CLOSURE PLAN EVALUATION FOR RISK OF ACID ROCK DRAINAGE[1]

by

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Abstract. Control of acid rock drainage (ARD) is a long-term issue for many mine sites and is often a primary objective of remediation efforts. Some sites continue to require monitoring and management of ARD long after mine operation has ceased and closure is complete. In New Zealand, an innovative and quantitative approach was applied to evaluate the expected risk of ARD after implementation of the closure plan for the Golden Cross Mine. In addition, this future risk was compared to current operating conditions to provide an estimate of the reduction in risk provided by the remediation activities. This approach was useful to both the mine proponent and the regulatory agencies in assessing the effectiveness of the existing closure plan and providing focus on the components of greatest risk.

Mine components remaining on site after closure that could potentially generate ARD under various failure scenarios were identified and evaluated. These components included the tailings decant pond, waste rock stockpiles, open pit mine and water treatment systems. For each component, a series of initiating events and failure scenarios were identified, and a decision tree methodology was utilized to estimate the probability of ARD generation for both current and closure conditions. Due to the implementation of closure plans designed to minimize or eliminate ARD through regrading, construction of engineered covers and water management designs, the risk of ARD generation will be significantly reduced over time.

A decision tree graphically illustrates key decision points, the events that may occur and the outcomes associated with combinations of decisions and events. Annualized probabilities are assigned for each individual event and uncertainty ranges are included to represent the level of confidence in the data. Commercially available *Crystal Ball* software was used to combine the individual probabilities through a Monte Carlo simulation. The decision tree approach provides an understanding of the probabilities of system performance under various adverse conditions. In particular, an explicit definition of the pathways to ARD generation forces a systematic and comprehensive analysis of potential failure mechanisms with consideration for the quantitative risk reduction effect of various remedial design features, stabilization measures, closure methods and monitoring.

Additional Key Words: decision tree methodology, probabilistic model

Introduction

Golden Cross Mine is a precious metals mine in New Zealand that conducted both underground and open pit mining operations. At closure, a total of approximately 4.5 million tonnes of ore and 8.5 million tonnes of waste were produced at the mine. Mining activities provide a means for producing acid rock drainage (ARD) through the development of the open pit, waste rock stockpiles and a tailings impoundment. As the operations at the mine were nearing completion, the expected risk of ARD after site closure was evaluated. This estimate of risk was compared to the risk during current conditions to provide an estimate of the effectiveness of implementing the rehabilitation and closure plan in reducing the risk of ARD from the site. The regulatory agencies have used the results from this analysis to evaluate and modify the closure plan to minimize risk of ARD generation.

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Evaluation Approach

For current and future conditions, mine components remaining on site after closure that could potentially generate ARD under various failure scenarios were identified and evaluated. The mine components evaluated included the tailings decant pond, waste rock stockpiles, the open pit mine and water treatment systems. In general, comprehensive empirical data regarding failure of the primary mine components is limited. Consequently, the probability of an environmental impact usually cannot be directly estimated from empirical data on the repeated occurrence of a particular type of failure. Therefore, for each component, a series of initiating events and failure scenarios were identified, and a decision tree methodology was used to estimate the probability of ARD generation under both current and post-closure conditions. These probabilities were then compared to determine the expected reduction in risk of ARD due to implementation of closure remedies.

The decision tree approach provides a systematic methodology to estimate the probability of generating ARD from a specific component. A similar approach is discussed in detail in the most recent U.S. Transportation Research Board (1996) Special Report 247 on *Landslide Hazard and Risk Assessment.* A decision tree graphically illustrates key decision points, the events that may occur, and the outcomes associated with combinations of decisions and events. The risk of ARD for each mining component is calculated as function of the probabilities of individual decisions and events occurring, which lead to the generation of ARD.

Annualized probabilities are assigned for each individual event, based on data from hydrologic modeling and engineering design analyses of stabilization measures currently in progress. Probability values assigned were supported by thoroughly reviewing the existing database, discussing issues with mine and environmental staff and applying engineering and scientific judgment. Guidelines for assigning reasonable quantitative probabilities had been developed previously during a technical workshop at the Golden Cross Mine. These guidelines were also used for this analysis of ARD risk and are presented below in Table 1.

Where appropriate, uncertainty ranges have been assigned to the probabilities to incorporate the level of confidence in the data used in this analysis. Incorporating uncertainty allows a more realistic representation of the individual probabilities by assigning a range of values rather than a discrete number. Commercially available *Crystal Ball* software, which utilizes a Monte Carlo simulation approach, was used to combine the individual probabilities to calculate an overall range of probability for each potential outcome.

