NATIONAL RADIOACTIVITY MONITORING PROGRAMME (NRMP)

Report on the Radioactivity Monitoring Programme in the Klip River Catchment

DEPARTMENT: WATER AFFAIRS AND FORESTRY

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The document covers the 2nd catchment studied in the National Radioactivity Monitoring Programme, viz., the Klip River Catchment South of Johannesburg.

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TABLE OF CONTENTS	PAGE

REPORT ON THE RADIOACTIVITY MONITORING PROGRAMME IN THE KLIP RIVER CATCHMENT.

EXECUTIVE SUMMARY

A radioactivity monitoring study was conducted by the Institute for Water Quality Studies (IWQS) of the Department of Water Affairs and Forestry (DWAF) in collaboration with a wide group of interested parties, in the Klip River Catchment during 1998/1999. The study served to establish the radiological status of the water resources in the catchment from the viewpoint of drinking water. The regular monitoring, both in time as well as in number of radionuclides measured served to clear up many areas of doubt, and has established with certainty the radiological status of the water resources in the catchment. The study covered mainly surface streams but with a few groundwater sources in the catchment. The evaluation of health risk was based on the levels of radioactivity in raw water samples that had been filtered prior to analysis, and on the assumed use of such water for drinking purposes on a continuous basis. The relative contributions to the health risk from ingestion of the *suspended* solids in the water and from radiation exposure scenarios other than drinking water use were (with the possible exception of fish consumption) shown to be insignificant in the previous study to this one, on the Mooi River catchment (DWAF, 1999). This study did not consider radioactivity in sediments or riverine banks.

The radiological variables measured were all from the natural radioactive decay chains of uranium-238, uranium-235, and thorium-232. In addition to radiological variables, a full set of chemical variables was also monitored.

The radiation doses calculated in the study were based on the conservative assumption that the water at every sampling point was used continuously as the sole source of drinking water.

In view of the long standing historic controversy surrounding the radiological status of water sources in the natural environment , extensive efforts were made to validate the accuracy of the radiological measurements, as well as to cross check the dose model. This worked well for the Mooi River study, but did not show consistent results when applied to the Klip River study, and thus the processing and interpretation of the data for this Klip River study had to be delayed until a uniform, concise and unambiguous method of dose calculation and evaluation had been developed (DWAF, 2002). The radioactivity dose calculation project, completed in 2002, led to the creation of a concise dose calculation routine (WaterRad), developed by PSI Risk Consultants cc, with which the dose calculations for the Klip study could now be finalised.

The new dose evaluation protocol (Appendix 4) takes into account the fact that the normal and typical average worldwide exposure to natural radioactivity in the diet

(from water and food) lies in the dose range 0.2 to 0.8 mSv/year and that no health effects from natural radioactivity have been observed in this dose range.

The natural background radiation dose in drinking water in the catchment was estimated at around 0,030 mSv/year. The great majority of sampling sites in the catchment showed a total drinking water radiation dose below 0,1 mSv/year, implying that no radiological problem exists from the viewpoint of drinking water. The general conclusion was that of the 20 sites monitored, 12 showed a water quality which is in the ideal class for continuous lifetime use in terms of the proposed interim water quality guidelines for radioactivity in drinking water. Eight sites had a dose between 0,1 and 1,0 mSv/year, showing a slight increase above natural background, but still fully acceptable for lifetime use with no significant detrimental effects to the user. No sites had a lifetime average annual radiation dose in excess of 1,0 mSv/year.

One interesting observation, was that despite the fact that the yearly mean dose, on which health effects are rightfully based was low at all sites in the Klip catchment, at several of the points there were isolated incidences of transient high levels of radioactivity. These were not sustained over time, however, and thus did not affect significantly the average dose. The points showing transient and elevated radioactivity deserve close watching and monitoring in the future.

A highly relevant and comforting finding of the study was that the total radiation dose at the lower end of the Klip river was very low, and in fact not significantly different from the natural background dose value. This is important, as the Klip river flows into the Vaal System, with widespread use for drinking water purposes.

A valuable finding of the study was that there is a good linear correlation between total radiation dose from all radionuclides and the uranium concentration in the water. This will, in the future, make it possible to use the uranium concentration for screening and routine monitoring purposes within the catchment.

As regards chemical variables, while it was found that elevated radiation dose is usually associated with elevated sulphate concentrations, the converse was not true, consequently sulphate concentration cannot be used as an indicator of radioactivity in the water.

The water analysis technique involves filtering of the raw water samples prior to radiometric analysis, and the primary intention of the study was to measure only the radioactivity in the water passing through the filter. It was not the intention of the study to look at radioactivity in the sediments or banks of surface water streams.

While an important aim of the study was to measure the concentrations of a large range of radionuclides in the natural uranium and thorium decay chains, it was not the intention to look at radon gas dissolved in the water. Dissolved radon, even at relatively high concentrations, does not contribute significantly to the drinking water health risk, and is generally considered to be of possible concern only where significantly elevated radon concentrations are associated with conditions that promote the dissolution and release of the gas into poorly ventilated enclosures. Such scenarios, which might include non-ventilated indoor spa baths and underground water treatment plants, are not known to exist in the Klip River catchment.

1. INTRODUCTION

1.1 Background

Preliminary screening surveys of radioactivity in water sources was carried out by the Institute for Water Quality Studies in 1995 and 1996 - DWAF(1995), DWAF(1996). The levels of the radioactive elements uranium and radium, found in streams in the vicinity of gold mining activities, were found to be elevated such that, in some cases, these streams might be regarded as unsuitable for continuous lifetime use as drinking water. Many radionuclides had not been measured, and there was no information on the variability of the radionuclide concentrations in the water sources. Due to the lack of detailed and definitive data on radionuclide concentrations, it was not possible to determine the safety or otherwise of the water sources when used for drinking water purposes without a more thorough and intensive monitoring programme. In order to obtain certain knowledge on the radiological status of the water sources to establish human health risk, it was essential that a more detailed investigation be conducted. This report summarizes the findings of a regular radiological monitoring programme that was conducted in the Klip River catchment during 1998/1999.

Please note, that this study addressed the filtered portion of the water. Also the study did not look at riverine sediments or banks. There is a concern that untreated water may be drunk by residents in informal settlements, where the suspended sediment is also swallowed, but there is difficulty in quantifying radiation dose in such cases due to the difficulty of obtaining consistent radioanalysis results where samples are not filtered, due in large part to the difficulty of obtaining repeatable and representative samples of the suspended matter.

1.2 Aims of the Klip River Radioactivity Study and Strategy Adopted

The strategy adopted to determine and evaluate radioactivity status of water resources initially addressed the following:

(a) To focus on one catchment at a time, in order of priority - the Mooi River catchment (also known as and also containing the Wonderfonteinspruit catchment) was selected as the first catchment to be studied, and formed the basis of the previous report. This report focuses on the second catchment studied, viz., the Klip river catchment south of Johannesburg.

(b) To undertake the monitoring programme in a coordinated, transparent manner with the participation of relevant governmental and non-governmental stakeholders.

The aims of the radioactivity monitoring programme were:

(i) To measure and report on the most important radioactive components in surface streams and in groundwater at selected sampling locations, at regular intervals over at least a hydrological year.

(ii) To establish the total dose risk from drinking water, the emphasis being placed on the dissolved component of the radionuclides present in the water samples, and not on the suspended component.

(iii) To estimate, from such measurements, the incremental radiation doses above estimated background that could be received by users of the water.

(iv) To identify where further investigative work, beyond the scope of the initial monitoring, was needed.

1.3 Management and coordination of the programme

The IWQS was responsible for the management and coordination of the radioactivity monitoring programme in the Klip River catchment. The establishment of a Coordinating Committee and Technical Committee, involving representation from a wide spectrum of organizations interested or involved in monitoring of radioactivity, assured transparency and the involvement of a range of scientific opinion and decision making on the issue. The Coordinating Committee consisted of numerous individuals and role players including Rand Water, Cydna Laboratories, the Directorate: Water Quality Management and the Gauteng Regional Office of DWAF, the National Nuclear Regulator (NNR), NECSA, the Chamber of Mines, and the Council for Geoscience.

The Technical Committee included representation from NECSA, the Chamber of Mines, the Gauteng Regional Office, the Council for Geoscience, the National Nuclear Regulator, and the IWQS

2. MONITORING PROGRAMME

2.1 Selection of catchment

The Klip River Catchment (Figure 1), was selected as the second priority catchment for intensive radioactivity monitoring for reasons including the following:

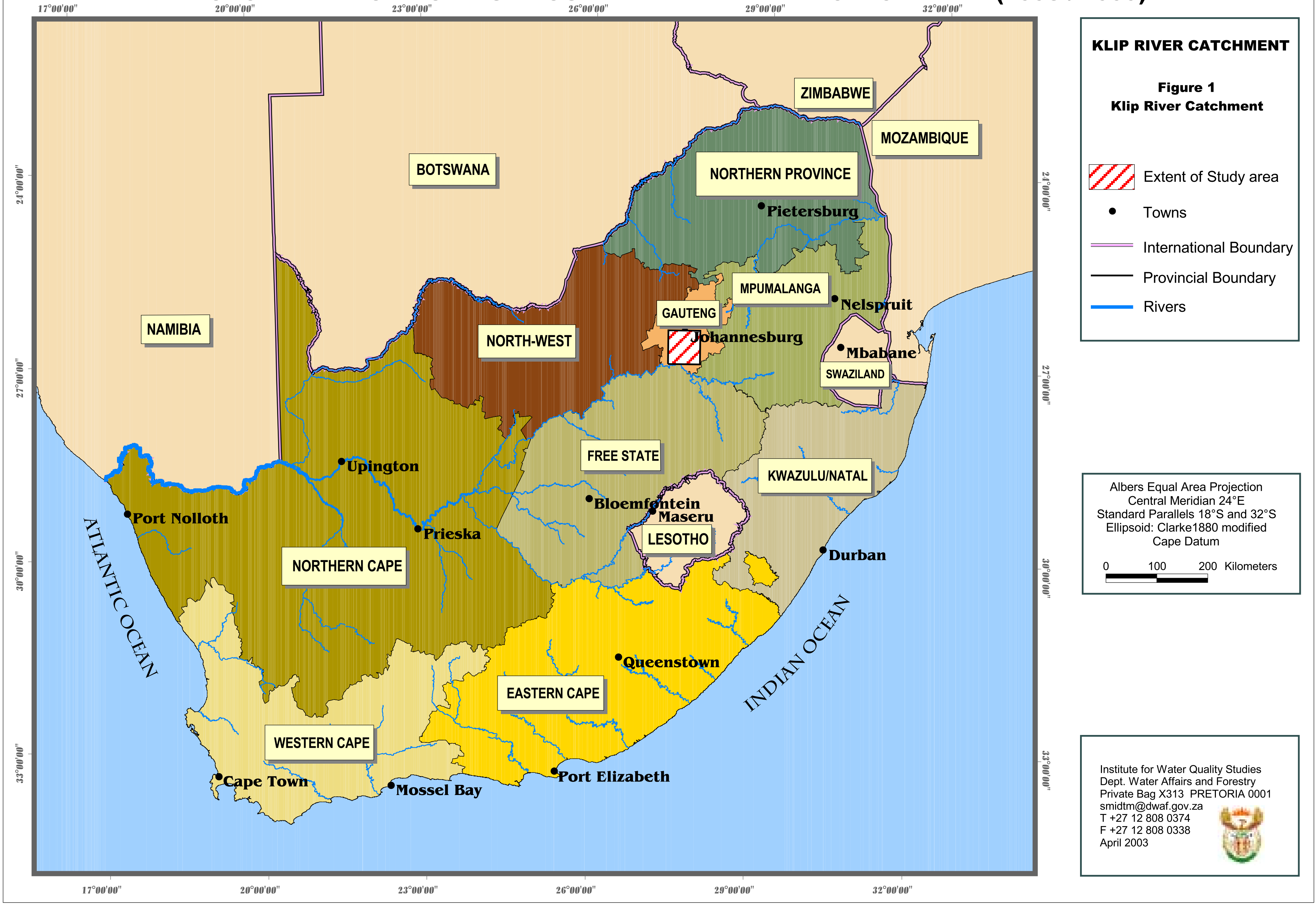
(i) Major gold mining activity was carried out in the region, with the potential for pollution of surface and ground water, in the past. Currently there are only two operating underground mining companies in the Klip River catchment, viz., Durban Roodepoort Deep and ERPM. Many of the old gold mine dumps are being reworked.

(ii) There are many settlements within the region, giving rise to possible consumption of untreated surface and ground water.

(iii) The upper section of the catchment has numerous diffuse sources from old and abandoned mine workings and mine residue deposits.

(iv) Formal townships, closely related to the mining activities, occur in the catchment.

RADIOACTIVITY MONITORING PROGRAMME: KLIP RIVER CATCHMENT (1998 / 1999)



2.2 Water use in the Klip River catchment.

While the majority of the population in the Klip River catchment receives treated potable water from Rand Water, there is a possibility of some direct use of the water for domestic uses. See appendix 1 for information of the results of the survey on water usage. There was insufficient funding to address all the water use categories identified in the survey and addressing of the recreational and fish consumption routes for exposure to radioactivity in water resources will need to be addressed in the future.

2.3 Selection of monitoring sites

During the initial stages of the monitoring programme 17 surface water sampling locations were selected on the recommendation of the Gauteng Regional Office (Figure 2). After consideration of the proposed sites by the Co-ordinating Committee, 4 groundwater sites were added, and sampling was started in January 1998
Table 1 summarises the sampling site information and identifies the location of the sites.

RADIOACTIVITY MONITORING PROGRAMME: KLIP RIVER CATCHMENT (1998 / 1999)

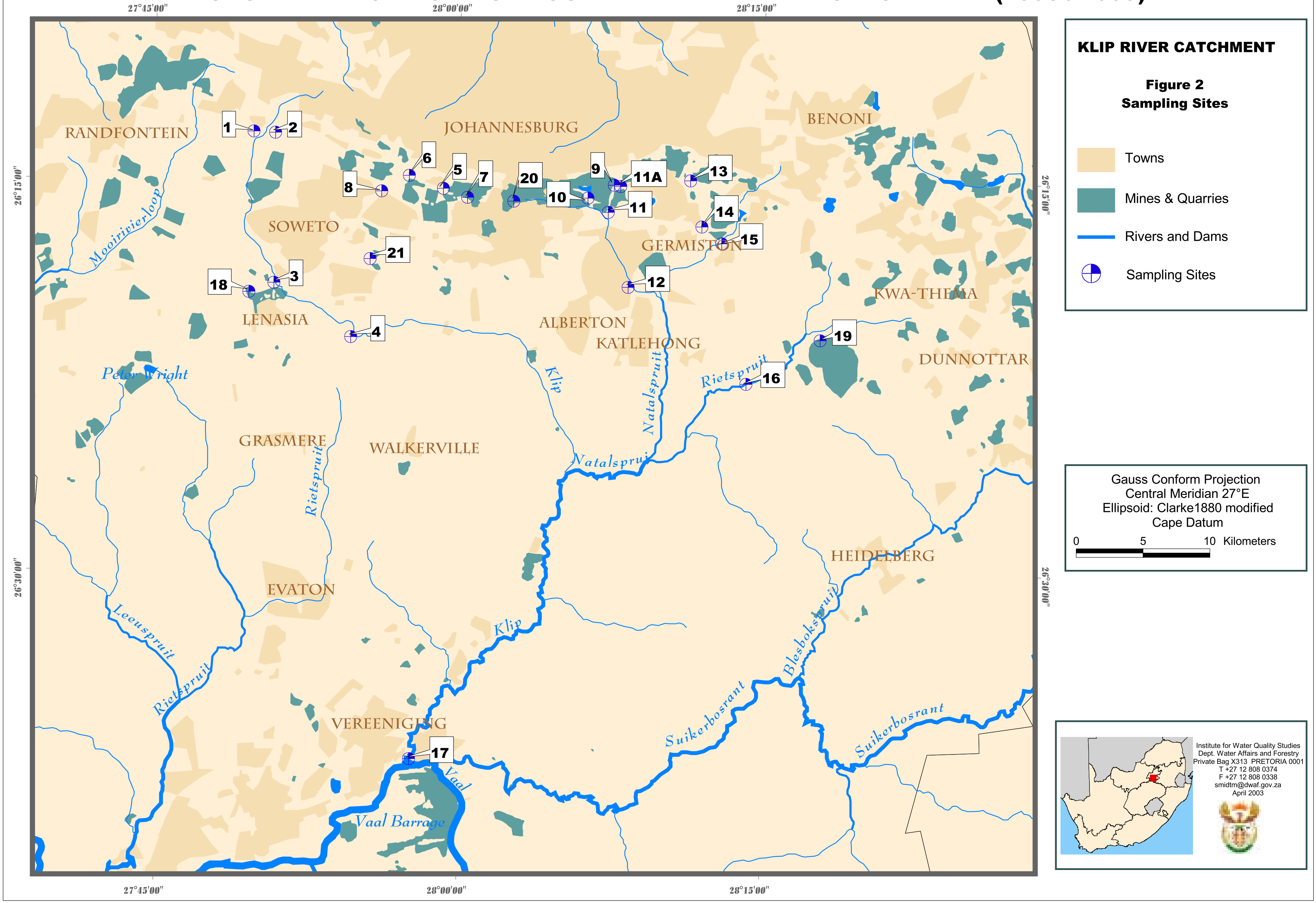


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TABLE 1: Klip River Site, station no's and monitoring points, together with positional data.

NO	QUAL Number	DESCRIPTION	LATITUDE (South)	LONGITUDE (East)
1	C2H218	Klip River at R41 upstream of Durban Deep Mine	26°10'36"	27°49'07"
2	C2H219	Klip River at Durban Deep Mine, downstream of Discharge from No 5 shaft	26°10'39"	27°50"13"
3	C2H039	Klip River at N12(old R29) downstream from Durban Deep Mine	26°17'39"	27°50'11"
4	C2H220	Klip River at Golden Highway (R553) downstream From Soweto and Eldorado Park	26°20'10"	27°54'11'
5	C2H221	Russel Stream (tributary of Klipspruit) at Nasrec Road (R5)	26°13'13"	27°58'55"
6	C2H222	Russel Stream (tributary of Klipspruit) at New Canada Road (R10)	26°12'37"	27°57'09"
7	C2H223	Russel Stream (tributary of Klipspruit)at Xavier Road (R17)	26°13'37"	28°00'11"
8	C2H224	Klipspruit at Soweto Highway (M70)	26°13'21"	27°55'44"
9	ZRM3DUM	Seepage from RM3 Dump draining into the Natalspruit	26°13'00"	28°07'45"
10	C2H225	Stream past City Deep Gold MIne at Lower Germiston Road (R33)	26°13'37"	28°06'24"
11	C2H226	Stream downstream from Simmer and Jack Gold Mine at Rand Airport Road (R46)	26°14'16"	28°07'27"
11A	C2H227	Stream past Simmer and Jack Gold Mine at Smith Avenue	26°13'03"	28°08'05"
12	C2H228	Natalspruit downstream from Alberton at Heidelberg Road (R554)	26°17'31"	28°08'31"
13	C2H229	Elsburg Spruit upstream from Elsburg Dam at Lower Boksburg road (R46)	26°12'46"	28°11'42"
14	C2H230	Elsburg Spruit downstream from Elsburg Dam At Brugstreet (R39)	26°14'55"	28°12'18"
15	C2H231	Tributary of Elsburg Spruit d/s of Cinderella Dam At Germiston/ Heidelberg Road (R35)	26°15'41"	28°13'20"
16	C2H232	Rietspruit past Mapleton Agricultural Holdings at R103	26°22'15"	28°14'40"
17	C2H233	Klip River, at Riviera Golf Course, upstream From confluence with Vaal River	26°39'50"	26°57'20"
18	ZGWB-ZUUR	Groundwater borehole at Zuurbekom waterworks	26°18'05"	27°48'53"
19	ZGWB-AREN	Groundwater borehole at Arendsnes poultry farm At Rooikraal	26°20'10"	28°18'29"
20	ZGWB-ROB	Groundwater borehole at Robinson refuse disposal Site at Robinson Deep Mine	26°13'47"	28°02'34"
21	ZGWB-GOUD	Groundwater borehole at Goudkoppies solid waste Dump	26°16'31"	27°55'09"

Factors taken into account in the selection of the sites included:

- the potential for possible direct drinking water use,
- the identification of significant point-source discharges from mines.

