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BULLETIN NO. 118

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IN THIS ISSUE

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Bureau of Reclamation

The Water Operation and Maintenance Bulletin is published quarterly for the benefit of those operating water supply systems. Its principal purpose is to serve as a medium of exchanging operation and maintenance information. It is hoped that the reports herein concerning laborsaving devices and less costly equipment and procedures will result in improved efficiency and reduced costs of the systems for those operators adapting these ideas to their needs.

To assure proper recognition of those individuals whose suggestions are published in the bulletins, the suggestion number as well as the person's name is given. All Bureau offices are reminded to notify their Suggestions Award Committee when a suggestion is adopted.

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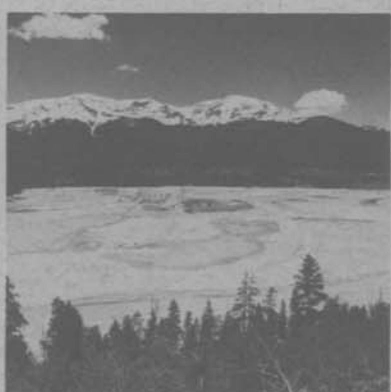

Cover photo:

Mt.Elbert Forebay reservoir, Fryingpan-Arkansas Project, Colorado. The reservoir is being prepared for placement of membrane lining.

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WATER OPERATION AND MAINTENANCE
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INTRODUCTION

The Burley Irrigation District has undertaken demonstration projects for utilizing well-graded soils for sealing purposes. See article beginning on page 1.

What about fly ash for sealing canals? The article on page 11 describes results of the Soils Mechanics Section in their quest to find an effective combination of soil and fly ash for sealing canals.

The results of ongoing studies of granular covers on 19 canals in the Bureau of Reclamation are given in the article starting on page 14.

The installation of the world's largest single cell membrane pond liner at the Mt. Elbert Powerplant is described on page 20.

EARTHEN CANAL SEALANTS [1]

With national priorities intensifying toward the conservation of water and energy, the Burley Irrigation District in Cassia County, Idaho, has contracted with the Bureau of Reclamation, Minidoka Project Office, under the Soil and Moisture Conservation Program, to undertake demonstration of earthen canal sealant projects.

The District delivers to their water users an average of 251×10^6 m^3 (204 000 acre-ft) of pumped water, requiring 26 000 000 kWh of power for the irrigation season, from approximately April 15 until October 15. The distribution loss due to seepage is estimated as greater than one-fourth of the total delivered water or 63×10^6 m^3 (51 000 acre-ft) for the season. This represents not only a large loss of energy, but of storage water to the system as well. In the past, the District has attempted a canal sealing and stabilization program but had not documented performance and costs. This program has helped verify results of a thin earth, well-graded soil lining program, and associated costs.

The concept of utilizing well-graded soils for sealing purposes has long been recognized by irrigation districts in general. Indirect evidence of such sealing-off effects were first recognized in Bureau of Reclamation drainage installations in the Riverton Project in the 1950's and also in the Imperial Valley in California. Small fractions of clay within gravel envelope materials were noted to cause a sealing-off of drainage water designed to enter the conduits.

Many irrigation districts have utilized well-graded soil materials in remedial repair and maintenance of canal banks and structures. Such use of materials by irrigation districts has been termed "dirty gravels."

Various research studies have been conducted for seepage control within water conveyance systems. In order to identify the potential for use of well-graded soils for seepage control, the District requested assistance from the Minidoka Project Office. The personnel involved in this program were Earl M. Corless, Irrigation Management Specialist; Denny R. Davis, Agronomist; and Angelo Colianni, Soil Conservationist.

Several soil samples were evaluated for particle size using the sieve and hydrometer methods. As well as conducting our own test, a set of soil samples were sent to the Regional Soils Laboratory in Boise, Idaho, for analysis. The analyses were comparable; therefore, the results were averaged to obtain the analysis shown on figure 1. Anderson gravel is shown to be one of the more well-graded materials. Using a constant head permeater setup, this material produced the greatest reduction in seepage, down to $0.052\ m^3/m^2 \cdot d$ ($0.17\ ft^3/ft^2 \cdot d$).

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[1] This article was written especially for this publication by Angelo Colianni, Soil Conservationist, Minidoka Project Office, Bureau of Reclamation, Burley, Idaho.

