NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

PAST AND ONGOING RESEARCH AT THE NATIONAL WATER RESEARCH INSTITUTE INTO THE IMPACTS OF THE MINING INDUSTRY ON AQUATIC ENVIRONMENTS

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NWRI Contribution No. 92-50

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MANAGEMENT PERSPECTIVE

This report summarizes the results of research conducted by scientists at the National Water Research Institute on the fate and effects of metals introduced into Canadian aquatic ecosystems by mining effluents and emissions. The reason for compiling this information at this time is the renewed interest in mine effluents and emissions that may arise from a focus on industrial sectors given priority under the Canadian Environmental Protection Act.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le présent rapport résume les résultats des recherches menées par des scientifiques de l'Institut national de recherche sur les eaux sur le devenir et les effects des métaux introduits dans les écosystèmes aquatiques au Canada par des effluents et des émissions découlant de l'exploitation minière. Le regain d'intérêt pour les émissions et les effluents miniers qui pourrait découler de l'importance accordée aux secteurs industriels prioritaires aux termes de la Loi sur la Proteciton de l'environnement est à l'origine de la collecte de ces données en ce moment.

ABSTRACT

The research staff of the National Water Research Institute have at various times been involved with the study of mining pollution at specific sites across Canada. These studies have dealt with the fate of metals introduced into aquatic ecosystems from various types of mining operations and by airborne input from base metal smelters. This report contains brief summaries of this research and provides a bibliography of the papers and reports published.

RÉSUMÉ

Les chercheurs de l'Institut national de recherche sur les eaux se sont intéressés, à différents moments, à l'étude de la pollution causée par l'exploitation minière à des endroits particuliers au Canada. Ces études ont porté sur le devenir des métaux introduits dans les écosystèmes aquatiques par différents types d'activités minières et par des rejets atmosphériques de fonderies de métaux communs. Le présent rapport comporte de courts résumés portant sur ces recherches et une bibliographie des documents et rapports publiés à ce sujet.

INTRODUCTION

Canada is one of the great metal producing nations of the world. Mining and metal ore benefication is one of Canada's most important industrial sectors. The mining industry involves extraction of metal ores from underground and open-pit mines with associated disposal of large quantities of waste rock and tailings, through various ore benefication processes such as roasting for gold ores and smelting for base metals. Over the years, however, many small local areas have been severely polluted by the wastes from this industry. Mining, unlike agriculture, does not use vast areas of land. It is a very focused activity at least in terms of the impact of waste rock and effluents. The same cannot be said for mining related emissions, particularly from the series of very large base metal smelters stretching across southern Canada from Trail, B.C. through Flin Flon and Thompson in Manitoba, to Sudbury in Ontario and Rouyn-Noranda in Quebec (Allan, 1974 and 1975).

In the late 1980's, the International Hydrology Program of UNESCO reviewed the global effects of the mining industry on temperate and tropical aquatic environments and examined available remedial measures. Two workshops brought together invited experts from various countries. The first meeting was in Bochum, Germany. The Canadian input dealt with the general impacts of mining and smelting in Canada (Allan, 1988). Other presentations dealt with acid mine drainage in Norway, abandoned lead mines in the United Kingdom, and the general physical, chemical and biological impacts of mine effluents and emissions (UNESCO, 1988). A major local theme at this first Workshop was the remedial program to deal with the huge open pit coal mines near Cologne, Germany. The second workshop was held in 1989 in Phuket, Thailand and was concerned primarily with impact of tin mining in that country (A.I.T., 1989). The Canadian contribution dealt specifically with gold mines and their aquatic impact in Canada (Allan and Mudroch, 1989). Other presentations dealt with copper mines in the U.S.A. and in Papua-New Guinea. Both of these Workshops provided overviews of the global scale and impacts from the mining and refining industry and made a series of recommendations on needed research, as well as examples of ongoing remediation and treatment processes for mine wastes.

