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POND LININGS FOR DESALTING PLANT EFFLUENTS

Evaluation of four types of lining materials for seepage control in brine disposal ponds

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16. ABSTRACT

A field and laboratory evaluation of 4 types of lining materials proposed for seepage control in brine disposal ponds was conducted. The 4 types included: compacted earth, flexible membrane linings, hard-surface linings, and soil sealants. Flexible membrane linings were the most effective for seepage control, followed by hard-surface linings, surface-applied soil sealants, compacted earth, mixed-in-place soil sealants, and ponded soil sealants. PVC plastic lining provided the most satisfactory sealing performance. A newly developed, sprayable liquid vinyl polymer that forms a surface film upon curing appears to have merit for sealing brine disposal ponds, and additional studies are recommended to fully evaluate its potential.

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Rogers C. B. Morton, Secretary
Ellis L. Armstrong, Commissioner

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Additional information on several soil sealants was provided by the Corp of Engineers, Vicksburg, Mississippi, and Norfolk, Virginia; and by L. R. Simmons, Bureau of Reclamation, Sacramento, California.

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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, Work Order No. 3, 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. Preparing a "State-of-the-Art" bibliography and review on brine disposal ponds.[1]* Included in the report is a survey, conducted in 1967-68, of the 50 states and the Federal Water Quality Administration (FWQA) on water pollution regulations pertaining to brine disposal ponds. The survey showed 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. Addresses of the various state agencies contacted in the survey are listed in Reference 1.

b. Testing soil samples from proposed brine disposal pond sites. This work was dependent upon requests from OSW.

c. Conducting laboratory tests on pond lining materials and soil sealants. Results of this work and work completed under Items "d" and "f" of the program are discussed later.

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

e. Developing techniques for increasing evaporation rates. A limited study[2] was conducted to determine the general effectiveness of spray systems to increase evaporation. Using 12 hollow cone spray nozzles, evaporation increases ranging from 18 to 59 percent were experienced with spray rates of 32 gallons (121.1 liters) per minute to 60 gallons (227.1 liters) per minute, respectively. Dr. George Löf of Colorado State University, Fort Collins, is continuing work on these techniques for OSW.

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

g. Preparing a manual[3] on the design, construction, and operation of brine disposal ponds. Specific design criteria presented in the manual are for a hypothetical brine disposal pond system based on data from the vicinity of Roswell, New Mexico, location of an OSW desalting test facility. Cost estimates are based on October 1969 prices.

h. Conducting an economic study of salt disposal. Results of this study are summarized in the manual.

Laboratory and field studies conducted under Items "c." and "f." of the program are summarized in OSW Research and Development Report No. 602.[4] Four types of lining materials were evaluated for seepage control in brine disposal ponds. The four types included: compacted earth, flexible membrane linings, hard-surface linings, and soil sealants. The study was important in that the development of low-cost lining materials is essential to reduce construction costs of brine disposal ponds.

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. The field studies also provided an opportunity to develop a monitoring system for continuous and routine measurement of seepage losses, Item "d." of the program. Recommendations on the monitoring system are included in Report No. 602 and also the manual. Among the linings evaluated were two soil sealants recommended by Diamond Shamrock Corporation, Painesville, Ohio, who conducted earlier studies for OSW on soil sealants.[5, 6]

The laboratory studies were conducted primarily to determine:

1. Effectiveness of various soil sealants for seepage control in soils from both Dalpra Farm and the Roswell, New Mexico Desalting Plant area. Roswell was originally selected for the field test site; however, subsequent studies indicated that Dalpra Farm was a more suitable location.

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

3. Physical properties data of the various lining materials.

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*References listed at end of report.

In the laboratory studies, three newly developed soil sealants appeared to have merit for low-cost seepage control, and they were recommended to OSW for field evaluation. The sealants are a sprayable liquid vinyl polymer that forms a surface film upon curing; a water soluble, and a non-water-soluble polyacrylamide. Those two can be applied by either mixing into the natural soil and compacting to achieve seepage reduction; or ponding, a method where the sealant is simply added to the water for subsequent deposition in the soil.

In March of 1970 the USBR entered into a second agreement with OSW, under Contract No. 14-30-2532, Work Order No. 4, to continue the field tests at Dalpra Farm, including the installation and evaluation of the three new soil sealants.

This report summarizes the work completed under the second agreement and the final evaluation of all lining materials. The conclusions and recommendations include all those previously reported[4] which are still appropriate plus any that are new or revised.

Although no definite seepage limits have yet been established for brine disposal ponds, seepage over 1 cubic foot per square foot per year* (1×10^{-6} cm/sec) or about 0.003 cubic foot per square foot per day (cfd) may be excessive in certain areas for these facilities.[1] In this study, a tentative seepage loss figure of 1 ft/yr or less was considered a satisfactory sealing performance for a lining material.

LINING MATERIALS INVESTIGATED

Original Linings

Nine lining materials were field tested under the original agreement. They are listed below according to type. Additional information on the linings is given in Report No. 602 and the Brine Disposal Pond Manual. The proprietary products discussed in this report are identified by laboratory sample number.

a. Flexible membrane linings.

1. Polyvinyl chloride (PVC) plastic film, 10 mils (0.25 mm) thick; a standard canal lining material. The PVC-lined pond was used to monitor the evaporation at the test site.

2. Low-grade polyethylene (PE) plastic film, 6 mils (0.15 mm) thick. This type of material was evaluated to determine the seepage control capabilities of a very low-cost plastic film.

3. Nylon-reinforced butyl-rubber sheeting, 45 mils (1.44 mm) thick. 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 higher in cost than other flexible membrane linings and their use is limited to special installations.

b. Hard-surface linings.

1. Asphaltic concrete, 2 inches (5.1 cm) thick. Hydraulic-type mix containing 7 percent asphalt based upon dry weight of aggregate.

2. Soil-cement, 6 inches (15.2 cm) thick, containing 8 percent Type I portland cement based upon dry weight of soil.

c. Compacted earth lining

1. Selected native soil compacted into a 12-inch (30.5-cm) thick lining.

d. Soil sealants. Surface treatment.

1. Liquid cutback asphalt, Sample No. B-5876, applied over the natural soil at an application rate of 2 gallons per square yard (gsy) (9.1 l/m^2).

e. Soil sealants. Mixed-in-place treatment.

1. Compacted soil lining, 6 inches (15.2 cm) thick containing 0.25 percent carboxymethylcellulose, Sample No. 48 D-37, and 0.05 percent alum, based upon dry weight of soil.

2. Compacted soil lining, 6 inches (15.2 cm) thick containing 2 percent attapulgite clay formulation, Sample No. 48 D-36, based upon dry weight of soil. Soil sealants 48 D-36 and 48 D-37 were recommended by the Diamond Shamrock Corporation for field evaluation.

f. Control.

1. The natural, untreated soil was also evaluated for comparative purposes.

*The seepage loss expressed as cubic foot per square foot per year was abbreviated in this report to read feet/year (ft/yr).

Under the second agreement, field tests were continued on the PVC, asphaltic concrete, compacted earth, soil sealants B-5876 and 48 D-37, and the natural soil.

New Linings

The new lining materials field tested under the second agreement are described below according to type. Information on installing these materials is given in the section titled "Field Installation."

a. Flexible membrane linings.

1. The 6-mil (0.15-mm) PE plastic lining was replaced with a 10-mil (0.25-mm) PE plastic lining. The thicker lining was formulated and manufactured for waterproofing applications. Field tests provided a direct comparison between the two grades and thicknesses of PE plastic.

b. Soil sealants—Surface treatment.

1. The sprayable liquid vinyl polymer, Sample No. B-5800, was applied over the natural soil at an application rate of 0.4 gsy (1.8 l/m^2), 75 percent mixture strength, to obtain a cured surface film thickness of 30 mils (0.76 mm).

Sealant B-5800 is supplied at 60 percent solids in water and by using mixtures containing more than 2 parts of B-5800 per part of water a residual film can be obtained. At lower concentrations B-5800 can be used as a soil stabilizer and dust control agent. The Bureau of Mines at the Salt Lake City Metallurgy Research Center is evaluating the material for stabilizing fine particles of troublesome mineral processing wastes.[7] These wastes, known as tailings, are a potential source of pollution when exposed to erosion by winds. The Corps of Engineers at the Waterways Experiment Station, Vicksburg, Mississippi, is also evaluating the vinyl polymer for various military applications such as helicopter pads, airport aprons, and temporary beach and road stabilization.

To study the application of B-5800 as a lining material, the manufacturer conducted laboratory tests on samples of Dalpra soil. Based on these tests they recommended the material be applied at a dilution of three parts B-5800 to one part water (75 percent mixture strength). The manufacturer also recommended prewetting the soil with a light application of water to reduce pinholing in the residual film.

The USBR conducted additional laboratory studies to determine the field application rate. As a result of these studies it was proposed to install B-5800 by a two-step application: (1) dilute mixture, 1 part B-5800 to 19 parts water, spray-applied at a rate of 2 gsy (9.2 l/m^2) to stabilize the subgrade, followed by (2) the 3:1 concentrated mixture at 0.4 gsy (1.8 l/m^2) to obtain a residual film thickness of about 30 mils (0.76 mm). Material cost for B-5800 is \$1.75/gallon or about \$0.15 per 10-mil (0.25-mm) thickness of residual film per square yard. In a letter dated May 22, 1970, the manufacturer concurred with the proposed field application and this was used at Dalpra Farm.

c. Soil sealants. Mixed-in-place treatment.

1. Compacted soil lining, 6 inches (15.2 cm) thick containing the polyacrylamide formulation, Sample No. B-6166, applied at an application rate of 2,000 lbs/acre (2,200 kg/ha). The sealant was mixed into the upper 2 inches (5.1 cm) of soil prior to compaction.

d. Soil sealants—Ponding treatment.

1. Polyacrylamide formulation, Sample No. B-6166, was applied at an application rate of 2,000 lbs/acre (2,200 kg/ha).

2. Water soluble polyacrylamide, Sample No. B-5604, was applied at an application rate of 200 lbs/acre (220 kg/ha).

Sealants B-6166 and B-5604 were supplied in a dry powder form. Sealant B-6166 was formulated to make the powder less dusty, easier to distribute, and easier to disperse into water. It contains 25 percent sealant B-5604, 25 percent sealant B-5605, and 50 percent inert materials. Sealant B-5604 being a water soluble polymer is designed to penetrate into very small soil capillaries and cause sealing by adsorption onto clays. Sealant B-5605 is a non-water-soluble polyacrylamide that forms a particulate gel product when added to water. Its function is to penetrate and enter into larger cracks or capillaries and become lodged thereby plugging the flow channel.

The manufacturer reports the gel can imbibe up to 1,000 times its original dry weight in distilled water and 100 times its weight in 3 to 4 percent brines. The sealant is available in two sizes of gel structure, which are designated by the manufacture as "regular" or "coarse." However, if the effort is justified, the physical properties of the gel, i.e., structure size, pliability, etc., can be changed by manufacturing techniques to meet specific requirements.

The water soluble polymer and gel material are generally used in combination and in equal amounts to provide wider sealing capabilities. Application rates vary from 100 lbs/acre (110 kg/ha) to 500 lbs/acre (550 kg/ha) of each sealant depending upon soil and water conditions. The material cost for each sealant is $2.40/pound.

Based on laboratory permeability tests summarized in Table 12 and consultations with the manufacturer, the latter two methods of sealant treatment listed above were selected for use at Dalpra Farm.

Besides these studies, the USBR is evaluating sealants B-5604 and B-5605 for seepage control in irrigation canals.[8] [9] Field tests are being conducted at the Panoche Water District, near Los Banos, California, and Truckee-Carson Irrigation District (TCID) near Fallon, Nevada. Panoche Water District soil is classed as Panoche clay, whereas the soil in TCID is classed as sand and sandy loam.

Three methods of treatment were used: dry dust application; slurry treatment-aardvark; and ponded. In the dry dust application, the sealant material was blown onto the water surface through a blower mounted on a boat. In one treatment, the dry sealant was dusted directly onto the dampened surface of the canal prism and then the pond was filled with water. In the slurry treatment, the sealant was introduced into the water in the canal or lateral from a boat using an eductor system. In the ponding method, the sealant was added to the water as the canal was being filled. Application rates of each material ranged from 100 lbs/acre (110 kg/ha) to 500 lbs/acre (550 kg/ha).

Comparison of pretreatment and posttreatment seepage tests at Panoche indicated a seepage reduction of 30 percent, while pretreatment and posttreatment seepage tests at TCID indicated a seepage reduction of 93 to 98 percent. All treated sections will be periodically observed to determine the most effective treatment method and rate, and the sealing permanency.

The Corps of Engineers, Norfolk, Virginia, were contacted for information on their use of sealants B-5604 and B-5605 in sealing a newly constructed 2-acre (0.8-ha) sewage lagoon. The Corps of Engineers reported they used the blower technique, described above, to apply the sealants. The sealants, obtained as the B-6166 formulation, were applied in less than 2 hours, and at an application rate of 400 lbs/acre (440 kg/ha) of active material. At the time of treatment, there were 5.5 acre-feet (6,800 m^3) of water in the lagoon. This produced an approximate 106 parts per million (ppm) concentration of B-6166. Laboratory tests on a sample of soil to be sealed achieved a 94 percent seal in 1-1/4 hours. The manufacturer expected an equivalent seal in the lagoon in 7 to 8 days. The seepage rate prior to treatment was calculated to be 21 ft/yr (2.1×10^{-5} cu m/sec). According to recent reports from operating personnel at the lagoon, satisfactory seepage control was obtained with the sealants.

CONCLUSIONS

1. Based on this evaluation, flexible membrane linings were generally the most effective for seepage control; followed by hard-surface linings; soil sealants—surface applied; compacted earth lining; soil sealants—mixed in-place; and soil sealants—ponded. Also, the flexible membrane linings were generally easier to install, requiring a minimum of equipment and labor.

2. The PVC plastic lining provided the most satisfactory sealing performance. Field seepage measurements and visual observations indicated the PVC was watertight for the 25 months it was tested. Physical properties tests showed no significant change in the plastic due to brine exposure. Because of its impermeability, physical properties, ease in handling and installing, PVC is preferred to other flexible membrane linings for use in shallow-type brine disposal ponds. For such use a 10-mil (0.25-mm) thick PVC film is considered satisfactory from a durability standpoint.

3. The 10-mil (0.25-mm) thick PE plastic lining appeared to be watertight for the 5 months it was field tested. However, hydrostatic puncture tests over coarse and fine aggregate indicated the PE had lower puncture resistance than PVC of equivalent thickness, and therefore it would be more susceptible to physical damage. Field seepage measurements and visual observations showed the thinner 6-mil (0.15-mm) PE had material defects and was inadequate as a lining.

