SITE REHABILITATION MANUAL

February 1981

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1.0 INTRODUCTION

1.1 Purpose of Guidelines

The purpose of this manual is to provide information to assist in the rehabilitation of disturbed sites commonly associated with construction, or with improper or over-use of land. It describes the problems associated with disturbed sites and the various factors that should be considered in rehabilitation planning. It includes a planning procedure, rehabilitation techniques, and references to additional information.

The information in the manual has been drawn from current literature and from the experience of departmental personnel.

The objective has been to provide a useful synthesis of information on the various facets of rehabilitation. It is recognized that there are a number of complex problem areas which are the subject of current research by a number of interested disciplines. It is not, however, the purpose of this document to rigorously pursue a review of ongoing research or research needs. It is equally recognized that in pursuing utilitarian objectives one must run the risk of some loss of accuracy.

As in other environmental fields there are many variables involved in the rehabilitation of disturbed sites. Generally, these can only be evaluated, weighed and traded off when due consideration has been given to all of them in a particular project context. In these guidelines the emphasis has been on the outline of alternative approaches and not on the selection of the favoured approach. No practical guideline can comprise a substitute for "due consideration" - which is left for park or regional staff.

1.2 Definition

"Rehabilitation", "reclamation" and "restoration" are used to describe improvement work carried out on disturbed soils.

Restoration indicates a return to a previously existing state. It is ecological reconstruction: on seriously disturbed sites it is complex, unpredictable in outcome and, on any practical scale, prohibitively expensive. In the literature reclamation is normally used to describe the improvements necessary to return a disturbed site (after resource extraction or large construction project) to a prescribed level of productivity, usually equal or better than the pre-disturbance productivity. The emphasis is on productivity rather than re-creating a previously existing set of environmental conditions and processes. Reclamation costs can be very high, and are only acceptable to the extent that they can be absorbed as a resource extraction cost (e.g. the Alberta Tar Sands), where resulting land values exceed reclamation costs (e.g. in urban areas) or where the national interest is paramount (e.g. the Netherlands, and polder reclamation).

Rehabilitation is here defined as those improvement practices carried out on disturbed lands with a view to the cure or prevention of environmental nuisances, and to bring the land to an acceptable level of productivity in an economic or aesthetic sense. Rehabilitation is the more flexible term, permitting a variety of improvement practices within the same disturbed site (rather than a uniform application) as may be warranted by patterns of environmental attributes, or by economic or other constraints. The lower threshold may refer to soil and vegetation stabilization where the environmental nuisance comprises erosion and degradation of nearby aquatic ecosystems, or it may simply be the screening of an eyesore where the eyesore is the only nuisance. More intensive rehabilitation practices may extend to reclamation or -on a small scale - restoration.

A practical goal and definition for rehabilitation is the return, or change to a stable vegetative state which is in harmony with the milieu. The hand of man may still be evident but is not necessary to the maintenance of the stability and biological productivity of the rehabilitated land.

1.3 Policy Considerations

The policy basis stems from Parks Canada policy (1979) draft guidelines on “Sand and Gravel Pits, Quarries and Topsoil Excavation in National Parks” (Section 5.13, Resource Conservation) .

The policy states that all excavated sites are to be rehabilitated. Schedules for material removal and site rehabilitation, and an assessment of environmental impacts, are required before any exploitation of granular resources. This manual should serve as a guide to help ensure that sound decisions are made throughout the planning process.

2.0 THE PLANNING APPROACH

2.1 Program Planning

Planning the rehabilitation of disturbed sites should be included as an integral part of the long term planning and management of a national park, and of the resource management planning process[1]. This will ensure that duplication in data collection is avoided and that a consistent approach is adopted for the identification of site rehabilitation needs. It also facilitates the priorization of individual projects and the effective coordination of available manpower, equipment and financial resources .

2.2 Role of the Basic Resource Inventory

An inventory of any disturbed sites within a park should be compiled during the basic resource inventory or as an update of the park data base for parks in which the basic resource inventory is completed.

The inventory should provide an appropriate level of information necessary to characterize the disturbed site, and to permit an assessment of the need and feasibility of rehabilitation. The attributes outlined below are important, but may not be vital for the description of every site. Each is potentially relevant in a given situation. The list is certainly not exhausted. Information groups include:

- bedrock, landforms and surficial materials including configuration, slopes and elevators. Include relevant physiographic processes.

- local climate (and microclimate where relevant) including mean annual precipitation, rainfall during year, summer months, growing season and maximum in 24 hour period, average actual evapotranspiration, mean moisture surplus/deficiency, warmest month, degree days above 5.6°C, and frost-free period.

- hydrology with concentration on groundwater conditions, discharge areas and water quality.

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1 See “Natural Resource Management Process Manual”, DRM 40-6, Parks Canada, March, 1980.

- natural and disturbed soil (seedbed) properties as relevant, including texture, kind and amount of clay, aeration, available water storage, capacity saturation percentage, organic matter content, bulk density, pH, cation exchange capacity, fertility (NPK and minor nutrients), soluble salts, electrical conductivity and sodium adsorption ratio. Include soil arability and agricultural capability ratings.

- vegetation on undisturbed (most similar and disturbed sites, including examination of pioneer species on nearby disturbed sites.

- nature of disturbance and information to assist in establishing priorities and implementing the rehabilitation program, including erosion type and amount, soil stability, access, environmental and other problems, etc.

- historic, present and potential land uses, and land use capability ratings.

Where disturbed sites are extensive there may be considerable variability in attributes, conditions and processes. North and south facing slopes will probably require different treatments, as will basal slopes as opposed to ridgetops. The basic resource inventory should reflect this.

2.3 Role of the Resource Description and Analysis

The resource description and analysis should include an analysis and evaluation of the need for, and feasibility of, the rehabilitation of disturbed sites within the park.

Where rehabilitation is considered necessary and feasible, the analysis and evaluation should establish rehabilitation priorities. Environmental effects may play a determining role here. For example, where remedial measures are not taken increased erosion, siltation and turbidity may have irreversible effects on aquatic ecosystems. The probability of future erosion problems associated with any site disturbance should be anticipated beforehand. The degree to which a borrow pit detracts from the aesthetics of a park should be assessed in relative terms.

Where visual impacts are involved three key factors must be considered. These are the quality of the visual setting affected, the amount by which the disturbance detracts from this quality, and the significance of the view in terms of the number of persons who are exposed to it. For example, the evaluator should consider whether the view is from a major travel route or a minor one, whether the area is in the centre of the viewing field or peripheral, how long the area is in view and whether the disturbance is visible from a few or from many positions, or from one or both travel directions.

Where visitor use areas such as campgrounds and picnic grounds are involved, degree of degradation can be ascertained by making comparisons to bench-mark conditions in undisturbed areas within the same biophysical land unit, e.g. the number and types of trees, shrubs and herbaceous plants, the numbers of seedlings and saplings, the degree of root exposure, the infiltration rate and degree of compaction of the soil, the relative amounts of leaf litter and humus, and the condition of tree crowns (Nixey and Severs, 1977).

2.4 Role of the Conservation Plan

The priority assigned to site rehabilitation projects should be assessed as part of the overall identification and priorization of resource management requirements for a park. The establishment of site rehabilitation priority should take into account the sensitivity/resilience of the site and the availability of specialized expertise and equipment. One should examine the potential benefits of grouping similar projects, or of scheduling projects to coincide with development activities having similar manpower and equipment requirements. In this way, for example, supplies of topsoil and plant materials, which might otherwise be wasted, may be transferred at critical times between projects.

Once priorities have been established, a detailed statement of rehabilitation objectives and constraints should be prepared. This should outline any specific resource management studies which may be required.

2.5 The Site Rehabilitation Management Plan

This sets out a course of action for meeting rehabilitation objectives. It details manpower equipment and financial requirements, activity planning, additional information needs and requirements for monitoring the effectiveness of the plan.

3.0 DISTURBED SITE TYPES

This section describes the various types of disturbed sites that commonly occur in national parks. It describes the nature of the problems associated with such sites, and it outlines basic rehabilitation practices used to remedy them. Many of these practices are common to a range of sites and in these cases more detailed guidelines are provided in later sections, e.g., erosion control, plant selection and planting procedures. Where there are specific measures pertaining to one particular site type these are described in detail in this section.

3.1 Cut and Fill Embankments

Cut and fill embankments are the projects of the construction of facilities such as highways, roads, railways, trails, parking areas and a variety of structures. These can be classified as disturbed sites where destruction of vegetation cover detracts from the visual quality of the park landscape, causes erosion-induced environmental problems. Bare soil areas on embankments can significantly reduce the quality of views as seen by traveling on roads and trails and it can also affect, in a major way, the visual impact that a facility has on the park setting as it is viewed from other positions in the landscape. Exposed embankments are often visible for many miles because the colour of exposed soils or rocks frequently contrasts sharply with the darker tones of surrounding vegetation.

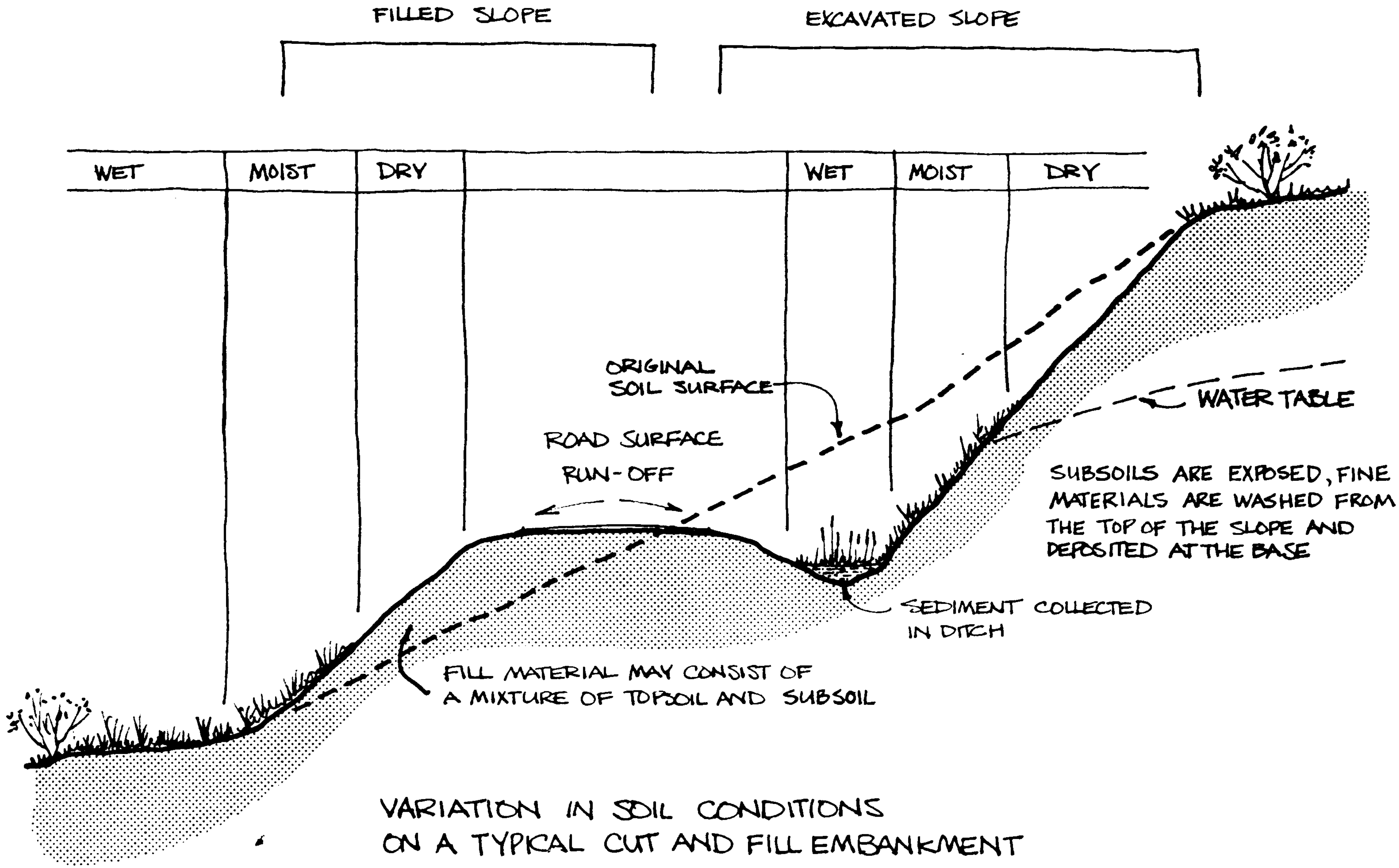
Bare embankments are subject to erosion which can result in water pollution, blockage of streams and drainage structures , and can increase roadside unsightliness where undermined trees fall into tangled masses.

In extreme cases erosion or mass slipping can threaten aquatic ecosystems, the safety of park users, and can cause damage to the facility itself, thus necessitating costly remedial work.

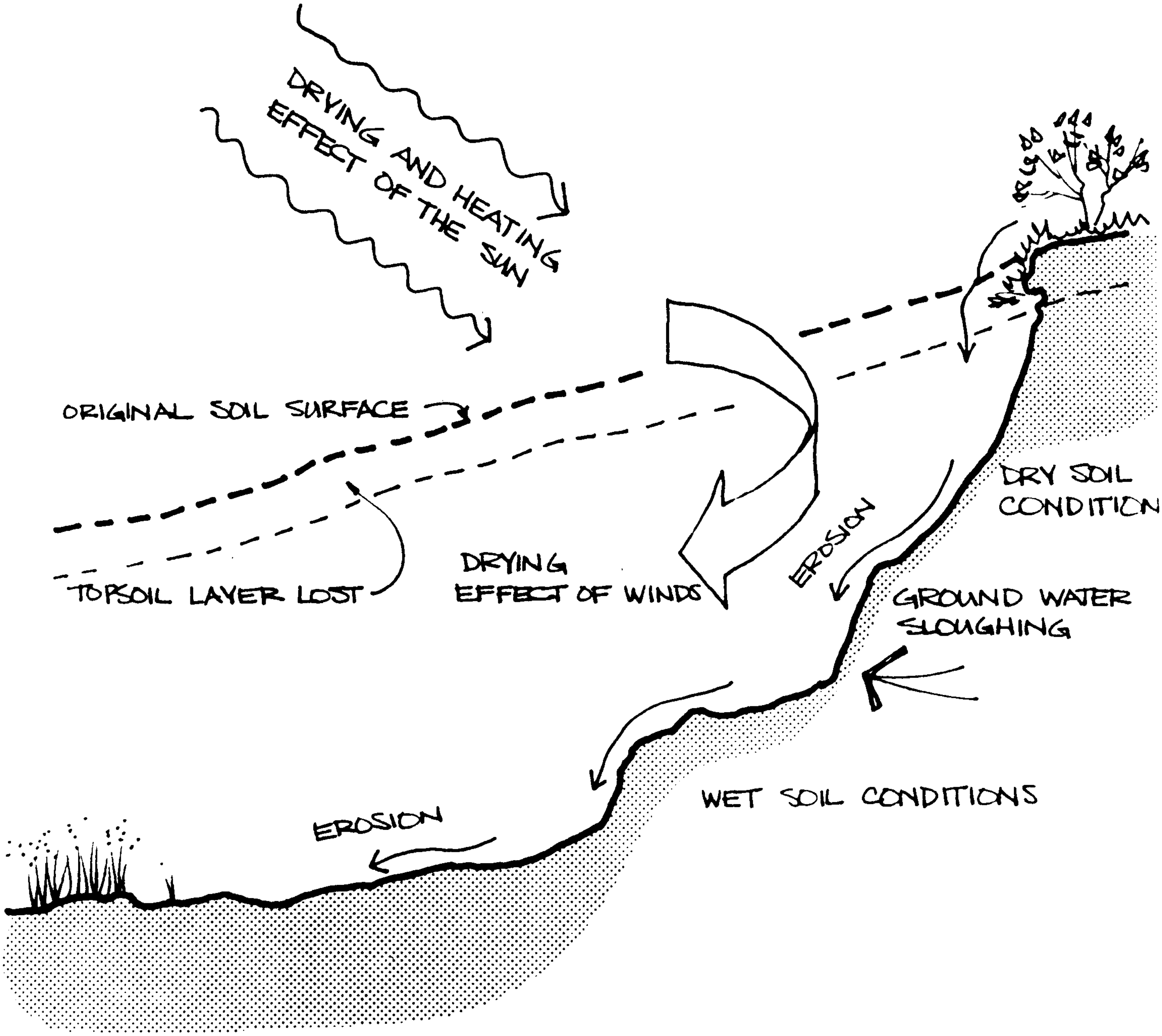
3.1.1 Assessment of Problems

An analysis of site conditions must be conducted to determine the reasons why plants have not established by natural means.

A frequent cause of this is steepness of slope. This results in erosion which dislodges seeds and newly germinated seedlings. It also has the effect of limiting the moisture supply in the soil since most precipitation is lost as runoff and does not penetrate the ground.



VARIATION IN SOIL CONDITIONS
ON A TYPICAL CUT AND FILL EMBANKMENT



ADVERSE CONDITIONS INFLUENCING PLANT DEVELOPMENT ON EMBANKMENTS

Moisture supply and temperature extremes may also be experienced at some sites due to exposure to sun and wind. This can be evident at both macro and micro scales.

Topsoil is generally absent on these sites because it has either been removed (excavated slopes) or buried (filled slopes). This often results in low N and P levels.[2] Where surface materials have not been ameliorated by soil forming processes they are not normally suitable for sucessful plant growth without improvements.

Plant failure could occur if there are no suitable seed sources close by.

3.1.2 Rehabilitation Practices

A number of useful practices are outlined below.

a) Reduce angle of slope by further cutting excavated slopes and by adding material to filled slopes.