The following provides a brief overview of past and current research at the National Water Research Institute concerning mining impacts in Canada. The Bibliography is comprehensive and more details are available in the individual papers.

HISTORIC GOLD MINING CONTAMINATION OF THE SHUBENACADIE RIVER HEADWATER LAKES, NOVA SCOTIA

A comprehensive study was carried out to evaluate the impacts from some of the earliest gold mines in Canada, located about 20 km north of Halifax, Nova Scotia (Mudroch and Clair, 1985 and 1986; Metcalfe and Mudroch, 1985). The mines operated near the shore of three Shubenacadie River headwater lakes from the 1880's until the 1930's. Mercury amalgamation, used for gold extraction, resulted in over one ton of Hg being also released in the mining area over the course of the operations. Arsenic associated with the gold ore was also released from crushed rocks and mill tailings which were stored near the lakes and exposed to weathering and erosion. A portion of the mill tailings had washed into the streams and lakes of the Shubenacadie River basin.

The results showed a relationship between concentrations of Au and Hg in lake bottom sediments suggesting that the lakes had received wastes from the Hg-amalgamation process. The downstream transport of As and Hg from the headwater lakes with their associated gold mining sites was quantified by analysis of water and suspended solids. Hg and As originating from the historic mining activities in the area were associated mainly with the inorganic fractions of the sediments. The metals were transported by resuspension of particles brought into the lakes by erosion of the mining wastes. However, a portion of the As found in sediments became mobilized and then was transported in the dissolved phase. Investigation of the bio-uptake of As and Hg by biota in lakes adjacent to the mining sites revealed accumulation of these metals by benthic invertebrates, which burrow in the lake bottom sediments, and a complex picture of species-specific uptake by clams. Nineteen of twenty-nine fish samples collected from the lakes near the center of the former gold mining site exceeded the Hg guideline of 0.5 ug/g recommended for human consumption. There was no significant accumulation of As in the fish. Recommendations were made for remedial action based on the results of this study, so as to prevent further pollution of the Shubenacadie River system.

THE EFFECTS OF GOLD MINING ACTIVITIES ON BACK BAY AND YELLOWKNIFE BAY, GREAT SLAVE LAKE, NORTHWEST TERRITORIES

In the vicinity of Yellowknife, Northwest Territories, gold mining activities have generated wastes with high concentrations of As and Zn. Some of the waste material was discharged into Yellowknife Bay of Great Slave Lake. Recently, Giant Yellowknife Mines have implemented a waste treatment process using alkaline chlorination accompanied by precipitation of the As and several other toxic metals, including Au, to improve the quality of the final wastes.

Research was conducted to identify the extent of the contamination originating from the gold mine wastes in Yellowknife Bay (Allan, 1979) and to assess the effectiveness of the effluent treatment process implemented by Giant in the early 1980's (Mudroch et al., 1989). Concentrations of As and Zn were determined in sediment cores collected at the depositional areas of Yellowknife Bay. Sedimentation rates were estimated using two radiometric approaches: the depth profiles of Cs-137 and Pb-210. The geochemical composition of the sediment cores indicated an input of similar material into sample areas over the past 50 years. Age profiles of the sediment constructed from the radionuclides measurements were used to determine the historical trends of As and Zn inputs to Yellowknife Bay. The historical record was in good agreement with the implemented remediation program and the usage patterns of both elements. It was estimated that at present sedimentation rates, it will take 20 years to cover the older As contaminated sediment by a 5-cm uncontaminated sediment layer, assuming a complete elimination of As input into Yellowknife Bay.

THE EFFECTS OF GOLD MINE EFFLUENTS ON THE QUALITY OF AQUATIC SEDIMENTS AND MACROPHYTES IN THE MOIRA RIVER BASIN, ONTARIO

The distribution of major and trace elements (Si, Al, Ca, Mg, K, Na, Fe, Mn, Ti, P, Ni, Co, Cu, Pb, Zn, Cr, Hg, Ag and As) in sediments collected from the Moira River and from Lake Ontario's Bay of Quinte was studied to evaluate the impact of past gold mining activities at Delora, Ontario (Mudroch and Capobianco, 1979 and 1980). Water and bottom sediments from 14 stations in the Moira River and the Bay of Quinte were analyzed.