TABLE 1
GUIDELINES TO EVALUATE THE REASONABLENESS OF SUBJECTIVE PROBABILITIES (WOODWARD CLYDE, 1998)

DESCRIPTION OF CONDITION OR EVENT	ORDER OF MAGNITUDE
Occurrences of the condition or event are observed in the available database.	10^{-1}
The occurrence of the condition or event is not observed, or is observed in one isolated instance in the available database; however, several potential failure scenarios can be identified.	10^{-2}
The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort.	10^{-3}
The condition or event has not been observed and no plausible scenario could be identified, even after considerable effort.	10^{-4}

The decision tree models presented herein contain three kinds of nodes and two kinds of branches. A decision node (shown as a square) is a point where a choice is required. The branches extending from a decision node each represent one of the possible alternatives or courses of action available at that point. An event node (shown as a circle) is a point where uncertainty is resolved (i.e. a point where a decision-maker learns about the occurrence of an event). The event branches extending from the event node each represent one of the possible events that may occur at that point. In general, decision nodes and branches represent the controllable factors in a decision problem while event nodes and branches represent uncontrollable factors or consequences. In either case, the set of branches emanating from a node must be mutually exclusive (i.e., if one is chosen, the others cannot be chosen) and collectively exhaustive (i.e. all possible alternatives must be included in the set). Each branch is assigned a subjective probability of occurrence determined through a combination of site knowledge, available data and expert judgment. The sum of probabilities for the branches in a set must equal one (100%). The third kind of node (shown as a triangle) is the terminal node and represents the final result of a combination of decisions and events. Terminal nodes are the endpoints of a decision tree and represent the risk of a particular series of decisions and events.

The decision tree approach is considered an appropriate methodology for evaluating risk of ARD at the Golden Cross Mine. A peer review committee consisting of third party government representatives supported this approach and methodology. In providing an estimate of the overall annual probability of the key components (tailings decant pond, waste rock stockpiles, open pit and water treatment systems) to generate ARD, the greatest risks are identified by the model, rather than by individual perception or intuition. The decision tree approach also improves the understanding of the probabilities of system performance under various adverse conditions. In particular, an explicit definition of the pathways to ARD generation forces a systematic and comprehensive analysis of potential failure mechanisms with consideration for the quantitative risk reduction effect of various remedial design features, stabilization measures, closure methods and monitoring.

Rehabilitation and Closure Plan Summary

The current mining conditions are defined as the period when active mining took place from 1990 to 1998. During this period, the major project components evaluated in this risk assessment were constructed and operated. Post-mining conditions are defined as the period after active mining has terminated (+1998) and the Rehabilitation and Closure Plan (Kingett Mitchell, 1998) has been implemented.

In order to evaluate post mining conditions and the associated risks, it is necessary to fully understand the elements of the Rehabilitation and Closure Plan and how they impact the risk of failure of the key mining components which will remain on site after mine closure. Kingett Mitchell & Associates (1998) has prepared a rehabilitation and closure plan for the Golden Cross site. The plan recognizes the need to integrate final reclamation and geotechnical remedial strategies, and is based on the following principles:

- To ensure the key environmental indicators of the reclaimed mine site are not significantly different in the long term compared with adjacent undisturbed areas. Key indicators include:
  - ◊ Landform stability
  - ◊ Groundwater resource and quality
  - ◊ Surface water resource and quality
  - ◊ Vegetation diversity and success
- To ensure that the risks and hazards associated with damage to the physical integrity of the key structures and facilities is not significantly greater than the risks and hazards associated with the region generally. Key long term structures and facilities are:
  - ◊ The tailing impoundment and mine waste stacks
  - ◊ The open pit and underground mines
  - ◊ Post-closure drainage systems
- To ensure that the amenity values of the site are consistent in the long term with the amenity value of the area generally. The amenity values of the area are:
  - ◊ Visual (landscape)
  - ◊ Recreational (tramping)
  - ◊ Economic (farming, forestry)
  - ◊ Environmental (water quality and wildlife)
- To ensure that post closure maintenance needs for the site are 1) minimized so that they are not significantly greater than for the adjacent land, and 2) clearly identified so that a post closure management regime can be planned.
- To ensure that all-statutory consent requirements are complied with by the company at closure of the mine and during the post closure period.

The plan incorporates the following key elements:

- Closure of the tailing impoundment utilizing a partial cap to expedite consolidation and subsequent improved tailing strength immediately adjacent to the impoundment. A wetland and/or shallow pond would be maintained on the remainder of the impoundment to reduce sulfide oxidation and dust generation from the tailings surface. An engineered spillway and channel will control the water elevation and be sized to accommodate the probable maximum flood event in the upgradient catchment area.
- The waste rock stacks will be covered with a diffusion layer to reduce sulfide oxidation, and a rehabilitation layer for revegetation and erosion control purposes.
- Surface diversions will be engineered to control and safely pass the 1 in 100 year or 1 in 1000 year storm events depending if the channels are constructed in natural ground or in fill, respectively.
- The open pit will be partially backfilled to create a positive drainage and a revegetated surface. This will also minimize infiltration to the underground workings. The remaining pit benches will also be revegetated with trees and shrubs.
- The underground mine will be partially flooded to a control level of 279 RL (Kiln Adit discharge level). This drainage will initially be routed to the water treatment plant prior to discharge to the

Waitekauri River. Long-term, a constructed biological "wetland" system will be constructed to polish drainage before discharge to the Waitekauri River.

- The active water treatment facilities will remain until water quality is suitable for direct discharge and/or the constructed biological treatment systems are in place and functional.

Evaluation of Waste Rock Stockpiles

The waste rock disposal area is approximately 28 hectares located immediately down gradient of the tailings embankment. The embankment and waste rock disposal area have been designed as an evenly sloping feature which surrounds a natural central ridge and abuts steeper slopes along its western edge and rolling country along its eastern edge.

