian habitat, a positive change (Bain and Evans 1995; A. Hanson, pers. comm.).

3.2 Log Dams and Power Dams

Log dams were built on rivers entering the bay in the last century, as a way of controlling the collection and movement of logs to the mills; these would have changed water movement (quantity and timing) and likely characteristics such as temperature and sediment concentrations (Kerekes, J., pers. comm.). Little to nothing presumably is recorded about their ecological effects; this needs confirmation by archival research.

In this century, many small power dams were built on Bay of Fundy rivers. These range from the Milltown pulp mill site and many upstream dams on the St. Croix River in New Brunswick, to the five power stations on the Gaspereau-Black River system in Nova Scotia, to the recent (1984) experimental Annapolis tidal-power project at Annapolis Royal and Granville Ferry, Nova Scotia. Detailed information on each river is in Tables 1 and 2 and Appendix 3. Such obstructions redirect and change water flows, often affecting the movement of fish, and in the case of the tidal power project turbines (though a recent event), fish survival. Where industries are present, their effluent discharges also may change water and sediment quality downstream.

Dams on macrotidal estuaries are also thought to have effects well beyond the estuary, due to changes in tidal resonance and consequently tidal range (Daborn 1988) and the smoothing of seasonal hydrological regimes (Dickie and Trites 1983). This can change water temperatures and salinities, sediment transport and deposition, and the distribution and availability of essential nutrients to biota (Also see Appendix 2).

3.3 Land Use in the Watersheds of Fundy Rivers

The land in most watersheds around the Bay of Fundy has been extensively changed through agriculture, forestry and to a limited extent, urbanization, since European settlement. Coastal marshes have been extensively dyked (see Section 3.1 above). Only a few patches of coastal virgin forest remain, such as those in inaccessible ravines along the west side of the Bay of Fundy, between Saint John and Fundy National Park, and in Cape Chignecto Provincial Park, beyond West Advocate Harbor, N.S. Upstream forests have been cut and since WW II, sprayed with pesticides. Agriculture exists in many watersheds, especially those of the Saint John, Petitcodiac, Tantramaar, Salmon, Cornwallis and Annapolis Rivers, with consequent inputs of nutrients and pesticide residues into the estuaries and embayments. Agricultural, municipal and industrial inputs have been documented for some watersheds, such as the St. Croix (see Eastern Charlotte Waters ACAP reports), Saint John River (many Saint John River Study reports and ACAP documents), Petitcodiac River (Hugh O'Neill, pers. comm.) and Annapolis River (CARP/ACAP reports).

Changes in land use affect water run-off volumes and patterns, soil retention, bank erosion rates, water quality and sediment loads. These variables are unfortunately not well described for most rivers flowing into the Bay. However, there are some recent reports on river water quality and loadings i.e. fluxes to the Bay, of metals (e.g. Pol 1996; Windom 1996; J.Dalziel and P.Yeats, pers. comm.; Dalziel et al. 1998). These await full interpretation and modeling in the context of the specific watersheds and their influence on the coastal Bay. Dalziel's recent report offers the opportunity to calculate fluxes of land-derived dissolved and particulate trace elements to the Bay.

4. IMPACTS OF BARRIERS ON RIVERS ENTERING THE BAY OF FUNDY (1950S TO LATE 1990S)

Many major physical obstructions or barriers have been constructed across rivers and estuaries since 1950 (for example, see Daborn 1988). These include large causeways and dams for highway crossings, hydro and tidal power generation, and protection of agricultural land. They were usually constructed with insufficient regard to the hydrology of the rivers, river basins and estuaries affected, and most often without any environmental impact studies conducted before hand. This was the era of big engineering and big causeways and dams in the Atlantic Provinces, an activity which seems to have slowed for the Bay of Fundy and its rivers[2], although there has been recent dual-highway construction across dykelands of high ecological value between Sackville, N.B. and Amherst, N.S., and across marshlands on the south-western outskirts of Saint John, N.B. There has been construction of freshwater impoundments for wildlife on dykelands of lower agricultural value (D.Wilson, and A. Hanson, pers. comm.). Interest in the construction of major barrages across portions of the upper Bay for the generation of tidal power is occasionally still re-awakened (Daborn 1977, Gordon and Dadswell 1984) but is considered too costly in an era of low crude oil prices and heightened environmental awareness.

[2]Such large construction projects have not stopped globally—see Abramovitz (1996) and Stackhouse (1998).

During the period of 1955–1971, some of the largest barriers were built on significant tidal rivers around the Bay of Fundy. These undoubtedly have had a major cumulative impact on the integrity of the respective river systems, their estuaries and perhaps on the greater Bay of Fundy itself (see Dickie and Trites (1983) and Daborn (1988)), yet the degree of impact has not yet been estimated.

The large barriers include, in chronological order:

- 1955: Shepody River – control structure, protection of agricultural land.
- 1958–60: Annapolis River, at Granville Ferry and Annapolis Royal – causeway with control structure to replace a former bridge, and provide farmland (reclaimed marshland) protection upstream.
- 1960: Tantramar River – control structure, farmland protection, highway crossing.
- 1964–66: Saint John River – Mactaquac Dam, above Fredericton – power generation, flood control.
- 1968: Petitcodiac River, at Moncton – causeway-dam, farmland protection.
- 1969: Avon River, at Windsor – causeway-dam, farmland protection.
- 1973: Memramcook River – control structure, farmland protection.
- 1984: Annapolis River – reconstruction of causeway-dam and startup of completed tidal power generating station.

Forty-four large and medium-sized rivers flow into the Bay of Fundy, 18 in New Brunswick, and 26 in Nova Scotia. What follows is a brief description of the current dams and causeways on 25 of these rivers, their measured or presumed impacts on ecological attributes such as water flow and fish passage, and steps taken to mitigate these effects (Tables 1, 2). The information base is anecdotal and scientific (see Appendix 3) and needs to be verified and supplemented.

The rivers are described in Tables 1 and 2 and Appendix 3, moving west to east around the Bay of Fundy. The numbers of rivers in each province on which dams or causeways or other structures exist are summarized in Table 3, and the functions they serve and the presence of structures to enable the passage of fish are enumerated in Table 4. This information should contribute to general statements concerning scope of the problem(s), the state of knowledge, and the benefits of making changes to permit freer flow in some rivers. The descriptions will also be used to identify several rivers to serve as more detailed case studies of barrier impact and remediation (see Section 5.1).

A summary of the changes attributed to these barriers follows. Effects on the rivers, their estuaries or the Bay of Fundy are described as confirmed, suspected or hypothesized, based on best evidence available at the time to the working group[3]:

> **1. Number of barriers** – There was a major increase of number of barriers (other than dykes) from 1900–1998. There are now at least 26 dams and 10 causeways on 25 of 44 large and medium-sized rivers. Some rivers (e.g. St Croix, N.B., Saint John, Gasperau, Bear) have multiple barriers, but most have one.

[3]Additional detailed descriptions of effects of barriers kindly provided by scientists in the Department of Fisheries and Oceans while this report was being completed are in Appendix 2.

Table 1. Summary of Status of Barriers on New Brunswick Rivers that Flow into the Bay of Fundy

River name and number	Status*	Description of barriers on river	Presumed impacts of barriers or alterations	Current or potential remediation	Comments and references
NB-1 St. Croix River	3 P,L,H, R,F	first dam 1860, at least 2 power dams for pulp and paper mills, and 3 others to control water levels, Oak Bay causeway, river now series of reservoirs, fishways present	fish passage reduced by pulp mill effluent and dams, shellfish closures in estuary	water levels regulated by IJC, fish passage regulated by DFO, pulp effluent now reduced	IJC control, Canadian Heritage River, major industrial and recreation area, ECW ACAP site with CEMP
NB-2 Digdiguash	1	natural barrier with blasted fish-way pools at mouth of river			Bradford and Hubley DFO (pers. comm.)
NB-3 Magaguadavic River	2 P	1 power dam at St. George, built ca. 1900; 1 water storage dam. Both have fish ways.	fish passage may be impeded due to water falls above the dams		B&H (pers. comm.)
NB-4 L'Etang River and Inlet	3 H,L, (P?)	highway causeway built ca. 1967, newer barrage created a settling pond for pulp mill wastes, controlled discharge through culvert.	severe water and air quality concerns from pulp mill effluent, effects on clam fishery and benthic habitat down-stream	remediation attempts since 1980s, highway re-routing may provide remediation opportunity	L'Etang ACAP site with CEMP (?); many studies of pollution impacts by D.Wildish, DFO, St. Andrews.
NB-5 Pocologan River	2 H	causeway with culvert for main highway built in 1960s	presumed impediment to fish passage		
NB-5 New River	1	no barriers; crossed by highway brdige.			
NB-7 Lepreau River	1	no man-made barriers; there are natural water falls on the river			good water flow data avail-able. B&H (pers. comm.)
NB-8 Musquash River	2 P	concrete dam and power station built in early 1900s at head of tide, above highway	presumed impediment to fish passage. Extensive marsh is bordered by major highway.	Musquash Estuary is proposed as MPA under Oceans Act.	Harvey *et al.* (1998)
NB-9 Saint John River	3 P,L	major concrete Mactaquac Dam built above Fredericton in 1964-66 for power and flood control, many others upstream (e.g. Beechwood, Tobique, Grand Falls, Edmunston) for power and water control	no fishway at Mactaquac. Many upstream impacts well-documented, e.g. impeding flow, increased erosion and sedimentation, decreased water quality, impeding fish passage	Some fish trucked around Mactaquac dam	Saint John ACAP site with CEMP, info from Atl. Centre for Soil Conservation at Grand Falls

