

# TOWARDS BETTER ABANDONED MINE HAZARD PRIORITIZING AN EXPERT SYSTEM APPROACH<sup>1</sup>

by

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**Abstract.** Making strategic decisions related to land rehabilitation is an important and a complex procedure. Any mistake could be very expensive. As a society we need to make decisions based on unbiased judgments. We propose a hazard rating system which allows a decision maker to compare different sites and to set priorities according to selected factors. It is important to have the risk evaluation determined by highly qualified, interdisciplinary experts. Another important factor in decision making procedure is public acceptance. Our system, which is based on examples of existing abandoned mines in Ontario, will provide a technique for taking into consideration both technical and social aspects of the decision making process. An implemented computer system will find the best possible alternative according to the selected preferences (by a panel of human experts). The methodology is based on Multicriteria Analysis and Pairwise Comparisons. The vector of weights (that is a relative importance of all combined objectives and criteria) is derived as the *eigenvector* of the pairwise comparison matrix, corresponding to the largest *eigenvalue*. The proposed expert system will allow us to use interdisciplinary knowledge provided by human experts to prioritize abandoned mine hazards. A reliable rating system will help to integrate diverse perspectives in reclamation for a better allocation of available resources.

**Key Words:** abandoned mines, hazard rating, human experts, expert system, resource allocation.

## 1. Introduction

The Ontario Abandoned Mining Lands Coordinating Committee, under the leadership of the Ministry of Northern Development and Mines, is responsible for coordinating the activities of government agencies involved in the reclamation of orphaned mines to ensure public health and safety and to protect the environment.

The Committee mandate includes:

- locating, identifying and assessing all abandoned mine hazards for which the

province has responsibility to rehabilitate,

- accelerating structural testing and further risk assessment,
- prioritising work and providing technical and procedural advice to appropriate ministries.

Our research focuses on the application of the latest results of *Multiple Criteria Decision Analysis* to data analysis and decision making. The final and the most important target of our

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research is to design an expert system which will provide the Ministry of Northern Development and Mines a solid device for making the important and complex decisions related to abandoned mines. Any decision related to abandoned mine hazards must contribute to the safe and secure living conditions of current and future generations. The best solution is to remove all signs of the abandoned mine which might be hazardous for people and the environment. This however is unrealistic in a short term perspective. This is why locating, identifying, assessing, and prioritising work on abandoned mine hazards is so important. Limited public and private funds should be allocated in a manner that will improve the public health and safety. An *expert system* approach is quite useful in this complex situation. We acknowledge that the *expert system* is based on the existing knowledge of the human experts and according to a current technology. Our approach is interactive in the sense that the solution depends on the input given by human experts. The input may (and usually is) altered by experts on the basis of the system analysis which shows the consequences of the given input to a decision making process. One function of the *expert system* is the creation of a standardized hazard rating system for abandoned mines. This paper summarizes the methodology and assumptions on which our hazard rating system is based. We will be trying to avoid mathematical terms which may only confuse the reader (details can be found in references provided).

Any decision related to abandoned mines impacts on a variety of groups of people. In particular the community which lives around the site is strongly affected by hazard. Taxpayers and different organizations want to know on which basis their money is spent. It is inescapable for a decision maker to arrive at a point in which economic and technical factors must be considered together with political and social factors for the basis of making a decision. All factors should be taken into consideration if a decision maker wants to have the decision based on the solid knowledge. A clear distinction should be made between technical and

measurable factors and social or political factors. In the creation of this abandoned mines hazard rating system we propose a way to link these two (in many cases contrary) aspects of a decision. We believe that a decision maker should be given a broad variety of possible options to work with. It is his/her arbitrary judgment to take or not to take them into consideration. It is nevertheless better to know about all aspects of the decision.

The proposed hazard rating score will consist of a two factors. The first factor will be derived by interviewing mining experts, safety inspectors, environmental experts, medical officers (according to the possible impact to the health of the people living around the site). The second factor will be obtained by reviewing the opinions given by people, formal and informal organizations, local government institutions etc. In general, the second factor characterizes public opinion. For example, the public factor will probably be close to zero for an abandoned mine located in a remote area with airplane access only. This may be an important factor for a decision maker. It could be briefly reported, for instance, as "the given site does not generate any public concern or complaints".

