Best Management Practices for Reclaiming Surface Mines in Washington and Oregon

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Front Cover: A reclaimed quarry in mountainous terrain. Naturally hazardous conditions (cliffs) are present in the immediate area. Chutes, spurs, scree slopes, and soil on the scree have created a natural appearance. Trees now grow on the slope where soil is located and complete the reclamation. The site will be used for forestry in the future. Note the person midslope for scale. Photo by M. A. Shawver.

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Preface

The term *best management practices* (BMPs) has generally been used to describe mechanical means of minimizing or eliminating water-quality problems. The BMPs presented here, however, apply as well to reclamation, planning, and specific methodologies to promote an integrated approach to mining. The techniques and guidance provided in this manual should not be construed as rules or laws, but merely the most effective and economical reclamation and mining practices known to Oregon Department of Geology and Mineral Industries (DOGAMI) and the Washington Department of Natural Resources (DNR) at the present time.

This manual provides information about planning the mine from start-up to final reclamation, incorporating water and erosion control during operation and reclamation, soil salvage and replacement, land shaping, and revegetation.

This manual was compiled and written by DOGAMI and DNR to provide technical information and guidance to landowners, land-use planners, and mine operators. We urge miners to use this manual as a resource in developing an environmentally and financially sound mine. However, while this manual is a broad overview of mine reclamation and development and other BMPs, it is not a comprehensive document, nor should it necessarily be considered the final word. Mining and reclamation will continue to evolve and improve. Locking in on technique or even just one BMP can be dangerous. Miners should consider the range of BMPs discussed here before selecting one to the exclusion of others.

Reclamation of mines, especially large mines, is a complex multidisciplinary undertaking and goes far beyond this document. Trained professionals such as agronomists, biologists, engineers, geologists, hydrogeologists, landscape architects, planners, and soil scientists can be helpful in planning and completing a mining project.

Implementation of BMPs is in everyone's best interest. For mine operators, using BMPs can result in more efficient and profitable mining. For society, BMPs can mean cleaner, more usable, and aesthetically pleasing lands. Effective reclamation as the final BMP at a site can reduce water pollution and loss of topsoil, provide fish and wildlife habitat, and allow timber production, agriculture, and other uses to be re-established.

Funding

This project was partially funded by U.S. Environmental Protection Agency grant X000798-01-0 as means of transferring technical information regarding mine regulation and environmental issues. The original grant was an agreement between Idaho, Oregon, and Washington in 1993 and has been referred to as the Tri-State agreement for mining. BMPs for mining already exist in Idaho and helped pro-

vide the impetus for Oregon and Washington to generate this BMP guidance.

Future Work

This second edition of the Best Management Practices manual incorporates the suggestions of many of our readers, including several new diagrams and topics. The manual continues to be a work in progress, improving through field experience and the feedback we receive from people using the manual. We would appreciate any comments, particularly on places where we have given too much or too little information. Comments should be directed to the authors.

Acknowledgments

The authors thank reviewers Garth Anderson, Rex Hapala, Bill Lingley, Mary Ann Shawver, and Dave Pierce of DNR; Gary Lynch and Ben Mundie of DOGAMI; Bob Raforth and Scott Morrison of the Washington State Department of Ecology; Brad Biggerstaff of GeoEngineers; Ron Savelieff of Cadman, Inc.; and Beth Norman of South Puget Sound Community College. Thoughtful review and editing by Kitty Reed of DNR helped improve this document immeasurably. Ken Thacker of the Bureau of Land Management made helpful suggestions to upgrade Chapter 7.

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1 Maps as Management Tools

INTRODUCTION

Preparing accurate maps of the mining property and its surroundings is a key step in developing a surface mining operation. Maps allow geographic information to be summarized in a compact form. Their primary purpose is to describe geographic features and the spatial relations of these features. Maps benefit the operator by clearly defining the area in which mining is permitted, and they assist in long-range planning for both efficient use of the mine resource and timely reclamation.

TYPES OF MAPS

Surface mining regulations in both Washington and Oregon require that maps be submitted before mining permits are issued. To meet regulatory requirements, maps must provide sufficient detail to characterize the site. Types of maps that may be required for permit applications are:

- *A site access map* showing the regional setting of the site and how to get there from the nearest town.
- *A pre-mining topographic map* establishing the location and setting of the mine site as it exists before mining.
- *A geologic map* giving a detailed description of the geologic setting and the type of deposit to be mined (required only if specifically requested).
- *A reclamation sequence map* showing the borders and sequence of segments to be mined and reclaimed, including the directions in which soils will be moved during salvage and replacement, and the location of storage areas and other mine-related features.
- *A final reclamation map* and at least two intersecting cross sections showing the mine site as it will appear after reclamation and revegetation.
- *A revegetation map* showing the location and types of plants used for revegetation. (This may be combined with the final reclamation map if the information will not obscure contours.)

MAP SIZES

The map size preferred for review is 11 x 17 inches, which is easy to photocopy and store. If maps are small, they may be grouped on a single sheet of paper. If the maps submitted are larger than 11 x 17 inches or if they are in color, seven or more copies must be provided. The copies will be forwarded to other reviewing agencies.

Because 11 x 17 inches is generally not practical for internal working purposes, draft and working copies may be larger. For example, some larger mines may require a scale of 1″ = 200′ or 1″ = 400′ and thus large sheets. Draft and working copies may be reduced on a photocopier for submission. Make sure the map scale reflects any reduction.

BASIC ELEMENTS

Basic elements required on every map are the:

- map scale, both written out as a ratio and shown graphically as a bar or rake scale
- north arrow
- explanation block or legend
- title block

Map Scale

Every map, regardless of the size of the site, should include a scale that indicates the relationship between the size of features on the map and the size of the same features on the ground. Most scales are represented by stating that 1 inch on the map represents a certain number of inches, feet, or miles on the ground. For example, 1″ = 200′ means that 1 inch on the map represents 200 feet on the ground.

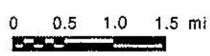
The scale that best represents a site will depend on the detail required and the size of the site, and the level of detail depends on the size and complexity of the mine. A map of a 50-acre rock quarry near a stream will normally require greater detail than a map of a 5-acre upland gravel extraction site. For some proposals, it may be acceptable to give only an approximate scale.

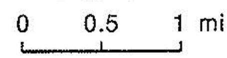
Site size	Suggested Map scale
3–6 acres	not less than 1″ = 50′
10–20 acres	not less than 1″ = 100′
20–80 acres	not less than 1″ = 200′
>80 acres	not less than 1″ = 400′

Note: If the map is reduced or enlarged, make sure the verbal scale is adjusted as well. Maps without a scale will not be accepted.

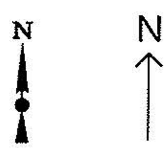
Graphic Scales

Map scales shown graphically should also be included. They will remain accurate when the map is reduced or enlarged. Examples of a bar scale (left) and a rake scale (right) are shown below:





North Arrow



All maps must show true north. This is typically done by drawing a line oriented N–S with an arrow pointing north. The north arrow in conjunction with the scale allows the map to be properly oriented during field inspections and to be related to other maps. Examples of north arrows are shown on the left.

Explanation Block

The explanation block or legend defines all symbols and patterns used and may contain the scale.

Title Block

The title block should contain the following information:

- title of map,
- application or permit number,
- name and address of applicant or permit holder(s),
- signature of applicant or permit holder(s),
- map or exhibit number, and
- date map was drawn or revised.

TOPOGRAPHIC CONTOURS

Topographic contours are lines on a map that connect points of equal elevation. For example, a 100-foot contour line links all points that have an elevation of 100 feet. Although not required on all maps, contours are useful in determining the steepness of slopes and the location of watercourses. Contours are deemed adequate for mine permitting if they accurately reflect the conditions of the site. Generally, contour intervals should be between 5 and 20 feet.

Typically, only large and/or complex sites require surveyed contour lines. Most applications for small sites can use a photocopied enlargement of a U.S. Geological Survey (USGS) topographic map. Enlarging a USGS 7.5-minute quadrangle (1″ = 2,000′) by 400 percent yields a map at a scale of 1″ = 500′. Care must be taken to ensure that the scale of the enlargement is accurate.

USGS maps are usually available at local hunting or sporting goods stores. They may also be ordered from the Washington Department of Natural Resources Photo and Map Sales (360-902-1234), the Nature of the Northwest Information Center (503-731-4444), or the U.S. Geological Survey (509-353-2524).

BOUNDARIES

Several types of boundaries may be required on maps: the permit area boundary, the mining area boundary (including present and future mining areas), and the property lines. The symbols for all should be included in the explanation block.

Permit Area Boundary

This is the boundary within which mining is permitted. Any mining, processing, or activity related to mining taking place outside this area constitutes mining without a permit and may invoke closure and/or civil penalties. In some places, the permit boundary may be coincident with the property boundary. However, the permit boundary may cross property lines and can include property held by different landowners. Once the boundary has been defined, changes to it typically require an amendment to the reclamation permit and may require land-use approval by the local jurisdiction.

The permit boundary is commonly indicated on maps as a dashed or solid line. This line type and width should be distinguishable from the property line boundary and should be clearly labeled as 'permit boundary'.

Mining Boundaries

Mining boundaries show the areas to be mined or excavated. Several maps may be needed to show areas affected by short-term and long-term operations.

Boundaries of Cities and Counties

Boundaries of cities, counties, and other municipalities must be shown if they cross the map area.

Property Lines

Tax lot maps from the county assessor's office are good sources of property line information. Property line locations are critical in determining setbacks to property lines and the likelihood of potential impacts to adjacent landowners.

The property line boundary is typically shown on maps as a solid line. The property line type and width should be distinguishable from the permit boundary line and should be clearly labeled. The letters 'PL' are commonly used to indicate a property line on maps, but this line and abbreviation must also be identified in the explanation block.

OTHER COMMON MAP ELEMENTS

The following map elements should be shown on one or more of the required maps.

Existing Watercourses, Ponds, and Wetlands

All streams, rivers, wetlands, and ponds on and adjacent to the site must be indicated on the map. Accurate location of these features allows reviewers to assess potential mining-related impacts and also aids the miner in the design of erosion and storm-water control systems to protect water quality.

Streams and rivers are represented by lines that are distinct from those used for haul roads, permit boundaries, and property lines. Ponds, wetlands, and lakes should be labeled and/or patterned to distinguish them from other mine features.

Processing Plant

Proper location of processing facilities makes good use of the topography for screening and noise control—for example, siting the facilities in a low area. (See Visual and Noise Screens, p. 3.6.) The location of the processing facilities can be labeled or a symbol may be used.

Haul Roads

Most roads can be placed to avoid potential problems. Proper location, construction, and drainage of roads can minimize turbid water and slope-stability problems. (See Passive Storm Water Control, p. 2.6, and Figs. 2.7 and 2.8.) Roads can be shown as lines whose width or line type (dashed, etc.) distinguish them from property lines and permit boundaries.

Soil and Overburden Stockpiles

Soil should be preserved for reclamation. The reclamation sequence map must show where topsoil, subsoil, and overburden will be stored until they are reapplied during reclamation. Soil stockpiles can be indicated by drawing a line around the proposed location, adding a distinctive pattern, and labeling the area 'topsoil', 'subsoil', or 'overburden'. (See Removing and Storing Topsoil and Subsoils, p. 3.13.)

Product Stockpiles and Waste-Rock Dumps

Stockpiles of usable rock and waste-rock dumps are generally indicated on maps by drawing a line around the proposed location, adding a distinctive pattern, and labeling the area 'stockpile' or 'waste dump'. Stability and potential erosion problems are criteria to be considered in selecting the location of a stockpile or dump. Site topography will influence these factors. (See Waste and Overburden Dumps and Stockpiles, p. 3.15.)

Interim Watercourses and Ponds

Temporary watercourses and ponds, including settling ponds and drainage ditches to control storm-water runoff, should be distin-

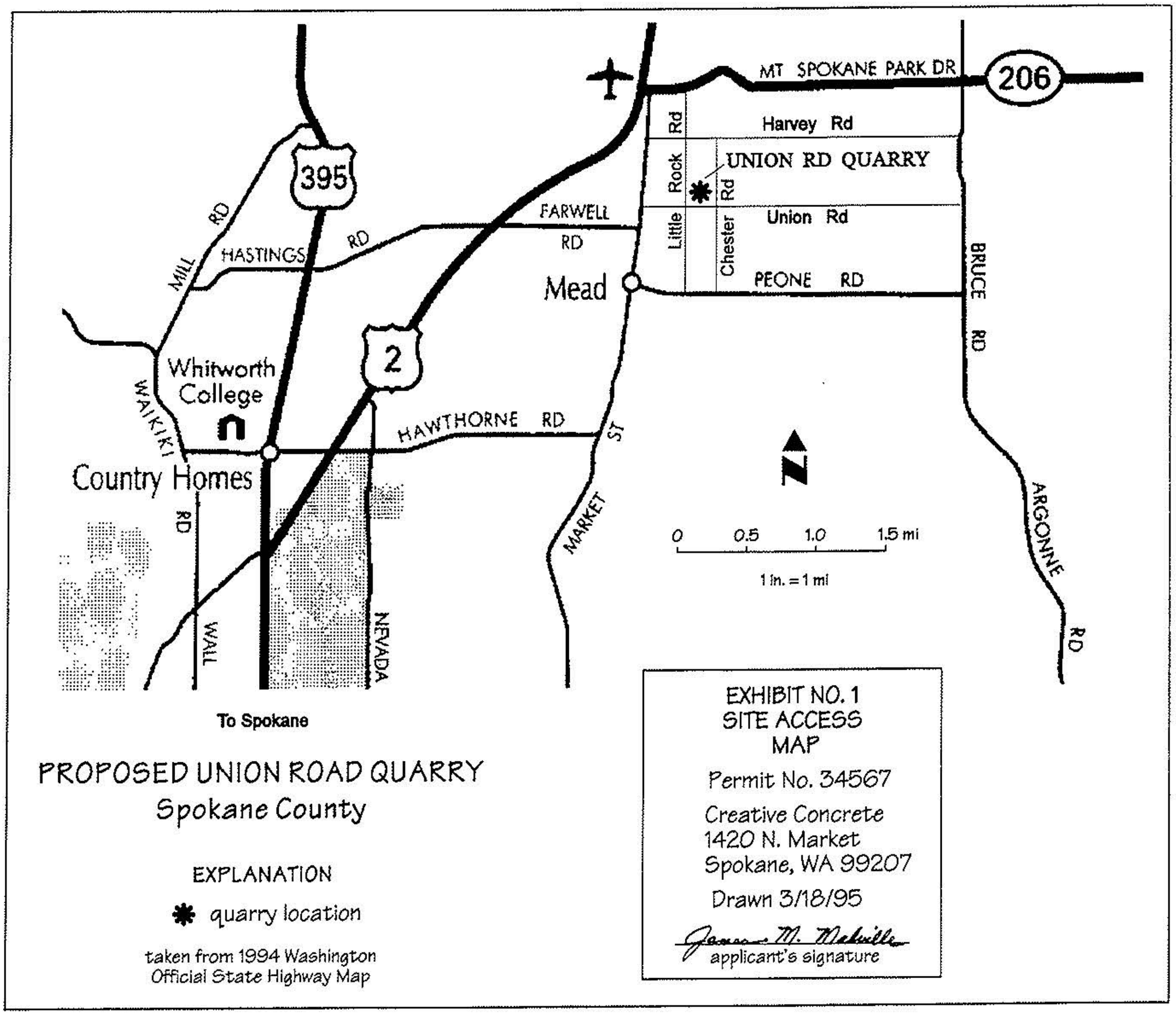


Figure 1.1. Site access map for the fictitious Union Road Quarry, taken from a highway map. Note verbal scale, bar scale, north arrow, and explanation and title blocks. (Not to scale; this map has been reduced to fit on the page.)

guished from permanent natural features. They may be represented by a unique line or pattern. (See Storm-Water and Erosion-Control Structures, p. 2.12.)

Typical Cross Sections

A cross section or profile shows what the mining site would look like if a vertical slice were taken through it. The purpose is to show the slope of the original land surface and reclaimed land surface, the water level of ponds and wetlands, and the types and placement of vegetation. Cross sections are usually taken through the areas that will show the most information. It is generally best if a cross section is drawn so that the vertical and horizontal scales are the same. In some cases, the vertical scale can be exaggerated to accentuate topographic features.

SITE ACCESS MAP

The site access map (Fig. 1.1) can be a copy or tracing of the pertinent part of a road map that clearly shows how to get to the site from

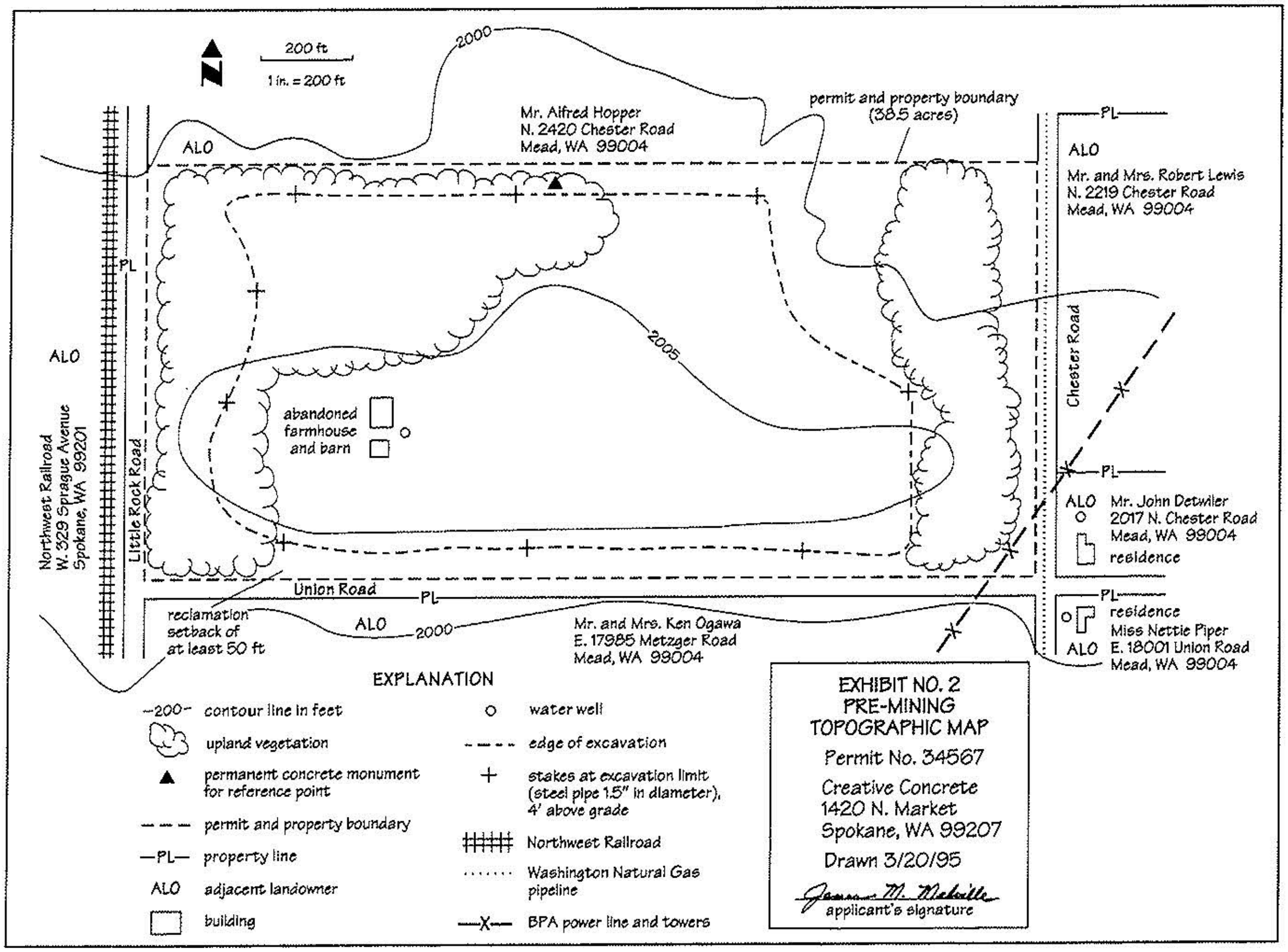


Figure 1.2. Pre-mining topographic map for the quarry in Figure 1.1. Note existing buildings and vegetation, pre-mining contours, verbal scale, bar scale, north arrow, and explanation and title blocks. (Modified from Norman and Lingley, 1992. Not to scale; this map has been reduced to fit on the page.)

the nearest town. The preferred size for this type of map is 8½ x 11 inches. A site access map shows the regional setting of the site and includes nearby geographical features and public road access to the site.

PRE-MINING TOPOGRAPHIC MAP

The pre-mining topographic map establishes the location and setting of the mine site (Fig. 1.2). It must show the following features:

- ☐ Permit area plus an appropriate border on all sides to show important adjacent features. The size of the border depends on site topography, drainage, neighbors, etc.
- ☐ Elevations and contours, natural ground slopes, drainage patterns, and other topographic features
- ☐ Boundaries and names of counties and municipalities (if they cross the map area)
- ☐ Boundaries of property ownership adjacent to the mine
- ☐ Names and addresses of adjacent property owners
- ☐ Locations and names of any other nearby mines

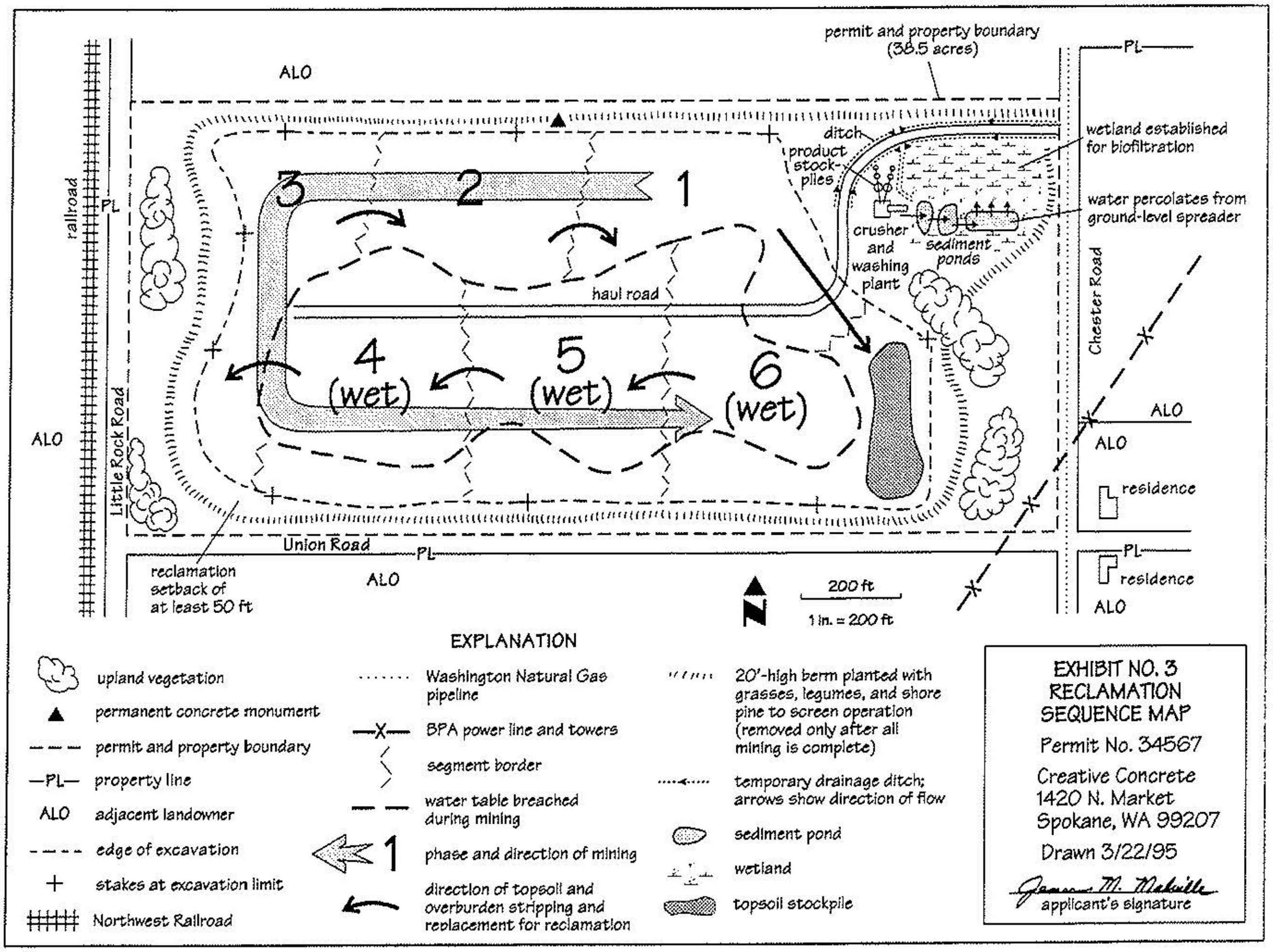


Figure 1.3. Reclamation sequence map for the site in Figure 1.2. This map shows the location and sequence of segments to be mined according to the operating and reclamation plan (counterclockwise from the northeast, in this instance), as well as details of soil placement, screening, and drainage. This site is mined first as a dry site, but as mining proceeds into the southern segments, the water table is penetrated. (Modified from Norman and Lingley, 1992. Not to scale; this map has been reduced to fit on the page.)

- ☐ Locations and names (if any) of all roads, railroads, utility lines, or any other rights of way
- ☐ Locations and names (if any) of all streams and natural and artificial drainways on or adjacent to the mine site
- ☐ Locations and names of significant buildings, parks, and other artificial features
- ☐ Locations and names (if any) of all wells, lakes, springs, and existing wetlands on or adjacent to the mine site
- ☐ Boundaries of the areas that will be disturbed by mining.

RECLAMATION SEQUENCE MAP

The reclamation sequence map shows the details of the plan for mining and segmental reclamation (Fig. 1.3). It should cover the same area as the pre-mining topographic map and display the following information:

- ☐ Permit area plus an appropriate border on all sides
- ☐ Boundaries of the areas that will be disturbed by mining

- ☐ Locations of all permanent boundary markers
- ☐ Locations of proposed access roads to be built in conjunction with the surface mining operation
- ☐ Locations and types of setbacks and berms
- ☐ Numbered segments and the direction and sequence of mining
- ☐ Soil storage areas and sequence of stripping, storing, and replacement on mined segments
- ☐ Overburden storage areas and sequence of stripping, storing, and replacement of overburden on mined segments
- ☐ Waste rock piles and how they will be reclaimed and stabilized
- ☐ Operation plant and processing areas
- ☐ Measures to be taken to protect adjacent surface resources, including prevention of slumping or landslides on adjacent lands
- ☐ Location and description of storm-water and erosion-control systems, including drainage facilities and settling ponds
- ☐ Other pertinent features.

FINAL RECLAMATION MAP

On most sites that require a state reclamation permit (reclamation plan), a description of the post-mining topography is usually sufficient, but for complex sites, post-mining topographic maps should be prepared (Fig. 1.4). This is a topographic map of the site as it will look after final reclamation, usually presented in the form of post-mining contour lines or post-mining pit outlines. It must show all applicable data required in the narrative portion of the reclamation plan and details of the mine reclamation. The map should cover the same area as the pre-mining topographic map, at the same scale, and should display the following information:

- ☐ Permit area plus an appropriate border on all sides
- ☐ Final elevations and contours, adjacent natural ground slopes, reclaimed drainage patterns, and other topographic features
- ☐ Locations and names (if any) of all roads, railroads, utility lines, or any other rights of way
- ☐ Locations and names (if any) of all streams and drainages
- ☐ Locations and names (if any) of significant buildings, parks, and other structures, facilities, or features
- ☐ Locations and names (if any) of all lakes, springs, and wetlands
- ☐ Location and depth of topsoil to be replaced
- ☐ Permanent drainage and water-control systems (with expanded view, if needed)
- ☐ Area to be revegetated and proposed species
- ☐ At least two cross sections (generally at right angles), with horizontal and vertical scales the same, that show the original and final topography and the water table (Fig. 1.5)

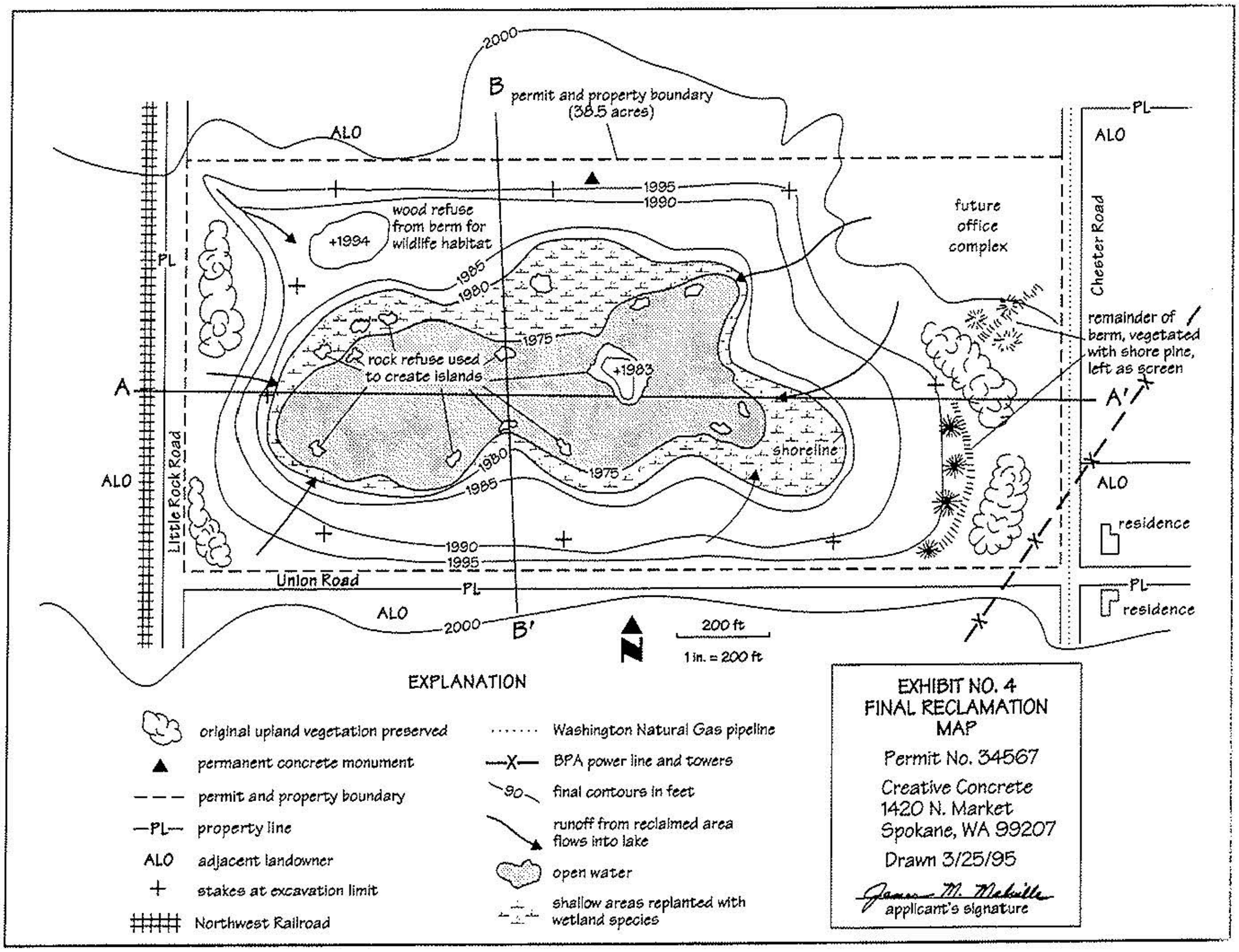


Figure 1.4. Final reclamation map of the site in Figure 1.2, showing how it will appear after reclamation. The site will accommodate a small office complex and wildlife habitat when it has been reclaimed. Cross sections A–A′ and B–B′ are shown in Figure 1.5. (Modified from Norman and Lingley, 1992. Not to scale; this map has been reduced to fit on the page.)

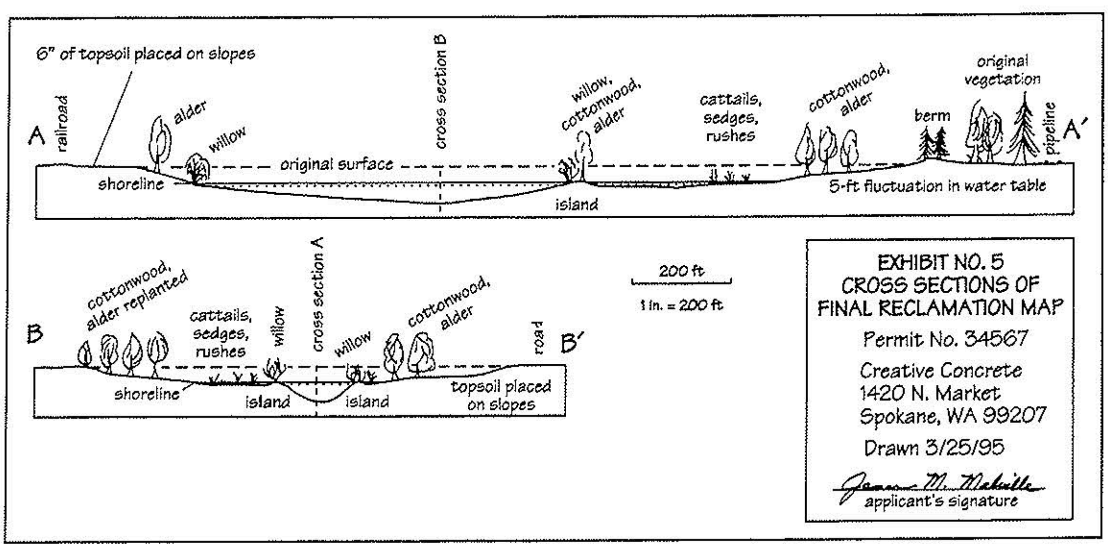


Figure 1.5. Cross sections for the final reclamation plan of the mine shown in Figure 1.4. The types and placement of vegetation and the slope of the pond banks are shown. (Modified from Norman and Lingley, 1992. Not to scale; this map has been reduced to fit on the page.)

- ☐ Other information pertaining to the permit and required by statute or special conditions of the permit.

GEOLOGIC MAP

In addition to the preceding four types of maps, a detailed description of the geologic setting and the type of deposit to be mined is sometimes required in geologically complex areas and for certain industrial mineral or metal mines.

MAP UPDATES

Current aerial photos or updated maps may be required as mining progresses.

REFERENCE

Norman, D. K.; Lingley, W. S., Jr., 1992, Reclamation of sand and gravel mines: Washington Geology, v. 20, no. 3, p. 20-31.

2 Storm-Water and Erosion Control

INTRODUCTION

Protecting water quality and preventing erosion are two important tasks mine operators must address. Federal legislation and increasing concern and scrutiny by state and local agencies and the public require that mine operators pay close attention to even small or temporary discharges of storm water. The quality of those discharges, particularly their turbidity, is a direct reflection of how sediment on the site is handled. Expensive solutions to water-quality problems can often be avoided by incorporating storm-water and erosion-control techniques into the mine development plan. For most mine sites, a good storm-water control system can minimize or even eliminate storm-water discharge during the operation phase. When mining ceases, erosion control is still necessary but should rely on techniques that can function without maintenance.

Controlling storm water and the erosion it causes requires integrated management starting at the top of the watershed above the mining area. No single action will produce permanently effective results. A good system has numerous individual components that must function separately but also respond as a unit during storms. The failure of one component can cause other components to fail and ultimately affect water quality. Furthermore, control practices are likely to change over the life of the operation. Good planning and constant maintenance are needed to keep the storm-water system working at peak efficiency.

This chapter describes basic techniques that can be combined to make a comprehensive storm-water and erosion-control system. Specific techniques appropriate to a given site depend on climate, topography, and the erodibility of the material present. The following general guidelines are applicable everywhere:

- Carefully plan the areas to be cleared in order to minimize disturbance.
- Retain sediment by using erosion-control BMPs.
- Interrupt the flow of surface water to reduce velocity.
- Use revegetation and mulching to stabilize cleared areas as soon as practical.
- Isolate fines produced during mining and processing.
- Develop a plan for maintaining storm-water and erosion-control structures. Follow the plan, and modify it as necessary to address changing conditions.

MAINTENANCE AND EMPLOYEE INVOLVEMENT

Although water quality is ultimately the operator's responsibility, maintenance of storm-water and erosion-control systems must be a priority for management and involve all mine employees. Managers should explain to staff why controlling storm water and erosion is so important. An effective program requires that everyone be on the lookout for seemingly insignificant situations that can snowball into major problems if not addressed in time.

We encourage operators and their employees to experiment with improving their storm-water systems. Operators should not feel limited to the information provided in this document. Common sense and innovation, with an emphasis on early recognition and response to erosion and sediment-transport problems, are the key to effective storm-water control.

EROSION

The rate of erosion is affected by four main factors (Fig. 2.1):

- *climate*, which determines how much rain and snow will fall on a site,
- *soil characteristics*, which determine erodibility and infiltration rates,
- *topography or slope*, which determines the velocity of runoff and the energy water will have to cause erosion, and
- *vegetation*, which slows runoff and prevents erosion by holding soils in place.

Each of these factors plays a role in determining which BMPs should be used to control erosion on a given site.

Erosion begins when raindrops displace soil particles. Raindrops may combine into sheets of water and flow over the surface (overland flow) to cause sheet erosion. Topography then concentrates water to produce rill and gully erosion. When water from rills and gullies combines, larger erosive streams and channels form (Fig. 2.2).

A single raindrop may move a splashed particle 2 feet vertically and 5 feet horizontally. The velocity of a raindrop is more than ten times higher than typical surface runoff velocities, which means that soil particles are more likely to be dislodged by raindrop impact than by surface runoff. Once the particles are mobilized, however, much less energy is required to keep them suspended or moving.

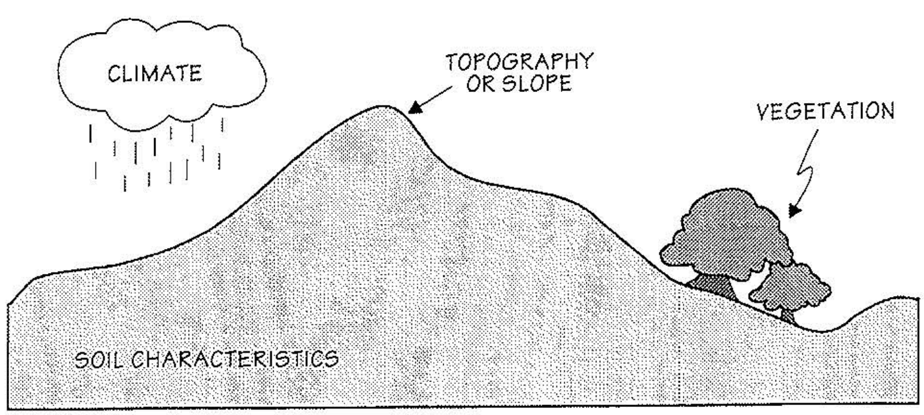


Figure 2.1. The rate of erosion depends on climate, soil characteristics, topography or slope, and vegetation.

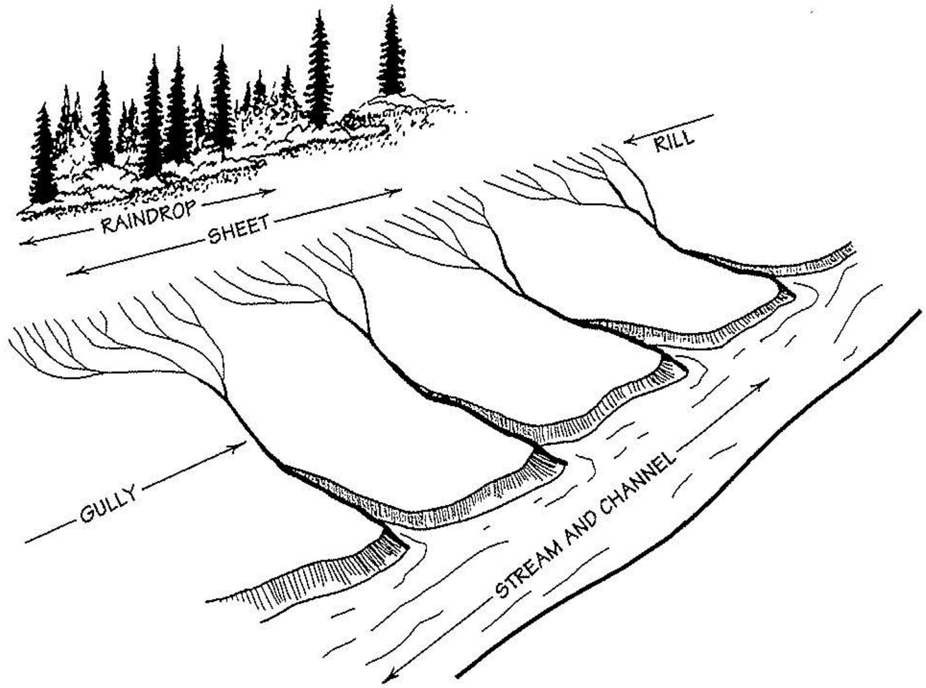


Figure 2.2. Topography created by different types of erosion. Raindrop erosion affects any bare surface. If the water does not infiltrate, raindrops combine into sheets of water (overland flow) to cause sheet erosion, and sheets further concentrate to produce rill and gully erosion. Water from rills and gullies then combines to form streams and channels. (Redrawn from Beckett, Jackson, Raedere, Inc., 1975.)

STORM-WATER REGULATION

The Washington Department of Ecology (DOE) and the Oregon Department of Environmental Quality (DEQ) regulate the discharge of storm water and waste water into public waters. The Stormwater Management Manual for the Puget Sound Basin (Washington State Department of Ecology, 1992) is a good source of 'best management practices' (BMPs) and is available from DOE.

For many mine sites, DOE requires a Stormwater Pollution Prevention Plan (SWPPP). As part of the SWPPP, an Erosion and Sediment Control Plan is required with the general discharge permit.

Mine sites in Oregon that discharge storm water off site need a Department of Environmental Quality (DEQ) storm-water permit, which can be obtained through DOGAMI-MLR. This typically requires the preparation of a storm-water plan to be submitted with the storm-water application. Sites that use water for processing and do not discharge water from the site must obtain a Water Pollution Control Facility Permit (WPCF permit) from DOGAMI-MLR. Sites that use water to process aggregate and discharge water from the site should contact DEQ to obtain an individual WPCF permit.

