Reclamation monitoring: The critical elements of a reclamation monitoring program in western North America. R.L. Johnson, Alberta Environmental Centre, P.J. Burton, University of Illinois, V. Klaassen, Monenco Consultants Limited, P.D. Lulman, TransAlta Utilities Corporation, D. Doram, TransAlta Utilities Corporation.

The potential for serious environmental impacts resulting from large scale surface mining is proportional to the difficulty of reclaiming the disturbed area. Reclamation monitoring programs are designed to measure the extent of environmental disturbance and the rate of recovery. This paper lays out a methodology for selecting, measuring, and interpreting critical elements of a reclamation monitoring program. The end land use is employed as a decision making key to identify the major factors affecting reclamation monitoring and to select the biophysical and economic characteristics requiring measurement. The latter portion of the paper explores the ways of optimizing the efficiency of monitoring programs. It outlines the relative advantages and weaknesses of several sampling designs commonly used in reclamation monitoring.

INTRODUCTION

Surface mine reclamation monitoring attempts to measure the extent of environmental change due to mining activities and the rate of recovery. More specifically, monitoring programs have one or more of the following objectives (Wilkey et al. 1980):

- to provide an overall assessment of the reclamation effort in order to determine its operational effectiveness;
- to develop, demonstrate, and evaluate the needed technologies for future reclamation efforts;
- to address the potential environmental problems that may develop at the mining site; and
- to provide economic assessment necessary to transfer the most cost effective reclamation techniques to future projects.

The achievement of all of these objectives depends on the selection of parameters to be monitored. Common difficulties in the selection of monitoring variables are (1) choosing the most environmentally 'critical' properties and (2) choosing properties which have little natural fluctuation and yet are ecologically or economically interpretable (Ward 1978). For terrestial systems there are few guidelines for parameter selection and no format for the design of monitoring programs.

This paper employs end land use to define the context of reclamation objectives and thereby lay out the precepts of monitoring programs. The selection of specific monitoring variables is predicated on understanding the underlying principles of soil and vegetation development in relation to the post-mining landscape. Finally, we concern ourselves with the design and implementation of a sampling program for reclamation monitoring and the interpretation of the collected results.

LAND USE CONSIDERATIONS IN RECLAMATION MONITORING

Land uses prior to disturbance in proposed mining areas are agriculture, wildlife habitat, forestry and recreation. Potential uses, after mining, are determined by the biophysical environment - soils, climate, water and vegetation - and by the effect of mining and reclamation on the environment. Economic factors, especially when agriculture or forestry is the designated land use, can also be important. Ideally, the end result of reclamation is a landscape where all potential uses, limited only by the environmental and economical restraints, are possible.

Table 1 outlines the major land uses, the dominant factors affecting the choice of land use, and the properties and processes which should be monitored to guage the success of the reclamation program. Although it is not made explicit in Table 1, a well structured program of reclamation monitoring starts prior to mining, and therefore prior to reclamation, in order to establish the baseline conditions of land productivity and stability.

Agriculture Land Use

The factors affecting the planning and use of agricultural land are soils, crops, climate, and economics. The collection of information prior to disturbance should follow standard procedures for soil and crop surveys. Materials handling for reclamation may mean that more detailed scales of surveys need be conducted than those presently available. Also the components of crop productivity (interrelationship of yield, quality, and management) can often be assessed only when site specific information is available. Economic information is often available from published sources like the Alberta Agriculture Consensus of Costs and Return data. Climatic data is important because reclamation conditions may offer new crop production possibilities which must be evaluated for their climatic adaptation.

The objectives of reclamation monitoring follow from the overall goal of establishing land capabilities, crop productivities, and reasonable management costs, similar to those that existed before mining.

