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ECONOMIC EVALUATION OF ACID MINE DRAINAGE TECHNOLOGIES

MEND Report 5.8.1

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ECONOMIC EVALUATION OF ACID MINE DRAINAGE TECHNOLOGIES

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SUPPLY AND SERVICES CANADA
HULL QUEBEC

GEOCON
Division of SNC ♦ LAVALIN Environment Inc.

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EXECUTIVE SUMMARY

This report presents an evaluation of the costs of applying various technologies to reactive mine wastes in order to prevent, control or treat acid mine drainage (AMD). The reactive wastes include either tailings or waste rock which generate, or which may generate in the future, AMD.

The AMD technologies selected for the purpose of this study include a composite soil cover, self-sustained and maintained water covers, some combinations of these covers, a plastic liner cover, waste removal and the long term collect and treat option with or without a simple soil (or vegetation) cover.

The objectives of this study were to evaluate the costs of currently applied, or perceived feasible, AMD technologies and their comparison with a reference to planning future research directions in the AMD area, and to evaluate the financial liabilities to the Canadian mining industry and Canadian public as related to reactive mine wastes. Because the AMD technology costs presented in this report have been estimated with a specific reference to these two objectives, important limitations apply to the study results if used for any other purpose. In essence, these limitations relate to the fact that the cost of an AMD technology considered for a waste site will depend on numerous site specific cost factors while the representative AMD technology costs presented in this report have been estimated with the purpose of addressing a large number of reactive waste sites.

The study has been carried out based on actual mine closure projects selected with a reference to the study objectives. Generic tailings/waste rockdisposal sites have also been considered to address specific cost issues such as the availability of borrow materials or the area-volume ratio in the case of a waste rock dump.

In addition to the direct costs of an AMD technology application, some incidental costs were also accounted for in the study. The estimated costs have been compared in terms of their net present values.

The following representative unit cost ranges have been derived for the two basic AMD technologies (1994$/ha of tailings footprint or 1994$/tonne of waste rock):

	Tailings	Waste Rock
Collect and Treat	180,000 - 280,000 (210,000)	0.4 - 2.0 (0.7)
Walk-away	100,000 - 300,000 (200,000)	1.0 - 1.5 (1.30)

where the values in brackets represent suggested typical (“average”) unit costs.

These unit costs have been derived with the purpose of identifying AMD technology costs of practical significance in the sense that the majority of the ***actual*** project costs are expected to fall into one of the representative cost ranges.

An inventory of the reactive wastes in Canada was compiled recently by MEND. Based on this inventory and the representative costs of AMD technology applications estimated in this study, the financial liabilities associated with the existing reactive tailings and waste rock in Canada have been evaluated as follows (in billions of 1994 dollars):

	Tailings	Waste Rock
Possible Range	1.a - 2.9	0.4 - 0.9
"Average" Estimate	2.5	0.5

The primary conclusion of the study is that the (unit) costs of AMD technology applications are very site specific and can vary widely. With a reference to the considered technologies and study cases, this is particularly true for the collect and treat option in the case of waste rock and for the self-sustained water cover option in the case of tailings.

In general, the composite soil cover and plastic liner technologies were confirmed to be the most expensive. From the cost perspective, it seems unlikely that these technologies would be considered preferable for typical mine sites. The study results also indicate that it is unlikely that a walk-away option would be selected for a major waste rock dump which generates net acidity at the time of closure.

A number of recommendations with regard to the most desirable future research directions in the AMD technology area have been developed based on the study findings and other considerations. Of particular importance seems to be carrying out a research evaluation of the performance risks associated with the implementation of various AMD technologies.

The study results indicate that the self-sustained water cover and the collect and treat technologies may represent the best options from the perspective of the implementation costs. Hence, in developing the recommendations with regard to future AMD research directions, an emphasis was made on these two technologies.

SOMMAIRE

Le present rapport fait état de l'évaluation des coûts de l'application de diverses techniques à des déchets miniers réactifs dans le but de prévenir, contrbler ou traiter le drainage mimer acide (DMA). Les déchets réactifs comprennent les résidus et les steriles produisant du DMA, ou susceptibles d'en produire dans l'avenir.

Les techniques DMA choisies pour la présente etude sont le recouvrement géologique de type multi couches, couverture aqueuse auto-entretenue ou entretenu par de l'eau, des combinaisons de ces deux techniques, une géomembrane (de plastique), l'enlevement des déchets et la collecte et le traitement à long terme du DMA avec ou sans couverture géologique simple (ou une couverture végétale).

Les objectifs de l'etude étaient d'évaluer les coûts des techniques DMA actuellement appliquées (ou perçues comme étant applicables), en les comparant à un étalon afin de planifier les orientations futures de la recherche dans le domaine du DMA, et enfin d'évaluer le fardeau financier qu'entraînera pour l'industrie minière canadienne et l'État la resolution du problème des déchets miniers réactifs. Les coûts des techniques DMA présentés dans le rapport ayant été évalués en fonction precise de ces deux objectifs, les résultats de l'etude doivent faire l'objet d'importantes reserves s'ils sont utilisés à d'autres fins. Pour l'essentiel, ces reserves sont que les coûts d'une technique DMA envisagée pour un site donné dependront de nombreux facteurs propres à ce site, alors que les coûts évalués dans l'etude pour une technologie DMA representative sont des coûts couvrant pour un grand nombre de sites de déchets réactifs.

L'étude a été fondéé sur des cas reels de fermeture de mine choisis en fonction de ses objectifs. On s'est également servi de cas généraux de halde de steriles et de parc à résidus pour determiner des facteurs de coûts précis, comme la disponibilité de matériaux d'emprunt et le ratio superficie/volume pour une halde de steriles.

Outre les coûts directs de l'application d'une technique DMA, certains coûts indirects ont également été pris en compte dans l'etude. Les coûts évalués ont été compares d'aprb leurs valeurs actualisées nettes.

Les fourchettes suivantes des coûts unitaires représentatifs ont été établies pour deux techniques DMA de base (en $ de 1994 par hectare pour les résidus et en $ de 1994 la tonne pour les steriles):

	Résidus	Stériles
Collecte et traitement	180 000 - 280 000 (210 000)	0,4 - 2,0 (0,7)
Abandon	100 000 - 300 000 (200 000)	l,o - 1,5 (1,30)

Les coûts entre parentheses sont des coûts unitaires types (moyens).

Ces coûts unitaires ont été Ctablis dans le but de determiner les coûts previsibles d'une technologie DMA, previsibles dans le sens que la plupart des coûts réels des projets devraient se situer dans l'une des fourchettes de coûts représentatifs.

Le NEDEM a dressé récemment un repertoire des sites de déchets réactifs du Canada. Grace à ce repertoire et aux coûts représentatifs de l'application des techniques DMA évalués dans l'etude, il a été possible de calculer le fardeau financier (en milliards de dollars de 1994) que representent les sites de stériles et de résidus actuels au Canada:

	Résidus	**Stériles**
Fourchette possible	1,8 - 2,8	**0,4 - 0,8**
Moyenne	2,5	**0,5**

La principale conclusion de l'etude est que les coûts (unitaires) de l'application des techniques DMA sont extrêmement fonction des caractéristiques du site et qu'elles peuvent varier considérablement. Pour les techniques étudiées et les cas sur lesquels l'etude a porté, cela est particulierement vrai de la collecte et du traitement du drainage des stériles ainsi que la couverture aqueuse auto-entretenu des residus.

En règle générale, la couverture multi couche (ou composite) ou par géomembrane (plastique) sont les techniques les plus coûteuses. Eu égard uniquement aux coûts, il est peu vraisemblable que ces techniques puissent Ctre choisies pour les sites miniers types. Les résultats de l'etude indiquent également qu'il est peu vraisemblable que l'option de l'abandon soit retenue pour un grand site de stériles qui produit de l'acide au moment de la fermeture.

On a pu par ailleurs formuler des recommandations sur l'orientation future souhaitable de la recherche dans le domaine du DMA en se fondant sur les résultats de l'etude et d'autres considerations. Il semble ainsi particulierement important de mener une recherche sur les risques de performance associés à la mise en oeuvre des diverses techniques DMA.

Enfin, l'etude indique qu'une couverture aqueuse auto-entretenue ainsi que la collecte et le traitement du drainage pourraient constituer les meilleures options, vu dans la seule perspective des coûts de mise en oeuvre. En consequence, l'accent a été place sur ces deux techniques dans la formulation des recommandations portant sur l'orientation future de la recherche.

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1.0 INTRODUCTION

1.1 General

This report on 'Economic Evaluation of Acid Mine Drainage Technologies' has been prepared by GEOCON, Division of SNC ♦ LAVALIN Environment Inc., in accordance with the proposal to Supply and Services Canada (SSC) dated 1994/02/1 1 and the terms and conditions of the contract No. 015SQ.23440-3-9248 between SSC and GEOCON. The technical requirements of the project were defined by the staff of the Mine Environment Neutral Drainage Program (MEND).

The report presents a summary of the costs of applying various technologies at reactive mine waste sites in order to prevent, control or treat acid mine drainage (AMD). These technologies are referred to as **AMD technologies.** The mine wastes include tailings and waste rock which generate, or which can potentially generate in the future, AMD. Based on the costs estimated for a number of site specific cases in this study, other available data and judgment, representative unit cost ranges for selected AMD technologies have been derived and used to evaluate the financial liability with regard to the existing reactive mine wastes in Canada. Also included in the report are recommendations on the most desirable research directions in the general area of AMD technologies.

The cost estimates presented in this report were developed and/or revised by Dr. B.W. Wang, P.Eng. with input from other GEOCON engineers, under the direction of Dr. M.B. Szymanski, P.Eng.

1.2 Project Objectives

The overall objectives of this project were:

1 evaluation of the costs of currently applied AMD technologies and their comparison with a reference to planning future research directions;

2 evaluation of the financial liabilities to the Canadian mining industry and Canadian public as related to acid generating mine wastes.

While the first objective is of particular interest to MEND (and, possibly, other technology development groups), the second objective is of interest to both MEND and regulatory authorities. Furthermore, it is believed that the findings of this study may be also of interest to mine owners or consultants involved in planning/designing for mine waste disposal and/or closure. Hence, the scope of the report has been somewhat enlarged as compared with the original intent to include comments and discussions relating to practical aspects of the implementation of various AMD technologies.

In more detail, the objectives of this study were:

- to select AMD technologies which are either proven or, at least, perceived feasible, given the current state of practical experience and research developments;
- to select representative examples of AMD technology applications that may be suitable for both existing and new mines;
- to derive representative unit cost ranges for the selected AMD technologies;
- to provide an updated estimate of the current financial liability to the Canadian mining industry and Canadian public with regard to AMD;
- to develop a software-based protocol for the economic evaluation of existing and emerging AMD technologies.

1.3 Report Organization

Important limitations apply to the estimated AMD technology costs presented in this report. These are discussed in Section 2.0. Brief definitions of the AMD technologies included in this study are given in Section 3.0. The intent of this section is to ensure that there are no misconceptions as to the meaning of the terminologies used to describe various AMD technologies. The current inventory of reactive mine wastes in Canada is presented in Section 4.0. The approach and methodology adopted to carry out this study are explained in Section 5.0. Descriptions of the cases studied and the estimated costs are presented in Section 6.0, while an evaluation of the financial liability with regard to reactive mine wastes in Canada is included in Section 7.0. Spreadsheet examples showing cost estimating procedures for selected AMD technologies are discussed in Section 6.0 and Appendix B. A background to the recommendations is provided in Section 9.0 while the conclusions and recommendations resulting from the project findings are included in Section 10.0.

2.0 LIMITATIONS

One of the primary objectives of this study was to arrive at representative costs for the implementation of selected AMD technologies. It has to be emphasized, however, that the unit costs and the unit cost ranges given in this report have been estimated for the specific purpose to provide a background to directing future AMD research and to evaluate the financial liabilities associated with the existing reactive mine wastes in Canada. Therefore, to avoid significant errors, care must be exercised when using these costs for any other purpose. The following discussion is provided to explain this recommendation in more detail.

The primary difficulty with arriving at a representative cost for the implementation of an AMD technology is the dependency of such a cost on site specific conditions. To substantiate this statement, consider two tailings deposits of the same geometry (tonnage, area). To assume that the (unit) costs of applying an AMD technology to these deposits would be the same, or even comparable, would generally be incorrect since, for instance, the two deposits (both generating net acidity) may have different properties which may affect the performance specifications pertinent to the technology application. Even if both tailings deposits have similar properties with regard to acid generation potential (sulphide content, net neutralization potential, sulphate generation rates) and are at the same stage of AMD development, there is a number of factors that may render these costs completely different:

a ***closure and/or operating requirements with regard to other mine components***
b ***probability of new ore discoveries in the general tailings area***
c ***distance to industrial centres***
d ***other mine sites in the area***
e ***planned land use for the general mine area***

f ***metal leaching rates and hydrogeochemistry of AMD***

g ***gradation, specific gravity and deposition history of tailings***
h ***type of tailings retention structures and associated facilities***

i ***geographic location***
j ***hydrologic, climatic and subsurface conditions***
k ***seismicity of the site***
l ***geomorphology of adjacent lands***
m ***location and type of available borrow materials***
n ***background environmental conditions***

o ***distance to the receivers***
p ***sensitivity and biologic characteristics of the receivers***
q ***attenuation/assimilation capacity between the deposits and the receivers***

r *current and future (expected) legislative requirements, public perception*
s *results of risk and chance of success analyses*
t *degree of engineering input*

u *the contractor (owner or an outside union/non-union contractor)*
v *construction methods, time and place of construction (economic conditions)*

Note that these factors have been listed with a reference to two tailings deposits with some common features. In general, the factors which may also influence significantly the cost of implementing an AMD technology include:

w *AMD characteristics, degree of AMD development*
x *type of waste (tailings, waste rock, oxidized ore)*
y *size and geometry of the waste*
z *other rehabilitation concerns (eg., cyanide trapped in tailings)*
other factors

These factors may influence the cost of an AMD technology application to the degree that, based on the cost consideration alone, the same technology may be judged viable for one site, while unrealistic for another.

Consider also, as another example, **a** composite soil cover designed to limit the rate of infiltration and oxygen flux into a mine waste so that the contaminant loading rates would be reduced to an acceptable level. The cost of the cover construction may depend, in the first place, on what are the acceptable loading rates for a given site. Furthermore, this cost may depend, in general, on most of the factors listed above but, perhaps most significantly, on the local climate, the availability of construction (soil) materials, their properties, distance from the borrow area(s), type and geometry of the waste, trafficability of the waste.

Therefore, with regard to estimating the implementation costs for various AMD technologies, the following statement applies:

> **It is not practically possible to provide an estimate of the (unit) cost of an AMD technology (tonnage or area based) that could be applied generally to any mine waste with actual or potential AMD. Such a cost must be examined on a site specific basis.**

Although it will not be possible to relate directly all of the above cost factors **(a** to **z)** to the estimates presented in this report, these factors may serve as a preliminary checklist when a tailings or waste rock deposit is being evaluated with a reference to the unit costs presented in this report. Judgment would have to be exercised then if, for the considered case, any of these factors are clearly outside of typical conditions.

It is also important to realize that drawing conclusions from the unit prices presented in this report with regard to the relative costs of various AMD technologies could lead, in some cases, to wrong conclusions. This is because in many actual cases, comparing the costs of two technically viable AMD technologies can lead to opposite conclusions (ie., at one site the application of Technology A can be more expensive than the application of Technology B, while at another site the opposite may hold true). This fact becomes particularly important with respect to Objective 1 of this study (Section 1.2).

Finally, it has to be pointed out that using the unit cost ranges provided in this report to arrive at some ***upper*** and ***lower*** bound cost estimates may also lead to errors. This is because for some AMD technologies the actual cost ranges (in terms of ***unit*** costs) may be very wide and the extreme cost cases have not been necessarily considered for the purpose of this study.

3.0 SELECTED AMD TECHNOLOGIES

The following brief descriptions of the AMD technologies selected for the purpose of this study explain their meaning, as used in this report. Included in the definitions are not only the physical means associated with each technology but also the fundamental performance specifications.

Composite Soil Cover

This technology involves the construction of a continuous soil cover consisting of one or more mineral or organic soil layers over an entire tailings or waste rock deposit, or over a portion of such a deposit. The principal performance specification is that a composite soil cover will limit, in the long term, the oxygen flux or the infiltration rate, or both, (resulting in a reduction of acid generation and contaminant leaching rates) to the degree that **the rates of contaminant loadings emerging from a covered deposit will be acceptable from the environmental protection perspective. The** only other performance criterion with regard to a composite soil cover is its design longevity requirement which includes, among numerous other issues, providing an erosion protection layer (an optimization of the capital costs associated with the construction of erosion protection measures and the long term maintenance and replacement costs would be typically required).

In the short term, however, the rates of contaminant loadings leaving a covered deposit may exceed those acceptable from the environmental protection standpoint and then a collect and treat operation has to be carried out during a transition period.

For the purpose of cost estimating, it has been assumed that a composite soil cover placed over a waste rock pile consists of fine rockfill (obtained by selective grading of the pile), a 0.4 m thick sand and gravel or sand layer, a 0.6 m thick clay till type material layer, a 0.4 m sand and gravel layer and an erosion protection layer (the erosion protection layer could actually be omitted under some conditions). A similar arrangement was assumed for estimating the cost of a composite soil cover constructed over a tailings deposit except that, where required, an allowance has been made for local placement of pit run granular material or fine rockfill beneath the bottom sand layer. Erosion protection may involve either placement of a 0.4 m thick layer of rip-rap or grass vegetation.

For the wastes which generate net acidity at the time of closure, it has been assumed that a transition period applies. During this period, the seepages emerging from a covered waste rock dump would be collected by a plastic discharge and collector pipe system and routed either by gravity or by transfer pump ponds to seepage collection facilities (SCFs) for final routing to a treatment plant. The collector pipes are located outside of the soil cover. A similar arrangement applies to a tailings deposit except that, in this case, an allowance has been made for a drainage berm (beneath the soil cover). It noted that, under some conditions, an open ditch collector system may be preferred over a pipe system (eg., in Scenario 1 discussed later in this report).

Self-sustained Water Cover

This technology involves providing a water cover over a portion of, or over an entire tailings deposit by constructing internal dykes, perimeter dams, runoff diversion dykes and ditches, as required. The principal performance specification for this technology is that the oxygen flux into a flooded deposit is limited so that **the rates of acid generation, metal leaching and contaminant loadings emerging from a water covered deposit, including those associated with the overflow, will be acceptable in the long term from the environmental protection perspective** under specified fluctuations in the water cover thickness. The only other performance specification with regard to a self-sustained water cover is that a minimum required depth of the cover is maintained continuously (up to a design return period) without the necessity to augment the water supply.

Similar to composite soil covers, a collect and treat transition period may apply in conjunction with permanent flooding of a tailings deposit.

For purpose of cost estimating, it has been assumed that a 0.3 m thick fine sand layer, placed over the tailings surface is required in the case where the tailings generate net acidity at the time of permanent flooding. Otherwise, no sand layer is necessary. The normal depth of water cover is 1 .0 m and 0.7 m for these two cases, respectively, with a minimum water cover depth of 0.3 m applicable to a design return period.

Flooding of a waste rock deposit has not been considered in this study.

Maintained Water Cover

This technology is the same as the self-sustained water cover technology except that **a pumping facility** would be required to supplement the runoff, as required to maintain a water cover within the permitted design depths. The pumping facility must be highly automated and designed so only minimal inspection and maintenance would be required.

It is noted that the 'maintained water cover'is the only truly "operate forever" technology considered in this study. In the case of the classical collect and treat technology, the operations will cease shortly after sulphide depletion takes place, while under the maintained water cover scenario, the pumping operation (not necessarily continuous) would have to be carried out indefinitely. Hence, the maintained water cover does not seem to represent an acceptable technology

except for an important consideration that may be applicable to some specific site conditions: cost deferral (eg., maintaining a water cover b y pumping for a number of years while deferring reconstruction of tailings dams or construction of new water retention dams in preparation for providing a self-sustained water cover).

Plastic Liner Cover

This technology involves the construction of a continuous plastic liner cover over a tailings or waste rock deposit and **the principal performance specification is the same as in the case of a composite soil cover.**

For the purpose of this study, it has been assumed that no collection of contaminated seepages would be required after liner installation unless cyanide is trapped in the tailings deposit (in some cases, collection and treatment during a transition period after liner installation would be required even if no cyanide was present).

A 60 mils HDPE liner with a 0.4 m thick sand bedding (over a waste rock deposit only) and a 0.6 m thick, grass vegetated sand/till cover over the liner have been selected for the cost estimation purposes.

Unless otherwise specified, the replacement of a plastic liner has been assumed to be necessary after 200 years. Although there seems to be no available data indicating that a plastic liner will last 200 years, there also seems to be no information indicating otherwise (in the technical literature the term “hundreds of years” is often used in this regard). The longevities of plastic liner of 50 years and 100 years have also been examined in this study for comparison purposes.

Collect and Treat

This technology involves long term collection and (lime) treatment of contaminated runoff (overland runoff and subsurface water flows). Design details to prepare a mine site for the implementation of this technology will vary widely from site to site and the performance specifications are more complex than in previous cases. Again, the **rates** of contaminant loadings emerging from a deposit subject to long term collection and treatment must be acceptable from the environmental protection perspective. One of the most essential performance specifications applicable to this technology is **the optimization of the amount of treated effluent (ie., long term operating costs) and the capital costs incurred in conjunction with the construction of runoff collection system and waste water treatment plant (WWTP).** Another performance specification of particular importance is the optimization of the capital costs associated with the construction of long lasting structures/facilities and the long term maintenance and replacement costs.

For the cost estimating purposes, it has been assumed that the (lime) treatment process involves generation of a stable, high density sludge (20-25% solids) having substantial residual alkalinity.

