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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 I

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.

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.

Introduction

As demonstrated by western society in the last hundred years, the material quality of life improves with the availability of natural resources and with cheap and abundant energy. Today's energy crisis, which arises from the curtailment of the energy supply, threatens this rate of improvement. It is therefore understandable that the prime concern of industrial planners is to develop reliable energy sources. In Canada, hydro-power plays an important role in this concept.

The utilization of power from water is as old as human civilization. In fact, the invention of the water wheel was a key step in reaching our present level of technology. Initially, effects on the environment were minimal but by the turn of the century, when technology was able to modify entire river systems, the consequences became perceptible. The major impact, however, started after the second world war when huge storage lakes were built for power development capable of holding the run-off of large drainage areas and storing it over entire seasons, years, and even longer. Today, these schemes are changing the hydrology not only of regions but of entire continents.

For rivers, this conflict has been somewhat recognized and reported upon (Atton, 1975; Dickson, 1975; Duthie & Ostrofsky, 1975; Efford, 1975; Geen, 1974; Ruggles & Watt, 1975; Townsend, 1975), but with a few exceptions (Asvall, 1976; Skreslet, 1973 a, b, 1976) it is generally assumed that when the river water meets the ocean it is quickly dispersed with little or no impact. However, this is not the case. Fresh water is a major factor in providing nutrients to coastal waters and continental shelves such as the Grand Banks of Newfoundland, and in producing a moderation of the climate.

It should be realized that the prime concern of this paper is not the development of power but the modification of the run-off, particularly its seasonal cycle. As will be demonstrated, this regulation represents a severe interference with the basic concept and balance of activities in the ocean.

Seasonal Variation of Fresh Water

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.

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

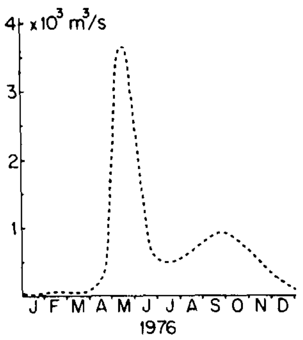

Fig. 1 Natural run-off to the Manicouagan River at Manic 5 power station.

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.

Similarly, although much larger in magnitude, one can consider the fresh water run-off from Hudson Bay and the Canadian North. Here, even more so than in the St. Lawrence, the winter run-off contribution is small but during the summer large quantities of fresh water are released which affect the surface layer of the coastal waters to a depth of 30–90 m. The peak of the fresh water arrives in July at Cape Chidley near the entrance to Hudson Strait with a discharge of about 300 000 $m^3 s^{-1}$ or about 30 times the flow of the St. Lawrence at Montreal – and in September between Newfoundland and Flemish Cap with a discharge of below 200 000 $m^3 s^{-1}$. This reduction in discharge is produced by a decline in speed over the Grand Banks region which lasts until the end of the year. A part of this fresh water continues along the coast of Nova Scotia – shown in Fig. 2b as a weak but noticeable drop in salinity at Halifax in January – reaching Georges Bank probably in the early spring. So, after being quickly transferred from the North and along the coast of Labrador during the summer, the fresh water affects the Grand Banks during the autumn, the Scotian Shelf during the winter and Georges Bank probably during the spring. The distance travelled by the fresh water wave during a period of 9 months is about 4000 km. On the Scotian Shelf, therefore, there are two freshening cycles annually, a

