Annotated Bibliography of Aquatic Biology and Habitat of the Petitcodiac River System, New Brunswick. Part 2.

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2001

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2561

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Fisheries and Aquatic Sciences No. 2561

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ANNOTATED BIBLIOGRAPHY OF AQUATIC BIOLOGY AND HABITAT OF THE PETITCODIAC RIVER SYSTEM, NEW BRUNSWICK

PART 2

by

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Cat. no. Fs -97-4/2561E ISSN 0706-6473

Correct citation for this publication:

Locke, A. 2001. Annotated bibliography of aquatic biology and habitat of the Petitcodiac River system, New Brunswick, Part 2. Can. Manuscr. Rep. Fish. Aquat. Sci. no. 2561: iii+62pp.

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Abstract

In March, 2000, a bibliography summarized the results of 251 published and unpublished reports on the aquatic biology and habitat of the Petitcodiac River system, New Brunswick (Locke and Bernier 2000). The current document adds 32 reports published since March 2000 and 8 older manuscripts that were obtained after publication of the original bibliography. The geographic limits of the area considered are the freshwater Petitcodiac River and its tributaries, and the estuarine/marine system down to the mouth of Shepody Bay.

Résumé

Les résultats de 251 rapports publiés ou non-publiés, au sujet de la biologie aquatique et de l'habitat de la rivière Petitcodiac, ont été résumés en mars 2000. Le présent rapport ajoute 32 rapports nouveaux (publiés après mars 2000) et 8 rapports plus agés. Les limites géographiques de la région sont définies comme étant les eaux douces de la rivière Petitcodiac et ses tributaires, et le système marin-estuarien jusqu'à l'embouchure de la Baie de Shepody.

Introduction

This document is intended as a supplement to the bibliography of scientific literature on the aquatic biology and habitat of the Petitcodiac River system, which was published in March 2000 (Locke and Bernier 2000). In the past year, monitoring activities of 1999, ongoing research in 2000, and several other important documents including the report of the Special Advisor to the Minister of Fisheries of Oceans have been published. These new reports, and some older manuscripts that were obtained after March 2000, are listed and summarized here. As in the first bibliography, the reports are listed in alphabetical order and each title is followed by a summary of the report. These summaries were written by Locke, but unless specifically identified as [Editor's Note], the material in these summaries reflects the statements of the author(s) of the original document.

Reference

Locke, A. and R. Bernier. 2000. Annotated bibliography of aquatic biology and habitat of the Petitcodiac River system, New Brunswick. Can. Manuscr. Rep. Fish. Aquat. Sci. no. 2518: iii+162pp.

ADI Ltd. 2001. Review of cost-benefit analysis and status quo issues related to the Petitcodiac River dam and causeway. Unpublished report. Prepared for Fisheries and Oceans Canada. ADI Ltd, Moncton NB. File (80) 2125-013.1. January 2001. 20 p. + appendix.

ADI Ltd. with NATECH Environmental Services Inc. were retained to: (1) Re-examine estimated costs which were identified in ADI and Washburn and Gillis (1992) and ADI (1996), (2) Identify, review and assess issues and concerns of maintaining the Status Quo or current operation of the causeway structure.

Stakeholders were interviewed in order to identify issues and concerns associated with maintaining the Status Quo option. Issues were incorporated into the cost-benefit analysis as feasible.

It was noted that information from the 1992 and 1996 ADI reports was being taken out of context and improperly interpreted or communicated by some stakeholders.

The Status Quo issues reviewed here were:

(1) Significant erosion and stream meandering is occurring now – more than was expected. Opening gates would not cause more erosion – it may even cause less erosion.
  - Implications: If more erosion is occurring than anticipated in previous ADI studies, then there may be additional erosion protection costs that were not included in earlier cost-benefit analysis. If opening the gates would not increase erosion relative to the Status Quo, then erosion protection costs should be reconsidered.
  - Consultant's Assessment:
    - The channel is expected to meander regardless of what option is chosen. Erosion protection will be required under all options. There is debate as to how much erosion protection. It is not certain whether the river has reached an equilibrium width or if width will continue to decrease.
    - Under the Status Quo, the mechanisms causing erosion are extreme weather events, ice jamming, wave action in the headpond and natural river meandering. Erosion may be increased if build-up of sediment in front of the gates delays opening of the gates in response to extreme weather events. In September 1999, silt build-up delayed the opening of gates for hours and caused the headpond to back up to an elevation of 8.0 m. The subsequent flow through the gates to lower the headpond to normal levels would likely cause erosion downstream of the causeway.
    - Under Open Gates and Bridge Options, erosion would likely be controlled by tidal action and could be further compounded by extreme weather and ice jamming. These events would have less of an effect than under the Status Quo.
    - Since 1996, a number of areas have already been protected from erosion for various reasons, and a number of areas currently show signs of erosion. Erosion protection work on the Riverview side of the river was partly related to Status Quo and partly to the planned gate opening experiment. Most of the park near the Riverview Fire Station was created by placing fill along the

river bank, and the fill was not protected against erosion. By 1996, 6-8 ft of the park land had been eroded, based on exposed storm sewer pipes.
    - ADI's opinion is that erosion at the closed Moncton landfill next to the causeway could occur only if the entire causeway was replaced by a bridge. "There will be no erosion along the face of this landfill under any of the other options". There is expected to be erosion at the old dumps downstream of the Gunningsville Bridge under all options including the Status Quo.

(2) Tidal water sedimentation in culverts and storm sewers is reducing their capacity and causing increased flood damage.
- Implications: Sediments in or downstream of culverts and storm sewers would tend to reduce capacity and may result in increased flood potential. If opening the gates assisted in flushing out the culverts, this would result in a benefit by reducing the risk of flood damage.
- Consultant's Assessment:
    - Siltation of culverts and storm sewers has always been a consideration near the Petitcodiac River. The causeway has increased the sediment deposition, which has raised the bottom and reduced the width of the river. Although the distance between the channel and the structure has been increased, the slope has been reduced. Thus, a number of storm sewers, culverts and sanitary sewer outfalls have been affected by silt buildup and their capacity has been reduced. These should be assessed to determine what effect reduced capacity will have with respect to flooding during extreme flooding.
    - The Status Quo is the option most likely to cause the most serious problems, but any option which does not widen and deepen the river channel significantly is of concern.
    - This is a Status Quo issue and a maintenance issue. The consultant stated it was beyond the scope of this study to estimate costs.

(3) Tides and storm surges are larger and more frequent than before.
- Implications: These could cause more erosion, resulting in a possible requirement for more erosion protection.
- Consultant's Assessment:
    - Daily tides are expected to stay at the same magnitude and frequency. Severe weather events may be more frequent. Sea level rise combined with an increase in storm intensity would have dramatic impacts on coastlines and may result in more storm surges.
    - The highest flood levels in Moncton's history were during the Nov. 4-5 1759 storm and the Saxby Gale of Oct. 4-5 1869. Neither of these storm surges developed from worst case tides. Water levels during the Saxby Gale would have been 0.6 m higher if the Gale had occurred 3 days later. During the Saxby Gale, tides in the Bay of Fundy were recorded to be 1.2 m higher than at any other time. High water levels in Moncton reached 10 m (the existing causeway elevation). It is possible that similar extreme wind storms coinciding with extreme tides could occur causing higher water levels. "The potential for severe floods is ever present, even if extreme events appear to be many years apart". With the expected rising of the sea level by 0.49 m

and subsidence of the shore line by 0.31 m by the year 2100, a Saxby type storm 100 years from now could result in 11 m flood levels.
    - It could be argued that under existing conditions a potential storm surge would be dampened due to higher flood plain resistance, compared to pre-causeway conditions. On the other hand, the removal of the causeway would likely reduce the flooding potential in areas downstream of the causeway. In addition, less silt buildup in the channel would assist in passing the freshwater runoff associated with the storm. It is also noted that the increase in storm surges, combined with the effects of sea level rise and problems with the operation of the gates at the causeway, increases the risk that someday the causeway structure could be overtopped by the river.
    - The consultant was not able to allocate costs related to potential impact of storm surges and climate change.

(4) The sea level is rising, and the land subsiding, over time.
- Implications: More silt deposition will occur because the river bottom is lower relative to mean sea level. There may also be problems with freshwater drainage from the headpond and local drainage structures. Flood surges would more easily affect land that has subsided.
- Consultant's Assessment:
    - This point is valid and should be reviewed seriously by City Engineers. Culverts near the Petitcodiac may have to be replaced with larger structures and the causeway gate structure and operating procedures may have to be adjusted to deal with the presence of more sediments.
    - The cumulative effect of crustal subsidence and climate change induced sea level rise could result in a sea level rise of 0.8 m over the next 100 years.
    - By opening the gates or constructing a bridge, the risk of problems associated with sea level rise and land subsidence will be reduced because of increased tidal flow in the river.
    - The consultant was not able to allocate costs to this issue.

(5) The capacity of the Petitcodiac River downstream from the causeway has been severely diminished due to sedimentation. This increases the risk of flooding.
- Implications: Sedimentation due to the causeway has reduced the depth and width of the river, thereby reducing its capacity to discharge stormwater resulting from weather events. Large buildups of sediment immediately upstream and downstream of the causeway could increase the risk of flooding.
- Consultant's Assessment:
    - The causeway has caused the river width to diminish and the bottom to rise. It can be expected that this has also occurred in tributaries such as Jonathan Creek and Hall's Creek. Recent reports by fishermen near Beaumont indicate this elevated channel extends a number of km below the causeway. Survey data show development of mounds of sediment immediately upstream and downstream of the causeway.
    - Normal spring high tide water levels are ~7.9 m. In September 1999, it is understood that the channel was silted in to an elevation of 4.8 m immediately below the causeway. However, the 8 m elevation mark was not exceeded downstream of the causeway during the flood. The consultant's

interpretation of this event is that 5 m of sediment was flushed out of the channel as a result of freshwater discharge during the flood. It is not known how long this took. To the consultant's knowledge, there was no documented tidal flood damage from the September 1999 runoff either upstream or downstream of the causeway. However, there was significant flooding and damage above culverts in the Moncton area, both inside and outside the tidal influence of the Petitcodiac.

- The mounds of sediment above and below the causeway, some of which are reported to be 4.8 m in elevation (0.3 m above the ceiling of the control gates), may reduce the capacity of the river to drain the headpond in the event of severe weather. This reduction in discharge capacity would continue until the mound of sediment was eroded.
- The mound of sediment can delay the lowering of the water surface elevation downstream and therefore could increase the flood risk in low-lying areas of Greater Moncton. This is a Status Quo issue. The consultant stated that the determination of flood risk is beyond the scope of this report.
- The Open Gates or Bridge options would reduce sediment deposition downstream, and over time a portion of the pre-causeway channel would return which would increase the hydraulic capacity of the river system.

(6) Either incoming tidal water has less sediment in it now than before, or the tidal water has a larger fluctuation in sediment concentration than assumed previously. (Perhaps an order of magnitude difference, 2.5 g/L vs. 25 g/L).

- Implication: Less sediment in the water means less sediment would be deposited above the causeway under the Gate Open or Bridge options, or sediment buildup would take longer.
- Consultant's Assessment:
  - The suspended solids data obtained during the gate-opening trial indicate concentrations less than half the amount stated in Bray (1982). Different analytical methods were used, as well as different sampling sites.
  - The results of a gate opening option would definitely include infilling over a period of time of parts of the headpond.
  - With gates open, the amount of sediment in the water might increase since more water flow may result in more erosion.
  - The consultant states that more study is required.

(7) Sediment deposition at the gates in the causeway control structure is getting worse. 0.1 m of sediment is being deposited with each tide. The gates can no longer function properly because the sediment impairs their operation.

- Implication: If the gates are stuck, they cannot be opened fast enough when the need arises. Upgrading of the gates may be required to ensure removal of sediment and proper gate operation. These costs would be added to Status Quo.
- Consultant's Assessment:
  - The problem of sediment deposits impairing gate operations has been known for some time but it is not clear if it is getting worse. It is certain that sediment buildup at the gates will increase over time. Upgrading of the gates will likely be required under Status Quo.

    - Capital and operating costs of technical solutions to the "sticking" gates, or the present management which involves opening gates in sequence "before it became impossible to open", should be added to the Status Quo option.

(8) Water quality in the estuary, especially near the sewage treatment plant, is affected by the Status Quo operation of the gates. The water quality would be improved if the gates were opened. Tidal flushing would be increased and freshwater flows would be released during the summer, rather than being stored in the headpond.
  - Implication: There are possibly implications on fisheries and recreational uses of the resource, and possibility of negative impacts upstream.
  - Consultant's Assessment:
    - Extensive water quality modelling has not been carried out either upstream or downstream of the causeway. Monetary values have not been placed on good water quality. The consultant could not evaluate this issue.

(9) The gates were intended to maintain the headpond at an elevation of 4.5 m and are now being operated at a level of 6 m.
  - Implication: A reduced headpond storage capacity increases the risk of upstream flooding.
  - Consultant's Assessment:
    - The design operating levels were 5.2 m normal, 6.7 m maximum, and 2.1 m low level.
    - There has been difficulty in maintaining a stable reservoir level, especially in summer.
    - If the headpond was maintained at 4.5 m, this would reduce the risk of upstream flooding but decrease the ability to use the headpond for recreational activity and affect the aesthetic issue as presented by property owners.
    - There is no strong evidence that a headpond level of 6 m is a concern for flooding upstream.

(10) Downstream sedimentation patterns are changing as a result of current operation of the gates.
  - Implication: This may negatively affect birds, fishing, and navigation in the area.
  - Consultant's Assessment:
    - Insufficient information available to adequately comment.
    - There is the threat that sediment deposition (issue #5) could affect areas further downstream – Beaumont residents report increasing "choking" of the river. An elevated channel downstream could affect navigation, fishing and birds. Traditional fishing grounds near Beaumont are already affected. Other fishing activity could be affected if sediment continues to be deposited further downstream.
    - Some species have thrived on sediment buildup, notably those along the banks downstream or on the lake bottom of the headpond.

(11) Leachate is coming from the old landfill, and changes in the river may affect this.

- Implication: Some gate operating scenarios could result in meandering of the river closer to the landfill, thus shortening the path that leachate would have to travel to reach the river.
- Consultant's Assessment:
  - Any leachate coming from the landfill is a Status Quo concern and should be dealt with outside the discussion about the future of the causeway.
  - It is unlikely any of the gate opening options would affect the landfill. With a bridge, some erosion control would be necessary for the landfill. Although dilution is not the solution, gate opening options increase the tidal prism. [Editor's Note: therefore diluting and presumably reducing any effects of leachate.]

(12) A number of tourism developments have occurred since the 1992 and 1996 ADI reports.

- Implication: These could affect the cost-benefit analysis.
- Consultant's Assessment:
  - Consultant was unable to adequately comment on this issue.
  - Recreational opportunities have been pursued, with limited facilities constructed, since the headpond was created. The Status Quo is that there is some recreational activity. To increase this would require additional facilities and therefore costs.
  - The benefits of increased development, if any, should be discounted in a fashion similar to the discounting done for fisheries and tourism benefits associated with Bridge or Gate Opening options.

Previous cost-benefit analyses were reviewed. Some additional items were added or deleted:

- Erosion protection: Some areas identified as needing erosion protection in 1992 and 1996 have since been protected. Erosion near the old dump site near Assumption Boulevard needs to be included regardless of option.
- Gate operations: NBDOT expenditures for the gates in the past 5 years have not included any major gate repairs or complete re-painting. In former ADI reports, operating amounts were underestimated.
- Aesthetics: Properties along the headpond which are valued above $100,000 were estimated to lose value at a rate of 5% if the headpond was eliminated. Residential homes downstream of the causeway may benefit from the widening of the river and return of the tidal bore; this would include homes along the proposed Riverside Drive.
- Tourism: The method of calculation was revised.
- Monitoring: Considerable work would be required before implementation of any change.

A "bottom line" for the various options was presented. [Editor's Note: It should be noted that this cost analysis is subject to various caveats noted by the consultant, only some of which are noted in the above summary.]

Option	Description	Cost
Status Quo		$1,457,000
Five gates open		$5,676,000
Scenario 1B	1 gate normally open, close to clip tide, 1 gate opened to drain headpond	$3,042,000
Scenario 1C	1 gate partly open to stifle tide, 1 gate opened to drain headpond	$3,042,000
Scenario 2B	2 gates normally open, close to clip tide, 2 gates opened to drain headpond	$4,188,000
Scenario 2C	1 gate partially open to stifle tide, 1 gate opened to drain headpond	$3,968,000
Scenario 3B	3 gates normally open, close to clip tide, 3 gates opened to drain headpond	$5,380,000
Scenario 3C	2 gates fully open to stifle tide, 1 gate opened to drain headpond	$5,160,000

Aubé, C.I. and A. Locke. 2000. Ichthyoplankton and invertebrate plankton communities, and water physico-chemistry of the Petitcodiac reservoir during the ice-free season, 1999. Pages 163-202 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

As in 1997 and 1998, plankton sampling was conducted biweekly from May to July (until no larval fish were collected) then monthly until October or November. Four stations were routinely sampled, from just below Boundary Creek to just above the causeway. Depth, water transparency, temperature, salinity, chlorophyll concentration and nutrient concentrations were recorded, and phytoplankton, invertebrate zooplankton and ichthyoplankton were sampled. The phytoplankton samples have been archived.

Salinities were mostly freshwater, the highest salinity being 1 ppt (PSU). Maximum temperature was 25 C (recorded in late June). Secchi depth ranged from 0.2 m to 2.5 m. Secchi depths were usually greatest at the station located furthest upstream.

A mixture of planktonic, benthic and terrestrial organisms was collected. Planktonic taxa typical of both freshwater lakes and estuarine/brackish waters were found. The major groups of invertebrate plankters included rotifers, cladocerans and copepods.

The ichthyoplankton found in the headpond were the diadromous rainbow smelt and gaspereau, and a representative of the genus *Morone*, believed to be white perch. Larval abundance peaked in June, after the mud-flushing, and was reduced to practically zero by July-August. Rainbow smelt were more commonly found in May, and gaspereau in June. The proportion of yolk-sac stage smelt larvae was high in May and declined to zero by mid-June. The proportion of yolk-sac stage gaspereau larvae was high at the end of May, and declined to zero by the end of June.

Six species of freshwater cladocerans were present. *Daphnia catawba* was the most common. Abundance of cladocerans peaked in mid-May and then declined.

Most of the copepods were immature (copepodites). About 60% of the adult copepods were the brackish calanoid *Eurytemora affinis*, 30% were the freshwater cyclopoid *Mesocyclops edax*, 8% were the freshwater cyclopoid *Acanthocyclops vernalis*, and 2% were harpacticoids.

Rotifers were the most abundant group of invertebrate zooplankton, with 22 genera identified. The most abundant genera were *Asplanchna, Brachionus, Euchlanis, Filinia*, *Hexarthra*, *Keratella*, *Ploesoma*, *Polyarthra* and *Synchaeta*. Abundance peaked at the end of June.