Current Conditions

Current conditions are characterized by the waste rock cover construction being incomplete. The waste rock material is placed following specifications particular to each waste rock category to minimize or preclude ARD. Field measurements and monitoring has shown that oxidation control has been very effective due to the low air void and very low oxygen diffusion characteristics of the placed waste rock. However, erosion or cracking of the waste rock may result in a pathway for infiltration of precipitation or surface water run-on through potentially ARD generating waste rock. If conditions are right for infiltration and the diffusive flux of oxygen into the waste rock, ARD will be generated. The rationale and assumptions used in the development of each failure mode for current conditions are described below and the decision tree for the waste rock stockpiles under current conditions is presented in Figure 1.

The most recent Golden Cross Mine, Rehabilitation and Closure Plan (Kingett Mitchell, 1998) estimates erosion rates ranging from 0.075 mm/year (expected) to 3.5 mm/year (extreme). Assuming the waste rock stockpiles are exposed to direct precipitation and surface water run-on during current conditions, these erosion rates could result in the generation of ARD.

Cracking creates a potential pathway for surface water (precipitation or run-on) to infiltrate into the waste rock stockpiles. Cracking may develop through desiccation of the waste rock through drying or through movement associated with landslide activity. Continued movement of the landslide may also result in surface slumping and associated crack development.

For the purposes of this analysis, the following assumptions for current conditions were used:

- Waste rock stockpiles have been designed at final reclaimed slopes of 4(H):1(V). Based on this final slope configuration, geotechnical stability failure of the waste rock stockpiles was not considered;

- Erosion and cracking of the waste rock stockpile have been assigned relatively high probabilities during current conditions since partial construction of the cover offers only limited protection during this period;

- Cracking is considered more likely than erosion due to continued slide movement during current conditions; and,

- During current conditions when the site is actively being managed, erosion and cracking of the waste rock may be detected and repaired. If the damage is observed and able to be repaired in a timely manner, infiltration and discharge will not occur. This scenario is considered in assigning the probabilities for the infiltration and discharge branches.

Closure Conditions

Acidic soil conditions could adversely affect vegetation and result in erosion, however, the placement of an engineered (non-acidic) Primary Control Layer (PCL) to envelop the ARD generating waste rock mitigates this condition. Erosion, cracking, or drying may compromise the PCL and allow precipitation to penetrate into the waste rock material. If conditions are right for infiltration and the diffusive flux of oxygen into the waste rock, ARD will be generated. The rationale and assumptions used in the development of each failure mode for closure conditions are described below and the decision tree for the waste rock stockpiles under post-mining conditions is presented in Figure 2.

Dunne & Leopold (1978) discuss soil loss from a variety of hill slopes with different vegetative covers. The overriding conclusion from this study is that good drainage control and a good vegetated cover are critical to controlling soil loss and erosion. In addition, Landcare Research (Tonkin & Taylor, 1998) state slopes flatter than 2.5(H):1(V) do not erode if they have adequate grass cover and flows are not concentrated. The corollary is that bare slopes erode significantly during intense rainfall. Observations of landforms in the general area of Golden Cross Mine support such a philosophy. Erosion has generally only occurred in gullies or where slumping has first occurred due to slope oversteepening or toe removal.