TABLE 1

End Land Use Considerations for Reclamation Monitoring

End Land Use	Dominant Influencing Factors	Factors and Processes Monitored
Agriculture	Vegetation	Cropping pattern, productivity, % cover.
	Soils	Soil fertility, chemistry, water, structure.
	Climate	Precipitation, evapotranspiration, temperature.
	Cost-Benefit	Capital investment, capital returns.
Wildlife	Species	Species diversity, numbers, area required for habitat.
	Vegetation	Diversity, % cover, palatability, succession.
	Soils	Landscape, toxic elements.
	Water	Quantity, quality of surface reserves.
Forestry	Vegetation	Establishment, productivity.
	Soils	Soil quality and site index.
	Water	Surface water.
	Cost-Benefit	Capital investments, capital returns.
Recreation	Vegetation	Species diversity, % cover.
	Soils	Landscape, soil mechanics.
	Water	Type (rivers, lakes, etc.) quantity and quality of surface reserves.

Wildlife Land Use

There are no government guidelines in Alberta dealing with areas to be returned to wildlife use, but two logical objectives follow from any consideration of wildlife habitat:

1. Successful habitation of a reclaimed area by the same or similar wildlife species present on pre-mined lands.
2. Development of a diverse, self-sustaining ecosystem which favours the proliferation of the desired wildlife species and does not require maintenance.

The components required in a monitoring program for wildlife habitat reclamation are conveniently broken into one pre-disturbance and three post-disturbance stages (Table 2). The need for information collected prior to disturbance is often met in formulating an environmental impact assessment, but reclamation monitoring after mining must concentrate on the interrelationship of wildlife species, vegetative production and diversity, and the availability and the quality of water. It is evident that topography and soils will affect these relationships directly but are secondary in a monitoring program to considerations of food, water, and shelter to the wildlife populations.

Forestry Land Use

The decision to use disturbed land for purposes of commercial forestry implies two objectives: (1) maximizing sustained yield of timber and (2) minimizing cost and time of timber production. The maximization of forest site quality - a concept translate into topographical, soil and vegetation variables by means of "site index" -

TABLE 2

Monitoring Reclamation Progress of Wildlife Habitat

Pre-Mine Environmental Conditions	Phase of Reclamation Program		
	Initiation	Evaluation	Stabilization
- on area to be mined and a control area - wildlife - vegetation & climate - topography & landscape - soils - water	- re-construct topography and landscape - soil replacement with possible ameliorations - revegetation (erosion control, productivity, diversity) - water (location, quality)	- wildlife - species and number using reclaimed area in comparison to a control area (spatial and diversity basis) - vegetation - growth rate analysis, community diversity by quantity index, turnover of plant communities (succession), use by wildlife as food and cover, etc.	- use of reclaimed area by similar species and numbers of wildlife as found on control area - diversity and productivity of plant community comparible to original community - similar to original or control vegetation with the ability to maintain itself (ecological stability)

is the most logical basis for achieving an acceptable level of productivity and minimizing long-term inputs. Since the measurement of site index, prior to disturbance, results in the identification of the critical environmental factors governing forest productivity, operational reclamation can design a landscape which optimizes site quality.

Reclamation programs and post reclamation monitoring will then use standard reforestation strategies to make optimal use of reclaimed areas. The choice of tree species, the density of tree establishment, and the eventual measurement of site index on reclaimed lands are the three components of value to the commercial forestry monitoring program.

Recreation Land Use

The designation of a reclaimed area to recreation land use means that topography, vegetation, soils, and water will be primary factors under consideration. Recreation is a broad term encompassing a wide range of possible activities, and the choice of monitoring variables can only be made after specific decisions are made about the recreational priorities. However, the mixture of trees, shrubs, forbs, and grasses should provide for a variety of uses. Soil properties of specific interest to recreation planning and implementation are compactibility and drainage. The quantity and quality of surface and groundwater are also attributes which will be influenced directly by recreational activities.

BIOPHYSICAL COMPONENTS OF RECLAMATION MONITORING

The most important and most difficult step in the design of monitoring programs is the selection of parameters, because reclamation progress is judged successful or unsuccessful by the quantity and rate of change which is measured. The difficulty lies in the selection of the best indicators of ecological recovery and ensuring that the measurements are practical and interpretable.

