DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-10

EFFECTS OF MECHANICAL AGITATION ON DRYING RATE OF FINE-GRAINED DREDGED MATERIAL

by

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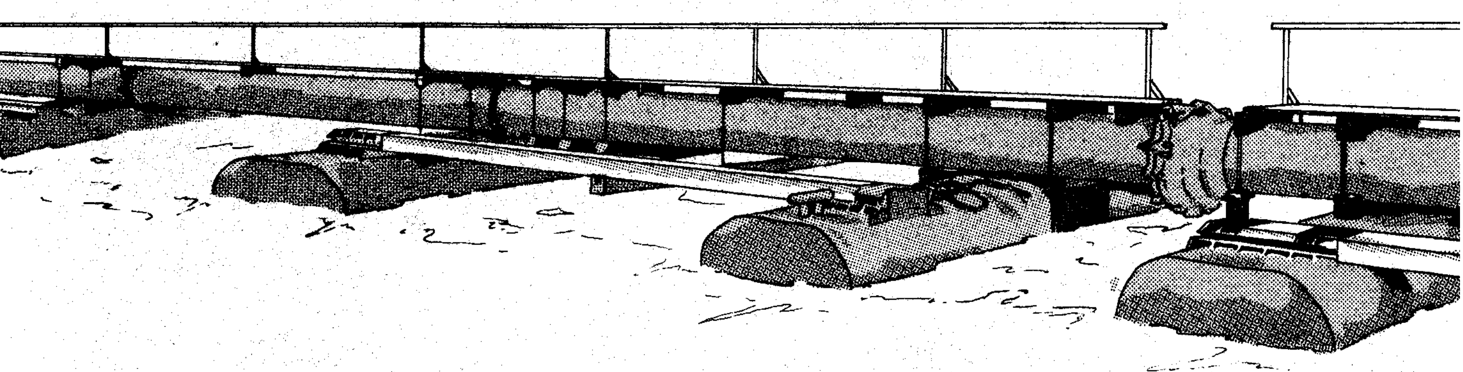

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1. The report transmitted herewith represents the results of a study of dredged material dewatering concepts evaluated as part of Task 5A (Dredged Material Densification) of the Corps of Engineers' Dredged Material Research Program (DMRP). This task, included as part of the Disposal Operations Project of the DMRP, is concerned with developing and/or testing promising techniques for dewatering or densifying (i.e., reducing the volume of) dredged material using mechanical, biological, and/or chemical techniques prior to, during, and after placement in containment areas.

2. Rapidly escalating requirements for land for the confinement of dredged material, often in the midst of urbanized areas where land values are high, have dictated that significant priority within the DMRP be given to research aimed at extending the life expectancies of existing or proposed containment facilities. While increased life expectancies can be achieved to some extent by improving site design and operation and to a greater extent by removing dredged material for use elsewhere, the attractive approach considered under Task 5A is densification of the contained dredged material. Densification will not only increase site capacity, but also will result in an area more attractive for various subsequent uses because of improved engineering properties of the material.

3. Because the areas involved are large, the feasibility of dewatering techniques is often governed by economics. For this reason, it is desired that maximum advantage be taken of natural evaporation, which is essentially free. During the early phases of the DMRP, studies were carried out and opinions were sought to determine the best way to promote evaporative dewatering. Two conflicting schools of thought were found to exist. One favored continuous agitation of the slurry to prevent surface crust formation that supposedly inhibited drying. The other postulated that the key to dewatering was to maintain good disposal area surface drainage, thus maximizing the rate of crust formation. The purpose of the studies reported herein was to evaluate the effectiveness of agitating dredged material to enhance evaporation. These studies were carried out by personnel from the Waterways Experiment Station (WES) Environmental Effects Laboratory, and Mobility and Environmental Systems Laboratory, and the Department of Agronomy and Crop Sciences, Texas A&M University.

4. The DMRP conducted a theoretical study of factors controlling the evaporation from soils slurries, a small-scale controlled-agitation experiment at WES during a period of low evaporative demand, a large-scale controlled-agitation experiment at WES during a period of high evaporative demand, and a 6-month field demonstration of periodically mixing surface crust with underlying very wet dredging material at the Upper Polecat Bay disposal area in the Mobile District. The following three general conclusions were reached:

a. Mechanical agitation of highly plastic clay slurry does not significantly alter the rate or amount of either evaporative water loss or slurry volume reduction as compared to unagitated material exposed to the same climatic conditions.

b. Maximum expected water loss rates from highly plastic clay slurries may be approximated by standard Class A Pan Evaporation under existing climatic conditions. However, the exact length of time the maximum rate will be maintained depends on soils properties, initial water content, water table location, and existing climatic conditions.

c. Periodic mixing of dried surface crust with underlying fine-grained highly plastic dredged material slightly above its liquid limit accelerates the rate of dredged material and surface subsidence. However, as a practical matter, the results achieved do not justify the efforts required in mixing.

5. Based on the results of this study, mechanical agitation on either a continuous or a periodic basis to dewater fine-grained dredged material is not recommended. Other work within Task 5A is developing guidelines for more effective methods of dewatering dredged material. In general, the most attractive method presently known appears to be removing surface water from the disposal area as soon as possible and allowing evaporation to remove water from the undisturbed material. Methods of accomplishing the removal of the surface water have been evaluated in other studies within Task 5A.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Appendixes A-C were reproduced in microfiche and are enclosed in an envelope in the back cover of this report.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of the Dredged Material Research Program (DMRP) research to determine a methodology for efficient dewatering of fine-grained dredged material slurry placed in confined disposal areas, the DMRP studied available literature and opinion concerning the best ways to promote evaporative dewatering of such material. Two conflicting schools of thought were found to exist. One favored continuous agitation of slurry to prevent desiccation crust formation, which supposedly inhibited drying, while the other postulated that the key (Continued)

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20. ABSTRACT (Continued).

to dewatering was to maintain good disposal area surface drainage and thus maximize the rate of crust formation.

In an attempt to determine the best method for promoting dredged material evaporative drying, the DMRP conducted a theoretical study of factors controlling evaporation of soil slurries, a small-scale controlled agitation experiment at the U. S. Army Engineer Waterways Experiment Station (WES) during a period of low evaporative demand, a large-scale controlled agitation experiment at WES during a period of high evaporative demand, and a 6-month field demonstration of periodically mixing surface desiccation crust and underlying very wet dredged material in Mobile, Alabama, at the Upper Polecat Bay Disposal Area of the U. S. Army Engineer District, Mobile.

Three general conclusions were reached:

a. Mechanical agitation of highly plastic clay slurry does not significantly alter the rate or amount of either evaporative water loss or slurry volume reduction as compared to unagitated material exposed to the same climatic conditions. Additional evaporation from exposed shrinkage crack surface area appears to supplement any decrease in surface evaporation rate as drying progresses.

b. Maximum expected water loss rates from highly plastic clay slurries may be approximated by standard Class A Pan Evaporation under existing climatic conditions. The exact length of time such rates will be maintained depends on soil properties, initial water content, water table location, and existing climatic conditions.

c. Periodic mixing of dried surface crust with underlying fine-grained highly plastic dredged material slightly above its liquid limit accelerates the rate of dredged material and surface subsidence. However, as a practical matter, the results achieved do not justify the effort required in mixing. Further, such periodic mixing destroys support capacity of the dredged material surface and prevents establishment of any vegetative cover.

It is recommended that Corps of Engineer Districts interested in dewatering fine-grained dredged material placed in confined disposal areas from slurry to normal soil form expend maximum effort in improving surface drainage to remove decant water and precipitation as rapidly as possible so that available evaporative forces may be used to dry the dredged material into crust. Use of mechanical agitation on either a continuous or periodic basis is not recommended.

PREFACE

This report presents the results of theoretical and experimental studies concerning the effect of continuous mechanical agitation on the evaporative drying rate of fine-grained clay slurries and dredged material. Investigations were conducted as part of the Dredged Material Research Program (DMRP). The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and is assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the Environmental Effects Laboratory (EEL).

Material presented in the report was developed under the DMRP Disposal Operations Project (DOP) Work Units 5A02 and 5A14. Various phases of the work were conducted by Dr. T. Allan Haliburton, DMRP Geotechnical Engineering Consultant, Dr. Gary N. Durham, Research Civil Engineer, Mobility and Environmental Systems Laboratory (MESL), WES, Dr. Kirk W. Brown, Associate Professor, Department of Agronomy and Crop Sciences, Texas A&M University, and Messrs. Robert E. Peters and Thomas B. Delaney, Jr., Research Civil Engineers, EEL, WES. The report was written by Dr. Haliburton, incorporating material furnished by the persons just mentioned. Technical assistance was provided by Mr. W. E. Willoughby, Research Civil Engineer, MESL, WES, and Mr. Jack Fowler, Research Civil Engineer, Soils and Pavements Laboratory, WES. The report was prepared under the general supervision of Mr. Charles C. Calhoun, Jr., DOP Manager, Dr. Roger T. Saucier, Special Assistant for Dredged Material Research, and Dr. John Harrison, Chief, EEL.

Directors of WES during this period were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

EFFECTS OF MECHANICAL AGITATION ON DRYING RATE OF FINE-GRAINED DREDGED MATERIAL

PART I: INTRODUCTION

1. In March 1973, the U. S. Army Engineer Waterways Experiment Station (WES), as directed by the Office, Chief of Engineers, U. S. Army, initiated the Dredged Material Research Program (DMRP). The DMRP is a $30-million, 5-year applied research effort to identify current problems associated with dredging and disposal of dredged material and to develop environmentally sound, technically feasible, and cost-effective alternatives for disposal of dredged material, including use of such material as a resource.

2. Task 5A of the DMRP, "Dredged Material Densification," is concerned with dewatering and densification of dredged material after placement in the confined disposal areas. Primary emphasis is given to fine-grained cohesive material produced from maintenance dredging operations. The purposes of dewatering include increasing available disposal area volume by removal of water and concentration of solids, reconverting dredged material to soil form for production uses such as borrow in raising containment area dikes and creating stable fastland at a known elevation with predictable geotechnical properties for future use and development.

3. Some investigators[1,2] have recommended continuous or periodic agitation of sedimented fine-grained dredged material, preventing surface desiccation crust formation, as a means for increasing its drying rate. By preventing crust formation, evaporative drying and resulting water content* reduction is supposedly maintained at a higher rate than would otherwise be possible. Thus, surface desiccation crust is an undesirable feature which hinders evaporative drying, and its formation should be prevented.

* As defined in this report, water content is the weight ratio of water to soil solids, expressed as a percentage.

4. Other studies[3,4] indicate that fine-grained dredged material drying is prevented by presence of a perched water table in confined disposal areas, with desiccation crust formation occurring to the base of the water table. In this view, optimum dewatering would be gained by promoting good disposal area surface drainage to rapidly remove precipitation and prevent surface ponding. Evaporative forces will then lower the internal water table and dry the material above into soil form.

5. In an attempt to determine the best procedure for promoting dredged material drying (i.e., either preventing or maximizing surface desiccation crust formation), the authors studied available literature on factors controlling evaporative drying and conducted one field and two laboratory experiments to ascertain the effects of crust prevention and nonprevention on drying rate of fine-grained dredged material.

PART II: THEORETICAL BASIS FOR EVAPORATIVE DRYING OF FINE-GRAINED DREDGED MATERIAL

6. Because of some doubt concerning the maximum evaporative drying rate possible from continuously or periodically agitating fine-grained dredged material placed in confined disposal areas, it was decided to review existing soil science literature, with a view toward developing the state of knowledge of bare cohesive soil evaporative drying behavior and postulating probable drying behavior of fine-grained dredged material. The results of this effort are presented in this Part.

Factors Governing Evaporation of Water from Bare Soils

7. Evaporative loss of water from bare soils is generally considered to occur in three stages.[5] During the first stage, when the soil is wet, water evaporates rapidly, essentially as from a free water surface, and environmental/climatic parameters control the rate of evaporation. Rate of evaporation from a free water surface under given climatic conditions is usually estimated by data obtained from a standard Class A Evaporation Pan. The amount of Class A Pan Evaporation in a given period is often referred to as the maximum potential water evaporation possible under given climatic conditions during the period, or often just called the "potential." During the second or declining stage of evaporation, the rate decreases as the supply of water brought to the soil surface falls short of the atmospheric demand, and evaporation is controlled by the capillary resupply potential of the soil. The third and final stage of drying is very much slower and is governed by absorption forces and molecular distances at the soil particle water-solid interface. For the purposes of this study, only first- and second-stage drying are of interest.

8. The first and second stages generally follow each other as wet soil dries in the field. However, as a result of the diurnal climatic pattern and the variability of climate from day to day, the process may shift back and forth between first- and second-stage drying one or more

times before final transition to second-stage drying occurs. For example, rewetting overnight may cause the environment to control water loss during the morning, while atmospheric demand may be greater than capillary resupply potential during the afternoon. Similar reversion to first-stage drying, after the second stage has begun, may also occur during periods of very low evaporative demand (i.e., on cloudy, humid days). Gardner and Hillel[6] report, however, that temporary interruption of the evaporative process has little effect on cumulative water loss. A simplified schematic of first- and second-stage drying is shown in Figure 1 for a typical cohesive soil, where potential evaporation is the maximum evaporation possible in first-stage drying.

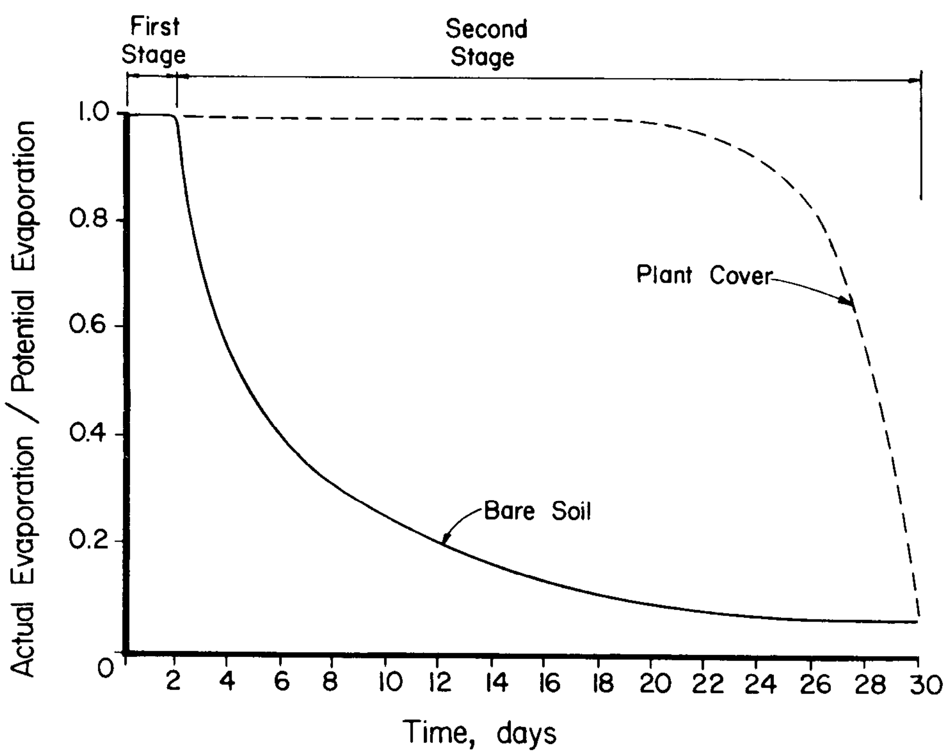


Figure 1. Time dependence of evaporation rate for bare soil and soil supporting deep-rooted vegetation

<u>First-stage drying</u>

9. During first-stage drying, the evaporation rate from a bare soil surface will depend primarily on the net supply of radiant energy, the temperature and vapor pressure of the ambient air into which the water is evaporating, and the wind speed, which acts to regulate the

rate at which vaporized water is transported from the surface. Barometric pressure will have only a very small influence on the process.

10. The net radiant energy Rn available at a surface for evaporating water is the algebraic sum of the incoming and outgoing short- and long-wave radiation and may be expressed mathematically as:

$$Rn = Rs - \alpha Rs + Li - Lo \qquad (1)$$

where

Rs = incoming short-wave or solar radiation

α = percent of the short-wave radiation reflected from the surface (called albedo)

Li = incoming long-wave radiation

Lo = outgoing or emitted long-wave radiation (this term is a function of the fourth power of the surface temperature)

11. The net radiant energy available at the soil surface may be partitioned into several components, expressed as:

$$Rn = LE + H + S \qquad (2)$$

where

L = latent heat of vaporization

E = evaporation rate

LE = latent heat flux from the surface into the atmosphere

H = sensible heat flux into the atmosphere (or the energy that heats the air)

S = soil heat flux or storage component

12. For water vapor to be transported from the surface to the atmosphere, a vapor pressure gradient must be present. The evaporative flux may be expressed as:

$$LE = C_1 f(u)(e_s - e_a) \qquad (3)$$

where

C_1 = a constant

$f(u)$ = wind speed function

e_s = saturation vapor pressure of the surface, which in turn, depends on the temperature

e_a = atmospheric vapor pressure.

Similarly, sensible heat transfer may be expressed as:

$$H = C_2 f(u)(T_s - T_a) \qquad (4)$$

where

C_2 = a constant

T_s = surface temperature

T_a = air temperature

Equations 3 and 4 show explicitly how wind speed, vapor pressure, and temperature influence the energy available to evaporate water from the surface. These parameters are available from weather bureau records, as are estimates of the radiant energy. Equations 2, 3, and 4 may be solved simultaneously to calculate the evaporation rate from wet soil surfaces. However, it is highly probable that simple correlations with any of the regulating meteorological parameters will be poor at best.

13. Several empirical methods have been developed to calculate the potential evaporation rate expected to equal bare soil evaporation during the first stage of drying (Penman's approach and the Blaney-Criddle method). These methods have been reviewed by Rosenburg, Hart, and Brown[7] and will not be discussed here.

14. The signs of each of the radiant energy fluxes in Equation 2 may be either positive or negative. For example, during the day the net amount of energy received will be positive at the soil surface, indicating that the sum of the components on the right of the equation must also be positive. At night, when the short-wave radiant energy fluxes are zero, the surface may be cooler than the atmosphere, and the net radiant flux may be away from the surface. The flux at such times, however, would be negligible. The latent heat flux will be away from the

surface, or positive, when water is evaporating. During periods of condensation, it will have the opposite sign. Sensible heat flux may be either positive or negative, depending on the relative temperatures of air and soil. If warmer air is being convected over the surface from a dry adjacent area, energy may be transferred to the surface from the air and thus may supplement the radiant energy supply. This condition, known as advection, may occasionally lead to evaporative fluxes that exceed the radiant energy input by 20 percent or, in the extreme, 50 percent. During the day, soil heat flux is normally into the surface as the soil is heated. During the night, the stored soil heat may be dissipated to evaporate water or to heat the air above the soil. The magnitude of the parameters of Equation 2 throughout a typical clear day over a wet soil surface, expressed in equivalent depths of water, may be as follows: $Rn = 1$ cm, $LE = 0.8$ cm, $H = 0.19$ cm, and $S = 0.01$ cm during the first stage drying. With advection, H may equal -0.3 cm, in which case LE may be as great as 1.29 cm of water lost per day. During cloudy days, the magnitude of all equation components will be reduced. Under no circumstances can more water be evaporated than there is energy available. Thus, the amount of water that can be evaporated is bounded within relatively narrow limits by available radiation and also by advective heat transfer, which, for most cases in coastal regions, would be small or nonexistent.

15. During the second stage of drying, less water is available at the surface such that more of the energy is dissipated as sensible heat and in soil heat storage. For a dry surface, the balance (Equation 2) on a clear day may be $Rn = 1$ cm, $LE = 0.25$ cm, $H = 0.70$ cm, and $S = 0.05$ cm.

16. The length of time required to complete first-stage drying is dependent on the rate at which water is removed, the size of the reserve from which the water is being supplied, and the ability of the soil to transport water to the surface. With hot, dry, clear weather, first-stage drying in a soil may last 1 day or less, while with mild or cloudy weather, 5 or more days may be required for the first stage. More total water may be lost during first-stage drying under mild cloudy

conditions during this 5-day or longer period compared to the amount lost during a hotter, drier first-stage drying period of only a day or so. This condition will occur because the amount of energy reaching the evaporative surface exceeds the requirement for evaporation, and water will not move to the surface fast enough to keep a dry layer from forming. If the soil is initially very wet, a longer period will be required to reach the second stage.

Influence of water table location

17. The presence of a water table below the surface may provide enough water to keep the soil wet enough so the evaporation process never enters the second stage. This possibility was investigated by Gardner and Firemen[8] and by Ripple, Rubin, and Hylckama.[9] Experimental data of Gardner and Firemen[8] are shown in Figure 2. They reported that, if the unsaturated permeability is great enough for the material being considered (as it is for natural soils) and water tables are within 600 to 900 mm of the surface, evaporation will continue at rates determined by the climate/environment, even under conditions of the highest expected evaporative demands. With lower climatic evaporative demands, water will continue to be lost at the maximum possible rate even when the water table is deeper.

18. If there is no water table or it is far enough below the surface to prevent rapid resupply, the surface soil will eventually dry to moisture contents at which the conductivity of water times the suction gradient is no longer sufficient to resupply water to the surface. At that point, second-stage drying will begin.