Figure 1
Decision Tree for Waste Rock Stockpiles - Current Conditions

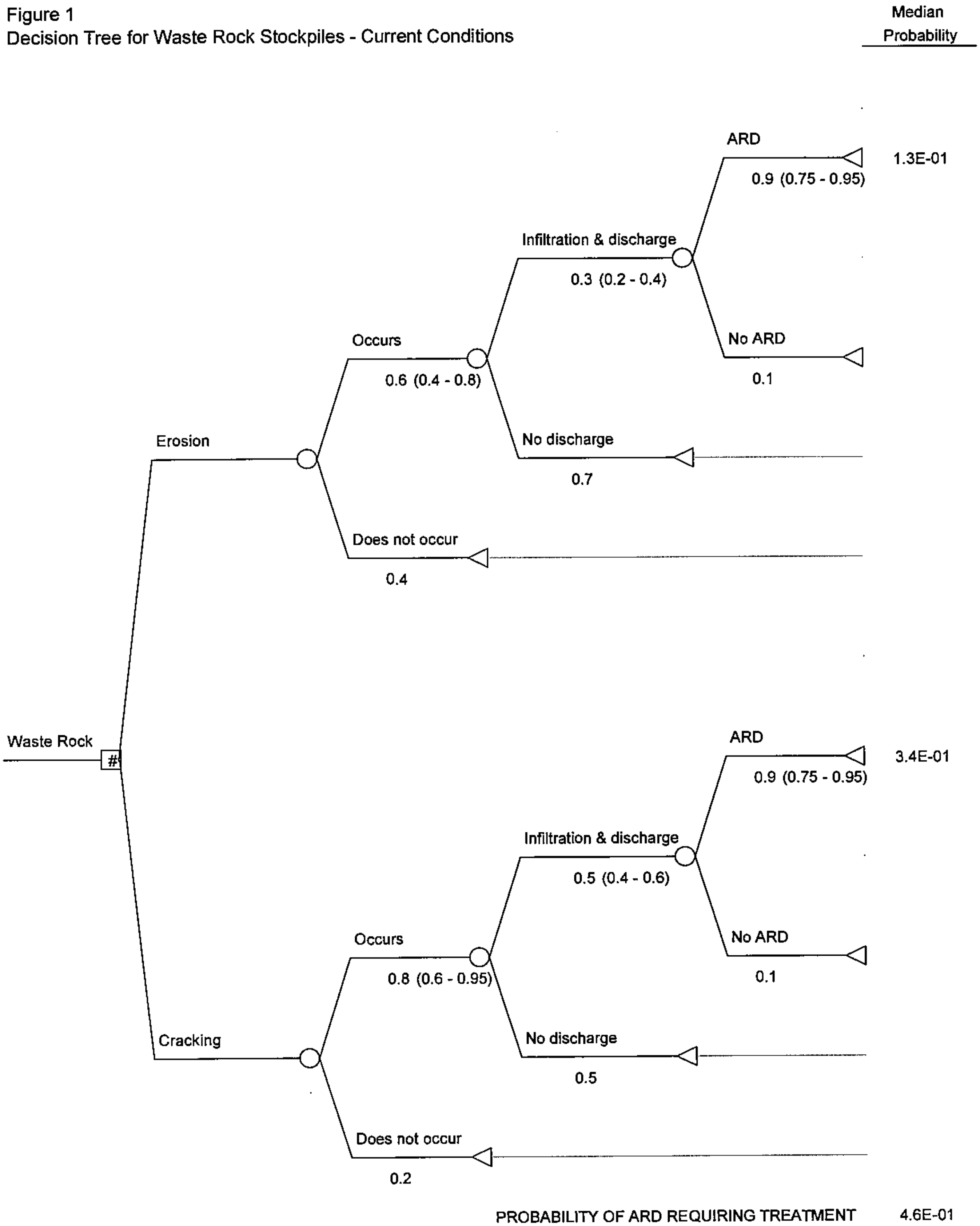
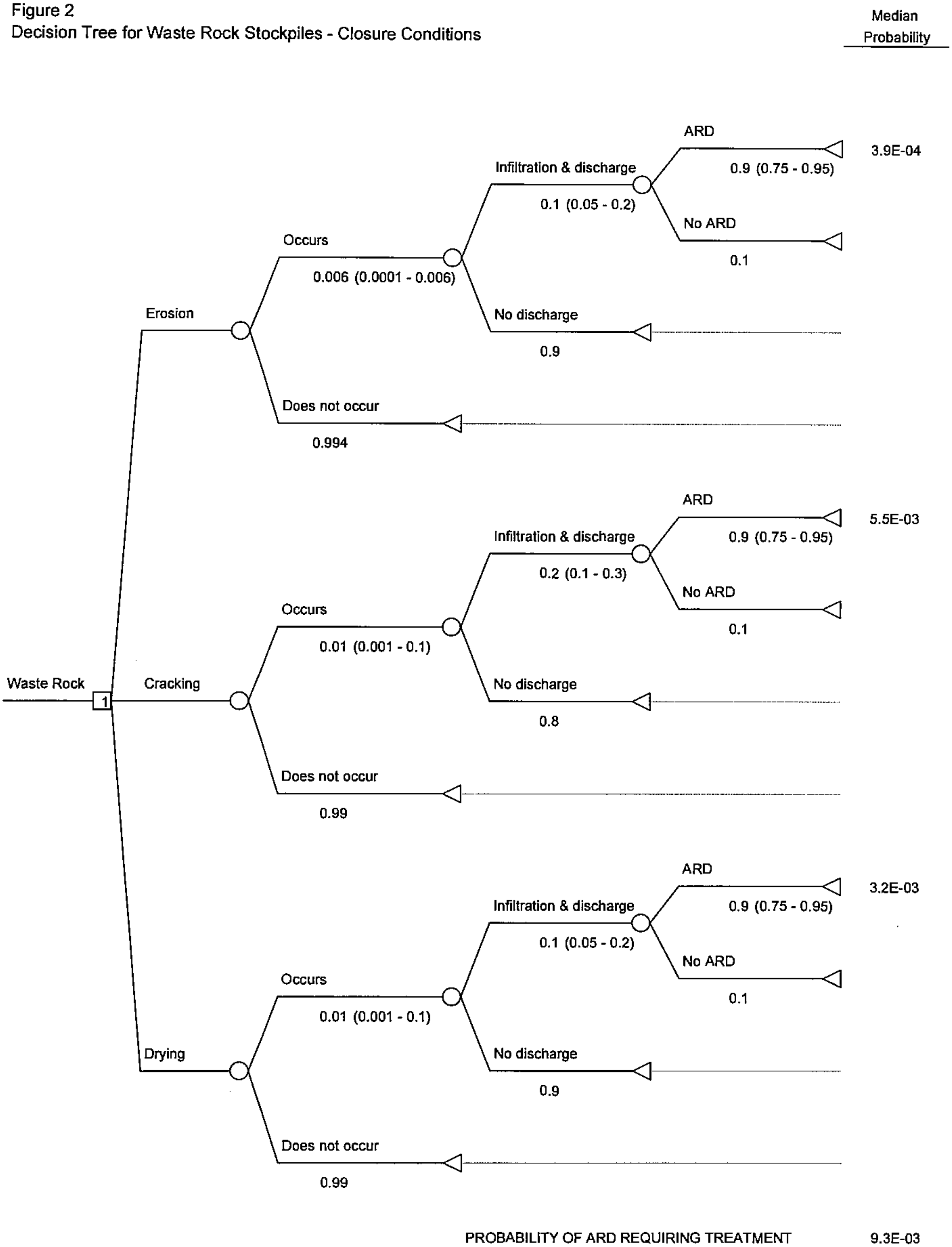