On the basis of our present familiarity with the problem we have considered two groups of criteria. They are recorded by us as technical factors and social factors. The *expert system* is used to calculate a final score for each site according to human expert's assessment. The assessment is done by considering one criterium at a time. For example, the human expert will evaluate all sites according to surface water contamination and will assign certain values (e.g. ranks). This evaluation process will be repeated for all criteria. Our task is now reduced to finding the weights (or relative importance) of each factor. Once having these weights for all factors we will evaluate each mine with the help of the expert system. To do this one must find the *eigenvector* corresponding to the largest *eigenvalue* of a matrix which has been derived from the human experts' judgment of relative importance of criteria.

## 2. Abandoned Mine Hazards

Under the Mining Act (1992, p.67) for the Province of Ontario "abandoned" means the proponent has ceased or suspended indefinitely advanced exploration, mining, or mine production on the site, without rehabilitating the site.

In planing remedial action for abandoned mine hazards Four factors have been considered: public safety, public health, environmental impact and aesthetic consideration. The public interest commonly centres more on aesthetics concerns rather than on public health or environmental impact. The greatest urgency for government agencies however is the identification and remediation of safety hazards. Public health and environmental problems are for the most part associated with mine wastes and effluent. The degree of urgency in implementing remedial action depends on the severity of the effects produced in each individual situation. Work on some projects might be delayed where practical, pending additional research which could lower costs and produce better long term results.

Public safety is largely related to abandoned mine workings and openings to surface, such as open shafts, stopes, adits and raises and areas of potential surface pillar collapse (Mackasey, 1989). The conclusion is drawn from the number of accidents and near accidents related to mine workings and mine openings. The most serious type of accident is likely to occur where significant land development has encroached on mined out lands and the potential for cave-ins has not been investigated. Accidents can also generally be expected to occur near built up areas because the hazardous sites are frequented by a large number of people who do not appreciate the dangers involved. It is therefore more urgent not only to define and remedy hazardous conditions in built up areas and other easily accessible locations as soon as possible, but also the protective measures must be more secure to deter both inadvertent access and planned adventurism.

Because of the complex inter-relationship between the nature of physical hazards and public factors such as location, access, public awareness etc., a hazard cannot be evaluated from its physical characteristic alone. In judging a safety hazard the following factors should be considered:

1. Character of opening, size and attitude (i.e. a steeply inclined empty shaft, stope or steep-walled mining cut should be rated high, whereas an adit, small pit or water filled shaft, should be rated lower).
2. Unsafe ground conditions, such as decayed or loose rock can lead to collapse or burial even when reasonable caution is exercised. Current research on surface crown pillars indicates that the stability of many pillars should be verified.
3. Location near a population centre increases the hazard rating substantially because of the number of people involved. Situations which may not be dangerous to adults can be catastrophic for children.
4. Curiosity encourages exploration which may lead to accidents. Former mining operations with unsafe buildings and unsecured openings such as accessible mine workings are substantially more hazardous than isolated prospect shafts.

The greatest hazards are likely to be unknown or unrecognized ones as illustrated by the types of accidents which have occurred, such as subsidence of insecurely filled stopes and crown pillar failure. Whereas an open stope might also be considered a first order hazard, the false security of backfilled stope or a deteriorated shaft cover could be considered to have a high hazard potential. A mined out area with open stopes and shafts protected by the perimeter fence, cannot be considered safe if children living in the neighbourhood can find ways to enter and play in those areas. A building with decayed walkways and ladders may be more attractive and therefore more hazardous than an

open water-filled shaft which is clearly visible and of very little interest. Because so many abandoned mines are located near built up areas, the character of the hazard and the location of the hazard are both important factors.

### 3. Technical Factors

It is important to have the risk evaluation determined by highly qualified, interdisciplinary experts. This evaluation will be expressed by the group of criteria called technical factors. The short narrative description of these factors is given below.

*Technical factors* represents the evaluation of the hazard of the site given by the highly qualified, interdisciplinary experts. According to the remarks given above, all technical factors could be clustered into four groups: public safety, public health, environment and aesthetics.