Second-stage drying

19. Second-stage drying is characterized by a rapid drop in the rate of water loss. In this stage, the aboveground environmental/climatic parameters are no longer as important. Instead, the intrinsic soil factors which regulate the flow of moisture to the surface determine the evaporative loss. The flow of water to the surface can be characterized by Darcy's law as:

$$Q = -K_{(\psi)} \frac{d\psi}{dz} \tag{5}$$

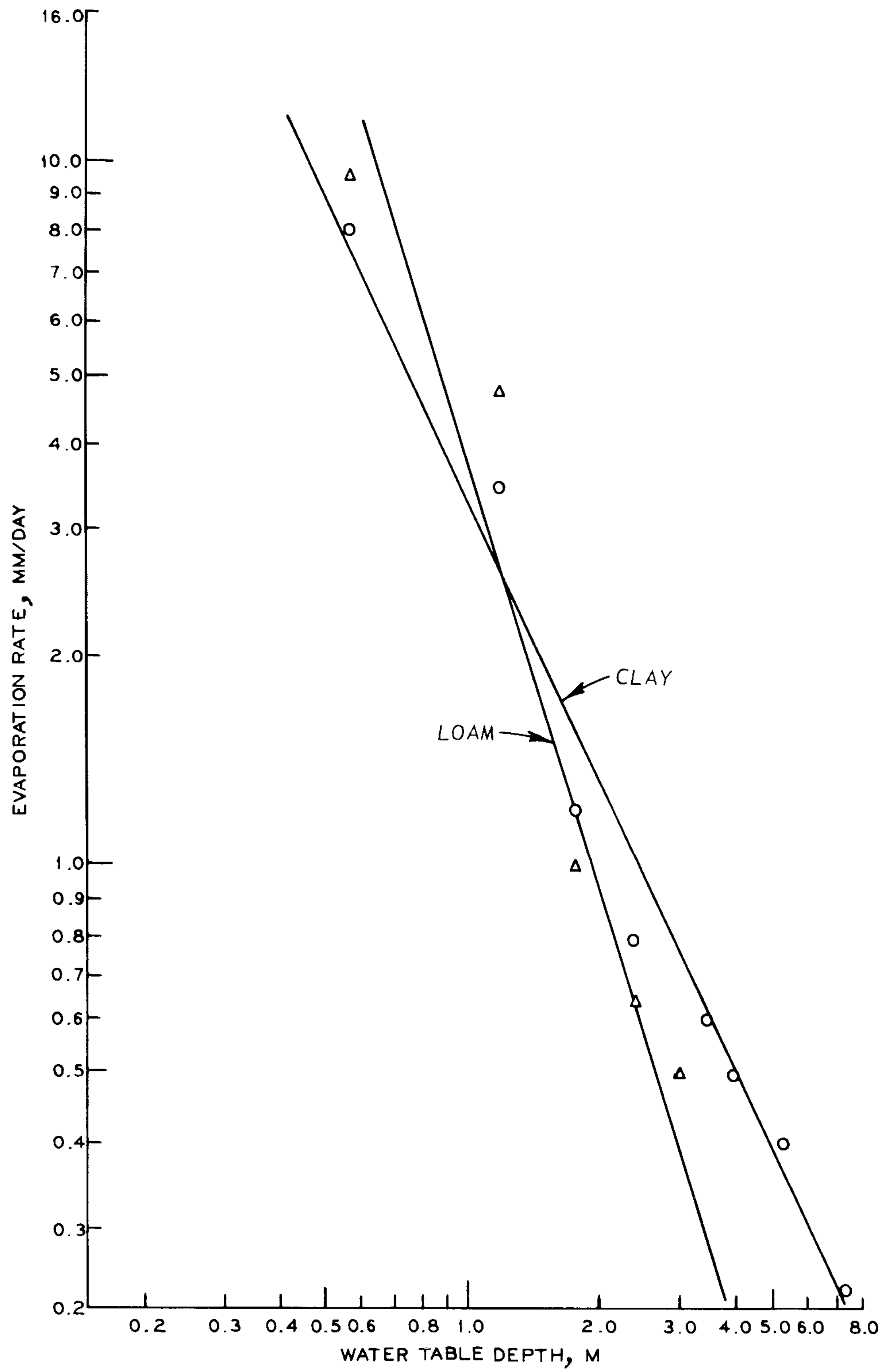


Figure 2. Evaporation rate that can be sustained with a water table at different depths (after Gardner and Firemen[8])

where

Q = flux (flow) of water

$K_{(\psi)}$ = permeability or unsaturated conductivity, which is a function of the soil moisture suction ψ

z = depth

Ultimately, for water to evaporate from soil, it must be transferred to, or at least very near, the soil surface. As the soil dries, the permeability and the suction gradient very near the surface will dominate the evaporative process. Covey and Bloodworth[10] noted that the suction near the soil surface and thus the suction gradient will be influenced by the evaporative demand of the environment. Unsaturated soil permeability is an intrinsic soil parameter which, in turn, depends on the suction. Thus, flow of water will depend on both climatic evaporative demand and soil properties. The role of climatic/environmental parameters during second-stage drying is, however, much reduced and often, for practical purposes, permeability determines rate of evaporative loss.

20. Suction gradients which cause water to move in soil are the net result of gravitational forces, matrix suction, osmotic suction, and, to a lesser extent, pressure differences. Temperature gradients can also be important in causing water movement. Water will move from regions of warm temperature to regions of cooler temperature, both in the liquid and vapor phases. Detailed discussions of these processes are available in a variety of texts including Rose[11] and Baver, Gardner, and Gardner.[12] Philip and DeVries[13] studied the effects of temperature and the influence of thermal regimes on water flow. Thermal effects contributed to water flow in soils of medium water content but had little effect on water movement in very wet soils.

Effect of drying shrinkage cracks

21. Large acreages of agricultural soils contain significant fractions of shrinking-swelling smectite-type clays. These soils develop shrinkage cracks as they dry. In the field, these may be 100 mm or more wide and reach depths of 1 to 1.5 m, depending on the soil. Loss of water from cracks in shrinking-swelling soils has been studied by Ritchie and Adams,[14] who investigated a drying cohesive soil enclosed in a lysimeter.

Although water losses were low, 81 percent of the loss occurred through shrinkage cracks.

Effect of drying
on soil volume change

22. The change of volume with decreasing water content for undisturbed peds of two smectitic field soils is shown in Figure 3. The

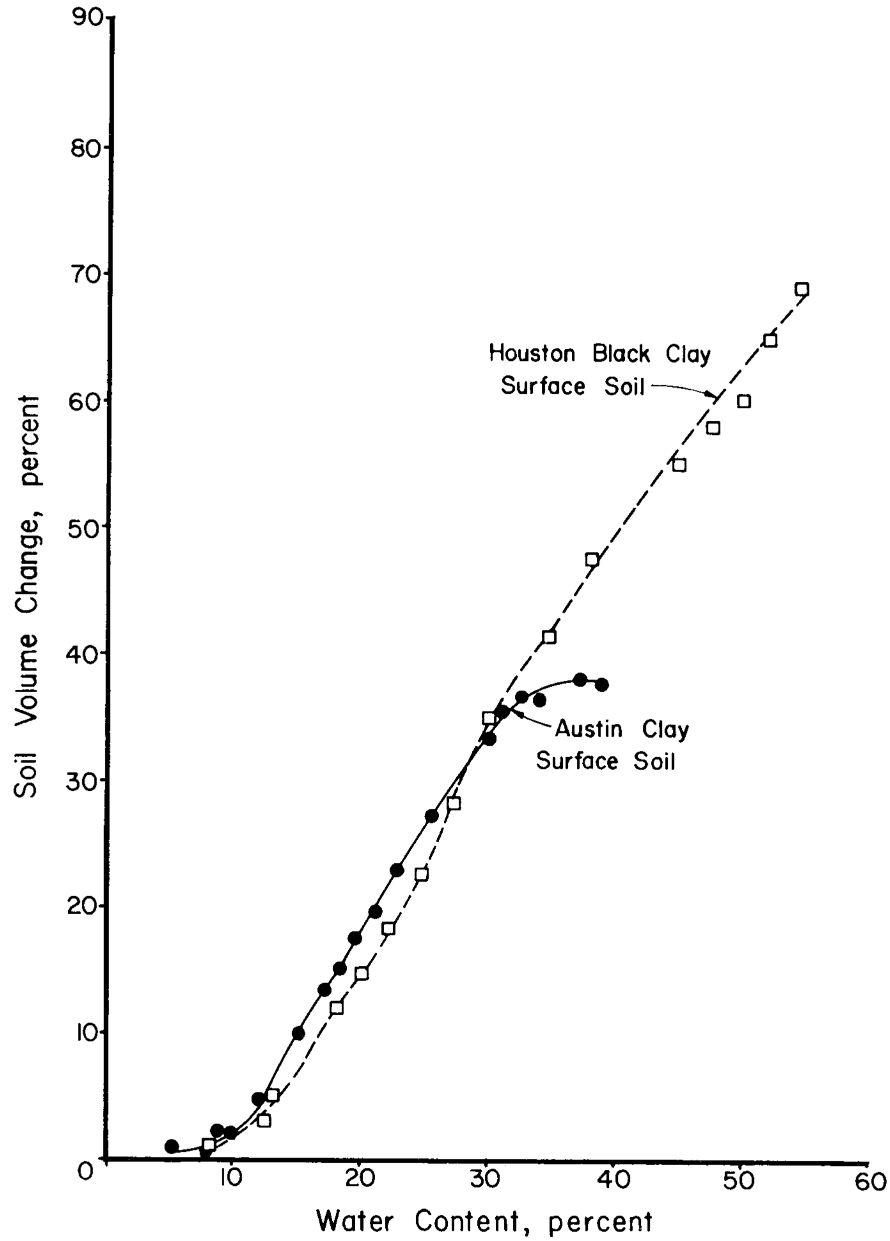


Figure 3. Soil volume change as a function of water content for two shrinking-swelling soils (after Johnston and Hill[15])

first increments of water removed from a saturated soil come from the large pores between the aggregates. Very little volume change results from such removal. As the water content decreased from 38 to 32 percent in the Austin clay shown in Figure 3, there was very little volume change. The Houston Black Clay shown in Figure 3 may not have started at complete saturation or may have lacked an appreciable noncapillary pore volume. Further reduction in volume for both soils was then nearly linear over a wide range of water contents. In the intermediate range, water was being removed from between the particles and the volume change was typically proportional to and nearly equal to the volume of water lost. At water contents below 12 percent, the rate of volume loss decreased below the rate of water loss. At lower water contents, repulsive forces between soil particles limit further volume decrease. Field soils containing clays with less surface area are expected to exhibit less volume change upon drying, and would fall below the curves shown in Figure 3. Field soils containing very little clay exhibit little or no change in volume as moisture is removed.

Influence on soil cultivation and mixing on evaporation

23. Cultivation of the thin surface layer is a practice commonly suggested to reduce evaporative losses. These techniques have been referred to as surface mulching, dust mulching, etc. By breaking up the surface, capillaries which conduct water are disrupted and cannot transfer water from the wet soil below. Willis and Bond[16] reported that tillage 1 day after evaporation began reduced the cumulative evaporation by 50 percent during the following 22 days when compared to an untilled control area.

24. The influence of thin surface crusts on evaporation rate has been investigated by several other researchers also. Bresler and Kemper[17] reported that rainfall-induced crusts reduce surface evaporation, perhaps as a result of capillary disruption when the crust shrank and broke away from the underlying soil. In most soils used for agricultural purposes, this retardation is desirable as, in most cases, the objective is to retard water loss. When such soils are excessively wet,

the only effective means of drying has been the use of tile drains. Surface manipulation, including mixing, is not usually practiced, both because of the lack of equipment traction in wet fields and the resulting destruction of soil capillary structure when wet soils are tilled.

Influence of vegetation on evaporative drying

25. Any consideration of evaporative loss of water from soil without mention of vegetation would not be complete, as a vigorous vegetative cover will shade the soil, thereby greatly reducing direct evaporation from a wet soil surface. Consequently, water will evaporate from the soil surface much slower during first-stage drying, which will thus last longer. In additon, the decline during second-stage drying will be much slower. With a thick plant canopy, 10 percent or less of the available radiant energy will reach the soil, to be partitioned as shown in Equation 2.

26. Decreased surface evaporation will, however, be offset by plant transpiration; both evaporation and transpiration will total the atmospheric evaporation potential or climatic evaporation demand so long as ample water is available. The root systems of vigorous vegetation will thoroughly exploit the top metre or more of the soil, extracting moisture throughout and supplying it to the leaves of transpiration. Root moisture extraction proceeds from the surface downward, and the zone from which moisture is extracted expands as roots penetrate deeper into the soil profile. Roots are very effective at extracting moisture from soil and may be 100 or 1000 times better transmitters than the soil itself. As a result, water can be supplied to meet the maximum climatic evaporative demand for a period as long as a month from a uniformly wet field soil. Only after the soil has dried to a considerable depth will the available water supply fall below the climatic demand. At this time, the plants will wilt and eventually die if no additional water is supplied. The contrast between evaporation from a bare soil and a vegetated soil (Figure 1) is striking. Water content profiles at the time evaporation becomes negligible from a bare soil and a vegetated soil are

shown in Figure 4. The effectiveness of vegetation in extracting water, especially at greater depths, is evident.

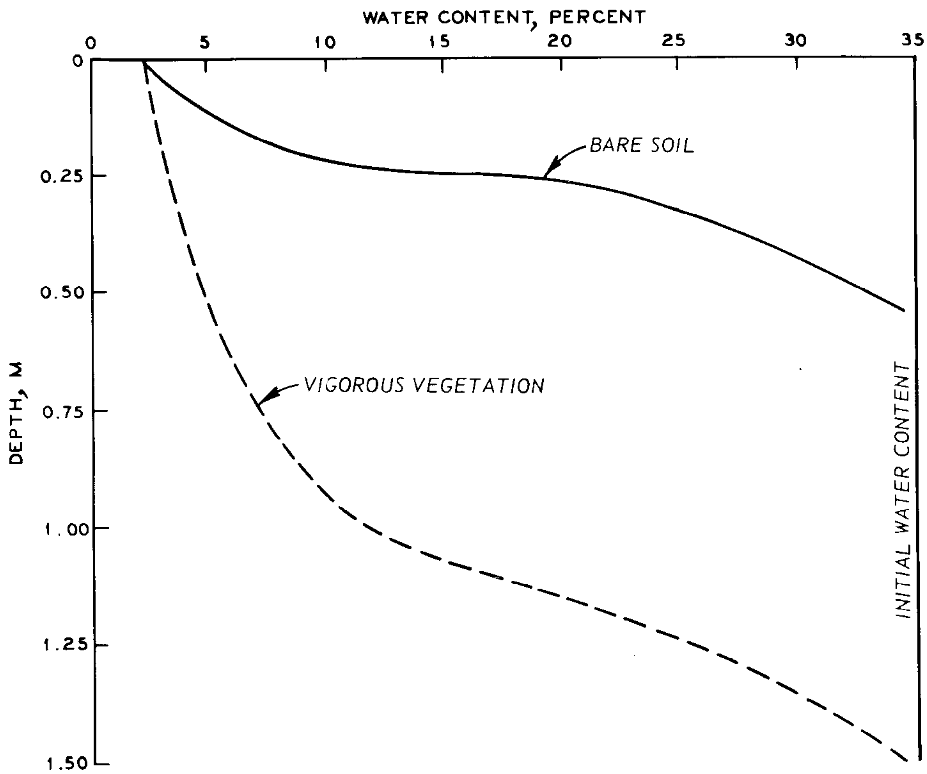


Figure 4. Water content profiles for two initially wet soils of uniform water content, one bare and one supporting vigorous vegetation, at the time evaporative losses from each become negligible

Evaporation of Water from Fine-Grained Dredged Material

27. After excess water is decanted from fine-grained dredged material, it may retain much more water than found in saturated soils. The natural water content may be 150 to 200 percent, or even greater at the surface, compared to saturated water contents of 35 to 45 percent from normal field soils. The dry unit weight of the initial slurry will be one third to one fourth that of typical soils. Even if dredged material permeability is rather low, there is so much water near the surface that first-stage drying of dredged material may be expected to last much longer than for a normal soil. As the water content is initially high,

the volume of fine-grained dredged material will shrink upon drying, irrespective of the type or amount of clay minerals present. Materials containing smectitic clays will shrink more than those with other types of clay minerals. As dredged material shrinks, cracks form which expose new wet surfaces from which water can evaporate. As discussed previously, evaporation from cracks is expected to proceed at approximately the environmental/climatic demand rate. As the material shrinks, the cross-sectional area of the cracks may increase the total evaporative surface area up to 30 percent or more. Evaporation during second-stage drying should thus proceed at rates much greater than from bare uncracked soil, simply because area exposed as cracks may continue to evaporate at high rates, even while evaporation from the drying material surface diminishes slowly.

28. Initially, the dry unit weight of dredged material slurries will increase with depth. As moisture evaporates, however, material near the surface will shrink, and the dry unit weight will be greater near the surface than in underlying wet material. As the material dries, soil particles will become closer together, until repulsive forces retard further shrinkage. Once the material has shrunk, a semistable matrix will be formed by desiccation consolidation, which should resist reswelling upon rewetting. This behavior differs from that of shrinking-swelling field soils, which exhibit very little hysteretic volume change. If precipitation falls during the first-stage drying of dredged material, evaporation will continue at the environmental/climatic demand rate. During second-stage drying, the evaporation rate should increase temporarily to equal the environmental/climatic demand, until all soil-absorbed water is evaporated. Rate of water loss should then decrease as second-stage drying behavior (capillary resupply) again controls.

Expected Influence of Continuous Dredged Material Agitation on Evaporative Drying Rate

29. Under no condition can it be expected that any treatment, short of adding large amounts of energy, would result in the evaporative

loss of water from fine-grained dredged material at a greater rate than the atmosphere would demand and can accept. Thus, there is an upper limit on evaporative loss which no amount of continuous agitation or periodic mixing can overcome. Continuous agitation should have no influence on rate of evaporative water loss during first-stage drying, as meteorological functions regulate the drying rate during this stage. Continuous agitation may, however, prolong the length of first-stage drying for a few days by exposing wet material at the surface. The formation of cracks will be retarded, however, and once the surface dries and second-stage drying is initiated, the evaporation rate will decrease rapidly to values below that of similar unagitated material. Furthermore, if agitation is shallow, disruption of capillaries which conduct water to the surface may result in the formation of a thin, very dry layer, acting as a barrier to further water loss. Deeper agitation during second-stage drying will require a large input of energy to raise the evaporation rate above that of similar unagitated material.

Expected Influence of Periodic Dredged Material Crust Mixing on Evaporative Drying Rate

30. As with continuous agitation, periodic mixing of desiccated surface crust with underlying wet dredged material during first-stage drying should have little influence on evaporation rate. If properly timed, mixing just at the end of first-stage drying may prolong water loss at the environmental/climatic demand rate for a few days.

31. Dredged material which is not rewetted by a water table near the surface should continue to evaporate water at or very near environmental/climatic demand rates until the desiccation cracks have penetrated to the bottom of the dredged material mass. Only then does second-stage drying appear to begin.[4] Thus, only during second-stage drying is it probable that mixing may be temporarily effective. The evaporation rate during this stage will decrease rapidly from the environmental/climatic evaporation potential, indicating the material has lost water at all depths. Mixing will expose new surfaces which are wetter than those found on the unmixed surface. However, the increased

evaporation will be only temporary. Within a few days after the new surface is turned up, rates of water loss will again decrease as second-stage drying takes over. But now, since capillaries have been disrupted and are no longer continuous, the evaporation rate is likely to be lower than it was before manipulation. Furthermore, it is possible that in the field the disrupted crust may present an open porous surface which may absorb considerably more rainwater than an undisturbed crust. Potential absorption of water would also be enhanced by mixing since the cracks which served as natural drainage channels would be blocked as a result of the mixing and, thus, much of the rainwater would be retained on the surface until it is absorbed or it evaporates. Mixing may thus actually slow the effective evaporative drying rate of fine-grained dredged material.

Summary

32. From the review of existing literature and state-of-the-art summary concerning observed drying behavior of agricultural soils and expected drying behavior of fine-grained dredged material, it would appear that:

- a. The maximum expected evaporation rate for fine-grained dredged material will be controlled by environmental/climatic demand, with an upper bound approximated by evaporation rate from a Standard Class A Evaporation Pan.
- b. Because of initially high water content, large shrinkage potential with resulting large exposed shrinkage crack evaporative surface area, and close proximity of the internal water table to the surface, first-stage (environmental/climatic demand) evaporative drying rates will occur in fine-grained dredged material for extended periods, as compared to conventional fine-grained soils.
- c. Dredged material agitation, either continuous or periodic, will have negligible effects on first-stage drying, and in some instances may inhibit second-stage evaporative drying, with a resulting decrease in the effective long-term evaporative rate.

PART III: SMALL-SCALE AGITATION EXPERIMENT

33. The experiment was designed to investigate the effects of mechanical agitation on drying rate when no drainage could occur from the bottom of a cohesive soil slurry.

Material, Equipment, and Test Procedures

34. Evaporation from two agitated and two unagitated treatments of cohesive soil slurry was determined, with two replicates of each treatment, as follows:

- a. Pans filled with tap water and left unagitated.
- b. Pans filled with soil slurry and left unagitated.
- c. Pans filled with tap water and mechanically agitated.
- d. Pans filled with soil slurry and mechanically agitated.

The soil, equipment, and test procedures used in the investigation are described in the following paragraphs.

Cohesive soil

35. The slurry was prepared from alluvial lake bed deposits of cohesive soil from Lake Centennial, Vicksburg, Mississippi. The soil had 98 percent of particles passing the U. S. No. 200 sieve, 62 percent finer than 5 μ, and 38 percent finer than the 1-μ size. Its liquid limit (LL) was 87 and its plastic limit (PL) was 29, with a specific gravity of solids of 2.72. The soil was classified CH by the Unified Soil Classification System (USCS).