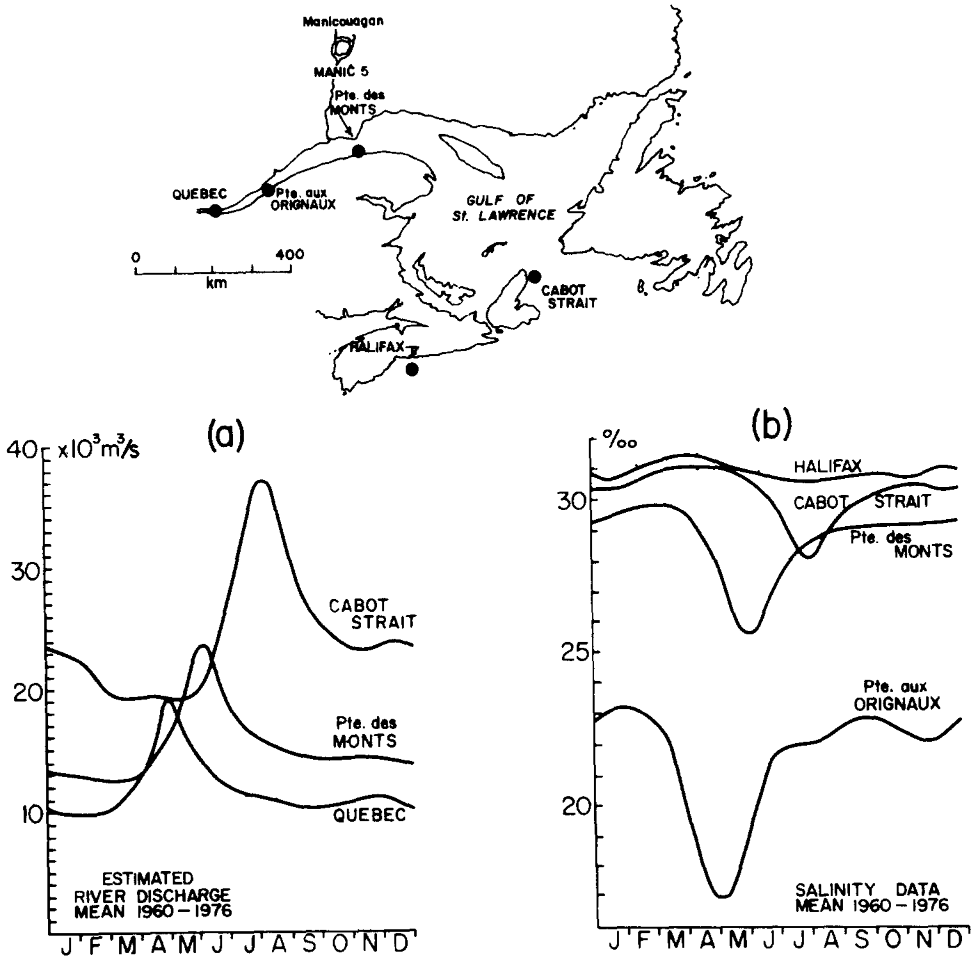

Fig. 2 Mean monthly (a) fresh water and (b) surface salinity variation for stations along the St. Lawrence system and Scotian Shelf.

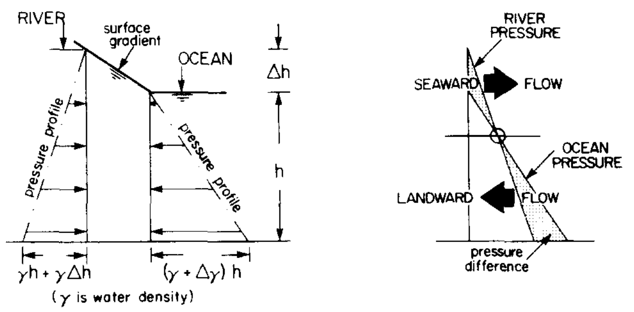

Fig. 3 Schematic diagram of pressure distributions for density currents.

larger one in summer from the St. Lawrence and a smaller one in winter from the Canadian North. On Georges Bank, these fresh water waves should arrive in autumn and spring respectively.

In assessing the man-made changes to water resources, it must be realized that the impact of river regulation on a physical property such as salinity declines the further north we go. The reason for this is that the fresh water deriving from melting sea ice increases relative to the land run-off. For instance, in the St. Lawrence estuary, the fresh water from sea ice is negligible; in the Gulf it increases to about one-fifth of the spring peak flow; in James Bay and southern Hudson Bay to between one-quarter and one-half and in Baffin Bay to between one-half and three-quarters of the spring and summer drainage. Thus, the further north, the smaller becomes the influence of the river run-off.