This paper limits itself to a consideration of two components of a terrestial monitoring program - vegetation and soil - and uses the underlying principles of vegetation and soil development in post-mining landscapes to identify the critical parameters of reclamation monitoring. The processes most important to the evaluation of stable plant and soil systems on western North America are:

- plant growth and succession;
- effects of vegetation on soil genesis;
- water balance;
- soil tilth and compaction;
- soil salinity and sodicity; and
- soil nutrient accumulation and supply.

Plant Growth and Succession

The status of the vegetation is indicative of and often determines the status of reclamation as a whole. The methods used for monitoring must be designed such that they are responsive to the processes of plant establishment, plant growth, and community stability. The productivity of planted species is important for assessing agriculture and forestry potential; the successional status of native plant communities is critical to the establishment of wildlife habitat and recreational areas. The success of planted species, the long-term processes of invasion by other plants, turnover in species composition, and community succession must be evaluated in terms of survivial, cover, and productivity.

Land reclamation programs generally include revegetation activities designed to establish a specific plant cover. Seeding and transplanting methods are used to establish monocultures or species mixtures for the purposes of erosion control, to assist in soil development, and to return the land surface to a productive use. The success exhibited by the introduced plants is an item of primary interest in assessing the reclamation status of a management area and hence in redesigning and improving future revegetation programs. The processes and conditions critical to defining the success of vegetation managed for production purposes are: germination and emergence, biomass productivity, plant vigour and survival, and longevity.

It is just as important to consider the long-term dynamics of a newly planted vegetative community as it is to determine the success achieved in establishing and growing introduced plants. These are some of the questions relevant to reclamation planning that the monitoring of plant community dynamics can address:

- How long can a seeded plant cover remain viable and productive?
- Which species of native plants invade a revegetated area of minespoil over time?

- Are invading species noxious weeds or are they amenable to future land uses and the improvement of soil quality?
- At what stage do plant community changes decelerate or become unimportant, and how long does it take to reach such a stage?
- How can natural community changes be managed or enhanced to achieve a desired land use at least expense?

The mechanisms of succession as first interpreted by Clements (1916) still provide a useful framework for the analysis and discussion of successional phenomena and the factors which are thought to govern such phenomena:

- exposure or deposition of a new substrate;
- invasion, either by sprouting of plant parts already present, or by the immigration of disseminules from surrounding areas;
- excesis, or stand development, referring to the germination, establishment, growth, and reproduction of the biota;
- competition among the plant individuals and populations, thereby modifying the development process;
- site or habitat modification resulting from the presence of plants and animals, further influencing the success of existing populations and the establishment of future species; and
- final stabilization of species composition.

The study of plant community dynamics and long-term succession can be difficult. The key aspect of the successional process is the change in plant populations. Vegetational changes are often so slow that they are very difficult to detect and measure, especially in later stages of succession.

Effects of Vegetation on Soil Genesis

The manipulation of vegetation types in relation to different parent material is critical to achieving full reclamation potential (Curry 1978). In a comparison of minesoil development in Montana covering 50 years of reclamation, Schafer et al. (1979) show that modern techniques of overburden and soil classification coupled with contemporary practices of vegetation management are more effective in re-establishing productive grassland communities in five years than 50 years of natural succession on poor quality mine soil.

Water Balance

The most important physical property of soils governing the successful re-establishment of vegetation on surface mined land in Western Canada is water balance. Reclamation of semi-arid (250 to 500 mm precipitation per year) environments depends on the conservation and efficient utilization of a limited precipitation. Under these conditions infiltration, runoff, leaching, and evaporation must be controlled to maximize the root absorption of soil water and the dry matter production per unit of soil water used. The soil properties which have been shown to affect runoff erosion on mined lands are: texture, rock fragmentation, exchangeable sodium, bulk density, and clay type (Power et al. 1978).

Soil Tilth and Compaction

Surface mining and reclamation involve the use of heavy machinery for the excavation and replacement of large quantities of overburden and soil. Machine traffic can cause soil compation to a degree at which growth is impeded. Even though frost action and wetting and drying cycles (pedoturbation) will loosen most compacted zones near the surface, compacted layers below 50 centimeters can persist indefinitely. The soil properties that are measured to assess the extent and effect of compaction are: strength, structure, consistence, plasticity, aggregrate size and stability, and bulk density.

