Alternatives for the Reclamation of Surface Mined Lands

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While the main focus of this report is the formation of lakes from former surface mines, this chapter briefly considers other alternatives for surface mine reclamation. The reasons for discussing other after uses, such as forestry, agriculture, natural wildlife and recreation, are twofold. Firstly, formation of lakes from former mine excavations will not always be the best strategy, and may even be difficult under some geological conditions. Secondly, in cases where the generation of lakes is the chosen approach, consideration will often still be required for impacted lands immediately surrounding the water body. In many existing reclamation schemes a mix of alternatives is chosen.

Reclamation of surface mined lands has been undertaken for over a century or more; however, it would seem that over the last 20 or so years there has been increased interest in reclamation strategies. Richardson (1977) notes that tree plantations were used to restore acid shale tips in Cumbria, England in 1898. Forestation of mine spoils in North America started in Indiana in 1928 (Medvick 1980). Increasing concern over restoration practices in recent decades has resulted in tougher regulations, such as the U.S. Surface Mining and Reclamation Act of 1977. Consequently, methods of surface mine reclamation continue to be studied and developed.

Given the large amount of previous work on the subject of reclamation, much of which is undertaken by the mining industry itself, no attempt will be made here to cover the topic in its entirety. Rather, an overview of surface reclamation activity will be given, with slightly more emphasis on practical methodology, as opposed to scientific principles. This chapter draws heavily upon a two-volume text on the subject edited by Hossner (1988), which is a good general source for further information.

1 Climate

The first consideration in any reclamation plan is the climate of the impacted region (U.S. NRC 1981). Precipitation, evapotranspiration, air temperatures and the length of the growing season are particularly important for the establishment of a new environment. Sufficient moisture is required for the establishment and maintenance of vegetation. The timing of rainfall should also be a consideration; it is clearly beneficial that the majority of annual precipitation occurs during the growing season. The frequency and intensity of storms also affect surface run-off and consequently the potential for soil erosion. Air temperatures, and in particular annual extreme values, influence the rate of plant growth, species formation and the rate of soil formation. Plant species diversity and the rate of soil formation will generally be greater at sites with long growing seasons.

While a choice of vegetation native to the region of the reclaimed lands should clearly alleviate concerns over suitability for the climate, consideration should also be given to microclimate effects. Air temperatures close to the ground surface are influenced by soil colour, surface aspect relative to the sun, soil moisture content and shading by existing plant communities (Hadley 1961).

2 Soil Reconstruction

Soil properties are of importance to possibly all reclamation alternatives, so some general discussion of soil reconstruction may be given here, before specifically focussing on forestry, agriculture, and wildlife environments. Post-mining establishment and growth of plants is often more limited by physical aspects of soil, rather than chemical problems (Dollhopf and Postle 1988); thus, the discussion here will give more emphasis to the former. Common physical problems include erosion, crusting, infiltration, compaction, excessive swelling and structural degradation. Generally speaking it is easier to correct for chemical defects, e.g. by the addition of fertilizer, than overcome physical soil problems. However, this generality should be clarified. The objective of reclamation is to create an environment that in the long run does not depend on intensive management in order to maintain a stable landscape (U.S. NRC 1981). A reclamation scheme that requires long-term chemical applications is therefore inadequate.

Arguably the primary physical problem in soil reconstruction is overcoming the effects of compaction. Soil compaction impedes plant growth by restricting water movement, nutrient intake and oxygen; accumulating carbon dioxide; and hindering root development. Further discussion of these problems by Kendle and Schofield (1992) is summarized in Table 1. A particularly crucial consequence of soil compaction is that it results in reduced infiltration capacity, leading to lower water availability, and increased run-off with associated problems of soil erosion. One of the greatest challenges of reclamation is to reestablish a landscape with a sustainable infiltration runoff relationship (U.S. NRC 1981).

One measure of the effect of soil compaction on root growth is the critical bulk density of soil at which root penetration is prevented or severely restricted. Table 2 provides a summary of critical bulk densities for non-mined soils reported by Barnhisel (1988); the data comes from several sources with differing experimental conditions.

