

## **EXECUTIVE SUMMARY**

### **HISTORICAL BACKGROUND TO THE STUDY**

Screening surveys of radioactivity in the Mooi River catchment were conducted by the Institute of Water Quality Studies (IWQS) of the Department of Water Affairs and Forestry (DWAf) in 1995 and 1996 (DWAf 1995, 1996).

Elevated levels of the radionuclides of uranium and radium were detected in streams close to gold mining activities. Many radionuclides of possible concern were not measured, and, in view of the lack of information concerning variability of radionuclide concentrations in the river systems, it was proposed that a full study of the water resources be completed.

In 1997, a monitoring study of radioactivity in the surface- and groundwaters of the Mooi River catchment was conducted, in collaboration with a wide group of interested parties (DWAf, 1999). The study did not consider radioactivity in sediments.

The great majority of sampling sites in the catchment showed low levels of water-borne radionuclides, with a total drinking water dose below 0.1 mSv/year. The sites that showed significant concentrations of water-borne radionuclides were associated with discharge of mine water into the river system. Levels of radioactivity in the water column dropped off with distance from the mining operations, with a greater attenuation of water-borne radioactivity downstream of the mining operations than could be explained by dilution by river water alone.

It was hypothesised that some of the radionuclides were preferentially accumulating in the sediments in the Mooi River system.

### **MOTIVATION FOR THE STUDY**

The sediment phase of aquatic systems is largely unexplored in South Africa. In 1997, the CSIR, in collaboration with IWQS, embarked on a study of the factors influencing metal accumulation in sediments.

From the results of the DWAf and CSIR studies, it was hypothesised that the sediments of the Mooi River (and, therefore, other rivers in South Africa) are accumulating radionuclides from the water column.

The sediment phase is in intimate contact with the water column phase of the aquatic ecosystem. Metals in the aquatic ecosystem are in quasi-equilibrium between sediment and water column phases. This means that the distribution of metals between the sediment and water column phases is governed both by thermodynamics (the relative stability of the metal in each phase), and by kinetics (the rate at which the metals move between phases).

Under typical conditions, the sediment phase binds metals more strongly than the aqueous phase. This means that there is a continuous migration of metal from the aqueous to the

sediment phase. Thus, under historical and currently acceptable water management criteria, the water column toxic metal concentrations might be maintained at a safe level for the preservation of health of the water users, while the sediments become enriched with respect to the toxic metals.

Radionuclides may not be highly concentrated in the aqueous column, but they may be absorbed preferentially into the sediment, where they can become available to the water column under scenarios of disturbance.

It is important to know under which conditions the radionuclides may be remobilised, and if this occurs, how much of a risk to human health it may be.

It is envisaged that the current cursory investigation of the radioactivity of the sediments will add to the data required to fully understand the fate of radionuclides in the Mooi River and the risk these radionuclides pose.

## **DESCRIPTION OF THE STUDY AREA**

The region of interest lies South-West of Johannesburg.

The watershed of the Mooi River, encompassing that of the Mooi Rivier Loop and Wonderfontein Spruit, has received the impacts from mining operations for more than sixty years.

The river of interest is the stream called the Mooi Rivier Loop and Wonderfontein Spruit. This stream provides input into the Boskop Dam, from which the town of Potchefstroom derives its drinking water.

The study required a control site, which needed to be near the river of interest, but which was believed to be unimpacted by mining operations. Klerkskraal Dam was chosen, because the dam is fed from a stream emanating from a dolomite eye. There are no mining operations upstream of Klerkskraal Dam, and any contamination the dam experienced would have arrived by an atmospheric route. Contaminants from this potential source were considered to be small in magnitude by comparison to water-borne contaminants arising from the mining operations in the watershed.

Study sites were chosen to be impoundments, where water flow is low, and where there is an opportunity for organic matter to accumulate. Radionuclides of interest may be immobilised under these conditions.

Sites are described in Table E.1.

