SEDIMENT SEALING OF IRRIGATION CANALS

(Report for the three-year period of 1957 through 1959)

by
R. D. Dirmeyer, Jr.
and
R. T. Shen

Colorado State University
Civil Engineering Section
Fort Collins, Colorado
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Civil Engineering Section
Fort Collins, Colorado

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FOREWORD

In addition to the important contract support from the Agricultural Research Service of the U.S. Department of Agriculture, noteworthy contributions to the work reported herein have also been made by other groups and individuals. At the risk of omitting important contributions, the help of the following organizations and individuals is gratefully acknowledged.

Trial	Organization	Names
All	Agricultural Research Service	O. J. Kelley L. E. Myers, Jr. M. E. Jensen
All	Colorado State University	A. R. Chamberlain N. A. Evans R. S. Whitney R. V. Asmus A. T. Corey
Lateral 19.3	The Central Nebraska Public Power and Irrigation District	Geo. E. Johnson Ted Johnson J. W. Boyd L. G. Mathieu
Coachella Canal	The Imperial Irrigation District	J. M. Sheldon A. J. Boles W. L. Riddle
	The Coachella Valley County Water District	Lowell Weeks
	Brown Mud Company	J. H. Glenn G. M. Brown
	A. R. Maas Chemical Co.	C. A. Sumner
	Dow Chemical Co.	D. J. Pye R. R. Jennings Jack West
	Cronese Products Co.	H. T. Wyatt C. H. Toll

Trial	Organization	Names
	Monsanto Chemical Co.	J. M. Deming L. V. Sherwood
Lateral 1	U.S. Bureau of Reclamation	P. W. Terrell R. J. Willson W. K. Lundgreen C. W. Thomas C. W. Jones
	The Pathfinder Irrigation District	S. L. Bowman
Twin Lakes	The Twin Lakes Reservoir and Canal Co.	W. A. Doe

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ADVANCE SUMMARY

The results of research and development work of sediment sealing at four test sites are reported:

1. Lateral 19.3 site in loessial soil -- The test site comprised about 4.4 miles of Lateral 19.3 of the Central Nebraska Public Power and Irrigation District near Bertrand, Nebraska. It is situated in loessial material which is a wind-deposited silt dominated by a typical vertical, tubular structure. The site was divided into four sections for testing:

   a. Mi 0 to 1.6--Underwater harrowing only
   b. Mi 1.6 to 2.6--No treatment--control reach
   c. Mi 2.6 to 3.4--Ponding with flocculated bentonite alone
   d. Mi 3.4 to 4.4--Ponding with flocculated bentonite followed by harrowing.

   The only test section that indicated a significant reduction of seepage loss in the season following the trial was the control or untreated reach. The sealing results in the treated sections were down-graded by several uncontrolled factors, such as bank erosion by wind-induced waves, bank sloughing, an unexpected increase in water hardness, and crayfish burrows.

2. Coachella Canal site in sandy materials -- The test site included 7.82 miles of the Coachella Canal in the Imperial Valley of Southern California. The bed materials are sandy. While several types of bentonite, including a number of local bentonites, were evaluated in the initial work, the trial installation was made with SS-13, an oil-base sealant. A ponding method of application was used. Comprehensive evaluations, including discharge, piezometer, and well measurements, indicated no significant sealing effect. The major reason for this seems to relate to the bed-load sand movement along the bottom of the canal.

3. Lateral 1 site in sand dune materials -- The test site comprised 5.75 miles of Lateral 1 of the Pathfinder Irrigation District in the North Platte Project of the Bureau of Reclamation. The canal materials are of dune sand origin. The sealing treatment consisted of ponding with a high-swell bentonite slurry (1 $\pm$% conc.). Field site evaluations for this trial indicated that a surface seal of only limited duration was produced. Subsequent laboratory investigations into the causes for the surface seal revealed no promising method of circumventing the problem--except by mechanical means, such as harrowing. Harrowing the canal bed during the ponding phase of the sediment sealing operation has produced reasonably satisfactory results in recent Wyoming work.

4. Twin Lakes site in rocky materials -- The test site was the Connection Canal (7700+ feet long) of the Trans-Mountain Diversion System of the Twin Lakes Reservoir and Canal Company near Aspen, Colorado. The canal is excavated in open rocky materials characterized by extremely high permeability. Good sealing results were produced at this site by utilizing a mixture of granular high-swell bentonite, pit-run low-swell bentonite, and wet sawdust in a multiple-dam method of application.

The Recommendations and Conclusions include: (a) summary of procedure recommendations for use of Wyoming high-swell bentonite in canal sealing; (b) statement concerning need for additional research and development on use of locally-occurring pit-run clays, including low-swell bentonites, in canal sealing; and (c) statement concerning need for additional basic research in regard to water measuring methods and seepage loss phenomena.

INTRODUCTION

This report is concerned with the bentonite project activities at Colorado State University, sponsored since January 1957 by the U. S. Department of Agriculture, Agricultural Research Service. The contract study provided for determining, through field and laboratory evaluations, the measurable and predictable conditions influencing the effectiveness and durability of experimental canal sediment linings.[1] The purposes of the contract study are briefly summarized below:

1. To develop methods of sealing pervious irrigation canals with water-borne colloidal-clay sediments.

2. To assemble design data for use by workers engaged in the design and operation of irrigation canals.

More specifically, the University project was to conduct the studies at not less than three and not more than six field trial sites for experimental canal sediment sealing installations. The sites were to be representative of the pervious materials and operating conditions found in sedimenting installations, previously made or planned in Colorado, Nebraska, Wyoming, South Dakota, Arizona, and California.

In the initial contract work, experimental installations were planned at five sites (See Fig. 1):

1. Lateral 19.3 site in loessial material near Bertrand, Nebraska.

2. Coachella Canal trial in sandy material near Holtville, California.

3. Lateral 1 site in sand dune material near Torrington, Wyoming.

4. Twin Lakes site in rocky material near Aspen, Colorado.

5. Coors Farm trial in sandy to gravelly material near Center, Colorado.

All of the above trial sites, except the Coachella Canal site, are in canals that are dry during the winter months; the Coachella Canal is operated continuously throughout the year.

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1 Reports previously transmitted to ARS in conformance with the contract are marked with an (*) in list of REFERENCES at the end of this report.

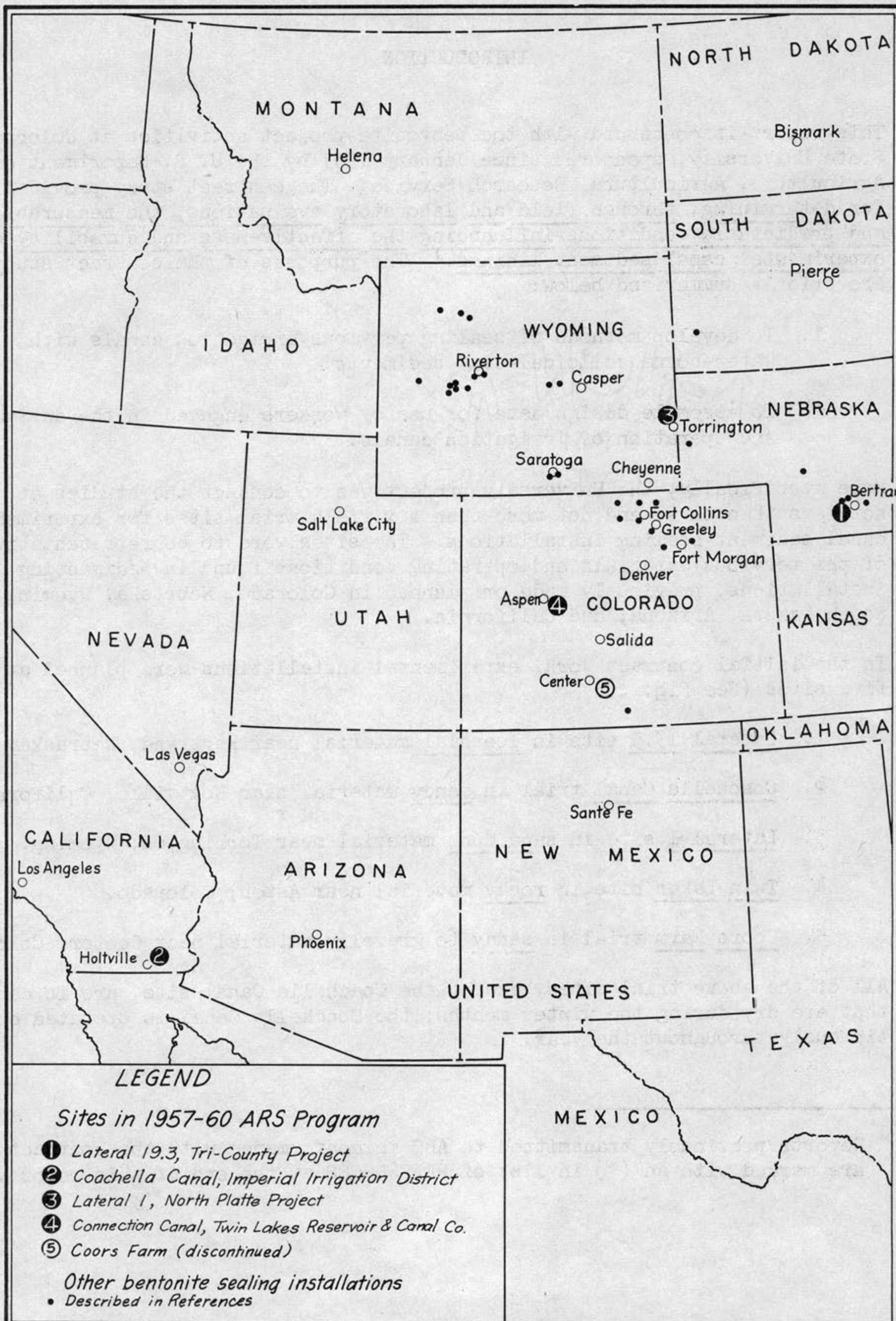

Fig. 1 General location map

While bentonites, both low-swell and high-swell, were evaluated in the planning work at the Coachella Canal site, a chemical sealing agent, SS-13[1], was used in the main trial in the Coachella Canal. In the other three trials, a Wyoming high-swell bentonite[2] was the sealing material.

This report summarizes the trial work completed at the first four sites listed above: Lateral 19.3, Coachella Canal, Lateral 1, and Twin Lakes sites. The trial installation planned for the Coors Farm site was not completed[3].

The Problem

For many irrigation projects, the beginning stage of operation utilizes direct flow water from a river, with little or no upstream storage or regulation. This is still a common case for many river systems where irrigation is practiced. Under these conditions, flows of muddy water are not uncommon, and excess sediment can become a problem. For example, in a bulletin (1)[4] relating to the silt problems of the lower Colorado River water, Fortier and Blaney had this to say in 1928:

> "Preventing silt from entering canal systems is a prime factor in the success of irrigation enterprises in that it eliminates the present high annual expenditures (in the Imperial Valley) for silt disposal and control in the canal system and upon the land, provides a freer passage of water through canals, renders structures serviceable and operative, and protects fields from depositions of fine silt which impairs the texture and productivity of the soil . . ."

---

1 SS-13 is an oil-base sealant, whose exact formulation is not for public disclosure.

2 Bentonite is a natural clay substance, composed mainly of the clay mineral, montmorillonite. The high-swell or sodium bentonite is the most common commercially available bentonite. It is mainly mined in Wyoming. It was used in the trial work mainly because of its availability and uniform characteristics.(2)

3 In 1957 when this site was selected, the water table in the Coors Farm area, and also in most of the rest of the San Luis Valley, was low and pump irrigation was necessary in many areas of the valley. The development of a low-cost canal sealing method was of immediate and widespread interest, but during the 1958 and 1959 irrigation seasons, above normal supplies of surface water were available and the water table was quickly restored to levels where subirrigation was again possible. Under the latter irrigation practice, leakage from the canals is desirable, and obviously canal sealing was not needed. For this reason, the trial work in this area was cancelled.

4 See REFERENCES at the end of the report.

On the other hand, however, it has been commonly noticed that muddy water seems to travel farther than clear water in ditches and on irrigated land, but usually the disadvantages of an uncontrolled muddy water far overshadow the advantages. Frequently, the advantages go unnoticed until canal cleaning or construction of an upstream dam reveals that there were, after all, some beneficial aspects to the muddy water. For example, in a drainage investigations report (3) for the Imperial Valley, Donnan, et al., in 1947 noted that:

> ". . . The 1940 map shows a spreading and enlarging of the high water-table areas in spite of a considerable increase in drainage facilities during the 10-year period (since the 1930 map). One reason for the apparently high water table of 1940 is that the excessive canal erosion of that year, due to the introduction of clearer water from the All-American Canal (and from Hoover Dam just completed) may have tended to aggravate seepage from the canal distribution system. . . ."

Similar effects have been noted in the North Platte Project (Wyoming and Nebraska) after Guernsey Dam was completed (4), and in the Big Horn Basin area (Wyoming) after Boysen Dam was completed. Thus, in irrigation canals that previously carried an intermittently muddy water supply, an entirely clear water supply can cause increased seepage loss, bank erosion, and growth of underwater weeds. It would appear then that while excess sediment can cause serious problems, a lack of sediment can also cause problems equally as serious. It is conceivable that the latter problems could be controlled by periodically adding back into the clear water a sediment of favorable characteristics to regain or duplicate only the benefits of natural silting.

Obviously, the idea of artificial silting in canals is not new. It is probably as old as irrigation itself. Many ditch organizations have tried silting--some with outstanding success but many with little or no visible favorable results. However, with clear-water problems of the magnitude caused by the construction of Hoover Dam, Guernsey Dam, Boysen Dam, and other similar dams throughout the West; an ample justification for an organized research project to develop canal sealing methods has been provided.

It is with the working hypothesis and justification outlined above that the sediment sealing project was organized at Colorado State University in July 1953. The project has been concerned mainly with colloidal clays, such as bentonite, as the sediment sealing agent and the early work was sponsored primarily by the Bureau of Reclamation and a number of irrigation districts and companies.

With the foregoing working hypothesis in mind, it will be realized that:

1. The research and development work as described herein emphasizes the artificial duplication of the beneficial effects of natural

silting. Duplicating the appearance or other physical characteristics of the conventional canal linings of concrete, asphalt, or compacted earth is not a goal of the work. If the conventional linings can be afforded, they should be used. Their costs are greater than for the sediment sealing methods and the benefits accompanying the conventional linings are also usually greater.

2. The measure of the effectiveness of the sediment sealing work should be based on a cost-to-benefits relationship--and not on a basis of whether or not a 100 per cent effective seal is produced or that the seal can be expected to last 100 years. In short, the sediment sealing is considered to be worthwhile if the direct costs of the work do not exceed the estimated value of the water saved for beneficial use by those diverting the water, plus any other observed benefits, such as reduced canal bank erosion or suppression of underwater weed growth. It will be noted, however, that the costs-to-benefits ratio is not calculated for the trials reported herein; the experimental cost is not a valid measure of the ultimate installation costs.

LATERAL 19.3 TRIAL

This site was included in the project program because it typifies the canal sealing and seepage problems of canals in loessial materials. Loess is an earth material which is found extensively as the sub-soil formation in many irrigated areas in Nebraska, Kansas, South Dakota, Washington, and Oregon. Its several unique features, as will be described in more detail later in this chapter, make it a troublesome foundation material for canals.

The Lateral 19.3 trial in this wind-deposited silt material was sponsored by the Central Nebraska Public Power and Irrigation District[1] of Holdrege, Nebraska. The District furnished the site, equipment (including a special mixer), supervision, labor, and materials. The advisory and evaluation activities of the University project were sponsored jointly by the District, the Agricultural Research Service, and the Colorado Agricultural Experiment Station.

The District has been cooperating with the sediment sealing project at the University since September 1953. Previous to the evaluation trial in Lateral 19.3, the District had completed three bentonite installations, which have been described in University reports (4, 5). The preliminary activites at the Lateral 19.3 trial are outlined in a University report (6). This chapter summarizes the Lateral 19.3 trial activities and results to January 1960.

Description of Trial Site

Lateral 19.3 is part of the E65 Main Lateral System of the District. It serves an area north and west of Bertrand, Nebraska. See Fig. 2 and Fig. 3. The elevation of the area is about 2600 feet above sea level.

The E65 Main Lateral is so named because it branches from the Main Supply canal at Mile 65, just above the inlet to Johnson Lake. It is 54.7 miles long, including its main branch E65-23.7. The system also includes about 194 miles of distribution laterals (including Lateral 19.3), supplying irrigation water to about 34,000 acres of land in the vicinity of Loomis and Bertrand, Nebraska.

The entire E65 irrigated area is underlain by Peorian loess. The Lateral 19.3 site was selected mainly because of its size, accessibility and general arrangement. The E65 irrigated area is on the bench or divide area separating the main valleys of the Platte and Republican Rivers so that the water-table depth is in excess of 100 feet for most of the area; consequently, seep damage to land in this area is not a major problem. It was not a factor in the selection of the Lateral 19.3 site.

Lateral 19.3 ranges in capacity from about 30 cfs at the upper end to about 10 cfs at Mile 4.4. Actually, the channel is much larger than the above capacities suggest. The average channel dimensions for each of the four ponds in the trial site (as obtained by District Survey crew--10-29-58) are outlined in Table 1:

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[1] Referred to as the District in this chapter.

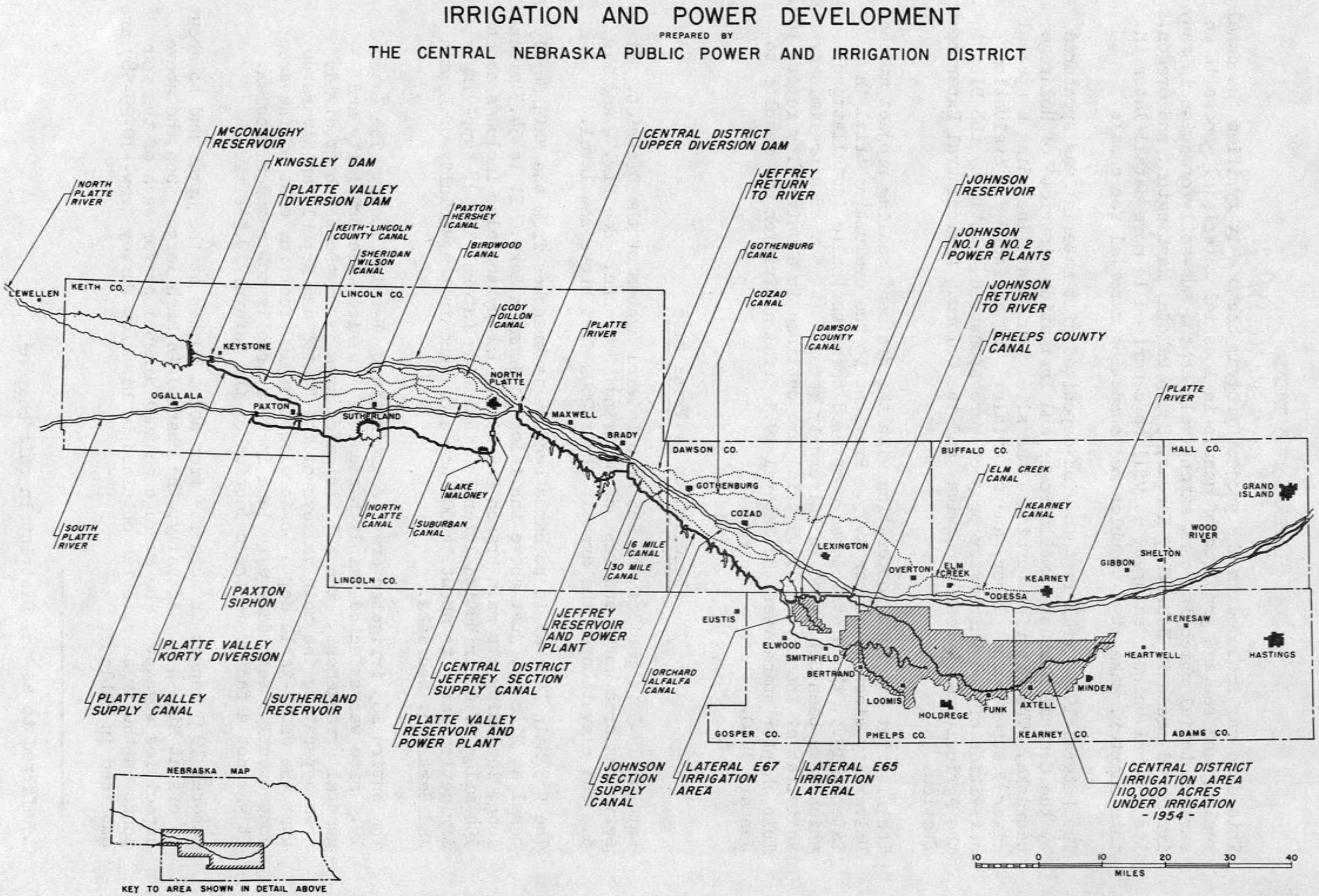

Fig. 2 Irrigation and power development of the Central Nebraska Public Power and Irrigation District

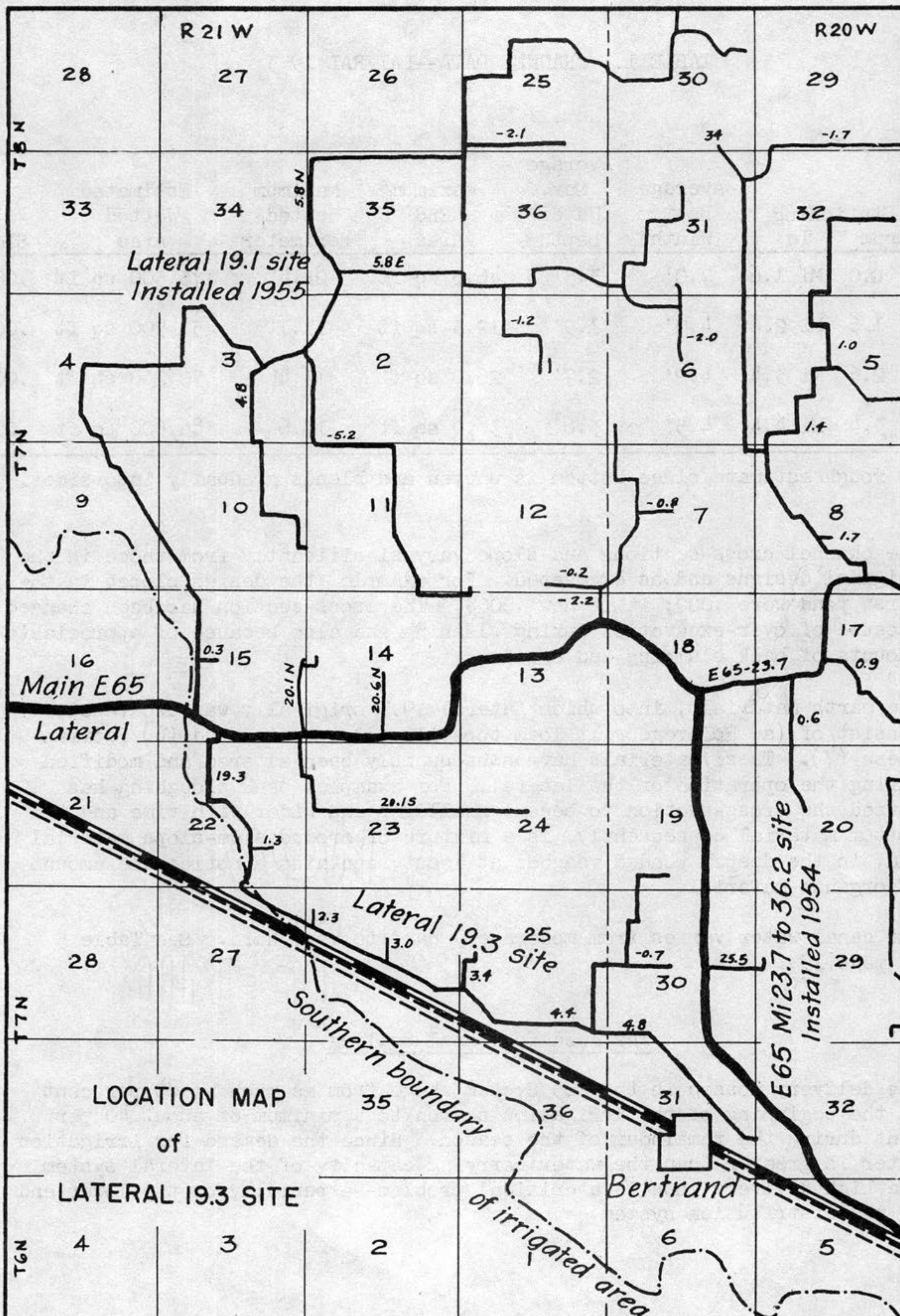

Fig. 3 Location map of the Lateral 19.3 site

TABLE 1. CHANNEL DATA--LATERAL 19.3

Pond No.	Stationing From	Stationing To	Average Bottom Width*	Average Max. Water Depth	Maximum End Area	Maximum Wetted Perimeter	Estimated Wetted Area	Slope
1	Mi 0.0	Mi 1.6	7.0'	3.5'	46.5 sq ft	21.4'	175,500 sq ft	.0003
2	Mi 1.6	Mi 2.6	4.0'	1.9'	12.3 sq ft	11.1'	55,900 sq ft	.0012
3	Mi 2.6	Mi 3.4	4.2'	2.7'	26.0 sq ft	15.4'	70,200 sq ft	.0006
4	Mi 3.4	Mi 4.4	4.5'	3.6'	38.0 sq ft	17.6'	86,600 sq ft	.0013

* Very rough estimate since bottom is uneven and blends gradually into sides.

The channel cross-sections and slope vary significantly from those in the original designs and as excavated. For example, the design slopes in the first pond were .002; it is now .0003. The cross-section has been changed because of over-excavation during cleaning and also because of appreciable amounts of bank slumping and erosion.

The earth materials, into which Lateral 19.3 originally was excavated, consist of (a) Holdrege silt loam topsoil and subsoil, and (b) Peorian loess (7). These materials have subsequently been altered and modified during the operation of the lateral. For example, bank sloughing has caused the cross-section to become shallower and wider with time and the bottom material consequently, is a mixture of eroded side-slope material and, in the deeper ponded reaches at least, contains a noticeable amount of organic material.

The canal water varies from moderately hard to very hard. See Table 5 on page 19.

The Need for Canal Sealing

The delivery losses in the E65 System range from as much as 80 per cent at the beginning of the irrigation season to a minimum of about 40 per cent during the remainder of the season. Since the demand for irrigation water is greater than the water carrying capacity of the lateral system, the high delivery loss is a critical problem--especially on the lower end of the distribution system.

Several methods of easing the problem have been considered by the District Engineers. Subsequent developments have included:

1. Supplying supplemental water into tailend laterals of the system by pumping from wells and the Phelps County Canal. This was a more economical solution than enlargement of the E65 Main Lateral.

2. Investigations into the sediment sealing methods of decreasing the seepage portion of the heavy delivery losses for the system.

In addition to the important potential water saving benefits, development of low-cost sealing methods for use in the E65 system is also important from a long range standpoint relating to the subsidence tendencies of the loessial material underlying the canals of the E65 system.

The loessial material in this area was deposited into a vegetal cover in a repetitive dust storm type of action. It has been altered to varying degrees by soil forming processes, but it generally retains the vertically trending "root and stem holes" or tube-like holes that characterize most loessial material. The subsidence and permeability features of loess are related to its structure.

As a consequence of this structure and low-bulk density, the loess has differing stability (a) under dry to partially saturated conditions, and (b) after prolonged saturation and loading. Under the dry to partially wet conditions, it commonly has a relatively high strength. Upon prolonged saturation and loading, the typical loess will settle. After the settlement is completed, the material will be denser and more stable than it was before, but during the settlement or transition period, critical and dangerous conditions of foundation settlement and general instability can result.

This structure of loess, and especially its permeability and stability characteristics, produces a unique response to weathering. The dry uncollapsed loessial material commonly weathers to nearly vertical side-slopes, such as commonly found in old road cuts in the loessial areas. Its weathering under water, however, is strikingly different. The saturated material is erosionally unstable except on very flat slopes and under relatively low water velocities.

Several techniques for controlling the settlement and seepage problems in loessial material under dams and major canal structures have been developed (8,9). However, since these methods involve consolidation of the in-place foundation material to considerable depth, they do not appear economically feasible for system-wide application in the case of the E65 Lateral System.

The bentonite sediment sealing investigations in the E65 system have been carried out with the thought that water salvage is the major potential benefit, but the sealing could have a stabilizing effect on the loessial foundation material under the laterals--at least to the extent that a reduction of canal seepage is reflected in a stabilized or reduced ground water level beneath the sealed sections of lateral[1]. It is also possible that the canal sealing could have some slight tendency to stabilize the lateral banks against excessive sloughing or erosion.

Preparation for Trial Installation

Preparation for the experimental work included: (a) seepage loss determinations, (b) sampling and testing of the site materials, (c) planning for the trial operation, and (d) final mix testing just before the trial.

Seepage Loss Determinations

The water measuring for the Lateral 19.3 trial was started in July 1957 and continued during the 1958 and 1959 irrigation seasons.

The first 4.4 miles of Lateral 19.3 was divided into four ponds. Inflow-outflow measurements were obtained for each pond by continuous recorders at the measuring stations. Each station was rated with a current meter by Mr. A. W. Hall, District Hydraulic Engineer, except at the headgate, which has a double-well measuring device. The lateral turn-out diversions for each pond were carefully measured by the patrolman for the lateral, Mr. Dean Houlden.

The possibilities of obtaining data on the ground water level fluctuations due to the seepage losses from the test reaches were investigated, but no nearby wells could be found that were suitable; and with the water table in excess of 100 feet deep in the area, test wells were not economically feasible.

Soil Sampling

During the period of October 28-30, 1958, the soil material exposed in Lateral 19.3 was examined and sampled. The results of the laboratory testing of the samples are summarized in Table 2.

---

[1] Past experience (8) indicates that the major subsidence problems are usually associated with a major rise of the ground water level into the loessial material.

TABLE 2. LATERAL 19.3 SOIL TESTS*

Pond	Station	Depth Inches	Sat. %	Ec x 10^3 at 25°C	H_2O Sol. Na me/Liter	H_2O Sol. Na me/100 gm	Total Na me/100 gm	Exch. Na me/100 gm	C.E.C. me/100 gm	ESP
1	20 + 00	0-2**	59.5	3.90	10.0	.60	1.62	1.02	23.8	4.3
		2-6	65.6	2.29	5.5	.36	1.20	.84	21.8	3.9
		6-12	52.2	1.18	4.0	.21	1.06	.85	20.8	4.1
2	100 + 00	0-4	48.4	1.16	4.9	.24	1.04	.80	19.4	4.1
		4-10	50.5	.82	3.7	.19	.96	.77	20.2	3.8
2	119 + 00	0-6	47.5	1.63	4.5	.21	.86	.65	18.2	3.6
		6-12	55.6	.82	2.7	.15	.80	.65	22.4	2.9
3	140 + 00	0-5	43.7	2.67	7.4	.32	1.00	.68	15.4	4.4
		5-12	44.1	1.21	4.5	.20	.87	.67	13.4	5.0
3	160 + 00	0-4**	58.8	3.68	8.7	.51	1.34	.83	19.8	4.2
		4-12	56.7	1.41	4.7	.27	1.18	.91	22.8	4.0
4	190 + 00	0-6	77.8	3.45	6.6	.51	1.34	.83	18.6	4.5
		6-12	56.7	4.23	7.6	.43	1.00	.57	17.8	3.2
4	210 + 00	0-3**	74.7	2.82	7.9	.59	1.56	.97	23.4	4.1
		3-12	63.5	3.11	6.5	.41	1.28	.87	24.2	3.6

* Analyzed by R. Miller, Soils Dept., CSU
** Dense black color due to organic content

TABLE 2 (cont'd)

Pond	Station	% Sand	% Silt	% Clay	Texture	pH	Lime
1	20 + 00	11.6	60.0	28.4	SCL	8.1	Yes
		11.2	58.8	30.0	SCL	8.1	Yes
		12.0	59.2	28.8	SCL	7.9	Yes
2	100 + 00	17.2	55.6	27.2	SCL	8.2	Yes
		16.8	54.0	29.2	SCL	8.1	Yes
2	119 + 00	17.2	57.6	25.2	SL	8.1	Yes
		15.6	52.0	32.4	SCL	8.0	Yes
3	140 + 00	19.2	60.0	20.8	SL	8.1	Yes
		23.6	55.2	21.2	SL	8.3	Yes
3	160 + 00	12.4	62.8	24.8	SL	7.7	Yes
		11.2	57.2	31.6	SCL	8.2	Yes
4	190 + 00	24.8	50.4	24.8	SL	6.1	No
		24.0	53.2	22.8	SL	7.2	Yes
4	210 + 00	14.0	53.2	32.8	SCL	8.1	Yes
		15.2	50.4	34.4	SCL	8.0	Yes

Consideration was also given to the possibilities of (a) obtaining undisturbed samples of the canal bed material for trial tests in the laboratory, and (b) detecting the depth of bentonite penetration in the canal bed material by laboratory test comparisons on samples collected before and after the field trial. Both possibilities were eliminated after exploring the extent and character of the larger holes, such as drying cracks and crayfish burrows[1], found in the site material, and then trying to visualize the effects of these holes on the validity of the sampling. It was decided that the sampling probably would miss entirely where the bentonite sealing could take place and, consequently, would yield test results that were meaningless, if not entirely misleading. See Figs. 4 and 5. Detailed observations, however, were obtained after the trial by digging into the bed material.

