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PROGRESS REPORT OF CANAL EROSION AND TRACTIVE FORCE STUDY LOWER-COST CANAL LINING PROGRAM

General Report No. 21

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

March 1, 1957

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DEPARTMENT OF THE INTERIOR
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*General Report No. 21
Compiled by: P. F. Enger
J. Merriman
Checked by: E. J. Carlson
Reviewed by: C. W. Thomas
H. J. Gibbs
Submitted by: H. M. Martin
W. G. Holtz

PROGRESS REPORT OF CANAL EROSION AND TRACTIVE FORCE STUDY LOWER-COST CANAL LINING PROGRAM

SUMMARY

To establish better design criteria for earth lined and unlined canals, field studies of erosion and tractive forces on fine cohesive soil materials have been conducted under the Lower-cost Canal Lining Programs of fiscal years 1956 and 1957. Additional sites have been selected for study during fiscal year 1958.

Eighteen test reaches have been selected and analyzed on canals and laterals of various sizes, soil types and stabilities, Tables 1 and 2, and 29 additional test reaches of various types have been selected for future study.

Three channel conditions are being studied; these include (1) canals where deposition is occurring, (2) stable canals, and (3) moderately scoured canals.**

Two trips are made to each test site. A field inspection party makes the first trip while the canal is in a dry condition and sites are selected and earth samples obtained. The second trip is made when the canal is flowing near maximum discharge to obtain hydraulic data and make vane shear tests on the soils.

Earth data are classified and analyzed to determine soil densities, compressive strengths, mechanical analysis, Atterberg limits, percentage of compaction for earth linings, and petrographic and chemical

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*See Laboratory Reports No. Hyd-435 and EM-481.

**Refer to "Outline of Canal Erosion and Tractive Force Study, Lower-cost Canal Lining Program" as revised July 15, 1956.

data. The data are presented in Tables 3 through 7. Hydraulic data are analyzed to determine velocity profiles, average velocities, discharge, hydraulic radius, average tractive forces, tractive force distributions, Manning's "n" values, suspended sediment concentration, and water temperature. Hydraulic data are presented in Tables 8 through 11.

An insufficient number of channels of each type (stable, eroding and depositing in various soil types) have been analyzed to date to establish definite trends. However, it is felt that by the analysis of additional sites and combinations of soil and hydraulic characteristics, definite trends can be established. At this time it is felt that grouping of soils in terms of gradation, plastic properties and density will establish a comparison of erosion caused by tractive forces. Some general trends indicating that the resistance to erosion increases with an increase in soil density and also varies with the plastic properties of the soil are becoming evident.

A laboratory erosion testing machine is being constructed and erosion tests, on undisturbed 8-inch-diameter soil samples from each test reach, will be conducted. The tractive force necessary to erode the samples will be determined and the values will be compared with the tractive forces which caused erosion in the field. The results of these tests will be presented in a final report.

INTRODUCTION

The investigations reported here have been conducted under the Lower-cost Canal Lining Program of FY56 and FY57. The program is intended to extend over a period of several years and include several earth lined and unlined canals with a variety of soils types which have been subjected to different climatic and hydraulic conditions.

The purpose of the program is to establish better design criteria for earth lined and unlined canals. To establish the behavior of soils under hydraulic forces, the physical properties of the soil are compared to the hydraulic forces, and the degree of erosion. Field and laboratory tests are correlated from selected reaches of earth lined and unlined canals. Chemical properties of the soil and water may be investigated in the future.

Canal and lateral reaches for the study were selected by a field inspection party consisting of an engineer from the Earth Laboratory, an engineer from the Hydraulic Laboratory, and a regional representative. An engineer from the Canals Branch was either present during selection of the test reaches, or he reviewed and approved the reports of those who did select the reaches. In November and December of 1955, 9 sites were selected in each of Regions 7 and 2.

The sites selected in Region 7 were in canals that lie along the Republican River drainage, Figure 1. They were all on earth lined and unlined canals which had been in operation for a number of years. Seven of the reaches are located on straight sections approximately 1,000 feet in length in canals which appeared to be stable. Two curved sections in one reach were selected on the Cambridge Canal. The canals vary in capacity, Table 8, the smallest in Region 7 having a design discharge of 30 cfs and the largest having a design discharge of 210 cfs.

Of the 9 sites selected in Region 2, 4 are on the Klamath Project in Oregon, Figure 2, 2 are located in the Friant-Kern Canal, and 3 are located in the Madera Distribution System, Figure 3. All the reaches in Region 2 are located on straight sections of earth lined or unlined canals and laterals which have been in operation for a number of years. The reaches appeared to be stable or slightly eroding for the discharges occurring in the past. The smallest lateral selected in Region 2 was designed for a discharge of 24 cfs and the largest canal was designed for a discharge of 5,000 cfs, Table 9.

Additional sites have been selected for testing during 1957. In general, reaches were selected where the soil, erosion and hydraulic conditions are relatively uniform over a length of approximately 1,000 feet. A variation in sizes from large to small and three conditions of erosion will be tested: (1) stable, (2) slightly scoured or on the point of scouring, and (3) moderately scoured. Emphasis was placed on selecting canals in more plastic (clayey) materials. To satisfy hydraulic conditions, reaches have: (1) operated near design discharge and will operate next season near design discharge, (2) a good record of previous operation available, (3) not been effected by backwater from checks or other structures, and (4) no excessive weed growth.

DATA OBTAINED

First trip to sites. The limits of each test reach selected were set by placing hubs, guard stakes and flags at the upper end, center, and lower end of the reach.

The soils encountered in Region 7 were all loessial with varying amounts of fine sand. Visual classifications of the soils are presented in Table 4. Gradation curves for all the materials are shown in Figures 4 and 5. Atterberg limits are plotted on Figure 6. Although loess soils are not generally considered to be very desirable for canals, because of their low strength when saturated and their fine particle size, in this area they appear to be giving good service.

The canals have retained their shape for the most part. Berms have been formed in many reaches of the canals. These berms are apparently caused by low velocities and/or the weed growth near or on the side slopes which promotes soil deposition.

The soils in Region 2 test reaches vary from a diatomaceous earth to a clay. Predominantly the soils are silts and sandy silts. Visual classifications are shown in Table 5. Gradation curves are presented in Figures 7 and 8, and Atterberg limits are plotted on Figure 9.

In general, the laterals in the Klamath Project were eroded and had heavy weed growth which caused deposition along the side slopes and formed berms. The canals in the Central Valley Project were either stable or slightly eroded.

Soil sampling. Soil samples for testing in the Denver laboratory taken from each test reach included sack samples, 3-inch drive samples, 8-inch undisturbed hand cut samples and samples of sediment where present.

The sack samples were tested to determine the gradation, the plastic properties, and the compaction characteristics of the material in each test reach. The 3-inch drive samples were tested to obtain unconfined compression values. The 8-inch hand cut samples were obtained for use as erosion test specimens. No erosion tests have been performed on these samples as the test procedure is not complete. The erosion test as contemplated at present is to be used as an index for estimating erosion in future canals. The values obtained from these tests will be correlated with the data and test values obtained from the canals under study. It is felt that in the future, laboratory erosion test results may be obtained as a regular portion of the percolation settlement test.

Second trip to sites. The second trip to the reaches previously selected in Regions 2 and 7 was made during the Summer of 1956. The trip was made at the time the canals and laterals were operating near peak discharge for the year by a hydraulic engineer from the Hydraulic Laboratory.

Data recorded at all test sections included: canal water surface slopes; the canal cross section at the middle of the reach; velocity contours at the middle of the reach, including velocities near the canal boundary where possible; the amount of sediment being carried in suspension; the temperature of the water; the shear resistance of the banks and bottom of the canal in place and in the saturated condition; and photographs showing the condition of test reaches.

To record the canal water surface slopes, an engineer's level and a water surface gage were used. A Type A current meter was used to measure the velocities at 0.2 and 0.8 of the depth for discharge measurements, and a pygmy current meter was used to measure velocities near the boundary, Figure 10. A DH-48 hand sampler was used to obtain a water sample for suspended sediment analysis, and a vane shear tester, Figure 11, was used to determine the in-place shear values of the soils.

Data obtained from the field. Records of the highest sustained flow each year for at least a 1-week period over the past few years were obtained from the project offices, and cross sections of the canal in previous years were obtained when available.

ANALYSIS OF DATA

Earth data. The materials from the various canals in which the test reaches were selected range from silty sands to clays with resulting large variations in test values. The results of the various tests are presented in tabular form in Tables 1 through 7 and graphs showing the soil properties of the various materials are shown in Figures 4 through 9. Compaction curves are presented in Figure 12. Test results shown include density values taken from the unconfined compression tests, unconfined compression test values, mechanical analysis, Atterberg limits, and standard compaction test values. The standard compaction tests were performed on soils obtained from test reaches in earth lined sections of canals.

Hydraulic data. The relative slope of the water surfaces was plotted, Figure 13, and a line showing the average water surface slope in each reach was drawn. In calculations it was assumed that the slope of the energy gradient was parallel to the slope of the water surface. Cross sections at the middle of each reach were drawn, Figures 14 and 15, and the cross sectional areas and the hydraulic radii were calculated. By use of the cross sectional areas and the 0.2 and 0.8 depth velocities, the total discharge in the canal or lateral was obtained. After the total discharge was obtained, the average velocity occurring in the section was determined from:

$$V_A = \frac{Q}{A}$$

where:

V_A = the average velocity in the section in ft/sec
Q = the total discharge in the section in cfs
A = the cross sectional area in ft^2

The roughness coefficient, "n" value, was computed from the Manning formula:

$$n = \frac{1.49}{V_A} R^{2/3} S^{1/2}$$

where:

R = the hydraulic radius, ft
S = the slope of the energy gradient, ft/ft

Hydraulic data summarized for Region 7 are shown in Table 8 and that summarized for Region 2 are shown in Table 9. Tables 10 and 11 show an analysis of the suspended load data.

The average tractive force τ_a acting on the perimeter of the canals and laterals was computed by two methods. The first method was by use of the formula $\tau_a = WRS$, where W is the unit weight of water and other units are as previously defined. The second method was to determine the average tractive force from the tractive force distribution around the perimeter of the canal. Using the velocity distribution near the boundary and velocities in the same plane at distances y_1 and y_2 from the boundary, the following formula was applied:

$$\tau_o = \frac{(v_2 - v_1)^2}{5.75 \log \frac{y_2}{y_1}}$$

The derivation of this formula is outlined in Appendix 1.

The tractive force distribution as determined from the velocity contours is shown in Figures 14 and 15 and the average tractive force as determined from each method is shown in Tables 8 and 9. Compared results were somewhat erratic. As shown in Tables 8 and 9, the compared tractive forces of the two curved sections in Region 7 and canals and laterals clogged with weeds were not in agreement.

COMBINED DATA

Short descriptions of each test reach as observed when data were obtained follow.

Region 7

Bartley Canal, Reach 1, compacted earth lining. Slight erosion from wave action near water surface level. Three to five inches of loose silt on bottom of the canal (see Figures 14 and 16).

Bartley Canal, Reach 2, unlined. Weeds generally grew on the banks above the water surface and extended into the water. Reach appeared stable with slight deposition near toe of side slope (see Figures 14 and 16).

Cambridge Canal, Reach 3, unlined. Weed growth near the water surface. Reach appeared to be stable with some deposition on bottom (see Figures 14 and 16).

Franklin Pump Canal, Reach 4, unlined. Cross section rounded but stable. Considerable weed growth near water surface (see Figures 14 and 17).

Superior Canal, Reach 5, unlined. Erosion taking place on banks above the water surface due to surface drainage. Wave erosion near water surface edge. Small deposits near toe of slope. Slight erosion on bottom (see Figures 14 and 17).

Franklin Canal, Reaches 6 and 7, unlined. Slight erosion from wave action near water surface. Sediment deposits near toe of slope (see Figures 14 and 17).

Cambridge Canal, two adjacent curved reaches, unlined. Weed growth near water surface edge. Deposition occurring on the inside of the curves (see Figures 14 and 18).

Region 2

Lateral M-2-A, Klamath, Reach 1, unlined. Aquatic weeds, pondweeds, and moss were growing across the entire section of the lateral. Lateral had eroded in the past. Channel boundary was well defined and solid. Pondweeds appeared to grow denser at the center of the lateral which created a resulting higher velocity in the area away from the center (see Figures 15 and 19).

Lateral M-2-A, Klamath, Reach 2, compacted earth lining. Heavy weed growth at water surface edge. Moss covered the boundary of the section. Reach appeared stable (see Figures 15 and 19).

Lateral J-1-B, Klamath, Reach 3, unlined. The lateral was full of moss and weeds. There were relatively clear channels along the sides of the section where water velocities were higher than in the center of the section. There appeared to have been scour in the past (see Figures 15 and 19).

Lateral J-13, Klamath, Reach 4, unlined. Reach was clear of aquatic growth. There was a heavy growth of weeds at the water surface edge. There appeared to have been some erosion in the past (see Figures 15 and 20).

Friant-Kern Canal, Reach 5, compacted earth lining. Aquatic weeds grew on the boundary to a height of approximately 1 foot. Sloughing had occurred on the side slope of the canal in this reach. The reach appeared stable with the exception of the bank sloughing (see Figures 15 and 20).

Friant-Kern Canal, Reach 6, compacted earth lining. Aquatic weeds grew on the boundary to a height of approximately 1 foot. The reach appeared stable (see Figures 15 and 20).

Lateral 32.2, Madera, Reach 7, compacted earth lining on slopes. Aquatic weeds grew along the edges of the lateral. Deposition was occurring in the weed area (see Figures 15 and 21).

Madera Canal, Reach 8, unlined. No weeds were growing in the reach. Erosion was occurring in this reach (see Figures 15 and 21).

Madera Canal, Reach 9, unlined. No weeds grew in the reach. Slight erosion appeared to be occurring in the reach (see Figures 15 and 21).

SOIL-HYDRAULIC RELATIONSHIP

It has become evident that combinations of soil and hydraulic characteristics will need to be made before definite trends can be ascertained. To date there has been insufficient data obtained to make this type of analysis feasible. It is felt that grouping of soils in terms of gradation, plastic properties, and density will permit a comparison with erosion caused by tractive forces of certain magnitudes.

Table 3 presents the average soils data including mean grain diameters, plasticity indices, saturated unconfined compressive strengths, dry densities, liquid limits and vane shear test values for each test reach. There are insufficient channels of each type (stable, eroding and depositing) to warrant presenting the data in graph form. Tables 8 and 9 present the average hydraulic data.

Twenty-nine reaches have been selected for additional tests. The test reaches are in Regions 1, 4, and 5, and the soil samples have been obtained from most of the reaches. The reaches selected vary in characteristics as follows:

	Regions 4 and 1	Canal	Station	Soil type
4	Eden Project	Means	24+17	CL
	Eden Project	Means	102+00	SP
	Eden Project	Eden	348+50	SM
	Eden Project	Eden	357+00	SC-CL
	Eden Project	Eden	464+95	CL-SC
	Eden Project	Eden	645+00	CL-SC
	Eden Project	Eden	834+00	SM
	Eden Project	Means	265+00	SM
	Paonia Project	Fire Mountain	419+00	CL*
	Paonia Project	Fire Mountain	648+00	CL*
	Paonia Project	Fire Mountain	1342+00	CL*
1	Minidoka Project	Lat 10A824	33+00	ML
	Minidoka Project	Milner Gooding	374+00	ML
	Minidoka Project	PA lateral	--	ML
	Yakima Project	P Lat 14	--	ML
	Yakima Project	P Lat 13	152+50	SM
	Yakima Project	Roza Main	Mile 57.9	ML
	Columbia Basin	Lat W27B	24+90	ML
	Columbia Basin	Lat W26A	378+90	ML
	Columbia Basin	E Lat 68T5	185+00	ML
	Columbia Basin	E Lat 33	34+00	ML
	Region 5			
	Tucumcari	Conchas	Mile 60.9	CL
	Tucumcari	Conchas Lateral	4056+00	CL with gravel blanket
	Tucumcari	Conchas Lateral	3962+86	CL
	Tucumcari	Hudson Lateral	Mile 5.2	CL
	Tucumcari	Hudson Lateral	1091+00	SC-CL
	W. C. Austin	West	188+00	CL
	W. C. Austin	Altus	799+50	CL-CH
	W. C. Austin	Ozark	316+00	CL-CH

*This material is Mancos chale--the CL classification applies when broken down.

