EROSION CONTROL ALONG THE TENNESSEE-TOMBIGBEE WATERWAY

by

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I. INTRODUCTION

During the past few years, there has been a tremendous change in the land use patterns of this country. The building of new roads, buildings, shopping centers and reservoirs has converted many acres of land from agricultural use to commercial or public use. With this construction has come one of the largest sources of pollution in the country today, the construction activity itself. Oftentimes, serious stormwater runoff, accelerated erosion, and sedimentation occur when heavy rain and wind storms sweep across exposed soil on construction sites. Often the results created by these storms are flooding, sedimentation in natural streams and water supplies, and creation of unsightly landscapes. The magnitude of these results is greatly dependent upon such factors as topography, climate and soil erodibility.

The seriousness of the problem of erosion around construction sites has been shown by the enactment of legislation, at both the state and federal level, to control water pollution resulting from construction activities. Creation of the Council on Environmental Quality which reports directly to the President, passage of the National Environmental Policy Act, and the establishment of the Environmental Protection Agency are all federal attempts at setting down guidelines and regulations to control pollution. Included in these regulations are requirements for prevention of pollution resulting from sedimentation produced by construction projects. Control of pollutants released during construction is viewed by the regulatory agencies as a part of broader land use and watershed management. For this reason, it is now considered to be one of the major problems requiring immediate and long-term solutions.

II. THE TENNESSEE-TOMBIGBEE WATERWAY PROJECT

The Tennessee-Tombigbee Waterway Project (Tenn-Tom) is a 232 mile, barge canal that stretches from Pickwick Lake on the Tennessee River, to Demopolis, Alabama, where it will meet the existing Black Warrior-Tombigbee Waterway which connects to the Gulf of Mexico at Mobile, Alabama (See Figure 1). The project is made up of three segments: the divide cut, a canal section that will parallel the east fork of the Tombigbee River for about 45 miles, and a 160 mile river section. When finished, the canal will consist of a system of 10 locks and dams which will impound enough water to provide a navigable channel from 9 to 12 feet deep and 300 feet wide. Approximately 300 million cubic yards of material must be excavated along the canal route. The largest amount of earthwork, 143,000,000 cubic yards, will occur in the Divide Cut. This section of the canal is situated in northeast Mississippi, and covers approximately 25 miles of the 232 mile waterway. Erosion control in the Divide Cut will be the primary topic discussed in this paper.

Reports from the areas of the Divide Cut currently under construction indicate that serious erosion problems are being encountered. These problems include sheet erosion and the formation of rills and gullies on the finished cut slopes, the formation of rills and deep gullies (some as deep as five feet) in certain fill areas, and a general lack of established vegetation. Current construction specifications are under review in order to determine if new measures to control erosion are needed. All aspects of the problem are being studied with major emphasis being placed on stabilizing the soil during the period necessary for establishing vegetation.

LOCATION OF THE TENNESSEE-TOMBIGBEE WATERWAY

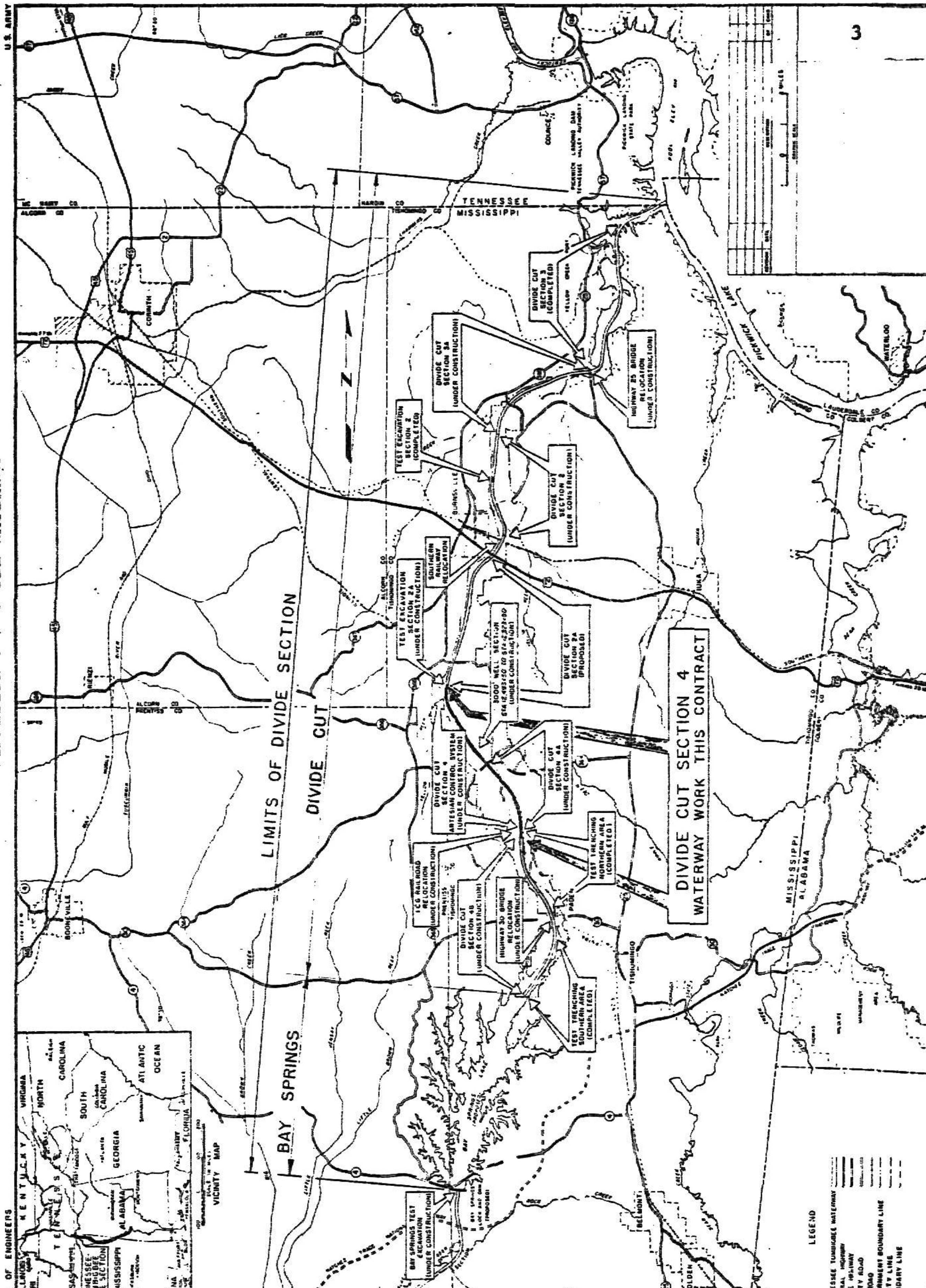


FIG.1

As shown by Figures 2 and 3, soil in the Divide Cut consists of deposits of sands, silts, clays and gravels. Alluvial soils consisting of silty sands, low plasticity silts, sandy clays, and gravels make up the upper soil layer. Other soil layers to be excavated consist of sediments of the Eutaw, McShan, and Gordo formations. Eutaw soils consist predominantly of sand. These sands are generally silty, fine to medium grained, and dense to very dense. McShan soils differ from the Eutaw soils in that there is more clay and silt present in the McShan. Large zones of hard, dark gray clay, fine to coarse grained sands and silt zones, and beds of medium to coarse gravel make up the Gordo soils.

The major portion of the soil excavated from the canal will consist of sands from the Eutaw formation. The slopes of the excavation will consist of fine, poorly graded sands interspersed with numerous, discontinuous clay layers. Due to the steepenss of the slopes, this type of soil is generally unstable and erodes very easily. Included in the Eutaw formation above elevation 560, are soils from Tombigbee member. This soil is primarily sand with a presence of sulphur. When excavated, the soil shows a pH of 5.6 to 6.0. After a short exposure to the elements, the pH changes to 1.9 to 2.3. This acidic condition is the result of the oxidation of sulphur to form sulfides and sulfates. Although more highly concentrated than normal, the presence of sulphur is not uncommon to Mississippi soils. Extensive sulphur production occurs as a by-product of the oil producing formations in other parts of the state. Growth of vegetation under these conditions is impossible without the application of lime, and the placing of plating material consisting of suitable soil from the alluvial layer as a growth media.