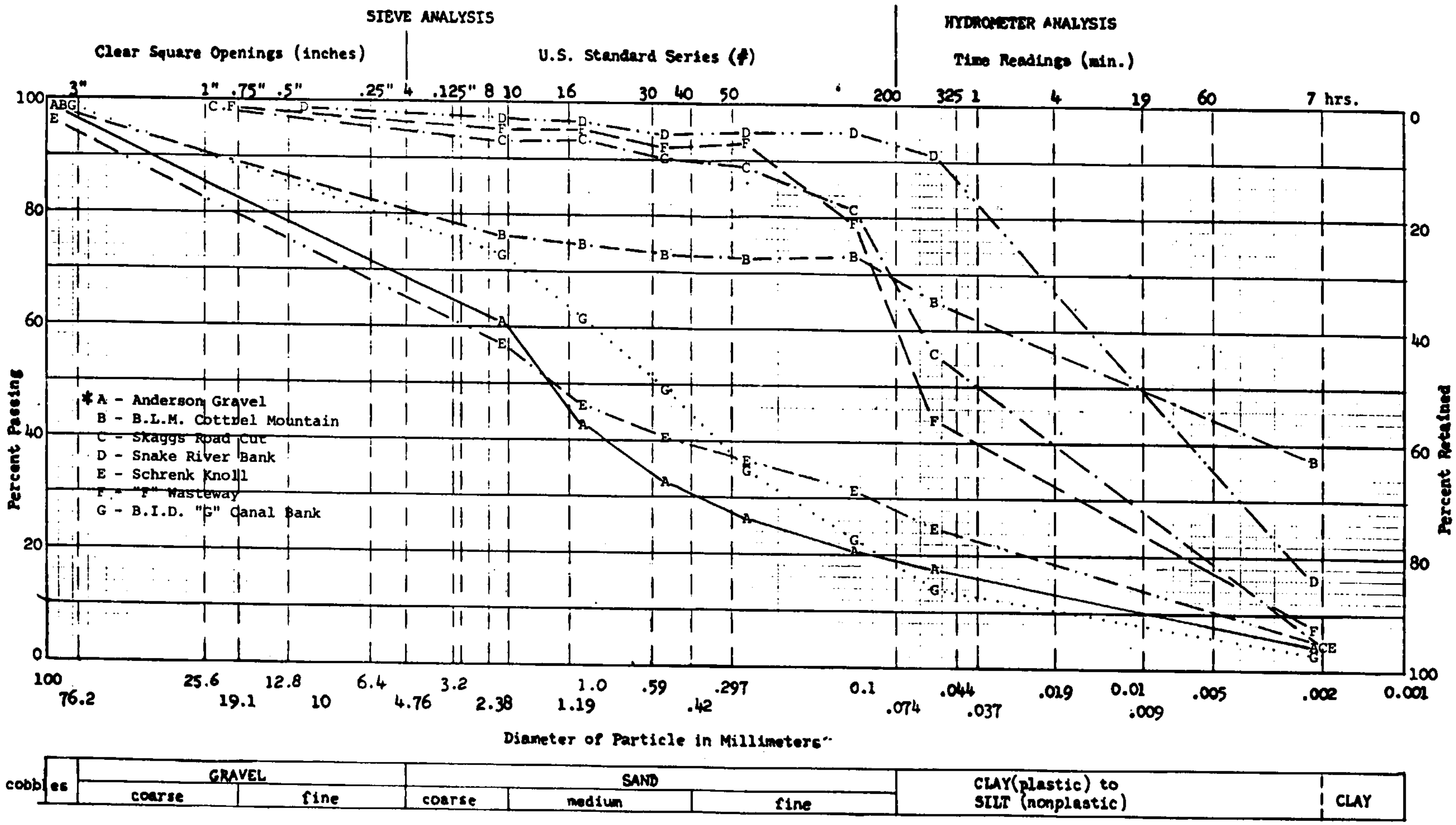


Figure 1.—Mechanical analysis of soil separates.

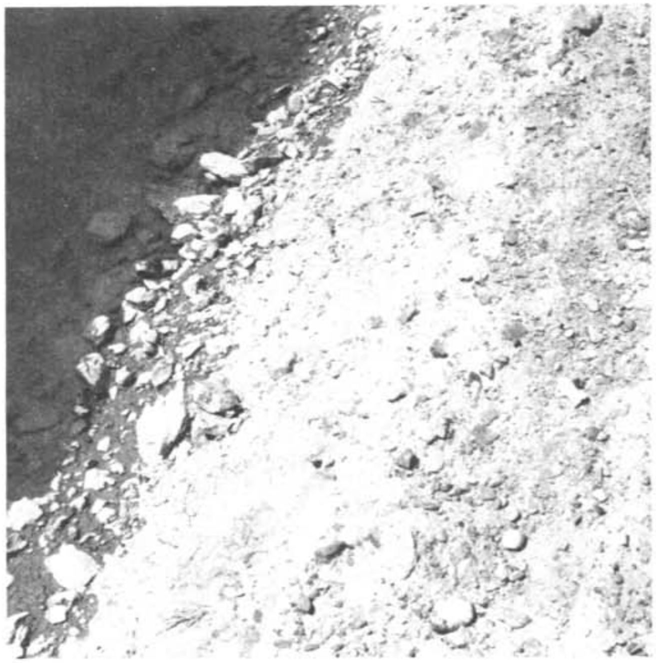


Figure 2.–Anderson gravel structural makeup in place on bank of G canal.

A sample of Anderson gravel was sent to the Applied Sciences Branch at the Engineering and Research Center in Denver, Colo., for petrographic examination. It was examined and studied megascopically, microscopically in immerson oils, by X-ray diffraction analysis, and by some qualitative chemical and physical properties tests. Expansive properties of the sample showed a 10-percent swell factor when performed by the free-swell test method. Analysis showed the material to contain moderate amounts of clay minerals. Figure 2 shows Anderson gravel inplace in the banks of G canal.

Mineralogical composition and estimated percentages were as follows:

Mineralogy	Percentage
Quartz	20
Feldspars	15
Illite	10-15
Cacite	10-15
Ca-Montmorillonite*	5-10
Kaolinite	5
Chlonite	5-10
Dolomite	5

(tabulation continued next page)

Hematite	2-3
Minor**	10-15

* Montmorillonite is a calcium-rich variety.
** Includes dust-size magnetite, manganese oxides, micas-?, siderite, trace of water soluble chlorides, and unidentified clay minerals.

Seepage testing was done through the use of the inflow-outflow method. It was best adapted due to the long test sections of the canal. The test section on the "G" canal began at 450 East 150 South, ended at 300 East 140 South (figs. 3 and 4).

Figure 3.–"G" canal in the second year of operation after lining work.

Seepage was measured in the 24+68.9-m (81+00-ft) length of canal through use of four bulkhead/weir stations, for three test sections. The stations were installed at approximately 0+15.2, 7+01.0, 17+06.9, and 24+68.9 m (0+50, 23+00, 56+00, and 81+00 ft). A Stevens-type "F" water stage recorder (figs. 5 and 6), was installed on the upstream side of each station and correlated to weir blade height. The tests were conducted at the initiation of the irrigation seasons; first, prior to the canal lining work on April 20 through 23, 1979; and second, after the lining work plus 1 year's operation on April 8 through 11, 1981.

