UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION 2

FIREBAUGH DRAINAGE INVESTIGATION

DELTA-MENDOTA CANAL
CENTRAL VALLEY PROJECT - CALIFORNIA

REPORT

FEBRUARY 1953

DIVISION OF
OPERATION AND MAINTENANCE
SACRAMENTO, CALIFORNIA

REPORT OF DRAINAGE INVESTIGATIONS
IN FIREBAUGH AREA, FRESNO COUNTY, CALIFORNIA

INTRODUCTION

In October 1950 landowners in the Firebaugh service area, Fresno County, California became concerned over the construction of the Delta-Mendota Canal across their properties by the Bureau of Reclamation. They contended that the type of lining proposed would not prevent seepage of their lands below the canal. They also contended that the deeply entrenched lined canal would restrict the free movement of groundwater and thus damage lands above the canal. Meeting with the landowners, Bureau officials agreed to install certain drainage facilities concurrently with the construction of the canal. At the same time the Bureau began investigations to determine groundwater conditions in the area before construction and operation of the canal. The purpose of the investigation was to ascertain the cause and effect of high groundwater in and adjacent to the service area of the Firebaugh Canal Company. In this area of approximately 41,000 acres, groundwater had risen to dangerously high levels as a result of an extensive increase in irrigation over the past decade. There was serious probability that coincident construction of the Delta-Mendota Canal would give rise to claims, even though not justified, that such conditions were caused by the canal.

Various Bureau offices participated in the investigations. The field work was done by the Construction Engineer's office at Tracy and the San Joaquin Valley District office. A drainage engineer from the Chief Engineer's office served in an advisory capacity. The Regional Director's office compiled and coordinated this report, the findings and conclusions of which are based upon data available as of September 1952.

Delta-Mendota Canal starts at the intake on Old River, a natural channel in the Sacramento-San Joaquin Delta near Tracy, California, and ends at Mendota Pool near Mendota. The total length of the canal is 113 miles, of which the first 95 miles have a concrete lining and the remaining 18 miles a compacted earth lining. The earth-lined section passes through the Firebaugh service area and, according to the land owners, will cause damage to their property. Excavation on the earth-lined portion of the canal started in February 1950 and ended in June 1951, about 15 months later. This section was primed by reverse flow from Mendota pool on June 30, 1951, and water was turned into it from the lower end of the concrete-lined section for the first time on July 12, 1951.

The investigation covered some 41,000 acres, including the service area of the Firebaugh Canal Company on the west side of the San Joaquin Valley near the town of Firebaugh, California. Specific objectives were:

1. To determine groundwater conditions before and after construction of the Delta-Mendota Canal.

2. To determine contributions, if any, from the canal to the groundwater.

3. To determine any possible relationship between the canal and groundwater conditions.

4. If high groundwater is not due to the canal, to determine its cause.

An investigation of this type requires the observation of hydrologic and soil and water chemistry data over a period beginning before the start of construction and continuing well into the operating period in order that the effect of project operation can be accurately established. In addition to data collected specifically for this investigation, the Bureau had previously collected considerable other data. In December 1947 and in the 3-month period February through April 1949, some 200 geological exploration holes were put down along the centerline of the canal. Their purpose was to obtain soil samples to determine construction conditions. Groundwater levels were recorded. For many years before these construction investigations, groundwater elevations and data on quality of water had been collected and compiled in connection with the routine hydrologic program. The Firebaugh Canal Company also collected groundwater data during this period.

More detailed groundwater investigations of the Firebaugh area were begun by the Bureau in September 1949 when a grid of groundwater observations wells was laid out. Installation of these wells began early in January 1950, and by March 1950, 113 wells of the regular grid had been installed and water elevations in them observed for the first time. By April 1951, 239 wells along the profile lines extending out from the canal were completed and under observations. Samples for quality of groundwater were taken and chemically analyzed for the first time in February 1950 from wells distributed over the entire network. Surface water samples for the same purpose were taken at points of diversion and return flow in the study area. Practically all wells in the regular grid and on profile lines running across the canal were completed and in operation by July 1, 1950. Although the ultimate program of hydrologic observation was not fully established by the start of the construction of the canal, the program was well underway, and data were available to provide an adequate indication of groundwater conditions prior to construction.

