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PULP MILL POLLUTION IN L'ETANG ESTUARY, A CASE HISTORY AND CLEAN-UP ALTERNATIVES

by

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ABSTRACT

Wildish, D. J., N. J. Poole, and D. D. Kristmanson. 1979. Pulp mill pollution in L'Etang estuary, a case history and clean-up alternatives. Fish. Mar. Serv. Tech. Rep. 884, iii + 6 p.

A multi-disciplinary study of pollution in L'Etang estuary caused by sulfite pulp mill effluent is reported. The pulp mill indirectly caused closure of a soft-shell clam fishery and has made the landward 4 km of the estuary completely anoxic, giving rise to offensive air pollution. Remedial measures are suggested which would eliminate these two major multiple-use resource conflicts. From the point of view of aquatic resource management, the results emphasize the need for careful consideration of siting point source effluents, the further development of numerical simulation techniques for predictive purposes and long-term planning for water resources.

Key words: L'Etang estuary, sulfite pulp mill effluent, resource use conflicts, management options, mathematical models

RÉSUMÉ

Wildish, D. J., N. J. Poole, and D. D. Kristmanson. 1979. Pulp mill pollution in L'Etang estuary, a case history and clean-up alternatives. Fish. Mar. Serv. Tech. Rep. 884, iii + 6 p.

Les auteurs rapportent les résultats d'une étude pluridisciplinaire de la pollution dans l'estuaire de l'Etang causée par l'effluent d'une fabrique de pâte au bisulfite. La fabrique a indirectement causé la fermeture de la pêche des myes et a rendu les 4 km en bordure de l'estuaire entièrement anoxiques, produisant une pollution atmosphérique grave. Des mesures correctives proposées permettraient d'éliminer ces deux principaux conflits amenés par l'utilisation multiple des ressources. Sur le plan de la gestion des ressources aquatiques, les résultats exposés soulignent la nécessité d'une étude attentive de la situation des effluents de source ponctuelle, la mise au point de techniques de simulation numérique à des fins de prévisions et la planification à long terme des ressources en eau.

INTRODUCTION

Wood and its products are the mainstay of the economy of the Maritime Provinces of Canada, and in New Brunswick much of the wood is processed into pulp and paper products for export to other parts of North America and Europe.

This presentation summarizes multiple use resource conflicts caused by the location of one pulp mill on the Bay of Fundy in southern New Brunswick. The mill was designed to produce 220 tonnes per day of corrugated paper. The pulping process used is a sulfite cook at high temperature, utilizing hardwood tree species. After passing through settling and aeration lagoons at the mill site, the effluent is passed, in an open ditch, to the L'Etang. The L'Etang is a marine-dominated tidal inlet or estuary which opens into the Bay of Fundy (Fig. 1). The coastal region here is an important fishing area for herring, *Clupea harengus harengus*, lobster, *Homarus americanus*, and soft-shell clams, *Mya arenaria*, and supports a number of fish processing plants. Tourism is also important in this region because of the beauty of the largely undeveloped coastline.

THE RECEIVING WATER

The L'Etang is 14 km long with a surface area of 30 km^2 (Fig. 1) and a freshwater catchment of 80 km^2. In 1967 a 0.2-km causeway was built to carry a highway across the upper part of L'Etang.

The causeway, which separates upper from lower L'Etang, contains four tubular culverts of 1.6-m diameter, one just above low water (LW), which allows sea water in or out depending on the tide, and the others near high water (HW) allow water movement only on spring tides. This resulted in a mean tidal amplitude in upper L'Etang of 0.1 m compared to $\simeq$ 8.0 m in lower L'Etang.