Equipment

36. Each of the eight pans (254 mm high and 609 mm in diameter) was cut from the bottom of a 209-ℓ (55 gal) oil drum. The pans were steam cleaned and painted, and the outside walls and bottoms were wrapped with fiberglass insulation and covered with aluminum foil to reduce convective heat transfer to the soil slurry. A typical pan is shown in Figure 5.

37. A steel sleeve (25 mm in diameter by 215 mm long) containing a steel shaft (12 mm in diameter by 342 mm long) with a rake assembly

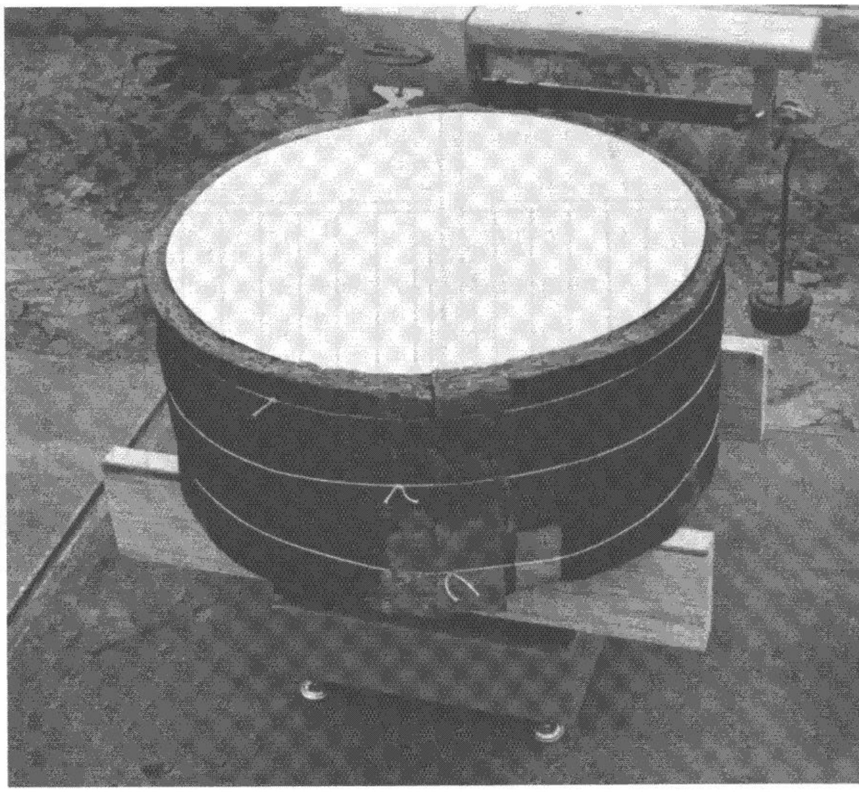


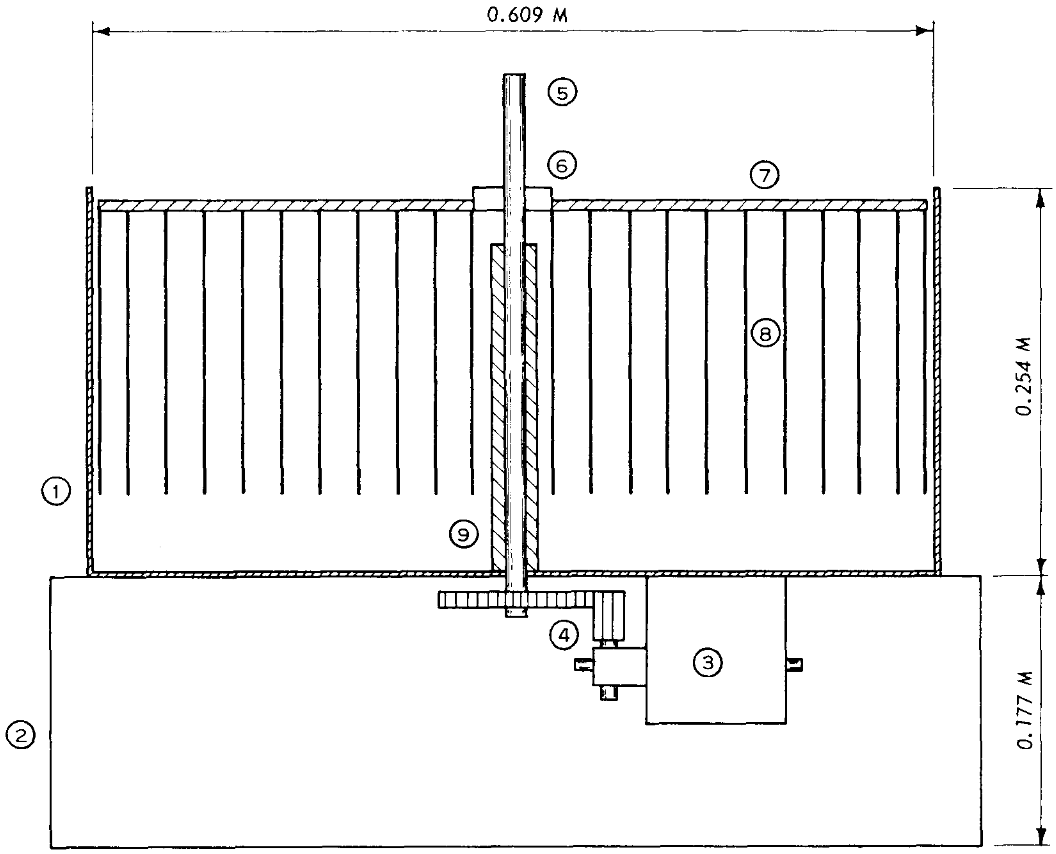
Figure 5. Evaporation test pan prior to filling

was attached in the center of each of four agitation pans, as shown in Figure 6. The rake assembly contained three rakes 120 deg* apart. Each arm of the rake assembly had 3-mm brass rod prongs, spaced 6 mm edge-to-edge. The prongs were offset on adjacent arms to ensure complete coverage during agitation. The rake assembly was driven by a gearhead motor and spur coupler such that one revolution of the assembly took 6.5 sec.

38. The rake assembly was modified after 3 days of operation. As the soil slurry dried, resistance to agitation increased, and the upper soil slurry mass sheared at the base of the rake assembly and rotated with the rakes. Every other prong was removed on each rake assembly (including those used in the water-only treatments), and agitation continued.

39. Each pan and frame assembly to be filled with soil slurry was

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 8.



LEGEND

1. BOTTOM SECTION OF 209-ℓ DRUM
2. SUPPORT FRAME
3. GEARHEAD MOTOR
4. SPUR COUPLER ASSEMBLY
5. CENTRAL SHAFT
6. ADJUSTABLE COLLAR
7. DRAG ARM
8. PRONGS OF RAKE ASSEMBLY (3 RAKES 120 DEG APART)
9. CENTRAL SLEEVE

Figure 6. Schematic of evaporation test pan agitation device

set on a small platform scale; each pan and frame assembly to be filled with water was set on concrete blocks the same height as the scales. The top of each pan was 0.609 m above the ground.

40. A totalizing anemometer and a hygrothermograph were mounted near the pan assemblies, 1.06 and 1.3 m above the ground surface, respectively.

Test procedures

41. A 3.6- by 2.4-m outdoor area was prepared by placing landing mat sections on the soil to provide a level surface. The pan and frame assemblies described previously were placed on the mats in two rows of four pans each, as shown in Figures 7 and 8. The pans in each row were 0.304 m apart, and the rows were 0.609 m apart. Meteorological instruments were installed at the northwest corner of the test area.

42. The soil slurry was prepared by mixing water with cohesive soil to a consistency that approximated sedimented dredged material (water content approximately 1.4 × LL). Pans were then filled with water or soil slurry to a depth of 178 mm. The rake prongs were placed to a depth of 76.2 mm (3 in.) in the tested materials, the depth necessary for effective agitation drying as reported by Dames & Moore.[1]

43. Agitation was not begun until 8 days after filling the pans; this time was required for termination of upward seepage of water from the soil slurry, which was decanted as it accumulated. Agitation began on 19 November 1974. The agitation rake assemblies were electrically activated to make one revolution (coverage) each hour, beginning at 0800 hr and ending at 1500 hr each working day. Pans were covered at the end of each working day and during inclement weather to prevent rainfall recharge. Initially, measurements were made at 0800 and 1500 hr each working day. Examination of the 0800-hr data indicated minimal evaporative losses during periods of cover, thus the 0800 hr measurements were terminated and measurements were made only at 1500 hr each working day, until the tests were terminated on 10 December 1974.

44. Water losses from the soil slurry treatments were determined by direct weighing. A hook gage was used to measure changes in surface elevation of the water treatments; pan geometry and the change in surface elevation were then used to calculate volume of water lost. After 3 days of operation, water was added to the water treatments to bring the water surface up to the initial test level. Similar additions were made on 4 December 1974 and 10 December 1974 to minimize the possibility of differences in evaporation rate from variation in lip height of the pans above the water surface.

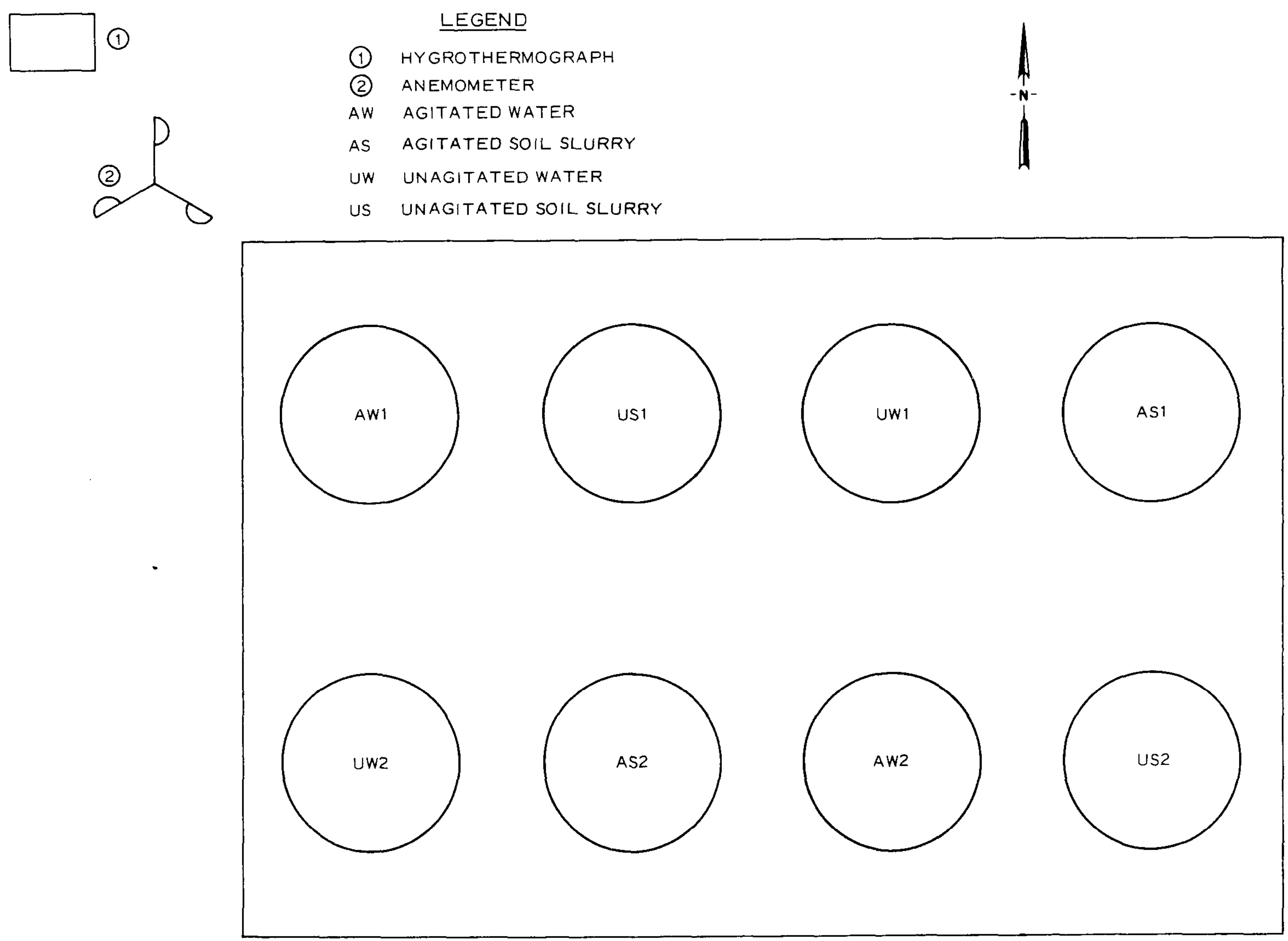


Figure 7. Relative positioning of evaporation test pans and meteorological equipment

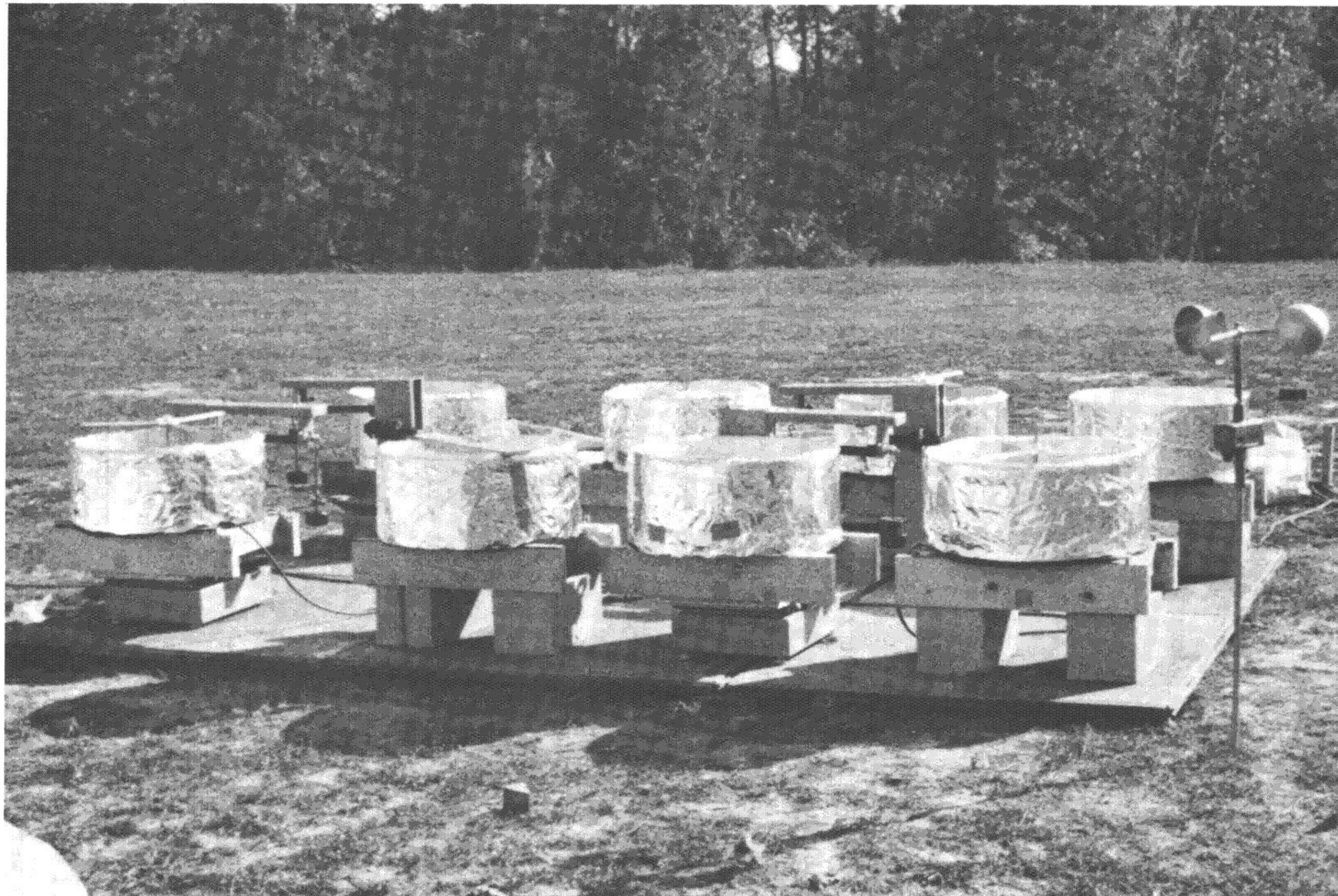


Figure 8. Evaporation test pans in place

45. Shrinkage and settlement of the soil slurry surface in each pan was measured daily at four different locations from a fixed elevation reference point.

46. Wind speed, relative humidity, and ambient temperature were recorded. Surface temperatures of the soil slurry and water treatments were measured with a thermometer.

Test Results and Discussion

47. Results are presented for (a) water loss and soil slurry crust formation, (b) settlement and shrinkage of the soil slurry, and (c) observed climatic conditions.

Water loss and soil slurry crust formation

48. Half the test treatments were agitated once per hour for a total of 145 times over a 21-day period. Average cumulative water losses are tabulated in Table 1 and shown in Figure 9. An analysis of variance indicated no significant differences at the 0.1 level in the total amount of water evaporated from agitated (6351.2 g) as compared with unagitated soil slurry treatments (6322.9 g). Water content was reduced from initial values of 119.3 and 126.8 percent to 89.0 and 95.7 percent in unagitated and agitated soil slurry treatments, respectively, representing decreases of 25.4 and 24.5 percent. Temperature data recorded in Table 2 indicate generally greater surface temperatures in the unagitated treatments but only 1°C greater for the water and 4°C for the soil slurry.

49. Examination of Figures 10 and 11 shows that a surface crust formed on the unagitated treatments while the surface of the agitated treatments was never completely free of standing water. The crust formed initially on 22 November 1974. Since both evaporation rate and total evaporation from the two treatments were not significantly different, the crust did not inhibit evaporation during the study.

50. WES data indicated a greater total loss from the unagitated pans of water than from those that were agitated; average evaporative losses were 6747.2 and 6238.6 g, respectively, from unagitated and

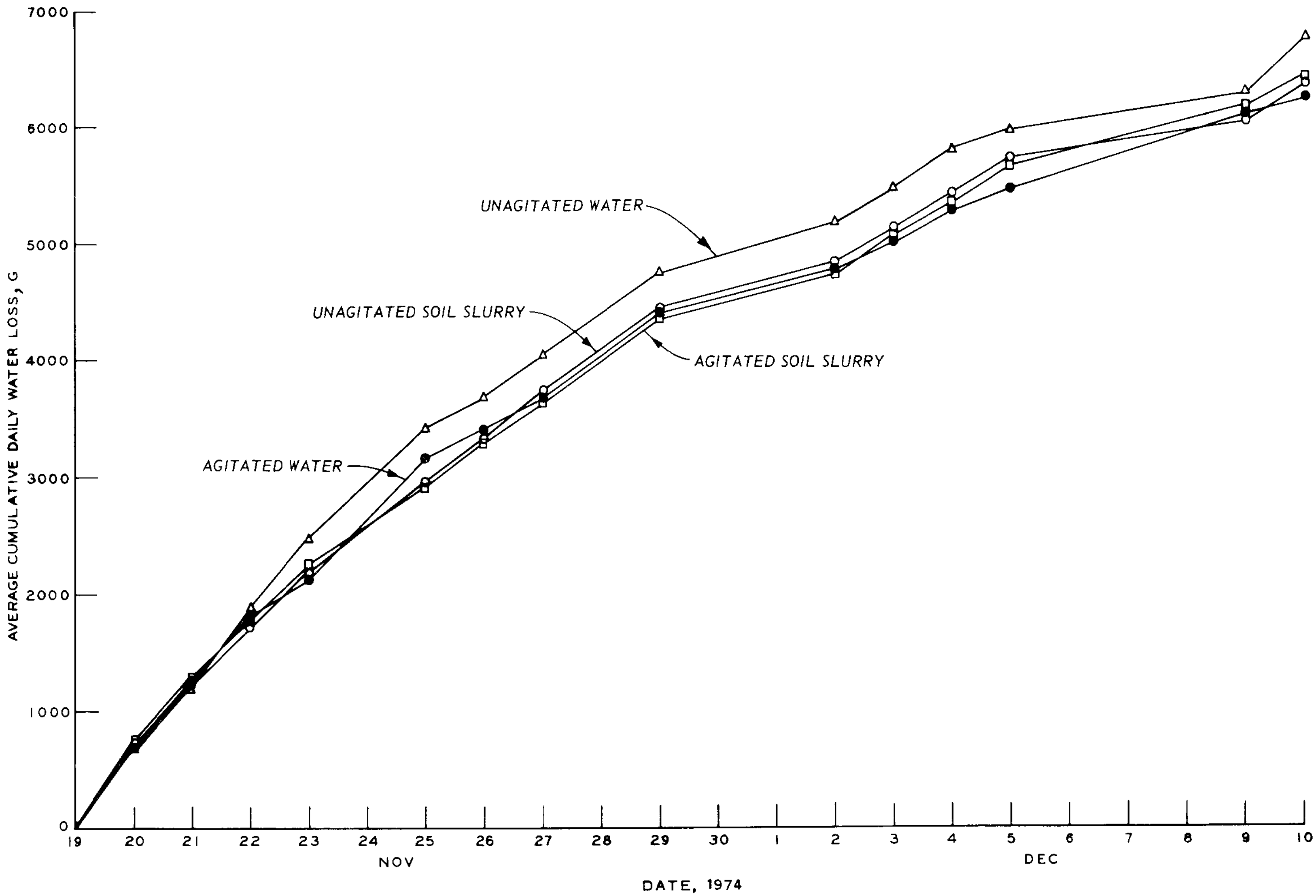


Figure 9. Average cumulative daily water loss versus time for agitated and unagitated treatments

Figure 10. Final condition of unagitated soil slurry

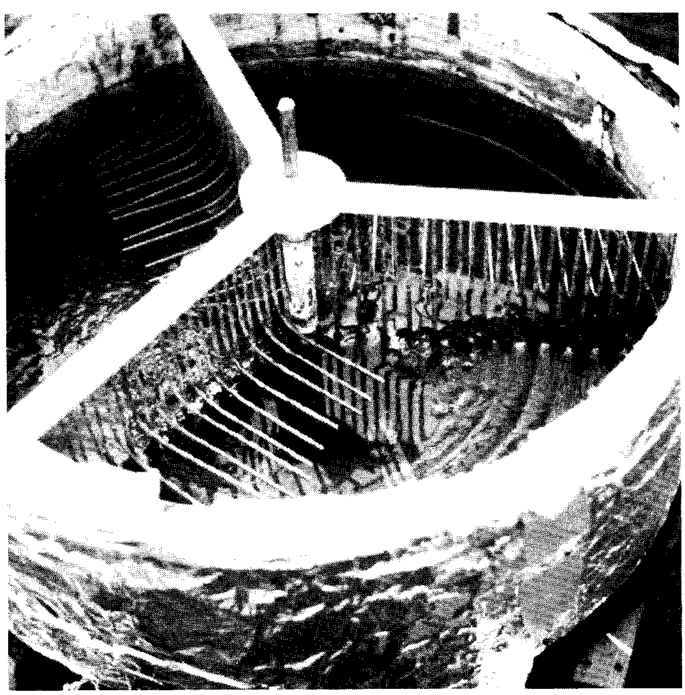


Figure 11. Final condition of agitated soil slurry

agitated treatments (calculated from Table 1). Soil science practice accepts Class A Pan Evaporation as being a reasonable indicator of the maximum evaporative potential available from a given set of climatic conditions. The unagitated water treatments most closely approximated Class A pan conditions, probably accounting for the greatest rate of water loss, as shown in Figure 9. However, differences in water loss between the two types of treatment were not statistically significant at the 0.1 confidence level. In fact, none of the differences in evaporative loss among any treatments were statistically significant at the 0.1 confidence level.