4. The nylon-reinforced butyl rubber would be considered as effective as the PVC lining for seepage control provided proper seaming is obtained. (Some problems were encountered during the field test in

obtaining watertight seams.). Also, this particular compounded material had low ozone resistance. Because of this deficiency it would not be acceptable for use under present USBR specifications. The cost of nylon-reinforced rubber would be expected to be 3 or 4 times that of PVC plastic lining.

5. 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 its first winter exposure. This cracking was primarily due to a chemical reaction between the brine and the low sulfate-resistant Type I portland cement in the lining. The cracking was also aggravated by freezing and thawing and wetting and drying cycles that occurred during the same period. 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.

6. The liquid-applied vinyl polymer film provided satisfactory seepage control. This system appears to have several advantages over a prefabricated sheet-type plastic film. These include: elimination of field seams; lower cost per unit thickness of film; and the cured film is more easily repaired. The cured film though, has lower tear and tensile strength, greater temperature susceptibility, and requires application over a smoother subgrade than the sheet-type plastic. However, this study indicates the sprayable material has merit for sealing brine disposal ponds and additional studies are recommended to fully evaluate its potential.

7. The liquid asphalt, spray applied over the natural soil, showed some seepage control. Good penetration was obtained in the silty sand. This material could be used for erosion control on pond banks and berm areas. No deterioration of the material was noted after 25 months' brine exposure.

8. Although the compacted earth lining at Dalpra Farm provided some seepage control, the silty sand used is not the type of soil which would produce the best lining. Tha use of clay material such as the Roswell soil would provide a much better compacted earth lining. In laboratory permeability tests conducted on Roswell soil, satisfactory seepage control was obtained from samples compacted above 80 percent of maximum laboratory density.

9. The soil sealants mixed in-place and compacted to achieve seepage reduction did not provide the seepage control required for brine disposal ponds. It appears that in applying and mixing small quantities of sealants, it is almost impossible to obtain uniform coverage; therefore, lean areas of coverage are obtained, thus increasing the chance for seepage. This was especially true for sealants applied at quantities less than 1 percent by weight of soil. Of the three sealants applied by this method, the water soluble and non-water-soluble polyacrylamide formulation showed the best sealing performance. However, poor natural drainage from the test pond reduce seepage and made it difficult to fully evaluate the polyacrylamide formulation. Nevertheless, the development of backpressure in the sand drainage layer nearly equal to the head in the test pond was indicative of inadequate sealing by this material.

10. The soil sealants applied by ponding were ineffective for seepage control. Field tests with the polyacrylamide formulation showed the gel portion of the compound did not penetrate the silty sand and was confined to the surface. Under such a condition the gel material is subject to movement and will not produce an adequate seal. Although soil sealants are easily applied by ponding, satisfactory coverage is questionable, especially for large-scale installations. Also, unless the sealant can penetrate into the soil, the resulting seal will not be permanent.

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

12. During the second test season the monitoring system started to have some maintenance problems. Damage to the protective lead (pb) thermocouple wire coverings could have been prevented by providing more rugged installation. The effects of recorder failures could have been minimized by the use of redundant or reserve equipment.

FIELD INSTALLATION

General

Location of the field test site at the Gilbert O. Dalpra Farm is shown in Figure 1. This site is approximately 35 miles (56 km) from the Denver Federal Center, a convenient location for the field test program. The native soil is a silty sand with relatively high seepage characteristics. Located at the test site is a demineralizer plant operated by the USBR for OSW where various membrane-type desalting units are

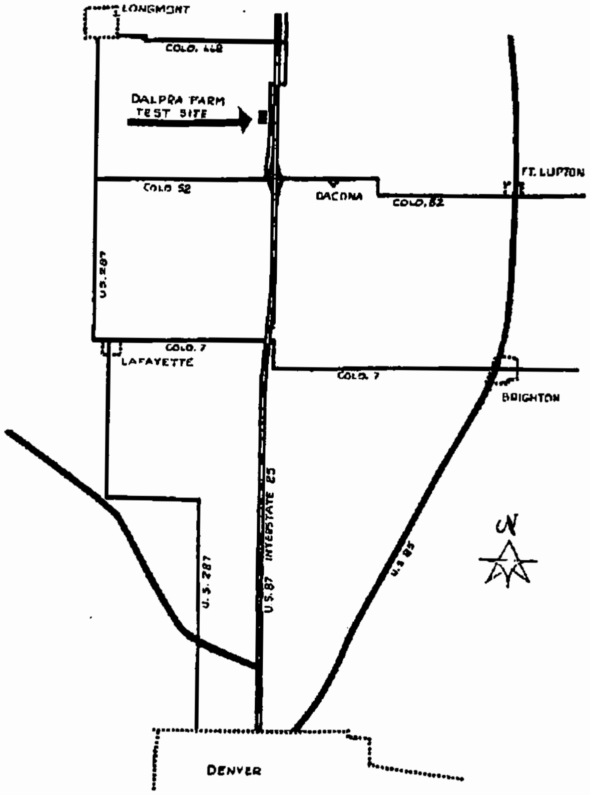


Figure 1. Location map

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. Here the effluent was readily available for pumping to the various test ponds.

Eighteen-foot (5.5-m) diameter corrugated-metal, bottomless tanks, each with a different base lining material were used as the test ponds. The installation of the test ponds is described in the previous report.[4] Briefly, the work included: (1) preparation of sand drainage pads, (2) installation of the required base linings on the sand drainage pads, and (3) erection of the metal tanks. The test ponds are shown in Photograph 1 and Figure 2.

Installation of New Linings

On June 24, 1970, a contract was awarded under Purchase Order No. 10-D-3570 to install the new linings. The work, completed on July 9, consisted of removing the soil-cement lining, soil sealant lining containing 48 D-36, and their sand drainage pads; and placement of two clean sand drainage pads, and three native soil linings. Placement of the soil linings is shown in Photograph 2. The linings were compacted to a 6-inch (15.2-cm) thickness at 90 percent of maximum density to provide a natural in-place condition. The sand-cone method[10] shown in Photograph 3 was used to determine the in-place density of both the soil linings and the sand drainage pads. Results of these tests are summarized in Table 1, and the gradation of the soil is shown in Figure 3.

After placement of the soil linings the following treatment methods were used to apply the soil sealants:

1. Tank No. 4—Surface treatment.

   Application of B-5800, previously discussed, is shown in Photograph 4. Due to restricted working area and to ensure a more uniform application, paint rollers instead of spraying equipment were used to apply the concentrated mixture. Also, the soil lining was divided into 1 square yard (0.81 m^2) grids for easier control coverage.

2. Tank No. 5—Ponding treatment.

   The dry sealant, B-6166, was slowly added to a 55-gallon (208-liter) drum which contained a sump pump for continuous mixing and pumping of the sealant-brine mixture into the tank. This procedure is shown in Photograph 5. At the time of application the tank contained a 2-foot (0.61-m) head of brine for use as the sealant carrier medium.

3. Tank No. 9—Mixed-in-place treatment.

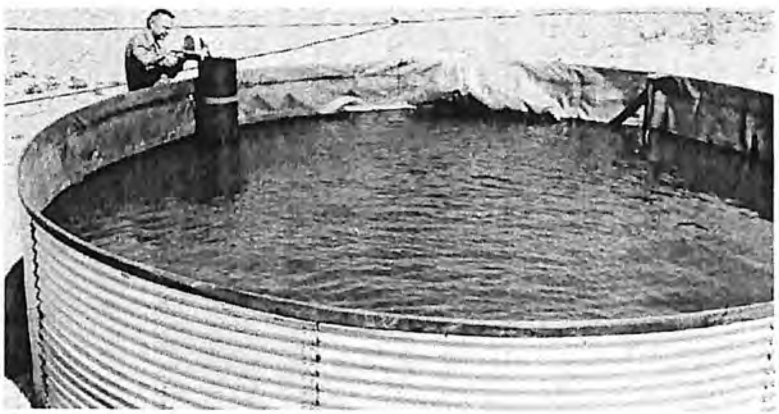
   After placement of about 8 inches (20.3 cm) of uncompacted soil, sealant B-6166 was broadcast on the surface at a rate of 2,000 lbs/acre (2,200 kg/ha); or on the basis of active material, 1,000 lbs/acre (1,100 kg/ha). The sealant was raked and mixed into the upper 2 inches (5.1 cm) of soil, and then the soil mixture was compacted into a 6-inch (15.2-cm) thick layer. The completed lining is shown in Photograph 6.

FIELD TESTS

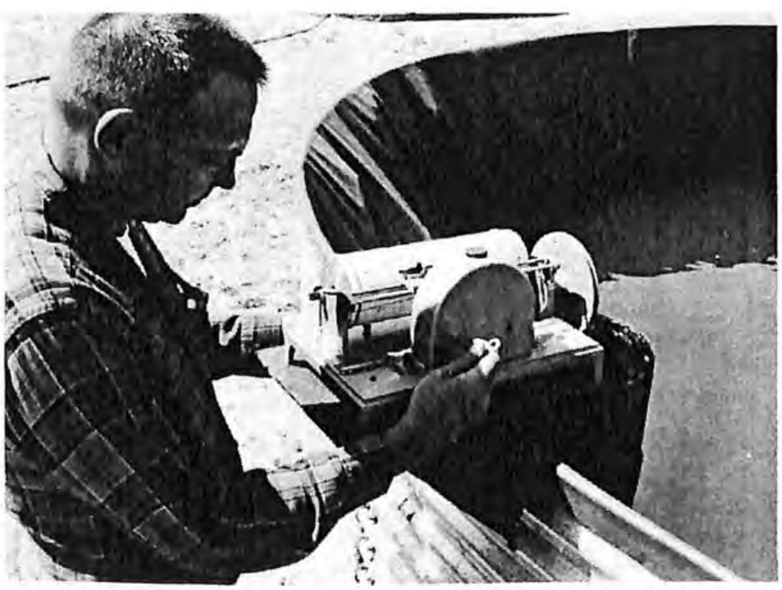
General

Field tests were conducted from April 29 through December 9, 1970. However, the final evaluation of the lining materials also includes results of tests conducted in 1969.

General view of test site. Brine effluent pond for demineralizer plant is shown in foreground. Photo P800-D-66522



View of evaporation pond showing stilling well, water level gage and thermocouples. Photo P800-D-66523



Water level gage. Photo P800-D-67362

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

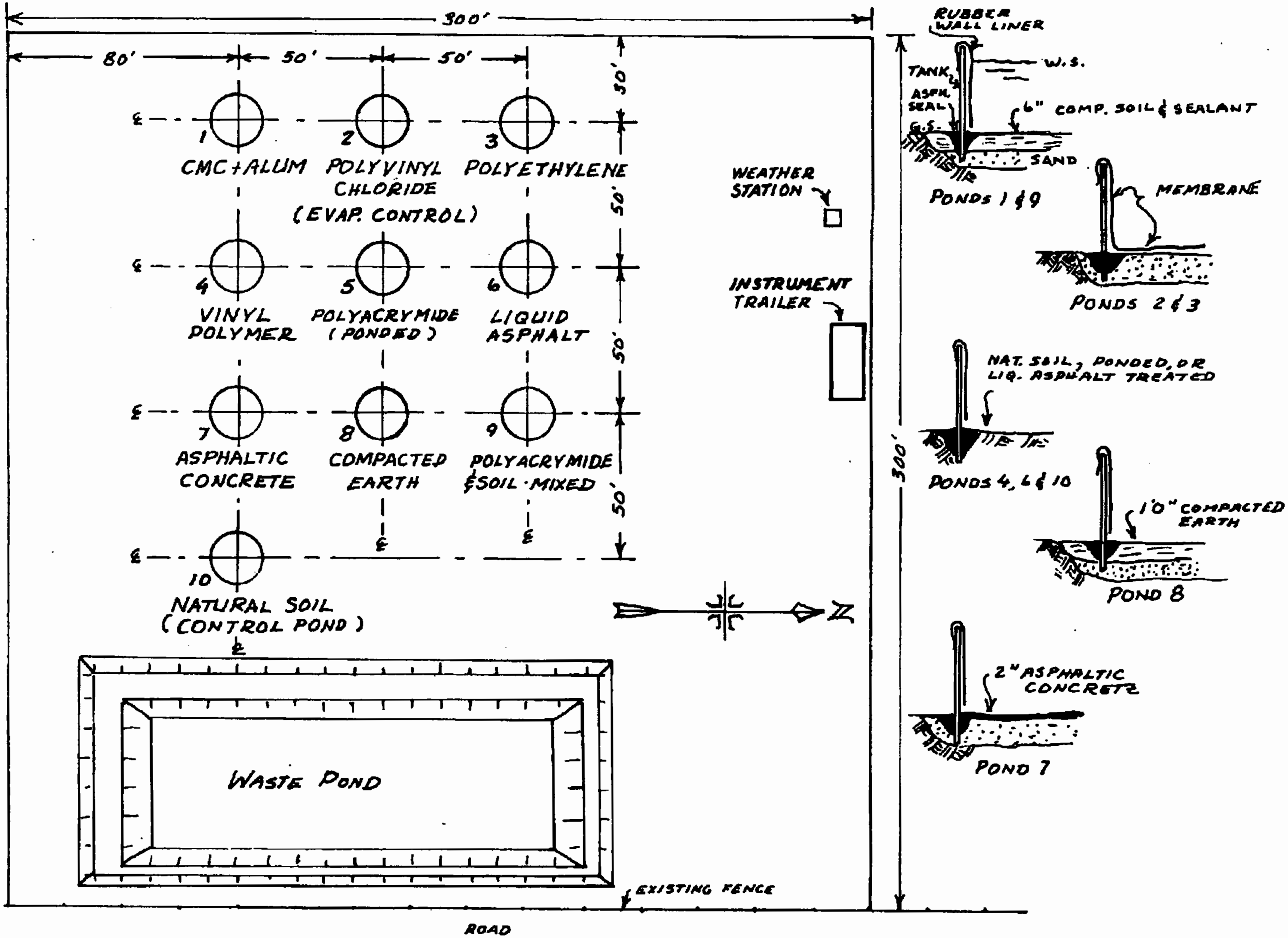
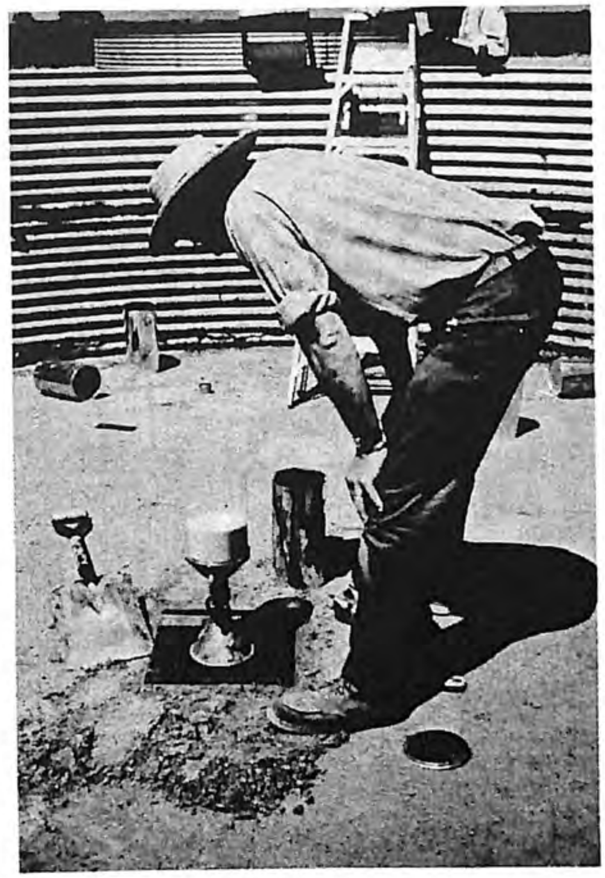


Figure 2. Dalpra Farm test site location plat.