   In many cases this measure is undesirable or can be carried out only to a minor degree because of existing vegetation of value at the top or base of slopes. Such being the case, slope adjustment should be limited to rounding the top of the cut slope.

b) Deflect surface water flow above the embankment to reduce erosion (see section 6.1.1).

c) Prepare planting bed by tilling or scarifying and incorporating materials such as fertilizer and organic matter (see section 5.1). This will not be possible on steep slopes.

d) plant species compatible with site conditions, and which will satisfy rehabilitation objectives. (See section 4). Generally in rehabilitation work revegetation is achieved primarily by seeding and by transplanting tree and shrub seedlings. Where it is

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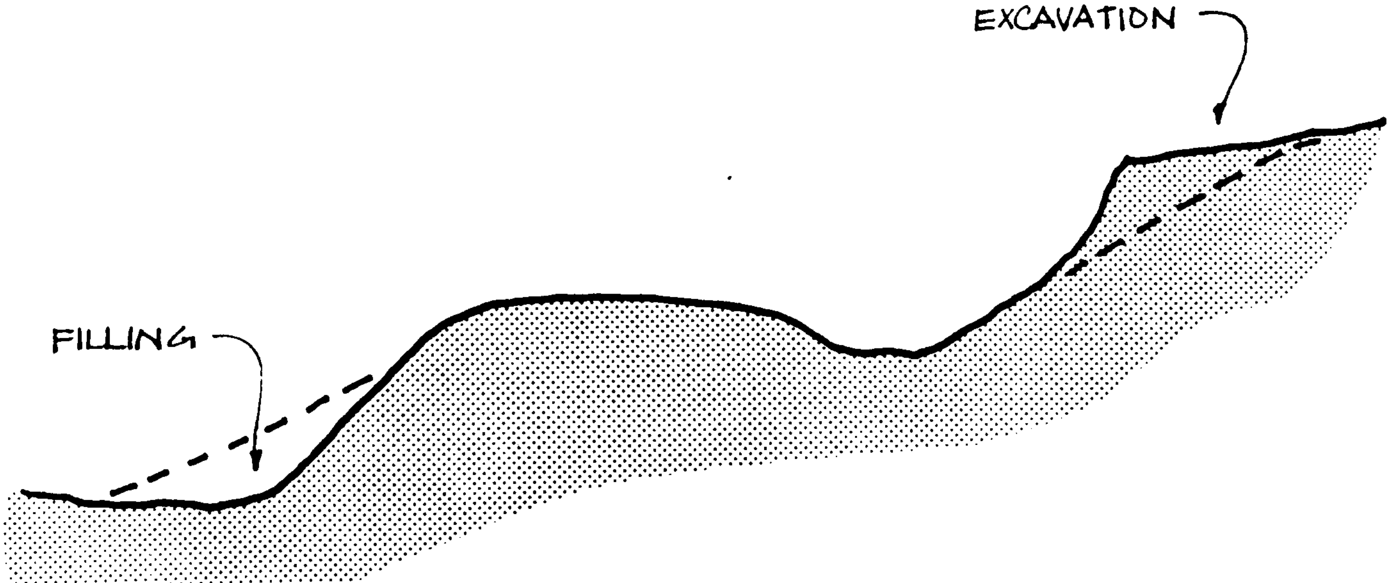
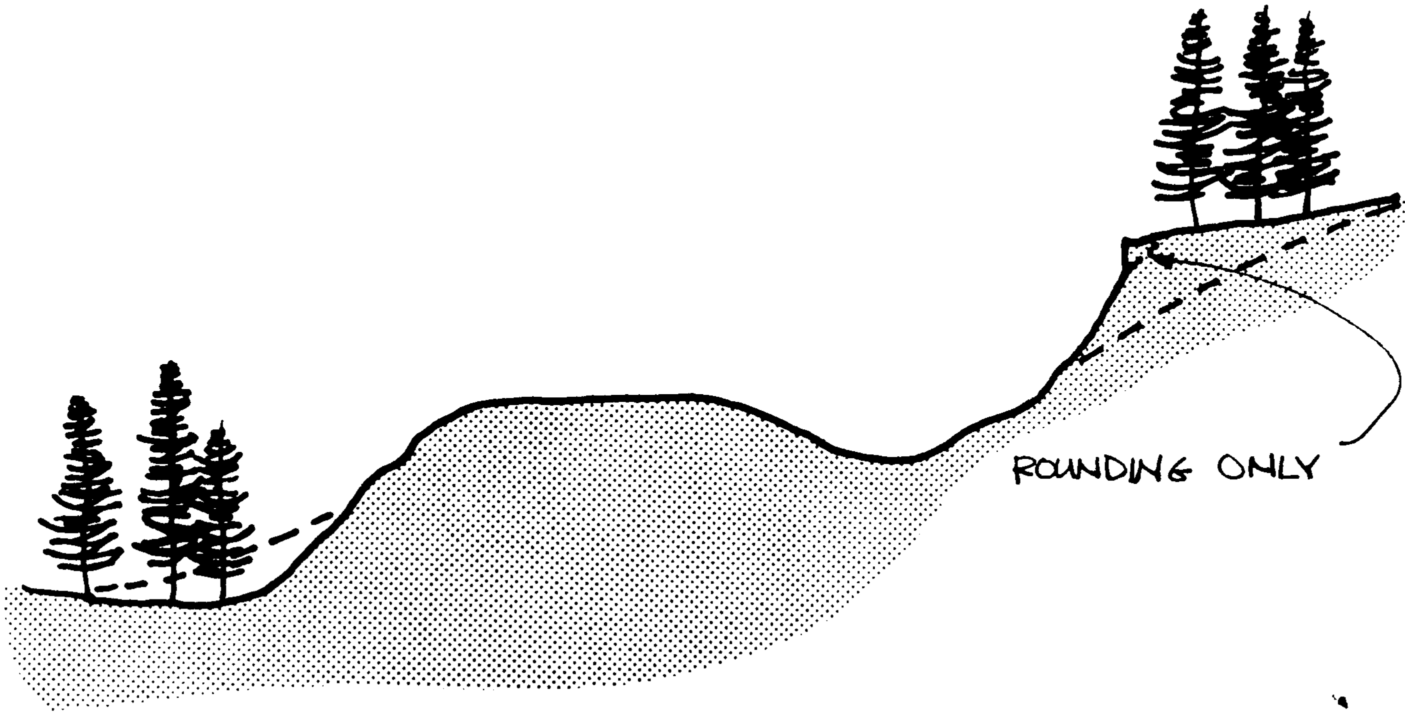
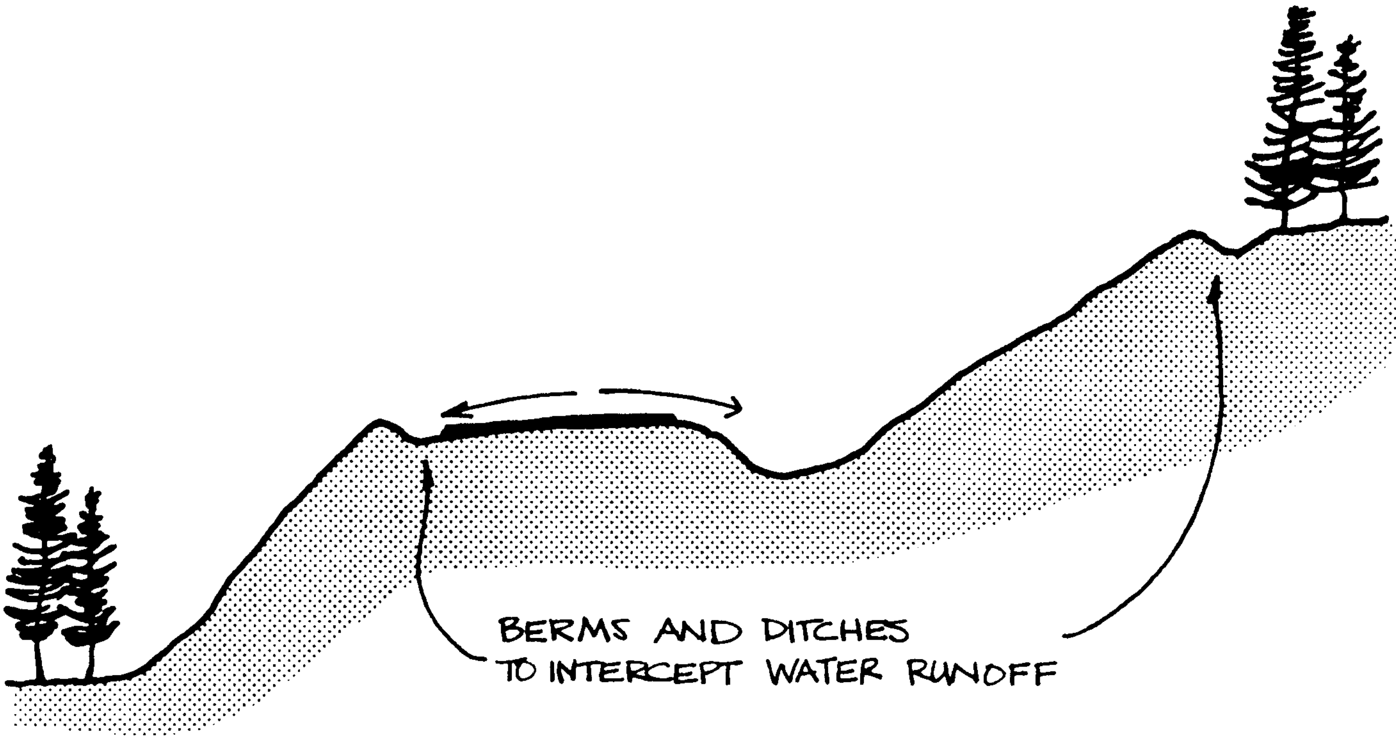
2 It is inappropriate to say, on a trans-Canada scale, that removal of topsoil will lower available plant nutrients. Removal will usually lower N and P. It may lower (or raise) K and micronutrients. Also, soil conditions may be more suitable as a seed-bed on filled slopes, but may also be much more susceptible to erosion, thus giving a net detrimental effect (especially in sandy areas). A number of variables may require examination.

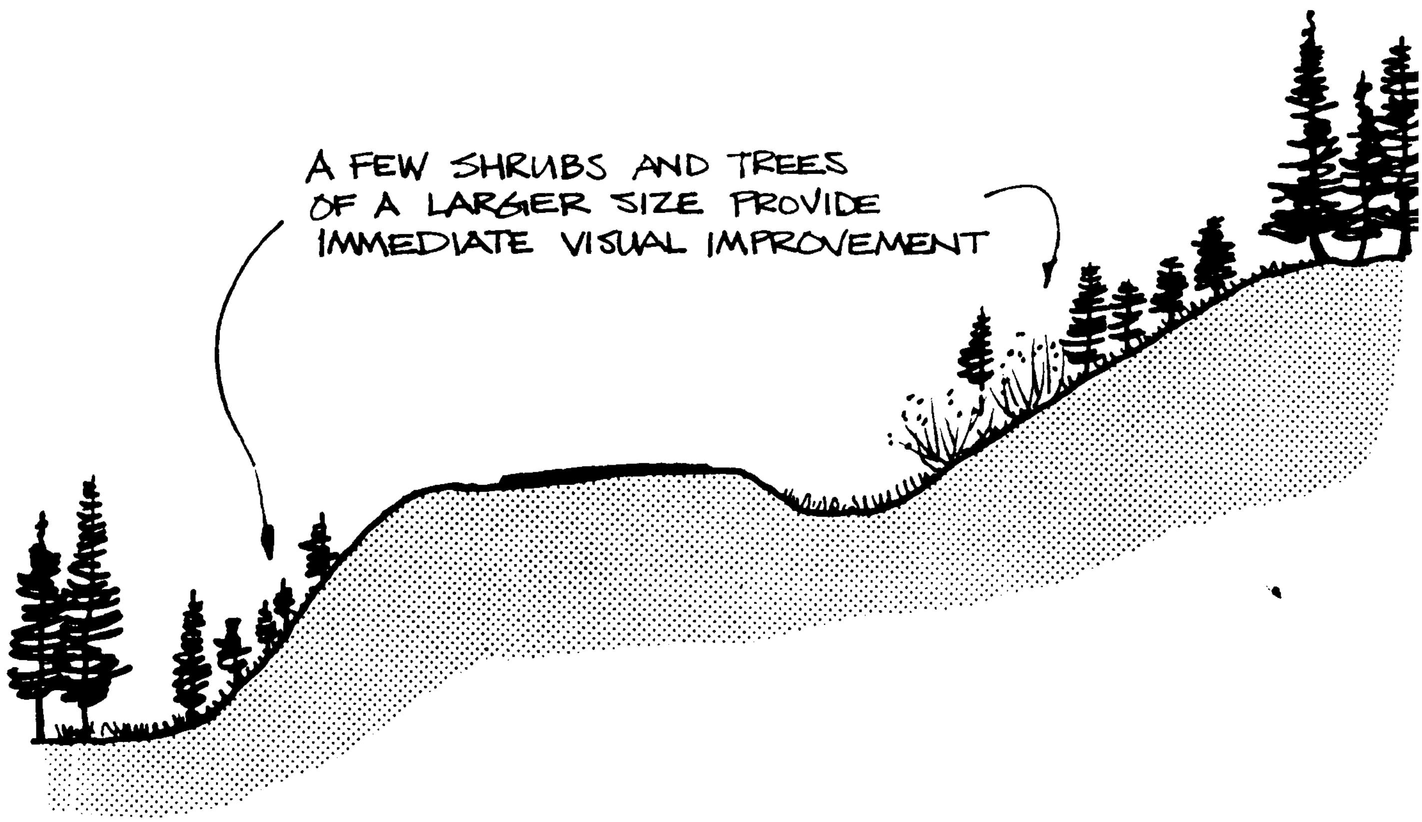


REDUCING SLOPE ANGLES



SLOPE ADJUSTMENT RESTRICTED BY VEGETATION


BERMS AND DITCHES
TO INTERCEPT WATER RUNOFF


A FEW SHRUBS AND TREES
OF A LARGER SIZE PROVIDE
IMMEDIATE VISUAL IMPROVEMENT

possible a few larger trees should be included as this will provide immediate visual improvement.

e) Apply an organic mulch such as peat, chopped straw, wood chips, etc. , to surface of embankment to control erosion, to increase the infiltration of surface water, to reduce losses of soil moisture resulting from evaporation, and to modify temperature extremes (see section 7).

f) Install wattling as an alternative erosion control technique. Where erosion problems are severe mulching and extra planting can also be included (see section 6.1.4).

g) Use gabions for unstable banks of limited extent, especially bordering lakes, streams and rivers.

3.2 Borrow Pits and Quarries

For visual reasons where close to highways, trails and other use areas , borrow pits and quarries are often in need of rehabilitation. Their unsightliness is generally due to inadequate vegetation cover. Resulting landforms also contrast sharply with adjoining natural landforms.

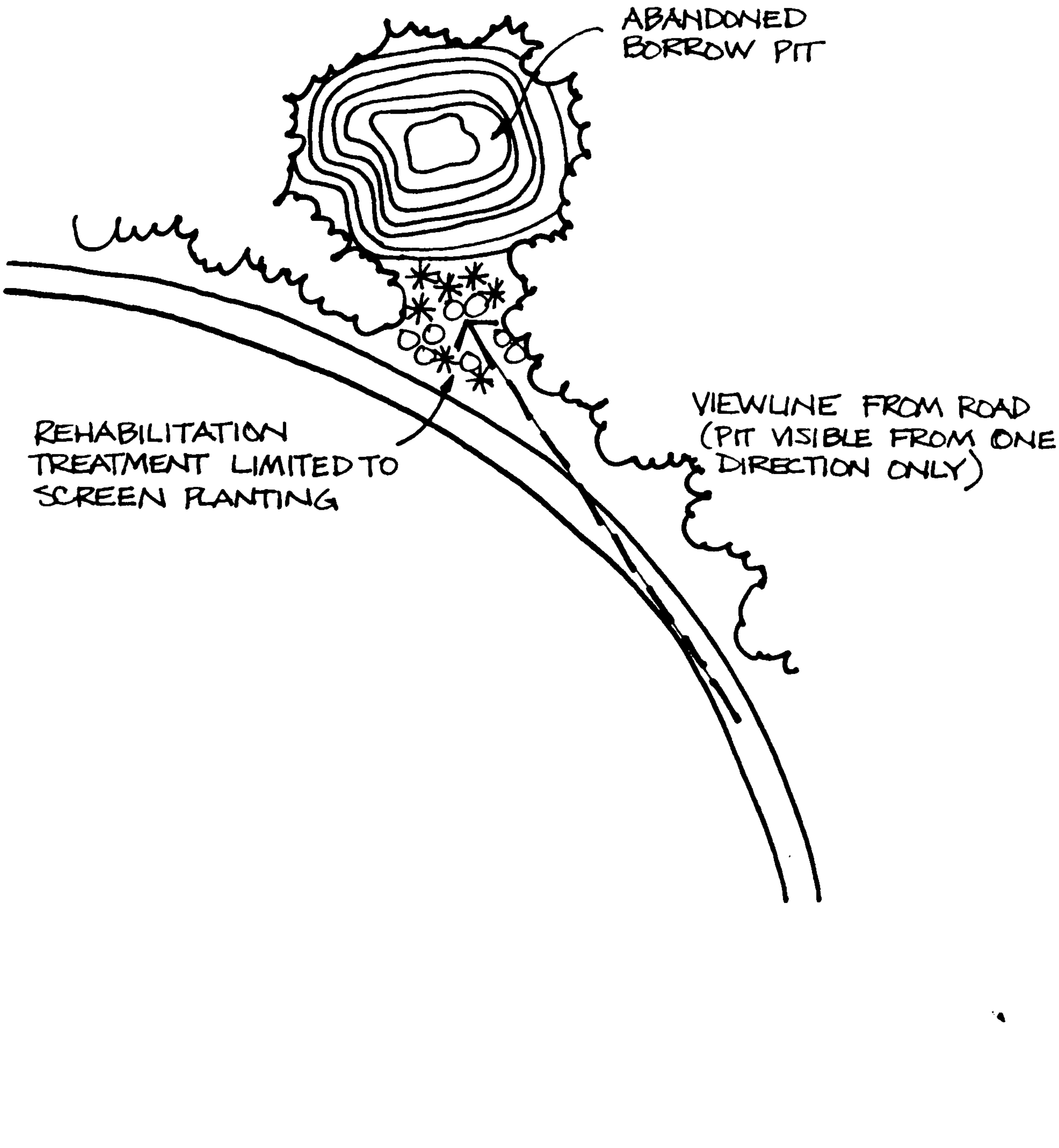
Another consideration is the removal or reduction of hazards to people or wildlife. These may be steep cliffs, unstable soil materials or dangerously contoured water bodies.

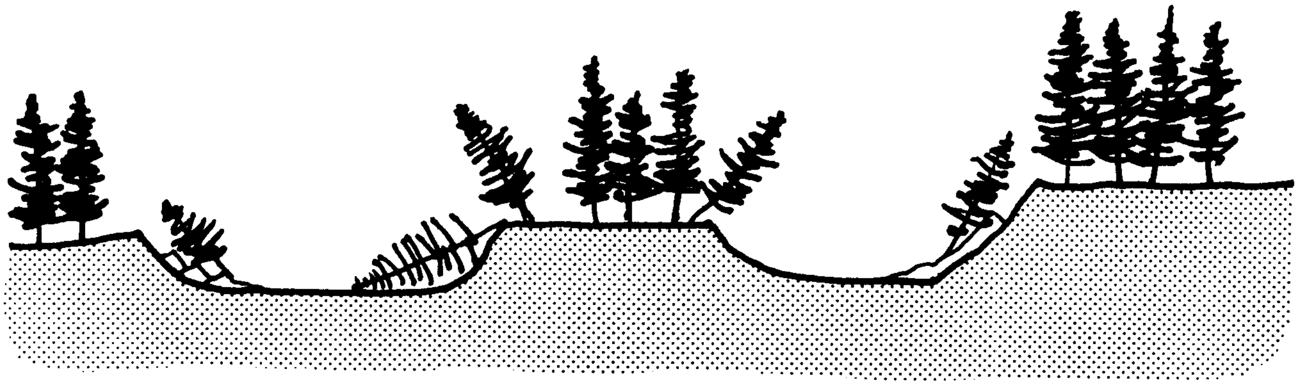
It may also be desirable to alter sites to control erosion constituting a threat to aquatic habitat, or to provide site conditions suitable for future land uses such as housing, parking lots, picnicing, camping or interpretation.

3.2.1 Assessment of Problems

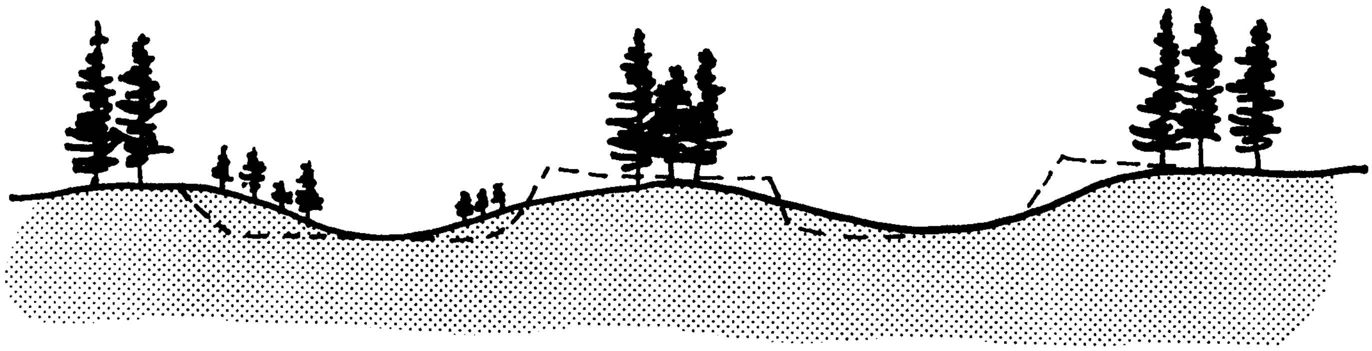
The site should be evaluated in order to determine the specific factors limiting natural regeneration. These will be basically the same as were described for embankments in section 3.1.1.