Other zooplankters included Ostracoda, Decapoda (*Cancer* sp. zoea), Mysidacea (*Neomysis americana*), Diptera, Hemiptera, Acari, *Argulus stizostethi* and the stickleback *Apeltes quadracus*. The brackish-water organisms found in the Petitcodiac reservoir, other than the calanoids, were the mysids and decapod zoea.

Aubé, C.I. and A. Locke. 2000. Chlorophyll *a* and nutrient concentrations in the Petitcodiac impoundment during the ice-free seasons of 1998 and 1999. Pages 231-255 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Chlorophyll *a* concentrations (median 2.1-2.3 μg/L, range 0.2-7.4 μg/L) were consistent with mainly oligotrophic and occasionally mesotrophic conditions at 4 sampling stations within the headpond (May-October). The data were collected as part of the plankton survey. Nutrient data were collected for phosphorus (median 5-7 μg/L, range 1-41 μg/L), nitrite (median 1-2 μg/L, range 1-12 μg/L), nitrate (median 4-11 μg/L, range 1-74 μg/L) and silicate (median 949-1461 μg/L, range 467-1918 μg/L). Both chlorophyll and nutrient concentrations were generally higher in near-bottom water and were sometimes highest at the sampling station nearest the causeway gates. Ammonia levels were occasionally very high at upstream sites, which were near agricultural areas. Conversion of our dissolved phosphate data to an estimate of total phosphorus suggested oligo- to mesotrophic conditions in the water column, in agreement with the chlorophyll *a* data. However, observations of extensive growth of algae upstream of the impoundment and of vascular plants in the impoundment suggested substantial nutrient inputs from agricultural sources. Large mats of attached green algae were widespread in shallow waters of the main Petitcodiac and North rivers from above the Wheaton Settlement/Scott Road area of the North River down to the head of the impoundment at the railroad bridge below Salisbury. Few or no algal mats were observed in the Pollett and Little rivers. In the headpond, plant growth was mainly in the form of vascular plants. In 1999, vascular plants dominated by *Polygonum lapathifolium* covered large portions of the bottom, forming an impenetrable mat in the littoral zone. Macrophytes may sequester many of the nutrients entering the system from upstream and act as a major nutrient sink. Plants can have a positive effect on the ecosystem by producing oxygen, but too much growth can have negative impacts (e.g., depletion of oxygen, prevention of access to fish spawning habitat, suffocation of fish eggs). It was also noted that the high turbidity of the headpond limits light penetration into the water and could probably prevent the occurrence of algal blooms even if large quantities of nutrients were to enter the headpond.

Beamish, F.W.H. 1980. Biology of the North American anadromous sea lamprey, *Petromyzon marinus*. Can. J. Fish. Aquat. Sci. 37: 1924-1943.

The Petitcodiac River was identified as a spawning site for anadromous sea lampreys. Samples from July 1973 to July 1974 allowed identification of larval lampreys, or ammocoetes, aged 0 to 6 years. A much smaller cohort represented the 2-year-old age class in late July of 1973. Metamorphosis of some individuals was probably delayed until age 7.

The sex of ammocoetes varying in length from 115-159 mm was determined from samples collected from 1973 to 1978. Overall, females were more abundant than males.

[Editor's Note: This paper repeats most of the same Petitcodiac data originally published in Beamish and Potter (1975).]

Beamish, F.W.H. and I.C. Potter. 1975. The biology of the anadromous sea lamprey (*Petromyzon marinus*) in New Brunswick. J. Zool., Lond. 177: 57-72.

The pattern of growth of the ammocoetes collected from the Petitcodiac system (Little River) was similar to those from sites on the Nashwaaksis River. The year classes corresponding to the 1971 spawning season were almost absent in the Petitcodiac, compared to the Miramichi and Nashwaaksis rivers. This suggests that in the Petitcodiac there was either a small breeding population in 1971 or a high mortality of this year class.

The absence of metamorphosed ammocoetes in a sample from November 11 1973 suggests that metamorphosed ammocoetes had commenced migration downstream or into other areas by November. The latest date for which a collection of a metamorphosing ammocoete was noted was in September.

Blaney, F., B. Burrell, D. Haché and J.-G. Deveau. 2000. A review of the 1998 and 1999 Petitcodiac River Causeway Gate experiments. A report submitted to the Federal-Provincial Gate Experiment Steering Committee. Report from the Engineering and Design Working Group.

<No abstract>

Coon, D. (facilitator), M. Breau (recorder) and 20 other participants. 2000. Report from the "On the Ground Action" Working Group. Pages 103-105 *In* J. Percy and J. Harvey (eds.) Tidal barriers in the Inner Bay of Fundy: Ecosystem impacts and restoration opportunities. Proceedings of a workshop, April 14-15 1999, Moncton, NB. Conservation Council of New Brunswick Marine Conservation Program. May 2000.

This document reports the results of a discussion of several questions related to tidal barriers:

"What criteria should be used to select sites to restore tidal flow or rehabilitate habitat?"
- blocked fish passage
- degree of ecological or physical damage
- degraded ecological productivity
- reduced nutrient exchange
- populations or species threatened
- original purpose no longer exists, and none has replaced it
- clear environmental and social benefits
- reduces the overall impact of tidal barriers on the Bay of Fundy
- community support exists throughout the watershed
- cost is not prohibitive when full costs considered.

"Are there tidal barriers that offer opportunities for restoration at this time?"
- Petitcodiac River causeway
- Memramcook River causeway
- Aulac River causeway

Daborn, G.R. 2000. Science panel (remarks by chair). Pages 25-40 *In* J. Percy and J. Harvey (eds.) Tidal barriers in the Inner Bay of Fundy: Ecosystem impacts and restoration opportunities. Proceedings of a workshop, April 14-15 1999, Moncton, NB. Conservation Council of New Brunswick Marine Conservation Program. May 2000.

This discussion ranged over a variety of topics and tidal barriers other than the Petitcodiac. It was noted that the information that we have on tidal barriers is mostly limited to larger barriers such as the Petitcodiac and Annapolis River causeways. Much of the ecosystem change that we are now seeing in the Bay of Fundy may be attributable also to the many small barriers that are only 100-200 m or less in length. The extensive accumulation of mud downstream of the Petitcodiac causeway is analogous to what is seen at Windsor, NS, where the mudflat is 9-10 km in length. There is also extensive sedimentation above the causeway. The Petitcodiac situation may eventually become the one that we know the best because of all the recent studies. We do not use, but should use, a watershed context for all of our evaluation of dams. We cannot simply look only at the Petitcodiac dam and its immediate surroundings; it is part of a much larger active watershed that has to be taken into consideration for any decision.

Daborn, G. (facilitator), M. Westhead (recorder) and unidentified working group members. 2000. Research agenda and potential partnerships working group. Pages 111-115 *In* J. Percy and J. Harvey (eds.) Tidal barriers in the Inner Bay of Fundy: Ecosystem impacts and restoration opportunities. Proceedings of a workshop, April 14-15 1999, Moncton, NB. Conservation Council of New Brunswick Marine Conservation Program. May 2000.

This report records the outcome of discussions held at the tidal barriers meeting:

General types of information that need to be collected are:
- specific hydrodynamic information (river flows, circulation patterns in estuaries)
- species/community information/inventory (quantitative distribution of species)
- data on broader watershed and ecological community perspectives
- climate and ecosystem change (effects of global warming and climate change, possibility of more intense and frequent storm activity, sea level rise, water runoff, circulation patterns, biological community structure and other consequences for coastal and estuarine areas)
- linking large-scale/far-field effects with small-scale/near-field effects
- system-wide assessment of losses (i.e., cumulative effects assessment)
- study natural examples of reversion.

Research needs specific to the Petitcodiac causeway issue:
- hydrodynamic data (over a few months)
- sedimentology, particularly sediment dynamics data
- information about effects of extreme climate events
- a review of the available historical information about the system
- natural resources surveys on similar unmodified systems
- hazard surveys (old dump sites, etc.)
- past and current resource use assessments
- chemistry (water quality, physical parameters, temperature, nutrients)
- all the various remediation options that are available.

Deveau, J.-G., F. Blaney and H. Dupuis. 2000. Petitcodiac River gate opening trial. Pages 53-71 *In* J. Percy and J. Harvey (eds.) Tidal barriers in the Inner Bay of Fundy: Ecosystem impacts and restoration opportunities. Proceedings of a workshop, April 14-15 1999, Moncton, NB. Conservation Council of New Brunswick Marine Conservation Program. May 2000.

Some background to the trial gate opening experiment was presented. In 1960, the City of Moncton asked for a feasibility study for a causeway. In 1963, it was decided to build the causeway. In 1966, the Maritime Marshland Reclamation Agency provided some federal funding. In 1968, the causeway was opened to traffic. It was stated that everyone in the watershed to whom Deveau had spoken says that this decision to build the causeway was wrong; the controversy is how to remedy the effects of that decision.

In terms of remediation and restoration, the main issues are anadromous fish passage, restoration of an estuarine mixing zone and the recognition that the headpond is an artificial system. There is also the question of the cumulative effects of the barrage on the whole Bay of Fundy. In opposition to these goals is the question of the aesthetic, recreational, and residential property values associated with the freshwater ecosystem that has been developed upstream of the causeway.

A Memorandum of Understanding was signed by government agencies in 1996. The first goal of the MOU was the implementation, monitoring and evaluation of a trial gate exercise, involving the manipulation of the gates on the Petitcodiac River causeway. The second goal was the identification and implementation of longer-term solutions to the fish passage and ecosystems health issues. The preamble to the MOU stated that the causeway has a direct impact on fisheries resources and the environment, and it also touched on the mandates of the four government departments: Environment Canada, Fisheries and Oceans Canada, N.B. Dept. of Transportation, N.B. Dept. of Environment. The scope of the work was to provide information to serve as a basis for deciding what actions should be taken in the long term.

The trial gate opening and tidal clipping was to manipulate post-freshet and pre-trial flushing so as to maintain a 2.5-m maximum headpond water level, as river discharge permits; and then, a limited opening to ensure a minimum deposition in the headpond, as the trial was restricted to the channel. An initial condition in proceeding with the experiment was that if it was decided that the experiment was not successful, then we would return to pre-trial conditions. The criteria for success were: no unacceptable erosion, no unanticipated movement of silt deposits, and that the gates can be operated so as to maintain water levels at or below 2.5 m for an acceptable period of time.

In 1997, rip-rap was placed on the river bank upstream and downstream of the causeway to shore up the critical exposed areas. Baseline monitoring was also carried out in 1997.

In 1998, a monitoring plan was developed. Open house information sessions were conducted. A court action by the Lake Petitcodiac Preservation Association delayed the project. Following the court proceedings, an environmental impact assessment screening was done in the spring of 1997. After that, an attempt was made to initiate the trial, but this was abandoned because the flushing attempt did not dislodge enough silt to conduct the trial as designed.

In 1999, in preparation for the trial, it was decided to formally proceed with environmental screening and assessment. The provincial partners registered the project under the Environmental Impact Assessment legislation and decided to use the federal environmental assessment to make their decision. A draft environmental assessment was released for public review in February. More open-house information sessions were held. On March 31, the final environmental assessment was released, with the decision that the project could proceed without any significant environmental impacts. The Department of Transport conducted their usual spring freshet, mud and ice management. On April 8, pre-trial flushing began and this was in progress at the time of this meeting.

The gate operation plan that was developed in 1998 and amended in 1999 was described. The plan was based on the 1996 ADI report and the MOU. The target elevation of 2.5 m in the headpond would be maintained as closely as possible. Fish passage opportunities would be maximized within this parameter, and the reversibility of the trial would be respected. The gate operation plan contained very strict protocols and time lines for suspension of the trial in the event of: an immediate risk to public safety, an emergency situation due to extreme weather conditions, fish passage being compromised, erosion threatening public land, buildings or other structures, or sediment deposition downstream which compromises the ability to maintain the 2.5 m water elevation. Monitoring and mitigative measures were in place for all of these.

Diagrams of the control gates show the activities involved in the pre-trial flushing of mud and what would happen during the trial itself, including what would happen with increasing sediment deposition during the season. It was noted that rain evens during the trial would extend the duration of the trial by reducing the accumulation of sediments below the causeway. This build up of downstream sediments was expected to be the factor that would limit the duration of the trial. If sediments exceeded a level where it was impossible to maintain the 2.5 m elevation in the headpond, the trial would have to be suspended. Once the trial was completed, the headpond would be refilled with fresh water and normal operation of the gates would be resumed.

The Engineering working group monitored the causeway and gate structures for possible damage, shorelines for erosion, and established some water elevation sites as well as bathymetry and aerial photography.

Environmental monitoring began in 1997, and reports are published annually. In addition to the monitoring by the Engineering group, other monitoring studies included: sediment transport (turbidity), sediment quality (chemical analysis and bioassays), aerial particulate monitoring, water quality (chemical analysis), water discharge, migratory birds, shorebirds and their food source (amphipods), fish, fish passage, plankton, fish habitat, benthos, freshwater mussels, contaminants in fishes and invertebrates, lobster and scallop fisheries downstream, etc.

It was noted by Percy and Harvey that because of low water levels in 1999, the pre-trial flushing did not dislodge the silt plug that had built up behind the gates over the winter months, or prevent the accumulation of silt on the downstream side of the causeway. In June, the trial gate opening was again abandoned. The MOU steering committee was said to be compiling a report which would recommend how to proceed after the existing MOU expired on December 31 1999.

Flanagan, J.J. 2001. Fish monitoring activities within the Petitcodiac River basin upstream of the Petitcodiac River causeway, 2000. Unpublished report, prepared for Fisheries and Oceans Canada. 13 p. + tables + figures + appendix.

The effects of modifications to the operation of the control gates at the causeway, which were intended to improve fish passage, were evaluated by monitoring fish populations above the causeway. The proposed gate operations for 2000-2001 were:

- For smelt: From mid-April to the end of May at night, one or more gates were to be open from 4 hr before maximum tide to when tide level equalled headpond water level.
- For shad, striped bass, gaspereau: Dates were not specified, but the gate operation was to be modified during daylight hours. During "large" high tides (>6.3 m), one or more gates were to be open from 4 hr before maximum tide and to be closed when the tide level reached the headpond level. During "medium" (5.5-6.3 m) and "low" high tides (<5.5 m), the gates were to remain open until a minimum of 1.5 hr after maximum high tide.
- For downstream salmon smolt migration: From mid-May to late June, at night, gates were to open on the receding high tide, maintaining the headpond water level between 4.5 and 6.1 m.
- During the summer the gates were to be manipulated to maintain the headpond level at 5.5-6.1 m.
- For fall adult salmon migrations: From end of summer to end of the fall migration, gates were to be operated similar to the shad, striped bass and gaspereau migration.
- The vertical slot fishway at the causeway was to remain closed except during the smelt migration when it remained open.

Ichthyoplankton was monitored weekly from May 12 to July 27, 2000 at the 4 sampling stations used in 1998-1999. Gaspereau and rainbow smelt dominated the larval fish community, but 2 white sucker larvae and 1 fourspine stickleback were also caught at station 3 (closest to the causeway). As in previous years, abundance of gaspereau larvae was very low compared to other rivers in the Maritimes. Two small peaks in the abundance over the season suggest that both species of gaspereau were represented. The number of smelt larvae was also very low. The distribution of both smelt and gaspereau larvae suggested that spawning took place above the headpond.

Fyke net surveys were conducted on the rivers above the causeway and in the Petitcodiac headpond. At the former (1999) fence site on the Petitcodiac River above Salisbury, American eel was the most abundant species in the net that sampled fish migrating upstream between May 9 and July 12. Other species caught in lesser numbers included gaspereau (mostly alewives), white sucker, lamprey, brook trout and various shiners. Brown bullhead was the dominant species in the downstream nets, mainly because of the 50 bullheads caught on May 23. Seven Atlantic salmon smolts were caught and released downstream on May 9. White suckers, shiners and lamprey were also present.

Fyke nets in the Pollett River indicated very few fish were migrating either upstream or downstream from May 10 to July 14. White sucker and American eel dominated the upstream-moving fish, and were not abundant. Only 1 adult gaspereau was captured. Brown bullhead, white suckers, shiners and dace were caught moving downstream. Downstream-moving fish were more abundant than upstream-moving, but were still scarce. One salmon smolt was caught moving downstream on May 17. Only 6 gaspereau (all alewives) were caught, and all on May 25.

Fyke netting in the remaining tributaries was carried out using single-leader nets that did not discriminate the direction of movement of the fish. In the Anagance River, shiners, brook trout, American eels, sea lamprey, threespine stickleback, brown bullhead, white sucker and minnows were caught. The two brook trout, measuring 25.0 and 11.5 cm in fork length (FL), were caught on June 6.

In the North River, fyke netting had to be stopped earlier than in other tributaries due to an increase of filamentous green algae which clogged the nets. On May 17, a trout of 15.5 cm FL was caught. A second trout, caught on June 6, was believed to be sea-run because of its large size (22.6 cm FL) and silvery colouration.

Fyke nets in Little River and Turtle Creek yielded the fewest fish. Most fish caught were resident fish while American eel and sea lamprey were the only diadromous fish caught.

The nearshore juvenile fish community of the headpond, from July 20 to September 29, was dominated by gaspereau. Most juvenile gaspereau (>78%) were caught from August 24 to September 14. White perch and smallmouth bass juveniles and many eels were also present. The mesh size of the nets was too large to retain the smallest juveniles.

The fishway trap located at the causeway was monitored from July 25 to October 8 for the presence of juvenile gaspereau. At this time the fishway was closed except for a small leak, so fish were not using it as a means of migrating in or out of the river system, but it served as a means of subsampling fish which would have been flushed from the system when one of the five sluice gates were open. The closed fishway was found to be an effective means of sampling the juvenile populations, and yielded much the same information as the fyke nets.

Electrofishing surveys were conducted in the Pollett and Little rivers on September 7-8. Timed sweeps in “open” sites (no barrier nets) were used to estimate juvenile salmonid abundance. No age 0 parr were found, indicating that few or no salmon spawned in the fall of 1999. Overall, fewer parr were collected in 2000 than in 1999. Very few older parr were found; ages 1, 2, and 4 were represented. The two age 4 parr were at Prosser Brook and were probably part of the cohort descended from the Big Salmon River stock of salmon. Scales were collected from all parr for ageing and a portion of the caudal fin was removed for DNA analysis (as part of a study of the genetic makeup of inner Bay of Fundy salmon).

Brook trout collected in the electrofishing survey were more abundant than in 1999, less abundant than in 1997, and about the same as 1998.

A fish counting fence was operated on the Pollett River (~1 km above the confluence of the Pollett River with the main stem Petitcodiac River) from June 9 to October 29. This site resulted in fewer operating problems for the fence compared to the previous site on the main stem Petitcodiac River, where filamentous green algae was an ongoing problem in the summer. However, the same problem with leaves blocking the flow of water through the fence and causing erosion under the fence occurred on two occasions in fall at the Pollett River site. Although parts of the fence remained until November 7, it was not operational after the final high-water episode on October 29.

