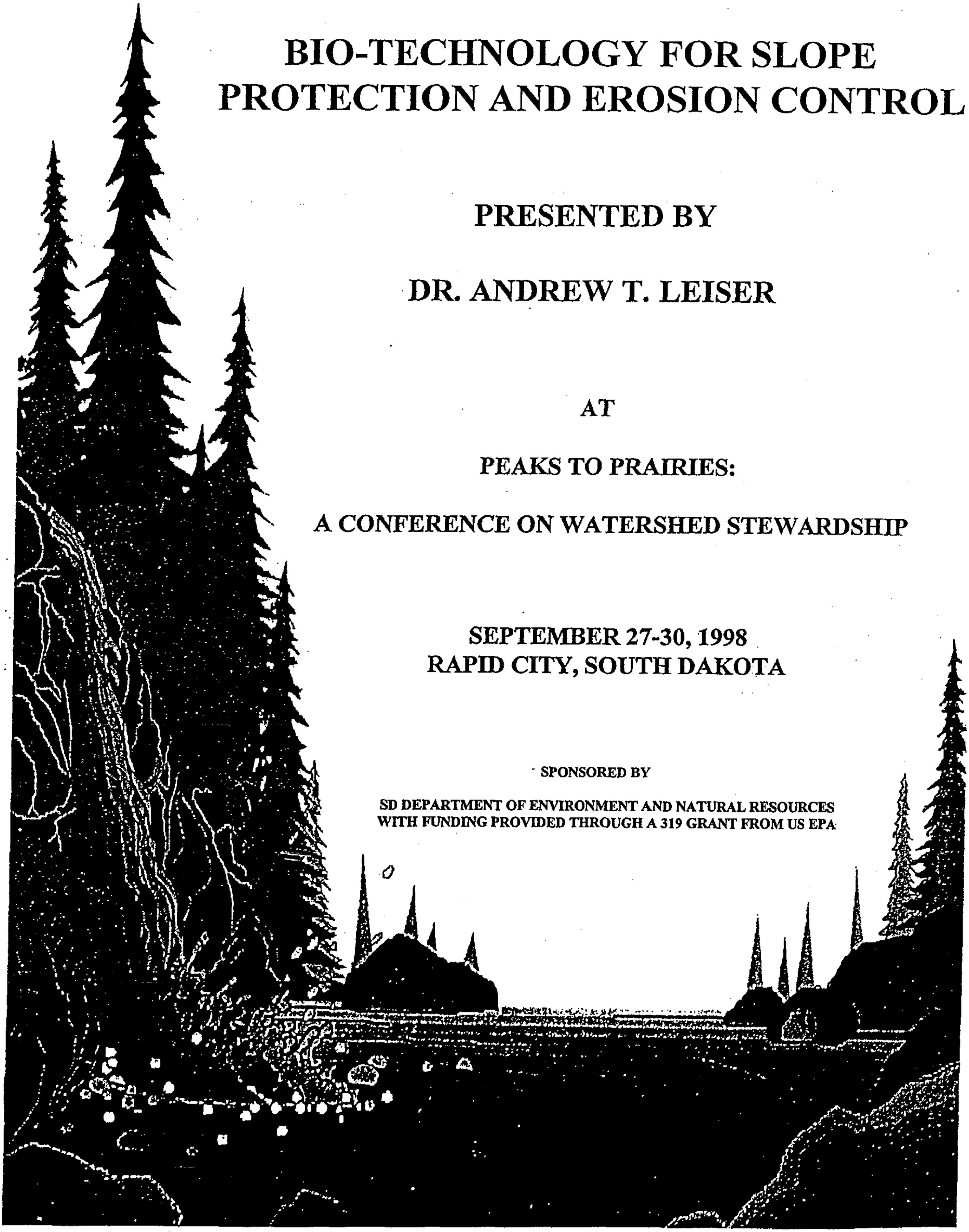

BIO-TECHNOLOGY FOR SLOPE PROTECTION AND EROSION CONTROL

PRESENTED BY

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AT

PEAKS TO PRAIRIES:

A CONFERENCE ON WATERSHED STEWARDSHIP

SEPTEMBER 27-30, 1998
RAPID CITY, SOUTH DAKOTA

SPONSORED BY

SD DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
WITH FUNDING PROVIDED THROUGH A 319 GRANT FROM US EPA

BIOGEOTECHNOLOGY

FOR

SLOPE PROTECTION AND EROSION CONTROL

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INTRODUCTION

The word "biotechnical" has been used for many years to describe the use of plants and plant materials (brush) and plants and engineered structures for slope protection and erosion control. Very recently "biotechnology" has been adopted by those engaged in "genetic engineering" for their field of science. The word "biogeotechnology" may serve to distinguish the slope protection and erosion control use of the word "biotechnical" from the genetic engineering use.

These techniques are useful for and could be described under other names as well, restoration ecology, wetland construction, revegetation or simply slope protection, erosion control, etc. These names might include concepts either more broad or more limited than those which will be discussed here.

Erosion is a natural phenomenon which (with other phenomena such as vulcanism and plate tectonics) has given the earth the landforms we see today. Man has done much to cause erosion in otherwise stable terrain. It may be desirable to control some natural erosion when it threatens our homes, highways or other infrastructure but it is mandatory to control erosion caused by man if we are to preserve a quality environment.

The traditional approach to erosion control in the United States in the past 50 years or more has been to construct culverts, to use retaining walls and other "hard" construction to deal with erosion problems. Worse, the approach has been to ignore the problem in all too many cases. In Europe, the U.S. before 1940, and other places in the world, a more environmentally friendly (or "soft") approach to erosion control has sometimes been used. The use of plants alone or in combination with structures has been used. In very recent years there has been a renewed interest in these techniques in the United States.

Advantages of "soft" or biogeotechnical techniques for erosion control are several, an improved environment, improved aesthetic values, and usually, moderate to large savings in costs. Plant roots can provide a great deal of reenforcement to unstable soils, prevent soil wasting through gabions and riprap and, with plant tops, greatly reduce surficial erosion. Cost-benefit ratios may be as much as tenfold greater for biotechnical solutions as opposed to traditional "hard" construction.

One must recognize the limitations on biogeotechnical methods. Plant roots usually are limited to the top two or three feet of soil except in special situations. these techniques alone will not control deep-seated or massive soil movements. A good plant cover can help de-water soils and help control some of these situations but they cannot be expected to control such problems.

There is no "cook-book solution" to any individual erosion problem. There is however a scheme or model one can follow to develop a successful erosion control or restoration project.

The scheme involves posing a series of questions, developing the answers to the questions, then a plan followed by procurement of quality plants and then careful implementation of that plan. This paper will explain this scheme or model and describe some of the biogeotechnical methodology. Discussions of the plant selection, procurement and planting will be discussed later.

PROJECT PHASES

There are three major phases or steps to any erosion control or revegetation project.

The first is the planning stage. This step includes site surveys, addressing the components or constraints of the project, choosing appropriate biogeotechnical treatments, selection of appropriate plant species and appropriate timetables for implementation. Portions of the second step may run concurrently with the first stage.

The second is the procurement stage. This stage includes the negotiation of growing contracts if necessary, the collection of seeds and/or plant propagation materials, location of woody materials for live construction (biogeotechnical treatments) and unrooted cuttings (if they are part of the plan, and the writing of specifications and contracts.

The final stage is the implementation. This stage may require special instruction for installation crews, site preparation, installation of biogeotechnical measures, planting, and aftercare. This stage must have close supervision throughout because these techniques, while not difficult, require close attention to detail. At present, few people in the United States have had in the experience in doing this work well. Many contractors have done hydroseeding or sowing of grass cover for revegetation, but few have installed integrated projects including biotechnical works, woody plants and herbaceous plantings.

PROJECT COMPONENTS OR CONSTRAINTS

Any erosion control/revegetation project has several components or constraints. These constraints apply whether the project is a highway cut, mine spoils, stream-side or riverbank, reservoir or lake-shore margin or other eroding area, or a wetland renovation or construction. These components are interdependent and must all be considered. These are the political, economic, environmental (climatatological), physical, edaphic (soils), and biological components of the project. All place constraints on the development of a project plan.

The political component includes both governmental regulations and public pressures. Restraints on the use of species of plants may be imposed by governmental jurisdictions or by public pressure (e.g. use of native or introduced species, source of propagation materials). Lack of grazing controls, limitations on use of chemicals for rodent, insect, or weed control or fertilizers are other examples of these constraints. The political component also includes the negative human factors of vandalism and trespass by foot and off-road vehicles as well as the positive factor of public pressure for improvement of the environment.

The economic component is perhaps the most common limiting component. This constraint invariably affects the final decisions on the selection and spacing of biotechnical work, planting densities, for pre-project experimentation and for after care. All too often, construction and engineering solution work takes precedence and biotechnical and revegetation work is done only if there is money left over.

The environmental component includes all of the aspects of the climate of a project site: rainfall (amount and distribution), temperature (heat and cold, time, duration, and intensity), humidity, day length, etc.

The physical component includes the physical parameter of the project: site stability, aspect (compass bearing) which in turn influences environmental factors, adjacent terrain (e.g. sources of off-site water impacts), wave action, stream velocities and flooding, slope angle, etc.

The edaphic component includes all the soil parameters; texture, fertility, erodability, chemistry, etc.

The biological component is one of the most important components. It includes the availability of suitable plant species, choices between native and introduced species, availability of plants from commercial nurseries, or for collection from the wild, the propagation and cultural practice for the plants, planting and after-care. This component also includes plant diseases, insects, predators, and even presence or absence of grazing animals.

All these components or constraints must be considered both separately and in combination. They are interactive and failure to consider any one of them can and usually will result in a project that is less than satisfactory.

PLANNING

Site Analysis:

A number of the components are considered during the site analysis. Two very general rules or guidelines apply almost universally. First, learn to "read" nature in the project area. Many of the answers can be found, kinds of plants, invader species, causes of the problems, etc. Second, **NEVER DISTURB THE SITE UNNECESSARILY.** Remember that we are trying to stabilize a site, hence the less we disturb it, the easier it will be to stabilize it.

Climate and Microclimate: The overall climate of the site must be considered. The selection of plant species, planting season, site preparation and planting methods are very dependent on this component. Summer and winter temperatures (intensities, timing and duration), rainfall amounts and seasonal distribution, season and duration of flooding will all enter into the final revegetation decisions. Fall rains and expected winter temperatures will affect the decisions about a fall planting season, at least in part. Late winter and spring rainfall patterns will affect decisions on spring planting seasons. Summer rainfall patterns may dictate the need for supplemental irrigation. The interaction of all these patterns will affect the choice of plant species.

Site Physical Parameters: The site aspect (compass bearing) will modify the microclimate. South and southwest facing sites are hotter and evapotranspiration is higher than on other bearings. North and northeast facing site are the coldest and have the lowest evapotranspiration. West and east facing sites have intermediate conditions.

The slope angle may be measured or expressed in three ways, angle in degrees, as a percent slope, or as a ratio. Percent slope is expressed from 0 to 100% (or more) with 100% being a slope of 45 degrees, i.e. one with equal horizontal and vertical distance. Slope ratios are usually expressed as the ratio of the horizontal:vertical distance as 1:1, a 45 degree or 100% slope. A 2:1 (50%) slope has a run twice as long as the vertical rise. A steep slope has a much greater risk of erosion than a gentle slope because of the greater acceleration on water and detritus.

The length of slope is also an important factor in the erosion process. On gentle slopes such as farm land, this factor is a linear function. The writer believes that on steep slopes, the length of slope is probably more nearly a function of the square of the length. Biogeotechnical treatments such as wattling can change a long slope into a series of short slopes with a great reduction in erosion.

Edaphic Factors: Soil texture, soil structure and soil fertility must all be evaluated. The first two factors relate to both erodability and to plant growth. Soil fertility is an important factor affecting plant growth. Some information on soil erodability can be obtained from the U. S. Soil Conservation Service. However, one is often confronted with either sub-soils, disturbed soils or even what could only be called soil forming material. Observations on site will often give sufficient information as to the inherent stability or instability of sites. The lack of gully formation or rills does not necessarily mean that erosion is not occurring. Many soils will erode more or less uniformly and exhibit neither rill nor gully formation.

The need for fertilizers may be determined by soil tests, pot tests or field trials. Soil analyses do not always indicate the plant response on site to fertilizers. Pot tests, done out-of-doors or in a greenhouse may give better indications of the plant responses. The ultimate decision on the use of fertilizers would be best determined by field trials using all the plant species that will be planted. This is not practical in most instances.

Pot tests using quick growing crops like beans and rye grass give a general picture of the soil fertility. The response of woody species to fertilizers does not always correspond to those of the test plants, but in view of costs and practical considerations, the results are quite useful. Such tests will usually reveal any toxic conditions. These tests are run by a "subtractive" method. Controls are no fertilizer and complete fertilizer. The need for essential elements are determined by choosing compounds such that these elements are subtracted one at a time. It is useful to include minus calcium and minus sulfur treatments because most grasses need adequate amounts of both these elements.

Fertilizer costs are often a small part of the cost of a project. If testing cannot be done, it is usually well to include small amounts of controlled release fertilizer for woody plants unless there is some evidence against their use.

There are several kinds or types of fertilizers. Conventional fertilizers are usually more or less water soluble and may contain one or several of the essential plant nutrients. Slow-release fertilizers are only slowly soluble and are of two general types. those with the nutrient elements in mineral (inorganic) form and those with organic compounds (e.g. ureaformaldehyde) supplying the nitrogen. The latter may be of little value in supplying nitrogen in very sterile substrate such as sand, mine waste or subsoils because there may not be sufficient biological activity in the soil to convert the nitrogen compounds to the inorganic or mineral form.

Grass species usually used in revegetation work often perform better or even require additional fertilizers for survival. Most grasses are either inefficient calcium absorbers or require large amounts of calcium and a pH near neutral or slightly basic reaction.

Many woody plants, especially natives, may not really need fertilizers even though grasses show responses to fertilizers in pot tests. Too much fertilizer will inhibit growth or even kill plants. In cold climates, too much fertilizer can increase winter kill by prolonging growth too late in the season or by producing succulent growth. If water is limiting for plant growth, additional fertilizer will be of little value.

Soil texture, structure and depth all affect the water-holding capacity of a soil. These factors need to be taken into account as well as climatic factors when determining the need for supplemental irrigation.

Biological Component: The potential for damage from insect, rodent, deer and other predation must be considered and protection be provided. Protective screen sleeves or deer and grazing animal exclosures must be provided if these risks are present.

Weed control is essential for establishment of most woody plants. This may be of little consequence on sterile soils but can be very important where many herbaceous weeds are present. Mulches or chemical weed control around each plant are often successful.

The vegetation existing on or near a site and on similar areas nearby which have revegetated naturally are the best indicators of the plant spectrum to use. These plants may be native or introduced "exotics". The choice must be made between natives or introduced species. Native plants are often mandatory in regional, state, or national parks. Native species have known adaptation to the climate and soils of a project area. For biogeotechnical construction and sticking unrooted cuttings, materials can often be found close by.

There may be, however, limited choice of native species. On reservoir sites in the Central Valley and foothills of California, for example, native species tolerant of late spring and early summer flooding are very limited. Search of the botanical literature resulted in a list of many species world-wide which tolerated these conditions. Field trials of some of these plants revealed that many could take flooding during this period. There were many species, however, that could not survive the late summer and fall drought of the region. There were species which could survive both stress situations which could expand the available plant spectrum for these sites.

The use of introduced species allows the potential for increasing the plant spectrum for any site. Use of them is usually permissible in urban situations and perhaps in others when suitable native plants are not available. An example is in mine restoration where it is desirable to revegetate regardless of the source of the species.

The availability of plant species of the appropriate spectrum, size and quality is more often than not, a limiting factor in the final selection process. Some natives are very difficult to propagate and grow, many that we might want are not commonly available in commerce, or not available in good quality plants. As demand increases and nurserymen gain more experience in growing natives, this limitation should become less important. Discussion of the selection process and of plant specifications will be covered in more detail later.

Special Problems: Many other problems must be considered in developing the final revegetation plan. The range of these problems will vary with the site. Along lakes, reservoirs or coastal areas, the wave action from boating or wind is an important consideration. In urbanized areas runoff may have been increased by hard surfaces. The occurrences of seeps may cause slope instability (or conversely, aid plant survival). In stream, river and delta areas the patterns of high flows must be considered. Mine wastes may present special problems with toxic levels of metallic ions such as copper, zinc, etc.

Combinations of "hard" construction and biogeotechnical methods will often be required. Plants alone will not solve every slope stability and erosion problem. Do not lose sight of these limitations.

DEVELOPING THE REVEGETATION PLAN

The revegetation plan can be developed after the site analysis is completed and the other components and constraints are defined. It is important to remember that site disturbance be kept at a minimum, both to minimize costs and to minimize future erosion. Do not destroy any existing vegetation unless it is absolutely necessary. Rill and most gully erosion can be eliminated during the installation of biogeotechnical construction and planting in most circumstances. The doctrine of "if it ain't broke, don't fix it" is applicable in erosion control work.

Site Preparation:

Site preparation planning must first consider safety of the workmen. Rocks, boulders, leaning trees and overhang must be removed. Control of off-site water sources must be planned. Severe erosion problems may have to be corrected but often, minor erosion can be remedies as work progresses. Complete regrading is usually neither required nor desirable.

