ALTERNATIVES ANALYSIS FOR MINE DEVELOPMENT AND RECLAMATION

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ABSTRACT

Mining projects have positive impacts on society in the form of jobs, taxes and regional development. There are (at least temporary) negative impacts such as noise, aesthetics and environmental degradation. The long term or residual environmental degradation after reclamation and closure, depends substantially on the development and reclamation options selected from the wide variety of alternatives generally available. There are numerous stakeholders who are unequally affected by the range of positive and negative impacts associated with mining projects. Thus the migrant job seeker or local business owner may endorse a particular project while the recreational fisherman may resent the loss of a recreational resource. The project approval process has evolved so that, today, all stakeholders, including the proponent, regulatory agencies and community representatives, participate in the project review process. Ultimate decision making, as to whether the project may proceed, and under which circumstances (which development and reclamation options are approved) requires collective understanding of the positive and negative impacts. It also requires a framework under which stakeholders can express their concerns and communicate their assessments of the relative values of positive and negative impacts. The valuations and methodology of arriving at the compromises between the positive and negative impacts, or value 'tradeoffs', must be understood, transparent and communicatible. This paper describes how the general methodology of "Multiple Accounts Analysis" may be adapted specifically for mine development and reclamation alternatives or options evaluation.

To account for all substantive impacts, a comprehensive list (ledger, or set) of 'accounts and sub-accounts' is prepared (e.g. jobs, taxes, water quality, fisheries habitat etc.) to include all impacts identified as being of substantive concern by stakeholders. A measure or 'indicator value' of the impact applicable to each account is developed which describes the impacts in relevant terms (number of jobs, amount of taxes, metal concentrations in water etc.). A basis for account list development is provided.

This list of accounts and indicators can be used for analysis and decision making for preferred option selection. Two forms of analysis may be used:

i) An arguments-based analysis whereby the analyst presents reasoned arguments of the relevant values of indicators in accounts and comparisons (tradeoffs) between accounts, and the reader must make a subjective selection of a preferred alternative; or
ii) A value-based analysis, in which the analyst assigns numerical values to the indicators in each account using ranking and scaling techniques. Tradeoffs are achieved by weighting each account prior to accumulating the numerical values in all accounts.

Both methods involve subjectivity in assigning values to indicators, and in the summation and tradeoffs needed to develop a 'cumulative' assessment of the net impact (from all accounts) for each alternative. Having clear and transparent methods and processes makes it easier for all stakeholders to share opinions and come up with a consensus agreement.

OBJECTIVE OF THE MULTIPLE ACCOUNTS ANALYSIS

In order to select the most suitable, or advantageous, option from a list of alternatives for mine development and/or reclamation options the evaluator(s) must weigh the benefits and losses of each option. This involves three basic steps:

1. Identify the impacts (benefits and losses) to be included in the evaluation (assessment accounts and sub-accounts);
2. Quantify the impacts (benefits and losses) for each of the accounts and sub-accounts;
3. Assess the combined or accumulated impacts for each option and compare these with other options to develop a preference list (ranking, scaling and weighting) of the options.

Often there is a threshold value for a particular impact which, if not achieved, constitutes a critical flaw. A critical flaw is one which, of itself, renders the option under evaluation unacceptable. Thus failure to meet a mandatory water quality standard may be a critical flaw. Thus, step 2 includes a screening of all options that fail to meet threshold values for all accounts or sub-accounts. All options which survive the threshold test at step 2 must be included in the integrated (combined and cumulative) impact assessment of step 3.

The diversity of impacts that must be considered makes integrated (combined and accumulative impacts) assessment difficult. How does one compare the 'apples and oranges' in one fruit basket with the 'plums and bananas' in another to decide which is the preferable. To a large extent any comparison is subjective and depends on the flavor preference (value basis) of the analyst. It is not possible, and probably not desirable, to remove this subjectivity as each analyst seeks to have his/her value basis applied in the analysis. It is therefore an advantage if the evaluation methodology (analysis) is systemized and transparent allowing the various analysts to clearly indicate their value basis and results. If the results of analyses from two analysts are similar, despite differences in value basis, then there is likely to be consensus on the option selected. If results are materially different then the root cause of the difference can be identified and discussions focused on the material, value basis, issues to determine if a consensus resolution can be reached.

