THE STATE OF MAINE
DEPARTMENT OF ENVIRONMENTAL PROTECTION

APPLICATION FOR SITE LOCATION OF DEVELOPMENT ACT PERMIT
AND NATURAL RESOURCES PROTECTION ACT PERMIT
FOR THE NEW ENGLAND CLEAN ENERGY CONNECT
FROM QUÉBEC-MAINE BORDER TO LEWISTON
AND RELATED NETWORK UPGRADES

PRE-FILED DIRECT TESTIMONY OF

ERIC S. SHERMAN

FEBRUARY 28, 2019

TESTIMONY OF ERIC J. SHERMAN

Please state your name and address.

My name is Eric J. Sherman. I was born in Greenville and have lived in Maine all but four of my 56 years. I live at 23 Birch Point Road in Greenville.

What is the name of your organization and business address?

I am a private citizen.

What is your current position?

I am a classroom teacher at Greenville Consolidated School located at 130 Pritham Avenue in Greenville.

What other occupations have you had in the greater Forks area?

I am entering my thirty-fifth year as an active registered Maine Whitewater Guide, and I have been a Registered Maine Recreational Guide for over twenty years.

Why did you intervene in these proceedings?

I became an intervenor because I hike, bike, ski, snowshoe, kayak, canoe, and raft in Maine's vast wilderness. I climbed Williams Mountain and Number 5 Mountain a few years ago; they are located in the proposed view shed of the NECEC, near Route 201 and Route 15 in the Rockwood/Jackman/Parlin area, and I took photographs from the fire towers. The NECEC transmission line will be visible from these mountains. Should the NECEC be approved, these are just two of the dozens of negative visual impacts it will cause. I spend a large portion of time from May through October working on the Kennebec and Dead rivers in The Forks area. I love Maine's wilderness, and I love sharing it with the people who come to this area for rafting, camping, sightseeing, and vacationing. I have concerns for the experiences of the guests who book raft trips on the Kennebec River, concerns for the other waterways and wildlife that will be affected, concerns that CMP/Avangrid/Iberdrola is touting this project as "green" and that it in fact is not guaranteed green and that Hydro-Quebec has been suspiciously absent from all proceedings, I have concerns that if this project happens, the North Maine woods as we know them will disappear because they will be open to more development, and finally, concerns that existing and future renewable energy projects in Maine could be eliminated because of the NECEC. Ironically all of my concerns are irrelevant in light of the fact that there is no public need in Maine for the NECEC as Maine generates more electricity than it consumes.

Before I elaborate on my concerns, in reviewing the mission, values, vision, and customer service commitment statements on the DEP mission statement, I cannot see how the DEP members and LUPC members involved can give the NECEC a go ahead. I have underlined language that directly addresses the issues that all of you are charged with. I cannot underscore the enormity of the decision if you should vote to approve the NECEC. The mission statement for the DEP states:

"*Legislative mandate directs DEP to prevent, abate and control the pollution of the air, Water and land. The charge is to preserve, improve and prevent diminution of the natural environment of the State. The Department is also directed to protect and enhance the public's right to use and enjoy the State's natural resources. The Department administers programs, educates and makes regulatory decisions that contribute to the achievement of this mission. In pursuing this mission, it is the policy of the Department to treat its employees and the public with courtesy, respect and* *consideration and to be fair and honest in its dealings, and to be mindful of the special qualities that make Maine a unique place to live and work."*

DEP VALUES: #1- We value a clean environment where public health and natural heritage are protected. DEP VISION: #1- A Maine where people include, in every aspect of their daily lives, a commitment to the protection and enhancement of our environment.

DEP VISION: #2- A Maine where stewardship of natural resources ensures a sustainable economy for future generations.[1]

Likewise, the LUPC's "About Us" statement mirrors the DEP's in that it promises to protect Maine's natural assets; it reads: *"Along with carrying out its planning and zoning responsibilities, the LUPC… For larger development projects requiring DEP review under the Site Location and Development Law, the LUPC certifies that the proposed land uses are allowed and that proposed development activities comply with applicable LUPC land use standards… The unorganized and deorganized areas include...the western mountains and up to the Canadian border. These areas are important to the vitality of both the State and local economies, are home to many Mainers, and are enjoyed by Maine residents and visitors in pursuit of outdoor recreation activities including hunting, fishing, boating, hiking, and camping.*

The Legislature created the Commission to extend principles of sound planning, zoning and development to the unorganized and deorganized areas of the State to:

- *Preserve public health, safety and general welfare;*
- *Support and encourage Maine's natural resource-based economy and*

[1] https://www.maine.gov/dep/about/index.html (last visited February 27, 2019)

strong environmental protections;

- *Encourage appropriate residential, recreational, commercial and industrial land uses;*
- *Honor the rights and participation of residents and property owners in the unorganized and deorganized areas while recognizing the unique value of these lands and waters to the State;*
- *Prevent residential, recreational, commercial and industrial uses detrimental to the long-term health, use and value of these areas and to Maine's natural resource-based economy;*
- *Discourage the intermixing of incompatible industrial, commercial, residential and recreational activities;*
- *Prevent the development in these areas of substandard structures or structures located unduly proximate to waters or roads;*
- *Prevent the despoliation (plundering), pollution and detrimental uses of the water in these areas; and*
- *Conserve ecological and natural values."*[2]

When I bring my crew to where we load the rafts at Harris Station Dam, my crews (and I) are awestruck at the enormity of the dam. I share with them the history of the dam, the natural history of the area, and the specifics of the hydropower generation of Harris Station. Believe me, the irony that a dam which drastically altered the landscape 65+ years ago is not lost on me in my protest against the NECEC. But that is history, and I'm looking ahead to the future which can avoid more destruction of

[2] https://www.maine.gov/dacf/lupc/about/index.shtml (last visited February 27, 2019)

our natural resources by dividing the forest from the Canadian border to the Forks. Except for the stairs at Carry Brook (which were constructed for safety reasons), once we leave Harris Station Dam, people don't see a man-made structure until we hit the ball field at West Forks where we see the Moxie Road briefly, the bridge, and some houses. The company I've worked for since 2001, Moxie Outdoor Adventures, has its lunch site just upstream of where the proposed lines will cross either over or under the river. In either scenario, those lines will be visible from our lunch site, and will be an eyesore that detracts from the wilderness experience of my guests, the other guests, the other guides, and me. If the lines go over the river (I'm aware that CMP/Avangrid/Iberdrola has said they will go under it), the lines will be right there for us to view for the duration of our lunch. If they drill under the river, which does not seem eco-friendly, we will still be able to see the lines running to the towers on the west side of the river coming from the north, and the lines going from the towers on the east side of the river running toward the southeast. I am aware that CMP/Avangrid/Iberdrola says they will leave a buffer zone along the river to minimize the scenic impact from the river, but from our lunch site, we will again be able to see the towers on both sides of the river from our upstream vantage point. From what I understand, going under the river will entail having some sort of stations on both sides of the river that will have driving access. This will open up this area to ATV and other traffic, and who wants to listen to the hum of ATVs and other vehicles while they eat lunch on their rafting trip?

The other river view of the power lines that CMP/Avangrid/Iberdrola has not addressed are from downriver looking back upriver. Once the lines are passed, there's a left turn in the river, a straight stretch where the confluence of Moxie Stream is passed, then a right turn in the river, and a long straight stretch from which the power lines will be able to be seen. These scenarios are unacceptable. People don't leave their homes in Boston and its suburbs and in Southern Maine and its developed areas to visit a place that looks like an industrial park, especially when they expect a wilderness experience.

The spot where the NECEC will cross Moxie Stream is a quiet, closed in area where the dense trees and bushes grow right to the stream's edge. Here it will open up a 300-foot-wide swath that will destroy the character of this beautiful place. It clearly states on the LUPC About Us page:

- *Prevent the development in these areas of substandard structures or structures located unduly proximate to waters or roads;*
- *Prevent the despoliation (plundering), pollution and detrimental uses of the water in these areas*[3]

I am very concerned for the wilderness, waterways, and wildlife that the powerline will affect from the Maine/Canada border all the way to Lewiston. I read an article that summarized the following about CMP/Avangrid/Iberdrola's plan:

"CMP/Avangrid/Iberdrola's proposed line includes above-ground transmission lines across 263 wetlands, 115 streams, 12 inland waterfowl and wading bird habitat areas, the Kennebec River Gorge, the Appalachian Trail, and near Beattie Pond, a Class 6 remote pond.[4]" In actuality, these figures should be much higher as they do not include the roads which will need to be built to the construction sites. This is

[3] *Id.*
[4] https://www.nrcm.org/projects/climate/proposed-cmp-transmission-line-bad-deal-maine/ (last visited February 27, 2019)

unacceptable. My family owns a camp on Moosehead Lake, and we are not allowed to cut a six-inch diameter tree within 100 feet of the lake due to LUPC laws that say there will be a negative impact on the water and wildlife. How can the corporate backed NECEC be approved when laws are so strict for private citizens? If it does get your agencies' approval, then there is a double standard that needs to be addressed.

Additionally, there will be a negative impact on the deer herd in the area of the new 53.5 miles of corridor. We already know that if this power line comes to fruition, the cut will go through some deer wintering yards, and that is a definite detriment to them. However, we need to consider the fact that having all of that area opened up will dramatically increase the kill both during and outside of hunting seasons. The number of deer taken on existing power lines is very high compared to that of forest kills. It's wide open and ATV or other vehicular access to those areas will increase the number of hunters that will go there, and the deer are sitting ducks. With this wide-open space interspersed between and among deer wintering yards, the coyotes will feast when deer get bogged down in deep snow under the transmission line. I'm sure the area's moose population will suffer similar fates. The native brook trout and other fish that live in the 115 streams, the waterfowl, wading birds, amphibians, and other species that live in the 263 wetlands will be adversely affected when the canopy of the trees is permanently removed. How can anyone justify the devastation that the 145-mile NECEC project will cause to the environment, when a single tree cut too close to Moosehead's shoreline causes a fine?

I am also concerned that if the power line is allowed, then a precedent will have been set. What will stop developers from building more transmission lines, gas lines, wind turbines, roads, bridges, cabins, condominiums, and who knows what else in this wilderness area? The NECEC may well be the beginning of the end of the wilderness feel and character of Maine's precious woods. There are people who live and work in the footprint of the proposed transmission line. The traditional jobs that are performed here are tourism based because of what this area has to offer: fishing, hunting, bird watching, moose watching, hiking, camping, rafting, canoeing, kayaking, snowmobiling, skiing, a get away from the hustle and bustle of city life, and yes, logging. But Maine laws control the actions of loggers, and the land that's cut grows back; it's not permanent like the NECEC will be. When this area looks like suburban Portland, who will want to visit and spend their money here? Why has there not been an economic impact study for this area before the proposed NECEC is built? Will there be a full environmental impact study for this area? Before permits are issued, these studies must be required. Your charge is "to preserve, improve and prevent diminution of the natural environment of the State." Do not just let the NECEC pass without thorough, fine-tooth combing of its serious effects.

Finally, the issue here is Maine- what Maine needs, not what CMP/Avangrid/Iberdrola and the Massachusetts legislature WANTS. CMP/Avangrid/Iberdrola has not demonstrated a public need in Maine for this project. Maine consistently generates more electricity than it consumes. Log in to the USGS Water Information System: Web Interface, and view the water flows from summer 2018[5]. Even on the hottest days when power was at its highest

[5] https://nwis.waterdata.usgs.gov/me/nwis/uv/?cb_00060=on&cb_00065=on&format=gif_default&site_no=01042500&period=&begin_date=2018-08-16&end_date=2018-08-16 (last visited February 27, 2019)

demand in New England (except for one afternoon, August 16, 2018), Harris Station Dam did not generate electricity at its maximum capacity to send into the New England power grid. If electricity was truly needed on those hottest of days, there was the potential to generate it right here in Maine. Contact ISO New England and ask for the number of times they've called existing hydropower producers and told them to stop producing electricity because the grid can't handle it. It's called CURTAILMENT, and it happens frequently. Will local producers be pushed out because Canadian power will be used first? It seems instead of importing unnecessary electricity from Canada, the existing power grid needs to be updated so LOCAL suppliers can get their electricity to market. Has CMP/Avangrid/Iberdrola and Massachusetts considered whether other projects within Maine, New Hampshire, Vermont, New York, Connecticut, Rhode Island, and Massachusetts itself can address demand for clean, renewable energy with a smaller environmental footprint than that of the NECEC project? There are solar projects awaiting utilization. For example, a dairy farmer on the mid-coast is exploring solar possibilities for his soon-to-be defunct dairy farm. He has acres and acres of open fields available; no existing forests will need to be permanently cut as it's already pastureland. If the NECEC goes through, will his solar project ever be a possibility? Can't projects like this dairy farmer's put Mainers to work long-term in order to supply the New England power grid, i.e. Massachusetts, with renewable energy? The promised 1,700 jobs touted in construction and maintenance of the transmission line are mostly temporary. When the NECEC is built, those jobs will disappear. Other local renewable energy projects, such as the dairy farm mentioned, won't be built, and real, permanent jobs for Mainers won't be created- Canadians benefit. In fact, those jobs could be eliminated altogether because the NECEC will obstruct transmission lines for those projects and glut the power market with electricity. To me it makes more sense to invest in clean, renewable energy projects based in Maine rather than import Canadian energy that will block out those Maine projects.

All you need to do is read your DEP Mission Statements and LUPC About Us statements and see that the NECEC does NOT meet the standards according to them. The people who live and work in this region want to protect this beautiful area's rivers, streams, wildlife, and the way we make our living. You get to decide whether CMP/Avangrid/Iberdrola's profits are more important than the values of the people who live in its path. Do not allow the nonessential NECEC project to come to fruition. Maine's wilderness, wildlife, and waterways must be preserved. And the people who live in and make their living in and from the Maine woods deserve to have a wilderness free of development to continue making that living. Thank you.

COMMENTS ON NON-HEARING TOPICS

I am also concerned that NECEC will not reduce global C02 emissions. There are fundamental problems with the source of the hydropower coming from a newer reservoir that emit a high percentage of CO2. MIT Professor of Earth Sciences, Dr. Brad Hager, writes about Hydro-Quebec that, "the extent to which some of the scientifically proven facts about hydropower get twisted and distorted is deplorable." But HQ itself twisted the facts, emphasizing information irrelevant to NECEC. Although their older reservoirs that provide power for Quebec may be clean, newer impoundments flooded to provide power for export are not. It is the CO2 emissions of these newer reservoirs that pertain to NECEC. Hydro-Quebec scientists published an impressive study of the CO2 emissions caused by creation of their new Eastmain-1 reservoir.

Quoting from their 2012 paper (https://www.google.com/url?q=https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011GB004187?fbclid%3DIwAR1WC60LTNoY0S_XYRktf1e-z7tn9d_i7uzdmsQPH5CoKjvb7JjXa5jW3I4&source=gmail&ust=1551434745346000&usg=AFQjCNFOYFHtg4IjHqjjAmeZNd2Z8B6a5g) comparing the emissions of this project to those from Natural Gas Combined Cycle (NGCC) power: ". . . during the first year, the Eastmain-1 reservoir was emitting up to 77% more C than NGCC, . . . after 25 years, reservoir emissions will be 50% lower than those of NGCC." In other words, the power from the new Eastmain-1 project was initially 90 times more CO2 intensive than the HQ average, but is expected to drop to "only" 25 times higher than that from older reservoirs. Why is this new power so dirty? As always happens, HQ dammed the best sites first, impounding narrow, deep valleys to provide power for Quebec. Later, anticipating a market for export, they dammed the poorer sites, building low impoundments that flooded broad lowlands. The CO2 footprint of a hydroelectric reservoir depends on its area divided by its depth. Old reservoirs that dam narrow, deep valleys, result in low CO2 per GWh. For newer reservoirs like Eastmain-1, the opposite occurs. The increase in hydropower generation for export comes at a cost of far higher CO2 emissions than the norm for Hydro-Quebec power. In evaluating NECEC, the system-average CO2/GWh is irrelevant. We must examine the impact of the additional generation from less efficient reservoirs developed for export capacity. Otherwise we are fooling ourselves." (*See* Attachment A, 1-21-19 email from Brad Hager to Sandra Howard)

In addition, there is concern that the Hydro-Quebec "built dams discharging waters depleted of dissolved silicate, and thereby, polluting the waters of the Gulf of Maine by starving them of the essential nutrients that support phytoplankton growth." (*See* Attachment B, Kasprzak 11-28-18 report) Mr. Kasprzak calls attention to the fact that if a company wished to construct dams and reservoirs here in the United States such as Hydro-Quebec has done in Canada, they would not pass the environmental laws we have in place. We must not reward Hydro-Quebec's irresponsible environmental practices by encouraging them to continue such methods. (*See* Attachment C, Kasprzak 10-15-18 Report and Attachment D, Kasprzak 1-15-19 report).

CMP/Avangrid/Iberdrola has not presented any evidence of a reduction in greenhouse gas emissions. This is not a clean energy project. Why has Hydro- Quebec refused to be cross examined in the hearings that have been held? This is a big red flag! Hydro-Quebec may send electricity generated by hydropower dams through the NECEC, but they will use coal and/or oil to supply Ontario, New York, New Brunswick, and

Quebec itself when demand is high, or when hydro dams are out of commission, or when there is a drought in the future; they cannot guarantee that this will reduce carbon emissions, though they are claiming it will. If they don't deliver the electricity they have contracted to send to Massachusetts, they will face stiff fines for it. Again, why hasn't Hydro-Quebec sent representatives to any of the informational meetings that CMP/Avangrid/Iberdrola has held, and why aren't they being subpoenaed to appear before the PUC, DEP, and LUPC and answer questions under oath? The fact that they have been absent during all of these proceedings should raise suspicion and doubt about what Hydro-Quebec and CMP/Avangrid/Iberdrola are up to.

Date: 2/20/19

Respectfully submitted,

By: Eric J. Sherman

Print Name: Eric J. Sherman

STATE OF Maine

COUNTY OF Piscataquis

Personally appeared before me on the above- named Eric Sherman, who being duly sworn, did testify that the foregoing testimony was true and correct to the best of his/her knowledge and belief.

Before me,

Kathleen Bishop

Notary Public/ Attorney at Law

My Commission expires 6/19/2023

KATHLEEN BISHOP NOTARY PUBLIC

Hydro-Quebec writes: "The extent to which some of the scientifically proven facts about hydropower get twisted and distorted is deplorable." But HQ itself twisted the facts, emphasizing information irrelevant to NECEC. Although their older reservoirs that provide power for Quebec may be clean, newer impoundments flooded to provide power for export are not. It is the CO2 emissions of these newer reservoirs that pertain to NECEC.

Hydro-Quebec scientists published an impressive study of the CO2 emissions caused by creation of their new Eastmain-1 reservoir. Quoting from their 2012 paper comparing the emissions of this project to those from Natural Gas Combined Cycle (NGCC) power: ". . . during the first year, the Eastmain-1 reservoir was emitting up to 77% more C than NGCC, . . . after 25 years, reservoir emissions will be 50% lower than those of NGCC." In other words, the power from the new Eastmain-1 project was initially 90 times more CO2 intensive than the HQ average, but is expected to drop to "only" 25 times higher than that from older reservoirs.

Why is this new power so dirty? As always happens, HQ dammed the best sites first, impounding narrow, deep valleys to provide power for Quebec. Later, anticipating a market for export, they dammed the poorer sites, building low impoundments that flooded broad lowlands. The CO2 footprint of a hydroelectric reservoir depends on its area divided by its depth. Old reservoirs that dam narrow, deep valleys, result in low CO2 per GWh. For newer reservoirs like Eastmain-1, the opposite occurs.

The increase in hydropower generation for export comes at a cost of far higher CO2 emissions than the norm for Hydro-Quebec power. In evaluating NECEC, the system-average CO2/GWh is irrelevant. We must examine the impact of the additional generation from less efficient reservoirs developed for export capacity. Otherwise we are fooling ourselves.

Brad Hager, Ph.D.
Cecil and Ida Green Professor of Earth Sciences
MIT School of Science
bhhager@mit.edu

1-21-19 sent by email to Sandra Howard

Reservoir Hydroelectric Dams

Silica Depletion

Silica Shelled Diatom Phytoplankton

A Gulf of Maine Catastrophe

Stephen M. Kasprzak
November 28, 2018

INTRODUCTION

I wrote a Report The Problem is the Lack of Silica on October 15, 2018 and submitted it at a public hearing by Maine's Public Utility Commission on the proposed New England Clean Energy Connect (NECEC) by Avangrid/Central Maine Power (CMP). This Report documented how Hydro-Quebec has significantly reduced the annual budget of dissolved silica to the northwest Atlantic and Gulf of Maine and how this reduction is the major driver in the starvation of many of the fisheries in these waters.

I handed out over 30 copies of this Report at the hearing and e-mailed more copies to interested parties. Someone shared my report with a scientist who commented *"the Gulf of Maine is too big to be affected by the releases from Hydro-Quebec's reservoir hydroelectric dams."*

This Report has been written to not only respond to the above observation, but also to the claim of Maine Marine Resources that "*Climate change is driving the decline in the shrimp fishery."*

The major source of the annual budget of fresh water and dissolved silicate to the Gulf of Maine is the St. Lawrence River, whose head waters are Lake Michigan, which is the fifth largest water body in the world. The St. Lawrence is the 27th largest river in the world, and its daily water flows of 300,000 to 500,000 cubic feet ($ft.^3$) per second dwarf the flows of Maine's largest rivers (see Graphs 1 and 2 on page 4).