Table 1. Effects of soil compaction (based on Kendle and Schofield 1992)

Increased mechanical impedance	Inhibits the ability of roots to push through the soil
Reduced aeration	Larger soil pores are compressed, restricting the movement of water. Oxygen takes longer to enter the soil and carbon dioxide escapes more slowly
Changes in moisture availability	Water is gradually forced from between soil particles. Remaining water is in smaller pores where it is bound tightly to soil particles making it unavailable to plants. Slower flow paths through the soil causes reduced infiltration. Run-off is greater over compacted soil potentially causing erosion of top-soil.
Changes in thermal conductivity	Closer packing of soil particles may give rise to increased thermal conductivity. This has both beneficial and detrimental potential implications
Changes in nutrient availability	Changes in moisture level and oxygen content may effect nutrient availability in several ways: • reduced absorption of nutrients by roots • less nitrogen mineralized from organic matter • increase the exchange of nutrient ions with solid particles • change the valence state of iron or manganese potentially leading to toxic levels of these metals • reduce sulphur to phytotoxic hydrogen sulphide • increase the solubilisation of soil phosphate • cause the anaerobic decomposition of soil nitrate leading to loss of nitrogen
Microbial population changes	Compaction can greatly reduce microbial activity, e.g. inhibiting the mineralisation of soil nitrogen. Some pathogenic diseases are more aggressive on wet, poorly drained soils.

Table 2. Effect of bulk density on root penetration for various plant species (Barnhisel 1988)

Plant species	Critical bulk density	Soil texture
Alfalfa	1.75	Sandy loam
Corn	1.69-1.80	Silty clay
Corn	1.80	Silty clay loam
Corn	1.67	Sandy clay loam
Corn		1.901 Sandy clay loam
Corn	1.80	Silty clay
Cotton	1.70	Sandy clay loam
Cotton	1.87	Sandy loam
Cotton	1.78	Sandy loam
Cotton	1.88	Sandy loam
Grain sorghum	1.60	Silt loam
Soybeans	1.60	Silty clay loam
Sunflower	1.75	Sands
Sunflower	1.46-1.63	Clays
Wheat	1.60	Silt loam

In addition to bulk density, several other soil properties may be measured to determine the suitability of overburden material for use as topsoil or subsoil: particle size distribution, rock fragments, clay mineralogy, hydraulic conductivity or infiltration rate, plant available water holding capacity and erodibility potential (Dollhopf and Postle 1988).

Suitable values for infiltration rates and plant available water are given in Tables 3 and 4 Two common methods of measuring infiltration rates are the use of ring infiltrometers and rainfall simulators (Bertrand 1965; Dingman 1994). Plant available water holding capacity is determined by desorbing the soil in a pressure plate apparatus (Richards 1965).

Table 3. Classification of infiltration rates (U.S. Soil Conservation Service 1951)

Descriptive term	Infiltration rate [mm/hr]
Very rapid	> 254
Rapid	127 – 254
Moderately rapid	63 – 127
Moderate	20 – 63
Moderately slow	5 – 20
Slow	1 – 5
Very slow	< 1

Table 4. Rating of plant available water-holding capacities for various moisture regimes potential (Dollhopf and Postle 1988)

Rating	Aquic and perudic [cm/100 cm]	Udic and ustic [cm/150 cm]	Aridic and xeric [cm/150 cm]
Very low	< 5	< 7.6	< 6.4
Low	5.1 – 7.6	7.6 – 15.2	6.4 – 12.7
Moderate	7.6 – 10.2	15.2 – 22.9	12.7 – 19.0
High	> 10.2	22.9 – 30.5	19.0 – 25.4
Very high		> 30.5	> 25.4

Topsoil for crop use should ideally consist of medium-grained materials such as silt loams, loams or silty clay loams (Jansen and Melsted 1988). Clays and organic matter provide nutrients and stabilize soil structure, but too much of these materials will give poor tilth, low conductivity and poor aeration. In particular, soils with a high content of smectite clay may be prone to shrink-swell, cracking, crusting, high saturation percentages and reduced infiltration; these effects are further increased by the presence of sodium salts (Dollhopf and Postle 1988). Jansen and Melsted (1988) suggest that 20 to 30 % clay or organic content is suitable for the surface and perhaps 20 to 35 % for the subsurface. Soils that are low in organic matter may seal over during heavy precipitation, resulting in low infiltration and crusting upon drying.

Rock fragments are not necessarily undesirable in all reclamation schemes. Many types of rock may hold water at low tension, thus making it more easily available for plant use (Ashby et al. 1984). Rock fragments may additionally reduce evaporation, alter soil temperatures and store additional nutrients (Lutz 1952). Nevertheless, coarse materials do cause difficulties if the end-use of the land is agricultural and requires tillage or mowing.

