

Proposed Yeelirrie Development Assessment of Tailings and Mine Waste Source Terms

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Executive Summary

The proposed Yeelirrie Development would mine a shallow uranium ore deposit of the mineral carnotite, a uranium-vanadium mineral phase. The ore would be processed for the recovery of uranium and the process tailings will be placed in the mined-out pit areas. During processing, the ore would be contacted with a concentrated solution of soda ash to dissolve the carnotite. Uranium would be recovered from the solution and the barren solution together with the tailings residue would be deposited in the tailings storage facility (TSF). The final tailings solution would be alkaline in nature and may contain elevated concentrations of metals (e.g. uranium, vanadium).

During operations, temporary storage areas to contain mine waste, ore and soil would be developed adjacent to the mine pit areas to manage mining in advance of production. At completion of operations, the residual ore would be backfilled preferentially to the remaining pit areas, and the balance of the soil and mine waste would be placed over the process tailings as a final closure measure.

Roads and hardstands areas would be sprayed with saline water to suppress dust. The saline water would evaporate on the surfaces of the roads and hardstands and could result in the accumulation of evaporites that may be released from the site during heavy rainfall events.

The objective of this report is to derive and present source term solute concentrations for:

- Temporary mine waste and ore stockpiles;
- The tailings storage facility; and,
- The roads and hardstands.

As well, the potential controls on solute transport in groundwater downstream of the tailings storage facility are discussed.

The report presents procedures for the estimation of solute release rates developed for each of the site components.

Temporary Stockpiles

The approach adopted for the waste and ore stockpile areas relies on experimental test results to assess the overall capacity of the waste and ore materials to release solutes. The physical interaction of rainfall and runoff with the exposed surfaces are also considered.

Base case and upper bound (or worst case) source terms were developed for the stockpile areas. The base case assumes that placed surfaces may leach solutes for up to one year, whereas the upper bound case assumes that all exposed surfaces remain active at all times.

Of significance is that the solute release capacity of the stockpile materials is finite; once the solute release has occurred it is not 'regenerated' (no new solutes are generated to replace the solutes that have been washed away). The experimental results further indicate that the solute release occurs rapidly. The rainfall data further indicate that during each calendar year typically two or more events would occur that could generate runoff. This means that salts should be flushed from the exposed surfaces of the waste and ore stockpiles rapidly. Consequently the upper bound case is likely to overestimate the solute release from the waste and ore stockpile areas.

We recommend that the solute release for the base case be adopted for the assessment of potential impacts on surface water quality in or around the mining area.

Tailings Storage Facility

The expectation is that porewater release from the tailings could occur only after the tailings cells have been decommissioned. The source terms developed herein therefore only considered the post closure conditions that may develop in the tailings.

The solute concentrations present the tailings porewater initially would reflect the process discharge water, or barren leach liquor, that would be present in the tailings during deposition.

The recharge and groundwater flow modelling completed by others indicate that the contact time between the tailings and the porewater would be several thousand years to possibly several hundred thousands of years. Therefore, fully equilibrated conditions would be expected to develop in the tailings porewater.

Aging tests were designed to assess the development of equilibrium conditions over time. The results from these tests indicated that equilibration and ion exchange reactions would be expected to occur in the tailings after deposition. However, the contact times expected in the field are much longer than possibly can be assessed in the laboratory tests. Therefore the test results would represent the initial conditions that may exist in the tailings. The upper bound concentrations were estimated by completing geochemical speciation modelling to assess fully equilibrated conditions and indicated that any residual carnotite that remains in the tailings would be leached. The uranium concentrations were predicted to increase in the longer term.

Groundwater modelling indicates high evaporative losses from all the cells causing groundwater flows to be 'drawn' into the tailings mass over time. The majority of the groundwater inflow would occur vertically from the base of the cells, with horizontal inflows typically contributing only a small proportion of the total inflows. The modelling further suggests that the vertical outflows from the majority of the cells significantly exceed the horizontal outflows; a reversal of flows at the base of the cells would be expected to release groundwater that was initially drawn into the tailings in the vertical flow direction with no net release of tailings porewater (process water). Horizontal flows would however be expected to displace porewater from the tailings.

Evaporative losses would also be expected to form evaporites in the vadose zone and accumulate salts over time. This would result in a net 'loss' of solutes from the tailings that would no longer be available for transport to the groundwater system.

Notwithstanding, we recommend that the average aging test results be adopted as the 'best estimate' source term for the tailings. The results from the PHREEQC calculations which show the fully equilibrated conditions that may develop in the tailings, should be adopted as the 'upper bound' estimate. We recommend that these source terms be applied to all the flows that leave the cells.

Due to the very long contact times and the relative solubility of the solutes present in the tailings, we expect that most of the soluble secondary minerals would dissolve and be displaced in the first pore volume displacement. The source terms therefore may be represented as step functions for the duration of the first pore volume displacement after which concentrations would be expected to revert to near background levels.

Source term estimates were also developed for the four cells that would be backfilled with unprocessed low grade ore and mine waste. Concentration estimates and source duration estimates are also presented for these cells.

Roads and Hardstands

The salt loadings associated with the roads and hardstands are continuously re-supplied by the application of spray water for dust suppression. Solute loadings for the roads and hardstands have been estimated based on the water application rates and salinity content of the spray water and are presented as solute loadings per unit surface area. Solute loadings have been calculated for a series of rainfall events and may be used to estimate effects on surface runoff water quality.

Solute Mobility

High evaporative losses from the tailings would lead to evapo-concentration of contaminants. Mass balance calculations based on the modelled flows suggest that uranium concentrations in the tailings porewater could increase to more than 1000 mg/L in the very long term. However, geochemical modelling indicates that carnotite should form and that the uranium concentration at the TSF outflow should decrease to very low concentrations, approaching current background levels. Vanadium concentrations however would remain elevated above background levels.

In conclusion, whilst the modelling and testing indicate that in the short term after closure uranium (and vanadium) concentrations would be expected to increase within the tailings porewater, the potential for solute release from the TSF would be limited by the very low flows that would be displaced from the tailings.

In the longer term, evaporation and subsequent interaction would lead to a net loss of alkalinity from the porewater which, together with other equilibration reactions, are expected to lead to the formation of carnotite. This would lead to uranium concentrations similar to current background concentrations. Vanadium concentrations would however remain above background levels and could be as high as 170 mg/L in the tailings porewater. Vanadium would be expected to be attenuated to some degree in the downstream clay quartz materials, but particularly in loams.

Table of Contents

Executive Summary	iii
Disclaimer	vii
1. Introduction	8
2. Background	9
2.1 Climate	9
2.2 Mining and Production Schedule.....	9
2.3 Ore Processing and Tailings Disposal.....	10
2.4 Roads and Hardstands.....	10
2.5 Geochemical Characterisation	10
3. Source Terms	12
3.1 Stockpiled Ore and Waste Materials	12
3.1.1 Approach	12
3.1.2 Assumptions and Basis of Calculations.....	15
3.1.3 Source Terms	21
3.2 Tailings Storage Facility	27
3.2.1 Tailings Cells	27
3.2.2 Other Materials	30
3.3 Roads and Hardstands.....	31
3.4 Contaminant Mobility in the Groundwater System	34
3.4.1 Secondary Mineralisation	34
3.4.2 Sorption and Ion Exchange	35
4. Conclusions and Recommendations	36
4.1 Mine Waste and ore stockpiles.....	36
4.2 Tailings Storage Facility	36
4.3 Roads and Hardstands.....	37
4.4 Effects on Solute Transport	37
5. References	39

List of Appendices

Appendix 1: Stockpile Solute Release Rates

Appendix 2: Roads and Hardstand Solute Release Rates

Disclaimer

The opinions expressed in this Report have been based on the information supplied to SRK Consulting (Australasia) Pty Ltd (SRK) by BHP Billiton (BHPB), Amdel Limited, Australian Nuclear Science and Technology Organisation (ANSTO), Australian Laboratory Services (ALS) and Particle and Surface Sciences Pty Ltd. The opinions in this Report are provided in response to a specific request from BHPB to do so. SRK has exercised all due care in reviewing the supplied information. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them.

1. Introduction

The proposed Yeelirrie Development would mine a shallow uranium ore deposit of the mineral carnotite, a uranium-vanadium mineral phase. The ore would be processed for the recovery of uranium and the process tailings would be placed in the mined-out pit areas. Temporary storage areas to contain mine waste, ore and soil would be developed adjacent to the mine pit areas to manage mining in advance of production. At completion of operations, the residual ore would be backfilled preferentially to the remaining pit areas, and the balance of the soil and mine waste would be placed over the process tailings as a final closure measure.

Processing would entail contacting the ore with a concentrated solution of soda ash to dissolve the carnotite. Uranium would be recovered from the solution and the barren solution together with the tailings would be deposited in the tailings storage facility (TSF). The final tailings solution would be alkaline in nature and may contain elevated concentrations of metals (e.g. uranium, vanadium).

The mine waste materials are likely to contain elevated concentrations of salts due to the presence of evaporites (accumulated salts) or saline porewater. These solutes may be released from the mine waste during operations and after closure.

During operations, the roads and hardstands would be sprayed with saline water to suppress dust. The saline water would evaporate on the surfaces of the roads and hardstands and would result in the accumulation of evaporites that may be released from the site during heavy rainfall events.

A laboratory program was initiated in 2009 based on a conceptual geochemical model for the TSF to gather further geochemical data describing the leaching and attenuation behaviour of contaminants at the Yeelirrie site. The outcomes of the geochemical characterisation program are reported elsewhere (SRK, 2011). The findings of the geochemical characterisation program together with the groundwater modelling completed by others (URS, 2011), are used herein to estimate solute potential release rates (source terms) for each of the site components.

This report describes the basis of and recommended source terms for the temporary ore and waste stockpiles, the roads and hardstands and the tailings storage facilities.

2. Background

Development of the source terms for the site components requires an understanding of the setting, design and operation of the various facilities. The following sections provide a summary mining and tailings disposal for the proposed development. More details can be found in the ERMP for the proposed Yeelirrie development.

2.1 Climate

The climate at proposed Yeelirrie Development is discussed in detail in Chapter 6 of the ERMP. In summary, the site is located in an arid, semi-desert region of Western Australia. The average annual rainfall is approximately 222 mm (238 mm at Yeelirrie Homestead), and the average net annual evaporation (pan) is approximately 2,900 mm. The monthly evaporation exceeds the monthly rainfall throughout the year.

High rainfall events associated with cyclones moving across the northern regions of Western Australia can occur from December to April.

Table 2.1 Summary of Site Rainfall and Evaporation Data

Month	Yeelirrie Homestead	SILO Data for Yeelirrie	
		Rainfall	Evaporation
January	28	26	418
February	31	29	331
March	32	30	293
April	25	24	200
May	26	24	132
Jun	23	25	90
July	17	17	98
August	13	12	136
September	4	4	201
October	10	7	288
November	10	8	341
December	20	17	392
Annual Average	238	222	2,918

The summers are very hot with maximum temperatures averaging 35 °C to 38 °C (with periods of up to 40 °C to 46 °C) and mild winters with minimum temperatures averaging 5 °C to 15 °C. The temperature very rarely falls below 0 °C.

2.2 Mining and Production Schedule

The mining and production at the proposed Yeelirrie Development are described in Chapter 3 of the ERMP. Extraction of the uranium-bearing ore from the Yeelirrie ore deposit would require excavation of an open pit mine. In advance of mining, the groundwater level within the ore deposit would be drawn-down to below the final mining elevation to reduce the moisture content of the ore and overburden in order to facilitate materials handling during the mining process.

Surface mining equipment would be used to undertake the mining. The overburden would be placed in stockpiles surrounding the open pit. The ore would be classified according to its uranium grade and stockpiled in specific categories comprising 'very high grade', 'high grade', 'medium grade', 'low grade' and waste. Each of these categories of materials would be segregated and placed in individual temporary stockpiles. The ore stockpiles would be removed during the life of mine as ore is required for processing.

Mining would start approximately a year in advance of when the metallurgical plant would be commissioned to provide in-pit tailings storage capacity for the first tailings produced.

2.3 Ore Processing and Tailings Disposal

Ore processing is described in Chapter 3, Project Description, of the ERMP for the proposed Yeelirrie Development. In summary, the metallurgical processing plant would treat ore mined from the open pit to extract uranium in a series of heated alkali leaching tanks. The leached slurry would then pass through a counter current decant system to recover the uranium-bearing pregnant leach solution (PLS) and thicken the solids to slurry. The thickened slurry would be pumped to the tailings storage facility. The tailings would be deposited at a solids content of about 37 to 41 % (wt), with a final dry density of about 1.2 to 1.4 t/m³ and a porosity ranging from 0.48 to 0.56.

The in-pit tailings storage facility would comprise a series of cells separated by internal divider walls or embankments. The embankments would be constructed from non-mineralised clay materials. The cells would range from 200,000 to 300,000 m², with dimensions of approximately 500 m by 500 m.

A total of 23 cells would be built within the pit void allowing for the permanent storage of the tailings. Three to four cells would be operated simultaneously over the project life. Only about 8 m of tailings would be placed in each cell so that, after filling, the final tailings level would be approximately 2 m below the original ground level. The cells would be operated for six to seven years.

Tailings would be deposited cyclically, with a drying phase following each deposition phase. Deposition would occur from a perimeter spigoting system so that excess water could be decanted and recycled to the process plant from a central pond. Once a cell has been filled, the resultant "bowl" or depression in the centre would be filled with tailings using a central discharge, and the tailings would be covered with low permeability materials, and shaped to shed water away from the underlying tailings. The cover would be engineered for closure but is expected to be no less than 2 m in thickness.

All remaining material mined from the pit would be backfilled into the remaining voids left unused for tailings disposal. As a result, after closure, no above-surface mining features such as waste rock stockpiles, or a pit void, would remain.

2.4 Roads and Hardstands

'Hardstand' areas represent all heavily-trafficked areas located adjacent to the haul roads and the pit, and include minor roads, vehicle parking areas, and machinery lay-down areas. It is assumed that they would have a design and composition similar to the haul roads.

The haul roads areas would be constructed from a mixture of slightly weathered to fresh granite mined from the project quarry and clay-quartz Waste from the pits. The road and hardstands would comprise approximately 300 mm of these materials placed on the natural terrain.

All trafficked areas would be sprayed periodically to suppress dust.

2.5 Geochemical Characterisation

Geochemical characterisation comprised several stages of analyses and testing. Initially, as part of the resource drilling program, approximately 14366 samples were analysed by a combination of inductively coupled plasma (ICP) and X-ray fluorescence (XRF) techniques for major and trace element composition (suite of 28 elements), as well as for U₃O₈ and carbonate content (CO₂ analysis). The elemental analysis included a number of key elements such as arsenic, chromium, copper, iron, molybdenum, nickel, lead, vanadium and zinc. Major elements included calcium, magnesium, potassium, sodium and sulphur. The samples analyses represented all of the material types (based on lithological descriptions) and ranged in uranium content to represent all of the material categories that would be mined. These results provided an understanding of the mineralisation of the various material types and provided the basis for selecting specific samples for more detailed characterisation and assessment of leach properties, in the next phase of testing.

A tailings characterisation program included more than 80 analyses of solids and solutions generated as part of the metallurgical investigation. A supplemental program included more detailed assessments of the tailings leaching properties and interaction of the leachates with materials that would underlie the tailings, or be located in the downstream environment.

The laboratory testing included detailed analyses, mineralogical examinations, surface characterisation and various leach testing procedures comprising bottle roll, column and equilibrium or aging testing that spanned 8 months. The evaluations included radionuclide analyses of solids and leach solutions.

The outcomes of the supplemental geochemical investigations are reported elsewhere (SRK, 2011). The key findings can be summarised as follows:

The mine waste and ore type materials contain finite quantities of readily soluble phases, which leach rapidly when contacted with water. These include primarily salts such as halites and sulphate, and to a lesser extent uranium, vanadium and zinc. Dissolution of these solutes is rapid and they are quickly depleted from the solids. Carnotite solubility is expected to place an upper limit on uranium and vanadium concentrations.

The tailings porewater quality initially is dominated by process water (barren liquor), which is alkaline and contains high concentrations of dissolved alkalinity (soda ash), uranium and vanadium. The elevated alkalinity is likely to continue to leach carnotite which would increase uranium and vanadium concentrations in the pore water. Ion exchange processes in the tailings would also result in lower dissolved sodium and potassium concentrations, while the formation of secondary carbonate minerals may decrease the dissolved alkalinity concentration. Combined, these may affect the solubility of carnotite in the very long term. Ion exchange reactions (involving swelling clays) could also reduce the permeability of the tailings and affect the rate of porewater displacement.

In general, carnotite solubility is expected to play an important role in limiting the solubility of uranium and vanadium along flow paths downstream of the facility. Geochemical conditions downstream of the TSF are expected to result in carnotite precipitating from solution, limiting uranium and vanadium concentrations. Contaminant transport may also be slowed due to sorption onto mineral surfaces (e.g. iron and aluminium oxy-hydroxides and clays). Sorption is not strong under the relatively carbonate-rich conditions expected in Yeelirrie groundwater, however, moderate sorption is expected for many elements, except for the very high dissolved carbonate concentrations that are likely to occur in the near-zone of the TSF.

These findings, and specifically the solute release rates determined during the geochemical characterisation program, were used herein to assess the solute release rates from the various site components as described in the next chapter.