Most fish captured in the counting fence, both upstream and downstream, were caught from June 6 to July 6. Most fish caught at this time were sea lamprey. Very few fish were caught in summer or fall. Only 2 gaspereau, both alewife, were caught (June 10 and 11). Three resident brook trout were caught, in total.

No salmon were caught at the counting fence. Based on return rates to the Mactaquac Dam, it was expected that 5-70 grilse should have returned to the Pollett River in 2000, from the smolts stocked in 1999. It is possible that fish arrived in fall after the counting fence was removed, or during high water events when the fence was not fully operational. However, the main run of the Saint John River smolts that were stocked in 1999 should have occurred in June-July based on the known run timing of this stock.

A redd count was planned but could not be carried out because of high water. In any case, only about 10% of the returning grilse were expected to be female, which meant an expected maximum of 7 female salmon making redds.

Vemco minilog thermometers were installed in the headpond 1 km above the causeway, in Turtle Creek 0.5 km downstream of the reservoir, and in the Pollett River 50 m above the counting fence. Temperatures were recorded hourly from July 18 to November 1 or 2. Water temperatures in Turtle Creek were about 5 C cooler than in Pollett River. The discharge from the Turtle Creek reservoir is cold because the intake is located in the hypolimnion of the reservoir.

It was concluded that the modified gate operation procedure had not resulted in effective migrations of diadromous species such as gaspereau and salmon in 2000. The collections of larval and juvenile gaspereau indicated that spawning of gaspereau did occur. Numbers of larval gaspereau were, however, low compared to previous years, even though advection of the larvae through open gates was probably more prevalent in the three previous years.

It was noted that although the gates might appear to have been opened quite extensively, based on the data presented in an appendix, in fact they were often only open 2-6 feet. This would have required fish to sound almost to the bottom of the river in order to pass under the gates, which many fish species will not do.

GEMTEC Ltd. 1999. Environmental assessment, former City of Moncton Westmorland Street landfill. Unpublished report, prepared for the City of Moncton. File 166.04. November 1999. 16 p. + appendices.

The study area was bounded by the Petitcodiac River, Assomption Blvd. (formerly Commercial St.), Lutz St., and City of Moncton lands adjacent to the Fire Station to the east. Near the river, the site is currently used for walking trails. Two small pond areas are present. Parking lots and buildings are present on the site adjacent to Assomption Blvd. These include the Moncton Press Club, Oulton's Business School and the Fire Station along the northern boundary of the study area. Properties within the area are owned by the City of Moncton, Maritime Cooperative Services (CO-OP) and The Moncton Press Club.

The study was conducted because debris consisting of old metal machine parts, concrete, glass, and wooden materials was observed along the eroding shoreline of the Petitcodiac River. It was generally believed that the City of Moncton, or others, once operated a landfill or dump site at this location.

Aerial photos from 1928 to 1996 were examined. The width of the Petitcodiac River "has been reduced dramatically in this location. Photos from 1982 and 1989 illustrate the meandering nature of the Petitcodiac River. In 1989 considerable volumes of silt have been deposited along the north bank of the river along the shoreline of subject property. The most recent aerial photo, taken in 1996, shows that this silt deposit is being gradually eroded, and that the river, in this location, is returning to its original (pre 1970) shoreline".

Interviews with area residents indicated that garbage was landfilled at the end of Robinson and Lutz Streets, as well as in the area west of Westmorland Street. This apparently took place from 1927 to 1948.

With the exception of the garbage exposed by erosion, there were no obvious signs of a former dump site. There were no patches of distressed vegetation that might indicate leachate close to the surface. Surface water in the ponds and marsh area "appears to be of good quality, and does not exhibit discoloration". No odours were detected.

There were no "major signs of leachate" along the river bank but on one occasion "a small quantity of discolored liquid was observed seeping from the embankment". Follow-up visits found no further trace of seepage.

The river banks in the area were described as "relatively steep and unstable". "The change in the main channel position over recent months and years is also quite obvious upon visual inspection. The distinct meander which now threatens the river bank in the area of concern is obviously moving downstream at a relatively fast rate." The original bank location prior to the construction of the causeway was further northwest as compared to the existing 1999 shoreline on the Moncton side. The west bank was approximately at its original location in 1982 but in 1989 had moved 80 m to the east. The present location of the west bank is near the 1963 location, having shifted westward ~50-80 m since 1989. "There is some indication that the rate of shift has been greater in recent months, possibly owing in part to the gate experiments (additional flows)." The return of the bank to its pre-causeway position and therefore to river bank material as opposed to marsh mud, may decrease the rate of erosion.

"In the case of this site, there is no doubt that the environment has been impacted adversely by the presence of garbage". It was, however, noted that most of this garbage was 70-75 years old and therefore the environmental impact would have declined significantly. Much of the organic waste was removed prior to disposal and fed to livestock, thus reducing the potential for leachate and methane. In addition, fill materials of varied description were found mixed with till fills in almost all areas along the water front. It is likely that the area used for disposal is considerably larger than shown in the figures.

"In terms of groundwater and surface water, no human receptors are located down gradient, and despite the presence of debris at the shoreline, in our opinion, this waste does not pose a significant environmental impact on the Petitcodiac River". Options concerning bank stabilization were discussed, but it was suggested that the situation be monitored further before taking any action. "Protecting one section of a meandering river frequently exposes another down stream area to a similar fate."

GEMTEC Ltd. and Neill and Gunter Ltd. 1995. Closure of the Moncton landfill. Unpublished report, prepared for the City of Moncton. File 20-818.01. May 10 1995. 90 p. + appendices.

This report discusses options for the closure of the Moncton landfill, located immediately downstream of the Petitcodiac causeway on the Moncton side of the river. The consultants investigated historical records to determine the types of waste in the site, collected data from surveying and exploratory digging and drilling at the site, and developed a closure plan. The landfill was operated by the City of Moncton from June 1971 until 1992. The site was used by Moncton, Dieppe, and (until about 1980) Riverview. In October, 1988, waste composition was estimated to be 48% domestic, 34% commercial, 17% construction and 1% institutional. Historical records indicate that disposals at the site included: petroleum contaminated soils, waste oil from service stations, liquid animal waste, asbestos pipe insulation, urea-formaldehyde foam insulation, cleaning solution (sodium hydroxide SCA-134), septic waste and sludge, and medical wastes. In the 1970s and 1980s, a variety of non-domestic wastes were taken to the Moncton landfill in the absence of any better alternatives. Much of this waste originated outside the Moncton-Riverview-Dieppe boundaries, but was accepted by the City at the request of the New Brunswick Dept. of the Environment, as being one of the "better sites" in the area and having procedures in place for handling these wastes.

The total landfill area was 35 ha. An older 19-ha section to the east and newer 16-ha section to the west are separated by a drainage channel which permits surface water to drain rather than pool around the north side of the site. The layer of garbage is as thick as 10-12 m. All incoming waste was end-dumped on grade, compacted and covered daily. Usually the waste was covered with imported soil, but several thousands of tonnes of petroleum contaminated soil were used as a substitute for cover material. There was no particular filling pattern. No leachate protection or treatment was provided. The leachate drained to the Petitcodiac River because of site topography. The eastern edge of the site beside Jonathan Creek is locally very steep, sometimes vertical, and has failed in small sections, exposing the garbage. Seepage samples collected between the site and the Gunningsville Bridge by NB-DOE over the years were found to exceed the limits for drinking water in iron, manganese and occasionally copper. Inspections by NB-DOE concluded that the facility was being operated in a satisfactory manner. A study by Cyr *et al.* (1987) similarly concluded that contaminants were being released from the landfill but the levels were considered to be within an acceptable range.

Site characterization by the closure study included digging of 20 test pits around the perimeter of the site for evaluation of the soil type and collection of leachate samples. An electromagnetic induction survey was carried out at the southern extent of the site, to evaluate ground conductivity as an indicator of leachate presence. The saline nature of the tidal muds, however, produced very high ground conductivities which masked any effects due to leachate.

Hydrogen sulphide odours were detected at various sections of the site in June 1994. In the drainage channel between old and new sections, gas was evident bubbling up through surface water in a number of places.

The distribution of water and therefore leachate within the waste is complex, with numerous perched lenses occurring above lower permeability layers in the garbage. One seep was bubbling vigorously in early June 1994 from a point only ~1m below the top of the slope in the older section.

Soil types and distributions under and around the site are described in some detail, as is groundwater.

For this site, ammonia, iron, copper and TOC (total organic carbon) were considered to be reasonable indicators of leachate presence. Bedrock groundwater was considered to be "conceivably impacted" at two or more sites tested on March 16 1994.

The site was evaluated as follows:

- potential for contamination of groundwater: "low"
- potential for contamination of run-off or surface water: "high"
- potential for contamination of [unspecified] aquatic resources: "high"
- potential for contamination of sensitive habitats: "low"
- overall threat to the environment: "moderate"

The reason for the "low" ranking of groundwater contamination potential is the nature of the receiving system: i.e., "downgradient existing or potential water supplies, aquatic resources or sensitive habitats". No downgradient (i.e., downstream) water supplies were present or "likely to be developed" in Moncton due to the saline nature of the potentially affected water. The report states: "The aquatic resources associated with the river are somewhat vulnerable to a water quality degradation due to leachate addition, although...the great degree of dilution which will occur even at times of low flow, will reduce such impacts. The classification with respect to aquatic resources is therefore 'medium'. No sensitive habitats have been identified close to the facility and as such a 'low' contamination potential is assigned for this aspect. On the basis of the above, the site would be classified as one capable of being a 'moderate' threat to the environment – the large quantity of leachate generating waste and the unimpeded route whereby contaminants can reach the Petitcodiac River being countered by the lack of potentially affected groundwater receptors and the limited impact predicted on the aquatic resource." A "site classification form" (Table 4.1) further indicates that the potential for contamination is "high" based on the nature and quantity of the contaminant materials and the run-off pathway, as well as "high" potential contamination of [unspecified] "aquatic resources" as the receptor. The form states: "...no downgradient receptors other than the Petitcodiac River. Classification [i.e., the determination of "moderate" threat to the environment] based on probable minimal impact on river."

Leachate production is estimated at 140,000 m^3/yr. Assuming this occurs over an 8-month period, the average daily flow would be ~580 m^3, but would vary directly with rainfall. The tidal silts and clays below the waste are relatively impermeable. The weight of the waste has depressed the soil beneath it to form a bowl which holds the leachate. Leachate then flows out along the toe of the landfill via seeps and eventually discharges to the Petitcodiac River. Typical leachate concentrations at the landfill are given for 38 chemical parameters. The concentrations would be expected to decline over time as the waste stabilizes.

Under average water flow conditions, assumed to be 27.9 m^3/sec, and if the leachate were fully mixed with the water in the river, the dilution factor of leachate in the Petitcodiac River would be 4200. This would dilute the leachate so as to meet the NBDOE and Canadian Water Quality Guidelines. The worst case scenario would be expected to occur when the river is at low flow, 1.5 m^3/sec. It was believed that dilution would not differ greatly from average conditions because the conditions that lead to low flow also result in lower leachate production.

“There is no doubt that the leachate seeps entering the river will degrade water quality along the near shore, particularly during periods of poor mixing, such as at low tide...There are no identified water based recreational uses in the area immediately downstream, so near shore water quality degradation is not expected to have an unacceptable impact. The concentrations do, however, have the potential of affecting aquatic life along the northern shore.”

Discharge of pollutants into the headpond was considered to be “an undesirable situation”. It was considered that the chances of any leachate entering the headpond were “very remote”. Leachate would only enter during above-average high tides (above 6.1 m).

The possibility of leachate being treated at the Greater Moncton Sewage Treatment Facility was considered. A concrete sanitary collector sewer is located just north of the landfill, and had sufficient available capacity to accommodate the entire leachate flow from the landfill. The anticipated average leachate flow of 580 m^3/day for an uncapped site would be an “insignificant addition” as would be the low concentration of BOD in the leachate. Most of the measured contaminants in the leachate were at levels lower than the allowable levels of the City of Moncton’s by-law that specifies allowable contaminant levels to the sewer. “Given the dilution provided by the sanitary sewage, it is unlikely that problems would be encountered either in the sewer line or the treatment plant.”

Construction of a leachate collection system would be difficult because of soft soil conditions between the landfill and the Petitcodiac River. The most practical way of recovering leachate for off-site treatment would be to install extraction wells directly into the waste deposits.

Greater Moncton Pest Control Commission. 2000. Mosquito control program, 1999 annual report. Pages 283-289 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

The mosquito monitoring and control program ran from April 27 to August 15. Larval densities ranged from 10-190 larvae/250 mL during the first two months of the program. These low densities were associated with below average precipitation during May and June (May 1999=30.2 mL, average for May= 91.2 mL; June 1999=32.0 mL, average for June=92.8 mL). Larval density increased in early to mid-July and remained high for the rest of the summer due to persistent humidity. Larval densities were much higher than normal for July and August in areas where natural water drainage was impeded.

Outhouse Point Marsh in Riverview and the marsh in St. Anselme “are developing into prime mosquito breeding areas”. It was suggested that this situation would continue due to continuing erosion of the surface drainage, and the development of larger permanent bodies of water in the marshes. Both areas were subject to flooding by high tides.

The golf course in Riverview was also a major breeding area, and the breeding area had been increased by construction.

Bird nests and muskrats were monitored. The major bird species was red-winged blackbird, accounting for 79% of the birds identified. The muskrat population in Greater Moncton had been relatively stable for 20 years.

Data were collected on the potential for new marsh areas to develop upstream of the causeway, while the gates were opened in June. It was suggested that the first few years following an opening of the gates might not provide “vast areas” of breeding, but that there was potential for the breeding areas to increase significantly in the following years. The initial surveys identified several areas judged to be “potentially high breeding areas”.

A stream monitoring program was conducted in Jonathan Creek.

Griffin, G. 1994. A watershed plan for restoration, development and management of diadromous fish stocks in the rivers composing the Shepody Bay ecosystem. Discussion paper. February 1994. 29 p. (Included as Appendix A in Sackville Rod and Gun Club, *et al.*, 1995).

Petitcodiac drainage rivers represent 4% of the province’s total drainage area but supported only 1% of the New Brunswick angling effort in 1990. Most angling effort was measured on the Pollett, North and Coverdale rivers, but the Coverdale was the only river to provide a “substantial” trout catch. Since 1970, Petitcodiac rivers have supported less and less angling effort. Angling success since 1980 is ranked the lowest for New Brunswick river drainages or drainage groupings.

The stream survey work on the Coverdale River in 1994 was discussed. Most of the brook trout production area was located above Parkindale. Below Parkindale to the confluence of the Petitcodiac River, the habitat had very limited production area for brook trout but was “ideal spawning and nursery area” for Atlantic salmon. The rearing area measured for the main stem Coverdale River was similar to that estimated by Pettigrew who calculated the river’s potential smolt production to be 21,500 smolts.

It was estimated that the Petitcodiac system was capable of generating 5,000 adult salmon, 5,000 angler days and $400,000 annually if properly managed.

Concern was expressed that Coverdale and other Petitcodiac Atlantic salmon stocks might already be extinct, but it was recommended that efforts be made in 1995 to collect salmon juveniles for deposit in a hatchery where they could be grown to mature adults. It was further recommended that Big Salmon River strain salmon should be stocked.

Hanson, A. 2000. City of Moncton landfill – 1999 monitoring results (Summary of a report prepared for the City of Moncton by GEMTEC Ltd.). Pages 9-24 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Concentrations of ammonia, iron and zinc in water samples collected from seeps exceeded the criteria for aquatic habitats from the CCME guidelines for Freshwater Aquatic Life. These FAL guidelines for ambient waters were used as a "convenient benchmark" but it was noted that they were not directly applicable to "end of pipe" samples. Concentrations of many measured parameters were higher in 1999 than in 1998, but were similar to concentrations in 1996 and 1997. An inverse relationship of concentration with rainfall was observed at the Jonathan Creek seep; concentrations were higher in July than in April and October when more dilution probably occurred.

Concentrations of ammonia and iron at the peat tank exceeded the FAL guidelines. However, peat filtration did reduce measured concentrations of several parameters. Biological oxygen demand of the leachate was reduced from 25 mg/L to <10 mg/L (April). By contrast, iron concentration at the outlet was higher than at the inlet chamber, increasing from 0.76 mg/L to 1.7 mg/L in April and from 0.96 mg/L to 3.78 mg/L in November.

Samples taken at low tide in the Petitcodiac River near the Gunningsville Bridge and near the causeway on July 28 met all FAL guidelines. BOD was below the detection limit and mercury concentration was less than the regulatory guideline. Water samples taken on three occasions in Jonathan Creek near the discharge point of the landfill perimeter drain slightly exceeded the FAL guidelines for iron, zinc and aluminum.

Water samples collected from boreholes on July 28 were similar to those from previous years. Parameters which exceeded the Canadian Drinking Water Guidelines included iron, manganese, colour, turbidity, sodium, chloride, boron and sulphate. Ammonia and organic carbon, considered to be indicators of leachate, were found at concentrations exceeding threshold values at a borehole within the landfill, but were detected at only one borehole outside the landfill boundary. BOD was high only within the landfill.

Methane sampling within monitoring wells and a soil gas survey on transects of the landfill (July 29) confirmed previous results indicating methane "hot spots" on the landfill. Vinyl chloride (the contaminant of most concern in landfill gas) was not detected.

Vinyl chloride was not detected in air samples, which were collected at four locations on the landfill surface on July 29.

PCBs were detected in one of the two samples collected on July 7; the PCBs were present just above detection limits in a seep sample (0.07 µg/L) but not detected in the borehole groundwater sample. According to the CCME – Interim Canadian Environmental Quality Assessment Criteria, sites contaminated with PCBs are considered remediated at PCB concentrations ≤ 0.1 µg/L.

Hanson, A. 2000. Volunteer-based monitoring of birds of the Petitcodiac River and Estuary 1999. Pages 49-52 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

American Black Duck was the most abundant species of waterfowl, especially downstream of the causeway. Mallards were most abundant in the headpond. American Green-winged Teal were abundant at all locations.

Gulls were the most numerous birds seen during the surveys, especially Great Black-backed Gulls and Herring Gulls. Less common were Lesser Black-backed Gull, Icelandic Gull, Glaucous Gull and Black legged Kittiwake.

Semipalmated Sandpipers used the lower reaches of the Petitcodiac River during their fall migration. Greater and Lesser Yellowlegs, and Semipalmated Plover were also sometimes abundant during late summer.

Birds modified their use of the Petitcodiac River during 1999 in response to changes in season, downstream water flows, tides, gate operations and food availability.

Hanson, A. 2000. Waterbird surveys of Petitcodiac headpond 1999. Pages 53-61 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Changes in the water level of the headpond during 1999 dramatically influenced bird use of the headpond. When water levels were reduced starting April 8, large areas became available for foraging dabbling ducks and gulls. Terrestrial species such as American Crow were also observed feeding on the mud flats. Large numbers of migrating Green-winged Teal were observed feeding on benthic invertebrates in mid- and late April. The remaining low-water river channel attracted Common Mergansers.

