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ISCOR VANDERBIJLPARK STEEL

ENVIRONMENTAL MASTER PLAN

SPECIALIST REPORT

IDENTIFICATION OF SECONDARY SOURCES OF POLLUTION ENVIRONMENTAL AND HUMAN RISK ASSESSMENT

Volume 1

BY
OCKIE FOURIE TOXICOLOGISTS

SERIES IV
DOCUMENT IVS/SR/029(a)
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Draft for discussion
CONFIDENTIAL
Research for IVS

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ISCOR VANDERBIJLPARK STEEL

ENVIRONMENTAL MASTER PLAN SPECIALIST REPORT

Identification of Secondary Sources of Pollution Environmental and Human Risk Assessment

Volume 1 of 5

SERIES IV
SPECIALIST REPORT IVS / SR / 029(a)

DECEMBER 2002

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Table of Contents

VOLUME 1 of 5

Table of Contents (continued)

Table of Contents (continued)

PAGE

Table of Contents (continued)

APPENDIXES

APPENDIX 1

VOLUME 2 of 5

DAM 10: ENVIRONMENTAL RISK QUANTIFICATION AND HUMAN RISK ASSESSMENT SUMMARY TABLES

1.1 Dam 10: Waters Inorganic

1.2 Dam 10: Waters Organic

1.3 Dam 10: Sediments Inorganic

1.4 Dam 10: Sediments Organic

Table of Contents (continued)

APPENDIX 2

VOLUME 3 of 5

EVAPORATION DAMS 1 - 4: ENVIRONMENTAL RISK QUANTIFICATION AND HUMAN RISK ASSESSMENT SUMMARY TABLES

EVAPORATION DAM 1

Table of Contents (continued)

APPENDIX 2 (continued)

EVAPORATION DAM 2

Draft for discussion
CONFIDENTIAL
Research for IVS

Table of Contents (continued)

APPENDIX 2 (continued)

EVAPORATION DAM 3

Table of Contents (continued)

APPENDIX 2 (continued)

EVAPORATION DAM 4

Table of Contents (continued)

VOLUME 4 of 5

MATURATION PONDS 1 - 3: ENVIRONMENTAL RISK QUANTIFICATION AND HUMAN RISK ASSESSMENT SUMMARY TABLES

MATURATION POND 1

Draft for discussion
CONFIDENTIAL
Research for IVS

Table of Contents (continued)

APPENDIX 3 (continued)

MATURATION POND 2

3.5 Maturation Pond 2: Waters Inorganic

3.6 Maturation Pond 2: Waters Organic

3.7 Maturation Pond 2: Sediments Inorganic

3.8 Maturation Pond 2: Sediments Organic

Table of Contents (continued)

APPENDIX 3 (continued)

MATURATION POND 3

3.9 Maturation Pond 3: Waters Inorganic

3.10 Maturation Pond 3: Waters Organic

3.11 Maturation Pond 3: Sediments Inorganic

3.12 Maturation Pond 3: Sediments Organic

Draft for discussion
CONFIDENTIAL
Research for IVS

Table of Contents (continued)

APPENDIX 4

VOLUME 5 of 5

SOILS: ENVIRONMENTAL RISK QUANTIFICATION AND HUMAN RISK ASSESSMENT SUMMARY TABLES

SOILS

Table of Contents (continued)

APPENDIX 5

VOLUME 5 of 5

LEACHATES: ENVIRONMENTAL RISK QUANTIFICATION AND HUMAN RISK ASSESSMENT SUMMARY TABLES

LEACHATES

EXECUTIVE SUMMARY

The potential risk to humans and the environment by secondary sources of contamination i.e. waters, sediments, soils and leachates at IVS, were investigated and quantified.

Waters in dams and ponds are largely homogeneous in composition with regard to inorganic contaminants. Dams 10 and 1-4 poses a potential unacceptable risk to the aquatic environment, mainly due to manganese in dam 10 and cadmium, lead and manganese in dams 1-4, ground water being the pathway of exposure. Cyanide, although only present in one sample in dam 1, also presented a potential unacceptable risk to the aquatic environment. The waters of the maturation ponds are also of potential unacceptable risk to the environment, particularly due to high concentrations of cyanides and fluorides present, not observed in the other dams. Unacceptable risk to human consumption of possible contamination of ground waters by dam and pond waters, were indicated mainly by manganese, aluminium, cadmium and titanium, being representative of the more potent inorganic contaminants, relative to the macro compounds present.

The macro compounds, e.g. sulfates, chlorides, calcium etc. are also present in significant concentrations in all dam and pond waters. Some of these contaminants also indicate a potential risk to the environment and man, ground water being the exposure pathway.

Organic contaminants (volatiles and semi-volatile) were generally not present in the waters of dams 10 and 1-4, being however present in significant concentrations in waters from the maturation ponds, which indicated a potential, risk to man and the environment.

Sediments were contaminated to a lesser extent by inorganics than waters, being however significantly contaminated by organics. Although inorganics and organics in sediments indicate a potential risk to humans and environment, was it concluded that such potential risk be interpreted with caution due to the observed immobility of contaminants. It was also proposed that specifically due to immobility of compounds in sediments, that contaminants (organics) are allowed to degrade *in situ*, and hence should *in situ* rehabilitation be considered.

Approximately 50% of surface soil samples within the Works area were impacted on by manganese (one sample by zinc) to the extent that it indicates a potential risk to the environment. Twenty nine percent of soil samples indicated potential risk to humans due to Al, Fe, Mn or Ti, ground water being the exposure pathway. Most of the soils were from the CRMF area, others from the CPA and South Western Slag Processing area. No organic contaminants were observed in any of the soil samples, hence soils contaminated with organics being of little concern to man and the environment.

Leachates generated under dry weather conditions were assessed according to composition, and not on a total load basis, total volumes generated per unit time not known. Most leachates indicated potential risk to man and the environment, mostly due to inorganics such as aluminium, fluorides, manganese and sulphates.

1. INTRODUCTION

The release of harmful substances to air, water and soil, burdens our planet with complex environmental problems, resulting in disregarding the protection of health and well being, not only of man, but the ecology in its broadest sense. Industry is continually burdened with such problems, to which pollution prevention provides a solution. Pollution prevention could be described as the elimination, avoidance and reduction of pollution and waste, particularly at source, by which it provides a comprehensive, multi-media (air, land, water) approach to environmental management. It should be regarded as the cornerstone of effective compliance strategies, and should be practiced as a first priority in production processes.

The philosophy (pollution prevention) depicted above however, is relatively speaking of a more simplistic nature in that pollution prevention could and should be introduced before and during operational practices of new or novel industries. What is of a much more serious, complex and eventually capital intensive nature, is what is commonly referred to as "historical pollution of the past". During the period of the "technical explosion" a century ago, neither scientists, engineers or regulatory authorities were adequately knowledgeable regarding potential contamination / pollution of waters, air and soils (land) due to dumping or disposal practices of slags, sludges, waters, dusts and all kinds of residues. This fact inevitably resulted in unprecedented practices, the consequences of which have to be addressed in our present time.

The Iscor Vanderbijlpark Steel Works falls within the category of industries that began during the "technical explosion" of the past century when inadequate knowledgeable practices were the order of the day. For many decades, wastes being *inter alia* slags, sludges and effluents have been dumped without any precautionary measures. This happened all over the World – refer for example to the well-known USA Superfund Sites – with numerous severely contamination consequences which are abundantly recorded in the International literature.

An Environmental Management Plan mainly endeavours a study to characterize the environment of an industry in an integrated holistic approach in scope, and as such, all environmental management approaches need to be addressed holistically. Rules and regulations that focus on single media (air, land, water) may often create large problems for other media that are not accounted for by a specific, single media orientated solution. Whilst the intensions may be good, *ad hoc* studies often only result in the transfer of contaminants from one medium to another.

A quantitative risk based approach should be followed by modeling and calculating acceptable /non-acceptable risk to both man and the environment according to good toxicological practice. This was performed for all sources identified at IVS, described and discussed in the chapters and volumes of this Specialist Study.

2. IMPACT AND RISK ASSESSMENT / RATIONALE FOR RISK EVALUATION

2.1 Introduction

Risk assessment is a complex process. It is a process, which endeavors to evaluate the possibility of harm to receptors caused by exposure to stressors. Very often risk assessment is run down by quoting the relationships "dose/response" and "exposure/effect" as being the end of it all. Although being the basis of pharmacokinetics, which could be described as the fundamentals of life, thorough cognisance has to be taken in risk assessment of other related fundamentals:

- Absolute safety does not exist
- No risk situations do not exist
- There are only choices among risks
- The mere presence of a chemical substance does not *ipso facto* imply a detrimental effect
- When safety to any form of life is the objective, the only rational approach is through the nature of the toxicity in question, and the application of benefits versus potential hazards under the condition of intended use of the compound.

These quotes are very important when risk assessment methodology is to be designed to formulate protection, which amongst others, has to ensure that regulatory actions will be protective of human health and ecosystems. Whilst it is important not to underestimate risk to all forms of life, it is equally important to note that compounded conservatism tends to overestimate risk and thereby not only being overly protective of health, but indeed likely to harm health, for example with regard to essential trace elements such as chromium^{3+}, iron and manganese. Thus, it is important not to muddle the much popular concept "precautionary principle" with over conservatism!

Risk assessment, both with regard to human health and the ecology, is primarily based on three steps. Should any one of these steps be absent, an evaluation of possible harm would not be feasible:

Release of contaminants, exposure conditions, fate and transport of pollutants, and contact between receptors and stressors, could all be termed the **Pathway** for exposure. Pathways determine whether a route of exposure would be direct or indirect, the result of which will provide a quantitative estimate of the risk posed to stressors. Direct pathways would be for example inhalation of atmospheric dispersed contaminants, and the ingestion of surface and ground waters to which contaminants were released. Indirect pathways could involve the total food chain for humans and the ecology alike.

In summary, the sources and pathways for a contaminant must be studied in great detail before biological effects can be related to exposure. Once this is done, the critical dose/response level can be established to ensure that adequate control exist to regulate the stressors in question.

The second step is the determination of potential adverse effects when exposed to contaminants. These evaluations are primarily based on toxicity information from laboratory toxicity studies in animals as well as results from epidemiological studies when available. Although some important pharmacokinetic differences do exist between animals such as rats and mice, and more importantly between animals and humans, is the principle of extrapolating from animal data to humans accepted in the scientific and regulatory community.

