QUARRY RECLAMATION TECHNIQUES

by

Wen-yuan Liu
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Golden, Colorado
Date 12/1/94

Signed: Wen-yuan Liu

Approved: Dr. Matthew J. Hrebar
Engineeering Report Advisor

Golden, Colorado
Date 1/13/95

Dr. Donald W. Gentry
Professor and Head, Department of Mining Engineering
ABSTRACT

This engineering report focuses on quarry reclamation and is divided into three parts: reclamation in Taiwan; reclamation experience in America and Europe, and recommendations for future reclamation in Taiwan.

The Shoushan Limestone Quarry, the oldest in Taiwan, is used as the example in this report. Both the ownership and the mining methods have changed several times over the life of the quarry. Significant effort has been extended to minimize these impacts and to return this quarry to a desirable and useful state. Revegetation, the most important step in the Shouahan reclamation, has made the pit compatible with the surrounding landscape. Moreover, multiple land uses are planned and will begin in the next few years following quarry closure.

Although this reclamation work satisfies the government and most of the public, it is still not a comprehensive reclamation. Reclamation should start in the premining phase. All factors that will affect the environment should be considered and the reclamation plan should be integrated into the mining plan to be compatible with the land use.
plan. The integrated approach is most economical.

The reclamation steps, from planning phase to postmining phase, are discussed in detail. These procedures include premining planning, landforming (integrated with the mining procedure), soil movement, revegetation, and postmining management. The final chapter presents discussion and suggestions relating to the quarry situation in Taiwan.
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1.0 RECLAMATION AT SHOUSHAN QUARRY

This engineering report focuses on quarry reclamation and is divided into three parts: reclamation practices in Taiwan; reclamation practices in America and Europe, and recommendations for future reclamation in Taiwan integrating the best of all practices.

1.1 Introduction

Limestone quarrying is the most common mining activity in Taiwan. Since all quarries located on mountains have been mined for a long time and no systematic plan integrates mining operations with the reclamation, quarrying inevitably has dramatic impacts on those areas with high scenic value. Large scar areas on mountains produce severe visual intrusion on the landscape. Due to urban development, some mines have become closer to the populous areas where buffer regions between mines and urban areas have gradually diminished. Several conflicts still exist between resource extraction and environmental conservation. Most of the people think mining activity will worsen their living
quality and produce low land values. Nevertheless several cases show that a proper reclamation plan could minimize impacts caused by mining activities and increase the land value of contiguous areas.

In Taiwan, limestone quarries are located mainly near the cities of in Kaohsiung, Suao, Chutung, and Hualien (Figure 1.). In order to minimize the effect of mining, the government has mandated that those quarries located on the western coast, where nine-tenths of the total population is concentrated, be closed by 1997. Quarries located in Kaohsiung and Chutung will create serious environmental problems after closure without implementation of a reclamation plan. A proper reclamation plan, made with broad and careful consideration, may solve those problems and promote profitable postmining use for those lands. Two of the plants owned by Taiwan Cement Corporation will close in 1994 and 1997, respectively. Much effort has been devoted to reclamation.

Taiwan Cement Corporation was established in May, 1946. Its business scope includes quarrying and marketing cement raw material and producing and marketing cement products.
Figure 1 Location of limestone resources in Taiwan
The Shoushan Quarry feeds the Kaohsiung Cement plant that produces cement at 1.9 MT/Yr. Mining activity in the Shoushan Quarry was started in 1917 by the Chenyard Corporation, which was owned by the Japanese. At that time, Taiwan was colonized by Japan. After World War II, the ownership of Shoushan Quarry was transferred to the Taiwan Cement Company.

The Shoushan Quarry is located on an eastern mountainside with an elevation from 0 to 280 meters, a north-south length of 800 to 1000 meters, and an east-west width from 200 to 300 meters. The total area is 91.8 hectares. The entire mountain is currently under military supervision.

The mining method of this quarry is bench-cutting. The sequence of bench mining method is from the top to the bottom. Initially, the main haulage roads were constructed from the base of the mountain to the topmost mining limit. After removing soil and trees, the first bench floor was prepared by drilling and blasting. A 10m buffer zone was left between the mine boundary and the first bench wall since 1917. This buffer zone has minimized environmental impacts outside the mine boundary. Bench height ranges from 10 to 12.5 meters.

An individual bench is designed to accommodate
materials-handling equipment utilization and to conform to safety regulations of surface mining including sufficient width to catch most of the fly rock from upper bench blasting. The bench slope is designed at 70 degrees.

The crawler-mounted and self-contained drills are used in drilling holes 7.5 centimeters in diameter. ANFO with gelatin dynamite as a primer is used with average powderfactor of 120-200 g/Mt resulting from the 3.1 M x 3.7 M pattern.

The blasted limestones are loaded by front loaders into trucks. They are then hauled to primary crushers. Three primary crushers, two gyratory crushers and one jaw crusher, each have a capacity of about 500 MT/Hr. After primary crushing to minus 17.5 cm in diameter, the limestone is conveyed to secondary crushers, where size is then reduced to minus 2.5 to 3.5 cm. The raw material is then qualified for the next grinding procedure. The subsequent procedures are associated with manufacturing and will not be discussed in this report.

1.2 Background

1.2.1 Geology

Shoushan Mountain is made of three stratigraphic elements with ages from Pliocene to Pleistocene: 1) the
coral limestones which form the prominent exposure; 2) the inter and superbedded marine shale; and, 3) big slopes of limestone blocks that reach to the sea. The southern side of this quarry is a younger coral limestone, about 30 to 60 meters thick, of light yellow color, overlying more or less horizontally, with an angular unconformity shale formation at about 80 meters elevation. The northern side of this quarry is an older reef limestone, about 10 to 100 meters thick, of white to gray color, with a N 10° - 20°E strike and a 30° - 40° dip to the southeast.

1.2.2 Climate

The Shoushan Quarry area is classified by the Life-zone Classification System as a subtropical moist-forest region. This region is characterized by:

1) Mean annual precipitation between 1000 and 2000 mm
2) Mean temperature between 18°C and 25°C

The average temperature of this area is 24.2°C. The months from May to September are hot with an average temperature of 27.5°C. The average precipitation is 1640 mm/yr and the average evaporation is 2005 mm/yr. May to September is categorized as the rainy season and November to February is the dry season (1).
1.2.3 Soils

The soil formation in this area is affected mainly by climate, topography and parent rocks. Therefore, its physical and chemical characteristics greatly vary. Generally speaking, the soils of this area are reddish brown (5YR4-5/4-8) or reddish brown laterite soils (10YR4-6/4-8), most of which are distributed on flatter topography 1.5 to 4.0 meters deep (2). In some steep topography, the tremendous precipitation caused by typhoons creates severe erosion, so the soil profile remains in a juvenescent phase with poor-development. According to the soil classification in America, this soil is approximately equal to Entisols, or Inceptisols. Because of the poor soil profile, the lithosols are developed with a similar property to the underlying parent rocks. The pH of the soils ranges from 7.6 to 8.2, and contains small traces of the elements N, P, and K.

1.3 Postmining land use

The land-use plan is not thoroughly developed, due to a long-period of excavation and the unpredictable developments of the contiguous areas. This plan has not been finalized at the Shoushan Quarry (3). The major reason is that Shoushan Mountain is the only one in Kaohsiung. The city
government plans to open it to the public, however it has been supervised by the military in the past. From the city government’s standpoint, the plan should align with the government’s plans to maximize the possibility of the most successful development. From the company’s standpoint, it is important to ensure the public well-being as well as to maintain the company’s profit.

The total area covered by this plan is 93.29 hectares. As shown in Table 1.1, 80% of the area can be used for diversified purpose, with slope gradients less than 55%.

Table 1.1 Slope Distributions of the Planned Area (3)

<table>
<thead>
<tr>
<th>Slope (%)</th>
<th>Area (Hectare)</th>
<th>Proportion (%)</th>
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<tr>
<td>0 ≤ S ≤ 30</td>
<td>54.28</td>
<td>58.7</td>
</tr>
<tr>
<td>30 ≤ S ≤ 55</td>
<td>24.44</td>
<td>26.2</td>
</tr>
<tr>
<td>55 &lt; S</td>
<td>14.6</td>
<td>15.1</td>
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The elevations of most areas are between 0 to 50 meters. Only the areas on the western side around the boundary are higher than 150 meters in elevation. The population concentration is affected by the mountain geography, with most of the 109,000 population concentrated on the east side of the mountain.
A number of problems regarding land-use exist: 1) a railroad lies on the east side, a mountain lies on the west side; 2) commercial activities are concentrated on the southern part due to unbalanced development between north and south.

The aim of the proposed plan is to minimize the above problems and to create several positive effects, such as: restoring the visual landscape, maximizing land utilization, promoting living quality, providing several public facilities, and creating a valuable asset to the community.

The land use plan will include residential areas (27.7 hectares); business areas (5 hectares); recreational areas (39 hectares); and other various public facilities. The public facilities will include 1) two parks, 2) an elementary school, 3) a junior high school, 4) areas for sewage disposal, waterworks, and transformer substation, 5) parking lots and squares, 6) a cement museum, 7) roads and green strips.

1.4 Reclamation processes

Systematic reclamation was not begun until 1986. Before that time, reclamation meant only revegetation. Thus, the environment experienced a strong impact. The quarry was mined from top to bottom by a bench-cutting
method. When the upper bench was pushed back, the next lower bench was mined. During the past seventy years, the boundary of the mine area has been changed several times. Every time the boundary was extended upwards, the revegetation on the lower bench located inside the previous boundary would be destroyed in order to comply with the bench-push-back rule.

1.4.1 Bench Removal

The final shape of the benches complied with the surface mining law, with a 10 meter to 12.5 meter bench height, a 12 meter to 15 meter bench width, and a 70 degree slope (See Figure 2.). The bench floors are designed with a three-degree slope to retain runoff. The final slope is around 40°.

1.4.2 Backfilling

(a) Bench slope

Because of long-term excavation and lack of previous soil preservation, it is difficult to replace soil on all the benches. Thus some substitutes were used to make up the deficiency. Backfilling would begin immediately after final excavation of a bench was completed. Bulldozers or backhoes places part of the final blasted rock which is less than 25
Figure 2. The Final Bench Layout of Shoushan Quarry

cm would be placed on the toe of the bench slope at an angle of 35 degrees. A 50 cm layer of fines was spread on the rubble. This layer was made of pure limestone and void of organic material, so an fertilizer (abounding in N. P. K.) at a rate 0.5 kg/m² was added. Finally, a one-meter thick soil layer was spread on the fines. This soil was amended by manure and fertilizer at the rates of 4 kg/M³ and 0.5 kg/m², respectively (See Figure 3.)
(b) Bench floor

Pits, 0.5 meter from the crest line, were excavated at a scale of 1 cubic meter every 5 meters along the crest. The soil was filled in and organic fertilizer was added. A soil berm was constructed along the planted pits. Its functions were to retain the runoff from eroding slope backfill and to work as a growing medium for plants (See Figure 4.).

Figure 3. Slope Backfilling of Shoushan Quarry
1.4.3 Vegetation establishment

(a) Bench slope (See Figure 5.)

For erosion control on the backfilled slopes, quick-growing grasses were usually adopted. Broadcasting is the usual method of introduction. The seed mixtures include *Rhus semialata* (Roxburgh samac), *Miscanthus sinehsis* (sward grass), *Cynodon dactylon* (Bermuda grass), *Sesbania pers* (Sesbania) *Paspalum notatum* (bahia), *Panicum maximum* (Guinea grass), *Boehmeria densiflora* (Purple woodnettle) and
Desmodium intertum (Intortum clover). Vegetation work should be completed before May. Some tree and shrub species were introduced later in order to reach a climax stage. These species included Macaranga tanarius (Macaranga), Hibiscus tiliaceus (Linden hibiscus), Hibiscus syriacus (Shrubby althaea), Broussonetia poyrifera (Common paper mulberry), Leucaena leucocephala (lead tree), and Acacia confusa (Taiwan acacia). Those species were introduced either by seeding or broadcasting.

(b) Bench floor

On the soil berm, most species are the same as the on the bench slope. Additionally, creeper (stolon) species were planted in order to creep down and work as a cover on the bald rock. The creepers applied in this area were Vernonia elliptica (Iron weed), and Wedelia chinensis (Chinese wedelia).

In pit planting, the planted trees were removed from the ground with the root-mass and soil intact and wrapped by hessian. The planting stocks are usually from 1 to 3 meters in height. The suitable stocks in this area were Ficus retusa (small-leaved banyan) and Cassia surattensis (Glossy shower senna). Some reclamation pictures are shown in appendix I.
Figure 5. Revegetation on Shoushan Quarry
1.4.4 Drainage and Runoff Control

There are three kinds of facilities in conducting runoff and minimizing erosion:

a) Chute (See Figure 6.)

