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# POND LININGS FOR DESALTING PLANT EFFLUENTS

## Field and laboratory evaluation of four types of lining materials for seepage control in brine disposal ponds

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A field and laboratory evaluation of lining materials proposed for use in brine disposal ponds was conducted. Flexible membrane linings were the most effective for seepage control, followed by hard-surface linings, compected earth, and soil sealants. The investigation and other studies show that soil sealants only reduce seepage and do not affect a complete seal, and that the service life of soil sealants is questionable. Recommendations on a monitoring system for measuring seepage losses from brine disposal ponds are included.


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UNITED STATES DEPARTMENT OF THE INTERIOR
Walter J. Hickel
Secretary

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Ellis L. Armstrong
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## INTRODUCTION

In the production of potable water at inland desalting plants, a large quantity of concentrated brine (effluent) is also produced. One method for the disposal of the effluent is the use of evaporation ponds. In June of 1967, the Bureau of Reclamation (USBR) was authorized by the Office of Saline Water (OSW), under Agreement No. 14-01-0001-1306, to conduct an eight-point program entitled "Surface Facilities for Disposal of Desalting Plant Effluents." The objective of the program was to develop design and operating criteria for brine disposal ponds.

Briefly the eight-point program, completed in June of 1970, consisted of:

a. Preparation of a "State-of-the-Art" bibliography and review on brine disposal ponds. Included in the review is a survey of 50 States and the Federal Water Quality Administration* on water pollution regulations pertaining to brine disposal ponds.[1]

b. Explore and evaluate soil samples for proposed brine disposal pond sites.

c. Laboratory evaluation of pond lining materials and soil sealants.

d. Development of a monitoring system for continuous and routine measurements of seepage losses.

e. Develop and evaluate techniques for increasing evaporation rates. Spraying to increase evaporation rates was investigated and reported by OSW.[2]

f. Conduct field tests on pond linings and soil sealants.

g. Preparation of a manual on the design, construction, and operation of brine disposal ponds.[3]

h. Conduct an economic study of salt disposal. Results of this study are summarized in the manual.[3]

This report summarizes the laboratory and field evaluation of various pond lining materials and soil sealants. Field studies were conducted at Dalpra Farm; a field test installation near Longmont, Colorado, where the USBR, under another OSW contract, is evaluating various desalting equipment. Included in the field tests were two soil sealants recommended by Diamond Shamrock Corporation, Painesville, Ohio, who conducted earlier studies for OSW on soil sealants.[4,5] In the laboratory evaluation, soils from both Dalpra Farm and the Roswell, New Mexico OSW Desalting Plant area were used. Also included in the report are recommendations on a monitoring system for measuring seepage losses from brine disposal ponds.

## WATER POLLUTION REGULATIONS

The feasibility of using brine disposal ponds will depend primarily on the development of low-cost pond liners and sealers. Such materials will also have to provide adequate seepage control as dictated by local water pollution regulations.

In the survey of state regulations concerning brine disposal ponds,[1] most states do not have specific regulations on maximum permissible seepage losses from brine disposal ponds, but many have some provisions for seepage control under other regulations. Many states appear to be studying the problem and may publish specific regulations in the future. Only four states listed any quantitative figure for seepage limits and these they inferred from other waste and sewage requirements. Minnesota gave a figure of 0.01 ft/day ($3.7 \times 10^{-6}$ cm/sec) maximum. Idaho, Nebraska, and Washington required seepage less than 0.02 ft/day ($7.5 \times 10^{-6}$ cm/sec).

In soils engineering, soils are customarily regarded as impervious if the coefficient of permeability** is less than 1 ft/yr ($1 \times 10^{-6}$ cm/sec) or about 0.003 ft/day.[6] Seepage over 0.003 ft/day ($1 \times 10^{-6}$ cm/sec) may be excessive in certain areas for brine disposal ponds,[1] and regulations for impervious ponds may specify seepage less than 0.003 ft/day ($1 \times 10^{-6}$ cm/sec) or even 0.

*Formerly Federal Water Pollution Control Administration (FWPCA).
1 2 3 4 5 6 References listed on page 30.
**The coefficient of soil permeability is based on a unit head of water on a unit depth of soil of unit area. Seepage through canal and pond linings are usually expressed in terms of volume of water loss over a unit area per unit of time (as cubic feet per square feet per day-cfd) regardless of water depth. In this report seepage units have beer abbreviated to velocity terms (as feet per day, or feet per year where values are very small).

## LINING MATERIALS INVESTIGATED

Four types of lining materials were investigated for possible use in brine disposal ponds, and they include: compacted earth, flexible membrane linings, hard-surface linings, and soil sealants.

**Compacted Earth Linings**

Compacted-earth lined ponds often are the lowest in construction costs. The costs range from $0.60 to $0.90 per square yard, depending upon thickness and density required for desired seepage control. Factors to be determined with compacted-earth lined ponds are: is the pond sufficiently impermeable, does the brine effect permeability, and is there assurance of continued impermeability over the life of the pond.

As in other earth construction, the design of earth lining for evaporation ponds will depend, in part, on the properties of the soil used. Because of the variation in soil composition, testing is required to define the properties needed for design purposes. For these evaporation ponds the effect of brine on the soil properties must also be evaluated. This can be accomplished by incorporating the brine into the soil test procedure wherever feasible.

In addition to the soils studied in this investigation there are some data available on an earth lined pond used for salinity alleviation at Malaga Bend Division of the McMillan-Delta Project near Carlsbad, New Mexico. Because of the similarity between this pond and the ponds proposed for desalting plant effluents, the available information is pertinent to this study.

The problem in the Malaga Bend area was the seepage of highly mineralized water into a 3-mile (4.8-km) reach of the Pecos River. This seepage increased the salt load in the river by about 430 tons (390 metric tons) per day. Alleviation of this contamination was accomplished by lowering the water table to below the river level by pumping from wells into a compacted-earth lined evaporation pond. The area of this pond is approximately 85 acres (34 ha) with a capacity of about 1,000 acre-feet ($1.2 \times 10^6$ cu m).

The earth lined pond was constructed by scarifying the native soil, a lean to plastic clay, to a depth of 18 inches (46 cm) and compacting the full 18 inches (46 cm) from the surface in one layer. The soil was compacted to at least 98 percent of maximum density with 22 passes of a 18,900-pound (8,600-kg) vibratory roller. Available information shows that seepage through the lining was estimated to be 0.5 ft/yr ($4 \times 10^{-7}$ cm/sec).

Although the available information is limited it does show that an effective earth lining can be obtained when clayey soils are used. The unit cost for this lining was about $0.70 per cubic yard in 1963 when the pond was constructed under USBR Specifications No. 500C-126. A report on the performance of this pond is being prepared by the U.S. Geological Survey Office at Carlsbad.

**Flexible Membrane Linings**

Polyvinyl chloride (PVC) and polyethylene are presently the most widely used plastic film materials for lining applications.[7] These flexible linings are easy to install, requiring a minimum of equipment and skilled labor. The linings are placed on prepared subgrades and normally covered with earth material to protect them from the elements and physical damage. Plastic membranes are low in cost, with complete installation, including cover materials, ranging in cost from $1.00 to $1.50 per square yard.

PVC is more resistant to puncture, more readily available in large fabricated sheets, and more easily repaired and field spliced than polyethylene. PVC is supplied in widths up to 65 feet (20 m) and to any length practical for handling, to minimize the amount of field joining required. This lining is generally supplied accordion folded in both directions so that the liner can readily be unfolded from a truck traveling on the subgrade.

For installing a PVC lining, adjacent sheets are joined using a 4-inch (10.2-cm) minimum width bonded-lap joint with solvent adhesive recommended by the PVC lining manufacturer.

A PVC lining, 10 mils (0.25 mm) thick, was evaluated in this study. The lining installed at the Dalpra Farm test site was shop fabricated in one piece to fit the interior vertical surface and base configuration of the test tank. USBR specifications[3..7] require that factory bonded seams shall be watertight and the strength of the bonded seams either in the machine or transverse direction of the film shall be not less than 80 percent of the breaking strength of the film when tested in a similar direction.

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[3] [7] Op. cit. p. 1.

Polyethylene plastic lining is lower in cost than PVC and exhibits greater resistance to soil bacteriological deterioration. This is primarily because the use of plasticizers is not necessary in the manufacturing of polyethylene. Some low-grade plasticizers used in the manufacturing of PVC to impart flexibility may be vulnerable to micro-organism attack and water leaching.

Polyethylene is available in seamless widths to 40 feet (12 m) and normally in custom roll lengths of 100 feet (30 m). An accordion-fold seam is used to join polyethylene lining. This type seam should be bonded together with tape or adhesive as recommended by the manufacturer.

A custom roll of polyethylene plastic, 6 mils (0.15 mm) thick, was obtained for evaluation at Dalpra Farm. The roll was wide enough to provide a seamless lining. This film was primarily manufactured for agricultural- and industrial-type use. Such a film occasionally has defects such as pinholes and blisters and is not expected to be as watertight as PVC.

A 45-mil- (1.14-mm-) thick, nylon-reinforced butyl-rubber liner was evaluated at Dalpra Farm. The lining was shop fabricated from 54-inch- (137.2-cm-) wide sheets. The sheets were joined using a 4-inch- (10.2-cm-) wide lap seam bonded with butyl adhesive. The rubber liner was originally scheduled for use in the evaporation monitoring pond but due to some seam problems it was not used for this purpose. Rubber linings are relatively high in cost ($2 to $3 per square yard installed) and this limits their use to only special installations.

**Hard-surface Linings**

Either asphaltic-concrete or soil-cement linings could be designed for use in brine disposal ponds requiring a durable, hard-surface lining. The use of such linings is primarily dependent upon source and type of locally available aggregate.

Asphaltic concrete is a carefully controlled mixture of asphalt cement and well-graded aggregate, thoroughly mixed and compacted while hot into a uniform, dense mass. Properly mixed and placed, asphaltic concrete forms a watertight, durable, erosion and chemically resistant lining for brine disposal ponds. These mixtures are higher in asphalt binder and mineral filler contents than asphaltic-concrete mixes used for highway surfacing. The higher contents are required to produce an essentially voidless mix for water impermeability.[8 9] A hydraulic-type mix, based on the USBR asphaltic-concrete lining specifications was installed at Dalpra Farm. Construction costs for a 2- to 3-inch- (5.1- to 7.6-cm-) thick compacted lining, which is generally sufficient for shallow evaporation ponds, will vary between $1.50 to $2.00 per square yard.

Soil-cement is a mixture of soil, portland cement and water. As the cement hydrates, the mixture becomes hard, and would form a hard-surface type of lining. In USBR experimentation with soil-cement as a canal lining, performance has been variable depending upon the soils, amount of cement, care taken during construction, and climatic conditions.[10] A well-graded sand with 15- to 30-percent fines passing a No. 200 sieve is usually best. Where such soil is readily available, the USBR sometimes uses soil-cement as an alternative lining for fresh-water reservoirs. Also, in locations where rock is scarce, soil-cement is used as an alternative to rock riprap for facing earth embankments containing bodies of water.[11] In this investigation, laboratory tests were conducted on Dalpra Farm soil with Type V portland cements of 6, 8, and 10 percent by weight by dry soil. Also, one seepage test of soil-cement at Dalpra Farm was conducted; although Type V sulfate-resistant cement would normally be recommended, Type I cement was inadvertently used in the seepage test. Detrimental effects of sulfates in the brine on soil-cement would require time, probably a longer period than covered by these tests. Therefore, the use of the less resistant Type I cement allowed a more critical evaluation of performance within the relatively short test period.

On a recent soil-cement lining for a 160-acre (64.8-ha) pond, soil-cement cost $6.32/cu yd ($8.27/cu m); this amounts to $1.05/sq yd ($1.26/sq m) for a 6 inch (15 cm) thickness.

**Soil Sealants**

Over the years the USBR has investigated[12] a number of admixtures and chemical agents for controlling seepage in canals. These materials ranged from the rather common products such as portland cement and sodium carbonate to specifically formulated asphalt emulsions, resinous polymers, petroleum emulsions, and various compounded agents.

The action of the agents can be physical plugging of pores, the formation of a distinct impermeable membrane, or chemical reactions with soil constituents. Application methods include surface spraying, subsurface injection, addition to water or

[8 9 10 11 12] Op. cit. p. 1.

brine for subsequent deposition in the subgrade, and mixing with soil. Most of these materials will produce specific results with certain soils, but produce highly variable results with different soils.

Prior to the USBR involvement in the OSW program, Diamond Shamrock conducted studies on soil sealants for OSW. The work was primarily concerned with evaluating the effectiveness of various chemical products in rendering soil from Roswell, New Mexico, impervious to waste brine.[4] Diamond Shamrock conducted additional studies in cooperation with the USBR. Their contract work was completed and reported in June of 1968.[5]

In these studies, over 160 formulations using 25 materials and several secondary additives were tested. Generally, the materials were mixed into the soil and then compacted to achieve seepage reduction.

Diamond Shamrock reported four classes of additives were effective in rendering local soil suitably impervious to brine effluent from the Roswell, New Mexico desalination plant. The four additives were: lignin derivatives gelled with sodium chromate or alum, carboxymethyl cellulose with alum, petroleum emulsions and an attapulgite clay formulation. In their tests conducted with Dalpra Farm soil, soil Sample No. 48D-11 was rendered satisfactorily impervious with either carboxymethyl cellulose and alum or the attapulgite clay formulation. However, a second soil sample (48D-18) could not be adequately sealed. Sample No. 48D-18 was a more sandy material than 48D-11.

Two mixtures were recommended by Diamond Shamrock for field testing at Dalpra Farm. These mixtures, along with their costs at the recommended applications rates, are listed below:

1. Two percent attapulgite clay formulation; material cost—$0.21 per square yard.

2. Combination of 0.25 percent medium molecular weight carboxymethyl cellulose with 0.05 percent alum; material cost—$0.46 per square yard.

Percentages are based on dry weight of soil. Alum is used to produce a stiffer gel product.

Based upon the ease of application, minimum subgrade preparation, low-cost, and waterproofing characteristics, a liquid cutback asphalt was selected for evaluation as possible lining material for brine disposal ponds. The liquid asphalt, Code B-5876, is a proprietary product formulated for deep penetration, and produces a hard-base asphalt residue upon solvent evaporation. Earlier USBR laboratory studies[13] indicated the proprietary product was superior to standard emulsified or cutback asphalt materials for stabilizing sandy soils. The material is easily spray-applied with conventional equipment. Cost of the liquid asphalt for a brine pond application would vary between $0.50 to $0.75 per square yard depending upon quantities involved. An application rate of 2 gsy* (9.2 $l/m^2$) was used at Dalpra Farm.

## CONCLUSIONS

### Field Investigation

The conclusions listed below are based on the field investigation conducted under the following conditions:

A. Natural soil at Dalpra Farm is a relatively pervious silty sand. The average seepage rate during the test season was 75 ft/yr ($7.5 \times 10^{-6}$ cm/sec).

B. Brine effluent had an average pH of 8.2 and contained over 80 percent sodium salts. The average Total Dissolved Solids (TDS) was about 3,000 parts per million (ppm).

C. Test season was from about May 1 to December 1, 1969.

D. Seepage comparisons are based on the assumption that all seepage losses occurred through the bottom of the ponds.

1. The four types of lining materials evaluated, listed generally in the order of decreasing effectiveness for seepage control are: flexible membrane linings; hard-surface linings; compacted-earth linings and soil sealants.

2. The PVC plastic was the most effective lining material. Field tests and visual observations indicated the PVC provided a watertight lining. Because of its impermeability the PVC-lined pond was used to measure the evaporation rate required in the water budget monitoring system. The nylon-reinforced butyl rubber was nearly as effective as the PVC lining. However, some

[4] [5] Op. cit. p. 1.
[13] Op. cit. p. 1.
*Gallons per square yard.

problems were encountered in obtaining watertight seams. Field measurements indicated the thin polyethylene plastic had some material defects and was inadequate as a lining. Thicker polyethylene plastic film specially formulated for lining purposes would probably perform effectively.

3. Of the two hard-surface linings evaluated, asphaltic concrete was the most effective and provided a satisfactory lining. As tested at Dalpra Farm, the asphaltic concrete did not deteriorate. Some cracking occurred to the soil-cement lining after winter exposure. The cracking was probably caused by either frost-heave or chemical reaction between the brine and soil-cement lining. For soil-cement linings to be satisfactory, Type V (sulfate resistant) cement should be used, and careful testing evaluation of the chemical and physical characteristics of the brine, available soil, and cement content would be needed for durability and imperviousness.

4. Although the compacted-earth lining provided a significant reduction in seepage, the soil used is not the type which would give the best lining. Use of clay material such as the Roswell soil would provide a much better compacted-earth lining.

5. This investigation and other studies have shown soil sealants to only reduce seepage and not affect a complete seal. Also, the service life of soil sealants is questionable. At this time, no soil sealant has provided all of the sealing properties needed for brine disposal ponds.

6. Of the three soil sealants evaluated, the liquid asphalt, spray applied over the natural, untreated soil, showed the most seepage reduction. Some seepage reduction was noted for the carboxymethyl cellulose and alum mixture. However, seepage was increasing at the end of the test season. The attapulgite clay formulation was not effective in reducing seepage. Its seepage characteristics were very similar to the natural, untreated soil.

7. The average evaporation computed from data obtained at the test site was about 38 in./yr (97 cm/yr). This compares with Weather Bureau averages for lake evaporation of 39 in./yr (99 cm/yr) and pan evaporation of 55 in./yr (140 cm/yr) for the years 1946 to 1955.

8. The instrumentation and analyses used at Dalpra Farm measured seepage to plus or minus one-third of a foot (10 cm) per year, which is adequate for these tests and generally for monitoring brine disposal ponds.

**Laboratory Investigation**

Laboratory tests were conducted primarily to determine: (1) the effectiveness of various soil sealants for reducing seepage in Roswell and Dalpra soil, and (2) physical properties of the lining material installed at Dalpra Farm. Based on the laboratory investigation, the following conclusions were indicated:

1. In the permeability tests conducted on lean-clay soil from the Roswell Desalting Plant area, compacted to above 80 percent maximum density, the effect of soil sealants was not evident. At 80 percent maximum density the effect of the sealants is more discernable. Within these data the methyl cellulose performed best as a sealant, reducing the permeability to zero. The other sealants, sodium silicate and lignin, performed well in some tests and poorly in others. Generally it appears that the most practical way to treat soils of this nature is to compact them to near maximum density and not use a sealant.

2. Permeability tests on Dalpra soil treated with the attapulgite clay formulation showed a reduction in permeability of 50 percent while tests with the carboxymethyl-cellulose- and alum-treated soil showed a reduction in permeability of 75 percent.

3. Laboratory tests conducted on the plastics and butyl-rubber lining materials indicated they had satisfactory physical properties for use in brine disposal ponds. However, the puncture resistance of the polyethylene, since it was thinner, was much lower than the puncture resistance for the PVC. Also, for the nylon-reinforced butyl, test results showed the bonded seams had low peel strength, and cracking was noted during the accelerated ozone test.

4. Laboratory tests showed a satisfactory hydraulic-type mix was used in the asphaltic-concrete lining and that adequate compaction was used during construction. Permeability tests conducted on core samples of the in-place lining indicated the asphaltic concrete was impervious.

5. Laboratory testing indicated that soil-cement containing 8 percent Type V portland cement would be adequate. Strength and durability test results were satisfactory, and permeability test results showed the soil-cement to be nearly impervious.

6. The liquid asphalt material, spray applied over the natural soil at a rate of 2 gsy (9.2 $l/m^2$), penetrated 1 to 1.5 inches (2.54 to 3.81 cm). The liquid asphalt was slow curing in Dalpra soil. Laboratory permeability tests were not reliable because of piping. However, no deterioration was noted in the permeability sample from exposure to the Dalpra brine effluent.

## INITIAL INVESTIGATIONS

### Roswell, New Mexico

The field test site was originally scheduled to be constructed at the Roswell Demonstration Plant. In August 1967 a field investigation was made at the Roswell site. Soil and well-water samples were obtained for laboratory testing. Also, some general observations were made concerning the area around the plant. It appeared that the high ground-water table, the clay soil in the area, and the lack of sufficient surface area would present construction problems. A tentative plan was made involving purchase of higher ground adjacent to the plant area to reduce the ground-water effect, and the installation of a drainage system to carry seepage from the test ponds. Drainage was necessary to avoid the effect of the relatively impervious soil.

Pending approval of this plan, laboratory testing was initiated. This testing included standard soils testing, chemical analyses of well water and soil, and a series of permeability tests. Test results are summarized in Appendix II; Tables 16, 18, and 20; and Figure 6.

In subsequent meetings between the USBR, OSW, and Diamond Shamrock, it was decided that the test installation construction problems, the difficulties OSW was having in purchasing sufficient land for the test installation, and the problems which would inevitiably arise in administration of the program from Denver, made use of the Roswell site impractical.

### Webster, South Dakota

Initially another desalting plant located at Webster, South Dakota, was tentatively considered as a field test site. However, when it was discovered that this plant was located within the Webster city limits, and that no suitable areas were available for the test installation, this installation was discarded. No field or laboratory testing was performed.

### Dalpra Farm

The site finally selected for the field test installation is located on the Gilbert O. Dalpra Farm near Longmont, Colorado. This site, shown on location map, Figure 1, offers several advantages over the other proposed sites. It is approximately 35 miles (56 km) from the Denver Federal Center, so daily trips to the site are practical and management of the tests is not difficult. The natural soil is a silty sand with a relatively high permeability rate thus eliminating drainage problems. In addition, a demineralizer plant operated by the USBR under contract for OSW is located at the field site. Various membrane-type demineralization units are evaluated using brackish, natural well water. The brine effluent from the plant is piped to a waste pond adjacent to the evaporation test pond area. The effluent is then readily available for pumping to the various test ponds.

Preliminary field investigation at the Dalpra Farm test site included field permeameter tests to evaluate the in-place soil permeability; logging of the subsurface soil to a depth of 10 feet (3 m) by visually classifying the soil taken from auger holes; in-place soil density testing, and procurement of soil samples for laboratory testing. Laboratory testing included gradation analysis, soil consistency tests, compaction tests, and permeability tests. Test results are summarized in Appendix II, Tables 17 and 21, and Figure 7.

## FIELD INSTALLATION

### General

The field test site at Dalpra Farm is shown in Figure 2 and Photograph 1. After consultation with Diamond Shamrock, 18-foot- (5.5-m-) diameter corrugated-metal, bottomless tanks were selected for use as the evaporation ponds. The construction of the test ponds was done primarily under contract, USBR Specifications No. DC-6668 (SF). The construction phase is discussed in Appendix III.

Ten bottomless tanks were installed, and each had a different lining material for evaluation, as listed below. Briefly, the linings included:

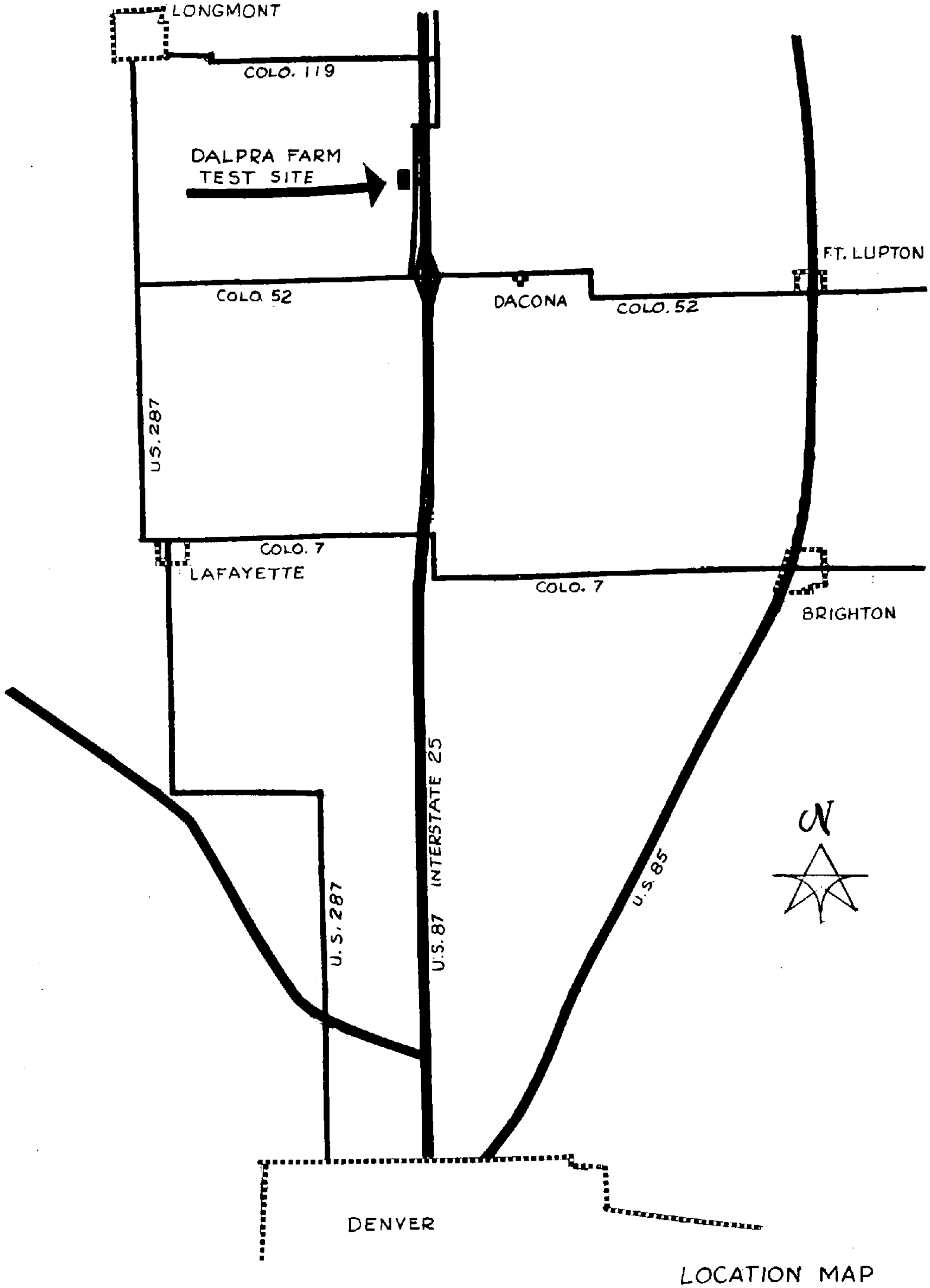





Figure 1. Location map.

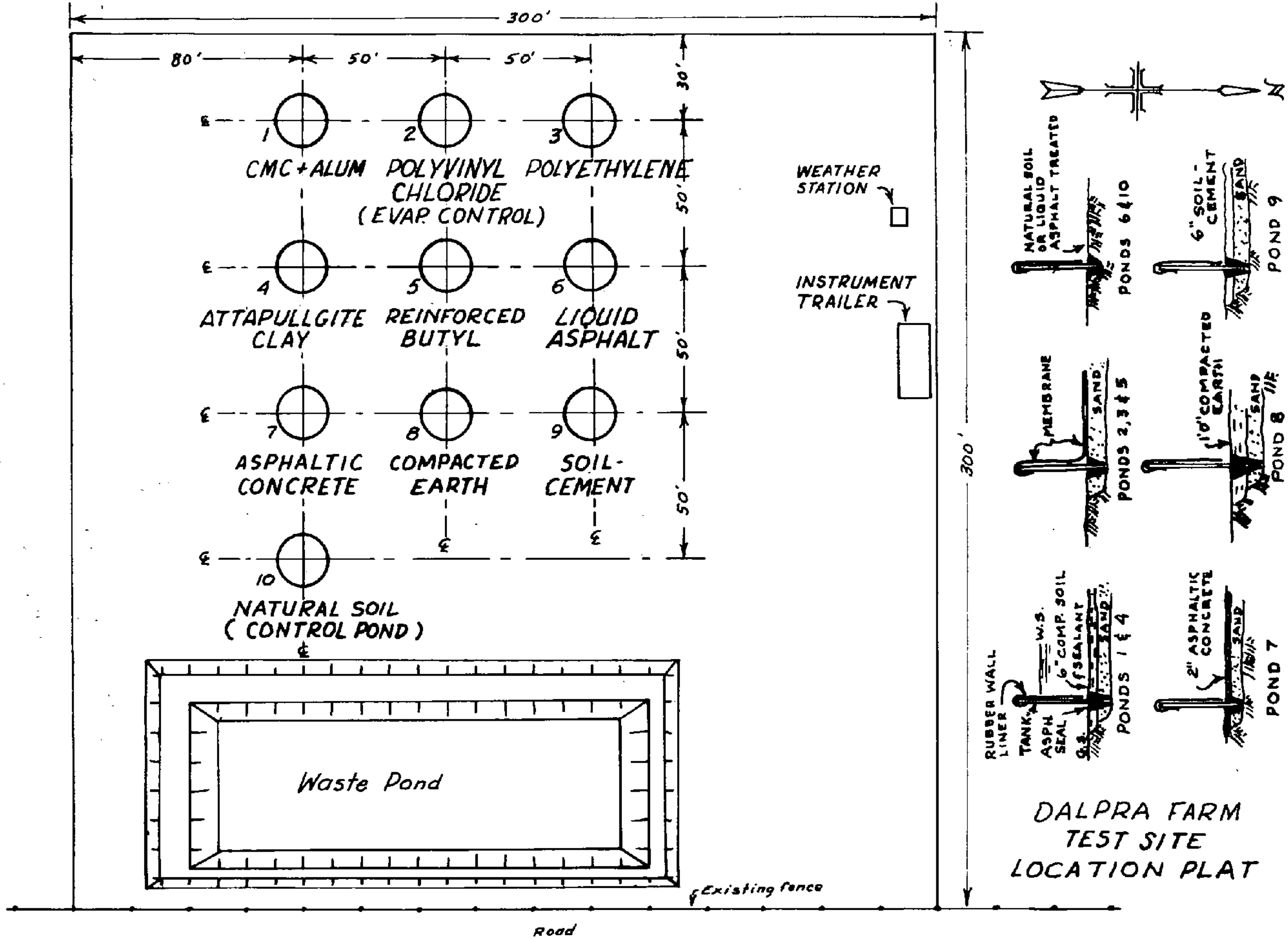
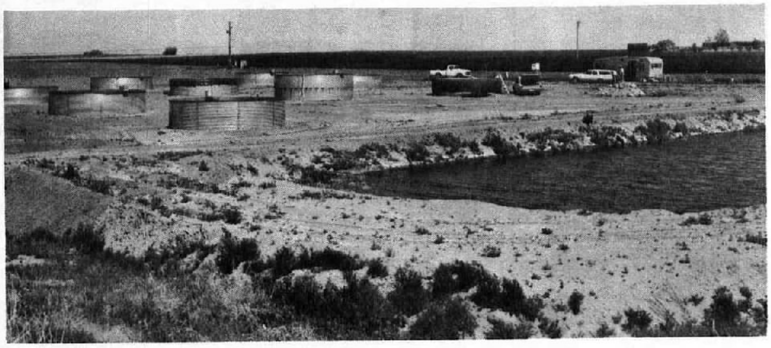
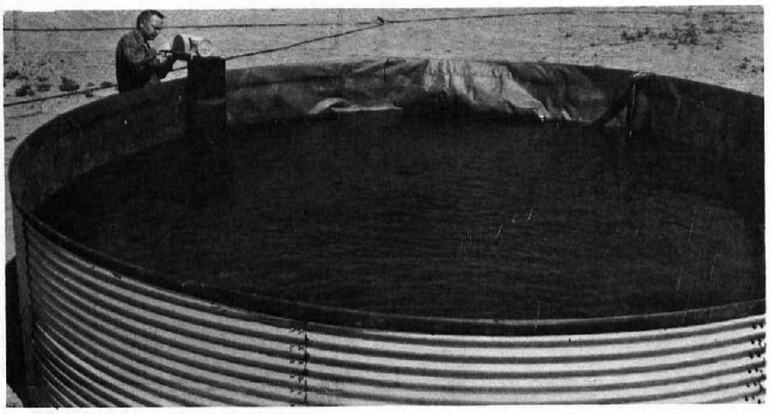



Figure 2. Dalpra Farm test site—Location plat.