River name and number	**Status***	**Description of barriers on river**	**Presumed impacts of barriers or alterations**	**Current or potential remediation**	**Comments and references**
NB-10 Big Salmon River	2 L	dam and mill site near mouth for logging	presumed impediment to fish passage		
NB-11 Point Wolfe River	1	once had dam and mill for logging		dam has been removed	Fundy National Park has information
NB-12 Upper Salmon (Alma) River	1	no barriers			Fundy National Park has information
NB-13 Shepody River	3 A	MMRA rock-filled dam constructed in 1955, 2 steel gates (16ft. by 20ft. each) and concrete control structure, to protect 2200 ha farmland; operated by NBDA; , completely impedes flow except when gates manually opened, adjacent saltmarsh dyked	reduced salmon run, reduced or eliminated nutrient export from river to adjacent saltmarsh and mudflats, banks subject to failure	There is a 3 pool (4ft. head) pool and fish way. There is an operating agreement for the tidal gates. (Bradford and Hubley, B&H). Gates are opened according to DFO specifications and as necessary at all other times (Rutherford, pers. comm.)	well documented. B&H (pers. comm.); Rutherford, DFO (pers. comm.).
NB-14 Petitcodiac River	3 A,H,L,R	rock-filled causeway/dam built 1967-68 with 5 spill gates and fishway (modified in 1981-82 but still ineffective), to protect farmland and create road crossing between Riverview and Moncton, created 21 km. reservoir, adjacent saltmarsh extensively dyked. Dam operated by NBDOT	obstructs fish passage (e.g. salmon, sea trout, gaspereau, smelt, shad), reservoir is eutrophied and de-oxygenated in summer, provides new recreation and waterfowl staging areas, extensive silting downstream restricting waterway, new mudflats/ saltmarsh developing, possible effects on mudflat composition, fauna and shorebirds, concern over contaminants in sediments in river and Shepody Bay.	partial opening of causeway gates proposed, could increase tidal movement and salinity in reservoir, redistribute sediments. There ia a 19 pool (20 ft. head) sluice and baffle fish way (B&H).	well-documented in many reports and web-sites, subject of ongoing discussion and dispute. B&H (pers. comm.)

River name and number	Status*	Description of barriers on river	Presumed impacts of barriers or alterations	Current or potential remediation	Comments and references
NB-15 Memramcook River	3 A,H	rock-filled causeway with concrete/steel gates opened at College Bridge in 1973 to protect farmland and provide road crossing; operated by NBDOT; completely impedes flow except when gates are manually opened.	sedimentation and formation of new mudflats below dam, much reduced passage of sea trout, gaspereau, possibly salmon. No fishway.	gates opened in spring to release run-off, removal or modification would permit fish passage. There is a 2 pool (3 ft. head) sluice and baffle fish way (B&H)	information at Mt. Allison University, and CWS, Sackville. B&H (pers. comm.)
NB-16 Tantramar River	3 A	rock-filled causeway with concrete/steel gates built in 1959-60, to protect 7000 ha of farmland (replaced 55 km of dykes); operated by NBDA; , completely blocks flow unless gates manually opened, adjacent saltmarsh extensively dyked	loss of nutrients and sediment input to bay, reduced sea trout run, increased siltation below dam, enough gaspereau remain to support small fishery, striped bass eliminated, bank swallow nests reduced from 1000s to 100s	Gates opened according to DFO specifications and as necessary at all other times (Rutherford, pers. comm.); removal or modification would permit fish passage. Tidal gates operating agreement (B&H).	information at Mt. Allison University, and CWS, Sackville, N.B. B&H, pers. comm.; Rutherford DFO (pers. comm.)
NB-17 Aulac River	2 A,F	rock/mud-filled dam to protect farmland, with 4 sluices with flapper-gates, at least 1 not functioning, permitting inflow of tidal water; dykes and aboiteaux on site since 1750s; much of watershed was diverted to Tantramar system in 1965. Dam operated by NBDA.	sea trout and gaspereau movement impeded even with functioning gates	impact already reduced by malfunctioning gates, dam could be left in present condition of restricted flow while still protecting fields from flooding	information at Mt. Allison University, and CWS, Sackville, N.B. B&H pers. comm.
NB-18 Missiguash River	2 A,F	MMRA built rock/mud dam with flapper gates above present highway crossing in 1960s (replaced in 1996, 3ft. to 4ft. diam. Pipes, Rutherford, pers. comm.) on site of historical aboiteaux, second dam built by DU to regulate water flow with fishway ~5km upstream. Dam operated by NBDA.	sea trout and gaspereau can still move up/down river	apparently no remediation required as fish passage seems unimpeded although water movement slightly restricted	

KEY TO STATUS CODES

1 no apparent man-made obstacles to water flow present (particularly in or near zone of tidal influence)
2 obstacle(s) present, particularly on minor rivers, which apparently permit some fish passage
3 substantial obstacle(s) present (often more than one), particularly on major rivers, which apparently prevent fish passage or block water flow

A creation or protection of **agricultural** land
H **highway** or road crossing
P hydro or tidal **power** generation
R **recreational** or urban use
L control of water **levels** and flows for other purposes
F presence of functioning **fishway**

Table 2. Summary of Status of Barriers on Nova Scotia Rivers that Flow into the Bay of Fundy

River name and number	Status*	Description of barriers on river	Presumed impacts of barriers or alterations	Current or potential remediation	Comments and references
NS-1 La Planche River	2 A,F	MMRA built rock/mud dam with flapper gates below present highway crossing in 1960s (?), second dam built by DU to regulate water flow with fishway upstream; Extensively dyked, with aboiteaux (Rutherford, pers.comm.)	sea trout and gaspereau can still move up/down river	apparently no remediation required as fish passage seems unimpeded although water movement restricted	Rutherford, DFO (pers. comm.)
NS-2 Maccan River	1	marshes extensively dyked			
NS-3 Nappan River	3 A,H	rock-filled dam with steel hinged gates built by MMRA in 1959, protects 398 ha of farmland, provides road crossing	presumed loss of fish passage	operating agreement for tidal gates (B&H pers. comm.)	information likely available from Nappan Agricultural Canada Research Station. B&H, pers. comm.
NS-4 River Hebert	1	marshes extensively dyked			flow information available from gauge site on Kelly River tributary
NS-5 Sand River	1	presently no barriers, although historically dammed for mill			
NS-6 Apple River	1	adjacent marshes were dyked; no dykes currently (Rutherford, pers. comm)			
NS-7 Parrsboro River	3 L	causeway-dam in harbour, with inactive mill and mill pond	presumed loss of fish passage as no fish structures present up to 1998 (check this!). Extensive sedimentation seaward of the causeway-dam (pgw pers.observ.).	fish way was upgraded in 1998	B&H pers. comm.

River name and number	Status*	Description of barriers on river	Presumed impacts of barriers or alterations	Current or potential remediation	Comments and references
NS-8 Harrington River	1	no barriers, but crossed by highway bridge			
NS-9 Economy River	1	no barriers, but crossed by highway bridge			
NS-10 Bass River	1	no barriers. Remains of old wharf pilings in the intertidal zone (pgw).			
NS-11 Portapique River	1	no barriers, but crossed by highway bridge			
NS-12 Great Village River	1	dykes with aboiteau. There is a 6 pool, pool and weir fishway (B&H pers. comm.)			B&H pers. comm.
NS-13 North (Salmon) River	1	bridges and abutments, crossing river in several locations (pgw). Marshes extensively dyked on both sides of the estuary.	Extensive loss of free marshes on both sides of the river and estuary (pgw pers.observ.)		pgw (pers. observ.)
NS-14 Shubenacadie River	1	a number of bridges and abutments. Marshes extensively dyked in estuary.			
NS-15 Tennycape River	2 H	causeway for road crossing, culvert restricts flow	fish passage presumably affected		
NS-16 Walton River	1	causeway and bridge crossing river in Walton (pgw)	restrictions of but no blockage of tidal flow into the estuary, wetlands and river above the town (pgw)		pgw(pers.observ.)
NS-17 Kennetcook River	1	a few dykes; major bridge and abutments on Route 236			pgw (pers. observ.)

River name and number	Status*	Description of barriers on river	Presumed impacts of barriers or alterations	Current or potential remediation	Comments and references
NS-18 St. Croix River	3 P	Panuke Lake Dam with power station at St. Croix village; also crossed by bridge on Route 101, and possible other bridges on smaller roads.	fish passage presumably impeded		
NS-19 Avon River	3 A,H,R	major rock-filled causeway built in 1970, one opening with steel gates that impedes all flow, no aboiteaux, protects 1300 ha farmland, provides highway crossing and recreation in reservoir	no fishway so fish passage is prevented, low flow in eutrophic reservoir, ongoing rapid accretion of sediment created 9 km mudflat, saltmarsh now developing, increased use as shorebird feeding area and Black Duck wintering area	headpond occasionally drained, modifying flow through causeway would reduce volume of reservoir, with likely erosion of mudflats downstream. Operating agreement for tidal gates. (B&H pers. comm.)	Chuck Sangster report on impacts of causeway (1996?) available from Windsor Municipal Office
NS-20 Gaspereau River	2 P,H,F	marshes extensively dyked, five power dams constructed in 1930s-1940s of rock/ concrete upstream of tidal influence, some with fishways ; there are also numerous storage dams.	fish runs impeded, gaspereau movement maintained, salmon run much reduced		NS Power supporting Acadia Centre for Estuarine Research studies on impacts of structures on passage of gaspereau. B&H pers. comm.
NS-21 Cornwallis River	1	no barriers, although marshes extensively dyked			Mike Dadswell, Acadia University, has recent data on fish movements in the Cornwallis system
NS-22 Canard River	2 A,H,F	aboiteaux in place since 1700s/1800s, marshland extensively dyked, mud/rock causeway used for road crossing			
NS-23 Habitant River	2 A,H,F	aboiteaux in place since 1700s/1800s, marshland extensively dyked, mud/rock causeway used for road crossing		operating agreement for tidal gates (B&H pers. comm.)	B&H pers. comm.