The chute was constructed at a slope of 35 degrees along a bench slope. The location of this chute was determined by surveying the lowest point of a bench every 100 meters. Both ends are connected with sediment traps which are used to retain sediment and slow the flow velocity.

b) Gutter

The gutters were constructed on two locations. One was constructed along the bench toe and the other was constructed on the side of the haulage roads. The gutters constructed along the bench toe are used to convey water from the chute. This water is then conducted to the gutters along the haulage road.

c) Sediment Basin

Nine sediment basins with total capacities of 70,000 M³ are located at an elevation between 0 and 50 meters. Their functions are to remove sediment from runoff and protect stream properties below from sedimentation.
Figure 6. Drainage chute constructed on slope at Shoushan Quarry.
2.0 QUARRY RECLAMATION IN AMERICA-REMINING PHASE

Hard rock quarries usually have a long life. Due to the high percentage of transportation cost in their products, generally quarries are located near areas of population concentration. Without careful plans for environmental impact, the quality of life style of the nearby residents will be degraded. Conversely, if quarries are well-planned with proper reclamation methods, environmental impacts will be minimized and valuable land uses can be maximized.

From a reclamation point of view, quarries can be classified as four types (4):

1) Shallow pits with little overburden: the method of reclamation depends greatly on flood potential of the pit. The potential productivity of the reclaimed soil will be determined by the nature of pit floor and the backfill material.

2) Shallow pits with large amounts of overburden: the overburden layers are removed with a large excavator, such as a dragline or bucket wheel excavator, and then dumped back progressively into the previous mined-out
area. In this sequence, mined-out quarries can be restored to their original productivity.

3) Deep pits and quarries with little overburden: in this kind of quarry, backfilling is not possible until the working benches reach the pit boundary. Generally, it will cause a sterile topsoil because of long-time stockpiling.

4) Deep pits and quarries with large amounts of overburden: the mineral deposits in this quarry have fairly high value, such as china clay. The working sequence is downward and outward. The usual problem is to temporarily stockpile the spoil. It is also rarely possible to progressively backfill into worked-out sections.

2.1 Premining planning

A thoughtful premining plan must coordinate the operation plans (i.e., excavation plan and reclamation program) and the site specific and general plans for post-mining land uses. Reclamation is not a separate part of the mining plan. It is a continually integrated operation which starts with initial mine planning, goes through the extraction phase and does not end until the new, postmining land use begins (5).
Before planning, the natural environment of the mine site has to be studied in detail in order to understand the site conditions, such as climate, soil, surface and ground water, topography, vegetation, wildlife and land use. This study provides baseline data which can be used for comparison with environmental data collected during the mining operation. The purpose is to monitor the pollution which will be caused by the mining operation, and to protect the operator if the pollution identified is coming from another source (6).

After knowing the condition of a mine site, the next step is to evaluate and decide on the postmining requirements of the area, consistent with the needs and desires of affected groups. The planner should recognize the interrelationship between the characteristics of the environment, the activities of mining, and the impacts on the public. With this knowledge, the planner can readily analyze alternative mining and reclamation schemes to achieve the best objectives. Ultimately, the last step is to develop a suitable mining, reclamation, and land use scheme which is the most feasible under the particular technical, social, and economic conditions (8). The concept of integrated mine planning is shown diagrammatically in Figure 7.
Figure 7. Sketch of the concept of integrated mining planning (5)
2.2 Site Investigation

Environmental studies required prior to mining are quite detailed. The base line data which should be prepared by the planner include the climate, soils geology, hydrology, vegetation, wildlife, land use and other significant features (8).

Climate

Three important weather phenomena should be investigated: temperature, prevailing wind directions, and precipitation. Seasonal changes in temperature determine the length of the growing season. Wind studies are used to set up the land form to minimize the tendency of erosion. Rain-fall information can assist in controlling erosion and sedimentation.

Soil

It is important to determine how soil will be handled during mining and excavation. The volume thickness profile and fertility status of the soil should be clearly recorded for ease of interpretation and the assessment of changes in the soil after reclamation.
Geology

Geological information (e.g. attitude, depth, thickness, stratigraphy, etc.) is the basis for establishing alternative reclamation and mining plans. Some geological conditions may impose limitations on land use or may dictate that special reclamation practices be applied.

Hydrology

It is important to study the water supply in the mining area, including surface and ground water. The scope of the investigation of surface water includes streams, ponds, reservoirs, drainage ditches, springs and irrigation canals. The scope of information of ground water includes the depth of the water table, direction of ground water movement, and the use condition of the ground water.

Wildlife

Wildlife in the investigated area include birds, animals, and aquatic wildlife. The habitat conditions of existing wildlife which should be investigated include: vegetative cover, water and food availability, species variation and relationship, migratory routes, and reproduction. Inventories of wildlife also have to be made.
Vegetation

Before mining, the inventories of vegetation, including trees, shrubs, and grasses, should be completed. The vegetation inventory should provide some information on the types of species, the amount of each species, maturity and height, and identification of any unique vegetation.

Topography.

The topography of the mine site is an important factor in mine planning since it affects slope stability, drainage, erosion and reclamation practices. The information which should be shown on the map includes: elevations, water bodies, roads, utilities, property boundary and permit area.

Natural Hazards

Some effort should be made to identify potential natural hazards, including areas which are prone to landslides, and areas which are potentially subject to flooding. This identification can help the operator to develop mining plans to avoid potential hazards.

Land Use

Land use data should include the proposed mine site and adjacent areas. The purpose of this data is to help the
regulatory authority to determine if the proposed quarrying operation is compatible with surrounding land uses.

2.3 Land use planning

Quarries have a relatively longer operational life than other kinds of mining activities. They are generally located very near populated areas due to the high percentage cost of transportation in the delivered product. It is difficult to predict and determine the culture, economic, and political climate that will affect postmining land use after 20 or 50 years. As mentioned before, integrated mining, reclamation, and land use planning are the keys to successful mining reclamation. Thus reclamation acts like a bridge by connecting the excavation phase with the postmining phases. Once the objective of the post mining land use plan is known, the excavation and reclamation can be easily organized towards this goal.

In planning the postmining land use, two directions can be followed:

The first direction is that the desired postmining land use is known. All efforts including grading, revegetation, and land forming are directed at achieving the end-use. In reaching the desired use, several guidelines must be kept in mind. First, an assessment should be made to ensure that
adequate technical and financial capabilities are available to reach the desired use. Secondly, the desired use should comply with local land use plans and zoning ordinances. Finally, the community's attitude towards the desired land use should be determined and considered (7).

The second direction is that grading, vegetation, and landforming efforts should be directed towards creating stable landforms having sufficient flexibility to be used in a variety of ways. Final land use typically is not previously known. In some quarries, the land form is characterized by shallow overburden compared to deposit depths. In this case, there is very little backfilling material for landforming, resulting in a significant depression in post mining land forms. Still, final topography that enhance the usefulness and intrinsic value of the land can be determined. Surrounding land use, public opinion, economic trends, and zoning have a direct effect on defining what is feasible (9).

Several possibilities for postmining land use can be described as follows:

1) Housing and industry: if quarries are located near urban areas, they can be developed for residential accommodation, or industrial or commercial land uses. The major restriction on this type of use is drainage
and the stability of the ground for building foundations. As a result, a wet, sand and gravel pit are obviously unsuitable.

2) Sport and intensive recreation: all quarries in urban or residential areas can be used as recreational areas. Also they can provide excellent sites for sporting activities, such as motorcycle race tracks, golf courses, rifle and archery ranges, among other activities.

3) Landfill and waste disposal: quarries can provide very useful sites for disposing domestic and industrial refuse and wastes, especially those near an urban center. Two common problems are associated with this use—public nuisance during the filling operation and the generation of gases and leachates. Possible pollution or impact on the surrounding environment should be evaluated before making a final decision. The filling operation plans must consider subsequent land uses.

4) Agriculture: if area is sufficiently large, adjacent to farming land with suitable soil and topography, it may be suitable for agriculture land use. Management of the land after reclamation must carefully encourage the development of soil structure to build-up natural
fertility.

5) Forestry: this use is an alternative agricultural use for poorer sites and can be combined with other uses, such as recreation. Establishment of trees can stabilize the slope and minimize erosion.

6) Nature conservation and wildlife refuge: many different types of quarries and pits, chalk and limestone quarries, flooded and partly flooded sand and gravel pits, etc., are able to provide wildlife habitat.

7) Water storage: deep quarries and pits that will hold water can be considered for water storage and can be combined with other uses such as recreation.
3.0 LANDFORM DESIGN AND GRADING

Quarrying always causes a significant change in the landscape compared with the previous or surrounding landscapes. In the past, quarry operation was considered only from an engineering and economic standpoint. This perspective attempts to extend the excavatable resources as much as possible and to quarry in the most economical way. Occasionally, it required a huge effort to backfill and reshape the mined-out area in order to create a desired landform. The time schedule for landform design starts before the fixed plant is installed. Overburden removal and excavation are conducted in accordance with the plan to develop the landform to meet the goals of postmining uses. Time and scale of operation are two of the most important factors. Other factors which should be surveyed and taken into account are described as follows:

1) Landscape characteristics, such as rolling or flat
2) Topography, including contours and elevation
3) Ecology, including plant and animal
4) Hydrology, including ground and surface water
5) Communications and communities, such as highways and
nearby habitations (11).

The general objective of this design is to discover the best ways of introducing a new development into the landscape with a minimum disruption to either aesthetic quality of the landscape or to the economic operation of the quarry. In this chapter, some techniques will be discussed for decreasing pit/quarry visibility. Next is a discussion of waste disposal methods with progressive regrading and seeding. Finally, shaping techniques in different types of quarries will be presented in some detail.

3.1 Screening technique

Visual impact problems may be lessened either by concealing the obtrusive feature, improving its appearance, or combining both. Several schemes are as follows:

1) Concealing the working face by changing the working sequences or layout: a quarry face is orientated to reduce visual impact (See Figure 8). In Figure 8(a), the working direction is along the sight-line, so it is visible for the entire mining life. If the direction is changed to be perpendicular to the sight-line, visual intrusion will lessen and progressive revegetation will follow to enhance the mine-out landscape (See Figure 8b) (11). In Figure 9, the
layout of the quarry is changed by leaving part of the resource as a spur to form a sight-line fence. The quarry can be seen from the previous access road as shown in Figure 10. It can be improved by curving the access road. (See Figure 10b)

2) Concealing the working face by constructing screening banks of soil and spoil: some information should be known, such as the quantities of overburden, site characteristics, landform design principles, and the direction of sight lines. If possible, screening banks should be designed as permanent banks which could fit into the landscape. An example (See Figure 11.) presents different screening effects obtained from the same bank by varying its location.

3) Vegetation screening (See Figure 12.): a limestone quarry in Japan, shows a bank 5 meters to 10 meters high formed around the quarry, making it virtually impossible to see the quarry from the outside. Additional, trees growing just outside the bank are not felled until immediately before the bank is leveled in order to act as a natural screen (12).

4) Combining the above methods: in Figure 13(a), quarry visibility and impact on the landscape are potentially increased by advancing the working face away from the
Figure 8. Orientating a quarry face to reduce visual impacts (11)
Figure 9. Using the surrounding topography to schedule quarry outline (11)
Figure 10. Concealing working face by using curving access road (9)
Figure 11. Different screening effects obtained by different location of the same bank (9)
Figure 12. Vegetation screening (15)

viewing point. Impact and visibility can be decreased by:

(a) changing the advance direction toward the viewpoint
(b) planting back slope after backfilling
(c) constructing an earth bank and planting for a future visual screen.
Figure 13. Some combined schemes for decreasing quarry visibility from a constant view point (13)
3.2 Spoil and Waste Dump Construction

In quarrying operations, dump construction should comply with landscape and postmining use plan. The dump could be constructed as a sight-line fence or as a part of a planned landform. Two dumping methods will be discussed in this section,

1) Dumping with progressive reclamation: This method will bring most of the dump into some use as soon as it is completed. This allows more time for growing vegetation and reduces the total impact (Figure 14.).

2) Perimeter dumping: A bank is constructed around the perimeter of the dumping area and rapidly revegetated (11) (Figure 15.).

Before dumping begins, topsoil and subsoil layers should be stripped and stockpiled separately. Some care should be taken to keep the soil in good condition, such as avoiding compaction and temporary seeding. Generally, quarrying and processing activities seldom generate harmful material. However some clay material which is impermeable to water requires extra care. This layer should be spread on the bottom of dumps to prevent future drainage problems.
Figure 14. Conventional dumping & progressive regrading and seeding (11)
Figure 15. Perimeter dumping (11)
3.3 Shaping and grading

Shaping and grading are ways to create the desired landform proposed in the mining plan. Shaping and grading can also improve harmony with the surrounding landscape, the stabilization of mined-out areas, and erosion controls. In this section, two kinds of properties of quarries will be discussed:

3.3.1 Flooded Excavations

Flooded excavations, including permanent-wet pits and intermittently-wet pits, have a water table which rises above the pit floor (14). Those pits can be designed to have several uses, such as wildlife habitat or recreation areas. Before a pit is flooded, it should be graded to provide a final shape which is appropriate to the intended use. If the quarry is designed for wildlife, banks must be shaped to provide shallow water holes in which water plants can root, islands to provide refuge for birds, and secluded bays to provide protected areas for young wild fowl (15). Islands and shallows can be made by backfilling. Those backfill materials can be calculated in the premining plan. Materials handling is the most expensive part of reclamation, so it may be beneficial to leave some materials in place rather than excavating to the full
extent of the property boundary. Various features designed for wildlife are shown in Figure 16.

