HYDRO-QUEBEC'S DAMS HAVE A CHOKEHOLD ON THE GULF OF MAINE'S MARINE ECOSYSTEM

By Stephen M. Kasprzak

January 15, 2019

PREFACE

I wrote an October 15, 2018 Report "The Problem is the Lack of Silica," and a November 28, 2018 Report, "Reservoir Hydroelectric Dams - Silica Depletion - A Gulf of Maine Catastrophe."

The observations, supplements and references in this Report support the following hypothesis, which was developed in these two earlier Reports:

Hydro-Quebec's dams have greatly altered the seasonal timing of spring freshet waters enriched with dissolved silicate, oxygen and other nutrients. This has led to a change from a phytoplankton-based ecosystem dominated by diatoms to a non-diatom ecosystem dominated by flagellates, including dinoflagellates, which has led to the starvation of the fisheries and depletion of oxygen and warming of the waters in the estuaries and coastal waters of the Gulf of St. Lawrence, Gulf of Maine and northwest Atlantic.

Physicist Hans J. A. Neu offered a similar hypothesis in his 1982 Reports and predicted the depletion of the fisheries by the late 1980's and a warming of the waters.

Anyone who wants to question this hypothesis has to also question more than 40 years of research, which the passage of time has documented the earlier research and predictions as correct.

If you stopped burning fossil fuels tomorrow, it will not stop the starving of the fisheries . This will only happen if you release the chokehold on the rivers and allow the natural flow of the spring freshet and the transport of dissolved silicate and other essential nutrients. The high outflows of the spring freshet will also strengthen the density current (haline circulation) and restore the natural balance in the mixing of Labrador Current and Gulf Stream waters and help cool the waters.

It should also help to reduce ocean acidity as larger and heavier silica-encased diatoms would sequester more carbon to the bottom of the ocean.

Climate change is not the only force destroying the Gulf of Maine, and it is time to recognize that hydroelectric reservoir dams may be part of the problem. Mr. Hue wrote the following in his 1982 Report:

> *"In conclusion, fresh water regulation may prove to be one of the most consequential modifications man can impose on nature. If we do not alter our course and give consideration to nature's needs there will be irreparable injuries inflicted on the environment for which future generations will condemn us.."*

My hypotheses can easily be tested by taking core samples in the bottom of the reservoirs and measuring dissolved silicate concentrations in the discharged waters from these reservoirs.

DEDICATION

This report is dedicated to Hans J.A. Neu.

He was a Senior Research Scientist with the Canadian Department of Fisheries and Oceans at the Bedford Institute of Oceanography , Dartmouth, Nova Scotia. A specialist for 27 years in estuarine and coastal hydrodynamics, he has studied the physical oceanography of the major waterways across Canada as well as on the continental shelf and north-west Atlantic. He died on January 28, 2009 at the age of 83.

His 1982 Reports "Man-Made Storage of Water Resources – A Liability to the Ocean Environment? Parts I and II" were published in Marine Pollution Bulletin Vol. 13, No. 1 and No. 2 and printed in Great Britain.

In 1982, Mr. H. Neu predicted the depletion of the fisheries and explained how reducing spring flows would negatively impact the transport of nutrients to the estuaries and coastal waters via the rivers and also from deep ocean waters via haline circulation and/or density currents.

The magnitude of this density current is fueled by fresh water entering the ocean via our rivers. *"In estuaries the density current varies with seasonal run-off, being at a minimum during low discharges in the winter and at its peak in spring and summer. In coastal waters which are some distance away from the fresh water sources (i.e. the Grand Banks the Scotian Shelf and Georges Bank)* and Gulf of Maine (added by me) *there can be delays of from several months to almost a year before the freshwater peak arrives*" (Hue Part 1 1982)

A February 9, 1977 article in the Sherbrooke Record in Quebec appears on page 4 and illustrates why I am dedicating this report to Hans J.A . Neu. It is very disquieting that the politicians, scientists and media failed to support his recommendations for more studying.

He was obviously right as proven by the collapse of so many fisheries by the late 1980's and the warming of the waters of the Gulf of Maine and St. Lawrence as well as the northwest Atlantic, which has been brought on by a much weaker density current due to the proliferation of reservoir hydroelectric dams by Hydro-Quebec over the past 70 years

He predicted in the 1970's and early 1980's the following negative impacts of reservoir hydroelectric dams:.

1. *"Far reaching consequences on the life and reproduction cycle in the marine environment of the region affected,"*(see Section II, on page 11.)
2. *"the next big decline (in fisheries stock) probably will be in the early or mid-eighties"* and *"will be worse, since regulation will have increased further in the meantime,"* (see Section II on page 11.)
3. *"There is a definite possibility that both winter and summer temperatures of the surface layer will increase; in winter due to an increase in upwelling of deeper warmer water, and in summer due to slower surface currents which will allow the surface layer to absorb more heat during its passage through the system. It can be assumed therefore that fresh water regulation modifies the climate of the coastal region to be more continental-like in the summer and more maritime-like in the winter."*(See Sections X-XIII on pages 22-24.)
4. *"Even if we cannot yet measure the effects with certainty in our own marine environment, similar changes must already have happened to the coastal waters of Atlantic Canada and the effect must increase as regulation of our rivers continues. Of particular concern is the increased development of hydro-power – under construction or in the design stage – in Labrador, Ugava Bay, James Bay and Hudson Bay, which are abound to threaten the productivity of the Grand Banks of Newfoundland." (See Section II on page 11.)*

Hydro dams blamed for decline in fish stocks

DARTMOUTH, N.S. (CP) — A physicist at the Bedford Institute of Oceanography says hydro-electric dams might be more to blame than overfishing for the decline of fish stocks off Atlantic Canada, and no new dams should be built until the effects are known.

Dr. Hans Neu told a seminar at the institute Tuesday that Canada, more than any other nation, has been building water control projects on its estuaries, and no one knows what effect they are having on the ocean into which the rivers flow.

Dr. Neu, whose studies have dealt with the physics of water circulation, urged biologists to carry out research to prove whether his belief is correct that dams are the chief cause of declining fish stocks.

He explained that dams disrupt the natural cycle by which nutrient-loaded fresh water flows from the rivers into the ocean.

In their natural state, rivers carry smaller flows during the winter, when precipiation is frozen as snow, and sharply increased flows after the spring thaw. This coincides with the life cycle of marine organisms, increasing food supplies as they come out of their winter hibernation and decreasing supplies when winter returns.

LEVEL CYCLES

But hydro-electric dams tend to level out the cycles, storing much of the spring and summer runoff in their reservoirs until winter, when consumer demand for power is greater.

This means that fresh-water nutrients reach the ocean in the winter, when the fish don't need them, and are lost into the barren depths beyond the continental shelf. In the ypring and summer the nutrient supply fails to increase as rapidly as is needed.

Interruptions of the fresh-water supply could have further effects, he said, by interrupting "haline currents"—currents set up by the meeting of fresh and salt water. If these currents were stopped altogether, he said, it is theoretically possible that the coastal waters could freeze over.

Dr. Neu cited a scientific study showing that Egypt's Aswan High Dam on the Nile, a hydro-electric and irrigation project, caused a decline in nutrients to the Mediterranean off Egypt, with the result that fishing dropped off sharply. The catch of sardinella had been 15,-000 tons in 1964 but declined to 4,600 tons in 1965 and only 554 tons in 1966. The dam also blocked passage of other marine life such as shrimp and eel.

MANY MAJOR DAMS HERE

Canada has more than 20 projects controlling flows at least as great as the Aswan High Dam, Dr. Neu said. There has been much concern over the effects these dams have on the inland environment, yet nobody has studied what harm they are doing to the ocean environment.

Neither the provinces who plan the projects nor the bankers who finance them could be blamed for wanting the dams to run profitably, he said.

"But shouldn't there be someone who will stand up and say: 'No, you can't do that.'"

He suggested construction of water-control projects be regulated internationally and that no new projects be permitted until their effects on the ocean are known.

SUPPLEMENTS

I. “*Hydro dams blamed for decline in fish stocks,”* in the Sherbrooke Record, Wed. Feb. 9, 1977 , pg. 4.

II. “*Maine study finds potentially* disastrous threat to single-celled plants that support all life,” Christopher Cousins, BDN Staff, June 10, 2012, pgs 7 & 8.

III. *“Hydroelectric dams are destroying the Gulf of Maine fishery,”* Roger Wheeler, Special to the Bangor Daily News, January 8, 2019, pgs 9 & 10.

IV. *“The St. Lawrence is Low on Air,”* Quebec Ocean Fact Sheet @, January, 2011, pgs 28 & 29.

V. *“Less and Less Oxygen in the St. Lawrence,”* Par Beatrice Riche, Editor of the Group for Research and Education of Marine Mammals, July 24, 2017, pgs 31 & 32.

VI. *“Hydroelectric dams produce green energy? Think again,”* Stephen M. Kasprzak, Editorial to Maine Sunday Telegram, December 23, 2018, pgs. 34-36.

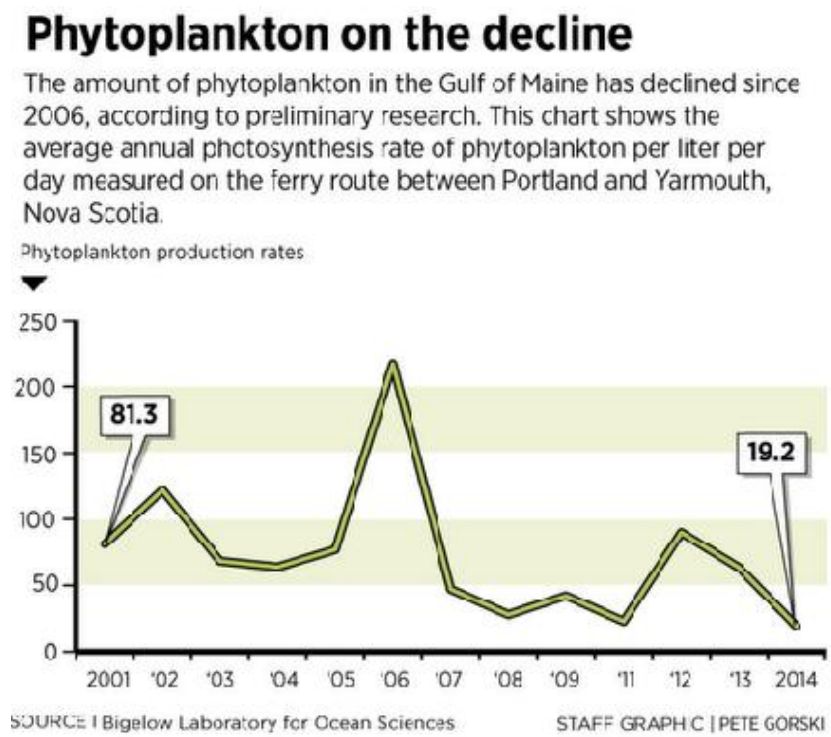
VII. *“Hydro-Quebec offers misleading claims about climate impact,”* Bradford H. Hager, Editorial to Portland Press Herald, January 5, 2019, pgs. 37-39.

VIII. *“Man -Made Storage of Water Resources – A Liability to the Ocean Envionment? Part II, “*by Hans J. A. Neu in Matine Pollution Bulletin, Volume 13, Number 2, pages 44-47, 1982, pgs. 40-43.

SECTION I   PHYTOPLANKTON IS ON THE DECLINE IN THE GULF OF MAINE

This Report and my two previous ones are focused on Hydro-Québec's reservoir hydroelectric dams and how they have negatively impacted phytoplankton, fisheries and water quality in the Gulf of Maine and its watershed, which includes the Gulf of St. Lawrence, James and Hudson Bays, and Labrador Sea.

The following graph, illustrates that phytoplankton biomass in the Gulf of Maine has fallen by 75%.



In the newspaper article, reprinted on the next two pages, Mr. Balch reasoned that above normal rainfall could be impacting phytoplankton regeneration rates.