Site stabilization:

The appropriate stabilization treatments are selected. These may be "hard" structures such as toe walls, gabions or riprap or biogeotechnical measures such as wattling, brush layering, trench packing, brush matting or combinations of these. The spacing and placement of these controls must be determined.

Revegetation:

Plant species, both total spectrum and quantities can be determined. It is often advisable to specify as many species as possible and require the use of some minimum number of these species. Maximum and minimum numbers of any one species may be specified. The season of planting will be based on the climatological information as well as the timetable for the project. Other factors affecting timing might be season of flooding in the case of sites along water, availability of supplemental irrigation, and size of the project. Some projects may require several planting seasons. The revegetation work may need to be coordinated with construction of engineered features.

Other Considerations:

Procurement of plants should be planned at the earliest opportunity. Large quantities of native plants and species not commonly grown will have to be grown on contract. Nurserymen need up to two years to produce a crop. Seed may have to be collected, stratification of the seeds may require as much as six months and most woody plants will require at least one growing season to reach suitable size.

Aesthetics should be considered in the project design, but must be considered in conjunction with other factors. A detailed landscape plan as used in urban situations is not usually needed. The planting plan may be generalized according to erosion control needs. Natural groupings of plants may be illustrated by a sample of a small section of the area. Planting should never be in straight lines in order to maximize erosion control. Any species may be planted singly or in small groups of three or more. This random placement both within and among species will improve erosion control and result in a more pleasing, natural looking finished product. Loss of some plants is inevitable but this will result in a more natural look.

It is usually advisable to provide for some replanting in the second and even third year. It is virtually impossible to avoid some plant mortality. The replant requirement can be based on percent survival and should give the contractor an incentive to do a careful job.

Specifications:

Specifications for the work, for plant quality and for planting methods must be written carefully, rigorously and in considerable detail. Some seemingly trivial details of installation of biotechnical works and planting techniques are all-important for a successful project. The inspection of the work and enforcement of the specifications must be equally rigorous.

BIOGEOTECHNICAL CONSTRUCTION

A brief description of several biogeotechnical construction methods will be given. Detailed construction methods are described in the attached sample specifications and diagrams.

Wattling:

The word "wattle" is derived from an Anglo-Saxon word, "watel", meaning interwoven twigs and hence a framework or hurdle of such. The word was adopted by Dr. Kraebel of the U. S. Forest Service in the 1930's to describe a process of erosion control where willow or other materials were placed in trenches, on contour, staked and partially covered with soil. The resulting "cable" of brush broke a long slope into a series of short slopes, slowing water run-off and trapping detritus. Rows of wattling were interplanted with woody plants and cereal grains. These wattles provided slope stability until the interplantings were established. The wattles also rooted and grew if of easily rooting species and installed at the proper time of year.

The attached specifications and diagrams show a modification of the method in which the brush is tied in bundles and overlapped. This construction is somewhat more efficient, but it is more difficult to get good soil coverage.

Wattling must be placed strictly on contour on steep sites. On riparian sites subject to stream or wave action wattling may be placed diagonally to wave action although this technique has not been well researched.

The spacing of wattling will vary with the steepness and erodability of the site. On very steep, highly erodible slopes a three foot vertical spacing might be required but greater spacing has been used successfully on some sites. The selection of spacing is a value judgement at the present time.

Wattling has several advantages: energy dissipation, temporary stabilization to allow establishment of other vegetation, sediment entrapment, and, if of easy-to-root species, the resulting plants become a part of the vegetation component. The wattling may often be crowded out by more dominant or better adapted species.

Wattling is indicated on basically stable slopes that have a shallow, unstable surface layer. It is also useful to repair which are wide enough to allow bending of the wattling bundles.

Brush Layering:

Brush layering is a technique much used in Europe and to a limited extent in the United States. Brush layering may be installed at the time of construction of new fills or in existing slopes by digging two to three foot or larger "steps" sloping slightly into the slope and placing brush on the step and covering with soil. Butts are placed inward and the brush is criss-crossed in a random fashion. The tips of the brush are left exposed to intercept and slow water and detritus.

Successive lifts are installed as needed. Criteria for vertical spacing is similar to that for wattling. In new fill the brush may be as long as is available. When placed at the right time of year the brush will root and grow.

Brush layering is indicated for new fills, shallow mass failures and repair of deep and/or narrow gullies.

Brush Trenching:

Brush trenching is a useful technique for intercepting shallow seeps and control piping, for spreading water in wetland construction or renovation, as energy dissipation along shorelines and as water breaks on abandoned roads. A narrow trench is dug, one to three feet deep, packed with a band of brush of the desired thickness and the trench is backfilled. Height above ground may vary according to the needs.

Spacing of rows will vary with the need. In wetland construction and renovation the rows may be spaced so that the vertical distance between successive rows is as little as six inches. Horizontal spacing will depend on the slope.

Brush Matting:

This procedure is the laying of a mat of brush sufficiently thick to prevent scour along streams, rivers or shorelines. The mat is staked and wired to hold it in place and in some instance it may be partially covered with soil. The site must have a fairly flat profile up and down slope but can follow the meander of the shore in a horizontal direction. The frequency of staking and method of wiring, line wire or fencing wire will depend on the expected erosion forces. The toe of the matting should be below the mean low water level and should be anchored with logs, stone or rows of wattling.

Combination Treatments:

The biogeotechnical methods can be used in any combination. Interplanting of cuttings or transplants usually should be done. All work and combinations of work should be "tied" together and to the surrounding stable areas. "A chain is only as strong as its weakest link."

IMPLEMENTATION

Sequence of work should be in certain patterns. Scaling and site preparation should take place from the top of a slope and working down. Installation of structural and biogeotechnical work should proceed from the bottom to the top and planting should proceed from the top to the bottom.

Tools: The tools required will depend upon the revegetation plan, the size of the plants, soils and size of the project and site conditions.

Chain saws, lopping and hand pruners and hatchets may be needed for the preparation of cuttings and materials for wattling, brush layering , brush trenching and brush matting. Heavy hammers and sledges are needed for staking the job, driving stakes in the installation of wattling and for installation of fencing and cages for plant protection.

Picks, mattocks and shovels are needed for site preparation, shovels and spades or tile spades for trenching for wattling and brush layering, and dibbles or small hand picks for planting smaller plants and cuttings. Star drills and hammers may be needed for planting unrooted cuttings in cemented soils. On some sites, power augers are useful for planting.

Other materials may include fertilizers, fencing for plant protection, wire or fencing for installation of brush matting and stakes for layout and biogeotechnical work. Each job will have its own requirements.

Planting: After site preparation and biogeotechnical work is done, planting can proceed. Plants, unrooted cuttings and brush for biogeotechnical construction are living things and must be handled accordingly. They should be kept moist or well watered, as cool as possible and protected until actually planted.

Size of planting holes depends on the size of the material to be planted and sometimes on the soil conditions. When soils are friable the holes may not need to be much larger than the plant root system. In heavy and compacted soils, a larger hole to allow backfilling of looser material may allow better initial root penetration. The depth of the holes must be greater when fertilizers are to be used beneath the plant than when no fertilizer is used.

When fertilizers are used the holes should be deep enough to place the fertilizer in the bottom of the hole, backfill with two or three inches of soil, place the plant, cover the roots with one to two inches of native soil and still leave a depression around the plant to collect water. Use only the quantities of fertilizer recommended by the manufacturer or as determined by soil or pot tests.

Older recommendations often called for amendments to be added to the backfill to loosen the soil and increase water holding capacity. Research has shown that although roots proliferate well in amended backfill, they do not penetrate the native soil as well as they do when no amendment is used. Amendments increase planting costs substantially.

Planting holes on slopes need special attention. First dig a "step" sloping into the bank and then dig the hole at the back of this step. Be careful to not loosen the front "lip" of the step. Hole size and planting techniques are as for more level sites.

Planting should be done immediately after digging the hole to reduce drying of the backfill. This is especially important where supplemental irrigation is not available. Plants should be removed from the containers even though they are "biodegradable". The object is to get the maximum contact between the roots and the native soil. If the rim of a "biodegradable" pot becomes exposed to the air, the pot will act as a wick and create a dry zone between the roots and the native soil.

Any circling roots on the outside of the root ball must be removed before planting.

In revegetation projects it is usually desirable to set the plants just below the level at which they were and to cover the root systems with two or three inches of soil to act as a mulch. This is contrary to the usual horticultural advice for planting in the irrigated landscape. Backfill should be thoroughly tamped to insure good root-soil contact and to eliminate air pockets. If irrigation is available, the plants should be watered in to aid this compaction and to supply supplemental water.

The use of berms around the planting hole may be useful to concentrate rainfall or irrigation. Berms should be two to four inches higher and of sufficient diameter to perform this function. On sloping ground it is desirable to leave the berm open on the uphill side to trap more run-off. The inside of the berm should be tapered toward the plant to concentrate water near the root system.

The use of mulches is of questionable value in sites subject to flooding. Plastic mulches may reduce aeration when plants are flooded. Organic mulches will float away. However, if a growing season will elapse between planting and flooding, mulches may increase plant survival. If plastic is used it should be removed before flooding.

Hydroseeding: Grasses and forbs may be established by hydroseeding where flooding does not coincide with the germination stage. Woody species usually cannot be established this way because seeds are not placed beneath the soil surface. Costs vary with the choice of species, rates of seeding,choice of mulch as binders, size of job, accessibility, etc. These cost may run $700 to $1,000 per acre and up.

Range Drills: Grasses and forbs may be economically seeded on gentle slopes with modified range drills or other seeding equipment.

Broadcast Seeding: Broadcast seeding of grasses should be done if the site is rough or flat enough to keep the seed on the slope and if drill seeding is not possible. Seed should be raked or dragged into the soil and the site covered with clean straw mulch. Stands are usually much better than those obtained with hydroseeding.

Direct or Spot Seeding: Woody species may be established on some sites by direct seeding. This technique requires fairly intensive management, but where successful, it produces excellent results and may be more economical than using transplants.

Plant Protection: On many sites it is essential to protect plantings from damage by animals. Rodents will often girdle plants at ground level. Rabbits, deer and domestic animals can kill plants by browsing and the larger animals can cause considerable damage by trampling.

Wire caging is usually used for protection. The mesh size and height will depend on the predator. Hardware cloth is needed for protection from mice and other small animals. The height will depend upon the ind or kinds of predators. They may be fairly low for rodents, of medium height for rabbits and as much as three or four feet for larger animals. The larger animals may browse the branches extending beyond the cage and even the tops but the plants will usually outgrow the need for protection. These cages may be anchored with wooden stakes or large "hairpins" made of number nine wire.

Fencing the entire site may be necessary where deer populations are heavy or where domestic animals graze.

Protection from grasshoppers may be accomplished with cages made of window screen. These cages may be reused when the plants have outgrown them.

Maintenance and After Care: The use of irrigation will improve growth and survival of plantings. The decision about irrigation must be made on economics contrasting over planting and increased plant mortality with the cost of irrigation. Irrigation may be impractical, in which case reliance must be placed on over planting. In some areas irrigation may not be required because of summer rainfall. On other sites the increase in survival may be worth the cost of irrigation. With proper selection of species and proper irrigation methods, irrigation should only be required for one or two years.

Many types of systems are available. Underground systems which are perforated have been used where vandalism may be a problem. Above ground systems may be conventional sprinklers or systems using drip, trickle or emitter distribution. Portable systems may be used to cover more than one section or project on a rotating basis.

Weed Control: The control of weeds is desirable in any revegetation planting. On riparian sites the use of chemicals often is not possible Persistent chemicals such as pre-emergence herbicides should never be used. Only those chemicals which degrade rapidly into harmless compounds should be used and their use should be limited to some distance from the water. The problems with mulches has already been discussed. In many cases only manual weed control is acceptable.

Fertilization: Additional fertilizer should not be needed for most woody plants if the correct species have been selected. The proper slow release fertilizers should give one to three years of benefit and the plants should be able to fend for themselves. On some soils, grass vegetation may need to be fertilized to maintain adequate stands.

SUMMARY

No vegetation techniques will resist severe erosion until established. Auxiliary methods such as riprap, gabions, bulkheads and groins often need to be used for protection until establishment of vegetative cover. In areas of severe stream or river flow these supplemental measures may be essential.

With proper site analysis and planning and with quality plants, planted with proper care, biogeotechnical methods and plants can not only solve many slope protection and erosion problems but they can greatly improve habitat, aesthetics and the over-all quality of the environment.

CONTOUR WATTLING INSTALLATION

Materials: Wattling bundles shall be prepared from live, shrubby stems of species which will root such as willow, baccharis, dogwood, etc. Where woody species are undesirable, e.g. channels with restricted flow or where shading would restrict the growth of herbaceous emergent or aquatic species, stems of non-rooting species or of dead material of species that would normally root shall be used.

Bundle Length: Wattling bundles may vary in length depending on the length of the species used. Bundles shall taper at the ends and shall be one (1) to two (2) feet longer than the average length of stems to achieve this taper. Butts of stems shall not be more than one and one-half (1 1/2) inch in diameter.

Bundle Diameter: When compressed firmly and tied, each bundle shall be eight (8) inches in diameter. Maximum allowable variation is plus or minus two (2) inches.

Bundle Construction: Stems shall be placed alternately and randomly so that approximately one-half (1/2) the butt ends are at each end of the bundle and the butts are staggered within the bundle.

Bundle Tying: Bundles shall be tied on not more than 15 inch centers with a minimum of two (2) wraps of binder's twine or heavier tying materials with a non-slipping knot.Tying may be done with strapping machines or other methods as long as the bundles are compressed tightly.

Time of preparation: The timing of preparation of wattling bundles is vital when used with the expectation of rooting. Preparation and installation of wattling shall be during the season of vegetative dormancy, i.e. from the time the resting buds are set and vegetative growth has ceased in late summer until bud break and the beginning of vegetative growth in the late winter or spring. Where non-rooting or dead brush is desired, preparation and installation may be done any time of the year.

Bundles shall be prepared not more than two days in advance of installation except as noted below. If provisions are made for storing, submerged in water or sprinkled often enough to be kept moist as well as covered, preparation may be up to seven (7) days in advance of installation. Bundles may be kept in suitable cold storage for up to three (3) months. Such storage shall have humidity control to avoid desiccation of the plant material.

Layout, Staking: Location of the rows of wattling shall be staked, on contour, using an Abney or similar type level. The stakes used in installation my be used for layout. Care must be exercised to maintain contour when traversing gullies to avoid diverting more water into these gullies.

Wattling Spacing: Vertical spacing of wattling rows shall be as on the drawings. [Spacing is a matter of judgement. It need never be closer than three (3) feet and may be as much as twenty (20) feet vertical distance (not slope face). Some factors affecting spacing are length, steepness and stability of slope, erodibility of the soil, expected precipitation and run-off.]

Stakes: Stakes must be strong and long enough to penetrate to the undisturbed substrate. The minimum sized stake shall be at least two by two (2 x 2) inches at the midpoint. Two by fours (2 x 4"s) cut on a diagonal are recommended. I n rocky substrate, rebar or other metal stakes may be required. After driving to a firm hold the rebar must be bent over the wattling to hold it in place. Live willow stems greater than one and one-half (1 1/2) inch in diameter may be used for staking.

Stake Spacing: Bundles shall be staked firmly in place with one row of stakes on the downhill side of the wattling on not more than three (3) foot centers. A second row of stakes shall be placed through the bundles at not more than five (5) foot centers. Where bundles overlap there shall be two stakes to "tie" the bundles together, one downhill and one through the ends of each bundle and between the last two ties of each bundle.

Installation: Bundles shall be laid in trenches dug approximately one-half the bundle diameter, immediately above the bottom row of stakes. Ends of the bundles shall overlap at least 12 inches. The last ties of each bundle shall overlap sufficiently that a stake may be driven between the last two ties of each bundle.

Backfilling: Wattling shall be covered with site soils, filling voids within, behind and below the bundles and tamped thoroughly. Water may be used to aid in backfilling. Workers should be encouraged to walk on the covered wattling as other work on the slope is done. Heavy clay materials may need to be pulverized in order to attain suitable back filling. Successful rooting of the wattling will only be attained if the filling is done properly.

Progression of Work: Work shall progress from the bottom to the top of the slope. On large jobs, work might be underway on two or more rows of wattling at one time.

Prevention of drying: Exposure of the wattling to sun and wind must be minimized throughout thee operation. Trenches shall be dug only as rapidly as placement and covering of the bundles is accomplished to minimize the drying of the brush and the soil removed from the trenches.

WILLOW WATTLING COSTS BREAKDOWN FOR A FIVE ACRE CUT SLOPE ON I-5 NEAR DUNSMUIR, CALIFORNIA. THE CONTRACT BID PRICE WAS $3.00 PER LINEAL FOOT.