In well-planned mining operations it is usual to save and store separately the A-horizon of the topsoil when it is rich in organic matter and microorganisms. Placement of A-soil over less nutritious mine spoils yields obvious benefits. Studies in North Dakota showed that vegetation yields increased in proportion to the depth of the topsoil up to a depth of 75 cm (Power 1978). Mixing of A-horizon with sub-soil overburden dilutes beneficial effects.

There may be benefits to segregating and storing other original soil layers. For instance when the A-horizon is too thin, or contains toxic material, it may be worth stockpiling a fertile B-horizon. In areas of the Indiana coal region, deeper Lacustrine sediments were found with organic matter comparable to or surpassing that in the A-horizon (Byrnes et al 1980).

Following the identification of suitable soils, the recontouring of the landscape is a key component of the soil reconstruction process. In addition to improving the aesthetic appearance of land, the primary objective of recontouring is to establish a landscape with a stable infiltration runoff relationship, thereby reducing the potential for erosion. This involves the control of ponding and encouragement of natural drainage. Further objectives of recontouring may be to eliminate landslide potential, control water pollution and eliminate hazards such as high cliffs and deep pits (U.S. EPA 1973).

The recontouring process can in cases improve the utility of the landscape beyond its pre-mining condition. For example grading can remove obstacles and create more favorable slopes for agricultural machinery. Nevertheless, in some countries legislation dictates that landscapes should be returned as near as possible to original contours.

A number of recontouring strategies can be used to combat increased runoff rates, which result from compaction and breakdown of soil structure. One approach is to reduce slopes below their pre-mining gradients to make water flow more slowly over the surface. This strategy was used in the Rhine region of Germany, where slopes were reduced to a maximum gradient of 1.5 % (Heide 1973). Experiments on surface configurations of mined lands by Dollhopf and Goering (1982) found that large surface depressions created by dozers could reduce runoff by 72 % and slope erosion by 92 % in comparison with more conventional chiseling treatment. Furthermore, microtopographic preparations such as chiseling and gouging tend to only be effective at runoff and erosion control for short periods of a year or two before filling with sediment. Dozer basins may be effective from 10 to 50 years. Other runoff control strategies include contoured terraces, furrows and trenches (U.S. NRC 1981; Verma and Thames 1978). Further discussion of the design of post-mining landscapes is given by Schaefer et al. (1980) and Ventura and Dougherty (1980). Computer software can aid in the recontouring design, to reduce costs and assess the aesthetics of a new landscape prior to regrading (Nicholson 1995; Russell 1996).

The type of machinery used in reclamation contouring can have considerable impact upon the extent of soil compaction. Rubber tired earth moving scrapers are poor in this respect. Rear loading dump trucks cause less compaction due to their lower dead weight. Dump trucks do require a separate loading system, but can be more efficient on long hauls. Despite their low ground pressure, dozers will cause compaction in any slightly moist soils. This is because of their large dead weight, compounded by vibration from the dozer tracks and the compressive force applied by the blade when pushing soil. Further discussion of spoil handling techniques is given by Harwood and Thames (1988).

3 Forestry

There are several reasons why forestry might be chosen in a surface mine reclamation scheme: slopes may be too steep for agricultural use; the production of timber gives an economic benefit; or trees might be planted simply for aesthetic reasons.

Once an area has been designated for forestry, two important considerations are whether or not grading of the surface and decompaction are required. As discussed in the previous section, excessive grading of mined lands causes increased compaction and reduced infiltration, leading to poor productivity in vegetation. If a site is generally not toxic to trees and appropriate amounts of nutrients (nitrogen, phosphorus, potassium) are present or can be applied, then survival rates and growth rates for trees may be greater if they are planted on non-graded spoil banks (Powell 1988). Slopes of the soil banks may well be steep, but intermittent depressions will prevent transport of eroded material. Steep banks and depressions also provide shelter to protect vulnerable species from sun and wind in harsh climates (Plass and Powell 1988). If grading can be avoided then a considerable cost saving is also achieved.

Where soils are too compacted for successful forestation, then deep ripping or other forms of decompaction are required. Under such circumstances re-grading may be required in order to create access for decompaction machinery. Powell (1988) suggests that it may be better to perform riping after the placement of top-soil, since the process of placing top-soil may itself cause yet further compaction. Furthermore, any rocks brought to the surface by ripping do not generally impact upon tree growth. However, in the proposed reclamation scheme for a site in Wales the problem of recompaction is avoided by well-organized placement of topsoil (Celtic Energy Ltd. 1997). Following ripping of the overburden, topsoil is to be placed in strips with delivery from the back of a truck. Two excavators, one mounted with a power fork, are used to spread the material and remove large stones. Neither trucks nor excavators pass over the finished surface.