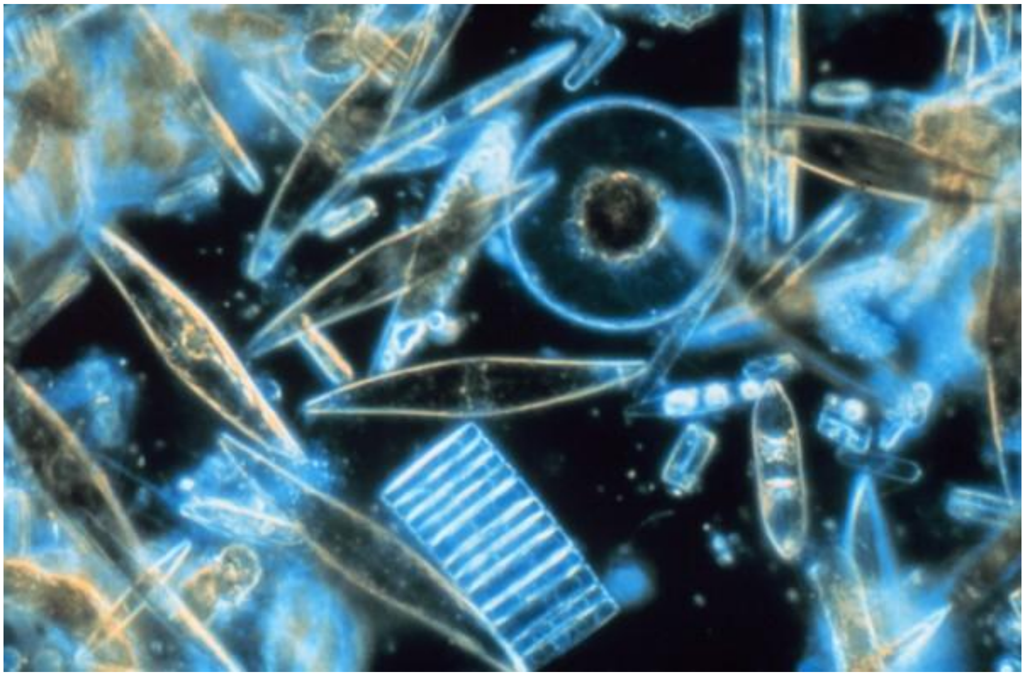
Above normal rainfall would be beneficial to phytoplankton regeneration rates by transporting more beneficial dissolved silica and nutrients to the coastal waters.

I believe the driving force of lower regeneration rates is the elimination of the "spring freshet" discharge into Gulf of St. Lawrence, James Bay and Hudson Bay and Labrador Sea.

The "natural" spring freshet of the Manicougan River as shown in Fig. 8 on page 16 has been eliminated. This freshet had a peak flow in l976 of about 3500 cubic meters per second (124,000 cubic feet per second) and the freshet began around April 1st and lasted into June. These freshets have been eliminated on hundreds of rivers by the reservoir hydroelectric dams listed in Tables 1-3 on pages 14 and 15.

In a 1980's study by Therriault and Lavasseur on Lower St. Lawrence Estuary they observed "*At high discharge rates (spring and fall) the whole Lower Estuary forms a single freshwater plume.*"

Maine study finds potentially disastrous threat to single-celled plants that support all life



Diatoms are one of the most common types of phytoplankton.

By Christopher Cousins, BDN Staff • June 10, 2012 5:02 pm

BOOTHBAY, Maine — Phytoplankton. If the mention of the tiny plant organisms that permeate the world's oceans isn't enough to pique your interest, consider this: They produce the oxygen in every other breath you take.

Still not interested? This is where it's hard not to take notice. In 2007, the reproduction rate of phytoplankton in the Gulf of Maine decreased suddenly by a factor of five — what used to take a day now takes five — and according to a recently released study by the Bigelow Laboratory for Ocean Sciences in Boothbay, it hasn't bounced back.

So what does it mean? According to Barney Balch, the lab's senior research scientist and lead author of the study, such a change in organisms at the bottom of the planetary food chain and at the top of planetary oxygen production could have disastrous consequences for virtually every species on Earth, from lobsters and fish that fuel Maine's marine industries to your grandchildren. But the 12-year Bigelow study focused only on the Gulf of Maine, which leads to the question, will it spread?

"I don't think it takes a rocket scientist to know that if you shut down the base of the marine food web, the results won't be positive," said Balch.

Balch said the study, which was published recently in the Marine Ecology Progress Series, provides one of the strongest links to date between increases in rainfall and temperature over the years and the Gulf of Maine's ecosystem. Key factors in the study's conclusions were driven by 100 years of records on rainfall and river discharge, both of which have increased by between 13 and 20 percent over the past century.

In fact, of the eight heaviest rainfall years in the past century, four of them fell between 2005 and 2010. Balch said that increased precipitation, along with water melting from the polar ice caps, could be the reason for the problems discovered in the phytoplankton regeneration rate. The fact that Gulf of Maine's water temperature has risen about 1.1 degrees Celsius — which is on par with what is being seen around the world — could also be a factor.

"The major change that we're seeing is that we are now able to put [precipitation and temperature data] into better context," said Balch. "It's so striking that the increase is so statistically significant."

Though heavier water flows into the Gulf of Maine might be a major factor, Balch said it may actually be side-effects of that phenomenon — such as decreased salinity and increasing amounts of materials like rotting plant matter being swept up in the stronger currents — that are actually causing the problem. In other words, when the water is brown it's bad for phytoplankton because the added material in the water starves the single-celled plants of sunlight.

During the 12-year study, which focused on the area of sea between Portland and Yarmouth, Nova Scotia, researchers noticed that plumes of material coming from Maine rivers were reaching 70-100 kilometers into the ocean — farther than had ever been seen before. The outflows also prevent nutrient-rich deep-ocean water from circulating into the Gulf of Maine.

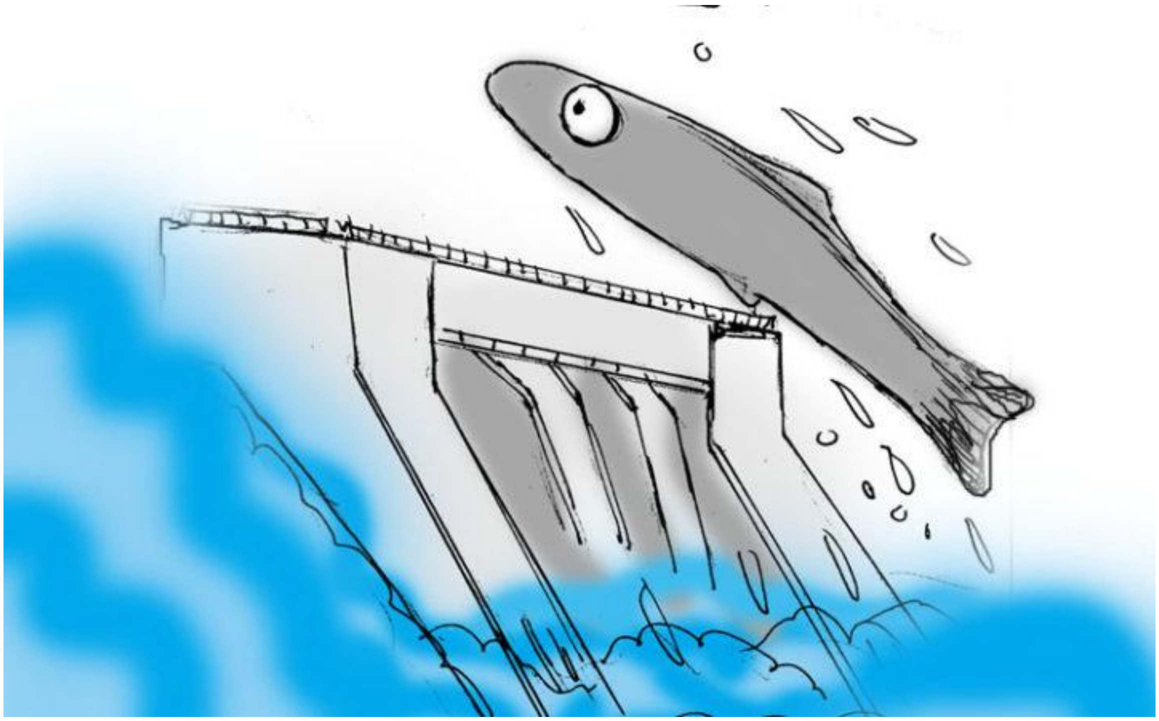
"When you collect the amount of data that we've collected, it's hard to discount the significance," said Balch. "I know there are skeptics out there who still discount the issue of climate change, but the evidence now is just striking. We need to be thinking very carefully about trying to slow this down. It didn't happen overnight and it's not going to go away overnight."

Balch said that the Gulf of Maine is small compared to the world's oceans, but not without the capacity to have a marked effect on the overall ecosystem of the Atlantic Ocean. If the problem with the phytoplankton persists, fishermen will notice its effects long before the world's oxygen supply suffers. Phytoplankton is a key food source for several species of larval fish and lobster populations.

"People shouldn't freak out about this but they should think very carefully about the long-term changes that we humans are making," he said. "This study shows the incredibly tight connection that there is between land and the ocean, especially in the coastal ocean."

THIS SPECIAL EDITORIAL TO THE BANGOR DAILY NEWS ON JANUARY 8, 2019 BY ROGER WHEELER EXPLAINS THE HOW AND WHY OF THIS DECLINE IN PHYTOPLANKTON IN THE GULF OF MAINE.

Hydroelectric dams are destroying the Gulf of Maine fishery



George Danby | BDN

By Roger Wheeler, Special to the BDN • January 8, 2019 9:08 am

In a June 10, 2012, BDN article, "Study finds potentially disastrous threat to single-celled plants that support all life on Earth," the late BDN reporter Christopher Cousins asked if the reader is interested in the rapid disintegration of the marine ecosystem. Yes, Chris, and although over six years late you have my full attention.

Since he wrote this compelling article, we now are aware that the essential nutrient of the most important single-celled plants is dissolved silicate and reservoir hydroelectric dams work to extinguish the annual free transport of this nutrient via the rivers into the ocean currents feeding the Gulf of Maine.

If we could magically engineer a tree that produces 10 times the oxygen of any existing equally sized tree on Earth, we would worship it. If we could engineer a tree that removes 40 percent of the carbon dioxide from the air and water and permanently buried its absorbed carbon in the depths of the soil, we would welcome it. With this special tree, we might have a fighting chance against accelerating global warming.

Here on Earth, there is a plant that is only 2 percent of the Earth's biomass but provides us with 20 percent of the oxygen we breathe. This plant removes a significant percentage of the carbon dioxide from the ocean and miraculously permanently sequesters the carbon it contains in the deep ocean sediments. This plant is the diatom, a phytoplankton, and it is a miracle "tree."

Tragically, we are destroying the diatom populations. Worldwide, diatom numbers, like other beneficial phytoplankton, are disappearing by about 1 percent per year. In the Gulf of Maine, phytoplankton, including diatoms, have decreased by a factor of five in just 17 years. Diatoms require adequate dissolved silicate to grow their heavy thick shells. Worldwide, the proliferation of tens of thousands of mega dams over the last 70 years is preventing silica and other important nutrients from reaching the oceans.

Ground zero for the impacts of dams is the Gulf of Maine. This area of the earth was the finest fishery because of its huge watershed delivering copious amounts of dissolved silicate annually to the Gulf of Maine. The rivers of New England, the Canadian Maritime Provinces and Quebec and Ontario all delivered nutrients like no other place on Earth. The St. Lawrence River, by discharge volume, is the second largest river in North America. Nothing is more important to estuaries and coastal water ecosystems than the seasonal timing and volumes of freshwater flow.

Now, the regulation of river flow in the US and Canada has moved to follow a highly unnatural policy of diminishing if not eliminating the nutrient delivering spring freshet, and maintaining low flows from spring through the fall while reservoir storage dams release high flows in the winter when flows were naturally at their lowest. In Canada, the size and numbers of dams and reservoirs are staggering.

Around the world and in Canada more hydro dam projects are planned. Not only do these dams change nutrient delivery in northern seas but they release vast quantities of warm reservoir water in the winter and eliminate the natural cold spring freshet waters. It is not surprising the Gulf of Maine is warming faster than any other ocean body. The numbers and sizes of the diatoms have been reduced as more and more reservoir dams have been discharging silica depleted water into the ocean currents that feed the Gulf of Maine. Unnatural freshwater flow regulation is a climate and marine ecological train wreck for the microscopic diatom to the noble right whale. Dams have weakened the natural function of diatoms to feed bountiful fisheries and reduce carbon dioxide levels.

We will not forget Chris Cousins' 2012 article and we will continue to sound this alarm.

Roger Wheeler of Standish is the president of Friends of Sebago Lake.

SECTION II REDUCING THE FLOW OF FRESH WATER DURING SPRING AND SUMMER WHILE INCREASING IT DURING WINTER CHANGES THE SEASONAL COMPOSITION OF THE RECEIVING WATERS IN ITS SURFACE LAYER AND THE SEASONAL STRENGTH OF THE DENSITY CURRENT.

> *"What is less well known is that upwelling is also generated by density currents associated with the excursion of large amounts of fresh water over coastal regions and continental shelves such as found along the Atlantic coast of Canada. The latter represents a continuous transport of nutrient laden water on a scale far surpassing that of Gulf Stream eddies."*

This was written by Mr. Hans Neu in a 1982 Report Man-Made Storage of Water Resources-A Liability to the Ocean Environment? Part II. I have reprinted Part II (see Pgs. 40-43) and have quoted Mr. H. Neu extensively from Part I of his Report.

I have read and reviewed thousands of Reports, and I would describe Mr.H. Neu as an Einstein in regards to estuarine and coastal hydro dynamics.

In 1982, he predicted the decline and eventual collapse of the fish stock of the Gulf of St. Lawrence.