Settlement and shrinkage of soil slurry

51. The soil slurry surfaces settled an average of 26.4 and 22.5 mm during the test period, representing a 20.5 and 17.0 percent volume reduction for the unagitated and agitated soil slurry, respectively. These values do not include the reduction in surface height from water decantation prior to 19 November 1974. An analysis of variance indicated no significant difference between treatments at the 0.1 level. On 25 November 1974, the unagitated soil slurry had shrunk enough to pull away from the sides of the pans. At the conclusion of the study, the distance between the soil mass and the pan walls was approximately 13 mm.

Climatic conditions

52. Daily measurements of cumulative wind velocity (per 24-hr period), average relative humidity, and average ambient air temperature are shown in Table 3.

Summary

53. The results of the WES study indicated that no significant increase in evaporation (and thus drying) rate was produced by agitation of the upper 76.2 mm of a highly plastic clay soil slurry, compared with evaporation from similar but unagitated material. Rates of water loss approximated but did not exceed evaporation rates from a free water surface. Surface crust formation did not inhibit evaporation rate of the unagitated material.

54. While the small-scale results agree with accepted theory, several factors inhibit use of the data as definitive indicators of behavior. The small size of the pans, short period of data collection, and conduct of the experiment during a period of low ambient temperature and solar radiation do not contradict possible arguments that, if a greater thickness of dredged material were agitated under more favorable climatic conditions and a thicker crust were allowed to form in the unagitated sections, marked benefits might result from agitation. For this reason, a larger scale agitation study was designed, to be conducted during the summer of 1975. This study is described in Part IV.

PART IV: LARGE-SCALE AGITATION EXPERIMENT

55. Results of the small-scale agitation experiment resulted in the decision to conduct a larger scale and longer duration controlled agitation experiment during the summer months when a higher evaporative potential was available than for the small-scale experiment.

Test Equipment, Material, and Procedures

Test equipment

56. The bin selected to contain the soil slurry was modified from those used in the WES mobility soil research studies. Standard WES soil bins are constructed of steel plate with a cross-sectional shape and dimensions as shown in Figure 12: 8.23 m long and fitted with removable

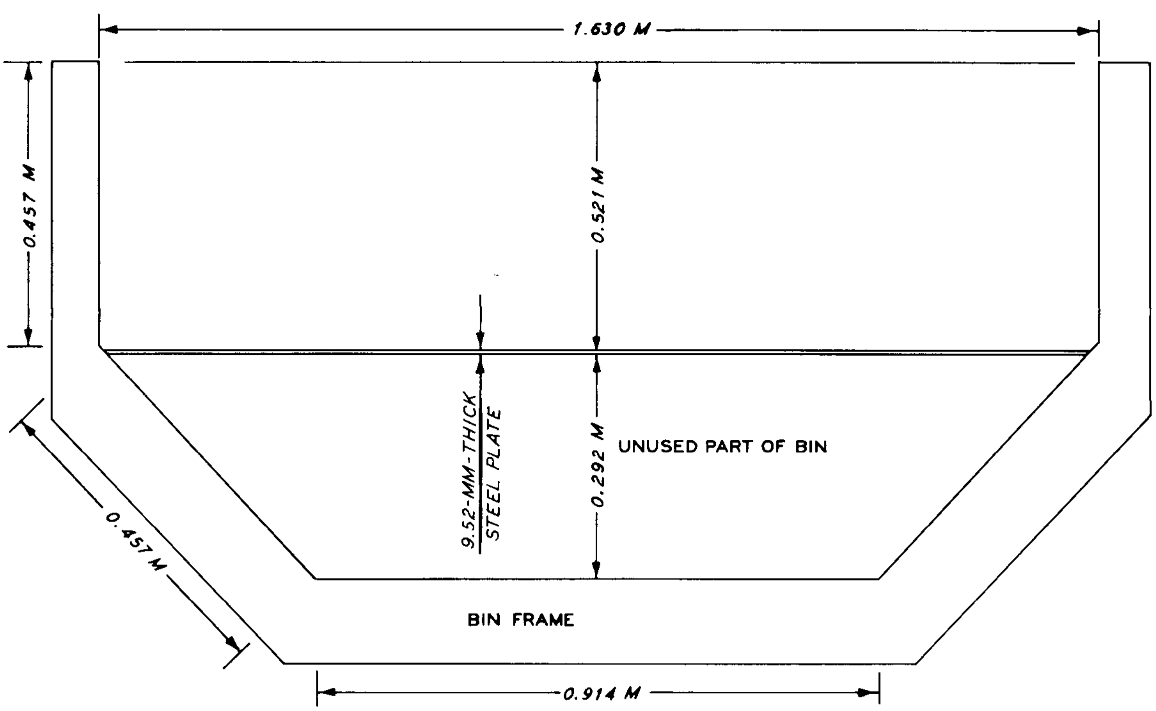


Figure 12. Section of end view of modified soil bin

end gates. Modifications for this testing program included installation of a 9.52-mm-thick steel flooring to form a 0.521-m-deep chamber plus a vertical separator at the bin midpoint, forming two sections of equal volume. All internal joints, including the end gates, were welded to form two equal watertight sections, 4.06 by 1.63 by 0.52 m.

57. Mechanical agitation was provided to the upper 76.2 mm (3 in.) of one of the two soil slurry test sections by the apparatus illustrated in Figure 13, consisting of two rows of times made by welding 9.52-mm-thick steel bars to an adjustable inner frame. The two tine rows were off-centered to develop more uniform coverage during agitation. The tine frame could be adjusted vertically and was set within a rigid frame mounted on four steel wheels, which were flanged to fit the upper outer edge of the soil bin. Power to propel the unit was supplied by an electric motor acting through a gear reducer, driving a sprocket attached to one of the agitation unit wheel hubs. The motor was equipped with a reverse switch and time delay mechanism. Limit switches were set at each end of the agitated test bin so that unattended movement of the agitator carriage was possible. One coverage of the test section took 2 min. A constant 76.2-mm tine penetration into the soil slurry was maintained throughout agitation by lowering the tine frame as necessary

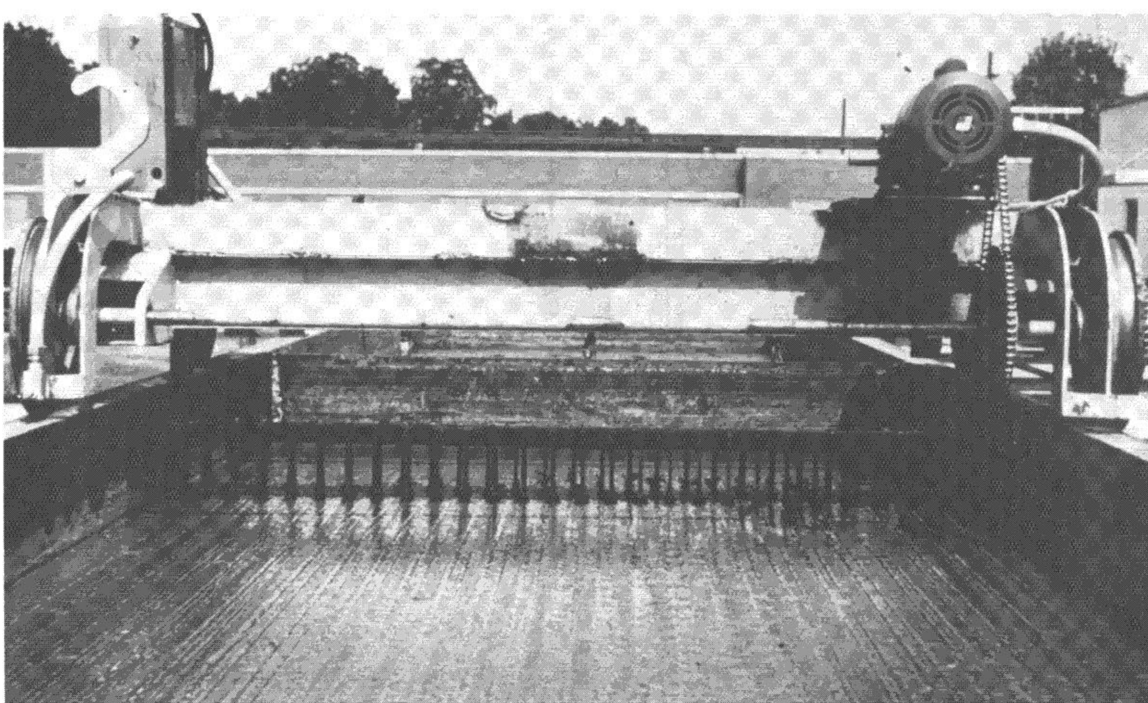


Figure 13. Mechanical agitation apparatus

to follow the soil slurry surface as it dried and settled.

Soil slurry preparation

58. The test soil was a highly plastic alluvial clay obtained from Mississippi River floodplain deposits near Vicksburg, Mississippi, and locally called Vicksburg Buckshot Clay. The soil had a grain-size distribution of 100 percent passing the U. S. No. 200 sieve, 40 percent finer than 5μ and 30 percent finer than 1μ. The LL of the soil was 65, with a PL of 24 and a specific gravity of solids of 2.68. This soil is classified CH by the USCS.

59. Slurry preparation was begun by obtaining soil that had previously been air dried and pulverized to a maximum particle size of 0.2 mm. Measured quantities of soil and water were mixed in an air-powered 0.283-m^3 capacity portable grout mixer to achieve the desired soil slurry consistency (approximately 2.7 × LL). Dual sets of mixing blades operating at approximately 3600 rpm for 10 min ensured thoroughly mixed slurry batches. Prepared slurry batches were placed in the soil bin by lifting the mixer with a forklift and allowing the slurry to drain, as shown in Figure 14. The soil bin was divided into two sections having equal 3.44-m^3 volumes; approximately 8 hr was needed to fill each section (with 17 batches of slurry). Each slurry batch

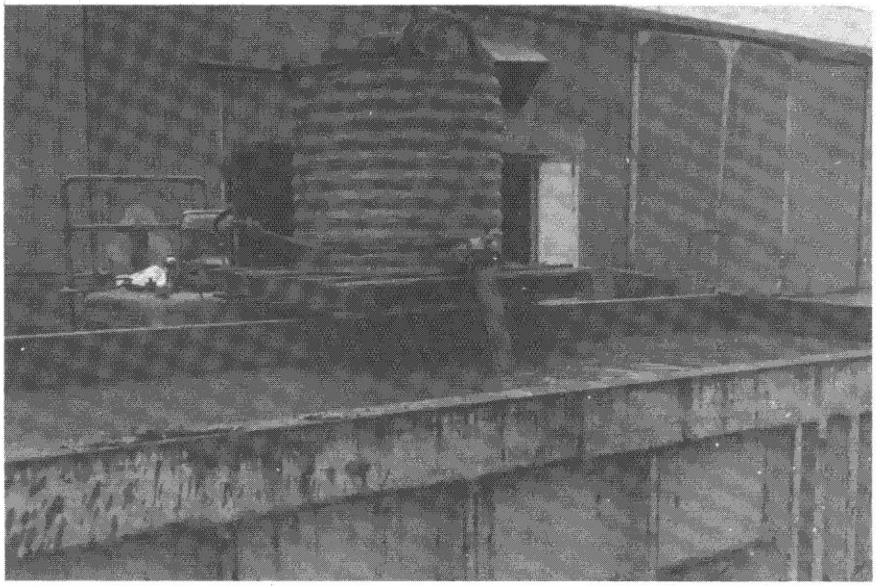


Figure 14. Emptying processed slurry from grout mixer

contained 189.27ℓ of water plus 122.47 kg of processed soil (air-dry water content of 7.5 percent) to yield a soil slurry with a design water content of 174 percent. Immediately upon complete filling of the second bin section, a portable electric bituminous-flash mixer was used to mix each section for 6 min to produce uniform consistency in both bins when beginning the test. Soil slurry was placed to a depth of 457 mm (18 in.) in each bin.

60. Immediately after stirring both test bin sections with the flash mixer, slurry samples were taken from each test section with an open-ended 200-ml burette (Figure 15a) equipped with an inside plunger. With the plunger seated in the lower opening, the burette was immersed in the slurry to the desired depth, and an approximately 30-ml slurry sample was obtained by raising the plunger for a few moments and re-seating the plunger prior to extracting the burette from the slurry. Eighteen such samples were taken in groups of three at approximately 1.5-m intervals along the traverse of the soil bin. Results of water content determinations on these samples are shown later. When the slurry became thicker, a burette with a larger end opening (Figure 15b) was used for sampling purposes.

Climatological data collection

61. An automated system was used to collect meteorological data, providing continuous data on wind velocity and direction, air temperature, humidity, rainfall, solar radiation, and slurry temperature. This system was augmented with a manual hook gage, standard Class A Evaporation Pan, and standard hygrothermograph. The meteorology instruments were located adjacent to the soil bin. Seven soil temperature sensors were placed in the control (unagitated) section, centered with respect to distance along the bin. Two sets of two sensors each were placed at the outside quarter points across the bin, at 229- and 305-mm depths; three sensors were placed in the center of the bin, at depths of 127, 279, and 432 mm. Temperature sensors were not placed in the agitated test section for fear of interference with action of the tines.

Test program

62. The two-section soil bin containing similar soil slurries was

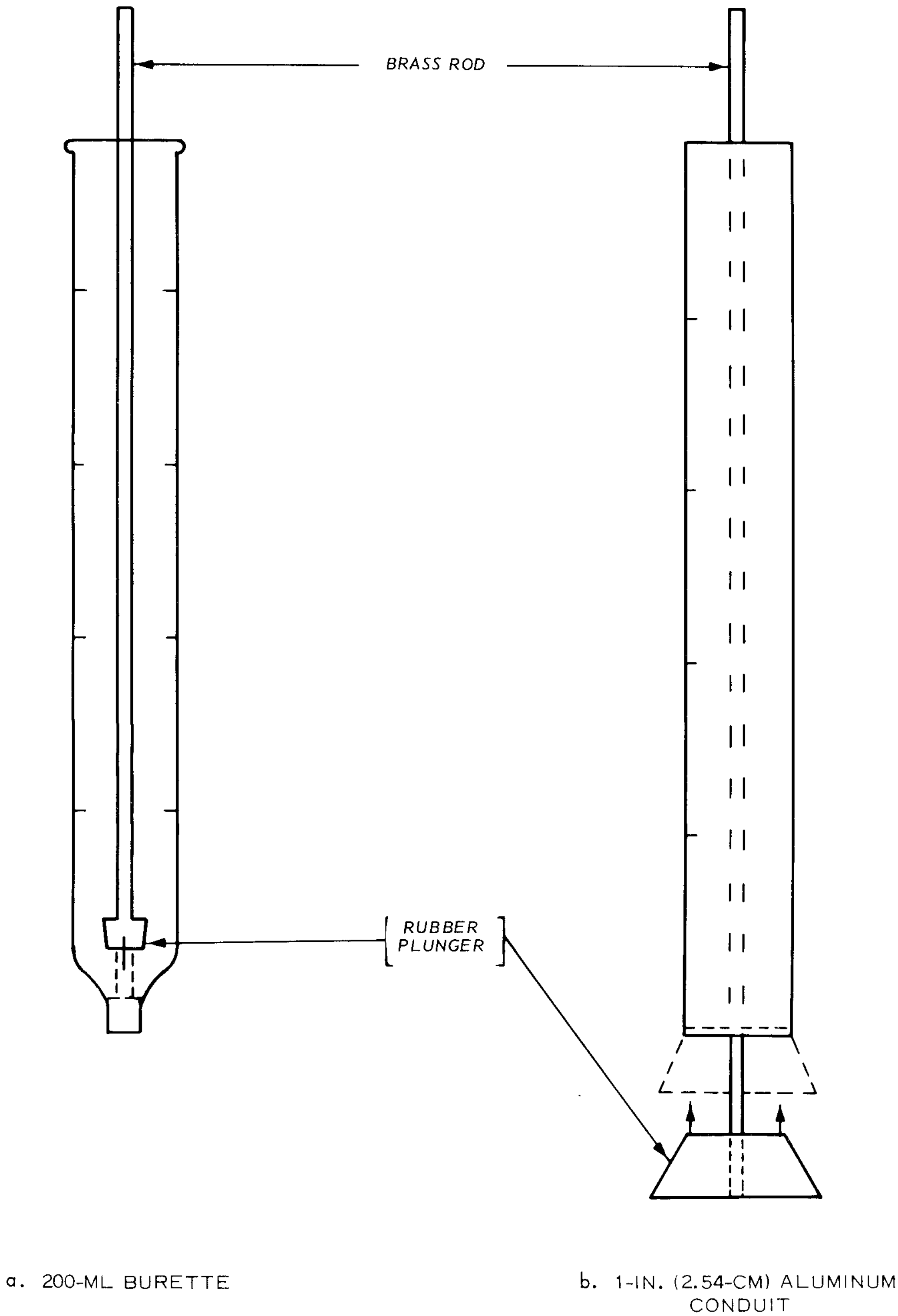


Figure 15. Apparatus used to obtain water content samples in soil slurry

exposed to existing weather conditions for a test period of 66 days. The test sections were prepared 17-18 July 1975, and testing was terminated on 22 September 1975. The two-section soil test bin was filled with clay slurry on 17 and 18 July 1975. Immediately upon filling, the slurry was remixed in place to ensure uniform consistency with depth; then as-placed water content samples were taken. The slurry was allowed to settle until 21 July 1975, at which time the surface water was decanted. Upward seeping water was measured and decanted daily until 6 August 1975. On 12 August 1975, 6 days after decanting ceased, hairline cracks appeared on the slurry surface in both test sections. Table A1 (Appendix A)* provides a record of time and weight of decanted water.

63. Mechanical agitation did not begin until 12 August 1975, 25 days after initial placement of the soil slurry. The slurry in the west half of the soil bin was agitated while the east half served as the undisturbed control. Agitation was provided during normal duty hours (0800 to 1630 hr) except during inclement weather when the test sections were covered with waterproof material or during any period of equipment malfunction. The test sections were also covered during off-duty hours. During the period 13-19 August 1975, surface water which accumulated overnight was decanted and measured each morning before re-agitation was begun. This water was counted as a loss, even though it was not evaporated.

64. One modification of the agitation mechanism was made after 46 days of operation. As the water content of the agitated soil slurry approached 75 percent, the material would not pass between the tines, resulting in the material being sheared at the base of the tines and sliding in a mass ahead of the tines until its passive resistance exceeded the tractive capacity of the agitation apparatus, causing it to stall or experience wheel slip. This problem was partially overcome by removing every other tine. As the slurry continued to dry, the same phenomenon recurred, primarily because the upper several centimetres of material dried considerably during nonagitation periods. Manually remolding

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* Appendixes are enclosed in an envelope in the back cover.

the top 76.2 mm of the agitated test section with a potato fork was thus often necessary at the beginning of normal duty hours, prior to application of mechanical agitation, with increasing regularity during the final 20 days of testing.