Planning for Operation

The four separate ponds in the Lateral 19.3 site made it possible to set up different treatments in three of the ponds, while retaining one untreated pond as a control section. The trial procedures for the ponds are listed in Table 3 below:

TABLE 3. LATERAL 19.3 TRIAL PROCEDURES

Pond	Procedure
1 Mile 0 to 1.6	Harrowing treatment only
2 Mile 1.6 to 2.6	No treatment--control reach
3 Mile 2.6 to 3.4	Dispersed bentonite mixture alone
4 Mile 3.4 to 4.4	Dispersed bentonite mixture plus harrowing

[1] The crayfish have been found in burrows extending in excess of 10 feet below the bottom of the canal.

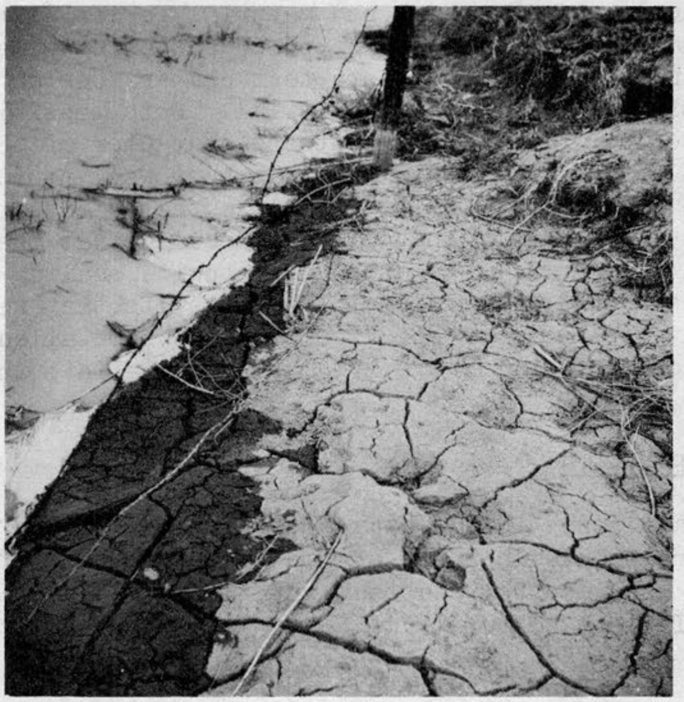

Fig. 4 Drying cracks in loessial material

Fig. 5 Crayfish burrows in Lateral 19.3 near Mi. 4.2

The calculation notes for determining the amounts of bentonite and dispersant required are included as Table 4.

Originally a treatment with a chemical dispersant only was planned for one of the ponds. Laboratory testing and a translation reference (10) had indicated that a sealing effect in loessial material could be obtained by treatment with dispersant only. In estimating the amount of dispersant that would be required, it was found that the cost would be prohibitive when compared with the potential benefits. For complete softening of water in Pond No. 3, the estimated cost was (a) \$3,280 for 200 ppm hardness, and (b) \$5,240 for 300 ppm hardness[1]. It was believed necessary to soften the water completely, if the desired conversion of the soil clay from a calcium to a sodium-dominated character was to be even partially achieved. Since the normal irrigation water is of a calcium-dominated character, there would be no assurance that the sealing action produced by the sodium substitution would be more than just a temporary condition. Also, to convert the channel material to a sodium-dominated soil could aggravate its already critical erosiveness.

Mixture Testing

On April 6, 1959, mixtures of the actual materials (canal water, bentonite, and dispersant) to be used in the sedimenting trial were tested in order to check the stability. The results indicated that the bentonite tended to flocculate. This is accounted for by the increase in hardness of the canal water over the previously tested water (See Table 5). Increasing the dispersant concentration from the planned 1.0 per cent to 1.5 per cent did not overcome this difficulty. From the standpoint of the ponding procedure, this was not a favorable development, but at this late date it was infeasible to postpone the operation. Thus, it was decided that the trial would be installed as planned--except that a bentonite mixture of flocculating tendencies would be substituted for the dispersed mixture originally planned.

In this case the flocculation tendency is interpreted as meaning that the sedimenting bentonite, which was of a sodium-dominated type, had been converted to a calcium-dominated nature. See Table 6. Actually, this conversion is inevitable in view of the calcium-dominated irrigation water, but in the ponding method of bentonite application a dispersed bentonite mixture is preferred--with the conversion to a calcium-dominated nature taking place during the harrowing, which terminated the ponding operation.

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[1]The amounts of dispersant required for complete softening of the irrigation water were obtained from a graph supplied by the Victor Chemical Works, Chicago, Illinois.

TABLE 4. LATERAL 19.3 CALCULATION NOTES

Pond No. 3

Length of reach	4,563 ft
Av. end area	26 sq ft
Vol. of Pond 3	118,638 cu ft
Plus 0.5' extra depth	31,128 cu ft
Plus est. shrink during filling	15,000 cu ft
Total est. Vol.	164,766 cu ft

$$\frac{164,800 \times 62.4 \times 1.2}{2000 \times 100} = 61.7 \text{ tons of bentonite}$$

$$\frac{61.7 \times 2000 \times 1}{100} = 1234 \text{ lbs of dispersant}$$

Pond No. 4

Length of reach	4,588 ft
Av. end area	38 sq ft
Vol. of Pond 4	174,344 cu ft
Plus 0.5' extra depth	35,786 cu ft
Plus est. shrink during filling	22,000 cu ft
Total est. Vol.	232,130 cu ft
Est. Vol. left from Pond 3	100,000 cu ft
Est. Vol. needed to fill Pond 4	132,130 cu ft

$$\frac{132,130 \times 62.4 \times 1.2}{2000 \times 100} = 49.4 \text{ tons of bentonite}$$

$$\frac{49.4 \times 2000 \times 1}{100} = 988 \text{ lbs of dispersant}$$

Total Materials for Lateral 19.3 Job

61.7 + 49.4 = 111.1 tons of bentonite

1234 + 988 = 2222 lbs of dispersant

TABLE 5. LATERAL 19.3 WATER ANALYSES

Sample Date	Location Mile	TDS ppm	TSS ppm	Ca ppm	Mg ppm	Na ppm	K ppm	Total Hardness as $CaCO_3$ ppm
3-3-54	0	656	312	70	26	--	----	282
8-20-58	0	750	110	92.5	30.5	75	12.6	---
8-20-58	4.4	744	45	91.5	29.5	77	12.4	---
10-7-58	0	512	47	55	19	70	12.2	217
10-7-58	4.4	513	57	52	17	68	13.6	210
4-7-59[1]	0	---	---	----	----	--	----	262
4-9-59	0	500	---	----	68	11	----	242
5-7-59	0	---	---	----	----	--	----	358
5-7-59	4.4	---	---	----	----	--	----	328
5-18-59	0	667	---	----	----	--	----	330
5-18-59	4.4	675	---	----	----	--	----	360
6-27-59	0	909	---	----	----	--	----	444
6-27-59	4.4	900	---	----	----	--	----	426
7-27-59	0	690	---	----	----	--	----	276
7-27-59	4.4	700	---	----	----	--	----	288
8-21-59	0	575	---	----	----	--	----	224
8-21-59	4.4	560	---	----	----	--	----	200
9-26-59	0	560	---	----	----	--	----	185
9-26-59	4.4	550	---	----	----	--	----	180

1 Sample of water used in bentonite trial work.

TABLE 6. ANALYSES OF BENTONITE USED IN LATERAL 19.3 TRIAL

	*1N Ammonium Acetate Extractable Ions				Cation Exchange Capacity me/100 gm
	Na^+	$Ca^{++} + Mg^{++}$ me/100 gm	K^+	Total Cations	
1. Granular Apr. 10, '59, Lat. 19.3 Inst.	93.5	48.0	1.5	143.0	82.5
2. Powdered - 4/9/59 Tri-County - Lat. 18.7	92.3	66.6	1.5	160.4	84.0
3. Tri-County - 4/9/59 Lat. 19.3 - MX - 80 American Colloid Co.	69.0	33.3	1.1	103.4	79.5
4. E-65-19.3 Sta. 160+00 Sample of bentonite layer on bottom of canal under 4 inches of silt	4.0	108.3	2.6	114.9	74.0

* Notes from Analyst

The 1N ammonium acetate extracts both water soluble and adsorbed (exchangeable) Na^+, $Ca^{++} + Mg^{++}$, and K^+. Hence the total cations extracted exceeds the cation exchange capacity. Not enough sample was available to make a saturated paste and determine water soluble ions. However, it looks as though most of the Na^+ is replaced by Ca^{++} + Mg when the bentonite is put in the ditch as lining, in this case, at least. The water in the canal is probably high in $Ca^+ + Mg^{++}$ and low in Na^+.

Installation Operation

The trial activities in Ponds No. 3 and No. 4 were completed during the period of April 6 to 9, 1959. The harrowing in Pond No. 1 was completed on June 25, 1959.

Mixing Procedure

The mixing phase of the Lateral 19.3 installation was completed on April 7, 1959.

A total of 101 tons of bentonite and 2100 lbs of dispersant, sodium tripolyphosphate, was applied from the mix point at the drop structure at Sta. 122+00 on the lateral. This point is about 1100 feet upstream from the water measuring location at Mile 2.6. The mixing was accomplished in about 10 hours, at an average rate of about 333 lbs of bentonite per minute. An excellent job of mixing was accomplished with the District's multiple jet mixer. See Fig. 6. The bentonite slurry at about 6 per cent concentration was discharged into a diluting flow of canal water at the drop structure. See Fig. 7. The final concentration of the sedimenting mixture was maintained at or near one per cent by adjustment of the flow of diluting water according to hydrometer readings.

The bentonite, all powdered except 10 tons of granular, was of a moderately high-swell type, supplied by the Benton Clay Company of Casper, Wyoming. The dispersant, a granular grade of sodium tripolyphosphate, was supplied by the Victor Chemical Works of Chicago, Illinois.

Ponding Operation

The mixture was first stored in Pond No. 3, and when it was full, the overflow was stored in Pond No. 4. Upon completion of the mixing at 8:15 p.m. on April 7, 1959, a small flow of about 100 gpm of clear water was continued into Pond No. 3. This caused a small amount of overflow of bentonite mixture into Pond No. 4.

On the following morning of April 8, 1959, Pond No. 3 lacked about 5 inches of being full and Pond No. 4 lacked about 2 feet of being full. Originally, it had been planned to hold the bentonite mixture in Pond No. 3 for at least 24 hours, but because of the flocculation and settle-out of bentonite, the mixture remaining in Pond No. 3 was drained immediately into Pond No. 4 during the morning of April 8, 1959. This was accomplished with an inflow into Pond No. 3 of about 10 cfs of canal water which subsequently was reduced to the 100 gpm flow after the bentonite mixture remaining in Pond No. 3 had been flushed into Pond No. 4.

The bentonite mixture was held in Pond No. 4 until all of the bentonite had settled out of suspension. The bentonite settle-out was hastened by harrowing. See Fig. 8. Two sections of a spring-tooth harrow for a total width of 8 feet were used for the harrowing. One round trip with the harrow was made on April 8, 1959, and two round trips or four passes were made on April 9, 1959.

In general, the bentonite flocculation and settle-out produced (a) an overtreatment of the bottom in Pond No. 3, except the last 200 to 300 feet, (b) an under-treatment of the banks in Pond No. 3 and the bottom of Pond No. 4, except the last 300 to 400 feet, and (c) virtually no bentonite treatment of the end sections in both ponds and of the bank areas in Pond No. 4.

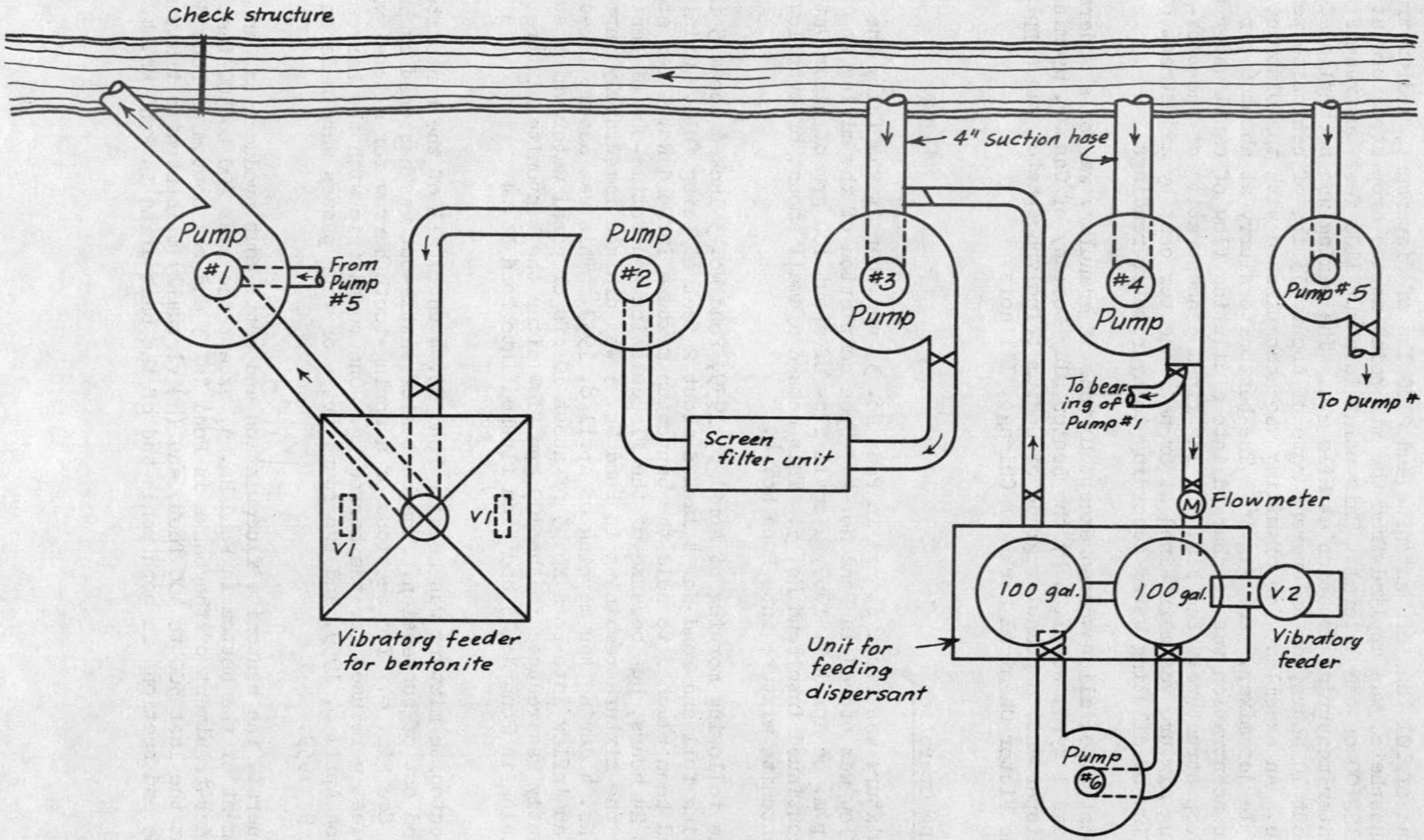

Fig. 6 Mixing equipment arrangement for the Lateral 19.3 trial

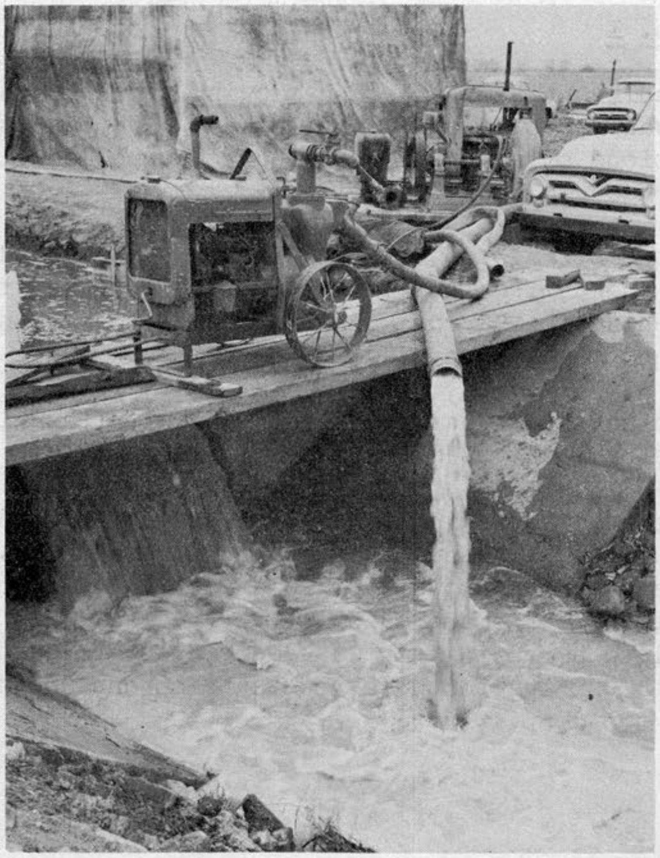

Fig. 7 Bentonite slurry being added to diluting water in the Lateral 19.3 trial

Fig. 8 Harrowing in Pond No. 4 in Lateral 19.3 trial

Harrowing in Pond No. 1

In an effort to establish the effect of harrowing alone on the seepage loss rates, Pond No. 1 was harrowed on June 25, 1959. Two passes (up and back) with two 4-foot sections of a spring-tooth harrow were made. A 4-foot single section of a rotary hoe was also tried.

The harrowing with the spring-tooth harrow in Ponds No. 1 and No. 4 produced some disturbance of the soil on the lateral bottom because it noticeably muddied the water behind the harrow, but harrowing of the banks was not feasible with the equipment setup used in the trial.

The rotary hoe would not track in a straight line with the hitching arrangement used and, therefore, was used for a short time only.

The major problems of the harrowing were (a) clogging by weeds, requiring frequent cleaning, and (b) inadequate coverage of bank areas. Neither the spring-tooth nor the rotary harrows were as effective as hoped for, and actually, because of the extreme erodability of the soil, it was questionable whether a complete harrowing job was desirable--at least not with an implement such as the spring-tooth harrow that loosens and springs the soil when it is set too deep.

Installation Costs

The total cost to the District for the Lateral 19.3 work was $5,585.00. This may be broken down to (a) bentonite $2,450.00, (b) dispersant $215.00, and (c) labor and equipment $2,910.00

Evaluation of Results

The general effectiveness of the trial procedures and sealing was evaluated by (a) visual observations, and (b) seepage loss measurements. (Fig. 9).

Visual Observations

After-treatment examinations of the soil materials in the treated sections were completed on November 27, 1959.

In Pond No. 3, the bentonite was found as a layer on the bottom of the canal buried under a 1 to 6-inch layer of eroded bank materials. This layer ranged from a trace to as much as 2 inches thick. The maximum thickness was found toward the lower end of the pond, except that only a trace of bentonite was found at the extreme downstream end. This layer diminished at the banks. No bentonite could be found on the side slopes except as a filler material in random cracks.

In Pond No. 4, the bentonite was found in some random cracks but no definite layer of bentonite could be found in the canal bottom.

Fig. 9 Water measuring set-up at Mi. 2.6 Lateral 19.3

Seepage Loss Measurements

The results of the water-loss measurements for 1957, 1958, and 1959 are summarized in Table 7[1]. The delivery loss experience for each of the trial ponds is discussed herein.

Pond No. 1 -- From the data in Table 7, it may be seen that the harrowing treatment on June 25, 1959, had no obvious effect. The loss rates for Pond No. 1 show considerable scatter between months and years; and the daily records immediately before, during, and immediately after the June 25, 1959, harrowing, also do not indicate a significant effect. The losses during this period were: June 23--3.3 cfs; June 24--3.5cfs; June 25--3.1 cfs; June 26--3.4 cfs; June 27--3.5 cfs; June 28--3.4 cfs; and June 29--3.4 cfs. This lack of effect is not surprising since the harrowing was cut to a minimum for fear of aggravating the bank sloughing problem.

Pond No. 2 -- This was the control pond which was not subjected to a treatment of any kind. Inexplicably, this is the only pond in which a significant decrease in seepage rate was noted for the season. The data in Table 7 show that the 1959 losses for Pond No. 2 are considerably reduced from those for the preceding two years, except for the month of June. No obvious reason for this incongruity can be noted--except perhaps that it represents a plus or minus variation or accuracy deviation in water measuring. It does seem significant, however, that this is the only pond in which the water is not ponded to any appreciable extent during normal operations. Note the water depths, wetted perimeter and end areas for each of the ponds as listed in Table 1 on page 12.

Pond No. 3 -- This pond was treated with a flocculating bentonite on April 7 and 8, 1959. No significant sealing effect can be noted in Table 7 for this pond, except perhaps for the month of April 1959 immediately following the installation. In view of the bank sloughing problem, the bentonite flocculation difficulties, and the visual observation results, it is concluded that the bentonite treatment was concentrated on the lateral bottom with only a partial and temporary sealing effect in the lateral side-slope material. This seems to pinpoint the seepage difficulties to the side-slope areas since the bottom is being naturally sediment-sealed by the bank sloughing action, and also since no significant difference in seepage rate was noted even though the bottom areas was adequately treated with bentonite

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1 Outlined in a memorandum from Mr. A. W. Hall to Mr. Ted Johnson, Assistant Chief Engineer for the District, dated December 7, 1959

TABLE 7. SUMMARY OF LOSS DATA FOR LATERAL 19.3

		Pond No. 1			Pond No. 2			Pond No. 3			Pond No. 4		
		Mile 0 to 1.6			Mile 1.6 to 2.6			Mile 2.6 to 3.4			Mile 3.4 to 4.4		
Month	Year	Av. Inflow cfs	Av. Loss cfs	CFD*	Av. Inflow cfs	Av. Loss cfs	CFD*	Av. Inflow cfs	Av. Loss cfs	CFD*	Av. Inflow cfs	Av. Loss cfs	CFD*
April	1959	6.9	4.8	2.3	1.9	0.5	0.8	1.4	0.6	0.8	0.8	0.4	0.4
May	1959	10.2	3.6	1.8	6.6	0.04	0.1	6.5	1.6	2.0	4.7	0.8	0.8
June	1958	10.8	1.8	0.9	8.5	0.3	0.5	8.2	3.0	3.6	5.0	1.5	1.5
June	1959	13.2	3.3	1.6	9.2	0.7	1.1	8.4	1.2	1.4	6.2	0.3	0.3
July	1957	19.0	1.8	0.9	10.0	0.9	1.4	9.1	1.5	1.9	5.5	1.3	1.3
July	1958	11.8	1.8	0.8	8.5	0.7	1.0	7.8	2.2	2.6	3.9	1.1	1.1
July	1959	13.5	3.1	1.5	9.0	0.2	0.4	7.6	1.8	2.2	3.6	0.7	0.7
Aug.	1957	12.4	2.0	1.0	9.7	0.5	0.8	9.0	1.6	1.9	6.2	0.9	0.9
Aug.	1958	13.2	2.3	1.1	12.4	1.1	1.7	11.3	1.3	1.6	7.1	1.1	1.1
Aug.	1959	12.5	2.5	1.2	9.3	0.3	0.5	9.0	1.1	1.3	8.9	1.3	1.3
Sept.	1957	11.8	1.6	0.8	11.8	1.6	2.5	8.5	1.4	1.7	5.0	1.4	1.4
Sept.	1958	12.6	2.8	1.4	12.6	2.8	4.4	10.0	1.3	1.6	6.4	1.45	1.5
Sept.	1959	11.9	1.4	0.7	9.0	0.05	0.8	9.0	1.4	1.6	6.1	1.3	1.3

* CFS = Cu ft/sq ft/24 hours.

Note: Data not corrected for evaporation--it seldom exceeds 0.05 ft/day.

Pond No. 4 -- This pond was treated with the bentonite left from Pond No. 3 and, in addition, the bottom area was harrowed during the ponding. The sealing results as indicated by the data in Table 7 are similar to those obtained for Pond No. 3, except that there is slightly more of a sealing effect in this pond.

Bank Erosion Problems

The erosion and sloughing of the banks of the canals in the E-65 System is a serious problem, not only becuase of the harmful effect on the bentonite sediment sealing work, but also because of its long-range effect on the width of the canal in relation to its limited right-of-way.

Several factors enter into the canal bank erosion problem. First, as the German origin and meaning of the word "Loess" implies, the loessial material is subject to loosening or dissolving when exposed to water.

Secondly, because of the extreme erodability of the soil and also because of the need for storage in the E-65 System, many of the canals are oversized. This greatly reduces the water velocities and hence also the erosion due to the flowing water, but it creates many wide canals in this area of frequent high winds. Thus, wave-induced beaching is now a serious contributing factor to the bank erosion. The seepage losses from the large deep sections are also greater than they would be for a smaller, faster flowing section.

A third complicating factor is the extreme infestation of crayfish in many sections of the E-65 Lateral System. The crayfish seem to favor making their burrows just below the water line. Crayfish have been encountered as previously mentioned, in burrows extending as much as 10 feet below the bottom of the canals. Thus, their burrows plus the burrowing of other animals, such as raccoons, in pursuit of the crayfish, contribute much toward the overall bank sloughing problem, and incidentally toward an early failure of any possible seal produced by the bentonite sedimenting or by natural sedimenting of the muddy canal water[1].

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1 The water entering the District canals is normally clear; it probably picks up its sediment content enroute by erosion of the banks and bed.

Conclusions and Recommendations

The first obvious conclusion is that the sealing results were not favorable. It is further concluded that before the District canals can be sealed with a method such as the bentonite sedimenting method, the erosion or bank stability problem must be controlled. Several suggestions and recommendations in regard to erosion control, and also in regard to needed changes in sediment sealing procedures, are listed below:

1. Crayfish control -- The first step must involve control of the crayfish population in the canals. This seems to be a field where additional research is badly needed--it is a serious and widespread need in many irrigated areas.

2. Stabilization of banks and bed -- After control of the crayfish, development of a low-cost, easily-installed stabilization method for the loessial materials exposed in the District canals is the next priority consideration. Since this chapter is concerned with the bentonite sedimenting, the recommendations include possible methods of stabilization that can be incorporated as part of the sediment sealing operation. It is believed that while a clay sediment alone will have some stabilization tendencies, its effect could be greatly enhanced by the addition of chemical binding or flocculating agents. It is recommended that a systematic search be made for chemicals that show promise in this regard.

3. Chemical agents -- As a beginning, it is recommended that the following chemical materials be tested: General Mills--Aliquat, Monsanto--IBMA, Dow--Separan. Aliquat is one of the chemicals used in treating "wash and wear" shirts. Its favorable potential in regard to soil stabilization applications relates to its waterproofing characteristics when applied to clay. It shows promise, when used as a spray material in loess soil, of controlling the "shrink and swell" on drying and wetting. The IBMA and Separan materials are commonly used as soil aggregators or flocculants. For example, Separan has been used as a flocculating agent for muddy waters used in ground-water recharge projects. In this application it has been noted that the "settled or flocculated" material is partially cemented or bound together. This potential cementing characteristic is of direct interest in canal bank stabilization as part of a bentonite sediment sealing operation.

4. <u>Modified operation</u> -- If chemical flocculating and soil binding agents are to be incorporated into bentonite sedimenting work, it will mean that an installation method differing radically from that used in the Lateral 19.3 installation must be developed. For one thing, a flowing water method of application should be substituted for the ponding method used unsuccessfully in the Lateral 19.3 work. This would remove several serious shortcomings of the Lateral 19.3 method. The work could be accomplished during the irrigation season rather than during a very short period just before the irrigation season. It could involve the use of a calcium bentonite which could be used in a low-cost pit-run condition rather than a sodium bentonite that must be obtained in processed form. By utilizing the natural mixing energy at canal drops, the calcium bentonite could be mixed at very low cost rather than with the relatively expensive machine mixing required for the sodium bentonite. In short, an effort should be made to find a clay material, stable in the hard water common to the E-65 System, that can be utilized in a low-cost pit-run form and mixed naturally by being dumped in at a canal drop. Thus, several repeated treatments during one season will be economically feasible. In addition, this material should be susceptible to binding by small amounts of chemical flocculating agents so as to obtain bank stabilization and canal sealing benefits.

5. <u>Water weed suppression</u> -- As a method is developed involving several treatments or intermittent additions of small amounts of colloidal clay sediment into the canal water, systematic observations of the effect on the growth of submerged water weeds should be included. It is likely that limited beneficial suppression effects will be noted.

6. <u>Possibilities of reducing operating depths</u> -- It is believed that the wave-erosion problems on the deep-ponded, wide reaches of canal may, in some instances, be of greater seriousness than the erosion problems caused by the faster flowing water of the unchecked reaches. It may not be feasible to do this because of other complicating factors, such as the elevation of turn-out gates, but it is recommended that the possibilities of reducing the water depths in the canals of the E-65 System be investigated. Reducing the depth would be helpful not only from the standpoint of the wave-erosion, but also from the standpoint of reducing the wetted area requiring stability and seepage control treatment.

COACHELLA CANAL TRIAL

The Coachella Canal site was included in the test program because of its continuously-operated feature. This site typifies the canal sealing and seepage loss problems found in continuously-operated canals of large size and in a warm climate.

The trial activities at this site were sponsored by the Imperial Irrigation District of Imperial, California, who accomplished most of the preliminary development and evaluation work and paid for the installation. The advisory and evaluation activities of the University project in this trial were sponsored jointly by the District, the Agricultural Research Service, and the Colorado Agricultural Experiment Station. Other cooperators in the development work by the District include: The Bureau of Reclamation, the Brown Mud Company of Torrance, California, the Dow Chemical Company of Pittsburg, California, and the Monsanto Chemical Company of St. Louis, Missouri.

Investigation into the possibilities of using water-borne sediments for sealing was started by the Imperial Irrigation District in 1955. The early exploratory efforts were made by J. M. Sheldon, Superintendent, All-American Canal Section of the District, in cooperation with R. D. Dirmeyer, Jr., of the University project. From this initial inventory of the canal seepage conditions in the District area during the fall of 1955 and the spring of 1956, it was decided that the research and development activities on sediment sealing methods for the District would be concentrated on Reach No. 2 of the Coachella Canal from Station 300+00 to 713+10

This chapter summarizes the Coachella Canal trial activities and results to January 1960.

Background Information

The Coachella Canal is one of the major supply canals delivering Colorado River water into the Imperial Valley. It delivers a limited amount of irrigation water to the East Mesa area of the Imperial Irrigation District, but its present main function is to deliver water to the Coachella Valley County Water District in the north end of the Imperial Valley, north of the Salton Sea. Operation of the Canal began in 1945; on May 1, 1952, the Imperial Irrigation District assumed operation and maintenance[1] of a portion of the canal from the All-American Canal to the 6A Check, a distance of 49 miles. See Fig. 10.

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[1] At joint expense with the Coachella Valley County Water District.