> *"Life as we know it in our coastal waters and its level of productivity has evolved over thousands of years in response to these seasonal variations. Changing this pattern by reducing the flow of fresh water during the biologically active season of the year, or even reversing the cyclic flow altogether, represents a fundamental modification of a natural system. Such a modification must have far reaching consequences on the life and reproduction cycle in the marine environment of the region affected. Thus, it follows that storage schemes already implemented in Canada are having an impact on the biological resources of the Atlantic coastal region. Unfortunately, data to prove this quantitatively are masked by other possibilities. For example, a drastic decline in fish catches in the late sixties and early seventies is currently attributed to over-fishing in the internationally regulated area prior to the establishment of the Canadian 200 mile zone. In recent years, it appears that as a result of the reduced fishing pressure, some stocks are showing significant recovery. This fact, however, also happens to coincide with a period of increasing natural discharge in our river systems.*
>
> *As demonstrated by Sutcliffe (1972, 1973) and Sutcliffe et. al. (1976,1977), fish catches, especially in the Gulf, varied correspondingly, being larger during the fifties but smaller during the sixties with an increase in the seventies after allowing a delay of a number of years for the fish to mature. This implies that the low flow period of the sixties imposed stresses on the productivity of the system. Unfortunately, at the same time as the flow was at its lowest level, regulation was "stepped up from an average of 4000 m^3s^{-1} to about 8000 m^3 s^{-1} with the implementation of the Manicouagan-Outardes-Bersimis hydro-power complex. I contend that this further reduction in the spring flow was probably the final straw in the decline of the fish stocks._The larger flows of the seventies decreased the proportional effect of the regulation and gave the fish stocks an opportunity to recover. The next big decline probably will be in the early or mid-eighties when another low discharge period is predictable from the long term cycles (11 and 22 yr) of water levels in the Great Lakes. This decline however, will be worse, since regulation will have increased further in the meantime."*_ Neu Part II 1982)

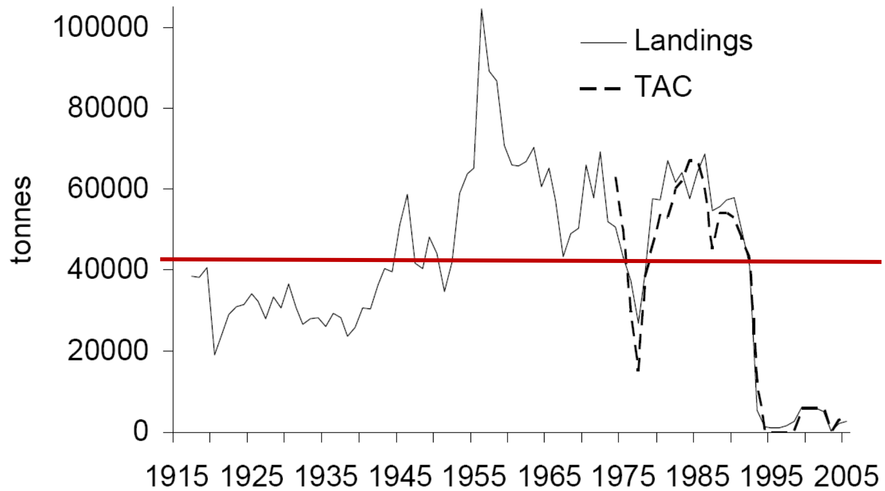


Figure 2: Landings and TAC (t) for the southern Gulf of St. Lawrence cod stock.

Source: Canadian Science Advisory Secretariat Science Advisory 2006/014
Assessment of Cod in the Southern Gulf of St. Lawrence, April 2006

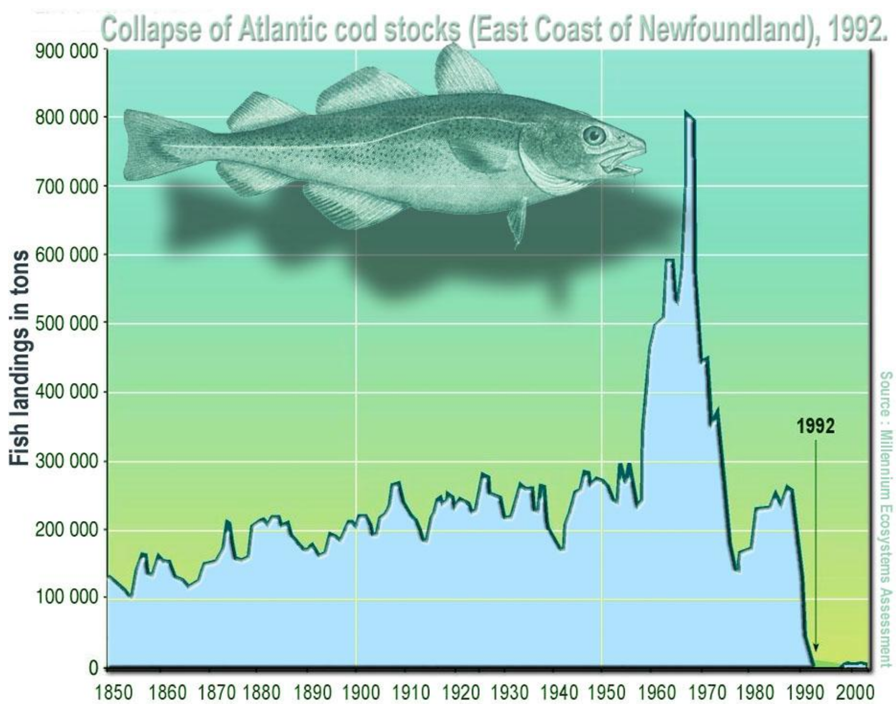
He also predicted the decline of the fishing stock of the Grand Banks of Newfoundland:

> *"Even if we cannot yet measure the effects with certainty in our own marine environment, similar changes must already have happened to the coastal waters of Atlantic Canada and the effect must increase as regulation of our rivers continues. Of particular concern is the increased development of hydro-power – under construction or in the design stage – in Labrador, Ungava Bay, James Bay and Hudson Bay, which are abound to threaten the productivity of the Grand Banks of Newfoundland.* (See Tables I - III.)
>
> *Until now it was assumed that hydro power is 'clean' with little or no impact on the environment, particularly that of the ocean. That this might not be the case is difficult to understand. Obviously, designing storage schemes and forecasting output of power is easier to grasp than to quantify the changes imposed on the population dynamics of the biota in the coastal region. There is the possibility that damages imposed by man-made lakes on the ecosystem may outweigh the benefits they provide. This is the crux of the problem. The prime task therefore is to establish a cost-benefit ratio in which all factors, also those which affect the ocean environment, as included. This should be a prerequisite for any further development."*
> (*Neu* Part II 1982).

The following appears in my October 15, 2018 Report: *"The Problem Is The Lack of Silica."*

STARVATION OF ATLANTIC NORTHWEST COD FISHERY

There have been two collapses of the Atlantic northwest cod fishery in the past fifty years, and they are illustrated in the graph below. Both collapses have been analyzed as one and the cause blamed on overfishing and global warming.



There is no doubt that overfishing caused the spike in cod landings during the 1960's and the subsequent decline in the 1970's.

However, the second and more lasting decline occurred in the 1989-1991 period. The major factor of this decline has been the lack of silica caused by the capture of the spring freshet in the reservoirs of hydroelectric facilities owned by Quebec Hydropower. These facilities have significantly reduced the transport of dissolved silica and other nutrients needed for healthy spring and summer diatom phytoplankton blooms in the northwest Atlantic and Gulf of Maine. Mr. H. Neu's predictions were correct, and thanks to Mr. H. Neu's Reports, we all know much more as to the how and why there was a lack of silica.

Table I

Reservoir Hydroelectric Generating Stations
Discharging into Estuary and Gulf of St. Lawrence River

Owner	Name	Capacity in Megawatts (MW)	Head (FT)	Commissioned	Watershed
Hydro-Quebec	Rapids Blanc	204	33	1934-35	St. Maurice
Hydro-Quebec	Bersimis-1	1,178	267	1956	Betsiamites
Hydro-Quebec	Bersimis-2	869	116	1959	Betsiamites
Hydro-Quebec	Jean-Lesage (Manic-2)	1,145	70	1965-67	Manicouagan
Hydro-Quebec	Outardes-4	785	121	1969	Outardes
Hydro-Quebec	Outardes-3	1,023	144	1969	Outardes
Hydro-Quebec	Outardes-2	523	82	1978	Outardes
Hydro-Quebec	Manic-5	1,596	142	1970	Manicouagan
Hydro-Quebec	Rene-Levesque (Manic-3)	1,244	94	1975-76	Manicouagan
Hydro-Quebec	Manic-5-PA	1,064	145	1989	Manicouagan
Hydro-Quebec	Sainte-Marguerite	882	330	2003	Saint-Marguerite
Hydro-Quebec	Touinstouc	526	152	2005	Touinstouc
Hydro-Quebec	Peribonka	405	68	2007-08	Peribonka
Hydro-Quebec	Romaine-2	640	156	2014	Romaine
Hydro-Quebec	Romaine-1	270	63	2015-16	Romaine
Hydro-Quebec	Romaine-3	395	119	2017	Romaine
		12,749			

Table II

Reservoir Hydroelectric Generating Stations Discharging
Into James Bay and Hudson Bay

Owner	Name	Capacity in Megawatts MW	Commissioned	Watershed
Manitoba hydro	Kelsey	287	1957	Nelson
Manitoba Hydro	Kettle	1,220	1970	Nelson
Manitoba-Hydro	Lang-Spruce	980	1977	Nelson
Manitoba –Hydro	Jenpeg	122	1979	Nelson
Hydro Quebec	Robert-Bourassa	5,616	1979-81	LaGrande
Hydro Quebec	LaGrande-3	2,417	1982-84	LaGrande
Hydro Quebec	LaGrande-4	2,779	1984-86	LaGrande
Manitoba-Hydro	Limestone	1,350	1990	Nelson
Hydro-Quebec	Brisay	469	1993	Caniapiscau
Hydro Quebec	LaGrande-2-A	2,106	1991-92	LaGrande
Hydro Quebec	Laforge-1	878	1993-94	Laforge
Hydro Quebec	LaGrande-1	1,463	1994-95	LaGrande
Hydro Quebec	Laforge-2	319	1996	Laforge
Hydro Quebec	Eastmain-1	507	2006	Eastmain
Hydro Quebec	Eastmain-1-A	829	2011-12	Eastmain
		21,342		

Table III
Summary of Tables 1 & 2
Annual Capacity in Mega Watts (MW) of Reservoir Hydroelectric
Generating Stations Discharging Into

	James Bay and Hudson Bay	St. Lawrence River	Labrador Current	Total
1930-39				
1940-49		204		204
1950-59	2,334	2,047		2,334
1960-69		2,953		2,953
1970-79	2,200	3,363	5,428	10,991
1980-89	10,812	1,064		11,876
1990-99	6,116	469		6,585
2000-2009	507	1,813		2,320
2010-2018	829	1,305		2,134
	21,220	12,749	5,428	39,397

SECTION III HYDRO-QUEBEC MANAGES ITS DAMS TO TRANSFER THE RUN-OFF FROM THE BIOLOGICALLY ACTIVE SEASON TO THE BIOLOGICALLY INACTIVE PERIOD OF THE YEAR.

> *"In higher latitudes during the winter, river run-off is at a minimum while power demand is at its maximum. This is shown in Fig. 7, where an average hydrograph and the seasonal power demand of a city in northern regions are plotted. As can be seen, water supply and power demand are out of phase by nearly half a year.*
>
> *Developers of electrical energy view this as an inconvenience of nature; thus they reverse the natural run-off cycle by storing the spring and summer flow in artificial lakes to be released during the winter. An example is shown in Fig. 8 for the Manicouagan River at Manic 5 power station (Neu Part I, 1982)."*

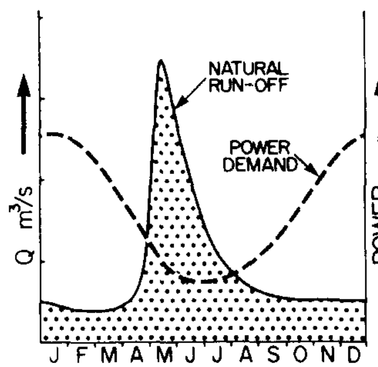


Fig. 7 Typical hydrograph and seasonal power demand.

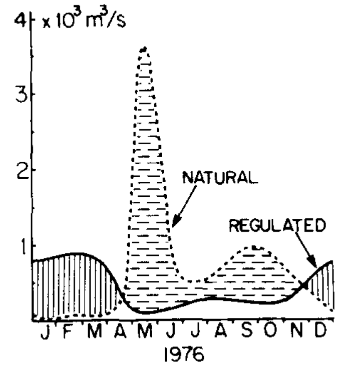


Fig. 8 Natural and regulated discharge of the Manicouagan River at Manic 5 power station.