65. Daily data acquisition consisted of:

a. Weight of excess surface water (if present) decanted from each test section was recorded.

b. Surface elevations were recorded with respect to the upper edge of the soil bin at 12 locations (six per test section) at locations shown in Figure 16.

c. Water content samples were taken at six locations (three in each test section) uniformly spaced along the length of the soil bin (Figure 16). At each location three samples at different depths were obtained. Initial water content samples were taken on 17 July 1975 and thereafter on a workday basis beginning 25 July 1975.

d. Relative humidity, ambient air temperature, wind speed and direction, solar radiation, and Class A pan evaporation were recorded on a continuous basis. Soil temperature in the control test section was also recorded at three depths. A hook gage was also used to measure pan evaporation twice daily as a check on recorded evaporation data. The standard Class A Evaporation Pan, equipped with a manual hook gage and recording hygrothermograph, was placed adjacent to the test sections and made operational on 22 July 1975. The automated system to measure meterological data plus soil temperature at 15-min intervals was installed and became operational on 24 July 1975. Nonavailability of equipment prevented this system from being operational at the outset of testing on 18 July 1975.

e. Cone penetration data in the upper 152.4 mm of the slurry were recorded after the material began to assume plastic properties. The cone index (CI) obtained from these data is a WES-developed indicator of soil strength and support capacity. The average CI for each depth was determined from three readings at each of three locations in each test section (Figure 16).

Test Results

66. This experiment was designed to study the effects of surface agitation and selected water parameters on the drying rates of a clay

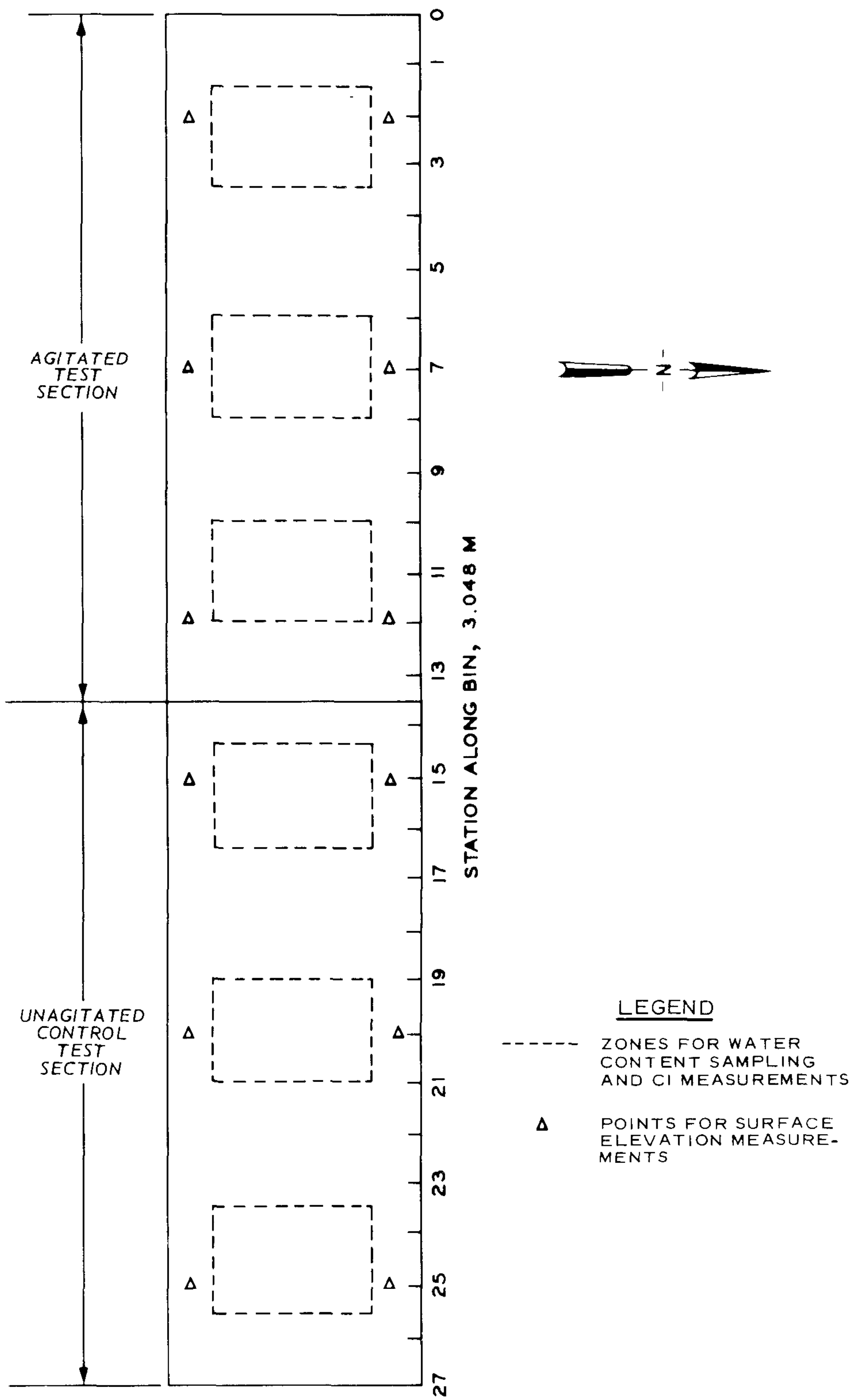


Figure 16. Plan view of test bin illustrating locations from which surface elevation measurements and water content samples were taken

slurry. A nonagitated test section was used as a basis for comparison. Both total and rate of moisture loss and resulting volume reduction of the slurry test sections were the important parameters. Climatological conditions prevailing during the study are considered independent variables and assumed the same for both test sections. Data analysis thus consisted primarily of examining the effect of mechanical agitation on rate and amount of water loss and volume change of the soil slurry.

Meteorological data

67. Evaporation is caused primarily by combinations of solar radiation, temperature, relative humidity, and wind speed; hence, particular attention was focused on measurement of these variables. The automated system used in the study is presently in the developmental stage and frequent data gaps and errors occurred from equipment malfunction. The partial data available were insufficient to permit thorough analyses; thus, meteorological data collected by other Corps of Engineers (CE) offices in the Vicksburg area were used to supplement data from the automated system. Meteorological data collected are summarized in Table A2 for the 66-day test period 18 July-22 September 1975.

68. In full sunlight the solar energy received on a surface perpendicular to the sun's rays above the earth's atmosphere is about 2 $cal/cm^2/min$; about one-third of this amount is absorbed in passing through the atmosphere. The pyrometers used to measure solar radiation produced an output in millivolts accumulated over a 1-min interval for 1 cm^2. These values were converted by means of a linear calibration relation to joules (J) per square centimetre per minute. The recording system sampled absorbed solar energy every 15 min; this value was assumed to be representative for the time period. If these data are summed over a given time period t, the total amount of solar energy available per unit surface is:

$$E = 15 \times \sum_{i=1}^{n} e_i \qquad (6)$$

where

E = solar radiation, J/cm^2

n = number of 15-min intervals in time period t

i = 1,2,3,...,n

e_i = recorded solar radiation value obtained each 15 min, $J/cm^2/min$

The values of solar radiation given in Table A2 were computed according to Equation 6 from raw data for two time periods: the time period between sunrise and sunset (times published by the U. S. Naval Observatory were used) and those time periods when the test sections were actually uncovered.

69. Air temperature highs ranged from 25° to 34°C, with nighttime lows from 12° to 24°C. The temperature during daily periods when the test sections were uncovered ranged from 24° to 31°C. Maximum nighttime relative humidity (not shown in table) ranged from 70 to 100 percent and minima during daylight hours from 35 to 80 percent.

70. Average daily wind speeds ranged from 0.5 to 2.4 m/sec.

71. Daily Class A pan evaporation during the test program is tabulated in Table A2. The cumulative total was about 189 mm, with daily increments ranging from lows of 0 to highs of 14 mm, with about 5 mm as a daily average.

Initial water content

72. Results of water content determinations on slurry samples taken after processing and prior to beginning of agitation were:

Depth from Surface	Water Content, percent					
	Agitated Section Station No.*			Control Section Station No.*		
mm	1	7	11.5	15	19	25.5
415	178	173	173	172	177	173
350	177	178	173	173	177	172
300	177	178	173	173	173	173
	Avg = 176			Avg = 174		

* Station numbers are shown in Figure 16.

These data indicate that homogeneous slurries existed initially in each section although the water content of the sections themselves differed about 2 percent.

Effects of mechanical agitation

73. Agitation of the upper 76.2 mm of one test section was started 12 August 1975 and continued for 2 hr that afternoon. Agitation continued thereafter on a daily basis for about 7 hr except during inclement weather or equipment failure. For the first 5 days of agitation, surface water appeared overnight after agitation ceased; it was decanted and measured prior to restarting agitation. Similar free water was not present on the surface of the unagitated test section. Table A3 provides dates and times of mechanical agitation during the study.

74. The unagitated test section developed surface desiccation/shrinkage cracks that became wider and deeper as the slurry dried. Average widths and depths of the shrinkage cracks are given in Table A4. On 22 September 1975 (test day 66), the shrinkage cracks in the unagitated section extended to the base of the soil bin. At this time, the slurry consistency in the agitated test section made it extremely difficult to agitate; the testing program was thus terminated. A photographic record of behavior during the test program is provided in Appendix B.

75. Comparative plots of water content versus depth for both test sections are given in Appendix C for specific test days during the program. Each data point represents the average of three water content determinations made along the traverse of both test sections at identical depths. Water contents determined for crust formed in the unagitated test section were not considered. Average water contents, sample location, and depth data are given in Table C1.

76. The plots of Appendix C indicate that during the first 25 test days (until 12 August 1975) when surface water was present and significant soil particle settlement was occurring water content decreased with increasing depth. After several days of transition, the water content at depth continued to decrease but at a slower rate than the water content at the surface. Based on the observed trends shown in Appendix C, it would appear that the water content profiles can be approximated as linear relationships. Based on linear water content versus depth data, the overall average water content behavior for each

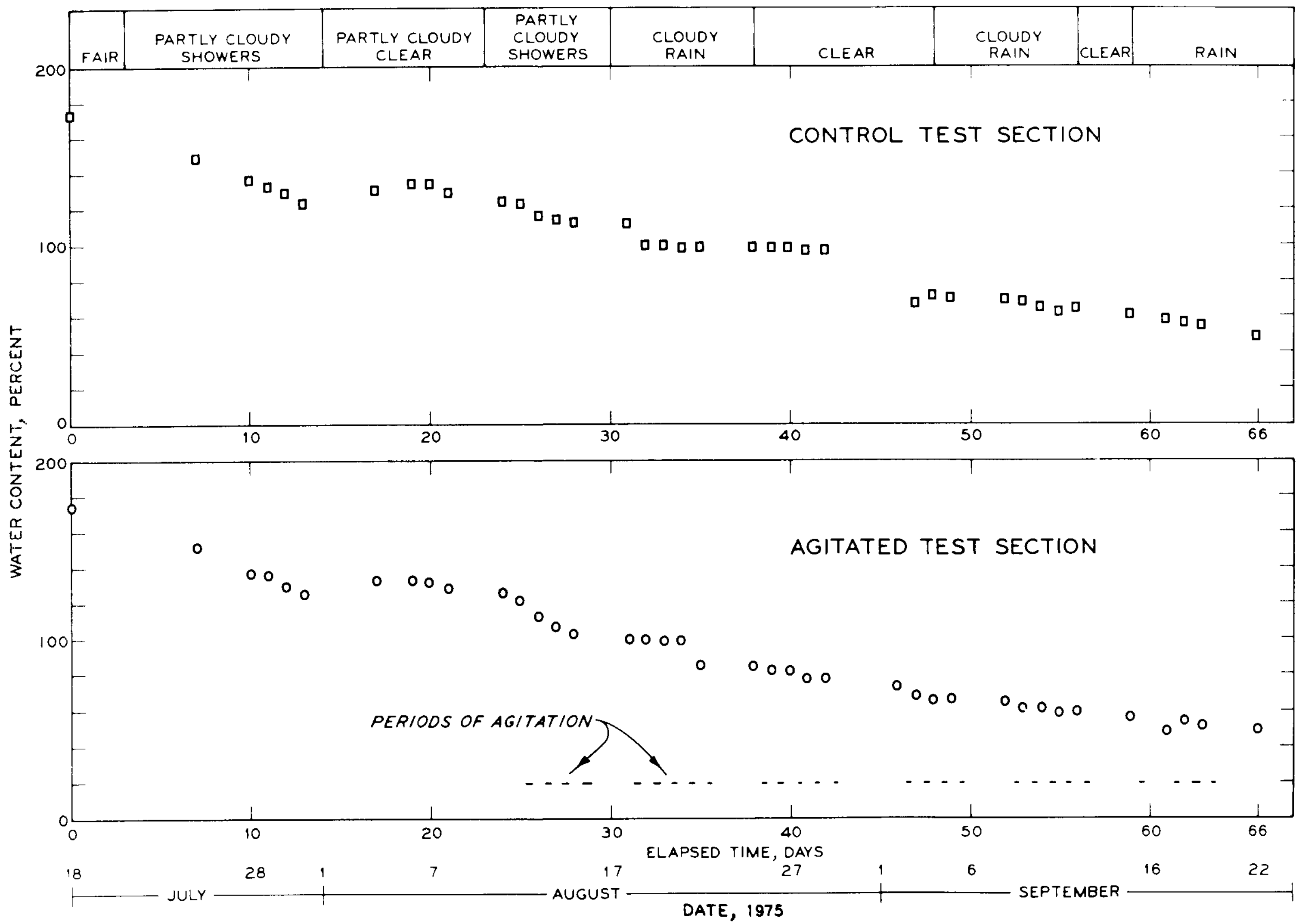


Figure 17. Water content versus time

test section was determined and tabulated in Table C2. These average water contents were used as the basis for further comparisons.

77. Figure 17 indicates the reduction in average water content with time for agitated and unagitated (control) test sections. The moisture content in the agitated test section decreased from an initial 176 percent to about 48 percent after 66 days. The water content of the control test section decreased from an initial 174 to 48 percent during the same period. Not only did the two sections have nearly identical beginning and final average water contents, but the rates of decrease shown in Figure 18 from initial to final water content values were very similar. It should be noted that the much lower water content values of the surface desiccation crust developed in the control section are not averaged into the average water contents of that test section, therefore biasing the control section data on the high side. Observed crust development during the test program is summarized in Table A5. Also water decanted between periods of agitation probably biased the agitation section data on the low side.

78. Volume reduction of both the agitated and unagitated control test sections was monitored over the study period. Individual surface elevation readings and the average value per test section and date are presented in Table A6. Differences between initial elevation (not shown in the table) and surface elevation on any given test day, expressed as a percentage for each test section, are tabulated in Table A7 and plotted versus test time in Figure 19. Lines of best visual fit were drawn through the respective data and are presented without data points in Figure 20. As seen in Figure 20, the comparative effect of agitation on lowering the surface of the soil slurry was slight; at the end of testing a vertical volume reduction of 63 percent occurred in the agitated section, compared with a value of 55 percent for the unagitated control test section.

79. Slurry in the control test section experienced further volume reduction from formation of desiccation/shrinkage cracks that did not form in the agitated test section. At the end of the study the volume of the shrinkage cracks present in the control test section was

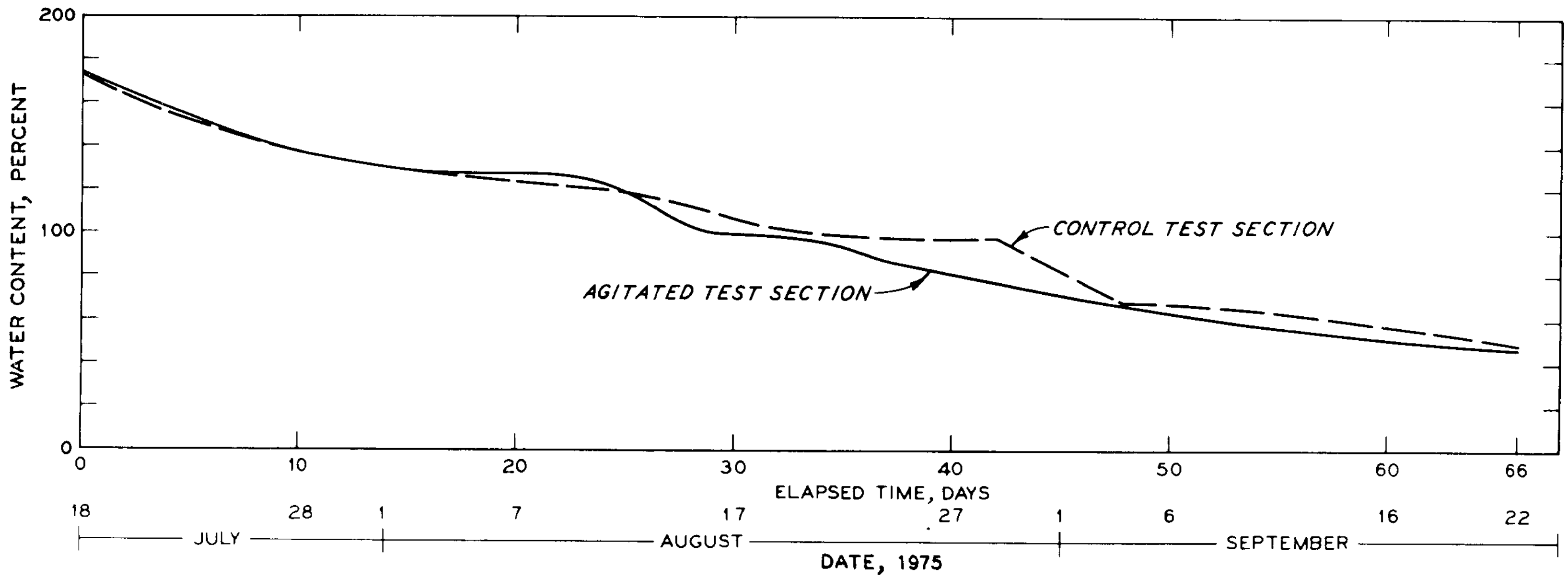


Figure 18. Comparison of water content versus time for agitated and control test sections

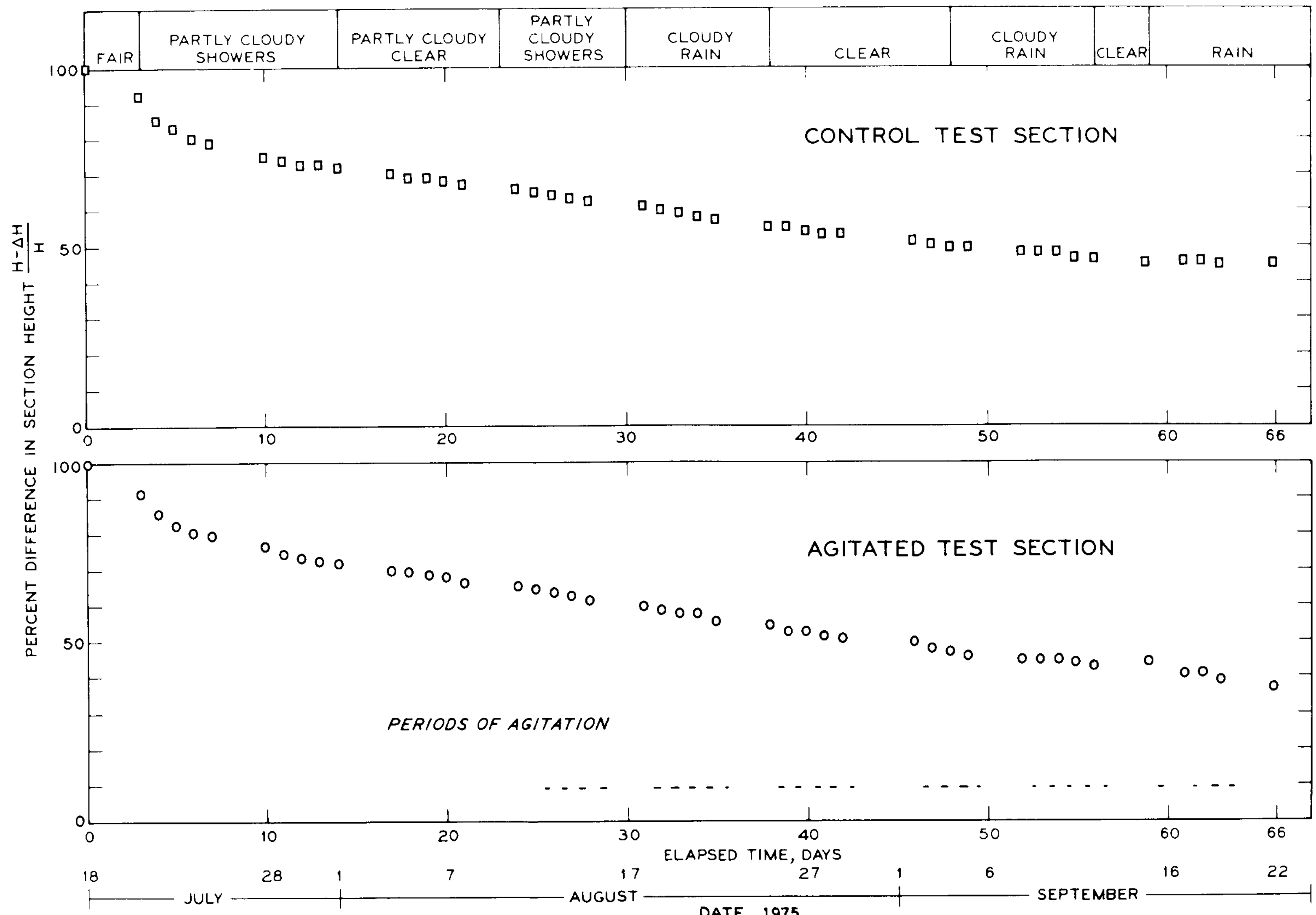


Figure 19. Vertical change in test sections, height H versus time

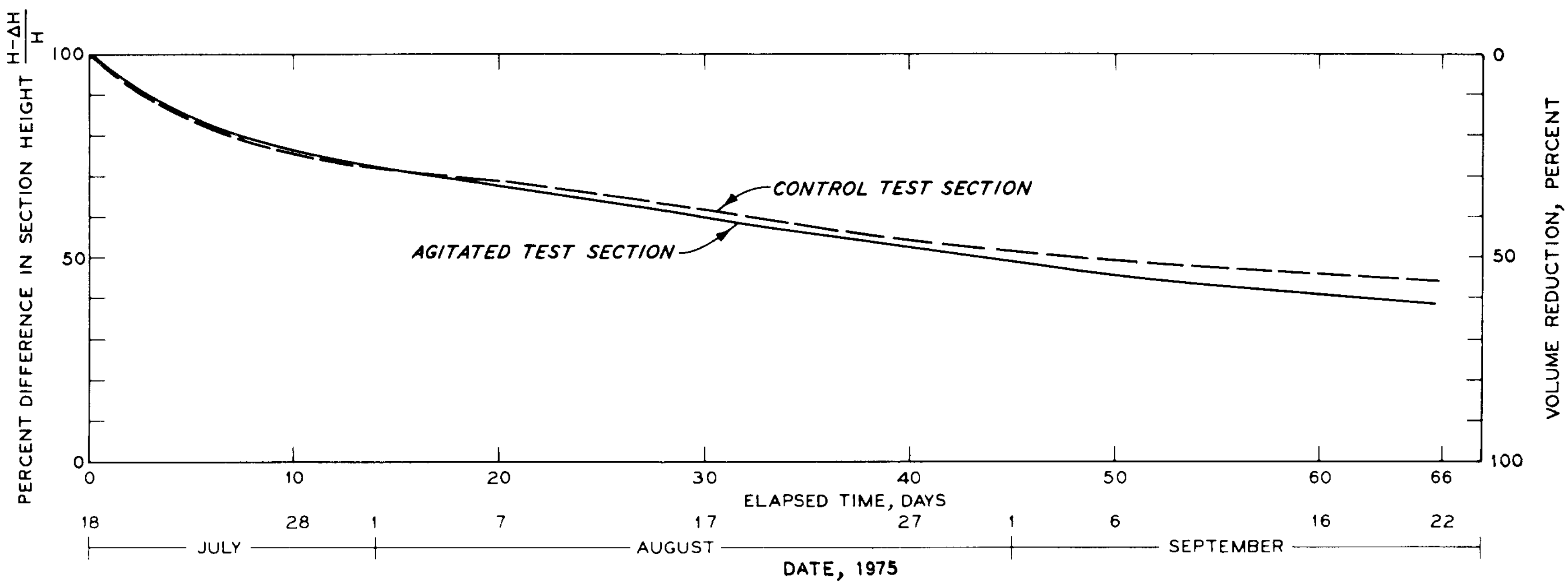


Figure 20. Comparison of vertical height changes versus time for agitated and control test sections

determined by measuring the amount of water required to rapidly fill the cracks flush with the soil surface. From these data it was calculated that an additional 7.7 percent in volume reduction could be attributed to void space formed by cracks. If the 7.7 percent (approximately 8 percent) is added to the 55 percent vertical volume reduction noted in the control test section, a total volume reduction of 63 percent occurred in the control test section, identical to that in the agitated test section.