Figure 16. Wetland reconstruction (10)

3.3.2 Dry Excavation

a) Quarry face

Exposed light rock faces left after excavation are generally not in harmony with the surrounding landscape. For instance, a technique called restoration blasting is applied in Britain. In those limestone quarries, the quarry face is considered to be dynamic landform (16)(17). This technique is the result of applying a series of drilling and blasting
design phases in order to reduce the engineered appearance of a quarry face and try to replicate the landform (buttresses, headwall, vegetated and unvegetated screes) of natural limestone landscape.

Selective blasting is another method to produce the desired natural appearance and stabilize a site. If cliffs will be part of the final landform, then chutes, spurs, scree slopes and rough cliff faces can be created by selectively placing shot holes (Figure 17.). This method also can be used to reclaim benches by placing shot holes which are drilled to progressively shallower depths (Figure 18.).

If enough appropriate overburden material is perched above the quarry and can be moved into position, backfilling against a steep quarry wall can proceed. When grading backfilled material on slopes, the creation of perfectly smooth surfaces should be avoided (7). Smooth surfaces are not as good as rough ones, since roughness keeps soil in place and is better for vegetative establishment. If slopes are longer than 75 feet, they should be shaped with terraces, berms and furrows to reduce erosion on slopes.
overburden or soil to be pushed onto scree slopes

Figure 24. Selective blasting (18)

Figure 25. Reducing bench slope by blasting (18)
b) Quarry floor

Solid rock floors should be blasted to fracture the rock so that water can drain slowly from the site. In addition, the quarry floor should be graded to 2% (1H:50V) and overburden on the floor should be ripped before placing topsoil to create seed beds for revegetation. If topsoil is placed using rubber wheeled equipment, ripping may be necessary to loosen this soil before revegetation.

Hills or boulder piles can be left on site to create a variety of landscapes. They should be covered with soil and seeded to improve the site appearance.

3.4 Runoff and Erosion Control

Most surface mining activities are impossible to excavate without disturbing the overlying vegetation. Disturbed areas experience 2,000 times higher erosion loss than an undisturbed forest site (19). From a reclamation standpoint, the most susceptible for runoff damage on the land surface are between the beginning of the grading operations and the establishment of adequate vegetation, because of extended periods of exposure. In this section, two parts, slope design and drainage system design, will be discussed.
3.4.1 Slope design

This procedure in evaluating an erosion control system can best be introduced in the planning phase. The revised Universal Soil Loss Equation (USLE) is useful for evaluating the erosion potential and expected soil loss during the grading period (20).

The original USLE is

\[ A = R \times K \times L \times S \times C \times P \]  \hspace{1cm} [3.1]

where
- \( A \) = soil loss per unit area
- \( R \) = rainfall
- \( K \) = soil erodability
- \( L \) = slope length
- \( S \) = slope gradient
- \( C \) = cropping management
- \( P \) = erosion control practices

\( C \) and \( P \) relate specifically to agricultural lands. Because slope excavation and rehabilitation are very similar to highway construction, an erosion control factor, \( VM \), can substituted for \( C \) and \( P \). \( VM \) accounts for the effects of all erosion control measures that are applied on any given site. Performance Evaluation (PE), which means how much percent effect there is in controlling the potential erosion of the site, can be obtained from equation [3.2], as follow:

\[ PE = \frac{(RKLS-RKLSVM)}{RKLS} \times 100 \]  \hspace{1cm} [3.2]
The only manageable factors of this equation are the slope factor, LS, and the erosional control factor, VM. The remaining factors are fixed by nature and cannot be changed by human intervention. As a result, planners can reduce the LS factor by choosing a proper combination of slopes and length and determining when to use berms, cross ditches, terraces or other control measures. Also, they can reduce the VM factor by using mulch and revegetation, and reducing the bare exposure time of the slope surface by careful management.

3.4.2 Drainage System Design

Drainage design in a reclaimed site can be divided into two parts: temporary channels which may have to handle 1-year frequency events, and permanent channels which are required to handle 100-year frequency storms (21). The first consideration for drainage design is to estimate the peak runoff (22). The following equation developed by the Soil Conservation Service (SCS) (1972, 1985) combines infiltration losses with initial abstractions, and estimates rainfall excess or the equivalent runoff volume:

\[ Q = \frac{(P - 0.2S)^2}{P + 0.8S}, P > 0.2S \]  \[3.3\]
where
Q = the accumulated runoff volume
P = the accumulated precipitation
S = the maximum soil water retention parameter

S is determined by the following equation: (22)

\[ S = \frac{1000}{CN} - 10 \quad \text{(S in inch)} \quad [3.4] \]
\[ S = \frac{25400}{CN} - 254 \quad \text{(S in mm)} \]

where CN (curve number) is determined by soil texture, soil type, and land use. CN can be checked from in Appendix I, II, III.

The second step is to determine the time of concentration by equation [3.5]:

\[ t_c = \sum_{i=1}^{n} \frac{L_i}{V_i} \quad [3.5] \]

where \( n \) is the number of flow segments, \( L_i \) is the length, and \( V_i \) is the flow velocity for the \( i^{th} \) segment. Flow velocity can be estimated by the following equation:

\[ v = a S^{1/2} \quad [3.6] \]
where $S$ is slope in ft/ft and $v$ is in fps. The coefficient $a$ is referenced in the Appendix V.

The next step is to estimate the peak flow which will enter the drainage system. The peak flow can be estimated by the following equation which was developed by SCS (1986):

$$q_p = q_u A Q F_p$$  \[3.7\]

where $q_p$ is the peak flow in cfs, $q_u$ is the peak discharge in cfs per inch of runoff per square mile, $A$ is the drainage area in square miles, $Q$ is the runoff in inches as described in equation [3.3], and $F_p$ is a pond and swamp adjustment factor. $F_p$ can be determined from the table in the Appendix VI. The value of $q_u$ is computed from the following equation:

$$\log(q_u) = C_0 + C_1 \log t_c + C_2 (\log t_c)^2$$  \[3.8\]

where the $C$'s can be obtained from in Appendix VII, VIII, and $t_c$ is computed from equation [3.5] in hours. An example of peak runoff estimate is shown in Appendix XIII.

The final step is to design the drainage facilities by the following relationship between inflow, $Q$, and channel area, $A$. 
\[ Q = v A \] [3.9]

The velocity factor, \( v \), can be calculated from Manning's equation:

\[
v = \frac{1.49}{n} R^{2/3} S^{1/2} \quad (English \ system) \quad [3.10]
\]

\[
v = \frac{1}{n} R^{2/3} S^{1/2} \quad (Metric \ system)
\]

where \( R \) is the hydraulic radius, equal to the cross-sectional area divided by water perimeter \((R = a/p)\), and \( S \) is a slope factor. Manning's \( n \) can be check from Appendix IX, X.
4.0 SITE PREPARATION

The site preparation essentially consists of reconstructing a plant-growth medium that will create the most favorable quality for plant growth. Once the graded surface is completed, the replacement of soils can proceed immediately. This step includes the movement of soils from undisturbed sites to mined-out sites. Here, the term soil refers to the surface layer which is most capable of supporting plant life. This layer includes topsoil (A horizon) and subsoil (B horizon). Due to movement, the physical and chemical properties of the soils will change to some degree depending on the handling technique. Therefore, the next step is to prepare the soil conditions most suitable for postmining land uses. In this chapter, soil movement, surface manipulation and soil amendment will be discussed.

4.1 Soil Movement

Before moving soil, some clear knowledge associated with soils should be known in the planning phase in order to assess the most appropriate handling method: 1) The total
available volume of soils is counted by considering the average depth of soil that will be removed from each soil mapping unit times the total area of the mapping unit that will be disturbed (23); 2) Postmining land uses (Table 4.1) determine what kinds of soil movement strategies will be applied (24). To determine undisturbed soil quality, some soil tests must be performed to determine the pH, conductivity, sodium adsorption ratio, particle size, and micronutrient content.

Table 4.1 Guideline for Soil Reconstruction (24)

<table>
<thead>
<tr>
<th>Land use</th>
<th>Maximum slope</th>
<th>Maximum available capacity in root zone</th>
<th>Minimum depth to high water table</th>
<th>Range in reaction in root zone</th>
<th>Maximum hard Fragments greater than 3 in.</th>
<th>Minimum depth to toxic material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>Percent</td>
<td>Inches 4.0</td>
<td>Inches 30</td>
<td>pH 4.5–8.4</td>
<td>Percent 1</td>
<td>Inches 45</td>
</tr>
<tr>
<td>Hayland</td>
<td>20</td>
<td>4.0</td>
<td>30</td>
<td>4.5–8.4</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Pastureland</td>
<td>30</td>
<td>2.5</td>
<td>18</td>
<td>4.0–9.0</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>Rangeland</td>
<td>40</td>
<td>2.0</td>
<td>12</td>
<td>4.0–9.0</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Woodland</td>
<td>40</td>
<td>2.0</td>
<td>18</td>
<td>3.6–5.4</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Recreation: intensive use</td>
<td>15</td>
<td>2.5</td>
<td>24</td>
<td>4.0–9.0</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>Recreation: non-intensive use</td>
<td>50</td>
<td>2.0</td>
<td>12</td>
<td>3.6–9.0</td>
<td>75</td>
<td>18</td>
</tr>
<tr>
<td>Wildlife</td>
<td>50</td>
<td>1.0</td>
<td></td>
<td>3.6–9.0</td>
<td>75</td>
<td>12</td>
</tr>
</tbody>
</table>

The depth of the replaced soils is a key point affecting the vegetation establishment. Several papers have revealed different depth of soils resulting in the optimal
establishment of vegetation, but all agree that soil is a better medium for plant growth than overburden. In North Dakota studies, even 2 inches improved infiltration and yielded greater perennial grass production than non-topsoil areas (27). Generally, the thickness of replaced soil is determined by three factors: quality of overburden to be covered, annual average effective precipitation, and soil quality. Hargis pointed out that 6 to 24 inches of soil coverage on overburden with no harmful properties, and up to 40 inches of coverage on overburden with harmful properties are suitable (26). Here, the harmful properties refer to overburden which may retard plant growth, such as heavy metals, high acidity, alkali, and saline content. Thicker soil layers can act as a buffer to segregate the root system from harmful materials. Schuman also agrees that no benefits are evident for more than 30 to 40 inches of topsoil (27).

The Surface Mining Control and Reclamation Act (1977) requires that all topsoil shall be removed in a separate layer from the area to be disturbed (28). However, under the following conditions, segregated removal is not necessary:

1. If a topsoil substitute has been approved by authorities, this substitute layer can be stripped with
the topsoil layer. For example, some shales and glacial drifts are virtually as fertile as the topsoil above them and separate stripping may be actually detrimental, such as over-compaction by machinery during removal (29).

2. If topsoil (A horizon) is less than 6 inches thick, all soils down to 6 inches will be removed as topsoil.

3. If the B horizon and C horizon, or other underlying materials, have the quality equal to or better than the topsoil, and authorities determine that the materials ensure desired soil productivity, those materials can be handled as topsoil. A guideline was developed for

Table 4.2 Guideline for rating soil (30)

<table>
<thead>
<tr>
<th>Factor affecting use</th>
<th>Good</th>
<th>Fair*</th>
<th>Poor@</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture class</td>
<td>vfs, fsl, sl, l, sil</td>
<td>lfs, ls, cl, scl, scl</td>
<td>s, c, sc, sic</td>
</tr>
<tr>
<td>Moist consistence</td>
<td>very friable, friable</td>
<td>loose, firm</td>
<td>Very firm excessive firm</td>
</tr>
<tr>
<td>EC (mmhos / cm)</td>
<td>&lt;4</td>
<td>4 - 8</td>
<td>&gt;8</td>
</tr>
<tr>
<td>Esp</td>
<td>0 - 5</td>
<td>5 - 15</td>
<td>&gt;15</td>
</tr>
<tr>
<td>pH</td>
<td>5.6 - 7.8</td>
<td>4.5 - 5.6 ; 7.5 - 8.4</td>
<td>&gt;4.5 ; &gt;8.4</td>
</tr>
<tr>
<td>Stoniness class</td>
<td>0</td>
<td>1</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Available water (%)</td>
<td>&gt;10</td>
<td>5 - 10</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Rock fragment</td>
<td>&lt;15</td>
<td>15 - 35</td>
<td>&gt;35</td>
</tr>
<tr>
<td>Saturation water (%)</td>
<td>25</td>
<td>25 - 80</td>
<td>&lt;25 ; &gt;80</td>
</tr>
</tbody>
</table>

* Mitigation of adverse properties will increase reclamation potential.
@ Material rated as poor may be suitable as topsoil only if adverse factor can be treated.
interpretations of the properties of mine soil by USDA Soil Conservation Service in 1978 (Table 4.2).