The hydraulic information will be obtained from these reaches during the Summer of 1957. At present the testing program for the soil samples is the same as for samples previously tested and reported here.

Laboratory erosion tests are to be conducted on undisturbed 8-inch-diameter soil samples. The soils samples have been obtained from each test reach and an erosion testing machine has been constructed. The tests will provide additional information for correlation with field data. The tractive force necessary to erode the sample will be determined from these tests and compared with tractive forces which caused erosion in the field.

The laboratory erosion test results which are to be included in the final report will probably permit a more direct method of analyzing the relationships which exist between soils with a variety of characteristics and tractive forces. However, this test, to be of value, must be correlated with the erosion caused by tractive forces under field conditions.

RECOMMENDATIONS AND CONCLUSIONS

At this time no concrete conclusions should be made regarding the relationships which exist (in stable, eroding or depositing canals) between soils properties and hydraulic conditions. It is felt that this is not due to the lack of these relationships but is merely because the data collected to date are too meager and analysis has not progressed to a point to permit definite conclusions. From study and experience it is known that some general soil properties definitely effect the stability of earth canals, these properties are the grain size distribution, the plastic properties, strength, and the density of the soils. The quality of this analysis depends upon whether enough canals are studied to give a variety of these soil properties along with a range of hydraulic conditions and degree of erosion.

As shown in Table 1 there are 18 test reaches of limited soils types in this report. An additional 29 test reaches have been selected from other regions. The test data for these 29 reaches are not yet available. For future study, it is recommended that the soils test data and the hydraulic data be completed for all 47 test reaches before any further test reach selections are made. This would accomplish two things (1) completion of this data would serve to direct the study and (2) allow selection of individual test reaches which represent soils and hydraulic conditions, which are not included in the 47 test reaches now selected.

APPENDIX

THEORY

Hydraulic. Fluid motion can be analyzed from two different points of view: (1) where pressures and velocities at a given point are considered and (2) where the fate of an individual particle is considered. The following is from a consideration of the fate of an individual particle. Th. v. Karman (1)* determined there was, in general, a correlation between the components of the velocity fluctuations (individual particles) in the direction of the main flow and perpendicular to that direction for turbulent flow. Therefore, it is concluded that shearing stress is transmitted through a plane parallel to the direction of flow by other than laminar friction. In most practical cases, except in the immediate vicinity of a solid boundary, these turbulent stresses are so large in comparison to the stresses due to the molecular or laminar friction, that the latter can be neglected. Prandtl (2) first used the theory of a "mean free path" or "mixing length" (l) in turbulent flow. Using the assumption that l was constant over the cross section of the mixing region, v. Karman (3) added $l = k\frac{u'}{u''}$ and assumed l was small in comparison with linear dimensions involved in the problem. k = 0.4 was then proposed which indicates l is only moderately small in comparison with dimensions involved in the geometry of the problem. From the preceding assumptions and derivations, the logarithmic formula for velocity distribution was first given by Th. v. Karman (3) in 1930. Prandtl (4) soon adopted the formula and with Nikuradse (5) determined the numerical values of the constants. According to Prandtl and Nikuradse the value of k varies from 0.38 to 0.41 to best fit experimental results.

H. A. Einstein (6) shows the general logarithmic velocity distribution equation for open channels can be written in the following form:

$$\frac{V_y}{\sqrt{\frac{\tau_o}{\rho}}} = 5.75 \log \left(30.2 \frac{y}{\Delta}\right)$$

where:

V_y = the average point velocity at distance y from the bed
τ_o = the shear at the boundary (tractive force)
ρ = the density of the water
Δ = the apparent roughness of the surface and contains a corrective parameter
5.75 = a constant which contains v. Karman's k value

*Numbers refer to bibliography at end of report.

If the preceding equation is used and the velocity at one point (V_1) is subtracted from the velocity of another point (V_2) which is slightly above V_1, we obtain:

$$V_2 - V_1 = 5.75\sqrt{\frac{\tau_o}{\rho}}\left[\log\frac{30.2y_2}{\Delta} - \log\frac{30.2y_1}{\Delta}\right]$$

or

$$V_2 - V_1 = 5.75\sqrt{\frac{\tau_o}{\rho}}\left[\log\frac{y_2}{y_1}\right]$$

from which

$$\tau_o = \rho\left[\frac{V_2 - V_1}{5.75\log\frac{y_2}{y_1}}\right]^2$$

If a constant distance from the boundary is set for y_1 and y_2 the equation further simplifies to the form of

$$\tau_o = C\,(V_2 - V_1)^2$$

The preceding equation indicates that if two velocities and their distances from the boundary are known to act in a given plane, the boundary shear in that plane can be found. The distance from the boundary should be measured perpendicular to the boundary, and velocities relatively close to the boundary should be used in the equation.

Applying the preceding method to the velocity contours, the shear distribution around the boundary can be established.

Using other accepted formula such as

$$\tau_a = WRS$$

where:

τ_a = the average tractive force acting on the boundary, lb/ft^2
W = the specific weight of water, 62.4 lb/cu ft
R = the hydraulic radius, ft
S = the slope of the energy gradient, ft/ft

the average tractive force can be checked.

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6. H. A. Einstein, Soil Conservation Service Technical Bulletin No. 1026

Major divisions of soils			Typical names of soil groups	Group symbols	7-1	7-2	7-3	7-4	7-5	7-6	7-7	7-8 & 7-9	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9
					Region & Tractive Force Reach																
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye.)	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size (For visual classifications, the ¼" size may be used as equivalent to the No. 4 sieve size)	CLEAN GRAVELS (Little or no fines)	Well graded gravels, gravel-sand mixtures, little or no fines	GW																	
			Poorly graded gravels, gravel-sand mixtures, little or no fines	GP																	
		GRAVELS WITH FINES (Appreciable amount of fines)	Silty gravels, poorly graded gravel-sand-silt mixtures	GM																	
			Clayey gravels, poorly graded gravel-sand-clay mixtures	GC																	
			Gravel with sand-clay binder	GW-GC																	
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS (Little or no fines)	Well graded sands, gravelly sands, little or no fines	SW																	
			Poorly graded sands, gravelly sands, little or no fines	SP																	
		SANDS WITH FINES (Appreciable amount of fines)	Silty sands, poorly graded sand-silt mixtures	SM						X					X						X
			Clayey sands, poorly graded sand-clay mixtures	SC							ML-SM								ML-SM	SC-CL	
			Sand with clay binder	SW-SC																	
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS Liquid limit less than 50		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	X	ML-CL	ML-CL	X	ML-CL			ML-CL				X					
			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL																	
			Organic silts and organic silt-clays of low plasticity	OL																	
	SILTS AND CLAYS Liquid limit greater than 50		Inorganic silts, micaceous or ditomaceous fine sandy or silty soils, elastic silts	MH									X	X			CL-CH				
			Inorganic clays of high plasticity, fat clays	CH																	
			Organic clays of medium to high plasticity	OH																	
HIGHLY ORGANIC SOILS			Peat and other highly organic soils	Pt																	

TABLE 1

Lower Cost Canal Lining
Tractive Force Field Study
Soil types in Regions 7 & 2

Table 2

SUMMARY SHEET OF CHANNELS TESTED

Unit	Reach No.	Side slopes	Bottom	Toe (ss)	General trend	Bottom width (ft)	Soil type
Region 7							
Bartley	1	S	D	D	Slight deposition	12	ML
Bartley	2	S	S	D	Stable	8	ML-CL
Cambridge	3	S	D	D	Slight deposition	13	ML-CL
Franklin Pump	4	S	E	D	Stable	6	ML
Superior Canal	5	E	E	D	Slight erosion	9	ML-CL
Franklin Canal	6 and 7	S	S	D	Stable	14	ML-SM
Cambridge	Curves	General deposition on inside of curve General erosion on outside of curve			Changing sections	12	ML-CL
Region 2							
M-2-A	1	E	E	E	Eroding	6	MH
M-2-A	2	S	S	S	Stable	4	MH
J-1-B	3	E	E	E	Eroding	9	SM
J-13	4	E	D	E	Slight erosion	10	ML
Friant-Kern	5	S	S	S	Stable	64	CL-CH
Friant-Kern	6	S	S	S	Stable	64	CL
Lateral 32.2	7	S	E	D	Stable	12	ML-SM
Madera	8	E	E	S	Eroding	20	SC-CL
Madera	9	E	D	S	Slight erosion--bottom armored with large sand particles	20	SC

S = Stable
D = Depositing
E = Eroding

Note: All canal and lateral side slopes were 1-1/2:1.

LOWER-COST CANAL LINING PROGRAM
TRACTIVE FORCE FIELD STUDY
CHANNEL CONDITIONS

Table 3

Canal or lateral	Reach No.	Mean grain diameter, mm	Plasticity index	Unconfined compressive strength*	Dry density lb/cu ft	Liquid limit %	Percent maximum compaction	Vane shear test values (psi)
Region 7								
Bartley Canal	1	0.040	7.3	4.0	104.3	24.3	94.4	1.84
Bartley Canal	2	0.029	10.2	1.0	88.4	30.0	--	1.81
Cambridge Canal	3	0.047	9.8	1.8	85.6	29.2	--	1.88
Franklin Pump Canal	4	0.023	10.3	2.2	88.9	35.1	--	2.07
Superior Canal	5	0.019	11.9	2.1	91.5	30.0	--	1.81
Franklin Canal	6 and 7	0.104	1.9	1.4	98.8	20.6	--	1.42
Cambridge Canal	Curved	0.027	10.9	0.7	103.3	17.6	--	1.45
Cambridge Canal	Curved	0.027	10.9	2.2	91.6	28.8	--	1.45
Region 2								
Lateral M-2-A Klamath	1	0.182	13.5	1.6	60.0	70.3	--	2.27
Lateral M-2-A Klamath	2	0.0034	32.4	3.3	53.9	84.0	83.5	1.29
Lateral J-1-B Klamath	3	0.18	0	1.6	92.7	--	--	1.68
Lateral J-13 Klamath	4	0.057	19.5	2.6	81.0	45.0	--	1.54
Friant-Kern Canal	5	0.0075	29.3	3.5	102.7	52.0	101.5	1.50
Friant-Kern Canal	6	0.056	10.1	5.4	115.2	27.0	99.2	1.55
Lateral 32.2 Madera	7	0.13	6.5	6.6	115.9	19.0	98.7	2.25
Madera Canal	8	0.16	10.3	0.9	120.5	26.0	--	2.20
Madera Canal	9	0.13	5.2	1.2	115.8	20.0	--	1.84

*Saturated.

LOWER-COST CANAL LINING PROGRAM
TRACTIVE FORCE FIELD STUDY
AVERAGE SOILS DATA

TABLE 4

EARTH TESTING
VISUAL CLASSIFICATION OF SOIL SAMPLES

IDENTIFICATION				GRADATION (ESTIMATED)				COLOR (WET STATE)	DESCRIPTION AND SOIL CLASSIFICATION	
LABORATORY SAMPLE NO.	EXCAVATION NO.	LOCATION OR STATION	DEPTH IN FEET	MAXIMUM SIZE	GRAVEL (% PLUS #4)	SAND (% #4 TO #200)	SILT AND CLAY (% MINUS #200)		1. DESCRIPTIVE CLASSIFICATION 2. PARTICLE SIZE, SHAPE, AND GRADATION (UNIFORMLY, WELL, POORLY GRADED, ETC.) 3. CONSISTENCY, ELASTICITY, ETC. 4. REACTION TO SHAKING TEST, DRY STRENGTH, ETC.	GROUP SYMBOL
Region 7 TF Section No. 1 Bartley Canal, Station 263+00 Missouri River Basin				30	0	20	80	Brown	Silt--with some fine sand, low plasticity, low dry strength (average of materials) LL = 24 PI = 7	ML
Region 7 TF Section No. 2 Bartley Canal, Station 762+36 Missouri River Basin				100	0	5	95	Brown	Silt--low plasticity, low dry strength, no acid reaction (average of materials) LL = 30 PI = 10	ML-C
Region 7 TF Section No. 3 Cambridge Canal, Station 1003+22 Missouri River Basin				100	0	0	100	Brown	Silt--low plasticity, low dry strength, no acid reaction (average of materials) LL = 30 PI = 10	ML-CL
Region 7 TF Section (curved) Cambridge Canal, Station 1240+00 Missouri River Basin				100	0	0	100	Brown	Silt--low plasticity, low dry strength, no acid reaction (average of materials) LL = 29 PI = 11	ML-CL
Region 7 TF Section No. 4 Franklin Pump Canal, Station 215+57 Missouri River Basin				200	0	0	100	Brown	Silt--low plasticity, low dry strength, no reaction (average of materials) LL = 35 PI = 10	ML
Region 7 TF Section No. 5 Superior Canal, Station 1053+72 Missouri River Basin				100	0	0	100	Brown	Silt--low plasticity, low dry strength, no acid reaction (average of materials) LL = 30 PI = 12	ML-CL
Region 7 TF Section No. 6 Franklin Canal, Station 947+24 Missouri River Basin				30	0	70	30	Brown	Sand--fine, silty, poorly graded, no reaction (average of materials) LL = 21 PI = 7	SM
Region 7 TF Section No. 7 Franklin Canal, Station 949+24 Missouri River Basin				50	0	50	50	Brown	Silt--very sandy, no reaction, low plasticity (average of materials) LL = 18 PI = 1	ML-SM

LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
VISUAL CLASSIFICATION OF SOIL
FROM TRACTIVE FORCE REACHES
REGION 7

TABLE 5

EARTH TESTING
VISUAL CLASSIFICATION OF SOIL SAMPLES

IDENTIFICATION				GRADATION (ESTIMATED)					DESCRIPTION AND SOIL CLASSIFICATION	
LABORATORY SAMPLE NO.	EXCAVATION NO.	LOCATION OR STATION	DEPTH IN FEET	MAXIMUM SIZE	GRAVEL (% PLUS #4)	SAND (% #4 TO #200)	SILT AND CLAY (% MINUS #200)	COLOR (WET STATE)	1. DESCRIPTIVE CLASSIFICATION 2. PARTICLE SIZE, SHAPE, AND GRADATION (UNIFORMLY, WELL, POORLY GRADED, ETC.) 3. CONSISTENCY, ELASTICITY, ETC. 4. REACTION TO SHAKING TEST, DRY STRENGTH, ETC.	GROUP SYMBOL
		Region 2 TF Section No. 1 Lateral M2A, Station 10+85 Klamath Project		1½"	15	60	25	Grey	Sand--coarse to medium, fairly well graded with clayey fines, (upper end) NP	SM
				#8	0	20	80	Grey	Diatomaceous earth--lean, with some medium sand, medium plasticity, medium reaction to acid, (lower end) LL = 70 PI = 27	MH
		Region 2 TF Section No. 2 Lateral M2A, Station 92+30 Klamath Project		#8	0	7	93	Grey	Diatomaceous earth--lean, medium plasticity, medium dry strength, reaction to acid, medium, (average of material) LL = 84 PI = 32	MH
		Region 2 TF Section No. 3 Lateral J1B, Station 6+50 Klamath Project		#8	0	26	74	Grey	Silt--sandy, nonplastic, medium reaction to acid (average of materials) NP	SM
		Region 2 TF Section No. 4 Lateral J13, Station 20+00 Klamath Project		1/4"	0	37	63	Grey	Silt--sandy and clayey, low plasticity, medium dry strength, no acid reaction, (average of materials) LL = 45 PI = 19	ML
		Region 2 TF Section No. 5 Friant-Kern Canal, Station 2065+00 Central Valley Project		1/4"	0	26	74	Brown	Clay--lean to fat, medium plasticity, acid reaction, medium dry strength (average of materials) LL = 52 PI = 29	CL-CH
		Region 2 TF Section No. 6 Friant-Kern Canal Station 2189+00 Central Valley Project		1/4"	0	45	55	Brown	Clay--lean, sandy, medium dry strength, medium plasticity, acid reaction (average of materials) LL = 27 PI = 11	CL
		Region 2 TF Section No. 7 Lateral 32.2, Madera Central Valley Project		#8	0	60	40	Brown	Silt--sandy, micaceous, low plasticity, medium dry strength, no reaction to acid, (average of materials) LL = 19 PI = 6	ML-SM
		Region 2 TF Section No. 8 Madera Canal, Station Central Valley Project		#8	0	65	35	Brown	Sand--medium to fine, clayey, poorly graded, no acid reaction, (average of materials) LL = 26 PI = 10	SC-CL
		Region 2 TF Section No. 9 Madera Canal, Station Central Valley Project		#8	0	60	40	Brown	Sand--coarse to medium, silty, poorly graded, no acid reaction, (average of materials) LL = 20 PI = 5	SM

LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
VISUAL CLASSIFICATION OF SOIL
FROM TRACTIVE FORCE REACHES
REGION 2

Summary of Laboratory Test Data

Sheet 1 of

Sample Identification			Gradation			Atterberg Limits		Compaction		Saturated Unconfined Compression		Erosion Test
Laboratory Sample No. 18F-	Location of Test Site	Sample Location	% Silt and Clay	% Sand	% Gravel	Liquid Limit	Plasticity Index	Maximum Density-pcf	Optimum Moisture-%	Moisture Content-%	Strength psi.	Wt. loss in % of initial dry wt. of 8" diam. sample 4" in length
382	Sta 263+00± – Bartley Canal Reg. 7 Tractive Force Section No. 1	℄ canal bottom										
383		Rt. slope @ w.s.										
384		Sediment-Rt. sl.	80.0	20.0	—	17.8	7.3					
385		Sediment-Lt. sl.	90.0	10.0	—	12.8	7.3					
386		℄ bottom 3" tube								24.1	4.6	
387		Rt. slope-3" tube									6.5	
388		Lt. slope-3" tube									1.0	
421		Sack	79.8	20.2	—	24.3	7.3	110.5	15.0			
389	Sta 762+36± – Bartley Canal Reg 7 Tractive Force Section No 2	Rt. slope @ w.s.										
390		℄ canal bottom										
391		Lt. slope @ w.s.										
392	Reg 7 Tractive Force Section No. 2	Sediment Lt. sl.	98.0	2.0	—	31.3	13.2					
393		Sediment ℄ sl.	97.0	3.0	—	31.3	13.2					
394		Sediment Rt. Sl.	96.0	4.0	—	31.3	13.2					
395		Rt. slope 3" tube								29.9	1.2	
396		℄ bottom 3" tube								37.5	0.5	
397		Lt. slope 3" tube								31.1	1.2	
422		Sack	95.0	5.0	—	30.0	10.2	..7.0	12.2			
406	Sta 1003+22± Cambridge Canal Reg 7 Tractive Force Section No 3	℄ canal bottom										
407		Rt. slope @ w.s.										
408		Lt. slope @ w.s.										
409		Sediment Lt. Sl.	99.4	0.6	—	32.8	.27					
410	Reg. 7 Tractive Force Section No 3	Sediment bottom	98.0	2.0	—	32.8	12.7					
411		Sediment Rt. Sl.	99.4	0.6	—	32.8	12.7					
412		℄ bottom 3" tube									3.7	
413		Rt. Slope 3" tube								34.6	0.8	
414		Lt. slope 3" tube									1.0	
424		sack	98.0	2.0	—	29.2	9.8					
398	Sta. 1240+00± - Cambridge Canal Reg 7 Tractive Force Section (curved)	Rt. Slope @ w.s.										
399		Lt. Slope @ w.s.										
400		℄ canal bottom										
401		Sediment bottom	86.0	14.0	—	28.1	8.5					
402		Sediment Lt. sl.	98.0	2.0	—	28.1	8.5					

Summary of Laboratory Test Data

Sample Identification			Gradation			Atterberg Limits		Compaction		Saturated Unconfined Compression		Erosion Test
Laboratory Sample No. 18F-	Location of Test Site	Sample Location	% Silt and Clay	% Sand	% Gravel	Liquid Limit	Plasticity Index	Maximum Density-pcf	Optimum Moisture-%	Moisture Content-%	Strength psi	Wt. loss in % of initial dry wt. of 8" diam. sample 4" in length
403	Reg 7 Tractive Force Section (curved)	Rt. slope 3" tube									0.9	
404		Lt. slope 3" tube									4.2	
405		℄ bottom 3" tube									4.5	
423		sack	92.0	8.0	—	28.8	10.9					
359	Sta 215+57± - Franklin Pump Canal. Reg. 7 Tractive Force Section No. 4	Lt. slope @ w.s.										
360		Rt. slope @ w.s.										
361		℄ canal bottom										
362		Sediment Rt. Sl.	98.0	2.0	—	37.5	12.7					
363		Sediment bottom	96.4	3.6	—	42.4	19.5					
364		Sediment-Lt. Sl.	95.0	5.0	—	42.4	19.5					
365		Lt. slope 3" tube								29.8	2.0	
366	Reg 7 Tractive Force Section No. 4	Rt. slope-3" tube								22.1	3.0	
367		℄ bottom-3" tube								29.6	1.6	
416		Sack	99.4	0.6	—	35.1	10.3					
350	Sta. 1053+72± Superior Canal - Reg. 7 Tractive Force Section No. 5	Rt. slope @ w.s.										
351		Lt. slope @ w.s.										
352		℄ canal bottom										
353		Sediment-Lt. Sl.	98.0	2.0	—	31.7	12.7					
354		Sediment-bottom	96.0	4.0	—	31.7	12.7					
355		Sediment-Rt. Sl.	99.6	0.4	—	31.7	12.7					
356		Rt. slope 3" tube								30.9	1.9	
357		Lt. slope 3" tube								30.6	2.2	
358	Reg. 7 Tractive Force Section No. 5	℄ bottom 3" tube									2.1	
415		Sack	97.0	3.0	—	30.0	11.9					
368	Sta 947+24± Franklin Canal - 1st Center Section - Reg. 7 Tractive Force Section No. 6	℄ canal bottom										
369		Lt. slope @ w.s.										
370		Rt. slope @ w.s.										
371		Sediment-bottom	61.0	39.0	—	22.2	7.9					
372		℄ bottom 3" tube									0.5	
373		Lt. slope 3" tube								14.5	1.9	
374		Rt. slope 3" tube									1.7	
417		sack	30.9	68.8	0.3		N.P.					
418		Sack	64.0	36.0	—	20.6	6.6					

SUMMARY OF LABORATORY TEST DATA

SHEET 1 of TABLE 6

Summary of Laboratory Test Data

Sample Identification			Gradation			Atterberg Limits		Compaction		Saturated Unconfined Compression		Erosion Test
Laboratory Sample No. 18F-	Location of Test Site	Sample Location	% Silt and Clay	% Sand	% Gravel	Liquid Limit	Plasticity Index	Maximum Density-pcf	Optimum Moisture-%	Moisture Content-%	Strength psi.	Wt loss in % of initial dry wt of 8" diam. Sample-4" in length
375	Sta 949+24± Franklin Canal-2nd Center Section-Reg. 7 Tractive Force Section No. 7	Lt. slope @ w.s.										
376		℄ canal bottom										
377		Rt slope @ w.s										
378		Sediment bottom	42.0	58.0	—	18.3	5.4					
379		Lt slope 3" tube									0.5	
380		℄ slope 3" tube								20.5	0.8	
381		Rt slope 3" tube								20.7	0.9	
419		sack	48.0	52.0	—	17.6	1.2					
420		sack	25.0	75.0	—		NP					
435	Sta 10+55 Lat M-2-A Tule Lake Div Klamath Proj - Reg 2 Tractive Force Section No 1	Rt slope @ w.s										
436		Lt slope @ w.s										
437		sediment bottom	16.9	50.6	32.5	NP						
438		Rt slope 3" tube								65.2	1.6	
439		Lt slope 3" tube										
482		sack lower end	22.2	62.6	15.2	NP						
483		sack upper end	74.2	25.0	0.8	70.3	27.0					
440	Sta 92+30 Lat M-2-A Tule Lake Div Klamath Proj Reg 2 Tractive Force Section No 2	Rt slope @ w.s										
441		Lt slope @ w.s.										
442		Rt slope 3" tube								82.9	2.7	
443		Lt slope 3" tube								68.5	3.9	
484	Reg 2 Tractive Force Section No 2	sack upper end	92.0	8.0	—	84.0	32.4	64.5	46.0			
485		sack lower end	94.2	5.8	—	84.0	32.4	64.5	46.0			
444	Sta 6+50 Lat J-1-B Tule Lake Div Klamath Proj Reg 2 Tractive Force Section No 3	Lt. slope @ w.s										
445		℄ canal bottom										
446		Rt slope @ w.s										
447		Lt slope 3" tube								26.1	1.6	
448		℄ bottom 3" tube								29.3	1.6	
449		Rt slope 3" tube								21.4	1.7	
488		sack upper end	24.0	75.3	0.7		NP					
487		sack lower end	28.2	71.1	0.7		NP					
486		sack center	21.4	78.3	0.3		NP					

Summary of Laboratory Test Data

Sample Identification			Gradation			Atterberg Limits		Compaction		Saturated Unconfined Compression		Erosion Test
Laboratory Sample No. 18F-	Location of Test Site	Sample Location	% Silt and Clay	% Sand	% Gravel	Liquid Limit	Plasticity Index	Maximum Density-pcf	Optimum Moisture-%	Moisture Content-%	Strength psi.	Wt loss in % of initial dry wt of 8" diam. Sample-4" in length
450	Sta. 20+00 Lat J-13 Tule Lake Div-Klamath Proj - Reg 2 Tractive Force Section No. 4	Lt. slope @ w.s										
451		Rt. slope @ w.s.										
452		℄ canal bottom										
453		Lt slope 3" tube								44.3	2.9	
454		Rt slope 3" tube								43.4	2.6	
455		℄ bottom 3" tube								60.4	2.3	
489		sack-upper end	52.0	48.0	—	45.0	19.5					
490		sack-lower end	71.0	29.0	—	45.0	19.5					
491		sack-℄	67.0	33.0	—	45.0	19.5					
456	Sta 2065+00 Friant-Kern Canal-Reg 2 Tractive Force Section No. 5	Lt slope @ w.s										
457		Rt. slope @ w.s.										
458	Reg. 2 Tractive Force Section No. 5	Rt slope 3" tube								22.6	3.2	
459		Lt. slope 3" tube								29.1	3.8	
492		sack-center	73.5	25.8	0.7	52.4	29.3	101.1	22.3			
460	Sta 2189+00-Friant-Kern Canal-Reg 2 Tractive Force Section No. 6	Lt slope @ w.s										
461		Rt slope @ w.s.										
462		Rt slope @ w.s.										
463		Lt slope 3" tube								19.4	5.8	
464		Lt slope 3" tube								18.2	5.8	
465		Rt slope 3" tube								19.0	4.7	
493		sack Lt upper end	55.4	44.6	—	26.1	10.1	116.1	14.4			
494		sack Rt lower end	55.0	44.2	0.8	26.7	10.1	116.1	14.4			
495		sack center	53.0	47.0	—	26.7	10.1	116.1	14.4			
466	Sta 455+40 Lat 32.2 Madera Dist Syst - Reg 2 Tractive Force Section No. 7	Lt slope @ w.s										
467		Lt slope @ w.s										
468		sediment Rt. St.										
469		Lt slope 3" tube								13.5	5.7	
470		Rt slope 3" tube								10.5	7.6	
471		Sediment 3" tube Rt St.								25.7	3.7	
496		sack-upper end	41.6	56.6	1.8	18.6	6.5	117.4	9.5			
497		sack lower end	45.0	55.0	—	19.6	6.5	117.4	9.5			
498		sack center	35.8	63.6	0.6	18.6	6.5	117.4	9.5			
472	Sta 645+00 Madera Canal-Reg. 2 Tractive Force Section No 8	Rt slope @ w.s.										
473		Lt slope @ w.s										

Summary of Laboratory Test Data

Sample Identification			Gradation			Atterberg Limits		Compaction		Saturated Unconfined Compression		Erosion Test
Laboratory Sample No. IBF-	Location of Test Site	Sample Location	% Silt and Clay	% Sand	% Gravel	Liquid Limit	Plasticity Index	Maximum Density-pcf	Optimum Moisture-%	Moisture Content-%	Strength psi.	Wt. loss in % of initial dry wt. of 8" diam. sample-4" in length
474	Reg. 2 Tractive Force Section No. 8	Rt. slope-3" tube								5.5	0.9	
475		Lt. slope-3" tube										
499		sack-upper end	31.2	68.8	—	25.5	10.3					
500		sack-lower end	32.8	65.4	1.8	25.5	10.3					
501		sack-center	40.3	59.4	0.3	25.5	10.3					
476	Sta. 645+00 Madera Canal-Reg. 2 Tractive Force Section No. 9	Rt. slope @ w.s.										
477		Lt. slope @ w.s.										
478		Lt. slope @ w.s.										
479		Rt. slope-3" tube										
480		Lt. slope-3" tube								15.6	1.3	
481		Lt. slope-3" tube								5.1	1.0	
502	Reg. 2 Tractive Force Section No. 9	sack-center	41.8	57.6	0.6	19.8	5.2					
503		sack-center	36.9	61.7	1.4	19.8	5.2					
504		sack-center	42.7	56.5	0.8	19.8	5.2					

SHEET 3 of TABLE 6

TABLE

SUMMARY OF UNCONFINED COMPRESSION TEST RESULTS

Sheet of

Sample Identification: Laboratory Sample No.	Sample Identification: Excavation No.	Sample Identification: Depth or Elevation (feet)	Specific Gravity	Specimen No.	Specimen Data, Initial: Dry Density (pcf)	Specimen Data, Initial: Moisture Content (%)	Specimen Data, Initial: Degree of Saturation (%)	Specimen Data, Final: Dry Density (pcf)	Specimen Data, Final: Moisture Content (%)	Specimen Data, Final: Degree of Saturation (%)	Test values at failure: Eff. Lateral Pressure (psi)	Test values at failure: Volume Change (%)	Test values at failure: Axial Strain (%)	Unconfined (Sat.) Compressive Strength (psi)	Cohesion (psi) (if applicable)
IBF-															
386		Reg 7-TF No 1			100.9	24.1		89.0	24.1		0.0	+13.4	5.6	4.6	
387		" " "			100.6			100.5			0.0	+0.1	6.4	6.5	
388		" " "			111.4			111.9			0.0	-0.4	0.4	1.0	
395		Reg 7 TF No 2			86.6	29.9		81.2	29.9		0.0	+6.7	3.6	1.2	
396		" " "			87.8	37.5		73.1	37.5		0.0	+20.2	3.8	0.5	
397		" " "			90.7	31.1		86.5	31.1		0.0	+4.9	5.2	1.2	
403		Reg 7 curve section			95.8			95.9			0.0	-1.5	0.6	0.9	
404		" " "			87.4			87.2			0.0	+2.2	9.0	4.2	
405		" " "			91.6	31.4		87.9			0.0	+4.1	4.8	1.5	
412		Reg 7-TF No 3			85.6			85.7			0.0	-0.1	7.2	3.7	
413		Reg 7-TF No 3			89.5	34.6		82.1	34.6		0.0	+9.0	4.8	0.8	
414		" " "			81.8			81.8			0.0	0	0	1.0	
365		Reg 7-TF No 4			86.9	29.8		84.3	29.8		0.0	+3.2	3.6	2.0	
366		" " "			87.7	22.1		85.0	22.1		0.0	+0.3	1.8	3.0	
367		" " "			92.2	29.6		85.6	29.6		0.0	+7.5	1.8	1.6	
356		Reg 7-TF No 5			95.6	30.9		87.8	30.9		0.0	+8.9	5.5	1.9	
357		" " "			96.1	30.6		91.8	30.6		0.0	+0.5	6.6	2.2	
358		" " "			82.9			82.9			0.0	0	0.1	2.1	
372		Reg. 7-TF No 6			102.4			102.4			0.0	0	0	0.5	
373		" " "			96.2	14.5		83.9	14.5		0.0	+12.2	1.3	1.9	
374		" " "			99.8			100.1			0.0	-0.3	0.5	1.7	
379		Reg 7 TF No 7			99.8			99.8			0.0	0	0	0.5	
380		" " "			113.9	20.5		102.9	20.5		0.0	+10.7	2.4	0.8	
381		" " "			96.1	20.7		95.8	20.7		0.0	+0.3	4.5	0.9	

