If the mean tetraethyl lead content per litre fuel is 0.54 m g⁻¹, using leaded fuel are allowed there, but not on the other two dams. The high lead content in the Potchefstroom Dam is that powerboats of 1 m (Fieser and Fieser, 1963), it can be calculated that the combustion of 1 l of fuel releases about 480 000 µg of lead into the water.

**TABLE 3**

<table>
<thead>
<tr>
<th>Dam</th>
<th>Locality</th>
<th>pH</th>
<th>EC (µS·cm⁻¹)</th>
<th>CEC (cmol·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klerkskraal</td>
<td>26 13°745'S 7.67 510.0 42.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27 09°063'E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boskop</td>
<td>26 31°531'S 7.49 2720.0 42.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27 07°348'E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potchefstroom</td>
<td>26 39°714'S 7.62 1490.2 39.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27 05°328'E</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig 4a Cd in Sediment profiles**

**Fig 4b Cu in Sediment profiles**

Apart from mining activities, a possible explanation for the high lead content in the Potchefstroom Dam is that powerboats using leaded fuel are allowed there, but not on the other two dams. If the mean tetraethyl lead content per litre fuel is 0.54 m g⁻¹ (Fieser and Fieser, 1963), it can be calculated that the combustion of 1 l of fuel releases about 480 000 µg of lead into the water.

Tetraethyl lead is insoluble in water and could accumulate in the sediment. This lead source may enter the food chain for detritus feeders like mudfish (see below).

Copper concentrations in the different sediment fractions decreased sharply from the largest mesh sizes to the smaller sizes, except for the clay fractions which were nearly three times higher compared to the 53 µm fraction (mean concentration 13.5 µg g⁻¹ with a standard deviation of 3.6). The three profiles investigated for Cu (Fig.4b) for the three dams had nearly the same Cu levels for each dam, with a range between 14 µg g⁻¹ and 23 µg g⁻¹ with a mean of 19 µg g⁻¹. Copper levels for the six sediment fractions had a mean value of 24 µg g⁻¹ dried sediment. This value is only about 14% compared to the Cu concentrations obtained by Wittmann and Förstner (1977a) on eight sampling sites in sediments draining the West Wits Goldfields area. These results indicate that large amounts of highly polluted localities investigated by Wittmann and Förstner (1977a) and the recent survey of the three Mooi River Dams in this study. In comparison with the Kromme Rijn River sediment in The Netherlands, 93.3 µg g⁻¹ copper was found (Buyckx et al., 2002).

On average, the Zn concentrations for Boskop Dam sediment fractions were significantly higher compared to the other two dams (Fig.2d). This applied to five of the six sediment fractions analysed (range for the six fractions: 11.5 to 59.3 µg g⁻¹). From the eight sediment localities investigated by Wittmann and Förstner, 1977a, the zinc concentrations at the drainage sites near the West Wits Goldfields were higher (range: 56 µg g⁻¹ to 6 440 µg g⁻¹) compared to the analysis in this study. By comparison, the Po River (Viganò et al., 2003) and Kromme Rijn River (Buyckx et al., 2002) Zn sediment concentrations were on average 244 µg g⁻¹ and 836.8 µg g⁻¹ respectively.

Generally, the clay fractions from the three dams in the Mooi River catchment had, on average, the highest metal concentrations when compared to the other five sediment types investigated. This is in accord with the knowledge that clays, including pelitic sediments have high adsorption values for metals (Yoshida et al., 1993). Furthermore, the four metals investigated were greatly reduced in their sediment concentration levels compared to the high levels found by the earlier investigators (Wittmann and Förstner, 1977a) near the respective slime dams at the West Wits Goldfields. These mines were recently renamed as Anglo Gold.

For the metal concentrations in sediment profiles, the highest Cd concentration (429 ±37 µg g⁻¹) was found in Boskop Dam (Fig. 4a), and the highest copper levels in Klerkskraal Dam (Fig.4b). These differences were statistically significant. No significant differences in the Zn concentrations (23.0±2.2 µg g⁻¹) between the sediment profiles for the three dams could be found.

**Cation exchange capacity (CEC) of dam sediment (Table 3)**

Of the 27 sediment samples collected, three samples from Boskop Dam and three samples from Potchefstroom Dam were obtained from sandy areas near the dam inflow. The sand samples had CEC values (not included in Table 3) of less than 20 centimol·kg⁻¹ dried sediment, compared to the mean value of 42 centimol·kg⁻¹ dried sediment for the other samples obtained from sediment samples with mesh sizes below 250 µm.
The most important chemical processes affecting the behaviour and availability of heavy metals in sediments are the adsorption of heavy metals from solution to the solid phase. Of the three mechanisms used in adsorption, namely CEC, organic complexation and co-precipitation, CEC is the most important. The adsorption of cadmium, lead, copper and zinc (existing as cations in the sediment solution) onto the negatively charged solid phase of the sediment colloids depends on the density of negative charges on the surface of the sediment colloids. High CEC values indicate a high capacity of sediments to adsorb metals. In this regard the CEC values found for sediments from the three dams indicated that there was a mean exchange capacity of 41.5 ±7.3 centimol kg⁻¹ (Table 3). This is about 60% compared to the highest value of 60 centimol kg⁻¹ reported for mineral soils (Yoshida et al., 1993). This value, however, is much less than the 200 centimol kg⁻¹ measured for agricultural soils (Alloway, 1990). For the three dams, the high calcium and magnesium levels (Table 2) found in the sediment could, as cations, play a major part in promoting cationic exchange capacity in dam sediment.