It is however very important to realize that generally all models used are simplification of reality. To use rodents as surrogates for humans, to extrapolate from high experimental doses to low environmental relevant doses, introduces uncertainty. To use indicator species such as for example certain fish species in dose/response assessments and extrapolate the results thereof to the aquatic environment, i.e. take in consideration the protection of more than one species, introduces uncertainties. Uncertainty factors, or safety factors are used in mathematical modeling to provide for these uncertainties, which results in health benchmarks used as single-point estimates, which again may have associated variabilities and uncertainties of up to an order of magnitude or more.

The importance of a full understanding of the above, lies in the fact (understandingly so) that risk assessment largely tends to favour conservatism, and is thus very likely to overstate actual risk and therefore being overly protective of human health and the ecology.

The third step in risk assessment is the quantification of exposure. Quantification of exposure could be termed the Estimated Environmental Concentration (EEC) being the magnitude and duration of exposure by the contaminants of concern, to receptors likely to be exposed or impacted on.

Quantification of exposure is normally based on either monitoring a specific situation or by modeling, i.e. predict a specific situation. Both these approaches suffer uncertainties similar to the evaluation of potential adverse effects from animal toxicity studies. One of the major uncertainties in the monitoring approach is the reliance on analytical methods and associated detection limits, which could result in contaminants not being detected. Normally for risk assessment purposes such an event will be indicated by zero exposure, which could be problematic with for example, carcinogenic substances with a genotoxic mode of action (mechanism).

It is believed in some scientific circles that modeling is to be preferred above monitoring. Such a statement has to be questioned, in that exposure quantification and the accuracy thereof would certainly depend on, amongst others, pathway, media and sources. Modeled data depends on data (information) provided, assumptions and relationships chosen for a specific model. These factors are more than often very subjective, do not represent the environmental situation, and could result in large discrepancies in estimating or predicting exposure.

It is therefore to be accepted that both methods describing exposure for risk assessment purposes would contain advantages as well as disadvantages, and that the two methods could differ in resultant ambient contaminant concentrations for a specific pathway. Calculated, modeled or measured exposure may therefore differ from actual exposure, and for this reason the tendency is again to opt for maximum exposure scenarios, also termed Worst Case Scenario.

In summary, the three steps described i.e. ① pathway, ② evaluation of dose/response relationships and ③ quantification of exposure, are the basis for describing potential risk, incorporating assumptions, uncertainties, safety factors etc., in the formulations thereof. Whilst the utmost must be done and considered to ensure the most sound scientific basis possible, care should be taken in the interpretation of results with special reference to conservatism in estimating ecological and human risk.

2.2 Ecological Risk Assessment

Some contaminants, when released to the environment, do not have apparent direct effects on living organisms, but do so indirectly by changing the chemical characterization of their habitat or environment. Other contaminants do display a dose/response or exposure/effect relationship to living organisms, and these contaminants are often referred to as being "toxic".

The assessment of the probability that adverse effects will occur in the environment is being complicated by the existence of multiple pathways and thousands of vertebrate and invertebrate species which ideally have to be considered in risk assessment. This is not possible. The only possible and feasible scenario would be the accomplishment of ambient concentrations of chemicals as ecological benchmarks which will not contribute to significant risk, and which will have to provide for the protection of more than one species. Such a scenario will depend on two cornerstones, one being that indicator species will have to be utilised in toxicity studies from which extrapolation to the total specific environment (i.e. aquatic environment) could be effectuated. Secondly, and most importantly, must the benchmark be an acceptable risk approach representing various species and trophic levels, which is also in line with the philosophy that no risk situations do not exist.

The departure point for a risk assessment of the environment, would be the decision or acceptance of the pathway to be followed. In this regard the aquatic pathway (ground or surface waters) is internationally accepted to be the more applicable due to its associated sensitivity. It could be stated, albeit with caution, that when the three environmental medias (air, land, water) is considered, that the aquatic pathway or route of exposure is the more appropriate to rely on for interpretation to the ecology.

As commonly known and referred to in paragraph 2.1, consists the risk assessment equation, of exposure on the one hand and effect on the other hand.

The exposure side is addressed by either measuring or monitoring of actual concentrations (dose) applicable, or by estimating the environmental concentration

(EEC) by for example mass balance equations. Such models are normally "worst case scenarios" which on the one hand is conservative (and may be too conservative), but allows upper bound risk estimates. The most negative part of such worst case scenarios is the fact that these models do not provide for the fate and transport of the contaminant in the environment. For example do organic contaminants biodegrade (aerobic and anaerobic), or degrade through hydrolysis and photolysis to ultimately mineralize to CO_2, very often by relatively short biological and environmental half-lives and dissipation rates. Factors such as these mentioned may well give rise to over estimation of risk.

By relating known biological and ecological responses of known concentrations (dose) of a contaminant to actual or estimated environmental concentrations, it is possible to quantify possible risk to the environment. Dose/response data is to be obtained from controlled tests with selected indicator species. Indicator species are carefully chosen according to specific criteria such as for example demonstration over years of testing that the species is sensitive to known effects produced, and produces dose-response data to a variety of contaminants. Data must therefore be of a high quality from a significant number of species in the aquatic environment to be able to derive protective criteria extrapolated to "all" species in such an environment.

Sensitive toxicity endpoint data such as those derived from chronic toxicity testing, i.e. no-observed-effect levels, would be the most desired data for benchmark purposes. However, such data only exist for a small percentage of contaminants of concern, and would relatively speaking be more readily available for novel molecules than for those we are so familiar with. Values more readily available in the International literature, are acute LC_{50} values which represents a 50% lethal concentration to a given indicator species. These acute toxicity levels, based on mortality (effect), is therefore to be used to derive acceptable risk levels in an ecological risk assessment, the pathway being the aquatic environment.

In using the available and applicable LC_{50} values published in the open literature, a safety factor has to be adopted or implemented to provide a large margin of safety so as to make provision for inter-species variation and sensitivity, as well as for the fact that effect is based on mortality and not chronic effects. Because the slopes of dose/response curves of the effects of a contaminant on most aquatic species is unknown, a model was used (in this study) to express the quantitative risk for 1/10 the LC_{50}, and to calculate actual risk from the actual concentration measured in specific media (water, sediment, etc.). The acceptable risk of 0,1 x LC_{50} is calculated from a cross section of typical dos/response data, with a typical slope of dose/response curves. From an exposure 10 times lower than the LC_{50}, approximately 0,00034% or one in a population of 300 000 exposed to the contaminant, is likely to die. Actual risk incorporating the concentrations of contaminants exposed to is quantified by the application of a probit model from which the severity of risk can be observed.

2.3 Human Risk Assessment

The broad philosophy for human risk assessment is very similar to ecological risk assessment. Both these philosophies aim at deriving dose/response information from which a dose could be calculated which would be unlikely to cause adverse health effects. Ecological risk assessment has the distinct advantage that, specifically with reference to site specific studies, tests could be performed with the actual species of relevance, resulting in high confidence acceptable risk values. The equivalent to acceptable risk values, being Acceptable Daily Intakes (ADI) or Reference doses (Rfd) in human risk assessment, will always be derived from animal toxicity studies, although epidemiology studies in exposed human populations could make important contributions.

Dose/response information from animal studies for extrapolation to humans can only be done with high confidence if a full toxicological dossier has been followed in tests performed. Such a dossier would for example inter alia include physical/chemical properties, acute, sub-acute, sub-chronic oral, dermal and inhalation studies, teratogenic, embryotoxicity and fetotoxicity, two- generation reproduction, mutagenicity, chronic toxicity and carcinogenicity studies, pharmacokinetics, and a very large and comprehensive number of ecotoxicity and environmental fate studies. Such toxicity studies for one molecule could take up to 12 years of research, the costs which could approach one billion American dollars.

Potential for human toxicity is, as mentioned, based on an approach, which assumes that laboratory animals are surrogates for human and other mammalian species. Acceptable daily intakes or References doses are determined from such tests for non-carcinogens, whilst Reference doses as well as oral slope factors and oral unit risk factors are used with administered doses to estimate the probability of increased cancer incidences over a lifetime.

2.3.1 Non-carcinogenic Contaminants

Non-carcinogenic substances are substances, which demonstrate in *inter alia* chronic and carcinogenicity studies, as well as genotoxicity studies, to have a threshold dose below which no adverse effects occur. Normally these studies are conducted according to very strict prescribed protocols, using more often than not, rats and mice as surrogates. The species strain must be known and very importantly, many years of historical data must exist on the specific strain at the specific laboratory. Duration of such tests is 18 – 24 months. Throughout the tests, in depth observations are made *inter alia* on opthatmological, haematological, biochemistry and histopathological examinations, which normally results in a no-observed-effect-level (NOEL), which is used in the derivation of an Rfd or ADI. The importance of such comprehensive studies is that, amongst others, relatively small (10 or 100) safety factors are used in deriving the Rfd or ADI, due to the high measure of confidence in the data. However, such data (and studies) are normally only available for novel molecules, and not for compounds known for decades or centuries. Data for the latter compounds is usually of a low measure of confidence, which means that safety factors normally used vary between 1 000 – 10 000.

2.3.2 Carcinogenic Contaminants

It can be stated that for most of the older contaminants for which no comprehensive toxicity studies were performed, a philosophy that all carcinogens have no threshold for effects, were applied. Data from this philosophy applied is omnipresent to be found in the International literature.

Many models exist and is being used to extrapolate from high doses (animal studies) to environmental (ambient) low doses, e.g. one-hit model (one critical molecular event results in a tumor), multistage model (cancer is believed to be a multistage process), linearised multistage model (95% confidence limit to reflect biological variability in the observed tumor frequencies and being used by the USEPA), multi-hit model, log-probit model etc. Results from these models (extrapolation from high to low doses), results in the slope of the line to represent slope factors being the excess cancer risk per unit dose.

This kind of data need to be commented on. Except for very important data in carcinogenic risk assessment such as type of tumor and relevance of tumor type, to disregard the mechanism by which tumors are produced, must be deplored. It is simply not true that only genotoxic mechanisms (direct interaction with DNA), is responsible for carcinogenesis. Many *in vitro* and *in vivo* tests are available to indicate a possible genotoxic mechanism (opposed to an epigenetic mechanism), and to apply non-threshold models to derive cancer risk values for epigenetic mechanisms is simply a wrong approach.