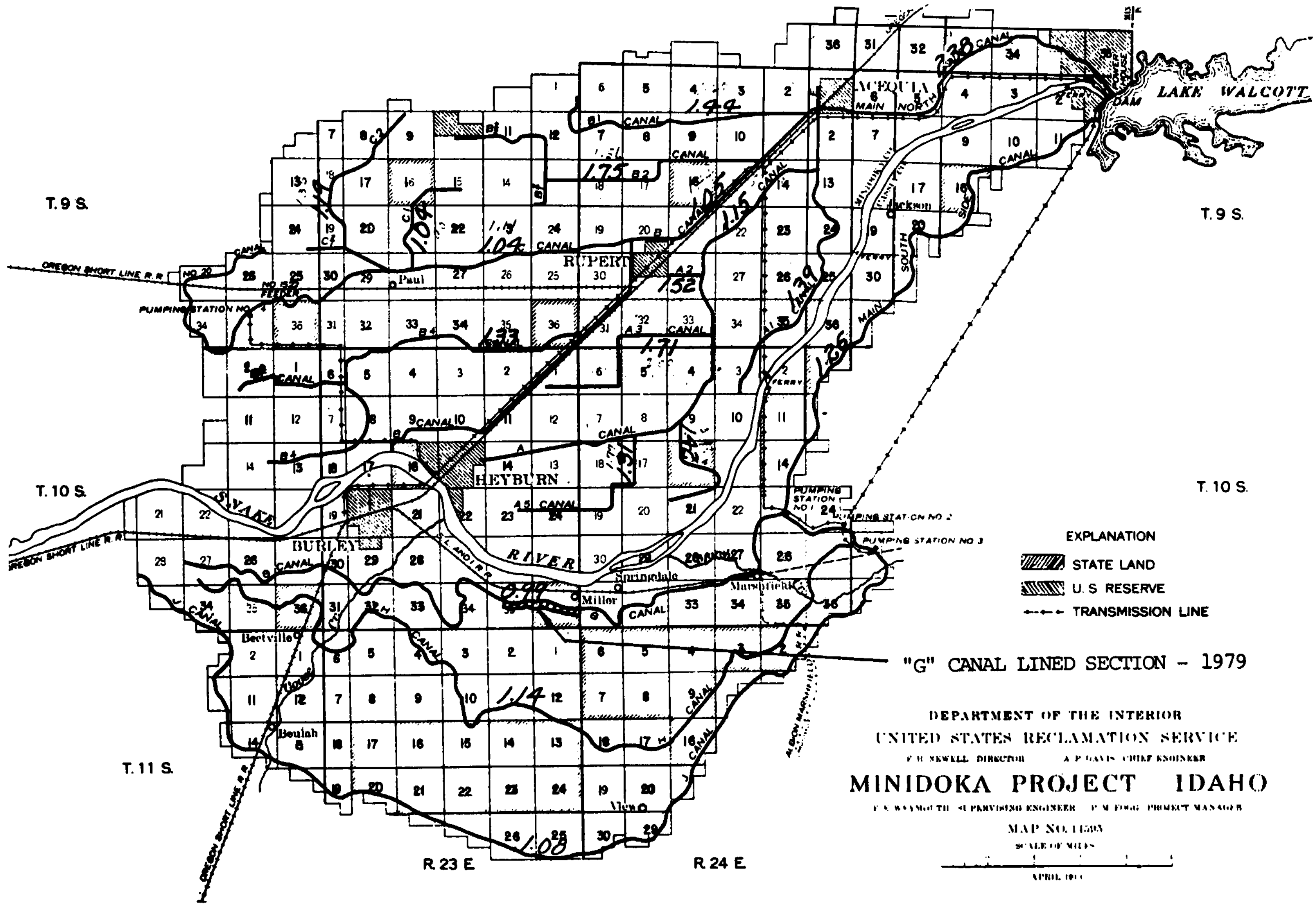


Figure 4.–Map showing canal losses in ft³/ft²·day–Season 1914.

Figure 5.–Bulkhead/weir No. 2 with water stage recorder setup for inflow-outflow test on April 8, 1981.

Figure 6.–Bulkhead/weir No. 2–Head being checked by Mr. Colianni and will be correlated to water stage recorder.

In order to establish the most reliable inflow-outflow data, a 24-hour period of time having minimal fluctuation in flow was selected. Average flows in cubic meters per second (cubic feet per second) for each station during the 24-hour periods are shown in table 1.

Table 1.—*Burley Irrigation District "G" Canal*

Seepage Loss in m^3/s (ft^3/s) per Section

Station	1979 m^3/s	1979 (ft^3/s)	1981 m^3/s	1981 (ft^3/s)
1	0.28	(9.87)	0.18	(6.39)
2	0.20	(7.11)	0.15	(5.34)
3	0.17	(6.18)	0.14	(4.82)
4	0.10	(3.56)	0.12	(4.29)

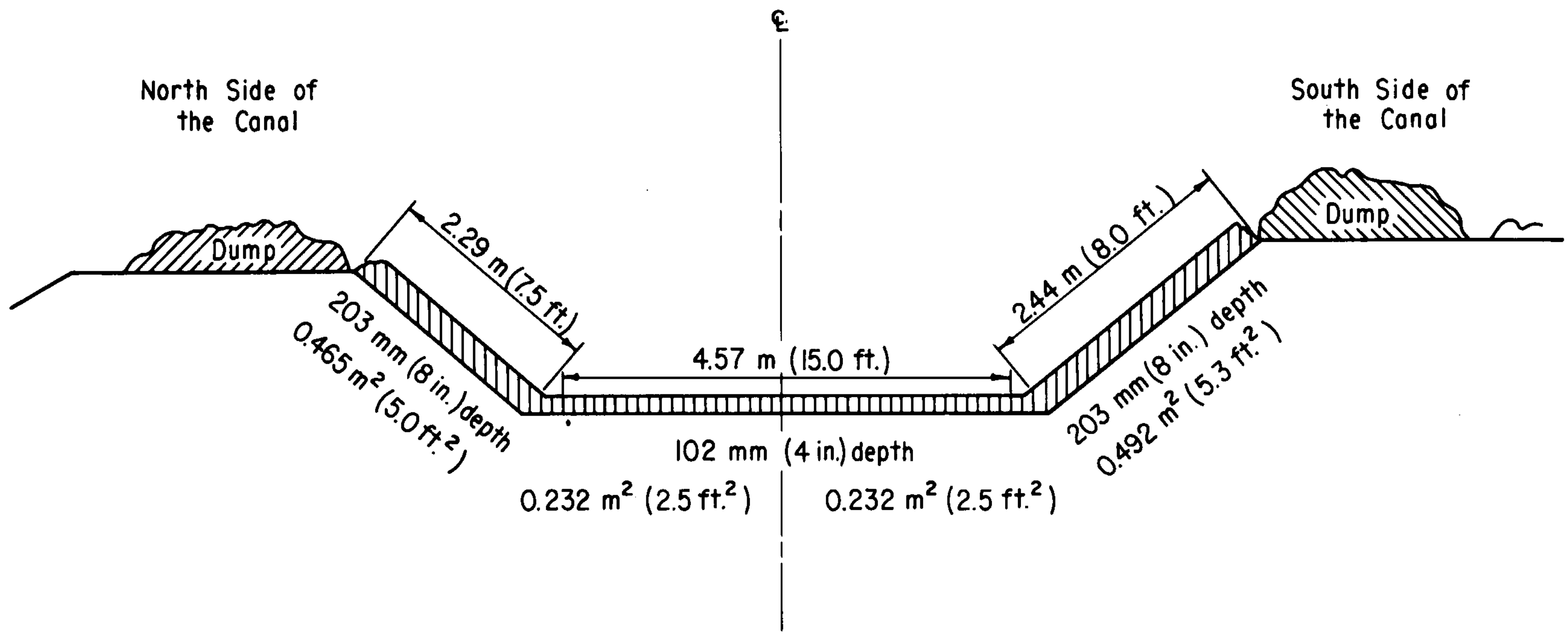
Average Flow Differences Between Stations

Station	1979 m^3/s	1979 (ft^3/s)	1981 m^3/s	1981 (ft^3/s)
1-2	0.078	(2.76)	0.030	(1.05)
1-3	0.104	(3.69)	0.044	(1.57)
1-4	0.179	(6.31)	0.059	(2.10)
2-3	0.026	(0.93)	0.015	(0.52)
2-4	0.10	(3.55)	0.030	(1.05)
3-4	0.07	(2.62)	0.015	(0.53)

With the theoretical maximum capacity flow of the canal at 2.24 m^3/s (79 ft^3/s) and an average wetted perimeter of 6.7 m (22 ft) with an area of 3.9 m^2 (42 ft^2), the velocity is running at 0.57 m/s (1.88 ft/s).

Installation costs of this lining project were low compared to other acceptable lining alternatives utilized by the Bureau of Reclamation. With a 203-mm- (8-in-) thick layer on the sides and 102-mm- (4-in-) thick layer on the bottom and a typical cross-sectional width of 9.3 m (30.5 ft), the cost of this thin, compacted earth lining was $10.33 per linear meter ($3.15 per linear foot) of canal (fig. 7).

TYPICAL CROSS SECTION OF CANAL "G"



Total volume of lining for both sides at 1931.2 m (6336 ft.) = 3054 m^3 (3995 $yds.^3$)

Figure 7.–Typical cross section of canal "G."