Figure 2
Decision Tree for Waste Rock Stockpiles - Closure Conditions



Under the maximum expected sheet erosion rate of 3.5 mm/year, it would take 171 years for the PCL to be compromised, assuming a cover thickness of 600 mm of topsoil over the PCL. Therefore, placement of the cover section proposed in the Rehabilitation and Closure Plan significantly reduces the probability of waste rock erosion from current conditions, when the cover section is incomplete.

As is the case during current conditions, cracking may create a potential pathway for surface water (precipitation or run-on) to infiltrate into the waste rock stockpile after closure elements are in place. Cracking may develop by desiccation of the waste rock through drying, deep-root penetration by surface vegetation or by movement caused by landslide activity. However, during closure conditions, ARD generation from cracking requires that precipitation penetrate through the cover section prior to contacting potentially acid generating waste rock. Therefore, the probability of cracking in the waste rock under closure conditions is considerably lower than during current conditions, when the cover section is incomplete.

Under current conditions, the geochemical specifications guiding the waste rock placement are effective in controlling sulphide oxidation through the exclusion of oxygen. The waste rock cap is designed to prevent possible exposure of the diffusion barrier layer to oxidation in the long term. Oxygen diffusion is sensitive to the degree of saturation, and provided the degree of saturation remains high enough, the oxidation rate will be low. However, should drying of the cover occur and cause an increase in permeability, infiltration and discharge of precipitation through ARD generating waste rock material is a potential result.

The following assumptions apply to closure conditions for the waste rock stockpiles:

- The potential ARD generating material, which is exposed under the current conditions, is assumed to be totally covered under the closure scenario.
- The probability of waste rock erosion is reduced (by a factor of 100) from current conditions due to the placement of 600 mm of topsoil over the Primary Control Layer (PCL), and construction of surface water diversion systems as presented in the rehabilitation plan.
- The probability of cracking is reduced (by a factor of 80) from current conditions due to the cover providing additional protection and stability.
- The probability of drying of the cover is assumed to be low due to the engineering design and the typically moist climate at the site.

Risk Assessment Results

The results of the risk assessment for the waste rock stockpiles during current and closure conditions are presented in Figures 1 and 2, respectively. Uncertainty ranges have been incorporated into the probabilities shown on the decision trees. The uncertainty ranges, which are presented in parentheses, are assumed to have triangular distributions. Triangular distributions are based on minimum, maximum and most likely values to form a triangular shaped distribution, where the values near the minimum and maximum are less likely than those near the most likely value. Triangular distributions are generally applied in cases where there is confidence in the range of values assigned.

The probabilities shown at the terminal node represent the median of the Monte Carlo simulation results, which incorporate the uncertainty distributions. The results indicate that under the current conditions (i.e. during cover construction), there is a 4.6×10^{-1} (see Table 1 for description of event occurrence) probability that generation of ARD will occur through erosion and cracking of the waste rock. These results are consistent with recent data, which indicates limited discharge of ARD from the waste rock stockpiles has occurred under current conditions. Under closure conditions, the probability of ARD generation from the waste rock stockpiles is reduced to 9.3×10^{-3}. The implementation of the recommendations presented in the Rehabilitation and Closure Plan (1998) provides approximately a 98% reduction in risk of generating ARD over the current waste rock conditions.

It is important to note that ARD generation by the waste rock stockpiles does not necessarily result in environmental impact, but may require a subsequent action (e.g. water treatment). Currently, ARD discharging from the waste rock stockpiles is captured and treated through the water treatment system prior to discharge from the project site. ARD will continue to be treated after closure of the site through a passive water treatment system. An evaluation of the risk of environmental impact from the site is presented in a following section.

Evaluation of Other Components

A process similar to that described above for waste rock stockpiles was applied to evaluate each of the other primary components remaining on-site after mining ceases (i.e. tailings decant pond, open pit and water treatment systems). For each component, specific failure modes and initiating events were identified. Fluctuations in the elevation of the decant pond provide a mechanism for oxidation reactions responsible for the formation of ARD. ARD may be generated from the open pit due to surface water runoff from the highwall and/or infiltration through the pit bottom. The environmental risks associated with water treatment system failure are defined as the release of untreated mine water into the Waitekauri River or non-compliance with the discharge consents.

Rather than discuss the evaluation and risk calculation in detail for each component, the results are summarized below.

Open Pit Mine

The risk of ARD generation of the open pit for both the current and closure conditions is significantly influenced by the assumed permeability of the pit bottom material. Under current condition, the analysis has assumed there is an 89% likelihood the current material in the pit bottom is highly permeable (i.e. 10^{-6}m/s). This assumption seems valid considering the current rate of infiltration that occurs when precipitation or runoff collects in the pit area. Under closure conditions, the analysis has assumed there is a 95% likelihood the pit bottom material will have low permeability (i.e. 10^{-8}m/s). In addition to the low permeability material placed in the pit bottom, any surface water collected in the pit after closure will be diverted to passive treatment systems for polishing prior to discharge to the Waitekauri River.