General view of test site. Brine effluent pond for demineralizer plant is shown in foreground.



View of evaporation pond showing stilling well, water level gage and thermocouples.

Water level gage.

Photograph 1. Dalpra Farm test site for evaluation of lining materials for use in surface facilities for disposal of desalting plant effluents.

1. Polyvinyl chloride, 10 mils (0.25 mm) thick. Tank No. 2.

2. Polyethylene, 6 mils (0.15 mm) thick. Tank No. 3.

3. Nylon-reinforced butyl rubber, 45 mils (1.14 mm) thick. Tank No. 5.

4. Asphaltic-concrete lining, 2 inches (5.08 cm) thick. Hydraulic-type mix containing 7.1 percent asphalt based on dry weight of aggregate. Tank No. 7.

5. Soil-cement, 6 inches (15.2 cm) thick, containing 8 percent cement based on dry weight of soil. Tank No. 9.

6. Compacted-earth lining, 12 inches (30.5 cm) thick. Tank No. 8.

7. Chemical soil sealant recommended by Diamond Shamrock Company, 6-inch- (15.2-cm-) thick lining containing 2 percent attapulgite clay formulation, based on dry weight of soil. Tank No. 4.

8. Chemical soil sealant recommended by Diamond Shamrock Company, 6-inch- (15.2-cm-) thick lining containing 0.25 percent carboxymethyl cellulose and 0.05 percent alum, based on dry weight of soil. Tank No. 1.

9. Liquid cutback asphalt, B-5876, spray-applied over the natural soil at an application rate of 2 gsy (9.2 $l/m^2$). Tank No. 6.

10. Natural soil, untreated. Tank No. 10.

With the exception of the natural soil, Tank No. 10, the linings were placed over previously prepared sand drainage pads. All tanks were 6 feet (1.8 m) high, except for the 8-foot- (2.4-m-) high tank used for the compacted-earth lining. The tanks were installed in the ground as shown in Figure 2. A nylon-reinforced butyl-rubber liner was placed on the interior vertical surface to insure uniform evaporation and thermal conditions for all ponds.

Equipment was installed to measure seepage and evaporation losses, brine temperature at both the water surface and at the interface of the lining, and to monitor the weather conditions.

The linings were tested using a 3-foot (0.9-m) head of brine effluent to provide a realistic measurement of the liners' seepage control effectiveness. A 50-gpm (180-l/min) pump was installed, along with a firehose, to supply brine from the demineralizer plant's waste pond to the various tanks. A watermeter, calibrated for reading to 0.1 gallon (0.38 l), was installed in the pumping system to measure the volume of brine inflow to each pond.

Construction of the ponds was completed in late September of 1968. Installation of the pumping, seepage, and evaporation monitoring systems was completed in mid-October, and initial filling of the ponds was started. However, during initial filling some leakage through the vertical (field) seams of the sides in several metal tanks was encountered. These tanks were dewatered so that additional mastic material could be placed over the problem seams to correct the leakage. Necessary repairs were completed in November. However, due to subfreezing weather, field tests were discontinued for the winter.

Field testing was resumed in the spring of 1969 and ran through the first week in December. The field evaluation of the various linings materials was based primarily on this test season. Generally, at least one trip per week was made to the field site to perform the following functions:

1. Fill the ponds as required to maintain a 3-foot (0.9-m) brine level. After each filling the water-level recorder charts were changed. The new charts were referenced by siphoning the brine surface level over the walls of the ponds and setting the charts to relate to 3.0-foot- (0.9-m-) depth marks on the outside of each pond. Average seepage and evaporation rates were based generally on weekly water-level recorder history.

2. Change weather and water temperature recording charts, and record anemometer and odometers readings for determining wind velocity history at the site.

3. Observe and note any unusual changes in the field tests and perform general maintenance as required.

**Monitoring System for Seepage and Evaporation Measurements**

Instrumentation was set up at the test site to record the variables needed to evaluate the lining materials tested and to obtain field measurement experience. Such experience was necessary in making recommendations for instrumentation required for proper operation and maintenance of brine evaporation ponds.

Seepage must be determined and its direct measurement is difficult. Since watertight ponds were the goal of this study, any seepage was expected to be small and of the same magnitude as evaporation. Thus, evaporation must be accurately determined.

Evaporation rates are affected by the following variables:

1. The amount of solar radiation energy absorbed by the body of the water.

2. Saturation vapor pressure, surface tension, and wave roughness of the water at the air interface.

3. The relative humidity, temperature, velocity, and boundary layer characteristics of the air above the water.

4. Salinity of the water.

The water budget, an accounting for all water gains and losses, is the simplest accurate means to determine evaporation or seepage, providing one of these is known. The PVC-lined pond was watertight and was selected for monitoring evaporation.

During operation, the water level for all ponds was kept the same within practical limits, so that similar exposure to wind and thermal conditions was maintained for all the tanks.

Instrumentation was installed to measure and record water-level changes caused by brine and precipitation inflow and evaporation and seepage outflow for water budget computations. Measurements of other meteorological factors were made to verify the evaporation determinations and to help explain any seepage anomalies that might occur during the test season. Instrumentation included:

1. Recording water level gages.—Both evaporation and seepage determinations are dependent upon good water-level records. Counter-weighted 5-inch (12.7-cm) float-type water level gages were used to measure and record weekly histories of water level in the test ponds. These gages were designed to respond from a static condition to a 0.01-foot (0.3-cm) change in water level. However, experience with this equipment at the test site suggested better accuracy because lag was minimized since stage reversal was rare and enough water surface wave action was present to keep the mechanism moving. Stilling wells were used to shield the floats and weights from effects of wind. Brine input was metered to provide a check against the other water-level measurements.

2. Rain gage.—To account for precipitation inflow in the water budget, a bucket collecting recording rain gage was installed at the test site. The bucket is mounted on a spring-type weighing mechanism which converts weight into inches of rainfall. The pen reverses at 6 inches (15.2 cm) to give a full scale of 12 inches (30.4 cm). The gage was calibrated by a set of weights. The manufacturer claims an accuracy of 0.5 of 1 percent full scale (plus or minus 0.06 of an inch rainfall). The smallest division on the chart is 0.05 inch (1.27 mm).

3. Temperature and relative humidity.—A hygrothermograph was used to record temperature sensed by a bimetal assembly and simultaneously records relative humidity by means of a human hair sensing element. The manufacturer claims that errors of relative humidity rarely exceed 4 percent. The hygrothermograph was calibrated before the test season in a laboratory temperature controlled 50 percent relative humidity room. After the test season the calibrations were checked again. The temperature read about 1° F (0.5° C) high and the relative humidity read about 2 percent units high. Reading on the 8-day recorder chart can be estimated to 1° F (0.5° C) and 1 percent relative humidity with the smallest divisions being 2° F (1.1° C) and 2 percent relative humidity.

4. Wind measurement.—A standard cup-type weather anemometer fitted with a battery-powered odometer was set at about the same elevation as the top of the test tanks. The anemometer and odometer totalized miles of wind passing over the test site.

5. Atmospheric pressure.—A microbarograph with a bellows-type sensing element was used to measure and record atmospheric pressure. The smallest division on the recorder chart is 0.02 inch (0.51 mm) of mercury. The instrument was calibrated before the test season with a laboratory mercury barometer. After the test season the calibration was checked and the microbarograph read 0.02 inch (0.51 mm) high.

6. Water temperature measurements.—To sense water temperatures in all of the test tanks, lead (Pb) protected acid vat-type thermocouples were used. One was installed on the bottom lining interface, and another 2.5 feet (0.76 m) directly above the

bottom thermocouple, and 1 foot (0.3 m) away from the wall of the tanks. For thermal comparison the pair of thermocouples was mounted on the north side of each tank.

## FIELD TEST RESULTS

### General

Seepage losses as presented were obtained by taking the total drop in water level during periods when the ponds were operating satisfactorily and dividing this value by the number of days of operation. After accounting for evaporation and precipitation, this value was multiplied by 365 to obtain the yearly value, expressed as ft/yr, and by 1.12; a constant for correcting for the difference in the lined area compared to the surface area of the water in the pond. The results of seepage determinations for the individual linings are summarized in Tables 7 to 15 in Appendix I. Also shown are the corresponding water surface elevations during the time interval.

### Effectiveness of Lining Materials

Summary of seepage losses for the lining materials is listed on Table 1 and shown graphically in Figure 3. Based on the results, flexible membrane linings were generally the most effective for seepage control; followed by hard-surface linings, compacted-earth lining, and soil sealants.

Table 1

COMPARISON OF SEEPAGE LOSSES FOR THE LINING MATERIALS EVALUATED AT DALPRA FARM

| Lining material | Code | Seepage losses ft/yr (cm/sec x $10^{-6}$) | | |
|---|---|---|---|---|
| | | Initial | Final | Average |
| Polyvinyl chloride plastic | PVC | 0 | 0 | 0 |
| Nylon-reinforced butyl | NBR | 0.57 | 0.06 | 0.25 |
| Asphaltic concrete | AC | 10.9* | 0.82 | 2.32 |
| Polyethylene plastic | PE | 2.72 | 6.34 | 3.96 |
| Soil-cement | SC | 7.98 | 5.73 | 6.60 |
| Sprayed liquid asphalt | LA | 15.9 | 6.14 | 10.7 |
| Compacted earth | CE | 34.8 | 6.02 | 16.1 |
| Carboxymethyl cellulose | CMC | 15.9 | 13.9 | 11.0 |
| Natural soil (untreated) | NS | 164.0 | 36.0 | 75.0 |
| Attapulgite clay formula | ACF | 124.0 | 36.0 | 75.0 |

*Includes small seepage loss through base perimeter joint.

1. Flexible membrane linings.—The PVC plastic was the most effective lining material evaluated for sealing the test ponds at Dalpra Farm. Seepage measurements, comparison to rain gage readings, and visual observations indicated this material provided a watertight lining. The TDS content of the PVC-lined pond increased from 3,900 to 5,900 ppm over a 10-month period. (Table 19 in Appendix II summarized the chemical analyses for the brine effluent at Dalpra Farm.)

The nylon-reinforced butyl-rubber lining, 45 mils (1.4 mm) thick, was nearly as effective as the PVC lining for seepage control. However, some problems were encountered in obtaining watertight seams. Placement of the rubber sheeting to fit the configuration of the circular metal tank resulted in occasional bends and folds in the lining. At several bends and folds, some separation of the bonded seams occurred and allowed a seepage path through the lining. Low peel strength of the bonded seams was also noted in laboratory tests.

After the problem seams were repaired with butyl-rubber adhesive and neoprene caulk, close comparison of water-level histories was noted between the butyl- and PVC-lined ponds. Data for the two ponds during the last 84 days of the test

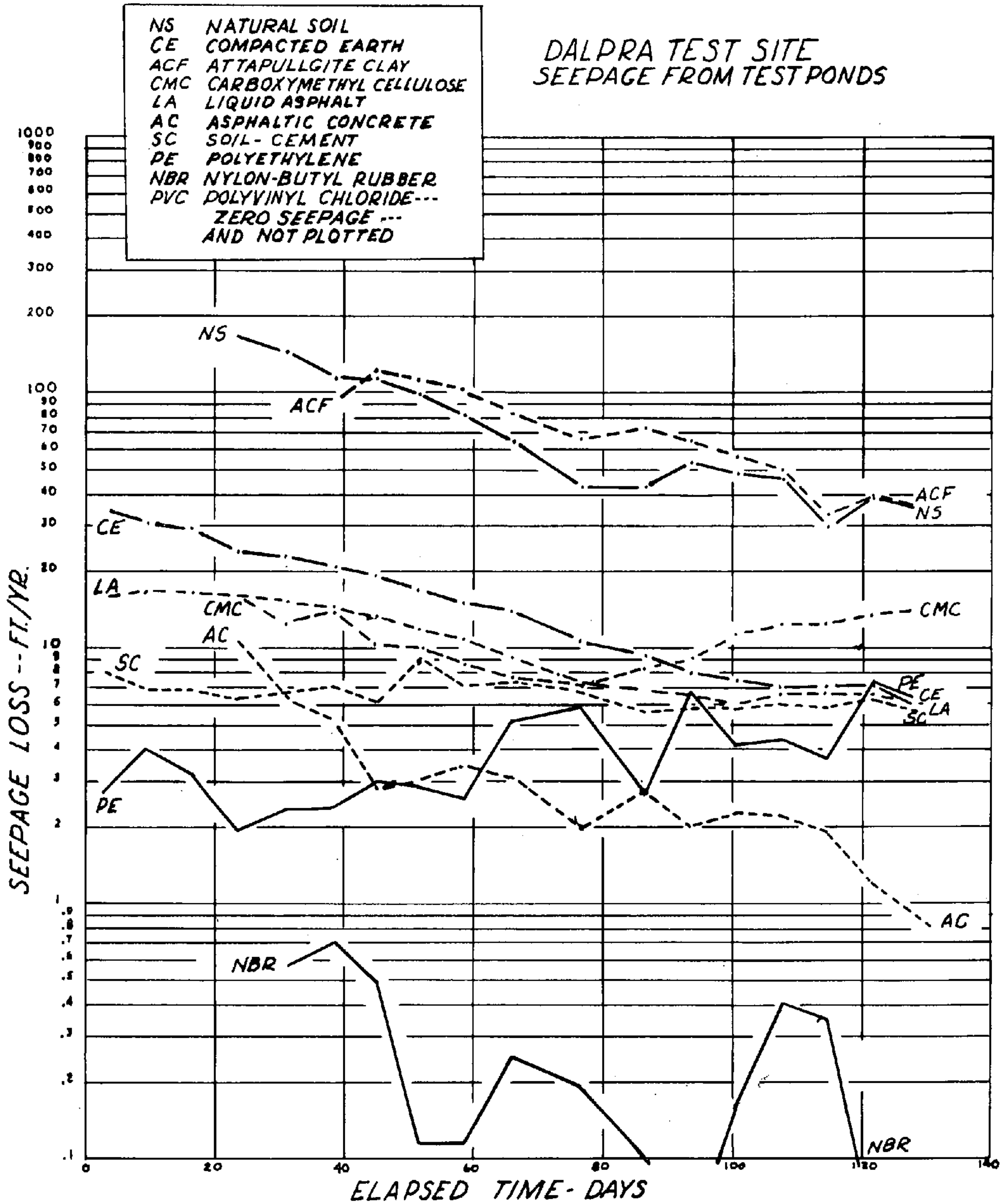



Figure 3. Dalpra test site—Seepage from test ponds.

season showed only a difference of water loss of 0.024 foot (0.73 cm). Some ozone cracking was noted in areas of the butyl liner subjected to high stress, especially at the rim of the tank where the butyl was folded and secured.

Field seepage measurements indicated the 6-mil- (0.15-mm-) thick polyethylene lining had small tears or pinholes. One suspicious area is near the 3-foot (0.9-m) brine level. Generally a significant increase in seepage occurred when the test pond was filled to this elevation. After a slight decrease in brine level, an abrupt decrease in seepage was noted. A thorough visual examination of this lining will be made when it is replaced with the 10-mil (0.25-mm) polyethylene lining.

2. Hard-surface linings.—Of the two hard-surface linings evaluated, asphaltic concrete appeared to be the more effective. Seepage measurements and visual observations indicated the 2-inch- (5.8-cm-) thick asphaltic concrete surfacing provided a satisfactory lining. The average seepage loss was 3.35 ft/yr ($3.3 \times 10^{-6}$ cm/sec). During the early stages of the test season, some problems were encountered in obtaining a watertight seal at the inside base perimeter joint. The pond had to be dewatered several times for repairs.

Some cracking occurred to the soil-cement lining after winter exposure. The cracks, which were up to 1 inch (2.5 cm) in width at the top, were probably caused by either frost action or chemical reaction between the brine and soil-cement lining. In May 1970 samples of the lining were obtained to further study the effect of brine on soil-cement.

Major cracks in the soil-cement were repaired before the start of the 1969 season. The seepage loss for the lining remained fairly constant at 6.6 ft/yr ($6.6 \times 10^{-6}$ cm/sec) as shown in Figure 3. Seepage probably occurred primarily through the fine cracks rather than through the soil-cement lining. Inspection of this lining in May 1970 showed that the condition was essentially the same as after repair before the test season in 1969. At that time about one-fourth inch (0.6 cm) of fine soil had accumulated as sediment on the surface of the soil-cement. This had apparently blown in from surrounding cultivated land and this sediment may have slightly reduced seepage in this and in the other ponds. Field testing was discontinued on the soil cement in May 1970.

3. Compacted-earth lining.—After the saturation period for the 12-inch- (30.5-cm-) thick compacted native soil, the seepage steadily decreased from 35 ft/yr ($35 \times 10^{-6}$ cm/sec) to 6 ft/yr ($6 \times 10^{-6}$ cm/sec) at the end of the test season.

The lining appeared to be in good condition after the 1968-69 winter season. No apparent deterioration was noted. Several observation holes were dug around the tank to observe the effectiveness of the sand drainage pad. No free water was found, indicating satisfactory drainage. Density tests will be conducted on this lining after seepage measurements are concluded in 1970.

4. Chemical soil sealants.—The attapulgite clay formulation was not effective in reducing seepage through the Dalpra-type soil (silty sand). The seepage losses were very similar to the natural soil as shown in Figure 3. Field testing was discontinued on this lining at the end of 1969 season.

The carboxymethyl cellulose and alum mixture provided some seepage control in the silty sand. The seepage loss for the 6-inch- (15.2-cm-) thick lining decreased to 7.12 ft/yr ($7.1 \times 10^{-6}$ cm/sec) at the approximate midpoint of its test season, Figure 3. However, at the end of the test season the seepage loss was 13.9 ft/yr ($14 \times 10^{-6}$ cm/sec) and was continuing to increase. Additional field testing will be conducted in 1970 to study this trend.

After surface drying, some shrinkage cracking and peeling were noted for both chemical soil sealant linings. However, upon rewetting, this condition generally disappeared.

The liquid asphalt B-5876, spray-applied over the natural soil, was most effective of the soil sealants in reducing seepage. The initial seepage loss was 15.9 ft/yr ($16 \times 10^{-6}$ cm/sec) and decreased to 6.14 ft/yr ($6.1 \times 10^{-6}$ cm/sec) at the end of the test season. Some evidence of saturation was noted at several areas around this pond. The penetration depth of the asphalt and condition of lining due to brine exposure will be determined after seepage measurements are concluded in 1970.

5. Natural, untreated soil.—The initial seepage loss of the natural soil at Dalpra Farm was about 164 ft/yr ($164 \times 10^{-6}$ cm/sec). At the end of the test season the seepage loss had decreased to 36 ft/yr ($36 \times 10^{-6}$ cm/sec). Some saturation was noted at several areas around the test tank. Also observed at several locations around the test pond were small boreholes about one-fourth inch (0.6 cm) in diameter. These holes were probably caused by water-seeking insects.

Upon surface drying, the natural soil had a greater tendency for shrinkage cracking than either the compacted-earth or the chemical soil sealant linings.

**Evaluation of Seepage Measurements**

Seepage determinations are only as accurate as the measurements required for water budget computations. That is as accurate as measurements of brine and precipitation inflow and evaporation outflow. For sufficient accuracy at least one watertight pond must be used to account for evaporation in the other test ponds. As previously mentioned, the PVC-lined pond was watertight and was selected for evaporation monitoring. Also to use the evaporation rate in the other test pond water budgets, the ponds should be verified as being thermally similar to the evaporation-monitoring pond. Assuming that all ponds are thermally similar, have the same wind exposure, and are evaporating at about the same rate, then the water temperature at similar points should be nearly equal.

To verify this assumption, the water surface temperature of the PVC pond, as measured by the top thermocouple, was compared to the water surface temperature for several other ponds. The comparison was based on temperature readings for two different days; August 3, one of the hottest days when the largest thermal difference would be expected, and September 18, an average seasonal day.

The comparison is summarized in Table 2. The mean difference from the PVC reading for August 3 was 0.3° F (0.2° C) and for September 18 –0.05° F (–0.03° C), with standard deviations of 0.9° F (0.5° C) and 0.3° F (0.2° C). The largest difference, 2.4° F (1.3° C), occurred on August 3 during the hottest part of the day. The results of the comparison indicate the ponds are thermally similar; and therefore, the evaporation rate determined from the PVC pond can be used for the other ponds.

A summary of weather and PVC pond measurements related to evaporation is listed in Table 3. The data in the table are averaged over the same time intervals used to determine average seepage loss rates for the different lining materials. Also shown in the table is the increase in salinity for the PVC pond as measured by the TDS content. Although the effect of salinity on evaporation was not investigated in this study, other investigators have found that 20,000-ppm brine reduces evaporation by 3 percent.[1] Therefore, the salinity concentrations measured in this study, up to 6,000-ppm total dissolved solids, would not produce significant reductions in evaporation rates.

To assess the evaporation error caused by difference of temperatures between the evaporation monitoring pond and the other ponds, correlations of evaporation versus temperature data were made. The data and curves representing the least square fit equations are shown in Figure 4. The index of determination for the air temperature curve is 0.906 with 1.0 indicating a perfect fit. The index for the water temperature curve is 0.873. Using the water temperature correlation, the change of evaporation rate was computed for 1° F (0.5° C) difference of water temperature. The results are listed in Table 4. The changes are also shown in Table 4 as a percentage of the annual tank evaporation.

The air temperature correlation also provided comparison with long-term meteorological data. Using average temperature data for the years 1931 to 1960 and the correlation curve, an average annual evaporation rate of 38 in./yr (97 cm/yr) for the test site was computed. This value compares to 39 in./yr (99 cm/yr) and 55 in./yr (140 cm/yr), the area's average lake and Class A pan evaporation, respectively.

Water surface readings approaching an accuracy of plus or minus 0.002 ft (0.06 cm) are the best to be expected with the type of monitoring system used at Dalpra Farm. The effect of a plus or minus 0.002 ft (0.06 cm) error in water-level measurement is shown in Table 5 as percent of the tentative seepage limits.

It is recognized that in addition to measurement errors, the deviation of the data points from the curves shown in Figure 4 result from using two variable correlations that do not account for wind velocity and relative humidity (vapor pressure). The use of these variables in evaporation determinations is discussed under "Seepage Monitoring for Brine Disposal Ponds."

It was expected that a watertight pond would give more representative values of precipitation than a small bucket rain gage. To determine the rain from the water-level gage, the chart trends before and after a storm were extended toward the storm time, and the difference between the extended lines were measured at the middle of the storm.

The precipitation values from the rain gage and from the PVC pond water-level gage charts were compared for 16 storms. There was no significant difference of rainfall determined by the two methods of measuring

[1] Op. cit. p. 1.

Table 2

COMPARISON OF TOP THERMOCOUPLE TEMPERATURE READINGS WITH PVC POND

| Pond* lining material | Average depth feet | Average depth meter | Temperature difference at 6 a.m. °F | Temperature difference at 6 a.m. °C | Temperature difference at 10 a.m. °F | Temperature difference at 10 a.m. °C | Temperature difference at 3 p.m. °F | Temperature difference at 3 p.m. °C | Temperature difference at 9 p.m. °F | Temperature difference at 9 p.m. °C |
|---|---|---|---|---|---|---|---|---|---|---|
| August 3, 1969 | | | | | | | | | | |
| NBR | 2.91 | 0.887 | -0.1 | -0.05 | -0.7 | -0.4 | 2.0 | 1.1 | 0.5 | 0.3 |
| PE | 2.78 | 0.847 | -0.4 | -0.2 | 0.2 | 0.1 | 1.5 | 0.8 | -0.1 | -0.05 |
| LA | 2.84 | 0.866 | -0.3 | -0.15 | -0.2 | -0.1 | 0.7 | 0.4 | 0.0 | 0.0 |
| SC | 2.85 | 0.869 | -0.7 | -0.4 | 0.0 | 0.0 | 2.4 | 1.3 | 0.1 | 0.05 |

Average = -0.3 °F (0.15 °C)

Standard Deviation = 0.9 °F (0.5 °C)

| Pond* lining material | Average depth feet | Average depth meter | Temperature difference at 6 a.m. °F | Temperature difference at 6 a.m. °C | Temperature difference at 10 a.m. °F | Temperature difference at 10 a.m. °C | Temperature difference at 3 p.m. °F | Temperature difference at 3 p.m. °C | Temperature difference at 9 p.m. °F | Temperature difference at 9 p.m. °C |
|---|---|---|---|---|---|---|---|---|---|---|
| September 18, 1969 | | | | | | | | | | |
| NBR | 2.99 | 0.911 | 0.1 | 0.05 | 0.1 | 0.05 | 0.3 | 0.15 | 0.1 | 0.05 |
| PE | 2.95 | 0.899 | -0.1 | -0.05 | -0.1 | -0.05 | -0.6 | -0.3 | -0.1 | -0.05 |
| LA | 2.94 | 0.896 | 0.2 | 0.1 | 0.5 | 0.3 | -0.2 | -0.1 | -0.2 | -0.1 |
| AC | 2.89 | 0.881 | -0.1 | -0.05 | 0.1 | 0.05 | -0.4 | -0.2 | -0.3 | -0.15 |
| SC | 2.91 | 0.887 | -0.6 | -0.3 | 0.0 | 0.0 | 0.8 | 0.4 | -0.1 | -0.05 |
| CMC | 2.87 | 0.875 | -0.4 | -0.2 | 0.0 | 0.0 | -0.2 | -0.1 | -0.2 | -0.1 |

Average = -0.06 °F (0.03 °C)

Standard Deviation = 0.3 °F (0.15°C)

*Code in Table 1.