Mining the material with a D-8 crawler tractor with ripper was found to break up the material in the form acceptable for placement into the canal. This was cost effective as compared with blasting techniques used previously. Also, using a large loader at the mine kept several 15-m^3 (20-yd^3) dump trucks transporting material 32 km (20 mi) to the canal bank roads for a cost of $0.07-per-cubic-meter per kilometer ($0.09-per-cubic-yard per mile). Unloading time between loads was minimized through use of a motor grader to blade material onto the canal banks and bottom.

The mostly angular and subangular structural characteristics of this material enabled it to repose at approximately a 1:1 slope. The climatological factors (moisture, temperature, etc.) from overwintering reacted with the chemical and mineralogical characters of this material causing it to cement tightly in place giving us good stability and protection against the erosive channel flows. Experience by the District in the past and as evidenced thus far in these canal sections, show that this clayey gravel material has good erosion resistance to approximately 0.61 m/s (2 ft/s).

The most marked reductions in seepage losses were in the third and first sections with 80 and 62 percent, respectively. This correlated to the sections where the highest losses were occurring prior to the lining work. Over the three test sections, we had an average reduction in seepage of 62 percent (table 2).

Table 2.—*Burley Irrigation District "G" Canal*

Inflow—Outflow Test Analysis

Station	Distance		Area		Loss – 1979		Loss – 1981	
	m	(ft)	m/s	(ft/s)	m^3/s	(ft^3/s)	m^3/s	(ft^3/s)
1-2	769.6	(2,525)	5160.8	(55,550)	0.1214	(4.29)	0.0462	(1.63)
1-3	1696.2	(5,565)	11374.2	(122,430)	0.0736	(2.60)	0.0314	(1.11)
1-4	2446.0	(8,025)	16402.1	(176,550)	0.0875	(3.09)	0.0291	(1.03)
2-3	926.6	(3,040)	6213.4	(66,880)	0.0340	(1.20)	0.0190	(0.67)
2-4	1676.4	(5,500)	11241.3	(121,000)	0.0716	(2.53)	0.212	(0.75)
3-4	749.8	(2,460)	5027.9	(54,120)	0.1183	(4.18)	0.241	(0.85)

Average losses in m^3/m^2/day (ft^3/ft^2/day) using an average wetted perimeter of 6.7 m (22 ft).

As visually evidenced prior to the lining work during the irrigation season, water seeping from the canal would saturate the cropped fields on the lower bench to the north, and to the point where production would be low to none. These 1.6 ha (4 acres) of cropland are back into production after 35 years (fig. 8).

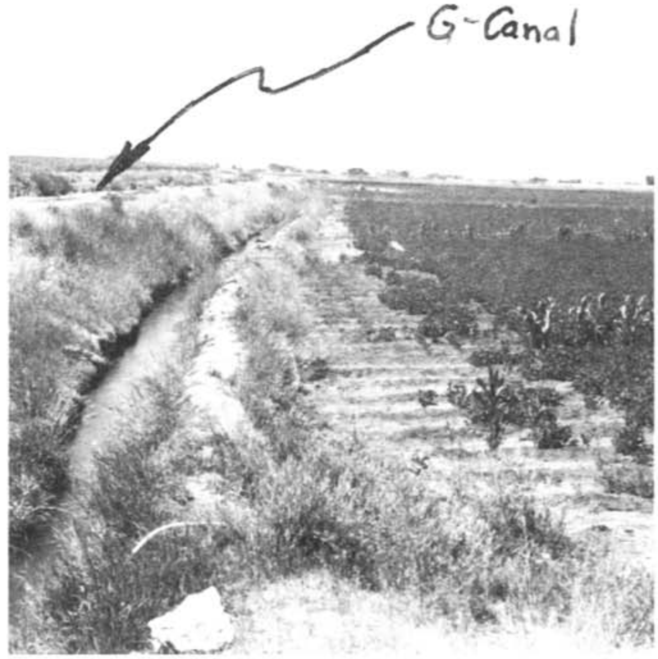


Figure 8.–Second season that landowner will harvest a bean crop from the 1.6 ha (4 acres) that were saturated for some 35 years prior to the lining work.

During the irrigation season, this canal carries 48 x 10^6 m^3 (38 720 acre-ft) per season. From the reduction in seepage losses, we are saving 1.85 x 10^6 m^3 (1499 acre-ft) per season for a 4-percent savings in water. Also, to lift the water to the head of this gravity canal takes 2 035 280 kWh per season for an energy savings of 81 411 kWh per season.

Initial results appear to have reduced seepage losses considerably. The long-term effectiveness will be evaluated after being subjected to the yearly wetting, drying, freezing, and thawing cycles, as well as the erosive force of flowing water on the canal banks. Material being considered as a canal sealant must prove to be effective and economical if it is to be utilized. Costs of implementing seepage control measures in the past may have been prohibitive. Today with the need to conserve energy and water, this type of work has become more cost effective.

* * * * *

WHAT ABOUT FLY ASH FOR SEALING CANALS?[2]

Some of the irrigation districts have shown an interest in trying fly ash to reduce canal seepage and stabilize canal slopes. Fly ash has been used to a limited extent for highway soil stabilization and for pond linings. During the past year, laboratory tests at the E&R Center have been performed to see if fly ash would make a good canal lining. Preliminary results indicate that it has good possibilities if the right combination of soil and fly ash is found and a lining of the material is properly constructed.

Properties of Fly Ash

Fly ash from coal-burning powerplants is collected by a wet or a dry process; it is only the dry powdery material that has been experimented with in soils work. The properties of a fly ash which would make it suitable for soils use depend upon the nature of the coal and the plant operation. Much of fly ash consists of tiny glass-like balls. Figure 9 shows a soil-fly ash mixture magnified 1000 times. Some fly ashes have a small amount of free lime and, when mixed with soil and water, it will set up to form a hardened mass. When fly ash lacks the lime, sometimes a small amount of commercial lime can be added to form a mixture suitable for soil stabilization.

Figure 9.–Soil-fly ash mixture.

[2] This article especially written for this publication by C. W. Jones, Soils Mechanics Section, Division of Research, Bureau of Reclamation, Denver, Colorado.

Requirements for Soil-fly Ash Lining

In laboratory tests, different amounts of fly ash have been tested with soil to determine (1) the amount of fly ash needed to reduce the permeability (measure of how fast the water will flow through) to acceptable limits, (2) the strength of the mixture, and (3) its durability under freeze-thaw and wet-dry conditions. The soil-fly ash mixture has better durability characteristics when sandy soils are used and no trials have been made thus far with clay soils. For sandy soils, it usually takes 15 to 30 percent of fly ash to make the mixture impervious. The fly ash by itself, with its round particles, may be quite pervious, so it is necessary to determine the right amount to fit into and plug the voids in the soil.

The soil-fly ash needs to have the right amount of water and to be well compacted for the best results. The fly ashes with the higher amounts of lime, when mixed with soil and water, will generate heat like quicklime, and one problem is that it may set up too rapidly before there is time to compact it, and the density will be too low for best results. Tests are still being made to find a chemical to dissolve in the mixing water to slow down the reaction. Since a chemical reaction takes place, the speed of the reaction decreases with temperature. Laboratory tests have shown that, if the soil-fly ash can be mixed and placed at about 7 °C (45 °F), good results are obtained if the mixture can be compacted within 30 minutes after mixing. If this can be done, then no additive to delay the time of set would be needed. However, the mixture should be placed when the temperature is well above freezing.

