THE DEVELOPMENT OF A FIELD METHOD FOR EVALUATING THE SUCCESS OF RECLAMATION EFFORTS ON ABANDONED MINE LANDS[1]

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Abstract: Abandoned Mine Lands (AML) are prevalent throughout Pennsylvania and in other areas of the US. Reclamation of these sites has been an ongoing concern of the Pennsylvania Department of Environmental Resources (PA DER) for over 20 yr. As the state of the technology improves, a variety of techniques have been utilized to rehabilitate AML. These reclamation efforts have resulted in vast improvements in the conditions of the sites, especially in water quality, erosion control, and aesthetic beauty. However, little work has been done to evaluate and document the success of individual reclamation techniques.

Working with the Bureau of Abandoned Mine Reclamation, PA DER, a study was conducted at The Pennsylvania State University to address this need. The main goal of the project was to develop an evaluation system that could be easily carried out in the field by one person. The result of this study was the development of the Reclamation Success Evaluation System (RSES). The system utilizes three main parameters to evaluate reclamation success: (1) Surface Water Quality, (2) Extent of Erosion, and (3) Success of the Vegetative Cover. A series of guidelines and recommendations was developed for each of these evaluation parameters.

The RSES was tested under field conditions by applying it to a watershed that contains both reclaimed and unreclaimed AML sites. This test proved that the RSES is an easily implemented and effective tool for evaluating the success of AML reclamation efforts. The system facilitates the comparison of reclamation efforts at different sites, it can be conducted by one person, and the results are easily interpreted.

Additional Keywords: acid mine dainage, revegetation, remediation.

Introduction

Abandoned Mine Lands (AML) pose a serious threat to the health and safety of humans and to the environment. Because of the direct hazards, the PA DER, Bureau of Abandoned Mine Reclamation (BAMR) has been working to reclaim abandoned mines lands for the last 20 yr. These reclamation efforts have resulted in vast improvements in the conditions of AML sites, especially in areas such as water quality, erosion control, and aesthetic beauty. However, no system exists that can be used to evaluate the long-term success of these reclamation efforts. Such a system would allow the BAMR to evaluate the effectiveness of its past reclamation efforts and to modify its reclamation techniques in order to improve the efficiency and success of its operations.

Working with the BAMR, The Pennsylvania State University developed a system to evaluate the success of AML reclamation efforts. This evaluation system is entitled the Reclamation Success Evaluation System or RSES. The development of the RSES is discussed in this paper. The field testing of the system and the results of the application will be the subject of a future paper.

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Development of the Reclamation Success Evaluation System

Guidelines for Developing the Evaluation System

To develop an effective evaluation system, several important guidelines were set forth. It was determined that the RSES must be easily performed by one person in the field. This requirement is necessary owing to the limited availability of BAMR staff to conduct site evaluations. Also, the varied educational backgrounds of the potential investigators must be taken into consideration. Secondly, because of the nature of AML and reclaimed areas, any necessary equipment must be easily transportable over potentially rough terrain. Thirdly, the RSES should not require a lengthy period of time to acquire the data, the results must be reliable and statistically valid, and the data should not require extensive mathematical manipulations. Overall, simplicity and reliability are the keys to an efficient evaluation system.

Selecting the Evaluation Criteria for the RSES. After carrying out an evaluation of the common disturbances that result both directly and indirectly from mining activities, it was determined that several possible criteria could be used to evaluate the success of a reclamation program. These include surface and ground water quality, changes in surface and ground water quantity, stream sedimentation, suspended solids concentration, surface erosion, soil quality, and the characteristics of the vegetative cover.

After evaluating each of the potential disturbances and assessing the requirements of an effective evaluation system, three evaluation criteria were chosen for the RSES. These are named: (1) Surface Water Quality, (2) Extent of Erosion, and (3) Success of the Vegetative Cover.

The first criterion, Surface Water Quality, is an important key to the success of reclamation and gives indirect clues to the state of the other two parameters. The second criterion, the Extent of Erosion, has broad implications with regards to soil and slope stability, stream pollution, and potential post mining land productivity. As with surface water quality, minimizing erosion is regarded as a crucial goal of surface mine reclamation efforts (Dollhopf *et al.* 1977, Hodder 1975, Toy 1989, Toy and Hadley 1987).