The proliferation (see Maps 1 & 2 on pages 3 & 5 and Tables 1-3 on pages 6 &11) of Hydro-Quebec's reservoir hydroelectric facilities on the major rivers discharging into the St. Lawrence River, James Bay, Hudson Bay and Labrador Current have significantly altered the natural hydrologic cycle and silica cycle, which has starved the silica encased diatom phytoplankton in the Gulf of Maine of dissolved silicate. Diatom phytoplankton is the essential basis of the marine food web, including Maine's shrimp.

The building of these dams would have violated section 401 of the Clean Waters Act and Maine's Natural Resources Act and never could have been built in Maine. These reservoir dams have been built not only on all of the major rivers, but also on many of the tributaries and outlets of thousands of lakes and ponds in the watersheds of these major rivers.

These rivers and water bodies are all part of the Gulf of Maine's ecosystem and for over 70 years Maine officials have stayed silent while Hydro-Quebec built dams discharging waters depleted of dissolved silicate, and thereby, polluting the waters of the Gulf of Maine by starving them of the essential nutrients that support phytoplankton growth.

In the late 1950's there was a major decline in the annual load of dissolved silicate transported to the Gulf of Maine via the St. Lawrence River. This decline was brought on, not by dams, but by a silica limitation in Lake Michigan, which is the head waters of St. Lawrence River.

A 1970's study on the eutrophication of Lake Michigan was done by Claire Schelsky and Eugene Stoermer and was summarized in *Silica Stories by Conley and DeLaRocha,* in 2017 (see Attachment 1).

I believe the cumulative impact of this annual silica limitation in Lake Michigan was the driving force behind the first red tide event in 1958 in the Gulf of Maine. Coincidence, I don't think so. See Attachment #1 and look at the graph in Case Study #1 and the huge increase in silica burial in Lake Michigan from 1930 on. Please note that this has never happened before in Lake Michigan's 14,000 year history.

"Thirty years ago paralytic shellfish poisoning (PSP) was virtually unknown in New England, yet now, significant portions of the region's intertidal shellfish resources are closed annually to harvesting because of toxicity. A further expansion of the problem occurred in 1989 when off-shore shellfish resources on George's Bank and Nantucket Shoals were shown to contain dangerous levels of toxin. (White et.al. 1993)

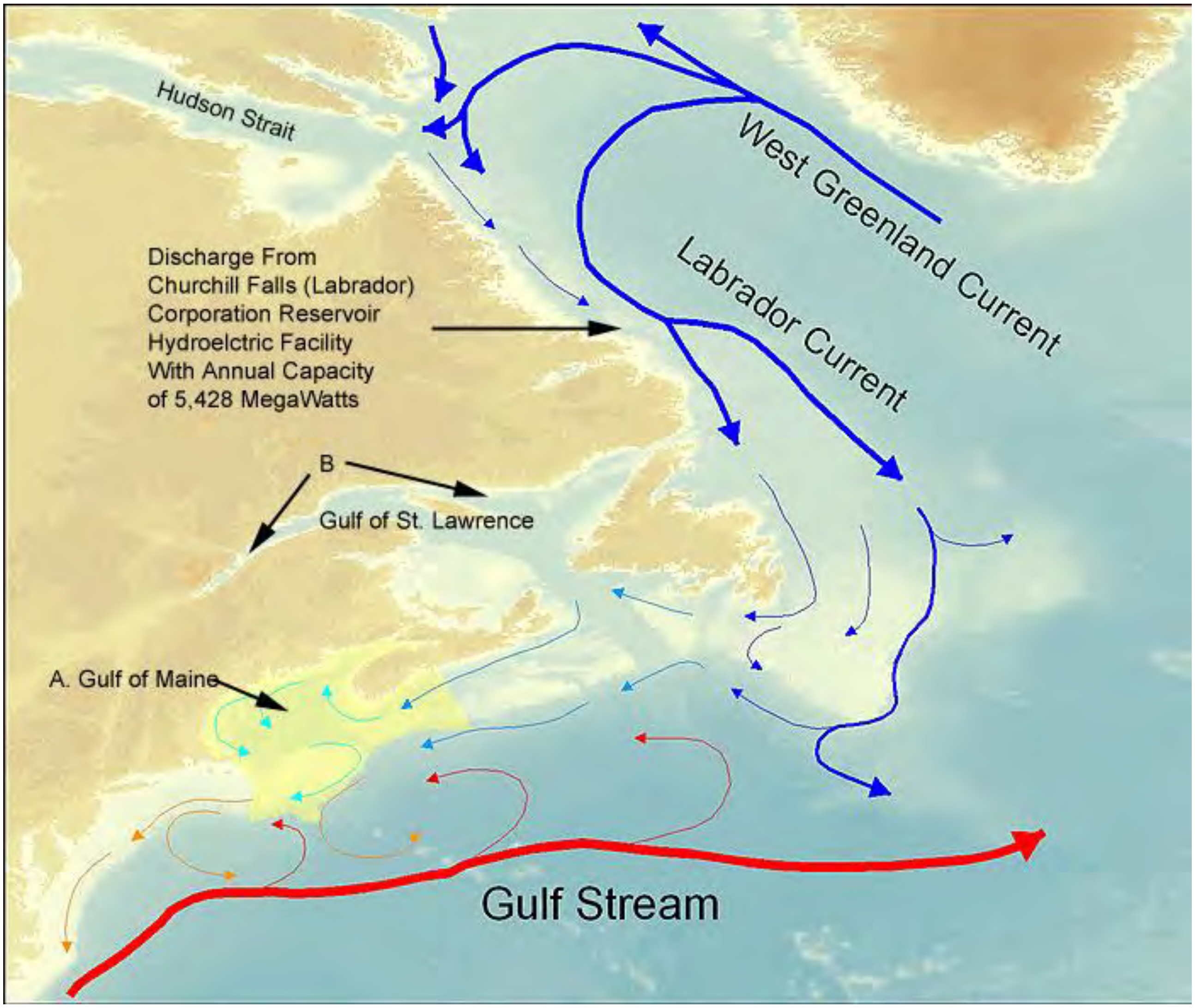
The following is the last paragraph of the Case Study #1:

"Overall, diatoms getting shut out of the latter part of the growing season in Lake Michigan while there is still plenty of nitrogen and phosphorus available for growth is a bad thing. It means a decrease in the flow of energy and materials through diatom-based food webs, which generally efficiently lead to fish, and an increase in the growth of noxious plankton species like dinodflagellates.[11] *Worse yet, what happens in Lake Michigan doesn't stay in Lake Michigan. Now stripped of their dissolved silica, the waters of Lake Michigan flow into Lake Huron and then Lake Erie, go over Niagara Falls, flow into Lake Ontario, and then via the Saint Lawrence River, arrive at the Atlantic Ocean at the Gulf of Saint Lawrence in all the full glory of their silica deficiency. You can almost hear the coastal diatoms screaming." (Silica Stories, Conley et. al. 2017.)*

On November 16, 2018, the Atlantic States Maine Fisheries Commission voted to close the Gulf of Maine winter shrimp season for three years. This agency said: "*The stock has shown very little signs of recovery. It's considered a depleted resource."*

With complete respect for these officials, the shrimp have become a depleted resource because we have allowed reservoir hydroelectric facilities to change the historic (before dams) natural silica cycle. This has depleted the essential nutrient dissolved silica from the waters of the Gulf of Maine and northwest Atlantic during the growing season of silica encased diatom phytoplankton.

Many of the major rivers now have more than one reservoir on them, which only compounds the negative impacts described above of captured dissolved silicate in the spring and the sinking and burying of biogenic silica in the reservoirs through the process of eutrophication.

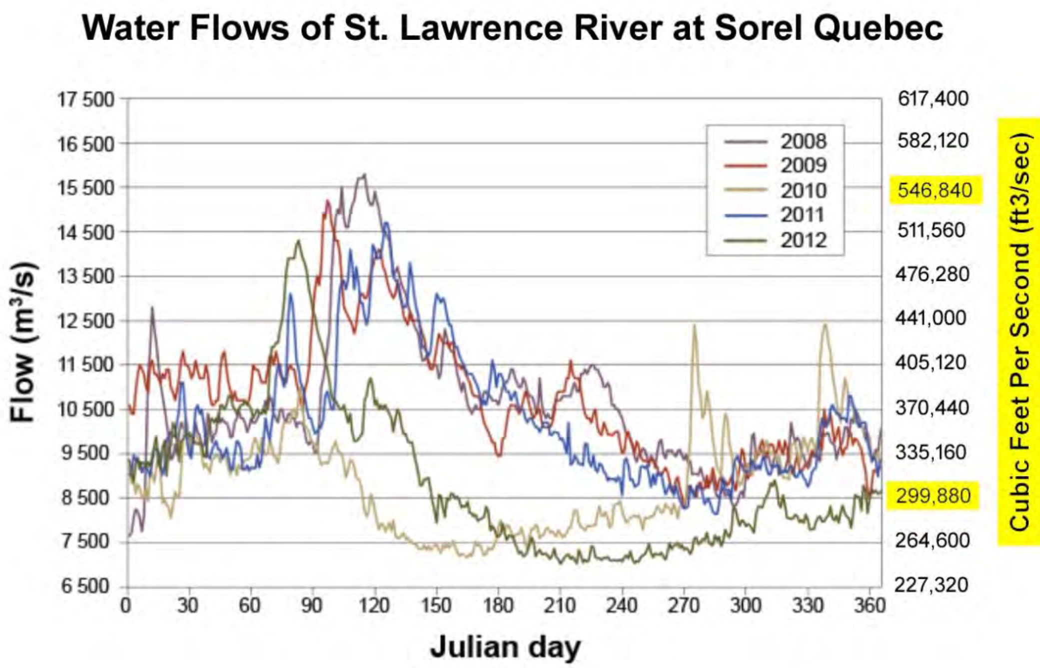


Map 1

A. Maine's six major rivers (see Graph 2 on page 4) discharge into the Gulf of Maine in the above area marked "A". The hydroelectric facilities on these rivers typically operate in a "run of river" mode and have an annual capacity of 526 MW. Maine's total capacity is only 723MW.

B. In the area marked "B," Hydro-Quebec has 16 reservoir hydroelectric facilities built on 9 rivers discharging into the St. Lawrence River and /or its Gulf (see Map 2 on page 5 for more details). These facilities have annual capacity of 12,749 MW (see Table I on page 6).

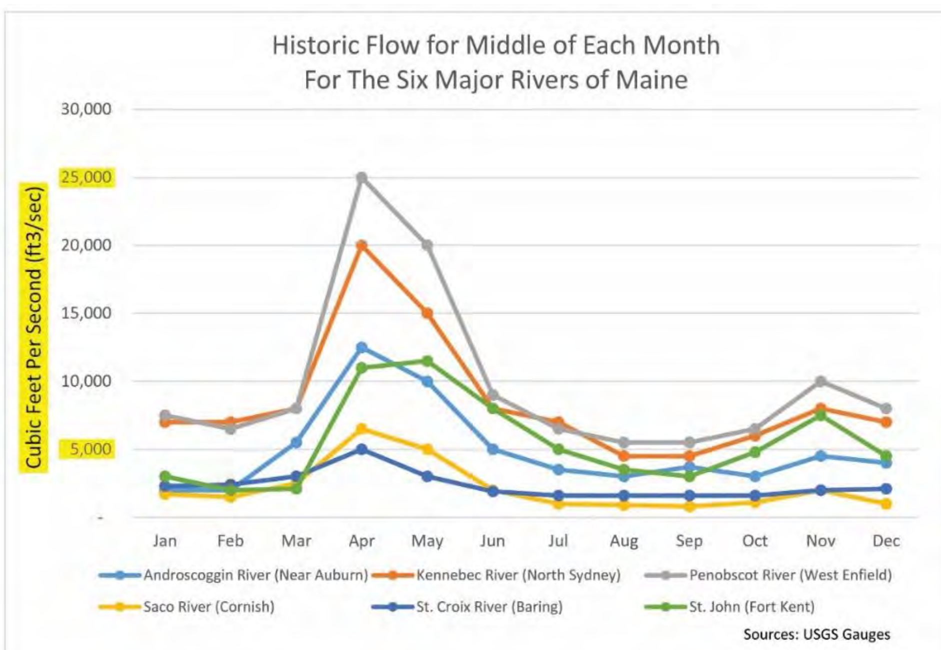
THE ST. LAWRENCE RIVER IS THE 27TH LARGEST RIVER IN THE WORLD AND HISTORICALLY TRANSPORTED WITHIN DAYS THE DISSOLVED SILICATE FROM ITS TRIBUTARIES INTO THE GULF OF MAINE.



Graph 1

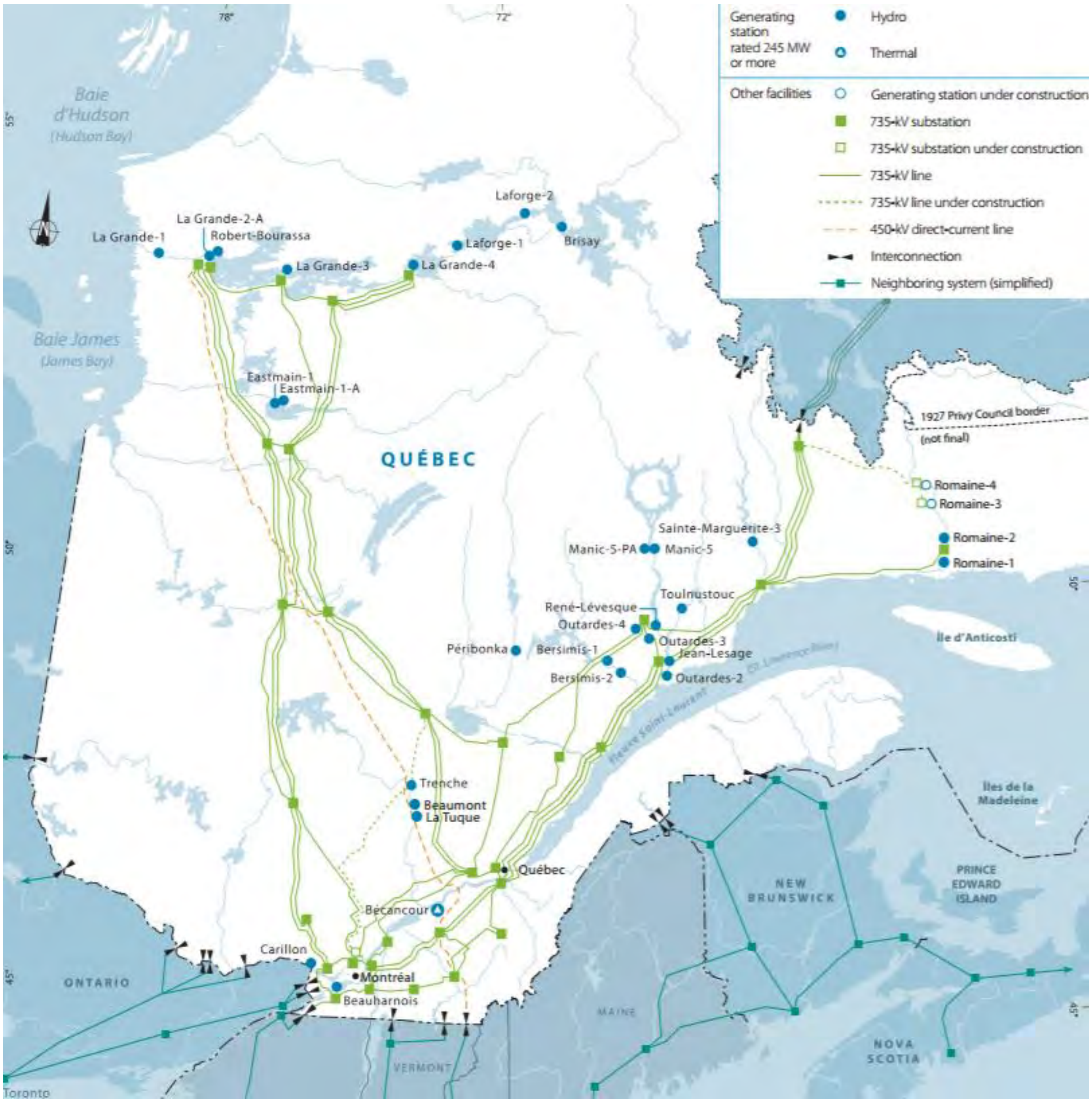
Source: St. Lawrence Action Plan 2011-2026

Water flows of St. Lawrence River dwarf the flows of Maine six major rivers



Graph 2

HYDRO-QUEBEC HAS BUILT 16 RESERVOIR FACILITIES ON 9 RIVERS IN SOUTHEAST QUEBEC THAT FLOW INTO THE ST. LAWRENCE RIVER. THESE 16 FACILITIES HAVE AN ANNUAL CAPACITY OF 12,749 MEGAWATTS (MW), COMPARED TO MAINE'S ANNUAL CAPACITY OF 753 MW.



Map 2

Table I

Reservoir Hydroelectric Generating Stations
Discharging into St. Lawrence River or Gulf

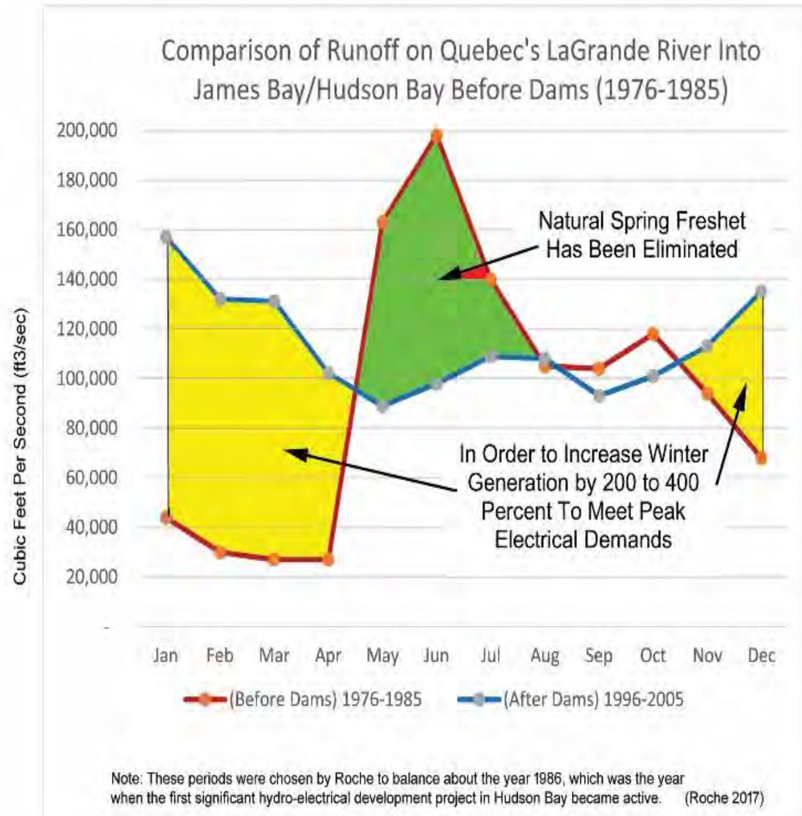
Owner	Name	Capacity In Megawatts (MW)	Commissioned	Watershed
Hydro-Quebec	Rapids Blanc	204	1934-35	St. Maurice
Hydro-Quebec	Bersimis-1	1,178	1956	Betsiamites
Hydro-Quebec	Bersimis-2	869	1959	Betsiamites
Hydro-Quebec	Jean-Lesage (Manic-2)	1,145	1965-67	Manicouagan
Hydro-Quebec	Outardes-4	785	1969	Outardes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

Discharging into Labrador Current

Owner	Name	Capacity In Megawatts (MW)	Commissioned	Watershed
Churchill Falls (Labrador) Corp.	Churchill Falls	5,428	1971-74	Churchill

THESE RESERVOIR DAMS HAVE CHANGED THE HYDROLOGIC CYCLE AND SILICA CYCLE FOR THE GULF OF MAINE BY CAPTURING AND STORING THE WATERS OF THE SPRING FRESHET IN ORDER TO MEET PEAK WINTER DEMAND FOR ELECTRICITY

I have plotted on Graph No. 1 the monthly flow curve of the LaGrande River before damming (1976-1985) and the flow curve after damming (1996-2005) (Roche 2017). I converted the water flows in Roche 2007 Report from KM^3/month to ft. ^{3}/sec.



Graph 3

Most of the hydroelectric facilities on Maine's rivers are operated in a "run of river" mode and have not eliminated the spring freshet. "Run of river" facilities have very little storage capability. Storage is typically measured in hours unlike large reservoir facilities which can store water for six months or more.

A HEALTHY FISHERY IN THE GULF OF MAINE AND NORTHWEST ATLANTIC IS BASED ON "THREE NUTRIENT-ENRICHMENT PROCESSES: COASTAL UPWELLING, TIDAL MIXING AND LAND-BASED RUNOFF, INCLUDING MAJOR RIVER OUTFLOW" (CADDY AND BAKUN, 1994).