SECTION IV THIS IS ANALAGOUS TO STOPPING THE RAIN DURING THE GROWING SEASON AND IRRIGATING DURING THE WINTER, WHEN NO GROWTH OCCURS (Neu Part 1, 1982).

Such an alteration in seasonal precipitation rates would be catastrophic for the world's ecosystem. The trees in our forests would die off and carbon sequestration through photosynthesis would suffer a devastating blow.

The farmer's crops and fields would be barren leading to widespread hunger and starvation of livestock and world's population.

Man-made storage of our rivers has destroyed our oceans in the same way, but unfortunately the destruction goes unnoticed and depletion of the fisheries has been buried under sparkling blue water on a sunny day.

SECTION V THE HYDROGRAPH IN FIGURE 1 SHOWS THE MANICOUAGAN RIVER DISCHARGE WITH A MAXIMUM IN MAY WHICH IS 30 TO 40 TIMES LARGER THAN DURING WINTER MONTHS OF JANUARY-MARCH.

"In northern latitudes, winter precipitation in the form of snow remains stored until the following spring. During this period, biological activities slow down and become dormant with little or no need for nutrients. With the onset of spring, the snow melts, creating large river flows particularly during the early part of the season. At the same time the annual growth cycle begins and the nutrients required to support the renewed activities are provided on the land by the fresh water directly, and in the ocean indirectly by increasing the entrainment of nutrient-rich deep ocean water into the surface layer.

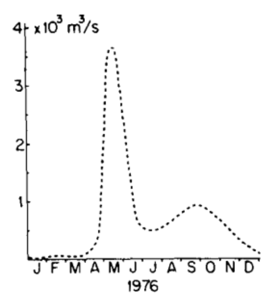
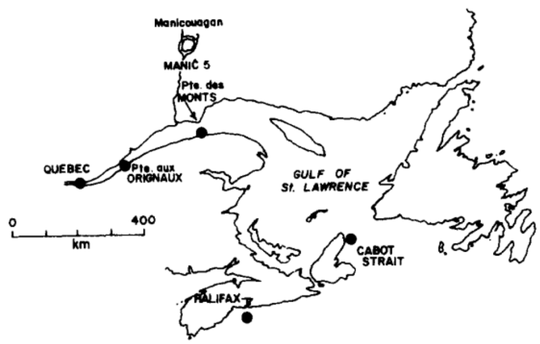


Fig. 1 Natural run-off to the Manicouagan River at Manic 5 power station.



Source: Neu Part I (1982)

A typical monthly run-off hydrograph of a snow-fed river is given in Fig. 1. It shows the Manicouagan River discharge with a maximum in May which is 30-40 times larger than during the winter months.

The seaward progress of the fresh water totals of the St. Lawrence and its tributaries, including the Manicouagan, is shown in Fig. 2a. These totals contain fresh water from melting surface ice which has formed in the system during the winter months. The estimated contribution at Cabot Strait is on the average about 4000 $m^3 s^{-1}$ and at its peak probably 6000, $m^3 s^{-1}$. The bulk of the spring freshet passes quickly through the estuary in May, then slows over the Magdalen Shoal in the southwestern Gulf in summer, and arrives at Cabot Strait by the beginning of August. From here it can be traced to Halifax and even to Georges Bank at the entrance to the Gulf of Maine in the autumn. (Man-Made Storage of Water Resources-A Liability to the Ocean Environment?"

(*Part* I, by Hans J. A. Neu 1982*).*

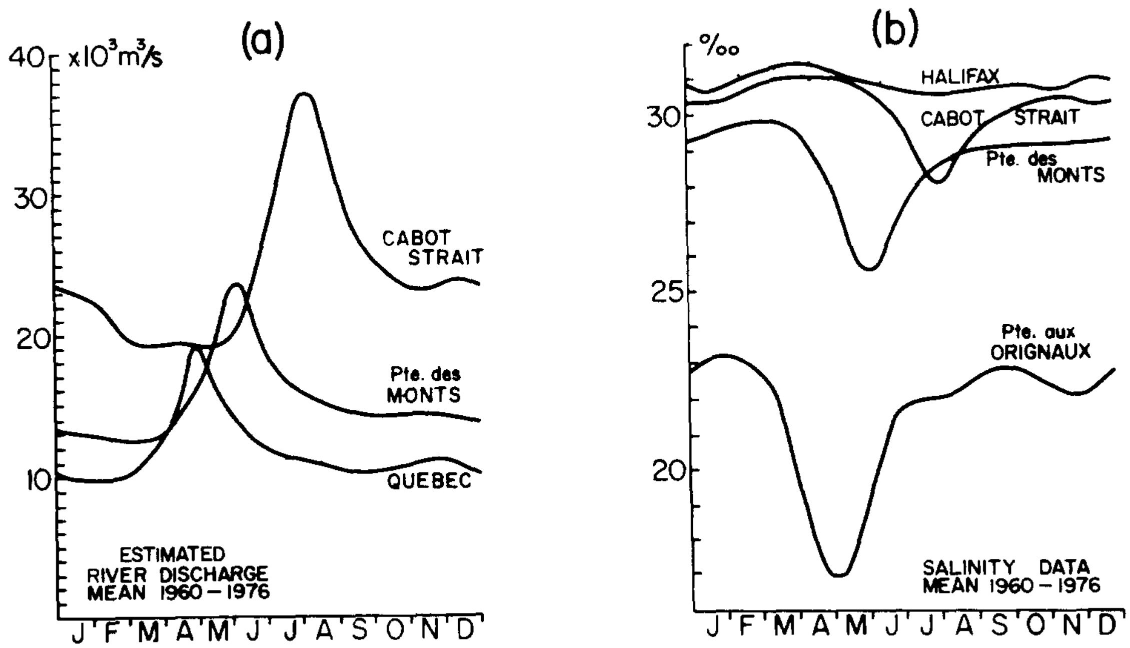


Fig. 2 Mean monthly (a) fresh water and (b) surface salinity variation for stations along the St. Lawrence system and Scotian Shelf.

Source: Neu Part I (1982)

SECTION VI MR. NEU PREDICTED IN HIS 1982 REPORT, "ARTIFICALLY STORING THE SPRING AND SUMMER RUN-OFF TO GENERATE POWER THE FOLLOWING WINTER MUST HAVE A SIGNIFICANT IMPACT ON THE OCEAN ENVIRONMENT AND ON THE CLIMATE OF THE MARITIME REGION."

> *"A primary reason for estuaries, embayments and continental shelves being among the most fertile and productive regions on earth is the supply of fresh water from land run-off which, on entering the ocean, induces mixing and the entrainment of nutrient-rich deep water into the surface layer. For temperate regions such as Canada, the natural fresh water supply varies sharply with season - being low during the winter when precipitation and run-off is stored as snow and ice, and very large during spring and early summer when the winter storage melts. Nearshore biological processes and adjacent ocean activities are attuned to this massive influx of fresh water - this is the time when reproduction and early growth occur. To modify this natural seasonal run-off for human convenience is to interfere with the hydrological cycle and with the physical and biological balance of the coastal region. Artificially storing the spring and summer run-off to generate power the following winter must have a significant impact on the ocean environment and on the climate of the maritime region."*

SECTION VII MR. NEU'S 1982 PREDICTION OF "MUST HAVE A SIGNIFICANT IMPACT," WAS BORNE OUT IN JUST A FEW YEARS, AS REVEALED BY THE FOLLOWING OBSERVATIONS:

1. ***"Serious levels of hypoxia (a lack of oxygen) first appeared in the St. Lawrence Estuary in the mid-1980's.*** *In 2003, this area covered approximately 1,300 km² (500 sq. miles) of the sea floor, and has continued to grow over the last few years. In 70 years, the concentration of oxygen has decreased by half at depths greater than 250 meters."* (Quebec Ocean Fact Sheet 2 – January 2011. See pages 28 & 29.)
2. **A tenfold increase in the accumulation rate of dinoflagellate cysts over the last four decades in the sediment of Lower St. Lawrence Estuary. Thibodeau, et.al. 2005**. This is equivalent to an average annual increase of 25% per year. Forty years from 2005 is 1965, and two large reservoir hydroelectric facilities were commissioned in 1956 and 1959. (See Table 1 on page 14.)
3. **Dissolved oxygen concentrations of 45 micromoles were recorded in June of 2017 in deep waters off Rimouski and Mantane, while concentrations are usually in 200-300 micromoles. (Whales online-Riche 7/24/17** Eutrophication is most likely the driving force in the oxygen depletion in the St. Lawrence Estuary**.**

SECTION VIII CLEARLY DIFFERENTIATES BETWEEN 2 TYPES OF MODIFICATION OF THE SILICA BIOGEOCHEMICAL CYCLE THAT OCCUR WITH EUTROPHICATION AND BOTH ARE CONTRIBUTING TO THIS OXYGEN DEPLETION IN THE ST. LAWRENCE ESTUARY

The first occurs behind the reservoir dams, where there is:

> *"a reduction in the water column silica reservoir through a modification of the biogeochemical cycling of silica. Increased diatom production results in increased deposition and preservation of diatom silica in sediments, which in turn leads to reductions in water column DSi concentrations." (*Conley, et. al. 1993)
>
> *"When the moving water of the river hits a reservoir and slows down and all those particles that were in suspension sink out, the water becomes a lot more clear. This means light can penetrate into the water more than the couple of feet or inches it could before and that means photosynthetic plankton living in the water can suddenly make a good living. Phytoplankton can finally fix carbon into organic matter faster they respire it away. They can begin to grow.*
>
> *But a dam means not only light, but also the time to put it to good use. Water that would have shot through that stretch of river in hours to days will now spend weeks to months to years in the extra reservoir volume. That's ample opportunity for phytoplankton like diatoms to build up biomass into thick blooms and to remove almost all the dissolved silica in the water. And because these stretches of quiet water with an enormously tall concrete wall at the downstream end are great places to build up sediments, the biogenic silica that has been produced stands a very good chance of sinking down and getting buried. The buck stops here, as they say, and as a result of downstream areas are starved of silica."* (<u>Silica Stories,</u> Conley et. al. 2017).

“The second occurs as N and P are added to aquatic systems through anthropogenic activities. Because DSi is not added to any significant extent with nutrient enrichment (Office and Ryther 1980*) additions of N and P will change the Si:N and Si:P ratios of receiving waters. These changes alone can have a substantial impact on ecosystem dynamics.*

While nitrogen and phosphorus are the 2 most important nutrients governing overall algal growth (Ryther and Dunstan 1971, Schindler 1977, Hecky and Kilham 1988), *the ratios of nutrients present* (Tilman et al. 1982) *and availability of dissolved silicate* (Kilham 1971, Egge & Aksnes 1992) *can regulate the species composition of phytoplankton assemblages (*Fig. 1). *Growth of diatoms depends on the presence of dissolved silicate* (DSi). *Whereas growth of non-diatom phytoplankton does not. When concentrations of DSi become low, other types of algae that do not require DSi can dominate algal community composition and decrease the relative importance of diatoms in phytoplankton communities.*

Schelske & Stoermer (1971, 1972) also hypothesized that the limitation of diatom flora by reduced DSi supplies would lead to drastic and undesirable changes in the ecosystem where the phytoplankton community was dominated by green and blue-green algae during summer when DSi was limiting for diatoms,. The hypothesis that modification of the phytoplankton flora would occur with eutrophication was formalized and its implications were discussed for the coastal ocean and marine systems by Officer & Ryther (1980) and Ryther & Officer (1981). These 2 studies identified essentially 2 distinctly different phytoplankton-based ecosystems; one dominated by diatoms and the other a non-diatom ecosystem usually dominated by flagellates, including dinoflagellates, chrysophytes, chlorophytes and coccolithophores, which may also contain large proportions of non-mobile green and blue-green algae. They suggested that the diatom food web contributed directly to large fishable populations, that other algal-based food webs were undesirable either because species remain ungrazed or fuelled food webs that are economically undesirable, and that changes in species composition would lead to oxygen depletion in bottom waters.(Conley et. al. 1993).

SECTION IX REDUCED DISSOLVED SILICATE HAS LED TO EXCESS NITROGEN IN OCEAN WATERS, WHICH IS AS HARMFUL TO THE MARINE ENVIRONMENT AS EXCESS CARBON IS IN THE ATMOSPHERE.