2.4 Sampling frequency and duration

For chronic radiation exposures, it is the cumulative radiation dose that is important, and not short period fluctuations. Thus the calculation of radiation doses to the public are normally integrated over a full year of exposure for the purposes of assessment. The exact yearly dose from environmental radioactivity, which varies over time, particularly in water sources, can only be determined with high frequency monitoring (ideally on a continuous basis). This was, however, not possible in practice due both to analytical capacity constraints and to budgetary constraints. A compromise had to be reached to ensure reasonable accuracy of the estimation of the integrated annual dose. Thus to achieve a reasonable estimate of integrated annual radiation dose, a monthly sampling frequency was adopted. It was established during the previous Mooi river catchment radioactivity monitoring programme that monthly sampling is adequate to give a reasonably accurate estimate of the total annual dose for drinking water consumption.

2.5 Catchment Geological and Radiological Characteristics

Because gold mining was established in the Klip River catchment long before radioactivity measurements were made, it was not possible to establish unequivocally the true natural background level, especially as the natural ground water recharge constitutes a significant proportion of the base flow of the river.

The dolomitic areas have very low (~10% of crustal average) radio-element contents. These dolomites also constitute the major groundwater source in the area.

The quartzites and shales in the area tend to be enriched in potassium, uranium and thorium and consequently, the daughter nuclides of uranium and thorium reach levels generally at 1.5-3 times the crustal average.

The granites tend to contain slightly elevated uranium concentrations and elevated potassium and thorium concentrations.

The highest naturally occurring uranium series activities in the area are found in the gold ores of the Witwatersrand Supergroup. These, however, are extremely limited in outcrop, generally sub-outcropping below hundreds or thousands of metres of younger cover rocks (Coetzee, 1995).

2.6 Variables measured and data collected

2.6.1 Radionuclides

The three natural radioactive decay series of relevance are those headed by the radionuclides uranium-238, uranium-235 and thorium-232. Details of these decay series and an explanation of terms are given in Appendix 3. The radiological variables requested from NECSA for analysis were gross alpha activity and the individual activities of uranium-238, radium-226 and thorium-232 plus, in addition, gross beta activity and the individual activities of radium-223, radium-224 and uranium-235. Also included was polonium-210, lead-210, thorium-230, thorium-227, uranium-234, and radium-228. This was done in order to clarify uncertainties in the dose calculated, relating to the non-equilibrium of nuclides with the parent nuclides in the water phase.

It was also decided that the protactinium-231 and actinium-227 in the water samples had to be determined on selected samples.

The use of gross beta measurements for estimating the contributions of beta emitters to the total radiation dose could not be considered, because the measurements were deemed to be unreliable owing to analysis problems caused by the effects of water chemistry. NECSA concurred that the well-established gross beta measurement techniques used by them could not be regarded as suitable for the determination of very low beta activity concentrations in waters characteristic of those sampled in this study. It was accordingly decided not to accept the gross beta data set, but rather to measure those beta emitters likely to contribute significantly to the total ingestion dose,

2.6.2 Chemical variables

Chemical variables, both major inorganic and trace metal constituents, were measured by the IWQS laboratories.

The chemical variables measured were:

(a) The following metals (dissolved fraction): aluminium, barium, iron, manganese, lead.

(b) The following major inorganic determinands: pH, electrical conductivity, total alkalinity, sodium, potassium, calcium, magnesium, ammonium, chloride, fluoride, sulphate, nitrate +nitrite (as N), phosphate as P, silicate as Si.

The most significant of the chemical variables measured was possibly sulphate, which is formed by the oxidation of pyrite in the ore, leading to acidic conditions conducive to the mobilization of some radionuclides into water.

The methods used for radiological analysis of the samples are given in Appendix 2.

2.6.3 Other data

No data on environmental levels of radioactivity in sediments, river banks, vegetation or other possible elements of the human food chain were gathered. Instead, potential radiological impacts from exposure pathways other than drinking water were estimated on an order-of-magnitude basis through the use of screening models during the previous Mooi river study.

Data on water usage by the various informal communities in the catchment were gathered primarily to establish usage for drinking water purposes. This was important for determining the degree of conservatism inherent in assuming sole continuous use of the water for drinking purposes.

2.6.4 Access to Analytical Data

Analytical results collected during the study can be obtained from the Institute for Water Quality Studies, Dept Water Affairs & Forestry, P Bag X313, Pretoria 0001, Tel: 012-8080374; Fax: 012-8080338; attention Ms Magda Smidt.

The official Departmental station numbers, provided elsewhere in the report (example C2H218) should be provided with all data requests. Data can be provided in an ASCII format and files can be provided via e-mail.

2.7 Quality Control

A number of actions were taken to address quality control. The AEC conducted the radiometric analyses of the water samples for the study. As a CNS-recognised laboratory, the AEC adopts approved methods and procedures for analysis, and incorporates specific quality control methods.

Measurements of uranium by both radiochemical and ICP-MS techniques, allowed comparisons to be made as an additional quality control check. The following good correlation for uranium concentration in mg/ℓ was obtained by linear regression from the 98 samples analysed in the previous Mooi River study.

$$[U]_{ICP\text{-}MS} = 0.993 \times [U]_{Radiochemical} - 0.563 \qquad (r^2 = 0.906)$$

In natural uranium, the activity ratio between uranium-238 and uranium-235 is 21.719. The following good correlations between the data for the two isotopes were obtained by linear regression for the previous Mooi River study:

Radiochemical (phase 2), 98 data: $^{238}U / ^{235}U = 21.341 \pm 0.115$ $(r^2 = 0.996)$

ICP-MS (phase 1), 570 data: $^{238}U / ^{235}U = 20.785 \pm 0.030$ $(r^2 = 0.999)$

ICP-MS (phase 2), 63 data: $^{238}U / ^{235}U = 22.171 \pm 0.571$ $(r^2 = 0.860)$

In the Klip river study the following correlations for uranium-238 concentration in mg/ℓ was obtained by linear regression from 258 samples analysed :

$$[U]_{ICP\text{-}MS} = 0.593932 \times [U]_{Radiochemical} + 0.010998 \qquad (r^2 = 0.659)$$

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Radiochemical, 258 data : ^{238}U / ^{235}U = 21.581 ± 0.036 (r^2 = 0.999)

ICP-MS, 264 data : ^{238}U / ^{235}U = 21.310 ± 0.053 (r^2 = 0.998)

3. BASIC RADIOLOGICAL CONSIDERATIONS

3.1 Exposure from natural background radioactivity and medical procedures

Most of the ionizing radiation to which people are exposed comes from sources which are natural features of the environment. These sources include radon gas and its decay products in the atmosphere (originating from natural uranium in soil and rocks), gamma rays from the ground, cosmic rays from outer space, naturally-occurring radioactivity in foodstuffs and drinking water, also derived from radionuclides in the soil, as well as inhalation of respirable airborne dust. The total radiation dose received by an individual, from these natural sources, is typically about 2.4 mSv/a (millisieverts per annum), but geological and geographical factors can cause doses from any one of such sources to be elevated by a factor of 10 in high-background regions (UNSCEAR,1993).

In addition to radiation from natural sources, man is exposed to radiation during medical treatment (X-rays, radiotherapy and nuclear medicine). Internationally, average doses to individuals from all medical sources range from 0.07 mSv/a to 1.8 mSv/a (UNSCEAR,1993).

Thus, a typical member of the public will receive, as a matter of course, a radiation dose of between 2.5 and 4.2 mSv/a. In regions with high natural background, doses of 10 mSv/a are not uncommon.

3.2 Exposure pathways

Exposure of humans, to ionizing radiation, may occur via various routes or ‘pathways’ that can be grouped simply as:

- exposures to penetrating radiation from sources external to the body, and
- exposures to both penetrating and non-penetrating radiation from radioactive substances taken into the body by ingestion, inhalation, or absorption through the skin.

Exposures from water containing radioactive contaminants essentially occur internally through ingestion, either by direct consumption or indirectly by consumption of animal or vegetable products that have themselves taken up the water.

A detailed study of the potential major ingestion pathways, reported in the previous Mooi River Study revealed only two pathways with potential for giving rise to significant exposures

- direct ingestion resulting from regular and continuous use of the water for drinking purposes, and
- regular consumption of fish obtained from contaminated water bodies.

With respect to the latter, there is very little information on the bioaccumulation rates of radionuclides in local fish species, and international experience shows that bioaccumulation can vary by as much as three orders of magnitude. The fish pathway therefore requires more research, and could not be addressed in the present study. Accordingly, the decision was taken, as with the previous study, to address only the drinking water pathway in the Klip River study.

3.3 Health effects of ionizing radiation

The process of ionization changes atoms and molecules. In cells, such changes may result in damage which, if not adequately repaired, may:

- prevent the cell from surviving or reproducing, or
- result in a viable but modified cell.

The two outcomes have profoundly different implications for the organism as a whole.

In the case of the former, the loss of large numbers of cells in a tissue can result in a loss in tissue function. Such effects are known as deterministic effects, and are characterized by a dose threshold above which the probability of causing harm increases steeply from zero to 100%. Above the threshold, the severity of harm also increases with dose. Threshold doses are generally two or three orders of magnitude above background doses, and deterministic effects are thus only now seen in the case of accidents or as a side effect of medical radiation therapy.

