

## CONTENTS

ACKNOWLEDGEMENTS .....	ii
EXECUTIVE SUMMARY .....	iv
Background and motivation .....	iv
Objectives and Scope .....	v
Results and conclusions .....	v
Physical and chemical conditions of the water and sediments of the different localities .....	v
Metal uptake by some emergent and floating aquatic weeds .....	vi
Metal uptake by the freshwater crab <i>Potamonautes warreni</i> .....	vi
Metal uptake by fish .....	vi
Metal uptake by the platanna <i>Xenopus laevis</i> .....	vii
Metal uptake by the redknobbed coot <i>Fulica cristata</i> , the reed cormorant <i>Phalacrocorax africanus</i> and sacred ibis <i>Threskiornis aethiopicus</i> .....	vii
Concentration ratios .....	vii
Water quality criteria for metals .....	vii
References .....	vii
<b>1. INTRODUCTION .....</b>	<b>1</b>
References .....	2
<b>2. DESCRIPTION OF SAMPLING AREAS .....</b>	<b>5</b>
2.1 The Germiston Lake .....	5
2.2 The Eisburgspruit at Germiston .....	5
2.4 The Blesbokspruit river system on the East Rand .....	8
2.5 The Florida Lake .....	12
References .....	12
<b>3. MATERIALS AND METHODS .....</b>	<b>15</b>
3.1 Collection of samples .....	15
3.2 Laboratory processing and analysis of material .....	15
3.3 Concentration Ratio (CR) .....	15
3.4 Statistical analysis of data .....	16
References .....	16
<b>4. PHYSICAL AND CHEMICAL CONDITIONS OF THE WATER AND SEDIMENTS AT THE VARIOUS SAMPLING LOCALITIES .....</b>	<b>17</b>

4.1 Conditions in Germiston Lake .....	17
4.2 Conditions in the Elsburgspruit .....	18
4.3 Conditions in the Natalspruit wetlands .....	19
4.4 Conditions in the Biesbokspruit catchment area .....	20
4.5 Conditions in the Florida Lake Roodepoort .....	21
4.6 Metal water quality criteria .....	22
4.6.1 Metal concentrations in the Germiston Lake .....	23
4.6.2 Metal concentrations in the Elsburgspruit and Natalspruit wetlands .....	23
4.6.3 Metal concentrations in the Biesbokspruit river system .....	23
4.6.4 Metal concentrations in the Florida Lake .....	24
References .....	24
5 METAL ACCUMULATION BY SOME OF THE NUMERICALLY DOMINANT AQUATIC AND SEMI-AQUATIC PLANTS .....	41
5.1 Introduction .....	41
5.2 Observations on metal uptake by algae .....	41
5.2.1 <i>Spirogyra</i> sp. ....	42
5.2.2 <i>Nitella</i> .....	42
5.3 Metal uptake by the moss <i>Bryum</i> .....	43
5.4 Metal uptake by some emergent aquatic vegetation .....	43
5.4.1 <i>Aisma plantago-aquatica</i> .....	43
5.4.2 <i>Polygonum lapathifolium</i> .....	44
5.4.3 <i>Schoenoplectus lacustris</i> .....	44
5.4.4 <i>Phragmites australis</i> .....	44
5.4.5 Observations on concentrations of the metals zinc, manganese, nickel and iron in the water, in the sediments and in two aquatic macrophytes, <i>Typha capensis</i> and <i>Arundo donax</i> in sections of the Elsburgspruit affected by goldmine and industrial effluents .....	45
5.4.6 <i>Typha capensis</i> in the Cowles and Nigel dams .....	48
5.5 Metal uptake by submerged aquatic weeds .....	49
5.5.1 <i>Lagerosiphon</i> species .....	49
5.5.2 <i>Potamogeton pectinatus</i> .....	49
5.6 Metal uptake by the rooted, floating leaved aquatic plant <i>Nymphaea cf</i> <i>spectabilis</i> .....	50
5.7 Metal uptake by two floating aquatic weeds .....	50
5.7.1 Metal uptake by the duckweed <i>Lemna gibba</i> .....	50