The upper L'Etang has a maximum depth of 4.0 m and a surface area of 1.33 km^2. A sharp halocline is present across which no mixing occurs except where the freshwater streams enter (Fig. 2). Sea water ($\simeq$ 22-25 S o/oo) enters via the lower culvert on the flood tide and moves landwards in the lower layer (Kristmanson et al. 1976). At the surface a less saline layer ($\simeq$ 10-22 S o/oo) moves generally seaward, although it is influenced strongly by wind effects. Pulp mill effluent is transported rapidly in the surface layer, with a 5- to 10-d retention time in the upper L'Etang.

Salinity in the lower L'Etang ranges from 22-31 o/oo and for most of its length there is no distinct halocline. As shown by drift bottle experiments, lower L'Etang has at least three tidal excursions and consequently a high residence time.

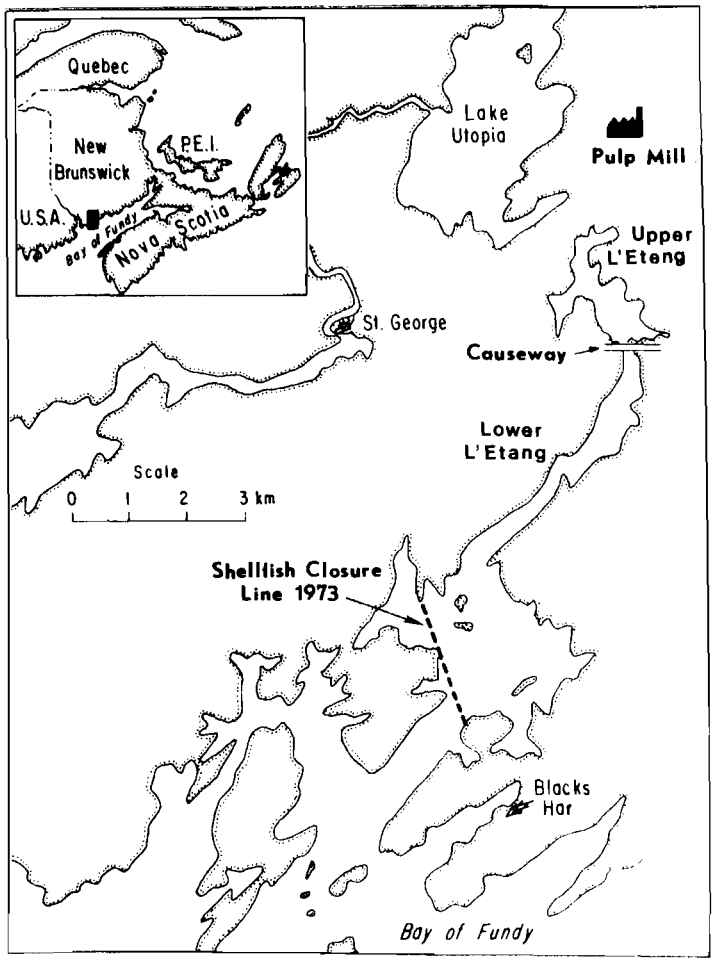

Fig. 1. Map of L'Etang estuary showing the location of the pulp mill.

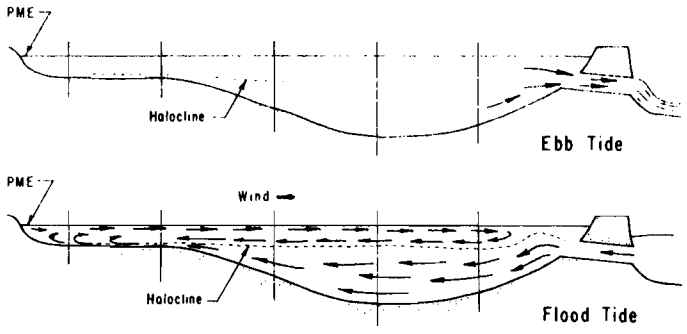

Fig. 2. Diagramatic concept of mixing in the upper L'Etang.

PULP MILL EFFLUENT

The mill became operational in April 1971 and the history of the events connected with the progressive decline of water quality caused by its effluent is shown in Table 1.