Visual aspects should also be studied. If the site is highly visible there will be a greater need for intensive treatment than if views are limited. Where the site is visible from only one direction it may be enough to concentrate efforts in establishing screen planting with limited or no modifications to the remainder of the site, leaving it to natural regeneration.

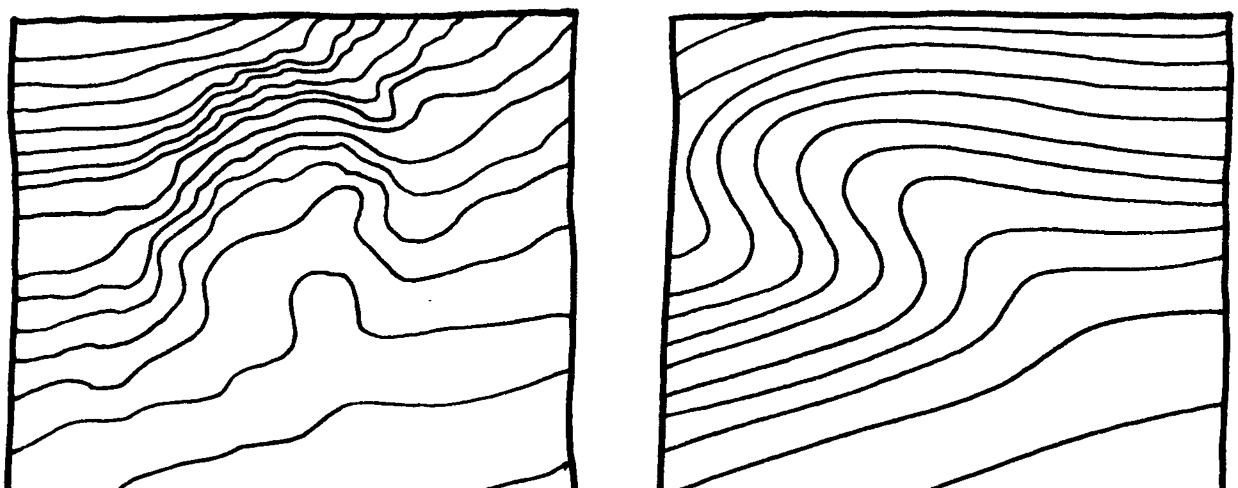

ABANDONED BORROW PIT
REHABILITATION TREATMENT LIMITED TO SCREEN PLANTING
VIEWLINE FROM ROAD (PIT VISIBLE FROM ONE DIRECTION ONLY)



PIT UNTREATED – UNNATURAL LANDFORMS



ADJUSTED LANDFORMS



PLAN VIEWS: LEFT – PIT UNTREATED
RIGHT – CONTOURS ADJUSTED TO MATCH LOCAL TERRAIN CHARACTERISTICS

3.2.2 Rehabilitation Practices - Borrow Pits

a) Modify site to remove hazardous slopes, to provide suitable grades for human use, to create visual improvements by harmonizing with adjacent landforms, and to provide a suitable seedbed or rooting medium.

b) Alter drainage patterns where these restrict vegetation establishment.

c) As required, prepare ground by tilling or scarifying, incorporating materials to improve planting medium.

d) Plant vegetation species which are compatible with site conditions and which will satisfy rehabilitation objectives (see section 4).

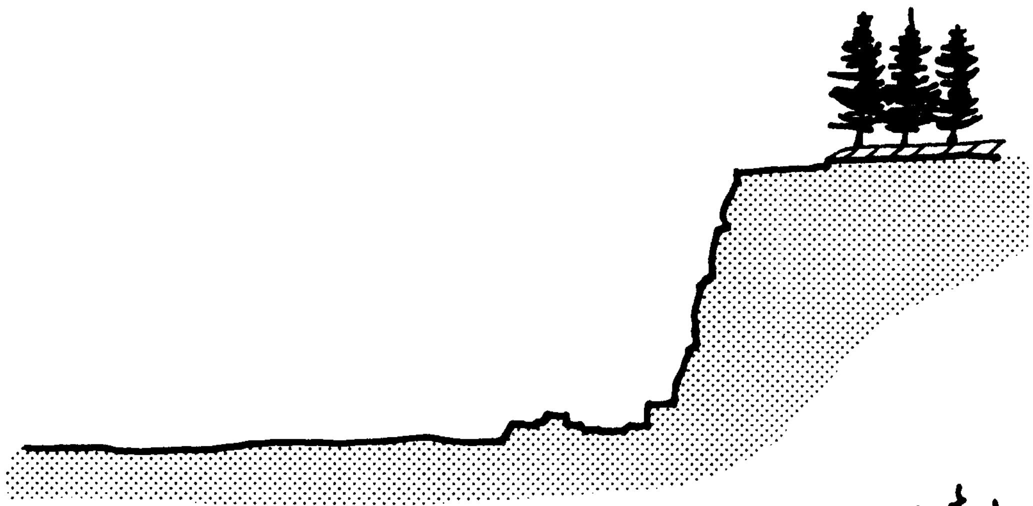
e) Apply mulches where erosion or harsh climatic conditions inhibit plant development.

f) Fill or drain hazardous water holes or improve for wildlife habitat or recreational use.

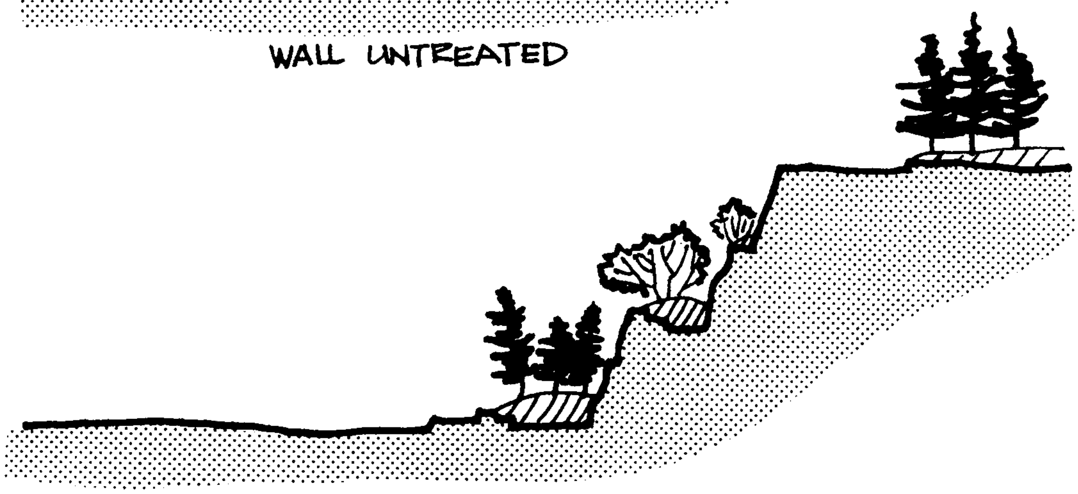
3.2.3 Rehabilitation Practices - Quarries

a) Alter form of quarry walls to create more natural appearance, to create ledges or pockets where plants can establish, or to reduce the hazard of falling rock. Blasting and the use of heavy rock moving equipment is required for this task. Where blasting is to be carried out the location of charges should be selected so as to break the rock along natural fracture lines and so reflect the natural forms of local rock outcrops. Uniform benching and highly obvious patterns of drilling scars should be avoided. It is important that a geologist and an experienced rock blaster be involved in this sort of work. (See Colorado Department of Highways, 1978).

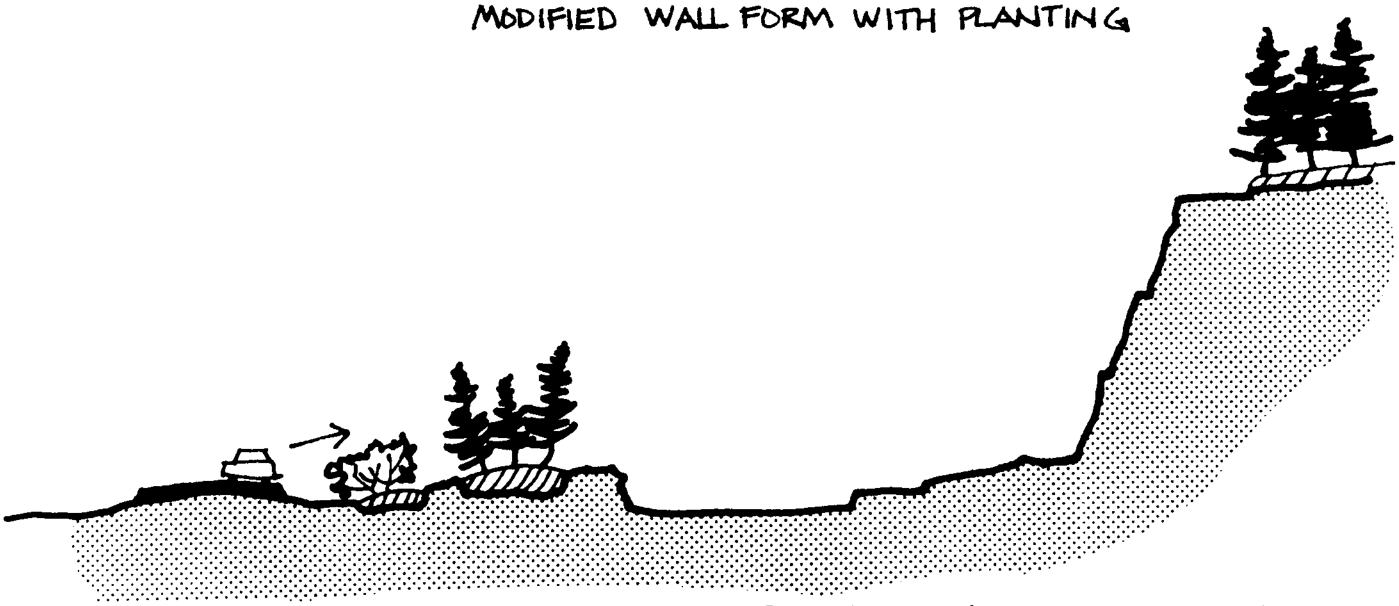
b) Further improvements can be made by planting vegetation on quarry walls. Ledges and depressions filled with suitable soil materials allow plantings to establish. Where there is access to the base or the top of the faces, cranes can be used for placing the soil. Soil can also be applied in slurry form by gravity feed through large hoses from above. This technique has been used experimentally in Britain and has been found to be quite successful (Humphries, 1977). The advantages of the technique are that it is cheaper to drop the slurry material than to pump it up from below. It is also



WALL UNTREATED



MODIFIED WALL FORM WITH PLANTING



VIEW OF WALL SCREENED BY FOREGROUND PLANTING easier to direct the slurry to desired positions, and to fill depressions in the rock, from above. Seed or cuttings, and fertilizer, can be applied with the slurry, or they can be applied later with a hydroseeder.

3.3 Visitor Use Areas

Visitor use areas in national parks can become degraded through over-use to such a degree that environmental quality and, in some cases, the safety of park visitors are seriously threatened and rehabilitation become necessary. Rehabilitation guidelines below are for those areas most frequently requiring attention in national parks, i.e. campgrounds, picnic grounds, backcountry campsites, and circulation areas associated with such facilities as interpretive displays, viewing points and park buildings.

3.3.1 Assessment of Problems

The cause of degradation of most visitor use areas is trampling resulting in loss of vegetation. Trampling damages or destroys plants through breakage of plant stems and branches, and through the loss of soil organic matter and the compaction of soil around plant roots which reduces soil aeration and moisture availability. As the ground cover is lost soils are more subject to erosion and sites can become muddy when wet and dusty when dry. With the loss of the shrub layer screening between campsites or between picnic sites may be reduced, and overall visual attractiveness of site areas is diminished.

Smaller trees are, of course, affected first since their branches and root systems are more vulnerable. Larger trees can survive much longer but will eventually be affected where adverse soil conditions are maintained for a number of years.

Increased stress makes them more susceptible to the effects of disease and insect infestation. In heavy textured soils, and where soils are shallow, compaction is often worse and the survival period may be considerably reduced. A major long-term problem results because natural regeneration in these areas is inhibited due to adverse soil conditions. The result is that eventually the tree cover disappears and with it the protection it provided against sun and wind, while scenic values are lowered.

Backcountry campsites frequently exhibit the same problems but these are often aggravated by the difficulties of maintenance and monitoring. Site limits are not usually clearly delineated, there are frequently no identified areas for tents (i.e. tent pads or platforms), fires may not be restricted to one area, and damage to trees occurs as firewood and tent-poles are cut.

The problems frequently associated with circulation areas are erosion, dusty and muddy conditions, exposed roots which can be a hazard to users, damaged vegetation in edge areas and overall reduction in visual quality.

3.3.2 Rehabilitation Practices

Treatment of visitor use sites differs and is frequently more complex than that of the other types of disturbed sites discussed in this manual since the cause of the disturbance - visitor activities - may still be ongoing. Therefore it is often necessary to decide not only how to remedy the effects of overuse but also how to avoid a re-occurrence. This section therefore deals with two subject areas: firstly, preventive practices to halt site degradation; and, secondly, remedial practices to rectify existing damage.

3.3.2.1 Preventive Practices

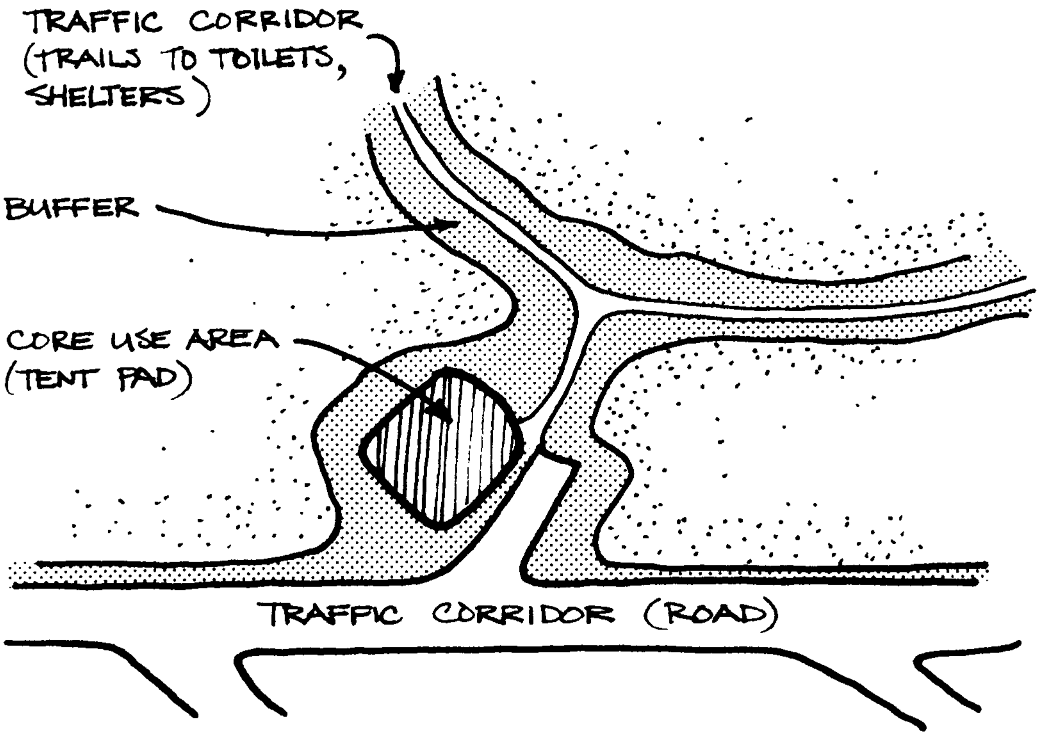
Preventive practices, ranging from design through site improvements and maintenance to regulatory and “communication” approaches, are discussed below in terms of their relationship to visitor use areas, and to their component use zones. In order to facilitate this discussion it is first necessary to define these zones (adapted from Nixey and Severs, 1977).

Core use zone - refers to the Unvegetated ground surface which is intended to provide the focal point of the site activity, i.e., the tent pad, table and stove areas at campsites, the table area at picnic sites and the circulation area at viewing stations (along trails, at interpretive displays, etc.).

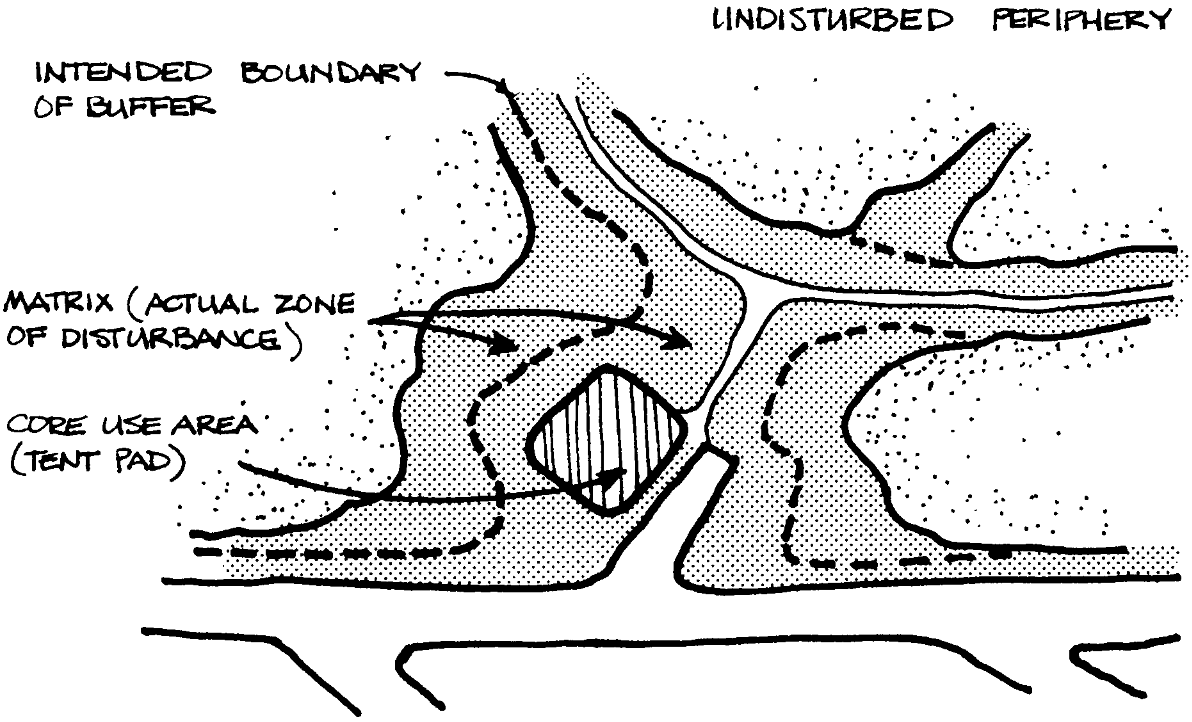
Traffic zones - includes trails and roads in the site area.

Periphery - the zone, surrounding the recreational site, not intended to support any activity as an aesthetically pleasing background for the site use.

Buffer zone - that part of a site which is meant to shelter the peripheral zone from activities occurring along trails and roads and in the



CAMPSITE USE AREAS – PLANNED USE, I.E. DESIRED USE PATTERN



CAMPSITE USE AREAS – DISTURBED SITE

core use zone. This consists of narrow strips beside trails and vehicle circulation and parking areas, and around the core use zone. Generally these are "hardened" to withstand some degree of use and have barrier characteristics to discourage excessive use of the zone itself and infringement into the periphery.

Matrix - the zone where there has been disturbance outside the intended use zones, i.e., outside the core and traffic zones.

A number of preventive practices are possible.

