SEDIMENT SEALING TRIAL WITH SS-13 IN COACHELLA CANAL IN SOUTHERN CALIFORNIA

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Prepared for United States Department of Agriculture
Agricultural Research Service Contract #12-14-100-507(41)

CER60RDD39

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A Summary of Development Activities carried on by the Imperial Irrigation District during the Period of 1955 - 1960.

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Fort Collins, Colorado

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FOREWORD

The summary of research and development activities relating to the sediment sealing trial completed in the Coachella Canal in October 1957 was originally scheduled for inclusion in the final report for the Agricultural Research Service (1)[1] ; however, since a chemical sealant SS-13, was used in the Coachella Canal trial rather than a colloidal clay as originally planned and as used in the other sediment sealing trials, a separate report is appropriate.

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.

Many people have made noteworthy contributions to this cooperative venture. At the risk of omitting important contributions by others, the significant help of the following individuals is gratefully acknowledged:

Organization	Individuals
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

[1] REFERENCE number.

Organization	Individual
Cronese Products Company	H. T. Wyatt C. H. Toll
Monsanto Chemical Company	J. M. Deming
Colorado State University	A. R. Chamberlain A. T. Corey R. S. Whitney

FIGURES

TABLES

CONTENTS

INTRODUCTION

This is a report of the research activities directed toward the development of a low-cost method of sealing irrigation canals in the Imperial Irrigation District of Southern California. The Sediment Sealing Research Project at Colorado State University cooperated with the District in these studies.

The activities at the Coachella Canal site were included in the University project program because of the continuously-operated feature of the Coachella Canal, which is not found in any of the other trial studies included in the University canal sealing research program. The Coachella Canal site typifies the canal sealing and seepage loss problems found in continuously-operated canals of large size and in a warm climate.

The investigation into the possibilities of using water-borne sediments for sealing canals was started by the District in 1955. The early exploratory efforts in this regard were accomplished 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 report summarizes the Coachella Canal trial activities and results to January 1960. Before the trial activities are discussed, some background information is presented that will be helpful to the reader.

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. 1.

The Imperial Irrigation District 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 900,000 acres of land and delivers water to almost 300,000 acres of land. To accomplish this delivery the District operates and maintains almost 1900 miles of irrigation canal. It is noteworthy also that the District has constructed and now operates and maintains almost 1800 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.

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

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 latter 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 30 feet above Pacific Sea level 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 240 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 deposits 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 process, 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.

The most recent incursion of the Colorado River into the valley occurred during 1904 and 1905 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

Needless to say, water is lost during delivery to the District lands. Some of this loss can be ascribed to evaporation and operational wastes, but a major part of the delivery loss is a seepage loss. Virtually all of the District canals are unlined and sandy pervious soils are quite common. This seepage loss water is not only important to the District from the standpoint of its direct use value, but its effect on the drainage situation in the valley is also important.

The direct use value is significant. For example, it has been stated (2) that the water lost each year from the Coachella Canal only would be sufficient to irrigate 25,000 to 30,000 acres of land. The losses from other District canals are not as high as those for the Coachella Canal; never-the-less, when considered on an acre-foot per year basis, the total District losses are significantly high.

What about the effect of this seepage water on the District drainage situation and also how about the possibilities of re-using the drainage waters for irrigation?

The obvious assumption in respect to the effect of the canal seepage on the drainage network is that a reduction in canal seepage will produce eventually a proportionate decrease in the outflow of nearby drains. This would provide several beneficial chain-reaction effects, such as, (a) increased efficiency of drainage in nearby lands, (b) decreased operation and maintenance costs for those drains influenced and (c) a decreased inflow of drainage water into the Salton Sea.

In respect to the possibilities of re-using the drainage water for irrigation, it is important to realize that in addition to water table control, the valley drains also have another important role of salt removal from the irrigated soils. Because of their origin, most of the virgin soils have accumulations of excess salt that must be leached from the soil before they can be farmed successfully under irrigation. Even then, salt removal problems remain. The irrigation water itself contains about one ton of salts per acre foot of water. Thus, some "over-irrigation" or downward leaching of salts into the ground water reservoir is important if the productivity of the irrigated land is to be maintained. The drainage network then, must remove not only excess water from beneath the irrigated lands, but also significant quantities of salt. The drainage water, therefore, is commonly marginal to too salty for irrigation use.

In summary, the canal seepage water is a contributing factor in the drainage of District lands and once the canal water enters the ground water reservoir, its quality is usually down-graded to an extent which eliminates its re-use as irrigation water. It would be wise to prevent or control the canal seepage losses to the maximum extent possible.

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

As previously mentioned, 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 quite a deep cut below the drop and gradually surfaces in the section down to the first curve at about station 500+00 (See Fig. 2). 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. 3). The reach is about 7.82 miles long. The nearest town is Holtville, California.

This section of canal was selected as being representative of conditions found elsewhere in the Coachella Canal, in the All-American Canal, and in the other major canals of the District area. 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 are lined with an uncompacted clay blanket, ranging in thickness from 6 to 12 inches in thickness; however, none of the lined portions are in Reach No. 2.

The design properties of the original canal are tabulated below:

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
288+15	800+00	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. 4 and 5.

Water analysis data are presented in Table 1. 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.