*Public Safety* contains the most important factors for the evaluation of the hazard rating score. These factors consider the possible death or serious injury of individuals. Severity can be described using the following terms (factors): the type of the site access, the state of the hazard, the type of the hazard and the magnitude of the hazard.

*Public Health impact* represents the possible level of the negative influence to the health of the individuals living in the vicinity of the site. This group is mostly associated with mine wastes and effluent. The major mine waste problem is mill tailings. These fall into two principal categories non-reactive and reactive tailings. The water or even blowing sand from the tailings areas may carry the harmful contaminants (e.g., mercury, arsenic, asbestos, radioactive substances, heavy metals) and be dangerous to the health of people residing in the area. The possible health

impact might be considered according to long-term and short-term consequences.

*Environmental impact* estimates the degree of the possible contamination of the environment. This group is mainly related to mine wastes. The contamination of the environment might be considered in terms of contamination of ground water, surface water, air or soil.

*Aesthetics and existing land use* should be taken into consideration when developing the system. This group consists of two factors: alternate uses (or proximity to conflicting land uses) and aesthetic appearance.

In each group there are a number of factors according to which the individual site will be evaluated. It is important to have standardized assessment form. This is necessary if we want to have a uniform scoring system for different sites being evaluated. A description of the assessment form currently in use is given at the end of the paper. It is important to note that the risk assessment should be independent of the scoring methodology to be utilized in the next step (which is the risk management step). In other words the method of computing the final score of risk should be flexible enough to accommodate future changes of the assessment form which may be done following the progress of our knowledge of the problem. An interesting attempt of using the approach based on probability theory in risk assessment is presented in Burmaster and Lehr (1991).

We will consider the following criteria in the technical factors group:

*Public safety:*

Site Access will rate the accessibility of the site in terms of ease of access (paved road to the site, gravel road to the site, bush road to the site, 4x4 or foot access only,

water/air access only).

Hazard State stands for the current state the hazard presents (present hazard, probable hazard in future, potential hazard in future)

Type of hazard will be used to rate the level of public safety presented by each hazardous item (equipment or property damage likely, personal injury likely, fatality likely or possible).

Magnitude of hazard will be used to describe the magnitude of the hazard. Two different types of risk are recognized: fixed risk and transient risk of the hazard. In the case of the fixed risk the possible magnitude depends on the "recognition" of the hazard (easily recognized, hard to recognized, hidden). In the case of the transient hazard its magnitude depends on the number of people likely to be affected by the hazard.

#### *Public Health:*

Short-term will represents the possible short-term consequences for the health of the people residing around the site. It might be related to the high degree of pollution and contamination of water or soil (in terms of the negative impact for the human health).

Long-term will represents the possible consequences for the health which might be very difficult to recognize at that moment, but might affect very sensitive individuals (for example newborns or children).

#### *Environment:*

Groundwater represents the possible contamination of the groundwater in terms of possibility (proven, potential), scale (the possible area affected) and the sensitivity of the surrounding

environment (high, moderate or low sensitive).

Surface water represents the possible contamination of the surface water in terms of possibility (proven, potential), scale (the possible area affected) and the sensitivity of the surrounding environment (high, moderate or low sensitive).

Air represents the possible contamination of the air in terms of possibility (proven, potential), scale (the possible area affected) and the sensitivity of the surrounding environment (high, moderate or low sensitive).

Soil represents the possible contamination of the soil in terms of possibility (proven, potential), scale (the possible area affected) and the sensitivity of the surrounding environment (high, moderate or low sensitive).

#### *Aesthetics:*

Land use stands for the existing land use (residential, first nations traditional use, recreational, national/provincial park, commercial, industrial, crown land) and the proximity to other uses. This factor can play a very important role when determining whether planning or land use conflict might be a problem.

Aesthetics describes the appearance of the site (particular mine wastes) in terms of access, visibility and area affected.

## **4. Social Factors**

*Social factors* represent the perception of the possible dangerous consequences of the abandoned mine, express by the local community. It should be the additional (to the technical factors) but very important component for a decision maker. The information can be

Hazard rating score

Technical factors

Social factors

Safety

Health impact

Envir. impact

Aesth. Land

Hazard ev. (local)

Existing record

Hazard ev. (global)

Land use, aesth.