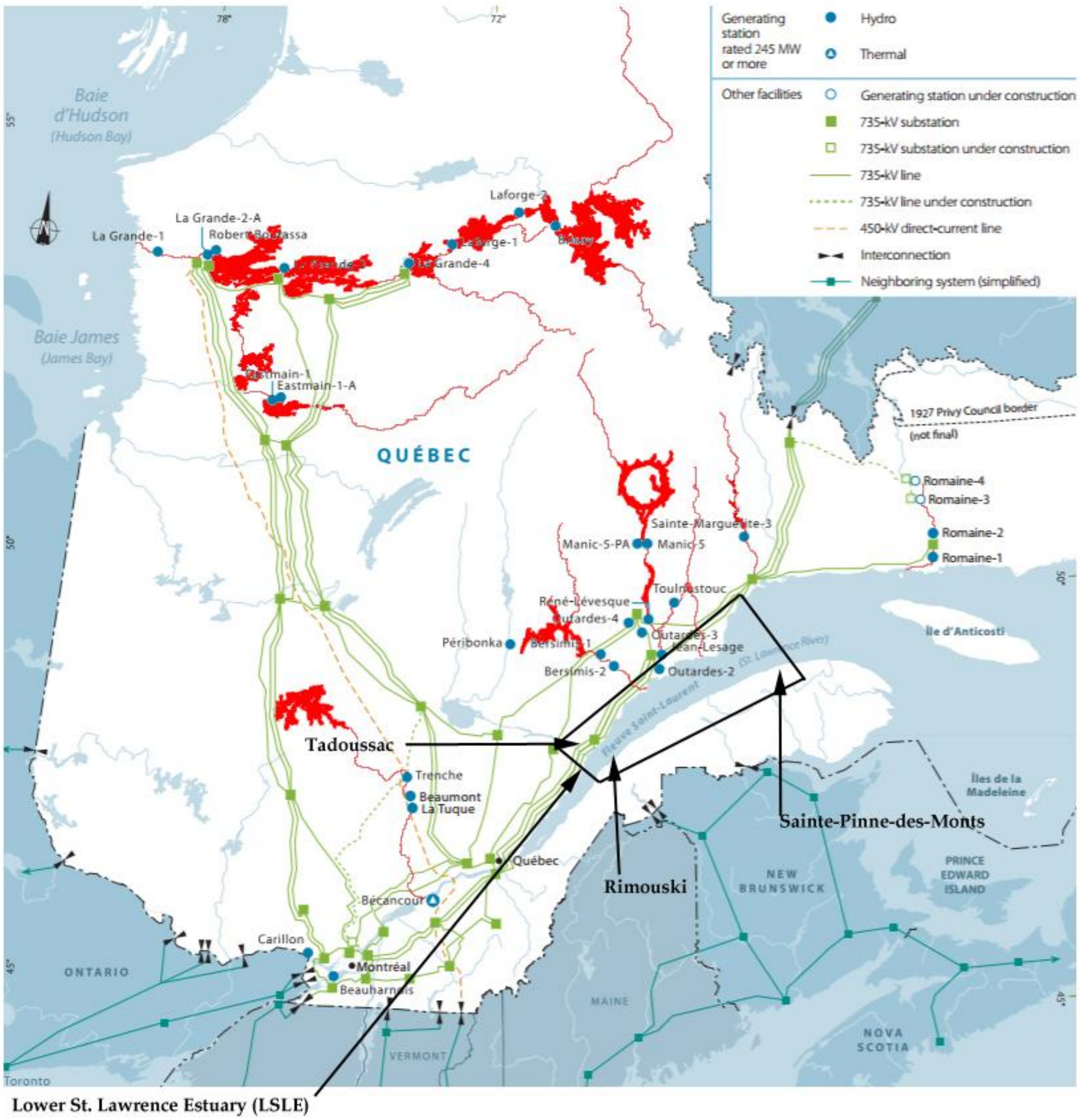
Less dissolved silicate in the upper waters of the Estuary and Gulf has allowed the increased nitrogen input from sewer treatment plants and storm water runoff to fuel an explosion in the growth of non-siliceous algal growth. This increase in algal growth (eutrophication) has lead to oxygen depletion throughout the water column and a limitation in some of the bottom waters.

Many politicians and scientists have turned their backs on how and why silicate retention behind dams affects marine biochemistry and the ecosystem structure in coastal waters and estuaries. These are probably some of the same people who have accused the fossil fuel industry of covering up how burning fossil fuels is causing climate change!

THE ST. LAWRENCE IS LOW ON AIR

The zone most affected by the reduction of oxygen in the St, Lawrence Estuary extends from Tadousssac at the confluence of the Saguenay River and the St. Lawrence to the northwest of the Gulf of St. Lawrence.

(Quebec Ocean Fact Sheet 2 January 2011)



Red Areas Highlighted Above Represent The Man-Made Storage of Water Resources Being Choked Off From Feeding The Marine Ecosystem

SECTION X HOW RIVER WATER INTERPLAYS WITH SALT WATER AND ITS SEASONAL VARIATION

"THE MOST OUTSTANDING FEATURE IN THE ENCOUNTER BETWEEN FRESH WATER AND SALT WATER IS THE FORMATION OF A CURRENT WHICH OCEANOGRAPHERS REFER TO AS HALINE CIRCULATION AND ENGINEERS AS DENSITY CURRENT. *The energy system which generates this motion is in principle the same as that which generates the winds in the atmosphere. While the winds are the result of inequalities in barometric pressure caused by non-uniform heating of the atmosphere under solar radiation, the density current in coastal waters and estuaries is primarily the result of the difference in density between fresh water of the run-off and the salt water of the ocean.*

There are basically two force components which generate this motion. First, fresh water entering the ocean raises the height of the water surface above the height of the ocean and establishes a horizontal pressure gradient. Water flows along this gradient resulting in a seaward flow of the surface water. The pressure gradient and thus the surface flows are maintained by the continuous input of river water. Second, sea water is more dense than river water and since pressure at depth depends on the water density times the water column height, there is a certain depth where the pressure from the low-density river water will be equal to the pressure from the denser sea water.

As shown schematically in Fig 3, below this depth the pressure difference is landward directed and above this point it is seaward directed. This arrangement imposes a two-layer flow system in which, as far as an estuary is concerned, the surface layer flows outward and the deeper layer flows inward. The major manifestation of this principle and the mixing involved is demonstrated by the large variation in salinity and temperature throughout an estuary.

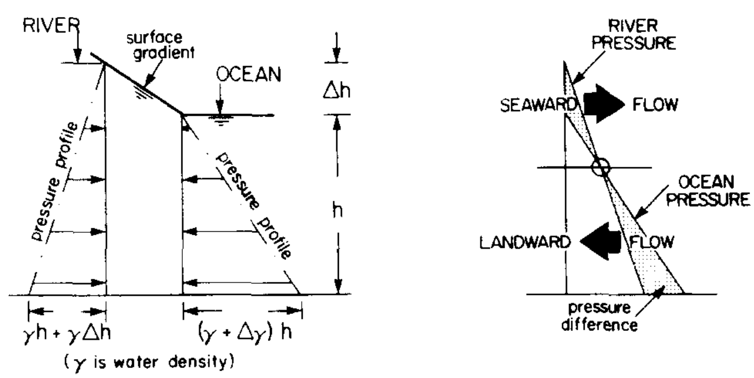


Fig. 3 Schematic diagram of pressure distributions for density currents.

SECTION XI OBVIOUSLY, THE TWO-LAYER CURRENT SYSTEM ACTS LIKE A LARGE NATURAL PUMP WHICH CONSTANTLY TRANSPORTS LARGE QUANTITIES OF DEEP OCEAN WATER ONTO THE CONTINENTAL SHELF AND THEN INTO THE EMBAYMENTS AND ESTUARIES.

Just as for the winds in the atmosphere, the, magnitude of the current is proportional to the pressure difference. Hence in times where more fresh water enters the ocean, the longitudinal gradient seaward increases and with it the strength of the current system. From this it follows that in estuaries the density current varies with the seasonal run-off, being at a minimum during the low discharges in winter and at its peak during the large discharges in spring and summer. In coastal waters which are some distance away from the fresh water source (i.e. the Grand Banks, the Scotian Shelf and Georges Bank) there can be delays of from several months to almost a year before the freshwater peak arrives.

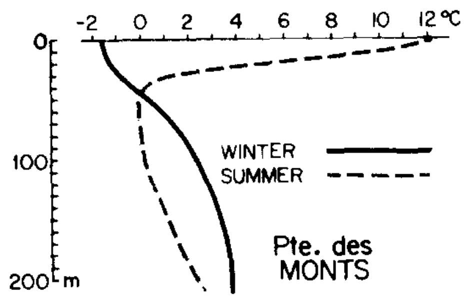


Fig. 6 Vertical temperature profile at Pointe des Monts in winter and summer.

SECTION XII CONCERNING THE TEMPERATURE OF THE WATER, SIMILAR VARIATIONS OCCUR BUT IN THIS CASE NOT EXCLUSIVELY DUE TO FRESH WATER BUT TO SEASONAL WARMING AND COOLING ALSO.

As shown in Fig. 6, the upper layer warms during the summer and cools during the winter. This trend is reversed in the deeper layer where during the summer an intermediate colder layer forms as a residue of preceding winter cooling, and is sandwiched between two warmer layers. This 'cold water' layer is characteristic of most of the coastal waters in the western North Atlantic. Although temperature, particularly during warming in spring, plays an important role in the biological activities of the upper layer, it has less influence on the density of the water, and hence on the motion and mixing, than the fresh water of the river.

SECTION XIII CONCERNING THE TEMPERATUARE OF THE WATER, THERE WILL ALSO BE CHANGES BUT SINCE THIS PROPERTY IS NON-CONSERVATIVE, IT IS DIFFICULT TO PREDICT THE FULL EFFECT.

There is a definite possibility that both winter and summer temperatures of the surface layer will increase; in winter due to an increase in upwelling of deeper warmer water, and in summer due to slower surface currents which will allow the surface layer to absorb more heat during its passage through the system. It can be assumed therefore that fresh water regulation modifies the climate of the coastal region to be more continental-like in the summer and more maritime-like in the winter.

SECTION XIV THE GREATEST CONSEQUENCES WILL ARISE, PROBABLY, FROM CHANGES IMPOSED ON THE DENSITY CURRENT.

This current determines the transport of deeper water from the ocean onto the shelf and from there into the embayments and estuaries. Reducing the flow of fresh water during the spring and summer decreases the strength of the density current to the point where, if taken far enough, it could be stopped altogether, while increasing the fresh water during the winter increases the current. Except where nutrients are produced locally, their rate of supply is directly related to the volume of salt water which carries them. A reduction in the transport of this water therefore decreases the influx of nutrients – the natural food supply – during the biologically active season of the year. An increase of supply during the winter does not compensate for these losses since primary and secondary production does not occur during this period, and the nutrients will return to the ocean body without being utilized.

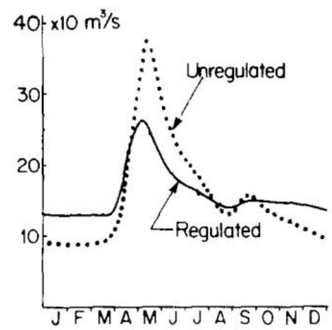


Fig. 11 Regulated and unregulated flow of the St. Lawrence at Pointe des Monts for 1976.

SECTION XV *TAKING THE ST. LAWRENCE AS AN EXAMPLE, WHERE TODAY MORE THAN 8000 $m^3 s^{-1}$ (APPROXIMATELY ONE-QUARTER TO ONE-THIRD OF THE PEAK DISCHARGE) IS HELD BACK IN SPRING (FIG. 11), THE SEASONAL INFLOW OF OCEAN WATER INTO THE GULF MUST ALREADY BE SIGNIFICANTLY MODIFIED.*

> *The reduction of the amount of water and with it the quantity of nutrients entering the system during the biologically active season must be in the order of 20-30% of its initial supply. According to El-Sabh (1975), the inflow into the Gulf through Cabot Strait is, at its peak in August, between 600 000 and 700 000 $m^3 s^{-1}$. Before regulation was implemented it probably was closer to a million cubic metres per second with all the extra nutrients that volume implies.*
>
> *Beyond any doubt, similar reductions in the shoreward transport of sea water and nutrients have occurred at other places during the summer, such as in Hamilton Inlet below the Churchill Falls power development in Labrador, and will now occur in James Bay after the first power scheme there is in operation."* (H.J.A. Neu, 1982)

SECTION XVI THERE ARE MANY IN THE SCIENTIFIC COMMUNITY WHO HAVE WARNED FOR YEARS ABOUT THE NEGATIVE IMPACTS OF RESERVOIR HYDROLOGICAL DAMS.

Scientists Venugopalan Ittekkot, Christoph Humborg and Peter Schafer wrote a 2000 Report "Hydrological Alterations and Marine Biogeochemistry: A Silicate Issue? Silicate retention in reservoirs behind dams affects ecosystem structure in coastal seas."

In this Report, they documented how reservoir dams will result in eutrophication and lower oxygen levels in downstream coastal waters:

> *"Freshwater and sediment inputs from rivers play a major role in sustaining estuarine and coastal ecosystems. Nutrients from rivers promote biological productivity in estuaries and coastal waters, and the sediments supplied by the rivers stabilize deltas and coastal zones and help to maintain ecosystems along the periphery of landmasses. In the last few decades human activities have caused enormous changes both in the nature and quantity of these inputs. Fluxes to the oceans of mineral nutrients, such as phosphate and nitrate, have increased worldwide by more than a factor of two (*Maybeck 1998)."