Simple Soil Cover (or Vegetation Cover)

This technology, as defined for the purpose of the present study, involves long term collection and treatment of seepages emerging from a covered waste rock or tailings deposit. The cover consists of one mineral (preferably low permeability) soil layer provided over the entire tailings or waste rock deposit, or over a portion of such a deposit. The only performance specification is that such a cover **will allow for the discharge of the overland runoff directly to the environment** (as an additional benefit, a simple soil cover would typically reduce the rate of infiltration). A vegetation cover may also satisfy this performance specification under some conditions.

In other words, there are no performance specifications other than the financial benefit with regard to the cost of the long term collect and treat operation (reduction in the amount of treated effluent) except that, similar to the composite soil cover, the longevity of a simple soil cover has to be assured. In this case, however, the longevity requirement need not be as strict as in the case of a composite soil cover since inspection and maintenance could be provided in conjunction with the collect and treat operation. A reduction in the contaminant loadings associated with a deep groundwater flow component (reduction in the hydraulic head) may become an additional benefit.

To estimate the construction cost, it has been assumed that a simple soil cover is constructed similar to the composite soil cover and consists of a 0.3 m thick layer of pit run, coarse sand and gravel or fine rockfill (where required), a 0.7 m thick layer of compacted till type material and a 0.3 m thick layer of lightly compacted till or other acceptable material. Hydroseeding of a simple soil cover has been included for the cost estimation purposes.

A "permanent" seepage collection system will be required in conjunction with the construction of a simple soil cover, similar to that required during a transition period after a composite soil cover is constructed.

Waste **removal**

This technology involves removal of tailings or waste rock from the original location and long term underwater disposal in an open pit (adding lime would often be required).

Typically, this technology would be feasible under two conditions: ▸ **collection and treatment of the groundwater plumes or overland runoff at the original deposition site is not required, and ▸ the groundwater contamination resulting from long term leaching of the AMD products (dissolved or in a solid form) accumulated in the waste placed in an open pit is acceptable from the environmental protection perspective.**

Other Technologies

The AMD technologies defined above were selected for the purpose of this study. It is emphasized, however, that there are numerous other AMD technologies (eg., lime/limestone conditioning, sulphide flotation, wood chip or compost covers, shotcrete or bituminous covers, SRB plots, downstream wetlands, etc.1 investigated and reported on in the technical literature today that have not been addressed in this study. The primary reasons for omitting these technologies are either insufficient available information on the application costs or very site specific costs (eg., the cost of installation of a sulphide flotation circuit or the percentage of recovered sulphides to be disposed of separately from the tailings deposit).

4.0 INVENTORY OF REACTIVE WASTES IN CANADA

Several studies to evaluate the inventory of reactive mine wastes in Canada have been carried out over the last 10 years. These include the estimates by Monenco (1984), F. Frantisak (1984), A.V. Bell (1987), J.C. Errington and K.D. Ferguson (1987), Nolan Davis and Associates (1987), R.D. John (1987), M.P. Fillion and K. Ferguson (1990), and D.G. Feasby, M. Blanchette and G. Tremblay (1991). Some of these estimates were carried out for parts of Canada or for a selected type of mine operations and/or wastes. The most recent and comprehensive estimate of the amount of reactive wastes in Canada, which accounts for all the relevant types of mine operations and wastes, was carried out by D.G. Feasby of MEND and presented at the 1994 'Mine Reclamation, Financial Assurance Workshop' in Toronto. This estimate, which has been used in the evaluation of the financial liabilities discussed in Section 7.0, is presented in the following table.

MINE TYPE	TAILINGS hectares of footprint	WASTE ROCK tonnes
Base Metal and Gold	11,340	687,000,000
Uranium	870	16,000,000
Coal	---	50,000,000
TOTAL	**12,210**	**753,000,000**

It is of interest to notice that the inventory of reactive wastes from GEOCON <u>mine closure nroiects</u> involving A MD indicates 1,530 ha of tailings and more than 200,000,000 tonnes of waste rock Ida ta from other mining projects, which did not involve designing for closure, are excluded from this inventory). In comparison with the GEOCON numbers, the inventory given in the table above seems to indicate that the estimate of the amount of waste rock in Canada could be on a low side. If so, this could be a result of the fact that in the case of GEOCON projects, not only the waste rock dumps are included, but also yard fills, ramps, roads, low grade or oxidized ore piles, etc., if reactive now or believed to become reactive in future. On a current Ontario project, for example, the total volume of various acid generating waste rock fills (roads, yards, ramps, ore pads, structural fills and an oxidized ore pile) has been estimated at about $1.5x10^6$ m^3 (23%), in addition to the waste rock dump at about $5.0x10^6$ (77%) m^3.

5.0 APPROACH

5.1 Approach and Methodology

There seem to exist three plausible approaches to estimate AMD technology costs with regard to the project objectives (Section 1.2):

1. Carry out a comprehensive study which would involve analyzing and incorporating into the cost evaluations most of the relevant cost factors (such as those listed under items **a** to **z** in Section 2.0) to obtain a common frame of reference for a variety of site specific conditions. Although carrying such a study is feasible, the required level of effort would be substantially higher than that allowed for in this project.

2. Carry out cost evaluations for selected generic sites, specifying a limited number of primary cost factors for (assumed) typical site conditions.

3. Carry out cost evaluations based on actual projects, selecting mine sites which are reasonably typical and/or troublesome from the selection of the preferred technology standpoint.

This study was carried out based primarily on approach 3, with some simple generic mine sites defined and evaluated in support of the cost estimates obtained for the actual mine sites. Therefore, past project experience constitutes the base of the approach employed in this study.

One of the advantages of carrying out this study based on the approach 3 was that actual **incidental** costs of applying various AMD technologies could be accounted for (an incidental cost is a cost additional to that of a technology application that often must be accounted for in carrying out actual projects; for instance, if the selection of a technology to be applied to a tailings deposit leads to an increase in the cost of the plant site rehabilitation, then this increase [the incidental cost] must be, in real life, included in the cost of the technology application).

Following approach 3 in itself does not automatically ensure that the derived cost estimates must be considered credible with a reference to the study objectives. However, a careful selection of the studied cases was made with the purpose of addressing the specific objectives of the study.

The actual projects selected for the purpose of this study were developed to a conceptual design level, that is, the cost estimates are expected to be within 15% to 25% of the actual costs (applicable to a given province).

In the actual projects, there were always site specific conditions which significantly influenced the costs of AMD technology applications and it was necessary to examine if these costs were reasonably representative. Hence, approach 2 was also employed for the purpose of this study. This was done by defining simple site conditions and using "typical" construction costs estimated based on GEOCON experience from construction sites (bid and actual contract prices) located in Newfoundland, New Brunswick, Quebec, Ontario and British Columbia.

Arriving at the typical construction costs for generic site scenarios was particularly important in the case of dry cover technologies (simple and composite soil covers, plastic liner covers) for which the implementation costs are strongly dependent on the availability of construction materials. For some of the actual projects, the site conditions could not be considered sufficiently representative in terms of the availability of borrow materials.

It is noted that numerous adjustments were made to the actual project conditions for the purpose of this study. These, however, did not influence the ***unit*** costs of the AMD technologies applications to a substantial degree.

In brief, the methodology employed to estimate the unit costs of applying various AMD technologies involved extracting the relevant information from the actual project files, making necessary adjustments to the mine site features, defining generic mine sites to address specific construction cost issues, supplementing the data available from GEOCON files with other information (eg., available from the technical literature), computing the costs of implementing various AMD technologies and, using some judgment, arriving at representative unit cost ranges.

To determine a (unit) cost of an AMD technology application, it was necessary to convert the total costs estimated for given conditions at a project site to the unit cost, based on a common denominator. The use of either footprint area or tonnage of a mine waste was selected for the purpose of this presentation.

It is important to note that the intent of this study is to provide cost ranges that may be applicable to reasonably typical site conditions only, ie., special cases that may fall outside of those ranges are not ruled out. This is consistent with the study objectives.

The short and long term operating and maintenance costs were reduced to the "net present value" costs using an assumed real rate of return of 3.5%.

5.2 Selection of Cost Estimate Scenarios and AMD Technologies

Three cost estimate examples (Scenarios 1, 2 and 3) were selected based on actual projects. The details of the mine site features were changed as compared with the actual projects (for example, the size of a tailings area, location of a plant site or the size of a watershed). Also, some mine features were added or adjusted to serve better the project objectives.

The most comprehensive **Scenario 1** involves an existing mine site (base metal, massive sulphides) with a major ‘upstream’tailings deposit, tailings spill pond, yard fill consisting of acid generating waste rock, underground workings and an open pit. Except for the tailings deposit, all other site features have been considered only for the purpose of estimating an incidental cost. In other words, this scenario has been selected to estimate the costs of the application of various AMD technologies to a tailings deposit. Neither underground workings nor the open pit can be simply flooded, however, the rates of the associated contaminant loadings are relatively low and it has been assumed that these could be sufficiently mitigated by providing soil/vegetation covers and limestone beds. The costs have been estimated for the following AMD technologies:

- complete self-sustained water cover (confined by new perimeter dams)
- composite soil cover
- partial self-sustained water cover (confined by an internal dyke) in combination with composite soil cover
- collect and treat
- collect and treat in combination with partial self-sustained water cover (confined by an internal dyke)
- collect and treat in combination with simple soil cover.

Scenario 1 represents the case of a relatively old mine where the tailings disposal method was originally selected without considering closure requirements.

Scenario 2 involves a tailings disposal facility at an active gold mine (in the early years of operation) where the tailings basin is formed by low permeability engineered tailings retention dams which incorporate a plastic liner. In this case, the cyanide trapped in tailings must also be considered in conjunction with the implementation of various AMD technologies. The neutralization potential available in tailings and the tailings basin operating practice indicate that net acidity would not be generated until at least the end of the mine operations. The AMD technology costs with regard to the tailings deposit were estimated for the following cases:

- self-sustained water cover
- maintained water cover
- plastic liner cover
- composite soil cover
- collect and treat with simple (vegetation) soil cover
- collect and treat

Scenario 2 represents the case of a modern mine.

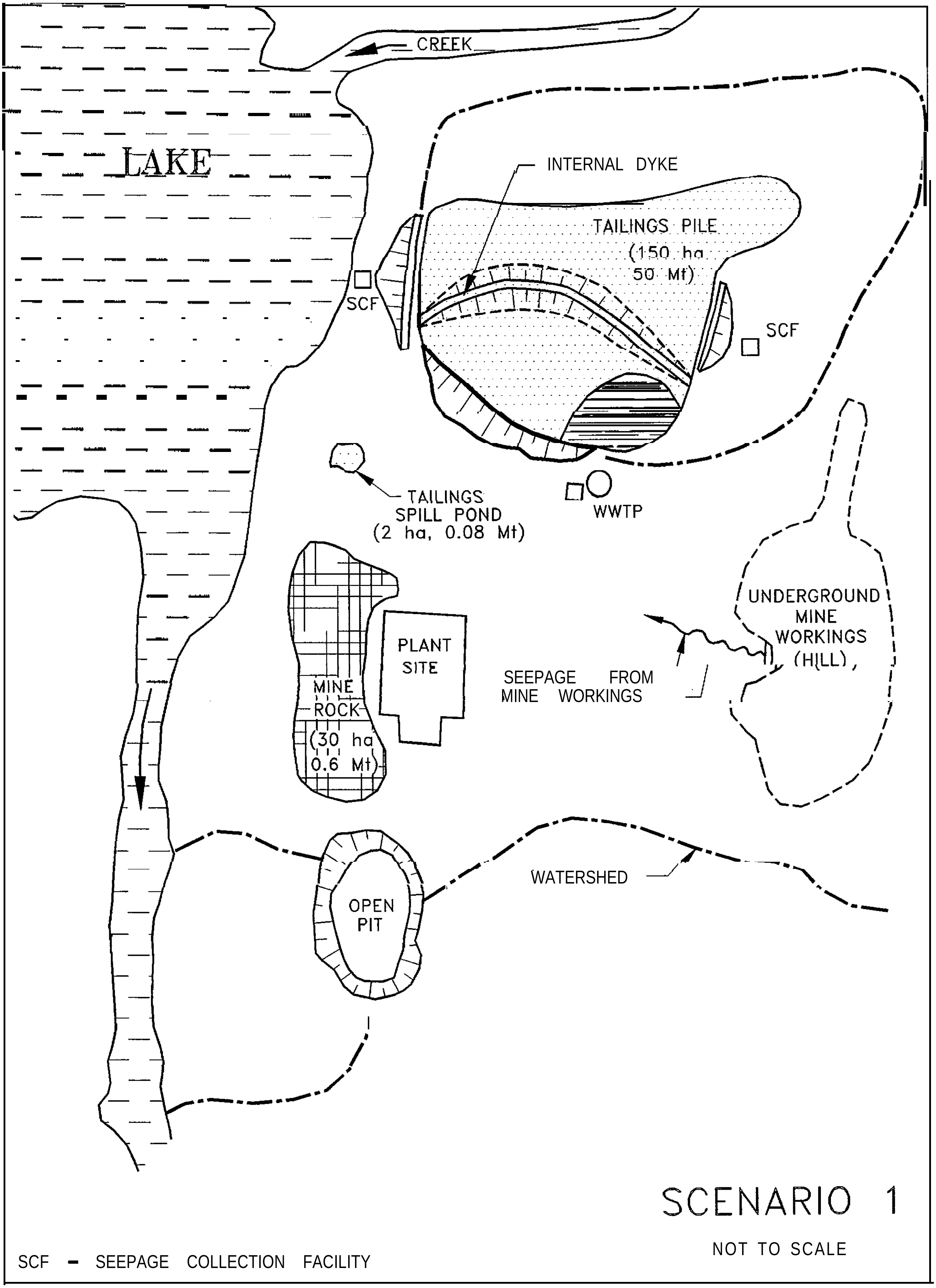
CREEK
LAKE
INTERNAL DYKE
TAILINGS PILE
(150 ha
50 Mt)
SCF
SCF
TAILINGS
SPILL POND
(2 ha, 0.08 Mt)
WWTP
UNDERGROUND
MINE
WORKINGS
(HILL)
PLANT
SITE
SEEPAGE FROM
MINE WORKINGS
MINE
ROCK
(30 ha
0.6 Mt)
OPEN
PIT
WATERSHED
SCENARIO 1
NOT TO SCALE
SCF - SEEPAGE COLLECTION FACILITY

Figure 5.1

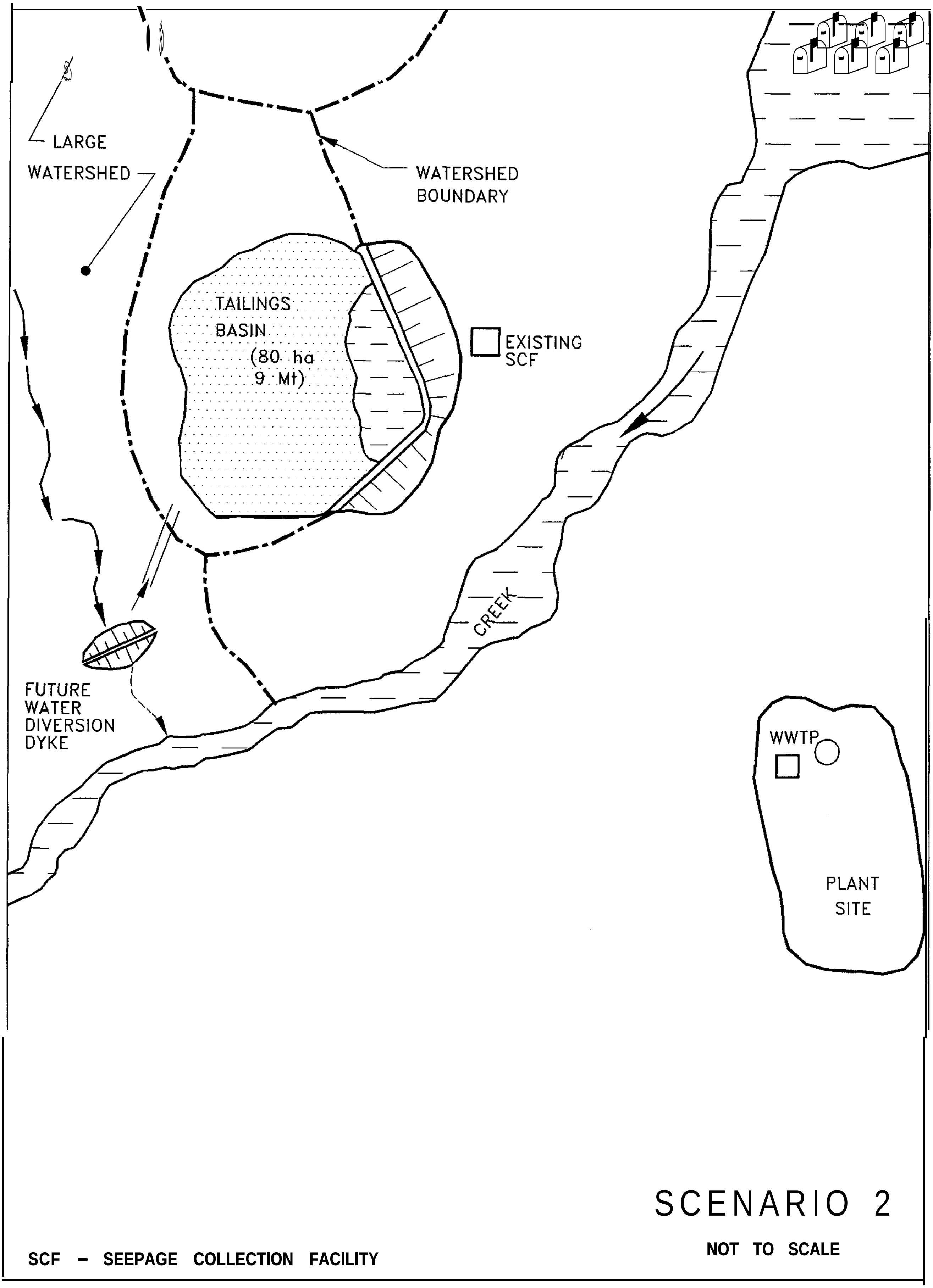
LARGE
WATERSHED
WATERSHED
BOUNDARY
TAILINGS
BASIN
(80 ha
9 Mt)
EXISTING
SCF
CREEK
FUTURE
WATER
DIVERSION
DYKE
WWTP
PLANT
SITE
SCENARIO 2
NOT TO SCALE
SCF – SEEPAGE COLLECTION FACILITY

Figure 5.2

Scenario 3 involves an active base metal mine site with four waste rock dumps, some of which have been generating net acidity and some of which are expected to generate net acidity in future. The mine site incorporates an open pit with the rock walls which presently generate AMD. Utilizing the open pit as a contaminated runoff storage pond allows for a delay in the start up of the treatment operation.

A tailings deposit has been incorporated into this scenario to account for a cost incidental to the rehabilitation of the waste rock dumps. If the runoff originating at the tailings basin has to be collected and treated, then the advantage of delaying the onset of the treatment operation would be substantially reduced since the open pit would fill up in a shorter time. Hence, the effective cost of the collect and treat technology applied to the waste rock dumps would increase.

The AMD technologies considered in this case include:

- collect and treat
- collect and treat in conjunction with a simple soil cover constructed over one or more of waste rock dumps.
- composite soil cover

Scenario 3 represents a typical waste rock disposal operation and has been selected primarily to emphasize the necessity to account for incidental costs.

Scenarios 4 and 5 (generic sites) involve a tailings deposit confined by permeable tailings dams and a waste rock dump, respectively. The AMD technologies considered in these cases include:

- collect and treat
- collect and treat in conjunction with a simple soil cover
- composite soil cover

These scenarios were selected for the purpose of estimating the AMD technology costs based on a reasonably typical availability of construction (soil) materials.

Scenarios 6 and 7 correspond to Scenarios 4 and 5, respectively, in terms of the site features. For these cases, the plastic liner installation and future replacement costs have been estimated, depending on an assumed longevity of the liner.

In addition to the above cases studied, a brief discussion is also presented on the costs of waste removal.