The concentrations of major elements were generally similar in all samples, revealing inputs of geochemically similar material to the whole study area. However, significant enrichment of As, Cu, Co and Ni was observed in the sediments collected from Bend Bay and Moira Lake, downstream of Deloro, a center for smelting from around 1900 to 1961. The trace element concentrations in the sediments decreased with increasing distance from the old mining and smelting site. Concentration profiles of As, C., Ni and Cu in sediments collected from Moira Lake provided a historical record of mining and smelting in the basin. The decrease of Co, Ni and Cu concentrations near the top of the sediment profile corresponded to 1960, when the smelting and mining operation was shut down. However, a similar decrease in As concentrations was not observed at the top of cores. It was concluded that a continuous source of As existed from the waste pits at Deloro. The impact of mining and smelting activities extended approximately 40 to 45 km downstream from Deloro.

Submerged macrophytes collected downstream of Deloro had accumulated high concentrations of trace elements (169 ug/g Ni, 860 ug/g Co and 1200 ug/g As). However, emergent macrophytes accumulated these trace elements to a much lesser extent (Mudroch and Capobianco, 1979).

THE IMPACT OF GOLD MINE TAILINGS ON LARDER LAKE, ONTARIO

Research at Larder Lake, Ontario, began in the summer of 1990, in an attempt to establish the effects of underwater, gold-mine tailings disposal. Sediment samples from strategic sample sites were collected for geochemical, physicochemical, and biological analyses. The research objectives were to establish the degree of dispersion of tailings within the lake system and to examine the possibility that metals are mobilised from submerged tailings into the lake water. Metal concentrations were measured in bottom sediments, interstitial sediment-water, and the lake water. The organic content of the bottom sediments (0-1cm), was used to confirm the spatial extent of the mine tailings.

The highest concentrations of metals, both total and dissolved, were not found in the vicinity of the source but in the sedimentary basins of the lake. This implied that two mechanisms were mainly responsible for dispersion of the tailings and the metals present in interstitial waters: 1) fine-grained sediment transport; and 2) mobilization from the particulate to the dissolved phase.

THE EFFECTS ON AQUATIC ENVIRONMENTS OF BASE METAL MINING AND SMELTING AT FLIN FLON, MANITOBA

Beginning in 1976, the environmental impacts of mining and smelting were examined in lakes in the vicinity of the mining-smelting complex at Flin Flon, Manitoba (Jackson, 1978a and b; 1979; 1984; 1989; Jackson and Klaverkamp, 1991; Klaverkamp et al., 1989). These studies led to the concept for an economical but effective technology for removal of metals from effluents. With this approach, sewage introduced into settling ponds along with the effluent would give rise to algal blooms, resulting in immobilization and sedimentation of metals through the combined effect of sulfide production, bio-accumulation, and alkaline conditions caused by photosynthesis and sulfate reduction.

In the late 1980's, additional research in the Flin Flon area led to the discovery of relationships between metal speciation and the effects of metals on fish, plankton, and sedimentary micro-organisms, demonstrating that environmentally controlled metal speciation in bottom sediments is more important than total metal abundance in determining biological effects.