TURBIDITY AND SUSPENDED SEDIMENT

Erosion results in stream water that has high turbidity and a large sediment load. Turbid, sediment-laden water can adversely affect frogs and toads, clams, bottom-dwelling insects, and the appearance of stream systems. High levels of turbidity can also interfere with the feeding habits of fish, especially juveniles, and clog gills. Settleable solids can cover spawning gravels and suffocate eggs.

Turbidity

Turbidity is a measure of the amount of light that can pass through water in a straight line. Turbidity is reported as Nephelometric Turbidity Units (NTU). A high NTU value means that little light is transmitted through the water because it is absorbed or deflected by particles in the water.

Suspended Sediment

Suspended sediment is composed of settleable and nonsettleable solids. Settleable solids (sand- and silt-size particles) are heavier than water and will settle in calm water. Nonsettleable solids (clay-size particles) take a long time (or distance) to settle out of suspension—in some cases, years—and are the chief cause of turbidity.

In Washington, turbidity must not be more than 5 NTU greater than the background turbidity when the background turbidity is 50 NTU or less, or there must not be more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU. There is no standard for suspended solids or settleable solids in the water-quality regulations.

For example, in the sand and gravel general discharge permit, DOE is allowed by regulation to give a facility a 10:1 mixing zone to meet an effluent limit. DOE sets the end-of-pipe effluent limit at 50 NTU and assumes that the background level for turbidity in the receiving water is zero. With a 10:1 mixing zone, this should result in a 5 NTU final effluent quality at the end of the mixing zone.

In Oregon, all sites that have point-source discharges of storm water must have a storm-water discharge permit. As of January 1, 1998, storm-water discharge permits for mine sites will be administered by DOGAMI-MLR. The general storm-water permit contains performance benchmarks for storm-water plans. Benchmarks have been set for pH, total suspended solids, and oil and grease. If benchmarks are exceeded, the plan must be modified to address the deficiency. Turbidity must be less than 10 percent above the background of the receiving stream or river.

EROSION CONTROL

Assuming that the general guidelines given on p. 2.1 are being followed, the two most important things that can be done to minimize erosion, sedimentation, and turbidity are preventing raindrop erosion and slowing surface-water runoff velocities in the bare areas.

Practices that reduce erosion can be classified as either short- or long-term, although considerable overlap exists between the two. All require maintenance to be effective. They are described in detail later in this chapter.

Short-term erosion-control methods include:

- mulching,
- slash windrows,
- straw bales,
- filter fabric fences,
- jute netting and/or mulch fabrics,
- brush sediment barriers, and
- plastic coverings.

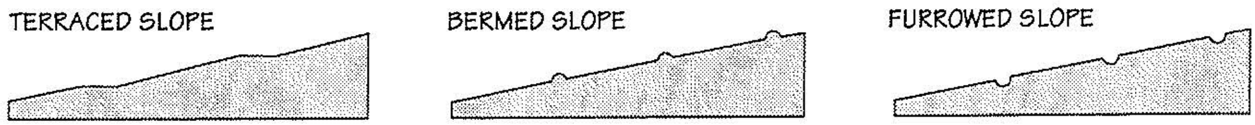


Figure 2.3. Small, discontinuous terraces, berms, and furrows can effectively slow runoff and decrease sediment transport. The relief is exaggerated for illustrative purposes. (From Banks, 1981.)

Long-term erosion-control methods include:

- vegetation,
- diversion ditches,
- rock check dams,
- rock-lined ditches, and
- contours, berms, swales, and ditches.

Controlling Raindrop Erosion

On flat ground, raindrop erosion is typically not a problem, but on slopes, more soil is splashed downhill than uphill. Covering steep slopes with plastic sheeting or mulch and/or revegetating bare areas reduces the erosion caused by raindrop impact. Gravel placed on berms or other bare areas at the plant site can also significantly reduce sediment movement during heavy rains.

Controlling Surface Runoff

Runoff velocities can be controlled by retarding flow and/or breaking up or minimizing slope length. Retarding flow on a slope can be accomplished with organic debris or geotextiles. Small, discontinuous terraces, berms, and furrows on the overburden cut above the mine or on reclaimed slopes can effectively slow runoff and decrease sediment transport (Fig. 2.3). Benches cut in overburden or other unconsolidated material likely to erode should be sloped into the hillside and away from the center of the bench to allow drainage to either side (Fig. 2.4). For reclamation, benches and terraces should have shapes and dimensions that appear natural so they blend in with the landforms of the area.

Other methods for reducing runoff velocities involve long-term structures incorporated into the drainage-ditch system. (See Storm-Water and Erosion-Control Structures, p. 2.12.) These structures should be used in the interior of the mine in conjunction with set-

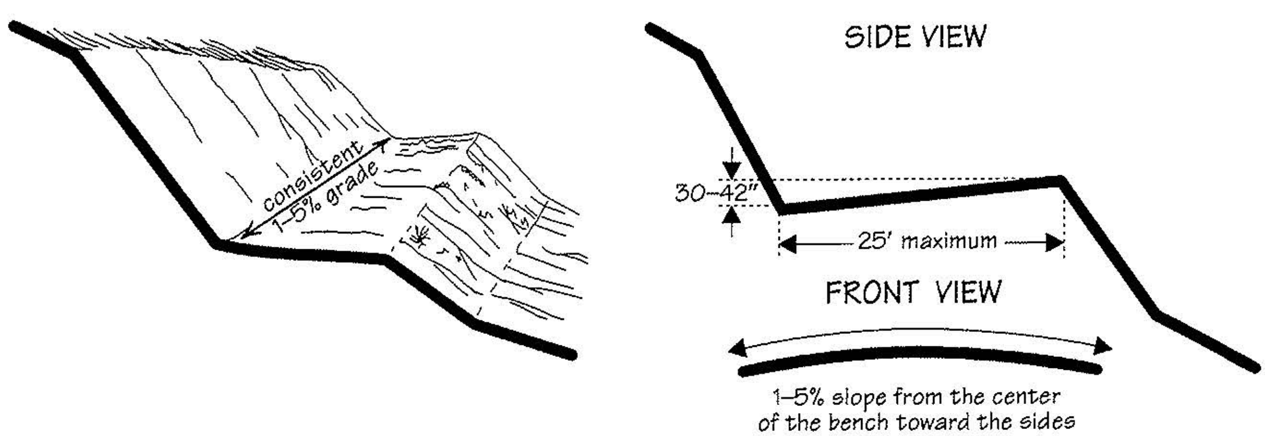


Figure 2.4. Benching and terracing of unconsolidated material to control runoff. Benches cut in overburden or other material likely to erode should be sloped into the hillside (side view) and away from the center of the bench (1–5% slope or grade) to allow drainage to either side (front view). (Modified from Law, 1984. Copyright © 1984 by Van Nostrand Reinhold Company Inc. Used by permission of the publisher.)

tling ponds. Using only one method is generally not successful. Attempting to trap or control sediment in settling ponds may not work unless some sediments have been dispersed and trapped upslope of the final pond or discharge point.

Long-term erosion-control methods are more cost-effective if properly planned and coordinated with mining activities. At many sites, short-term erosion control will be needed until long-term controls are established. Some methods, such as revegetation, can be effective in both the short and long terms.

STORM-WATER DIVERSION

Conventional storm-water control methods tend to concentrate flows using ditches, berms, and ponds. The best strategy for storm-water control, however, is to divert storm water and overland flow around the mining site and back into the original drainage (Fig. 2.5). Keeping 'clean' water separate from 'dirty' water is the easiest way to minimize the amount of water that has to be treated or contained. To do this, mine operators must know where and how much water enters the mine site during storms of various sizes. Depending on the size of the operation, the type and duration of precipitation, the type of material being mined, and the topography, passive control of storm water may be all that is needed.

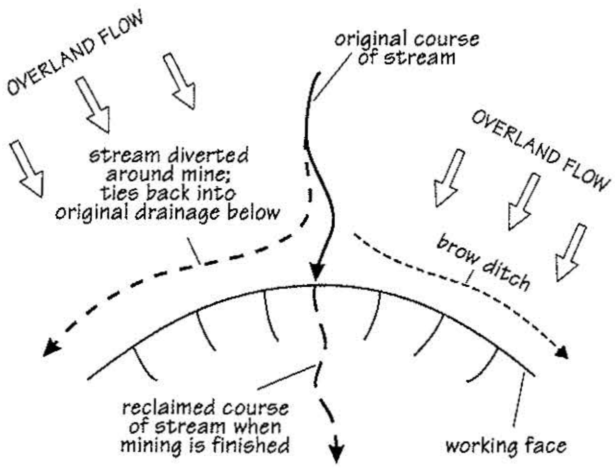


Figure 2.5. The best strategy for storm-water control is to divert streams and overland flow around the mining site. Not to scale.

If storm water cannot be diverted around the site, that water should be isolated from the storm water onsite to provide the best possible protection of surface waters.

PASSIVE STORM-WATER CONTROL

Passive storm-water control techniques rely on gravity to do their work. Their goal is to disperse storm water at numerous locations rather than to concentrate flows, which then have to be treated to remove sediment. Passive control structures are typically nonengineered and can easily be built at any mine site. They should be placed to prevent overland flow over any significant distance.

Small operations on permeable materials (such as sand and gravel, cinders, and pumice) and sites developed on flat or gently sloping terrain are good locations to use passive techniques. These techniques will also work on quarry sites where the rock is highly fractured and/or the size of the disturbance is fairly

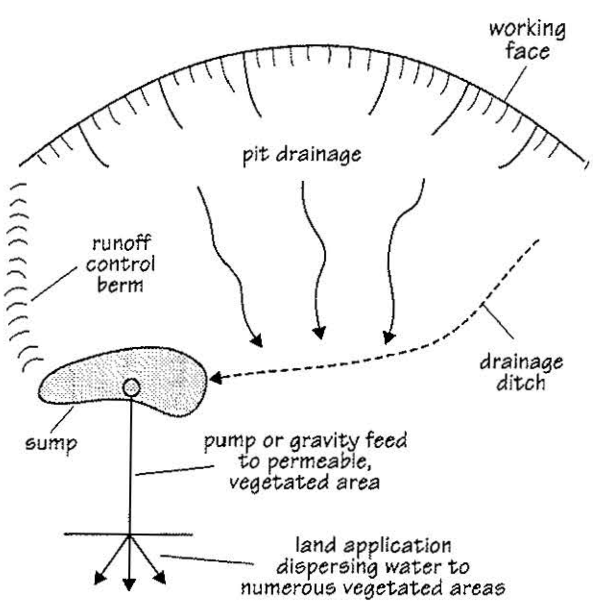


Figure 2.6. Berms and ditches divert runoff to a collection sump from which it can be dispersed into vegetated areas at numerous locations around the mine site. Not to scale.

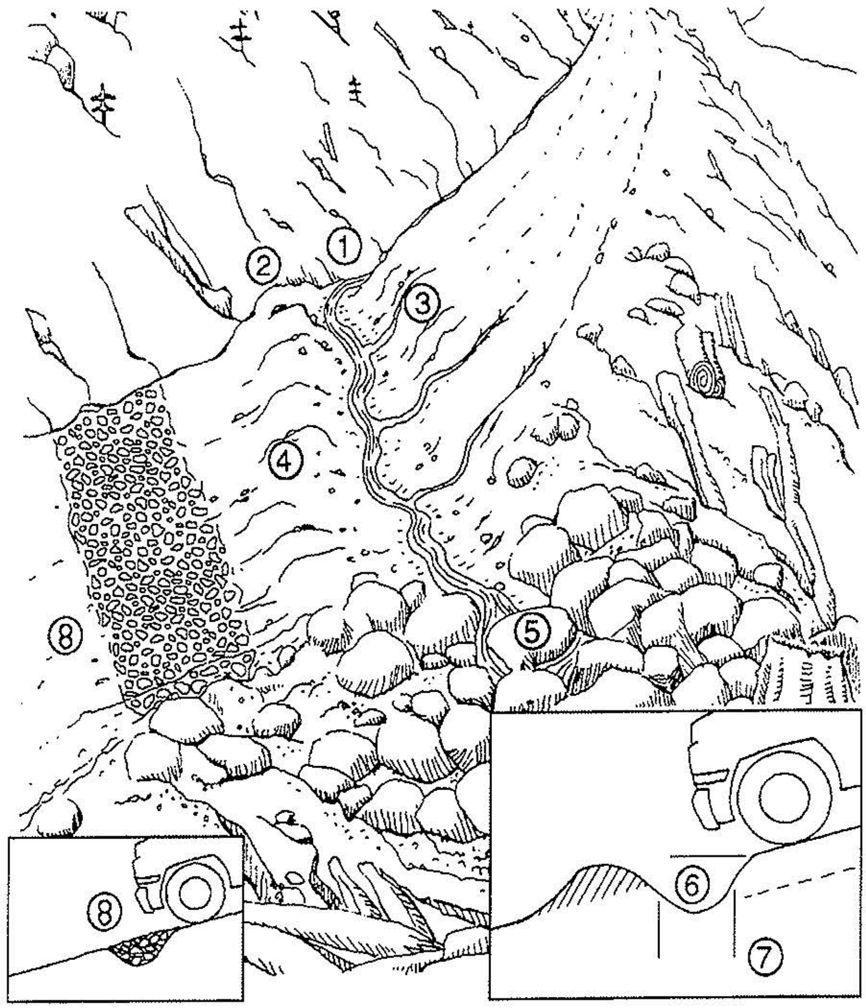


Figure 2.7. The water bar or cross-ditch intercepts, directs, and disperses surface-water flow off a road to stable sites on the downhill side of the road. 1, The cross-ditch is cut into the roadbed from the cutbank or ditchline completely across the road surface, extending beyond the shoulder of the road. 2, Physical blockage of the the ditchline is required to deflect water flow into the cross-ditch. 3, The cross-ditch should be placed at a minimum skew of 30° to the ditchline—greater on steep road gradients. 4, The excavated material is spread on the downhill grade of the road, creating a berm. 5, Water should always be dispersed onto a stable slope with vegetation or riprap protection. 6, The cross-ditch berm should dip to allow vehicle crossover without destroying the ditch. 7, The cross-ditch must be cut to the depth of the ditchline to prevent water ponding and to ensure drainage from the ditchline. 8, An alternative to creating a water bar is to place a French drain in essentially the same configuration. The water bar and the French drain are shown together here for purposes of illustration. They would not normally be used so close together. (Modified from Chatwin and others, 1991.)

small. Passive techniques can and should be incorporated into designs for larger sites that require offsite discharge of storm water.

At most sites, roads and processing areas are the biggest sources of sediment because equipment is constantly being moved across them. Good road design and limiting traffic movement to specific areas can minimize disturbance and therefore sediment production.

The techniques suggested in the next few pages can reduce the amount of contaminated water that requires treatment prior to discharge offsite. Applying an appropriate combination of these techniques may eliminate offsite discharge of storm water altogether.

- ☛ Construct berms and ditches to divert runoff away from natural drainages and slopes and into vegetated areas around the mine site. If possible, select vegetated areas on gentle slopes. Doing this at numerous locations is the key to success (Fig. 2.6).
- ☛ Construct closely spaced water bars (Fig. 2.7) on roads susceptible to erosion, for example, ungraveled roads, roads with steep grades, and roads on highly erodible soils. Very little maintenance is required if water bars are properly constructed, placed in correct locations, and closely spaced.

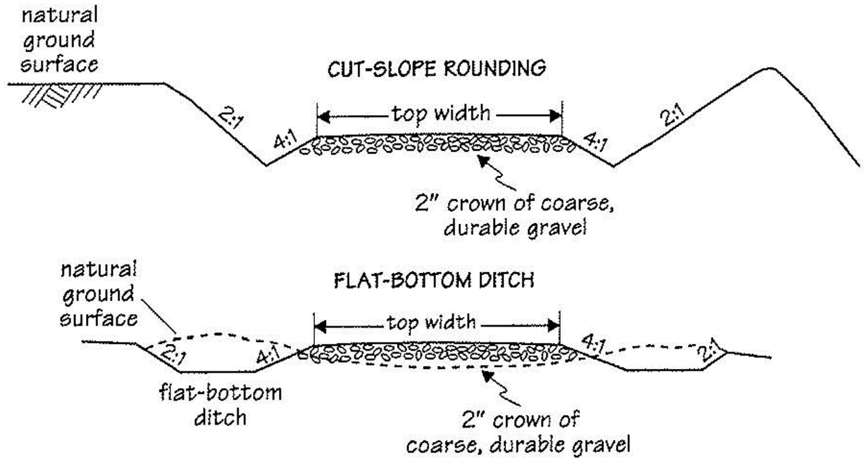


Figure 2.8. Profiles of elevated haul roads with drainage ditches on the sides to keep runoff from entering heavy traffic areas where it is more likely to pick up sediment. (Modified from U.S. Bureau of Land Management, 1992.)

Wide water bars, also called rolling ditches, can perform the same function as conventional water bars while providing smoother passage for vehicles.

- ☛ Use water bars on exploration roads above the mine cut or other roads that receive only occasional use.
- ☛ Elevate frequently used roads (Fig. 2.8), such as haul roads, and other heavy traffic areas to keep runoff away from these areas where it is more likely to pick up sediment.
- ☛ Make sure roads are well covered with durable, coarse rock of appropriate size.
- ☛ To retain storm water on wide working benches during the winter, use temporary berms.
- ☛ On the pit or quarry floor, establish and maintain a slope that allows turbid water to drain toward a low point where it can be collected in a pond or a sump to allow water to infiltrate (Fig. 2.9). This practice stops sediment-laden sheetwash from leaving the pit and may create beneficial wetlands after

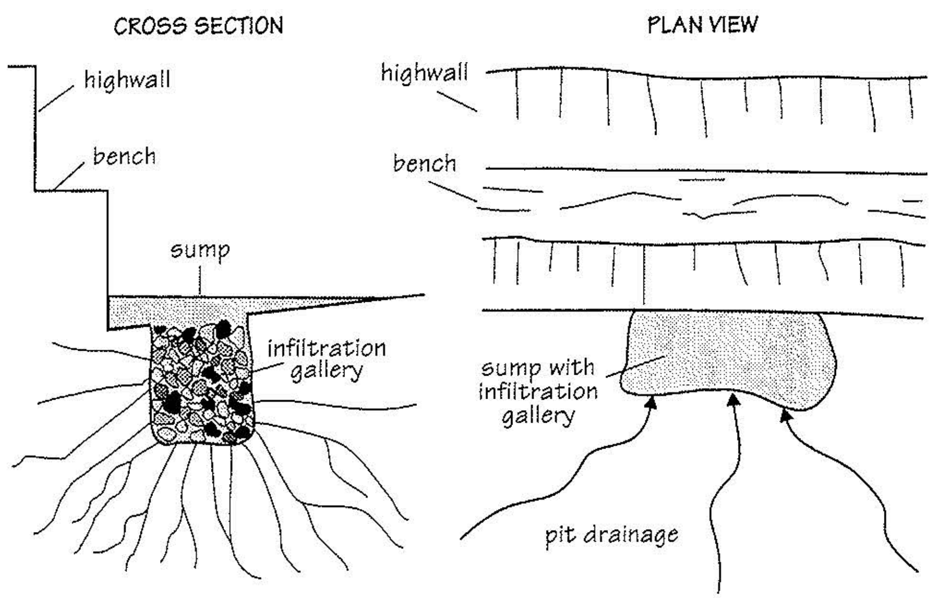


Figure 2.9. Establish and maintain a slope that allows water to drain toward the highwall to collect sediment and help form wetlands or to allow water to infiltrate (note infiltration gallery) if the area must be drained. This practice is not recommended if oil and grease are present as potential groundwater contaminants. Discharge to ground water may require a permit. (See also Fig. 2.26.)

reclamation. However, this method is not recommended if oil and grease are present to contaminate ground water.

- In both excavation and processing areas, develop and maintain places that will readily accept runoff and precipitation. For hard-rock sites, fracture the quarry floors and/or leave shot rock in place. For gravel and soft-rock quarries, rip and/or minimize areas compacted by heavy equipment.
- When processing rock on the excavation floor, make sure adequate drainage is provided. Fines produced during processing will potentially decrease permeability and increase runoff. This will likely result in an increase in the amount of turbid water to be treated.
- Use filter berms built of porous materials, such as sand and gravel or processed quarry rock that contains no 200-mesh or smaller material, to remove sediments. (See p. 2.19.)
- Use dry wells or infiltration galleries and horizontal subdrains to allow storm water to infiltrate into the ground rather than run off the site. (See p. 2.20 and 2.20.)
- Regrade, reshape, revegetate, and otherwise protect areas that have the potential to produce runoff or sediment.
- Minimize the disturbed area by maximizing the area reclaimed each fall.
- Establish and maintain vegetated buffer strips between disturbed areas and any natural drainage. Silt fines may be incorporated into the soil in these areas.
- Minimize the amount of water requiring treatment by isolating ground water from storm water. Sumps and trenches or shallow wells at the lowest point of the excavation can dewater the mine area prior to mining.

In Washington, any process water to be discharged to ground is regulated by the Department of Ecology. This includes process water discharged to dry wells and drain fields.

SEDIMENT CONTROL ON THE MINE SITE

If sediment gets into the water onsite, it can become an environmental contaminant requiring treatment. Removing soil fines from water can be a difficult and costly process. The best approach is to isolate the source of the sediment. Passive storm-water controls can reduce or eliminate suspended fines before they reach the settling pond system. Undersize or reject fines may be a saleable aggregate product and, in some mines, may be an appropriate or necessary soil amendment for reclamation. (See Replacing Topsoil and Subsoil, p. 4.5.)

Soils with sand as the dominant particle size are coarse-textured, light, and easily erodible. Water soaks into these soils rapidly. Silts and clays make fine-textured, heavy soils that are slow to erode

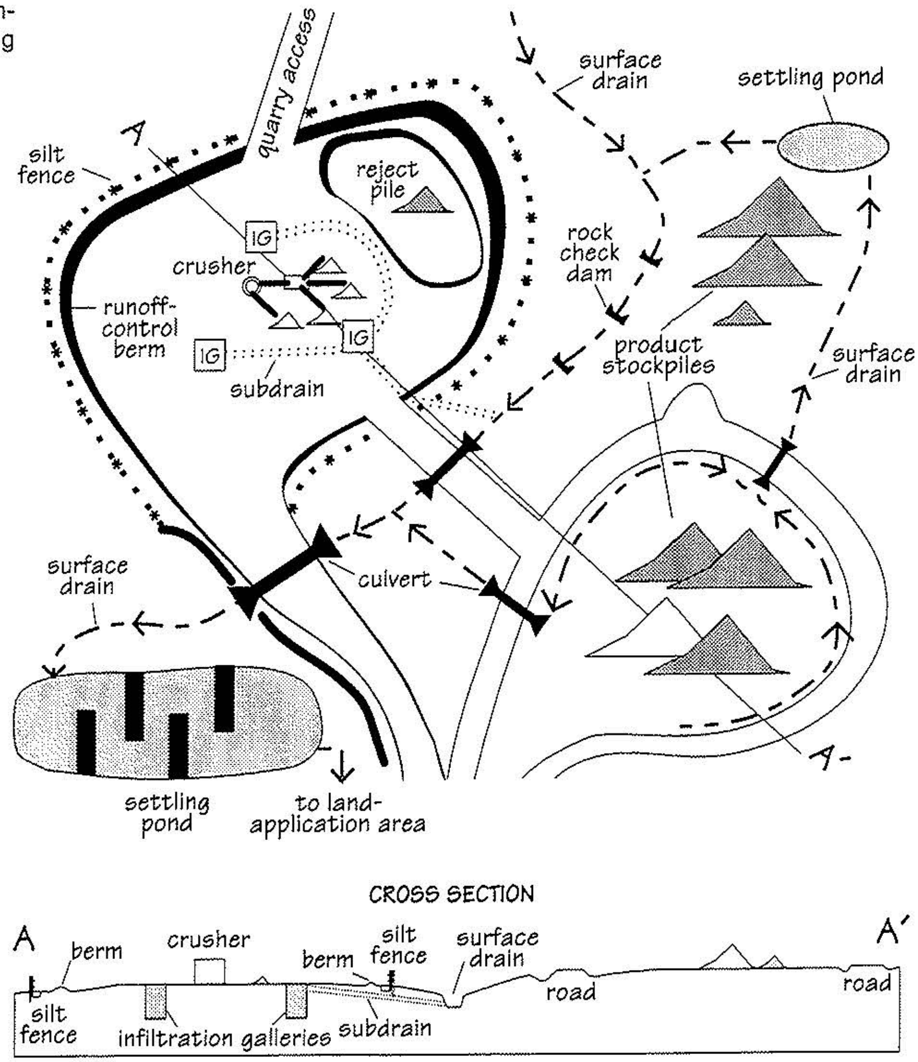


Figure 2.10. Hypothetical storm-water control at an upland processing area. IG, infiltration gallery.

and slow to drain. Clay-rich soils commonly cause the greatest impacts on water quality because they contain fine particles that settle slowly, travel far, and remain in suspension for a long time in settling ponds. Soils dominated by the clay fraction may require several large settling ponds in series. Flocculants can help settle clay particles. (See Flocculants, p. 2.26.)

One of the best methods for removing sediment from water is onsite land application. Turbid water is sent through dispersal systems that allow it to slowly soak into vegetated areas. The potential downslope/downstream impacts of land application should be assessed before constructing this type of control. (See Land Application, p. 2.25.)

For effective sediment control, operators need to determine both the dominant particle size of the source materials and the amount of precipitation and/or storm flow that can be anticipated. Particle-size analysis of soil, overburden, and reject fines produced from processing may be necessary at some sites to determine if they are likely to erode into the storm-water system. Ideally, representative storm-water runoff from the site or from a similar site (if

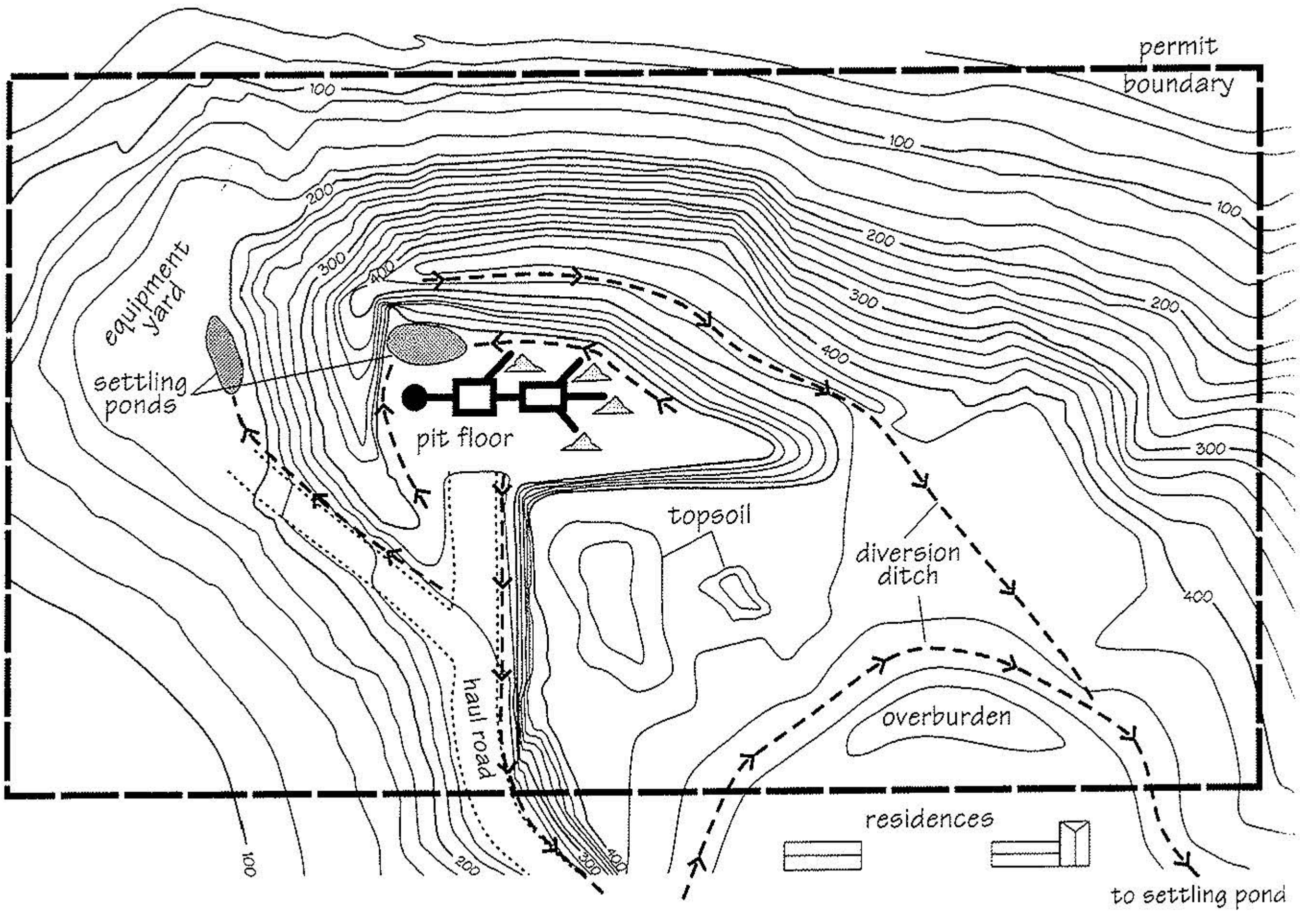


Figure 2.11. An example of a storm-water control system at a quarry site. Figure 3.5 shows visual and noise screening techniques at the same site.

mining has not yet started) should be sampled to predict the size range of the suspended particles that may require treatment.

The two basic methods of removing sediments are by filtering and by gravity separation. Filtering may be accomplished by using:

- designed sand, gravel, or rock graded filters with appropriate size gradations and layers,
- undisturbed soils or embankments,
- filter fabrics,
- infiltration galleries,
- French or trench drains, and
- dispersal (sheet flow) through vegetated areas.

Gravity separation requires that water velocity be reduced to facilitate settling. Settling ponds or dispersal on flat terrain (as in land application) use gravity separation. In still water, a sand particle (0.05–2 mm) will settle at rates of 1 foot/second to 1 foot/several minutes. A silt particle (0.05–0.002 mm) may take several minutes to 6 hours to settle 1 foot. Clay particles (<0.002 mm) can take from 1 day to several months to settle. Pond surface area, retention time, and the particles' settling velocity determine the effectiveness of a settling pond system.

STORM-WATER AND EROSION-CONTROL STRUCTURES

The techniques discussed above and the structures described below can be organized in many different ways. The erosion/sedimentation controls at a site will likely change over time as the configuration of the site changes. Examples of storm-water control systems for an upland processing area and a quarry floor are shown in Figures 2.10 and 2.11, respectively. The profile shown in Figure 2.10 illustrates possible proper drainage techniques in a processing area. The location and choice of the various structures and techniques are site-specific.

Conveyance Channels and Ditches

Channels and ditches are permanent, designed waterways shaped and lined with appropriate vegetation or structural material to safely convey runoff to a sediment pond, vegetated area, or drainage. The advantages of open channels are that they are generally inexpensive to construct, can be lined with vegetation, and make it easy to trace the water. One disadvantage of grass-lined channels is that they may, if improperly designed, erode during high flows and become a source of sediment themselves.

The design of a channel or ditch cross section and lining is based primarily on the volume and velocity of flow expected in the channel. If flow is low and slow, grass channels are preferred to riprap or concrete lining. Although concrete channels are efficient and easy to maintain, they allow runoff to move so quickly that channel erosion and flooding can result downstream. Grass-lined or riprap channels (Fig. 2.12) more closely duplicate a natural system. Riprap and grass-lined channels, if designed properly, also remove pollutants via biofiltration (removal of pollution by plants). Engineered channels are recommended when the discharge will be greater than 50 cubic feet per second.

In addition to the primary design considerations of capacity and velocity, other important factors to consider when selecting a cross section and lining are land availability, compatibility with surrounding environment, safety, maintenance requirements, and outlet conditions.

Slash Windrows and Brush Sediment Barriers

Most mine sites have to be cleared of woody vegetation prior to mining. Slash windrows and brush barriers can be easily and inexpensively constructed with the vegetative debris. These are effective for filtering coarse sediment and reducing water velocity.

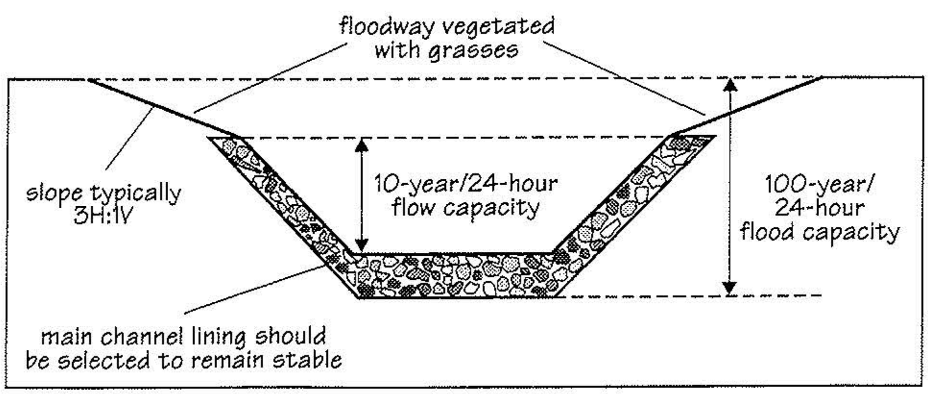
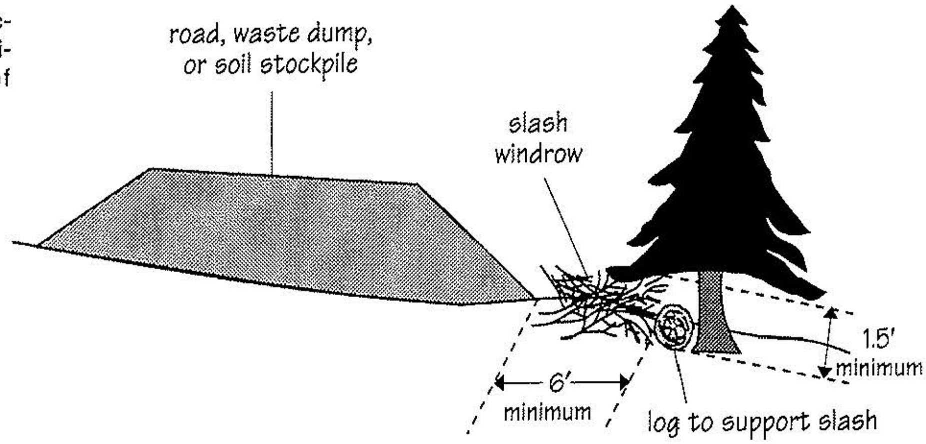


Figure 2.12. Details of construction for a rock-lined diversion ditch.

Figure 2.13. Details of construction of a slash windrow filter. (Modified from Idaho Department of Lands, 1992.)



Slash windrows are constructed by piling brush, sticks, and branches into long rows below the area of concern. The windrow may be supported at the base by large logs or rocks (Fig. 2.13).

Brush sediment barriers require somewhat more effort, planning, and expense, but they are generally more effective than slash windrows. Brush sediment barriers are linear piles of slash, typically wrapped in filter fabric or wire mesh. Construction details are provided in Figure 2.14.

☛ Slash windrows should be used below roads, overburden and soil stockpiles, and any other bare areas that have short, moderate to steep slopes.

☛ Brush sediment barriers are most effective on open slopes where flow is not concentrated; they can help prevent sheet flow and rill and gully erosion during heavy rains.

Straw Bales

Straw bales are a well-known temporary erosion-control method (Fig. 2.15). They are fairly cheap and readily available. However, they are frequently installed incorrectly, making them ineffective.

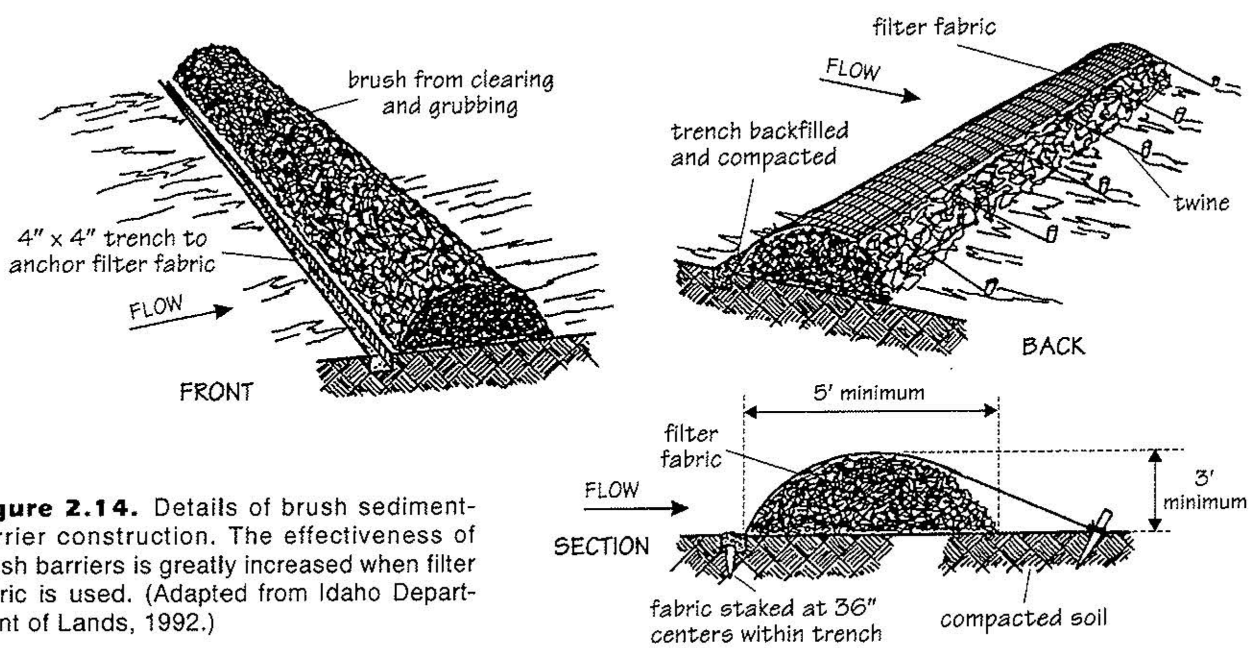


Figure 2.14. Details of brush sediment-barrier construction. The effectiveness of brush barriers is greatly increased when filter fabric is used. (Adapted from Idaho Department of Lands, 1992.)

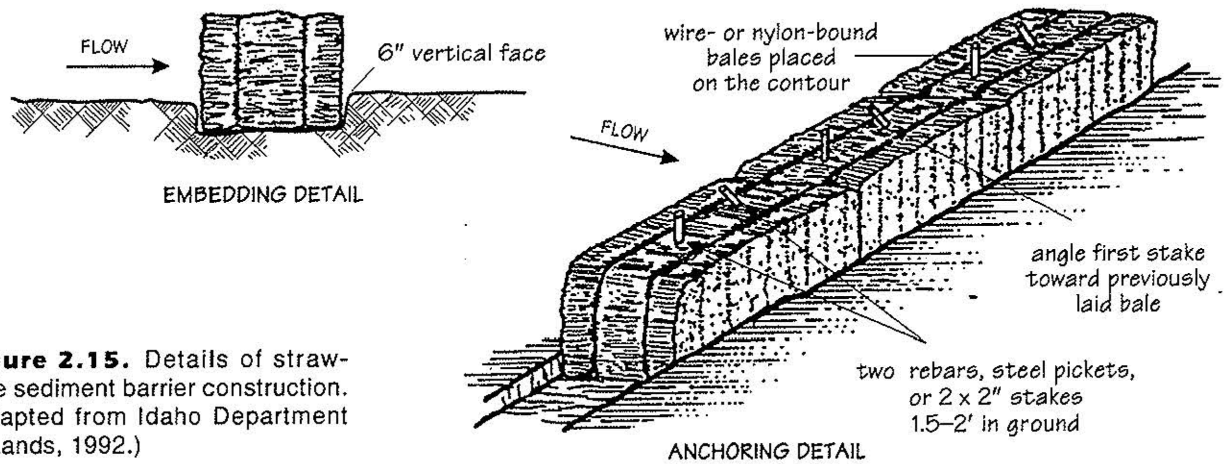


Figure 2.15. Details of straw-bale sediment barrier construction. (Adapted from Idaho Department of Lands, 1992.)

Simply placing straw bales on the ground surface without proper anchoring and trenching will provide only minimal erosion control. Proper ground preparation, placement, and staking are necessary to provide a stable sediment barrier. Straw bales also require frequent repair and replacement as they become clogged with sediment. Only certified weed-free straw should be used.

Straw bales used in conjunction with a check dam or filter berm constructed of sand and gravel, as shown in Figure 2.16, provide a more effective erosion-control system that requires less maintenance and can handle larger volume flows.

- ☛ Straw bales are most practical below disturbed areas where rill erosion occurs from sheet runoff.
- ☛ Straw bales may be used in minor swales and ditch lines where the drainage area is smaller than 2 acres and/or where effectiveness is required for less than 3 months.

Bio Bags Bio bags are woven nylon net bags filled with bark chips. They are about the size of straw bales and can be used as an alternative to straw bales for erosion control. Bio bags are much lighter than straw

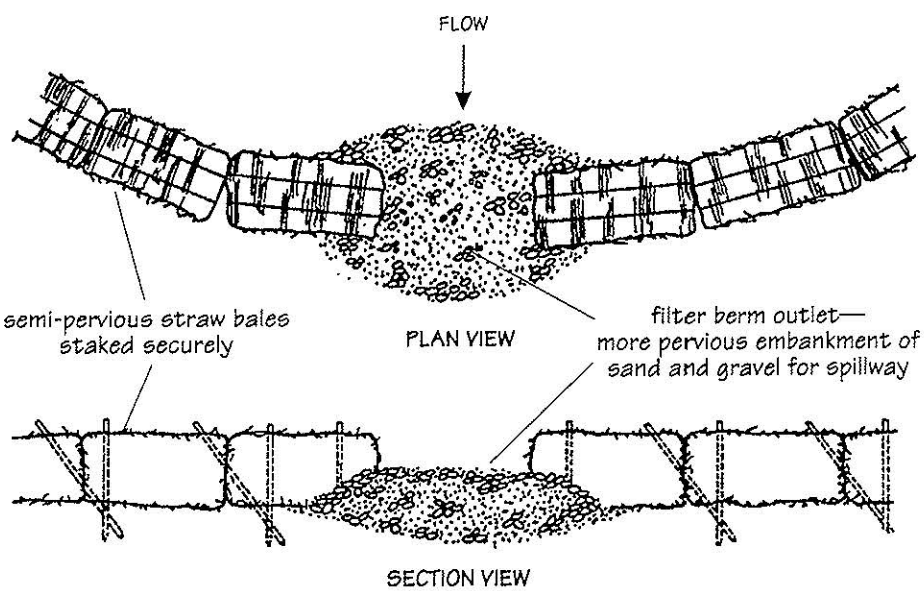


Figure 2.16. Details of construction for a straw-bale barrier combined with a gravel check dam. (Adapted from Idaho Department of Lands, 1992.)

bales; they must be staked down to keep them in place. They are more permeable, but slow water sufficiently to cause sand, silt, and clay to drop out. They fit the contours of the land, avoiding the bridging problem of straw bales. They hold together better and can therefore be removed more easily when saturated. Wildlife won't tear them apart to eat them, and they will not introduce grass and weed seeds to the site.