In addition to collection of groundwater data, information was obtained on soil conditions, agricultural use of the land, irrigation water requirements, and measurements of the amount and composition of dissolved salts in the groundwater and in the drains. Crop maps of the area were made for the years 1949, 1951, and 1952. A land classification made in 1951 recorded numerous soil observations and determinations of the salt content of the soil. Many samples of soils were collected along the profile lines crossing the canal to determine the chemical analyses of the soils and water and the permeability of the soils.

The findings of the Firebaugh Drainage Investigation are contained in this volume, called the Report, and in another volume called "EXHIBITS". The report volume, in addition to its narrative, contains an Appendix in which are provided the substantiating material required for ready reference in reading the report. The Exhibits volume contains the bulk of the observed data on groundwater and soils and practically all of analytical material, such as maps, profiles, and hydrographs.

SUMMARY

Historical data indicate that a serious groundwater situation, accompanied by saline and alkaline conditions, has existed in varying degrees for many years. Reports of surveys by Federal and State and other agencies record the existence of the unfavorable situation for several years prior to the time of the Delta-Mendota Canal construction. The 1944 report by the United States Bureau of Agricultural Economics is one important example.

The physical location of the Firebaugh Service Area in relation to the adjacent topographic features places it in an unfavorable position at the foot of long, relatively smooth slopes averaging 25 feet per mile. Through the years, saline and alkaline waters moving down slope have increased deposits of salts in the root zone of plants in flatter areas. Analyses of samples from soil profiles and groundwaters show high concentrations of salts.

A substantial portion of the 22,640 acre Firebaugh Service Area either is now or has been affected by high groundwater. Approximately 18,890 acres or 83 percent of the area, had water within 12 feet of the ground surface at some time during 1951; 12,880 acres, or 57 percent of the area, had water within 8 feet of the ground surface during 1951; 5,070 acres, or 22 percent of the area had water within 4 feet of the ground surface. The depth to water was more than 12 feet under only 3,750 acres, or 17 percent of the total service area, during 1951.

1952 Conditions

Local interests have made some attempts over the years to relieve and protect their properties by the installation of drainage works and canal linings. These, undoubtedly, have done considerable good; however, the work done by the local interests thus far is only a beginning of what is needed to drain and protect the service area.

The development of groundwater contours from observation well data shows conclusively that the movement of perched groundwater is down-slope and conforms closely to surface topography. This is also shown on profiles taken up-slope across the area. There is evidence that a substantial portion of the groundwater causing trouble within the Firebaugh Service Area originates outside and above the area. This water is from excessive irrigation plus natural precipitation on both the fan and the tributary drainage area. It is supplemented within the area by local excessive irrigation and natural precipitation.

A study of the substrata of the Firebaugh Service Area shows them to have relatively low permeability, with no extensive porous aquifers through which excess groundwaters can move freely. This results in the building up of high groundwater within the subsoils of some portions of the area.

As these highly saline and alkaline groundwaters rise to a position where the capillary fringe reaches the ground surface, evaporation takes place, leaving the dissolved salts behind, thus causing an accumulation of salts in the upper portion of the soil profiles.

An extensive grid of groundwater observations wells has been established from which fluctuations and trends are obtainable from readings made over a period of several years. The logs of these wells disclose the character of the subsoil profile; and analyses of the groundwaters indicate their chemical characteristics. Laboratory testing of samples of subsoil materials obtained from the observation wells and other test holes gives the permeability rate for the various subsoil types.

In addition to the extensive regular grid of observation wells, there have also been installed 19 sections of closely spaced wells on profile lines starting as near the centerline of the Delta-Mendota Canal as possible and extending outward from the canal several hundred feet. By studying the frequent readings taken at these wells, percolation from the Delta-Mendota Canal, if any, can be promptly observed. It is also possible to observe the effect on the groundwater by the closed sub-surface drains installed parallel to the Delta-Mendota Canal. Likewise, if there should occur a piling up of groundwater on the right or up-hill side of the canal, this accumulation of groundwater will be promptly reflected by the fluctuations in the profile wells.