(a) Spreading soil in tank. Photo P800-D-68959

(b) Compacting soil in tank with a Wacker compactor. Photo P800-D-68960

Photograph 2. Reconstruction of OSW test ponds at Dalpra Farm.



Photograph 3. Field density test using sand-cone method. Top photo P800-D-68961. Bottom photo P800-D-68962

Table 1

SUMMARY OF IN-PLACE DENSITY TESTS
OSW TEST SITE, DALPRA FARM

Tank No.	Material	Compacted density (lb/ft³) (g/cc)	Maximum density (percent)	Moisture content of soil (percent)	Relative density (percent)
4	Soil lining	110.8 (1.77)	93.0	9.1	–
4	Sand pad	115.0 (1.84)	–	5.8	71.0
5	Soil lining	110.5 (1.77)	93.0	8.6	–
9	Soil lining	111.0 (1.78)	93.0	9.3	–
9	Sand pad	115.9 (1.85)	–	5.9	76.0

Note: Maximum density (dry)–119.0 lb/ft^3 (1.91 g/cc)
Optimum moisture content–12.0 percent

Specification requirements:
Compacted density of soil linings–less than 95 percent of maximum density.
Relative density of sand pads–70 to 80 percent.

The linings were tested using a 3-foot (0.9-m) head of effluent. This level was used to provide a realistic operating condition. The effluent contained about 80 percent sodium salts, and had an average total dissolved solids (TDS) content of 3,000 ppm.

During operation the water level for all ponds was kept, within practical limits, at the 3-foot (0.9-m) level so that similar exposure to wind and thermal conditions was maintained for all tanks.

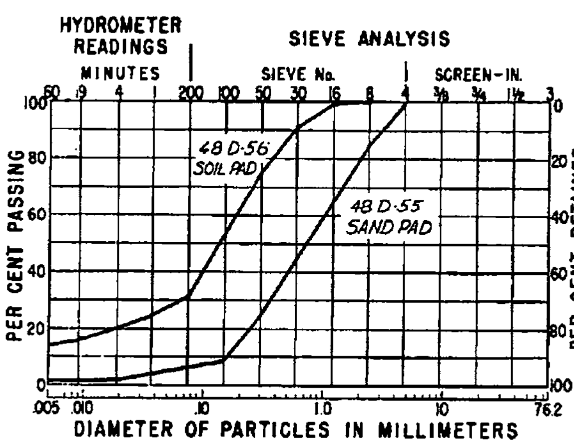


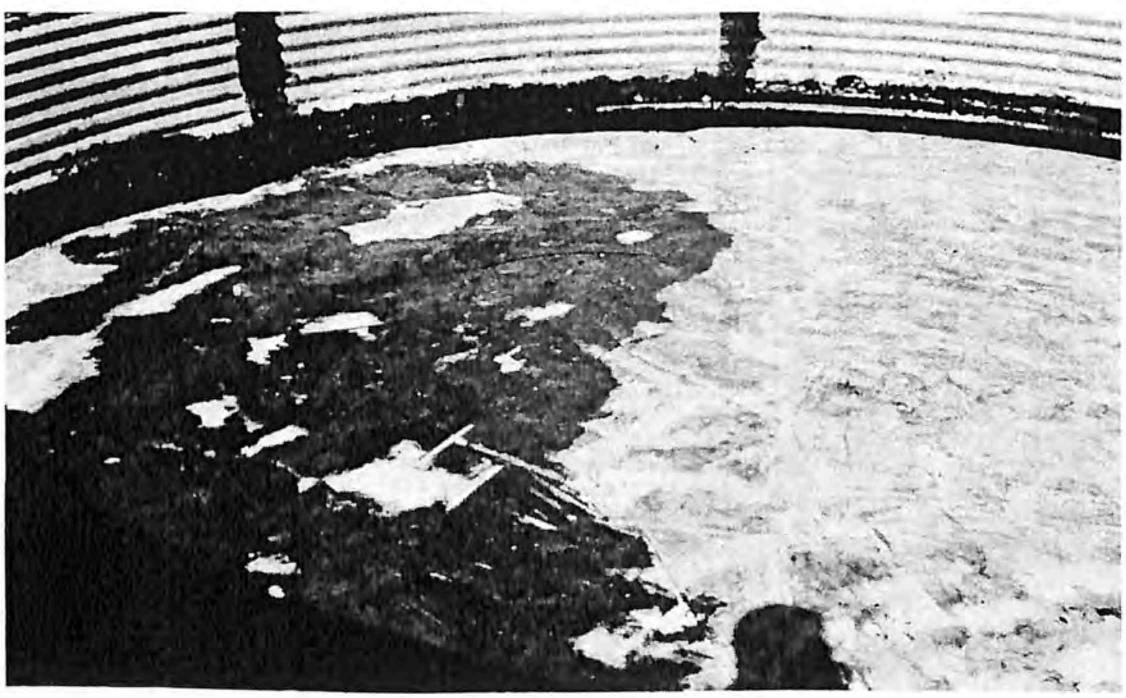
Figure 3. Mechanical analyses soil lining and sand pad.

The water budget method, an accounting for all water gains and losses, was used to determine the seepage control effectiveness of the various lining materials. The water budget is the simplest accurate means to determine evaporation or seepage, providing one of these is known. In these studies the evaporation was the known value, and it was determined from the PVC-lined pond, which was watertight.

Monitoring System

The same instrumentation that was used during the 1969 test season to measure and record water level changes caused by brine and precipitation inflow and evaporation and seepage outflow for water budget computations was continued in service. Measurements of the same meteorlogical factors were also continued to furnish data necessary for making evaporation corrections if any significant thermal differences between the test ponds and the evaporation determining pond were noted. The continued operation of the monitoring system provided further check of the durability of the instrumentation. The instrumentation and evaporation correction methods are discussed in more detail in Reference 4. Briefly the instrumentation used during both the test seasons included:

(a) Application of B-5800 to form a residual vinyl plastic film. The material was applied as a concentrated mixture, 3 parts B-5800 to 1 part water, in two equal applications at a total rate of 0.4 gsy (1.8 l/m^2). Photo P800-D-68963



(b) B-5800 at left has cured leaving a translucent film material at right, freshly applied, shows appearance before curing. Photo P800-D-68964

Photograph 4. Installation of soil sealants by surface treatment methods.

Photograph 5. Installation of soil sealants by ponding treatment method. The dry powder or slurry mixture, depending upon the sealant, was slowly added to the 55-gallon (208-liter) drum where it was continuously mixed and then pumped into the test tank. Photo P800-D-68965

1. Recording water level gages.

2. A rain gage to account for precipitation inflow in the water budget.

3. A hygrothermograph to record air temperature and relative humidity.

4. A weather anemometer and odometer to record miles of wind passing over the test site.

5. A 24-point temperature recording system to measure water temperatures in the test tanks.

Computation of Seepage Losses

Seepage losses were computed 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, the seepage loss was multiplied by 365 to obtain the yearly value, and by 1.12, which is a constant used to correct for the difference in the lined area compared to water surface area.

Test Results

Summary of seepage losses for the lining materials is listed in Table 2, and shown graphically in Figures 4 and 5. The results of seepage determinations for the individual linings are summarized in Tables 15 to 24 in Appendix 1. Also shown in the tables are the water surface elevations during the time interval.

A summary of weather and PVC pond measurements related to evaporation is listed in Tables 3 and 4. The data in the tables are averaged over the same time intervals used to determine average seepage losses. Also shown in the tables 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 9,200-ppm TDS content, would not produce a significant reduction in evaporation.

Samples from various field lining materials were obtained for laboratory testing. Results of these tests are discussed and tabulated in the next section, "Discussion of Test Results." Laboratory test methods are described in detail in Report No. 602.

DISCUSSION OF TEST RESULTS

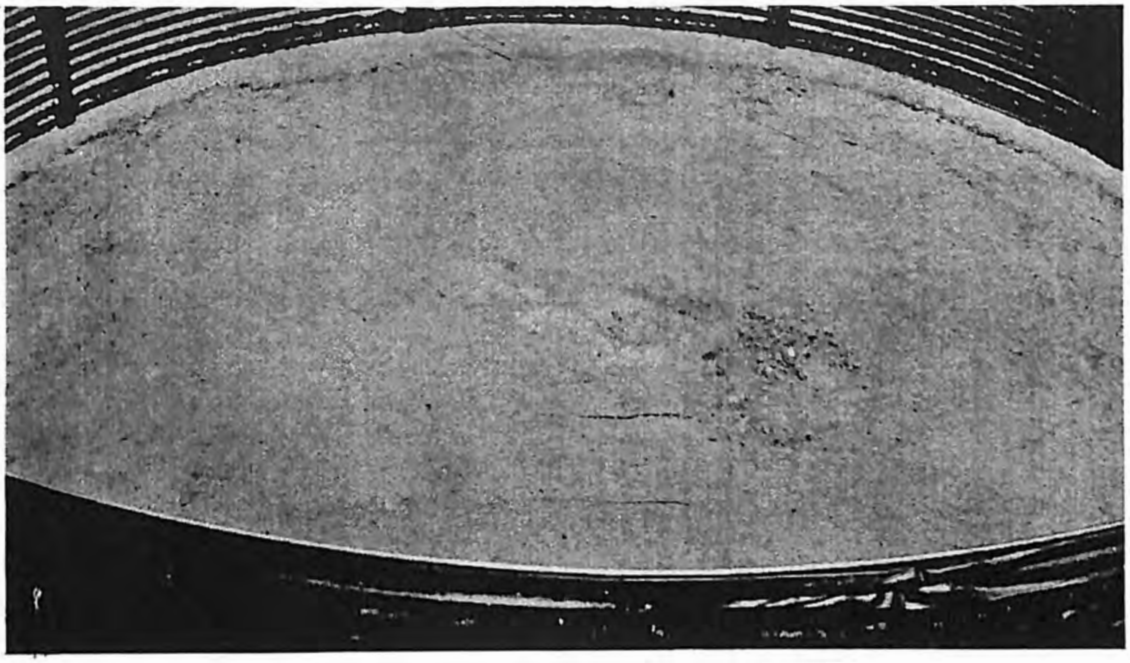
Flexible Membrane Linings

Field test results summarized in Table 2 indicate the flexible membrane linings were the most effective type evaluated for seepage control. Also, these linings were generally the most easily installed requiring a minimum of labor and equipment.

a. Polyvinyl chloride plastic.

This lining provided the most satisfactory sealing performance. The PVC was removed after 25 months' service and random samples of the lining were obtained for laboratory evaluation. During removal of the lining the sand drainage pad was inspected and found to be dry, indicating the PVC was watertight.

Tensile strength, ultimate elongation, and tear resistance of the field samples were determined and compared to the original values. The results summarized in Table 5 showed a slight stiffening of the PVC occurred during brine exposure. This stiffening is attributed to partial loss, migration, or chemical change of the plasticizer; the agent used in the manufacturing of PVC to impart flexibility. However, the stiffening of the PVC was not serious and the physical properties measured were near or above the USBR specifications requirements for



(a) View of completed soil lining containing sealant B-6166 in dry condition. Photo P800-D-68966

Photograph 6. Installation of soil sealants by mixed in-place treatment method.

Table 2

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

Lining material	Seepage losses 1969 ft/yr or cm/sec x 10^{-6}			Seepage losses 1970 ft/yr or cm/sec x 10^{-6}		
	Initial	Final	Average	Initial	Final	Average
Polyvinyl chloride plastic	0	0	0	0	0	0
Polyethylene plastic (10 mils)	–	–	–	0	0	0
Nylon-reinforced butyl rubber	0.57	0.06	0.25	0	0.20	*0.25
Asphaltic concrete	10.9	0.82	2.32	0.16	0	0.70
Sealant B-5800 (S)	–	–	–	9.88	0.25	0.94
Polyethylene plastic (6 mils)	2.72	6.34	3.96	211.0	180.0	**195.0
Sealant B-6166 (M)	–	–	–	12.0	2.67	5.64
Soil-cement	7.98	5.73	6.60	7.77	8.59	**8.18
Sealant B-5876 (S)	15.9	6.14	10.7	11.0	2.80	8.52
Compacted earth	34.8	6.02	16.1	15.1	6.37	10.30
Sealant 48 D-37 (M)	15.9	13.9	11.0	14.3	7.30	13.50
Natural soil, untreated	164.0	36.0	75.0	626.0	17.6	53.0
Sealant 48 D-36 (M)	124.0	36.0	75.0	–	–	–
Sealant B-5604 (P)	–	–	–	85.3	71.6	80.0
Sealant B-6166 (P)	–	–	–	112.0	88.0	107.0

(S) designates surface applied treatment.
(M) designates mixed-in-place treatment.
(P) designates ponded treatment.

*Average of 5 weeks testing in 1970.
**Average of 2 weeks testing in 1970.

Code:

Sealant Number	Material
B-5800	Vinyl polymer formulation.
B-6166	Field formulation containing equal parts of water-soluble and non-water-soluble polyacrylamide.
B-5876	Liquid cutback asphalt.
B-5604	Water-soluble polyacrylamide.
48 D-36	Attapulgite clay formulation.
48 D-37	Carboxymethylcellulose.