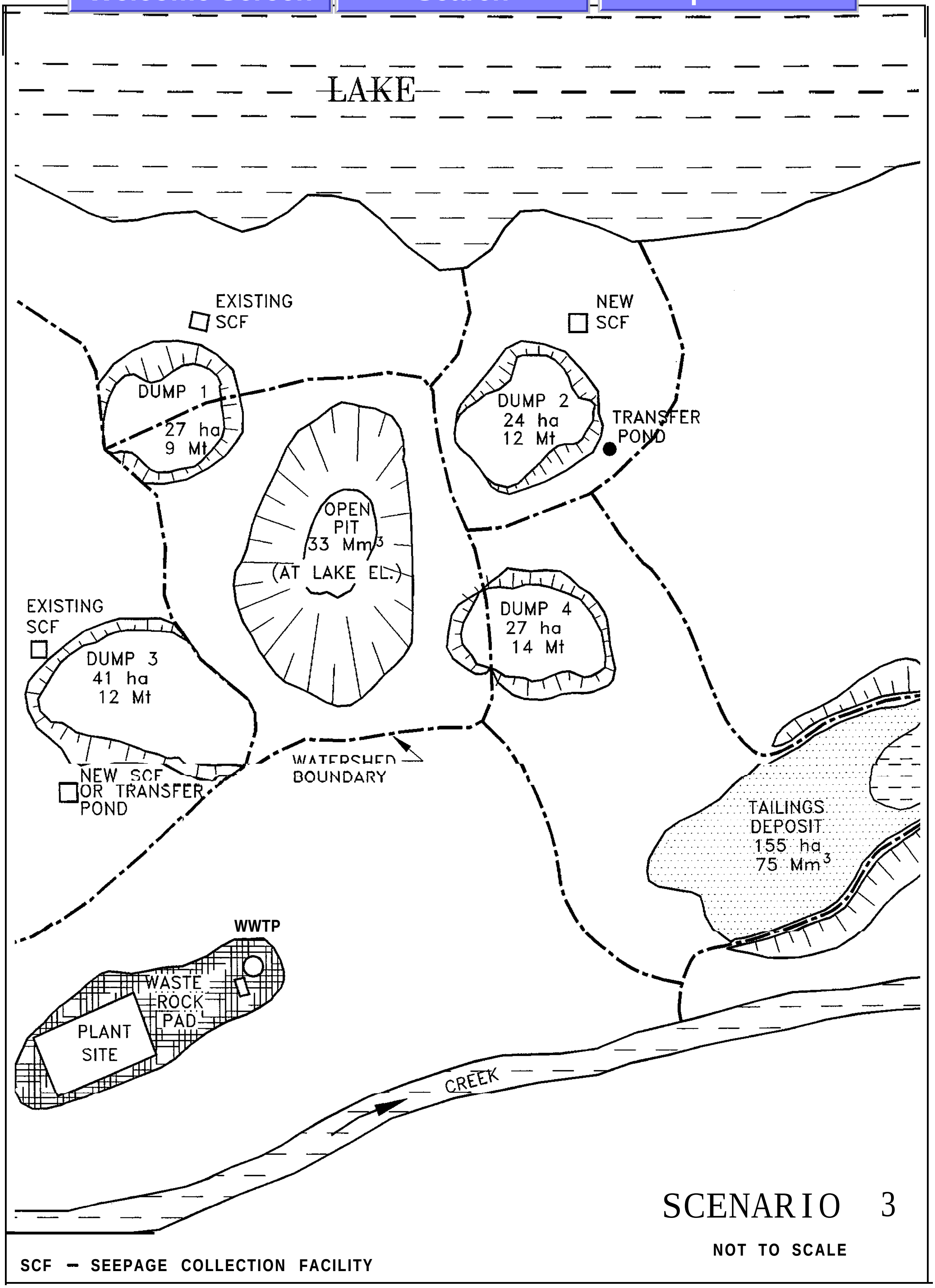
LAKE
EXISTING SCF
NEW SCF
DUMP 1
27 ha
9 Mt
DUMP 2
24 ha
12 Mt
TRANSFER POND
OPEN PIT
33 Mm3
(AT LAKE EL.)
EXISTING SCF
DUMP 3
41 ha
12 Mt
DUMP 4
27 ha
14 Mt
NEW SCF OR TRANSFER POND
WATERSHED BOUNDARY
TAILINGS DEPOSIT
155 ha
75 Mm3
WWTP
WASTE ROCK PAD
PLANT SITE
CREEK
SCENARIO 3
NOT TO SCALE
SCF — SEEPAGE COLLECTION FACILITY

Figure 5.3

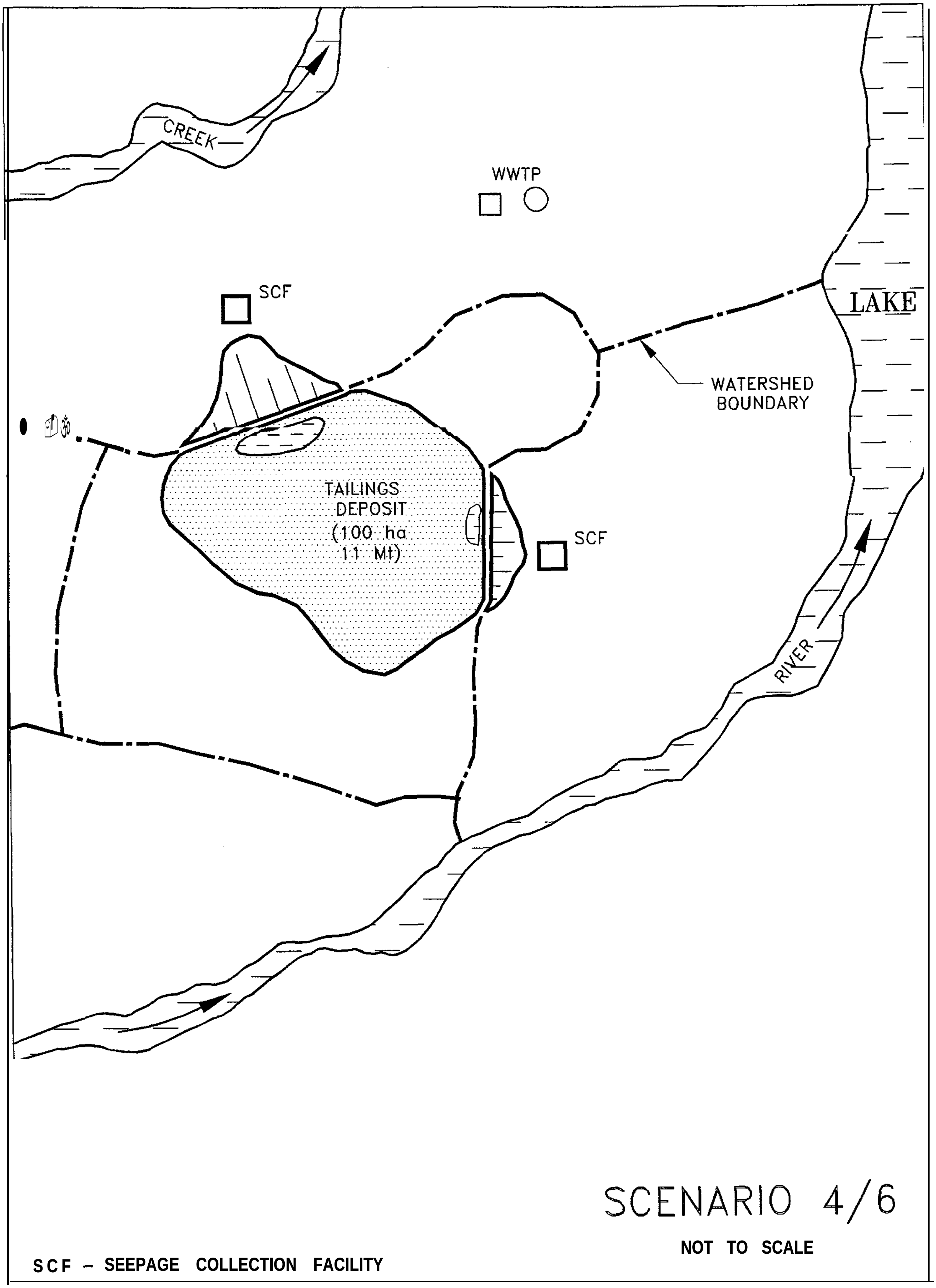
CREEK
WWTP
SCF
LAKE
WATERSHED
BOUNDARY
TAILINGS
DEPOSIT
(100 ha
11 Mt)
SCF
RIVER
SCENARIO 4/6
NOT TO SCALE
SCF – SEEPAGE COLLECTION FACILITY

Figure 5.4

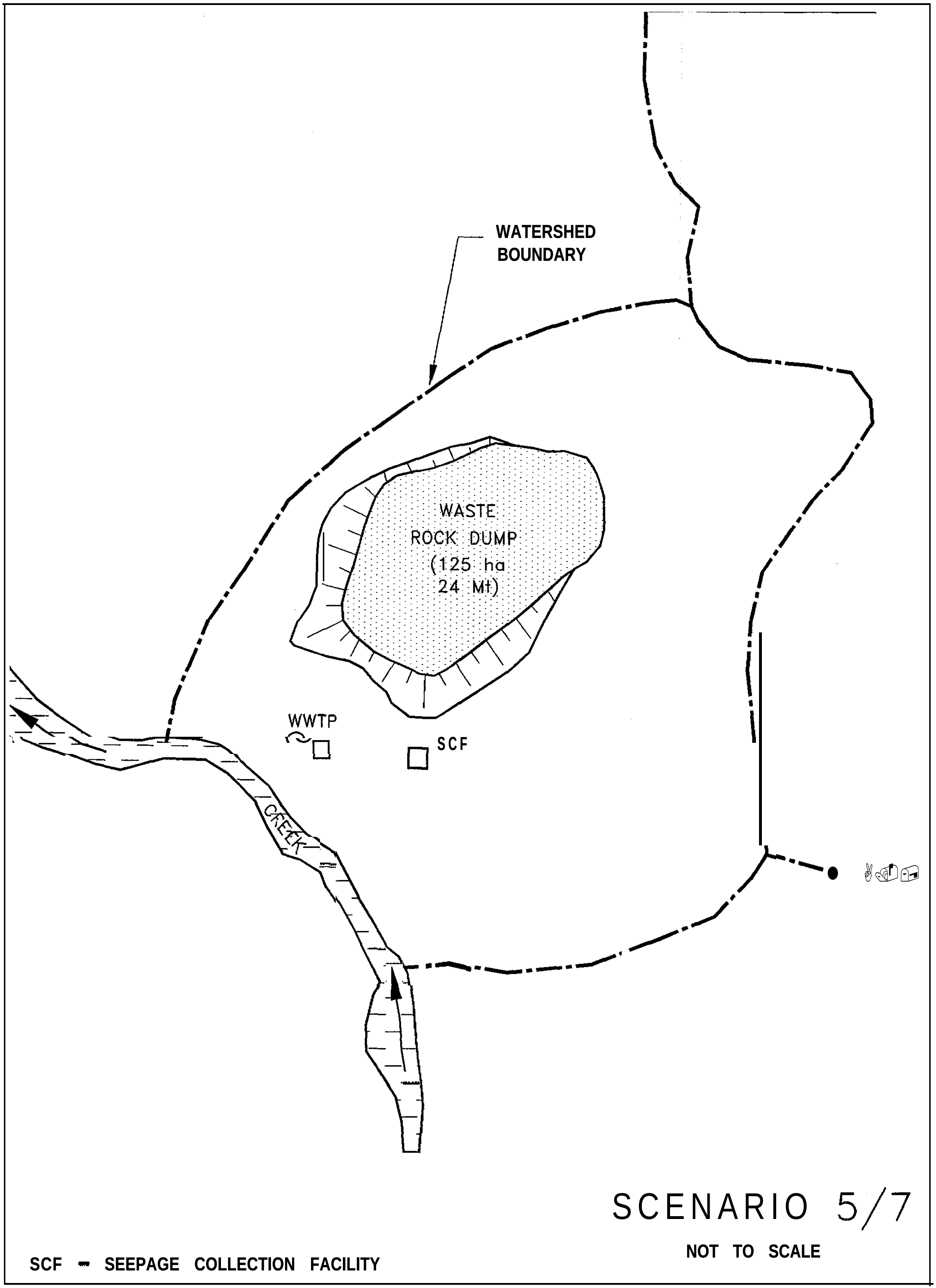
WATERSHED
BOUNDARY
WASTE
ROCK DUMP
(125 ha
24 Mt)
WWTP
SCF
CREEK
SCENARIO 5/7
NOT TO SCALE
SCF - SEEPAGE COLLECTION FACILITY

Figure 5.5

5.3 Protocol Formulation

Development of an easy-to-use protocol for the economic evaluation of AMD technologies was included in the original scope of work for this project. However, during the course of this study it became apparent that the development of an easy-to-use protocol for the economic evaluation of both well established and emerging AMD technologies was not feasible. This is because such a protocol (spreadsheet) would have to be very large and complex (i.e., difficult to follow) and even then it would not be practically possible to account for all plausible site specific issues. For instance, to account for all reasonably possible incidental costs, mine owners approach and legislative requirements with regard to progressive rehabilitation, various cases of abandoned decant and other structures or for various pre-mine and planned land uses, would not be practically possible.

Instead, five fairly comprehensive spreadsheet examples were developed for selected AMD technologies and site specific conditions. If required, these spreadsheets should provide the reader with a framework sufficient to develop a new spreadsheet for any AMD technology and site specific conditions.

A spreadsheet for estimating the implementation costs for several AMD technologies (soil cover, synthetic membrane cover, lime addition, composite soil cover, water cover and collect and treat) was developed in 1992 by Noranda Technology Centre, with an input regarding the construction costs provided by GEOCON. This spreadsheet is available from MEND.

6.0 COST ESTIMATES

6.1 Cost Estimate Summaries

Detailed breakdowns of the costs estimated for each of the selected scenarios are attached in Appendix A. Summaries of these costs are presented in Tables 6.1 to 6.6 included in this section. A brief discussion relevant to the estimated costs is presented below.

General

The AMD technology application costs are presented in the form of either capital (unit) costs or final (unit) costs. The unit costs were obtained from the total costs estimated for a given scenario based on either the footprint area of a tailings deposit or the tonnage of a waste rock dump.

The **capital costs** include the AMD technology implementation costs incurred at the time of mine closure (eg., the cost of the construction of a water retention dam or a soil cover).

The costs incurred after closure can be either "permanent" (eg., the cost of long term collection and treatment), temporary (eg., the cost of collection and treatment during a transition period) or incurred at some time in future (eg., the cost of plastic liner replacement or construction of a WWTP, if deferred). These costs have been converted to their net present values and added to the capital costs to obtain the **final costs.**

Only major cost items have been included in the reported estimates. There will always be a number of site specific work items which have to be carried out in conjunction with the implementation of an AMD technology (eg., replacing a culvert, extending a powerline or reclaiming a borrow pit). In most cases, these costs will not substantially affect the relative comparisons of the unit costs presented in Tables 6.1 to 6.6. However, in terms of the absolute unit costs, the estimates presented in these tables may be somewhat on the low side.

The costs of long term pumping from seepage collection facilities, inspection, monitoring, maintenance and engineering **(the 'additional' costs)** have been assumed, as a first approximation, at 15% of the capital costs for each of the considered AMD technologies (these costs are shown under Item C on the spreadsheets attached in Appendix A). More detailed designs for each of the considered cases would have to be developed to generate accurate cost estimates in this regard. As a general rule, the assumed additional costs are expected to be overestimated in the case of the (high capital cost) walk-away technologies. These additional costs ***have not*** been included in the 'capital unit costs' presented in Tables 6.1 to 6.6. However, they have been included in the 'final unit costs' given in these tables.

A 'standard' unit cost of lime treatment ($0.40/m^3 of treated effluent) has been applied to all scenarios. This includes the cost of lime, polymer and power, with labour and the WWTP maintenance costs accounted for separately. In actual cases, the treatment cost may vary from site to site, depending primarily on the influent quality and quantity, type of WWTP, sludge handling and permissible discharge limits.

The *total* unit treatment costs actually used for cost estimating are always higher than the $0.40/m^3 rate since the labour and WWTP maintenance costs have been accounted for separately. These latter costs have been assumed at $160,000/year for each of the considered cases. Consequently, the total unit costs for treatment decrease with an increase in the rate of treated influent (eg., it follows from the data given on the first spreadsheet in Appendix A that the long term total treatment costs are $0.53/m^3 and $0.76/m^3 for Scenarios 1-4 and l-6, respectively). The total treatment costs used for the purpose of this study would be applicable to typical AMD with an average acidity concentration in the order of 1000 to 3000 mg/l.

To confirm the reasonability of the above assumptions, the total unit treatment costs were computed from the spreadsheets attached in Appendix A, taking into account the labour/main tenance costs and the WWTP in fluen t rate, and compared with the actual costs reported by various lime treatment plant operators (data on 18 lime treatment operations are available to GEOCON). This comparison indicated that the computed costs were well within the range of the actual costs.

The unit cost for cyanide treatment (Scenario 2) was assumed at $0.60/m^3 excluding the $160,000/year component to cover the labour and WWTP maintenance costs, based on data obtained from an actual project.

Although the selected scenarios were developed primarily for existing mines, the unit costs estimated for the walk-away AMD technologies would not be substantially lower in the case of a new mine, except for the water cover option. In this case, a purposeful selection of a tailings basin and tailings deposition scheme as well as an investment in well engineered tailings dams adequate also for closure could lead to very substantial savings. With regard to the remaining walk-away options (composite soil and plastic liner covers), the costs could be somewhat reduced in the case of a new mine, primarily by an adequate shaping a deposit during the mine operations and, possibly, by control/prevention of AMD generation prior to closure.

It seems that planning for long term collection and treatment in the case of a new mine is unlikely.

In estimating the costs, consideration was always given to either actual or assumed site conditions. For instance, factors such as tailings surface trafficability or size of a watershed were factored into the construction prices.

The implementation costs relating to the majority of AMD technologies will depend, among other factors, on the availability of soil (construction) materials. Under typical conditions, such a dependence will be particularly applicable to the soil and plastic liner cover technologies. This was the primary reason for introducing the generic scenarios 4 and 5 where an attempt was made to select "average" borrow material conditions (the costs with regard to Scenarios 1, 2 and 3 were estimated based on the actual site conditions).

Since the unit costs for the construction of soil covers over waste rock dumps have been expressed per tonne of rock, it is important in making any related conclusions to take-into account the relationship between the tonnage of rock and the dump area. As the average height of the waste rock dumps in the case of Scenario 3 was about 20 m, it was decided to introduce an average height of the waste rock dump at about 10 m for the purpose of defining Scenario 5 which gives, therefore, a substantially different volume-area relationship.

Scenarios 6 and 7 were included to emphasize the fact that the cost of plastic liner technology depends on an assumed longevity of the liner. Because the liner replacement cost is relatively low when converted to its net present value, this technology can be looked at from two different perspectives:

- the cost of liner installation and subsequent liner replacement,
- the cost of liner installation and the implementation of another (presently known or unknown) AMD technology after the liner deteriorates.

Relevant implications and an example of cost analysis for the plastic liner option are discussed by Szymanski and MacPhie (1 994).

A final unit cost depends on an assumed value of the real rate of return. If required, the final unit costs for other (than 3.5%) real rate of return values can be readily calculated by selecting relevant cost items and corresponding time periods identified on the spreadsheets attached in Appendix A.

For the "long term" collect and treat items identified on the spreadsheets, an ***infinite*** time period was assumed to calculate the net present values while, in reality, a collect and treat operation would cease shortly after sulphide depletion. This means, in practical terms, that the long term collect and treat operations were assumed to be required in excess of an 80 year period (the net present value of an annual cost incurred over 80 years corresponds to approximately 94% of the net present value calculated for an infinite time period).

The cast of treatment of either AMD or cyanide during a transition period, when converted to its net present value, **depends on** the assumed length of this period (for the transition periods in excess of about 80 years, this dependency is not significant). As **a** first approximation, the lengths of transition periods were assumed at 20 to 30 years with regard to the collection and treatment of seepages from tailings basins and at 3 years for seepages emerging from a waste rock pile. It is believed, however, that at many sites the (required) transition periods could be longer than those assumed herein, particularly where sensitive receivers are located close to the tailings/waste rock deposits.

Commentary

The estimated capital and final unit costs for the various AMD technology applications for **Scenario 1** are summarized in Table 6.1. It follows from this table that the capital costs associated with any of the considered collect and treat options are substantially lower than those associated with the walk-away options, however, these cost differences decrease when compared in terms of the final costs. It is interesting to note that the capital costs estimated for the walk-away technologies compare reasonably well with the final costs estimated for the collect and treat technologies (Table 6.1). In other words, the cost of the collection and treatment ***during transition period(s),*** including the cost to provide/upgrade runoff collection and transfer facilities, makes up (approximately) the difference in terms of the final costs.

The 'transition' costs associated with the walk-away options may often become a critical factor in comparing the costs of various AMD technologies for a site. The length of a. transition period is obviously crucial from the final cost perspective.

From the incidental costs standpoint, the results of Table 6.1 demonstrate that in this particular case, the selection of collect and treat option for the plant site (including the open pit, tailings spill pond and underground mine workings) would increase the effective cost of the collect and treat options for the tailings area. Should a walk-away scenario be selected for the tailings area, the plant site would have to be rehabilitated to the same scenario since providing a WWTP and sludge disposal facilities, in conjunction with the rehabilitation of the plant site only, would be prohibitively expensive.

In other words, the cost of rehabilitating the plant site to a walk-away scenario is lower than the cost associated with the long term collection and treatment of the contaminated runoff from this site (the difference constitutes the incidental cost with regard to the tailings basin closure). This results from a relatively high "net present value" of the collect and treat option for the plant site. It has to be realized, however, that there are other (than the cost) factors that would typically be taken into consideration in selecting a preferable closure option for the plant site (performance risks, short and long term environmental impacts, scheduling of rehabilitation works, etc.).

TABLE 6.1
SCENARIO 1 - UNIT COST SUMMARY (1994$/ha of tailings footprint)

AMD TECHNOLOGY	without incidental costs		with incidental costs
	capital cost	final cost	final cost
Self-sustained Water Cover	254,000	349,000	349,000
Composite Soil Cover (CSC)	293,060	370,000	370,000
Partial Water Cover and CSC	223,000	303,000	303,000
Collect & Treat (C&T)	62,000	199,000	214,000
C&T with Partial Water Cover	93,000	2 10,000	225,000
C&T with Simple Soil Cover	157,000	246,000	26 1,000

notes:

- the first three cases represent walk-away options; the tailings generate net acidity and a transition period will apply to any of these options during which contaminated seepages must be collected and treated; in the case of water cover scenarios, another (shorter) transition period applies, associated with the collection and treatment of the overflow,
- the costs shown for the first option may be underestimated - the increase in the hydraulic gradients upon flooding of the entire tailings pile would be very substantial and, without an additional study, it cannot be ruled out that more extensive seepage collection facilities than those allowed for in the cost estimates would be required during a transition period,

  in the case of the second option, the question of the integrity of the cover in the slimes (tailings pond) area as related to long term settlement has been addressed at a preliminary level only and the costs for this option may have been underestimated,

  soil construction materials are available within a distance of 5 to 20 km; only limited processing of the materials would be required..