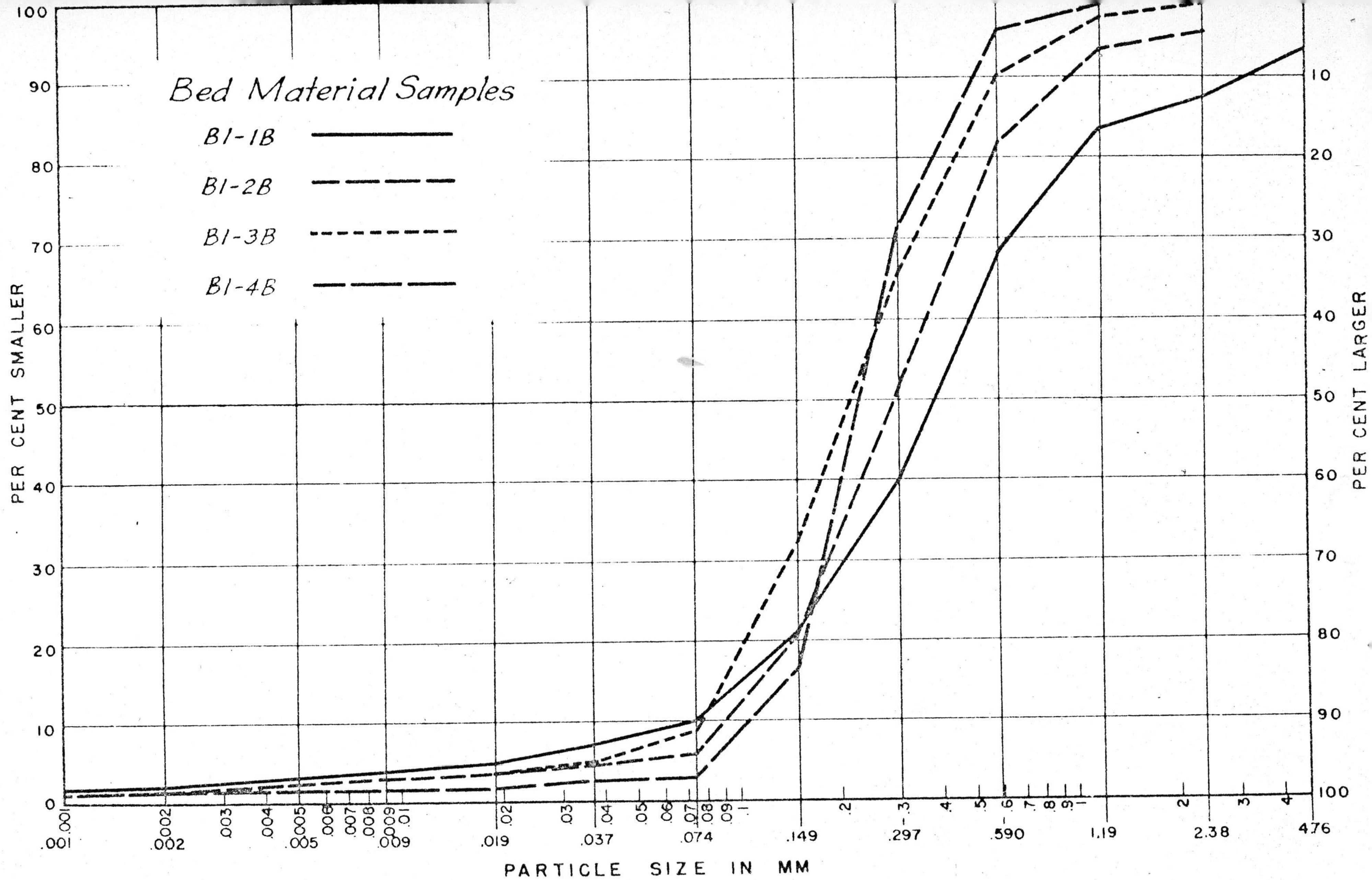

Fig. 4 Size distribution curves for bed material samples

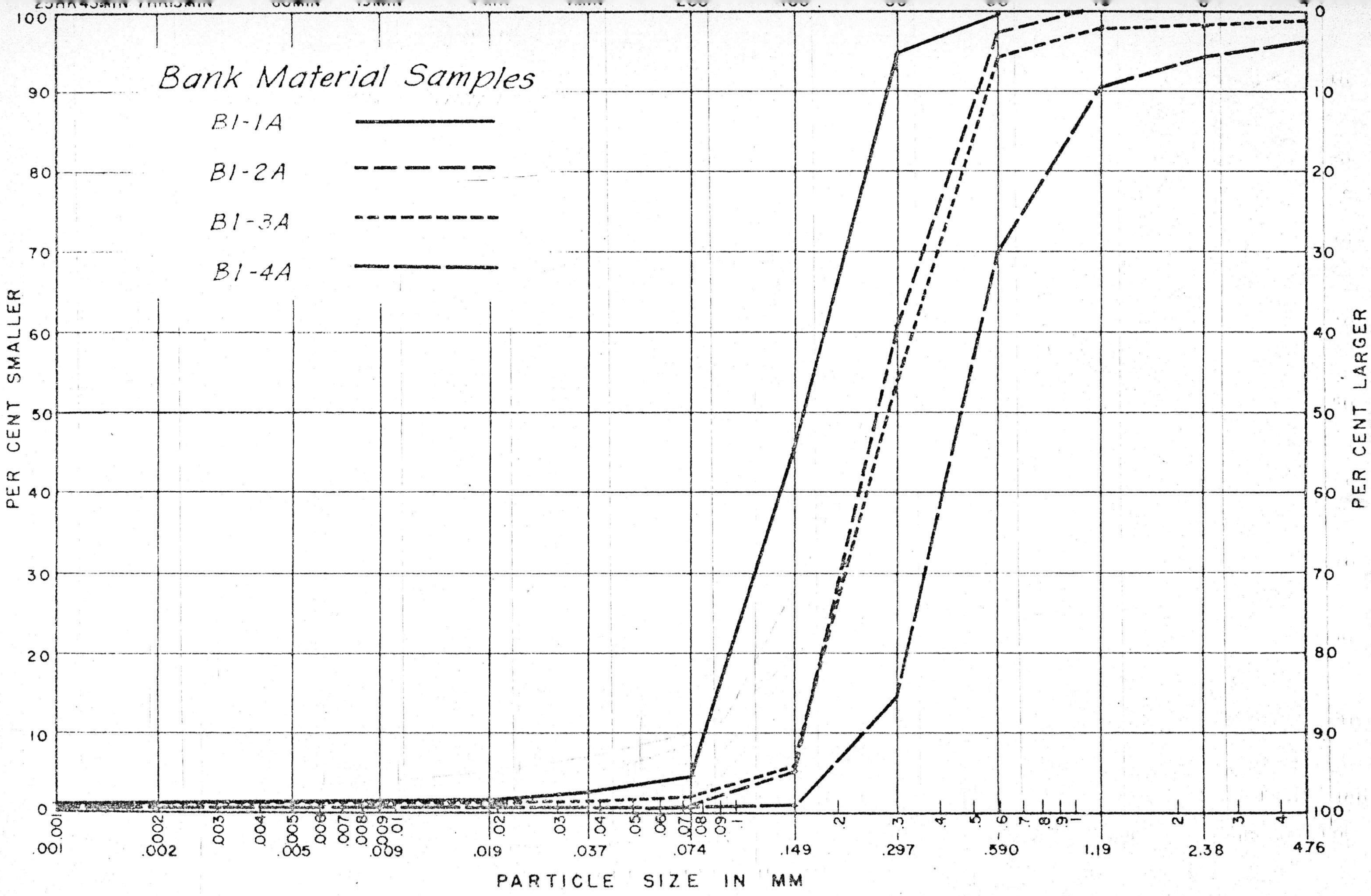

Fig.5 Size distribution curves for bank material samples

TABLE 1

WATER ANALYSIS DATA
COACHELLA CANAL, CALIF.

Date Sampled	ECx10^c	Dissolved ppm	Solids Tons/a.f.	ppm Ca	ppm Mg	ppm Na	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, Diagnosis and Improvement of Saline and Alkali Soils, U. S. Dept. of Agr. Hand b. 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 determining 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:

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 165+50 -- length 17.38 miles.

Reach No. 4 -- Sta. 165+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.

For the sake of comparison, the water loss data before the sedimenting installation are not reported here, but are reserved for the evaluations discussion where they will be summarized together with the post-installation data.

Piezometer Installations

Starting in February 1957, piezometer stations were established as indicated in Table 2. 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 1-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 was installed 300 feet west of the canal center line at each station, and in addition, the "D" piezometer was installed about 5 feet west of the highwater line. 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.

TABLE 2.

LIST OF PIEZOMETERS AND WELLS

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., 1957

* 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.

Ground Water Level Observations

In addition to the water level observations obtained from the piezometers in the immediate vicinity of the canal, data have also been obtained regarding the ground water level variations in the East Mesa area below the Coachella Canal. The Bureau of Reclamation installed a wide-spaced network of observation wells in this area, starting in 1940. The water level observations have been continued in the area by the District since 1952, and in recent years additional wells have been added to the original network in areas of particular interest.

A major purpose of the ground water level observations was to trace the progress of the seepage waters into the East Mesa area from the All-American and Coachella Canals. The data obtained from this phase of observations are discussed in the evaluations section of this chapter.

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. 4 and 5.

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. 6.

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 (3); 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 (4). The clays were tested for grit content, colloidal yield, filter loss, and viscosity; the methods used were similar to those recommended by Fisk (5) for evaluation of bentonites for drilling mud use. Distilled water was used in this testing, the results of which are summarized in Table 3.

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 (6).

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

Table 3

RESULTS OF CSU LAB TESTING OF POTENTIAL SEDIMENTS

Sample No	Material	Grit Content %	Colloidal Yield %	Wall Building Filter Loss (Ml)	Wall Building Cake (in)	Viscosity (centipoises)
S1-1	Coyote Well	1.3	53.5[1]	40	3/32	3
S1-2	Ackins Claim	12.1	42.9[1]	189	8/32	2
S1-3	Thermo Claim	2.5	48.9[1]	88.5	1/8	2
S1-4	Burslem Claim	20.7	28.9	69	3/16	2
S1-5	Armaseal	4.7	65.2	41	1/16	<4
S1-6	Mass Clay	5.7	60.1	38	1/16	1
S1-7	Western Clay (Utah)	17.5	55.5	28.5	1/16	6
S1-8	Western Clay (Utah) reserves	5.0	41.3	33.3	1/8	3
S1-9	Bent. Corp. (Utah)	4.1	84.6	14.5	5/64	8
S1-10	Baroid (Wyo) crushed	4.8	89.4	16.5	1/8	22
S1-11	Baroid (Wyo) 200-mesh	2.9	88.2[1]	16	3/32	25

[1]Dispersant (Sodium tripolyphosphate--0.75gms) added where tendency for flocculation noted.

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 filtered at 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.

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 summer of 1957 (6).

The drive samples were obtained directly from the canal bottom by means of the sampling equipment, previously mentioned and as shown in Fig. 6. This device was designed to obtain from the submerged canal bed, sample columns of 2-1/2 inch diameter and 17 inch length, encased in the transparent lucite permeameter insert tubes in a relatively undisturbed condition. These tubes were then assembled and tested in the permeameter system in Fig. 7.

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 4.

The samples generally consisted of fine sand with medium sand layers. The individual sand grains are predominately 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

Results of Laboratory Permeameter Testing by District

pt. o.	Sampling location (station)	Amount of dispersant (gm/liter)[1]	Length of treatment (hours)[2]	Percolation rate converted to 20°C before treatment	(Cu ft/sq ft/day and unit hydraulic gradient) Minimum[3]	Ultimate[4]
Treatment with California clay (Coyote Wells--18.2 gm/liter)						
821	303+27	0.44	0.75 0.75	4.03 - 3.18	0.34	0.34(5)
882	303+27	0.44	1.50	2.38 - 2.01	0.17	0.18(5)
037	303+27	2.72	0.75 0.75	7.38 - 4.51	0.22	0.22(10)
682	459+67	1.36	1.00	31.90 - 0.66	0.56	2.11(31)
830	459+67	1.36	0.75	21.13 - 3.57	0.32	7.50(17)
Treatment with Wyoming bentonite (10.5 gm/liter)						
820	303+27	0.21	0.75 0.75	5.27 - 4.68	0.22	0.22(6)
884	303+27	0.21	1.50	46.80 - 31.94	2.86	2.86(5)
035	303+27	0.50	0.75 0.75	17.08 - 14.88	0.52	0.83(9)
684	459+67	0.21	0.87	22.40 - 2.93	0.49	8.87(24)
833	459+67	0.21	0.45	26.80 - 2.00	0.63	0.98(27)
Treatment with Utah bentonite (11 gm/liter)						
819	303+27	0.22	0.75 0.75	21.92 - 3.52	0.16	0.18(8)
883	303+27	0.22	1.50	1.80 - 0.70	0.22	0.26(12)
036	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)						
404	303+27	0.21	1.22	10.73 - 2.24	3.22	5.59(19)
683	303+27	0.21	0.67	16.12 - 6.42	0.45	2.66(50)
831	459+67	0.21	0.75	24.8 - 1.19	0.62	2.11(19)
832	459+67	0.21	0.83	27.28 - 1.95	0.67	1.39(37)
Treatment with "SS-13" (0.58 cc/liter)						
402	303+27	none	20.83	74.7 - 76.4	0.65	0.75(18)
405	303+27	none	16.92	20.0 - 16.9	0.41	2.00(18)
211	695+65	none	21.67	8.67 - 1.28	0.27	0.86(27)
212	459+67	none	21.67	23.55 - 0.48	0.20	0.57(22)
213	303+27	none	21.58	3.85 - 0.13	0.12	0.24(22)
Without treatment						
917	695+65	none	--------	0.66 - 0.16	0.15	0.16(16)
918	695+65	none	--------	7.58 - 0.87	0.72	0.87(16)
919	695+65	none	--------	5.42 - 0.19	0.17	0.19(16)

he dispersant used was tetrasodium pyrophosphate (Monsanto Chemical Co., and Dow Chemical Co.

wo separate treatments are shown by two figures indicating their respective lengths.

he lowest figure throughout the run, usually immediately after treatment before the surface as scraped.

he numbers in parentheses indicate the total number of days for which each run was conducted.