Bio bags may not be as readily available as straw bales. Their unit price is comparable to that of straw bales, but because they are smaller, more units are needed per application, making them slightly more expensive. They are not as biodegradable as straw bales.

Burlap Bags Filled with Drain Rock

Woven burlap bags filled with drain rock can be used as an alternative to bio bags. They conform well to irregular ground and are easily installed. They do not need to be staked down and are less prone to washing away than bio bags. They can easily be created using recycled burlap bags and the aggregate that is already present on most mine sites.

Silt Fences

A silt fence is made of filter fabric that allows water to pass through. Woven fabric is generally best. Depending on its pore size, filter fabric will trap different particle sizes. The fence is placed perpendicular to the flow direction and is held upright by stakes (Fig. 2.17). A more durable construction uses chicken wire and T-posts to support the fabric vertically.

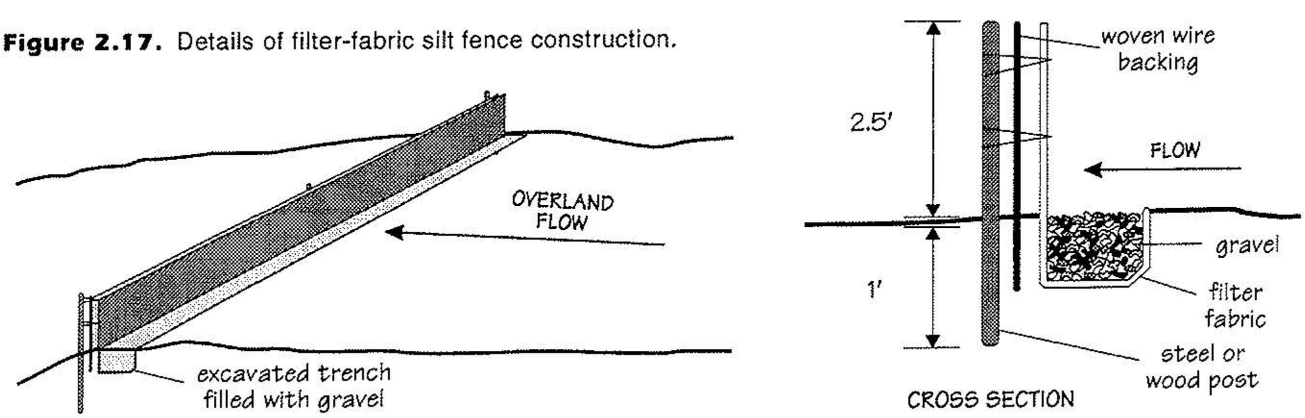
It is essential to bury the bottom of the filter fabric to prevent flow under or around the fence. Maintenance is required to keep the fence functioning properly. Rock check dams or other methods may be needed to slow water enough to allow it to pass through the fence. Although silt fences are more complicated and expensive to install than straw bales, they provide better erosion control in some situations, for example, in coastal climates where hay bales decay rapidly or in locations that are difficult to access with vehicles.

☛ Silt fences should be used below disturbed areas where runoff may occur in the form of sheet and rill erosion.

Erosion-Control Blankets

Erosion-control blankets are made of a variety of artificial and natural materials, including jute, coconut husk fibers, straw, synthetic

Figure 2.17. Details of filter-fabric silt fence construction.



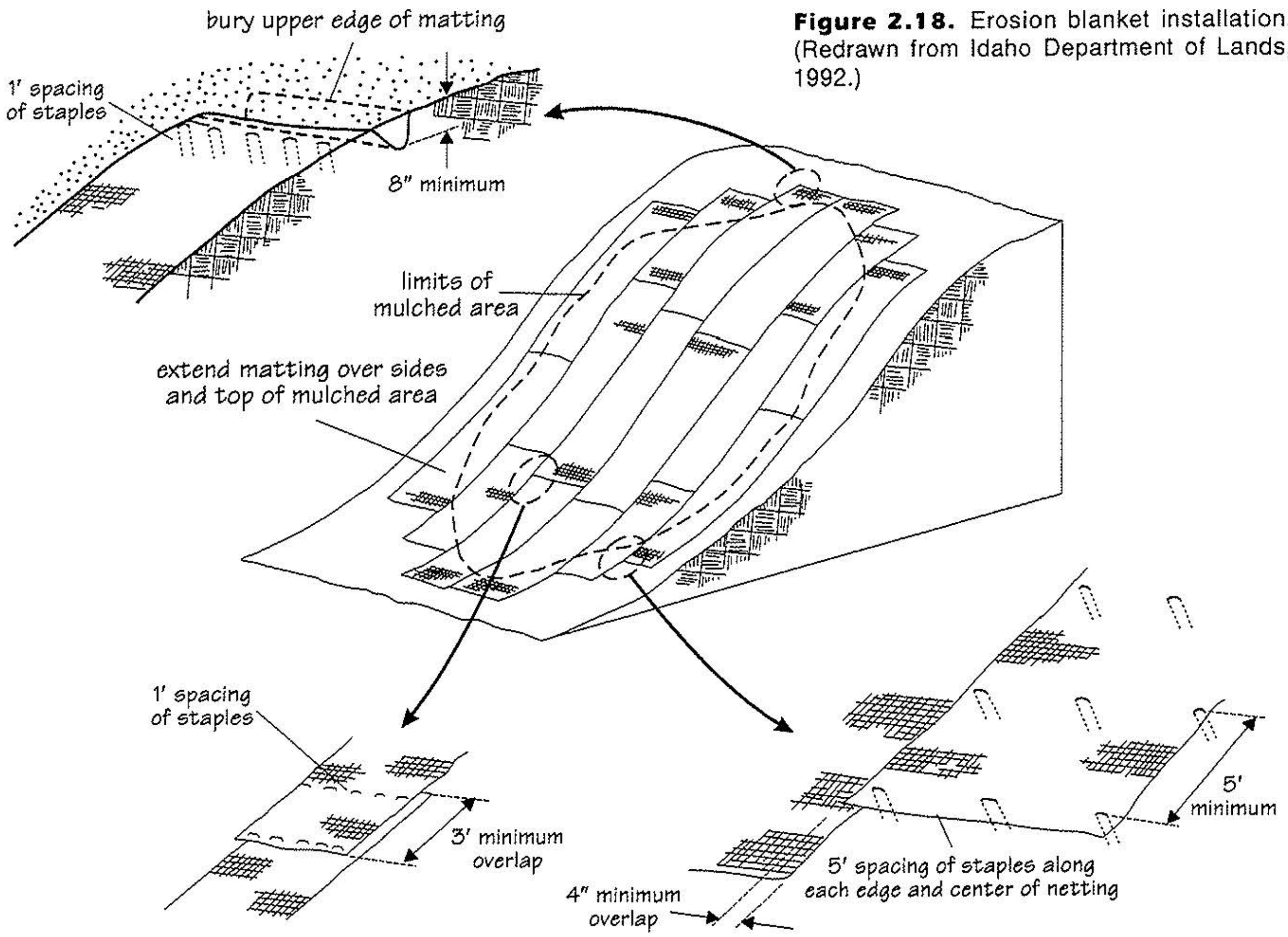


Figure 2.18. Erosion blanket installation. (Redrawn from Idaho Department of Lands, 1992.)

fabrics, plastic, or combinations (Fig. 2.18). Applying erosion blankets over large areas can be prohibitively expensive. However, small applications in areas that are oversteepened and/or prone to erosion, in conjunction with cheaper methods such as hydromulching and/or hay mulch and netting, can be very effective. The effectiveness of jute netting and mulch fabrics is greatly reduced if rills and gullies form beneath these fabrics. Therefore, proper anchoring and ground preparation are essential.

☛ Erosion-control blankets can be used on steep slopes where severe erosion-control problems are anticipated.

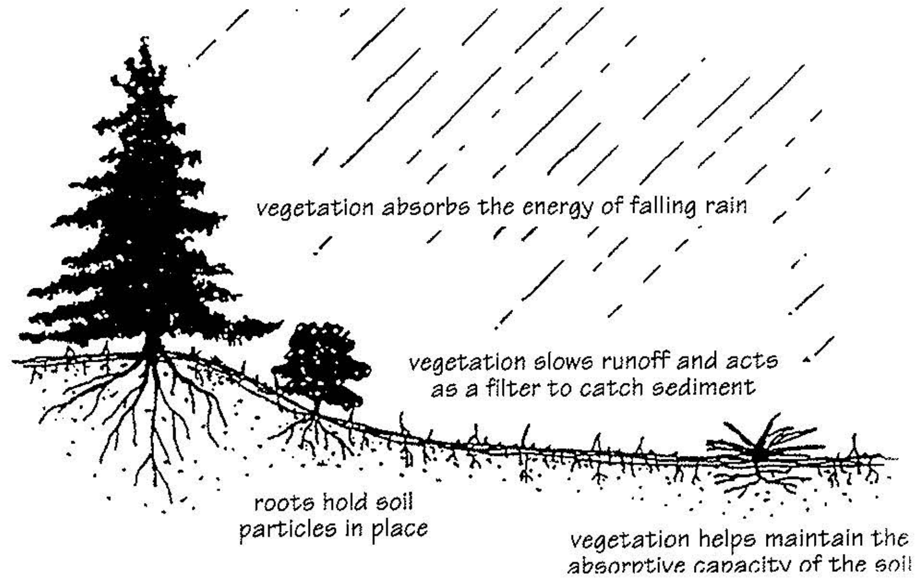
Where water infiltration is not desirable, for example, on the surface of an active landslide, an impermeable erosion blanket may be appropriate. In this situation, special care must be taken to provide a place where the energy the water has gained can dissipate, such as a slash windrow, brush sediment barrier, or rock blanket at the base of the slope.

Vegetation

Vegetation absorbs some of the energy of falling rain, hold soils in place, maintains the moisture-holding capacity of the soil, and reduces surface flow velocities (Fig. 2.19).

☛ The most effective way to use vegetation is to leave it undisturbed to prevent erosion and reduce the speed of surface water flows.

Figure 2.19. Effect of vegetation on storm-water runoff. (Modified from Washington State Department of Ecology, 1992.)



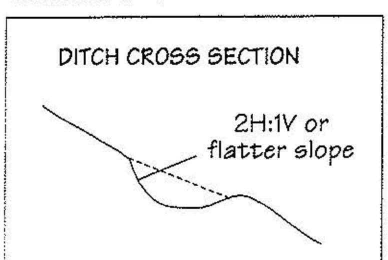
- If a new area must be cleared for mining, clear only the amount needed for expansion within one year.
- As an area is cleared of vegetation, save the sod or slash and stake it down across the cleared slopes to temporarily reduce storm-water runoff until the area is mined.
- Replace topsoil and replant mined areas as soon as possible.
- Revegetate overburden and topsoil stockpiles over the winter or when they will remain unused for more than six months. (Topsoil should not be replaced in this situation; see Interim Reclamation, p. 3.1.)

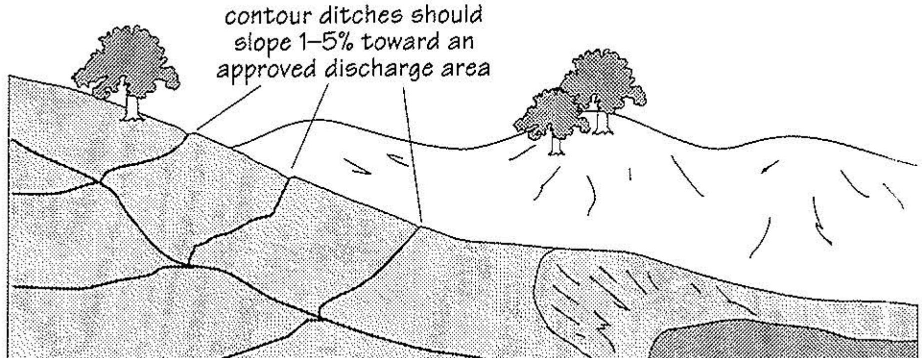
Contour and Diversion Ditches

Contour ditches are constructed along a line of approximately equal elevation across the slope (Fig. 2.20). Diversion ditches guide water around unstable areas to prevent both erosion and saturation with water (Fig. 2.21), reducing the likelihood of slope failure. Both types of ditches should have a 1 to 5 percent grade directed away from steep slopes to the appropriate drainage or vegetated areas.

Ditch channels may need to be lined to prevent scouring and minimize sediment transport. When their slope is greater than 5 per-

Figure 2.20. Placement and construction of contour ditches.





cent, ditches are typically lined with rock. Where slope stability is of concern, impermeable liners may be used. Rock check dams, described below, should be placed in diversion and contour ditches at decreasing intervals as the slope increases.

☛ Contour and diversion ditches should be used to direct surface runoff away from disturbed areas and prevent rills and gullies from forming.

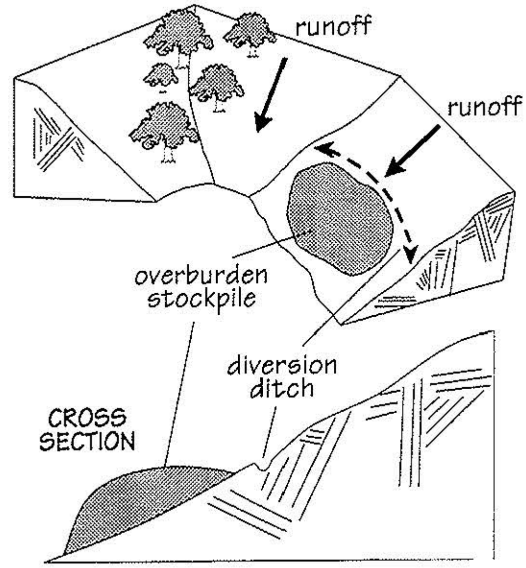


Figure 2.21. A diversion ditch can be placed upslope from an overburden pile to prevent saturation of the pile.

Rock and Log Check Dams

Check dams are typically constructed from coarse crushed rock ranging from about 2 to 4 inches in diameter, depending on the water velocities anticipated. A check dam can generally withstand higher velocity flows than a silt fence, and the integrity of the structure will not be affected if it is overtopped in a large storm event. The tops of check dams are lower than the channel margins so that water can spill over (instead of around the sides) during heavy storms (Fig. 2.22).

The effectiveness of rock check dams for trapping sediment can be improved by applying filter fabric on the upstream side. The bottom of the fabric must be anchored by excavating a trench, applying the fabric, and then filling the trench with coarse rock. This structure functions like a silt fence, but it is more durable. Choosing the proper size of filter fabric mesh is important to minimize clogging.

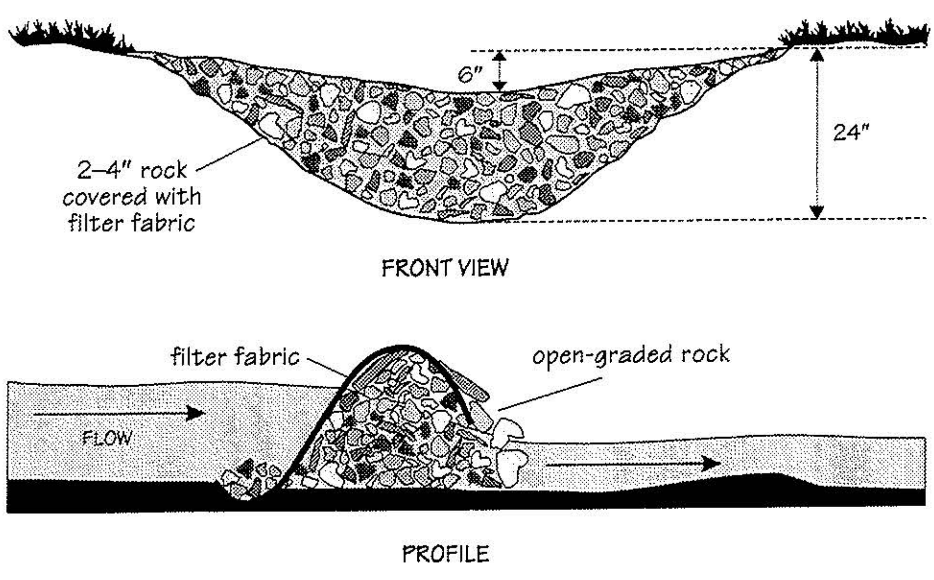
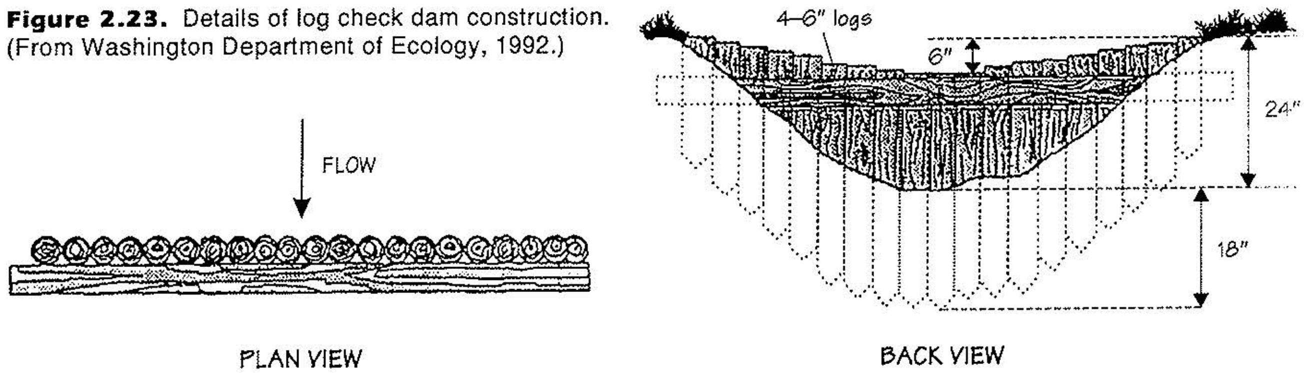


Figure 2.22. Details of rock check dam construction.

Figure 2.23. Details of log check dam construction. (From Washington Department of Ecology, 1992.)



The filter fabric must be replaced when it becomes clogged. Gabions (wire baskets filled with coarse rock) and filter fabric would function in the same manner.

Where they are readily available, logs can be used to construct check dams instead of rock (Fig. 2.23).

- Check dams can be used to slow surface flow in ditches.
- Check dams are a common means of establishing grade control in a drainage to minimize downcutting.

Concrete Check Dams

Concrete check dams (Fig. 2.24) can be an effective long-term alternative to straw bales, bio bags, and rock-filled burlap bags. They can often be constructed from waste concrete that is cleaned out of mixer trucks, but time constraints may prevent this. Concrete check dams are most appropriate along ditches that are relatively permanent.

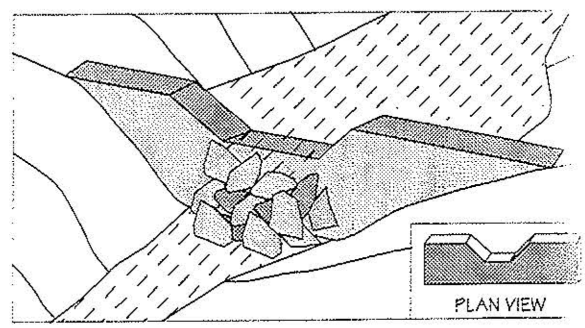
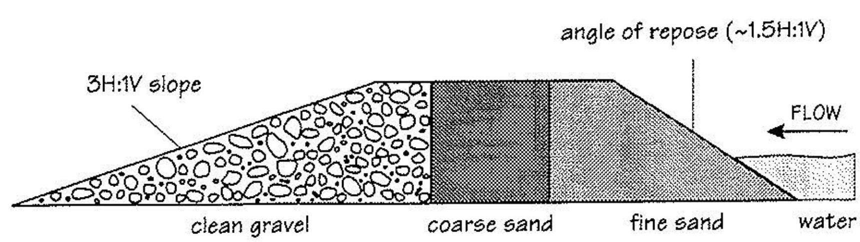


Figure 2.24. Waste concrete check dam. It should be a minimum of 4 inches thick; length and width vary to fit application.

Filter Berm

A filter berm (Fig. 2.25) allows the passage of water but not soil particles. It can be constructed of sand and gravel or crushed and screened quarry rock free of 200-mesh or smaller material. Using pit-run sand and gravel or quarry rock is not recommended because silt and clay will be present. In the ideal berm, fine sand, coarse sand, and gravel are placed sequentially from the upstream side to

Figure 2.25. Idealized cross section of a filter berm showing details of construction.



the downstream end of the berm. The sand may need periodic replacement as it becomes clogged with sediment.

☛ Filter berms should be used in channels with low flow.

Trench Subdrains and French Drains

The terms 'trench subdrain' and 'French drain' are sometimes used interchangeably. A French drain is a ditch partially backfilled with loose, coarse rock to provide quick subsurface drainage and covered with a compacted clay cap. A trench subdrain is a ditch backfilled all the way to the top with loose, coarse rock, which allows water to enter more freely (Fig. 2.26). Both types of drains are designed to allow the movement of water while preventing or minimizing the movement of soil particles, and both require an outlet to remove water. Either can be improved by placing perforated pipe in the drain. (See also Figs. 3.11 and 6.6.)

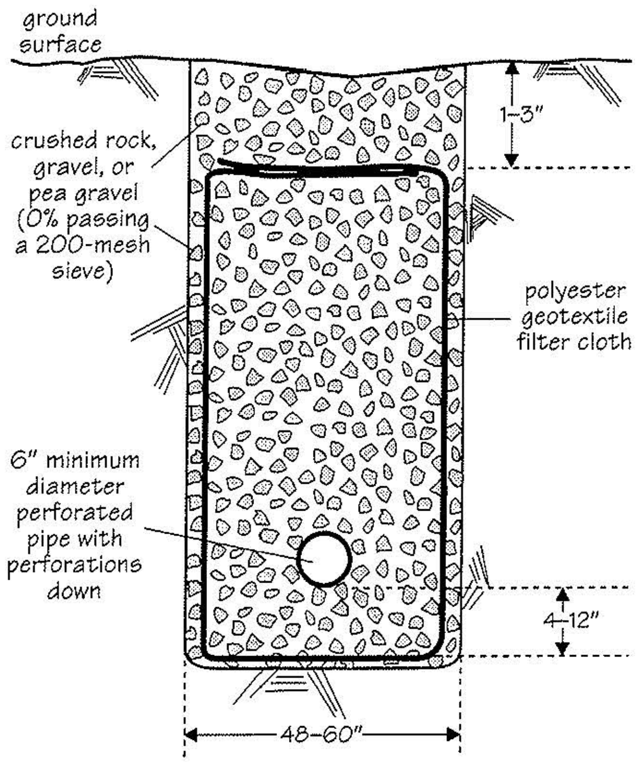


Figure 2.26. Details of trench subdrain construction.

Several filtering methods can improve the long-term effectiveness of these drains. Early applications relied on open-graded aggregate free of 200-mesh or smaller material, but this may eventually become clogged. Current practice is to wrap the perforated pipe in filter fabric so that sediment is trapped on the surface of the fabric rather than in the pore spaces. Because maintenance may eventually be required for subdrains, placement of clean-outs along the pipes is recommended.

☛ Drains are used for dewatering landslides and agricultural lands and stabilizing highway road cuts.

☛ Drains are also well suited for storm-water control.

Infiltration Galleries and Dry Wells

Infiltration galleries (or dry wells) are similar to trench subdrains and French drains except that there is no direct outlet for the water that enters them. These drains are deeper than they are long.

Infiltration galleries are created by excavating a hole— the deeper the better—which is then backfilled with coarse rock (Fig. 2.27). Typically, the holes are dug to the maximum reach (≈20′ of the backhoe used. If possible, water percolation should be improved by fracturing the bottom of the hole. This may require drilling and shooting. Backfilling to the sur-

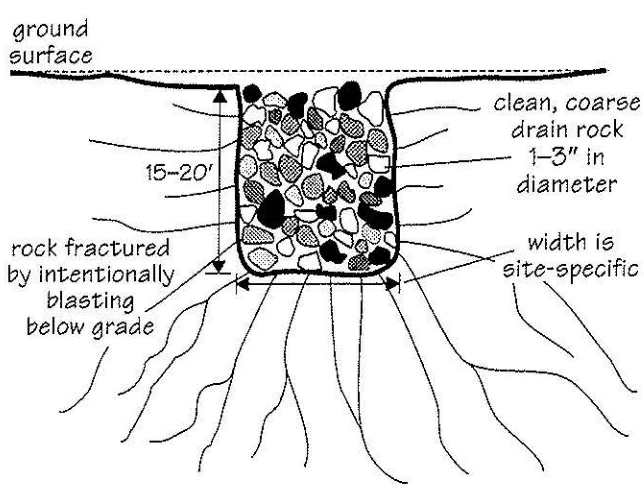


Figure 2.27. Details of infiltration gallery construction. (See also Fig. 2.9.)

face with coarse rock allows heavy equipment to pass safely over these structures, making them well suited for installation around a crusher or screening plant. Because there is no outlet for water, these galleries should be located where fines and storm water accumulate. Grading should direct storm-water runoff to them. The exact size and number of infiltration galleries needed is site specific. Maintenance is typically limited to periodic replacement of the fill with clean rock.

☛ Infiltration galleries are best suited for quarry sites or areas where natural infiltration of storm water is minimal and the water table is low enough to allow drainage. They should be used alone only where grades prevent connection to a gravity-flow subdrain or where volumes of storm water are small.

☛ Infiltration galleries should not be used if oil and grease are present to contaminate the ground water.

Wheel Washes

Tracking of mud and rocks onto roads can become a problem at many mine sites during the winter. A permanent wheel wash can be installed near the exit to wash excess dirt and mud off truck tires. A series of railroad rails spaced 2 to 8 inches apart can be used to shake loose rocks and dirt while the vehicle is driving through the wheel wash (Fig. 2.28). Make sure that water used to wash trucks is treated to remove solids and turbidity before being discharged from the site.

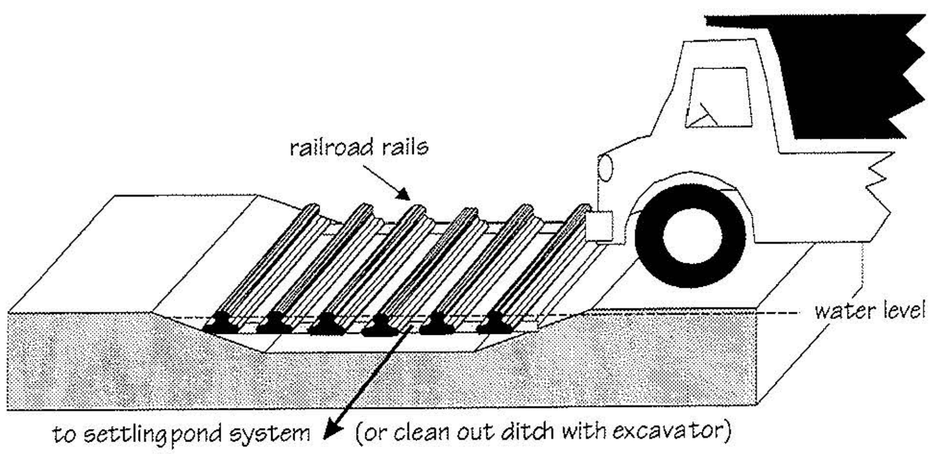


Figure 2.28. Wheel washes can be used to keep mud and rocks from being tracked onto roads. Dirty water can be sent to a settling pond, or the wheel wash can be cleaned out with an excavator.

STORM-WATER SETTLING PONDS

Most mine operations cannot rely solely on passive storm-water control methods and must employ settling ponds as an integral part of their storm-water system. These flat-bottomed excavations can range from small hand-dug sumps to ponds covering several acres. They slow water velocities enough to allow sediment to settle out of suspension. The number and size of ponds needed will depend on the site conditions. Construction of numerous ponds in the upper part of the drainage systems enhances effective trapping of sediments. For example, upper quarry benches and floors can be bermed so that they function as sediment basins during the rainy season.

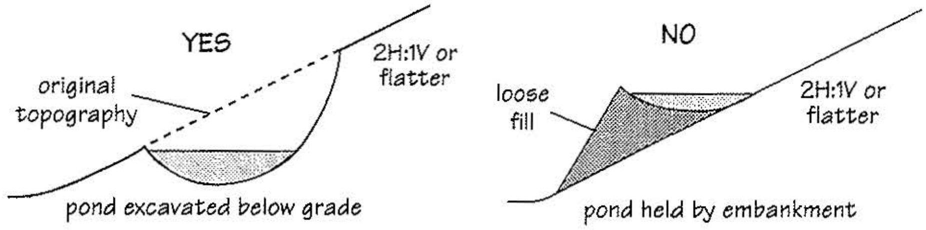


Figure 2.29. Details of settling-pond construction. The excavation method on the left is preferred because it is less likely to fail and cause flooding than an constructed embankment (right).

Two types of ponds are commonly used—detention and retention. Detention ponds reduce the velocity of storm water, allowing sediment to settle before it moves off-site. Retention ponds are large enough to accept all storm water without surface discharge.

Ponds can be developed by building embankments or by excavating below grade. Excavated ponds are preferable because they are less likely to fail than embankments (Fig. 2.29). Embankments have to be carefully constructed using the same techniques that would be used for constructing waste and overburden dumps and stockpiles (see p. 3.15). Ideally, ponds should be situated at the bottom of a slope. Soil or geotextile liners may be required where stability is a concern. Many ponds are designed for the life of the operation, whereas others are used for only a short time.

☛ Settling ponds are the best method of gathering turbid water to allow sediment to settle out.

In Washington, water impoundments that contain more than 10 acre-feet of water must be approved by the Dam Safety Section of the Department of Ecology.

In Oregon, water impoundments with dams more than 10 feet high or with a capacity of more than 9.2 acre-feet of water must be approved by the Dam Safety Section of the Oregon Water Resources Department.

Configuration, Location, and Size

Storm-water detention ponds should be designed to maximize both velocity reduction and storage time. That is, storm water entering a pond should spread out and migrate as slowly as possible toward the discharge point. Baffles constructed across the pond (Fig. 2.30) can reduce flow rates. A good rule of thumb is that the flow path of the pond should be at least five times the length of the pond. The inlet and outlet should be located so as to minimize the velocity and maximize the residence time.

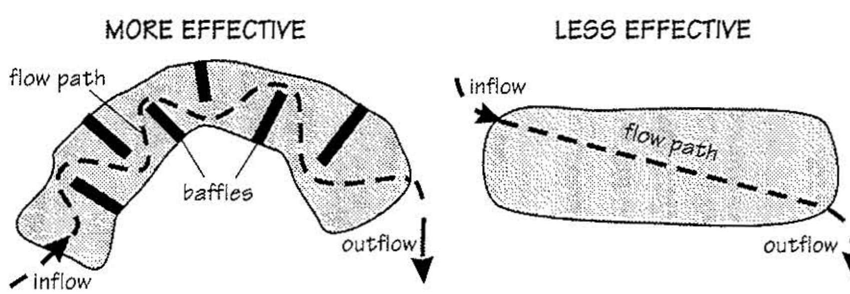


Figure 2.30. Details of detention pond design. The pond on the left, which maximizes the length of the flow path, is preferable to the pond on the right, which does not keep water in the pond long enough for optimum settling.

If ponds are to be placed in the lowest area of the watershed, several should be constructed in a series. This will enable the first pond to slow the high-velocity waters coming into it and allow subsequent ponds to settle out sediments more effectively. For maximum treatment effectiveness, ponds should be placed as close as possible to those areas most likely to contribute sediment, such as the pit floor, the processing plant, and other areas of heavy equipment activity.

There are several widely used methods for determining the appropriate size of storm-water ponds for a given site. Most methods begin with estimating the size of the watershed and estimating runoff using infiltration rates. This information is then used to calculate the amount of runoff on the basis of annual precipitation or a storm event of a certain size. Observations of flow characteristics and locations made near the mine during storm events can be invaluable in developing a good storm-water pond system.

However, choosing an appropriate size for storm-water ponds can be difficult without site-specific information such as a storm hydrograph—a graph of the volume of water flowing past a certain point during a storm event. When hydrographic information is not available, theoretical calculations are used to estimate the flow volume for a given storm event. The calculations quickly become complicated because storm intensity and duration can have a significant effect on the amount of runoff. Also important, but even more complicated, are determining the influence of road systems, vegetative cover, and amount of compaction on runoff volumes.

The Natural Resources Conservation Service (formerly Soil Conservation Service) has developed a simplified method for estimating storm-water runoff. This method can work well if the limitations are understood, and it yields a good starting point for determining pond size. For more information, contact the local office of the Natural Resources Conservation Service.

There are many resources for information on designing storm-water ponds. (See the list of references at the end of the chapter.) For determining spillway designs and diversion ditch liner specifications, Urban Hydrology for Small Watersheds (Soil Conservation Service, 1986) is a good resource.

☛ For most mining situations, storm-water ponds should be designed to handle at least a 25-year/24-hour event or larger.

In Washington, RCW 78.44 sets a standard for water control: "Diversion ditches, including but not limited to channels, flumes, tightlines and retention ponds, shall be capable of carrying the peak flow at the mine site that has the probable recurrence frequency of once in 25 years as determined from data for the 25-year, 24-hour precipitation event published by the National Oceanic and Atmospheric Administration." The data for 25-year, 24-hour precipitation events can be found in Miller and others, 1973. Furthermore, if the site is located in a watershed that is prone to erosion, heavy storms, and/or flooding, design specifications may require planning for a 100-year storm event.

Maintenance Settling ponds must be cleaned out regularly to remain effective. Spillways should be kept open and ready to receive overflow during large storms. Settling ponds should be constructed and placed so that onsite equipment can be used to maintain them. In some situations, sediment can be pumped out of settling ponds as a slurry instead of being removed with heavy equipment. Regardless of the method of sediment removal, all sediment removed should be placed in a stable location so that it will not enter waterways.

Drainage The method of releasing water from storm-water ponds can be critical in determining their efficiency. Standpipes, spillways, and infiltration are the most common release methods.

Standpipes are vertical pipes rising from the bottom of the pond and connected to a gently sloping pipe that passes through the side of the pond to the discharge point (Fig. 2.31). Antiseep collars must be attached to the pipe where it passes through the dam or settling pond wall to prevent water from flowing along the outside of the pipe. A grate or screen should be placed over the standpipe intake to prevent debris from clogging it.

Spillways are overflow channels that are part of the construction of all water impoundments. For small settling ponds used intermittently and designed for low maintenance, spillways may handle all water discharged from the pond. Where water is recirculated to the processing plant or where discharge is through a standpipe or subdrain, a spillway allows overflow during extremely wet weather or when the primary drain system becomes clogged.

Spillways should be located in undisturbed material and not over the face of a constructed dam. If the spillway is placed on erodible material, it must be rock lined to limit erosion that would compromise the safety of the dam.

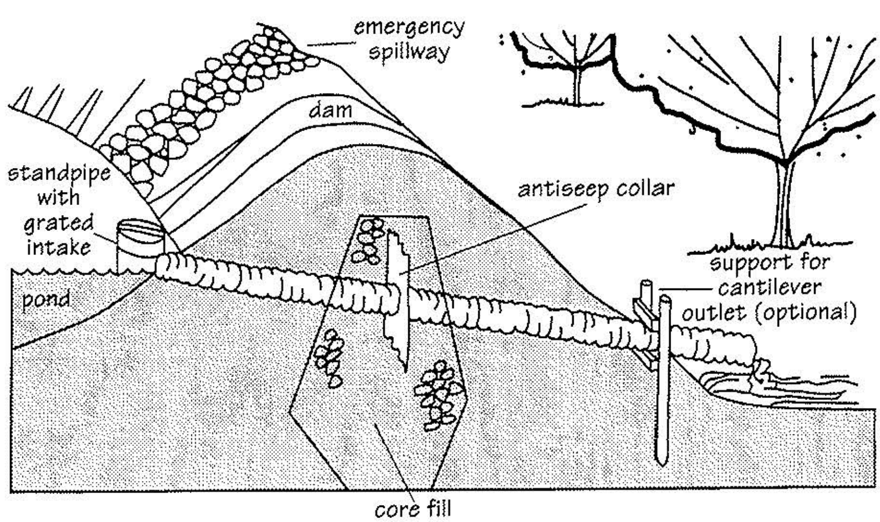


Figure 2.31. Section through a berm showing standpipe with antiseep collar. (Modified from U.S. Soil Conservation Service, 1982.)

STORM-WATER TREATMENT

In some places, additional treatment is required to reduce the turbidity of storm water prior to discharge to public waters. (See p. 2.3.) When storm water contains abundant clay-size particles too fine to settle using conventional pond treatment, land application is the treatment of choice. Alternative treatment methods include the addition of flocculants or the use of water clarifiers.

Land Application

Land application involves sending storm water through dispersal systems that allow the turbid water to slowly soak into vegetated areas. Land application may be a feasible technique to handle all sediment-laden water, or it may just increase storm-water storage capacity. Some of the most common distribution systems are perforated pipe laid across a slope, level spreaders, and sprinkler systems. Where large flat areas are available and water dispersal is not an issue, water can be discharged directly from the distributor pipe, eliminating the need for a perforated application pipe. Turbid water must not be allowed to enter wetlands or creeks.

Perforated Pipe. Plastic pipe with holes drilled in it can disperse a fine spray of water over a large surface area (Fig. 2.32). This method works well if the pipes are laid along slope contours; pipes laid perpendicular to slope contours develop excessive hydraulic head at the lower perforations, resulting in uneven distribution of water and increased erosion potential.

Level Spreader. A level spreader is a trench excavated along the contour and filled with gravel or other permeable material that will allow turbid water to percolate into the ground. Level spreaders work best where the surrounding soil is fairly permeable.

Sprinkler Systems. Sprinkler systems use commercially available sprinklers to apply storm water. Sprinkler systems work well where:

- There is sufficient hydraulic head to distribute the storm water from sprinkler heads.

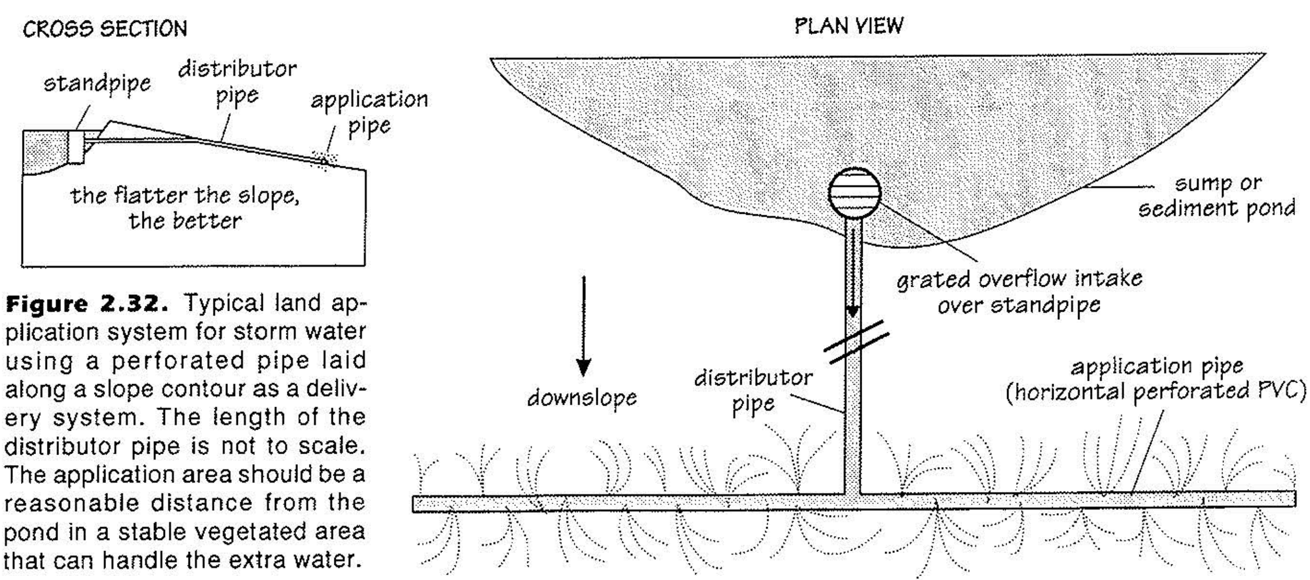


Figure 2.32. Typical land application system for storm water using a perforated pipe laid along a slope contour as a delivery system. The length of the distributor pipe is not to scale. The application area should be a reasonable distance from the pond in a stable vegetated area that can handle the extra water.

- The storm water contains only fine clays that will not clog sprinkler heads.
- There is sufficient vegetation to prevent erosion at the sprinkler heads.

Land application systems generally cannot handle the surges in water volume during a large storm because the storms often occur in winter when the soils may already be saturated. Assuming that soils will always accept the storm water can be a serious error. A simple infiltration analysis can determine the capacity and infiltration rate of a site's soils. The design of a land application system should assume that soils are saturated and that existing or planted vegetation will filter sediments. Concentration of the outflows from a land application system should be avoided because it may cause soil erosion and create problems elsewhere.

Flocculants

Flocculants are most commonly used to clean storm-water discharges or water recycled from rock-washing operations. Proper use of chemical flocculants can reduce the size of settling ponds required for a given site. Most flocculants are not toxic to aquatic organisms and fish. However, the supplier or manufacturer and the state water quality agency should be asked about the environmental effects of the flocculant chosen.

Most flocculants are composed of high-density (heavy) organic polymers with a strong positive charge. The positively charged particles act like a magnet to attract negatively charged clay particles. The adsorption of clay onto the flocculant speeds settling of smaller and lighter clay particles. Alum is an inorganic flocculant that works in much the same way as the organic flocculants.

Chemical flocculants are designed for use with specific types of clay. The key to using a chemical flocculant is maintaining the proper mixture of flocculant and pond water and thoroughly mixing and agitating the flocculant mixture in the pond, making sure not to overagitate. Flocculants are commonly diluted in a large container before they are added to the settling pond.