The subsurface closed drains which were constructed through all areas having groundwater within 10 feet of the ground surface are operating satisfactorily and should prevent high groundwater mounds under normal irrigation practice. In addition, these drains will also benefit in varying degree the adjacent farm lands.

Groundwater collected in the 6.7 miles of subsurface drains, together with water collected by surface drains, is discharged into the Delta-Mendota Canal where it mingles with the regular canal water. The chemical characteristics of these drainage waters are such that some adverse effect upon the salinity of the canal water will occur.

In order to better study the effect of land use upon the subsoil and the groundwater, a land classification map and a crop survey map have been prepared showing the 1951 crop-year conditions. Using water diversions of record and applying accepted consumptive-use quantities, it was determined that approximately 25,700 acre-feet of water, in excess of crop needs, were applied to the agricultural lands of the Firebaugh Area. Much of this excess water found its way into the subsoil below the crop roots and contributed to the development of the groundwater problem.

CONCLUSIONS

The following conclusions have been reached as a result of this investigation:

(a) That a high groundwater problem has been present over a considerable portion of the Firebaugh Service Area for many years.

(b) That the groundwater and soils of the area have contained heavy concentrations of soluble salts for a long period of time, probably even before they were developed for agricultural purposes; and that conditions may grow worse as time goes on.

(c) That the lands are drainable but that the works constructed to date by the property owners have been inadequate in correcting the condition except in very localized places.

(d) That from groundwater contours there is movement of perched water into the Firebaugh Service Area from irrigated lands above.

(e) That from laboratory tests on substrata samples, the permeabilities of the area are generally low and the groundwater movement correspondingly slow.

(f) That from permeameter measurements, cross profiles of groundwater position and field inspection the only instance of percolation from the Delta-Mendota Canal is that observed at station 4725, where the extent of percolation is deemed negligible.

(g) That from studies of groundwater profiles and seasonal changes in elevation the only instances of impedance of groundwater flow as a result of Delta-Mendota Canal construction are those in evidence at stations 5187+34 and 5216, where it may well be that poor surface drainage is a contributing factor of considerable consequence. In these instances the areas affected are negligibly small and immediately adjacent to the canal.

(h) That adverse changes in downhill groundwater positions are due to losses from unlined company canals, laterals, surface drains, and excessive irrigation, and not from losses from the Delta-Mendota Canal.

(i) That the land-use studies correlated with irrigation deliveries show excessive applications of water above consumptive use on the service area of the Firebaugh Canal Company.

(j) That the construction of the Delta-Mendota Canal and appurtenant works through the Firebaugh service area has not adversely affected the general groundwater position.

RECOMMENDATIONS

(1) In order to be fully informed of groundwater conditions in the Firebaugh Service Area particularly adjacent to the Delta-Mendota Canal a limited observation program should be maintained. The intensity maintained during the investigational period should be modified but not entirely abandoned. Wells on the special profile lines should be maintained in good condition, though the frequency of observations may be reduced to once each three months initially and possibly to once each six months after stability of groundwater position is established.

(2) To assure against impulsive decisions to authorize drainage construction under pressure, the Government's responsibility, if any, should be fully established before any commitments are made.

CHAPTER I

DELTA-MENDOTA CANAL DESIGN AND CONSTRUCTION

The Delta-Mendota Canal originates at the intake headworks on the bank of Old River, a natural channel in the Sacramento-San Joaquin Delta near Tracy, and terminates at Mendota Pool near Mendota. Its total length, including intake canal, pumping plant, penstock, and canal section, is 117 miles. The length of the canal section alone is 113 miles. Of this length, the first 95 miles have a concrete lining and the remaining 18 miles have a compacted earth lining.