Wattling Supplied by Commercial Source

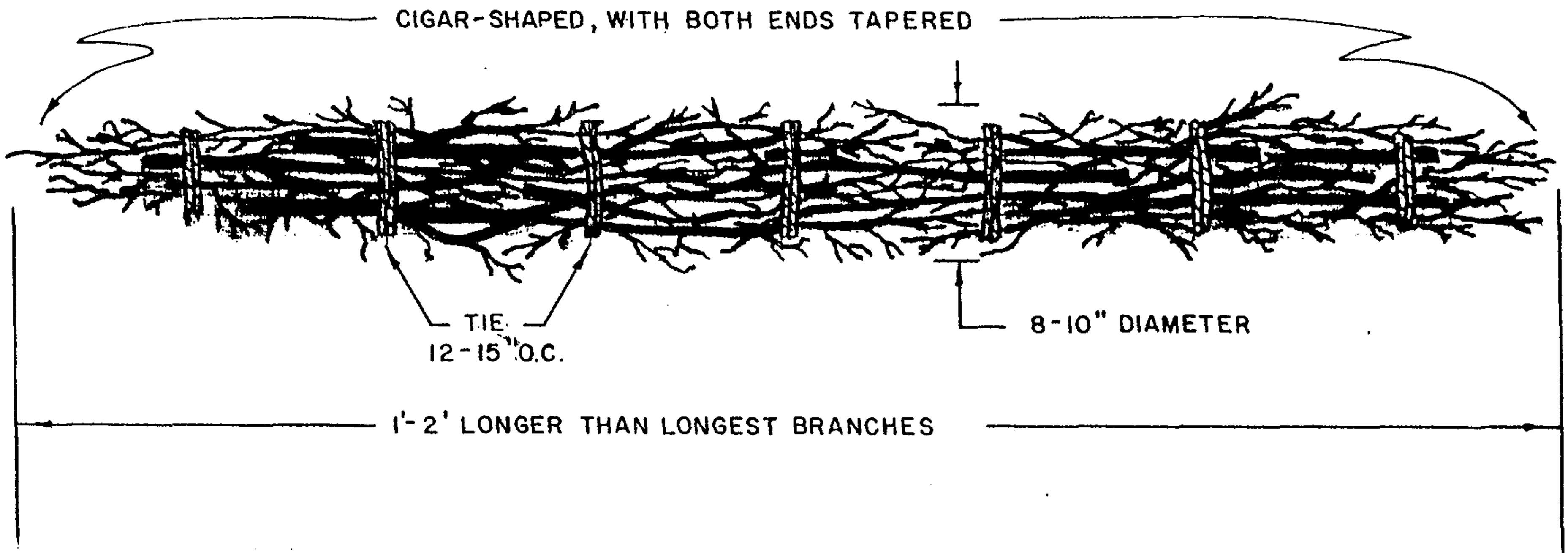
Total length of wattling	14,772 lineal ft.
Costs	
Laborers, 662 hrs @ $12.48/hr	$8,261.76
Foreman, 108 hrs @ $14.85/hr	1,603.80
Pickup Truck, 108 hrs @2.00/hr	216.00
1 ton Flat Bed Truck, 80 hrs @$2.75/hr	220.00
Willow Bundles, 2,110 @ $2.21/bundle	4,663.73
Total Cost	$14,965.29
Cost per lineal foot	$1.01

Wattling Supplied by Youth Conservation Corps
Labor $1.00 Higher

Total length of wattling	12,914 lineal ft.
Costs	
Laborers, 275 hrs @$13.48/hr	$3,707.00
Foreman, 73 hrs @$15.85/hr	1,157.05
Pickup Truck, 57 hrs @$2.00/hr	114.00
1 ton Flat Bed Truck, 57 hrs @$2.75/hr	156.75
Willow Bundles, 1,845 @$1.00/bundle	1,845.00
Total Cost	$6,979.80
Cost per lineal foot	$0.54

NOTES: Costs of stakes not included in either job. Wattling bundles were 7-9 feet long. Net length due to overlapping of ends for total job was ±7 feet.
Second half of job with more experienced workers, the labor cost dropped from $0.56 to $0.29 per lineal foot.

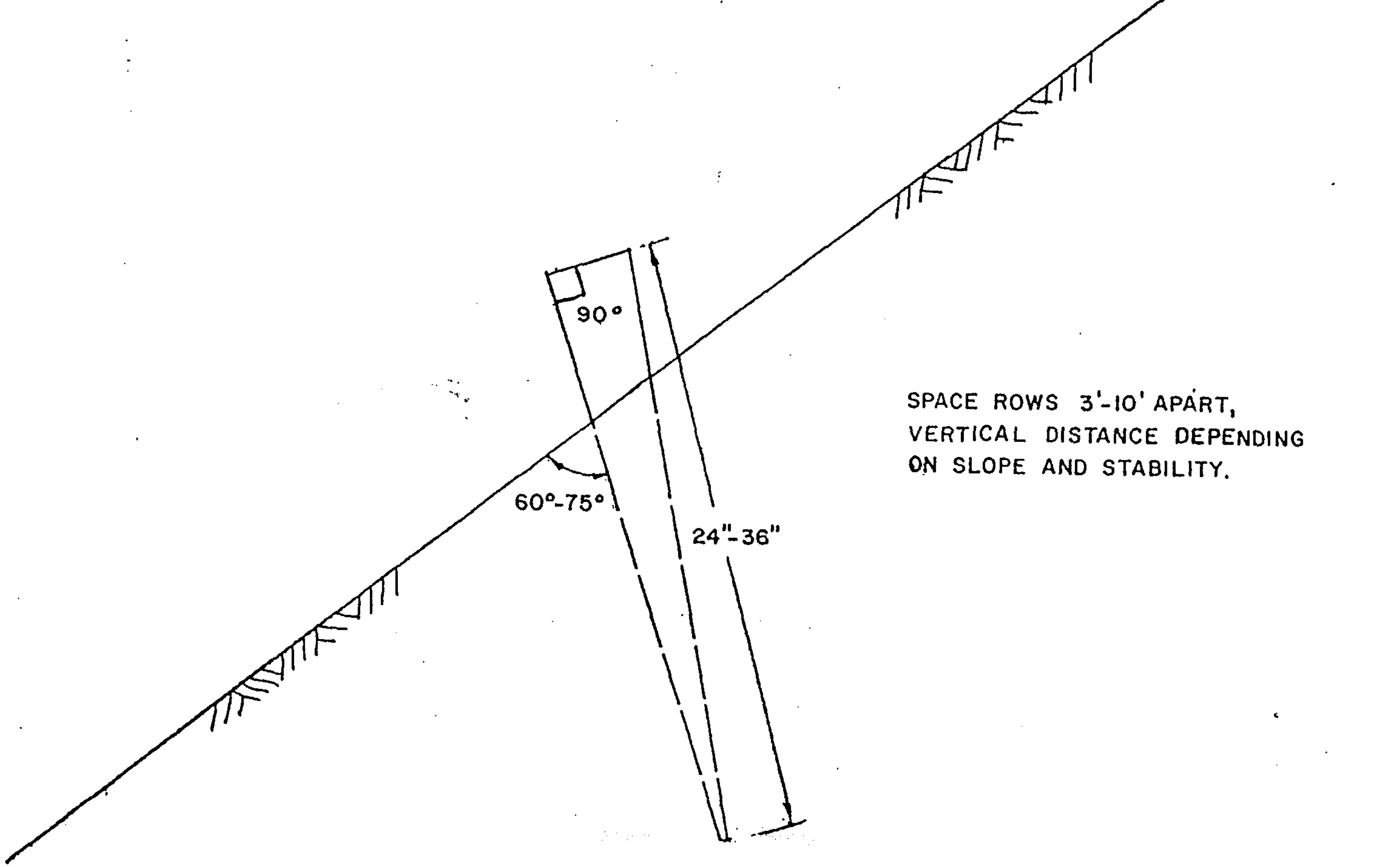
WATTLING BUNDLES



BUNDLES OF LIVE BRUSH, SPECIES WHICH ROOT PREFERRED

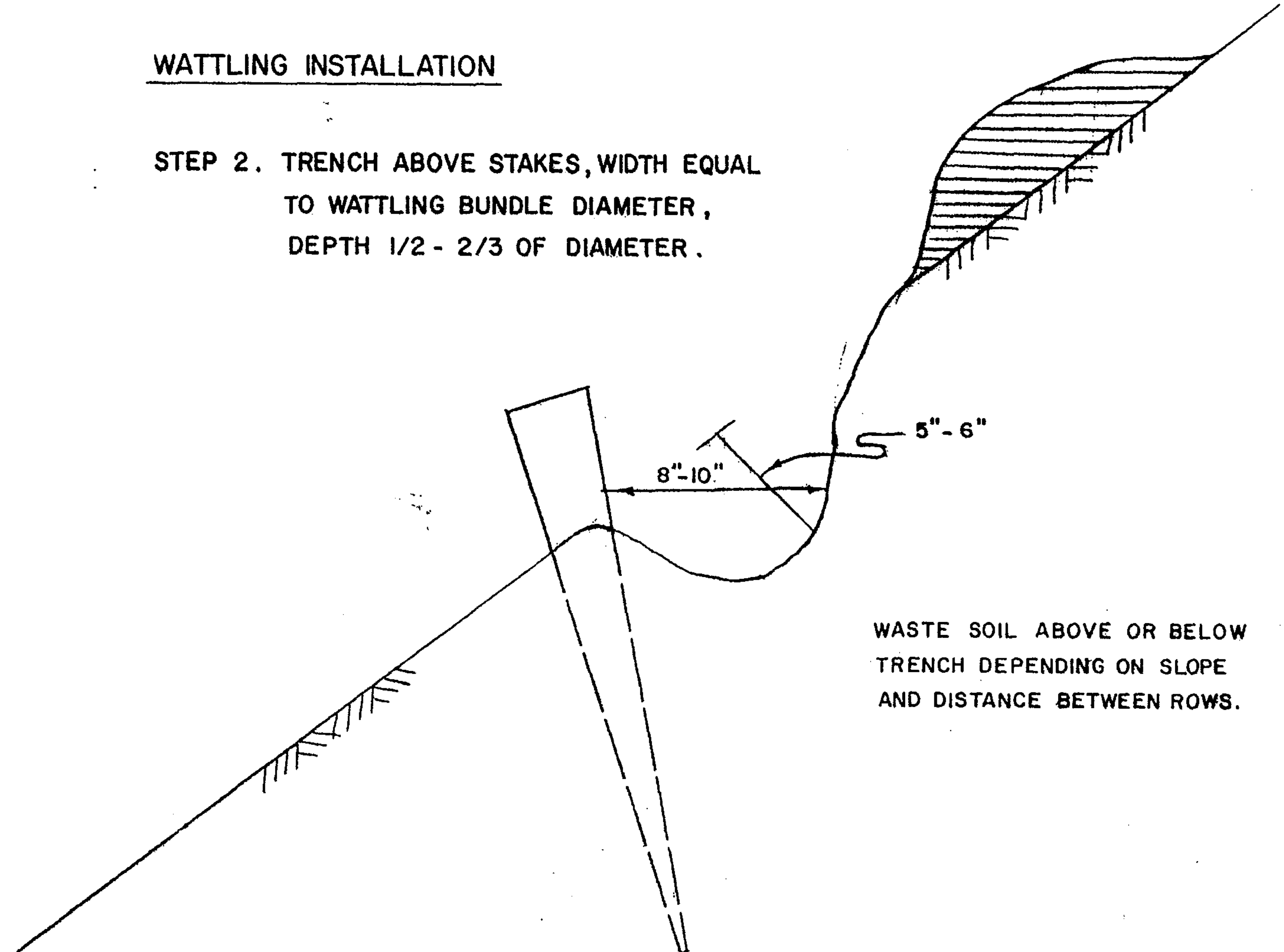
WATTLING INSTALLATION

STEP I. STAKE ON CONTOUR, 3'-4' O.C.



WATTLING INSTALLATION

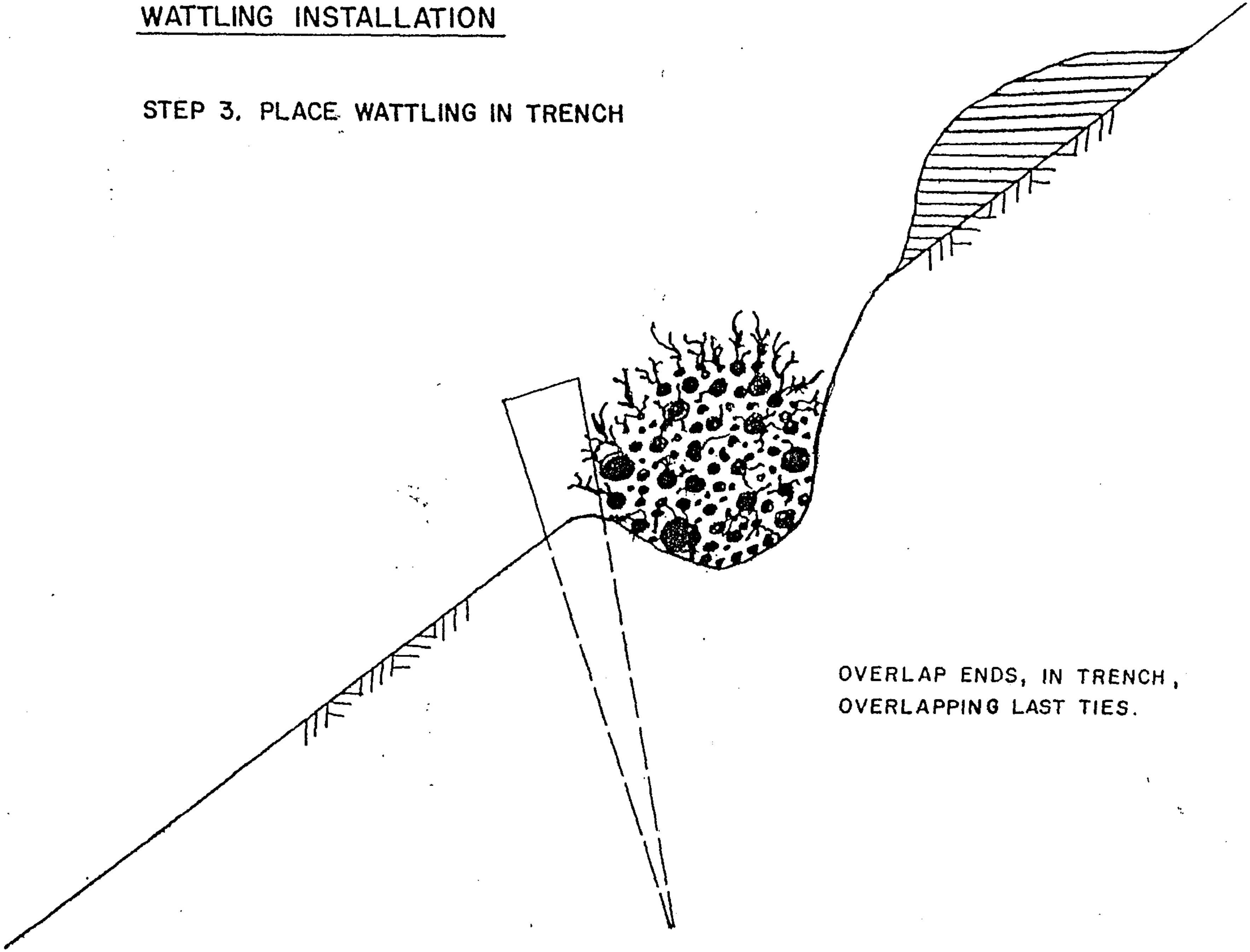
STEP 2. TRENCH ABOVE STAKES, WIDTH EQUAL TO WATTLING BUNDLE DIAMETER, DEPTH 1/2 - 2/3 OF DIAMETER.



WASTE SOIL ABOVE OR BELOW TRENCH DEPENDING ON SLOPE AND DISTANCE BETWEEN ROWS.