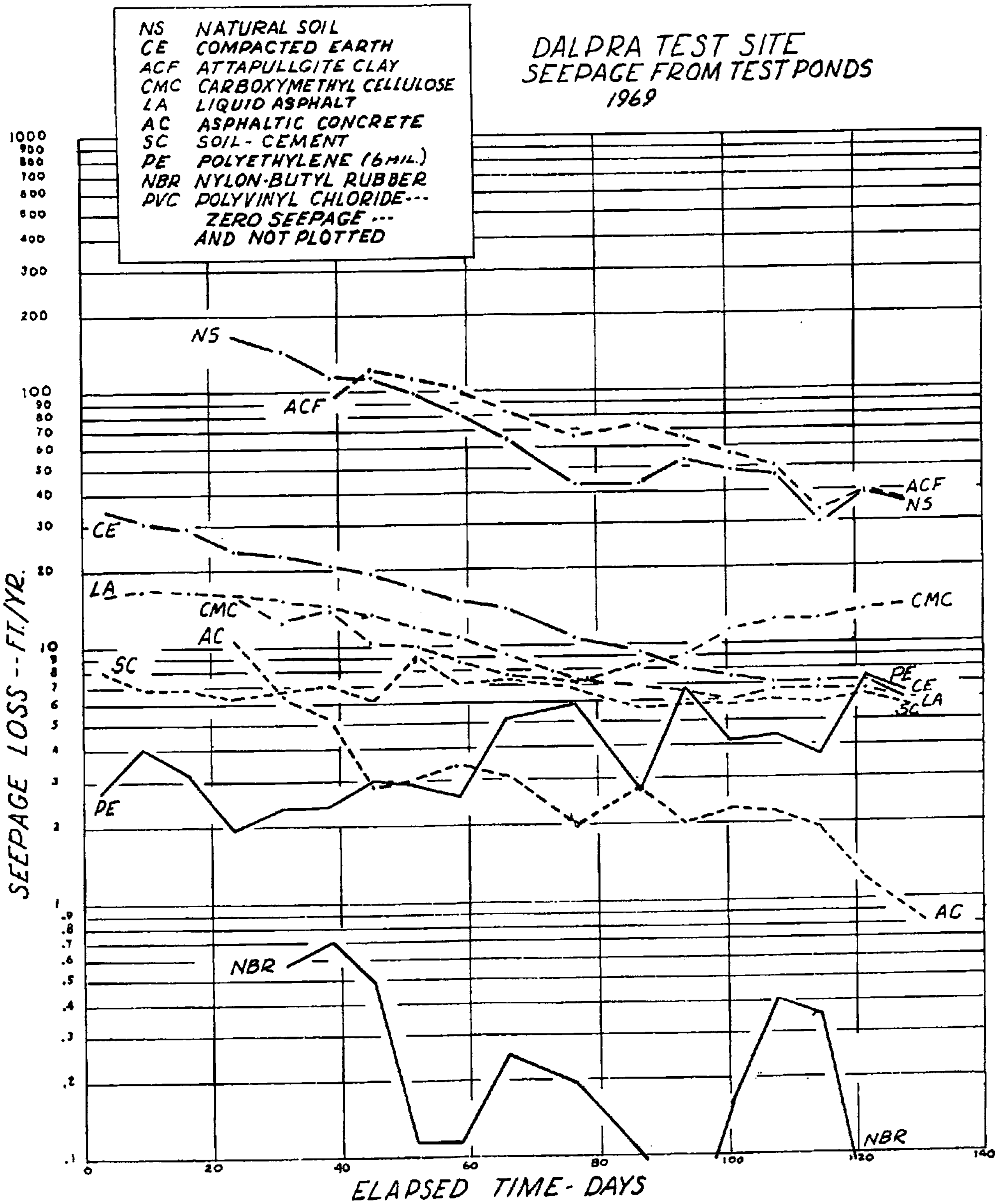


Figure 4. Seepage from test ponds (1969).

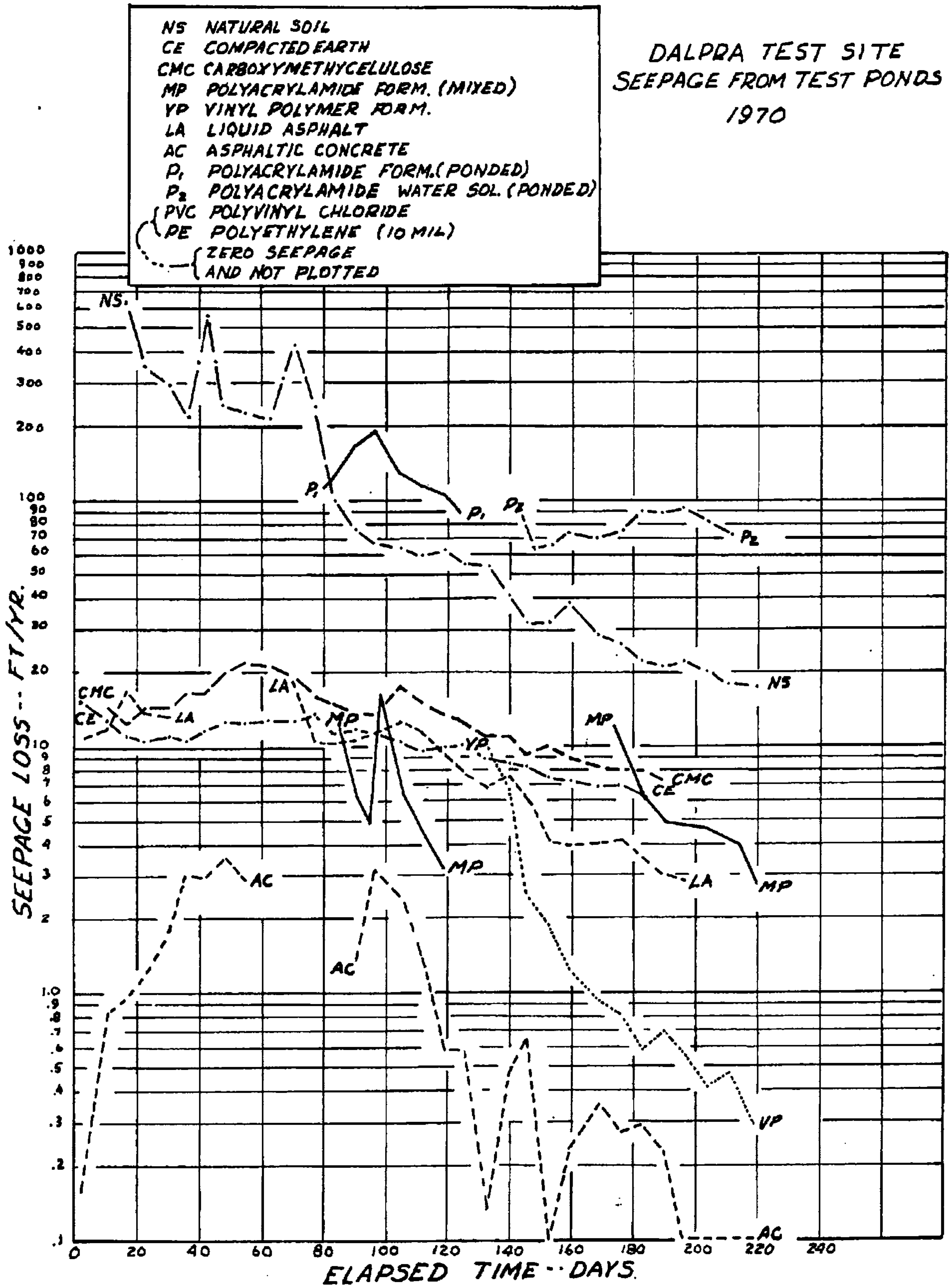

NS NATURAL SOIL
CE COMPACTED EARTH
CMC CARBOXYMETHYCELULOSE
MP POLYACRYLAMIDE FORM. (MIXED)
VP VINYL POLYMER FORM.
LA LIQUID ASPHALT
AC ASPHALTIC CONCRETE
P1 POLYACRYLAMIDE FORM.(PONDED)
P2 POLYACRYLAMIDE WATER SOL. (PONDED)
PVC POLYVINYL CHLORIDE
PE POLYETHYLENE (10 MIL)
ZERO SEEPAGE AND NOT PLOTTED
DALPRA TEST SITE
SEEPAGE FROM TEST PONDS
1970
SEEPAGE LOSS -- FT/YR.
ELAPSED TIME -- DAYS

Table 3

EVAPORATION DATA—1969

Date From	Date To	Evapo-ration feet/year	Air temper-ature °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	76.2	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)–1969

Date From	Date To	Evapo-ration cm/year	Air temper-ature °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	

Table 4

EVAPORATION DATA—1970

Date From	Date To	Evapo-ration ft/yr	Air temper-ature °F	Relative humidity percent	Wind velocity mph	Water depth feet	TDS ppm
4-24	4-29	6.94	56	49	—	2.66	6,950
4-29	5-6	5.48	50	50	—	2.96	
5-6	5-13	7.67	60	46	6.69	2.89	
5-13	5-20	6.88	59	54	5.08	2.94	
5-20	5-27	6.88	66	53	5.01	2.95	
5-27	6-3	6.15	60	57	5.09	2.95	
6-3	6-8	7.67	66	44	4.22	2.95	
6-8	6-15	5.84	63	53	5.33	3.08	
6-15	6-22	7.41	67	51	3.70	3.06	
6-22	6-29	7.30	76	54	3.15	2.94	
6-29	7-6	8.51	73	51	3.49	2.93	
7-6	7-13	6.26	75	55	3.02	2.95	
7-13	7-20	7.41	75	49	2.91	2.91	8,340
7-20	7-27	6.10	73	51	2.93	2.90	
7-27	8-3	7.41	76	48	2.24	2.93	
8-3	8-10	6.42	75	54	1.97	2.94	
8-10	8-17	6.83	74	50	1.98	2.93	
8-17	8-24	5.27	71	53	1.78	3.00	
8-24	8-31	6.16	–	–	1.73	2.94	
8-31	9-8	5.75	71	51	2.66	2.97	
9-8	9-14	5.78	61	46	4.10	2.87	
9-14	9-21	4.28	63	48	3.50	2.96	
9-21	9-28	2.56	53	53	3.28	3.02	8,700
9-28	10-5	3.60	62	48	2.01	2.99	
10-5	10-12	2.81	55	65	4.10	2.96	
10-12	10-19	1.88	53	52	2.93	2.94	
10-19	10-25	2.43	45	50	3.90	2.93	
10-26	11-2	2.24	39	49	3.66	2.88	
11-2	11-9	2.09	42	54	4.88	2.85	
11-9	11-16	1.62	45	53	4.20	3.02	9,170
11-16	11-22	2.31	37	52	3.07	3.01	
11-24	11-30	*1.95	47	52	7.05	*2.95	
12-2	12-7	*2.70	41	51	7.30	*2.89	

*Data from PE-lined pond.

Table 4A

EVAPORATION DATA (METRIC UNITS)–1970

Date From	Date To	Evapo-ration cm/year	Air temper-ature °C	Relative humidity percent	Wind velocity km/hr	Water depth meters	TDS ppm
4-24	4-29	212	13.3	49	–	0.811	6,950
4-29	5-6	167	10.0	50	–	.903	
5-6	5-13	234	15.6	46	10.8	.881	
5-13	5-20	210	15.0	54	8.17	.897	
5-20	5-27	210	18.9	53	8.06	.900	
5-27	6-3	187	15.6	57	8.19	.900	
6-3	6-8	234	18.9	44	6.79	.900	
6-8	6-15	178	17.2	53	8.58	.939	
6-15	6-22	226	19.4	51	5.95	.933	
6-22	6-29	222	24.4	54	5.07	.897	
6-29	7-6	262	22.8	51	5.62	.894	
7-6	7-13	191	23.9	55	4.86	.900	
7-13	7-20	226	23.9	49	4.68	.888	8,340
7-20	7-27	186	22.8	51	4.71	.884	
7-27	8-3	226	24.4	48	3.60	.894	
8-3	8-10	196	23.9	54	3.17	.897	
8-10	8-17	208	23.3	50	3.18	.894	
8-17	8-24	161	21.7	53	2.86	.915	
8-24	8-31	188	–	–	2.78	.897	
8-31	9-8	175	21.7	51	4.28	.906	
9-8	9-14	176	16.1	46	6.60	.875	
9-14	9-21	130	17.2	48	5.63	.903	
9-21	9-28	78	11.7	53	5.28	.921	8,700
9-28	10-5	110	16.7	48	3.24	.912	
10-5	10-12	86	12.8	65	6.60	.903	
10-12	10-19	57	11.7	52	4.71	.897	
10-19	10-25	74	7.2	50	6.28	.894	
10-26	11-2	68	3.9	49	5.89	.878	
11-2	11-9	64	5.2	54	7.85	.869	
11-9	11-16	49	7.2	53	6.76	.921	9,170
11-16	11-22	70	2.8	52	4.94	.918	
11-24	11-30	*59	8.3	52	11.4	*.900	
12-2	12-7	*82	5.0	51	11.8	*.881	

*Data from PE-lined pond.

new material. The random samples were also inspected for pinholes and none were found.

b. Polyethylene plastic.

The 10-mil (0.25-mm) thick PE lining appeared to be watertight for the 5 months it was tested. Physical properties of the new material were determined and they are summarized in Table 6. Tentative USBR specifications requirements are also listed for comparison. The laboratory text results indicated the PE had satisfactory physical properties for use as a lining in shallow-type, brine disposal ponds.

Field seepage measurements and visual observations showed the thinner 6-mil (0.15-mm) PE had material defects and was inadequate as a lining. Some seepage control, though, was provided by the material during its first year's service. The average seepage loss for this period was about 4 ft/yr (4 x 10^{-6} cm/sec). Near the end of the 1969 test season, however, the seepage loss was starting to increase and by the Spring of 1970 it had reached 195 ft/yr (1.9 x 10^{-4} cm/sec).

The 6-mil (0.15-cm) PE lining was removed in May of 1970 after 20 months' service and thoroughly examined for material defects. Particular attention was given to the area at the 3-foot (0.9-m) brine level, where a significant increase in seepage occurred when the test pond was filled to this depth. The visual examination summarized in Table 7 revealed a large number of pinholes and thin spots in the lining, with a substantial number near the 3-foot (0.9-m) level. Inspection of the metal tank at the corresponding depth also showed corroded areas due to brine seepage.

Random samples of the PE lining were tested to determine the change in tensile strength, ultimate elongation, and tear resistance. The test results summarized in Table 5 indicated essentially no change in the 6-mil (0.15-mm) PE plastic after 20 months' brine exposure.

The puncture resistance of the three plastics was also determined and the test results are summarized in Table 8. The test method used is described in Report No. 602, page 104.[4] The results showed that PVC is more resistant to puncture than either of the two PE plastics. Also the puncture resistance for the same type of plastic is dependent upon material thickness.

c. Butyl rubber.

The nylon-reinforced butyl-rubber lining, 45 mils (1.44 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. The problem seams were repaired with butyl-rubber adhesive and neoprene calk.

After repair, close comparison of water-level histories was noted between the butyl- and PVC-lined ponds. The butyl lining was removed after 1 year's service and the physical properties of several random samples were determined. The results summarized in Table 9 indicated a slight stiffening of the lining due to brine exposure.

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. Cracking was also noted during the laboratory ozone test. The low ozone resistance indicates a poorly compounded material, and it would not be acceptable for use under present USBR specifications.

Hard-surface Linings

a. Asphaltic concrete.