Quebec's population has doubled since 1951 from about 4,000,000 to over 8,000,000, which means much higher annual fluxes of phosphate and nitrate from sewerage treatment plants and storm water runoff into the Gulf.

> *"This increase has led to accelerated algal growth, known as eutrophication, and consequently to deterioration in water quality because of oxygen depletion. Toxic algal blooms occurring in coastal waters, which have devastating effects on fisheries and on biodiversity in general, are also attributable to euthrophication. Oxygen-deficient conditions, in turn, promote the production of greenhouse gases such as nitrous oxide and methane and their emission from coastal waters to the atmosphere."*

"The observed continuing increase in nutrients such as nitrate and phosphate and the reduction in silicate concentrations in rivers clearly indicate that nonsiliceous phytoplankton species will be more prolific in the receiving waters of many dammed rivers of the world. The occurrence of potential toxic flagellate blooms may become more frequent. Many important regulatory and socioeconomic functions of water bodies will be affected. The ability of these water bodies to sustain economically important fisheries resources will be reduced; severe perturbations can be expected in the biogeochemical cycling of elements, with adverse consequences for the role of coastal seas as sinks for anthropogenic gases such as CO^2."

SECTION XVII IN A 2005 STUDY, "RECENT EUTROPHICATION AND CONSEQUENT HYPOXIA IN THE BOTTOM WATERS OF THE LOWER ST. LAWRENCE ESTUARY: MICRO PALEONTOLOGICAL AND GEOCHEMICAL EVIDENCE," BY THIBODEAU, DEVERNAL, AND MUCCI, THE AUTHORS ANALYZED TWO SEDIMENT BOX CORES RECOVERED FROM THE LOWER ST. LAWRENCE ESTUARY AND OBSERVED THE FOLLOWING:

"A ten-fold increase in the accumulation rate of dinoflagellate cysts and benthic foraminifera in the sediment over the last four decades." And *"our results imply that a significant increase in marine productivity in the Lower St. Lawrence Estuary occurred since the 1960's."*

THIS IS MUCH MORE THAN "A SIGNIFICANT INCREASE

A TEN FOLD INCREASE IS THE SAME AS A 1,000 PERCENT INCREASE. OVER A TIME FRAME OF 40 YEARS THIS WOULD BE AN AVERAGE INCREASE OF ABOUT 25 PERCENT PER YEAR OF DINOFLAGELLATE CYSTS IN THE SEDIMENT.

The driving force for this epic increase of dinoflagellates is the gigantic reservoirs behind these hydroelectric dams, which have changed the silica cycle and natural hydraulic cycle in the St. Lawrence and Gulf of Maine. Changes in the hydraulic cycle have also significantly reduced the annual input of dissolved oxygen and warmed the waters of these rivers.

"Most studies addressing the causes of eutrophication have concentrated on the elements nitrogen and phosphorus, mainly because both nutrients are discharged by human activities. Silicate, however, also plays a crucial role in algal growth and species composition. For example, the growth rates of diatoms (silica-shelled phytoplankton) are determined by the supply of silicate. Researchers have noted a decrease in the level of dissolved silicate in many coastal marine regions of the world in the last few years (Conley et al; 1993). The increased growth of silicate-utilizing diatoms-the result of nitrate-and phosphate-induced eutrophications-and the subsequent removal of fixed biogenic silica via sedimentation out of the water column (Billen et al. 1991.1996) are thought to explain the decrease in dissolved silicate. The resulting changes in the ratios of nutrient elements (e.g., silicon: nitrogen:phosphorus, or Si:N:P) have caused shifts in phytoplankton populations in water bodies (Admiral et. al. 1990, Turner and Rabalais 1994). Shifts from diatoms to nonsiliceous phytoplankton have been observed much earlier in the season in several estuarine and coastal regions (in the receiving marine waters of the Rhine River, for example).

"The source transport, and sink characteristics of silicate, as they relate to changes in the hydrology of rivers, are distinct from those of nitrogen and phosphorus. Large-scale hydrological alterations on land, such as river damming and river diversion, could cause reductions of silicate inputs to the sea (Humborg et al. 1997). By contrast, although all nutrients (nitrogen, phosphorus and silicon) get trapped in reservoirs behind dams, nitrate and phosphate discharged from human activities downstream of the dams more than make up for what is trapped in reservoirs; for silicate, there is no such compensation. The resulting alteration in the nutrient mix reaching the sea could also exacerbate the effect of eutrophications-that is, silicate limitation in perturbed water bodies can be set in much more rapidly than under pristine conditions, leading to changes in the composition of phytoplankton in coastal waters."

And

"One of the issues to be resolved is whether the reduction in silicate in coastal waters is caused by its increased removal through enhanced diatom production or by a decrease in direct inputs from rivers. Although both processes are likely to affect silicate decrease, enough evidence is available to suggest that hydrological alterations such as river damming and river diversions could be the crucial factors (Milliman 1997). Given the large numbers of dams in operation today (Rosenberg et al. 2000) and the extent of river flow that is dammed or diverted (Voorosmarty and Sahagian 2000), reduction of silicate could be of global significance." (Ittekkot, Humboarg and Schafer 2000).

SECTION XVIII I HAVE REPRINTED, ON PAGES 7 AND 8, A JANUARY 2011 FACT SHEET "THE ST. LAWRENCE IS LOW ON AIR," BECAUSE THE READER HAS TO READ IT FOR THEMSELVES IN ORDER TO BELIEVE THAT THERE IS NO MENTION OF THE PROLIFERATION OF RESERVOIR HYDROELECTRIC DAMS DURING THE PAST SEVENTY YEARS AS A POSSIBLE CAUSE IN LOW OXYGEN IN THE ST. LAWRENCE.

In the section, "Caused by human activity-but only in part," the author fails to mention that the discharged waters from the dams into the rivers have much less dissolved silicate to offset the increased input of nitrates and phosphates from municipal wastewater, as well as fertilizer and manure in nearby agriculture fields. As a result, the diatom populations have declined and dinoflagellate populations have exploded.

In the section "A link to climate change, the author explains that the cause of less oxygen is because:

"The proportion of water coming from the Labrador Current Water has decreased, and thus more of the water entering the gulf comes from the less oxygenated Gulf Stream. This situation has contributed not only to a reduction in oxygen levels in the deep waters of the St. Lawrence Estuary, but also to an increase in water temperature of 1.65°C.

As discussed in Sections XII and XIII, the storage of water resources may be the driving force in this increase in water temperature.

Québec OCÉAN

THE ST. LAWRENCE IS LOW ON AIR

A serious danger is threatening the St. Lawrence River: a lack of oxygen. This phenomenon, called hypoxia, is a serious concern for the St. Lawrence Estuary, but also affects the gulf. Findings from a recent scientific cruise[1] confirm that a large portion of the estuary is slowly but surely suffocating.

In fact, the levels of oxygen in the deep waters of the estuary are so low that it could have serious repercussions on the marine ecosystems. Some scientists are even using the term "dead zones" to describe these areas of low oxygen that are expanding from year to year. When the concentration of oxygen in the bottom waters falls below 30% (hypoxia), many marine organisms, including fish, molluscs, and crustaceans, can no longer survive. Currently, certain parts of the estuary have oxygen levels below 15% saturation.

The critical zone

The zone most affected by the reduction of oxygen in the St. Lawrence Estuary extends from Tadoussac, at the confluence of the Saguenay River and the St. Lawrence, to northwest of the Gulf of St. Lawrence.

Serious levels of hypoxia first appeared in the St. Lawrence Estuary in the mid-1980s. In 2003, this area covered approximately 1,300 km^2 of the seafloor, and has continued to grow over the last few years. In 70 years, the concentration of oxygen has decreased by half at depths greater than 250 meters.

Caused by human activity—but only in part

Researchers have calculated that between one-third and one-half of the decrease in oxygen is the result of factors related to the river and the activities of those who live near it. Municipal wastewater, as well as fertilizer and manure used in nearby agricultural fields, results in the input of large quantities of nitrates and phosphates into the river. This creates an additional source of nutrients for the plankton, which multiply rapidly from spring through summer. When these abundant plankton die and fall to the bottom of the river, it gradually decomposes in the water, consuming the ever-decreasing supply of oxygen.

Credit : Lise Duchesne

Entrance of the Bic Park, South shore of the St. Lawrence estuary.

A link to climate change

Scientists believe that changes in circulation in the Atlantic Ocean, possibly due to global warming, could contribute to the reduced oxygen in the St. Lawrence.

The water that enters the St. Lawrence is a mixture of two large water masses: the shallower Labrador Current Water is cold and oxygenrich, while the deeper North Atlantic Central Water, originating in the Gulf Stream, is warmer and less oxygenated. The deep water flowing into the estuary slowly loses its oxygen as it moves toward Tadoussac.

The problem is that the proportion of water coming from the Labrador Current Water has decreased, and thus more of the water entering the gulf comes from the less oxygenated Gulf Stream. This situation has contributed not only to a reduction in oxygen levels in the deep waters of the St. Lawrence Estuary, but also to an increase in water temperature of 1.65 °C.

If this trend continues, the deep waters of the estuary could, in the next fifty years, become anoxic (without oxygen). In a word, suffocation! According to that sad scenario, the deep waters of the estuary could no longer support any form of life, with the possible exception of some microorganisms.

Oxygen concentration will be determined by scientists in the sediment sample and its living organisms.

A better understanding of the phenomenon and its consequences

To better understand the causes of hypoxia, Québec-Océan researchers are pursuing their studies on the impact of low concentrations of oxygen on organisms living in the deep waters. They are also developing simulation models to predict the concentrations of oxygen in the estuary and the Gulf of St. Lawrence. These advanced models take into account not only the circulation of the water masses, but also the exchange of oxygen between nutrients, sediments and plankton.

[1] *Hypoxia 2010 Cruise, lead by Prof. Alfonso Mucci on the Coriolis II.*

Find out more

- Will "Dead Zones" Spread in the St. Lawrence River?
- Hypoxia 2010 Cruise
- The Deep Waters of the Estuary: A Dead Zone? (French only)
- Biodiversity - A quantifiable economic value (French only)
- Coastal water threatened with suffocation as a result of human activities (French only)
- The estuary is holding its breath

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SECTION XIX THIS CHANGE IN "PROPORTION" WHICH IS MENTIONED AND HIGHLIGHTED IN THE PREVIOUS PAGES, IS TAKING PLACE 700 PLUS MILES DOWNSTREAM FROM THE ST. LAWRENCE ESTUARY IN THE NORTHWEST ATLANTIC AND IS BASED ON A HYPOTHESIS WHICH IS NOT PROVEN.

This hypothesis was studied in the following 2 reports:

1. Lefort S. "A Multidisciplinary Study Of Hypoxia In The Deep Water Of Estuary And Gulf Of St. Lawrence: Is This Ecosystem On Borrowed Time?" PhD thesis, McGill University; 2011.
2. Lefort S. Gratton Y, Mucci A., Dadou I, Gilvert D. ,"Hypoxia In The Lower St. Lawrence Estuary: How Physics Controls Spatial Patterns,". J Geophys Res. 2012; CO7019.

And the authors of the second report concluded:

The result strongly suggests that the physics of the system and the source water properties are mostly responsible for oxygen depletion and its distribution pattern in the deep water column.

Three years later Daniel Bourgault and Frederic Cyr wrote a Report: "Hypoxia in the St. Lawrence Estuary: How a Coding Error Led to the Belief that "Physics Controls Spatial Patterns" and wrote the following Abstract and Conclusion:

"*Abstract*

Two fundamental sign errors were found in a computer code used for studying the oxygen minimum zone (OMZ) and hypoxia in the Estuary and Gulf of St. Lawrence. These errors invalidate the conclusions drawn from the model, and call into question a proposed mechanism for generating OMZ that challenges classical understanding. The study in question is being cited frequently, leading the discipline in the wrong direction."

And

"Conclusion

The equation, boundary conditions, and parameters proposed by Lefort (2011) (1) and Lefort et al. (2012) (2) are inappropriate when solved correctly for explaining the observed oxygen field and hypoxia in the St. Lawrence Estuary. It is by unfortunate chance that their unrealistic Eq2 combined with their proposed boundary conditions, parameters and numerical scheme produced remarkable but puzzling agreement with observations. Hypoxia in the St. Lawrence Estuary and the OM in the Gulf of St. Lawrence Estuary and the OM in the Gulf of St. Lawrence are important feature to reproduce correctly with proper theory, and the community must not be left continuing to believe that their model succeeded in reproducing them."

The authors also wrote the following in their Report: "*THE AUTHORS HAVE BEEN INFORMED AND HAVE CONFIRMED THE UNFORTUNATE ERROR."*

SECTION XIV IT APPEARS THAT THIS HYPOTHESIS HAS CONTINUED SUPPORT AND THE WORD OF THIS UNFORTUNATE ERROR HAS BEEN SLOW IN GETTING OUT!

I have reprinted below a July 24, 2017 article "Less and Less Oxygen in St. Lawrence."