Soil Salinity and Sodicity

In surveying the problems of salt-affected soils in mined areas, Sandoval and Gould (1978) summarize their observations about the interactions of soil quality and soluble salts in these points:

- salinization is reversible and frequently controllable.
- sodic soils often show a lack of structural stability and a severely restricted infiltration rate, and therefore need special treatment for improvement and management.
- chloride(Cl^-) and sodium (Na^+) are most often the specific ions causing direct plant toxicity.
- when chloride or sodium is toxic boron (B) can accumulate in toxic amounts.
- calcium (Ca^{2+}) uptake by plants is often reduced in sodic salts as a result of sodium induced deficiencies.
- phosphorus solubilities increases with sodium domination of the soil exchange complex, but plant assimilation of phosphorus at high pH values is less than at neutral soil pH levels.

In the assessment of processes affecting mined lands which involve salinization and/or an increases in exchangeable sodium, the dynamics of salt and water flow are the primary determinants of the severity of deteriorating soil quality and should form the basis for prescribing remedial action. The most commonly monitored variables which can be interpreted for diagnostic or remedial purposes are: hydraulic conductivity, soluble cations and anions, saturation percent, exchangeable cations, cation exchange capacity, pH, and electrical conductivity. Calculations of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are valuable indices of cation relationships.

Soil Nutrient Accumulation and Supply

Soil fertility is of major importance in regulating plant growth on mined lands. The two primary components of soil fertility are organic matter content and cation exchange capacity. Reclamation can begin from a premise that soil science has shown to be valid: any practice which increases the production and protection of stable soil organic matter (humus) will enhance the quality of the soil environment. The humus acts as the reservoir of nutrient elements in soils; most of the soil nitrogen, phosphorus, and sulphur are contained in the organo-mineral complexes (Witkamp 1971). Furthermore, humus provides the soil with an increased surface area which enhances the exchange capacity; it acts as a glue in soil structure affecting both micro- and macrostructures; it decreases bulk density, thereby aiding infiltration and water percolation; and it increases water holding capacity (Allison 1973).

Cation exchange capacity is the capacity of the soil to hold cations and to exchange species of these ions in reversible chemical reactions. The two components of total cation exchange capacity in the soils - the mineral and organic colloids - are often imbalanced in developing soil profiles. The contribution of the mineral fraction is fixed by the kinds and amounts of clay minerals, and only intense weathering processes can affect it. The organic fraction, on the other hand, is a result of biological activity, in soil, and although it may make a negligible contribution in the beginning, the organic colloids can increase rapidly after initial vegetative colonization (Olson 1958, Chandler 1942).

Essential nutrients are divided somewhat arbitrarily into those required by the plant in large or small quantities. Nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium, are used in tens or hundreds of kilograms per hectare per year; and the micro-nutrients or trace elements may be used in kilograms or grams per hectare per year. The difference between total nutrient content and available nutrient levels in soil is great for nearly all elements. Therefore, it is often important to measure both pools in order to relate present availability to future demands and increases in pool size.

Overall, a reclamation monitoring program must reflect the vegetation and soil interactions expected under the environmental conditions prevalent in the plains and mountain areas of western North America. The critical measurements will depend upon land use, geology, and climate, but in nearly all cases some aspect of plant growth, plant community succession, water balance, soil tilth, salinity or sodicity, and soil fertility will be included (Table 3). The specific properties

TABLE 3

Critical Components and Related Properties of a Reclamation Monitoring Program in Western North America

Component	Properties
Plant Growth and Succession	Biomass productivity Cover Longevity
Effect of Vegetation on Soil Genesis	Organic matter accumulation Rooting depths
Water Balance	Infiltration Runoff Water holding capacity Hydraulic conductivity
Soil Tilth and Compaction	Soil strength Bulk density
Salinity and Sodicity	Saturation percent Soluble cations and anions Electrical conductivity Exchangeable cations and cation exchange capacity pH
Soil Nutrient Accumulation and Supply	texture pH total and available nitrogen carbon-nitrogen ratio Available phosphorus Available potassium Available sulphur

included in a monitoring program will reflect the special problems of soil, geology, and climate, the rate of plant community and soil development, and the level of understanding of undisturbed ecosystem interactions.