In summary, in order to perform risk assessment to the ecology, the estimated environmental concentration, as measured or modeled (EEC), is related to known biological responses with a safety factor, to allow for inter-species variation and sensitivity (Acceptable Risk Value). For human risk assessment, exposure is quantified by calculation of the potential daily intake (PDI), and subsequent relating the PDI as a percentage of the ADI or Rfd, as quoted or published in the International literature.

3. APPROACHES AND METHODOLOGY

Identification of secondary sources of contamination and pollution at IVS, is primarily directed towards characterization of the Steel Works environment. Three of the more important objectives of identification of such sources are to firstly characterize the contaminants, which might have, and are able to specifically contaminate ground waters, surface waters and soils. Fingerprinting of a source is a very important aspect of an integrated holistic approach, in that it could be instrumental in ground water geohydrological studies, as well as surface water management objectives.

The second objective of importance is to be able to quantify possible risk to the ecology and humans induced by the sources, and the third objective is to allow the correct measures for pollution control and rehabilitation to be introduced.

3.1 Sources of Possible Contamination

Possible sources of contamination at IVS are mostly confined to the Central Plant Area (CPA) and the Consolidated Residue Management Facility (CRMF) in the North-western part of the Works.

Very little open areas (soils) are available in the CPA area due to buildings and tarred roads covering most of the infrastructure. Never-the-less do small areas of open soils exist which could be contaminated by for example contaminated process waters at business units not properly bunded, particulate fall-out from stack releases, and surface waters (rain water) being contaminated by process water spills and resultant contaminated soils and paved areas.

The CRMF area consists mainly of three activities, i.e. the current dump site where waste streams such as inorganic slags, sludges, dusts and other mixed residues were disposed of through the years. Some organics, although of minor quantities relative to slags, sludges and dusts, were also disposed of on this disposal facility. Much of this material was however either used as fuels or disposed of at other registered facilities such as Holfontein. Currently no organics such as tars are being disposed of on this facility.

The second activity in the CRMF area is that of evaporation dams, i.e. dam 10, dams 1-4 and the maturation ponds. These dams were used through the years for evaporation and storage of process and contaminated surface waters, containing both inorganic and organic substances. Through the years, some sludges were also disposed of in specifically dam 10, however this activity was stopped more than 20 years ago. Currently dam 10 is nearly empty (not in use anymore). For detailed information on the evaporation dams, the reader is referred to the Process and Surface Water Specialists Reports.

The third main activity in the CRMF is the stacking and reclaiming of raw materials. With regard to potential contamination of ground and surface waters, leachates from these activities under wet weather conditions is regarded as a source of contamination, albeit of a lesser extent than expected from disposed sludges, slags and dusts as well as sediments in evaporation ponds and dams.

Other minor sources of contamination of specifically ground and surface waters, such as for example rubble heaps, may also be present in the CRMF area. Although these sources cannot be ignored, should the contribution of contamination relative to the evaporation dams and disposal facility in the CRMF area, be regarded of a much smaller possible impact to the environment.

3.2 Sampling Methodology

3.2.1 Waters in Evaporation dams

Dams 10, 1 – 4 and maturation ponds 1 – 3 varies in size, comprising of the following surface areas (rounded off):

Dam 10, Evaporation Dams & Maturation Ponds (MP)		**Area (ha)**	**Total Volume (m^3)**
Dam	10	64	998 548
Dam	1	13	75 343
Dam	2	12	45 653
Dam	3	20	-
Dam	4	42	978 247
MP	1	12	181 547
MP	2	6,5	375 112
MP	3	6,5	145 266

In order to be able to take water samples in a grid covering the total area of a dam, a raft 3m x 3m was constructed, with a hole or opening in the center of the floor area to allow accurate sampling. A small 8 horsepower outboard motor attached to the raft facilitate movement from one sampling point to another.

Two heavy anchors at opposite corners of the raft allowed the raft to be anchored before sampling to avoid any drift during the sampling period. The raft was equiped with cooler boxes filled with ice to keep samples between 0 – 4°C during actual sampling, whilst a light delivery van, equipped with two 100ℓ fridges (0 – 4°C), was waiting at the shores of the dams to transport samples immediately after each sampling run to the laboratories. Sampling locations were accurately plotted by means of a Global Positioning System for future reference.

The following procedure was followed at each sampling position: The water depth to the bottom was measured after which sampling commenced. Water samples were taken with a disposable teflon bailer;

- One litre samples at the top and bottom of dam, poured into one liter pre-washed polyethylene bottles. These samples were designated for inorganic macro-element analysis;
- 350 millilitre samples at top and bottom of dam, poured into 350 ml pre-washed polyethylene bottles, to which 3,5 ml of a 20% sulphuric acid solution was added. These samples were designated for inorganic micro-element analysis, and the addition of sulphuric acid was to prevent possible adsorption onto walls of container;
- One litre samples at bottom of dam, poured into a pre-washed and thermal dried one litre Schott glass bottle designated for semi-volatile organic constituents; and
- 50 ml samples in duplicate at top of dam, poured into special pre-cleaned 50 ml EPA vials to the brim, and closed without any air bubbles present. These samples were designated for volatile organic constituents present in waters.

All samples were immediately secured in the ice filled cooler boxes, which were taken to the fridges after every second sampling position.

3.2.2 Sediments in Evaporation Dams

Sediment samples were taken at every sampling location. The samples were taken by pulling a dredger for about 5 metres, and the sediment poured into 1 litre glass Consul jars and cooled. The dredger accumulated sediments from the first 1 – 10 cm from the floor of the dam.

3.2.3 Soils within the perimeter of the IVS Works Area

Soils were sampled all along the perimeter of the Works at regular intervals, in order to quantify possible contamination mainly via fallout, leachates and contaminated storm water/process waters. Secondly were soils sampled throughout the interior of the Works, specifically covering the Management Areas within the perimeter of the Works.

Sampling location were plotted by means of a Global Positioning System for future reference. Samples taken were a composite sample from a one metre square area and 10 cm deep. The composite sample was approximately one kilogram in mass, poured into one litre wide-mouth polyethylene bottles.

3.2.4 Leachates under Dry Weather Flow Conditions

Some sources of possible contamination did not warrant actual analysis of the source itself. Stockpiles of raw materials would for example be classified in this category. Other sources, for example the old dump, would not lend itself to any meaningful characterization, due to either the impossibility of taking a homogeneous and/or a representative sample. Composition of coal or iron ore is well known, whilst actual waste streams being disposed of at the residue facility are being characterized or analyzed on a regular basis.

The same kind of arguments hold for leachates under wet weather conditions. These leachates are being thoroughly dealt with in the surface and process water specialist studies. It was therefore decided to characterize the kind of sources referred to by sampling leachates, where available, under dry weather flow conditions. Analysis of these leachates would provide some indication of the composition of the specific source and the possible risk thereof to man and the environment. More importantly would such information contribute to management measures needed for pollution control and rehabilitation.

Two one litre samples were taken, in a polyethylene bottle for inorganic analysis, and one in a glass bottle for organic contaminant analysis. Samples were dispatched to the laboratories the same day of sampling.

3.3 Analytical Methodology

Dam waters and leachates were analysed for inorganic micro and macro constituents by Waterlab Research (Pty) Ltd, and for organic volatile and semi-volatile constituents by the CSIR Bio/Chemtek laboratories. Standard Atomic Absorption Spectrometry methods were used for determination of inorganic micro constituents, and standard colorimetric colour development and titrimetric methods for inorganic macro constituents.

Volatile organics were determined by purge and trap GC-MS, using method GC.050, based on USEPA 8260. Semi- volatile organics were determined using a GC-MS method based on USEPA 8270.

The sediments were also analysed for inorganic micro and macro constituents as well as volatile and semi-volatile organics, as described for waters and leachates. Organics on all sediments were performed with extractions on the intact sediment sample. In order to broaden the picture of possible environmental contamination from sediments, were the analysis for inorganics, extended to also include mobility of constituents in the sediments. Analysis were thus performed as a total analysis, i.e. the total concentration of a contaminant in the sediment, and/or the TCLP mobility of the contaminant in question. Results of the different methodologies of analysis will be discussed and referred to in paragraph 4, Discussion of Results.

Soils were analysed for mobile inorganic and organic compounds. Inherently soils naturally contain many of at least the inorganic contaminants also present in contaminated media, and is it therefore important to try and distinguish between "natural" compounds present, and those present due to contamination. This was done by only analyzing for constituents according to the extent that they could be mobilized. The organic acid TCLP method as developed by the USEPA, and adopted and described by the Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste (MR), Second Edition 1998, Department of Water Affairs and Forestry (DWAF), was used for mobility testing for both inorganic and organic contaminants.

3.4 Target Compound Analysis

It is not practical to test or analyse for all compounds that could or may be present in either contaminated or non-contaminated waters, sediments, soils and even leachates. The sky could be the limit!