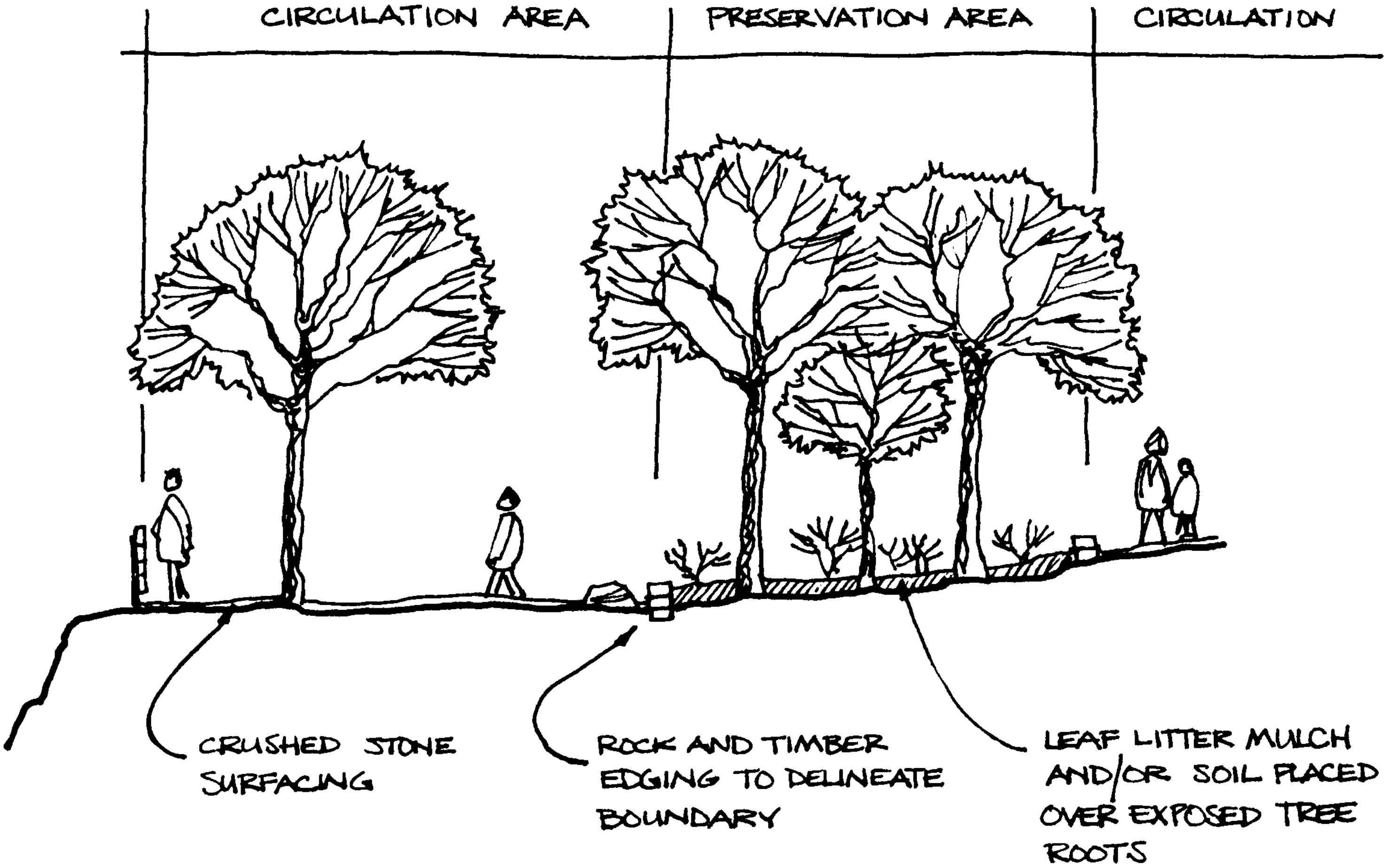
a) Improved Boundary Definition

Part of the reason for damage occurring to buffer and periphery zones may be because of the lack of a well defined boundary to the buffer zone. This can be alleviated by applying a surfacing material to trails, roads and tent pads which clearly demarks an edge line. At backcountry campsites where tent pad areas may not be delineated at all it may be desirable to do this by building gravel-reinforced pads or wooden tent platforms. Rocks and logs can also be used to reinforce edge lines. In high-use circulation zones, e.g., viewing points, it may be necessary to use less natural elements such as asphalt pavement and timber curbs to delineate edges.

b) Barriers

Direct measures may be required in some situations to discourage penetration into periphery zones. Barriers can be created in buffer zones by using plants which discourage entry because of thorns, "barbed" foliage or dense growth, e.g., briars, juniper, spruce or alder. Dense plantings of varied plant heights are effective because this creates a solid visual barrier which hides potential shortcut routes. Logs, rocks and low bushes placed beside the trail or around the tent pad will discourage excessive wandering. Unless they constitute a particular fire hazard leaf litter and fallen branches should not be "cleaned out" of buffer or periphery zones. They help to discourage penetration as well as provide valuable mulch.

Fences can be used in critical areas or where there is insufficient room for more natural types of barriers.



DEFINITION OF BOUNDARIES IN CIRCULATION AREAS

SHORTCUTTING IS DISCOURAGED BECAUSE OF DENSE SHRUB PLANTING AT EDGES AND BECAUSE VISUAL CONNECTION BETWEEN TRAIL AND CAMPSITE IS BLOCKED BY VEGETATION OF VARIED HEIGHTS

c) Redesign of Site Area

Circulation patterns often contribute significantly to trampling problems. These are largely influenced by locations of site facilities such as kitchen shelters, toilets, and wood supply depots. It may be possible to relocate some of these in order to reduce shortcutting and shift circulation back to trails or roads.

d) “Hardening” Site

“Hardening” refers to the reinforcement of selected conditions or qualities in order to make the site more resilient to use.

The surfaces of trails and circulation areas can be reinforced with materials such as gravel, crushed stone or wood shreds to prevent erosion, puddling and muddiness.

A mulch layer should be maintained in buffer zones to reduce soil compaction. Where additional material is required this ideally should consist of leaves and branches of plant specienative to the site. With regard to the application of organic mulches, see section 7.0 for the importance of maintaining an acceptable carbon-nitrogen balance.

In some situations non-native plants such as domestic grasses, more resilient to trampling, are useful for reducing impacts in buffer zones. Limiting the use of non-native plants in national parks is a policy objective. However, their use is justified where the net result is decreased erosion of soil and visual quality. It is recognized, moreover, that many use (and even park) areas are already far from being natural in some respects. Where this approach is taken selection can be made from plants requiring fertilizer in order to thrive so as to guarantee that they will not invade all zones. Even as a short-term measure fertilizer applications can be expensive. An effective alternative can be the selection of plants which will grow but will not reproduce under alien site conditions , or which act as a “nurse crop” (i.e., have a shorter life span than the “nursed” native species).

e) Improved Maintenance

Existing maintenance practices should be studied to determine if any are causing site damage. “Clean-up” operations, where leaf litter and branches are removed, and “grass” mowing in buffer and peripheral zones should be prohibited. They remove the natural mulch and destroy tree and shrub seedlings.

Maintenance practices such as fertilizing, watering, the "weeding out" of undesirable plants and treatment of plant diseases can be initiated or intensified to provide more durable plant covers.

Undergrowth can be encouraged in buffer zones by maintaining optimal light conditions through the pruning of trees. "Optimal" is used in the sense of achieving an appropriate balance between the light needs of the understory and the maintenance of the tree canopy for shade shelter and visual purposes (see 3.3.2.2.).

Where fires are allowed firewood should be supplied so that users do not collect wood from site areas.

Signs of damage such as felled trees, shortcut routes, littering, or unauthorized campsites should be removed immediately to prevent emulation.

f) User Education

The importance of this measure should not be minimized. This manual cannot do justice to this vital but often neglected approach. User education can heighten the park experience of the visitor, foster the application of the word and spirit of the National Parks Act and, in a more strictly rehabilitation sense, assist in stemming and reducing the mounting costs of environmental damages resulting from unconscious or willful actions.

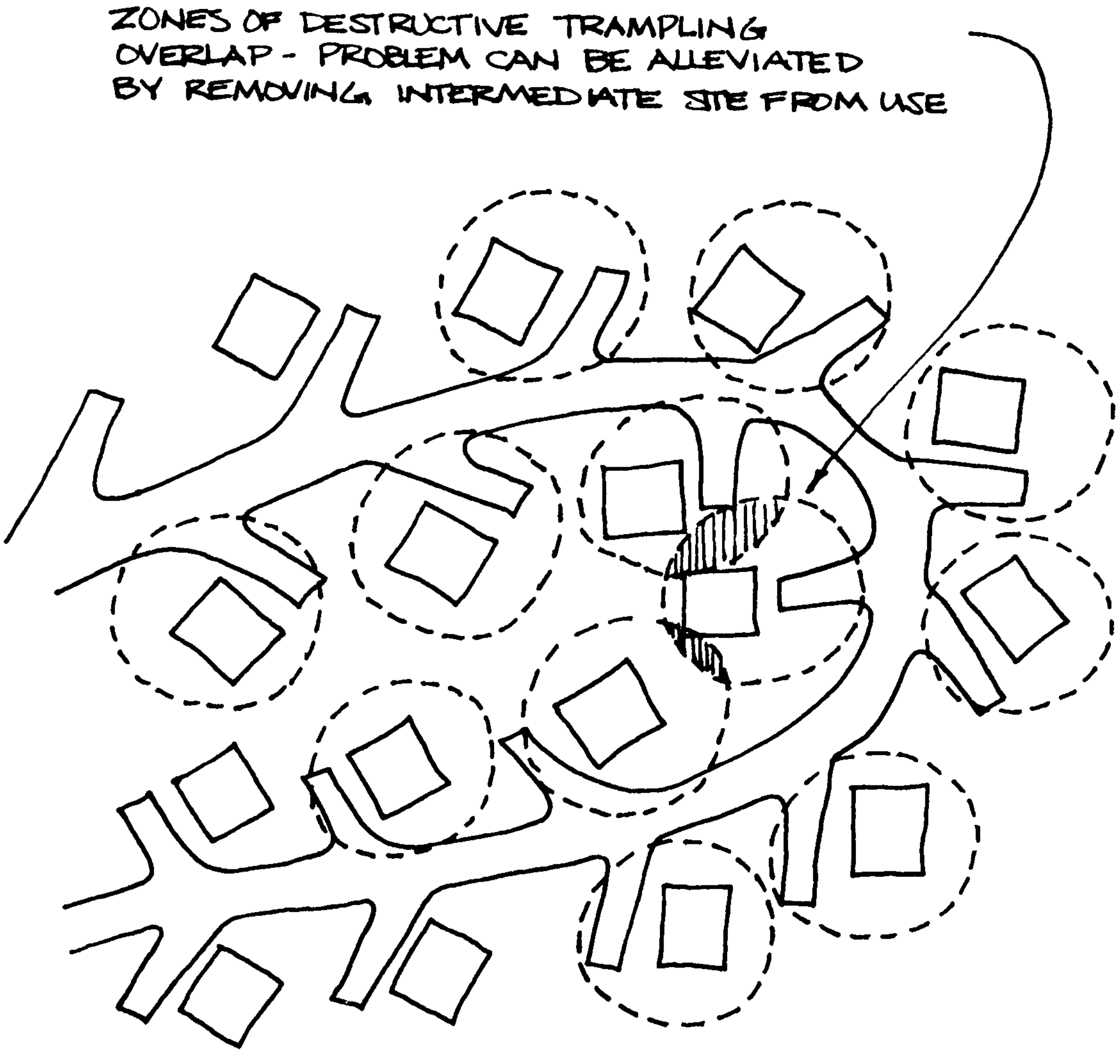
Rehabilitation success can be aided if the program is explained to the park visitors and their assistance is requested. Frequently users view the natural environment as being static and are unaware, for example, that shortcutting or the "cleaning up" of leaves and branches from around the edges of their campsites can have a deleterious effect.

g) Regulation and Surveillance

The enforcement of regulations may sometimes be required to combat such user acts as the cutting or the gathering of firewood, cutting tent poles at backcountry campsites, and pitching tents in non-designated areas.

h) Changes in Levels or Type of Site Use

Where environmental degradation has progressed to the extent where it is impossible to maintain a satisfactory vegetative cover it may be necessary either to permanently close the site, reduce the quality objective, or change the use to one



PRE-TREATMENT : NO EYE LEVEL SCREENING

TREATMENT : INTENSIVE REVEGETATION MEASURES SHOULD BE CONCENTRATED IN KEY AREAS WHERE LONG RANGE VIEWS THROUGH CAMPGROUND WILL BE CLOSED OFF where vegetative cover is not a paramount attribute for certain types of building or for a parking lot.

Where problems are not critical but still cannot be alleviated to the desired degree through the various measures described above (design modification, increased maintenance, etc.) it may be necessary to lower use levels in order to achieve an acceptable quality level. This can be done in several ways:

i) where sites are located close together the matrix zones, where destructive trampling has occurred, often overlap with the result that vegetation screens between sites are lost. If screening is required then the most appropriate solution may be to remove intermediate sites in key areas and to concentrate rehabilitation efforts in these places;

ii) levels may be lowered by limiting the number of persons permitted to use a site, e.g., at backcountry campsites;

iii) by closing use areas during periods of adverse weather conditions, e.g., periods of excessive wetness or dryness, when the site would be severely stressed if use were allowed to continue.

In developing a strategy from the above options (a-h) a number of factors should be considered. The objectives of the rehabilitation effort, i.e., the level of rehabilitation/environmental quality required, should be a key factor in determining the effort and the types of measures needed. For example, greater effort will be needed if the aim is to provide shrub layer for screening purposes between campsites, in addition to tree cover, than if the goal is limited to maintaining a tree canopy.

The natural capability of a site for the designated use should also influence the selection of options. The less resilient the site the greater the effort required to meet rehabilitation objectives. In some cases a site may have such low resiliency that the cost of “hardening” it, or of the intensive maintenance program required to achieve the objectives desired, would not be justified. It then might be necessary to reassess the objective in terms either of environmental quality or an acceptable level of use. In extreme cases it may be necessary to permanently close a facility or to change to a use more in keeping with the natural capability of the site.

The costs and benefits of alternative approaches should be considered. From the point of view of costs alone, the initial higher capital cost of new construction may be, in the long term more economical than the ongoing costs of an increased maintenance commitment.

Careful consideration should be given to proposals for reduction in use levels. Reducing use levels is basically an undesirable option but may be unavoidable in cases where a site cannot support the existing level of use, or where by intensive site transformation costs of providing that level are not feasible. Reductions in use levels are undesirable for three main reasons: they can result in visitor dissatisfaction, they may necessitate large expenditures for the development of replacement facilities and they may result in a shift of impacts to other facility areas.

3.3.2.2 Remedial Practices

The level of rehabilitation treatment provided will depend on the speed of recovery required and the environmental conditions of the treatment areas. In areas that are to be permanently closed to use structures and surfacings of roads, trails, tent pads etc. should be removed and compacted soil areas should be scarified. Areas can then be left to natural regeneration processes or seeded over if erosion control is necessary.

Where part or full site use is to be retained, compacted soil areas should be reconditioned by scarifying. In some cases the addition of organic materials, other soils and fertilizers may be required prior to planting (see section 5.0 for planting procedures).

Steps should be taken to control precipitation runoff on areas susceptible to erosion. Ditches and water bars can be used to divert water and the soil surface should be scarified and mulched to increase the infiltration rate.

Where plant growth is to be encouraged in areas previously used for fires or for wood chopping, ashes, woodchips and sawdust should be removed and a nitrogen rich fertilizer applied to assist in restoring a desirable carbon-nitrogen ratio in the soil (Fitzmartyn, 1979).

In situations where a canopy of mature trees is producing very dense shade it may be beneficial to clear out some of the trees to encourage plant growth at ground level. Cordell (1974) reports from his studies (Tennessee) that reducing canopy cover by 60 percent doubled the grass cover from that produced under a 90 percent canopy, and reducing it to 30 percent more than tripled grass production. He points out that a balance is required between retaining canopy cover to provide shading for recreationists and removing it to support plant growth. He recommended a 60 percent cover based on findings of a study in North Carolina which indicated that 63 percent of interviewed campers preferred moderate shading over very light or very heavy shading.

During the reconstruction period of the rehabilitation program, e.g. removal or re-shaping of tent pads, construction of trails and barriers etc., it is generally necessary to close sites to use. However it should not be necessary, nor is it practical, to close sites for long periods of time for the purposes of re-establishing plant cover. If adequate measures are taken to limit the impacts of site use, and by a sound public relations program, it should be possible to permit a level of use during the rehabilitation period. In this way, it was possible to permit use of a YMCA camp in Cape Breton Island National Park during a rehabilitation program.

Herrington and Beardsley (1974) carried out a successful plant establishment program during the time that a campground was involved in active use. The only interruption of use was one day each week when the visitors were required to leave the campground to permit irrigation of the newly planted areas. The campground was closed from 2 o’clock on Tuesday afternoons until 8 on the following morning. There was no evident hostility to this requirement and they speculate that this was either because there were other campgrounds near-by or because of the efforts made to explain the program to the visitors.

4.0 PLANT SELECTION

There are a number of factors that should be considered in the selection of plant species for rehabilitation work. These can be divided into three main categories: factors relating to the species’ ability to survive and develop in its new environment, factors relating to the species’ ability to satisfy the rehabilitation objectives, and factors relating to the availability of plants and the costs of establishment. Whenever possible the assistance of plant experts at local universities or agricultural or forestry research stations should be utilized for the selection of plants.

4.1 Plant Selection - Hardiness

Many disturbed sites present harsh environmental conditions for plant growth even after physical alterations have been made to improve these. The following paragraphs describe key factors that should be considered for the successful selection of plant species.

4.1.1 Physical and Chemical Soil Properties

A careful analysis must be made of the soils of the site to determine what limitations there will be to plant growth. Such an analysis should indicate nutrient availability, pH level, soil texture and structure and the presence of toxic materials.

Nutrients may be in short supply on disturbed sites especially where topsoil has been removed or buried by cut and fill operations. Nutrient availability can also be restricted by excessively high or low pH levels.

Soil texture and structure are important because they affect the availability of moisture. Coarse textured soils have low moisture holding capacity with the result that less moisture is held in the top soil layers for use by plants. This is especially significant for seedling establishment since the roots are restricted to the top few centimetres of soil. Where the soil structure has been altered by compaction, soil porosity is reduced and the capacity for air and water infiltration is restricted. This physically inhibit root growth and thus restrict nutrient uptake.

Test samples should be taken from a number of different locations on the site since soil conditions can vary considerably. For example, soil texture is likely to be coarser at the top of slopes than at the bottom because fine soil particles tend to be carried away by water movement. For the same reason nutrient supply is in most cases likely to be better at the base of slopes than at the top of slopes.

Soil moisture conditions can vary considerably depending on the position on the slope and the location of the water table. On filled slopes soil texture and nutrient supply can vary significantly since the fill may come from a variety of sources. Where de-icing chemicals are used on a road surface adjacent to slopes there is likely to be an accumulation of salts at the base of the slopes. Specific instructions for taking samples should be obtained from the testing agency.

4.1.2 Temperature

Annual and daily maximum and minimum temperature fluctuations have an important influence on plant survival. These are influenced by:

- geographic and elevational position

- topographic position

  Sites along valley floors where cold night air settles can have lower minimum temperatures than positions on the sides of valleys.

- aspect

  Aspect determines the exposure of the site to the effects of sun and wind. Temperature fluctuations are much more severe and soils are likely to be drier on southern slopes than on northern slopes.

  East facing slopes will receive as much sunlight as west facing slopes but not lose as much moisture through evaporation and transpiration because of cooler temperatures early in the day.

- shelter

  Landforms, vegetation or man-made structures can block sunlight and wind to reduce temperature extremes. These objects can also influence snow deposition which can moderate winter temperature effects.

4.1.3 Soil Moisture

Soil moisture is a key factor in influencing plant development . This is most critical during germination and seedling stages of growth since roots have not yet penetrated to a depth in the soil where moisture is more available.

The effect of limitations in moisture supply on germination varies with the plant species depending on such factors as seed size and shape. Dessication is less of a problem with small seeds because they have a larger contact to surface area ratio (Fitzmartyn 1979). Burying of seed and mulching help to reduce this problem by conserving moisture in the upper soil layers.