Local interests in the Firebaugh Area objected* to the earth-lined type of construction because they believed percolation from the canal would be sufficient to raise groundwater levels in adjacent lands. They objected also to any type of lined construction, believing that the canal lining would act as a subsurface dike obstructing the groundwater flow and causing it to rise. As the lesser of two evils they expressed a definite preference for concrete lining together with tile drains along the canal. In response to their demands and without benefit of technical data or study, a decision was made to construct, concurrently with the canal, a system of closed drains parallel to the canal on the upslope side. Notwithstanding the construction of these drains, the responsibility of the Bureau for such drainage has not been established.

* Refer to letters from: Dearing, Jertberg and Avery to Regional Director, October 4, 1950; Firebaugh Canal Company to Construction Engineer, Tracy, May 18, 1949; and Construction Engineer's reply to Firebaugh Canal Company, August 16, 1949.

Design Criteria

The decision to line portions of the canal with earth and the design of these portions were preceded by an extensive investigation of the existing soil and groundwater conditions along the proposed canal line. A study of soil profiles, which were developed from soil boring data along the canal line, revealed that at about Station 4535+00 a general change in soil conditions existed.

For a considerable reach above this point the soil mantle includes a shallow layer of clay-loam topsoil which was underlain by a relatively thick layer (up to 16 feet in thickness) of sand with excess silt with lenses or strata of medium to fine clean sand. Along certain lengths of the canal the bottom grade-line extended beneath these layers into a clay soil. A lining of some sort was considered necessary for the canal in these soils from the standpoint of high seepage losses and instability of unlined slopes. Suitable material for a soil lining was not available either from canal excavation or from borrow areas in the vicinity. Therefore, a concrete lining was selected as being the most practical and effective. An under-drain system was required wherever high groundwater was encountered.

Below Station 4535+00 profiles showed that a shallow layer of clay-loam topsoil was underlain by a 2- to 12-foot strata of lean clay and beneath by heavy clay. There were, however, lenses and strata of silty and clean fine sand existing within (and in some places beneath) the lean clay strata. Although the lean and heavy clay were relatively impervious, the sandy soil was pervious and a lining was considered necessary to control seepage through this material. The ground water was high in some areas along this reach and low in other areas. The soil profiles are included in Laboratory Report EM-222.

Consideration was given to the construction of concrete lining in this reach of canal but this was considered inadvisable because of the expansive nature of the clay soils of the canal subgrade. Laboratory tests on representative samples of the clay subgrade soils had shown that upon saturation they would swell to a high degree. Experience on both the Friant-Kern and the Delta-Mendota Canals had demonstrated that such soils can produce considerable distress in a concrete lining.

As the lean clay from canal excavation was considered suitable for a heavy-type earth lining, this type of lining was considered the most practical for this reach. Another reason for selecting a heavy-type earth lining in this reach of the canal arose from the existence of the high groundwater table. In some areas the groundwater elevations measured during the canal exploration stage were up to 10 feet above the canal bottom grade. A heavy-type earth lining would allow the use of flatter, more stable slopes, and would eliminate the necessity for the construction of an extensive under-drain system that a concrete lining would require. All-in-all, the construction of the earth lining was considered to be less difficult and more suitable.

In view of the canal preconstruction investigation of which the main points are mentioned in the preceding paragraphs, the first plan was to construct a heavy-type earth lining only in areas where pervious sandy strata intersect the canal section. Later, the decision was made to extend the lining over the entire reach of the canal from Station 4535+00 to 5485+00. The difference in cost between partial and complete lining was not considered to be great because of the advantage in unit prices to be obtained by one type of construction throughout. The lining in the bottom of the canal was compacted to a 2-foot depth, and that on the slopes was built up with 6-inch layers compacted to an 8-foot horizontal width with a 2-foot horizontal width of loose, or partially compacted, soil left on the slope. The side slopes were 2-1/2 to 1.

Preconstruction Soil Tests on Lining Material

Prior to the selection of soil for the earth lining of the Delta-Mendota Canal, the proposed material was first sampled and tested in the laboratory to determine the suitability for lining. The laboratory tests consisted of mechanical analysis, Atterberg limits, specific gravity, compaction, and permeability. The test procedures for these and the field control tests made during lining construction are presented in the appendix. The main purpose of the tests was to determine the compaction and permeability characteristics of the soil proposed for lining.