On the basis of a fingerprint of which inorganic and organic contaminants may be expected from Steel Works, compounds were targeted for analysis. These lists of compounds were then complemented by those compounds, which by virtue of toxicity, chemical/physical characteristics and environmental fate could be of greatest concern. The target list resulted in 19 inorganic micro-compounds, 8 inorganic macro-compounds, 55 Volatile and 63 semi-volatile organic compounds as follows:

Inorganic micro-compounds:

Aluminium
Arsenic
Barium
Boron
Cadmium
Chromium^{3+}
Chromium^{6+}
Cobalt
Copper
Cyanide
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Titanium
Vanadium
Zinc

Inorganic macro-compounds

Calcium
Chloride
Fluoride
Magnesium
Potassium
Sodium
Sulphate
Nitrate

Organic Volatile compounds

Dichlorodifluoromethane
Vinyl Chloride
Bromomethane
Trichlorofluoromethane
1,1-Dichloroethene
Dichloromethane
trans-1,2-Dichloroethene
1,1-Dichloroethane
cis-1,2-Dichloroethene
2,2-Dichloropropane
Bromochloromethane
Chloroform
1,1,1-Trichloroethane
1,1-Dichloropropene
Carbon Tetrachloride
1,2-Dichloroethane
Benzene
Trichlorethene
1,2-Dichloropropane
Dibromomethane
Bromodichloromethane
Toluene
1,1,2-Trichloroethane
1,3-Dichloropropane
Tetrachloroethene
Dibromochloromethane
1,2-Dibromoethane
Chlorobenzene
1,1,1,2-Tetrachloroethane
Ethylbenzene
m,p-Xylene
o-Xylene
Styrene
Bromoform
Isopropylbenzene
1,1,2,2-Tetrachloroethane
1,2,3-Trichloropropane
Bromobenzene
n-Propylbenzene
2-Chlorotoluene
1,3,5-Trimethylbenzene
4-Chlorotoluene
tert-Butylbenzene
1,2,4-Trimethylbenzene
sec-Butylbenzene
4-Isopropyltoluene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
n-Butylbenzene
1,2-Dichlorobenzene
1,2-Dibromo-3-chloropropane
1,2,4-Trichlorobenzene
Hexachlorobutadiene
Naphthalene
1,2,3-Trichlorobenzene

Organic Semi-Volatile compounds

N-Nitrosodimethylamine
bis(2-Chloroethyl)ether
Phenol
2-Chlorophenol
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2-Dichlorobenzene
bis(2-chloroisopropyl)ether
2-Methylphenol
Hexachloroethane
N-Nitroso-di-n-propylamine
4-Methylphenol
Nitrobenzene
Isophorone
2-Nitrophenol
2,4-Dimethylphenol
bis(2-Chloroethoxy)methane
2,4-Dichlorophenol
1,2,4-Trichlorobenzene
Naphthalene
4-Chloroaniline
Hexachlorobutadiene
4-Chloro-3-methylphenol
2-Methylnaphthalene
Hexachlorocyclopentadiene
2,4,6-Trichlorophenol
2,4,5-Trichlorophenol
2-Chloronaphthalene
2-Nitroaniline
Acenaphthylene
Dimethylphthalate
2,6-Dinitrotoluene
Acenaphthene
3-Nitroaniline
2,4-Dinitrophenol
Dibenzofuran
2,4-Dinitrotoluene
4-Nitrophenol
Fluorene
4-Chlorophenyl-phenylether
Diethylphthalate
4-Nitroaniline
4,6-Dinitro-2-methylphenol
Azobenzene
4-Bromophenyl-phenylether
Hexachlorobenzene
Pentachlorophenol
Phenanthrene
Anthracene
Carbazole
Di-n-butylphthalate
Fluoranthene
Pyrene
Butylbenzylphthalate
Benzo[a]anthracene
Chrysene
bis(2-Ethylhexyl)phthalate
Di-n-octylphthalate
Benzo[b & k]fluoranthene
Benzo[a]pyrene
Indeno[1,2,3-cd]pyrene
Dibenz[a,h]anthracene
Benzo[g,h,i]perylene

4. DISCUSSION OF RESULTS

Results of each source are reproduced in tables, consecutively numbered, and will be referred to in the discussions thereof. Furthermore, are the tables colour-coded for ease of reference, green indicating potential risk to be acceptable, and red indicating an unacceptable risk. Actual potential risk of a contaminant have been quantified, by means of a probit model for the environment, the acceptable benchmark being one mortality in a population of 300 000 in the aquatic environment (pathway). Acceptable/Non-acceptable risk to humans is expressed as a margin of safety (refer glossary of abbreviations).

4.1 Dam 10

4.1.1 Inorganic Contaminants in Waters

4.1.1.1 Ecological Risk Quantification (Tables 1 – 17)

The sampling positions or locations are reproduced in Figure 1.1. Three aquatic pathways have been evaluated:

(a) "Dam water as is" indicate exposure, should the water in the dam represent the aquatic environment.

(b) "Dam water in river" indicate exposure, should the water in the dam reach the Vaal River. The scenario applied was a maximum capacity of 0.39 m^3/S (being the maximum pump capacity at dam 10 westbank pumphouse) and a dry weather Vaal River flow rate of $12m^3/S$.

(c) "Dam water for ground water" indicate exposure to groundwater, following a worst case scenario of both a total volume when spilling, being 834426 m^3 and a current volume of 575564 m^3 (October 2001) in the dam.

The waters at sampling during October 2001 was too low to be able to take both a surface (S) and deep (D) sample at sampling position one, and was therefore only a surface sample taken.

Surface and deep water samples indicate (except the deep samples at positions 7 and 8) to be homogeneous in inorganic composition throughout the dam. The deep samples at positions 7 and 8 indicate relatively higher concentrations in iron, lead, titanium and zinc.

Manganese concentration in the water varies between 3.16 – 3.48 ppm, on average being 3.37 ppm. This could relate to an unacceptable risk of one mortality in a population of 2 (which correlates with an LC_{50} of 3.0 mg/l) should the dam water represent aquatic exposure. To ground water the manganese will result in an unacceptable risk of one mortality in a population of 3 in the worst case of the dam reaching full capacity. Should the dam water reach the Vaal River according to the scenario in (b), the risk to the aquatic environment would be one mortality in a population of 1×10^{10} which indicate a much lower risk than the acceptable risk level of one mortality in 300 000.

The results also indicate similar conclusions for the macro-inorganic constituents, resulting in unacceptable risk for the two pathways, representing environmental quality and ground water exposure, and acceptable risk according to Vaal River exposure.

These results should be interpreted correctly. The risk assessment for manganese is acceptable in that the acceptable risk used in the calculations is derived from the open literature. However no such data is available for the macro-constituents being much less potent compounds. To be able to assess the possible risk of these compounds to the aquatic environment, an absolute worst case scenario was followed by adopting drinking water standards for humans to be the acceptable risk to aquatic species. This must be regarded too conservative, e.g.:

Information on levels of Nitrate seem to indicate a no-effect-level (NOEL) of 90 mg/l to aquatic species. This value is a factor 10 larger than the Acceptable Risk Level of 9 ppm used in the present risk assessment. It is also to be accepted that aquatic life has to tolerate a range of dissolved solids in order to survive under natural conditions. The literature reports dissolved solid concentrations of up to 15 000 mg/l to be well tolerated.

This is a factor 60 higher than for example the 250 ppm used for chlorine, and a factor 150 higher than the 100 ppm used for sodium in the present assessment. Should 15000 mg/ℓ be accepted or used as an acceptable risk level, then concentration of all the inorganic macro-compounds would be well within an acceptable risk for the aquatic environment.

Water samples taken at the bottom of the dam at locations 7D and 8D (tables 13 and 15) differs from all other samples, reporting high concentrations of iron and manganese (7D) and iron, lead, manganese, titanium and Zinc (8D) Assessment of possible risk of these contaminants also indicate an unacceptable risk to the aquatic environment, the pathways being (a) and (c). For the Vaal River pathway scenario however, possible risk to the aquatic environment for these contaminants are well within the acceptable risk level.

4.1.1.2 Human Risk Quantification (Tables 18 – 34)

For human risk assessment, the same three pathways than those described for the environment, have been considered. The risk assessment displays a similar pattern to the environmental risk assessment, except for the added inorganic micro-compounds, iron and titanium.

Levels in the water for these compounds are also unacceptable for human consumption, for example would the iron, manganese and titanium in the waters result in a potential daily intake (PDI) of 0.025, 0.116 and 0.0067 mg/kg/day (Table 19) from consumption of the water from the dam, for iron, manganese and titanium respectively.

Percentage margin of safety/risk indicate a potential unacceptable risk of 836% of 252% and 222% for the three compounds respectively. The ADI of iron (0.003 mg/kg/day) however, is not based on health effects, but was calculated from a maximum drinking water guideline value (RSA Drinking Water Standards) of 0.1 mg/l. No health based values for iron exist. The EPA Secondary Drinking Water Regulations, which are non-enforceable guidelines based on cosmetic and aesthetic effects, recommend a value of 0.3 mg/l for iron. This value would result in a MOS of 250%, considerably lower than the RSA value of 836%, but also based on cosmetic and aesthetic effects. The risk assessment of iron should therefore be interpreted with great care.

Macro-constituents in Tables 18 – 34 also indicate unacceptable margins of safety in human consumption. Once again however, acceptable daily intakes for these compounds are not available and hence were improvised by calculating from drinking water standards, denoted as "RSA Rfd" in the tables. Possible risk to human consumption due to consumption of dam 10 water is therefore also not based on health effects, and should the margin of risk (%) be interpreted as unacceptability with regard to drinking water standards only.

Dissolved salts (carbonates, chlorides, sulfates, nitrates, sodium, potassium, calcium, magnesium) are objected to in drinking water mainly due to possible physiological effects such as laxative effects (sodium, iron, chlorides, etc.). Drinking Water Standards for these anions and cations, e.g. 100 – 500 mg/ℓ are therefore recommended to be aesthetically acceptable and has no or little relevance to health effects.

Exposed scenarios from worst case ground water being contaminated by dam 10 water, similarly indicate manganese, iron and the inorganic macro-compounds to be of an unacceptable risk. The arguments however for iron and the macro-elements described above, also holds for this exposure pathway.

Similar to the environmental risk assessment, do possible risk to humans according the "dam water in river" exposure scenario, indicate river water contaminated with dam 10 water, to be an acceptable risk for human consumption, with large margins of safety for all contaminants considered.

4.1.2 Organic Contaminants in Waters

4.1.2.1 Ecological Risk Quantification (Tables 35 – 51)

The exposure scenarios considered are the same as those considered for inorganics, as described in paragraph 4.1.1.1

The organic compounds listed in Tables 35 – 51 for risk assessment of dam water, are those compounds from the target list (paragraph 3.4), which were found in any one of the surface or deep water samples from dam 10.

Organic contaminants, different to the inorganic contaminants, do not portray a picture of being homogeneously present throughout the water. Compounds were only found in one surface sample

(3.5), whilst also only found in the deep samples of locations 2, 6, 7 and 8. This is not totally surprising due to the organic contaminants being of very low solubility in water, and possibly due to differences in organic content of sediments in the dam, which will be referred to.

Concentrations of those organics found in the deep water samples, indicate concentrations which varied on average between 2 – 37 ppb, with acceptable risk levels mostly of the order of 0.5 ppb to the aquatic environment. According to the exposure scenario of the dam water representing the equivalent found in the environment (scenario a), quantification of risk is appreciable, being on average of the order of 3.31E+01, i.e. one mortality in a population of 3, and thus of an unacceptable risk to the environment.