At least two ponds should be used to remove suspended solids. The first pond should allow slow mixing of the flocculant and the water to be treated, with a retention time of 20 minutes. The second pond should ideally retain water for 3 to 8 hours. Alternatively, the flocculant mixture can be injected into the waste-water stream before it enters the settling ponds. Ponds must be situated where they can easily be cleaned on a frequent basis.

In Washington, a National Pollution Discharge Elimination System (NPDES) permit from the Department of Ecology is required if flocculant-treated storm water is to be discharged offsite.

Water Clarifiers

Water clarifiers are a mechanical method of separating solids and water. They consist of a series of closely spaced inclined plates. A flocculant is injected to assist in separation. These systems are

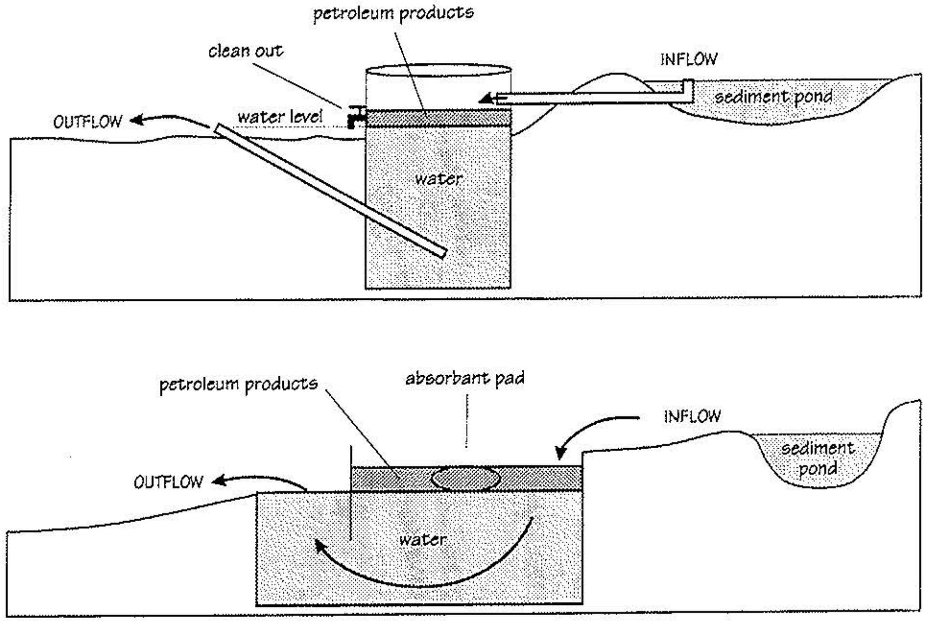


Figure 2.33. Two different types of oil/water separators used to remove petroleum products from storm water. The inflow must be free of sediment or frequent cleaning out will be necessary. The top system uses a clean-out spigot to remove the oil as it floats atop the water. The bottom system uses an absorbent pad to soak up the oil. Design specifications will depend on site conditions and storm-water volumes.

widely used as a final treatment for sewage effluent prior to discharge. In some situations, it may be possible to rely on smaller storm- and process-water ponds if a water clarifier is used. Due to their initial capital costs, however, clarifiers are not used extensively in the aggregate industry.

Oil Separators

Petroleum products can be removed from storm water through the use of oil/water separators. The precise layout and design is usually site-specific but two examples are depicted in Figure 2.33. Oil/water separators take advantage of the fact that oil floats on water. They collect the oil on the surface of the water while allowing the water to flow through. The oil collected can be removed by absorbent pads or skimmed with a bucket. Contaminated absorbent pads and water should be disposed of according to DEQ rules in Oregon and DOE rules for Washington.

Keys to effective oil/water separators:

- There must be sufficient surface area to allow the petroleum to remain on the surface.
- The water velocity and volume must be low enough to prevent oil/water mixing or overspillage.
- The majority of settleable solids must be removed from the storm-water stream before it reaches the oil/water separator or the separator will quickly become filled with sediment.

STREAM BUFFERS

Vegetated stream buffer zones (areas that will not be mined, disturbed, or developed) vary in width from site to site. (See Permanent Setbacks or Buffers, p. 3.4.) Factors usually considered in establishing buffers are the purpose of the buffer, the size of the stream, and the rate of meander of a stream. The primary reasons to establish and maintain buffers are to:

- Preserve water quality in the stream by filtering sediments through a vegetated buffer.
- Protect the existing stream or river channel.
- Protect riparian habitat.
- Minimize the potential for turbid water/sediment discharges into public waters.
- Maintain tree cover over streams to moderate water temperature to insure fish survival.
- Prevent stream capture or avulsion because of lateral migration of a river into a pit.
- Protect the habitat of threatened or endangered riparian and aquatic species.

STREAM DIVERSION

Stream diversion can be beneficial to water quality and mine operations by isolating public waters from the mine activity. To insure the long-term stability of landforms, a highly technical approach to stream diversion has been required at large open-pit mines in the western states where numerous sections of land are being affected. For aggregate sites in the Pacific Northwest where the scale is significantly smaller, a less technical approach is appropriate because typically only a small portion of the total watershed is being impacted.

Streams can be classified as perennial or permanent (containing water all year round), intermittent (containing water only at certain times of the year), or ephemeral (containing water only when it rains). Technical discussions and research on classification of drainages, drainage density, and reconstruction techniques for reclaimed mine sites are ongoing and complex.

IMPORTANT: Before diverting any perennial, ephemeral, or intermittent streams, check to see if a permit is needed.

In Washington, contact the Departments of Ecology, Fish and Wildlife, and Natural Resources.

In Oregon, contact the Departments of Environmental Quality, Fish and Wildlife, and Geology and Mineral Industries and the Division of State Lands.

Perennial or Permanent Streams

Diversion of perennial streams is beyond the scope of this manual and will not be covered. If a perennial stream must be diverted, the proper state and local agencies should be consulted.

Intermittent or Ephemeral Streams

Diversion of intermittent or ephemeral streams is not as critical as for perennial streams but may still require permits. The basic rule of thumb is to replace existing drainages and drainage conditions. In some mines, segments of drainages may be significantly altered, particularly those located in an upland quarry site. The same channel carrying capacity, length, characteristics, and gradient as the original stream should be maintained in the diversion.

On quarry sites after mining, channel length may be shortened if streams are directed over the highwall to enhance reclamation diversity. Channel stability is not generally affected by steepening the gradient or shortening the channel if the channel foundation is hard rock. Decreasing channel length or increasing channel gradient on alluvial or colluvial materials should not be undertaken without thorough analysis.

If the drainage diversion will be short term, a rock-lined diversion channel may be all that is needed. For diversions that will be in place for several years, the diverted stream should be shaded, habitat areas, such as pools and riffles, rootwads or logs (see Fig. 4.12), should be created, and vegetation should be used to stabilize the banks (see Biotechnical Stabilization, p. 7.13).

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3 Operation and Reclamation Strategies

INTRODUCTION

Four general strategies can be used in surface-mine reclamation. Some mines may use all four of these strategies:

Post-mining reclamation – reclamation only after all resources have been depleted from the entire mine.

Interim reclamation – temporary reclamation to stabilize disturbed areas.

Concurrent (progressive or continuous) reclamation – reclamation as minerals are removed; overburden and soil are immediately replaced.

Segmental reclamation – reclamation following depletion of minerals in a sector of the mine (Norman and Lingley, 1992).

In Washington, the Department of Natural Resources (DNR) encourages segmental reclamation wherever site conditions permit.

In Oregon, segmental reclamation is considered a variant of concurrent reclamation. The Department of Geology and Mineral Industries (DOGAMI) encourages concurrent reclamation wherever possible.

POST-MINING RECLAMATION

Reclaiming after all resources have been depleted from the entire mine is generally discouraged by regulating agencies because it results in large areas being left unreclaimed for long periods, but it may be necessary at many quarries and metal mines and at some sand and gravel deposits (Fig. 3.1).

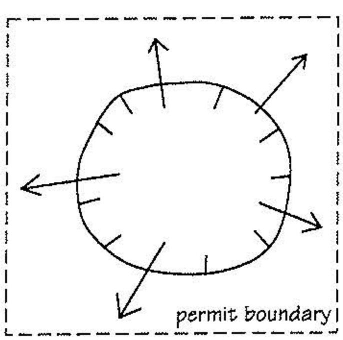


Figure 3.1: For a mine site beginning a center-outward excavation, the preferred segmental reclamation method is not possible, and post-mining reclamation then becomes the method by default.

Advantage

- Complete resource depletion is more easily attainable in some instances.

Disadvantages

- Stockpiled soils will have deteriorated during the mine's life and will not be as fertile as the soils in place.
- Revegetation will probably be more expensive and take longer.
- The site generates negative public opinion for a long period.
- The land is not providing a beneficial use while unreclaimed.
- No reclaimed segments are available as test plots for revegetation.
- Bonding liability is very high.

INTERIM RECLAMATION

Interim reclamation is done seasonally to stabilize mined areas or stockpiles and to prevent erosion. If a mine is to remain inactive for more than 2 years or if a stockpile, excavated slope, or storage area needs rapid stabilization, it may be appropriate to temporarily reclaim it by doing earthwork and using fast-growing vegetation, such as cereal grains or legumes that establish quickly, to stabilize the site. However, topsoil should not be moved for interim reclamation; significant amounts are lost each time topsoil is moved. (See The Soil Resource, p. 3.10.)

Advantages

- Soil viability is maintained.
- Fewer storm-water control structures are needed because the erosion-prone area is vegetated.
- Air and water quality are improved in the short term.
- Sites that use interim reclamation are often easier to convert to final reclamation than those that do not.

Disadvantages

- Areas may be redisturbed as plans change.
- Cost may be greater than when material is moved only once.

CONCURRENT OR PROGRESSIVE RECLAMATION

Concurrent or progressive reclamation typically involves transporting material from the new mining area to the reclamation area in one circuit (Fig. 3.2). This is the method used in strip mining minerals such as coal where a small amount of mineral is mined compared to a large amount of overburden moved.

Concurrent reclamation is viewed by the public as the preferred technique. However, progressively reclaiming land that overlies known mineral resources can be wasteful. Thin soils may render progressive reclamation impractical or impossible on some sites. It is also impractical for those operations that must blend different sand and gravel sizes from various parts of the mine site to achieve product specifications.

Advantages

- Soil is immediately moved to the reclamation area.
- Soil and subsoil profile are more easily reproduced than in other types of reclamation.
- Materials are moved only once.

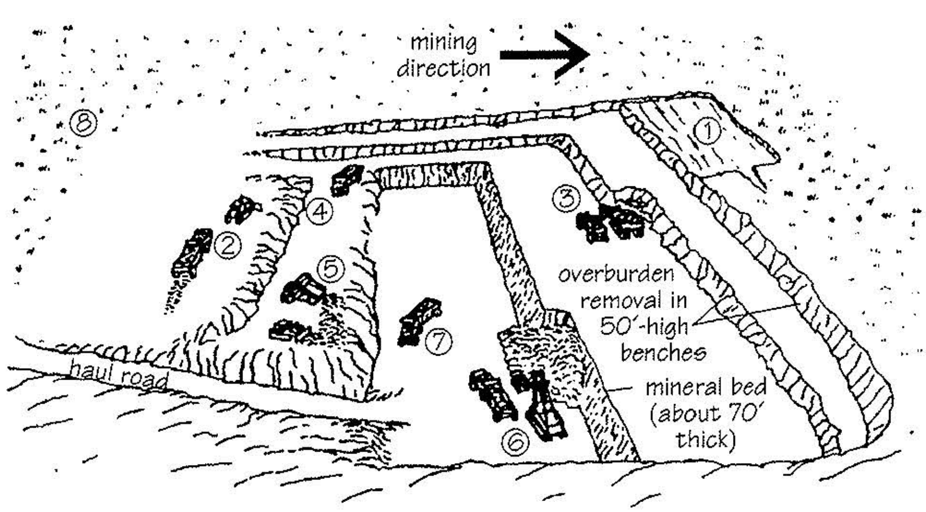


Figure 3.2. Concurrent or progressive extraction and reclamation of a shallow dry pit.
1, removal of topsoil;
2, spreading topsoil on graded wastes;
3, loading of overburden;
4, hauling of overburden;
5, dumping of overburden;
6, loading of product;
7, hauling of product;
8, reclaimed land.

(Modified from U.S. Bureau of Land Management, 1992.)

- Disturbance at any given time is minimized.
- Offsite impacts are minimized in any given area.
- Mined land can be reclaimed earlier for agriculture or grazing.
- Bond liability tends to be low.

Disadvantages

- Progressive reclamation is generally not feasible in quarries or deep gravel deposits.
- Progressive reclamation typically does not work if the water table is above the excavation depth.

SEGMENTAL RECLAMATION

In segmental reclamation, the mine is divided into segments with fairly uniform characteristics and the order of mining and reclaiming these segments is determined (Fig. 3.3). Prior to mining, soil in the first segment is stockpiled to minimize handling and protect the resource. After resource extraction from the first segment, its slopes are reshaped according to the reclamation plan. Soil is then stripped from the second segment and spread on the slopes of the first segment.

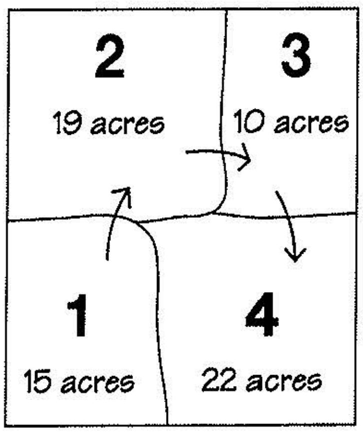


Figure 3.3. A segmental reclamation plan with four segments showing segment size and direction of working.

Revegetation of the floor of the first segment does not occur until the area is no longer needed for mineral processing or maneuvering trucks. Immediately prior to replacing topsoil and planting, the pit floor is plowed or ripped because most plants cannot grow in soils that have been overcompacted by heavy machinery. Prompt planting in the correct season with grasses, legumes, and trees will quickly produce a cover that reduces erosion, retains moisture, and moderates soil temperature.

Segmental reclamation works best in homogenous deposits where aggregate mining proceeds in increments. Typical working cells or segments will be larger in heterogeneous deposits (for example, fluvial deposits) where blending minerals from many places in the mine may be required (Norman and Lingley, 1992).

Advantages

- Topsoil for most segments is handled only once and is not stored. This reduces reclamation cost and preserves soil quality.
- Final slope angles and shapes can be established during excavation rather than as a separate operation.
- Clay and silt, which are critical for retaining the moisture and nutrients essential for vegetation, are less likely to be washed away because they are immediately revegetated.
- The potential for establishing a diverse self-sustaining soil/plant ecosystem is enhanced because revegetation of reclaimed segments will be monitored as mining continues.
- Restoration of chemical, physical, and biological processes is less expensive when reclamation is started as soon as possible and spread over the life of the mine.

- Reclamation is less expensive because it does not require mobilization of personnel or equipment for the sole purpose of reclamation.
- Short-term environmental impacts are reduced.
- Bonding liability at any given time is minimized.

Disadvantages

- Thin soils may render this technique impractical.
- It is impractical for those operations that must blend different sand and gravel sizes from various parts of the mine site in order to achieve product specifications.
- Poorly planned segmental reclamation may result in disturbing more land per unit of mineral produced.

By law (RCW 78.44) in Washington, a segment is defined as a 7-acre area with more than 500 linear feet of working face. Larger segments must be approved by DNR in a segmental reclamation agreement.

MINING TO RECLAIM

Mining the slope to the final contours reduces reclamation costs by eliminating some of the earthwork necessary for final reclamation. This can result in reclamation being completed earlier, the performance security being reduced, and operating costs being lower in the long run.

SITE PREPARATION

Before mining begins, steps must be taken to mark permit boundaries, setbacks, buffers, segments, and storage and processing areas. Setbacks, buffers, and storage areas should remain undisturbed until reclamation. Keeping equipment and stockpiled materials out of these areas will help preserve them. Flagging, fences, or monuments will alert operators to areas to be avoided. If vegetation is present on slopes that might be unstable if bare, then those plants should be protected. Activity near trees and shrubs should be kept outside the area below the longest branches (or drip line).

Permit and Disturbed Area Boundaries

Permit boundaries and the limits of the area to be disturbed (permit boundary minus setbacks and buffers) should be identified with clearly visible permanent markers. Markers should be maintained until the reclamation permit is terminated.

Permanent Setbacks or Buffers

Permanent setbacks or buffers are necessary at many mines (Fig. 3.4). They are lands (that may or may not have vegetation) that remain undisturbed during mining to provide habitat and/or visual and noise screening.

In Washington, the minimum permanent setback for quarries (mines in consolidated deposits) permitted after June 30, 1993, is 30 feet. This area cannot be mined, and the material cannot be used for reclamation. Permanent setbacks are not required for gravel pits (unconsolidated deposits) but may still be useful if the mine has close

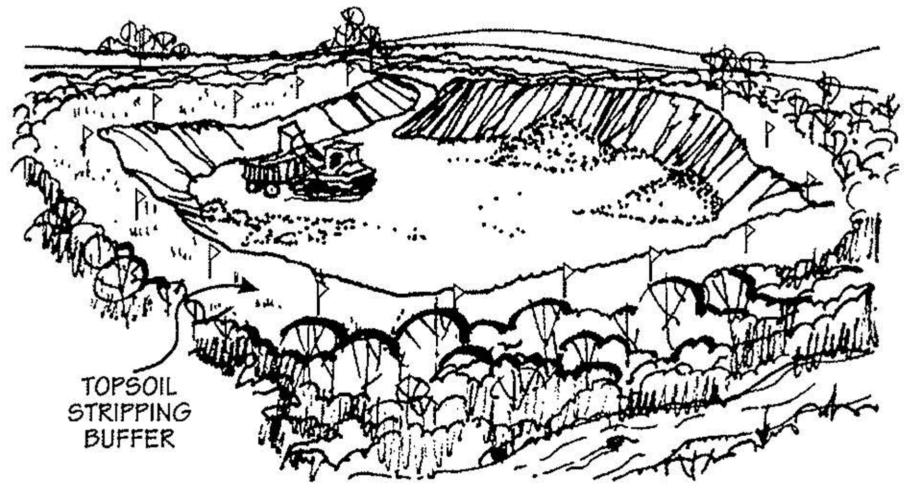


Figure 3.4. Buffer strips of native vegetation protect adjacent land and water and visually screen the operation. Note that the flags marking the limits of the disturbed area show employees where to stop mining. (Modified from Green and others, 1992.)

neighbors or adjacent scenic resources. However, setbacks may still be required by local government.

In Oregon, mine setbacks are site-specific and designed to provide lateral support for adjacent lands. Setbacks for the purpose of minimizing conflicting land uses are determined by the local land-use authority.

Reclamation Setbacks

Reclamation setbacks are lands along the margins of surface mines that must be preserved to provide enough material to accomplish reclamation. If the cut-and-fill method will be used to restore slopes (rather than mining to a final slope), the reclamation setback from the property boundary (or permanent setback, where used) should be wide enough to ensure that sufficient material is available for reclamation.

In Washington, the width of the reclamation setback for pits (mines in unconsolidated deposits) permitted after June 30, 1993, must equal or exceed the maximum anticipated height of the adjacent working face.

Note: A setback equal to the working face will provide only enough material for a 2:1 slope. To meet the standards of the law for slopes of between 2:1 and 3:1, a setback of 1.5 times the vertical height of the working face is required.

Setbacks to Protect Streams and Flood Plains

Streams and flood plains are dynamic locations that frequently experience dramatic changes during flooding. They are prone to damage by, and slow to fully recover from, improperly planned and executed mining operations. Mining in or near streams and flood plains requires greater care on the part of the operator and is subject to closer regulation than mining in less sensitive areas.

In Washington, no mine, including haul roads, stockpiles, and equipment storage, may be located within 200 feet of or on the 100-year flood plain of a stream that has a flow greater than 20 cubic feet per second unless a Shoreline Permit is issued by the local jurisdiction (Washington Department of Ecology, 1992). Wide setbacks may be necessary for stream and flood-plain stability to preserve riparian zones and to prevent breaching of the pit at a later date. The depth of excavation and pit size may be limited in these areas.

In Oregon, mining is not explicitly prohibited on the 100-year flood plain. Setbacks are site-specific to protect riparian areas and stream integrity. Depending on flood frequency, bank stability, and the potential for lateral migration of the river channel, wider setbacks may be required or depth of excavation may be limited.

Conservation Setbacks

In special instances, setbacks that will not be mined or disturbed may be necessary to protect unstable slopes, wildlife habitat, riparian zones, wetlands, or other sensitive areas or to limit turbid water discharge from areas that will be disturbed.

Topsoil and Overburden Storage Areas

Prior to mining a segment, all available topsoil and overburden should be stockpiled in separate, stable storage areas for later use in reclamation or immediately moved to reclaim adjacent depleted segments. Topsoil needed for reclamation cannot be sold, removed from the site or mixed with sterile soils.

In Washington, topsoil should not be used to create screening berms required by local government because this may preclude its timely use for reclamation.

VISUAL AND NOISE SCREENS

The value of visual and noise screens cannot be overstated. The adage ‘out of sight, out of mind’ is particularly applicable to mine sites. The more the public can be screened from the unpleasant aspects of mining, such as dust, noise, and an unsightly view, the less likely they are to aggressively oppose mining operations.

The following are some ways to reduce the noise and visual impacts of mining (Figs. 3.5 and 3.6):

- Plan mine development to minimize offsite impacts.

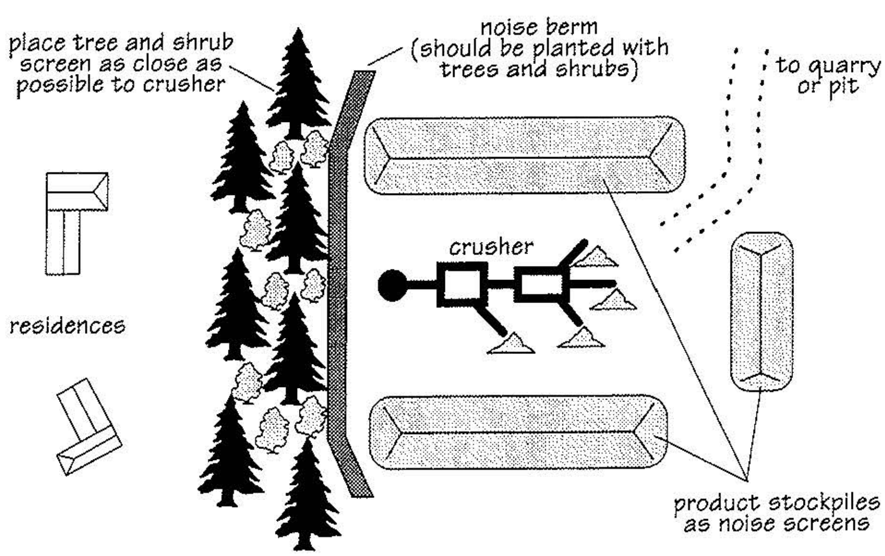


Figure 3.5. Visual and noise screening techniques used at a processing area.

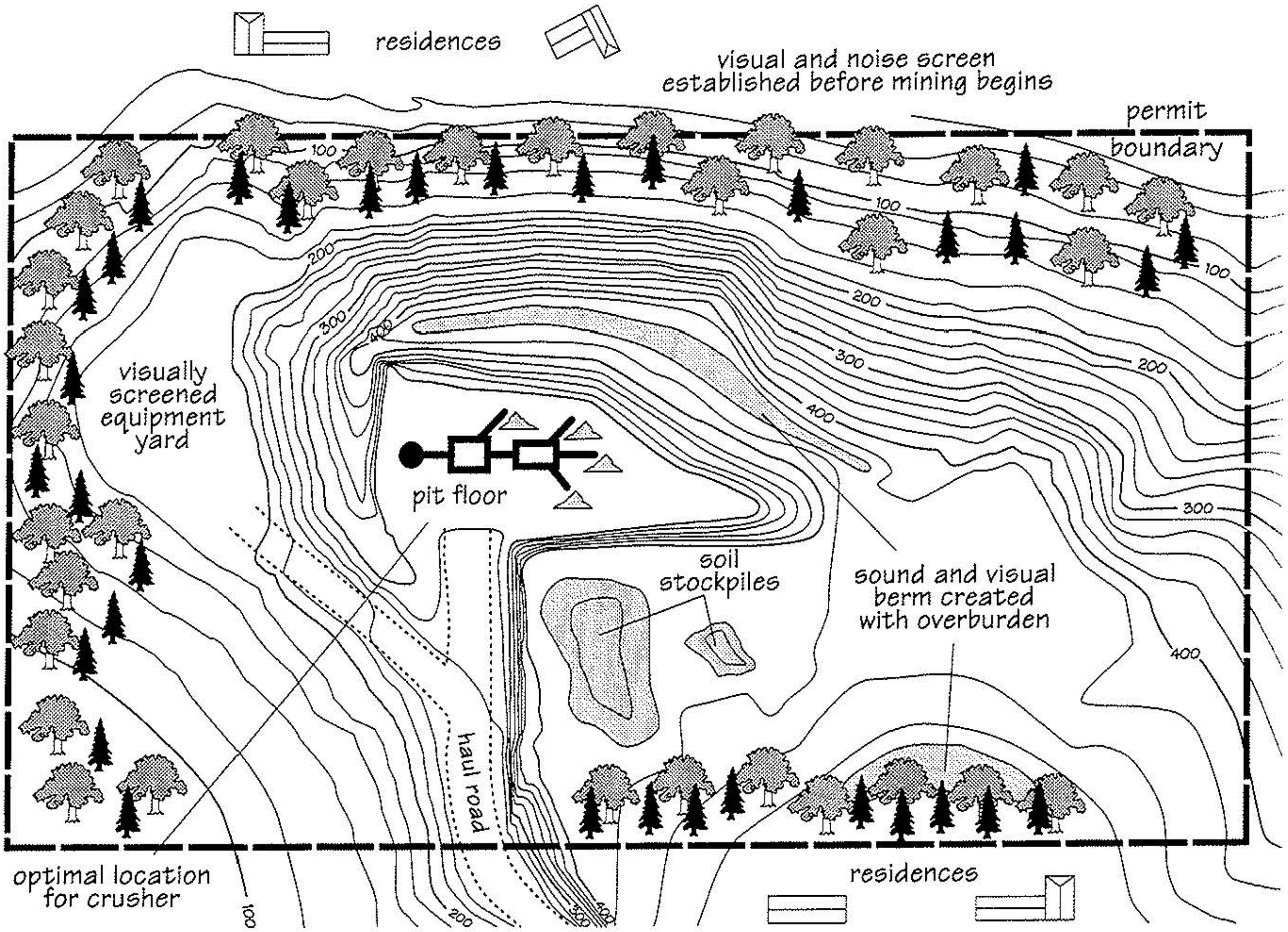


Figure 3.6. Visual and noise screening techniques used at a quarry site. Figure 2.11 shows the storm-water control system at the same site.

- Use existing topography as a noise and visual screen.
- Store overburden in berms along the site perimeter. Plant vegetation on them immediately to reduce noise.
- Plant trees and other visual screens—the denser and wider the better—well ahead of the mining to give them time to establish before they are needed.
- Plant tree barriers as close to the noise source as possible and between noise sources and the neighbors.
- Plant trees that will quickly grow tall enough to screen the mine. Plant shrubs to fill in the gaps, particularly if the foliage is sparse on the lower parts of the trees. Use evergreens if the site will be operated year round.
- Reduce noise by placing loud stationary equipment, such as the crusher, in an excavated area below the surrounding terrain.
- Surround the crusher with product stockpiles to reduce noise.
- Enclose the crusher in a building.
- Muffle the exhaust systems on trucks and other equipment.

Figure 3.7. Noise levels and human response for some common noise sources. (Modified from Barksdale, 1991.)

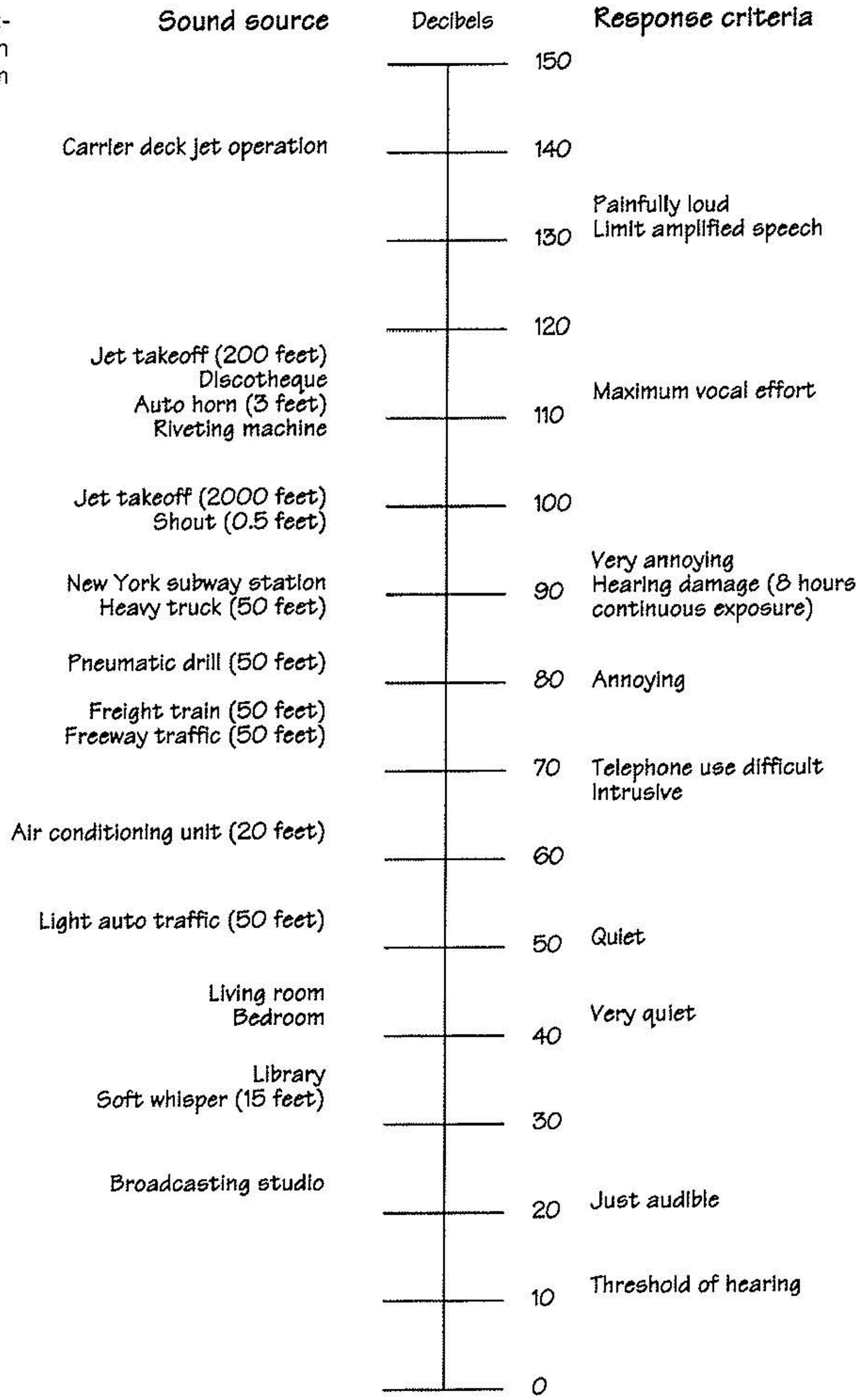


Table 3.1. Summary of noise measurements and projected noise levels in decibels (dBA) for common mining equipment (Barksdale, 1991)

Noise source	Measurements	Projected noise levels		
		1,000 ft	2,000 ft	3,000 ft
Primary and secondary crusher	89 dBA at 100 ft	69.0 dBA	63.0 dBA	59.5 dBA
Hitachi 501 shovel, loading	92 dBA at 50 ft	66.0 dBA	60.0 dBA	56.5 dBA
Euclid R-50 pit truck, loaded	90 dBA at 50 ft	64.0 dBA	58.0 dBA	54.4 dBA
Caterpillar 988 loader	80 dBA at 300 ft	69.5 dBA	63.5 dBA	60.0 dBA

- Use screens coated with rubber in the crusher, and line dump trucks beds with rubber.

How Noisy Is It?

Figure 3.7 summarizes the noise level, in decibels (dBA), from some common sources. Table 3.1 summarizes noise measurements for common mining equipment.

Noise-Control Methods

Noise-control measures, such as berms and tree barriers, can reduce the noise experienced by adjacent landowners by as much as 12 dBA, whereas earthen berms with vegetation can reduce noise up to 15 dBA, depending on the size and configuration of the berms, the type and density of vegetation, and the distance to the listener.

Visual Screens

The least expensive visual screen is the existing topography and vegetation on the site. Plan to leave large buffer zones of trees and vegetation between the mining site and nearby roads and buildings. Narrower buffer screens can be created with vegetation (preferably native evergreens), walls, fences, or berms, although they are generally less effective than buffer zones, which rely on distance for their effectiveness.

REMOVING VEGETATION

In a well-planned operation, vegetation is removed from areas to be mined only as needed and is preserved when possible to screen the site and limit erosion that may result in turbid water discharge.

Disposing of Vegetation

Grass and small shrubs can be incorporated into the topsoil stockpile, and larger material can be chipped and used as mulch or to add organic matter to the soil. Burial of large volumes of woody debris is permissible only in areas above the water table because anaerobic decomposition of woody debris produces nitrates, which can degrade water quality. Vegetation should not be buried in areas where building construction is planned because the soil may settle as the vegetation decays.

In Washington, a permit from the county health district is required for burial of more than 2,000 cubic yards of debris. If burning will take place, a burning permit may be necessary.

In Oregon, a permit from the Department of Environmental Quality is generally required for burial of debris and may be required for burning.

Transplanting Vegetation

Bushes and small trees, together with some surrounding soil, can be scooped up using backhoes or front-end loaders with tree spades and transplanted to mined-out segments or areas to be used as screens. (See p. 7.9.) This technique is a cost-effective means of quickly establishing a natural appearance in reclaimed segments, introducing seed trees, and providing screening. These plants are already adapted to the area. Moving the soil along with the plant protects rootlets and microorganisms that are important to plant health.

Additionally, the soil may contain seeds or shoots of other vegetation, which may spread across nearby areas.

Using Vegetation for Habitat

Vegetation that cannot be transplanted live can be set aside (with leaves, needles, and roots intact) for future use as fish and wildlife habitat. Placed in ponds, it can provide shelter for small fish, and collected into piles, it can provide shelter for small animals. (See Structures That Enhance Habitat, p. 4.12.) Salvaged coarse woody material, such as logs, should be distributed across a regraded area at the rate of about 8 tons per acre.

THE SOIL RESOURCE

Soil is one of the most important components of successful reclamation. Without soil, vegetation cannot be established. A typical soil is composed of approximately 45 percent minerals (sand, silt, and clay particles), 5 percent organic matter, and 50 percent pore space for air and water. Organic matter, air, and water in a soil allow it to support a tremendous amount of animal and plant life, most of which is invisible to the naked eye.

The word 'topsoil' is often used to describe a broad range of soil types. It may refer to high-quality river-bottom loams suitable for intensive agriculture or to the top layer of the soil resource, generally the most fertile slice.

In Washington, topsoil is defined in the reclamation law [RCW 78.44] as the "naturally occurring upper part of a soil profile, including the soil horizon that is rich in humus and capable of supporting vegetation together with other sediments within four vertical feet of the ground surface".

In Oregon, soil salvage requirements are determined on a site-specific basis.

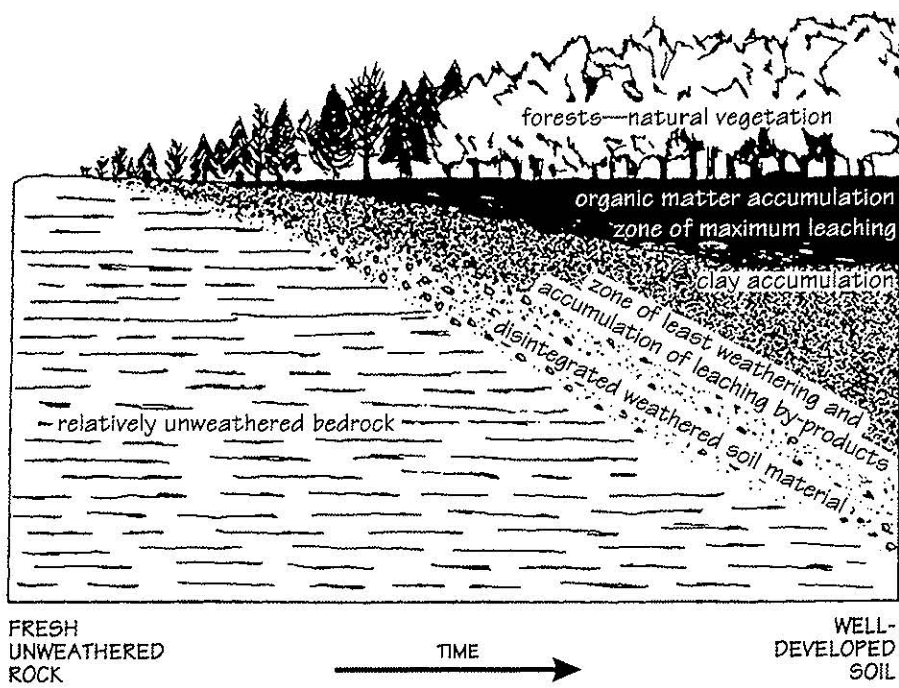


Figure 3.8. Soil profile development over time. Organic matter accumulates in the upper horizons, and the rate of accumulation is dependent on the type and amount of vegetation present. Clay and the by-products of chemical leaching accumulate in the lower horizons. (Modified from THE NATURE AND PROPERTIES OF SOILS, 8/E by Brady, ©1974. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ.)

Soil Development

Soils may be defined in terms of soil profile development (Fig. 3.8). Weathering creates chemical and physical changes in bedrock or other parent material. Over time, layers or soil horizons develop. A soil horizon is chemically and/or physically different from the soil horizons above or below. A soil horizon may be leached of certain minerals, or it may be altered by the deposition or formation of other minerals.

Plants decay and contribute organic matter to the top of the soil profile (topsoil). This is where organic matter accumulates and the maximum leaching of minerals occurs. Water moving through the upper soil carries clay and dissolved minerals to deeper layers (subsoil).

The conceptual soil profile in Figure 3.9 shows the major horizons in a soil weathered from bedrock. Climate is the most influential factor in soil formation because it determines the degree of weathering that occurs. Thin, poorly developed soils are common in

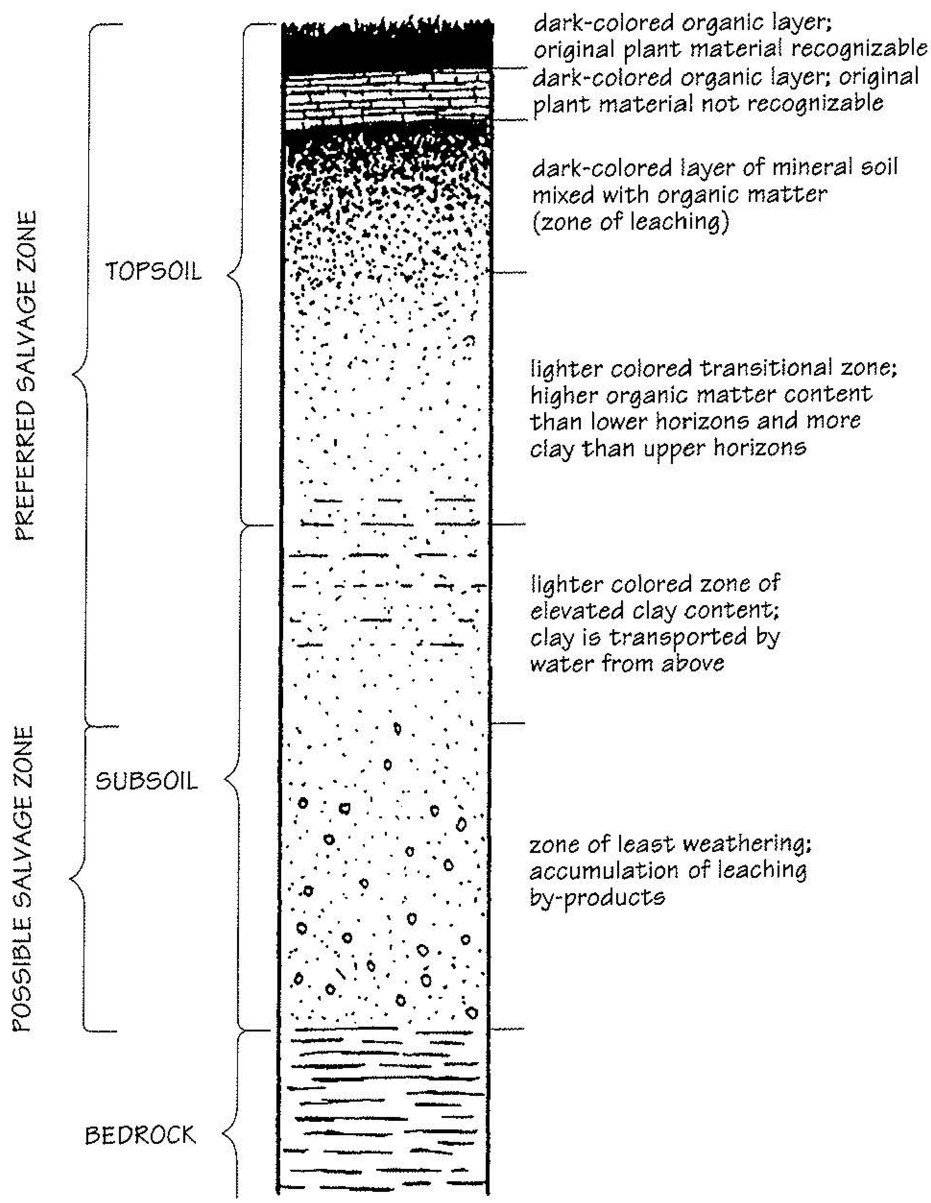


Figure 3.9. A diagrammatic sketch of the residual soil profile that develops over time on a bedrock surface. The thickness of the layers can vary widely within a mine site and between nearby sites. No scale is intended here. (Modified from THE NATURE AND PROPERTIES OF SOILS, 8/E by Brady, ©1974. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ.)

arid areas, whereas thick, well-developed soils are common in wetter areas.

Topsoil can be identified by its dark color and organic content. It also has a high water-retention capacity. Subsoils commonly contain fewer nutrients. Overburden is the material removed to allow access to the material that is being mined. At most aggregate operations, overburden consists of clay and silt that is poorly drained. Examples include volcanic ash overlying basalt or decomposed rock that overlies an unweathered rock.