5.7.2 Bioaccumulation of metals by the water fern <i>Azolla filiculoides</i> in the Biesbokspruit wetland ecosystem affected by sewage, mine and industrial pollution.....	50
References.....	55
<b>6. BIO-ACCUMULATION OF METALS BY THE FRESHWATER CRAB <i>POTAMONAUTES WARRENI</i> FROM THE NATALSPRUIT WETLAND.....</b>	<b>89</b>
6.1 Introduction.....	89
6.2 Materials and methods.....	89
6.3 Results.....	91
6.3.1 Sediments.....	91
6.3.2 Crabs.....	92
References.....	96
<b>7. BIO-ACCUMULATION OF METALS BY THE SOUTHERN MOUTHBROODER <i>PSEUDOCRENILABRUS PHILANDER</i> AND THE EUROPEAN PERCH, <i>PERCA FLUVIATILIS</i> FROM TWO MINE POLLUTED WATERS IN THE GAUTENG PROVINCE.....</b>	<b>97</b>
7.1 Introduction.....	97
7.2 Bio-accumulation of metals by <i>Pseudocrenilabrus philander</i> in the Spaarwater dam.....	97
7.2.1 Materials and methods.....	96
7.2.3 Results.....	99
7.3 Metal concentrations in the organs and tissues of the European perch <i>Perca fluviatilis</i> from the mine polluted Florida Lake.....	100
7.3.1 Introduction.....	100
7.3.2 Materials and methods.....	101
7.3.3 Results.....	102
<b>8. METAL UPTAKE BY THE ADULTS, LARVAE AND JUVENILES OF THE PLATANNA <i>XENOPUS LAEVIS</i> FROM THE MINE- AND INDUSTRY-POLLUTED NATALSPRUIT WETLANDS.....</b>	<b>109</b>
8.1 Introduction.....	109
8.2 Materials and methods.....	109
8.3 Results.....	111
8.3.1 Metal concentrations in the organs and tissues of <i>X. laevis</i> frogs (Tables 8.2 and 8.3).....	111
8.3.2 Metal concentrations in the four developmental stages of <i>X. laevis</i> larvae and juveniles (Table 8.4).....	112
8.3.3 Metal concentrations in <i>Rana angolensis</i> stage 1 tadpoles.....	113

References	113
9 COMPARATIVE METAL CONCENTRATIONS IN THE ORGANS AND TISSUES OF THE REDKNOBBED COOT <i>FULICA CRISTATA</i> , REED CORMORANT <i>PHALACROCORAX AFRICANUS</i> AND SACRED IBIS <i>THRESKIORNIS AETHIOPICUS</i> FROM THE METAL-POLLUTED NATALSPRUIT WETLAND	115
9.1 Introduction	115
9.2 Description of the study area	117
9.3 Materials and methods	117
9.4 Results	118
9.4.1 Variations in organ and tissue metal concentrations in the three bird species	118
9.4.2 Statistical evaluation of the metal concentrations in the organs and tissues of the three bird species	119
References	121
10 GENERAL DISCUSSION	126
10.1 Physical and chemical conditions of the water and sediments	126
10.2 Bioaccumulation of metals by the aquatic and semi-aquatic vegetation	129
10.3 Metal uptake by the fresh water crab, <i>Potamonautes warreni</i>	130
10.4 Metal uptake by fish	131
10.5 Metal accumulation by the platanna <i>Xenopus laevis</i>	134
10.6 Metal uptake by aquatic and semi-aquatic birds	134
10.7 Construction of the metal transfer of a simplified food web for the sacred ibis <i>Threskiornis aethiopicus</i> from the Natalspruit wetland ecosystem	137
10.8 Concentration ratios	137
10.9 Water quality criteria for metals	138
10.10 Recommendations	138
References	139

## LIST OF TABLES

List of aquatic and semi-aquatic plants and animals which occur in the flood plains of the metal polluted streams of the Elsburgspruit, Natalspruit and Blesbokspruit catchment areas	xx
List of aquatic and semi-aquatic plants and animals which occur in the flood plains of the metal polluted streams of the Elsburgspruit, Natalspruit and Blesbokspruit catchment areas (Continued)	xxi