Effluent volumes in the range 62-210 m^3/tonne and BOD_5 of 75-300 kg/tonne of product could be expected from a mill of this kind (Poole et al. 1978). The treatment facilities present at mill start-up included an ammonia stripping plant, settling and mechanical aeration lagoons. After 1973, with the change to sodium base cooking, the stripping plant was no longer utilized. Problems were encountered with pulp fibres clogging the aeration lagoons and from 1975 to 1977 the six 75-HP aerators were not used. In 1973 a total BOD_5 load of 13,600 kg/d, that is 65 kg/tonne of finished product, was released in the effluent. Only two aerators were then operational and the treatment was only 38% efficient. At the same time 800 kg/d of suspended fibres were present in the effluent. Because of variations in the nature of the effluent, amount of product produced per day and shutdowns, the treated effluent volume, its BOD_5, and content of suspended fibres varied between wide extremes. In 1979, the suspended solids averaged 3,000 lb/d whilst the BOD_5 value after treatment averaged 50,000 lb/d from an output of 275 tonnes of product/day (R.G. Lutes, pers. comm.).

After minimal dilution with sea water, for instance as the surface layer enters lower L'Etang, the dilute effluent was not lethal at 100% to winter flounders (Wildish et al. 1974). Consequently, any deleterious effects of the effluent to other biota are caused by secondary microbial activity in the receiving water.

BIOLOGY

UPPER L'ETANG

Concentrations of dissolved oxygen (DO) in 1970 before mill start-up were 5.0-5.5 mg/L at temperatures of 15°C. A decline in DO occurred during 1971, and by the end of summer 1972 the water entirely lacked oxygen, and H_2S and other gases were given off from parts of the system. Very high levels of soluble carbohydrates and lignosulfonates were present in the surface layer in 1975 (Poole et al. 1976b). Pulp fibres settle out from the water column during its passage through the upper L'Etang, consequently high carbon values ($\simeq$30% volatile solids) were recorded for these sediments. Sediment microbial activity is enhanced by the carbon input resulting in utilization of DO and production of sulfide by obligate, anaerobic, sulfate-reducing bacteria; these bacteria use the sulfate present in sea water as their terminal electron acceptor and are an important component of the obligative and facultative anaerobic, microbial populations that dominate this system. The chemical oxidation of sulfide plus oxygen uptake by other heterotrophs far exceed the supply of oxygen to the water and sediment (Poole et al. 1977). Some of the sulfide produced is released into the atmosphere where it causes the characteristic and unpleasant smell of putrefaction. The redox values of the sediment are in the order of -160 mV, relative to the normal hydrogen electrode; these levels are typical of anoxic sediments where sulfate reduction is the dominant microbial process. Chemical and biological oxygen uptake rates range from 4-13 g/m^2/d, among the highest recorded in the literature (Poole et al. 1976a). From 1972 onwards few, if any, eukaryotic organisms were present in upper L'Etang.

Table 1. Chronology of events related to water quality in L'Etang estuary.

Date	Event
1967	Construction of the causeway separating upper and lower L'Etang
April 1971	Pulp mill operational
1971-72	Gradual development of anoxia in upper L'Etang
1971-	Gradual development of anoxia/hypoxia in landward 2-3 km of lower L'Etang
Summer 1972	Complaints of smell and reduced scallop numbers in lower L'Etang
1973	Change from ammonia to sodium sulfite cooking
1973	Closure of shellfisheries in L'Etang to line shown in Fig. 1
1974	Low catches of herring in weirs of lower L'Etang

LOWER L'ETANG

In the most landward part of lower L'Etang a progressive decrease in DO took place in bottom water (Fig. 3). No LW samples of bottom water were taken until 1976 due to the lack of a small boat; the data after this suggested a tidal influence on DO. This could be partly explained by the effect of pressure associated with the tides. Thus, release from the sediments of H_2S or HS^- occurs at LW causing an immediate chemical oxygen demand, whereas at HW the pressure hinders gas release. Another factor involved is that there is a greater volume of sea water at HW into which sulfides can dissolve. Sediment redox potentials in this area are also in the region of -160 mV.