The outcome is very different if the irradiated cell is modified rather than killed. It may then be able to produce a clone of modified daughter cells which, in spite of the highly effective defence mechanisms within the body, may cause, after a prolonged and variable delay, a malignant condition - a cancer. The probability, but not the severity, of the cancer increases with dose. This effect is called stochastic (meaning of random or statistical nature).

Epidemiological studies have shown, with good statistical significance, that this dose-response relationship is linear for accumulated doses of more than about 200 mSv. It is widely assumed that this linear relationship, with certain corrections, holds true also at lower doses, all the way down to zero - that is, there is no dose threshold for stochastic effects. This linear relationship yields, for low doses and dose rates, a nominal probability of fatal cancer induction of 5×10^{-5} per mSv. Due to the high incidence of cancer induced by other carcinogens, it will be difficult, if not impossible, to obtain conclusive epidemiological evidence supporting this linear relationship at low doses. Some evidence suggests the opposite, in that there is actually a beneficial effect.

Stochastic effects can also take the form of hereditary effects which may be of many different kinds and severity, and are expressed in the progeny of the exposed person. Although the existence of hereditary effects in man is not in doubt, the risk estimates appear to be so small that it is not surprising that epidemiology has not yet detected hereditary effects of radiation in humans with a statistically significant degree of confidence.

Notwithstanding the fact that there is no evidence of statistically significant health effects associated with exposure to low levels of radiation, the internationally accepted principle is to keep radiation exposures as low as reasonably achievable.

3.4 Radiation protection principles and the system of radiation protection

Internationally a system of radiation protection has been agreed upon, based on the health effects described in the above section 3.3. This system has been recommended by the International Commission on Radiological Protection (ICRP), which is a non-governmental scientific organization that has been publishing this and related recommendations for over half a century. Different countries evaluate and implement the recommendations in a manner that is appropriate to their circumstances.

The following recommendations of the ICRP (1991) are based on the assumption that there is indeed a linear non-threshold relationship between radiation dose and the probability of contracting cancer. Central to the system of radiation protection for proposed and continuing human activities that increase exposure to radiation are the following general principles:

1. No activity, which results in the exposure of persons to radiation, should be adopted unless the activity produces a net positive benefit.
2. All radiation doses should be kept as low as reasonably achievable (ALARA), taking economic and social factors into account.
3. The radiation doses should not exceed limits recommended by the ICRP.

For situations where the sources of exposure are already in place and radiation protection has to be considered retrospectively, remedial action to reduce the exposures should be based on the following general principles:

a) The remedial action should be justified in the sense that the costs, including social costs, should be more than offset by the reduction in radiation dose likely to be achieved.

b) The form, scale and duration of the remedial action should be optimized so that the net benefit to society is maximized.

Dose limits do not apply in the case of such remedial action, because their use might result in measures being taken that are out of all proportion to the net benefit obtained.

To apply the above principles to, for instance, radioactivity in water, it is necessary to calculate the radiation doses which result from the use of the water.

3.5 Calculation of dose for the drinking water ingestion pathway

The annual radiation dose from any given radionuclide and for any given age group, and dose conversion factor (DCF) is expressed as:

$$\text{Annual dose (mSv/a)} = \text{Activity concentration (Bq/}\ell\text{)} \times \text{Annual consumption (}\ell\text{/a)} \times \text{DCF (mSv/Bq)}$$

The total radiation dose for that age group is then the sum of the doses from individual radionuclides. This implies that the activity concentration of every radionuclide must be known. However, it was not feasible to measure every radionuclide, and this had to be taken into account in the calculation of age group specific doses.

Dose calculation is discussed in detail in DWAF (2002), the report on dose calculation drawn up by PSI Risk Consultants cc, which describes the development of the WaterRad radioactivity dose calculation computer software package.

3.5.1 Dose Conversion Factor

Each of the radionuclides in the three decay chains of interest has its own 'dose conversion factor' (DCF) for the ingestion pathway, relating the dose received, in mSv, to the amount of radioactivity ingested, in Bq (becquerels, or number of nuclear disintegrations per second). The DCFs used are those published by the International Atomic Energy Agency (IAEA, 1996; Goldstein et al, 1997). The IAEA gives different dose conversion factors for the various age groups. The WaterRad Dose calculation package gives the dose for each age group class.

3.5.2 Activity concentration

In many solid materials such as rocks and soil, the mobility of the elements in the decay chains is limited, even over long periods of time, and the mixture of radionuclides is therefore relatively undisturbed. In such cases, the radionuclides may be said to be in secular equilibrium, meaning that all the radionuclides in a given decay chain have similar activity concentrations.

In water systems, however, the dissolution and precipitation characteristics of the various decay chain elements may differ significantly, leading to a high degree of disequilibrium. Assumptions of equilibrium are therefore no longer valid. On the other hand, measurement of the activity concentration of every single radionuclide is neither economically feasible nor necessary in order to obtain a reasonable estimate of the ingestion dose. Certain radionuclides will contribute very little to the overall radiation dose because they have very small DCFs and / or their parents may be present only at very low activity concentrations.

Consideration was initially given to the use of gross alpha measurements for estimating the dose contributions from the radionuclides that were not individually measured. In practice, however, the uncertainties inherent in the determination of gross alpha activity, typically around 20% to 30%, lead to unacceptably large uncertainties in the final dose determination.

The use of gross beta measurements for estimating the contributions of beta emitters to the total radiation dose could not be considered, because the measurements were deemed to be unreliable owing to elevation of the beta measurements caused by water chemistry. NECSA concurred that the well-established gross beta measurement techniques used by them could not be regarded as suitable for the determination of the very low beta levels in the waters characteristic of those sampled in this study. It was accordingly decided not to use the gross beta data in dose calculation, but rather to directly measure the more important beta emitters, with the highest dose conversion factors.

3.6 Estimation of natural background:

In the study, a number of points were monitored where radionuclides were detected at or close to the detection limits of the methods applied. The dose values for such points cluster around 0,03mSv/a.

4. DRINKING WATER QUALITY CONSIDERATIONS

From the preliminary screening surveys (DWAF,1995; DWAF,1996a) uranium was found to be the main radioactive element present, and has both a potential for a chemical toxicity and a radiological hazard. Current DWAF Water Quality Guidelines (DWAF,1996b) give criteria for uranium-238 concentrations in drinking water. These criteria are based on the chemical toxicity of uranium to the kidney rather than its radiological toxicity.

From a radiological perspective, it is the total radiation dose from all radionuclides in the water that is important, and the Technical Committee has proposed interim guidelines in this regard, taking into account the following:

(i) The World Health Organization (WHO) recommends a reference level for radiation dose, received from the continuous consumption of drinking water for a full year, of 0.1 mSv/a (WHO,1993). This value is only about 5% of the total dose from the natural background, and can therefore be regarded as an ideal situation. From Section 3.3 it can be deduced that, on the conservative basis of the linear non-threshold theory, a radiation dose of 0.1 mSv/a represents a probability of attributable fatal cancer of 4 in 10 000 over a 70 year lifetime. By contrast, cancer from all causes is responsible for about 2 000 in 10 000 deaths, it thus being evident that, for the WHO reference level of 0,1 mSv/a, the increase in the probability of cancer induction, if it exists at all, is insignificantly small.

(ii) The dose limit to members of the public due to all anthropogenic sources is currently recommended internationally at 1 mSv/a (ICRP,1991; Goldstone et at 1997) and this has been implemented in several countries. This value is based on acceptance of the linear non-threshold theory, and can therefore be regarded as conservative.

(iii) The dose limit for members of the public recommended internationally was previously 5 mSv/a, and many countries still adopt this limit. It is common practice in uranium mining remedial action programmes to design the programmes such that compliance with the 5 mSv/a limit is achieved in the short term, and with the 1 mSv/a limit in the longer term.

(iv) Dose limits to members of the public relate to the combined effect of all exposures from human activities. It is common practice to place a dose constraint on releases from individual facilities. Such a constraint is normally set at some fraction of the dose limit of 1mSv/a - commonly of the order of 0.25 mSv/a, i.e., allowing for the combined dose from up to four separate facilities on a single individual not exceeding the 1mSv/a limit. Although this approach is intended for new rather than existing operations, it may have some relevance to water systems in gold mining areas in that it embodies the

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concept of allowing for doses from other sources of exposure without causing the 1 mSv/a dose limit to be exceeded. The reference value of 0,25 mSv/a is the dose limit already imposed by the CNS on individual mines.

Table 2 gives information on the DWAF (1996b) guidelines for uranium, while Table 3 embodies the proposed guidelines on radiation dose in drinking water (Taken from DWAF,2002, page 33). The DWAF guidelines have taken into consideration all the above limits for the protection of the public from anthropogenic sources of radiation.

The basis for the colour coded classification system was chosen to be in line with the approach used in the joint Assessment Guide, published by DWAF, the Department of Health, and the Water Research Commission (WRC,1998). The meaning of the colour classes given in that guide are as follows:

- Blue, class 0 = Ideal water quality. Suitable for lifetime use.
- Green, class I = Good water quality. Suitable for use, rare instances of negative effects.
- Yellow, class II = Marginal water quality. Conditionally acceptable. Negative effects may occur in some sensitive groups.
- Red, class III = Poor water quality. Unsuitable for use without treatment. Chronic effects may occur.
- Purple, class IV = Dangerous water quality. Totally unsuitable for use. Acute effects may occur.

The practical meaning intended for interpretation of the classes is that “blue” or “green” water is fit for lifetime use without any further questions. Yellow class or marginal water, is however, only fit for interim use, and should not be used for a lifetime if at all possible. Red and Purple class water are seen as unfit for use.