The delivery of nutrients to coastal waters via upwelling is a hypothesis, and *"there is a caveat to this mechanism: nutrients in the up welled waters must be continually replenished in order for this transient upwelling to sustain phytoplankton growth over the long term,"* and "*this supply is only effective as long as there is a mechanism by which nutrients are replenished in the upper thermo cline."* (Williams and Fallows, 2011.) This mechanism was the historic (before dams) silica cycle.

***"EIGHTY PERCENT OF THE ANNUAL INPUT OF DISSOLVED SILICATE TO THE OCEAN IS TRANSPORTED VIA OUR RIVERS AND STREAMS."*(PAUL TREGUER ET. AL. 1995).** In the Gulf of Maine, the majority of this annual budget was historically delivered by the roaring rivers of the spring freshet, which Hydro-Quebec has now eliminated.

> *"Reservoirs built in those cool, temperate zones that play host to much of Europe, Asia, and North America and therefore a large percent of the world's industrialized nations are the worst, retaining nearly half of this region's seaward sediment flux. Nearly half! This enormous retention of sediment occurs because there are a lot of dams in these regions and is made worse by cool, temperate zone rivers tending to be turbid (full of particles.).*
>
> *Less obvious to the naked eye is the deprivation of downstream areas of dissolved silica. This deprivation occurs because a portion of the suspended material normally transported by a river dissolves en route, releasing dissolved silica into the river system to be delivered to the sea. But once particles are buried in a reservoir sealed in their sedimentary tomb, there is little chance of this happening. This is one way that dams starve downstream areas of dissolved silica that would normally have been used to fuel the growth of diatoms, reeds and grasses, and other silica-producing organisms.*
>
> *But there is a second process at work behind dams that is even more insidiously silica-stealing: diatom blooms. 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."* (Silica Stories Conley et. al. 2017).

HYDRO QUEBEC AND THE ADVOCATES OF HYDROELECTRICITY CLAIM IT IS A POWER SOURCE THAT IS CLEAN AND RENEWABLE BECAUSE IT USES THE EARTH'S ANNUAL WATER CYCLE TO GENERATE ELECTRICITY. THERE IS SOME TRUTH TO THIS CLAIM, AS IT PERTAINS TO "RUN OF RIVER" HYDROELECTRIC DAMS, BUT IS A FALSEHOOD WHEN IT COMES TO LARGE RESERVOIR DAMS BECAUSE THEY HAVE ALTERED THE "HYDROLOGIC CYCLE," WHICH IS DEFINED AS FOLLOWS BY BRITANNICA:

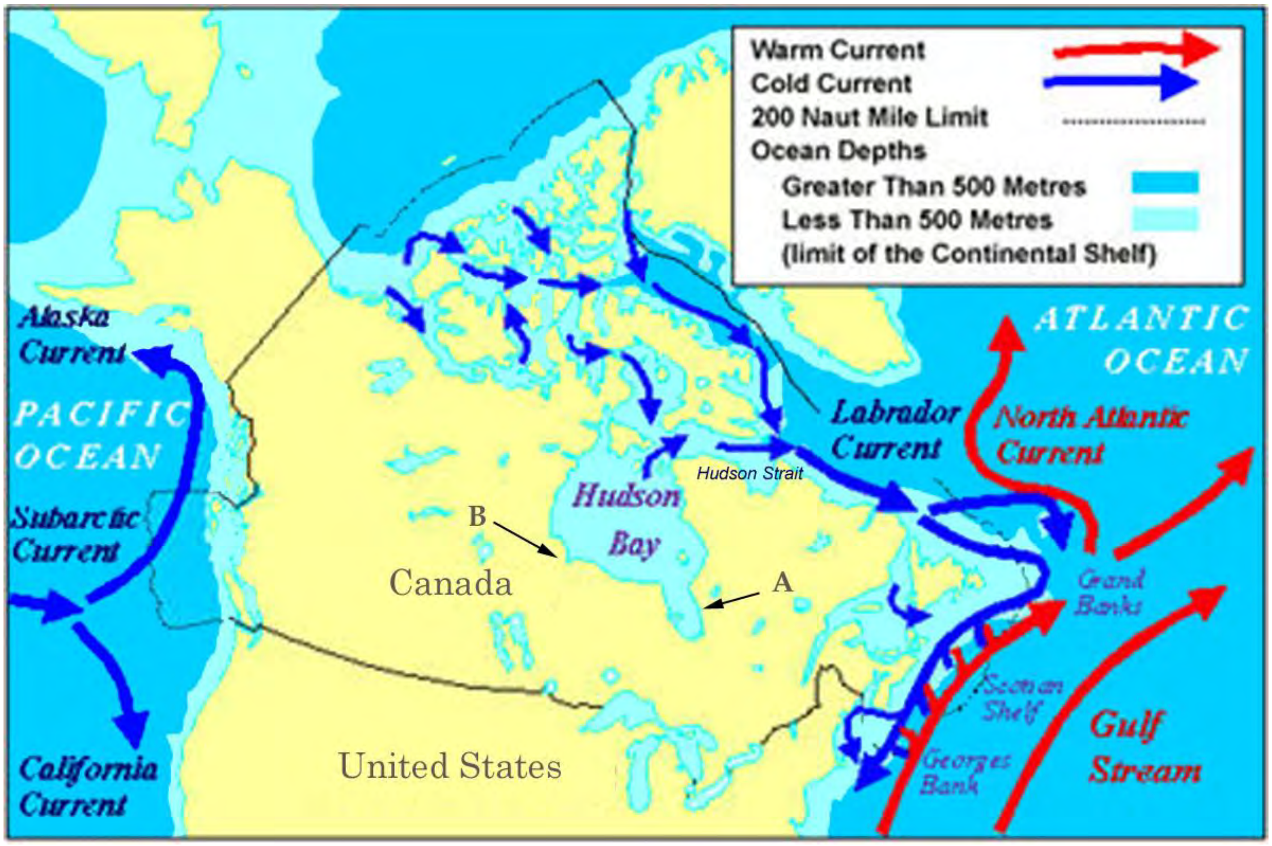
"Water on earth exists in all three of its phases-solid, liquid and gaseous. The liquid phase predominates. By Volume, 97.957 percent of the water on earth exists as oceanic water and associated sea ice. The gaseous phase and droplet water in the atmosphere constitutes 0.001 percent. Fresh water in lakes and streams makes up 0.036 percent, while groundwater is 10 times more abundant at 0.365 percent.

Each of the above is considered to be a reservoir of water. Water continuously circulates between these reservoirs in what is called the "hydrologic cycle," which is driven by energy from the sun, evaporation, precipitation, movement of the atmosphere, and the downhill flow of river water, glaciers, and groundwater keep water in motion between the reservoirs and maintains the hydrologic cycle."

The construction and management of reservoir dams by Hydro Quebec not only has significantly altered the hydrologic cycle, but also negatively impacted the silica cycle.

> *"Today, rivers and the release of groundwater through submarine springs deliver 85% of the reactive silica that enters the oceans.*
>
> *Up at the top of the ocean, dissolved silica taken up by silica biomineralizers like diatoms becomes incorporated into biogenic silica, most of which dissolved before it manages to sink all the way to the seafloor.*
>
> *Once added to the ocean, dissolved silica is available for use by silica biomineralizers such as diatoms. Furthermore, because our friends the diatoms are impressively numerous, fast-growing, and notably siliceous, it is a safe bet that most of the 240 teramoles ($240 x 10^{12}$ mol aka $1.4 x 10^{10}$ metric tons) of biogenic silica produced in the upper ocean each year is being produced by diatoms. Thus the production of biogenic silica in the oceans is depicted in the upper part of the ocean on the silica cycle.*
>
> *The fate of almost all of this biogenic silica that is made each year is to rapidly dissolve. The modern day ocean is after all extremely undersaturated with respect to noncrystalline silica. So strong is the power of this undersaturation, slightly more than half of the biogenic silica produced each year dissolved even before it has had time to sink only 100 to 200 meters. In the end only 2-3% of the biogenic silica produced in the oceans each year becomes permanently buried in ocean sediments.*
>
> *But permanent export of 2-3% of each year's crop of biogenic silica is enough to (more or less) equal the amount of reactive silica coming in to the ocean via rivers, submarine groundwater springs, and mid-ocean ridge hydrothermal fluids. And because the gross amount of biogenic silica production is so high, a removal efficiency of 2-3% is enough to keep ocean waters all but entirely depleted of dissolved silica."* (Silica Stories, Conley et.al. 2017).

IN A RECENT CANADIAN STUDY OF TRENDS IN RIVER DISCHARGE FROM 1964-2014, THE AUTHORS FOUND: *THAT THERE HAS BEEN A THREE-FOLD INCREASE IN RIVER DISCHARGE DURING WINTER, WHEN ELECTRIC DEMAND PEAKS, INTO THE ESTUARIES OF LABRADOR SEA AND EASTERN HUDSON BAY FOR THE 2006-2013 PERIOD COMPARED TO 1964-1971 AND A FORTY PERCENT REDUCTION IN DISCHARGE DURING THE SUMMER."* (Recent Trends and Variability in River Discharges Across Northern Canada, Dery et. al. 2016).



Map 3

A. In this area marked "A," Hydro Quebec has 9 reservoir hydroelectric facilities in the watershed of the LaGrande River and 2 on the Eastmain River. The annual capacity of these 11 facilities is 17,383 MW (see Map 2 on page 5 and Tables 2and 3 on page 11 for more detail).
B. In the area marked "B," Manitoba Hydro has 4 reservoir hydroelectric facilities in the watershed of the Nelson River with an annual capacity of 3,837 MW (see Tables 2 and 3 for more details).
C. The proliferation of these reservoir hydroelectric facilities in the Gulf of Maine's ecosystem over the past 70 years is summarized in the next two Tables. I did not include facilities with an annual capacity of less than 200 MW. There are thousands of them also altering the silica cycle.

Table 2

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
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
		21,220		

Table 3
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

ACCORDING TO A 2007 REPORT BY STRANEO AND SOUCIER: ***"OUR RESULTS SUGGEST THAT APPROXIMATELY 15% OF THE VOLUME AND 50% THE FRESHWATER CARRIED BY THE LABRADOR CURRENT IS DUE TO HUDSON STRAIT OUTFLOW."***

The St. Lawrence River is the largest river in Quebec, and the second largest is the LaGrande, which flows into James Bay/Hudson Bay. Hudson Bay flows into Hudson Strait and continues south into the Labrador Current.

The Labrador Current is 6 to 12 miles wide and transports approximately 6 million cubic meters of fresh water each second southward, which is approximately 10% of the volume of the Labrador Current. This fresh water is carrying dissolved silica and other essential nutrients which stimulate biological productivity in the coastal waters of Labrador, which becomes progressively more productive from north to south.

Further south an inshore branch of the Labrador Current continues around the southern shore of Newfoundland and enters the Gulf of St. Lawrence (see Map 3 on page 10). The outflow of the St. Lawrence tends to follow the south shore and mixes with the Labrador Current. The circulation on the Scotia Shelf is dominated by a southwestward coastal current flowing from the Gulf of St. Lawrence to the Gulf of Maine.

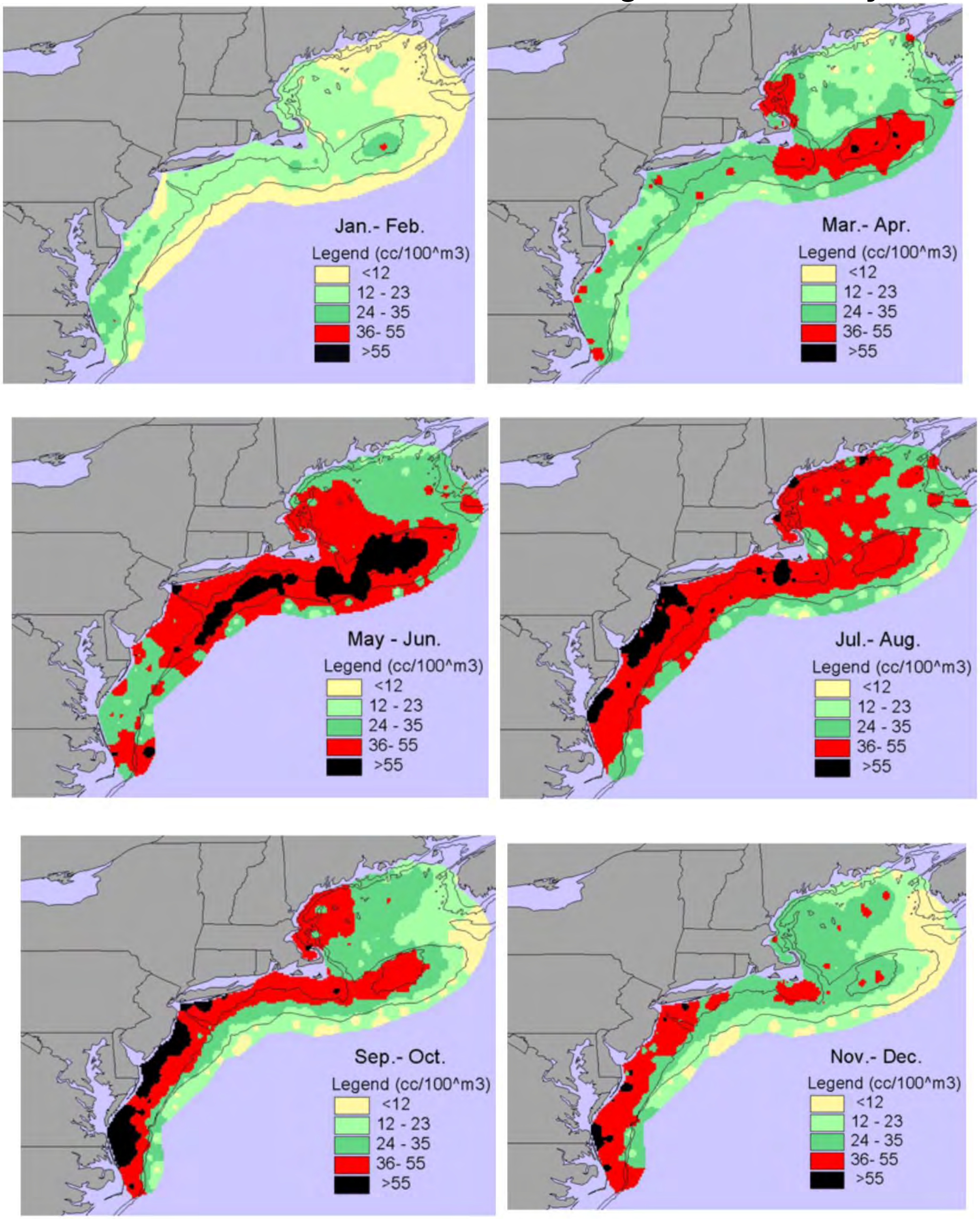
Silica-encased phytoplankton is the foundation of the aquatic food web, the primary producers, feeding everything from microscopic animal-like zooplankton to multi-ton whales. Small fish and invertebrates also graze on the plant-like organisms, and then those smaller animals are eaten by bigger ones. Phytoplankton is responsible for most of the transfer of carbon dioxide from the atmosphere to the ocean.

On the next page are satellite images showing how the pastures of zooplankton start blooming during the March through June period, in conjunction with the March/June period of the spring freshet of Maine's rivers discharging into the Gulf of Maine (see Map 1 on page 3 and Graph No.2 on page 4).

BEFORE RESERVOIR DAMS THE GULF OF MAINE WAS THE BENEFICIARY OF A PROLONGED SPRING FRESHET FROM ITS RIVERS, THE ST. LAWRENCE RIVER AND ITS TRIBUTARIES, AND THEN THE RIVERS OF NL, NORTHWEST QUEBEC AND MANITOBA VIA THE LABRADOR CURRENT.

Hydro-Quebec has eliminated the historical (before reservoir dams) spring freshet from the major rivers into the St. Lawrence River. This freshet occurred during the April/June period, and the dissolved silicate in this freshet was quickly transported to the Gulf of Maine via the high river flows of the St. Lawrence River as measured at Sorel, Quebec in Graph No. 1 on page 3.

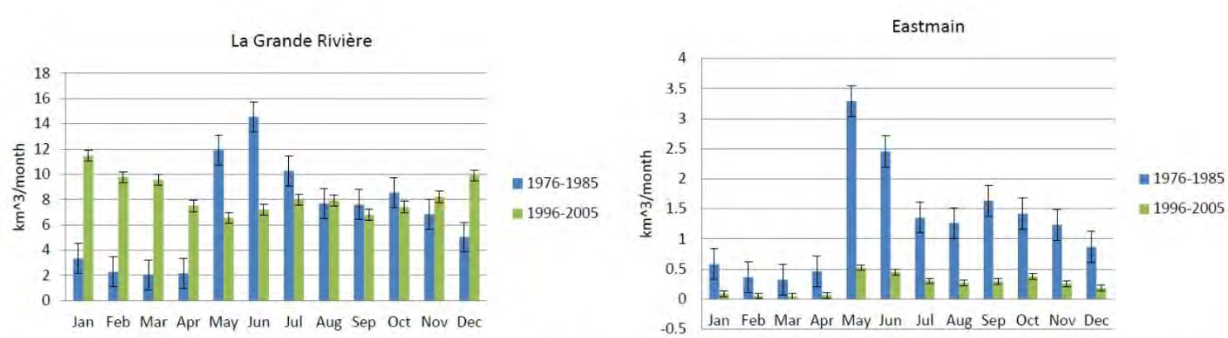
Biovolume of Zooplankton
Northeast U.S. Continental Shelf Large Marine Ecosystem



Source: NOAA – Northeast Fisheries Science Center

Roche wrote the following in his 2007 Report:

"In 1980, 80% of the flow from the Eastmain River was diverted in the LaGrande River, and seasonal runoff was impounded so that it could be released to produce electricity in the winter; consequently, the natural spring freshet into James Bay does not occur at either river. The plume from the Eastmain River is now much smaller and the size and shape of the summer plume from the LaGrande River are essentially unchanged; however, the area of the under-ice plume from the LaGrande River has trebled (Figure 3.1) and can now extend 100 km (62 miles) northward under the land fast ice of James Bay."



Comparison of runoff from two of the major rivers most affected by damming or diversion for the pre-1986 and post-1986 periods.

Source: Ray Roche (2017)

The high influx of dissolved silicate from LaGrande and Eastmain Rivers during the spring freshet is no longer available to be transported via the Labrador Current to the Gulf of Maine.

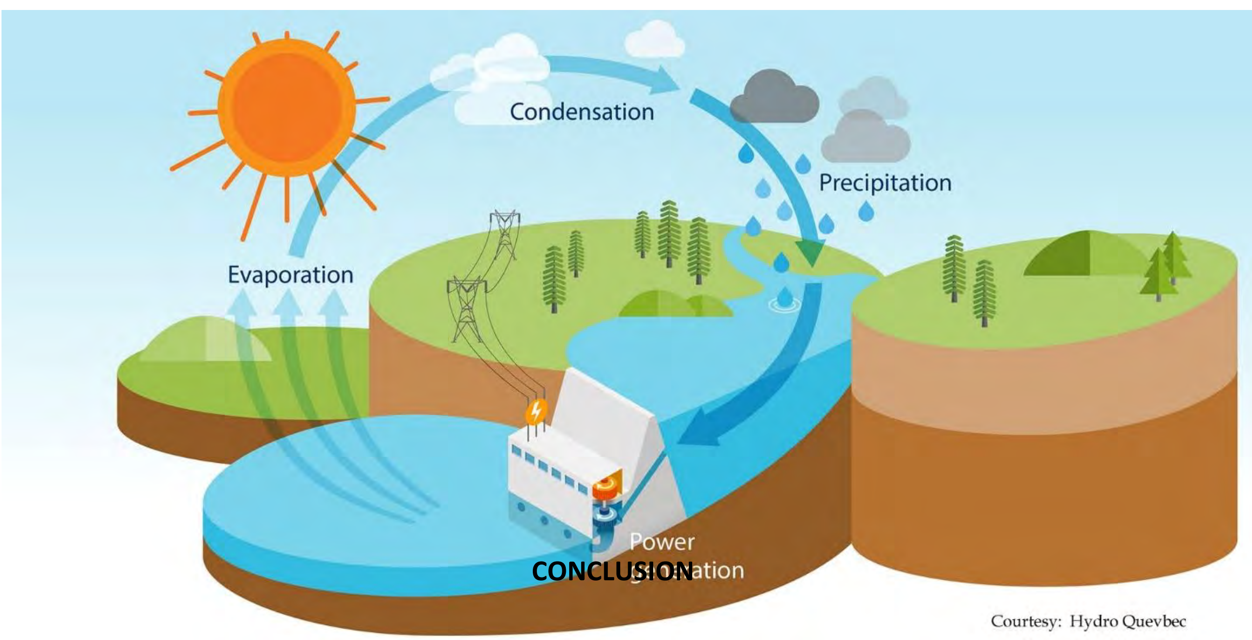
WHO DO YOU BELIEVE, THE AUTHORS OF SILICA STORIES OR HYDRO-QUEBEC?

"Dams in particular have had huge effects on the biogeochemistry, ecology and silica cycling of watersheds, creating lakes where there were not lakes before, trapping particles that would have otherwise been transported downstream, and obliterating seasonal flooding in favor of regulated year-round flow. Altogether this means most rivers of any note have multiple dams upon them and clogging up their spider vein watersheds. This has had a massive effect on the silica cycle, taking a lot of silica entirely out of the game before it can be transported downstream to coastal waterways.