For selection of plants attention must also be given to the time when optimum moisture conditions exist. The period of maximum plant growth should coincide with the time of season when there is a good supply of moisture. If most of the yearly moisture supply is available for a short period rather than spread out there will be greater difficulties in plant establishment.

Soil moisture supply is influenced by soil texture and colour, slope, temperature extremes and soil moisture reqime. Some techniques for conserving soil moisture supply are described in Section 6.2.

4.1.4 Resistance to Pests

In the selection of plants consideration should also be given to the ability of plants to avoid or withstand the attacks of browsing animals, insects or plant diseases.

4.1.5 Resistance to Human Activities

Human activities within the rehabilitation area can have a considerable influence on the survival of plants and efforts should be made to select species able to tolerate certain of man's activities: on roadside sites there are effects of maintenance such as mowing, the use of de-icing chemicals and snow ploughing, and in visitor use areas there are effects from trampling and vandalism.

4.1.6 Conclusion

The relationship of the various factors affecting plant development is complex and in many cases soil and plant specialists should be consulted for selecting appropriate species and for determining methods for improving site growing conditions.

A general guide for selection of plant species for highly disturbed areas is to make the selection from species of adjacent vegetation types that persist under more xeric conditions (Monsen 1975). Monsen reports on a study in Idaho in which plants successfully established on exposed strata of road cuts were selected from lithic soils of ridge crests and steep canyon walls.

Plummer (1977) supports this approach. He points out that genetic differences occur within populations of a species from different geographical and aptitudinal areas (referred to as ecotypes). These differences between ecotypes have evolved over long periods of time as a result of natural selection. By carefully matching site conditions therefore it should be possible to identify ecotypes that would be successful for revegetating disturbed sites.

The biophysical inventory mapping available for most national parks should be useful in helping to identify areas where similar ecotypes can be found. Where, however, the disturbance has radically changed the nature and properties of the surface layers the ecotype from a land unit similar to the pre-disturbed state may not be adapted to the disturbed state.

Plummer (1975) points out that plants considered to be pioneer species are often useful in rehabilitation of drastically altered sites. Some of these are slow to invade disturbed areas because of a lack of native seed crops or because of unstable soil conditions. However, they can be quite successful if planted artificially and if soil conditions are improved.

Except where heroic and costly practices are taken smaller plants have much higher survival rates than “landscape - size” material. It is generally wise to overplant in order to allow for expected mortality. Small plants not only are more cost-effective than tall plants, they also can be easily grown from seed or cuttings in private nurseries, generally for a lesser cost than collected plants.

4.2 Plant Selection - Rehabilitation Objectives

In addition to selecting plants on the basis of their ability to survive and develop, they must be looked at for their ability to fulfill the specific objectives of the rehabilitation program, such as erosion control, improvement of visual quality, or the provision of shelter in campgrounds. The following paragraphs point out some of the key attributes that should be looked for in plants that are to fulfill such roles.

4.2.1 Erosion Control

Plants that spread to produce a mat-like covering of vegetation over the soil are preferable to those that concentrate their growth in scattered clumps. The speed of germination and of outward growth are important. Plants with fibrous root systems are well suited to erosion control because of their ability to hold soil particles in place. Deep rooted plants are useful in combating mass soil slipping.

4.2.2 Soil Improvement

Plants which produce a substantial quantity of leaf litter which decomposes readily are beneficial because this material acts as a mulch, which moderates soil temperature fluctuations, conserves soil moisture and reduces erosion, and it provides a supply of nutrients for plant growth.

Leguminous plants are valuable because they increase the nitrogen supply in the soil by fixing atmospheric nitrogen.

4.2.3 Ecological Compatibility

It is important that careful attention be given to selecting plants that will support the desired successional development of the plant community in the rehabilitation area. A thorough understanding of the dynamics of the local ecosystems is required to create optimum conditions for plant community development.

Various exotic plant species can be useful for rehabilitation work because of characteristics which make them well suited to surviving harsh site conditions and to controlling erosion. However, caution must be exercised in their use. They should not be introduced to an area if there is a chance that they will be persistent, or will in some other way upset the environmental balance in adjoining areas. This is of particular importance in national parks where a high value is placed on preserving natural conditions.

Where exotic plants are envisaged the aim should be to use species which will provide for initial soil stabilization and conditioning and will then begin to decline to allow more slowly developing native plants to establish. Various agronomic species of grass are used effectively in this way: they establish quickly but cannot sustain themselves for very long and are replaced by the better adapted local plants . This process can also be achieved if the introduced species is supported initially by fertilizing which is later terminated to support the establishment of native plants.

4.2.4 Fire Resistance

Fire resistance is an important consideration in plant selection for locations where forest fires are prevalent. The following characteristics should be looked for (Nerd, 1977):

- low growing prostrate shrubs
- high moisture content in foliage
- rapid decomposition of leaf and twig litter.

4.2.5 Attractiveness to Wildlife

In some situations it may be advisable to avoid the use of vegetation that is attractive to wildlife. Plants attractive to large animals should not be used for roadside rehabilitation work because of the likelihood of collisions occurring between the animals and automobiles. Plants attractive to bears should not be used where they would increase the chances of contacts between bears and humansl e.g. , along trails, or near campgrounds.

Low forms of plants should be selected for use along highway verges in areas frequented by large animals. This allows drivers better visibility so that they have more time to react if the animals approach the roadway.

In some cases, where there is no threat of conflict between animals and humans, it may be desirable to select plants that will provide food and shelter for wildlife.

4.2.6 Minimal Maintenance

Notwithstanding the discussion of "improved maintenance" above (3.3.2.le)), in view of cost, budgetary and staff constraints, maintenance in many cases will be minimal or nil. While it will be impossible to avoid maintenance costs in every case it is important to consider the no maintenance condition during the rehabilitation process.

4.3 Plant Selection - Availability

A major factor effecting the selection of plant species is the availability of the plants or their seed, and the ease with which they can be planted. In many cases native plants are not available from commercial nurseries or are not available in large enough quantities. Where site conditions are particularly harsh and specific ecotypes are needed, this will be even more of a problem.

Obtaining sufficient quantities of wild seed for some species can also be difficult. In some years, depending on weather conditions, production of viable seed can be very low. Some species may never produce abundantly. Obtaining viable seed is often also difficult because of uneven ripening and seed shattering. Seeds of some species are difficult to remove from the plants or cause physical discomfort to the collector. (Monsen and Christensen, 1975).

4.4 Combinations of Plant Species

There are a number of reasons why it may be desirable to use a mixture of plant species in the treatment of disturbed sites.

a) A mixture may be more compatible with varied environmental conditions, e.g., differences in moisture and nutrient availability, in exposure to sun and wind.

b) A mixture may offer complementary capabilities for erosion control. A combination of herbaceous plants with shrubs and trees is effective because the herbaceous plants form a mat which reduces the erosive effect of impacting raindrops and running surface water, while the larger roots of the shrubs and trees provide strong ties into the deeper soil layers. In some cases tree cover alone would be adequate to control erosion, but the herbaceous plants are needed to provide protection during the establishment period. Combinations of plants which come into leaf early in the spring with plants that retain their foliage late into the autumn are effective in reducing erosion caused by rainfall impact over an extended period of time.

c) A mixture is normally more aesthetically pleasing. A mixture of plants which provides a variety of height, form and colour often appears more natural and blends more successfully with vegetation in adjacent areas than one which consists of a very limited number of species. The degree of variety should be similar to that found naturally in the area. In the case where only a few species exist naturally the selection for the treatment area should be similarly limited.

d) The introduction of a variety of species normally enhances survival of the cover. With a very limited number of species the chances of the plants being eradicated by adverse conditions such as climatic extremes, or disease or pest attack, are greater.

Although there are benefits to using mixtures of plants for disturbed site rehabilitation for there can be problems as a result of competition. Most commonly these problems exist between herbaceous and woody plants. Herbaceous plants often compete vigorously for moisture, nutrients and light, and they can severely affect the development of woody plants interplanted with them.

Combinations of vigorous herbaceous plants with fragile, slow developing, woody species are not likely to be successful. Where vigorous herbaceous plants are to be used, shrub and tree selections should be from species with demonstrated competitive ability. Quick growing plants will likely be most successful. Typical pioneer species will often be successful competitors.

The rooting habit of trees may also affect the susceptibility to competition from herbaceous plants (Vogel, 1973). Presumably trees with shallow rooting systems would be at a greater disadvantage than those with deeply penetrating roots.

The relative sizes of plants are significant. It is best to use seedlings that are larger than the mature height of the herbaceous plants to be used. If shorter they may be shaded out and, in the autumn, they may be buried under a mat of vegetation resulting from the death of above-ground portions of the herbaceous plants.

The relative timing of the planting of the herbaceous and the woody plants can be significant. Vogel (1973) concludes from a study done on competition between various herbaceous plants and trees that it is preferable to plant the competing plants at the same time. He found that if the trees were planted into established stands of herbaceous plants their growth was considerably retarded.

Bengtson (1973) on the other hand points out that if non-persistent species of grass are used, supported by fertilizer applications, that woody species can be successfully established one or two seasons later when the grass’s vigour begins to dwindle. The grass improves the soil conditions by adding organic material to the soil and by stabilizing the soil against erosion.

Problems can occur if herbaceous and woody plants are seeded simultaneously. Usually seeds of woody plants require a longer period of stratification than do those of most herbaceous plants. The result is that by the time that the trees and shrubs begin to grow the herbaceous plants are well established and better able to compete. If simultaneous seeding is favoured selection should be of woody plants that have a short period of seed stratification or ones that can be altered by artificial means (Monsen and Christensen, 1975).

Erratic germination, which commonly occurs with woody plants, also creates problems in that plants may not germinate when moisture conditions are most favorable. Where competition is expected to be significant it will be best to transplant woody species rather than to plant seed.

Competition can also be reduced by limiting the density of plantings or balancing the proportions of plant types used.

Selection can be made of plants which do not have coinciding maximum growth periods. One may make a spurt of growth in the spring and then slow to minimal growth while the other may grow at a constant rate throughout the summer season.

Where mice or other rodents are common (e.g. in a heavy grass sward - a good winter habitat) care should be taken to protect young trees from being debarked or girdled. The bark may be protected by an anti-rodent chemical, by wire netting, or by plastic shields manufactured for that purpose.

5.0 PLANTING METHODS

This section provides guidelines for the steps that are generally required for the planting of disturbed areas. It deals with the alternative methods, seeding, transplanting and vegetative reproduction.

5.1 Seeding

In order to ensure effective germination and cover growth, careful attention should be paid to the preparation of the seedbed, time of seeding, seeding method and to post-seeding practices.

5.1.1 Seedbed Preparation

5.1.1.1 Tilling

A good seed bed, in terms of physical condition, is one which is sufficiently fragmented at the surface (depth of 12 mm to 5 cm) that the seed can be placed into the soil and then covered with a layer of loose soil particles. Providing a soil cover for the seed is one of the most important requirements for successful plant establishment, especially where shortage of soil moisture is critical. The lower success rate for seeds sown onto unbroken ground also occurs because more seed is lost to water and wind erosion, and to birds and rodents.

On sites where heavy equipment has been used, such as in road construction, the soil surface may be severely compacted, especially in the case of clay soils. To loosen such soils heavy soil “ripping” equipment will be necessary. A claw attachment mounted on the back of a bulldozer is frequently used for this task. Careful assessment should be made of the soil conditions to determine the optimum depth for the ripping, since soils at lower depths may contain undesirable materials such as dense clays or accumulations of salts.

Where compaction is not severe the soil should be loosened to a depth of 15 cm to 20 cm and the top 10 cm should be further worked until it is broken into fairly fine fragments.

On large and relatively flat areas (maximum grade of 1:3) a tractor-mounted disc harrow is generally suitable for soil tilling. Where the soil surface is exceptionally hard a chisel plow is useful for loosening the soil prior to discing. Rototillers and cultipackers can be used for fine filling of the topmost layers and spike-tooth harrows are well suited to breaking clods of earth and for smoothing the seedbed.

All equipment should be operated across rather than up and down slopes so that grooves and tire tracts in the soil act as checks to erosion. Reference has been made to breaking compacted soil "into fairly fine fragments" and "smoothing the seedbed". These words are used in a relative rather than an absolute sense. Care should be taken not to over-"manicure" slopes: this is costly and can be erosion-prone . On a micro-scale irreqularities along the contour are normally desirable: the irregularities lessen down-slope erosion, provide useful microclimatic conditions and a soil mulch for the seed. Final smoothing of the slope tends to occur naturally.

For large operations where slopes are too steep for use of the more standard types of equipment, specialized equipment is sometimes used for soil tilling. There are crane attachments which can be operated from the base of slopes, and where there is adequate space and access to the top of slopes, a tractor mounted device called the "clodbuster" can be used. A "clodbuster" is a chain with spikes along it and a ball at the end. This is dragged across the slope and as the chain turns the spikes and the links spin around and break-up the soil surface.

On areas too small for the use of tractors and where grades are not steep, hand-operated rototillers are useful for tilling. On areas where grades are too steep for mechanical equipment or where access is limited - as is likely to be the case with many sites in national parks - tilling will have to be done by hand tools such as mattocks, picks, hoes and rakes.

Caution must be taken when tilling soil in situations where there are living roots of trees or shrubs under the surface. This is a common situation in campgrounds and picnic areas and along the edge of trails where soils have been compacted. Sandy soils are easier to deal with than clay soils because they can usually be adequately worked by raking or very shallow harrowing or rototilling. With clay soils tilling is more difficult. Clay soils that are densely compacted cannot be easily broken and require heavier cultivating which increases the danger for the plant roots. The problem is further aggravated because, in clay, plant roots tend to concentrate closer to the soil surface than they do in other soil types. The best approach is to assess each situation individually. If the plants involved are healthy, and only a portion of the root area will be affected, then heavy tilling using rototillers, aerators or soil slicers may be acceptable. However if all sides of the plant need to be treated such action could be quite damaging. Treatment of such sensitive areas then might best be phased over several years.

5.1.1.2 Soil Amendments

In many cases in order to successfully establish a plant cover on disturbed sites various amendments must be added to the soil. This is particularly true where the original topsoil layer has been lost, as is commonly the case where there has been excavation, where excavated material has been deposited, or where there has been severe erosion. The layer of topsoil in an undisturbed area has gradually developed over hundreds, or even thousands of years, and is generally well suited to plant growth. It contains plant nutrients derived from the decomposition of plant and animal matter; it contains micro-organisms which assist in the production of nutrients, and its structure is generally such that it allows for an adequate movement of air and moisture within the plant rooting zone. Where this topsoil layer has been lost site potential for supporting plants is significantly reduced and measures must be taken to improve the remaining soil material to a condition suitable for plant growth.

Soil tests should be conducted in order to determine what materials should be added to the soil and at what rates. Tests can also be made of the undisturbed soils of adjacent areas since it will be desirable to match, as closely as possible, the natural conditions of the area. The latter tests, however, may be impractical since plants on the disturbed site may never grow sufficiently to tap the deep source of nutrients the established plants utilize.

Coen[3] suggests the application of nutrients to meet the needs of the plants to be established. Once established nutrients should be added to facilitate movement towards the desired eventual plant community. The restoration of natural conditions and processes can be complex and costly: expert advice should be sought.

a) Addition of Topsoil

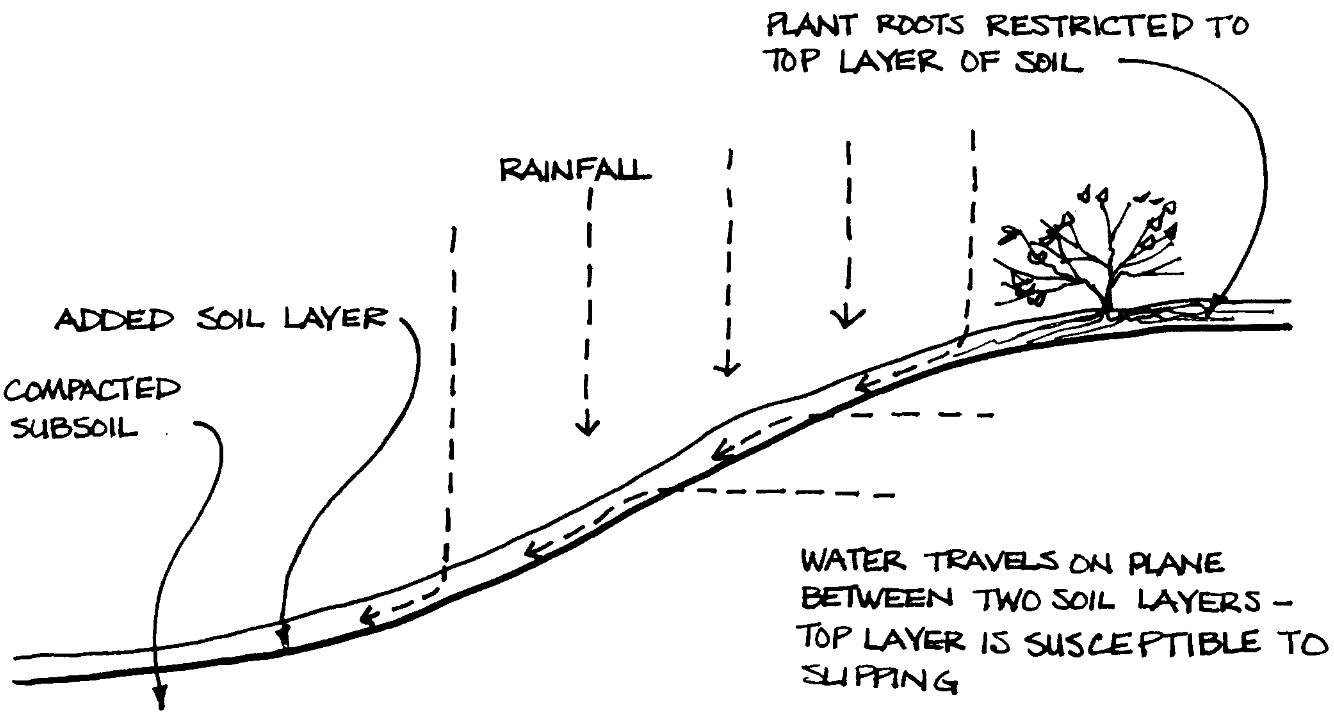
Where a supply of topsoil is available this obviously can be of great benefit in improving the plant growing properties of disturbed soils. Therefore a first step in the rehabilitation of a site should be to check to see if there are any acceptable sources of topsoil. In many cases conventional sources of topsoil will be too expensive and there are obvious environmental restrictions to “borrowing” topsoil from natural areas within parks. However there may be future construction projects planned for areas nearby to rehabilitation sites which could provide inexpensive topsoil. Where such sources of topsoil are likely to be available this should be considered in the planning of a park’s overall rehabilitation program. Priorities for use of topsoil should be established and a schedule set to match that of the construction activity. The ideal situation is to be able to move excavated topsoil directly to rehabilitation sites without any interim storage period. Double-handling increases costs, and storage can be detrimental to the micro-organisms within the soil.

Noting the qualifications in paragraph 2 above, and particularly where the disturbance is not severe, donor and recipient sites should be as similar as possible in terms of biophysical characteristics i.e., from similar biophysical land classification units. This would promote the quickest recovery to a natural state and the soil would likely contain seeds from plants adapted to the conditions of the treatment site.