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TABLE 2: Current DWAF 1996(b) guideline on uranium-238 in domestic water, with colour classes

Uranium-238 (Bq/ℓ)	Uranium-238 (mg/ℓ)	Effects	Colour Class
Target water quality range 0 to 0,89 Bq/ℓ	Target water quality range 0 to 0,070 mg/ℓ	No significant effects. Annual cancer risk less than 1 in 4 000 000.	Blue, Ideal(<0,25 Bq/ℓ) and Green (0,25 to 0,89 Bq/ℓ)
0,89 to 3,6	0,070 to 0,284*	Annual cancer risk less than 1 in 1 000 000. May potentially be a slight risk of renal toxicity in sensitive individuals where renal function is impaired, but unlikely to have demonstrable renal toxicity in healthy individuals.	Yellow
3,6 to 18	0,284 to 1,42	Annual cancer risk less than 1 in 200 000, but significant risk of chemical toxicity with renal damage.	Red
>18	>1,42	Increasing cancer risk in long term. Increasing risk of renal damage in short term.	Purple

* If 0,284 mg/ℓ is exceeded, human health may be at risk due to chemical toxicity.

Table 3: Radiation dose ranges for drinking water with health effects and intervention decision time frames indicated (DWAF,2002).

Dose class/colour	Dose range: mSv/a	Health effects	Intervention decision time frame
Class 0 (Blue, ideal water quality)	0.01 to 0.1	No observable health effects	Intervention not applicable
Class 1 (Green, good water quality)	>0.1 to 1	No observable health effects. Typical range of worldwide natural dietary ingestion from water and food.	No intervention required, but ALARA principle applies (keep dose as low as reasonably achievable)
Class 2 (Yellow, marginal water quality)	>1 to 10	Small increase in cancer mortality risk	Consider intervention within 2 years
Class 3 (Red, poor water quality)	>10 to 100	Cancer risk statistically detectable in very large population groups	Intervention required within 1 year
Class 4 (Purple, unacceptable water quality)	>100	Health effects clinically detectable	Immediate intervention required.

5 DISCUSSION OF RESULTS

5.1 Annual Doses within the Klip River Catchment for the Drinking Water Exposure Route

The annual doses for the drinking water route of consumption, for the Klip River Catchment, are shown in Table 4. These were calculated using the dose calculation routine described in DWAF(2002), Radioactivity dose calculation & water quality evaluation guideline for domestic water use.

Table 4: Average annual dose in mSv/a for the different age groups for the drinking water route;

Site	0-1yr	1-2yr	2-7yr	7-12yr	12-17yr	17-70yr	Lifetime average annual dose mS/m
1	0.120	0.055	0.039	0.039	0.070	0.031	0.037
2	2.467	0.575	0.452	0.430	0.730	0.562	0.584
3	0.195	0.076	0.055	0.054	0.091	0.050	0.056
4	0.112	0.053	0.037	0.037	0.064	0.030	0.073
5	0.526	0.149	0.113	0.111	0.197	0.124	0.121
6	1.100	0.275	0.211	0.201	0.344	0.251	0.264
7	0.625	0.174	0.132	0.128	0.226	0.148	0.180
8	0.160	0.054	0.039	0.042	0.087	0.037	0.043
10	0.130	0.058	0.041	0.043	0.082	0.033	0.040
11	0.504	0.140	0.106	0.102	0.173	0.116	0.124
11A	0.445	0.161	0.117	0.117	0.211	0.108	0.122
12	0.828	0.214	0.165	0.156	0.260	0.194	0.204
13	0.098	0.044	0.031	0.031	0.059	0.024	0.029
14	0.570	0.158	0.121	0.115	0.191	0.137	0.144
15	0.334	0.093	0.071	0.067	0.111	0.079	0.084
16	0.376	0.110	0.083	0.079	0.132	0.090	0.096
17	0.116	0.051	0.036	0.036	0.061	0.029	0.034
18	0.117	0.059	0.041	0.041	0.070	0.032	0.038
19	0.206	0.094	0.066	0.068	0.127	0.055	0.064
20	0.523	0.173	0.128	0.133	0.260	0.132	0.147
21	0.146	0.065	0.045	0.045	0.078	0.036	0.042

Note: There was no data collected from site 9 (Seepage from RM3 dump draining into the Natalspruit).

The radioactivity classes, according to DWAF (2002), and also shown in Table 3, in which the annual average radioactivity dose for the sample sites are categorised are shown in Table 5 and in Figure 3 (For the lifetime average annual dose).

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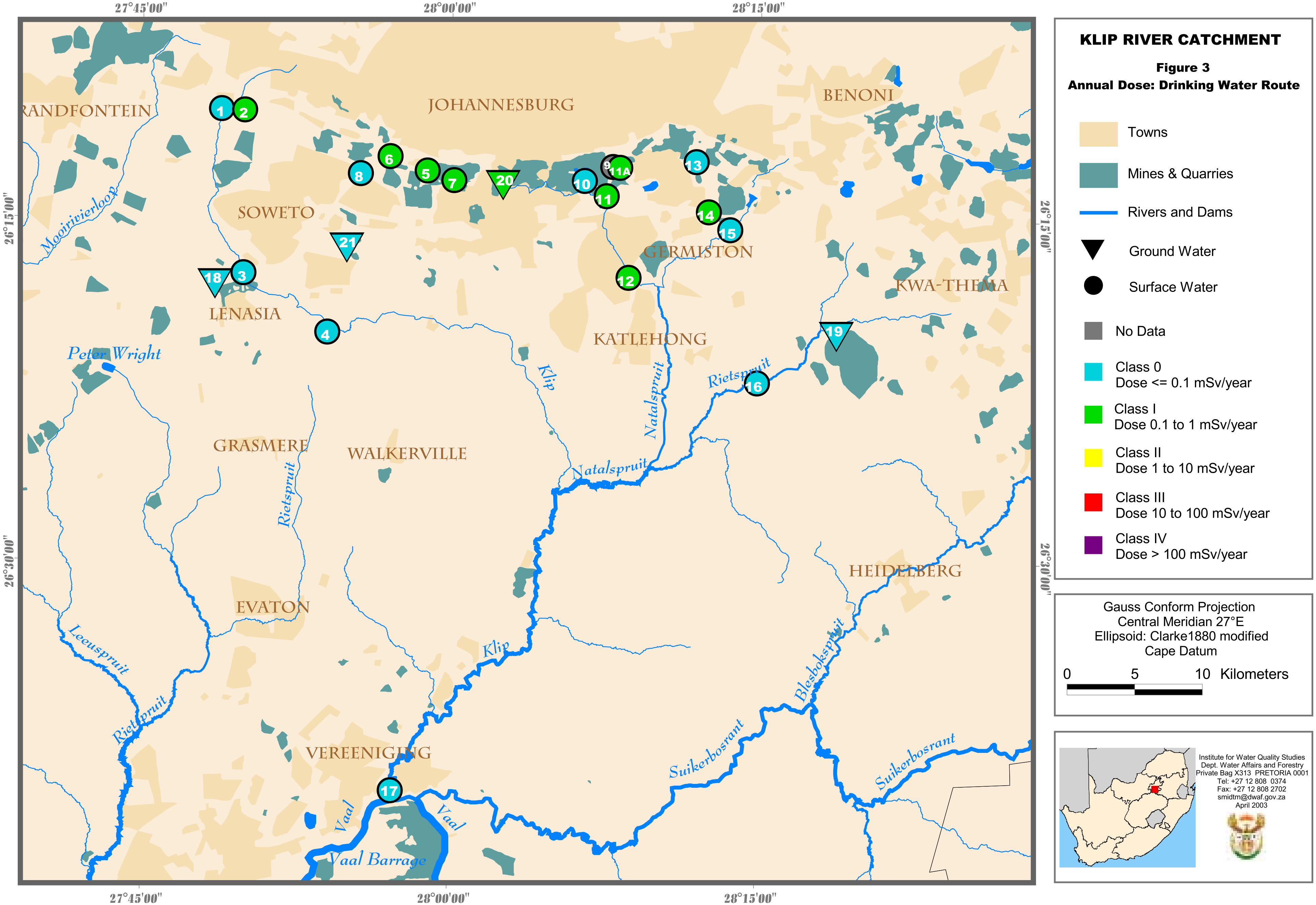
Table 5: Radioactivity classes found for the Klip River sites for lifetime average annual dose.

Site No	Radioactivity class	Intervention decision time frames
1	0 (Ideal water quality)	Not applicable
2	1 (good water quality)	No intervention is required
3	0 (Ideal)	Not applicable
4	0 (Ideal)	Not applicable
5	1 (Good water quality)	No intervention is required.
6	1 (Good water quality)	No intervention is required.
7	0 (Ideal)	Not applicable.
8	0 (Ideal)	Not applicable
10	0 (Ideal)	Not applicable
11	1 (Good water quality)	No intervention is required.
11A	1 (Good water quality)	No intervention is required.
12	1 (Good water quality)	No intervention is required.
13	0 (Ideal)	Not applicable.
14	1 (Good water quality)	No intervention is required.
15	0 (Ideal)	Not applicable.
16	0 (Ideal)	Not applicable
17	0 (Ideal)	Not applicable
18	0 (Ideal)	Not applicable
19	0 (Ideal)	Not applicable
20	1 (Good water quality)	No intervention is required
21	0 (Ideal)	Not applicable

RADIOACTIVITY MONITORING PROGRAMME: KLIP RIVER CATCHMENT (1998 / 1999)



13 of the sites are classified from the radiological point of view for drinking water in the ideal class (dose 0 to 0,1 mSv/a); 8 sites are in the good class (dose 0,1 to 1 mSv/a). There are no sites in the yellow class (class 2) or higher (>1 mSv/a) implying that there is no indication that intervention is necessary.