80. A block of dried slurry, shown in Figure 21, was taken at

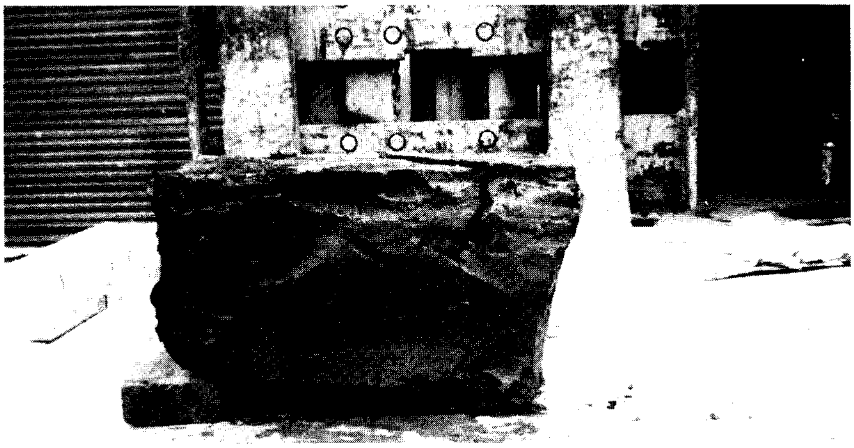
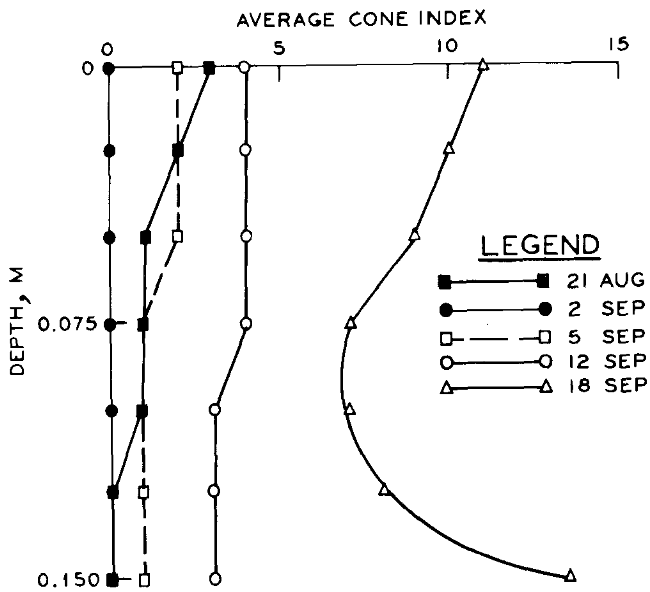


Figure 21. Block sample from sta 21 (control test section)

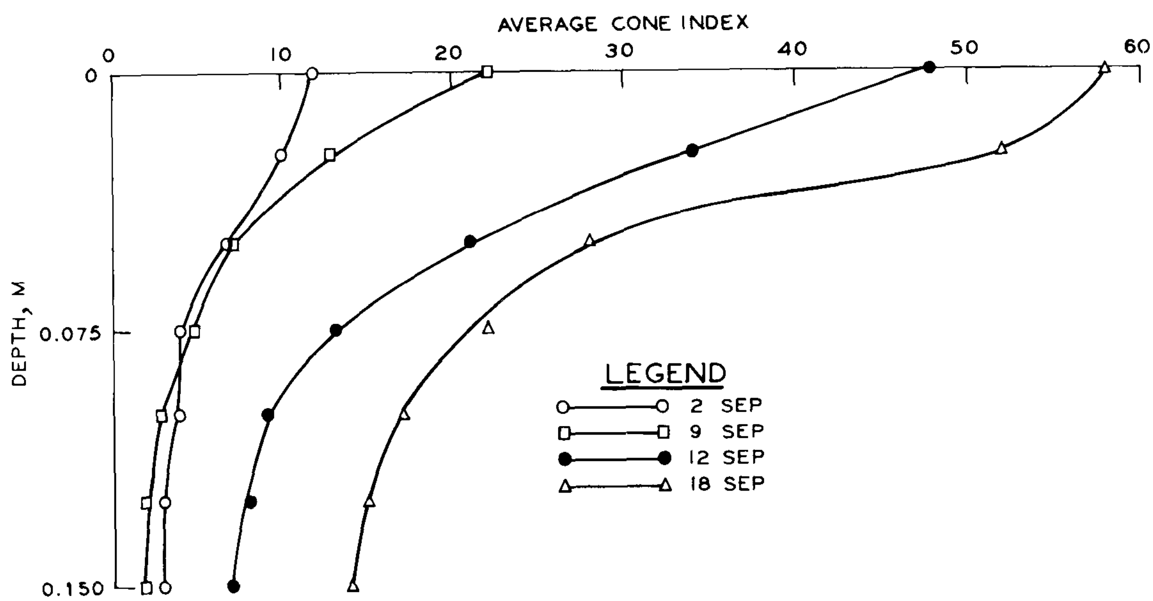
sta 21 on test day 66 in the control section to obtain water content and density data at selected depths. Results of these measurements are as follows:

Depth, cm	Water Content, %	Dry Density g/cc	Dry Density pcf
0.0-2.5	30.3	1.55	96.6
2.5-5.1	36.8	1.38	86.0
5.1-7.6	41.1	1.31	81.7
7.6-10.2	44.0	1.20	74.7
10.2-12.7	46.1	1.21	75.8
12.7-15.2	48.4	1.14	71.4

81. On about 21 August 1975, the slurry in the control section provided some resistance to penetration; on that date CI measurements were begun and continued periodically. The CI data tabulated in



a. Agitated test section



b. Unagitated control section

Figure 22. Comparison of CI profiles for agitated test sections and unagitated control test sections

Table A8 and plotted in Figures 22 and 23 show that the unagitated control section achieved a higher shearing resistance and support capacity with time than the agitated section. When the CI for fine-grained soils reaches a value of about 6, a man can walk on the soil with some difficulty; when the CI reaches about 20, a man can walk with little difficulty. Some low-ground-pressure, special-purpose tracked vehicles can make one pass on an 8 to 10 CI soil. Other DMRP research conducted by Mobility and Environmental Systems Laboratory (MESL) established minimum CI values required for support and operation of various vehicles in dredged material containment areas.[18] Only a few small reconnaissance

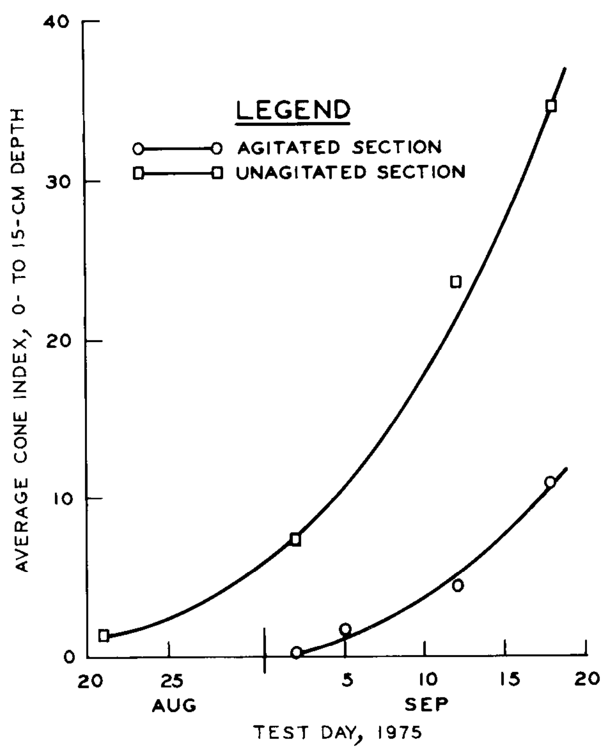


Figure 23. Comparison of CI change with time for agitated test sections and unagitated control test sections

vehicles could make one pass over material with support capacity of the agitated section, while several tractors, dozers, and draglines could travel and work on material with the support capacity of the unagitated test section.

Summary

82. Based on the data developed in this experiment:

a. Evaporative drying of a highly plastic clay slurry is not accelerated by continuous mechanical agitation of the upper 7.62 cm of the material.

b. Prevention of surface crust formation does not increase the amount of water lost or volume gained by evaporative drying, but the support capacity of the material is reduced.

83. Data presented in the previous sections essentially confirm the results of the small-scale laboratory experiment and agree with the expected behavior predicted from currently accepted soil science theory. When subjected to climatic conditions of both low and high evaporative potential, the drying rate of highly plastic clay slurries was not significantly influenced by mechanical agitation.

PART V: PERIODIC MIXING OF CRUST AND UNDERLYING DREDGED MATERIAL

84. To determine if first-stage drying rates could be prolonged under field conditions, a periodic mixing field experiment was conducted. This concept, periodic mixing of dry surface crust with underlying very wet dredged material, allowing a new crust to form, remixing, etc., may also be compared to mechanical stabilization of plastic clay by addition of cohesionless material, with the blocks of dried surface crust (representing coarse aggregate) added to the very wet and highly plastic underlying dredged material. The Upper Polecat Bay disposal area of the Mobile District, Mobile, Alabama, had been previously selected for conduct of all DMRP field demonstrations of dewatering technology,[19] thus the field demonstration was carried out there.

Field Study

Test site

85. The southwest corner of the Upper Polecat Bay disposal area was selected for the field demonstration. The disposal area was created in 1970 by end-dumping sand from previous new work dredging to form a perimeter dike around an existing marsh at el 1 to 2.* The sand displaced existing soft cohesive foundation material down to approximately el -16 and the dike was constructed up to approximately el 16. Dredging operations in 1970 and 1972 in the Mobile River adjacent to the site resulted in placement of approximately 2.4 to 3.0 m (8-10 ft) of sedimented fine-grained dredged material over the area. At the location of the agitation test site, fine-grained dredged material had been placed to approximately el 8.0 to 8.5 above a fine silty sand (SM by USCS) foundation at approximately el 1.0 to 1.5, placed by unconfined new work dredged material disposal prior to 1970. In November 1975, approximately 0.3 m of ponded surface water covered the site, with approximately 2.13 to 2.29 m of dredged material of "axle grease" consistency existing beneath a 5-cm

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* Elevations (el) are in feet above mean low water (mlw).

crust. Surface water was removed in November 1975, and by February 1976 a 15-cm crust existed. Two 0.405-ha (1 acre) test plots were laid out as shown in Figure 24: one plot was to be periodically plowed and one plot was to act as an undisturbed control area. A perimeter ditch was placed around the test area so that precipitation would rapidly run off into an existing drainage ditch to the west of the test site. Casagrande-type piezometers were placed in the test and control areas as shown in Figure 24.

Test material

86. Results of engineering tests on the fine-grained dredged material in the test and control areas indicated the material in each area had about the same engineering properties, with (average values) 93 percent of the material passing the U. S. No. 200 sieve, 75 percent of the material finer than 5μ and 41 percent finer than 1μ size. Specific gravity of solids averaged about 2.72. The LL of the dredged material ranged from 73 to 171 (average about 100 to 120), with the PL varying from 27 to 56 (average about 35). Most of the samples tested had about 5 percent organic material (dry weight basis), but Atterberg limits plotted slightly above and parallel to the A-line, thus classifying the material as CH by the USCS. Results of X-ray diffraction analyses indicated the majority of the clay fraction present to be montmorillonite; the remainder consisted mostly of chlorite, with some clay-mica and a trace of kaolinite. Field tests indicated a coefficient of permeability on the order of 1 to 10 × 10^{-5} cm/sec, considerably higher than expected for a clay soil but attributable perhaps to the high void ratio of the sedimented dredged material. Consolidation tests run on the material confirmed its high compressibility, with coefficient of compressibility C_c of approximately 0.6 to 1.3 (average about 1.1). Water content measurements made at the start of the experiment indicated that below crust the material was up to 20 to 30 percent water content above its LL.

Test program

87. During the first week of February 1976, piezometers were installed and allowed to stabilize, and initial cross-sectional survey

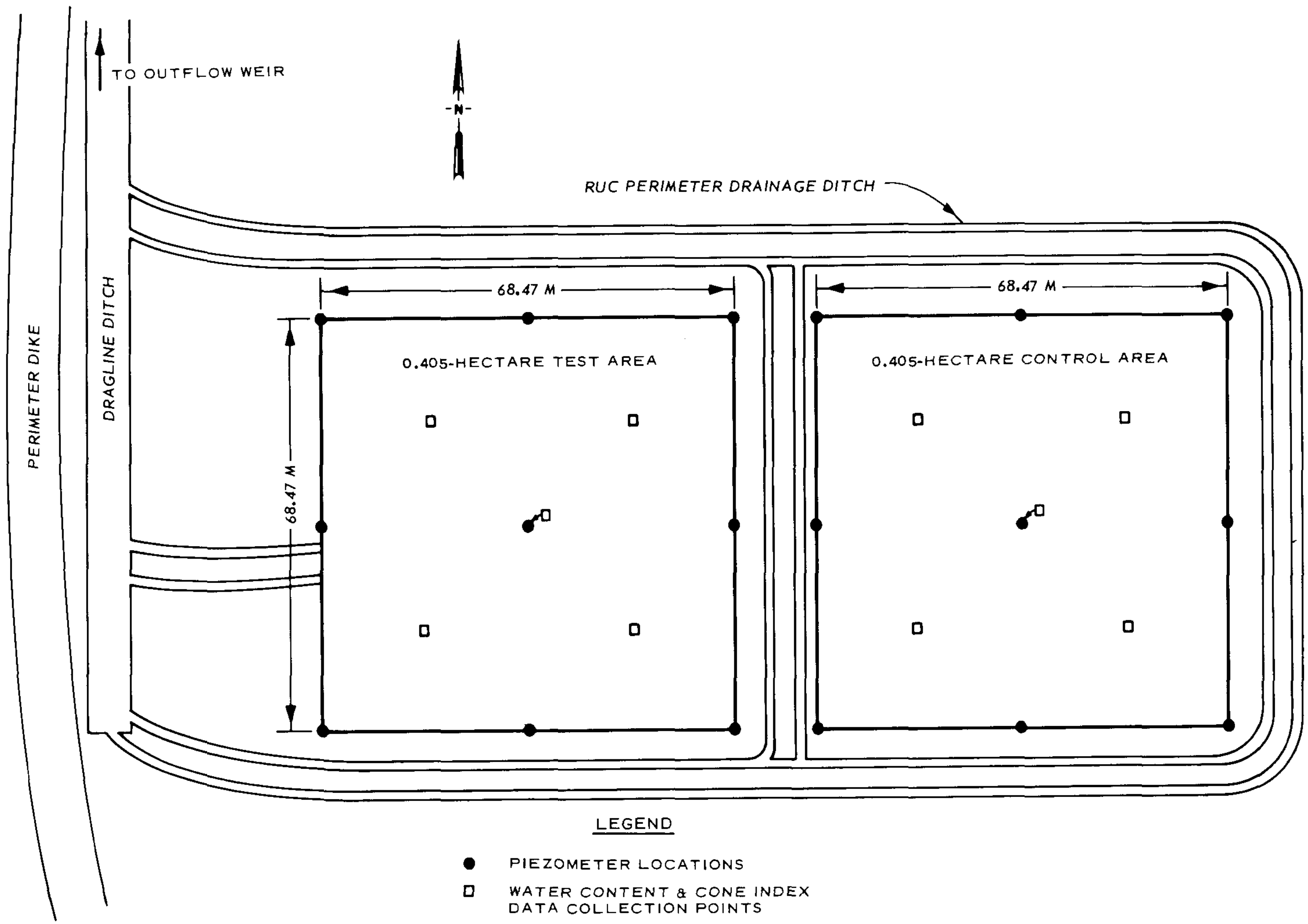

Figure 24. Plan of periodic mixing test and control areas, Upper Polecat Bay disposal area, Mobile, Alabama

data (7.62-m grid) were taken on both the test and control areas. Initial water content samples and CI data were taken at locations indicated in Figure 24. The perimeter ditch was then placed around the test and control areas with the Riverine Utility Craft (RUC). After these preparations the existing approximately 15-cm (6 in.) thick surface crust in the test plot was thoroughly mixed with underlying wet dredged material by action of the RUC rotors. Approximately 3 hr was required to achieve thorough mixing. The test process (obtaining cross-sectional survey data, water content samples, CI data, and piezometer levels followed by RUC rotor mixing of the surface crust with underlying wet dredged material) was repeated monthly until July 1976. Drying crust thickness that developed monthly varied from 2.5 cm (1 in.) to 10.2 cm (4 in.) during the test period. In March 1976, approximately 1.5 hr was required to remix the approximately 7.6-cm (3 in.) surface drying crust with underlying wet dredged material. Thereafter, time required for RUC rotor mixing increased, up to 6 hr in July 1976. RUC effort required to mix the material during this last period was such that transmission overheating problems developed frequently, thus the mixing program was terminated. Figure 25 is a photo of the RUC mixing operation carried out during the first week of April 1976, and Figure 26 is an aerial photo of the mixing test site and adjacent control site.

Results and Discussion

88. During the test program, several qualitative observations could be made:

a. After initial mixing, the test area usually required more effort to accomplish mixing each succeeding month, except in June 1976, following a month of high precipitation.

b. The control area surface crust thickness and surface firmness increased with time, except for softer surface conditions in June 1976.

c. Precipitation quickly ran off the surface of the control area into the perimeter ditch but was often trapped in ruts caused by RUC rotors in the test area.