The capital and final unit costs estimated for **Scenario 2** are summarized in Table 6.2. The relatively high costs of the plastic liner and composite soil covers result from the fact that the tailings deposit consists of relatively fine tailings (poor drainage characteristics), existing low permeability tailings retention dams (relatively slow consolidation of the tailings) and the expected tailings beach configuration at the end of the mine operations. Hence, it is anticipated that the construction of a dry cover would be very difficult (compaction impossible) and expensive, at least for a period of time after closure. On the other hand, leaving the site for a period of time to allow for drying out the tailings would lead to the onset of AMD generation in the tailings beaches and, as a result, this approach is not considered feasible.

It follows from Table 6.2 that the water cover options are particularly suitable in the case of Scenario 2. The substantial difference between the capital and the final costs for these options results from the fact that the cyanide contaminated seepages would have to be treated during a transition period.

TABLE 6.2
SCENARIO 2 - UNIT COST SUMMARY (1994$/ha of tailings footprint)

AMD TECHNOLOGY	capital costs	final costs
Self-sustained Water Cover	13,000	71,000
Maintained Water Cover	11,000	83,000
Plastic Liner Cover	297,000	404,000
Composite Soil Cover	307,000	415,000
Collect & Treat with Simple Cover	91,000	200,000
Collect & Treat	63,000	227,000

notes:
- tailings do not generate net acidity at time of closure,
- treatment of cyanide contaminated porewater is required after closure, regardless of the selected technology option,
- for the 'collect & treat with simple cover' option, a vegetation type cover was assumed to be adequate; it is expected that replacement of such a type of cover with a simple soil cover would increase the costs substantially,
- soil construction materials are available in the mine area (1 to 4 km), however, it is not certain if the low permeability materials available in the area would be adequate for the construction of a composite soil cover.

The dependence of the collect and treat technology cost on the amount of the overland runoff and seepages that have to be collected and treated is indicated in Table **6.3** for **Scenario** 3 (see also the corresponding spreadsheet in Appendix A for the treatment rates). The cost of a simple cover construction over one or more of the waste rock dumps represents the principal variable. The results of Table 6.3 demonstrate that providing a simple soil cover in order to divert the overland runoff (and reduce infiltration into a waste rock dump) need not be cost effective. This effectiveness depends mainly on the cost of the construction of a soil simple cover and associated seepage collection system, and the performance (hydraulic conductivity) of the cover. For the studied conditions, providing simple soil covers over the dump(s) would not reduce the final costs sufficiently to offset the costs associated with the construction of the simple soil covers and related facilities. ***(The same conclusion can be drawn from the results of Table 6.1. Therefore,***

within the framework of the performance specifications defined in Section 3.0, the simple soil cover option does not indicate a cost advantage in the cases studied.) The composite soil cover represents the most costly option for Scenario 3.

TABLE 6.3
SCENARIO 3 - UNIT COST SUMMARY (1994$/tonne of waste rock)

AMD TECHNOLOGY [SSC = Simple Soil Cover]	without incidental costs		with incidental costs
	capital cost	final cost	final cost
SSC applied to Dumps 1,2,3,4	0.16	0.24	0.34
SSC applied to Dumps 1,2,3	0.13	0.21	0.33
SSC applied to Dumps 1,2	0.09	0.16	0.29
SSC applied to Dump 1	0.06	0.14	0.29
Collect & Treat without SSCs	0.03	0.11	0.26
Composite Soil Cover	0.89	1.07	1.07

notes:
- the first five cases represent long term collect and treat scenarios,
- the deferral of the long term treatment costs and the WWTP construction cost is applied until the time that the open pit fills up; runoff collection and pumping to the pit would be carried out prior to this time,
- there is a low permeability material adequate for cover construction available at the site, however, there are no known granular material borrow pits in the vicinity of the mine,
- the incidental costs are introduced assuming that the contaminated runoff from a nearby tailings area has to be pumped to the pit, thus reducing the length of the deferral period.

The incidental costs indicated in Table 6.3 are obviously very high. This indicates, again, that in the overall evaluation of AMD technology costs, the incidental costs must not be ignored.

The unit costs presented in Table **6.4** for **Scenario 4** indicate a lower capital unit cost for the composite soil cover as compared with Scenarios 1 and 2. It is believed that the unit costs obtained for the two latter scenarios were on a high side for a number of reasons but, chiefly, because of the cost of the material supply and the expected high construction cost in the case of Scenario 2. Scenario 4 represents a somewhat optimistic case with regard to the cost of soil cover construction.

TABLE 6.4
SCENARIOS 4 & 6 - UNIT COST SUMMARY (1994$/ha of tailings footprint)

AMD TECHNOLOGY	capital cost	final cost
Collect and Treat'	97,000	238,000
Simple Soil Cover'	182,000	264,000
Composite Soil Cover'	231,000	29 1,000
Plastic Liner Cover[2]	257,000	296,000

1 - Scenario 4 2 - Scenario 6

notes:

- soil construction materials, suitable for a cover construction, are assumed to be available within 1 to 4 km from the site,
- the tailings are generating AMD and treatment during a transition period is assumed for the composite soil cover option,
- only relatively minor works would be required to prepare the tailings for the construction of a soil cover or plastic liner installation,

In terms of the capital unit costs associated with the collect and treat option for waste rock, the unit costs presented in Table 6.5 seem to be more representative of average conditions than those estimated for Scenario 3. The generally higher costs in the case of **Scenario** 5 result from the fact that the cost of the WWTP construction has been deferred in the case of Scenario 3.

An allowance has been made in Scenario 5 for regrading some of the rock dump slopes and bedrock grouting in conjunction with the construction of the seepage interception and routing system (in Scenario 3, the possibility of significant contamination of a bedrock aquifer was ruled out). The final unit costs for the collect and treat options are substantially lower for Scenario 3 as compared with Scenario 5, primarily because of the deferral of the treatment costs in the former case.

The higher cost of providing a composite soil cover in the case Scenario 5, as compared with Scenario 3, is primarily due to the different assumed dump volume/area ratios. In this regard, Scenario 3 is probably more representative of a typical mine site where often yard, road, pad and other rock fills exist with a low volume/area ratio (moving and/or reshaping of such low fills would obviously result in additional costs).

The unit costs associated with the installation of a plastic liner (longevity = 200 years) for Scenarios 4 and 5 are given in Tables 6.4 and 6.5, referred to as **Scenarios 6 and** 7, respectively. The final unit costs for the plastic liner option are compared in Table 6.6 with an assumed liner longevity as a variable. The cost of liner replacement for longevities over 200 years is of no practical consequence if other inherent uncertainties in the cost estimating are taken into consideration.

TABLE 6.5
SCENARIOS 5 & 7 - UNIT COST SUMMARY (1994$/tonne of waste rock)

AMD TECHNOLOGY	capital cost	final cost
Collect and Treat'	0.16	0.64
Simple Soil Cover'	0.55	0.85
Composite Soil Cover'	1.12	1.31
Plastic Liner Cover²	1.38	1.59

1 - Scenario-5 2 - Scenario 7

notes:

- soil construction materials, adequate for soil cover construction without processing, are assumed to be available within 1 to 4 km from the site,
- the mine site is assumed to be located in an area of low seismicity,
  the waste rock is generating AMD and treatment during a transition period is assumed for the composite soil cover option.

TABLE 6.6
SCENARIOS 6 & 7 - UNIT COST SUMMARY: PLASTIC LINER LONGEVITY

LONGEVITY OF PLASTIC LINER	Scenario 6 - Tailings final unit cost (1994$/ha of tailings footprint)	Scenario 7 - Waste Rock final unit cost (1 994$/tonne of waste rock)
50	346,000	1.83
100	303,000	1.63
200	296,000	1.59

note:

in the case of tailings, the liner is assumed to be placed over the tailings footprint and the tailings retention dams (regraded).

Finally, it is emphasized that the cost of any AMD technology application can be influenced by numerous site specific cost factors (as discussed in Section 2.0). The cost of providing a self-sustained water cover represents an excellent example of the dependency of an AMD technology cost on site specific conditions. This is indicated by the comparison of the results included Tables 6.1 and 6.2.

(On a current GEOCON project, interception of a contaminatedplume by a grouted open ditch was planned in conjunction with a collect and treat option. A similar ditch was successfully constructed on another GEOCON project in the past. However, as the results of a field investigation showed, a highly permeable rock formation extended to a depth of more than 20 m and the cost of constructing the ditch would be so high that this option had to be abandoned. This indicates the dependency of capital costs on the site specific conditions also in the case of the collect and treat technology - more typically, the highly permeable bedrock would extend to a depth of 5 to 10 m and constructing a grouted ditch, according to a certain performance specification, would be substantially less expensive. Numerous examples of this sort can be provided.)

6.2 Waste Removal

Removal of reactive wastes (waste rock or tailings) to an open pit is an AMD technology option often talked about and actually implemented in the past at some mine sites (eg., at Owl Creek Mine in Timmins, Ontario). The objective of this technology is to store potentially reactive wastes permanently under the water table.

Since waste rock is often stockpiled close to an open pit, moving waste rock into the pit can be accomplished at a relatively low cost, typically in the order of $1 .0 to $1.5/tonne. However, as follows from the cost estimates presented in Tables 6.3 and 6.5, this option need not be the most cost effective. It should be noted that adding lime/limestone, which might be required in conjunction with removal of the waste rock generating net acidity, has not been accounted for in those estimates (lime addition to neutralize pit water would constitute a cost of the pit rehabilitation, however, adding lime to neutralize the liquid phase trapped in waste rock would have be included under the waste rock removal option).

Removal of a tailings deposit into an open pit may also be considered. On a recent project, the cost of tailings removal by shovel and truck to a pit located within 1 km of the tailings site was reported at between $1 .5/m^3 and more than $5.0/m^3, the latter value applicable to the case where the groundwater table was close to the tailings surface. Assuming that, on the average, tailings can be removed at $3.0/m^3 and a typical depth of a tailings deposit at 10 m, the cost of the tailings removal would translate to $300,000/ha of tailings footprint which is comparable with the costs estimated previously for other AMD technologies (Tables 6.1, 6.2 and 6.4).

It is important to realize that in cases where the removed waste deposit (tailings or waste rock) generates AMD at the time of removal, additional costs associated with a complete clean up of the former waste site may apply (in an extreme case, a transition period might be-necessary during which a collection and treatment of the seepages and/or overland runoff would have to be carried out at a former waste site over a number of years).

It is believed that the waste removal costs quoted above could be underestimated, at least for some mine sites.

6.3 Representative Cost Ranges

A summary of the unit cost ranges estimated for Scenarios 1 to 5 is presented in Table 6.7. The final unit costs include the short and/or long term collection and treatment costs (where applicable), the incidental costs (where applicable) and the additional costs (which include pumping from seepage collection facilities, maintenance, inspection and engineering costs).

It follows from Table 6.7 that the costs of applying various AMD technologies can vary widely, particularly for the collect and treat option in the case of waste rock and for the self-sustained water cover option in the case of tailings.

The relatively low cost of the collect and treat option for waste rock, given under the ‘lowest estimate’ heading, results from the fact that it was possible to defer significantly the costs of the treatment operation and WWTP construction. This is certainly not a typical case.

Another result shown in Table 6.7 that clearly stands out is the ‘lowest estimate’ cost for the self-sustained water cover (and maintained water cover as well). This has to do with the fact that the tailings basin for which these costs were estimated had been designed and constructed in accordance with modern standards. It is felt that although such low costs could not possibly be applicable to most of the older mines, they could still be considered typical for some of the existing and new mines.

On the other hand, the ‘highest estimate’ unit cost for the self-sustained water cover shown in Table 6.7 **($349,000/ha)** applies to the situation where the tailings site is particularly poorly suited for providing a water cover.

TABLE 6.7 SUMMARY OF COST ESTIMATES FOR SELECTED SCENARIOS
(costs per tonne of waste rock or hectare of tailings footprint, 1994$)

note: upper estimates = capital unit costs; lower estimates = final unit costs

	AMD TECHNOLOGY	lowest estimate	one estimate	highest estimate
WASTE ROCK	COLLECT AND TREAT	0.03		0.16
		0.26		0.64
	COLLECT AND TREAT with SIMPLE SOIL COVER	0.16		0.55
		0.34		0.85
	COMPOSITE SOIL COVER	0.89		1.12
		1.07		1.31
	PLASTIC LINER COVER (longevity of 200 years is assumed)		1.38	
			1.59	
TAILINGS	COLLECT AND TREAT	62,000		97,000
		214,000		238,000
	COLLECT AND TREAT with SIMPLE SOIL/VEGETATION COVER	91,000		182,000
		200,000		264,000
	COLLECT AND TREAT with PARTIAL WATER COVER		93,000	
			225,000	
	COMPOSITE SOIL COVER	23 1,000		307,000
		29 1,000		415,000
	COMPOSITE SOIL COVER with PARTIAL WATER COVER		223,000	
			303,000	
	SELF-SUSTAINED WATER COVER	13,000		254,000
		71,000		349,000
	MAINTAINED WATER COVER		11,000	
			83,000	
	PLASTIC LINER COVER (longevity of 200 years is assumed)	257,000		297,000
		296,000		404,000

Finally, it has to be emphasized that the 'lowest' and 'highest' estimates presented in Table 6.7 must not be considered as the lower and upper limits. [On a ***recent GEOCON project, where the construction of rehabilitation measures has been in large part completed, the estimated final cost of the collection and treatment option for a tailings basin ($204,000/ha) is lower than any of the estimates presented in this study. On another current GEOCON project, the final cost for a collect and treat option has been estimated at $2.1/tonne of waste rock. In this case, however, the contaminated runoff collection area includes also an open pit watershed which represents an 'incidental cost' component].***

Based on a review of the results shown in Table 6.7, data from other projects and judgment, a set of representative unit cost ranges for the two basic AMD technologies has been derived and is presented in Table 6.8.

TABLE 6.8 PROPOSED REPRESENTATIVE UNIT COST RANGES FOR BASIC AMD TECHNOLOGIES *(final* unit costs)

BASIC AMD TECHNOLOGY	TAILINGS 1994$/ha of footprint	WASTE ROCK 1994$/tonne of rock
COLLECT AND TREAT	180,000 - 280,000 [210,000]	0.4 - 2.0 [0.7]
WALK-AWAY (transition period may apply)	100,000 - 300,000 [200,000]	1.0 - 1.5 [I .30]

note: - values in brackets represent suggested 'typical' unit costs

It is essential to realize that the unit cost ranges and the typical unit costs presented in Table 6.8 have been derived with the purpose of identifying AMD technology costs of practical significance only in the sense that the majority of the ***actual*** (past or future) project costs would be expected to fall into one of the cost ranges presented in this table. For example, the composite soil cover option at $415,000/ha (Table 6.7) is outside of the range of the representative cost ranges included in Table 6.8 since it is unlikely that such an option would ever be implemented in practice.

It is also interesting to note that, according to the results of Table 6.8, it is not likely that a walk-away option would be selected for the rehabilitation of a waste rock dump. This conclusion, it is felt, applies. to larger waste rock dumps which generate significant AMD at the time of closure.

A comparison of the unit cost ranges estimated in this study with those compiled recently by D.G. Feasby of MEND (1994) is presented in Table 6.9 in terms of the final costs. For the comparison purposes, however, the incidental costs (where applicable) have been excluded.

TABLE 6.9 COMPARISON OF UNIT COSTS FOR BASIC AMD TECHNOLOGIES (after D.G. Feasby, 1994, and this project)

AMD TECHNOLOGY		TAILINGS 1994$/ha of footorint	WASTE ROCK 1994$/tonne of rock
Collect and Treat	G. Feasby	**120,000**	**0.53**
	this project	**199,000 - 238,000**	**0.11 - 0.64**
Composite Soil Cover	G. Feasby	290,000	**0.88**
	this project	291,000 - **415,000**	**1.07 - 1.31**
Water Cover	G. Feasbv	**120.000**	
	this project	**71,000 - 349,000**	

In general, the cost ranges derived from this study are higher than the costs estimated by MEND. For instance, there is a considerable difference in the unit costs applicable to the collect and treat technology in the case of a tailings deposit. Also, the present estimates of the composite soil cover costs for waste rock are somewhat higher than those estimated by MEND. The are numerous factors that could lead to such differences, for example, different assumptions on the length of transition periods, the construction requirements with regard to seepage collection facilities, the costs to upgrade a WWTP in preparation for a remote operation, etc. Nevertheless, it seems that both estimates represent the same "order of magnitude".

There are a number of cases where actual project costs of the applications of various AMD technologies have been reported in the technical literature, however, there is usually no detailed information included to allow for a meaningful comparison (in terms of unit costs and the work items considered) with the results presented herein.

7.0 FINANCIAL LIABILITIES

The following estimates of the financial liabilities are based on the inventory of reactive mine wastes in Canada presented in Section 4.0. The unit costs used to arrive at these estimates are based on the representative cost ranges discussed in Section 6.0.

Using the representative unit cost ranges and the typical unit costs included in Table 6.8, the financial liabilities associated with reactive tailings and waste rock in Canada are estimated as:

'Average' Estimate:

- tailings - $2.5 billion
- waste rock - $0.5 billion

where some judgment was used in selecting the unit costs. Further judgment must be applied to arrive at the upper and lower bound estimates of the financial liabilities. As a first approximation, the following limits could be used:

Lower Bound Estimate:

- tailings - $1.8 billion
- waste rock - $0.4 billion

Upper Bound Estimate:

- tailings - 2.9 billion
- waste rock - 0.9 billion

It is noted that the above estimates do not represent all the liabilities associated with acid mine drainage since open pits and underground mine workings have not been accounted for in this study. Therefore, it is expected that the above estimates are underestimated with regard to the overall AMD problem.

To evaluate the liability associated with open pits and underground mine workings to a first approximation, an estimate could be made with regard to a minimum total runoff which would have to be collected and treated to ensure an adequate control of the AMD generated in open pits and underground workings in Canada. It seems that considering the collect and treat technology *for this purpose* would yield sufficiently accurate results.

8.0 EXAMPLES OF COST ESTIMATE SPREADSHEETS

As pointed out in Subsection 5.3, it is considered that the development of one, easy-to-use 'protocol' spreadsheet for evaluating the costs of various AMD technologies is not feasible. Such a spreadsheet would have to be very large and would certainly be difficult to use.

Consider, for instance, the costs related to the construction of a composite soil cover or setting up a sulphide flotation operation. While in the first case an additional cost may have to be incurred to adjust the tailings discharge system to prepare the tailings surface for cover construction, costs associated with an adjustment to the mill process might have to be incurred in the second case. To account for all (reasonably) possible site specific conditions and a number of AMD technologies in developing a single easy-to-use protocol-spreadsheet would be a major project in itself. ***(This is similar to the schedules of quantities and prices used in construction contracts: it is not feasible to prepare such a schedule which would cover, for instance, all earthwork type projects carried out in all climatic regions of Canada, and ranging from underpinning foundations, through dam construction or excavation and disposal of PCB contaminated soils, to offshore dredging).***

Nevertheless, it is possible to illustrate a typical procedure that can be applied to estimating the costs of AMD technologies (actually, this is similar to the preparation of a schedule of quantities and prices). The cost estimate spreadsheets discussed previously (Appendix A) provide such an illustration. To illustrate the cost estimating procedure further, five additional, more detailed example spreadsheets were prepared for selected AMD technologies and these are attached in Appendix B. These spreadsheets refer to either waste rock or tailings deposits. The other mine components have been included to allow for the insertion of incidental costs, where applicable.

The attached example spreadsheets need not be best designed if an entire mine site is analyzed. In such cases, one of the most essential issues in developing a cost evaluation spreadsheet is to divide it into ***logical*** components. For instance, for some mine sites it is best to divide a spreadsheet into 'physical' components (eg., type of wastes or watersheds), while for others it may be advantageous to divide the spreadsheet into 'technological' units (eg., soil cover areas, clean-up areas, etc.). This might be important in identifying potential cost savings.

9.0 BACKGROUND TO RECOMMENDATIONS

As pointed out previously, the primary objective of this project was to develop recommendations with regard to further research requirements in the area of AMD technologies. It is believed, however, that providing recommendations based on cost considerations alone could lead to serious misunderstandings and would be of limited value. Defining future research requirements. must be also based on other objectives such as potential chance of success (in carrying out a research task), technical guidelines, regulatory (present and future) requirements, public perception, etc. Although outside of the scope of this project, the following discussion is offered to back up the project recommendations in developing of which other (than the cost) factors have also been taken into consideration.

It is important to realize that, today, the decisions with regard to the selection of a preferable AMD technology at actual project sites are based on environmental benefits and the chance of success in addition to cost considerations (possible exceptions noted). Although the first of these factors is probably too site specific to influence future research planning, the second factor must not be overlooked in this respect. Identifying low risk options is certainly one of the most important research tasks with respect to AMD technology developments. It seems that identifying high risk options might be of equal benefit.

There is no doubt that the best way to deal with AMD is to prevent acid generation in the first place. In many cases, it is too late for this approach and, even in the case of a new mine, economics may require that the development of some AMD be permitted. Perhaps the.most attractive option with regard to the prevention of acid generation is underwater disposal. This has been long recognized by MEND. From the AMD technology basic cost perspective, nothing can be added in this regard since the effective cost of underwater disposal can not be estimated without considering complex environmental, regulatory and public perception issues.

Besides underwater disposal (which is different from providing a water cover), it seems that the best and proven technology to deal with AMD is the collect and treat option. This results from the following facts:

- both the collection and treatment processes are relatively well understood and have been practiced successfully for many years; they can be designed based on well established engineering principles, with a high chance of success;

- the sulphides will be consumed with time and the problem will be alleviated at some time in future (assuming that sludge disposal is handled properly);

- there will be continuous or periodic presence of maintenance crews/operating personnel at the site, and the long term site inspection (and swift reaction to potential problems) will be more realistic than in the case of walk-away options;

- the site will not be forgotten for as long as sulphides are there;

- there is a **good** chance that a better technology will be developed prior to the end of the treatment operation which could allow for cost savings;

AMD technology costs aside, the most often quoted shortcoming of the collect and treat option is having collect and treat operations "all over the place" for **a long time.** It is not often said, however, that most of the walk-away technologies mean, at this time, having potential problems (eg., encapsulated sulphide deposit or a water retention dam) all over the place **forever.** Moreover, it will often happen that having a collect and treat operation associated with a **relatively long** transition period is part of a "walk-away" solution. Furthermore, at this stage of the AMD technology developments, it seems that the risk of failure for most of the **walk-**away technologies is significant. What follows is that providing inspection and maintenance **forever** may have to be associated with the "walk-away" technologies, at least in practical terms.