Soil Fertility

Soil fertility is created by the recycling of organic matter and the weathering of minerals. Soil systems continually produce and recycle organic matter through the vegetative cover they support. Organisms in soil convert organic matter (through decomposition) to a form plants can use. Decomposition of organic matter also produces fairly strong acids that can react with minerals in the soil to extract base cations such as Ca^{++}, Mg^{++} and K^{+}, which are essential for plant growth.

Unweathered geologic materials and subsoils are typically less desirable as reclamation media for mined lands because they lack the organic matter and elevated concentrations of dissolved minerals found in more fertile soils.

Soil Types

Rocks weathering in place form residual soils. Eolian, alluvial, or colluvial soils form from weathering of materials deposited by wind, water, or gravity, respectively. Alluvial soils, although they are generally young soils with poorly developed soil profiles, are typically fertile because they include silts and flood deposits containing abundant organic debris.

Soil Inventories

The Natural Resource Conservation Service (NRCS, formerly the Soil Conservation Service) is responsible for classifying, naming, and mapping the nation's soil resources. Traditionally the mapping focus has been on the agricultural suitability and fertility of soils. NRCS soil surveys also provide information about erosion hazards, flooding potential, soil stability, and suitability for various uses, including drain fields, road building, timber harvesting, and housing development, as well as information on suitable trees to plant and potential wildlife habitat and recreational development.

For most areas, Order III soil surveys are available as published or unpublished maps on a countywide basis. Unpublished surveys may be available at the local NRCS office; published surveys should be available at the local library. Order III maps are at a scale of 1:20,000. Boundaries are field checked, but most of the mapping is done in the office from aerial photographs.

In an Order III survey, soils are grouped into 'associations' and 'complexes' on the basis of genetic similarities. That is, if soils have the same parent material and have been subjected to the same soil-forming processes, they may be grouped together on an Order III

Survey map, even though the depth of the individual soils in the group may be significantly different.

For mine development and reclamation, it is important to know how much soil is present and where it is in the project area. Order I and Order II soil surveys can provide this information. They are commonly available for areas of intensive agricultural production and can be obtained from the NRCS, DOGAMI, or DNR.

On-site soils investigations can be accomplished with a backhoe or a shovel and a hand auger. If the mine operator is doing the soil investigation, the NRCS, DOGAMI, or DNR should be contacted for information about soil types at the mine site and for recommendations on how to handle them. Understanding the approximate fertility level of each soil type and different soil horizons will contribute to wise use of the resource.

REMOVING AND STORING TOPSOIL AND SUBSOILS

Topsoil, subsoil, and overburden should be removed separately before mining and retained for reclamation. Placing several inches of soil with elevated organic matter over a lower quality subsoil material can make a dramatic difference in revegetation success. If adequate soils are not reserved to accomplish the approved reclamation plan, miners may need to import soil—often at considerable expense. It is important to ensure that soil resources are protected and used to their maximum potential, because few mine operations can afford to import soils.

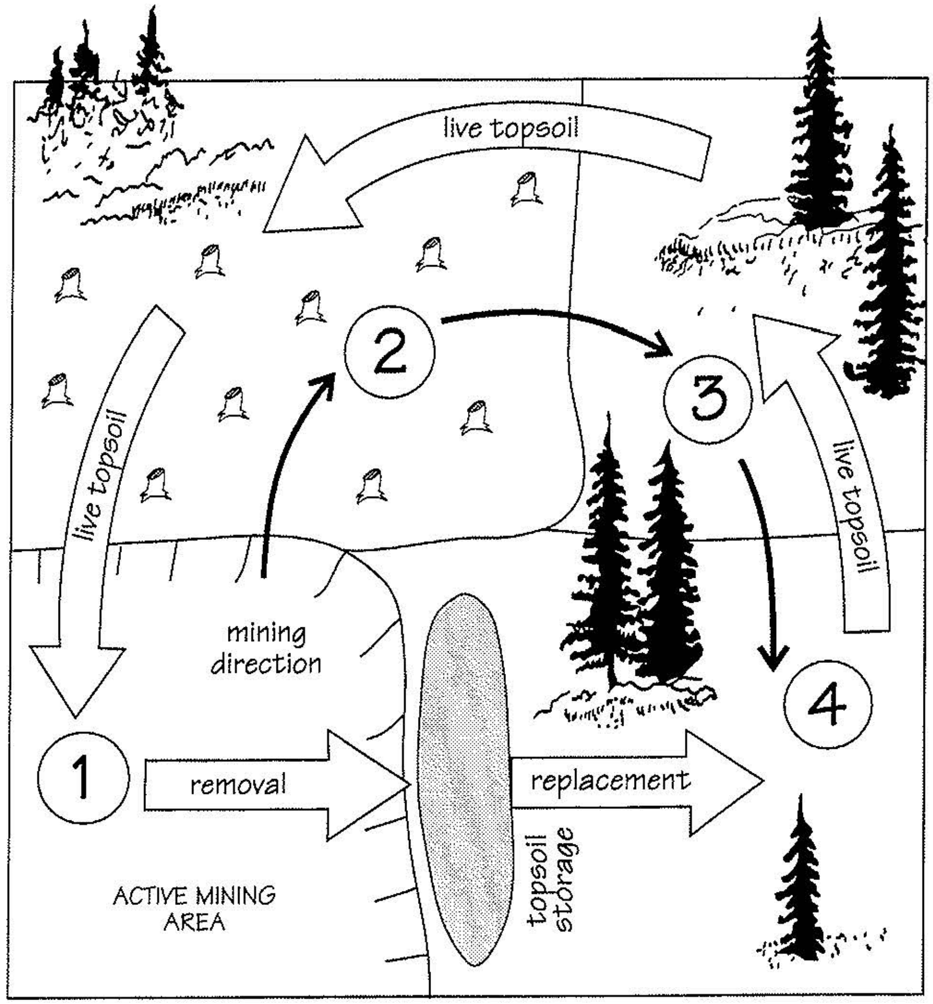
The pore space in soil is essential for the proliferation of bacteria, fungi, algae, and soil-dwelling insects and worms. One gram of soil may contain as many as 3 billion soil bacteria. Consequently, soils must be properly handled and stored to protect both the pore spaces and soil organisms. Porosity, or structure, can be permanently damaged if soils are stripped when they are excessively wet or dry. This is a particular problem with clay-rich soils and loams. Stockpiling aggregate on top of a soil stockpile, compaction caused by the passage of heavy equipment, burial by overburden, or creation of large soil stockpiles can destroy the dynamic qualities of a soil.

Live Topsoiling

'Live topsoiling' means placing stripped soil directly onto an area that has been mined out or backfilled or on a reshaped surface for reclamation (Fig. 3.10). Soil should be spread with a minimum of equipment traffic to avoid compaction and protect pore spaces. Because the soil contains viable seeds and the soil organisms are relocated to the same ecological niche, revegetation can occur within a short time (Munshower, 1994).

In both Washington and Oregon, live topsoiling is recommended wherever possible. However, live topsoiling may not be practical, particularly in quarry operations where concurrent reclamation opportunities are limited or where the soil contains noxious or undesirable weeds and the site is being reclaimed to cultivated cropland.

Figure 3.10. Topsoil handling in a four-segment mine. Segment 1 is the first to be mined. Its topsoil is removed and stored just inside segment 4. When mining of segment 1 is finished, topsoil is taken from segment 2 and place directly on segment 1 (live topsoiling). The topsoil from segment 3 is placed on segment 2. The topsoil from segment 4 is placed on segment 3. When mining is completed, the stockpiled topsoil from segment 1 is used to reclaim segment 4.



Stripping and Salvage

Before soils can be stripped and stockpiled, areas to be stripped and storage areas should be marked. (See Fig. 1.3.) Equipment operators who are stripping soils by horizon or separating soils from subsoils should have enough information to identify and segregate topsoil, subsoil, and overburden. A color change is typically the most obvious indicator of a change in soil horizons. Soil horizons that contain a fairly large amount of organic matter can generally be recognized in the field by their darker color and position at the top of the soil profile. Another technique is to identify stripping depths on survey stakes placed on 100 to 200 foot centers. It is best to move the soil only once. This also reduces operating costs.

By law in Washington [RCW 78.44], topsoil needed for reclamation cannot be sold or mixed with sterile soil unless specific authority has been granted in the permit documents. Subsoils capable of supporting vegetation must be salvaged to a depth of 4 feet and stored in a stable area if not immediately used for reclamation.

In Oregon, subsoil salvage depth must be adequate to accomplish reclamation according to the approved plan.

Constructing Storage Piles

Choosing an appropriate method for storage pile construction is also important. Continually driving heavy equipment over the soil while constructing scraper-built or end-dump piles can permanently damage soil structure and reduce the pore space essential for microorganisms. This type of construction should be avoided.

Soil storage piles should be constructed to minimize size and compaction so soil organisms can 'breathe'. Extensive experience and research have shown that the size of soil storage piles can significantly affect soil viability (Allen and Friese, 1992). Soil storage piles should be no more than 25 feet in height. Available plant material such as grasses, shrubs, and chipped tree limbs should be incorporated into the piles. However, if large amounts of woody material are added, soil may become nitrogen deficient.

Soil storage piles should be revegetated. They are good areas to do test seedings to prepare for final revegetation. To retain soil microbes deep in the soil pile, it can be aerated by deep ripping, discing, and tilling every 2 or 3 years.

Recent research (Allen and Friese, 1992) has shown that soil microbes can be regenerated in sterile soils by spotting live soil throughout the area and by using inoculated trees and shrubs. Microbes will spread to other areas in a relatively short time (weeks to a few months).

WASTE AND OVERBURDEN DUMPS AND STOCKPILES

Large amounts of overburden exist at many mine sites, and operations frequently create large volumes of waste rock. Dumps and stockpiles are created to temporarily or permanently store both overburden and unwanted material separated from the salable product on the site, for example, crusher scalpings, oversize material, and reject fines. During reclamation, overburden and waste can be used to create landscape diversity. It is important to plan the location of overburden or waste piles so they can be used in reclamation.

Site Selection

Dumps and stockpiles can result in landslides and increased sediment load that may pollute nearby waters if they are not properly designed and maintained. Careful planning is necessary to ensure that dumps and stockpiles are placed in a geologically stable location, and that they can be revegetated successfully. Locations next to waterways or springs or seeps will probably not be acceptable. Ideally, from both construction and water-quality protection standpoints, these materials should be removed and placed only during dry periods.

Site Preparation

Storage sites for overburden and waste rock should be properly prepared. All vegetation, soil, and subsoil must be stripped from the site prior to dump construction. Any buried vegetation will rot; this soft material provides little resistance to sliding and increases the potential for downslope movement. Slash cleared from the stockpile area can be used below the stockpile to filter runoff. (See Slash Windrows and Brush Sediment Barriers, p. 2.12.)

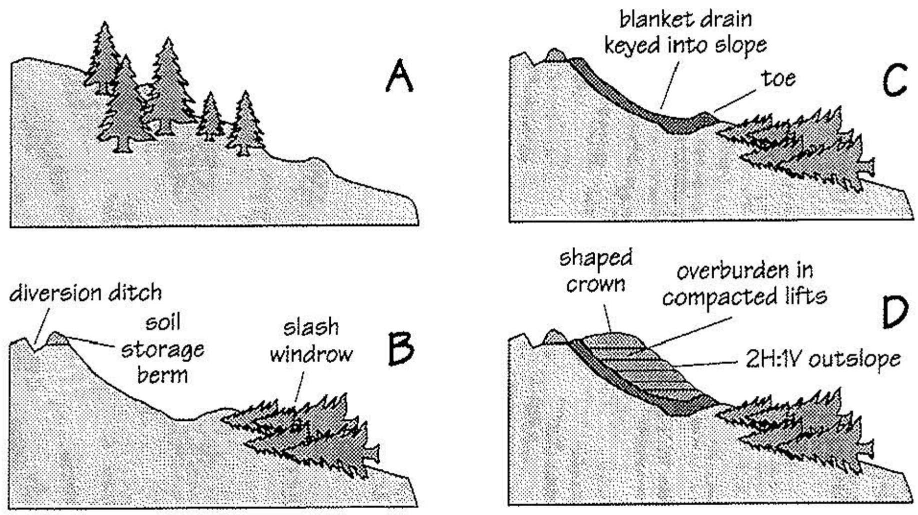


Figure 3.11. Proper procedures for waste dump construction. Trees removed from the site are used to construct a slash windrow to filter runoff. A blanket drain (a French drain that covers a slope instead of being confined to a trench; see Trench Subdrains and French drains, p. 2.20 and Fig. 6.6.) is laid down first to prevent the buildup of water, and the dump itself is constructed of thin, compacted layers.

Before overburden is stockpiled, all vegetation should be cleared, and the drainage for the pile must be prepared. Undrained and uncompacted fill dumped over vegetation without drainage is prone to mass wasting and landslides that waste topsoil. Soil placed over permanent waste piles will promote self-sustaining vegetation. (See Topsoil and Overburden Storage Areas, p. 3.6.)

Large dumps and stockpiles or those located on steep ground should have diversion ditches constructed above them (Fig. 3.11B). (See Contour and Diversion Ditches, p. 2.17.) A blanket drain should be installed on any slopes where drainage problems are anticipated (Fig. 3.11C). (See also Trench Subdrains and French Drains, p. 2.20.)

Dump and Stockpile Construction

Stability is important, particularly for dumps that will become permanent features. Both dumps and stockpiles should be constructed using thin, compacted layers (Fig. 3.11D). Before compaction, layers may be as thin as 12 to 18 inches. When compacted by rubber-tired equipment, they will result in a much more stable dump than one prepared by simply end-dumping or pushing with a bulldozer.

Dumps and stockpiles on hillsides or filling ravines need a properly constructed toe to key the pile into competent material. The toe should have a blanket drain to prevent the buildup of water. (See Fig. 6.6.)

Dumps and stockpiles should be shaped to prevent water from ponding. The top should be sloped to direct runoff to a drainage system and to avoid critical areas, or it should be crowned to disperse runoff around the perimeter. The slopes of the dump or stockpile should be constructed with appropriate runoff control structures. The top and overall shape should be rounded off to blend into the natural topography. (See Slope Stabilization, p. 6.6.)

Most final slopes should be between 2H:1V and 3H:1V. Generally, the flatter the slope, the more stable it will be and the easier to access for reclamation. Terraces should be constructed at 30-foot intervals vertically, or other methods of slope shaping should be use to reduce water velocities.

When shaping is complete, the dump or stockpile should be seeded and mulched to establish vegetation.

DUST CONTROL

Neighbors often complain about dust from mining operations. Dust is generated by the crusher, rock drills, and other mining equipment, and from disturbed areas, including haul roads and stockpiles.

In Washington, the Department of Ecology or the local air pollution control authority has review and permit authority over rock crushers, batch plants, fugitive dust emissions from mining operations, and haul roads. Contact these agencies for further information.

In Oregon, emissions from on-site processing require a permit from the Department of Environmental Quality.

Controlling Dust with Water

Controlling fugitive dust is usually a matter of frequent application of water or chemicals. Water trucks are typically used for conveying these liquids. However, sprinklers and irrigation pipe installed in the berms alongside haul roads can significantly decrease dust without the expense of using a water truck several times a day.

Controlling Dust with Chemicals

Chemical dust suppressants, such as magnesium chloride, are appropriate where water is in short supply. Most chemical dust suppressants require repeated application. There are numerous chemical dust suppressants designed for a variety of uses. The local and state water-quality agency can provide information about appropriate chemicals and how to apply them.

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4 Restoring Landforms

INTRODUCTION

Land shaping is an important but often underemphasized part of the reclamation process. Common objectives for land shaping include:

- minimizing erosion,
- reducing slope angles to provide stability for post-mining development,
- contouring aesthetically pleasing landforms to blend with the surrounding area,
- forming shapes and slopes consistent with the subsequent use planned for the site (Fig. 4.1),
- increasing revegetation success, and
- providing diverse wildlife and fish habitat.

SUBSEQUENT USE

Reclamation of a mine site, and thus its subsequent use, can be driven by high land values, zoning, and/or environmental protection and the state regulations that set minimum standards for reclamation and water quality.

In urban areas, high land values motivate miners to reclaim for intensive use. For example, in Portland, Oregon, gravel pits are typically backfilled with construction waste and developed as building sites. Building sites can also be developed directly without backfilling. Government-owned sites where the water table is high often become parks with ponds. In rural areas, less intensive uses such as wildlife habitat, agriculture, or timber production can also be profitable. (See Agricultural and Forestry Subsequent Uses, p. 7.17.)

Imagination and careful planning can yield a wide variety of landforms that make the site better for a specific use than it was prior to mining. For example, wetlands and fishing ponds can be created from rock quarries and gravel pits if proper water conditions exist. Many agricultural sites have been enhanced by selective gravel removal, making them easier to irrigate or till after gravel-rich knobs

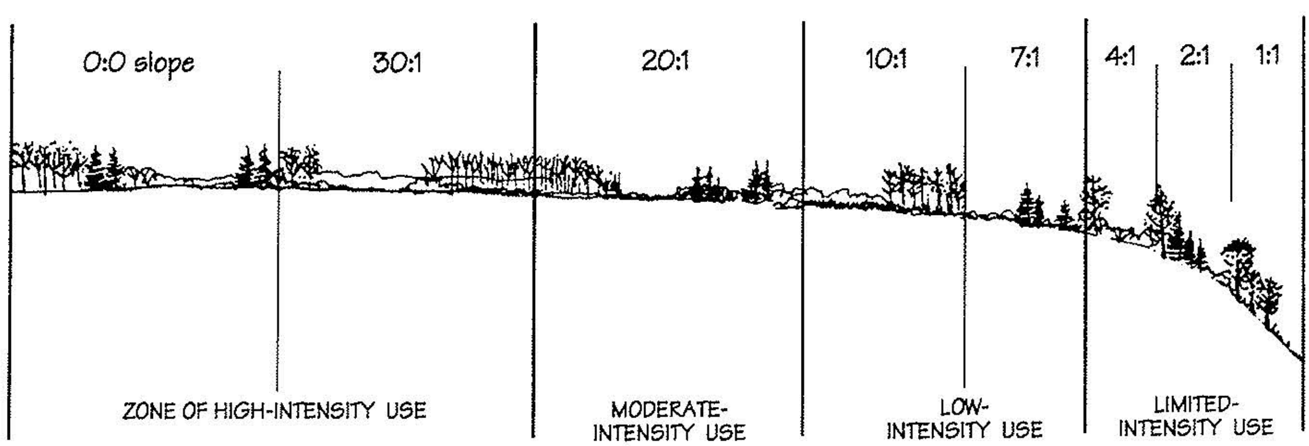

Figure 4.1. The steepness of the final slope strongly influences the intensity of proposed land use for reclaimed mine sites. Fewer options are available on steeper slopes. (From Green and others, 1992.)

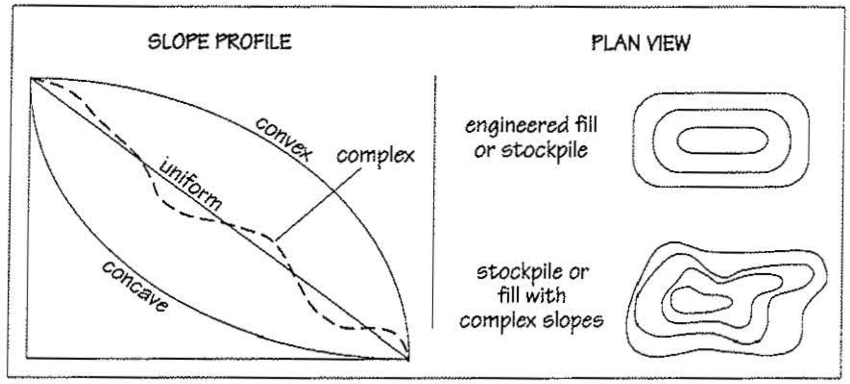

Figure 4.2. A, profile of common slope types. B, plan view of different stockpile designs. Complex slopes are preferred.

have been selectively removed from the fields. Mining can level areas of hilly topography making them more suitable for agricultural or industrial uses. In eastern Oregon and Washington, many of the mine sites developed on rangeland are returned to their previous condition by revegetation, generally with native species.

In Washington, RCW 78.44.031 identifies subsequent use as a criterion for guiding the reclamation scheme, while RCW 78.44.141 sets forth reclamation standards that must be met for various uses.

In Oregon, the subsequent use of the mined land must be compatible with the local comprehensive land-use plan.

SLOPE TYPES

Profiles of four basic slope types are shown in Figure 4.2. Convex slopes erode rapidly and yield the most sediment. Concave slopes are less affected by erosion and typically yield less sediment than convex slopes. The steepness of the slope is a major factor influencing the amount of sediment production. Surface-water runoff velocities are higher on longer, steeper slopes, and more soil particles are typically dislodged and transported. Sediment production on uniform slopes is intermediate between concave and convex slopes. Long uniform slopes should be avoided because they can be severely eroded in a single storm event.

☛ Complex slopes generally produce the least sediment and are the most stable. Complex slopes are preferred for mine site reclamation.

CREATING SLOPES

Where the goal of reclamation is to restore natural slopes that blend with surrounding landforms, sinuous slopes that are curved in plan and section and irregular in profile should be created (Fig. 4.3). Irregular slopes will intercept more runoff and reduce its velocity, trap seeds, and speed revegetation. Rectilinear slopes should be avoided because they are prone to sheet erosion and gullying and because they look unnatural.

Natural-looking topography can be achieved early on through a well-planned extraction operation and equipment operators who fully understand the post-mining use of the site. Sinuous slopes can be formed by mining to the prescribed angles (generally the most

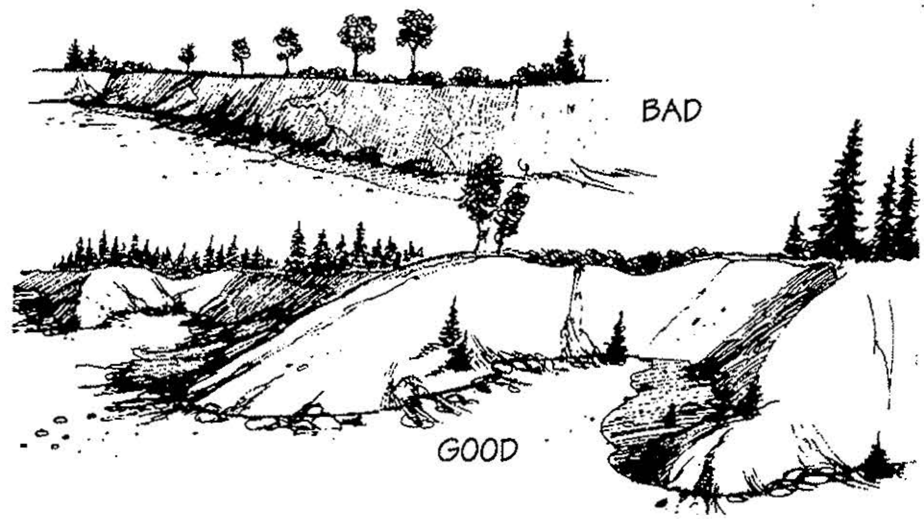

Figure 4.3. A key element in restoring topography is creating natural-looking slopes that blend with the surrounding landforms. Rectilinear slopes (top) are inappropriate for reclamation in unconsolidated materials. Slopes should be curved in plan and section and irregular in profile (bottom). (Redrawn from Green and others, 1992.)

inexpensive means of reclamation) or by using the cut-and-fill method, which requires a reclamation setback or material from overburden stockpiles. (See Reclamation Setbacks, p. 3.5.) Backfilling to create appropriate slopes can be the most expensive reclamation technique when it is done after mining.

A reclaimed site should consist entirely of stable slopes. A rule of thumb is that slopes are unstable if pioneer plants cannot establish themselves naturally, if the slopes ravel or show signs of soil creep and tension cracks, or if landsliding is noted. (See Identifying Unstable Slope Conditions, p. 6.3.) In general, unconsolidated materials are stable and can sustain vegetation at slopes of 3 feet horizontal to 1 foot vertical (commonly expressed as 3H:1V) (Fig. 4.4) (Norman and Lingley, 1992).

For variety, a few locally steeper areas (1.5H:1V to 2H:1V) may be created (if stable), especially if they mimic locally steeper slopes nearby. However, steep slopes greatly increase the potential for erosion. Long, steep slopes produce more and faster runoff and allow less infiltration than a series of short, gentle slopes separated by

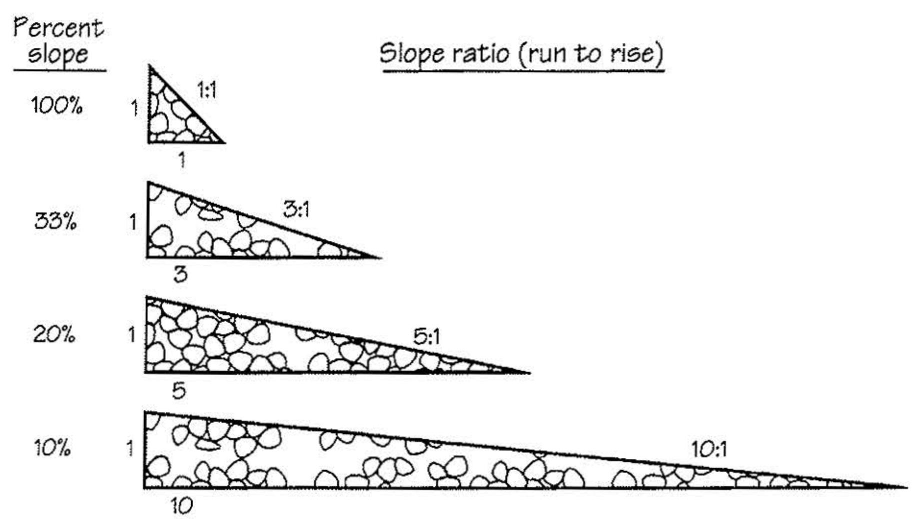

Figure 4.4. Slopes are expressed as the ratio of horizontal run to vertical rise. This diagram shows the percent slope of several common ratios. (Redrawn from Green and others, 1992.)

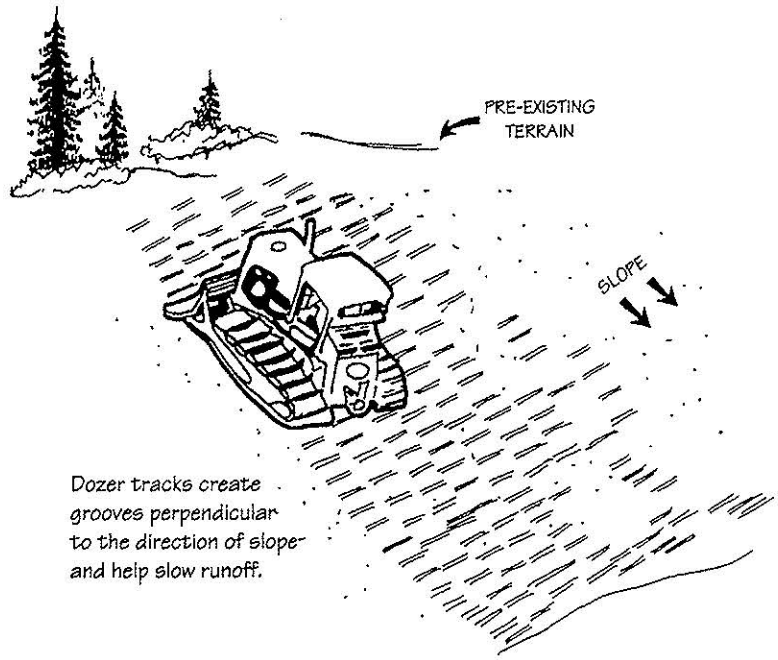

Figure 4.5. Dozer tracking can reduce runoff and enhance revegetation. Tracked equipment should be run up and down a slope, not across, to increase slope roughness. (Modified from Law, 1984.)

benches or terraces. New drainages or contour ditches should be established within the reclaimed area to contain the expected surface water runoff. Any water diverted during reclamation or land shaping should be directed to the drainage it occupied before mining to prevent drying up or flooding of areas downstream. This water should have approximately the same velocity, volume, and quality as the drainage it is entering.

Some guidelines for slope shaping are:

- Slopes steeper than 3H:1V should be kept shorter than 75 feet by creating breaks in slope, such as irregular terraces, berms, or basins. (See Figs. 2.3 and 2.4.)
- If the site is to be dry after mining, then pit floors should be graded to a slope of 2 to 5 percent to promote drainage.
- Some mounds, hills, and depressions can be left on pit floors to vary the topography for subsequent use (Norman and Lingley, 1992).
- In the final grading, bulldozers or other tracked equipment should be run up and down a slope, not across it, to increase slope roughness (Fig. 4.5). (Older bulldozers are generally unable to back up sand and gravel slopes steeper than 3H:1V.)
- Final slopes should be revegetated immediately to minimize erosion.

REGRADING

After the land has been shaped, it should be regraded to produce a rough, irregular surface, particularly on slopes (Fig. 4.5). This ensures that replaced soil is keyed into the substrate to slow erosion.

Roads, pit floors, and stockpile areas should be ripped at close intervals to provide drainage prior to replacing the soil. Placing a loose, friable soil over a compacted base does not increase soil moisture-holding capacity, drainage, or slope stability and will result in inadequate root development and penetration. A good rule of thumb is that ripper spacing should be less than or equal to the depth of ripping.

REPLACING TOPSOIL AND SUBSOIL

Understanding the soil resources of a site and the post-mining land use will lead to effective site development, using the best management practices for soil replacement. The type of vegetation planned for reclamation may dictate soil replacement depth. Deeper soils will be needed for agricultural production or establishing trees, particularly for timber production. More important than the depth of the replaced soil is how replacement is done. Soils should not be compacted. The less equipment is run over soils, the better. The most skilled and experienced equipment operators should be used for soil replacement—their skill will pay off.

Topsoil should be replaced on slopes as soon as possible after restoring topography. Soil horizons from stockpiles should be replaced separately in the proper order for best use of the resource. After the topsoil is spread, it should be tilled to construct a proper seed bed.

A minimum soil replacement depth of 12 inches of topsoil is recommended for reclamation for most post-mine uses. Upland sites may have soil depths, prior to mining, of 6 inches or less. On these sites, reject soil fines and rock fines produced during rock processing may be used to supplement pre-existing soil resources as a growth medium. Generally fines would be mixed with organic material and put in place before the topsoil is added.

The minimum recommended soil depth for timber production is 4 feet over rock and 2 feet over gravel or soft overburden to establish an effective rooting depth of 4 feet. Timber growth rates are generally directly related to the depth of the soil available.

A common problem in reapplying topsoil and subsoil is spreading them too thickly initially so that little is left for remaining areas. If the volume of topsoil at the site is limited, its application should be restricted to low areas or excavated depressions that will conserve soil, retain moisture, and catch wind-blown pioneer seeds. These low areas are also ideal sites for planting trees.

Varied soil replacement depths mimic natural soil-forming processes and should be incorporated into reclamation strategies where possible. Thinner layers of soil on the upslope areas and thicker layers on the lower slopes may naturally encourage different vegetation types. These parts of the slopes should be planted differently to encourage post-mining vegetation diversity.

In Washington, topsoil is defined as the naturally occurring upper part of a soil profile, including the soil horizon that is rich in humus and capable of supporting vegetation, together with other sediments within 4 vertical feet of the ground surface [RCW 78.44].

In Oregon, topsoil is not defined by law; however, sufficient soil must be retained onsite for reclamation.

AMENDING OR MANUFACTURING SOIL

Where little or no topsoil exists prior to mining, it may be necessary to amend or even manufacture soils. Amending soil can significantly reduce the time required for revegetation and performance security release. (See The Soil Resource, p. 3.10.)

Reconstructed soils should have the same soil characteristic as topsoil. Soil characteristics that have the greatest effect on plant growth are the amount of organic matter, moisture-holding capacity, drainage, and available nutrients.

Adding Organic Matter

Organic matter improves both the fertility and physical condition of a soil. The chief problem with using subsoils for reclamation is usually a lack of organic matter. Subsoils can be used in place of topsoils if they are combined with organic products, such as wood chips, paper sludge, rice hulls, mushroom compost, mint clippings, farm manure, processed municipal biosolids, straw, or native hay. In some instances, trading loads of rock for manure and straw from local dairies, farms, and ranches may be mutually beneficial. However, weeds should not imported with the manure or straw. Knowing the quality of the hay can prevent this from happening.

Quarry sites are generally developed where mineable rock is at or very near the surface. In these cases, reject fines, scalpings, or other fine-grained materials can be used to replace topsoil, provided they are amended with organic matter.

Biosolids and some other soil amendments may not be appropriate at sites near sensitive aquifers or waterways.

A solid waste permit from the local health district may be needed for application of biosolids, paper mill sludge, manure, etc. In Washington, contact the Department of Ecology. In Oregon, contact the Department of Environmental Quality or the local health department.

Improving Moisture-Holding Capacity

In the arid regions of the Pacific Northwest, the moisture-holding capacity of a soil is often the factor limiting planting success. A thick soil will hold more water than a thin one, and clay soils will hold more water than sandy soils. Moisture-holding capacity can be increased by adding large amounts clay or other fine-grained geologic material or by increasing the thickness of the subsoil. A mulch layer at the surface also helps conserve water by insulating the soil against evaporation.

Improving Drainage

In areas that are not being developed as wetlands, soils that do not drain well can cause plants to rot. Adding organic matter, sand, or other coarse materials improves drainage by modifying the structural characteristics of a soil. Adding lime or gypsum neutralizes acidic soils, which usually develop in wet areas.

Using Fertilizers

Natural Fertilizers. Adding organic matter can improve both the fertility and physical condition of a soil or fine-grained substitute. However, it may not provide any short-term fertility benefits and possibly no long-term benefits unless it is worked into the top 6 inches of soil. The smaller the particle size and the greater the surface area of the fertilizer, the faster it will be broken down by soil microbes.

The natural range of carbon to nitrogen in soils is 8:1 to 15:1. Organic amendments that help reclaimed soil achieve this ratio provide significant benefits. For example, amendments high in carbon and low in nitrogen, such as wood chips, may require additions of nitrogen-rich fertilizers (Table 4.1). This is because when an organic amendment rich in carbon is added to the soil, all the nitrogen available to plants will be tied up by soil microbes trying to consume the carbon. Soil microbes need nitrogen to consume the carbon and can preferentially absorb nitrogen before plant roots can use it. This means that there will be no nitrogen available to plants until the carbon: nitrogen ratio has dropped to 8:1–15:1. Therefore, adding amendments high in nitrogen will help plants grow under these conditions. Amendments in which carbon greatly exceeds nitrogen should be used sparingly.

Table 4.1. Nitrogen and carbon content of common organic soil amendments. The natural range of carbon to nitrogen in soils is 8:1 to 15:1. Organic amendments that help reclaimed soil achieve this ratio provide significant benefits. (Modified from FERTILIZERS AND SOIL AMENDMENTS by Follett, Murphy, and Donahue, © 1981. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ.)

Material	Organic Carbon (C) (%)	Total Nitrogen (N) (%)	Carbon: Nitrogen (C:N) Ratio
Sewage sludge (dry weight basis)			
Aerobic	35	5.60	6:1
Anaerobic	30	1.90	16:1
Alfalfa hay	43	2.40	18:1
Grass clippings, fresh	43	2.20	20:1
Leaves, freshly fallen	20–80	.50–1.00	40:1–80:1
Peat moss	48	.83	58:1
Corncobs	47	.45	104:1
Red alder sawdust	50	.37	135:1
Paper, mostly newspaper	43	.26	172:1
Hardwood sawdust	50	.20	250:1
Douglas fir			
Old bark	59	.20	295:1
Sawdust	51	.07	728:1
Wheat straw	45	.12	375:1
Pine sawdust	51	.07	729:1

Chemical Fertilizers. If a quick cover of vegetation is needed to provide erosion control or if the soil or manufactured soil substitute is of poor quality, applying a fertilizer is recommended. Organic matter should be added to achieve a long-term response before seeding directly into soil substitutes. Avoid applying fertilizers in areas where runoff into streams could occur.

Some research shows that native plants do not respond well to chemical fertilization, and fertilizers are not generally needed for the long-term survival of these species. Fertilization tends to depress plant community diversity by indirectly decreasing desirable native plant populations such as warm season grasses and legumes. Fertilizers tend to give a competitive advantage to opportunistic species such as annual grasses and herbaceous plants, many of which are weeds.

RESTORING DRAINAGE

Where the pit or quarry is mined below the water table or surface drainage collects on the mined property, productive ponds and wetlands can be formed with careful water management.

Where appropriate to the subsequent use, a pond creates additional plant and habitat diversity, even though it may contain water only on a seasonal basis. Shallow process-water ponds, as well as low places on excavation floors and in stockpile areas at upland sites, can be developed as seasonal wetlands, even in arid areas east of the Cascades.

Extraction ponds (ponds being mined for gravel) and some upland rock pits with a permanent water source make ideal sites for constructing wetlands if the water table is shallow. Sediment from washing and screening rock can be deposited to form shallow deltas that, when combined with the permanent water supply, can easily be revegetated with wetlands species.

CREATING PONDS FOR WILDLIFE

Ponds for wildlife habitat should have irregular outlines (Fig. 4.6). The bottom of the pond should also be irregular so as to offer a variety of habitat possibilities for plants, bottom dwellers, and fish (Fig. 4.7). Both water deeper than 10 feet and benches and bars with water depths less than 2 feet should be provided. As a general rule, 25 percent of the pond should be less than 2 feet deep, 25 percent 2–6 feet deep, and 50 percent deeper than 10 feet. Water deeper than

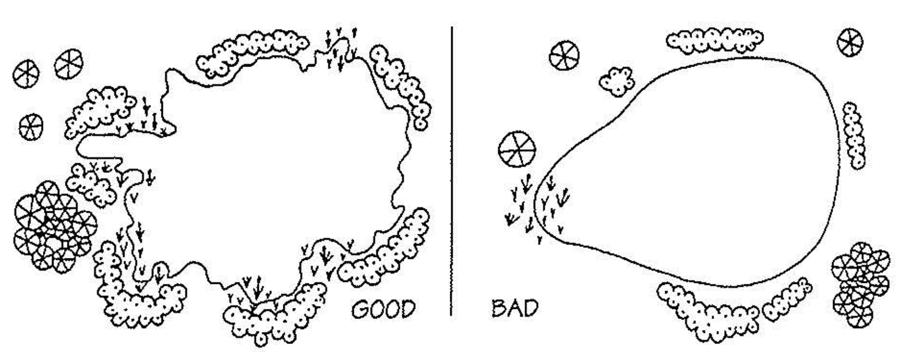

Figure 4.6. The shoreline of ponds used for wildlife habitat should be irregular and planted for cover with a mixture of open meadows and shrubs in the surrounding area. The shape of the pond on the left is better suited to supporting wildlife than that of the pond on the right. (Redrawn from Szafoni, 1982.)

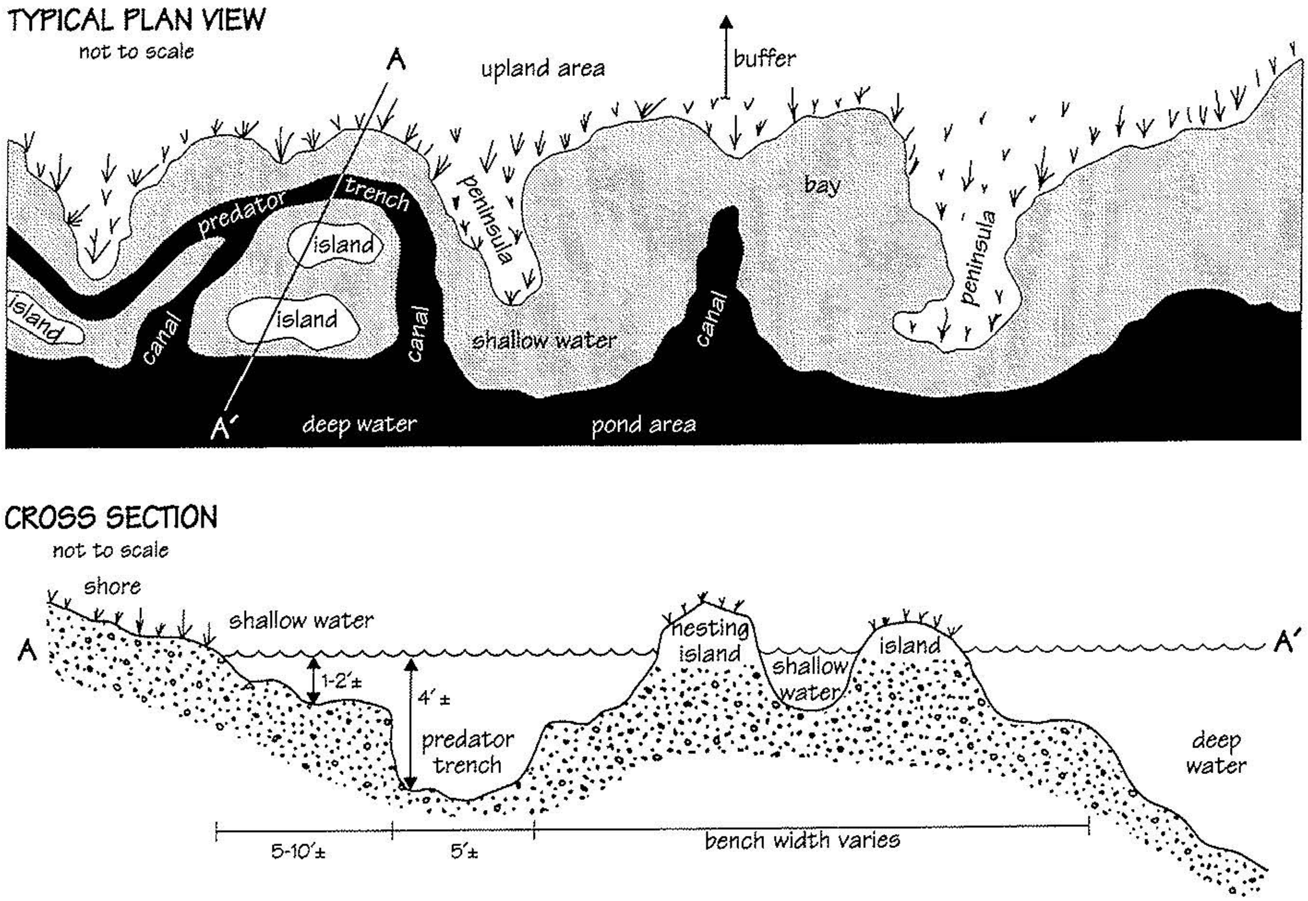

Figure 4.7. Plan view and cross section of a well-designed irregular wetland or pond shoreline. Note the large areas of shallow water. Steep slopes along parts of the shore will discourage the growth of wetland plants and provide clear access to the pond. Bird nesting sites are provided. The trench discourages predators, but the shallow water offers sites for food for fish and cover plantings. Islands can be constructed from fill, unmined material, or sediments saved from digging the trench.