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.

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.

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

<u>Experimentations with "Separan"</u>

In this program, carried out by the Dow Chemical Company, the effects of adding small quantities 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 (1) a series of laboratory tests, (2) a model ditch experiment at Dow's Pittsburg, California, plant, and (3) 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:

> "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 artifically 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.

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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.

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 seal 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 adsorption of the suspension to seal off the pores.
>
> 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."

---

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

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. As result of this field site testing, Dr. Deming of Monsanto summarized[1*] the results as follows:

> "The presence of the HEMA 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 HEMA 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[1] with the sediment which is in suspension in the water."

Thus, the HEMA 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

Discarding the idea of using a dispersed bentonite as the sealing agent, 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 reportedly penetrates the bed soils easily. Originally the sealing was attributed by

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

1 As an incidental note, we believe that part of the so-called "silt" as referred to in this reference, is $CaCo_3$ or a lime deposition.

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."

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 4.

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. 4 on page 8, and (b) sandy bed materials actually collected from Reach No. 2 of the Coachella Canal. The testing was performed in an equipment set-up as shown in Fig. 8. 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. 9 (7).

Following the laboratory testing, 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. 10 shows the location of the casings and furnishes logs of the material 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 5 for a summary of test results from the casing tests. (8, 9).

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.

As a comparison with the loss rates obtained in the casing tests, the overall loss figures for Reach No. 2 during the same time are listed in Table 6. It may be seen that the two types of loss figures do not agree, but all factors considered (such as the natural variation in canal bed conditions) the actual range in variation does not seem excessive. 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.

Thus, 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.

2. The tendency to re-seal after erosion was a favorable characteristic, but not conclusively proven.

3. The life of the seal was not fully evaluated in the testing performed.

Table 5

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 in operation.

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

(c) Not subjected to erosion treatment.

TABLE 6

WATER LOSS FOR REACH NO. 2 DURING THE FIELD EXPERIMENTS
WITH SS-13 IN CASINGS

Date	Head End Discharge (cfs)	Loss in Reach No. 2 (cfs)	Wetted Perimeter (1000 sq ft)	Converted Water Loss in Reach No. 2 (1000 cu ft ds)	Converted Water Loss in Reach No. 2 (cu ft per sq ft per day)
			DURING TREATMENT TEST		
May 28	1,016	82	3,187	7,180	2.25
29	1,025	77	3,195	6,650	2.08
30	1,025	81	3,195	6,995	2.19
June 1	1,016	89	3,187	7,690	2.41
2	1,025	93	3,195	8,030	2.51
3	1,037	102	3,200	8,810	2.75
4	1,040	114	3,205	9,850	3.07
5	1,037	131	3,200	11,310	3.54
			DURING EROSION TEST		
June 10	1,184	160	3,285	13,830	4.20
11	1,167	114	3,275	9,850	3.01
12	1,170	115	3,275	9,935	3.03
13	1,170	93	3,275	8,030	2.45
14	1,177	126	3,280	10,890	3.32
15	1,180	121	3,285	10,450	3.18

TRIAL INSTALLATION
(10,11)

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 seemingly favorable sealing qualities, (b) its ready miscibility with canal water, and (c) a cost less than estimated for the dispersed bentonite treatment.

The natural clays and bentonites were not used in this first experiment because it was speculated that a surface seal of limited life would be produced unless chaining of the canal bottom was accomplished during the sedimenting. Also, the problem of mixing as much as 900 tons of clay into the canal water in a period of 12 hours or less at the time seemed insurmountable.

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 at least 20 hours, or as long as practical, 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 ahead of the start of 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. 228+15 (Fig. 11). It consisted of a 22,000 gal. storage tank, two tank trucks, a pump and discharge pipes (Fig. 12). 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.

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. The SS-13 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. 13 for concentrations within the reach.

It was planned that the pond surface for the SS-13 mixture would reach elevation 117.0; it actually reached 115.66 or 1.34 feet lower than planned.

[1]The specific gravity of SS-13 is 0.91, and the weight is about 57 lbs/cu ft.

The treated water was ponded in the reach 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 to consider (estimated at 0.5 cfs). On the night of October 30-31, during the ponding interval, about 0.38 inches of rain fell on the reach. Allowance was made for this amount of water in the seepage rate determined for the ponding interval.

At 7:40 am., October 31, 1957, the canal flow was resumed. The earth dam (Fig. 14) 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. 15).

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 as follows:

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.

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

The volume of SS-13 mixture lost during the ponding interval in Reach No. 2 was estimated at 1.05 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.

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 (1) visual observations, and (2) seepage loss measurements and indications.

Visual Observations

Virtually all of the sampling work for the preliminary planning activities was accomplished from a boat witlout 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 very firm that drive sampling with a special stainless steel sampler (Fig. 6) 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. Incidently, 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, we expected more of a drop-off at the end of each dune--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 shovel 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 to be indicated.

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 7. 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 (2), 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

TABLE 7

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

Sample		% Soil less than 2 mm.	Cation exchange capacity (meq/100 g. 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
" "	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"	91.6	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

*Testing by Soil Department, Colorado State University.

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

2-3-58

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 perimeter must be taken into account so as to avoid, to some extent, the distortion due to stream discharge fluctuations[1].

The loss data in this form are plotted in Figs. 16 and 17. It can be seen that:

(a) Before the SS-13 treatment, Reach Nos. 1, 3, and 4 roughly agreed with each other and fluctuated within annual cycles. Reach No. 2, however, showed not only higher losses but also an erratic behavior in relation to the time of year.

(b) After the SS-13 treatment, Reach Nos, 3 and 4 deviated slightly from their congenity with Reach No. 1. Whether this deviation was large enough to be meaningful is open to conjecture. 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.

(c) There is no observable evidence that the SS-13 treatment of Reach No. 2 affected the seepage rate in any way. While this statement may be considered valid in a general sense, it can be further substantiated by an analysis of the discharge records.

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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.

It is to be 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. 18, 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 any change in loss rate as a result of SS-13 application in Reach No. 2 can be detected from the discharge analysis.

<u>Comparison with the All-American Canal</u> - These two canals 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 only difference is that the All-American Canal is controlled by closely spaced drop structures whereas the Coachella Canal is partly uncontrolled--Reach Nos. 2 and 3 (and the southern portion of Reach No. 4). Mr. A. J. Boles reports that

> 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 be observed on the Coachella."

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 2). For complete records of the fluctuations in piezometric head, see Ref. (2).

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

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.

Sta. 459+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 temporary 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 lenses carried in by the bed-load sand.

Sta. 695+65 (downstream end of Reach No. 2) - The piezometric head has behaved in approximately the same manner as at Sta. 459+67, but to a less pronounced degree. There is a slight surface crust. The sealing was slight and temporary.

Ground-Water Records

A network of wells has 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 source of ground water in the East Mesa area depends solely 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 (2).

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 later 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 will require several more years of use before it will decline to a minimum. According to this line of reasoning, it would help to install control drop structures in Reach Nos. 2, 3, and 4 so that a lower and more uniform velocity of flow can be obtained to hasten the stabilization process.

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 8, 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 for the Coachella Canal (12, 13, 14)

TABLE 8

MEASURED PAN EVAPORATION DATA AT 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	11.57	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 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.
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 dried out in preparation of the SS-13 treatment
5. The amount of sand in motion on the bottom of the canal seems to be related to the amount of sand drifting over the nearby land. Bank or bed erosion does not seem to be important as a source of bed-load sand in the Coachella Canal.

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 (15). The case of the Coachella Canal can be analyzed from the data listed in the Table below:

TABLE 9

DATA FOR SAND DUNE ANALYSIS

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

[1] At minimum and maximum discharges and temperatures.

[2] From recorded figures for 1927 and 1958.

[3] From Fig. 4.

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

[5] From averages recorded in Ref. 2.

[6] From Ref. 16 (shape factor has been assumed to be 0.5 to 0.9 according to Ref. 17.

[7] From Ref. 18.

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 $\frac{V_*}{\gamma}$, 4.2 to 41.6 (where $V_* = \sqrt{gDS}$). The values of these parameters as shown in the Simons' curve define a domain lying largely within the realm of dunes for the median diameter stipulated.

Conclusion

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 gauging stations. Simons has produced in a laboratory flume variegated loops of rating curves by increasing and decreasing the discharge over an alluvial bed (19). In field study of fan waves in the Mississippi River, Carey established a similar looped curve for the river discharge at Tarbert Landing, Mississippi (20). 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.

CONCLUSIONS AND RECOMMENDATIONS

From the observations made of the conditions of the bed and the banks of the Coachella Canal, several conclusions can be made.

1. The bank materials in Reach No.2 are essentially stable--at least from the standpoint of erosion or bank cutting. The shoreline 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" seems to consist more of sand blown in from the desert than of sediment deposited by the canal water.

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 (15) but the reasons for the lime deposition are less evident. The lime seems to be precipitated as a solubility action as the hard canal water seeps into the canal bed.

3. The source of the bed-load sand seems to be mainly from the nearby desert rather than from bank or bed erosion. Each year the amount of bed-load sand seems to very with the amount of wind and vegetation on the nearby land.

An understanding of these site conditions are important because the life of the sediment seal is directly involved. The preliminary testing and procedure development on a laboratory scale is also directly involved. For example, it is now obvious that most of the laboratory testing was concentrated on the sand dune materials rather than on the stable base materials. Obviously, procedures designed to seal a transient material that is in motion when the canal water is flowing are not helpful.

Thus, in consideration of these important site conditions, the following recommendations are offered:

1. The ponding method of sedimenting is not recommended. A sedimenting method is needed that can be utilized without disturbing or interrupting the normal irrigation water deliveries.
2. 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.
3. The use of one of the local low-swell clays, such as the Coyote Wells clay, is recommended. This material can be mixed by dumping in at a drop structure. Its excess calcium content probably will enhance the natural lime precipitation and cementation of the canal bed as well as materially assist in the settling of the clay out ahead of the sand dunes.