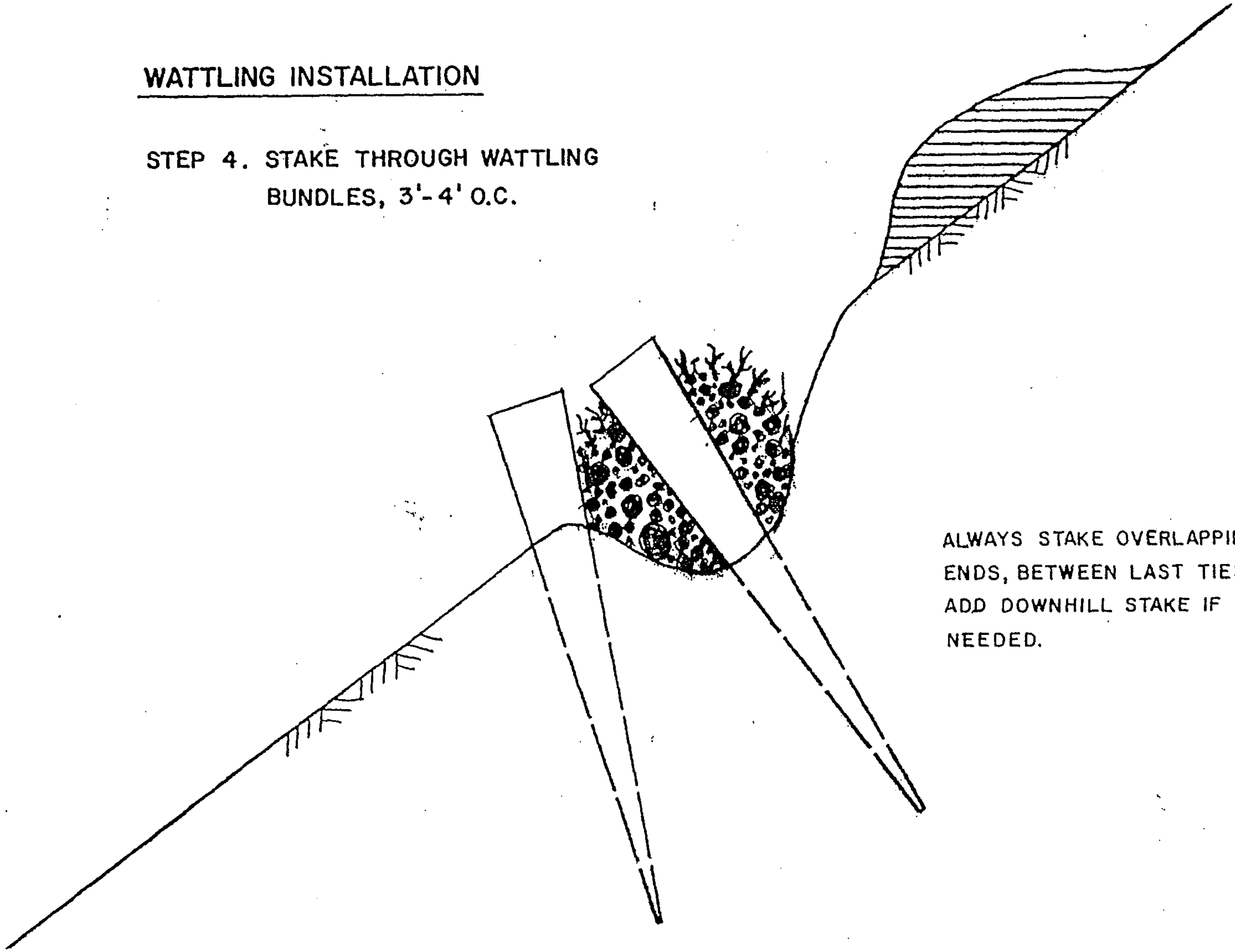
WATTLING INSTALLATION

STEP 3. PLACE WATTLING IN TRENCH



WATTLING INSTALLATION

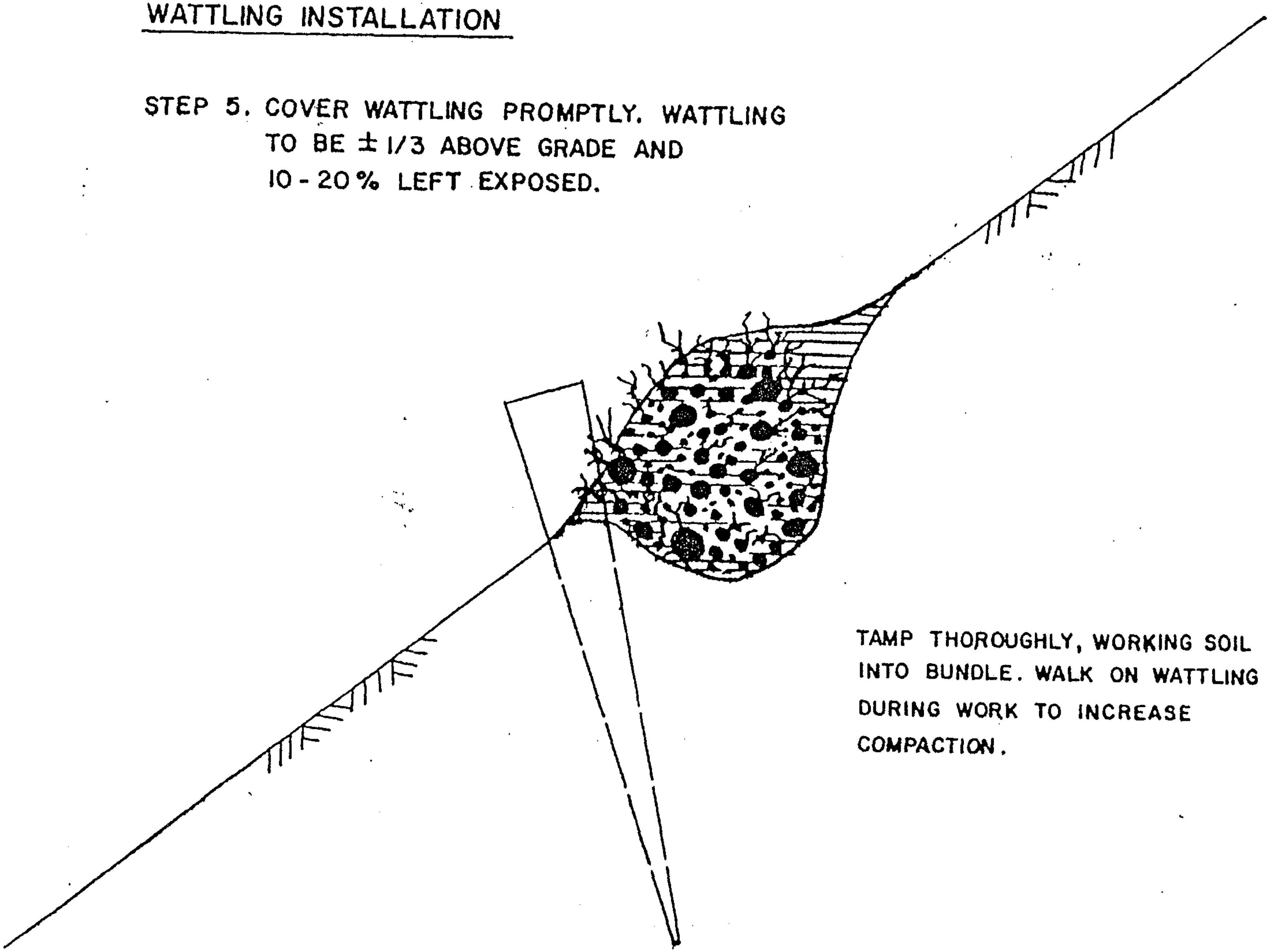
STEP 4. STAKE THROUGH WATTLING BUNDLES, 3'-4' O.C.



ALWAYS STAKE OVERLAPPING ENDS, BETWEEN LAST TIES. ADD DOWNHILL STAKE IF NEEDED.

WATTLING INSTALLATION

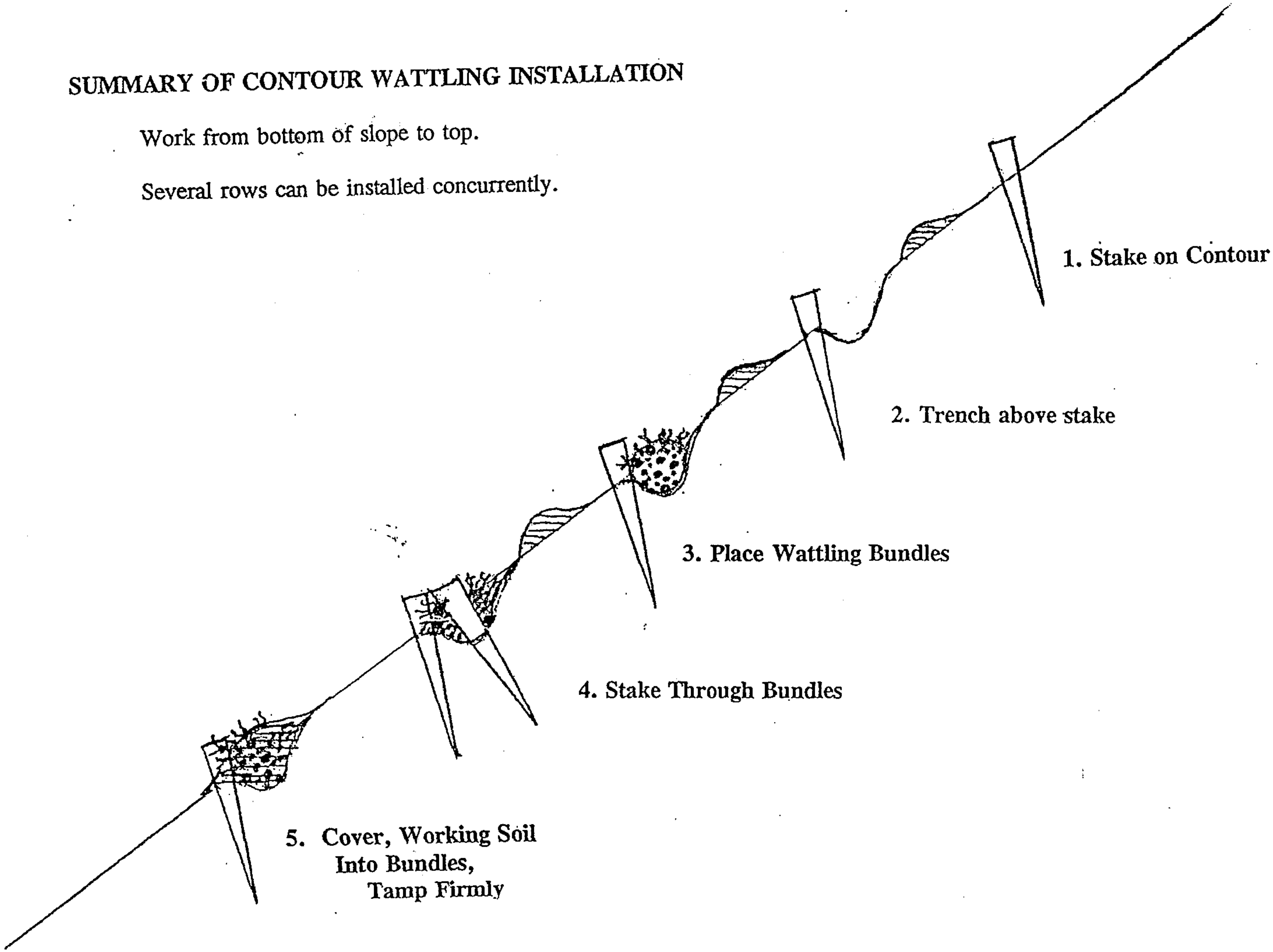
STEP 5. COVER WATTLING PROMPTLY. WATTLING TO BE ± 1/3 ABOVE GRADE AND 10 - 20 % LEFT EXPOSED.



SUMMARY OF CONTOUR WATTLING INSTALLATION

Work from bottom of slope to top.

Several rows can be installed concurrently.



BRUSH BOX CONSTRUCTION

Definition: Brush boxes are biotechnical construction consisting of live or dead brush contained between two rows of stakes to intercept overland flow and trap sediments or in lakes or reservoirs to intercept and dissipate wave energy. They are placed on contour when on land and to above water level in lakes or reservoirs. They may also be used as longitudinal dikes or groins along water courses.

Materials: Live brush shall be used, at least in the basal portions, when a woody plant barrier is desired. The upper portion of the box may be inert (dead) brush. Dead brush shall be used when woody plant growth is not desired, *e.g.* when herbaceous wetland or emergent vegetation is desired. Brush may be of any length and diameter if sufficiently flexible to pack tightly between the stakes.

Stakes are best made from lumber or small log poles. They shall be of sufficient length to drive to a firm hold with freeboard four to eight inches higher than the finished height of the box.

Tying material is usually wire, 12 gauge or larger but could be cordage of suitable strength. The tying material is to hold the brush tightly compressed and to keep the tops of the stakes from spreading.

Dimensions: The brush boxes shall be sized for the intended use, sediment traps, energy dissipaters etc. Basal width shall be about one-half to two-thirds the height for stability. Stakes shall be sized in proportion to the expected forces. Two-by-four "construction" stakes are suitable for small boxes to at least 12 inches high. Installation in water should usually have non-tapered stakes of larger diameter. Brush boxes may be of any length.

Construction: Set and drive a double row of stakes, spaced as noted above, where desired. The top of the stakes should be four to eight inches higher than the finished top of the box. Dig a shallow trench two to four inches deep between the stakes if installation is on the ground. If the site is two rocky to trench, earth should be mounded on the up-grade side of the box top prevent water and sediments from flowing under the box. Brush is placed randomly between the two rows of stakes with butt ends alternated and staggered. Place sufficient brush so that when compressed tightly the desired height is obtained. Wire or tie cordage between opposite stakes and diagonally between the pairs of stakes while compressing the brush. Drive the stakes sufficiently to compress and hold the brush in place.

Time of installation: Brush boxes of dead brush may be installed at any time. If live brush is desired the installation should done while the brush is dormant. Alternatively, cuttings of an easily rooting species may be planted during the dormant season to establish the live woody plants. (If live woody barrier is desired, see also instructions on handling brush under the wattling specifications.)

Use as sediment traps: Where heavy sedimentation t such as at the mouth of a gully several rows of brush box may be constructed. When sediments accumulate to the top of the boxes, additional rows of boxes may be constructed.

BIOTECHNICAL CONSTRUCTION

SAMPLE SPECIFICATIONS

BRUSH MATTING

Materials: Live brush of willow, baccharis, dogwood or other species which will root shall be used. When species that will root are in short supply substitution of other species for up to 50% of the material may be approved. Wattling for the anchor row will be constructed and handled as noted in Contour Wattling Specifications. Stakes shall be as described in the same specifications. Tie wire shall be single strand, galvanized, annealed 12 gauge wire such as fence wire, or various types of fencing as indicated in the drawings.

Time of Work: Timing of the work will be as specified for contour wattling, i.e. the period of vegetative dormancy. When non-rooting or dead, rooting species are specified, work may be done at any time of the year.

Slope Preparation: The slope shall be free of debris and more or less a flat slope from top to bottom but may be undulating in a horizontal plane within the area to be treated.

Trenching: A trench, eight (8) to twelve (12) inches deep shall be constructed just below the low water line and flush with (exterior to) the plane of the slope face.

Brush Placement: Brush shall be placed butt down in the trench, against the bank, and perpendicular to the base line. The layer of brush shall be placed to a thickness of two (2) to four (4) inches when compressed. See the drawings for the required thickness.

Anchoring: A single row of wattling, log or rock of suitable size will be placed on top of the butts and in the trench at/below low water line. Wattling or logs will be properly anchored. See wattling specifications for preparation, tying and anchoring wattling bundles.

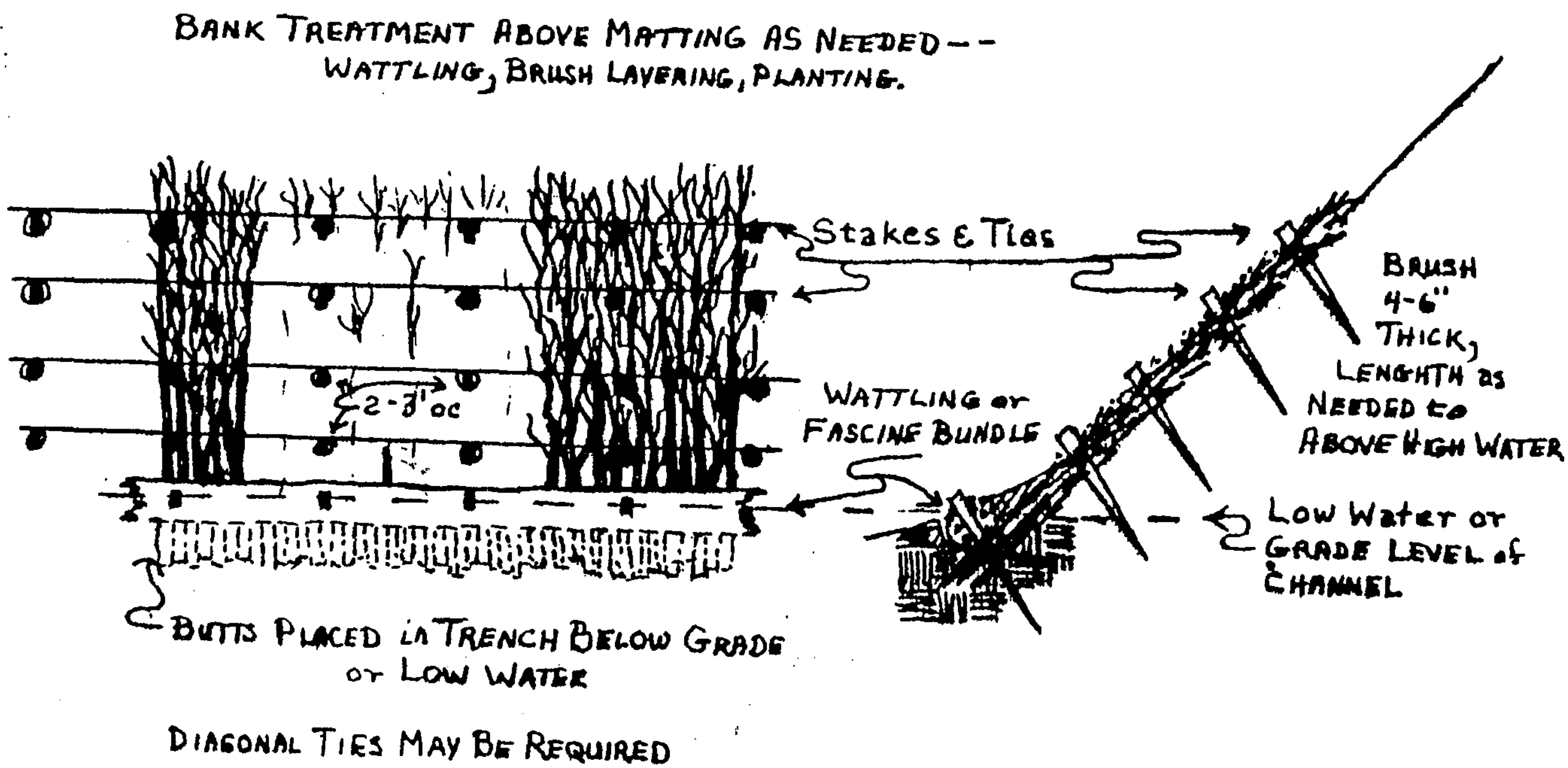
Staking and Tying: Construction stakes as detailed in Wattling Specifications or other approved staking shall be to a firm hold on three (3) to four (4) foot centers, extending beyond the matting on either side and one (1) foot above the anchoring row to one (1) foot below the specified height of the mat. Stakes shall be of sufficient length to drive to a firm hold and shall be driven to within four (4) inches of the top of the matting when compressed.