Obviously, the provision of large quantities of fresh water in spring and summer and the subsequent sweeping of the coastal region and continental shelf by this water are features of the Canadian North and the Canadian Atlantic region. It appears that this seasonal fresh-water movement is in tune with the relatively short reproduction cycle and growing season of the area. It is interesting to note that the two regions receiving major seasonal fresh water sources, the Grand Banks and Georges Bank, are ranked among the greatest fishing grounds in the world.

Fresh–Salt Water Interplay 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 the 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.

Figure 4 shows salinity profiles at various locations along the St. Lawrence system to the Scotian Shelf. These profiles are in pairs to compare directly the two extreme seasons of winter and summer. The change in surface salinity along the system is also shown in Fig. 2b. As can be seen, the fresh water affects primarily the upper layer, consisting of a mixed layer, about 25 m thick, and a transition layer, about 50 m thick, in which the salinity increases from that of the mixed layer to that of the deeper layer. The water of the deeper layer is ocean water which originates off the continental shelf. It must be realized that this deep water enters the system and penetrates more than 1000 km upstream without any significant contact with the fresh water of the system.

The upper layer is deflected by the Coriolis force toward the right, thus forming (in cross-section) a triangular-shaped layer with the thicker side along the Gaspé Peninsula and the coast of Cape Breton. Evidently, the variation in salinity during spring and summer (Figs 2a, 2b and 4) is a function of the fresh water supply and is confined to the upper layer. The rate of change decreases toward the sea but can still be noticed on the Scotian Shelf.

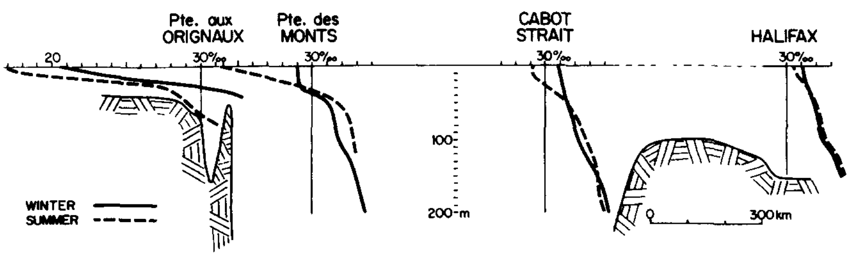

Fig. 4 Mean vertical salinity profiles along the St. Lawrence and Scotian Shelf for minimum (winter) and maximum (spring and summer) run-off.