In 'practical terms' means here having limited rehabilitation budgets. Given an unlimited budget, a soil cover or a water retention dam can be designed and constructed so that no further inspection and maintenance would be required. Such budgets, however, seem to be extremely elusive.

It is therefore important to be practical also in developing recommendations with regard to the most desirable future research directions. An attempt in this regard is made in the following section.

In general, it seems that the research efforts could be divided into the three principal groups:

1 Improvements in the AMD technologies which are already proven (to lessen the risks and costs as well as to increase the effectiveness).

2 Development of new, generally applicable technologies ***(superior*** to those already proven).

3 Development of site specific technologies (eg., for mine sites in permafrost areas or for weak-moderate AMD cases).

From this perspective, it is believed that, besides the collect and treat technology, the water cover technology could also be included in the first group.

10.0 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions follow from the project findings:

- The (unit) costs of the application of AMD technologies are very site specific. This is best demonstrated by the comparison of the self-sustained water cover costs estimated in this.study, however, the same also applies to composite soil covers and other walk-away AMD technologies.

- In the case of walk-away technologies, the cost of collection and treatment during a transition period(s), including the associated cost to upgrade and/or construct collection and treatment facilities, may be very substantial.

  Furthermore, the cost of the rehabilitation of the temporary collection and treatment facilities after a transition period ends (neglected for the purpose of this study) has to be taken into consideration.

- The cost of the collect and treat technology seems to be less site specific, except for the influence of incidental costs. One of the most important cost factors in this regard is the amount of runoff to be collected and treated. However, providing a simple soil cover (to limit the amount of treated influent) does not seem to yield cost benefits, at least for the cases studied.

- The results of the study confirm that, from the AMD technology cost perspective, the water cover technology, whether maintained or self-sustained, can be very attractive for sites which are well suited for this technology application (see Scenario 2).

- Incidental costs may significantly increase the cost of an AMD technology application (see Scenario 3).

- In some cases, site specific conditions may dramatically reduce the costs of a technology application (see Scenario 3).

- The composite soil cover and plastic liner technologies seem to be the most expensive. This conclusion, however, does not need to apply to all sites and should be considered as a general rule only.

From the technology development standpoint, it seems that the costs of these two options cannot be significantly lowered. Regardless of the performance requirements, it is unlikely that the cost of plastic liner installation could be reduced by a significant amount or that the overall thickness of a composite soil cover, being the primary cost factor, can be substantially reduced for practical (construction) reasons.

cl The unit cost ranges derived from the cases studied are presented in Table 6.7. The representative unit costs have been derived with a reference to the two basic AMD technologies. These are presented in Table 6.6.

RECOMMENDATIONS

The following recommendations are given with respect to the most desirable future research directions in the AMD technologies area. As stated before, although these recommendations are based on the cost evaluations discussed in this report, other factors have also been taken into consideration in their formulation.

General

❑ Provide a concise research report on:

- **long** term risks associated with various AMD technologies with a reference to site specific conditions leg., ***why should we put an effort into researching the rate of oxygen flux into a composite soil cover if such a cover, when constructed over a waste rock dump, is to fail under a moderate earthquake - typical rock dumps are known to be loose and non-homogeneous),***

- **shorter** term risks associated with various AMD technologies with a reference to site specific conditions ***leg., why should we put an effort into researching the rate of oxygen flux into a composite soil cover if such a cover, when constructed over a tailings deposit, is to fail as a result of tailings consolidation - many tailings deposits are known to include a former tailings pond portion consisting of very loose, fine and unconsolidated tailings, submerged at the end of the disposal operations),***

- **short** term risks associated with various AMD technologies with a reference to potential construction problems ***leg., why should we put an effort into researching the rate of oxygen flux in to a composite soil cover if such a cover cannot be constructed, at a reasonable cost, over a tailings deposit in the first place).***

Such reports are already available for some AMD technologies (from the MEND files), however, the relevant risk issues should be reviewed from the AMD technologies ***comparison*** perspective - only then a complete background to directing future research would be available.

It is emphasized that the above statements are not intended as a critique of the composite soil cover technology. They have been made merely to provide ***an example*** for the discussion purposes.

Collect and Treat Technology

(as indicated in this report, the collect and treat technology has significant advantages)

cl Address the question of sludge utilization even if not **100%** profitable.

cl Develop methods to lower the treatment costs, including the cost of WWTP construction.

cl Provide a report on presently available technologies in the area of the remote control/operation of WWTP and influent collection/transfer facilities.

cl Carry out a research study to determine the attenuation capacity of typical subsurface soils occurring in the mining regions of Canada with regard to contaminated groundwater flow (this recommendation also applies to other AMD technologies).

Water Cover Technology

(as indicated in this report, the water cover technology may be very cost effective for some sites)

cl Carry out research with regard to predicting the lengths of the transition periods during which a collect and treat operation is required, including predictions with regard to the seepage quality (variable with time after flooding). A similar research requirement applies to the composite soil and other “dry” cover technologies.

☐ Address the question of a sand layer (mixed with lime?) placed in conjunction with a water cover developed over tailings that generate net acidity at the time of flooding, depending on the expected hydraulic gradients (ie., a follow up to the past investigations by Noranda Technology Centre and other research groups is required).

☐ Carry out research with regard to a ***minimum*** (short duration) and ***normal*** water cover depths.

El Address the problem of the dissolution of AMD products (at neutral or moderately acidic pHs) precipitated within the tailings mass prior to flooding. A similar problem applies to either tailings or waste rock to be moved to an open pit (waste removal technology).

Composite Soil Cover Technology

cl Develop a simple, reliable technique, preferably analytical with an experimental support, to model the rate of infiltration and oxygen fluxes into a composite soil cover.

☐ Develop criteria for allowable deformation (and other allowable abuse) of various soil covers.

Other Covers

cl Carry out research with regard to other "dry" covers (such as bituminous or shotcrete covers, etc.), including field trials after the feasibility of a cover is confirmed in terms of the associated performance risks and implementation costs.

☐ Develop practical methods and obtain cost estimates for developing a vegetation cover, with an organic layer of sufficient thickness, over a tailings deposit located in Canada. Include evaluation of the time required to develop such a cover to the state that it would be fully functional without the need for further maintenance.

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APPENDIX A

COST ESTIMATE SPREADSHEETS FOR SELECTED SCENARIOS

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) T12374/007150

TABLE A.1a. COST ESTIMATE FOR SCENARIO 1 (1994 Dollars)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	WALK-AWAY OPTIONS: 1: Self Sust. Water Cover UNIT PRICE	AMOUNT	2: Comp.Soil Cover (CSC) UNIT PRICE	AMOUNT	3:CSC with Part.Water Cov. UNIT PRICE	AMOUNT	COLLECT AND TREAT OPTIONS: 4: Collect & Treat (C&T) UNIT PRICE	AMOUNT	5: C&T with Part.Water Cov UNIT PRICE	AMOUNT	6: Simple Soil Cover UNIT PRICE	AMOUNT
	A.	TAILINGS SITE														
	A.1	TAILINGS PILE														
	A.1.1	Regrade tailings dam slopes	200,000	m3	--	--	$4.0	$800,000	$4.0	$800,000	$3.0	$600,000	$3.0	$600,000	$4.0	$800,000
	A.1.2	Regrade surface of tailings area														
		- Walk-a-way options	varies	m3	$2.0	$300,000	$2.0	$860,000	$2.0	$600,000	--	--	--	--	--	--
		- Collet & treat options	varies	m3	--	--	--	--	--	--	$2.0	$50,000	$2.0	$400,000	$2.0	$860,000
C	A.1.3	Provide toe drain	40,000	m3	--	--	--	--	--	--	$12.0	$480,000	$12.0	$480,000	--	--
A	A.1.4	Provide toe berm	11,000	m3	--	--	$12.0	$132,000	$12.0	$132,000	--	--	--	--	$12.0	$132,000
P	A.1.5	Provide spillway(s)	L.S.	--	--	$100,000	--	$70,000	--	$150,000	--	$70,000	--	$150,000	--	$70,000
I	A.1.6	Construct dams/dykes														
T		A.1.6.1 Site/Foundation prep.	155,000	m2	$6.0	$930,000	--	--	L.S.	$200,000	--	--	L.S.	$200,000	--	--
A		A.1.6.2 Foundation treatment	15,000	m2	$50.0	$750,000	--	--	--	--	--	--	--	--	--	--
L		A.1.6.3 Bedrock grouting	2,000	m	$1,000	$2,000,000	--	--	--	--	--	--	--	--	--	--
		A.1.6.4 Fills - perimeter dams	1,950,000	m3	$12.0	$23,400,000	--	--	--	--	--	--	--	--	--	--
		Fills - Internal dykes	120,000	m3	--	--	--	--	$13.0	$1,560,000	--	--	$13.0	$1,560,000	--	--
	A.1.7	Cover tailings surface														
		A.1.7.1 Flat area - water cover (sa	1,280,000	m2	$6.0	$7,680,000	--	--	--	--	--	--	--	--	--	--
C		Flat areas - soil cover	1,280,000	m2	--	--	$26.0	$33,280,000	--	--	--	--	--	--	$12.0	$15,360,000
O		Flat areas - partial flooding cas	576,000	m2	--	--	--	--	$30.0	$17,280,000	--	--	$2.0	$1,152,000	--	--
S		- partial flooding case (sand	640,000	m2	--	--	--	--	$6.0	$3,840,000	--	--	$6.0	$3,840,000	--	--
T		Flat areas - vegetation cover	1,280,000	m2	--	--	--	--	--	--	$2.0	$2,560,000	--	--	--	--
		A.1.7.2 Slopes	210,000	m2	--	--	$33.0	$6,930,000	$33.0	$6,930,000	$2.5	$525,000	$2.5	$525,000	$15.0	$3,150,000
		A.1.7.3 Hydro-seeding - simple so	1,490,000	m2	--	--	--	--	--	--	--	--	--	--	$0.5	$745,000
	A.1.8	Provide clean runoff channel	varies	m	--	--	$40.0	$56,000	$40.0	$36,000	--	--	--	--	$40.0	$56,000
	A.2	SEEPAGE COLLECTION FACILITIES														
	A.2.1	Provide collection ditches (in rock	2,000	m3	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000
	A.2.2	Provide grout curtain along ditche	600	m	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000
	A.2.3	Provide/Upgrade collection ponds														
		A.2.3.1 Prepare site	5,000	m2	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000
		A.2.3.2 Bedrock grouting	150	m	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000
		A.2.3.3 Construct dykes	10,000	m3	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000
	A.2.4	Provide pumps/pumphouses/pipel	L.S.	--	--	$500,000	--	$300,000	--	$400,000	--	$500,000	--	$500,000	--	$400,000
	B.	WATER TREATMENT & SLUDGE DISPOSAL														
	B.1	Provide WWTP & sludge disposa	L.S.	--	--	$1,500,000	--	$500,000	--	$500,000	--	$3,500,000	--	$3,500,000	--	$1,000,000
Total Capital Cost						$38,145,000		$43,913,000		$33,413,000		$9,270,000		$13,892,000		$23,558,000
C. MAINTENANCE, INSPECTION, ENGINEERING (15%)						$5,722,000		$6,587,000		$5,012,000		$1,391,000		$2,084,000		$3,534,000
	D.	TREATMENT, REPAIR & MAINTENANCE														
	D.1	Labours & WTP maintenance	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000
	D.2	Water treatment - first transitio	varies	m3	--	1,500,000	--	--	--	868,800	--	--	--	1,151,000	--	--
		- first transition cost	varies	--	$0.40	$600,000	$0.40	--	$0.40	$347,520		--	$0.40	$460,400		--
Annua		- second transition (20 years)	varies	m3	--	802,800	--	403,300	--	629,400	--	--	--	911,400	--	--
		- second transition cost	varies	--	$0.40	$321,120	$0.40	$161,320	$0.40	$251,760		--	$0.40	$364,560		--
Oper'g		- long term	varies	m3	--	0	--	0	--	0	--	1,243,000	--	724,400	--	440,500
		- long term cost	varies	--	$0.40	$0	$0.40	$0	$0.40	$0	$0.40	$497,200	$0.40	$289,760	$0.40	$176,200
Cost	E.	SLUDGE DISPOSAL														
	E.1	Prepare site	L.S.	--	--	$3,000	--	$2,000	--	$3,000	--	$4,000	--	$4,000	--	$2,000
	E.2	Construct retention dykes - t	L.S.	--	--	$8,000	--	$5,000	--	$8,000	--	--	--	$10,000	--	--
		- long term	L.S.	--	--	$0	--	$0	--	$0	--	$10,000	--	$10,000	--	$5,000
	Sum of operation cost/annum - first transition period					$771,000		$167,000		$518,520		--		$634,400		--
	Net present value - first period					$1,465,000		$317,000		$985,000		--		$1,205,000		--
	Sum of operation cost/annum - second transition period					$492,120		$328,320		$422,760		--		$538,560		--
	Net present value - second period					$6,994,000		$4,666,000		$6,008,000		--		$7,654,000		--
	Sum of operation cost/annum - long trem					$0		$0		$0		$671,200		$463,760		$343,200
	Net present value - long term					$0		$0		$0		$19,177,000		$6,659,000		$9,806,000
	Total net present value for treatment operation					$8,459,000		$4,983,000		$6,993,000		$19,177,000		$15,518,000		$9,806,000
TOTAL COST FOR TAILINGS SITE CLOSURE						**$52,326,000**		**$55,483,000**		**$45,418,000**		**$29,838,000**		**$31,494,000**		**$36,898,000**
Cost per Area of Tailings Footprint			150	ha		$349,000		$370,000		$303,000		$199,000		$210,000		$246,000

Disk(MEND): SCENAR-1.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) T12374/007150

TABLE A.1b. COST ESTIMATE FOR SCENARIO 1 INCLUDING INCIDENTAL COSTS (1994 Dollars)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	WALK-AWAY OPTIONS						COLLECT AND TREAT OPTIONS					
					1: Self Sust. Water Cover		2: Comp.Soil Cover (CSC)		3:CSC with Part.Water Cov.		4: Collect & Treat (C&T)		5: C&T with Part.Water Cov.		6: Simple Soil Cover	
					UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT
	A.	TAILINGS SITE														
	A.1	TAILINGS PILE														
	A.1.1	Regrade tailings dam slopes	200,000	m3	--	--	$4.0	$800,000	$4.0	$800,000	$3.0	$600,000	$3.0	$600,000	$4.0	$800,000
	A.1.2	Regrade surface of tailings area														
		- Walk-a-way options	varies	m3	$2.0	$300,000	$2.0	$860,000	$2.0	$600,000	--	--	--	--	--	--
		- Collet & treat options	varies	m3	--	--	--	--	--	--	$2.0	$50,000	$2.0	$400,000	$2.0	$860,000
C	A.1.3	Provide toe drain	40,000	m3	--	--	--	--	--	--	$12.0	$480,000	$12.0	$480,000	--	--
A	A.1.4	Provide toe berm	11,000	m3	--	--	$12.0	$132,000	$12.0	$132,000	--	--	--	--	$12.0	$132,000
P	A.1.5	Provide spillway(s)	L.S.	--	--	$100,000	--	$70,000	--	$150,000	--	$70,000	--	$150,000	--	$70,000
I	A.1.6	Construct dams/dykes														
T		A.1.6.1 Site/Foundation prep.	155,000	m2	$6.0	$930,000	--	--	L.S.	$200,000	--	--	L.S.	$200,000	--	--
A		A.1.6.2 Foundation treatment	15,000	m2	$50.0	$750,000	--	--	--	--	--	--	--	--	--	--
L		A.1.6.3 Bedrock grouting	2,000	m	$1,000	$2,000,000	--	--	--	--	--	--	--	--	--	--
		A.1.6.4 Fills - perimeter dams	1,950,000	m3	$12.0	$23,400,000	--	--	--	--	--	--	--	--	--	--
		Fills - Internal dykes	120,000	m3	--	--	--	--	$13.0	$1,560,000	--	--	$13.0	$1,560,000	--	--
	A.1.7	Cover tailings surface														
		A.1.7.1 Flat area - water cover (s	1,280,000	m2	$6.0	$7,680,000	--	--	--	--	--	--	--	--	--	--
C		Flat areas - soil cover	1,280,000	m2	--	--	$26.0	$33,280,000	--	--	--	--	--	--	$12.0	$15,360,000
O		Flat areas - partial flooding cas	576,000	m2	--	--	--	--	$30.0	$17,280,000	--	--	$2.0	$1,152,000	--	--
S		- partial flooding case (sand	640,000	m2	--	--	--	--	$6.0	$3,840,000	--	--	$6.0	$3,840,000	--	--
T		Flat areas - vegetation cover	1,280,000	m2	--	--	--	--	--	--	$2.0	$2,560,000	--	--	--	--
		A.1.7.2 Slopes	210,000	m2	--	--	$33.0	$6,930,000	$33.0	$6,930,000	$2.5	$525,000	$2.5	$525,000	$15.0	$3,150,000
		A.1.7.3 Hydro-seeding - simple s	1,490,000	m2	--	--	--	--	--	--	--	--	--	--	$0.5	$745,000
	A.1.8	Provide clean runoff channel	varies	m	--	--	$40.0	$56,000	$40.0	$36,000	--	--	--	--	$40.0	$56,000
	A.2	SEEPAGE COLLECTION FACILITIES														
	A.2.1	Provide collection ditches (in rock	2,000	m3	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000	$50.0	$100,000
	A.2.2	Provide grout curtain along ditche	600	m	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000	$1,000	$600,000
	A.2.3	Provide/Upgrade collection ponds														
		A.2.3.1 Prepare site	5,000	m2	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000	$7.0	$35,000
		A.2.3.2 Bedrock grouting	150	m	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000
		A.2.3.3 Construct dykes	10,000	m3	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000	$10.0	$100,000
	A.2.4	Provide pumps/pumphouses/pipe	L.S.	--	--	$500,000	--	$300,000	--	$400,000	--	$500,000	--	$500,000	--	$400,000
	B.	WATER TREATMENT & SLUDGE DISPOSAL														
	B.1	Provide WWTP & sludge disposa	L.S.	--	--	$1,500,000	--	$500,000	--	$500,000	--	$3,500,000	--	$3,500,000	--	$1,000,000
Total Capital Cost						$38,145,000		$43,913,000		$33,413,000		$9,270,000		$13,892,000		$23,558,000
C. MAINTENANCE, INSPECTION, ENGINEERING (15%)						$5,722,000		$6,587,000		$5,012,000		$1,391,000		$2,084,000		$3,534,000
	D.	TREATMENT, REPAIR & MAINTENANCE														
	D.1	Labours & WTP maintenance	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000
	D.2	Water treatment - first transitio	varies	m3	--	1,500,000	--	--	--	868,800	--	--	--	1,151,000	--	--
		- first transition cost	varies	--	$0.40	$600,000	$0.40	--	$0.40	$347,520		--	$0.40	$460,400		--
Annua		- second transition (20 years)	varies	m3	--	802,800	--	403,300	--	629,400	--	--	--	911,400	--	--
		- second transition cost	varies	--	$0.40	$321,120	$0.40	$161,320	$0.40	$251,760		--	$0.40	$364,560		--
Oper'g		- long term	varies	m3	--	0	--	0	--	0	--	1,243,000	--	724,400	--	440,500
		- long term cost	varies	--	$0.40	$0	$0.40	$0	$0.40	$0	$0.40	$497,200	$0.40	$289,760	$0.40	$176,200
Cost	E.	SLUDGE DISPOSAL														
	E.1	Prepare site	L.S.	--	--	$3,000	--	$2,000	--	$3,000	--	$4,000	--	$4,000	--	$2,000
	E.2	Construct retention dyke - tr	L.S.	--	--	$8,000	--	$5,000	--	$8,000	--	--	--	$10,000	--	--
		- long term	L.S.	--	--	$0	--	$0	--	$0	--	$10,000	--	$10,000	--	$5,000
	Sum of operation cost/annum - first transition period					$771,000		$167,000		$518,520		--		$634,400		--
	Net present value - first period					$1,465,000		$317,000		$985,000		--		$1,205,000		--
	Sum of operation cost/annum - second transition period					$492,120		$328,320		$422,760		--		$538,560		--
	Net present value - second period					$6,994,000		$4,666,000		$6,008,000		--		$7,654,000		--
	Sum of operation cost/annum - long trem					$0		$0		$0		$671,200		$463,760		$343,200
	Net present value - long term					$0		$0		$0		$19,177,000		$6,659,000		$9,806,000
	Total net present value for treatment operation					$8,459,000		$4,983,000		$6,993,000		$19,177,000		$15,518,000		$9,806,000
TOTAL INCIDENTAL COSTS						$0		$0		$0		$2,190,000		$2,190,000		$2,190,000
TOTAL COST FOR TAILINGS SITE CLOSURE						**$52,326,000**		**$55,483,000**		**$45,418,000**		**$32,028,000**		**$33,684,000**		**$39,088,000**
Cost per Area of Tailings Footprint (with incide			150	ha		$349,000		$370,000		$303,000		$214,000		$225,000		$261,000

Disk(MEND): SCENAR-1.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994)