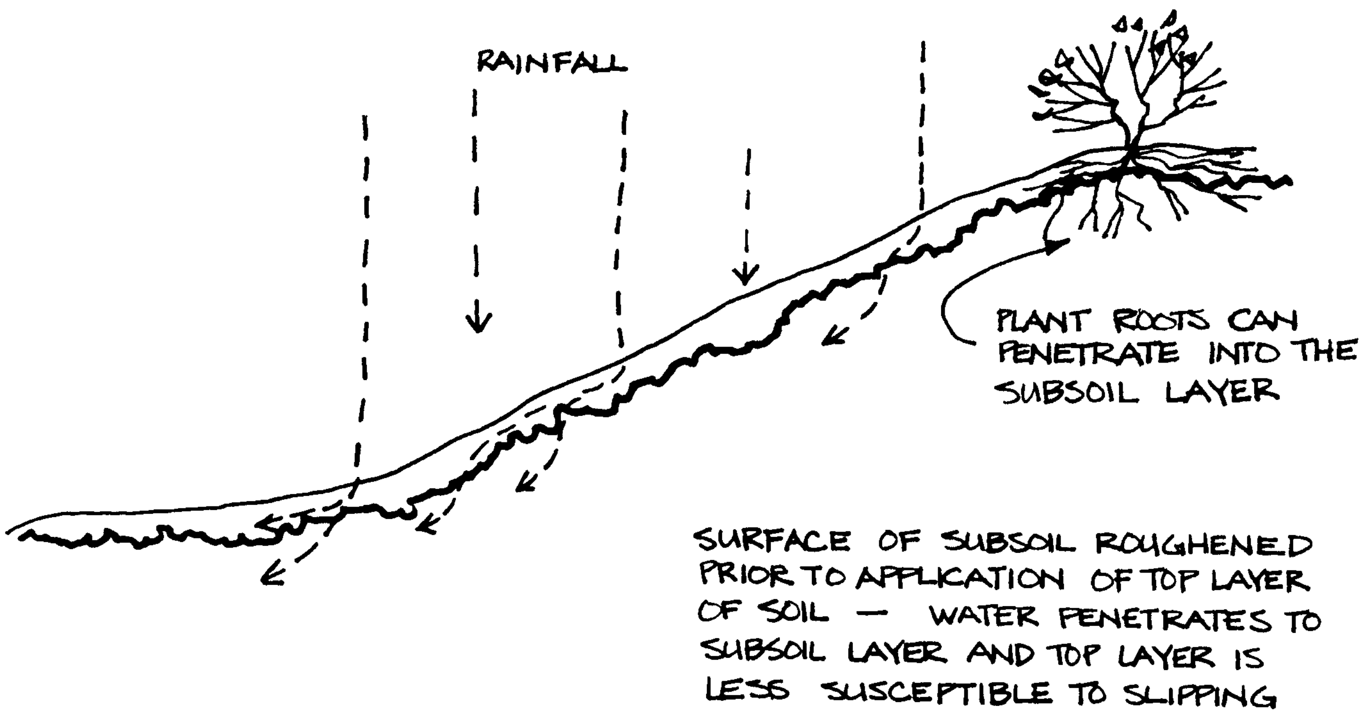
b) Addition of Subsoil

In some situations subsoil materials, which may be available from current construction activities, can also be used to improve soil conditions for planting on disturbed sites. Fine textured "plastic" soils can be used to improve the texture of coarse soil types (sandy and gravelly soils).

3 Personal communication G. Coen, pedologist, Agriculture Canada, Edmonton, Alberta.



IMPROPER PLACEMENT OF SOIL



PROPER PLACEMENT OF SOIL

This helps to bind the soil particles together and increases their capacity to hold nutrients and moisture, and reduces their susceptibility to erosion. In addition clay and silt subsoil material may contain plant nutrients (Foote, 1970).

Where the soil of the treatment site is heavy clay, sandy subsoils can be used to "lighten" these in order to provide for better air and water penetration and for easier root growth.

Immediately prior to the application of additional soil material the existing soil surface should be cultivated. This is desirable because the roughened surface that results provides a better bonding between the two soil layers and because it improves conditions for root growth and the movement of air and water.

c) Addition of Organic Materials

Organic materials such as straw, bark shreds or decomposing leaves can be added to clay or sandy soils to improve soil structure. In clay soils organic material "opens up" the soil to allow for better air and moisture movement and in sandy soils it helps to bind the soil particles together which increases the soils ability to retain moisture and to resist erosion. As the organic material decomposes it provides nutrients for plant growth. See section 7.0 with regard to organic mulches and the carbon-nitrogen balance.

d) Addition of Fertilizers

Fertilizer application, in many cases, is essential in order to achieve the successful establishment of plants on disturbed sites. Achieving a quick and dense stand of vegetation is often the most critical requirement. Once such a cover is achieved, site conditions are often sufficiently altered (climatic modification and erosion control) to allow for the continued development of the plant community.

The fertilizer mix and the rate of application should be determined on the basis of soil tests, and qualified soil specialists should be consulted. Various factors which should be considered are discussed below.

Suitable application rates for fertilizer will vary with plant species and with soil characteristics, i.e., soil texture, organic matter content, ion-exchange capacity, depth and available nutrient supply (Fitzmartyn, 1979).

The total nutrient content of the soil does not always coincide with the actual amount of nutrients available for plant use. Nutrients may be "locked up" in chemical and microbiological processes because of imbalances in the soil condition. As well, nitrogen can be limited under cold soil conditions because of low rates of bacterial activity and because of the relative lack of other nutrients. The pH level of the soil can also restrict the availability of nutrients (Fitzmartyn, 1979).

A two or three step fertilizing program may be beneficial for sites with particularly difficult growing conditions, e.g., steep slopes or soils with a very low nutrient content. A first application is made at the time of seeding and a second at the beginning of the next growing season. In some locations, such as at the top of steep slopes where degeneration occurs more quickly, a third application may be necessary. Where such multiple applications are to be used consideration must be given to the effect that this may have on the relative vigor of different species in the plant mix. Repeated fertilizing may endanger woody plants if an herbaceous "nurse" crop is supported for too long a period.

Fertilizer can be applied with standard tractor-operated equipment where sites are accessible and grades are not steep (maximum grade of 1:3). On small sites or sites with steep slopes hand applicators are often most practical. On very steep slopes the best approach is to use a hydroseeder by which the fertilizer is applied in a mixture with the seed and water. Where hydroseeder application is used it is advisable that the load should be emptied within thirty minutes of the fertilizer being added or the "salt effect" of the fertilizer may decrease the germination of the seed (Foote, 1970).

When fertilizer is applied dry, the area should be watered thoroughly afterwards to prevent seedling's from being burned by the chemicals.

e) Addition of Lime

Application of lime may be required on overly acidic soils where this condition restricts plant development. Generally a pH range of 6 to 7.5 is desirable but this can vary depending on the species of plants involved. Lime can also be beneficial in that it improves the structure of clay soils and, in creating a more favorable environment for bacteria, hastens the decay of organic material. As with fertilizing the application rate should be determined on basis of soil tests.

Ideally lime should be added and worked into the soil a few weeks before planting. However this is not usually possible on sites that are highly susceptible to erosion.

5.1.2 Seed Planting Methods

There are three methods of seed planting commonly used in rehabilitation work: drill seeding, broadcast seeding and hydroseeding.

5.1.2.1 Drill Seeding

Drill seeding is generally considered to be the best method of planting seed because the seed is buried immediately upon application and because it is possible to accurately control the depth, distribution and rate of seeding. An even distribution of seed is particularly important for controlling erosion. Other advantages of drill seeding are that it is possible to pack the soil over the seed and lower seed application rates can be used. With drill seeding establishment is generally more successful than with other techniques due to optimum conditions for germination and because seeds are less likely to be lost to rodents and birds, and to the effects of erosion.

Several points of caution should be noted with regard to drill seeding. Frequent checks should be made to ensure that the different species of seed in a seed mixture do not separate out (this can occur because of equipment vibration) and that the seed load is evenly distributed across the seed reservoir. Care must also be taken to ensure that the drill is properly adjusted so that the seed is not placed too deeply in the soil. Drilling should be done across slopes so that depressions left by the drills and the wheels act as checks to erosion. (Foote, 1970) .

5.1.2.2 Broadcast seeding

Broadcast seeding is a term used to describe seeding techniques by which seed is deposited onto the soil surface in a dry condition. This can be achieved with equipment mounted on or pulled by tractors (cyclone spreaders) or by a machine that is hand carried. Broadcasting is a more suitable method than drill seeding where the soil surface is irregular or rocky. Hand broadcasting spreaders are used where slopes are too steep for vehicles or where vehicle access is not possible. Where seeding is done by hand or with hand-operated spreaders the seed should be divided into two lots and these applied separately and at right-angles to each other to ensure even distribution.

Spot planting will be necessary for seeds that need to be planted at greater depths than those of the bulk of the planting mix or where the seeds are too large to be accommodated by the seeding equipment.

5.1.2.3 Hydroseeding

The hydroseeding technique is generally the most expensive but is extremely useful for seeding slopes too steep for the operation of mechanized equipment. Blight[4] states that, in the western mountain parks, steep slopes and rocky soil conditions don't allow drill seeding, and broadcast seeding followed by raking or harrowing are also impossible. Thus generally, in the mountain environment, hydroseeding is the only realistic option: in terms of cost hydroseeding is competitive with drilling and cheaper than broadcast or hand seeding.

Seed can be sown by this method onto nearly vertical slopes if a fibrous material, which holds the seed to the soil surface, is added to the water and seed mixture. Another advantage is that the fertilizer can be applied in the same operation.

There are a number of precautions which should be taken with hydroseeding (adapted from Kay, 1973):

a) Gear pumps with the paddle type of agitator are recommended rather than centrifugal pumps. Kay reports that his studies have shown that centrifugal pumps with by pass agitation systems can damage the seed. This is particularly true when there are large seeds in the mix as would be the case with the seeds of woody plants. Kay recommends that, when the centrifugal type of pump is used, the delivery time (the time from which the agitation of the seed in the tank begins until the seed is sown) should be limited to a maximum of twenty minutes and that wood fibre should be included in the mix (recommended rate of 500 kg/14000 L water/ha).

b) Care must be taken to see that the correct size of nozzle is used. Sometimes hydromulching nozzles are used when there is no mulch included with the mix, with the result that there is an uneven distribution of the seed.

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4 Personal communication L.G. Blight, Parks Canada, Calgary, Alberta.

c) Unevenness of distribution also occurs because it is difficult for the gun operator to discern the pattern of distribution that he is making. To overcome this, colour dyed wood fibre should be added to the seed mixture.

d) Hydroseeding should not be carried out when wind speeds are in excess of 23 km/h.

5.1.3 Time of Seeding

The proper time for seeding depends upon the plant species being used and climatic conditions. For many grasses late summer planting is desirable because of suitable temperature and moisture conditions, and because plants are able to become well established before the dry summer season arrives. Early spring planting is usually the next best time to plant. If irrigation is available the timing is not as critical.

Late autumn seeding is desirable for seeds which require a cold period to overcome inherent dormancies. This must be done late enough that germination does not occur but prior to the ground freezing. Autumn planting is well suited to alpine conditions where spring access is limited by snow conditions (Fitzmartyn, 1979). Seeds which have embryo-dormancies and are to be spring planted will need to be chilled for suitable periods prior to planting (Zak, 1976).

5.1.4 Post-Seeding Practices

Where possible seed should be covered with a thin layer of soil. The depth of this layer is critical for the germination and survival of many plant species. For very small seeds the required depth may be as little as 6 mm. This factor should be considered when seed mixes are being planned, because a portion of the seed may be lost if requirements for depth of soil cover vary considerably between species.

On flat and gently sloping areas harrows (spike tooth drags) and cultipackers can be used for covering seed. The cultipacker is particularly good because it firms the soil over the seed.

On slopes steeper than 1:3, because of the difficulty of equipment operation, seed covering will likely best be achieved by hand raking. Where this is not possible because of extreme steepness or lack of sufficient loose soil, mulching material can be applied to secure the seed to the soil surface and to protect it from the drying effects of sun and wind. Hydroseeding, with fibre mulch included in the mix, is well suited to the purpose.

5.2 Transplanting

Transplanting is an alternative method of planting which has some advantages over seeding on small and particularly harsh sites, where the economic advantage of seeding is reduced. Successful establishment is more likely because roots and above-ground portions of plants are well developed and therefore less susceptible to desiccation. Where transplants are planted with ‘the soil intact around the roots the chances of success are increased because nutrients are available immediately and because microfauna, which are necessary for the breakdown of organic matter into food, are introduced immediately to the new site. The invasion of micro-organisms by the natural means of wind and water transport can be a very slow process. Another advantage is that transplants reach adulthood and are capable of producing seeds more quickly than seeded plants. (Fitzmartyn, 1979).

Bareroot seedlings of some plant species can be successfully transplanted also. These can be handled more easily than transplants with root-soil intact and can often be taken directly from areas near the site. It is essential however that the roots not be allowed to dry out during the period between digging and planting.

5.3 Vegetative Reproduction

Vegetative reproduction is a planting method which uses cuttings of the above-ground portions or the roots of plants. These can with some species, notably willow, poplar and alder, given adequate moisture conditions, be directly planted at the treatment site. With other plants, however, an intermediate planting stage in prepared rooting media, is required in order to achieve root development prior to final planting. Where direct planting of cuttings can be used, great savings in time can be achieved and a great amount of material can be planted relatively inexpensively. However where the intermediate planting step is required costs compared to that of seeding (including the costs of collection in the wild) are likely to be greater. Another advantage of the vegetative propagation technique over seed or seedling planting is that the plants are more likely to be adapted to the site conditions if collected from similar sites.

Wattling is a special technique of vegetative transplanting which is very useful for stabilizing soils on sites with severe erosion problems. With this technique bundles of living branches are set into the soil in rows across the slope. These combat erosion by slowing rainfall runoff, entrapping sediment and by anchoring the soil with roots which develop from the nodes of the living branches (see section 6.1.4).

6.0 TECHNIQUES FOR EROSION CONTROL AND MOISTURE CONSERVATION

6.1 Erosion Control

In the rehabilitation of disturbed sites, especially those involving cut or fill embankments, erosion control measures are usually required in order to allow vegetation to become established. Without this protection plants have difficulty establishing because of soil loss from around the roots and because of crusting of the soil surface which often results from the impact of rain drops. Once a cover of vegetation is in place this will usually prevent further erosion.

6.1.1 Ditching and Berming

If surface water runoff from above the site is a major cause of the erosion then a ditch or a berm can be used to divert the water around the area. Berms are often preferable to ditches since the soil surface is not disturbed and there is, therefore, less chance of erosion occurring in the diversion channel.

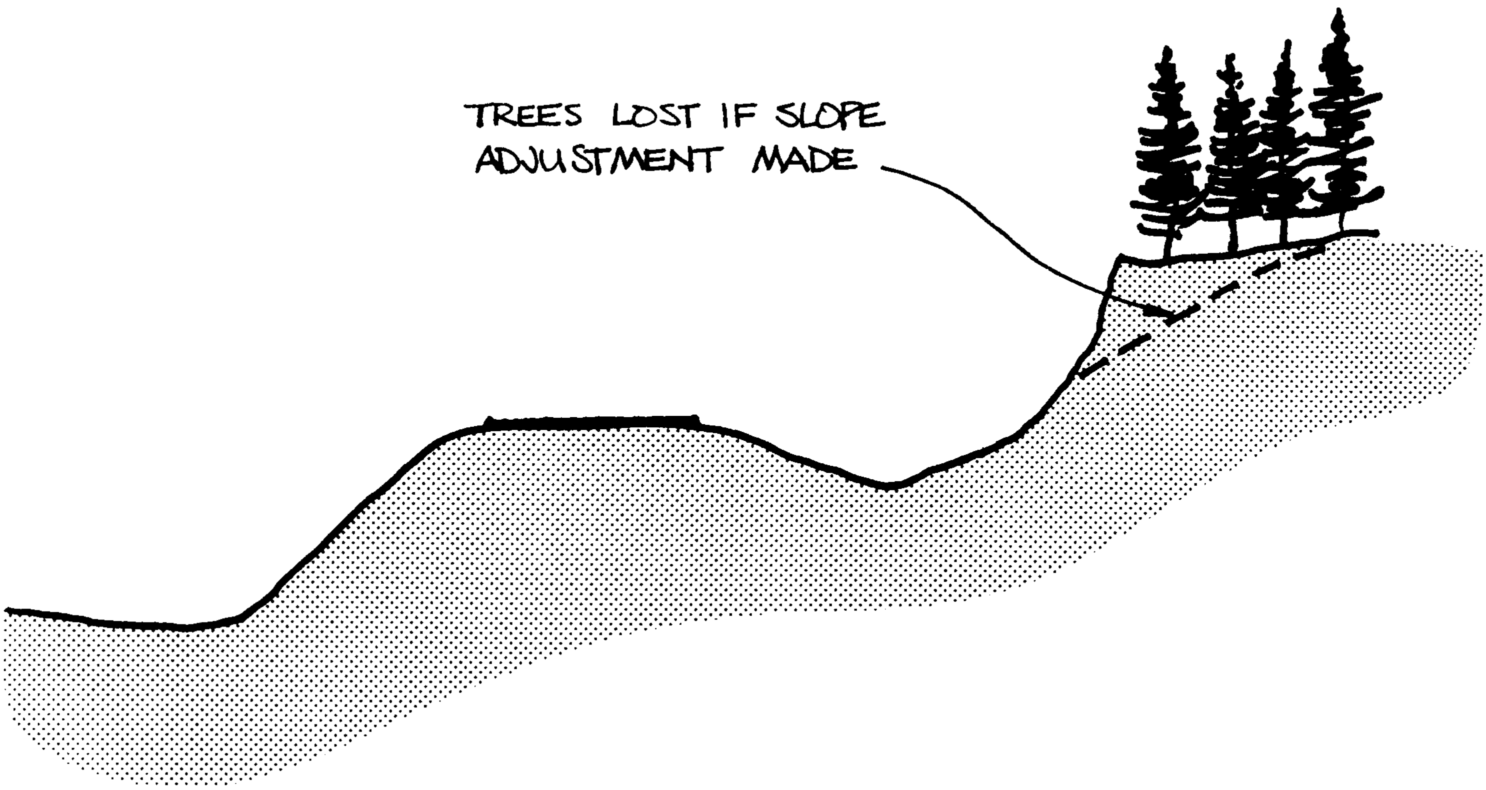
6.1.2 Mulches

Mulches can be effectively used to control erosion occurring from rainfall impact and surface runoff. This technique is described in more detail in section 7.0.

6.1.3 Slope adjustment

Generally mulches cannot be expected to be very effective on very steep slopes (i.e. exceeding 1:1). In this case one solution is to reduce the grade by cutting back the top of the slope and/or by filling at the base of the slope. In many cases, however, this is an undesirable approach because the area of disturbance is greatly enlarged and may necessitate the removal of large quantities of trees and other vegetation.

Reference has already been made to the use of gabions for stabilizing unstable banks of limited extent (section 3.1.2e).