3. Source Terms

3.1 Stockpiled Ore and Waste Materials

Based on the operating strategy adopted for the proposed development, the stockpiled materials would be placed on the surface adjacent the mining area only after the materials have been drained in-situ (i.e. the materials would be dewatered by excavating drainage channels around the materials to be mined, allowing the phreatic surface to be lowered before the materials are mined). The stockpiled materials would remain on the surface only for a finite time (higher grade materials until they are processed and waste or below grade materials until they are backfilled at the end of operations).

Possible mechanisms for the release of water and contained solutes from the stockpiled materials include:

- Release of excess porewater (groundwater) present at the time of placement as toe seepage or percolate to groundwater (i.e. drain-down);
- Displacement of porewater by, or percolation of, incident rainfall as toe seepage or percolation to groundwater,
- Runoff from the surfaces of the mined materials due to incident rainfall.

As noted above, the materials would be drained down before they are mined and consequently there should be no porewater release as a result of excess moisture drain-down. Second, rainfall in the area is low (average rainfall 238 mm/year) and evaporation rates are high (about 3,300 mm/year). We understand from the unsaturated modelling undertaken by BHPB and their consultants that it is unlikely that percolation would result from incident rain during the period that the materials would be stockpiled on surface (i.e. within the operational timeframe). Therefore, no source term was developed for the cases listed in the first two bullets above.

The last mechanism for solute release occurs when incident rainfall causes ponding on the surfaces of the stockpiles, which then leads to runoff. During the ponding the water would dissolve any readily soluble solutes that are present on the surfaces of the stockpile materials, and would be transported away in the runoff. The immediately available solute would comprise evaporites that form at the surface after evaporation of residual porewater that may have been present in the material at the time of placement. The solute accumulation may further be enhanced over extended dry periods when, due to the high evaporation rates, water is transported to the surface due to capillary suction, and the salts deposited at the surface when the water is evaporated. The depth of capillary transport would depend on the matric suction of the material, and the duration (i.e. total evaporation that could occur) of the dry period. Therefore, the solute loading that could be brought to surface would be limited to the finite amount associated with the layer affected. This type of accumulation is commonly observed as a salt crust or hardpan in arid areas.

The following sections briefly describe the approach that was adopted for the development of the runoff source terms. The estimates of solute loadings that may be expected to occur from the stockpiled materials are also presented.

3.1.1 Approach

3.1.1.1 Water Quality

The water quality of the runoff that could be generated from the stockpiles would depend on a number of factors. The key factors are as follows:

Type and area of materials exposed

The various lithological units that would be stored would differ in their potential for solute release. Therefore, the total rates of solute release would depend on the types of materials that are exposed at surface, and the total area exposed to runoff water.

Evaporation

Evaporation from soil surface is normally considered as a three-phase process:

- In Phase 1 evaporation, water retained on the soil surface or in near surface pores evaporates directly at rates that approach the maximum potential evaporation rate.
- Phase 2 evaporation begins once the surface water is gone. It requires water to be transported upwards to the surface from deeper in the soil profile. Matric suction provides the driving force. Phase 2 evaporation slows over time, as the water needs to be drawn from increasing depths. Nonetheless, Phase 2 evaporation is very significant in arid regions, and is generally the main reason why net percolation is significantly less than infiltration.
- In Phase 3 evaporation, the water moves to the soil surface as a vapour only. It is generally only noticeable once the Phase 2 process has removed the mobile liquid water from the upper soil. Phase 3 evaporation can be significant in arid regions where there are long dry periods between rain events. Significantly however Phase 3 evaporation does not result in solutes being transported to the surface.

In the stockpiles Phase 2 evaporation is likely to cause a reversal in water flows to the surface which would lead to the net transport of salts to the soil surface. The depth of Phase 2 evaporation that may contribute salt transport (or salt wicking) to the surface is dependant on the soil properties of the materials.

Solute release

The solute release by the materials would determine the amount of solutes that may accumulate on the surface between consecutive events that generate runoff. The sequential bottle roll tests and the column tests in general show a rapid decrease in solute concentrations for consecutive steps. This indicates a finite capacity of the materials to release solutes, and that most of the solutes in general would be removed from the surface after the first runoff event. The contribution from subsequent runoff events would therefore be minimal and may be considered 'inactive'.

Period of accumulation

The duration over which solutes are accumulated would depend on a number of factors including:

- the period between consecutive rainfall events that generate runoff as well as the period between rainfall events where percolation results and
- the concurrent transport of salts beyond the lower extent of the zone of evaporation that could cause a net transport of solutes to the surface.

A review of the climate data suggest that the maximum period between consecutive events that are likely to result in runoff would be approximately 120 days. This means that the maximum period over which Phase 2 evaporation could contribute to salt wicking to the surfaces of the stockpiles is about 4 months, which would restrict the depth of influence of evaporation.

Clearly the factors that may impact the solute release, transport to the surface and then release to runoff are complex.

3.1.1.2 Runoff

During a rainfall event, surface ponding occurs when the capacity of the soils to take up water is exceeded. When the surface ponding capacity is exceeded runoff occurs.

The rate at which a soil can take in water is dependent on its physical properties, including grain size distribution, permeability and matric suction. Complete consideration of those properties and the physical processes controlling infiltration requires a model that is quite complex. The accuracy of such complex estimates is highly dependent on the assumed material properties, which in the case of the stockpiled materials are not well characterised.

When the main interest is in runoff, a simpler form of infiltration modelling is normally adopted. The Green-Ampt method is one such simplification that was developed nearly 100 years ago and remains in wide usage for runoff calculations. It provides an explicit consideration of key soil properties and their effects on infiltration rates, without requiring numerical solution.

The Green-Ampt method assumes that rainfall produces a front of water moving into the soil. Above the water front, the soil is assumed to be saturated; and below the front it is assumed to be unsaturated at a constant water content. The driving forces for the downward movement of the wetting front are gravity, the head imposed by surface ponding, and the matric suction extorted by the soil just below the wetting front. Putting those assumptions into Darcy's law allows solutions to be derived for many different parameters of interest. The common formulation for infiltration estimates is:

$$I = \frac{[(\theta_s - \theta_i)\psi_f]}{[(p/K_s - 1)]}$$

Where:

I is the total amount of water infiltrated (cm),

p is the rainfall rate (cm/s),

K_s is the saturated hydraulic conductivity (cm/s),

ψ_f is the matric suction at wetting front,

θ_i is the initial moisture content (dimensionless), and,

θ_s is the saturated moisture content (dimensionless).

The Green-Ampt formulation also includes material properties (K_s and θ_s) and parameters dependent on material properties (ψ_f and θ_i) that, in the case of the stockpile materials, are not well characterised. As discussed further below, that limitation restricts the accuracy of any of the estimates presented herein.

Estimating infiltration is only part of the runoff calculation. The complete sequence of calculations was as follows, for precipitation events of various intensity and duration:

- Estimate the precipitation intensity (p) and the total precipitation (P);
- Estimate the amount "lost" to infiltration (I) by the Green-Ampt method; and,
- Assume the remainder is available for runoff ($R=P-I$).

3.1.1.3 Source Term Derivation

As noted before, when rainfall occurs there is an initial short-term infiltration that occurs before ponding and run-off occurs. One approach to estimate the net solute release to the surface runoff would be to allow the initial infiltrating water to dissolve and remove salts from the surface of the material. The infiltrated water would remove the dissolved salts from contact with the subsequent ponding that may occur. This approach would be appropriate for salts that dissolve and reach equilibrium conditions rapidly (i.e. within the short timeframe that the initial abstraction would occur). Dissolution of only the most soluble salts, such as sodium chloride, could be expected to occur within the initial timeframe. Most salts would be expected to dissolve slowly, and may not even reach equilibrium conditions for the period that the water ponds on the surface before it is removed as runoff.

For the purpose of this assessment, the following simplified five step approach was adopted:

- 1 The schedule of placement was used to estimate the total area of exposure for each lithological unit. The placement schedule also provided some indication of the maximum exposure time (before the surface is removed either to be processed or backfilled at the end of operations). However as noted above, i) the solids have a finite capacity to release solutes, ii) that the majority is released within the first contact, and iii) the maximum period between rainfall events that would produce runoff is 120 days. Therefore it was assumed that any given surface is active only in the year that it is placed.
- 2 The area of exposure was multiplied by the assumed depth of influence of the Phase 2 evaporation and multiplied with the bulk density to calculate the total mass of material that could contribute to the salt loading at the surface through the salt wicking process. (The assumption is conservative as it does not allow for any salt transport out of the zone due to percolation. This also assumes that the salts are available at the surface instantaneously at the time the event occurs; in reality, the wicking process

would be slow and would depend on the frequency and intensity of rainfall events prior to the event that results in runoff.)

- 3 The solute release estimates (in mg/kg or g/tonne) were obtained from the leach extraction and column tests that were completed on the various materials. Because the sampling program was limited and not all of the material types were equally represented, the results were ordered in terms of uranium release (loading to the leachate). The highest uranium loading assigned to the Very High Grade material, and the next highest to the High Grade material and so on so that the lowest uranium was assigned to the below grade waste materials.
- 4 The solute release estimates were then multiplied by the total mass of rock (in tonnes) that might contribute to the salt loading (step 2) and divided by the total volume of water yielded by the rainfall event to provide a corresponding concentration. These concentrations were then compared to equilibrium concentrations that may apply (i.e. where the concentrations exceeded the solubility of known phases that form rapidly, the concentration was corrected to the equilibrium concentration).
- 5 The revised concentration was then multiplied by the net runoff volume to obtain the total solute loading that would result to surface water.

The outcome of the latter approach would yield the maximum possible, or upper bound, estimate of concentrations that may occur in runoff from the stockpiles.

3.1.2 Assumptions and Basis of Calculations

3.1.2.1 Stockpile Placement Schedule

The estimated areas of exposure of the various material types at any given time are shown in Table 3.1. Note that this reflects the area in existence at the time, i.e. not the active or newly placed area. To obtain the active area for any given year, subtract the area from the preceding year.

3.1.2.2 Material Properties

The average mineralogical compositions for the various grades of materials were estimated by BHPB from the resource model. The results are illustrated in Figure 3.1 and show that the VHG and HG materials generally would have a higher carbonate content and a marginally lower clay content when compared to the remaining categories of materials. On that basis it was assumed that the VHG and the HG materials could be represented as "silty clayey loam" whereas the balance of the materials likely could be represented as "sandy clay" materials. The soil properties adopted for these material types are summarised in Table 3.2.

Table 3.1 Estimated Total Stockpile Areas

At end of project year	Stockpile Area (m ²)					
	Very High Grade (VHG)	High Grade (HG)	Medium Grade (MG)	Low Grade (LG)	Waste (W)	Topsoil (TS)
-1	147,000	63,000	53,000	79,000	114,000	94,000
1	224,000	105,000	185,000	109,000	259,000	216,000
2	239,000	189,000	303,000	149,000	346,000	328,000
3	<i>178,500</i>	<i>224,000</i>	<i>377,000</i>	<i>179,500</i>	<i>391,500</i>	<i>377,000</i>
4	118,000	259,000	451,000	210,000	437,000	426,000
5	<i>131,000</i>	<i>343,500</i>	<i>573,000</i>	<i>201,000</i>	<i>563,000</i>	<i>454,500</i>
6	144,000	428,000	695,000	192,000	689,000	483,000
7	<i>72,000</i>	<i>376,500</i>	<i>695,000</i>	<i>192,000</i>	<i>652,000</i>	<i>454,500</i>
8	0	325,000	695,000	192,000	615,000	426,000
9	0	<i>205,000</i>	<i>695,000</i>	<i>192,000</i>	<i>615,000</i>	<i>426,000</i>
10	0	85,000	695,000	192,000	615,000	426,000
11	0	<i>42,500</i>	<i>678,000</i>	<i>209,000</i>	<i>735,500</i>	<i>407,500</i>
12	0	0	661,000	226,000	856,000	389,000
13	0	0	<i>604,500</i>	<i>279,000</i>	<i>1,096,000</i>	<i>495,500</i>
14	0	0	548,000	332,000	1,336,000	602,000
15	0	<i>22,000</i>	<i>646,000</i>	<i>400,000</i>	<i>1,399,000</i>	<i>671,500</i>
16	0	44,000	744,000	468,000	1,462,000	741,000
17	0	<i>22,000</i>	<i>859,500</i>	<i>425,500</i>	<i>1,373,000</i>	<i>699,500</i>
18	0	0	975,000	383,000	1,284,000	658,000
19	0	<i>27,000</i>	<i>1,086,500</i>	<i>435,000</i>	<i>1,529,500</i>	<i>766,000</i>
20	0	54,000	1,198,000	487,000	1,775,000	874,000
21	0	<i>27,000</i>	<i>1,088,000</i>	<i>380,000</i>	<i>1,327,500</i>	<i>714,000</i>
22	0	0	978,000	273,000	880,000	554,000
23	0	0	<i>906,500</i>	<i>257,500</i>	<i>846,000</i>	<i>526,000</i>
24	0	0	835,000	242,000	812,000	498,000
25	0	0	<i>712,000</i>	<i>242,000</i>	<i>771,000</i>	<i>443,500</i>
26	0	0	589,000	242,000	730,000	389,000
27	0	0	<i>468,500</i>	<i>242,000</i>	<i>693,000</i>	<i>360,500</i>
28	0	0	348,000	242,000	656,000	332,000
29	0	0	<i>305,500</i>	<i>242,000</i>	<i>607,000</i>	<i>271,000</i>
30	0	0	263,000	242,000	558,000	210,000
31	0	0	<i>131,500</i>	<i>217,000</i>	<i>357,500</i>	<i>115,500</i>
32	0	0	0	192,000	157,000	21,000

Note: Values in italics interpolated.

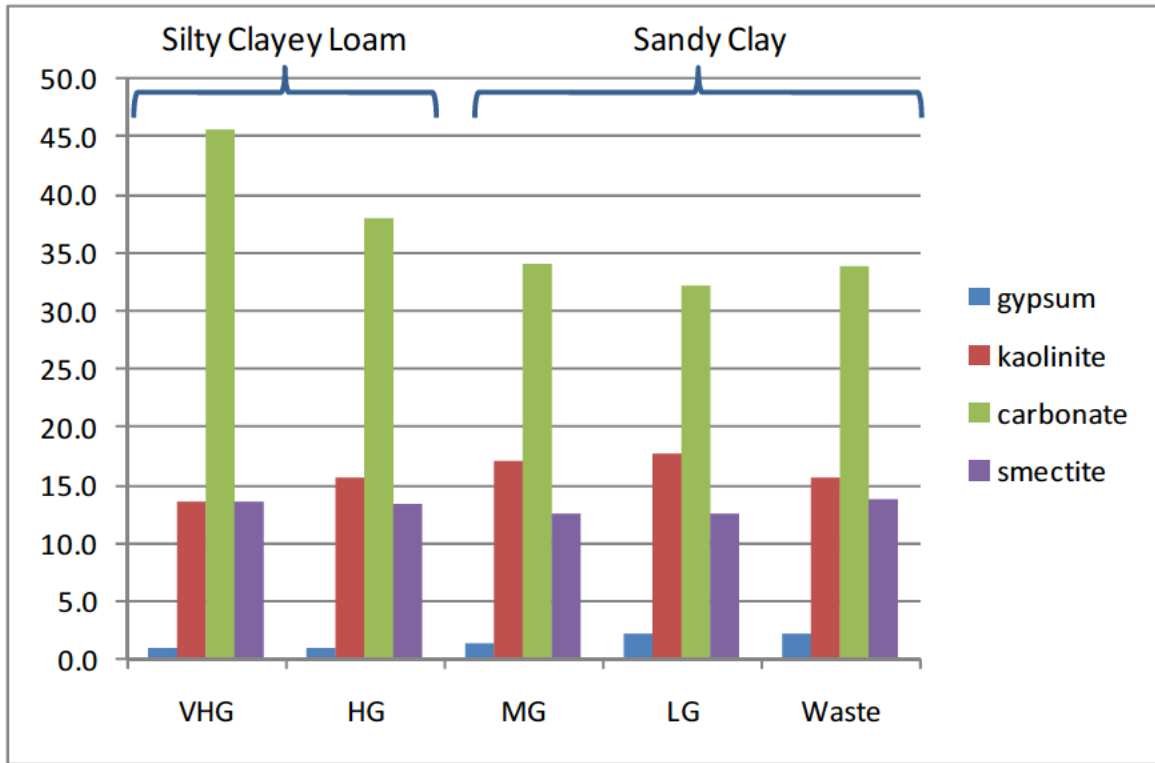


Figure 3.1 Mineralogical Composition of Various Material Categories to be Stockpiled

Table 3.2 Assumed Soil Properties for Green-Ampt Parameters

Soil type	Porosity	Effective porosity	Suction Head (mm)	Hydraulic Conductivity (mm/h)
Silty clayey loam	0.47	0.43	273	1.0
Sandy clay	0.43	0.32	239	0.6

Source: *Handbook of Hydrology*, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993, pp 5.1-5.39

3.1.2.3 Rainfall Data and Runoff

The rainfall intensity – return period estimates were derived by URS (see ERMP, Appendix G1 Surface Water). The data used in the assessments are summarised in Table 3.3. The total rainfall is obtained by multiplying the rainfall intensity with the duration of the event.