Access  
Hazard state  
Type  
Magnitude

Short-term  
Long-term

Ground-water  
Surface water  
Soil  
Air

Land use  
Aesth.

582

Figure 1. Structure of hazard rating criteria

gathered by interviewing the individuals and the organizations which should, or want to, express their opinion about the existing situation. This would be obtained by asking people to fill in the simple questionnaires. For example to rate the listed number of items from the most to the least dangerous, according to their opinions. This information will, in all likelihood, represent wide variety of opinions. In many situation the opinions will be contradictory and dependent on the particular point of view of a respondent. The decision maker must take this variety of opinions into consideration during the decision making process. There is no doubt, we believe that it is better to recognise and consider these opinions. The proposed system will allow the decision maker to store; update and use this information as required.

In this group the following criteria are proposed:

*Hazard evaluation (local)* stands for the estimation of the hazardous state of the abandoned mine given by the local community, as well as any local organization which wants to express its opinion. It should be considered the most important factor in the group of social factors. Generally speaking the people living around the abandoned mine can be affected by a possible accident so their concerns should be given top consideration.

*Existing record* will cover the complaints which have been expressed by the individual citizens or organizations and the information about the accidents which happened in the past. The intention of this factor is to answer the following question: does the site liberate any negative perception in the community?

*Hazard evaluation (global)* stands for the opinions from a club or association which might create any human activity in the area close to the abandoned mine. For example: Snowmobile Association, Cross Country Skier Club, Hunting and

Fishing Association, etc.

*Aesthetics appearance and land use* will stand for the possible land use or aesthetics appearance of the site. The information could be gathered from the local community, agencies, environmental groups and from the institutions responsible for the future land development.

## 5. Methodology

Having all above criteria listed, the most logical approach at this point is to evaluate each site according to only one criterion. The group of experts should have a standardized assessment form and during the evaluation should follow strictly the rules. Otherwise the results would be useless. We will give the description of the assessment form and point system which is currently in use in Ontario. The ideal assessment form should be designed in collaboration with experts in mining, safety inspectors, environmental experts and risk assessment experts. It would reflect the current state of knowledge related to the risk assessment.

The final goal is to rate all abandoned mines according to their hazards. We should have a procedure which is able to change the numerical values given in the assessment form into certain numerical values which reflect the hazardous condition of the site. We are then face with the problem of assigning a weight to each criterion. We must prioritize all criteria according to their contribution to the final score. The simplest approach to the problem would be to distribute a constant number of points (it might be 100) among the criteria in such a way that the number of points allocated to the criterion reflects its relative importance. In the next paragraph we will give a short description of the method based on *pairwise comparisons*. Having all weights for the criteria and the assessment for the abandoned mine one could simply multiply the score for each criterion by its weight add all results and obtain the score for the mine. This simple

additive method can be easily written in a linear equation form. This procedure is rather widely used (see for example Fowkes, 1989) but has certain weaknesses which in our opinion can be overcome. Two major questions can be raised: 1) does the method of assigning the weights guarantee the proper prioritisation of all criteria and, 2) is the linear additive function the best in calculating the final score for the site?

## 6. Pairwise Comparisons of Criteria

Consider a matrix  $C$  with  $n$  rows and  $n$  columns in which the entry  $c_{ij}$  in  $i$ -th row and  $j$ -th column denotes the relative importance of the criterion (objective)  $i$  compared with objective  $j$ , as expressed by a decision maker or by an expert. Let  $w_i$  denote the unknown weight of the criterion  $i$ . How can the vector  $w = [w_1, w_2, \dots, w_n]$  be estimated on the basis of  $C$ ?

One possible solution can be the following. If the decision maker's or the expert's assessment would be completely consistent, one would have

$$c_{ij} = \frac{w_i}{w_j}$$

for all pairs  $(i, j)$ . It is not difficult to see that in this case:

$$\sum_{j=1}^n c_{ij} w_j = C w_j \quad \text{for all } i, j$$

which reads in matrix form:

$$Cw = nw$$

The last expression is an *eigenvector* expression, indicating that  $n$  is the largest *eigenvalue* of  $C$ , and  $w$  would be the corresponding *eigenvector*. This result holds true in the case of complete consistency. In the case of inconsistencies this is no longer true, however. Therefore Saaty (1977) proposes to estimate  $w$  as the *eigenvector* corresponding to the largest eigenvalue in this

case. It can be shown that the largest eigenvalue is never smaller than  $n$ . Although there is no analytical proof that this method works well for the inconsistent matrices the superiority of this approach is evident for the small number of criteria as proven statistically (Duszak and Koczkodaj, 1992). A new definition of consistency (Koczkodaj, 1993) allows us to locate the most inconsistent judgments and reexamine them. New and more consistent judgements may be expressed in an interactive way. It will contribute to reduction of the overall of inconsistency.