List of aquatic and semi-aquatic plants and animals which occur in the flood plains of the metal polluted streams of the Elsburgspruit, Natalspruit and Blesbokspruit catchment areas (Continued), .....	xxii
Table 4.1 Improvement of physical and chemical conditions in the water of Germiston Lake over a period of twenty years between 1969 and 1989 .....	26
Table 4.2 Summary of physical and chemical conditions of the water of Germiston Lake during 1989-1991. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980) .....	27
Table 4.3 Metal analysis of the bottom sediments at nine sampling localities in Germiston Lake with an indication of the organic contents of the sediments at each site. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980) .....	28
Table 4.4 Physical and chemical conditions of the water of the Elsburgspruit, Germiston, investigated over a period of ten successive seasons at seven localities during autumn 1987 - Winter 1989. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water (Kempster <i>et al.</i> 1980) .....	29
Table 4.5. Metal concentrations ( $\mu\text{g/g}$ ) in the organic component of bottom sediment material from six sampling localities on the Elsburgspruit during winter 1988 and the summer and winter of 1989. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980) .....	30
Table 4.6. Summary of water quality condition at six localities on the Natalspruit wetlands during the four seasons of 1989. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980) .....	31
Table 4.7. Metal concentrations ( $\bar{x} \pm \text{SD}$ ) ( $\mu\text{g/g}$ as dry mass) in the sediments as well as in its inorganic, organic and silt fractions of the soft bottom substrate based on composite samples from six localities in the Natalspruit wetlands during the 1989 investigation. Values for coefficient of variability in brackets. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980) .....	32
Table 4.8. Improvement of physical and chemical conditions in the water of the Blesbokspruit (summer and winter, 1989) and the Spaarwater Dam (summer, 1992). Values in bold indicate metal concentrations exceeding maximum limits laid down for the	

protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980).....	33
Table 4.9. Physical and chemical conditions of the Cowles and Nigel dams in the Blesbokspruit catchment area during the four seasons of 1989.....	34
Table 4.9 Continued.....	35
Table 4.10 Metal concentrations in the water ( $\mu\text{g/l}$ ) at nine selected localities of the Cowles and Nigel dams during the four seasons of 1989. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980).....	36
Table 4.11 Metal concentrations ( $\mu\text{g/g}$ ) in the sediments of the Cowles and Nigel Dams at nine selected localities in the Blesbokspruit catchment during the four seasons of 1989. 1. The Cowles dam. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980).....	37
Table 4.11 Continued. Metal concentrations ( $\mu\text{g/g}$ ) in the sediments of the Cowles and Nigel Dams at nine selected localities in the Blesbokspruit catchment during the four seasons of 1989. 2. The Nigel dam. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980).....	38
Table 4.12. Physical and chemical analyses of the water of the Florida Lake during bimonthly sampling periods at 8 randomly selected localities between February 1990 and December 1991. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water (Kempster <i>et al.</i> 1980).....	39
Table 4.13 Concentration of selected metals in the water column and bottom sediments of the Florida Lake, Roodepoort, based on bimonthly samples taken at eight localities over a period of one year during 1990 - 1991. Values in bold indicate metal concentrations exceeding maximum limits laid down for the protection of aquatic life in river and dam water. (Kempster <i>et al.</i> 1980).....	40
Table 5.1 Preliminary findings on the ability of some of the numerically dominant aquatic and semi-aquatic plants in the catchment areas of the mine and industrially polluted Elsburgspruit-Natalspruit, Blesbokspruit and Klipriver systems.....	62
Table 5.2 Bimonthly mean metal concentration ( $\bar{x} \pm \text{SD}$ ) and concentration ratios for the water ( $\text{CR}_w$ , %) and sediments ( $\text{CR}_s$ , %) of <i>Spirogyra</i> sp. in the Florida Lake, Gauteng, during March 1990 - March 1991. Results expressed as $\mu\text{g/g}$ dry mass (sediments) or $\mu\text{g/l}$ (water).....	63
Table 5.2 Continued.....	64