Before any topsoil is stripped, brush and trees should be removed (31). Those woody materials could be burned, buried or shredded. The first step in soil handling is to strip or lift the desired layer. In order to precisely strip the desired layer, two common methods are applied, either by observing the color change or installing stakes to indicate the depth. Stripping requires a variety of equipment, including dozers, scrapers, shovels, and excavators. Usually, stripping is avoided when the soil condition is too wet. Wet conditions cause problems such as compaction and the deterioration of soil structure. Miss Corker introduced a simple method useful in the field of hand-rolling a sample from the relevant layer on the back of a spade. If a tread of 3 mm diameter is observed without crumbling, the soil is too wet to move (32).

The next step is direct material transport to a mined-out site. Otherwise, these materials may be transported to storage. For shallow quarrying, it is possible to minimize the storage by progressive restoration (33), (Figure 19.) but for deep quarrying, stockpiling is the only way to reuse these materials. Stored topsoil tends to reduce biological activities, through loss of organic matter
Figure 19. Progressive reclamation (33)
and nutrients. Therefore, some protection should be provided to minimize damage to soils. Planting is usually a good method of protection when applied on a stockpile. If stockpiled soil material will not be used within 30 days, seeding and mulching should be used to control erosion (34). If the stockpile is to be left less than 2 years, annual plants adapted to the area should be used. If the stockpile is to be left more than 2 years, perennial vegetation should be used.

The last step of topsoiling is to replace soil separately on the graded spoil. Some regulations require that the leveled spoils should be roughened and loosened before topsoil is applied. The purpose of these regulations is mainly to prevent topsoil from slipping on slopes. Additionally, root systems are allowed to penetrate through the soil-spoil interface. Otherwise, in order to provide a good contact with successive layers, the surface of each layer should be scarified to 2 to 6 inches (35).

Figure 20 shows different machines applied in soil movement (35).

During topsoiling operation, compaction of soils caused by the operation of heavy machinery is a major problem. If the bulk density of mine soils is greater than 1.7 g/cm³, the soils simply cannot hold enough water to sustain
Figure 20. Soil movement by different machines (35)
vigorous plant life during a drought season. Moreover, these compacted zones may also perch water on unexpected locations, causing saturation and undesirable anaerobic conditions in the rooting zone.(36) Ripping is a useful way to solve the problem. Although scarifying every replaced layer provides a good contact interface, heavy machinery still causes a compression of underlying layers when operating on upper layers. Sweigard and Escobar (37) reported that deep ripping of truck-replaced subsoil will produce better results than simply ripping scraper-replaced material, because truck operations cause less compaction in deeper subsoil. Bacon and Humphries (38) also found that deep ripping to a minimum of 650 mm will lessen the compaction more than sequential ripping.

4.2 Amendments and Fertilizers

The main object of mine-land reclamation is to restore a desirable plant community that will minimize erosion and promote nutrient cycling activity without needing repeated fertilizer input to maintain satisfactory productivity. In some quarries, deep topsoil is scarce. As a result, spoil topsoil substitutes are commonly used. For those cases, suitable amendments and fertilizers should be applied in order to develop an improved medium for plant growth. In a
case in Virginia state, several amendments and fertilizers (sawdust, sewage sludge and different content of N-P-K-fertilizers) were applied on a different spoil mix. The result showed that carefully selected, placed, and fertilized rock spoils can equal fertilized and limed topsoil in the first year of productivity (18).

In addition, soils need to be treated by amendments and fertilizers since their chemical and physical properties have already been changed during the transportation and storage processes. The problem is how to apply amendments and fertilizers in appropriate quantity and quality. Several factors, such as postmining land use, organic matter contents, and proposed vegetation, strongly influence this decision making. McGinnies suggests conducting field trials to gain experience in making better decisions (29). He states that the best way to judge soil is by observing the quality of vegetation growing on the site. Several general amendments and fertilizers will be discussed in the following section, but applied quantities and methods depend on specific site specifications.

4.2.1 Amendments

Amendments are categorized into two groups: inorganic amendments and organic amendments. Generally, inorganic
amendments are used to change the physical properties of the soil and spoil in order to create a more favorable environment for plant growth, and to maximize water infiltration. The inorganic category includes clay materials, volcanic materials, sand, fly ash, and sand limes.

a) Clay materials: The incorporation of clay into sandy spoil or soil affects the water relationships and the ability of the spoil or soil to retain fertilizer. The clay amendments change the pore size distribution within soil or spoil so that a greater proportion of pores available for holding water have a smaller diameter (40). This means that the field capacity is increased. Some properties of clays are described in Table 4.3.

Table 4.3 Properties of Clays (40)

<table>
<thead>
<tr>
<th>Clay mineral</th>
<th>Diameter, m X 10^-6</th>
<th>Exchange Capacity, meg/100g</th>
<th>Surface area, m^2/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montmorillonite</td>
<td>0.01-1.0</td>
<td>80-150</td>
<td>700-800</td>
</tr>
<tr>
<td>Illite</td>
<td>0.1-2.0</td>
<td>10-40</td>
<td>100-120</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>0.1-5.0</td>
<td>3-15</td>
<td>5-20</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>---</td>
<td>100-150</td>
<td>---</td>
</tr>
</tbody>
</table>

* Surface area of clay usefulness in 100 g.
b) Volcanic Materials

The use of volcanic materials to change the soil or spoil property depends on the particle size of the materials. Volcanic materials also can provide several micronutrient elements used by plants.

c) Sand:

To add sands to clay soil or spoil changes the pore size distribution in the soils and improves the air-water environment for plant roots, especially in soils that are seasonally too wet for satisfactory crop production.

d) Fly ash:

The addition of fly ash can improve both the physical and chemical properties of spoil or soil. As an amendment for physical properties, fly ash increases the water-holding capacity of soil and the availability of this water to plants. Copp's experiment shows an increase of 4% in available water for the spoil and about a 6% increase for the refuse (42). Fly ash should be applied with other fertilizers because it contains no nitrogen and is low in potassium (41). The amount of fly ash to be used depends on the characteristics of both the spoil and the fly ash.
Generally, the amount of fly ash is mixed to obtain a pH of 7 (42). The problem in using fly ash is the concentration of trace elements that are toxic to some plants. However, plants which are tolerant to these toxic elements can be selected.

e) Limes:

Limes are added usually to correct soil acidity (46). Because lime is relatively insoluble, all particles should pass a 60-mesh or finer screen to be effective within a few weeks. Also, lime must be tilled into the root zone to exert maximum effect on soil acidity.

Organic amendments function well in soil or spoil, contains nutrients, improve the waterholding capacity and improve aeration and drainage of soil or spoil (35). A wide variety of organic amendments are shown in Table 4.4

a. Farm manure: Some manure is high in heterogeneous material and is available for plant growth. Fresh manures contain high levels of ammonia which are toxic to young seedlings.

b. Sewage sludge: This is the organic and inorganic material removed from waste water at sewage treatment plant (45). Sewage sludge applications on mine land
### Table 4.4 Organic bulk amendment (44)

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Special problems</th>
<th>Usual application rate (dry t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmyard manure</td>
<td>rich in nutrients</td>
<td>can be toxic to seedlings when fresh, can smell</td>
<td>5–40</td>
</tr>
<tr>
<td>Pig slurry</td>
<td>rich in nutrients</td>
<td>high water content, may be high in copper, can smell</td>
<td>5–20</td>
</tr>
<tr>
<td>Poultry manure</td>
<td>rich in nutrients, easy to handle</td>
<td>high in ammonia, can be toxic to seedlings</td>
<td>2–10</td>
</tr>
<tr>
<td>Sewage sludge – digested</td>
<td>widely available, usually free</td>
<td>high water content, may contain toxic metals &amp; pathogens, smell</td>
<td>5–50</td>
</tr>
<tr>
<td>Sewage sludge – raw</td>
<td>widely available, usually free</td>
<td>high water content, may contain toxic metals &amp; pathogens, smell</td>
<td>5–50</td>
</tr>
<tr>
<td>Mushroom compost</td>
<td>contains lime</td>
<td>only locally available</td>
<td>5–20</td>
</tr>
<tr>
<td>Domestic refuse, composted</td>
<td>usually free</td>
<td>low in nutrients, may contain miscellaneous objects</td>
<td>20–70</td>
</tr>
<tr>
<td>Brewery sludge, digested</td>
<td></td>
<td>uncommon, low in nutrients</td>
<td>5–20</td>
</tr>
<tr>
<td>Peat</td>
<td>high water holding</td>
<td>low in nutrients</td>
<td>5–10</td>
</tr>
<tr>
<td>Straw</td>
<td>widely available, decays slowly</td>
<td>low in nutrients</td>
<td>5–20</td>
</tr>
<tr>
<td>Sawdust Woodchips Bark</td>
<td>decays slowly</td>
<td>low in nutrients</td>
<td>10–30</td>
</tr>
</tbody>
</table>
generally increase the concentrations of macronutrients (N, P, K, Ca and Mg) in grass and legume species, crops, and trees (46). Sludge-amended sites generally have a great percentage of vegetation cover. This application also improves the physical properties of the spoil, since sludge has a high organic content. The chemical properties of soil and spoil also can be changed by applying sewage sludge. The combined application of sludge and lime neutralizes the acidic spoil and increases the Cation Exchange Capability (CEC) of the spoil material. Sludge applications generally increase the concentration of trace metal in plants. However, most of the time these increased levels in the plants are below the suggested tolerance level.

c. Peat: Incorporation of peat into soil will remarkably improve the physical condition of the soil. Applied in sandy soil, it will increase the waterholding capacity and nutrient-retention capacity. Applied to clay soil, it will increase water infiltration, make the soil more friable, and decrease the volume-weight ratio, thus enhancing root penetration (40).

d. Wood wastes: These include saw dust, wood chips and bark fragments. These materials have a high C/N ratio,
so nitrogen fertilizers are always applied with this type of amendment.

e. Earthworms: The introduction of earthworms can help significantly in land reclamation and soil reconstruction (47). Earthworms burrow in the soil improving aeration, drainage, root penetration and reducing compaction. Additionally, they consume organic matter and mineral fraction and release plant nutrients through their excretory system. Therefore, the root system will continually obtain nutrients.

4.2 Fertilizers

All the elements essential for plant growth, except carbon and oxygen, are obtained from the soil (48). Root systems absorb water and nutrients to sustain plant growth. The major inorganic nutrient elements plants require are called micronutrients, including nitrogen, phosphorus, potassium, sulfur and magnesium. Micronutrients include iron, manganese, boron, copper, zinc and molybdenum. The addition of fertilizers function to compensate for the deficiencies within disturbed soil and help to build up the soil plant system in a short time. The applied rate of fertilizers will depend on which kind of use is going to be
Table 4.5  A guide to nutrient inputs for low intensity use (35)

<table>
<thead>
<tr>
<th>Use</th>
<th>kg/ha</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P*</td>
</tr>
<tr>
<td>Grass-legume swards:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ungrazed - low erosion</td>
<td>60</td>
<td>80-100 (250)</td>
</tr>
<tr>
<td>erosion</td>
<td>50</td>
<td>80-100 (250)</td>
</tr>
<tr>
<td>Grazed - low intensity</td>
<td>80-100</td>
<td>80-100 (250)</td>
</tr>
<tr>
<td>moderate (sheep, beef)</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>100-120</td>
<td>80-100 (250)</td>
</tr>
<tr>
<td>productive (dairy, beef)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>120-150</td>
<td>80-100 (200)</td>
</tr>
<tr>
<td>Maintenance of grass without legume:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unproductive</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>productive</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Trees - spot treatment broadcast</td>
<td>50</td>
<td>50 (100)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>50 (100)</td>
</tr>
</tbody>
</table>

Values are given for acidic neutral soils of reasonable texture.  ( ) = values for calcareous soils (pH > 7.5). These rates should be modified according to soil requirements.

*P₂O₅ = P / 5/2; K₂O = 5/4
built. Table 4.5 contains suggested fertilizer rate for low intensity use.

Two aspects should be taken into account (35):

1. The nutrients for building up a suitable ground cover,
2. The nutrients to maintain the vegetation and allow for build up of the soil fertility through organic matter.

Over 99% of soil nitrogen comes from organic fraction. If the soil organic matter pool is small, the nitrogen cycle will be impeded. The addition of nitrogen fertilizers to disturbed lands will augment supplies of critical components of the nitrogen cycle and encourage rapid reestablishment of the nitrogen cycle in the soil (45).

Nitrogen fertilizers are in the highest demand for disturbed soils. Another way to supply N to soils is to plant legumes. Certain bacteria (Rhizobium) that live in root nodules of legumes are able to utilize atmospheric N to build organic N compounds, which can be absorbed by plants (49). As a result, legumes can be seeded with less N fertilizer than grasses, but they have a higher requirement for P.