15 feet can provide a cool summer refuge for fish (Norman and Lingley, 1992).

In-Water Slopes

Slopes should be very gentle, 5H:1V or flatter, to allow development of wetland plant species (Fig. 4.8). In general, the more shallow areas, the better. Slope variations will enhance the plant diversity in created wetlands.

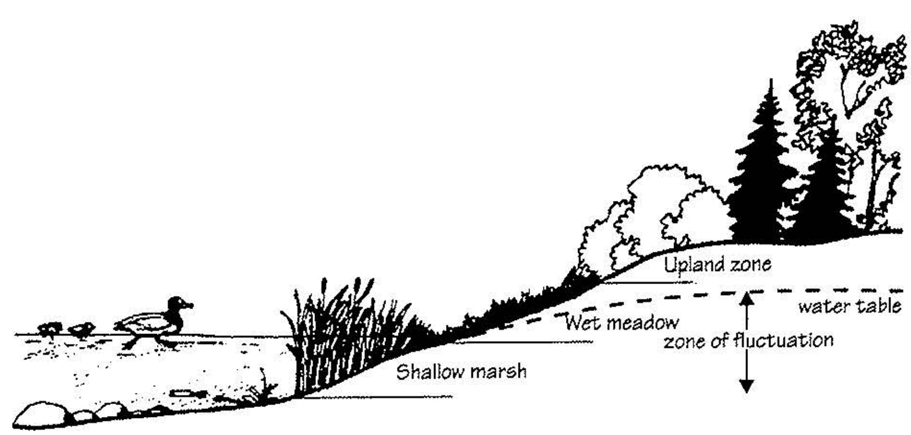

Figure 4.8. Slope variations will enhance the habitat diversity of created wetlands. To successfully establish wetland vegetation, seeds and transplants must be placed in sites with the correct water depth. (Modified from Green and others, 1992.)

The most economical means of shaping final pond slopes is to create them as material is excavated (Fig. 4.9). In mines that are being dewatered while operations proceed, resloping must be done before allowing the pits to fill with water.

Windward pond shores can be protected from wave erosion by placing boulders at the range of pond levels.

In Washington, slopes in unconsolidated materials (sand, gravel, or soil) below the permanent water table should not be steeper than 1.5H:1V. Slopes at the water/land interface should be between 2H:1V to 3H:1V. Solid rock banks must be shaped so that a person can escape from the water in those places.

Oregon statutes require a 3H:1V slope to 6 feet below the low-water mark of a pond to provide a means of escape in the event that someone were to fall in.

Special Considerations Near Rivers

Mining sand and gravel near a river can eliminate wetlands and fish and wildlife habitat, cause channelization of the river, and may even result in channel capture, if not planned properly. If mining is allowed by local jurisdictions, leaving ponds and depressions can replace lost fish and wildlife habitat and wetlands. By locating mining sites in relatively stable areas of the flood plain and not excavating overly deep or large pits, reclamation of fish and wildlife habitat can be done without extensive engineering to ensure river stability.

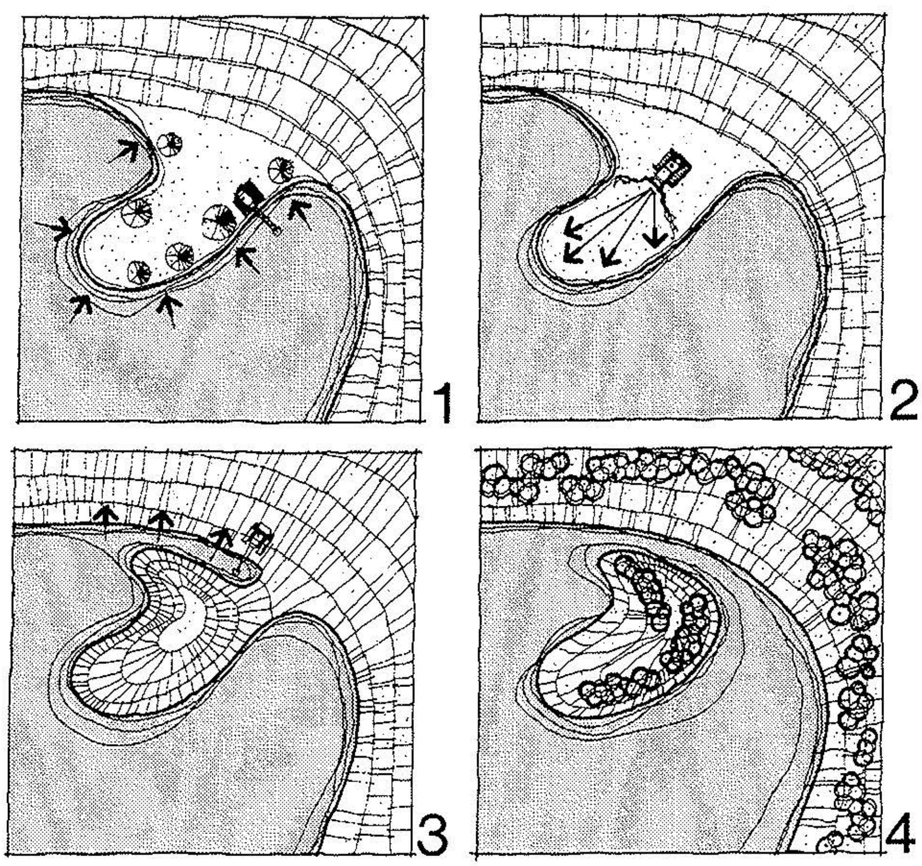

Figure 4.9. Islands can be developed in undrained pits during operations. They start as peninsulas (1), which are then graded to provide the appropriate final shapes and slopes (2). Channels can then be dredged to separate the tips of the peninsulas from the mainland (3). Step 3 should not be undertaken until final water levels are known. (4) Final configuration of constructed island. (Redrawn from Michalski and others, 1987.)

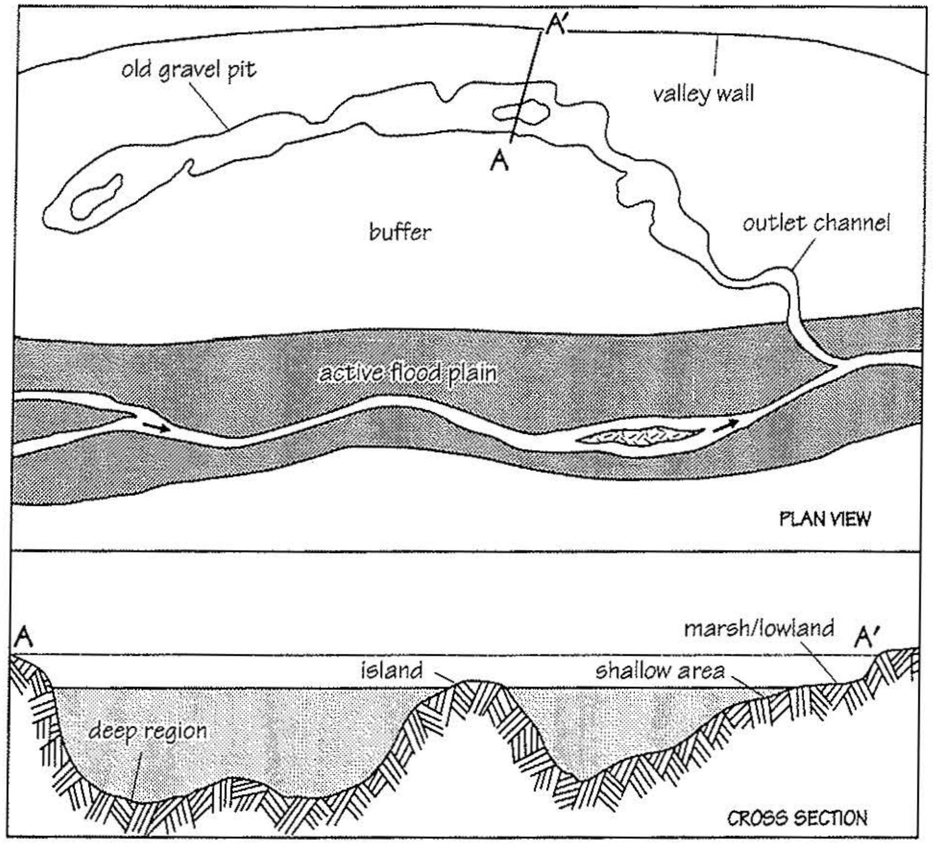

Figure 4.10. Plan view and cross section of a reclaimed gravel pit with pond shape that mimics a natural river system. Not to scale. (Modified from Woodward-Clyde, 1980.)

A desirable post-mining pond configuration for a gravel pit near a river is long, narrow, and moderately deep, with irregular islands and peninsulas. It should be connected to the river on the downstream side (Fig. 4.10) (Woodward-Clyde, 1980) to mimic a natural river system on a flood plain.

BUILDING HABITAT

Subsoils, mine waste rock, construction fill, or boulders can be used to create rock reefs, islands, and other features to provide habitat.

Islands

Islands can be formed as part of the mining process or made after the basic mine shape is in place (Fig. 4.9). If the mine itself consists of individual cells separated by dikes, portions of the dikes can be removed to create post-mining peninsulas or islands for use as habitat. If the excavation is dewatered, silt and sand can be compacted or boulders can be placed on the floor of the excavation to create islands for bird and turtle loafing.

Many small islands are better than a few large islands. They should range from 0.1 to 0.5 acres if they are meant to provide waterfowl nesting sites. Smaller islands may provide only resting sites, and larger islands may encourage predators to take up residence. Adequate separation of the island from the mainland, with water depths between them exceeding 30 inches, will discourage predators. Soil, logs, and rocks should be placed on the island to enhance habitat diversity.

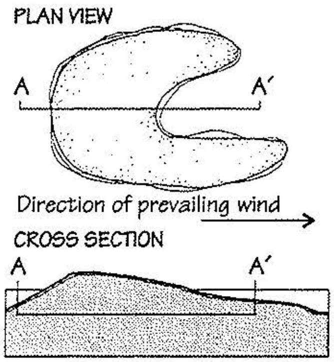

Figure 4.11. Plan view and cross section of a horseshoe island. (Redrawn from Michalski and others, 1987.)

Irregular islands are better than round islands (Fig. 4.8). Horseshoe-shaped islands are ideal for waterfowl (Fig. 4.11). The opening of the horseshoe should be in the lee of the prevailing wind to provide shelter for young birds. The banks between the prongs of the horseshoe should be more gently sloped than the outer banks to increase the sheltering effect.

Structures That Enhance Habitat

To create cover for fish and habitat for aquatic insects, submerged and anchored tree crowns can be placed along steep banks (Fig. 4.12). Where possible, logs and stumps should be lashed together and anchored to form reefs (Fig. 4.13). These lashed materials can be either placed by helicopter or dragged into place by bulldozer. Root wads with soil attached also provide ideal cover (Cederholm and Scarlett, 1991; Cederholm and others, 1988).

Depending on the plan's habitat objective, branches that stick out of the water may be removed to minimize roosting by predatory birds until a robust fishery is established. Alternatively, protruding branches and logs just breaking the surface may be left to provide sunning areas for turtles and other amphibians.

Structures that can be constructed in or near ponds to enhance habitat for wildlife include:

- trees, logs, and root wads lashed together, submerged, and anchored (Fig. 4.12),

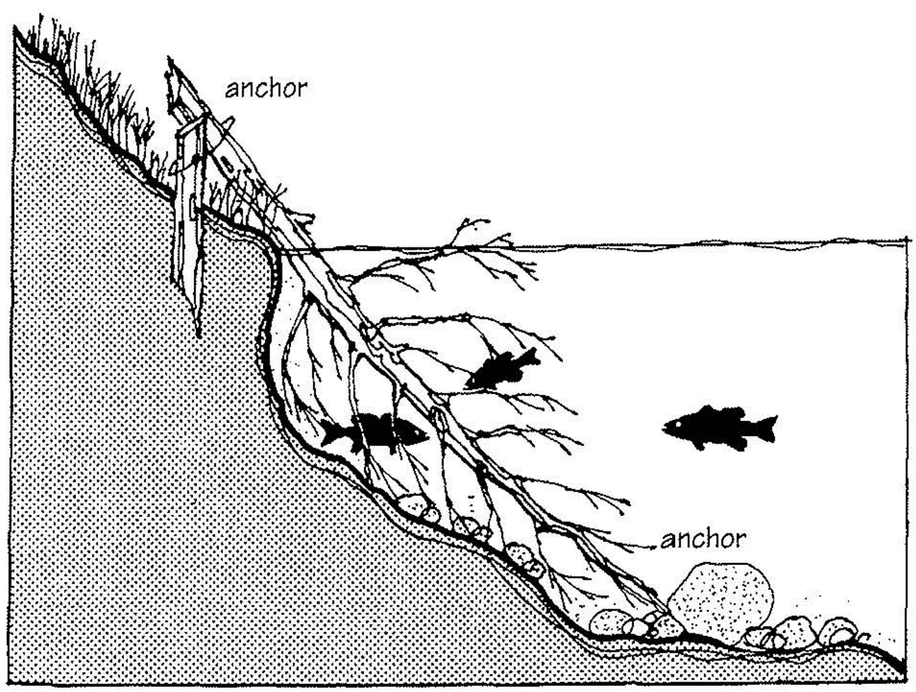

Figure 4.12. A submerged tree crown, anchored top and bottom, provides cover where the bank drops off steeply in some parts of the pit. (Modified from Michalski and others, 1987.)

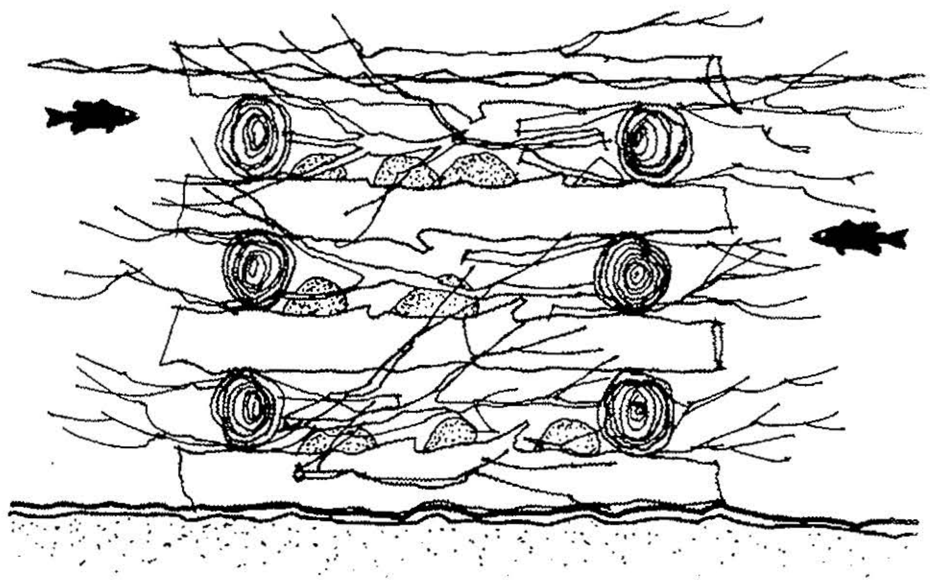

Figure 4.13. A submerged crib structure provides habitat for aquatic insects and cover for fish that feed on them. Rocks are used to anchor the crib in place. (Modified from Michalski and others, 1987.)

- submerged crib structures (Fig. 4.13),
- piles of angular rock (Fig. 4.14),
- nesting boxes (Fig. 4.15), and
- nesting poles and snags for osprey and cavity-dwelling birds (Fig. 4.16).

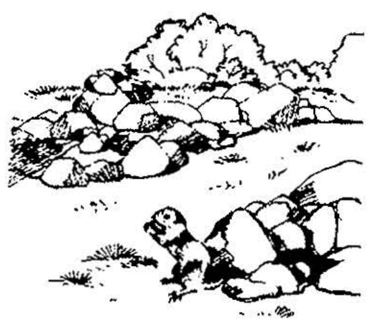

Figure 4.14. Piles of rock provide homes for small mammals. (From Green and others, 1992.)

Groups interested in wildlife or fish habitat enhancement, such as Ducks Unlimited or Trout Unlimited, the Boy Scouts (and similar groups), or schools, can be invited to help in enhancing reclamation of a pond by constructing nesting boxes, planting willows, or other activities. U.S. Fish and Wildlife staff may provide technical assistance, and the agency may be a source of potential grants.

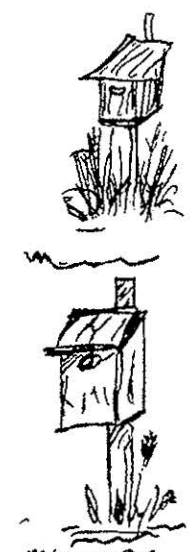

Figure 4.15. Typical nesting boxes.

Off-Channel Ponds for Salmon

At mine sites near rivers, off-channel ponds can be connected to the river by a stable outlet channel that allows access for fish (Fig. 4.10). The channel, excavated after mining, must be shown on the reclamation plan. Ponds like these can provide valuable habitat for salmon (Cederholm and Scarlett, 1991; Cederholm and others, 1988).

The following questions should be addressed in selecting sites for creating off-channel salmon habitat:

Figure 4.16. Snags make good nesting sites for cavity-dwelling birds. (From DeGraaf and Shigo, 1985.)

- Is the section of river or stream near a site used in any way by salmon? Is any part of the whole river or stream used for spawning, travel to spawning areas, or for rearing of fry?
- Will the depth of excavation be compatible with final off-channel habitat (that is, not too deep for spawning, but deep enough to provide cold-water habitat)?
- Is the potential mine site stable? Or is it prone to capture during floods and by lateral migration of the river?
- Is the substrate of the excavation going to be suitable for the habitat desired?
- Is there sufficient water circulation to provide oxygen and keep the water cool?
- Can an outlet channel be connected to the river where it can be easily found by migrating fish?

The Oregon or Washington Department of Fish and Wildlife should be consulted before undertaking any off-channel pond creation project.

Outlet Channels

Outlet channels allow fish to enter and leave the off-channel ponds. They are integral parts of off-channel habitat and should mimic natural river sloughs whenever possible. In some situations, a weir is necessary to control the water level in the outlet channel and ponds.

Outlet channels should join the river system where fish are likely to notice them—for example, near a pool or eddy where fish tend to rest. Riffles or fast water areas are less desirable outlet sites because fish may not find the outlet, and it may be left high and dry during low water. Joining an outlet channel to an existing tributary or slough instead of the river is a good strategy where feasible.

FORMING WETLANDS

Natural wetlands can be defined in terms of three broad environmental indicators: soils, hydrology, and vegetation. The viability of created wetlands can be enhanced by addressing these three elements in the reclamation plan.

Soils

Soils are essential to vegetation, both above and below the water surface. In creating wetlands, pond banks and bottoms should be covered with at least 12 inches of fine materials that have a large clay component to help seal the bottom of the pond. In some places, process fines can be substituted for soils; however, they are less desirable than native soil because they are less fertile. Material routinely removed from roadside ditches may be a good source of wetland soil and vegetation if it is not contaminated with oil and grease. If any wetlands on the project are disturbed, that soil should be used in new wetland creation.

In Washington, a solid waste permit from local jurisdictions may be necessary for disposing of material acquired from ditch cleaning.

Hydrology

A wetland must have water present at least seasonally. A common reclamation challenge at many mine sites is the seasonal fluctuation of the water table. The highly permeable nature of sand and gravel creates a situation where vegetation on pond banks is inundated during the wet season and high and dry during the summer. This results in a zone, similar to that found along reservoirs, in which upland and wetland plants will not readily grow. Here are some ways to reduce water fluctuation and the related adverse effects:

- Seal the bottom of the pond and the downstream banks with clay-rich material. This can happen naturally over time, but it may take many years.
- Reduce bank slopes to 5H:1V or flatter to allow a more gradual transition from the wetland to upland environment.
- Install a head-gate or weir at the outlet of the pond to retain water.
- Anchor jute netting or some other organic mulch fabric over the bank slopes to capture fines and retain soil moisture.

Vegetation

Wetlands are characterized by many plant species that do not grow in upland areas. Most created wetlands in western Washington and Oregon will develop a wetland community on their own if conditions are hospitable and given enough time. Willows, cattails, and other wetland plants will often volunteer on the site in a year or two. To speed the reclamation process, however, suitable species can be obtained from nearby sources or purchased for planting.

Propagating wetland species can be difficult and can, in some places, produce a plant community composed of only a few species, that is, far less diverse than natural populations on undisturbed sites. The best way to establish a diverse community is to transplant soils and plants from an existing wetland, particularly one that is being eliminated by mining. Care must be taken when planting nursery stock to replicate as nearly as possible the plant community surrounding the site being reclaimed.

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5 Reclamation Techniques for Quarries

HIGHWALL AND BENCH RECLAMATION

Many quarry operations create benches and highwalls composed of solid rock. Shaping the tall rock faces and engineered benches created during production blasting can be difficult. Vertical cliffs may be incorporated in the reclamation landscape if natural cliffs exist in the area of the mine. The extent and types of cliffs present should be shown on maps and cross-sections submitted in the permit application.

Primary reclamation concerns for these areas are stability and aesthetics. Some post-production blasting may be necessary to break up linear features. The effects of blasting the highwall should be carefully considered when preparing both the operating and reclamation plans. If blasting is contemplated, seek the help of a qualified professional before proceeding. A poorly designed blasting plan can result in unsafe conditions that are difficult and expensive to fix.

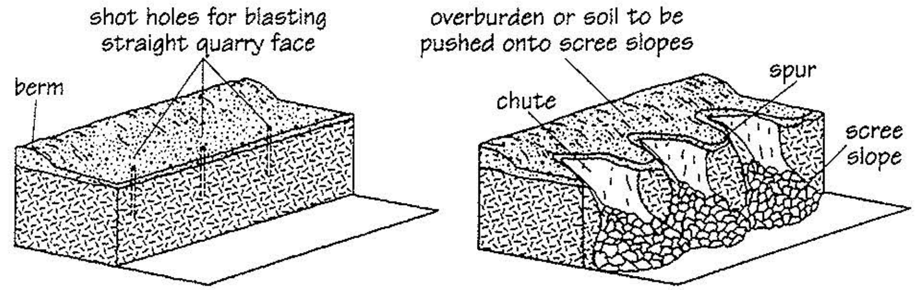
Public access and safety should also be addressed as part of the reclamation plan wherever steep cliffs are to be left. After mining, a bench or berm may be needed at the base or top of steep highwalls to catch falling rock. Placing a berm at the top of the quarry or a 10-foot-high by 15-foot-wide bench near the top will improve safety by discouraging access and reducing the likelihood of injury due to falling.

Where adequate moisture is present (west of the Cascade Range), wide benches may be revegetated. Benches to be revegetated should slope toward the highwall to trap moisture and soil. (See Fig. 2.4.) They should also slope gently to the side to promote drainage. Enough soil should be placed on the bench to support the proposed vegetation.

West of the Cascades, trees planted on benches may eventually break up the line of the face, although it may take years before benches are screened from view, even in smaller quarries. Revegetation may not be a viable reclamation technique in dry areas, larger quarries, and open pits unless combined with other methods discussed in this chapter. In arid areas east of the Cascades, bench revegetation will probably not obscure linear features.

Several methods of reclaiming quarry walls are effective in achieving stable slopes and preparing the site for the proposed subsequent land use. Excavated quarry slopes are generally more stable than fill slopes. However, once a material is blasted, it is no longer considered consolidated and must be reclaimed to a shallower angle, depending on the nature of the rock.

Figure 5.1. Blasting at the holes shown in the left sketch can create scree slopes (right), which may then be stabilized by plantings.



RECLAMATION BLASTING

Reclamation blasting is a fairly new technique. The amount of fracture desired often differs from that for production blasting. Chutes, spurs, scree slopes, and rough cliff faces can be intentionally created by strategically placed blast holes (Fig. 5.1) (Norman, 1992; Coppin and Bradshaw, 1982). Because few people have the field experience necessary for this type of blasting, the use of a contractor familiar with this technique is recommended.

Highwalls

Selective blasting produces a natural appearance and stabilizes a site. Selective blasting can be used to modify benches, break up linear features, and blend highwalls with their natural surroundings. Proper blasting of highwalls leaves rough surfaces that can provide nesting and perching habitat for birds (Fig. 5.2). However, the rough surface should be free of loose rock.

Reclamation blasting that reduces the entire highwall to a scree or overburden slope is essentially a cut-and-fill method. This technique can be used only where there is sufficient material remaining in a setback behind the quarry face to create the desired slope. Blasting for this purpose will not be possible if the operator has mined to the permit boundaries.

The highwall profiles of Figure 5.3 show two conceptual blasting patterns for reclamation. In 5.3A, vertical holes are drilled across the bench floor. The outermost row of holes is only lightly charged to minimize flyrock and keep the blasted material on the slope. Most of the rock fracturing is done by the explosives in the

Figure 5.2. Proper blasting of highwalls leaves rough surfaces that can provide nesting and perching habitat for birds. (From Green and others, 1992.)

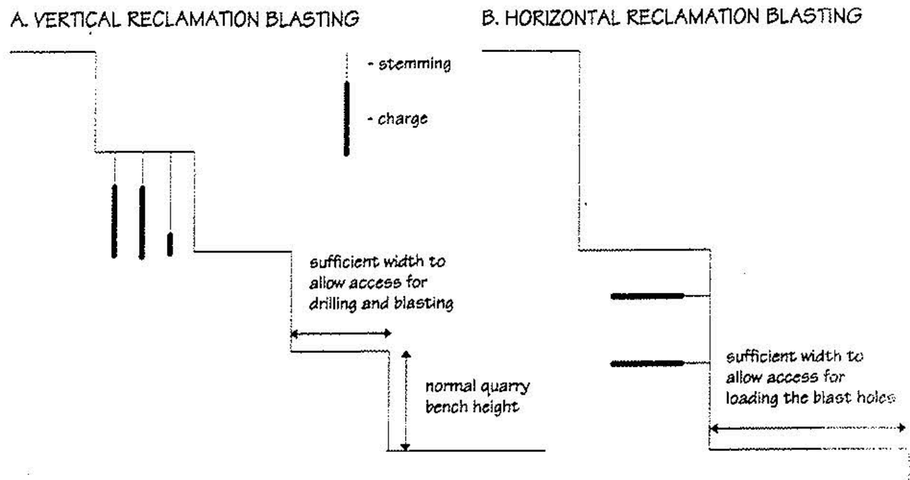


Figure 5.3. Conceptual blasting patterns for obliterating quarry benches.

rows farther back from the face. The blasthole design of Figure 5.3B uses horizontal blast holes. PVC pipe can be inserted into the drilled holes to keep them open and serve as a water drain. The final pit configuration must allow for access to the drilled holes for loading with explosives.

The final choice of blast pattern, delays, stemming depth, etc. depends upon the rock type, structural geology, blasting agent, and other highly variable conditions that cannot be addressed in this manual. Although this method can be less expensive than backfilling (Thorne, 1991; Petrunyak, 1986), the operator has only one chance to get it done right. Doing proper research and consulting appropriate experts before starting reclamation blasting cannot be stressed enough.

After the blasting is completed, topsoil and overburden stored above the final slope can be pushed onto the blasted rubble to promote revegetation. For quarries in which there are multiple benches, the final slope will approximate the overall slope of the benches. Proper setback must be accounted for from the lowermost bench to the uppermost one.

Benches

If selective blasting of benches is impractical or dangerous, other reclamation methods may be necessary, such as leaving wide benches that can be revegetated or pushing rock over the side of the pit to hide the benches (Fig. 5.4).

MINIMIZING OFFSITE IMPACTS

Minimizing offsite impacts from blasting is in the best interest of both neighboring landowners *and* mine operators. It can reduce litigation and negative publicity for a project. All blasting should be done by professionally trained and certified experts. Blasting techniques have improved dramatically since the days of black powder fuses and dynamite. Vibrations, noise, and fly rock can be greatly reduced when proper techniques are employed.

Causes of Damage

Vibrations from the blast may damage nearby structures and residences. A blast creates a wave that travels through rock and uncon-

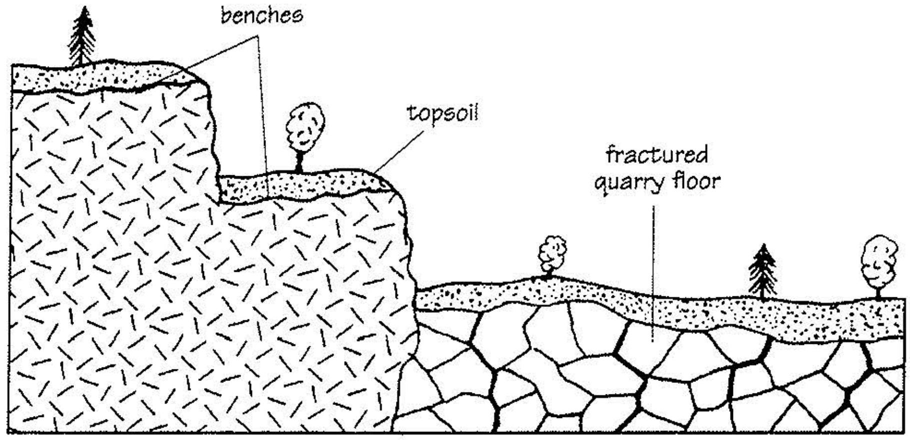


Figure 5.4. Topsoil placed on benches and on a fractured quarry floor will prepare the site for revegetation.

solidated materials. When the wave arrives at nearby structures, it can cause them to vibrate. Sound waves from the blast, transmitted through the air, are usually more detectable by humans, but it is the back and forth movement of the ground wave that causes the damage, not the accompanying sound. The amplitude and intensity of the ground wave are determined by the number of pounds of explosive detonated at one time. Most problems can be avoided when the amount of explosive is minimized and the blast is properly timed.

Vibration Effects Under Various Conditions

Unconsolidated material will vibrate more strongly in response to the ground wave than will competent rock. All other factors being equal, the potential for vibration damage is greater if a structure is built on fill, sand, dirt, or other unconsolidated material than if it is built on compacted material or competent rock. The more competent the material, the less movement will occur.

The way the structure is built can also have an effect on the kind and amount of damage. A structure with a concrete slab floor usually develops more cracks than one with a perimeter foundation built on solid rock.

Pre-Blast Survey

In order to establish pre-blast conditions at nearby residences, a pre-blast survey should be performed by an outside specialist rather than by a member of the organization doing the blasting. Typically, after a blast has taken place, owners of nearby structures will find cracks, settlement, and displacement, all of which were pre-existing, but never noticed. All structures within any possible damage range must be thoroughly surveyed before any blasting is done.

The importance of a pre-blast survey of all surrounding structures cannot be overstated. The lack of a proper survey by a qualified specialist is an open invitation to lawsuits. Without a survey, the damage could be real or imagined, but an expensive lawsuit will be required to establish liability.

Use and Placement of Vibration-Measuring Equipment

The blast contractor should monitor the blasting with vibration-measuring equipment, but the equipment should be placed and the results read by a qualified independent third party. Monitoring equipment that provides an immediate printout is generally better than equipment requiring post-blast data manipulation and interpretation because the results are available immediately and cannot be changed once recorded.

Blasting Plans and Logs

The mine operator should require a blasting plan and blasting logs. Blasting plans are prepared before the blast. Blasting logs are made on the site as each hole is primed, loaded, stemmed, wired, and connected to the circuit. Blasting logs must accurately describe the work on each hole and must be kept for 2 years after the work is completed in case they need to be referred to later.

BACKFILLING

Quarries located in populated areas should consider total or partial backfilling when it is economically feasible (Fig. 5.5). Advantages of backfilling include reducing slopes, increasing post-mining property values, and reducing safety hazards. (See Chapter 4.) In urban areas, many quarry sites are backfilled. If buildings or other structural improvements are to be placed on top of the old excavation, the backfill material must be structurally sound and stable. Dumping fill material over the highwall can also help disguise the linear benches. If overburden or waste rock is strategically placed, backfilling may be done with a short push or haul.

Fill Materials

In some quarries, operators will decide to rebuild slopes after all rock is removed by:

- concurrent backfilling using overburden mined elsewhere on the site,
- bringing in fill material from construction projects offsite, and
- retaining enough overburden or mine waste for resloping after completion of mining.

Overburden should be stored where it can be readily and economically moved into position during reclamation. Mining plans should take the backfill process into account. Operators need to be sure there is enough onsite material or identify a likely source.

If fill is accepted from construction sites, a monitoring plan should be established by the operator to prevent disposing of

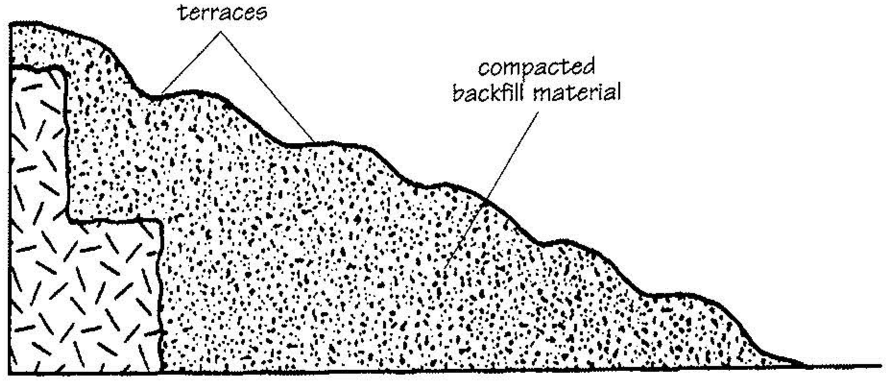


Figure 5.5. Quarry slopes that are backfilled should be compacted so that the final slope is stable; a 3H:1V angle (with terraces, if it is long) generally results in a stable slope. Topsoil should be spread over the compacted slope to make revegetation possible.

hazardous or unapproved material on the site. Local permits from health departments may be necessary before importing fill.

Fill Slopes

Stability and erosion control are primary concerns for slopes created by backfilling. Backfilled slopes may be prone to erosion and gullying if they are smooth, planar, and long. (See Creating Slopes, p. 4.2.) As slope length and steepness increase, runoff velocity and soil erosion also increase, and infiltration decreases. Careful location of drainages and water-control features enhances slope stability and revegetation potential (Banks and others, 1981; Washington Department of Ecology, 1992). (See Chapter 2.)

Temporary protection of bare slopes from rain or snow-melt runoff may be necessary if backfilling occurs over a long period and if establishing permanent vegetation must be delayed. Temporary protection can include covering the slope with plastic sheeting or mulches or matting and seeding with grasses. (See Chapter 2.)

A final slope angle of 2H:1V to 3H:1V is recommended. The gentler the slope, the easier soil application will be and the more quickly vegetation will establish. Backfilled slopes may require compaction to ensure stability.

DRAINING PIT FLOORS

If wetland creation is not part of the reclamation plan, pit floors can present special drainage problems. There are two basic ways to improve drainage in quarry floors: blasting and ripping.

Blasting

Impermeable pit floors of solid rock can be blasted to fracture the rock so that water can drain slowly from the site and roots can penetrate (Fig. 5.4). The least expensive way to blast the pit floor is to

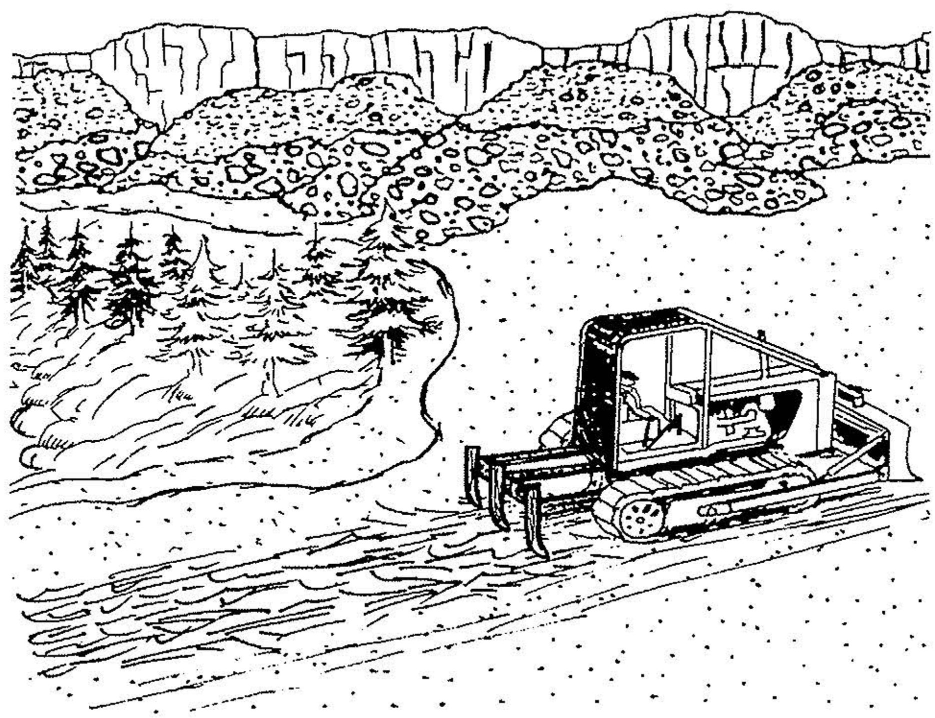


Figure 5.6. Ripping or decompaction of pit floors is typically accomplished with rippers mounted on heavy equipment.

drill an extra 10 feet on the last production shot and leave some of the fractured material in place.

Ripping

Ripping or decompaction is typically accomplished with rippers mounted on heavy equipment (Fig. 5.6). Rippers consist of a vertical shank or shanks that can shatter compacted or hard areas to depths of 7 feet. Before ripping or tilling compacted mine wastes or soils, at least one backhoe pit should be dug on the site to determine the thickness of the compacted zone, thus the depth of tilling. As a rule of thumb, ripper spacing should be less than the depth of ripping.

If soil is replaced using equipment with rubber tires, discing, plowing, or shallow ripping may be necessary to loosen the soil to create seedbeds and suitable substrate for ground cover or trees.

In locations where topsoil is minimal or absent and ripping is not possible, selective drilling and blasting may improve revegetation success. A basalt quarry in Australia achieved 85 percent survival of tree seedlings after four years by blasting 7-foot-deep holes into the pit floor (Rock Products, 1995). This technique fractures the rock, provides a moisture trap where roots are able to penetrate, and, if ammonium nitrate explosives are used, may provide some residual nitrate to stimulate plant growth.

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6 Landslides and Slope Failures

Many upland mining sites are situated in terrain that has potentially unstable slopes or is already unstable. Construction of spoil dumps, stockpiles, and mine cuts can destabilize areas that were stable prior to mining. If mines are located in potentially unstable areas, such areas should be identified before mining, and the mine plan should be developed so as to minimize risk to the environment. Common mining-related causes of landsliding are:

- removing the toe (support) of the slope,
- saturation of unstable slopes due to poor water management (such as constructing a pond on a slope),
- placing waste rock over vegetation on steep slopes causing failure as the vegetation rots,
- adding weight to an unstable slope, and
- placing weight (generally overburden) on an unstable area.

Landslides do not recognize property lines. Conditions on adjacent property may be 'causing' the slide on the mine site, and slides occurring on the mine site may damage adjacent properties. If stability is a concern or major faulting is encountered, a geotechnical consultant should be involved in mine planning.

TYPES OF SLOPE FAILURES

The movement of soil and rock under the influence of gravity is called mass movement or mass wasting. Rockfalls, slides, earthflows, slumps, soil creep, raveling, and (more commonly) combinations of flow types are all forms of mass movement that can occur at mine sites.

Rockfalls

Rockfalls travel most of the distance through the air (Fig. 6.1). Movement is extremely rapid and includes free fall, tumbling, and rolling of fragments of bedrock or soil. Rockfalls may occur in a mine as pressure is released on the free face.

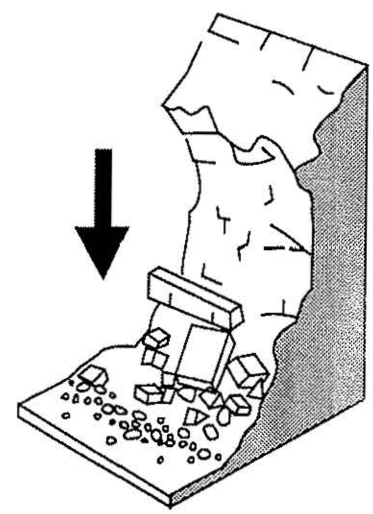


Figure 6.1. Rockfall on a steep or overhanging face. (Redrawn from Chatwin and others, 1991.)

Slides

Slides move along one or more zones of weakness. Movement along the failure surface may be rotational, as in a slump, or translational along a more or less planar surface (Fig. 6.2).

Live tree roots contribute to holding the soil together and help tie the upper soil horizon to the subsoil. Runoff and surface erosion, when combined with a decrease in tree-root tensile strength caused by stripping vegetation and soil, have contributed to many land-

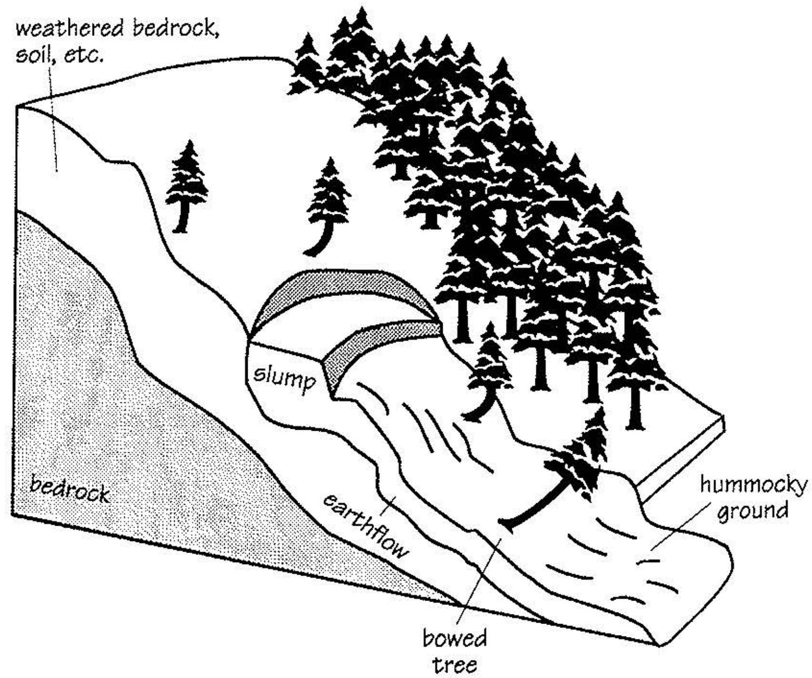


Figure 6.2. A complex slide called a slump-earthflow. (Modified from Chatwin and others, 1991.)

slides by removing the slope support. Scars from debris slides (shallow soil slips) may commonly be seen on steep slopes that have been stripped of vegetation. Removing the toes from steep slopes such as on talus, sand and gravel, or clay deposits can result in a landslide.