The results of the risk assessment show that under current conditions, there is a 9.8×10^{-2} (see Table 1) probability of ARD generation. Under closure conditions, the probability of ARD generation is reduced to 1.3×10^{-3}. The implementation of the recommendations presented in the Rehabilitation and Closure Plan (1998) provides approximately a 99% reduction in risk over the current open pit conditions.

Water Treatment

Prior to the completion of closure activities, active treatment of the water discharging from the mine site will continue to be performed by a water treatment plant, in order to protect the water quality of the nearby Waitekauri River. Once closure conditions are achieved, however, the risk of ARD generating from the mine is significantly reduced and active treatment will no longer be necessary. Although the water is expected to be suitable for direct discharge to the Waitekauri River, passive wetland systems will be constructed to further reduce the risk of ARD impacts to surface water quality. The active water treatment facilities will remain until water quality is suitable for direct discharge and/or the constructed biological treatment systems are in place and functional.

The results of the risk assessment for water treatment indicate that under current conditions, while active water treatment methods are in place, there is a 5.4×10^{-3} (see Table 1) probability of environmental impact. During current conditions, it has been assumed that 2,000 m^3/day of flow is recycled in the milling process, thereby reducing the water treatment requirement by approximately 20%. Historically, the water treatment plant on site has operated at nearly 100% compliance.

During the first year of closure, passive treatment systems are not assumed to be functional yet, and the flow that was recycled in the milling process no longer is required. As a result, the probability of environmental impact increases to 7.6×10^{-3}. In the following closure years, with passive treatment systems in operation, there is a 1.1×10^{-3} probability of environmental impact. The implementation of the recommendations presented in the Rehabilitation and Closure Plan (1998) provide an 80% reduction in the risk of environmental impact from current water treatment conditions through subsequent closure years.

Tailings Decant Pond

Lime is currently used in the milling process to buffer and neutralize the ARD generation potential of the tailings. In addition, the tailings have remained fully saturated throughout the operational period, preventing oxidation of the tailings, which could lead to the generation of ARD. Therefore, the risk of the decant pond generating ARD is considered to be negligible during current conditions.

During the closure period, the decant pond is considered to have the potential to generate ARD. Extensive drought conditions must occur to cause a significant fluctuation in the elevation of the decant pond. The drought would have to continue for a long enough period to cause discharge from the decant pond to discontinue and the elevation to drop below the level of the spillway. Then, the generation of ARD could occur through the oxidation and later re-saturation of ARD generating material. These reactions could yield low pH (acidic) water that has the potential to mobilize heavy metals in the tailings material. It is considered highly unlikely that these types of conditions could occur, given the typically moist environment at the site. A water balance model was utilized in order to quantify the likely ranges of water inputs and outputs from the tailings pond after closure (Kingett Mitchell). Based on precipitation records spanning over 20 years, model results showed that the probability of significant water level fluctuations is very low. Therefore, probability of ARD generation from the decant pond is assumed to be 1.0×10^{-5}.

Overall Site Environmental Risk

The risk of each key component to generate ARD has been established in previous sections. ARD generation from the waste rock stockpiles, open pit and tailings decant pond were combined to determine the site-wide risk of environmental impact. However, since discharge from some components is routed to the water treatment system, the environmental risk of ARD leaving the site boundary may require two failure conditions; that ARD is generated by a specific component and the water treatment system fails to perform as designed. Therefore, the probability of water treatment failure has been applied to each component where appropriate to estimate the overall risk of ARD discharging from the site untreated. The presence of water treatment systems designed to eliminate ARD reduces the environmental risk of the site to levels considerably lower than results for the individual components evaluated independently. The overall site environmental risks associated with the generation of ARD are presented in Figure 3 for current conditions and in Figure 4 for closure conditions.

Under current conditions, with active water treatment systems in place, the overall environmental risk is calculated to be 3.0×10^{-3}. Using the probability guideline definition presented in Table 1, a risk level of 10^{-3} is acceptable and described as follows:

"The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort."

Assumptions made for calculating the overall environmental risk of the site for the closure period include:

- The water treatment failure probability is based on closure conditions after the first year, when passive water treatment systems are in place and functional. Using the probability of failure for the first year of closure (i.e. prior to completion of the passive systems) results in higher overall environmental risk, however, the risk remains at the order of magnitude of 10^{-5}.
- Water treatment of the discharge from the tailings decant pond is expected for the first five years of closure. The analysis does not incorporate this condition, but represents direct discharge from the spillway into the Waitekauri River. Applying water treatment to this scenario would decrease the overall environmental risk further.

After closure, the overall site environmental risk is 2.1×10^{-5}. To understand the meaning of this level of environmental risk, it is useful to put it into context with the definition of risks presented in Table 1of this report. From an engineering perspective, 10^{-4} is defined as follows:

"The condition or event has not been observed and no plausible scenario could be identified, even after considerable effort."

Based on this definition, the overall risks are an order of magnitude lower than the lowest engineering risks defined by the technical experts responsible for developing guidelines to evaluate the reasonableness of subjective probabilities for the site.