The fertilizers applied for tree seedbeds are very low in nutrients, approximately 50 kg each of N, k and P/ha. Over-fertilization will cause the luxuriant herbaceous
species to crowd the tree seedlings.

The common fertilizer forms for different kinds of nutrients are described in Table 4.6 Another common fertilizer is a compound fertilizer, which contains various combinations of N, P and K. The percent composition is printed on the outside of the container, such as N: P₂O₅ : K₂O. In order to get the P and K percentages, multiply by 0.43 and 0.83 respectively.
Table 4.6 The Common Fertilizer forms for different kinds of nutrients (45)

<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical Formula</th>
<th>Compound %</th>
<th>Element %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>NH₂CONH₂</td>
<td>46% N</td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>NH₄NO₃</td>
<td>35% N</td>
<td></td>
</tr>
<tr>
<td>Anhydrous ammonia</td>
<td>NH₃</td>
<td>82% N</td>
<td></td>
</tr>
<tr>
<td>Ammonium phosphate</td>
<td>NH₄H₂PO₄</td>
<td>12% N</td>
<td>27% P</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>(NH₄)₂HPO₄</td>
<td>21% N</td>
<td>23% P</td>
</tr>
<tr>
<td>Ammonium Sulfate</td>
<td>(NH₄)₂SO₄</td>
<td>21% N</td>
<td>24% S</td>
</tr>
<tr>
<td>Superphosphate</td>
<td>Ca(H₂PO₄)₂</td>
<td>20% P₂O₅</td>
<td>9% P</td>
</tr>
<tr>
<td>Triple superphosphate</td>
<td>Ca(H₂PO₄)₂</td>
<td>46% P₂O₅</td>
<td>20% P</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>H₃PO₄</td>
<td>73% P₂O₄</td>
<td>32% P</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>KNO₃</td>
<td>46% K₂O</td>
<td>39% K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14% S</td>
</tr>
<tr>
<td>Potassium Sulfate</td>
<td>K₂SO₄</td>
<td>54% K</td>
<td>45% K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18% S</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>KCl</td>
<td>62% K₂</td>
<td>52% K</td>
</tr>
</tbody>
</table>
5.0 REVEGETATION

For general mined-land reclamation, the major objectives are to establish vegetative cover to control erosion and to restore land productivity. As in the "Surface Mining Control and Reclamation Act" requirements, reclamation is mandated to establish a diverse, effective and permanent vegetation cover which comprises native or introduced species to achieve the approved postmining land use. In developing revegetation strategies, it seems that every quarry is unique. Thus variations are involved not only between quarries but also within quarries (50).

Once the land is disturbed by quarrying, it is impossible to replicate the previous conditions of soil structure, plant community, and wildlife population. It might take 50 years or longer to evolve. In order to maximize the succession rate of the proposed reclaimed site, an evaluation should be made of the vegetation and mine soils on unreclaimed quarries (51). This information could help operators identify plant species capable of establishment on site and help determine minesoil properties that limit plant growth. Some quarrying causes deep
depressions and changes both macro- and micro-environments. After topsoiling, several environmental characteristics within the site, such as slope and aspect can be renewed. Facing this unknown environment, several mines conducted field trials, called test plots, during or after the mining operation. Their aims were to develop the most suitable strategies for vegetation establishment. A successful revegetation strategy is to establish a quick-growing ground cover for erosion control and stabilization purposes. Subsequently, the established ground cover will encourage invasion plants to build up soil structure and fertility. This phase is always combined with the previous stage. Finally, more species are naturally introduced and form the final desired plant community by careful management. Some reclamation shows that the plant cover has an inhibitory effect on the invasion of new plants, due to highly competitive species of ground cover. In Wilson's experiment (52), the effect of sowing commercial seed mixture of introduced species was to suppress the native species. As a result, it is important to consider a phased succession during species selection.

5.1 Selection Criteria

Postmining land use is the one of major elements
affecting species selection. A poor choice may doom the revegetation effort and affect the bond release. If postmining land use is livestock grazing, plant species selection should meet the needs of the animals that will be inhabiting the area. Also, palatability and nutritional volume of those species should be considered during selection (53). If a forest is the postmining land use, care must be taken in selecting ground cover species (grasses and legumes). These species should be short, and seeded and fertilized at low to moderate rates, so the resulting cover is complete without being excessively tall (54). On very extreme sites, such as with very dry weather, only few species can adapt to the site. It is not possible to create a guideline for species selection for postmining land use.

5.1.1 Site-Specific Adaptation

Plant species selection for reclamation depends heavily on site-specific conditions, including soil, climate, and topography. Soil status which is affected by the species-selection decision include pH, texture and nutrient content. Although soil should be amended to suit a wide range of species, sometimes it is hard to obtain due to leaching or an extreme adhesive condition. Carefully selecting plant
species could be an alternative way to achieve the reclamation goal. Generally, soils in the east are more acidic than those in the west of America. Species selection on those sites should focus on low-pH-tolerant species, such as weeping love grass and Bermuda grass which can tolerate extremely low pH soil (38). One important reason for considering soil-adapted species is to minimize the high level of management after revegetation.

Climate factors, precipitation and temperature, will influence the length of growing season. A short growing season will damage some unsuitable species. For example, in a dry region, plant species with characteristics such as drought resistance and tolerance of exposure are most suitable.

Topographic factors affecting the decision making of the species selection include slope and aspect. Plant species applied on slopes should be capable of holding the soil tightly to reduce erosion and should be able to survive on less moisture. Warm season grasses, which produce relatively deep root systems very quickly, are suitable for soil-stabilization purposes. Generally, north and east aspects are cooler and moister than are south and west sides. As a result, more drought-resistant and less sunshine-demanding species are preferable for application on
south and west aspects.

5.1.2 Native and Introduced Species

The Office of Surface Mining (OSM) regulations require that introduced species may be applied if: 1) They are beneficial after field trial. 2) They can achieve a quick, temporary, and stabilizing cover. 3) They are compatible with native species and animals. 4) They are not poisonous or noxious (Section 816.12) (56). The primary reason for using introduced species is their rapid establishment and aggressive growth characteristics. On the other hand, those properties might cause introduced species to be too competitive to native species. In this situation, native species have difficulties growing. Highly aggressive introduced species may dominate the site after a long time. This establishment of only a few species may cause a relatively unstable community that is sensitive to environmental disturbance (57). Redente reports that reducing the amount of aggressive grass seed used in mixture and increasing the amount of seed of some forbs and shrubs may improve plant diversity (58). Some introduced species are less palatable or even toxic to livestock or wildlife. For example, tall fescue has been criticized for causing poor animal performance and other livestock health problems.
(59). Caution should be taken when selecting introduced species for grazing use.

5.1.3 Diversity

The main purpose of revegetation is to apply numbers of species which will encourage species invasion to fasten the successional rate to reach the climax stage. Two techniques of species selection have been broadly used to meet the diversity goal (60). The first technique is to use broad seed mixes of numerous grasses, forbs, and shrubs to establish diverse plant communities. This could provide a limited amount of diversity on some sites. The second technique is the seeding of different combinations of a few basic seed mixes. For example, different grades and aspects of slope and quarry floor will be planted with different seed mixes. This technique is more expensive than the first one. The proportion of species mixtures will depend on the role of each species and its competitive ability. The following guideline is suggested by Coppin and Bradshaw:

1. Trees and shrubs: Pioneer or nurses species are mixed in a ratio 1:5 to 1:3 with appropriate climax species. It is necessary to consider the future size and height of each species. Generally, 3-6 species are enough.

2. Ground cover: Grasses are mixed with legumes in a
ratio of 2:1 to 5:1. Herbs can also be added to increase wildlife interest and diversity. Generally, 6-10 species are suitable. Pioneer species should be kept to a single species at a low proportion in the mix (61).

Because pre-disturbed topsoil contains viable plant propagules, direct-haul topsoil is a good medium to encourage the development of diverse native plant communities. This can proceed in shallow quarries with available topsoil.

5.2 Seeding and Planting

5.2.1 Seed rate and handling

To calculate seeding rate for species mixtures, use a percent of seeding rate for each species equal to the percent of that species needed in the mixture (65). Calculate seeding rates on a pure live seed (PLS) basis using the following formula:

\[
PLS = \frac{\text{Purity} \times \text{Germination}}{100}
\] [5.1]
To determine bulk seeding rate:

\[
\text{Bulk lbs. of seed/acre} = \frac{\text{PLS lbs/acre}}{\%\text{PLS/100}}
\]  

[5.2]

If broadcasting is applied, double the above seeding rate. If drilling is applied, the Soil Conservation Service recommends 20 PLS per 0.09 m² as a minimum number of seeds. When species are dormant, calculate PLS based on the field test results.

Seeds should be stored in cool, dry, well-aerated bags. Before storage, seeds should be dried to a certain degree depending on the storage period (61). For 1-3 years period, reduce seed moisture content to equilibrium with 65%-45% relative humidity. For a longer period, dry to equilibrium with 25% relative humidity.

Some seeds with hard coats have an inbuilt dormancy mechanism. Thus, they should be treated with some procedures to break the dormancy before being applied. Three methods are used in scarifying those dormant seeds:

1. Mechanical Scarification: The seeds are tumbled in sand-paper-lined drums for 5 to 10 minutes.
2. Acid scarification: The seeds are soaked in a solution of hot (60°C) sulfuric acid for around 5 minutes.
3. Hot water scarification: This is the easiest way. The seeds are poured into boiling water, and cooled for 6 to 12 hours.

5.2.2 Seeding

Seeding is the most efficient method to establish plants on a regraded site. There are two methods, drill seeding and broadcast seeding. Drill seeding buries seeds with soils. Generally, this method produces a good establishment. Broadcast seeding places seed on the exposed surface. Different mulching techniques are always applied during or immediately after broadcasting. Every seeding method has some site limitations. Generally, broadcasting has fewer limitations than drilling. Hydroseeding, a special broadcasting method, is a better way to seed on a steep slope or on inaccessible areas. Applying seeding methods depends on the site characteristics of the seeded areas. The limitations for different seeding methods are described in Table 5.1 (63). Determining the seeding season is very critical for successful establishment of vegetation. Generally, seeding should occur before or at the beginning of growing season. This decision is very site specific due to climatic variation. As a result, every area may have a different time for seeding. The Soil Conservation Service
Table 5.1 The limitation for different seeding methods (63)

<table>
<thead>
<tr>
<th></th>
<th>Drilling</th>
<th>Broadcasting</th>
<th>Hydroseeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Topography and</td>
<td>slopes &lt;15°</td>
<td>not on steepest slopes (&gt; 20°)</td>
<td>50 m reach with spray, up to 500 m</td>
</tr>
<tr>
<td>terrain</td>
<td></td>
<td></td>
<td>reach with extension hoses</td>
</tr>
<tr>
<td>2 Obstructions</td>
<td>limited</td>
<td>few limits</td>
<td>few limits</td>
</tr>
<tr>
<td>3 Season</td>
<td>limited by high soil moisture</td>
<td>limited to warm seasons with sufficient rainfall, a mulch extends the sowing season</td>
<td></td>
</tr>
<tr>
<td>4 Rainfall</td>
<td>important</td>
<td>critical</td>
<td>critical</td>
</tr>
<tr>
<td>5 Soil texture</td>
<td>not stoney soils</td>
<td>critical, coarse texture allows seed to fall into cracks and hollows with better microclimate</td>
<td></td>
</tr>
<tr>
<td>6 Compaction</td>
<td>slightly acceptable</td>
<td>not acceptable</td>
<td>not acceptable</td>
</tr>
<tr>
<td>7 Seed rates</td>
<td>low rates are sufficient</td>
<td>increase sowing rate to allow for heavy losses during establishment</td>
<td></td>
</tr>
<tr>
<td>8 Seeding depth</td>
<td>controlled</td>
<td>no control, surface sown</td>
<td>no control, surface sown</td>
</tr>
<tr>
<td>9 Seed distribution</td>
<td>uniform, in rows</td>
<td>can be very variable, split the application into two passes in different directions</td>
<td></td>
</tr>
<tr>
<td>10 Seed establishment</td>
<td>most effective</td>
<td>variable results</td>
<td>variable results</td>
</tr>
<tr>
<td>11 Fertilisation</td>
<td>separate operation, or with special equipment gives deep placement</td>
<td>separate operation required</td>
<td>can be done in same operation but no deep placement</td>
</tr>
<tr>
<td>12 Mulching or incorporation</td>
<td>not required</td>
<td>required, separate operation</td>
<td>required, can be done in same operation</td>
</tr>
<tr>
<td>13 Equipment</td>
<td>seed drills available in most localities</td>
<td>various hand, tractor and aerial methods</td>
<td>special equipment, scarce</td>
</tr>
<tr>
<td>14 Cost</td>
<td>usually inexpensive</td>
<td>cheapest, but add mulching/ incorporation costs</td>
<td>expensive</td>
</tr>
</tbody>
</table>
suggests different times of seeding for every state. For pasture and hayland planting in Montana (64), spring seedings should be completed by May 15, late summer seedings should be done by August 15 only when soils have a minimum of 2 ft of moisture, and late fall seedings should be completed by October 15, only for dormant species. The difficulty of late spring seedings in semiarid areas is in predicting precipitation events. Sometimes when it rains, it is too wet for seeding equipment to access. Seeding probably has to wait until season rains are over. Those seeded species may lose their impetus for germination if they miss the spring precipitation.