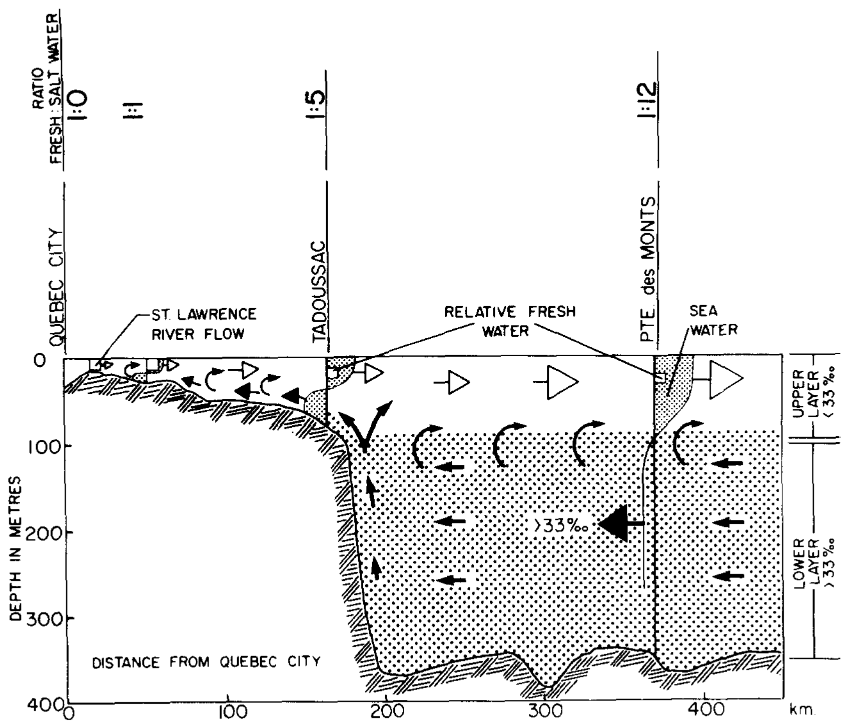

Fig. 5 Schematic presentation of density current in the St. Lawrence Estuary.

The waters off the coast of Labrador, and on the Grand Banks display the same behaviour.

The transport involved in the density current of an estuary can be demonstrated by the continuity principle. As shown in the schematic presentation for the St. Lawrence system in Fig. 5, the seaward directed upper layer contains the fresh water discharge of the river plus the salt water entrained from the landward directed deeper layer, the net flow of salt through the system being zero.

Between Ile d'Orleans and Ile aux Coudres, the average salinity of the upper and deeper layers are 11‰ and 22‰ respectively. Mixing equal volumes of river water (S = 0‰) and saltier water (S = 22‰) results in a salinity of 11‰ for the mixture; therefore, to one unit volume of river water was added the same amount of saltier water at this point. This ratio quickly increases seaward. Taking 33‰ as the reference salinity for sea water, these ratios are 1:5 at Tadoussac and 1:12 at Pointe des Monts, while further seaward they increase to about 1:25 at Cabot Strait, and even more along the coast of Nova Scotia where also fresh water from sources in the Canadian North is present. Obiously, 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. The amount of ocean water required to maintain the level of salinity on the shelves of Atlantic Canada, the embayments and inland seas such as the Bay of Fundy, the Gulf of St. Lawrence and Hudson Bay included, varies from about 2 Sverdrup to more than 7 Sv (1 Sv = 1 million $m^3 s^{-1}$), depending on the season of the year and the salinity limits chosen.

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.

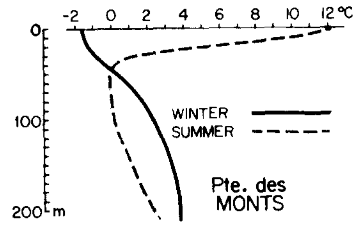

Fig. 6 Vertical temperature profile at Pointe des Monts in winter and summer.

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.

There are other factors which also play a role in this large-scale circulation, especially the wind and the tide. They greatly affect the intensity of mixing in a particular section of the system; however, the haline circulation and its transport as a whole would prevail in their absence.

Principle of Regulation

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.

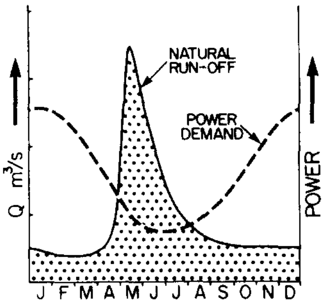

Fig. 7 Typical hydrograph and seasonal power demand.

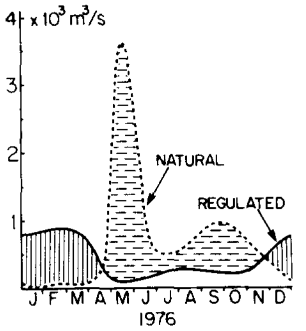

Fig. 8 Natural and regulated discharge of the Manicouagan River at Manic 5 power station.

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.

The ultimate limit of seasonal regulation is achieved when spring and summer flows are completely stopped and the entire annual run-off is released during the winter months. Obviously, such a hydrograph is unrelated to and in outright conflict with natural conditions. Run-off is transferred from the biologically active to the biologically inactive period of the year. This is analogous to stopping the rain during the growing season and irrigating during the winter, when no growth occurs. Even if there were no scientific proof available to verify the danger of such modification, logic alone would show that seasonal regulation ignores the natural consequences of fresh water discharge.