TABLE

SUMMARY OF UNCONFINED COMPRESSION TEST RESULTS

Sheet of

Sample Identification: Laboratory Sample No.	Sample Identification: Excavation No.	Sample Identification: Depth or Elevation (feet)	Specific Gravity	Specimen No.	Specimen Data, Initial: Dry Density (pcf)	Specimen Data, Initial: Moisture Content (%)	Specimen Data, Initial: Degree of Saturation (%)	Specimen Data, Final: Dry Density (pcf)	Specimen Data, Final: Moisture Content (%)	Specimen Data, Final: Degree of Saturation (%)	Test values at failure: Eff. Lateral Pressure (psi)	Test values at failure: Volume Change (%)	Test values at failure: Axial Strain (%)	Unconfined (Sat.) Compressive Strength (psi)	Cohesion (psi) (if applicable)
IBF-															
438		Reg 2-TF No 1			60.0	65.2		56.9	65.2		0.0	+5.5	3.6	1.6	
442		Reg 2-TF No 2			49.8	82.9		49.8	82.9		0.0	0	6.6	2.7	
443		" " "			58.0	68.5		53.2	68.5		0.0	+9.0	3.6	3.9	
447		Reg 2-TF No 3			88.3	26.1		84.8	26.1		0.0	+4.2	3.2	1.6	
448		" " "			89.5	29.3		82.9	29.3		0.0	+8.0	1.4	1.6	
449		" " "			100.5	21.4		93.5	21.4		0.0	+7.5	1.3	1.7	
453		Reg 2 TF No 4			72.9	44.3		69.1	44.3		0.0	+3.6	6.8	2.9	
454		" " "			75.0	43.4		67.9	43.4		0.0	+10.5	3.6	2.6	
455		" " "			95.0	60.4		89.6	60.4		0.0	+6.0	4.3	2.3	
458		Reg 2 TF No 5			111.0	22.6		99.1	22.6		0.0	+12.0	3.0	3.2	
459		" " "			97.0	29.1		88.2	29.1		0.0	+11.0	0	3.8	
463		Reg 2-TF No 6			113.0	19.4		106.1	19.4		0.0	+8.5	4.5	5.8	
464		" " "			115.5	18.2		107.9	18.2		0.0	+7.0	3.0	5.8	
465		" " "			117.0	19.0		105.9	19.0		0.0	+10.5	5.2	4.7	
469		Reg 2-TF No 7			129.0	13.5		118.9	13.5		0.0	+8.5	2.4	5.7	
470		" " "			124.8	10.5		121.9	10.5		0.0	+2.3	4.3	7.6	
471		" " "			94.0	25.7		87.4	25.7		0.0	+7.5	7.5	3.7	
476		Reg 2-TF No 8			120.5	5.5		114.2	5.5		0.0	+5.5	3.4	0.9	
480		Reg 2-TF No 9			118.5	15.6		106.8	15.6		0.0	+3.7	6.0	1.3	
481		" " "			113.0	5.1		105.1	5.1		0.0	+7.5	1.8	1.0	

SUMMARY OF UNCONFINED COMPRESSION TEST RESULTS

TABLE 7

Table 8

Canal	Station at center of reach	Reach No.	Q_d Design discharge cfs	Q_m Max sustained discharge from past years' performance cfs	Q_t Discharge at time of test cfs	Q_t/Q_d	Area ft^2	Average velocity ft/sec	Hydraulic radius ft	Slope of water surface ft/ft x 10^{-4}	Manning "n" value observed	Manning "n" value used in design	τ_{a_1} = WRS lb/ft^2	τ_{a_2}, From $\tau_o = C(V_2-V_1)^2$ lb/ft^2	τ_{a_2}/τ_{a_1}
Bartley	263+00	1	130	97	72.6	0.56	53.2	1.36	2.23	3.02	0.0220	0.0225	0.0184	0.0174	0.95
Bartley	762+36	2	75	52	36.1	0.48	24.7	1.46	1.56	1.32	0.0197	0.025	0.0202	0.0134	0.66
Cambridge	1003+22	3	210	167	132.5	0.63	90.4	1.47	3.06	2.08	0.0205	0.0225	0.0176	0.0184	1.04
Franklin Pump	215+57	4	30	13.7	18.0	0.60	13.7	1.31	1.19	0.926	0.0216	0.025	0.0214	0.0282	1.31
Superior	1053+72	5	75	49.7	65.3	0.87	37.0	1.76	1.99	2.88	0.0196	0.025	0.0270	0.0121	0.45
Franklin	947+24	6 & 7	180	62.2	99.1	0.55	45.8	2.16	1.98	2.17	0.0188	0.0225	0.0370	0.0202	0.55
Cambridge	1240+00	Curved 1	175	102	54.6	0.31	31.4	1.74	1.68	1.34	0.0170	0.0225	0.0141	0.0214	1.52
Cambridge	1243+00	Curved 2	175	102	54.6	0.31	40.7	1.34	1.95	1.34	0.0170	0.0225	0.0164	0.0064	0.39

LOWER-COST CANAL LINING PROGRAM
TRACTIVE FORCE FIELD STUDY
REGION 7
HYDRAULIC DATA

Table 9

Canal or Lateral	Station or mile at center of reach	Reach No.	Q_d Design discharge cfs	Q_m Max sustained discharge from past years' performance cfs	Q_t Discharge at time of test cfs	Q_t/Q_d	Area ft^2	Average velocity ft/sec	Hydraulic radius ft	Slope of water surface ft/ft x 10^{-4}	Manning "n" value observed	Manning "n" value used in design	τ_{a_1} = WRS lb/ft^2	τ_{a_2}, From $\tau_o = C(V_2-V_1)^2$ lb/ft^2	τ_{a_2}/τ_{a_1}
Lateral M-2-A, Klamath	6+85	1	69	40.4	20.2	0.29	21.7	0.93	1.35	10.6	0.063	0.025	0.089	0.031	0.35
Lateral M-2-A, Klamath	92+30	2	24.4	4.35	5.6	0.23	12.1	0.46	1.09	1.09	0.036	0.025	0.0074	0.0079	1.06
Lateral J-1-B, Klamath	6+50	3		29	18.1	--	30.0	0.60	1.73	12.95	0.128	--	0.140	0.014	0.10
Lateral J-13, Klamath	15+00	4		36.2	27.4	--	40.0	0.68	1.97	0.65	0.028	--	0.0080	0.0073	0.91
Friant-Kern Canal	*37.49	5	5,000	2,560	2,910	0.58	1,206	2.42	10.9	0.73	0.026	0.020	0.049	0.031	0.63
Friant-Kern Canal	*39.82	6	5,000	2,560	2,620	0.52	1,123	2.35	10.7	0.60	0.024	0.020	0.040	0.038	0.95
Madera Lateral 32.2	455+40	7	182	50	59.1	0.32	33.6	1.76	1.76	6.41	0.031	0.0225	0.071	0.032	0.45
Madera Canal	*11.35	8	825	894	692	0.84	302	2.29	5.80	0.79	0.019	0.0225	0.029	0.031	1.06
Madera Canal	*31.50	9	625	505	488	0.78	209	2.33	4.58	2.78	0.029	0.0225	0.080	0.059	0.73

*Mile point.

LOWER-COST CANAL LINING PROGRAM
TRACTIVE FORCE FIELD STUDY
REGION 2
HYDRAULIC DATA

Table 10

Canal	Reach No.	Concentration ppm total suspended matter	Sediment concentration ppm retained on U.S. Standard No. 230 screen	Sediment concentration ppm retained on pan
Bartley	1	329	38	291
Bartley	2	337	25	312
Cambridge	3	468	63	405
Franklin Pump	4	62	12	50
Superior	5	326	21	305
Franklin	6&7	114	12	102
Cambridge	Curved	270	28	242
Cambridge	Curved	270	28	242

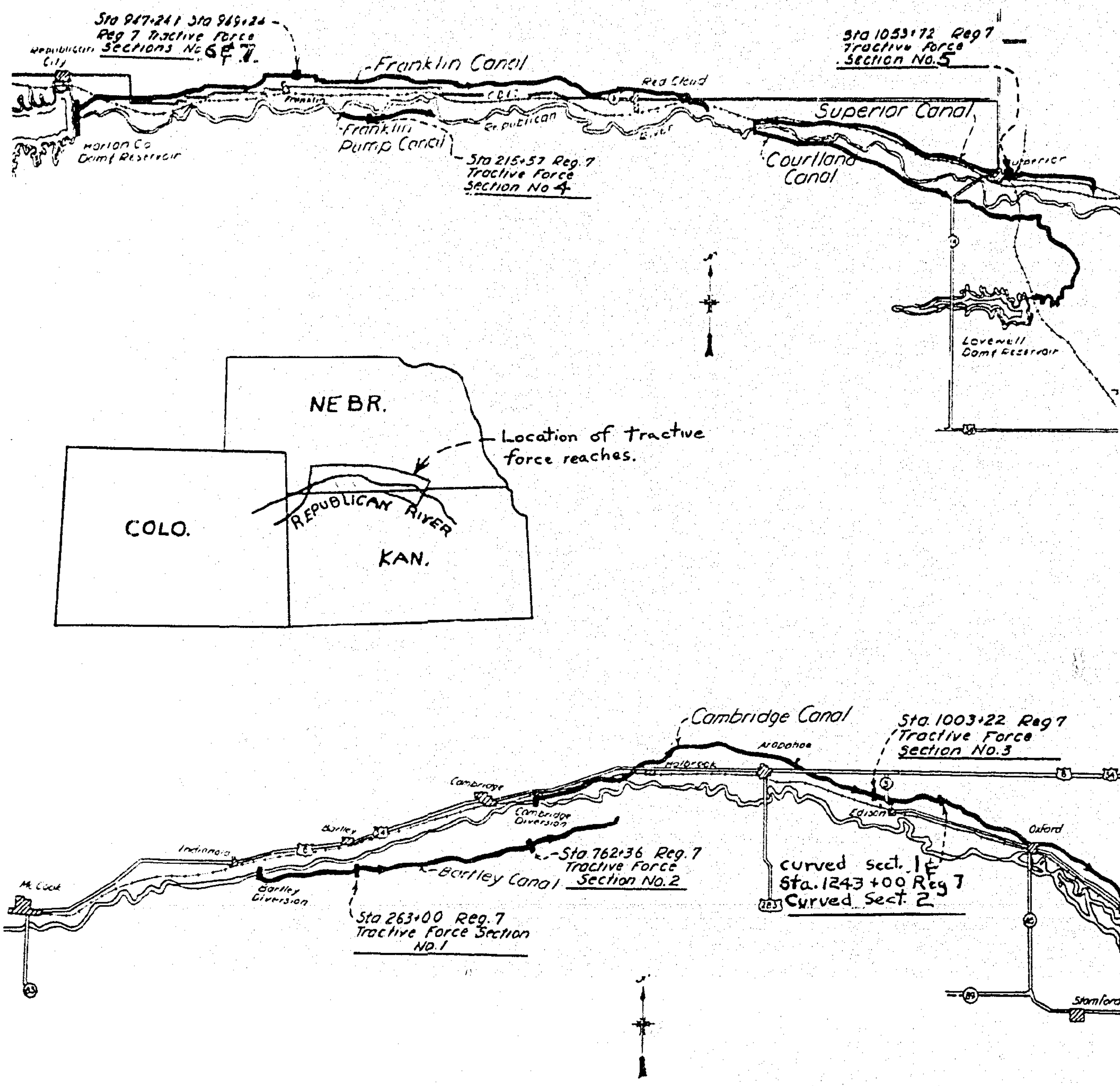
LOWER-COST CANAL LINING PROGRAM
TRACTIVE FORCE FIELD STUDY
REGION 7
SUSPENDED SEDIMENT ANALYSIS

Table 11

Canal or lateral	Reach No.	Concentration ppm total suspended matter	Concentration ppm organic matter	Total concentration ppm mineral matter	Mineral sediment concentration ppm retained on U.S. No. 230 screen	Mineral sediment concentration ppm retained on pan	Dissolved solids ppm
Lateral M-2-A, Klamath	1	26	6.2	19.8	5.1	14.7	282
Lateral M-2-A, Klamath	2	12.2	4.4	7.8	5.6	2.2	315
Lateral J-1-B, Klamath	3	15.5	5.0	10.5	5.3	5.2	239
Lateral J-13, Klamath	4	2.7	1.5	1.2	1.0	0.2	316
Friant-Kern Canal	5	11.6	4.8	6.8	5.3	1.5	22
Friant-Kern Canal	6	60.2	6.8	53.4	31.8	21.6	21
Lateral 32.2, Madera	7	3.5	1.3	2.2	1.6	0.6	24
Madera Canal	8	2.9	1.0	1.9	1.6	0.3	20
Madera Canal	9	23.3	2.4	20.9	16.6	4.3	23