5.2.2.1 Drill Seeding

The seed buried depth depends on the size of seeds and soil texture. The North Dakota Soil Conservation Service suggests that when soil texture is medium to fine, optimum seeding depth is from 1/2 to 3/4 inch, and when texture is coarse, optimum depth is from 1/2 to 1 inch (65). In Montana, the Service suggests that small grass, forb and legume seeds should be planted no deeper than 1/2 inch, and large seeds should be planted no deeper than 1 inch. Generally, seeding depth should not be greater than 1 inch, because seeding too deep will delay emergence and total
emergence. A typical drill seeding procedure is for the drill seeder to open a furrow, drop seeds through a tube into the furrow, cultipack rolls over the soil and firm the surface.

5.2.2.2 Broadcast Seeding

It is advantageous to apply broadcasting on coarse textured soil since seed will naturally fall into cracks creating a favorable environment for seeds to germinate. Small area broadcasting can be done by hand. In areas with a maximum slope of less than 15 degrees, broadcasting can be done by a broadcast seeder. On a very large scale or in inaccessible areas, an aircraft spreader can be applied. After the aircraft spreader, a broadcasting cultipacker could be used to suppress the seeds into the soil to provide a good soil-seed contact. The broadcasting rate should be greater than normal, about twice the normal rate. Hydroseeding is an expensive method which is used for seeding inaccessible areas such as steep slope. Seeds dispersed in water-based slurry are pumped out and spread by spray gun. This slurry always includes fertilizer or other amendments. Munshower (53) suggests excluding hydromulching at the same time. This use may suspend seeds above the soil as hydromulch dries.
5.2.3 Planting

Planting establishes certain plant species by moving a plant propagule or a whole plant to a new site. The propagule can be a cutting part, sprig, rhizome or bulb (66). In reclamation practice, when some tree or shrub species cannot be established or exhibit poorly on a disturbed site, planting will usually give visibility more quickly. Transplanting should proceed during the dormant period, and could be done either in late fall or early spring. Spring planting is usually better since climatic conditions are optimal.

5.2.3.1 Plant handling

Whole planting stocks include three types, bareroot stock, wilding stock and containerized stock. When bareroot plants reach a predetermined height, hardening process is conducted to reduce their physiological activity to reach dormancy. Then they are removed from soils, with stems and roots trimmed, and stored in a cool, dark, moist environment (53). Wildings are dug by tree spade and transplanted to the disturbed site directly. Containerized plants are grown in a greenhouse in root containers. The roots are usually well developed and firmly established during the nursing period.
Successful transplanting depends on proper handling of stocks. The handling refers to the time when the stocks are lifted from the nursery until they are planted into the designated area. Care should be taken during the handling process as follows (63):

1. The roots should be dipped in a thick slurry of clay and soil immediately after lifting.
2. Bareroot plants should be not only protected from sun and wind but also stored in low temperatures (1°C - 4°C)
3. Plants that have broken dormancy should not be stored, but planted immediately.
4. Bare roots should be lightly dampened with water during loading.
5. Upon arrival, the final planting position should not expose the roots be exposed for longer than a few minutes, especially in strong sunlight or wind.
6. The total time from lifting to planting should be limited as much as possible.

5.2.3.2 Planting practice

Planting proceeds either by hand or by machine. Before beginning, planting positions should be cleared of any obstructions or vegetation covers and loosened to
Figure 21. Hand planting (63)
relieve soil compaction. The sizes of planting pits depend on the roots. Care should be taken not to cramp or distort the roots (See Figure 21.).

Preparing to plant on a slope begins with forming a ledge which is excavated with a slight backslope to collect water (Figure 22.). Trees should be staggered in rows to avoid too regular an appearance. For shrubs, the space (each direction) is about 8 to 10 feet (2.5m - 3m). For trees, the space is about 18 to 20 feet (5.5 - 6m) (67). After planting, the area should be fenced to exclude any animal disturbance.

Figure 22  Slope planting (63)
5.3 Mulches

Mulching on the soil surface will increase soil moisture, prevent erosion, moderate soil temperature, and increase seeding germination. Materials can be organic or inorganic, natural or man-made, soil-enriching or inert.

Runoff water from areas above that to be mulched should be diverted before mulching (68). All areas to be mulched should be reasonably smooth, free of rills. As previously mentioned, the seedbed should be worked to break up compacted areas. This prepared seedbed must be soft enough to permit proper covering of seed and anchoring of mulch, and firm enough to support the weight of a person without sinking into soil more than one-half inch.

Mulch materials applied after seeding include hay, straw, wood fiber, gravel and crushed stone. Using hay as a mulch is beneficial for the seedbed to develop a diverse plant community, because this mulch contains many leaves, flowers, and seed heads. The Soil Conservation Service suggests that at least 50 percent of the herbage by weight must be 10 inches or longer before being applied to the site (69). Seed hay must be used if the same species is used in the seeding. Otherwise, hay should be free of seed.

Straw is less expensive, but it will introduce weedy species to the disturbed site. Therefore, straw should be
selected with care to reduce the weedy species introduction. The Soil Conservation Service suggests that straw should consist of wheat, oats, flax, barley, or rye straw from which grains have been removed. At least 50 percent of the stems by weight should exceed 6 inches if anchored netting is used. Otherwise, at least 50 percent of the stems by weight should exceed ten inches, if anchored by machines.

Wood fiber, as suggested by the Soil Conservation Service, should be cut from good green timber. The cut should be made to provide maximum fiber length. At least 50 percent of the fibers should be 6 inches in length by weight in the bale (68).

Using gravel and crushed stones as mulches is efficient in erosion control and encourages the invasion of adapted indigenous species (71). The Soil Conservation Service suggests that rock mulches be used for seedings, the size should range from 1/4 to 1/2 inch in diameter, and if used for weed control or traffic, the size should be increased to 2 or 3 inches in depth (69).

Some mulch is subject to loss by wind or water. This can be overcome by using anchors. The methods of anchoring mulches include crimping, netting, and use of tacks. Crimping utilizes a heavy straight, disk-type mulch tiller to mash part of the mulch into the seedbed. It is commonly
used after mulching with straw or hay. Netting is usually used in critical erosion-prone areas. The materials include paper jute, cotton and plastic. Using netting as an anchor is very labor intensive and more expensive than crimping. Tacks are usually used by combining mulch and water as a liquid status sprayed by hydromulch machines. There are two types of tacks suggested by the Soil Conservation Service, asphalt emulsion tack and resin emulsion. Asphalt emulsion consists of liquid emulsions of water and natural bituminals of asphalt. Wolf’s experiment concluded that asphalt may be toxic to seedlings when applied as a binder for straw because of unpredictable characteristics by different manufacturers (72). Resin emulsion tack consists of liquid emulsion of water and natural petroleum resins. The applied rates for these two kinds of tacks are described in Table 5.2. The applied rates of mulches with different anchoring methods are described in Table 5.3.
Table 5.2 The use rate of tacks (69)

<table>
<thead>
<tr>
<th>Mulch</th>
<th>Soil Type</th>
<th>Rate + Cups per sq. ft</th>
<th>Material</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin Emulsion*</td>
<td>Loamy Sand</td>
<td>5/8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Petroset SB</td>
<td>and Sandy Loam</td>
<td>5/8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Aero spray 70</td>
<td></td>
<td>1/8</td>
<td>6 1/2</td>
<td></td>
</tr>
<tr>
<td>Curosol AH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petroset SB</td>
<td>Loam</td>
<td>5/8</td>
<td>4 1/2</td>
<td></td>
</tr>
<tr>
<td>Aero Spray 70</td>
<td></td>
<td>5/8</td>
<td>4 1/2</td>
<td></td>
</tr>
<tr>
<td>Curosol AH</td>
<td></td>
<td>1</td>
<td>4 1/2</td>
<td></td>
</tr>
<tr>
<td>Asphalt Emulsion</td>
<td>All Soils except</td>
<td>4</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>SS-1</td>
<td>silty clays and clays</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutback Asphalt</td>
<td>All soils</td>
<td>4</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>RC-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+ Conversion of Cups to Gallons: 16 Cups = 1 gallon

* Not Recommended for use on clay
Table 5.3 Application rates of mulches (69)

<table>
<thead>
<tr>
<th>Method of Anchoring and Mulching</th>
<th>Rate of Mulch lbs / Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchored with disk:</td>
<td></td>
</tr>
<tr>
<td>Hay</td>
<td>5,000</td>
</tr>
<tr>
<td>Straw</td>
<td>6,000</td>
</tr>
<tr>
<td>Excelsion weed fiber</td>
<td>4,000</td>
</tr>
<tr>
<td>Anchored with tacks:</td>
<td></td>
</tr>
<tr>
<td>Hay</td>
<td>3,000</td>
</tr>
<tr>
<td>Straw</td>
<td>3,000</td>
</tr>
<tr>
<td>Excelsior wood fiber</td>
<td>3,000</td>
</tr>
<tr>
<td>Anchored with netting:</td>
<td></td>
</tr>
<tr>
<td>Hay</td>
<td>3,000</td>
</tr>
<tr>
<td>Straw</td>
<td>3,000</td>
</tr>
</tbody>
</table>
6.0 POSTMINING MANAGEMENT

Postmining management should begin as soon as the vegetation is established. It includes irrigation, weed control, vegetation and soil monitoring, and certain management necessities for different land use. Postmining management is not a crucial part in successful reclamation, but it will enhance the success. A successful reclamation from premining planning, landforming, topsoiling, revegetation to postmining management, consists of several mutually related links. If one step fails, it will break the chain and increase the difficulties of postmining management. For example, if an operator does not carefully select plant species, the established cover will be occupied by a few species unsuitable for postmining land use, requiring heavy management.

The Surface Mining Control and Reclamation Act (Section 515-(19)) requires that a diverse effective and permanent vegetative cover be established. The term "diversity" could be interpreted not only as vegetative diversity but also as habitat diversity (73). This is an important concept in wildlife management. In order to get the bond release,
efforts should be made to achieve the "diverse" goal. The management period will last 5 to 10 years depending on postmining land use and climate.

6.1 Irrigation and Fertilization

Irrigation should provide adequate water, but not cause erosion or runoff. As a result, frequent, light irrigations are used during seedling emergence (74). In Arizona, irrigation may not be required in some areas where the annual precipitation exceeds 20 inches. The methods of irrigation depend on topography, texture and permeability of the soil, quality and quantity of water available, and delivery rate. Sprinkler, flood, and drip irrigation are usually used. In hot, dry, windy weather, sprinkler irrigation is inefficient since evaporation is very high (75). Drip irrigation is more efficient in watering individual plants or small clumps of plants.

Fertilizers are usually applied during seedbed preparation. Initial fertilization effects will generally last for the first two growing seasons. Steady decreases in standing biomass and ground cover will occur after that time even on the best soils. Long-term productivity of a plant/soil system depends on two factors: (1) The accumulation of organic matter and N. (2) Establishment of
an organic - P pool and the minimization of P-fixation (36). After the organic soil nitrogen level reaches 700 kg/ha (630 lb/ac), the nitrogen cycle will become independent. The needs of fertilizer input should depend on the test of soil status and the types of established vegetation (see Chapter 4).

6.2 Weed control

Weeds generally cause severe problems after revegetation. They may be aesthetically displeasing, noxious, or too competitive with desired plants. Especially after trees have been established, it is important to control weeds growing around the trees (1 m diameter area). The methods of weed control include chemical weed control, mechanical weed control and grazing for weed control. The use of chemical control should depend on the weedy types and state or federal regulations. Mowing is a mechanical weed control. Clip weeds prior to maturity of weed seed, at the heights that will cause minimum leaf damage to the forage seedlings. Grazing as a management tool of weed control is cheaper than mechanical control. Newly-developed soils are fragile and susceptible to rumpling damage. Also wet soils are easily damaged by animal encroachment. As a result, timing is very important. The grazing period should be
restricted to the summer month and after the year of establishment when the soil is not too wet.

6.3 Special management related to different land use
6.3.1 Grassland management

The value of pasture grassland in building-up a dense sward is very important in improving soil structure, preventing erosion and gullying on slopes, decreasing temperature fluctuations at the surface, building up the humus content and organic population in soil, and providing food for livestock or wildlife. The management of grassland includes grazing, mowing and fertilizing. There are two factors which should be considered during grazing operations: grazing animals and stocking rate.

Sheep and cattle are usually selected for grazing, but horses are a suggested animal. Usually horses should not be used in the first year. Stocking rate depends on soil fertilizers greatly. In poor sites, 1 to 5 sheep and 0.2 to 1 cattle per hectare is suitable; and twice the amount on fertile sites (76). Grassland is often managed progressively toward wildlife interest after 2 or 3 years. Management should focus on build-up of the soil nutrient pools. The following step is to manage the growth of shrubs and trees desired for
wildlife habitat.