Progressive local extinctions of the macrofauna were found in the most landward 4 km of the estuary resulting from low DO, presence of H_2S, or changed microbial populations which are due to the presence of pulp mill wastes. Between 1972 and 1975 the vacant sediments were recolonized by hypoxia-tolerant species such as *Capitella capitata*, *Polydora ligni*, *Peloscolex benedeni*, and *Nereis diversicolor*.

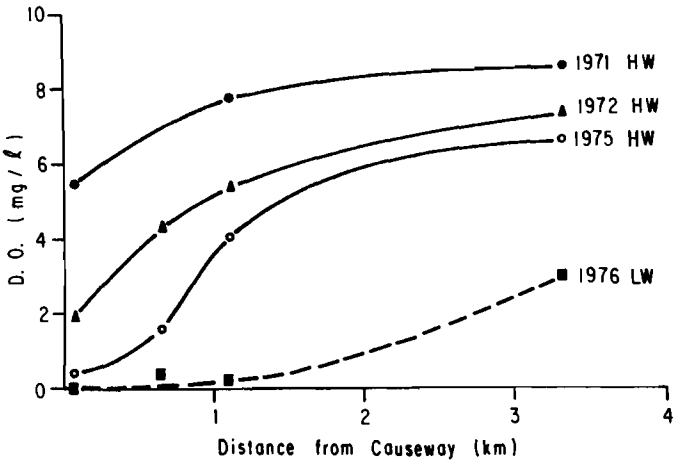

Fig. 3. Dissolved oxygen concentration of bottom water in lower L'Etang.

Crude estimates of secondary benthic production for the affected inter- and sub-tidal area were made based on pre-operational biomass data for the area (Wildish et al. 1977). The total surface area of the anoxic-hypoxic zone is 275 ha. Total mean production lost was estimated as 121.2 tonnes dry weight per year. The standing stock biomass as wet weight for the same area is 798 tonnes.

FISHERY RESOURCE

Benthic production in the affected area is probably lost as a food resource for fish since recolonizing hypoxia-tolerant worms are probably not available as food. This is because fish, such as young herring, avoid pulp mill effluent at concentrations found here (Wildish et al. 1976). Below the anoxic/hypoxic zone there are, however, indications of increased production, particularly of amphipods which are a good source of food for bottom feeding fish, and which may partly offset this loss.

The major fishery in the L'Etang is for the soft-shell clam, *Mya arenaria*, an intertidal, lamellibranch mollusc. An estimate of the yield based on an areal fraction of the total fishery district yield, as given by MacPhail (unpubl. data), is used in Table 2.

Over 30 major clam flats were surveyed by MacPhail in L'Etang, making a total clam flat area of 62 ha and yielding 6-13% of the total for New Brunswick. The flats here are not affected by paralytic shellfish poisoning and gave employment to 100 diggers during 6 winter months. The 1973 closure of part of the flats amounted to 39 ha, resulting in an estimated loss of 63% of the annual yield. The closure resulted from the presence of high fecal coliform counts due apparently to the inadequate treatment of sewage produced in the pulp mill.

Herring are caught in fixed weirs at the seaward end of L'Etang. Recently, three weirs have been worked (Table 3) in the L'Etang. A further ten weirs are worked nearby on Frye Island. Because of the very low catches in 1974 and fears expressed by the fishermen that pulp mill effluent caused herring to avoid their weirs, we undertook some laboratory avoidance experiments (Wildish et al. 1976) to test this hypothesis. The effective concentration of the avoidance response (2.5-2.9 mg/L as sodium lignosulfonate) is higher than concentrations found

Table 2. Annual soft-shell clam yield (wet weight plus shell in tonnes). Data recalculated from MacPhail (1949, unpublished data).