The final parameter, Success of the Vegetative Cover, is linked to the other parameters through the site hydrology and soil stability. Good vegetative cover results in reducing the volume of surface runoff, increases soil and slope stability, and leads to the formation of an organic layer. Also, a lush vegetative growth is visually correlated with successful reclamation. Although questions have been raised concerning the use of the vegetative cover as an effective measurement of reclamation success (Lusby and Toy 1977), this parameter was selected for inclusion because it provides a simple and effective measure of productivity.

Several other parameters could potentially be as effective, or more so, for evaluating the success of reclamation than the three that were ultimately selected for the RSES. Among others, these include soil microbial population, vegetative species, land use, and ground water chemistry. However, the purpose of the RSES is to provide a rapid method of evaluating the success of the reclamation efforts. Most often, these alternate parameters cannot be easily evaluated within the guidelines of this system. They require extensive time, cost and/or resources for their implementation, measurement and evaluation. The RSES can be used as an initial indicator of potential problem and, where required, a further, more detailed evaluation of a property can then be carried out.

Development of the Surface Water Quality Evaluation System

To examine the relationship between reclamation and surface water quality, it was necessary to decide which chemical analyses are required and to establish a detailed field sampling methadology. Because this project was conducted under the auspices of the DER, their laboratory facilities were used to perform all water quality testing. Three major series of DER water sample tests are relevant to AMD pollutants. These are the Basic AMD Analysis (pH, acidity, alkalinity, sulfate, total iron, and ferrous iron), the Basic AMD Analysis plus

Selected Metals (all of the above plus aluminum, manganese, and hardness as total $CaCO_3$), and the Drinking Water Analysis (all of the above plus arsenic, barium, cadmium, chromium, mercury, NO_2 total, NO_3 total, selenium, lead, copper, zinc, and chloride). The specific laboratory procedures used to determine these parameters can be found in "Bureau of Laboratories Methods Manual, Volume I" (Department of Environmental Resources 1992).

To collect the maximum amount of data related to the water quality, the Drinking Water Analysis was chosen for this study, although this degree of thoroughness may not be necessary for all projects. Most projects will probably only require the Basic AMD plus Selected Metals Analysis.

Description of the Surface Water Quality Evaluation System. The surface water quality of a reclaimed area can be evaluated by several different methods. First, it can be compared to standards set by State and/or Federal governments. This could include the US Environmental Protection Agency's (EPA) Drinking Water Standards, the DER's Mine Drainage Discharge Standards, or the Pennsylvania Fish and Game Commission's Stream Classification Criteria. Second, a comparison can be made between historical pre-reclamation and post-reclamation water quality. Finally, a comparison can be made between the water quality upstream and downstream of the project and of specific sites within the project. The optimum method or combination of methods that should be used to compare water quality data for a specific project is dependent on the specific project's field conditions and availability of data.

The first method of evaluation, comparing post-reclamation samples to standards, could be useful when reclamation efforts were initiated to solve a specific water quality problem. The second method involves comparing pre-reclamation and post-reclamation water qualities. Where pre-mine data are available, this method provides a simple and clear analysis of any changes in the water quality over time. Locating historic water quality information and assessing its reliability can, however, be time consuming. It is therefore important to decide what information is necessary for a specific project and how far back in time the data must be searched prior to completing the search.

Possible sources of historic water quality information include National Abandoned Land Inventory System-NALIS (computer database administered by the DER for Pennsylvania); Pennsylvania's Fish and Game Commission; mining permit files, Mining and Reclamation Regional Offices, DER; office files, BAMR, DER (regional offices often have more thorough water quality data than can be found on NALIS); the US Geological Survey (USGS), and NAWDEX (computer data administered by the USGS).

Additional concerns for comparing pre-mining and post-mining water quality include the facts that this method ignores any external impacts on the system, does not take into account the long term or seasonal variations in precipitation or ground water quality, and does not account for the potential impact of new mining activities in the area. These concerns notwithstanding, where historical water quality is available, this method of comparison offers a good picture of how water quality has changed in response to mining and reclamation activities.

The third method involves comparing water samples from points upstream and downstream of the individual sites in a project. This comparison isolates the water chemistry changes that can be attributed to conditions at each site, including any mining, industrial, or human activities that may influence the surface water quality. The upstream and downstream water quality data can also be compared with any reliable historical data.