TREES LOST IF SLOPE
ADJUSTMENT MADE

6.1.4 Wattling

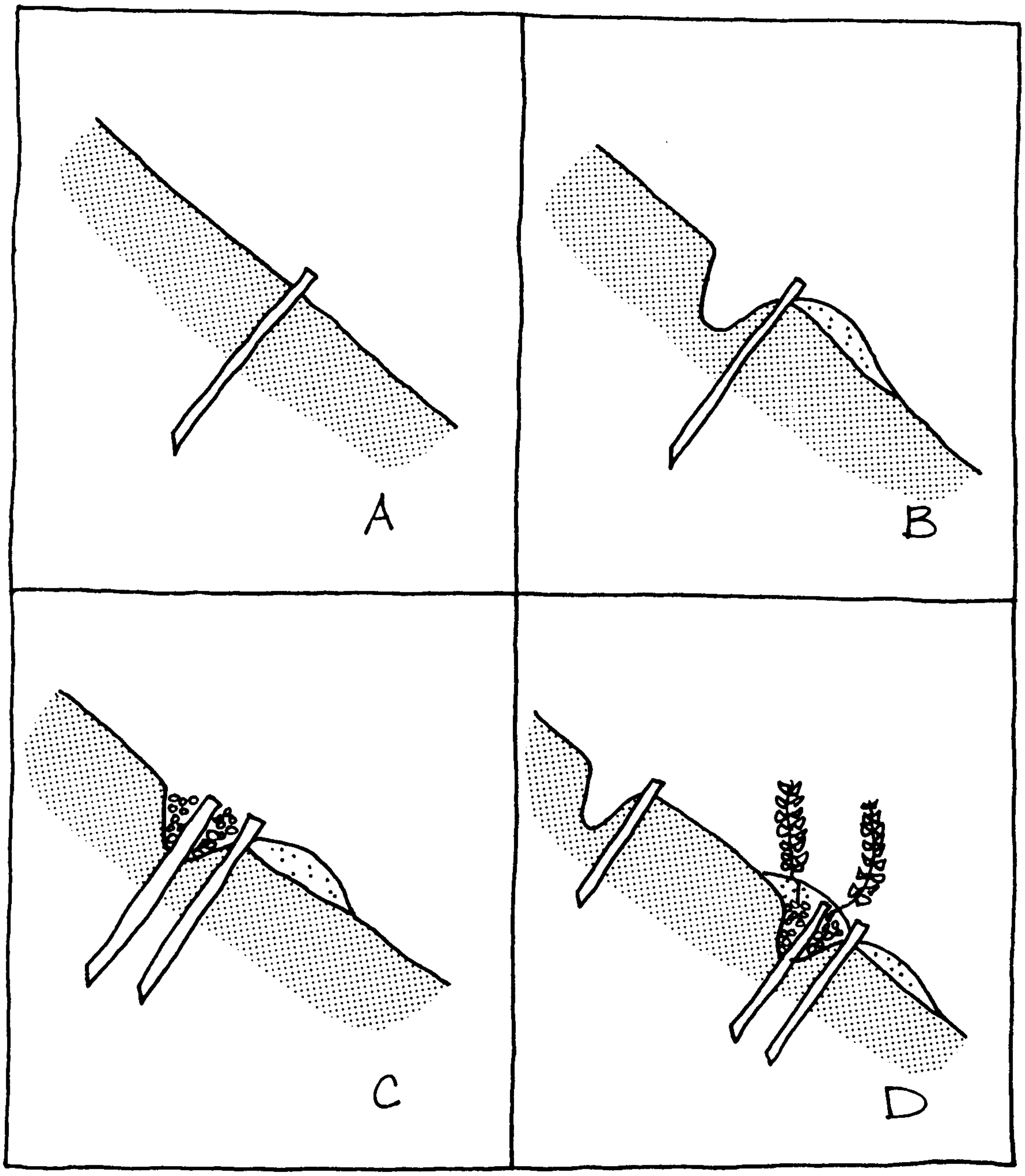
Wattling can be used as an alternative method for dealing with erosion control on very steep slopes or where, for other reasons, there are extreme erosion problems. Wattling, as described by Leiser and Nussbaum (1974), is a technique in which bundles of flexible twigs are laid in trenches across cut or filled slopes. The bundles are staked down to hold them in place and they are partially covered with soil. The value of the wattles is that they slow the speed of surface water flow, increase water infiltration and entrap sediment being carried down slope. The small terraces created on top of the bundles contain the trapped sediment and provide conditions that are well suited for the establishment of plants. If the wattling is made of plant species which root easily, such as willow, the branches will root into the soil and securely fix the wattling to the slope surface.

Leiser and Nussbaum report that in a test on one of the most problematic slopes in the Tahoe Basin (California), wattling almost completely eliminated erosion in one season. They concluded that "...no mulches (excelsior, fibre, jute), plastic or organic sprays or woodfibre treatments alone have given such satisfactory and consistent results".

Material for wattles may be any stiff, leafy brush that can be obtained in reasonably straight lengths of 1 m or more (the longer the better). Long slender branches are preferred to those that are short and thick. Stem thickness in excess of 25 mm are unnecessarily large. Wide spreading and very stiff brush which is difficult to compress should be avoided. Leafy material is most desirable because the leaves do most of the soil holding in that they plug the spaces between stems and prevent water from carrying soil down slope. If the material available has little foliage then straw or some other organic material should be bound into the wattles (Kraebel, 1936).

6.1.5 Deep Chiseling, Gouging and Dozer Basins

Deep chiseling, gouging and the digging of dozer basins are techniques for improving soil moisture conditions in arid areas (Hodder, 1977). These techniques increase infiltration capacity of the soil, and therefore combat soil erosion. A description of these techniques is given in section 6.2.2 which deals with the subject of soil conservation.



STEPS IN WATTLING INSTALLATION

A - STAKES SET IN CONTOUR ROWS B - TRENCH DUG ABOVE STAKES, HALF DIAMETER OF BUNDLES C - BRUSH WATTLES PACKED INTO TRENCH AND STAKES PLACED THROUGH WATTLES D - NEXT ROW OF WATTLING STARTED AND SOIL USED TO BURY LOWER ROW

6.2 Moisture Conservation

Shortage of soil moisture in disturbed sites is a common cause of failure in vegetation establishment. Selection of appropriate plant species is of prime importance, but in addition there are various techniques of moisture conservation which will help.

Mulching is one of the most common techniques. Mulches decrease surface runoff from rainfall and snow melt and therefore increase infiltration of water into the soil. Once the water is captured mulches act to conserve it by reducing evaporation.

On coarse textured soils it is beneficial to incorporate organic material into the soil. This helps to guard against moisture losses from evaporation and from percolation to lower soil layers where it would not be available for initial plant growth.

6.2.1 Planting Techniques for Dry Soils

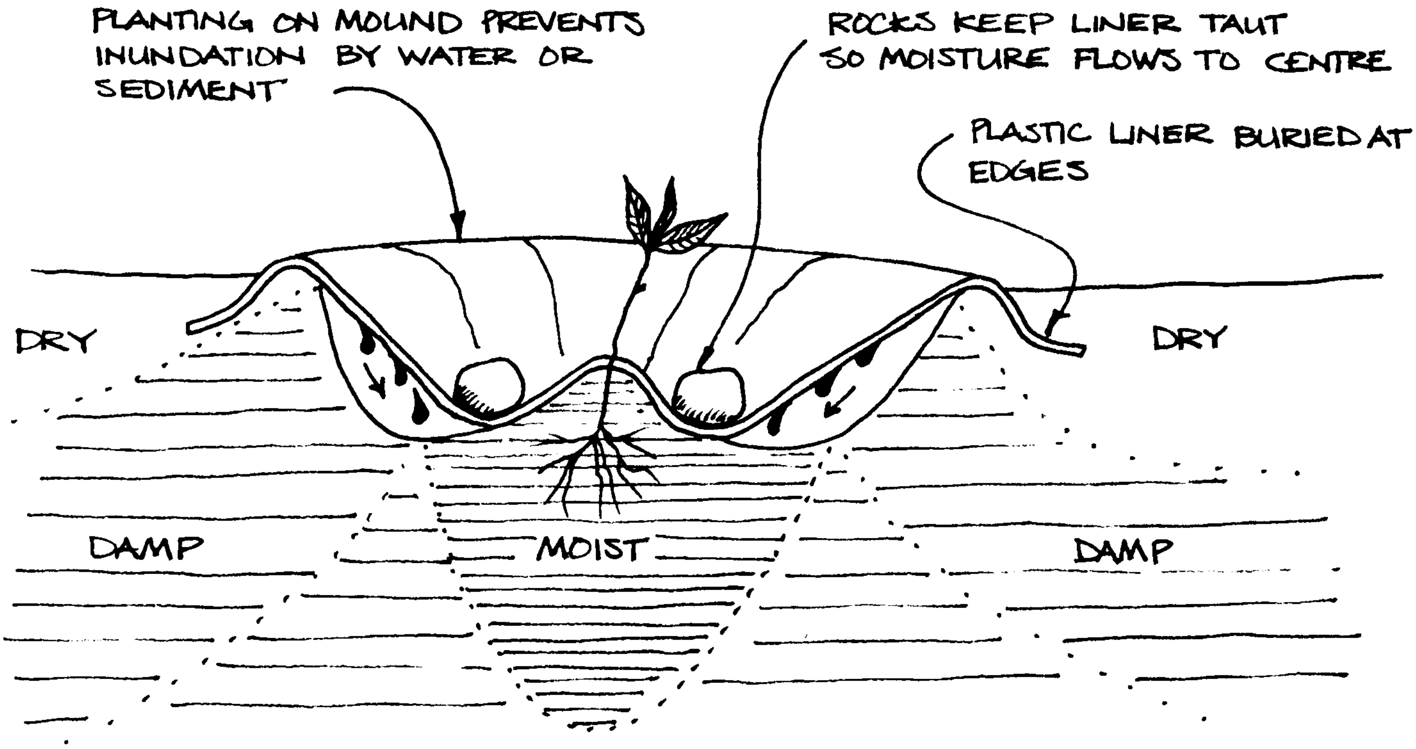
Three innovative techniques for planting on dry soil areas, developed by the Montana Agriculture Experiment Station. (Hodder, 1973), are reviewed below. Measurements have been metricated.

a) Condensation Traps

A condensation trap is composed of a deep planting basin containing a regular stock seedling. The entire basin is covered with a plastic sheet and heeled in around the edge to contain a large amount of air. The plant foliage is guided up through a hole in the plastic sheet. Rocks are placed on the sheet around the plant to provide protection, to weight the plastic and to keep it taut in a funnel form. Water vapour condenses on the underside of the plastic sheet, trickles down to the plant location and effectively irrigates it.

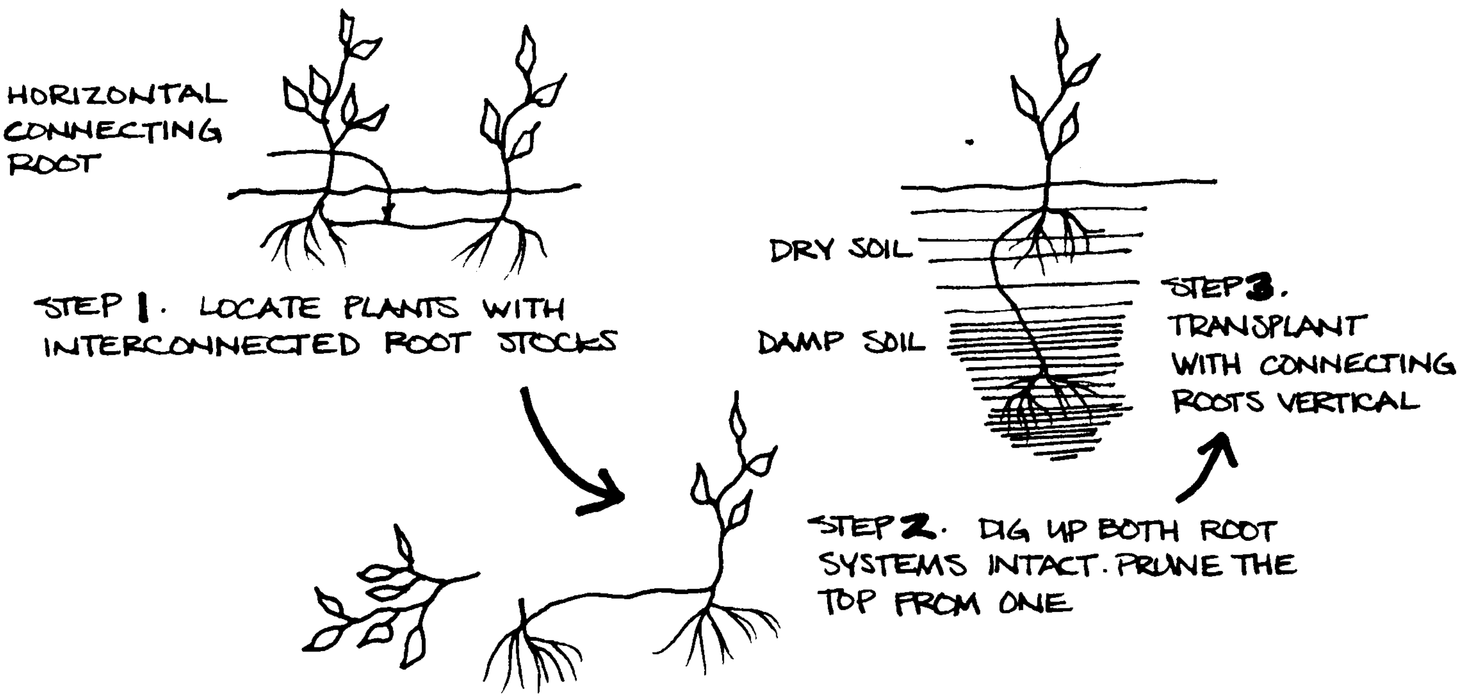
b) Supplemental Root Transplants

A pair of interconnected seedlings of a rhizomatous shrub species are carefully removed. The top of one seedling is pruned off at the crown leaving two root systems connected to the uncropped seedling. The horizontally connected root systems are then planted in a vertical attitude, one being placed deeper where there is more soil moisture and the other planted in a normal manner in the drier surface soil.



IRRIGATION BY CONDENSATION TRAP

FROM HODDER, 1973



SUPPLEMENTAL ROOT SYSTEM FOR DRYLAND PLANTING

FROM HODDER, 1973

c) Tubelings

Tubelings are plant seedlings planted and nursery developed in 2-ply paper cores or tubes. The tubes are 60 mm in diameter and .6m in length. The paper core is reinforced with a 12 mm square mesh plastic sleeve. When the root system develops and extends from the bottom and sides of the tube, the tubeling is ready for transplanting. A powered soil auger is used to drill holes in the field. Tubelings are dropped in, sealed around the top and left without further care or maintenance. The purpose of the tubeling is to force root development downwards where moist conditions can sustain plant growth. A number of other containers in use may substitute for the tubeling described here.

6.2.2 Surface Soil Modification

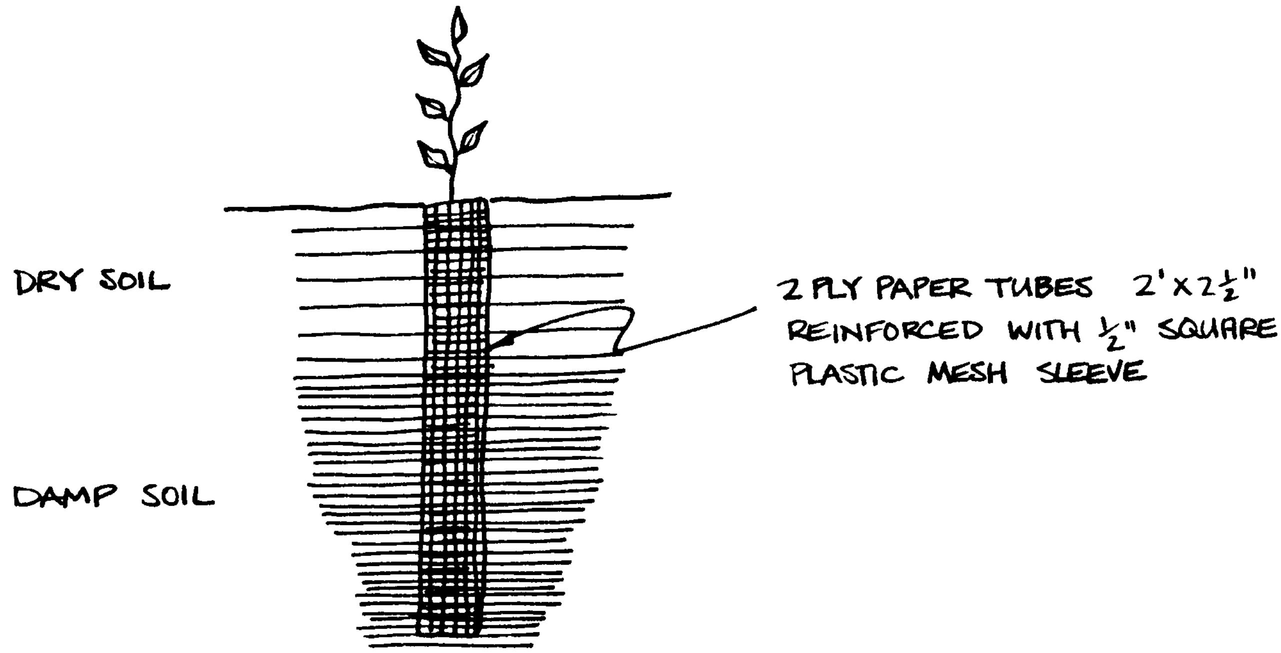
Several other methods for improving soil moisture conditions, involving modifications to the shape of the soil surface are summarized from Hodder (1973). Again, measurements have been metricated.

a) Deep Chiseling

Deep chiseling loosens compacted surface soils to a depth of .15 - .2 m. The process creates a series of parallel slots along the contour. This effectively impedes water flow and markedly increases the infiltration rate. Chiseling forms a cloddy seedbed which is ideal for broadcast native seed mixtures. Benefits of chiseling are relatively temporary since erosion from low intensity storms may be sufficient to fill the cultivation slots and thus permit high run-off again. This treatment is effective on relatively flat slopes during the first spring in helping establish a vegetative cover which, when adequate, will comprise a lasting erosion control system.

b) Gouging

Gouging is a surface configuration composed of many depressions approximately .25m deep, .45m across and .6 m long. This pattern is amenable to gradual slopes and flat areas. It is surprisingly effective in conserving runoff from moderate intensity storms and in causing differential melting of snow in the winter, thus retaining snow moisture which would otherwise be lost. It also creates a cloddy seedbed ideal for broadcast seeding.



TUBLING PLANTINGS FOR DRYLAND PLANTING

FROM HODDER, 1973

c) Dozer Basins

Dozer basins are large depressions designed to accomplish what terracing or contouring are intended to do but without the characteristic precision, hazards and expense. Dozer basins are usually about 1 m deep, 8 m long, and placed on the rough contour interval of about 9 m. Precipitation intercepted within each mini-drainage (area) accumulates in the basin bottom in quantities sufficient to thoroughly saturate the basin limits. The increased soil moisture availability assures the establishment of a nucleus stand of vegetation during the first growing season. Thereafter it can spread between basins to make a complete cover.

7.0 MULCHES AND MULCHING TECHNIQUES

Mulching is one of the most important horticultural - agronomic practices in disturbed site rehabilitation. It is important because it provides an extremely effective means for improving adverse site conditions for plant growth. Mulches control erosion by slowing the speed of surface water runoff, by holding soil particles in place and by entrapping sediments, by breaking the impact of raindrops and by shielding the soil particles from winds. They modify fluctuations in soil temperature extremes[5], conserve soil moisture by increasing the water infiltration rate and by reducing evaporation[5], prevent soil crusting, which restricts water infiltration and air circulation, and can provide nutrients for plant growth.

Many different materials are used for mulching including those traditionally used in agriculture as well as new products developed in response to the recent increased attention being given to environmental concerns. The materials range from straw, hay, sawdust, wood-chips, bark, wood-fibre, manure, brush, peat, shredded paper to organic and inorganic films (as "tackifiers" and soil-binders) , gravel and crushed stone.

Qualities which should be looked for in the selection of a mulch include:

a) ability to resist erosion;

b) sufficient porosity to allow rainfall to infiltrate the soil and to allow plants to grow up through it;

5 Note: too much mulch can raise surface temperatures and decrease available water. This is not usually a problem in view of cost considerations.

c) insolubility in water;

d) sufficient resistance to weathering so as to remain intact until the plants are securely established;

e) non-toxic;

f) not contain undesirable weed seeds;

g) not attraction to rodents or insects which might damage the plants;

h) not a fire hazard;

i) and relatively cheap to obtain and to apply.

Fitzmartyn (1979) indicates other factors that must be considered in mulch selection. Different mulches have different pH (acidity) levels and if the level is considerably different from that of the soil in the treatment area then the selection of plant species may have to be changed accordingly. The pH level can also vary within one type of mulch material, (in peat the pH can vary from 3 to 7.5).

The carbon/nitrogen (C:N) ratio in the organic mulch is also important. If the carbon is greatly in excess of the nitrogen the microflora involved in the decomposition of the mulch will compete with the plants for the available soil nitrogen and reduce the plants' chance of survival. For mulches with a high C:N ratio, nitrogen rich fertilizers should be applied to compensate for the lack of balance. A favorable C:N ratio is 20:1; sawdust can have a ratio of 440:1 and straw 80:1, but the ratio will vary with the source (Fitzmartyn, 1979).