A further technique for decompaction is the use of small explosive charges to create cylindrical holes of up to 50 cm diameter and 75 cm depth, suitable for the placement of a single tree (Richardson 1977).

The choice of tree or shrub species depends upon a number of factors, such as geographic and topographic location, climate, soil characteristics, land management objective, species availability and legal restrictions (Plass and Powell 1988). Considerable knowledge exists with respect to the geographic and climatic zones of species adaptability. Microclimate is also important with greater species selection possible on cooler slopes facing away from the sun. The land management objective may be to create a pleasant woodland with "attractive growth forms, unusual foliage, showy flowers and interesting fruiting bodies" (Davidson 1977); or it may be to create a commercial plantation. Characteristics of several tree and shrub species that are useful to wildlife are given in Table 8. Legal restrictions in some areas may prohibit the choice of anything but native species.

Soil chemistry, and in particular pH, is important in species selection. Tables 5a and b list trees and shrubs that are known to tolerate acid and alkaline spoil material respectively. Powell (1988) notes that the yellow poplar, northern red oak, sycamore, river birch, Norway maple, red maple, sugar maple, cottonwood, bigtooth aspen and quaking aspen will only grow on acid material when no moisture deficiencies exist during the growing season. Several tree species are able to tolerate both acid and alkaline conditions. The European black alder (*Alnus glutinosa*) is particularly hardy and is ideal as a nurse species; it grows rapidly, produces abundant leaf litter and it tolerates a wide range of pH (Richardson 1977).

To establish an attractive mixed forest suitable for wildlife, the species selection should contain a high proportion of hardy, soil–building nurse trees, such as black locust, alder, birch, shrub lespedezas and autumn olive (Powell 1988). Once these trees are established other natural forest vegetation will invade from nearby non-disturbed woodlands. It may take several decades for a diverse well-balanced "natural" forest to form, but in the interim the site will remain stable. If the area is very large and other seed sources are remote, then placement of a few tree spades in strategic locations is desirable. Tree spades should contain a few hardwoods such as oaks, maples and cherry, which are close to seed-bearing age. Soil moisture conditions should also be considered in species selection, with, for example, willows and poplars chosen for wetter areas.

For commercial tree plantations, choice of a single pine or conifer species makes harvesting easier and satisfies market requirements (Plass and Powell 1988). However, to reduce the potential impact of disease or insect damage it may be less risky to establish three or four species with similar growth rates (Powell 1988).

A variety of techniques may be used to plant seedlings or seeds (Plass and Powell 1988). If the terrain is accessible and rock-free, then a mechanical tractor drawn machine can be used to plant seedlings; otherwise hand planting is normal. The seedlings may be planted in growth containers to supply nutrients and minimize damage to roots. In areas with predictable rainfall in the growing season, poplars and willows have been successfully grown from cuttings. An efficient alternative to planting seedlings is to use direct seeding. Seeds may be planted by hand, from a tractor or even by helicopter or fixed-wing aircraft for large areas. Care should be taken when handling seedlings prior to planting, as plants are vulnerable to drying out and other damage while out of the soil (Richardson 1977). In areas of low annual precipitation, such as parts of western USA, new seedlings are sometimes irrigated for the first year using sprinkler systems.

Table 5a. Trees and shrubs known to tolerate acid spoil material (Richardson 1977)

Trees	
Acacia baileyana	acacia
A. melanoxylon	blackwood acacia
Acer negundo	box elder
A. platanoides	Norway maple
A. platanus	American sycamore
A. rubrum	red maple

Table 5.a (continued)

A. saccharum	sugar maple
Alnus glutionosa	European black alder
A. incana	grey alder
Betula nigra	river alder
B. pubescens	birch
B. nigra	river birch
B. verrusoca	silver birch
Elaeagnus umbellata	autumn olive
Larix decidua	European larch
L. leptolepis	Japanese larch
Liquidambar styracifura	sweet gum
Liriodendron tulipifera	yellow polar
Populus deltoides	cottonwood
P. grandidentata	bigtooth aspen
P. tremuloides	quaking aspen
P. x *canadensis*	black Italian poplar hybrids
Pinus banksiana	jack pine
P. contorta	lodgepole pine
P. echinata	short leaf pine
P. nigra var. *Austriana*	Austrian pine
P. nigra var. *calabrica*	Corsican pine
P. resinosa	red pine
P. rigida	pitch pine
P. Strobus	white pine
P. sylvestris	Scots pine
P. virginiana	Virginia pine
Platanus occidentalis	sycamore
Quercus borealis	red oak
Q. rubra	northern red oak
Robinia fertilis	bristly locust
R. pseudoacacia	black locust
Salix x *purpurea*	willow hybrids
Shrubs	
Amorpha fruticosa	false indigo
Eleagnus angustifolium	Russian olive
E. umbellata	autumn olive
Rhux capillina	dwarf sumac