As described previously, the Green-Ampt approach was adopted to estimate runoff and initial abstraction for the various rainfall events. The results are summarised in Table 3.4 for the Very High Grade and High Grade materials (silty clayey loam) and in Table 3.5 for the balance of the materials (sandy clay).

Table 3.3 Precipitation Intensity (mm/hr) Estimates for the Yeelirrie Site

Rainfall Intensity (mm/h)							
Return	Storm duration (hours)						
Period (yrs)	0.083	1	6	12	24	48	72
1	43.2	12.5	3.5	2.1	1.3	0.8	0.6
5	54.0	15.6	5.0	3.3	2.1	1.3	1.0
10	58.8	18.9	6.1	4.1	2.6	1.7	1.2
20	58.8	22.5	7.7	5.3	3.3	2.2	1.6
50	96.0	27.7	9.9	6.8	4.5	2.9	2.2
100	126.0	36.0	13.1	8.9	5.8	3.7	2.8
500	-	-	-	-	6.8	4.3	3.2
1000	-	-	-	-	8.2	5.1	3.6

Table 3.4 Estimated Initial Abstraction and Runoff for VHG and HG Materials

Initial Abstraction (mm)							
Return Period (yrs)	Storm Duration (hours)						
	0.083	1	6	12	24	48	72
1	1.7	6.4	29.6	66.4	243.5	37.4	40.3
5	1.4	5.0	18.3	31.9	68.1	224.0	71.8
10	1.3	4.1	14.3	23.5	45.9	111.7	295
20	1.3	3.4	10.9	17.2	31.4	61.8	117
50	0.8	2.7	8.2	12.6	20.9	37.6	61
100	0.6	2.1	6.0	9.2	15.2	27.0	42
500	-	-	-	-	12.6	22.0	34
1000	-	-	-	-	10.1	18.0	28
Potential Runoff (mm) = Total Precipitation - Initial Abstraction							
Return Period (yrs)	Storm duration (hours)						
	0.083	1	6	12	24	48	72
1	1.9	6.1	NR	NR	NR	NR	NR
5	3.1	10.7	11.5	7.6	NR	NR	NR
10	3.6	14.8	22.3	25.7	16.2	NR	NR
20	3.6	19.1	35.3	45.9	48.5	42.9	NR
50	7.2	25.0	51.5	69.1	87.1	103.6	97.7
100	9.9	33.9	72.4	97.8	123.9	150.6	156.4
500	NR	NR	NR	NR	150.7	185.3	193.1
1000	NR	NR	NR	NR	187.3	224.9	229.4

Note: NR = no runoff

Table 3.5 Estimated Initial Abstraction and Runoff for MG, LG and Waste Materials

Initial Abstraction (mm)							
Return Period (yrs)	Storm Duration (hours)						
	0.083	1	6	12	24	48	72
1	1.0	3.5	14.6	27.9	59.8	233.7	40.3
5	0.8	2.8	9.6	15.6	28.4	57.7	105.5
10	0.7	2.3	7.6	12.0	21.0	39.7	64.7
20	0.7	1.9	5.9	9.0	15.3	26.5	41.0
50	0.4	1.5	4.5	6.7	10.7	17.9	26.2
100	0.3	1.2	3.4	5.0	8.1	13.5	19.5
500	-	-	-	-	6.7	11.3	16.4
1000	-	-	-	-	5.5	9.4	14.1
Potential Runoff (mm) = Total Precipitation - Initial Abstraction							
Return Period (yrs)	Storm Duration (hours)						
	0.083	1	6	12	24	48	72
1	2.6	9.0	6.2	NR	NR	NR	NR
5	3.7	12.9	20.3	23.9	21.3	6.0	NR
10	4.2	16.6	29.0	37.3	41.1	39.6	25.1
20	4.2	20.6	40.3	54.1	64.5	78.2	75.8
50	7.6	26.1	55.2	75.0	97.3	123.3	132.3
100	10.2	34.8	75.1	101.9	131.0	164.1	178.6
500	NR	NR	NR	NR	156.6	196.0	210.6
1000	NR	NR	NR	NR	191.9	233.5	243.6

Note: NR = no runoff

3.1.2.4 Solute Loadings

The solute loadings were obtained by i) summing the total solute release from each of the three sequential extraction tests, or, ii) summing the release for all the available pore volume displacements from the column tests. These total loadings were calculated for each of the samples and then sorted by lithological type. The average solute release was then obtained for each lithological type for all the samples from that unit. Since the original sampling programme could not be directed at the various categories (as at the time of sampling the categories had not been defined nor had the cut-off grades been established) the lithological units were arranged according to the uranium release and then assigned to have the highest release rate correspond with the VHG material and so on. The results are summarised on Table 3.6. The following is noted:

- Whilst assignment of the hardpan lithology to the HG material type is not ideal, it does reflect the second highest uranium release capacity and accordingly is considered appropriate.
- Total salt release generally is high for all materials (Cl, Na, K, Mg, SO₄) with the exception of the HG material type. The salt release from this material is approximately 50 % lower. This prompted a review of the test results, which indicated that salt release from samples within each material type is very variable. The variability appears to be independent of the depth of the sample location and the material type. It is possible that the salt release from the HG material types has been underestimated. Note however that the HG category represents a relatively minor surface area (see Table 3.1) and the discrepancy may be of little consequence in the overall estimates.

As noted before the release estimates presented in the table represent the maximum possible potential release from the waste rock materials and do not include the potential effects of solubility controls which would limit the total release.

Table 3.6 Estimated Stockpile Total Solute Release Capacity

Category	Very High Grade (VHG)	High Grade (HG)	Medium Grade (MG)	Low Grade (LG)	Waste (W)
Lithology	LT	HT	T	TCQ	CQ
	Carbonated Loam	Carbonated Hardpan	Calcrete	Transition Calcrete	Clay Quartz
Parameter	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
Ag	0.033	0.030	0.029	0.033	0.030
Al	0.334	0.245	0.163	0.595	0.177
As	0.107	0.041	0.042	0.070	0.033
B	9.51	2.98	7.37	6.21	8.86
Ba	0.210	0.351	0.189	0.098	0.099
Be	0.030	0.030	0.036	0.033	0.030
Bi	0.033	0.030	0.027	0.033	0.030
Br	18.6	10.8	12.1	7.2	9.0
Ca	780	139	1172	160	124
Cd	0.040	0.024	0.041	0.032	0.030
Cl	2172	539	2098	2031	2432
Co	0.031	0.030	0.027	0.033	0.030
Cr	0.035	0.032	0.029	0.052	0.030
Cu	0.054	0.084	0.041	0.040	0.035
F	10.686	10.6	12.1	12.2	10.5
Fe	0.623	0.600	0.582	1.068	0.600
Hg	0.002	0.002	0.001	0.001	0.001
K	486	117	387	353	363
Li	0.033	0.030	0.029	0.037	0.030
Mg	288	123	346	204	206
Mn	0.086	0.034	0.031	0.033	0.102
Mo	0.251	0.177	0.220	0.342	0.175
Na	2591	1362	1913	1990	1922
Ni	0.036	0.034	0.044	0.033	0.030
NO3	148	21.3	41.1	17.2	79.9
P	3.824	2.295	2.691	1.200	0.600
Pb	0.030	0.030	0.027	0.033	0.030
Sb	0.033	0.030	0.029	0.033	0.030
Se	0.068	0.034	0.053	0.050	0.059
Si	144	388	109	92	141
Sn	0.044	0.336	0.031	0.033	0.030
SO4	4150	753	4216	996	1263
Sr	7.56	1.52	10.5	2.91	2.28
Tl	0.703	0.032	0.498	0.209	0.516
U	4.50	3.84	1.37	0.745	0.294
V	1.23	0.139	0.560	1.12	0.624
Zn	0.843	0.194	0.711	0.677	0.780
Ra226*	0.657	0.008	0.103	0.019	0.000

Notes: * units for Ra226 are Bq/kg
total loadings above do not consider solubility constraints.

3.1.2.5 Solubility controls

As noted in Section 3.1.1.3, integral to the source term prediction is the application of solubility controls on the dissolution of salts. In order to impose any solubility controls where they may exist, water quality estimates were generated for a range of conditions and, based on speciation modelling, upper solution concentrations were established. These were compared to the experimental results to verify the PHREEQC predicted results, or, to provide a reasonable limit for solutes where thermodynamic data did not exist in the database. Although there was some variability in the concentrations for the different rainfall events

assessed, average concentration limits were established that could be imposed across the entire range of rainfall event conditions. These are summarised in Table 3.7.

Table 3.7 Summary of assumed Solubility Controls for Runoff Water Quality Estimates

Parameter	Concentration	Comment
Ag	0.006	experimental results
Al	0.68	Gibbsite, experimental results
Ba	0.53	Barite
Be	0.061	experimental results
Bi	0.059	experimental results
Br	0.034	experimental results
Ca	694	Gypsum; calcite
Cd	0.055	experimental results
Cr	0.072	experimental results
Cu	0.080	Malachite, experimental results
Fe	0.050	Iron oxy-hydroxide
Hg	0.002	experimental results
Pb	0.005	experimental results
Sb	0.005	experimental results
Si	85	Amorphous Silica
Sr	23	Celestite
Tl	0.36	experimental results
U	2.1	Carnotite/Schoepite
V	1.4	Carnotite, experimental results

Note: Experimental data represent maximum concentration observed in all tests

3.1.2.6 Depth of Evaporative Influence

The depth of influence of the Phase 2 evaporation is a primary control on the total loading of solutes that would be available for release to the runoff. The depth of Phase 2 evaporation that may contribute salt transport (or salt wicking) to the surface is dependant on the soil properties, but typically ranges up to about 1 meter. The depth of leaching (i.e. the depth of material for which upward water flux could occur) that could contribute to the salt loading to the surface would also depend on the period during which no precipitation occurs. During this period evaporation near the surface would 'draw' water from lower down which would then carry salts from lower down through capillary movement. The longest period in the rainfall record without precipitation is about 120 days. During that period, the evaporation from the soils (i.e. not from the surface) is estimated to be up to 50 mm equivalent. Since the materials would be drained before placement, the field moisture capacity estimates for the material types can be used to estimate the depth of soil moisture depletion for that period. The approximate depth of material to supply 50 mm of evaporation would be about 0.28 m for the sandy-clay material, and about 0.19 m for the silty clay loam material. Conservatively, a depth of contribution of 0.5 m was adopted for both material types.

3.1.3 Source Terms

The purpose of the source term calculations is to generate solute loadings in a form that could be used by others to estimate site wide runoff water quality. Since the solute loadings vary by material type, and since the exposure areas vary over time, the most appropriate output was to provide solute loadings as a function of area for each type of material (i.e. solute loads in units of g/m^2). The total loading can then be determined simply by multiplying the loading with active area for any given time.

As will be shown below, the solute loadings vary according to the storm intensity and duration because the initial abstraction, and thus the proportion of the solute loadings that are 'returned' to the underlying soils, varies by event as shown in Table 3.4 and Table 3.5. Therefore, to allow an assessment of water quality for any combination of events, it was necessary to generate solute loadings for all the events given in the aforementioned tables.

As shown by the sequential leach extraction tests and the column tests, the solutes are depleted relatively rapidly from the mine materials, with the majority of solutes removed in the first flush. This indicates that most of the available solutes would similarly be removed from the surface of the stockpiled materials during

the first flush, and that subsequent flushes would result in much lower solute concentrations. Therefore, potentially, a surface that had already been flushed by an event, may not contribute significantly to a second event. Since climate data indicate that the maximum period between events that could generate runoff is about 120 days, it would suggest that two to three runoff events could occur each calendar year. Therefore, the solute release potential should largely be depleted from a newly placed surface within a calendar year.

Consequently two approaches were adopted to assess solute loadings: i) Base Case, and ii) Upper Bound Case. For the base case it is assumed that placed surfaces remain active for one calendar year. For the upper bound case it is assumed all surface remain active at all times. Clearly this is very much an upper bound case since it assumes that a surface placed in year one of operations would deliver solutes at the same rate in year 20 as in year 1. Clearly this is not possible and therefore represents an absolute worst case scenario.

In the following sub sections example results are presented and the estimated overall solute loadings are summarised for various rainfall events.

3.1.3.1 Example Results

Example plots have been prepared for key parameters (Cl, U, V) comparing the base case and the upper bound case. Two rainfall events have been selected for illustration purposes. Figure 3.2 shows the results for a rainfall event with a 1:5 year return period and 1 hour duration, whereas the results for a 1:100 return period and a 1 hour duration are shown in Figure 3.3.

As shown in the figures, the salinity concentration in runoff from the HG material is somewhat lower than for the other material types. The reason for this is the difference in solute release from the samples selected to represent the HG material (i.e. based on U release rather than total solute release as discussed before). The concentration in runoff from the remainder of the materials is comparable and proportional to the overall solute release potentials for each material type.

The base case estimates show a rapid decrease after initial placement of the materials. This is because the surfaces remain active for one year only. The inactive surfaces contribute flow but no solute loadings and therefore 'dilute' the solute loadings from the newly placed active areas. When no new areas are placed, the concentrations diminish to very low values.

In the upper bound or worst case estimates, all surfaces remain equally active for as long as they are in existence. For example, the waste material remains in place for life of mine and therefore the chloride concentration remains constant for the entire operational period. In the case of the VHGM material, the stockpile exists for a finite period and then is removed. The HG material stockpile is placed and removed on three occasions hence the appearance and disappearance of the concentration profile for this material type (see Table 3.1). Note that the uranium and vanadium concentrations tend to reach the solubility constraint for all materials concerned, hence there are no differences in concentrations amongst the different piles.

A comparison between the two rainfall events (which results in different flow volumes) indicates that the concentrations of solutes that are not solubility limited (e.g. Cl) would decrease proportionally with the flow volume. However, in this particular comparison, the concentrations of solutes that are solubility limited (i.e. U and V) would remain constant. Only for much higher flow volumes would a difference in concentrations be observed. To illustrate, Figure 3.4 shows the upper bound concentrations for Cl and U for a 1:50 year, 72 hour event. As shown, the Cl concentrations are much lower than for the above mentioned cases. However, whilst uranium concentrations remain at solubility for the various ore grade materials, the concentration for the waste type material decreases to below equilibrium (i.e. there is insufficient uranium available in the waste materials to reach equilibrium concentrations).

Once the effective solute concentrations have been established for the stockpile surface, the effective loadings are developed that can be used by others in the site water and load balance. The estimated solute loadings are developed and discussed in the next section.

In summary it is important to note that the solute release capacity of the stockpile materials is finite; in other words once the solute release has occurred it is not 'regenerated' (no new solutes are generated to replace the solutes that have been washed away). Recognising that runoff typically represents in excess of 50 % of total rainfall, more than 50 % of the solutes would be removed in the first rainfall event that generates runoff. In the second event in excess of 50 % of the remaining load would be removed or in excess of 75 % of the

available load, and by the third event in excess of 87.5 %. Recognizing further that the climate data suggest that the surfaces could be flushed two or three times a year (maximum dry period of 120 days) clearly most of the solutes would be removed within one year of placement. Consequently, a surface that has been exposed for 20 years, and flushed on average for three times each year, cannot therefore deliver the same solute loading as a newly placed surface less than one year old. The solute concentrations presented for the upper bound or worst case scenario is therefore possible for any given year only if the surfaces had not been subjected to runoff in any of the preceding years since the surface had been placed.