Of the two hard-surface linings evaluated, asphaltic concrete was the more effective. Seepage measurements and visual observations indicated the 2-inch (5.8-cm) thick asphaltic surfacing provided a satisfactory lining. The average seepage loss during the 1970 test season was 0.7 ft/yr (7 x 10^{-7} cm/sec).

The pond was dewatered in June and inspected to determine the effect of winter exposure. The surface was covered with a layer of sediment, about 1/4-inch (0.6-cm) thick, consisting of fine soil and algae. A small amount of such foreign material is beneficial in reducing seepage. However, over a longer period of time the accumulation could reduce storage capacity and produce a maintenance problem. The asphaltic concrete lining appeared to be in good condition except for some minor hairline cracks. These cracks caused by thermal and loading

Table 5

EFFECT OF BRINE EXPOSURE ON PVC AND PE (6-MIL) PLASTIC FILMS

Sample	Physical property									
	Tensile strength				Elongation		Elmendorf tear resistance			
	L		T		L	T	L		T	
	Psi	kg/cm^2	Psi	kg/cm^2	Percent	Percent	g/mil	n/mm	g/mil	n/mm
PVC-requirement*	2,000	140	2,000	140	250	250	160	64	160	64
PVC—original	2,600	182	2,800	196	334	307	200	80	275	110
PVC—25 months' brine exposure	3,075	215	2,900	203	237	287	117	47	257	103
PE—requirement*	1,700	119	1,200	84	225	350	100	40	100	40
PE—original	2,020	141	1,970	138	420	540	135	54	235	94
PE—20 months' brine exposure	2,080	146	2,130	149	426	528	115	46	194	78

L denotes longitudinal direction.
T denotes transverse direction.

*Minimum USBR specifications requirements.

Table 6

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	10 mils (0.25 mm)	ASTM: D 374 Method C
2. Tensile strength, minimum			ASTM: D 882
Longitudinal	1,700 psi (119 kg/cm^2)	1,800 psi (126 kg/cm^2)	
Transverse	1,200 psi (84 kg/cm^2)	1,850 psi (130 kg/cm^2)	
3. Ultimate elongation, percent minimum			ASTM: D 882
Longitudinal	225	494	
Transverse	350	576	
4. Elmendorf tear resistance, minimum average			ASTM: D 1922
Longitudinal	100 g/mil (40 n/mm)	150 g/mil (60 n/mm)	
Transverse	100 g/mil (40 n/mm)	155 g/mil (62 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	0.02 (gain)	ASTM: D 1239

Table 7

VISUAL EXAMINATION OF THE 6-MIL (0.15-MM) POLYETHYLENE LINING

Location	Lining area ft² (m²)	Number of pinholes: Less than 1/16-inch (1.6-mm) average length of opening	Number of pinholes: Over 1/16-inch (1.6-mm) average length of opening
Bottom	254 (23.6)	129	11
Side, 0-3 ft (0.9 m) depth	169 (15.7)	68	18

Table 8

PUNCTURE RESISTANCE OF PLASTIC LININGS
PRESSURE CELL TEST RESULTS

Laboratory sample number	Type of material	Thickness mils (mm)	Test condition*: Over No. 8 (2.38 mm) to No. 4 (4.76 mm) sieve size rock base — Water pressure at puncture psi (kg/cm²)	Time** hours	Test condition*: Over 3/4- to 1-1/2-inch (19.1 to 38.1-mm) size rock base — Water pressure at puncture psi (kg/cm²)	Time** hours	Remarks— small holes are punctures less than 1/16-inch (1.6-mm) average length of opening
B-6006	Polyvinyl chloride	10 (0.25)	— (—)	—	22.5 (1.6)	7	6 small holes
B-6230	Polyethylene	10 (0.25)	22.5 (1.6)	1.5	15.0 (1.1)	1	12 small holes (over coarse rock) 3 small holes (over fine rock)
B-5878	Polyethylene	6 (0.15)	12.5 (0.9)	3.5	— (—)	—	20 small holes

*Water pressure increased by 2.5 psi (0.175 kg/cm²) increments at 4-hour intervals.
**Time of puncture after reaching highest water pressure.

Table 9

EFFECT OF BRINE EXPOSURE ON NYLON-REINFORCED BUTYL RUBBER

Sample	Physical property									
	Breaking strength				Tear strength				Hydrostatic resistance	
	L		T		L		T			
	ppi	kg/cm	ppi	kg/cm	lb	kg	lb	kg	psi	kg/cm²
Original	122.2	21.8	114.5	20.5	21.0	9.5	20.8	9.4	193	13.5
1-year brine exposure	112.6	20.1	97.6	17.5	17.6	8.0	15.0	6.8	193	13.5

Note: L denotes longitudinal direction.
T denotes transverse direction.

stresses were confined to the surface and did not contribute to any seepage through the lining.

Compressive strength tests conducted on remolded samples of the hot-mix used in the lining are summarized in Table 10. The samples were subjected to either brine or tap water exposure. Results showed the asphaltic concrete was more affected by the brine. After 15 months' exposure the average compressive strengths were determined to be 459 psi (32 kg/cm^2) for the brine, and 505 psi (35 kg/cm^2) for the tap water immersed samples. For comparison, the average compressive strength of newly compacted samples (4-day air cured) was 729 psi (51 kg/cm^2). A graphical analyses of the data indicated the major decrease in compressive strength with respect to time occurred during the first 12 months' exposure. Any decrease after this period was expected to be minimal.

Generally any significant changes in the physical properties of asphaltic concrete under water immersion can be attributed to poor quality aggregate. For example, certain clay-type aggregate will produce excessive volume swell characteristics upon wetting.[11] In this study, however, the Clear Creek aggregate used in the asphaltic concrete mix appeared to be satisfactory.

b. Soil-cement.

In the soil-cement investigation, laboratory tests were conducted on Dalpra soil with Type V portland cement contents of 6, 8, and 10 percent by weight based on dry soil. The 8 percent content appeared to be adequate and it was specified for the test lining. Although Type V sulfate-resistant cement would normally be recommended, Type I, a more common cement, was inadvertently used in the test lining. 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 soil-cement performance within the relatively short test period.

Some cracking occurred to the soil-cement after its first winter exposure (1968-69). The cracks, which were up to 1 inch (2.5 cm) in width at the top, were repaired before the start of the 1969 test season. The seepage loss for the lining remained fairly constant at 6.6 ft/yr (6.6 x 10^{-6} cm/sec) as shown in Figure 4. Seepage probably occurred primarily through the fine cracks rather than through the soil-cement lining.

The pond was dewatered in May of 1970 after obtaining seepage measurements for several weeks. Based on these measurements, the average seepage loss after the 1969-70 winter was about 8 ft/yr (8 x 10^{-6} cm/sec). Inspection of the lining showed essentially no change since the previous inspection in May of 1969. Two samples of the lining were obtained for laboratory evaluation. Sample No. 1, shown in Photograph 7, was cut from near the south side of the lining in an area visually sound and free from cracking. Sample No. 2, shown in Photograph 7, was taken closer to the center of the lining in an area of cracking and partial disintegration.

Visual examination of Sample No. 1 indicated an approximately 4-inch (10.2-cm) slab of soil-cement in reasonably good condition. Sample No. 2 was largely disintegrated and could not be distinguished from the local soil except for the top inch or inch and a half (2.5 to 3.7 cm) which was still reasonably

Table 10

EFFECT OF BRINE EXPOSURE ON ASPHALTIC CONCRETE
REMOLDED SAMPLES OF HOT-MIX USED IN LINING

Age	Test condition	Compressive strength	
		Psi	kg/cm^2
4 days	Air, 25° C	729	51
	Tap water, 48.9° C	664	46
6 months	Brine—3,500 ppm 25° C	551	39
	Tap water, 25° C	594	42
12 months	Brine—3,500 ppm, 25° C	451	32
	Tap water, 25° C	579	41
15 months	Brine—3,500 ppm, 25° C	459	32
	Tap water, 25° C	505	35
	Air, 25° C	839	59

Note: Remolded samples were 4- by 4-inch (10.2- by 10.2-cm) cylinders compacted at 2,500 psi (175 kg/cm^2) for 2 minutes. The test cylinders were loaded at a head motion rate of 0.2 inch (0.5 cm) per minute until failure.

(a) Sample No. 1. Typical of best soil-cement. Photo P800-D-68968

(b) Sample No. 2. Typical of poorest soil-cement. Photo P800-D-68969

Photograph 7. Samples of soil-cement lining obtained for petrographic analyses.

sound. It is apparent that disintegration proceeded from the bottom.

The cement chemistry was examined by separating a portion of the cement paste from the soil-cement by light grinding and abrasion followed by sieving. The X-ray analysis of this hydrated cement concentrate showed the presence of much ettringite, the deterioration product commonly found in concrete affected by sulfate attack. Also present were subcrystalline calcium silicate hydrate, calcium hydroxide, and some calcium carbonate. Other minerals from the soil were also present. Differential thermal analysis (DTA) confirmed the results of the X-ray diffraction analysis.

The amount of ettringite present appears to be enough to have produced a considerable expansion of the lining. This would readily explain the heaving that occurred during the first winter's exposure, and may also be a factor in the cracking. The cracking could also be a result of freezing and thawing and wetting and drying cycles that occurred during the same period.

The final disintegration of the lower portions of the lining in the cracked areas is apparently a result of leaching and affects those areas adjacent to cracks because of the increased percolation in those areas.

Compacted Earth Lining

The average seepage loss from the 12-inch (30-cm) thick compacted native soil for the 1970 test season was approximately 10 ft/yr (1×10^{-5} cm/sec) as compared to 16 ft/yr (1.6×10^{-5} cm/sec) for 1969.

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. Also, a plastic tube was installed in the tank as shown in Photograph 8 to detect any water pressure that might develop in the drainage layer.

The tank was dewatered in November for inspection and to obtain density measurements on the 2-year old lining. The compacted earth appeared to be in good condition. Density test results are summarized in Table 11.

Soil Sealants—Surface Treatment

The sealant materials applied directly to the natural soil surface were generally more effective for seepage control than were those materials mixed in-place, or applied by ponding.

a. Sealant B-5800.

The vinyl polymer film provided a satisfactory seal with an average seepage loss during the 1970 test season of 0.9 ft/yr (9×10^{-7} cm/sec). In laboratory permeability tests with Dalpra soil, Table 12, the film was almost watertight. Without an evaporation correction, the coefficient of permeability "k" was 0.06 ft/yr (6×10^{-8} cm/sec) as compared to 17 ft/yr (1.7×10^{-5} cm/sec) for the control (untreated) sample. The average thickness of the film in this test was 14 mils (0.36 mm).

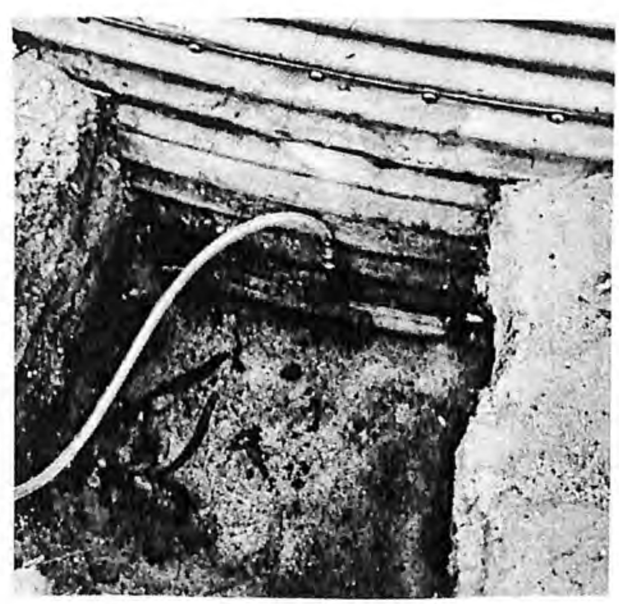
Physical properties tests were conducted on several residual films for comparison to PVC, a sheet-type plastic film. The results summarized in Table 13 indicated the residual film has less tensile and tear strength and greater temperature susceptibility and water absorption characteristics than the sheet-type film. Also, when the treatment is thin the residual film has a tendency to stiffen upon exposure to the atmosphere.

The manufacturer is working with the Corps of Engineers to modify and improve the material to provide better strength and durability properties, storage stability, and sprayability. The Corps of Engineers have used the film reinforced with fiberglass on airfield shoulders at their Yuma Proving Grounds, Arizona. This system has remained in good condition for approximately 2 years.

For the field installation at Dalpra Farm, two applications were used to obtain a 30-mil (0.76-mm) thick vinyl polymer film. Although a 24-hour curing period was allowed between applications, the cured film from the first treatment became tacky when the sun was hot; air temperature during installation was 95° F (35° C) to 100° F (38° C). Under such a condition the cured film could be susceptible to damage from heavy foot traffic or equipment movement. Therefor, in large-scale installations the treatment should be either a single application, or two lesser applications applied within a relatively short time to minimize traffic over the treated areas. Other observations noted during the field test included:

1. Sealant B-5800 should be applied over a very smooth, firm substrata to obtain good coverage with no holes in the cured film. This involves additional subgrade preparation which is not normally required for installing sheet-type linings.

2. Stabilization of the subgrade with a dilute mixture of B-5800 is not necessary if adequate soil compaction is used during construction.



Photograph 8. Plastic tube installed in tank to detect any water pressure that might develop in sand drainage layer. Photo P800-D-68970

Table 11

FIELD DENSITY TEST RESULTS ON SOIL LININGS
AFTER 25 MONTHS' BRINE EXPOSURE

Tank number	Material	In-place density					
		Initial condition			Final condition		
		pcf	g/cc	Percent maximum	pcf	g/cc	Percent maximum
1	Carboxymethylcellulose plus alum mixture	110.0	1.76	95	108.0	1.73	91
8	Compacted earth	117.0	1.87	98	114.0	1.82	96

However, prewetting the soil is necessary to ensure a more uniform, pinhole-free film.

3. During the second application the fresh material appeared to bond securely to the cured film. Also, prior to filling the test pond some weed penetration was noted in the film. Several of the weeds were removed and the lining was easily repaired by simply applying fresh material over the weed punctures. Regarding weed control, a soil sterilant could be applied by inclusion in the treatment mixture.

4. The decrease in seepage during the test period was primarily due to sediment and algae growth on the lining surface. However, some decrease was due in-part to resealing of pinholes and other flaws in the cured film. The resealing observed in both the field and in the laboratory, was attributed to a slight flow of the film. This flow was probably caused by either water pressure, or slight softening of the film due to water absorption.

Results of this study indicate B-5800 has merit for low-cost seepage control in brine disposal ponds. For example, the use of a sprayable material to obtain a film would eliminate the need for making field seams. Additional studies, however, are required to fully evaluate the potential of B-5800. Such studies should be conducted to determine: (1) service life of the film under brine exposure; (2) optimum installation techniques and material requirements including application over sloped areas; and (3) resistance of film to damage during earth-cover placement.

b. Sealant B-5876.