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

5. The use of chemical flocculating agents along with the clay sediment should be investigated. Materials, such as Separan and IBMA can be used to settle the clay out ahead of the sand dunes. The flocculants also have some stabilizing or binding properties that are needed if the clay is to be protected from erosion.

6. 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.

7. Increased attention should be directed toward drift fences or other similar devices that would keep the desert sands out of the canals.

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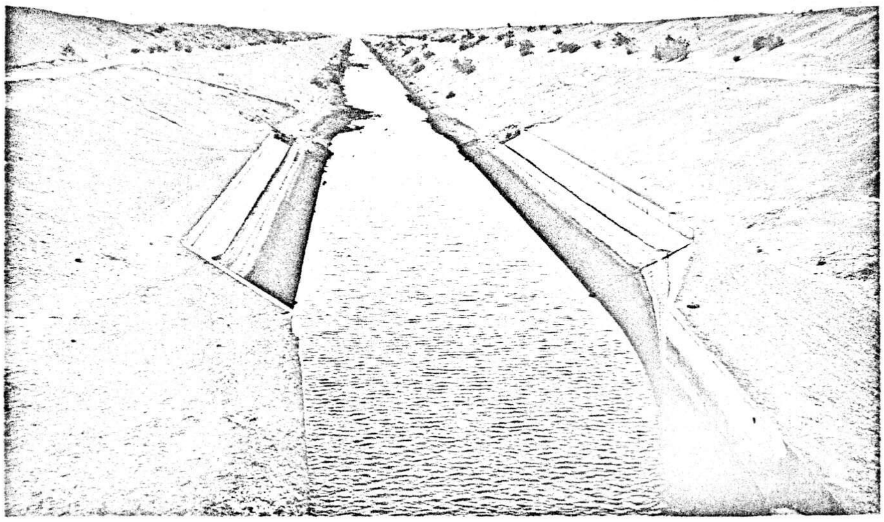


Fig. 2   View downstream from drop at Sta. 228+15

Photograph showing
(Being processed)

Fig. 3 View upstream from canal bridge at Sta. 713+10.

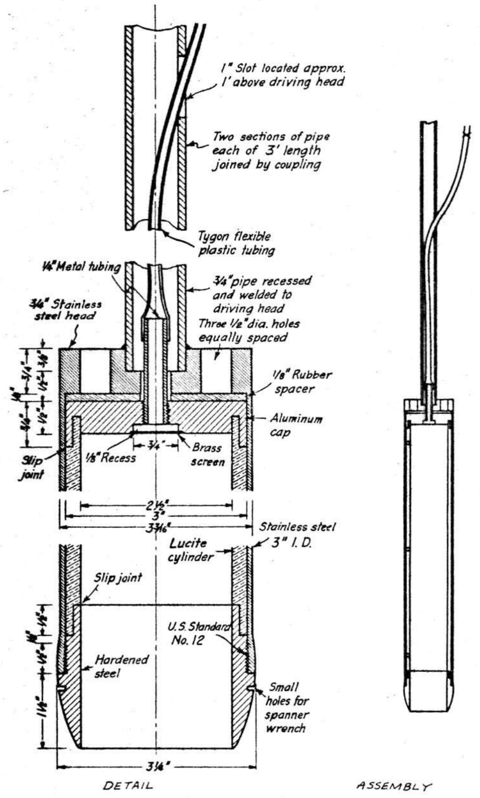


Fig 6 Drive sampler

Fig. 6 Drive Sampler

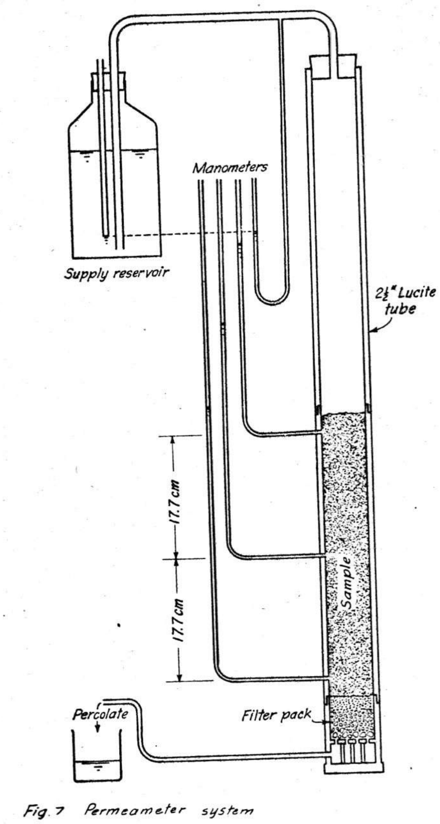


Fig. 7 Permeameter system.

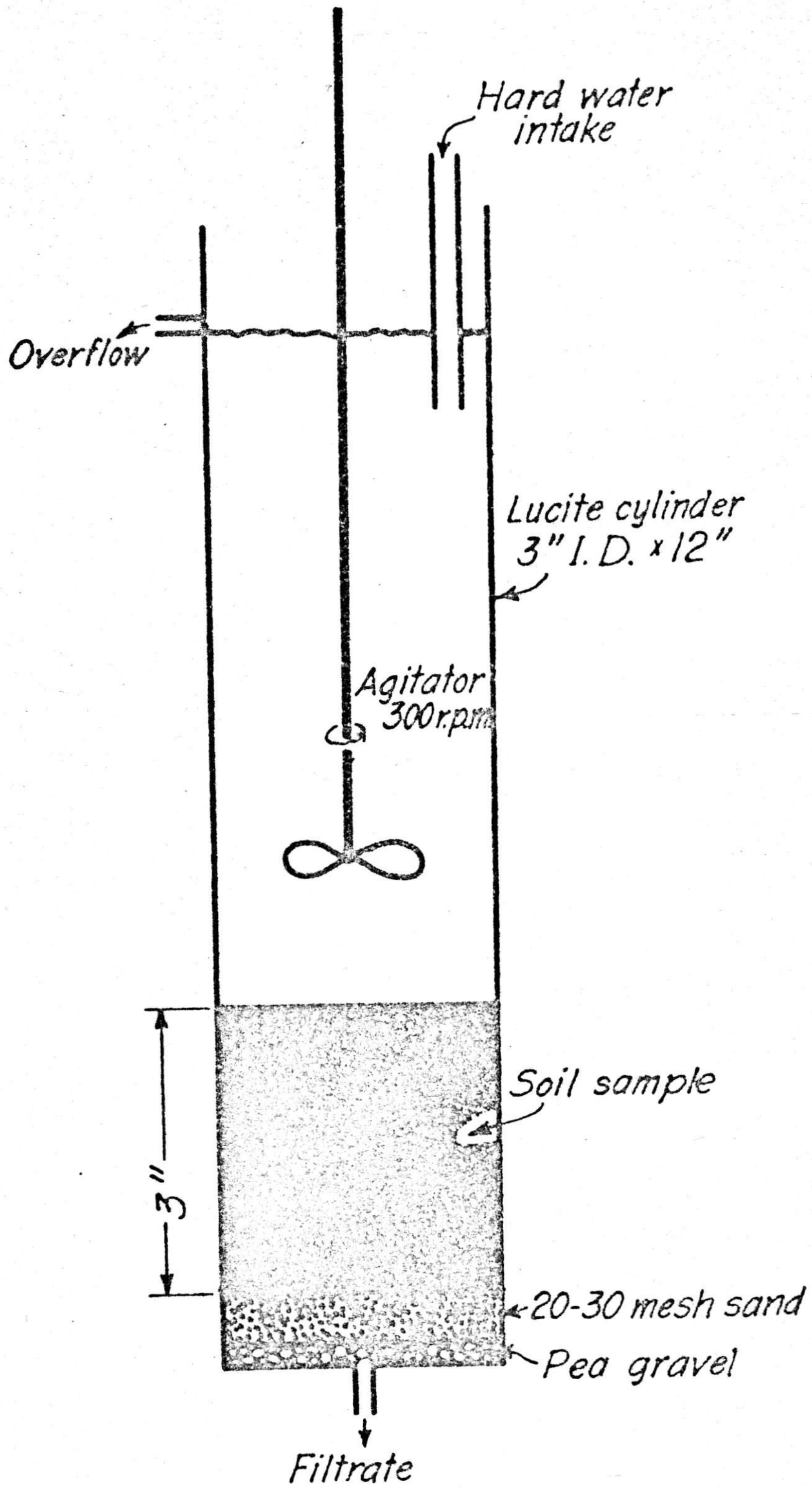
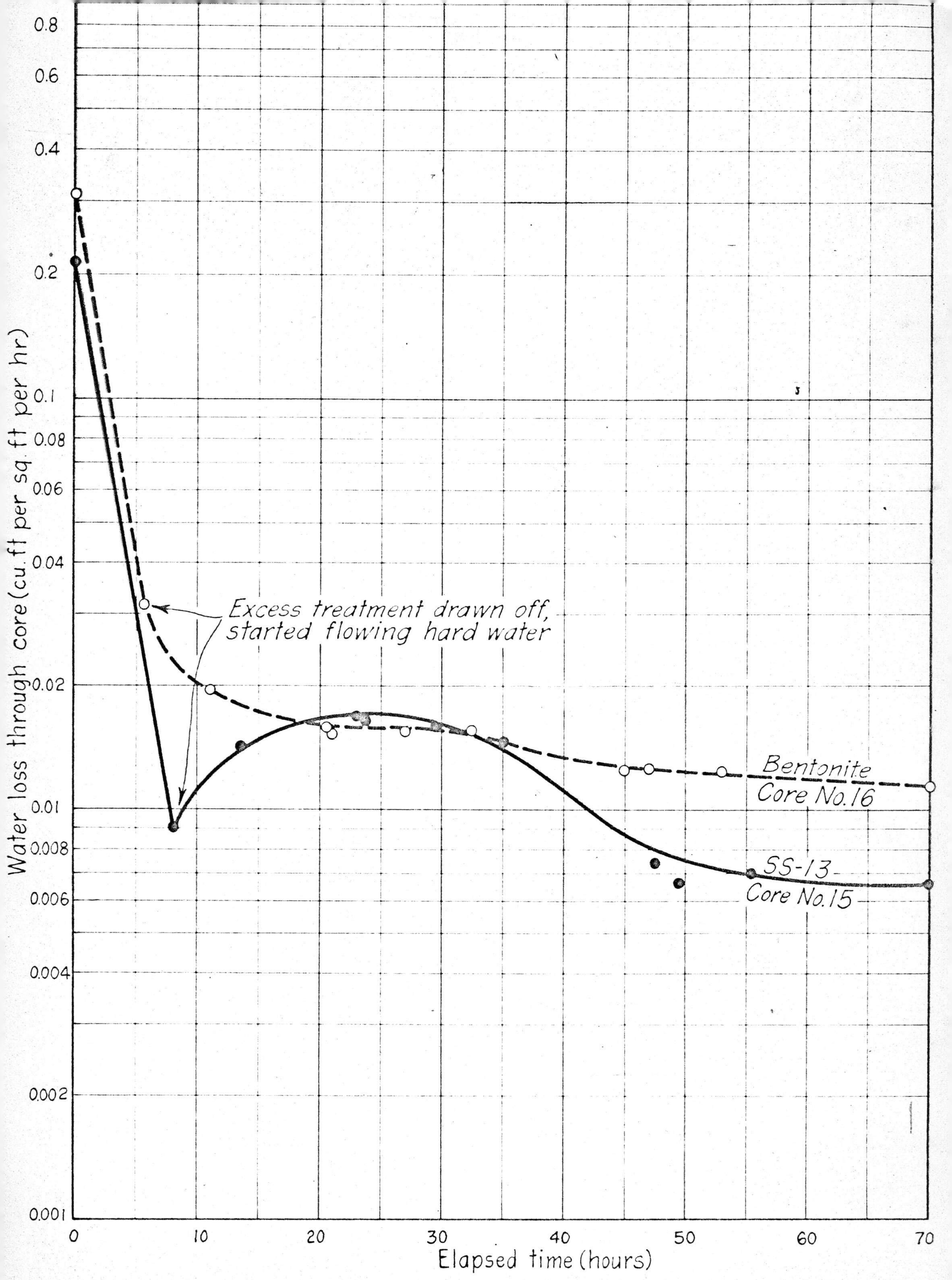
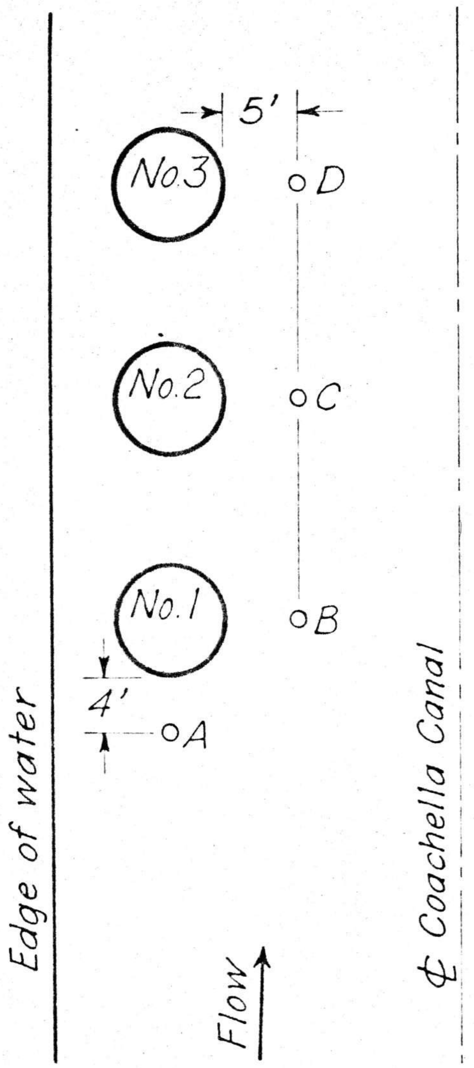