In the case of the hazard rating system we have 16 different criteria. We must assign the weight to each criterion to reflect its relative importance. If we confine our attention only to technical factors we have 12 criteria to be compared. Assigning the weight to each criterion is a very difficult procedure in this case. Having for example 100 points to be distributed among all criteria, or assigning the importance of a criterion in percentage one would probably have a difficult task. The obtained result must have a high degree of credibility. Is the expert absolutely sure that the weights he has obtained are indeed the best and most reliable? The task becomes much more difficult when we have a number of the experts coming from different fields. This is usually the case. Some of them are in favour of one group of criteria and others prefer the other groups of criteria. How can we find a compromise to satisfy all experts? How can the existing conflict of interests be resolved? These types of questions are addressed by the theory of Multiple Criteria Decision Analysis, Multiple Attribute Decision Making, and Concordance Analysis. The theoretical foundations were established at the beginning of the 1970's. The interested reader can find more information in (Nijkamp et al., 1991; Chin-Lai and Kwangsun, 1981).

For the purposes of our system we have selected and modified the part of the theory based on the *pairwise comparisons* and *hierarchy*. As the number of criteria is too large and in many cases very difficult to compare we must cluster them



into groups and build a proper hierarchy. For example how does one compare the contamination of the air with the record of existing complaints from the local community, what is more important and what weights we should assign to these factors?. Instead of comparing all criteria at once the expert should compare criteria or groups of criteria in one level of the hierarchy only. In our approach the largest number of criteria to be compared in one step has been reduced to four. In this case the accuracy of the method based on *pairwise comparisons* and *eigenvectors* is much better than other methods, see Duszak and Koczkodaj (1992). In our case for example the expert or group of experts should answer the following type of questions:

- How many times in your judgment is the group public safety more important than the group environmental impact?
- How many times is the access more important than the magnitude of the hazard in regard to the public safety?

- How many times is the surface water contamination more important than the contamination of the air in regard to negative environmental impact?

The set of questions will be generated by the system according to the existing hierarchy. When the experts, individuals or organizations (in the case of recognition of public preferences) have answered all questions, the system will calculate the weights of all criteria (factors). It is mathematically proven that these weights are the best according to the given answers (judgments). Of course we need a certain standard scale is required to answer the question. The following scale seems to be the most appropriate (Harker and Vargas, 1986) and has been adopted for this study.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two criteria contributed equally to the objective
3	Weak importance of one over another	Experience and judgments slightly favour one criterion over another
5	Essential or strong importance	Experience and judgments strongly favour one criterion over another
7	Demonstrated importance	The criterion is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one criterion over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

Table 1. Comparison Scale

## 7. Risk Assessment

The hazard rating system being proposed conforms with the existing data and existing method of risk evaluation under development by the Ontario Ministry of Northern Development and Mines. All factors in group *public safety, environment* and *aesthetics* have been selected to be consistent with available data. So far there is no available information for *public health*, but even without this data the system is able to evaluate the hazards of each abandoned mine.

The basic step is the evaluation of each site. This part of the problem is related to risk assessment. Of course in real-life situations the assessment of different sites might be given by different groups of experts. From the user and decision maker point of view, attention must be paid for selecting the best interdisciplinary highly qualified group of experts. Because the results gathered from different sites by different experts must be comparable the standardization of the assessment forms should be done before evaluations commence. A short description of the proposed assessment forms and point system used will be given below. It is important to emphasize again the distinction between risk assessment and risk management. Both factors are very important and closely related. Maximum effort should be taken to make sure both above mentioned factors are based on unbiased science, state of the art technology and up to date accumulated knowledge. In creating the hazard rating system our attention is mostly confined to the management of risk. It is clear that the better the risk assessment the better the results we can expect when the decision is made.