Some alternatives evaluations can reach conclusion or agreement after completion of step 2. This is typically referred to as Multiple Accounts Evaluation in the literature (Gregory and Keeney, 1994, Keeney, 1988, Gregory and Slovic, 1997). Other evaluations however, in particular those involving multidisciplinary problems and numerous stakeholders with differing viewpoints, must be taken to the end of step 3. This is termed a Value-Based Decision Process similar to that described by Gregory et al. (1992) and BC Hydro (1994). Together, the Multiple Accounts Evaluation and the Value-Based

Decision Process have been defined here as a Multiple Accounts Analysis. This method of analysis is ideal for the assessment of options for mine development and/or mine reclamation.

Details of the analysis extent, complexity and stakeholder interaction must be developed jointly between the proponent and regulatory agency representatives. The process should be kept as simple as possible (the KISS principle) maintaining focus on the major issues. Maintaining simplicity is itself an issue of communication and negotiation with the stakeholders.

METHODOLOGY

The Multiple Accounts Analysis is a two staged process. The first stage consists of the development of a multiple accounts ledger, an explicit list of accounts (and sub-accounts) of the impacts from various development alternatives, and, for each sub-account, indicators which give a clear understandable description of those impacts. This stage allows the determination of alternatives that are critically flawed (do not meet threshold values). The second stage constitutes the Value-Based Decision Process applied to the remaining alternatives. It involves ranking, scaling and weighting the indicator values in the sub-accounts in a systematic transparent manner such that the value basis for the combination or accumulation of effects is readily apparent. In this manner, all the 'fruit in a basket' can be compared equally, amongst themselves and with 'fruit in other baskets'.

The various impacts, particularly environmental and socioeconomic impacts, during development, operations, closure and post closure for a mine development and reclamation are sometimes difficult to accurately describe or quantify without an enormous amount of investigation and analysis. This makes the early quantification of accounts, and hence the evaluation and selection of the most advantageous of options more difficult. Therefore, much of the assessment is necessarily based on judgement rather than deterministic analysis. The anticipation and assessment of the performance of the engineered structures, natural processes at work and environmental impact requires a sound understanding of the current technologies as well as considerable experience on a wide variety of similar projects in order to recognize and identify potential impacts, issues and risks. It is important therefore that the meetings and negotiations with stakeholders be lead by credible, experienced specialists who can assist in the establishment of appropriate indicators and the associated ranking, scaling and weighting factors. Fortunately the 80/20 rule (20% of the effort often gets you 80% of the result) usually applies. Since the accuracy of quantification as well as the ability to rank, scale and weigh alternatives all have some uncertainty, it is appropriate to use a fairly coarse classification methods.

FRAMEWORK FOR ASSESSMENT

The framework for the assessment of the various options available involves an separate multiple accounts analysis or <u>each</u> of the options for <u>all</u> major components of mine development and/or reclamation (e.g. tailings site selection and design options, mill site and metallurgical process options, etc.). The assessments are typically based on four fundamental accounts, namely Environmental, Socio-economic, Project Economics and Technical accounts (Figure 1). These main accounts are then broken down into a list of more specific sub-accounts.