TYPICAL SOIL PROFILES IN THE NORTHERN SECTION OF THE DIVIDE

CUT OF THE TENNESSEE-TOMBIGBEE WATERWAY

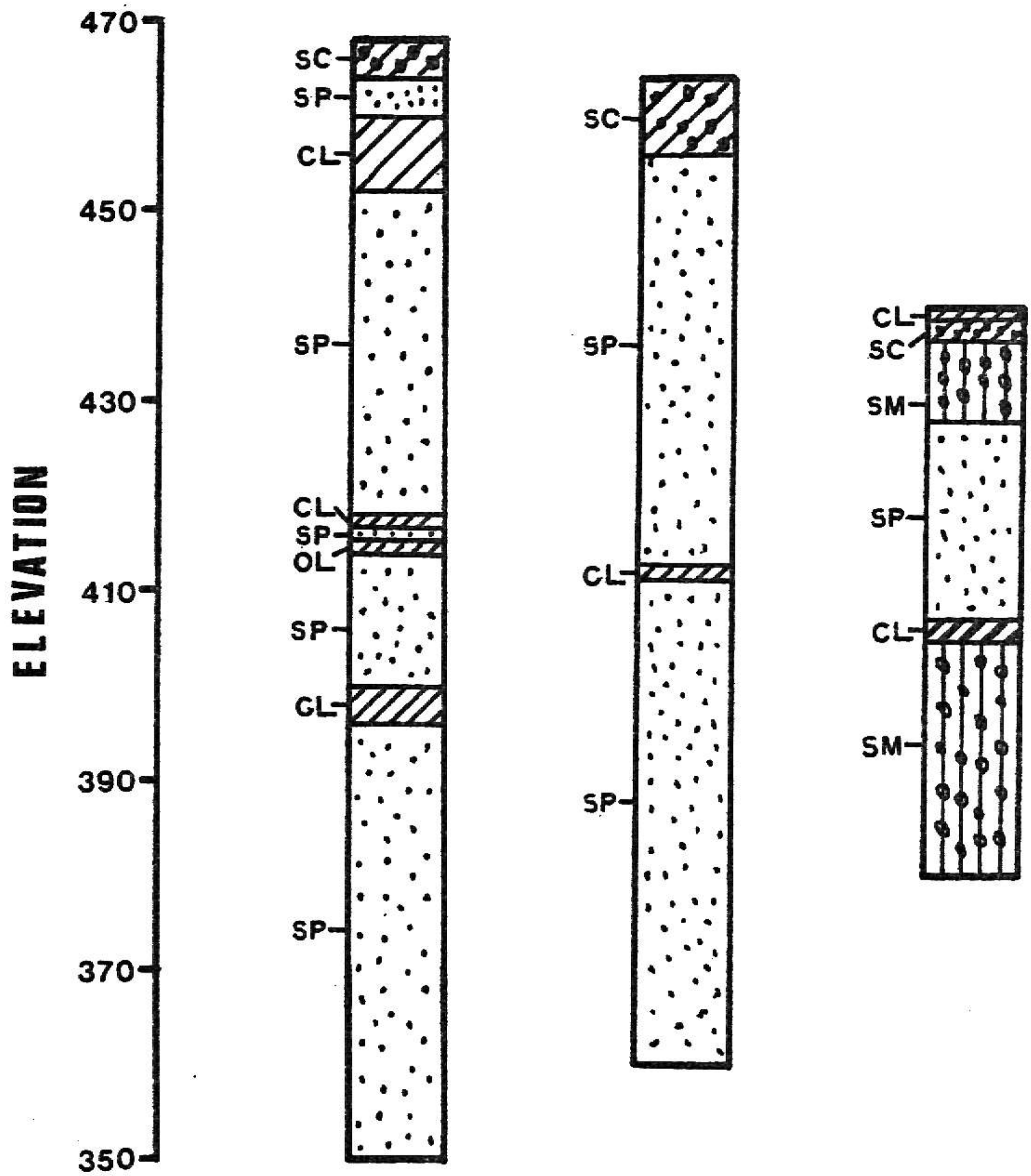


FIG. 2

TYPICAL SOIL PROFILES IN THE SOUTHERN SECTION OF THE DIVIDE CUT OF THE TENNESSEE-TOMBIGBEE WATERWAY

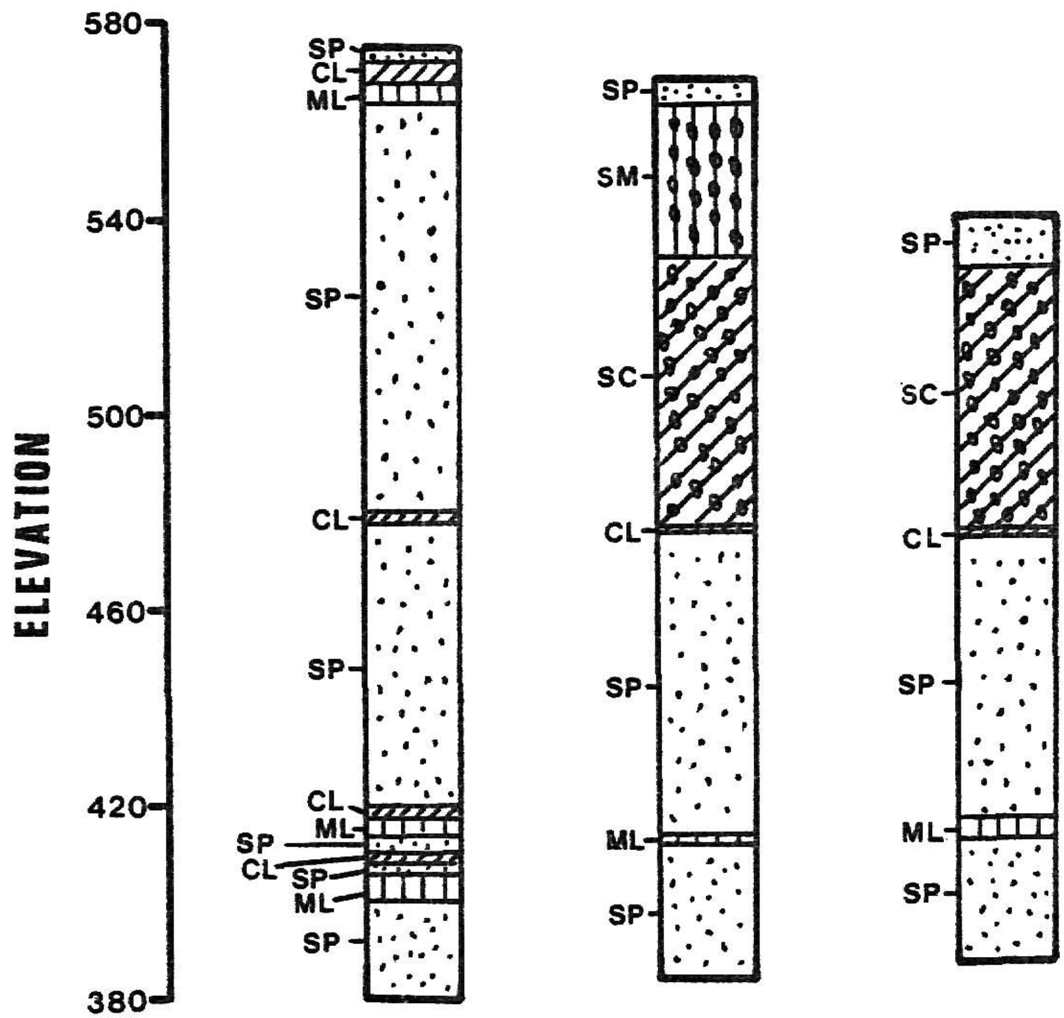
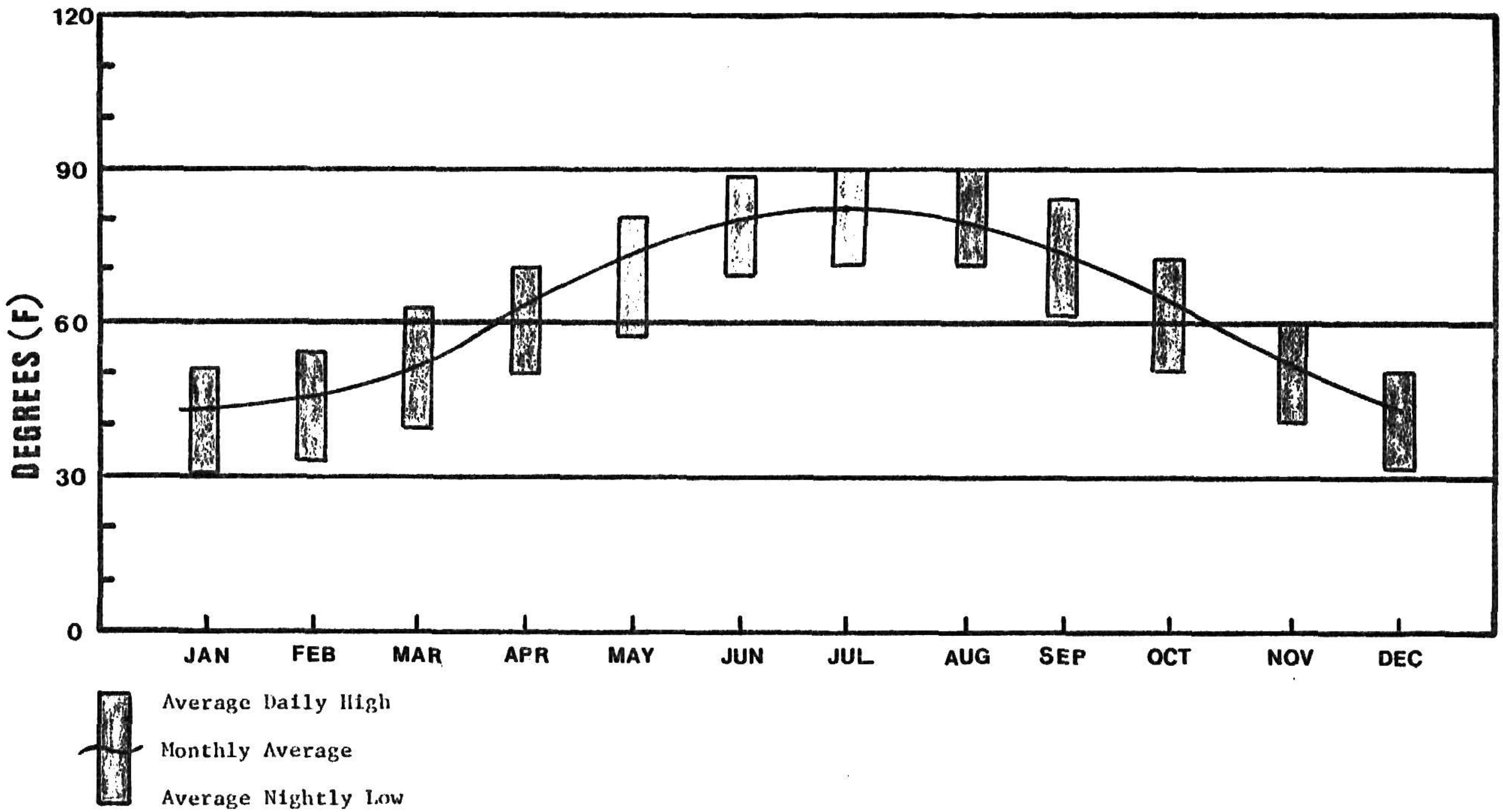


FIG. 3

The climate in northeastern Mississippi can be classified as generally mild in the winter with short duration cold periods, to hot in the summer. July and August temperatures average 81°F, while January temperatures average 41°F. The mean temperature for the year is around 61°F (See Figure 4)(6). Snow may fall during the winter, but it does not remain on the ground for any appreciable period. The moderate climate in this area generally allows a growing season of from 180 days to 200 days. Precipitation averages 51 inches per year with one-third of this occurring during January through March. July is also a wet month. The driest months are August and October (See Figure 5)(6). A great deal of the rainfall occurs during intense, short duration thunderstorms common to the area.

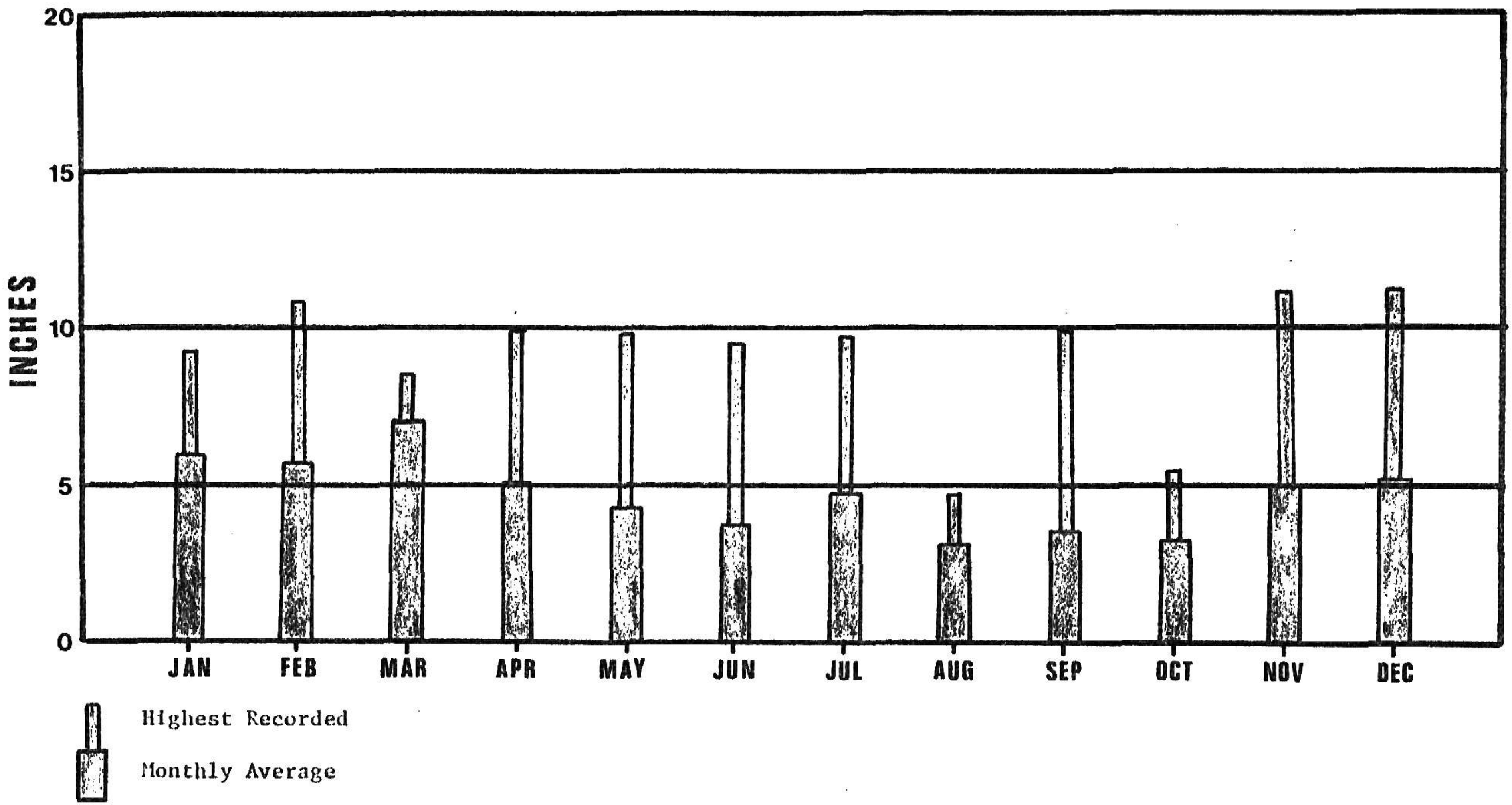
Due to economic considerations, the volume of the excavation was reduced by designing the slopes in the deepest part of the Divide Cut with a 1:2 and 1:3 ratio (See Figures 6 and 7). The steepness of these slopes necessitates the rapid development of vegetation to control erosion. Effective erosion control techniques must also be employed during the growth period to insure uniform establishment of vegetation. The erosive characteristics of the soil on these steep slopes, coupled with the intense, short-duration thunderstorms which are prevalent in the area, require that every aspect of erosion control be considered throughout both the construction and post-construction phases.