Curing

Soil-fly ash needs to be kept moist for about a week by adding water or retaining moisture in the mixture by a cover such as moist soil. The compacted mixture gains strength slowly over a long period of months and even years. According to reports, it does not shrink and crack as much as soil-cement.

First Field Test

To our knowledge, the first and only canal field trial with soil-fly ash was made in November 1980 in the Pathfinder Irrigation District of the North Platte Project near Torrington, Wyoming. This was a very small test section about 21 m (70 ft) long in a 0.3-m^3/s (10-ft^3/s) lateral. The canal is located in dune sand, and fly ash was mixed with soil and water in the lateral bottom with a garden rototiller. The 125-mm- (5-in-) thick lining was compacted in the lateral bottom with a hand-operated, plate-type vibratory compactor. The next day, after the lining in the bottom had started to set up, more new material was mixed in the bottom and dragged up on the side slope of the lateral with a Gradall. The empty Gradall bucket was dragged on the slope lining in an attempt to compact it. About 230 mm (9 in) of loose moist soil were placed on the lining for curing.

Tests later showed that the fly ash was not nearly as uniformly mixed with the soil as was desired. Compaction on the lateral bottom was good but on the slopes it was very poor, and the permeability on the slopes was much too high. Next fall, after the irrigation season, we shall examine the lining.

For better controlled test sections, a larger rototiller and compactor should be used. Highway construction equipment normally used for soil stabilization would be necessary if a large quantity of lining were to be placed.

Cost of Fly Ash

Although it may be possible to deal directly with some powerplant managers to obtain fly ash, particularly for a test section, the managers usually deal with fly ash disposal companies who sell it if it has some use. Costs may run around $8.8 to $11 per metric ton ($8 to $10 per ton). Hauling it in large trucks which handle portland cement may cost around $0.048 to $0.055 per metric ton-kilometer ($0.07 to $0.08 per ton-mile). Therefore, for a soil-fly ash lining to be economical, the haul distance would need to be reasonable.

Chemical Tests for Pollution

Our chemical laboratory has been conducting tests to see if there is any danger of leaching materials from a soil-fly ash lining and causing pollution to canal water or underlying aquifers. Tests on a soil-fly ash mixture with a water leach to determine available metal concentrations have not shown significant levels of EPA-regulated heavy metals. Fly ash is not considered to be a hazardous waste.

Summary

It is really necessary to try the particular soil and fly ash in laboratory tests to determine the amount of fly ash required and to get some idea how it would work in a field installation. The better the construction procedure, the better the product. Time will tell what the effectiveness will be in reducing seepage, stabilizing slopes, and resisting weathering.

* * * * *

GRADATION OF SAND AND GRAVEL CANAL COVER LAYERS[3]

How do you select the right sand and gravel for a cover layer to prevent canal erosion? This article will summarize the results to date of a study of the performance of covers on 19 different canals in the Bureau of Reclamation.

Cover Test Sections

In the early 1960's, we started to collect information on the stability of covers on asphalt membrane linings which were popular in those days and on a few unlined canals. Most of these membranes had two cover layers with the first one of fine-grained soil, usually from canal excavation. This was placed to protect the membrane from damage during placement of the second coarse layer of sand and gravel, which was needed to resist erosion from flowing water and wind-wave action. Typical test reaches were selected, the design properties were tabulated, the cover materials were sampled and tested, and the performance of the covers was recorded by operation and maintenance people. Figures 10 and 11 show the granular cover on the Kennewick Main Canal, Yakima Project, Washington, which is in good condition after 25 years of service.

In the later 1970's, the test reaches were revisited and further observations were made on performance. Also, during that period, some data were collected on covers for plastic membrane linings which were becoming popular in place of asphalt. Table 3 lists the granular cover test reaches.

The study has shown both good and bad cover performance, depending mostly on the gradation (particle size distribution) of the coarse cover layers. In a few cases, there was some settlement and cracking of the covers when the canals were first placed into operation, but this was taken care of by a small amount of maintenance. Although this has not been considered a serious problem, it could probably be prevented by moisture and density control and compaction of the cover layers. Compaction has been done on an experimental basis, and no problems have been found where this has been done.

Cover Grading Recommendations

The investigation resulted in recommendations for the grading of cover materials. Figure 12 shows the gradation range for fine cover layers on most of the test reaches, and they have generally performed well. The gradation for lateral W20 caused the coarse layer to be somewhat unstable and such soils, predominantly in the medium to coarse sand range, are not recommended. Figure 13 shows upper and lower limits of gradation for stable coarse layers. Covers that were finer grained than the upper stable limit generally performed poorly.

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[3] This article especially written for this publication by C. W. Jones, Soils Mechanics Section, Division of Research, Bureau of Reclamation, Denver, Colorado.

Figure 10.–Granular cover on Kennewick Main Canal.

Figure 11.–Granular cover on Kennewick Main Canal.

Table 3.—*Cover test reaches*

Canal or lateral	Project	State
Asphalt membrane lining		
West Canal, 5th section	Columbia Basin	Washington
Lateral PE 38.9	Columbia Basin	Washington
Lateral W20	Columbia Basin	Washington
Lateral W22E	Columbia Basin	Washington
Angostura Main Canal, Angostura Unit	Pick-Sloan Missouri Basin Program	South Dakota
Wyoming Canal	Riverton	Wyoming
Pilot Canal	Riverton	Wyoming
Pavillion Main Lateral	Riverton	Wyoming
Fort Laramie Canal	North Platte	Wyoming
Helena Valley Canal, Helena Valley Unit, Helena-Great Falls Division	Pick-Sloan Missouri Basin Program	Montana
Earth lining		
Hudson Canal	Tucumcari	New Mexico
PVC (polyvinyl chloride) lining		
Wyoming Canal	Riverton	Wyoming
Helena Valley Canal, Helena Valley Unit, Helena-Great Falls Division	Pick-Sloan Missouri Basin Program	Montana
East Bench Canal	Pick-Sloan Missouri Basin Program	Montana
Amarillo Canal	Navajo Indian Irrigation	New Mexico
PE (polyethylene) lining		
Amarillo Canal	Navajo Indian Irrigation	New Mexico
Unlined		
Kennewick Main Canal	Yakima	Washington
Atrisco Feeder Canal	Middle Rio Grande	New Mexico
Upper Meeker Canal, Meeker-Driftwood Unit	Pick-Sloan Missouri Basin Program	Nebraska