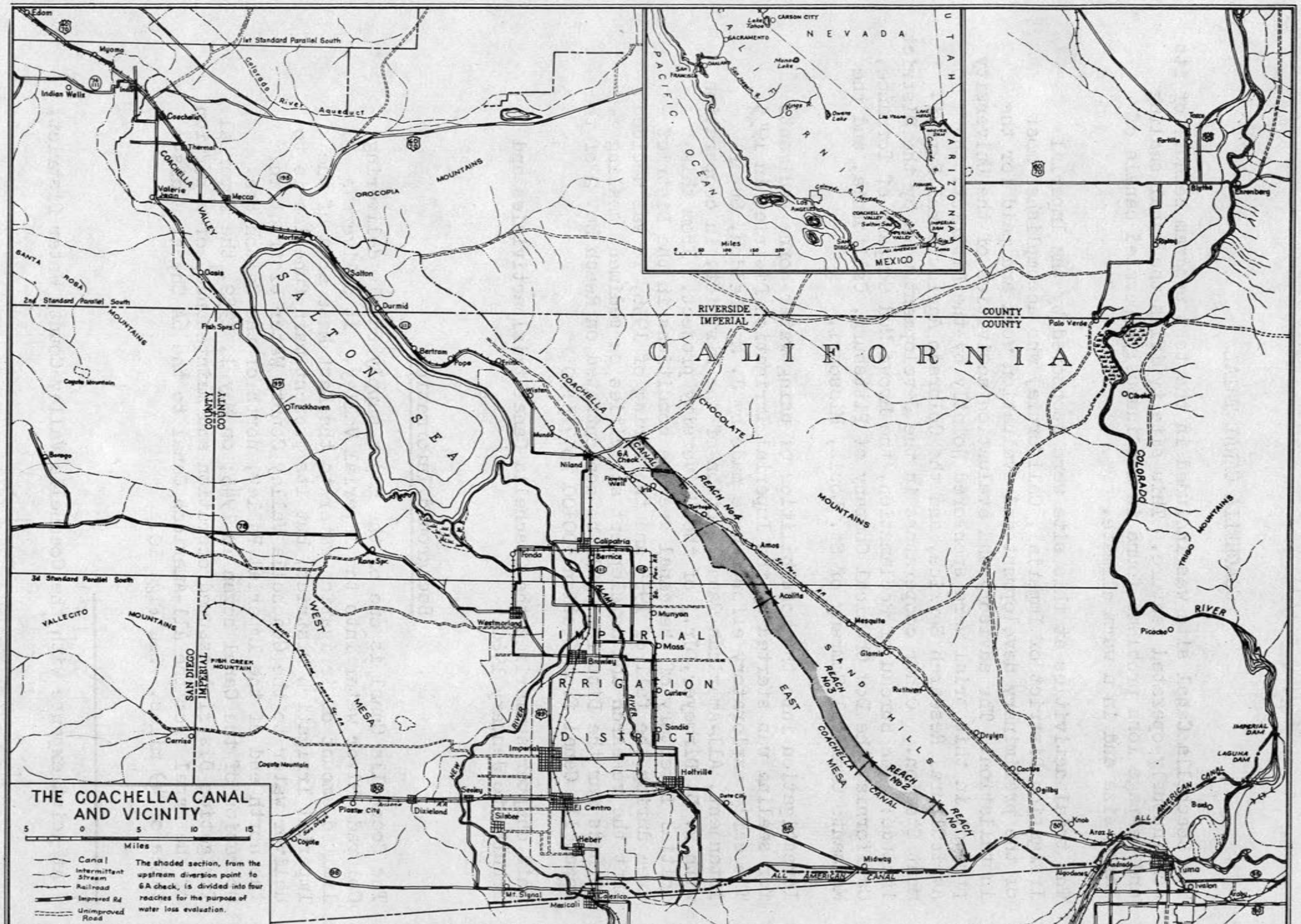

Fig. 10 Location map of Coachella Canal site

The Imperial Irrigation District[1] serves an area extending from the International Boundary about 45 miles north to the Salton Sea and having an average width of about 25 miles. It includes within its boundaries some 1,000,000 acres of land and delivers water to about 500,000 cultivated acres of land. To accomplish this delivery the District operates and maintains about 1800 miles of irrigation canal. It is noteworthy also that the District has constructed and now operates and maintains almost 1500 miles of open drain, ranging in depth from 4 to 14 feet.

Climatically, the Imperial Valley is characterized by low annual rainfall, low humidity and high summer temperatures. Since the average annual precipitation is only about three inches in this relatively frost-free desert area, all of the crops are grown under irrigation.

Water for irrigation was first brought from the Colorado River into this below-sea-level area in 1901. Obstructing sand dunes on the American side of the International Boundary and a natural channel on the Mexican side made a Mexican route favorable for the original main canal. However, in 1942 a cut-off entirely on the U.S. side was completed through the sand dunes. The 80-mile-long All-American Canal brings water to the southern end of the Valley, where it is conveyed northward in four main canals, one of which is the Coachella Canal. The other canals branch into laterals delivering water to each 160-acre tract.

The soils of the Imperial Valley reflect the complex geological history of the area. The valley is a graben which has been gradually depressed, and at the same time, encroached upon by the delta of the Colorado River. Thus, in relatively recent geologic time, the Colorado River has flowed alternately into the Salton Sea basin, raising the water level of the Salton Sea, and then into the Gulf of California, permitting evaporation to shrink the Salton Sea. At the present time, a low flat ridge with a maximum elevation of about 47 feet above Pacific Sea level and 60 miles wide separates the Salton basin from the Gulf. The maximum depth of the basin is about 271 feet below the Pacific Ocean level and the present surface level of the Salton Sea is about 234 feet below the Pacific Ocean level.

As a result of the actions described above, a random mixture of stratified soils is found in the Imperial Valley. Colorado River delta deposists are interlayered with alluvial fan materials from the surrounding mountains. This complex mixture of soil materials has been further altered and modified by drying and wetting processes and wind and wave erosion as the shore line of the Salton Sea alternately advanced and declined. Extensive sand dune areas are found, especially on the east side of the valley.

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1 Referred to as the District in this chapter.

The most recent incursion of the Colorado River into the valley occurred during 1905 and 1907 when the flood flows of the river eroded the channel of the old main canal past the point of control. Bringing the channel back under control proved to be an extremely expensive chore, but the rampaging river did produce one important benefit. Two deep channels were formed in the valley: the Alamo and the New River channels. These channels now act as main drainage trunks, carrying the flow from the drainage ditches to the Salton Sea.

The Need for Canal Sealing

With the beginning of operation of the Coachella Canal in 1945 it was apparent that large quantities of water were being lost from the unlined earth section. Later studies show that, while the actual rate per square foot of wetted area was not excessive, the total accumulative amount lost was quite large because of the great size of the canal and its length. This canal, together with the All-American Canal offered a good opportunity to save substantial quantities of water if an economical sealing method could be determined. District records indicate that for the upper fifty miles of canal the annual loss has ranged from 130,000 to 190,000 acre-feet per year.[1] The value of conserving such large amounts of water is self-evident.

Conventional canal linings of concrete, asphalt or compacted earth possibly could be employed for control of the seepage losses, but aside from the tremendous cost of these linings when applied on a large scale, the necessity of placing these linings in a dry canal would be a major stumbling block for the continuously-operated canals in the District area. Therefore, the development of a sediment sealing method, requiring little or no interruption of water deliveries, is a pressing research need in the District area.

Description of Trial Site

The site selected for the research and development work in the District area is Reach No. 2 of the Coachella Canal. This reach starts at the water measuring cable-way at station 300+00, a short distance downstream from the check and drop at station 288+15. It starts in a cut (about 34 feet deep) below the drop and gradually surfaces in the section down to the first curve at about station 500+00 (See Fig. 11). The downstream end of Reach No. 2 is at the water measuring cable-way just a short distance upstream from the canal bridge at station 713+10 (See Fig. 12). The reach is about 7.82 miles long. The nearest town is Holtville, California.

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[1] Personal communication with Mr. A. J. Boles, Chief Civil Engineer, Imperial Irrigation District, Imperial, California.

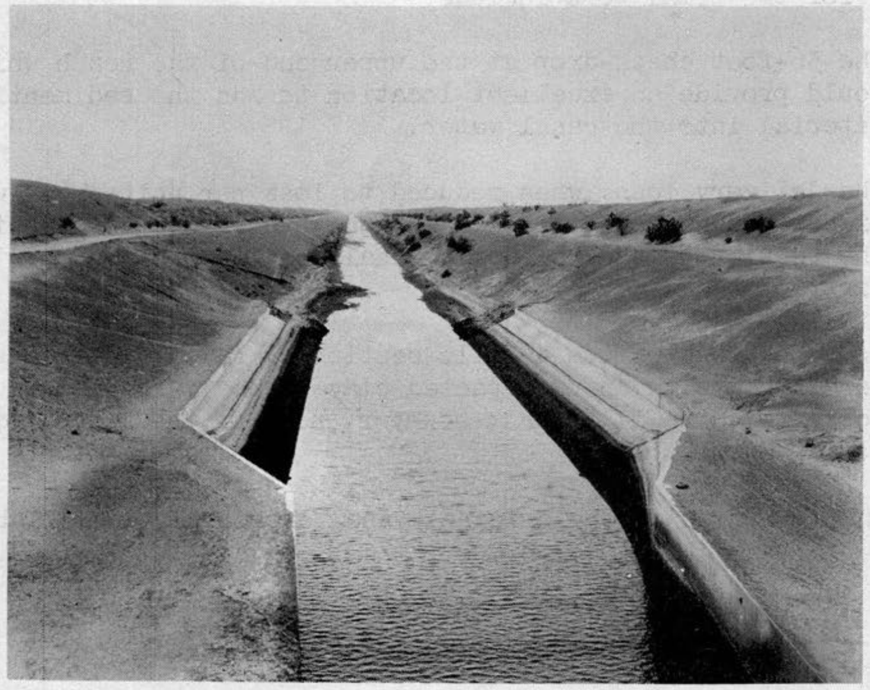

Fig. 11 View of the Coachella site downstream from drop at Sta. 228+15

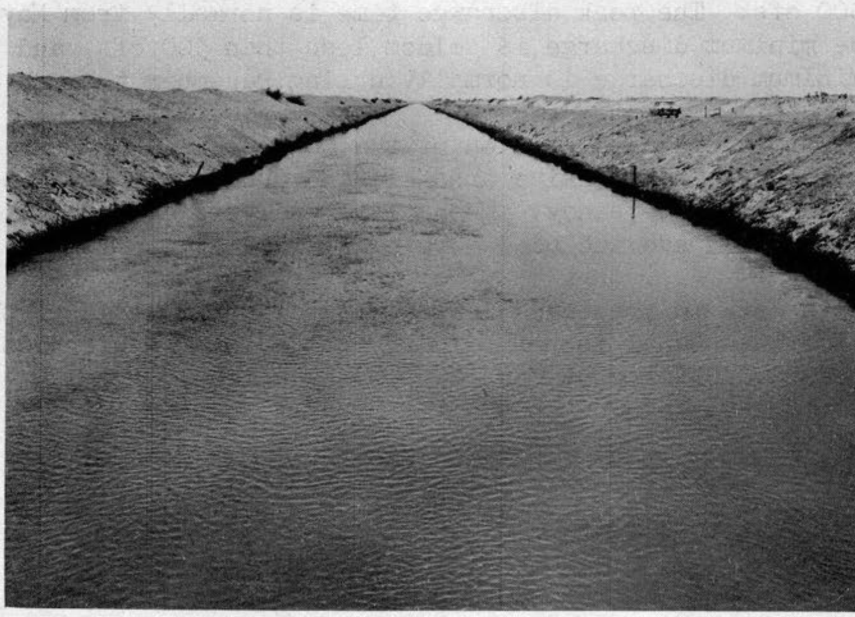

Fig. 12 View of the Coachella site upstream from canal bridge at Sta. 713+10

This section of canal was selected as being representative of conditions found elsewhere in the Coachella Canal, and to some extent in the All-American Canal. Other factors leading to the selection of this site for the trial work include:

1. The 36-foot check-drop at the upper end of the reach which would provide an excellent location to add the sedimenting material into the canal water.

2. The delivery loss, when reduced to loss per unit area, was higher for Reach No. 2 than for the other four reaches in the section of the Coachella Canal that is operated by the District.

3. Some portions of the 49-mile section operated by the District were lined with an uncompacted clay blanket, ranging in thickness from 6 to 12 inches; however, none of the lined portions was in Reach No. 2.

The design properties of the original canal are tabulated in Table 8 below:

TABLE 8 DESIGN DATA--COACHELLA CANAL

Station From	Station To	Max. Cap. cfs	Side Slope	Max. Area sq ft	Max. Vel. ft/sec	Bot. Width ft	Max. Depth ft	Grade
0	288+15	2500	2 to 1	833.3	3.0	60	10.33	.0001
293+85	827+50	2200	2 to 1	733.0	3.0	52	10.14	.0001+

The maximum discharge into the Coachella Canal, up to the present time, is about 1300 cfs. The peak discharge time is normally from May through August. The minimum discharge is seldom less than 300 cfs, and the period of minimum discharge is normally during December through January.

Since the District-operated section of the Coachella Canal runs along the western edge of an extensive area of sand dunes, the canal bed and bank materials are quite sandy. Mechanical analysis data for a set of bed and bank samples are included herein as Figs. 13 and 14.

Water analysis data are presented in Table 9. The silt load of the water in the All-American Canal is periodically tested by the District and it seldom exceeds 0.010 per cent (or 100 ppm) by weight.

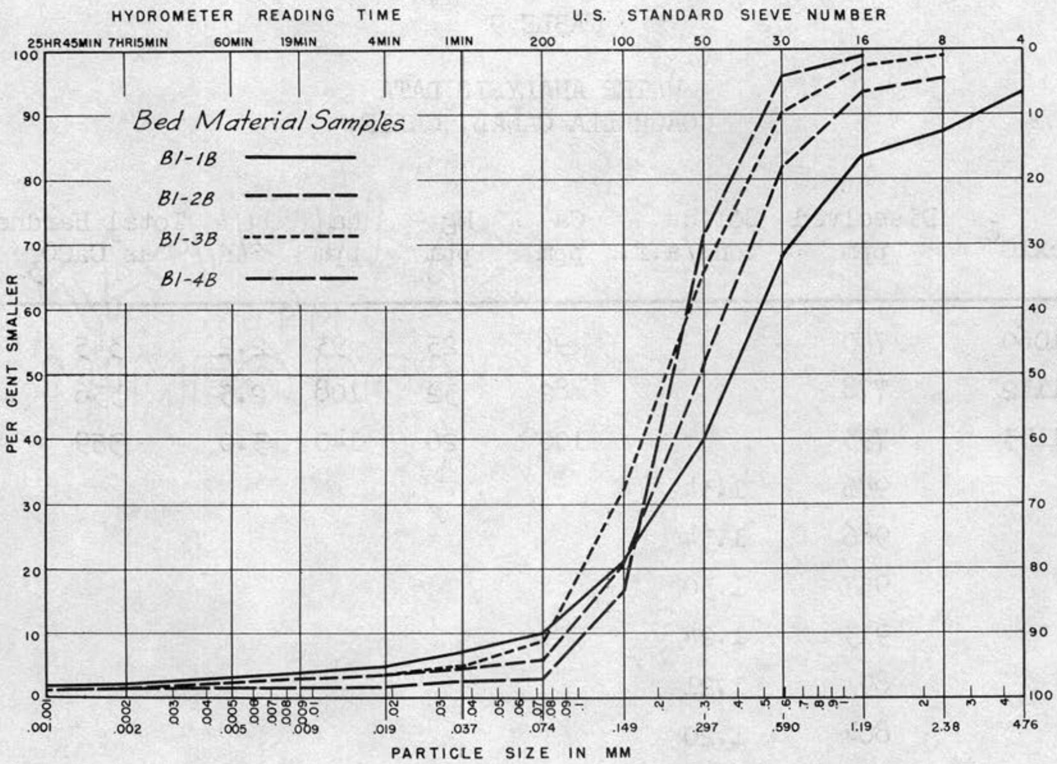

Fig. 13 Size distribution curves for bed material samples in the Coachella Canal

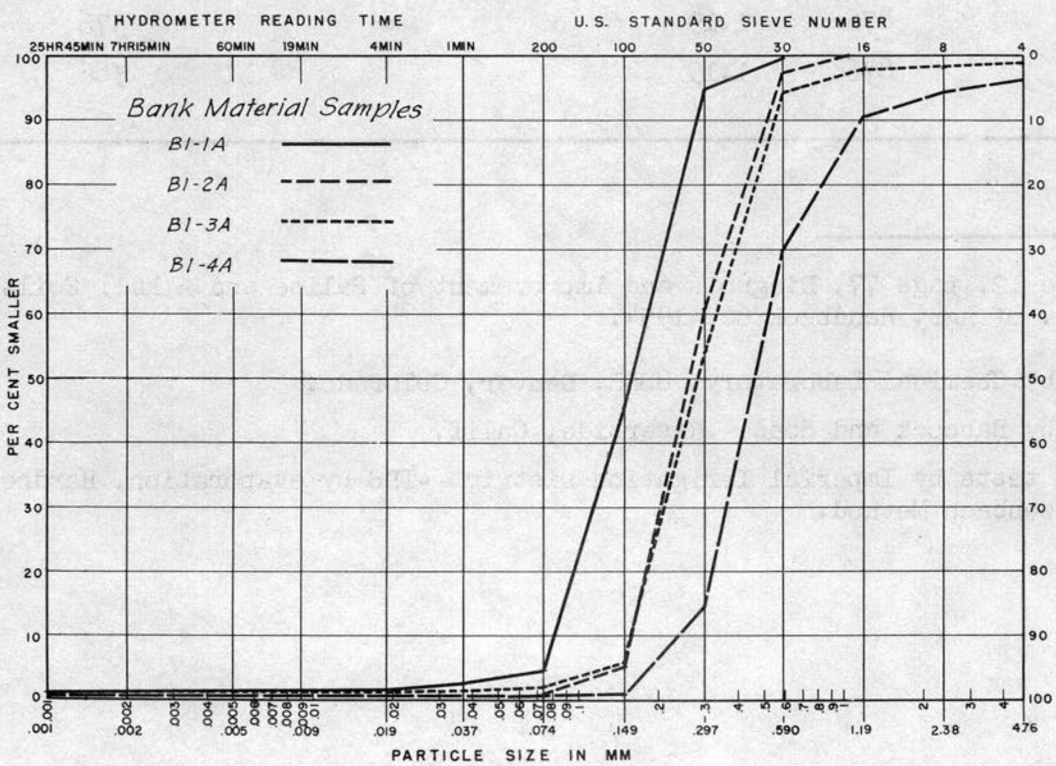

Fig. 14 Size distribution curves for bank material samples in the Coachella Canal

TABLE 9

WATER ANALYSIS DATA
COACHELLA CANAL, CALIF.

Date Sampled	Ecx10[6]	Dissolved ppm	Solids tons/a.f.	Ca ppm	Mg ppm	Na ppm	SAR	Total Hardness as $CaCO_3$
3-21-43[1]	1060	740		96	25	93	2.2	345
7-7-54[2]	1112	778		82	32	108	2.5	336
11-7-57[3]	1133	793		100	26	140	3.0	359
1-3-57[4]		986	1.34					
2-1-57		986	1.34					
3-1-57		957	1.30					
4-3-57		913	1.24					
5-1-57		891	1.21					
5-31-57		884	1.20					
7-1-57		780	1.06					
7-31-57		847	1.15					378
8-31-57		876	1.19					372
10-1-57		891	1.21					376
11-1-57		876	1.19					376
11-27-57		876	1.19					386

[1] From Table 12, page 77, Diagnois and Improvement of Saline and Alkali Soils, U.S. Dept. of Agr. Handbook 60, 1954.

[2] Analysis by Chemical Laboratory, USBR, Denver, Colorado.

[3] Analysis by Babcock and Sons, Riverside, Calif.

[4] Remaining tests by Imperial Irrigation District--TDS by evaporation, Hardness by Schwarzenbach Method.

Before-Trial Activities

Because of the large size and general complexity of the Coachella Canal trial site, considerable preliminary work was accomplished before the trial installation was made. The preliminary activities included: (a) setting up procedure for evaluating the sealing results, (b) development of methods for sampling of the canal bed and bank materials, (c) sampling and evaluation of potential sediment-sealing agents, and (d) small-scale sealing experiments, both in the laboratory and at the field site, with the most promising sediment-sealing agents.

Evaluation Methods

Three methods for detection of the sealing results were set up: Inflow-outflow measurements, piezometer readings and ground water level observations.

Inflow-outflow Measurements -- In January 1955, the District-operated section of the Coachella Canal was sub-divided for water measuring purposes into the following reaches (11):

Reach No. 1 -- Sta. 10+00 to 300+00 -- length 5.49 miles.
Reach No. 2 -- Sta. 300+00 to 713+10 -- length 7.82 miles.
Reach No. 3 -- Sta. 713+10 to 1653+50 -- length 17.38 miles.
Reach No. 4 -- Sta. 1653+50 to 2619+10 (6A Check) -- length 18.30 miles
District-operated section -- Sta 10+00 to 6A Check -- Total length 48.99 miles.

Two new current metering stations, including continuous gage recorders, were set up at the canal bridges at Sta. 713+10 and 1653+50. Discharge measurements had been obtained at the other current metering stations (Sta. 10+00, 300+00, 6A Check) since 1945.

Piezometer Installations -- Starting in February 1957, piezometer stations were established as indicated in Table 10. Three stations were set in the trial reach, and one in Reach No. 1, as a control station in an untreated reach. These piezometers were installed at the west side of the channel bottom, each set consisting of three 3/8-inch pipes spaced at approximately 1-foot intervals apart. The piezometer tips were sunk to 1, 3, and 5 feet below the canal bed surface. In May and June, 1957, a deep piezometer designated "D" was installed 300 feet west of the canal centerline at each station, and in addition, an

TABLE 10

LIST OF PIEZOMETERS AND WELLS FOR COACHELLA CANAL LOSS STUDY

STATION	LOCATION*	IDENTIFICATION	TIP ELEVATION (ft above sea level)	DATE OF INSTALLATION
161+05**	0+35 E	"A"	49.50	Installed Feb., 1957
161+05	0+35 E	"B"	47.50	Installed Feb., 1957
161+05	0+35 E	"C"	45.50	Installed Feb., 1957
161+05	2+03 W	"D"	117.92	Installed June, 1957
303+27	0+65 E	"A"	112.90	Installed Feb., 1957
303+27	0+65 E	"B"	110.90	Installed Feb., 1957
303+27	0+65 E	"C"	108.90	Installed Feb., 1957
303+27	2+05 W	"D"	93.63	Installed June, 1957
303+27	0+42 E	Well	113.88	Installed May, 1957
439+67	0+58 E	"A"	109.58; 110.38	Installed Feb., 1957 reset Aug., 9
439+67	0+58 E	"B"	107.58	Installed Feb., 1957
439+67	0+58 E	"C"	105.58	Installed Feb., 1957
439+67	2+16 W	"D"	93.40	Installed June, 1957
439+67	0+33 E	Well #1	114.67; 112.56	Installed May, 1957 reset Jan., 14, 1958
439+67	2+05 W	Well #2	114.20	Installed Sept., 1957
695+65	0+36 E	"A"	107.72; 107.86	Installed Feb., 1957 reset Aug., 15
695+65	0+36 E	"B"	105.72	Installed Feb., 1957
695+65	0+36 E	"C"	103.72	Installed Feb., 1957
695+65	2+32 W	"D"	90.91	Installed June, 1957
695+65	0+20 E	Well #1	110.77; 109.23	Installed May 1, 1957 reset Jan. 14, 1958
695+65	1+00 W	Well #5815.40	98.60	Originally existent
695+65	0+20 E	Recorder Well		Installed Oct., 1957
713+00	On bridge	Recorder Gage		Installed Oct., 1955

* With reference to hubs set on the edge of the west bank; each set of "A", "B" and "C" piezometers at approximately the edge of the bottom of the channel.

** In Reach No. 1, all other stations in Reach No. 2.

observation well was installed about 5 feet west of the highwater line except at Sta. 161+05. The purpose of the piezometers was to obtain information on the hydraulic gradient conditions or the head loss incurred as the water percolates into the bed materials from the canal.

As with the water loss data, the piezometer data are reserved for the evaluations.

Ground Water Level Observations -- A network of water table observation wells is available for measurement of changes in the water table as affected by the Coachella Canal. Spacing of the wells varies from a few hundred feet for some of the wells close to the canal to about three miles for the wells farther away from the canal. Records of some of these wells are available for several years before water was turned into the Coachella Canal. Readings currently are made at monthly or quarterly intervals depending on the location of the well and activity of changes in the water table.

The major purpose of the ground water observation well network is to secure a history of the changes in ground water elevation which could prove of considerable value in drainage studies when the Mesa is placed under cultivation in the future. Another purpose for the well network is to trace the progress of the seepage waters in the East Mesa toward the cultivated area of the Imperial Unit of the District.

Development of Sampling Equipment

Since the canal has water in it continuously, samples of the canal bed, of necessity, were collected from a boat. Considerable difficulty was experienced in retention of the wet materials, especially the loose sands, in the sampler during recovery into the boat. Also, since the canal is seldom clear, the difficulties were compounded, to some extent, by the general inability to observe or examine the bed materials directly.

The general reconnaissance probings of the canal bed were accomplished with a simple tube sampler with a flap valve at the top. The results of the laboratory analyses of a set of preliminary samples collected with this sampler have been referred to previously. See Figs. 13 and 14.

The samples of the canal bed materials that were used in the preliminary sealing experiments in the District laboratory were collected in a special sampler designed for this work and constructed by the District. See Fig. 15.

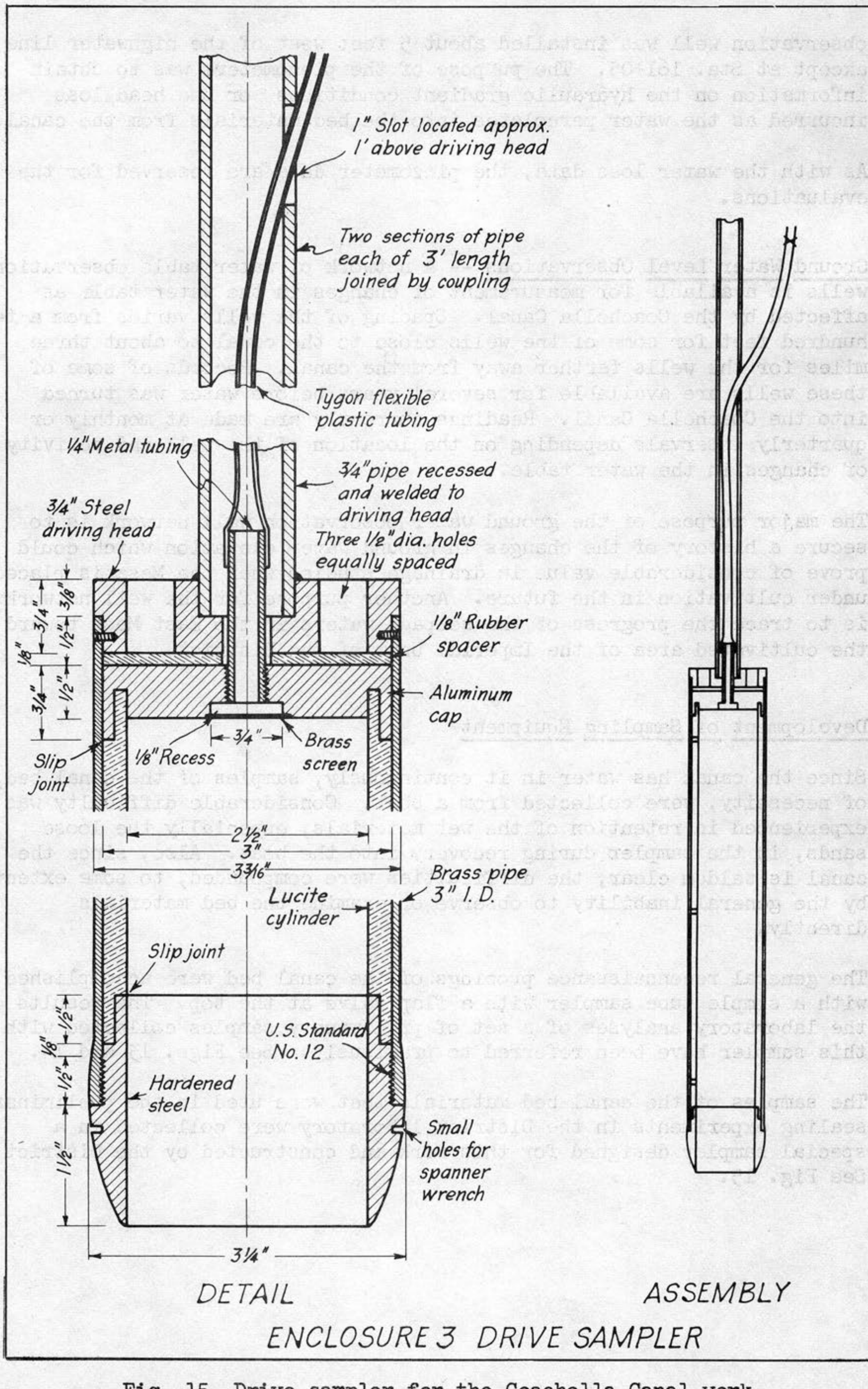

Fig. 15 Drive sampler for the Coachella Canal work

COLORADO STATE UNIVERSITY
CIVIL ENGINEERING SECTION
FORT COLLINS, COLORADO

Dear Sir:

Enclosed is a copy of the report, "Sediment Sealing of Irrigation Canals" (CER60RDD33) as requested by you.

As an oversight, we have shown, in Figure 15 on page 44, an early version of the drive sampler design. The brass pipe outer tube was found unsatisfactory and was subsequently replaced by a one-piece (driving head and outer tube) stainless steel unit. Please make a note to this effect on Figure 15.

We thank you for your interest in this report, and will welcome from you any comments or discussion after you have read the report.

R. D. Dirmeyer and R. T. Shen

Potential Sedimenting Clays

Exploration for possible sources of natural clay sedimenting materials was begun in 1954. Samples of nearby deposits were sent by the District to the Bureau of Reclamation (12); additional sampling and testing subsequently was made by the District, the University, and several chemical companies. The results of the USBR testing are not summarized here because the most favorable materials from their preliminary testing are included in the later testing.

The potential sedimenting materials evaluated at the University included commercial bentonites, as well as local clays (13). The clays were tested for grit content, colloidal yield, filter loss, and viscosity; the methods used were similar to those recommended by Fisk (14) for evaluation of bentonites for drilling mud use. Distilled water was used in this testing, the results of which are summarized in Table 11.

Additional testing of the potential sedimenting clays was completed in the District laboratory to determine the relative efficiency of three dispersing agents: Sodium tripolyphosphate, tetrasodium pyrophosphate, and sodium polyphosphate. Of the three, tetrasodium pryophosphate was found the most efficient with the canal water used in this testing (15).

The A.R. Maas Chemical Company of South Gate, California, also completed supplemental testing of potential sediments. The miscibility and filter loss characteristics of several sediments were evaluated. In general, the miscibility of the sediments or the ease with which the clay materials can be dispersed into water seems to bear an inverse relationship to the colloidal yield and to the filter loss character. The Wyoming clays are relatively difficult to mix but exhibit high colloidal yield and high resistance to passage to water; whereas the local clays, especially the very gritty ones, are easily mixed into the water, but exhibit a relatively low colloidal yield and low resistance to water passage (when subjected to a pressure of 100 psi).

Thus, in the preliminary testing of the potential sedimenting agents, the Wyoming bentonites indicated the most favorable results. This is not surprising since until only recently the Wyoming high-swell bentonite had been used as the test standard.

In any case, the results of the clay testing are not directly relevant to the Coachella Canal trial installation, which ultimately utilized a non-clay sealing agent, SS-13.

TABLE 11

RESULTS OF COLORADO STATE UNIVERSITY LABORATORY TESTING
OF POTENTIAL SEALANTS FOR THE COACHELLA CANAL

Sample No	Material	Grit Content %	Colloidal Yield %	Wall Building Filter Loss (cc)	Wall Building Cake (in)	Viscosity (centipoises)
Sl-1	Coyote Well	1.3	53.5*	40	3/32	3
Sl-2	Ackins Claim	12.1	42.9*	189	8/32	2
Sl-3	Thermo Claim	2.5	48.9*	88.5	1/8	2
Sl-4	Burslem Claim	20.7	28.9	69	3/16	2
Sl-5	Armaseal	4.7	65.2	41	1/16	4
Sl-6	Maas Clay	5.7	60.1	38	1/16	1
Sl-7	Western Clay (Utah)	17.5	55.5	28.5	1/16	6
Sl-8	Western Clay (Utah) reserves	5.0	41.3	33.3	1/8	3
Sl-9	Bent. Corp. (Utah)	4.1	84.6	14.5	5/64	8
Sl-10	Baroid (Wyo) crushed	4.8	89.4	16.5	1/8	22
Sl-11	Baroid (Wyo) 200-mesh	2.9	88.2**	16	3/32	23

* Dispersant (sodium tripolyphosphate--0.75 gms.) added where tendency for flocculation noted.