River name and number	Status*	Description of barriers on river	Presumed impacts of barriers or alterations	Current or potential remediation	Comments and references
NS-24 Pereaux River	2 A,H,F	aboiteaux in place since 1700s/1800s, marshland extensively dyked, mud/rock causeway used for road crossing			
NS-25 Annapolis River	3 A,H,P,F	rock-filled causeway built at Granville Ferry in 1960 to protect 1740 ha of farmland and provide highway crossing, fishway provided, tidal power generation turbines installed in early 1980s, other tributaries (Nictau, Paradise, Lequille) have small power dams upstream	reduced fish passage (e.g. striped bass, possibly other spp.) due to causeway and turbines, indications of sedimentation of clam beds in Annapolis Basin, substantial downstream erosion of river banks	remedial action to reduce erosion of banks at Fort Anne, dykes at Annapolis Royal have been rebuilt	
NS-26 Bear River	2 P	small power dam(s) located upstream of Bear River, well beyond tidal influence, some dyking of saltmarsh			

*** KEY TO STATUS CODES** (see Table 1)

[1] Additional rivers and creeks (Rutherford, DFO, pers. comm.3/99) - NS-0 Missiguash R. - dykes and aboiteau; NS-6A- Spicer Brook (drains into Advocate Harbour) - aboiteau; NS-11a- Mill Brook - aboiteau; NS-12A-Chiganois River-aboiteau; NS-12B-Small river on north side of mouth of Salmon River-aboiteau; NS-13A-small tributary of Salmon River, south side - aboiteau; NS13B-Old Barns River(?)-aboiteau; NS14A-Selma Brook - aboiteau; NS14B-East Noel River - aboiteau; NS14C-Burnt Coat River - aboiteau.

TABLE 3. MAN-MADE BARRIERS ON MEDIUM AND LARGE RIVERS FLOWING INTO THE BAY OF FUNDY

	New Brunswick	Nova Scotia	Total
No man-made barriers present (code 1)	5 (28%)	14 (54%)	19 (43%)
Barriers present with some ecological impact (code 2)	6 (33%)	7 (27%)	13 (30%)
Barriers present with major ecological impact (code 1)	7 (39%)	5 (19%)	12 (27%)
Total number of rivers considered	18	26	44

Key to Status Codes:

1 no apparent man-made barriers to water flow present (particularly in or near zone of tidal influence)
2 barrier(s) present, particularly on minor rivers, which apparently permit some fish passage
3 substantial barrier(s) present (often more than one), particularly on major rivers, which apparently prevent fish passage or block water flow

TABLE 4. FUNCTIONS OF BARRIERS AND PRESENCE OF FISHWAYS ON RIVERS FLOWING INTO THE BAY OF FUNDY

	New Brunswick	Nova Scotia	Total
Protection or creation of agricultural land (A)	6 (46%)	6 (50%)	12 (48%)
Highway or road crossing (H)	5 (38%)	8 (67%)	13 (52%)
Hydro or tidal power generation (P)	4 (31%)	4 (33%)	8 (32%)
Recreational or urban use (R)	2 (15%)	1 (8%)	3 (12%)
Control of water levels or flows for other purposes (L)	5 (38%)	1 (8%)	6 (24%)
Presence of functional fishway or aboiteaux (F)	3 (23%)	6 (50%)	9 (36%)
Total number of rivers considered with obstructions (status codes 2 and 3)	13 (72%)	12 (46%)	25 (57%)

EFFECTS: Confirmed. Physical barriers are now present on 72% of the rivers considered in New Brunswick, and 46% in Nova Scotia (57% overall for the two provinces). The changes that are or might be attributed to these barriers are geographically widespread.

2. Length of tidal river systems – The length of tidal portions of many Bay of Fundy watersheds has decreased substantially from 1900–1998.
EFFECTS: Confirmed. The length, area, and volume of estuarine habitat have been reduced in almost all river systems with barriers, and often substantially reduced, e.g. Annapolis River, Avon River, Petitcodiac River. The impact on each river and its estuary should be quantified, and summed. See #3–9 also.

3. Volume of freshwater – The volume of freshwater entering the Bay of Fundy from some rivers with dams (e.g. St. Croix, Saint John, Gaspereau) may have decreased from 1900–1998.
EFFECTS: Suspected or Unknown. Temporal and spatial measurements of freshwater input from such river systems are needed over a number of years, for confirmation.

4. Volume of brackish and salt water – The volume of seawater moving upstream in inter-tidal portions of rivers has been substantially reduced by dams and causeways whose gates block further flow upstream, and by aboiteaux into former salt marsh (now dyked).
EFFECTS: Confirmed. Land behind most barriers in tidal portions of rivers has become substantially drier, and the water fresher or completely freshwater, with the loss of periodic tidal flooding which once provided nutrients and sediments. In addition, "the introduction of a small volume of salt water through leakage at an aboiteaux can lead to a high degree of stratification and anaerobic conditions in the hypolimnion; mixing is important" (J.Gibson, pers. comm.). These impacts should be quantified.

5. Hydrodynamics of the water entering the Bay – River flows are often markedly impeded or altered in volume, speed, timing and direction in river systems with barriers.
EFFECTS: Confirmed. This has been described in several cases, such as the St. Croix, N.B., Saint John and Annapolis Rivers (Plant 1985). A study of individual and cumulative impacts is required.

6. Downstream effects of a barrier – Reduced water movement (flow rates and patterns) below barriers causes sediments and other particles to drop from suspension and accumulate as deposits of mud, silt and sand.
EFFECTS: Confirmed. Substantial, often massive, changes in the distribution of sediments has been documented in many estuaries (e.g. St. Croix N.B., Petitcodiac, Memramcook, Avon, Annapolis). The tidal bores are reduced on the Petitcodiac and Salmon Rivers. Huge (in volume and distance) mudflats have developed on the Petitcodiac and Avon estuaries. Sediment accumulations may be major sinks and sources of toxic chemicals such as pesticides and herbicides in the industrialized or urban estuaries. This requires quantification. As well, for the freshwater environments in general, "fluctuations in water level associated with dam operation may cause a downstream reduction in habitat quality and fish mortality as a result of strandings" (J.Gibson, pers. comm.).

7. Area of open coastal saltmarsh – The large-scale drying out of former saltmarsh and subsequent conversion to agricultural land was greatly facilitated by the historical building of dykelands and maintained by dyke restoration, modern dams and causeways. Dykes protected 33,275 hectares of land for the 3 Maritime Provinces in 1970 (Hustvedt 1987, p. 89–90). There has been considerable maintenance of dykelands since the 1950s as the land is once again highly valuable for agriculture. Current dykeland in the upper Bay of Fundy in New Brunswick has 77 operating aboiteaux (Collette 1996); in Nova Scotia in 1992, there were 284 operating aboiteaux mostly with flap gates (Jansen, 1996).

EFFECTS: Confirmed. There has been a major reduction of 75–90% of the saltmarsh habitat in the Bay of Fundy area since European settlement began, especially from 1600–1800, with a recent slight but insignificant increase on the Avon River estuary as marsh grasses have started to become reestablished on the Windsor mud flats since 1987. Some dykes in disrepair have permitted the re-development of small amounts of saltmarsh, e.g. Annapolis Basin, near Habitation; parts of Shepody Bay. Accurate field data are needed. Open marshes are key nurseries for coastal fish and invertebrates, and habitat for birds.

8. Amount of carbon and other nutrients entering the Bay and its estuaries – The amount of organic carbon and associated nutrients available as detritus to the bay as a whole from the decay of saltmarsh plants (Gordon et al. 1985; Gordon and Cranford 1994), and from river watersheds, has decreased as a consequence of dyking and dams, from 1600 (approx.)–1998.
EFFECTS: Hypothesized. Changes of organic inputs into the Bay are thought to have been greatly reduced as a result of construction of barriers to water movement into the Bay, but have not been well documented. The consequences of barriers to overall primary and secondary productivity of the estuaries and major parts of the Bay of Fundy itself, such as in Cumberland and Minas Basins, are an important concern.

“It should be noted that the influence of barriers on nutrient transport upstream may also be important. For example, in the Gaspereau River watershed, we believe that several tons of alewives die of natural causes during their spawning run each year, resulting in a substantial nutrient input to that ecosystem” (J. Gibson, pers. comm.).

9. Influence on migratory fish – Construction of barriers across rivers, and dykes across smaller streams, have seriously affected populations of many species of anadromous fish (e.g. salmon, shad), and the one catadromous species.
EFFECTS: Confirmed. Although ameliorated in some cases through the construction of fish ladders and aboiteaux, severe impacts on migratory fish populations are considered among the most serious biological effects of dams and dykes. The turbines at the tidal power dam at Annapolis Royal kill or injure many fish on each passage upstream or downstream (Collins 1984; Dadswell and Rulifson 1994). Most fish ladders impede the movement of many individuals or species of fish, and as only 36% of rivers considered in this study had structures to assist fish passage, many local populations have been seriously reduced and often extirpated as a direct result of barriers. The association of these impacts to the current failure of the salmon fishery in middle Bay of Fundy is possible but requires study.