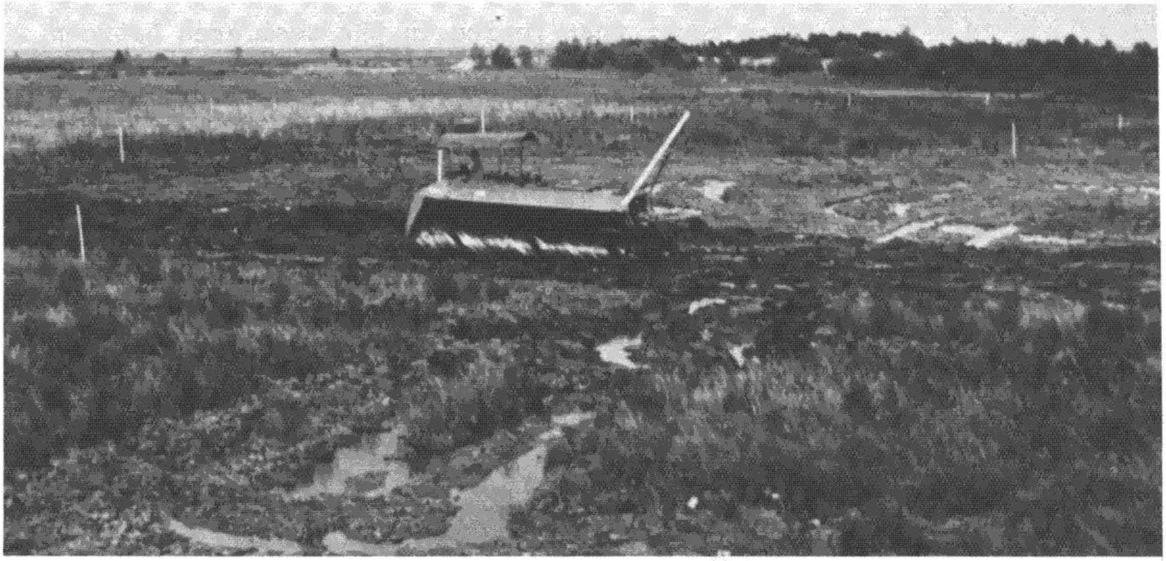

Figure 25. RUC mixing surface crust with underlying wet dredged material in test area, April 1976

Figure 26. Aerial photo of periodic crust mixing test area and control area (right foreground), looking from the west

_d_. The surface crust that formed in the test area between monthly mixing was just sufficient to support the weight of a man.

_e_. Final consistency of the test area after mixing always appeared to be slightly below the LL, despite the increase in mixing time required to obtain this condition.

89. Cross-sectional profiles for the test area are shown in Figure 27. Some intermediate surveys have been omitted for drawing clarity.

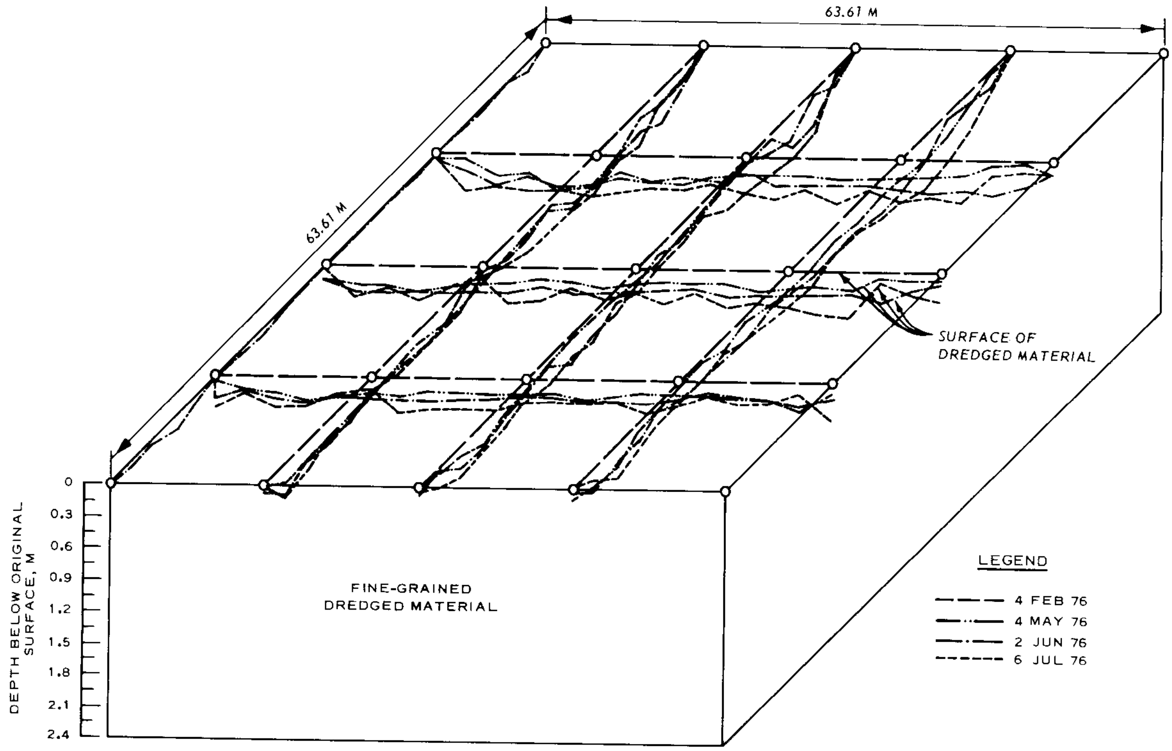

Figure 27. Results of periodic cross-sectional surveys of crust mixing test area

Data indicate the surface of the test plot subsided up to 0.45 m (1.5 ft) during the test period, with an average settlement of approximately 0.32 m (1 ft). The surface of the adjacent control area settled approximately 0.11 m (0.33 ft) during the test period, thus an increase of 0.21 m (0.7 ft) of surface settlement or about 10 percent of original thickness was obtained by the periodic mixing, or 858 m^3 of volume per 0.405 ha. Actual volume gain was probably not quite this much, because the desiccation cracks in the control area increased in depth, width, and number during the test period. The volume of these cracks was not measured but was found to be about 8 percent of crust volume in the large-scale continuous agitation experiment described in Part IV.

90. Water content/depth and precipitation data with time are shown for the test area in Figure 28 and for the control area in Figure 29. Each data point is the average of five determinations taken throughout the area at locations shown in Figure 24. Samples were taken at the same locations each month, using a Hvorslev-type piston sampler. Examination of the data indicated that initially the test area dredged material was slightly wetter than the control area material, but that drying appeared to occur at approximately the same average rate for both sections. At the time mixing was terminated, the water content of the test area material was in the vicinity of the average LL of the material. The amount of precipitation appeared to affect behavior in the upper 0.6 m of the material of both sections, but underlying material was not greatly affected. This behavior is better illustrated by study of Figures 30-33, where monthly change in water content at selected depths is plotted along with precipitation for the test period. Figures 30 and 31 for the 0.04- and 0.3-m depths indicate high variability basically related to precipitation. However, Figures 32 and 33 for the 0.91-m and 1.21-m depths, respectively, indicate a rather constant drying trend of about 10 percent water content decrease per month despite the effects of precipitation or mixing. The general trend still follows precipitation with an approximate 1-month lag and may reflect the reduced evaporative demand at the surface during periods of high precipitation. For all practical purposes, the mixing did not affect water content-time behavior.

91. Results of average CI data at various depths are plotted versus time for the test area in Figure 34 and for the control area in Figure 35. Data are averages of values collected at locations shown in Figure 24. Monthly precipitation is also plotted in the figures. Data in Figure 34 indicate that below 0.15 m the support capacity of the test area remained approximately constant with depth and increased only slightly with time. In July 1976, when the average CI of the test area

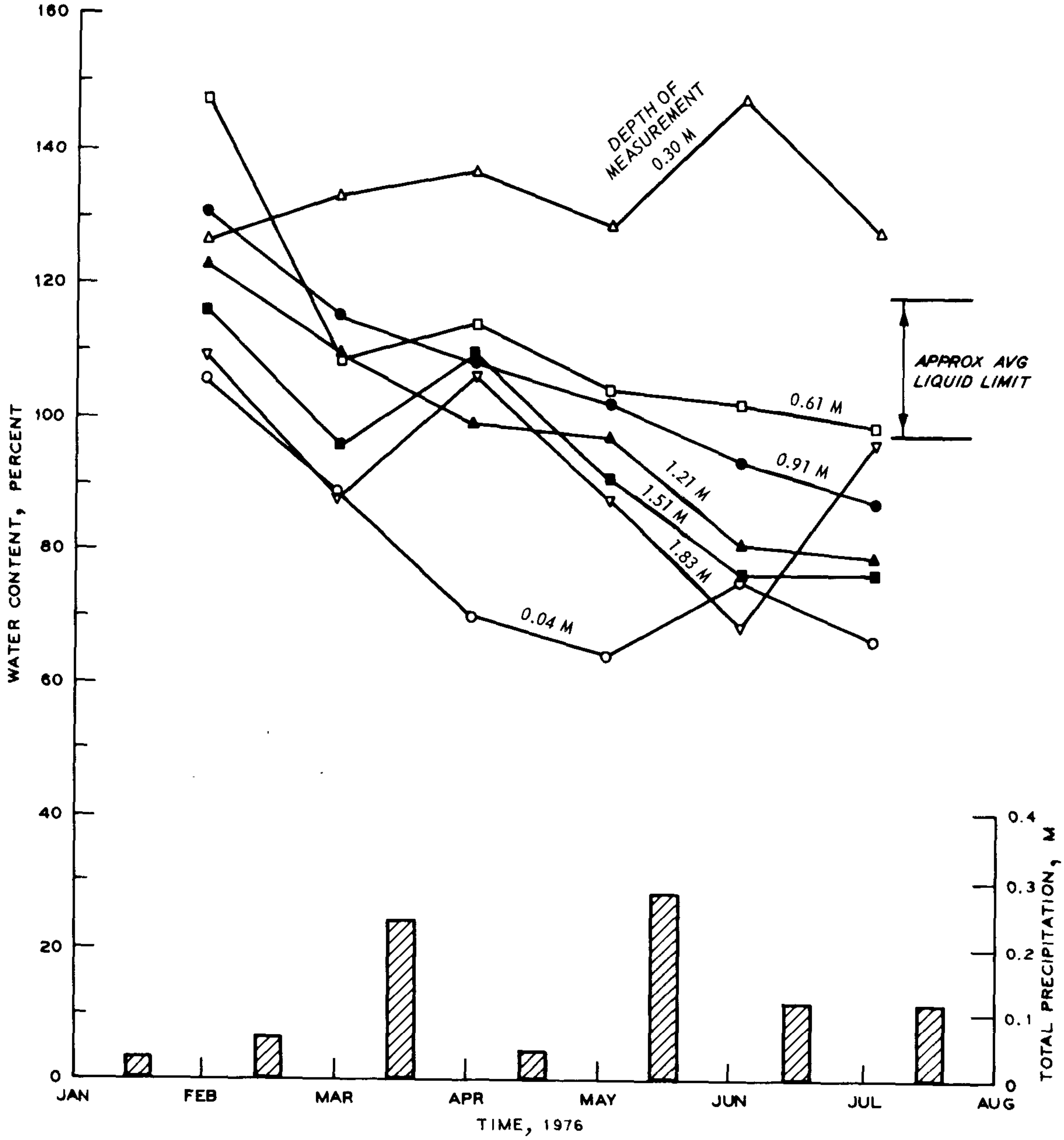

Figure 28. Water content and precipitation with time for periodic mixing control area

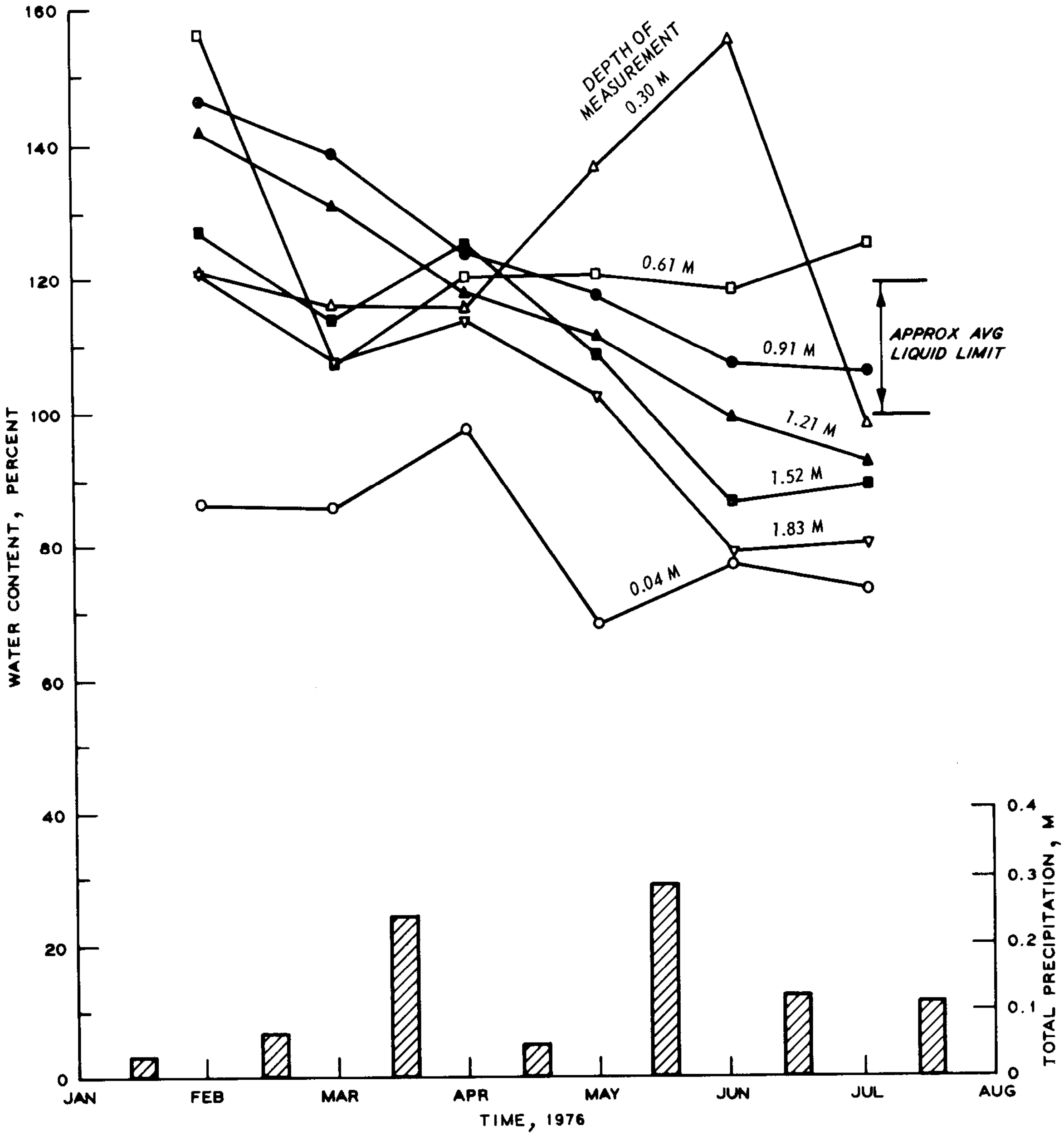

Figure 29. Water content and precipitation with time for periodic mixing test area

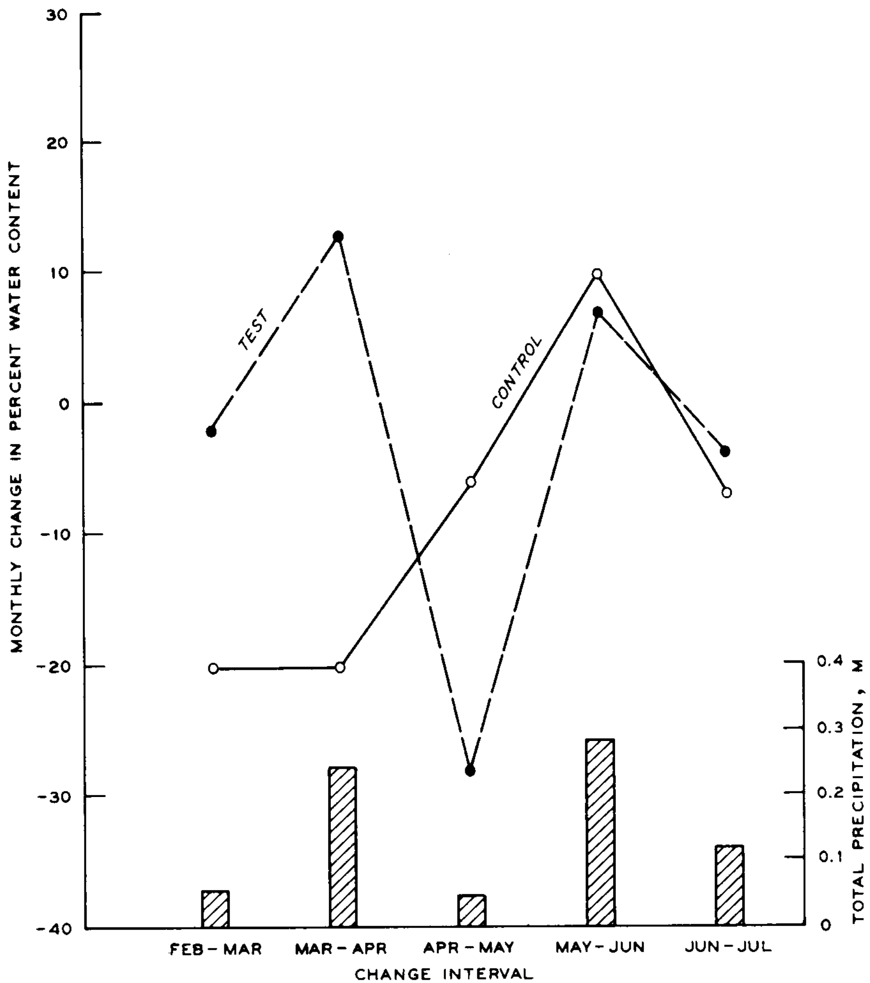

Figure 30. Monthly change in water content with time and precipitation, 0.04-m depth

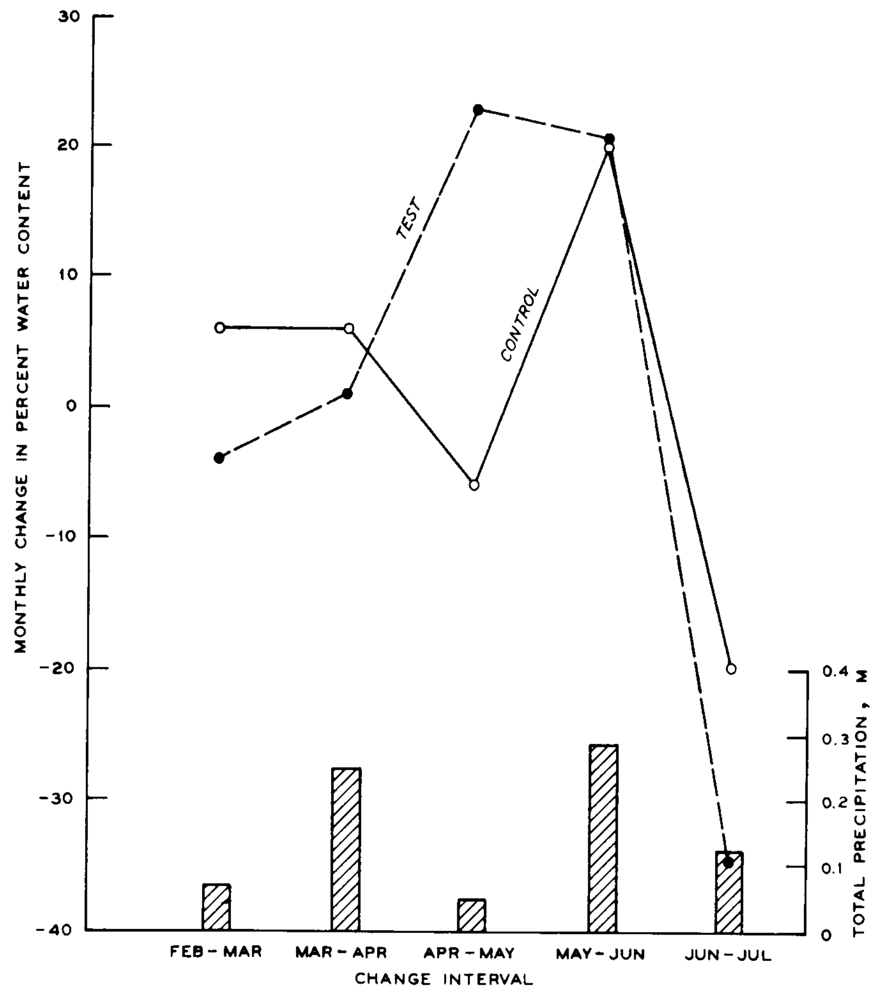

Figure 31. Monthly change in water content with time and precipitation, 0.3-m depth

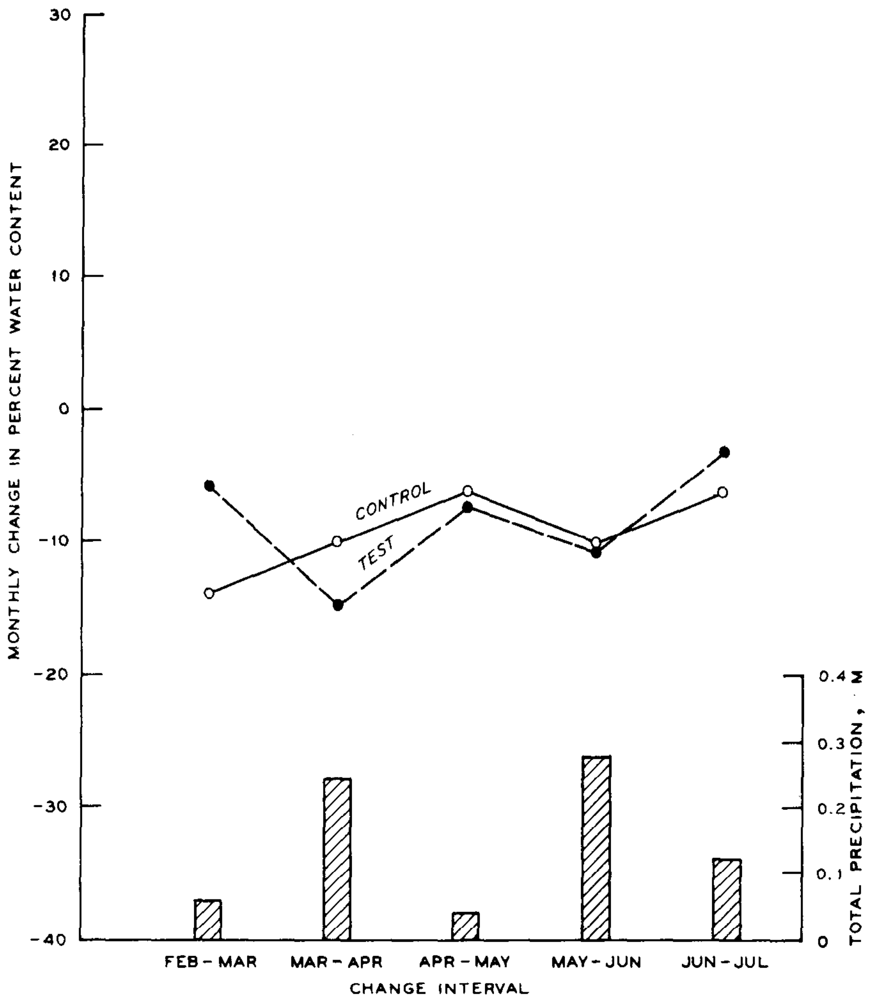

Figure 32. Monthly change in water content with time and precipitation, 0.91-m depth