Preliminary Sediment Sealing Experiments

Before initiating the large-scale field trial in Reach No. 2 of the Coachella Canal, preliminary evaluations were conducted, both in the laboratory and at the field site, to explore the sealing potential, penetration capabilities, and operational characteristics of the various sealing agents proposed for use in the Coachella Canal trial. The testing was accomplished by the District, the Dow Chemical Company of Pittsburg, California, the Monsanto Chemical Company of St. Louis, Missouri, and the Brown Mud Company of Torrance, California.

Experimentation by District -- A series of laboratory permeability tests, involving drive samples of the canal bed material and several of the most promising sealing mixtures, were conducted in the District laboratory during the spring and summmer of 1957 (15).

The samples were obtained directly from the canal bottom by means of the sampling equipment, previously mentioned and as shown in Fig. 15. This device was designed to obtain from the submerged canal bed, sample columns of $2\frac{1}{2}$-inch diameter and 17-inch length, encased in the transparent lucite permeameter tubes in a relatively undisturbed condition. These tubes were then assembled and tested in the permeameter system in Fig. 16.

In the laboratory testing phase, each sample was first saturated with canal water (collected at Sta. 10+00) and its initial permeability was determined by actual measurement. Then a sedimenting treatment was applied. Following the treatment, the surface layer or filter cake was removed by scraping and the canal water was again introduced. The permeability of the column was measured at frequent intervals throughout the test.

The results of the tests with the various sedimenting agents are summarized in Table 12.

The samples generally consisted of fine sand with medium sand layers. The individual sand grains are predominantly calcium carbonate. Thin layers of lime, silt, and decayed organic matter are interspersed throughout the sands. In some of the samples, a thin green coating was found on the surface of the sample; in others the green coating was buried under 1 to 6 inches of a loose sand (possibly bed-load sand). The lime and silt-cemented layers were more often encountered in the top layers than in depth at Sta 300+00, while in the samples from the other sampling stations in Reach No. 2 this tendency was reversed. Some random clay balls were found buried in the sands.

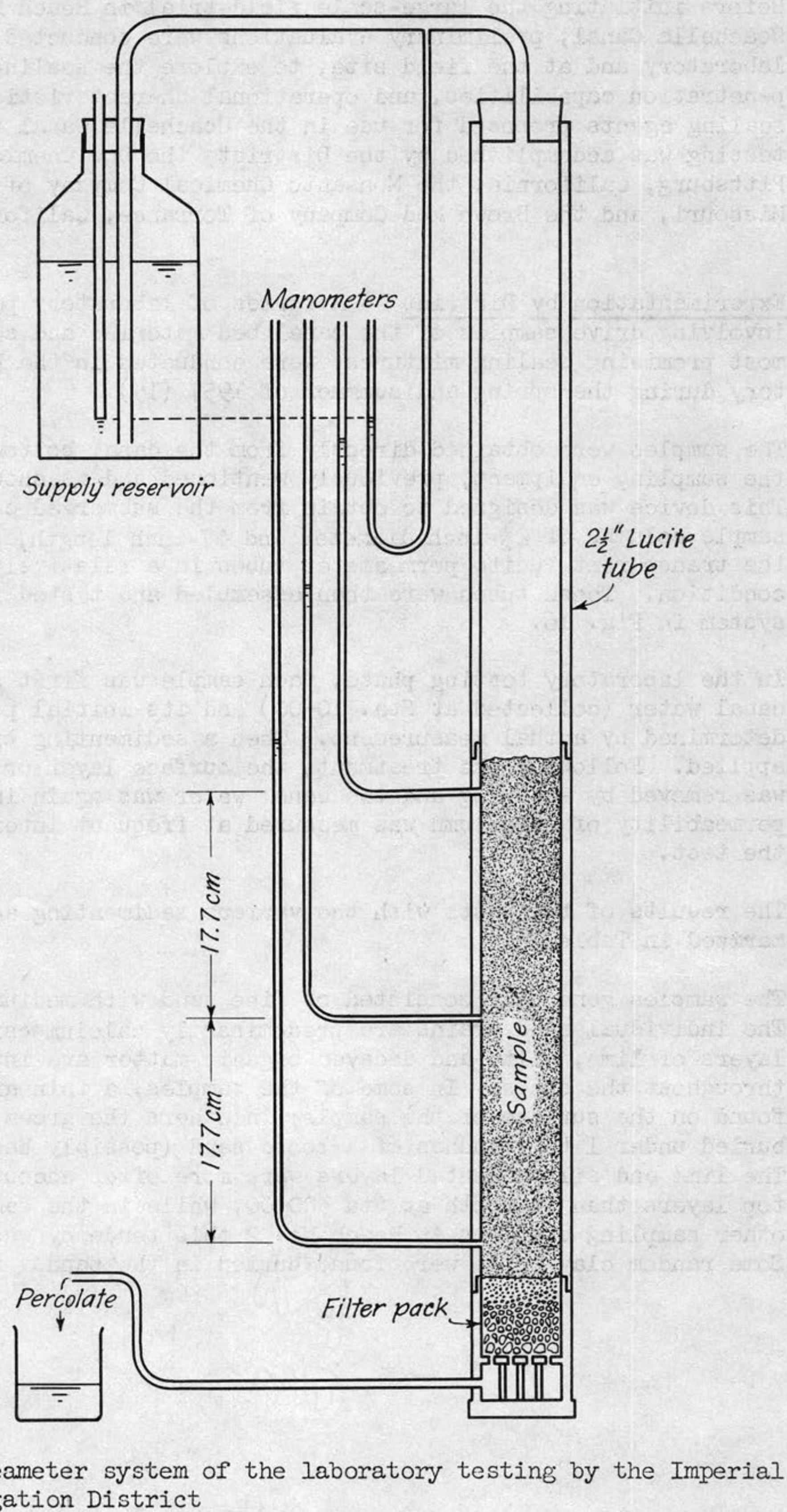

Fig. 16 Permeameter system of the laboratory testing by the Imperial Irrigation District

TABLE 12

RESULTS OF LABORATORY PERMEAMETER TESTING BY THE IMPERIAL IRRIGATION DISTRICT

Expt. No.	Sampling location (station)	Amount of dispersant (gm/liter)[1]	Length of treatment (hours)[2]	Percolation rate converted to 20°C before treatment[3]	Percolation rate after treatment[5] Minimum[4]	Ultimate[5]
Treatment with California clay (Coyote Wells--18.2 gm/liter)						
40821	303+27	0.44	0.75 0.75	4.03 - 3.18	0.34	0.34(5)
40882	303+27	0.44	1.50	2.38 - 2.01	0.17	0.18(5)
41037	303+27	2.72	0.75 0.75	7.38 - 4.51	0.22	0.22(10)
41682	439+67	1.36	1.00	31.90 - 0.66	0.56	2.11(31)
41830	439+67	1.36	0.75	21.13 - 3.57	0.32	7.50(17)
Treatment with Wyoming bentonite (10.5 gm/liter)						
40820	303+27	0.21	0.75 0.75	5.27 - 4.68	0.22	0.22(6)
40884	303+27	0.21	1.50	46.80 - 31.94	2.86	2.86(5)
41035	303+27	0.50	0.75 0.75	17.08 - 14.88	0.52	0.83(9)
41684	439+67	0.21	0.87	22.40 - 2.93	0.49	8.87(24)
41833	439+67	0.21	0.45	26.80 - 2.00	0.63	0.98(27)
Treatment with Utah bentonite (11 gm/liter)						
40819	303+27	0.22	0.75 0.75	21.92 - 3.52	0.16	0.18(8)
40883	303+27	0.22	1.50	1.80 - 0.70	0.22	0.26(12)
41036	303+27	0.50	0.75 0.75	3.85 - 2.99	0.94	1.19(9)
Treatment with dispersant solution only (0.21 gm/liter)						
41404	303+27	0.21	1.22	10.73 - 2.24	3.22	5.59(19)
41683	303+27	0.21	0.67	16.12 - 6.42	0.45	2.66(50)
41831	439+67	0.21	0.75	24.8 - 1.19	0.62	2.11(19)
41832	439+67	0.21	0.83	27.28 - 1.95	0.67	1.39(37)
Treatment with "SS-13" (0.58 cc/liter)						
41402	303+27	none	20.83	74.7 - 76.4	0.65	0.75(18)
41403	303+27	none	16.92	20.0 - 16.9	0.41	2.00(18)
42211	695+65	none	21.67	8.67 - 1.28	0.27	0.86(27)
42212	439+67	none	21.67	23.55 - 0.48	0.20	0.57(22)
42213	303+27	none	21.58	3.85 - 0.13	0.12	0.24(22)
Without treatment						
42917	695+65	none	----------	0.66 - 0.16	0.15	0.16(16)
42918	695+65	none	----------	7.58 - 0.87	0.72	0.87(16)
42919	695+65	none	----------	5.42 - 0.19	0.17	0.19(16)

[1] The dispersant used was tetrasodium pyrophosphate (Monsanto Chemical Co., and Dow Chemical Co.)

[2] Two separate treatments are shown by two figures indicating their respective lengths.

[3] Cu ft/sq ft/day at unit hydraulic gradient.

[4] The lowest figure throughout the run, usually immediately after treatment before the surface was scraped.

[5] The numbers in parentheses indicate the total number of days for which each run was conducted.

The permeability rate for most of the samples was significantly greater at the outset than the indicated overall rate of the field site. The laboratory rate usually decreased with time. Virtually all of the samples, even the untreated control samples, were eventually reduced to a low rate indicating sealing. Because of this tendency for all of the samples to seal with time, it is difficult to make valid comparison of the effects produced by the various sealing agents. In other words, the canal water alone produced a sealing effect comparable to that produced by the sealing agents and no one sealing agent exhibited a pronounced superiority over the other agents.

One disturbing factor was that the above-mentioned sealing with time was not being duplicated under natural conditions in the Coachella Canal. It is true that a downward trend in delivery loss from one year to the next can be noted, but not of the magnitude nor rapidity experienced in the laboratory testing. It was believed that this absence of sealing with time could have been the result of either of two conditions:

1. The Canal had not been in operation sufficiently long for sealing to take place.

2. The extreme length of uncontrolled reach has resulted in a cut and fill of the canal bed which has prevented formation of a seal.

Following the laboratory testing described above, the District accomplished similar testing in large cylinders sunk in the canal bed. The latter testing is discussed later as part of the experimentation accomplished by the Brown Mud Company in regard to the SS-13 material.

Experimentations with "Separan" -- In this program, carried out by the Dow Chemical Company, the effects of adding small quantitites of Dow's Separan, a commercial flocculating agent, both into the natural canal water and also into the clay sediment-sealing mixtures, were evaluated. The testing consisted of (a) a series of laboratory tests, (b) a model ditch experiment at Dow's Pittsburg, California, plant, and (c) standpipe tests in the Coachella Canal.

In a confidential report made available to the District and the University[1], the work is summarized as follows:

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[1] Transmitted to University by letter, dated September 10, 1957, from Mr. Robert R. Jennings, Research Department, The Dow Chemical Company, to R. D. Dirmeyer, CSU.

"Laboratory tests first demonstrated the possible utility of Separan (R) 2610 and suspensions of fine solids for the sealing of irrigation canals. The techniques developed in the laboratory were applied to one small ditch, and the leakage rate was decreased by a factor of ten at a very moderate cost. On-site testing in the bed of the Coachella Lateral of the All-American Canal System gave variable results, although it appeared that Separan might have some application here, too.

A technique involving the use of sediment naturally present in the water rather than artificially introduced sediment has shown promise in laboratory tests. This method is attractive because of its low cost and simplicity".

Considered in the light of subsequent developments, especially when the dominating influence of the movement of sand along the bottom of the Coachella Canal is fully appreciated, this work with Separan offers several promising approaches to the Coachella sealing problem that should be explored. The considerations involved will be discussed at greater length later in this chapter.

Experimentation with IBMA -- Apparently similar in performance to Dow's Separan is a polymer manufactured by the Monsanto Chemical Company, known as "IBMA." During 1957, IBMA was tested in Monsanto's St. Louis Agricultural Laboratory, as a sealant in sand columns. The tests were similar to those conducted for Separan, except that no sand from the Coachella Canal bed was used in this initial laboratory testing by Monsanto.

As a result of the laboratory testing, Dr. Sherwood of Monsanto had this to say[1]:

"It is our understanding that a 2% concentration of bentonite has been a fairly standard requirement in field tests (actually 1%). Possibly this can now be greatly reduced since our most efficient suspension concentrations were in the range of 0.25% to 0.75% bentonite in water. Obviously it is difficult to predict field concentration ranges from laboratory studies because field operating pressure gradients, as well as field specifications for dispersed suspensions, may differ. However, in spite of differences in conditions of testing, the addition of IBMA to bentonite suspensions will have the following influences:

1. For a given pore size and suspension concentration, the addition of IBMA will speed up absorption of the suspension to seal off the pores.

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[1] In a letter to Mr. J. M. Sheldon of the Imperial Irrigation District, dated May 9, 1958.

2. Complete sealing of porous beds can be obtained with a more dilute colloidal clay suspension. These dilute suspensions do not seal if IBMA is not added.

3. These more dilute suspensions result in obtaining greater depth penetration of the sealing agent.

4. The seal which is formed will be much more permanent if bonded by IBMA."

Although not a part of the before-trial activities, follow-up testing by Monsanto during 1959, included tests on one foot diameter cylinders embedded in the banks of the Coachella Canal. Dr. Deming of Monsanto summarized[1] the results of his field testing as follows:

"The presence of the IBMA with bentonite appears to offer considerable advantage over the seal obtained with bentonite alone. However, with the amount of Ca bentonite which is already present on the bottom of the canal and that which is in suspension in the water, I favor the use of IBMA alone rather than add more clay. The polymer will stabilize the "silt" seal which has already formed on the bottom of the canal and accelerate the closing of any openings in this "silt" layer with the sediment which is in suspension in the water."

Thus, the IBMA testing, which was carried out independently of the Separan testing, has resulted in similar conclusions. A sphere of action has been outlined that will be discussed later in this chapter.

Development and Testing of SS-13 -- With their experience with oil-based drilling muds (for oil-well drilling) as a valuable background, the Brown Mud Company conducted investigations, both in the laboratory and at the trial site, and developed a material designated SS-13. This is a semi-viscous creamy suspension of diesel oil and a number of polymer additives not for public disclosure pending patent application.

This material avoids several of the major problems encountered with a dispersed bentonite as the sealing agent. For example, it penetrates sandy bed soils easily where the dispersed bentonite will not. Originally the sealing was attributed by the Company to a delayed reaction with calcium in the canal water. In a November 23, 1959, information circular issued by the SS-13 Sales Company of Phoenix, Arizona, the material is described as follows:

"SS-13 consists of resinous polymers and heavy atoms mixed in a carrier of common diesel fuel. Its function is to increase the ionic attraction of the soil particles for water, thus increasing the thickness of the hygroscopic envelope of water around each particle. This decreases the voids or passages through which water can move, and retards the flow through soil."

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[1] In a letter to Mr. J. M. Sheldon, Imperial Irrigation District, dated July 7, 1959.

The development testing of SS-13, prior to the main Coachella trial (installed October 1957), consisted of (a) laboratory testing in the Company laboratory, and (b) field site testing in cooperation with the District. Tests completed with SS-13 in the District laboratory have been reported previously in Table 12.

The laboratory testing by the Brown Mud Company was accomplished on permeameter samples compacted so that the rate of loss was approximately the same as the actual indicated canal loss. Samples used in this testing included: (a) a synthetic sand patterned after the material depicted previously in Fig. 13 on page 39, and (b) sandy bed materials actually collected from Reach No. 2 of the Coachella Canal. The testing was performed in an equipment setup as shown in Fig. 17. An interesting feature of this equipment is the provision for simulating canal water turbulence. A plot of typical data from this testing is shown in Fig. 18 (16).

Following the laboratory testing by both the Brown Mud Company and the District, the District installed three 42-inch diameter casings in the Coachella Canal at Sta. 695+00 to test the performance of the SS-13. These were driven to a depth of approximately 2 feet. Fig. 19 shows the location of the casings and furnishes logs of the materials encountered in nearby test borings.

The testing was accomplished by noting the changes in loss rate for each casing upon treatment with SS-13. The loss rates were obtained under constant head conditions imposed by a float-valve operated inflow from a calibrated drum set on top of each casing. At the end of SS-13 treatment each casing was flushed with canal water and then the after-treatment loss rate determined. The effects of two kinds of erosion on the seal were also determined. See Table 13 for a summary of test results from the casing tests (17, 18).

The first phase of the SS-13 treatment in the casing tests was accomplished during the period of May 28, 1957 to June 5, 1957; the follow-up erosion treatment was completed on June 10, 1957.

In the casing test procedure, it would have been helpful to determine the loss rate on an untreated casing--not only as a control to record the natural variations in loss during the treatment period, but also to see if the untreated control would seal to the same extent that they did in the laboratory testing.

As result of the laboratory and field site testing of the SS-13, it was concluded:

1. The sealing produced by SS-13 was appreciable, although not significantly better than that produced by the other treatments, including the canal water alone.

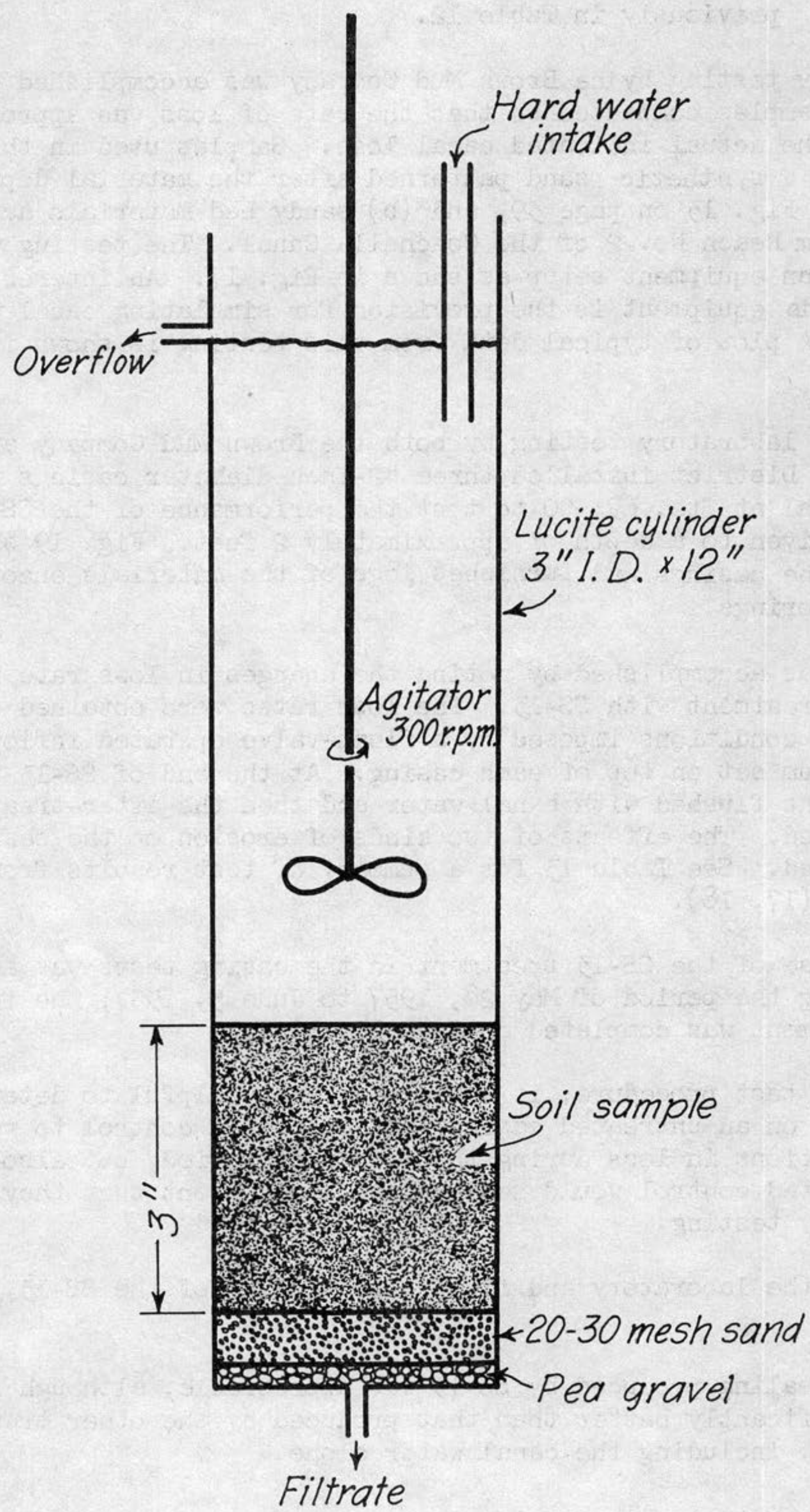


Fig. 17 Laboratory set-up for SS-13 testing on 3-in. long cores

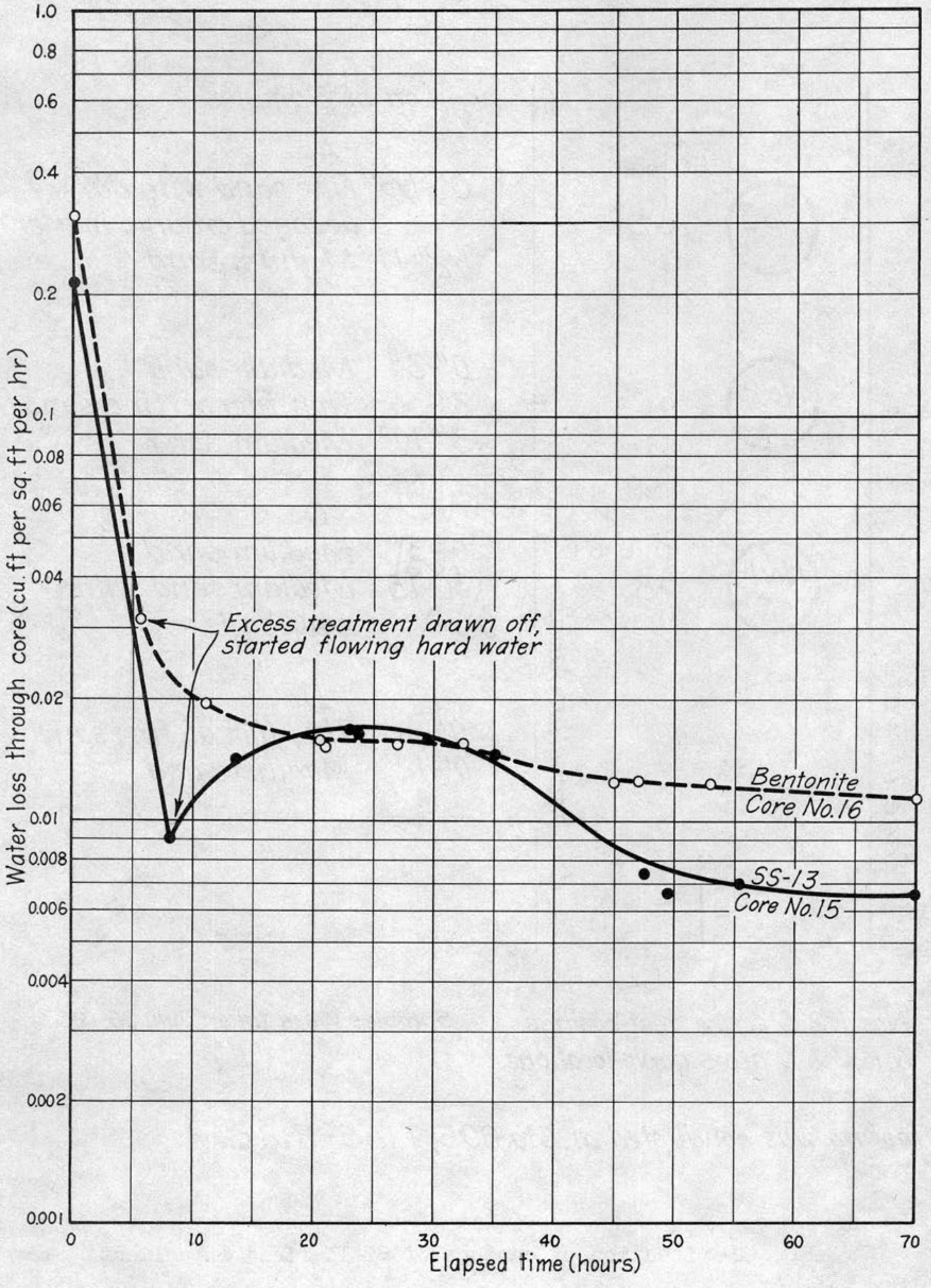
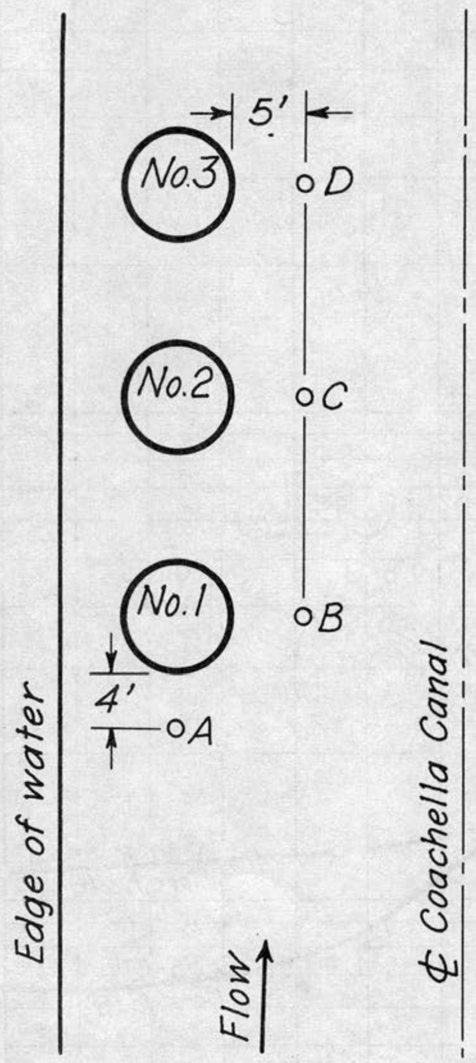


Fig. 18 Graphical representation of results of laboratory testing of SS-13



Log of Samples

A

0"-1/2" Fine sand with dark decayed organic matter
1/2"-11" Medium sand

B

0"-3" Medium sand
3"- Thin film of fine sand
3"-10" Medium sand

C

0"-3" Medium sand
3"-15" Medium sand with clay balls

D

0"- Thin film of fine sand
0"-12" Medium sand

Nos. 1, 2, & 3 are test casings.
A, B, C, & D are sample locations.

Samples were taken July 26, 1957

Testing was conducted at Sta. 695, T15S-R18E.

Fig. 19 Location of casings of SS-13 field experiment

TABLE 13

RESULTS OF SS-13 FIELD EXPERIMENTS

	Casing No. 1	2	3
Depth of water in casing (inches)	54	57	52.5
Concentration of SS-13 by vol. (%)	0.1	0.075	0.1*
Length of SS-13 treatment (hours)	24	22.5	19
Amount of SS-13 applied (lbs/sq ft)	0.046	0.030	0.023
Erosion after SS-13 treatment	(a)	(b)	(c)
Loss rates (cu ft/sq ft/24 hrs)			
Just before SS-13 treatment	1.31	1.17	0.81
At end of SS-13 treatment	0.61	0.53	0.46
Av. loss during first 15 hrs after SS-13 flushed from each casing	0.68	0.49	0.67
16 hrs after treatment removed	0.54	0.42	0.50
6 days after treatment removed	0.24	0.18	0.29
After erosion			
2 hrs after	1.05	0.28	0.28
2 days after	0.53	0.29	0.22
4 days after	0.43	0.18	0.22

* SS-13a--a slight variation in formula

(a) Subjected to stirring with 2-inch pike pole for 10 minutes while pumps were in operation.

(b) Subjected to jetting with 2-inch pump while 1-inch pump withdrew water from casing.

(c) Not subjected to erosion treatment.

2. Since sealing in depth was considered important, the tendency of SS-13 to re-seal after erosion was a favorable characteristic.

3. None of the tests was extended sufficiently to provide definite information on the life of the seal.

Trial Installation
(19, 20)

Sedimenting on the scale contemplated in this trial had never been done, thus, it will be recognized that this project was a new and difficult task without precedent. The ultimate answers to some of the development problems were not evident until late in the investigations; some questions remain now yet unanswered.

In selecting the sealing material to be used in the Coachella Canal trial, none of the field and laboratory tests of the proposed sealing materials was considered by the District to be sufficiently favorable or representative of the actual canal conditions to provide conclusive reason for adoption of one material over another. It was decided, however, that the "dispersant only" testing was so unfavorable that it could be eliminated from the final considerations. Thus, while the preliminary testing provided valuable background information, it did not answer the practical question of how the remaining sealing agents would perform under the conditions actually existing in the Coachella Canal. An actual field trial installation was needed to resolve this question. SS-13 was the sealing material selected for the first large-scale trial.

The SS-13 material, developed by the Brown Mud Company, was adopted because of (a) its favorable sealing qualities indicated by laboratory and field tests, including its re-sealing characteristics after erosion which indicated penetration of SS-13 into the bed material, (b) its simple application method or easy miscibility into canal water, (c) its lower cost of application than that estimated for the dispersed bentonite treatment.

The native clays and commercial bentonites were not used in this first experiment because:

1. It was believed that the clay sediment should be chemically dispersed. To accomplish this dispersion in the hard canal water, large amounts of dispersant would be required.[1]

---

[1] It is now (1960) believed that this assumption was in error--recent testing and experimental trial work in other localities indicate that chemical dispersion of the clay is not needed.

2. It was speculated that a surface seal of limited life would be produced unless chaining of the canal bottom was accomplished during the sedimenting.[1]

3. It was estimated that 900 tons of bentonite would have to be mixed into the canal water in a period of 12 hours. This mixing rate presented difficult and expensive problems.[2]

Channel Preparation

It was decided that the canal would be drained immediately prior to the trial installation and that a mixture of SS-13 and water would be ponded for at least 20 hours, or as long as practicable, in Reach No. 2. This was made possible by the Coachella Valley County Water District agreeing to a 4- to 6-day interruption of service from the canal, beginning October 27, 1957.

The District constructed an earth dam at Sta. 730+00 of sufficient height to pond water in Reach No. 2 to elevation 117.0. The central portion of the dam was left open during the draining of the canal on October 28, 1957.

No special preparation of the channel was necessary. However, since the SS-13 was to be applied to a saturated bed material, clear water was run into the ponded section for 50 minutes before the SS-13 application. The dam at Sta. 730+00 was closed at 6:15 am on October 29, 1957. The clear-water inflow at Sta. 288+15 of about 400 cfs was started at 5:40 am, October 29, 1957.

Mix Point Preparations

The Brown Mud Company set up a supply and mixing plant for the SS-13 on the bridge at Sta. 288+15 (Fig. 20). It consisted of a 22,000-gal. storage tank, two tank trucks, a pump and discharge pipes (Fig. 21). The arrangement was such that the trucks could alternate in supplying SS-13, and the storage tank was used as a standby supply of SS-13. A Sparling flowmeter was installed in the discharge pipe so that the amount and supply rate of SS-13 could be metered accurately. At the discharge end of the flowmeter, a water jet was originally included to assist in uniformly mixing the SS-13 into the canal water; however, it was shut off after 2 hours because adequate mixing was obtained without the jet.

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[1] It is now (1960) believed that a closer study of the bed-load sand movement in the Coachella Canal will reveal a better method than chaining to circumvent the surface seal problem.

[2] Recent experience in other localities (1960) indicates that with a native clay there is no need to mechanically mix the clay into the water, nor is this high rate of mixing necessary.