LOWER-COST CANAL LINING PROGRAM
TRACTIVE FORCE FIELD STUDY
REGION 2
SUSPENDED SEDIMENT ANALYSIS

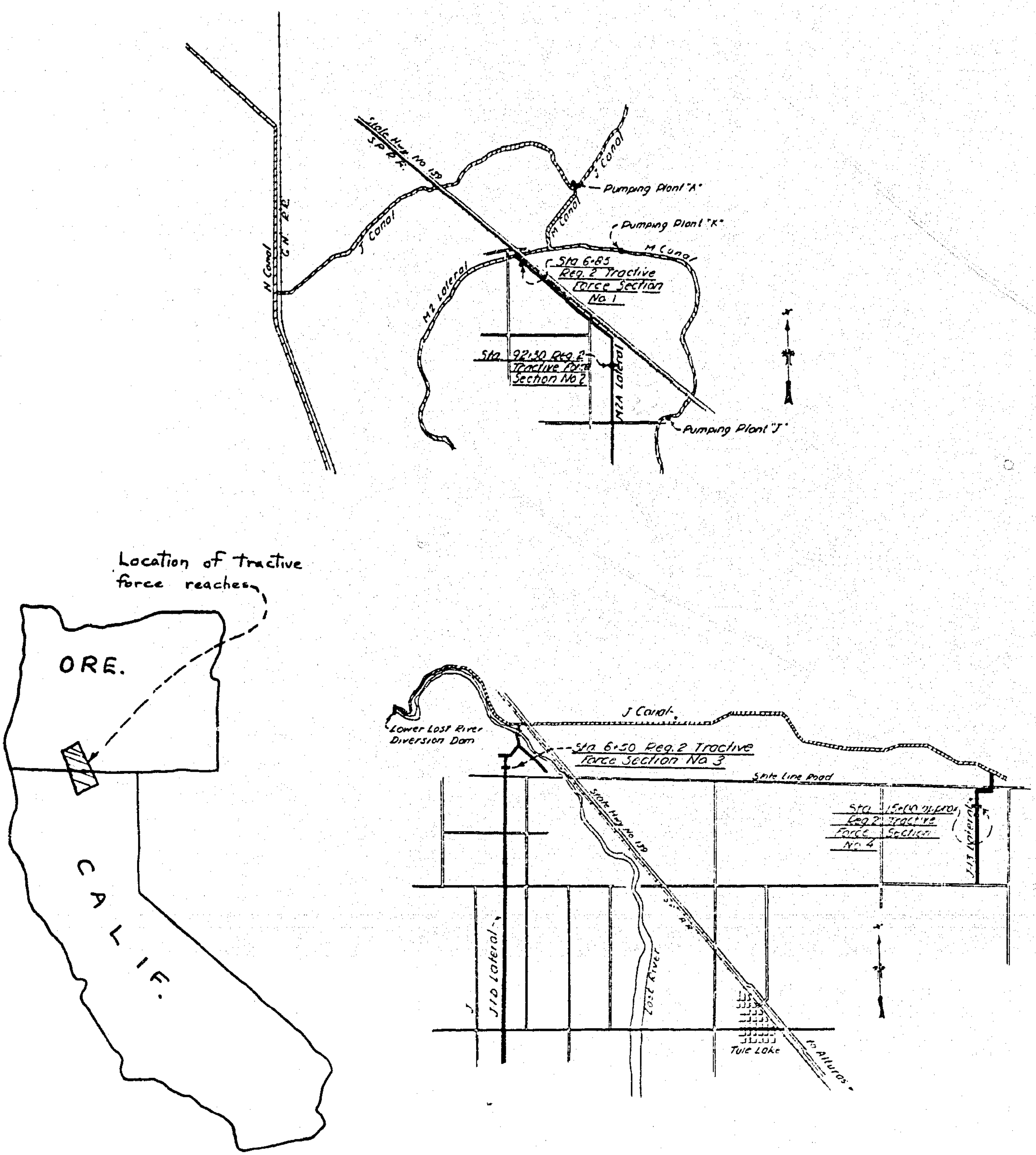
FIGURE 1



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
TEST REACHES REGION 7

55c

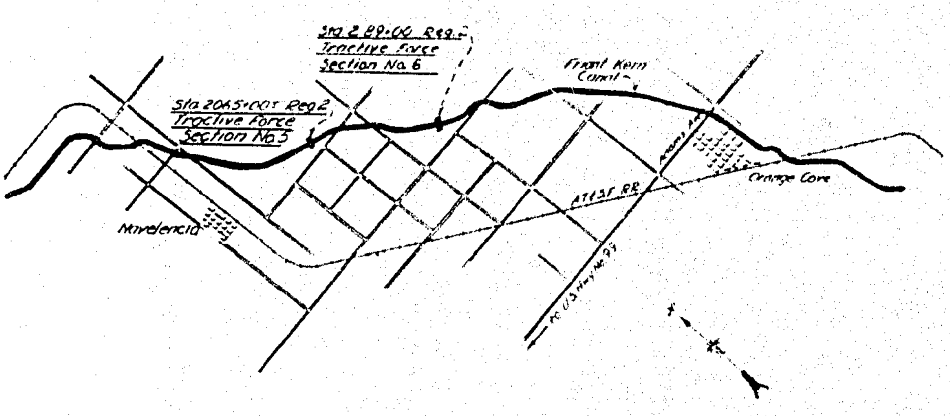
FIGURE 2

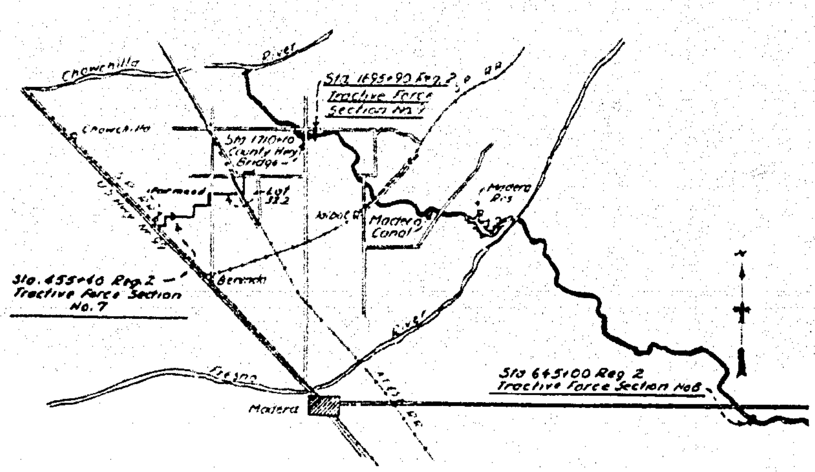


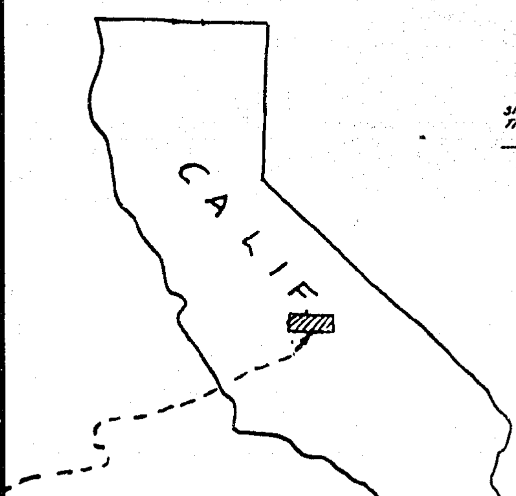
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
TEST REACHES REGION 2
2-4-57

550

FIGURE 3





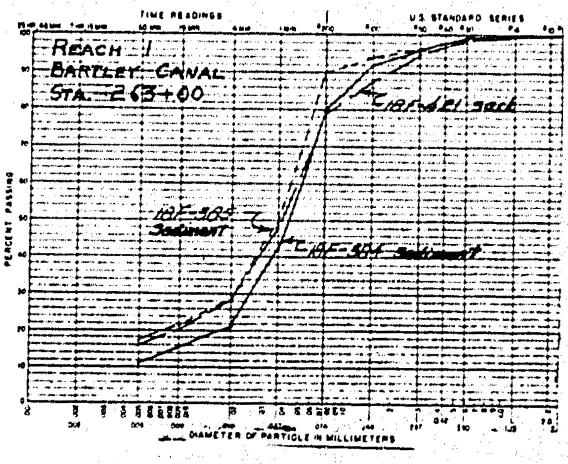


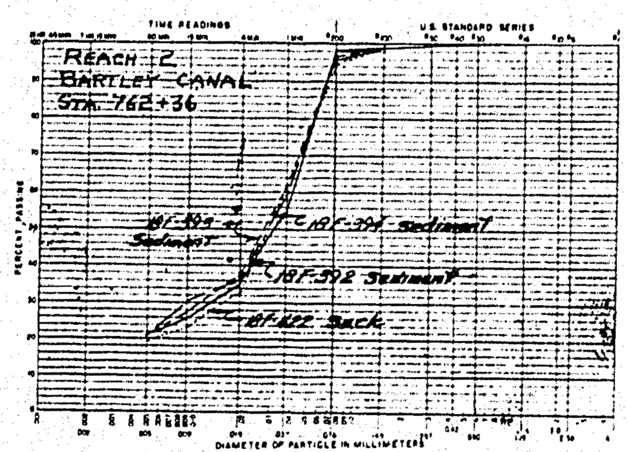
Location of tractive force reaches.

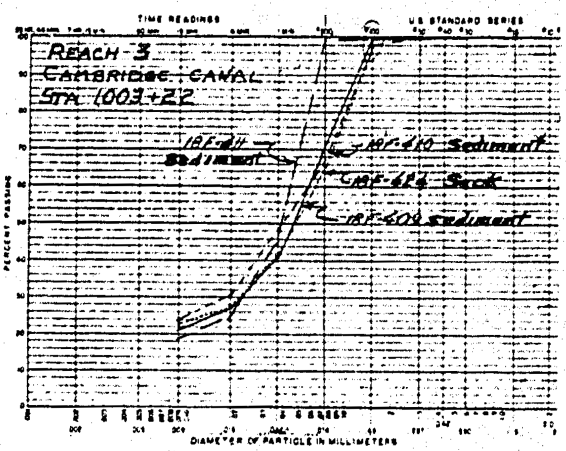
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
TEST REACHES REGION 2
2-4-57

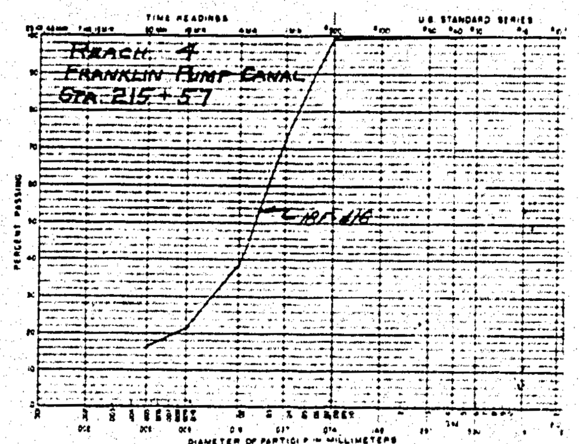
550

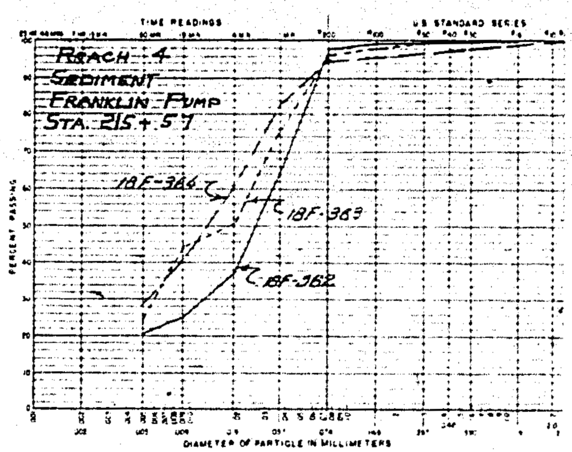
FIGURE 4







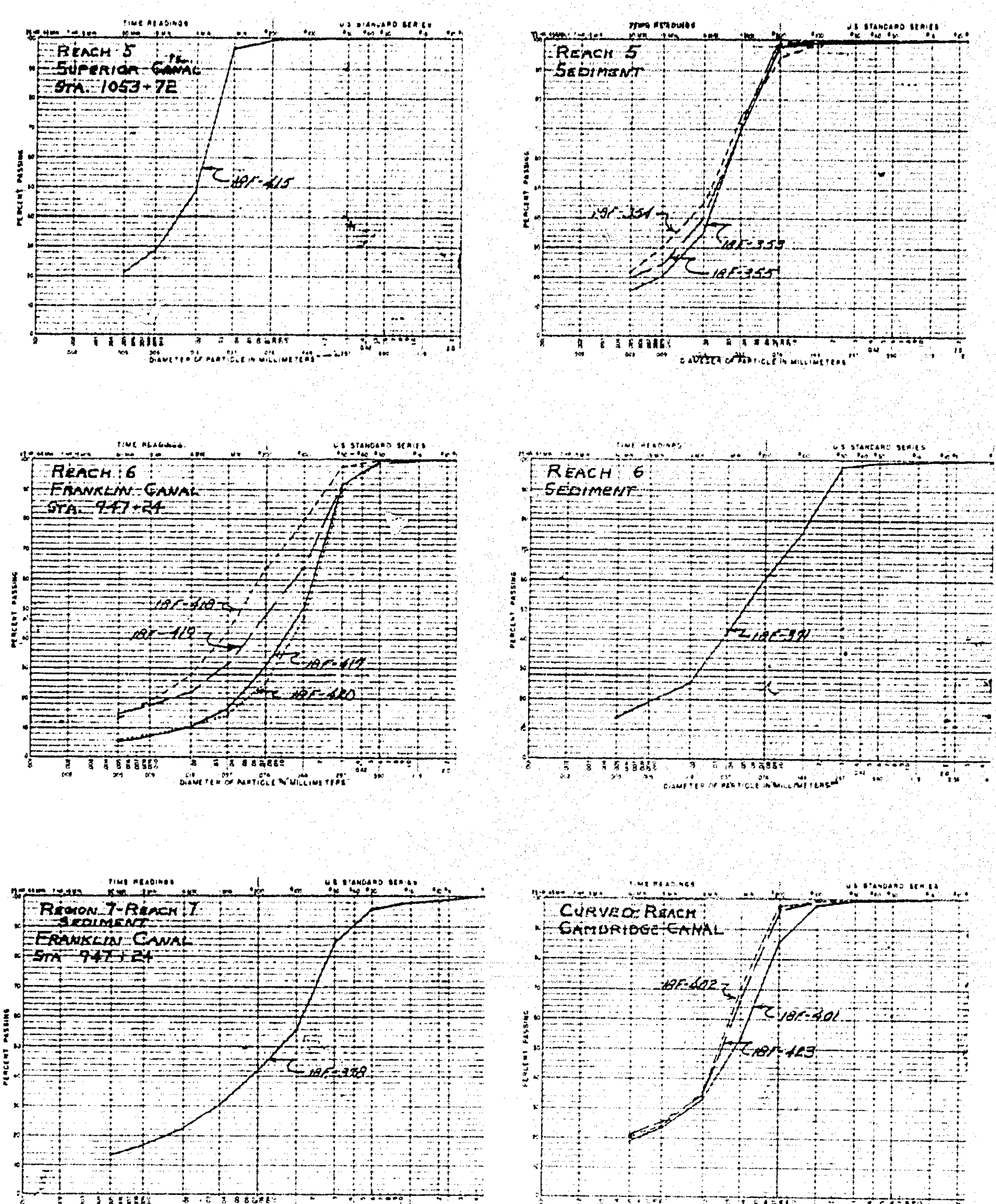




LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDIES

SOIL SIZE ANALYSES REACHES 1 TO 4
REGION 7

FIGURE 5

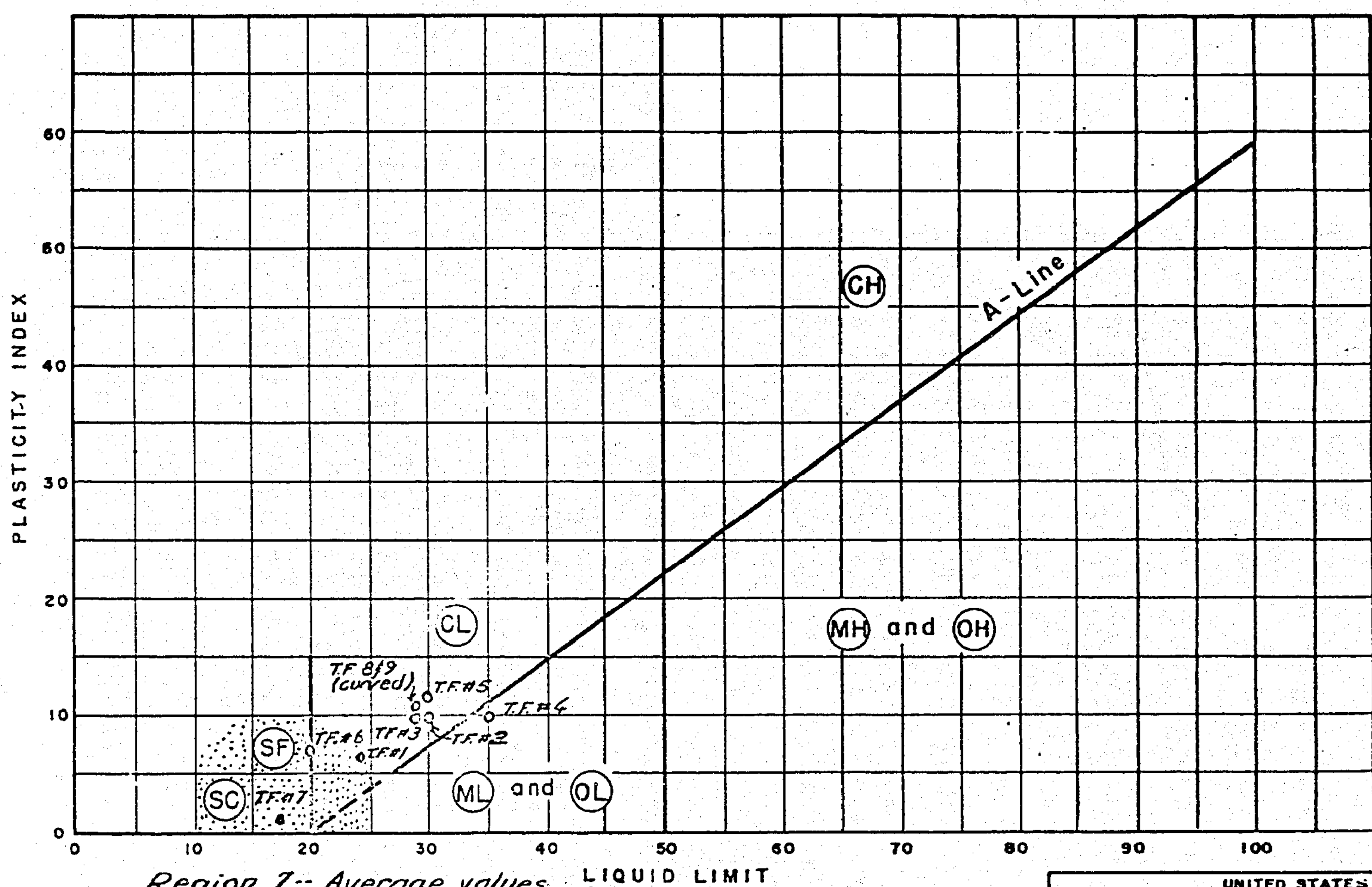


LOWER COST CANAL LINING

TRACTIVE FORCE FIELD STUDIES

SOIL SIZE ANALYSES REACHES 5 TO 7

REGION 7



Region 7-- Average values at each test reach.