Table 3

EVAPORATION DATA

| Date From | Date To | Evaporation feet/year | Air temperature °F | Inside tank bottom °F | Water surface °F | Relative humidity percent | Wind velocity mph | Water depth feet | TDS ppm |
|---|---|---|---|---|---|---|---|---|---|
| 5-16-69 | 5-21-69 | 5.48 | 62.3 | – | – | 57 | 4.70 | 2.98 | 4,480 |
| 5-21-69 | 5-24-69 | 2.43 | 49.3 | – | – | 71 | 4.71 | 2.94 | |
| 5-24-69 | 5-31-69 | 9.18 | 69.3 | 66.1 | 71.3 | 48 | 4.76 | 2.85 | |
| 6-1-69 | 6-6-69 | 6.21 | 64.3 | 65.0 | 70.2 | 44 | 3.90 | 2.72 | |
| 6-6-69 | 6-8-69 | 4.93 | 62.3 | 67.8 | 68.8 | 66 | 3.65 | 2.66 | |
| 6-8-69 | 6-10-69 | 3.65 | 63.3 | 64.3 | 68.1 | 63 | 3.54 | 3.00 | 4,880 |
| 6-11-69 | 6-15-69 | 2.74 | 49.3 | 57.8 | 59.7 | 72 | 3.44 | 3.03 | |
| 6-18-69 | 6-23-69 | 5.84 | 66.3 | 64.4 | 70.3 | 53 | 3.71 | 3.02 | |
| 6-23-69 | 6-27-69 | 8.22 | 61.4 | 65.7 | 67.4 | 46 | 5.65 | 2.97 | |
| 6-27-69 | 7-2-69 | 7.81 | 69.7 | 68.2 | 73.1 | 46 | 4.74 | 2.86 | |
| 7-2-69 | 7-7-69 | 6.57 | 67.1 | 70.0 | 74.0 | 58 | 3.49 | 2.98 | |
| 7-7-69 | 7-14-69 | 8.35 | 74.7 | 73.7 | 77.6 | 45 | 3.27 | 2.89 | |
| 7-14-69 | 7-21-69 | 7.09 | 72.5 | 74.4 | 77.5 | 54 | 3.25 | 2.88 | 4,968 |
| 7-22-69 | 7-29-69 | 7.67 | 73.8 | 75.7 | 80.2 | 48 | 1.98 | 2.90 | |
| 7-29-69 | 8-4-69 | 5.96 | 73.6 | 77.2 | 79.4 | 53 | 2.31 | 2.79 | |
| 8-4-69 | 8-11-69 | 8.14 | 73.9 | 76.0 | 78.9 | 48 | 2.34 | 2.66 | |
| 8-11-69 | 8-18-69 | 6.78 | 70.4 | 74.5 | 75.2 | 51 | 2.43 | 2.97 | 5,856 |
| 8-18-69 | 8-25-69 | 5.27 | 70.1 | 73.5 | 74.9 | 56 | 1.88 | 2.88 | |
| 8-25-69 | 9-2-69 | 5.20 | 69.3 | – | – | 51 | 1.80 | 2.78 | |
| 9-2-69 | 9-9-69 | 5.27 | 66.8 | 71.4 | 72.6 | 56 | 2.36 | 2.68 | |
| 9-9-69 | 9-15-69 | 4.26 | 62.0 | 66.4 | 67.2 | 58 | 2.15 | 2.98 | |
| 9-15-69 | 9-22-69 | 4.17 | 61.0 | 66.5 | 68.0 | 58 | 2.00 | 2.97 | |
| 9-22-69 | 9-29-69 | 4.64 | 61.2 | 64.1 | 66.1 | – | 2.52 | 2.92 | 5,928 |
| 9-29-69 | 10-7-69 | 3.97 | 56.4 | 58.1 | 59.3 | 50 | 4.46 | 3.03 | |
| 10-7-69 | 10-20-69 | 1.09 | 40.9 | 45.6 | 46.1 | 58 | 3.90 | 3.14 | |
| 10-20-69 | 10-27-69 | 1.51 | 44.7 | 49.6 | 51.0 | 56 | 2.66 | 3.19 | |
| 10-27-69 | 11-3-69 | 0.68 | 40.0 | 44.9 | 45.2 | – | 4.01 | 3.21 | |
| 11-3-69 | 11-10-69 | 1.41 | 41.3 | – | – | 58 | 2.03 | 3.23 | |
| 11-10-69 | 11-17-69 | 1.30 | 40.3 | – | – | 62 | 2.97 | 3.20 | |
| 11-17-69 | 11-24-69 | 0.57 | 35.3 | – | – | 62 | 3.34 | 3.20 | |
| 11-24-69 | 12-1-69 | 0.57 | 32.3 | – | – | 65 | 0.80 | 3.19 | |
| 12-1-69 | 12-8-69 | 1.04 | 29.3 | – | – | 63 | 2.61 | 3.17 | |

Table 3A

EVAPORATION DATA (METRIC UNITS)

| Date From | Date To | Evaporation cm/year | Air temperature °C | Inside tank bottom °C | Water surface °C | Relative humidity percent | Wind velocity km/hr | Water depth meters | TDS ppm |
|---|---|---|---|---|---|---|---|---|---|
| 5-16-69 | 5-19-69 | 167.0 | 16.8 | – | – | 57 | 7.56 | 0.908 | 4,480 |
| 5-21-69 | 5-24-69 | 74.1 | 9.6 | – | – | 71 | 7.58 | 0.896 | |
| 5-24-69 | 5-31-69 | 279.8 | 20.7 | 18.9 | 21.8 | 48 | 7.66 | 0.869 | |
| 6-1-69 | 6-6-69 | 189.3 | 17.9 | 17.8 | 21.2 | 44 | 6.28 | 0.829 | |
| 6-6-69 | 6-8-69 | 150.3 | 16.8 | 19.8 | 20.4 | 66 | 5.87 | 0.811 | |
| 6-8-69 | 6-10-69 | 111.3 | 17.4 | 17.9 | 20.0 | 63 | 5.70 | 0.914 | 4,880 |
| 6-11-69 | 6-15-69 | 83.5 | 9.6 | 14.3 | 15.4 | 72 | 5.53 | 0.924 | |
| 6-18-69 | 6-23-69 | 178.0 | 19.0 | 18.0 | 21.2 | 53 | 5.97 | 0.920 | |
| 6-23-69 | 6-27-69 | 250.5 | 16.3 | 18.7 | 19.6 | 46 | 9.09 | 0.905 | |
| 6-27-69 | 7-2-69 | 238.0 | 20.9 | 20.1 | 22.8 | 46 | 7.63 | 0.872 | |
| 7-2-69 | 7-7-69 | 200.3 | 19.5 | 21.1 | 23.3 | 58 | 5.62 | 0.908 | |
| 7-7-69 | 7-14-69 | 254.5 | 23.7 | 23.1 | 25.3 | 45 | 5.26 | 0.881 | |
| 7-14-69 | 7-21-69 | 216.1 | 22.5 | 23.5 | 25.3 | 54 | 5.23 | 0.878 | 4,968 |
| 7-22-69 | 7-29-69 | 233.8 | 23.0 | 24.2 | 26.8 | 48 | 3.19 | 0.884 | |
| 7-29-69 | 8-4-69 | 181.7 | 23.1 | 25.1 | 26.3 | 53 | 3.80 | 0.850 | |
| 8-4-69 | 8-11-69 | 248.1 | 23.3 | 24.4 | 26.0 | 48 | 3.77 | 0.811 | |
| 8-11-69 | 8-18-69 | 206.7 | 21.3 | 23.6 | 24.0 | 51 | 3.91 | 0.905 | 5,856 |
| 8-18-69 | 8-25-69 | 160.6 | 21.1 | 23.0 | 23.8 | 56 | 3.02 | 0.878 | |
| 8-25-69 | 9-2-69 | 158.5 | 20.7 | – | – | 51 | 2.90 | 0.847 | |
| 9-2-69 | 9-9-69 | 160.6 | 19.3 | 21.9 | 22.5 | 56 | 3.80 | 0.817 | |
| 9-9-69 | 9-15-69 | 129.8 | 16.6 | 19.1 | 19.5 | 58 | 2.46 | 0.908 | |
| 9-15-69 | 9-22-69 | 127.1 | 16.1 | 19.1 | 20.0 | 58 | 3.22 | 0.905 | |
| 9-22-69 | 9-29-69 | 141.4 | 16.2 | 17.9 | 18.9 | – | 4.05 | 0.890 | 5,928 |
| 9-29-69 | 10-7-69 | 121.0 | 13.5 | 14.5 | 15.2 | 50 | 7.18 | 0.924 | |
| 10-7-69 | 10-20-69 | 33.2 | 4.9 | 7.5 | 7.8 | 58 | 6.28 | 0.957 | |
| 10-20-69 | 10-27-69 | 46.0 | 7.0 | 9.8 | 10.5 | 56 | 4.28 | 0.972 | |
| 10-27-69 | 11-3-69 | 20.7 | 4.4 | 7.2 | 7.3 | – | 6.45 | 0.978 | |
| 11-3-69 | 11-10-69 | 43.0 | 5.2 | – | – | 58 | 3.27 | 0.984 | |
| 11-10-69 | 11-17-69 | 39.6 | 4.6 | – | – | 62 | 4.78 | 0.975 | |
| 11-17-69 | 11-24-69 | 17.4 | 1.8 | – | – | 62 | 5.37 | 0.975 | |
| 11-24-69 | 12-1-69 | 17.4 | 0 | – | – | 65 | 1.29 | 0.972 | |
| 12-1-69 | 12-8-69 | 31.7 | -1.5 | – | – | 63 | 4.20 | 0.966 | |

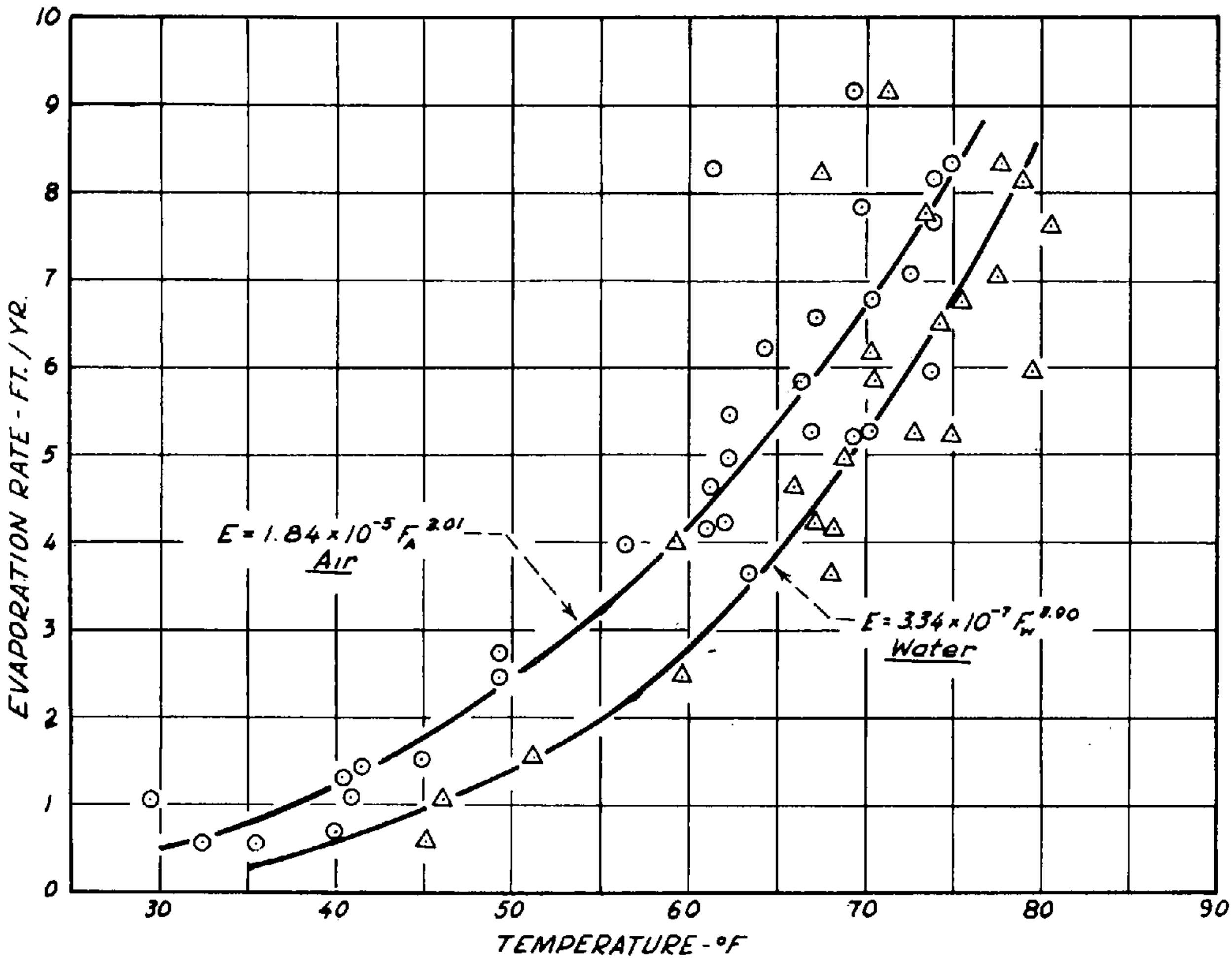



Figure 4. Relationship of Evaporation rates to temperature. Dalpra test site.

Table 4

THE EFFECTS OF TEMPERATURE ON RATE OF EVAPORATION

| Temperature of water | | Rate of change of evaporation | | Percent of annual tank evaporation |
|---|---|---|---|---|
| °F | °C | ft/week/°F | cm/week/°C | |
| 80 | 26.7 | 0.0082 | 0.451 | 13 |
| 70 | 21.1 | 0.0056 | 0.308 | 9 |
| 65* | 18.3 | 0.0045 | 0.248 | 6 |
| 50 | 10.0 | 0.0021 | 0.138 | 3 |
| 30 | -1.1 | 0.0005 | 0.028 | 1 |

*The average water temperature during the test season.

Table 5

ESTIMATED ERRORS IN WATER-LEVEL MEASUREMENTS

| Tentative seepage limit | | Percent error ±0.002 ft (0.06 cm) is of per day limit | Tentative seepage limit | | Percent error ±0.002 ft (0.06 cm) is of per week limit |
|---|---|---|---|---|---|
| ft/day | cm/day | | ft/week | cm/week | |
| 0.003 | 0.091 | 67.0 | 0.021 | 0.147 | 9.6 |
| 0.010 | 0.305 | 20.0 | 0.070 | 2.135 | 2.9 |
| 0.020 | 0.610 | 10.0 | 0.140 | 4.270 | 1.4 |
| 0.030 | 0.914 | 6.7 | 0.210 | 6.398 | 1.0 |

precipitation. The differences were within the plus or minus 0.002 foot (0.06 cm) reading from the water-level charts.

In summary, to use a water budget for monitoring a brine disposal pond, the instrumentation used at Dalpra Farm was adequate, but the following modifications would be advantageous:

1. Provide larger floats on the water-level recorders to increase recorder response.

2. Arrange enough water-level recorders, for example, three to four per large pond to account for tilt of water surface caused by the prevailing winds.

3. Install permanent hook gage in each pond for referencing the water-level charts.

4. Use one floating thermocouple per pond and provide it with solar shielding. This should help attain more exact correlation of evaporation.

5. Provide two or three anemometers to verify that the wind velocity is being measured and that one or more of them do not need maintenance.

6. Use digital encoders and telemetering systems to reduce the drudgery of reading, collecting, storing and recovering data.

## LABORATORY INVESTIGATION

Laboratory testing was conducted primarily to determine:

1. Soil properties data for field construction control and other laboratory tests.

2. Effectiveness of various chemical soil sealants for reducing seepage in Roswell and Dalpra soil.

3. Physical properties of the plastic linings, rubber lining, asphaltic concrete, soil-cement, and liquid asphalt installed at Dalpra Farm. Similar tests will be conducted when the linings are removed to determine any significant changes caused by the brine exposure.

The results of all laboratory tests are presented in tabular or graphical form in Appendix II. Laboratory test methods are described in Appendix IV.

*Pounds per cubic foot.

## LABORATORY TEST RESULTS

### Soil Testing

1. Roswell soil.—Standard tests run on samples from the Roswell Desalting Plant area show the soil to have the following properties:

a. Soil is a lean clay with about 91 percent of the particles finer than 0.074 mm and about 25 percent finer than 0.001 mm.

b. The maximum density is 108.8 pcf* (1.74 g/cc) at an optimum moisture content of 17 percent.

c. The liquid limit is 33 percent and the plasticity index is 17 percent.

Table 16 and Figure 6 of Appendix II summarize all the results of standard properties tests run on this soil.

2. Dalpra soil.—Standard tests run on composite samples from Dalpra Farm show the soil to have the following properties:

a. Soil is a silty sand with about 70 percent fine to medium sand and about 30 percent finer than 0.074 mm.

b. The maximum density is 119 pcf (1.91 g/cc) at an optimum moisture content of 12 percent.

c. The liquid limit is 20 percent and the plasticity index is 3 percent.

Table 17 and Figure 7 of Appendix II summarize all the results of standard properties tests run on Dalpra soil.

### Soil Sealants

1. Roswell soil.—Permeability tests were run to determine the effectiveness of chemical soil sealants in reducing seepage through this soil. Forty-nine tests were run to include a variation in placement density, the type of mix and permeant water used, and the type of sealant applied. Test results are summarized in Table 20, Appendix II.

The soil was placed at one of four densities; 80, 85, 90, or 95 percent of maximum density. Denver tapwater and a synthetic Roswell effluent were both used in wetting the soil for compaction and as the permeant fluid. The synthetic effluent was manufactured in the USBR chemical laboratory to simulate as closely as possible the chemical analysis of the actual effluent from the Roswell plant. The water analyses of the Roswell effluent is shown in Table 18, Appendix II. Sealants used included 0.3 percent sodium silicate, 10 percent lignin, and 1 percent methyl cellulose.

No firm conclusion can be drawn from the results of these tests. The soil without sealant at densities above 80 percent maximum has a low permeability rate. At 80 percent maximum density there is sufficient flow to indicate the effect of the sealants. Within these data the methyl cellulose performed best as a sealant, reducing the permeability to zero. The other sealants performed well in some tests and poorly in others.

2. Dalpra soil.—Permeability tests were conducted on composite soil Sample No. 48D-X35 treated with the two chemical soil sealant mixtures recommended by Diamond Shamrock Company. Duplicate tests were run using each sealant and duplicate tests without sealant were run for comparison.

Test results are summarized in Table 21 in Appendix II. The results indicate an average reduction in permeability due to sealant application of about 50 percent for the 2 percent attapulgite clay formulation, and 75 percent for the combination of 0.25 percent carboxymethyl cellulose with 0.05 percent alum.

**Flexible Membrane Linings**

1. Plastic linings.—Physical properties test results for the PVC and polyethylene plastic linings are summarized in Tables 22 to 24 in Appendix II. Tentative USBR specifications are also listed in the tables for comparison. Laboratory test results indicate the plastic films have satisfactory physical properties for use as evaporation pond liners. However, the 6-mil (0.15-mm) polyethylene had a low puncture resistance of 12.5 psi (0.9 kg/cm$^2$) tested over fine aggregate, as compared to 22.5 psi (1.6 kg/cms,2s,) for the 10-mil- (0.25-mm-) thick PVC tested over coarse aggregate.

2. Nylon-reinforced butyl-rubber lining.—Laboratory test results are summarized in Table 25 in Appendix II. Results indicate the following conclusions:

a. The 45-mil (1.14-mm) nylon-reinforced butyl-rubber lining had satisfactory breaking and tear strength.

b. The Mullen test indicated the reinforced rubber had satisfactory hydrostatic resistance characteristics.

c. The reinforced rubber appeared to have excellent resistance to age deterioration as noted in the heat-aging tests.

d. Some ozone cracking was noted after 3 days of tests at 100$^\circ$ F (37.7$^\circ$ C) and 50 pphm (parts per hundred million.)

e. Peel strengths of the bonded seams were generally low. An average peel strength of 2.9 pounds per inch (0.52 kg/cm) was obtained in laboratory tests. A tentative minimum requirement would be near 3.5 pounds per inch (0.7 kg/cm).

**Asphaltic Concrete**

The laboratory test results are summarized in Tables 26 to 30 in Appendix II. A sample of the in-place lining is shown in Photograph 2. The following conclusions are indicated from the laboratory tests:

1. An asphalt content of 7.06 percent (based on the dry weight of aggregate) was determined for the in-place sample (B-5686). An asphalt content of 7 to 8 percent was specified.

2. Physical properties tests conducted on the extracted asphalt indicated a 40-50 penetration grade asphalt conforming to Federal Specification SSA-706c.

3. Sieve analyses indicated the aggregate portion of the mix was within the specification limits. The specific gravity of the aggregate was determined to be 2.59.

4. The average density of the in-place lining sample was 143.36 pcf (2.296 g/cc). This value was 99.2 percent of laboratory standard density and shows that satisfactory compaction was used during the construction of the lining. Generally, specification requirements are a minimum of 98 percent of laboratory standard density.

5. The results of the immersion-compression tests on the remolded mixes (B-5576) indicated the sampled mix produced satisfactory density, water

absorption, volume swell, and compressive strength properties. Visual examination of the remolded specimens at the end of the water curing did not reveal any clay popouts or surface blistering which is indicative of good quality materials.

6. Sustained load tests conducted at 140° F (60° C) showed excellent mix stability.

7. Permeability tests conducted on two core specimens obtained from the in-place lining sample indicated the asphaltic concrete should provide a watertight lining.

**Soil Cement**

The laboratory test results are summarized in Table 31 and Figures 8 to 11 in Appendix II. The following conclusions are indicated from the test results:

1. Of the three cement contents evaluated; 6, 8, and 10 percent, results show that the 8-percent cement content to be adequate for Dalpra soil.

2. At 8 percent cement content the weight loss after 12 test cycles was about 8.5 percent from the freeze-thaw test and about 5 percent from the wet-dry test.

3. Unconfined compression strength test results for specimens with 8 percent cement content were determined to be: 363 psi (25.5 kg/cm$^2$) for 3-day curing; 475 psi (33.2 kg/cm$^2$) for 7-day curing; and 647 psi (45.3 kg/cm$^2$) for 28-day curing.

4. Permeability test results show an average of about 2.0 ft/yr ($2.0 \times 10^{-6}$ cm/sec) for the soil cement with 8 percent cement content.

**Spray-applied Liquid Asphalt**

Laboratory test results are summarized in Tables 32 to 35 in Appendix II. The following observations were noted during the laboratory evaluation:

1. At the total application treatment rate of 2 gsy (9.2 l/m$^2$) of the liquid asphalt, a penetration depth from 1 to 1.5 inches (2.54 to 3.81 cms) can be expected in Dalpra soil. Penetration characteristics are shown in Photograph 3.

2. Compressive strength test results indicate the liquid asphalt treated samples are slow curing, and generally had lower compressive strength values than the untreated samples. The slow curing may be possible due to the absorption of a large portion of the liquid asphalt by the rather high fines content (30 percent) of the soil. Such a condition could reduce the rate of solvent evaporation.

3. Laboratory permeability tests were not reliable because of suspected piping. However, no deterioration was noted in the permeability sample from exposure to the Dalpra brine effluent.

## RECOMMENDATIONS

**General**

Each proposed brine disposal pond site must be given individual consideration relative to selection and usage of materials. Soil analyses including field and laboratory testing are necessary to provide data for design purposes, material selection, and construction control.

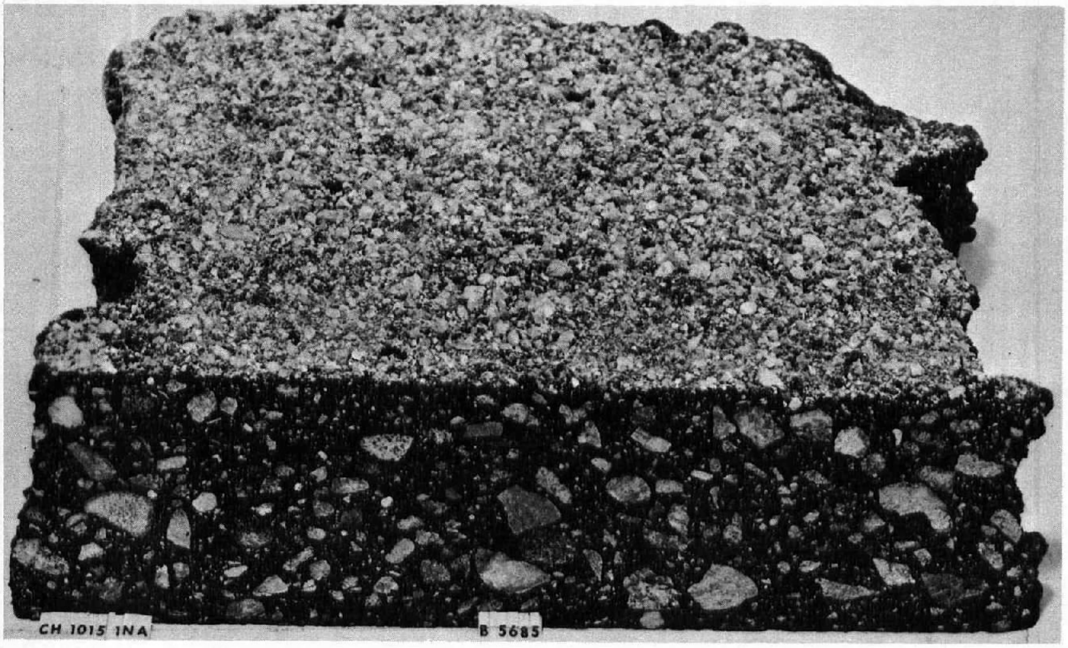
The primary requirement for lining brine disposal ponds will be determined by local regulations and/or the amount of seepage control necessary to prevent pollution of soil or ground water. Prior to the design and construction of any brine disposal pond, the state and the Federal Water Quality Administration should be contacted for their latest regulations on brine disposal ponds. Addresses for the state agencies are listed in Reference 1.

Pond operating conditions have to be considered in the selection of lining material. For example, desalting plant operations involving salt recovery may require the use of hard-surface linings. Also, brine disposal ponds could be designed for multipurpose use; i.e., recreational, game preservation; such uses may require a combination of lining materials.

**Lining Materials**

Physical properties requirements and construction guidelines for the flexible membranes, asphaltic concrete, soil cement, and compacted-earth linings are discussed in Reference 3.

Flexible membrane linings.—These linings are recommended for use in areas where stringent seepage control is required. The most widely used materials include PVC plastic, polyethylene plastic formulated as a waterproof liner, and asphalt membrane linings. A 10-mil- (0.25-mm-) thick plastic lining is generally accepted as the best from a durability and economy standpoint. Also, for the plastic lining particular




Photograph 2. Cross-sectional view of asphaltic concrete lining installed at Dalpra Farm.


Photograph 3. Penetration of liquid asphalt B-5876 into 2- by 2-inch (5.08- by 5.08-cm) compacted Dalpra soil at application rates of 0.5, 1.0, and 2.0 gsy (2.3, 4.6, and 9.2 $l/m^2$). Maximum penetration was about 1.6 inches (4.06 cm).

attention should be given when making field seams to ensure they are watertight.

Hard-surface linings.—Asphaltic concrete could be designed for use in brine disposal ponds requiring a durable, hard-surface lining. Such a design would involve a hydraulic-type mix. The use of such a lining is primarily dependent upon source and type of locally available aggregate. Costs for this lining is generally higher than for either compacted earth or flexible membrane linings.

At this time we believe that the performance of soil cement, if used as a general type of lining in brine disposal ponds, would be quite variable. Much would depend upon the types and concentrations of salts in the brine as well as upon the soil properties and the quality of construction. For resistance to sulfate action, Type V cement would be required. Each particular installation proposed would require careful investigation to insure that there would not be adverse reactions between the brine and soil cement to cause deterioration.

Compacted-earth linings.—These linings consist of natural or processed soil placed and compacted to a specified thickness and density to achieve desired seepage control. Although originally determined for canal linings, the criteria set forth in Table 6 will assist in selecting soils for compacted-earth linings. Generally, compacted clayey gravels (GC), clayey sands (SC), and clays of low to high plasticity (CL, CH, and OH) would provide a sufficiently impervious layer for most situations. In less critical areas, compacted silty gravels (GM), silty sands (SM), silts (ML, OL, and MH) may be sufficiently impermeable.[6]

Soil sealants.—Three recently developed materials are presently under evaluation for possible use in brine disposal ponds. The materials are:

1. A modified vinyl polymer (B-5800) supplied at 60 percent solids in water. The material is spray-applied to form a vinyl film. Material cost is about $0.50 per square yard.

2. A water-soluble polymer (B-5604) that penetrates into the soil and causes sealing by absorption onto clays.

3. A particular gel material (B-5605) which never does dissolve in water, but it swells up into a very soft pliable particle. It can penetrate and enter into larger cracks or capillaries and become lodged and plug the flow channel by this mechanism.

The water-soluble polymer and gel material are used in combination and in equal amounts. Material costs are from $0.10 to $0.80 per square yard depending on quantities used. Preliminary laboratory permeability tests summarized in Table 21, Appendix II, indicate the three materials provided satisfactory seepage control in Dalpra soil. Field testing will be conducted at Dalpra Farm to further evaluate the sealant materials.

**Seepage Monitoring for Brine Disposal Ponds**

Accurate determinations of brine seepage losses may be required by statute or regulation. This requirement should be determined in advance of the preliminary design since the brine disposal ponds should be arranged, instrumented, and operated in such a manner to provide the required accuracy in the determination of seepage losses.

Ideally, an evaporation pond system should consist of similar ponds. One or more of the ponds should be watertight and would be used to monitor evaporation. All the ponds should have the same structural configuration, should be oriented so that the long side of the individual ponds is in the direction of the prevailing wind and should be operated at equal brine depths. Similar wind and solar exposure will result in similar evaporation conditions for all ponds. However, it should be recognized that topographic conditions, availability of land, and other factors may combine to require irregular pond layouts.

The evaporation-monitoring pond should be made as watertight as possible, using impermeable lining materials. Field tests conducted at Dalpra Farm indicated that polyvinyl-chloride (PVC) plastic lining was the most efficient lining material. Even though local regulations might permit use of less impervious linings, the evaporation-monitoring ponds should still be impervious. For economy, smaller ponds or diked-off portions of the larger ponds could be made impervious and used to monitor evaporation. However, precautions are needed to assure that the smaller ponds represent evaporation in the larger ponds. If one smaller pond is used, it should be centered in the system. Several smaller ponds could be distributed over the system for better averaging of relative humidity and wind exposure.

[6] Op. cit. p. 1.