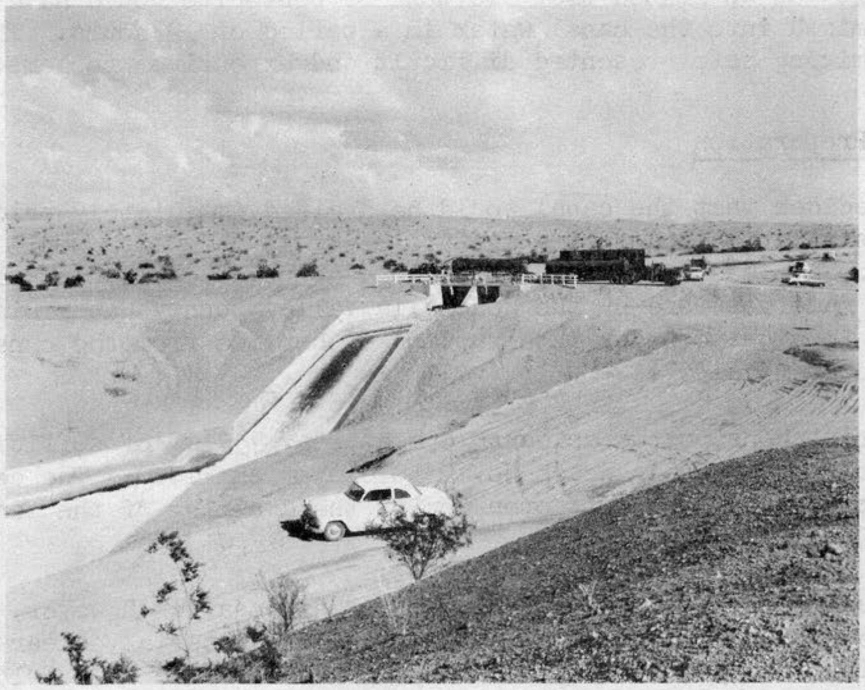

Fig. 20 View of the mixing operation at the Coachella Canal trial

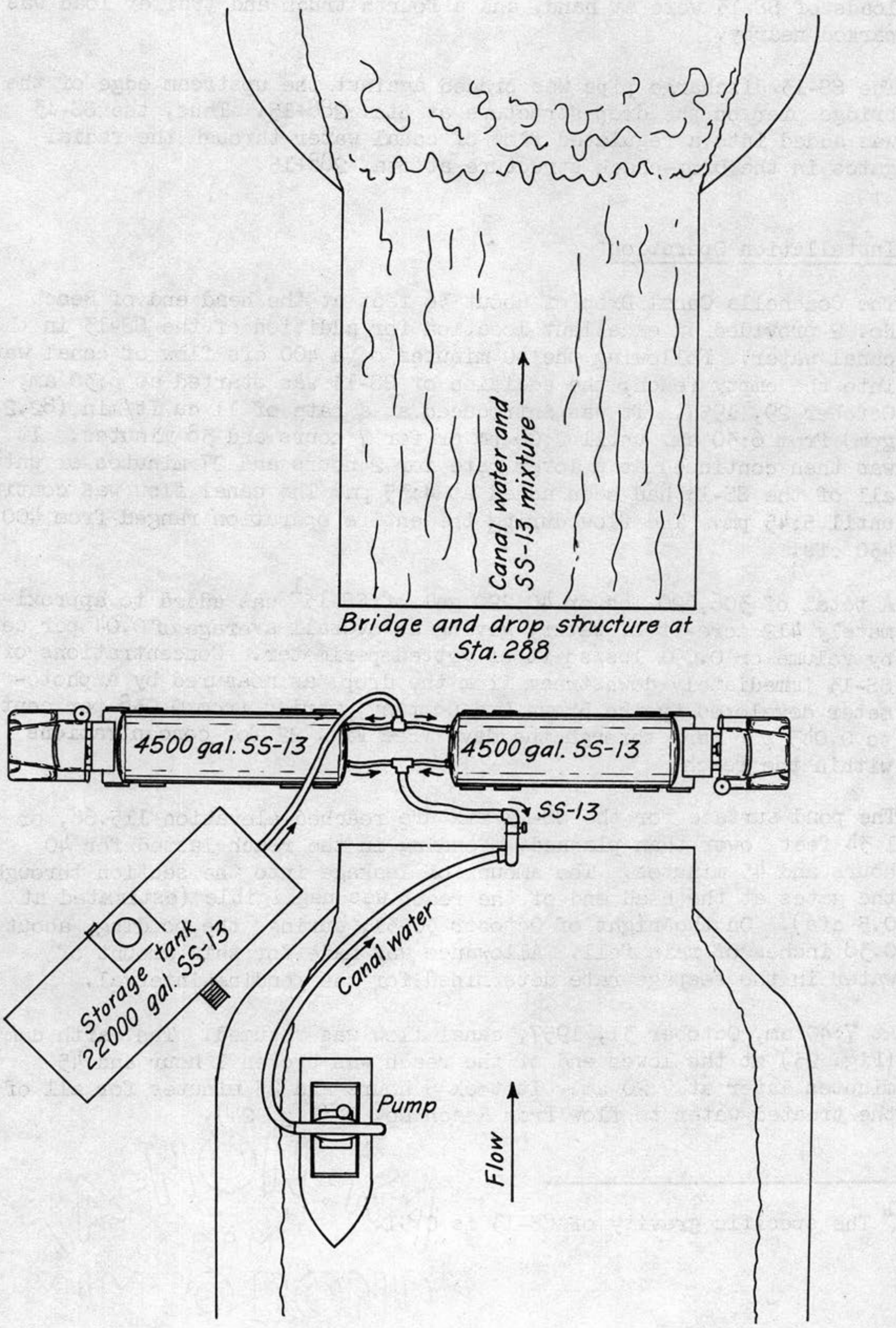

Fig. 21 Mixing arrangement for SS-13

All of the SS-13 was hauled to the site before the start of the operation on October 29, 1957. The storage tank was full, three truck loads of SS-13 were at hand, and a fourth truck and trailer load was parked nearby.

The SS-13 discharge pipe was braced against the upstream edge of the bridge pier on the drop structure at Sta. 288+15. Thus, the SS-13 was added into a regulated flow of canal water through the radial gates in the Drop-check structure at Sta. 288+15.

Installation Operation

The Coachella Canal Drop of about 36 feet at the head end of Reach No. 2 provided an excellent location for addition of the SS-13 in the canal water. Following the 40 minutes of a 400 cfs flow of canal water into the empty reach, the addition of SS-13 was started at 6:30 am; October 29, 1957. It was introduced at a rate of 11 cu ft/min (82.2 gpm) from 6:30 am. until 2:08 pm or for 7 hours and 38 minutes. It was then continued at a lower rate for 2 hours and 27 minutes or until all of the SS-13 had been added at 4:35 pm. The canal flow was continued until 5:45 pm. The flow during the entire operation ranged from 400 to 430 cfs.

A total of 306,620 lbs or 40,220 gal. of SS-13[1] was added to approximately 412 acre-ft of water, giving an overall average of 0.04 per cent by volume or 0.091 lbs/sq ft of wetted perimeter. Concentrations of SS-13 immediately downstream from the drop, as measured by a photometer developed by the Brown Mud Company, varied from 0.038 per cent to 0.045 per cent through the day. See Fig. 22 for concentrations within the reach.

The pond surface for the SS-13 mixture reached elevation 115.66, or 1.34 feet lower than planned. Ponding in the reach lasted for 40 hours and 45 minutes. The amount of leakage into the section through the gates at the head end of the reach was negligible (estimated at 0.5 cfs). On the night of October 30-31, during the ponding, about 0.38 inches of rain fell. Allowance was made for this amount of water in the seepage rate determined for the ponding interval.

At 7:40 am, October 31, 1957, canal flow was resumed. The earth dam (Fig. 23) at the lower end of the reach was broken 1 hour and 45 minutes later at 9:20 am. It took 5 hours and 25 minutes for all of the treated water to flow from Reach No. 2 (Fig. 24).

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[1] The specific gravity of SS-13 is 0.91.

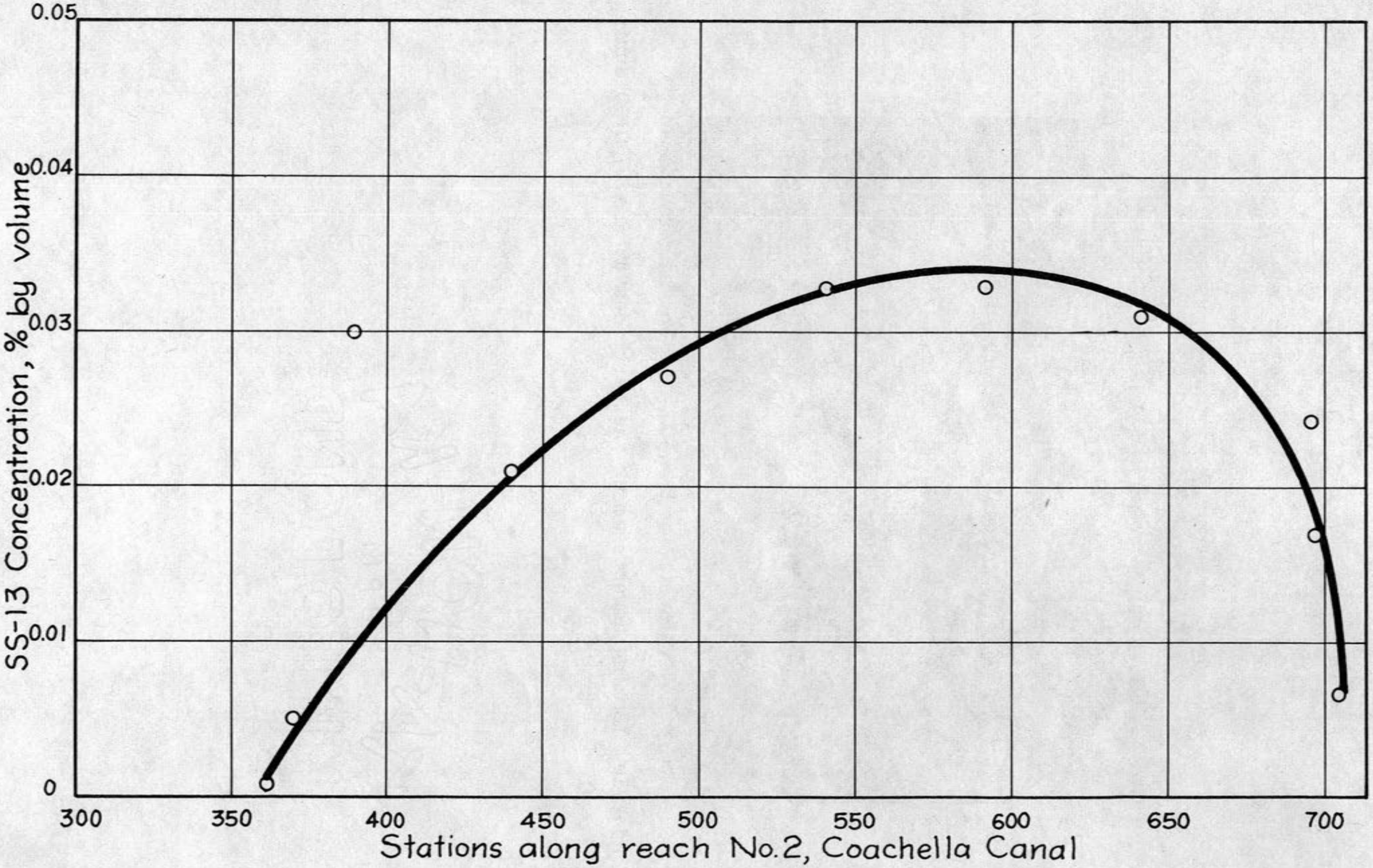

Fig. 22 Concentration profile during installation of SS-13, 11:30 a.m., October 30, 1957

Fig. 23 View looking downstream at the earth dam at Sta. 730+00 during SS-13 ponding

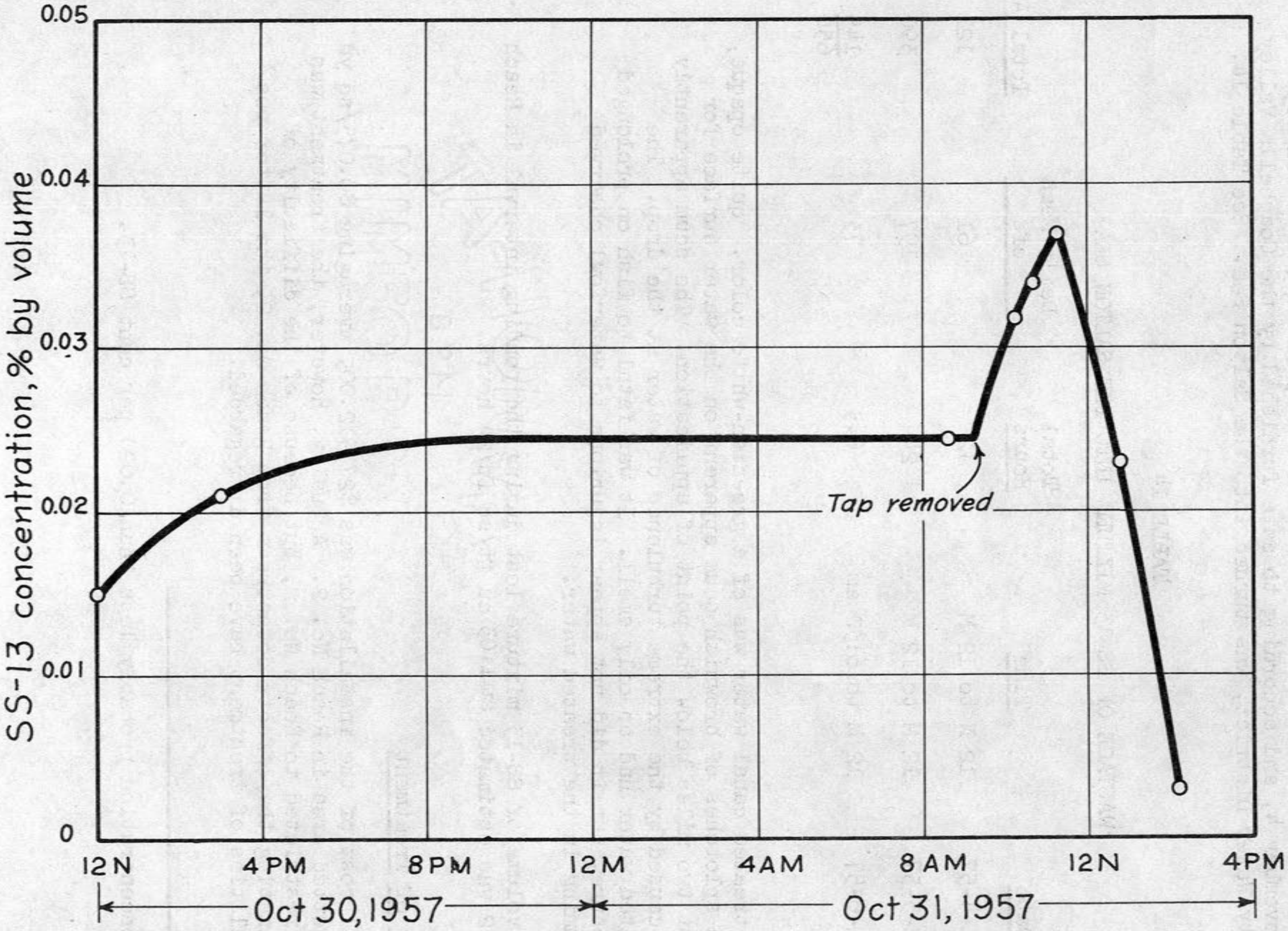

Fig. 24 Concentration history at Sta. 695 during SS-13 ponding

The slug of treated water was followed downstream. The diluted mixture[1] reached the Coachella Canal Wasteway No. 1 (Sta. 4782+00) on November 4, and according to data furnished by the Coachella Valley County Water District, was turned into the Salton Sea. See Table 14.

TABLE 14

WASTAGE OF SS-13 MIXTURE INTO THE SALTON SEA

Date	Time	Total Hours	Daily Mean cfs	Total AF
11-4-57	12 N to 12 M	12	61	121
11-5-57	12 M to 12 M	24	197	390
11-6-57	12 M to 6:30 am	6.5	73	145
				656

The treated canal water was of a greenish-white color, quite opaque, with splotches of brownish scum apparent on the water surface for about two miles below the point of application. The scum apparently was caused by the extreme turbulence of water at the drop. The treated water had an oily smell. It was fatal to fish on prolonged exposure, but it did not appear injurious to waterfowl observed swimming in the treated water.

The volume of SS-13 mixture lost during the ponding interval in Reach No. 2 was estimated at 1.03 cu ft/sq ft/24 hours.

Cost of Treatment

Total cost of the installation was $27,912.00, averaging $0.075/sq yd of wetted area in Reach No. 2. Actually, however, the treatment was not restricted to Reach No. 2, but because of the difficulty of estimating the effects downstream from Reach No. 2, the latter possibilities of treatment have been disregarded.

---

[1] Concentration probably less than 0.020 per cent SS-13.

After-Trial Evaluations

The general effectiveness of the preliminary planning activities, and of the sealing produced by the SS-13 treatment has been evaluated by (a) visual observations, and (b) seepage loss measurements and indications.

Visual Observations

Virtually all of the sampling work for the preliminary planning activities was accomplished from a boat without actual observation of the canal bottom. This caused difficulties. For example, in the preliminary sampling work it was difficult to picture why the canal bed was very soft at one time or place, while at other times in almost identical sampling locations, the bed was very firm. During the fall of 1956, a 3-inch diameter plastic tube could be easily pushed into the canal bed at almost all locations. Later during the early part of 1957, the bottom was found to be so firm that drive sampling with a special stainless steel sampler (Fig. 15) and a sledge hammer were necessary. The drive samples of the bed material showed that the bed sand was lime-cemented in some locations; later sampling at the same approximate locations would encounter loose clean sand. In some areas, air would bubble up when the sampler was withdrawn from the bed.

On October 28, 1957, the canal was drained and for the first time it was possible to observe the canal bed directly. The observations made at this time, combined with observations of bed load sand movement in an experimental flume in the Hydraulics Laboratory at the University, helped to answer some of the puzzling questions posed by the early sampling work.

The canal bottom from Sta. 300+00 gave the appearance of being essentially stable. The bottom sands were, for the most part, stabilized with a lime ($CaCO_3$) cementation, which in some areas was found to be a composite of many very thin laminations of lime. Infrequent blow-outs or wash-outs into the lime-stabilized sands were noted where apparently the water had eroded through the surface encrustation, but the sand in some of the wash-outs was encrusted with a surface layer of lime. It is perhaps significant that most of the sand itself is $CaCO_3$.

From Sta. 420+00 to the end of Reach No. 2 at Sta. 713+10, loose sandy materials were found as an intermittent mantle over lime-cemented sands. In most areas, the loose sand material occurred as dune deposits, with the dunes regularly spaced at about 20 to 30 feet apart down the canal. From the probing and sampling experience, more drop-off at the end of each dune was expected--as much as 2 to 3 feet rather than the 2 inches to 1 foot found. Since the actual amount and topography of the bed-load sand is of critical importance in the canal sealing, this general subject is discussed in more detail later in this chapter.

A fairly well-developed silt berm was found on all of the canal bank areas. In an estimated 35 per cent of the total bank area, small localized mud flows of the silty to sandy berm material were triggered by the rapid drawdown period on October 28 and again, to a lesser extent, on October 31, 1957. In the remaining 65 per cent (estimated) of the canal bank areas, no slumpage occurred. The bank materials in these areas did not appear water-saturated--at least when a hole was dug, water did not collect in the hole at an immediately observable rate. In these same general areas, air bubbled up from some of the holes dug in the bottom under water. A fairly effective surface seal (before treatment) in these areas seemed probable.

The before-treatment samples of the canal bed material were collected as the water was draining from the reach on October 28; the after-treatment samples were collected from a boat on November 4, 1957. The results of the laboratory testing of the samples are reported in Table 15. A faint odor of SS-13 could be detected in most of the surface layer samples collected after the SS-13 treatment, but the SS-13 could not be detected by chemical tests in the laboratory.

Seepage Loss Measurements

The seepage losses in Reach No. 2, before and after the SS-13 treatment, were evaluated by both direct and indirect methods. Inflow-outflow measurements constituted a direct method; indirect methods included the piezometer and ground water level observations.

The study of losses from the Coachella Canal was initiated in 1955 under the direction of Mr. A. J. Boles, Chief Civil Engineer of the Imperial Irrigation District. The results of this study have been reported in detail in Reference (11), therefore only information of significance and conclusions drawn therefrom are presented here.

Discharge Analysis -- The transitory quality of the flow conditions complicated the discharge measurements. Many adjustment techniques were adopted in order to arrive at a reasonable comparison. In any case, since the effectiveness of the treatment must be appraised in terms of water saved, the accumulated yearly loss in acre-feet should be the ultimate criterion. However, for a logical comparison, the wetted perimenter must be taken into account so as to avoid, to some extent, the distortion due to stream discharge fluctuations[1].

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[1] It is evident that percolation rate would not increase in direct proportion with volume of discharge unless the upper bank zones were saturated already and hydraulic gradient within the bed remains constant during any increase or decrease of discharge.

TABLE 15

RESULTS OF CHEMICAL TESTING* OF COACHELLA CANAL BOTTOM SAMPLES
BEFORE AND AFTER SS-13 TRIAL

Sample		% Soil less than 2 mm.	Cation exchange capacity (me/100 gm 2 mm. sample)
Sta. 300+00 - East edge bottom	0-4"	68.3	3.1
" " "	4-8"	82.9	2.4
Center of canal	0-1 1/2"	96.3	3.8
" of	1 1/2-6"	96.0	---
13" from W. bank	0-2"	75.1	4.0
" " " "	2.5"	88.2	2.8
SS-13 Trial-after sample	0-1 1/2"	90.3	4.0
Composite of 7	1 1/2-6"	9.16	1.8
Sta. 350+00 - East edge	0-3 1/2"	74.9	3.6
" "	3 1/2-6"	96.7	4.7
Center	0-2 1/2"	98.6	1.4
"	2 1/2-6"	100.0	4.5
West edge	0-2"	70.8	4.8
" "	2-6"	97.4	2.4
SS-13 Trial-after sample	0-3"	95.8	4.8
Composite of 5	3-6"	97.6	1.8
Sta. 500+00 - East bank	0-6"	86.7	3.5
Center	0-6"	99.4	2.7
West	0-3 1/2"	80.4	4.3
"	3 1/2-6"	98.8	2.8
SS-13 Trial-after sample	0-3"	96.3	1.9
Composite of 6	3-6"	97.0	4.9
Sta. 697+00 - East bank	0-2 1/2"	82.1	3.4
" "	2 1/2-6"	91.0	1.4
Center	0-4"	98.9	1.7**
"	4-6"	99.6	3.2
West	0-1"	93.8	3.8
"	1-6"	94.9	2.0
Sta. 700+00			
SS-13 Trial-after sample	0-3"	99.2	1.6
Composite of 6	3-6"	99.4	4.5

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*Testing by Soil Department, Colorado State University

**Result low. Sample coarse, would not pack when centrifuged, and some fine material was unavoidably lost.

The loss data in this form are plotted on Figs. 25 and 26. It can be seen that:

1. The losses computed by the inflow-outflow method for the years of study agree very closely for Reaches 3 and 4. The values for Reach Nos. 1 and 2 both before and after the SS-13 treatment are erratic in the amount and seasonal distribution, particularly so for Reach No. 2. Apparently these reaches are too short for consistent quantitative comparison of losses even on a monthly basis because even large changes in loss could be obscured by the inherent errors in inflow-outflow measurements.

2. After the SS-13 treatment, Reach Nos. 3 and 4 manifested almost no change. Reach No. 2 continued to be erratic. Reach No. 1, lying upstream from Reach No. 2 and hence free from both the influence of the SS-13 presence and the effects of the drawdown necessitated by the installation operation, ironically showed signs of decreased losses.

It is expected that the variations in stream discharge systematically affect the computed loss rates because of the fluctuations in flow velocities and water surface elevation. From Fig. 27, it can be seen that in Reach Nos. 3 and 4 definite relationships exist within a reasonable range of scatter while in Reach Nos. 1 and 2 the relationships are rather evasive because of the wide scatter of data. It should be pointed out that since the outflow discharge readings of Reach No. 1 also serve as the inflow discharge readings of Reach No. 2, any inaccuracy in the measurement at Sta. 300+00 would yield misleading data in both reaches. Other possible causes for this data scatter may be moss growth, ground water condition, shortness of reach, and unstable depth.

Notwithstanding the scatter of data, one can state with reasonable certainty that no evidence of a major change in loss rate as a result of SS-13 application in Reach No. 2 can be detected from the discharge analysis. However, evaluation of the experiment cannot be based conclusively on such discharge data alone.

In comparison, the Coachella Canal and the All-American Canal are constructed of the same material, traverse over similar topography and geology, carry water of the same quality and sediment of the same amount and type. The main difference is that the All-American Canal is controlled by closely spaced drop structures whereas the control structures on the Coachella Canal are widely spaced. Mr. A. J. Boles reports that:

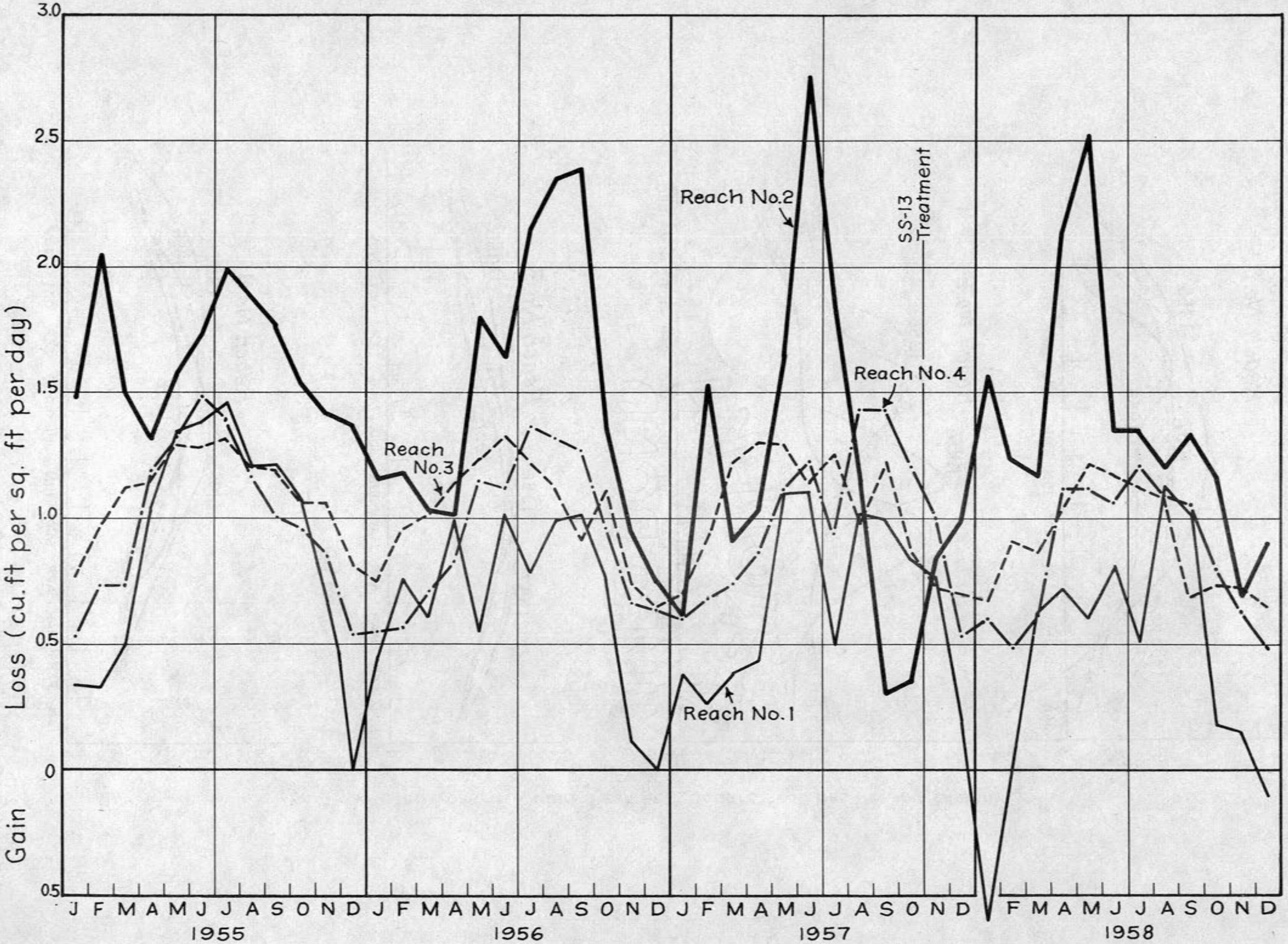

Fig. 25 Results of loss study by reaches in the Coachella Canal

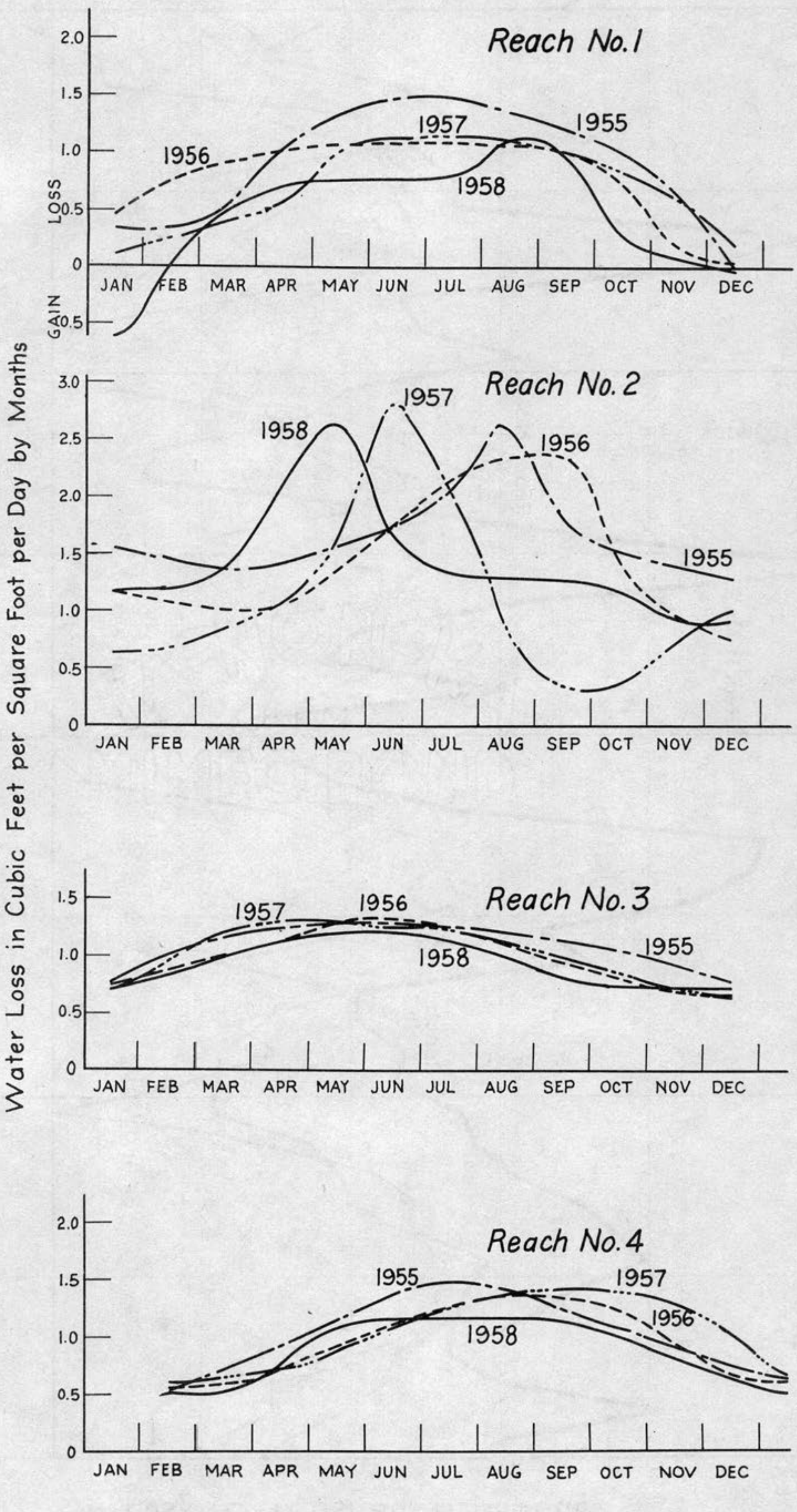

Fig. 26 Seasonal variation of losses by reaches in the Coachella Canal

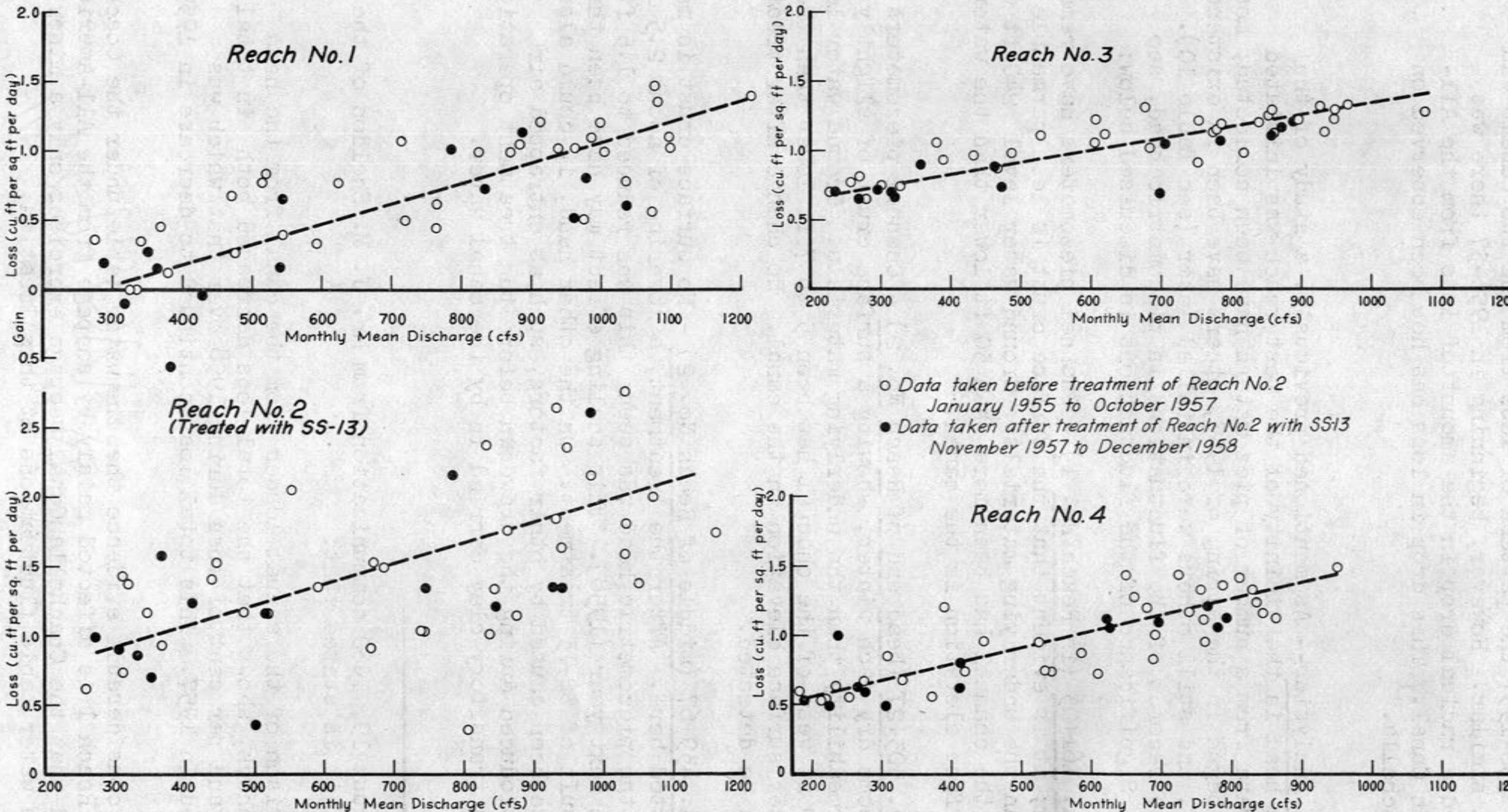

Fig. 27 Variation of loss with discharge by reaches in the Coachella Canal

"Until 1956-1957 the pattern of loss from the two canals was in fact similar. However, beginning in 1956-57 there was observed a radical drop in the amount of loss from the All-American Canal. This drop in loss has not been observed on the Coachella."[1]

Piezometric Analysis -- As mentioned previously, a study of the piezometric head in the vicinity of the test reach was initiated in 1957. Data from a number of piezometers have been collected; most wells were begun in the spring of 1957, others have been in existence before 1957, and still others were installed later (see Table 10). For complete records of the fluctuations in piezometric head, see Ref. (11). Significance of the fluctuations is discussed below:

1. Sta. 161+05 (in Reach No. 1) - Channel piezometers have remained dry; it is evident that the surface crust is less permeable than the underlying materials. Ground water level 240 ft west of the channel has been more than 30 ft lower than the water-surface elevation in the canal.[2]

2. Sta. 303+27 (head end of Reach No. 2) - Channel piezometers have become dry each winter, showing a surface crust of slightly less permeability than the underlying materials. Ground water level 240 ft west of the channel has been 5 to 7 ft lower than the water surface elevation in the canal. No change after treatment can be detected.