6.3.2 Woodland management

The aim of management of woodland areas is to develop a strong root system which will improve and protect the soil structure and produce wind-firm trees (77). The major tasks are weed control, plant maintenance and fertilization. Two to three visits per year to eliminate outgrowing weeds. The replacement of dead trees should be done once a year during the first three years. Also, staked trees should be inspected and ties loosened in every visit. This support can be removed after three years. If a tree cannot support itself at that time, then it should be discarded. Pruning should cut out the dead parts of the wood plant to encourage the production of healthy live buds or shoots.

When the trees grow very tall, the space between them is inadequate so they become crowded. Thinning removes the less successful trees and any climax trees that are in excess of the requirements of the final stand (76).

6.3.3 Wetland management

It is important to deter the visit by herbivores after vegetation is established. There are three methods in controlling herbivores. The first one is to fence the
reclaimed areas. This should be done after seedbed preparation. The second one is weed control. Eliminating weeds around the young tree can discourage browsing by rodents. The third one is to disk a buffer zone which will impede the crossing of rodents and provide a fire break. This fire break should be harrowed annually to maintain its function.

Unlike woodland management, total removal of competition is not necessary as long as acceptable survival and resistance to climatic extremes, diseases, and pets are obtained. Although intensive management of competitive plants can lead to high growth rates, it also raises the management costs. Some efforts should be made to minimize competitive plants during site preparation and species selection phases. As a result, a thorough plan should consider those details in order to minimize the cost of postmining management.
7.0 CONCLUSIONS AND SUGGESTIONS

This chapter provides conclusions regarding U.S. and European reclamation techniques that would be applicable in Taiwan. These conclusions also integrate Taiwan reclamation experience to date. The conclusions are followed by a number of recommendations on a conceptual reclamation design for new quarries in Taiwan.

The quarry conditions (e.g., quarry scale, environmental policy, climate, etc.) in the U.S. and Taiwan are not identical, with different emphases on reclamation. Most quarries in Taiwan are close to highly populated areas with significant visual impact caused by quarrying. Several screening techniques mentioned in Chapter 3 can be used to conceal working benches and processing plants. Vegetated soil banks are an excellent way to block the sight line.

Slope design, including angle, is another critical issue in current reclamation in Taiwan. From an economical standpoint, slopes should be designed as steep as possible to extract maximum resources. However, steep slopes will cause some difficulties in backfilling and revegetating. The suggested final slope in the new Hoping Quarry is 30
degrees. This slope angle should be studied in detail using the Universal Soil Loss Equation (Chapter 3). The timing of backfilling and revegetation operations are also critical to successful reclamation and should be included in the design.

The major difference between current Shoushan Quarry reclamation and the suggested reclamation is in the backfilling operation. In the Shoushan Quarry, twelve-meter benches were backfilled only to seven meters. The upper portions of the face bench were left as a bare rock face. Although hydroseeding was applied, growth conditions on the rock face were still poor. It is suggested that the upper benches will be cut and backfilled on the bench toe as described in this chapter. This design will make soil-replacement possible on the entire bench slope.

After the quarries on the west coast of Taiwan are mandated to close, most of those quarry companies will move to Hoping on the eastern coast to continue production of cement products.

The Hoping area contains large quantities of metamorphic limestone with an estimated minable reserve around 15 billion metric tons (78). This area is characterized by high elevation and steep slopes, most of which are greater than 37 degrees. The traditional hillside bench-cutting method is not suitable for this steep and high
topography. For example, if the topmost bench is set at an elevation of 1,000 M, the total haulage distance with a 10% gradient will be 10,000 M. This haulage distance would result in uneconomic haul times and severe environmental damage due to haul road construction and bench extraction in the steep topography. A more efficient and less environmentally damaging method should be applied.

This method uses a shaft as a link in the transportation system. All raw materials would be dumped into shaft collar, dropped by gravity to the crusher level, crushed by a primary crusher at the bottom of the shaft, and then transported to the surface by a belt conveyor. A major benefit of this design is to minimize the environmental disturbance. As shown in Figure 23, the shaft transportation method with solid spur left in place reduces the visual impact, when compared to the traditional bench-cutting method. The other benefit is that it disturbs less vegetation cover than the traditional bench-cutting method. For example, at the same production base, the traditional method disturbs two times more the surface vegetation than the shaft transportation system.
An addition to the major change in benching and hauling, the following recommendations are proposed by the author to provide better environmental controls during and after the mining operation:

1. Soil material should be carefully preserved. Since it takes about 5 years to complete the excavation of one 10 meter bench, these soils must be kept viable until they are replaced on mined out areas. Soil can be stored in a number of ways. It can be used to construct a screening berm with tall trees planted on
the berm. The functions of these berms are to conceal the processing plants. Soil can be used as a seedbed to nurse tree or shrub species which cannot grow in harsh conditions. The rest of the soil should be stockpiled on either flat or sloped areas away from areas of the operation of heavy machines and natural waterways. Surface drainage and vegetation cover must be used to lessen the erosion and keep the soil intact.

2. A 10-meter high bank should be kept around the quarry. (See Fig 12.) It will make the landscape appear more natural from any viewpoint. Trees growing outside the bank should not be felled until the base of the bench is started. This bank also can be used to prevent runoff from eroding the slope.

3. The working bench facing populated areas should be kept one bench lower than the working bench facing toward the mountain. This working sequence will minimize the blasting noise transmitted to populated areas, since the outside bench will serve as a sound barrier (Figure 31).
4. A final landform with a series of benches is not natural compared with the adjacent landscape. From the standpoint of quarry operators, it is most profitable to mine as much ore as possible which results in a steep slope after mining. This steep, final slope could be potentially unstable and difficult to revegetate. As a result, the final slope should be determined in the planning phase in order to set up the shaft location. Figure 25 shows a proposed final slope with a landform design and vegetation design. In the landform design, the major consideration is to
Figure 25. Suggested quarry reclamation
select the bench geometry that will be adequate to accommodate the drainage system, backfilling and revegetation procedures, and postmining maintenance, in order to create a final pit slope of 30 degrees. Every two 12-meter-wide bench floors are followed by a 20 meter-wide bench floor. This 20-meter-wide bench floor can be used for vehicle transportation and for construction of the drainage systems. The upper one-half of the bench will be cut by blasting to a slope of 40 degrees. Those blasted rocks then are broken into sizes less than 25 cm in diameter, backfilled against the toe of the bench, and graded to a 40-degree slope. The bench floors should be shattered by explosives to a depth of 1 to 1.5 meters and planted with deep-rooting trees. The shattered floor will help the root system penetrate and aid tree growth. After backfilling, the remnant 10 meter bench floors should be graded to a 3-degree-incline toward the conduit. This aids in collecting runoff in the drainage systems and minimizing erosion.

The depth of replaced soil will depend on the total amount available, but at least one meter of soil is required. Because of the steep slope, placing soil is difficult and cost intensive. A backhoe
characterized with high flexibility can be used in this topography. A raised berm should be constructed on the edges of the terraces to confine the water inside the terraces. This will help to provide water for trees and to minimize erosion.

Deep-rooting trees should be planted on terraces and small trees or shrubs should be planted on slopes in 3M x 3M spaces. The Seed mix should contain both fine-rooting plants (e.g., grass) and deep-rooting plants (e.g., forbs). At least one type of legume should be included in this mixture. The introduced species with high competitive characteristics should be used in low rates or replaced by annual species.

5. Postmining land uses are difficult to decide since the Hoping Quarry will operate for more than 200 years. The postmining landform could be either a revegetated slope with an open area or a deep depression. The best way is to establish diverse revegetation which can adapt to several land uses.

The recommendations above should be considered to be preliminary conceptual designs subject to change with the availability of more detailed information which will allow more detailed analysis.
As mining engineers, it is our responsibility to reclaim mined areas. Every quarry is unique, with its own characteristics and problem areas. Mining engineers must anticipate those areas and seek solutions together with environmental specialists. Ignoring the problems will often result in a more serious conditions at later stages which requires a lot more money and effort to correct. It is hoped that these recommendations will serve as a basis for a sound reclamation plan at Hoping and other quarries.
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Appendix I

Reclamation Pictures at Shoushan Quarry
Figure 1  Combination steps and chute
Appendix II

Rainfall maps (Soil Conservation Service, 1986) (22)
2-YEAR 24-HOUR RAINFALL (INCHES)

5-YEAR 24-HOUR RAINFALL (INCHES)
Appendix III

Hydrological groups (Soil Conservation Service, 1986) (22)
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acworth</td>
<td>Adair</td>
<td>Adams</td>
<td>Adams County</td>
</tr>
<tr>
<td>Ada</td>
<td>Adeline</td>
<td>Adelanto</td>
<td>Adelaide</td>
</tr>
<tr>
<td>Adkins</td>
<td>Adirondack</td>
<td>Aiken</td>
<td>Aik</td>
</tr>
</tbody>
</table>
### Appendix IV

**Runoff curve numbers for selected land uses (SCS, 1986)**

<table>
<thead>
<tr>
<th>Land use description</th>
<th>Hydrologic soil group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>Cultivated land</strong></td>
<td></td>
</tr>
<tr>
<td>Without conservation treatment</td>
<td>72</td>
</tr>
<tr>
<td>With conservation treatment</td>
<td>62</td>
</tr>
<tr>
<td><strong>Pasture or range land</strong></td>
<td></td>
</tr>
<tr>
<td>Poor condition</td>
<td>68</td>
</tr>
<tr>
<td>Good condition</td>
<td>39</td>
</tr>
<tr>
<td><strong>Meadow</strong></td>
<td></td>
</tr>
<tr>
<td>Good condition</td>
<td>30</td>
</tr>
<tr>
<td><strong>Wood or forest land</strong></td>
<td></td>
</tr>
<tr>
<td>Thin stand, poor cover, no mulch</td>
<td>45</td>
</tr>
<tr>
<td>Good cover*</td>
<td>25</td>
</tr>
<tr>
<td><strong>Open Spaces, lawns, parks, golf courses, cemeteries, etc.</strong></td>
<td></td>
</tr>
<tr>
<td>Good condition (grass cover on 75% or more of the area)</td>
<td>39</td>
</tr>
<tr>
<td>Fair condition (grass cover on 50 to 75% of the area)</td>
<td>49</td>
</tr>
<tr>
<td><strong>Commercial and business areas (85% impervious)</strong></td>
<td></td>
</tr>
<tr>
<td>89</td>
<td>92</td>
</tr>
<tr>
<td><strong>Industrial districts (72% impervious)</strong></td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>88</td>
</tr>
<tr>
<td><strong>Residential</strong></td>
<td></td>
</tr>
<tr>
<td>Average lot size</td>
<td></td>
</tr>
<tr>
<td>1 acre or less</td>
<td>65</td>
</tr>
<tr>
<td>½ acre</td>
<td>38</td>
</tr>
<tr>
<td>¼ acre</td>
<td>30</td>
</tr>
<tr>
<td>⅛ acre</td>
<td>25</td>
</tr>
<tr>
<td>⅛ acre</td>
<td>20</td>
</tr>
<tr>
<td>Paved parking lots, roofs, driveways, etc.*</td>
<td>98</td>
</tr>
<tr>
<td>Streets and roads</td>
<td></td>
</tr>
<tr>
<td>Paved with curbs and storm sewers*</td>
<td>98</td>
</tr>
<tr>
<td>Gravel</td>
<td>76</td>
</tr>
<tr>
<td>Dirt</td>
<td>72</td>
</tr>
</tbody>
</table>

---

*Good cover is protected from grazing, litter, and brush cover soil.
*Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltrations could occur.
*The remaining pervious areas (lawns) are considered to be in good pasture condition for these curve numbers.
*In some warmer climates of the country a curve number of 95 may be used.
Appendix V

Graphical solution of Eq. [3.3] (22)

Curves on this sheet are for the case $I_a = 0.2S$, so that

$$Q = \frac{(P-0.2S)^2}{P+0.8S}$$
Appendix VI

Coefficient a for Eq. [3.6] (22)

<table>
<thead>
<tr>
<th>Surface</th>
<th>a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overland flow</td>
<td></td>
</tr>
<tr>
<td>Forest with heavy ground litter</td>
<td>2.5</td>
</tr>
<tr>
<td>Hay; meadow</td>
<td>2.5</td>
</tr>
<tr>
<td>Trash fallow; minimum tillage</td>
<td>5.1</td>
</tr>
<tr>
<td>Contour; strip cropped</td>
<td>5.1</td>
</tr>
<tr>
<td>Woodland</td>
<td>5.1</td>
</tr>
<tr>
<td>Short grass</td>
<td>7.0</td>
</tr>
<tr>
<td>Straight row cultivation</td>
<td>8.6</td>
</tr>
<tr>
<td>Bare; untilled</td>
<td>10.1</td>
</tr>
<tr>
<td>Paved</td>
<td>20.3</td>
</tr>
<tr>
<td>Shallow concentrated flow</td>
<td></td>
</tr>
<tr>
<td>Alluvial fans</td>
<td>10.1</td>
</tr>
<tr>
<td>Grassed waterways</td>
<td>16.1</td>
</tr>
<tr>
<td>Small upland gullies</td>
<td>20.3</td>
</tr>
</tbody>
</table>