Application of the Surface Water Quality Evaluation System

The Surface Water Quality Evaluation System for the RSES is conducted by carrying out the following steps:

1. Delineate and map the watershed boundaries (USGS watershed boundaries).

2. Locate and map all known mining areas (or sites): abandoned, active, and reclaimed. These data can be compiled from USGS maps, DER AML Inventory Overlays, the DER Bureau of Mining and Reclamation's Mining Permit Maps, and any other available sources.
3. Search government and mine documents for historical water quality data. These data are used to identify potential sampling point locations. 4. Carry out a field investigation of the project area to confirm the data. Map any undocumented waterways, seeps, and discharges. Other sources of water contamination sources (raw sewage, illegal dumps) should also be recorded.
5. Determine field sampling point locations. Samples should be collected at the headwaters and mouth of the project's main streams, upstream and downstream of each distrubed sites, and from all impoundments, seeps and discharges. Historic sampling point locations should be used wherever possible. In areas that are heavily mined on both sides of the stream, it may be extremely difficult to establish sampling points that will isolate and evaluate the effects of mining operations on one side of the stream. All sampling point locations should be clearly marked in the field and noted on the project map.
6. Collect water samples from all established sample point locations. The water samples should be analyzed for the specific analysis series necessary for the particular project.
7. Analyze the surface water quality data with respect to one or more of the three evaluation methods.

Development of the Extent of Erosion Evaluation System

Evaluating the extent of erosion is a common method of determining the success of reclamation on numerous types of disturbed lands (De Boodt and Gabriels 1978, Schaller and Sutton 1978). In fact, the Surface Mining Control and Reclamation Act of 1977 requires that coal mining companies prevent erosion on their sites and that the site be stable (erosion free) prior to the release of the company's bonds.

The dominant erosional force at abandoned and recently reclaimed mining sites in the Eastern US is water, resulting in sheetwash, rills, gullies, and slumping. Sheetwash is the even removal of a thin layer of soil from a fairly broad area of land by a "sheet" of water that does not create channels. This form of erosion occurs in areas that lack ground cover and quickly leads to the formation of rills and gullies. Rills are very small channels where soil material has been removed due to the concentrated flow of water. Gullies are larger erosional channels where soil and larger material has been eroded away. Slumping is an erosional feature that occurs on a slope due to saturated, unstable soil conditions. Technically, it is the downward movement of a soil or rock mass, usually with a backward rotation on a horizontal axis, parallel to the slope from which it descends (Bates and Jackson 1984). Other, more serious erosional features that are less common at mine sites, but more dangerous, include mud flows, landslides, and debris flows.

Several techniques exist to measure the extent of erosion on a site, including: (1) soil erosion mapping, (2) hill slope profile mapping, and (3) the evaluation of sites with the aid of a visual rating system.

Soil Erosion Mapping. Soil erosion mapping, a method commonly used in agriculture, involves mapping either the actual erosional features or the potential soil erosion hazards. Data collection for this technique utilizes satellite photography, aerial photography, or field surveys. This form of evaluation provides a good visual representation of the erosional features and is adaptable to any scale. However, the method is time consuming and expensive, and its effectiveness has not yet been determined with respect to coal mining and reclamation. Also, the method does not allow an easy comparison of different project and sites, since the results are purely visual. For these reasons, soil erosion mapping did not meet the guidelines of the RSES.

Hill Slope Profile Mapping. Hill slope profile mapping, which looks at cross-sectional views of a hill slope, have been used to assess erosional problems in numerous mining studies (Elliot 1990, Haigh 1980, Haigh and Wallace 1982, Toy 1989). It is an excellent method of examining the relationship between the extent and severity of erosion and hill slope features such as slope grade and concavity. This method requires several surveys of the slope profile over time in order to measure any changes. Owing to extensive time and work requirements, this method was ruled out for use in the RSES.

Visual Rating System Evaluation. The final method, a visual rating system, uses a scale to classify the extent and/or type of erosional features found on a specific site. Although numerous articles are available that detail the use of a rating system to identify potential soil erosion hazards or site erosivity (Bollinne *et al.* 1980, Hallsworth 1987, Morgan 1980), few extend this method further by using it to measure present erosional features (Schwing and Vogt 1980). The method assigns a rating, or classification, to each site or sub-site in a project. A simple example of the classifications would be to place each site into one of four classes: (1) no erosion, (2) limited erosion, (3) moderate erosion, and (4) extensive erosion. Each of the classifications is then assigned a color and mapped onto a project map for visual interpretation. An example of this type of map can be seen in Figure 1 (symbols are utilized instead of colors on this map). Depending upon the detail required for the project, the ratings can be assigned by carrying out a field evaluation of the sites or by the analysis of aerial photographs.