Worse yet, in our humble opinion as silica fans, nitrogen and phosphorus eutrophication frees up diatoms in lakes, ponds, and reservoirs to grow-grow-grow and in so doing strip out incredible amounts of dissolved silica from the water. This is a major double whammy. This silica, now bound up in the beautiful frustules of biogenic silica that diatoms produce, ends up being buried in the sediments accumulating in lakes, ponds, and reservoirs instead of supporting diatom growth in estuaries and the ocean. That represents a serious break in the silica cycle that carried silica, weathered from silicate rocks, out to the ocean to support silica biomineralizers in the sea and the profundity of food webs based upon them." (Silica Stories by Conley et.al. 2017).

Hydropower is renewed through the natural water cycle

Hydropower starts with energy from the sun. The sun's heat causes water to evaporate and rise into the atmosphere, where it condenses and turns into clouds that are blown about by the wind. When the droplets and ice crystals that form clouds become too heavy, they fall back onto the ground as rain or snow. The water then flows through the rivers, and generating stations harness this cycle to produce electricity.



CONCLUSION

Courtesy: Hydro Quevbec

CONCLUSION

Quebec Hydro paints a benign picture of hydropower as renewable but fails to mention how it wrecks the silica cycle and the natural flow of water and nutrients especially dissolved silica which is critical for healthy fisheries and mediation of climate change.

The coastal diatoms of the Gulf of Maine have never stopped screaming for more dissolved silicate. The depletion of the shrimp, cod and other fisheries in the Gulf are the canaries in the coal mine who have been telling us for decades that there is a silica limitation in the Gulf of Maine.

This limitation has been caused by the proliferation of reservoir hydroelectric dams over the past 50 years on the major Canadian rivers, which for millennia have supplied nutrients to the Gulf.

For the Gulf of Maine's fisheries and mediating climate change nothing could be more important than restoring the natural timing, duration and quantity of fresh water flows transporting the annual load of dissolved silicate to the Gulf.

> *"But a lot of the excessive biogenic silica that freshwater diatoms are now able to produce gets buried in reservoirs and lakes, preventing its delivery downstream to the sea.*
>
> *Scientifically speaking, it took us some time to notice that dissolved silica was disappearing and yet some more time to grasp why. Of course, in retrospect, it's totally obvious. Of course this is what happened when we overloaded waterways with nitrogen and phosphorus. But in the beginning, we were probably too shocked by the eutrophication-fueled overgrowth of phytoplankton in general and all of the clogging and fouling of waterways and all of the fish-killing it was doing. Plus who would expect excessive nutrient addition to result in nutrient loss?*
>
> *And hardly anyone had the cleverness to foresee that dams would sequester silica.*
>
> *It took study of three different systems over an embarrassingly large number of decades for us to figure out what has been going on." (*Silica Stories by Conley & DeLaRocha 2017)

In Attachment 1 of this Report are these three case studies (referred to above) from Silica Stories by Conley and DeLaRocha 2017.

ATTACHMENT 1

EXCERPTS FROM SILICA STORIES, by DANIEL J. CONLEY and CHRISTINE DE LAROCHA 2017

But natural is not the state of many rivers on Earth at this point. Never mind everything else we've done to them, for the last hundred or more years we've been continuously adding mind-boggling amounts nitrogen and phosphorus to rivers, groundwater, and lakes. The main culprits are fertilizers and animal waste flowing out of farms and off of fields, and poorly treated sewage (containing human waste and phosphate-containing detergents) from our houses, villages, towns, cities, and other settlements. As there is no equivalent addition of silica to balance things, the ratios of nitrogen to silica and of phosphate to silica in inland waterways have dramatically shifted against silica.

Thanks to our messiness, for the last few decades, diatoms in eutrophic systems *have not* been limited by nitrogen or phosphorus. They have been able to bloom until they have removed nearly all of the dissolved silica from the lake or river or pond or reservoir they are growing in. Some of this silica has recycled back into the water because some biogenic silica inevitably dissolves after the death of the diatom that made it. But a lot of the excessive biogenic silica that freshwater diatoms are now able to produce gets buried in reservoirs and lakes, preventing its delivery downstream to the sea.

Scientifically speaking, it took us some time to notice that dissolved silica was disappearing and yet some more time to grasp why. Of course, in retrospect, it's totally obvious. Of course this is what happened when we overloaded waterways with nitrogen and phosphorus. But in the beginning, we were probably too shocked by the eutrophication-fueled overgrowth of phytoplankton in general and all of the clogging and fouling of waterways and all of the fish-killing it was doing. Plus who would expect excessive nutrient addition to result in nutrient loss?

And hardly anyone had the cleverness to foresee that dams would sequester silica.

It took study of three different systems over an embarrassingly large number of decades for us to figure out what has been going on.

8.5 Case Study #1: The Laurentian Great Lakes

The first case that came to light of how we're screwing up the silica cycle has nothing to do with a dam, but strictly with eutrophication. It was also our first inkling that freshwater ecosystems were being shifted into silica limitation as a side effect of all the phosphorus and/or nitrogen we were spilling into waterways.

The time was the 1970s. Two to-be-giants in the field of limnology[7], Claire Schelske and Eugene Stoermer[8], both of the University of Michigan, had been

[7]Limnology is the study of inland waters, including rivers, ponds, lakes, reservoirs, wetlands, estuaries, and groundwater, with focus on the interactions between organisms and their environment.

[8]Incidentally, Eugene Stoermer was also the co-namer of the Anthropocene.

studying the Laurentian Great Lakes that lie along the US-Canadian border. Before they started this work, a series of measurements on the intake waters of filtration plants serving the city of Chicago had shown that dissolved silica concentrations in Lake Michigan were decreasing. Claire and Eugene quickly discovered that the situation had escalated to the point where diatoms in Lake Michigan were running out of dissolved silica before the end of summer. This caused the growth of diatoms to screech to a halt several months before the end of their natural growing season, which had previously extended into autumn. Because diatoms serve as the base of key food webs, the knock on effect of premature stoppage in their growth was food shortage for fish and invertebrates in autumn in Lake Michigan.

One of the first things Claire and Eugene wondered was whether the mid-summer silica depletion was something new or if it had merely previously escaped notice. The two of them sleuthed through what old, patchy datasets they could dig up from various water quality agencies. The resulting data, plotted in Fig. 8.2, revealed that the mid-summer exhaustion of dissolved silica was new. It had first showed up in Lake Michigan and settled itself fully in sometime between 1955 and 1969.

Now all they had to do was figure out why it was happening.

At first it must have been a head-scratcher. The decades leading up to and including the one that they were in had seen an explosive growth of algae beginning

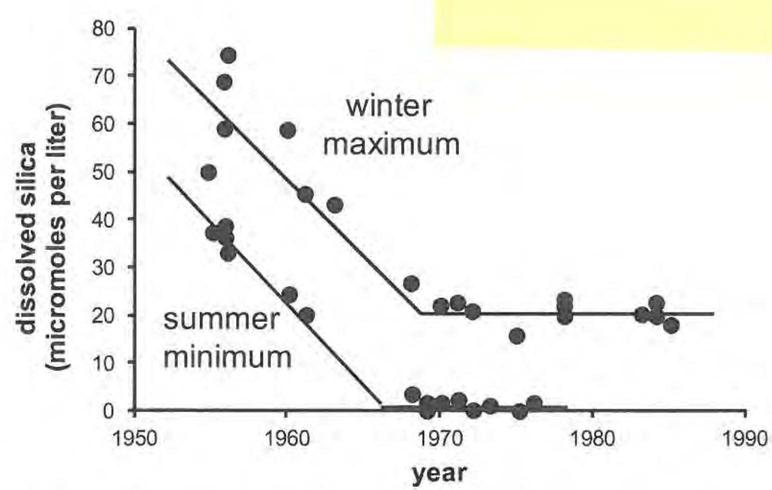


Fig. 8.2 The typical maximal concentrations of dissolved silica in winter and the typical minimum concentrations in summer in the surface waters of Lake Michigan significantly decreased during the 1950s and 1960s. This was due to excess production of biogenic silica fueled by phosphorus eutrophication. This figure has been redrawn from Internationale Revue der gesamten Hydrobiolie und Hydrologie 73, Schelske CL, Historic trends in Lake Michigan silica concentrations, 559–591, (1988), copyright © 1988 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, with permission from Wiley

to choke freshwaters across the globe. Diatom populations hitting the wall due to silica scarcity flew against the grain of this trend. It was out of step with everything turning most rather unexpectedly, unprecedentedly green.

But, when Claire and Eugene sat down and thought about it, the answer became obvious. There was a growing understanding, all over the world, that lakes, ponds, rivers, and estuaries were clogging up with excess algal growth because their concentrations of nitrogenous and phosphatic nutrients (that all phytoplankton, including diatoms, need in order to grow) were going off the charts. One reason, very well accepted at that point, was agricultural runoff that was full of biologically utilizable nitrogen and phosphorus from all the manure produced by livestock and from fertilizers applied to fields. The other widely acknowledged cause for eutrophication was human-generated sewage. But neither of these things, though, was adding much in the way of dissolved silica.

What Claire and Eugene also quickly came to realize was that, in the Great Lakes' case, the problem wasn't so much one of agricultural runoff nor was it one of too many people generating too much sewage. The problem was detergents that contained a lot of phosphate.

Detergents are crafty chemicals. One side of them is good at binding oils and fats (which, on their own, are insoluble in water) and another side of them is good at being dissolved in water. When detergents bind an oil or a fat, they thus drag it into solution. That is their cleaning power.

But detergents are not as effective in hard water, which is water that has a lot of calcium and magnesium dissolved in it. The doubly charged cations of Ca^{2+} and Mg^{2+} bind to detergents, precipitating them. Instead of foaming and doing a spanking great job of cleaning, in hard water, detergents form stubborn scum.

Most store-bought detergents have a water softener included in them to chemically preoccupy Ca^{2+} and Mg^{2+} so the detergent can do what a detergent's gotta do. Starting from about the 1950s and still in many cheaper detergents sold today, that water softener has been a phosphate such as trisodium phosphate or sodium hexametaphosphate (pronounced hexa-meta-phosphate).[9] Washing such phosphate-containing detergent down the drain, especially in areas lacking effective sewage treatment facilities, drains that phosphate straight into the nearest lake, river, or ocean, where it can feed the algae.

Take yourself back to the middle years of the twentieth century, when the human population was just beginning to embark upon the steep, wild, and crazy part of its exponential increase. At the same time modernization was marching along, introducing the washing machine and the dishwasher and then boosting their use. So not

[9]These days we are tending towards using zeolites instead because they don't add massive amounts of a major nutrient to the water, although by even this very late date, there are few *national* laws against the use of phosphate in detergents.

only were there vastly more people than ever before living along the shores of the Great Lakes, flushing toilets and generating agricultural runoff, they were also enthusiastically doing laundry and washing dishes and the detergents they were using consisted of up to *50%* phosphate.

There is only so much even a Great Lake can take, even if it is the fifth largest lake in the world. For Lake Michigan, this was the waste water from millions of loads of laundry and dishes done each week by the people of Chicago, Milwaukee, Green Bay, and other sites on the shore on top of all the other sewage and agricultural runoff. Algae began growing like gangbusters.

As we've said before, Claire Schelske and Eugene Stoermer realized that this phosphorus eutrophication was the key to the disappearance of the silica from Lake Michigan. With the phosphorus brakes released on their growth, diatoms in Lake Michigan could grow until they had converted basically all of the dissolved silica in the lake's sunlit surface waters into diatom frustules that ended up in the sediments.

In other words, dissolved silica was disappearing from Lake Michigan because it was being turned into particulate silica by diatoms growing in the surface waters of the lake and exported, via sinking, to the bottom of the lake.

Ecologically speaking, this was dire news, but intellectually it was kind of cool. Phosphorus eutrophication was leading to silica oligotrophication, a paradox that made perfect sense. And, as ideas go, it was one that Claire and Eugene could test.

Even long-lived lakes are only temporary features of the landscape; they're busy filling up with layer upon layer of sediment. You can take advantage of this if you want to learn about the history of a lake, ecologically and climatically speaking. All you need to do is carefully take a sediment core, slice it lengthwise in half, and, moving downwards from the top of the core, begin your journey back through time.

The core that Claire Schelske, Eugene Stoermer, and their collaborators took in the middle of the deepest part of Lake Michigan (which is found within Grand Transverse Bay) was 40 centimeters long (about 16 inches) and, based on radiometric dating[10], covered the last century and a half. The milligrams of biogenic silica to be found per gram of core versus depth within the sediment core are shown in Fig. 8.3 and that's all that is needed to show the story.

Before 1920 or 1930, only 10 milligrams of every gram of sediment that was accumulating on the lakebed was biogenic silica, a content that can also be expressed as 10 parts per thousand, or 1% biogenic silica. As biogenic silica accumulation rates go, that's pathetic. Those pre-postmodern Lake Michigan diatoms should hang their heads in shame at the poor job they were doing of exporting silica to the sediments. Or maybe they should be proud, because this is the level of export of silica that the lake could maintain, given the amount that was being delivered to it each year in runoff.

[10]Using the isotope lead-210 (^{210}Pb), which has a half-life of 22 years and is a particulate material which is continually falling out of the atmosphere following its production by the decay of radioactive radon gas.

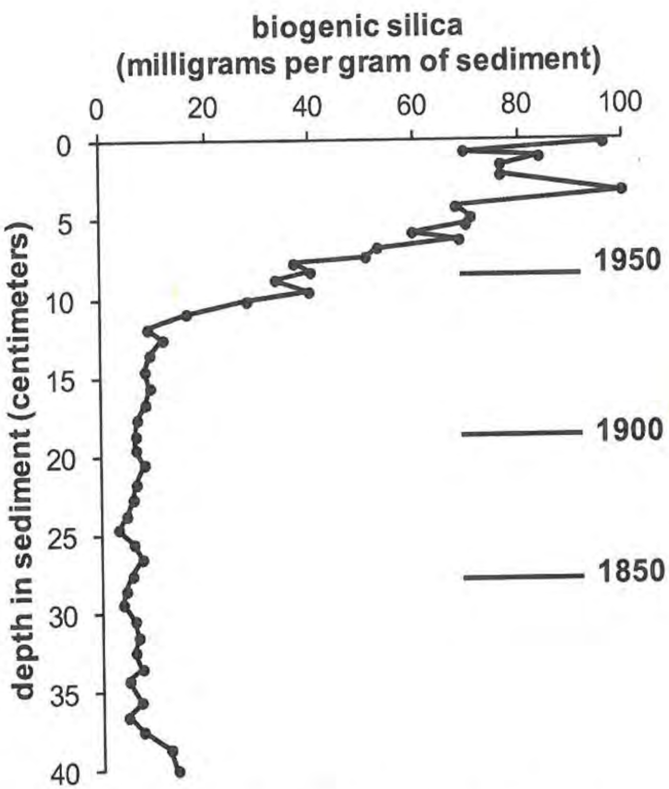


Fig. 8.3 Biogenic silica concentration versus depth in a core from Grand Traverse Bay, Lake Michigan records the transfer of Lake Michigan's silica into the sediments during the twentieth century's explosion in the use of phosphate detergents and fertilizers. This figure has been redrawn from Hydrobiologica 143, Schelske CL, Conley DJ, Stoermer EF, Newberry TL, Campbell CD, Biogenic silica and phosphorus accumulation in sediments as indices of eutrophication in the Laurentian Great Lakes, 79–86, (1986), copyright © Dr W. Junk Publishers, Dordrecht, with permission from Springer

As you move forward in time in the sediment core from 1930 it is like running up a ramp. The biogenic silica content of the sediments steadily climbs, reaching a peak of 100 milligrams of biogenic silica per gram of sediment (or 10% biogenic silica) by 1970. This you can see clearly in Fig. 8.3. What Fig. 8.3 does not show is what you would see if you made this measurement on lake sediments stretching back to the birth of Lake Michigan. The biogenic silica content of the older sediments (not shown here) reveal that such an astonishing change in silica burial had never happened before, not once in Lake Michigan's 14,000 year history.

Thus Claire and Eugene had managed to show that the disappearance of dissolved silica was due to excessive production of biogenic silica and that this excessive production of biogenic silica had never happened before people moved in by the tens of millions and started doing a lot of laundry in cities and towns along the shore of Lake Michigan.

There is another big detail of the shift that is revealed by the sedimentary record—the shift in the composition of the diatom population with the eutrophication of Lake Michigan. Diatom frustules are, after all, quite distinctive, and can be used to tell one diatom species from another.

Sediments older than the expansion of European settlements around Lake Michigan in the 1800s had a lot of different diatom species in them, representing a wide range of ecological niches (high light, low light, high silica, low silica, benthic, planktonic, spring growing, summer growing, autumn growing, etc.). But as phosphorus eutrophication (and silica depletion) increased, the variety of diatoms in the sediments narrowed to only those species that grow in late winter/early spring. This is the very start of each year's growing season, when dissolved silica concentrations are still high from winter mixing. Diatoms that would have grown later in the year were missing because by the time it was their turn to grow, there was no dissolved silica left for them to use. Benthic diatom species, meaning those that grow on the bottom of the lake (in shallow waters), also disappeared, most likely because the overgrowth of plankton due to eutrophication made it too dark down there for them to grow.

Overall, diatoms getting shut out of the latter part of the growing season in Lake Michigan while there is still plenty of nitrogen and phosphorus available for growth is a bad thing. It means a decrease in the flow of energy and materials through diatom-based food webs, which generally efficiently lead to fish, and an increase in the growth of noxious plankton species like dinoflagellates.[11] Worse yet, what happens in Lake Michigan doesn't stay in Lake Michigan. Now stripped of their dissolved silica, the waters of Lake Michigan flow into Lake Huron and then Lake Erie, go over Niagara Falls, flow into Lake Ontario, and then via the Saint Lawrence River, arrive at the Atlantic Ocean at the Gulf of Saint Lawrence in all the full glory of their silica deficiency. You can almost hear the coastal diatoms screaming.

[11]The addendum here is that the water quality (and dissolved silica content) began improving in the first decades of the twenty-first century due to improvements in sewage treatment and to the phasing out of phosphate detergents. Then the quagga mussel invaded, via larval stages that most likely arrived in water released from the ballast tanks of transoceanic shipping vessels. The quagga and its relatives are voracious filter feeders and they've colonized enough of Lake Michigan to keep the waters clear of algal blooms, regardless of the lake's nutrient status. Unfortunately, this means that phytoplankton still aren't making it into the food chains that lead to fish, causing a collapse in the lake's fisheries. Poor Lake Michigan can't catch a break from the trouble caused by human beings.

8.6 Case Study #2: The Baltic Sea

Once the research on Lake Michigan became known, people started to have a look at other large inland bodies of water to see if the same things were happening to their local silica cycles. One of the more recent and most intensively investigated places has been the Baltic Sea.

Lake Michigan is big, but the Baltic Sea is massive. It is that large inland sea that sits in the midst of northern Europe. You could think that the Baltic Sea is too big to be notably affected by the activities of humankind. But once you start paying attention, you quickly come to pity the Baltic Sea. All but entirely encircled by Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany, and Denmark and additionally containing portions of Belarus, Ukraine, Norway, Slovakia, and the Czech Republic in its watershed, the Baltic Sea is subject to continual insult by the agriculture and sewage of 90 million people. This insult, which comes partly in the form of four to eight times more nitrogen and phosphorus than it tended to receive a century ago, is delivered in 16,000 metric tons of freshwater *per second* flowing off the land. Consequently, concentrations of nitrate and phosphate in the Baltic Sea have increased over the last century.

But concentrations of dissolved silica have declined. This decline has been severe. For example, concentrations of dissolved silica in subsurface waters in a central area of the Baltic Sea have decreased by one-third to two-thirds since the late 1960s, the time when monitoring began at that location.

So far so Great Lakes? It seems pretty similar. Just add eutrophication and watch those diatoms go (until they run out of dissolved silica).

Maybe. But maybe not.

There is a certain key difference in the situation of Lake Michigan and the Baltic Sea. Excess phosphorus is mainly delivered to Lake Michigan directly, from sources that originate along the shore. But the Baltic Sea is receiving waters high in phosphorus and nitrogen via rivers that travel great distances to get to the Baltic Sea and generally encounter multiple lakes and dams along the way. This gives silica plenty of opportunity to be removed and trapped in sediments long before it arrives into the Baltic Sea itself. So maybe excess production of biogenic silica within the Baltic Sea itself is stripping dissolved silica out of its waters. But maybe that silica is being removed upstream and because the Baltic Sea is being thus deprived of dissolved silica, its poor diatoms aren't growing (or producing biogenic silica) much at all. If we want to help solve the problem (in part because we'd like to get the Baltic back to supporting food webs that produce something besides enormous swarms of jellyfish) we need to know which one is going on. Plus we're just plain old curious.

The first question to tackle: do outputs of silica from exceed inputs of silica to the Baltic Sea? If so, at least some of the problem is due to eutrophication-fueled diatom growth within the Baltic itself. The straightforward way to answer the question is to put together a silica budget with inputs on one side and outputs on the other.

For a small reservoir or lake, this should be easy. You need to measure three things. One is the amount of dissolved silica flowing in with water flowing in from rivers and streams. Another is the amount of biogenic silica accumulating on the lake bed. The third is the amount of dissolved silica flowing out in the stream that serves as the lake's outflow.