Effect of Regulation on Physics and Dynamics of the Ocean

Reducing the flow of fresh water during spring and summer and increasing it during the winter changes the seasonal composition of the water in the surface layer and the seasonal strength of the density current.

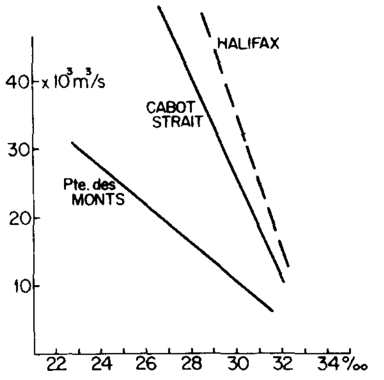

Fig. 9 Run-off versus surface salinity in the St. Lawrence and on the Scotian Shelf.

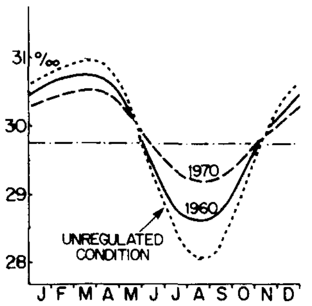

Fig. 10 Seasonal surface salinity variation on the west side of Cabot Strait prior to regulation and in the sixties and seventies.

In Fig. 9, the salinity variation of the surface layer versus fresh water discharge is given for the St. Lawrence and the Scotian Shelf. As can be seen, a reduction of the spring flow of 10 000 $m^3 s^{-1}$ increases the salinity at Pointe des Monts by 4‰, at Cabot Strait by 1.8‰, and near Halifax by 0.9‰. From this relationship, estimates were made of the seasonal variations which occurred at the south side of Cabot Strait for two periods of time, i.e. before regulation commenced and in the seventies. The results are given in Fig. 10. The solid line is the monthly salinity based on the 10 years mean from 1955 to 1964, referred to as the 1960 condition. At this stage, the spring flow was reduced by about 4000 $m^3 s^{-1}$. From the data of Fig. 9 mean monthly salinities were derived for the period prior to regulation, that is for natural conditions, and for the 1970 period when regulation in spring was increased to an average of 8000 $m^3 s^{-1}$. It can readily be seen that drastic modifications have been made to the salinity of the surface layer and that much of the cyclic variation has disappeared by 1970. The remaining seasonal difference will probably be gone with the development of the rivers along the north shore of the Gulf of St. Lawrence, which is already planned and will be implemented soon. As this trend continues, the cyclic variation will be reversed, the surface salinity becoming saltier in spring and summer, and fresher in the winter. This represents a fundamental change in the seasonal salinity patterns of the coastal region and continental shelf.

Concerning the temperature 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.

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.

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.

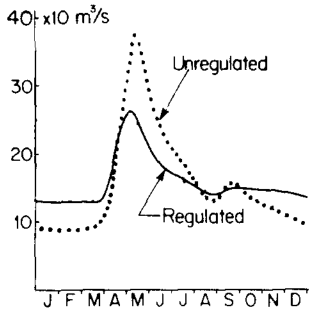

Fig. 11 Regulated and unregulated flow of the St. Lawrence at Pointe des Monts for 1976.

This article will be continued in the next issue of the Bulletin. In the second part, the effect on marine biology will be discussed and related to major schemes in Canada and Russia, the two countries where hydrological control on a continental scale is already contemplated. Their largest freshwater resources will be reviewed relative to the global hydrology, and alternative solutions to offset some of the negative effects will be suggested.

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

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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

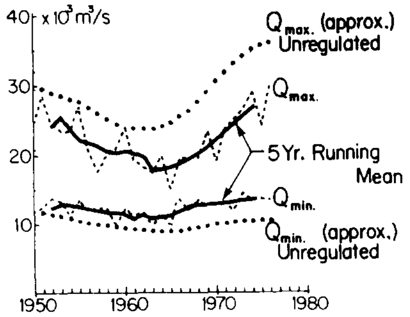

Fig. 1 Annual monthly $Q_{-\max}$ and $Q_{-\min}$ of the St. Lawrence river at Pointe des Monts.