Table 5b. Trees and shrubs known to tolerate alkaline spoil material (Richardson 1977)

Shrubs	
Robinia fertilis	bristly locus
R. hispida	rose acacia
Sarothamnus scoparius	broom
Ulex europaeus	gorse
Trees	
Alnus glutionosa	European black alder
A. incana	grey alder
Betula verrucosa	silver birch

Table 5b. (continued)

Fraxinus excelsior	ash
Juniper	juniper
Larix decidua	European larch
L. leptolepis	Japanese larch
Picea sitchensis	sitka spruce
Pinus banksiana	jack pine
P. nigra var. *Austriana*	Austrian pine
P. resinosa	red pine
P. sylvestris	Scots pine
P. virginiana	Virginia pine
Populus alba	white poplar
P. x *canadensis*	black Italian poplar hybrids
Prunus avium	wild cherry
Robinia pseudoacacia	black locust
Salix alba var. *vittellina*	willow
Salix alba var. *britzensis*	willow
Shrubs	
Atriplex halimus	orache
Colutea aborescens	black senna
Cratoegus monogyna	hawthorn
Eleagnus angustifolium	Russian olive
E. umbellata	autumn olive
Hippophae rhamnoides	sea buckthorn
Lespedeza bicolor	shrub lespedeza
Lonicera maackii	amur honeysuckle
L. tatarica	Tartarian honeysuckle
Ribes aureum	golden currant
Robinia fertilis	bristly locus
R. hispida	rose acacia
Symphoricarpos orbiculatus	coral berry
Ulex europaeus	gorse
Viburnum dentatum	arrowwood

Typical tree density for diverse mixed forest is 2250 trees per hectare (2 m spacing) and 1600 trees per hectare (2.5 m spacing) for tree farms (Powell 1988). Higher density may be used to maximize the production, and encourage the retention, of leaf litter (Celtic Energy Ltd. 1997)

A difficult issue when planning a woodland restoration scheme, is whether or not to grow herbaceous ground cover. Vegetation between the trees may provide desirable supplementary nitrogen. In particular, ground vegetation may be used to stabilize toxic sites prior to forestation. However, an established ground cover will compete with trees for essential nutrients, and thus may be detrimental to growth.

Several approaches may be taken to prevent or remove unwanted ground cover. Once the height of tree seedlings exceeds the height of the ground cover, then cutting or mowing may be effective provided the ground surface is not too rough or steep. To restrict the initial growth of ground cover a plow may be used to turn over vegetation.

Alternatively, herbicides may be applied.

Vogel (1973) notes that there is evidence to suggest that some grasses and legumes are more compatible with trees and shrubs than others. This depends upon rooting characteristics, moisture demands and the growing season.

Fertilizers, lime, mulches and other organic materials may be applied to improve plant growth during early critical years. Fertilizers should be supplied sparingly as excess amounts will clearly encourage vegetative ground cover. Liming is only required for extremely acidic soils. Mulch typically consists of hay, straw and waste wood products reprocessed to a uniform size. Spread on the ground, it encourages the growth of seedlings by reducing surface temperature, controlling soil moisture losses and protecting from prevailing winds. Organic materials may be added to the soil prior to planting in order to provide nutrients and also improve physical characteristics. An example additant is "Biogram", a highly processed sludge, which has been successfully applied at many reforested sites in Wales (Celtic Energy Ltd. 1997). One of the benefits of Biogram is that the most soluble nitrogen forms are rinsed from it during processing. The remaining nitrogen is released slowly over time, rather than being rapidly washed away as leachate.

4
Agriculture

Agricultural land can be broadly classified as cropland, pasture (and hayland) and rangeland. Cropland contains annual, biennial or perennial crops produced on a short-term rotational basis (Powell 1988). Pastureland is used to produce domesticated forage plants for grazing by livestock (American Society for Surface Mining and Reclamation 1983). When grasses and legumes are cut and dried for fodder on a frequent basis, then such land may be classified as hay cropland rather than pasture (Grandt 1988). Rangeland, as commonly seen in the western United States, consists of permanent herbaceous and/or woody vegetation primarily used to provide food for domestic livestock, or indigenous wildlife, without constant management (Powell 1988).