Included in the erosion control problems are the fill or disposal areas where the material excavated from the canal will be placed. The excavated soil shows a volumetric swell factor of approximately 20%, which means areas with a capacity totaling 172 million cubic yards will be needed. This massive amount of soil must be stabilized during its placement in the



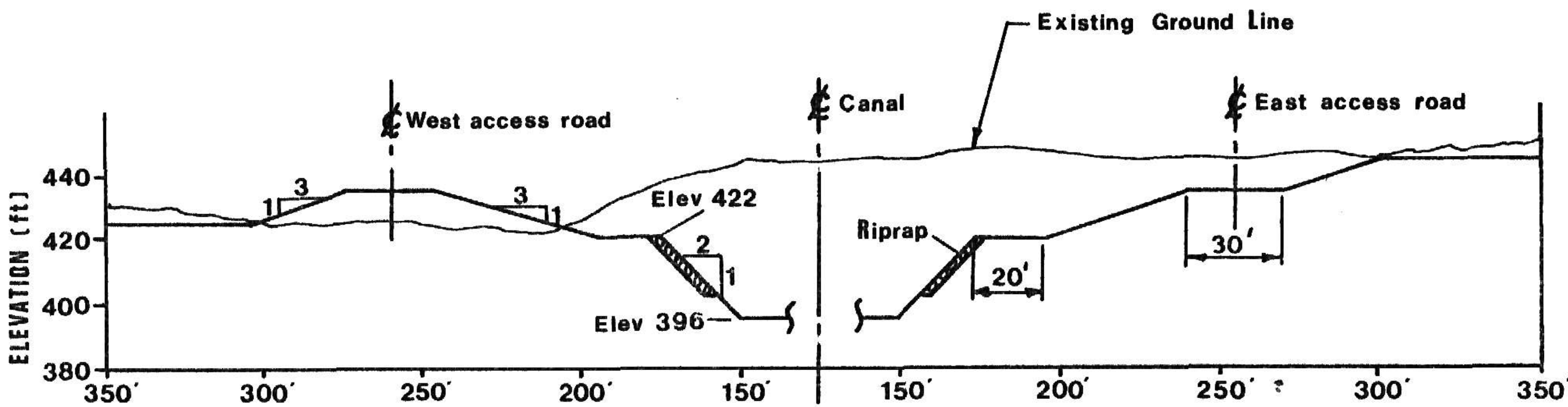
MONTHLY AVERAGE TEMPERATURES IN NORTHERN MISSISSIPPI

FIG. 4



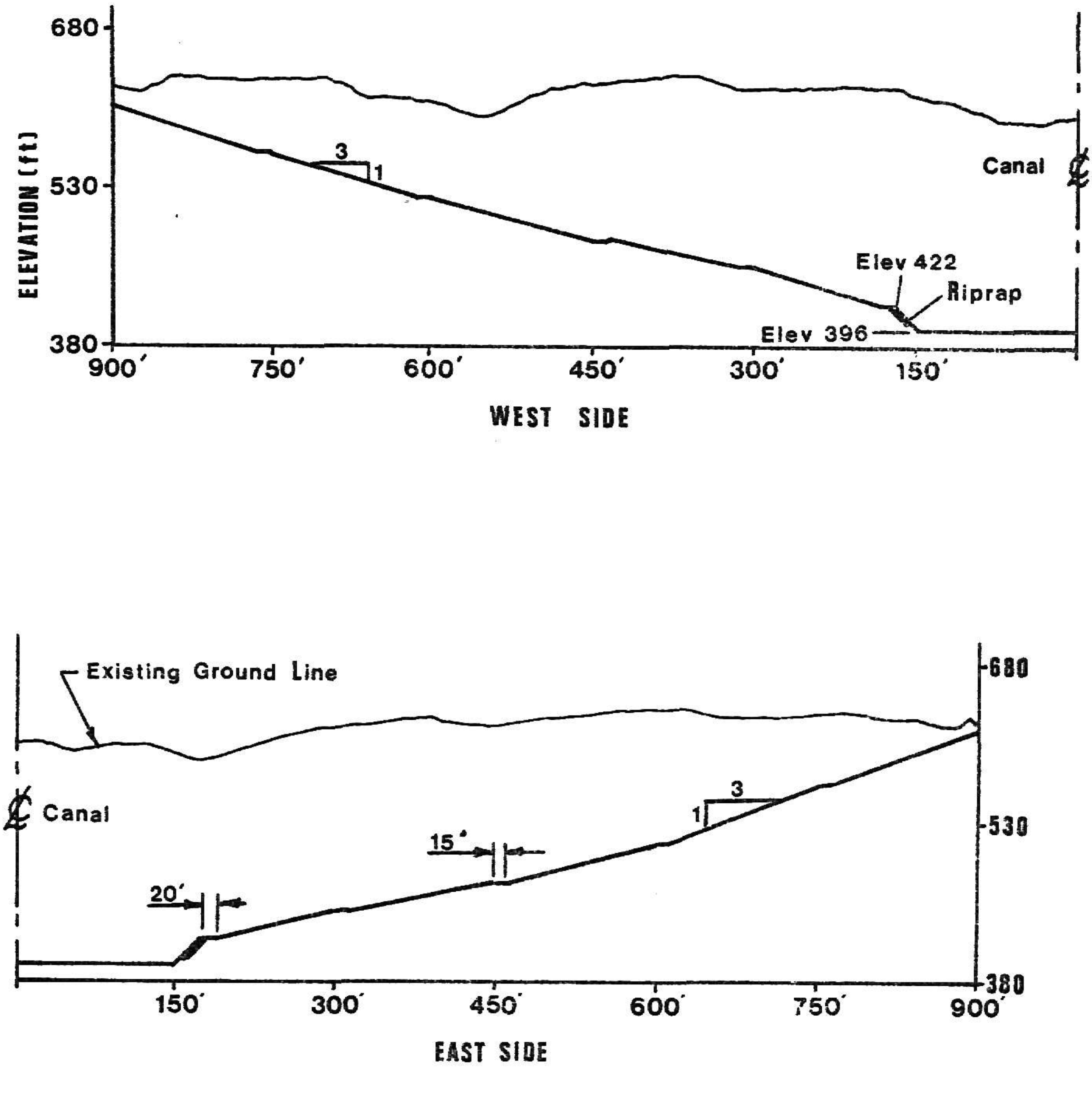
MONTHLY AVERAGE RAINFALL IN NORTHERN MISSISSIPPI

FIG. 5



TYPICAL CROSS SECTION OF THE NORTHERN SECTION OF THE DIVIDE CUT OF THE TENNESSEE-TOMBIGBEE WATERWAY

FIG. 6



TYPICAL CROSS SECTION OF THE SOUTHERN SECTION OF THE DIVIDE

CUT OF THE TENNESSEE-TOMBIGBEE WATERWAY

FIG. 7

fill area and be revegetated after the disposal area is full. If allowed to erode, some of this soil will find its way back into the canal as sediment, and some will flow into the surrounding natural waterways, creating pollution.

III. SCOPE OF THIS PAPER

Stabilization of the soil along the Tenn-Tom Waterway Project until vegetation is well enough established to take over erosion control is the primary purpose behind the research conducted for this paper. Since the canal itself is protected from erosion by rip-rap, only the problems of erosion of the slopes above the canal from sheet, rill and gully erosion produced by runoff have been considered. Economic considerations have limited the type of erosion control techniques considered, in that no changes in the design of the canal have been made due to the cost of changing the contracts already issued. These economic considerations have also limited the application of some types of more expensive, erosion control techniques to areas where lesser expensive methods have been found unsatisfactory. Vegetative techniques have been limited to those tested and found to be satisfactory for application in northern Mississippi.

IV. LITERATURE REVIEW

IV-A. Physical Factors Affecting Erosion

Four major physical factors affect the severity of erosion; they are climate, vegetative cover, type of soil, and the length and steepness of slope. The climate parameters affecting erosion include the amount, intensity, and frequency of rainfall. It is obvious that erosion is normally more severe on bare soils in areas having a large amount of rainfall than in areas having little rainfall; however, intensity and frequency of rainfall must be considered when comparing areas of similar precipitation. The amount of runoff and potential erosional force is influenced by both of these rainfall factors. If the intensity of rainfall exceeds the infiltration rate of the soil, and the surface depression storage, runoff will occur. Frequency of rainfall influences the moisture content of the soil, which in turn has a major influence on the infiltration rate. The higher the frequency, the higher the moisture content of the soil, which results in a lower infiltration rate and a greater potential for runoff.

The establishment of vegetation on areas subjected to erosional forces is the most desirable means of controlling erosion. Vegetation shields the soil from the impact of raindrops, retards surface flow of water, improves infiltration, and aids in removing subsurface water between storms by transpiration. Vegetation establishment should be an integral part of the planning phase for all construction activities that involve the soil. In many cases, the regrowth of vegetation is easily obtained by a minimum of effort. On the other hand, there are areas where the soil conditions, climate or slope will not allow the vegetation to become established without supportive measures. In these areas, a great deal of attention must be paid to preventing erosion prior to the establishment of vegetation. Such areas are the subject of this paper.

As mentioned, the type of soil is another major physical factor affecting erosion. Soil texture, structure, and moisture content are properties associated with erodibility. Texture refers to the relative distribution of the various sized, primary soil particles. Fine-textured soils such as silty soils and soils containing fine sand, are most susceptible to erosion from rain splash and runoff. The arrangement of primary soil particles is referred to as soil structure. The ability of the soil to absorb water, and its physical resistance to erosion are influenced by its structure. Soils that are granular and contain a large amount of fines, such as silt and fine sand with little clay content, are usually more erodible than soils with a blocky or massive structure.

The velocity of runoff flowing down a slope is generally increased by the increased steepness of the slope. This increase in velocity enables the runoff to carry more and larger soil particles down the slope, thereby increasing erosion. The amount of runoff is usually increased by the increased length of the slope. This increase in runoff will increase the concentration of water at the base of the slope causing a greater chance of erosion. Long slopes are generally broken up by utilizing terraces, ditches or dikes to intercept the runoff, reducing its velocity and preventing its accumulation at the base of the slope.

In order to realize the full potential for soil erodibility and ascertain the best method for erosion control and revegetation in the Tenn-Tom construction area, theories relating to soil loss have been

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studied along with many different erosion control practices. Compaction, the categories of accelerated water erosion, the physical factors affecting erosion, and the process of sedimentation along with the Universal Soil Loss Equation have been studied. The general categories of erosion control methods included compaction, mulching, soil stabilizers, mats, vegetative techniques and hydroseeding. The use of a fabric fence to control sedimentation resulting from the erosion of the fill areas has also been studied. In cases where specific products were mentioned, information was requested from the manufacturer in order to compare the manufacturer's recommendation with the test results.

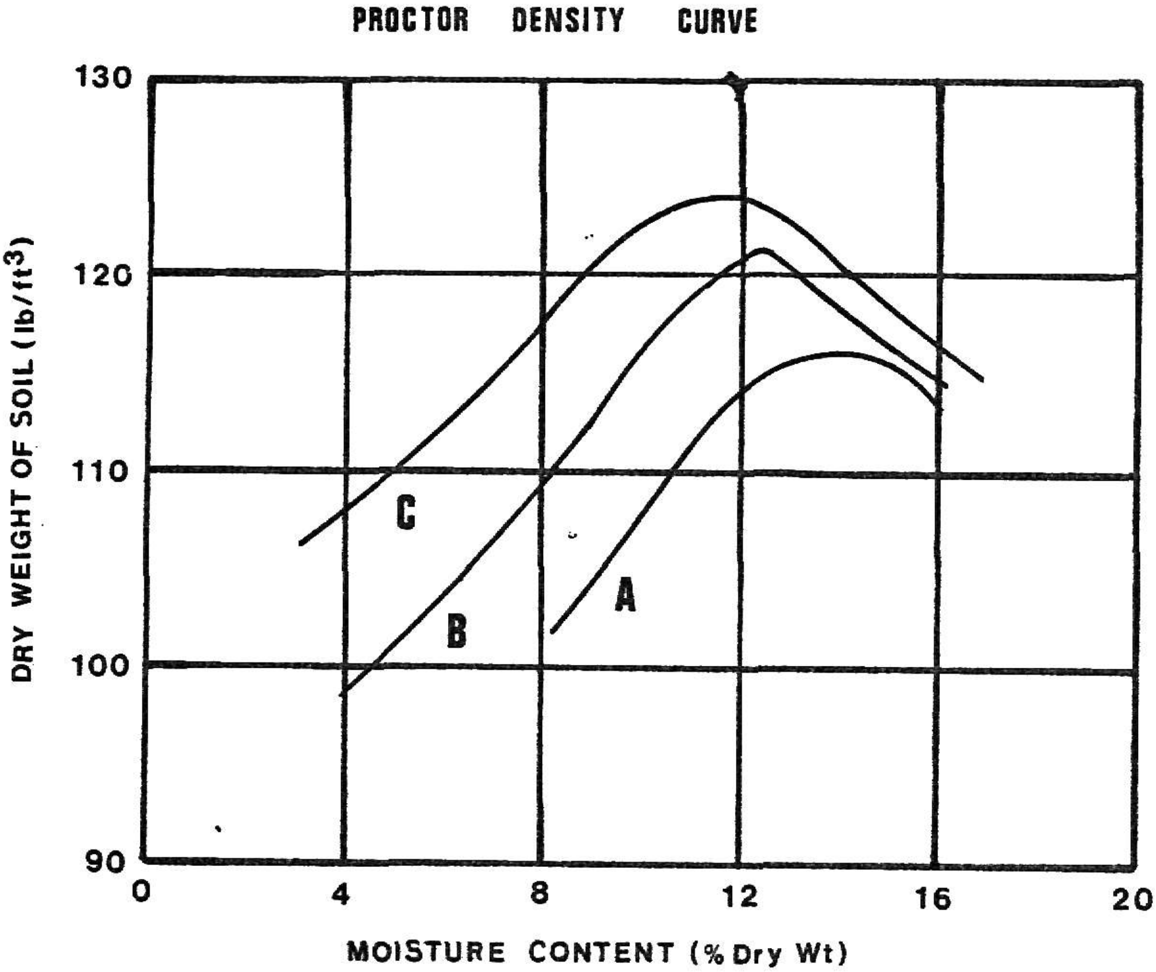
IV-B. Sedimentation and the Universal Soil Loss Equation

The process of sedimentation, which includes detachment, dispersion, transportation and deposition, has been the subject of many studies. This paper is primarily concerned with the detachment phase of the process. This is the portion of sedimentation that can be controlled by application of erosion control techniques. The entire process of sedimentation is presented with an analysis of each factor by The American Society of Civil Engineers (2). The primary emphasis of this publication is to predict the amount of sedimentation to be expected under certain conditions.