THE AQUATIC IMPACTS OF MINING AND SMELTING OPERATIONS AT SUDBURY, ONTARIO

The effects of mining and smelting on the geochemistry of lakes in the Sudbury region have been examined. Specifically, the influx of trace metals (Nriagu et al., 1982; Nriagu, 1983; Nriagu and Wong, 1983; Carignan and Nriagu, 1985, Carignan and Rosa, 1990) and sulfur (Nriagu and Coker, 1978; Nriagu and Harvey, 1978) into the lakes, the speciation and cycling of trace metals in contaminated lakes (Nriagu and Gaillard, 1984; Arafat and Nriagu, 1986) and the regeneration of metals from sediments in response to changes in the acidity of the lake water (Nriagu and Rao, 1984) were examined, as were the historical records of sulfur and metal pollution contained in the sediments and the response of sediments to reduced metal emissions in the Sudbury basin. The effects of metal contamination on certain enzymes and on bacterial activity in the sediments were also investigated (Nriagu and Soon, 1984).

Within the same mining region, evidence was found of impairment of the benthic communities in a large part of the Whalesback Channel at the mouth of the Spanish River. These effects appeared to be related to high metal levels originating from mining and smelting activities in the Sudbury basin, rather than pulp and paper effluents. A more extensive survey was conducted in 1990, which included measures of sediment toxicity, chemistry and physics plus benthic invertebrate community structure. Fifty three stations were sampled in the Whalesback and North Channels. Significant spatial differences in the benthic community inside and outside the Whalesback Channel are apparent. The community in the Whalesback is extremely depauperate with the lowest numbers of all the major taxonomic groups. The amphipod, Pontoporeia hoyi, oligochaetes (worms) and sphaerids (fingernail clams) were the major taxa.

In order to determine the factors responsible for the reduced community in the Whalesback Channel, relationships between sediment characteristics and the community groups were examined using multiple discriminant analysis. Eleven major ions, eight metals and five estimates of physical structure of the sediments were used. These were first examined separately and then the most important discriminating variables were examined jointly. Copper, nickel, zinc, % sand and % silt correctly predicted 70% (32 of 45) of the stations, and predicted another 9 sites to the next most similar group. These five variables thus are considered to be the most likely factors accounting for both the differences in the community and by implication for the reduced community in the Whalesback Channel. The impacted sites have the highest metal levels, therefore it is suspected that these high levels of metals are the primary cause of the impaired community in the Whalesback Channel and particularly the absence of Pontoporeia. To relate observations on the community structure with sediment quality rather than other factors, a sediment bioassay was performed. The effects on reproduction in Tubifex tubifex were used as a measure of sediment toxicity. The reduced benthic fauna, particularly the decrease in numbers of Pontoporeia and the impaired Tubifex reproduction, suggest that the high levels of zinc, nickel and copper, have had a significant detrimental impact on the fauna of the Whalesback Channel.

THE AQUATIC IMPACTS OF URANIUM MINE TAILINGS

Research was conducted on the abandoned uranium mine tailings in Langley Bay, Lake Athabasca (Waite et al., 1988; Platford and Joshi, 1988; Waite et al., 1989 and 1990; Joshi et al., 1989). From 1955 to 1964 the Gunnar Uranium Mine (Canada) produced approximately 5 million tonnes of waste material, large quantities of which subsequently washed into Langley Bay, a shallow bay opening onto Lake Athabasca. A comprehensive sediment, water and biota sampling program was carried out in 1983, 1984, and 1986 to study the dispersion of contaminants in the system and their uptake by biota. Analytical techniques were developed to measure several uranium-series radionuclides in biota by low-energy high-resolution gamma-ray spectrometry. A technique was also developed to estimate the radiation doses received by the biota.

Results indicated that the Ra contamination, though widespread in the Langley Bay sediments, comprised about 10% of the waste form released by the mill and that the contaminated sediments, and not water, provided most of the radiation dose to bottom feeders. The distribution of both radioactive and stable isopotes in fish organs was also studied. The radionuclides have reached high concentrations in the whitefish and macrophyte populations and, to a lesser extent, the pike population. Measurements of in situ sediments showed release rates of about 15 pCi Pb and 156 pCi Ra per sq. m. per hour, along with traces of other radionuclides. A toxicological examination of the two fish species revealed no significant differences between the contaminated and control populations.

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