Year	1920	1925	1930	1935	1940	1945
L'Etang	121	157	219	341	344	115
New Brunswick	1010	1769	2037	2697	3012	1998

Table 3. Annual herring yield (wet weight in tonnes) for L'Etang estuary.

Weir	1969	1970	1971	1972	1973	1974	1975
Watts Head	56	37	14	53	22	0	32
Speed Bar	37	11	5	53	15	0	7
Finger Bay	17	8	4	-	-	1	28
Total	110	56	23	106	37	1	67

in the vicinity of the weirs (maximum of 1.5 mg/L). Further to this, herring yields of the whole of the fishery district followed the trend of the data in Table 3, with very low yields in 1974 suggesting that other factors were operating, rather than just the localized effects of the pulp mill effluent.

The small scallop fishery in lower L'Etang, fished by draggers and scuba divers and found seaward of the hypoxic zone, is periodically fished out, though a good set in 1975 was present. The divers complain that the scallops cannot be seen in the pulp mill effluent-stained water.

MULTIPLE-USE RESOURCE CONFLICT

One basis for determining whether serious resource-use conflict exists in the aquatic ecosystem is to attempt a balance of the economic effects for the whole watershed area. Of the positive effects, the pulp mill gives year-round employment to upwards of 175 persons. Ancillary workers such as woodsmen and truck operators also have increased employment opportunities. The negative effects of the presence of the mill include the loss of 63% of the major fishery, that is approximately 60 clam diggers for 6 man months of the year. Ancillary workers, notably local fish processing operators, may face reduced employment opportunities. Locally the ratio of fishermen to fish plant operators is 1:1. A further negative effect is the presence of atmospheric pollution, mainly H_2S gas released from upper L'Etang, which adversely affects local home owners and tourists who use the causeway highway to travel in the Maritimes from the eastern U.S.A. and Canada. The presence of pulp mill effluent also has some potential negative effects since it precludes use of L'Etang as a source of cooling water, such as would be required for a fish processing plant, or for aquaculture. The lower L'Etang was, before the mill became operational, suitable for saltwater salmonid culture in pens or raft oyster culture. The availability of fresh water also meant that the area was suitable for hatchery rearing of young salmonids.

We believe that the positive and negative effects approach equality and conclude that serious resource-use conflict does therefore exist.

CLEAN-UP ALTERNATIVES

The two major aims of a clean-up operation in L'Etang would be to remove the air pollution which results from microbial activity in upper L'Etang, and allow re-opening of the soft-shell clam fishery in lower L'Etang. The latter objective could be achieved by ensuring that domestic sewage, both from the pulp mill and local homes, is properly treated before discharge into the L'Etang. The mill installed a trickling filter system for domestic sewage in 1977, although, by June 1979, no fecal coliform counts in L'Etang water or clams had been made to check the efficacy of this treatment.

The other objective is more difficult to achieve but a number of alternative options are possible:

1. Replacement of the present causeway with a bridge, thus allowing free tidal exchange but no additional treatment of the effluent.

2. Diversion of pulp mill effluent from the L'Etang and release in a submarine diffuser to a better mixed body of water, or complete recycling or treatment of the effluent including removal of most BOD, solids, and color at the mill site.

3. No additional treatment, or diversion, of pulp mill effluent but provision of aeration in upper L'Etang.

The first alternative would not lead to a rapid improvement in the condition of upper L'Etang. This is because of the accumulation of fibres in the sediment and hence a long-term oxygen demand coupled with the poor flushing of the system. There is also a considerable retardation in the rate of pulp fibre degradation in anoxic sediments with a high sulfide concentration. This retardation is believed to be due to the toxicity of sulfide towards the anaerobic cellulolytic and sulfate-reducing bacteria (Parkes and Poole 1976). The initial result would be a spreading of the anoxic/hypoxic zone seawards.