The brush matting shall be tied down with twelve (12) gauge galvanized, annealed line wire in horizontal runs and then diagonally between each horizontal row of stakes. Ties to the stakes shall be of such manner that if wire breaks between two stakes the integrity of the remaining wiring is maintained. A clove hitch meets this requirement. If stakes without taper are used, the wire shall be secured to the stake in such a manner that it cannot come off as the stakes are driven to compress the mat. After tying the stakes shall be driven further to compress the mat and place tension on the wire.

In high energy stream environments, fencing wire of appropriate size and gauge may be specified.

<u>Covering:</u> Following placement and tying, the matt shall be partially covered with soil, worked into the voids and well tamped when the brush is of live, rooting species. Covering is not required when dead brush or non-rooting species are specified.

CHANNEL PROTECTION - BRUSH MATTING



BRUSH LAYERING.

Materials. Live brush of willow species shall be used. When there is a shortage of willow, up to 50 percent of the brush may be of non-rooting species. When non-rooting species are used they shall be mixed randomly with the rooting species.

Time of Work. Work shall be done during the planting season specified for woody plant species, i.e., fall and early spring.

Size of Brush. Length of brush shall vary according to the particular installation and shall be as shown on the Drawings. Hand-trenched brush layering used for small gully repair shall be from 2 to 3 feet long.

Vertical Spacing. Vertical spacing shall be as shown on the Drawings.

Trenching. Hand trenching shall start at the bottom of the slope as in wattling placement. Trenches shall be dug 24 to 36 inches into the slope, on contour, sloping downward from the face of the bank 10 to 20 degrees below horizontal.

New Fill. Brush layering in new fill shall be placed on successive lifts of well compacted fill.

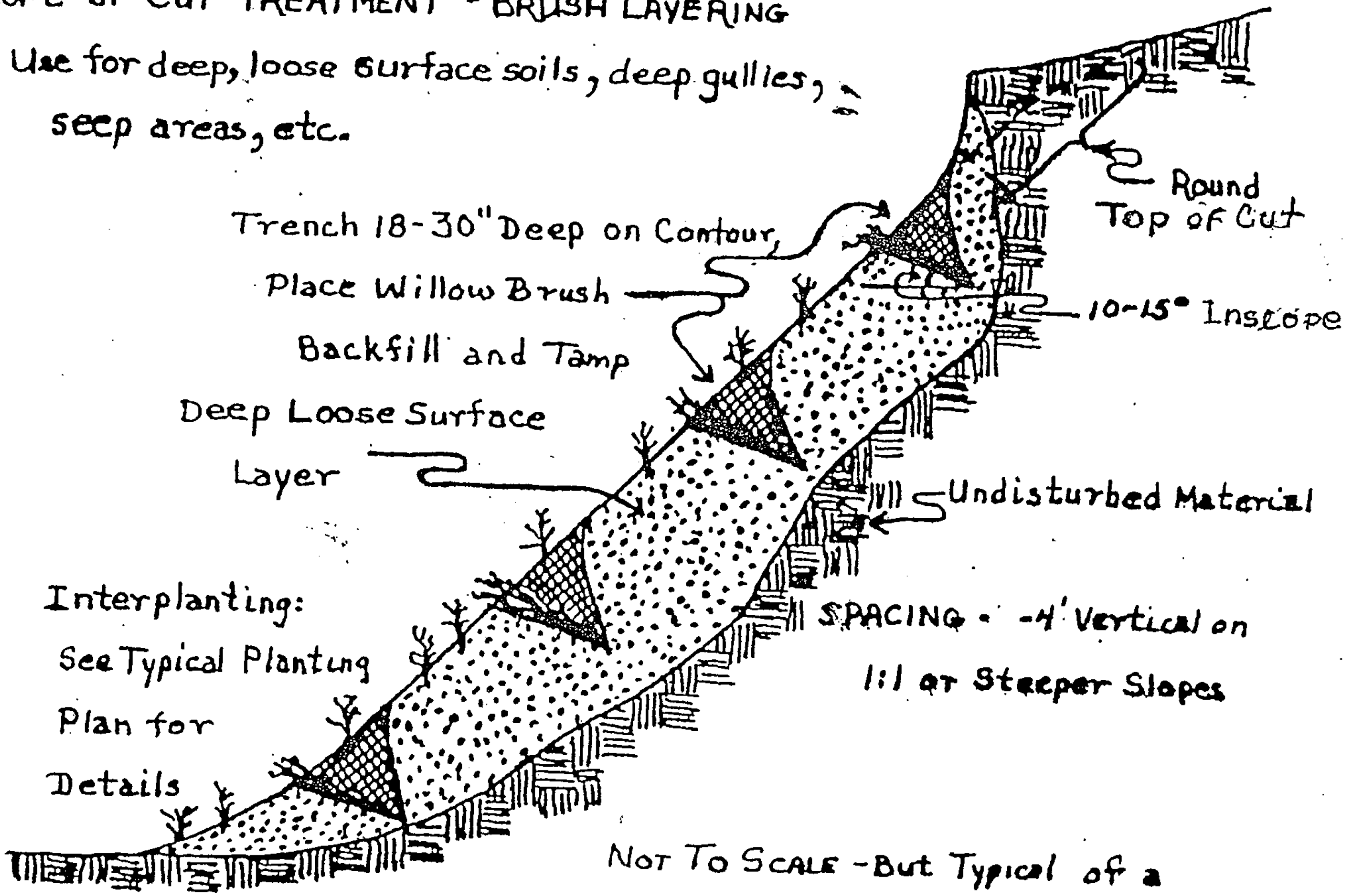
Placement. Brush shall be placed with butts inward and no less than 6 inches or more than 18 inches of the tips extending beyond the fill face. Brush shall be 4 inches thick in hand trenched placement work and 6 inches thick in fill work. Thickness shall be measured after compression by the fill or covering soil.

Covering. Brush layers shall be covered with soil immediately following placement and the soil compacted firmly. Covering may be done by hand or with machinery.

Interplanting. Where required by the Drawings, interplanting of woody plants (transplants and/or unrooted willow cuttings) and grasses shall follow placement of the brush layering.

Slope or Cut Treatment - Brush Layering

Use for deep, loose surface soils, deep gullies, seep areas, etc.

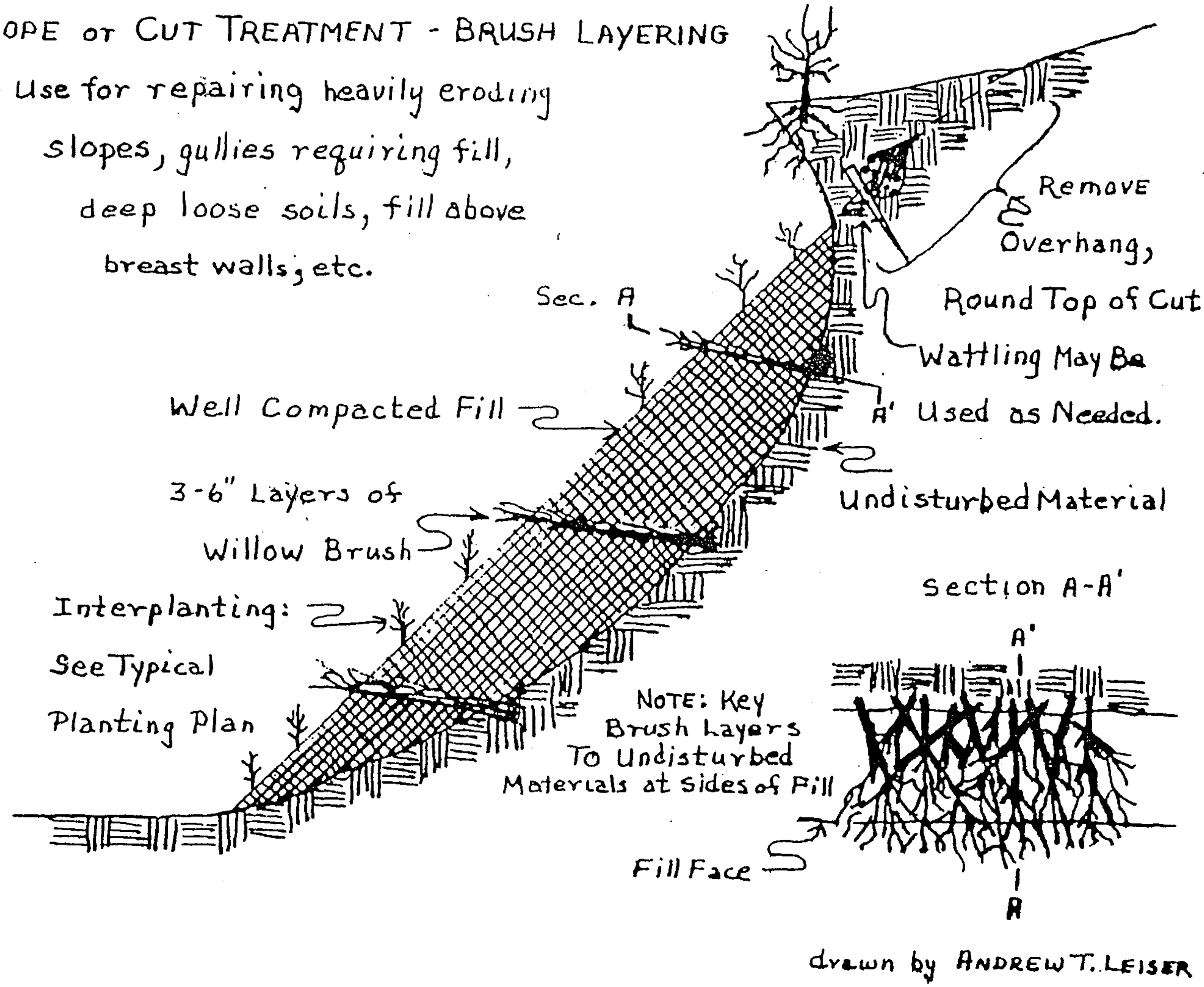


Not To Scale - But Typical of a 12-15' High Slope
± 1" = 2.5'

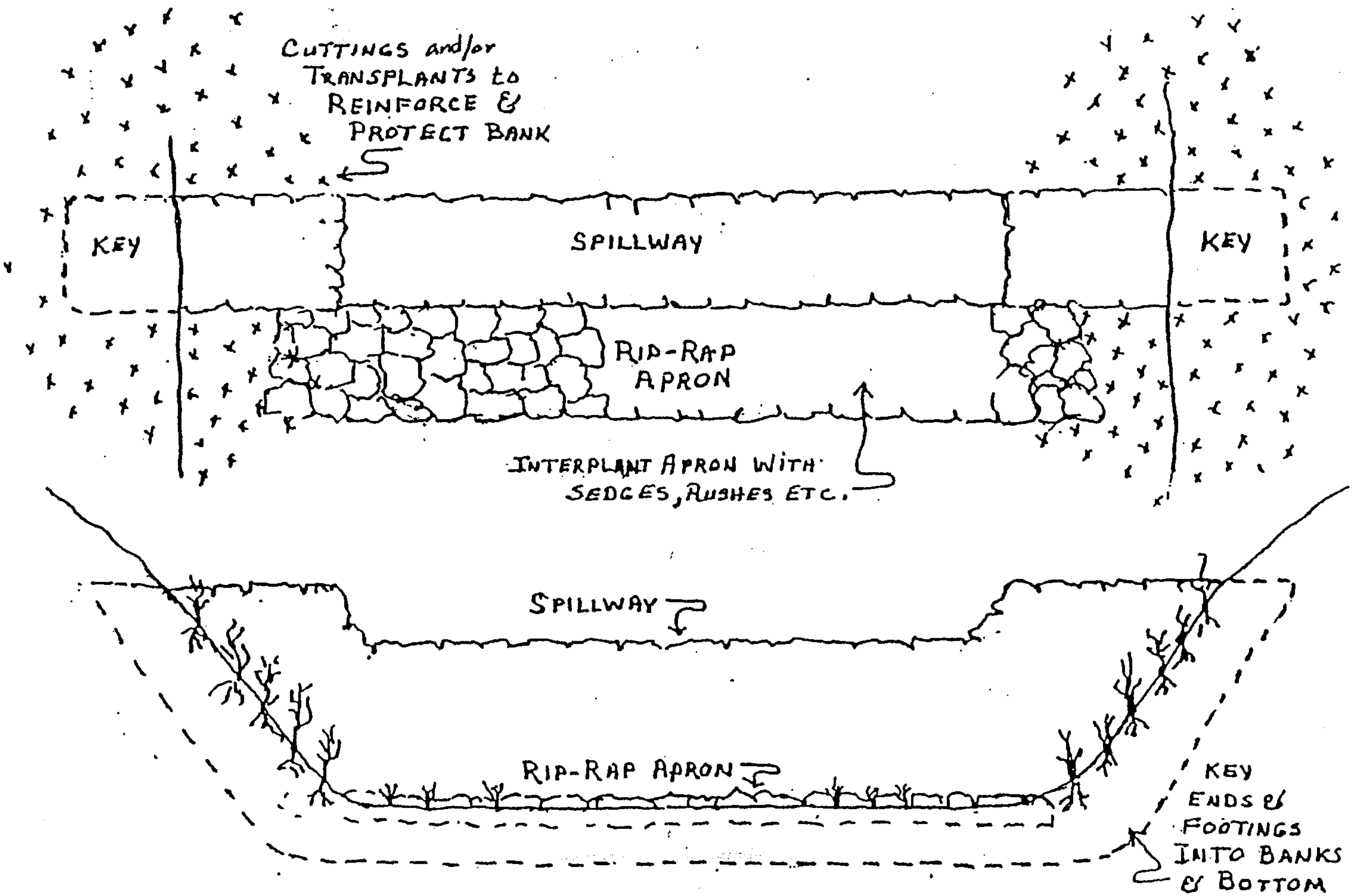
drawn by ANDREW T. LEISER

SLOPE or CUT TREATMENT - BRUSH LAYERING

Use for repairing heavily eroding slopes, gullies requiring fill, deep loose soils, fill above breast walls, etc.