**Table E.1 Sites in study area**

Site No.	Site Name	Site Code	Site Description
1	Tudor Dam	(TUD1)	Located at the top of the catchment - dry, and had a crust which resembled a mixture of gypsum and ferric oxide, mixed with organic detritus originating from the reed beds that have cycled through growth and burning for some time.
2	Attenuation Dam	(ATT2)	Lies downstream of Tudor Dam.
3	Donaldson Dam	(DON3)	A recreational dam, where fish are caught for human consumption.
4	Harry's Dam	(HAR5)	Dam directly upstream of Abe Bailey Dam, and Carletonville.
5	Abe Bailey Dam	(ABE4)	Slightly raised above the level of the river of interest, and is only expected to receive input during flood events.
6	The Sluice	(SLU6)	A site where mine water is directly input through a concrete channel into the river.
7	Andre Coetzee's Dam	(A-C7)	Directly downstream of the sluice, and is currently a recreational dam used for fishing and boating. The sediments of this dam are unusually reducing, with copious quantities of methane generation in evidence.
8	Muiskraal	MUIS10)	On the river, next to a bridge.
9	Boskop Dam	(BOS8)	Downstream of Muiskraal. Main water source for Potchefstroom.
10	Klerkskraal Dam	(KKD9)	Below a dolomitic eye. Upstream of Boskop Dam. Not influenced by Wonderfontein spruit pollution. Pollution source is not from large mining operations. This site was chosen as the reference site for the catchment.

## AIMS OF THE STUDY

The main aim of the present study was to establish if there was a potential threat posed by radionuclides to humans in the Mooi River catchment.

This aim led to the following research questions:

- Have radionuclides (e.g. Uranium) preferentially accumulated in river sediments?
- Can the radionuclides be remobilised under realistic environmental conditions?
- Under what conditions might they be remobilised (i.e. in what form are the radionuclides in the sediments)?

## APPROACH IN THE STUDY

The approach adopted in the study involved the following

- Determination of the concentrations of selected radionuclides ( $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{234}\text{U}$ ,  $^{223}\text{Ra}$ ,  $^{232}\text{Th}$ ,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$ ) in the sediments of the Mooi River (Wonderfonteinspruit and Mooi Rivier Loop) between Krugersdorp and Potchefstroom in the Witwatersrand gold-mining region of South Africa by field gamma spectrometry and by chemical analysis of the sediments.
- Determination of the conditions under which the radionuclides may be remobilised by sequential chemical extraction.
- Determination of the risks represented by potential remobilisation of possible stored radionuclides to man in a Tier 1 risk assessment.

## RISK METHODOLOGY EMPLOYED IN THE PRESENT STUDY

### Tiers of Risk Assessment for Contaminated Sediments

Sediment Ecological Risk Assessments (SERA's) should be conducted in a tiered or phased approach (Ingersoll *et al*, 1997, USEPA 1992b). An initial analysis (Tier 1) is conducted, using very conservative assumptions about exposure and effects, then a decision is made on how to proceed.

Typically, this initial screening-level risk assessment is conducted using available data and conservative assumptions about effects, or existing effects-based benchmark values or guidelines.

The present study, entitled "Tier 1 Risk Assessment Of Radionuclides In Selected Sediments Of The Mooi River" is explicitly a first-tier risk assessment, in which concentrations of environmental contaminants are compared to benchmarks, such as legislative action levels.

Environmental exposures are viewed as concentrations of parent radionuclides (U-238) measured by direct analysis and by inference from gamma spectroscopy.

Traditional radiological risk calculations involve analysis of scenarios of exposures and uptake, and thus constitute investigations at orders of Tier 2 or higher.

In tiers subsequent to the Tier 1 assessment, additional data may be collected that better define the risk of adverse effects. At each tier, a pass/fail decision is made whether to proceed to advanced tiers, and if so, which methods to employ in the subsequent tiers.

## Legislative Framework Guiding the Risk Assessment

### *National Nuclear Regulator Act*

In 1999, the National Nuclear Regulator Act (Act 47 of 1999) was gazetted. Section 36 of this act called for the development of standards for handling nuclear material as follows:

36. (1) The Minister must, on the recommendation of the board, make regulations regarding safety standards and regulatory practices.  
 (2) Before any regulations are made in terms of subsection (1), the Minister must, by notice in the *Gazette*, invite the public to comment on the proposed regulations and consider that comment.

### *Exclusions from the National Nuclear Regulator Act*

The exclusion level for radioactive concentration of any single radionuclide in a solid is currently 0.2 Bq/g.

This implies that if a solid material is associated with a human activity, and it has a radiation intensity of below 0.2 Bq/g per radionuclide, the activity is excluded from the Act. Above this exclusion level, it is required that a site-specific hazard assessment is to be performed.

### Tier 1 Risk Assessment in the Current Study

The current study uses the Tier 1 Risk Assessment method, with the risk being calculated by the Quotient method, in which the following ratio is calculated:

$$\text{RiskQuotient} = \frac{\text{Radioactive Concentration of Radionuclide}}{\text{Regulatory Exclusion Limit for Radionuclide}}$$

$$= \frac{\text{Radioactive Concentration of Radionuclide}}{0.2\text{Bq/g}}$$

## RISK ASSESSMENT

### Scenarios Modelled

The following chemical scenarios were considered.