### 7.1 Public Safety category description and point system

This will list the type of hazard to be assessed. Each of the following hazards present on the site should be assessed individually:

- surface openings
- pits
- underground subsidence

- blowing fines
- dams/dykes
- buildings(>10sq.m.)
- fire hazard
- chemical hazard
- waste hazard
- explosion hazard
- other hazards

Each hazard should be assessed according to the following criteria: site access, hazard state, type of hazard, magnitude of hazard.

Site access. This section would rate the accessibility of the hazard in terms of ease of access. The following scores should be used:

- populated area, more than 50 people living within one km (paved road to the site), 5 points
- populated area, less than 50 people living within one km (gravel road to the site), 4 points
- remote area, easy access by road or other means (bush road to the site), 3 points
- remote area, poor access by road or other means (4x4/ foot access only), 2 points
- remote area, water or air access only, 1 point

Hazard state. This section would rate the current state the hazard presents. The following scores should be used:

- present or recurrent hazard (i.e. hazard exists), 3 points
- probable hazard in future (i.e. hazard is likely to exist in the near future), 2 points
- potential hazard in future (i.e. hazard may existing in the near future), 1 point

Type of hazard. This section would rate the level of public safety hazard presented by each hazard. The following scores should be used:

- fatality likely or possible, 3 points
- personal injury/ health affects likely, 2 points
- equipment/property damage likely, 1 point

**Magnitude of hazard.** Evaluation in this section should be preceded by the distinction between two types of risk: fixed and transient. The basic difference is that a person would have to go to a fixed hazard, but a transient hazard could come to a person.

The following score should be used to rate the magnitude of hazard for the fixed hazard (e.g. open shaft):

- hidden, 3 points
- obscured/hard to recognize, 2 points
- easily recognized, 1 point

For the transient hazard the magnitude of hazard could be expressed in terms of the number of people likely to be affected by the hazard. The following scores should be used:

- ten or more individuals, 5 points
- four to nine individuals, 4 points
- three individuals, 3 points
- two individuals, 2 points
- one individual, 1 point

### **7.2 Environment category description and point system**

The hazard presented to the four areas of environmental concern:

- ground water e.g., tailings area seep
- surface water e.g., elevated metals in each lake or river affected
- soil e.g., metal contaminated soil in concentrator area or loading areas
- air e.g., blowing dust from tailings area

Each area is evaluated according to the following factors: potential, scale and sensitivity of the surrounding environment.

**Potential.** Weighs the potential of the described hazard to impair the environment. Two categories are defined:

- proven i.e., the hazard has been proven through field study, 2 points
- potential i.e. the hazard is anticipated in the future and could be proven through field study, 1 point

**Scale.** Reflects the extent of proven or potential impact that the hazard presents in hectares:

- more than 100 hectares, 4 points
- 10 - 100 hectares, 3 points
- 1-10 hectares, 2 points
- 0-1 hectares, 1 point

**Sensitivity of the surrounding environment.** Weighs the influence of the hazard on the surrounding environment (e.g. fish and wildlife habitat):

- highly sensitive, 3 points
- moderate sensitive, 2 points
- low sensitive, 1 point

### **7.3 Aesthetics and land use category description and point system**

**Land use.** Other existing land use must be taken into account when determining whether planning or land use conflict will be a factor. A current list would be scored as follows:

- residential area, 5 points
- first nations traditional use, 5 points
- recreational area, 4 points
- national/provincial parks, 4 points
- commercial area, 3 points
- industrial area, 2 points
- crown land, 1 point

Other land uses can be designated as required.

Proximity to other uses can play a very important role in determining land use conflicts. A scoring for each conflict would be determined by the distance to the conflict:

- 0-100 meters, 4 points
- 100-1000 meters, 3 points
- 1000-10000 meters, 3 points
- more than 10000 meters, 1 point

It should be noted that only the highest score for each conflict is to be used in the final scoring for this section. For example a mine/mill is 500m from a commercial area but is 1500m from a residential area. The first example would score 3+3=6. The second example would score 5+2=7. Therefore the score of 7 would be used for this mine/mill conflict.