Figure 1. Multiple Accounts Analysis for Alternatives Selection.
(during Construction, during Operations, during Closure, and Post Closure)

Mine Components	Accounts	Sub-Accounts	Indicators	Ranking, Scaling, & Weighting
e.g. • Tailings Site Selection • Waste Rock Dump Options • Open pit vs. Underground Mine • Water Management Options • Infrastructure Options (roads, power) • Mill Site and Process Options	Technical Accounts			. . .
	Environmental Accounts			
	Project Economic Accounts			
	Socio-economic Accounts			

SUB-ACCOUNTS

Because most projects involves local, Provincial, Federal, local community, multicultural, environmental and land use issues, advice and input should be sought from a variety of stakeholders, to be identified jointly by the proponent and regulatory authorities, on the identification and selection of sub-accounts. Sub-accounts can be defined as any material impact (benefit or loss) by any of the options being evaluated. Initial identification of a comprehensive list of sub-accounts ensures that no 'a priori' judgements have been made regarding the selection of any alternatives. However, this comprehensive list can be carefully scrutinized and those impact accounts which are either similar for all options or not materially influential in selecting between options, can be dropped from the evaluation 'Ledger' or list. A typical comprehensive list of sub-accounts is given in Figure 2. Care should be taken to ensure that no redundancy or double counting of sub-accounts is done. However, some accounts must consider only impacts not accounted for in other accounts (i.e. 4.14 must exclude what is considered in 4.9). It becomes apparent upon first inspection of Figure 2 that certain sub-accounts will have variable impacts based on the various options and others will have similar impacts regardless of the options chosen. For instance, a tailings storage facility located 2 km from the mill would have a significantly less tailings delivery risk and cost associated with it than one located 15 km from the mill, however, both sites would have a similar impact on community services. Therefore a short list of fundamental (high value) sub-accounts can be defined (Figure 3) from the general list of sub-accounts given in Figure 2. These fundamental sub-accounts represent those issues which may have significantly different values for the different options being considered.

INDICATORS

Each sub-account may have one or more indicators which provide a measure, either qualitatively or quantitatively, of the impact (benefit or loss) of each option. For example, the sub-account of water quality may have a list of indicators including pH, concentration of Total Dissolved Solids (TDS), sulfate concentration etc. These indicators are likely different at different stages of mining and therefore should be divided into time periods (during construction, operation, post closure). Sub-accounts such as water quality, or capital costs etc. that can be expressed in parametric terms that can be readily measured are relatively straightforward with respect to the assignment of indicators. It is more difficult to measure and assign values to the impacts on sub-accounts such as aesthetics or outdoor recreation and tourism. Figure 4 is presented as a template for listing the indicators of each of the fundamental sub-accounts using the example of outdoor recreation and tourism during operations (Fundamental Sub-account 4.1 from Figure 3). The relevance of some of the values shown on this Figure is discussed in the following sections.

It is at this point of the evaluation that the Multiple Accounts Evaluation concludes and the Value-Based Decision Process begins. The Value-Based Decision Process takes this list of indicators, sub-accounts and accounts and assesses the combined impacts for each of the alternatives being evaluated (i.e. allows the 'apples' and 'oranges' to be compared).

RANKING, SCALING AND WEIGHTING

For each of the development or reclamation options being assessed, the options must be **ranked** in order from best to worst with respect to the indicators for each sub-account. Ranking is a simple ordered list and makes no attempt to distinguish how great the difference in impact is between options on the list. In practice there may be very little difference in the impact from the best to the worst.

Figure 2. Ledger of Accounts and Sub-Accounts (Mine with ARD)

Accounts	Sub-Accounts	Indicators
1.0 Technical	1.1 Dams	1.1.1 ...
	1.2 Mine	
	1.3 Diversions	
	1.4 Covers	
	1.5 Water Treatment	
	1.6 Access Road	
2.0 Environmental	2.1 Climate	
	2.2 Air Quality	
	2.3 Hydrology & Water Management	
	2.4 Water Quality	
	2.5 Aquatic Ecology	
	2.6 ARD/ML	
	2.7 Fish & Fish Habitat	
	2.8 Terrain & Soils	
	2.9 Vegetation	
	2.10 Wildlife	
3.0 Project Economics	3.1 Capital Cost	
	3.2 Operational Cost	
	3.3 Closure Cost	
	3.4 Profitability/Taxes	
	3.5 Economic Risk	
4.0 Socio-economics	4.1 Income (direct/indirect)	
	4.2 Taxes (direct/indirect)	
	4.3 Regional Government Development	
	4.4 Government Expenditures	
	4.5 Labour Market Analysis	
	4.6 Population	
	4.7 Housing	
	4.8 Transportation & Traffic	
	4.9 Navigable waters (recreational)	
	4.10 Community Services	
	4.11 Health & Safety	
	4.12 Land Tenure	
	4.13 Fishing	
	4.14 Outdoor Recreation & Tourism	
	4.15 Aesthetics	
	4.16 Archaeological resources	
	4.17 Sacred/Traditional Sites	