10. Positive changes associated with barriers – not all of the biological and ecological changes attributed to barriers on the tidal rivers and their estuaries have been negative. For example, the mud flats created below the Windsor causeway have now consolidated (circa early 1990s), marshes are become established on the flats near the causeway during the 1990's, and avian habitat exists i.e. shorebirds are often observed in the summer feeding on the flats, and they are frequented by gulls year-round (pers. observ.). Marshes have also grown below the Petitcodiac causeway. There are anecdotal reports that lobster fishing improved in Shepody Bay in the years after the Petitcodiac causeway was constructed, but the association with the causeway and the changes it caused in the estuary remain unproven. There may be other examples such as these which need to be documented.

In summary, barriers across 57% of 44 rivers have caused a number of significant physical and biological changes to these rivers, their estuaries and adjacent shorelines of the Bay of Fundy. Cumulative changes occurring on the 25 affected rivers have severely impacted many aquatic and marine species e.g. migratory fish, and the natural communities and coastal habitats of which they are part e.g. the salt marshes. Understanding the full extent of these individual and cumulative effects on the integrity of the whole coastal ecosystem, and the possibility for remediation of the rivers, are challenges that must be considered by environmental scientists, hydrologists, sedimentologists, geologists, engineers, managers and policy makers.

5. BAY OF FUNDY CASE STUDIES AND OTHER COASTAL EXAMPLES OF THE INFLUENCE OF BARRIERS ON RIVERS

5.1 Bay of Fundy

Considerable published data, unpublished data and anecdotal information are available for several Bay of Fundy rivers. This offers the opportunity for more comprehensive investigation of the effects of barriers on the living resources and ecological integrity of specific rivers, their estuaries and the Bay itself. Candidates for study could include the two largest rivers – the St. Croix and Saint John in New Brunswick – and six medium-sized rivers – the Shepody, Petitcodiac and Tantramar rivers in New Brunswick, and the Shubenacadie, Avon and Annapolis rivers in Nova Scotia. These rivers could be used as case studies to examine the evidence of individual and cumulative impacts (hydrological, chemical, biological, ecological) due to barriers and to explore the potential for river remediation in each case. The St. Croix ACAP community site has already begun the process of examining how to remediate the effects of 10 major dams on the St. Croix (ACAP 1996), providing an example to evaluate and possibly follow; this is particularly important due to its international stature under the International Joint Commission and its designation as a National Wild River.

5.2 Other Atlantic Coastal Locations

Rivers of the north shore of the Gulf of St. Lawrence have a large number of hydroelectric dams on them, with downstream impacts such as reduced mixing, reduced nutrients, higher temperatures and lower productivity in the estuaries (see papers by Ken Drinkwater, BIO-DFO; Drinkwater 1985;

Dickie and Trites 1983). There is considerable information on PEI causeways and their impacts, and the positive ecological effects of the recent modification of some, such as the North, Wilmot and West Rivers (see Proceedings of the Tidal Barriers Workshop, in press, CCNB 1999). Effects and predicted effects of Hydro Quebec projects (e.g. the La Grande) on rivers entering the eastern Hudson Bay are well documented. Effects include reduced water volumes, less mixing in the estuaries, reduced nutrients, reduced sediments, deteriorating habitat quality for shorebirds and seabirds generally, and far-field effects on salinity regimes in coastal waters (see papers by Ken Drinkwater, BIO-DFO; Drinkwater 1985).

Barriers on rivers and estuaries are a broader Gulf of Maine issue, highlighted in a recent CEC (Commission for Environmental Cooperation) report. Concerns about dams and tidal flow restrictions are described and initial actions are identified (Percy 1998). Dam removal is now occurring in Maine (CCNB 1999), and tidal restrictions in salt marshes are being assessed in Massachusetts (Purinton and Mountain 1998).

5.3 Other Watersheds and Coasts

The presence of physical barriers such as dams on rivers and causeways across estuaries obviously are not unique to Canada. “There are more than 36,000 major dams in the world, and hundreds of thousands of smaller ones” (p.299, McKinney and Schoch 1998). Other writers put the figures as high as “38,000 large dams and countless smaller dams” (Abramovitz 1996). Very few large rivers in the world now run free, and many of those are being threatened with obstructions eg. the Stickine River in northwestern B.C. No values were found for numbers of causeways and dykes on rivers and their estuaries.

There is a very large literature on the effects of dams on riverine and estuarine systems (see ASFA abstracts 1973 to date; for Canada, see Delisle and Bouchard 1990, and Chapters 12 and 26 in Government of Canada 1991). Dams and other similar physical barriers on rivers and streams are often considered to be among the most destructive of human enterprises due to their overall negative impacts on aquatic ecosystems and hydrological resources (see review by Abramovitz 1996, and recent article by Lovett 1999).

The James Bay project in Quebec, and the Columbia (USA), Snake (USA), Mississippi (USA), Colorado (USA) and Nile (Egypt) rivers provide stark examples of major downstream effects of barriers i.e. dams, one or more, on riverine and estuarine systems. These examples are well documented (e.g. see Harden (1996) on the Columbia River, Lovett (1999) on the Snake River, and Postel (1998) for a global overview). Effects have been measured on water quality, fate of contaminants, fish migration, sediment transport, nutrient transport and the size and condition of their deltas (highly productive biologically and reduced significantly in size), as well as on human health. Ecological effects are extensive and considered largely irreversible.

6. SUMMARY AND CONCLUSIONS

Given the importance and many values of the living resources and ecology of the rivers and estuaries of the Bay of Fundy, there is a clear need to consider the barriers issue in depth. Barriers, especially dams, causeways and dykes, exist on at least 25 of 44 major Bay of Fundy rivers. They have caused or are thought to have caused a wide range of ecological effects on the rivers themselves and their estuaries around the bay. These include: reduced lengths of tidal rivers, changed freshwater discharges, reduced movement of saltwater upstream, changed hydrodynamics, sedimentation (often severe), reduced open salt marsh, reduced nutrient transfer to the Bay, and interference with the movement of fish and invertebrates. Effects on some systems are becoming understood with time and effort e.g. the Petitcodiac, Avon and Annapolis Rivers and their estuaries. However, the full scope of environmental impacts of most of the barriers, alone and together, and the potential benefits of remediation efforts, are not well understood at the present time. This is due in part to the complexity and inter-disciplinary nature of the problem(s), the low profile of the issue generally (the Petitcodiac and Annapolis Rivers being obvious exceptions), and the shortage of resources to study the problem in an integrated manner in the depth that it deserves. At the very least, we should re-examine and strengthen the information on the condition of individual rivers and the Bay of Fundy as a whole, and consider the options for action.

7. RECOMMENDATIONS

Several actions should be considered by the appropriate federal and provincial natural resource, transportation/highway and energy agencies, and all interested parties and stakeholders, at their earliest convenience:

1) **Data and Information Base**: to strengthen the data and information base on changes in rivers related to barriers, especially by “ground-truthing” the presence and extent of barriers on all Fundy rivers and streams (major and minor) and their estuaries, and by measuring features such as the area and condition of remaining open salt marshes. This might be accomplished through one or more jointly funded, coordinated research projects, followed by a Workshop with research papers and reviews.
2) **River Flow Characteristics:** to determine total annual flows into the Bay of Fundy from the rivers and the level of change in volumes or changes in other flow characteristics, due to barriers, and the influence this might have or have had on estuaries and the broader Bay of Fundy. This would follow from Gregory et al. (1993).
3) **Modeling Changes and Cumulative Effects:** following from Points 1) and 2), to build a simulation model of the changes (Section 4) to test the hypothesis of gradual cumulative effects (positive or negative) on biological and ecological processes in important geographic parts of the Bay of Fundy or the greater Gulf of Maine.
4) **Determining Effects of Rehabilitation and Remediation:** following from Point 3), to run the model as a way of testing effects of local and area-wide rehabilitation efforts, and as a way of setting priorities for remediation initiatives.
5) **Conducting a Pilot Project on Selected Rivers and Species:** given the number of habitats and species across all rivers and estuaries in the Bay of Fundy, and the need to simplify an approach to quantifying impacts and effects of remediation, one project could be “to explore the usefulness of an index river/species approach to identifying the impacts of barriers on the living resources of the Bay of Fundy and the means of mitigation” (R. Bradford, pers. comm., 3/99).

8. BIBLIOGRAPHY

Abramovitz, J.N. 1996. Chapter 4. Sustaining Freshwater Ecosystems. Pages 60–77 in *State of the World, A Worldwatch Institute Report on Progress Towards a Sustainable Society.* L.R. Brown et al. (eds.), W.W.Norton and Co., New York.

ACAP. (Atlantic Coastal Action Program). 1996. *Caring for Our Coast: A Plan for Community Management of the St. Croix Estuary Area.* Unpubl. Report, Sept. 1996.

Anonymous. 1993. Eastern Canadian Soil and Water Conservation Centre, Summary Session on Agriculture and Dykelands, Feb. 10, 1993, Moncton, N.B. (D.Wilson, Environment Canada, Dartmouth, N.S., pers. comm.].

Bain, J. and M. Evans. (Eds.). Dykelands Enhancement Workshop, Feb. 28–March 1, 1995, Amherst, N.S. Canadian Wildlife Service, Environment Canada, Sackville, N.B. 57p.

CCNB (Conservation Council of New Brunswick). 1999. Proceedings, Tidal Barriers Workshop, Moncton, N.B., April 13–14th, 1999. (In press).