Included in this book is a chapter on the Universal Soil Loss Equation. This equation was developed by Walter H. Wischmeier and Dwight D. Smith in 1959, as a method of predicting the amount of soil loss that could be expected from farm land under certain rainfall and soil conditions (26). Various factors such as the rainfall, the soil erodibility, the length and steepness of slope, the type of crops planted, and erosion control practices utilized were included in the equation. This equation was modified in 1968, by Wischmeier, in order to further define the parameters (27). This modification was carried further by Wischmeier in 1971, when a "soil erodibility nomograph" (See Figure 11) was published (28). By utilizing this nomograph and historical data furnished by the U. S. Department of Agriculture for a particular area, it is possible to predict the amount of soil that would be lost to erosion at a specified location. This nomograph, according to Wischmeier, can be utilized on construction sites as well as agricultural land (28).

IV-C. Compaction

One of the most widely used and oldest methods of soil stabilization is compaction. Prior to 1800, most compactive efforts consisted of driving herds of animals such as goats and sheep across areas where greater soil strength was required. Between 1800 and 1930, mechanical rollers were developed to replace the animals; these included the "sheepsfoot" roller which consisted of a log with seven inch railroad spikes driven into it. The theory of compaction was advanced during the 1930's and 1940's, by the work of R. R. Proctor (19). While working for the Bureau of Waterworks and Supply, Los Angeles, California, Proctor began to conduct extensive soil tests in an effort to determine the relationship between the soil's moisture content and unit weight, and the compactive effort. His efforts produced the "Proctor Curve" which became the primary topic of discussion among early soils engineers in this country (Figure 8). Further testing by various agencies resulted in the establishment of standard test procedures, the results which could be utilized as a basis of comparison between laboratory and field results. Standards were established by such groups as the American Association of State Highway Officials and The American Society for Testing Materials. Modifications have been made at various times to accommodate modern wheel loads and compaction equipment (12).



ORIGINAL PROCTOR CURVE SHOWING THE EFFECT OF THE AMOUNT OF COMPACTIVE EFFORT ON DRY DENSITY AND MOISTURE CONTENT. CURVE "A" IS FOR A "LIGHT" COMPACTIVE EFFORT, CURVE "B" FOR A "MEDIUM" COMPACTIVE EFFORT, AND CURVE "C" IS FOR A "HEAVY" COMPACTIVE EFFORT. THE SOIL UTILIZED IN THE TEST WAS A SANDY CLAY.

FIG. 8

Compaction is the primary means of increasing soil strength in areas where the slopes are not steep and the soil is of a cohesive nature. Steep slopes limit the amount of compactive effort that can be applied due to the type of equipment available for the compactive effort. The application of compactive effort on a soil causes an increase in relative density, a decrease in permeability, and a decrease in compressibility. This increases the strength of the soil and its ability to withstand the erosive forces of wind and water (23). This decrease in permeability increases the amount of runoff that occurs during rainfall. L. D. Meyer, et al. (13) reported that a compacted soil showed only slightly less soil loss than an area that was scalped with no compaction. This was attributed to the increase in runoff due to the decrease in permeability of the soil. Meyer also reported that there was a marked decrease in the growth of vegetation on a plot that had been compacted after seeding. Test results showed a decrease in the available moisture due to the decrease in permeability.

IV-D. Mulching

Mulching, on the other hand, provided the best method of controlling erosion. In the same tests, Meyer (13) reports that mulching controlled erosion, reduced water loss by evaporation, and moderated the soil temperature. Mulches come in many forms; straw, hay, woodchips, bark, excelsior, fiberglass, paper, leaves, manure, and stone are just a few of the items that can be utilized as a mulch. As reported by a study compiled for the U. S. Environmental Protection Agency (EPA)(9), the relative effectiveness and relative cost of mulches varies widely, as does their application rate, availability, and suitability for various conditions.

The value of straw as a mulch material was shown by Meyer, et al., in 1970, where tests conducted on slopes of 17% showed a soil loss reduction of 80% when mulched with straw at a rate of 1 ton/acre (14). Similar results were reported by Richardson and Diseker (20), and Barnett, et al. (3) for test plots treated with 2 ton/acre of straw. These results also showed straw to be superior to jute, water-soluble latex, plastic film and sawdust. In all cases, the straw was anchored with a binder such as asphalt.

Woodchips, bark and wood excelsior have in many cases proven to be superior to straw as a mulch material. This is especially true in areas where slopes are steep. Slopes as steep as 2:1 were successfully stabilized in tests conducted by Sarles and Emanuel (22). Recent experiments conducted by Osborne and Gilbert (17) on highway slopes also indicate that hardwood bark mulch is superior to straw for immediate erosion control and long term stability when applied at a rate of 30 cubic yards/acre. Wood, when combined with a chemical soil stabilizer, hastened the germination of the grass seed and provided better erosion control on mine-spoil piles in West Virginia (18). The decreased germination time was found to be the result of increased moisture retention in the soil mulched with wood. This result was duplicated by Dudeck (8) on plots where excelsior was mulched with an asphalt binder. Case studies on vegetation of soils of low productivity compiled by the Office of Water Planning and Standards, U.S. EPA (17), indicate that wood products are acceptable as a mulch material in all cases, and preferable to any other material in most cases. Sawdust and other wood wastes were tested by Bollen and Glennie (4) and found to be acceptable as a mulch, but only under certain conditions. In this case, the size of the particles was found to have a direct effect on the amount of packing that occurs, which in turn, affected the amount of aeration and infiltration that took place in the soil. A comparison of straw, woodchips and stone as mulch materials was made by Meyer, et al. (15). This study concluded that rock was a better mulch material than either straw or woodchips. However, the conclusion also showed the cost of stone to be extremely high by comparison.

IV-E. Soil Stabilizers

In all of the tests conducted on mulches except stone, the erosion control capability of the mulch was greatly improved by the addition of a binder or tacking material. These binders are generally referred to as "soil stabilizers" and fall into two broad categories: petroleum products and polymers. Petroleum products include asphalt and resins while polymers are generally confined to latex emulsions. Extensive tests on 34 of these products were carried out by Armbrust and Dickerson (1) in 1971 (See Table 1). Data on their effectiveness as a soil stabilizer, influence on seed germination, and relative cost was obtained. Resin-in-water emulsions were tested by Chepil, et al. (5), with the conclusion being that only mulches anchored with a soil stabilizer were better than this product. Studies done by and for the U.S. EPA (9,10) also attest to the fact that a mulch should be placed with a soil stabilizer to enhance its capability to control erosion.

Portland cement is a soil stabilizer that does not fit into either of the above categories. It has been tested by Romkens, et al. (21), and found to be effective in controlling erosion on slopes less than 7%. The use of this product on steeper slopes is questionable since erosion can occur under the hard crust created by the hardened soil-cement layer.

IV-F. Soil Mats

The most effective means of stabilizing the soil against erosion is to place a mat over it. Mats are generally made of a biodegradable product such as excelsior, jute or paper. Test results compiled for the U.S. EPA (9) indicate that properly placed mats can effectively control the erosion of soil in areas such as ditches and on steep slopes. These results also show mats to be second only to sodding in the total cost of placement. This fact is due to the amount of labor necessary to properly install a mat. Proper installation is a critical requirement for all types of mats since erosion can occur under a mat that has not been properly placed. Recent testing of various mat material has included fiberglass. Snell (24) combined the techniques of hydroseeding and a soil stabilizer with fiberglass matting to reduce erosion to zero along the banks of a fast moving stream. Although this technique was effective, it was found to be quite costly, and only practical in cases where other, lesser expensive, methods have been tried and found to be lacking. The primary utilization of mats is limited to areas where severe erosion occurs due to the volume or velocity of runoff.

IV-G. Establishment of Vegetation

Vegetation has been the most widely used long term method of slope protection. After erosion has been physically controlled, attention should be focused on the methods to establish this vegetation. The soil conditions, such a pH and the availability of nutrients for plant growth, and the type of seed to best fit the area are necessary considerations. Acidic soils should receive lime treatments to bring their pH to a range of 6 to 7 (10). The amount of lime to accomplish this is determined by initial soil tests. These tests should also determine the amount of nutrients available in the soil for plant growth. The selection of fertilizer type and amounts are based on the results of these tests (10). Extensive testing of seed types and seeding rates has been carried out in Mississippi by the State Highway Department (16). The tests have resulted in the publication of recommended seed mixtures and seeding rates based on the soil and climatic conditions found in various parts of the state. Tests have also been conducted by Graetz (11) and Vaden (25) to determine what types of seeds and seeding methods provide the best soil stabilization and esthetic beauty. Although conducted in states other than Mississippi, these results are applicable in that the types of seeds utilized can be planted with success in Mississippi.

Hydroseeding is a recently developed technique which allows the mulch, seed and fertilizer to be mixed together in a slurry tank and ejected hydraulically. This technique reduces the manpower requirements for these operations and provides a highly effective measure of erosion control. Due to the high cost of equipment, hydroseeding has not been tested to any large degree. References to hydroseeding indicate that the method provides extremely good erosion control on steep slopes and in areas where access is limited (9,10). In all cases, the mulch material utilized was a wood fiber produced from clean, whole woodchips.

IV-H. Sedimentation Control

One method of controlling the sedimentation resulting from runoff around construction sites without additional earthwork has been accomplished by utilizing a fabric fence. Dallaire (7) reports that sedimentation carried by runoff from fill areas was successfully intercepted by placing a filter fabric, such as Celanese's Mirafi 140, on a fence constructed from livestock wire and wooden posts. The bottom edge of the fabric was buried in a trench to prevent the eroded soil from passing under it. The filter fabric allows the water to pass, but intercepts the soil particles. The fabric was also applied to a brush barrier that had been pushed up during the cleaning of the site. In this case, the fabric and brush were left in place and allowed to become overgrown by vegetation. The livestock wire fence required removal once vegetation became established on the fill area. In both cases, the pollution of the local streams was reduced considerably by the filtration process.

V. DISCUSSION OF THEORY

In a classical sense, erosion is defined as the process by which the land surface is worn away by the action of water, wind, ice or gravity. Natural erosion accounts for the transformations that take place in the topographic features of the land. Except for some cases of shore and stream channel erosion, natural erosion is a very slow process. This process has occurred at a relatively uniform rate over thousands of years. The sediment from this type of erosion does not, to any large extent, create an environmental problem. The final result is a constant wearing away of the high ground and a building up of the lowlands.

The destruction of natural vegetation by man can greatly accelerate the overall rate of erosion. Activities such as exposing the soil surface, altering drainage patterns, and covering permeable soil surfaces with impermeable structures can create serious erosion problems. Water-generated sediment is a result of these activities and produces the major share of all non-natural sediments generated in this country. This type of erosion is normally referred to as "accelerated" erosion. The severity of this erosion is normally related to such factors as climate, vegetative cover, type of soil, and the length and steepness of slopes.

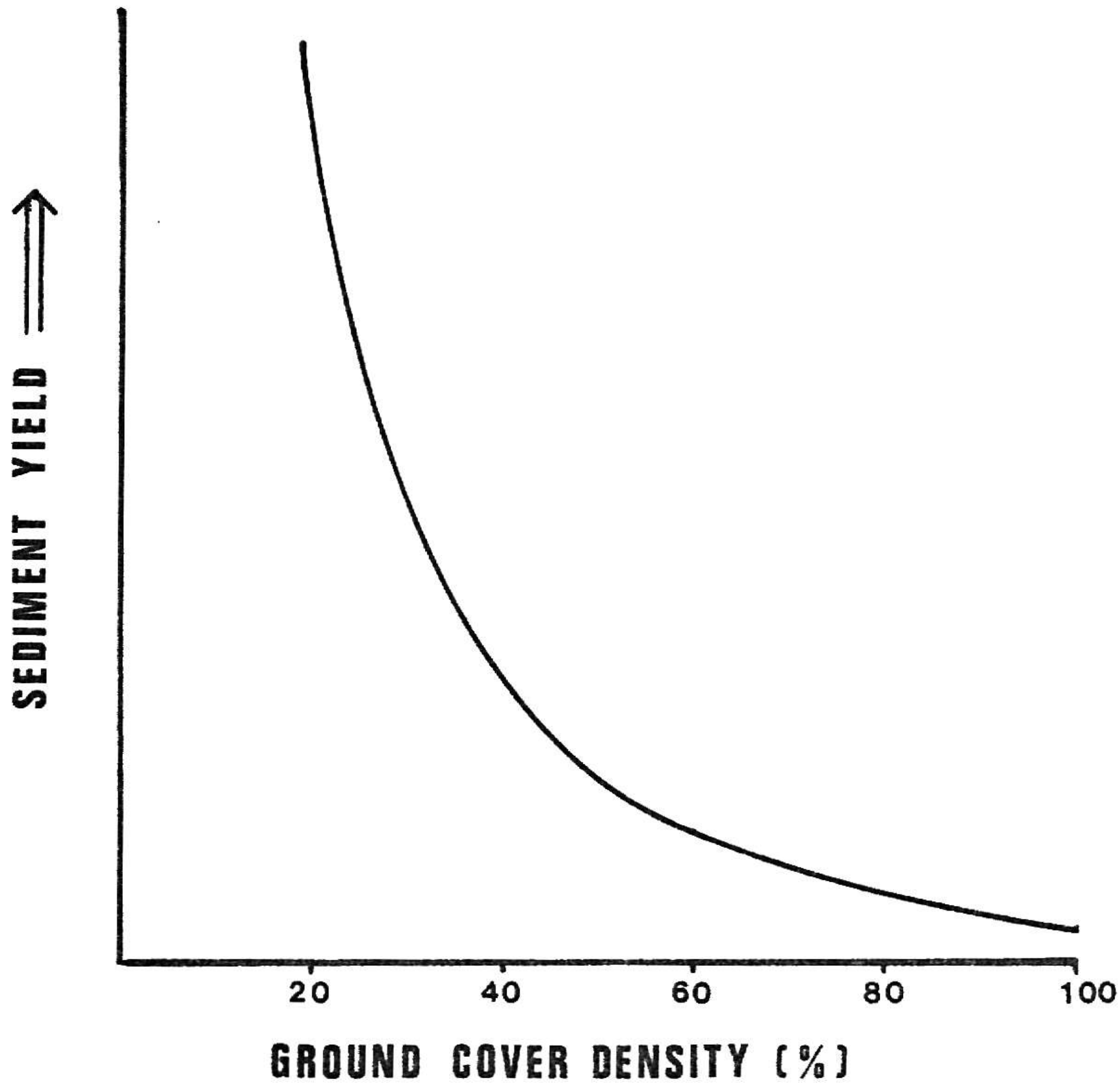
V-A. Categories of Accelerated Erosion

Accelerated water erosion can be divided into three major categories: overland erosion, stream channel erosion, and shore erosion. Stream channel and shore erosion will not be addressed in this paper since they are generally a result of a much larger problem which began with overland erosion.