Headpond water levels were lowered before even early nesting species would have initiated egg laying. This may have prevented Mallards from nesting adjacent to the headpond. There were fewer broods using the headpond than in other years. The earliest date that Mallard broods were observed was May 26. Canada Goose goslings were first observed on June 1. No breeding Common Loons were observed; they are less adaptable to changing water levels.

A pair of Bald Eagles nesting adjacent to the headpond had a successful breeding season.

Great Black-backed Gulls, Herring Gulls and Ring-billed Gulls used the headpond as a roosting site. Gulls could be observed moving up the river with the tidal bore, feeding on fish that were migrating upstream with the incoming tide.

The headpond was used by migrating Canada Geese, Mallards, Common Goldeneye and Common Merganser during the fall.

The lower headpond water levels created favourable foraging conditions for dabbling ducks and piscivorous species such as Common Merganser. By late summer and fall, bird use of the headpond was similar to that observed in previous years.

Hanson, A. 2000. Shorebird banding in Shepody Bay during 1999 (Summary of a memo by Peter Hicklin, October 29 2000). Pages 63-73 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

A field study was conducted at Johnson's Mills to examine the intertidal mudflat habitat and body condition of Semipalmated Sandpipers over a three-year period, to detect changes since the 1980s, and to monitor conditions during the years when causeway gates on the Petitcodiac and Memramcook rivers were opened.

In 1999, a total of 1576 Semipalmated Sandpipers, 3 Least Sandpipers and 6 White-rumped Sandpipers were banded from July 26-August 13 and August 24. Of this total, 11 birds had been banded in the Bay of Fundy in previous years (1 bird in 1988, 8 birds in 1997, 2 birds in 1998), 5 birds were recaptured after banding in 1999, and 1 bird had been banded at Delaware Bay, New Jersey, in 1992.

Individual weights of birds varied from 20.5 g to 44.5 g. Body condition increased sharply between July 28 and August 4, and declined thereafter to the end of the banding period on August 13. Birds captured on August 24 had the highest mean condition index. These birds with slightly higher body weights and with much higher body condition index scores were probably western (short-billed) Semipalmated Sandpipers, which would be expected to arrive later at the Bay of Fundy than birds breeding in the eastern Arctic.

Birds banded in 1999 had significantly lower weights than those banded in 1997 and 1998. Condition index was also lower in 1999. The difference in weights may have been caused by differences in capture dates, since weight is strongly influenced by date of capture. Comparing weights during the period of greatest weight (July 27-August 2), birds were slightly heavier in 1999 than in 1997. No comparison with 1998 was possible since dogs were on the beach at that time and no sandpipers were captured. During the period of declining body weight (August 3-14), weights in 1999 were lower than in 1997 and 1998. Weights in 1999 were also lower than those in the 1980s.

Corophium densities on the Grande Anse mudflat at Johnson's Mills were high and the amphipods were more consistently distributed across a transect of the mudflat in 1978 than in any of the years sampled in the 1990s. In 1994, densities of *Corophium* were significantly lower and the amphipod was present at only two samples in the transect. Densities were higher in 1996 and 1997. In 1997, the amphipod was present primarily in the uppermost five stations of the transect. This distribution pattern persisted in 1998 and 1999. Densities were again low in 1999. *Corophium* densities at Daniel's Flats, located across Shepody Bay from Grande Anse, were 29% lower in 1999 than in 1998, and the declines occurred primarily in the lowermost stations.

The lower body weights of sandpipers in 1999, compared to earlier years, may be due to a number of factors. Harrassment by Peregrine Falcons may be an important factor. After a long absence, Peregrine Falcons returned to nesting sites in Chignecto Bay in 1989. During 1994-1998, a pair on Grindstone Island fledged 1-3 young annually, and a pair in Shepody Bay fledged its first young in 1991 and up to three young in each of 1996 and 1998. Since banding of sandpipers was initiated at Johnson's Mills in 1997, Peregrine Falcons have been observed to hunt and harass the sandpipers at all tidal stages. In years with suitable migration conditions (such as 1999), harassment from Peregrine Falcons may induce birds to migrate as soon as they reach the threshold amount of fat reserves. Under this scenario of fat birds leaving as soon as possible, only individuals below the threshold weight would remain on the staging area. In years without a northerly tail wind (such as 1997), shorebirds have been observed to delay migration and banded birds have had high body weights. Food availability has also varied annually. The presence and density of *Corophium* in the lower 900 m of the intertidal transects have declined from 1997 to 1999, whereas densities in the upper 400-500 m have increased. The amphipods in the upper 500 m would not be available to foraging birds by mid- to low tide, as the amphipods would be in their burrows. It is not known whether this annual variation is affected by manipulation of water control structures on upstream tidal rivers.

The weights of Semipalmated Sandpipers trapped in 2000 were similar to those observed during the 1980s.

Hanson, A., J.G. Deveau and M. Belliveau. 2000. Petitcodiac River water levels and flows – spring 1999. Pages 3-7 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

River flows measured near the village of Petitcodiac were multiplied by 3.5 to estimate freshwater flows at the causeway gates in 1999. The maximum flow during the spring freshet in March was 291 m^3/sec. Flows were only 50 m^3/sec when pre-trial mud flushing began on April 8, and gradually declined to 10 m^3/sec by late April. The peak flow during rain events in April was 108 m^3/sec. By June, flow was < 10 m^3/sec.

Water levels in the headpond near the gates were 5.6-6.0 m (elevation above MSL) during the spring freshet; levels fluctuated daily according to water flows and what gates were opened. By May 12, the water level had reached 2.45 m. Water level increased somewhat during the third week of May due to storm events and periodic impoundment. After the pre-trial flushing was terminated on June 2, water level increased to 5.225 m on June 28.

Water level in the headpond above the confluence of Turtle Creek fluctuated by 0.3 m daily in May, but only 0.1-0.2 m in June.

Hanson, A. and H.M. Dupuis. 2000. Environmental monitoring of the Petitcodiac River system, 1999: Foreword. Pages iii-v *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

The Petitcodiac River causeway was completed in 1968 and met all regulatory requirements of the time, including installation of a fishway. It was soon apparent that the fishway was not operating correctly and renovations and adjustment of operations have not prevented the decline of fish stocks. Atlantic salmon and shad were noted to be extirpated or approaching extirpation.

Major events in the years 1996-1999, related to the planned trial gate opening, include:

1996 – A study report, funded by the provincial Environmental Trust Fund, was released in February; options were presented to restore fish passage and partially restore the ecosystem of the Petitcodiac River. A Memorandum of Understanding was signed between federal and provincial government departments in December, with an agreement for a limited trial gate opening.

1997 – Background environmental and physical data were collected.

1998 – The Trial Gate Opening was scheduled for a 6 or 7 month period beginning in spring 1998. It was to commence with pre-trial mud flushing which would begin after normal springtime ice, mud and floodwater management, and was expected to start at the beginning of April. During this phase the water level of the headpond would fluctuate but there would be no tidal salt-water intrusion. Mud-flushing would continue until the river flow was low enough, and river channel sufficiently cut, to maintain the headpond water level below elevation 2.5 m above MSL throughout the full tidal cycle. The gate opening trial would then begin; one or more gates would be fully opened at low tide and subsequently closed to "clip" the rising tide such that the water level in the river channel upstream of the causeway did not exceed a maximum elevation of 2.5 m. The gates would be reopened once the falling tide was lower than the "headpond" elevation, thereby allowing the headpond to drain. Following this protocol, silt-laden salt water would be confined to the historical river channel in the headpond.

The Trial Gate Opening did not proceed as planned in 1998, due to a delay caused by a legal challenge. Pre-trial mud flushing did not commence until May 31, and the late start and prevailing low freshwater flows made it impossible to cut the upstream mud plug and establish conditions for the initiation of the trial. The water level in the headpond decreased from 6.20 m on May 31 to 2.55 m on June 10. The flushing exercise was terminated on June 19, as the water level could not be maintained below 2.7 m. The water level in the headpond was about 6 m by late June.

1999 – Pre-trial flushing was initiated on April 8. Removal of the downstream sediment was completed within a few days of mud flushing. However, cutting the upstream channel was less successful. The spring freshet was earlier than normal and was finished by April 8. Low freshwater flows combined with large spring tides resulted in conditions to initiate the trial not being attained. The decision was made on June 1 to terminate the experiment.

Hanson, J.M. and A. Locke. 2000. The status of the dwarf wedgemussel, *Alasmidonta heterodon,* in Canada. The Canadian Field-Naturalist 114: 271-278.

This publication, which was "in press" in March, 2000, is included here in order to provide the complete literature citation. For the abstract, see Locke and Bernier (2000).

Hanson, J.M. and S.M. Richardson. 2000. Petitcodiac Headpond monitoring activities 1997-1999: macrophytes, macroinvertebrates, and freshwater mussels. Pages 203-229 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

The freshwater ecosystem of the Petitcodiac Headpond consisted of organisms that had colonized since 1988 (the last saltwater incursion) and that have been able to survive frequent water level drawdowns. Since 1988, there had been several major drawdowns. In 1990, 1991 and 1992, attempts to re-establish Atlantic salmon required drawdowns in spring to aid downstream migration of smolts. These three drawdowns would have eradicated much of the littoral zone community through desiccation and exposure. Thus the littoral zone commmunities observed in this study were no more than 4 years old in 1997. Therefore, this clearly was not a stable or mature ecosystem when the current study commenced in 1997. Drawdowns in 1997, 1998 and 1999 resulted in most of the headpond bottom being exposed to air. In terms of this study, 1997 was intended to be a year free of drawdowns, but repairs to the causeway resulted in a 7-day drawdown in June 1997. The 1998 drawdown was supposed to begin in early spring but was delayed until early June, and lasted 19 days. The 1999 program began in May, but ended after 55 days without removing the mud plug because sediment deposits below the gates became excessive. All drawdowns since 1988 have resulted in minimal salt-water incursion.

The benthic community was sampled at 11 sites, which were established to cover the full length of the headpond. Subsets of these sites were sampled for macrophytes, macroinvertebrates and freshwater mussels. Macrophytes were sampled in early August (maximum macrophyte biomass) at 10 locations using quadrats in water depths of 0.3-1.0 m. Benthic invertebrates were sampled in late July-early August at 8 stations (4 depths) using Ekman grab samples washed on a 500 μm sieve. Freshwater mussels were sampled at 6 sites (4 depths) using Ekman grab samples washed on a 6 mm sieve.

Both the duration of the drawdowns and the harshness of the environmental conditions during each drawdown increased over the three years of study (1997-1999). Degree-days (> 5 C) associated with each drawdown increased annually: 28.5 degree-days in 1997, 163.9 degree-days in 1998, 304.1 degree-days in 1999.

There were clear differences in the macrophyte community between years. In 1997, the dominant macrophyte taxon occurring at depths < 1 m was *Najas flexilis*, followed by the pondweed *Potamogeton epihydrus*. Collectively, however, the pondweeds (*Potamogeton* sp.) dominated the biomass. Other abundant taxa included *Sagittaria latifolia*, *Typha latifolia*, *Nitella* sp., and *Juncus effusus*; the remaining biomass was largely mosses, especially *Fissidens* spp. In 1998, the dominant taxon was *Juncus effusus*, followed closely by *Potamogeton epihydrus*. *Najas flexilis*, which had been the dominant taxon in 1997, was reduced to third place in 1998. The remaining biomass was mostly *Fissidens* spp. As in 1997, pondweeds collectively dominated the biomass. *Polygonum lapathifolium* was seen for the first time in 1998, but was present only in trace amounts. By 1999, *Polygonum* sp had become the dominant taxon, followed by *Juncus effusus* and the pondweed *Potamogeton epihydrus*. Collectively, pondweeds were second in dominance. Several species disappeared from the sampling area, notably *Najas flexilis* which had been a dominant species in 1997 and 1998. *Sagittaria latifolia*, *Typha latifolia*, *Nitella* sp., and most mosses also disappeared. *Polygonum lapathifolium* was the only species to increase in biomass.

The biomass of the macrophyte community significantly decreased after 1997 (15.56 g/m^2) to 3.71 g/m^2 in 1998 and 5.76 g/m^2 in 1999. The slight (and non-significant) increase from 1998 to 1999 was the result of colonization of the headpond by *Polygonum*.

The macroinvertebrate community also changed over the three years. The 1997 littoral zone (<2 m depth) biomass was dominated by oligochaetes, followed by gastropods, sphaerid clams and chironomids. The most common gastropods were *Amnicola limosa, Valvata sincera, Gyraulus parvus* and *Heliosoma anceps*; *Fossaria modicella* and *Physa heterostropha* were rare. Insects represented a small proportion of the total biomass and were dominated by chironomids and ephemeropterans (*Hexagenia limbata*). Coleopterans, neuropterans (*Sialis* sp.), trichopterans, hemipterans, and anisopterans (*Macromia* sp., *Progomphus* sp., *Didymops* sp.) were rare. Zygopterans and tabanids were absent. Amphipods (*Gammarus tigrinus*, *G. fasciatus*) and leeches were uncommon. In 1998, gastropods dominated the littoral zone biomass, followed by oligochaetes and sphaerid clams. Chironomids again dominated the insects, and leeches and amphipods represented a low proportion of the total biomass. In 1999, the littoral zone was overwhelmingly dominated by oligochaetes, followed by gastropods and chironomids. Sphaerids were reduced to fifth in the order of dominance. By the end of the 1999 drawdown, leeches, amphipods and many insects (e.g. trichopterans, coleopterans, sialids) were all but eliminated.

There were significant differences in both species composition and total abundance of littoral zone macroinvertebrates between years. Total biomass decreased significantly from 1997 to 1998 but did not decline further in 1999. No species increased in biomass over the three years. Only oligochaetes increased from 1998 to 1999, but the biomass in 1999 only increased to slightly more than half the 1997 biomass.

Sublittoral zone biomass in 1997 was overwhelmingly dominated by oligochaetes. Chironomids and molluscs were also important. In the sublittoral zone, the dominant molluscs were sphaerid clams rather than gastropods. Ephemeropterans (*Hexagenia limbata*), trichopterans, and anisopterans were present in low numbers. Amphipods were virtually absent. Leeches were scarce, but fourth in the order of dominance. In 1998, oligochaetes remained the dominant taxon, followed by molluscs, chironomids and ephemeropterans. The other insects were present in minute quantities. Again, amphipods were virtually nonexistent and leeches were reduced to very low numbers. In 1999, oligochaetes dominated the sublittoral zone biomass, followed by ephemeropterans and chironomids. Molluscs were present in much smaller quantities than in previous years. Most other taxa were eliminated or reduced to trace amounts.

As observed for the littoral zone, sublittoral zone biomass also declined over the three years. Biomass changed from 17.80 g/m^2 in 1997 to 5.34 g/m^2 in 1998 and 2.59 g/m^2 in 1999.

Two species of freshwater mussels, *Pyganodon cataracta* and *Elliptio complanata*, were found in the headpond. *Pyganodon* was overwhelmingly dominant.

Age and length frequencies for *Pyganodon* differed little between years. The oldest mussels found in the headpond were born in 1988. Freshwater mussels smaller than 50 mm may have been eliminated from the system by the 1999 drawdown (although this may have been an artifact of small sample size).

The density of *Pyganodon* in the littoral zone was reduced drastically over the three years, from 14 individuals/m^2 in 1997, to 4.4 individuals/m^2 in 1998 and 0.22 individuals/m^2 in 1999. The sublittoral zone was also severely affected in 1998, as the population was reduced from 6.67 individuals/m^2 in 1997 to 1.97 individuals/m^2 in 1998. In contrast to the littoral zone, the average mussel density in the sublittoral zone in 1999 (1.1 individuals/m^2) was not reduced from 1998.

The headpond contained neither a mature nor a stable benthic community due to the frequent drawdowns since its formation. The littoral zone community present at the beginning of the study in 1997 was a maximum of 4 years old while the sublittoral community was a maximum of 10 years old. The frequent disturbances associated with normal operations of the causeway gates mean that the headpond is disturbed several times annually and the benthic community reflected these frequent disturbances, even in 1997. Under normal operations, most drawdowns are less than 1 m and last a few days. The 1997-1999 drawdowns were about 3 m, exposing most of the benthic habitat including the entire littoral zone to air, thus representing major perturbations to the entire aquatic ecosystem of the headpond.

The submergent macrophyte species that were found in the headpond were those that are typically found in water bodies that experience frequent disturbance. The species composition was quite different from the only published study of New Brunswick lakes. The drawdowns allowed some emergent species, such as *Juncus*, to colonize areas that would normally be dominated by submergent species. The macrophyte that benefited from the drawdowns was *Polygonum lapathifolium*, which quickly established itself as a dominant. This species is notorious for its ability to rapidly invade and dominate new habitat. Purple loosestrife *Lythrum salicaria*, which is a highly invasive species of wetlands, was present in the headpond in all years but did not spread during the study.

The macroinvertebrate community was species poor, especially for insects. The dominance by oligochaetes and molluscs was typical of water bodies stressed by drawdowns and/or low oxygen levels. The presence of the mayfly *Hexagenia limbata* indicates that low oxygen was not a factor. Oligochaetes and chironomids, which can survive drawdowns through burrowing and which rapidly recolonize, typically dominate the macroinvertebrate communities of newly filled reservoirs. These strategies apparently did not work during 1998 because both populations decreased substantially.

The macroinvertebrate community of the headpond was very different from that of natural lakes in New Brunswick, which are dominated by insects.

Thin-shelled freshwater mussels such as *Pyganodon cataracta* may be killed by exposure in 8 hours to 1 week, depending on conditions. Large numbers of dead clams (equal to 24% of the number collected alive in the littoral zone) were collected after the relatively short (7 days) drawdown in 1997. The 1998 and 1999 drawdowns would have been lethal to any clams in the littoral zone. The very low densities of mussels found in the littoral zone in 1999 probably represent animals that migrated back to the littoral zone from the sublittoral refugium once the headpond was refilled.

Howard, C.D.D. and C.E. Sweet. 1968. Notes from field inspection of sedimentation, Chignecto Bay and Minas Basin, November 21-24 1967. Unpublished report, February 5 1968.

The partially completed causeway was visited. Low water lasted for approximately 4 hr at the construction site. Sediment deposition was on the upstream side of the right bank construction and the downstream side of the left bank fill was exposed and drained during low water. The open waterway between the side embankments was 700 ft wide (aerial photos provided). [Editor's Note: It is apparent from these photos that the area presently occupied by the causeway gates was not part of the original river, but was on the river bank.]

Sediments had been laid down in clearly visible lamina varying in thickness from 1/8 to ¼ of an inch. Each lamina probably represented the deposit left after one tidal cycle. The project had been underway for 18 months and the thickness of the deposits was consistent with the above description.