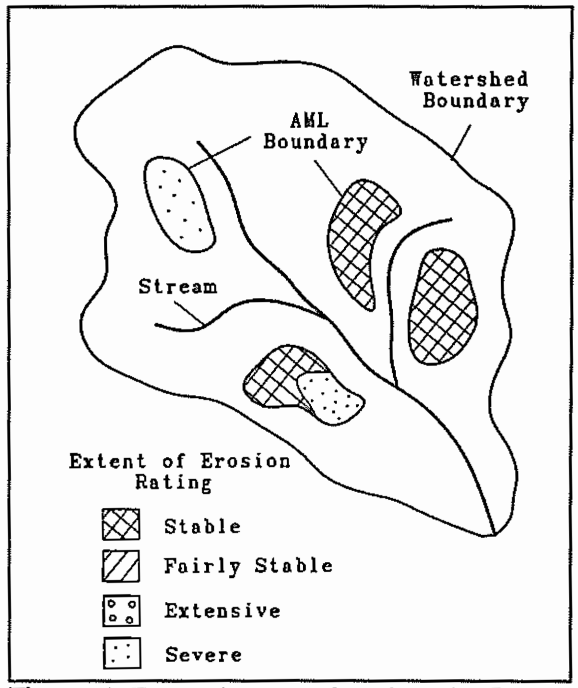

Figure 1. Example map showing the Extent of Erosion Evaluation results.

Application of the Extent of Erosion Evaluation System

Because of its simplicity and ease of evaluation, the Extent of Erosion Evaluation section of the RSES employs the use of a visual rating system. To ensure a uniform evaluation between sites, an Extent of Erosion Evaluation Form was developed. This form (Figure 2), which is self-explanatory and easy to complete, is completed as each site as it is examined in the field. In addition to completing the form, the location of each site should be noted on the project map, and photographs should be taken for future reference. The number of erosion evaluations required for a project will vary depending on the size of the project area and on the detail required for the study.

The extent of erosion at a project can be evaluated by one of three methods: (1) comparison to a nearby undisturbed site, (2) comparison to a nearby abandoned, unreclaimed site, or (3) evaluation of the information on its own. Where historical information is available, the Extent of Erosion data should also be compared to historical records for pre-mining and/or pre-reclamation conditions.

Development of the Success of the Vegetative Cover Evaluation System

The success of the vegetative cover is an important aspect in reclamation because of its impact on other parameters such as soil movement and surface erosion. One method of decreasing erosion is through the interception of raindrops by the vegetative cover. Plants absorb some of the raindrop's kinetic energy, thereby reducing the energy that is available to dislodge soil particles. The degree to which the vegetative cover is effective at reducing erosion is a function of the height and continuity of the plant canopy, the density of the ground cover, and the root density (Morgan 1986). The vegetative cover also dissipates the energy from surface water runoff, thereby decreasing the related erosional force. Since erosion force varies from a cube to a fifth power of velocity, the presence of vegetation is extremely important factor in inhibiting erosion (Morgan 1986).

An increase in the vegetative cover also results in an increases in both the evapotranspiration rate and the infiltration rate (Schwab *et al.* 1981), leading to changes in the water budget. Finally, wildlife diversity and populations respond positively to an increase in available habitat and food supply that is brought on by the establishment of a successful vegetative cover.

Parameters Used To Measure the Vegetative Cover. For the development of the RSES, two decisions had to

EXTENT OF EROSION EVALUATION FORM

RSES

INVESTIGATOR________________________________DATE________________

LOCATION____

SLOPE LENGTH & DEGREE____

DESCRIPTION____

____

____

____

EROSION RATING

1	2	3	4
SEVERE	EXTENSIVE	FAIRLY STABLE	STABLE

EROSION RATING DEFINITIONS:

SEVERE: More than 70% of the site affected by erosional features (gullies, rills, slumps). Erosional features dominate the landscape. Features do not have vegetation associated with them. In general, they extend the entire slope length. They appear to actively eroding or of recent
origin.

EXTENSIVE: More than 30% and less than 70% of the site affected by erosional features. Erosion is an active or recent process. Vegetation is not associated with features.

FAIRLY STABLE: Less than 30% of the site affected by erosional features. Vegetation may be established along rills and gullies. Erosional features do not dominate the landscape--they are not visible from a distance.