- Resuspension of sediment into water of existing quality (as measured on the sampling trip). This is also equivalent to infiltration of overlying water of current quality into sediment by hydraulic head.
- Infiltration of surface water into sediment of quality represented by extremes of pH historically observed.
- Movement of the redox profile due to bioturbation or input/decrease of carbon.
- Significant elevation of redox potential by exposure to atmospheric oxygen.

These scenarios were all superimposed on the following calculated Eh-pH diagrams.

### Scenario Evaluation

#### *Scenarios Simulated by Chemical Equilibrium Modelling*

In all scenarios considered, there was the possibility of uranium being solubilised by environmental processes that fall within the bounds of reason. The scenario under which uranium is least likely to be mobilised is that of strongly reducing environmental conditions.

The scenario under which uranium is most likely to be solubilised is that of high oxidation potential and low- to intermediate pH. This scenario is likely if the sediments of an impoundment are exposed by drainage, or by dredging operations. Increased oxidation potential automatically enhances the potential for low pH conditions.

Thorium is expected to remain in the chemically inert fraction, and transport of thorium is most likely to be as a particulate with comparatively limited migration potential.

#### *Scenarios Simulated by Sequential Chemical Extraction*

In all of the sediments tested, uranium was mobilised by reaction with weak acid. Uranium was also mobilised by increase in oxidation potential, and by decrease in oxidation potential.

Thorium was not expected to be extracted significantly in the extraction procedures. There is evidence that thorium remained in the inert fraction of the sediments.

### *Scenarios Observed in Field Site Assessments*

There is evidence that uranium is transported in a soluble form along the length of the Wonderfontein Spruit and Mooi Rivier Loop. Uranium is input at defined sources, e.g. Tudor Dam and the Sluice, and it reports at localities downstream where one would not expect particulates to reach (i.e. they may be filtered by reed beds).

There is evidence that uranium is transported from the Sluice into Andre Coetzee's dam, where it is currently largely immobilised by the low oxidation potential in the dam.

## CONCLUSIONS

The main aim of the study was to determine possible risks to humans of radionuclides in the sediments of the Mooi River catchment.

The study answered the research questions as follows:

- Radionuclides have been found to accumulate in the sediments of the Mooi River catchment.
- The main radionuclide of interest, being uranium, seems to be adsorbed to the environmental phases: carbonate, iron and manganese oxyhydroxides, and organics (with a slight possibility of being included in sulphide components).
- Uranium may be remobilised into the water column by perturbation of TDS, pH or oxidation potential.

The criterion for the Tier 1 Risk Assessment was the 200 Bq/kg limit stipulated by the Nuclear Energy Act of 1993 for unconditional deregulation of sites.

The sites Tudor Dam (TUD1), Attenuation Dam (ATT2), Donaldson Dam (DON3), Harry's Dam (HAR5), Sluice (SLU6) and Andre Coetzee's Dam (A-C7) had U-238 levels higher than the Nuclear Energy Act (1993) stipulation, and, therefore, had a positive Tier 1 Risk Quotient.

The sites are ranked in order of increasing Tier 1 risk as follows:

Highest Tier 1 Risk Quotient	Tudor Dam
	Andre Coetzee's Dam
	Sluice
	Attenuation Dam
	Donaldson Dam
	Harry's Dam
Lowest Tier 1 Risk Quotient	

## RECOMMENDATIONS

The objective of a Tier I Risk Assessment is to determine whether or not more detailed investigations are required.

Thus, it is recommended that a more detailed exposure assessment be conducted for the following impoundments, in the order of risk from highest to lowest, as indicated above. A Tier II risk assessment would involve determining sources of radionuclides and pathways of radionuclides to man.

The chemical and hydro-dynamics of the catchment should be monitored over a year, in order to better model contaminant transport in the catchment.

A theoretical model of Potchefstroom's water treatment works should be constructed, to assess the ability of Potchefstroom to treat possible radionuclides flushing into the water source.

Considering the proximity of Andre Coetzee's Dam to the Boskop Dam, it is recommended that the extent of uranium deposition in Andre Coetzee's dam be assayed.

Uranium is immobilised in this dam by environmental processes that buffer the pH at a high level and the redox at a low level. The extent of this buffering capacity should be known in order to evaluate the risks of re-release of U-238 during possible dredging operations.