3. Sta. 439+67 (middle of Reach No. 2) - No surface crust is manifested here. After the treatment, a lowering of about 2.5 ft in the piezometric head was seen; this was reduced to 1.5 ft in the next year (1958). This sealing effect may have been the result of SS-13 treatment. On the other hand, it could also have been caused by other factors, such as entrapped air introduced during the drawdown before the treatment operation and transitory clay carried in by the canal water.

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[1] In an August 19, 1960 communication from Mr. J. M. Sheldon of the District, it is stated that:

"Comparison of the annual losses from the canal from the head to 6A check, shows that the total loss decreased both in total amount and per cent of loss during 1958 over that which was observed in 1957. This total loss continued to decrease in 1959."

[2] There is considerable evidence that the water table under the Coachella Canal in Reach 1 is affected mainly by seepage from the All-American Canal and that the Coachella Canal seepage exercises only a minor effect on water table fluctuations at this location.

4. Sta. 695+65 (downstream end of Reach No. 2) - The piezometric head has behaved in approximately the same manner as at Sta. 439+67, but to a less pronounced degree. There is a slight surface crust.

Ground Water Records -- A network of wells had been installed, some as early as 1940, for determining the ground-water level in the vicinity of the All-American Canal and the Coachella Canal. Since the rise of ground water above the original water table in the East Mesa area depends mainly on the seepage from these two canals, the water-table elevation serves as a good indicator of the water loss trend. Although no quantitative measurements of seepage can be obtained, this method is very useful because of the reliable accuracy in defining the trend. A detailed description of the study from 1940 to date is contained in Ref (11).

Results of this study show that the water table near the All-American Canal and the Coachella Canal had been rising steadily until about 1951, showing strikingly similar behavior. From 1951 to 1956, the water table near the All-American Canal became almost constant while that near the Coachella Canal continued to rise at approximately the same rate as before. In October 1956 the SS-13 treatment took place in Reach No. 2 of the Coachella Canal. From September 1956 to June 1959, the water table in the All-American Canal showed a steady decline. Mr. Boles reports:

"....It seems probable that in late 1956 or early 1957 there was some change in the canal water, suspended sediment or canal perimeter along the All-American, which practically sealed the canal and reduced the losses about fifty per cent. If a reason for this sealing can be found and a similar situation created and maintained in the Coachella Canal, the problem of seepage from the Coachella Canal would be solved.

"What few wells we have close to the Coachella Canal show that the drop in water table and reduction in loss observed along the All-American Canal beginning in 1956-1957 did not occur along the Coachella Canal."

It may be postulated that the apparent seepage reduction in the All-American Canal is a natural result from continued operation for a length of time, a phenomenon confirmed in the permeameter tests in the laboratory. Since the Coachella Canal has been in operation for a shorter period than the All-American Canal, the permeability of its channel may, within a few years, decrease in a manner similar to the All-American.

Evaporation Loss -- It has been assumed that seepage constitutes the major part of the delivery losses in the Coachella Canal. As can be seen in Table 16, pan evaporation loss does not exceed 0.5 inch/day. These figures are averages of measuring pan evaporation at three stations on the Salton Sea; a pan conversion factor of approximately 0.7 is applicable to the Salton Sea (21, 22, and 23). What the factor would be for a flowing stream such as the Coachella Canal has not been determined.

TABLE 16

MEASURED PAN EVAPORATION DATA AT THE SALTON SEA

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1956	3.57	5.37	7.98	10.00	12.28	12.15	11.92	12.44	10.49	8.63	5.34	4.62
1957	2.91	3.30	7.13	10.06	11.85	13.41	11.28	11.37	10.21	6.78	4.76	2.61

Note: These figures (in inches) are averages of the fresh-water evaporation records at three stations on the shores of the Salton Sea equipped with buried Young-Type screened pan, 2-ft diameter, 3-ft depth, and 1/4-inch mesh screen.

Bed Sand Analysis

In the summer of 1958, when it was apparent that the SS-13 treatment had not significantly reduced the seepage in Reach No. 2, a speculation was advanced that the presence of a moving bed-load had prevented the sealing action from penetrating into the stable bed proper. To verify this theory, an examination of the channel bed was made on July 20 to 23, 1958.

Investigative Survey -- It can be recognized that during the winter months of low flow and small velocity, the bed-load movement is not crucial, whereas during the summer months of high flow and relatively great velocity, the bed-load movement becomes an active factor. This is the reason the examination was made on July 20 to 23, 1958; however, because the water was turbid, direct observations of the canal bed were not possible. Consequently, with limited observations and equipment, the bed-load study was not as thorough as could be desired. The observations of this study in Reach No. 2 may be summarized as follows:

1. The depth of water varied between 5.4 and 7.8 ft, with sand bar crests measuring 0.2 to 1.0 ft in height.

2. The channel bottom itself seemed firm with intermittent lime crust, while the sand bars or dunes were soft. The soft and firm alternation along the channel centerline were each 4 to 10 ft in length.

3. The loose sand crests moved gradually downstream. At one location, they were timed to move apparently 9 to 13 ft per hour, but this rate cannot be considered general.[1]

4. The softness in the bed, hence the amount of loose sand, was less prevalent at this time than in the previous fall, when the canal was drained in preparation for the SS-13 treatment.

5. Some of the sand in motion on the bottom of the canal seems to be related to the amount of sand drifting over the nearby land.

6. Bank or bed erosion is not considered important as a source of bed-load sand in the Coachella Canal.

If the rate of movement mentioned in Item 3 above is maintained throughout the length of the canal it seems difficult to attribute the main source of the bed-load material to wind-blown sand. According to District opinion, it is likely that the Colorado River contributes the major part of the bed-load sand. The sand dune area traversed by the All-American Canal are probably a minor source of bed-load sand.

Theoretical Considerations -- Recent experimentation carried out by the U.S. Geological Survey has uncovered much valuable information in regard to sand dune behavior. Regimes of ripple, dune, plane bed, standing wave, and antidune can now be delineated with reasonable precision (24). The case of the Coachella Canal can be analyzed from the data listed in Table 17.

Effect of Sand Dunes -- The field survey, and theoretical analysis have confirmed beyond doubt that sand dunes are prevalent as a moving bed-load. This factor easily explains the periodic shifting of the rating curves for the gaging stations. Simons and Richardson have produced in a laboratory flume variegated loops of rating curves by increasing and decreasing the discharge over an alluvial bed (28). In field study of fan waves in the Mississippi River, Carey and Keller established a similar looped curve for the river discharge at Tarbert Landing, Mississippi (29). It seems likely that the SS-13 mainly sealed the surface of the bed-load sand, which subsequently shifted and destroyed the seal. In the light of the sand dune phenomenon, the sealing power of SS-13 would be irrelevant unless it can be made to act, through the moving sand, on the channel bed proper.

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[1] Rate of movement seems high according to Imperial Irrigation District opinion and the rate noted above probably represents a local condition.

TABLE 17

DATA FOR SAND DUNE ANALYSIS IN THE COACHELLA CANAL

	Minimum[1]	Maximum[1]
Stream discharge at Sta. 714+10,[2] Q(cfs)	170	1,070
Velocity of flow,[2] V(fps)	1.0	2.2
Median diameter of particles,[3] d(ft)	7.21×10^{-4} (0.22 mm)	1.18×10^{-3} (0.36 mm)
Water depth,[4] D(ft)	1.5	7.8
Slope,[4] S(dimensionless)	0.00013	0.00033
Temperature[5] (°F)	52	87
Fall velocity of sediment,[6] ω(fps)	0.072	0.197
Kinematic viscosity,[7] ν(ft²/sec)	1.37×10^{-5}	0.825×10^{-5}

The range of Froude number $\frac{V}{\sqrt{gD}}$ (where g is the gravitational acceleration) is calculated from the above data to be 0.216 to 0.139. Although the Froude number calculated from local deviations of velocity and depth may well fall outside this range, it is expected to be less than unity, hence the tranquil flow regime.

The range of $\frac{V*}{\omega}$ is computed to be 1.10 to 1.46, and the range of $\frac{V*}{\nu}$, 4.2 to 41.6 (where $V* = \sqrt{gDS}$). These values, according to Simons and Richardson (24,28) indicate a domain within the realm of dunes.

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1 At minimum and maximum discharges and temperatures.

2 From recorded figures for 1957 and 1958.

3 From Fig. 13.

4 From recorded readings of bottom and water-surface elevations for 1957 and 1958.

5 From averages recorded in Ref. 11.

6 From Ref. 25 (shape factor has been assumed to be 0.5 to 0.9 according to Ref. 26.

7 From Ref. 27.

Conclusions and Recommendations

Three methods of evaluating the sealing results produced by the SS-13 treatment were used: (a) Inflow-outflow comparisons of discharge, (b) piezometric analysis of hydraulic gradient conditions in canal perimeter materials, and (c) analysis of ground water fluctuations in the area adjacent to test section of canal. None of the methods indicated a major change in loss rate from the test section after the treatment. Some slight change in the piezometer readings was noted but this change produced no significant change in the ground water levels.

In searching for reasons for this essentially unfavorable result, several conclusions concerning the trial site conditions seem pertinent:

1. The bank materials in Reach No. 2 are essentially stable--at least from the standpoint of erosion or bank cutting. The shore line is protected by a narrow band of grass. Where local wash-outs occur, they are controlled immediately--mainly by installation of chicken-wire deflectors. Silt berms are forming, however, and the banks must be re-sloped periodically. The silt sediments seem to be formed by sediment carried by the canal which is caused to deposit by the bank vegetation trailing along the water at the edge of the canal.

2. The bottom or bed materials in Reach No. 2 vary in several important respects from the bank materials. While the canal bed in this reach is essentially stable, it is mantled by shifting dunes of bed-load sand materials. The stable base materials are cemented with $CaCO_3$. Clay materials are also found in some areas as a binding material. The presence of the clay materials can be explained by a deposition ahead of the bed-load sand dunes (24) but the reason for the lime deposition is less evident. It seems to be precipitated as the hard canal water seeps into the canal bed.

3. The source of the bed load sand seems to be the All-American Canal which in turn is diverted from the Colorado River. Some of the sand is undoubtedly obtained from wind-blown material from the sand dunes and from a portion of Reach 1. In most reaches of the canal, the canal section is either protected by high banks on each side or traverses terrain with sufficient vegetation cover or stable top layer to prevent addition of wind-blown sand in any large amounts to the canal.

Since the life of the sediment seal is involved directly, an appreciation of these site conditions is important. With this thought in mind, future laboratory and field testing should be concentrated on developing procedures to seal the stable base materials rather than the moving bed-load sand. Obviously, procedures designed to seal the bed-load sand, which is in motion when the canal water is flowing, will produce a temporary seal only.

Thus, in consideration of the unfavorable sealing results and the above-mentioned site conditions, the following recommendations are offered:

1. Studies of the bed-load sand movement are needed before additional experimental work is initiated. Adequate knowledge of the canal bed conditions is an important prerequisite to any future work.

2. A sedimenting method is needed that can be used without disturbing or interrupting the normal irrigation water delivery. It is recommended that, if at all possible, the ponding method in future experiments not be used.

3. Because of the need for periodic sloping of the canal banks and also because of the shifting bed-load sand problem, an extremely low-cost method of sedimenting is needed that can be repeated periodically without incurring costs that exceed the benefits.

4. Experiments with local low-swell clays, such as the Coyote Wells clay, should be made. A dispersing agent is not recommended since the excess calcium content in this clay will possibly enhance the natural lime precipitation and cementation of the canal bed, and materially assist in the settling of the clay out ahead of the sand dunes.

5. The major installation should be accomplished at maximum flow when the movement of bed-load sand is also at a maximum.

6. Laboratory experiments with chemical flocculating agents have not been conclusive and should be continued. The experiments should include: (a) addition of agent to canal water alone, and (b) combination of agent with local clay materials.

7. The use of ground water level and piezometer observations as the main evaluation method is recommended, supplemented to the maximum possible extent by water-loss measurements of canal flow.

LATERAL 1 TRIAL

This trial installation in sand dune material was sponsored by the U. S. Bureau of Reclamation, who supervised and paid for the installation, and by the Pathfinder Irrigation District of the North Platte Project, who furnished the site and part of the equipment and labor. The evaluation activities of the University project were sponsored jointly by the Agricultural Research Service, the Bureau of Reclamation, and the Colorado Agricultural Experiment Station.

The details of the evaluation studies carried out by the University project, both at the field site and in the laboratory, are available in a published report (30). For this reason, only the highlights of the work are summarized herein.

The Trial Site

From Fig. 28, it may be seen that the Lateral 1 site includes the first 5.75 miles of the lateral. Water in the lateral is supplied by the Interstate Canal, which is the main canal for the areas north of the river in the North Platte Project. This canal starts at Whalen Dam. The Pathfinder Irrigation District of Mitchell, Nebraska, operates the Interstate Canal System, including Lateral 1.

After consideration of several potential sites in sandy material in the North Platte Project area, the Bureau of Reclamation proposed to experiment on a section of Lateral 1 from the headgate on the Interstate Canal downstream to where the lateral divides into two branches, a distance of about 5.75 miles. The site is described by Mr. W. K. Lundgreen of the Bureau of Reclamation office in Torrington, Wyoming, as follows:

> "Lateral 1 of the Pathfinder Irrigation District delivers water to lands in Wyoming and Nebraska. The bulk of this land lies north and east of Henry, Nebraska. The lateral headgate is located at approximately mile 46.7 of the Interstate Canal. From the headgate, the lateral was constructed on a contour. A system of rather steep drops was built to help control the grade. The entire lateral runs through a sand hill area. Much of the land that was proposed for irrigation, under this lateral, has been abandoned by the District.
>
> ". . .This lateral has shown a high seepage loss and has been a maintenance problem to the District. In addition, it was ideal for the various tests that were to be carried out. The test section, approximately six miles long, had only one farm delivery throughout the entire reach. ..."

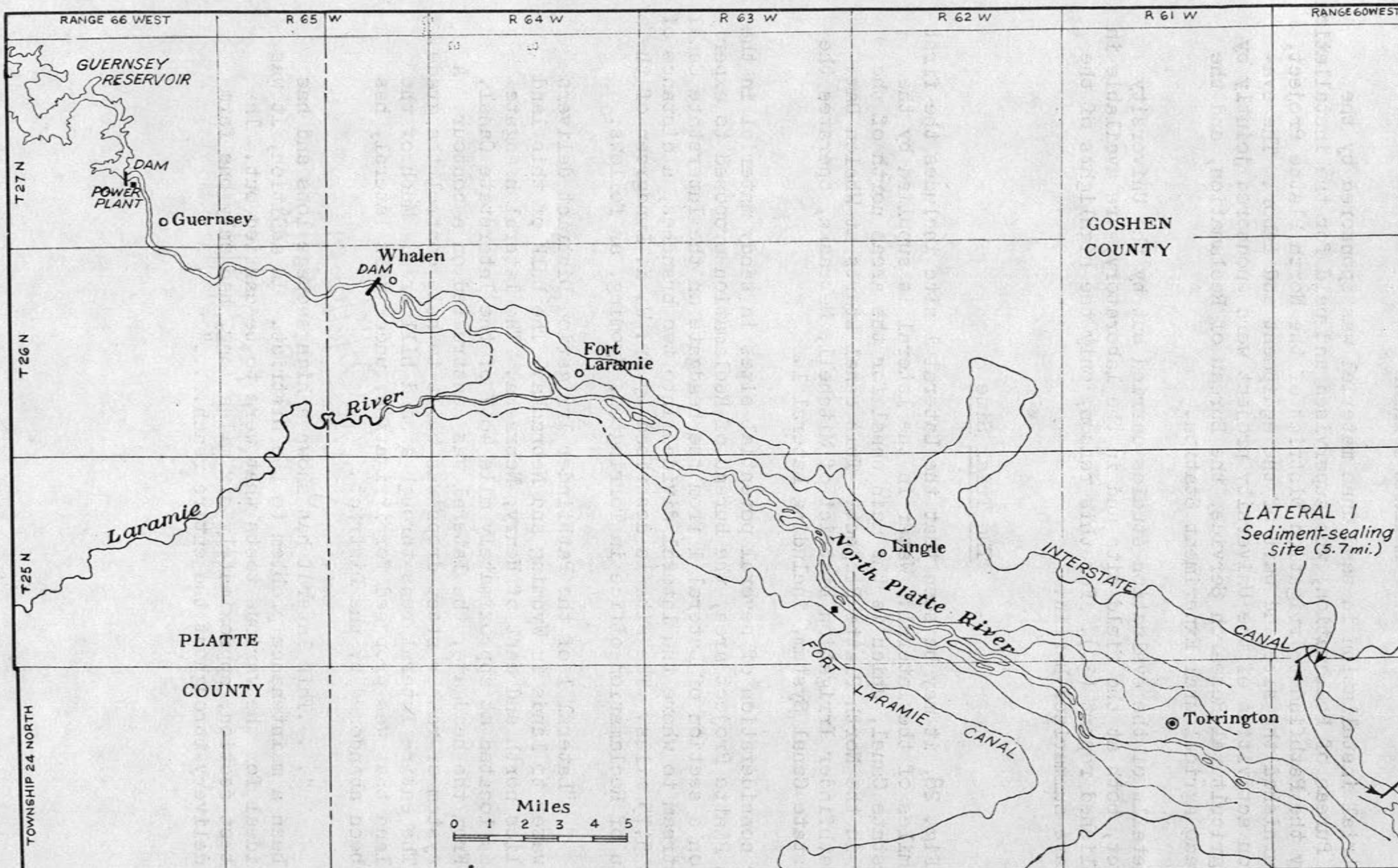

Fig. 28 Location map of Lateral 1

Thus, the test reach lies entirely in a dune sand area. It has a capacity at the head end of about 80 cfs. The channel was originally constructed with a bottom width of 7.0 ft, a water depth of 4.0 ft, and side slopes of 1.5 to 1 for most of the reach.

The sandy material varies to some extent in the 5.75-mile test reach; but in general, the bulk of the sand particles are smaller than 0.3 mm (50-mesh sieve). From 95 to 98 per cent of the samples will pass the No. 50 sieve and about 5 per cent of the samples will pass the No. 200 sieve. The quality of water, which is variable and fairly high in hardness, will be discussed in the evaluation part of this discussion.

The Need for Canal Sealing

Before 1927, the water reaching Whalen Dam carried considerable silt, and while this caused extensive canal cleaning problems it also had some hidden benefits. After storage was begun in 1927 behind Guernsey Dam, which is about 10 miles above Whalen Dam, the project water became almost entirely clear. This minimized the canal cleaning problems, but the estimated delivery losses, including seepage and operational losses, rose steadily from about 33 per cent in 1926 to about 57 per cent in 1931 (31).

In recent years, it has been found that by lowering the water level in Guernsey Reservoir, a muddy canal water could be produced in the project area. This caused an immediate but somewhat temporary reduction in seepage losses in the project canals. This was especially noticed for the Interstate Canal. Unfortunately, however, when the reservoir level was lowered for a "silt run" in the 1959 season, very little muddy water was produced (32). A prevalent belief in the project area relates this changed condition to the recent completion of Glendo Dam, some 20 miles upstream from Guernsey Dam, and to the storage of the new spring flows of muddy river water in Glendo Reservoir rather than in Guernsey Reservoir.

In any event, the major justification for the bentonite sediment sealing trial in Lateral 1 relates to this widely observed beneficial effect of muddy canal water and to the reasonable assumption that it should be possible to develop a controlled method of adding and manipulating an artificial sediment to produce a dependable low-cost seal in the project canals--more especially in sandy material such as found in the Lateral 1 experimental site.

The Trial Installation

The experimental trial was installed in Lateral 1 during the spring of 1956, before the irrigation season and while Lake Minatare was being filled. It was installed before the scheduled cleaning of the lateral could be completed.

Since the before-treatment procedures of water-loss measurements, water-table observations, and canal soil and water tests are discussed under the evaluations section of this discussion, they are not covered at this time. However, in addition to the site evaluation testing, preliminary testing for the installation included (a) trial mix tests of bentonite and canal water to determine how much and what kind of dispersing agent to use, and (b) laboratory percolation tests with samples of canal soils and trial bentonite mixtures to gain some idea of the amount of bentonite penetration that could be expected.

Mixing Procedures

The mixing operation for the Lateral 1 trial was completed during a $3\frac{1}{2}$-day period from March 29 to April 1, 1956.

A total of 240 tons of bentonite was applied from the mix point at Station 0+00 on Lateral 1. The mixing was accomplished with (a) an air-slide hopper, (b) a multiple jet mixer powered with a 4-inch high-pressure pump, and (c) an air-compressor that supplied air for the hopper and for supplemental air-jetting in the dilution pool. The bentonite-water slurry from the mixer contained about 6 per cent bentonite. It was discharged into the weir pool just below the headgate for Lateral 1 where it was diluted to a 1 per cent concentration. See Fig. 29.

The powdered bentonite, a moderately high-swell type (1200 per cent free-swell) was supplied by the Baroid Division of the National Lead Company from their plant at Osage, Wyoming. The dispersant, both powdered and granular tetrasodium pyrophosphate, was supplied by the Monsanto Chemical Company. The total quantity of materials used in the $3\frac{1}{2}$-day operation amounted to 481,200 lbs of bentonite and 7,000 lbs of dispersant.

The mixing was accomplished by the Cronese Products, Inc., Glendale, California, on a contract basis of unit price per ton of bentonite used.

The final concentration of the bentonite mixture was controlled by adjustment of the dilution flow from the headgate. The need for adjustment was determined by hydrometer readings of samples collected just below the mix point. While there was some variation in concentration--tending toward the low side early and toward the high side late in the mixing operation--the average concentration was close to the desired concentration of 1 per cent.

Ponding Operation

For the purpose of ponding the bentonite mixture, the 5.75-mile section was divided into nine ponds by means of existing check structures and one temporary earth dam. The ponds varied in size considerably, each was

Fig. 29 Bentonite mixing operation for the Lateral 1 trial

allowed a sedimenting period of at least 24 hours. Each time as the bentonite water was routed to the next downstream pond, clear canal water was run into the vacated pond to protect the filter cake of bentonite remaining on the channel sides and bed. See Fig. 30.

The ponding operation began on March 29 and ended on April 10, 1956. After April 10, an attempt was made to regulate the clear-water inflow so that all nine ponds were maintained full but with no overflow from the last pond. This was not entirely possible because of variations in the loss, but in general, a flow of about 1-1/2 cfs came close to accomplishing this purpose. The flow of water into the lateral was cut off on April 19, 1956, and by May 7, 1956, the treated section was almost entirely dry.

Installation Costs

The total contract cost of this installation was estimated at $11,791 (33). The total area treated was estimated at 72,778 sq yds, including about 4,000 sq yds along the bottom of the lateral beyond the last check structure at mile 5.75. The unit cost, therefore, was about $0.16/sq yd.

Evaluations Summary

The effectiveness of the sedimenting installation was evaluated by (a) visual observations, (b) seepage loss measurements, and (c) laboratory test comparisons.

Visual Observations

As previously mentioned, the treated section of the lateral was allowed to dry completely immediately following the installation. This drying resulted in the bentonite layer becoming severely cracked. No visual evidence of bentonite penetration beyond the surface coating was noted except a few random cracks in the soil that were filled with bentonite. See Fig. 31.

Seepage Loss Measurements

Since the available measurement methods are of limited accuracy, several approaches were used by the Bureau of Reclamation; namely, inflow-outflow measurements, seepage meter measurements, observation well studies, and ponding tests. Except for the favorable results of the constant-head ponding test immediately following the experimental treatment, none of the other tests indicated any significant sealing effects. The results

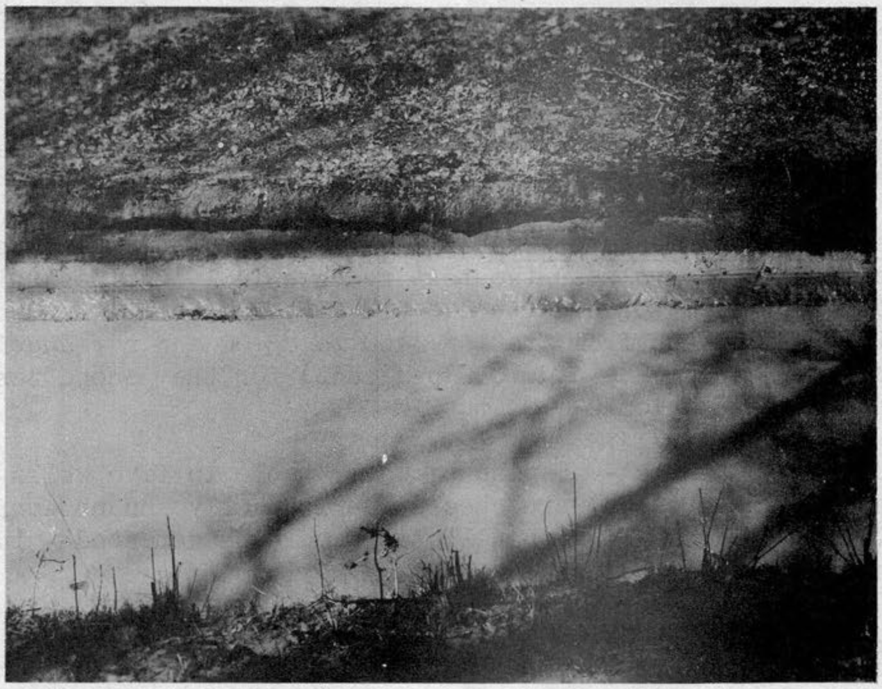

Fig. 30 Bentonite cake formed by sedimenting in the Lateral 1 trial

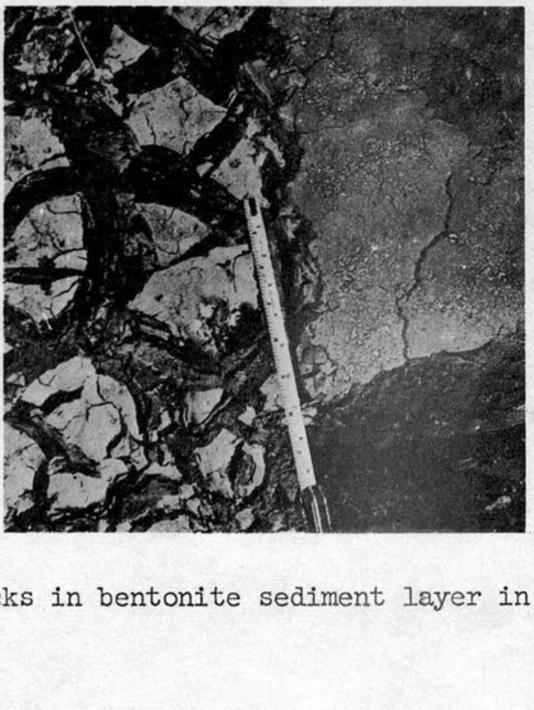

Fig. 31 Drying cracks in bentonite sediment layer in the lateral 1 trial

of the various seepage loss measurements are summarized below:

1. Inflow-outflow measurements -- The 1955 and 1956 flow records show that the apparent reduction in loss possibly caused by the bentonite treatment is from 19.8 per cent to 15.9 per cent; or 3.9 per cent by weir readings, and from 22.2 per cent to 18.0 per cent or 4.2 per cent by current meter readings; in each case the reduction is 19 to 20 per cent of the original loss.

2. Seepage meter measurements -- The results of seepage metering at 100-ft intervals in two test reaches indicates possibly a reduction from 3.3 cfd[1] to 2.8 cfd (15.8 per cent) for the first test reach from Station 1+00 to 83+00 and a reduction from 2.8 cfd to 2.6 cfd (8.2 per cent) for the second test reach from Station 230+00 to 310+00.

3. Observation wells -- Depths to water table in five wells along the 5.75-mile reach were checked periodically and no appreciable effect of the sealing installation could be detected-- in fact, the water table had risen slightly by 1956.

4. Ponding tests -- While the results from these tests were somewhat inconclusive owing to differing conditions between the 1955 and 1956 tests, no significant difference in loss rates for the two years could be detected--in both years the losses ranged from a minimum of about 0.35 cfd at low ponding depths to a maximum of about 1.35 cfd at high ponding depths.