The arrival of the tidal bore was described. It could be heard before it arrived. Air temperature dropped noticeably. Wave patterns suggested extensive bed sediment movements. Approximately 3.5 hr after the arrival of the bore, the waters grew quiet and continued to flow upstream.

It was noted that the causeway under construction had resulted in large deposits of silty sand on both sides of the river. The maximum differential head across the 700 ft wide opening between the rubble mounds on opposite river banks was about 1 ft. It was suggested that temporary sheet piling could be driven to obstruct the flow and precipitate the sedimentation in the same manner as the rubble mounds. It was suggested that this technique would have been effective in accelerating the closure of the river and might provide a suitable foundation for additional fill.

The remainder of the report deals with visits to the Shepody River dam and Cape Enrage. Aerial photos and cross sections of the Shepody River support a statement that "Except for a meandering narrow thalweg [channel], the entire estuary has filled with sediments since construction of the dam."

Jackman, P., K.G. Doe, J.G. Deveau and A. Hanson. 2000. Petitcodiac River and Headpond sediment analysis 1999. Pages 25-47 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Bottom sediments were collected using and Eckman dredge to sample the surface 5 cm at sites between the Gunningsville Bridge and headpond below Turtle Creek. Only two samples were collected from the headpond proper, the rest were from the bridge or causeway. Suspended sediments were settled from water samples collected at the causeway and Gunningsville Bridge. All collections took place between mid-April and mid-June.

The toxicity of freshwater sediments (salinity < 2 ppt) was tested using the amphipod *Hyalella azteca*. Estuarine sediment toxicity was tested using the amphipod *Eohaustorius estuarius*. A Microtox solid phase test was used to further test toxicity of all samples. Grain size, total organic carbon, metals, and organic and inorganic pollutants were analysed.

The freshwater sediments had no effect on amphipod survival and growth. The marine bottom sediments did not reduce amphipod survival, but some of the suspended sediment samples from the Gunningsville Bridge resulted in reduced survival by about 30%. These sediments could be considered "borderline toxic", but sediment particle size was probably a factor influencing survival. The fine particles found in these samples could have coated the gill surfaces of the amphipod, resulting in respiratory problems. It was noted that this would not have occurred in the natural environment. The concentration of fine suspended sediment in the river would have been much lower than the settled test sediment used in the laboratory tests. Although some of these fine sediments settle to the bottom, in the natural environment they are mixed with the coarser bottom sediments, which did not affect the amphipods.

According to the Microtox Solid Phase toxicity assays, none of the sediments were toxic. This test takes into account the particle size of the sediments. In general the samples with more fine sediments (high percentage of clay) caused higher mortality (lower EC50, i.e., the concentration of the substance calculated to result in 50% mortality). However, the highest mortality (lowest EC50) was associated with bottom sediment from the two samples collected in the headpond, and these did not have high proportions of clay.

Total PAHs for all sediment samples were below the National Guideline for the Disposal at Sea Program. Individual PAH concentrations were also acceptable by the appropriate criteria for fresh or marine waters. One sample of Anthracene and Benzo (a) pyrene collected in suspended sediment below the causeway on the incoming tide exceeded one criterion but was well within the limits of another.

Total PCBs were below detection limits in both the headpond and river.

Metals (chromium, cobalt, nickel, copper, zinc, mercury, lead, iron, manganese, cadmium) were below the Interim Sediment Quality Guideline, except for lead in one suspended sediment sample from the causeway on the incoming tide.

Kenchington, E., D. Roddick and M.J. Lundy. 2000. Petitcodiac River causeway monitoring programme: Scallop stock surveys final report. Pages 95-121 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Scallop monitoring sites were established in three areas: Cape Chignecto area (Cape Chignecto, Advocate Bay, Ile Haute), Apple River area (between Apple River and Alma), and Grindstone area (in Chignecto Bay above Apple River). Monitoring took place in all three areas in January-February 1998 and September 1999. Only the first two areas were monitored in January 1999. Shell heights of all scallops (including clappers, or paired empty shells) and meat weights of live scallops were measured. Data from the 1998 survey were lost. Shells were returned to the laboratory for ageing, which at time of writing was incomplete. Scallop digestive glands were sampled from 15-25 scallops in January-February 1998 and frozen for future contaminant analysis. Average numbers of live and dead scallops per standard tow (800 m tow length with 8 gang gear) were determined using lined gear to estimate pre-recruits (< 80 mm shell height) and unlined gear to estimate recruited scallops (> 79 mm shell height). Distribution of scallops was mapped.

There were significantly more scallops per standard tow in the Chignecto area than the others. Maximum numbers per tow were found in Advocate Bay. Meat yield for a standard shell height of 95 mm was greater in the Cape Chignecto area than in the Apple River area, indicating that the Cape Chignecto area is more productive.

There were no significant differences in the results of the three surveys, with respect to numbers of scallops per tow. The Chignecto area was divided into Advocate Bay and Cape Chignecto subareas, and the January 1999 survey of the Cape Chignecto subarea was found to have had more scallops/tow than the 1998 survey.

The 1997 year class was especially prominent in the Advocate Bay subarea as 40 mm scallops in September 1999. The relatively large numbers of recruited scallops evident in January 1999 in the Cape Chignecto and Advocate subareas and to a lesser extent in the Apple River area were fished out by the time of the September 1999 survey.

There was no change in the percentage of clappers caught during the surveys. The percentage of clappers was only about 2% in the Apple River area and averaged 10% (declining over the three surveys) in the Cape Chignecto area.

It was concluded that the trial openings of the causeway had little if any effect on the scallop stocks in the upper reaches of the Bay of Fundy.

Lawton, P. and D.A. Robichaud. 2000. Report on 1999 DFO fisheries monitoring in Lobster Fishing Area 35 relative to the Petitcodiac River causeway. Pages 77-94 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

There has been a "striking and progressive" increase in reported lobster catches from 1980 onwards for STDs (statistical districts) 79 (Alma) and 44 (Advocate Harbour). Lobster catches in LFA (lobster fishing area) 35 (Alma, Wood Point, Apple River, Joggins, Advocate Harbour, Scots Bay, Delhaven, Parrsboro, Five Islands) are at historic highs since landings reports began in 1957. The lobster fishery in the upper Bay of Fundy is clearly a regionally-significant commercial fishing activity.

The latest (1998) stock status report on the Bay of Fundy lobster fishery noted dramatic shifts in the sampled size distribution in the upper Bay lobster fishery. The average size of sampled lobsters had decreased by approximately 10 mm CL (carapace length). This was driven by an increased representation of sub-legal lobsters (75-80 mm CL) and lobsters in the first molt group in the fishery (81-94 mm CL). This suggests improved recruitment conditions in the upper Bay in the 1980s.

Preliminary assessment of the latest fishery sampling data (1999 spring and fall lobster seasons) shows some evidence of a decline in numbers of sublegal lobsters and the first molt group in the fishery. Recruitment could have been reduced, or this change could reflect the early molt that occurred during July in LFA 35. Early molting to legal size and subsequent removal from the fishery in July could also explain the slight decline in catch rate in the fall, which occurred off Alma, Advocate and Parrsboro. This fall catch decline did not occur in St. Martins, but the spring season there closed at the end of June.

The shift in precruit abundance in the Alma area is unlikely to be caused by the causeway opening, but by factors acting on a larger scale.

Results of commercial trap sampling by fishermen were presented in summary figures but discussion was deferred to a later publication.

Experimental juvenile traps caught 0.8 lobsters/trap haul in Minas Basin and 5.32 lobsters/trap haul off Alma. It was suggested that this method would not be effective in detecting potential impacts of the causeway, or other environmental changes, because of the wide range of catch rates. Only very major changes would be detectable.

Locke, A. 2000. Fish communities of the Petitcodiac River and tributaries in 1999. Pages 123-162 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

As in 1997 and 1998, rainbow smelt and gaspereau were found to have spawned in or above the Petitcodiac reservoir. The first smelt were observed at the causeway gates on April 15. Spawning had occurred in the main river above Salisbury by May 6. At this time the gaspereau migration had already started. Mud-flushing activities at the causeway gates (April 8 to June 2) created conditions conducive to upstream passage of smelt and gaspereau and downstream passage of the Atlantic salmon smolts stocked in the Pollett River on May 10-12. At least one American shad in spawning condition reached the counting fence above Salisbury during the mud-flushing but there was no evidence of successful spawning of this species. The shad arrived immediately before a decision not to proceed with the gate opening trial resulted in closure of the gates on June 2. Hundreds of American eels and gaspereau were observed below the causeway in the week following the gate closure. Opening the vertical-slot fishway on June 5 seemed to have allowed successful passage of eels but not of the gaspereau. No upstream-migrating gaspereau reached the fish counting fence after June 7 and very few anadromous fishes of any species were seen after June 2. It is likely that the gaspereau observed below the gates in early June represented the expected blueback herring run that did not appear at the counting fence. Implementation of 10- to 20-minute daily gate openings on June 11 did not result in anadromous fish migration into the system. Large quantities of filamentous green algae prevented regular operation of the fence from mid-July until mid-September. The fence was destroyed by a flood on September 23. The fishway trap also could not be operated regularly. A snorkelling survey and gill-netting in November failed to detect any evidence of adult salmon or their redds. Electrofishing next year may provide some data on this year's spawning activity. Electrofishing in 1999 detected very few juvenile salmon in the Pollett and Little rivers, and brook trout abundance also seemed lower than in 1998.

Eleven of the 25 fish species reported from the freshwater reaches of the Petitcodiac River and tributaries are diadromous (i.e., species which must migrate between freshwater portions of the Petitcodiac River and the Bay of Fundy to complete their life cycles). Two of the anadromous species probably also have non-migratory freshwater populations in the Petitcodiac system. The remaining species are resident in fresh water. With the exception of the sea lamprey and two species of sticklebacks, all of the diadromous species formerly had commercial, recreational or food fishery value to the human population of the Petitcodiac watershed. Species once fished commercially here and known to have spawned in the Petitcodiac include the anadromous alewife, blueback herring, rainbow smelt, American shad, striped bass and Atlantic salmon. Anadromous Atlantic tomcod and sturgeon were also once fished in the estuary. Tomcod are reported to have spawned in the watershed, but their habit of spawning in winter makes detection difficult. There is no record of sturgeon spawning in the river. Of the diadromous fishes once commercially fished in the watershed, American eel, which does not spawn locally, was the only one still fished in 1999.

Recreational fishing was formerly carried out in the Petitcodiac on several anadromous fishes (rainbow smelt, American shad, Atlantic salmon, brook trout, striped bass). Anglers still catch the occasional large, silver-coloured brook trout believed to be sea-run, but otherwise these recreational fisheries no longer exist. Freshwater fishes currently angled or with angling potential include land-locked brook trout, white perch, and illegally introduced smallmouth bass and chain pickerel. The recreational fishery for smallmouth bass was closed in Inner Bay of Fundy watersheds, including the Petitcodiac, in 1999. It was also noted that high mercury levels have been recorded in smallmouth bass, chain pickerel and white perch in lakes and reservoirs across the province. No data exist specifically for the Petitcodiac, but mercury levels in these species consistently exceeded guidelines for human consumption throughout New Brunswick as recently as 1994. As a general trend, there is some indication that mercury levels may be lower in anadromous sport fish with the exception of very long-lived fish such as sturgeon.

The strong representation of diadromous species in the native "freshwater" fish community of the Petitcodiac is a typical situation in New Brunswick, which has a very depauperate native freshwater fauna relative to other parts of North America. Such depauperate communities may be particularly susceptible to species invasions, especially in the presence of environmental disturbances such as major changes in habitat. Thus, three invasive freshwater species (smallmouth bass, chain pickerel, brown bullhead) have apparently arrived and become established in the system subsequent to the installation of the causeway. Such introductions usually result in severe damage to the existing fish community and are a common cause of species extinctions (habitat loss is the only cause of extinctions which is more common). Negative impacts of invading species include direct interactions such as predation and competition with native fishes, and introduced diseases and parasites. The risk of introducing new diseases or parasites to the system is greater when, as was the case for the Petitcodiac, the fish introductions were unauthorized and had not undergone standard health inspections required in the permitting process.

Operations at the fishway, fish fence, snorkelling, gill netting and visual observations did not detect any returning grilse from the 21,000 Atlantic salmon smolts that were stocked in May 1998. Observations in 1998 had confirmed the arrival of smolts in the headpond within two days of stocking, and successful passage through the causeway gates. It was not possible to quantify the proportion of smolts that successfully migrated from the headpond.

A similar experiment was conducted with 15,000 smolts released in the Pollett River in May 1999. Gillnetting in the headpond confirmed the arrival of smolts and they were observed jumping below the gates. One or more gates were open for 12-19 hr/day during the presumed period of smolt migration, which should have been adequate for downstream passage.

Ichthyoplankton sampling in the headpond detected larvae of rainbow smelt, gaspereau and a *Morone* species. The latter could be positively identified only to genus, but was believed to be white perch rather than striped bass because of the large number of white perch juveniles found in the fishway in late summer and fall.

Spot-checks for larval fish and drifting fish eggs detected smelt eggs in the Petitcodiac River near the site where the counting fence was later installed (just above Salisbury), confirming that some spawning of smelt took place upstream of this location.

Gill-netting in the headpond was conducted about once a month. Salmon smolts were present only briefly in mid-May. Gaspereau were captured from the first sampling in mid-May (captured while moving upstream) through to mid-June (captured while moving downstream). Both alewife and blueback herring were present. As in previous years, white suckers were captured in all months. Smallmouth bass and brown bullheads were captured only in July and August.

A gill net with 9.8 cm (4 in) mesh was used at the fish fence site in the Petitcodiac River in an unsuccessful attempt to detect returning adult salmon in November.

A fyke net was used at the fence site in May to detect upward migrating fishes. The catch included suckers, pre-spawning gaspereau, creek chub and blacknose shiner in spawning colours, and blacknose dace.

The headpond was visited frequently during the early part of the mud-flushing and no fish kills or strandings were observed. The gate operator observed a few smelts and sticklebacks stranded on the cement base of the gates during a gate opening on April 15. Some freshwater mussels were exposed along the shore of the headpond, but mortalities would have been minimized by the timing of the drawdowns. Because the mud-flushing was started early in the year, most mussels had not yet moved into shallow water from their deep overwintering habitat.

A search of the tributaries for visual evidence of spawning smelt on April 21 did not detect either adult fish or eggs at 9 sites.

Smelt in spawning condition were present at the causeway gates on April 15. A female with eggs was recovered following stranding on the cement base of the gates.

Gaspereau were first observed below the gates on May 26. The migration had started at least three weeks earlier, based on the presence of gaspereau in the fyke net set at the fence site on May 7. Gaspereau were also very abundant in the gill nets set overnight in the reservoir from May 19 to 20. Difficulties with passage of gaspereau were observed in June, when the gates were closed most of the time but the fishway was open. The freshwater flow in the fishway was not sufficient to cover the bottom of the fishway trap until June 9. Large numbers of gaspereau present in the headpond in late May indicated that gaspereau had good opportunities for upstream migration during most of the flushing period. However, passage was evidently much worse after the gates were closed on June 2. From June 11 until at least June 15, hundreds of gaspereau were seen below the gates. These fish did not seem to be attempting to use the fishway. After the arrival of the tidal bore, gaspereau were swept into the fishway by the tidal current. Most of those observed to enter the fishway in this manner were killed by being repeatedly bounced off the cement walls.

The fishway was probably more successful in providing passage for eels. Hundreds of eels were observed below the gates on June 3-4. Following opening of the fishway on June 5, these eels disappeared from below the gates.

Several pools were snorkelled in the Pollett River on November 9. These appeared to be good holding pools for salmon but contained no salmon. There was also no evidence of redds on nearby gravel bars. A stretch of the Petitcodiac River between Powers Pit Road and the mouth of the Pollett River was also snorkelled, but visibility was poor because a farmer was spreading manure on the adjacent field. The only fish observed was a smallmouth bass about 10 cm long.

A fish counting fence was operated in the Petitcodiac River above Salisbury from May 25 to September 23. Operation of the fence at this site was difficult because the substrate tended to erode and at times there was so much filamentous algae that the fence had to be cleaned continously. Because of these problems, the fence was usually left open during and following rain, and the fish counts were incomplete. Few fish were counted after mid-July, mainly due to the difficulty of operating the fence in summer when algae were most abundant. The fence was eventually destroyed by a flood on September 23.

The fence captured relatively large numbers of gaspereau, both ascending and descending the river. Considerable mortality of gaspereau was observed in the downstream trap on several days – in part due to the combined effects of high temperatures and crowding in the trap but also a result of the depleted physical condition of the fish after spawning. Mortalities were rare for upward-migrating gaspereau captured at the fence. The majority of the gaspereau intercepted were alewife.

There was extensive spawning activity of creek chubs and blacknose shiners in the vicinity of the fence during the gaspereau migration. Brook trout were intercepted at the fence, mostly moving upstream, from May 28 to June 16. Sea lampreys were captured during upstream migration from May 29 until June 9, and moving downstream until June 24. White suckers were frequently captured through May and June. American eels (2 individuals) were also captured.

A single female shad in spawning condition was captured moving upstream on June 3, the day after the mud-flushing terminated.

The trap at the vertical-slot fishway in the causeway was operated intermittently, normally only when the causeway gates were closed, on neap tides (to reduce mortalities of fish during reverse tidal flow at the fishway), and when electric power to raise and lower the trap was available (due to renovations at the gate structure). Adult gaspereau were captured until the end of July, although many were dead. Large numbers of gaspereau juveniles were found in late July and through September. Other species found in the trap were eels, silversides, suckers, white perch and smallmouth bass, and a single shad collected in early July. Water temperature in the trap reached 29 C on the morning of July 28.

Few salmon parr were detected during electrofishing on the Little and Pollett rivers. No age 0 parr (from spawning in 1998) were detected. Age 1 parr (from 1997 spawning run) were present in the Pollett River near Elgin and in the Little River near the confluence of Mitton Brook. No age 2 parr were found. A single age 3 parr was collected at Prosser Brook; this was probably the offspring of the Big Salmon River cage-reared salmon released in 1995. Brook trout were found at fewer than half the sites sampled. Trout were most abundant at the Prosser Brook site, as in the three previous years, but were only half as abundant as in 1998.

Causeway gate operations with respect to fish passage were described.

Locke, A. 2001. Conditions for diadromous fish passage at the Petitcodiac River causeway. Proceedings of the 4th Bay of Fundy Workshop, Environment Canada (Atlantic Region) Occasional Technical Report xx:xx-xx. (in press)

Diadromous species require migration between freshwater rivers such as those in the Petitcodiac system and marine waters such as the Bay of Fundy to complete their life cycles. In order to enter or leave the fresh waters of the Petitcodiac, diadromous species must transit the area where the causeway is now located. Diadromous taxa clearly dominated the ecology and fisheries of the Petitcodiac, in the days before the causeway.

Table 1. Pre-causeway fish species list.