Earthflows Earthflows, composed of soil and rock, move slowly downslope as a viscous fluid. The amount and rate of movement vary according to the particle size and water content of the earthflow. Clay-rich zones are especially vulnerable to plastic flow when saturated. If enough water is present, the material can 'liquefy', causing an earthflow.

Slumps In a slump, the movement is rotational, producing a bowl-shaped failure surface. Slumps and slump-earthflows typically leave behind a steep scarp that is itself vulnerable to further slumping. Slumps also commonly occur in areas underlain by till and/or glacial lake deposits, both of which are vulnerable to failure when they are saturated.

Soil Creep Soil creep is the very slow (inches per year) downslope movement of surface materials (Fig. 6.3).

Raveling Raveling is downslope movement of particles and commonly occurs on sand and gravel slopes that are too steep. Reclaimed slopes of 2H:1V to 3H:1V usually do not ravel.

ANATOMY OF A LANDSLIDE

Most landslides are combinations of several kinds of slope failure. The method of failure may be different in different parts of the slope. A landslide, in this case a slump-earthflow (Fig. 6.4), has the following parts (Varnes, 1978):

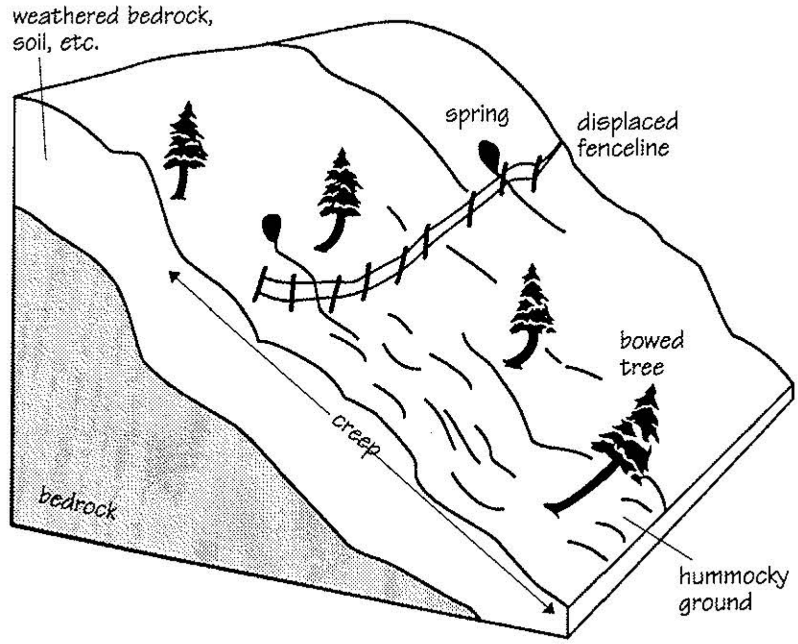


Figure 6.3. Conditions that lead to and indications of soil creep. (Modified from Chatwin and others, 1991.)

Main scarp – A steep surface separating the undisturbed ground from the slide mass, caused by the movement of slide material away from undisturbed ground. The projection of the scarp surface under the displaced material becomes the surface of the rupture.

Minor scarp – A steep surface in the displaced material produced by differential movements within the sliding mass.

Head – The upper part(s) of the slide material along the contact between the displaced material and the main scarp.

Toe – The lower margin of displaced material most distant from the main scarp.

Crown – The material that is practically undisplaced and adjacent to the highest parts of the main scarp.

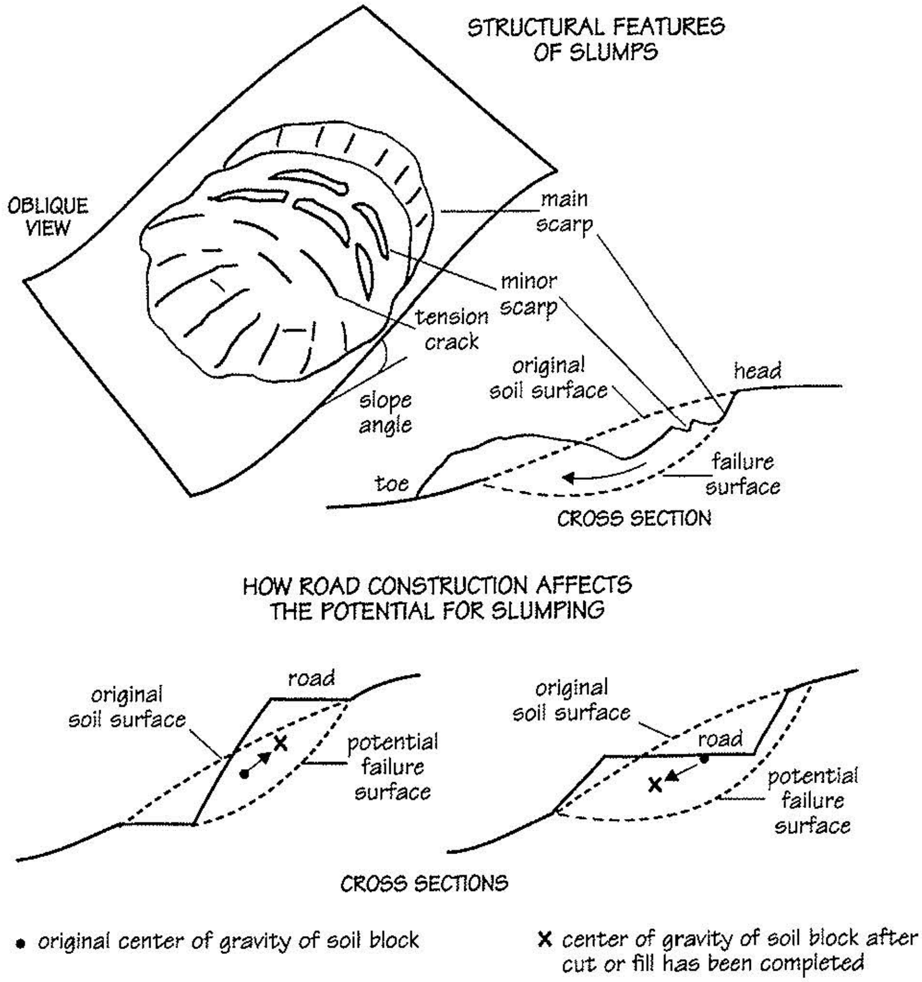
IDENTIFYING UNSTABLE SLOPE CONDITIONS

Regardless of the cause, instability can often be identified in the field through careful observation. Tension cracks, hummocky topography, springs and seeps, bowed trees, abrupt scarps, and toe bulges are all readily observable indicators.

Tension Cracks

Tension cracks, also known as transverse cracks, are openings that can extend deep below the ground surface (Fig. 6.4). Tension cracks near the crest of an embankment or hillside can indicate mass movement. However, cracks may occur anywhere on the slide. They are perpendicular to the direction of movement and are typically continuous in a pattern across the width of the landslide. Tension cracks can fill with water, which lubricates the slide mass and may cause additional movement. Correction of slope failures must include preventing surface water from reaching tension cracks.

Figure 6.4. Structural features of slumps and the effect of cutting and filling on the stability of short slopes. (Redrawn from Burroughs and others, 1976.)



Hummocky Ground Hummocky ground can indicate past or active slide movement. A slide mass has an irregular, undulating surface (Figs. 6.2 and 6.3).

Displaced and Distorted Trees Vegetation, particularly trees, records the downslope movement of soil. Trees may be uprooted and may lean in a variety of directions (jackstrawed trees) as their roots are broken or moved in a rapid slide movement (Fig. 6.5). Bowed tree trunks may indicate soil creep; trees attempt to remain upright as the soil moves slowly downslope (Figs. 6.2 and 6.3).

Springs and Seeps Ground water that collects at the contact between permeable layers that overlie relatively impermeable layers or rock strata dipping with the slope can cause instability. Carefully investigate springs, seeps, and areas of lush vegetation. Alder, horsetail, devils club, cow parsnip, and skunk cabbage typically grow in wet sites.

Scarps Fresh scarps are a clear sign of recent slope failure (Fig. 6.4). Older scarps may be covered by vegetation and hard to identify. The presence of several scarps can indicate several active failure surfaces or movement downslope along a larger failure surface.

Toe Bulge The toe of a slide commonly bulges out onto the more stable ground surface below the slide (Fig. 6.4). A toe bulge often gives the appearance of a mud wave displacing trees and vegetation in its path. The bulged toe should be noted in the site inventory along with the other slide features to define the size of the failed area. Removing the toe may reactivate the slide mass.

SURFACE DRAINAGE CONTROL IN UNSTABLE AREAS

The quantity and distribution of water in a slope, whether it is a slide mass, overburden, or soil stockpile, greatly influences its stability. Water saturation builds up pore pressure, which causes an increase in downhill-directed forces (Fig. 6.5). This increases the weight (increases driving force) and particle lubrication (decreases resisting forces). Slope failure can occur when more water is present in the soil than the pore spaces can accommodate.

If motion on a slide at the mine site responds directly to rainfall, surface drainage improvements may decrease slide activity. Control of surface drainage, by itself, is seldom sufficient to stop landslides, because rainfall from outside the site can eventually show up as ground water in the slide. Surface drainage improvements are typically combined with other abatement techniques. (See Chapter 2.)

When soils, subsoils, and geologic material are excavated, drainage paths through the pore spaces are disrupted. Therefore, drainage control may be needed for constructed permanent and temporary storage or disposal piles and reclaimed slopes that are created by backfilling.

Listed below are techniques for improving slope drainage. (See Chapter 2 for specifics.) These techniques may not stop landsliding altogether, but they may prevent a slide from becoming worse:

☛ To improve slope stability, lower the water table by providing more drainage. Adequate drainage prevents water saturation and the build up of pore pressure.

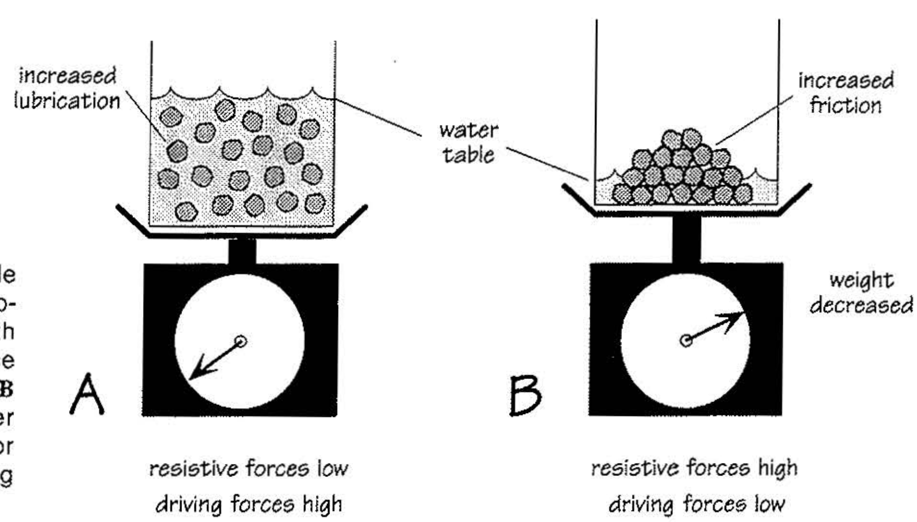


Figure 6.5. Forces acting on slide masses and large stockpiles. **A** represents a slide mass saturated with water. It has both low resisting force and high driving forces (weight). **B** represents a stabilized slope after the water table has been lowered or the water has been removed using drainage methods.

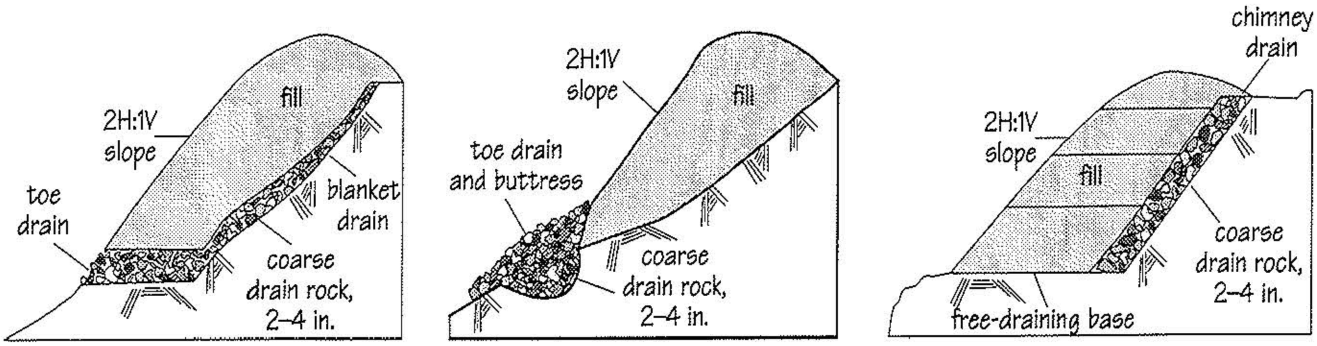


Figure 6.6. Details of toe, blanket, and chimney drain construction shown in cross section. (See also p. 2.19.)

- Berms and ditches should be built above and along the unstable slope to intercept and divert overland flow. They should be lined or sealed to prevent infiltration.
- Slopes adjacent to the slide mass should be graded to direct overland flow away from the slide area.
- The area above a slide should be crowned or sloped so that surface water is directed away from the slide and graded so water does not pond.
- Where drainage must cross an unstable slope, using a pipe should be considered.
- Avoid concentrating water on spoil dumps or natural slopes, thereby reducing their stability. Concentrated surface flows near slides should be handled in ditches lined with impermeable fabric, if necessary. (See Fig. 2.16.)
- If a slide area is to be regraded, the regrading should not produce a depression in the slope that could pond or concentrate water.
- If a slide is triggered, benches or cross-slope ditches should be used. They should be sloped and lined to move water away from the slide area.
- As part of grading operations, any exposed tension cracks should be sealed and compacted to prevent infiltration, then seeded to prevent erosion.

SLOPE STABILIZATION

Toe, blanket, chimney, and other types of permanent drains (Fig. 6.6) can help prevent saturation of a constructed slope. The minimum thickness of an underdrain or rock blanket should be 3 feet, because fines will eventually migrate into this zone. The drains should be thick enough to keep running freely for a long time. In some cases, a geotextile liner should be used to insure that the integrity of the drain is not compromised by soil movement.

Slope length and height may require construction of cross-slope drains to intercept runoff without creating gullies and erosion. Grading to break up long slopes and creating berms, furrows, and terraces will compartmentalize the runoff. The more landscape diversity that is incorporated into the final grading, the less a site will need cross-slope drains to ensure stability.

SLOPE FAILURES ABOVE THE MINE

Overburden failures above mine cuts can be a problem if proper slope angles are not maintained above the rock face. If the contact between the overburden and the rock dips toward the highwall or open face and the overburden slope is near vertical or steep (1V:1H), a failure is likely. To prevent this from occurring, operators should make sure the overburden cut has a gentle slope and is well drained.

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6.8 LANDSLIDES AND SLOPE FAILURES

7 Revegetation

INTRODUCTION

Mines west of the Cascades in Washington and Oregon are fairly easy to reclaim because they typically have deeper soil horizons due to abundant precipitation. Mined areas east of the Cascades are more difficult to reclaim because soils are thinner, the region is drier, and temperatures are more extreme. Therefore, successful revegetation in the eastern part of the state is more dependent on proper plant selection, appropriate timing of planting, adequate fertilization, presence of organic matter in the soil, and irrigation.

West of the Cascades, even though revegetation can be accomplished without separately salvaging and replacing the soil because of the abundant moisture, species diversity will be limited until a soil horizon rebuilds, and this may take decades. Additionally, plant vigor may quickly decline after the first planting if ample amounts of organic matter are not provided or supplemental chemical fertilizers are not added to initiate the cycle of plant growth, decomposition, and nutrient recycling. Amounts of fertilizer should be based on site-specific needs determined by soil tests. (See Amending or Manufacturing Soil, p. 4.6.)

Natural plant communities develop through a succession from pioneer species to climax species (Fig. 7.1). Pioneer species are aggressive and tend to grow rapidly to fill disturbed areas, whereas climax plant communities develop over longer periods and tend to be slower growing. Each phase in the plant succession prepares the ground for the next. Nitrogen-fixing legumes, shrubs, and trees may play a crucial role in soil reconstruction.

It is tempting, particularly with trees, to plant only climax species (for example, Douglas fir) even if the ground is not fully prepared. However, natural communities develop slowly in a succes-

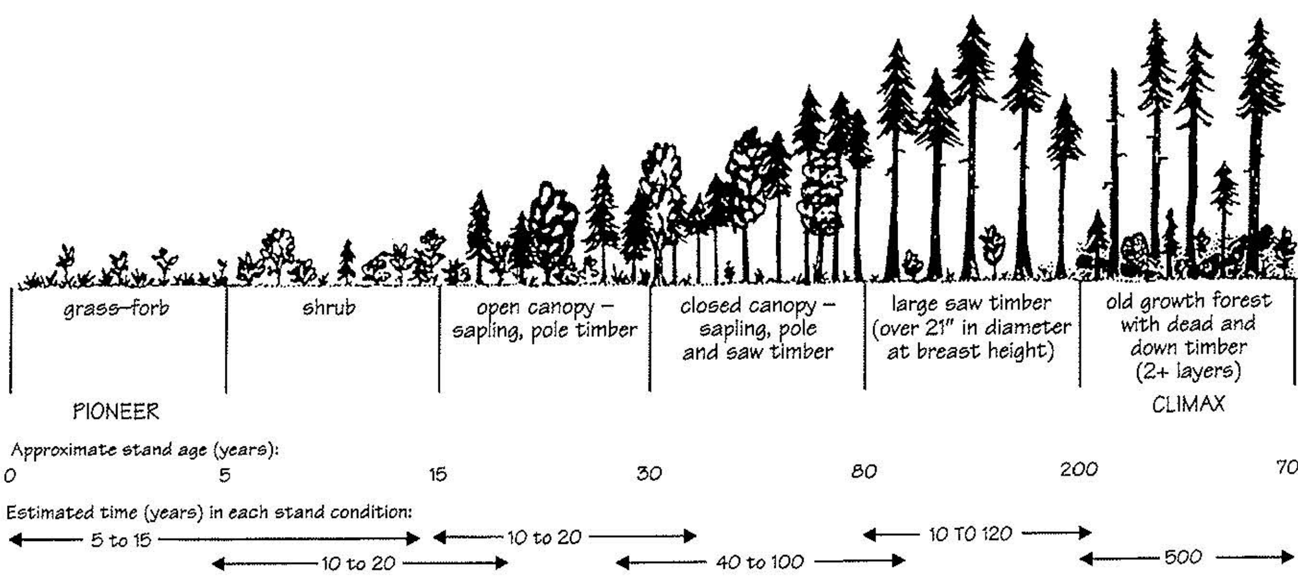

Figure 7.1. Sequence from pioneer to climax vegetation for a Douglas fir forest after clear cutting. The same recovery process occurs naturally in mined areas. (From Brown, 1985.)

sion. Mimicking this progression during reclamation is impractical, but planning a phased succession for both ground cover and trees will establish a good climax mix (Norman and Lingley, 1992).

Grasses may be appropriate as either quick pioneer soil builders under developing woodland or as climax species for rangeland. Pioneer trees will act as fast-growing nurse trees for slowly maturing forest trees that find it difficult to establish in disturbed ground or in areas with no canopy.

Revegetation is important because it:

- reduces erosion,
- reduces storm-water runoff,
- provides habitat and forage for animals,
- reduces visual and noise impacts,
- reduces reclamation liability, and
- increases the value of property by returning it to agriculture, forestry, or other beneficial use.

Note: While vegetation significantly reduces erosion, it cannot prevent slippage of a soil that is not stable due to improper placement techniques. For example, soil placed on steep slopes requires additional stabilization techniques to ensure revegetation success. (See Chapter 6.)

SPECIAL PROBLEMS AT MINE SITES

Plants need fertile soil, sunlight or protection from the sun, and water to thrive. Mining often removes fertile soil. (Salvaging and replacing soil is discussed in The Soil Resource, p. 3.10.) Even in the best of conditions, plant growth cannot be guaranteed immediately after mining. Mine sites generally offer harsh conditions that make it difficult to establish vegetation. Some common problems affecting revegetation are:

- high surface temperature (especially on south-facing slopes),
- steep slopes,
- poor water retention,
- lack of adequate soil,
- erosion before seedlings establish,
- only limited periods during the year suitable for seeding,
- lack of water
- poor conditions for germination,
- slopes inaccessible to equipment, and
- grazing impacts.

By being aware of these potential problems, an operator can improve the quality of reclamation and save money by being successful on the first attempt. Revegetation early in the reclamation process is critical because it may take several seasons to establish widespread healthy vegetation. For example, by planning ahead and choosing appropriate techniques, an operator can place young trees in strategic locations to provide a significant visual screen within a few years.

SUCCESSFUL REVEGETATION STRATEGIES

Trial-and-error revegetation that relies on natural precipitation and hardier natural pioneer species (such as alder) is generally less expensive, uses less labor, and is more effective than waiting until mining is complete to plant the entire site with commercial plants. Segmental mining results in fairly small areas on which to begin this process. Test plots can be used to determine which species will be successful. Areas in which plants fail to establish can be reseeded with more appropriate vegetation (Norman and Lingley, 1992).

Steps to successful revegetation of mined land can be summarized as follows:

- ☛ *Plan before you start.* Know in advance what has to be done, but allow for modification if necessary.
- ☛ *Strip and store the topsoil, subsoil, and overburden separately.* Minimize handling and storage.
- ☛ *Strip a small area at a time.* Strip only the area that can be revegetated within a reasonable time to minimize erosion.
- ☛ *Move soil materials under dry conditions (June–September).* Wet soils are easily damaged.
- ☛ *Carefully calculate volumes of soils necessary for reclamation to ensure that sufficient amounts are retained.*
- ☛ *Reclaim the mine in segments.* Segmental reclamation allows for 'live topsoil' replacement, which often enhances revegetation.
- ☛ *Shape slopes for subsequent use.* Slopes between 40H:1V and 20H:1V are desirable for agriculture purposes. For forestry, the slopes can be steeper.
- ☛ *Replace overburden (if any), subsoil, and topsoil in the correct sequence.*
- ☛ *Eliminate compacted soil.* Where compaction has occurred, rip the mine floor as deeply as possible before reapplication of stored overburden, subsoil, and topsoil.
- ☛ *Develop a post-reclamation management program.* Choose plants that increase soil fertility and improve soil structure, such as deep-rooted nitrogen-fixing legumes, for the first plantings. Monitor progress and determine why plants did not thrive.
- ☛ *Get good advice from the experts.* Take advantage of the expertise available in various government agencies and though local farmers.
- ☛ *Be patient.* Successful revegetation may be a slow process taking several seasons or years.

CLASSES OF VEGETATION

Four basic classes of vegetation—grasses, forbs, shrubs, and trees—are important for reclamation. Forbs, which include legumes such as alfalfa, clover, and lupines, are any herbaceous plant that is not grass or grasslike. Forbs and shrubs have many similarities but differ in that shrubs have a woody stem. They will be considered together in this discussion. Many sites naturally support a mixture of two, three, or all four types of vegetation.

Grasses

Grasses are either perennial or annual. Annual grasses start from seed every year, whereas perennial grasses die back but start from the same root mass each year. Annual grasses green up and establish quickly, but put most of their energy into seed production. Perennial grasses put significant energy into root development and foliage; individual plants persist for many years.

Grasses typically are shallow rooted (6 inches to 2 feet) but, because of their ability to provide complete ground cover, are effective for erosion control. Grasses provide significant nutrition to both livestock and wildlife and provide cover for small animals and birds. Newly established grasses, freshly fertilized, are a favorite food for grazing animals. Therefore, such areas should be fenced for optimum revegetation success.

Forbs and Shrubs

Forbs and shrubs include everything from small wildflowers (forbs) to sagebrush plants (shrubs) that may reach 6 feet in height. They are nutritious and provide significant cover. Many plants of this class have a single taproot with a shallow fibrous root system around it. Although mature forbs and shrubs can establish significant root wads, they typically provide only minimal erosion protection for several years.

Trees

Trees are generally the slowest of the three classes to establish themselves and mature. They typically have a deep, extensive root system. Evergreens or conifers (except larch) keep their leaves or needles all year long. Deciduous trees lose their leaves every fall and, compared to conifers, grow faster and add leaf litter to the ground.

SELECTING PLANTS FOR A SITE

Wherever possible, native species should be used in revegetation. Native plants often out-compete introduced (exotic) species over time and are the most useful to wildlife, although some introduced species can out-compete some native species, especially in arid environments. The vegetation surrounding a mine site can be used as a guide when selecting native species. Re-establishing native species can be greatly accelerated by using native seed mixes and locally transplanted species.

If sufficient preplanning is done, soil and native vegetation can be transferred from areas being stripped for new mining to areas in the final stage of reclamation. This approach is less expensive and often more successful than long-term soil storage. Soil hauled directly from a new mining area to a reclamation area carries with it viable seeds of native vegetation that can rapidly establish on the reclaimed area. This typically reduces the need for added seed and plant material.

Commercial sources typically sell native and non-native bareroot and container plant stock, as well as native grass seed mixtures. Bareroot stock should be planted during the winter and is typically less expensive than plants sold in containers. Generally, plants in containers have a better survival rate than bareroot plants. A plant-selection guide is given in Tables 7.1 through 7.4.

The best source of native shrubs and trees is in or near the site to be revegetated. Avoid transplanting native species from an elevation significantly higher or lower than the area in which they will be planted.

Weeds (imported or local) can render reclamation ineffective. Local extension agents can provide lists of noxious weeds and suggest methods for their control.

Information on plant availability and nurseries carrying suitable plants can be obtained from Hortus Northwest, PO Box 955, Canby, OR 97013, *Phone:* 503-570-0859, *Fax:* 503-399-6173.

Grasses and Legumes

Grasses and legumes are very effective at stabilizing disturbed areas because of their extensive root systems. They also increase water infiltration, contribute organic matter to the soil, and, in the case of legumes, fix atmospheric nitrogen into the soil.

In determining what mix of grasses and legumes is best for a given site, the climate, soil conditions, sun exposure, and objective of the seeding must be considered. The Oregon Department of Geology and Mineral Industries (DOGAMI), The Washington Department of Natural Resources (DNR), and the local Natural Resource Conservation Service (NRCS) offices can provide valuable information about seed mixes that are suited to various site conditions. The Washington or Oregon *Interagency Guide for Conservation and Forage Plantings* is also a useful resource for determining seed mixes. Tables 7.1 through 7.4 contain descriptions of some of the most common grasses, legumes, and woody plants.

Some grasses, such as annual rye, grow quickly, while others, such as many of the perennial bunch grasses or sod-formers, grow rather slowly. Cereal grains, the same as those cultivated for food, can be very effective in establishing a rapid vegetative cover that will still allow native species to establish. Cereal grains help protect against soil erosion because they possess 50 percent more below-ground biomass (roots) than grasses.

The success of legume plantings can be greatly improved by treating the seeds with legume inoculant, available from many seed suppliers.

Forbs and Shrubs

Many forbs establish easily from seed and can be just as important as grasses and trees for reclamation. Some shrubs do well from seed, many do not. Bareroot plants, which can often be purchased inexpensively and easily from nurseries, are an effective way to establish shrubs. Young plants in containers are generally easiest to establish but are the most expensive to purchase.

Trees

A variety of species suitable for revegetation projects are available in containers at nurseries. Tublings (plants grown in narrow, deep containers) may be useful on rocky areas and steep slopes. Bareroot transplants are successful for many species and are more economical to purchase than containerized plants. Nurseries can provide both tublings and bareroot stock.

Native Plants for Arid Regions

For the high desert areas of Washington and Oregon, a selection of the following species are recommended when native plants are specified in the reclamation plan:

- basin big sagebrush (*Artemisia tridentata tridentata*)
- Wyoming big sagebrush (*Artemisia tridentata wyomingensis*)
- mountain sagebrush (*Artemisia tridentata vayseyana*)
- fourwing saltbush (*Atriplex canescens*)
- antelope bitterbrush (*Pershia tridentata*)
- Lewis flax (*Linium lewisii*)
- white yarrow (*Achillea millefolium*)
- annual sunflower (*Helianthus annuus*)

In the higher areas of eastern Washington and Oregon where sites will be reforested, the following seed mix of non-pervasive exotics has been used to control erosion and noxious weed invasion in the short term. These plants die out as long-term native plants take over from nearby natural areas when the sites are relatively small (less than 15 acres or long, narrow sites):

Sheep fescue	4 pounds/acre
Kentucky bluegrass	4 pounds/acre
Dutch white clover *(the clover should be inoculated)*	2 pounds/acre

SOWING SEEDS

Grasses and cover crops such as legumes are relatively easy to establish from seed. In most places, grass and legume seeds should be planted no deeper than 1/4 inch. For the best chance at revegetation success, topsoil should be spread between September 15 and October 15. Seeding with grasses and legumes should be done within 3 days after final shaping (R. Shinbo, personal commun., 1995). However, if proper conditions of soil moisture and temperature are present, revegetation can also be successful at other times of the year. Proper conditions for reclamation and revegetation exist between March 1 and November 1 for sites west of the Cascades in some years. During the winter, bare slopes should be protected with mulch or other erosion-control techniques until the next seeding period.

Summer plantings should be avoided unless irrigation is planned. Fall plantings may be preferable in areas with long growing seasons, winter rains, or summer drought; they allow plants to establish themselves over the winter. Optimal planting dates will vary slightly from year to year and with weather conditions. The local county extension service can provide information on planting dates.

Seed Drills

Seed drills are used extensively in agricultural applications where soil has been tilled and is free of rocks. Range drills are used in irregular terrain or on rocky soils. In arid areas with coarse-textured soils, improved success with drilling may be obtained by placing the seeds 1 inch deep.

Range drills may be available for use from some federal agencies, such as the NRCS and the Bureau of Land Management. Agricultural seed drills are commonly not suited for reclamation seeding because of the rocky soil. Neither type of drill is suitable for the rough and steep terrain found on many mine sites.

Broadcast Seeding

Seeds can be broadcast using many different methods. Spreading handfuls of seed by hand is quick and easy but produces incomplete coverage in many cases. The use of hand-operated mechanical spreaders is a far more effective way to spread adequate amounts of seed evenly. Hand-operated mechanical spreaders come in many different sizes and styles, but most are relatively cheap. In many cases, they can be rented from a local shop. Regardless of the method of broadcast, the seeds must be covered with mulch and/or soil to germinate successfully. Broadcast seeding in arid environments should be followed by dragging a meadow or flex harrow (a bar or chains in rocky areas) over the seeded area to insure adequate seed/soil contact.

Hydroseeding

Hydroseeding can effectively convey, in one application, seed, fertilizer, and mulch onto steep slopes and other areas inaccessible to other seeding equipment. The mulch blanket retains moisture; a tackifier or binder added to the hydromulch slurry can prevent it from eroding away. Revegetation success can often be increased by using a two-step hydromulching process in which seed, mulch, and fertilizer are applied with the first application. Then the entire area is remulched with another application of mulch only. The two-step technique is especially useful in arid areas where the seed germinating in the mulch may dry out before roots become established enough to provide water.

Seedbed Preparation

Seedbed preparation establishes conditions conducive to seed germination and seedling growth. Seedbed preparation on mining sites is especially important because the heavy equipment commonly compacts the soil, which inhibits seed germination. In order for a seed to germinate and thrive, there must be contact between seed and soil, adequate moisture, and moderate soil temperature. The soil

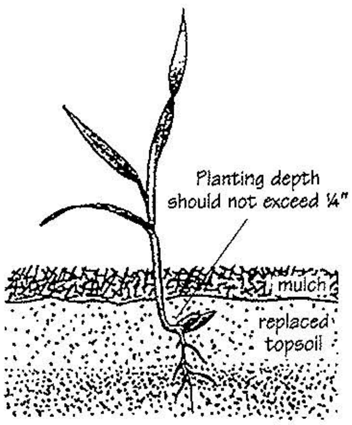

Figure 7.2. Cross section of seed germination.

must be loose enough to allow root penetration once the seed has germinated (Fig. 7.2). A soil or mulch covering of 1/4 inch moderates temperature and prevents seed loss to birds. Mulching also conserves the much-needed moisture for continued seedling development.

Depressions, small pits, and irregularities in the seedbed can greatly enhance the ability of seeds to germinate and thrive. A sheepsfoot roller, land imprinter, or bulldozer can be used to create micro-depressions. Bulldozer tracks parallel to the contours can enhance seed germination and reduce runoff (see Fig. 4.5).

Mulching

The primary purposes of mulch are to retain moisture, prevent erosion, and moderate soil temperature fluctuations. Among materials that can be used as mulch are:

- hay or straw,
- processed mint clippings,
- wood chips,
- grass clippings, and
- wood fiber.

Mulches can be applied with blowers, hydromulching equipment, or manually. Mulch may be anchored to prevent water or wind erosion by crimping it, adding tackifiers or binders, or by covering it with natural or synthetic netting.

Hay or straw mulch can be anchored using a modified agricultural disc implement that crimps the hay into the soil.

Logs and other woody debris, placed perpendicular to the slope in seeded areas, will help stabilize mulch and can provide valuable shade and microhabitat for the emerging seedlings.

Cattle as a Reclamation Tool

Using cattle to control erosion and enhance revegetation of tailings dams and waste rock dumps is now a relatively widespread activity in Arizona and Nevada. Judging by the success in these states, cattle can be a valuable reclamation alternative for some hard-to-reclaim sites in Washington and Oregon, especially those in arid areas with steep slopes.

Carefully monitored and controlled cattle grazing can dramatically reduce wind and water erosion on slopes and accomplish many of the tasks required for successful revegetation. The hooves of the cattle compact and blend soil materials and, at the same time, create abundant depressions that catch moisture and prevent erosion. Cattle urine and excrement provide fertilizer that is generally well distributed and mixed into the slope by grazing activity, and the microbes in the manure are an important ingredient in building a healthy soil.

In order for cattle to be used for reclamation, they must be restricted to relatively small areas using easily moveable fences, such as an electric tape fence. Cattle must be moved from one area to another regularly to prevent overgrazing. Salt blocks, water, and feed must also be periodically moved to insure that the entire slope being treated is covered. A pilot project was started in Lake County, Oregon, in 1997. The results are not yet available. Contact DOGAMI-MLR for the latest information on this technique.

TRANSPLANTING

Transplanting is the technique used for relocating containerized stock, bareroot stock, or plants from elsewhere on site and planting them in another.

Planting Times

Containerized plants have an advantage over bareroot stock in that they can be successfully transplanted almost any time of year. However, transplanting should not be done during the summer unless irrigation is provided.

Trees and shrubs should be planted while they are dormant, generally from November 1 through March 1. Bareroot stock and transplants are usually planted in the spring because the plants have to be dormant before they can be dug. Bareroot plants may not be shipped from the nursery until late fall or mid-winter. Spring planting may be appropriate for bareroot stock if the site is subject to frost heaving in the late fall or winter.

Spring plantings should be done as soon as site conditions allow. Typically plants should be placed in the ground just before or just after shrubs at the site break dormancy. That can be determined by looking at buds. Buds begin to swell when the plants are 'breaking' their dormant condition.

Plants should be adequately acclimatized. This is particularly critical when the environment of the growing nursery or location is different from the planting site. Plants can be acclimatized by moving them to the site before the planting date. Bareroot materials should be kept under refrigeration or the roots should be buried in a shallow trench and kept moist until planting.

Planting Techniques

If moisture conservation is important, planting should be done immediately after digging the planting holes to reduce drying of the backfill.

When transplanting, keep the majority of the root mass intact (Fig 7.3). Even if care is taken in transplanting, some roots will break. Often the damage is to the fine roots that are essential for providing nutrients and moisture. Pruning the above-ground stem(s) reduces evapotranspiration and increases the likelihood of survival by reducing the plant's demand for nutrients and moisture.

It may be helpful to construct berms 2 to 6 inches high around the planting holes to concentrate rainfall and runoff. On sloping ground, leaving the berm open on the uphill side of a planting can be beneficial (Fig. 7.4).

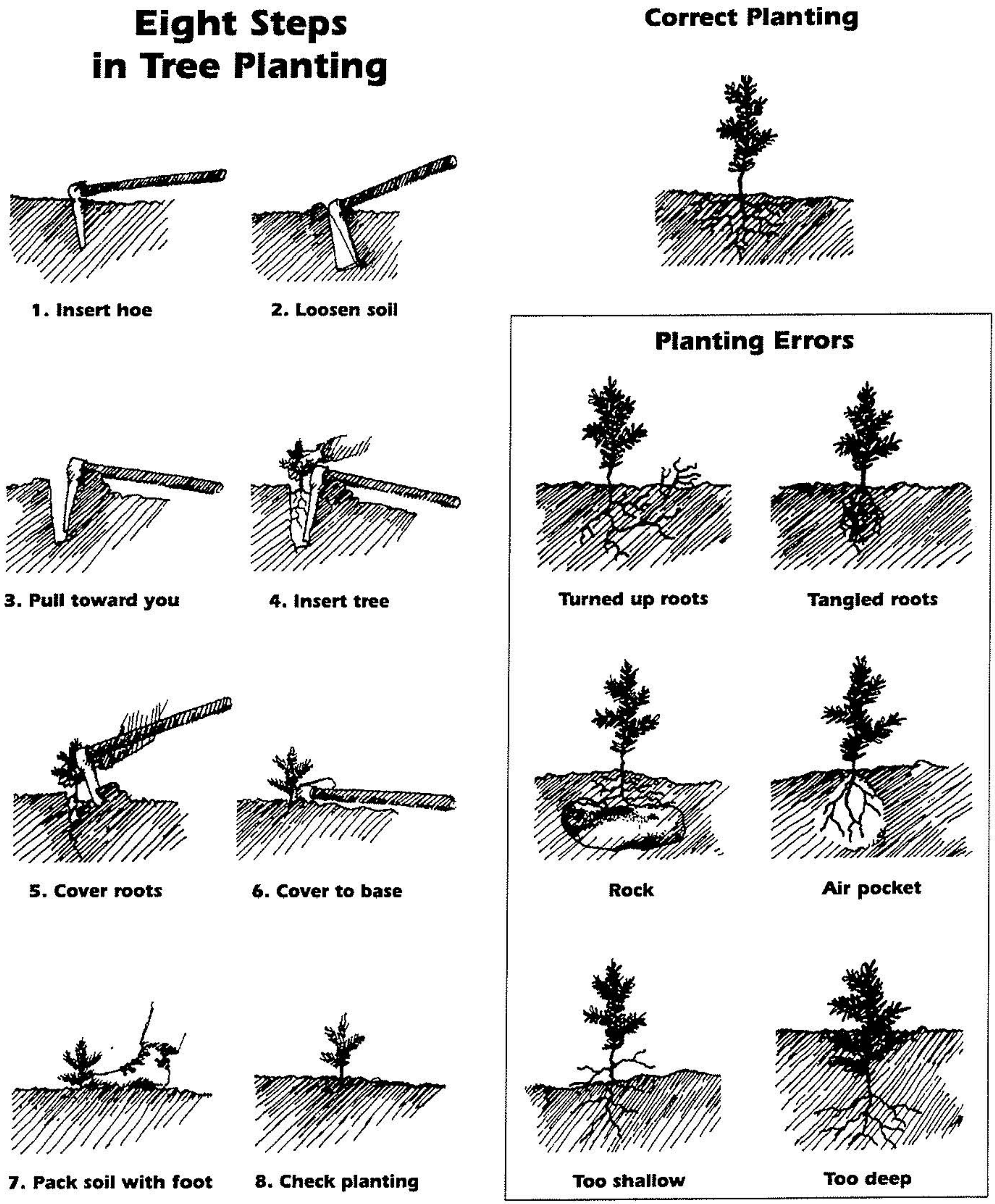

Figure 7.3. Steps in transplanting bareroot or container plants.

Mulch will help retain moisture. However, it must be anchored to prevent erosion by water or wind. Mulch is of little use on sites that flood since the mulch washes away.

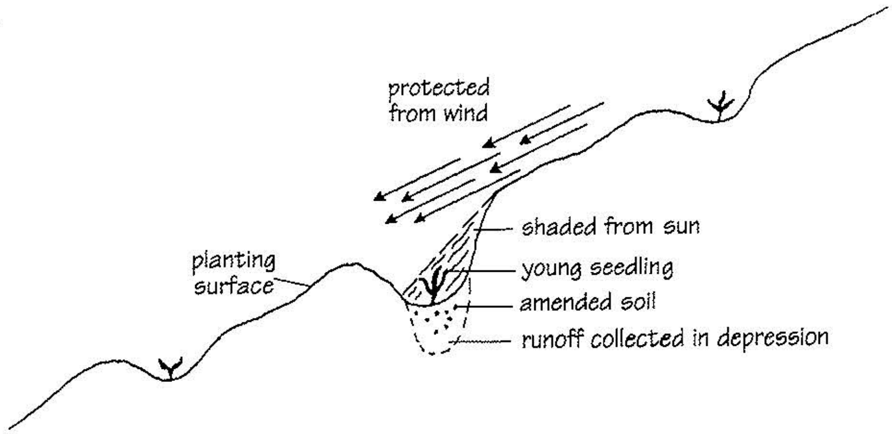

Figure 7.4. Transplanted seedlings on a slope. Small berms on the downslope side of the planting holes help retain runoff. (Redrawn from Banks, 1981.)

Tools Required

Choice of planting tools will depend upon the revegetation plan, the size of plant materials, and planting conditions. Shovels, picks, pry bars, posthole diggers, hand or power augers, front-end loaders, or backhoes may be needed to develop the planting site. For gathering plant materials from the site, chainsaws, lopping and pruning shears, buck saws, mechanical tree spades, and backhoes or front-end loaders are useful. Straw or hay for mulch for moisture retention, fencing and wire for plant protection, and cages and stakes for support may also be required. Fencing or cages are highly recommended if deer, beavers, or other plant 'predators' are in the area. They appear to seek out recently established trees and shrubs.