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

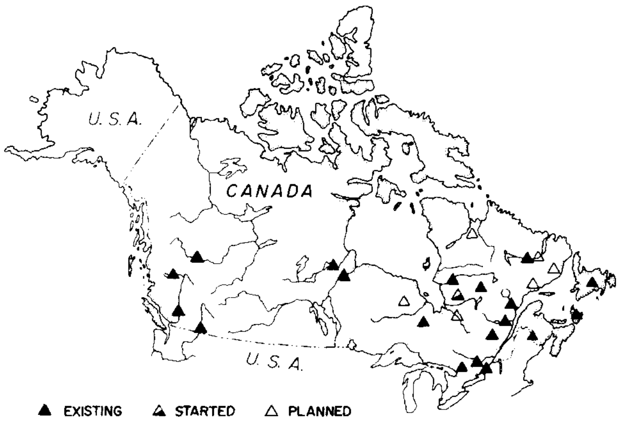

Fig. 2 Major storage schemes in Canada.

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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REPORTS

The Uranium Content of Sediments from the Jordan Gulf of Aqaba

NEIL C. HULINGS
Yarmouk University Marine Science Center, P.O. Box 570, Aqaba, Jordan

The uranium content of nearshore sediments in the Jordan Gulf of Aqaba has been determined. The concentrations are shown to vary according to sediment type or habitat in unpolluted areas, while in a polluted area the concentration is related to phosphate dust pollution.

Phosphate dust pollution is considered to be one of the major pollution problems in the Jordan Gulf of Aqaba. Since 1966, the export of phosphate (composed of 53% calcium as CaO and 32% phosphorus as P_2O_5; Freemantle *et al.*, 1978) through Aqaba has increased from around 750 000 tonnes to over 3 000 000 tonnes in 1980 (data from Jordan Phosphate Company). During the transfer to storage bins and loading of ships, considerable quantities of dust go into the air and much of it settles into the adjacent water. Freemantle *et al.* (1978) estimated that around 1% of the phosphate is lost during the loading process.

A number of studies, mostly preliminary, have been conducted in an attempt to evaluate the magnitude of phosphate dust pollution in the Jordan Gulf. Among the studies are those of Hulings & Abu Hilal (in preparation) on nutrient levels including reactive phosphate in the surface waters, Freemantle *et al.* (1978) and Mulqi (1978) on the calcium, magnesium and phosphate content of water and sediments and Hashwa (personal communication) on the bacterial activity on phosphate dust.

This report includes data on the uranium content of nearshore sediments in the Jordan Gulf collected in April 1975. Since the phosphate of Jordan contains high uranium, up to 240 ppm (Jordan Phosphate Company, personal communication), the presence of uranium in sediments could be another indication of phosphate pollution. Other sources of uranium in the sediments, however, have to be taken into consideration.

Methods

Sediment samples were collected from seven nearshore localities along the 27 km coastline of Jordan by using SCUBA during April 1975. The localities were distributed along most of the coast, from the Jordan-Israel border (locality 1) in the north to the southern Jordan-Saudi Arabia border (locality 7). Of particular note is locality 2 which was 100 m immediately south of the phosphate loading terminal. The other localities were in a variety of habitats including seagrass beds (localities 1 and 4), within or very near coral reefs (3 and 6) and level, terrigenous sand bottoms (5 and 7). The sediment that was collected was at the sediment–water interface.

The sediments were analysed for uranium by using the delayed neutron activation technique at Texas A & M University. Mo *et al.* (1971) have documented the accuracy of the instrumentation used in the analyses reported herein.

Results

Table 1 shows the uranium concentration (ppm) by locality, depth and sediment type or habitat. The sediments