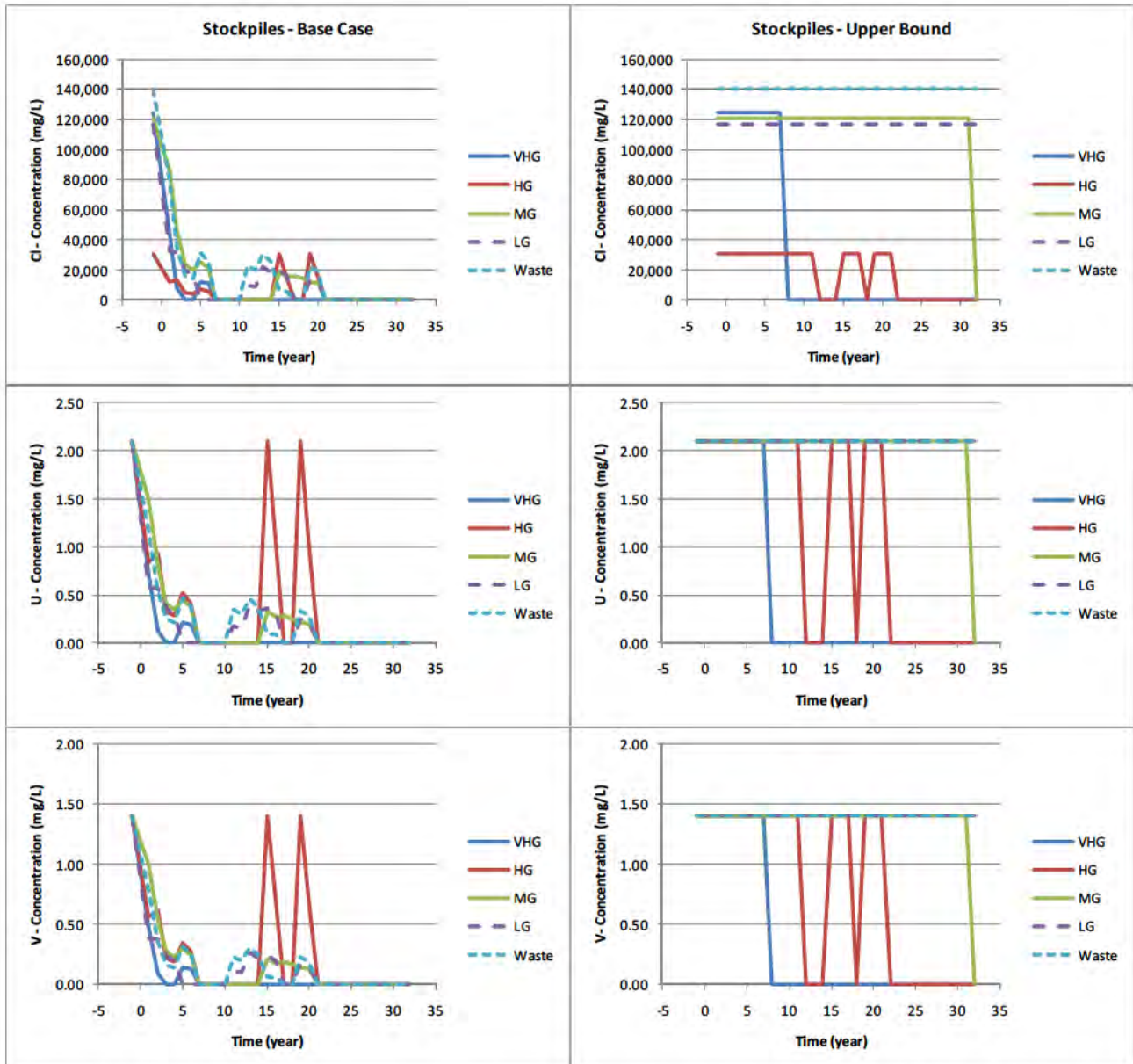


Figure 3.2 Comparison Base Case and Upper Bound of Solute Concentrations in Runoff from the Stockpiles over the Life of Project for a 1:5 year, 1 hour Duration Event

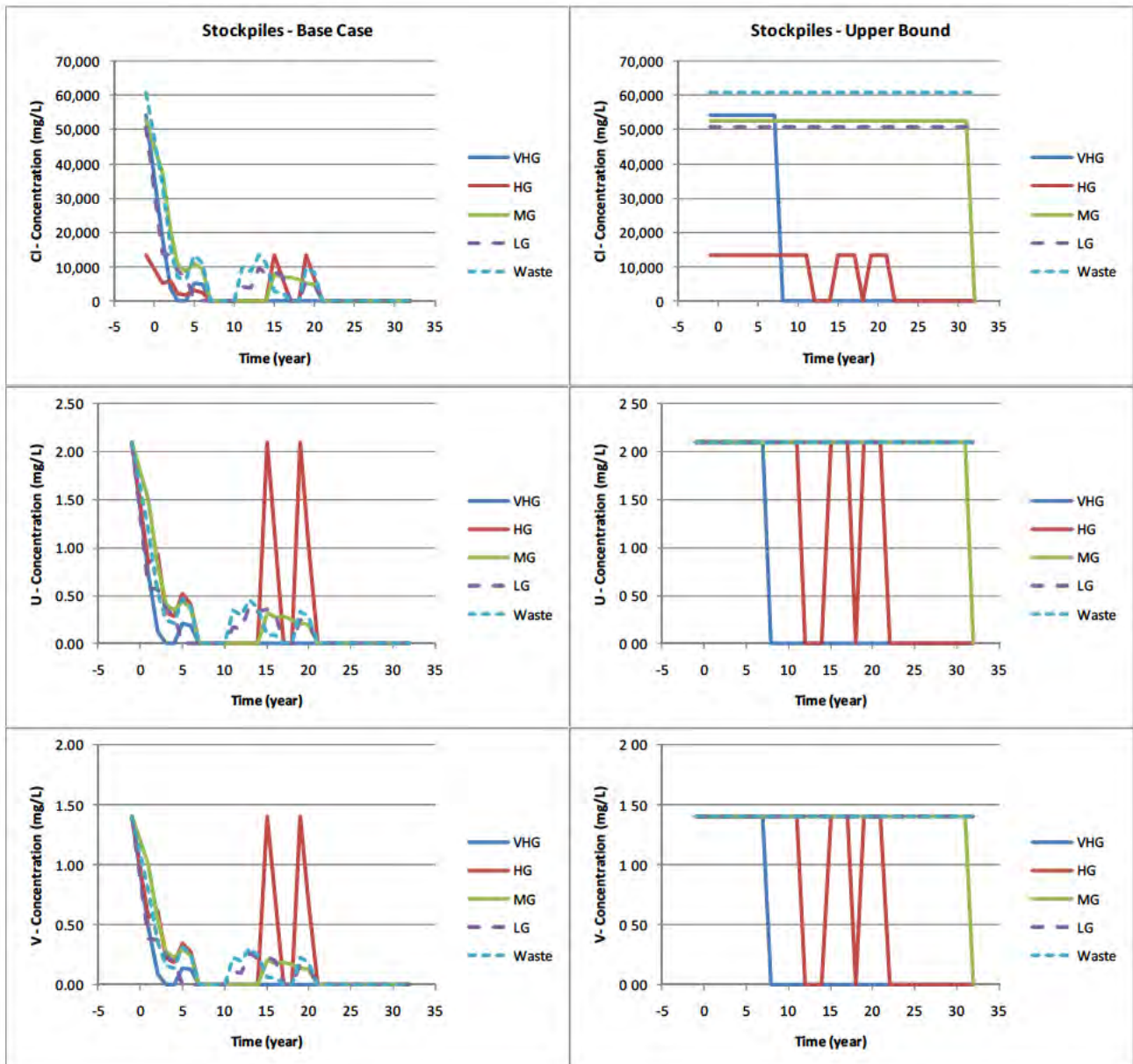


Figure 3.3 Comparison Base Case and Upper Bound of Solute Concentrations in Runoff from the Stockpiles over the Life of Project for a 1:100 year, 1 hour Duration Event

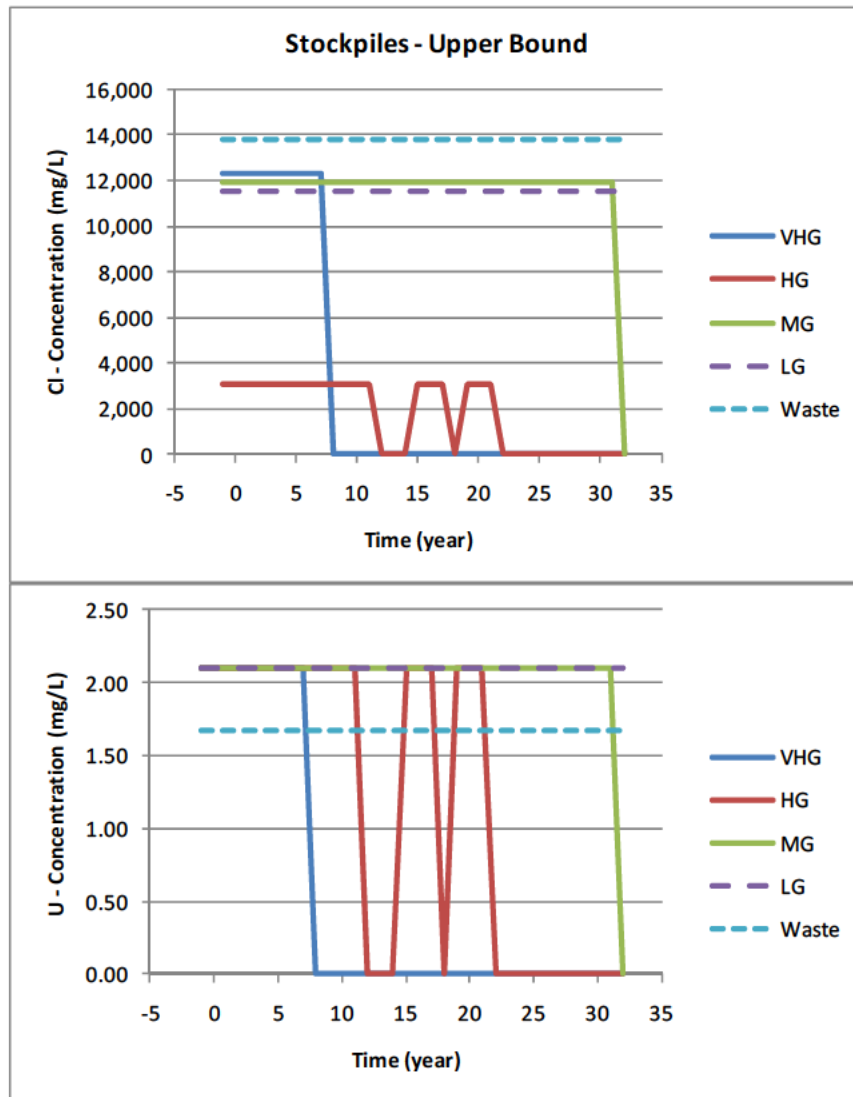


Figure 3.4 Upper Bound Solute Concentrations in Runoff from the Stockpiles over the Life of Project for a 1:50 year, 72 hour Duration Event

3.1.3.2 Solute Loadings

Solute loadings were estimated as a net mass release per unit surface area. The release rate is multiplied by the applicable surface area to obtain the total loading for any given rainfall event. The release applies equally for the base case and the upper bound (or worst) case; the difference is the surface area that is active (i.e. contributes loading).

The loading estimates were prepared for a selection of storm events that would allow development of the site water management strategy. It should be noted that while some events may be predicted to generate runoff, this may not necessarily be the case. First, the surfaces of the stockpiles are not likely to be perfectly flat and level so that in some cases ponding could occur without resulting in runoff. Furthermore, since the materials contain clays, desiccation is likely to lead to cracking which could increase abstraction and reduce runoff. Therefore, only more significant events would be expected to generate runoff.

The loading estimates are summarised in Table 3.8 for key elements and the complete results are provided in Appendix 1. It should be noted that in some cases the VHG and HG material do not generate runoff and therefore no loadings are shown. The reason for this is that the initial abstraction of the VHG and HG materials are greater than that of the MG, LG and waste type materials. In some cases where the solute concentrations for the VHG and HG materials are higher than those estimated for the other materials, it is

possible that the net loading from the VHG and HG are lower because the amount of runoff generated is less for these materials than for the MG, LG and waste materials (note: Load = concentration x volume).

Table 3.8 Summary of Estimated Solute Loadings for Selected Rainfall Events

ARI (years)	Duration (hours)	Stockpile	Al mg/m2	As mg/m2	Cl mg/m2	K mg/m2	Mg mg/m2	Na mg/m2	Ra226 Bq/m2	U mg/m2	V mg/m2
5	1	VHG	7.2E+00	6.6E+01	1.3E+06	3.0E+05	1.8E+05	1.6E+06	4.0E+02	2.2E+01	1.5E+01
		HG	7.2E+00	2.5E+01	3.3E+05	7.2E+04	7.6E+04	8.4E+05	5.0E+00	2.2E+01	1.5E+01
		MG	8.7E+00	3.1E+01	1.6E+06	2.9E+05	2.6E+05	1.4E+06	7.6E+01	2.7E+01	1.8E+01
		LG	8.7E+00	5.2E+01	1.5E+06	2.6E+05	1.5E+05	1.5E+06	1.4E+01	2.7E+01	1.8E+01
		Waste	8.7E+00	2.4E+01	1.8E+06	2.7E+05	1.5E+05	1.4E+06	0.0E+00	2.7E+01	1.8E+01
5	6	VHG	7.9E+00	3.7E+01	7.6E+05	1.7E+05	1.0E+05	9.0E+05	2.3E+02	2.4E+01	1.6E+01
		HG	7.9E+00	1.4E+01	1.9E+05	4.1E+04	4.3E+04	4.7E+05	2.8E+00	2.4E+01	1.6E+01
		MG	1.4E+01	2.6E+01	1.3E+06	2.4E+05	2.1E+05	1.2E+06	6.3E+01	4.3E+01	2.8E+01
		LG	1.4E+01	4.3E+01	1.2E+06	2.2E+05	1.3E+05	1.2E+06	1.6E+01	4.3E+01	2.8E+01
		Waste	1.4E+01	2.0E+01	1.5E+06	2.2E+05	1.3E+05	1.2E+06	0.0E+00	4.3E+01	2.8E+01
5	48	VHG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		HG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		MG	4.1E+00	3.5E+00	1.8E+05	3.3E+04	2.9E+04	1.6E+05	8.7E+00	1.3E+01	8.4E+00
		LG	4.1E+00	5.9E+00	1.7E+05	3.0E+04	1.7E+04	1.7E+05	1.6E+00	1.3E+01	8.4E+00
		Waste	4.1E+00	2.8E+00	2.1E+05	3.1E+04	1.7E+04	1.6E+05	0.0E+00	1.3E+01	8.4E+00
5	72	VHG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		HG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		MG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		LG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		Waste	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
20	1	VHG	1.3E+01	8.2E+01	1.7E+06	3.7E+05	2.2E+05	2.0E+06	5.0E+02	4.0E+01	2.7E+01
		HG	1.3E+01	3.1E+01	4.1E+05	9.0E+04	9.4E+04	1.0E+06	6.2E+00	4.0E+01	2.7E+01
		MG	1.4E+01	3.4E+01	1.7E+06	3.2E+05	2.8E+05	1.6E+06	8.4E+01	4.3E+01	2.9E+01
		LG	1.4E+01	5.8E+01	1.7E+06	2.9E+05	1.7E+05	1.6E+06	1.6E+01	4.3E+01	2.9E+01
		Waste	1.4E+01	2.7E+01	2.0E+06	3.0E+05	1.7E+05	1.6E+06	0.0E+00	4.3E+01	2.9E+01
20	6	VHG	2.4E+01	7.4E+01	1.5E+06	3.3E+05	2.0E+05	1.8E+06	4.5E+02	7.4E+01	4.9E+01
		HG	2.4E+01	2.8E+01	3.7E+05	8.1E+04	8.5E+04	9.4E+05	5.6E+00	7.4E+01	4.9E+01
		MG	2.7E+01	3.3E+01	1.6E+06	3.0E+05	2.7E+05	1.5E+06	8.1E+01	8.5E+01	5.7E+01
		LG	2.7E+01	5.5E+01	1.6E+06	2.8E+05	1.6E+05	1.6E+06	1.5E+01	8.5E+01	5.7E+01
		Waste	2.7E+01	2.6E+01	1.9E+06	2.9E+05	1.6E+05	1.5E+06	0.0E+00	8.5E+01	5.7E+01
20	48	VHG	2.9E+01	4.0E+01	8.0E+05	1.8E+05	1.1E+05	9.6E+05	2.4E+02	9.0E+01	6.0E+01
		HG	2.9E+01	1.5E+01	2.0E+05	4.3E+04	4.6E+04	5.0E+05	3.0E+00	9.0E+01	5.1E+01
		MG	5.3E+01	2.8E+01	1.4E+06	2.6E+05	2.3E+05	1.3E+06	6.9E+01	1.6E+02	1.1E+02
		LG	5.3E+01	4.7E+01	1.4E+06	2.4E+05	1.4E+05	1.3E+06	1.3E+01	1.6E+02	1.1E+02
		Waste	5.3E+01	2.2E+01	1.6E+06	2.4E+05	1.4E+05	1.3E+06	0.0E+00	1.6E+02	1.1E+02
20	72	VHG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		HG	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		MG	5.2E+01	2.4E+01	1.2E+06	2.3E+05	2.0E+05	1.1E+06	6.0E+01	1.6E+02	1.1E+02
		LG	5.2E+01	4.1E+01	1.2E+06	2.1E+05	1.2E+05	1.2E+06	1.1E+01	1.6E+02	1.1E+02
		Waste	5.2E+01	1.9E+01	1.4E+06	2.1E+05	1.2E+05	1.1E+06	0.0E+00	1.6E+02	1.1E+02
100	1	VHG	2.3E+01	9.1E+01	1.8E+06	4.1E+05	2.4E+05	2.2E+06	5.6E+02	7.1E+01	4.7E+01
		HG	2.3E+01	3.4E+01	4.6E+05	1.0E+05	1.0E+05	1.2E+06	6.9E+00	7.1E+01	4.7E+01
		MG	2.4E+01	3.6E+01	1.8E+06	3.4E+05	3.0E+05	1.7E+06	8.9E+01	7.3E+01	4.9E+01
		LG	2.4E+01	6.1E+01	1.8E+06	3.1E+05	1.8E+05	1.7E+06	1.7E+01	7.3E+01	4.9E+01
		Waste	2.4E+01	2.9E+01	2.1E+06	3.2E+05	1.8E+05	1.7E+06	0.0E+00	7.3E+01	4.9E+01
100	6	VHG	4.9E+01	8.9E+01	1.8E+06	4.0E+05	2.4E+05	2.2E+06	5.5E+02	1.5E+02	1.0E+02
		HG	4.9E+01	3.4E+01	4.5E+05	9.8E+04	1.0E+05	1.1E+06	6.7E+00	1.5E+02	1.0E+02
		MG	5.1E+01	3.6E+01	1.8E+06	3.3E+05	3.0E+05	1.6E+06	8.8E+01	1.6E+02	1.1E+02
		LG	5.1E+01	6.1E+01	1.7E+06	3.0E+05	1.8E+05	1.7E+06	1.6E+01	1.6E+02	1.1E+02
		Waste	5.1E+01	2.8E+01	2.1E+06	3.1E+05	1.8E+05	1.7E+06	0.0E+00	1.6E+02	1.1E+02
100	48	VHG	1.0E+02	8.2E+01	1.7E+06	3.7E+05	2.2E+05	2.0E+06	5.0E+02	3.2E+02	2.1E+02
		HG	1.0E+02	3.1E+01	4.1E+05	9.0E+04	9.4E+04	1.0E+06	6.2E+00	3.2E+02	1.1E+02
		MG	1.1E+02	3.5E+01	1.7E+06	3.2E+05	2.9E+05	1.6E+06	8.5E+01	3.4E+02	2.3E+02
		LG	1.1E+02	5.8E+01	1.7E+06	2.9E+05	1.7E+05	1.7E+06	1.6E+01	3.4E+02	2.3E+02
		Waste	1.1E+02	2.7E+01	2.0E+06	3.0E+05	1.7E+05	1.6E+06	0.0E+00	2.4E+02	2.3E+02
100	72	VHG	1.1E+02	7.6E+01	1.5E+06	3.5E+05	2.0E+05	1.8E+06	4.7E+02	3.3E+02	2.2E+02
		HG	1.1E+02	2.9E+01	3.8E+05	8.3E+04	8.8E+04	9.7E+05	5.8E+00	3.3E+02	9.9E+01
		MG	1.2E+02	3.4E+01	1.7E+06	3.1E+05	2.8E+05	1.6E+06	8.3E+01	3.8E+02	2.5E+02
		LG	1.2E+02	5.7E+01	1.6E+06	2.9E+05	1.7E+05	1.6E+06	1.5E+01	3.8E+02	2.5E+02
		Waste	1.2E+02	2.7E+01	2.0E+06	2.9E+05	1.7E+05	1.6E+06	0.0E+00	2.4E+02	2.5E+02

In conclusion, as discussed before, the above loadings are valid for active surfaces for the first event of the given proportion. Loadings in runoff from subsequent events from the same surface would be 50 % or less, and most solute release would be depleted to very low levels after the second or third event.