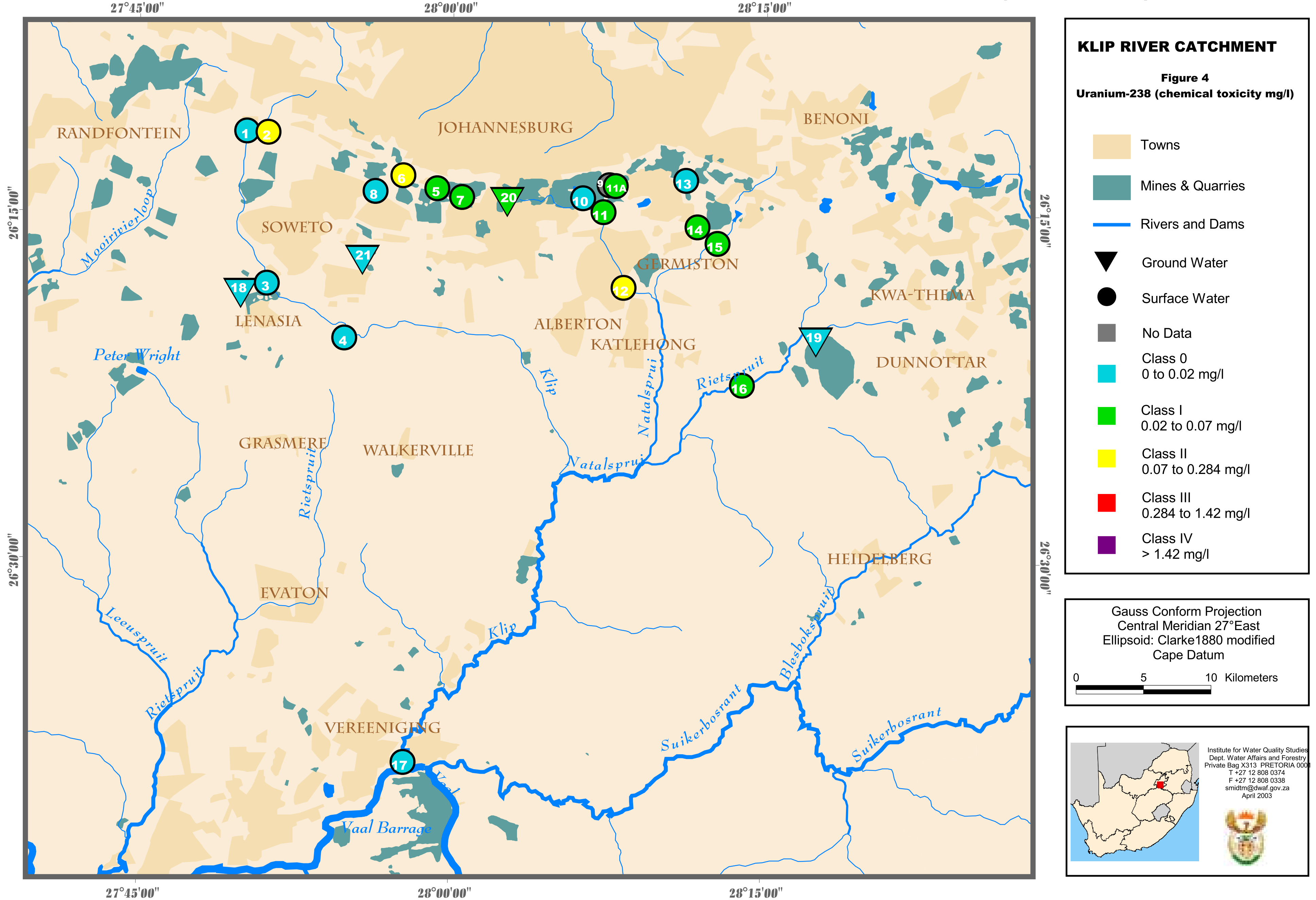
From the viewpoint of the highest risk group (infants under 1 year of age), two sites classified in the yellow marginal class, viz., site 2 (C2H219, which is on the Klip river at Durban Deep Mine, downstream of discharge from No 5 shaft) and site 6 (C2H222, Russel stream tributary of Klipspruit at New Canada Road, R10). It is noteworthy that the radioactivity status of these two points only falls in the yellow marginal class because of the high dose for the under 1year old age group, and that for all other age groups the radioactivity at these two sites falls in the green class 1 (good water quality).

5.2 Discussion of predominance of uranium

The results of the monitoring in the Klip River catchment have shown that of the radionuclides measured, the parent radioactive element uranium, is responsible for the major portion of the measured alpha activity.

A map representing the measured uranium-238 chemical toxicity values is given in Figure 4, with the proposed colour classes. It can be seen immediately from this map that the chemical toxicity from uranium may be significant at sites 2, 6 and 12 but that at the remaining sites, there is no significant chemical toxicity from uranium. At the three elevated sites for uranium content, the water is still acceptable for interim use, up to a period of seven years continuous use. Where water is only used intermittently for drinking water use the period of exposure may safely be proportionately extended.

RADIOACTIVITY MONITORING PROGRAMME: KLIP RIVER CATCHMENT (1998 / 1999)



6 Steps taken by the Regional Office to initiate investigative and remedial action by the mines:

While the study on the Klip River showed that intervention according to the 2002 DWAF dose guideline (DWAF,2002) is not required, nevertheless in terms of the ALARA principle, of the goal of achieving minimal radiation doses to the public "as low as reasonably achievable", the Gauteng Regional Office has taken steps to minimize radiation exposures which included the following:

1. Requesting mines where appropriate to undertake impact assessments and also to identify users of the water, with attention particularly being given to drinking water use.
2. To request mines where appropriate to apply for new permits, and to re-evaluate permit conditions.
3. Extension of routine water quality monitoring to include points of concern.
4. Request erection of warning notices or fences where appropriate to discourage direct use of contaminated water for drinking purposes.
5. Request mines to investigate recycling of contaminated water and to limit as far as possible the discharge of water containing unacceptable levels of contamination.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusions

The aim of the radioactivity monitoring programme in the Klip River was to determine the total radioactivity dose from surface and some ground water sources that are or could be used potentially as drinking water supplies. After a year of data collection, the results showed that of the 21 monitoring sites covered by the study, 13 were in the ideal class, showing no radioactivity problem, and 8 sites were in the good water class for lifetime use. Only 2 sites showed marginal radioactivity status for the under 1 year old age group, who are the most sensitive class for radioactivity status of water. The two latter sites were C2H219 (Klip River at Durban Deep mine, downstream of the discharge from No 5 shaft) and C2H222 (Russel stream at New Canada Road).

7.2 Recommendations

The following recommendations can be made from the results of the study:

(i) That as the dose is in the blue and green classes for lifetime exposure for the majority of the sites, that no immediate intervention action is indicated as being necessary to reduce radioactivity levels in surface and ground waters in the Klip River catchment. The issue of radioactivity should be integrated into the existing holistic approach used in catchment mangament. For practices, the ALARA principle applies of maintaining the radioactivity doses as low as possible, and ongoing efforts by the mines to keep radiacitivity inputs to water resources should be kept as low as possible.

(ii) Two of the sites showed marginal radioactivity status for infants, namely the Klip river at Durban Deep mine downstream from the discharge from No 5 shaft, which needs closer monitoring, and the Russel stream at New Canada road. At both of these sites care should be taken that the water is not used by infants under 1 year of age.

(iii) A cost-effective approach needs to be adopted for future monitoring to provide reassurance that radiation dose levels remain at the current relatively low levels.

(iv) The potential for ongoing radiological impacts, after mine closure, on water sources in the Klip River catchment should be taken into account in the site-specific mine decommissioning plans that are required as part of the mines' Environmental Management Programme (EMP) obligations.

(v) Since this study was concerned only with radioactivity in water sources intended for drinking water use, the question of radioactivity in the sediments in the KlipRiver catchment remains largely unexplored. An investigation of radioactivity in sediments needs to be undertaken, with a view to understanding the role played by water chemistry. Because of the huge uncertainties in the uptake of radionuclides in fish, studies on the fish consumption exposure pathway should be conducted. These studies will require a substantial research effort. It needs to be established whether potential radiation dose from this route in the first instance is likely to be significant or not.

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Appendix 1

Water User Assessment for the Klip River Catchment

1.1 Introduction:

Water users in the Klip River catchment are best analysed according to the five user groups, viz., domestic, industrial, agricultural and recreational users, and the natural environment. The requirements of all identified users within a river catchment are the foundation upon which a successful Water Quality Management Plan (WQMP) must be based. The needs of water users can be divided into two broad categories, namely qualitative and quantitative requirements.

Quantitative considerations include the following:

- Present and projected water demands of domestic, industrial and agricultural users;
- Water levels and flow patterns to maintain natural aquatic systems, to meet recreational user and downstream water user requirements and to maintain appropriate levels for raw water abstraction works.

Qualitative considerations are centred on meeting the water quality requirements of all the identified users in a river catchment. The natural environment is considered part of the reserve itself, and is therefore also included as a user.
Users within the Klip river catchment are the prime focus of this situation analysis, but the immediate downstream users in the Vaal Barrage are also important since the Klip river catchment can be viewed as a single point source to the Vaal Barrage and its users. Other users further downstream must also be considered eventually within the wider context of the Vaal River system as a whole.

While the main emphasis of a WQMP must be placed on the water quality requirements of the catchment users, it remains essential to take account of their qualitative requirements as well. This is because river system operation is largely demand driven. The magnitude and geographical distribution of demand centres will strongly influence the development of the water distribution network, the phasing and location of new water resource schemes, and hence flow patterns in river systems, used as the conveyance system for raw water supply and receiving bodies for effluent return flows. This situation is exemplified by the recently commissioned Lesotho Highlands Water Scheme to supply the Vaal river and to serve the water demands of Gauteng and beyond.

1.1.1 Major Water Users.

Each of the five water user groups in the Klip river are discussed further below.

1.2.1 Domestic users.

Most domestic water users in the Klip river catchment are supplied with potable water by Rand Water, which is responsible for providing drinking water to more than 6 million people in Gauteng and its surrounding areas. Only a few individuals and communities abstract water in the catchment directly from groundwater via boreholes and these water users are largely confined to the more remote agricultural areas mainly in the lower Klip river. Rand water also abstracts groundwater to a very limited extent from the Zuurbekom underground water compartment to the west of the upper Klip river catchment for domestic use. Urban use of borehole water is chiefly limited to watering gardens.

Rand Water generally supplies potable water to a local authority which then distributes that water to end users. Increasingly, however, Rand Water is supplying water directly to previously unserved end users, especially those living in informal settlements. Furthermore, Rand Water supplies potable water to local authorities and end users living outside the Klip River catchment from Rustenberg in the west, to Pretoria in the north, Bethal in the east, and Sasolburg in the south. Water use in these areas thus has an impact on Rand Water's water demand.