But the Baltic Sea is no little lake. Nearly 100 rivers of note flow into the Baltic Sea and you'd have to monitor each one for several years. There is at least only one outflow of water from the Baltic Sea (aside from evaporation): water leaves via the Denmark Straits to the Atlantic Ocean. But sometimes, because of storms, winds, currents, and tides, the water flows in instead, bringing dissolved (and biogenic) silica with it. As far as measuring how much biogenic silica is getting buried in Baltic Sea sediments, the complication here is that the Baltic Sea is made up of numerous basins, such as Bothnian Bay, the Bothnian Sea, the Gulf of Finland, the Baltic Proper, the Gulf of Riga, the Denmark Straits, and the Kattegat, and they all behave differently (and exchange water with each other). Figuring out how much biogenic silica is accumulating in the sediments requires careful study of sediment accumulation rates (and correction for sediment winnowing and focusing due to currents) in all of these regions.

Despite the near impossibility of the task of determining whether more silica is leaving the Baltic Sea than is coming in, there have been several attempts to put together silica budgets for the Baltic Sea. (Scientists do love them a challenge.)

In their quest, two different groups of researchers have fed monthly measurements of dissolved silica from the major rivers flowing into the Baltic and measurements of wintertime dissolved silica concentrations at various locations within the Baltic Sea into a computer model of Baltic Sea circulation in order to calculate how much dissolved silica is disappearing from Baltic Sea water as it flows out to the North Atlantic. Both groups came up with much the same result, that recently roughly 1,300,000 tons of silica has been accumulating in the sediments of the Baltic Sea each year. As both modeling efforts produced a Baltic Sea whose dissolved silica concentrations decreased from year to year during the model runs, an export of 1,300,000 tons of biogenic silica to the sediments must be enough for the total export of silica from the Baltic Sea to be exceeding silica's input.

So the Baltic Sea is probably at least a little bit like Lake Michigan. Eutrophication is causing it to overproduce biogenic silica. But when you actually look at the data that were fed into the models, you realize that something else pretty major is going on.

Many of the major rivers flowing into the Baltic Sea have concentrations of dissolved silica that are, frankly, shocking.

The Neva River, which is the greatest of the rivers flowing into the Baltic Sea, contains *8* micromoles of dissolved silica per liter when it reaches the Baltic Sea. Can you hear the diatoms weeping? No self-respecting river should contain such a measly amount of dissolved silica. An *average* (as in mediocre, hum-drum, run-of-the-mill) river has 160 micromoles of dissolved silica per liter and an overachiever has 1000 micromoles of dissolved silica per liter. A number like *8* is almost unfathomable. To yield up only 8 micromoles per liter dissolved silica, the Neva River's catchment is only producing a net 63 kilograms of silica per square kilometer of catchment area per year, another number to make a diatom cry.

The Vistula, the Baltic Sea's number two river in terms of the delivery of water, is better, but at 119 micromoles of dissolved silica per liter and 580 kilograms of silica produced per square kilometer, still below average. The number three river, the Daugava, averages around 60 micromoles of dissolved silica per liter, a yield of 411 kilograms of silica per square kilometer, more dismal numbers.

But if you look at the rivers draining into the Baltic Sea from the emptier, more northern areas of the catchment, you'll find that they are not like this. The Närpiönjoki in Finland has an average dissolved silica content of 267 micromoles of dissolved silica per liter, representing a catchment yield of 2285 kilograms of silica per square kilometer. The numbers for the Isojoki, also in Finland, are similar: 195 micromoles of dissolved silica per liter and 2105 kilograms of silica per square kilometer.

What's the difference between the respectably silica-containing rivers and the failures? The silica-poor rivers draining into the Baltic Sea are found in more heavily populated areas while the silica-rich rivers are running wild. The silica-poor rivers are suffering from notably greater eutrophication and they contain much greater (natural and manmade) reservoir volume.

Take that astonishingly low-silica river, the Neva River, for example. Just upstream of St Petersburg (not so far from the Baltic shore), it runs through Lake Ladoga, one of the largest lakes in Europe. Lake Ladoga has been heavily eutrophicated since the 1960s. You can all but walk on the phytoplankton blooms, they grow so thick. This is where a lot of the Baltic Sea's silica is ending up. Buried in Lake Ladoga's sediments.

Similar, although less severe losses of silica must be occurring in lakes and reservoirs along other eutrophicated rivers that feed into the Baltic Sea.

Once you have data (on silica concentrations, water flows, surface area of river catchments, and so on), you can cross-examine them to tease out the combined effects of eutrophication and damming on the silica content of rivers draining into the Baltic Sea. You could, for example, plot the concentration of dissolved silica in a river (or, if you'd prefer, its yield of dissolved silica per catchment area) versus the amount of time water spends in the river's catchment area. Dams and natural lakes both increase the residence time of the water within the catchment. Thus a long residence time indicates the water spends a lot of time in places favorable to diatom blooms and export of silica to sediments.

In practice, residence time of water in a river catchment is not an easy thing to measure. So you can try to use a proxy, some other more easily or accurately measurable factor that is relatable enough to residence time that it can serve as a stand in. You might try hydraulic load, the amount of water, expressed as meters of height, that passes over a point in the river system each year. High hydraulic loads

are associated with short residence times (fast flowing water) while low hydraulic loads indicate long ones (fairly slow, stagnant flow).

The result? The lower the hydraulic load (and the longer the residence time of water in the river system), the lower the catchment's dissolved silica yield per area and the lower the concentration of dissolved silica in the river. This is true for all types of river feeding into the Baltic Sea, meaning that reservoir volume (be it natural lakes or manmade due to damming) is giving diatoms a chance to bloom and remove silica before the silica reaches the Baltic Sea. That the problem is worse in eutrophicated river systems is also clear because concentrations of dissolved silica are lower in these rivers regardless of their hydraulic load.

This is all illustrated nicely in Fig. 8.4. The yields of dissolved silica per catchment area from a subset of the Baltic Sea catchments that are not eutrophicated and whose flows are not interrupted by dams (represented on the plot by the black triangles) range from 800 to almost 1300 kilograms of silica per square kilometer. These highest silica yields belong to fairly pristine catchments where water doesn't spend too much time hanging around. There is neither the time nor the added nitrogen and phosphorus for diatoms to bloom and remove dissolved silica. These rivers hit the Baltic Sea with a healthy load of dissolved silica and this most likely represents the natural state of the system.

The subset of the Baltic Sea catchments that are not eutrophicated but are subjected to damming (represented by the black circles on Fig. 8.4) give yields of 280 to 1100 kilograms of silica per square kilometer and the yields clearly decrease as the residence time of water in the watershed increases because waters are detained in lakes and reservoirs on their way to the Baltic Sea. There is just enough naturally occurring nitrate and phosphate for diatoms to bloom and remove some dissolved silica from the river system, thus preventing it from reaching the Baltic Sea.

The subset of the Baltic Sea catchments investigated that are both eutrophicated and dammed (the gray circles on Fig. 8.4) have yields of 60 to 600 kilograms of silica per square kilometer. There are two things going on here. Eutrophication in general is keeping the yields low because diatoms are growing and removing silica. But the lowest of the low yields are occurring in catchments where the residence time of the water is the greatest and this is because of lakes and by reservoirs produced by damming.

These are, you might say, damning results for both eutrophication and damming.

Worse, we're starting to suspect that there is another process contributing to the problem. Rates of silicate weathering within damned catchment areas are probably lower than in non-dammed catchments. When you build a dam, a lot of what used to be the soils of grasslands and forests becomes the bottom of a reservoir. Weathering reactions tend to be vigorous in the soils of grasslands and forests and the dissolved silica the weathering produces is efficiently flushed into rivers when it rains. But not much silicate weathering is going to be going on at the bottom of a reservoir. As a result, not only is the reservoir sequestering silica that used to flow onwards to the ocean, it is also preventing some silica from being added to the river in the first place.

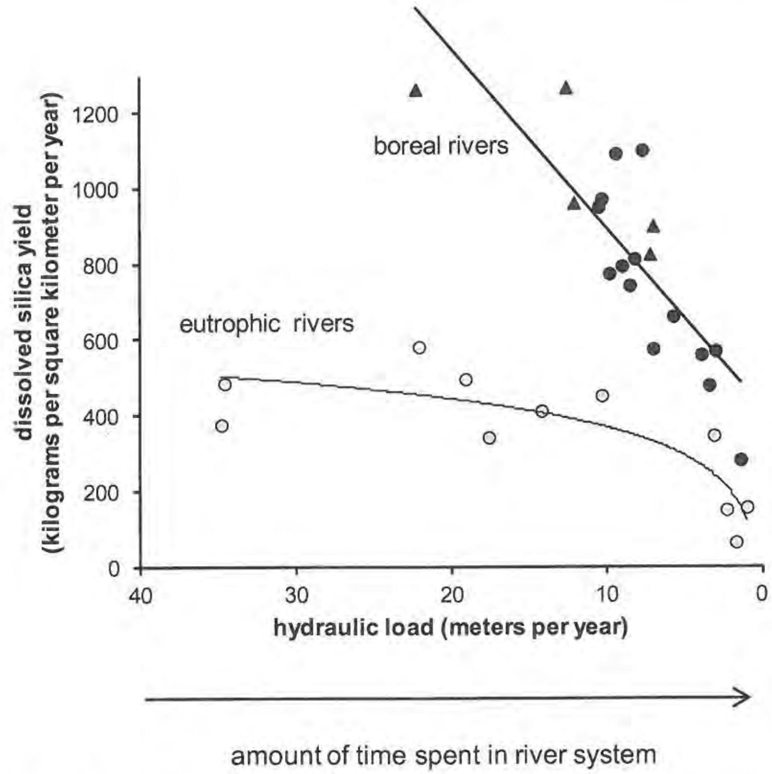


Fig. 8.4 Yield of dissolved silica compared to hydraulic load for pristine boreal rivers (*black triangles*), eutrophicated but undammed boreal rivers (*black circles*), and heavily eutrophicated and dammed rivers (*gray circles*) draining into the Baltic Sea. Hydraulic load serves as a proxy for residence time, with residence time increasing to the *right* of the figure. This figure has been redrawn from Journal of Marine Systems 73, Humborg C, Smedberg E, Medina MA, Mörth C-M, Changes in dissolved silicate loads to the Baltic Sea—the effects of lakes and reservoirs, 223–235, (2008), copyright © 2007 Elsevier B.V., with permission from Elsevier

The patterns revealed by the set of river catchments of Fig. 8.4 can be used to estimate that the combination of eutrophication and damming has decreased the amount of dissolved silica delivered into the Baltic Sea by 30–40% during the last century.

That is the sort of number that you should not announce to a silica enthusiast unless you've taken the precaution of sitting them down in a chair.

In other words, right now is a really lousy time to be a Baltic Sea diatom. All those dams we've built within the Baltic Sea catchment area and all the nitrogen and phosphorus we're pouring into it too… We're denying Baltic Sea diatoms the silica they need to survive.

8.7 Case Study #3: The Black Sea

The same sort of thing has been going on in the Black Sea. But it took us some time to understand the problem here because we got hung up on the idea that the Black Sea's silica problems stemmed from one single spot on the Danube River. It was at the time a compelling story, though, and it got a lot of people interested in the problem of silica and dams.

The Danube River, the second longest river in Europe, arises in the Black Forest, meanders through or along Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Moldova, Ukraine, and Romania, collecting water from an even greater portion of Europe, and then pours into the Black Sea. Like the also enormous catchments of the two other major rivers that flow into the Black Sea (the Don and the Dieper), the Danube River catchment was dammed to the hilt between the 1960s and the present day and eutrophication is a serious problem.

At this point, you will probably nod knowingly when we tell you that for decades phytoplankton overgrowth in the Black Sea has been common and concentrations of dissolved silica have declined and that all of this has occurred alongside shifts in the composition of photosynthetic populations away from diatoms. Populations of benthic macrophytes such as seagrasses and macroalgae have also taken a serious hit and anoxia has become more widespread. This is bad, not only for Turkey's Black Sea anchovy fishery, but also for entire Black Sea beach resort industry that is important to the economies and vacations of Turkey, Bulgaria, Romania, Ukraine, Russia, and Georgia.

By 1997, which was long after Claire Schelske's and Eugene Stoermer's groundbreaking discovery that eutrophication resulted in silica removal within the Laurentian Great Lakes but a few years before the work on the Baltic Sea described in the previous section, it became clear that the Black Sea was missing a lot of dissolved silica. Monitoring that had begun in 1960 had revealed that dissolved silica concentrations had briefly shot up and then steadily dived in the Black Sea, dropping from an average of about 60 micromoles of silica per liter in the mid-1970s down to below 10 by about 1995. It was as if some single abrupt change in the system kicked off a dramatic disappearance of silica.

Enter the Iron Gate dam.

Iron Gate I runs across the Danube along a stretch that serves as the Romanian–Serbian border and is a hydroelectric generation plant. It's also the largest dam on the Danube River. It was so very most suspiciously completed in 1972, right before dissolved silica went into its dive. The obvious explanation was that the dissolved silica that was now missing from the Black Sea was accumulating as 1.3 million kilograms of biogenic silica accumulating in the sediments trapped by Iron Gate I every year. It had to be the case! The circumstantial evidence was screaming.

Simple stories are seductive. Impound a single dam on a major tributary of a fair-sized sea and send the downstream coastal areas into silica freefall. Even scientists can get enthusiastic over ideas that are too good to be true.

Of course the story turned out to be wrong, but it also turned out to be the story that got researchers interested in the effect of dams on silica. Although the problem of dams resulting in downstream waters depleted of dissolved silica had first come to light in a well-researched and well-written 1980 publication in a top-notch scientific journal by top-notch scientific researchers[12], somehow the news hadn't sunk in.

The dam's name probably helped too. With a name like that (Iron Gate) the dam had to be: Huge! Solid! Fearsome! Authoritarian! And rather like the Iron Curtain. Nothing, not even silica, could get through. Even silica scientists (initially) felt swayed. Damn that dam for stealing all the Black Sea's silica.

However, the name was merely an accident of history. Iron Gate I and its younger sibling, Iron Gate II, were not named for their formidability. They were named for their locality.

The Iron Gates are a picturesque series of gorges that the Danube runs through. That narrowed stretch of river is over a hundred miles long and its name may have originated from a number of pestilential bedrocks shoals, now long since removed, that could rip apart the hulls of ships that failed to steer around them. Perhaps hundreds of years ago, a person with poetry in their heart likened them to the spikes on an iron gate. In an alternate universe, one with a shortage of poets, there may be two Damned Shoals dams instead and nobody who thinks that particulate silica is piling up behind them.

In this universe, at least, biogeochemists eventually decided to put the hypothesis to the test.

One of the first things they noted was that, yes, the reservoir upstream of Iron Gate I is nothing to sneeze at. It is 120 kilometers (75 miles) long and holds 2.4 billion cubic meters of water. But this has more to do with the river than the dam. The Danube River carries so much water by the time it reaches the Iron Gates, the Iron Gate I dam needs 1100 meters of length in order to span the river. That's 3600 feet. So it doesn't take much diminishment in flow (or increase in water residence time) to create a large reservoir volume at this location.

Indeed, the Iron Gate dams do not significantly increase the residence time of water along this stretch of the Danube. Iron Gate I, like Iron Gate II, is a hydroelectric power generating station. Water flows FAST through the dam. It has to turn turbines.

When you measure how long the water spends in this reservoir (plus in the much smaller one downstream of it now that they've built Iron Gate II), you find that it's six and a half days, which is hardly any time at all. If we were a diatom bloom, we'd file a complaint. It's not enough time to get our work done.

[12]Larry Mayer and Steven Gloss, two widely known and respected biogeochemists, had first noted the effect on dams on dissolved silica in 1980 in a published paper on the Colorado River in Arizona before and after the construction of Edward Abbey's favorite of favorites, the Glen Canyon Dam.

Silica budgets constructed for Iron Gate I, its reservoir, and its sediments have confirmed this. The Iron Gate dams are not a big trap for silica. It looks like about 850,000 tons of silica flows into the reservoir as dissolved silica each year and 810,000 tons flows out. The 40,000 tons of silica trapped is not nothing but it is well short of the postulated 600,000 tons.

Now that the research on silica losses in the Baltic Sea catchment area has been done, it's clear that the disappearance of silica from the Black Sea isn't the work of one fearsome dam. It's due to the tens of thousands of dams that have been built along the often eutrophicated rivers that head ultimately to the Black Sea. And of course, the eutrophication-fueled overgrowth of diatoms within the Black Sea itself has probably contributed to the decades-long decline in dissolved silica concentrations that has occurred within the Black Sea. This isn't as superficially exciting a story as one single dam having an impact so severe it was changing the ecology and biogeochemistry of the entire Black Sea, but it is profound.

8.8 The Global View

The Larentian Great Lakes, the Baltic Sea, and the Black Sea are all major bodies of water, but they are still just a drop in a bucket compared to all the fresh and salt water on Earth. But they represent a crisis that is unfolding across the Earth.

Those 850,000 dams we currently have, about 60,000 of them large, disrupt flow *on more than half* of all river systems. Various different modeling studies have calculated that altogether these dams decrease the total global flux of dissolved silica to the ocean by 5%.

Does that seem small?

It isn't. Five percent represents a deficit that adds up year after year into enough of an enormous lack of dissolved silica that diatoms in estuaries and the coastal ocean, where they are most needed to support fisheries, could be operating at a disadvantage.

Natural but now eutrophicated lakes are even worse than reservoirs, in that they seem to be better at retaining silica in their sediments. Including them in the global estimate would bring the total amount of silica flux diminished to nearly *30%*, a truly apocalyptic number.

The next time you're down at the beach, you may want to hug a diatom. They could certainly use the moral support. But they'd like it even more if you pushed your legislatures for laws requiring that detergents to be sold phosphate-free. This needs to include dishwasher detergents (which, in many places, are exempt from restrictions). Our diatom friends could also use more and better sewage treatment plants, incentives and support for farmers to do something about the millions of tons of phosphate and nitrogen fertilizers and animal waste flowing off of their lands, the removal of dams no longer needed, and some serious, sober second thoughts about building any more.

THE PROBLEM IS THE LACK OF SILICA

Silica Shelled Diatom Phytoplankton

The Foundation of the Aquatic Food Web

Atlantic Cod

Atlantic Salmon

"Diatoms are at the bottom of the food chain and suck up nearly a quarter of the atmosphere's carbon dioxide . . . Size matters for the creatures that eat them and also for carbon sequestration, as large diatoms are more likely to sink when they die . . . If smaller size diatoms dominate, then carbon sequestration becomes less efficient, and there may be more carbon dioxide in the atmosphere, which would exacerbate global warming. " (Litchman et. Al. 2000).

Stephen M. Kasprzak
October 15, 2018

This Report is being written as a supplement to the editorial "*Reject CMP Power Line Because Hydro-Quebec Facilities Damage Ecosystem,"* which was published in the Portland Press Herald on October 9, 2018 (see Attachment 1). It also documents how Hydro-Quebec has significantly contributed to the lack of silica in northwest Atlantic and Gulf of Maine.

ABSTRACT

There is a commonly held belief that climate change is the driving force behind the decline in the population of cod, salmon, capelin and other fisheries in the Gulf of Maine and northwest Atlantic, as well as warming their waters.

There is another factor, namely, the lack of silica!

This Report documents how the lack of silica is the driving force in the decline of the fisheries and not overfishing. The following two quotes are consistent with my claim that the fisheries are being starved:

Research scientist with the Department of Fisheries and Oceans (DFO) Dr. Mariano Koen-Alonso says the sudden and sharp decline in cod stock is something being seen across the ecosystem.

"We've seen very important reductions in biomass of many species across the board," said Koen-Alonso. "We have to look at the big picture here, there are several factors and species involved."

"With reductions in the biomass of the cod's food sources such as shrimp and capelin, Koen-Alonso says the cause of the cod's decline appears to be more bottom-up than top-down. Bottom-up meaning that a lack of food and poor conditions are the driving force in the shrinking biomass, rather than predators or overfishing which are chief factors in a top-down cause of depletion.

Koen-Alonso says the signs show the capelin's declining numbers can also be traced to the food chain." (Northern Pen May 10, 2018).

and

"Atlantic ocean plant life, the phytoplankton, has been observed to be in tremendous decline. International science teams have measured more than 26% lost in the last 30 years. How bad is 26%? Remember when we destroy just 1 in 10 of any form of life we say that we have decimated that life. It's bad. Very bad. And the starvation and disappearance of Atlantic Cod stand as testimony to the collapse of the Atlantic Ocean pastures. Ocean pasture grass is plankton." (Russ 2014).

The building and management of Quebec Hydropower's reservoir hydroelectric facilities have reduced river discharge during spring freshet into Eastern Hudson Bay and Labrador Sea by forty to fifty percent and increased winter discharge by 300 percent.

"Eighty percent of the annual input of dissolved silicate to the ocean is transported via our rivers and streams." (Paul Treguer et. al. 1995). In our northern latitudes, the majority of this annual budget is delivered by the roaring waters of the spring freshet.

Less dissolved silicon, during spring months, is starving the silicon diatom phytoplankton blooms, which are the essential basis of marine food web.