Table 6

*Important physical properties of soils and their uses for canal linings*
(Identifications based on Unified Soil Classification System)

| MAJOR DIVISIONS OF SOILS | | | TYPICAL NAMES OF SOIL GROUPS | GROUP SYMBOLS | SOIL PROPERTIES: PERMEABILITY | SOIL PROPERTIES: SHEARING STRENGTH | SOIL PROPERTIES: COMPACTED DENSITY | SUITABILITY FOR CANALS: EROSION RESISTANCE | SUITABILITY FOR CANALS: COMPACTED EARTH LININGS |
|---|---|---|---|---|---|---|---|---|---|
| COARSE-GRAINED SOILS More than half of material is larger than No. 200 sieve size | GRAVELS More than half of coarse fraction is larger than No. 4 sieve size | CLEAN GRAVELS (Little or no fines) | Well-graded gravels, gravel-sand mixtures, little or no fines | GW | 14 | 16 | 15 | 2 | — |
| | | | Poorly graded gravels, gravel-sand mixtures, little or no fines | GP | 16 | 14 | 8 | 3 | — |
| | | GRAVELS WITH FINES (Appreciable amount of fines) | Silty gravels, poorly graded gravel-sand-silt mixtures | GM | 12 | 10 | 12 | 5 | 6 |
| | | | Clayey gravels, poorly graded gravel-sand-clay mixtures | GC | 6 | 8 | 11 | 4 | 2 |
| | | | Gravel with sand-clay binder | GW-GC | 8 | 13 | 16 | 1 | 1 |
| | SANDS More than half of coarse fraction is smaller than No. 4 sieve size | CLEAN SANDS (Little or no fines) | Well-graded sands, gravelly sands, little or no fines | SW | 13 | 15 | 13 | 8 | — |
| | | | Poorly graded sands, gravelly sands, little or no fines | SP | 15 | 11 | 7 | 9 coarse | — |
| | | SANDS WITH FINES (Appreciable amount of fines) | Silty sands, poorly graded sand-silt mixtures | SM | 11 | 9 | 10 | 10 coarse | 7 Erosion Critical |
| | | | Clayey sands, poorly graded sand-clay mixtures | SC | 5 | 7 | 9 | 7 | 4 |
| | | | Sand with clay binder | SW-SC | 7 | 12 | 14 | 6 | 3 |
| | (For visual classifications, the $\frac{1}{4}''$ size may be used as equivalent to the No. 4 sieve size) | | | | | | | | |
| FINE-GRAINED SOILS More than half of material is smaller than No. 200 sieve size | SILTS AND CLAYS Liquid limit less than 50 | | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity | ML | 10 | 5 | 5 | — | 8 Erosion Critical |
| | | | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays | CL | 3 | 6 | 6 | 11 | 5 |
| | | | Organic silts and organic silt-clays of low plasticity | OL | 4 | 2 | 3 | — | 9 Erosion Critical |
| | SILTS AND CLAYS Liquid limit greater than 50 | | Inorganic silt, micaceous or diatomaceous fine sandy or silty soils, elastic silts | MH | 9 | 3 | 2 | — | — |
| | | | Inorganic clays of high plasticity, fat clays | CH | 1 | 4 | 4 | 12 | 10 Volume Change Critical |
| | | | Organic clays of medium to high plasticity | OH | 2 | 1 | 1 | — | — |
| (The No. 200 sieve size is about the smallest particle visible to the naked eye) | | | | | | | | | |
| HIGHLY ORGANIC SOILS | | | Peat and other highly organic soils | Pt | * | | | ** | |

* Numbers above indicate the order of increasing values for the physical property named
** Numbers above indicate relative suitability (1 = best)

If all the ponds are evaporating at the same rate in the same weather environment, the water surface temperatures would be the same. To verify that evaporation values obtained apply to all ponds, water surface temperature measurements are required. To monitor temperature, solar-shielded thermocouples should be placed in as nearly similar positions as possible near the water surface of all ponds. If the mean daily water surface temperature of any of the ponds deviates more than plus or minus $2^{o}$ F ($1^{o}$ C) from the evaporation-monitoring ponds for two days or longer, then evaporation values from the evaporation-monitoring ponds should be corrected before using them for computing seepage in another pond. Any variable that changes evaporation rate also changes water surface temperature. Therefore to correct evaporation rates, least square fits or correlation of the form presented in Figure 4, showing evaporation versus water surface temperature can be used. A plot, Figure 5, of the change of evaporation rate per degree of temperature change determined from the correlation is useful for making approximate corrections. The rate of change of evaporation rate is read from Figure 5 at the average of the evaporation-monitoring pond and the other pond temperature. This rate of change is multiplied by the quantity temperature in the evaporation-monitoring pond minus the temperature in the other pond. This product is subtracted form the evaporation rate for the evaporation-monitoring pond.

Another approach for making more exact corrections that fully accounts for wind velocity and relative humidity (vapor pressure) is the use of the evaporation relation expressed as:

$$E = Nu\,(P_w - P_a)$$

where E is the evaporation, N is the mass transfer coefficient, u is the wind velocity, and $P_w$ and $P_a$ are water vapor pressures of the water surface and air. For an operating pond,

$$E_o = Nu\,(P_w - P_a)_o$$

and for the evaporation-monitoring pond,

$$E_m = Nu\,(P_w - P_a)_m$$

hence

$$E_o = \frac{(P_w - P_a)_o\,E_m}{(P_w - P_a)_m}$$

This method of correction more closely represents the true physics of evaporation.

Both evaporation and seepage values are dependent upon good water-level measurements. Counterweighted float-type water-level gages are convenient for measuring and recording weekly histories of water level in the ponds. To shield the float and counterweights from wind, stilling wells should be used. These wells should be made of brine-resistant material or coated to prevent corrosion. To dampen out water surface wave disturbances, the port area into the wells should be 1/1,000 of the well area. The wells are set within the ponds. Since the top of the wells act as support for the water-level gages, the wells must be anchored firmly to the pond bank so that gage reference will not change.

In ponds with sloping banks, platforms independent from the well support need to be constructed to provide access for reading and maintenance. These platforms should be wide, firm, and extend over the water sufficiently to make a satisfactory and safe work area. If the ponds are large, three or four water-level gages might be required to account for tilt of water surface due to prevailing winds. Hook gages with a stilling well should be provided in each pond for water-level gage referencing. The hook gage should be mounted on a separate support, should be readable from the platform and carefully referenced to a permanent bench mark. Referencing of water-level gages to hook gages should be done on calm days to prevent lag due to fluctuating water level affecting the gage readings.

One or more standard weather rain gages should be used to measure rainfall. Experience at the test site indicated that watertight ponds can also be used to check rain gage measurements if distinction can be made between rain and brine inflow.

Water budgets will both detect and measure seepage from brine disposal ponds. There are other methods that only detect seepage. Some localities require chemical tests of soil and perimeter well water to determine contamination of soil and pollution of ground water. The perimeter wells also might detect changes of ground water level related to seepage. Chemical analyses do not always indicate the source of pollution. Ponds could be tagged with fluorescent dyes or other tracers.[14] As a further precaution, each pond could be tagged with a different tracer which would help the operators determine which pond should be taken out of service, inspected and repaired.

[14]Op. cit. p. 1.

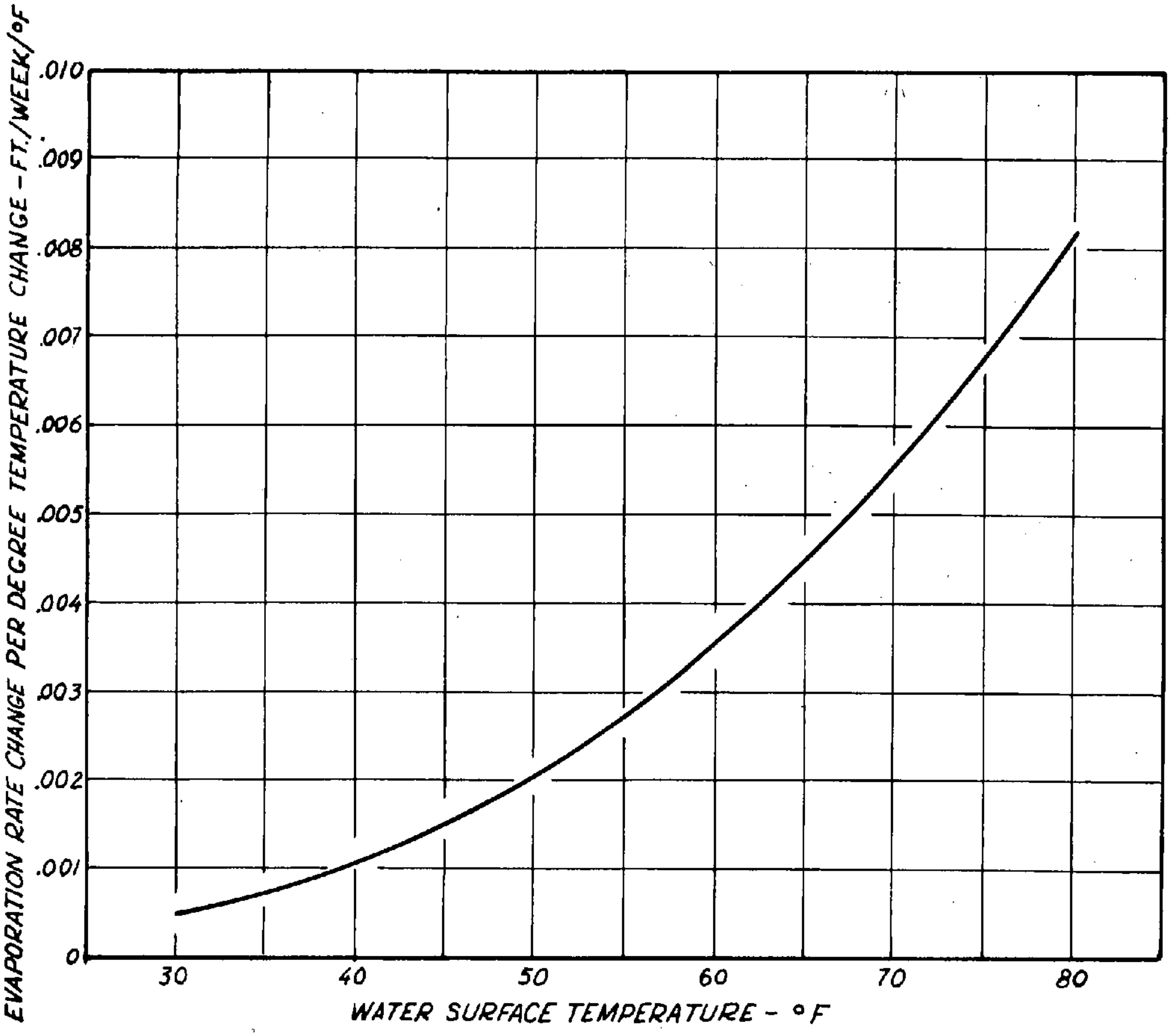



Figure 5. Computed Corrections for evaporation rate at different temperatures. Dalpra test site.

Documentation should be kept of weather data, pond water surface temperature, plant brine movements, brine concentrations of the ponds, plant inflow and perimeter well water and the water loss from the evaporation-monitoring ponds. These records will prove that local minimum seepage requirements are being met, will provide protection from pollution complaints and will help to attain more efficient operation of the pond disposal system.

## FUTURE FIELD TESTS

Field tests will be conducted at Dalpra Farm (OSW Agreement No. 14-30-2532, Work Order No. 4) to evaluate three newly developed soil sealants for low-cost seepage control in brine disposal ponds.

The water-soluble polymer, B-5604, and the gel material, B-5605, will be applied by two methods: (1) mixed into the natural soil and compacted to achieve seepage reduction, and (2) ponded. Application rate for both methods will be 500 lb/acre (0.057 kg/m$^2$) of each material. The vinyl polymer formulation, B-5800, will be spray applied in a concentrated mixture (three parts B-5800 to one part water) to form a continuous film. An application rate of 0.5 gpsy (2.3 l/m$^2$) will be used to attain a film thickness of about 30 mils (0.76 mm). Before the concentrated mixture is applied, a dilute mixture (1 part B-5800 to 19 parts water) will be used to stabilize the natural soil.

Besides evaluating the new soil sealants, the 6-mil (0.15-mm) polyethylene lining will be replaced with a 10-mil (0.25-mm) polyethylene lining. The thicker material will be formulated and manufactured for use in waterproofing applications. It is anticipated that the 10-mil (0.25-mm) polyethylene lining will provide seepage control similar to the PVC lining. In addition, field tests will continue on the original linings as required.

The contract work is scheduled to be completed and reported on or before March 1, 1971.

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## MATERIALS LISTING

| Laboratory Sample No. | Material |
|---|---|
| 48D-36 | Attapulgite clay formulation. Chemical sealant recommended by Diamond Shamrock Company. |
| 48D-37 | Carboxymethyl cellulose plus Alum mixture. Chemical sealant recommended by Diamond Shamrock Company. |
| B-5876 | Liquid cutback asphalt. Proprietary product formulated for deep penetration. |

| Laboratory sample No. | Material |
|---|---|
| B-5576 | Asphaltic concrete hot-mix sample. |
| B-5685 | Sample of in-place asphaltic-concrete lining. |
| B-5800 | Chemical sealant. A modified vinyl polymer supplied at 60-percent solids in water. |
| B-5604 | Chemical sealant. A water-soluble polymer. |
| B-5605 | Chemical sealant. A particulate gel material. |

# APPENDIX I

# SUMMARY OF

# FIELD SEEPAGE MEASUREMENTS

# TABLES 7–15

Table 7

SEEPAGE LOSSES FOR NYLON-REINFORCED BUTYL RUBBER

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 6-20 | 6-23 | 35.5 | 2.82 | 0.860 |
| 6-23 | 6-27 | 4.09 | 2.64 | 0.805 |
| 6-27 | 7-2 | 1.64 | 2.51 | 0.765 |
| 7-2 | 7-7 | 3.44 | 2.49 | 0.759 |
| 7-7 | 7-14 | 0.64 | 2.28 | 0.695 |
| 7-14 | 7-21 | 0 | 2.13 | 0.649 |
| 7-29 | 8-4 | 3.96 | 2.91 | 0.887 |
| 8-4 | 8-9 | 4.91 | 2.75 | 0.838 |
| 8-9 | 8-11 | 28.9 | 2.57 | 0.783 |
| 8-11 | 8-18 | 53.4 | 2.50 | 0.762 |
| 8-28 | 9-2 | 0.573 | 2.98 | 0.908 |
| 9-2 | 9-9 | 0.701 | 2.88 | 0.878 |
| 9-9 | 9-15 | 0.478 | 2.98 | 0.908 |
| 9-15 | 9-22 | 0.114 | 2.99 | 0.911 |
| 9-22 | 9-29 | 0.114 | 2.93 | 0.893 |
| 9-29 | 10-7 | 0.253 | 3.03 | 0.924 |
| 10-7 | 10-20 | 0.188 | 3.14 | 0.957 |
| 10-20 | 10-27 | 0 | 3.19 | 0.972 |
| 10-27 | 11-3 | 0.057 | 3.21 | 0.978 |
| 11-3 | 11-10 | 0.172 | 3.22 | 0.981 |
| 11-10 | 11-17 | 0.409 | 3.19 | 0.972 |
| 11-17 | 11-24 | 0.348 | 3.19 | 0.972 |
| 11-24 | 12-1 | 0.057 | 3.18 | 0.969 |
| 12-1 | 12-8 | 0 | 3.16 | 0.963 |

Table 8

SEEPAGE LOSSES FOR POLYETHYLENE PLASTIC LINING

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 5-16 | 5-21 | 2.87 | 2.95 | 0.899 |
| 5-21 | 5-24 | 1.64 | 2.88 | 0.878 |
| 5-24 | 5-31 | 1.64 | 2.76 | 0.841 |
| 6-1 | 6-6 | 6.22 | 2.88 | 0.878 |
| 6-6 | 6-8 | 5.11 | 2.85 | 0.867 |
| 6-8 | 6-10 | 3.07 | 2.83 | 0.863 |
| 6-11 | 6-15 | 2.66 | 2.83 | 0.863 |
| 6-18 | 6-23 | 3.44 | 2.67 | 0.814 |
| 6-23 | 6-27 | 0.82 | 2.58 | 0.786 |
| 6-27 | 7-2 | 0.90 | 2.48 | 0.755 |
| 7-2 | 7-7 | 5.57 | 2.92 | 0.890 |
| 7-7 | 7-14 | 3.16 | 2.79 | 0.850 |
| 7-14 | 7-21 | 5.26 | 2.76 | 0.841 |
| 7-22 | 7-29 | 4.44 | 2.76 | 0.841 |
| 7-29 | 8-4 | 2.72 | 2.79 | 0.850 |
| 8-4 | 8-11 | 4.04 | 2.80 | 0.853 |
| 8-11 | 8-18 | 3.16 | 2.94 | 0.896 |
| 8-18 | 8-25 | 1.93 | 2.80 | 0.853 |
| 8-25 | 9-2 | 2.35 | 2.88 | 0.878 |
| 9-2 | 9-9 | 2.40 | 2.86 | 0.871 |
| 9-9 | 9-15 | 2.94 | 2.95 | 0.899 |
| 9-15 | 9-22 | 2.80 | 2.95 | 0.899 |
| 9-22 | 9-29 | 2.51 | 2.84 | 0.866 |
| 9-29 | 10-7 | 5.17 | 2.99 | 0.911 |
| 10-7 | 10-20 | 5.89 | 2.99 | 0.911 |
| 10-20 | 10-27 | 2.69 | 2.91 | 0.887 |
| 10-27 | 11-3 | 6.73 | 2.98 | 0.908 |
| 11-3 | 11-10 | 4.15 | 2.89 | 0.881 |
| 11-10 | 11-17 | 4.44 | 2.80 | 0.853 |
| 11-17 | 11-24 | 3.62 | 2.72 | 0.829 |
| 11-24 | 12-1 | 7.42 | 2.95 | 0.899 |
| 12-1 | 12-7 | 6.34 | 2.83 | 0.863 |

Table 9

SEEPAGE LOSSES FOR ASPHALTIC-CONCRETE LINING

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 7-7 | 7-14 | 9.58 | 2.84 | 0.866 |
| 7-14 | 7-21 | 22.8 | 2.87 | 0.875 |
| 7-22 | 7-29 | 14.5 | 2.80 | 0.852 |
| 8-18 | 8-25 | 10.9 | 2.90 | 0.884 |
| 8-25 | 9-2 | 6.45 | 2.89 | 0.881 |
| 9-2 | 9-9 | 5.15 | 2.90 | 0.884 |
| 9-9 | 9-15 | 2.80 | 2.95 | 0.899 |
| 9-15 | 9-22 | 3.04 | 2.94 | 0.896 |
| 9-22 | 9-29 | 3.44 | 2.94 | 0.896 |
| 9-29 | 10-7 | 3.12 | 2.99 | 0.911 |
| 10-7 | 10-20 | 2.05 | 3.06 | 0.933 |
| 10-20 | 10-27 | 2.80 | 3.05 | 0.930 |
| 10-27 | 11-3 | 2.05 | 3.02 | 0.920 |
| 11-3 | 11-10 | 2.34 | 3.00 | 0.914 |
| 11-10 | 11-17 | 2.22 | 2.93 | 0.893 |
| 11-17 | 11-24 | 1.87 | 2.90 | 0.884 |
| 11-24 | 12-1 | 1.23 | 2.98 | 0.908 |
| 12-1 | 12-7 | 0.82 | 2.95 | 0.899 |

Table 10

SEEPAGE LOSSES FOR SOIL-CEMENT LINING

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 6-11 | 6-15 | 14.9 | 2.88 | 0.878 |
| 6-18 | 6-23 | 9.74 | 2.68 | 0.817 |
| 6-25 | 6-30 | 11.2 | 2.88 | 0.878 |
| 6-30 | 7-7 | 7.60 | 2.54 | 0.774 |
| 7-7 | 7-14 | 8.13 | 2.72 | 0.829 |
| 7-14 | 7-21 | 8.95 | 2.67 | 0.814 |
| 7-22 | 7-29 | 5.62 | 2.45 | 0.747 |
| 7-29 | 8-4 | 7.98 | 2.91 | 0.887 |
| 8-4 | 8-11 | 6.78 | 2.68 | 0.817 |
| 8-11 | 8-18 | 6.84 | 2.91 | 0.887 |
| 8-18 | 8-25 | 6.31 | 2.70 | 0.823 |
| 8-25 | 9-2 | 6.66 | 2.91 | 0.887 |
| 9-2 | 9-9 | 7.00 | 2.89 | 0.881 |
| 9-9 | 9-15 | 6.21 | 2.92 | 0.890 |
| 9-15 | 9-22 | 9.18 | 2.89 | 0.881 |
| 9-22 | 9-29 | 7.07 | 2.90 | 0.884 |
| 9-29 | 10-7 | 7.16 | 2.95 | 0.899 |
| 10-7 | 10-20 | 6.67 | 2.93 | 0.893 |
| 10-20 | 10-27 | 5.62 | 2.94 | 0.896 |
| 10-27 | 11-3 | 5.78 | 2.99 | 0.911 |
| 11-3 | 11-10 | 5.73 | 2.91 | 0.887 |
| 11-10 | 11-17 | 5.96 | 2.94 | 0.896 |
| 11-17 | 11-24 | 5.84 | 2.85 | 0.869 |
| 11-24 | 12-1 | 6.20 | 2.95 | 0.899 |
| 12-1 | 12-8 | 5.73 | 2.95 | 0.899 |

Table 11

SEEPAGE LOSSES FOR COMPACTED-EARTH LINING

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 6-11 | 6-15 | 28.9 | 2.94 | 0.896 |
| 6-18 | 6-23 | 25.0 | 2.81 | 0.856 |
| 6-25 | 6-30 | 23.8 | 2.79 | 0.850 |
| 7-2 | 7-7 | 27.2 | 2.80 | 0.853 |
| 7-7 | 7-14 | 37.4 | 2.80 | 0.853 |
| 7-14 | 7-21 | 51.7 | 2.78 | 0.847 |
| 7-22 | 7-29 | 37.6 | 2.82 | 0.860 |
| 7-29 | 8-4 | 34.8 | 2.85 | 0.869 |
| 8-4 | 8-11 | 30.8 | 2.66 | 0.811 |
| 8-11 | 8-18 | 28.8 | 2.82 | 0.860 |
| 8-18 | 8-25 | 23.5 | 2.76 | 0.841 |
| 8-25 | 9-2 | 23.2 | 2.87 | 0.875 |
| 9-2 | 9-9 | 21.2 | 2.76 | 0.841 |
| 9-9 | 9-15 | 18.8 | 2.81 | 0.856 |
| 9-15 | 9-22 | 17.4 | 2.82 | 0.860 |
| 9-22 | 9-29 | 14.8 | 2.83 | 0.863 |
| 9-29 | 10-7 | 13.7 | 2.87 | 0.875 |
| 10-7 | 10-20 | 10.6 | 2.90 | 0.884 |
| 10-20 | 10-27 | 9.42 | 2.91 | 0.887 |
| 10-27 | 11-3 | 8.02 | 2.98 | 0.908 |
| 11-3 | 11-10 | 7.42 | 2.93 | 0.893 |
| 11-10 | 11-17 | 7.13 | 2.93 | 0.893 |
| 11-17 | 11-24 | 7.02 | 2.80 | 0.853 |
| 11-24 | 12-1 | 7.07 | 2.94 | 0.896 |
| 12-1 | 12-8 | 6.02 | 2.94 | 0.896 |

Table 12

SEEPAGE LOSSES FOR SOIL SEALANT LINING
(Carboxymethyl cellulose Plus Alum)

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 8-19 | 8-25 | 15.9 | 2.85 | 0.869 |
| 8-25 | 9-2 | 12.4 | 2.83 | 0.863 |
| 9-2 | 9-9 | 13.8 | 2.83 | 0.863 |
| 9-9 | 9-15 | 10.1 | 2.90 | 0.884 |
| 9-15 | 9-22 | 10.0 | 2.91 | 0.887 |
| 9-22 | 9-29 | 8.60 | 2.88 | 0.878 |
| 9-29 | 10-7 | 7.58 | 2.95 | 0.899 |
| 10-7 | 10-20 | 7.12 | 2.91 | 0.887 |
| 10-20 | 10-27 | 8.36 | 2.92 | 0.890 |
| 10-27 | 11-3 | 9.01 | 2.96 | 0.902 |
| 11-3 | 11-10 | 11.10 | 2.90 | 0.884 |
| 11-10 | 11-17 | 12.2 | 2.88 | 0.878 |
| 11-17 | 11-24 | 12.3 | 2.68 | 0.817 |
| 11-24 | 12-1 | 13.3 | 2.88 | 0.878 |
| 12-1 | 12-7 | 13.9 | 2.89 | 0.881 |

Table 13

SEEPAGE LOSSES FOR SOIL SEALANT LINING
(Attapulgite Clay Formulation)

| Date From | Date To | Seepage loss, ft/yr (cm/sec x $10^{-6}$) | Average head, feet | Average head, meters |
|---|---|---|---|---|
| 5-16 | 5-21 | 58 | 2.70 | 0.823 |
| 5-21 | 5-24 | 57 | 2.60 | 0.792 |
| 5-24 | 5-31 | 80 | 2.56 | 0.780 |
| 6-1 | 6-6 | 58 | 2.54 | 0.774 |
| 6-6 | 6-8 | 41 | 2.24 | 0.683 |
| 6-8 | 6-10 | 46 | 2.50 | 0.762 |
| 6-11 | 6-15 | 37 | 2.58 | 0.786 |
| 6-18 | 6-23 | 81 | 2.73 | 0.832 |
| 6-23 | 6-27 | 105 | 2.76 | 0.841 |
| 6-27 | 7-2 | 109 | 2.33 | 0.710 |
| 7-2 | 7-7 | 139 | 1.88 | 0.573 |
| 7-7 | 7-10 | 202 | 2.22 | 0.677 |
| 7-22 | 7-29 | 146 | 2.36 | 0.719 |
| 8-19 | 8-25 | 124 | 2.05 | 0.625 |
| 9-2 | 9-9 | 93 | 2.16 | 0.658 |
| 9-9 | 9-15 | 121 | 2.03 | 0.619 |
| 9-15 | 9-22 | 111 | 2.03 | 0.619 |
| 9-22 | 9-29 | 102 | 2.08 | 0.634 |
| 9-29 | 10-7 | 83 | 1.82 | 0.555 |
| 10-7 | 10-20 | 66 | 1.49 | 0.454 |
| 10-20 | 10-27 | 73 | 2.36 | 0.719 |
| 10-27 | 11-3 | 65 | 2.47 | 0.753 |
| 11-3 | 11-10 | 56 | 2.49 | 0.759 |
| 11-10 | 11-17 | 50 | 2.60 | 0.792 |
| 11-17 | 11-24 | 33 | 1.84 | 0.561 |
| 11-24 | 12-1 | 39 | 2.66 | 0.811 |
| 12-1 | 12-7 | 36 | 2.73 | 0.832 |

Table 14

SEEPAGE LOSSES FOR SPRAY-APPLIED LIQUID ASPHALT B-5876

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 5-21 | 5-24 | 24.6 | 2.81 | 0.856 |
| 5-24 | 5-31 | 20.5 | 2.82 | 0.860 |
| 6-1 | 6-6 | 19.2 | 2.85 | 0.869 |
| 6-6 | 6-8 | 17.4 | 2.70 | 0.823 |
| 6-8 | 6-10 | 16.4 | 2.82 | 0.860 |
| 6-11 | 6-15 | 19.2 | 2.83 | 0.863 |
| 7-2 | 7-7 | 17.2 | 2.67 | 0.814 |
| 7-7 | 7-14 | 16.9 | 2.89 | 0.881 |
| 7-14 | 7-21 | 14.9 | 2.78 | 0.847 |
| 7-22 | 7-29 | 16.4 | 2.79 | 0.850 |
| 7-29 | 8-4 | 15.9 | 2.84 | 0.866 |
| 8-4 | 8-11 | 16.9 | 2.78 | 0.847 |
| 8-11 | 8-18 | 16.5 | 2.85 | 0.869 |
| 8-18 | 8-25 | 16.1 | 2.83 | 0.863 |
| 8-25 | 9-2 | 15.1 | 2.84 | 0.866 |
| 9-2 | 9-9 | 14.5 | 2.83 | 0.863 |
| 9-9 | 9-15 | 13.4 | 2.87 | 0.875 |
| 9-15 | 9-22 | 11.8 | 2.87 | 0.875 |
| 9-22 | 9-29 | 10.9 | 2.87 | 0.875 |
| 9-29 | 10-7 | 9.16 | 2.93 | 0.893 |
| 10-7 | 10-20 | 7.18 | 2.89 | 0.881 |
| 10-20 | 10-27 | 6.78 | 2.93 | 0.893 |
| 10-27 | 11-3 | 6.49 | 2.98 | 0.908 |
| 11-3 | 11-10 | 6.02 | 2.89 | 0.881 |
| 11-10 | 11-17 | 6.55 | 2.93 | 0.893 |
| 11-17 | 11-24 | 6.55 | 2.82 | 0.860 |
| 11-24 | 12-1 | 6.49 | 2.84 | 0.866 |
| 12-1 | 12-7 | 6.14 | 2.95 | 0.899 |

Table 15

SEEPAGE LOSSES FOR NATURAL SOIL (Untreated)

| Date | | Seepage loss, | Average head, | |
|---|---|---|---|---|
| From | To | ft/yr (cm/sec x $10^{-6}$) | feet | meters |
| 6-18 | 6-23 | 257 | 2.34 | 0.713 |
| 6-23 | 6-27 | 202 | 2.48 | 0.756 |
| 6-27 | 7-2 | 146 | 1.83 | 0.558 |
| 7-22 | 7-29 | 192 | 2.17 | 0.661 |
| 7-29 | 8-4 | 145 | 2.44 | 0.744 |
| 8-19 | 8-25 | 164 | 1.77 | 0.539 |
| 8-25 | 9-2 | 146 | 2.20 | 0.670 |
| 9-2 | 9-9 | 113 | 1.98 | 0.604 |
| 9-9 | 9-15 | 112 | 2.15 | 0.655 |
| 9-15 | 9-22 | 99 | 2.13 | 0.649 |
| 9-22 | 9-29 | 82 | 2.11 | 0.643 |
| 9-29 | 10-7 | 64 | 2.26 | 0.689 |
| 10-7 | 10-20 | 46 | 2.16 | 0.658 |
| 10-20 | 10-27 | 46 | 2.60 | 0.792 |
| 10-27 | 11-3 | 53 | 2.48 | 0.756 |
| 11-3 | 11-10 | 48 | 2.59 | 0.789 |
| 11-10 | 11-17 | 46 | 2.64 | 0.805 |
| 11-17 | 11-24 | 30 | 2.00 | 0.610 |
| 11-24 | 12-1 | 39 | 2.64 | 0.805 |
| 12-1 | 12-7 | 36 | 2.68 | 0.817 |

# APPENDIX II

## LABORATORY TEST RESULTS

Summary of Standard Soil Tests

for Roswell and Dalpra Farm Soils

Tables 16 and 17

Figures 6 and 7

Chemical Analyses of Soil and Water

from OSW Desalination Plant

Roswell, New Mexico

Table 18

Chemical Analyses of Water from

Dalpra Farm Test Site

Table 19

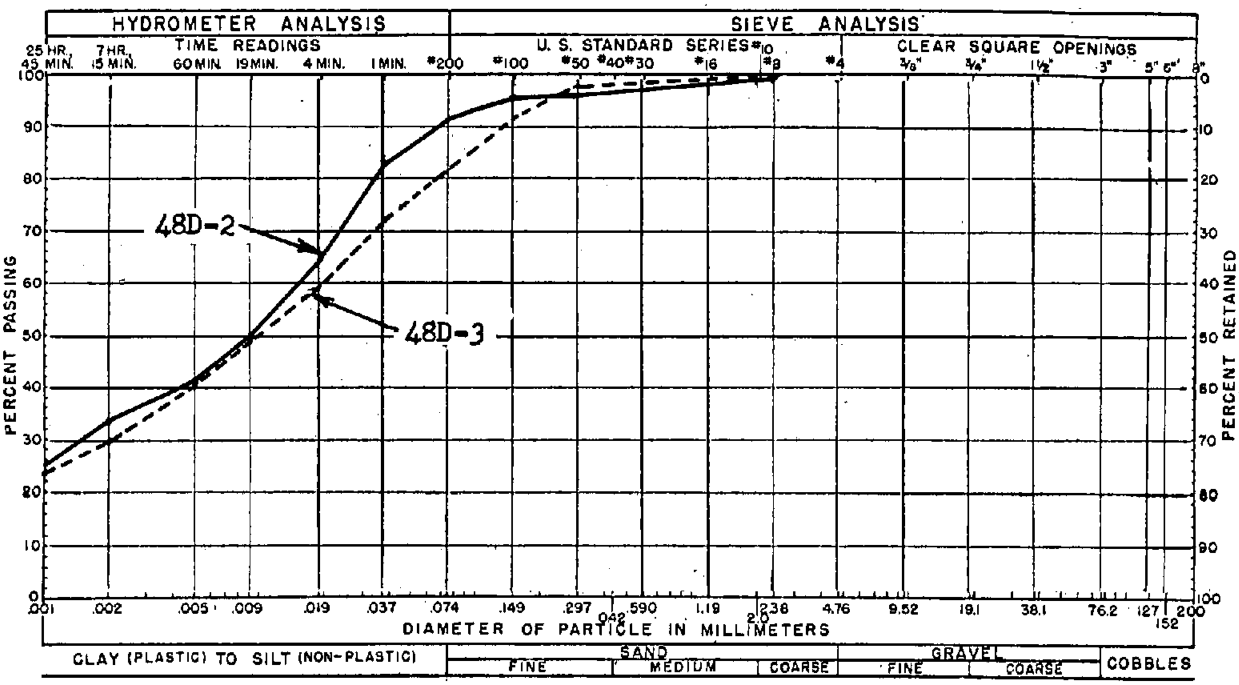
ROSWELL, NEW MEXICO
SOIL TEST DATA
SUMMARY STANDARD PROPERTIES, PROCTOR COMPACTION AND PERMEABILITY TESTS

Table 16
Sheet 1 of 1

| Identification | | | Grain-size Fractions In Percent | | | | | | Consistency Limits | | | | | Compaction Test | | | Permeability Test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Laboratory Sample No. 48D- | Field Designation | Depth of Strata (ft) | Clay to Silt: Smaller than 0.005 mm | Clay to Silt: 0.005 mm to 0.074 mm | Sand 0.074 mm to No.4 size | Gravel No.4 size to 3 inches | Cobbles 3 inches to 5 inches | Oversize Larger than 5 inches | Liquid Limit (%) | Plasticity Index (%) | Shrinkage Limit (%) | Classification Symbol (Unified System) Laboratory or Visual* | Specific Gravity | Maximum Dry Density (pcf) | Optimum Moisture Content (%) | Penetration Resistance (psi) | Load (psi) | Settlement (%) | Permeability (ft./yr.) |
| 2 | Roswell | | 41 | 50 | 9 | – | – | – | 33 | 17 | – | CL | 7.72 | 108.8 | 17 | – | | | |
| | | | | | | | | | | | | | | 1.74 gm/cm$^{-3}$ | | | | | |
| 3 | Roswell | | 41 | 40 | 19 | – | – | – | 34 | 16 | – | CL | 2.77 | – | – | – | | | |

*Indicate Visual Classification by an asterisk.