Chaisson, A. MS 1996. Technical evaluation and monitoring program for an option to operate the gates to clip the tides at the Petitcodiac River Causeway. ADI Ltd., Fredericton, N.B. 63p plus figs.

Collette, L. MS1996. Correspondence to H. Hansen, Fisheries and Oceans, Halifax, N.S., Dec. 13, 1996. New Brunswick Agriculture, Moncton, N.B. 10p. (Courtesy of R. Bradford, DFO, Halifax).

Collins, N.H. 1984. Potential fish mortality associated with large hydroelectric turbines. Pages 551–563 in Update on the Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy (Gordon, D.C., Jr., and M.J.Dadswell, eds.). Can. Tech. Rep. Fish. Aquat. Sci. No. 1256.

Daborn, G.R. (Ed.). 1977. *Fundy Tidal Power and the Environment.* The Acadia University Institute, Acadia University, Wolfville, N.S.

Daborn, G.R. 1988. Effects on fish habitat of physical modifications in estuaries. Pages 81–91 in *Characteristics and Conservation of Fish Habitat. Proceedings of the Fish Habitat* Awareness Seminar, Acadia University, 22–24 June 1988, Acadia Centre for Estuarine Research, Acadia University, Wolfville, N.S. ACER, Acadia University, Wolfville, N.S. ISBN 0-662-17176-4.

Daborn, G.R. 1997. Chapter One. Fundy Marine Ecosystem Science Project: Science Overview. Pages 1–9 in Percy, J.A., P.G.Wells and A.J. Evans. (Eds.). *Bay of Fundy Issues: A Scientific Overview.* Workshop Proceedings, Wolfville, Nova Scotia, January 29 to February 1, 1996. Environment Canada – Atlantic Region, Occasional Report No. 8. ISBN 0-662-25570-4.

Daborn, G.R., C.L. Amos, H.A. Christian, and M. Brylinsky. 1995. Stability of the shoreline at Fort Anne National Historic Site. ACER Publication No. 37, 184p.

Daborn, G.R. and M. J. Dadswell. 1988. Natural and anthropogenic changes in the Bay of Fundy – Gulf of Maine – George's Bank System. Pages 547–560 in *Natural and Man-made Hazards*. M.I. El-Sabh and T.S. Murty (eds.). D. Riedel Publishing Company, Dordrecht.

Dadswell, M.J. and R.A.Rulifson. 1994. Macrotidal estuaries: a region of collision between migratory marine animals and tidal power development. Biol. J. Linn. Soc. 51:93-113.

Dalziel. J.A., P.A.Yeats, and B.P. Amirault. 1998. Inorganic chemical analysis of major rivers flowing into the Bay of Fundy, Scotian Shelf and Bras d'Or Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 2226: vii and 140p.

DFO. Department of Fisheries and Oceans. MS1999. Unpubl. Notes, March 1999 (F. Scattolon, pers. comm.).

Delisle, D. and M.A.Bouchard. (Eds.). 1990. Joules in the water – managing the effects of hydroelectric development. Proceedings of a Symposium sponsored by the Canadian Society of Environmental Biologists, April 6–7, 1989, Montreal, Quebec. Collection Environnement et Geologie, Vol. 9, Universite de Montreal.

Dickie, L.M. and R.W.Trites. 1983. The Gulf of St. Lawrence. Pages 403–426 in *Ecosystems of the World 26: Estuaries and Enclosed Seas*. B.H. Ketchum (ed.). Elsevier, Amsterdam.

Drinkwater, K. 1985. Effects of River Runoff on the Marine Environment off Eastern Canada: a Submission to the Inquiry on Federal Water Policy. Bedford Institute of Oceanography, Dartmouth, N.S.

Eaton, P.B., A.G.Gray, P.W.Johnson and E.Hundert. (Eds.). 1994. Section 4.3.1 Dams, diversions, causeways and other obstructions. Pages 320–324 in *State of the Environment in the Atlantic Region*. Environment Canada, Dartmouth, N.S. ISBN 0-662-20520-0.

Environment Canada and the Government of Canada. 1991. Section 20. Upper Bay of Fundy Dikelands: Changing the Tides. Pages 20–1 to 20–18. In *The State of Canada's Environment*. Minister of Supply and Services, Ottawa, ON. ISBN 0-660-14237-6.

Gordon, D.C., Jr. 1984. Integration of ecological and engineering aspects in planning large scale tidal power development in the Bay of Fundy, Canada. Water Sci. Tech. 16:281-295.

Gordon, D.C., Jr. 1989. Habitat loss in the Gulf of Maine. Pages 106–119 in *The Gulf of Maine: Sustaining Our Common Heritage*. Proceedings of an International Conference held in Portland, ME, December 10–12, 1989. The Maine State Planning Office and the Canadian-American Center of the University of Maine, Augusta, ME. December 1989.

Gordon, D.C., Jr. 1990. Experience from the Bay of Fundy and recommendations for Gulf Region. Pages 45–48 in Proceedings of Gulf Habitat Science Workshop, E.M.P. Chadwick (Ed.)., Can Industry Rep. Fish. Aquat. Sci. No. 206.

Gordon, D.C., Jr. and P.J. Cranford. 1994. Export of organic matter from macrotidal salt marshes in the upper Bay of Fundy, Canada. Pages 257–264 in *Global Wetlands: Old World and New* (Ed. by W.J. Mitsch). Elsevier Science B.V., Amsterdam.

Gordon, D.C., Jr., , P.J. Cranford and C. Desplanque. 1985. Observations on the ecological importance of salt marshes in the Cumberland basin, a macrotidal estuary in the Bay of Fundy. Estuar. Coastal Shelf Sci. 20:205–227.

Gordon, D.C., Jr., and M.J. Dadswell. 1984. Update on the Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1256.

Government of Canada. 1991. *The State of Canada's Environment*. Minister of Supply and Services Canada, Ottawa.

Greenberg, D.A. and C.L. Amos. 1983. Suspended sediment transport and deposition modeling in the Bay of Fundy, Nova Scotia – a region of potential tidal power development. Can. J. Fish. Aquat. Sci. 40(Suppl.1):20–34.

Gregory, D., D. Petrie, F. Jordan and P. Langille. 1993. Oceanographic, geographic and hydrological parameters of Scotia-Fundy and southern Gulf of St. Lawrence Inlets. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 143. 248p.

Harden, B. 1996. *A River Lost. The Life and Death of the Columbia*. W.W.Norton and Co., Inc., New York and London. 271p.

Harding, G.C.H., P.G.Wells and K.F. Drinkwater. 1979. The distribution and abundance of lobster larvae (*Homarus americanus*) in St. George's Bay, Nova Scotia, in 1975 and 1976 and the possible effect that the Canso Causeway has had on the Chedabucto Bay lobster fishery. Pages 101–111 in Canso Marine Environment Workshop, Part 3 of 4 Parts. Fishery Impacts. F.D. McCracken (ed.). Fisheries and Marine Service, Ottawa, ON., Technical Report No. 834, January 1979.

Harding, G.C.H., K.F. Drinkwater and W.P. Vass. 1983. Factors influencing the size of American lobsters (*Homarus americanus*) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence and Gulf of Maine: a new synthesis. Can J. Fish. Aquat. Sci. 40(2):168–184.

Harvey, J., D. Coon and J. Abouchar. 1998. *Habitat Lost: Taking the Pulse of Estuaries in the Canadian Gulf of Maine*. Conservation Council of new Brunswick, Fredericton, N.B. 81p. ISBN 0-9695708-6-4.

Hustvedt, E. 1987. *Maritime Dykelands. The 350 Year Struggle*. Department of Government Services, Publishing Division, Province of Nova Scotia. 110p. ISBN 0-88871-085-2.

Jansen, H. MS1996. Tidal gate structures. Memo and attachments to John Ritter, Fisheries and Oceans, Moncton, N.B. 14p. (Courtesy of R. Bradford, DFO, Halifax).

Lovett, R.A. 1999. As salmon stage disappearing act, dams may too. Science 284:574–575. (April 23, 1999).

McKinney, M.L. and R.M.Schoch. 1998. *Environmental Science. Systems and Solutions*. Web Enhanced Edition. Jones and Bartlett Publ., Sudbury, MA. 639p. plus Appendices.

Percy, J.A. 1996. Dykes, Dams and Dynamos. The Impacts of Coastal Structures. Fundy Issues No. 9, Clean Annapolis River Project, Annapolis Royal, and ACER, Acadia University, Wolfville, N.S. 6p.

Percy, J.A. 1997. Chapter Five. Marine Resources of the Bay of Fundy. Pages 103–137 in Percy, J.A., P.G.Wells, and A.J. Evans. 1997. (below).

Percy, J.A. 1998. Land-based activities and their physical impacts on marine habitats of the Gulf of Maine. CEC, Global Programme of Action Coalition for the Gulf of Maine, Working Paper, May 1998. Commission for Environmental Cooperation, Montreal, Canada. 72p.

Percy, J.A., P.G. Wells and A.J. Evans. 1997. (Eds.). *Bay of Fundy Issues: A Scientific Overview*. Workshop Proceedings, Wolfville, Nova Scotia, January 29 to February 1, 1996. Environment Canada – Atlantic Region, Occasional Report No. 8. Environment Canada, Dartmouth, N.S. and Sackville, N.B. ISBN 0-662-25570-4.

Plant, S. 1985. Bay of Fundy Environmental and Tidal Power Bibliography. Second Edition. Can. Tech. Rep. Fish. Aquat. Sci. 1339.