A point of reference is provided by the U.S. Environmental Protection Agency (USEPA), which under its hazardous waste management system regulations (USEPA, 1990a) has selected a single risk level of 10^{-5} as the highest risk level that is likely to be experienced by an exposed population. Since these regulations provide a rigorous standard intended to be protective of human health, a risk level of 10^{-5} is certainly acceptable in terms of environmental risk. Note that comparing the quantitative environmental risk (presented herein) with human health risk (USEPA) is for comparative purposes only and is not intended to suggest any direct linkage between human health risks and environmental risks.

A numerical value of probability of environmental impact can be better understood when put in context with other identifiable risks with annualized probabilities in New Zealand. Table 2 was developed by Woodward Clyde (1996) in order to provide a comparison of risks.

Put into the context of the risks presented in Table 2, environmental impact caused by mining components at the site during current conditions is comparable to the chance of a stopbank failure, but less likely than being injured in a motor accident. Once closure plans have been implemented, the probability of impacts from the site is less than all the events listed except drowning in New Zealand.

TABLE 2
PROBABILITY OF EVENTS IN NEW ZEALAND

EVENT	ANNUAL PROBABILITY
Cyclones	4 x E-01
Earthquake exceeding Magnitude 4 in Bay of Plenty	1 x E-01
Tsunami greater than 1 meter in NZ	7 x E-02
Tsunami greater than 10 meters in NZ	1.4 x E-02
Injury in Motor Accident	5 x E-03
Stopbank Failure	2 x E-03
Volcanic Activity in the Bay of Plenty	7 x E-04
Death in Motor Accidents in NZ	2 x E-04
Drowning in NZ	2 x E-06