GPO 834301




GRADATION ANALYSIS

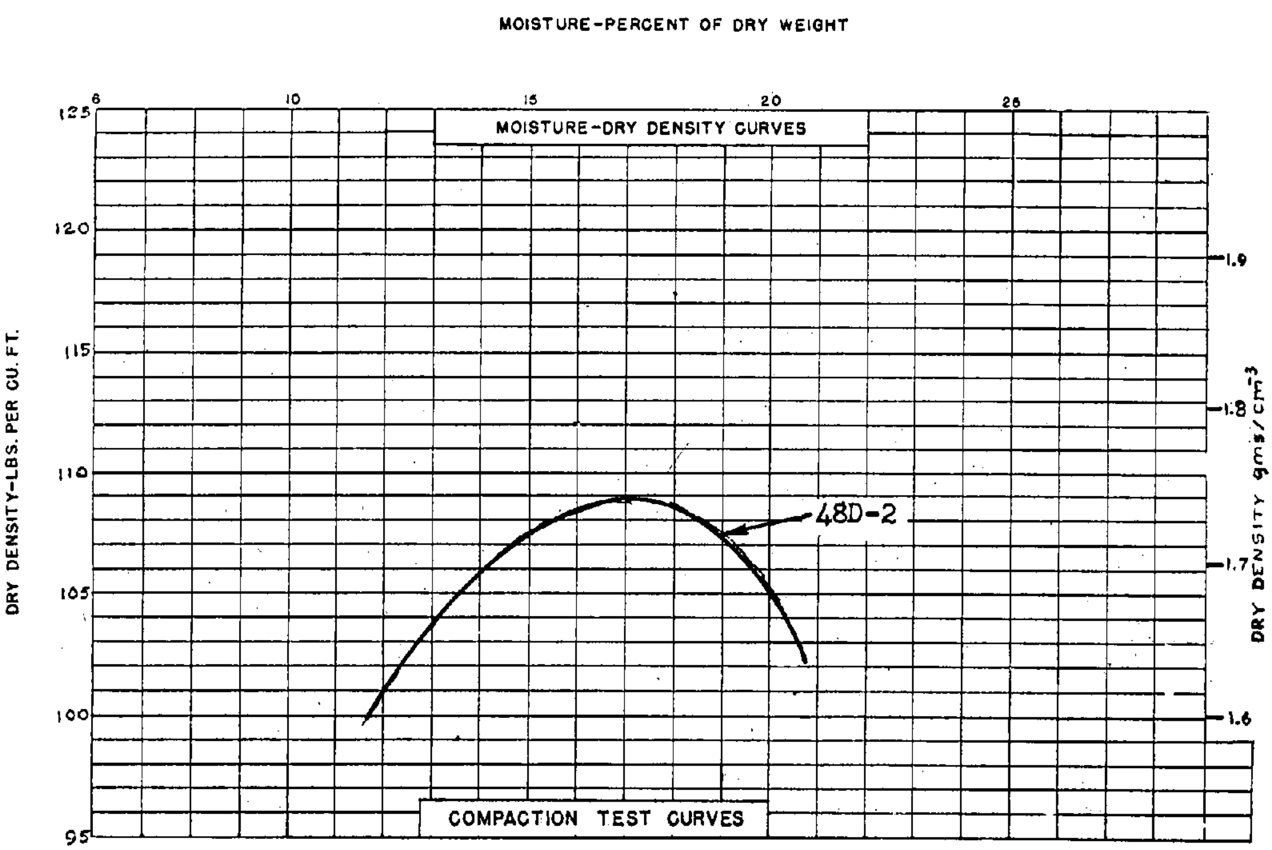


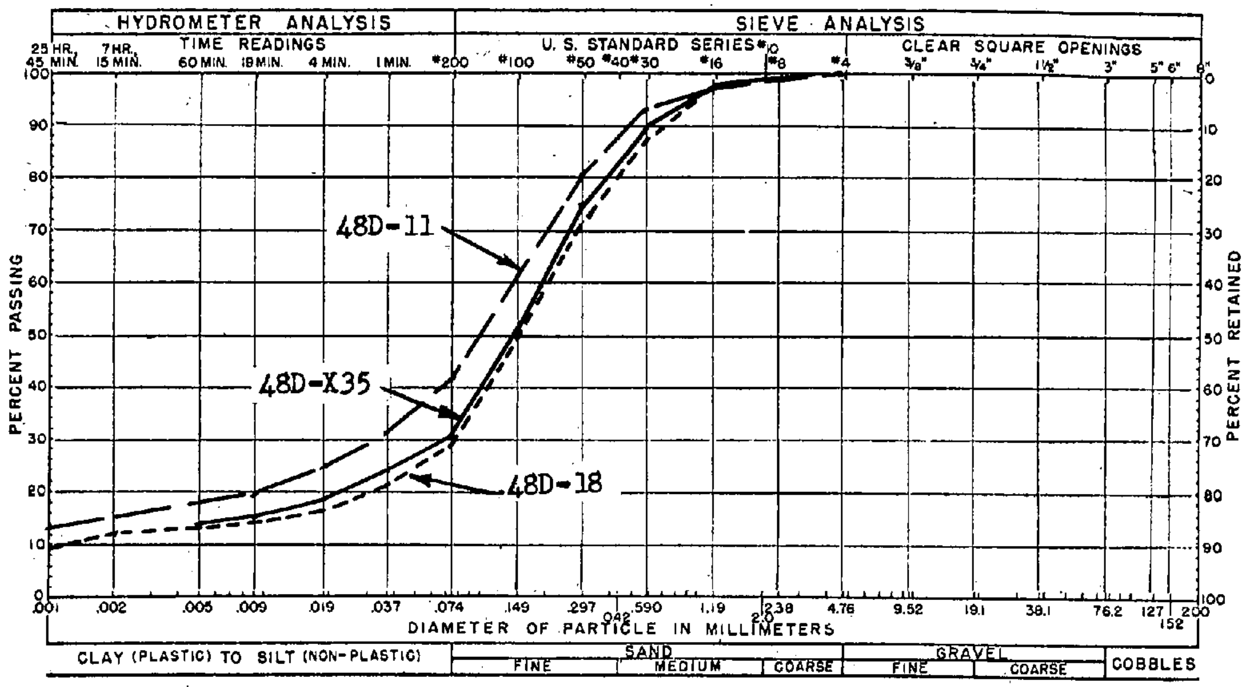

Figure 6. Standard soil properties—Roswell site.

DALPRA FARM
SOIL TEST DATA
SUMMARY STANDARD PROPERTIES, PROCTOR COMPACTION AND PERMEABILITY TESTS

Table 17
Sheet 1 of 1

| Identification | | | Grain-size Fractions In Percent | | | | | | Consistency Limits | | | Classification Symbol (Unified System) Laboratory or Visual* | Specific Gravity | Compaction Test | | | Permeability Test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Laboratory Sample No. 48D- | Field Designation | Depth of Strata (ft) | Clay to Silt: Smaller than 0.005 mm | Clay to Silt: 0.005 mm to 0.074 mm | Sand 0.074 mm to No.4 size | Gravel No.4 size to 3 inches | Cobbles 3 inches to 5 inches | Oversize Larger than 5 inches | Liquid Limit (%) | Plasticity Index (%) | Shrinkage Limit (%) | | | Maximum Dry Density (pcf) | Optimum Moisture Content (%) | Penetration Resistance (psi) | Load (psi) | Settlement (%) | Permeability (ft./yr.) |
| 11 | Sack sample from area of A. H. No. 2 | | 17 | 25 | 58 | – | – | – | 24 | 7 | – | SM | – | 119.0<br>1.91 gm/cm$^{-3}$ | 12.6 | – | – | – | – |
| 18 | Sack sample from area of A. H. No. 1 | | 13 | 16 | 71 | – | – | – | – | – | – | SM | – | 120.5<br>1.93 gm/cm$^{-3}$ | 11.4 | – | – | – | – |
| 27 | Sample from stock pile | | 16 | 23 | 61 | – | – | – | – | – | – | | | | | | | | |
| 28 | Sample from stock pile | | 14 | 18 | 68 | – | – | – | – | – | – | | | | | | | | |
| X35 | Composite of 48D-27 and 48D-28 (this sample was selected as representing the soil at the field test area) | | 14 | 17 | 69 | – | – | – | 20 | 3 | – | SM | 2.67 | 119.0<br>1.91 gm/cm$^{-3}$ | 11.7 | – | – | – | – |

*Indicate Visual Classification by an asterisk.




GRADATION ANALYSIS

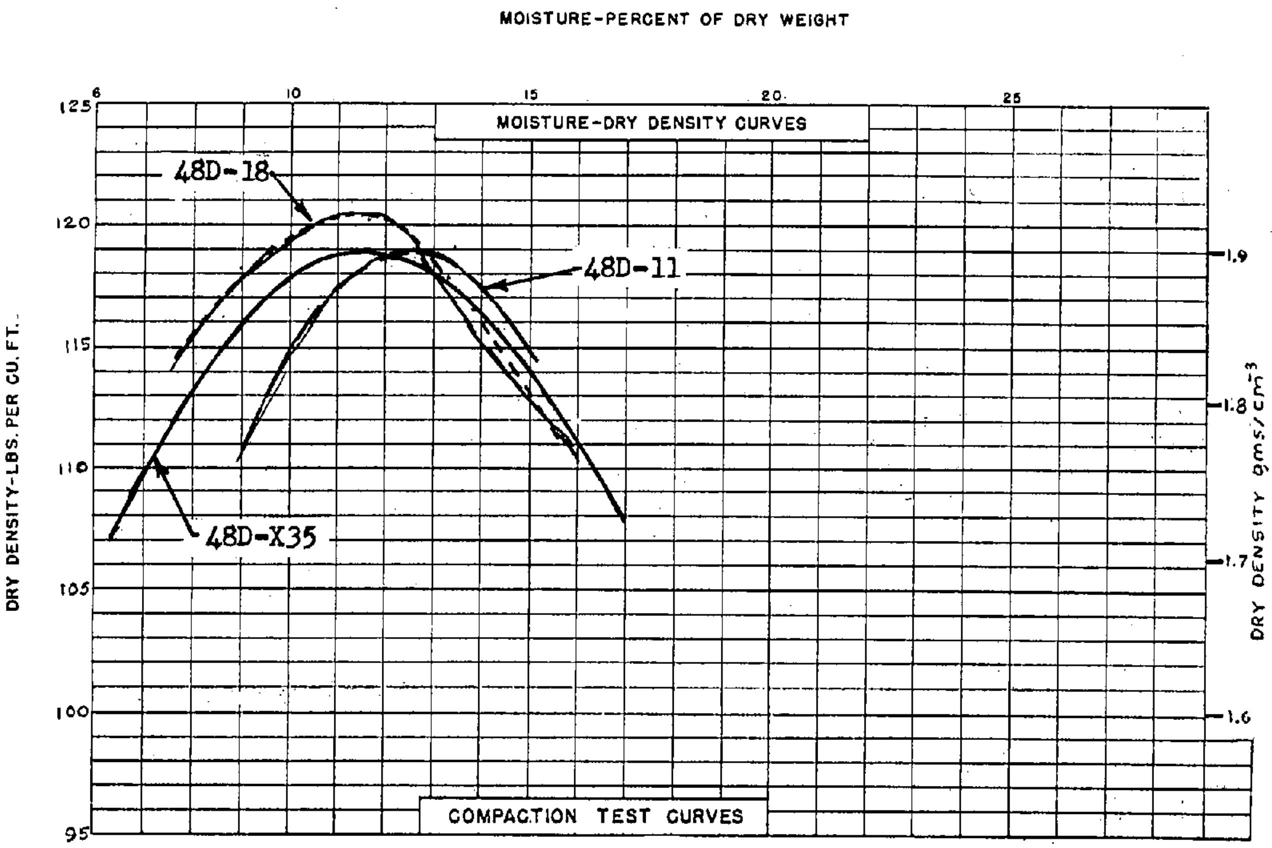



Figure 7. Standard soil properties—Dalpra site.

Table 18

CHEMICAL ANALYSIS OF SOIL AND WATER FROM OSW DESALINATION PLANT
Roswell, New Mexico

**SOIL**

| ION or compound | USBR test results (calculated as oxides) |
|---|---|
| $SiO_2$, percent | 42.73 |
| $Al_2O_3$, percent | 8.31 |
| $Fe_2O_3$, percent | 2.04 |
| $CaO$, percent | 20.17 |
| $MgO$, percent | 3.03 |
| $Na_2O$, percent | 1.02 |
| $K_2O$, percent | 1.60 |
| $SO_3$, percent | 0.88 |
| LOI including $CO_2$, percent | 20.00 |

**WATER**

| ION or compound | USBR test results* |
|---|---|
| Ec x $10^6$ at 21° C | 24,133. |
| Specific gravity | 1.0125 |
| TDS at 180° C | 15,685. |
| Calcium, ppm | 555. |
| Magnesium, ppm | 160. |
| Sodium, ppm | 4,816. |
| Potassium, ppm | 39. |
| Carbonate, ppm | 0.0 |
| Bicarbonate, ppm | 182. |
| Sulfate, ppm | 1,488. |
| Chloride, ppm | 7,924. |
| Nitrate, ppm | 0.0 |
| Iron, ppm | – |
| Silica, ppm | – |
| pH | – |

*Analysis of well water.

Table 19

CHEMICAL ANALYSES OF DALPRA BRINE EFFLUENT

| Sample No. | Source | Date | Conductivity $K \times 10^6$ at $25^{\circ}$ C | pH | TDS (ppm) |
|---|---|---|---|---|---|
| B-5860 | PVC pond | 11-25-68 | 4,783 | 8.3 | 3,876 |
| B-5862 | PVC pond | *5-19-69 | 5,520 | 8.2 | 4,480 |
| B-5863 | PVC pond | 6-10-69 | 5,930 | 8.2 | 4,880 |
| B-5864 | PVC pond | 7-18-69 | 6,033 | 8.0 | 4,968 |
| B-5880 | PVC pond | 8-18-69 | 6,965 | 8.5 | 5,856 |
| B-5884 | PVC pond | 9-29-69 | 7,059 | 8.0 | 5,928 |
| B-5859 | Waste pond | 11-25-68 | 4,783 | 8.3 | 3,816 |
| B-5861 | Waste pond | *5-19-69 | 4,653 | 8.0 | 3,704 |
| B-5879 | Waste pond | 8-18-69 | 2,862 | 8.3 | 2,080 |
| B-5883 | Waste pond | 9-29-69 | 2,402 | 8.1 | 1,712 |

*Chemical components in brine sampled May 19, 1969.

| ION or compound | PVC pond (ppm) | Waste pond (ppm) |
|---|---|---|
| Calcium | 103 | 95 |
| Magnesium | 53 | 50 |
| Sodium | 1,178 | 938 |
| Potassium | 15 | 16 |
| Carbonate | 0 | 0 |
| Bicarbonate | 146 | 161 |
| Sulfate | 2,707 | 2,227 |
| Chloride | 128 | 114 |
| Nitrate | 0 | 0 |

**Laboratory Permeability Test Results**

**for Roswell and Dalpra Soils Treated**

**with Various Soil Sealants**

**Tables 20 and 21**

Table 20

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Roswell | None | Tap | Tap | 1 | 87.0 | 80 | 39.9 | 5.3 | 20.1 |
| 2 | Roswell | None | Tap | Tap | 1 | 92.5 | 85 | Trace | Trace | Trace |
| 2 | Roswell | None | Tap | Tap | 1 | 97.9 | 90 | 0 | 0 | 0 |
| 2 | Roswell | None | Tap | Tap | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | None | Roswell synthetic effluent | Roswell synthetic effluent | 1 | 92.5 | 85 | 0 | 0 | 0 |
| 2 | Roswell | None | Roswell synthetic effluent | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | None | Roswell well water | Roswell well water | 1 | 92.5 | 85 | Trace | Trace | Trace |
| 2 | Roswell | None | Roswell well water | Roswell well water | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | None | Tap | Tap | 8 | 92.5 | 85 | 65.1 | 29.3 | 40.6 |
| 2 | Roswell | None | Tap | Tap | 8 | 97.9 | 90 | 5.5 | 4.0 | 4.2 |
| 3 | Diamond Alkali (Roswell) | None | Tap | Tap | 1 | 87.0 | 80 | 13.2 | 3.2 | 4.7 |
| 3 | Diamond Alkali (Roswell) | None | Tap | Tap | 1 | 92.5 | 85 | Trace | Trace | Trace |
| 3 | Diamond Alkali (Roswell) | None | Tap | Tap | 1 | 97.9 | 90 | Trace | Trace | Trace |
| 3 | Diamond Alkali (Roswell) | None | Tap | Tap | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 3 | Diamond Alkali (Roswell) | None | Roswell synthetic effluent | Roswell synthetic effluent | 1 | 92.5 | 85 | 4.4 | 0.5 | 1.8 |
| 3 | Diamond Alkali (Roswell) | None | Roswell synthetic effluent | Roswell synthetic effluent | 1 | 103.4 | 95 | Trace | Trace | Trace |

*Average "K" obtained after the permeabilities became nearly constant.

Table 20—Continued

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | Diamond Alkali (Roswell) | None | Roswell well water | Roswell well water | 1 | 92.5 | 85 | Trace | Trace | Trace |
| 3 | Diamond Alkali (Roswell) | None | Roswell well water | Roswell well water | 1 | 103.4 | 95 | Trace | Trace | Trace |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Tap | 1 | 87.0 | 80 | 129 | 356 | 245 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Tap | 1 | 87.0 | 80 | 206 | 486 | 312 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 81 | 433 | 202 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 64 | 341 | 176 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 1 | 97.9 | 90 | 36 | 280 | 116 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 1 | 97.9 | 90 | 13 | 35 | 27 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 16 | 139 | 54 |
| **2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 7 | 31 | 20 |
| 2 | Roswell | None | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 308 | 48 | 65 |

*Average "K" obtained after the permeabilities became nearly constant.
**Test results unreliable because sealant gelled before application to soil.

Table 20—Continued

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Roswell | None | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 245 | 47 | 65 |
| 2 | Roswell | None | Roswell well water | Roswell synthetic effluent | 1 | 97.9 | 90 | 3.3 | 0.6 | 0.7 |
| 2 | Roswell | None | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | None | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | 10 percent lignin | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 72 | 23 | 30 |
| 2 | Roswell | 10 percent lignin | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 139 | 24 | 38 |
| 2 | Roswell | 10 percent lignin | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 55 | 15 | 26 |
| 2 | Roswell | 1 percent methyl cellulose | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 0 | 0 | 0 |
| 2 | Roswell | 1 percent methyl cellulose | Roswell well water | Roswell synthetic effluent | 1 | 87.0 | 80 | 0 | 0 | 0 |
| 2 | Roswell | 1 percent methyl cellulose | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | 1 percent methyl cellulose | Roswell well water | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Tap | 1 | 87.0 | 80 | 21 | 0 | 0.8 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Tap | 1 | 87.0 | 80 | 70 | 0 | 0.8 |

*Average "K" obtained after the permeabilities became nearly constant.

Table 20—Continued

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 1 | 87.0 | 80 | 114 | 0 | 0.6 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 1 | 87.0 | 80 | Trace | Trace | Trace |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 1 | 97.9 | 90 | 0 | 0 | 0 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 1 | 97.9 | 90 | 0 | 0 | 0 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 1 | 103.4 | 95 | 0 | 0 | 0 |
| 2 | Roswell | None | Roswell well water | Roswell synthetic effluent | 8 | 87.0 | 80 | 566 | 494 | 522 |
| 2 | Roswell | 0.3 percent sodium silicate | Roswell well water | Roswell synthetic effluent | 8 | 87.0 | 80 | 506 | 417 | 453 |
| 2 | Roswell | 0.3 percent sodium silicate | Tap | Roswell synthetic effluent | 8 | 87.0 | 80 | 20 | 11 | 14 |

*Average "K" obtained after the permeabilities became nearly constant.

Table 21

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 107.1 | 90 | 1.6 | 0.6 | 0.6 |
| 11 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 110.8 | Field density | 0 | 0 | 0 |
| 18 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 114.5 | 95 | 14 | 11 | 19 |
| 18 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 108.4 | 90 | 106 | 72 | 125 |
| 18 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 107.2 | Field density | 115 | 71 | 142 |
| X35 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 104 | 5 | 10 |
| X35 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 185 | 22 | 34 |
| X35 | Dalpra Farm | 2 percent 48D-36 | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 83 | 6 | 10 |
| X35 | Dalpra Farm | 2 percent 48D-36 | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 65 | 4 | 10 |
| X35 | Dalpra Farm | 0.25 percent 48D-37 plus 0.5 percent alum | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 26 | 4 | 6 |
| X35 | Dalpra Farm | 0.25 percent 48D-37 plus 0.5 percent alum | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 16 | 4 | 6 |
| X35 | Dalpra Farm | B-5604 (800 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 263 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (800 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 292 | 0 | 0 |
| X35 | Dalpra Farm | None | Tap | Tap | 1 | 107.0 | 90 | 292 | 51 | 73 |

[1] Sealant placed dry on soil.
[2] Sealant placed as slurry on soil.
*Average "K" obtained after the permeabilities became nearly constant.

Table 21–Continued

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| X35 | Dalpra Farm | B-5605 (800 lb/acre)[1] | Tap | Tap | 1 | 107.0 | 90 | 312 | 5 | 7 |
| X35 | Dalpra Farm | B-5605 (400 lb/acre)[1] | Tap | Tap | 1 | 107.0 | 90 | 178 | 2 | 4 |
| X35 | Dalpra Farm | B-5604 (600 lb/acre)[2] | Tap | Tap | 1 | 107.0 | 90 | 241 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (600 lb/acre)[2] | Tap | Tap | 1 | 107.0 | 90 | 255 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (100 lb/acre)[2] | Tap | Tap | 1 | 107.0 | 90 | 212 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (100 lb/acre)[2] | Tap | Tap | 1 | 107.0 | 90 | 190 | 0 | 0 |
| X35 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 212 | 48 | 63 |
| X35 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 286 | 42 | 56 |
| X35 | Dalpra Farm | B-5605 (400 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 252 | 14 | 40 |
| X35 | Dalpra Farm | B-5605 (400 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 108 | 14 | 28 |
| X35 | Dalpra Farm | B-5604 (800 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 204 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (800 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 144 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (100 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 139 | 0 | 0 |
| X35 | Dalpra Farm | B-5604 (100 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 224 | 3 | 3 |
| X35 | Dalpra Farm | B-5605 (800 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 204 | 28 | 33 |

[1] Sealant placed dry on soil.
[2] Sealant placed as slurry on soil.
*Average "K" obtained after the permeabilities became nearly constant.

Table 21—Continued

SUMMARY OF PERMEABILITY TEST RESULTS

| Soil Sample No. 48D- | Soil source | Type sealant used | Mix water | Permeant water | Diameter sample (inches) | Placement density PCF | Placement density Percent laboratory maximum | Permeability "K" ft/yr Initial | Permeability "K" ft/yr Final | Permeability "K" ft/yr Average* |
|---|---|---|---|---|---|---|---|---|---|---|
| X35 | Dalpra Farm | B-5605 (800 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 232 | 40 | 51 |
| X35 | Dalpra Farm | B-5605 (400 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 255 | 25 | 32 |
| X35 | Dalpra Farm | B-5605 (400 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107 | 90 | 159 | 18 | 24 |
| X35 | Dalpra Farm | B-5605 (800 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 71 | 0 | 0 |
| X35 | Dalpra Farm | B-5605 (800 lb/acre)[1] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 261 | 13 | 21 |
| X35 | Dalpra Farm | None | Tap | Dalpra Farm effluent | 8 | 107.0 | 90 | 81 | 36 | 17 |
| X35 | Dalpra Farm | B-5605 (800 lb/acre)[1] | Tap | Dalpra Farm effluent | 8 | 107.0 | 90.0 | 29 | 0.8 | 0.9 |
| X35 | Dalpra Farm | B-5604 (100 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 195 | 7 | 8 |
| X35 | Dalpra Farm | B-5604 (100 lb/acre)[2] | Tap | Dalpra Farm effluent | 1 | 107.0 | 90 | 513 | 2 | 7 |
| [3] 54 | Dalpra Farm | B-5876 2 gal/yd[2] | Tap | Dalpra Farm effluent | 8 | 107.0 | 90 | Test results not reliable because of suspected piping. | | |
| [3] 54 | Dalpra Farm | B-5800 0.25 gal/yd[2] | Tap | Dalpra Farm | 8 | 107.0 | 90 | 0.12 | 0.02 | 0.06 |

[1] Sealant placed dry on soil.
[2] Sealant placed as slurry on soil.
[3] 48D-54 from same source as 48D-X35 and is nearly identical.
*Average "K" obtained after the permeabilities became nearly constant.

**Physical Properties Test Results for**

**Flexible Membrane Linings**

**Polyvinyl-Chloride Plastic**

**Polyethylene Plastic**

**Nylon-Reinforced Butyl Rubber**

**Tables 22 to 25**

Table 22

PHYSICAL PROPERTIES OF POLYVINYL-CHLORIDE LINING INSTALLED AT THE DALPRA FARM TEST SITE

Bureau of Reclamation Specifications Are Also Listed for Comparison

| Property | USBR requirements | Laboratory test results | Test method |
|---|---|---|---|
| 1. Thickness | 10 mils (0.25 mm) ± 10 percent | 10 mils (0.25 mm) | ASTM: D 374, Method C |
| 2. Tensile strength, each direction, minimum | 2,000 psi (140 kg/cm$^2$) | 2,600 psi (182 kg/cm$^2$) L<br>2,800 psi (196 kg/cm$^2$) T | ASTM: D 882 |
| 3. Bonded factory seam strength each direction minimum percent of tensile strength | 80 | 80 plus | ASTM: D 882 |
| 4. Ultimate elongation each direction, percent minimum | 250 | 334 L<br>307 T | |
| 5. Resistance to soil burial: | | | |
| Tensile strength loss, each direction—percent, maximum | 5 | Pass | See note below |
| Elongation loss, each direction—percent maximum | 20 | Pass | |
| 6. Water extraction, percent weight loss, maximum | 1.0 | Gain 0.32 | ASTM: D 1239 |
| 7. Tear resistance (Elmendorf), each direction, minimum average | 160 g/mil (64 n/mm) | 200 g/mil (80 n/mm) L<br>275 g/mil (110 n/mm) T | ASTM: D 1922 |
| 8. Low temperature impact, $0^{\circ}$ F ($-17.8^{\circ}$ C), ± $3.6^{\circ}$ F ($2^{\circ}$ C) | Not more than 2 specimens out of 10 shall fail | No failures | ASTM: D 1790 |

Note:
L denotes longitudinal direction
T denotes transverse direction

Test method for resistance to soil burial is described in Appendix IV.