UNITED STATES
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BUREAU OF RECLAMATION

PLASTICITY CHART FOR A.C. SYSTEM

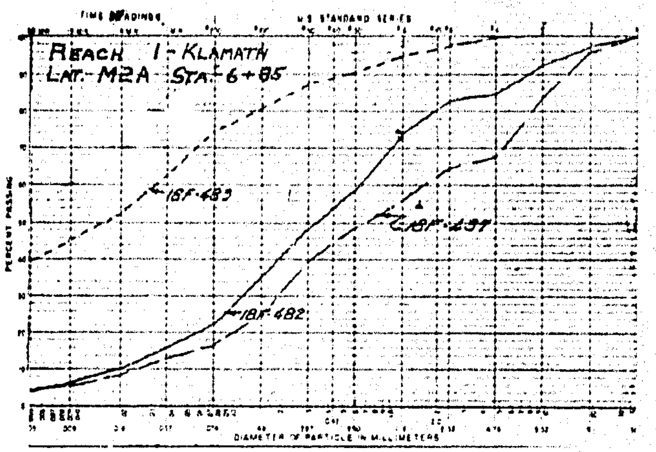
(After A. Casagrande)

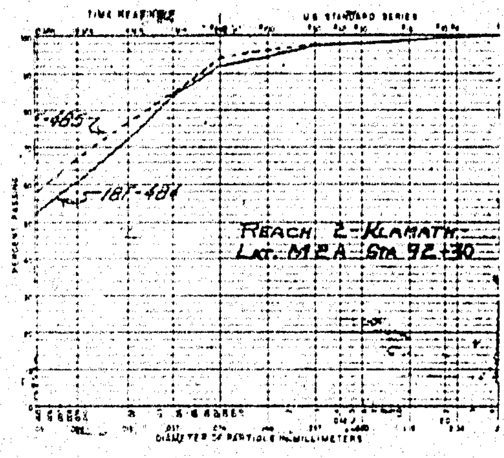
DRAWN	CHECKED	DATE

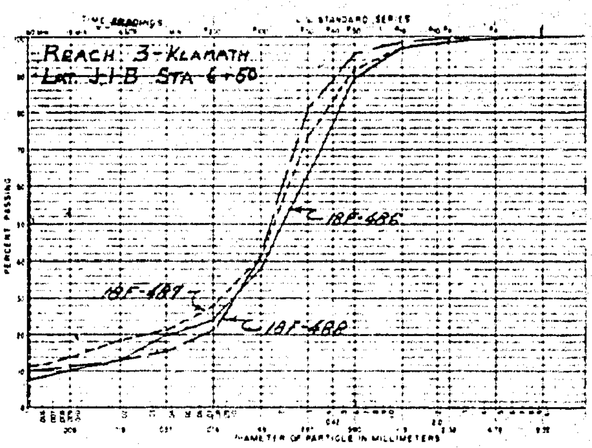
EM-127-49

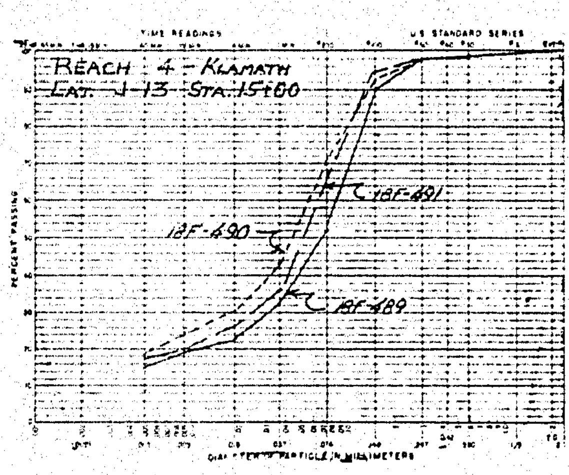
Figure 6

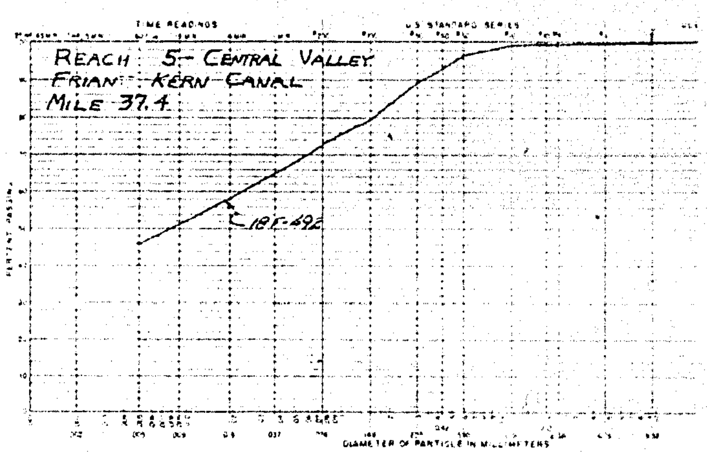
FIGURE 7







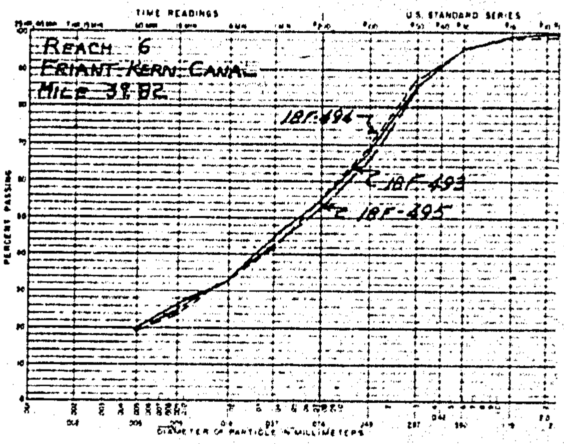


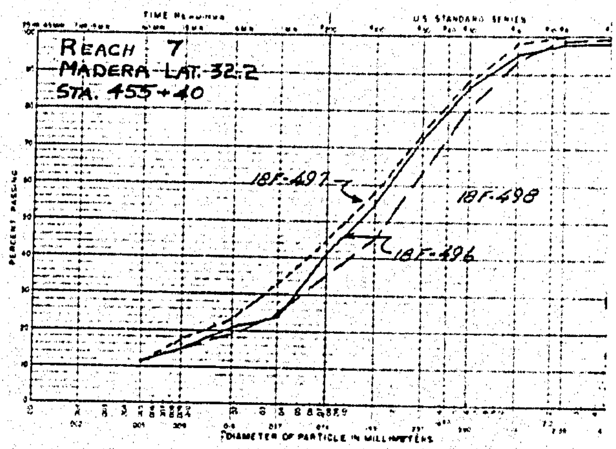


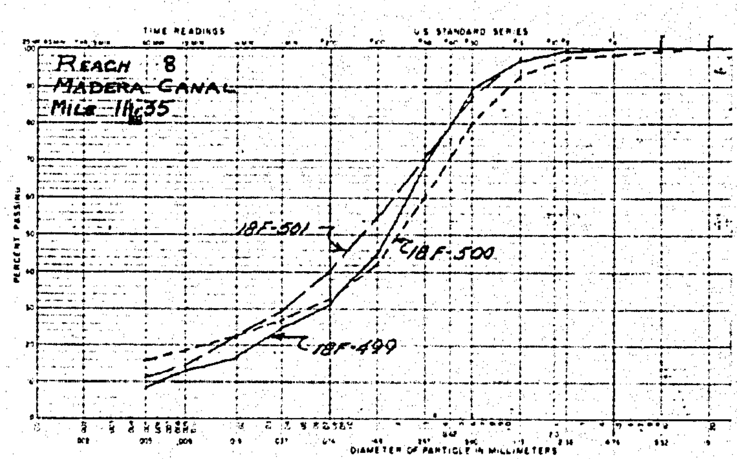
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDIES

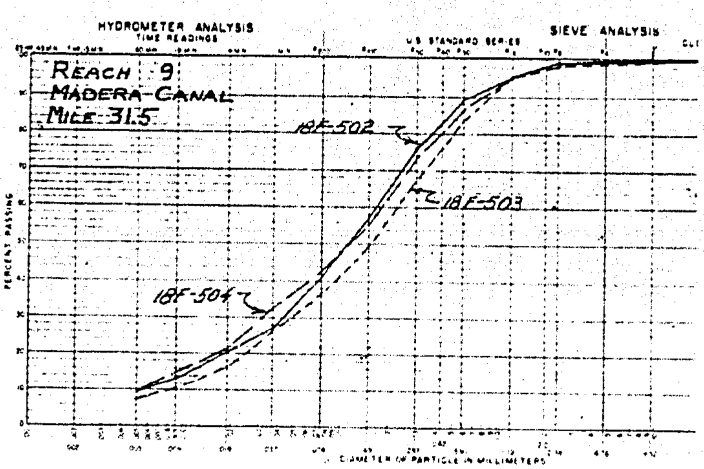
SOIL SIZE ANALYSES REACHES 1 TO 5
REGION 2

FIGURE 8





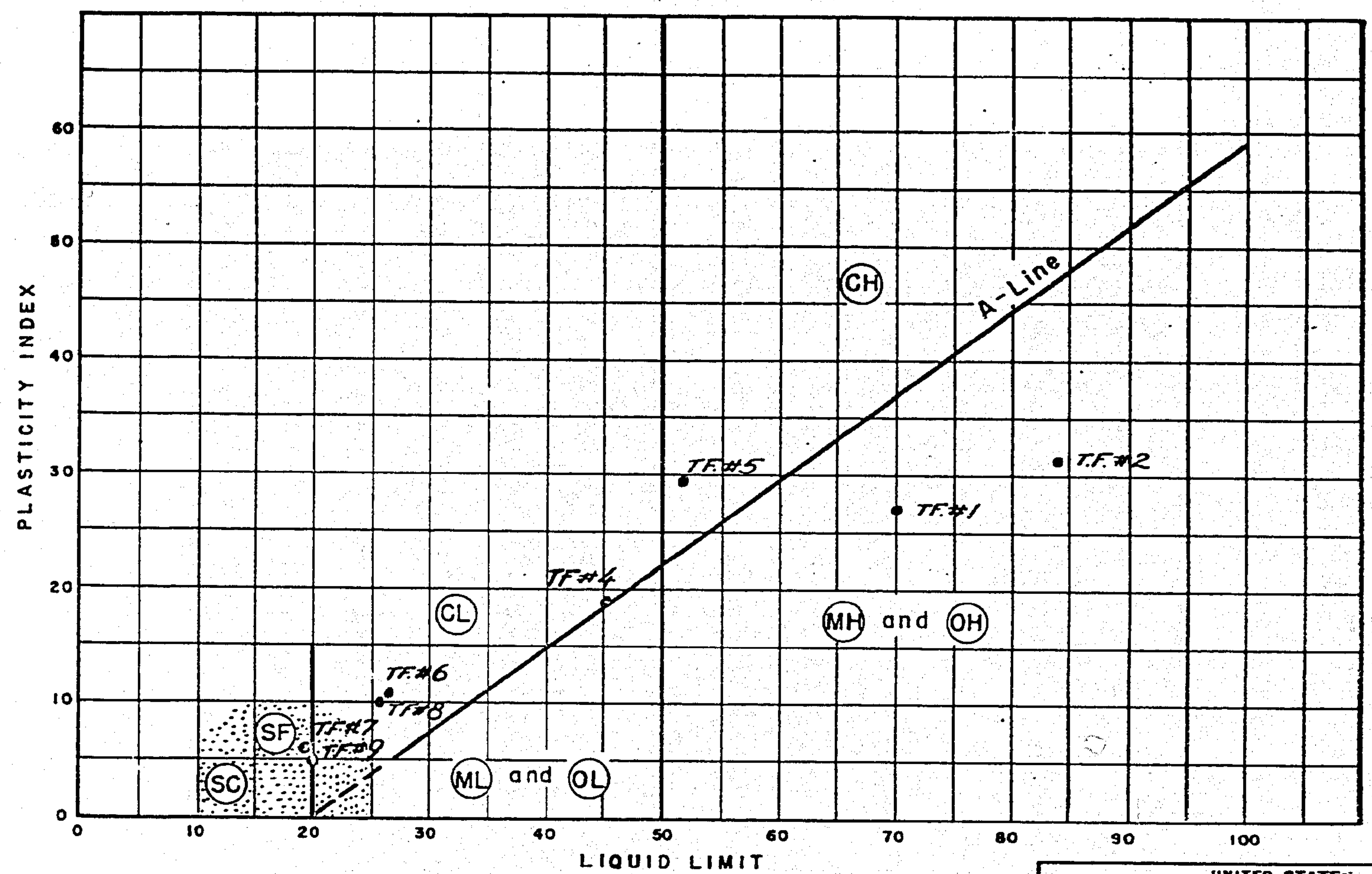




LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDIES

SOIL SIZE ANALYSES REACHES 6 TO 9
REGION 2

Figure 9



Region 2 -- Average values at each test reach

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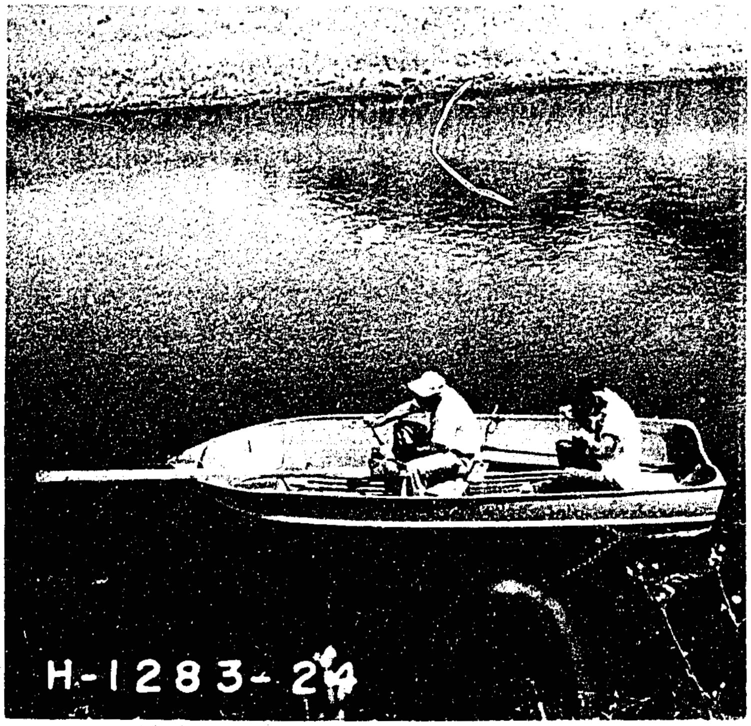
PLASTICITY CHART FOR A.C. SYSTEM
(After A. Casagrande)