STABLE: Erosional features, if present, are vegetated and do not appear active.

Figure 2. Extent of Erosion Evaluation Form for the RSES.

be made with respect to measuring vegetation success: the specific parameter to be measured and the method of measurement. The most common parameters measured in other studies include the percentage, density, and frequency of the vegetative cover (Holmberg 1983). The percentage of the vegetative cover refers either to the percentage of ground surface under live aerial parts of plants (the crown cover) or the aerial parts plus the mulch (the basal cover). Density of the vegetative cover refers to the number of plants per unit area. Frequency of the vegetative cover is the number of plots with a specific plant species divided by the total number of plots (Holmberg 1983).

The frequency and density parameters were ruled out for use with the RSES because of the specialization, time and research required to impliment them. Consequently, the percentage of vegetative cover was chosen as the parameter to measure for the success of the vegetative cover. The Notched Boot Method was selected for determining ground cover percentage because this method does not require any equipment other than paper, a pencil, and footwear to perform and produces reliable results that are easily interpreted.

Application of the Vegetative Cover Evaluation System

The directions for the Notched Boot Method as outlined in Oleson (1981) and carried out by Office of Surface Mining (1987) follow:

> The examiner makes a "point" - a white mark or notch - about 1/8 inch wide on the tip of one shoe sole. A course is selected, preferably a straight line, which will cross an average or representative part of the sampling area. A transect usually consists of 100 paces. If there is insufficient space to complete the 100 pace transect in a straight line, it may be folded back and forth across the slope. At each two steps (one pace) a hit is recorded if the shoe sole point touches vegetation and a miss is recorded if bare ground is encountered. The average of more than one transect will increase the accuracy of the results.

For this method, only living and dead plant matter that is in direct contact with the soil is recorded. The hits and misses are then transformed into a percentage of the vegetative cover and the results recorded directly onto a field map along with the location of the transects. Unless there is a large diversity in the apparent vegetative cover, it is suggested that one transect be performed for every 10 acres.

For interpretation, these percentages are then grouped into relevant classification ranges. If all areas in a project contain over 80% vegetative cover, for example, the ranges may be 80-85%, 86-90%, 91-95% and 96-100%. However, in areas where the vegetative cover ranges from 0% to 100%, the classification system must be adjusted to include the total range.

As was done with the Extent of Erosion Evaluation, the classification ranges are then assigned a color code to facilitate interpretation and comparison, and the color for each site is recorded on the project map. Figure 3 is an example map of the results (using symbols instead of colors). Because historical data about past vegetative characteristics are usually very limited, information should be gathered from nearby undisturbed sites and abandoned sites for comparison purposes.

Success of the Reclamation Success Evaluation System

To test the applicability of the RSES in the field, it was used to evaluate the reclamation efforts of a watershed in central Pennsylvania. A test case was chosen that contained several unreclaimed abandoned mine sites, active mining sites, and sites that have been reclaimed by BAMR and previous mining companies. The present poor water quality in this area indicated
that AMD is being generated at the mined and/or reclaimed sites.

The RSES proved to be an effective tool for assessing the success of reclamation efforts at the test project. The guidelines that were set forth during the development of the RSES were achieved: (1) The RSES was easily performed by one person in the field, (2) no heavy or cumbersome equipment was required to perform the evaluation, (3) the evaluation system produced reliable results, and (4) the system did not require an extensive amount of time to perform. The major exception to was the time necessary to locate and analyze the historical water quality data, although locating this data becomes easier with time and experience.

Despite the successes, several minor implementation problems become obvious when the RSES was tested in the field. This led to several modifications of the evaluation system.