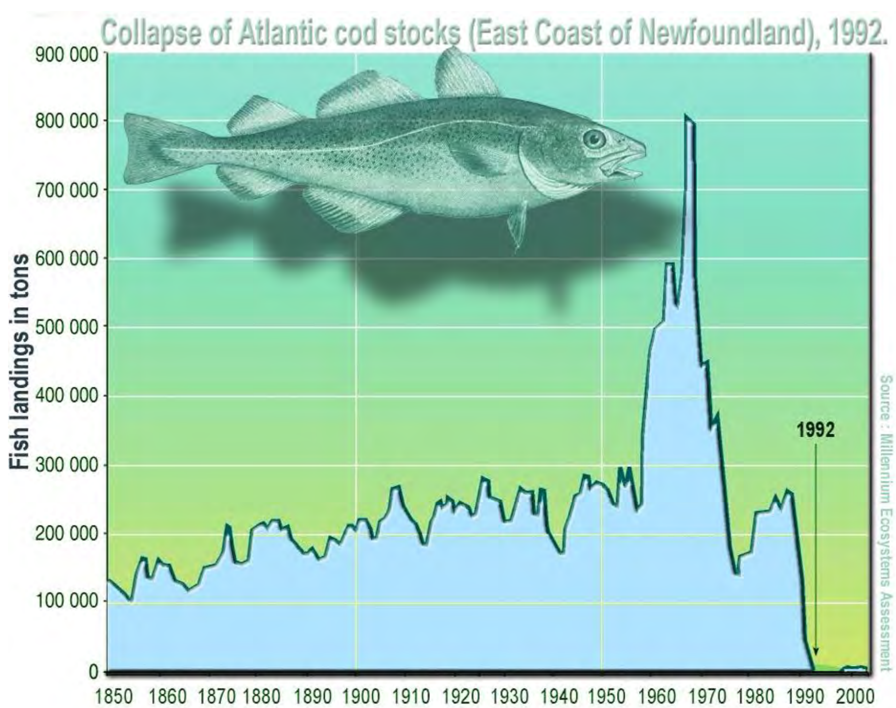
The advocates of hydroelectricity claim it is a power source that is clean and renewable because it uses the earth's annual water cycle to generate electricity.

They fail to mention that hydroelectric reservoir facilities have changed the seasonal pattern of annual natural water cycle by significantly reducing the spring run-off and summer outflows and using the captured waters to double and triple the winter outflows, due to high winter demand for electricity.

This is just the opposite to a typical unregulated river, which experiences low flows in winter when water is stored in the seasonal snowpack, then high flows during the snowmelt-driven freshet in spring and early summer.

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.

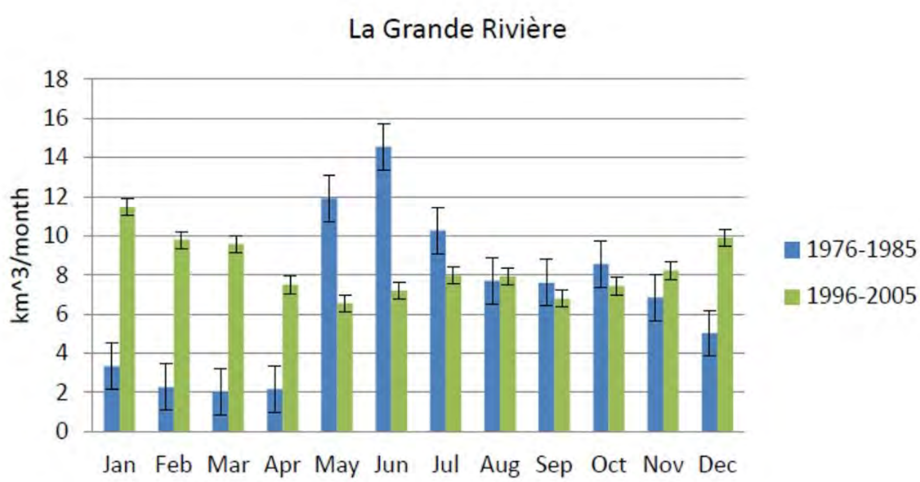
"The growth rate of diatoms (silica-shelled phytoplankton) are determined by the supply of silicate." (Venugopalan Ittekkot et. al. 2000).

"Diatom phytoplankton populations are the usual food for zooplankton and filter feeding fishes and contribute in a direct way to the large fishable populations in coastal zones." (C.B. Officer et. al. 1980).

***"The lack of silica can change aquatic ecosystems from those dominated by diatoms to non-diatom based aquatic ecosystems usually dominated by flagellates."*(**E. Struyf 2009).

QUEBEC HYDROPOWER HAS REDUCED SPRING FRESHET RIVER FLOWS BY 40 TO 50 PERCENT

A good example is the three LaGrande reservoir hydroelectric facilities, which have an annual capacity of 7,302 megawatt (MW). Two of the reservoir facilities went online in 1986 and the third in the early 1990's. The graph below illustrates how the dams have been used to capture the waters of the spring freshet which are then used to increase winter outflows by more than 300%.



Comparison of runoff by damming or diversion for the pre-1986 and post-1986 periods (Ray Roche 2007)

The following points should help put into perspective the scale of this facility:

1. Maine's annual hydroelectric generating capacity is 723 MW, compared to 7382 at LaGrande
2. The June outflow (1976-1985) of 14.5 cubic kilometers (KM^3)/month has been reduced to 7.0 KM^3./month (1996-2005). This reduction of 7.5 KM^3/month equals 102,129 cubic feet ($ft.^3$)/sec
3. The historic median flow in June on the Penobscot River at W. Enfield in Maine is 10,000 ft^3/sec
4. This June reduction in outflows from the LaGrande River into Hudson Bay would be analogous to eliminating 10 Penobscot Rivers flowing into the Gulf of Maine in June
5. The May reduction in outflows of 5.5KM^3/month would be analogous to eliminating 7 Penobscot Rivers flowing into the Gulf during May

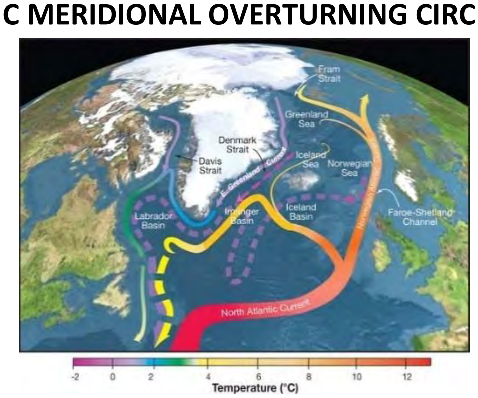
QUEBEC HYDROPOWER IS USING THE CAPTURED WATERS OF THE SPRING FRESHET TO INCREASE WINTER RIVER DISCHARGE THREE-FOLD

In a recent Canadian study of trends in river discharge from 1964-2013, the authors found: ***"that there has been a three-fold increase in river discharge during winter, when electric demand peaks, into the estuaries of Labrador Sea and Eastern Hudson Bay for the 2006-2013 period compared to 1964-1971 and a forty percent reduction in discharge during the summer."*** (*Recent Trends and Variability in River Discharges Across Northern Canada* Dery et. al. 2016).

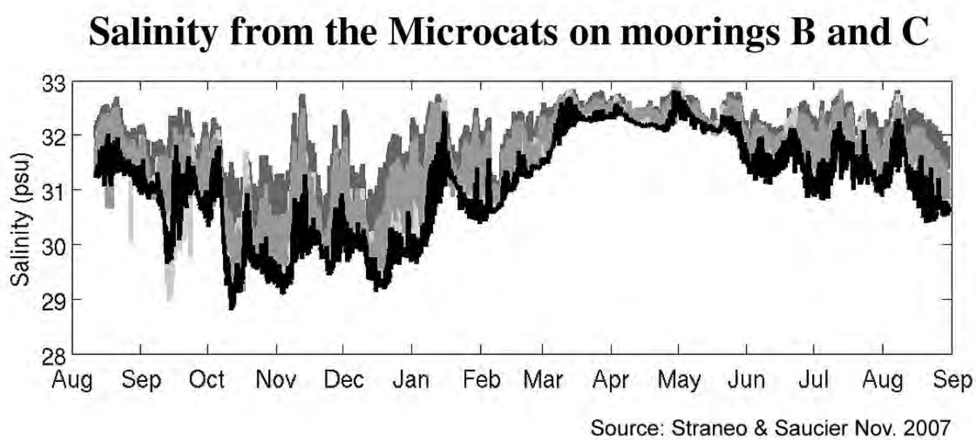
The earlier LaGrande Riverine Graph shows January-April outflows have been increased four-fold on average. Before reservoir hydroelectric facilities were built in Quebec and Newfoundland/Labrador (NL), the brooks, streams and rivers in these watersheds freely and naturally transported 80% of the annual budget of dissolved silica and other nutrients to the ocean.

The riverine spring freshet historically transported the majority of the annual load of silica and other nutrients into the Hudson Bay and eventually the Labrador Sea and Current via the Hudson Strait and then into the Gulf of Maine via the Labrador Current. These captured waters of the spring freshet are now being saved and historic summer generation reduced by forty percent in order to increase winter generation by threefold or more.

ATLANTIC MERIDIONAL OVERTURNING CIRCULATION



THE OUTFLOWS FROM THESE RESERVOIR DAMS ARE SO LARGE THAT SALINITY LEVELS IN HUDSON STRAIT ARE IMPACTED, AS SHOWN IN THE FOLLOWING GRAPH FROM A 2007 STUDY, <u>THE OUTFLOW FROM HUDSON STRAIT AND ITS CONTRIBUTION TO THE LABRADOR CURRENT</u>, BY STRANEO AND SAUCIER.



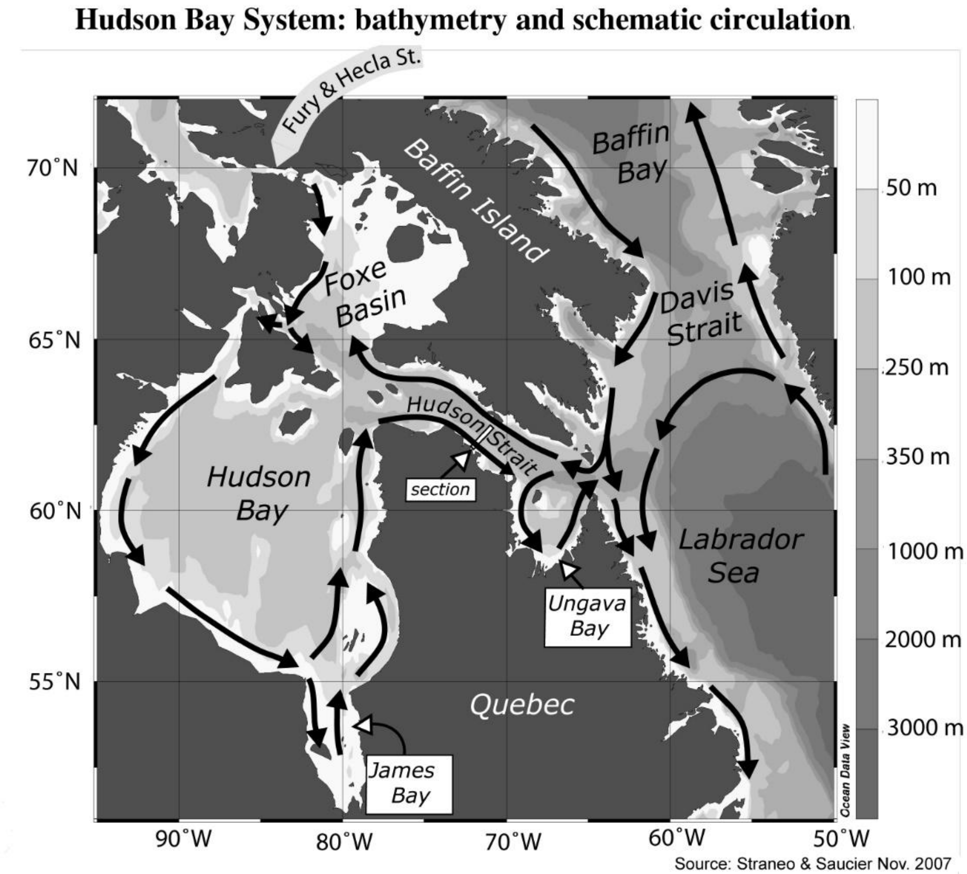
This graph shows the waters with the highest salinity flow past the moorings in the Hudson Strait during the mid-March through June period. Historically (pre-1970) this time period would have had the lowest salinity waters because of the high flows of the natural spring freshet flowing into Hudson Bay and then into Hudson Strait. This finding is another piece of evidence that these dams are starving the silica diatom phytoplankton of silica and other nutrients during the spring and summer.

The threefold increase in winter discharge from the dams results in waters with the lowest salinity from mid-October through mid-January.

Straneo and Saucier wrote the following in their 2007 Report:

"Our results suggest that approximately 15% of the volume and 50% of the fresh water carried by the Labrador Current is due to Hudson Strait outflow. This is a striking new result, which suggests that we need to rethink the source waters for the Labrador Current and, in general, the fresh water pathways into the sub polar North Atlantic. They indicate that the role of Hudson Strait had been previously overlooked due to the absence of direct measurements from the Strait."

The surface area of water in Maine is only 4,537 square miles, compared to Quebec with 68,312 square miles and NL with 12,100 square miles. It is obvious that the Gulf of Maine is very dependent on the dissolved silica and nutrients transported by the rivers of these provinces during the spring freshet to fuel the Gulf's diatom phytoplankton blooms.



These blooms are the essential basis of the marine food web and their decline in both size and quantity are starving all the fisheries.

QUEBEC HYDROPOWER HAS SIGNIFICANTLY REDUCED SILICA AND NUTRIENT-ENRICHMENT ATTRIBUTED TO LAND BASED RUNOFF AND COASTAL UPWELLING IN HUDSON BAY AND LABRADOR SEA

"Most fisheries production world-wide is associated with three nutrient-enrichment processes: coastal upwelling, tidal mixing and land-based runoff, including major river outflow" (Caddy and Bakun, 1994).

"Many documented reductions in fisheries production have been attributed to river regulation, modifying natural variation in freshwater flow. Protecting natural flow regimes is likely to be an effective management strategy to maintain the production of estuarine and coastal fisheries" (Gillson, 2011).

Land based runoff has been significantly reduced as Quebec Hydropower manages it reservoir dams to capture the spring freshet and reduced summer outflows. Compounding this reduction in annual input of silica and other nutrients from land based runoff is the fact that nutrient enrichment from coastal upwelling is so limited in Hudson Bay.

The following was written in Bay Sys 2016 Mooring Program Cruise Report by Claire Hornby: *"The high riverine freshwater input in James Bay is causing a strong thermohaline stratification at the entrance to Hudson Bay,"*

and

"In Hudson Bay, a massive freshwater input by river runoff causes a strong stratification restricting upward nutrient flux into the surface layer and limiting phytoplankton production particularly in summer."

This is a double whammy negatively impacting the abundance of silica shelled diatom phytoplankton.

ABUNDANCE OF DIATOM PHYTIOPLANKTON HAS DECLINED

The results of a 2010 Study by Daniel Boyce using a 100-year data set concluded that the abundance of diatom phytoplankton had declined by 40% since 1950, and in a recent NASA study in "Global Biogeochemical Cycles," the authors have concluded the global diatom populations have declined by 1% per year from 1998 to 2012.

"Atlantic ocean plant life, the phytoplankton, has been observed to be in tremendous decline. International science teams have measured more than a 26% loss in the last 30 years. How bad is 26%? Remember when we destroy just 1 in 10 of any form of life we say that we have decimated that life. It's bad. Very bad. And the starvation and disappearance of Atlantic Cod stand as testimony to the collapse of the Atlantic Ocean pastures. Ocean pasture grass is plankton." (Russ 2014).

I offer the following analogy to help understand these spring blooms of the silicon diatom phytoplankton pastures and their dependence on the timely deliverance of this essential nutrient.

In the winter our lawns and fields are brown and barren. Spring heralds in more sunlight and the ground warms up. After the first rains deliver much needed nutrients to the lawns and fields, they seem to green up almost overnight. The farm animals begin grazing on the fresh and luscious grass, and the grasses begin transferring through photosynthesis carbon dioxide out of the atmosphere.

Out on the ocean, silica diatom phytoplankton are the pastures of the aquatic food web and one of earth's atmospheric thermostats for carbon levels. During late fall and through the winter these phytoplankton pastures are barren.

Spring heralds in more sunlight, and the oceans warm up. As the snow melts and rain falls on the landscape, the spring freshet begins to flow through our brooks and streams turning the rivers into a tumultuous roar.

These roaring waters are scrubbing silica, which is the second most common element, from the earth's crust.

Quebec Hydropower manages its reservoir hydroelectric generating facilities to capture the spring freshet. Spring discharges are now only 40% to 50% of historic (before reservoir damming) flows and silica diatoms are being starved of silica and other nutrients at this critical time of the growing season.

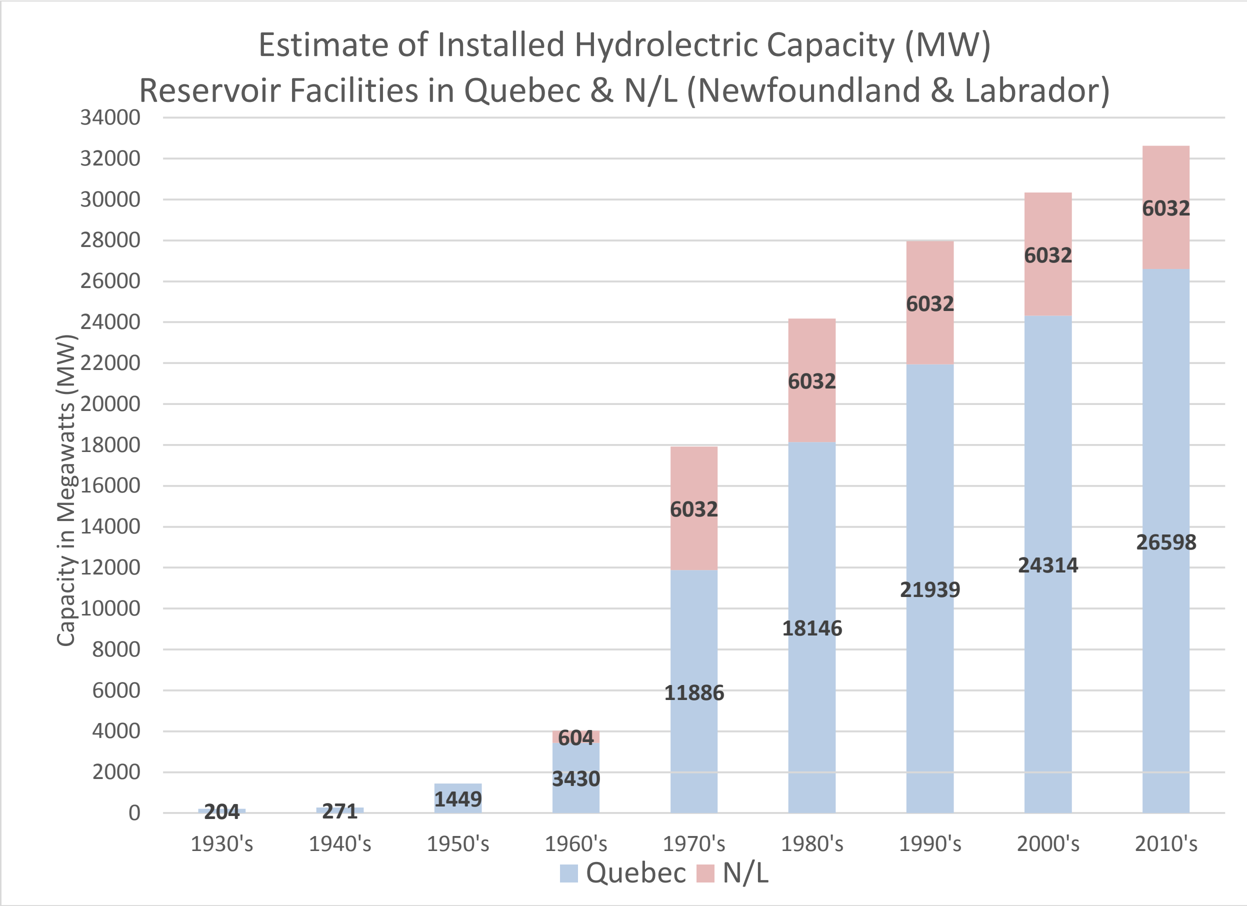
Starving the diatoms of silica means Quebec Hydropower's actions are starving the fisheries and maybe contributing to the increasing levels of carbon in our atmosphere.

Historically (thousands of years) if there was too much carbon in the atmosphere, then the atmosphere and oceans would warm up. This was followed by more evaporation and increased rainfall and snow, which resulted in roaring rivers transporting more silica to the oceans. This increased the size and abundance of silica diatom phytoplankton blooms, which provided more food for the fisheries and increased transference of carbon dioxide to the oceans. This, in turn, cooled off the atmosphere and oceans.