There can be difficulties in using mulches in alpine areas because the insulating effects of the mulch can delay the start of an already short growing season.

Mulching will vary from the small patch-up jobs where trial and error will prevail, and where cost is not an important factor, to comprehensive rehabilitation projects where there can be significant environmental implications, and where rehabilitation costs can be correspondingly significant. In the latter case, where relevant research is not available, it may be necessary to organize a research project or program prior to site disturbance: such research can lead to an optimal approach in benefit-cost terms.

A good deal of research has been carried out in the Western and South-western U. S., and the rest of this section is based largely on the work of Kay (1973, 1974, 1977 and 1978) there. The emphasis has been abstracting information of general relevance to a variety of landscapes. Details of a number of research experiments have been omitted as having limited practical relevance to a wide variety of Canadian landscapes.

Where research is indicated sources of expertise within the region should be consulted, and a review of Kay's papers will be methodically worthwhile.

Above all, it is important not to translate successful research in a particular environment into a panacea approach for all. The project environment is not normally homogeneous but a mosaic of ecosystems which is in turn complicated by a superimposed pattern of proposed actions (or actual disturbances). Research orientation, at whatever appropriate itensity, will reflect these patterns as well as rehabilitation objectives and the results of relevant research.

Similarly, rehabilitation practices will reflect the same patterns. A broadly conceived benefit-cost "analysis" will determine a need for high rehabilitation costs in one disturbed land unit, and for zero expenditures in another (i.e. the latter will be left to revegetate naturally).

7.1 Organic Mulches

7.1.1 Straw and Hay

Wheat, oat and barely straw, and wild or cultivated hay are commonly used for mulching.

Straw can contain 0.5 to 5.0 percent cereal seed by weight. This can contribute considerably to the plant cover and initial erosion control effectiveness , but may be detrimental in the long run because of competition between the cereal and the seeded plant species. Moreover, in this way undesirable exotics can be introduced.

Use of wild grass hay should be considered since it can provide a good source of native plant material. The hay should be harvested when seeds are ripe but not shattered. It should be taken from locations with similar environmental conditions. Some grass straw (notably annual ryegrass, Lotium multiflorums) can contain inhibitors that have a toxic effect on seedlings if used in excess.

Straw can be applied with specially designed straw blowers or straw beaters, or can be spread by hand. Blowers are reported by manufacturers to be capable of applications of 13.6 metric tonnes per hour and to have a maximum range of 27 metres. The length of straw can be important and can be controlled in most blowers by adjusting or removing the flail chains. Baled straw may be long or short depending on agricultural practices. Straw to be crimped or punched should be relatively long to be incorporated effectively into the soil: tufts of straw should remain above the surface to act as checks to erosion. For mechanical mulching the straw length should be between 15 and 45 cm. Damp mulch is preferred since it does not break when pushed into the earth.

The “beater” type of mulch spreader is effective on flatter areas (maximum gradient of 1:3) but blowers are needed for steep slopes. Application by blower should be limited to times when winds are light so that an even distribution can be obtained.

The amount of straw to be used will depend upon the erodibility of the site (soil type, rainfall, length and steepness of slope etc.), and the type of straw. Increasing rates of application give increasing protection. Straw to be held down with a net should be applied at a rate of 3.4 to 4.5 metric tonnes per hectare and straw held with a tackifier at 2.2 to 3.4 metric tonnes per hectare. If too much straw is used it can smother seedlings by blocking light penetration and preventing the growth of plant shoots . Generally a good rule of thumb is that some soil should be visible through the straw mulch when looked at from above. Higher rates of application are possible if the straw is vertically positioned (in tufts) by crimping or punching. Excessive amounts on the surface can be a fire hazard.

Straw or hay usually needs to be held in place until plant growth starts . The problem is wind, not water. Water puddles the soil around the straw and helps hold it in place. Also, wet straw “mats down” and is not easily moved. Common methods of holding straw in place are crimping, disking, or rolling into the soil, covering with a net or wire, or spraying with a chemical tackifier.

Crimping is accomplished with commercial machines which utilize blunt notched disks which are forced into the soil by a weighted tractor-drawn carriage. They will not penetrate hard soils and cannot be pulled on steep slopes. On small sites where use of mechanical equipment is restricted the straw can be crimped with shovels.

Rolling or “punching” is done with a specially designed roller. A sheepsfoot roller, commonly used in soil compaction, is not satisfactory for incorporating straw. Specifications of the California Department of Transportation quoted by Kay (1978), contain the following provisions “Roller shall be equipped with straight studs, made of approximately 7/8 inch inch steel plate, placed approximately 8 inches apart, and staggered. The studs shall not be less than 6 inches long nor more than 6 inches wide and shall be rounded to prevent withdrawing the straw from the soil. The roller shall be of such weight as to incorporate the straw sufficiently into the soil so that the straw will not support combustion, and will have a uniform surface” .

The roller may be tractor-drawn on flat areas or gentle slopes, whereas on steeper slopes with top-of-slope access the roller may be lowered by gravity and raised by a winch in yo-yo fashion, commonly from a flat-bed truck. Requirements are soil soft enough for the roller teeth to penetrate, and access to the top of the slope. It can be used on much steeper slopes than a crimper. Punched straw may not be as effective as contour crimped straw, because of the staggered arrangement of tucked straw instead of the “whisker dams” made by crimping.

A variety of nets used to hold straw in place include twisted-woven kraft paper, plastic fabric, poultry netting, concrete reinforcing wire, and jute. These should be anchored at enough points to prevent the net from whipping in the wind, which rearranges the straw. Price and required length of service should determine the product used.

Perhaps the most common method of holding straw is the use of a tackifier. This method may be used on relatively steep slopes which have limited access and soil too hard for crimping or punching. Asphalt emulsion, the tackifier used most commonly, is applied at 2200-5500 l/ha, either over the top of the straw or applied simultaneously with the straw blowing operation. Wood fibre alone is effective as a short-term tackifier, but glue must be added to give protection beyond a few weeks.

Wood fibre, used in combination with new products[6], has been demonstrated to be equally effective as asphalt emulsion tackifiers, similar in cost and environmentally more acceptable.

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6 These include new products from natural sources as well as emulsions used in making adhesives, paints, etc.

7.1.2 Hydraulic Mulching

Hydraulic mulching, or "hydromulching", is a technique by which a mulch is applied as a water slurry. The slurry may also contain seed, fertilizer, erosion-control compounds, growth regulators, soil amendments, etc. The technique has become increasingly popular because of low labor requirements . Mulches must have a particle size small enough for ready pumping through 0.5-inch (or closest metric equivalent) nozzles, and must not be too buoyant to remain in suspension with moderate agitation. Used most commonly are specially manufactured fibres mad e from alder and aspen. Hemlock, also used, is more difficult to pump. Many recycled paper and agricultural products have been marketed or tested. Among those marketed are office waste, corrugated boxes (PFM), chopped newspaper and seed screenings.

The most important property of a hydromulching material is that it adhere to the soil even on steep slopes and hold the seed in place during heavy rainfall and wind.

Laboratory tests conducted by Kay (1978) indicated that virgin wood fibres of aspen and alder offered considerable soil protection. They were consistently superior to other commercial products tested, including those made of office waste, newsprint, and seed screenings. He speculated that the shorter fibre length of the commercial products was responsible for their relative inefficiency.

Another important property of mulch is its moisture-holding capacity. In general, products with the longest fibres and best slope-adhering characteristics also have the highest moisture-holding capacity.

Commercial fibres are usually dyed with a green dye which lasts only a few hours or days. This visual aid assists in obtaining an even distribution.

Rates of hydromulch vary from 550 to 3500 kg/ha. The rate of 225 kg/5700 L water is suggested as being necessary to disperse seeds evenly in the slurry, and in order to protect seed passing through the centrifugal pumps commonly used in hydraulic seeders (see section 5.1.2.3a). This would cover 0.4 to 1.2 hectares, with best coverage on 0.4 ha and possible distribution problems if used on 1.2 ha. A minimum of 1,120 kg/ha is necessary to hold the seed on a slope.
Wood fibre is an essential addition to most hydraulically applied chemicals, including straw tackifiers. Many soil-binding chemicals will not hold seed, fertilizer, or

straw to a slope unless wood fibre is included. Regional experts and Kay (1978) should be consulted prior to embarking on a costly project.

7.1.3 Wood Residues

Woodchips, bark, shavings and sawdust can be used effectively as mulches. These may be available as waste from the forest product industries or from sites where trees are being cleared.

Advantages of wood residues over straw and hay are that they are easier to apply, are longer lasting and are less susceptible to blowing or to catching fire. Disadvantages are competition for available nitrogen (section 7.0), and lowering of the pH if the material is strongly fermented. Packing, which retards aeration and infiltration, can be a problem. To maintain the soil pH level, lime can be added to the mulch material. Tests should be carried out to determine these requirements.

Woodchips and bark can be applied with a conventional straw-blower to a distance of 18 metres. Kay (1978) indicates that application rates of two to six times that of hay or straw are required to achieve the same erosion control effectiveness. However, if too thick a layer is applied the seedlings germinating from the seed beneath may be smothered. A balance must be found between the two requirements. The optimum rate will depend upon factors such as the particle size of the mulch, soil conditions, plant species, and gradient of slope.

Another wood residue mulch is excelsior or shredded wood. This consists of curled wood fibres with approximate dimensions of .5 mm x 1.0 mm x 20 cm. The fibres are randomly intertwined which provides a good resistance to dislocation by wind or water. This is reported to be as effective as straw plus asphalt with the advantage that it does not need to be anchored on slopes of less than 1:3 gradient. On very windy areas, on steep slopes, and in drainage ways a tackifier or net anchoring is necessary.

Excelsior is available in rolls with paper or plastic netting but is expensive, laborious to apply and sometimes decomposes too quickly.

Use of wood residue mulches are generally best restricted to slopes less than 1:3 or steep slopes which are scarified or serrated, except in the case of excelsior which can be effectively anchored.

7.1.4 Fabric or Mats

Fabric or mats, including jute, excelsior, and woven paper or plastic fibres, are provided in rolls to be fastened to the soil with wire staples. Fibreglass roving (which is blown on with compressed air and tacked with asphalt or plastic emulsions) is also available as a non-biodegradable substitute. Use of these products is limited by their cost and effectiveness. The rolls require high labour inputs for installation, cost at least four times as much as tacked straw, and are not adapted to fitting to irregular surfaces or rocky areas . Erosion from beneath these products is common because they do not have intimate contact with the soil. They must be heavy enough or anchored in enough spots to prevent wind whipping. Mats must be frequently checked so that tears and poorly anchored sections can be mended before extensive damage occurs.

These materials have an advantage over hay and straw in that they are weed-free. However, they can be unsightly, a fire hazard, and in some cases they are not sufficiently biodegradable while in others they deteriorate too quickly.

Due to high costs mats are probably most suitable for use on small areas, where erosion problems are particularly difficult.

7.2 Chemical Mulches

Organic and inorganic chemicals to be used as mulches or soil binders are usually applied in a water carrier or as part of a hydraulic seeding slurry. They are expensive and very specialized, and must be used correctly for maximum effectiveness. These are discussed here as either fibre tackifiers to be used as part of a seeding, or as plastic emulsions which may be used with a seeding or alone as a soil binder.

7.2.1 Fibre Tackifiers

Fibre tackifiers are generally advertised to hold fibre in place, promo t e germination, hold moisture, and retard erosion. Chemical groups represented are styrene butadiene, polyvinyl acetate homopolymers, vinyl acrylic copolymers: organic chemicals include an alginase and an absorbent polymer derived from starch.

Although virgin wood fibres as a hydraulic mulch adhere well to slopes without the addition of glues or tackifiers, interests continues in products which would improve their resistance to wind or rain. Generally, the results suggest that it would be better to add more fibre than tackifier. Most products do, however, make the slurry easier to pump, and thus permit the addition of more fibre. Most products are sensitive to fertilizer, and lose their effectiveness when applied together.

The state of the art seems to be very much in a state of flux, and prospective users should be circumspect in their selection and methods. Recent tests have shown that the application is much more effective when sprayed after the hydroseeding-mulching slurry rather than mixed in the slurry.

There is a hazard to the seed in using highly effective mulches or additives. These products or combinations may retain enough moisture to allow germination when the moisture in the soil is too low to permit establishment. Simply covering the seed with soil may be more effective in that the seedbed will remain dry until enough moisture is available for both germination and sustained growth.

When enough moisture for growth is present or can be easily provided, a new product, Super Slurper might help keep the soil surface moist during the germination period. Super Sluper is the starch-derived absorbent poylymer referred to above. A U.S. Department of Agriculture patent, the dry powder forms a viscous water-absorbing surface if moisture is present, and is reported to absorb up to 1000 times its own weight.

7.2.2 Soil Binders

Plastic emulsions have been used for about a decade to bind surface soil particles into a crust for protection from wind and water erosion, and for dust control. Again a number of chemical groups are represented. All are an intimate mixture of high-molecular-weight polymeric particles dispersed in a continuous aqueous phase. They are basic ingredients in paint, glue, and other products.

The emulsions are sold as a liquid concentrate. They give better initial protection than other commonly used erosion-control practices. All retard soil erosion if used in sufficient quantity. Their most effective use appears to be at intermediate stages of construction or where plant materials are not desired (e.g. undesirable plants associated with the transplanting of trees and shrubs). The inclusion of fibre with the emulsion improves its performance.

Limitations in the use of soil binders are related to:

a) their high cost;

b) the critical amount of water required for effective use. The optimal dilution rate can be expected to vary with the product used, the soil type and temperature, and with moisture conditions. Soil binders are commonly used too diluted, at rates too 10W, or where they should not be used.

c) the generally deleterious effect on plant establishment and delaying grass seedling emergence. The development of tip burn in grass seedlings is apparently the result of applying fertilizer with the emulsion and seed. Separate application of fertilizer after germination of seeds has avoided this problem. The inclusion of fibre in the application also mitigates these effects. The deleterious effect on plant establishment is particularly marked in low rainfall areas, and on soils with low moisture holding capacity, since the emulsion crust sheds most of the water.

d) weather conditions after application. Minimum temperature requirements of between 7 to 13°C should be observed. Rain or frost before curing is completed may destroy the emulsion, as may frost-heaving.

e) the need for protection of treated areas from vehicles and animals, and the need to repair breaks in the crust.

7.3 Soil and Rock Mulches

Soil and rock are ranked by Kay as two of the most effective mulch materials. The microsites created by rough seedbeds or rock are highly effective in retaining soil moisture and producing favorable atmospheric moisture and temperature regimes. Kay cites a study showing that mulches of crushed stone or gravel 25 mm deep provided more effective erosion control than 4500 kg/ha of straw. Field observations have shown gravel cover to be effective in reducing wind and water erosion and in encouraging invasion by indigenous plants.

8.0 RELATIVE COSTS AND EFFECTIVENESS

There is a paucity of reliable information in the literature which describes project actions and related costs sufficiently well to permit sound extrapolation, and to assist in the preparation of estimates. In order to fill this void, as well as to disseminate useful information on rehabilitation practices, regional and park officers responsible for rehabilitation projects are invited to forward salient information to National Resources Division for national distribution. In the meantime, the figures below are included to give a “ball park” appreciation of possible costs and relative effectiveness of alternative treatments.

A study (Lowe, 1979) was carried out in 1978 in Southern Ontario of the rehabilitation of pit and quarry sites. Two estimates of backfilling and grading (including, in one case, hydroseeding) of extracted areas before planting were $8406 per ha and $6655 per ha. Actual planting costs (plants plus labour) ranged from $25 to $3150 per ha: low costs resulted from use of government nursery seedlings rather than larger stock from commercial nurseries, found in some screen, and in recreational and visual amenity plantings. No descriptions were given in support of the cost figures.

In North Dakota the reclamation costs of four lignite mining sites, mined by four separate companies, under a reclamation act in effect until 1976, and embracing backfilling, grading, the removal, stockpiling, and replacement of up to 45 cm of topsoil, soil amendments and seeding, averaged about $5930 per ha (LaFevers, 1978). The difference in cost between Southern Ontario and North Dakota can be explained by price increases between 1974-1976 and 1977-1978, and probably by differences in the economy of scale arid in regulations reflecting the population densities and patterns in the two regions.

The “Table Summary of Methods and Costs of Common Erosion-control Practices” is summarized from a more detailed table by Kay (1978), dealing with mulches in erosion control practice in the semi-arrid and arrid regions of the Western U.S. In any transposition to current Canadian dollars attention should be paid to foreign exchange and inflation factors, to differential cost increases related to energy cost escalation as well as to location of manufacture and transportation costs.

Rehabilitation practices vary considerably in cost and effectiveness. Sometimes the characteristics of the site to be stabilized determine the only practical treatment. Usually, however, there are alternative methods which should be considered.

The most expensive practice is not necessarily the most effective. For example, straw plus a tackifier (N° 4 in the table) is more effective for both erosion control and plant establishment than many of the more expensive treatments. A rough seedbed or covering the seed with soil may be the cheapest and most effective treatment for establishing vegetation.

Mulch treatments increase in effectiveness with both the amount of mulch per unit area and the length of the fibre. While it is possible to apply excessive amounts of mulch, economic considerations usually prevent it and there are optimum depths for plant development. The importance of fibre length, however, should not be overlooked. Increasing the fibre length (as from wood cellulose fibre to straw) may greatly increase the effectiveness of erosion control and germination. This relatively large increase in effectiveness can be achieved at little or no increase in cost .

Table Summary of Methods and Costs of Common Erosion-control Practices[1]

Treatment	Comments	Pregermination Erosion Effectiveness[1]	Effectiveness For Plant Establishment[2]	Approx. Cost per Hectare U.S.[3]
1. Seed and fertilizer broadcast on the surface, no soil coverage or mulch.	Inexpensive and fast - most effective on rough seed-beds with minimum slope and erodability where seed will cover naturally with soil - suitable for remote or critical areas where machinery cannot be taken.	1	1-4	620
2. As above plus soil mulch (i.e. raking or dragging a chain, etc.)	Does not require special equipment - generally effective treatment - labour cost high in areas not accessible by egpt.	1	3-4	790
3. As in 2 above, followed by hydro-mulch of wood fibre at 2240-3360 kg/ha.	Very effective - combines advantages of seed coverage and mulching	2-3	6-8	1680-2140
4. Straw or hay broadcast with straw blower on the surface at 3360 kg/ha and tacked down (asphalt emulsion, Terratack II, etc.). Seed and fertilizer broadcast with hydroseeder or by hand.	Common in U.S. - very effective as energy absorber mulch - straw forms small dams to hold some soil - may be weedy depending on straw source - not for cut slopes steeper than 1:2 - cost would increase significantly if slopes over 15 metres from access, or application is uphill - examine for possible environmental effects of chemicals.	5-7	8-10	1610
5. Roll-out mats (jute, excelsior, etc.), held in place by wire staples. Seed and fertilizer as in 1 or hydroseeder.	Some comprise an effective mulch; is weed-free and adapted to small areas - can be installed any season or cuts or fills - unsightly - difficult to install on rocky soils.	5-	5-10	5930-6670
6. Polyethylene 4 mil sheets - seed and fertilizer as in 1 (or hydro-seed) using clear plastic (or black if no seed used).	Useful temporary control - unsightly - wind a problem in installation and maintenance - may be difficult to establish plants.	10	?	5930-6670

[1] After Kay (1978) [2] 1 = minimal, 10 = excellent [3] Reference is made to U.S. 1973-75 $ and has not been translated to current $. The approximate costs assume: seed plus fertilizer $150, fibre $165/tonne, 5650 litre hydroseeder with two man crew $55/hr, labour $13/hr, straw $55/tonne, straw mulcher with 4 man crew $64/hr, plus markup of 30% for overhead and profit.

APPENDICES

A

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