DRAWN	CHECKED	DATE

EM-127-49

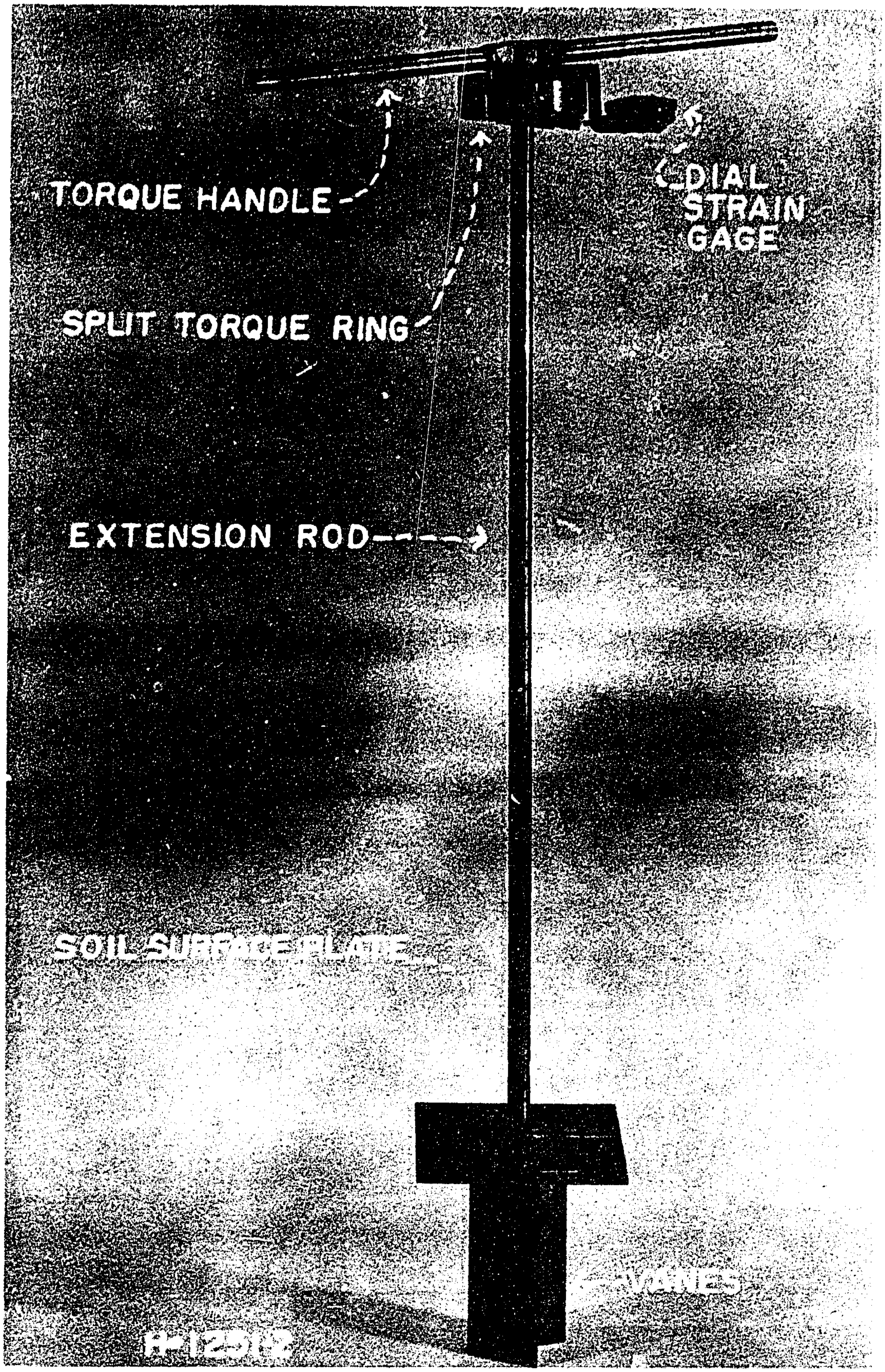
(a) VELOCITY MEASUREMENTS NEAR THE BOUNDARY BEING RECORDED WITH A PYGMY CURRENT METER



(b) VELOCITY MEASUREMENTS BEING RECORDED WITH A TYPE A CURRENT METER FROM A BOAT

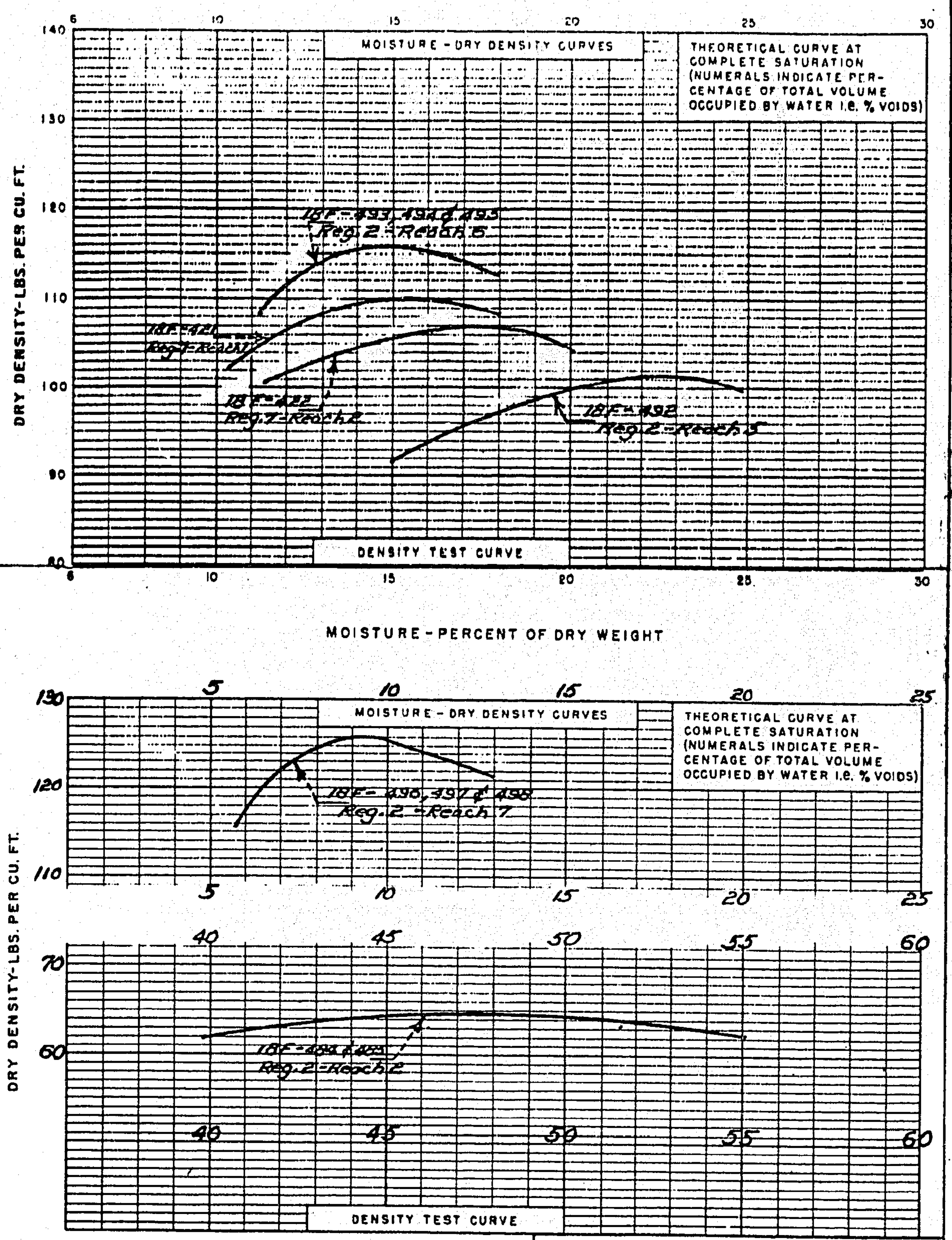
LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
OBTAINING HYDRAULIC DATA

FIGURE 11



LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
VANE SHEAR TESTER

FIGURE 12



COMPACTION	SOIL PROPERTIES
___ BLOWS PER LAYER	___ SPECIFIC GRAVITY
___ LAYERS	___ SOIL CLASSIFICATION
___ LB. HAMMER	___ % LARGER THAN TESTED
___ IN. DROP	___ MAX. STD. DRY DENSITY (P.C.F.)
___	___ OPT MOISTURE (%)
	___ PEN RES. AT OPT. MOIST. (PSI)

55C

REV. 9-17-46

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

COMPACTION TEST CURVES
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
REGIONS 2 & 7

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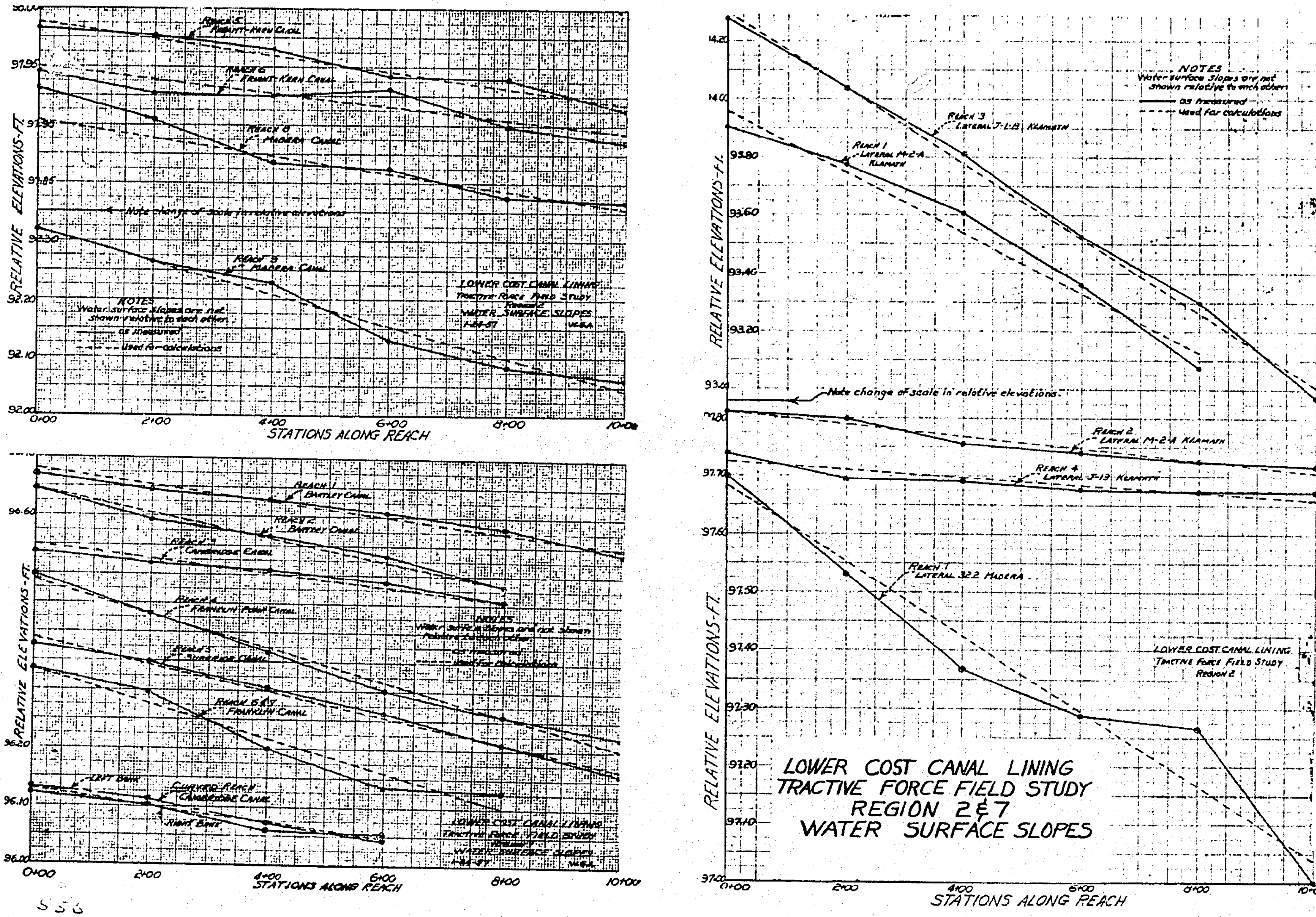
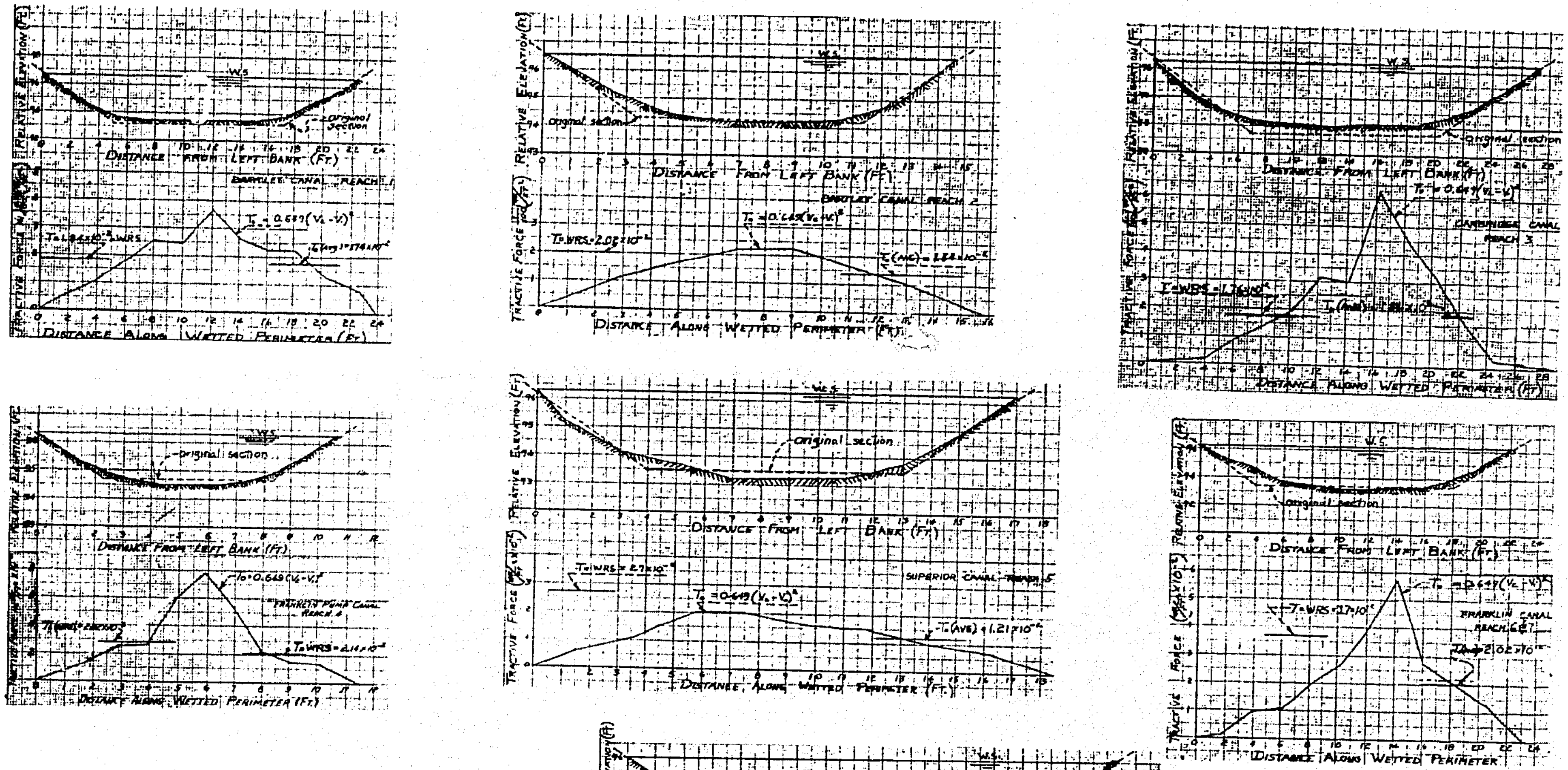
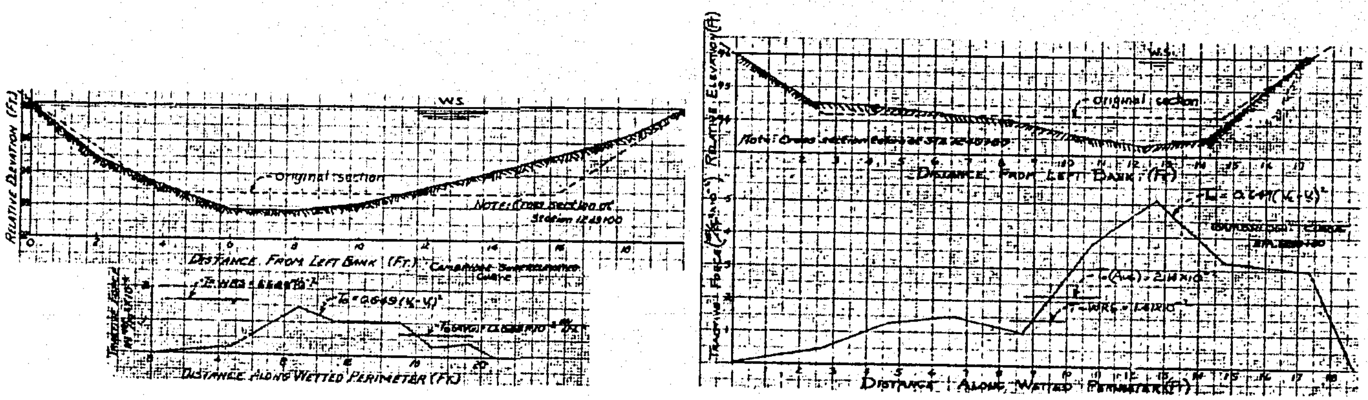
FIGURE No.