Pol, R.A. MS1996. Chemical loadings (exports) to the Bay of Fundy. A Framework for Concentrations and Exports from Atlantic Canada Rivers. Draft Report, Environment Canada, Moncton, N.B. Jan., 1996. 12p plus attach.

Postel, S. 1998. Where Have All the Rivers Gone? Pages 173–195 in The World Watch Reader on Global Environmental Issues, L.R.Brown and E.Ayres, Eds., W.W.Norton, New York, N.Y.

Prouse, N.J., T.W. Rowell, P. Woo, J.F. Uthe, R.F. Addison, D.H. Loring, R.T.T. Rantala, M.E. Zinck and D. Peer. 1988. Annapolis Basin soft-shell clam (Mya arenaria) mortality study: a summary of field and laboratory investigations. Can Man. Rep. Fish. Aquat. Sci. 1987. 19p.

Purinton, T.A. and D.C. Mountain. 1998. Tidal Crossing Handbook. A Volunteer Guide to Assessing Tidal Restrictions. Parker River Clean Water Association, Byfield, MA. 69p.

Simon, A.W. 1978. *The Thin Edge*. Harper and Row/Avon Books, New York. 191p.

Stackhouse, J. 1998. *Decline and fall of the big dam era*. Globe and Mail, March 28/98, p. D4.

Sykes, J. B. 1978. *The Concise Oxford Dictionary of Current English*. 6th Edition, Sixth Impression (with corrections and Addenda). University Press, Oxford. 1368p.

Thurston, H. 1990. Tidal Life. *A Natural History of the Bay of Fundy*. Camden House Publ., Camden East, ON. 167p. (published, 2nd edition, 1998).

Wells, P.G. MS1998. The Bay of Fundy: Current Program Activities and Management Issues of the Federal Natural Resource Departments in the Maritimes. A Report to the Federal Natural Resource Departments Atlantic Pilot Project Coordinating Committee. Environment Canada, Dartmouth, N.S. Feb. 1998. 14p plus attach.

Wells, P.G. and S.J. Rolston. 1991. (Eds.). *Health of Our Oceans. A Status Report on Canadian Marine Environmental Quality*. Conservation and Protection, Environment Canada, Dartmouth, N.S. and Ottawa, ON. 2nd Ed. 186p. incl. indexes.

Wells, P.G., W. Barchard, M. Chevalier, L. Hildebrand, T. McRae, B. Moores and M. Richardson. 1991. Chapter Five. The Atlantic. Pages 79–112 in Wells et al. 1991. *Health of Our Oceans. A Status Report on Canadian Marine Environmental Quality*. Conservation and Protection, Environment Canada, Dartmouth, N.S., and Ottawa, ON.

Windom, H.L. 1996. Chapter 16. Riverine contributions to heavy metal inputs to the Northeast Shelf ecosystem. Pages 313–325 in *The Northeast Shelf Ecosystem. Assessment, Sustainability and Management*. Ed. By K.Sherman, N.A.Jaworski and T.J. Smayda. Blackwell Science, Cambridge, MA.

APPENDIX 1. MEMBERS OF THE ENVIRONMENT CANADA WORKING GROUP – JUNE 1997

Richard Elliot, CWS, Sackville, N.B. (Coordinator)

Peter Wells, Environment Canada, Dartmouth, N.S. (Chair, Writer)

Don Ambler, Environment Canada, Dartmouth, N.S.

Dave Wilson, Environment Canada, Dartmouth, N.S.

Bill Brimley, CWS, Sackville, N.B.

Tony Erskine, CWS, Sackville, N.B.

Al Smith, CWS, Sackville, N.B.

Peter Hicklin, CWS, Sackville, N.B.

Tom Clair, CWS, Sackville, N.B.

APPENDIX 2. ADDITIONAL INFORMATION ON IMPACTS OF BARRIERS PROVIDED BY THE FEDERAL DEPARTMENT OF FISHERIES AND OCEANS, MARCH 1999.

Sedimentation and Tidal Barriers (Tim Milligan, DFO, Bedford Institute of Oceanography)

The transport and deposition of sediment is controlled by turbulence and particle flocculation. For coarse-grained sediment (medium silt and larger), erosion and sedimentation are directly linked to the overall energy of the environment. In simple terms, the greater the energy, the larger the particle which can be transported. For fine-grained sediments, flocculation confounds this simple relationship between particle size and transport by forming large, fast sinking particle aggregates that effectively increase the settling velocity of the constituent grains by up to several orders of magnitude. The formations of flocs in a suspension depends upon the collision rate of particles, the likelihood that particles remain attached after collision, and the rate at which the flocs are broken up by turbulence. Flocculation rate increases with particle concentration, due to the high probability of contact. It also increases with higher sticking efficiency resulting from, for example, the excretion of long chain polysaccharides by diatoms. Up to a certain level, turbulence will favor aggregation due to increased particle encounter rate; beyond that level, turbulence limits aggregation due to floc breakup by energetic shear. Floc size, hence the settling velocity of fine particulate material, is controlled by turbulence and particle composition. Changes to any of the controlling factors (concentration, composition or turbulent energy) will have an immediate effect on the transport and deposition of sediments.

Tidal barriers ideally illustrate the effect of altering at least one of these controlling factors. The deposition of several meters (depth) of mud for many kilometres downstream of the barriers at Windsor, N.S., and Moncton-Riverview, N.B., is a dramatic example of what happens when turbulent energy within the system is decreased. Their construction disturbed the dynamic equilibrium between erosion and deposition that occurs within estuaries. New mud flats were the result.

The naÏve view, which still persists in many engineering models, is that the clay fraction of a suspension settles on the order of 0.00001 m.s-1. The settling velocity in most environments is actually closer to 0.001 m.s-1, or approximately 3–4 m.h-1. Settling velocities on this order are sufficient to deliver much of the material in suspension to the seabed during slack water, especially in the Bay of Fundy where very high concentrations of sediment exist. Coupled with decreased erosion stress resulting from diminished tidal flow, deposition rates on the order of 1 m.yr-1 as observed at Windsor are not surprising.

A secondary effect, which could also be expected to occur at these locations, is more rapid aggregation as a result of higher concentrations of sediment in the water column during re-suspension i.e. sediment traps sediment. This effect is associated with activities such as dredging, aquaculture, municipal outfalls and other sources of particulate material. In some cases, not only is particle concentration increased, but the nature of the material being introduced leads to higher sticking efficiencies.

Alterations to sediment dynamics are not restricted to human activities in the coastal zone. Global sea level rise has resulted in changes in tidal amplitude, which translates into changes in turbulent energy in many environments. In the Bay of Fundy system, higher tidal velocities in some regions has led to increased bottom scour. Fine sediment released by erosion of the bottom has the potential, by increasing aggregation rate, to affect transport and deposition. At the same time, however, greater turbulent energy can cause floc breakup, resulting in lower effective settling velocities. In an energetic system such as the Bay of Fundy, especially with its very high sediment load, it can be expected that the sediment dynamics will adjust rapidly to change.

Diadromous Fish Passage of Tidal Barriers on Bay of Fundy Rivers
(R.Bradford, Fisheries and Oceans, Moncton, N.B.)

More than 33 rivers in the inner Bay of Fundy provide supporting habitat for diadromous fish, species that migrate between fresh and salt water. During the past 350+ years, barriers to fish passage, in the form of dykes, causeways and dams, have been constructed either across or along the tidal portions of many of these rivers. The perceived impact on fish production varies with barrier type and the degree to which access to habitat essential for spawning, rearing, foraging and wintering is either hindered or altered. Generally, the range in degree of impact is extreme, from instances where previously self-sustaining populations of fish are no longer viable to instances where the impact may be negligible. There are few, if any, examples where a man-made barrier on tidal waters has eliminated all species of diadromous fish from a river flowing into the Bay of Fundy, although fish production for the river system may be negatively affected (e.g. reduced biomass).

Variability among species in the impact of tidal barriers on population viability and production is partly a reflection of taxonomic and ecological diversity, and variability in life-history attributes among the diadromous fish occurring in bay of Fundy rivers. The diadromous assemblage of fish consist of those that live in the rivers and spawn at sea (catadromous species) and those that ascend rivers from the sea to reproduce (anadromous species). The American eel (*Anguilla rostata*) is the sole catadromous species in the Bay of Fundy region. The anadromous species of fish include clupeids (American shad (*Alosa sapidissima*), alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*)), salmonids (Atlantic salmon (*Salmo salar*), brook char (*Salvelinus fontinalis*), naturalized populations of brown trout (*Salmo trutta*)), osmerids (rainbow smelt (*Osmerus mordax*)), percids (striped bass (*Morone saxatilis*)), and gadids (Atlantic tomcod (*Microgadus tomcod*)).

Freshwater residence time can vary substantially among these species: from days to weeks (e.g. striped bass, rainbow smelt, Atlantic tomcod), to a few months (alosids), to several years (Atlantic salmon, American eel). The life-history stages at which transition between river and sea occur is correspondingly variable among species. This factor can contribute to the variable effectiveness of fish passage facilities constructed to move fish around barriers. Not all designs are necessarily effective for all species.

Tidal barriers constructed within foraging and rearing habitat could impact fish production either as impediments to fish passage or through alteration of the productive capacity of habitat (e.g. salt marsh to hay field). The potential impacts are poorly understood at present, as these have not received the same scrutiny as the issues associated with fish migration for the purposes of reproduction.