	Diadromous species	Freshwater species
Fished - Commercial, Recreational Or Both	Alewife Blueback herring American shad Rainbow smelt Atlantic salmon Brook trout Atlantic tomcod American eel Striped bass Sturgeon (not identified to species)	Brook trout White perch
Not fished	Sea lamprey Threespine stickleback Fourspine stickleback	White sucker Creek chub Lake chub Blacknose dace Northern redbelly dace Blacknose shiner Golden shiner Banded killifish Ninespine stickleback

In general, fish undertake seasonal migrations between fresh and salt water for spawning, feeding, or overwintering. Fish that spawn in fresh water need upstream passage past the causeway for spawners, downstream passage for spent fish, and downstream passage for larvae or juveniles.

There is good evidence from the literature that the following migrations took place in the Petitcodiac system. The annual habits of some species may have involved two or more round trips between salt and fresh water, transiting the area where the causeway is now located.

Table 2. Fish migrations formerly recorded in the Petitcodiac estuary.

Fish species	Purpose of migration		
	Spawn	Feed	Overwinter
Sea lamprey	X		
Alewife	X		
Blueback herring	X		
American shad	X	X	
Rainbow smelt	X		
Atlantic salmon	X		
Brook trout	X	X	
Atlantic tomcod	X		
American eel	X	X	X
Striped bass	X	X	?
Threespine stickleback	X		
Fourspine stickleback	X		
Sturgeon (species not indicated)		X	

The causeway was built with a vertical-slot fishway. It was apparent almost immediately that this fishway was not working well. Over the past three decades, the fish passage facilities have been modified repeatedly in attempts to improve their efficiency. The current configuration includes the modified vertical-slot fishway and a pair of "surface ports" in the gate closest to the fishway.

The history of fish passage in the system included:

- 1969 – Poor fish passage was documented. Physical problems included "reverse flow" of water through fishway at high tides, and poor attraction of fish to the fishway. Flow conditions allowing salmon to pass through open gates were determined (Dominy 1970). Design problems of the fishway are detailed in Riley (1971).
- 1970-1971 – Discharge patterns were modified to improve attraction flow; gates were opened intermittently.
- 1971-1972 – Studies indicated that only salmon had better fish passage under normal flows. Salmon, shad, alewives, smelt and striped bass all used the fishway when fishway flow was reversed. In 1972, alewives and smelt passed through the fishway in greatest numbers when fishway flow was reversed.
- By 1979 – Significant problems with siltation had further worsened fish passage (Semple, 1979; ADI Ltd., 1979); ADI report recommended modifications to fishway and reductions of leakage through the gates. Semple recommended permanent gate opening.
- 1983 – Gates were open for much of the season for construction of a water pipeline. One gate was modified to provide attraction flow and an alternate means of passing salmon during certain stages of the tide (the "surface ports", a.k.a. the "stoplog" system, a.k.a. the "bypass notch" – Fig. 1). Leakage through the other gates was sealed. The height of the vertical slot baffle at the entrance to the fishway and the walls of the fishway was increased. The unfortunate result of the fishway

alterations was to increase the deadly "blender effect" of reverse tidal flow through the fishway.

- 1988 – Gates were open for fish passage, April 14-June 7, Sept. 26-Oct. 31; tidal water was allowed to pass upstream.
- 1989 to early 1990s – Gates were open in May-June at low tide mainly for downstream passage of salmon smolts; tidal water was not permitted to enter headpond.
- 1998 – Gates were open May 31-June 18 for mud flushing (for planned Trial Gate Opening experiment).
- 1999 – Gates were open April 8 – June 2 for mud flushing (for planned Trial Gate Opening experiment).
- 2000 – More modifications to gate operations, intended to increase opportunities for passage through open gates.

By 1970, the flow conditions necessary for passage of salmon through open gates were identified and it was noted that salmon did not use the fishway when gates were open.

Although in early years of the causeway, the gate openings recommended by fishery scientists were apparently intended to provide attraction flow to bring fish to the fishway rather than directly provide passage, within a decade Semple (1979) wrote that fish passage at the causeway could best be accomplished by complete removal of the causeway gates.

Quite possibly, the gate openings of the past three decades, whether intended for fish passage or for other purposes such as flood control or mud flushing, may be one of the major reasons why there are still residual populations of diadromous species in the system.

Locke, A., J.M. Hanson, S. Richardson, I. Aubé and G. Klassen. 2001. Estuary+Causeway=Species, populations and habitats lost in the Petitcodiac River. Proceedings of the 4th Bay of Fundy Workshop, Environment Canada (Atlantic Region) Occasional Technical Report xx:xx-xx. (in press)

Almost half the fish species formerly recorded from the freshwater portion of the river were diadromous, and most have been adversely affected by the causeway. Anadromous species whose populations have been greatly reduced (**r**), or eliminated (**e**), from the system include Atlantic salmon (*Salmo salar* **e**) (part of the genetically distinct Inner Bay of Fundy stock), American shad (*Alosa sapidissima* **e**), sea-run brook trout (*Salvelinus fontinalis* **r**), tomcod (*Microgadus tomcod* **e**), striped bass (*Morone saxatilis* **e**), and rainbow smelt (*Osmerus mordax* **r**). American shad probably served as the host for the glochidia of the dwarf wedgemussel, *Alasmidonta heterodon*, which is now listed as extirpated in Canada and endangered in the U.S.A. The Petitcodiac River was the only known Canadian location of *A. heterodon*, which was described as "common" in the river in the decade preceding causeway construction. The causeway was probably the direct cause of the extirpation of this unique northern population, by excluding the glochidial host from the system, thus interrupting the mussel's life cycle.

Benthic and planktonic communities of the headpond are depauperate, and the species composition is typical of a strongly disturbed ecosystem. Most taxa are marine/estuarine in origin, or belong to freshwater groups with rapid dispersal. The headpond is subject to intrusion of salt water via the fishway and frequent water level fluctuations. Water temperature regularly exceeds 25^{o}C in the summer, a thermal regime which is not well tolerated by many of the native fishes. Illegally introduced warm-water species (smallmouth bass *Micropterus dolomieui* and brown bullhead *Amiurus nebulosus*) have flourished and are spreading to riverine parts of the watershed. Chain pickerel (*Esox niger*) has also been illegally introduced but to date has not spread to the extent of the other two species.

The majority of negative effects of the causeway are reversible, but several may not be, e.g., species extirpations and introductions.

At the time of writing (September 2000), the future of the watershed was uncertain. The Trial Gate Openings planned for 1998 and 1999 were not able to proceed because of inability to use the spring runoff to flush accumulated mud from the vicinity of the gates, so that the agreed-upon parameters of the experiment could not be achieved. In 1998, this was the result of a delay caused by a court challenge, and 1999 was a year with very little spring runoff.

Based on three years of study of the freshwater environment, the authors predict the following:

- If the gates are opened or causeway is partially replaced by a bridge

- improvements in the runs of anadromous fish species will occur almost immediately (but some unique genetic material, such as the Petitcodiac strain of Atlantic salmon, is gone forever)
- the river channel will partially re-establish
- salt marsh will develop on the shallow flats of the present headpond
- the introduced smallmouth bass will continue to expand its distribution throughout the freshwater portions of the river, but the populations of introduced brown bullhead and chain pickerel may crash with the loss of the headpond.

- If the gates are not opened (status quo)

- continued loss of anadromous fish species
- increased populations of invaders (both plant and animal)
- continued sedimentation and infilling (both above and below the causeway)
- shallow areas will become choked by weeds, and within decades the impoundment will become a freshwater marsh with a narrow river channel.

In closing, it was noted that in terms of ecosystem values, there are only a handful of macro-tidal estuaries in the world, whereas there are literally millions of small, shallow impoundments supporting centrarchids, esocids, cyprinids, alosids and ictalurids, in North America alone.

New Brunswick Department of Environment and Local Government. 2000. Water quality of the Petitcodiac headpond (1997-1999). Pages 291-311 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Thirty-eight chemical, physical and biological parameters were measured for water samples located along 11 transects upstream of the causeway. Water hardness values ranged from soft (0-30 mg/L as $CaCO_3$) to hard (121-190 mg/L as $CaCO_3$). Phosphorus levels were higher than normally found in natural New Brunswick waters. Levels of chlorophyll *a* were approximately double those found in typical New Brunswick. The pH readings were slightly alkaline, averaging 7.4 and ranging from 6.6 to 8.2. The headpond was well oxygenated. Bacteria counts (*Escherichia coli*) were elevated at times during the fall of all three years (maximum value 1090 cells/100 mL). Levels of the remaining variables, including metals and major ions, were within the ranges acceptable for the support of aquatic life.

Average water quality measurements were similar for the three years. The concentrations of numerous substances tended to increase toward the lower end of the headpond. Spatial variations in concentration were attributed to inflow of fresh and marine waters at opposite ends of the headpond, and residence time and mixing characteristics of headpond waters.

Overall, the water quality of the Petitcodiac headpond was suitable to sustain aquatic life.

New Brunswick Department of Transportation. 2000. Report on 1999 monitoring by the Department of Transportation. Folio pages, not numbered *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. Appendix.

Physical features of the river and headpond related to sedimentation, erosion and meandering processes taking place in the Petitcodiac River were monitored in 1999. The studies included sounding surveys at established section lines upstream of the gates, at Halls Creek and Fox Creek. Channel bathymetry at Gunningsville Bridge was monitored regularly. Location surveys of banks were undertaken, mainly at erosion sites. Aerial photographs were taken from Hopewell Cape to Salisbury at low tide and with the headpond drawn down on May 7.

Included in this Appendix are cross-sections of the survey lines showing bathymetry and changes since 1979, detailed bathymetry in the vicinity of the mud plug in 1999, bathymetry at the Gunningsville Bridge in 1999, bank erosion surveys showing various dates in 1999, and a comparison of the river shoreline in 1969 with a July 1999 survey.

Niles, E. 2001. Review of the Petitcodiac River causeway and fish passage issues. Report of the Special Advisor to the Minister of Fisheries and Oceans Canada. February 9 2001. 75 p.
Available at:
www.mar.dfo-mpo.gc.ca/e/reports/PetitcodiacReview-e.htm English version
www.mar.dfo-mpo.gc.ca/f/reports/PetitcodiacReview-f.htm French version

Eugene Niles was appointed as a Special Advisor in August 2000, with a mandate to “develop recommendations on a viable long-term strategy for restoring fish passage in the Petitcodiac River”. The Terms of Reference further required that existing fish passage, environmental, social and economic data be examined; the short- and long-term viability of all options be considered; and a general range of costs be provided for all options evaluated. The process essentially consisted of reviewing the existing literature and extensive consultations with stakeholders.

A brief history of the causeway was presented, as follows. On January 7 1960, Moncton City Council passed a resolution asking the provincial government to conduct a feasibility study for a causeway. This study was conducted by Maritime Marshland Rehabilitation Administration (MMRA), and its report of March 30 1961 examined three sites, one of them being the current location. On July 3 1961 the federal Department of Fisheries advised of a requirement for a fishway in the structure. On July 30 1963, City and provincial authorities met and decided to propose a causeway at the current location. In November 1963 the MMRA was authorized to proceed with the engineering design. The project was given approval under the Navigable Waters Protection Act on June 3 1964. MMRA agreed to contribute $800,000 to the estimated total cost of $3 million, because of perceived benefits to agricultural lands. The Provincial Water Authority approved the project, believing that it would provide a source of fresh water for industrial use as well as for recreation. Construction started on February 6 1966 and ended on March 10 1968. The gates remained open until May 3 1968. Fish passage problems have been documented since 1969 and continue to this day. The provincial government opened the gates in 1988, 1989 and 1990 in an attempt to improve fish passage. A federal/provincial Memorandum of Understanding was signed in December 1996 to proceed with a trial gate opening to collect information required in developing a long-term solution to the fish passage issue. However, for a number of reasons the physical conditions required to conduct the trial could not be achieved and the project was terminated on June 1 1999 after attempts in 1998 and 1999. A good deal of information was obtained as a result of these experiments. Although there is currently no specific agreement in place, the Department of Fisheries and Oceans and NB Department of Transportation continue to work in cooperation to monitor and adjust the operation of the gates “to facilitate fish passage as best they can under the circumstances”. NBDOT instituted DFO-approved interim adjustments to the usual gate operations (in effect until April 1 2001) in an attempt to improve fish passage. In August 2000, the Minister of Fisheries and Oceans Canada, Hon. Herb Dhaliwal, announced his intention to have a thorough review of all issues and existing information. This report documents the results.

The passage of fish through the causeway has been problematic since the closure of the causeway. The fishway, designed for Pacific salmon, has been “inefficient at best for [Atlantic] salmon and completely unsuitable for other species". Concerns about the potential impact of a causeway on fish runs were expressed as early as 1961 by biologists familiar with the river. Reports in 1969, 1970 and 1971 detail fish passage problems. In 1975, the number of salmon counted through the fishway in 1969 to 1972 ranged from 140-895 fish, compared to an estimated annual pre-causeway run of 2,000-3,000 salmon. The same document reports that the causeway was considered to have virtually eliminated shad, sea-run brook trout, and striped bass from the system. Similar reports were made in 1976 and 1977. At this time, operational problems were reported with the causeway and gates. These included:

- erosion along the banks of the reservoir
- inability to maintain stable reservoir levels during the summer
- siltation of the reservoir upstream of the causeway as well as downstream of the causeway construction
- unsatisfactory fishway operation
- ice jamming at the causeway end of the reservoir
- a number of lesser mechanical problems concerned with gate operation and maintenance.

In 1978, NBDOT commissioned ADI Ltd. to carry out a study of these problems. Their report of December 1979 considered three alternatives: Operation as is or "status quo", Operation without gates, Eliminate gate leakage and modify operation. The first alternative was not considered practical because it would continue to allow large volumes of silt to enter the reservoir and would not improve control of reservoir water levels. The second was predicted to cause massive erosion of the river downstream and massive siltation of the headpond, and velocities of flow through the open gates might be too high for fish passage. The third alternative required modifying the gates to seal leakage in both directions, modifications to the fishway to reduce salt water and silt entering the headpond, and modifying the gate operations to better attract fish to the fishway. Although DFO and the NB Dept. of Natural Resources recommended removing the gates to permit free flow, and even the removal of a portion of the causeway if necessary to restore the river to its former tidal flow condition, the NB government decided in the spring of 1980 to proceed with the third alternative. These changes did improve fish passage but only marginally except for the year 1983. A large run of 1,912 salmon in 1983 was attributed to stocking of 91,000 hatchery reared fingerlings in 1980 and the headpond drawdown for construction of a water main across the headpond from February to September 1982. In 1988, the provincial government opened the gates and allowed free tidal flow from April 15-June 7 and September 26-October 31. There were significant improvements in the shad fishery in 1988. The gates were again opened May 3-June 15 1989, but only during low tide to prevent siltation of the headpond. Landings in the shad fishery returned to pre-1988 levels. Gates were again opened at low tide from May 15-June 15 1990. In 1991, DFO once again stated that in order to maximize anadromous fish production, free flow of the river was necessary April 1 to December 15, annually. In May 1991, a provincial government inter-departmental committee prepared a report which defined a series of options for the Petitcodiac dam and causeway:

1. Gates operated to maintain headpond and minimize tidal exchange (Status Quo)
2. Operate gates to help fish passage

3. New fishway design
4. Fish trap and transport
5. (a) One gate open
5. (b) Five gates open
6. Replace causeway with bridge
7. Separate the river from the headpond.

The ADI report of 1992 concluded that none of these options had quantifiable benefits that were greater than the costs associated with the option. It stated that only the "Status Quo" and "Five gates open" options were worth further consideration. "Status Quo" would maintain the headpond year-round and maintain agricultural land, but would not improve fish passage. "Five gates open" would result in significantly improved fish passage and tourism opportunities, but the headpond would be eliminated and agricultural lands would be flooded by tidal water. Several reports from 1992 to 1995 continued to document the problem of fish passage and in 1995 DFO again stated its support for the opening of 1 or more gate(s) from April 1 to December 15 each year "to allow free flow which would make some provision for fish passage". Meanwhile, in 1994 Chiasson had written "A flow control model for the Petitcodiac gates" which was followed up with the report by ADI (1996) outlining several options for gate management. A Memorandum of Understanding between the federal and provincial governments in December 1996 provided for a trial gate opening exercise, consisting of ADI's alternative #2: leaving one or more gates fully open, closing them so as to clip the tide and maintain a maximum elevation of 2.5 m in the headpond. After 2 failed attempts to initiate the experiment, it was apparent that the limitation to 2.5 m elevation was too restrictive, and that maintaining an elevation of 3.5 m would have allowed the experiment to proceed in either year.

A number of scientific opinions, some contradictory, were summarized:

- in spite of stocking of 2.7 million salmon, the genetically distinct Inner Bay of Fundy salmon has been eliminated from the Petitcodiac River
- opening the gates may restore 50-90% of the river below the causeway – but exact prediction is difficult because of the difficulty of modelling the macrotidal system
- modelling is feasible if accompanied by physical experiments done in a stepwise manner
- sediments may or may not accumulate in the headpond if gates are open
- siltation of the headpond, formation of salt marshes, and restoration of the estuary would be a positive thing – there are only a handful of macrotidal estuaries in the world and every effort should be made to restore the Petitcodiac estuary
- opening the gates will result in improvements in anadromous fish runs
- it may be possible to re-establish the extirpated dwarf wedgemussel from other populations
- maintaining the gates closed will result in the extirpation of more anadromous fish species and over time the headpond will fill in to become a freshwater marsh while the river below the causeway continues to fill in and this infilling spreads down toward Shepody Bay
- some dams/causeways should never be removed because there may be further damage to an already damaged ecosystem

- the Precautionary Principle may apply to removal of an obstacle – if there is doubt about the effects, don't do it
- this interpretation of the Precautionary Principle differs significantly from the definition adopted at the Rio Declaration on Environment and Development: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"
- attempts at restoration should be made cautiously and only after appropriate studies followed by long term monitoring

The Special Advisor consulted with 26 stakeholders. Fifteen prefer the establishment of full tidal exchange in the river; at least six of these are of the opinion that only full tidal exchange is acceptable. The remaining 9 think that opening all or some of the gates to provide limited free flow is acceptable; the Special Advisor is not certain that they all understand that this will provide only about 50-60% of full tidal exchange. Five stakeholders prefer maintaining the Status Quo or at most replacing the current fishway. Six stakeholders have taken no position.

It was noted that one stakeholder is the Fort Folly Band, and that the causeway has had a significant and negative impact on their traditional way of life.

It was further noted that some stakeholders represent hundreds of individuals while others represent less than ten.