Fig. 8 Laboratory setup for SS-13 testing on 3-in. long cores



...g. 9 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. 10 Location of casings of SS-13 field experiment

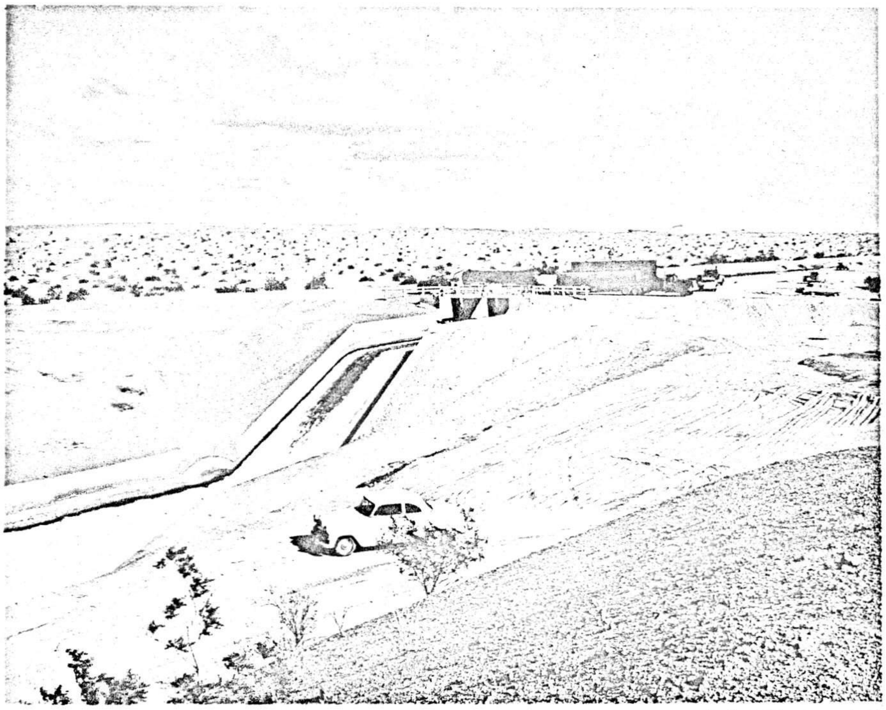
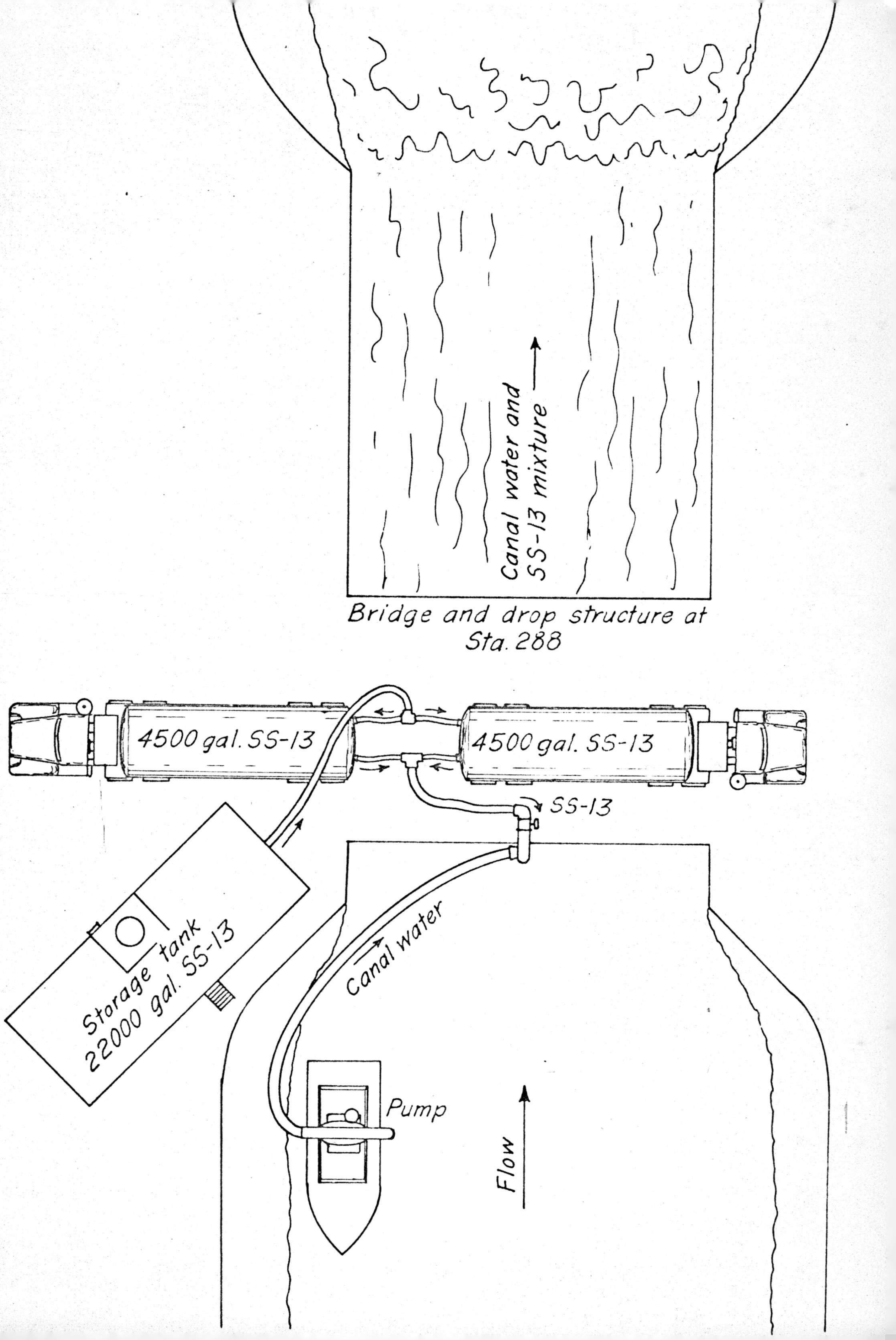


Fig. 11. Mixing of SS-13.