T12374/007150

TABLE A.2. COST ESTIMATE FOR SCENARIO 2 (1994 Dollars)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	OXYGEN BARRIER OPTIONS: 1: Self sustained water cover UNIT PRICE	AMOUNT	2: Maintained water cover UNIT PRICE	AMOUNT	3: Plastic liner cover UNIT PRICE	AMOUNT	4: Composite soil cover UNIT PRICE	AMOUNT	COLLECT AND TREAT OPTIONS: 5: Vegetation cover UNIT PRICE	AMOUNT	6: Collect and treat UNIT PRICE	AMOUNT
	A.	TAILINGS SITE														
	A.1	TAILINGS BASIN														
	A.1.1	Cover tailings surfaces (including bedding)	800,000	m2	--		--	--	$23.0	$18,400,000	$30.0	$24,000,000	--	--	--	--
Capit.	A.1.2	Provide tailings cover (vegetation)	800,000	m2	--	--	--	--	--	--	--	--	$4.0	$3,200,000	--	--
	A.1.3	Provide sand layer over plastic liner	800,000	m2	--		--	--	$6.0	$4,800,000	--	--	--	--	--	--
	A.2	WATER SUPPLY														
Cost	A.2.1	Construct diversion dyke	57,000	m3	$8.0	$456,000	--	--	--	--	--	--	--	--	--	--
	A.2.2	Provide pumphouse & pipelines	L.S.	--	--	--	--	$300,000	--	--	--	--	--	--	--	--
	A.3	Provide runoff control strutures	L.S.	--	--	$100,000	--	$50,000	--	$50,000	--	$50,000	--	$50,000	--	$50,000
	B.	WATER TREATMENT & SLUDGE DISPOSAL														
	B.1	Upgrade/Provide WWTP	L.S.	--	--	$500,000	--	$500,000	--	$500,000	--	$500,000	--	$4,000,000	--	$5,000,000
Total Capital Cost						$1,056,000		$850,000		$23,750,000		$24,550,000		$7,250,000		$5,050,000
C. MAINTENANCE, INSPECTION, ENGINEERING (15%)						$158,000		$128,000		$3,563,000		$3,683,000		$1,088,000		$758,000
	D.	TREATMENT, REPAIR & MAINTENANCE														
	D.1	Labours & WTP maintenance	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000
	D.2	Seepage water treatment	Tra. period	years		30		30		30		30		30		30
		- transition quantities	varies	m3	$0.60	270,000	$0.60	270,000	$0.60	112,000	$0.60	112,000	$0.60	142,000	$0.60	142,000
		- cost	varies	--	--	$162,000	--	$162,000	--	$67,200	--	$67,200	--	$85,000	--	$85,000
		- long term quantities	varies	m3	$0.40	0	$0.40	0	$0.40	0	$0.40	0	$0.40	113,000	$0.40	113,000
		- cost	varies	--		$0		$0		$0		$0		$45,000		$45,000
Annual	D.3	Overland runoff treatment		yr		2		2								long term
		- runoff quantities		m3	$0.60	443,000	$0.60	221,500	$0.60	0	$0.60	0	$0.40	0	$0.40	234,000
		- cost		--	--	$266,000	--	$132,900	--	$0	--	$0	--	$0	--	$94,000
Oper'g	E.	PUMPING COST														
	E.1	- long term (< 200 yr)	72,000	m3	--	--	$0.15	$11,000	--	--	--	--	--	--	--	--
	E.2	- long term (> 200 yr)	326,000	m3	--	--	$0.15	$49,000	--	--	--	--	--	--	--	--
Cost	F.	SLUDGE DISPOSAL														
	F.1	Construct sludge cells - transition	L.S.	--	--	$29,000		$25,000	--	$8,000	--	$8,000	--	$38,000	--	$38,000
		- long term	L.S.	--	--	$0		$0	--	$0	--	$0	--	$11,000	--	$35,000
	G.	PLASTIC LINER REPLACEMENT														
		Net present value (200 yrs)	L.S.	--	--	--	--	--	--	$22,000	--	--	---	--	--	--
	Sum of operation cost/annum - transition period					$617,000		$479,900		$235,200		$235,200		$283,000		$377,000
	Net present value - transition period					$7,008,000		$6,671,000		$4,949,000		$4,949,000		$7,260,000		$11,641,000
	Sum of operation cost/annum - long trem					$0		$129,000		$0		$0		$216,000		$334,000
	Net present value - long term					$0		$1,458,000		$22,000		$0		$436,000		$734,000
	Total net present value for treatment operation					$7,008,000		$8,129,000		$4,971,000		$4,949,000		$7,696,000		$12,375,000
TOTAL COST FOR TAILINGS SITE CLOSURE						$8,222,000		$9,107,000		$32,284,000		$33,182,000		$16,034,000		$18,183,000
Cost per Area of Tailings Footprint			80	ha		$103,000		$114,000		$404,000		$415,000		$200,000		$227,000

Disk(MEND): SCENAR-2.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994)

T12374/007150

95-01-19

TABLE A.3a. COST ESTIMATE FOR SCENARIO 3 (1994 Dollars)

COST TYPE	ITEM No.	WORK ITEM DESCRIPTI	QUANTITY	UNIT	COLLECT AND TREAT OPTIONS (INFILTRATION REDUCTION SOIL COVER) Case 1: Collect & Treat UNIT PRICE	AMOUNT	Case 2: Cover Dump 1 UNIT PRICE	AMOUNT	Case 3: Cover Dumps 1 & 2 UNIT PRICE	AMOUNT	Case 4: Cover Dumps 1 to 3 UNIT PRICE	AMOUNT	Case 5: Cover Dumps 1 to 4 UNIT PRICE	AMOUNT	WALK-AWAY OPTION Composite Soil Cover UNIT PRICE	AMOUNT
CAPITAL COST	A.	WASTE ROCK DUMPS														
	A.1	CONST. SCFs (incl. ditch/pond/dyke, pumps/stations &														
	A.1.1	Dump 1 (upgrade)	L.S.	--	--	$100,000	--	$50,000	--	$50,000	--	$50,000	--	$50,000	--	$0
	A.1.2	Dump 2 (new)	L.S.	--	--	$300,000	--	$300,000	--	$200,000	--	$200,000	--	$200,000	--	$150,000
	A.1.3	Dump 3 (upgrade & new	L.S.	--	--	$250,000	--	$250,000	--	$250,000	--	$150,000	--	$150,000	--	$100,000
	A.1.4	Dump 4 (upgrade)	L.S.	--	--	$300,000	--	$300,000	--	$300,000	--	$300,000	--	$200,000	--	$150,000
	A.2	REGRADING/CONTOURING														
	A.2.1	Dump 1 - Slopes	50,000	m3	--	--	$1.0	$50,000	$1.0	$50,000	$1.0	$50,000	$1.0	$50,000	$1.0	$50,000
		- Flat surfaces	150,000	m3	--	--	$0.50	$75,000	$0.50	$75,000	$0.50	$75,000	$0.50	$75,000	$0.50	$75,000
	A.2.2	Dump 2 - Slopes	100,000	m3	--	--	--	--	$1.0	$100,000	$1.0	$100,000	$1.0	$100,000	$1.0	$100,000
		- Flat surfaces	130,000	m3	--	--	--	--	$0.50	$65,000	$0.50	$65,000	$0.50	$65,000	$0.50	$65,000
	A.2.3	Dump 3 - Slopes	90,000	m3	--	--	--	--	--	--	$1.0	$90,000	$1.0	$90,000	$1.0	$90,000
		- Flat surfaces	300,000	m3	--	--	--	--	--	--	$0.50	$150,000	$0.50	$150,000	$0.50	$150,000
	A.2.4	Dump 4 - Slopes	40,000	m3	--	--	--	--	--	--	--	--	$1.0	$40,000	$1.0	$40,000
		- Flat surfaces	200,000	m3	--	--	--	--	--	--	--	--	$0.50	$100,000	$0.50	$100,000
	A.3	SOIL COVER (no bedding)														
	A.3.1	Dump 1 - Slopes	110,000	m2	--	--	$5.0	$550,000	$5.0	$550,000	$5.0	$550,000	$5.0	$550,000	$35.0	$3,850,000
		- Flat surfaces	160,000	m2	--	--	$4.5	$720,000	$4.5	$720,000	$4.5	$720,000	$4.5	$720,000	$30.0	$4,800,000
	A.3.2	Dump 2 - Slopes	110,000	m2	--	--	--	--	$5.0	$550,000	$5.0	$550,000	$5.0	$550,000	$35.0	$3,850,000
		- Flat surfaces	130,000	m2	--	--	--	--	$4.5	$585,000	$4.5	$585,000	$4.5	$585,000	$30.0	$3,900,000
	A.3.3	Dump 3 - Slopes	100,000	m2	--	--	--	--	--	--	$5.0	$500,000	$5.0	$500,000	$35.0	$3,500,000
		- Flat surfaces	310,000	m2	--	--	--	--	--	--	$4.5	$1,395,000	$4.5	$1,395,000	$30.0	$9,300,000
	A.3.4	Dump 4 - Slopes	60,000	m2	--	--	--	--	--	--	--	--	$5.0	$300,000	$35.0	$2,100,000
		- Flat surfaces	210,000	m2	--	--	--	--	--	--	--	--	$4.5	$945,000	$30.0	$6,300,000
	A.4	VEGETATE SOIL COVER (hydro-seeding)														
	A.4.1	Dump 1	27	ha	--	--	$4,000	$108,000	$4,000	$108,000	$4,000	$108,000	$4,000	$108,000	$4,000	$108,000
	A.4.2	Dump 2	24	ha	--	--	--	--	$4,000	$96,000	$4,000	$96,000	$4,000	$96,000	$4,000	$96,000
	A.4.3	Dump 3	41	ha	--	--	--	--	--	--	$4,000	$164,000	$4,000	$164,000	$4,000	$164,000
	A.4.4	Dump 4	27	ha	--	--	--	--	--	--	--	--	$4,000	$108,000	$4,000	$108,000
	A.5	COLLECTOR PIPELINES														
	A.5.1	Dump 1	200	m	--	--	$60.0	$12,000	$60.0	$12,000	$60.0	$12,000	$60.0	$12,000	$60.0	$12,000
	A.5.2	Dump 2	400	m	--	--	--	--	$60.0	$24,000	$60.0	$24,000	$60.0	$24,000	$60.0	$24,000
	A.5.3	Dump 3	600	m	--	--	--	--	--	--	$60.0	$36,000	$60.0	$36,000	$60.0	$36,000
	A.5.4	Dump 4	150	m	--	--	--	--	--	--	--	--	$60.0	$9,000	$60.0	$9,000
	A.6	DISCHARGE PIPES AND TRANSFER POND														
	A.6.1	Dump 1 (3 pipes)	L.S.	--	--	--	--	$6,000	-	$6,000	--	$6,000	--	$6,000	--	$6,000
	A.6.2	Dump 2 (6 pipes & 1 po	L.S.	--	--	--	--	--	-	$137,000	--	$137,000	--	$137,000	--	$137,000
	A.6.3	Dump 3 (5 pipes & 1 po	L.S.	--	--	--	--	--	-	--	--	$135,000	--	$135,000	--	$135,000
	A.6.4	Dump 4 (3 pipes)	L.S.	--	--	--	--	--	-	--	--	--	--	$6,000	--	$6,000
	B.	WATER TREATMENT & SLUDGE DISPOSAL														
	B.1	Present cost of WWTP	L.S.	--	--	$9,000,000	--	$9,000,000	--	$8,500,000	--	$8,000,000	--	$7,500,000	--	$3,000,000
		Deferred capital cost for WWTP - NPV				$552,000		$380,000		$254,400		$79,600		$24,000		$3,000,000
Total Capital Cost						$1,502,000		$2,801,000		$4,132,000		$6,328,000		$7,680,000		$42,511,000
C. MAINTENANCE, INSPECTION, ENGINEERING (15%)						$225,000		$420,000		$620,000		$949,000		$1,152,000		$6,377,000
Oper'g Cost (annual	D.	PUMPING OPERATION (current)														
	D.1	Labour & pump maintenan	L.S.	--	--	$80,000	--	$80,000	--	$80,000	--	$80,000	--	$80,000	--	--
	D.2	PUMPING (into pit) QUAN	varies	m3	--	197,000	--	165,500	--	123,100	--	75,700	--	40,600	--	--
	D.3	PUMPING COST		--	$0.15	$29,600	$0.15	$24,800	$0.15	$18,500	$0.15	$11,400	$0.15	$6,100	--	--
		Up-front cost for pumping operation				$3,131,000		$2,994,000		$2,814,000		$2,611,000		$2,460,000		--
	E.	TREATMENT, REPAIR & MAINTENANCE														
	E.1	Labours & WTP maintena	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000
	E.2	WATER TREATMENT	--	m3	$0.40	$162,244	$0.40	$143,200	$0.40	$124,000	$0.40	$98,000	$0.40	$79,200	$0.40	$69,600
	F.	SLUDGE DISPOSAL														
	F.1	Prepare site	L.S.	--	--	$6,000	--	$5,000	--	$4,500	--	$4,000	--	$3,000	--	$3,000
	F.2	Construct sludge cells	L.S.	--	--	$16,000	--	$14,000	--	$12,000	--	$10,000	--	$8,000	--	$8,000
		Deferred operating cost - NPV				$603,000		$389,000		$257,000		$77,000		$23,000		$2,001,000
TOTAL COST FOR WASTE DUMP SITE CLOSURE						$5,461,000		$6,604,000		$7,823,000		$9,965,000		$11,315,000		$50,889,000
Cost per Tonne of Waste Rock			47,600,000	ton.		$0.11		$0.14		$0.16		$0.21		$0.24		$1.07
FLOW INTO PIT (M m3) AND FILL-IN TIME (years)					M m3/yr	years	M m3/yr	years	M m3/yr	years	M m3/yr	years	M m3/yr	years	M m3/yr	Trans. period (yrs)
					0.406	81	0.358	92	0.310	102	0.245	134	0.198	167	0.174	10

Disk(MEND): SCENAR-3.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) T12374/007150

TABLE A.3b. COST ESTIMATE FOR SCENARIO 3 (1994 Dollars)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTI	QUANTITY	UNIT	COLLECT AND TREAT OPTIONS (INFILTRATION REDUCTION SOIL COVER) Case 1: Collect & Treat UNIT PRICE	AMOUNT	Case 2: Cover Dump 1 UNIT PRICE	AMOUNT	Case 3: Cover Dumps 1 & 2 UNIT PRICE	AMOUNT	Case 4: Cover Dumps 1 to 3 UNIT PRICE	AMOUNT	Case 5: Cover Dumps 1 to 4 UNIT PRICE	AMOUNT	WALK-AWAY OPTION Composite Soil Cover UNIT PRICE	AMOUNT
CAPITAL COST	A.	WASTE ROCK DUMPS														
	A.1	CONST. SCFs (incl. ditch/pond/dyke, pumps/stations &														
	A.1.1	Dump 1 (upgrade)	L.S.	--	--	$100,000	--	$50,000	--	$50,000	--	$50,000	--	$50,000	--	$0
	A.1.2	Dump 2 (new)	L.S.	--	--	$300,000	--	$300,000	--	$200,000	--	$200,000	--	$200,000	--	$150,000
	A.1.3	Dump 3 (upgrade & new	L.S.	--	--	$250,000	--	$250,000	--	$250,000	--	$150,000	--	$150,000	--	$100,000
	A.1.4	Dump 4 (upgrade)	L.S.	--	--	$300,000	--	$300,000	--	$300,000	--	$300,000	--	$200,000	--	$150,000
	A.2	REGRADING/CONTOURING														
	A.2.1	Dump 1 - Slopes	50,000	m3	--	--	$1.0	$50,000	$1.0	$50,000	$1.0	$50,000	$1.0	$50,000	$1.0	$50,000
		- Flat surfaces	150,000	m3	--	--	$0.50	$75,000	$0.50	$75,000	$0.50	$75,000	$0.50	$75,000	$0.50	$75,000
	A.2.2	Dump 2 - Slopes	100,000	m3	--	--	--	--	$1.0	$100,000	$1.0	$100,000	$1.0	$100,000	$1.0	$100,000
		- Flat surfaces	130,000	m3	--	--	--	--	$0.50	$65,000	$0.50	$65,000	$0.50	$65,000	$0.50	$65,000
	A.2.3	Dump 3 - Slopes	90,000	m3	--	--	--	--	--	--	$1.0	$90,000	$1.0	$90,000	$1.0	$90,000
		- Flat surfaces	300,000	m3	--	--	--	--	--	--	$0.50	$150,000	$0.50	$150,000	$0.50	$150,000
	A.2.4	Dump 4 - Slopes	40,000	m3	--	--	--	--	--	--	--	--	$1.0	$40,000	$1.0	$40,000
		- Flat surfaces	200,000	m3	--	--	--	--	--	--	--	--	$0.50	$100,000	$0.50	$100,000
	A.3	SOIL COVER (no bedding)														
	A.3.1	Dump 1 - Slopes	110,000	m2	--	--	$5.0	$550,000	$5.0	$550,000	$5.0	$550,000	$5.0	$550,000	$35.0	$3,850,000
		- Flat surfaces	160,000	m2	--	--	$4.5	$720,000	$4.5	$720,000	$4.5	$720,000	$4.5	$720,000	$30.0	$4,800,000
	A.3.2	Dump 2 - Slopes	110,000	m2	--	--	--	--	$5.0	$550,000	$5.0	$550,000	$5.0	$550,000	$35.0	$3,850,000
		- Flat surfaces	130,000	m2	--	--	--	--	$4.5	$585,000	$4.5	$585,000	$4.5	$585,000	$30.0	$3,900,000
	A.3.3	Dump 3 - Slopes	100,000	m2	--	--	--	--	--	--	$5.0	$500,000	$5.0	$500,000	$35.0	$3,500,000
		- Flat surfaces	310,000	m2	--	--	--	--	--	--	$4.5	$1,395,000	$4.5	$1,395,000	$30.0	$9,300,000
	A.3.4	Dump 4 - Slopes	60,000	m2	--	--	--	--	--	--	--	--	$5.0	$300,000	$35.0	$2,100,000
		- Flat surfaces	210,000	m2	--	--	--	--	--	--	--	--	$4.5	$945,000	$30.0	$6,300,000
	A.4	VEGETATE SOIL COVER (hydro-seeding)														
	A.4.1	Dump 1	27	ha	--	--	$4,000	$108,000	$4,000	$108,000	$4,000	$108,000	$4,000	$108,000	$4,000	$108,000
	A.4.2	Dump 2	24	ha	--	--	--	--	$4,000	$96,000	$4,000	$96,000	$4,000	$96,000	$4,000	$96,000
	A.4.3	Dump 3	41	ha	--	--	--	--	--	--	$4,000	$164,000	$4,000	$164,000	$4,000	$164,000
	A.4.4	Dump 4	27	ha	--	--	--	--	--	--	--	--	$4,000	$108,000	$4,000	$108,000
	A.5	COLLECTOR PIPELINES														
	A.5.1	Dump 1	200	m	--	--	$60.0	$12,000	$60.0	$12,000	$60.0	$12,000	$60.0	$12,000	$60.0	$12,000
	A.5.2	Dump 2	400	m	--	--	--	--	$60.0	$24,000	$60.0	$24,000	$60.0	$24,000	$60.0	$24,000
	A.5.3	Dump 3	600	m	--	--	--	--	--	--	$60.0	$36,000	$60.0	$36,000	$60.0	$36,000
	A.5.4	Dump 4	150	m	--	--	--	--	--	--	--	--	$60.0	$9,000	$60.0	$9,000
	A.6	DISCHARGE PIPES AND TRANSFER POND														
	A.6.1	Dump 1 (3 pipes)	L.S.	--	--	--	--	$6,000	-	$6,000	--	$6,000	--	$6,000	--	$6,000
	A.6.2	Dump 2 (6 pipes & 1 po	L.S.	--	--	--	--	--	-	$137,000	--	$137,000	--	$137,000	--	$137,000
	A.6.3	Dump 3 (5 pipes & 1 po	L.S.	--	--	--	--	--	-	--	--	$135,000	--	$135,000	--	$135,000
	A.6.4	Dump 4 (3 pipes)	L.S.	--	--	--	--	--	-	--	--	--	--	$6,000	--	$6,000
	B.	WATER TREATMENT & SLUDGE DISPOSAL														
	B.1	Present cost of WWTP	L.S.	--	--	$9,000,000	--	$9,000,000	--	$8,500,000	--	$8,000,000	--	$7,500,000	--	$3,000,000
		Deferred capital cost for WWTP - NPV				$2,794,300		$2,699,800		$2,299,800		$1,952,300		$1,708,500		$3,000,000
Total Capital Cost						$3,744,000		$5,121,000		$6,178,000		$8,200,000		$9,365,000		$42,511,000
C. MAINTENANCE, INSPECTION, ENGINEERING (15%)						$562,000		$768,000		$927,000		$1,230,000		$1,405,000		$6,377,000
Oper'g Cost (annual	D.	PUMPING OPERATION (current)														
	D.1	Labour & pump maintenan	L.S.	--	--	$80,000	--	$80,000	--	$80,000	--	$80,000	--	$80,000	--	--
	D.2	PUMPING (into pit) QUAN	varies	m3	--	197,000	--	165,500	--	123,100	--	75,700	--	40,600	--	--
	D.3	PUMPING COST		--	$0.15	$29,600	$0.15	$24,800	$0.15	$18,500	$0.15	$11,400	$0.15	$6,100	--	--
		Up-front cost for pumping operation				$3,131,000		$2,994,000		$2,814,000		$2,611,000		$2,460,000		--
	E.	TREATMENT, REPAIR & MAINTENANCE														
	E.1	Labours & WTP maintena	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000	--	$160,000
	E.2	WATER TREATMENT	--	m3	$0.40	$387,200	$0.40	$368,000	$0.40	$351,200	$0.40	$322,800	$0.40	$304,000	$0.40	$69,600
	F.	SLUDGE DISPOSAL														
	F.1	Prepare site	L.S.	--	--	$6,000	--	$5,000	--	$4,500	--	$4,000	--	$3,000	--	$3,000
	F.2	Construct sludge cells	L.S.	--	--	$16,000	--	$14,000	--	$12,000	--	$10,000	--	$8,000	--	$8,000
		Deferred operating cost - NPV				$5,049,000		$4,688,000		$4,079,000		$3,464,000		$3,092,000		$2,001,000
TOTAL COST FOR WASTE DUMP SITE CLOSURE						$12,486,000		$13,571,000		$13,998,000		$15,505,000		$16,322,000		$50,889,000
Cost per Tonne of Waste Rock			47,600,000	ton.		$0.26		$0.29		$0.29		$0.33		$0.34		$1.07