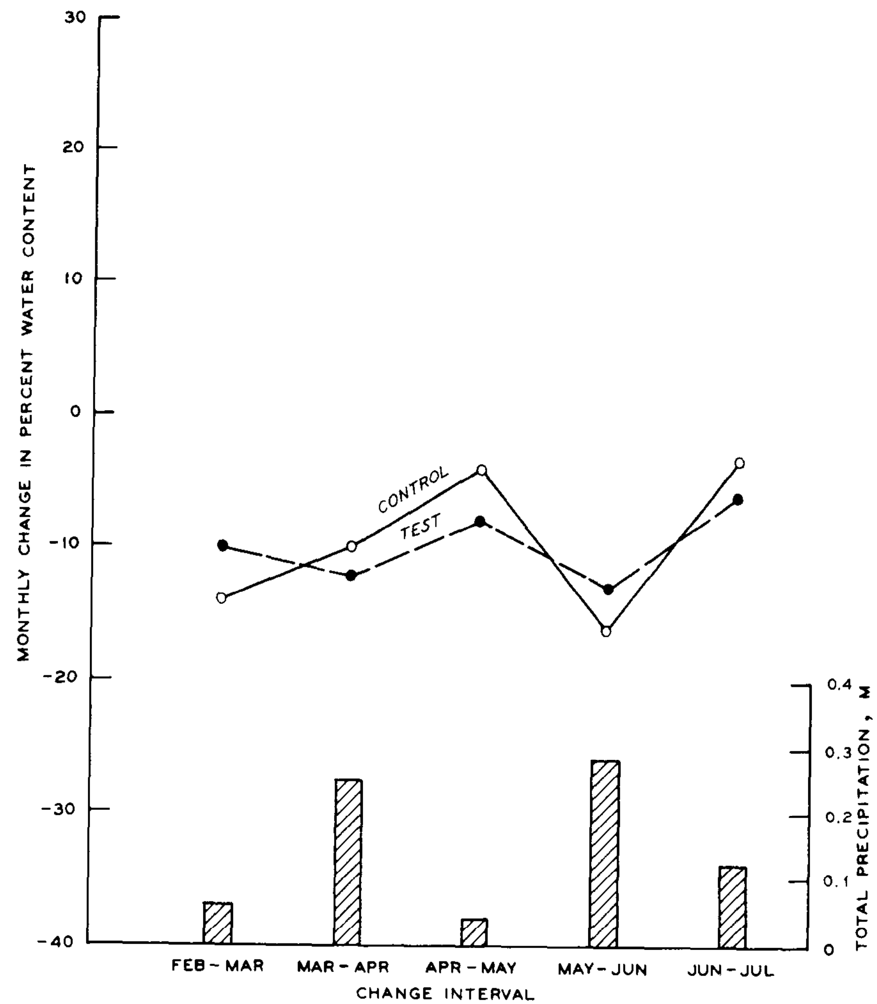

Figure 33. Monthly change in water content with time and precipitation, 1.21-m depth

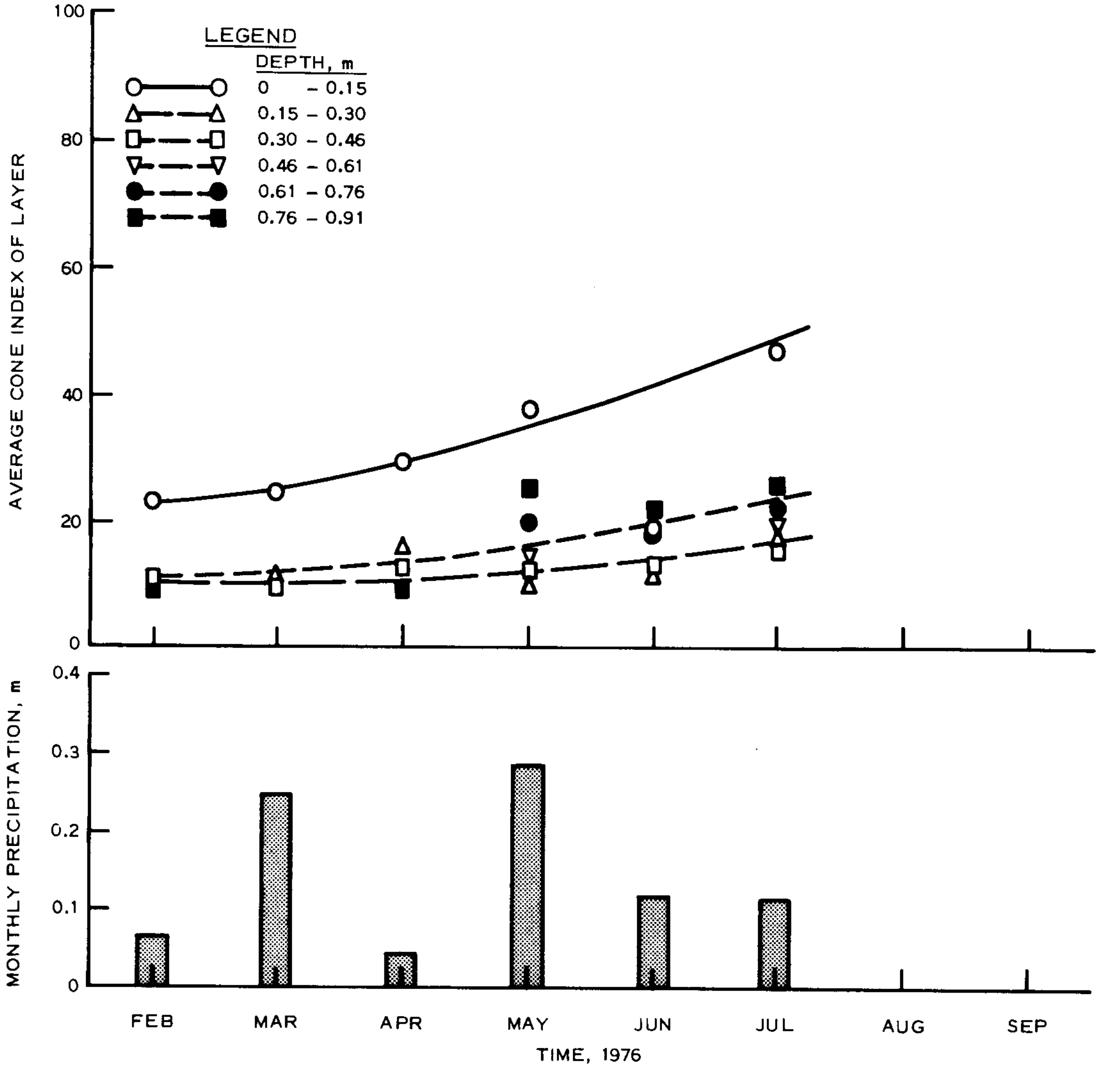

Figure 34. Change in average CI data with time, depth, and precipitation for periodic mixing test area

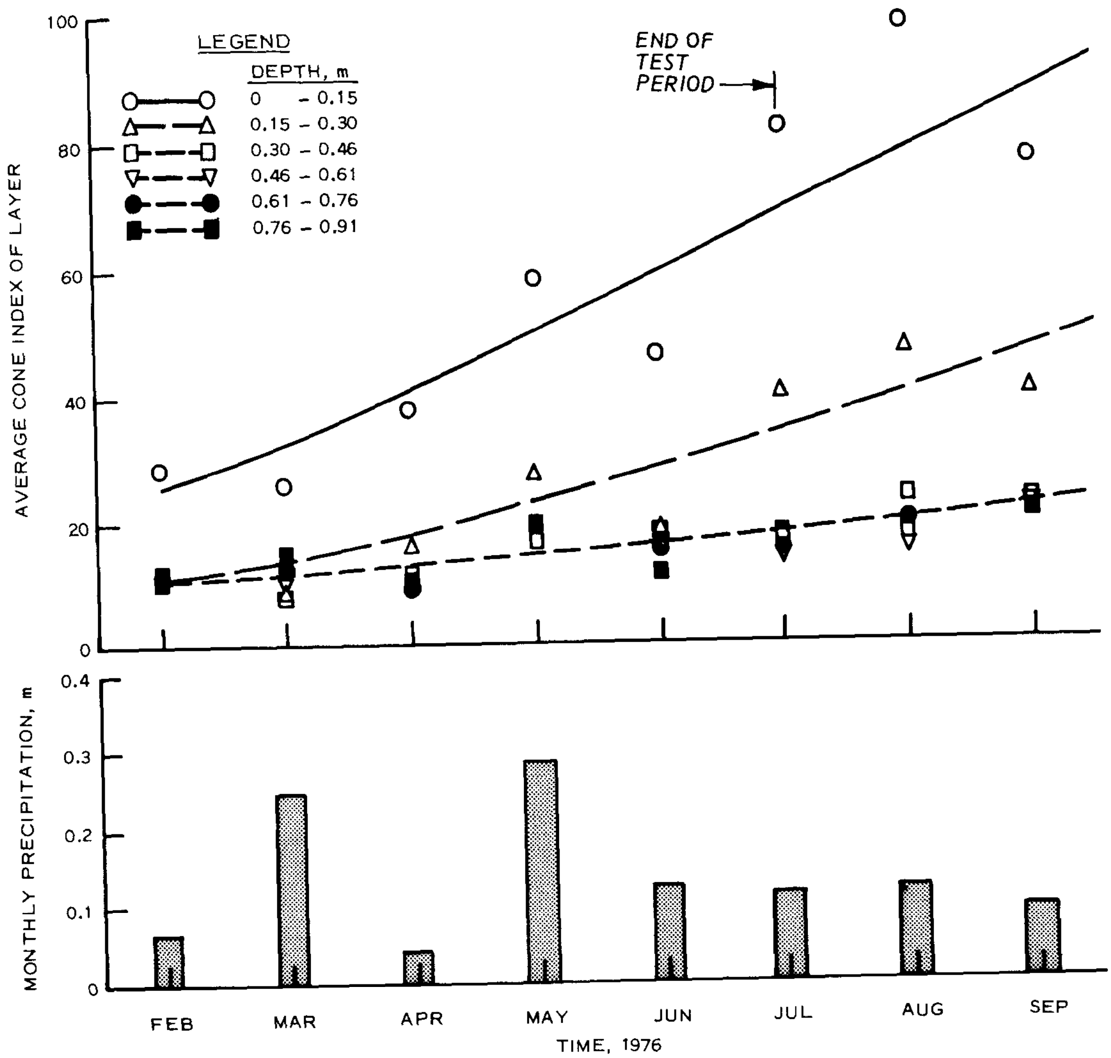

Figure 35. Change in average CI data with time, depth, and precipitation for periodic mixing control area

dredged material approached 20, the RUC had extreme difficulty in mixing the crust and underlying material, causing the test to be terminated. The average CI of the crust would support a man and, after May 1976, support a low-ground-pressure vehicle for a single pass. However, below the crust the average CI was such that a man would have trouble traversing the area. In the control section, the average CI in the upper 0.3 m increased greatly with time, reflecting increased surface crust development as the water table dropped. Below 0.3 m the average CI data were markedly similar to that of the test area below 0.15 m. The average CI of the control area crust in July 1976 would have supported numerous vehicles for a single pass and allowed low-ground-pressure vehicles or conventional vehicles on mats to work in the area.

92. As may be seen in Figure 26, a rather extensive volunteer freshwater vegetative cover became established over the control area, while the surface of the test area remained entirely bare during the test. The pore water of the dredged material had an initial saline concentration approaching that of seawater in Mobile Bay. Precipitation apparently leached sodium chloride from the surface crust in the control area while the periodic mixing continually brought saline soil to the surface, inhibiting vegetation establishment between mixing cycles.

93. Approximately 17 hr of continuous RUC operating time was required for the six mixing cycles, plus approximately 4 hr of downtime from mechanical problems. Approximate cost of RUC operation (primarily labor and fuel) is $75 per hour, thus the cost of providing an additional 858 m^3 of disposal area volume was $1,575 or $1.84 per m^3. Under normal conditions, a RUC could be expected to mix about 1.0 to 1.5 ha per working day, depending upon initial material consistency and equipment downtime. Lower unit operating costs could probably be obtained with a cable-drag plow system pulled between the perimeter dikes or from a central tower to the perimeter dikes but at considerably higher capital investment. The estimated capital cost of a RUC is approximately $75,000, while a semipermanent cable system might cost two to three times this amount.

Summary

94. Based on the data obtained, it may be stated, for the given test conditions and material:

a. Periodic RUC rotor mixing of dried surface crust and underlying fine-grained CH dredged material initially above the LL resulted in an increase of 0.21 m of vertical subsidence over a 6-month period, compared with an adjacent unmixed area subjected to the same climatic conditions. Corrections were not made for any additional volume gained in the control area from increase in size, depth, and number of crust desiccation cracks. Cost of creating disposal area volume was estimated at $1.84 per m^3.

b. Water-content data from below the zone of RUC rotor mixing (approximately upper 0.6 m) appeared unaffected by the mixing action; below this zone, water-content profiles and drying trends in the test and control areas remained approximately the same. This behavior tends to indicate that observed surface subsidence is not related to thickness of dredged material, if the thickness is greater than the RUC rotor mixing depth.

c. Once the average CI below the crust in the RUC rotor mixing zone approached 20, corresponding to a water content approximating the LL of the dredged material, the RUC was ineffective in mixing surface and underlying material. These data infer that, for the test conditions and material, the 6-month value of 0.7-ft additional subsidence is an absolute value, not an indication of subsidence rate expected from the process. If the data are generalized, it might be expected that RUC rotor mixing would be ineffective once the water content of any fine-grained dredged material approached its LL and/or its CI approached 20. While additional mixing at lower water contents could perhaps be obtained by RUC-towed or cable-drawn plows or discs, Willoughby[18] indicated that drawbar requirements for pulling implements in fine-grained dredged material increase markedly once the CI exceeds 20.

d. Reduction of surface support capacity by periodic mixing is a detriment to conducting further dewatering work in a disposal area, for if the volume gain from mixing is inhibited once the water content in the upper 0.6 m approaches the LL, other equipment may have to be brought into the area to work on the surface to continue the dewatering.

e. Prevention of vegetation establishment degrades the aesthetics of the area, reduces available habitat, and further reduces equipment support capacity that might be expected from any vegetative mat.

95. While some volume gain was achieved by the periodic mixing process, the net overall effect of mixing does not appear to justify the effort required, thus substantiating the original drying theory presented in Part II. Behavior of both test and control areas appeared to be more nearly influenced by precipitation than any other factor. The most important operation may thus be to rapidly remove precipitation before it can be absorbed by upper layers of the dredged material.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

96. Based upon the information presented and discussed herein, the following were concluded:

- a. Mechanical agitation of highly plastic clay slurry does not significantly alter the rate or amount of either evaporative water loss or slurry volume reduction, as compared with unagitated material exposed to the same climatic conditions. Additional evaporation from exposed shrinkage crack surface area appears to supplement any decrease in surface evaporation rate as drying progresses.
- b. Maximum expected water loss rates from highly plastic clay slurries may be approximated by Standard Class A pan evaporation under existing climatic conditions. The exact length of time such rates may be maintained depends on soil properties, initial water content, water table location, and existing climatic conditions.
- c. Periodic mixing of dried surface crust with underlying fine-grained highly plastic dredged material at water contents above its LL slightly accelerates the rate of dredged material drying and volume reduction. However, as a practical matter, the results achieved do not appear to justify the effort required in mixing. Further, such periodic mixing destroys the support capacity of the dredged material surface, prevents establishment of any vegetative cover, and allows local ponding in surface ruts produced by mixing.

97. It is recommended that CE Districts interested in dewatering fine-grained dredged material placed in confined disposal areas from slurry to soil form expend maximum effort in improving surface drainage to remove decant water and precipitation as rapidly as possible, so that available evaporative forces may be used to dry the dredged material into crust. Use of mechanical agitation on either a continuous or periodic basis is not recommended.

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Table 1

Average Daily and Cumulative Water Loss from Agitated and Unagitated Water and Soil Slurry

	Daily Water Loss, g				Cumulative Water Loss, g					
	Water**		Soil Slurry†		Water*				Soil Slurry†	
					Unagitated		Agitated			
Date 1974	Unagitated	Agitated	Unagitated	Agitated	1	2	1	2	Unagitated	Agitated
November										
20	726.0	699.7	737.1	737.1	726.0	--	699.7	--	737.1	737.1
21	513.2	575.2	510.2	538.6	1239.2	--	1274.9	--	1247.3	1275.1
22	659.6	540.0	482.0	496.1	1898.8	1595.0	1814.9	1620.0	1729.3	1771.8
23	580.4	317.2	454.6	467.8	2479.2	--	2132.1	--	2183.9	2239.6
24	--	--	--	--	--	--	--	--	--	--
25	939.8	1035.9	793.8	708.7	3419.0	--	3168.0	--	2977.7	2948.3
26	256.6	236.6	340.2	354.3	3675.6	--	3404.6	--	3317.9	3302.6
27	363.5	265.9	396.9	341.2	4039.1	--	3670.5	--	3714.8	3643.8
28	--	--	--	--	--	--	--	--	--	--
29	693.0	737.8	722.9	723.0	4732.1	--	4408.3	--	4437.7	4366.8
30	--	--	--	--	--	--	--	--	--	--
December										
1	--	--	--	--	--	--	--	--	--	--
2	445.8	382.3	354.3	396.9	5177.9	--	4790.6	--	4792.0	4763.7
3	300.7	222.7	311.9	269.3	5478.6	--	5013.3	--	5103.9	5033.0
4	302.9	266.8	311.9	297.6	5781.5	5455.0	5280.1	5035.0	5415.8	5330.6
5	201.5	176.6	311.8	354.4	5983.0	--	5456.7	--	5727.6	5685.0
6	--	--	--	--	--	--	--	--	--	--
7	--	--	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--	--	--
9	278.7	572.4	354.4	453.6	6261.7	--	6029.1	--	6082.0	6138.6
10	485.5	209.5	240.9	212.6	6747.2	6440.0	6238.6	6140.0	6322.9	6351.2

Note: All values are average of two replicate treatments.

* Water losses in column 1 represent cumulative total of losses calculated from hook gage readings, surface elevation, and pan geometry; those losses in column 2 are actual amounts of water added to bring water surface to original level.

** Water losses calculated from hook gage readings, surface elevation, and pan geometry.

† Water losses calculated from change in weight of treatments.

Table 2

Average Surface Temperatures of Soil Slurry and Water Treatment

Date 1974	Surface Temperature, °C*			
	Water		Soil Slurry	
	Unagitated	Agitated	Unagitated	Agitated
November				
19	23.0	23.5	23.2	23.5
20	19.7	19.7	22.2	21.2
21	17.7	17.5	22.5	20.7
22	18.2	18.7	19.7	19.2
23	20.5	20.5	21.0	20.0
24	--	--	--	--
25	13.0	12.2	17.0	13.0
26	13.0	12.7	21.0	15.5
27	13.0	12.5	19.0	13.0
28	--	--	--	--
29	13.7	13.7	21.7	17.0
30	--	--	--	--
December				
1	--	--	--	--
2	9.5	9.0	17.2	11.5
3	10.2	9.2	19.5	12.5
4	11.0	10.2	17.0	11.5
5	12.7	12.0	21.0	16.0
6	--	--	--	--
7	--	--	--	--
8	--	--	--	--
9	9.7	9.0	17.7	13.0
10	8.7	8.2	11.2	8.7

* Values represent average of measurements for replicate treatments.

Table 3

Climatic Data

Date 1974	Cumulative Wind Velocity km	Relative Humidity %	Air Temperature °C
November			
19	154.14	68	23.3
20	286.56	22	18.8
21	290.58	22	21.6
22	329.84	26	23.3
23	370.87	40	23.3
24	--	--	--
25	545.45	36	11.1
26	548.50	18	16.1
27	583.42	41	13.8
28	--	--	--
29	613.99	26	13.3
30	--	--	--
December			
1	--	--	--
2	751.72	46	9.4
3	775.69	36	11.1
4	792.27	22	13.8
5	807.39	18	17.7
6	--	--	--
7	--	--	--
8	--	--	--
9	971.67	35	7.7
10	978.59	23	13.8

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Haliburton, T Allan

Effects of mechanical agitation on drying rate of fine-grained dredged material / by T. Allan Haliburton ... [et al.]. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.

78 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-10)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit Nos. 5A02 and 5A14.

Appendixes A-C on microfiche in pocket.

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