Canal water and SS-13 mixture
Bridge and drop structure at Sta. 288
4500 gal. SS-13
4500 gal. SS-13
SS-13
Storage tank 22000 gal. SS-13
Canal water
Pump
Flow

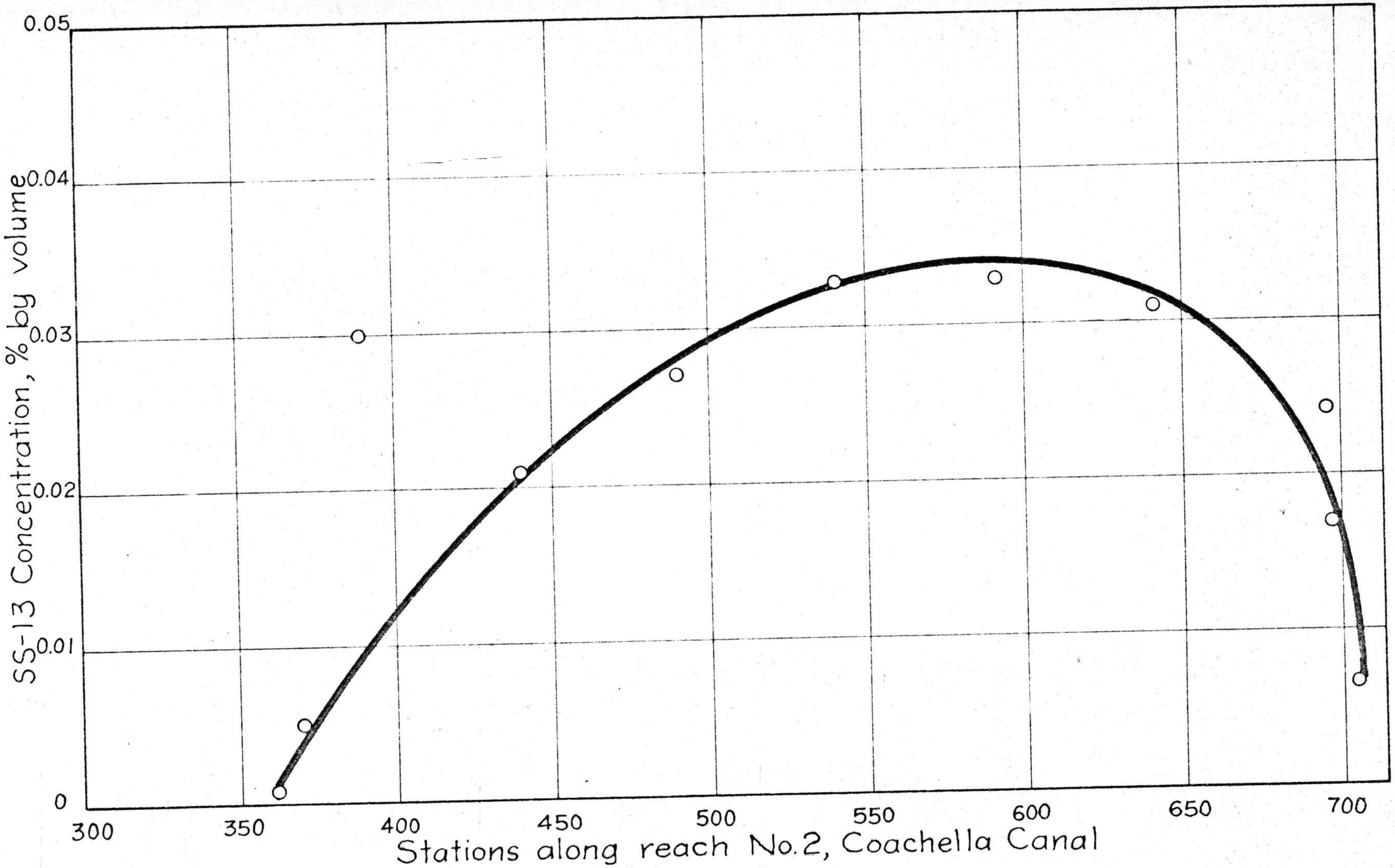


Fig. 13 Concentration profile during installation of SS-13, 11:30 a.m. October 30, 1957

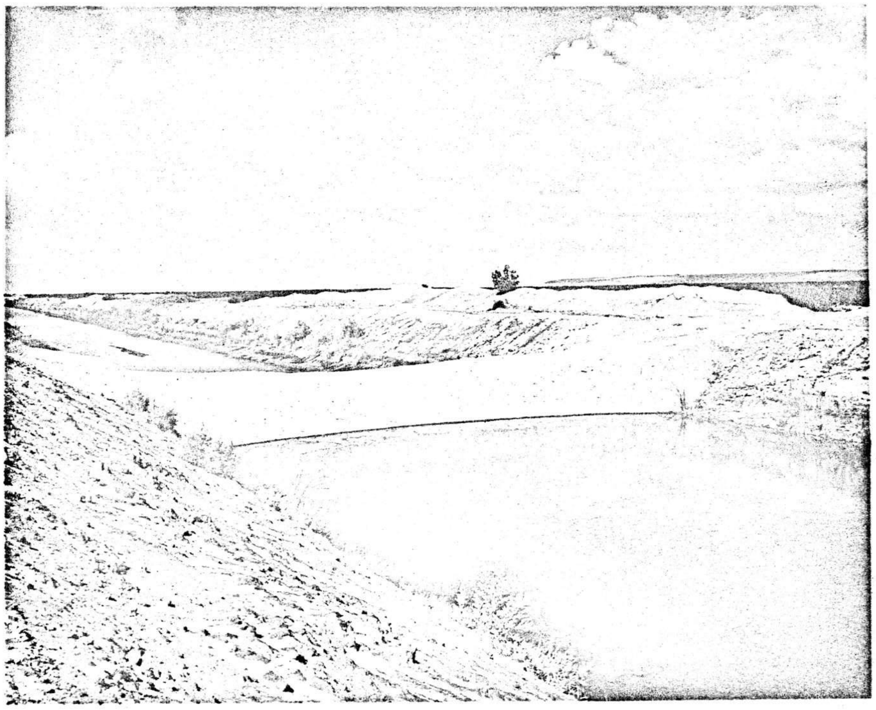


Fig. 14 View looking downstream at earth dam at Sta. 730+00 during ponding.