FLOW INTO PIT (M m3) AND FILL-IN TIME (years)	M m3/yr	years	M m3/yr	years	M m3/yr	years	M m3/yr	years	M m3/yr	years	M m3/yr	Trans. period (yrs)
- With incidental costs	0.968	34	0.920	35	0.878	38	0.807	41	0.760	43	0.174	10

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TABLE A.4. COST ESTIMATE FOR SCENARIOS 4/6 (1994 Dollars)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	COLLECT AND TREAT OPTIONS 1: Collect & Treat UNIT PRICE	AMOUNT	2: Simple soil cover UNIT PRICE	AMOUNT	WALK-AWAY OPTIO 3: Composite soil cover UNIT PRICE	AMOUNT	SCENARIO 6 4: Plastic liner cover UNIT PRICE	AMOUNT	
	A.	TAILINGS SITE											
	A.1	TAILINGS PILE											
	A.1.1	Preparation of tailings basin											
		A.1.1.1 Regrading/contouring tailings	300,000	m3	--	--	$2.5	$750,000	$2.5	$750,000	--	--	
		A.1.1.2 Upgrading dams	40,000	m3	$12.0	$480,000	--	--	--	--	--	--	
		A.1.1.3 Regrading dams	60,000	m3	--	--	$2.5	$150,000	$2.5	$150,000	$2.5	$150,000	
		A.1.1.4 Vegetation cover	1,000,000	m2	$3.0	$3,000,000	--	--	--	--	--	--	
	A.1.2	Provide soil cover											
C		A.1.2.1 Drainage berm	3,000	m	--	--	$30.0	$90,000	$30.0	$90,000	--	--	
A		A.1.2.2 Soil cover - simple soil c	1,000,000	m2	--	--	$12.0	$12,000,000	--	--	--	--	
P		- composite soil cover	1,000,000	m2	--	--	--	--	$18.0	$18,000,000	--	--	
I		A.1.2.3 Hydro-seeding	1,000,000	m2	--	--	$0.5	$500,000	$0.5	$500,000	$0.5	$500,000	
T	A.1.3	Provide plastic liner cover											
A		A.1.3.1 Base fill (tailings pond)	200,000	m3	--	--	--	--	--	--	$10.0	$2,000,000	
L		A.1.3.2 Install liner	1,000,000	m2	--	--	--	--	--	--	$16.0	$16,000,000	
		A.1.3.3 Provide liner cover up	1,000,000	m2	--	--	--	--	--	--	$7.0	$7,000,000	
	A.1.4	Provide drainage control measures	L.S.	--	--	$150,000	--	$50,000	--	$50,000	--	$50,000	
	A.2	SEEPAGE COLLECTION FACILITIES											
	A.2.1	Provide diversion ditches	varies	m	$50.0	$100,000	$50.0	$25,000	$50.0	$25,000	--	--	
	A.2.2	Provide collection pipe system	2,000	m	--	--	$150	$450,000	$150	$450,000	--	--	
	A.2.3	Provide grout curtain along ditches	450	m	$1,000	$450,000	$1,000	$450,000	$1,000	$450,000	--	--	
	A.2.4	Provide transfer ponds (2)	L.S.	m				$300,000		$300,000	--	--	
C	A.2.5	Provide seepage collection ponds											
O		A.2.3.1 Prepare sites	varies	m2	$6.0	$60,000	$6.0	$48,000	$6.0	$48,000	--	--	
S		A.2.3.2 Bedrock grouting	varies	m	$1,000	$150,000	$1,000	$100,000	$1,000	$100,000	--	--	
T		A.2.3.3 Construct dykes	varies	m3	$10.0	$80,000	$10.0	$60,000	$10.0	$60,000	--	--	
	A.2.6	Provide pumps/pumphouse/stations/pipeli	L.S.	--	--	$250,000	--	$200,000	--	$150,000	--	--	
	B.	WATER TREATMENT & SLUDGE DISPOSAL											
	B.1	Provide WWTP (new), incl. sludge pump	L.S.	--	--	$5,000,000	--	$3,000,000	--	$2,000,000	--	--	
Total Capital Cost						$9,720,000		$18,173,000		$23,123,000		$25,700,000	
C. MAINTENACE, INSPECTION, ENGINEEING (15%)						$1,458,000		$2,726,000		$3,468,000		$3,855,000	
	D.	TREATMENT, REPAIR & MAINTENANCE											
	D.1	Labours & WTP maintenance	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	--	
Annual	D.2	Water treatment - transition (20 y	varies	m3	--	--	--	--	--	25,000	--	--	
		- cost	varies	--	--	--	--	--	$0.40	$10,000	--	--	
Oper'g		- long term	varies	m3	--	650,000	--	70,000	--	0	--	--	
		- cost	varies	--	$0.40	$260,000	$0.40	$28,000	$0.40	$0	--	--	
Cost	E.	SLUDGE DISPOSAL											
	E.1	Prepare site	L.S.	--	--	$3,000	--	$1,500	--	$1,500	--	--	
	E.2	Construct sludge cells - trans	L.S.	--	--	--	--	--	--	$3,000	--	--	
		- long term	L.S.	--	--	$20,000	--	$3,000	--	$0	--	--	
	Sum of operation cost/annum - transition period					--		--		$174,500	--	--	
	Net present value - transition period					--		--		$2,480,000	--	--	
	Sum of operation cost/annum - long trem					$443,000		$192,500		$0	--	--	
	Net present value - long term					$12,657,000		$5,500,000		$0	--	--	
	Total net present value for treatment operation					$12,657,000		$5,500,000		$2,480,000			
F. LONGEVITY OF PLASTIC LINER (years)											50	100	200
G. DEFERRED COST FOR LINER REPLACEMENT											$5,016,000	$761,800	$23,660
TOTAL COST FOR TAILINGS SITE CLOSURE						$23,835,000		$26,399,000		$29,071,000	$34,571,000	$30,316,800	$29,578,660
Cost per Area of Tailings Footprint			100	ha		$238,000		$264,000		$291,000	$346,000	$303,000	$296,000

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Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) T12374/007150

TABLE A.5. COST ESTIMATE FOR SCENARIOS 5/7 (1994 Dollars)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	COLLECT AND TREAT OPTIONS: 1: Collect & Treat UNIT PRICE	AMOUNT	2: Simple soil cover UNIT PRICE	AMOUNT	WALK-AWAY OPTION: 3: Composite soil cover UNIT PRICE	AMOUNT	SCENARIO 7: 4: Plastic liner cover UNIT PRICE	AMOUNT	
	A.	WASTE DUMP SITE											
	A.1	WASTE DUMP											
	A.1.1	Site preparation											
C		A.1.1.1 Regrading/contouring dump surfa	150,000	m3	--	--	$2.0	$300,000	$2.0	$300,000	$2.0	$300,000	
A		A.1.1.2 Regrading dump slopes	varies	m3	$3.0	$120,000	$3.0	$360,000	$3.0	$360,000	$3.0	$360,000	
P	A.1.2	Provide soil/plastic liner cover											
I		A.1.2.1 Bedding	1,300,000	m2	--	--	--	--	--	--	$4.5	$5,850,000	
T		A.1.2.2 Soil cover - simple soil cov	1,300,000	m2	--	--	$7.0	$9,100,000	--	--	--	--	
A		- composite soil cover	1,300,000	m2	--	--	--	--	$18.0	$23,400,000	--	--	
L		A.1.2.3 Hydro-seeding	1,300,000	m2	--	--	$0.5	$650,000	$0.5	$650,000	$0.5	$650,000	
		A.1.2.4 Plastic liner cover - ins	1,300,000	m2	--	--	--	--	--	--	$14.0	$18,200,000	
		- liner cover	1,300,000	m2	--	--	--	--	--	--	$6.0	$7,800,000	
		A.1.2.5 Perimeter bedrock grouting	300	m	$1,200.0	$360,000	$900.0	$270,000	$900.0	$270,000			
	A.2	SEEPAGE COLLECTION FACILITY											
	A.2.1	Provide collection pipe system	900	m	--	--	$150.0	$135,000	$150.0	$135,000	--	--	
C	A.2.2	Provide seepage/runoff collection pond											
O		A.2.2.1 Prepare site	L.S.		--	$40,000	--	$40,000	--	$40,000	--	--	
S		A.2.2.2 Bedrock grouting	150	m	$1,000	$150,000	$1,000	$150,000	$1,000	$150,000	--	--	
T		A.2.2.3 Construct dyke	5,000	m3	$10.0	$50,000	$10.0	$50,000	$10.0	$50,000	--	--	
	A.2.3	Provide pumps/pumphouse/pipelines	L.S.	--	--	$200,000	--	$150,000	--	$100,000	--	--	
	A.3	PROVIDE CLEAN RUNOFF DIVERSION	varies	m	$40.0	$28,000	$40.0	$16,000	$40.0	$28,000	$40.0	$16,000	
	B.	WATER TREATMENT & SLUDGE DISPOSAL											
	B.1	Provide WWTP, incl. sludge pumping faci	L.S.	--	--	$3,000,000	--	$2,000,000	--	$1,500,000	--	--	
Total Capital Cost						$3,948,000		$13,221,000		$26,983,000		$33,176,000	
C. MAINTENANCE, INSPECTION, ENGINEERING (15%)						$592,000		$1,983,000		$4,047,000		$4,976,000	
	D.	TREATMENT, REPAIR & MAINTENANCE											
	D.1	Labours & WTP maintenance	L.S.	--	--	$160,000	--	$160,000	--	$160,000	--	--	
	D.2	Water treatment - transiti	varies	m3	--	--	--	--	--	60,000	--	--	
		- transition cost	varies	--	--	--	--	--	$0.40	$24,000	--	--	
Annual		- long term	varies	m3	--	500,000	--	60,000	--	0	--	--	
		- long term cost	varies	--	$0.40	$200,000	$0.40	$24,000	$0.40	$0	--	--	
Oper'g	E.	SLUDGE DISPOSAL											
Cost	E.1	Construct sludge cells	L.S.	--	--	--	--	--	--	$2,000	--	--	
		- long term	L.S.	--	--	$15,000	--	$2,000	--	$0	--	--	
	Sum of operation cost/annum - transition period					--		--		$186,000		--	
	Net present value - transition period					--		--		$521,000		--	
	Sum of operation cost/annum - long trem					$375,000		$186,000		$0		--	
	Net present value - long term					$10,714,000		$5,314,000		$0		--	
	Total net present value for treatment operation					$10,714,000		$5,314,000		$521,000			
F. LONGEVITY OF PLASTIC LINER (years)											50	100	200
G. DEFERRED COST FOR PLASTIC LINER REPLACEMENT											$5,670,000	$861,200	$26,750
TOTAL COST FOR WASTE DUMP SITE CLOSURE						$15,254,000		$20,518,000		$31,551,000	$43,822,000	$39,013,200	$38,178,750
Cost per Tonne of Waste Rock			24,000,000	ton.		$0.64		$0.85		$1.31	$1.83	$1.63	$1.59

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APPENDIX B

EXAMPLES OF DETAILED COST ESTIMATE SPREADSHEETS

EXAMPLE SPREADSHEETS

Five spreadsheets showing cost estimate examples for various AMD technologies are presented in this appendix. The following comments apply:

- The spreadsheets were developed to include only the major cost items which would be typically associated with applying an AMD technology. For instance, work items such as stabilizing a toe section of a tailings dam, plugging a decant structure or providing a security berm, which are strongly site/project specific, have not been included in the example spreadsheets.

- The material quantities and unit prices given in the example spreadsheets are shown for illustration purposes only. Actual unit prices may vary significantly from those shown.

- The example spreadsheets were developed with respect to cost estimating at the conceptual design level. Typically, spreadsheets developed for cost estimating at the detailed design level would be considerably more detailed and could include items such as the cost of contract bonds, breakdown of bedrock grouting (time, plant, materials and testing), watering fill materials or the cost of light plant usage. At the conceptual design level, such costs may be included in the unit prices or, with respect to some project requirements, neglected where relevant experience is available.

- The main cost estimate items indicated on the example spreadsheets could be applied, in principle, to the majority of mine sites (adding an open pit, a backfill quarry or other mine site features, as required). However, as pointed out in the report, it might be advantageous to divide a cost estimate spreadsheet into technological or other components, depending on the project specifics.

- The estimating of capital costs using the example spreadsheets is straightforward. Any number of work items can be inserted, changed or added. The units of work can be changed from ‘unit prices’ to ‘time and materials’, or another pricing arrangement.

  A formula available in the QuattroPro spreadsheet program (@PV) was used to calculate the net present value of a short term operation cost (during a transition period). Other net present value calculations are straightforward. The real rate of return value used in the spreadsheets (0.035) can be readily changed by inserting a new value in the appropriate formulas.

- The first spreadsheet presents an example of cost estimate for the water cover option. In this case it was assumed that a seepage collection facility would have to be operated during a transition period.

  The costs shown were estimated for a self-sustained water cover, however, this spreadsheet includes also provisions for estimating the cost of a maintained water cover.

- The second spreadsheet presents an example of cost estimate for a composite soil cover. Examples of cost estimates for both a tailings deposit and a waste rock pile are included in this spreadsheet. Note that the requirements with regard to a seepage collection system to be operated during a transition period (if necessary) would be typically different than the seepage collection requirements (if any) applicable prior to the cover construction.

- An example of cost estimating for the plastic liner option is shown on the third spreadsheet. The 'base fill' item in the case of a tailings deposit was introduced to make an allowance for some additional works that may be required in conjunction with liner installation over a very soft (eg., tailings pond) area.

- The spreadsheet 4 presents a simple example of cost estimating for the collect and treat option. From the technology cost perspective, it is important to realize that the cost of a treatment plant construction/upgrading (in preparation for long ***term*** operation) will constitute typically a very substantial cost component.

- The cost estimating for waste removal (spreadsheet 5) is quite straightforward except, perhaps, for the lime neutralization requirements. Note that some variations of this technology may require capping of the pit after backfilling, stabilizing pit walls or providing runoff diversion measures. The question of the quality of the runoff originating at a former waste disposal site would have to be addressed if the waste generates AMD at the time of removal and this could make the cost estimating procedure more complex.

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) - Example Spreadsheet 1 T12374/007150

TABLE B.1. COST ESTIMATE - WATER COVER OPTION (1994$)

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTIT	UNI	UNIT PRICE	AMOUNT	SUB-ITEM TOTAL	ITEM TOTAL
CAPITAL COST – BASE COST	A.	TAILINGS BASIN PREPARATION						
	A.1	MISC. WORKS OUTSIDE TAILINGS BASIN	L.S.	--	--	$20,000		
	A.2	TAILINGS SURFACE/TAILINGS DAM REGRADING						
	A.2.1	Grading tailings surface	60,000	m3	$3.0	$180,000		
	A.2.2	Regrading existing dam slopes	4,500	m3	$7.0	$31,500		
	A.3	GENERAL SITE CLEAN UP (pipes, garbage, etc.)	L.S.	--	--	$15,000		
	A.4	UPGRADE EXIST. TAILINGS DAM TOE DRAIN						
	A.4.1	General fill	2,200	m3	$15.0	$33,000		
	A.4.2	Drain core	150	m	$25.0	$3,750	$283,250	
	B.	BORROW AREA/QUARRY DEVELOPMENT						
	B.1	BORROW AREA						
	B.1.1	Access road (cut & fill)	12,000	m3	$3.0	$36,000		
	B.1.2	Site clearing, incl. access road	5	ha	$6,000.0	$30,000		
	B.1.3	Grubbing & stripping (including disposal)	8,000	m3	$4.5	$36,000		
	B.1.4	Drainage/diversion ditches	200	m	$35.0	$7,000		
	B.1.5	Rough grading after use - restoration	3,000	m3	$3.0	$9,000		
	B.2	QUARRY						
	B.2.1	Access road upgrade	1,500	m	$50.0	$75,000		
	B.2.2	Site clearing	2	ha	$7,500.0	$15,000		
	B.2.3	Grubbing & stripping (including disposal)	1,000	m3	$6.0	$6,000		
	B.2.4	Drainage ditches (if required)		m		$0		
	B.2.5	Earth excavation (including machine cleaning)	1,200	m3	$8.0	$9,600		
	B.2.6	Rough grading after use - restoration	L.S.	--	--	$2,000		
	B.2.7	Rough scaling/trimming of quarry wall (after use) - for sa	L.S.	--	--	$5,000		
	B.2.8	Safety berm along quarry perimeter	3,000	m3	$10.0	$30,000	$260,600	
	C.	WATER COVER						
	C.1	CONSTRUCTION OF PERIMETER DAM(S)						
	C.1.1	Prepare site						
		C.1.1.1 Site clearing	4	ha	$7,500.0	$30,000		
		C.1.1.2 Grubbing & stripping (including disposal)	5,000	m3	$6.0	$30,000		
	C.1.2	Dam construction						
		C.1.2.1 Earth excavation	6,000	m3	$8.0	$48,000		
		C.1.2.2 Rock excavation	500	m3	$50.0	$25,000		
		C.1.2.3 Bedrock treatment (dental concrete, slush grout)	3,000	m2	$45.0	$135,000		
		C.1.2.4 Bedrock grouting	500	m	$1,000.0	$500,000		
		C.1.2.5 Low permeability cutoff/core	40,000	m3	$15.0	$600,000		
		C.1.2.6 Dam shell fill	85,000	m3	$12.0	$1,020,000		
		C.1.2.7 Erosion protection (rip-rap)	7,000	m3	$20.0	$140,000		
	C.2	SAND COVER OVER TAILINGS SURFACE	600,000	m2	$3.0	$1,800,000		
	C.3	WATER DIVERSION FACILITIES						
	C.3.1	Water diversion dyke and ditch						
		C.3.1.1 Site preparation	2	ha	$6,000.0	$12,000		
		C.3.1.2 Dyke construction (fill materials)	5,000	m3	$12.0	$60,000		
		C.3.1.3 Ditch construction	3,000	m3	$8.0	$24,000		
	C.3.2	Water supply facility (if maintained water cover)						
		C.3.2.1 Site preparation	L.S.	--	--			
		C.3.2.2 Pump, pumphouse, pipelines, etc.	L.S.	--	--		$4,424,000	
	D.	OVERFLOW/EMERGENCY SPILLWAY	L.S.	--	--	$50,000	$50,000	
	E.	SEEPAGE COLLECTION FACILITIES (transition period)						
	E.1	SITE PREPARATION						
	E.1.1	Site clearing	3	ha	$7,500.0	$22,500		
	E.1.2	Grubbing & stripping (including disposal)	4,000	m3	$6.0	$24,000		
	E.2	COLLECTION POND(S) AND DITCHES						
	E.2.1	Earth excavation	1,500	m3	$8.0	$12,000		
	E.2.2	Rock excavation	200	m3	$50.0	$10,000		
	E.3	SEEPAGE CUTOFF AND RETENTION DYKE						
	E.3.1	Bedrock treatment (dental concrete, slush grout)	600	m2	$45.0	$27,000		
	E.3.2	Bedrock grouting	200	m	$1,000.0	$200,000		
	E.3.3	Low permeability blanket/cutoff	1,500	m3	$15.0	$22,500		
	E.3.4	Dyke fill	4,000	m3	$15.0	$60,000		
	E.3.5	Erosion protection (rip-rap)	500	m3	$20.0	$10,000		
	E.4	PUMPHOUSE						
	E.4.1	Power supply	L.S.	--	--	$40,000		
	E.4.2	Pumps	2	each	$60,000	$120,000		
	E.4.3	Intake structure & wet well	L.S.	--	--	$120,000		
	E.4.4	Pumphouse, incl. slab, inside piping & controls	L.S.	--	--	$80,000		
	E.4.5	Pipelines (including heat tracing, bedding, burying, etc.)	600	m	$85.0	$51,000		
	E.5	REHABILITATION OF SCF SITE	L.S.	--	--	$80,000	$879,000	
	F.	WASTE WATER TREATMENT PLANT						
	F.1	Upgrade WWTP	L.S.	--	--	$3,000,000		
	F.2	Provide discharge pipelines (effluent & sludge)	2,000	m	$90.0	$180,000		
	F.3	Rehabilitaion of WWTP site	L.S.	--	--	$50,000	$3,230,000	$9,127,000
OTHER COST	G.	PLANT SITE						
	G.1							
	G.2							
	H.	INFRASTRUCTURE						
	H.1							
	H.2							
	I.	UNDERGROUND MINE WORKINGS						
	I.1							
	I.2							
	J.	INSPECTION, MAINTENANCE, ENGINEERING (Note: Convert to net present value, as applicable)						
	J.1							
	J.2							
K. OTHER CONSTRUCTION COSTS (mob., demob., dewatering, sediment control, etc.)								$913,000
L. Total Capital Cost								**$10,040,000**
Annual Operating Cost	M.	COST OF TREATMENT						
	M.1	Labour & WWTP maintenance	L.S.	--	--	$160,000		
	M.2	Runoff & seepage treatment						
	M.2.1	First transition period	400,000	m3	$0.40	$160,000		
	M.2.2	Second transition period	80,000	m3	$0.40	$32,000		
	N.	SLUDGE DISPOSAL						
	N.1	Prepare site	1	ha	$12,000	$12,000		
	N.2	Construct sludge cells (fill materials) - transition periods	8,000	m3	$12.00	$96,000		
	O.	COST TO MAINTAIN WATER COVER (pumping)		m3	$0.15			
Net Present Value	P.	NET PRESENT VALUE - TREATMENT OPERATIONS						
	P.1	First transition period	Duration	(yrs) 2	Operating cost per year	$428,000	Net present value	$813,000
	P.2	Second transition period	Duration	(yrs) 20	Operating cost per year	$300,000	Net present value	$4,264,000
	P.3	Long term pumping cost for maintaining water cover	Duration	(yrs) indefi	Operating cost per year		Net present value	
	Total net present value of treatment cost							**$5,077,000**
TOTAL COST FOR MINE CLOSURE, INCLUDING OPERATING COSTS								**$15,117,000**