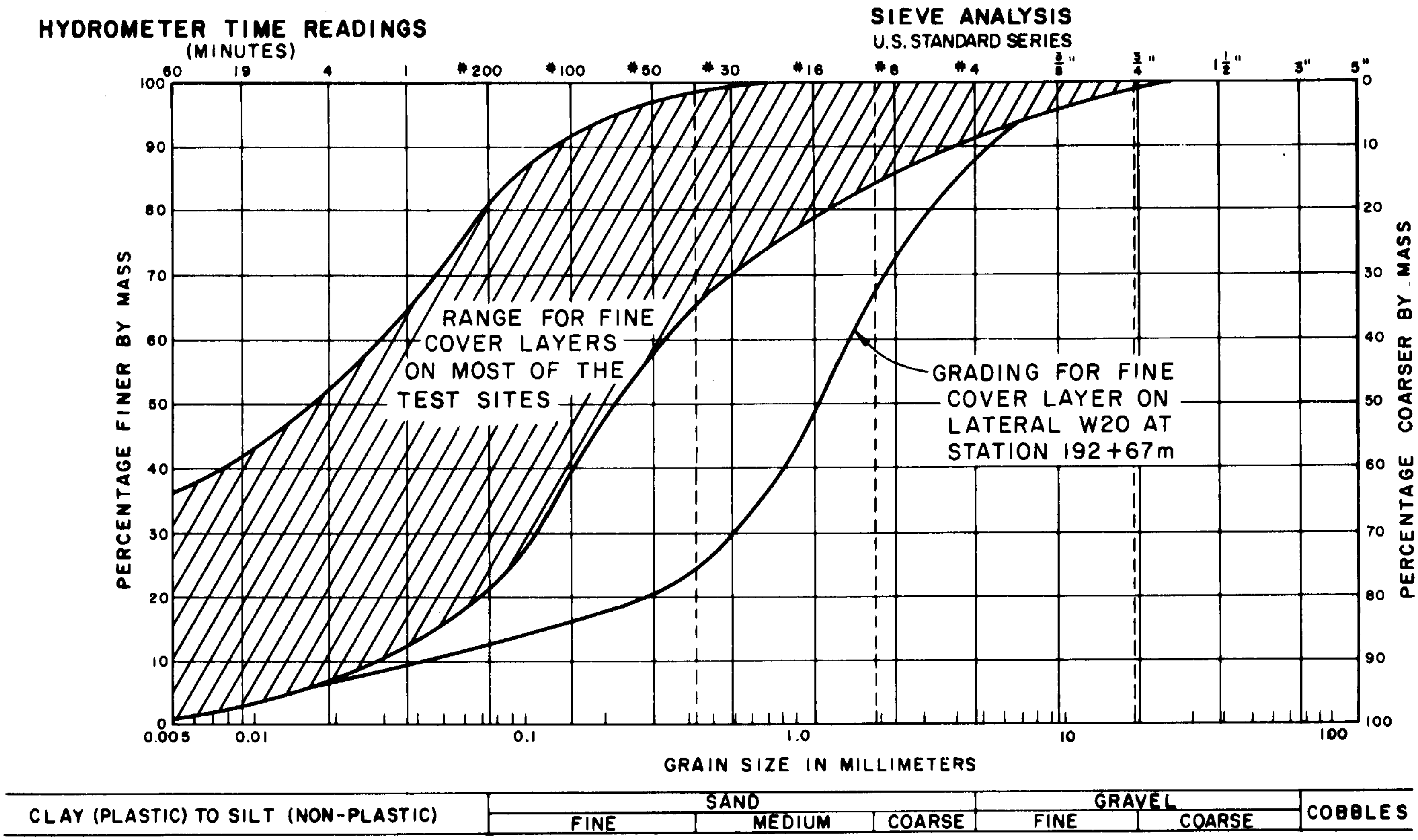

Figure 12.–Gradation range for fine cover layers.

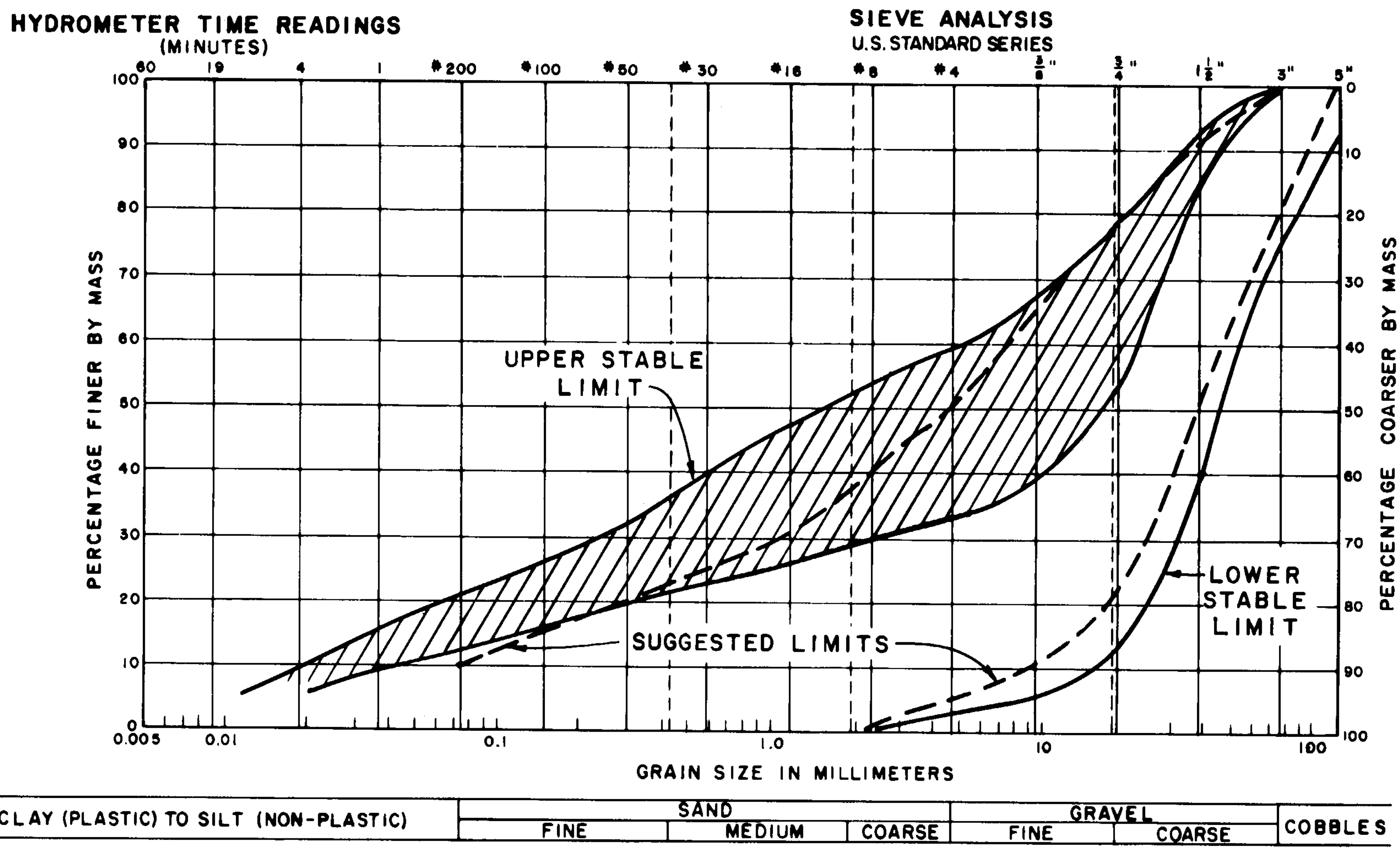

Figure 13.–Upper and lower limits of gradation for stable coarse layers.