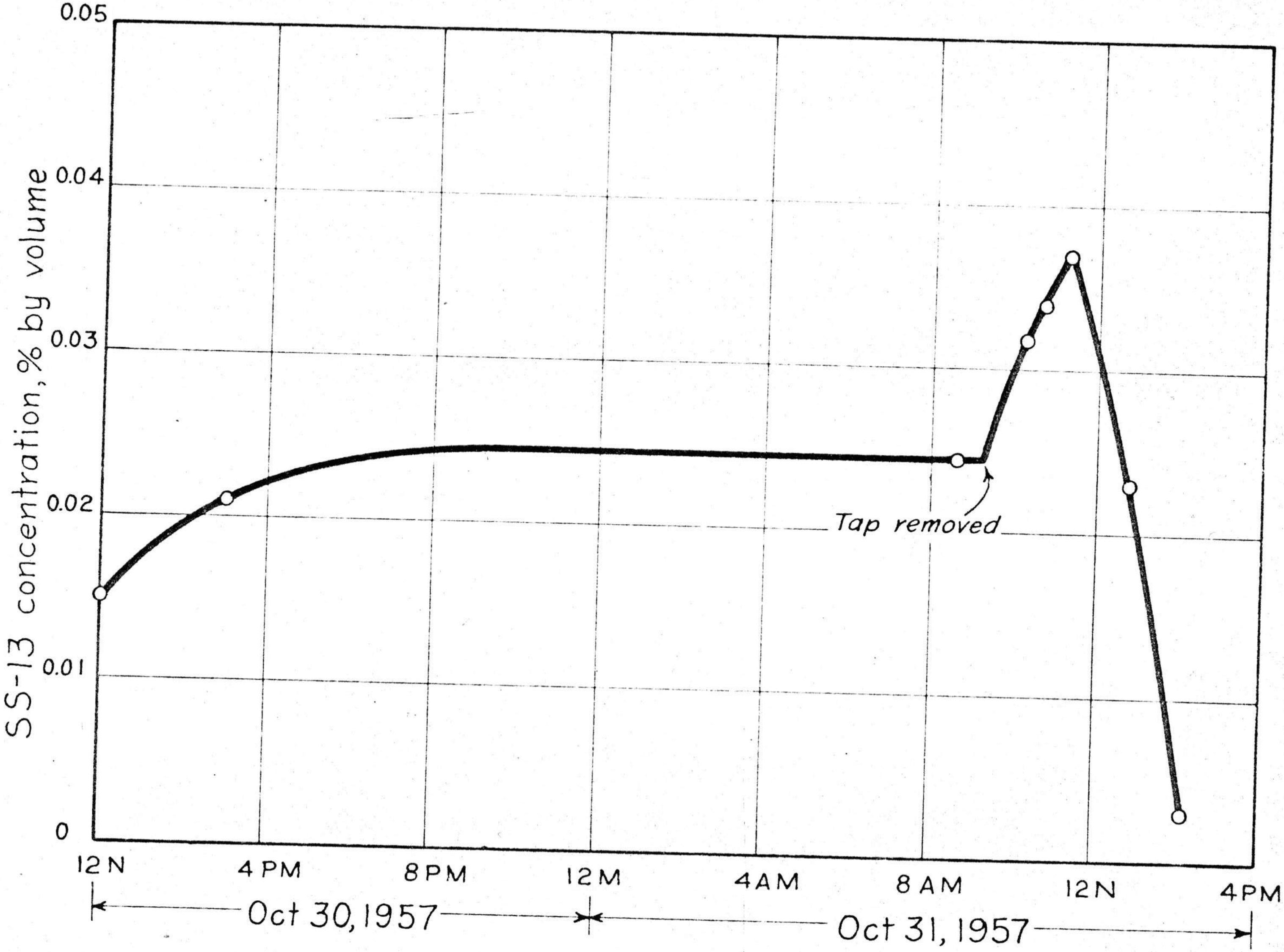


Fig. 15 Concentration history at Sta. 695 during installation of SS-13

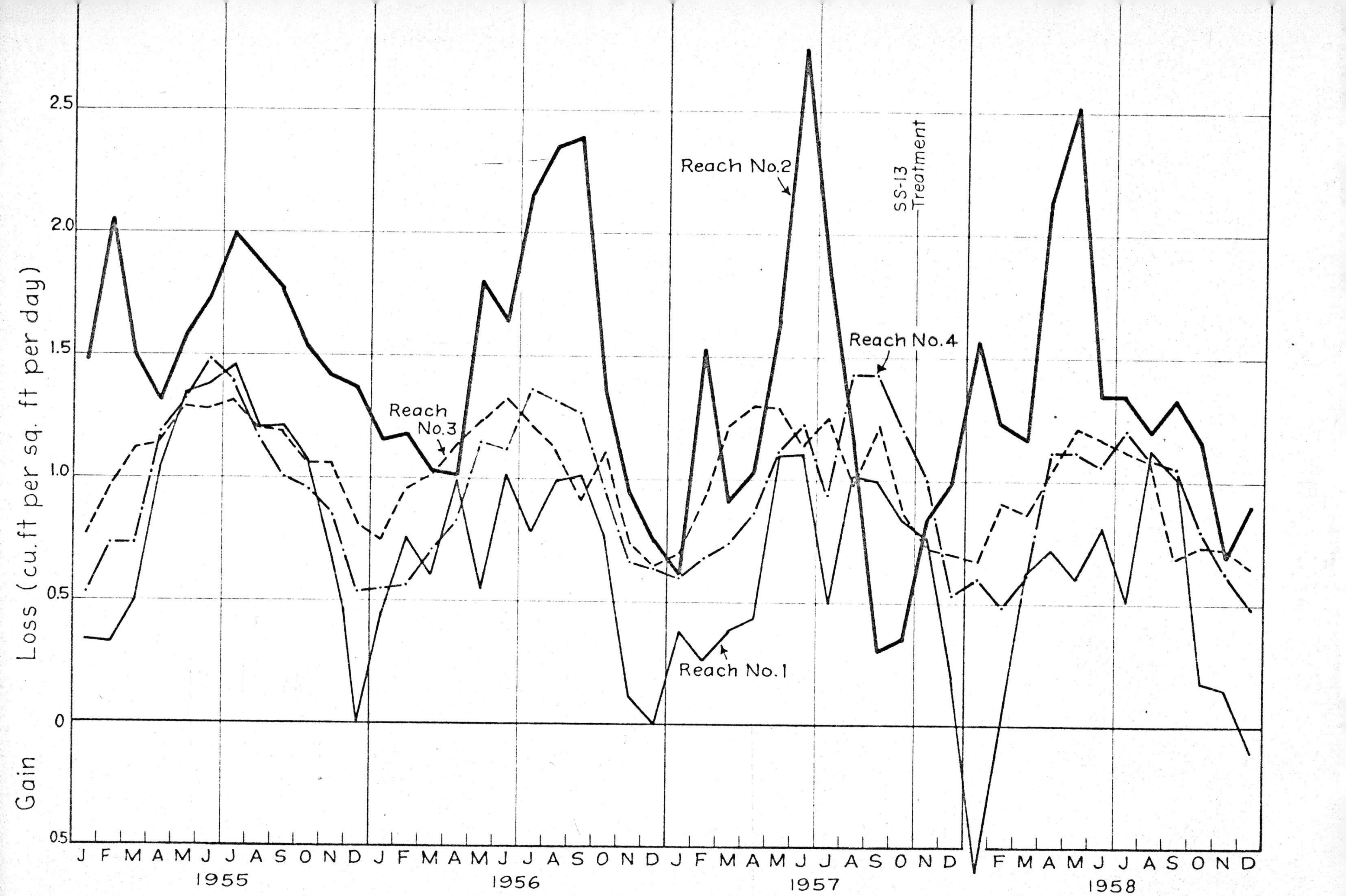


Fig. 16 Superimposed plot of losses by reaches

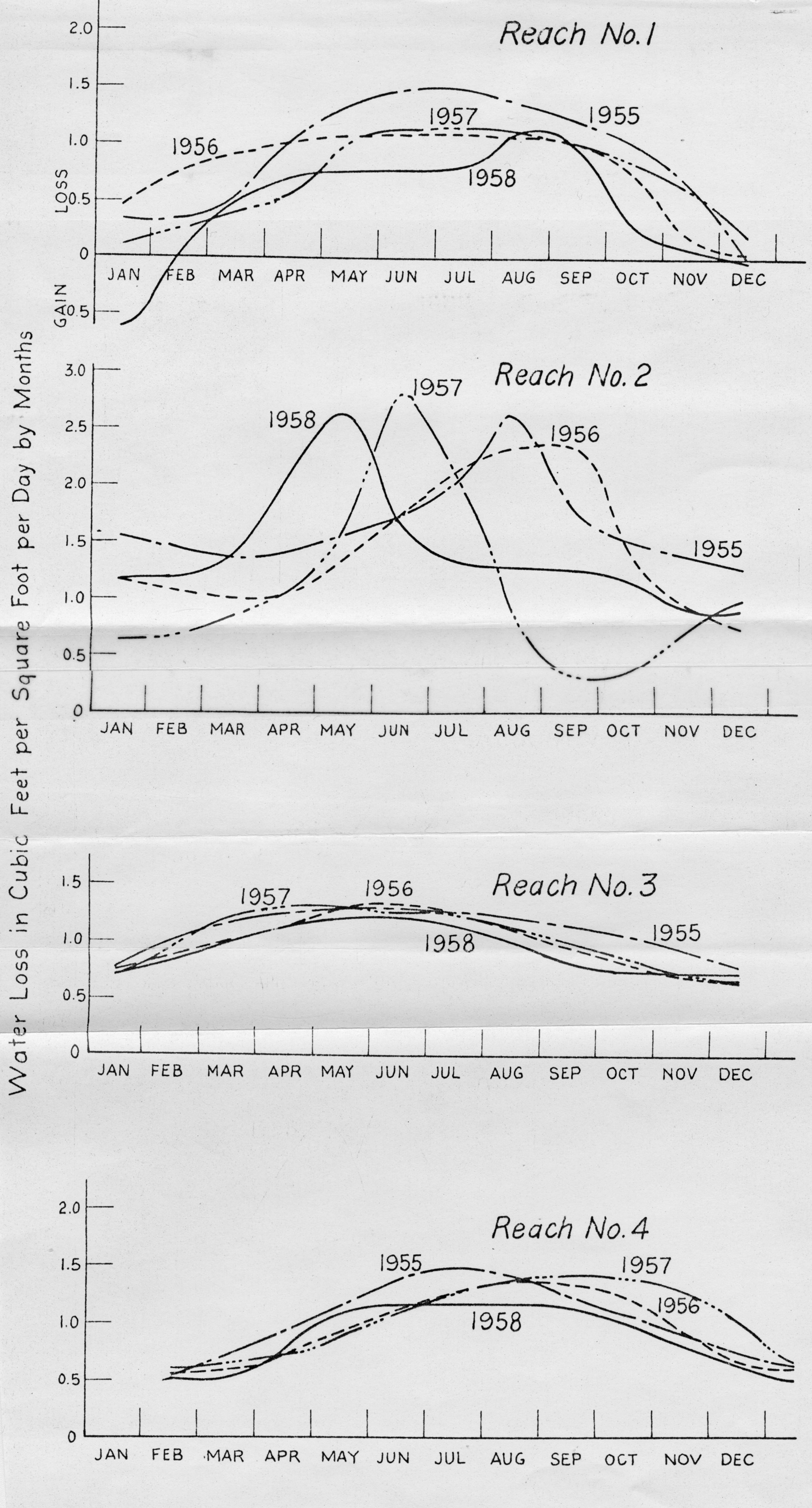


Fig. 17 Separated plots of losses by reaches

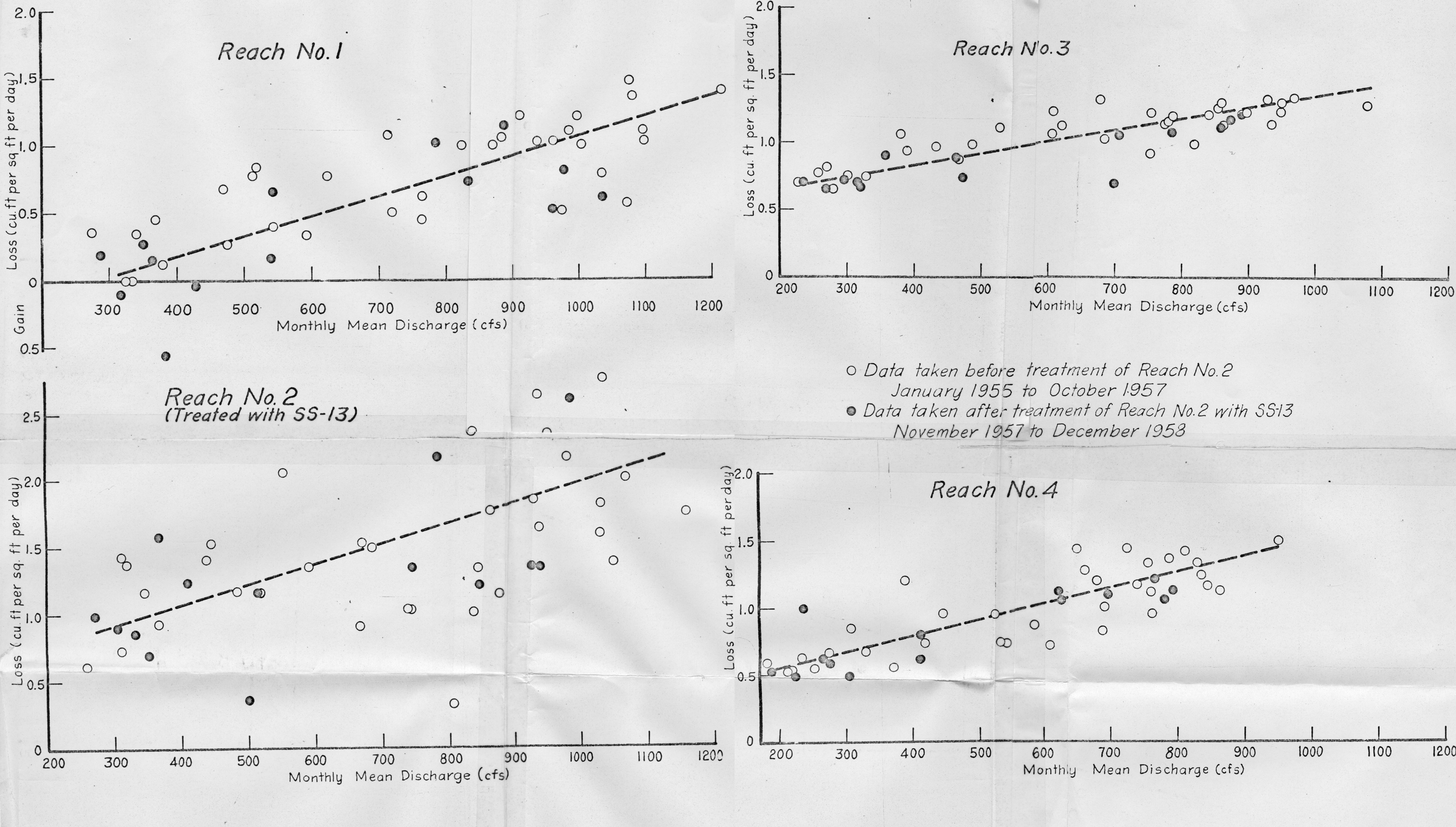


Fig.18 Plot of monthly loss by reaches

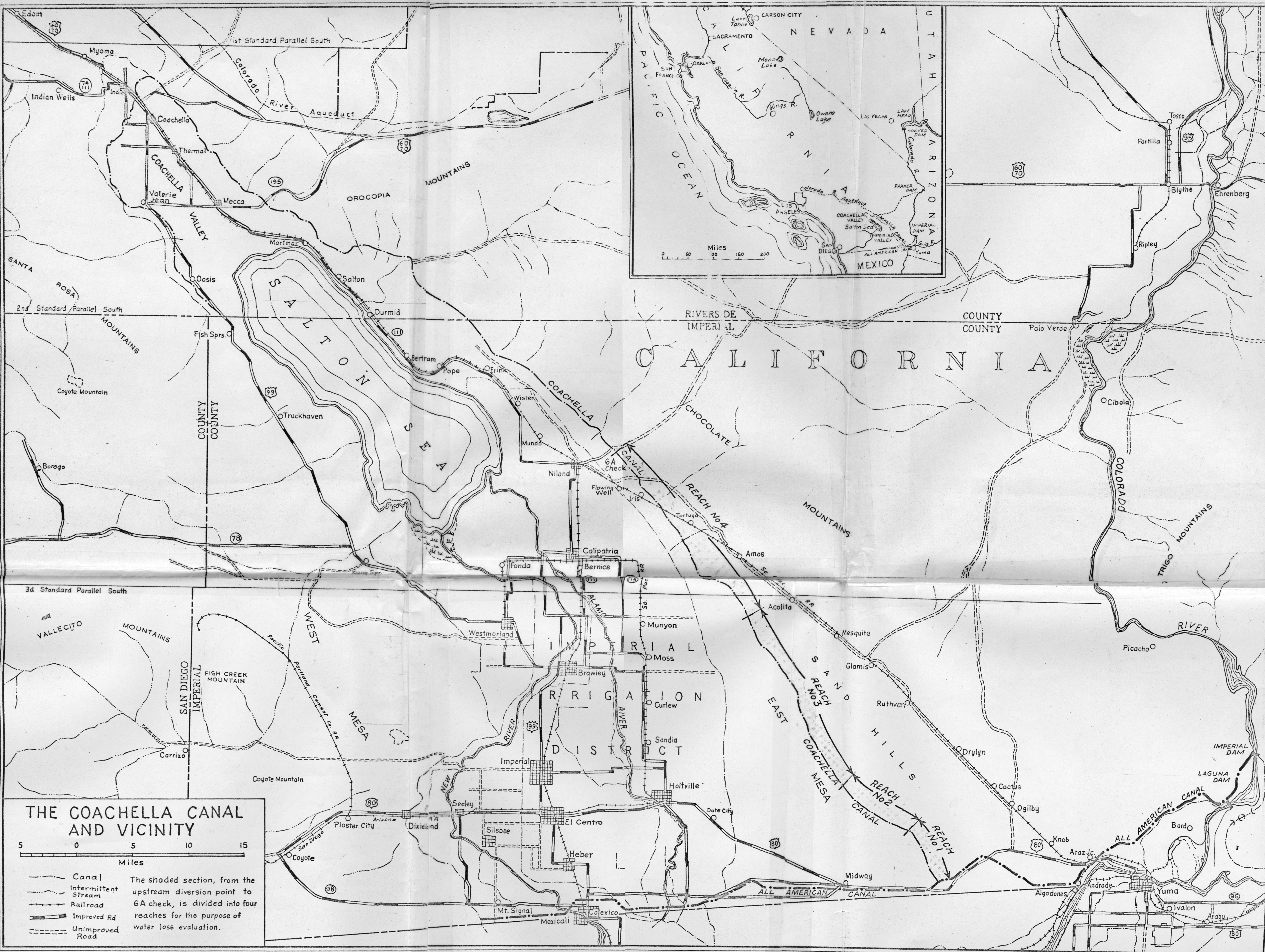

THE COACHELLA CANAL AND VICINITY
5 0 5 10 15
Miles
Canal
Intermittent Stream
Railroad
Improved Rd
Unimproved Road
The shaded section, from the upstream diversion point to 6A check, is divided into four reaches for the purpose of water loss evaluation.
Edom
Myoma
1st Standard Parallel South
Colorado River Aqueduct
Indian Wells
Indio
Coachella
Thermal
COACHELLA VALLEY
Valerie Jean
Mecca
OROCOPIA MOUNTAINS
Mortmar
Salton
Durmid
Bertram
Pope
Frink
Wister
Mundo
Niland
SALTON SEA
SANTA ROSA MOUNTAINS
Oasis
2nd Standard Parallel South
Fish Sprs.
Coyote Mountain
Truckhaven
COUNTY
COUNTY
Borego
Kane Spr.
3d Standard Parallel South
VALLECITO MOUNTAINS
SAN DIEGO
IMPERIAL
FISH CREEK MOUNTAIN
Pacific Portland Cement Co. RR