4.1
Pasture

Pastureland is generally the most easy to establish, following soil reclamation, and it is particularly advantageous when soil depths and slopes are such that a continuous vegetative cover is required to prevent erosion (Ries and Stout 1988). In principle a single species or simple mix of species can be planted with minimum effort and expense to provide land stabilization, erosion control and productive pasture.

Powell (1988) outlines the procedure for establishing pasture on reclaimed land. Following contouring, the soil surface may be worked to establish water impounds for the safe capture of excess surface drainage. Topsoil, if available, should be replaced, although reasonable yields of grasses can be achieved by directly planting on non-toxic overburden material.

Following chemical treatment of the soil, a proper seedbed should be established to increase the degree of seed germination and survival. However, there must be some tradeoff between seedbed preparation and site stabilization. Classically, a firm seedbed is desirable. Nevertheless, re-graded or topsoiled mined lands usually have poor soil structure and low infiltration potential. So tillage treatments, e.g., disk or chisel plough, producing increased surface roughness, increased water infiltration and a less dense rooting zone, often give rise to a better long-term yield, even though they do not promote a firmer seedbed.

The species to be planted should ideally seed vigorously, be long-lived, adapt to a range of soil and microclimate conditions, resist disease and insect damage, respond to fertilization and be reasonably drought resistant. Usually a mix of species is required to achieve all of these characteristics. If, as in humid regions, a slow growing grass such as bluegrass is chosen as the dominant species, then faster growing perennials or annual grains may be used in the initial mix to provide erosion control during early months. In semi-arid regions a mixture of cool and warm season species is desirable. The most useful species for pastureland in the semi-arid and arid western USA are crested wheatgrass (*Agropyron cristatum* [L.] Gaertn., *A. desertorum* [Fisch] Scult., and related taxa), tall wheatgrass (*A. elongatum* Host.), intermediate/pubescent wheatgrass (*A. intermedium* [Host] Beauv.), western wheatgrass (*A. smithii* Rydb.), smooth bromegrass and alfalfa (Thornburg 1982).

The seeding time can be very important. It is firstly determined by the species, but also may depend upon microclimate, seedbed preparation, seeding method and the application of mulch. Surface mulches are commonly used to conserve soil moisture and lessen erosion, especially on smooth surfaces.

4.2 Cropland

Grandt (1988) summarizes nine criteria used by the U.S. Soil Conservation service to describe prime cropland:

1. There must exist moisture regimes and available water capacity within a depth of 1 m or in the root zone of less than 1 m, to produce the commonly grown cultivated crops adapted to the region in 7 or more years out of 10 (some regimes are permitted irrigation).

2. Temperature regimes have a mean annual temperature higher than 32°F at a soil depth of 20 in.; mean summer temperature higher than 47°F at a 20 in. depth, with a 0 horizon present; and mean summer temperature higher than 59°F at a 20-in. depth, if no 0 horizon.
3. Soils have pH between 4.5 and 8.4 in all horizons to 1-m depth.
4. There is no water table or the water table is maintained at sufficient depth to allow common cultivated plants to grow.
5. Conductivity of saturation extract is less than 4 mhos/cm and exchangeable sodium percentage (ESP) is less than 15 within 1 m or less of the surface.
6. Soils are not flooded during growing season or are flooded less than once in 2 years.
7. Erodibility factor (K) x percent slope is less than 2 and soil's erodibility factor (I) x climatic factor (C) is less than 60.
8. Permeability rate is at least 0.06 in./hr in the upper 20 in., and mean annual soil temperature at that depth is less than 59°F.
9. There is less than 10 % rock fragments in upper 6 in. coarser than 3 in.

While reclamation of surface-mined lands to these guidelines would be desirable, Powell (1988) considers that such a goal is not completely necessary. It is argued that successful crop growth on reclaimed land can generally be attributed to the existence or creation of physical characteristics that give rise to maximum water infiltration and maximum expansion of the root system. Roots of most agricultural crops can reach depths of 6 ft and achieve horizontal spreading of 4 ft. within a month of growing in a proper environment.

Legumes are perhaps the primary plant species to be used for restoring mined lands to productive cropland use (Grandt 1988). They aid in improving soil tilth, increasing soil nitrogen and improving the numbers, kind and activities of microorganisms, which are important in the decay of organic matter. Alfalfa, sweet clover and birdsfoot trefoil have taproots or modified taproots that adapt well to growth on mined lands.