The liquid cutback asphalt applied over the natural soil provided some seepage control. The average seepage loss for the 1970 test season was 8.5 ft/yr (8.5×10^{-6} cm/sec) as compared to 10.7 ft/yr (1.1×10^{-5} cm/sec) for 1969. The pond was dewatered in November for inspection and to determine the depth of asphalt penetration.

The treated surface appeared to be in good condition with no apparent deterioration from brine exposure. A trench, 1-foot (0.3-m) deep, was dug across and through the center of the lining. The maximum depth of asphalt penetration was 8 inches (20.3 cm), which occurred at the center. The average depth was 3.5 inches (9 cm). Asphalt penetration is shown in Photograph 9. In laboratory tests the average penetration was 1.6 inches (4.1 cm). However, the moisture content of the soil sample treated in the laboratory was 11 percent, while in the field the moisture content of the soil was nearer 5 percent. A higher moisture content will retard penetration. Also, the laboratory soil sample was compacted to a higher density, which in-turn reduces penetration.

c. Sealants B-5604 and B-5605.

Laboratory permeability tests conducted on Dalpra soil treated with the water soluble and non-water-soluble polyacrylamide sealants are summarized in Table 12. The sealants, tested individually, were applied on the soil surface either in the dry powder form, or mixed with polyethylene glycol and applied as a slurry. Application rates varied from 100 lbs/acre (110 kg/ha) to 800 lbs/acre (880 kg/ha). Test results indicated the water soluble polyacrylamide, B-5604, generally provided more effective seepage control in the silty sand.

Results of laboratory tests were discussed with the manufacturer. He recommended for the field tests, mixing the powdered sealant into the dry soil before

Table 12

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 0.05 percent alum	Tap	Dalpra Farm effluent	1	107.0	90	26	4	6
X35	Dalpra Farm	0.25 percent 48D-37 plus 0.05 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	107.0	90	263	0	0
X35	Dalpra Farm	B-5604 (800 lb/acre)[2]	Tap	Dalpra Farm effluent	1	107.0	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 12–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	107.0	90	139	0	0
X35	Dalpra Farm	B-5604 (100 lb/acre)[1]	Tap	Dalpra Farm effluent	1	107.0	90	224	3	3
X35	Dalpra Farm	B-5605 (800 lb/acre)[2]	Tap	Dalpra Farm effluent	1	107.0	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 12–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	107.0	90	232	40	51
X35	Dalpra Farm	B-5605 (400 lb/acre)[2]	Tap	Dalpra Farm effluent	1	107.0	90	255	25	32
X35	Dalpra Farm	B-5605 (400 lb/acre)[2]	Tap	Dalpra Farm effluent	1	107.0	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	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.

Table 13

PHYSICAL PROPERTIES TEST RESULTS OF VINYL POLYMER FILM (B-5800)
Average thickness of film was 30 mils (0.76 mm)

Test	Test results	PVC plastic film*	ASTM test method
Tensile strength	1,030 psi (72 kg/cm^2)	2,000 psi 140 kg/cm^2)	D 882
Ultimate elongation	320 percent	250 percent	D 882
Elmendorf tear resistance	130 g/mil (52 n/mm)	160 g/mil (64 n/mm)	D 1922
Water extraction	7 percent gain	Not more than 1 percent wt loss	D 1239
Low temperature impact 0° F (−178° C) ± 3.6° F (2° C)	5 failures out of 5 tested	Not more than 2 specimens out of 10 shall fail	D 1790 D 1790

*Minimum USBR requirements for 10-mil (0.25-mm) polyvinyl chloride plastic lining.

it was compacted rather than leaving the sealant exposed on the surface. It was felt that incorporating the sealant into the soil would provide a more permanent seal. The manufacturer also recommended using both sealants to provide wider sealing capabilities.

Regarding the slurry application, the manufacturer suggested having a small head of water in the tank before adding the sealant. He felt that applying the slurry directly on the surface would cause some of it to adsorb quickly into the soil at some areas where it was not needed. By putting the slurry mixture into the head of water, the sealant would have a better chance to flow down into those capillaries that were leaking. However, since this method was very similar to the ponding treatment it was not used in this study.

Soil Sealants—Mixed In-Place Treatment

a. Sealant B-6166.

The native soil lining containing the water soluble and non-water-soluble polyacrylamide formulation had an average seepage loss of 5.6 ft/yr (5.6 x 10^{-6} cm/sec) for the test season. However, back pressure developed in the sand drainage layer which reduced seepage through the lining and made it difficult to fully evaluate the effect of the sealant. Attempts were made, with limited success, to alleviate the back pressure by installing several drain tubes in the sand layer, and replacing the perimeter seal. The back pressure though, not only indicated poor natural drainage from the tank but also showed inadequate sealing by B-6166.

The sealing performance of this lining could possibly have been improved by additional compaction. The soil was placed at 90 percent of maximum density as compared to 95 percent for the compacted earth, and the two other mixed in-place sealant linings.

b. Sealant 48-D-37.

The average seepage loss remained fairly constant for the native soil lining treated with the carboxymethylcellulose plus alum mixture, 13.5 ft/yr (1.3 x 10^{-5} cm/sec) for 1970, and 11 ft/yr (1.1 x 10^{-5} cm/sec) for 1969. In laboratory permeability tests with Dalpra soil, Table 12, the reduction in seepage due to sealant application was 75 percent.

The pond was dewatered in November for inspection and to obtain soil density measurements. The soil lining appeared to be in good condition with no apparent adverse effects from brine exposure. Some shrinkage, cracking, and peeling did appear after surface drying. However, upon rewetting this condition generally disappeared.

c. Sealant 48 D-36.

Field tests indicated the attapulgite clay formulation was not effective in reducing seepage through the native soil. The seepage history of this

(a) Overall view. Photo P800-D-68971

(b) Close-up view of asphalt penetration into natural soil. The 3-inch (7.6-cm) ruler is shown for comparison. Photo P800-D-68972

Photograph 9. Penetration of liquid asphalt, B-5876, into natural soil at Dalpra Farm. The material applied at 2 gsy (9.1 l/m^2) penetrated to an average depth of 3.5 inches (9 cm).

lining was very similar to the natural soil as shown in Figure 4. Field testing was discontinued on this lining at the end of the 1969 season. Laboratory permeability tests conducted on samples of Dalpra soil treated with 48 D-36, showed a reduction in seepage of 50 percent when compared to the untreated soil. These test results are summarized in Table 12.

Results of tests on the mixed in-place sealants indicate they did not provide the sealing requirements for brine disposal ponds. Also noted in this investigation was that in applying and mixing small quantities of sealant, it is possible to create lean areas of coverage, thus increasing the chance for seepage. This was especially true with B-6166 and 48 D-37, which were applied at quantities less than 1 percent by weight of dry soil.

d. Other tests.

In addition to the laboratory and field studies conducted on Dalpra soil, laboratory permeability tests were run on soil samples from the Roswell, New Mexico Desalting Plant area. Roswell soil, a lean clay, was treated for seepage control with either methyl cellulose, lignin, or sodium silicate, soil sealants recommended by the Diamond Shamrock Company. These sealants were mixed into the soil and then compacted to achieve seepage control.

The results, summarized in Report No. 602, showed seepage control in the lean clay was more dependent on soil placement density than sealant treatment. The untreated soil at densities above 80 percent maximum had a low permeability rate. At 80 percent maximum density, there was sufficient flow to indicate the effect of sealant treatment. 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. Therefore, it appears that the most practical way to treat soils of this clayey nature is to compact them to near maximum density and not use a sealant.

Soil Sealants—Ponding Treatment

a. Sealant B-6166.

This material applied by ponding was field tested from July 20 through September 9. The seepage measurements obtained during this period indicated the sealant was ineffective for seepage control in the native soil. The average seepage loss for the test period was 107 ft/yr (1.1 x 10^{-4} cm/sec). Several weeks after treatment some gelatinous material was noted floating near the surface of the pond. Examination of this material showed its buoyancy was caused by entrapped air.

The pond was dewatered and inspection of the pond surface showed the gel portion of the sealant, B-5605, did not penetrate the soil and was confined to the soil surface. Under such a condition, Photograph 10, the gel material is subject to movement and will not produce an adequate seal. A sample of the sealant removed from the pond surface is shown in Photographs 11 and 12.

b. Sealant B-5604.

A new ponding test was started on September 21 using only the water soluble polymer. The sealant was applied, as described under "Installation of New Linings," in a glycol slurry mixture at an application rate of 200 lbs/acre (220 kg/ha). The average seepage loss resulting from this treatment was 80 ft/yr (8 x 10^{-5} cm/sec).

Field test results indicate both sealants applied by ponding were unsatisfactory in providing the seepage control required for brine disposal ponds. Although these materials are easily applied by ponding, the uniform distribution of the sealants by this method is questionable. Also, unless the sealants can somehow penetrate into the soil, the resulting seal will not be permanent.

Natural Soil

Standard properties tests conducted 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.

Field seepage measurements were obtained on the natural, untreated soil for comparison to the various test linings. The average seepage loss was 75 ft/yr (7.5 x 10^{-5} cm/sec) for 1969 and 53 ft/yr (5.3 x 10^{-5} cm/sec) for 1970. Saturation of the soil as shown in Photograph 13 was the primary reason for the decrease in seepage that occurred during the test season. Upon inspection of the natural soil, it appeared to be more susceptible to shrinkage cracking after drying than those soil linings that were compacted.

Monitoring System

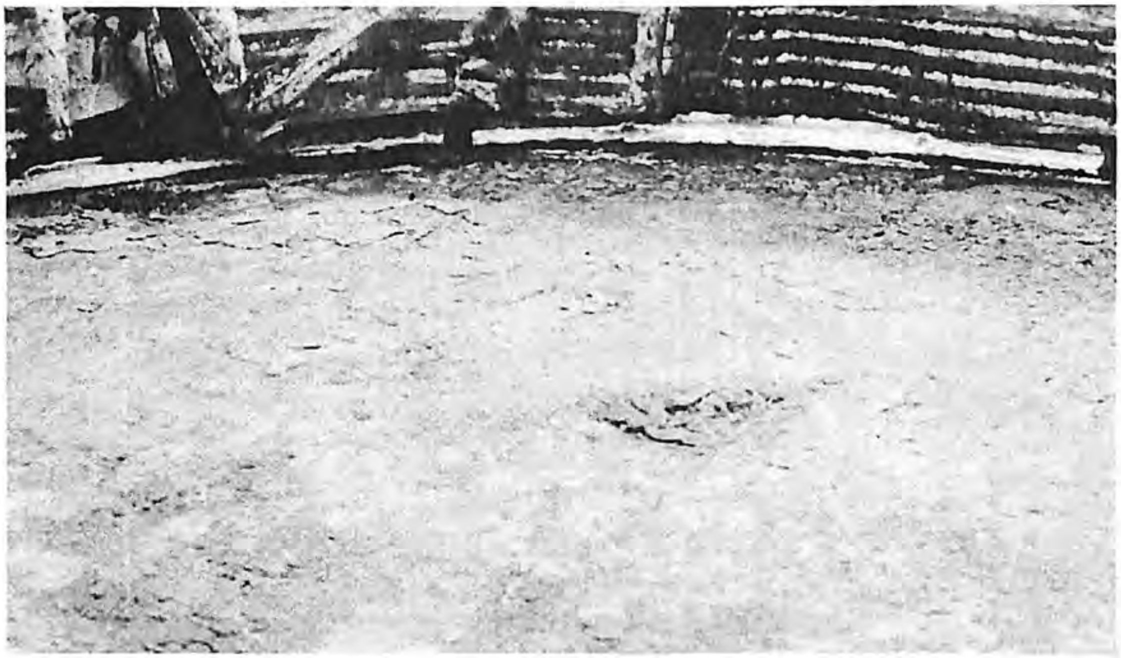
Besides further verifying that the monitoring system was adequate for measuring seepage, the additional test season provided a check of the ruggedness and durability of the instrumentation. The monitoring system was relatively free from maintenance problems during the 1969 test season. However, during the 1970 test season maintenance problems began to occur. Often the hydgrothermograph clock and chart drive stopped due to the combined affects of dust and cold temperature. Two attempts to clean the clock did not seem to help. Although the instrument was not functioning properly, high and low values could be determined. Deterioration of the lead (pb) protective coverings of the acid vat-type thermocouple wiring was noted during and after the 1970 test season. Some of the lead coverings were cut by the corners of the support brackets. Also, several areas of the lead coverings had cold working cracks closely spaced along their length caused by wind and wave whipping. The 24-point temperature recorder was out of service for 3 weeks for shop repair because the sprocket drive on one end of the chart drum broke loose causing damage to the drive-mechanism system.