Disk(MEND): EXAMPLE1.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) - Example Spreadsheet 2 T12374/007150

TABLE B.2. COST ESTIMATE FOR COMPOSITE SOIL COVER OPTION (199

95-01-19

COST TYPE	ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	SUB-ITEM TOTAL	ITEM TOTAL
CAPITAL COST – BASE COST	A.	SITE PREPARATION						
	A.1	PERIPHERY OF TAILINGS & WASTE ROC						
	A.1.1	Clearing	5	ha	$6,000	$30,000		
	A.1.2	Grubbing & stripping (including disposal)	5,000	m3	$10.0	$50,000		
	A.1.3	Earth excavation (key trench)	15,000	m3	$10.0	$150,000		
	A.1.4	Rock excavation (key trench)	1,000	m3	$50.0	$50,000		
	A.2	TAILINGS SURFACE & WASTE ROCK DU						
	A.2.1	Grading (tailings basin)						
		A.2.1.1 Tailings surface contouring	30,000	m3	$3.0	$90,000		
		A.2.1.2 Reshaping of dam slopes	7,000	m3	$5.0	$35,000		
	A.2.2	Grading (waste rock dump)						
		A.2.2.1 Surface contouring/leveling	15,000	m3	$2.5	$37,500		
		A.2.2.2 Dump slope regrading	12,000	m3	$4.5	$54,000		
	A.3	GENERAL CLEAN UP (garbage, trash, debri	L.S.	--	--	$20,000		
	A.4	SEEPAGE COLLECTOR/DISCHARGE SYS						
	A.4.1	Granular fill (tailings basin only)	11,000	m3	$12.0	$132,000		
	A.4.2	Drainage pipes (incl. bedding, etc)	400	m	$25.0	$10,000		
	A.4.3	Transfer Ponds (incl. pump and sump)	2	each	$50,000	$100,000	$758,500	
	B.	BORROW/QUARRY AREA						
	B.1	Borrow Area Development and Restoration	L.S.	--	--	$20,000		
	B.2	Quarry Area Development and Restoration	L.S.	--	--	$30,000	$50,000	
	C.	SOIL COVER CONSTRUCTION						
	C.1	TAILINGS BASIN						
	C.1.1	Flat area (tailings beach)						
		C.1.1.1 Bottom (granular) layer	250,000	m2	$4.5	$1,125,000		
		C.1.1.2 Low permeability layer	250,000	m2	$12.0	$3,000,000		
		C.1.1.3 Top sand & gravel layer	250,000	m2	$3.0	$750,000		
		C.1.1.4 Hydroseeding (if required)		ha				
	C.1.2	Tailings dam slopes						
		C.1.1.1 Bottom (granular) layer	50,000	m2	$5.0	$250,000		
		C.1.1.2 Low permeability layer	50,000	m2	$13.5	$675,000		
		C.1.1.3 Top sand & gravel layer	50,000	m2	$4.0	$200,000		
		C.1.1.4 Hydroseeding (if required)		ha				
	C.2	WASTE ROCK DUMP						
	C.2.1	Flat area (top surface of dump)						
		C.2.1.1 Bottom (granular) layer	120,000	m2	$3.5	$420,000		
		C.2.1.2 Low permeability layer	120,000	m2	$11.0	$1,320,000		
		C.2.1.3 Top sand & gravel layer	120,000	m2	$3.0	$360,000		
		C.2.1.4 Hydroseeding (if required)		ha				
	C.2.2	Slope area (graded slopes of dump)						
		C.2.1.1 Bottom (granular) layer	80,000	m2	$4.0	$320,000		
		C.2.1.2 Low permeability layer	80,000	m2	$11.5	$920,000		
		C.2.1.3 Top sand & gravel layer	80,000	m2	$3.5	$280,000		
		C.2.1.4 Hydroseeding (if required)		ha			$9,620,000	
	D.	RUNOFF DIVERSION DITCHES	L.S.	--	--	$50,000	$50,000	
	E.	SEEPAGE COLLECTION FACILITIES (trans						
	E.1	Seepage collection/discharge system	L.S.	--	--	$200,000		
	E.2	Pipelines	L.S.	--	--	$200,000		
	E.3	Transfer pond facilities	L.S.	--	--	$120,000		
	E.4	Rehabilitation of seepage collection facilities	L.S.	--	--	$50,000	$570,000	
	F.	WASTE WATER TREATMENT PLANT						
	F.1	Upgrade treatment facility	L.S.	--	--	$1,500,000		
	F.2	Provide discharge pipelines (effluent & sludg	2,000	m	$90.0	$180,000		
	F.3	Rehabilitation of WWTP site	L.S.	--	--	$50,000	$1,730,000	$12,778,500
OTHER COST	G.	PLANT SITE						
	G.1							
	G.2							
	H.	INFRASTRUCTURE						
	H.1							
	H.2							
	I.	UNDERGROUND MINE WORKINGS						
	I.1							
	I.2							
	J.	INSPECTION, MAINTENANCE, ENGINEERI						
	J.1	(Note: Convert to net present value, as appli						
	J.2							
K. OTHER CONSTRUCTION COST (mob., demob., dewatering, sediment control, etc.)								$1,278,000
L. Total Capital Cost								$14,057,000
Annual Operating Cost	M.	COST OF TREATMENT (transition period(s						
	M.1	Labour and WWTP maintenance	L.S.	--	--	$160,000		
	M.2	Treatment cost						
	M.2.1	Transition period - tailings	45,000	m3	$0.40	$18,000		
	M.2.2	Transition period - waste rock	30,000	m3	$0.40	$12,000	$190,000	
	N.	SLUDGE DISPOSAL						
	N.1	Prepare site	400	m2	$7.5	$3,000		
	N.2	Construct sludge cells (fill materials)						
	N.2.1	Transition period - tailings	600	m3	$15.0	$9,000		
	N.2.2	Transition period - waste rock	500	m3	$15.0	$7,500	$19,500	
Net Present Value	O.	NET PRESENT VALUE - TREATMENT OPERATIONS						
	O.1	Transition period - tailings	Duration	(yrs) 20	Operating cost per year $190,000		Net present value	$2,700,000
	O.2	Transition period - waste rock	Duration	(yrs) 2	Operating cost per year $182,500		Net present value	$347,000
	Total net present value for treatment operation							$3,047,000
TOTAL COST FOR MINE CLOSURE								$17,104,000

Disk(MEND): EXAMPLE2.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) - Example Spreadsheet 3 — T12374/007150

TABLE B.3. COST ESTIMATE FOR PLASTIC LINER COVER OPTION (1994$)

95-01-19

COST TYPE		ITEM No.	WORK ITEM DESCRIPTION	QUANTIT	UNIT	UNIT PRICE	AMOUNT	SUB-ITEM TOTAL	ITEM TOTAL
CAPITAL COST	BASE COST	A.	SITE PREPARATION						
		A.1	PERIPHERY OF TAILINGS & WASTE ROCK SITES						
		A.1.1	Clearing	3	ha	$7,500.0	$22,500		
		A.1.2	Earth excavation/backfill (key trench)	1,500	m3	$10.0	$15,000		
		A.2	TAILINGS SURFACE & WASTE ROCK DUMP						
		A.2.1	Grading (tailings basin)						
			A.2.1.1 Tailings surface contouring	30,000	m3	$3.0	$90,000		
			A.2.1.2 Reshaping of dam slopes	7,000	m3	$4.0	$28,000		
		A.2.2	Grading (waste rock dump)						
			A.2.2.1 Surface contouring/leveling	15,000	m3	$2.0	$30,000		
			A.2.2.2 Dump slope regrading	12,000	m3	$2.5	$30,000		
		A.3	MISC. WORKS & GENERAL CLEAN UP (garbage, tra	L.S.	--	--	$30,000		
		A.4	SEEPAGE COLLECTOR/DISCHARGE SYSTEM						
		A.4.1	Granular fill (tailings basin only)	10,000	m3	$12.0	$120,000		
		A.4.2	Drainage pipes (incl. bedding, etc.)	150	m	$25.0	$3,750		
		A.4.3	Transfer Ponds (incl. pump and sump)	2	each	$50,000	$100,000	$469,250	
		B.	BORROW AREA						
		B.1	Development	L.S.	--	--	$20,000		
		B.2	Restoration	L.S.	--	--	$10,000	$30,000	
		C.	LINER INSTALLATION						
		C.1	TAILINGS BASIN						
		C.1.1	Flat area						
			C.1.1.1 Base fill (tailings pond area)	120,000	m3	$10.0	$1,200,000		
			C.1.1.2 Plastic liner	350,000	m2	$15.0	$5,250,000		
			C.1.1.3 Liner cover material	350,000	m2	$4.0	$1,400,000		
			C.1.1.4 Hydroseeding (if required)		ha				
		C.1.2	Tailings dam slopes						
			C.1.2.1 Plastic liner	50,000	m2	$17.0	$850,000		
			C.1.2.2 Liner cover material	50,000	m2	$8.0	$400,000		
			C.1.2.3 Hydroseeding (if required)		ha				
		C.2	WASTE ROCK DUMP						
		C.2.1	Flat area (Top surface of dump)						
			C.2.1.1 Primary bedding material (if required)		m2				
			C.2.1.2 Bedding material	300,000	m2	$5.0	$1,500,000		
			C.2.1.3 Plastic liner	300,000	m2	$14.0	$4,200,000		
			C.2.1.4 Liner cover material	300,000	m2	$6.0	$1,800,000		
			C.2.1.5 Hydroseeding (if required)		ha				
		C.2.2	Slope area (graded slopes)						
			C.2.2.1 Primary bedding material (if required)		m2				
			C.2.2.2 Bedding material	60,000	m2	$7.0	$420,000		
			C.2.2.3 Plastic liner	60,000	m2	$16.0	$960,000		
			C.2.2.4 Liner cover material	60,000	m2	$8.0	$480,000		
			C.2.2.5 Hydroseeding (if required)		ha			$18,460,000	
		D.	RUNOFF DIVERSION DITCHES	L.S.	--	--	$20,000	$20,000	
		E.	SEEPAGE COLLECTION FACILITIES (transition perio		--	--			
		F.	WASTE WATER TREATMENT PLANT (transition peri						
		F.1	Upgrade/provide treatment facility		--	--			
		F.2	Provide discharge pipelines (effluent & sludge)		m				$18,979,000
	OTHER COST	G.	PLANT SITE						
		G.1							
		G.2							
		H.	INFRASTRUCTURE						
		H.1							
		H.2							
		I.	UNDERGROUNG MINE WORKINGS						
		I.1							
		I.2							
		J.	INSPECTION, MAINTENANCE, ENGINEERING						
		J.1	(Note: Convert to net present value, as applicable)						
		J.2							
K. OTHER CONSTRUCTION COST (mob., demob., dewatering, sediment control, etc.)									$1,898,000
L. Total Capital Cost									$20,877,000
Annual Operating Cost (if required)		M.	COST OF TREATMENT						
		M.1	Labour and WWTP maintenance		--				
		M.2	Water treatment - transition		m3				
		N.	SLUDGE DISPOSAL						
		N.1	Prepare site		m2				
		N.2	Construct sludge cells (fill materials) - transition		m3				
Net Present Value for Operation		O.	UP-FRONT COST FOR OPERATION & LINER REPLACEMENT						
		O.1	Transition period (if required)	Duration	(yrs)	Sum of operation cost pe		Net present value	
		O.2	Longevity of liner						yrs 200
		O.3	Deffered cost for liner replacement			Current cost for liner replaceme	$15,340,000	NPV - 1st repl. $15,800	NPV - 2nd repl. $16
			Total net present value for treatment operation & liner replacement						$15,816
TOTAL COST FOR MINE CLOSURE									$20,892,816

Disk(MEND): EXAMPLE3.WQ1

Economic Evaluation of AMD Technologies (MEND PROJECT - 1994) - Example Spreadsheet 4 T12374/007150

TABLE B.4. COST ESTIMATE FOR COLLECT & TREAT OPTION (1994$)

95-01-19

COST TYPE		ITEM No.	WORK ITEM DESCRIPTION	QUANTIT	UNIT	UNIT PRICE	AMOUNT	SUB-ITEM TOTAL	ITEM TOTAL
		A.	SITE PREPARATION						
		A.1	PERIPHERY OF TAILINGS & WASTE ROCK SITES						
		A.1.1	Clearing in preparation for seepage collection facilities	3	ha	$7,500.0	$22,500		
		A.1.2	Grubbing & stripping (including disposal)	8,000	m3	$10.0	$80,000		
		A.2	TAILINGS SURFACE & WASTE ROCK DUMP						
		A.2.1	Grading (tailings basin)						
			A.2.1.1 Surface contouring	6,000	m3	$3.0	$18,000		
			A.2.1.2 Reshaping of dam slopes	5,000	m3	$5.0	$25,000		
		A.2.2	Grading (waste rock dump)						
			A.2.2.1 Surface contouring/leveling	7,000	m3	$2.5	$17,500		
			A.2.2.2 Slope reshaping for stability	25,000	m3	$4.5	$112,500		
		A.2.3	Toe drain/berm and slope protection (tailings basin only)						
			A.2.3.1 Toe drain fills	3,000	m3	$15.0	$45,000		
			A.2.3.2 Toe berm	6,000	m3	$15.0	$90,000		
			A.2.3.3 Slope protection material	9,000	m3	$15.0	$135,000		
		A.3	MISC. WORKS & GENERAL CLEAN UP (garbage, trash, d	L.S.	--	--	$20,000	$565,500	
C	B	B.	BORROW/QUARRY AREA						
		B.1	Borrow Area Development and Restoration	L.S.	--	--	$20,000		
A	A	B.2	Quarry Area Development and Restoration	L.S.	--	--	$40,000	$60,000	
		C.	TAILINGS SURFACE VEGETATION						
P	S	C.1	Lime/soil cover	50	ha	$35,000	$1,750,000		
		C.2	Hydroseeding	50	ha	$5,000	$250,000	$2,625,500	
I	E	D.	RUNOFF DIVERSION & SPILLWAY						
		D.1	Runoff diversion ditches	900	m	$80.0	$72,000		
T		D.2	Overflow/emergency spillway (tailings basin only)	L.S.	--	--	$80,000	$152,000	
		E.	SEEPAGE COLLECTION FACILITIES						
A		E.1	DITCHES & POND (including dyke & pumphouse areas)						
	C	E.1.1	Earth excavation	10,000	m3	$10.0	$100,000		
L		E.1.2	Rock excavation	2,000	m3	$50.0	$100,000		
	O	E.2	SEEPAGE CUTOFF AND RETENTION DYKE						
		E.2.1	Bedrock treatment	5,000	m2	$20.0	$100,000		
	S	E.2.2	Bedrock grouting	800	m	$1,000.0	$800,000		
C		E.2.3	Low permeability blanket/cutoff	2,000	m3	$15.0	$30,000		
	T	E.2.4	Dyke fill	3,000	m3	$15.0	$45,000		
O		E.2.5	Erosion protection material	1,500	m3	$15.0	$22,500		
		E.3	PUMPHOUSE						
S		E.3.1	Power supply	L.S.	--	--	$20,000		
		E.3.2	Pumps	L.S.	--	--	$100,000		
T		E.3.3	Intake structure (intake pipe & wet well)	L.S.	--	--	$50,000		
		E.3.4	Pumphouse & associated components	L.S.	--	--	$150,000		
		E.3.5	Pipelines	1,500	m	$30.0	$45,000	$1,562,500	
		F.	WATER TREATMENT & SLUDGE DISPOSAL						
		F.1	Provide treatment facility	L.S.	--	--	$5,000,000		
		F.2	Provide discharge pipelines (effluent & sludge)	2,000	m	$90.0	$180,000	$5,180,000	**$10,145,500**
		G.	PLANT SITE						
	O	G.1							
	T	G.2							
	H	H.	INFRASTRUCTURE						
	E	H.1							
	R	H.2							
		I.	UNDERGROUND MINE WORKINGS						
	C	I.1							
	O	I.2							
	S	J.	INSPECTION, MAINTENANCE, ENGINEERING						
	T	J.1	(Note: Convert to net present value, as applicable)						
		J.2							
K. OTHER CONSTRUCTION COST (mob., demob., dewatering, sediment control, etc.)									$1,015,000
L. Total Capital Cost									$11,161,000
		M.	COST OF TREATMENT						
		M.1	Labour and WWTP maintenance	L.S.	--	--	$160,000		
Annual		M.2	Water treatment - Long term	320,000	m3	$0.40	$128,000		
Operating		N.	SLUDGE DISPOSAL						
Cost		N.1	Prepare site	200	m2	$7.50	$1,500		
		N.2	Construct sludge cells (fill materials)	800	m3	$15.00	$12,000	$301,500	
O. UP-FRONT COST FOR OPERATION (based on real rate of return of 3.5% /yr)									**$8,614,000**
TOTAL COST FOR MINE CLOSURE									**$19,775,000**

Disk(MEND): EXAMPLE4.WQ1

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TABLE B.5. COST ESTIMATE FOR WASTE REMOVAL OPTION (1994$)

95-01-19

CASE I: WASTE ROCK

COST TYPE		ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	SUB-ITEM TOTAL	ITEM TOTAL
CAPITAL COST	BASE COST	A.	PREPARATION WORKS						
		A.1	GENERAL CLEAN UP & MISC. WORKS	L.S.	--	--	$50,000		
		A.2	ACCESS ROAD TO DISPOSAL SITE (if required)		km			$50,000	
		B.	BORROW AREA (development & restoration, if req		--	--			
		C.	WASTE ROCK						
		C.1	WASTE ROCK DUMPS	10,000,000	ton.	$1.5	$15,000,000		
		C.2	CONTAMINATED OVERBURDEN	300,000	m3	$3.5	$1,050,000		
		C.3	OTHER WASTES (scattered piles, mine road, etc.)	100,000	m3	$5.0	$500,000	$16,550,000	
		D.	RESTORATION OF DISTURBED AREAS						
		D.1	ROUGH GRADING	50,000	m3	$3.0	$150,000		
		D.2	VEGETATION	220	ha	$5,000.0	$1,100,000	$1,250,000	
		E.	SEEPAGE COLLECTION FACILITIES (if required)		--	--			
		F.	WATER TREATMENT						
		F.1	LIME ADDITION	L.S.	--	--	$200,000		
		F.2	OTHER TREATMENT COST (labour, pumping, m	L.S.	--	--	$50,000	$250,000	$18,100,000
	OTHER COST	G.	PLANT SITE						
		G.1							
		G.2							
		H.	INFRASTRUCTURE						
		H.1							
		H.2							
		I.	UNDERGROUND MINE WORKINGS						
		I.1							
		I.2							
		J.	INSPECTION, MAINTENACE, ENGINEERING						
		J.1	(Note: Convert to net present value, as applicable)						
		J.2							
K. OTHER CONSTRUCTION COST (mob., demob., dewatering, sediment control, etc.)									$1,810,000
TOTAL COST FOR MINE CLOSURE (Case I)									**$19,910,000**

CASE II: TAILINGS

COST TYPE		ITEM No.	WORK ITEM DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT	SUB-ITEM TOTAL	ITEM TOTAL
CAPITAL COST	BASE COST	A.	PREPARATION WORKS						
		A.1	GENERAL CLEAN UP (removal of surface facilities	L.S.	--	--	$50,000		
		A.2	ACCESS ROAD TO DISPOSAL SITE		km			$50,000	
		B.	BORROW AREA (development & restoration, if req		--	--			
		C.	TAILINGS REMOVAL						
		C.1	TAILINGS	20,000,000	m3	$3.5	$70,000,000		
		C.2	CONTAMINATED OVERBURDEN	100,000	m3	$3.5	$350,000		
		C.3	OTHER WASTES (tailings spills, mine road, etc.)	50,000	m3	$5.0	$250,000	$70,600,000	
		D.	RESTORATION OF DISTURBED AREAS						
		D.1	ROUGH GRADING	50,000	m3	$3.0	$150,000		
		D.2	VEGETATION	220	ha	$5,000.0	$1,100,000	$1,250,000	
		E.	SEEPAGE COLLECTION FACILITIES (if required)		--	--			
		F.	WATER TREATMENT & SLUDGE DISPOSAL (if r						
		F.1	Upgrade treatment facility		--	--			
		F.2	Rehabilitation of WWTP site		--	--			$71,900,000
	OTHER COST	G.	PLANT SITE						
		G.1							
		G.2							
		H.	INFRASTRUCTURE						
		H.1							
		H.2							
		I.	UNDERGROUND MINE WORKINGS						
		I.1							
		I.2							
		J.	INSPECTION, MAINTENACE, ENGINEERING						
		J.1	(Note: Convert to net present value, as applicable)						
		J.2							
K. OTHER CONSTRUCTION COST (mob., demob., dewatering, sediment control, etc.)									$7,190,000
L. Total Capital Cost									$79,090,000
Annual Operating Cost (if required)		M.	COST OF TREATMENT						
		M.1	Labour & WWTP maintenance		--				
		M.2	Water treatment - transition		m3				
		N.	SLUDGE DISPOSAL (transition)						
		N.1	Prepare site		m2				
		N.2	Construct sludge cells (fill materials)		m3				$0
O. UP-FRONT COST FOR OPERATION				Assumed duration of transition period (years):					$0
TOTAL COST FOR MINE CLOSURE (Case II)									**$79,090,000**

Disk(MEND): EXAMPLE5.WQ1