Forage grasses such as tall fescue (*Festuca arundinacea*), bromegrass (*Bromus inermis*), orchardgrass (*Dactylis glomerata*) and bermuda grass generally establish more slowly on mined lands than do legumes. However, forage grasses are important for stabilizing against erosion and improving soil structure due their fibrous root system.

Small grain crops, e.g. wheat, rye, oats and barley, can be seeded immediately following the re-grading of mined lands. Thus, they are ideal for initial erosion control and as nurse crops for spring-seeded legumes and grasses.

Wheat adapts particularly well to growth on mined soils due to its shallow root system. Grandt (1988) recommends that fungicide-treated wheat should be planted in 8-in. spacings, approximately 1 to 2 in. deep at the rate of 90 lb./acre. It requires large amounts of phosphorus applied in the fall, with 1.5 times the application prior to seeding. Nitrogen should be applied in two application: 20 to 30 lb. N/acre in the fall (drill-applied) and around 50 lb. N/acre in the spring (top-dressed).

High yields of rowcrops have been produced on mined and graded soils even without topsoil. Grandt (1988) reports that yields of corn grown in Knox county, Illinois, USA, eventually exceeded county averages following crop rotation with alfalfa. Corn will perform well under favourable moisture conditions, but is sensitive to moisture stress (Dunker et al. 1982).

Other crops that have been successfully planted on surface mined lands include fruit tress (Seastrom 1965; Fantisch 1973) and vegetables (Mays and Bengston 1978; Jones et al. 1979; Morse and O'Dell 1983).

4.3 Rangeland

Powell (1988) notes that most non-mined native rangelands are not as productive for livestock as they potentially could be. Hence, reclaimed rangeland following surface mining can often be of greater utility. The reclaimed vegetation should, nevertheless, still be similar to pre-mining or nearby vegetation.

Establishment of grasses and forbs is key to productive rangeland. These firstly supply the majority of high quality feed for livestock, and secondly protect the soil from erosion by wind and rain. Suitable grass species must be drought resistant, winter hardy and must fit into livestock and wildlife needs (Asay 1979). Wheatgrasses, needle grasses brome grasses and wildryes have proven suitable in the Northern Great Plains of the USA (Powell 1988). Rangeland in the Southern Great Plains and Intermountain region is predominantly Russian wildrye, mountain bromegrass and wheatgrass. Species in arid areas of the southwestern USA include alkali sacaton, wheatgrasses, Indian ricegrass and wildryes. Blue gamma grass and non-grass species such as alfalfa, sanfoin and yellow sweet clover are also found in all of the above regions.

Supply and control of water is clearly important for establishing ground cover for rangelands in semi-arid and arid regions. Tillage tools can be used to leave very rough surfaces with microridges and small depressions that trap water and give it time to infiltrate. Mulching can also be used effectively to control soil moisture. Supplemental irrigation during the first two-years after planting can promote a long-lasting improvement in species diversity. Typically, irrigation will simulate an above average precipitation year, such as would occur every 2 years out of 10 (Powell 1988).

The establishment of trees and shrubs on reclaimed rangeland adds diversity to the vegetation and generally enhances the utility of the land for wildlife. Some trees and shrubs may naturally invade reclaimed areas, while others may require direct seeding or planting, sometimes with irrigation. Shrubs can be established in arid regions receiving as little as 8 in of rain per year (Aldon

1975; Hassell 1982). Boles (1983) proposes that 1 shrub per 9 m^2 is a sufficient density for rangeland used by both domestic livestock and indigeeous wildlife. For sites developed exclusively for wildlife habitat, a density of 1 shrub per m^2 is recommended in patches covering 5 to 20 % of the total area.

5 Wildlife

Creation of wildlife habitats on reclaimed land may come about under two circumstances (Powell 1988):

1. A critical wildlife habitat was destroyed by the mining operation and so the mining company has as an obligation to restore the habitat close to original conditions. Examples of this type include cases where elk breeding grounds, nesting and feeding sites for eagles, or wetlands have been destroyed.
2. The pre-mining area was a general habitat, but not of crucial significance to one or more particular species. Restoration of wildlife should still be strongly encouraged in such cases, although it may not be a legal requirement. Often, it may be possible to improve upon pre-mining conditions. Habitat enhancement might include planting of seed bearing shrubs, critical placement of brush piles, construction of water resources and creation of borders that did not exist under pre-mining conditions.