Overland erosion is a result of rain splash and runoff. This category creates the largest source of sediment during construction operations, and includes such types of erosion as sheet, rill and gully. Sheet erosion is the result of rain splash and runoff which causes the removal of a uniform layer of soil from the land surface. The impact of raindrops on the bare soil surface (rain splash) breaks up the larger soil particles into finer particles, which makes them more susceptible to ensuing runoff. These finer particles also settle into the pores of the soil, creating a "surface sealing," which decreases the rate that water penetrates the soil, causing increased runoff. Runoff spread uniformly over a slope is generally referred to as "sheet flow." When sheet flow is heavy, water concentrates in low areas to form rivulets which cause rill erosion. These rivulets, if uncontrolled, will continue to erode the soil until a gully is formed. In areas subjected to a concentrated flow of water, gully erosion is a major problem.

V-B. Sedimentation

The combined process of soil detachment, dispersion, transportation and deposition are referred to as sedimentation. No matter how good the methods of erosion control are, some sedimentation is to be expected. A certain amount of soil is going to become detached from the slopes during the processes previously described in the section on "accelerated erosion." This is shown by Figure 9, where some sedimentary yield occurs even though the ground cover density is 100% (10). The detached soil particles are then transported by the runoff until the velocity of the water is reduced to a point where sedimentation takes place. This process may occur in stages where the heavier, coarser grained particles are dropped first with the finer particles remaining in suspension until the water no longer has any velocity.



QUALITATIVE DIAGRAM OF SEDIMENT YIELD AS A FUNCTION OF GROUND COVER

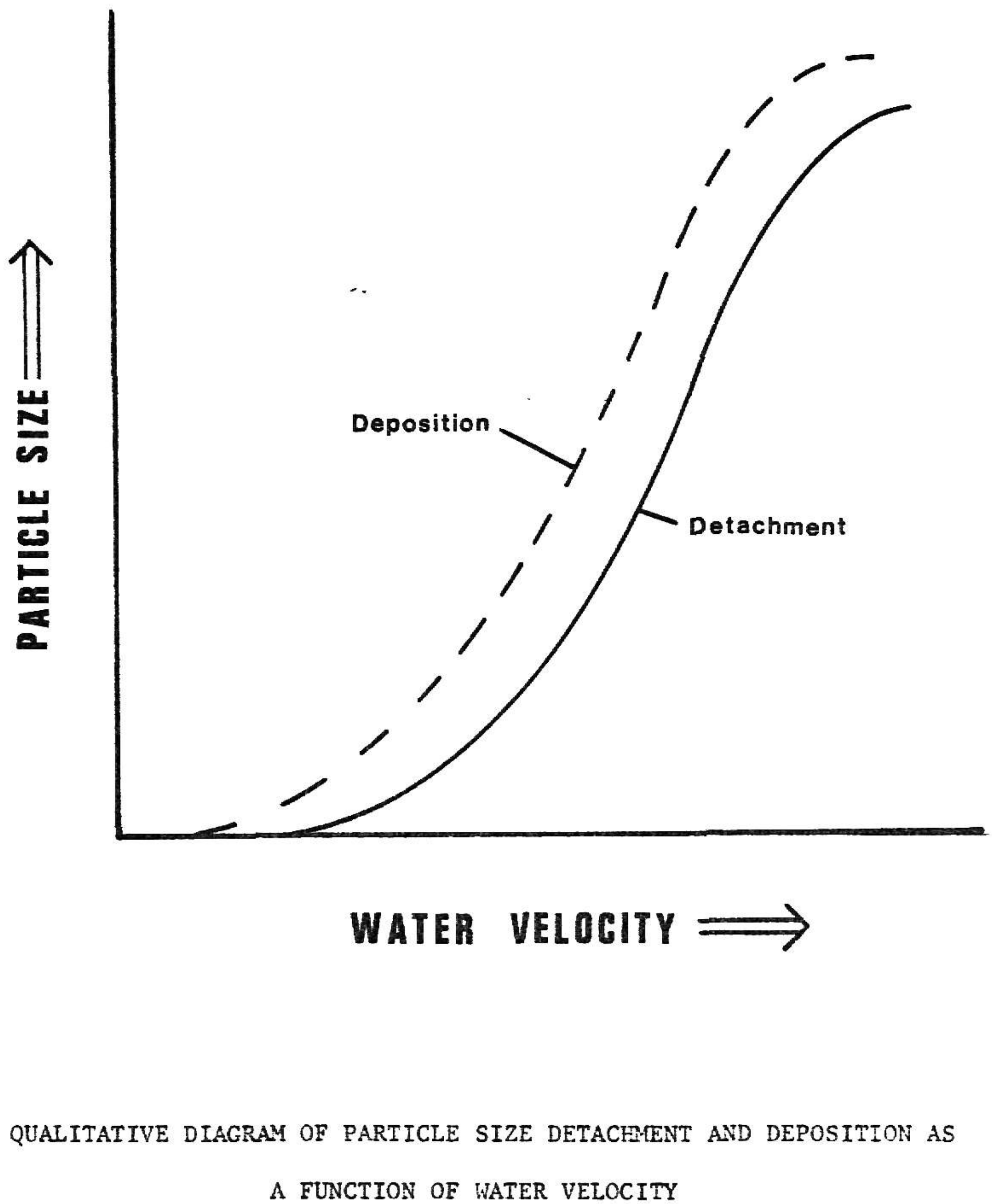
FIG. 9

As the velocity of the water increases, the water has a greater potential for eroding and transporting soil. As Figure 10 shows, the relative grain size of the soil particles being carried by the water is directly dependent upon the velocity of the water. This curve is very general and only applies to coarser grained soils. There is also a direct relationship between the velocity of the water and desposition. This relationship is shown by the dashed curve on Figure 10. It should be noted that this velocity is lower than the transportation velocity due to the initial force required to start the particle moving.

V-C. Universal Soil Loss Equation

Past attempts to quantify the amount of soil loss that can be expected during rainstorms have generally met with failure. The parameters affecting the problem were generally too broad and were not universally applicable to all types of soils. Various combinations of rainfall, length of slope, percent of slope, land cover factors, and soil erodibility characteristics were examples of parameters that were tested with little or no success until recently. In 1959, Walter H. Wischmeier and Dwight D. Smith, both engineers employed by the U. S. Department of Agriculture (USDA), derived a "universal soil loss equation" (26). This equation was presented to the International Congress of Soil Science in 1960. Its primary application at that time was to agricultural land.

The equation was based on extensive research conducted by the USDA with regards to what parameters were needed in order to predict the amount of soil loss that could be expected under certain conditions and in certain locations. The results lead to the development of a mathematical model containing the following factors:



QUALITATIVE DIAGRAM OF PARTICLE SIZE DETACHMENT AND DEPOSITION AS A FUNCTION OF WATER VELOCITY

FIG. 10

R - the expected annual value of the rainfall erosion index in the locality

K - a quantitative measure of the erodibility of the soil

L and S - factors for length and percent of slope, respectively

C - a cropping management factor

P - a factor for special erosion control practices

The formula containing these factors was determined to be: A = RKLSCP, where A is the computed, annual soil loss.

The rainfall factor R, the topographic factors L and S, the cropping management factor C, and the erosion control factor P were determined for various parts of the United States from the thirty years of data gathered by the USDA. The problem in applying this universal formula lies in the value of K, the soil erodibility factor. Actual soil loss data was collected for specific soil types from which the value of K for that particular soil was determined. Many experiments were conducted by agricultural and soils engineers in their own areas in order to arrive at a value for K which suited their particular soil conditions. Attempts were also made to determine the soil factors which had the greatest influence on K.

In 1968, Wischmeier updated his formula by specifying what soil factors influenced K (27). Properties such as percentage of sand, silt, clay and organic matter, pH, structure and bulk density, steepness and concavity or convexity of slope, pore space filled by air, residual crop effects, and various interactions of these variables were considered during the testing of K factor parameters. Statistical analysis was utilized on the test results to obtain the correlation for each variable. From these tests, it was found that the K value was greatly dependent upon the amount of sand, silt, and clay present, the organic content, soil moisture, bulk density, pH, the volume of pore space filled by air, and the thickness of the granular soil layer. At this time, the application of this equation was determined to be valid only in cases where the sand content did not exceed 65%, and the clay content did not exceed 35%.

Further modification of the method for determining the K factor was made in 1971, by Wischmeier (28). This modification was the result of extensive testing carried out during the preceeding three years by the USDA. The discovery of a new statistical parameter that successfully reflected the influence of particle size interrelations led to the publishing of a "soil erodibility nomograph for the determination of K" (See Figure 11). The only parameters required for the use of this nomograph are percent silt, percent sand, organic matter content, and permeability.

The percentages of sand, silt and organic matter are obtained from a sieve analysis of the soil. The range of sizes for sand are .1 to 2.0 mm, and for silt, .002 to .1 mm in diameter. This classification is different from that normally used, in that the very fine sand is included in the silt portion of the sieve analysis. There is a maximum limit of 4% placed on the organic content of the soil. The validity of the use of the nomograph on soils with an organic content above 4% has not been determined.

Soil structure and permeability are basically qualitative parameters rather than quantitative. The soil structure for all previous tests was determined from the soil profile. The significance of this parameter was determined to be important, therefore the data from these tests was analyzed and related to the K value observed during the tests. Permeability

