EXECUTIVE SUMMARY

THE OCCURRENCE AND ACCUMULATION OF SELECTED HEAVY METALS IN FRESH WATER ECOSYSTEMS AFFECTED BY MINE AND INDUSTRIAL POLLUTED EFFLUENT

Final Report to the
Water Research Commission

by

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Background and motivation

The establishment of gold and coal mines in South Africa during the past century led to the creation of several industrial zones surrounding some of the major cities, which directly or indirectly supported the mining industry. Many of these were metal-processing factories. Processed and unprocessed effluents and seepage waters from both the mines and industries were discharged into streams and were found to contain variable amounts of heavy metals (Wittman and Förstner, 1976 a-d, 1977 a,b; Kempster *et al.*, 1980; Van der Merwe *et al.*, 1990). The pollution from the mining areas in particular led to severe acidification of a number of tributaries of the Vaal River (Harrison, 1958, 1961; Schoonbee and Van der Merwe, 1989). Water pumped from some mines varied in pH, affecting the solubility and the consequent deposition in stream and lake sediments as well as the uptake of certain metals by the flora and fauna of the affected water bodies. Estimates of the volume of water pumped from mines reaching the Elsburgspruit alone amounted to as much as 10 938 m^3/d (Wells, 1989), directly and/or indirectly through seepage and effluents from existing mine dumps.

The effect of mine effluent water containing metals on stream ecosystems has received considerable attention elsewhere in the world (Eyres and Pugh-Thomas, 1978; Salomons and Mook, 1980; Norris, 1986). From these investigations it is clear that certain metals may have a pronounced effect on the composition and presence of certain aquatic biota in lakes and rivers and that changes in the water pH and associated physical and chemical variables which affect this parameter may have a direct bearing on the toxicity of some metallic ions. Research by Abo-Rady (1980) and Mortimer (1985), to name but two researchers, showed that rooted aquatic macrophytes can be used as bio-indicators to evaluate the extent of metal pollution in aquatic ecosystems. It is also known that floating aquatic weeds can be employed in the removal of potentially toxic metals from polluted waters (Muramoto and Oki, 1983; Abbasi and Nipaney, 1985; Jain *et al.*, 1989). Some aquatic invertebrates were also found to be extremely sensitive to metal pollution (Bryan and Ward, 1965; Burrows and Whitton, 1983; Yasuno *et al.*, 1985). Aquatic vertebrates such as amphibia and fish have also been studied to determine the various routes of metal uptake via their food (Baudin, 1989), gills (Matthiesen and Brafield, 1977), through the drinking of water (Eddy, 1981) and simply through absorption via the skin. The release of toxic metals into the aquatic environment was shown to be detrimental to aquatic birds (Koeman *et al.*, 1972; Bull *et al.*, 1983).

In view of the increasing threat of metal-containing effluents to the water quality conditions of wetland areas on the Witwatersrand in particular and because of the planned and unplanned residential encroachment on these potential recreational areas and wildlife sanctuaries, the need was expressed by researchers at the Rand Afrikaans University to evaluate stream conditions and, where possible, to establish further research programmes on the problem of metal pollution of the aquatic environment on the Witwatersrand. The present series of investigations comprised the first phase of the envisaged project.

Objectives and Scope

The investigations conducted during 1988-1994 had the following objectives:

- **Selection of representative localities in lakes and rivers affected by metal-containing effluents and seepage water from mines and metal-processing industries.**
- **To determine the occurrence and concentration of selected metals in mine- and industry-polluted waters and sediments in catchments of the Natalspruit-Elsburgspruit, Blesbokspruit and in the headwaters of the Klip River in the Roodepoort municipal area.**
- **To establish metal concentrations in semi-aquatic and aquatic weeds in these mine and industrially polluted waters with observations on the ability of some plants to accumulate certain metals in their roots and/or shoots.**
- **To evaluate some benthic macro-invertebrate organisms as possible indicators of metal pollution in streams with special reference to the freshwater crab, *Potamonautes warreni*.**
- **To study the occurrence of metals in target organs and tissues of fish from mine- and industry-polluted aquatic habitats.** Nine indigenous and exotic fish species were considered for investigation from one or more of six different sampling localities on the East and West Rand. The report deals with two of the fish species concerned, namely the southern mouthbrooder *Pseudocrenilabrus philander* and the perch *Perca fluviatilis*.
- **To evaluate the clawed frog or platanna *Xenopis laevis* as a potential indicator of metal pollution in aquatic ecosystems.**
- **To compare concentrations in organs and tissues of some aquatic and semi-aquatic birds.** Attention was specifically given to the redknobbed coot, *Fulica cristata*, the sacred ibis *Threskiornis aethiopicus* and the reed cormorant, *Phalacrocorax africanus*.