There is an overlap area where some covers performed well and others did not. This is probably due to differences in design and operating conditions.

The tractive force (shearing action) of the flowing water on the canal surfaces was calculated by the formula $T = wds$:

Where:

- T = tractive force in newtons (lb/ft^2)
- w = mass of water on a unit area in kg/m^2 (lb/ft^2)
- d = canal water depth in meters (feet)
- s = longitudinal slope of canal (dimensionless)

For the test reaches, the tractive forces (as calculated from design data) ranged from 1 Pa (0.02 lb/ft^2) to 10 Pa (0.2 lb/ft^2); most of the covers with a tractive force less than 5 Pa (0.1 lb/ft^2) performed well. Some of the failures of the covers were considered to be caused by high tractive forces. As shown, covers performed well when (1) the maximum particle size was 76 mm (3 in) or more, (2) less than 50 percent passed the No. 4 sieve, and (3) less than 10 percent passed the 75 μm (No. 200) sieve.

One concern on granular covers that should not be overlooked is to make sure that the covers will not break down into finer particles by weathering. There are a few materials, such as Brule Clay on the North Platte Project, which seem to be solid enough for cover material but which deteriorate after a few years.

For more details on the granular cover investigation, you can get a copy or Report No. REC-ERC-81-7, "Performance of Granular Soil Covers on Canals," dated August 1981. See inside of back cover for ordering information.

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MEMBRANE LINER SEALS 112.5-HECTARE (278-ACRE) RESERVOIR [4]

Installation of the world's largest single-cell membrane pond liner was completed in September 1980 in a 112.5 ha (278-acre) forebay reservoir near Leadville, Colorado. Lining of the reservoir by a B. F. Goodrich installation crew (fig. 14), was a major step in construction of the Mt. Elbert Powerplant, which will provide electrical power to Colorado customers during peak load hours.

The Mt. Elbert plant was constructed as part of the Fryingpan-Arkansas Project which will divert water from the western slopes of the Rockies, where it is plentiful to the relatively dry Arkansas River Valley on the eastern slopes. Water is carried through the Charles H. Boustead Tunnel to the Turquoise Lake Reservoir. From there, it passes through the 18.0 km (11.2-mi) Mt. Elbert conduit to a manmade reservoir near the powerplant. When filled, the forebay reservoir will hold 13.65×10^6 m^3 (11 070 acre-ft) of water, with a surface elevation of 2940.01 m (9645.7 ft).

Figure 14.–Installation crew positions section of the membrane liner. Each section measures 1300 m^2 (14 000 ft^2).

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[4] Reprinted by special permission of the Editor, Public Works, from February 1981 issue.

From the forebay, water is released through two 4572-mm (180-in) diameter penstocks, dropping 135.6 m (445 ft) to drive two 100-MW hydroelectric turbine generators. Power will be generated year around to meet demands for electricity during peak load periods.

After passing through the turbines, the water is stored in Twin Lakes, which have been enlarged to accommodate the flow. The powerplant generators have been designed to operate in reverse as 126.82-MW (170 000-hp) motors. During nonpeak hours, when power is less expensive and demand is lower, the water will be pumped from the Twin Lakes back to the forebay reservoir.

The forebay is situated in an ideal depressional area, on a hillside between Turquoise and Twin Lakes. During the original excavation project in 1974-75, core samples were taken and tested as part of an extensive drilling and exploration program. These tests helped to determine the soil strength parameters and established the feasibility of using the excavated soil to dam the forebay. The testing also led to the determination that several areas in the proposed forebay site were permeable and that the forebay needed to be covered with a leak-proof blanket.

A 1.5-m- (5-ft-) deep lining containing clay and clay-silt materials was spread over the entire reservoir bottom and side slopes. To monitor water levels, pore pressures, and slope movement, an extensive network of observation wells, piezometers, and surface movement points was installed for the dam and hillside between the reservoir and Twin Lakes.

In the fall of 1977, the forebay was partially filled and seepage monitored for a 1-year period. The elevation of water in the observation wells on the hillside rose slightly, indicating that water was seeping through the lining. Although this condition was normal and within safe limits, project engineers and outside consultants felt that in time the seepage might decrease the soil strength and weaken the hillside. The decision was made to install a membrane liner, which would cut off all seepage.

Two major requirements were established for selection of the liner:

1. The liner had to have a projected life expectancy of 50 years.

2. The liner had to be installed quickly, since the region has only 5 months of weather warm enough to permit installation each year.

The elevation of the forebay site and severe climatic conditions led to additional specifications. The membrane has to withstand a wide range of temperatures, since the forebay freezes over during the long winter months. And though the liner would be covered with soil, it had to be resistant to ultraviolet light.

Forebay Preparation

The prime contractor for the forebay project was Green Construction Company, headquartered in Des Moines, Iowa. The project was directed by Green's office in Denver. The total contract price was $17.8 million.

Preparation for installation of the liner was a major exercise in modern earth-moving techniques. The riprap and coarse gravel bedding which previously lined the forebay slopes were removed, and an additional 0.6 m (2 ft) of material excavated from the bottom of the reservoir. This material was processed to remove all pieces larger than 25 mm (1 in) in diameter, using three screening plants. No crushing was permitted, and the gravel, cobbles, boulders, and rock fragments larger than 25 mm (1 in) were distributed in gravel protection areas or the quarry reject protection area.

The processed material, primarily clay and silt, was placed in a 150-mm (6-in) layer on the floor and sides of the reservoir to form a base for the membrane liner. Once in place, the membrane liner was covered with an additional 450 mm (18 in) of the processed material, and the gravel bedding and riprap spread on the slopes.

The earth-moving and processing operations were performed by a 120-man crew, utilizing an equipment fleet that included 16 scrapers and 23 bulldozers–Caterpillar D68's, D8's, and D9's. A total of 1.5×10^6 m^3 (2 million yd^3) of material were moved during the operation.

Some preparation of the 150-mm (6-in) subgrade base had to be completed before the liner could be installed. The graded materials were moisture conditioned with sprinkled water, spread, scarified, graded, and compacted. Compaction was accomplished first by pneumatic tired rollers, then finish-rolled with a smooth steel drum. Each area was visually inspected before the liner was installed to insure that no sharp projections existed.

The lining was installed as each section of subgrade was completed. After the liner was inspected and tested, the 450-mm (18-in) earthfill cover was spread across it and compacted by normal equipment travel.

The Membrane Liner

Membrane liners have not been used extensively for Federal projects, and there was a lack of available data from which to evaluate a project of the magnitude of the Mt. Elbert installation. This meant that extensive study and testing were required to determine the optimum specifications and methods of installation of the liner.