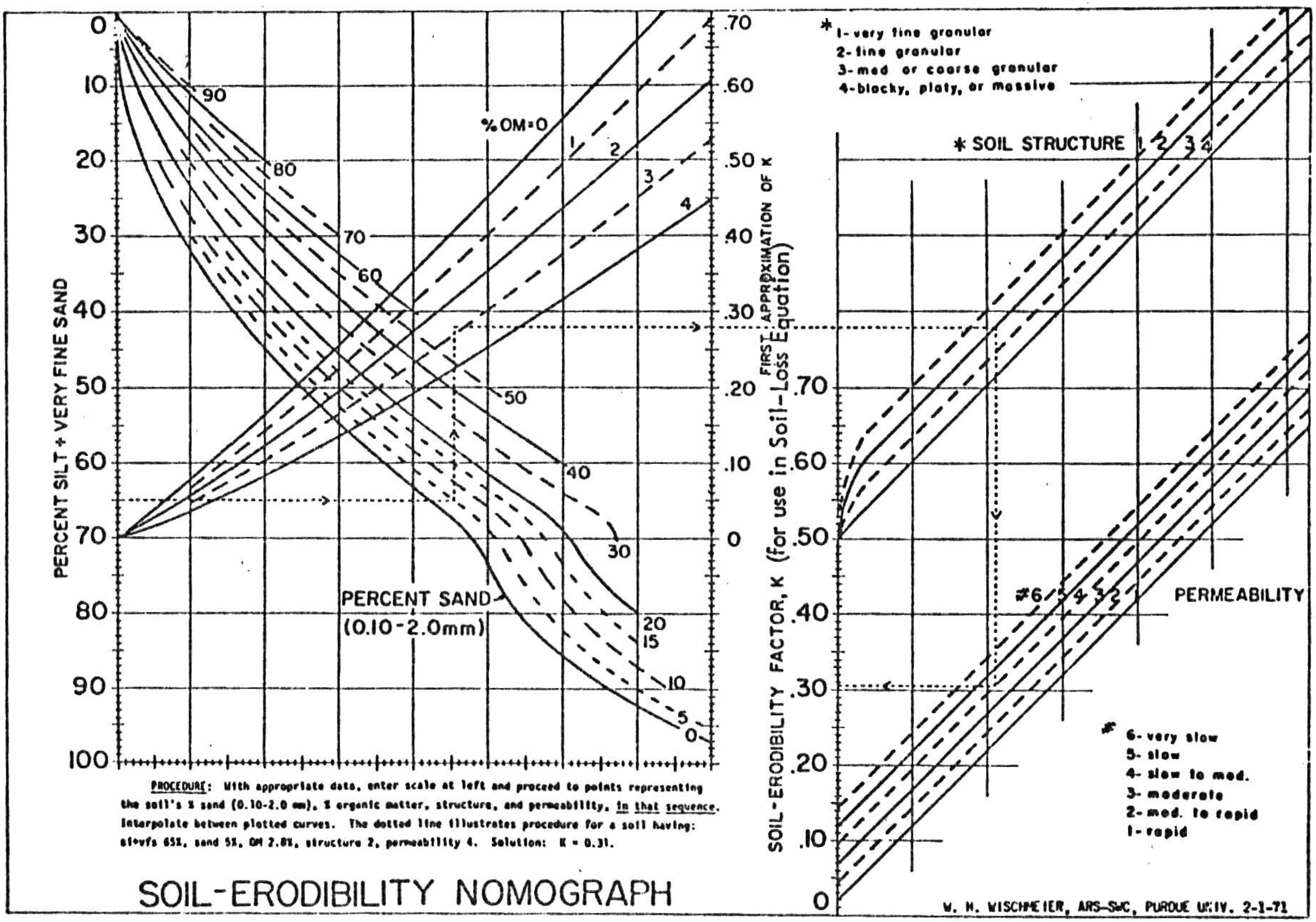

PERCENT SILT + VERY FINE SAND
%OM=0
PERCENT SAND
(0.10-2.0mm)
FIRST APPROXIMATION OF K
SOIL-ERODIBILITY FACTOR, K (for use in Soil-Loss Equation)
* 1-very fine granular
2-fine granular
3-med or coarse granular
4-blocky, platy, or massive
* SOIL STRUCTURE 1 2 3 4
# 6/5 4 3 2
PERMEABILITY
6-very slow
5-slow
4-slow to mod.
3-moderate
2-mod. to rapid
1-rapid
PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.
SOIL-ERODIBILITY NOMOGRAPH
W. H. WISCHMEIER, ARS-SWC, PURDUE UNIV. 2-1-71

FIG. 11

classes range from one to six. Fragipan soils were coded six, massive clay layers five, silty clay or silty clay loam soils having a weak, subangular or angular, blocky structure were coded four, silty clay loams were coded three. Codes one and two are applicable to coarser structures which show rapid permeability.

Application of this nomograph to soils with a known K value has produced extensive correlation. In fact, the development of the soil erodibility nomograph has, according to Wischmeier, improved the capability to predict soil loss to the point where it can now be applied to construction projects. With this nomograph and information on local rainstorms, the contractor can predict the sediment yield to be expected from areas he plans to develop. Experiments are now being conducted to determine what effect erosion control methods such as mulching have on the parameter P in the soil loss equation. This information will aid in selecting the best method of erosion control for a given area.

V-D. Theory of Compaction

Compaction of the soil consists of removing air by pressing or vibrating the soil praticles into a more dense state. In the case of granular materials, some water may also be expelled as the porosity is reduced by compaction. The amount of compaction or increased density that can be obtained is dependent upon the type of soil, moisture content of the soil and compactive effort applied. Coarse grained soils react differently to certain compactive efforts than do fine grained soils. Cohesionless soils, which depend upon gravity and the resulting grain to grain contact forces for stability, are more readily compacted by the application of a vibratory force than by an application of a steady pressure. This vibration disturbs the contact between the grains, causing the soil to assume a more stable, dense configuration. On the other hand, compaction of cohesive or fine grained soils is achieved by the application of pressure which expels the air from the pores of the soil. The amount of effort required to achieve compaction is directly dependent upon the moisture content of the soil (23).

If the compactive effort is held constant for a given soil, the moisture content will determine the state at which maximum dry unit weight or dry density occurs. If the soil is dry, a great deal of effort is required to produce densification and low values of dry unit weight are obtained. As more moisture is added to the soil, it becomes easier to work due to the decrease in surface tension within the soil. Moisture can be added until a point is reached where the maximum dry unit weight can be obtained with the least amount of effort. If the moisture content is increased beyond this point, there is a drop in the dry unit weight due to the filling of the voids in the soil by the remaining air and water (12).

There is an optimum moisture content and a maximum dry unit weight for each compaction effort applied per unit volume of a given soil (See Figure 8). In most cases, the point where maximum dry unit weight and optimum moisture content occur is determined by applying a known compactive effort. Such tests as AASHO and Modified AASHO are standard methods of determining the optimum moisture content of a soil and the maximum dry unit weight for a given compactive effort. These laboratory results are then applied to field conditions by placing limits on the moisture content of the soil being compacted, and specifying to what dry unit weight the soil must be densified.

VI. METHODS FOR EROSION CONTROL

Several methods exist for the control of erosion. One method is compaction which should be carried out to prevent erosion in areas where soil is being placed in lifts, such as in the disposal areas. However, in order to control erosion on steep slopes, a type of mulch along with a soil stabilizer is needed. In some areas where the terrain creates unusually heavy runoff, there may also be a need to utilize a mat. The physical control of soil erosion is not the only benefit in utilizing mulching and soil stabilization; other benefits include the reduction of moisture loss through evaporation and the moderation of the soil temperature. These benefits, in most cases, shorten the time required to produce suitable vegetation which is a major consideration when the soil on the slopes shows little or no resistance to erosion.

VI-A. Compaction

One of the most often utilized methods of erosion control around construction sites is compaction. In most cases a certain amount of compactive effort is applied to a soil to hold it in place during the growth period. This method, in itself, generally works for cohesive soils and in areas where the slopes are not steep, and the rainfall intensity is moderate. On the other hand, if the slopes are steep and the soil is prone to erosion, as is generally the case along the waterway, there is little that this can accomplish alone. Furthermore, the results of one rainfall runoff test conducted on various soil surfaces indicate that the overall soil loss from an area that consisted of compacted fill was only slightly less than the loss from a scalped area with no compaction. The primary reason for this fact was attributed to the decrease in soil permeability due to the compaction. This test was conducted on land with a moderate slope (12%)(14).

The results presented above do not mean that compaction should not be utilized in the disposal areas. The primary purpose of compaction in this case is to consolidate the soil in order to minimize future settlement and to aid in erosion control during the time the disposal area is being utilized. The specified compaction should be carried out for each lift placed in the fill until the last lift is in place. At this point, the necessary erosion control methods should be applied according to the slope and soil conditions. No compaction of the seedbed is required.

Little, if any, compaction should be applied to a cut slope. If the soil on the cut slope is capable of supporting vegetation there should be no need for compaction. This case generally calls for scarifying the soil to a depth of six to eight inches which will allow the seeds to establish a good root structure. When the soil in the cut slope is incapable of supporting vegetation, a growth medium or topsoil must be plated on the soil. This may require some compaction if more than one lift is needed to obtain the desired topsoil thickness. Again, no compaction should be applied to the final lift.

Another reason for not compacting the final lift lies in the fact that the growth of the vegetation is retarded, due to loss of permeability. Results of vegetation experiments indicate that the lowest percentage of vegetation establishment occurred on compacted slopes (20%). The comparison was made to slopes that had been seeded after scarifying, after the application of topsoil on scalped areas, and after mulching with hay. The hay mulch showed the largest percentage of establishment (86%)(14).

VI-B. Wood Mulch

As noted in the literature review, a number of different mulches have been tested. The most effective of these being wood or bark chips. Sarles and Emanuel (22) report that slopes greater than 2:1 were successfully stabilized by the use of hardwood bark. The application rate in this case was 50 cubic yards per acre. In this same test, straw was unable to provide the protection needed on these steep slopes. Osborne and Gilbert (17) reported the same results for tests conducted on slopes of 3:1. The application rate was varied with final results showing a mulch rate of 30 cubic yards per acre to be adequate for maximum erosion control. Tests conducted on the stabilization and vegetation of mine spoils in West Virginia also showed wood mulch to be superior to straw in controlling erosion and establishing vegetation (18).

Other forms of wood utilized for erosion control include loose excelsior and sawdust. Dudeck (8) found that the moisture retention capability of the soil was greatly increased in plots mulched with loose excelsior. This increased water retention considerably improved the grass stands obtained. Fine wood shavings, held in place by a binder during the growth period, were also tested for their ability to improve the moisture content of the soil. Again there was a marked improvement in moisture retention. Sawdust has been tested as an erosion control product by Bollen and Glennie (15). These tests indicated that particle size was a consideration when wood products were utilized as a mulch. It was found that millrun sawdust was a good mulch material, but re-saw sawdust packed too tightly when applied, therefore retarding aeration and infiltration.

With the exception of sawdust, the use of wood products as a mulch enhances the growth of vegetation. This is especially true when excelsior and hardwood bark are utilized. In all cases, nitrogen must be added to the soil since wood residues do not contain the amount of nitrogen needed by the plant roots. The increased vegetation growth is attributed to the increased moisture content of the soil, and the greatly improved erosion control provided by the wood product. The improvement in erosion control is the result of the wood product's ability to resist erosion caused by overland sheet flow, to better dissipate energy from falling raindrops, and to remain in place when subjected to high winds. Another advantage of a wood mulch is that it can be rapidly applied with the proper equipment, and left in place during periods when it is not advantageous to seed, but erosion control is still required. The area can then be seeded at a later date with little or no further soil preparation.

Woodchips, depending on their availability, are comparable to straw in cost (9). In areas such as northern Mississippi, where sawmills exist, woodchips are by far the better mulch material for steep slopes. The only disadvantages are the lack of available nitrogen, the packing of fine particles, and the low pH of some woods. An application of from five to ten pounds of fertilizer nitrogen per ton of bark can correct the nitrogen shortage (10). Sarles and Emanuel (22) recommend that the woodchips be screened or shredded prior to application to eliminate the fine particles. This will reduce the chance that packing will occur. The low pH is a result of fermentation of the wood, and can be corrected by the application of ten pounds of lime per cubic yard of wood. The use of woodchips should be a consideration in all cases where steep slopes are to be stabilized. The final results may outweigh the increased cost of wood over straw.

VI-C. Straw Mulch

The most widely used, but less effective mulch is straw or hay. Straw is relatively inexpensive, easy to handle, and produces good results on shallow to moderate slopes. There are many types of machines on the market to spread straw over large areas with very little manpower required. Blower type spreaders are capable of applying straw to steep slopes where beater type spreaders cannot reach. Blower type spreaders also allow the injection of a binder into the airstream, which coats the straw, increasing its ability to control erosion. Other methods of anchoring the straw include a disc packer, a mulch tiller, a modified sheepsfoot roller, or a weighted farm disc.

The primary reason for straw or hay being the most widely used mulch is due to cost. If suitable straw can be purchased in the local area, the relative cost of straw mulching is lower than any other method of mulching (9). In cases where local straw is unacceptable, usually the result of an excess of weed seed in the straw, the cost of transportation may increase the cost to a point where other types of mulch should be considered. Such is the case in Mississippi where local weeds infest the available straw. Straw, like wood products, can be placed at a time not advantageous to seeding.

VI-D. Other Mulch Material

Only the most common kinds of mulches have been discussed to this point. Other mulching materials include crushed stone, animal manures, composted sewage sludge, asphalt, resins, and latex. Stone as a mulching material was tested by L. D. Meyer, et al. (15) and found to be superior to straw and wood for erosion control. The test was run on 150 foot long plots with a 20% slope. The results indicated that for slopes less than 40 feet in length, an application rate of 240 tons/acre of crushed stone provided better erosion control than 12 tons/acre of woodchips. Slopes greater than 40 feet long were also stabilized at a rate of 240 tons/acre of crushed stone which provided better erosion control than 25 tons/acre of woodchips. However, a cost comparison between crushed stone and woodchips indicates that any advantage of crushed stone over woodchips in erosion control is negligible due to the high cost of stone. Animal manures and composted sludge are good mulches on land with little or no slope, but provide very little in the way of soil stabilization. Care must also be exercised in not applying the animal manures or sewage sludge so heavily that runoff waters will pollute nearby streams (10). Asphalt, resins and latex alone are not generally used as a mulch material. They are applied as a tack coat to other mulches to aid in stabilization of the mulch. If applied too heavily, they will retard the growth of vegetation.

VI-E. Soil Stabilizers

Soil stabilizers come in many forms. Petroleum products, such as asphalts and asphalt emulsions, and resin-in-water emulsions reduce evaporation, prevent soil crusting, and promote seed germination. Latex emulsions or polymers are diluted with water and sprayed on the soil to provide a rubbery film, resistant to erosion. Portland cement is sprayed on the soil to provide a hard crust. There are many different commercial products available for each type of stabilizer listed. They vary greatly in cost, effectiveness, and application methods (See Table 1). Some stabilizers are designed to be used with mulches, such as asphalts, while others are surface soil treatments as are latex emulsions.