THE PROLIFERATION OF RESERVOIR HYDROELECTRIC FACILITIES OVER THE LAST FIFTY YEARS HAS PRODUCED A LACK OF SILICA WHICH HAS NEGATIVELY IMPACTED THE ABUNDANCE OF DIATOM PHYTOPLANKTON AND STARVED THE FISHERIES AND MAY BE CONTRIBUTING TO CLIMATE CHANGE

Quebec Hydropower not only built huge reservoir hydroelectric facilities throughout Quebec, but also built the 5,428 (MW) Churchill Falls Generating Station in Newfoundland and Labrador (NL).

The graph below illustrates how the annual capacity in MW's from Quebec Hydropower's reservoir hydroelectric facilities increased by 450 percent from 4,034 MW in the 1960's to 17,918 in the 1970's. and by another 200% in the 2010's to 32,630 MW.



Earlier I used an analogy to show how the reduction in May and June outflows from the LaGrande facilities is equivalent to eliminating 7 Penobscot Rivers flowing into the Gulf of Maine during May and 10 Penobscots flowing into the Gulf in June.

The LaGrande facilities have 3 reservoir facilities and one Run of the River, and their total annual capacity is 8,738 MW.

The graph above shows a total annual capacity for reservoir facilities of 32,630 MW.

It would not be unreasonable to estimate that the reduced May and June outflows from these facilities would be the equivalent of eliminating 26 (7 Penobscots x 32,630 MW ÷ by 8,738 MW) Penobscot Rivers flowing into Gulf during May and 37 in June.

These estimates are conservative as I did not include, in the above graph, facilities in Manitoba and Ontario.

THE CUMULATIVE EFFECT OF FIFTY-PLUS YEARS OF REDUCED ANNUAL INPUT OF DISSOLVED SILICATE FROM ALL THESE DAMS IS DESTROYING BOTH THE FISHERIES AND ECOSYSTEM OF GULF OF MAINE

The following quotes from a scientific report, *Hydrological Alterations and Marine Biogeochemistry: A Silicate Issue?*, by Ittekkat et. al. (2000) describes some of the processes that are responsible for the decline we are seeing in the ecosystem and fisheries of Gulf of Maine and Northwest Atlantic.

"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 help to maintain ecosystems along the periphery of land masses."

"Most studies addressing the causes of eutrophication have concentrated on the elements nitrogen and phosphorus, mainly because both these nutrients are discharge by human activities. Silicate, however, also plays a crucial role in algal growth and species composition."

"The source, transport and sink characteristics of silicate, as they relate to change 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 (Humbug 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 dam 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 eutrophication—that is, silicate limitation in perturbed water bodies can set in much more rapidly than under pristine conditions, leading to changes in the composition of phytoplankton in coastal waters."

QUEBEC HYDROPOWER'S RESERVOIR FACILITIES AND OPERATIONS ARE INCONSISTENT WITH MAINE'S NATURAL RESOURCES PROTECTION ACT

The proliferation of large reservoir hydroelectric dams by Quebec Hydropower over the last 50 years never would have been allowed in Maine because the construction and management of these dams would have violated Section 401 of the Clean Waters Act and Maine's Natural Resources Protection Act.

To put this in perspective, Quebec Hydropower has 66 hydropower generating sites, and 38 are Run of River with a total capacity of 11,100 megawatts (MW), and 28 are reservoirs with a total capacity of 26,800 MW.

Maine's annual hydropower generating capacity is only 723 MW.

Quebec Hydropower's reservoir facilities have basically eliminated the spring freshet on these rivers by capturing and storing the spring run-off.

This would be an act of pollution on Maine's rivers under the Clean Waters Act, because the storage of these free-flowing cold waters has reduced by 40% to 50% the historic and natural delivery of the annual budget of dissolved silicate to the Gulf of Maine via the waters flowing through the Hudson Strait and the Labrador current.

In 2006, the Maine Department of Environmental Protection (MeDEP) and S. D. Warren argued before the U. S. Supreme Court over whether S. D. Warren was polluting the Presumpscot River and violating Section 401 of the Clean Water Act (CWA), because it was using too low a minimum flow during hot summer months.

MeDEP argued that dissolved oxygen levels were too low in the river downstream of the Eel Weir Dam and a higher flow was needed to provide more dissolved oxygen for aquatic life.

The Supreme Court agreed with MeDEP in a 9 to 0 decision, and Justice Souter wrote "***The decision interprets term "discharge" according to its "ordinary and natural meaning"*** and rejects efforts by S. D. Warren to have the Court read into CWA Section 401 any requirement that the regulated activity result in the ***"addition of a pollutant."***

In other words, holding back clean water laden with dissolved oxygen was polluting downstream water, which did not have enough dissolved oxygen to support the river's fisheries and aquatic life.

Furthermore, the construction of these reservoirs have not only flooded and eliminated the functions and values of hundreds of thousands of acres of wetlands, but have also captured the cold and free-flowing water of thousands of miles of brooks, streams and rivers in these reservoirs, along with the dissolved silica, which was being transported in the spring freshet by these once naturally free-flowing water bodies.

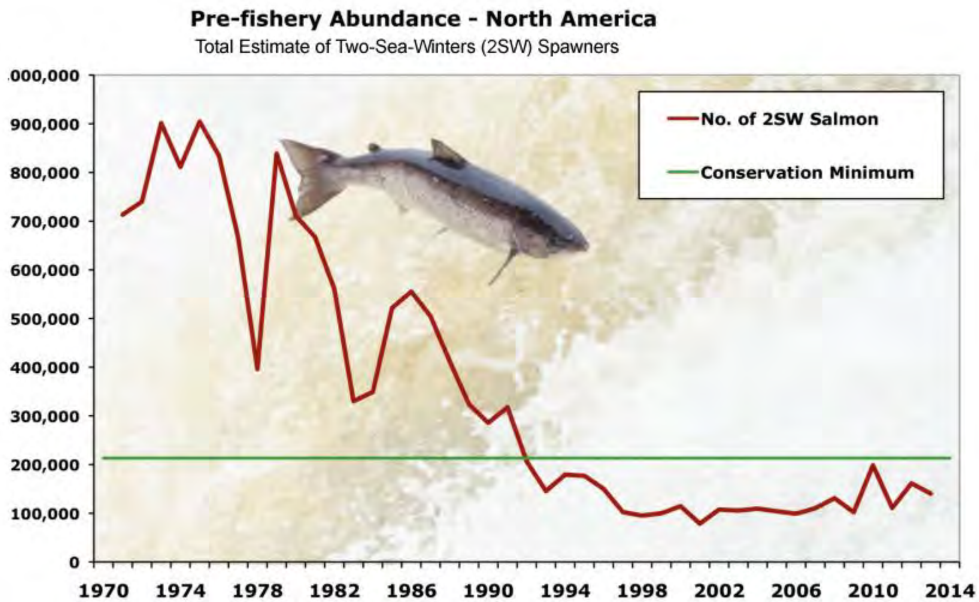
Quebec Hydropower's reduction of spring and summer outflows is polluting Hudson Bay, Labrador Sea and the Gulf of Maine by depriving the silica encased diatom phytoplankton population of its much needed dissolved silica during its growing season.

Diatoms are algae cells enclosed with cell walls made of silica, and their growth rate and size are determined by the availability of dissolved silica and the temperature of the water. In March, with more daylight hours, the diatom population increases its rate of photosynthesis enabling it to start dividing and multiplying into a healthy diatom bloom and the more silica, the bigger the diatoms and bloom.

These reservoirs prevent the cold natural waters of the spring freshet from reaching the coastal estuaries, and these retained waters are then exposed to "aging" as the water temperature quickly rises and changes in its biochemistry occur before being discharged from the dam.

The Gulf of Maine is one of the most important oxygen producing ocean "rain forests" in the world, and its diatom rich ecosystem is responsible for superior fisheries, ameliorating ocean acidification and regulating climate change. The cumulative effect and the proliferation of reservoir hydropower in its ecosystem are destroying it.

QUEBEC HYDROPOWER RESERVOIR FACILITIES ARE NOT ONLY STARVING THE SILICA DIATOM PHYTOPLANKTON POPULATION, BUT ALSO THE ATLANTIC SALMON FISHERY (SEE GRAPH BELOW)



Pre-fishery Abundance (PFA) graph for North American 2SW salmon showing the total number needed to meet the total Minimum Conservation Limit in North American rivers in green (corrected for 11 months of natural mortality). The PFA numbers are those 11 months before they return to their home rivers in North America.

Source: Atlantic Salmon Federation 2015

IT IS NO LONGER A QUESTION OF MAY!

There were early warning signals that the proliferation of these reservoir hydroelectric facilities may have a negative impact on the food chain in the northwest Atlantic and Gulf of Maine.

Sutcliffe et. El. (1983) hypothesized that reducing the spring freshet by hydroelectric regulation in the Hudson Bay area may affect northern cod populations along the Labrador coast.

The following was written in a 1998 Canadian study:

a. ***"Hydroelectric development on major rivers is seasonally altering the physical structure of the water column in coastal waters,"*** **and *"the implications of these hydro developments on the marine environment are not fully understood."* (Harding 1992)**
b. ***"Hydroelectric development has markedly reduced this spring run-off, and this may be enough to delay the phytoplankton bloom and thereby shorten an already brief growing season for larvae fishes and benthic invertebrates." (*Morin et al. 1980)**

THE GULF OF MAINE AND CHINA SEA ARE WARMING AT AN ALARMING RATE, AND NOW THERE IS ANOTHER AREA

The countries who are the biggest producers of hydroelectricity are warming their nearby oceans**.** The Gulf of Maine and South China Sea are two areas in the global ocean, which are warming the fastest, and they are located next to the two largest producers of hydroelectricity in the world. Number one is China, and number two is Canada. Quebec Hydropower is Canada's largest producer, and it's warmer than natural discharge waters flow via the Labrador Current into the Gulf of Maine.

The third area is Barents Sea, and scientists say *"changes are so sudden and vast that in effect, it will soon be another limb of the Atlantic, rather than a characteristically icy Arctic Sea."* The Barents Sea is being impacted by Norway and Russia, which are the 5^{th} and 6^{th} largest producers of hydroelectricity in the world.

The water impounded by these large reservoirs is heated by the sun, and the discharged water from the impoundment is much warmer than the natural free flowing water upstream of the reservoirs. The temperature of the Gulf of Maine's waters is responding to the cumulative impact of more and more reservoir hydropower generation sites being built in the past fifty years. Since 1969, Quebec Hydro has built 22 reservoir hydropower dams, which is almost one every other year.

Since 1986, the area of the under ice plume from the LaGrande River has trebled and can extend 100 KM (62 miles) under the land fast ice of James Bay in the Hudson Bay (Roche 2017). Plumes of this magnitude, with warmer than natural flowing waters, could be contributing to thinner and weaker ice in the impacted area.

MORE CARBON IN THE AIR

The reduction in both the size and abundance of diatom phytoplankton blooms have contributed to the increased carbon in the air by significantly reducing the natural transference of carbon dioxide from the atmosphere to the ocean.

Mighty Diatom

(silica shelled phytoplankton)

The mighty diatoms are the microscopic plants that dominate all other ocean species in converting carbon dioxide to carbon and releasing oxygen.

"Diatoms are at the bottom of the food chain and suck up nearly a quarter of the atmosphere's carbon dioxide . . . Size matters for the creatures that eat them and also for carbon sequestration, as large diatoms are more likely to sink when they die . . . If smaller sized diatoms dominate, then carbon sequestration becomes less efficient and there may be more carbon dioxide in the atmosphere, which would exacerbate global warming" (Litchman et. al.2000).

Here in Maine, we criticize those that irresponsibly bring destruction to the world's oxygen producing forests, and yet we are fully complicit in policies that diminish the freshwater delivery of the critical necessary nutrients like silica to our own "ocean rain forests."

The proliferation of reservoir hydroelectric facilities on Quebec's major rivers has greatly altered the seasonal timing of silica-laden freshwater quantities delivered to Hudson Bay, Labrador Sea and eventually the Gulf of Maine. The diatom plankton ecosystems have not evolved to be starved of nutrients in the spring and summer and then fed nutrients under lower light and temperature conditions in late fall and winter. As a result, diatom population is adversely affected, and the rest of the food chain is starving and the percent of carbon dioxide in the atmosphere is increasing.

Quebec Hydropower's management is contrary to the good science found in the conclusion of a 2004 scientific report Lost to the Tide: the Importance of Freshwater Flow to Estuaries, by University of Rhode Island oceanographer Scott Nixon, et. al;

1. ***" Realization that fresh water serves an important ecological function in estuaries means that all engineering interventions in the flow of water to the coast should be looked at very carefully to see if diversions are really necessary and to see if releases from storage can be programmed to parallel the natural pattern as closely as possible."***
2. ***"It is important to understand that the freshwater that reaches the coast plays an important role in sustaining the productivity of estuarine ecosystems, which are also very important to people. Maintaining the flow of fresh water to the coast should be a consideration in fresh water management decisions."***

Mr. Jonathan Gilson wrote the following in a 2011 Report, in which, he referenced 217 Reports to support his conclusions:

"Episodic flood and drought events have pronounced impacts on fisheries production due to rapid change in physicochemical conditions modifying species richness and diversity. Many documented reductions in fisheries production have been attributed to river regulation modifying natural variation in freshwater flow. Protecting natural flow regimes is likely to be an effective management strategy to maintain the production of estuarine and coastal fisheries."

CONCLUSION

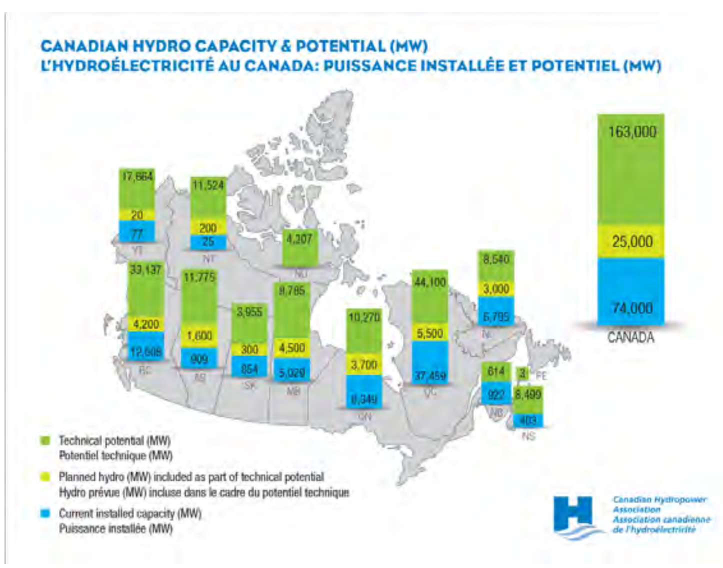
Let's put some of the above observations in layman's terms. It would be declared an extreme drought by meteorologists if total spring and summer precipitation was forty percent below normal. If it happened for fifty continuous years on land in the northern latitudes, the people would have starved to death. In the ocean waters of Newfoundland, Labrador and Maine, the fisheries are being starved to death.

For the past fifty years, a three-fold increase in river discharge of these warmer than normal reservoir waters (mid-thirty degree Fahrenheit) during the three months of winter represents a deluge of biblical proportion to the frozen seas. There are thousands of reservoir hydroelectric facilities throughout the northern latitudes operating in a similar manner.

The cumulative impact is predictable! Since the start of regular satellite observations in 1979, there has been an overall decline in Arctic sea ice in the past forty years. However, total sea ice in the Antarctic has increased by one percent per decade. Is this deluge of warmer than natural discharged waters a key factor in the decline of Arctic sea ice?

This Report has documented how the building and management by Quebec Hydropower of its reservoir hydroelectric facilities has captured the spring freshet and reduced the historic transport of dissolved silica. These actions are the driving force in the starvation of the fisheries and may be contributing to increase carbon levels in the atmosphere. Canada has ambitious plans to build many more reservoir facilities, which will only exacerbate the problem and may prove to be the tipping point.

MAP OF EXISTING AND FUTURE FACILITIES



Reject CMP Power Line Because Hydro-Quebec Facilities Damage Ecosystem

I am publicly writing to ask Maine's Department of Environmental Protection (MeDEP) to deny a permit for the 145-mile transmission corridor proposed by Avangrid-CMP to carry hydroelectricity generated by Quebec Hydropower from Canada to Massachusetts because Quebec Hydropower reservoir hydroelectric facilities are starving the fisheries in the Gulf of Maine and warming its waters.

In a recent 2016 Canadian study of trends in river discharge from 1964-2013, the authors found: that there has been a three-fold increase in river discharge during winter , when electric demand peaks, into the estuaries of Labrador Sea and Eastern Hudson Bay for the 2006-2013 period compared to 1964-1971 and a forty percent reduction in discharge during the summer. (*Recent Trends and Variability in River Discharges Across Northern Canada* Dery et. Al. 2016).

Let's put these findings in layman's terms. It would be declared an extreme drought by meteorologists if total spring and summer precipitation was forty percent below normal. If it happened for fifty continuous years on land in the northern latitudes, the people would have starved to death. In the ocean waters of Newfoundland, Labrador and Maine, the fisheries are being starved to death.

For the past fifty years, a three-fold increase in river discharge of these warm reservoir waters (mid-thirty degree Fahrenheit) during the three months of winter represents a deluge of biblical proportion to the frozen seas. There are thousands of reservoir hydroelectric facilities throughout the northern latitudes operating in a similar manner.

The cumulative impact is predictable! Since the start of regular satellite observations in 1979, there has been an overall decline in Arctic sea ice in the past forty years. However, total sea ice in the Antarctic has increased by one percent per decade. Is this deluge of warmer than natural discharged waters a key factor in the decline of Arctic sea ice?

The proliferation of large reservoir hydroelectric dams by Quebec Hydropower over the last 50 years never would have been allowed in Maine for the following reasons:

1. The construction and management of these dams would have violated Section 401 of the Clean Waters Act and Maine's Natural Resources Protection Act.
2. These dams are starving the fisheries of Hudson Bay, Labrador Sea and the Gulf of Maine, by reducing the transport of the annual budget of dissolved silicate during spring freshet to silicon diatom phytoplankton, which is the essential basis of the marine food web.

Attachment 1

Page 1

3. The reduction in diatom phytoplankton blooms have increased carbon in the air by significantly reducing the natural transference of carbon dioxide from the atmosphere to the ocean.
4. These reservoir dams are warming the waters of the Hudson Bay, Labrador Sea and the Gulf of Maine by capturing the spring freshet behind these dams and holding these waters to maximize hydropower generation during peak demand in the winter months.

If a permit is issued, it should be conditioned on Quebec Hydropower changing the management of their reservoir facilities to a Run of River mode, which uses the natural flow of the river. This would help restore large silicon diatom phytoplankton blooms to feed the fisheries and increase carbon dioxide transference from the atmosphere to the ocean. It should also help reduce the warming of the waters of Hudson Bay, Labrador Sea and the Gulf of Maine.

> *"Half of the Gulf of Maine's ecosystem lies in Canada, where much of the water feeding the Gulf and affecting its temperature comes from*," was written by Colin Woodward in 10/15/15 Maine Sunday Telegram article.
>
> Quebec Hydropower's reservoir facilities have eliminated the spring freshet on these rivers by capturing and storing run-off.

The proliferation of reservoir hydroelectric facilities on Quebec's major rivers has greatly altered the seasonal timing of silica-laden freshwater quantities delivered to Hudson Bay, Labrador Sea and eventually the Gulf of Maine. This would be an act of pollution on Maine's rivers under the Clean Waters Act.

The diatom plankton ecosystems have not evolved to be starved of nutrients in the spring and summer and then fed nutrients under lower light and temperature conditions in late fall and winter. As a result, diatom population is adversely affected, and the rest of the food chain is starving and the percent of carbon dioxide in the atmosphere is increasing.

It is time to recognize that there may be a key regional factor starving the fisheries and warming Hudson Bay, Labrador Sea and the Gulf of Maine. If the fisheries are starving in all these waters, then the obvious place to look is the food chain.

Stephen M. Kasprzak

Attachment 1
Page 2

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.

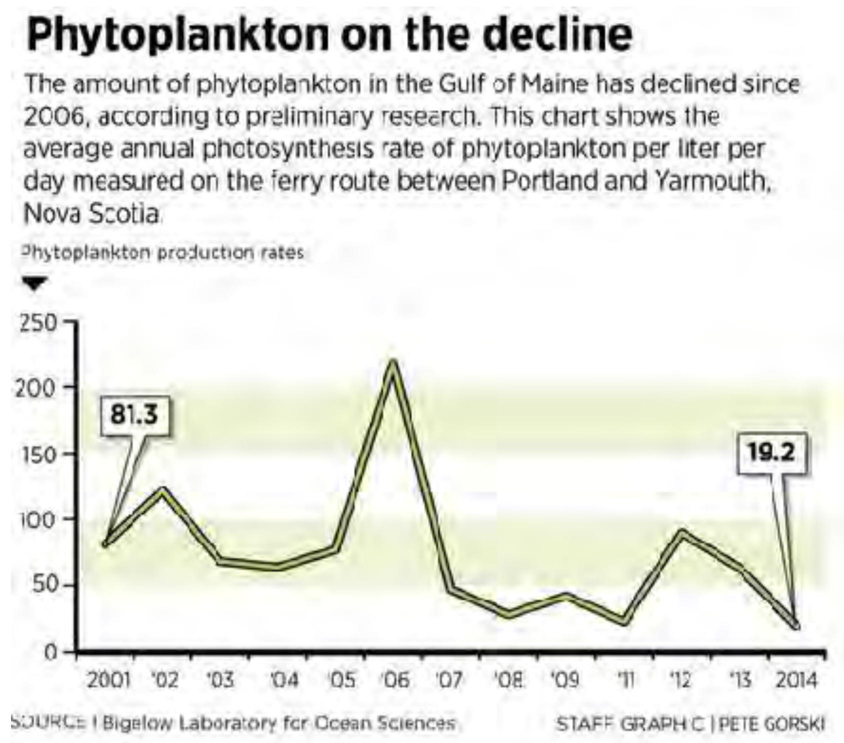
VII. *“Hydro-Quebec offers misleading claims about climate impact,”* Bradford H. Hager, Editorial to Portland Press Herald, January 5, 2019, pgs. 37-39.