Certain inhabitants of the many informal settlements in the Klip river catchment use water directly from rivers for domestic purposes, e.g., washing clothes. The extent of this type of use in the catchment is unknown, but the number of informal settlements in the catchment has grown significantly over recent years. These communities are generally supplied with potable water in water tankers or standpipes. Furthermore, it would appear to a large degree that experience and community knowledge of the potential health risk associated with drinking water directly from the Klip river is good, and has prevented widespread use of the water for drinking purposes. Nevertheless, these users with their limited means of direct water treatment could be severely impacted upon by poor water quality in the Klip river catchment.

1.2.2 Industrial users

Most industrial users in the Klip river catchment are supplied with water by Rand Water, either directly or via local authorities. A few industrial users abstract water directly from the river system (e.g., Hippo Quarries in the upper Klip river), while some make use of ground water (e.g., East Rand Gold Company, ERGO), or use purified sewage effluent (e.g., Orlando Power Station in the upper Klip river, although this practice ceased in September 1998). A number of industries, such as Nampak and Everite, which in the past used river water in their industrial processes, have ceased to abstract water and now rely instead on water supplied by Rand Water. In general the direct use of river water in the Klip river catchment for industrial purposes has fallen steadily over the years. This has been due both to the result of declining in-stream quality, as well as to the increasing ease with which to connect to a potable water supply reticulation system.

1.2.3 Agricultural users

Agricultural water use in the Klip river catchment mainly comprises crop irrigation and livestock watering. This takes place largely in the rural and per-urban areas in the catchment between the metropolitan areas of Johannesburg in the north and Vereeniging in the south. Information regarding the extent of irrigation and the use of water for irrigation remains somewhat contradictory, but knowledge about this use is improving.

As part of its drive under the new Water Act to charge all users of river water according to the volumes of water that they use, DWAF is presently collecting information on irrigation in the Klip river catchment. Investigations have been completed for the Klip river itself, but data remains to be collected for the Rietspruit segment of the catchment. The survey is focussing on riparian irrigation only and estimates of the amount of river water consumed for irrigation have been made based on discussions with local farmers. The survey provides valuable data to supplement existing irrigation data which has been based on satellite images.

The new on-the-ground survey by DWAF estimates that approximately 4400 ha of land could potentially be irrigated in the catchment. This compares with a recent DWAF estimate of 2670 ha of irrigated land a 1970's survey estimate by Stewart, Sviridov and Oliver, and Wits Hydrological Research Unit of 55 km^2 of irrigated land based on satellite images. The information on irrigation should continue to be verified to ensure more consistency, but the recent data does suggest that irrigated land in the catchment has declined over recent decades, especially in the Rietspruit catchment.

Based on an irrigation quota of 6100m^3/ha and an estimate of land which is presently actively irrigated, the recent DWAF ground survey indicates that the volume of water used from the river for irrigation amounts to just over 11 million m^3 per annum. It is assumed that the DWAF survey does not include farmland located inland from the river which is irrigated by borehole water.

The main irrigated crops grown in the Klip river catchment are maize, fodder crops, vegetables (especially carrots, spinach, cabbage, onions, potatoes and salad greens), instant lawn, nursery plants and private gardens. Livestock watering is also undertaken using river water for dairy and beef cattle, sheep and pigs. Farm sizes making use of irrigation systems range from >100ha to smallholdings of <10ha. The latter are most common on the banks of the lower Klip river.

The irrigation of crops in the catchment is an important component of the local economy and constitutes part of the market gardening belt surrounding and supplying Johannesburg. Sprinkle and pivot irrigations systems are most commonly used although flood irrigation was used extensively in the past, as exemplified by the number of furrows and canals shown on the 1:50 000 topographic maps of the catchment. Irrigation of gardens is partcularly prevelant at Henley-on-Klip, where many houses have river frontages.

Misuse of the potable water supply and sewage systems in the catchment has been observed in some urban townships and informal settlement areas to irrigate crops, especially mielies.

Treated sewage effluent, approximately 20Mℓ/day from Johannesburg's southern wastewater treatment works is also used to irrigate crops and water livestock on the GJMC owned Olifantsvlei farm, south of Eldorado Park, in the upper Klip river. ERWAT irrigates sewage sludge to land adjacent to its four wastewater treatment plants in the Rietspruit catchment.

1.2.4 Recreational users.

Recreational activities in the Klip river catchment include a wide range of non-contact, intermediate contact and full contact recreation including:

- Riparian home ownership;
- Picnicking;
- Fishing;
- Birdwatching and enjoyment of nature;
- Boating and cannoeing
- Swimming;
- Windsurfing, and
- Water-skiing.

These activities are particularly popular at impoundments in the urban areas of the Witwatersrand (e.g., Florida lake, Wemmer Pan, Germiston lake, Boksburg lake, etc.), which serve as important recreational hubs for city dwellers. Fishing is a popular recreational pastime in these impoundments and in the Klip river itself, but generally the fish species caught are not considered sensitive. The fact that fish may be consumed by fishermen, however, raises the issue of health.

The Vaal Barrage, into which the Klip river flows is also a key recreational area for both permanent residents and, in particular for weekend visitors. Full contact recreational activities are especially common on the Vaal Barrage. The number of people regularly using the Vaal Barrage as a recreational facility heightens any risks associated with poor water quality. Furthermore, the recreational attractions are of significant economic value, generating income which could be compromised by significant changes in water quality.

A number of small holiday resorts are situated on the banks of the middle Klip river. Additionally, existing and proposed hotels, riparian homes and commercial centres throughout the Klip river catchment, view the proximity to a water resource as being of economic and aesthetic importance. In particular, the Henley-on-Klip community in the lower Klip river is very active in promoting and protecting the Klip river as a recreational resource.

Although not identified as recreational activities, certain cultural practices of township dwellers also rely on the Klip river system. These include church baptisms and the use of river water in traditional medicine.

1.2.5 Natural environment.

The natural environment is both a resource and a water user and is heavily impacted upon by human activities in the Klip river catchment. Alien fuana and flora have established themselves in the river system and on its banks and this has affected the water uptake. The ecological diversity of aquatic life in the river system has also been significantly affected by an altered flow regime and deterioarating water quality.

There are no river areas in the Klip river catchment which can be considered pristine and therefore sensitive. Additionally, there are a few officially declared nature reserves in the catchment. The Klipriviersberg Nature Reserve offers some protection to the head waters of a number of tributaries (e.g., Bloubosspruit) of the Klip river in the upper Klip river segment of the catchment. Near to the Natalspruit/Elsburgspruit confluence in Germiston (in the Rietspruit catchment) is the Rondebult Bird Sanctuary, which in effect acts as a maturation pond for ERWAT's Rondebult wastewater treatment plant, but still remains popular with birders.

Aesthetics form an important component of the environment and river courses are increasingly being recognised as green belts. With this in mind, DWAF treats rivers as an integrated system and therefore as part of the wider environment in the catchment. Although the banks of the Klip river have been affected by urban development in its upper reaches and have been denuded by agricultural practices in places, there are places, such as Henley-on-Klip, where the banks of the river form an important part of the whole aesthetics of the river. Attractive areas along the river are, therefore, recognised as a high priority use within the whole river system.

The Vaal-Barrage Conservancy has been established by landowners adjacent to the Vaal Barrage at the foot of the Klip river. The objectives of this organisation are to promote the protection of the fauna and flora and the ecology of the Vaal Barrage. A similar organisation has recently been formed by landowners at Henley-on-Klip.

Water quality, biodiversity and recreational activity are inextricably linked so that changes in water quality in one river reach can affect significant changes in biodiversity and recreational potential over a much larger scale downstream.

Anthropogenic activities have shaped and continue to shape the ecology of the Klip river system. Treated effluent discharges enrich the system and foster the growth of reedbeds. Exotic plants have established themselves in the river system. Water abstraction, effluent discharges and urban run-off change flow patterns and nutrient levels. Siltation from mine dumps and construction sites modifies soil chemistry and affects the sediment composition of rivers. Weirs and bridges locally modify water depths and flow patterns, whilst effluent discharges and urban run-off are maintaining water chemistry at levels different to ancestral conditions.

Wetlands are common in the upper reaches of the Klip river catchment. They are of value because they sustain biodiversity, improve water quality and provide recreation opportunities. Their purification abilities help attenuate pollution, although they may also become a trap for wastes and suspended solids and they are frequently viewed by residents of nearby communities as a health hazard, or a haven for vagrants and criminals.

The dominant vegetation in the wetlands are reedbeds (*Phragmites communis* and *Typha capensis*), which are expanding because of nutrient enrichment of the river system and alteration of river banks. Many wetlands are thus artificially created as a result of human activities. They do, however, provide a sanctuary for birdlife, small animals and aquatic life.

No threatened fauna and flora are known to occur either in the Klip river catchment or in the riparian vegetation, although the rare rock catfish, *Austroglanis sclateri* has been observed.

The biological integrity of the Klip river system is considerably impaired. This is partially to be expected since the Klip river is an extremely altered system. Alterations to the system include:

- A completely modified hydrological regime - the strong seasonality of rainfall in this area is cancelled by more constant contributions from treated wastewater;
- A change in the chemical quality of water – rain water largely reaches the river via urban run-off, effluent discharge and mine drainage;
- Changes in stream morphology brought about by the building of weirs, bridges, recreational facilities etc., and
- Degradation and destruction of natural riparian habitats as a result of formal and informal urbanisation, and industrial, agricultural and domestic activities close to the river banks.

1.3 Water quality requirements.

1.3.1 Domestic use.

Most of the domestic water users in the Klip river catchment area are supplied with potable water treated to a high standard by Rand Water. However, a number of informal communities and farm labourers are living on land immediately adjacent to streams and rivers in the catchment. It is thought that in at least some instances, raw water from the river is used for domestic purposes. This is a highly undesirable situation, since bacterially uncontaminated water cannot be guaranteed, even in pristine streams. Domestic water refers to all uses to which water can be put in the domestic environment (drinking, food preparation, bathing, washing dishes and laundry, and gardening). Although it is believed that few people use the river water directly for drinking purposes, washing clothes is a common practice.