The other two scenarios, modeled to ground water (scenario c) and water to Vaal River (scenario b) also display a similar risk quantification profile than the inorganic contaminants. A worst case scenario modeled to ground water indicate risk to ground water to be of the same order of magnitude than scenario (a), whilst dam water to Vaal River again indicate that in such an event, risk to the aquatic environment would be acceptable.

4.1.2.2 Human Risk Quantification (Tables 52 – 66)

Possible risk to humans, according to the three scenarios as been described, is quantitatively reproduced in Tables 52 – 66.

With reference to carcinogens and the short discussion thereof, must the following be noted. According to the 9th Report on Carcinogens (2001), National Toxicology Program of the US Department of Health and Human Services, is none of the organic compounds found in the waters, classified as a known human carcinogen. Some of the compounds (benzo(a)anthracene, chrysene, bis(2-ethylhexyl)phthalate, benzo(a)pyrene and others) are classified to be "Reasonably anticipated to be human carcinogens". Others such as for example pyrene, fluorene and phenanthrene, are indicated by the USEPA Drinking Water Standards and Health Advisories (2000), that they are not classifiable as a human carcinogen. However, although the terms of reference of this study do not include discussions on toxicology, clinical as well as ecological ***per se***, was it considered to be opportune to at least test the benchmark values used as Acceptable Daily Intakes or Reference doses. Due to ① the relative abundant studies performed on benzo(a)pyrene (BaP), ② being one of about 500 individual polynuclear aromatic compounds (PAH), ③ the fact that these compounds are formed by pyrolytic processes, ④ their presence in many foodstuffs, waters, air and soils and ⑤ very importantly, the recommendation (EPA) that toxicity equivalent factors (TEF) be used to derive concentrations for other PAH^{s} from those established for BaP, to apply the "test" to the benzo(a)pyrene reference dose adopted.

The most important toxicological effect is that BaP has been proved in a wide range of in vitro and in vivo studies to be a carcinogen, and more importantly, that the meganism is known to induce tumors by a genotoxic mechanism. It induces lung tumors, leukaemias, oesophageal, forestomach, larrynx, skin and mammary tumor in rats and mice. Tumors are also not only induced at the site of contact, but transplacental carcinogenisis in the offspring of pregnant females have been observed.

BaP is readily absorbed from the GI tract (30%). In air it absorbs onto particulate matter and the half-life of BaP in the lungs depend on the particulate matter absorbed on – 2 hours if it was ferric oxide and up to 60 hours if it was carbon. Absorption from the skin is extensive.

After absorption (orally), BaP tends to persist in the kidney and testes, and is metabolized mainly in the liver by cytochrome P450 enzymes to a range of epoxides and oxides. Most of the metabolites are excreted in both urine and faeces. An important conclusion of all this work for modeling, extrapolation etc. to derive benchmark levels, is the fact that it is a carcinogen, that the mecanism is known and that metabolism studies have indicated apparent little differences in BaP metabolism between species.

In the current human risk assessment, Ockie Fourie Toxicologists (OFT) uses a Reference dose of 0.0002 mg/kg/day for BaP in waters, corresponding to an excess lifetime cancer risk of 10^{-4}. It proved to be the correct decision. Using different and several mathematical models by different studies, the Rfd quoted and used by OFT was also quoted in these studies, amongst others the WHO. The dose/response data from mice and rats for several different tumors were subjected by the EPA to a number of different mathematical models and the results averaged. This average value generated a reference dose of 0.00002 mg/kg/day (60kg) which only differs with a factor of 10 to the WHO, considered to be small in the context of the models used.

Thus, a Rfd of 0.0002 mg/kg/day for human risk assessment is considered appropriate. Incorporating the toxicity equivalent factors recommended by the USEPA, Rfd values for other Polycyclic Aromatic Hydrocarbons were calculated. These compounds are being considered to be of the order of factors 10 – 100 more potent than BaP, which is reflected in the Rfd values used.

The 7 compounds Indenol(1,2,3-cd)pyrene, benzo(b)&(k) fluoranthene, chrysene, benzo(a)anthracene, benzo(a)pyrene, phenanthrene, acenophylene), of the 118 compounds analysed for and found at 5 of the sampling locations, belong to the PAH group of chemicals and are regarded as carcinogens with a genotoxic mechanism for this assessment. Margins of risk varies up to 3167%. (Table 62) should the water in the dam be consumed, and must be regarded as excessive. The risk by consuming contaminated groundwater as modeled is much less, varying between 200 – 400%. The risk by consuming river water (scenario b), is similar to the inorganic compounds, also acceptable.

4.1.3 Inorganic Contaminants in Sediments

4.1.3.1 Ecological risk Quantification (Tables 67 – 69)

Sediments of dam 10 were subjected to a total analysis. This means that risk assessment was conducted according to a very worst case scenario, in that the assumption was made that the **total compound** is **theoretically available to leach** to ground waters. The validity of such an extreme assumption was tested with sediments from dams 1 – 4 and the maturation ponds, and is being reported on in volumes 2 - 4 as well as in paragraph 9 (Risk Assessment Summary).

Only one pathway was considered, being exposure to ground water. For modeling purposes, the area of dam 10 was taken to be 64 hectare, and the average depth of sediment for the total 64 hectare, 1.5 meters.

Results indicated sediment to contain very high concentrations of for example aluminum, iron, chromium, manganese, titanium and zinc. Possible risk to ground water was modeled which resulted in a mortality of 100% in the aquatic environment for these micro-constituents (1.00E+02%). It therefore indicates that the potential for severe contamination of ground water from dam 10 sediments is a reality.

Different to the waters, indicate the macro-constituents to be less homogeneous in the sediments. It also indicate the more mobile and soluble salts to be in much lower concentrations in the sediments than in the waters. e.g.1223 ppm > 406ppm, and 1079 ppm > 637 ppm, for chlorides and sulphate respectively. Other macro-compounds (except calcium) seems to be in equilibrium between waters and sediments.

It is not possible to postulate why differences between waters and sediments exist. Dumping of sludges, extent of process and contaminated storm waters disposed of in the dam over many years, is not known. Neither is the composition of those sludges and waters disposed of known.

What is of importance is the current situation with regard to possible risk to ground waters, future risk to ecology and man, and importantly, pollution and rehabilitation measures needed to remedy the situation.

Possible risk to ground water from for example chlorides and sulphates in the sediments, are appreciably lower than from water in the dam. The risk to ground water for chlorides and sulphates from dam water, indicate on average to be one mortality in a population of 44 for chlorides, and one mortality in a population of 31 for sulphates. For sediments the chloride risk is one mortality in a population of 26316, and for sulphates one mortality in a population of 198. Thus, whereas the inorganic micro-constituents in the sediments portrays a much larger or severe risk than the macro-elements to ground water, is the opposite true for dam waters which indicate inorganic macro-constituents to be of greatest concern.

4.1.3.2 Human Risk Quantification (Tables 70 – 73)

The possible risk for humans by inorganic micro-constituents in the sediments (pathway being ground water) is similar to the risk trend for the ecology being of a very severe nature. Margins of risk for elements such as aluminum and iron is typically of the order of 10^6% - 10^7%, for manganese and titanium 10^4%, and others such as barium, chromium and zinc, 10^2% - 10^3%. (For the ecology these compounds resulted in mortality rates of 100%). Except for calcium which represents an average risk of 280% to humans (compared to 171% from waters), is average risk to humans from macro-constituents of the same order between sediments and waters.

4.1.4 Organic Contaminants in Sediments

4.1.4.1 Ecological Risk quantification (Tables 74 – 76)

In contrast to waters, 32 organic compounds were found in sediments, ranging in concentration between 1.5 ppm and 6800 ppm. Most of the contaminants and more specifically the semi-volatiles indicate a possible 100% mortality risk in the aquatic environment (Pathway being ground water, similar to inorganic contaminants). Taking in consideration the potency of these compounds, the theoretical risk which organics from dam 10 sediments signify to the aquatic environment should be regarded serious albeit no different to the effect of the inorganic micro-contaminants which also resulted in a mortality risk of 100%.

It could however be postulated or argued, that although both the inorganic micro and organic contaminants in the sediments from dam 10 could result in 100% mortality in the aquatic environment, that comparatively the inorganics may be of a more significant risk to ground waters.

Inorganics, depending on speciation, do absorb to a more or lesser extent in the environment, which would have an influence on aquatic environmental concentrations. Most of the organics and more specifically the more potent PAH$^{\geq}$, ① absorbs strongly on sediments and clays, ② have a very low solubility in water ($\mu g/\ell$), ③ biodegrades as well as degrade by photolysis, and ④ although they do bioaccumulate, are they also metabolized and/or depurated in aquatic systems. Taking these environmental fate factors in consideration, it may well be that the inorganics in dam 10 sediments should be regarded a more serious threat to ground waters and associated aquatic environment than the more potent organics. Simply the fact of the organics being biodegradable, associated with very low solubilities, could favour these compounds for more lenient practices specifically with regard to considering remediation options.

4.1.4.2 Human Risk Quantification (Tables 77 – 80)

Sediment samples from the eastern part of the dam i.e. sample positions 2, 5 and 7 display a comparatively higher potential risk to humans, if compared to the sample positions in the western part of the dam. It is not possible to explain this phenomenon at this point in time. It most probably also is only of academic interest. Be it as it may, this "separation" in the sediments might very well be of interest, should for example rehabilitation or remediation have to be implemented over time. Two observations illustrate the discrepancy in the eastern and western sediments of the dam;

1. Margins of risk (No 2, 5 and 7) is noticeably higher than the same compounds in the western part of the dam, and
2. Almost all the volatile organic compounds from the eastern sediments also indicate appreciable risk to humans, whereas almost all the volatiles from the western sediments displays large margins of safety.

As mentioned above, may the reasons for this discrepancy be of academic interest and therefore not warrant any further investigations. It is however believed that note will have to be taken of this phenomenon in the approach to rehabilitation of dam 10. Finally, the hypothesis that the risk displayed by the inorganic contaminants (as discussed in 4.1.4.1), when considering remedial options, is also considered to be valid in performing human risk quantification for organics in sediments.