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.

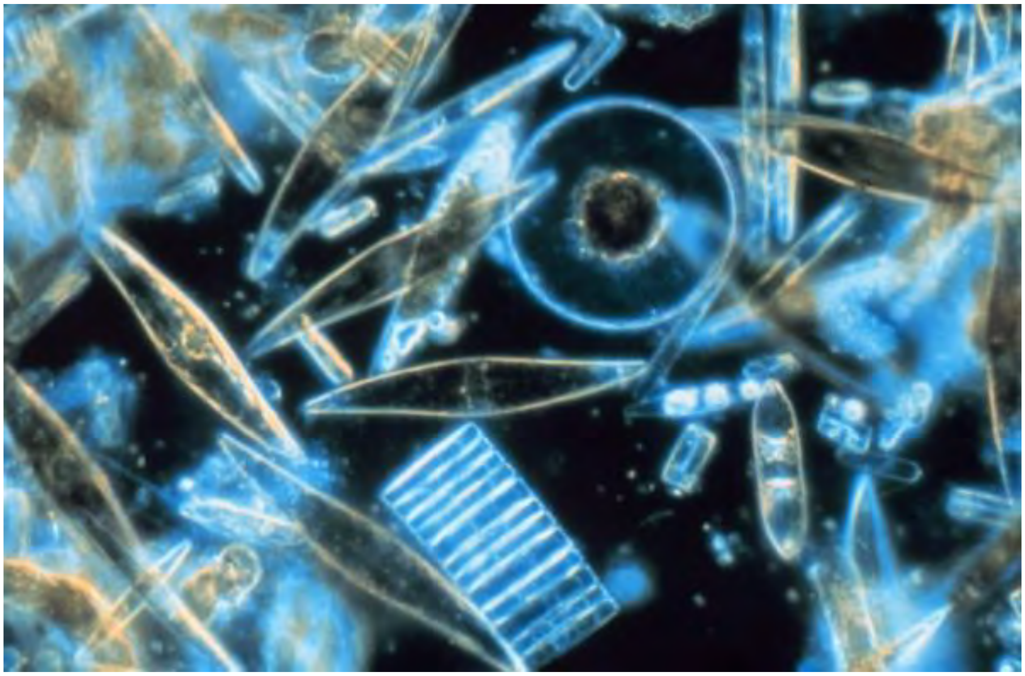
Above normal rainfall would be beneficial to phytoplankton regeneration rates by transporting more beneficial dissolved silica and nutrients to the coastal waters.

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.

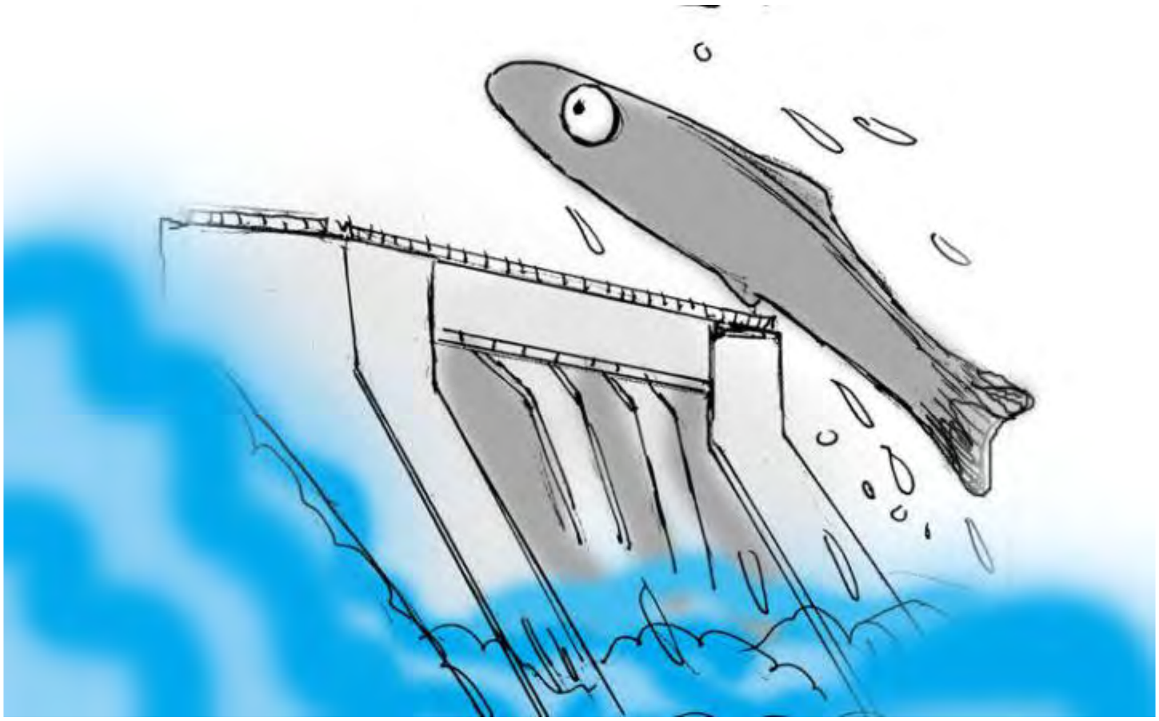
"When you collect the amount of data that we've collected, it's hard to discount the significance," said Balch. "I know there are skeptics out there who still discount the issue of climate change, but the evidence now is just striking. We need to be thinking very carefully about trying to slow this down. 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 $m^3 s^{-1}$ 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. This decline however, will be worse, since regulation will have increased further in the meantime."_* Neu Part II 1982)

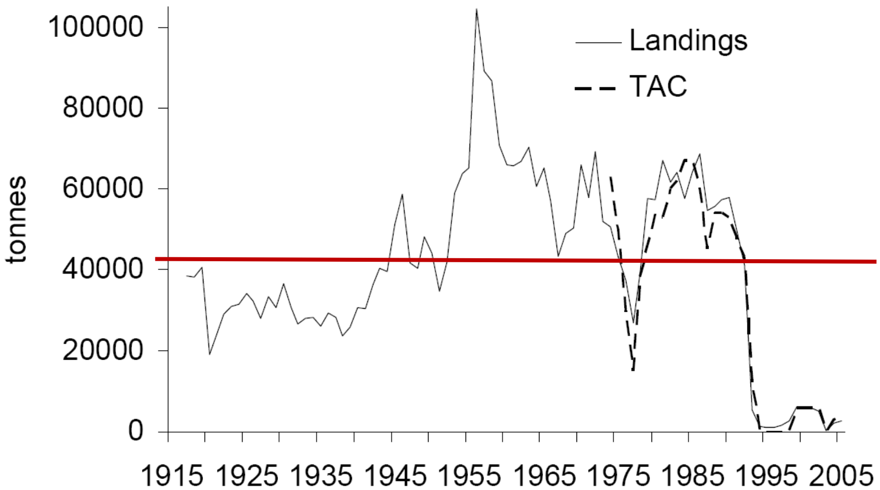


Figure 2: Landings and TAC (t) for the southern Gulf of St. Lawrence cod stock.

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

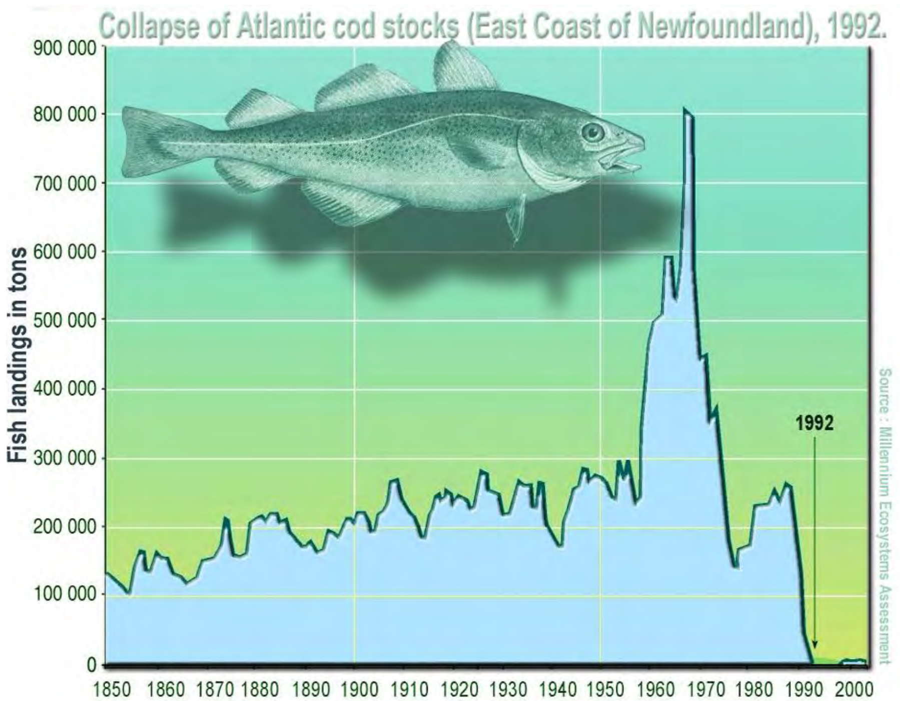
He also predicted the decline of the fishing stock of the Grand Banks of Newfoundland:

> *"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 <u>lack of silica</u> 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 <u>lack of silica</u>.

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)."*

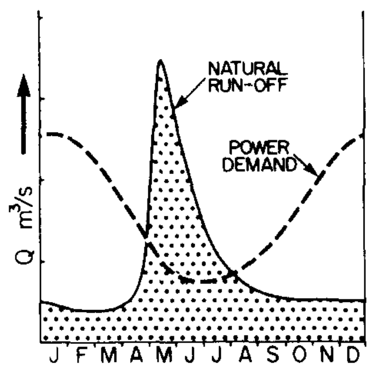


Fig. 7 Typical hydrograph and seasonal power demand.

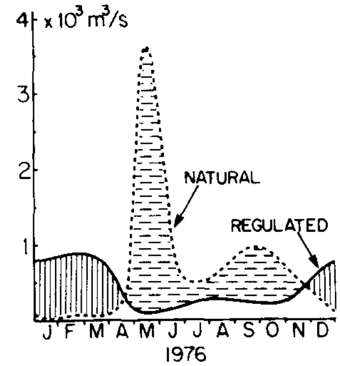


Fig. 8 Natural and regulated discharge of the Manicouagan River at Manic 5 power station.

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.

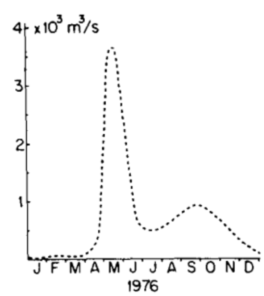
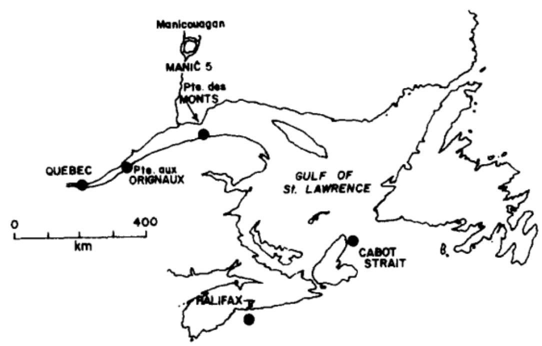


Fig. 1 Natural run-off to the Manicouagan River at Manic 5 power station.



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*).*

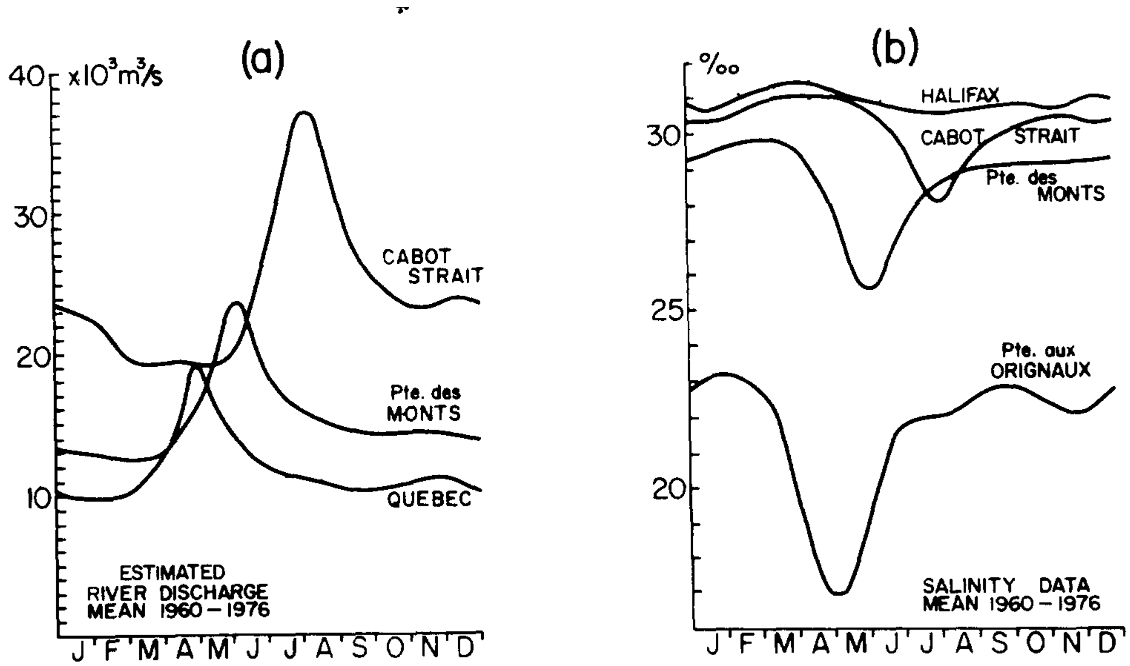


Fig. 2 Mean monthly (a) fresh water and (b) surface salinity variation for stations along the St. Lawrence system and Scotian Shelf.

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."* (Silica Stories, 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.

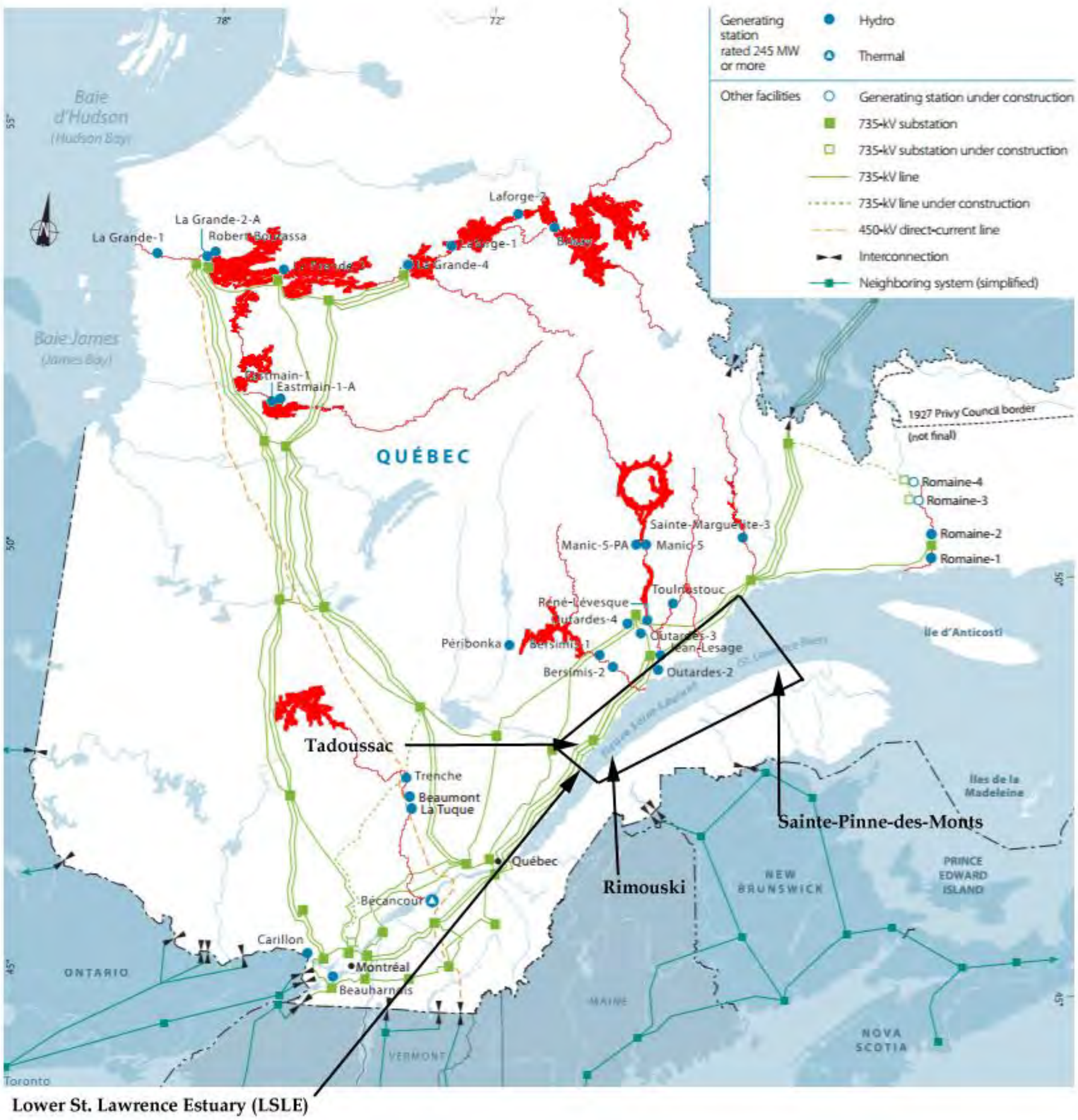
Less dissolved silicate in the upper waters of the Estuary and Gulf has allowed the increased nitrogen input from sewer treatment plants and storm water runoff to fuel an explosion in the growth of non-siliceous algal growth. This increase in algal growth (eutrophication) has lead to oxygen depletion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

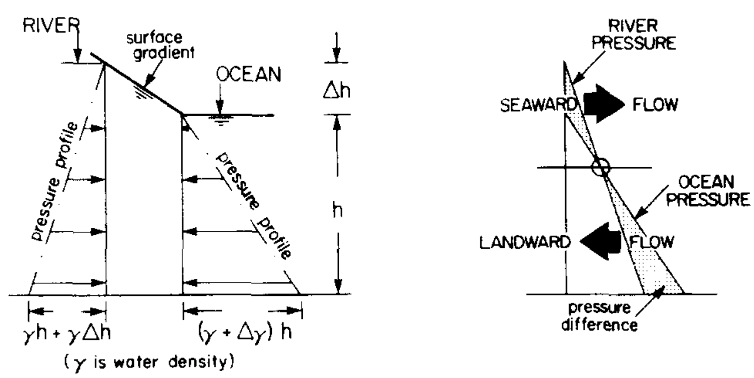


Fig. 3 Schematic diagram of pressure distributions for density currents.

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.

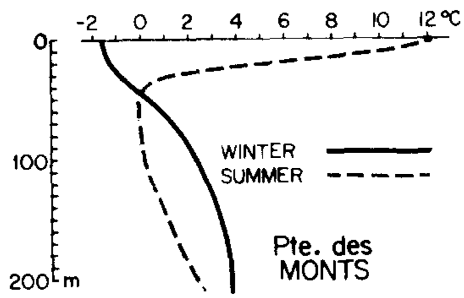


Fig. 6 Vertical temperature profile at Pointe des Monts in winter and summer.

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.

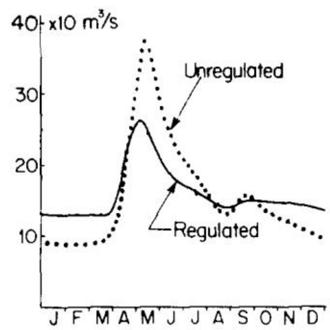


Fig. 11 Regulated and unregulated flow of the St. Lawrence at Pointe des Monts for 1976.

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.

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 oxygen-rich, 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.


Crédit: Bjorn Sunday

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

Québec OCÉAN Le groupe interinstitutionnel de recherches océanographiques du Québec

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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.

ABOUT THE AUTHOR

Stephen M. Kasprzak is a resident of Cape Porpoise.

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.

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

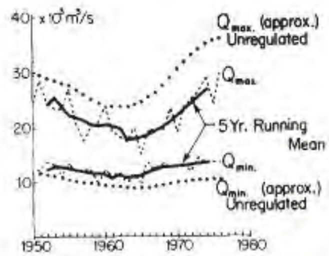

Fig. 1 Annual monthly Q_{-max} and Q_{-min} of the St. Lawrence river at Pointe des Monts.

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.

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