WEST MESA
Carrizo
Coyote Mountain
Plaster City
Dixieland
Coyote
San Diego Arizona R.R.
Seeley
Silsbee
Imperial
NEW RIVER
Westmorland
Fonda
Calipatria
Bernice
ALAMO RIVER
IMPERIAL IRRIGATION DISTRICT
Brawley
Munyon
Moss
Curlew
Sandia
Holtville
El Centro
Heber
Mt. Signal
Calexico
Mexicali
Date City
Midway
ALL AMERICAN CANAL
COACHELLA CANAL
6A Check
Flowing Well
Iris
Tortuga
Amos
Acolita
Mesquite
Glamis
Ruthven
Drylyn
Cactus
Ogilby
Knob
Araz Jc.
Algodones
Andrade
Yuma
Ivalon
Araby
Bard
REACH No 4
REACH No 3
REACH No 2
REACH No 1
CHOCOLATE MOUNTAINS
SAND HILLS
EAST MESA
So. Pac. R.R.
RIVERSIDE
IMPERIAL
COUNTY
COUNTY
CALIFORNIA
Palo Verde
Cibola
COLORADO RIVER
TRIGO MOUNTAINS
Picacho
IMPERIAL DAM
LAGUNA DAM
Blythe
Ehrenberg
Ripley
Tosco
Fartilla
CARSON CITY
Lake Tahoe
SACRAMENTO
NEVADA
SAN FRANCISCO
OAKLAND
San Joaquin R.
Mono Lake
Kings R.
Owens Lake
LAS VEGAS
LAKE MEAD
HOOVER DAM
PACIFIC OCEAN
UTAH
ARIZONA
CALIFORNIA
LOS ANGELES
Colorado Aqueduct
PARKER DAM
COACHELLA VALLEY
Salton Sea
IMPERIAL VALLEY
COACHELLA CANAL
IMPERIAL DAM
SAN DIEGO
ALL AMERICAN CANAL
Gila R.
Yuma
MEXICO
Miles
0 50 100 150 200

Fig. 1