3.2 Tailings Storage Facility

3.2.1 Tailings Cells

The tailings would be deposited with perimeter spigots to form beaches with a pond located centrally in each cell. The excess water would flow towards the pond and would be recovered for recycling to the process. The deposition location would be cycled around the cell to allow the beaches to consolidate before the next layer of tailings is deposited. During tailings deposition, the active cells may be equipped with under-drains, and the surrounding area would be dewatered so that any seepage losses would in effect be captured by the dewatering system and returned to the milling process. It is only after the tailings cells have been decommissioned and operations cease that the porewater from the tailings could potentially be released to groundwater. The source term therefore only considered the post closure conditions that may develop in the tailings.

The solute concentrations present in the tailings porewater initially would reflect the process discharge water, or barren leach liquor, that would be present in the tailings during deposition. The aging tests indicate that different reactions are expected to occur in the tailings after deposition. These include equilibration and ion exchange reactions, both of which would affect the concentrations of a number of solutes. The progress, or degree of equilibrium that would be reached, would depend on the contact time between the porewater and the tailings. The porewater is expected to be displaced over time by recharge from meteoric water that could infiltrate from surface, and/or groundwater that may flow through the tailings, due to hydraulic gradients that may develop across the tailings deposit over time.

The recharge and groundwater flow modelling completed by others (URS, 2011) assess both low and high recharge conditions. The results from their modelling are summarised in Table 3.9 for the low recharge case and in Table 3.10 for the high recharge case. The results in the tables represent average steady state flows.

As shown in the tables, the modelling suggests high evaporative losses from all the cells, which would in effect result in groundwater flows being 'drawn' into the tailings mass. The majority of the groundwater inflow would occur vertically from the base of the cells, with horizontal inflows contributing only a small proportion of the total inflows.

The results further indicate that in about 50 % or more of the tailings cells (e.g. 2a, 2b, 6, 7a through 9b, and 13), the vertical outflows significantly exceed the horizontal outflows. For this vertical outflow to occur, a reversal of flows would need to happen at the base of the cells, which could occur only during periods of high recharge and/or low evaporation (i.e. only periodically during the year for short periods). Since the vertical groundwater inflow is much greater than the vertical outflows, essentially groundwater that had flowed into the tailings would be displaced out of the tailings again. Consequently little or none of the porewater originally present in the tailings would be expected to be released to groundwater in the vertical outflow from the cells. Horizontal flows however would be expected to displace porewater from the tailings.

Another consequence of the evaporative losses would be that water would be drawn from the tailings into the vadose zone from where it would be evaporated. The solutes associated with this upward flux would tend to form evaporites in the vadose zone and accumulate over time as a salt build-up, which would remove salts from the porewater of the tailings. The net 'loss' of solutes from the tailings would result in a decrease of the total amount of salts that would be available for transport to the groundwater system.

Even though only the horizontal flows would be expected to carry the initial porewater out of the tailings, the total flows were used to assess the time for a complete pore volume displacement from the tailings to occur. The estimates are summarised in Table 3.9 and Table 3.10 respectively for the low and high recharge flows. The estimates assume a tailings porosity of about 0.5 and indicate the time to tailings porewater displacement at steady state flows would vary by cell, and would be dictated by the recharge rate. The retention times are shown to vary from 3000 to in excess of 270 000 years for the tailings cells. The retention time in the backfill cells (10, 11, 22, 23) would be lower and would range from about 100 to 31000 years.

Based on the very long displacement times, equilibrium conditions would be expected to be reached within the tailings porewater.

Table 3.9 Estimated Porewater Retention Times for Backfilled Cells - Low Recharge Estimates

Area	Cell	Cell Area (m ²)	Approx. Tailings Depth (m)	Surface Flows (kL/day)		Groundwater Flows (kL/day)				Source Duration (years)
				Recharge	Evap.	Horizontal Flows		Vertical flows		
						In	Out	In	Out	
Tailings	1a	335,000	8	0.218	3.783	0.019	0.007	3.553	0.000	509800
	1b	50,000	8	0.033	0.472	0.006	0.007	0.440	0.000	77200
	2a	117,500	8	0.077	0.638	0.007	0.006	0.585	0.025	42200
	2b	192,500	8	0.126	2.550	0.013	0.003	2.434	0.019	96700
	3a	192,500	8	0.126	4.156	0.011	0.009	4.028	0.000	246700
	3b	207,500	8	0.135	3.584	0.011	0.007	3.445	0.000	332100
	4a	230,000	8	0.150	4.472	0.009	0.013	4.327	0.000	194100
	4b	242,500	8	0.158	2.134	0.008	0.016	1.984	0.000	167300
	5	105,000	8	0.068	1.315	0.005	0.005	1.247	0.000	214100
	6	202,500	8	0.132	0.240	0.001	0.005	0.198	0.086	24400
	7a	52,500	8	0.034	0.299	0.009	0.007	0.275	0.013	29700
	7b	102,500	8	0.067	0.220	0.004	0.007	0.183	0.026	33500
	8a	150,000	8	0.098	0.704	0.016	0.012	0.604	0.003	116600
8b	147,500	8	0.096	0.603	0.012	0.016	0.527	0.017	49600	
9a	175,000	8	0.114	0.245	0.011	0.005	0.186	0.061	29300	
9b	172,500	8	0.112	0.402	0.008	0.002	0.332	0.048	37900	
12	327,500	8	0.214	5.943	0.052	0.001	5.679	0.000	2397400	
13	292,500	8	0.191	4.180	0.010	0.001	3.992	0.012	253100	
Other	10	272,500	8.8	0.256	19.895	86.662	60.257	0.000	5.613	600
	11	172,500	8.7	0.163	9.760	17.614	11.193	5.613	0.000	200
	22	502,500	9.2	0.328	14.842	1.767	0.082	12.960	0.128	30200
	23	425,000	8.6	0.277	15.067	4.764	0.116	10.189	0.045	31000

Table 3.10 Estimated Porewater Retention Times for Backfilled Cells - High Recharge Estimates

Area	Cell	Cell Area (m ²)	Approx. Tailings Depth (m)	Surface Flows (kL/day)		Groundwater Flows (kL/day)				Source Duration (years)
				Recharge	Evap.	Horizontal Flows		Vertical flows		
						In	Out	In	Out	
Tailings	1a	335,000	8	2.184	6.234	0.026	0.007	4.030	0.000	520200
	1b	50,000	8	0.326	0.715	0.003	0.006	0.392	0.000	89700
	2a	117,500	8	0.766	1.078	0.019	0.007	0.591	0.292	4300
	2b	192,500	8	1.260	3.579	0.022	0.003	2.448	0.144	14300
	3a	192,500	8	1.260	5.389	0.012	0.007	4.129	0.000	281800
	3b	207,500	8	1.350	4.806	0.013	0.005	3.446	0.000	423900
	4a	230,000	8	1.500	5.746	0.010	0.010	4.246	0.000	255800
	4b	242,500	8	1.580	3.102	0.011	0.014	1.526	0.002	166200
	5	105,000	8	0.685	2.203	0.011	0.007	1.514	0.000	171200
	6	202,500	8	1.320	1.032	0.004	0.007	0.249	0.535	4100
	7a	52,500	8	0.342	0.570	0.025	0.011	0.325	0.111	4700
	7b	102,500	8	0.668	0.714	0.019	0.011	0.282	0.245	4400
	8a	150,000	8	0.978	1.594	0.020	0.013	0.665	0.056	23700
8b	147,500	8	0.962	1.237	0.019	0.018	0.449	0.175	8400	
9a	175,000	8	1.140	0.658	0.035	0.009	0.116	0.625	3000	
9b	172,500	8	1.120	0.731	0.027	0.002	0.155	0.573	3300	
12	327,500	8	2.140	7.792	0.047	0.001	5.611	0.000	2981200	
13	292,500	8	1.910	5.638	0.011	0.001	3.783	0.062	50400	
Other	10	272,500	8.8	2.560	22.763	78.164	53.646	0.000	5.909	100
	11	172,500	8.7	1.630	10.313	18.993	16.607	5.909	0.000	100
	22	502,500	9.2	3.280	16.109	1.638	0.157	12.093	0.741	7100
	23	425,000	8.6	2.771	16.629	4.271	0.139	9.935	0.210	14300

Two strategies were considered for the assessment of the porewater quality that may develop in the tailings. First, the aging tests represent 'partially' equilibrated porewater; whilst not fully equilibrated it is the best source of hard data that represent the tailings porewater quality. Second, PHREEQC modelling was undertaken to assess the potential equilibrated conditions that may develop in the tailings.

During processing, the ore is expected to be blended to provide a steady uranium grade feed to the process plant. Consequently, the tailings deposited in the cells would comprise a blend of various ores throughout the life of operations. The blend ratios are likely to vary over time as well. Since the blend ratios are not known, nor which blend ratio would serve as feed for any given cell, it is not possible to assign any particular ore type tested in the current programme to any given cell. For this reason, the average concentrations of aging test results were determined. We recommend that the average aging test results be adopted as the 'best estimate' source term for the tailings. The results are shown in Table 3.11. The table also shows the results from the PHREEQC calculations which show the fully equilibrated condition that may develop. In this case any residual carnotite present in the tailings is expected to dissolve. We therefore recommend that the equilibrated solution concentrations be adopted as the 'upper bound' estimate.

Table 3.11 Summary of Tailings Source Term Estimates

Parameter	units	¹ Best Estimate Concentrations	² Upper Bound Concentrations
pH	pH unit	10	10
Total Alkalinity	mgCaCO ₃ /L	58,750	38,524
Ag	mg/L	0.05	<0.05
Al	mg/L	0.12	0.12
As	mg/L	1.42	1.42
B	mg/L	35	35
Ba	mg/L	0.1	0.1
Be	mg/L	<0.05	<0.05
Bi	mg/L	<0.05	<0.05
Br	mg/L	55	55
Ca	mg/L	3.7	0.22
Cd	mg/L	<0.05	<0.05
Cl	mg/L	16583	16461
Co	mg/L	<0.05	<0.05
Cr	mg/L	0.15	0.15
Cu	mg/L	0.46	0.46
F	mg/L	9.0	9.0
Fe	mg/L	1.33	1.33
Hg	mg/L	<0.0005	<0.0005
K	mg/L	1325	1343
Li	mg/L	<0.05	<0.05
Mg	mg/L	6.7	6.7
Mn	mg/L	0.04	0.04
Mo	mg/L	1.6	1.6
Na	mg/L	33917	33686
Ni	mg/L	0.06	0.06
NO ₃	mg/L	474	471
P	mg/L	1.0	0.32
Pb	mg/L	0.45	0.45
Ra-226	Bq/L	5.0	5.0
Sb	mg/L	<0.05	<0.05
Se	mg/L	0.26	0.26
Si	mg/L	12.1	12.0
Sn	mg/L	<0.05	<0.05
SO ₄	mg/L	10867	29859
Sr	mg/L	0.20	0.20
Tl	mg/L	<0.05	<0.05
U	mg/L	110	249
V	mg/L	53	82
Zn	mg/L	0.5	0.5

Notes: ¹ Average of aging test results; ² PHREEQC predictions

Based on the PHREEQC estimate, the uranium concentration in equilibrium with the residual barren liquor would be expected to increase to about 250 mg/L when in equilibrium with carnotite. We note however that the average U₃O₈ content for numerous tailings samples was about 84.9 ppm. The incremental U concentration that can result in the porewater should this uranium dissolve is about 155 mg/L, and summed with the average barren liquor concentration of about 55 mg/L, the maximum average concentration would be about 210 mg/L. Nevertheless, the uranium content of the tailings is likely to vary due to process upsets and inefficiencies and it is possible that in some cases the upper bound may be reached. Furthermore, the percolate may, as it leaves the tailings, contact below grade material that has been left in place in the

surrounding area and additional leaching could occur. We therefore recommend that the PHREEQC predicted equilibrated concentration be retained as the upper bound concentration.

Due to the very long contact times and the relative solubility of the solutes present in the tailings, we expect that most of the soluble secondary minerals would dissolve and be displaced in the first pore volume displacement. We recommend that the concentrations given in the above table be applied as a step function for the duration of the first pore volume displacement after which concentrations would be expected to revert to near background levels.

3.2.2 Other Materials

As noted above, cells 10 and 11, as well as 22 and 23, would be backfilled with materials other than tailings. It is our understanding that these cells are likely to be backfilled primarily with materials from the waste and possibly low grade type stockpiles, with an approximate composition of 33 % LG material and the balance waste. The leach extraction test results were used to calculate potential porewater quality for the backfilled materials based on this ratio. The results are shown in Table 3.12. As for the tailings, the source concentrations would apply for the first pore volume displacement (duration shown in Table 3.9) after which porewater quality would revert to background levels.

Table 3.12 Summary of Estimate Solute Concentration in Percolate from Cells 10 and 11 and Cells 22 and 23

Parameter	Units	Concentrations
Ag	mg/L	0.006
Al	mg/L	1.85
As	mg/L	0.266
B	mg/L	46.7
Ba	mg/L	0.005
Be	mg/L	0.181
Bi	mg/L	0.005
Br	mg/L	49.3
Ca	mg/L	325
Cd	mg/L	0.179
Cl	mg/L	13445
Co	mg/L	0.181
Cr	mg/L	0.219
Cu	mg/L	0.215
F	mg/L	64.7
Fe	mg/L	4.4
Hg	mg/L	0.005
K	mg/L	2107
Li	mg/L	0.188
Mg	mg/L	1203
Mn	mg/L	0.462
Mo	mg/L	1.35
Na	mg/L	11380
Ni	mg/L	0.181
NO3	mg/L	345
P	mg/L	4.68
Pb	mg/L	0.181
Ra226	Bq/L	0.037
Sb	mg/L	0.005
Se	mg/L	0.326
Si	mg/L	47.3
Sn	mg/L	0.181
SO4	mg/L	6868
Sr	mg/L	14.5
Tl	mg/L	0.360
Total Alkalinity (CaCO3)	mg/L	103
U	mg/L	2.60
V	mg/L	4.61
Zn	mg/L	4.36

3.3 Roads and Hardstands

The roads and hard stands around the site would be sprayed with general use water for dust suppression during operations. Whilst the materials that would be used for road and hardstand construction would be sourced locally, they are not expected to generate solutes in themselves. However, the spray water is expected to contain same salts. The general use water would represent a blend of raw water (from supply water wells) and recycled water. A water balance was prepared for the site by others (see ERMP, Appendix G1 Surface Water), which was used to estimate the general use water quality. The water balance enabled calculation of the water quality over time for the life of operations. The results are presented in Appendix 2.

After wetting of the road and other surfaces with the spray water, the water is expected to evaporate rapidly while the salts would accumulate on the surface or near surface of the road and hardstand base. The rate of salt accumulation would depend on the rate of water application and the salt content of the spray water.