PROPAGATING FROM CUTTINGS

The easiest and most economical method for propagation of some species of woody plants is the use of cuttings. Willows and cottonwoods are the two most common plants propagated from cuttings (Fig. 7.5). The best time to collect cuttings is while the plants are dormant, typically between November 1 and March 1. Cuttings taken near or at the planting site or from a similar elevation zone will have a good chance of surviving on the site.

Determining Cutting Length

Cuttings should be at least 3 feet long, but the length of the cutting depends on the planting depth required. At least two-thirds of the cutting length should be placed in the ground. The planting depth depends on the mid-summer water table and the potential for erosion in the planting area. Where erosion potential is high or the water table is deep, planting depth and cutting length should be increased. The above-ground stem should have at least three buds exposed. The minimum stem diameter for cuttings should be 3/4 inch.

Collecting Cuttings

Healthy-looking plants should be used. Willows are particularly susceptible to willow bore—avoid plants with burls, lumps, or scabs surrounded by smooth bark. Several years of drought conditions or other plant stresses will diminish the reserves in the plant and may affect the survival rate. Transplant stock should be selected from wetter areas. Avoid suckers (the current year's growth) because they may not contain adequate stored energy reserves. Trim off all side branches and remove the apical (top) bud; the apical bud draws too much energy and may affect survival.

Storing Cuttings If cuttings need to be stored longer than several days, they should be kept in a cooler at 24° to 32°F. A mixture of 50 percent latex paint and 50 percent water can be used to mark and seal the top of the cuttings and reduce moisture loss. All cuttings should be soaked prior to planting for at least 24 hours to initiate root growth. At a minimum, the bottom third of the cutting should be submerged. The entire cutting may be soaked once the paint has dried. Rooting hormone added to the water may improve the survival rate. A diagonal cut should be made on the bottom for ease of planting and a straight cut on the top.

Planting Cuttings Cuttings can be placed either in the spring or fall, preferably when the plants are dormant. If cuttings are taken in the fall before

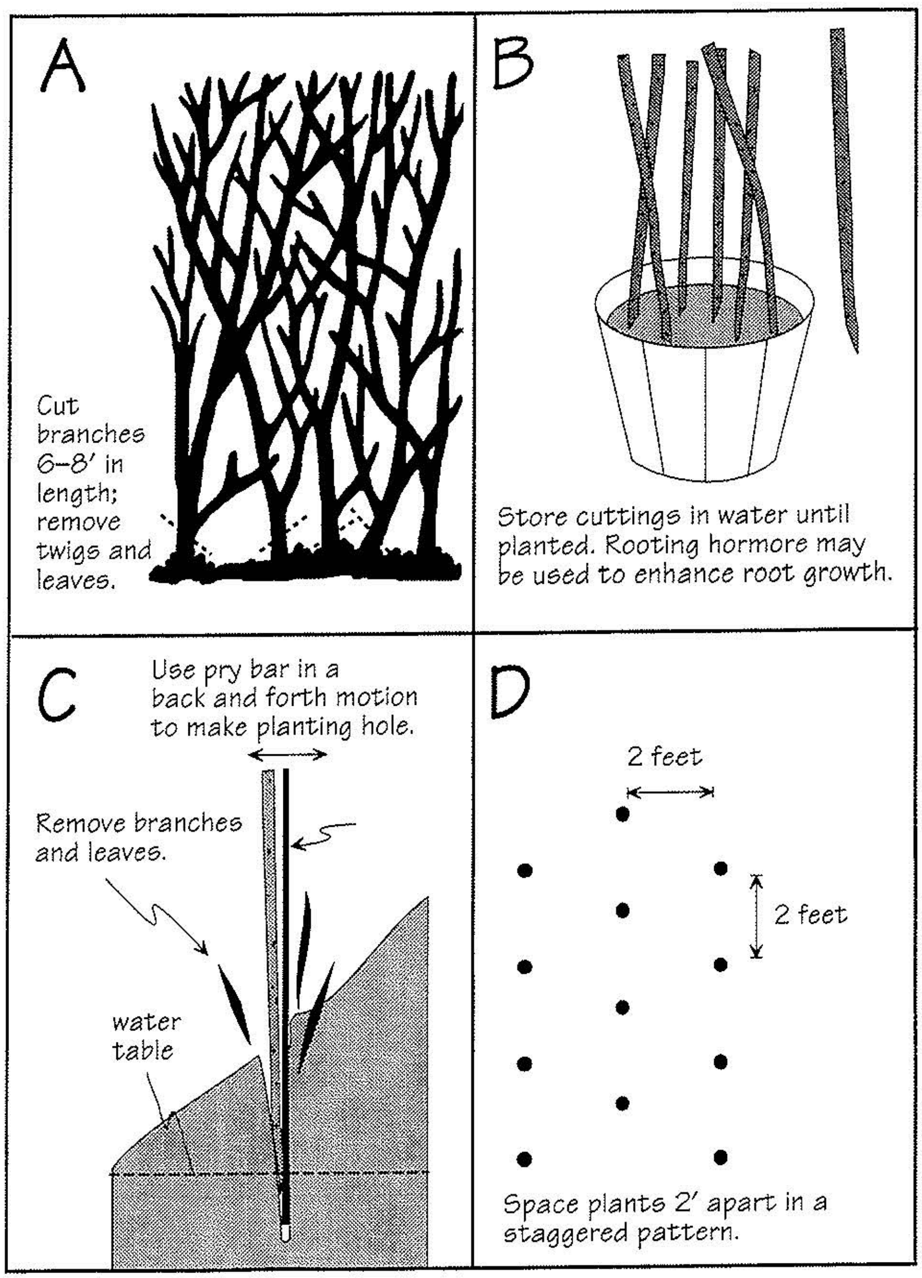

Figure 7.5. Steps in propagation by cuttings.

dormancy, the leaves should be stripped. (A general rule of thumb is that cuttings should be taken in the late fall or early winter and that rooted plants should be taken in the spring.)

Cuttings must be planted with the buds facing up. Be sure to keep track of which end of the cutting is the top—a cutting planted upside down is not likely to survive.

For successful plantings, the following guidelines are suggested:

- Select cutting stock from a nearby plant source.
- Cut when plant is dormant (usually late fall or winter).
- Use cutting of proper diameter and length.
- Properly store and maintain the cuttings before planting.
- Add root hormones to storage water.
- Use good planting techniques.

Optimum spacing of the cuttings will depend on the site and the purpose of the planting. To achieve good density, plant cuttings 2 feet apart in rows offset by 1 foot (Fig. 7.5D). Cuttings can be planted wiggling a pry bar or a piece of rebar back and forth to develop the planting hole (Fig. 7.5C). Critical factors are preventing damage to the bark and ensuring good contact between the cutting and the soil. Pack the soil around the cutting; air pockets around the cuttings will kill the roots. Driving the cutting directly into the ground with a hammer is not recommended because it causes the cutting to split.

BIOTECHNICAL STABILIZATION

The term 'biotechnical stabilization' refers to the use of plants to revegetate and stabilize slopes and stream banks instead of engineered structures, such as gabions, retaining walls, or riprap. The planting techniques discussed above may also be used as components of a system where biotechnical methods are employed. Rock or other structures can be incorporated in the design where planting alone is not enough to stabilize an eroding bank. For a comprehensive review of this subject, the *Soil Conservation Service Engineering Field Book*, Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction, is recommended.

Brush Layering

In brush layering, live woody plant materials, such as willow, cottonwood, and dogwood, are placed in layers on a slope to reinforce the soil and prevent shallow slope failures (Figs. 7.6 and 7.7). The layers also act as a living fence to trap sediment and debris. Brush layering has been successfully used to repair partial fill-slope failures, increase streambank stability, and enhance riparian vegetation. However, brush layering will not correct a deep unstable slope condition where mechanical methods of control are needed. If brush layering is used to stabilize an eroded bank, place a blanket of large rock from just above the ordinary high-water mark to just below the ordinary low-water mark.

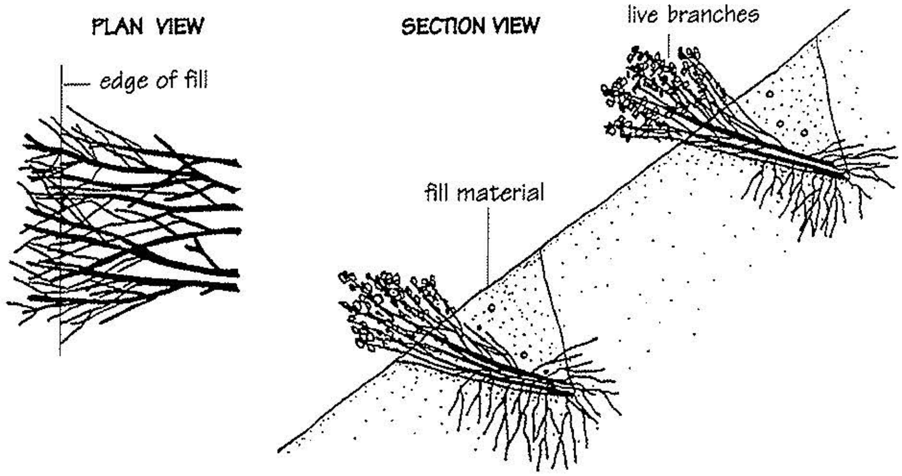

Figure 7.6. Details of brush layering in trenches. Start this process from the top down. (Modified from Bellevue Storm and Surface Water Utility, 1989.)

Starting at the top of a slope, brush layering is installed by trenching along the contour and then placing the live plant materials prior to backfilling the trench (Fig. 7.6). It may be appropriate to mix species of brush in the trench. Generally the brush-layer branches should be 6 to 8 feet in length, but they can be longer. The number of contour trenches opened at any one time should be limited to prevent destabilization of the slope.

Trenches should be excavated so that three-fourths of the live plant material can be buried in the trench, leaving one-fourth of the plant above the ground surface. Once the materials are placed, the excavated soil is then pulled down into the trench to reshape the slope.

Brush layering can also be used on fill slopes. In this situation, live plant materials can be placed on successive lifts of backfill. If this method is used, grading equipment can be used for hauling and

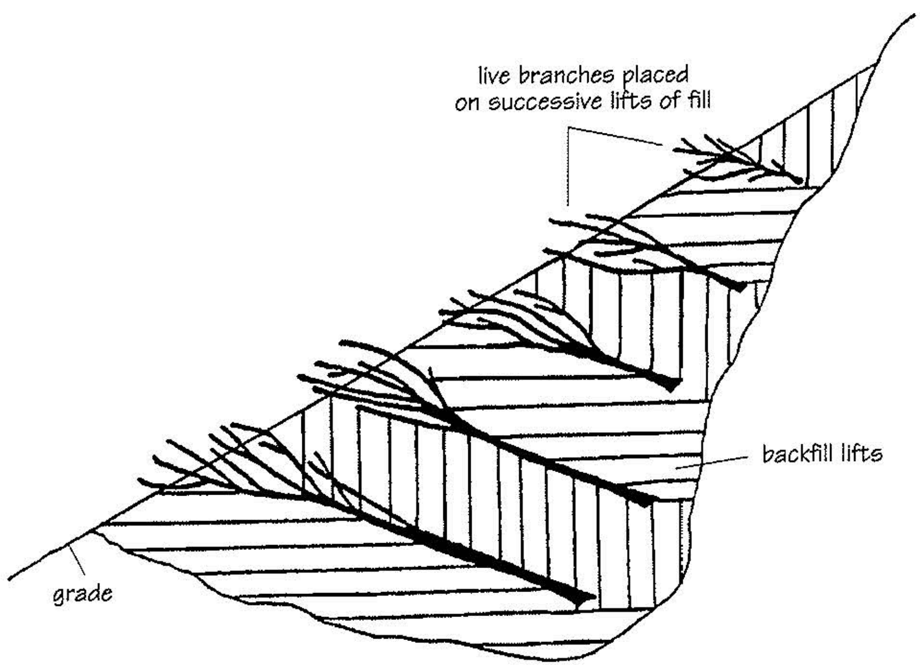

Figure 7.7. Brush layering of live plant materials on successive lifts of fill. Grading equipment can move and place the vegetation. (Modified from Bellevue Storm and Surface Water Utility, 1989.)

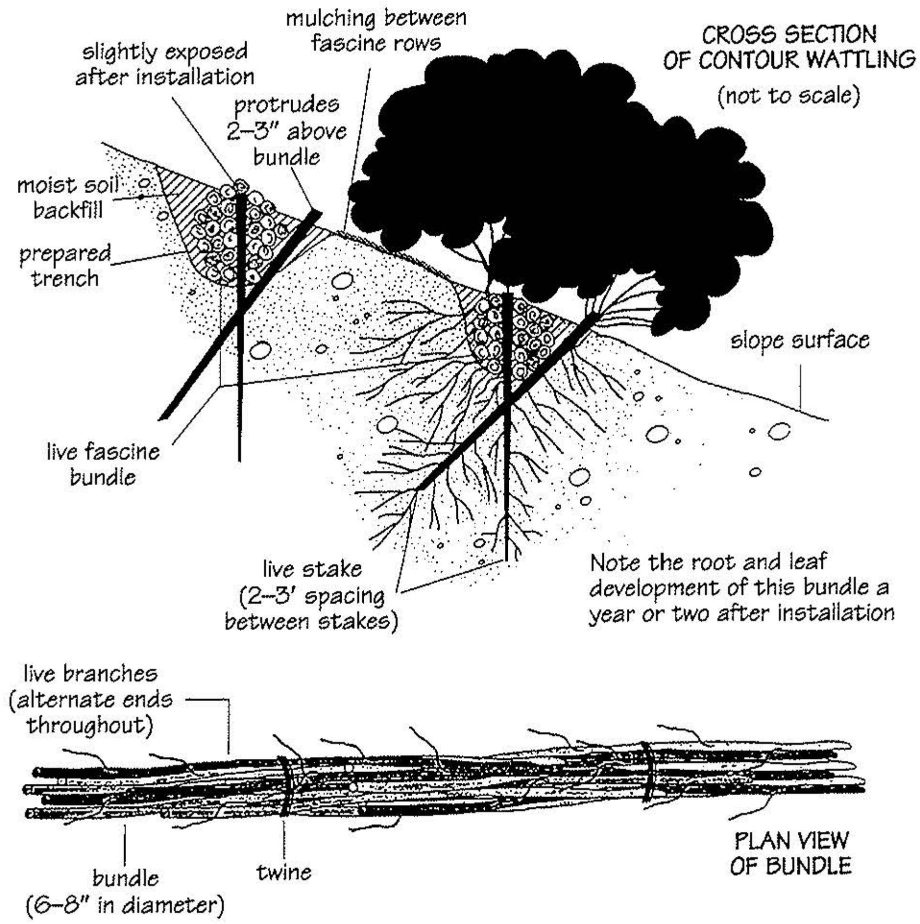

Figure 7.8. Wattle construction and placement. Wattles are bundles of live plant material, 6–8 inches thick, tied with twine. The butt ends and the tops are alternated and tied together, repeating this process until the necessary length is created. The bundles are then placed in shallow trenches along the contour and partially covered with soil so that about 10–20 percent of the bundle is exposed. (Modified from U.S. Soil Conservation Service, 1992.)

placing the vegetation (Fig. 7.7). Brush layering is less labor intensive than wattling.

Contour Wattling

The first recognized use of contour wattling was in the 1930s. Wattling controls erosion by stabilizing surface soils, reducing erosive runoff velocities, increasing infiltration, and trapping sediments. It can be very effective in stabilizing gullies. The bundles are placed across the gully.

Wattles are cigar-shaped bundles of live plant material, sometimes called 'live fascines'. The bundles are 8 to 10 inches thick and are compressed by tying with twine. The butt ends and the tops of plants are alternated and tied together, repeating this process until the necessary length is created (Fig. 7.8).

Wattles are placed in shallow trenches along the contour. On riparian sites, they can be placed diagonally to the water flow or wave action. After placement, the wattles are partially covered with soil so that approximately 10 to 20 percent of the bundle is exposed. Either live or dead stakes will secure the wattles on the slope.

Woody plants that work well with this technique are willow, red-osier dogwood, and snowberry. Over time, the planted wattles may be crowded out by more dominant species.

RIPARIAN AND WETLAND AREAS

Riparian areas are those on or near the banks of streams or other bodies of water. They are the zone of direct interaction between terrestrial and aquatic environments. Wetlands are areas that are permanently wet or intermittently water covered. (See Forming Wetlands, p. 4.14.) Vegetation in both areas requires water in the rooting zone on a permanent or seasonal basis. Classification of an area as riparian or wetland is based on factors such as vegetation type, surface and subsurface hydrology, topography, and ecosystem function.

Ecological Functions

Restoring or creating vegetated riparian areas or wetlands can:

- increase plant species diversity for habitat reconstruction,
- enhance erosion control and stream bank and/or slope stabilization,
- help to moderate water temperatures,
- improve water quality by filtering sediments and other contaminants,
- provide food for wildlife,
- provide leaf litter for worms and insects,
- slow floodwater, and
- disperse floodwater.

Alluvial mining operations or those with intermittent or perennial streams in the disturbed area should plan to revegetate wetlands and riparian areas. The woody and herbaceous vegetation that grows in the riparian zone is important in maintaining the health of streams, lakes, and wetlands.

Plant Selection

Knowing which riparian species are best suited for a particular planting technique is essential for successful revegetation. Species such as willow, cottonwood, and red-osier dogwood can be propagated by cuttings, while others, such as red alder, salmonberry, snowberry, thimbleberry, Douglas' spiraea, vine maple, and Pacific ninebark, can only be propagated by transplanting the root mass with the above-ground stem. Those species that have a fibrous, spreading root system can generally be propagated by root division.

Planting riparian areas with native trees (cottonwoods, poplar, alders, willows, fir, pines, maples), grasses, legumes (lupine), and forbs can provide nesting cover and accelerate the restoration of productive habitat. Planting willow, poplar, and cottonwood cuttings is an effective method of building a root matrix and slowing erosion. (See Chapter 2.) In ponds, aquatic grasses, sedges, rushes, and tubers should be planted to provide cover and food for insects and fish. Generally, non-native species should be avoided unless rapid stabilization is required. Aggressive native species such as common cattail and Douglas' spiraea should be used cautiously, because they may crowd out other plants.

To insure good growth and survival, species should be planted in environments they are adapted to. Some species are more tolerant of constant inundation than others. For example, big leaf maple and

Oregon ash should be planted high enough up the bank so that the roots are above the water table. Table 7.1 is a plant selection guide listing plant growth characteristics, requirements, and planting conditions necessary for propagation. (For more information on wetlands vegetation selection, see Vegetation, p. 4.15.)

AGRICULTURAL AND FORESTRY SUBSEQUENT USES

Often the post-mining use calls for commercial agriculture or reforestation. For those situations, the operator may want to plan reclamation with a professional forester or an extension service agent. The Oregon Departments of Forestry or Agriculture and the Washington Department of Natural Resources are other good sources of information.

Topsoil

For a mine site to be reclaimed for agriculture or forestry, topsoil must be replaced. Operators who have not saved topsoil and subsoil for reclamation will generally not be able to use the site for agriculture or forestry because topsoil replacement would be too costly.

Other conditions to avoid are excessively stony soils resulting from mixing soils and subsoils with the sand and gravel deposit, compacted pit floors, and inadequate treatment of applied topsoil and subsoil to ameliorate compaction problems. In addition, slopes steeper than 3H:1V will not be as productive for agriculture or forestry.

Segmental reclamation and live topsoiling increase the chances of productive agricultural and forestry land after mining. Detailed knowledge of the sand and gravel deposit is also necessary. The composition of the pit floor is an important component in developing a reclamation plan. For example, if the pit floor is on impermeable or compressible silty and clayey material, severe soil compaction will occur, soil drainage will be impeded, and a perched water table causing excessive wetness will result.

Factors to Consider

From an agricultural standpoint, at least 8 inches of topsoil with suitable subsoils or a minimum of 3 feet of combined topsoil and subsoil overlying a zone saturated with water is needed for most plants during the growing season. Therefore mineral extraction should not occur below the water table. Knowledge of the hydrologic conditions of the site is necessary for reclamation to be successful.

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Table 7.1. A partial listing of appropriate native plants suitable for erosion control and slope stabilization. Water requirements: dry—once established, tolerates dry soil conditions during the growing season; moist—requires moist soil throughout the growing season; wet—tolerates saturated soil year-round; usage—relative water uptake by plant. Light requirements: full sun—requires sun throughout the day; sun/shade—requires shade for about half the day; full shade—requires shade throughout the day. Rooting characteristics: fibrous—lacks a central root, root mass composed of fibrous lateral roots; tap—with a stout, central main root; shallow, moderate, or deep refers to relative rooting depth (influenced by soil and ground-water conditions). Planting: sizes given are those that are generally found in nurseries; other sizes may also be available. (Modified from Myers Biodynamics Inc., 1993, with additional data from Ken Thacker, Bureau of Land Management)

Scientific name common name	Form and habit	Water requirements	Light requirements	Soil	Rooting characteristics	Planting	Comments
Acer circinatum vine maple	deciduous shrub; may spread aggressively	moist	sun/shade full shade	any soil; tolerates shallow flooding during the growing season	moderate fibrous	to 4′ tall in containers; balled and burlapped plants to 10′ tall	Large specimens widely available; spreads by root and seed
Achillea millefolium white yarrow	perennial forb	dry	full sun	any well drained soil	fibrous	direct seeding in fall or spring	Aggressive once established
Alnus rubra red alder	deciduous tree; seeds prolifically on bare soil	moist	full sun	any soil	moderately deep fibrous	bareroot seedlings up to 3′ tall; larger plants in containers	Fast grower in poor mineral soils; typical 40–50-yr lifespan; large limbs become brittle; provides food for birds
Arctostaphylos uva-ursi kinnikinnick	low-growing shrub; spreads to form dense evergreen carpet	dry	full sun	any slightly acid soil	shallow fibrous	rooted plants in containers	Widely available evergreen ground cover; tolerates salt spray
Artemisia tridentata tridentata basin big sagebrush	tall evergreen shrub	dry	full sun	deep, well drained soil along drainages	very deep fibrous with taproot	direct seeding in fall; containerized stock in early spring	Variable ecotypes
Artemisia tridentata vayseyana mountain sagebrush	evergreen shrub	dry	full sun	deep, well drained, cool soils	very deep fibrous	containerized stock in early spring	Variable ecotypes, variety 'Hobble Creek'
Artemisia tridentata wyomingensis Wyoming big sagebrush	evergreen shrub	dry	full sun	deep, well drained soil	very deep fibrous with taproot	containerized stock in early spring	Variable ecotypes
Atriplex canescens fourwing saltbush	evergreen shrub	dry	full sun	salt and alkaline tolerant	deep fibrous	cuttings or containerized stock in early spring	Tolerant of grazing; nitrogen fixer
Cornus stolonifera or *Cornus sericea* red-osier dogwood	deciduous shrub; does not spread	moist to wet	full sun sun/shade	any soil; tolerates shallow flooding during the growing season	shallow fibrous	rooted plants to 6′ tall in containers; bareroot and cuttings 18–24″ tall	Produces bright red stems
Elymus elymoides bottlebrush squirreltail	perennial bunchgrass	dry	full sun	well drained, disturbed sites	deep fibrous	direct seeding in fall or early spring	Very drought tolerant
Elymus lanceolatus streambank wheatgrass	perennial sod former	dry	full sun	well drained soils	fibrous, spreading with rhizomes	direct seeding in fall or early spring	Variety 'Sodar'
Elymus trachycaulus slender wheatgrass	perennial bunchgrass	dry	full sun	well drained, cold soils	deep fibrous	direct seeding in fall or early spring	Variety 'Primar'

Table 7.1. A partial listing of appropriate native plants suitable for erosion control and slope stabilization *(continued)*

Scientific name common name	Form and habit	Water requirements	Light requirements	Soil	Rooting characteristics	Planting	Comments
Gaultheria shallon salal	evergreen shrub; forms thickets by underground runners	dry to moist	sun/shade full shade	any soil; tolerates shallow flooding during the growing season	shallow fibrous	rooted plants 4–12″ tall	Widely available; difficult to establish; slow growing; tolerates salt spray
Helianthus annuus annual sunflower	annual forb	dry	full sun	any; prefers disturbed areas	fibrous	direct seeding in fall or spring	Easily established; food value for birds
Holodiscus discolor ocean spray	deciduous shrub; does not always spread aggressively	dry to moist	full sun sun/shade	any soil; tolerates shallow flooding during the growing season	moderate fibrous	to 2′ tall in containers; bareroot 6–12″ tall	Produces attractive sprays of creamy white flowers; will root spread
Linium lewisii Lewis flax	perennial forb	dry	full sun	well drained; tolerant of rocky conditions	deep fibrous	direct seeding in fall or spring	Variety 'Appar'
Lonicera involucrata black twinberry	deciduous shrub; does not spread	moist	full sun	any soil	shallow fibrous	to 6′ tall in containers; bareroot 18–24″ tall	Produces yellow twin flowers and black twin berries; some success reported from cuttings
Myrica californica wax myrtle	evergreen shrub; does not spread	dry to moist	full sun sun/shade	slightly acid soil with organic matter	moderate fibrous	rooted plants to 10′	Tolerates salt spray; high wildlife usage
Oemleria cerasiformis indian plum	deciduous shrub; forms open stands by underground runners	moist	full sun to full shade	any soil	shallow fibrous with underground runners	to 4′ in containers; bareroot 6–8′ tall	Male and female flowers are on separate plants; only female flowers produce the 'plums'
Oryzopsis hymenoides indian ricegrass	perennial bunchgrass	dry	full sun	well drained; prefers sandy soil	deep fibrous	direct seeding in fall or early spring	Variety 'Nezpar'; very drought tolerant
Pershia tridentata antelope bitterbrush	perennial shrub	dry	moderately shade tolerant	deep, well drained soil; best on coarse soils	deep fibrous	containerized stock in early spring	Variable ecotypes; high forage value; nitrogen fixer
Physocarpus capitatus Pacific ninebark	deciduous shrub; does not spread	moist	full sun sun/shade	any soil	shallow fibrous	to 6′ tall in containers; bareroot 18–24″ tall	Produces masses of tiny white flowers that change to reddish seed clumps
Populus trichocarpa northern black cottonwood	deciduous tree; does not spread	moist; usage high	full sun	any soil; tolerates shallow flooding during the growing season	fibrous, shallow to deep and widespread	to 10′ tall in containers; cuttings 18–24″; whips 4′ tall	Fast grower in moist to saturated soils; also widely used for streambank stabilization; potential for wind throw
Pseudoroegneria spicata bluebunch wheatgrass	perennial bunchgrass	dry	full sun	well drained soil	deep fibrous	direct seeding in fall or early spring	Varieties 'Secar' and 'Goldar'
Pseudotsuga menziesii Douglas fir	coniferous tree; does not spread	dry to moist; usage moderate	full sun	any soil	tap, modified tap; shallow to deep and widespread	12–18″ bareroot seedlings; larger plants in containers	Not good for slope stabilization; high root strength but typical shallow; can be planted in stands; good eagle and osprey perch and nest trees; potential for wind throw in thin or disturbed soils
Rhamnus purshiana cascara, buckthorn	deciduous tree/shrub; does not spread	moist	full sun	any soil	moderately deep tap	to 6′ tall in containers; bareroot 18–24″ tall	Shiny black berries are favored by cedar waxwings
Ribes sanguineum red currant	deciduous shrub; does not spread	dry to moist	full sun sun/shade	any soil	shallow fibrous (not extensive)	to 4′ tall in containers; bareroot to 18″ tall	Ornamental native; produces clusters of white to red flowers

Table 7.1. A partial listing of appropriate native plants suitable for erosion control and slope stabilization *(continued)*

Scientific name common name	Form and habit	Water requirements	Light requirements	Soil	Rooting characteristics	Planting	Comments
Rosa nutkana Nootka rose	deciduous shrub; forms thickets by underground runners	moist	full sun	any soil, prefers rich soils	shallow fibrous (not extensive)	rooted plants to 2′ tall in containers; bareroot to 18″ tall; cuttings 12–18″	Thickets of stems create a formidable barrier; pink flowers followed by large red hips; tolerates salt spray
Rubus parviflorus thimbleberry	deciduous shrub; forms thickets by underground runners	moist	full sun sun/shade	any soil	shallow fibrous	rooted plants in containers	May be difficult to find in some native plant nurseries
Rubus spectabilis salmonberry	deciduous shrub; forms thickets by underground runners	moist	sun/shade full shade	any soil	shallow fibrous	to 4′ tall in containers; bareroot 6-8″ tall; cuttings 18-24″	Spreads quickly once established; berries provide food for a variety of songbirds
Salix hookeriana Hooker willow	deciduous shrub; does not spread	moist to wet	full sun	any soil	moderately deep fibrous	to 6′ tall in containers; bareroot and cuttings 18–24″ tall; whips 4′; whips not recommended	Variety, 'Clatsop', has vigor, disease resistance, and attractive foliage; salt spray tolerant
Salix lasiandra Pacific willow	deciduous multi-stemmed tree; does not spread	wet; usage high?	full sun	any soil; tolerates shallow flooding during the growing season	fibrous, moderately deep and widespread	to 10′ tall in containers; cuttings 18–24″; whips 4′	Fast grower in saturated or shallowly flooded areas; 25-year lifespan; large limbs become brittle
Salix scouleriana scouler willow	deciduous tree/shrub; does not spread	dry to moist; usage high?	full sun	any soil	fibrous, moderately deep and widespread	to 10′ tall in containers; cuttings 18–24″; whips 4′; whips not recommended	Of the willows listed here, this species tolerates the driest conditions
Salix sitchensis Sitka willow	deciduous tree or shrub; does not spread	moist; usage high?	full sun	any soil	fibrous, moderately deep and widespread	to 10′ tall in containers; cuttings 18–24″; whips 4′; whips not recommended	Fast grower in moist to saturated soils; widely used for streambank stabilization
Sambucus racemosa red elderberry	deciduous shrub; does not spread	moist	full sun to full shade	any soil	shallow fibrous	to 6′ tall in containers; bareroot 18–24″ tall	Produces red nonedible berries; some success reported from woody cuttings
Spiraea douglasii Douglas' spiraea	deciduous shrub; spreads by seed and underground runners	moist to wet	full sun	any soil; tolerates shallow flooding during the growing season	shallow fibrous	to 6′ tall in containers; bareroot and cuttings 18–24″ tall	Spreads quickly and aggressively in most sites
Symphoricarpus albus snowberry	deciduous shrub; forms thickets by underground runners	dry to moist	full sun to full shade	any soil; tolerates shallow flooding during the growing season	shallow fibrous	rooted plants to 24″ tall; bareroot 6–18″ tall	Tolerates high winds and often grows on vegetated slopes overlooking salt water
Vaccinium ovatum evergreen huckleberry	evergreen shrub; does not spread	dry to moist	sun/shade full shade	slightly acid	shallow fibrous	rooted plants to 2′ tall in containers	Attractive, but slow-growing; difficult to establish; tolerates salt spray
native plant seed mixes	annual and perennial grass and forb mixes available	dry to wet; usage medium to high	species dependent	species dependent	shallow fibrous	seed; seeds of woody plants also available (success typically low); very slow to establish	Avoid exotic commercial mixes; seed mixes typically used in conjunction with other types of plantings; typically short-term erosion control technique

Table 7.2. Plant selection guide for legumes, except for lupines—Species characteristics, adaptations, and seeding rates. (See Table 7.3 for lupines.) PLS, pure live seed. (Modified from Grassland West, 1994)

Scientific name common name	Adaptation	Minimum precipitation (inches/year)	Bloat/nonbloat	PLS pounds/acre	Seeds/pound	Varieties
Astragalus cicer cicer milkvetch	best on medium to clayey textures	12 to 18	NB	20 to 25	145,000	Lutana, Monarch
Coronilla veria crownvetch	well-drained, most soil, neutral pH	20 to 25	B	15 to 20	110,000	Emerald, Penngift, Chemung
Hedysarum boreale northern sweetvetch	drought-tolerant native legume	12	NB	10 to 15	30,000	Timp
Lotus corniculatus birdsfoot trefoil	medium to clay soils	18 to 24	NB	4 to 6	418,000	Dawn, Empire
Medicago sativa alfalfa	deep, well-drained soils, all textures	15 to 18	B	8 to 15	210,000	Legacy, Cimarron, Vector, Angler, Cody
Melilotus alba white sweetclover	drought, saline, and alkaline tolerant	12	B	10 to 15	260,000	
Melilotus officinalis yellow sweetclover	wide range of soils	12	B	10 to 15	260,000	Madrid
Onobrychis viciaefolia sainfoin	deep, well-drained soils of all textures	15 to 18	NB	35 to 45	30,000	Eski, Remont, Renumex
Trifolium fragiferum strawberry clover	wet, saline and alkaline tolerant; shade	15 to 18	B	5 to 15	300,000	O'Connors, Salina, Fresa
Trifolium hirtum rose clover	warm winter ranges, green crop	15 to 20	B	20	140,000	Hykon
Trifolium hybridum alsike clover	heavy silt to clay soils, alkaline sites	18 to 20	B	6 to 8	680,000	
Trifolium pratense red clover	heavy, fertile, well-drained soils	18 to 20	B	8 to 10	275,000	Kenland, Redland, Arlington, Mammoth
Trifolium repens white dutch clover	medium to clayey, shallow soils	18 to 20	B	2 to 6	850,000	
Trifolium repens latum ladino clover	medium to clayey, shallow soils	18 to 20	B	2 to 6	800,000	
Vicia americana American vetch	wide range of soils, best in meadows	18 to 20	NB	10 to 20	75,000	
Vicia dasycarpa woolly pod vetch	wide range of soils, best on rich loam	18 to 20	NB	35 to 40	100,000	Lana
Vicia villosa hairy vetch	wide range of soils, tolerates poor sandy sites	18 to 20	NB	25 to 35	20,000	

Table 7.3. Plant selection guide for lupines—Species characteristics, adaptations, and seeding rates. PLS, pure live seed. (Modified from Grassland West, 1994)

Scientific name **common name**	**Adapted range**	**Annual/ perennial**	**Color**	**Height (inches)**	**Native/ introduced**	**Seeding rate (PLS pounds/acre)**	**Seeds/ pound**
Lupinus alpestris mountain lupine	Rocky Mountains and western North America	perennial	blue	12 to 20	N	25	12,500
Lupinus arizonicus desert lupine	southwest deserts	annual	blue	12 to 48	N	3	135,000
Lupinus caudatus tailcup lupine	Rocky Mountains and western North America	perennial	blue	12 to 24	N	12	27,600
Lupinus densiflorus aureus golden lupine	Pacific coast	annual	yellow	24 to 36	N	35	13,500
Lupinus perennis wild lupine	throughout North America	perennial	purplish-blue	12 to 24	N	11	21,000
Lupinus sericeus silky lupine	Rocky Mountains and western North America	perennial	blue	12 to 24	N	10 to 25	12,900
Lupinus succulentus arroyo lupine	Pacific coast and northwestern North America	annual	blue	24 to 28	N	20	15,600
Lupinus texensis Texas bluebonnet	southcentral and southwestern North America	annual	blue and white	16 to 20	N	16 to 20	16,000

Table 7.4. Plants for special-use situations. PLS, pure live seed. (Modified from Grassland West, 1994. Copyright ©1994 by Grassland West. Used by permission of the publisher)

Scientific name Common name	Cool/warm season	Minimum precip. (in./yr)	Bunch/sod former	Native/ introduced	PLS lb/acre	Planting dates
DROUGHT-TOLERANT BUNCHGRASSES						
Agropyron inerme beardless bluebunch wheatgrass	C	8	B	N	7 to 8	spring or fall
Agropyron desertorum standard crested wheatgrass	C	10	B	I	6 to 8	spring or fall
Agropyron elongatum tall wheatgrass	C	8	B	I	6 to 8	spring or fall
Agropyron sibiricum Siberian wheatgrass	C	6	B	I	6 to 8	fall
Agropyron spicatum bluebunch wheatgrass	C	8	B	N	6 to 8	spring or fall
Bouteloua curtipendula sideoats grama	W	8	B	N	3 to 6	spring or fall
Elymus cinereus Great Basin wildrye	C	12	B	N	9	spring or fall
Elymus elymoides bottlebrush squirreltail	C	6	B	N	8 to 10	spring or fall
Elymus junceus Russian wildrye	C	12	B	I	8 to 10	spring or fall
Eragrostis curvula weeping lovegrass	W	16	B	I	2	April to August 15
Festuca longifolia hard fescue	C	16	B	I	10	spring or fall
Festuca ovina sheep fescue	C	10	B	N	10	spring or fall
Oryzopsis hymenoides Indian ricegrass	C	9	B	N	6 to 8	spring or fall
Poa nevadensis Nevada bluegrass	C	10	B	N	3	spring or fall
Sporobolus cryptandrus sand dropseed	W	10	B	N	1	April to May 31
Stipa comata needle and thread	C	10	B	N	8	spring or fall
DROUGHT-TOLERANT SOD-FORMING GRASSES						
Agropyron dasystachyum thickspike wheatgrass	C	8	S	N	6 to 8	spring or fall
Agropyron riparium streambank wheatgrass	C	8	S	N	6 to 8	spring or fall
Agropyron smithii western wheatgrass	C	10	S	N	10	spring or fall
Bouteloua gracilis blue grama	W	12	S	N	2 to 3	spring or fall
Buchloe dactyloides buffalograss	W	12	S	N	4 to 8	June to August 15
Cynodon dactylon Bermuda grass	W	10	S	I	15	April to August
Elytrigia intermedia intermedia intermediate wheatgrass	C	14	S	I	15	spring or fall
Elytrigia intermedia trichophorum pubescent wheatgrass	C	14	S	I	10 to 12	fall
Festuca rubra red fescue	C	18	S	I	10	spring or fall
Poa compressa Canada bluegrass	C	18	S	I	1 to 2	spring or fall
Schizachyrium scoparium little bluestem	W	14	S	N	3 to 4	spring or fall

ACID-TOLERANT GRASSES

Scientific name common name	Cool/warm season	Minimum precip. (in./yr)	Bunch/sod former	Native/ introduced	PLS lb/acre	Planting dates
Agrostis alba redtop	C	20	S	I	1	spring or fall
Agrostis palustris creeping bentgrass	C	20	S	I	.5 to 1	spring or fall
Agrostis tenuis colonial bentgrass	C	18	S	I	2	spring or fall
Alopecurus arundinaceus creeping foxtail	C	25	S	I	3 to 4	spring or fall
Alopecurus pratensis meadow foxtail	C	25	B	I	4 to 5	spring or fall
Cynodon dactylon Bermuda grass	W	10	S	I	15	April to August
Eragrostis curvula weeping lovegrass	W	16	B	I	2	spring or fall
Festuca longifolia hard fescue	C	16	B	I	10	spring or fall
Festuca rubra red fescue	C	18	S	I	10	spring or fall
Festuca rubra, var. *commutata* Chewings fescue	C	18	B	I	4 to 5	spring or fall
Lolium perenne perennial ryegrass	C	12	B	I	25 to 35	spring or fall
Panicum virgatum switchgrass	W	18	S	N	5 to 8	June to August
Poa compressa Canada bluegrass	C	18	S	I	1 to 2	spring or fall
ALKALINE-TOLERANT GRASSES						
Agropyron desertorum standard crested wheatgrass	C	10	B	I	7 to 10	spring or fall
Agropyron elongatum tall wheatgrass	C	8	B	I	6 to 20	spring
Agropyron riparium streambank wheatgrass	C	8	S	N	6 to 8	spring or fall
Agropyron smithii western wheatgrass	C	10	S	N	10	spring or fall
Agropyron trachycaulum slender wheatgrass	C	16	B	N	6 to 8	fall
Cynodon dactylon Bermuda grass	W	10	S	I	15	April to August
Distichlis stricta inland saltgrass	W	8	S	N	10	June to August
Elymus canadensis Canada wildrye	C	12	B	N	7	spring or fall
Elymus cinereus Great Basin wildrye	C	8	B	N	9	spring or fall
Elymus junceus Russian wildrye	C	12	B	I	8 to 10	fall
Lolium perenne perennial ryegrass	C	12	B	I	25 to 35	spring or fall
Puccinellia distans alkaligrass	C	15	B	N	2 to 3	spring or fall
Sporobolus airoides alkali sacaton	W	6	B	N	2 to 3	July to October

GRASSES AND LEGUMES TOLERANT OF OCCASIONALLY SATURATED SOILS

Scientific name Common name	Cool/warm season	Minimum precip. (in./yr)	Bunch/sod former	Native/ introduced	PLS lb/acre	Planting dates
Agrostis alba redtop	C	20	S	I	1	spring or fall
Agrostis palustris creeping bentgrass	C	20	S	I	.5 to 1	spring or fall
Alopecurus arundinaceus creeping foxtail	C	25	S	I	3 to 4	spring or fall
Alopecurus pratensis meadow foxtail	C	25	B	I	4 to 5	spring or fall
Festuca elatior meadow fescue	C	25	B	I	6	spring or fall
Lolium perenne perennial ryegrass	C	12	B	I	25 to 35	spring or fall
Phalaris arundinacea reed canarygrass	C	16	S	N	5 to 10	spring or fall
Poa trivialis Poa trivialis	C	25	S	I	4	spring or fall
Trifolium hybridum alsike clover	C	35	B	H	6 to 8	spring
COLD-TOLERANT GRASSES						
Deschampia caespitosa tufted hairgrass	C	20	B	N	1 to 2	spring or fall
Elymus cinereus Great Basin wildrye	C	12	B	N	9	spring or fall
Elymus elymoides bottlebrush squirreltail	C	6	B	N	8 to 10	spring or fall
Festuca elatior meadow fescue	C	25	B	I	6	spring or fall
Festuca longifolia hard fescue	C	16	B	I	10	spring or fall
Festuca ovina sheep fescue	C	10	B	N	10	spring or fall
Festuca rubra red fescue	C	18	S	I	10	spring or fall
Festuca rubra, var. *commutata* Chewings fescue	C	18	B	I	4 to 5	spring or fall
Poa alpinum alpine bluegrass	C	20	B	N	1	spring or fall
Poa pratensis Kentucky bluegrass	C	18	S	N	2 to 3	spring or fall

GRASSES PROVIDING TEMPORARY COVER

(These grasses are generally planted in the spring for temporary cover.
They should not be used for permanent revegetation.)

Arrhenatherum elatius
tall oatgrass

Avena sativa
oats

Bromus arvensis
field brome

Hordeum vulgare
barley

Lolium multiflorum
annual ryegrass

Secale cereale
winter rye

Sorghum vulgare, var. *sudanense*
Sudangrass