5.1 Evaporation dams 1 - 4

Dams 1 – 4 were and are mainly used as a series of evaporation dams. Waters from dam 10 as well as leachates and storm waters which reports to du Preez corner are pumped to dam 1. As this dam fills, it spills to the other three dams. The waters of these dams is therefore expected to be of the same order of contamination as dam 10, but could portray some differences due to the input from du Preez corner. Secondly should the waters of all 4 dams be very similar in composition, due to cascading from one dam to the other. These dams were never used for disposal of any other material such as sludges, etc. It is therefore to be expected that contamination, and degree of contamination would be different to dam 10. The dams differ in area, being approximately 12, 9 hectare, 12,07 hectare, 19,9 hectare and 42,02 hectare, in total 86,9 hectare.

An added dimension was incorporated in the risk assessment of these dams. In characterizing dam 10 a worst case scenario was followed by performing risk assessment on the total composition of sediments. It is recognized that all contaminants in the sediments may not be mobilized, which if true, would contribute to overestimation of risk.

The sediments of dams 1 – 4 were therefore not only analysed for total contaminants present, but also subjected to a mobility test (TCLP) for contaminants present. Due to the low solubilities of organic compounds and the costs involved for analysis, was this exercise performed for inorganic micro and macro-contaminants only.

Due to expected similarity of waters between the individual dams, will the risk of the individual dams only be reported on briefly, with specific reference to mobility of contaminants in sediments.

5.1.1 Evaporation Dam 1

5.1.1.1 Inorganic Contaminants in Waters

5.1.1.1.1 Ecological Risk Quantification (Tables 81 – 84)

Two micro-compounds indicate possible risk to the aquatic environment for two of the scenarios as described in paragraph 4.1.1.1, i.e. scenario (a) being exposed should the water in the dam represent the aquatic environment, and scenario (c) being the exposure to ground water. The two compounds, are cadmium and cyanide present in the waters. Cadmium is indicated to present a risk due to its classification in the Minimum Requirements (MR), being a Hazard Group I substance. These substances are to indicate acceptable risk only at concentrations $^{1}/_{100}$ x LC_{50}, and not at $^{1}/_{10}$ x LC_{50}, due to toxicity characteristics such as for example teratogenicity and carcinogenicity. Thus, a precautionary principle is followed. Cyanide (present in only one sample) represents an environmental risk of one mortality in a population of 2 for scenario (a), and one mortality in a population of 42 for scenario (c) being ground water exposure. Similar to dam 10 waters, will the aquatic environment not be adversely affected, exposure being the Vaal River scenario (b). Inorganic macro-contaminants, similar to dam 10, are indicated by the different sample positions to be homogeneous throughout the dam. These compounds also indicate possible risk to the environment, when the acceptable risk is considered to be drinking water quality. The reader is however referred to discussions in this regard (paragraph 4.1.1.1).

5.1.1.1.2 Human Risk Quantification (Tables 85 – 88)

The small quantities of inorganic contaminants in waters, indicate only possible risk to humans if the water is consumed as present in the dam. Margins of risk generally varies between 117% and 396%, on average being 158% for the indicated micro-contaminants arsenic, cadmium, iron, lead and titanium.

Only sodium and sulphates indicate margins of risk to 200%, drinking water quality being the acceptable daily intake, via scenario (c) ground water exposure. None of the other inorganics indicate possible risk via the ground water exposure scenario, whilst no unacceptable risk is indicated by any of the inorganic contaminants, the Vaal River being the exposure scenario.

5.1.1.2 Organic Contaminants in Waters

5.1.1.2.1 Ecological Risk quantification (Tables 89 – 90)

Practically no organic contaminants were found in water. The only compounds present were phenol and its derivatives in trace amounts, which resulted in an environmental acceptable risks, 10^{-14}% (expressed by the model as a zero risk).

5.1.1.2.2 Human Risk Quantification (Tables 91 – 92)

Phenol and its derivatives in the dam water indicate margins of safety generally less than 10%, should the water in the dam be consumed daily for a lifetime. These margins of safety are nearly negligible in the ground water and river water scenarios, to be without concern when consumed.

5.1.1.3 Inorganic contaminants in Sediments

5.1.1.3.1 Ecological risk Quantification (Tables 93 – 94)

Inorganic contaminants in the sediments of dam 1 and for example dam 10 displays similar possible risks to the environment. Although risks for some specific contaminants do differ between the two dams, do both dams display 100% mortality for the aquatic environment (ground water). Thus, with regard to inorganic micro and macro contaminants in sediments, should both these dams be on par when rehabilitation measures are to be considered.

However, as mentioned in the risk assessment of sediments from dam 10, is the mobility of contaminants in the sediments of dams 1 – 4 also to be addressed. Results on mobility characteristics indicate that most of the compounds in the sediments are immobile, hence notable lower theoretical risk to the environment, e.g. (some examples):

Risk Quantification from Sediments

Sample No	Contaminant	Total Analysis Risk %	Mobility Analysis Risk %
9, 10, 12	Aluminium	1.0E+02	0.00E+00
11	Aluminium	1.0E+02	2.22E–14
10	Barium	8.56E–02	0.0E+00
9	Iron	1.00E+02	8.80E–03
12	Chromium	9.01E+01	0.00E+00
12	Titanium	1.00E+02	0.00E+00
12	Chlorides	7.75E–02	3.55E–13
9	Sulphates	4.56E–04	0.00E+00
12	Magnesium	4.54E+01	1.33E-13

These examples from Tables 93 and 94 clearly indicate that the contaminants in the sediments should not leach to unacceptable risk levels in ground water. The mobility tests were performed at acidic pH^{s} of 2.9 – 4.9, whilst the pH of dam 10 and 1 – 4 waters varies between 6.2 for dam 4, and pH 7.7 – 8.9 for the other dams.

The exception to these results is manganese. Concentrations levels in the mobility tests for sampling position 9, 10, 11 and 12 decreased from (in ppm) 300 to 22, 150 to 11, 120 to 18 and 58 to 4.2 for the 4 samples respectively. The resultant mobility concentrations result in unacceptable risk levels of 9.85E+01, 9.85E+01 and 9.99E+01 and 6.11E+01 respectively. This is not surprising in that the oxidation state of manganese is normally of such a nature that it dissolves easily in specifically acetic acid solutions, the organic acid used in the TCLP mobility test.

Unfortunately do the mobility risk evaluations remain a theoretical risk to ground waters as indicated. It should be concluded that these results indicate a much more acceptable scenario regarding possible pollution from sediments to ground water which should be considered in rehabilitation strategies.

5.1.1.3.2 Human Risk Quantification (Tables 95 – 98)

Margins of risk for micro and macro contaminants as indicated is appreciable, and of the same order of magnitude as experienced in the ecological risk quantification for dam 10 sediments. Specifically are the margins of risk for aluminium, iron, manganese and titanium excessive, on average $5x10^{6}$%, $6x10^{6}$%, $9x10^{3}$% and $4x10^{5}$% for the four compounds respectively. Macro contaminants also indicate margins of risk ranging from 103% - 6098%.

Due to the relative immobility of these compounds however, as observed from the TCLP tests, do the risk to humans via ground water contamination diminish by orders of magnitude, being on average 390%, 1.8×10^{5}%, 660% and 0% for aluminium, iron, manganese and titanium respectively. Similarly do only calcium present an unacceptable risk by human consumption of ground water. These results indicate that the theoretical risk from sediments in dam 1, due to contamination of ground water by inorganic contaminants, is not as severe as expected, but will need attention in considering pollution and rehabilitation measures.

5.1.1.4 Organic Contaminants in Sediments

5.1.1.4.1 Ecological Risk Quantification (Tables 99 – 100)

Results from analysis of the samples indicate appreciable semi-volatile contaminants at sampling positions 10 and 11, with only one compound present in the sediments at sampling positions 9 and 12. Sampling position 9 is the point of intake of waters from dam 10 and leachates from du Preez corner. Position 12 is in the most southern part of the dam, whilst position 10 and 11 are midway between 9 and 12. The observation of lower organic contaminants at position 9 and 12 is also observed to a certain extend for inorganics in sediments.

It is postulated that this phenomena might be due to particulate matter containing organics not settling or precipitating to sediments at the inlet point (position 9) due to turbulence keeping the matter in suspension, then precipitating further down the dam at positions 10 and 11, the water being depleted of organic suspension and particulates reaching position 12 on the other side of the dam.

Positions 10 and 11 indicate unacceptable risk of semi-volatiles up to mortality rates of 100%, volatiles of organics not being present in the sediments. In contrast to these unacceptable risks, do positions 9 and 12 only indicate the presence of fluoranthene with an unacceptable mortality risk of one in a population of 2. Although the sediments at these two positions do indicate unacceptable risk due to this one compound, do this result, together with inorganic contaminants predominantly not being mobile, indicate limited pollution potential from this dam as well as opening up several options to be considered in rehabilitation practices.

5.1.1.4.2 Human Risk Quantification (Tables 101 – 102)

The fluoranthene being present in ground water as modeled from sediments result in acceptable risk levels for humans with margins of safety of 11.7% and 12.4% for positions 9 and 12 respectively. However, for 4-methylphenol, a more potent volatile organic contaminant, an unacceptable margin of risk of 237% is indicated. This compound does not pose an unacceptable risk to humans in any of the other sediments sampled in dam 1. As to be expected, are margins of risk for the semi-volatiles in sediments at positions 10 and 11 unacceptable, ranging between 550% - 426333% at position 10, and 103% - 79833% for position 11. Consideration of biodegradability and low solubility of these compounds – as discussed in paragraph 4.1.4.1 – in remediation options, becomes more relevant considering ① the apparent no contamination of sediments in certain areas of the dam, and ② the immobility of inorganic contaminants present in the sediment. These factors should also be carefully considered in evaluating ground water results with regard to pollution of these waters.

5.1.2 Evaporation dams 2, 3 and 4

Due to only one inlet to these dams (dam 1) and the cascading of these waters to the other dams, is it prudent to discuss these dams as one entity.