Similar to the stockpile areas, the accumulated salts near the surface of the roads and hardstands are expected to dissolve in runoff and report to surface water during rainfall events. Therefore, a calculation approach similar to that described for the stockpiles, but with a few modifications to account for the ongoing salt accumulation, was adopted to estimate the potential loadings from the roads. The calculation steps were as follows:

- 1 The total solute application rate for any given year was calculated by multiplying the specific water application rate ($L/m^2/day$) with the solute concentration (mg/L) to give a solute accumulation rate ($mg/m^2/day$). The dust suppression water application rate was determined by BHPB to be about $0.85 L/m^2/day$. As discussed for the stockpiles, the climate data suggest that the longest dry period is about 120 days. Therefore, the maximum solute accumulation was obtained by multiplying the accumulation rate with 120 days. This yields the maximum potential solute load that could report to runoff.
- 2 As described for the stockpiles, the Green-Ampt model was used to calculate the amount of initial abstraction and runoff for any given rainfall event. The material properties for the roads and hardstands were assumed to be similar to that of a sandy clay loam, with a porosity of 0.40, effective porosity of 0.33, a suction head of 218 mm and a hydraulic conductivity of 1.5 mm/h.
- 3 As before, the total available solute was dissolved into the total amount of water. The solute concentrations were calculated and corrected for solubility constraints as necessary. Then, accounting for the initial abstraction, the net loading to surface runoff was calculated as a loading per unit surface area for the 120 day period. The solute loadings can then be used to calculate the maximum release for any given event for any given year, with the proviso that the dry period (between runoff generating events) does not exceed 120 days.

Example runoff water quality results for the roads and hardstands are presented in Figure 3.6 for a 1:5 year – 1 hour duration rainfall event, and in Figure 3.6 for a 1:100 year 1 hour duration event. These concentrations represent the water that would flow directly off the applicable surface areas and do not consider any dilution from run-on or other runoff within the catchment. The chloride concentrations are not dissimilar to those estimated for the stockpile runoff. The uranium and vanadium originates primarily from the recycle water.

The solute loadings calculated for a series of rainfall events are provided in Appendix 2. Note that unlike the stockpile loadings, the salt loadings are continuously re-supplied by the application of spray water. The estimated solute loadings provided in the appendix are therefore applicable to the given year.

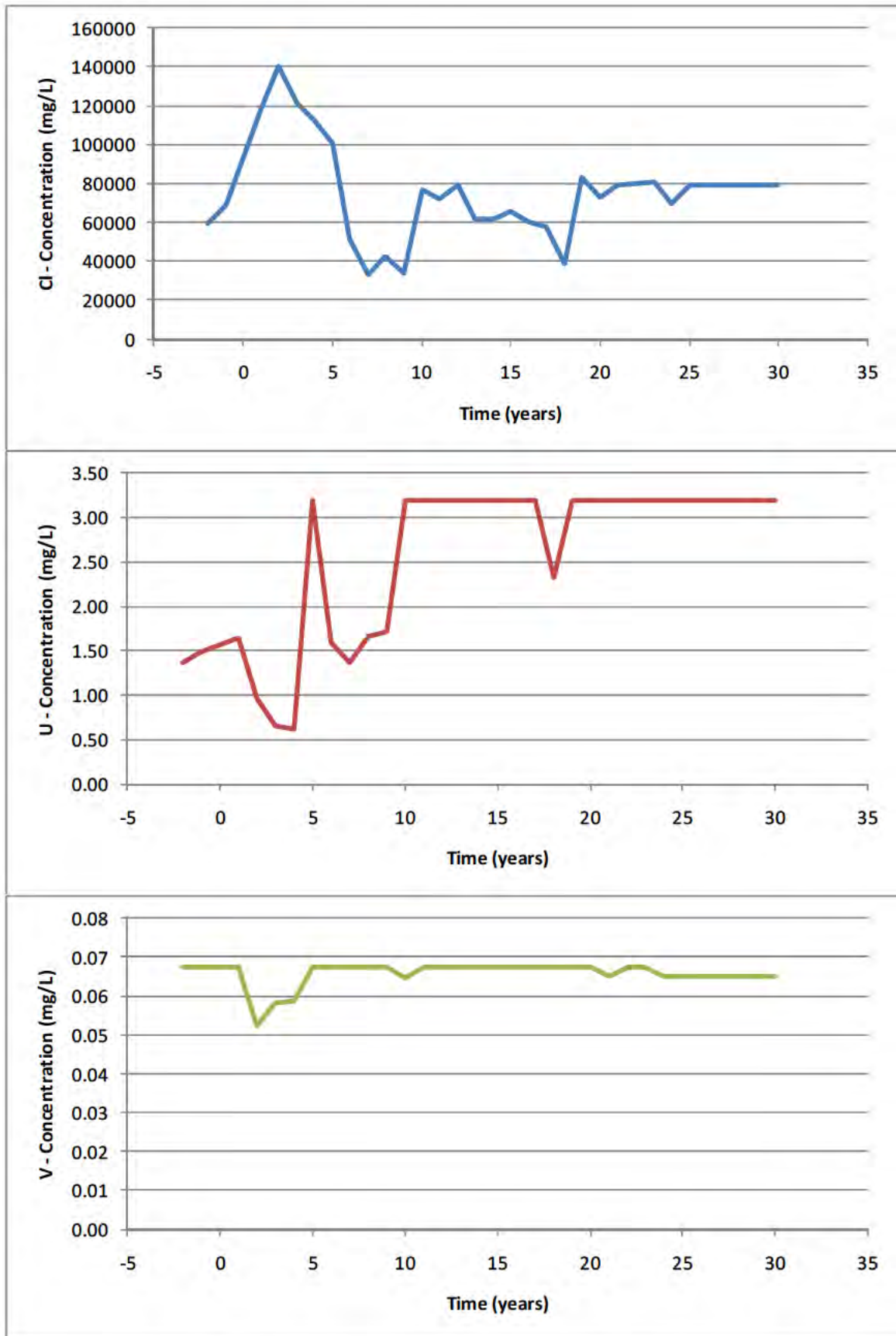


Figure 3.5 Example Roads and Hardstand Runoff Water Quality Calculated for a 1:5 year 1 hour Duration Event

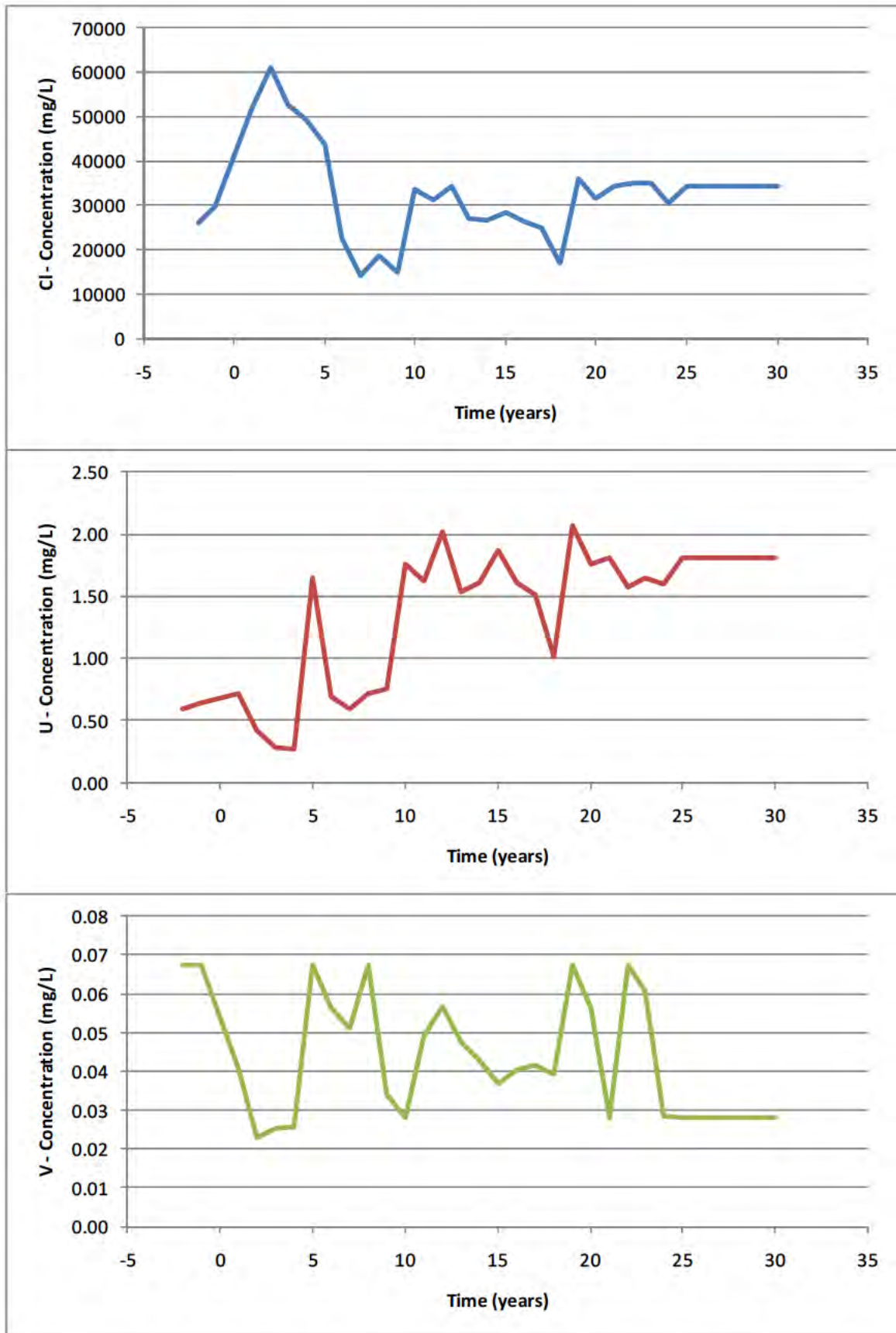


Figure 3.6 Example Roads and Hardstand Runoff Water Quality Calculated for a 1:100 year 1 hour Duration Event

3.4 Contaminant Mobility in the Groundwater System

The transport of contaminants along groundwater flow paths may be attenuated as follows:

- Incorporation within precipitating secondary minerals. Precipitation may occur due to changing chemical conditions along the seepage flow path, e.g. increasing pH, or changes in solute concentrations.
- Mineral surface interactions, such as sorption and ion exchange.

Many contaminants, should they be released into Yeelirrie surface or groundwater, would likely form neutral or anionic species in solution and are unlikely to participate strongly in cation exchange reactions. These contaminants include: U, V, Se, Mo, and As. Mobility of these elements is most likely to be controlled by a combination of sorption and precipitation of minerals such as sulphates and carnotite along the flow path. Sorption would likely be low (at the high dissolved carbonate conditions) to modest (low dissolved carbonate). The likelihood of precipitation is high in the near surface environment due to the high evaporation rates observed, and further afield where carbonate concentrations are expected to decrease).

These effects are discussed briefly in the following sections.

3.4.1 Secondary Mineralisation

The source term concentrations as developed and recommended herein, were used by others as input to some initial groundwater transport modelling and a preliminary estimate of contaminant concentrations downstream of the TSF was made. Simple mass balance calculations were also completed on the basis of the flow modelling results for the high recharge rate case (URS, 2011). Since the groundwater flow modelling suggests that flows would vary through each of the cells the concentrations that would occur would be different for the different cells. Adopting the steady state flow conditions and considering the effects of evaporation on the solute concentrations, the calculations showed that, for example for Cell 2a, the uranium concentration could increase over a period of many centuries to about 1500 mg/L or more. This high concentration would result from the evapo-concentrating effect (from evaporative losses) at the water table interface. The movement of water into the overlying soils through capillary action would lead to some of the solutes accumulating as salts in the vadose zone. Therefore, not all of the solutes may necessarily be available for transport downstream of the TSF.

Nevertheless, these potentially very high concentrations were assessed using the PHREEQC modelling to determine the effects of solubility limits on the uranium concentration within and immediately downstream of the TSF facility. To complete the PHREEQC modelling it was necessary to also estimate other solute concentrations, including the alkalinity, potassium, and sodium and vanadium concentrations at the equivalent location. The concentrations for these solutes were assumed to increase proportionally with the uranium concentration (relative to the initial source concentrations). The concentrations were then corrected first for ion exchange reactions (whereby sodium and potassium would displace calcium from the available ion exchange sites) and second for the formation of calcite (reaction of the liberated calcium with the excess alkalinity). The corrected concentrations were then assessed using PHREEQC.

The results suggest that carnotite would form and that the uranium concentration at the TSF outflow should decrease to less than 0.05 mg/L. The vanadium concentration would decrease from about 500 mg/L to about 170 mg/L. Although also taken up in the formation of carnotite, the vanadium concentration would be higher than the uranium concentration because there is an excess of vanadium that would be released from the tailings (i.e. more vanadium is available than can stoichiometrically be consumed by the formation of carnotite).

In summary, even though the porewater of the tailings at deposition would contain elevated concentrations of uranium, the modelling suggests that the uranium mobility in the long term would be restricted to the near-field of the TSF by the formation of carnotite. This is very much similar to the existing conditions that currently limit the mobility of the uranium within the ore deposit. However, vanadium would be released at concentrations above background levels. The reason for this is that during ore processing uranium is removed while vanadium remains in the solution phase and reports to the tailings. Therefore, when carnotite is re-precipitated, not all of the vanadium would be removed. Some proportion of this vanadium would however be 'lost' to the vadose zone and would not be released to the downstream environment.

3.4.2 Sorption and Ion Exchange

Clays are likely to play an important role in controlling contaminant mobility. Most Yeelirrie materials contain significant quantities of clay. Swelling clays in particular, have a high capacity to adsorb cationic species and are particularly strong adsorbents for alkaline metals (Na, K) and alkaline earths (Ca, Mg). Results from the geochemical investigation indicated that the very high Na levels in some leachates (i.e. tailings porewater) result in displacement of other elements from exchange sites when contacted with materials outside the mining area. In other words, high Na 'fronts' moving through Yeelirrie materials may be coincident with Ca leaching fronts (cation exchange studies indicate that current site occupancy is dominated by Ca). If trace contaminants such as Sr and Ra also occupy such sites, there is the possibility that these elements, as well as Ca, would be leached as the Na front advances. The front however would diminish as it moves away from the TSF area, as the sodium is sorbed and other ions released. These effects would therefore be limited to the near range of the TSF.

As part of the geochemical investigation, sorption coefficients were estimated for the various solutes as summarised Table 3.13. These coefficients may be used to assess, for example, the attenuation of vanadium in the downstream environment should it be necessary. Note however that the sorption is a reversible process.

Table 3.13 Summary of Recommended Sorption Coefficients

Solute	Sorption coefficient, cm^3g^{-1}	
	Loams	Clay-Quartz
As	350	1.3
Ba	0	0
B	51	3
Cd	0	5.3
Cr	4	10
Cu	0.93	1.1
Mn	2	2
Mo	47	0.67
Ni	0	0
Se	50	0.83
Sr	0	0
Tl	0	0
Sn	0.7	1.9
U	420	1.1
V	480	2.7
Zn	0	0
Ra-226	0	2.8

4. Conclusions and Recommendations

The outcomes of the supporting field and laboratory geochemical investigations, together with an understanding of the site conditions and the design and proposed development of the site components, were used to develop source terms for:

- Temporary mine waste and ore stockpiles that would be developed adjacent the mining area;
- The tailings storage facility that would be developed in the open pit areas; and,
- The roads and hardstands that would be sprayed with saline water for dust suppression.

In addition, the potential controls on solute transport in groundwater downstream of the tailings storage facility are discussed. The conclusion and recommendations for each area of the site are described below.

4.1 Mine Waste and ore stockpiles

A procedure for the estimation of solute release rates has been developed and is described. The approach relies on experimental test results to assess the overall capacity of the waste and ore materials to release solutes, and considers the physical interaction of rainfall and runoff with the exposed surfaces. Two source terms representing a base case and an upper bound (or worst case) were developed. The two cases are differentiated on the basis of the duration for which the exposed surfaces would continue to leach solutes. The base case assumes that placed surfaces remain active for one calendar year. This is not unreasonable since the experimental test results showed that the solute release occurs rapidly and generally is removed within the first flush.

The upper bound case assumes that all exposed surfaces remain active at all times. The solute release presented for the upper bound or worst case scenario is therefore possible for any given year only if the surfaces had not been subjected to runoff in any of the preceding years since the surface had been placed. Rainfall data indicate that typically during each calendar two or more rainfall events would occur that could generate runoff. Therefore, the upper bound case very much represents an absolute worst case and is considered unlikely to materialise.

Of further significance is that the solute release capacity of the stockpile materials is finite; once the solute release has occurred it is not 'regenerated' (no new solutes are generated to replace the solutes that have been washed away). Whilst a proportion of the available solute would be 'returned' to the exposed material by abstraction, the majority (> 50 %) would be flushed away during the first runoff event. The proportion of the solutes would continue to diminish by more than 50 % for every subsequent runoff event, so that by the third event solute release would become insignificant. For the base case the surfaces are assumed to remain active for one calendar year. As noted before, during each calendar typically two or more events would occur that could generate runoff. Therefore, the base case is reasonable.

We recommend that the solute release for the base case be adopted for the assessment of potential impacts on surface water quality in or around the mining area.

4.2 Tailings Storage Facility

During operations and active deposition, dewatering activities and water management strategies proposed for the tailings cells would be expected to preclude the loss of porewater to the groundwater system. Only after the tailings cells have been decommissioned and operations cease could the porewater from the tailings potentially be released to groundwater. The source terms developed herein therefore only considered the post closure conditions that may develop in the tailings.