Figure 3. Fundamental (High Value) Sub-accounts
(Mine with ARD in a permafrost area with a high fishing and tourism recreational value).

Accounts	Fundamental Sub-accounts (e.g. Tailings Options)	Indicators
1.0 Technical	1.1 Constructability with local access, materials, permafrost	1.1.1 ...
	1.2 Achieve Stability of Dams, Dykes and Diversions	
	1.3 Maintain 'Zero' Discharge	
	1.4 Minimize Contaminated Seepage (control pore water quality or prevent seepage)	
	1.5 Maintain Covers (ARD control)	
	1.6 Minimize Post Closure Operating and Maintenance Requirements	
2.0 Environmental	2.1 Water Quality (preserve)	
	2.2 Fish and Fish Habitat (minimize disturbance and achieve mitigation/compensation)	
	2.3 Wildlife (minimize disturbance and achieve mitigation/compensation)	
	2.4 Permafrost Degradation/Agradation (control)	
	2.5 Post Mining Land Use (self-sustaining, appropriate use)	
3.0 Project Economics	3.1 Capital Cost (minimize)	
	3.2 Operational Cost (minimize)	
	3.3 Closure Cost (minimize)	
	3.4 Construction Schedule	
4.0 Socio-economics	4.1 Outdoor Recreation, Fishing and Tourism during Operations (minimize loss)	
	4.2 Post Closure Outdoor Recreation, Fishing and Tourism (minimize loss, maximize recovery)	
	4.3 Traffic Disturbance (minimize with routing, type and quantity)	

Figure 4. Example of Indicators for a Fundamental Sub-account (e.g. Tailings Impoundment Site Option #1).

Account: 4.0 Socio-economic								
Sub-account: 4.1 Outdoor Recreation Fishing and Tourism During Operations								
◄ Multiple Accounts Evaluation ►						Value-Based Decision Process ►		
	Indicators	**Indicator parameter**	**unit**	**critical flaw threshold**	**Indicator Quantity**	**Indicator Value (S)**	**Weight (W)**	**S x W**
4.1.1	Hiking trails lost	Length	km	None	0.5 km	9	3	27
4.1.2	Tailings impoundment visible from trails	Length	km	None	15 km	7	1	7
4.1.3	River within 300 m of mine development	Length	km	None	1.5 km	3	5	15
4.1.4	Visual impact	Value		None		5	2	10
Sub-account Merit Score $\Sigma(S \times W)$								**59**
Sub-account Merit Rating $(S \times W)/\Sigma W$								**5.4**

Since the separation of the best option from the worst may be either very slight or very significant, a **scaled** value (S) can then be assigned to each option for each of the indicators using a nine point scale. The three and five point scales often used by other workers are simple subsets or lesser subdivisions of the original nine point scale as illustrated in Figure 5. The authors have found a nine point scale is readily understood and provides a range and discretion suited to this type of analysis. The 'best' option in the ranking is always given a value of 9 merit points. If the 'worst' option is considered to be half as good as the best, it would be given a value of 5 merit points and the other options distributed between these values. An example is the sub-account 'distance from mill to tailings impoundment' that accounts for the potential impacts of long tailings and return water pipelines, the potential for leaks and spills, impoundment inspection and management constraints, etc. If all the impoundments are at a similar distance from the mill then the scaled effect of the 'worst' option may not be very different from the 'best' option and may be made in proportion to the actual tailings pipeline distance. An example is provided in Figure 6.