The localities where the investigation took place were mainly in wetland regions on the East and West Rand, Gauteng, where the water of the polluted streams traverse expansive wetlands consisting of floating, emergent and submerged aquatic vegetation and where these plants play an important role in the recovery from pollution of the affected waters.

All the above objectives have largely been met.

Results and conclusions

Physical and chemical conditions of the water and sediments of the different localities

Research showed that the Germiston Lake had recovered substantially from mine and industrial pollution following the first steps taken to rehabilitate this lake in the early 1970's. Since then, there was a consistent decline in mineral loads of the lake water. However, metal concentrations in the lake sediments remained high and metals released into the water column appear to be gradual under the prevailing alkaline conditions. Transfer of metals through the biological component of the lake ecosystem takes place without any signs of metal toxicity to organisms studied. The lake water is discharged into the Elsburgspruit where serious metal pollution of its water by both the mines and industries took place. Seepage of water from industrial, ash and mine dumps further complicated the situation. Although considerable recovery from organic and inorganic pollution occurs in the Elsburgspruit and, despite the ability of the wetlands to assist in the recovery of the stream, considerable metal loads still pass through the dense mats of submerged and emergent weeds into the Natalspruit. A similar situation was found to exist in the main Blesbokspruit ecosystem where abnormal concentrations of Fe, Zn, Ni and at places Cu were found to exist. Water in both the Cowles and Nigel dams contained appreciable loads of most of the metals investigated, with Fe and Mn in particular, occurring in relatively high concentrations in the water and sediments of both dams. The Florida Lake showed the best recovery from past mine pollution in its catchment area.

Metal uptake by some emergent and floating aquatic weeds

The emergent aquatic weeds *Typha capensis*, *Arundo donax* and the water fern *Azolla filiculoides* were evaluated for their ability to retain metals in their organs and tissues and estimates were made on their ability to remove metals from polluted aquatic environments under local environmental conditions.

Metal uptake by the freshwater crab *Potamonautes warreni*

The concentrations in which the metals occurred in the Natalspruit and in the crab *P. warreni* followed similar trends. Indications are that the accumulation of the metals Pb, Cr and Fe, in particular, in the body of the crab may be regulated successfully in the metal-polluted waters of the Natalspruit and probably also in other similarly mine-polluted waters where it occurs.

Metal uptake by fish

Investigations showed that the southern mouthbrooder *Pseudocrenilabrus philander* appears to be reasonably tolerant to various concentrations of the metals Fe, Mn, Zn, Cu, Ni and Pb in the Spaarwater dam and that a possible mechanism exists whereby concentrations of these metals are bioregulated by this fish species. Bioregulation improves with the age and size of the fish.

Concentrations of Fe, Ni and Zn were the highest of all the metals analysed in the organs and tissues of the perch *Perca fluviatilis* and closely reflected the ratio of the metals in the lake sediments. Comparatively high concentrations of Pb in most organs were mainly related to surface runoff waters from the streets which enter the lake via various stormwater drains.

Metal uptake by the platanna *Xenopus laevis*

The concentration of metals by the frogs and tadpoles of *X. laevis* showed that certain organs and tissues were able to accumulate certain metals in much higher concentrations than others. This can be linked to sites of metal uptake, storage and excretion in the frogs and also the possibility that metal bioregulation may take place. Whole body metal analysis more closely reflects the metal loads present in the water and sediments. Metal analysis of the river frog *Rana angolensis* larvae yielded similar results as those for *X. laevis*.

Metal uptake by the redknobbed coot *Fulica cristata*, the reed cormorant *Phalacrocorax africanus* and sacred ibis *Threskiornis aethiopicus*

The concentrations of cadmium, copper, nickel and lead were determined in the liver, kidney, bone and blood of all three species which occurred in the Natalspruit wetlands. The investigation suggests that the dietary preferences of these birds and the metal contents of their diets as such, may be the two most important factors which determined the metal concentrations in the bodies of these birds.

Concentration ratios

The concentration ratios for the metals investigated suffer the same weaknesses and limitations as pointed out by Bein *et al.* (1994) for the radionuclide radium in mine polluted aquatic ecosystems. Both the CR_w (water) and CR_s (sediments) of the metals were calculated to evaluate the possible efficiency of particular aquatic flora and fauna to accumulate the metals under different environmental conditions. In the present study more importance is attached to the CR_s values as they represent the history of metal pollution at a given site whereas the CR_w values evaluate the concentrations of metals in streams at a specific period and which may differ considerably within hours depending on the periodic release of effluents from mines and industries during the day.

Water quality criteria for metals

A comparison of the maximum limits suggested for the protection of aquatic life in rivers and lakes (Kempster *et al.*,1980) with results obtained during the present survey showed that all the different ecosystems investigated were endangered by excessive loads of the seven metals under consideration, in both the water and sediments. This tendency is usually not reflected by the prevailing general physical and chemical conditions at the various sites.

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