The following issues were raised by stakeholders:

- 3 stakeholders felt the terms of reference for this review were too restrictive – they should include the estuary, the river, and fish habitat restoration as well as fish passage – another felt the terms of reference were simply imprecise
- "a number" state that there is an urgent need to restore a world unique but badly damaged macrotidal estuary – there are only a handful in the world and it is necessary to take action before damage becomes irreversible – some damage may already be irreversible
- a new ecosystem has become established above the causeway, with new fish and bald eagles, osprey and loons – restoring fish passage by destroying the headpond would endanger some of the wildlife
- there is an urgent need to restore the Inner Bay of Fundy salmon – only a few hundred remain in captivity as breeding stock – unless free tidal flow is re-established, stocking is futile – one should not wait until there is evidence of salmon return before providing fish passage
- the benefit of trying to restore salmon in the Petitcodiac River when the stock is in decline throughout the region is questionable – benefit of maintaining existing species is greater – there is a thriving commercial fishery for eels in the headpond – improved catches in the past 2 years are attributed by the fishermen to the gate operation changes
- 2 existing fish species in the headpond (smallmouth bass and chain pickerel) were illegally introduced and may over time cause irreparable damage to native species – this may already have happened – elimination of these species is advocated, as soon as possible

- there is a need to protect and restore other fish species that depend on the Petitcodiac River for feeding and/or reproduction – rainbow smelt and gaspereau are declining – shad, sea-run brook trout and striped bass are no longer evident but can be re-introduced from other populations provided the environment is improved
- it is necessary to consider the benefit of maintaining fish species with little or no commercial value vs. recreational species with economic spin off – there are "only a handful of commercial fishers in the shad fishery and none in the gaspereau fishery while there are many hundreds now enjoying bass tournaments with significant economic spin off" [Editor's Note: Bass fishing has been illegal in the Inner Bay of Fundy rivers, including the Petitcodiac, for several years. Presumably this statement refers to bass fishing elsewhere. With the recent changes in gate operation, a commercial gaspereau fisherman returned to the river below the causeway to try again.]
- various opinions regarding the tidal bore – opening the gates will restore it – it still exists, but further down the river – only full tidal exchange will restore it
- scientifically, many factors make it very difficult to predict what will happen to the bore – it is only clear that the causeway has caused changes which adversely affected it – not possible to say what the bore would have looked like today if causeway had never been built
- potential benefit of headpond is just starting to be realized and will "far surpass" any potential increase generated by a restored bore – marina, sea cadet sailing school, recreational sailing, sea plane moorings, fishing tournaments, tour boat, speed boat regatta, snowmobiles, ATVs
- full tidal exchange will result in flushing of accumulated sediment and permit recreational sailing, rafting and tour boat downriver, as well as commercial and recreational fishing
- stakeholders representing property owners point to "dramatic building activities" on both sides of lake
- property owners downriver in places like Memramcook from Dover to Beaumont have seen their property value negatively impacted by sedimentation – summer homes are no longer occupied as recreational areas such as beaches and river fronts disappeared
- there has never been a full cost-benefit analysis of these issues

The following concerns were raised by stakeholders:

- sewage treatment – sewage discharged into the river poses a risk to residents both upstream and downstream – this risk applies to all options including Status Quo – stakeholders are concerned that this material will be carried into headpond and cause health hazard, also that free flow may damage sewer lines
- water supply – two major supply lines, one in the headpond and one in the causeway structure – major modifications may require expensive relocation
- infrastructure – opening gates may result in damage to water supply and sewage lines near the edge of the river
- mosquitoes – some stakeholders believe a freshwater headpond is less of a health risk than a salt marsh – experts consulted say the health risk is about the same, only the timing of breeding is different

- abandoned landfill sites – the long abandoned sites downriver are likely of little or no risk, but the more recently closed landfill near the causeway contains toxic material – the toxicity of leachate from this landfill is questionable (City and provincial monitoring found acceptable levels of toxic materials in leachates, but Environment Canada investigating toxic leachate reported from area of Gunningsville Bridge) – concerns that toxins will be washed into headpond where they will pose a health risk, or downstream to lobster fishery
- tidal sediment – concern that vast amounts of sediment will be washed down to Shepody Bay and affect lobster fishery, shorebird reserves, tourism
- emergency water supply – the headpond can be used as a backup supply for firefighting – also for training and testing of rescue apparatus

The following options were considered:

1. Status Quo
    - "Most stakeholders consider this option to be unacceptable"
    - if a solution to fish passage problems had been possible under the Status Quo, it would have been found by now – considerable effort has been made over an extended period of years
    - along with the perceived benefits, this option is not without risk
        - during droughts, maintaining the headpond levels appears to have been prioritized over keeping the gates free of sediments – flooding was a real possibility in September 1999 when it took many hours to open the gates
        - toxic leachate and sewage are probably entering the headpond through the fishway – 5 to 10 million m^3 of tidal water enter through the fishway annually
        - continued sediment accumulation can be expected downstream – possibly, equilibrium has been reached between the causeway and Gunningsville Bridge, but not in the section of the estuary below Hillsborough
        - "A review of studies and reports does not indicate that any serious investigation or evaluation of the risks associated with the Status Quo option has taken place to date."
2. Status Quo Plus, defined as replacing the fishway
    - ADI (1992) proposed a new fishway design but it was not seriously considered because it would still be necessary to leave gates open for an extended time for downstream fish passage
    - a number of fishway designs were presented by stakeholders but "none appeared to answer the problem of operating in this silt laden environment as well as satisfying the multi-species requirements"
    - the same risks apply as with option 1, in addition to the $4-6 million cost of constructing the fishway, which could take 2 years
3. Opening the gates during peak migration periods in spring and fall
    - peak migration periods for most species are April-June and October-November [Editor's Note: this refers to upstream migration only]
    - attempts of this nature were made in 1988, 1989 and 1990 [Editor's Note: In 1989 and 1990 these attempts did not involve "free tidal flow", but only freshwater flushing.]

- the gates would need to be open for periods longer than indicated above to allow for downstream migration
- some stakeholders suggest this is the minimum that should be done – five gates open would cause less turbulence and less sediment deposition than only one gate
- erosion protection is already in place so erosion would be minimal
- benefits of the headpond would be maintained for part of the year
- there is no consensus that this is the most viable option
- risks have not been fully evaluated, many are same as option #1
  - sewage treatment plant – the plant could hold sewage during normal flow, for sufficient duration to prevent sewage being carried upstream by incoming tides – but would need additional storage capacity for rainstorm events, and secondary treatment – cost $30 million
  - landfill and toxic leachate
  - effects of sediment on downstream habitat
  - potential for flooding of agricultural lands upstream of causeway – 1000 acres may need protection
  - sediment deposition in headpond

4. Opening gates permanently except for ice control in winter
   - many stakeholders suggest this is the minimum that should be done
   - benefits to fish are greater
   - disadvantage is loss of the headpond
   - all of the risks associated with option #3 are also applicable here, but degree and rate of impact may be greater
5. Replacing gates with partial bridge
   - considered the optimum option by many stakeholders
   - an opening of 250-275 m (estimated) would cause less turbulence than open gates, and promote almost full tidal exchange – "the potential for fish passage will be as close to pre-causeway conditions as is possible"
   - may result in flushing of sediment downstream – potential for restoration of tidal bore, etc.
   - added benefit is restoration of the estuary and perceived benefit to entire Bay of Fundy ecosystem as the "the ultimate goal" for "a number of stakeholders"
   - all risks associated with option #4 are applicable, plus possible impacts on the landfill near the causeway, which could require expensive mitigation
   - cost of this option could be $20-50 million
6. Removing entire causeway and replacing it with a bridge
   - not considered viable because of cost, especially when considering the requirement to remove or protect the landfill
7. Fish trap and transport
   - ruled out by ADI (1992) because of high cost, and ineffective
   - does not improve downstream fish passage
8. Separate the river from the headpond
   - described as totally impractical

The Special Advisor's opinion is the cost-benefit accounting has never been done properly for any of these options. He recommends a process of "Full Cost Accounting" that is sometimes used as a preliminary step in Environmental Assessment (EA) also known as Environmental Impact Assessment (EIA), in order to fill these information gaps. He recommends that the next step in the process should be an EIA, concluding that all viable options would trigger an EIA by both provincial and federal legislation. Many stakeholders have advocated for some time the need for an EIA, and none voiced any opposition to an EIA. During this review this was the only area of consensus. The scope and triggers for provincial and federal EIA's were summarized. It was noted that "any EA/EIA must include some experimental openings of the gates to model and verify impact of tidal flow... scientists and experts charged with the conduct of these experiments must be given reasonable latitude and flexibility to ensure objectives can be met". The Village of Memramcook suggested that similar experiments could be carried out first on the Memramcook River as a smaller model.

The decision to be made with regard to an EA is whether to define 4 smaller projects, one for each viable option, or one larger project. The opinion of the Special Advisor is that an EA based on the most aggressive option, the replacement of the causeway by a partial bridge, is the logical approach to address all issues, concerns and risks associated with each option.

The first requirement, then, would be to propose a project that would trigger the EA process. A stepwise implementation approach is suggested, although this is different from the normal EA process.

It is suggested that Full Cost Accounting or a similar procedure be used, and that each option be evaluated, starting with the Status Quo (option 1) and progressing sequentially through the viable options up to and including Partial Bridge (option 5). "Should the evaluation indicate the need to do experimental openings of the gates to model and verify the impact of tidal flow, these openings should be scheduled at a time most likely to enhance fish passage opportunity". It was further suggested that a mediation mechanism be put into place early in the process.

The appendices to the report contain several communications from stakeholders including comments on the draft report. In some cases, these comments contain information that was not incorporated in the main report. Highlights follow:

- NB Dept. of Environment and Local Government (letter signed by K. Jardine, Minister)
    - The minister stated her intention of discussing the Petitcodiac River Causeway issue with Ministers Dhaliwal (Fisheries and Oceans Canada) and Anderson (Environment Canada)
- Village of Memramcook (letter signed by B. LeBlanc, Mayor)
    - In this letter, the suggestion is made to carry out a feasibility study in the Memramcook River. The village council considers the negative effect of the mud deposited above the Memramcook causeway to be a pressing issue.
- Lake Petitcodiac Preservation Association (letter signed by N. Roach, President)
    - Several potential uses of the lake were overlooked: it is the only body of fresh water in eastern New Brunswick big enough for an aviation sea plane base or aircraft landings. This has considerable untapped tourist potential but the uncertainty of lake levels over the years means that the information cannot be

supplied to Transport Canada in advance to be included in aviation publications. The lake could even be used as a landing site for travellers destined for PEI where there is no suitable freshwater landing, or to Nova Scotia. The lake is also a source of fresh water for fighting large fires – that can not be done with salt water or rapidly from an airport.

  - Our communities are losing tourist dollars now.
  - Why spend millions of tax dollars "to bring a few more salmon into our lake when there are already many kinds of fish, birds and animals that are doing very well in this fresh water system"
  - The current fishways work, just not as well as they should or could. Fish decline is due to many other factors like pollution.
  - Our fresh water system is just as important as our salt water system. We should not destroy what we have today in favour of an unknown. We can not turn back the clock. The risks to our environment and the livelihood of others are terrible, if the gates are opened.
  - The only options that are credible and viable are Status Quo and Status Quo Plus Fishway Improvements. The only solution to fish passage is a proper fish ladder suited to tidal and fresh water, with no tidal water whatsoever allowed in the lake. There are resources for developing such a ladder all around the world that have not been tapped.
- Petitcodiac Riverkeeper (20 pages of comments presented by D. LeBlanc, Executive Director)
  - Supports the idea of registering an EA for the Partial Bridge option
  - States for the record that the Terms of Reference to the Special Advisor exclude important issues, including: fish habitat, ecosystem, river channel or tidal bore restoration; quantification of benefits associated with each option; several important stakeholders, e.g., the tourism industry, youth environmental associations, the artistic community
  - Commends the Special Advisor on the final paragraph of his Draft report, absent from the Final report: "should Governments decide, however, to pursue the higher goals of restoring the estuary, restoring the river and the Tidal Bore, or to rehabilitate the system as a whole, then Option 5 (Replace the Causeway with a Bridge Span) becomes the logical option available to achieve this".
  - Agrees that regardless of what happens to the causeway, the issues of landfill leachate and treatment plant sewage must be addressed
  - Suggests that a distinction must be made between "health risks" and "environmental risks" on the issue of coliform bacteria. Also notes that high levels of coliform bacteria are sometimes present in the headpond. Sewage settling ponds and agricultural runoff upstream probably contribute to this.
  - Is of the opinion that the "New Fishway" option should not be seriously considered, given the low probability of a successful outcome
  - The "peak migration period" defined for fish by the Special Advisor is based only on the upstream migration. Downstream migration takes place at different times. In 1979, DFO defined critical migration times in the Petitcodiac as April to mid-June and September to November.

- Both DFO and NBDOT are on record as recognizing that there are likely to be greater risks of sediment deposition in the headpond with a gate management policy such as Gates Open During Peak Migrations as opposed to Gates Open Permanently.
- In comparing the Gates Open During Peak Migration option vs. Gates Permanently Open, the following points were made:
    - Erosion risks are approximately similar
    - Costs are approximately similar
    - Risks of sedimentation downstream (i.e., as far as Shepody Bay) are approximately similar
    - Risks of sedimentation upstream and downstream during fall may be greater with the Peak Migration option as new sediments deposits would be created downstream from the causeway during summer
    - Opening the gates only during peak migrations has “physical impacts” on fish passage functions outside the peak migration periods
    - Closing gates in summer will create adverse biological and environmental conditions for fish upstream and downstream from causeway
    - At most, 2.5 months during the summer is what fundamentally differentiates the two options
    - DFO is on record on numerous occasions as advocating free flow from at least April 1 to December 15 as its minimum preferred strategy, as opposed to peak migration
    - Similar experimental “peak migration” openings were carried out in 1988, 1989 and 1990, without lasting results
    - The current “severely endangered” status of fish stocks in the Petitcodiac River “merits that we reject options for which the ultimate fish passage outcome is significantly uncertain”.
    - It was recommended that the “Peak Migration” option be identified as being non-viable under the current Terms of Reference
- Comparing the Gates Open Permanently vs. Partial Bridge options:
    - The tidal flow width of 5 gates open is ~40 m, while “initial estimates” suggest 250-275 m would be required to create “full tidal flow” conditions
    - This tidal flow difference will create unnatural turbulence conditions immediately upstream and downstream from the causeway gates and “a long term impact on fish passage and fish populations which is undetermined for the time being”.
    - The maximum gate ceiling is 4.5 m under “free flow” conditions, while average neap high tides are in the 6 m range, and spring and fall high tides can reach 7.9 m. This will adversely affect fish passage. Some species, e.g., smelt, are not known to have the ability to “dive” under the gate structure to reach the upstream sections during their migration. Salmon is one of the few species that may be able to do this.
    - Other disadvantages of Gates Open are:
        - Long-term viability of the gate structure to operate under year-round conditions
        - Long-term deposits of silt immediately upstream from the causeway

    - Long-term deposits of silt immediately downstream of the causeway
    - The potentially limiting effect on the restoration of the river estuary and tidal bore and thus a restricted economic benefit
    - Potentially limiting physical effect on the costs associated with maintaining storm sewer lines free from silt deposits
    - Potentially limiting effect on reducing flood risks
    - Perceived reversibility of this option owing to the fact that the gate structure remains intact
    - Socio-economic implications of not proceeding with the "ideal option" (Partial Bridge) to restore the river, its estuary, and the tidal bore.
  - Thus, the Riverkeeper believes it is premature to suggest that the Partial Bridge may not be required, and that acceptable fish passage "should not require resorting to" this option
- Several statements were made regarding the tidal bore:
  - The tidal bore, seen from the Moncton Bore Park was one of the earliest tourist attractions in Atlantic Canada (Bore Park established in 1907)
  - The Petitcodiac River Tidal Bore was recognized internationally, and was featured on the front page of the "London Illustrated News" in 1910 along with the Qiantang River bore, and described as one of the "Natural Wonders of the World"
  - Before construction of the causeway, the tidal bore was considered to be one of New Brunswick's and Moncton's best known tourist attractions
  - Since the 1960s, tidal amplitudes have increased and will continue to rise into the next century. Stronger tidal amplitudes create stronger conditions for a tidal bore
  - Other tidal bore producing estuaries in the world, unaffected by human interference, continue to produce equal or larger bores than was the case in the 1960s.
  - The Qiantang River Bore in China, described as the world's most impressive (2 m+) attracts yearly over 250,000 tourists and residents to a 3-day festival which is the key anchor attraction in that region's tourism destination strategy
  - Apart from the Inner Bay of Fundy, only one other estuary in North America is known to produce tidal bores: Cook Inlet in Alaska
  - A relatively unknown tidal bore in the 1960s, the Shubenacadie River, in now the focus of a multi-million dollar industry (river zodiac adventures) and considered the key anchor attraction in that region's tourism destination strategy.
  - Based on visitation numbers to other regional attractions (Hopewell Rocks – 200,000 visitors; Bouctouche Dune – 250,000 visitors) and the fact that under current conditions the Moncton tidal bore still attracts 40,000-50,000 visitors annually, it is conceivable that a restored tidal bore, adequately promoted, could attract 200,000+ visitors and be considered one of New Brunswick's top tourist attractions
  - Peak viewing times for the tidal bore occur during the tourism shoulder season (late March to mid-June, September-November)

- [Editor's Note: A number of specific comments were made re recommendations that are no longer part of the report. Since these refer to the draft report rather than the final version, they will not be repeated here.]

- Conservation Council of New Brunswick (5 pages of comments signed by J. Harvey, Marine Conservation Director)
  - Concerned about the narrowness of the mandate to consider fish passage as opposed to river or habitat restoration. Even with this constraint, the "long term viability" of the options is not fully considered. Out of 5 possible options only the Status Quo has been ruled out. This is despite evidence that Replacing the Fishway and Gates Open during Peak Migration options have little chance of long term viability.
  - Replacing the Fishway option:
    - Experience and the best judgement of a number of scientists and consultants suggest this option is "technically speculative". No basis for judging its long term (say, 50 years) viability. Sedimentation would continue to be a problem.
    - This should be ruled out as an option.
  - Gates open during Peak Migration:
    - This will unnecessarily limit the ability of all species to optimize their use of the river. Downstream passage is not accomodated, nor is the passage of "fish unlucky enough to attempt to navigate the river outside peak times".
    - Not viable over the long term since it requires a high degree of ongoing management and monitoring. Also, this requires a much greater degree of knowledge of fish and their utilization of the river and estuary than we currently possess.
    - Described as "yet another speculative experiment that is unnecessarily constrained by the externally imposed goal of trying to maintain some semblance of a head pond. This is exactly the trap that the 1998 and 1999 gate openings fell victim to. The mistake should not be repeated."
  - Gates open permanently:
    - A much more realistic opportunity for viable fish passage. The long term viability of the river and therefore of the species that inhabit it, remains in question.
  - Partial bridge:
    - This option has the best chance of providing a long term, viable option for fish passage..."the most fail-safe option".
  - The Petitcodiac River has suffered through three decades of tinkering with this or that to improve the conditions for fish, all to no avail. It's time to get beyond this and adopt a strategy which has a high possibility of success.
  - The recommendations in the draft report are contradictory: The first recommendation is to propose that Partial Bridge be the project submitted for EA review. The concluding statement is that "providing for adequate fish passage, in my view, should not require resorting" to the Partial Bridge option.
  - Specific comments were made regarding each of the recommendations in the draft report. Since some of these recommendations changed in the final report, the comments will not be repeated here.