Table 23
PHYSICAL PROPERTIES OF POLYETHYLENE LINING
INSTALLED AT THE DALPRA FARM TEST SITE
Tentative Bureau of Reclamation Requirements Are Also Listed for Comparison

| | Property | USBR requirement | Laboratory test results | Test method |
|---|---|---|---|---|
| 1. | Thickness | 12 mils (0.30 mm) ± 25 percent | 6.2 mils (0.16 mm)* | ASTM: D 374 Method C |
| 2. | Tensile strength, minimum | | | ASTM: D 882 |
| | Longitudinal | 1,700 psi (119 kg/cm$^2$) | 1,970 psi 138 kg/cm$^2$) | |
| | Transverse | 1,200 psi (84 kg/cm$^2$) | 2,020 psi (141 kg/cm$^2$) | |
| 3. | Ultimate elongation, percent minimum | | | ASTM: D 882 |
| | Longitudinal | 225 | 540 | |
| | Transverse | 350 | 420 | |
| 4. | Elmendorf Tear Resistance, minimum average | | | ASTM: D 1922 |
| | Longitudinal | 100 g/mil (40 n/mm) | 135 g/mil (54 n/mm) | |
| | Transverse | 100 g/mil (40 n/mm) | 235 g/mil (94 n/mm) | |
| 5. | Low temperature impact, 0° F (−17.8°C), ± 3.6° F (2° C) | Not more than 2 specimens out of 10 shall fail | No failures | ASTM: D 1790 |
| 6. | Water extraction, percent weight loss, maximum | 1.0 | 0.11 (gain) | ASTM: D 1239 |

*A 6-mil-(0.15-mm-) thick lining was evaluated at Dalpra Farm.

Table 24

## PUNCTURE RESISTANCE PRESSURE CELL TEST RESULTS

| Laboratory Sample No. | Type of material | Thickness | | Test condition*: Over No. 8 (2.38-mm) to No. 4 (4.76-mm) sieve size rock base — Water pressure at puncture | | | Test condition*: Over 3/4- to 1 and 1/2-inch- (19.1- to 38.1-mm) size rock base — Water pressure at puncture | | | Remarks— Small holes are punctures less than 1/16-inch (1.6-mm) average length |
|---|---|---|---|---|---|---|---|---|---|---|
| | | mils | mm | psi | kg/cm² | Time** hours | psi | kg/cm² | Time** hours | |
| B-6006 | Polyvinyl chloride*** | 10 | 0.25 | – | – | – | 22.5 | 1.6 | 7 | 6 small holes |
| B-5878 | Polyethylene*** | 6 | 0.15 | 12.5 | 0.9 | 3.5 | – | – | – | 20 small holes |
| B-4391 | Polyvinyl chloride | 10 | 0.25 | – | – | – | 27.5 | 1.9 | 1 | |
| B-3141 | Polyethylene | 6 | 0.15 | 10 | 0.7 | Immediate | – | – | – | 2 small holes |

*Water pressure increased by 2.5-psi (0.175-kg/cm$^2$) increments at 4-hour intervals.
**Time of puncture after reaching highest water pressure.
***Lining installed at the Dalpra Farm test site.

Samples No. B-4391 and B-3141 are listed for comparison.

Table 25

PHYSICAL PROPERTIES OF NYLON-REINFORCED BUTYL-RUBBER LINING INSTALLED AT THE DALPRA FARM TEST SITE

| Property | Laboratory test results | ASTM test method |
|---|---|---|
| Thickness | 46 mils (1.14 mm) | D 751 |
| Weight | 42.3 $oz/yd^2$ (1.44 $kg/m^2$) | D 751 |
| Mullen hydrostatic | 193 psi (13.5 $kg/cm^2$) | D 751 |
| Breaking strength L | 122.2 ppi (21.8 kg/cm) | D 751 Method A |
| (Grab) T | 114.5 ppi (20.5 kg/cm) | |
| Elongation L | 10.3 percent | D 751 |
| T | 10.7 percent | |
| Tear strength L | 21.0 lb (9.5 kg) | D 751 Method B |
| (Tongue) T | 20.8 lb (9.4 kg) | |
| Heat aging—115.6° F, 7 days | | D 573 and D 751 |
| Original hydrostatic | Minus 0.3 percent | |
| Original breaking strength | Minus 1.3 percent | |
| Original elongation | Plus 3.9 percent | |
| Ozone—Degree of cracking 37.8° C, 7 days, 50 pphm (Procedure B) | Cracked in 3 days | D 1149 and D 518 |
| Bond tests | | D 751 Method B |
| Seam breaking strength (cutstrip method) | 100 percent of sheet strength | |
| Peel strength | 2.9 ppi (0.52 kg/cm) | D 1876 |

Note: L denotes longitudinal direction
T denotes transverse direction

## ASPHALTIC-CONCRETE LINING

Tables 26 to 30

Table 26

ASPHALTIC-CONCRETE LINING–DALPRA FARM
Asphalt Cement Properties–Laboratory Sample No. B-5685

| Tests | Specification requirements* | Laboratory results |
|---|---|---|
| Penetration | | |
| At 25° C, 100 g, 5 sec | 40–50 | 41 |
| At 0° C, 200 g, 60 sec | No requirement | 16 |
| At 46.1° C, 50 g, 5 sec | No requirement | 173 |
| Ductility | | |
| At 25° C, 5 cm/min | Not less 40 cms | Plus 100 cms |
| Softening point (ring and ball) | 40° C–60° C | 54.5 |

*Federal Specification SS-A-706b.

Table 27

ASPHALTIC-CONCRETE LINING—DALPRA FARM
Aggregate Gradation—Laboratory Sample No. B-5685

| Sieve size | Cumulative percent passing | | |
|---|---|---|---|
| | Dry | Washed | Specification limits |
| 3/4-inch (19.1-mm) | 100.0 | 100.0 | 100 |
| 1/2-inch (12.7-mm) | 90.3 | 90.4 | 85-100 |
| 3/8-inch (9.52-mm) | 80.5 | 80.6 | |
| No. 4 (4.76-mm) | 65.0 | 65.2 | 55-80 |
| No. 10 (2.0-mm) | 55.1 | 55.4 | 35-60 |
| No. 40 (0.42-mm) | 26.3 | 28.3 | 18-30 |
| No. 100 (0.15-mm) | 10.2 | 13.5 | |
| No. 200 (0.074-mm) | 6.1 | 9.6 | 5-12 |

Table 28

ASPHALTIC-CONCRETE LINING—DALPRA FARM
Immersion-Compression Test Results
100 percent Laboratory Standard Density—Remolded samples (B-5576)

| Cylinder No. | Density pcf | Density g/cc | Curing conditions 4 days | Density after immersion pcf | Density after immersion g/cc | Air void percent | Volume swell percent | Absorption percent | Deformation in. | Deformation mm | Compressive strength psi | Compressive strength kg/cm$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 145.02 | 2.32 | Air, 25° C | – | – | 0.56 | – | – | 0.13 | 3.30 | 754.2 | 52.8 |
| 4 | 144.52 | 2.31 | Air, 25° C | – | – | 0.90 | – | – | 0.16 | 4.06 | 704.1 | 49.3 |
| Aug. | 144.77 | 2.32 | | – | – | 0.73 | – | – | 0.14 | 3.56 | 729.2 | 51.0 |
| 2 | 143.46 | 2.30 | Water, 48.9° C | 143.40 | 2.29 | 1.63 | 0.32 | 0.29 | 0.16 | 4.06 | 649.2 | 45.4 |
| 3 | 143.90 | 2.30 | Water, 48.9° C | 143.84 | 2.30 | 1.32 | 0.36 | 0.30 | 0.17 | 4.32 | 677.8 | 47.4 |
| Aug. | 143.68 | 2.30 | | 143.62 | 2.30 | 1.48 | 0.34 | 0.30 | 0.16 | 4.06 | 663.5 | 46.4 |

Table 29

ASPHALTIC-CONCRETE LINING—DALPRA FARM
Test of Flow Under Sustained Load
Remolded samples (B-5576)

| Cylinder No. | Density pcf | Density g/cc | Percent LSD* | Temperature °C | Load psi | Load $kg/cm^2$ | Deformation inch | Deformation mm | Test results, hours Stabilized | Test results, hours Failed |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 145.08 | 2.32 | 100.4 | 25 | 3.0 | 0.21 | 0.02 | 0.51 | 16 | |
| | | | | 60 | 5.0 | 0.35 | 0.01 | 0.25 | 24 | |
| | | | | 60 | 7.5 | 0.52 | 0.02 | 0.51 | 24 | |
| | | | | 60 | 10.0 | 0.70 | 0.03 | 0.76 | 24 | |
| | | | | 60 | 15.0 | 1.05 | 0.02 | 0.51 | | 6 |
| | | | | | | | Total 0.10 | 2.54 | | |
| 2 | 145.33 | 2.33 | 100.5 | 25 | 3.0 | 0.21 | 0.01 | 0.25 | 16 | |
| | | | | 60 | 5.0 | 0.35 | 0.02 | 0.51 | 24 | |
| | | | | 60 | 7.5 | 0.52 | 0.01 | 0.25 | 24 | |
| | | | | 60 | 10.0 | 0.70 | 0.02 | 0.51 | 24 | |
| | | | | 60 | 15.0 | 1.05 | 0.02 | 0.51 | 24 | |
| | | | | 60 | 17.5 | 1.22 | 0.02 | 0.51 | 72 | |
| | | | | 60 | 20.0 | 1.40 | 0.02 | 0.51 | 24 | |
| | | | | | | | Total 0.12 | 3.05 | | |

*LSD, Laboratory Standard Density, 144.57 pcf (2.31 g/cc), is based on the average of eight cylinders molded at 3,000 psi (210 $kg/cm^2$) held for 2 minutes.

Table 30

ASPHALTIC-CONCRETE LINING–DALPRA FARM
Test of Permeability
Core specimens from in-place lining sample (B-5685)

| Specimen No. | Density | | Percent LSD* | Air voids percent | Thickness | | Load | | Permeability | |
|---|---|---|---|---|---|---|---|---|---|---|
| | pcf | g/cc | | | in. | cm | psi | $kg/cm^2$ | ft/yr | cm/sec |
| 1 | 144.40 | 2.31 | 99.9 | 0.98 | 2.3 | 5.84 | 15 | 1.05 | 0 | 0 |
| 2 | 144.46 | 2.31 | 99.9 | 0.98 | 2.3 | 5.84 | 20 | 1.40 | 0 | 0 |

Note: Core specimens were cylindrical, 3 inches (7.62 cm) in diameter.

*LSD, Laboratory Standard Density, 144.57 pcf (2.31 g/cc)

**Soil-Cement Lining**

**Table 31**

**Figures 8 to 11**

Table 31

SOIL–CEMENT
Summary of Unconfined Compression and Permeability Test Data

| Cement content | | Specimen placement conditions | | | | Unconfined compressive strength | | | | | | Permeability (K) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Density | | | Moisture content | 3-day | | 7-day | | 28-day | | | |
| Percent by dry weight | Percent by volume | Percent of maximum | pcf | $gm/cm^{-3}$ | percent | psi | $kg/cm^{-2}$ | psi | $kg/cm^{-2}$ | psi | $kg/cm^{-2}$ | ft/yr | cm/sec |
| 6 | 7.05 | 98 | 117.2 | 1.88 | 10.5 | 282 | 19.8 | 316 | 22.2 | 468 | 32.9 | | |
| | | | | | | 297 | 20.9 | 332 | 23.3 | 472 | 33.2 | | |
| | | | | | | 282 | 19.8 | 332 | 23.3 | 466 | 32.8 | | |
| | | | Average values | | | 287 | 20.2 | 326 | 22.9 | 469 | 33.0 | – | – |
| 8 | 9.12 | 98 | 117.2 | 1.88 | 10.5 | 352 | 24.7 | 465 | 32.7 | 653 | 45.9 | | |
| | | | | | | 371 | 26.1 | 481 | 33.8 | 641 | 45.1 | | |
| | | | | | | 370 | 26.0 | 479 | 33.7 | 646 | 45.4 | | |
| | | | Average values | | | 364 | 25.6 | 475 | 33.4 | 647 | 45.5 | 2.60 | $2.6 \times 10^{-6}$ |
| 10 | 11.3 | 98 | 117.2 | 1.88 | 10.5 | 470 | 33.0 | 574 | 40.4 | 856 | 60.2 | | |
| | | | | | | 458 | 32.2 | 574 | 40.4 | 825 | 58.0 | | |
| | | | | | | 468 | 32.9 | 557 | 39.2 | 831 | 58.4 | | |
| | | | Average values | | | 465 | 32.7 | 568 | 39.9 | 837 | 58.8 | 0.25 | $25 \times 10^{-7}$ |

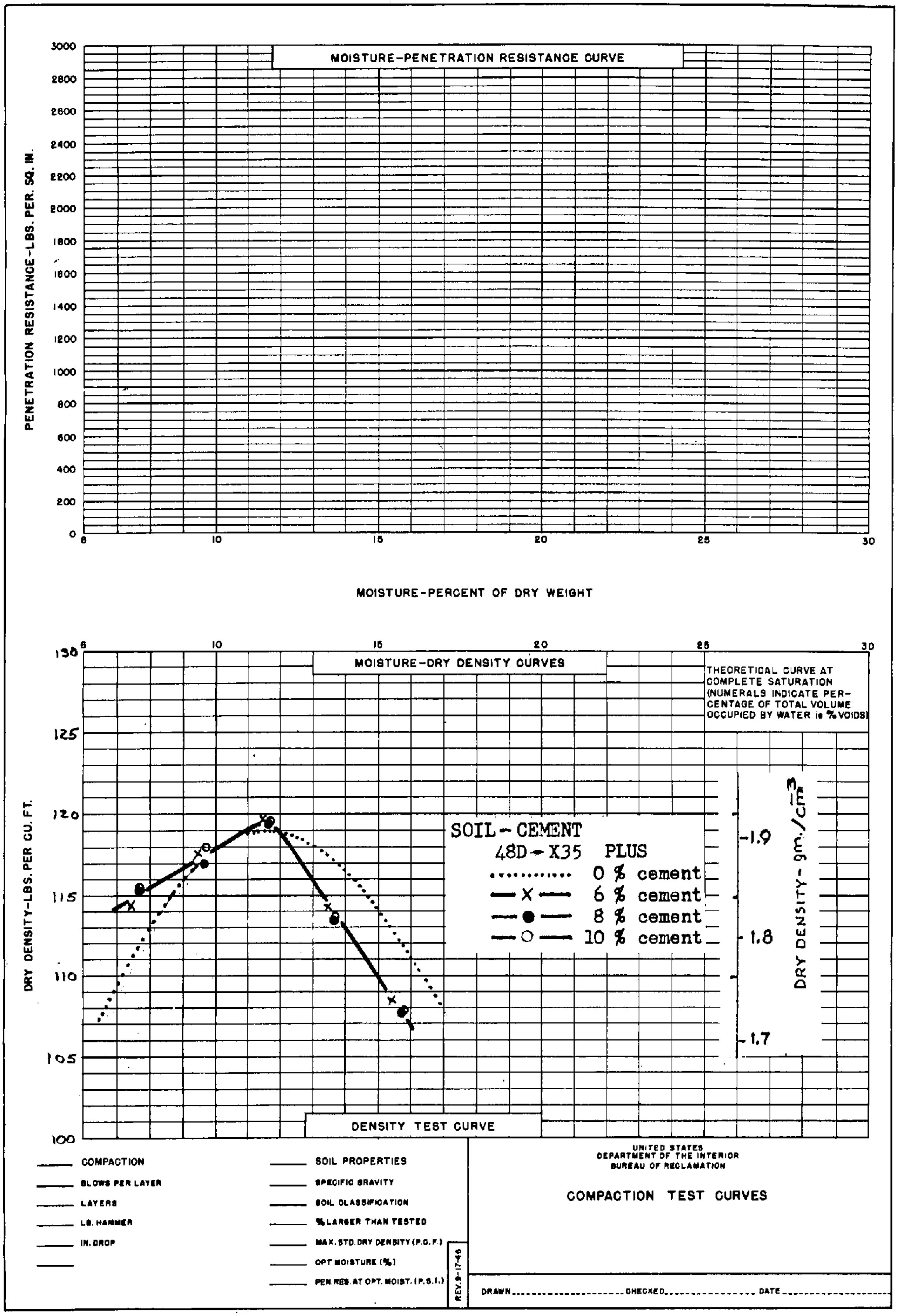



Figure 8. Compaction test curves.

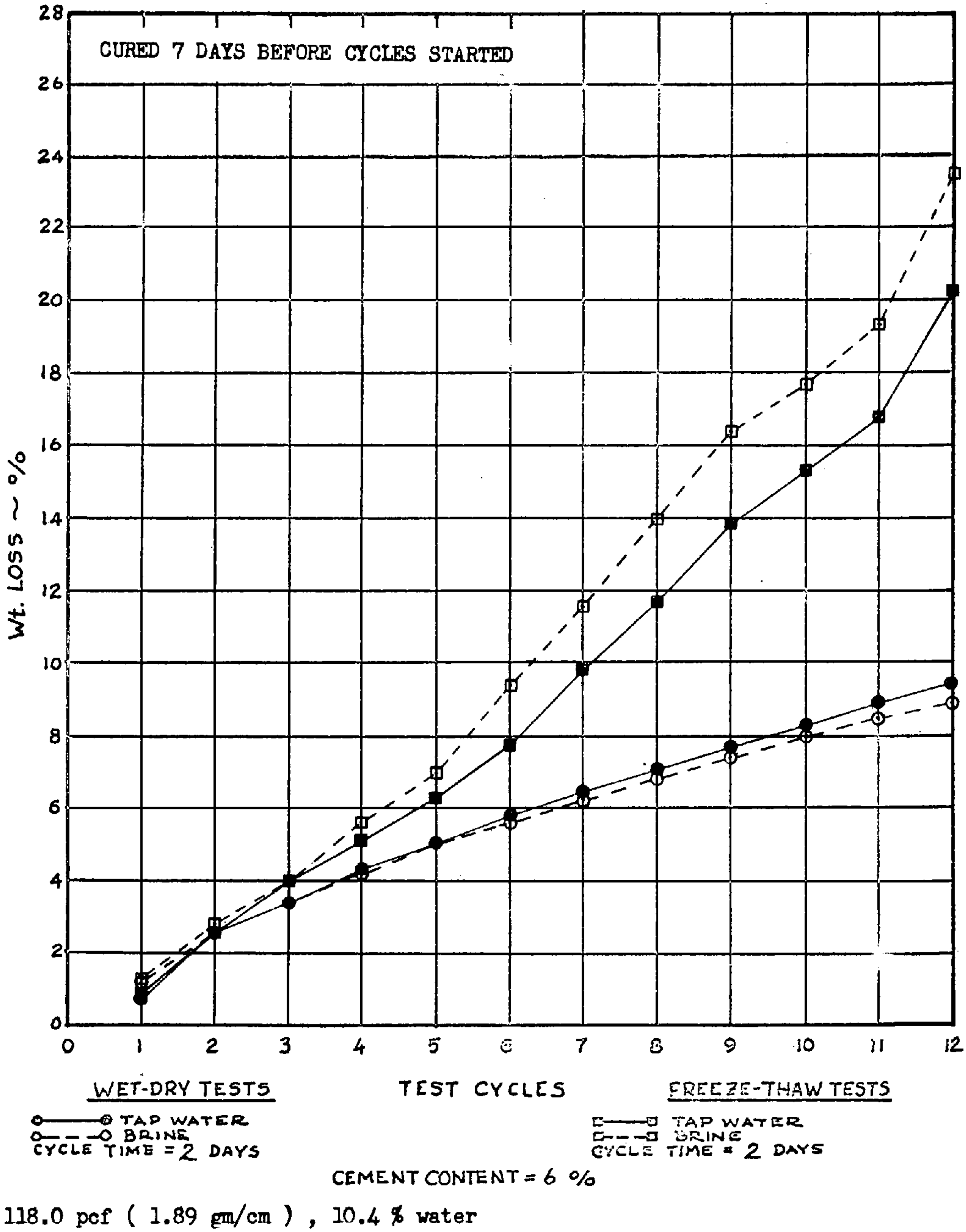
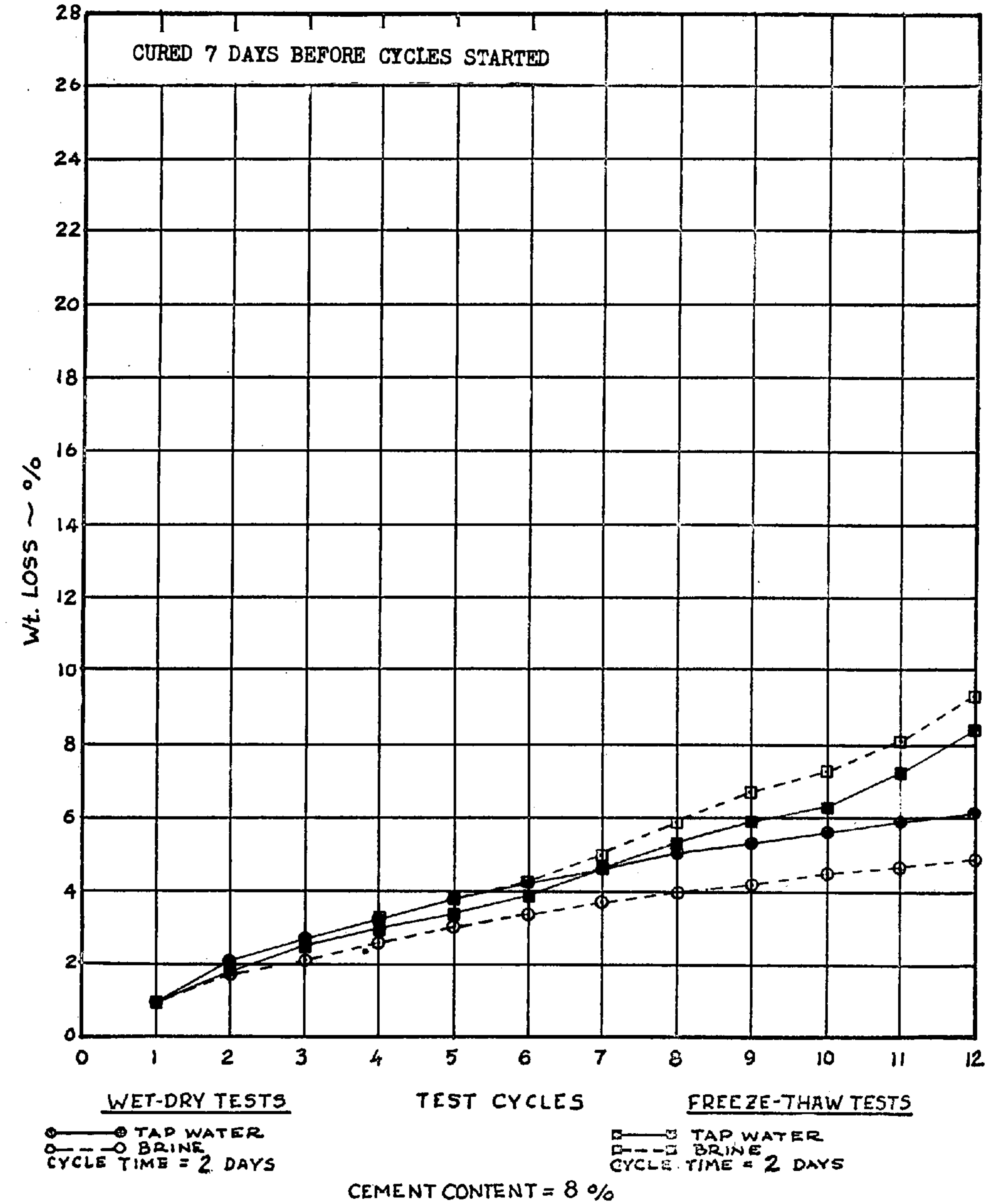



Figure 9. Soil-cement tests—Dalpra farm.




117.7 pcf ( 1.89 gm/cm ) , 10.5 % water

Figure 10. Soil-cement tests—Dalpra farm.

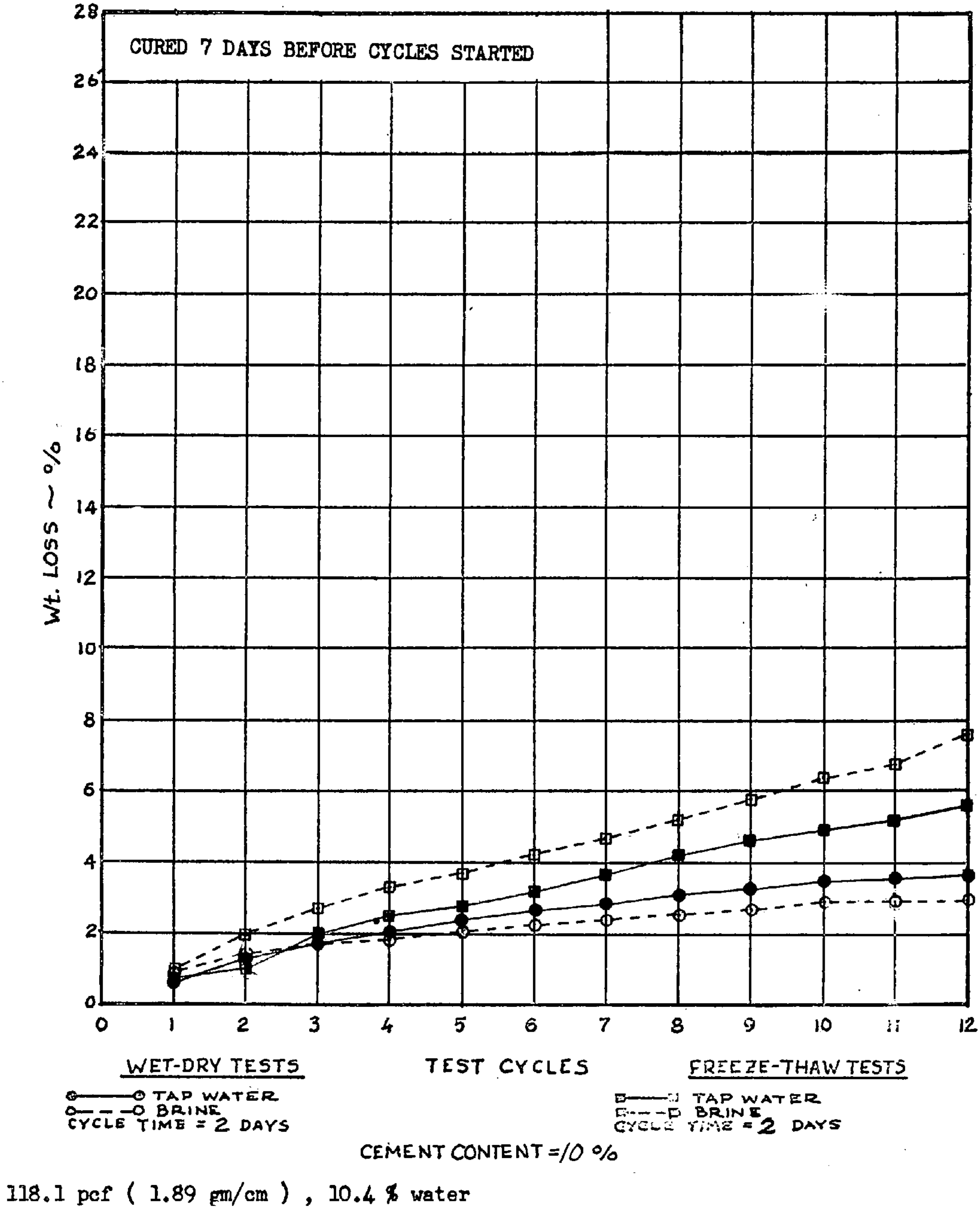



Figure 11. Soil-cement tests—Dalpra farm.

**Spray-applied Liquid Asphalt B-5876**

**Tables 32 to 35**

Table 32

PHYSICAL PROPERTIES OF LIQUID ASPHALT B-5876

| Tests | Test results |
|---|---|
| Flash point $^{o}$ C (C.O.C.) | 65 plus |
| Viscosity at 60$^{o}$ C, CS | 84 |
| Specific gravity | 0.950 |
| Distillation | |
| Distillate (percent of total distillate to 360$^{o}$ C) | |
| to 190$^{o}$ C | 0 |
| to 225$^{o}$ C | 6.0 |
| to 260$^{o}$ C | 54.2 |
| to 315$^{o}$ C | 91.6 |
| Residue from distillation to 360$^{o}$ C, volume percent by difference | 58.5 |
| Tests on distillation residue | |
| Penetration, 0$^{o}$ C, 200g, 60 sec | 5 |
| Penetration, 25$^{o}$ 100 g, 5 sec | 17 |
| Penetration, 46.1$^{o}$ C, 50 g, 5 sec | 105 |
| Ductility, 25$^{o}$ C, cms | 100 plus |
| Softening point, $^{o}$ C (ring and ball method) | 67 |

Table 33

PENETRATION TEST RESULTS

| Application rate gsy | Application rate m/l | Penetration into 2-inch- (5.08-cm-) high cylinders* in. | Penetration into 2-inch- (5.08-cm-) high cylinders* cm | Duration of test hours | Volume of cutback asphalt penetrated, percent |
|---|---|---|---|---|---|
| 0.5 | 2.3 | | | 4 | 75 |
| | | 0.6 | 1.52 | 8 | 100 |
| 1.0 | 4.6 | | | 4 | 50 |
| | | | | 8 | 75 |
| | | 1.1 | 2.79 | 24 | 100 |
| 2.0 | 9.2 | | | 4 | 25 |
| | | | | 8 | 50 |
| | | 1.6 | 4.06 | 24 | 100 |

*2- by 2-inch (5.08- by 5.08-cm) cylinders of Dalpra soil (48D-X35) compacted by 715-psi (50-kg/cm$^2$) loading for 1 minute.