Figure 3
Decision Tree for Overall Site Risk - Current Conditions

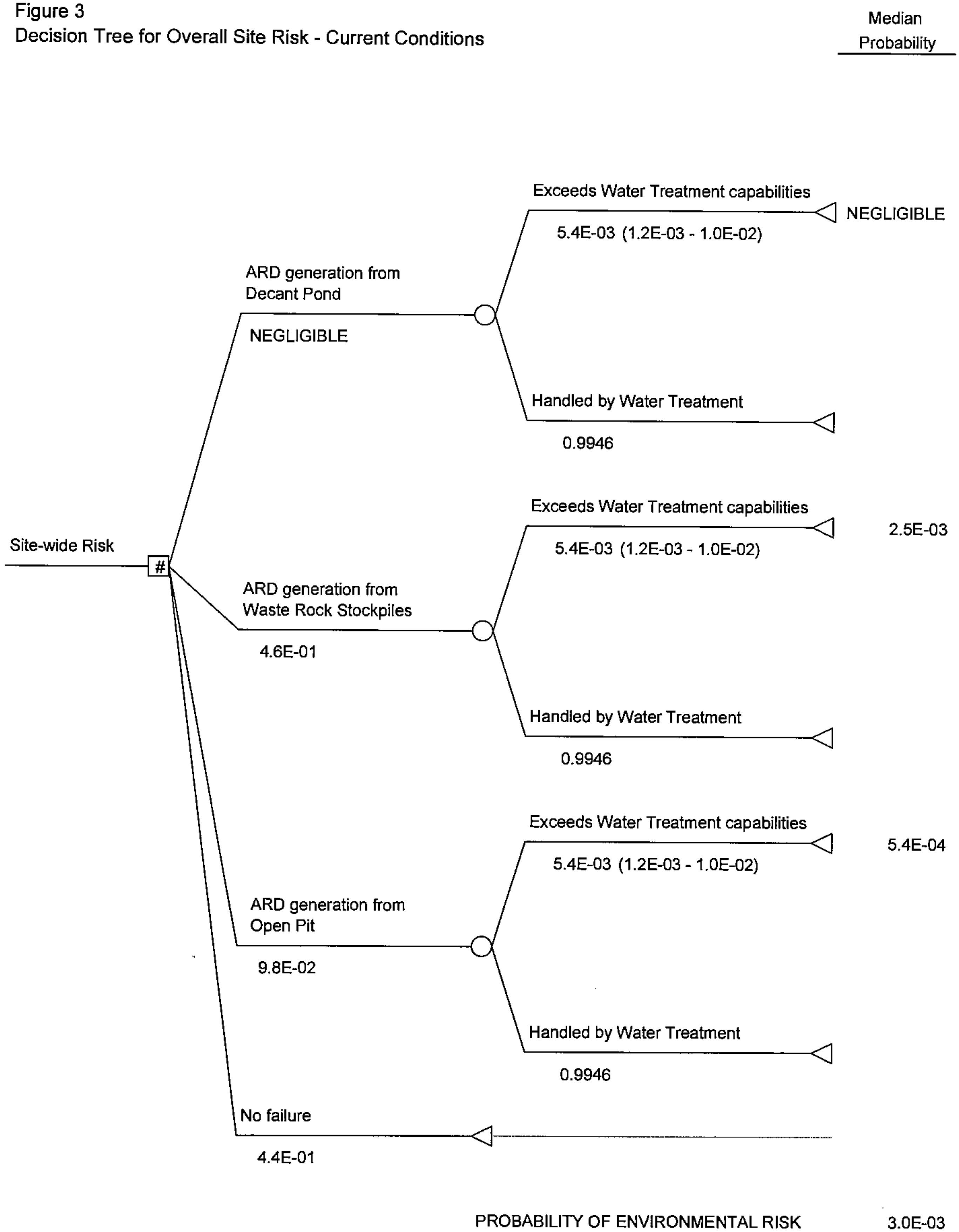
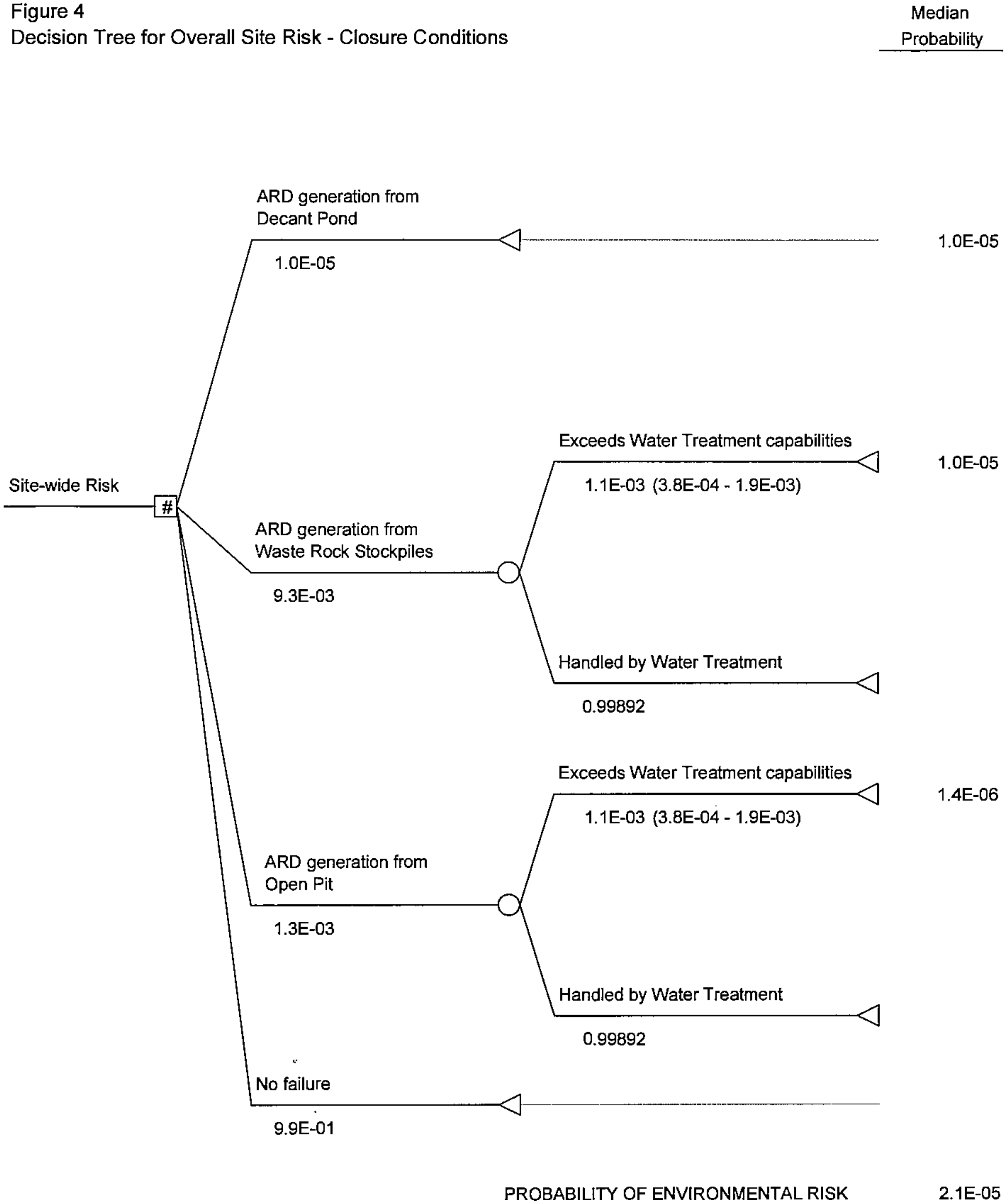


Figure 4
Decision Tree for Overall Site Risk - Closure Conditions



Conclusions

An innovative probabilistic risk assessment approach was used to evaluate the effectiveness of the mine rehabilitation and closure plan and provide support for its acceptance. This approach also enabled concerned parties to focus on the components with the greatest potential for environmental impact. Therefore, the risk assessment was meaningful to both the mine proponent and regulatory agencies.

The results of the risk assessment indicate the current environmental risks are reduced from 3.0 x 10^{-3} to 2.1 x 10^{-5} after closure. This difference and Closure Plan (1998), which is designed to significantly reduce the probability of environmental impact. Engineered covers and water management represents a reduction by two orders of magnitude in site environmental risks as a result of the implementation of a comprehensive Rehabilitation designs will reduce the potential for generation of ARD, and water treatment systems reduce the environmental risk of the site. The active treatment system currently in operation and passive treatment systems proposed under closure conditions are designed to effectively manage the potential sources of ARD. Therefore, adverse impacts to the receiving stream are unlikely.

In conclusion, the implementation of the Rehabilitation and Closure Plan is successful in achieving an acceptable level of environmental risk.