Laboratory Test Comparisons

Samples of the bed material, the canal water, and the bentonite were collected, before and after the treatment. The results of this testing by the Bureau of Reclamation laboratory in Denver are summarized below:

1. Soil tests -- Three tests were used: benzidine staining, X-ray diffraction, and exchange capacity. None of the tests indicated any appreciable penetration of bentonite into the sandy canal materials.

2. Water tests -- Analysis of the water before and after the treatment revealed a major change in the water quality. The canal water collected on May 3, 1955, contained 622 ppm of total dissolved solids and a total hardness of 282 ppm (as $CaCO_3$).

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[1] Cu ft/sq ft/24 hours.

This water had been used to determine how much dispersant to use for the trial with the assumption that the water in the following spring would be similar. This assumption was in error as the canal water at the time of the installation on April 29, 1956, contained 942 ppm of total dissolved solids and a total hardness of 412 ppm (as $CaCO_3$).

3. Bentonite tests -- X-ray diffraction and the free-swell tests on the bentonite revealed 75-80 per cent montmorillonite, predominantly of the sodium variety, with some of the calcium variety and a free-swell of about 1200 per cent. The non-clay constituents were chiefly biotite, magnetite, hematite, and gypsum.

Conclusions Relating to Field Trial

It is evident that initially for the particular combination of sandy materials, canal water, and sedimenting bentonite involved in the Lateral 1 installation, a seal of limited life was produced and that a lack of bentonite penetration into the canal sub-grade materials was the major problem.

Factors which possibly accentuated this lack of penetration during and immediately after the treatment include:

1. Flocculation or aggregation of bentonite during the ponding phase of the operation. This was undoubtedly brought on by the unexpected increase in hardness of the canal water.

2. Only partial completion of canal cleaning which was to have been completed prior to the bentonite installation.

3. The severe dry-out immediately following the bentonite treatment.

Significantly, at the end of the first season after the treatment, ample evidence of bentonite could be found in the lateral bottom; in the form of discontinuous curled-up chips, buried under 2 to 6 inches of bed-load sand. Thus, the bentonite did eventually penetrate into the bed but not to a serviceable extent. After the first season of lateral operation, no significant sealing effect could be detected.

Follow-up Laboratory Program

The lateral 1 failure aroused apprehension concerning the practicability of sealing a sandy material with a bentonite sediment. In July 1957, a fundamental laboratory study was begun by the sediment sealing project, with the concurrence of its Technical Advisory Committee[1]. The purposes of the study were:

1. To find the causes of the formation of the surface layer of bentonite, in terms of the physical and chemical properties and reactions of the materials, and

2. To recommend practical field methods of obtaining the desired penetration of the bentonite and (or) dispersant in the canal bed materials to form a more permanent seal.

As it turned out, the laboratory study did provide significant information in regard to the first purpose above; and in the course of this work, several interesting relationships of soil, water, sediment and air were revealed, but very little of practical significance was developed that would relate directly to the second purpose above. Later field activities, however, did provide a practical methods of circumventing the surface seal problem (34).

Since this report covers only the field installation work at the four ARS contract program sites, and also since the laboratory work is reported in detail in the published reference previously cited (30), only a brief outline of the work is included below:

1. <u>Preliminary field work</u> -- A detailed re-examination was made at the site. This included: sample coring throughout the test reach, bulk density determinations at representative locations, and collection of a 3000 lb disturbed soil sample for use in the laboratory program. The latter sample was a composite of samples from six representative cross-sections of the canal channel.

2. <u>Preliminary laboratory work</u> -- This included: thorough mixing of the composite sample; characterization of the soil, consisting of mechanical analysis, determination of moisture content at saturation, and variation of permeability both with moisture content and with density; manufacture of synthetic water, fashioned after the canal water during the installation trial; and trial mixes of bentonite, with varying amounts of dispersant, in water.

3. <u>Permeameter loading</u> -- The design of the permeameter, and its assembly, is shown in Fig. 32. The sand obtained from the field site was packed in the permeameters at an average density of

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[1] Composed of representatives from the Agricultural Research Service, the Bureau of Reclamation, and Colorado State University.

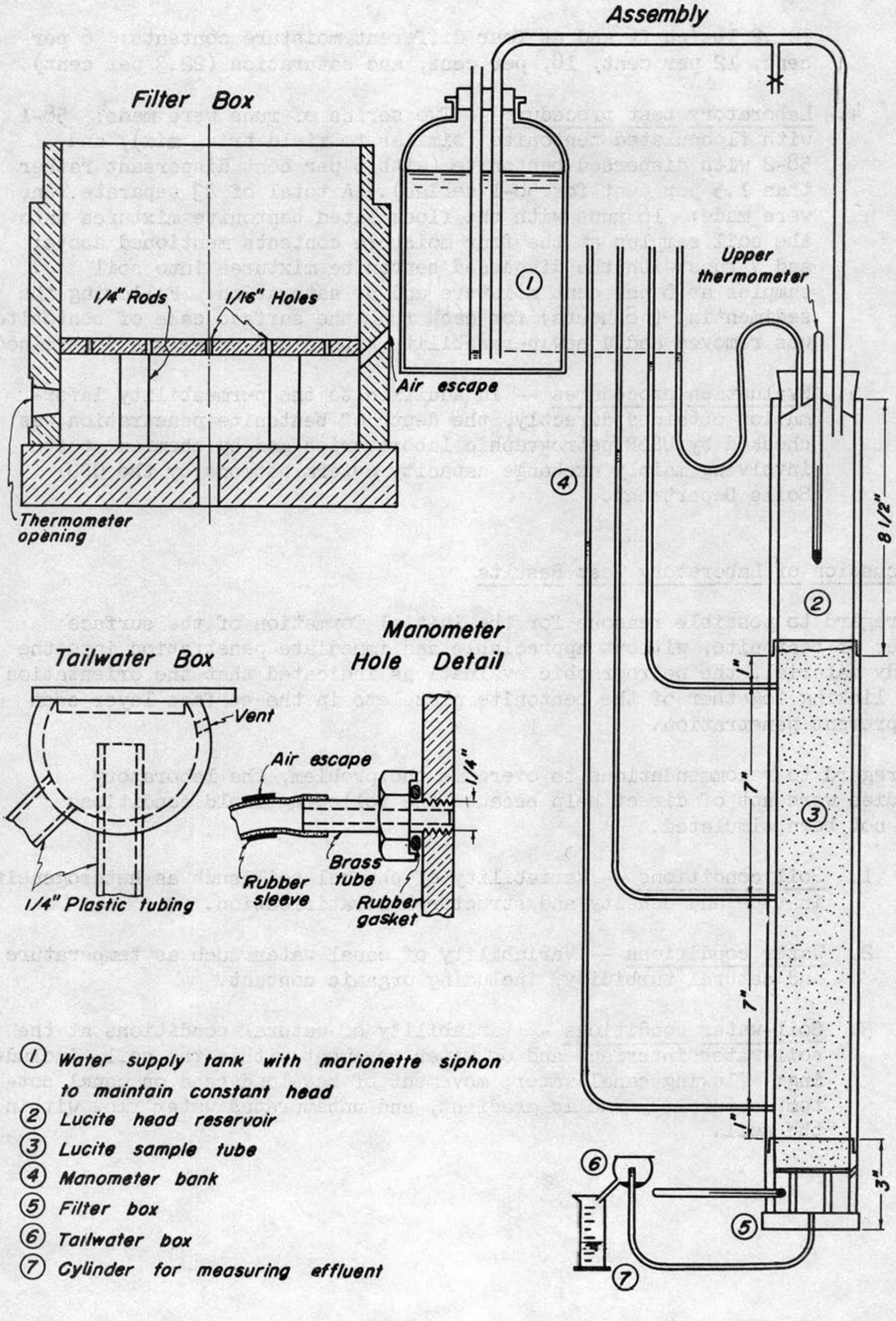

Fig. 32 Design and assembly of the permeameter system for laboratory testing of Lateral 1 samples

101.2 lbs/cu ft and at four different moisture contents: 6 per cent, 12 per cent, 18, per cent, and saturation (22.3 per cent).

4. Laboratory test procedure -- Two series of runs were made: 58-1 with flocculated bentonite (similar to field trial mix), and 58-2 with dispersed bentonite (with 5 per cent dispersant rather than 1.5 per cent for 58-1 series). A total of 23 separate runs were made: 16 runs with the flocculated bentonite mixtures into the soil samples at the four moisture contents mentioned above; and 7 runs with the dispersed bentonite mixtures into soil samples at 6 per cent moisture and at saturation. Following the sedimenting (48 hours) for each run, the surface cake of bentonite was removed and a new permeability with clear water was determined.

5. Evaluation procedures -- In addition to the permeability information obtained directly, the depth of bentonite penetration was checked by USBR petrographic laboratories and by chemical tests involving mainly exchange capacity determinations by the CSU Soils Department.

Discussion of Laboratory Test Results

In regard to possible reasons for the initial formation of the surface layer of bentonite, without appreciable and immediate penetration into the sandy material, the petrographic evaluations indicated that the orientation and linking together of the bentonite platelets in the surface layer seem to prevent penetration.

In regard to recommendations to overcome the problem, the laboratory studies were not of direct help because the following field conditions had not been simulated.

1. Soil conditions -- Variability of channel soil such as heterogeneity in type and density and structural stratification.

2. Water conditions -- Variability of canal water such as temperature and natural turbidity, including organic content.

3. Soil-water conditions -- Variability of natural conditions at the soil-water interface and of water movement within the soil, including: flowing canal water, movement of bed-load sand on canal bottom, natural hydraulic gradient, and unsaturated water flow within the soil.

With the above limitations in mind, several conclusions can be made that may be of value:

1. In all of the runs, an effective sealing was produced by the surface filter cake of bentonite. Either type of bentonite treatment--flocculated or dispersed--seemed to be equally as effective. Removal of the cake, however, in both cases, destroyed the seal.

2. According to the microscopic examination, the dispersed bentonite did not penetrate beyond the top inch of the soil columns, and the flocculated bentonite penetrated even less. The cation exchange capacity determinations, which may be a more sensitive test, showed traces of penetration through entire columns, but the quantity was far too small to bring about any beneficial sealing effect.

3. In the laboratory runs with a dispersed bentonite mixture, the increase in exchangeable sodium percentage of the treated soil was quite pronounced. This increase produced a slight sealing effect in the soil in some of the runs, but nothing significant.

Conclusions and Recommendations

In recent bentonite sealing work in Wyoming (34), the surface seal problem, as encountered in the Lateral 1 trial, has been overcome by harrowing of the canal bed and banks during the bentonite ponding phase of the sedimenting procedure. However, even with the addition of harrowing, the bentonite ponding method or, as it is referred to in the 1960 ACP Handbook for Wyoming, the bentonite dispersion method[1], is of doubtful applicability in Lateral 1 because of the following site conditions.

1. The hardness of the canal water, and especially the variability or unpredictable level of hardness.

2. The presence and movement of bed-load sand on the bottom of Lateral 1.

Both conditions, especially the bed-load sand, will tend to shorten the life of the bentonite seal obtained with the ponding method. With extra effort, additives and cost, it is possible that a longer lasting seal could be produced, but a more fruitful avenue of approach is indicated. It is recommended that the possibilities of intermittently adding lake sediments

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[1] Installation and specification details available at USDA-ASC offices in Wyoming.

into the project water during its travel through Guernsey Reservoir be fully investigated[1].

Reference is made to the conclusions and recommendations contained in the Lateral 19.3 chapter (page 31) relating to the use of locally available clays. The bed-load sand problem of the Lateral 1 site is a complicating factor, but according to Simons et al. (35) a portion of the clay sediment will be deposited temporarily under the advancing sand materials. Stabilizing the buried clay layer so that it is not subsequently eroded and washed downstream is a major problem. The flocculating agents previously mentioned in the Lateral 19.3 chapter show promise of stabilizing the clays. Therefore, it is recommended that the investigations mentioned above include evaluation of the flocculating agents, such as Dow's Separan and Monsanto's IBMA.

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[1] The Bureau of Reclamation has already initiated studies in this regard.

TWIN LAKES TRIAL

This trial installation in rocky materials was sponsored by the Twin Lakes Reservoir and Canal Company of Ordway, Colorado, who supervised the work and furnished the labor, equipment and materials. The University activities at this trial were sponsored jointly by the Company, the U. S. Department of Agriculture (ARS), and the Colorado Agricultural Experiment Station.

Details of the evaluation work accomplished by the University project at this field site are available in an interim report (36). For this reason, and also because of the summary nature of this report, only the highlights of the work at this site are included herein.

The Trial Site

The Twin Lakes trial site is in the Connection Canal of the Trans-Mountain Diversion System of the Twin Lakes Reservoir and Canal Company[1].

The Company serves an area of approximately 56,000 acres of land in the Arkansas River Valley, east of Pueblo, Colorado, and in the vicinity of Ordway, Colorado. The irrigation water for this area is obtained from the Arkansas River, where the Company has both direct flow and storage rights In addition to its supply of river water, which in many years is extremely limited, the Company also obtains an important part of its supply from the western side of the Continental Divide from its Trans-Mountain Diversion System, south of Independence Pass and above Aspen, Colorado.

The Trans-Mountain System, as shown on Fig. 33 collects snow-melt water from an alpine area on the headwaters of the Roaring Fork River, a tributary of the Colorado River. The water from the west portal network of canals, including the Connection Canal, runs into Grizzly Reservoir. From there it is transported under the Continental Divide through Tunnel No. 1 and stored in Twin Lakes Reservoir, south of Leadville, Colorado.

The Connection Canal between Tunnel No. 2 and Grizzly Reservoir is 7,700 feet long and has a maximum capacity of about 350 cfs. Because of the differing nature of the rocky materials it traverses, the cross-section varies; but in general, the canal has a bottom width of about 15 feet, a maximum water depth of about 5 feet, and side slopes that range from nearly vertical in the rock cuts to about 1 to 1 in the intervening reaches in rock slide or talus materials. The average slope of the canal is 0.00055 or about 4.2 feet in the 7,700-foot length of canal. There are no constructed inlets or outlets in the Connection Canal. However, there are numerous natural inlets and outlets in the coarse rocky materials of this canal. See Fig. 34.

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[1] Referred to as the Company in this chapter.

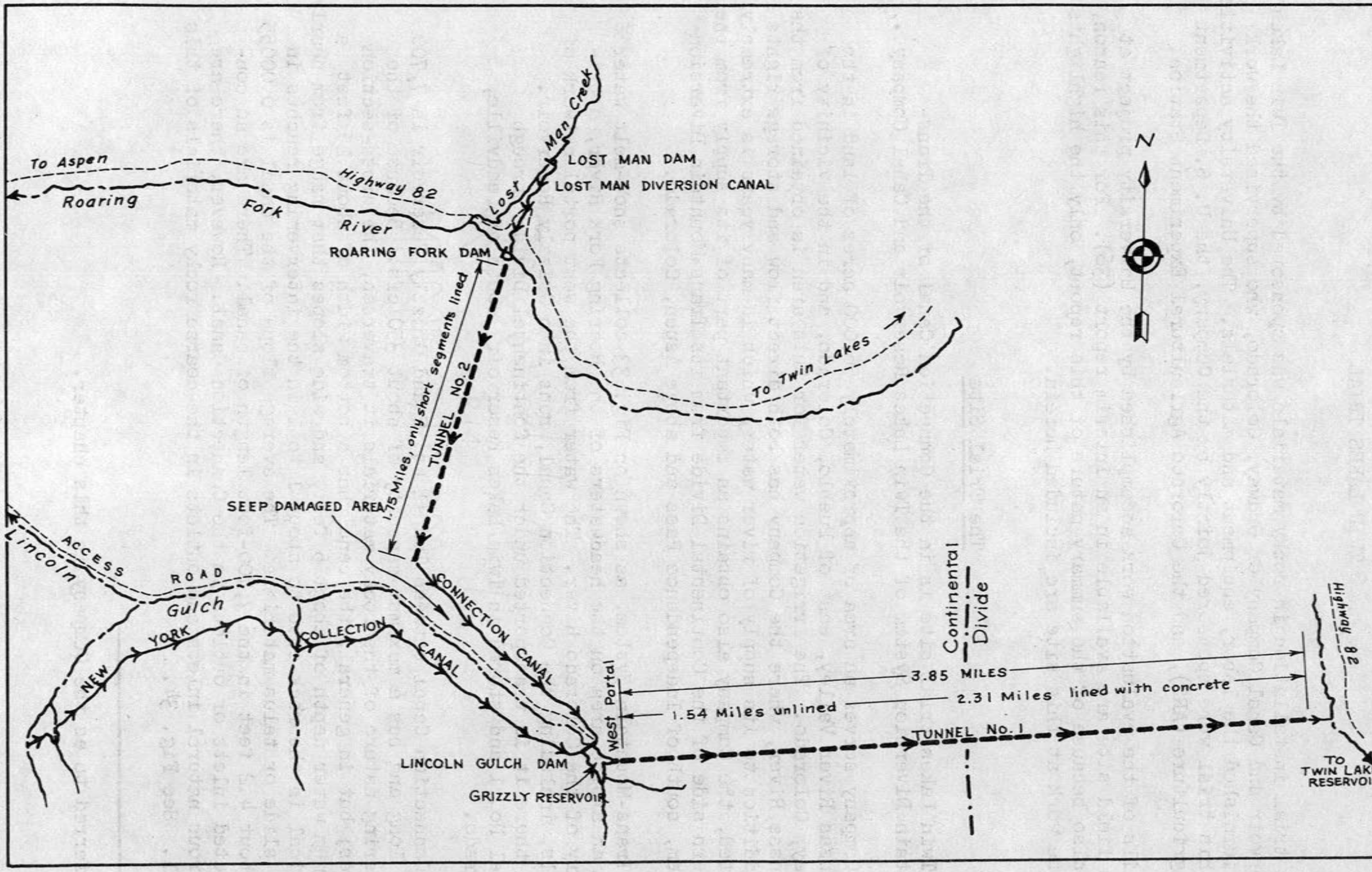

Fig. 33 Trans-mountain diversion system of Twin Lakes Reservoir and Canal Co.

Fig. 34 Fractured bedrock exposed in the Connection Canal site

The Connection Canal site was selected for the Twin Lakes trial because (a) the canal enlargement work had just been completed during the preceding summer, (b) extensive seepage losses from the canal were being experienced, and (c) the canal seepage water was seriously damaging the access road into the west portal camp area.

The Need for Canal Sealing

Coarse rocky materials, such as open gravels and fractured rock, are directly responsible for excessive seepage loss in many irrigation canals. In many of these rocky areas, the altitude is high, the growing season is short, and the funds available for canal improvements are commonly very limited. Thus, especially in the higher areas, the development of an extremely low-cost, easily installed method of canal sealing is a vital research need. The Twin Lakes trial site was included in the University ARS contract program on bentonite sealing with this general research need in mind.

Prior to 1955, the Company's Trans-Mountain Diversion system was not fully developed. The canals were too small and were accessible only by foot. For many years, a major part of the snow-melt harvest from this sytem was being lost before the canals could be opened and cleared of snow, and even then the canals could carry only a part of the available run-off during the main snow-melt season, which normally starts during the first two weeks in June and in most years is virtually completed by the middle of July. Thus, with the view of increasing the water yield, a major program of improvements was started in the summer of 1955.

The improvement program originally was restricted to: (a) cleaning, enlargement, and partial realignment of the west portal canals, (b) construction of access roads on the canal banks, and (c) installation of buried pipe in the smaller sections of canal in unstable ground. It was also obvious that canal lining or sealing was an important need in the canal reaches not put into pipe. Actually, under the harsh environment of the area, the buried pipe probably would be the best answer for the entire west portal collection canal system. However, cost is a limiting factor; the buried pipe is being placed where it is an absolute necessity in unstable ground areas, and for the remaining canal reaches situated in stable but pervious materials, development of sediment sealing methods was started in the summer of 1956.

Since the combined problem of high seepage loss and cost limitations of the Twin Lakes site typifies that found in many canals in mountainous country, the University research team and the Company embarked on a cooperative program with the goal of developing a sealing technique that is economical, effective, and enduring in rocky materials.

The Trial Installations

The major installation work was carried out in the Connection Canal during July and August of 1956, but additional procedure development work was also conducted in the Connection Canal and the nearby Collection Canal during the summers of 1957 and 1958. The evaluation work was started in 1956 and was continued through the summer of 1959.

Preliminary Activities

With enlargement of the Connection Canal during the summer of 1955, the canal seepage problems were intensified. This problem, plus the pressing shortage of irrigation water in the area served by the Company, resulted in a high priority being placed on efforts to develop a low-cost sealing method for the west portal canals. Because of the urgency of the situation, the initial planning, materials testing, and purhcase of materials were accomplished before the canals were examined in the field. The preliminary work was accomplished during the spring of 1956 when snow conditions prevented field site examinations. This was not a serious disadvantage since excellent background information was furnished by the Company's Manager-Engineer, Mr. Wallace A. Doe, and the Directors, through both discussion and color slides.

Because of the coarse rocky nature of the canal bed material, it was assumed that, in addition to bentonite, supplemental bridging agents, such as local clays or sawdust, would be required. A preliminary plan including bentonite specifications and a cost estimate for the development and installation work, was prepared. The estimated total cost for development, materials, equipment, and labor was $25,000.

Price quotations and bentonite samples were received from seven different producers. The results of the testing of the bentonite samples in the University laboratory are summarized in Table 18.

The Company ordered 500 tons of Wyoming bentonite from the American Colloid Company at Upton, Wyoming. It was a dried, granular (max. size 1/2") type of bentonite, supplied in bulk form, and delivered to Aspen, Colorado. In addition to the high-swell bentonite, 300 tons of the Lamberg bentonite were also ordered. This pit-run material was ordered primarily for use as a bridging agent intended to provide the silt and sand-size particles presumed to be deficient in both the Wyoming bentonite and the canal bed material. The Lamberg material was delivered by truck directly from the pit near Howard, Colorado, to the west portal area.

Since the site was not accessible during the planning work, no laboratory testing, other than the bentonite testing, was feasible. Obviously, however, in considering the coarse heterogeneous nature of the field site materials, no appropriate testing scheme on the order of laboratory permeameters could be devised without serious disparity from the actual field site conditions. Small scale testing at the field site with seepage meters was also not feasible--because of the coarse rocky canal bed materials.

TABLE 18. SUMMARY OF BENTONITE TESTING RESULTS FOR TWIN LAKES WORK

Source of Sample	Grit Content	Colloidal Yield	Remarks
Wyoming Bentonite	%	%	
Royal Earth Company	2.7	86.4	
Eastern Clay Products	3.3	83.1	
American Colloid Co	3.4	86.7	
Black Hills Bent. Co	4.5	81.3	
Benton Clay Co	4.8	65.6	
		66.1	w/5% dispersant
Wyo-Ben. Products	6.3	74.1	
Colorado Bentonite			
Lamberg #1	10.9	54.2	
Lamberg #2	10.4	12.4	
		25.6	w/5% dispersant
Lamberg #3	9.4	99.1	
Las Animas	6.6	55.5	

Note: Grit is larger than 44-micron size.
Colloidal yield is the amount remaining in suspension after standing for 24 hours.

Trial Activities

During the summer of 1956, the west portal crew completed two main sedimenting operations: The first from August 1 to August 5, and the second from August 25 to September 1.

In the first operation, approximately 50 tons of the granular Wyoming bentonite was dumped into the dry Connection Canal; 8 tons were formed into a dam about 100 feet downstream from the concrete check at the outlet end of Tunnel No. 2, and the remaining 32 tons were spread on the canal bottom between the check structure and this dam. After the bentonite was placed, a flow of about 12 cfs was turned into the canal and ponded on the bentonite. As the water overtopped the bentonite dam, two methods of mixing were tried: (a) jetting with compressed air, and (b) working a back-hoe power shovel back and forth in the bentonite in an attempt to mix it into the flowing canal water. See Fig. 35

The resulting mixture of bentonite and water was run down the Connection Canal and trapped by check boards at the temporary check structure at the lower end of the canal. After checking the canal to a depth of about 4.3 feet at the lower structure, all the water flowing into the canal was lost by seepage and numerous leaky zones were located and marked. It was observed that several of the leaks were flowing milky bentonite water, while other were flowing clear water.

The persistence of a relatively high seepage rate and the milky water springs suggested a need for coarser sediment particles than was provided by the dispersed bentonite alone. Thus, the west bank of the Connection Canal was blanketed from Sta. 34+00 to Sta. 76+92.5 with 40 tons of the coarse pit-run Lamberg (or Howard) bentonite and a second sedimenting operation was conducted.

The second sedimenting operation consisted of placing dams of the Wyoming bentonite (total of 150 tons) immediately above and below the leaky zones located during the first trial run. The stationing (starting at downstream portal of Tunnel No. 2) of the dams and the amounts of bentonite in each dam were as follows: 20 tons each at Stas. 7+00, 11+00, 15+00, 21+00, 27+00, 37+00; 5 tons at Sta. 39+00; and 25 tons at Sta. 63+00. In this operation, the inflowing water (about 6 cfs) was stored behind the upstream dam of bentonite and, as the water overtopped the dam, a back-hoe was used to make a narrow cut in the dam, thus attaining a flow of high velocity water through the dam. The mixing of the dam material with the water was assisted by working the back-hoe shovel back and forth in the breach in the dam. This produced a relatively coarse, lumpy slurry of bentonite. The same operation was repeated at each dam and if not all of the bentonite was eroded away at any of the dam locations, the remaining material was scratched up into a new dam and the "break-out" process was repeated until the major part of the bentonite was transported and deposited downstream.

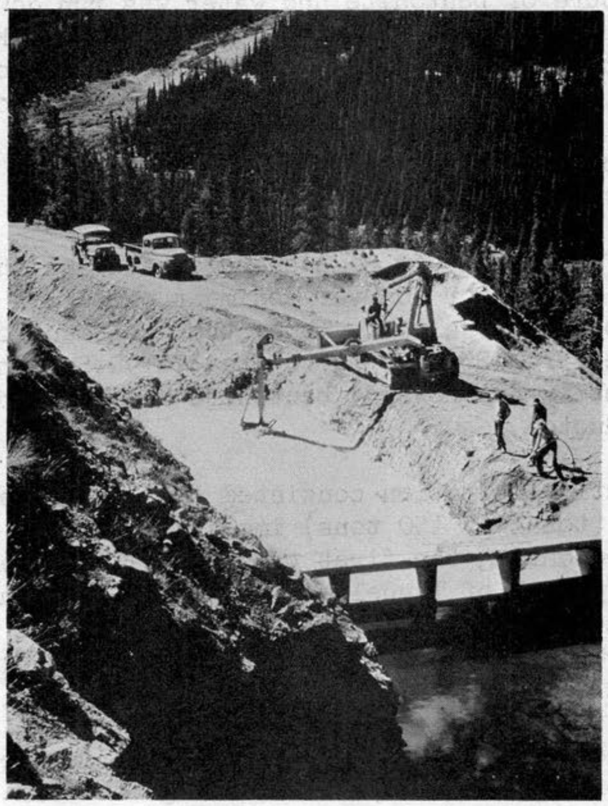

Fig. 35 Mixing bentonite with back-hoe at head end of the Connection Canal

Installation Costs

The total estimated cost of the work, to date, in the Connection Canal is about $10,000. The total treated area is estimated at 17,100 sq yds, not including the upper bank areas that have not been treated to any appreciable extent. The unit cost, therefore, is about $0.58 sq yd.

Discussion of Sealing Results

The sealing efficiency of the trial work in the Connection Canal was evaluated by (a) visual observations of the springs below the canal, and (b) inflow-outflow measurements in the canal. Since the seepage losses vary significantly with the season, this discussion is divided into four sections: (a) Early spring conditions, (b) Peak flow conditions, (c) Summer and fall conditions, and (d) Winter conditions.

Early Spring Conditions

At the beginning of the snow-melt period, up to 90 inches of snow covers the area and blocks the west portal canals. Thus, before the canals are fully opened, appreciable quantities of ground and surface water may flow into the canals from the uphill bank. During this time, seepage loss observations are not feasible; but this inflow condition should be kept in mind as it has an important bearing on the sealing effect produced in the uphill canal bank, on the life of the seal in that area, and on the seepage loss evaluations.

Peak Flow Conditions

Later in the snow-melt period and after the canals are brimfull, it has been possible to obtain some information on the seepage loss conditions. Before the bentonite trial work in the Connection Canal, the seepage areas below the canal would become noticeably more extensive as the peak flow period was reached. These conditions were especially noticed since the access road lies directly below the Connection Canal. According to Mr. Doe, who supervised the construction activities in the area from 1955 to 1959, the road has been drier since the bentonite treatment in the Connection Canal than it was before, but it is not a clear-cut case because (a) obviously during the snow-melt period, the area receives water from sources other than canal seepage alone, and (b) the access road was improved during the period of 1955-1959.

For inflow-outflow evaluation, current meter stations were set up at the upper and lower ends of the Connection Canal. A comparison between the apparent losses before and after the 1956 bentonite treatment is shown in Fig. 36. The 1956 before-treatment data have been computed from sketchy current meter readings and can represent only a very approximate trend. The 1959 after-treatment data have been obtained from continuous records of gage readings that were carefully calibrated against current meter measurements. Here again, however, exact measurements and comparisons are difficult because (a) during the snow-melt peak flow period the canal discharge is constantly changing, and (b) the ground-water inflow between the two current metering stations is not measurable.

Summer and Fall Conditions

As the snow-melt water disappears and the depth of water in the canal decreases, the accuracy in seepage loss observations and measurements increases. Before the bentonite treatment in 1956 and after the enlargement work in 1955, low flows (under about 6 cfs) of water would not carry through to Grizzly Reservoir. After the bentonite treatment, the low flows would carry through and to determine the actual shrinkage of flow temporary weirs were installed at the upper and lower ends of the Connection Canal. See Figs. 37 and 38. Figure 39 shows that a significant reduction in seepage losses in the Connection Canal was produced by the bentonite treatment. Immediately following the 1956 installation work, with an inflow of about 4.0 cfs, the loss was reduced to about 0.9 cfs from the total loss for the same general flow range before the treatment. Seepage loss measurements under similar conditions in 1957, 1958, and 1959 indicate a gradual increase in the losses.

To determine the effect of varying the ponding depth at the lower end of the canal, the outflow measurements were obtained with the weir set at one, two, and three boards high. Data from the ponding (1958) are plotted in Fig. 40. It can be seen that, under ponding conditions, seepage loss increases rapidly as the water depth increases. As a rough check on the increase in loss with ponding depth, the flows in the springs below the Connection Canal were recorded. Because of the canal slope, only the lower end of the Connection Canal was influenced by the changes in the ponding levels. It was found that the increase in pond depth was accompanied by an increase in seepage loss and that the increase in seepage from the canal caused approximately an equal increase in spring flow below the ponded reach of canal.