Table 34

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS FOR DALPRA SOIL TREATED WITH LIQUID ASPHALT B-5876

Samples Were Air Cured at 23° C and 50 Percent Relative Humidity

| Soil | Liquid content* percent | Application and application rate | Compressive strength of 2- by 2-inch (5.08- by 5.08-cm) cylinders after various ages of curing: 3 days psi | 3 days $kg/cm^2$ | 7 days psi | 7 days $kg/cm^2$ | 14 days psi | 14 days $kg/cm^2$ | 28 days psi | 28 days $kg/cm^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 48D-X35 | 1 6.7 | Mixed | 87.4 | 6.1 | 109.4 | 7.7 | 128.0 | 9.0 | 145.6 | 10.2 |
| | 2 5.0 | 1 gsy (4.6 $l/m^2$) | | | | | | | | |
| 48D-X35 | 1 1.7 | Mixed | 57.8 | 4.0 | 88.2 | 6.2 | 127.6 | 8.9 | 141.3 | 9.9 |
| | 2 10.0 | 2 gsy (9.2 $l/m^2$) | | | | | | | | |
| 48D-X35 | 1 1.7 | Penetrated | 105.2 | 7.4 | 109.8 | 7.7 | 118.4 | 8.3 | 126.0 | 8.8 |
| | 2 10.0 | 2 gsy (9.2 $l/m^2$) | | | | | | | | |
| 48D-54 | 1 11.7 | Mixed | 363.0 | 25.4 | 396.0 | 27.7 | 432.0 | 30.2 | 443.0 | 31.0 |
| | 2 0 | Control | | | | | | | | |

*Optimum moisture content is 11.7 percent based on dry weight of sand. No. 1 is water content and No. 2 is the cutback asphalt content. All samples were fabricated at 715-psi (50.1-$kg/cm^2$) loading held for 1 minute.

Table 35

UNCONFINED COMPRESSIVE STRENGTH TEST RESULTS FOR DALPRA SOIL TREATED WITH LIQUID ASPHALT B-5876

Samples Were Oven Cured at 60° C

| Soil | Liquid content* percent | Application and application rate | Compressive strength of 2- by 2-inch (5.08- by 5.08-cm) cylinders after various ages of curing: 3 days psi | 3 days $kg/cm^2$ | 7 days psi | 7 days $kg/cm^2$ | 14 days psi | 14 days $kg/cm^2$ | 28 days psi | 28 days $kg/cm^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 48D-X35 | 1 6.7 | Mixed | 155.3 | 10.9 | 166.9 | 11.7 | 244.9 | 17.1 | 318.6 | 22.3 |
| | 2 5.0 | 1 gsy (4.6 $l/m^2$) | | | | | | | | |
| 48D-X35 | 1 1.7 | Mixed | 204.8 | 14.3 | 276.8 | 19.4 | 484.3 | 33.9 | 598.1 | 41.9 |
| | 2 10.0 | 2 gsy (9.2 $l/m^2$) | | | | | | | | |
| 48D-X35 | 1 1.7 | Penetrated | 220.2 | 15.4 | 280.0 | 19.6 | 366.5 | 25.7 | 496.6 | 34.8 |
| | 2 10.0 | 2 gsy (9.2 $l/m^2$) | | | | | | | | |
| 48D-54 | 1 11.7 | Mixed | 418.2 | 29.3 | 430.0 | 30.1 | 488.0 | 34.2 | 547.0 | 38.3 |
| | 2 0 | Control | | | | | | | | |

*Optimum moisture content is 11.7 percent based on dry weight of sand. No. 1 is water content and No. 2 is the cutback asphalt content. All samples were fabricated at 715-psi (50.1-$kg/cm^2$) loading held for 1 minute.

# APPENDIX III

**Construction of Test Ponds**

**Photographs 4 and 5**

**Table 36**

**Figure 12**

# APPENDIX III

## CONSTRUCTION OF TEST PONDS

### General

Briefly, the construction of the tests ponds consisted of: (1) preparation of drainage pads, (2) installation of required base linings on the drainage pads, and (3) erection of metal tanks. The construction sequence is shown in Photographs 4 and 5.

Nine drainage pads were prepared by excavating native soil 1 foot (0.3 m) deep, and backfilling with sand over a 25-foot (7.6-m) square area. The required base linings were then installed on the sand pads. Trenches were excavated for the base of the metal tanks and the tanks were erected. The tanks consisted of nine arch sections bolted together to form an 18-foot- (5.5-m) diameter tank. A mastic, recommended by the manufacturer of the tanks, was applied in the seams of the bolted sections to provide watertight joints. After assemblage of the tanks, the trenches were backfilled with native soil, tamped, and the backfill inside the tanks treated with asphaltic materials to seal against water loss. A rubber liner was then installed on the interior vertical surface of each tank to insure uniform evaporation conditions.

### Installation of Linings

Flexible membrane linings.—Shop-fabricated sheets of PVC and nylon-reinforced butyl rubber and a custom roll of polyethylene were obtained in sizes large enough to cover the base as well as the sides of the tanks. The linings were placed with sufficient slack to prevent undue stresses when subjected to the brine waterload.

Asphaltic concrete.—Hot-mix asphaltic concrete was placed on the sand pad. The mix was spread, rolled and compacted to a 2-inch- (5-cm-) thick lining. Laboratory tests conducted on samples of the in-place lining indicated satisfactory compaction was used.

Soil-cement lining.—Type I portland cement was dry mixed with a rototiller at 8 percent by weight into selected native soil. Mixing was accomplished in a separate area. Water was added as shown in Photograph 4 to give an optimum moisture content of 12 percent. The soil-cement mixture was then spread on the sand pad and a pneumatic tire roller, as shown in Photograph 4, used to compact the material into a 6-inch- (15.2-cm-) thick layer to a minimum of 95 percent maximum density. The surface of the lining was then moistened and covered with a protective layer of wet earth for a 7-day curing period.

Compacted-earth lining.—Selected native soil was moistened to a 11 percent content, mixed, placed on the sand pad, and then compacted in two lifts to a 12-inch- (30.4-cm-) thick layer at 95 percent maximum density.

Soil sealants.—Carboxymethyl cellulose at a 0.25 percent content and alum at a 0.05 percent content were dry mixed into native soil. Water was mixed into the soil mixture at a moisture content of 10 percent. The soil mixture was then spread on the sand pad and a vibrating roller used to compact the material into a layer 6 inches (15.2 cm) thick to a minimum of 95 percent maximum density. The 6-inch- (15.2-cm-) thick lining containing the 2 percent attapulgite clay formulation was constructed in the same manner.

After Tank No. 6 was erected and the trench backfilled and tamped, the natural soil inside the tank was smoothed and treated with the liquid asphalt. The material was spray-applied at a rate of 1.5 gsy (6.8 $l/m^2$) for the first treatment. After a curing period of 5 days, a second application of 0.5 gsy (2.3 $l/m^2$) was applied. Except for several small areas on the shaded side of the tank, good penetration was noted.

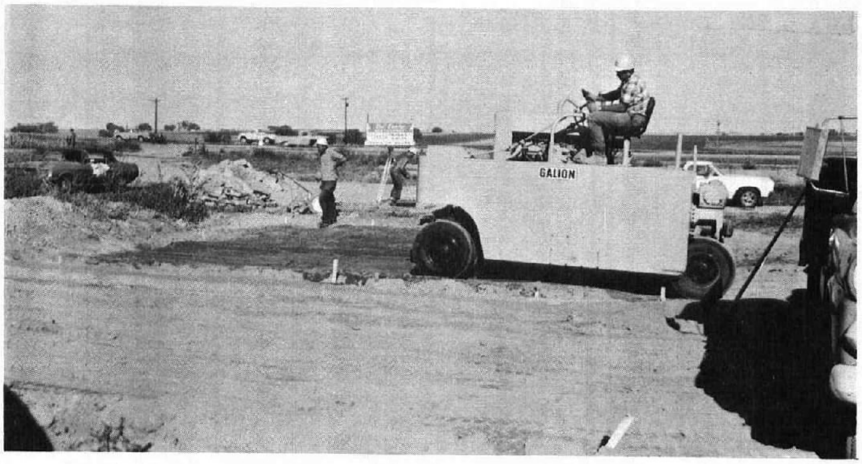
### Compaction Control Tests

Field tests were performed to determine that the soil linings were compacted to the specified 95 percent of maximum density, 119 pcf (1.91 g/cc). The density determinations were made using the balloon method, Photograph 4, a common field test for this purpose. Tests were run in areas of the lining outside the tank perimeter so as not to introduce a possible seepage area.

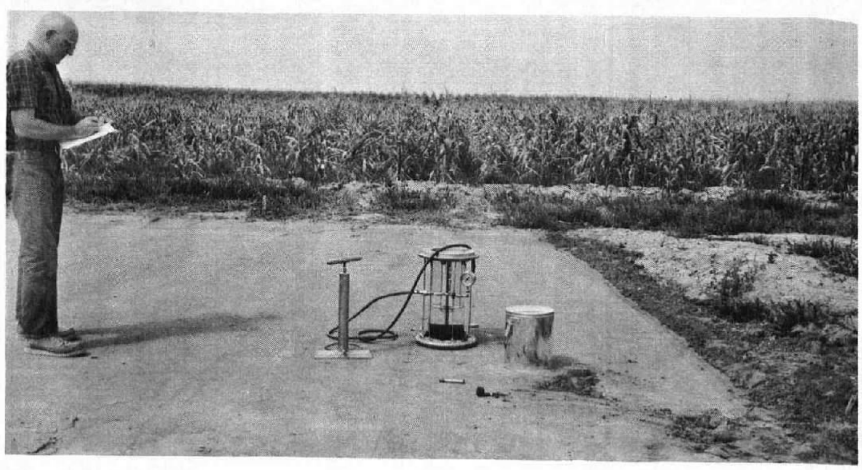
Results of these tests, summarized in Table 36 of this Appendix, showed the linings for the chemically sealed ponds, the soil-cement lined and the compacted-earth lined ponds to meet or exceed the specified 95 percent of maximum density criteria.

Although density control was not required for the sand pads underlying the linings, they were compacted. Density tests run on the compacted sand showed it to be at about 80 percent relative density, 114 pcf (1.83 g/cc), which is normally an acceptable condition for backfill and other construction purposes and was satisfactory for this job. Field control tests for the sand pads are summarized in Table 36 and Figure 12 of this Appendix.

Mixing water into lining material prior to compaction. Photo P800-713-48NA

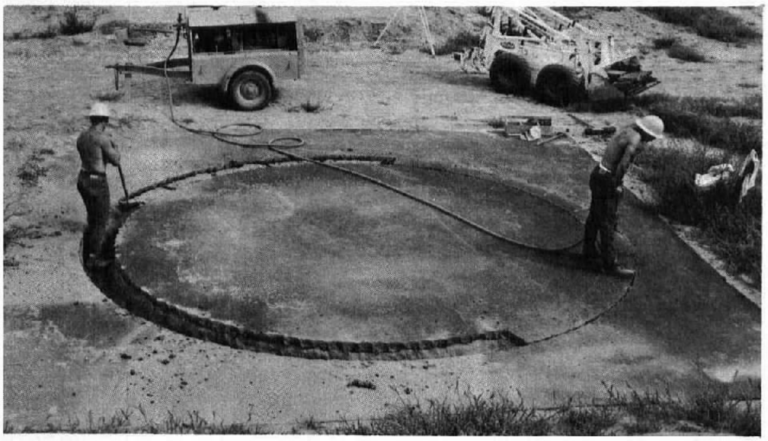



Compaction of lining with pneumatic tire roller. Photo P800-713-49NA

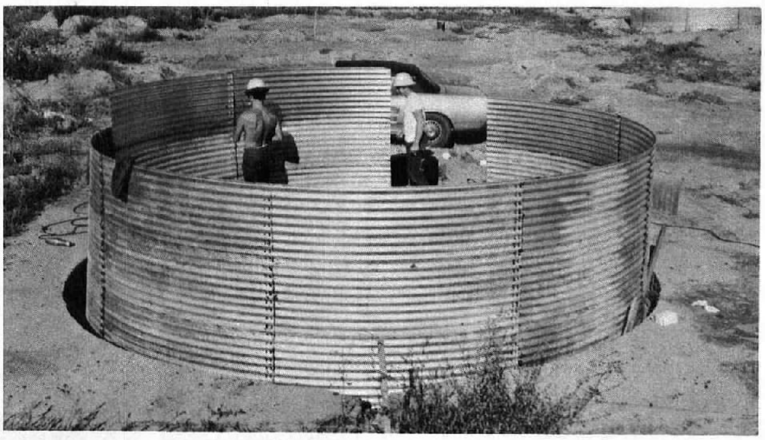


Field density test using balloon method. Photo P800-713-40NA

Photograph 4. Typical compacted lining construction sequence.



Excavating 1-foot (0.3-m) wide trench through lining and sand pad prior to tank placement. Photo P800-713-39NA



Erection of tank. Photo P800-713-43NA

Completed tank with a flexible membrane lining in place. Photo PX-D-67365



Photograph 5. Typical tank installation sequence.

Table 36

SUMMARY OF IN-PLACE DENSITY TESTS FOR COMPACTION CONTROL

| Type of tank lining | Properties of materials: Compaction test: Max. density pcf | Compaction test: Max. density gm/cm | Compaction test: Opt. moist. % content | Relative density test: Min. density pcf | Relative density test: Min. density $gm/cm^{-3}$ | Relative density test: Max. density pcf | Relative density test: Max. density $gm/cm^{-3}$ | Specified placement conditions: Compacted density pcf | Compacted density $gm/cm^{-3}$ | Percent of maximum density | % Moisture content | % Relative density | Thickness of lining in (cm) | In-place conditions: Density pcf | Density $gm/cm^{-3}$ | Percent of maximum density | % Moisture content | % Relative density | Thickness of lining in (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Compacted earth | 119 | 1.91 | 11 | – | – | – | – | 113 | 1.81 | 95 | 11 | · | 12 (30.5) | 117 | 1.87 | 98 | 11 | – | 12 (30.5) |
| Soil-cement | 120 | 1.92 | 12 | – | – | – | – | 114 | 1.83 | 95 | 12 | – | 6 (15.2) | 117 | 1.87 | 98 | 12 | – | 6 (15.2) |
| Chemical sealant | 116 | 1.86 | 14 | – | – | – | – | 110 | 1.67 | 95 | 10 | – | 6 (15.2) | 110 | 1.71 | 95 | 10 | – | 6 (15.2) |
| Chemical sealant | 116 | 1.86 | 14 | – | – | – | – | 110 | 1.67 | 95 | 10 | – | 6 (15.2) | 110 | 1.67 | 95 | 10 | – | 6 (15.2) |
| Sand-pad (drainage layer) | – | – | – | 105 | 1.68 | 119 | 1.91 | * | * | – | * | * | 6 (15.2) | 114 | 1.83 | – | 3 | 80 | 6 (15.2) |

*Not specified

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Bureau of Reclamation

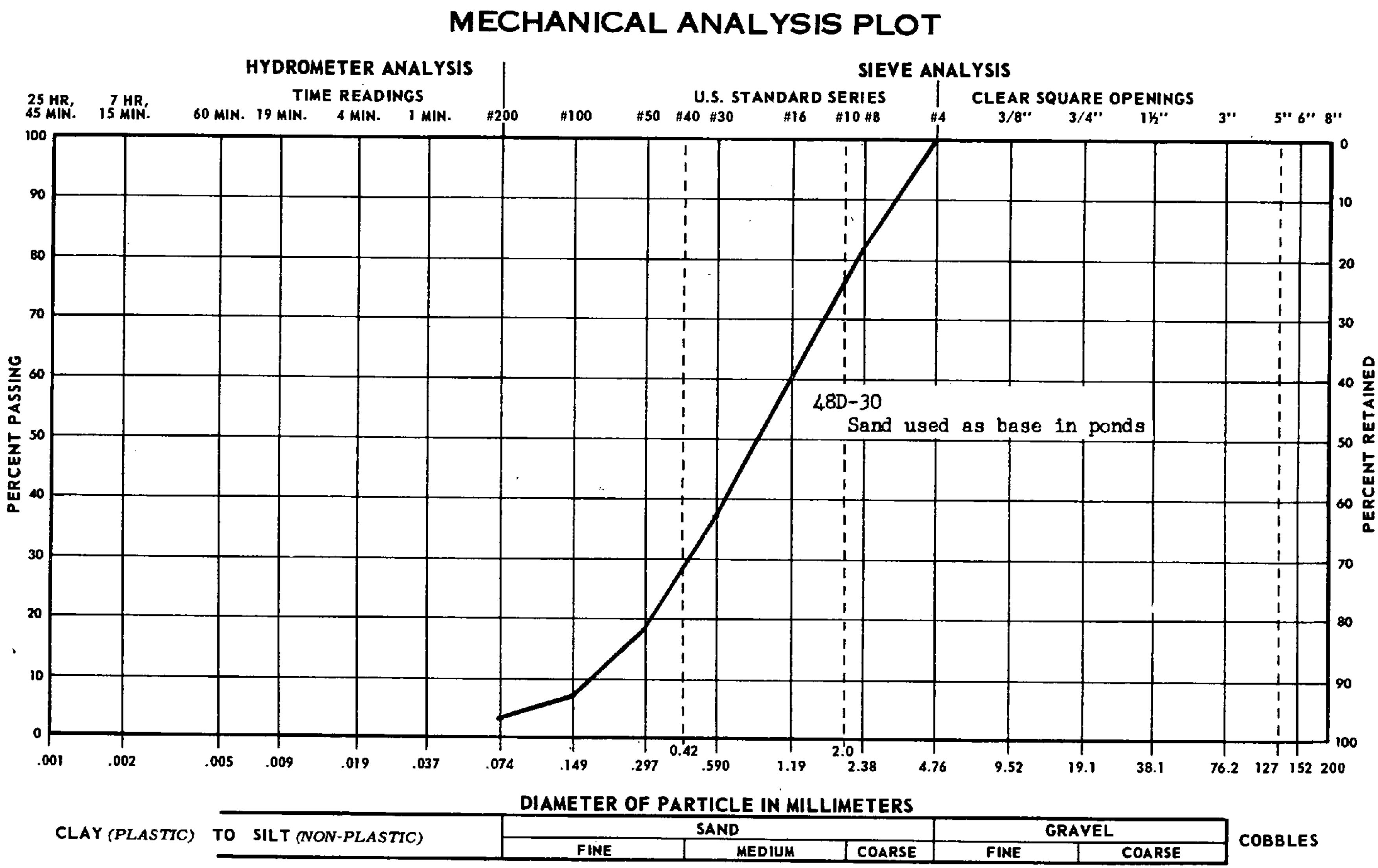


Figure 12. Mechanical analysis plot.

# APPENDIX IV

**Laboratory Test Methods**

**Photographs 6 to 11**

**Figure 13**

## APPENDIX IV

## LABORATORY TEST METHODS

**General**

The laboratory evaluation was conducted using either tests developed in the laboratory for specific USBR requirements or standard ASTM test methods. The tests are briefly described in the following paragraphs and, where appropriate, referenced to provide additional information.

**Soil Testing**

A. Visual classification.—The soils were classified using the "Unified Soil Classification System," page 379 in the USBR Earth Manual, First Edition, Revised.[6]

B. Gradation.—This term, as applied to soils, refers to the distribution and size of grains. The test procedure is given in Designation E–6.[6] A soil is said to be well graded if there is a good representation of all particle sizes from the largest to the smallest, and poorly graded if there is an excess or deficiency of certain particle sizes within the size range, or if the range of predominant size is extremely narrow.

C. Consistency.—Depending upon the water content, fine soils or the fine fraction of coarse-grained soils can vary from a viscous liquid when wet to a hard condition when dry. Four states are recognized for describing the consistency of soils. In terms of decreasing water content these are: liquid, plastic, semisolid, and solid. Laboratory tests were conducted in accordance with Designation E–7[6] to determine the water content limits for these states of consistency. The water contents are reported as liquid limit (LL), the plastic limit (PL), and shrinkage limit (SL). The water content over which a soil is in the plastic state (LL-PL) is defined as the plasticity index (PI). These tests, also known as Atterberg Tests, are useful to identify and classify soils and to estimate certain soil properties.

D. Compaction.—The Proctor Compaction Test Designation E–11[6], was conducted to evaluate the density and moisture-density relationships of Dalpra and Roswell soils. The test is performed to determine the maximum density of soil by compacting soil specimens at several water contents into a standard-size cylindrical mold using a standard compactive effort.

E. Permeability.—Permeability tests were conducted on Roswell and Dalpra soils treated with various soil sealants. Three techniques were used to apply the sealants: mixtures with the soil and compaction to achieve seepage reduction, surface application, and ponding. The tests were run using three test methods described below:

1. One-inch- (2.54-cm-) diameter permeameters.—Most of the testing was done in this size permeameter, a standard test used to evaluate soil sealants for use in irrigation canals. The soil specimens in these permeameters, Photograph 6a, were 1 inch (2.54 cm) in diameter and 12 inches (30.5 cm) long, in acrylic resin plastic tubes 18 inches (45.7 cm) long. A piece of No. 50 screen was fastened on the bottom of the permeameter tubes by melting the screen into the plastic on an electric hotplate. A one-half-inch (1.27-cm) filter of No. 16 to 30 sand was placed on the screen. The soil was compacted in 2-inch (5.08-cm) layers at optimum moisture. A constant waterhead above the soil specimen surface was maintained by head tanks operating on the Mariotte principle. Each head tank supplied liquid to two duplicate soil specimens. Since the head tanks were volumetrically calibrated, average permeabilities of two specimens were computed directly from head tank volume readings during recorded time periods. The permeabilities of individual specimens were obtained at intervals by measuring the liquid caught in containers below the specimens.

The saturation of the specimens with carbon dioxide gas prior to the start of the permeability tests which would be dissolved by the first water of the test and tend to produce gas-free voids, was considered. However, the soil was found to be calcareous, and there was the possibility of some of the calcareous material being leached out by the carbonic acid formed by water and carbon dioxide. This would possibly affect the soil structure sufficiently to change the soil permeability. Therefore, the carbon dioxide gas was not used.

2. Eight-inch- (20.3-cm-) diameter standard permeameter.—To treat a larger size soil specimen for comparison with the results obtained from the small 1-inch- (2.54-cm-) diameter specimens, tests were made in a

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[6] Op. cit. p. 1.

standard 8-inch- (20.3-cm-) diameter permeameter test apparatus shown in Photograph 6b. The procedure for this type of permeability test is presented in Designation E–13[6]. The 8-inch- (20.3-cm-) diameter specimens were compacted in 1-inch (2.54-cm) layers to a 5 inch (12.7 cm) height. The specimens were spring-loaded and 1-psi (0.07-kg/cm$^2$) load was applied. In this type of permeameter, the water flows upward through the soil from a constant-head tank. In this particular test, the porous stones commonly used at the top and bottom of the soil specimen were replaced by sand filters which were less likely to be plugged with sealant than would the porous stones.

3. Eight-inch- (20.3-cm-) diameter plastic permeameters.—In some of the tests where the sealant was placed on the surface of the soil, and where the sealant was mixed with the soil, 8-inch- (20.3-cm) diameter by 8-inch- (20.3-cm-) long plastic permeameter cylinders were used (Section 9, page 486, of Designation E–13[6]). This permeameter, Photograph 6c, allows the use of a much larger soil specimen than the 1-inch- (2.54-cm-) diameter permeameters, and it is the type usually used for canal lining soils where no load during the test is required.

**Plastic Linings**

Samples of the 10-mil (0.25-mm) PVC and 6-mil (0.15-mm) polyethylene linings installed at Dalpra Farm were obtained for laboratory testing. Physical property testing consisted of:

A. Tensile strength, elongation, and bonding strength.—These properties were determined as specified in ASTM: D 882, Method A. This testing was accomplished in an electronic recorder-type testing machine housed in an environmental control chamber which provides precisely controlled temperature, humidity, and cleanliness conditions meeting ASTM and USBR specifications testing requirements. These facilities are shown in Photographs 7 and 8.

B. Soil burial.—Standard test specimens are buried in soil rich in cellulose-destroying micro-organisms to determine their resistance to bacteriological deterioration.[7] At different ages of soil burial, the tensile strength and elongation of the test specimens are determined. The soil burial test cabinet is shown in Photograph 9. The microbiological activity of the soil is frequently checked by burying untreated 10-ounce cotton duck for 1- and 2-week periods. Satisfactory activity is indicated by tensile strength losses above 70 percent of strength in 1 week and above 90 percent in 2 weeks.

C. Water extraction.—The percent loss in weight from extraction by distilled water was determined in accordance with ASTM: D 1239.

D. Elmendorf tear resistance.—The tear resistance of the plastic films was determined as specified in ASTM: D 689.

E. Low temperature impact.—The resistance of the plastic films to impact at low temperatures was conducted in accordance with ASTM: D 1790. The test was conducted at 0° F (–17.8° C) plus or minus 3.6° F (2° C).

F. Puncture resistance.—To determine puncture resistance, plastic specimens, 2 feet (0.6 m) in diameter were tested under water pressure over graded aggregate acting as a simulated subgrade. The test was conducted using the laboratory equipment shown in Photograph 10. Either a coarse aggregate, 3/4 to 1 and 1/2 inch (1.9 to 3.8 cm), or a fine aggregate, sieve size No. 4 (4.8 mm) to 3/8 inch (9.5 mm), were used in the test. Of the two, the coarse aggregate simulated a more severe test condition. The test is started at a low water pressure of 2.5 psi (0.175 kg/cm$^2$) and then increased in increments of 2.5 psi (0.175 kg/cm$^2$) for fixed periods until failure.[7]

**Rubber Lining**

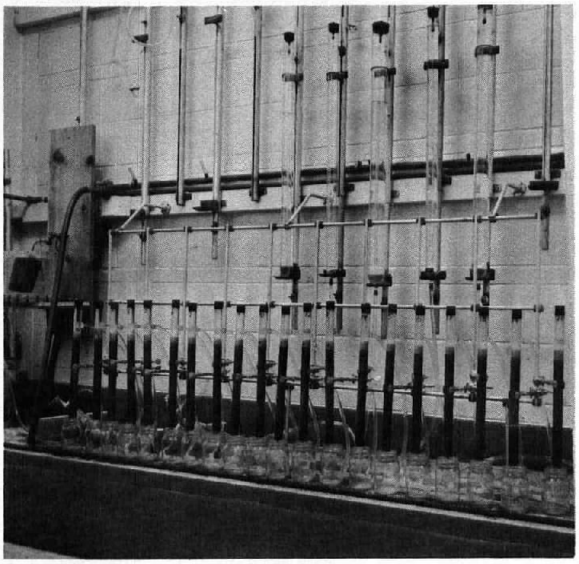
Samples of the 45-mil (1.14-mm) nylon-reinforced butyl-rubber sheeting installed at Dalpra Farm were obtained for laboratory testing. Since there are no standard specifications developed yet for this type lining, the laboratory evaluation was limited primarily to the testing methods contained in ASTM: D 751, Testing Coated Fabrics:

A. Hydrostatic resistance.—The Mullen Hydrostatic Testing Machine was used to determine the hydrostatic resistance.

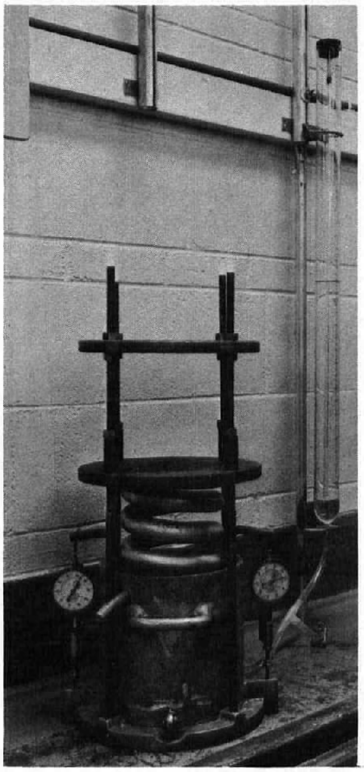
B. Breaking strength.—Tensile breaking strength was obtained with the universal testing machine shown in Photograph 8. Elongation was obtained by recording differential grip motion.

C. Heat aging.—Test specimens were placed in a 240° F (115.5° C) oven for 7 days to determine the

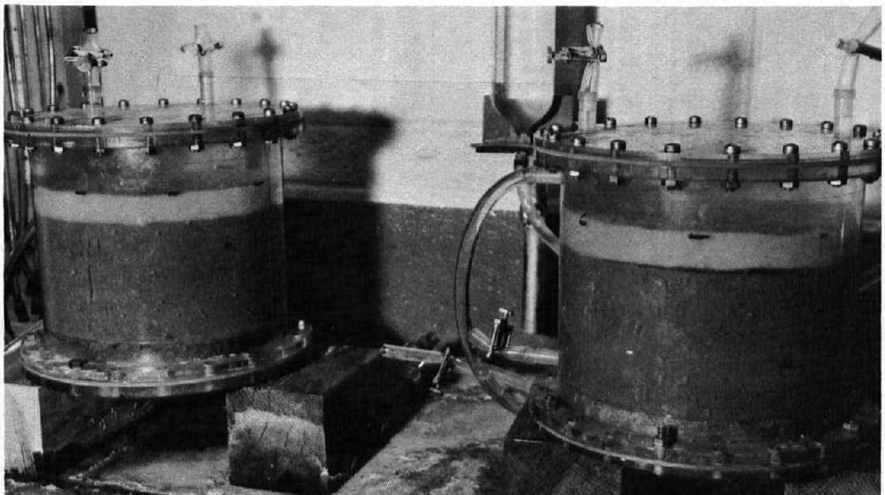
[6] [7]Op. cit. p. 1.