Other alternatives have been examined with the aid of mathematical modelling techniques (Kristmanson et al. 1976). The three-box model (Fig. 4) has been used to determine an oxygen budget for upper L'Etang. Sources of oxygen supply were considered to be from clean fresh and sea water, from photosynthetic activity of algae, and atmospheric diffusion. Oxygen utilization was due to uptake of oxygen by bottom sediments, respiration by planktonic bacteria and algae, and oxygen lost to the system on passing across the causeway. This analysis clearly demonstrated the dominance of sediment oxygen demand in shallow systems of this kind. At normal chlorophyll a levels (10 mg/m^3) clean-up by option 2 would cause no immediate improvements because of the long-term sediment oxygen demand. The model has been used to calculate the total oxygen requirements (4,265-16,135 kg/d) of the upper L'Etang. This would be just balanced by one to four 150-HP aerators (assuming one transfers 4,536 kg O_2/d). Thus,

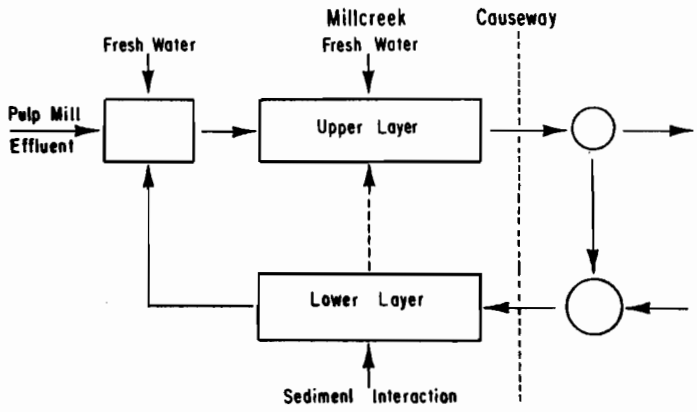

Fig. 4. Conceptual model of pulp mill effluent mixing in upper L'Etang.

provision for six such motors should result in the upper L'Etang remaining oxic and ensure maximum degradation of organic matter by aerobic, heterotrophic micro-organisms.

DISCUSSION

The importance of choosing the correct site to release pulp mill effluents, so that rapid dilution and assimilation of organic wastes occur, has been emphasized repeatedly. A pre-operational mixing study of L'Etang was commissioned by the pulp mill which indicated its poor flushing characteristics, but the assimilation efficiency of the receiving water was not determined. A 1974 review has demonstrated the unsatisfactory nature of some methods of estimating receiving water assimilation efficiency (Wilson and MacLeod 1974). Recent mathematical modelling of estuaries (Parker and Sibert 1973, Sibert and Parker 1973) has, however, included dynamic inputs from reaeration, planktonic bacterial respiration, and photosynthesis. Our own work in L'Etang has shown the dominance of sediment oxygen demand in determining the oxygen balances of shallow, as compared to its relative insignificance in deeper, West Coast estuaries. We believe that further research involving collaboration between hydrographers, biologists and microbiologists is required to further develop such simulation methods.

The L'Etang case history presented we believe has relevance to aquatic resource management strategies in general. Clearly, aquatic resource managers should have planning authority for much larger geographic areas, for example the whole Bay of Fundy and its watershed, so that resource-use conflicts can be solved at the planning stage. A framework for decision making should include a zoning scheme:

Conservation zone, where only non-polluting recreational uses would be permitted;

Multiple-use zone, where a given use must not reduce the actual or potential value of another use;

Single-use zone, where one use only is permitted, e.g., industrial or for aquaculture.

Then the demands for fishing, aquaculture, recreational, industrial or domestic water abstraction, waste disposal assimilation, seabed mining, or shipping channel uses can be decided with the minimum conflict between users.

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