Impacts of Tidal barriers on Ecosystem Energy Flow in the Bay of Fundy (B.Hargrave, DFO, Bedford Institute of Oceanography)

Dykes, causeways and dams on rivers entering the Bay of Fundy constructed over the past 300+ years have undoubtedly altered the rates of freshwater discharge and tidal exchange in this macrotidal bay. In offshore areas, this could have changed the geographic extent and balance between organic input from phytoplankton, rivers and salt marshes. Phytoplankton-derived organic matter is largely consumed within the water column, while organic debris and intertidal micro-algae are respired by organisms in and on sediments and in shallow regions of the inner Bay. The rates and proportion of energy flow through pelagic and benthic communities have probably been altered over the past three to four centuries, reflecting changes in riverine water flow and the extent of salt marshes.

In the outer areas of the Bay of Fundy (seaward of Digby and Saint John), water depth and tidal energy dissipation allow seasonal thermal stratification to occur. Reduced water turbidity and stratification in the photic layer results in phytoplankton biomass accumulation, which leads to a highly productive euphotic zone. Dissolved nutrient supply is predominantly by horizontal tidal exchange and vertical mixing. Phytoplankton production depletes the surface layer of nutrients during the summer. Historically, with higher freshwater input (due to climate variation and human-induced reduction in river discharge), stratification and the resulting development of phytoplankton populations could have been more extensive than in recent times.

In the mid-region of the Bay of Fundy (seaward of Cumberland and Minas Basins), an area of intermediate stratification develops during summer. Phytoplankton production is stimulated through nutrient supply by vertical mixing. Benthic communities with biomass dominated by filter-feeding molluscs receive freshly produced organic matter advected to the bottom by tidal mixing. Since these areas are most impacted by changes in variables affecting water column stratification and primary production, they have probably varied in geographic extent over time.

Of all areas in the Bay of Fundy, marine ecosystem energy flow has been most altered by human activity within the inner regions (Shepody Bay, Cumberland Basin, Minas Basin, Cobequid Bay). These areas are characterized by highly turbid water that is seldom stratified due to shallow depth and high rates of tidal flow and energy dissipation. High concentrations of fine-grained sediment occur in the water column due to turbulence- and wave-induced resuspension. The high suspended sediment load leads to reduced light penetration which, combined with the absence of stratification, results in relatively low rates of phytoplankton production. Micro-algae growing on exposed intertidal sediments during ice-free periods provide a source of organic matter to benthic invertebrates such as the amphipod, Corophium volutator, the main prey species for many migratory birds.

Non-living organic matter produced within salt marshes provides an important additional source of organic matter for the inner Bay, but it is of lower quality than that produced by phytoplankton and benthic micro-algae. Removal of 75% (approx.) of the salt marsh area by dyking over past centuries has reduced this supply of non-living detritus and also lowered micro-algal production as a source of organic matter by the proportion of intertidal area converted to agricultural land. Dissolved nutrient inputs to the upper reaches of the Bay of Fundy from salt marsh drainage would also have been reduced along with the decrease in particulate organic matter supply, following conversion of dyked land to agricultural production.

APPENDIX 3. RAW NOTES AND ADDITIONS FROM THE JUNE 1997 MEETING

The information below was compiled anecdotally at the one-day workshop, June 1997. It needs to be independently reviewed, verified and improved upon with additional documentation.

NEW BRUNSWICK

5.1 St. Croix River - NB #1
Status
- drainage basin (? need ref.)
- river was dammed in 1860, at Milltown (power dam); at Woodland, ME, in yr??, for a pulp and paper mill/power dam. There is a fish ladder.
- there are at least five dams on this river, two for power/water level, and three for water level. Water levels are maintained for recreation. (Ref: IWD 1991-1992).
- there is a large highway causeway at Oak Bay, near St. Stephen.
- the watershed is largely privately owned.
- key references - IJC - water quantity Charles Power; water quality Peter Eaton. Also Lee Sochasky in St. Croix.

Impacts
- there are many and they are well documented (where??)
- fish passage was greatly reduced due to pulp and paper mill pollution.
- a series of reservoirs, going upstream, exist. Water level is controlled.
- there are annual shellfish closures (due to bacterial counts) below the dams and the Oak Bay causeway.

Remediation
- no action (is needed?)
- there has been increased quality through the proposed controls.
- there are many conflicting interests. It is an International River, a Canadian Heritage River, a site of a NOAA project on loss of habitat effects; the focus of an ACAP site (the St. Croix ACAP program).
- information gaps - no (little?) pre-barrage data exist.

5.2 Digdiguash River NB #2
Status
- no obstructions, except bridge crossings.

5.3 Magaguadavic River NB#3
Status
- there is a dam at St. George, and another one further upstream, for power generation. They were built circa 1900.

Impacts
- it is presumed that fish passage is impeded.

Remediation
- there are historical data on the hydrology, for comparison.

5.4 L'Etang River and Inlet NB #4

Status

- there are two obstacles, a major highway causeway built in 1967 and a newer barrage designed to control the pulp mill effluent i.e. used as a settling pond .
- this is a well documented problem re changes to air and water quality in the river and estuary (Wildish, D., St. Andrews).
- there have been many concerns regarding the clam fishery downstream.

Impacts

- this was a total river blockage, in order to have a settling pond for the pulp and paper mill wastes. At present, there is an outlet for controlled discharge.
- air and water quality were affected since the late 1960's. Many studies were conducted of the various impacts. It was not until the 1980's that governments took action. Air quality problem has been resolved (pers. observ., Wells)

Remediation

- rerouting the main highway may offer an opportunity to remediate the L'Etang Estuary more completely.

5.5 Pocologan River NB #4A

Status

- there is a recent causeway, built in the late 1960's, with a culvert.
- the main highway crosses the causeway.

Impacts

- unknown

Remediation

- unknown

5.6 New River NB #4B

Status

- there are no dams on this river.

5.7 Lepreau River NB #5

Status

- there are no dams on this river.
- there are good flow data (it is a good natural control).

5.8 Musguash River NB #6

Status

- there is a dam at the head of tide, above the current four-lane No. 1 Highway.
- it is used as a reservoir and for power generation.
- there is a concrete dam and power house.
- they were built in the early 1900s.
- some of the marshes were dyked (verify?).

Impacts

- there is reduced nutrient flow to the salt marshes (ref.?).
- the highway and rail crossing must be causing effects i.e. runoff to the river and estuary.

Remediation

- the saltmarsh is gradually recovering, as the dykelands were abandoned. The marsh is now managed by Ducks Unlimited.
- the river is still dammed.

5.9 Saint John River NB#7

Status

- there is the Mactaquac Dam, upstream from Fredericton.
- it is a huge concrete dam, built 1964-66, used for power and flood control.
- there is no fishway for salmon; fish are trucked around the dam.
- there are many dams on the Saint John - e.g. Beechwood, Tobique, Grand Falls, Edmundston.
- dams are for power and water/flood control, as well as to assist with logging (the older ones).

Impacts

- they are very well documented.
- they include impeding fish movement; impeding water flow; changes in water quality and pollution dilution; additional erosion of banks and sedimentation into the river.
- ACAP at Saint John are studying some of the effects, especially harbour quality.
- information source - Atlantic Centre for Soil Conservation (Lise Oullette, Grand Falls).

Remediation

- no information.

5.10 Big Salmon River NB#8

Status

- a former log driving, dam/mill site.

Impacts

- no information.

Remediation

- no information.

5.11 Wolfe River NB#9

Status

- was used formerly for log driving, had a dam and mill.
- may have been a small dam at Bennett Lake. No dam at present.
- reference- Parks Canada (Fundy Park).

Impacts

- no information.

Remediation

- no information

5.12 Upper Salmon/Alma River NB#10

Status

- no dams.
- reference- Parks Canada.

Impacts

- no information.

Remediation

- no information.

5.13 Shepody River NB#11

Status

- an MMRA dam was constructed in 1955 (1.8M$). It is a rock-filled dam, with 2 large steel gates and a concrete control structure.
- there is no fish passage.
- the dam protects approx. 2200 ha. of agricultural dykelands.

Impacts

- there are unstabilized vertical banks above the dam, hence a risk of bank failure exists.
- the damming destroyed a good salmon run (ref. DFO documents).
- the gates are opened in the Spring to accommodate sea-run trout passage.
- rainbow trout are resident above the dam.
- nutrient export/sediment export to the saltmarsh and flats (Daniels flats, Mary's Point) from upstream was probably reduced or stopped altogether.
- effects on Shepody Bay and the greater Bay of Fundy relative to the Petitcodiac River changes need to be identified.

Remediation

- changes in sediment and nutrient movement and deposition need to be confirmed.
- there are benefits to anadromous fish, if changes were made to the opening patterns of the gates on the dam (eg. open more often, longer periods, continuously?).

5.14 Petitcodiac River NB#12

Status

- a dam was built in 1967-68, modified in 1981-82, producing the causeway across the river at Moncton.
- it is a rock-filled dam with 5 spill gates and a fishway.
- its function is to protect farmland, and provide a road crossing.
- there are many data available in recent reports/WWW page

Impacts

- the effects of the causeway are well described and recorded (eg. major sediment deposition downstream (readily seen), impediment to fish passage (DFO has data), loss of tidal bore (well-known), loss of nutrient transfer from upper watershed to Shepody Bay (speculative, no data seen), etc). Loss of the tidal bore was well publicized, as it was a tourist attraction.
- a 21 km freshwater reservoir was made, which suffers from eutrophication in the warmer months; also no oxygen is left in the lake in the summer, which prevents/impedes fish passage and use (incr. temp., high nutrients).