The solute concentrations present the tailings porewater initially would reflect the process discharge water, or barren leach liquor, that would be present in the tailings during deposition.

The aging tests indicated that different reactions would be expected to occur in the tailings after deposition, including equilibration and ion exchange reactions. The recharge and groundwater flow modelling completed by others indicate that the contact time between the tailings and the porewater would be several thousand

years to possibly several hundred thousands of years. Fully equilibrated conditions would therefore be expected to develop in the tailings porewater.

The aging tests were designed to assess the development of equilibrium conditions over time. However, the contact times expected in the field are much longer than possibly can be assessed in the laboratory tests. Therefore the test results would represent the initial conditions that may exist in the tailings. The upper bound concentrations were estimated by completing geochemical speciation modelling to assess fully equilibrated conditions. The results indicated that any residual carnotite that remains in the tailings could be leached due to the elevated soda ash concentrations in the porewater. The uranium concentrations were predicted to increase in the longer term.

The groundwater transport modelling indicated that high evaporative losses from all the TSF cells would occur after closure. This would result in groundwater flows 'drawn' into the tailings mass over time. The majority of the groundwater inflow would occur vertically from the base of the cells, with horizontal inflows typically contributing only a small proportion of the total inflows. The modelling further suggests that the vertical outflows from the majority of the cells significantly exceed the horizontal outflows. For this vertical outflow to occur, a reversal of flows would need to happen at the base of the cells, and consequently little or none of the porewater originally present in the tailings would be expected to be released to groundwater in the vertical outflow from the cells. (Consider a sponge that was used to 'suck up' water from a table – when squeezed to discharge the water, the water sucked up last would be released first.) Horizontal flows would be expected to displace porewater from the tailings, however.

Evaporative losses would also be expected to form evaporites in the vadose zone and accumulate over time as a salt build-up, which would remove salts from the porewater of the tailings. The net 'loss' of solutes from the tailings would decrease the total salt loading that would be available for transport to the groundwater system.

Notwithstanding, we recommend that the average aging test results be adopted as the 'best estimate' source term for the tailings. The results from the PHREEQC calculations which show the fully equilibrated conditions that may develop in the tailings, should be adopted as the 'upper bound' estimate. We recommend that these source terms be applied to all the flows that leave the cells.

Due to the very long contact times and the relative solubility of the solutes present in the tailings, we expect that most of the soluble secondary minerals would dissolve and be displaced in the first pore volume displacement. The source terms therefore may be represented as step functions for the duration of the first pore volume displacement after which concentrations would be expected to revert to near background levels.

Source term estimates were also developed for the four cells that would be backfilled with unprocessed low grade ore and mine waste. Concentration estimates and source duration calculations are also presented for these cells.

4.3 Roads and Hardstands

The salt loadings associated with the roads and hardstands are continuously re-supplied by the application of spray water for dust suppression. Solute loadings for the roads and hardstands have been estimated based on the water application rates and salinity content of the spray water and are presented as solute loadings per unit surface area. Solute loadings have been calculated for a series of rainfall events and may be used to estimate effects on surface runoff water quality.

4.4 Effects on Solute Transport

Groundwater transport modelling completed by others indicated very high evaporative losses from the tailings which would lead to evapo-concentration of contaminants (i.e. increased solute concentrations). Simple mass balance calculations based on the modelled flows suggest for example that uranium concentrations could increase to more than 1000 mg/L in the very long term. However, geochemical modelling based on the changes in solute concentrations and the influence of ion exchange, indicates that carnotite would be expected to form and that the uranium concentration at the TSF outflow should decrease to very low concentrations, approaching current background levels. The vanadium concentrations however would remain elevated above background levels (at about 170 mg/L) because there is excess vanadium that

would not be taken up in the precipitation reactions (i.e. more vanadium is available than can be consumed by the formation of carnotite).

In conclusion, whilst the modelling and testing indicate that in the short term after closure uranium and other solute concentrations would be expected to increase within the tailings porewater, the potential for solute is first of all limited by the very low flows that would be displaced from the tailings. In the longer term, evaporation and subsequent interaction would lead to a net loss of alkalinity from the porewater and an increase in the potassium concentration, which, together with other equilibration reactions, are expected to lead to carnotite precipitation. The formation of carnotite would lead to uranium concentrations that would be similar to current background concentrations. However, vanadium concentrations would be expected to remain above background levels and could be as high as 170 mg/L in the tailings porewater. As noted before, the rate of vanadium release would be limited by the rate of porewater release from the tailings. Furthermore, vanadium would be expected to be attenuated to some degree in the downstream clay quartz materials ($K_D = 2.7 \text{ cm}^3/\text{g}$), but particularly in loams ($K_D = 480 \text{ cm}^3/\text{g}$).

5. References

- Parkhurst, D.L. and Appelo, C.A.J. *User's guide to PHREEQC (Version 2) – A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations*. Water-Resources Investigations Report 99-4259, 1999.
- SRK, 2011. *Proposed Yeelirrie Development: Geochemical Assessment of Tailings and Mine Waste*, Project Number BHP047/1, March 2011.
- URS, 2011. *Groundwater Study - Proposed Yeelirrie Development*. Document Reference 42907583/W0436.498/0, March 2011.

Appendices

Appendix 1: Stockpile Solute Release Rates

Depth of influence (m) 0.5

Dry Period (days) 120

Event ARI Years	Conditions Duration hours	Location Stockpile	Loadings TDS mg/m ²	Ag	Al	As	B	Ba	Be	Bi	Br	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	Hg	K	Li	
				mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²
			LG	4.8E+06	4.7E-01	5.1E+01	6.1E+01	5.4E+03	4.0E+01	4.6E+00	4.5E+00	2.5E+00	5.2E+04	4.1E+00	1.7E+06	2.8E+01	5.4E+00	6.0E+00	1.0E+04	3.7E+00	1.7E-01	3.0E+05	3.2E+01
			Waste	5.4E+06	4.7E-01	5.1E+01	2.8E+01	7.6E+03	4.0E+01	4.6E+00	4.5E+00	2.5E+00	5.2E+04	4.1E+00	2.1E+06	2.6E+01	5.4E+00	6.0E+00	9.0E+03	3.7E+00	1.7E-01	3.1E+05	2.6E+01
100	48		VHG	6.7E+06	9.5E-01	1.0E+02	8.2E+01	7.3E+03	8.0E+01	9.2E+00	8.9E+00	5.1E+00	1.0E+05	8.3E+00	1.7E+06	2.3E+01	1.1E+01	1.2E+01	8.2E+03	7.5E+00	3.3E-01	3.7E+05	2.5E+01
			HG	2.5E+06	9.5E-01	1.0E+02	3.1E+01	2.3E+03	8.0E+01	9.2E+00	8.9E+00	5.1E+00	1.0E+05	8.3E+00	4.1E+05	2.3E+01	1.1E+01	1.2E+01	8.1E+03	7.5E+00	3.3E-01	9.0E+04	2.3E+01
			MG	5.8E+06	1.0E+00	1.1E+02	3.5E+01	6.1E+03	8.7E+01	1.0E+01	9.7E+00	5.5E+00	1.1E+05	9.0E+00	1.7E+06	2.2E+01	1.2E+01	1.3E+01	1.0E+04	8.2E+00	3.6E-01	3.2E+05	2.4E+01
			LG	5.0E+06	1.0E+00	1.1E+02	5.8E+01	5.2E+03	8.1E+01	1.0E+01	9.7E+00	5.5E+00	1.1E+05	9.0E+00	1.7E+06	2.7E+01	1.2E+01	1.3E+01	1.0E+04	8.2E+00	3.6E-01	2.9E+05	3.0E+01
			Waste	5.6E+06	1.0E+00	1.1E+02	2.7E+01	7.4E+03	8.2E+01	1.0E+01	9.7E+00	5.5E+00	1.0E+05	9.0E+00	2.0E+06	2.5E+01	1.2E+01	1.3E+01	8.7E+03	8.2E+00	3.6E-01	3.0E+05	2.5E+01
100	72		VHG	6.3E+06	9.9E-01	1.1E+02	7.6E+01	6.8E+03	8.3E+01	9.6E+00	9.3E+00	5.3E+00	1.1E+05	8.6E+00	1.5E+06	2.2E+01	1.1E+01	1.3E+01	7.6E+03	7.8E+00	3.5E-01	3.5E+05	2.3E+01
			HG	2.4E+06	9.9E-01	1.1E+02	2.9E+01	2.1E+03	8.3E+01	9.6E+00	9.3E+00	5.3E+00	9.9E+04	8.6E+00	3.8E+05	2.1E+01	1.1E+01	1.3E+01	7.6E+03	7.8E+00	3.5E-01	8.3E+04	2.1E+01
			MG	5.7E+06	1.1E+00	1.2E+02	3.4E+01	6.0E+03	9.5E+01	1.1E+01	1.1E+01	6.0E+00	1.2E+05	9.8E+00	1.7E+06	2.2E+01	1.3E+01	1.4E+01	9.8E+03	8.9E+00	4.0E-01	3.1E+05	2.3E+01
			LG	4.9E+06	1.1E+00	1.2E+02	5.7E+01	5.0E+03	7.9E+01	1.1E+01	1.1E+01	6.0E+00	1.2E+05	9.8E+00	1.6E+06	2.7E+01	1.3E+01	1.4E+01	9.9E+03	8.9E+00	4.0E-01	2.9E+05	3.0E+01
			Waste	5.5E+06	1.1E+00	1.2E+02	2.7E+01	7.2E+03	8.0E+01	1.1E+01	1.1E+01	6.0E+00	1.0E+05	9.8E+00	2.0E+06	2.4E+01	1.3E+01	1.4E+01	8.5E+03	8.9E+00	4.0E-01	2.9E+05	2.4E+01
1000	24		VHG	8.8E+06	1.2E+00	1.3E+02	9.2E+01	8.1E+03	9.9E+01	1.1E+01	1.1E+01	6.3E+00	1.3E+05	1.0E+01	1.9E+06	2.6E+01	1.3E+01	1.5E+01	9.1E+03	9.3E+00	4.1E-01	4.2E+05	2.8E+01
			HG	2.9E+06	1.2E+00	1.3E+02	3.5E+01	2.5E+03	9.9E+01	1.1E+01	1.1E+01	6.3E+00	1.2E+05	1.0E+01	4.6E+05	2.6E+01	1.3E+01	1.5E+01	9.1E+03	9.3E+00	4.1E-01	1.0E+05	2.6E+01
			MG	8.3E+06	1.2E+00	1.3E+02	3.6E+01	6.5E+03	1.0E+02	1.2E+01	1.1E+01	6.5E+00	1.3E+05	1.1E+01	1.8E+06	2.3E+01	1.4E+01	1.5E+01	1.1E+04	9.6E+00	4.2E-01	3.4E+05	2.5E+01
			LG	5.3E+06	1.2E+00	1.3E+02	6.1E+01	5.4E+03	8.5E+01	1.2E+01	1.1E+01	6.5E+00	1.3E+05	1.1E+01	1.8E+06	2.9E+01	1.4E+01	1.5E+01	1.1E+04	9.6E+00	4.2E-01	3.1E+05	3.2E+01
			Waste	5.9E+06	1.2E+00	1.3E+02	2.9E+01	7.8E+03	8.7E+01	1.2E+01	1.1E+01	6.5E+00	1.1E+05	1.1E+01	2.1E+06	2.6E+01	1.4E+01	1.5E+01	9.2E+03	9.6E+00	4.2E-01	3.2E+05	2.6E+01
1000	48		VHG	8.7E+06	1.4E+00	1.5E+02	9.0E+01	7.9E+03	1.2E+02	1.4E+01	1.3E+01	7.6E+00	1.6E+05	1.2E+01	1.8E+06	2.5E+01	1.6E+01	1.8E+01	8.9E+03	1.1E+01	5.0E-01	4.1E+05	2.7E+01
			HG	2.9E+06	1.4E+00	1.5E+02	3.4E+01	2.5E+03	1.2E+02	1.4E+01	1.3E+01	7.6E+00	1.2E+05	1.2E+01	4.5E+05	2.5E+01	1.6E+01	1.8E+01	8.9E+03	1.1E+01	5.0E-01	9.8E+04	2.5E+01
			MG	8.3E+06	1.5E+00	1.4E+02	3.6E+01	6.4E+03	1.2E+02	1.4E+01	1.4E+01	7.9E+00	1.6E+05	1.3E+01	1.8E+06	2.3E+01	1.7E+01	1.9E+01	1.0E+04	1.2E+01	5.2E-01	3.4E+05	2.5E+01
			LG	5.3E+06	1.5E+00	1.6E+02	6.1E+01	5.4E+03	8.4E+01	1.4E+01	1.4E+01	7.9E+00	1.4E+05	1.3E+01	1.8E+06	2.9E+01	1.7E+01	1.9E+01	1.1E+04	1.2E+01	5.2E-01	3.1E+05	3.2E+01
			Waste	5.9E+06	1.5E+00	1.5E+02	2.9E+01	7.7E+03	8.6E+01	1.4E+01	1.4E+01	7.9E+00	1.1E+05	1.3E+01	2.1E+06	2.6E+01	1.7E+01	1.9E+01	9.1E+03	1.2E+01	5.2E-01	3.1E+05	2.6E+01
1000	72		VHG	8.4E+06	1.4E+00	1.6E+02	8.6E+01	7.6E+03	1.2E+02	1.4E+01	1.4E+01	7.7E+00	1.6E+05	1.3E+01	1.7E+06	2.4E+01	1.7E+01	1.8E+01	8.6E+03	1.1E+01	5.1E-01	3.9E+05	2.6E+01
			HG	2.8E+06	1.4E+00	1.6E+02	3.3E+01	2.4E+03	1.2E+02	1.4E+01	1.4E+01	7.7E+00	1.1E+05	1.3E+01	4.3E+05	2.4E+01	1.7E+01	1.8E+01	8.5E+03	1.1E+01	5.1E-01	9.4E+04	2.4E+01
			MG	8.2E+06	1.5E+00	1.4E+02	3.5E+01	6.3E+03	1.3E+02	1.5E+01	1.4E+01	8.2E+00	1.7E+05	1.3E+01	1.8E+06	2.3E+01	1.8E+01	2.0E+01	1.0E+04	1.2E+01	5.4E-01	3.3E+05	2.5E+01
			LG	5.3E+06	1.5E+00	1.7E+02	6.0E+01	5.3E+03	8.3E+01	1.5E+01	1.4E+01	8.2E+00	1.4E+05	1.3E+01	1.7E+06	2.8E+01	1.8E+01	2.0E+01	1.0E+04	1.2E+01	5.4E-01	3.0E+05	3.1E+01
			Waste	5.8E+06	1.5E+00	1.5E+02	2.8E+01	7.5E+03	8.4E+01	1.5E+01	1.4E+01	8.2E+00	1.1E+05	1.3E+01	2.1E+06	2.6E+01	1.8E+01	2.0E+01	8.9E+03	1.2E+01	5.1E-01	3.1E+05	2.6E+01