A further list of wildlife rehabilitation techniques is given in Table 6.

The choice of vegetation is clearly important. This requires an understanding of the habitat and food preferences of the target wildlife species. Examples of the usefulness to wildlife or various trees and shrubs are given in Table 7. A number of studies of the adaptation of wildlife to reconstructed habitats have been undertaken for various species ranging from large animals down to the smallest microbes. Table 8 provides some example cases. Majer (1989) gives a more comprehensive bibliography of fauna studies in reclaimed lands.

Table 6. Examples of typical wildlife rehabilitation techniques and concomitant benefits (Table 8.1 from Viert (1989))

Technique	Principal benefit
Topogranhic manipulations such as creation of undulating and broken topography, undrained surface depressions, and microtopographic features.	Provides diversity of physical habitat, visual and thermal cover, and the necessary conditions for development of varied biotic habitat features.
Leave intact or modify remaining highwall.	Provides opportunities for cliff nesting raptor species.
Establish or enhance impoundments	Provides still-water habitat, and a source of water for wildlife.

Table 6. (continued)

Direct-haul topsoil for reapplication and spread in nonuniform depths	Native seed and soil microbia aid establishment of floral diversity.
Reconstruct stream channels and streamside habitats.	Predisposes development of riparian systems.
Create large boulder and rock piles randomly distributed about the rehabilitated area.	Provides habitat for small mammals, perch sites for raptors, and substitutes for natural rimrock.
Create large, irregularly shaped brush piles.	Provides temporary substitute for lost micro-habitats and shelters.
Establish shrub/tree plantings along lee sides of rock/brush piles or randomly within rehabilitated area.	Takes advantage of additional snowpack moisture and/or acts as a 'live snowfence'.
Establish shelterbelts within large expanses of rehabilitated grasslands.	Provides wind erosion protection, habitat diversity, and travel routes for wildlife.
Design the shape and spatial distribution of revegetated communities to maximize interspersion and 'edge effect'.	Provides a means to maximize community diversity, wildlife diversity, and wildlife populations.
Select plants to be revegetated based on forage and cover values to wildlife.	Forces consideration of these wildlife needs during seed mix determination.
Improve land management practices to preclude deleterious grazing.	Eliminates habitat degradation due to overutilization by livestock.
Add special structures to rehabilitated areas as necessary (e.g. implanted dead trees for snags, artificial nesting structures, etc.)	Provides for certain physical habitat needs of wildlife species not provided by other techniques.

Table 7. Usefulness to wildlife of various trees and shrubs as cover (C), browse (B), herbage or foliage (H), mast (M), fruit (F) or seeds (S) (from Rafaill and Vogel 1978)

Trees	Uses	Shrubs	Uses
drsEastern red cedar	CFB	Indigobush	CBS
Spruces	CSB	Dogwoods	FBC
Pines	CSB	Hawthorns	CFB
Maples	SB	Autumn olive	FBC
European black alder	CSB	Bicolor lespedeza	SHC
Birches	BSC	Amur privet	FC
Chinese chestnut	MB	Japanese honeysuckle	CBF
Flowering dogwood	FBC	Bush honeysuckle	FBC
Russian olive	FC	Bayberry	FCB
Ashes	SB	Sumacs	FBC
Black walnut	M	Rose	CFBS
Sweetgum	SC	Coralberry	FBC
Tulip poplar	SB	Cranberrybush, arrowwood	FBC
Crab apples	FCB		
Sycamore	SB		
Oaks	MBC		
Black locust	SCB		
Sassafras	BFCS		

Table 8. Example studies of the adaptation of wildlife to reconstructed habitats

Source	Species
Murray (1978)	antelope
Van Waggnor (1978)	small mammals
Parmenter et al. (1985)	vertebrates (cliff-nesting birds, waterfowl, amphibians)
Hingsten and Clark (1984)	small mammals
Allaire (1980)	bird species
Armbruster (1983)	migratory bird species
Phillips and Beske (1989)	golden eagles and other raptors
Holl (1996)	moths
Zarger et al. (1987)	aquatic macroinvertibrates, fish, small mammals, birds
Proctor et al. (1983)	fish and wildlife
Brenner and Helms (1991)	macroinvertibrates
Luff and Hutson (1977)	soil fauna
Starks and Shubert (1982)	soil algae
Armstrong and Bragg (1984)	earthworms
Scullion (1994)	earthworms
Harris and Birch (1989)	microbial activity
Williamson and Johnson (1990)	microbial activity

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