The aim must be to ensure that all such communities have access to a supply of potable water that has been treated to an acceptable standard. It follows that the target water quality objectives for rivers in the study area should be aimed at meeting the requirements for raw water that will be purified before domestic use takes place, rather that for the actual requirements for potable water. In this context, the main requirements are the minimisation or elimination where possible of intractable toxic substances, salinity, organic matter, metals, plant nutrients and associated nuisance algae.

1.3.2 Industrial use

Raw water is presently abstracted from the Klip river catchment for slimes dam reclamation and dust suppression. Until September 1998, the Orlando Power station in Soweto abstracted approximately 25Ml/d of water from Orlando Dam for cooling purposes in the power station. Most of the water abstracted comprises treated sewage effluent released from the Goudkoppies Wastewater Treatment Works upstream of Orlando Dam. The sensitivity of water used in power generation to high salinity levels is a concern in the Klip river catchment because of the mining activities at the head of the catchment. Otherwise, raw water abstractions for industrial use in the catchment are confined mainly to “dirty” water uses, such as for the hydraulic transport of gold mining slimes to and from reduction plants and for the suppression of dust at quarry operations and on gravel roads. Hippo Quarries has a permit to abstract $350m^3$ /d of water from the upper Klip river for dust suppression at its quarry operations near the Durban Roodepoort Deep Mine. They currently use only about half of this quota. At Angelo Pan, near the Elsburgspruit on the East Rand, ERGO abstracts approximately 20Ml/d of water for use as process water in their workings for gold mine dump reclamation.

The water quality requirements for these type of industrial use are unlikely to affect the water quality objectives set for the Klip river, which will be dominated by much more sensitive water uses.

1.3.3 Agricultural use

Agricultural water use takes place throughout the Klip river catchment outside of the urban areas and comprises both livestock watering and crop irrigation. The irrigation of private gardens using river water also occurs. Irrigation is the most senstive agricultural use with respect to salinity related variables such as electrical conductivity or total dissolved salts, sodium, chloride, sulphate and bicarbonate. Crop damage to plants as a result of salinity effects include:

- Leaf damage,
- Reduced plant growth, and
- Impairment of plant physiology

Bacteriological pollution is also of concern if irrigated crops are to be eaten raw, of if the river water is used for dairy cattle watering. Uptake of metals in irrigated crops may also pose a limited risk.

1.3.4 Recreational use

Non-contact recreational use is common to virtually all river reaches, while full contact recreation occurs at a number of localities in the Klip river catchment.
Full contact recreation is particularly sensitive to bacteriological pollution, which is prevelant throughout the catchment. This has adverse effects for much needed recreation in these tributaries as well as in the Vaal River Barrage, which is a prime recreational area. In common with most other categories of water use, recreation is alos impacted upon by eutrophication resulting from elevated nutrient levels. This causes the rapid growth of nuisance algae and water plants which can become entangled in fishing lines, oars and boat rudders. Furthermore, when the algae decays, it can release odours as well as algal toxins which may be detrimental to human health (e.g., gastroenteritis), and cause skin irritations.

1.3.5 Natural environment

The natural environment is a user present in every river reach. As such its water quality requirements must always be taken into consideration. The natural environment or aquatic system is frequently found to be the most sensitive user, particularly with regard to free ammonia, nitrite, hydrogen sulphide, dissolved oxygen levels, turbidity and metals.

Appendix 2:

Methods of analysis used by AEC for the radiological analysis of the samples (information supplied by A Faanhof):

The analytical method used for gross activity was aeration followed by liquid scintillation counting, with evaporation followed by gas-flow detector counting as an alternative method. The method used for U-234; U-235; U-238; Pa-231; Th-232; Th-230; Th-228; Th-227; Ac-227; Ra-228; Ra-226; Ra-224; Ra-223; Po-210; and Pb-210 was radiochemical separation followed by alpha particle spectrometry; Internal yield tracer and certified efficiency calibration standards. As an alternative method U-234, U-238 and Th-232 were also determined by sample atomisation followed by mass determination using chemical calibration standards.

APPENDIX 3: INFORMATION ON DECAY CHAINS.

NATURALLY OCCURRING RADIONUCLIDES (TECHNICAL COMMITTEE)

Tables A4.1, A4.2 and A4.3 list the radionuclides in each of the three radioactive decay chains of relevance to this study. Every radionuclide, when ingested, gives rise to a radiation dose to the individual. The amount of dose varies by orders of magnitude from one radionuclide to another, as illustrated by the tabulated values of annual dose per unit activity concentration in water. Details of the calculations involved are given in Appendix 8.

<u>Notes on Tables A3.1, A3.2 and A3.3</u>

1. The annual dose per unit activity in water is defined for the purposes of this study as the radiation dose, in millisieverts, received annually by an individual from the sole continuous use of drinking water at two litres per person per day containing 1 becquerel of activity of the radionuclide concerned per litre of water, averaged over a lifetime of 70 years.
   (1 becquerel = 1 nuclear disintegration per second).
2. Radionuclides in ***bold italics*** are those measured in all or part of this study.
3. Radionuclides marked with an asterisk* are the radon isotopes and their short half-life daughters.
4. Dose conversion factors not given by the IAEA are left blank and are taken as negligible.
5. Uranium-238 and uranium-235 occur naturally in the approximate activity ratio 21 : 1.
6. Gross alpha activity, as measured in this study, is taken to be the sum of the activities (in becquerel) of all the alpha emitters (excluding radon and radon daughters), per litre of water.
7. Gross beta activity, as measured in this study, is taken to be the sum of the activities (in becquerel) of all the beta emitters (excluding radon daughters), per litre of water. The list of beta emitters includes potassium-40, a naturally occurring radionuclide which is found in water, but which does not form part of the uranium-238, uranium-235 or thorium-232 decay series. It is not of interest in dose calculations because its concentration in the body is essentially independent of intake.

Table A3.1: Uranium-238 series radionuclides

Radionuclide	Type of radiation emitted	Annual dose per unit activity concentration in water (mSv/a) per (Bq/ℓ)
Uranium-238	Alpha	0.033
Thorium-234	Beta	0.0027
Protactinium-234m	Beta	
Uranium-234	Alpha	0.036
Thorium-230	Alpha	0.15
Radium-226	Alpha	0.27
Radon-222*	Alpha	
Polonium-218*	Alpha	
Lead-214*	Beta	0.00012
Bismuth-214*	Beta	0.000087
Polonium-214*	Alpha	
Lead-210	Beta	0.59
Bismuth-210	Beta	0.0010
Polonium-210	Alpha	1.0

Table A3.2: Uranium-235 series radionuclides

Radionuclide	Type of radiation emitted	Annual dose per unit activity concentration in water (mSv/a) per (Bq/ℓ)
Uranium-235	Alpha	0.034
Thorium-231	Beta	0.00027
Protactinium-231	Alpha	0.52
Actinium-227	Beta	0.85
Thorium-227	Alpha	0.0080
Radium-223	Alpha	0.11
Radon-219*	Alpha	
Polonium-215*	Alpha	
Lead-211*	Beta	0.00015
Bismuth-211*	Alpha	
Thallium-207*	Beta	

Table A3.3: Thorium-232 series radionuclides

Radionuclide	Type of radiation emitted	Annual dose per unit activity concentration in water (mSv/a) per (Bq/ℓ)
Thorium-232	Alpha	0.167
Radium-228	Beta	0.886
Actinium-228	Beta	0.00034
Thorium-228	Alpha	0.064
Radium-224	Alpha	0.069
Radon-220*	Alpha	
Polonium-216*	Alpha	
Lead-212*	Beta	0.0057
Bismuth-212*	Alpha 36% Beta 64%	0.00021
Thallium-208*	Beta	
Polonium-212*	Alpha	

Appendix 4: Dose evaluation Ranges for drinking Water Quality (DWAF,2002).

Class /Colour	***Dose range; mSv/a***	***Health Effects and Typical Exposure Scenarios***	***Intervention Decision Time Frames***
Class 0 **(Blue - Ideal water quality)**	0.01 – 0.10	• There are no observable health effects. • This is the range of exposure from ideal quality water sources. • Most treated water falls in this water quality range. • Additional doses that result from human activities that fall within this range are difficult or impossible to determine and/or to distinguish from variations in background doses with sufficient confidence.	Intervention not applicable for this class of water.
Class 1 **(Green - Good water quality)**	> 0.10 – 1	• There are no observable health effects. • It is the range of exposure from some natural and untreated water sources (e.g. ground water / wells) as well as water sources that could be influenced by mining and mineral processing activities. • A dose between 0.2 to 0.8 mSv/a is the typical worldwide range of ingestion radiation dose resulting from water as well as food. • A dose equal to 1 mSv/a corresponds to the regulatory public dose limit for human activities involving radioactive material.	No intervention is required although ALARA principles apply.
Class 2 **(Yellow - Marginal water quality)**	> 1 – 10	• A small increase in fatal cancer risk associated with this dose range. • Probably only a small number of natural water sources of this quality exist, resulting from exceptional geological conditions. • Abnormal operating conditions at some nuclear certified mineral and mining processes may result in a dose in this range when a person drinks the untreated water. Intervention will most likely be required to improve the quality of water that is released into the public domain. • The total natural background radiation from <u>all</u> exposure pathways, not only water, falls in this range.	Intervention considerations within 2 years.
Class 3 **(Red - Poor water quality)**	> 10 – 100	• Health effects are statistically detectable in very large population groups. • This range represents excessive exposure. • It is highly unlikely to find water of this poor quality in the natural environment.	Intervention is required in less than 1 year.
Class 4 **(Purple - Unacceptable water quality)**	> 100	• Health effects may be clinically detectable and a significant increase in the fatal cancer risk (greater than one in a thousand). • A dose greater than 100 mSv can usually only occur during a major accident at a nuclear facility. These facilities have to demonstrate that such an accident cannot happen with a frequency of more than once in a million years.	Immediate intervention is required.