5.1.2.1 Inorganic Contaminants in Water

5.1.2.1.1 Ecological Risk Quantification (Tables 103 – 105; 119 – 112 and 139 – 145)

As expected are results very similar to those of dam 1. Dam 2 indicates unacceptable risks to mainly cadmium, lead and manganese for the two exposure pathways where the water represents those to be the environment and the ground water pathway. Exposure to the Vaal river pathway is again acceptable. These results (dam 1 and 2) differ however from dams 3 and 4 in that relatively high levels of manganese was also found in the waters, to the extent that risk to the aquatic environment according to the Vaal River pathway is also unacceptable. This was only evident at one sampling point in dam 3 (2.50E+00, one in 40 mortality) and for dam 4, 5.11E+00 i.e. one mortality in a population of 20. Including dam 10 are there thus 2 dams (3 and 4) which, according to the Vaal River exposure pathway, would not be acceptable to the aquatic environment. Sodium and sulphates also indicate an unacceptable risk to the aquatic environment by the water of dam 3, ranging from one mortality in a population of 289855 (very marginally), to one mortality in a population of 163399. Considering that the acceptable risk levels for macro-contaminants in the models are Drinking Water Standards, would these small deviations be of no concern to aquatic species. The manganese levels in dam 3 and 4 are much higher than those in dams 1 and 2, and cannot be explained, considering that the manganese levels in the sediments are of the same order of magnitude in all the dams.

5.1.2.1.2 Human Risk Quantification (Tables 106-108; 123-126 and 146-152)

The three pathways for the three dams are similar to those of dam 1. Dam 2, 3 and 4 displays unacceptable risks for aluminium, arsenic, cadmium, iron, lead and titanium of the order of 112 - 576%, and manganese 2826%, for exposure where the waters in the dam represent the aquatic environment. Iron, cadmium, lead and manganese (dam 4) and iron and titanium (dam 2) present unacceptable risks, the ground water being the pathway, whilst none of these contaminants displays a risk via the Vaal river pathway. Dam 3 does not display a micro contaminant risk to ground water, whilst dam 4 display risk for more such contaminants than the other dams. Thus, differences between the dam waters do exist, albeit small, and although a cascading meganism exist from dam 1 to dam 4. For inorganics, the overall picture for the dams is however similar.

5.1.2.2 Organic Contaminants in Waters

5.1.2.2.1 Ecological Risk Quantification (Tables 109; 127 – 128 and 153 - 159)

No organic volatile or semi-volatile compounds were found in the waters of dam 2, 3 and 4.

5.1.2.2.2 Human Risk Quantification (Tables 110; 129 – 130 and 153 - 159)

No organic volatile or semi-volatile compounds were found in the waters of dam 2, 3 and 4.

5.1.2.3 Inorganic Contaminants in Sediments

5.1.2.3.1 Ecological Risk Quantification (Tables 111 - 112; 131 - 132 and 167 - 169)

The possible risk displayed by inorganic contaminants in sediments from dam 2, 3 and 4 could not be more similar to those of dam 1. All three of the dams display 100% mortality for several of the contaminants, notably aluminium, iron copper, manganese, titanium, vanadium and zinc. Several other contaminants such as chromium, barium and nickel also display unacceptable risks to ground water, albeit of a lesser degree. Of importance for these 3 dams, similar to dam 1, is the mobility characteristics, which indicates the contaminants to be immobile. The pH values for the waters of dams 2, 3 and 4 are 8.5; 8.1 – 8.9 and 6.2 respectively. Similar to dam 1, are the two contaminants expressing unacceptable risk according to mobility characteristics iron and manganese, and should these results be taken into account when remediation of these dams are considered.

5.1.2.3.2 Human Risk Quantification (Tables 113 - 115; 133 - 135 and 170 - 175)

Unacceptable risk to humans as modeled from sediments in all three the dams, are similar to dam 1 appreciable, particularly the margins of risk for contaminants such as aluminium, iron, manganese and titanium (10^6%). These margins of unacceptable risk decreases considerably to acceptable margins of safety due to immobility, except for aluminium, iron and manganese of the micro-contaminants and calcium being of the macro-contaminants. It may well be that these margins of risk will decrease even further, (may well be to acceptable margins of safety), under alkaline water conditions.

5.1.2.4 Organic Contaminants in Sediments

5.1.2.4.1 Ecological Risk Quantification (Tables 116; 136 and 176 - 177)

Organic contaminants in sediments from dam 2 record 100% mortality for benzo-(b)&(k)fluoranthene, carbozole and anthracene, fluoranthene being a mortality of one in a population of 2. No volatile organic contaminants were present. The sampling position of these compounds (No. 16) was adjacent to the inlet position in dam no. 1. Organics at the sampling positions to the south in the dam were not present (position No. 17), whilst only one compound fluoranthene was present at position No. 18. This compound relates to an unacceptable risk with a mortality of 5.02E+1%.

Only 2 contaminants were found in the sediments of dam 3, both at the same sampling position (No. 8). Again these compounds were fluoranthene (5.49E+01%) and benzo(b)&(k)fluoranthene

(1.00E+02%). Different to dams 1 and 2 however, is position No. 8 in the most southern part of dam 3 (being present in the northern parts of dam 1 and 2).

Dam 4 is the largest dam, comprising 42 hectares, the other being approximately 12 hectares. More sampling positions were therefore utilized for sediment sampling in order to cover the total area. In the center part of the dam (positions 3 and 5) no organics were present. At the other positions only one or two compounds were present in the sediments. These again were fluoranthene, benzo(b)&(k)fluoranthene at unacceptable risks to the aquatic environment.

The 1 – 4 dams display, relative to dam 10, only a few organic contaminants at localized areas of the dams. Although of unacceptable risk to the environment. It is believed that organics from these dams constitute minor pollution possibilities, which from a risk point of view, may allow *in situ* degradation as an option of rehabilitation.

5.1.2.4.2 Human Risk Quantification (Tables 117 - 118; 137 – 138 and 178 - 180)

Margins of risk for humans was only recorded at the most northern part of dam 2, however being excessive for the potent compounds chrysene (15133%), benzo(b)&(k)fluoranthene (20667%) and phenanthrene (1513%). In dam 3 only one compound, benzo(b)&(k)fluoranthene indicate a margin of risk (19333%). Similarly in dam 4 only benzo(b)&(k)fluoranthene (17833%) indicates a margin of risk of any significance to humans.

These results are in agreement with the conclusions for ecological risk quantification, i.e. pollution of ground water by organics to the extent that it would be an unacceptable risk to humans, is fairly remote. It could therefore be considered to allow these compounds to degrade *in situ*.

6.1 Maturation Ponds 1 - 3

Similar to dams 1 – 4, and due to one inlet to these dams, would it also be prudent to discuss these dams as one entity.

6.1.1 Inorganic Contaminants in Water

6.1.1.1 Ecological Risk Quantification
(Tables 181 – 187; 211 – 215 and 229 – 232)

The waters portray a similar risk quantification for inorganic contaminants for the three pathways of exposure. Of importance in these dams, and different to the others, is the risk due to high concentrations of cyanide. Concentrations vary between 12.75 ppm which results in an unacceptable risk of 100% mortality for all three the pathways (a, b and c). Cyanide in maturation pond 3 is higher than those in the other ponds, on average 17 ppm for the 4 sampling positions, which of cause also relates to an unacceptable environmental risk of 100% mortality for the three pathways considered. Other micro-contaminants of concern are those also found in the other evaporation dams, i.e. iron, lead and manganese. The concentrations of these compounds are relatively high, not only resulting in 100% mortality for the 2 scenarios where the pond water represent environmental exposure, and pond water modeled for ground water exposure, but also unacceptable risks of 100% mortality where the Vaal River is the pathway for exposure. This is particularly evident for cyanide and manganese.

The unacceptable environmental risk of macro-contaminants for ground water is similar to the other dams, except for fluoride. Average concentration is of the order of 65 ppm with a high of 85 ppm for sample position no. 3.3 in pond 3. Such a concentration will result in a unacceptable environmental risk of 100% when the pond water represent the environment, 100% mortality risk to ground waters, and a mortality of one in a population 1786, the Vaal River being the pathway of exposure.

6.1.1.2 Human Risk Quantification
(Tables 188 – 194; 216 – 220 and 233 – 236)

In addition to the "normal" results as observed in the other dams, i.e. margins of risk (10^2 – 10^3%) for aluminium, iron, lead, manganese and some of the macro-contaminants, for the ground water pathway, do cyanide and fluoride also pose unacceptable risks to the ground water and the Vaal River pathways. Unacceptable cyanide margins of risk are typically 10^2 – 10^3% in ground water, margins of safety being recorded for the Vaal River Pathway. Margins of risk of fluorides are relatively high (10^3%) in the ground water pathway, being between 100% and 200%, the Vaal River being the pathway.

From an inorganic point of view, are the waters of these ponds of a potential larger risk to both environment and humans. This is mainly due to concentrations being higher for those contaminants also being of unacceptable risk in the other dams, but more importantly also due to cyanides and fluorides being present in these ponds.

6.1.2 Organic Contaminants in Waters

6.1.2.1 Ecological Risk Quantification (Tables 195 – 198; 221 – 222 and 237 – 238)

Semi-volatiles, similar to the dams and due to relatively low solubility, are present in small quantities in the waters. However, being potent contaminants, do they result in unacceptable risk to the aquatic environment. The difference between pond waters and those of the dams, is the presence of phenol and its derivatives. Pond 1 indicates for example unacceptable risk for these compounds of the order of one mortality in a population of 3 in ground water. For pond 3 the risk of these compounds is nearly a mortality of 100% in ground water. Risk to the Vaal River from maturation pond 1 is acceptable for the phenols, however for pond 3 the risk is unacceptable to Vaal River, being of the order of one mortality in a population of 67568 (Table 238, 4-Methyl-phenol). Similarly is the risk of semi-volatiles in pond 1 acceptable to the environment, the Vaal river being the pathway, whilst anthracene and benzo(b)&(k)fluoranthene in the waters of dam 3 indicate unacceptable risk to the Vaal River pathway. It is clear from these results that a difference in water quality (organics) exist between pond 1 and 3, the latter being of a more unacceptable risk to the environment.

The waters of pond 2 are vastly different to those of ponds 1 and 3 (Tables 221 – 222). Many more volatile organics, including naphthalene as well as nearly the full range of semi-volatiles are present in pond 2 waters. Unacceptable risks to the environment are excessive for all three of the aquatic pathway scenarios, oftenly recording mortalities of 100%.

6.1.2.2 Human Risk Quantification (Tables 199 – 202; 223 – 224 and 239 – 240)

Margins of risk for humans are very similar to those of the ecology being pond 2 > pond 3 > pond 1. 4-Methylphenol in pond 1 results in a margin of risk for ground water of 2293%, being 267% for the Vaal River scenario. This is the only contaminant to be of risk in the Vaal River scenario, whilst several semi-volatiles indicate margins of risk of 100 – 567%.