Table 5.3 Mean metal concentrations ( $\mu\text{g/g}$ dry mass) in the wort <i>Nitelle</i> sp. and in the bottom sediments of Germiston Lake during the four seasons of 1989 with an indication of sediment metal concentration ratio (CR %)	65
Table 5.3 Continued	66
Table 5.4 Metal concentrations in <i>Eryum</i> sp. and the stream sediments (mg/g dry mass) at two localities in the Blesbokspruit during the summer and spring of 1989-1990	67
Table 5.5 Concentrations ( $\mu\text{g/g}$ dry mass) of metals in the organs of <i>Alisma plantago-aquatica</i> and stream sediments of the Blesbokspruit and their concentration ratios (CR) expressed as percentage of the sediment metal concentrations	68
Table 5.6 Mean concentrations ( $\bar{x} \pm \text{SD}$ ) ( $\mu\text{g/g}$ dry mass) metals in organs of <i>Polygonum lapathifolium</i> during the summer of 1988-1989 at four localities on the Blesbokspruit and their sediment concentration ratios (CR) expressed as percentage of the sediment metal concentration	69
Table 5.6 Continued	70
Table 5.7 Concentrations ( $\mu\text{g/g}$ dry mass) of metals in the organs of <i>Schoenoplectus lacustris</i> and stream sediments of the Blesbokspruit and their concentration ratios (CR) expressed as percentage of the sediment metal concentrations	71
Table 5.8A Bimonthly mean metal concentration ( $\mu\text{g/g}$ dry mass) ( $\bar{x} \pm \text{SD}$ ) of <i>Phragmites australis</i> in the Florida Lake, Gauteng, during March 1990 - March 1991	72
Table 5.8B Mean concentrations ( $\mu\text{g/g}$ dry mass) ( $\bar{x} \pm \text{SD}$ ) of metals in the organs of <i>Phragmites australis</i> at five localities on the Blesbokspruit and their concentration ratios (CR) expressed as percentage of the sediment metal concentration, during the summer growing season of 1989	73
Table 5.8B Continued	74
Table 5.9A Mean values for selected chemical and physical parameters reflecting conditions in the water of the Elsburgspruit (localities 1, 2 and 3) and on a tributary (locality 4) during the different seasons of 1988	75
Table 5.9B Metal concentrations in the water ( $\mu\text{g/l}$ ), the sediments ( $\mu\text{g/g}$ dry mass), <i>Typha capensis</i> and <i>Arundo donax</i> ( $\mu\text{g/g}$ dry mass) at four selected localities in the Elsburgspruit system under various pH environmental conditions, with an indication of changes in the percentage thereof at the different sampling localities	76
Table 5.10A Mean concentrations ( $\mu\text{g/g}$ dry mass) ( $\bar{x} \pm \text{SD}$ ) of metals in the organs of <i>Typha capensis</i> in the Cowles and Nigel dams, Blesbokspruit catchment during spring (1989)	77
Table 5.10A Continued	78

Table 5.10B Mean concentrations ( $\mu\text{g/g}$ dry mass) ( $\bar{x} \pm \text{SD}$ ) of metals in the organs of <i>Typha capensis</i> in nine localities on the Cowles and Nigel dams, Blesbokspruit catchment during spring (1989) .....	75
Table 5.10B Continued .....	80
Table 5.11 Bimonthly mean metal concentration ( $\bar{x} \pm \text{SD}$ ) ( $\mu\text{g/g}$ dry mass) and concentration ratios for the water ( $\text{CR}_w$ %) and sediments ( $\text{CR}_s$ %) of <i>Lagarosiphon</i> spp. in the Florida Lake, Gauteng, during March 1990 - March 1991 .....	81
Table 5.11 Continued .....	82
Table 5.12 Bimonthly mean metal concentration ( $\bar{x} \pm \text{SD}$ ) and concentration ratios for the water ( $\text{CR}_w$ %) and sediments ( $\text{CR}_s$ %) of <i>Potamogeton pectinatus</i> in the Florida Lake, Gauteng, during March 1990 - March 1991. Results expressed as $\mu\text{g/l}$ (water) and $\mu\text{g/g}$ dry mass (sediment) .....	83
Table 5.12 Continued .....	84
Table 5.13 Bimonthly mean metal concentrations ( $\bar{x} \pm \text{SD}$ ) ( $\mu\text{g/g}$ dry mass) of <i>Nymphaea cf. spectabilis</i> in the Florida Lake, Gauteng, during March 1990 - March 1991. Results expressed as $\mu\text{g/l}$ (water) and $\mu\text{g/g}$ dry mass (sediment) .....	85
Table 5.14 Metal concentrations in the tissues of <i>Lemna gibba</i> ( $\mu\text{g/g}$ dry mass) the stream sediments ( $\mu\text{g/g}$ ) and water ( $\mu\text{g/l}$ ) during the early summer of 1990 at two localities on the Cowles dam in the catchment of the Blesbokspruit with an indication of the metal concentration ratios for the sediments ( $\text{CR}_s$ %) and water ( $\text{CR}_w$ %) .....	86
Table 5.15 Values ( $\mu\text{g/g}$ dry mass) obtained for the different metals in <i>Azolla filiculoides</i> and the bottom sediments with concentration ratio (CR) values at the four different localities in the Blesbokspruit wetlands .....	87
Table 5.16 Estimated densities of <i>Azolla filiculoides</i> in t/ha expressed as dry mass with an indication of the quantities of the different metals accumulated by this plant at the four localities in the Blesbokspruit wetlands .....	88
Table 6.1 Bio-accumulation of metals ( $\bar{x} \pm \text{SE}$ ; $n = 10$ ) by <i>Potamoonautes warreni</i> compared with the metal concentrations ( $\bar{x} \pm \text{SE}$ ; $n = 10$ ) in the sediments at six localities in the Natalspruit wetland area polluted by mine, industrial and sewage effluents. CR = concentration ratio .....	96
Table 7.1 Metal concentrations in the water, sediments and <i>Pseudocrenilabrus philander</i> as well as the concentration ratios (CR) for the various metals in the fish and sediments in the Spaarwater pan. Results are based on dry mass values of the sediments and the whole-body dry mass analysis of the fish .....	106
Table 7.2 Analysis of selected metals in the water column ( $\mu\text{g/l}$ ) and sediments ( $\mu\text{g/g}$ dry mass) of the Florida Lake, Gauteng, South	