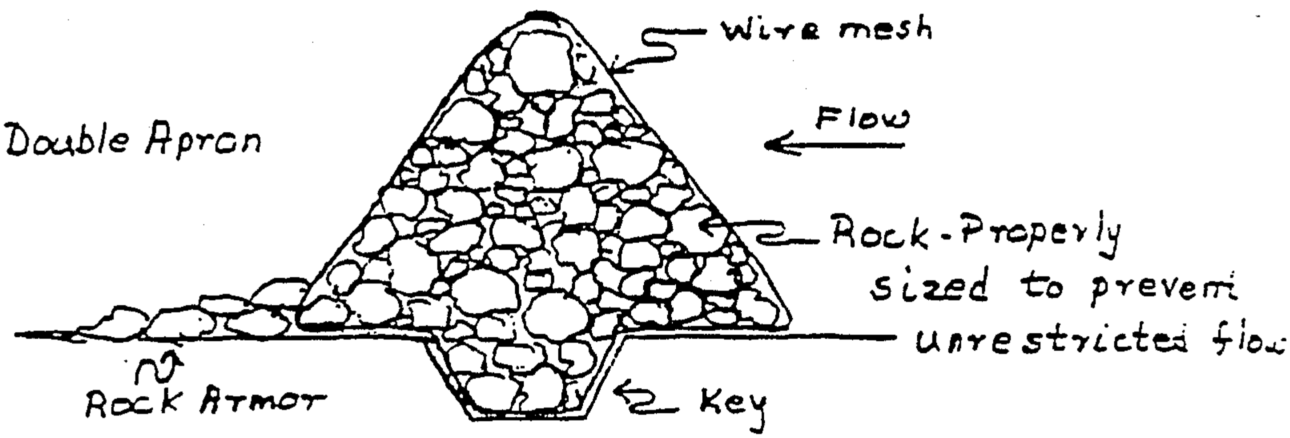


CHECK DAMS - SCHEMATIC -- NOT TO SCALE



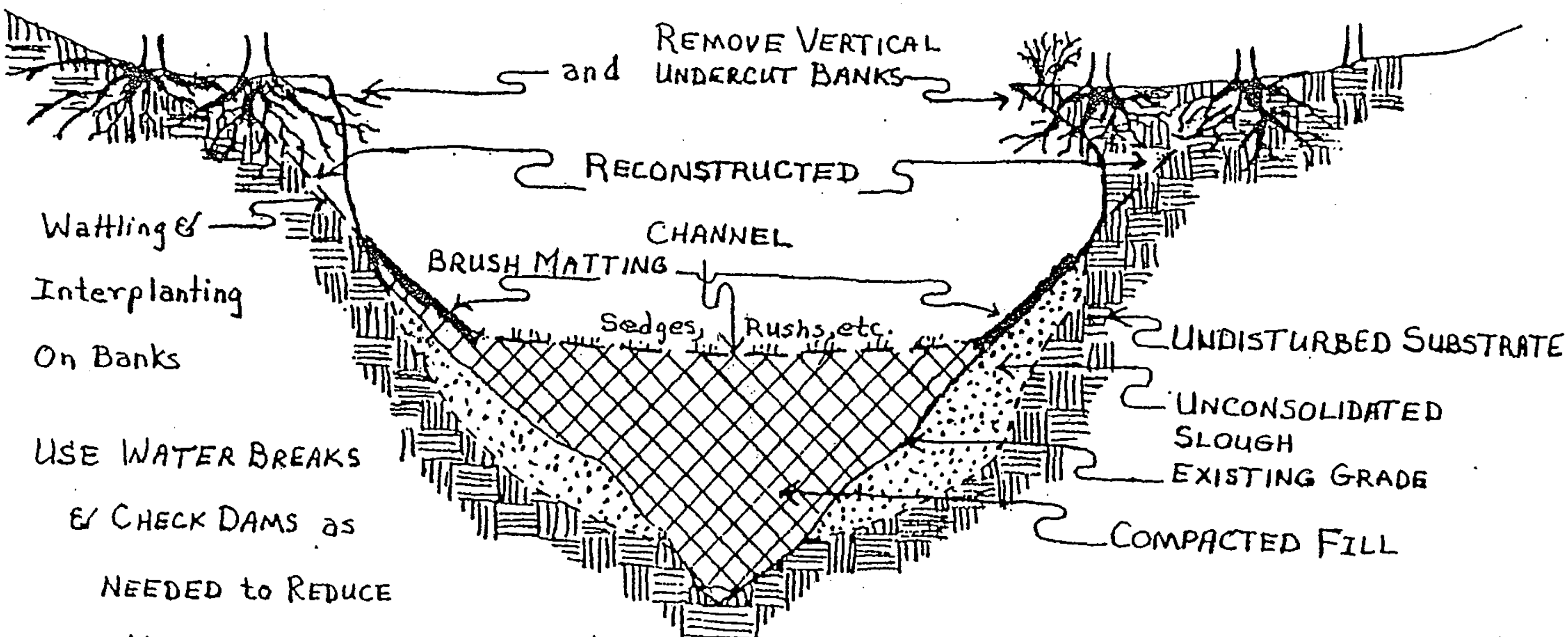
Check Dams

Double Apron

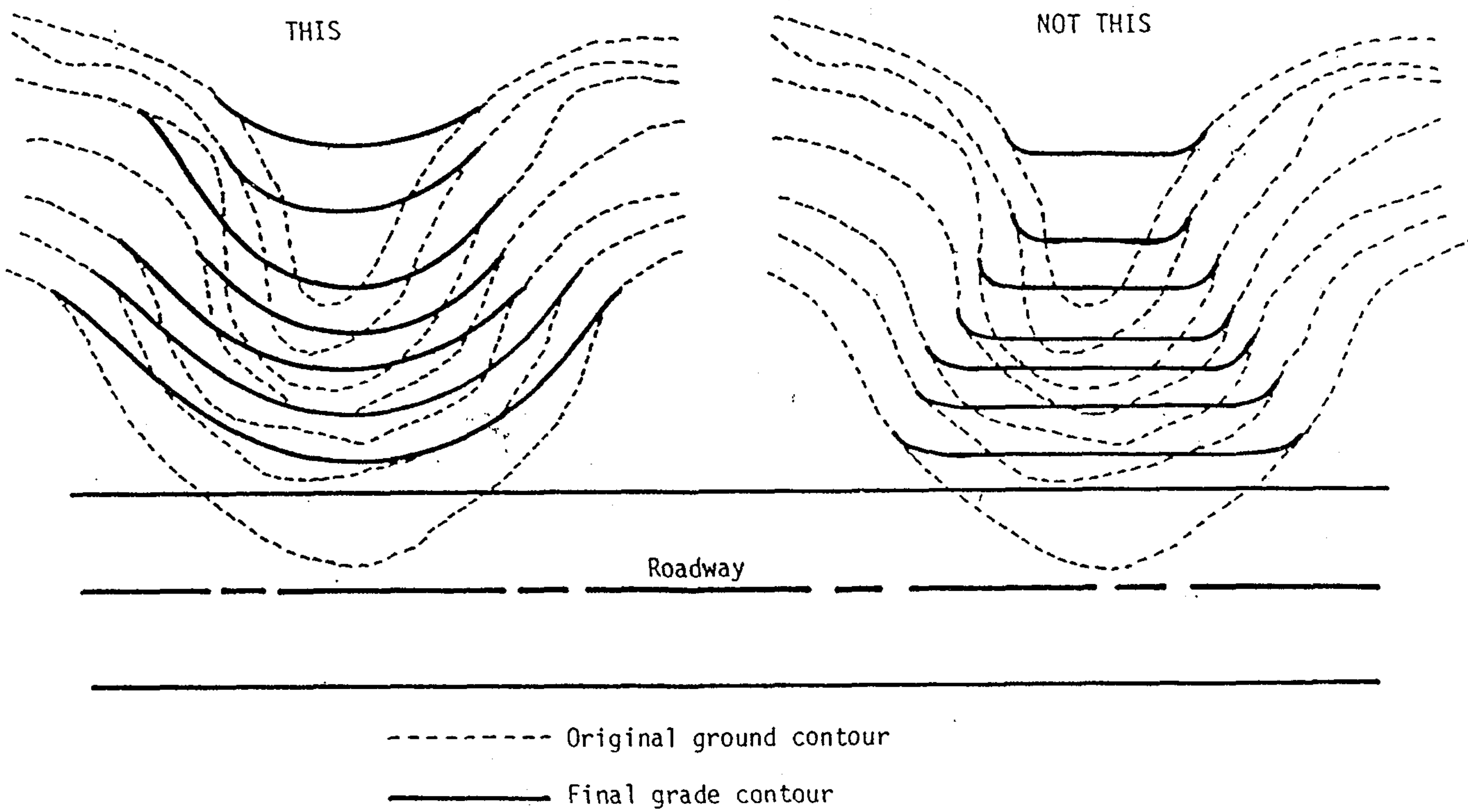


GULLIED CHANNEL RECONSTRUCTION

SEE WATTLING, BRUSH LAYERING, PLANTING, BRUSH MATTING CHECK DAM & WATER BREAK SHEETS for DETAILS.

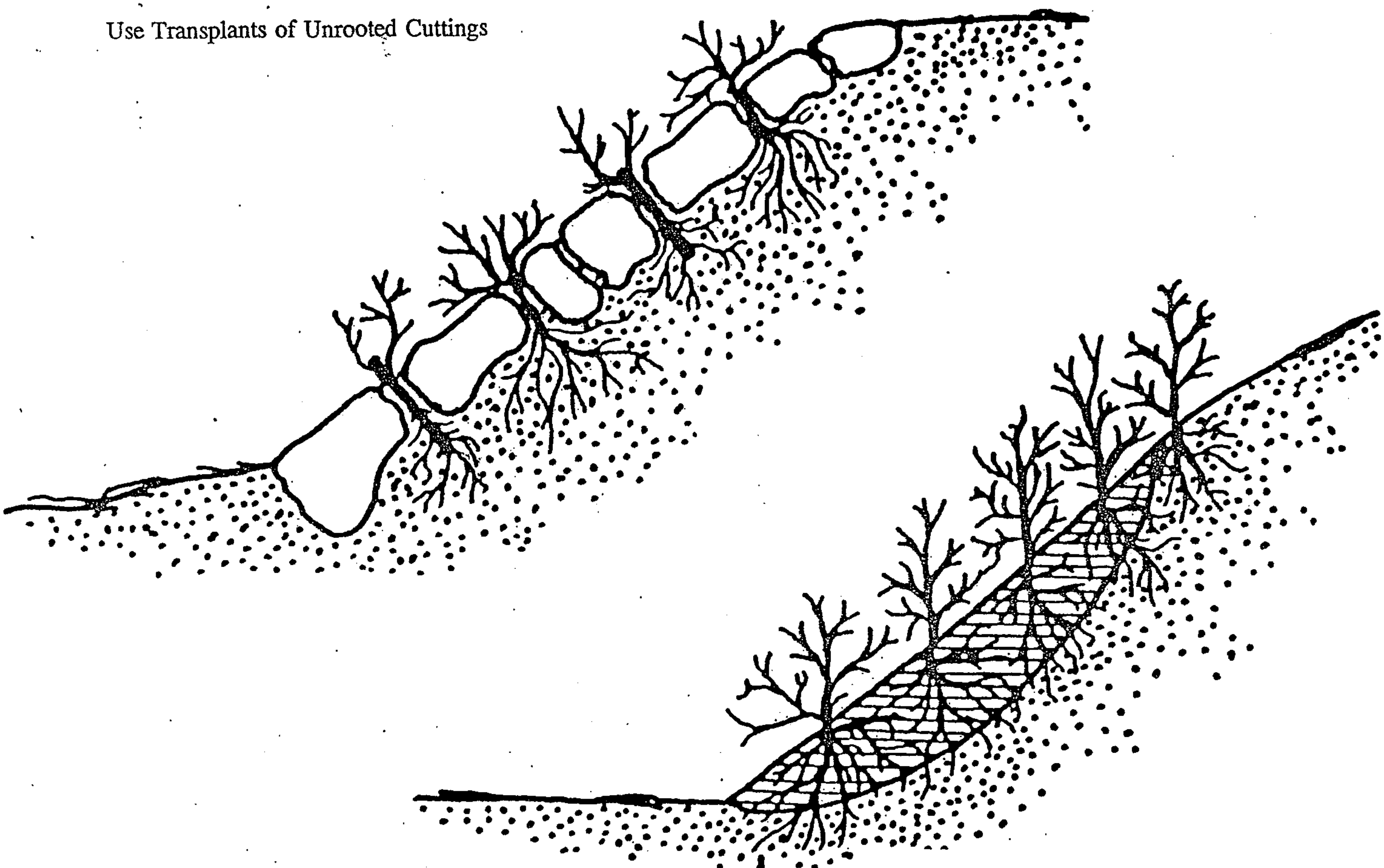


USE WATER BREAKS & CHECK DAMS as NEEDED to REDUCE VELOCITY of FLOW


THIS
NOT THIS
Roadway
Original ground contour
Final grade contour

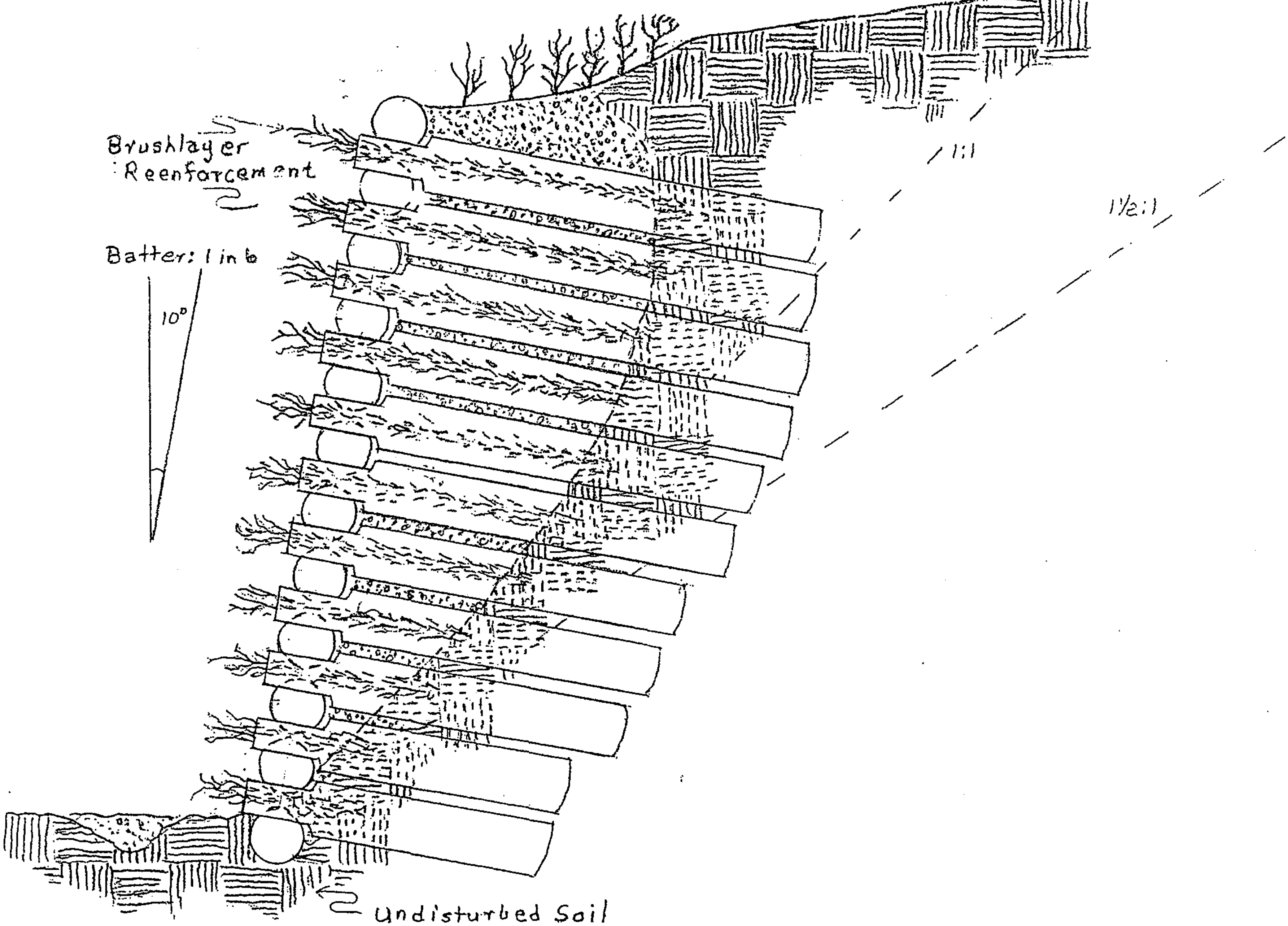
PLANT REENFORCEMENT OF RIPRAP & SMALL FILLS

Use Transplants of Unrooted Cuttings



NOT TO SCALE

LOG CRIB WALL with BRUSH LAYER REENFORCEMENT



BIOTECHNICAL CONSTRUCTION FOR GULLY CONTROL

Burchard H. Heede did research on gully control for the U. S. Forest Service Forestry Sciences Laboratory of the Rocky Mountain Forest and Range Experiment Station at Tempe, Arizona. This paper is a summary of his paper Designing Gully Control Systems for Eroding Watersheds presented at the Tenth International Congress on Sedimentology in Israel, July 1978.

The published abstract is a good introduction to the paper. "Effective design of gully control systems must consider the gully network as a whole and be based on geomorphologic indicators such as type of network stream order and stage of development. Consideration of geomorphologic characteristics allows a ranking of gully treatment priorities that, in turn, promises the highest return for expenditures. Relationships between sediment catch, channel gradient, treatment cost, and height of check dams in a treatment system are presented. Return is considered within a physical rather than economic framework. Future soil savings are the main focus."