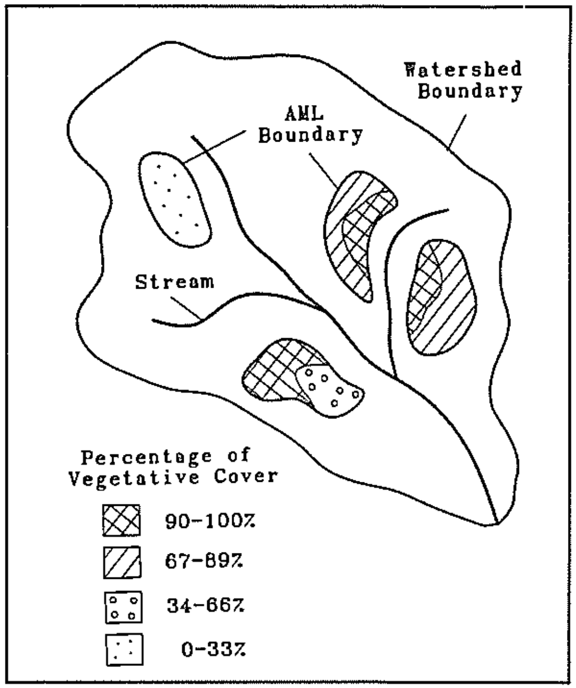

Figure 3. Example map showing the Success of the Vegetative Cover Evaluation results.

Success of the Extent of Erosion Evaluation

The Extent of Erosion Evaluation was extremely successful at fulfilling the RSES guidelines. The largest weakness is the qualitative, visual nature of the measurement. This could lead to wide variations in the results obtained by different investigators. To help minimize the deficiencies associated with the visual rating system, the description of the ratings on the Extent of Erosion Evaluation Form were made more exact, leaving less room for individual variations in interpretations.

Success of the Vegetative Cover Evaluation

The percentage of vegetative cover as the measurement parameter was extremely successful at meeting the RSES guidelines. The Notched Boot Method provided excellent, clear results which are easily interpreted, and it minimized the equipment necessary for the field study. This was important since access to certain areas within the field test site was extremely difficult. The use of color coding provided a system that clearly presents the results for interpretation.

Success of the Surface Water Quality Evaluation

The Surface Water Quality Evaluation was the most complex of the three RSES evaluation parameters, involving the collection of historical water quality data, the establishment of sampling locations, the collection of samples, and the comparison of the data. When this evaluation was tested, a major drawback became apparent - the historical data were difficult to find and to interpret. However, despite its difficulties, this step is necessary to effectively evaluate changes in water quality.

Originally, the RSES used a Surface Water Quality Evaluation Sheet, but re-recording data from the laboratory reports was found to be too cumbersome. As an alternative method, the present system was implemented where the sampling point locations are marked on the project map and the water quality data are grouped and presented in tabular form.

Future Development and Uses of the RSES

The development of the RSES involved analyzing commonly used field practices and adapting the most suitable to the specific requirements of an effective evaluation system. The RSES was designed to be easily performed, yet to be thorough and reliable. These requirements are not easily fulfilled under all potential situations. The RSES, at its present stage of development, does have shortcomings, as any new evaluation system will.

One shortcoming is the lack of consideration given to seasonal and yearly changes within a study area. To alleviate this problem, if time allows, water samples should be collected over a calendar year at regular time intervals, in order to provide a more distinct profile of the seasonal changes in surface water quality. This detail in the evaluation system was beyond the scope and guidelines of the present version of the RSES.

Similar seasonal variations also exist in the vegetative cover. Numerous events can also affect the results of a field investigation, including drought, a harsh winter, variations in plant species, recent seeding or planting of the area, seasonal variations in plant growth, and insect infestation. For a more detailed study, these events need to be taken into consideration.

The test watershed contained a wide variety of conditions that were useful in evaluating the RSES under varying conditions. However, for further development and testing of the RSES, it should be applied to other AML and reclaimed sites. This will further test its effectiveness and reliability under different conditions.

Several improvements to the system are also possible that would make it more efficient. The Surface Water Quality Evaluation System presently lacks a method of categorizing the overall effect of reclamation on water quality. Further research is needed to determine if such a system can be developed and implemented into the RSES, while still meeting the established guidelines. Another possible refinement of the RSES would be the integration of the agricultural technique of Soil Erosion Mapping into the system. This technique shows the potential for providing an effective method of evaluating erosional feature due to mining activities. Future work should also be carried out to examine any correlations between the Success of the Vegetative Cover and the Extent of Erosion results.

There are several potential applications of the RSES to measure the success of reclamation efforts of AML. Informal field investigations have shown that revegetation and control of erosion on AML do not always result in an improvement in surface water quality. This is especially true in areas where AMD is prevalent. An evaluation system such as the RSES could be used to quantitatively verify this informal theory on a broad scale. The results from these site evaluations could then be compared to the reclamation techniques used on the specific sites. This would allow the identification and expanded use of the specific reclamation techniques that are the most successful at improving surface water quality. Conversely, unsuccessful techniques could be eliminated from reclamation practices.

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