Again, no mention of reservoir hydroelectric dams as a possible cause or reduction in dissolved silicate concentrations I remind the reader that these dams are owned by Hydro-Quebec, which is owned by the Province of Quebec.

LESS AND LESS OXYGEN IN THE ST. LAWRENCE

24 / 07 / 2017

Par Béatrice Riché

Editor of Group for Research and Education on Marine Mammals

During their recent mission aboard the *Coriolis II*, researchers observed the lowest concentrations of dissolved oxygen ever recorded in the deep waters of the St. Lawrence River. Why is there less oxygen in the deep waters and what are the consequences for the species of the St. Lawrence?

Coriolis II, the research vessel of the Institute of Ocean Sciences in Rimouski. © UQAR
From June 12 to 21, 13 researchers from McGill, Concordia and Moncton universities plied the St. Lawrence River between Québec City and Anticosti Island aboard the *Coriolis II*, the research vessel of the Institute of Ocean Sciences in Rimouski (ISMER/UQAR). The multidisciplinary team had several objectives: to learn more about surface water acidification, to monitor oxygen concentrations in deep waters and to map the sediments (including petroleum products) of the seafloor.

Researchers observed an area of hypoxia, i.e., a very low oxygen zone, in the deep waters between Tadoussac and Sainte-Anne-des-Monts. The lowest concentrations were recorded off Rimouski and Matane: 45 micromoles of dissolved oxygen per kilogram of water, while concentrations are usually in the order of 200-300 micromoles per kilogram. Oxygen levels in the deep waters of the St. Lawrence have been declining for at least a decade. Researchers are concerned by this trend.

Multiple causes

There are a number of factors that might explain the magnitude of hypoxia in the St. Lawrence: the changing composition of water bodies entering the Gulf, climate change and pollution.
Two major currents of water penetrate the Gulf of St. Lawrence: the Labrador Current and the central North Atlantic Current. The water in the Labrador Current is cold and well oxygenated, while the central North Atlantic water is warmer and less oxygenated. Studies have shown that over the last few decades, the proportion of water from the Labrador Current entering the Gulf of St. Lawrence has declined, while that from the central North Atlantic has increased. This has two consequences on the deep waters of the St. Lawrence Estuary: a decrease in their oxygen concentration and an increase in their temperature.

Climate change may exacerbate hypoxia, as the higher the water temperature, the less soluble oxygen is. A study published last January by the Maurice Lamontagne Institute of Fisheries and Oceans Canada revealed that average deep water temperatures in the Gulf of St. Lawrence at depths of 250 and 300 metres have also reached levels never observed in the last hundred years.

Pollution may also play a significant role in the hypoxia phenomenon. The application of fertilizers and manure to farmland and municipal wastewater discharges contribute significant quantities of nitrates and phosphates to the river. These nutrients cause a proliferation of plankton. When the latter dies and sinks to the seabed, the decomposition process results in a depletion of the water's oxygen content.

Implications for species of the St. Lawrence

According to Yves Gélinas, research professor at Concordia University's Department of Chemistry and Biochemistry and one of the 13 researchers involved in the mission, some oxygen concentrations recorded at the mission "are too low to allow for the long-term survival of a number of living organisms […] in these waters".Indeed, just like their terrestrial counterparts, marine organisms require oxygen. But although oxygen depletion has a detrimental effect on most species, others have a different tolerance level. Cod, for example, are unable to tolerate the low oxygen concentrations currently found in the deep waters of the Estuary and avoid these areas. However, other species, such as redfish, plaice and shrimp, congregate in low oxygen areas to avoid predators.

For those St. Lawrence whales that feed on benthic prey – including belugas, sperm whales, harbour porpoises and several others – “their feeding grounds are likely to change,” points out Robert Michaud, Scientific Director of the Group for Research and Education on Marine Mammals (GREMM). How will whales adapt to these changes? Will they change their feeding grounds or the species they consume? For Robert Michaud, these issues are at the heart of the challenges we face in understanding and protecting the whales of the St. Lawrence.

Sources

Lack of oxygen may threaten St. Lawrence biodiversity (in French, Radio-Canada, 2017-07-04)
Thirteen scientists study St. Lawrence aboard *Coriolis II* (in French, Radio-Canada, 2017-06-11)

Maine Voices
Posted December 23, 2018

Maine Voices: Hydroelectric dams produce green energy? Think again

Building such dams in Maine would violate federal and state environmental laws, for good reason.

BY **STEPHEN M. KASPRZAK** SPECIAL TO THE TELEGRAM

CAPE PORPOISE — Before advocating for the 145-mile line to carry hydroelectricity generated by Hydro-Quebec (Our View, Dec. 9), the Maine Sunday Telegram Editorial Board should first explain why hydroelectricity produced by reservoir dams should be called "green energy." The construction of these dams in Maine would be prohibited by Section 401 of the Clean Water Act of 1972 and Maine's Natural Resources Protection Act.

Every reservoir hydroelectric facility represents an environmental catastrophe, not only to the dammed river, but also to the ocean regions where the rivers' currents convey nutrients.

Commissioned in 1969, the Outardes-4 hydroelectric reservoir dam on the Outardes River discharges into the St. Lawrence River. Its surface area is 252 square miles – five times bigger than Sebago Lake.

ABOUT THE AUTHOR

Stephen M. Kasprzak is a resident of Cape Porpoise.

Four other hydroelectric facilities, built from 1967 to 1989 on the nearby Manicouagan River, also discharge into the St. Lawrence. The Manicouagan Reservoir is a giant head pond created by the Daniel-Johnson Dam and has a surface area of 750 square miles – equivalent to 16 Sebago Lakes.

There are four other reservoirs on the Manicouagan River, and the Mavic-Outardes hydro project has an annual capacity of 5,579 megawatts. Maine's total annual hydroelectric capacity is 753 MW.

The St. Lawrence, the largest-volume river in North America, is the major supplier of dissolved silicate to the Gulf of Maine, as daily flows are 40 to 50 times greater than any of Maine's major rivers.

The Churchill Falls Generating Station was built in the 1970s in Newfoundland-Labrador on the Churchill River, which discharges in the Labrador Current.

There are 11 generating units and a series of 88 dykes, which have a total length of 40 miles and created the Smallwood Reservoir with a surface area of 2,200 square miles – equal to 46 Sebago Lakes. The annual capacity is 5,428 MW.

The Robert-Bourassa hydroelectric project was completed in 1986 in Quebec on the LaGrande River, which discharges into James Bay. It has an annual capacity of 10,800 MW and five reservoirs with a surface area equal to 89 Sebago Lakes.

A second phase of hydroelectric dams was built on the LaGrande River in the 1990s with an annual capacity of 5,200 MW. The surface area of these three additional reservoirs equals 13 Sebago Lakes.

The surface areas of the above reservoirs, built on just four rivers, are equal to 169 Sebago Lakes or 982 transmission corridors 145 miles long by 300 feet wide.

Before these dams were built, the silica cycle was in a steady state with input balancing off the output. The major output loss is in the ocean waters, where it is estimated that the burial rate of biogenic silica is 2 to 3 percent per year. A cumulative loss of 3 percent per year would result in a 50 percent loss of silica in only 23 years.

This ocean loss was offset naturally each year by the input of dissolved silicate transported by the rivers. Rivers account for 80 to 85 percent of the annual input of dissolved silicate to the oceans. In temperate rivers with reservoir dams, scientists have calculated an annual silica removal as high as 50 percent.

The cumulative impact of less silica being transported each year to the ocean has resulted in fewer and smaller diatoms. Depleted diatom populations fail to support a healthy food chain or ameliorate ocean acidity, and they'll release less oxygen into the atmosphere. This has led to the starvation of creatures and fishes that eat them and increased acidity. The silicate of the smaller diatoms dissolves before the carbon can be sequestered to the ocean floor.

These reservoir dams have had other catastrophic impacts. For example, the temperature of the high-volume winter discharged waters flowing into the ocean has increased. These reservoir waters are now thermally stratified lakes. In northern temperate lakes, the bottommost waters are typically close to 4 degrees Celsius year-round, which is much warmer than the super cold river waters flowing under ice in the winter. It is not surprising the Gulf of Maine is warming so fast.

How long will the media and officials remain silent about all the key causes of the demise of the Gulf of Maine because of Canadian hydropower dams and unnatural freshwater flow regulation?

Posted January 5,2019

Commentary: Hydro-Quebec offers misleading claims about power's climate impact

We can't trust the utility's publicists to represent correctly their own carbon emissions.

BY **BRADFORD H. HAGER**SPECIAL TO THE PRESS HERALD

Hydro-Quebec's claim that – as paraphrased by Portland Press Herald Staff Writer Edward D. Murphy – the electricity they would send south is "produced with none of the carbon emissions blamed for global warming" is dead wrong, directly contradicted by scientific research sponsored by Hydro-Quebec itself. I care deeply about aggressively addressing climate change, and I agree with the Press Herald Editorial Board (Our View, Dec. 9) that the most important question in evaluating the proposed transmission line to Massachusetts is whether it will reduce total greenhouse-gas emissions.

But to answer this question correctly, we must use the best available science. The Press Herald should avoid passing along Hydro-Quebec's misinformation. Either the utility officials who claim their power is carbon-free are ignorant of the science published by their colleagues, or they are ignoring this established science in their attempt to sell power.

ABOUT THE AUTHOR

Bradford H. Hager is an MIT earth sciences professor and a part-time resident of Mercer.

International Hydropower Association data show that Hydro-Quebec electricity is just about as dirty as hydropower gets. Why? When Hydro-Quebec dams rivers on northern Quebec's relatively flat terrain, it floods vast areas of forests and wetlands under shallow water. The amount of power Hydro-Quebec produces per acre flooded is among the lowest of any hydropower in the world. The trees, bogs and soils Hydro-Quebec floods have been storing carbon since the last Ice Age. When flooded, this stored carbon decomposes, releasing CO_2 and methane. To make things worse, drowned trees are gone forever and cannot grow back to remove CO_2 in the future.

Here's an example of their own best available science that Hydro-Quebec did not provide to the Press Herald: About a decade ago, Hydro-Quebec built dams to divert the Rupert River to the Eastmain hydro facility, flooding 175 square miles of virgin forest and wetlands. As a result, the first year after flooding, as much CO_2 was released as would have been released by a coal-fired power plant generating the same amount of electricity!

Fortunately, the release of CO_2 slows with time. Unfortunately, it never becomes insignificant. After five years, the total emissions from these Hydro-Quebec dams and natural gas power plants are about equal; after 10 years, the total release from hydro is "only" two-thirds that of natural gas. Extrapolating for a century, Quebec's hydro is about half as dirty as gas – something of an improvement, but in no way "carbon free."

How can we make the best of this situation? To reduce total regional emissions, Hydro-Quebec should export its somewhat-dirty hydropower to neighboring New Brunswick, displacing the much dirtier power produced there from burning coal while Maine and Massachusetts pursue truly carbon-free sources. That would result in a meaningful decrease in overall greenhouse-gas emissions.

Hydro-Quebec knows that their hydropower causes significant greenhouse-gas release. Yet, when marketing their project, they omit this information. This should make us skeptical about their other claims.

Hydro-Quebec's assertion that it has "wasted" enough water to provide 10 terawatt hours of electricity because it lacks transmission capacity is not backed by documentation. In contrast, a 2017 study of Hydro-Quebec's export capacity found that the limiting factor for total energy output is generation, not transmission capacity. This makes sense – why would Hydro-Quebec pay the high cost of building dams and installing generators and not also provide adequate transmission capability?

Like any hydropower operation, Hydro-Quebec must deal with large variations in rainfall. It is expensive to build enough generation to handle peak flows, and then let the generators stand idle during years that are either dry or have normal rainfall. During unusually wet times, the water is "wasted" because it is more economical to spill water occasionally than to waste generation capacity most of the time. While it may be true that enough water to generate 10 terawatt hours of electricity has been spilled during times of unusually high water, that in no way shows that the rate and timing of this spillage could have been used to fulfill a contract for a more steady supply of power.

We can't trust Hydro-Quebec publicists to represent correctly the scientific research that their company supported about their own carbon emissions. The Press Herald and the Maine Public Utilities Commission should not accept what Hydro-Quebec says about "clean" energy and spillage without requiring and thoughtfully reviewing documentation.

Attachment I

VIEWPOINT

Viewpoint is a column which allows authors to express their own opinions about current events.

Man-Made Storage of Water Resources—A Liability to the Ocean Environment? Part II

HANS J. A. NEU

Mr. H. Neu is a Senior Research Scientist with the Canadian Department of Fisheries and Oceans at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. A specialist for 27 years in estuarine and coastal hydrodynamics, he has studied the physical oceanography of the major waterways across Canada as well as on the continental shelf and in the north-west Atlantic.