Aesthetics is evaluated in terms of access, visibility and area affected by the site.

Access weighs ease of access public has to the site:

- paved road, 4 points
- gravel road, 3 points
- bush road, 2 points
- air/water access only, 0 points

Visibility category reflects visibility of mine site from a normal vantage point and is scored as follows:

- highly visible, 2 points
- moderately visible, 1 point
- slightly visible, 0 points

Area affected reflects the area in field of view from normal vantage point affected by special mine activities expressed in hectares:

- more than 100 hectares, 3 points
- 10-100 hectares, 2 points
- 1-10 hectares, 1 point
- less than 1 hectare, 0 points

## 8. Comparison of the Hazard Rating Systems

The previous hazard rating system can lead very easily to heavy misinterpretations of results. As a simple but illustrative example we can consider the following sites. Site A which is one 500 ft. deep shaft and site B approximately at the same place (with the same access) consists of one building, a piece of old machinery and steep embankment. Assume further that the hazards in site B are of the lowest possible category. In this case there is no doubt that the site A is more dangerous than site B and should be scored higher.

The possible evaluation of both sites is given in the table 2. The points assigned to each hazard follow exactly the rules given in the assignment form. Surprisingly the final score obtained by the previous system for the site A is equal to 140 (14 times 10, where 10 is a public safety factor) and for the site B is equal to 240 ((8+8+8) times 10, where 10 is the same public safety factor). This unwanted result is caused by addition of points for each selected hazard.

Site	Assessment points				Score by previous system	Score by new system
	Access	State	Type	Magnitude		
A	5	3	3	3	140	100
B	5	1	1	1	240	80
	5	1	1	1		
	5	1	1	1		

Table 2. Comparison of two sites.

The calculation of the score of the previous system is based on the simple additive formula. This method, however, favours the sites with many hazards. To avoid the situation we have described above we propose another formula for calculating the final score. Let us consider only

one criterion. If we have a hazard with the maximal number of points assigned to it during the evaluation procedure, the score for this site is thus maximal according to this criterion. For all hazards smaller than maximal, we assign a score equal to its ratio to the maximal number of

points assigned under this criterion multiplied by the weight of the criterion. The results obtained by our approach for the two simple examples A and B are summarized in the last column in Table 2. The site A is scored higher (standardized 100 points) than the site B (standardized 80 points) as it was expected. This simple example demonstrates that the scores obtained by our approach are more intuitive and credible than the score obtained by the old system.

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### 10. References

Burmester, D.E., Lehr, J.H. 1991. It's Time to Make Risk Assessment a Science. *Ground Water Monitoring Review*. 1991, editorial.

Ching-Lai H., Kwangsun Y. 1981. *Multiply Attribute Decision Making. Methods and Applications*, Springer-Verlag, Berlin Heidelberg.

Duszak Z., Koczkodaj W.W. 1992. *Statistical Tests of Subjective Judgments based on Pairwise Comparisons*. (Computer Science, Laurentian University, Research Report).

Fowkes J. Site, A computer program for the performance of site ranking for the Wyoming Abandoned Mine Lands. F/W Assoc., Wyoming.

Harker T.P., Vargas L.G. 1987. The theory of Ratio Scale Estimation: Saaty's Analytic Hierarchy Process. *Management Science* Vol. 33 (11) pp. 1386-1403.

Koczkodaj W.W. 1993. A New Definition of Consistency of pairwise Comparisons. *Mathematical and Computer Modelling* (accepted for publication). 1993.

Mackasey W.O. 1989. Concepts in Dealing with Abandoned Mine Hazards. *Surface Crown Pillar Evaluation for Active and Abandoned Metal Mines*. International Conference Proceedings. Timmins. pp. 135-141.

Mining Act, Revised Status of Ontario, 1990, Chapter M.14, (Office Consolidation, January 1992). Printed by the Queen's Printer for Ontario. ISBN 0-7729-6527-7.

Nijkamp P., Rietveld P., Voogd H. 1990. *Multicriteria Evaluation in Physical Planning*, North-Holland, Amsterdam.

Saaty T.L. 1977. Scaling Methods for Priorities in Hierarchical Structure, *Journal of Mathematical Psychology*, vol. 15, 234-281.