- downstream, there is extensive siltation/mud infilling (restricting the waterway), suspected changes to mudflats in Shepody Bay, concerns about toxic chemicals and their sources, transport and effects; etc.
- biological effects above the causeway - little or no passage of salmon, gasperaux, smelt, shad; also improved waterfowl (geese) staging area.
- biological effects below causeway - increase in saltmarsh area; possible enhanced lobster fishery in Shepody Bay; possibly reduced numbers of Corophium and sandpipers (being investigated, note 1997 data of Hicklin that suggests Corophium numbers are again high, and likely very variable from year to year). There are no sea-run trout now.
- there is a recreation/suburban area above the causeway, of considerable economic value; this contrasts with the loss of fisheries and navigable waters downstream.

Remediation

- depends upon the degree of opening.
- open 5 gates, reduce oxygen debt in water above the causeway, achieve better water temperature range (more normal), achieve increased salinity in the reservoir (lake).
- possibly increased movement of sediments above causeway would occur with more frequently opened gates. This might flush contaminants into the lower river and bay.
- consider remedial use of marsh plants (as in the Fraser River Estuary Management Program or FREMP).

5.15 Memramcook River NB#13

Status

- there is a rock-filled causeway, with concrete/steel gates, at College Bridge. It was built in 1973.
- there is no fishway.
- the causeway was built for agricultural reasons (protection of land) and for the highway crossing to St. Joseph.

Impact

- high sedimentation below the causeway; mudflat accretion has occurred.
- there are presumed additive impacts on Shepody Bay downstream (speculation).
- the river had sea-run trout, some passage for gaspereau (now reduced), probably salmon at one time (none now?).
- the gates are opened in the spring to let spring run-off out, and to prevent up-stream flooding.

Remediation

- presumably similar to the Petitcodiac i.e. opening gates and/or removal of the dam.

5.16 Tantramar River NB#14

Status

- the marsh is (was?) approx. 50,000 acres in total.
- a rock-filled causeway, with concrete-steel gates, was built in Fall 1959-1960.
- Agriculture Canada, responsible for 7000 ha of dykeland, replaced 28 mi of dykes.
- the causeway accommodates the TCH. This has been recently modified for the four-lane highway.
- no water exits the marsh, except when the gates are especially lifted to release accumulated water (same as at Memramcook and Shepody dams).

* potential case study area.

Impacts
- gates are open in the Spring to let winter runoff out; this runoff erodes the accumulated sediment below the dam.
- there is increased siltation below the dam; new mudflats have formed and there is a channel, two-thirds constricted.
- there is still a gasperaux run (a commercial gill-net fishery).
- there is a reduced sea-run trout run (Note Colin Patterson study at Mount Allison University in 1960's).
- striped bass are now gone.
- there may be tom cod - status unknown.
- loss of nutrient cycling to the Bay of Fundy (presumed).
- it is now easier to drain the marsh than when it was simply dyked.
- the bank swallow populations are greatly reduced, from 1000's to 100's of nests.

Remediation
- removal or modification of the dam would improve fish passage
- the river channel, when it was freshwater, was used to water cattle (?).

5.17 Aulac River NB#15

Status
- aboiteau have been on river since the 1750's, at current site since 1829, 1840, and 1860.
- there is a rock, mud-filled dam; 3 sluices with flapper gaps (1 or more not working, probably 3 not working).
- there are tidal flows through the structure; it is not beyond repair.
- in 1965, much of the Aulac drainage was diverted to the Tantramar marsh and river.

Impacts
- sea-run trout and gaspereau are impeded, even with the working tidal gates.
- the dam permits fish passage, while preventing flooding of fields.

Remediation
- there is already reduced impact.
- recommended that the dam be left in its present condition of restricted but not impeded flow.

5.18 Missaguash River NB#16

Status
- aboiteaux are just upstream from the TCH.
- there is an MMRA built structure (date?); there were two earlier aboiteaux on the river.
- the dam is rock mud with flapper gates.
- there is a DU (?) dam and fishway approx. 5 km further upstream.

Impacts
- sea trout and gaspereau still move up the river.

Remediation
- none needed? The dam and gates work reasonably well at present.

NOVA SCOTIA

5.19 LaPlanche River NS#1

Status

- there is a causeway , with gates, downstream from the TCH.
- it is the same as NB#16 structure; there is a 2nd dam further upstream.

Impacts

- sea trout and gaspereau still move upstream.

Remediation

- works reasonably well now.

5.20 Maccan River NS#2

Status

- dyked but no dam(s) in place.

Impacts

- no information.

Remediation

- no information.

5.21 Nappan River NS#3

Status

- there is a rock-filled dam, built by MMRA in 1959.
- it protects 398 ha dykeland.
- it has a road over it.
- it has steel, hinged gates.
- there is an Agriculture Canada station at Nappan (ref?).

Impacts

- there presumably is loss of fish passage.

Remediation

- could be opened up to allow fish passage.

5.22 River Hebert NS#4

Status

- dyked but there is no dam.
- there is a water gauge on Kelly River tributary, a good control river for runoff data.

Impacts

- no data

Remediation

- no data

5.23 Sand River NS#5

Status

- there is no dam. There was once a mill on the river, with a mill dam.

Impacts

- no data

Remediation

- no data

5.24 Apple River NS #6

Status

- the surrounding land is dyked but there is no dam on the river.

Impacts

- no data

Remediation

- no data

5.25 Parrsboro River NS#7

Status

- there is a dam in the harbour.
- there is an inactive mill and mill pond.
- there are no fish structures.

Impacts

- no data

Remediation

- no data

5.26 Harrington River NS#8

Status

- there are no dams

5.27 Economy River NS#9

Status

- there are no dams

5.28 Bass River NS#10

Status

- there are no dams.

5.29 Portapique River NS#11

Status

- there are no dams.

5.30 Great Village River NS#12

Status

- there are no dams.

5.31 North/Salmon River NS#13

Status

- there are no dams, but there are many dykes in the watershed.

5.32 Shubenacadie River NS#14

Status

- there are no dams but there are many dykes in the watershed.

5.33 Temycape River

Status

- there is a causeway used as a road.

Impacts

- river flow is restricted by culverts.

Remediation

- no information.

5.34 Walton River NS#15

Status

- no information.

5.35 Kennetcook River NS#16

Status

- no dams, few dykes.

5.36 St. Croix (NS) River NS#17

Status

- there is the Panuke Lake Dam, with water storage for power generation; the power station is at St. Croix Village.

Impacts

- no information

Remediation

- no information

5.37 Avon River NS#18

Status

- there is a major rock-filled causeway crossing the river at Windsor, built in 1970.
- it is a closed structure; there is one opening, with steel gates, no aboiteau.
- there is no fishway (confirm?).
- it has produced approx. 1300 ha farmland.
- uses - roadway, recreation on headpond, farmland.

Impacts
- physical-chemical effects above barrier - a small freshwater reservoir, which is eutrophic.
- physical-chemical effects below barrier - an huge, very visible, growing accretion of sediments, creating at this time 8 km long mudflats and mudbanks.
- biological effects above barrier - no data.
- biological effects below barrier - increase in shorebird feeding area; increased use by black ducks in winter; salt marshes are becoming established, removal of sediments from the coastal ecosystem.
- social impacts are undocumented.

Remediation
- removing or modifying the causeway would reduce size of the reservoir.
- unknown effects on the mudflats downstream.
- no data are known, pertaining to the potential effects on the estuary of causeway removal or modification.

5.38 Gasperaux River NS#19
Status
- there are five power dams on the river, rock and concrete. Built in 1930-40's.
- some dams have fishways.
- there is a gaspereau run, and some salmon.

Impacts
- some impacts on fish populations (?).

Remediation
- no information

5.39 Cornwallis River NS#20
Status
- lots of dykes and dyked land in watershed, but no dams.

5.40 Canard River NS#21
Status
- aboiteau since the 1700's/1800's , lots of dyked land.
- no dams.

5.41 Habitant River NS#22
Status
- aboiteau since the 1700/1800's, lots of dyked land.
- no dams.

5.42 Pereaux River NS#23
Status
- aboiteau since the 1700's/1800's, lots of dyked land
- no dams

5.43 Annapolis River NS#24

Status

- Granville Ferry causeway, built in 1960, is rock-filled. It is porous to allow some water exchange through the barrier.
- it produced 1740 ha of agricultural land upstream.
- it is used as a roadway, the additional agricultural land is secondary.
- there is a fishway - striped bass, shad, gaspereau, etc. The bass angling fishery is popular and of local economic importance.
- turbines were installed in the early 1980's for the new small tidal power station.
- tributaries entering the Annapolis River and Basin (Nictau, Paradise, Lequille) have small power dams on them.
- sediment report is available from Wilmot.
- CARP (Annapolis Royal) and COGS (Lawrencetown) have many relevant data and information on the River, as does the Acadia Centre for Estuarine Research (Wolfville).

Impacts

- there has been loss of peach growing potential along the river
- there is reduced fish passage (striped bass numbers are down).
- there has been erosion and slumping of agricultural land upstream.
- fish need to go down through the turbines - highly hazardous passage. Fish are still killed by the turbines.
- there has been downstream sedimentation of clam beds in the Basin; this may be an indirect effect, and is not unequivocal.
- there has been substantial erosion of intertidal sediment supporting the walls of Fort Anne, Annapolis Royal.

Remediation

- remedial action on the banks surrounding Fort Anne, to reduce their erosion.
- dykes at Annapolis Royal have been rebuilt.

5.44 Bear River NS#25

Status

- no tidal dams
- small power dams further up river, beyond Bear River.
- some dyking of marshes below Bear River

Impacts

- no information

Remediation

- no information.