REACH 5 FRIANT-KERN CANAL
REACH 6 FRIANT-KERN CANAL
REACH 8 MADERA CANAL
REACH 9 MADERA CANAL
Note change of scale in relative elevations
NOTES
Water surface slopes are not shown relative to each other.
as measured
Used for calculations
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
WATER SURFACE SLOPES
RELATIVE ELEVATIONS-FT.
STATIONS ALONG REACH
REACH 1 BARTLEY CANAL
REACH 2 BARTLEY CANAL
REACH 4 FRANKLIN PUMP CANAL
REACH 6 & 7 FRANKLIN CANAL
CURVED REACH CAMBRIDGE CANAL
LEFT BANK
RIGHT BANK
REACH 3 LATERAL J-1-B KLAMATH
REACH 1 LATERAL M-2-A KLAMATH
REACH 2 LATERAL M-2-A KLAMATH
REACH 4 LATERAL J-13 KLAMATH
REACH 1 LATERAL 32.2 MADERA
Note change of scale in relative elevations.
NOTES
Water surface slopes are not shown relative to each other
as measured
Used for calculations
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
REGION 2
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
REGION 2 & 7
WATER SURFACE SLOPES

FIGURE 13





Note: All cross sections taken at middle of reach, except curved sections.

LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDIES

CROSS SECTIONS AND TRACTIVE FORCE DISTRIBUTIONS REGION 7

FIGURE 14

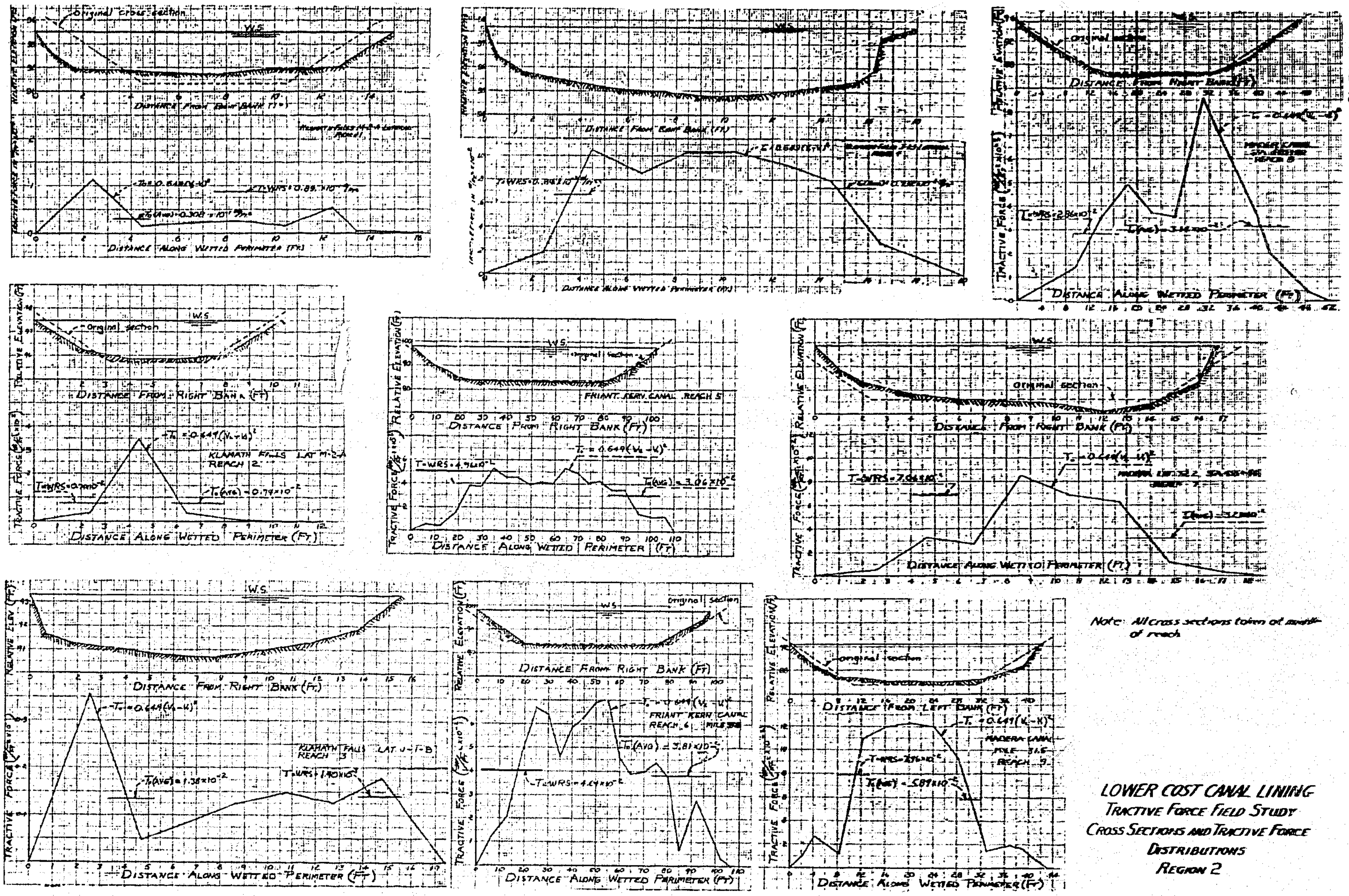


FIGURE 15

Note: All cross sections taken at middle of reach

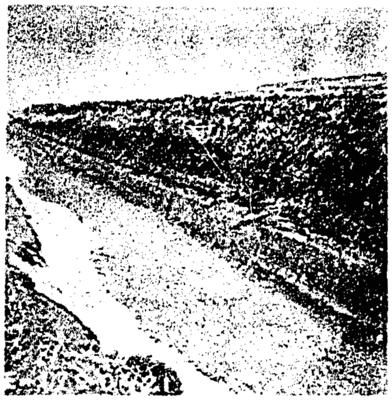
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
CROSS SECTIONS AND TRACTIVE FORCE DISTRIBUTIONS
REGION 2

FIGURE 16

REACH DRY

DISCHARGE 73 cfs

REACH 1
BARTLEY CANAL

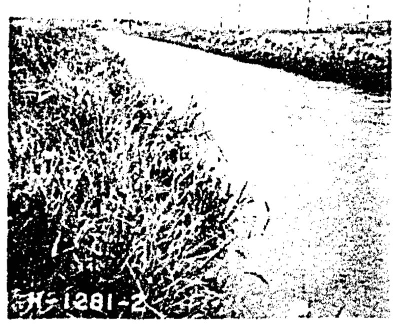


REACH DRY

DISCHARGE 36 cfs

REACH 2
BARTLEY CANAL

REACH DRY

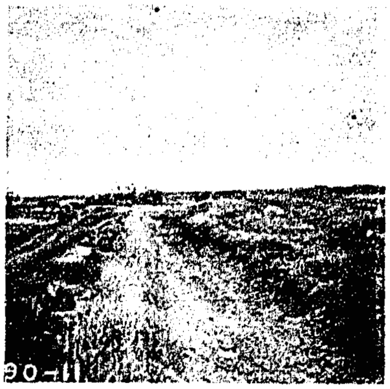


DISCHARGE 132 cfs

REACH 3
CAMBRIDGE CANAL

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
PHOTOGRAPHS OF REACHES 1 TO 3
REGION 7

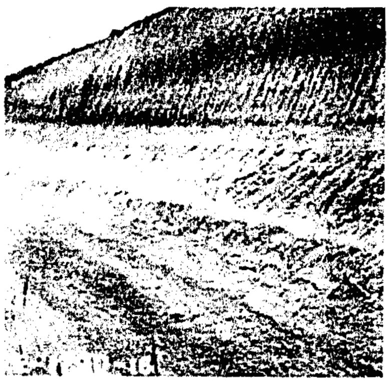
FIGURE 17



REACH DRY

DISCHARGE 18 cfs

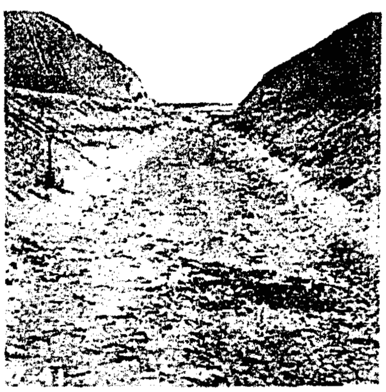
REACH 4
FRANKLIN PUMP CANAL



REACH DRY

DISCHARGE 65 cfs

REACH 5
SUPERIOR CANAL

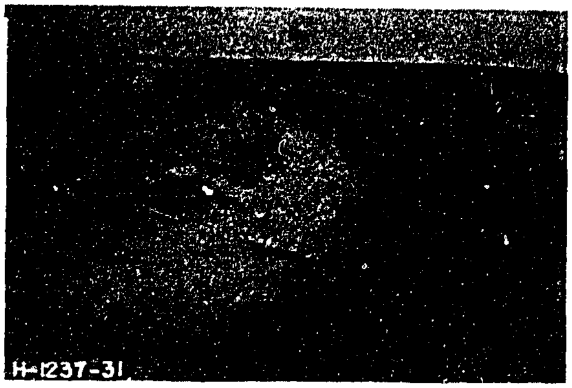


REACH DRY

DISCHARGE 99 cfs

REACHS 6 & 7
FRANKLIN CANAL

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
PHOTOGRAPHS OF REACHES 4 TO 6
REGION 7



REACH DRY

DISCHARGE 55 cfs

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
PHOTOGRAPHS OF CURVED REACHES
ON CAMBRIDGE CANAL
REGION 7

FIGURE 19

DISCHARGE 20 cfs

AQUAITIC WEED
GROWTH IN LATERAL

REACH 1
LATERAL M-2-A KLAMATH PROJECT

H-1241-3

REACH DRY

DISCHARGE 6 cfs

REACH 2
LATERAL M-2-A KLAMATH PROJECT

H-1241-6

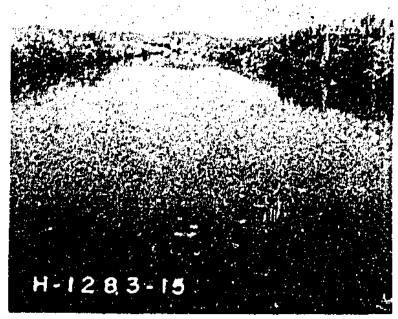
REACH DRY

DISCHARGE 18 cfs

REACH 3
LATERAL J-1-B KLAMATH PROJECT

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
PHOTOGRAPHS OF REACHES 1 TO 3
REGION 2

H-1241-8

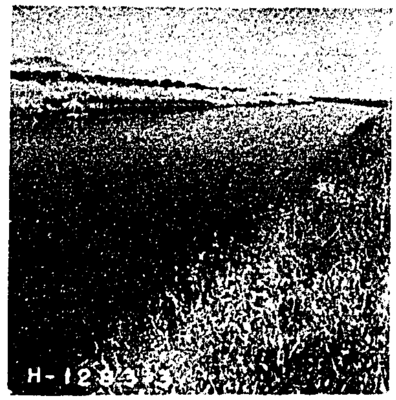


REACH DRY

DISCHARGE 27 cfs

REACH 4
LATERAL J-13 KLAMATH PROJECT

E-1792-3

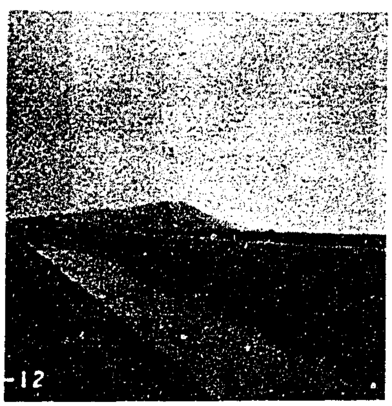


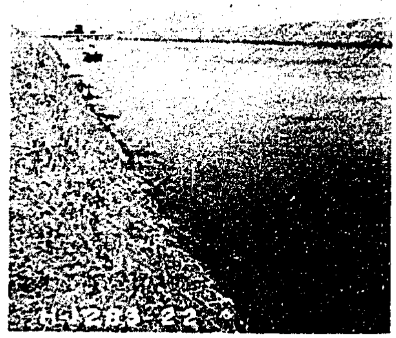
REACH DRY

DISCHARGE 2910 cfs

REACH 5
FRIANT KERN CANAL

E-1792-12





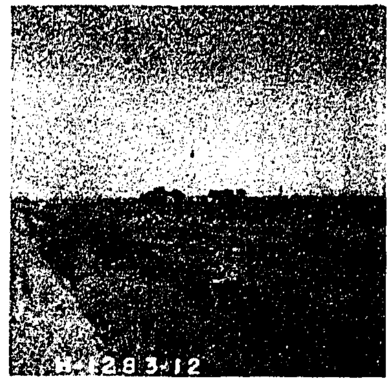
REACH DRY

DISCHARGE 2620 cfs

REACH 6
FRIANT KERN CANAL

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
PHOTOGRAPHS OF REACHES 4 TO 6
REGION 2

FIGURE 21

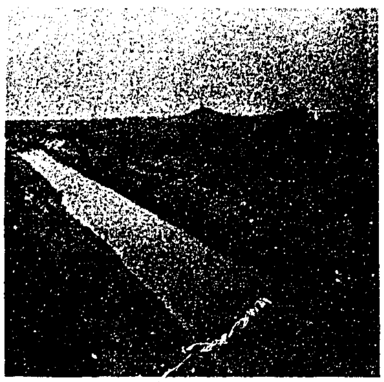


REACH DRY

DISCHARGE 55 cfs

REACH 7
MADERA LATERAL 32.2

E-1792-16

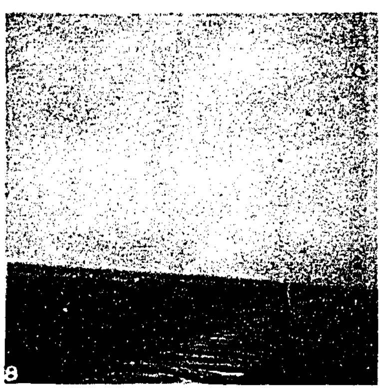


REACH DRY

DISCHARGE 692 cfs

REACH 8
MADERA CANAL

E-1792-18



REACH DRY

DISCHARGE 488 cfs

REACH 9
MADERA CANAL

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD STUDY
PHOTOGRAPHS OF REACHES 7 TO 9
REGION 2