The first part of this article (Mar. Pollut. Bull., **13**, 7–12, 1982) *described the impact of the seasonal freshwater runoff on bodies of water—such as the Gulf of St. Lawrence and the coastal region—through changes in the salinity and temperature distribution and through changes in the current generated by the density difference between the fresh river water and the ocean. The strength of the current and thus the transport of deep ocean water to the coastal region depends on the amount of fresh water released into the ocean. Therefore modifying the natural seasonal runoff by storing water for power production during the winter interferes with the timing of the physical and dynamic balance of the coastal region. The impact of this interference on the marine life and on the climate of the region is now discussed.*

As on land, the basis of life in the ocean is the plant community which alone can synthesize energy and living tissue from raw materials in the presence of sunlight by photosynthesis. The circulation of the ocean determines the areas where nutrients can reach those upper levels where there is sufficient light for photosynthesis to proceed. Thus, upwelling areas are the fertile parts of the ocean which are highly significant to the marine environment.

Regions of upwelling can be related to large ocean currents like the Humboldt off South America, the boundary currents along the shelf break of the continental margin, and even the warm-core eddies of the Gulf Stream penetrating the shelf region. What is less well known is that upwelling is also generated by density currents associated with the excursion of large amounts of fresh water over coastal regions and continental shelves such as found along the Atlantic coast of Canada. The latter represents a continuous transport of nutrient laden water on a scale far surpassing that of Gulf Stream eddies.

This excursion, being subjected to large seasonal variations, is co-related with the biological activities and productivity in temperate regions. The area affected extends as far as the fresh water reaches. Within this area there is intense primary as well as secondary productivity which is tuned to the seasonal variation in climate and run-off. This productivity is nourished by the seasonal nutrient supply which in turn is regulated by the seasonal fresh water run-off.

Life as we know it in our coastal waters and its level of productivity has evolved over thousands of years in response to these seasonal variations. Changing this pattern by reducing the flow of fresh water during the biologically active season of the year, or even reversing the cyclic flow altogether, represents a fundamental modification of a natural system. Such a modification must have far reaching consequences on the life and reproduction cycle in the marine environment of the region affected. Thus, it follows that storage schemes already implemented in Canada are having an impact on the biological resources of the Atlantic coastal region. Unfortunately, data to prove this quantitatively are masked by other possibilities. For example, a drastic decline in fish catches in the late sixties and early seventies is currently attributed to over-fishing in the internationally regulated area prior to the establishment of the Canadian 200 mile zone. In recent years, it appears that as a result of the reduced fishing pressure, some stocks are showing significant recovery. This fact, however, also happens to coincide with a period of increasing natural discharge in our river systems. As shown in Fig. 1, where the five-year running means of each year's monthly maximum (spring) and minimum (winter) discharges are plotted for the St. Lawrence at Pointe des Monts, larger spring flows existed in the fifties and middle seventies and lower flows in the middle of the sixties. As demonstrated by Sutcliffe (1972, 1973) and Sutcliffe *et al.* (1976, 1977), fish catches, especially in the Gulf, varied correspondingly, being larger during the fifties but smaller during the sixties with an increase in the seventies after allowing a delay of a number of years for the fish to mature. This implies that the low flow period of the sixties imposed stresses on the productivity of the system. Unfortunately, at the same time as the flow was at its lowest level, regulation was

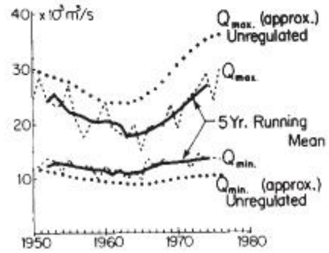

Fig. 1 Annual monthly Q_{-max} and Q_{-min} of the St. Lawrence river at Pointe des Monts.

stepped up from an average of 4000 $m^3\ s^{-1}$ to about 8000 $m^3\ s^{-1}$ with the implementation of the Manicouagan–Outardes–Bersimis hydro-power complex. I contend that this further reduction in the spring flow was probably the final straw in the decline of the fish stocks. The larger flows of the seventies decreased the proportional effect of the regulation and gave the fish stocks an opportunity to recover. The next big decline probably will be in the early or mid-eighties when another low discharge period is predictable from the long term cycles (11 and 22 yr) of water levels in the Great Lakes. The decline, however, will be worse, since regulation will have increased further in the meantime.

The Aswan Dam regulation in Egypt is similar in size to the regulation schemes in Canada, though located in the subtropical and tropical region and therefore not directly comparable with our coastal waters. It is, however, the only case known to the author where a large scale regulation scheme was assessed with respect to the ocean environment prior to its construction and reported upon after it was in operation. Western scientists predicted that retaining the run-off of the rainy season would significantly affect the biological balance in the southeastern Mediterranean. The prediction became fact. Aleem (1972) reported: "Construction of the Aswan High Dam in Egypt, and subsequent cessation (since 1965) of surplus Nile flood water (*ca*. 35. 10^9 m^3 of water annually) from discharging into the Mediterranean Sea, has had an impact on marine life in coastal waters adjoining the Nile Delta and on brackish-water life in the lakes. Nutrient concentrations have fallen considerably in these waters; phytoplankton bloom associated with the Nile flood have disappeared and, consequently, *Sardinella* catches have dropped from *ca*. 15 000 tons in 1964 to 4600 tons in 1965 and to 554 tons in 1966. Depletion of nutrients, reduction of organic matter and of mud and silt deposition affect also benthic life on the Continental Shelf and in brackish-water lakes adjoining the sea."

According to Tolmazin (1979), the fishing industry of the Black and Azov Seas has also suffered disastrous declines over the past 20 years. This coincided with the introduction of a number of regulation lakes in the major rivers flowing south into the Russian inland seas, the Caspian Sea included. The Dnieper, the Don and the Volga have been brought almost completely under man's control. Tolmazin (1979) concludes that creating these lakes caused this decline and quotes the following estimate: "The loss of fish food all over the country now amounts to more than one thousand million rubles per year, including the finished products made from raw fish". He concedes that "The damage inflicted on other branches of the economy is very difficult to assess".

Even if we cannot yet measure the effects with certainty in our own marine environment, similar changes must already have happened to the coastal waters of Atlantic Canada and the effect must increase as regulation of our rivers continues. Of particular concern is the increased development of hydro-power – under construction or in the design stage – in Labrador, Ungava Bay, James Bay and Hudson Bay, which are bound to threaten the productivity of the Grand Banks of Newfoundland.

Until now it was assumed that hydro power is 'clean' with little or no impact on the environment, particularly that of the ocean. That this might not be the case is difficult to understand. Obviously, designing storage schemes and forecasting output of power is easier to grasp than to quantify the changes imposed on the population dynamics of the biota in the coastal region. There is the possibility that damages imposed by man-made lakes on the ecosystem may outweigh the benefits they provide. This is the crux of the problem. The prime task therefore is to establish a cost–benefit ratio in which all factors, also those which affect the ocean environment, are included. This should be a prerequisite for any further development.

Regulation Schemes

The two countries with the largest fresh water resources are Canada and the USSR. Soon after the second world war, Russia announced plans to develop its hydrologic potential. One of these was the creation of a central Siberian fresh water lake into which the rivers Ob, Lena and Jenisey would be diverted, each the size of the St. Lawrence. In spite of the announcements Russia has not yet started this project. It is assumed and hoped that this delay is more for ecological than for economical reasons. Another plan was for significant water diversion and storage in the Pechora–Vychegda–Kama scheme which diverts water, originally flowing north into the Barents Sea, south through the Volga into the Caspian Sea. The volume of water stored is about 200 km^3. This scheme is somewhat similar to the water diversion proposals by the US under the so-called North American Water and Power Alliance for diverting Alaskan and Canadian rivers south to the US. From the viewpoint of their impact on nature, water regulations and water diversions are similar. Both remove the fresh water from the biologically active season of the year.

In the rivers flowing south, the Dnieper, Don and Volga, the total amount of water stored in 18 storage schemes is 142.3 km^3, that is the same amount as stored in Manic 5, one of the many large Canadian storage lakes.

In Canada, during the last 25 years, a number of power developments with large storage schemes have been installed (Fig. 2). The most important of a total of more than 300 are: the Churchill Falls in Labrador; the Manicouagan system, the Outardes, Bersimis and Lac Saint Jean complex in the Laurentians north of the St. Lawrence; the LaGrande system into James Bay; to the west the St. Maurice and further west the Ottawa River system and the

Fig. 2 Major storage schemes in Canada.

Great Lakes Regulation; the Nelson-Churchill and Saskatchewan River schemes in the midwest; the Peace River and Columbia River storage schemes in British Columbia; to name just a few. A number of new schemes are under construction or in the design stage. They include several projects in the James Bay area; a new scheme in Labrador; the Gulf of St. Lawrence north shore development which includes the rivers from Sept Isles to the Strait of Belle Isle; a possible Ungava Bay scheme and the development of the rivers in Ontario on the James Bay and Hudson Bay, and others further west.

The dimensions of these schemes, particularly their storage capacity, are colossal. Manic 5, the largest lake of the Manicouagan system, stores 142 km^3, one-quarter of which is live storage. This volume of water would cover half of Nova Scotia to a depth of 10 m. It is comparable with the storage capacity of Lake Nasser in Egypt, one of the largest man-made lakes in the world. While the construction of the Aswan Dam, which forms Lake Nasser, created great political upheaval and much scientific discussion as to its effect on the southeastern Mediterranean, Manic 5 was being constructed during the same period without any reaction at all.

To indicate the scale of the quantity of water stored in these lakes, all rivers on earth at any one time contain about 1300 km^3 of water. The existing artificial storage in Canada already holds back this amount. Excluding the far north, Canada has an annual run-off of about 1500–2000 km^3; this is not much more than the integrated artificial storage. Assuming that between one-third and one-quarter of this storage is live storage, then about 400 km^3 of water is annually shifted from the summer to the winter season. The natural ratio of these two seasons is about 4:1, this means that prior to regulation, the two volumes were 1600 km^3 and 400 km^3 respectively. Under the existing conditions, the summer flow is therefore reduced to 1200 km^3 and the winter flow increased to 800 km^3, making the ratio 3:2.

Obviously, these changes which are already implemented are a fundamental modification to the fresh water regime of Canada and to the physics and dynamics of its coastal regions. There is no doubt in the mind of the author that if Canada continues this development and the USSR follows its lead, the hydrological balance of our globe would be threatened and as a result the biological productivity of our oceans, primarily in their coastal waters, may be seriously jeopardized.

Possible Alternatives

Since it is obvious that the transfer of fresh water from the biologically active to the biologically inactive season of the year is the prime problem of water regulation, it leads to the question: can hydro power be fully developed economically without storage? There is no simple answer to this question because it depends on many factors.

One possibility would be to separate seasonal peak power production from general power production where power would be produced from 'run of the river' stations without significant storage. The peak power part would consist of a twin-lake system with a large head difference between the lakes as might be available in the Laurentians or Rocky Mountains. The water in the system would form a closed circuit and the system should be big enough to satisfy the seasonal demand of a region. In spring and summer, when large amounts of excess energy would be available from the 'run of the river' stations, water would be pumped from the lower lake into the upper lake, while during the winter when large quantities of energy are required but little is supplied by river stations, the water stored in the upper lake would be utilized. If the system were placed on the coast, the lower basin would not be necessary and the water recycled would be ocean water. The usefulness of salt water, however, must first be investigated because it may create other ecological problems. The operational efficiency of transferring power from 'run of the river' stations to peak power via pumping is about 65%.

The major benefit of such a scheme would be that the seasonal run-off of rivers, as designed by nature, would not be modified; thus the role that fresh water plays in coastal ecosystems would continue as in the past.

Alternatively, appropriate studies might be carried out into how much of a spring peak is necessary to maintain a reasonable level of primary production in the estuaries and coastal region. This knowledge could perhaps influence the present philosophy of power production to be more compatible with nature in the use of existing hydro-power systems.

Conclusions

Life in the ocean, as life on land, is intimately related to its environment. The ecosystem is a very closely interwoven fabric of all living things coupled with the natural processes that determine the character, quality and quantity of life that can be supported. Man, with his increasing ability to modify his environment, still has his place in it. But, until he understands its complexities to the extent that he can anticipate the disadvantageous consequences of his actions, man cannot hope to safely exploit the environment to his advantage.

The question then, is whether the interpretation given here is in accordance with the facts supported by scientifically verified predictions and conclusions. Unfortunately, we are not yet able to give an answer. The problem is so large and so complex that it would take years, even decades, of intensive studies before some of the statements given in this analysis could be verified in detail. This time scale applies in particular to the biological field; climatological effects may show up sooner.

Decisions, however, have to be made which do not permit such a delay. Thus, in the interim, these decisions have to be based on theoretical and semi-empirical principles, observations and sound engineering.

In conclusion, fresh water regulation may prove to be one of the most consequential modifications *man* can impose on nature. If we do not alter our course and give consideration to nature's needs there will be irreparable injuries inflicted on the environment for which future generations will condemn us.

The author greatly appreciates the assistance given initially by E. S. Turner, formerly with the National Research Council, and F. Jordan who helped to analyse data, developed graphs, and assisted in the preparation of the paper.

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