Pond 3 does not indicate any risk via the Vaal River scenario. However, margins of risk for the phenols and semi-volatiles are excessive, ranging between 267 – 36987% for the phenols and

165 – 4733% for the semi-volalites. Once again the two compounds with the largest marging of risk is 4-methylphenol and benzo(b)&(k)fluoranthene.

Margins of risk from the waters of pond 2 should be classified as an extreme risk. For the semi-volatiles the risk ranges between 235% and 2258167% for benzo(b)&(k)fluoranthene. Margins of risk for volatiles ranges between 423% (2-Methylnaphthalene and 54456% for 4-Methylphenol (Table 223, sample no. 2.2).

Similar to the inorganics do these results indicate the inlet to these ponds. The practice not to allow these waters to mix with those of the larger pond 1, which is not in use at this point in time should be applauded, and should not be allowed in future.

6.1.3 Inorganic Contaminants in Sediments

6.1.3.1 Ecological Risk Quantification (Tables 203 – 204; 225 and 241)

Sediments (inorganic) for dam 10 was characterized by performing a total analysis, for dams 1 – 4 a total as well as mobility tests were performed. For the maturation ponds only mobility tests were performed. This was done due to the results of dams 1 – 4 indicating most inorganic contaminants to be immobile.

Results of the sediments of pond 1, indicate aluminium, chromium, iron, manganese and fluoride to be mobile. Unacceptable risk to ground water were the largest for manganese (8.10E+01), and the least for aluminium 6.19E-03. Results of pond 3 indicate only iron and manganese to be of an unacceptable risk, ranging between 1,17E-01 to 4.25E+01. Sediments from pond 2 are similar, except that fluoride and calcium also present unacceptable risks of 2.56E+01 and 2.73E-02 respectively.

6.1.3.2 Human Risk Quantification (Tables 205 – 206; 226 and 242)

Margin of risk from sediments for humans via groundwater contamination reveals for pond 1 only aluminium to be of risk, indicating a MOS of 347%. In pond 3 the risk of sediments is somewhat different to pond 1, being 2475% for aluminium 28417% for iron and 197% for manganese. As expected from the water results, do the sediments from dam 2 prove to be the most contaminated. Margins of risk are 2365%, 40333%, 658%, 171% and 596% for aluminium, iron, manganese, calcium and fluoride respectively.

Results from sediments, with regard to unacceptable risk to humans, is therefore in agreement with those of waters: pond 2 > pond 3 > pond 1. It is therefore indicated that remediation procedures could differ between for example ponds 1 and 2.

6.1.4 Organic Contaminants in Sediments

6.1.4.1 Ecological Risk Quantification (Tables 207 – 208; 227 and 243)

The sediments of these three ponds contain the same volatile and semi-volatile compounds in all three ponds. Although the concentrations of compounds differ between ponds, is the risk to the environment similar.

The risk to the ecology could only be described as very excessive, most of the contaminants resulting in an unacceptable risk of 100% mortality. From a concentration point of view, the sediments in pond 1 are more polluted than pond 3. The concentrations in pond 2 once again are higher than those of the other 2 ponds. This all is very academic in that the contamination in all three ponds is excessive being of a potential unacceptable risk to the environment.

6.1.4.2 Human Risk Quantification (Tables 209 – 210; 228 and 244)

Similar to the risk to the environment, is there little to discuss with regard to the risk to humans. Margins of risk is of the order of 10^6% to 10^7% for many a contaminant and thus of a potential extreme risk to humans should they leach to ground water.

7.1 Soils

7.1.1 Inorganic Contaminants in Soils

7.1.1.1 Inorganic Environmental Risk Quantification and Human Health Risk Assessment (Figures: 4.2; 4.3 & 4.4 and Tables: 245 - 275)

Many if not most of the inorganic contaminants which may contaminate soils from the activities of a steel plant, would be naturally present in soils, albeit at trace contaminant level. For this reason would it be meaningless to perform any analyses to quantify the total concentration present of a contaminant in soils. Similar to the sediment mobility analysis, were soils therefore characterized by mobility of contaminants present.

Risk to the environment is similarly expressed as acceptable/unacceptable via the ground water pathway scenario. Human risk assessment was performed by ① compliance/non-compliance South Africa Guideline values, and ② health based risk values as was done for waters and sediments. For ease of reference are all results also reproduced in figures 4.2 – 4.4, except for the risk quantification (in percentage), which are reproduced in the tables.

Many of the soils indicate to be contaminated by manganese and to a lesser extent by zinc to the level which they could present an unacceptable risk to the environment. Most of these soils are from the CRMF area, the Slag Processing Areas and a few from the Consolidated Plant Area (CPA). Figure 4.2 indicate the concentrations found of mobile manganese and zinc, and the quantification of the unacceptable risks in tables 245 - 275. The largest unacceptable risk for manganese was at sampling point 8 (South East Slag Processing Area) indicating one mortality in a population of 8, and for zinc, (TETP/South Western Park Area) one mortality in a population of 389.

Figure 4.3 indicate that groundwater potentially contaminated from soils sampled, would not be in compliance, given the South African Drinking Water Standards. The contaminants involved are mainly manganese, zinc, aluminium and iron. However, potential unacceptable risk to human health are indicated only at 9 sampling positions with margins of risk ranging between 121% and 700% (the latter being for iron which is based on Drinking Water Standards).

7.1.2.1 Organic Environmental Risk Quantification and Human Health Risk Assessment (Figures: 4.5 & 4.6 and Tables: 276 - 291)

Virtually no organic contaminants were present in the soils. Organic contamination, when present was acceptable to both man and the environment.

It is to be concluded from the soil assessment that areas do exist where soils have been impacted on by inorganic contaminants, to potential unacceptable risk levels for the environment and humans. The horizontal and vertical extent of this contamination is not known at this stage and will have to be determined to facilitate any remediation options.

8.1 Leachates

8.1.1 Inorganic Environmental Risk Quantification and Human Health Risk Assessment (Tables 292-299)

Sources of Leachates, Seepages and Dry-Weather Flows were identified at the:

- Sinter Mixing Bed
- CETP Old Sludge Dams
- Hattingh Canal (Top)
- Coal Stacking Area
- CETP Sludge Dams
- Vaaldam Canal
- North Works Run-off Canal (NWAK)
- Hecketts / Steelserv
- Arc Furnace / BOF Slag

Quantification of risk to the environment from inorganic contaminants indicated the following:

Sinter Mixing Bed

Manganese indicated an unacceptable risk to the environment of one mortality in a population of 7, with a margin of risk to humans of 128%. Macro-contaminants were also of an unacceptable risk to the environment and man (Table 292) and should it be concluded that this activity at present do have a negative impact on man and the environment. Pollution control should therefore be considered.

CETP Old Sludge Dams

Seepage from these old activities does impact negatively on both the environment and man. Specifically are the risk to the environment of cyanide (one mortality in a population of 1.3), lead (one in 1923) and manganese (100% mortality) of great concern. To humans the Margin of Safety (MOS) for cyanide is acceptable (6.67%), however the margins of risk for lead (312%) and manganese (1159%) is of such a nature that pollution control should be seriously considered.

Coal Stacking Area

Manganese presents a risk of almost 100% to the environment (9.75E+01) and a margin of risk of 594% to humans.

CETP Sludge Dams

Unacceptable risk to the environment and humans from these dams is not that extravagant, compared to the old sludge dams, but is nether-the-less unacceptable.

North Works Run-off Canal (NWAK)

Run-off in this canal during dry-weather flow conditions, is relative to other seepages, of a minor concern. An unacceptable risk of 2.45E-02 for lead in the environment with a corresponding 280% margin of risk to humans, and a marginal unacceptable risk by fluorides are the only contaminants indicating possible unacceptable risk.

It could be summarized that some of the dry weather flows, such as described, should be attended to in order to minimize if not prevent unacceptable risks to humans and the environment.

Vaaldam Canal

Potential unacceptable risk to the environment and humans were indicated by Pb, Mn and sulphates. However, these potential risks were comparatively mild, ranging from 1 mortality in a population of 6 135 for manganese to 1 in 19 493 for sulfates in the environment, and margins of safeties of 136% for sulphates to 242% for lead to humans.

Hecketts/Steelserve Area

Potential high unacceptable risk to the environment were indicated by aluminium (3.08E-02%), fluorides (3.90E+01%) and cyanides (5.96E+01%), and for humans margins of safety, which varied from 158% for lead to 722% for fluorides. These leachates also indicated the presence of arsenic with a potential unacceptable MOS of 600% to humans. A very high unacceptable MOS of 11 560% to humans was also indicated by aluminium.

Arc Furnace / BOF Slag Area

Similar to the pattern of most other leachates, were potential unacceptable risk indicated by specifically aluminium, lead and fluorides.

8.1.2 Organic Environmental Risk Quantification and Human Health Risk Assessment (Tables 300-303)

Organic contaminants were not evident in the leachates, except for phenanthrene at the CETP sludge dams (Table 301). Although the phenanthrene was of no concern with regard to the environment, was it (marginally) of an unacceptable risk to humans.

9. RISK ASSESSMENT SUMMARY

1. Waters of the evaporation dams (10 & 1-4) indicated potential unacceptable risk to environment and humans, due to micro and macro inorganics present. The waters

however contained very little to none organics, with resultant comparatively smaller risk to environment and man.

2. Waters from the maturation ponds indicated potential high unacceptable risk due to both inorganics and organics, to both man and the environment.

3. Sediment of ponds and dams are generally contaminated to a large extent by inorganics, but more specifically by organics. However, organic contamination was only at a few sampling points in dams 1-4, indicating these dams to be largely devoid of organic sediment contamination and associated potential risks. Dam 10 sediments indicated the dam to be "devided" into a East and West section, the one being more contaminated than the other, however both potentially unacceptable to both man and the environment. The sediments of the maturation ponds are highly contaminated by both inorganics and organics.

4. Inorganic contaminants in sediments were found to be immobile to a large extent, which not only result in smaller potential impacts and risk, but also may allow *in situ* closure of dams by capping with slags and soils.

5. Surface soils indicated contamination in some areas (CRMF, CPA), with resultant potential unacceptable risk due to mainly manganese.

6. It is important to note that risks quantified and referred to in this study, are potential risks derived from estimated environmental exposure generally modeled under *worst case* conditions.

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