(a) Standard 1 inch (2.54 cm) diameter permeameters. Photo PX-D-67366



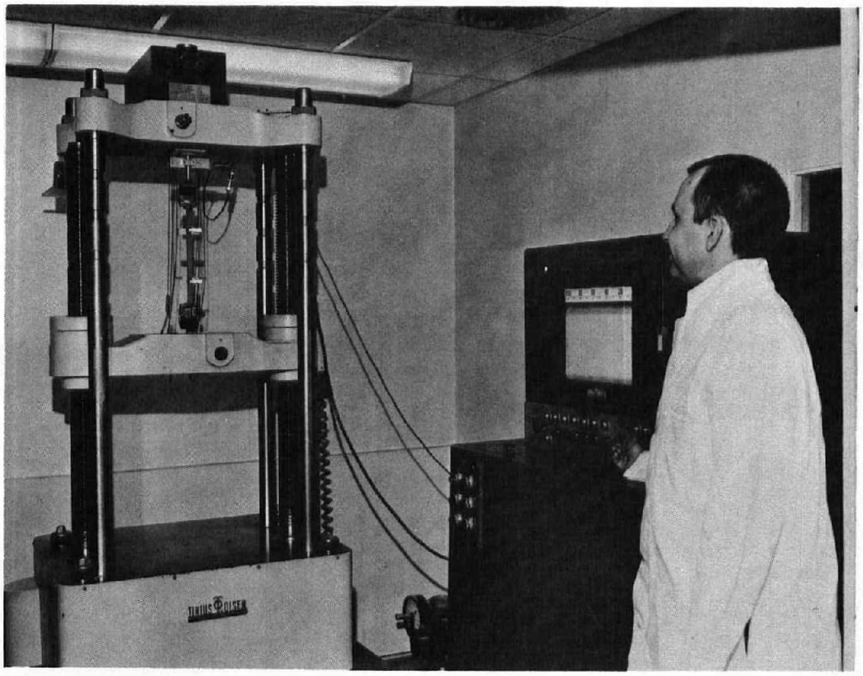
(b) Standard 8-inch (20.3 cm) diameter permeameter. Photo PX-D-67368



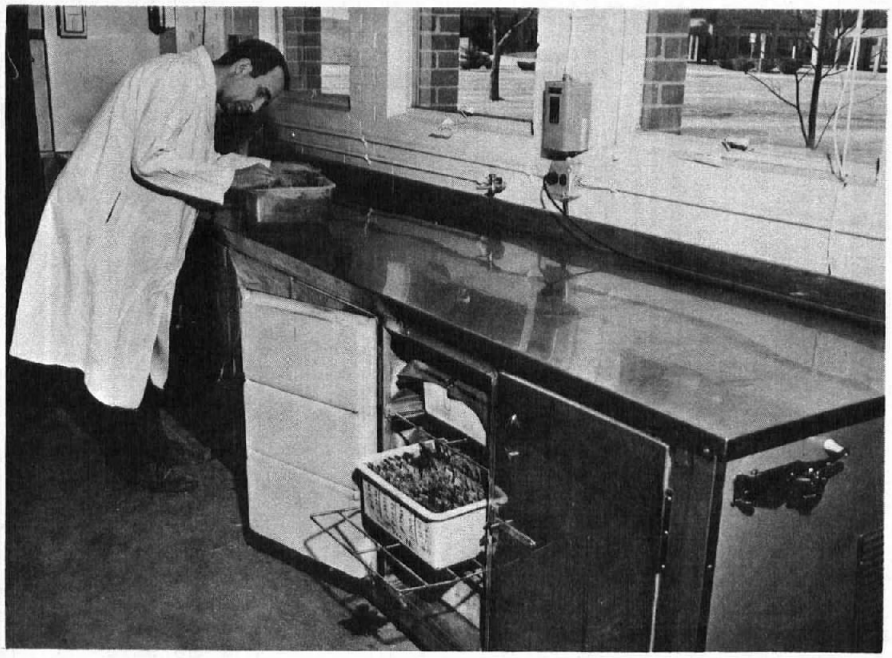
(c) 8-inch diameter plastic permeameter. Photo PX-D-67367

Photograph 6. Equipment used in laboratory permeability studies.

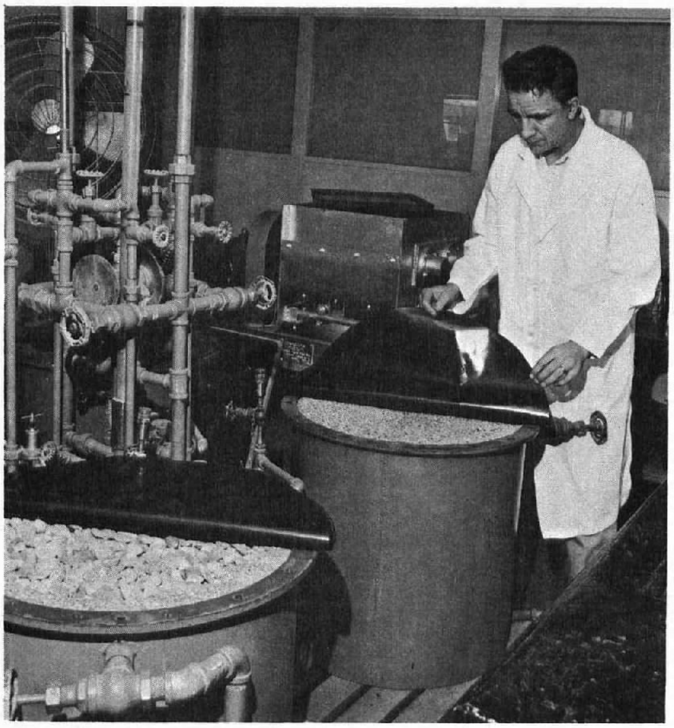
Photograph 7. Environmental control chamber where physical properties testing of plastics is conducted under closely controlled temperature and humidity conditions. Photo PX-D-61982



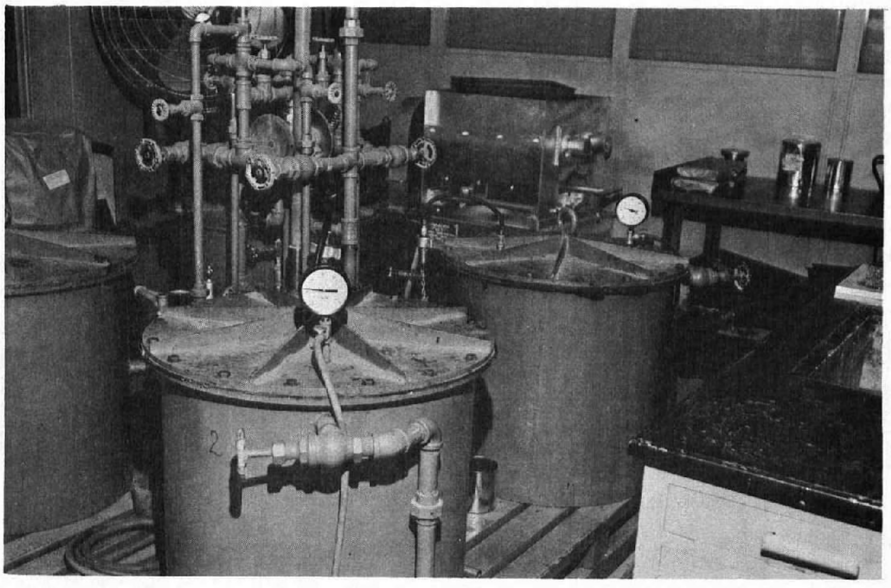
Photograph 8. Universal testing machine with recorder and extensometer equipment for measuring tensile strength and elongation properties of plastics. Photo PX-D-61983



Photograph 9. Soil burial test cabinet for aging of specimens set in composted soil placed in plastic containers. A constant temperature of 90° F and 80 percent relative humidity is maintained in the test cabinet. Photo PX-D-60275



A. Plastic samples placed over coarse aggregate (3/4- to 1-1/2-inch size) in one test cell and over fine aggregate (No. 8 to No. 4 sieve size) in second test cell. Photo PX-D-61984



B. Test in progress with water pressure introduced on top of plastic samples. Photo PX-D-61985

Photograph 10. Pressure cell equipment for testing puncture resistance of plastic membrane lining. Photos PX-D-56556NA and PX-D-56557NA relative resistance to age deterioration. The heat aging test followed ASTM: D 573 for the heat environment and ASTM: D 751 for tensile breaking strength after heating. The grab method was used for both original and aged specimens.

D. Ozone test.—This test was conducted using the standard loop specimen of Procedure B in ASTM: D 518.

E. Tearing strength.—The tearing strength of the reinforced material was determined by the tongue tear procedure, Method B, in ASTM: D 751.

F. Bonded seam strength.—The seam breaking strength was determined by Method B, cut strip method of ASTM: D 751. The peel strength of the seams was determined according to ASTM: D 1876.

**Asphaltic-Concrete Lining**

Samples of both the hot-mix (B-5576) and in-place asphaltic-concrete lining (B-5685) installed at Dalpra Farm were obtained for laboratory testing.

A. Mix composition.—Solvent extraction was used to remove the asphalt from the mixed sample. The percentage of asphalt was based on the dry weight of aggregate. After the solvent was removed by distillation, standard physical properties tests were conducted on the asphalt residue. The aggregate portion obtained from the extraction tests was subjected to the standard laboratory gradation test. This test is performed on the aggregate washed on the No. 200 sieve (0.074 mm) to accurately determine the quantity of filler material.

B. Laboratory standard density.—Standard test cylinders 4 inches (10.16 cm) in diameter by 4 inches (10.16 cm) high of the sampled mix, B-5576, were molded using a universal testing machine and the double plunger method while the mix was held at a temperature of 300° F (149° C). A compressive load of 3,000 psi (210 kg/cm$^2$) was applied for 2 minutes for compacting the cylinders. The average density obtained for the cylinders by this method of fabrication is considered the Laboratory Standard Density (LSD). The average densities of the in-place samples were compared to the LSD to determine if adequate compaction was used during construction of the lining.

C. Immersion-compression test.—This test is based upon ASTM: D 1074 and D 1075, and is used to determine the compressive strength of asphaltic-concrete mixes for both air and water-cured conditions. Four standard test cylinders were fabricated as described above. Two specimens were water cured at 120° F (48.9° C) for 4 days prior to testing. The other two were air cured at room temperature for comparison to the immersion test. At the end of the curing period, the water-immersed specimens were tested for volume change and absorption. The specimens were also inspected for clay popouts or blisters at the surface. The compressive strengths of the four cylinders were then determined.[9]

D. Sustained-load test.—This test is conducted to determine the stability of asphaltic-concrete mixes for placement on slopes.[9] Standard cylinders are tested at 140° F (60° C) in the sustained-load apparatus shown in Photograph 11.

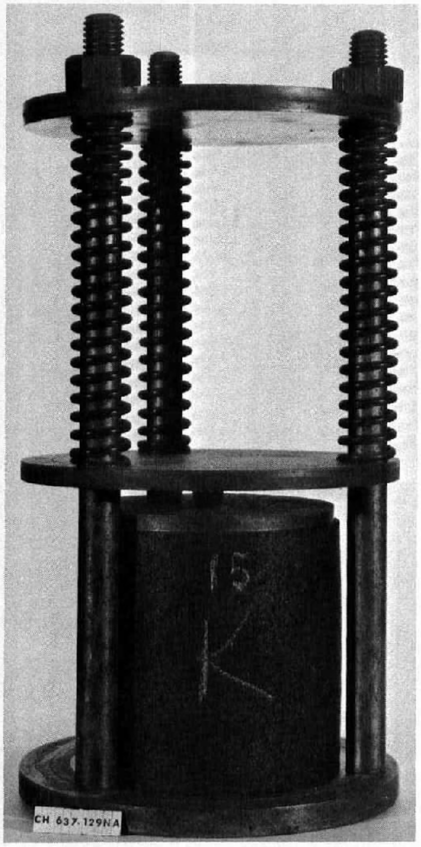
**Soil cement**

Because one of the ponds was to be lined with soil cement it was necessary to obtain data for determining the percent cement required. Freeze-thaw, wet-dry and unconfined compression tests were run for this purpose. Three cement contents were tested; 6, 8 and 10 percent of the dry weight. All of the test specimens were compacted to 98 percent of maximum density, 117.2 pcf (1.88 g/cc), and at optimum moisture of 10.5 percent. Permeability tests were also conducted on the soil cement.

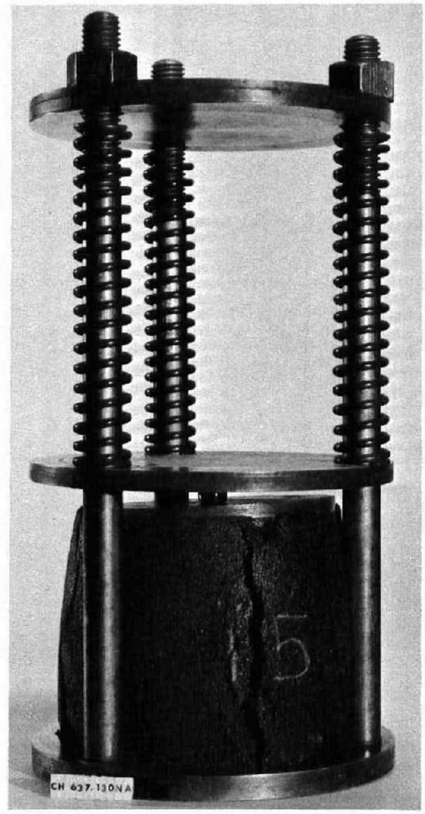
A. Freeze-thaw and wet-dry tests.—The freeze-thaw test (Methods of Freezing and Thawing of Compacted Soil-Cement Mixtures, ASTM D 560), and wet-dry test (Methods of Wetting and Drying Tests of Compacted Soil-Cement Mixtures, ASTM D 559) simulate internal expansion and shrinkage forces similar to those produced by changes in moisture content and temperature. The tests determine the minimum cement content to produce a structural material that will withstand these forces. These tests are evaluated in terms of weight loss after a prescribed number of test cycles.

Six specimens were prepared for the freeze-thaw tests, two at each of the three cement contents. At each cement content one of the specimens was prepared using tapwater in making the specimen and for the free-water source; for the other specimen, tapwater was used in making the specimen but brine was used as the free-water source. The six specimens prepared for the wet-dry tests were identical to the freeze-thaw specimens.

[9] Op. cit. p. 1.



PX-D-56556NA



PX-D-56557NA

Photograph 11. Sustained-load test showing test cylinder before and after failure.

B. Unconfined compression test.—Compressive-strength tests (Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory, ASTM: D 1632, and Compressive Strength of Molded Soil-Cement Cylinders, ASTM: D 1633) are generally made as supplementary to the freeze-thaw and wet-dry tests. Compressive-strength test data are used to determine the increase in strength with time. Tests are evaluated from the pressure needed to fail specimens after 3, 7, and 28 days of curing.

For the unconfined compression tests, three specimens were prepared at each of the three cement contents. Tapwater was used for fabricating these specimens.

C. Permeability tests (Radial Flow Method).—The tests were performed on soil-cement specimens, prepared the same as those for unconfined compression tests. The specimens were prepared for testing and tested in the following manner:

1. After 28 days of curing in the 100 percent relative humidity room, one-half-inch- (1.27-cm-) diameter holes were drilled lengthwise through the center of the specimen.

2. A 2.75-inch- (6.99-cm-) diameter by 0.25-inch- (0.61-cm-) thick plates with holes in the center for 0.125-inch- (0.3-cm-) pipe threads were epoxied to the top and bottom of each specimen. A pressure valve was attached to the bottom plate, and a connection for 0.25-inch (0.61-cm) compression fitting to the top plate.

3. The soil-cement specimen was then submerged in a container of water. A constant bore head tank with water was connected to the top 0.25-inch (0.61-cm) compression fitting. The

desired water head was maintained by closing the bottom valve on the specimen and applying air to the water surface in the head tank through a precise regulator.

4. A series of readings were obtained at the following heads: 4.617 feet (1.407 m), 9.235 feet (2.815 m), 13.852 feet (4.222 m), 18.47 feet (5.63 m) and 23.087 feet (7.037 m).

Permeability equipment is shown in Figure 13.

**Spray-applied Liquid Asphalt**

Laboratory tests were conducted primarily to determine three factors: penetration of the liquid asphalt in Dalpra soil, curing characteristics of Dalpra treated soil, and permeability of the treated soil. Physical properties of the special cut-back asphalt, B-5876, were determined and are summarized in Table 32 of Appendix II.

A. Fabrication of test cylinders.—Soil samples used in the laboratory evaluation were 2 inches (5.08 cm) in diameter by 2 inches (5.08 cm) high in size. The cylinders were fabricated using double-plunger-type molds and a compactive effort of 715 psi (50 $kg/cm^2$) held for 1 minute. For tests where the liquid asphalt was mixed into the soil, the mixing was accomplished in a mechanical mixer prior to cylinder fabrication.

B. Penetration tests.—To determine the penetrating capabilities of the liquid asphalt into Dalpra soil, standard test cylinders were compacted in 4-inch- (10.16-cm-) high molds. A 2-inch (5.08-cm) portion of the mold extending above the soil cylinder provided a reservoir for applying the liquid asphalt. The liquid asphalt was heated to $140^{\circ}$ F ($60^{\circ}$ C) as recommended by the manufacturer, and poured into the top of the molds in quantities to produce application rates of 0.5, 1.0, and 2.0 gsy (2.3, 4.6, and 9.2 $l/m^2$). The depth of penetration and percentage of liquid asphalt that penetrated the soil cylinders were measured after 4, 8, and 24 hours.

C. Curing characteristics.—The compressive strength of both mixed and penetrated soil samples was used to measure the relative curing and binding characteristics of the liquid asphalt. The tests involved curing conditions of $140^{\circ}$ F ($60^{\circ}$ C) oven and 50 percent relative humidity at $73.4^{\circ}$ F ($23^{\circ}$ C) for ages 3, 7, 14, and 28 days.[13]

D. Permeability test.—This test, as described under soil testing, Subparagraph e., was conducted on an 8-inch- (20.3-cm-) diameter soil sample treated with the liquid asphalt. The liquid asphalt was applied in two applications: 1.5 gsy (6.8 $l/m^2$) for the first treatment, and then after a 3-day curing period the second application of 0.5 gsy (2.3 $l/m^2$).

[13] Op. cit. p. 1.

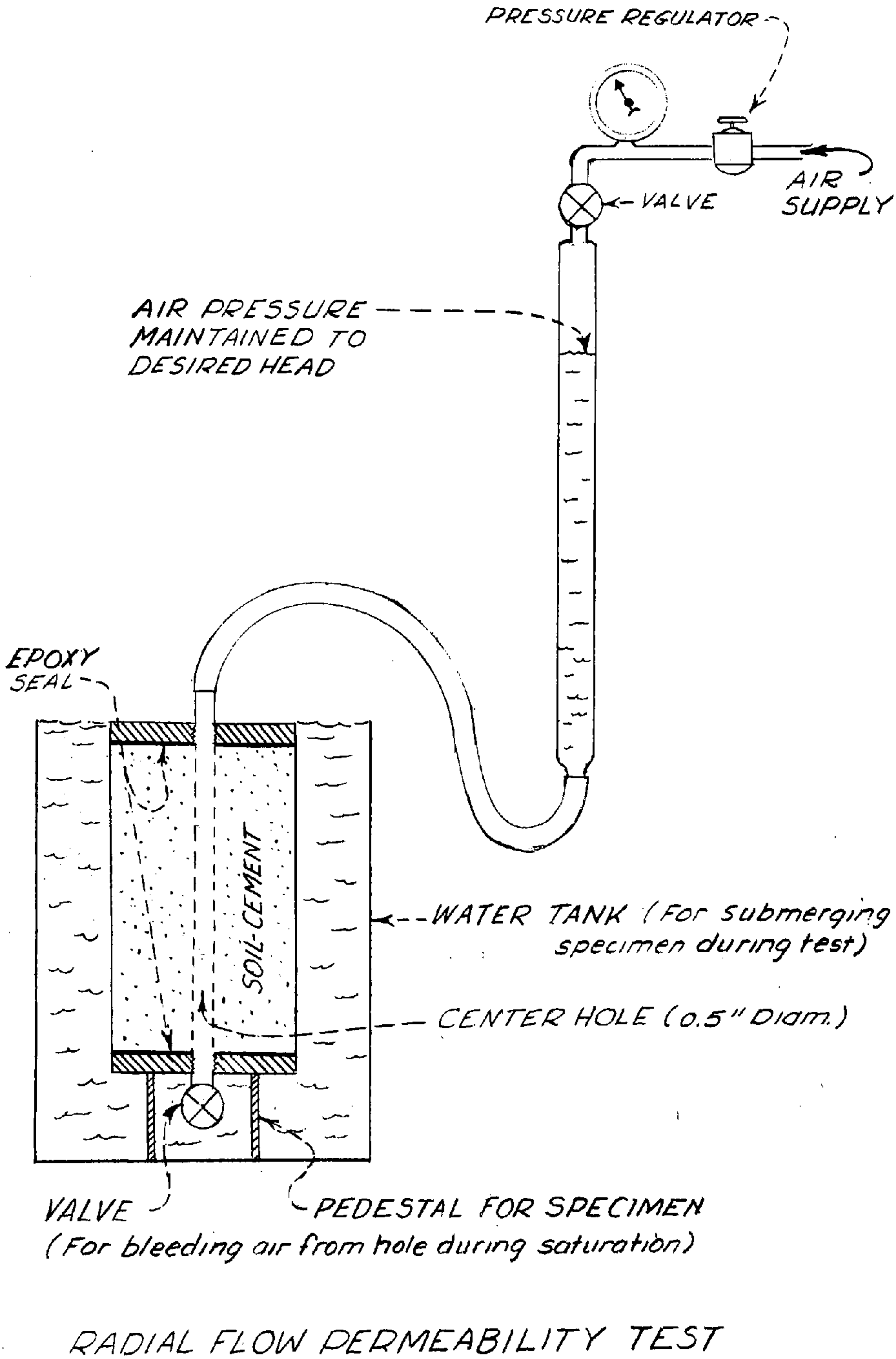



Figure 13. Radial flow permeability test.

## ABSTRACT

A field and laboratory evaluation of lining materials proposed for use in brine disposal ponds was conducted. Flexible membrane linings were the most effective for seepage control, followed by hard-surface linings, compacted earth, and soil sealants. The investigation and other studies show that soil sealants only reduce seepage and do not affect a complete seal, and that the service life of soil sealants is questionable. Recommendations on a monitoring system for measuring seepage losses from brine disposal ponds are included.



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REC-OCE-70-30
Morrison, W R; Dodge, R A; Merriman, J; et al
POND LININGS FOR DESALTING PLANT EFFLUENTS
Bur Reclam Rep REC-OCE-70-30, Div Res, Sept 1970. Bureau of Reclamation, Denver, 112 p, 13 fig, 11 photo, 39 tab, 14 ref, 4 append

DESCRIPTORS—/ *research and development/ *linings/ seepage/ soil tests/ *ponds/ earth linings/ flexible linings/ *soil treatment/ polyethylenes/ laboratory tests/ *field tests/ soil cement/ asphaltic concrete/ seepage losses/ asphalt/ disposal/ *plastics/ *instrumentation/ *brine disposal/ water stage recorders/ temperature sensors/ *soil sealants
IDENTIFIERS—/ Office of Saline Water/ polyvinyl chloride/ permeability tests

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# CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

## Table I

### QUANTITIES AND UNITS OF SPACE

| Multiply | By | To obtain |
|---|---|---|
| | **LENGTH** | |
| Mil | 25.4 (exactly) | Micron |
| Inches | 25.4 (exactly) | Millimeters |
| | 2.54 (exactly)* | Centimeters |
| Feet | 30.48 (exactly) | Centimeters |
| | 0.3048 (exactly)* | Meters |
| | 0.0003048 (exactly)* | Kilometers |
| Yards | 0.9144 (exactly) | Meters |
| Miles (statute) | 1,609.344 (exactly)* | Meters |
| | 1.609344 (exactly) | Kilometers |
| | **AREA** | |
| Square inches | 6.4516 (exactly) | Square centimeters |
| Square feet | 929.03* | Square centimeters |
| | 0.092903 | Square meters |
| Square yards | 0.836127 | Square meters |
| Acres | 0.40469* | Hectares |
| | 4,046.9* | Square meters |
| | 0.0040469* | Square kilometers |
| Square miles | 2.58999 | Square kilometers |
| | **VOLUME** | |
| Cubic inches | 16.3871 | Cubic centimeters |
| Cubic feet | 0.0283168 | Cubic meters |
| Cubic yards | 0.764555 | Cubic meters |
| | **CAPACITY** | |
| Fluid ounces (U.S.) | 29.5737 | Cubic centimeters |
| | 29.5729 | Milliliters |
| Liquid pints (U.S.) | 0.473179 | Cubic decimeters |
| | 0.473166 | Liters |
| Quarts (U.S.) | 946.358* | Cubic centimeters |
| | 0.946331* | Liters |
| Gallons (U.S.) | 3,785.43* | Cubic centimeters |
| | 3.78543 | Cubic decimeters |
| | 3.78533 | Liters |
| | 0.00378543* | Cubic meters |
| Gallons (U.K.) | 4.54609 | Cubic decimeters |
| | 4.54596 | Liters |
| Cubic feet | 28.3160 | Liters |
| Cubic yards | 764.55* | Liters |
| Acre-feet | 1,233.5* | Cubic meters |
| | 1,233,500* | Liters |

Table II

QUANTITIES AND UNITS OF MECHANICS

| Multiply | By | To obtain |
|---|---|---|
| **MASS** | | |
| Grains (1/7,000 lb) | 64.79891 (exactly) | Milligrams |
| Troy ounces (480 grains) | 31.1035 | Grams |
| Ounces (avdp) | 28.3495 | Grams |
| Pounds (avdp) | 0.45359237 (exactly) | Kilograms |
| Short tons (2,000 lb) | 907.185 | Kilograms |
| | 0.907185 | Metric tons |
| Long tons (2,240 lb) | 1,016.05 | Kilograms |
| **FORCE/AREA** | | |
| Pounds per square inch | 0.070307 | Kilograms per square centimeter |
| | 0.689476 | Newtons per square centimeter |
| Pounds per square foot | 4.88243 | Kilograms per square meter |
| | 47.8803 | Newtons per square meter |
| **MASS/VOLUME (DENSITY)** | | |
| Ounces per cubic inch | 1.72999 | Grams per cubic centimeter |
| Pounds per cubic foot | 16.0185 | Kilograms per cubic meter |
| | 0.0160185 | Grams per cubic centimeter |
| Tons (long) per cubic yard | 1.32894 | Grams per cubic centimeter |
| **MASS/CAPACITY** | | |
| Ounces per gallon (U.S.) | 7.4893 | Grams per liter |
| Ounces per gallon (U.K.) | 6.2362 | Grams per liter |
| Pounds per gallon (U.S.) | 119.829 | Grams per liter |
| Pounds per gallon (U.K.) | 99.779 | Grams per liter |
| **BENDING MOMENT OR TORQUE** | | |
| Inch-pounds | 0.011521 | Meter-kilograms |
| | $1.12985 \times 10^6$ | Centimeter-dynes |
| Foot-pounds | 0.138255 | Meter-kilograms |
| | $1.35582 \times 10^7$ | Centimeter-dynes |
| Foot-pounds per inch | 5.4431 | Centimeter-kilograms per centimeter |
| Ounce-inches | 72.008 | Gram-centimeters |
| **VELOCITY** | | |
| Feet per second | 30.48 (exactly) | Centimeters per second |
| | 0.3048 (exactly)* | Meters per second |
| Feet per year | $0.965873 \times 10^{-6}$* | Centimeters per second |
| Miles per hour | 1.609344 (exactly) | Kilometers per hour |
| | 0.44704 (exactly) | Meters per second |
| **ACCELERATION*** | | |
| Feet per second$^2$ | 0.3048* | Meters per second$^2$ |
| **FLOW** | | |
| Cubic feet per second (second-feet) | 0.028317* | Cubic meters per second |
| Cubic feet per minute | 0.4719 | Liters per second |
| Gallons (U.S.) per minute | 0.06309 | Liters per second |
| **FORCE*** | | |
| Pounds | 0.453592* | Kilograms |
| | 4.4482* | Newtons |
| | $4.4482 \times 10^{-5}$* | Dynes |

| Multiply | By | To obtain |
|---|---|---|
| **WORK AND ENERGY*** | | |
| British thermal units (Btu) | 0.252* | Kilogram calories |
| | 1,055.06 | Joules |
| Btu per pound | 2.326 (exactly) | Joules per gram |
| Foot-pounds | 1.35582* | Joules |
| **POWER** | | |
| Horsepower | 745.700 | Watts |
| Btu per hour | 0.293071 | Watts |
| Foot-pounds per second | 1.35582 | Watts |
| **HEAT TRANSFER** | | |
| Btu in./hr ft$^2$ deg F (k, thermal conductivity) | 1.442 | Milliwatts/cm deg C |
| | 0.1240 | Kg cal/hr m deg C |
| Btu ft/hr ft$^2$ deg F | 1.4880* | Kg cal m/hr m$^2$ deg C |
| Btu/hr ft$^2$ deg F (C, thermal conductance) | 0.568 | Milliwatts/cm$^2$ deg C |
| | 4.882 | Kg cal/hr m$^2$ deg C |
| Deg F hr ft$^2$/Btu (R, thermal resistance) | 1.761 | Deg C cm$^2$/milliwatt |
| Btu/lb deg F (c, heat capacity) | 4.1868 | J/g deg C |
| Btu/lb deg F | 1.000* | Cal/gram deg C |
| Ft$^2$/hr (thermal diffusivity) | 0.2581 | Cm$^2$/sec |
| | 0.09290* | M$^2$/hr |
| **WATER VAPOR TRANSMISSION** | | |
| Grains/hr ft$^2$ (water vapor transmission) | 16.7 | Grams/24 hr m$^2$ |
| Perms (permeance) | 0.659 | Metric perms |
| Perm-inches (permeability) | 1.67 | Metric perm-centimeters |

Table III

OTHER QUANTITIES AND UNITS

| Multiply | By | To obtain |
|---|---|---|
| Cubic feet per square foot per day (seepage) | 304.8* | Liters per square meter per day |
| Pound-seconds per square foot (viscosity) | 4.8824* | Kilogram second per square meter |
| Square feet per second (viscosity) | 0.092903* | Square meters per second |
| Fahrenheit degrees (change)* | 5/9 exactly | Celsius or Kelvin degrees (change)* |
| Volts per mil | 0.03937 | Kilovolts per millimeter |
| Lumens per square foot (foot-candles) | 10.764 | Lumens per square meter |
| Ohm-circular mils per foot | 0.001662 | Ohm-square millimeters per meter |
| Millicuries per cubic foot | 35.3147* | Millicuries per cubic meter |
| Milliamps per square foot | 10.7639* | Milliamps per square meter |
| Gallons per square yard | 4.527219* | Liters per square meter |
| Pounds per inch | 0.17858* | Kilograms per centimeter |