### Metal analysis of fish tissues

No significant concentration differences were found when the fish tissues, sampled in the four seasons, were analysed and compared for cadmium. This also applied for copper and zinc. Lead was not seasonally analysed.

The highest Pb (range 3.4 to 7.9 µg g⁻¹, Fig. 3b) and Zn (range 119.0 to 188.0 µg g⁻¹; Fig. 3d) concentrations for all three dams were found in the gills of L. capensis. Compared to all the other seven tissues, liver tissue (106 µg g⁻¹ to 178 µg g⁻¹) had the highest Cu levels. In a 17 month study (Nussey et al., 2000) on L. umbratus at the upper reaches of the Olifants River (Witbank Dam), the Pb in dried tissues were 14.0, 6.9, 8.0 and 5.6 µg g⁻¹ for gills, liver muscle and skin respectively, while the sediment averaged 22.9 µg g⁻¹. The Pb concentrations in tissues were significantly higher compared with Mooi River Pb levels in L. capensis. The combined six sediment fractions (Fig 2b), if added, gave Pb concentrations not significantly different for the Pb values found in the Olifants River. Although the pH of the water at Witbank Dam was not measured, it is known (Nussey, 1998) that relatively low water Pb values (range 6.10 to 8.61) and soft water are encountered in the upper reaches of the Olifants River (Steenkool Spruit), compared to the high Pb values (range 8.14 to 8.76) and hard water (230 mg L⁻¹, as CaCO₃) found in Mooi River water (Van Aardt and Booyens, 2004). This difference in pH and hard water could, in part, explain why the Pb levels in L. capensis were much lower in the Mooi River catchment. Precipitation or chelation of Pb to the sediment in hard water with pH above eight has been demonstrated in the Mooi River catchment. Precipitation or chelation of Pb to the sediment in hard water with pH above eight has been demonstrated in the Mooi River catchment.

<table>
<thead>
<tr>
<th>Sediment fractions (µm)</th>
<th>Pb</th>
<th>Cd</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
</tr>
<tr>
<td>500</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
</tr>
<tr>
<td>250</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
</tr>
<tr>
<td>106</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
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<tr>
<td>53</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
</tr>
<tr>
<td>clay fraction</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
<td>K, B, P</td>
</tr>
</tbody>
</table>

(Wittmann and Förstner, 1977a)

It is interesting to note that the higher lead concentrations found in Potchefstroom Dam sediment when compared with the other two dams were also reflected in fish tissue sampled from Potchefstroom Dam. Significantly higher concentrations of lead were found in gill tissue, gonads and blood compared with the other tissues (Fig 3b). From this finding it can be stated that the mudfish, L. capensis, a detritus feeder living from the muddy substrate in Potchefstroom Dam, acquires the high tissue lead through uptake by the gills and also by sucking in and digesting the relatively high lead load in mud sediment. The lead originates from alkyl lead after fuel combustion when lead bromides are formed. In a soil environment these compounds change chemically to insoluble Pb carbonates, oxycarbonates and oxides (Davies, 1990).

Lead concentrations in fish tissue obtained from mudfish (L. umbratus) from other catchment areas in South Africa (Heath and Claassen, 1999) were significantly higher (range: 14 µg g⁻¹ to 454 µg g⁻¹). The analyses in this study has shown lower lead levels (range: 1.3 to 9.1 µg g⁻¹; mean: 7.9 µg g⁻¹) when compared with Labeo roscus (range: 3.4 µg g⁻¹ to 879.1 µg g⁻¹; mean: 497 µg g⁻¹) (Heath and Claassen, 1999).

Analysis of metals with low vapour pressures such as lead and cadmium, can be more accurately analysed using electro-thermal AAS (Fridberg et al., 1979). In optimal conditions, sensitivity (Willard et al., 1974) can be improved hundredfold with electro-thermal AAS. This, in part, could explain the different analytical results from investigators analysing the same Cd and Pb samples with or without electro-thermal AAS analytic methods (Ure 1990; Fridberg et al., 1979; Wittmann and Förstner, 1977a).

An important conclusion from this study is that higher values prescribed by national and international standards (Wittmann and Förstner, 1977b) for metal concentrations were found in Boskop Dam sediments. This could be ascribed to mining activities in the vicinity of Boskop Dam, especially when considering that Klerkskraal Dam, acting as a control dam, had significantly lower metal concentrations. The high levels of heavy metals found in the sediments in the close vicinity of the West Wits Goldfields (Anglo Gold) in the late seventies by Wittmann and Förstner (1977a or b), and similar to this study regarding sediments and fish tissue in the Mooi River dams should be evaluated jointly. In this regard it is fortunate that the high pH, high alkalinity and hardness of the dolomitic water in the Mooi River prohibits the dissolution

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ISSN 0378-4738 – Water SA Vol. 30 No. 2 April 2004 217
of these potentially toxic metal compounds from the dam sediment where they are deposited. However, a drastic change of the physical properties of the water such as lowering of the pH below 6.5, together with a physical disturbance of not only dam sediment, but sediments in the Mooi River, could potentially release large amounts of toxic metals from the sediment colloids’ surface into the water column.

Acknowledgements

We wish to thank the Research Focus Area: Environmental Sciences and Management, for financial assistance, and the School of Environmental Sciences and Development, Potchefstroom University for CHE, Potchefstroom, South Africa, for providing the research facilities

References


NUSSUY G (1998) Metal Ecotoxicology of the Upper Olifants River at Selected Localities and the Effect of Copper and Zinc on Fish Blood Physiology. Thesis: Ph.D, Faculty of Natural Sciences, Rand Afrikaans University, Johannesburg, South Africa.