Africa, based on a bimonthly sampling programme at eight localities during 1990-1991 (n=56, $\bar{X} \pm SD$ ) .....	107
Table 7.3 Metal concentrations ( $\mu\text{g/g}$ dry mass, $\bar{x} \pm SD$ ) in the organs and tissues of the perch <i>Perca fluviatilis</i> as well as the respective calculated concentration ratios for the water column (CRw%) and lake sediments (CRs %) in the Florida Lake, Gauteng, South Africa .....	108
Table 8.1 Tadpole and juvenile developmental stages in the life cycle of the platanna, <i>X. laevis</i> according to Schoonbee <i>et al.</i> (1992) and Nieuwkoop and Faber (1956).....	111
Table 8.2 Mean metal concentration ( $\mu\text{g/g}$ dry mass) in organs and tissues of the platanna <i>Xenopus laevis</i> (n = 9).....	111
Table 8.3 Wet and dry mass, moisture content and mean concentrations of seven metals (as $\mu\text{g/g}$ dry mass) in whole bodies of the platanna <i>Xenopus laevis</i> (n = 4).....	112
Table 8.4 Mean metal concentrations ( $\mu\text{g/g}$ dry mass) in four developmental stages of <i>Xenopus laevis</i> larvae and juveniles from the mine- and industry-polluted Natalspruit wetland ecosystem. ....	113
Table 8.5 Mean metal concentrations (expressed as $\mu\text{g/g}$ dry mass) in stage 1 <i>Rana angolensis</i> larvae from the metal-polluted Natalspruit wetland ecosystem (n = 136).....	113
Table 9.1 Metal concentrations in the kidney of three bird species from the natalspruit wetlands. Results are expressed as sample size, $\bar{x} \pm SD$ ( $\mu\text{g/g}$ dry mass), coefficient of variation (CV%) and range (minimum - maximum).....	124
Table 9.2 Metal concentrations in the bone tissue of three bird species from the Natalspruit wetlands. Results are expressed as sample size, $\bar{x} \pm SD$ ( $\mu\text{g/g}$ dry mass), coefficient of variation (CV%) and range (minimum - maximum) .....	124
Table 9.3 Metal concentrations in the blood of three bird species from the Natalspruit wetlands. Results are expressed as sample size, $\bar{x} \pm SD$ ( $\mu\text{g/g}$ dry mass), coefficient of variation (CV%) and range (minimum - maximum) .....	125
Table 9.4 Metal concentrations in the liver of three bird species from the Natalspruit wetlands. Results are expressed as sample size, $\bar{x} \pm SD$ ( $\mu\text{g/g}$ dry mass), coefficient of variation (CD%) and range (minimum - maximum) .....	125
Table 9.5 Analysis of variance (H) and multiple comparisons analysis of the concentrations of four metals in organs and tissues of three bird species from a mine-polluted wetland. Mean metal concentrations within a row sharing a common superscript are not significantly different at the $p < 0.05$ level of significance.....	126