    - CCNB concurs with the "substantial brief" prepared by Petitcodiac Riverkeeper in response to the draft report
- Alma Fisherman's Association (3 page letter signed by J. Wood)
    - "The association remains convinced that the construction of the causeway has had a positive effect on the marine ecology of the lower estuary, Shepody and Chignecto Bays". These areas have become extremely productive of lobster and scallop in the past 15 years. Possibly true for other species as well, no data available.
    - Supports the necessity of an EA. The lack of consensus of scientists to which the report refers may be partly due to "their virtual complete lack of knowledge" of the lower estuary and the bays. Without study of this area it is impossible to assess the system as a whole. DFO has stated intentions to open the gates since at least 1980, this makes it difficult for any DFO staff to support other options and no resources have been allowed to study the downstream area. "This is not right nor in the overall interest of the ecological future of the area".
    - The recommendation of a Partial Bridge is the "worst case scenario and not acceptable".
    - Essential that any EA be developed with input from all, and accepted before any further activity goes ahead.
    - The Association does not support opening the gates. Leachate and sewage issues must be examined. Dilution is not the solution. Contamination from the dump has potentially catastrophic results for the fishery.

O'Neill, H.J., H. Dupuis, B. Burrell and D. Sullivan. 1998. Petitcodiac River trial gate opening project. Pages 101-104 *in* Burt, M.D.B. and P.G. Wells (eds.) Coastal monitoring and the Bay of Fundy. Proceedings of the Maritime Atlantic Ecozone Science Workshop, St. Andrews, NB, November 11-15 1997.

The history of the Petitcodiac causeway was summarized, and the "Memorandum of Understanding Respecting a Trial Opening of the Petitcodiac Causeway Gates" of December 5, 1996 was briefly described. Project activity in 1997 was described; this focussed on installation of erosion control measures, development of the environmental monitoring plan, collection of baseline data, and development of a gate management plan. The scope of the planned 1998 Trial Opening Project was described.

Sackville Rod and Gun Club, Shepody Fish and Game Club, Petitcodiac Sport's Club, Moncton Fish and Game, Albert County Hunters, Université de Moncton, New Brunswick Department of Natural Resources and Energy. 1995. Fish, fish habitat and sport fishery study for selected streams in the Shepody Bay watershed with recommendations for management. Unpublished progress report, April 1995. (For Canada/New Brunswick Recreational Fisheries Program). 121 p.

Opportunities for restoration and enhancement of a recreational fishery in the rivers which comprise the Shepody Bay ecosystem were identified. The environmental and economic impacts of past manipulation of the following rivers in the Inner Bay were also discussed: Petitcodiac, Tantramar, Shepody and Memramcook. All of these rivers had experienced "dramatic declines in fish stocks due mainly to tidal control structures which have been built in the estuaries". The fish stocks discussed were sea trout, striped bass, eels, shad, gaspereau, smelts, tomcod, sturgeon, Atlantic salmon, non-anadromous trout, perch and rainbow trout. The document was prepared from the input of various non-profit groups involved in the enhancement of the above rivers. Only the comments on the Petitcodiac will be summarized here.

The Petitcodiac was considered to be the most studied of the rivers. Pre-causeway production was stated to be 200,000-250,000 shad annually, and early Acadian populations salted 1,500 barrels of shad for winter consumption. The commercial shad fishing industry in 1992 had a landed value of $45,000 according to ADI (1992). Local catches were adversely affected by reduced turbidity associated with the causeway. Because the entire shad population of North America feeds in Shepody Bay in summer, negative environmental changes in this area have effects which extend far beyond the mouth of the rivers. A remnant shad population still existed in the Petitcodiac in 1988, according to a DNRE observation.

The former shad run provided a viable sport fishery in the broad slow moving waters of the lower rivers within the Petitcodiac system.

Gaspereau were also present and considered important to the food web in the Petitcodiac ecosystem.

Smelt were also "vital" in the food chain, and supported a recreational dip net fishery in the rivers.

There was no estimate of the striped bass populations. A "recent request" by commercial shad fishermen for a bass harvest permit indicated that they were still present in the estuary. Native river stocks were unknown. The species appeared at the base of the control gates when gates were open for headpond adjustments. No adult striped bass had been recorded at the fishway since 1989. However, a few juveniles had been noted in the main river and Halls Creek.

Sea trout were regularly taken in the spring but their appearance and numbers was greatly influenced by rainfall and the need to open the control gates for water level adjustments.

Large sturgeon were taken in the shad drift net fishery, as of 1993.

The production potential of the Petitcodiac River system was stated as 5,000-6,000 Atlantic salmon annually, from Pettigrew (1986). To meet this target, 2,500 fish would need to spawn annually. Recreational angling in the Petitcodiac system was estimated to be worth $850,000 annually, by Washburn and Gillis (1986).

Over a three week period in 1991, over 3.6 tonnes (8,000 lb) of American eels were harvested from the Petitcodiac estuary in a commercial fishery. In 1992 and 1993, “this fishery has all but collapsed”.

In the Greater Moncton area, 10,500 sport fishing permits were purchased annually (DNRE data, 1989). There was no available sport fishery in the area which was easily accessible to this large population of anglers.

The results of the Atlantic salmon stocking that had been going on since 1979 were described as “dismal”.

Appendix F of the report provides stream survey information for the Coverdale (Little) River from a study conducted in 1994. In total 14 reaches were surveyed, and information on habitat type (proportion of riffle, rapid, run, and pool habitat, pool type, substrate, vegetation, and amount of woody debris) are tabulated. Temperature, flow rate, pH, total phosphate, calcium and alkalinity are summarized for five sites in August-September 1994.

Appendix H includes a letter from C.A. Bleakney, Fishery Warden, to C.R. Lavoie, which presents information on the timing and numbers of salmon in the system. (Bleakney, C.A. 1970. Letter to C.R. Lavoie, Canadian Dept. of Fisheries and Forestry, Moncton. Sept. 1 1970. 2 p.) In 1966 during the week ending July 30, he saw more than 20 salmon in the Power Pool to Mitton Pool area. During the week ending August 20, hundreds of salmon died on the mud flats in this area due to the very low, warm water at that time, and the high tides. Three salmon were hooked on fly during the week ending August 20, and three more during the next week. In 1967, he saw more than 60 salmon in the Tait Stretch and almost as many more in the Salmon Pool during the week ending August 26, and there were many more scattered in the smaller pools. There was also at least twenty taken on fly during the month of August that year. He had seen “a goodly number of salmon in this area in June” [Editor’s Note: year unknown] and in another year [Editor’s Note: this year also not identified] a good number had been taken on fly in the last week of July. In 1953 his records showed salmon in the area on July 14, and by August 31, nine of these had passed through the trap in the Sanatorium Dam, 13 had been taken by fly, and more than 30 salmon were in the pool below the Sanatorium Dam on August 28. In 1957, his first salmon sighting was on July 9. On July 20, he had covered the Petitcodiac River by boat from Sentell Rapids to Nelder Pool and saw 26 salmon. On August 24, he patrolled the Petitcodiac River from the mouth of the Pollett River to Mitton Pool and saw more than 200 salmon from a row boat. The Research department moved 97 salmon from pools in the Petitcodiac and Coverdale Rivers, by truck, to the Pollett River above the Forest Glen dam, and another 86 salmon were counted through the trap in the Sanatorium Dam fishway, all before the end of August.

The following reports, which are included as appendices, are abstracted separately:

- Griffin, G. 1994. A watershed plan for restoration development and management of diadromous fish stocks in the rivers composing the Shepody Bay ecosystem. [abstracted here]
- Ritter, J.A. 1991. Effects of Moncton-Riverview causeway on anadromous fish stocks of the Petitcodiac River. [abstracted in Locke and Bernier 2000]

Sentinelles Petitcodiac Riverkeeper. 2000. A discussion paper on restoration options for the Petitcodiac River. Unpublished manuscript, Petitcodiac Riverkeeper, Moncton. March 14 2000. 15 p.
Available at:
www.petitcodiac.org

Various options are presented for restoration, using the 1992 ADI Ltd. report as a base and adding observations from the past few years. Estimates are 1992 figures and are based on a 10-year time-line projection. The optimum conditions for the restoration of the Petitcodiac River would be obtained from an option that fulfilled the following criteria:

(1) restoration of conditions to allow free flow and the recovery of ecological integrity in the Petitcodiac River system and Shepody Bay estuary
(2) restoration of conditions to allow "approximately 100%" tidal exchange and nutrient supply to the estuary
(3) restoration of conditions to allow maximum fish passage for anadromous fish species in the Petitcodiac River system, and the restoration of critical fish habitat
(4) restoration of hydrological conditions to allow maximum recovery of the Petitcodiac River tidal bore and the river channel functions.

Detailed costs and benefits, both quantifiable and intangible, are presented for each option.

The present situation (status quo) was not considered to be an option for restoring free flow, fish passage and the ecological integrity of the river system. Under the assumption that the quantifiable gain from the status quo was $0, the net quantifiable cost was estimated at between 1.5 and 3.5 million dollars. A long list of intangible losses was also presented.

Restoration option #1 was "Gates opened". By this it was meant that the gates would remain operational, be operated by a gate-keeper, and that measures would be in place to protect marshlands from flooding. The net quantifiable cost was estimated at 4 to 6 million dollars. This was described as the least desirable restoration option.

Restoration option #2 was "Partial bridge span". A bridge span of 250 m, which was about 25% of the original river width at the causeway site, was the length estimated to restore "approximately 100%" tidal exchange, based on hydrological estimates done in the ADI study. This objective has often been used by engineers and hydrologists when establishing parameters to "fully restore" river systems. Gates would be opened in Year 1 and the bridge operational in Years 3-5. The net cost of this option was estimated to be 15.8 to 12.8 million dollars.

Restoration option #3 was "Full bridge span". Gates would be opened in Year 1 and the bridge (1 km wide) operational in Years 5-7. The net cost of this would be 75.8 to 72.8 million dollars.

The preferred option was the partial bridge span. This option would restore the river more effectively than opening the gates. It would be much less expensive and should be just as effective as a full bridge span.

Sentinelles Petitcodiac Riverkeeper. 2000. No. 97 – An overview of 96 reports on the Petitcodiac River (1961-2000). No. 97 – Résumé de 96 rapports sur la rivière Petitcodiac (1961-2000). Unpublished manuscript, Petitcodiac Riverkeeper, Moncton, NB. June 29 2000. 73 p.
Available at:
www.petitcodiac.org

This report repeats verbatim 94 summaries of papers on the Petitcodiac River, from Locke and Bernier (2000), plus adds summaries of 2 new references. For readers interested in the effects of the causeway, this report condenses the more comprehensive bibliography presented by Locke and Bernier. Only reports published since the construction of the causeway, or that are related to the planning of the causeway are included, and they are listed in chronological rather than alphabetical order.

Sentinelles Petitcodiac Riverkeeper. 2000. Investigation Brief (Moncton Landfill). Unpublished manuscript, Petitcodiac Riverkeeper, Moncton, NB. December 5 2000.
Available at:
www.petitcodiac.org

The Moncton Landfill site was visited on October 16-17 2000. A pipe (designated as JC pipe) at the northeastern corner was discharging what appeared to be water, which then flowed over the ground for ~100 m and ultimately discharged to Jonathan Creek. Two seeps (locations where water emerges from the ground) (designated S-1 and S-2) along the eastern face of the landfill mound also discharged directly to Jonathan Creek. Several pipes emerging from the toe of the waste mound along the southern edge were thought to have been installed for the purpose of conveying leachate to the marshlands adjacent to the northern shore of the Petitcodiac River.

Water and sediment samples collected at the JC Pipe and S-1 on July 19 2000 and at S-1 on July 20. All three water samples were lethal to *Daphnia magna* in a 48-hr bioassay. Two of the samples contained high concentrations of Total Ammonia was 108-133 mg/L. The estimated concentration of unionized ammonia (the most toxic form) would have exceeded the Canadian Water Quality Guideline for the Protection of Freshwater Aquatic Life (FAL) and may have exceeded the LC50 (concentration at which a substance is toxic to 50% of the test organisms). PCBs were not detected in the two sediment and water samples collected on July 19.

Water and sediment samples were collected from the JC pipe on October 25. A rainbow trout bioassay test found that trout became stressed immediately and died in less than 24 hr when exposed to 25-100% concentrations of the water sample. High ammonia levels were again present in the water sample. Other substances found in the water sample were 4,4-DDT (0.040 mg/L), petroleum hydrocarbons indicative of gasoline, benzene (9.3 µg/L), toluene (7.0 µg/L), xylenes (94.0 µg/L), ethylbenzene (46.0 µg/L). Only toluene exceeded the FAL (by 2.5 times). PCB Aroclor 1242 was present at 0.04 ppm in the sediment sample; the Canadian Sediment Quality Guideline for the protection of freshwater aquatic life is 0.06 ppm.

Metals were analysed in 3 sediment samples: JC Pipe and S-1 sampled on July 19 and JC Pipe sampled on October 25. The guidelines were exceeded for arsenic. The guidelines were not exceeded for cadmium, lead, chromium, copper, mercury and zinc.

St-Hilaire, A., A.R. LeBlanc, T. Milligan, H. Dupuis and G. Bourgeois. 2000. Monitoring of turbidity in the Petitcodiac River in 1999. Pages 257-281 *in* Environmental Monitoring Working Group. Environmental Monitoring of the Petitcodiac River system, 1999. Petitcodiac River Trial Gate Opening project. October, 2000. 308 p.

Turbidity data were gathered at the same 3 sites as during 1997 and 1998, using nephelometers suspended from surface buoys (Dover, headpond near boat launch) or moored on an abandoned wharf (downtown Moncton). Recording took place from April to November, with interruptions due to battery failures and theft of equipment.

Suspended sediment concentrations at Dover varied between 0 and 6.9 g/L. Lower concentrations occurred at or near slack water. Maxima during neap tides appeared to be < 5 g/L, while maxima during spring tides were >5 g/L.

Suspended sediment concentrations in downtown Moncton varied between 0 and 11.8 g/L. Daily maxima during spring and neap tides were >9 g/L and <8 g/L respectively.

Suspended sediment concentrations in the headpond varied between 0 and 3.4 g/L. Concentrations were high during April and May, and decreased to <0.3 g/L from June to mid-August. Sediment concentrations exceeded 2 g/L on three subsequent occasions in late August and in November, but were not recorded during the heavy rainfall of September 23-26.

Wells, P.G. 2000. Environmental impacts of barriers on rivers entering the Bay of Fundy. Pages 15-22 *In* J. Percy and J. Harvey (eds.) Tidal barriers in the Inner Bay of Fundy: Ecosystem impacts and restoration opportunities. Proceedings of a workshop, April 14-15 1999, Moncton, NB. Conservation Council of New Brunswick Marine Conservation Program. May 2000.

This is essentially a brief overview of the longer report by Wells (1999) (see Locke and Bernier, 2000, for the reference). It was noted that the causeway/dam issue has been with us since at least the end of the 1800s. The types of barriers and observed effects were reviewed. There are at least 26 dams and 10 causeways on 25 of 44 medium or large rivers flowing into the Bay of Fundy. This is probably an underestimate if smaller tributaries of these rivers were also considered. In New Brunswick, 39% of Fundy rivers have barriers with major ecological impact, 33% have barriers with some ecological impact, and 28% have no barriers. In Nova Scotia, 19% have major ecological impact, 27% have some impact and 54% have no barriers.

The following effects have been confirmed as being due to barriers:

- length of tidal system is reduced
- volume of brackish and salt water moving upstream into the system is reduced
- hydrodynamics of water entering estuaries and bay is impeded
- downstream effects occur, such as sedimentation and accumulation of deposits of sediment
- the area of open coastal salt marsh is reduced
- movement of migratory fish is impeded.

It is further hypothesized that the quantities of carbon and nutrients entering the bay, and their recycling, are reduced by the presence of tidal barriers.

The major recommendations of the report are:

- Strengthen the data and information base on the condition of individual rivers and their estuaries.
- Verify changes in the river flow characteristics.
- Model changes in a number of river systems to test the hypothesis of the potential of a system wide cumulative effect occurring in the bay due to the barriers being in place.
- Determine the beneficial effects of remediation both on single rivers such as the Petitcodiac, and other river systems.

Zahner-Meike, E., and J.M. Hanson. 2001. Effects of muskrat predation on Najads. Pages 163-184 *In* G. Bauer and K. Wächtler (eds.) Ecology and evolution of the freshwater mussels Unionoida. Ecological Studies Vol. 145. Springer-Verlag, Berlin.

Freshwater mussels from muskrat middens in tributaries of the Petitcodiac were measured and aged in order to examine the impacts of predation. Muskrat predation was not, overall, a major factor causing mortality although there were some major effects on a local scale. It could result in conservation problems, however, in cases where rare species are the target prey.

Muskrat predation on *Margaritifera margaritifera* was examined at two sites in the Little River for which the stream characteristics are described in some detail. Shoreline sites at three impoundment or ponds were studied, where muskrat middens contained shells of *Pyganodon cataracta*: a site on Turtle Creek near the Highway 112 bridge crossing (within the area flooded by the Petitcodiac headpond), an artificial pond on the North River near Second North River, and a reservoir in the headwaters of the Little River. Conditions and vegetation at these sites are described.

Only *M. margaritifera* was present at the two Little River running-water sites. Almost all individuals <75 mm in length were eliminated from the site with muskrat predation. *Margaritifera* that were > 110 to 115 mm in length appeared to be immune to muskrat predation. There was no evidence of predation in spring or early summer, but clear evidence by mid- to late summer. Predation was most likely the result of seasonal dispersal of juvenile muskrats. There did not appear to be sufficient vegetation in the river to support muskrats year-round. It was unlikely that muskrats could overwinter in this area due to a lack of other food types but suitable habitat occurred several km upstream.

P. cataracta was almost the only species found at the impoundment or pond sites. In contrast with the case for *Margaritifera*, muskrats selectively removed the largest *Pyganodon*; specimens up to 130 mm were eaten. Relationships of total weight, shell weight and meat weight are presented for both species. *Margaritifera* >110 mm long may be too heavy for muskrat to handle. *Pyganodon* has a much thinner shell than *Margaritifera* and is probably a more profitable prey for the muskrats.

The impact of muskrat consumption of *Pyganodon* varied between the near elimination of the entire population in a small pond (aided by overgrowth by the macroalgae *Chara*) and an amount representing an insignificant proportion of a population of millions of animals in the Petitcodiac headpond. The impact of muskrats on *Margaritifera* in the Little River was also expected to be minor compared to the estimated half-million mussels of this species living in the river.

Specimens of *Pyganodon cataracta* up to 17 years of age were collected in the Little River near Prosser Brook [the oldest specimen of this species found in the headpond was aged 9 years].