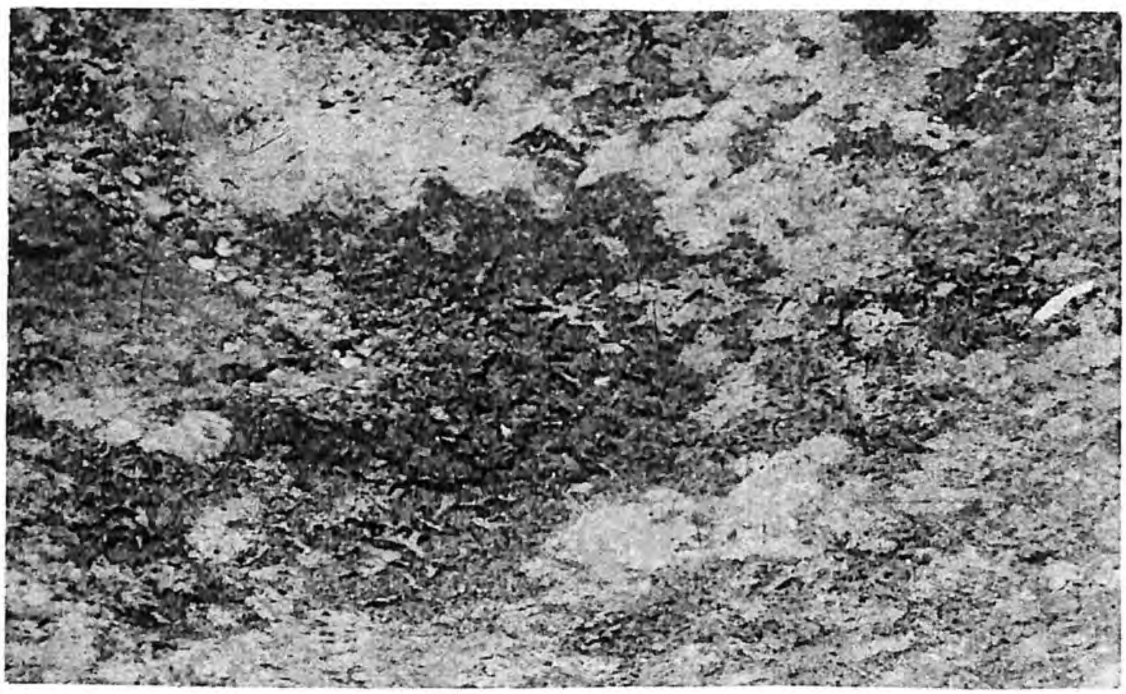
RECOMMENDATIONS

General

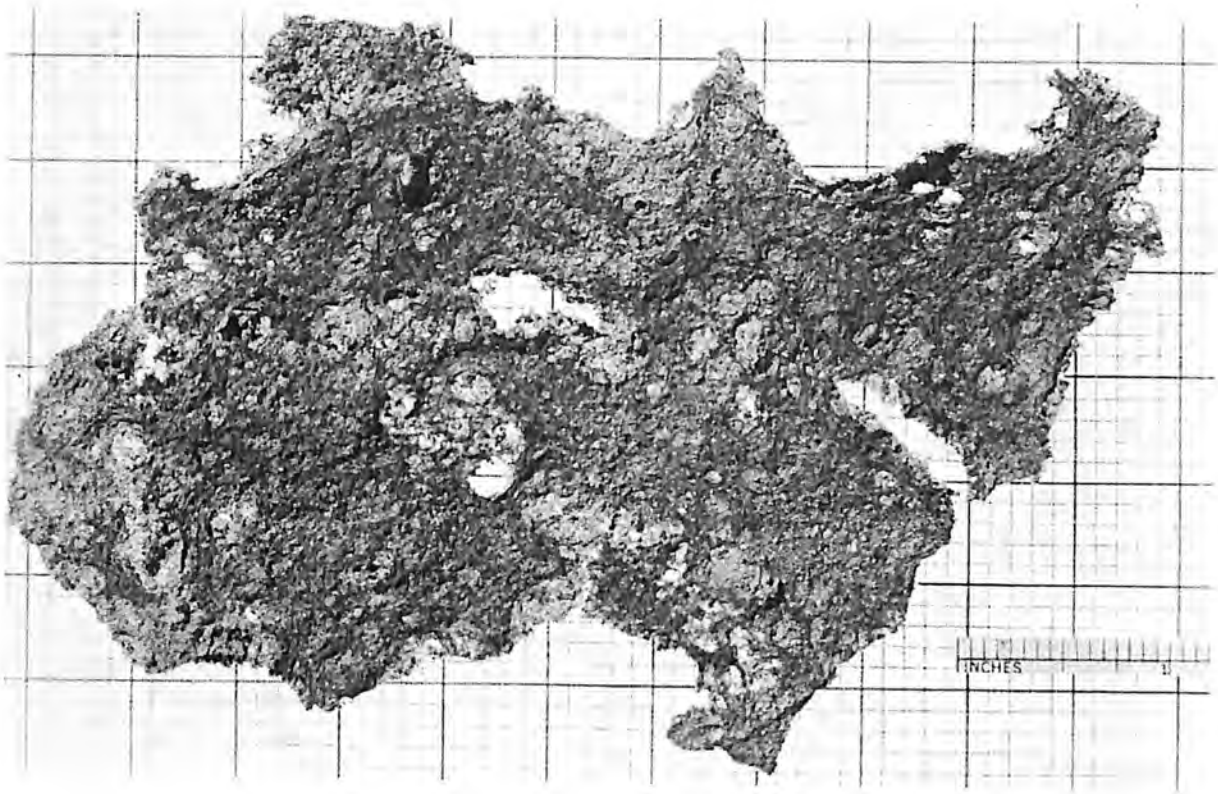
Each proposed brine disposal pond site must be given individual consideration relative to selection and usage of materials. Soil analyses including field and laboratory testing are necessary to provide data for design purposes, material selection, and construction control. For such analyses the effect of brine on the various materials must also be evaluated. This can be accomplished by incorporating the brine into the test procedure wherever feasible.

The primary requirement for lining brine disposal ponds will be determined by local regulations on maximum permissible seepage losses. Therefore, prior to the design and construction of any brine disposal pond, the state and the FWQA should be contacted for their latest regulations. Addresses for the state agencies are listed in References 1 and 3; FWQA can be contacted at:

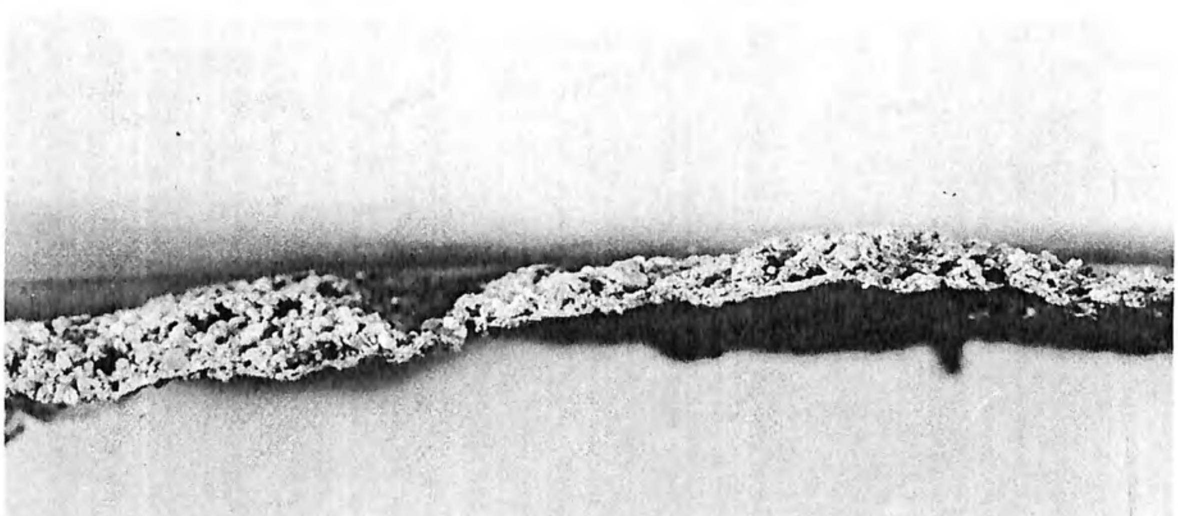




Photograph 10. Appearance of soil surface after ponding treatment with sealant B-6166. The material was applied at a rate of 2,000 pounds per acre (2,200 kg/ha). View shows that a major portion of the sealant did not penetrate the soil. Top photo P800-D-68973. Bottom photo P800-D-68974

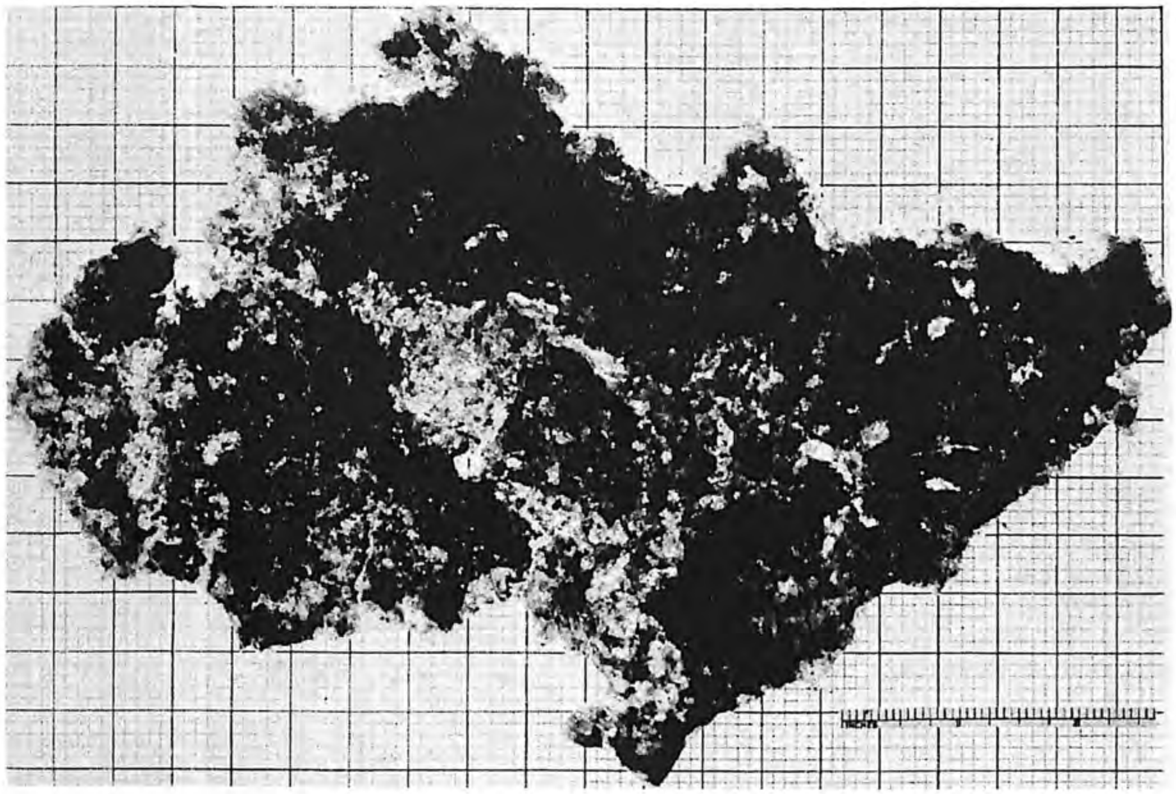


(a) Top view of sample. Photo P800-D-68975

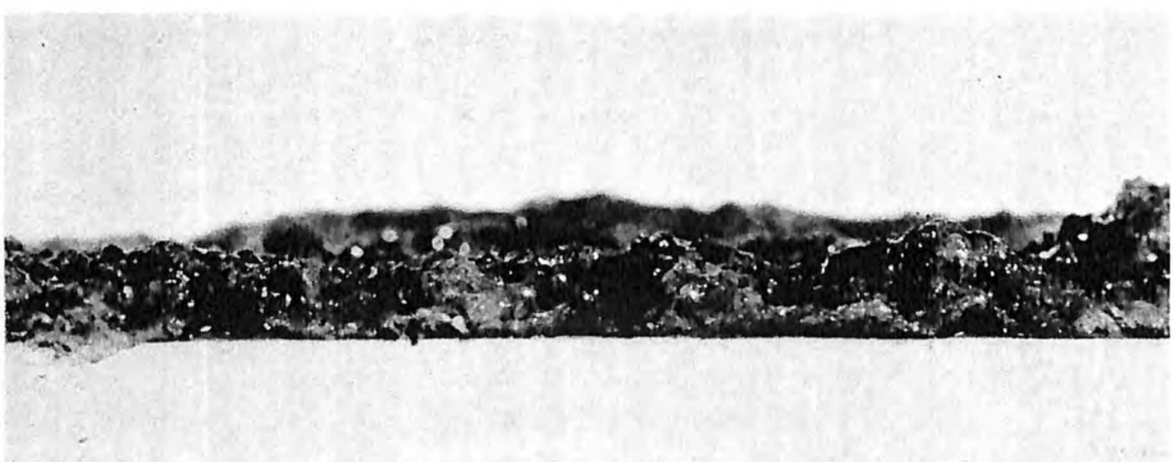


(b) Side view of sample at 5X magnification. Photo P800-D-68976

Photograph 11. Sample of sealant B-6166 removed from soil surface in dry condition.



(a) Top view of sample. Photo P800-D-68977



(b) Side view of sample at 5X magnification. Photo P800-D-68978

Photograph 12. Condition of sample shown in Photograph 11 after wetting. Note the volume increase due to hydration which produces sealing.

Photograph 13. Saturation condition around test tank containing natural, untreated soil. Such a condition will reduce seepage. Photo P800-D-68979

Federal Water Quality Administration
Environmental Protection Agency
Washington, D.C. 20242

Pond operating conditions have to be considered in the selection of the lining materials. 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

a. Compacted earth linings.

First consideration should be given to the possible use of the native soil as a lining material since this would provide 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 soil of a type to produce a sufficiently impermeable lining? Does the brine affect soil permeability? Is there assurance of continued impermeability over the life of the pond? Although originally determined for canal linings, the criteria set forth in Table 14 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 (CM), silty sands (SM), silts (ML, OL, and MH) may be sufficiently impermeable.[10]

b. Flexible membrane linings.

These linings are recommended for use in areas where stringent seepage control is required. The linings consist of flexible impermeable materials placed on prepared subgrades and normally covered with earth materials to protect them from the elements and physical damage. Available materials include PVC and PE plastic films, synthetic rubbers, and hot spray-applied asphalt cement. As previously mentioned, synthetic rubbers are higher in cost which limits their use to special installations. PVC plastic has several advantages over PE and asphalt, thus it is perferred for use in brine disposal ponds. These advantages include:

1. Installation. PVC is easier to install, requiring a minimum of equipment and skilled labor. Asphalt membrane lining installation, for example, requires special heating and spraying equipment, and sometimes even additional subgrade preparation.

2. Physical properties. PVC is more resistant to puncture, more readily available in large fabricated pieces, and more easily repaired and field spliced than PE.

The installation cost for a 10-mil (0.25 mm) thick PVC lining in a brine storage pond, with cover material, is estimated to be $\$1.10/\text{yard}^2$ [3] This compares closely to the cost for installing a buried asphalt membrane lining. Although a PE lining would be slightly more economical, its serviceability would be expected to be less.

To ensure a watertight lining, extreme care is required in making field seams. Adjacent sheets of PVC lining should be joined using a 4-inch (10.2-cm) minimum width bonded lap joint with a solvent adhesive recommended by the plastic lining manufacturer.

c. 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 to reduce the voids and insure a watertight lining.

To provide watertightness, hydraulic-type mixes are higher in asphalt binder content (7 to 12 percent), and mineral filler content than mixes used for highway surface courses.

Table 14

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 1/4" size may be used as equivalent to the No. 4 sieve size)								
(The No. 200 sieve size is about the smallest particle visible to the naked eye)									
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	—	—
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)

The use of asphaltic concrete lining is primarily dependent upon source and type of locally available aggregate. Construction costs for a 2- to 3-inch (5.1- to 7.6-cm) thick lining, which is generally sufficient for shallow evaporation ponds, will vary between $1.50 to $2.00 per square yard. This is higher than that for either compacted earth or PVC 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 portland 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.

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

Monitoring System

Maintenance problems encountered during the second test season indicate the desirability of redundant or reserve equipment. Such precaution would be especially recommended during the early plant operation when thermal similarity is being checked and evaporation correlations are being established.

Future Studies

Additional studies should be conducted on the sprayable vinyl polymer to fully evaluate its potential for low-cost seepage control in brine disposal ponds. From such studies, specifications guidelines could be developed.

The USBR, under its Water Resources Engineering Research Program (WRER), will continue to evaluate promising new sealers and liners as they are developed by industry. Results of these studies pertinent to brine disposal ponds will be made available to OSW.

