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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 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

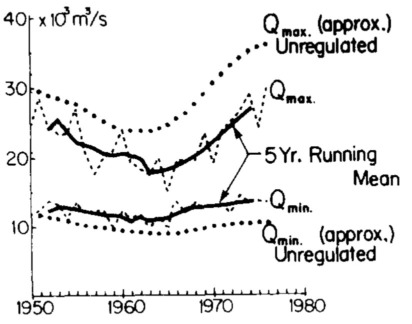

Fig. 1 Annual monthly Q_{-max} and Q_{-min} of the St. Lawrence river at Pointe des Monts.

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

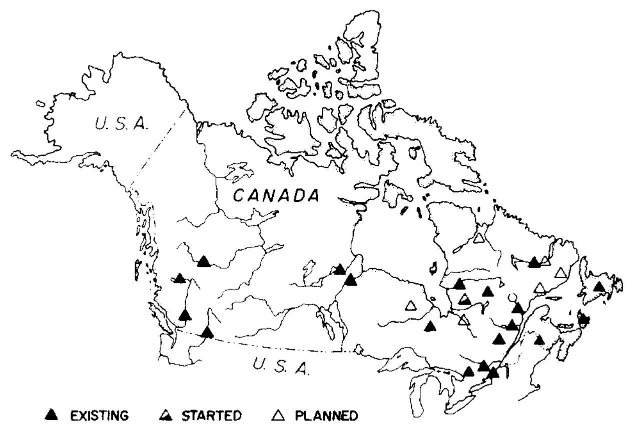

Fig. 2 Major storage schemes in Canada.

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

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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