SAMPLING DESIGN AND STATISTICAL ANALYSIS

The evaluation of reclamation progress and success must be quantitative. A visual or subjective assessment of large areas of reclaimed land my be important to aesthetics and public acceptance of reclamation success, but qualitative assessments cannot answer many of the most important question which a monitoring program must address:

- Is productivity the same as it was before mining?
- Is productivity increasing and at what values will it level off?
- What soil nutrients are limiting and how much fertilizer should be applied?
- Is the ecosystem stable and self-maintaining?

Questions of this kind require numerical analytical data in order to be answered.

A consistent sampling program must be developed and followed which will give a representative description of the population or area under study. The first step is to define the population and choose a sampling design. The next step is to decide on the size of sample; in general, the larger the size, the more closely a sample is expected to represent a population. The choice of an appropriate sample size depends on the level of reliability desired, the variability of the population, and the cost of sampling.

Sample selection can be subjective, random or systematic. Subjective sampling requires that an individual, who is well acquainted with the material, choose samples which are considered representative. Such a procedure may be carried out where only a very few samples can be analyzed, and is completely dependent on the knowledge and skill of the sampler. Random sampling is usuallly superior to subjective methods of sample selection, because each unit of a population or an area has an equal probability of being chosen and there is a theoretical basis for the quantitative evaluation of a sample's quality or error. Probability theory can be applied and objective conclusions can be drawn. Systematic samples can be successfully representative if the even-spaced interval over which samples are selected has no relationship to any periodicity of the response being measured.

If a major objective of a study is to compare different subsets of a population, as well as to document the status of the whole population, or if the population or study area is very heterogeneous, stratified random sampling may be desireable. If separate random samples are selected from each natural or otherwise predetermined stratum (subset) of the population, population variance is decreased. Variance could alternatively be decreased by increasing the sample number in an unstratified random sample.

Although a number of different formulae can be used to determine the appropriate number of samples needed to represent a population, they reduce to a common form:

$$n = \frac{Z^2 S^2}{e^2},$$

where n = the number of samples required
Z = standard normal deviate,
S^2 = variance, the square of standard deviation,
and e = tolerable error or conficence limits, expressed in the units being measure.

If the original calculation of variance (S^2) is based on less than 60 samples, it is adviseable to substitute t^2 (from Student's tabulated t values) for Z^2.

Other statistical considerations which are important to reclamation monitoring are (1) the use of permanent plots in place of successive random sampling, (2) the methods of evaluating statistical significance of differences, and (3) the use of time series analysis or simulation modelling for predictive purposes. The advantages and disadvantages of permanent plot sampling have not been tabulated to date. Orloci (1978) and Wester (1977) have discussed the use of simple and multivariate analysis for evaluating changes in biophysical variables over space and times. The use of time series analysis and modelling has been fully reviewed by Pielou (1981) and Kessel (1980).

In summary, a reclamation monitoring program in western North America can be made most efficient and effective by considering a minimum of three stages:

1. A decision of land use to which the reclamation effort is directed.
2. An evaluation of biophysical components, including vegetation, soils, and climate, which influence the reestablishment of a stable plant community. The choice of specific monitoring variables, such as plant productivity, organic matter accumulation or exchangeable sodium percentage, will follow from the selection of critical components.
3. The design and implementation of an adequate sampling program to quantitatively measure the rate of change and degree of stability in vegetation and soils.

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NINTH ANNUAL MEETING CANADIAN LAND RECLAMATION ASSOCIATION

RECLAMATION IN MOUNTAINS, FOOTHILLS AND PLAINS: **DOING IT RIGHT!**

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