Competitive bids were obtained from several companies with lining experience. The bid which was selected as most feasible and competitive was submitted by the Fabricated Polymers Division of B. F. Goodrich. In addition to being cost effective, B. F. Goodrich was the only domestic manufacturer who could both supply and install the liner. Also, they could guarantee delivery of sufficient quantities of the membrane within the required time limits.

The membrane liner is a three-ply construction, consisting of two plies of sheeting material laminated to one ply of reinforcing fabric scrim (a 1,000 denier polyester with 10 cords to the inch). The resulting membrane has a thickness of 1.14 mm (45 mils).

The sheeting material is manufactured from a chlorinated polyethylene (CPE) compound which contains Resin 4213, a product of Dow Chemical U.S.A., as its majority resin. The sheeting also contains stabilizers, carbon black, and inorganic fillers. The compound is calendered to produce a uniform sheet.

The scrim fabric is sandwiched between the two sheets of CPE, and extends to within 6 mm (1/4 in) of the edge of the membrane sheet. The edges are sealed so that moisture cannot be drawn into the membrane by capillary action through the scrim fibers.

The lining material was manufactured at the B. F. Goodrich facility in Marietta, Ohio. Sheets were produced in 1.5-m (5-ft) rolls, which were then bonded to form larger blankets. Two panel sizes were used for the Mt. Elbert Project–21 by 61 m and 30 by 43 m (70 by 200 ft and 100 by 140 ft). The lining material is marketed under the trade name "Flexseal."

A "hot-air" seaming process was used to form the 21- by 61-m (70- by 200-ft) panels. A Leister machine runs along the seams, heating them until they fuse. The 30- by 43-m (100- by 140-ft) panels were bonded by the diaelectric method, which utilizes high-frequency sound to generate heat for fusion. All of the seams were made so that the reinforcing scrim overlapped by 25 mm (1 in), and bonding extends to the edges of each sheet so that there are no loose flaps on the surface of the panel. The bonds were made so that, under duress, the parent material would tear before the bonded sections separate.

The factory-made seams were checked using forced air on the upper seam edge and surface. The use of high-pressure air enabled inspectors to detect loose edges, riffles which indicate unbonded areas within the seam, or other undesirable bonding conditions. Pressure was obtained by using a 350-kPa (50-lb/in^2) air stream directed through a 5-mm (3/16-in) nozzle, held not more than 150 mm (6 in) from the seam.

The panels are accordian folded and rolled for shipment to the field. Each panel weighs approximately 2268 kg (5000 lbs), and eight were shipped per truckload. The lining was packaged in snug wrappers which protect it from abrasive damage and from moisture.

Prior to shipment, a 300-mm (12-in) strip was cut from each panel width and sent to a testing laboratory in Denver. No panel could be installed until this testing verified the integrity of the panel.

At the installation site, the blankets were unloaded at strategic locations throughout the forebay area as they were delivered. The liner was moved into place with a front-end loader, then positioned by a 20-man installation crew.

The 30- by 43-m (100- by 140-ft) panels were placed along the slopes of the forebay, with the 30-m (100 ft) edge at the top and the 43-m (140-ft) length toward the center of the reservoir. This avoided the requirement for a field seam at the bottom of the slope. The slope liners were anchored at the top.

Special precautions were taken with the panels that joined concrete structures. Before the lining was bonded, the concrete was cleaned and redwood battens were employed to attach the lining.

Specifications for the membrane lining required a 150-mm (6-in) overlap along every seam (fig. 15), made in the field, with at least 112 mm (4 in) of the overlap bonded from the exposed edge inward. Before bonding, all edge sections were cleaned to remove dirt, dust, moisture, and other foreign materials. All cut edges were sealed with a CPE bodied solvent adhesive.

Figure 15.–Seams joining panels were sealed with special adhesive, then tested with an air gun. After inspection, a capping strip was applied.

After each seam was bonded, it was tested with a 350-kPa (50-lb/in^2) air gun in a procedure similar to that used in the inspection process at the manufacturing plant. No field seams were permitted to be made when the ambient air temperature dropped below 2 °C (35 °F). When the temperature was between 2 °C and 10 °C (35 °F and 50 °F), the panels were heated with a hot air gun prior to bonding.

After each seam was inspected, it was capped with a 75-mm (3-in) wide, 0.7-mm (30-mil) thick cap strip, cut from an unreinforced sheet of CPE material.

Each day, all membrane installed during the day was visually inspected for tears and punctures. Imperfect spots were marked, and were subsequently cleaned and repaired with a piece of unreinforced CPE sheet which had rounded edges to insure a good seal.

A test seam, 2 m (6 ft) long, was made at the beginning of each day. This seam was tested and marked with the location of other seams made that day. If the test seam later proved to be less than standard, other seams made that day were checked for defects. This testing procedure also insured that the quality of seams did not vary from one installation crew to another, as the test seams from different crews could be compared during inspections.

Provision had been made to test samples of the membrane liner at regular intervals to monitor the liner's durability and compliance with warranty specifications. Ten 1.2- by 6.1-m (4- by 20-ft) test sections have been installed at the western end of the forebay, where wide fluctuations of water level will occur. The test sections include factory seams, field seams, patches, and other representative operations performed during installation of the membrane.

The test sections have been laid over the permanent liner, separated from it by 50 mm (2 in) of soil. The sections are then covered with 450 mm (18 in) of fill material, which is replaced over the permanent liner as the test sections are removed. Sections will be removed 6 months and 12 months after completion of the liner installation, and at 1-year periods thereafter.

This testing procedure is expected to provide invaluable data for the use of membrane liners for liquid and slurry-retention applications, since the specifications for the Mt. Elbert Project are the most stringent for any such installation to date.

Environmental Considerations

The Mt. Elbert installation, and its parent Fryingpan-Arkansas Project, may be the most extensively studied environmental project ever undertaken by the Federal Government.

Testing began several years ago for environmental impact, and is expected to continue for some time in the future. These tests have been the subject of extensive coverage in environmental publications.

Among the environmental considerations for the installation were the variations in water levels in the Twin Lakes, and the possible dispersion of sediment in the water due to turbulence from the power generation operations. These are expected to be minimal, since outflow from the power station is discharged toward the bottom of the lake.

The area surrounding the inlet and outlet channel adjacent to the powerplant has been partitioned off to prohibit public access. Thus, public safety in this area has been significantly enhanced.

Project Completion

Installation of the membrane liner took 62 working days, and was completed September 20, 1980. The forebay reservoir is scheduled to be filled in the fall and winter of 1980-1981. Startup of the Mt. Elbert Powerplant is scheduled to begin in mid-1981, with the plant undergoing testing before it is brought on line.

The Mt. Elbert installation is the largest application of a membrane liner in a single cell to date. With its successful installation and testing, however, this aplication may well lead to larger installations in reservoirs and waterways within the next few years.

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A free pamphlet is available from the Bureau of Reclamation entitled, "Publications for Sale." It describes some of the technical publications currently available, their costs, and how to order them. The pamphlet can be obtained upon request to the Bureau of Reclamation, Engineering and Research Center, P O Box 25007, Denver Federal Center, Bldg. 67, Denver CO 80225, Attn D-922.