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MATERIALS LISTING
Chemical Soil Sealants

Laboratory sample number	Material
48D-36	Attapulgite clay formulation
48D-37	Carboxymethylcellulose plus alum mixture
B-5876	Liquid cutback asphalt
B-5800	Liquid vinyl polymer formulation
B-5604	Water soluble polyacrylamide
B-5605	Nonwater soluble polyacrylamide
B-6166	Formulation containing 25 percent B-5604, 25 percent B-5605, and 50 percent inert materials

APPENDIX I

SUMMARY OF

FIELD SEEPAGE MEASUREMENTS

TABLES 15-24

Table 15

SEEPAGE LOSSES FOR POLYETHYLENE
PLASTIC LINING (10-mil)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
7-14	7-20	0	2.95	0.899
7-20	7-27	0	2.87	.875
7-27	8-3	0	2.93	.893
8-3	8-10	0	2.94	.896
8-10	8-17	0	2.93	.893
8-17	8-24	0	3.00	.914
8-24	8-31	0	2.95	.899
8-31	9-7	0	2.98	.908
9-8	9-14	0	2.87	.875
9-14	9-21	0	2.97	.905
9-21	9-28	0	3.02	.920
9-28	10-5	0	3.01	.917
10-5	10-12	0	2.96	.902
10-12	10-19	0	2.94	.896
10-19	10-25	0	2.93	.893
10-26	11-2	0	2.88	.878
11-2	11-9	0	2.85	.869
11-9	11-16	0	3.00	.914
11-16	11-22	0	2.99	.911
11-24	11-30	0	2.95	.899
12-2	12-7	0	2.89	.881

Table 16

SEEPAGE LOSSES FOR ASPHALTIC CONCRETE LINING—1970

Date		Seepage loss, ft/yr (cm/sec x 10^{-6})	Average head	
From	To		Feet	Meters
5-1	5-6	0.16	2.97	0.905
5-6	5-13	0.82	2.84	.866
5-13	5-20	0.94	2.93	.893
5-20	5-27	1.19	2.94	.896
5-27	6-3	1.75	2.94	.896
6-3	6-8	*2.94	2.94	.896
6-8	6-15	*2.90	3.07	.936
6-15	6-22	*3.56	2.98	.908
6-22	6-29	*2.80	2.91	.887
7-7	7-13	*7.29	2.94	.896
7-13	7-20	*8.12	2.66	.811
7-20	7-27	*5.08	2.94	.896
7-30	8-3	1.33	2.96	.902
8-3	8-10	3.10	2.91	.887
8-10	8-17	2.45	2.90	.884
8-17	8-24	1.34	2.99	.911
8-24	8-31	0.58	2.92	.890
8-31	9-7	0.58	2.97	.905
9-8	9-14	0.13	2.85	.869
9-14	9-21	0.47	2.95	.899
9-21	9-28	0.64	3.00	.914
9-28	10-5	0	3.00	.914
10-5	10-12	0.23	2.93	.893
10-12	10-19	0.35	2.99	.911
10-19	10-25	0.27	2.96	.902
10-26	11-2	0.29	2.90	.884
11-2	11-9	0.23	2.87	.875
11-9	11-16	0	3.00	.914
11-16	11-22	0	2.99	.911
11-24	11-30	0	2.95	.899
12-2	12-7	0	2.88	.878

*Leakage at perimeter seal.

Table 17

SEEPAGE LOSSES FOR COMPACTED EARTH LINING—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
5-1	5-6	15.1	2.87	0.875
5-6	5-13	12.7	2.81	.856
5-13	5-20	11.0	2.84	.866
5-20	5-27	11.0	2.85	.869
5-27	6-3	10.6	2.86	.872
6-3	6-8	11.0	2.88	.878
6-8	6-15	10.6	2.99	.911
6-15	6-22	11.5	2.79	.850
6-22	6-29	12.4	2.83	.863
6-29	7-6	12.5	2.83	.863
7-6	7-13	12.6	2.84	.866
7-14	7-20	13.2	2.80	.853
7-20	7-27	11.1	2.84	.866
7-27	8-3	11.5	2.83	.863
8-3	8-10	11.3	2.84	.866
8-10	8-17	10.3	2.85	.869
8-17	8-24	9.64	2.91	.887
8-24	8-31	9.75	2.86	.872
8-31	9-7	9.99	2.88	.878
9-8	9-14	8.93	2.90	.884
9-14	9-21	8.53	2.89	.881
9-21	9-28	8.29	3.03	.924
9-28	10-5	7.65	2.89	.881
10-5	10-12	7.19	2.93	.893
10-12	10-19	6.78	2.94	.896
10-19	10-25	6.95	2.95	.899
10-26	11-2	6.37	2.92	.890

Table 18

SEEPAGE LOSSES FOR SOIL SEALANT LINING

(B-5800, Surface Treatment)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
9-8	9-14	9.88	2.87	0.875
9-14	9-21	5.49	2.92	.890
9-21	9-28	2.45	3.07	.936
9-28	10-5	1.87	3.03	.924
10-5	10-12	1.23	2.95	.899
10-12	10-19	0.93	2.99	.911
10-19	10-25	0.82	2.94	.896
10-26	11-2	0.58	2.88	.878
11-2	11-9	0.70	2.84	.866
11-9	11-16	0.58	2.99	.911
11-16	11-22	0.41	2.97	.905
11-24	11-30	0.47	2.93	.893
12-2	12-7	0.25	2.86	.872

Table 19

SEEPAGE LOSSES FOR SOIL SEALANT LINING
(B-5876, Surface Treatment)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
4-29	5-6	11.0	2.86	0.872
5-6	5-13	11.9	2.83	.863
5-13	5-20	16.8	2.79	.850
5-20	5-27	13.9	2.80	.853
5-27	6-3	13.1	2.84	.866
6-3	6-8	*21.7	2.85	.869
6-8	6-15	*33.5	2.79	.850
6-15	6-22	*29.4	2.66	.811
6-22	6-28	*76.1	2.22	.677
7-7	7-13	18.0	2.86	.872
7-13	7-20	10.5	2.78	.847
7-20	7-27	10.2	2.85	.869
7-27	8-3	10.5	2.84	.866
8-3	8-10	11.2	2.84	.866
8-10	8-17	12.4	2.84	.866
8-17	8-24	11.3	2.89	.881
8-24	8-31	9.34	2.86	.872
8-31	9-7	7.94	2.89	.881
9-8	9-14	6.75	2.88	.878
9-14	9-21	7.42	2.91	.887
9-21	9-28	6.02	3.06	.933
9-28	10-5	4.20	2.94	.896
10-5	10-12	3.97	2.96	.902
10-12	10-19	4.02	2.95	.899
10-19	10-25	4.16	2.96	.902
10-26	11-2	3.51	2.94	.896
11-2	11-9	2.98	2.85	.869
11-9	11-16	2.80	2.98	.908

*Leakage at perimeter seal.

Table 20

SEEPAGE LOSSES FOR SOIL SEALANT LINING
(B-6166, Mixed In-place)—1970

Date		Seepage loss, ft/yr (cm/sec x 10^{-6})	Average head	
From	To		Feet	Meters
7-23	7-27	12.5	2.90	0.884
7-27	8-3	6.37	2.87	.875
8-3	8-6	4.77	2.95	.899
8-6	8-10	*15.8	2.77	.844
8-10	8-17	6.54	2.87	.875
8-17	8-24	4.50	2.96	.903
8-24	8-31	3.21	2.91	.877
8-31	9-7	**40.1	2.56	.780
9-18	9-21	30.7	2.86	.872
9-21	9-28	20.6	2.89	.881
9-28	10-5	7.48	2.90	.884
10-20	10-25	***12.0	2.89	.881
10-26	11-2	6.19	2.92	.890
11-2	11-9	4.79	2.95	.899
11-9	11-16	5.26	2.95	.899
11-16	11-22	4.56	2.95	.899
11-24	11-30	4.02	2.96	.903
12-2	12-7	2.67	2.83	.863

*Installed drainage tube.

**Leakage at perimeter seal.

***Installed new perimeter seal.

Table 21

SEEPAGE LOSSES FOR SOIL SEALANT LINING

(48D-37, Mixed In-place)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
5-6	5-13	14.3	2.80	0.853
5-13	5-20	12.3	2.84	.866
5-20	5-27	14.3	2.83	.863
5-27	6-3	14.3	2.84	.866
6-3	6-8	16.2	2.86	.872
6-8	6-15	16.2	2.96	.902
6-15	6-22	19.9	2.74	.835
6-22	6-29	21.3	2.76	.841
6-29	7-6	21.0	2.74	.835
7-6	7-13	18.7	2.78	.847
7-13	7-20	15.9	2.71	.826
7-20	7-27	14.3	2.82	.860
7-27	8-3	13.4	2.82	.860
8-3	8-10	13.1	2.83	.863
8-10	8-17	17.1	2.77	.844
8-17	8-24	14.8	2.87	.875
8-24	8-31	13.1	2.82	.860
8-31	9-7	12.5	2.86	.872
9-8	9-14	11.0	2.85	.869
9-14	9-21	10.9	2.87	.875
9-21	9-28	9.06	3.01	.917
9-28	10-5	10.0	2.84	.866
10-5	10-12	8.94	2.90	.884
10-12	10-19	8.18	2.92	.890
10-19	10-25	8.11	2.91	.887
10-26	11-2	7.83	2.91	.887
11-2	11-9	7.30	2.74	.835

Table 22

SEEPAGE LOSSES FOR SOIL SEALANT LINING
(B-5604, Ponding Treatment)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
9-21	9-24	85.3	1.50	0.457
9-24	9-28	63.5	2.73	.832
9-28	10-5	65.0	2.83	.863
10-5	10-12	74.4	2.91	.887
10-12	10-19	70.3	2.91	.887
10-19	10-26	76.1	2.90	.884
10-26	11-2	89.6	2.89	.881
11-2	11-9	88.8	2.89	.881
11-9	11-16	91.6	2.89	.881
11-16	11-22	81.4	2.89	.881
11-22	11-29	71.6	2.90	.884

Table 23

SEEPAGE LOSSES FOR SOIL SEALANT LINING
(B-6166, Ponding Treatment)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
7-20	7-21	112.0	2.82	0.860
7-23	7-24	124.0	2.84	.866
7-27	8-3	266.0	2.63	.802
8-3	8-10	191.0	2.76	.841
8-10	8-17	130.0	2.83	.863
8-17	8-24	113.0	2.85	.869
8-24	8-31	102.5	2.82	.860
8-31	9-7	88.0	2.89	.881

Table 24

SEEPAGE LOSSES FOR NATURAL SOIL
(Untreated)—1970

Date		Seepage loss, ft/yr	Average head	
From	To	(cm/sec x 10^{-6})	Feet	Meters
5-13	5-20	626.0	2.22	0.677
5-20	5-27	344.0	2.57	.783
5-27	6-3	292.0	2.54	.774
6-3	6-8	214.0	2.73	.832
6-8	6-15	562.0	2.31	.704
6-15	6-22	241.0	2.70	.823
6-22	6-29	223.0	2.72	.829
6-29	7-6	212.0	2.74	.835
7-6	7-13	427.0	2.48	.756
7-13	7-20	238.0	2.71	.826
7-20	7-27	100.0	2.88	.878
7-27	8-3	76.5	2.90	.884
8-3	8-10	67.0	2.91	.887
8-10	8-17	64.0	2.91	.887
8-17	8-24	59.2	2.91	.887
8-24	8-31	61.8	2.92	.890
8-31	9-8	55.0	2.93	.893
9-8	9-14	52.8	2.92	.890
9-14	9-21	41.1	2.93	.893
9-21	9-28	32.3	2.96	.902
9-28	10-5	31.7	2.90	.884
10-5	10-12	37.6	2.95	.899
10-12	10-19	28.2	2.96	.902
10-19	10-25	25.8	2.96	.902
10-26	11-2	21.7	2.95	.899
11-2	11-9	21.2	2.94	.896
11-9	11-16	22.5	2.96	.902
11-16	11-22	20.0	2.95	.899
11-24	11-30	18.2	2.95	.899
12-2	12-7	17.6	2.67	.814

7-1750 (3-71)
Bureau of Reclamation

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
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*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
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*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
Short tons (2,000 lb)	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
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	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
Pounds per cubic foot	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
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	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
Feet 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
Miles 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
Pounds	*4.4482	Newtons
Pounds	$*4.4482 \times 10^5$	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	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 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*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

GPO 835-188

ABSTRACT

A field and laboratory evaluation of 4 types of lining materials proposed for seepage control in brine disposal ponds was conducted. The 4 types included: compacted earth, flexible membrane linings, hard-surface linings, and soil sealants. Flexible membrane linings were the most effective for seepage control, followed by hard-surface linings, surface-applied soil sealants, compacted earth, mixed-in-place soil sealants, and ponded soil sealants. PVC plastic lining provided the most satisfactory sealing performance. A newly developed, sprayable liquid vinyl polymer that forms a surface film upon curing appears to have merit for sealing brine disposal ponds, and additional studies are recommended to fully evaluate its potential.

REC-ERC-71-25
Morrison, W R; Dodge, R A; Merriman, J
POND LININGS FOR DESALTING PLANT EFFLUENTS (FINAL REPORT)
Bur Reclam Rep REC-ERC-71-25, Div Gen Res, May 1971. Bureau of Reclamation, Denver, 51 p, 5 fig, 26 tab, 13 photo, 11 ref, append

DESCRIPTORS—/ research and development/ *linings/ seepage/ soil cement/ soil tests/ *ponds/ earth linings/ flexible linings/ polyethylene/ *soil treatment/ laboratory tests/ field tests/ seepage losses/ permeability tests/ asphalts/ disposal/ *plastics/ *brine disposal/ *instrumentation/ bituminous concretes/ polyvinyl chloride/ impervious membranes/ seepage control/ *soil sealants/ impervious linings
IDENTIFIERS—/ Office of Saline Water/ polyacrylamide/ vinyl polymer

CODE SHEET
For Laboratory Report No. REC-ERC-71-25

Laboratory Sample No.	Material	Description	Source
48D-36	Zeogel	Chemical sealant, attapulgite clay formulation	National Lead Co.
48D-37	7MT	Chemical sealant, medium molecular weight carboxymethylcellulose	Hercules, Inc.
B-5876	Peneprime	Liquid cutback asphalt	Accent Petroleum, Inc.
B-5800	DCA-70	Chemical sealant, a modified vinyl polymer	Union Carbide Corp.
B-5604	SA 1193	Chemical sealant, water-soluble polyacrylamide	Dow Chemical Co.
B-5605	NC 1209L	Chemical sealant, non-water-soluble polyacrylamide	Dow Chemical Co.
B-6166	E703	Chemical sealant, formulation containing B-5604 and B-5605	Dow Chemical Co.