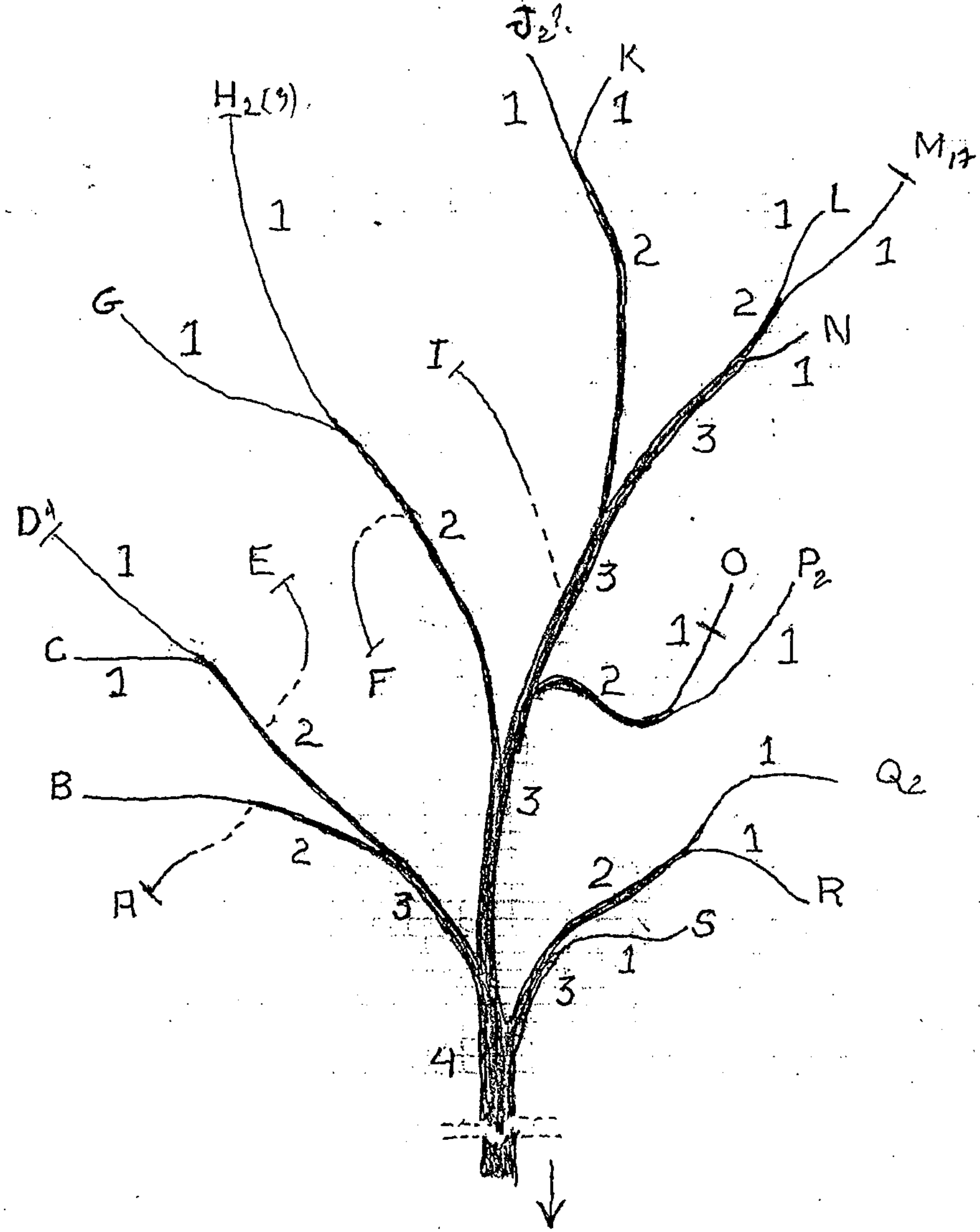
The process is to map a gully system and then assign priorities to treatment based on the gullies based on the potential for future erosion. Discontinuous gullies are among the highest priority followed by the main gullies, i.e. those gullies in which erosion will trigger erosion of still other gullies. Heede ranks gullies as follows.

1. Stream ordering
   First order gullies do not control any other gullies,
   Second order gullies influence one or more first order gullies.

The higher the order, the larger number of orders (not necessarily numbers of gullies) are controlled. The decisions are subjective. Each gully is designated by a letter plus a number designating the number of tributaries.

2. Stage of development
   Stages indicate the potential for future erosion and expected changes in channel morphology.
   a. Frequent and pronounced bed scarps, beginning of meanders in straight stretches, and steep, undercut or concave walls indicate young or youthful stages.
   b. Bedrock or vegetated, sloped and revegetated banks indicate old age.
   c. Intermediate conditions indicate intermediate or mature stages.

3. Treatment potentials are based on the following:
   a. Gully (or stream) order.
   b. Number of tributaries.
   c. Stage of development (estimate of future erosion).


J2?
K
H2(?)
M17
L
N
G
I
D
E
F
C
O
P2
B
Q2
R
A
S
4

Treating those gullies with large expected erosion will yield the greatest returns. Discontinuous gullies have the highest expected returns by preventing them from merging with other gullies. Old gullies have the lowest priority expect when they may have a large influence on tributaries. The assignment of priorities is a matter of individual judgement. Gullies with head cuts should always be treated.

Heede used dollar estimates of labor and materials is assigning priorities. For biotechnical work the main factor is labor. This may be from regular staff, prison crews, or volunteers. Biotechnical solutions are particularly attractive in those parts of the country that do not have readily available rock.

The final solutions should include at least the following:

All headcuts;
All discontinuous gullies;
The mainstream or longest gully.

These treatments do not have to be done all at once. If labor availability, the quantity of work to be done require that work is done other than during the dormant season for willow, one should always plan on returning during the dormant season and stick sufficient unrooted cuttings to assure a good stand of willow. Dense stands of live willow will slow run-off and allow sediment precipitation.

Isolated discontinuous gullies that are relatively small may be treated by grading and seeding of grasses (Heede) or by biotechnical means, trench packing, brush boxes, wattling, etc.

Consideration should always be given to exclude grazing where gully control or restoration is desired. In some instances in parts of the arid west this practice alone has resulted in healing of the gully systems and restoration of stream flow.

Control of gullies with check dams can become very expensive. In some areas of decomposed granite in northern California control of water and erosion at the source was more effective and much more cost effective than by check dams.

The choice of vegetation for gully control or restoration should be based on the native plant community. Some authors limit recommendations to grass species. In many cases a mix of woody and herbaceous would be a better choice.

Heede makes frequent references to establishing grade control in reference to bedrock. Most of his research was done in mountain areas. In much of the northern great plains bedrock is not a factor in gully formation or control.

OBTAINING PLANTS AND HANDLING OF PLANT MATERIALS

Andrew T. Leiser
Department of Environmental Horticulture
University of California, Davis, California

INTRODUCTION

During the planning step for a revegetation project the choice of the plant species will have been made on the basis of the information obtained in the site analysis and on the various limiting components of the total project: biological, environmental, physical, and economic.

The procurement and handling of plant materials is of paramount importance to a successful revegetation project. Plants are living things and must be grown and handled properly if success is to be obtained. Many failures are due to the poor quality of planting material and to improper handling during shipping, storage, or holding period and on the planting site.

The procurement of the proper plants, properly grown, of the proper size, condition (e.g. acclimatized or "hardened off"), of good vigor, in sufficient quantity, and at the proper time for the planting project is one of the most difficult aspects of the revegetation project. There are a number of reasons this is true. Many of the plant species desired may not be available from commercial or governmental nurseries. Available plants may not have been propagated from seeds or vegetative materials collected from climatic areas similar to that of the project. This is especially true of those species which grow over wide geographic areas. Of the total plant spectrum grown in nurseries, relatively few species are grown in deep tubes which are often most suitable for plantings under difficult site conditions. Native plants, especially shrubby species, are often impossible to obtain because the commercial nurseries grow primarily for ornamental use - the urban market. Nurserymen have had relatively little experience growing many of the native plants because of lack of demand. The quantities of native and introduced plants needed may be insufficient even if the species are grown. Interstate plant quarantines may restrict shipment from nurseries where the plants are available, e.g. oaks - species may not be moved from the midwest to California.

The procurement process, therefore, often must be started at an early stage in the project. Seed or cuttings may have to be obtained. Contract growing often must be arranged in advance and the soil mix, container size, and plant size and quality must be specified. Such ontracts may have to be made as long as 18 to 24 months before planned planting dates.

Some explanations of these problems and suggestions for solving them will be suggested in this paper.

PROCUREMENT AND PLANT SELECTION

Importance of Ecotypes or Provenances

The existence of ecotypes or provenance (source) variation for many species is not known. Most studies of plants with a wide geographical range (altitudinal, latitudinal, climatic) have shown wide differences in response among plants collected throughout the range to a variety of environmental factors: heat, cold, drought, soils, and flooding tolerance.

Cornus stolonifera, red-osier or American dogwood is a riparian species ranging in the West from Alaska to California to Newfoundland south to Virginia, Kentucky and Nebraska in the East and Mid-west. Extensive studies on this species indicate large differences in hardiness. Some of the differences are due to latitudinal distribution. Some are due to climatic differences as in the case of collections from Western Washington and Minnesota which are about the same latitude. In the latter case, absolute hardiness in mid-winter was similar but the Washington collection did not attain this degree of hardiness until much later in the season.

Acer rubrum, red or swamp maple, another riparian species, is found from Newfoundland south to Florida and west to Minnesota to Texas. Collections from many parts of its range were grown in tests conduted simultaneously in several states with a wide range in climate. Large differences were shown in growth rate, fall color and hardiness. Differences in hardiness were sometimes due to plants growing too late in the fall or breaking dormancy too early in the spring.

Acer macrophyllum is a West Coast, sometimes riparian species. Collections from a wide range of California habitats, when grown at Davis in the Sacramento Valley, exhibited large differences in growth rates and tolerances to summer heat and winds. The best selection for Davis conditions were from a dry, Southern California location at about a 5,000 foot elevation.

Fraxinus pennsylvanica is considered by older botanists to consist of two varieties, F. pennsylvanica, red ash, on upland sites and F. pennsylvanica var. lanceolata, green ash. The total species range from Cape Breton Island and Nova Scotia west to Alberta and Montana and south to Central Texas and Northern Florida. Provenance studies show pronounced ecotypic differences in moisture and low temperature tolerances. The varietas, F. pennsylvanica var. lanceolata has glabrous rather than pubescent petioles and seems to inhabit more riparian habitats. This varietas or type appears to have a wider tolerance to wet soils. More studies are warranted of possible ecotypes of this flood-tolerant species.

Studies on Eucalyptus cumaldulensis, river red-gum in Israel and elsewhere have shown large differences in tolerance to soils and available water among ecotypes. This species is flood tolerance but our studies were not of sufficient scope to permit testing of ecotypes for flood tolerance.

Similar studies have not been made as far as I know on Quercus lobata, valley oak. This species has a wide geographic range from Northern to Southern California and sites range from dry foothills to riparian where annual flooding occurs in winter and spring. It is very probable that ecotypic variations occur within this species. Many of our losses of the species when urbanization occurs seem to be due to lack of water rather than too much water.

The best rule to follow with native plants is that, when information on ecotypes is not known, use seeds of other propagation material from as near site conditions as possible. When studies have shown ecotypic differences, use seed sources shown to most closely fit site conditions. This may require the contractor to produce proof of origin of the propagation materials.

Timing: Timing of plant production and of planting season is critical. For most sites there will be a time or times when plantings will be most successful. Drought, cold (including time of snow melt), season of flooding, annual seasonal variations and the choice of deciduous and bare-root plants vs. containerized plants all affect the choice of planting time, sometimes called the "planting window". This "planting window" is the time or times when conditions are best suited for plant establishment. This timing affects both the growing schedule and the planting contract specifications. Timing should be such that plants are of optimum size and top: root ratio, and condition for planting during the "planting window". The decision must be made on a site-to-site basis.

Advance Planning: A large advanced lead time is required for species not readily available. Seed of some species are available from seed dealers but others may have to be collected. Many species do not set a reliable seed crop every year. This is an important factor in plant selection as well as in obtaining seed from the most desirable ecotypes.

Fall Versus Spring Planting: Fall plantings may be preferred in areas with late growing seasons, winter rains and summer drought. This allows a longer period of establishment before late spring when flooding or drought occur. However, bare-root plants may not be available until late fall or even mid winter. Late fall plantings may not be desirable where late fall droughts occur, or where frost heaving is severe before new root growth occurs.

Spring planting dates are usually required for bare-root stock, where sites are subject to late fall and winter frost heaving problems, or where flooding occurs in late fall to early spring. Spring planting should be scheduled as early as site conditions permit. Summer plantings should be avoided unless adequate rainfall or supplemental irrigation is assured.

Types of Plant Materials

Direct "sticking" of unrooted cuttings of easy-to-root native or introduced species is often successful and is one of the most economical methods of plant establishment.

Direct seeding of woody species may be successful if proper care is used in selection of species, preparing planting "spots", and planting. Direct seeding is more economical than transplanting.

Bare root transplants are successful for many species. The "planting window" is more restricted and survival may be lower than for transplanting container-grown stock.

"Tublings", plants grown in relatively small and deep containers, have proven very useful on difficult sites. Root-top ratios are favorable when properly grown. Roots are deep to allow maximum use of limited water supplies and root disturbance at planting time is minimal. Tree species used in reforestation and some Eucalyptus may be readily available but shrub species are frequently not available unless grown under contract.

Plants in gallon or larger cans are often available for species in regular commercial production but are limited in variety of species best suited for revegetation projects. Plants in larger containers increase the cost for purchase and planting substantially. Survival is frequently reduced because of limited root systems in relation to size of the tops of the plants.

Growing Quality Tubling or Other Container Plants

Roots of container-grown plants should be well developed, adequately filling the soil mass so that it holds together when removed from the container but not so overgrown as to be "pot-bound".

A common fault of container-grown stock is the presence of kinked or girdling roots. These poor root systems result from poor transplanting of seedlings or rooted cuttings and from failure to remove circuling roots when shifting plants to larger containers. Such roots have been shown to reduce growth and sometimes ultimate survival because of girdling of the crown or loss due to wind throw.

Times does not permit a detailed description of the top. It is covered quite thoroughly in the references listed for Baker et.al. and Tinus. Many designs and sizes of growing tubes are available. Many are designed to minimize or eliminate kinked and girdling roots.

Soils or growing media must be well-drained because, in containers a perched water table exists after irrigation. Plants should be of good vigor and nutrient status.

Hardening-off and Holding Plants

Plants should be adequately "hardened-off" and "acclimatized". This is particularly critical when the environment of the growing nursery is different from the planting site. This can often be done by moving the plants near the site as long as possible before planting time, or, with bare-root materials, holding under refrigeration until planting time when the planting season starts late in the spring at the site than in the nursery.

During the holding period and when moved on site, plants must be carefully watered and refertilized if necessary. Plants must be thoroughly watered immediately prior to planting. On hot sites plants may need to be partially shaded to prevent overheating of root systems and should be removed from such protection only as the work progresses and planted immediately. Lethal temperatures can occur in dark colored containers in a few hours under hot, sunny conditions.

Planting

Plants should be removed from containers at planting time unless the containers are biodegradeable. Biodegradeable containers should be "shouldered off" to prevent drying of the root system through "wicking" action. These should also be removed if roots have not penetrated the container sufficiently to have intimate contact with the site soils.

Circling roots on the outside of the root ball must be removed at planting time.

Plants should be planted promptly as holes are dug to minimize drying of the hold and backfill soil. The backfill should be thoroughly tamped to obtain intimate contact with the plant roots.

Handling Live Brush and Cuttings

Live brush and cuttings have been severed from their root systems. Careful handling to prevent drying is essential. They may be stored in the adjacent lake or stream or thoroughly shaded and kept moist if not stored in water. No more materials should be cut than can be planted within one or two days. They should be exposed during the planting process as short a time as possible. Like container plants they should be moved on-site only as work progresses if hot or dry conditions exist.

SUMMARY

Plants and plant materials are living organisms and must be treated as such. They may need to be fed (fertilized) and must never suffer drought or other undue stress. The success or failure of any revegetation project, no matter how well planned, depends on the proper selection, production, care, and handling of the plant materials at each step of the project.

GENERAL PLANTING SPECIFICATIONS

WOODY PLANT SPECIFICATIONS.

Container-Grown Plants. Woody plants shall be container-grown except as noted below.

Container Size. Containers shall have a minimum size of 9 cubic inches in volume and a depth of 8 inches. Maximum size shall be that of a one quart milk carton.

Growing Medium. Growing medium shall be well filled with roots so that roots and medium form a cohesive unit when removed from the container.

Top Growth. Top growth shall be commensurate with root growth, free from dead wood or foliar diseases, and be a minimum of 5 inches high. Shrub species shall be pruned during production if necessary to stimulate branching and avoid "legginess", i.e., bare lower stems and inability to stand upright.

Root Systems. Roots shall be in good condition and actively growing with white tips.

Bare Root Planting. Bare root planting may be allowed by the Engineer for selected conifer species. Storage, pretreatment, and planting techniques must be approved by the Engineer prior to planting.

ON-SITE CARE OF PLANTS.

When plants are moved from the nursery to the job site they shall continue to receive regular irrigation. All plants shall be watered immediately before planting (i.e., the same day) so that moisture in the containers is at or near field capacity. Handling during planting shall be such that overheating or excessive drying is avoided.

If temperatures at the nursery and the job site are significantly different, the plants shall be delivered to the job site a minimum of one week prior to planting.

PLANTING SPECIFICATIONS.

Planting Windows. All planting must be done in the spring or fall during the "planting windows". Dates of the suitable planting periods will vary from year-to-year. The spring planting window begins immediately after snowmelt and when the ground is not frozen and usually continues for four to six weeks.

The fall planting window is usually from late September through late October and may continue into early November. In all cases, the scheduling of planting is subject to approva by the Engineer. The Contractor shall submit a proposed planting schedule to the Engineer approximately two weeks prior to when planting operations are to begin.

Planting on Slopes. Planting on slopes shall proceed from the top to the bottom of the slope, except that installation of brush layering or wattling shall proceed from the bottom to the top.

Planting Pattern and Densities. Plantings shall be randomly staggered to avoid straight rows.

Areas designated as "High Density" on the Drawings shall be planted at a density of 62 plants per 1,000 square feet (approximately 4 feet on center). Areas designated as "Moderate Density" on the Drawings shall be planted at a density of 28 plants per 1,000 square feet (approximately 6 feet on center).

Planting patterns and densities may vary within sites to avoid unfavorable site conditions such as rock outcroppings, existing vegetation, and engineering structures. The total number of plants per individual site shall be as designated on the Drawings.

Planting. Actual planting of the plants shall follow the digging of holes as rapidly as possible so that the excavated soil does not dry out. The planting shall take place no longer than two to three minutes following digging. Care shall be used to use only the moist soil excavated for the backfill. Backfill shall be tamped firmly to eliminate all voids and to obtain intimate contact between the root systems and the native soils. Excess soil shall be smoother and firmed around the plants leaving a slight depression to collect rainfall. Plants shall be placed 1 to 2 inches lower than they were grown in the nursery to provide a soil cover over the root system.