Cutback asphalts and asphalt emulsions are available in different curing rates. The cutbacks are generally slow, medium and rapid-curing, while the asphalt-in-water emulsions are usually rapid-setting (10). When asphalt alone is utilized as an erosion control material, the surface

Table 1

Test Data for 34 Soil Stabilizers (1)

	Material[a]	Chemical Composition	Manufacturer	Cost/acre
1.	Elvanol 71-30	Powder, polyvinyl alcohol	DuPont	$ 6.90
2.	CMC-7-H	Powder, sodium carboxymethyl cellulose, high viscosity	Hercules, Inc.	7.30
3.	Elvanol 50-42	Powder, polyvinyl alcohol	DuPont	8.20
4.	WICALOID	Liquid, latex	Wica Chemicals	14.40
5.	Gypsum Hemihydrate	Powder, gypsum hemihydrate	National Gypsum Co.	16.60
6.	E802 Mazofern Brand Fermented Corn Extractives	Liquid, corn steep water	Corn Products Sales Co.	22.00
7.	SEPARAN NP-10	Powder, polyacrylamide	Dow Chemical Co.	25.20
8.	Goodrite 2570X1	Liquid, styrene-butadiene latex	B. F. Goodrich Co.	25.40
*9.	Polyco 2460	Liquid, styrene-butadiene copolymer	Borden Chem. Co.	26.90
*10.	SBR Latex S-2105	Liquid, styrene-butadiene latex	Shell Chem. Co.	27.40
11.	CMC-7-L	Powder, sodium carboxymethyl cellulose, low viscosity	Hercules, Inc.	28.40
12.	CMC-7-M	Powder, sodium carboxymethyl cellulose, medium viscosity	Hercules, Inc.	28.40

Table 1 (Cont'd.)

	Material[a]	Chemical Composition	Manufacturer	Cost/acre
13.	AEROSPRAY 52 Binder	Liquid, synthetic resin-in-water emulsion	American Cyanamic Co.	$ 29.90
14.	Technical Protein Colloid 1-V	Granular, protein colloid	Swift and Co.	31.30
15.	SOILGARD	Liquid, elastomeric polymer	Alco Chem. Corp.	32.20
16.	Technical Protein Colloid 5-V	Granular, protein colloid	Swift and Co.	34.60
*17.	COHEREX	Liquid, petroleum resin-in-water emulsion	Golden Bear Oil Co.	34.60
*18.	DCA-70	Liquid, polymer of some type	Union Carbide	36.60
*19.	Polyco 2605	Liquid, vinylchloride copolymer	Bordon Co.	40.80
20.	Gantrez AN-119	Powder, polymeric anhydride	General Analine and Film Corp.	43.60
21.	Technical Protein Colloid 2260	Liquid, protein colloid	Swift and Co.	46.00
*22.	Petroset SB	Liquid, rubber emulsion	Phillips Petroleum Co.	49.50
23.	Geon 652	Liquid, vinylchloride latex	B. F. Goodrich Co.	51.20
24.	NC 1556 L	Liquid, modified polyacrylamide	Dow Chemical Co.	59.49
25.	Curasol AE	Dry, polyvinyl acetate emulsion	American Hoechst Corp.	89.70
26.	Gantrez ES-335I	Liquid, monoester resin	General Analine and Film Corp.	103.10

Table 1 (Cont'd.)

	Material[a]	Chemical Composition	Manufacturer	Cost/acre
27.	Technical Protein Colloid 2236	Liquid, protein colloid	Swift and Co.	$ 103.20
28.	Soil Seal	Liquid, formulation of copolymers	Soil Seal Corp.	149.60
29.	Aquatain	Liquid, sodium polypectate, glycerin and ammonia	Larutan Corp.	172.50
30.	ORTHO Soil Mulch	Liquid, asphalt emulsion	Chevron Chem. Co.	242.20
31.	Anionic Asphalt Emulsion	Liquid, asphalt emulsion	Phillips Petroleum Co.	436.10
32.	AGRI-MULCH	Liquid, asphalt emulsion	Douglas Oil Co.	445.70
33.	Soil Erosion Control Resin Adhesive Z-3876	Liquid, resin, polyvinyl alcohol	Swift and Co.	1,159.90
34.	Experimental	Liquid, styrene-butadiene emulsion in mineral oil	Ashland Chem. Co.	Unknown

[a] Arranged in order of increasing cost per acre.

*Judged the best in ease of handling, erosion control, and emergence of plants.

of the soil is sprayed with a thin film. The type of asphalt utilized should be of the slow curing variety to allow vegetation to break through the film more easily. Straw, on the other hand, is anchored with a rapid-setting asphalt. The application rate of asphalt films is extremely important since the film is virtually nonporous. Sufficient soil moisture must be present to provide germination as most of the rainwater will run off. Chepil, et al. (5) report that the rate of application of any asphalt product should not exceed 1,200 gal./acre. Asphalt emulsions applied at this rate will generally last all winter on a sandy soil, but will disintegrate within two weeks to three months on clay or silty clay due to the swelling and shrinking of the soil. Cutback asphalt films, on the other hand, are more resistant to weathering and will remain intact six to twelve months (10). If this application rate is exceeded, the emergence and growth of the vegetation will generally be retarded.

The ideal film, according to Chepil, et al. (5), is "stable against erosion, sufficiently porous to allow water to enter, yet insoluble in water and resistant enough to weather that it lasts until permanent vegetation becomes established." Next to a well-anchored mulch, the resin-in-water emulsion comes closest to meeting these requirements. Resin-in-water emulsions should be diluted with water at a 1:1 ratio and applied at a rate of 600 gal./acre (10). This application rate will give approximately the same duration of protection as asphalt emulsions. The advantage of this film over asphalt is in the porosity. Seedlings have a better emergence rate through resin-in-water films than through asphalt on latex films (10).

Latex emulsions are elastometric polymer emulsions that, when diluted with water and sprayed on the soil, produce a rubbery film resistant to erosion (5). The emulsion spray remains on the soil surface with very little penetration taking place. This film, like asphalt emulsions, limits the penetration of water into the soil and the emergence of the seedlings.

As indicated by Table 1, the cost and effectiveness of asphalt, asphalt emulsions, resins-in-water emulsions, and latex emulsions varies greatly. In 1971, the cost to effectively control erosion with these stabilizers on a one acre test plot varied from $6.90 for a latex emulsion to $1,159.90 for a combination latex and resin emulsion (1). The wide variance in cost was primarily the result of the amount of stabilizer needed to effectively control erosion. Asphalt emulsions averaged $340.00 per acre, resin-in-water emulsions averaged $33.00 per acre, while latex emulsions ranged from $6.90 to $149.60 per acre. Test results indicated that, of the 34 stabilizers tested, those that performed best as an erosion control method averaged $36.00 per acre in cost (1). All costs are based on controlling erosion for a period of two months during the prime growing season. Acceptable soil stabilizers are generally comparable to asphalt tacked straw in cost, but are not as effective in controlling erosion over a long period of time (9).

VI-F. Portland Cement

The primary use of Portland cement as a soil stabilizer has been on moderate or gentle slopes. The cement is sprayed as a suspension at a rate of 1.1 ton/acre to provide a surface seal or crust on the soil. This surface seal protects the soil from the impact of raindrops. It has been found to be effective on slopes less than 7% (21), but was of little or no use on steeper slopes. This is due to its failure to penetrate the soil surface deeply enough to prevent erosion from occurring under the crust.

VI-G. Soil Mats

Soil mats are the most effective and most costly means of protecting the soil from erosion and enhancing vegetation growth. Mats protect the soil from erosion by reducing the energy of falling raindrops and overland flow, and they improve vegetation growth by conserving the soil moisture and moderating the soil temperature. The most common materials for mats include excelsior, jute and paper. Fiberglass is also utilized, but to a lesser degree. Excelsior mats generally consist of a wood excelsior blanket covered by a weave of twisted Kraft paper, biodegradable, plastic mesh or similar material (9). The excelsior consists of wood fibers of which 80% are eight inch or longer. The mats are held in place by metal staples. The fact that the mats are held down by metal staples makes them highly effective in controlling erosion on steep slopes and in highly erodible soils (9). This fact also makes excelsior mats and mats in general the most costly method of erosion control. The labor cost is extremely high due to the requirement to drive the staple into the ground. When compared to all other methods of controlling erosion, excelsior mats were found to be second only to sodding in cost per acre. For this reason, their application should be restricted to areas such as ditches, and areas where the terrain creates above average runoff as compared to the total area.

Jute netting is the least expensive of the commonly utilized mats. This mat consists of a heavily woven mesh made up of natural jute fibers. Jute normally comes in 4 feet wide rolls which are placed at the top of a slope and unrolled downhill. The jute is then stapled down and the top end buried six inches deep to prevent erosion from occurring beneath the mat (9). Staples should be driven every one foot along overlaps, and one foot apart and four inches apart below the top where the end is buried. At places where one roll of matting ends and another begins, the top strip should overlap the trench where the upper end of the lower strip is buried by at least four inches. Jute mat is considerably cheaper than excelsior mat, but is still twice as expensive as a wood chip mulch (9).

Paper mats consist of a knitted synthetic netting interwoven with paper strips. The synthetic netting is a yarn that can be varied in composition according to the need for permanence. The same conditions apply to the paper strips. The entire mat is biodegradable and exhibits the same erosion control abilities as do jute and excelsior. Paper mats are applied in much the same manner as jute. An advantage of paper over jute is that the paper weighs one-fourth as much as jute, which allows for easier handling. Determination of the cost of paper mats was not made since there is such a variation in composition depending upon the application.

Fiberglass mats have been tested in a few areas and found to be acceptable for erosion control. In most cases the mats were only being tested as a comparison to other products, such as jute, and were judged to be as good, but much more expensive. One test on slopes of 1:5:1 indicated that fiberglass mats, when applied over a hydroseeded slope and tacked down with an asphalt emulsion, reduced the erosion to almost zero (24). This is a very expensive process since three methods were combined to produce the results. No other data was found that indicated that there is any advantage to the use of this product.

The ability of mats to control erosion can be severely reduced by improper installation. Mats must contact the soil surface uniformly in order to prevent erosion from occurring below the mat. This is very difficult to attain in areas where the surface is irregular due to rocks or other surface material. For this reason, all areas to be covered by a mat must be made as smooth as possible and all large rocks removed. Mats must also be securely tied to the slope by the staples. This includes securing the ends by burying them in a trench. In many cases, this has been found to be difficult where rock is present. If not properly tied down, mats will have a tendency to blow loose in the wind and become ineffective (22).

VI-H. Establishment of Vegetation

Once the soil has been stabilized against erosion, the next step is to expeditiously establish vegetation. Well established vegetation provides the key to long term erosion control. The successful establishment of vegetation depends upon proper soil preparation, the soil conditions, and the growth season. Disking the soil to a depth of from four to six inches is the recommended procedure for preparation of the soil prior to applying lime and fertilizer (10). Soil conditions include soil pH and the amount of nutrients available for growth. If soil tests indicate a low pH (below 6), consideration should be given to applying lime to the top four to six inches of soil. Lime should be applied until the soil pH is at least six but not more than seven (10). In highly acidic regions, the soil should be tested periodically to determine if additional applications of lime are required. Soil tests should also be made to determine the natural growth potential of the soil. If there is a need to supply nutrients to the soil, the amount and type of fertilizer should be carefully prescribed. As in the case of lime, soil tests should be made periodically to determine the need for additional nutrients. Lime and fertilizer should not be applied in the same operation in order to prevent the loss of nitrogen as ammonia (10).

The actual selection of the species of grasses and legumes is normally not an engineering task. For this reason, the information presented is based primarily on research conducted by the Mississippi State Highway Department as presented in their publication, "The ABC's of Roadside Vegetation - An Informal Guide for Planting and Establishing Roadside Vegetation" (16). Recommended seeding mixtures for roadside vegetation are extracted and presented in Table 2. Table 3 shows the monthly probability for successful establishment of each species in northern Mississippi. Only those species recommended for northern Mississippi are considered. Sodding and the utilization of Bermuda grass sprigs were also eliminated based on their cost.

The seeding rates and seeding mixtures recommended by the Mississippi State Highway Department have also been tested by other state highway departments. Sericea was tested by Graetz (11) for erosion protection along highways. It was found that a combination of Sericea and Lovegrass or Fescue provided a quick and long lasting cover. The seed was applied after tilling lime and fertilizer into the soil. A vegetative mulch was utilized to hold the soil in place during the growth period. Similar tests were run by Vaden (25) for protection of water storage areas in Virginia. In these tests the soil was treated with from two to three tons/acre of lime, one ton/acre of fertilizer, 70 lbs./acre of fescue (Kentucky 31), and 2 lbs./acre of white clover. The soil was also mulched with straw to control erosion prior to the establishment of vegetation. The test areas were later overseeded with Sericea Lespedeza to provide a thicker cover and deeper root structure. In both of these cases, the vegetative stands achieved provided long term erosion control and esthetic beauty to the test areas.