*Results in fps: multiply by 0.305 to get m/sec.*
Appendix VII

Adjustment factor, \( F_p \), for Eq. [3.7] (22)

<table>
<thead>
<tr>
<th>Percentage of pond and swamp areas</th>
<th>( F_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.00</td>
</tr>
<tr>
<td>0.2</td>
<td>0.97</td>
</tr>
<tr>
<td>1.0</td>
<td>0.87</td>
</tr>
<tr>
<td>3.0</td>
<td>0.75</td>
</tr>
<tr>
<td>5.0</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Appendix VIII

Applicable region for various SCS Type curves (SCS,1986)(22)
### Appendix IX

**Coefficients for Eq. [3.8] (22)**

<table>
<thead>
<tr>
<th>Rainfall type</th>
<th>$I/P$</th>
<th>$C_0$</th>
<th>$C_1$</th>
<th>$C_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.10</td>
<td>2.30550</td>
<td>-0.51429</td>
<td>-0.11750</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>2.23537</td>
<td>-0.50387</td>
<td>-0.08929</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>2.18219</td>
<td>-0.48488</td>
<td>-0.06589</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>2.10624</td>
<td>-0.45695</td>
<td>-0.02835</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2.00303</td>
<td>-0.40769</td>
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<tr>
<td></td>
<td>0.40</td>
<td>1.87733</td>
<td>-0.32274</td>
<td>0.05754</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>1.76312</td>
<td>-0.15644</td>
<td>0.00453</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>1.67889</td>
<td>-0.06930</td>
<td>0.0</td>
</tr>
<tr>
<td>IA</td>
<td>0.10</td>
<td>2.03250</td>
<td>-0.31583</td>
<td>-0.13748</td>
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<tr>
<td></td>
<td>0.20</td>
<td>1.91978</td>
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</tr>
<tr>
<td></td>
<td>0.25</td>
<td>1.83842</td>
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<td>-0.02597</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1.72657</td>
<td>-0.19826</td>
<td>0.02633</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>1.63417</td>
<td>-0.09100</td>
<td>0.0</td>
</tr>
<tr>
<td>II</td>
<td>0.10</td>
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<td>-0.61512</td>
<td>-0.16403</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>2.46532</td>
<td>-0.62257</td>
<td>-0.11657</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2.41896</td>
<td>-0.61594</td>
<td>-0.08820</td>
</tr>
<tr>
<td></td>
<td>0.40</td>
<td>2.36409</td>
<td>-0.59857</td>
<td>-0.05621</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>2.29238</td>
<td>-0.57005</td>
<td>-0.02281</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>2.20282</td>
<td>-0.51599</td>
<td>-0.01259</td>
</tr>
<tr>
<td>III</td>
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<td>2.47317</td>
<td>-0.51848</td>
<td>-0.17083</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>2.39628</td>
<td>-0.51202</td>
<td>-0.13245</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2.35477</td>
<td>-0.49735</td>
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<td></td>
<td>0.40</td>
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<td></td>
<td>0.50</td>
<td>2.17772</td>
<td>-0.35803</td>
<td>-0.09525</td>
</tr>
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</table>
## Typical value for Manning's n (22)

<table>
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<tr>
<th>Type and description of conduits</th>
<th>( n ) Values*</th>
<th>Type and description of conduits</th>
<th>( n ) Values*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channels, lined</strong></td>
<td></td>
<td><strong>Natural Streams</strong></td>
<td></td>
</tr>
<tr>
<td>Asphaltic concrete, machine placed</td>
<td>0.014</td>
<td>(a) Clean, straight bank, full stage, no riffles or pools</td>
<td>0.025</td>
</tr>
<tr>
<td>Asphalt, exposed prefabricated</td>
<td>0.015</td>
<td>(b) Same as (a) but some weeds and stones</td>
<td>0.030</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.012</td>
<td>(c) Winding, some pools and shoals, clean</td>
<td>0.035</td>
</tr>
<tr>
<td>Concrete, rubble</td>
<td>0.016</td>
<td>(d) Same as (c), lower stages, more ineffective slopes and sections</td>
<td>0.040</td>
</tr>
<tr>
<td>Metal, smooth (flumes)</td>
<td>0.011</td>
<td>(e) Same as (c), some weeds and stones</td>
<td>0.033</td>
</tr>
<tr>
<td>Metal, corrugated</td>
<td>0.021</td>
<td>(f) Same as (d), stony sections</td>
<td>0.045</td>
</tr>
<tr>
<td>Plastic</td>
<td>0.012</td>
<td>(g) Sluggish river reaches, rather weedy or with very deep pools</td>
<td>0.050</td>
</tr>
<tr>
<td>Shotcrete</td>
<td>0.016</td>
<td>(h) Very weedy reaches</td>
<td>0.075</td>
</tr>
<tr>
<td>Wood, planed (flumes)</td>
<td>0.009</td>
<td><strong>Pipe</strong></td>
<td></td>
</tr>
<tr>
<td>Wood, unplanned (flumes)</td>
<td>0.011</td>
<td>Asbestos cement</td>
<td>0.009</td>
</tr>
<tr>
<td><strong>Channels, earth</strong></td>
<td></td>
<td>Cast iron, coated</td>
<td>0.011</td>
</tr>
<tr>
<td>Earth bottom, rubble sides</td>
<td>0.028</td>
<td>Cast iron, uncoated</td>
<td>0.012</td>
</tr>
<tr>
<td>Drainage ditches, large, no vegetation</td>
<td>0.040</td>
<td>Clay or concrete drain tile (4–12 in.)</td>
<td>0.010</td>
</tr>
<tr>
<td>(a) &lt; 2.5 hydraulic radius</td>
<td>0.045</td>
<td>Concrete</td>
<td>0.010</td>
</tr>
<tr>
<td>(b) 2.5–4.0 hydraulic radius</td>
<td>0.035</td>
<td>Metal, corrugated</td>
<td>0.021</td>
</tr>
<tr>
<td>(c) 4.0–5.0 hydraulic radius</td>
<td>0.030</td>
<td>Steel, riveted and spiral</td>
<td>0.013</td>
</tr>
<tr>
<td>(d) &gt; 5.0 hydraulic radius</td>
<td>0.025</td>
<td>Vitrified sewer pipe</td>
<td>0.010</td>
</tr>
<tr>
<td>Small drainage ditches</td>
<td>0.035</td>
<td>Wood stove</td>
<td>0.010</td>
</tr>
<tr>
<td>Stony bed, weeds on bank</td>
<td>0.025</td>
<td>Wrought iron, black</td>
<td>0.012</td>
</tr>
<tr>
<td>Straight and uniform</td>
<td>0.017</td>
<td>Wrought iron, galvanized</td>
<td>0.013</td>
</tr>
<tr>
<td>Winding, sluggish</td>
<td>0.0225</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Selected from numerous sources.
Appendix XI

Properties of typical channels (22)

Note: Freeboard = D-d for all selection

<table>
<thead>
<tr>
<th>Cross-sectional area a</th>
<th>Wasted perimeter, p</th>
<th>Hydraulic radius R = ( \frac{a}{p} )</th>
<th>Top width</th>
</tr>
</thead>
<tbody>
<tr>
<td>( bd + Z^2 )</td>
<td>( b + 2d \sqrt{Z^2 + 1} )</td>
<td>( \frac{Z^2}{b + 2d \sqrt{Z^2 + 1}} )</td>
<td>( l = b + 2dZ )</td>
</tr>
<tr>
<td>( T = b + 2dZ )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Trapezoidal cross section

<table>
<thead>
<tr>
<th>Cross-sectional area a</th>
<th>Top width</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Zd^2 )</td>
<td>( Zd^2 + \frac{2Z}{2} ) or ( \frac{d}{2} ) approx.</td>
</tr>
<tr>
<td>( T = \frac{D}{2} )</td>
<td></td>
</tr>
</tbody>
</table>

Triangular cross section

<table>
<thead>
<tr>
<th>Cross-sectional area a</th>
<th>Top width</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{2}{3} ) ( d^3 )</td>
<td>( \frac{4d^2}{3} ) or ( \frac{2d}{3} ) approx.</td>
</tr>
<tr>
<td>( T = \left( \frac{D}{2} \right)^2 )</td>
<td></td>
</tr>
</tbody>
</table>
Appendix XII

An example of peak flow estimation (22)

[Example problem]

The water shown in Figure A is located in Eastern Kentucky. One seam of coal is to be surface mined as indicated. The entire watershed is 100 acres in size. The average width of the area to be stripped is 180 ft. The stripped area is about 4500 ft long. The average width of the area above the stripped area is 500 ft, and it is about 3500 ft in length. The water watershed is predominately forested. The soils are predominately Muskingum and Shelocta with about 50% of the watershed in each. Average land slope are around 55% with stream slopes average 5%. The maximum elevation rise in the watershed is 450 ft, and the maximum flow length is around 5000 ft. A diversion channel is to be placed along the upper periphery of the area to be stripped. Estimate the 10-year, 24-hr runoff volume before and immediately after mining and the 10-year peak flow into the diversion channel.
[Solution]

An example is illustrated in Figure A.

From appendix II, the 10-year, 24-hr rain is found to be 5.25 in.

Appendix III indicates that the hydrologic soil groups are Muskingum (HSG C) and Shelocta (HSG B). The CNs before mining (Appendix III) are Muskingum (HSG C, CN=70) and Shelocta (HSG B, CN=55):

$$\overline{CN} = \frac{0.5(70)+0.5(55)}{0.5+0.5} = 62.5$$

From Appendix IV for P=4.25 and CN=62.5, read Q=1.03 in. $Q_{5.25}$?
also can be computed from Eq[3.3] and Eq[3.4]. Therefore, the runoff volume from the 10-year, 24-hr rainfall before mining is 1.03 in. or 1.03/12 x 100 = 8.6 acre-feet.

After mining, the disturbed area is 180ft x 4500ft or 18.6 acres. The undisturbed area is 100-18.6 = 81.4 acres.

The CNs on the disturb area (Appendix III) are Muskingum (HSG C, CN=88) and Shelocta (HSG B, CN=81):

\[
\overline{\text{CN}} = \frac{\left(\frac{18.6}{2}\right)(88) + \left(\frac{18.6}{2}\right)(81) + \left(\frac{81.4}{2}\right)(70) + \left(\frac{81.4}{2}\right)(55)}{100} = 66.6
\]

From Appendix IV for P=4.25 and CN=66.6, read Q = 1.28 in. = 10.63 acre-feet.

Eq[3.7] will be used to calculate the peak flow in the diversion. The maximum length of flow within the diversion depends on the direction the diversion is sloped. Here we assume the diversion slopes toward the nearest main draw, so the maximum flow length is about 600 ft if the draws are evenly spaced. We use 700 ft to reflect the uneven spacing and to be conservative. The maximum area drawing into a diversion is thus

\[
A = \frac{700 \times 500}{43560} = 8 \text{ acres.}
\]

The time of concentration is the time it takes overland flow to travel 500 ft down the slope plus 700 ft to the diversion outlet. The overland flow velocity is estimated
from Eq[3.6]. The coefficient a from Appendix V is 2.5.

The overland flow velocity is

\[ v = 2.5(0.55)^{1/2} = 1.85 \text{ or about 2 fps}. \]

A reasonable design velocity estimate from the diversion yet to be designed is 6 fps.

\[ t_c = \frac{500}{2} + \frac{700}{6} = 250 + 116 (\text{sec}) = 6 \text{ min}. \]

The CN for the area above the diversion is 62.5.

Therefore the 10-year, 24-hr runoff volume is 1.03 in. as computed earlier. The pond factor, \( F_p \), from Appendix VII is 1.0. \( I_a \) is computed from \( I_a = 0.2S \), where \( S \) is given by

\[ S = \frac{1000}{CN} - 10 = \frac{1000}{62.5} - 10 = 6. \]

Therefore \( I_a = 0.2(6) = 1.2. \) \( I_a / P \) is \( 1.2 / 4.25 \) or 0.28.

Appendix VII shows Kentucky is the SCS type II rainfall region. Appendix VIII gives \( C_0 = 2.47, C_1 = -0.62, \) and \( C_2 = -0.12. \)

Eq[3.8] gives

\[ \log(q_u) = 2.47 - 0.62 \log(0.1) - 0.12[\log(0.1)]^2 = 2.97 \]

or

\[ q_u = 10^{2.97} = 933 \text{ cfs/in./mile}^2. \]

Eq[3.7] gives \( q_p \) as

\[ q_p = q_u A Q F_p = 933 \times \frac{8}{640} \times 1.03 \times 1 = 12 \text{ cfs}. \]