GRASS SEEDING.

Areas to be Seeded. Areas to be seeded shall be as shown on the Drawings. These will include areas with grass only and areas with transplants of trees and shrubs in which grasses will be seeded before or after the woody species are planted.

Seed. All seed shall be delivered to the site tagged and labeled in accordance with the State Agricultural Code and shall be acceptable to the County Agricultural Commissioner. Seed shall have a minimum pure live seed content of 80 percent (percent purity X percent germination) and weed seed shall not exceed 0.5 percent of the pure live seed.

Fertilizer. Fertilizer shall be ammonium-phosphate-sulfate (16-20-0 :: N-P_2O_5-K_2O). All fertilizer shall be delivered in unbroken and unopened containers, labeled in accordance with applicable state regulations, and bearing the warranty of the producer for the grade furnished. Fertilizer shall be uniform in composition, dry and free flowing, granular, or pelleted.

Straw. Straw shall be new, derived from cereal grains and be free from mold and noxious weed seed. Straw shall be furnished in air-dried bales. Contractor shall furnish evidence that clearance has been obtained from the County Agricultural Commissioner, as required by law, before straw obtained from outside the county is delivered to the site of the work.

Wood Fiber. Wood fiber shall be wood cellulose fiber that contains no germination or growth-inhibiting factors. It shall be produced from non-recycled wood such as wood chips or similar material and shall have the property of even dispersion and suspension when agitated in water. It shall be colored with a non-toxic, water soluble green dye to provide a means of metering for even distribution.

Tackifier. Tackifier shall consist of Plantago seed husks (Psyllium) such as Ecology Control, M-Binder, Sentinel, or equal. When combined with wood fiber and water it shall have the property of even dispersion and suspension.

Time of Seeding. Unless otherwise approved by the Engineer, seeding shall be done late in the fall so that seed will not germinate prior to snowfall. The seeding schedule shall be approved by the Engineer as specified in Section 48B-3.01. Seeding shall be completed in normal years by early November. In areas where both woody plants and grasses are required, planting of woody plants shall be done prior to seeding of grasses.

In cases where spring seeding has been approved by the Engineer, seednig shall be immediately following snowmelt. Spring seeding shall be completed by May 1.

Site Preparation. Graded slopes shall be left rough. Compacted areas of less than 5:1 slope (20 percent) shall be scarified or lightly ripped on contour. Existing rills, gullies, or other erosion damage shall be repaired and any biotechnical erosion control measures shall be installed prior to seeding.

All physical erosion control improvements, such as water diversion channels, earth berms, dikes, ditches, and retaining walls shall be installed prior to grass seeding.

Fertilizer Application. The fertilizer shall be applied so as to be uniformly distributed. Fertilizers shall not be applied more than two weeks prior to seeding.

Fertilizer shall be broadcast prior to the final scarification of sites with slopes of less than 5:1 (20 percent) or may be applied with appropriate seed drilling equipment at the time of seeding. On sites not requiring or not subject to scarification, fertilizer shall be applied prior to hand raking or dragging.

Seed Application. Grass seed shall be uniformly distributed at the rate of 50 pounds of pure live seed per acre (1.1 lbs/1,000 ft^2).

Seed Sowing Methods. Seed shall be broadcast by mechanical hand or power-operated spreaders, drilled with a Brillion seeder, or hydroseeded as specified below.

In level areas and slopes of less than 3:1, seed shall be broadcast by mechanical hand or power-operated spreaders or drilled (on contour) with a Brillion seeder as site conditions permit. Broadcasted seed shall be covered by raking or dragging with chain, chainlink fence, or other approved means unless previously planted with cuttings or transplants.

On slopes greater than 3:1, seed shall be applied by hydroseeding. They hydroseed slurry will consist of the following:

Grass seed	50 pounds/acre
Woodfiber mulch	500 pounds/acre
Water	As needed
Fertilizer (if not broadcast)	250 pounds/acre

The slurry shall be continuously mixed as ingredients are added and mixed at least five (5) minutes following the addition of the last ingredients before application begins. Slurry shall be continuously mixed until used and application must be completed within two (2) hours of the last addition. Water shall be potable. The slurry shall be applied at a rate that is non-erosive and minimizes runoff.

Mulch Application. All grass seeded areas (except those hydroseeded) shall be mulched with straw within two (2) working days following seeding, unless prevented by weather and approved by the Engineer. Straw shall be uniformly distributed at the rate of not less than two (2) nor more than four (4) tons per acre.

Straw may be applied in two ways, either as whole straw applied by hand or with a straw blower.

Whole Straw Application -- Spreading shall be by hand. Straw shall be crimped into the ground using a straw crimping machine in two directions. Small areas may be crimped by hand using a digging or tile spade. On slopes steeper than 3:1 (33 percent) whole straw shall be anchored with tackifier rather than by crimping.

Straw Blower Application -- All straw applied with a straw blowing machine shall be anchored with tackifier as described below. Application by blower will only be done when wind velocities are low enough to prevent blowing of the straw off the slope. Such applications shall be anchored with tackifier on the day of application.

Tackifier. Tackifier shall be applied with uniform coverage and shall consist of the following materials:

Material	Rates per Acre
Plantago seed husks (Psyllium) e.g. Ecology Control, M-Binder, or Sentinel.	100 lbs.
Wood Fiber	200 lbs.
Water	No more than 250 gal.

The materials shall be mixed to form a slurry and applied by hydroseeder or similar equipment equipped with a continuous agitation system of sufficient operating capacity to produce a homogenous slurry. The discharge system shall be capable of applying the slurry at a continuous and uniform rate. Mixing, agitation, and holding times shall be the same as specified above for hydroseeding.

UNROOTED CUTTINGS OR LIVE STAKING

Cutting Materials. Cuttings (live stakes) shall be prepared from live *Salix* spp. (willow) obtained from on site or from other sites in the Lake Tahoe Basin and shall be free from obvious signs of canker diseases. Cuttings shall be dormant or, if collected in the fall before becoming deciduous, the leaves shall be removed (stripped) from the stems.

Cutting Size. The diameter of cuttings shall not be less than 3/8-inch nor more than 1-1/2-inch. The length of cuttings shall be a minimum of 12 inches.

Cutting Preparation. Cuttings shall be cu to size in a manner which does not result in frayed ends or bark. During preparation, the orientation of cuttings shall be maintained, i.e., all cuttings shall be arranged basipetally (tops up, bases down). Cuttings shall be tied in bundles of 50 and the cut topes painted with a water base paint, e.g., interior latex paint to seal the cuts and identify the tops. A highly visible color, red, orange, yellow, etc., shall be used.

Cutting, Care, and Handling. Cuttings shall be prepared no longer than one week before planting. Cuttings shall be maintained in moist conditions at all times. They may be stored out-of-doors in shade and submerged in water, either in natural streams or ponds or in containers. When stored in containers, the water shall be changed daily. They may be stored, wrapped in wet burlap, under refrigeration at 32-45°F. During planting, the cuttings shall be kept moist until planted. This may be accomplished by carrying in planting bags or buckets, covered with moist vermiculite, sawdust, or similar material, or in water.

Planting Cuttings. Cuttings may be pushed into ground that is soft. In hard ground where this is not possible, cuttings shall be planted with dibbles, star drills, or other devices to avoid damaging the bark of the cuttings. Cuttings shall not be driven with hammers.

Cuttings shall be planted to within 2 to 3 inches of the tops and the soil tamped firmly around them to a firm hold. No air pockets or voids shall remain around the cuttings.

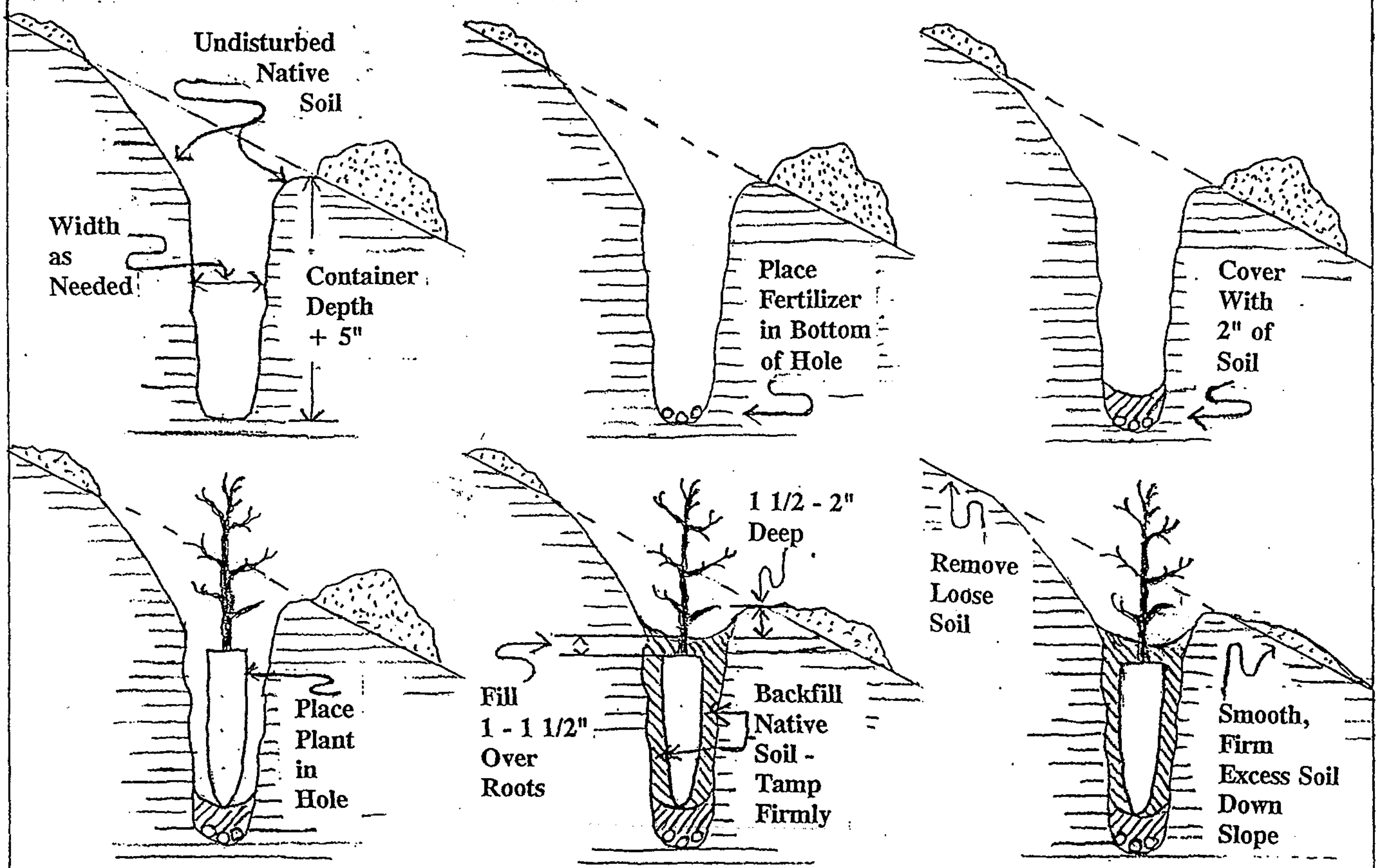
PLANTING RIPARIAN SPECIES.

Source. Transplant materials of Riparian species shall be from the project site, insofar as possible. The rush-sedge sod shall be salvaged from Riparian sites prior to construction activity for reuse following construction. Sods shall be stored in shade, with roots on soil and shall be kept irrigated until use.

Planting. Riparian species shall be planted in either of two ways, by replacing the whole sods or by dividing the solds into 4- to 6-inch plugs or divisions for planting. Sodding shall be used for very small, highly erodable areas such as immediately adjacent to check dam aprons, narrow gully repairs, etc. Planting plugs shall be used for revegetating large areas. Plugs shall be used for planting any interstices in check dam aprons, riprap, etc.

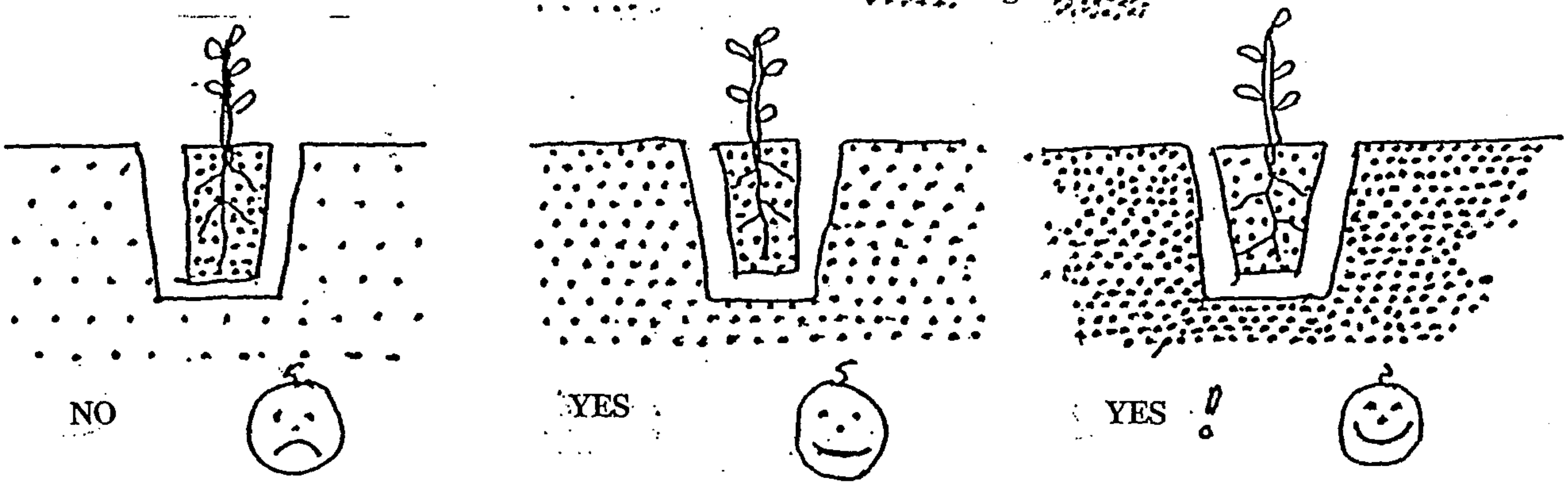
Plugs shall be planted on 1-foot centers. Plants shall be planted at the same depth at which they grew and shall be firmed into the soil without voids or air pockets. Planting shall be during the times specified for woody plant species except that with permission of the Engineer, they may be planted at other times in wet areas or when irrigation will be supplied.

PROPER PLANTING PROCEDURES

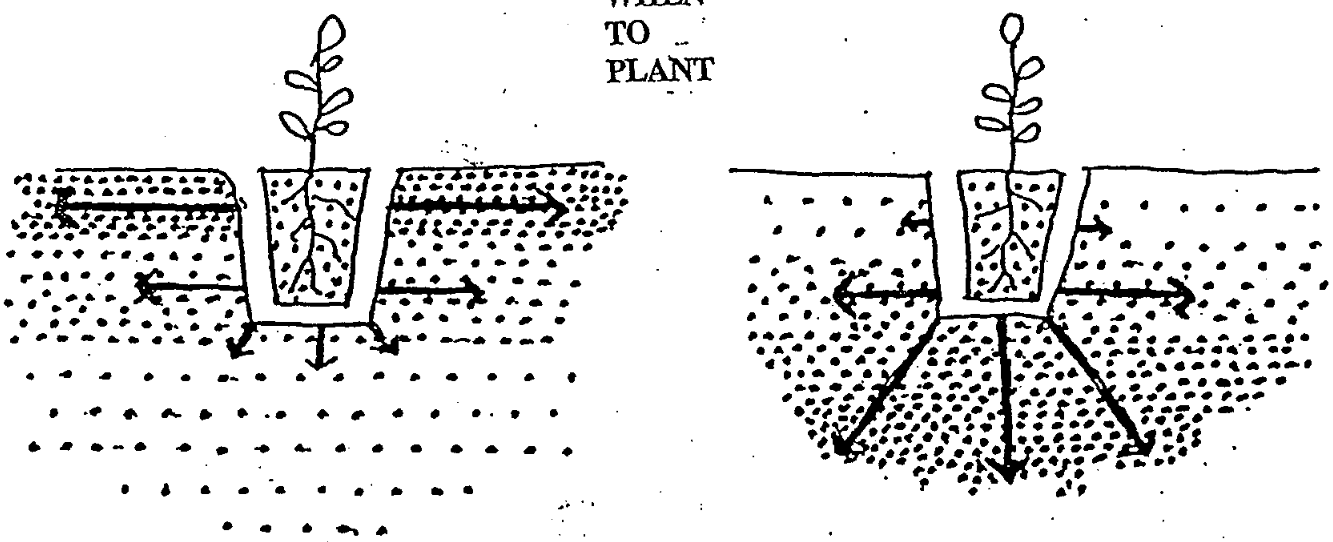


ROOT GROWTH AND SOIL MOISTURE

Moisture: Low Intermediate High



WHEN TO PLANT



ARROWS SHOW RELATIVE ROOT GROWTH

FREQUENT, SHALLOW IRRIGATION
SHALLOW ROOTS

INFREQUENT, DEEP IRRIGATION
DEEP ROOTS