Depth of influence (m) 0.5

Dry Period (days) 120

Event ARI Years	Conditions Duration hours	Location Stockpile	Mg	Mn	Mo	Na	Ni	NO3	P	Pb	Ra226	Sb	Se	Si	Sn	SO4	Sr	Tl	tal Alkalini	U	V	Zn
			mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	Bq/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
100	48	LG	1.8E+05	2.9E+01	2.9E+02	1.7E+06	2.8E+01	1.5E+04	3.8E+02	3.8E-01	1.6E+01	3.8E-01	4.3E+01	6.4E+03	2.8E+01	6.5E+05	1.7E+03	2.7E+01	9.8E+04	1.6E+02	1.1E+02	5.8E+02
		Waste	1.8E+05	8.8E+01	1.5E+02	1.7E+06	2.6E+01	6.9E+04	3.8E+02	3.8E-01	0.0E+00	3.8E-01	5.0E+01	6.4E+03	2.6E+01	9.6E+05	1.7E+03	2.7E+01	9.8E+04	1.6E+02	1.1E+02	6.7E+02
		VHG	2.2E+05	6.6E+01	1.9E+02	2.0E+06	2.7E+01	1.1E+05	7.5E+02	7.5E-01	5.0E+02	7.5E-01	5.2E+01	1.3E+04	3.4E+01	2.0E+06	3.5E+03	5.4E+01	2.0E+05	3.2E+02	2.1E+02	6.4E+02
		HG	9.4E+04	2.6E+01	1.4E+02	1.0E+06	2.6E+01	1.6E+04	7.5E+02	7.5E-01	6.2E+00	7.5E-01	2.6E+01	1.3E+04	2.6E+02	5.7E+05	1.2E+03	2.4E+01	2.0E+05	3.2E+02	1.1E+02	1.5E+02
		MG	2.9E+05	2.6E+01	1.8E+02	1.6E+06	3.6E+01	3.4E+04	8.2E+02	8.2E-01	8.5E+01	8.2E-01	4.4E+01	1.4E+04	2.6E+01	1.4E+06	3.8E+03	5.9E+01	2.1E+05	3.4E+02	2.3E+02	5.9E+02
100	72	LG	1.7E+05	2.8E+01	2.8E+02	1.7E+06	2.7E+01	1.4E+04	8.2E+02	8.2E-01	1.6E+01	8.2E-01	4.2E+01	1.4E+04	2.7E+01	7.8E+05	2.4E+03	5.9E+01	2.1E+05	3.4E+02	2.3E+02	5.6E+02
		Waste	1.7E+05	8.5E+01	1.5E+02	1.6E+06	2.5E+01	6.6E+04	5.0E+02	8.2E-01	0.0E+00	8.2E-01	4.9E+01	1.4E+04	2.5E+01	1.1E+06	1.9E+03	5.9E+01	2.1E+05	2.4E+02	2.3E+02	6.5E+02
		VHG	2.0E+05	6.1E+01	1.8E+02	1.8E+06	2.5E+01	1.1E+05	7.8E+02	7.8E-01	4.7E+02	7.8E-01	4.8E+01	1.3E+04	3.1E+01	1.9E+06	3.6E+03	5.6E+01	2.0E+05	3.3E+02	2.2E+02	6.0E+02
		HG	8.8E+04	2.4E+01	1.3E+02	9.7E+05	2.4E+01	1.5E+04	7.8E+02	7.8E-01	5.8E+00	7.8E-01	2.4E+01	1.3E+04	2.4E+02	5.4E+05	1.1E+03	2.2E+01	2.0E+05	3.3E+02	9.9E+01	1.4E+02
		MG	2.8E+05	2.5E+01	1.8E+02	1.6E+06	3.6E+01	3.3E+04	8.9E+02	8.9E-01	8.3E+01	8.9E-01	4.3E+01	1.5E+04	2.5E+01	1.4E+06	4.1E+03	6.4E+01	2.3E+05	3.8E+02	2.5E+02	5.8E+02
1000	24	LG	1.7E+05	2.7E+01	2.8E+02	1.6E+06	2.7E+01	1.4E+04	8.9E+02	8.9E-01	1.5E+01	8.9E-01	4.1E+01	1.5E+04	2.7E+01	7.9E+05	2.4E+03	6.4E+01	2.3E+05	3.8E+02	2.5E+02	5.5E+02
		Waste	1.7E+05	8.3E+01	1.4E+02	1.6E+06	2.4E+01	6.5E+04	4.9E+02	8.9E-01	0.0E+00	8.9E-01	4.7E+01	1.5E+04	2.4E+01	1.0E+06	1.9E+03	6.4E+01	2.3E+05	2.4E+02	2.5E+02	6.3E+02
		VHG	2.5E+05	7.3E+01	2.1E+02	2.2E+06	3.0E+01	1.3E+05	9.4E+02	9.4E-01	5.6E+02	9.4E-01	5.8E+01	1.6E+04	3.8E+01	3.5E+06	4.3E+03	6.7E+01	2.4E+05	3.9E+02	2.6E+02	7.2E+02
		HG	1.1E+05	2.9E+01	1.5E+02	1.2E+06	2.9E+01	1.8E+04	9.4E+02	9.4E-01	6.9E+00	9.4E-01	2.9E+01	1.6E+04	2.9E+02	6.4E+05	1.3E+03	2.7E+01	2.4E+05	3.9E+02	1.2E+02	1.7E+02
		MG	3.0E+05	2.7E+01	1.9E+02	1.7E+06	3.8E+01	3.6E+04	9.6E+02	9.6E-01	9.0E+01	9.6E-01	4.7E+01	1.6E+04	2.7E+01	3.7E+06	4.4E+03	6.9E+01	2.5E+05	4.0E+02	2.7E+02	6.2E+02
1000	48	LG	1.8E+05	2.9E+01	3.0E+02	1.7E+06	2.9E+01	1.5E+04	9.6E+02	9.6E-01	1.7E+01	9.6E-01	4.4E+01	1.6E+04	2.9E+01	8.7E+05	2.6E+03	6.9E+01	2.5E+05	4.0E+02	2.7E+02	5.9E+02
		Waste	1.8E+05	8.9E+01	1.5E+02	1.7E+06	2.6E+01	7.0E+04	5.2E+02	9.6E-01	0.0E+00	9.6E-01	5.1E+01	1.6E+04	2.6E+01	1.1E+06	2.0E+03	6.9E+01	2.5E+05	2.6E+02	2.7E+02	6.8E+02
		VHG	2.4E+05	7.2E+01	2.1E+02	2.2E+06	3.0E+01	1.2E+05	1.1E+03	1.1E+00	5.5E+02	1.1E+00	5.7E+01	1.9E+04	3.7E+01	3.5E+06	5.2E+03	8.1E+01	2.9E+05	4.7E+02	3.2E+02	7.0E+02
		HG	1.0E+05	2.8E+01	1.5E+02	1.1E+06	2.8E+01	1.8E+04	1.1E+03	1.1E+00	6.8E+00	1.1E+00	2.8E+01	1.9E+04	2.8E+02	6.3E+05	1.3E+03	2.6E+01	2.9E+05	4.7E+02	1.2E+02	1.6E+02
		MG	3.0E+05	2.7E+01	1.9E+02	1.7E+06	3.8E+01	3.6E+04	1.2E+03	1.2E+00	8.9E+01	1.2E+00	4.6E+01	2.0E+04	2.7E+01	3.6E+06	5.4E+03	8.4E+01	3.0E+05	4.9E+02	3.3E+02	6.1E+02
1000	72	LG	1.8E+05	2.9E+01	3.0E+02	1.7E+06	2.9E+01	1.5E+04	1.0E+03	1.2E+00	1.6E+01	1.2E+00	4.4E+01	2.0E+04	2.9E+01	8.6E+05	2.5E+03	8.4E+01	3.0E+05	4.9E+02	3.3E+02	5.9E+02
		Waste	1.8E+05	8.8E+01	1.5E+02	1.7E+06	2.6E+01	6.9E+04	5.2E+02	1.2E+00	0.0E+00	1.2E+00	5.1E+01	2.0E+04	2.6E+01	1.1E+06	2.0E+03	8.4E+01	3.0E+05	2.5E+02	3.3E+02	6.7E+02
		VHG	2.3E+05	6.9E+01	2.0E+02	2.1E+06	2.9E+01	1.2E+05	1.1E+03	1.1E+00	5.3E+02	1.1E+00	5.4E+01	2.0E+04	3.5E+01	3.3E+06	5.3E+03	8.3E+01	3.0E+05	4.8E+02	3.2E+02	6.8E+02
		HG	9.9E+04	2.7E+01	1.4E+02	1.1E+06	2.7E+01	1.7E+04	1.1E+03	1.1E+00	6.5E+00	1.1E+00	2.7E+01	2.0E+04	2.7E+02	6.0E+05	1.2E+03	2.5E+01	3.0E+05	4.8E+02	1.1E+02	1.6E+02
		MG	2.9E+05	2.6E+01	1.9E+02	1.6E+06	3.7E+01	3.5E+04	1.2E+03	1.2E+00	8.7E+01	1.2E+00	4.5E+01	2.1E+04	2.6E+01	3.6E+06	5.6E+03	8.8E+01	3.2E+05	5.1E+02	3.4E+02	6.0E+02
1000	72	LG	1.7E+05	2.8E+01	2.9E+02	1.7E+06	2.8E+01	1.5E+04	1.0E+03	1.2E+00	1.6E+01	1.2E+00	4.3E+01	2.1E+04	2.8E+01	8.5E+05	2.5E+03	8.8E+01	3.2E+05	5.1E+02	3.4E+02	5.8E+02
		Waste	1.8E+05	8.7E+01	1.5E+02	1.6E+06	2.6E+01	6.8E+04	5.1E+02	1.2E+00	0.0E+00	1.2E+00	5.0E+01	2.1E+04	2.6E+01	1.1E+06	1.9E+03	8.8E+01	3.2E+05	2.5E+02	3.4E+02	6.6E+02

Appendix 2: Roads and Hardstand Solute Release Rates

Dust Suppression Application Rate 1 L/m2/day
Event ARI 20 years
Event Duration 1 hrs

Solute Loadings mg/m2

Table with 32 columns: Processing Year, TDS, K, Na, Ca, Mg, SO4, S, HC03, Cl, Nitrate, F, Silica_diss B, U, V, Al, As, Ba, Cd, Cr, Co, Cu, Fe, Li, Mn, Mo, Ni, Pb, Se, Sr, Zn. Rows contain numerical data for each parameter across various years.

Dust Suppression Application Rate 1 L/m2/day
Event ARI 20 years
Event Duration 6 hrs

Solute Loadings mg/m2

Table with 32 columns: Processing Year, TDS, K, Na, Ca, Mg, SO4, S, HC03, Cl, Nitrate, F, Silica_diss B, U, V, Al, As, Ba, Cd, Cr, Co, Cu, Fe, Li, Mn, Mo, Ni, Pb, Se, Sr, Zn. Rows contain numerical data for each parameter across various years.

Dust Suppression Application Rate 1 L/m²/day
 Event ARI 1000 years
 Event Duration 48 hrs

Solute Loadings mg/m²

Processing Year	TDS	K	Na	Ca	Mg	SO4	S	HC03	Cl	Nitrate	F	Silica_diss B	U	V	Al	As	Ba	Cd	Cr	Co	Cu	Fe	Li	Mn	Mo	Ni	Pb	Se	Sr	Zn	
		mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²		
-2	2055785	68577	537943	46951	50192	359029	119545	21585	837257	5965	178	5837	1650	19	4.57	0.54	1.03	12.74	0.06	5.84	0.92	1.15	8	2.8	23.6	28.34	1.04	0.10	4.60	958	2.7
-1	2354494	79131	613736	52338	58903	409440	136345	22016	966657	6978	187	5781	1819	21	4.68	0.54	1.07	13.64	0.07	6.41	0.99	1.19	7	2.9	26.0	31.03	1.03	0.10	4.84	1038	2.1
1	3856227	133274	960081	73651	118002	635512	211828	19405	1676941	17552	209	6576	2085	23	1.32	0.54	0.40	15.06	0.07	6.48	1.10	0.95	5	1.1	41.1	29.83	0.22	0.09	3.02	982	0.5
2	4476077	150749	1094363	80205	140136	732212	244077	19781	1975613	29389	217	6294	2085	14	0.74	0.54	0.24	15.06	0.07	8.49	1.10	0.85	5	0.5	41.1	27.01	0.18	0.09	2.66	838	0.5
3	3855328	132554	929522	65218	123656	631241	210490	26164	1702899	23408	255	7231	2085	9	0.82	0.54	0.17	15.06	0.07	4.47	1.10	0.55	5	0.6	41.1	15.90	0.18	0.09	1.83	507	0.5
4	3596900	123520	866787	61274	115411	588416	196209	25395	1587901	21987	244	7231	1951	9	0.82	0.54	0.16	14.34	0.07	4.17	1.04	0.55	6	0.7	38.8	14.85	0.20	0.09	1.75	480	1.0
5	3222293	62630	798909	56537	129040	541698	180567	29261	1412648	3697	50	3725	2117	53	4.41	0.54	4.42	14.63	0.07	1.25	1.11	2.69	44	5.0	282.7	14.07	4.76	0.53	8.18	905	66.2
6	1698807	47968	420426	31428	60728	281541	93884	23526	725779	5194	152	6374	1220	22	1.82	0.54	1.13	8.24	0.04	0.86	0.71	0.98	17	2.2	70.7	9.15	1.35	0.36	3.35	429	16.0
7	1092221	26176	270412	22077	41636	180222	60107	20303	460796	2863	125	6187	820	19	1.66	0.54	1.08	5.90	0.03	0.43	0.53	0.94	18	2.1	62.5	7.30	1.35	0.42	3.05	354	16.5
8	1392340	27025	339078	27603	55824	230306	76780	21073	604401	2988	89	5587	924	23	2.35	0.54	1.86	8.52	0.04	0.56	0.61	1.35	26	2.6	121.4	6.89	2.24	0.37	3.78	429	30.4
9	1163056	33199	303325	24064	40537	188471	62833	20085	477269	4535	114	7027	1073	24	1.10	0.54	0.62	5.37	0.03	0.34	0.72	0.92	23	2.7	22.5	5.80	0.85	0.13	3.23	421	12.3
10	2650763	83296	717292	46459	88981	439161	146415	27600	1083278	7285	152	7231	2594	57	0.91	0.54	0.94	4.58	0.04	0.60	1.39	1.40	29	5.1	0.6	13.45	0.80	0.09	6.87	882	12.1
11	2394071	65354	626723	42695	84970	392175	130750	25494	1010387	5859	128	6438	2073	53	1.58	0.54	1.42	7.25	0.04	0.67	1.37	1.71	42	5.0	62.1	11.92	1.93	0.32	6.12	805	24.4
12	2539044	61796	647993	44576	92601	404824	134980	24635	1113459	5475	134	5374	1968	65	1.83	0.54	1.52	9.67	0.04	0.76	1.90	2.35	71	6.3	96.3	13.02	3.27	0.72	6.19	914	35.1
13	2005516	50686	514241	36608	72384	320608	106897	22837	867426	5117	127	6006	1619	50	1.54	0.54	1.15	8.02	0.04	0.59	1.45	1.81	53	4.9	67.2	10.24	2.35	0.50	5.03	725	26.3
14	1988918	50804	510394	36211	71155	315097	105064	22509	863714	5231	133	6018	1615	52	1.38	0.54	0.97	7.91	0.03	0.57	1.57	1.85	58	5.2	57.5	10.36	2.38	0.55	4.94	741	25.2
15	2098931	53905	538533	37596	74283	327463	109196	22410	921239	5522	147	5875	1697	61	1.19	0.54	0.74	8.16	0.03	0.58	1.89	2.08	71	6.0	48.2	11.29	2.67	0.70	5.08	819	25.7
16	1946375	50070	499829	35526	69346	307423	102507	22275	845408	5243	135	6066	1589	52	1.31	0.54	0.88	7.76	0.03	0.55	1.58	1.83	59	5.2	52.3	10.21	2.33	0.55	4.83	734	24.3
17	1858501	47418	476283	34262	66504	294049	98046	21991	806221	5079	131	6093	1510	49	1.35	0.54	0.91	7.69	0.03	0.54	1.48	1.75	55	4.9	54.2	9.68	2.24	0.52	4.65	697	24.0
18	1258341	30590	316707	25294	45654	196476	65510	19477	546302	4260	118	6293	995	33	1.27	0.54	0.69	7.04	0.03	0.40	1.07	1.36	44	3.6	46.3	6.53	1.77	0.40	3.27	494	19.7
19	2621721	59032	659807	45927	98012	417502	139205	24667	1164407	5036	124	4797	1900	67	2.24	0.54	1.90	11.11	0.04	0.84	1.95	2.59	77	6.6	131.3	13.25	3.90	0.83	6.33	933	42.6
20	2353687	58206	602702	41946	85824	378679	126257	24339	1021655	5303	126	5683	1861	57	1.82	0.54	1.52	8.95	0.04	0.71	1.61	2.07	58	5.5	90.3	11.86	2.80	0.57	5.85	826	31.9
21	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2
22	2664152	68144	690717	47234	97794	443824	147956	27188	1126401	5495	107	5997	2193	51	2.31	0.54	2.25	8.62	0.05	0.82	1.18	1.83	34	4.7	113.9	12.61	2.35	0.27	6.87	826	33.3
23	2712237	73534	711399	47818	97330	451328	150462	27546	1136837	6023	119	6400	2342	53	1.96	0.54	1.95	7.61	0.05	0.78	1.26	1.74	33	4.9	85.8	13.08	1.98	0.23	6.99	855	28.1
24	2401824	75203	648582	42701	80719	397166	132414	26351	981169	6859	146	7231	2347	52	0.91	0.54	0.86	4.64	0.04	0.56	1.28	1.31	28	4.7	2.1	12.19	0.78	0.10	6.26	806	11.7
25	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2
26	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2
27	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2
28	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2
29	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2
30	2720829	85516	736516	47519	91337	450989	150359	27950	1112156	7399	153	7231	2662	58	0.91	0.54	0.97	4.58	0.04	0.62	1.42	1.42	30	5.2	0.6	13.80	0.81	0.09	7.05	904	12.2

Dust Suppression Application Rate 1 L/m²/day
 Event ARI 1000 years
 Event Duration 72 hrs

Solute Loadings mg/m²

Processing Year	TDS	K	Na	Ca	Mg	SO4	S	HC03	Cl	Nitrate	F	Silica_diss B	U	V	Al	As	Ba	Cd	Cr	Co	Cu	Fe	Li	Mn	Mo	Ni	Pb	Se	Sr	Zn	
		mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	
-2	1914227	63855	500901	43718	46736	334307	111314	20099	779605	5555	165	5435	1536	18	4.25	0.54	0.96	11.86	0.06	5.44	0.86	1.07	8	2.7	22.0	26.39	0.97	0.09	4.28	892	2.5
-1	2192367	73683	571475	48734	54847	381247	126957	20500	900094	6498	174	5383	1694	19	4.36	0.54	1.00	12.70	0.06	5.97	0.92	1.11	7	2.7	24.2	28.89	0.96	0.09	4.51	966	1.9
1	3590693	124097	893971	68580	109877	591752	197242	18068	1561469	16344	194	6123	1942	21	1.23	0.54	0.37	14.02	0.07	6.04	1.02	0.89	4	1.0	38.2	27.78	0.21	0.08	2.81	914	0.5
2	4167861	140369	1019007	74682	130487	681793	227270	18419	1839575	27366	202	5861	1942	13																	