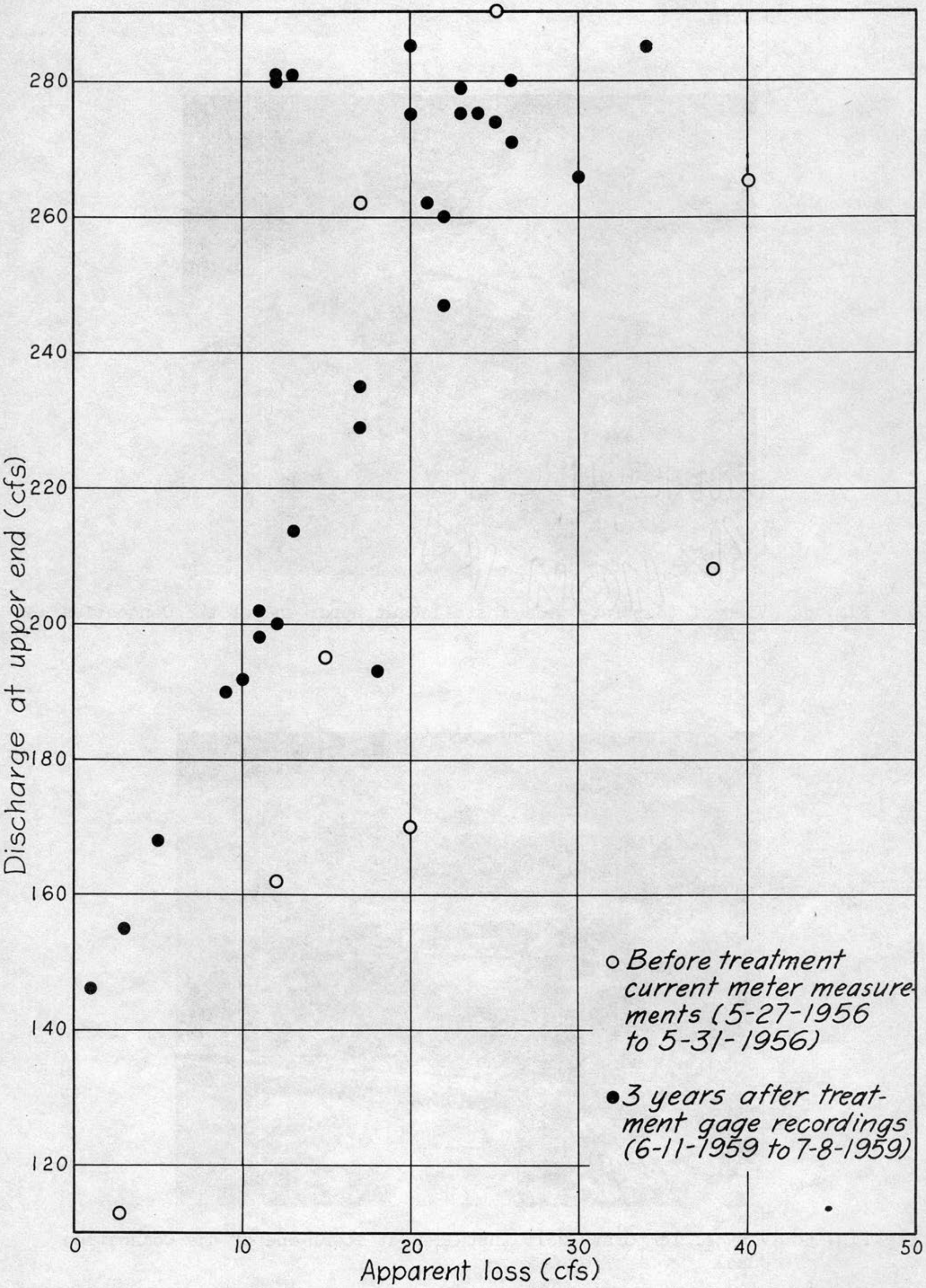

Fig. 36 Comparison of losses at high flow in the Connection Canal

Fig. 37 View of temporary weir installed at upper end of the Connection Canal

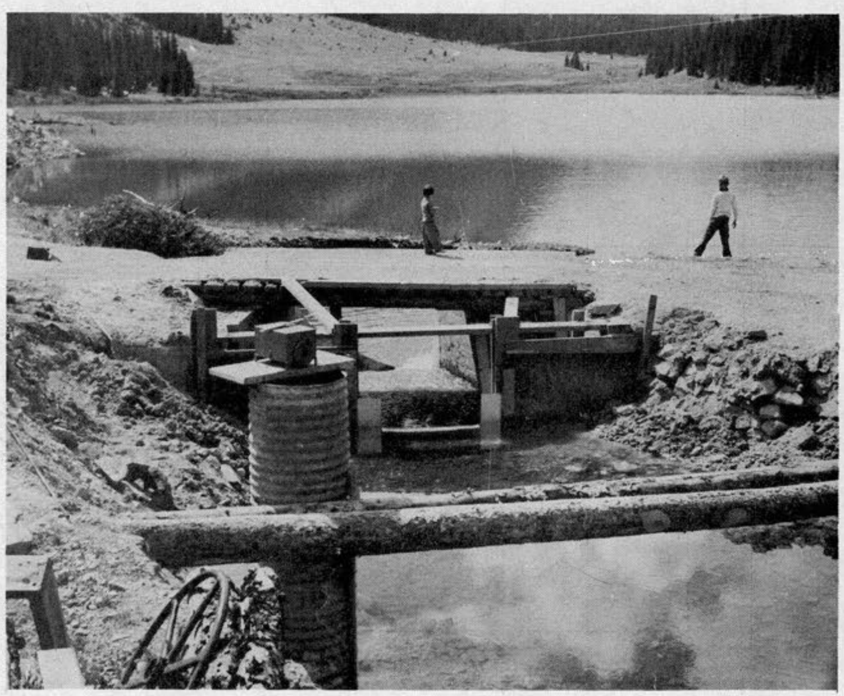

Fig. 38 View of temporary weir installed at lower end of the Connection Canal

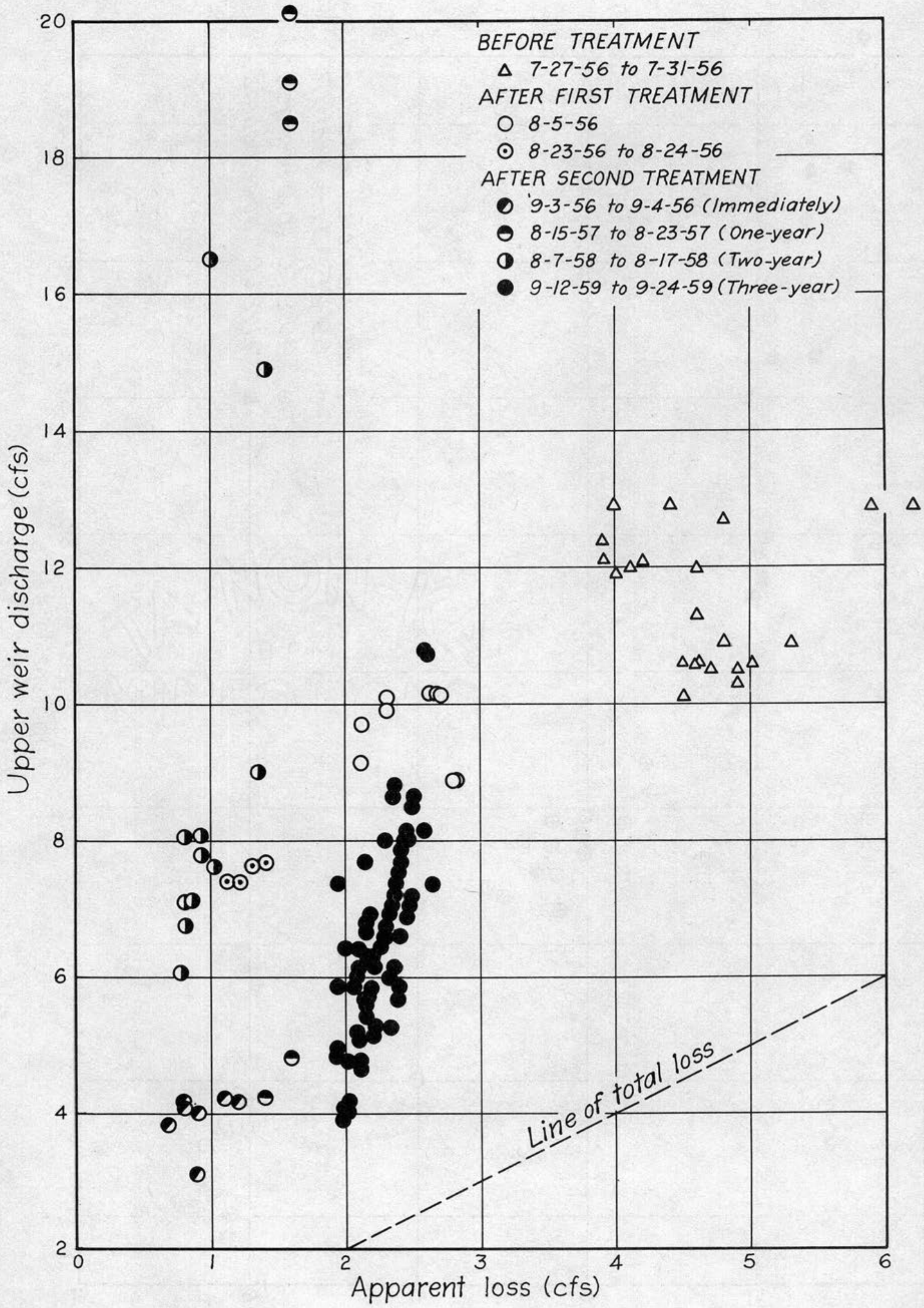

Fig. 39 Comparison of losses at low flow in the Connection Canal

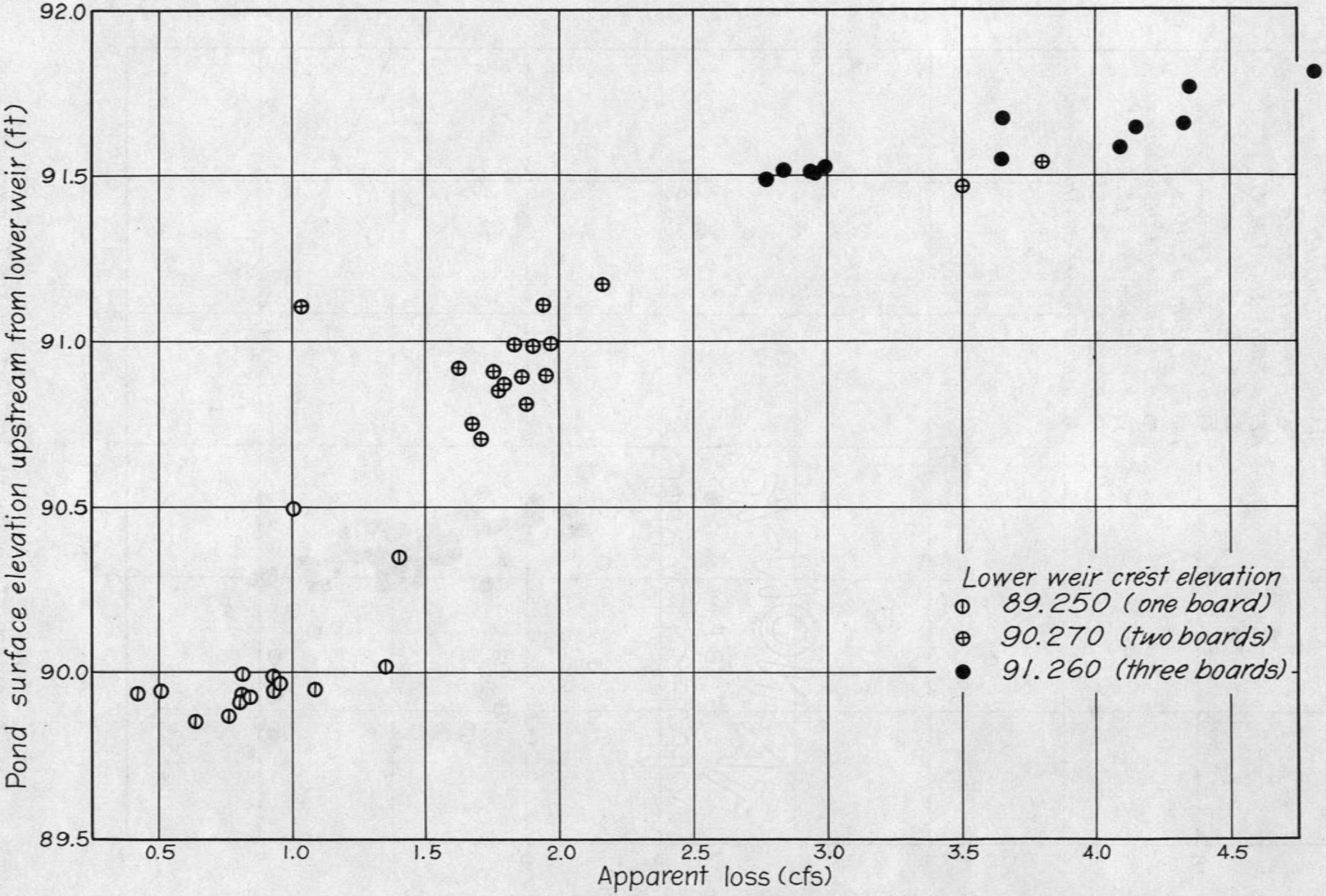

Fig. 40 Variation of losses in the Connection Canal with changes in ponding depth

Winter Conditions

Since the bentonite treatment, it has been possible to maintain small flows of water in the Connection Canal during the winters while before it was not. This is beneficial in that a pilot bore under the snow can be maintained, except in those areas crossed by the spring snow slides, and this makes the opening process in the spring much faster than it was before. Once the flow of water is re-established under the snow cover, the water will do a surprisingly fast job of melting the snow left in the canal.

Canal Sealing Observations

From the foregoing seepage loss measurements and observations, it is concluded that:

1. The multiple-dam method of bentonite sealing as used in the 1956 trial work in the Connection Canal resulted in a good seal under low to medium flow conditions in the canal. It seems likely that the seal was concentrated mainly in the canal bottom and lower bank areas. The sealing effect has shown some deterioration with time. This has probably been caused by the harsh environment conditions, characterized for example, by heavy inflows of ground and surface waters in the uphill bank areas and by extreme frost action. The latter deteriorating actions stress the need for an effective follow-up maintenance procedure, economical enough so that it could be repeated annually.

2. The blanketing of the canal banks with Colorado bentonite helped to alleviate the seepage that developed under deeper ponding depths, and if it had been extensive enough it probably would have helped to decrease the seepage losses under peak flow conditions in the Connection Canal. The feasibility of extensive blanketing of the bank areas at the present time is questionable because of (a) the extremely limited life expectancy of material placed on the uphill bank owing to the disruptive action of inflowing ground and surface waters, and (b) the unresolved advisability of doing a complete job of canal sealing that would be of most value during peak flow periods when the carrying capacity of the Trans-Mountain system is commonly exceeded.

3. A hydrologic study of the west slope system is needed to resolve the last question. Such a study may indicate several prerequisites to a complete sealing of the west portal canals, such as (1) more storage capacity in the west portal area, (2) increased carrying capacity in Tunnel No. 1, part of which is now unlined, and (3) more storage capacity at Twin Lakes Reservoir.

Follow-up Activities

During the summers of 1957 and 1958, additional work was done on procedure development. The objectives of this work were to (a) improve the multiple-dam method for use not only as an initial installation method but also as a simplified follow-up maintenance procedure, and (b) experiment with an air-jet method of blowing the granular Wyoming bentonite into water ponded over the pervious canal bed zones.

Multiple-dam Work

The nearby Collection Canal (See Fig. 33) offered an excellent site for the additional development work. The new work could be accomplished in this site without disturbing the after-treatment phase of the seepage loss evaluations in the Connection Canal. A high seepage loss was being incurred in this canal--especially in the section of canal from Tabor Gulch down to Grizzly Reservoir that was enlarged during the summer of 1957.

During the summers of 1957 and 1958, several small-scale tests were run with various combinations of (a) the Wyoming bentonite, (b) the Colorado bentonite, and (c) wet sawdust. The combination that produced the best sealing results with the least amount of mixing effort was found to be a mixture, in equal parts, of the above materials. The blending of the materials was accomplished during the loading into the truck with a front-end scoop loader and also at the time it was dumped into the canal.

In the main trial installation in the Collection Canal during the fall of 1958, the dams of the 3-way sealing mixture were spaced about 100 yards apart. Since this trial was arranged mainly to provide standby work for the construction crew during a break-down of equipment on a nearby pipe laying job, the dams were placed in the 1.8 miles of the mostly dry canal between Tabor Gulch and Grizzly Reservoir. About 6 to 10 cfs of water was entering the canal at Tabor Gulch but it was dissipated in about the first 200 yards of canal. After the material was dumped, the crew went back to the pipe laying job; the actual sedimenting operation was planned for after the pipe job was completed. Thus, when water started flowing from the Collection Canal into the lake several days later, it came as a surprise. An investigation indicated that the unattended water broke through the first dam in the canal at Tabor Gulch. This carried sufficient material to seal the second pond, the second pond was filled with water, and then the second dam broke. See Fig. 41. This procedure was repeated in each pond and at each dam, and upon its own accord so to speak, the water appeared several days later at the reservoir.

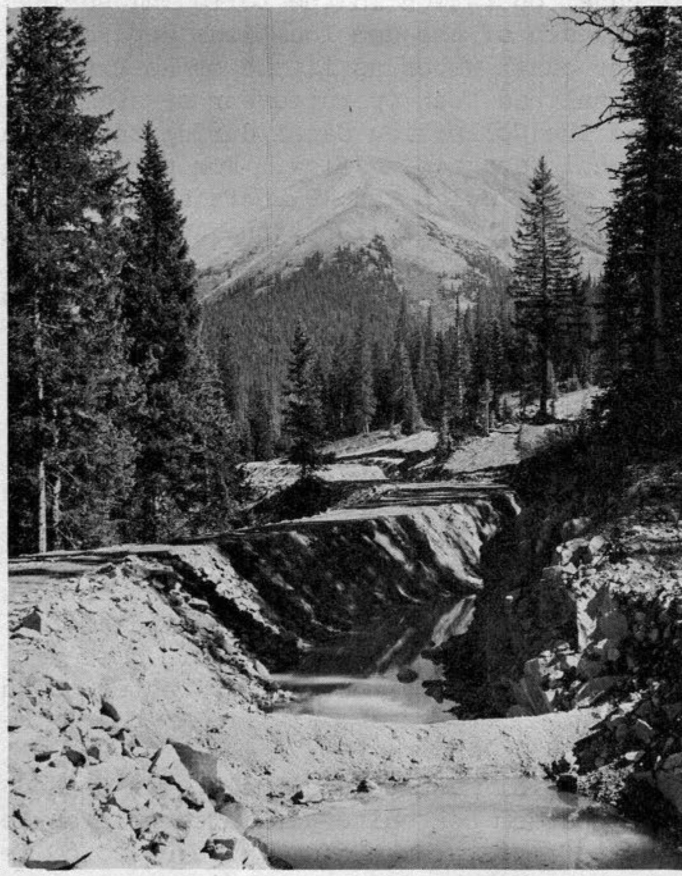

Fig. 41 View of dam built of a mixture of Wyoming bentonite, Colorado bentonite, and sawdust

During the regular canal operation in the following spring, (1959), the remaining material at each of the dam locations apparently was eroded into suspension in the canal water as little or no trace of the dams could be found after the canal had been operated for several weeks. Current-meter measurements in the Collection Canal during the spring of 1959 indicated that the canal was gaining flow. For example, on June 10, 1959, the inflow just below Tabor Gulch was 49.2 cfs and the canal outflow into the lake was 53.9 cfs. On June 11, 1959, the apparent inflow was 34.5 cfs and the outflow was 35.8 cfs. However, at this same time variable amounts of snow-melt water were entering into the canal from the slopes above.

Air-Jet Work

In order to place just slightly wetted and relatively unswelled granules of a high-swell bentonite directly into the pervious canal bed zones, a method of blowing the materials into the ponded water with a cone jet device (See Fig. 42) was tried. Compressed air rather than water was used in this jet device. About 10 feet of 2-inch diameter black plastic pipe was placed on the discharge end of the jet. A flexible pipe was used so that the air-blown material could be directed to where it was desired.

While the volume of material handled was small, the method worked resonably well. The coarser bentonite particles or granules could be shot, in a sand-blast effect, through a distance up to 60 feet. (See Fig. 43). However, when this was done, the fine-powder fraction of the bentonite was largely lost in a fogging effect. This latter effect was largely eliminated when the blast of air and bentonite was discharged under water (See Fig. 44) and a surprisingly good mixing action was obtained.

Perhaps for specialized applications, the air-jet method will find some application, as both the granular and powdered grades can be satisfactorily mixed into water with this method, but it is a relatively slow and expensive mixing or bentonite dispersing method. Also, the endurance of the sealant placed in this way is doubtful, even if the granules swell after entering the rocky material. The bentonite, without coarser bridging materials, seems to fail in the very coarse rocky materials, apparently after it wets, swells and softens.

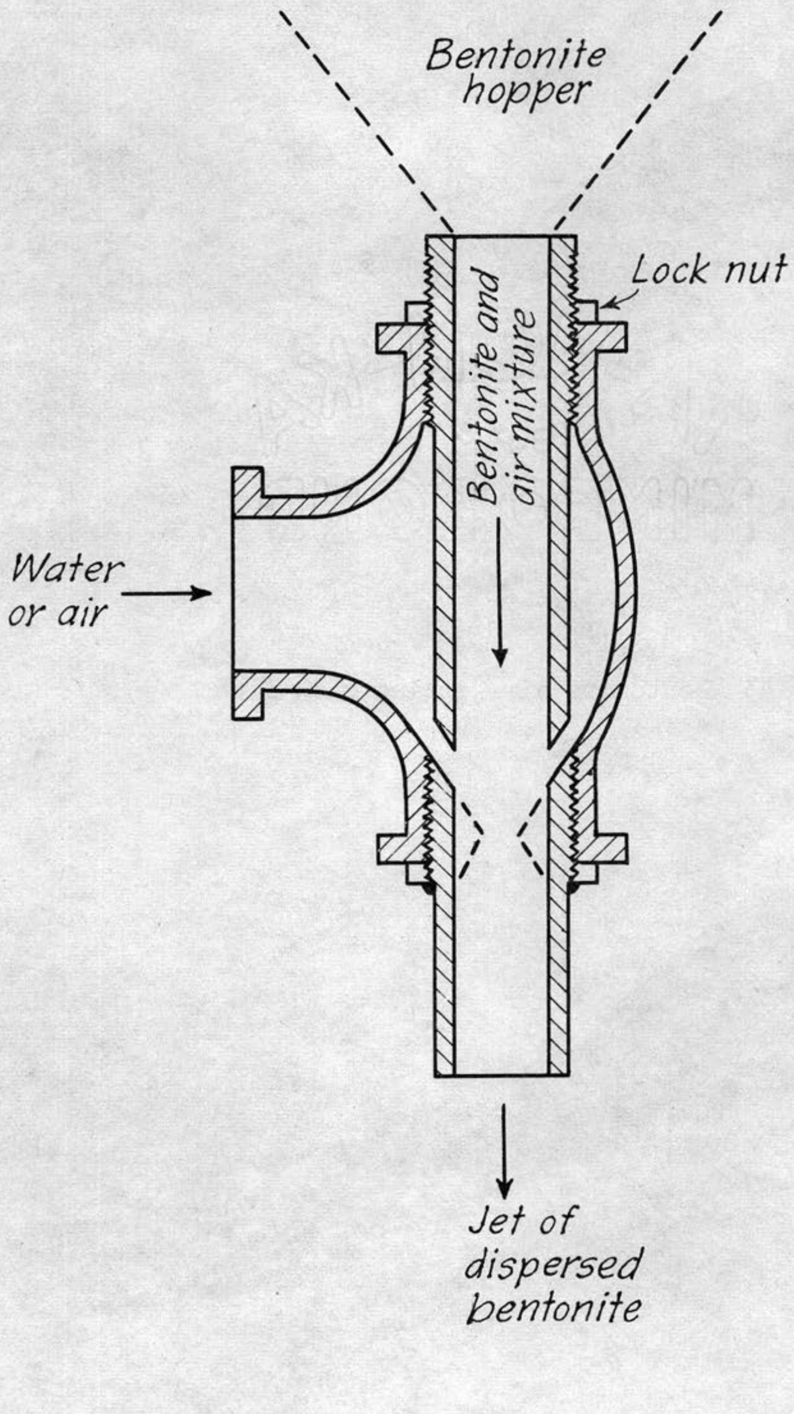

Fig. 42 Details of cone-jet bentonite disperser

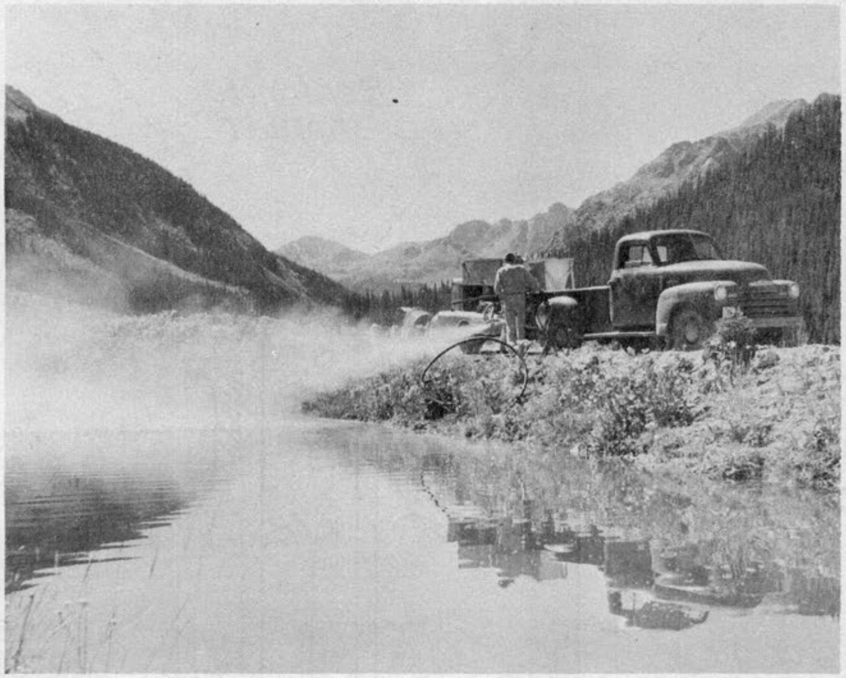

Fig. 43 Bentonite air-jetting with discharge into the air

Fig. 44 Bentonite air-jetting with discharge under water

Conclusions and Recommendations

From the research and development activities carried out in the Connection Canal and the Collection Canal during the summers of 1956, 1957, 1958, and 1959 by the Twin Lakes Reservoir and Canal Company, several conclusions can be made:

1. Best Procedure -- The multiple-dam method utilizing a 3-way mixture of Wyoming bentonite, Colorado bentonite, and wet sawdust and installed in late summer apparently gives the best sealing results with the least requirement of labor and equipment for sealing the coarse rocky materials of the west portal canals. This treatment concentrates the sealing effect in the canal bottom and lower bank areas. Blanketing of the upper bank areas would be helpful, but at the present time economic justification for the additional expense is doubtful.

2. Maintenance -- Because of the disruptive actions of the severe environment in the west portal area and the need for some canal cleaning each spring, an annual renewal or maintenance treatment is needed. The multiple-dam method with the 3-way sealing mixture of Wyoming bentonite, Colorado bentonite, and wet sawdust is recommended. Late summer is probably the best time for the maintenance work.

3. Colorado Bentonite Alone -- Because of the coarseness of the rocky materials in the west portal area, use of the Colorado bentonite alone in a multiple-dam method is not recommended[1].

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[1] During the summer of 1959, a number of preliminary trials with Lamberg bentonite were installed in canals and reservoirs in the Salida, Gunnison, and San Luis Valley areas of Colorado. The initial sealing results in this work have been very favorable, but additional evaluation work is needed. A new program has been started in Colorado to explore more fully the possibilities of the Colorado bentonites, including the Lamberg bentonite, in sealing canals and reservoirs in Colorado.

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GENERAL CONCLUSIONS AND RECOMMENDATIONS

Since detailed conclusions and recommendations for each trial site have already been given in their respective chapter, this discussion will be brief and restricted to general observations, not relative to any particular trial site.

1. Availability of information -- General information on the use of high-swell Wyoming bentonite for canal and reservoir sealing purposes has been compiled from these and other trial studies and is available in Extension Service publications in Colorado and Wyoming (37).

2. The bentonite dispersion method -- This method was used in the Lateral 1 and Lateral 19.3 trials described in this report. It has also been used widely in Wyoming (34). This method is recommended for use in sandy to silty canals of under 100 cfs capacity that are not actively eroding or cutting their banks or bed. It involves (a) mixing of the bentonite into the sedimenting water with a jet mixer, (b) ponding of the bentonite mixture in the canal reach being sealed, and (c) harrowing during the bentonite ponding to insure penetration of bentonite into the bed materials. A chemical dispersant, such as sodium tripolyphosphate or hexametaphosphate, has been used in some installations where the canal water is hard. (See item 4)

3. The bentonite multiple-dam method -- This method was used in the Twin Lakes trial described in this report. It is recommended for use in rocky canals that are not actively eroding and where harrowing of canal bed is not practicable. It involves (a) spacing of dams of granular bentonite plus a bridging agent, if required, at appropriate intervals through the canal reach being sealed, and (b) running a small head of water into the canal and, as the flow overtops each dam, breaking the dam into a lumpy slurry.

4. Effect of water quality on sedimenting operation -- If the water is hard, the dispersed bentonite, when still-ponded, will tend to flocculate and settle from suspension in the water. As previously mentioned, chemical dispersants have been used in the bentonite dispersion method to counter-act this action. This delays conversion of the sodium bentonite over to a calcium bentonite, but since the conversion in a hard water system is inevitable, the use of chemical dispersant is not recommended.

5. Influence of canal bed material on sedimenting operation -- As previously mentioned, if the canal bed is sandy, the dispersion method may be applicable. If the canal bed is rocky, the multiple dam method may be applicable. A clear cut assignment of method, however, based on bed material alone, is not possible. For example, if bed-load sand is being carried by the canal water or if the canal water is hard, the dispersion method is not recommended. For a more complete discussion of the reasons for these recommendations, reference is made to the conclusions and recommendations contained at the end of the chapters for each of the trials in sandy and loessial materials.

6. Applicability of pre-treatment sampling and testing to determine sedimenting method -- Because of the wide range of conditions found in irrigation canals, a pre-treatment testing of samples of water and soil is not feasible in many instances, and therefore is not recommended as a general practice. In most instances, when work is initiated in a new area, small-scale sediment sealing trials are preferred for development of procedures adapted to the local conditions. One exception to this general statement is the sampling and laboratory evaluation of potential sediment sealing clays. This type of sample testing is most necessary if local low-cost clays are to be substituted for high-swell bentonites in the sediment sealing work.

7. Effect of erosion on sedimenting procedures -- In both the dispersion and multiple-dam methods, a stable channel is an important prerequisite if an enduring seal is to be obtained. Obviously, however, even though a special effort was made to select stable sites, the channels in the trial sites were unstable, in varying degrees and differing respects as summarized below:

   a. Lateral 19.3 Site -- Canal banks are beaching and eroding thus, canal cross-section is becoming wider and shallower.

   b. Coachella Canal Site -- Bed-load sand is being moved along canal bottom.

   c. Lateral 1 Site -- Canal longitudinal slope is slowly flattening and bed-load sand is being moved along canal bottom.

   d. Twin Lakes Site -- Rock debris washes into canal each spring, requiring annual removal.

8. Maintenance needs -- In consideration of the possibilities of all canal channels being to some extent unstable, it is concluded that the seal produced by a clay sediment, such as bentonite, will require maintenance or periodic renewal. The extent and frequency of this required maintenance will depend on local conditions.

In considering the costs to benefits in relation to the life of the sediment sealing and the maintenance needs, it is obvious from the trial results reported herein that every effort must be made to reduce the costs and simplify the installation procedures. In this regard the following recommendations are made:

1. Explore fully the possibilities of using locally-occurring low-swell bentonite and other plastic clay materials as canal sediment sealing materials that can be obtained and delivered to the canal site in a pit-run form at much less cost than the processed high-swell bentonite or chemical sealants.

2. Explore fully the possibilities of eroding the pit-run materials into the canal water without resorting to the pumps, jet and air compressor method required when the powdered bentonite is used.

3. Use the example of natural silting as a guide rather than the standards set for the conventional canal linings of concrete, asphalt and compacted earth.

4. Allocate time and funds for follow-up evaluation of field trials so that the extent, frequency and effectiveness of the maintenance procedures can be determined.

In the course of the investigations described in this report, several basic and applied research needs were noted:

1. Simpler, less expensive, and more accurate water measuring devices are needed for use by irrigation districts and companies.

2. Fundamental studies of the phenomena involved in the seepage of water from canals are needed.

As may be seen from the field trial studies, the discharge measurements give erratic results and the seepage conditions from one site to another do vary radically. The variability of field site conditions relates not only to the basic differences in the permeable materials involved, but also to the influence of the canal environment in modifying the canal perimeter materials. The flowing water erodes material in one area and deposits it in another. Plant roots converge in the canal perimeter materials. Animal life of innumerable forms and activities, inhabit and modify the canal bed and bank materials. All of these factors influence the ultimate permeability of the soils. Perhaps most important of all, the canal bed permeability is by no means constant: it varies with the modifications mentioned above, with the location of the ground-water level, and with changes in the canal water, such as dissolved air content, temperature, and natural sediment content. The relative temperature of the soil and the water is also important because of the changes in dissolved air content in the water with temperature change. If air is being released as the water percolates into the canal bed, the permeability of the canal bed soil will be influenced. In some canals, lime or calcium carbonate is deposited on the canal perimeter materials. Additional information relating to the actual hydraulic gradient conditions in the canal perimeter materials is needed.

In short, the conduct of an applied research study such as described in this report, is very dependent upon a complete understanding of the canal site conditions. Additional fundamental studies of canal seepage and the development of more accurate measuring methods are urgently needed.

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