Figure 5. Subdivisions of Scaling System

Scale Factor

9	**BEST**
8	*very good*
7	GOOD
6	*good 'ish*
5	**INTERMEDIATE**
4	*poor 'ish*
3	POOR
2	*very poor*
1	**WORST**

Figure 6. Example of scaling and positioning of "ranked" options.

Scale Factor

9	**Option A** (e.g. 4.5 km from mill to tailings)
8	
7	
6	**Option C** (e.g. 8 km from mill to tailings)
5	**Option B** (e.g. 9 km from mill to tailings)
4	
3	
2	
1	

To enable the analyst to introduce their value bias between individual indicators, a weighting factor is applied to each indicator. If the analyst considers the relative "importance" (on his value scale) of one indicator is twice that of another then the relative weightings would be 2 to 1.

For the sub-account considered in Figure 4 (Outdoor recreation, fishing and tourism during operations) the key indicators were identified as the length of trails lost (through the wooded landscape in which the facility was being located), the length of trails and roads from which the tailings facility was visible, the visual impact, and the length of river within 300 m of the tailings site (zone over which recreational fishermen would be disturbed by the presence of the tailings impoundment). The length of hiking trails lost (or replaced) would be 0.5 km. This was the least impact of all tailings sites so it had a numerical value of 9 assigned to it. The relative weight of "hiking trails lost" compared to "visibility of tailings impoundment" and the "disturbance to fishermen" (river within 300 m of tailings impoundment) was judged to be 3, 1 and 5 respectively. The total merit score for this particular tailings impoundment site (Tailings Impoundment Site Option 1) is 59. This score can be compared with scores for other site options for the same sub-account. However, to be able to compare this value against values for other sub-accounts, it is necessary to "normalize" the score on the same 1 to 9 scale used to rate each indicator value. This is achieved by dividing the <u>sub-account merit score</u> by the sum of the weightings to yield the <u>sub-account merit rating</u> (a value in the range of 1 to 9).

For certain sub-accounts the impacts may be similar for the various options. For example the socio-economic impacts do not change with the tailings pond locations. For the selection of the most advantageous option for tailings pond location the socio-economics are not a distinguishing account and the socio-economics can be assigned a neutral value ("N"), or be dropped from the ledger of accounts.
The process of adding together the sub-account merit ratings to obtain the overall rating for the account follows the same procedure of weighting and normalization. Figure 7 illustrates the summation of the sub-accounts for the socio-economic factors defined in Figure 3. The weighting for post closure outdoor recreation, operational recreation and traffic disturbance were assessed to be 3:2:1. The <u>resulting account merit score</u> is 39.4 and the normalized <u>account merit rating</u> is 6.6.

Figure 7. Example of Account Value-Based Decision Process Rating Determination (e.g. Tailings Impoundment Site Option #1).

	Sub-account	Sub-account Merit Rating (R)	Weight (W)	R x W
4.1	Outdoor recreation, fishing and tourism during operations	5.4	2	10.8
4.2	Post Closure outdoor recreation, fishing and tourism	6.8	3	20.4
4.3	Traffic disturbance	8.2	1	8.2
		Account Merit Score	Σ(R x W)	**39.4**
		Account Merit Rating	(RxW)/ΣW	**6.6**

PREFERRED OPTIONS SELECTION

A similar process is used to add together the four main accounts to develop an option merit rating for Tailings Impoundment Option 1. It is now possible to compare the option merit ratings for all tailings impoundment siting options (all values between 1 and 9) and the Preferred Option (or options) identified as the option with the highest merit rating(s).

The list of sub-accounts, indicators, and the ranking, scaling and weighting processes are well defined, transparent and communicatible. The tedium of setting up tables and their completion is well handled by spreadsheets, and the sensitivity of the results can be tested for differences in analysts' opinions or values. The Multiple Accounts Analysis method therefore provides a sound basis for presenting, discussing and exploring differences of opinion (between stakeholders) in what is otherwise a complex value based options selection process.

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