Table 2

Recommended Seeding Mixtures for Roadside Vegetation in Mississippi (16)

Species Combinations	Spring lb./acre	Summer lb./acre	Fall lb./acre	Winter lb./acre
Bahiagrass (Wilmington)	30	30		
Annual Lespedeza	15	15		
Lespedeza Vergata	20	20		
Bahiagrass (Wilmington)			30	30
Bermudagrass			15	15
Tall Fescuegrass			30	30
Crimson Clover			15	15
Tall Fescuegrass	30		30	30
Annual Lespedza	20		--	--
Sericea Lespedeza	20		20	20
Weeping Lovegrass	10	10		
Bahiagrass (Wilmington)	30	30		
Weeping Lovegrass	10	10	10	
Sericea Lespedeza	20	20	20	
Weeping Lovegrass	10		10	
Vetch (Reseeding)	25		25	

Table 3

Monthly Probability for Successful Establishment of Recommended Species on Roadsides in Mississippi (16)

North Mississippi

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bahiagrass (Wilmington)	1	2	5	7	8	8	7	6	3	2	1	1
Bermuda Grass (Seed)	1	2	4	8	9+	7	6	5	2	1	1	1
Crimson Clover	2	2	3	1	0	0	0	4	9	8	5	4
Crownvetch	1	1	4	5	2	1	1	1	6	5	2	1
Annual Lespedeza	1	1	7	9	9+	5	2	1	0	0	0	0
Lespedeza Vergata	1	1	2	5	7	4	2	2	1	1	1	1
Sericea Lespedeza	1	1	3	7	8	6	3	3	2	2	1	1
Tall Fescuegrass	4	4	5	5	2	0	0	4	7	9	9	6
Weeping Lovegrass	1	1	4	4	9	8	7	7	4	2	2	2

NOTE: 0 = None to 9+ = over 90% chance of success

Hydroseeding is a method that allows for application of the fertilizer, seed and mulch in one operation. The proportionate quantities of seed, fertilizer and mulch are combined in a "slurry" tank and hydraulically applied to the soil. Wood fiber is normally utilized as the mulch material. The wood fiber is produced from clean, whole woodchips which are dyed green with a nontoxic dye in order to aid visual metering of the application process (9). Soil percolation and absorption are improved by the wood fiber mulch. The normal rate of application for wood fiber mulch is 1,000 to 1,500 lbs./acre. Hydroseeding provides a means of mulching and seeding very steep slopes and hard to reach places. Commercial hydroseeding machines can blow the slurry mix a distance of 200 feet and still obtain good soil coverage. The only problem with the hydroseeding technique is that the machines are very expensive. This fact makes it difficult to find a contractor capable of providing the necessary equipment to handle very large operations.

When consideration is being given to the type of seed to be utilized, the prime growing season of the area should be determined. This information will provide data on the amount and intensity of rainfall, and the temperature extremes that will be encountered at various times of the year. The seed type and mixture should be varied based on the fact that some grasses are better able to withstand long, dry spells or temperature extremes, while others are not. This data will also aid in determining if some form of irrigation is needed in order to maintain the growth through periods of little or no rainfall.

VI-I. Sedimentation Control

Controlling the sedimentation resulting from erosion can also aid in the overall control of erosion and the establishment of vegetation. This is especially true in areas where runoff is channeled to a specific area. If separation of the suspended particles can be effected at this point, a "dam" is formed from the sediments. This dam slows the runoff, stabilizes the soil, and if a filter is present, purifies the water. Such a dam can be created by the erection of a "silt fence." Tests conducted in North Carolina by Dallaire (7), indicate that a filter fabric such as Mirafi 140 (manufactured by Celanese), can be placed on a fence erected between fill areas and natural streams to intercept sediments being carried by runoff. Two methods were utilized to hold the fabric during the tests. In one case, the fabric was nailed to a fence consisting of wooden poles driven into the ground with livestock wire stretched in between. The second method utilized was to place the fabric on a brush fence that was pushed up during the cleaning of the fill area. In the first case, the fence was later removed when vegetation became well enough established to prevent erosion. The brush fence was allowed to decay and became a part of the natural vegetation. In both cases, the lower end of the filter cloth was buried in the ground deep enough to prevent water from carrying the sediment under the fence. The height of the fence in both cases was from 1/4 to 1/3 the height of the fill. Results of these tests indicate that almost 100% of the sediment was removed from the runoff as it passed through the fence. In cases where the erosion is so severe that the sediment reaches the top of the fence prior to establishment of vegetation, a scoop loader can be utilized to remove the sediment in front of the fence, or a new fence can be erected on top of the sediment.

VII. CONCLUSIONS AND RECOMMENDATIONS

The recommended techniques for control of the erosion along the Divide Cut section of the Tenn-Tom Waterway are based primarily on economic considerations. No attempt has been made to change the design of the canal slopes by making them shallower, nor have any recommendations been included for additional berms or terracing. Any such recommendations would involve additional contract costs and delays in construction. It is believed that the problem can be solved utilizing existing technology and methods. In cases where different erosion control techniques are equal in effectiveness and in cost, both techniques are presented for further testing on the site itself. The most effective techniques may not have been selected due to the cost involved. In these cases, a cheaper, less effective technique should be tested under controlled conditions in order to determine if the additional expense of a more effective technique is justified.

For the purpose of discussion, erosion control along the Tenn-Tom Waterway has been divided into two major areas: the prevention of erosion along the channel banks, above elevation 422, and control of erosion in the fill or disposal areas during and after use. Below elevation 422, the channel slopes will be protected with a graded riprap underlaid with filter material (See Figure 2). The methods of controlling the erosion in these two areas are quite different due to the steepness of the slopes. Most of the disposal areas are designed in such a manner that the slopes are 10% on the channel side, tapering to 1% until the fill intersects the existing terrain. This is in contrast to the 50% and 33% slopes in the cut areas along the channel. Different techniques will also be presented for each area depending on the time of year construction is taking place. These recommendations are based primarily on the growing season required for establishment of vegetation.

VII-A. Seedbed Preparation

The control of erosion on the slopes of the canal requires that vegetation be quickly established and that the soil be protected from erosion in the interim period. This can be accomplished by utilizing a three-step, hydroseeding technique during the prime growing season (April-September), and a four-step, hydroseeding-mulch combination during October through March. The three-step procedures include liming, fertilization and hydroseeding, while the four-step procedure is the same with the addition of a wood mulch. The primary preparation for both methods consists of properly preparing the seedbed after final grade is reached. This procedure consists of insuring that all slopes are contour finished with no tracks going from top to bottom of the slope, tilling the soil to a depth of from 6 to 8 inches with disc or harrowing equipment, incorporating lime to a depth of 6 to 8 inches, and applying an appropriate amount of dry fertilizer. The dry fertilizer is also worked into the soil at a depth of 6 to 8 inches. The necessary amounts of lime and fertilizer should be determined from previously run soil tests. The fertilizer and the lime should be applied separately to preclude loss of nitrogen as ammonia. This preparation should take place as rapidly as possible and be followed immediately by hydroseeding. In the case of the highly acidic Tombigbee soil, additional lime should be applied prior to plating. Plating should consist of 24 inches of suitable material compacted in lifts of six inches until 18 inches are in place. At this point the same requirements for incorporation of fertilizer and lime should be followed for the remaining six inches. The final lift is not compacted. The final grade in all cases should be left with all wheel marks running with the contours, and perpendicular to the direction of surface water flow. Cleat marks left by track driven equipment should also be perpendicular to the direction of surface water flow.

VII-B. Seeding

Hydroseeding of the slopes should be done with a machine capable of mixing the seed, fertilizer, soil stabilizer, and mulch in one batch, and ejecting it with enough force to attain adequate coverage at the highest point being treated. The recommended seed mixture for April through September is 10 lbs./acre of Weeping Lovegrass, 30 lbs./acre of Wilmington Bahiagrass, and 20 lbs./acre of Sericea Lespedeza. For October through March the mixture should be 30 lbs./acre of Tall Fescue grass (Kentucky 31) and 15 lbs./acre of Crimson Clover. The recommended seeding rates and seeding mixtures are based on data contained in Tables 2 and 3. Weeping Lovegrass was chosen for the April through September mix due to its high probability of establishment and its ability to produce rapid cover. Bahiagrass and Sericea were also chosen on the basis of their high probability of establishment. Sericea is also a perennial legume which will supply nitrogen to the soil. Tall Fescue was chosen for the October through March mixture because of its hardness. It is a vigorous plant after its establishment, and does well in soils of low pH. Fescue also has a high potential for establishment during the fall and winter. Crimson clover is a legume which has a fair degree of probability for establishment, and is hardy in the winter. All the selected types also have a potential for some degree of establishment regardless of the time of year in which they are planted. These seeds should be combined with 1,500 lbs./acre of wood cellulose, and 40 lbs./acre of a soil stabilizer such as Tera Tack III or the equivalent. All legume seeds should be innoculated with five times the normal amount of innoculant as suggested by the manufacturer. The equivalent of 10 lbs. of fertilizer nitrogen/acre should be added to the mix to overcome any problems associated with the lack of nitrogen in the wood.

VII-C. Mulching and Mats

In addition to hydroseeding during the months of October through March, a woodchip mulch should be spread over the treated slopes at a rate of 50 cubic yards per acre. This treatment will provide additional erosion control during the winter to compensate for the lack of vegetation. Areas where this treatment is applied should be checked for erosion in the spring. Any erosion found should be repaired, and the entire area reseeded with the recommended April through September mix. No soil stabilizer or wood fiber mulch would need to be utilized in this reseeding process.

In areas where erosion persists due to the concentration of runoff, it is recommended that a jute or paper mat be utilized. These areas should be repaired and reseeded utilizing the slurry recommended for April through September. After this is accomplished, a mat should be laid over the affected area and carefully stapled down according to the specifications of the manufacturer. Consideration should be given to providing water to these areas at a later date to aid in growth if there has been insufficient rainfall. It is further recommended that this work only be carried out in prime growing season for the best results. This technique is also applicable to ditches and areas where runoff is intentionally directed. These areas should be hydroseeded according to the season, and covered with a mat immediately upon completion of final grade.

VII-D. Disposal Areas

Control of erosion in the disposal areas can be accomplished by utilizing proper hydroseeding techniques and a fabric fence, in conjunction with the already specified dikes and berms. The hydroseeding technique utilized in this area should be the same as that specified for the slopes along the canal. The specified seed mixes for each time of year should be followed along with the recommendations for liming and fertilization. The slopes in the fill areas should be prepared for seeding and receive an application of seed as soon as the fill is placed, to a height where erosion becomes a problem. In all cases, seed should be applied on previously unseeded slopes, regardless of height, when a disposal area is not being utilized for a period longer than 90 days from August through December, and 60 days from January through July. This recommendation is based upon the amount and intensity of rainfall occurring during these months. When a contractor has finished utilizing a fill area, any erosion that has occurred on previously seeded slopes should be repaired and reseeded, along with any previously unseeded areas. Disposal areas containing soil from the Tombigbee member should receive a layer of suitable plating material 24 inches deep prior to seeding. It is recommended that this final seeding only take place in the months of April through June, when the potential for rapid growth is best.

Current project specifications include requirements for berms and dikes to control runoff and sedimentation from the disposal areas. It is recommended that these berms and dikes be supplemented by a fabric fence installed in locations outside the disposal areas. The primary purpose of this fabric fence would be to intercept and filter the runoff from the disposal areas. As previously mentioned, this method was utilized in North Caolina, and found to be very effective in controlling pollution that results from soil being carried by runoff. These fences would be installed in critical areas only, such as outlets to natural streams or ponds, since the fabric is expensive and the erection time consuming. The installation should be done utilizing the natural brush and trees that have been removed from the disposal area in the manner previously described. This type of installation will enhance the erosion control, and provide a natural looking barrier that will blend into the landscape as time passes.

VII-E. Maintenance of Vegetation

Once vegetation becomes established, attention should be directed at maintaining the growth. Six months after seeding, all areas should be checked for nutrients and re-fertilized with the appropriate type and amounts of fertilizer. An annual re-fertilization, based on soil testing, should be carried out for the following three years. Soil tests should also be conducted annually to determine if additional lime is needed to reduce the acidity. Mowing should not be carried out until the grass has matured to a seed stage. It is recommended that mowing be done with a reel-type mower since this will reduce the chance of damage to the mulch.

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EROSION CONTROL ALONG THE TENNESSEE-TOMBIGBEE WATERWAY

by

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ABSTRACT

The control of soil erosion and the establishment of vegetation around construction sites requires a constant effort on the part of the contractor. These efforts often end in failure when the methods used do not suit the peculiarities of the soil, slope and climate. There are many methods available to stabilize the soil and provide the growth medium in areas where erosion control and vegetation establishment are hampered by steep slopes, soils of low productivity, low and high rainfall, and soils with little or no cohesion. If the proper method is utilized, the results are the expeditious establishment of vegetation and less soil loss to erosion. These methods, along with their relative cost and relative effectiveness, are the subject of this paper. A specific application of these methods has been made to the Divide Cut section of the Tennessee-Tombigbee Waterway Project (Tenn-Tom), being built by the Corps of Engineers in northeastern Mississippi. The soil in this area is highly prone to erosion, is toxic, and has little or no inherent fertility. Erosion control is a major problem along the waterway where the slopes are 2:1 and 3:1, and in the fill areas where the soil excavated from the waterway is being placed. Recommendations include the best method for controlling erosion during the growth period and the type of vegetation best suited for this particular project.