From the compaction test the densities that could be obtained under a simulated field compaction effort with different moisture contents were determined. The maximum density with the corresponding optimum moisture content then became important test values for earthwork control because they became goals of attainment during soil placement. From laboratory permeability tests the coefficients of permeabilities of the soil placed at maximum density and lesser densities were determined and stability values were estimated.

Since permeability and stability values decrease with density, the test results were used to select minimum placement densities for adequate seepage control through the compacted earth lining. Thus, minimum densities for earthwork control of the soil were established in the construction specifications. By this procedure, it was established for the clay lining of Delta-Mendota Canal that the soil placement densities should be at least 95 percent of the maximum soil density as determined by test on the soil during construction.

Earthwork Control Tests

During construction, field control tests were made as lining material was placed to insure that adequate stability and imperviousness was being achieved. This was accomplished by comparing the densities obtained on lining material in place with densities on the same material obtained under standard laboratory conditions. Where the field density was less than 95 percent of the maximum laboratory density, the material in the area represented by the test was rerolled to the required density or replaced with more suitable material as necessary. Moisture contents of material being placed were controlled in accordance with the moisture-density relationships from the laboratory compaction tests so that the best possible field density could be obtained. In some instances, the excessive moisture in required excavation, used for lining materials, made the moisture control very difficult.

A further aid in the earthwork control was obtained by means of plasticity needle readings on the soil in the lining compared with the soil compacted at known density and moisture content in the laboratory.

Permeability Tests

In order to check the permeability of the lining material, tests were made during construction. An unusual effort was made to determine the permeability characteristics of the soil of the lining on the Delta-Mendota Canal and a greater variety of tests were made than is commonly done on such projects. These consisted of laboratory tests on selected disturbed and undisturbed samples, well-permeameter tests in the canal slopes and casing-type tests in the canal bottom.

Summary of Earthwork Control and Permeability Tests

A detailed summary of earthwork control is presented in the Appendix. Table 1 of the summary gives average density test values over 10,000-foot intervals (except for the first and last intervals which are shorter) along the earth-lined section. As shown at the bottom of the table, over the entire length there were 799 tests made and the average percentage compaction was 96.5 of the laboratory maximum density. Also in Figures 1 and 2 the results of a statistical analysis in which the number of tests falling at various percentages above and below that specified are shown for construction Schedules 1 and 2. It should be noted that although about 20 to 30 percent of the number of tests fall below the percentage specified, this is not an unusually large number for such earthwork. Also, as shown in Figure 3 in the plot of the average coefficient of permeability against the percent density, the permeability is not greatly increased at the lower density percentages within the range of densities obtained on this project.

In Figure 4 is a plot from a statistical analysis showing the percentage of well-permeameter tests made falling at different permeability test values within the range encountered. In Table 2 of the Earthwork Control Summary are listed average values over 10,000-foot length sections of the canal of seepage computed from the well-permeameter tests made in the canal slopes. As seen at the bottom of the table the results based on 80 tests indicated that the seepage loss over the entire canal reach between Station 4535+00 and 5485+00 was computed to be 117,462 cubic feet per day. This is a very small loss for a canal the size of Delta-Mendota and amounts to 0.009 cubic foot per square foot of wetted perimeter per 24 hours or about 0.118 acre-foot per mile per day. The method of computing the seepage from the well-permeameter test results is described in the Earthwork Control Summary.

Because some seeped "spots" appeared in the bottom canal lining in high groundwater areas, five field permeability tests of a special casing-type, were made in these localized seeped areas to determine if this reversed flow would have any significant effect upon the efficacy of the lining. The number of these tests was necessarily limited to structure locations where the casing could be forced into the bottom lining by a jacking operation. The permeability values obtained from these tests were all extremely low (coefficient of permeability all below 0.2 of a foot per year) and it was concluded that the localized groundwater seepage was not detrimental to the lining.

Design Details

A detailed description of the canal as finally constructed appears in United States Bureau of Reclamation Specifications Number 2857, dated January 5, 1950. The earth lining has a nominal thickness of 3.7 feet perpendicular to the sides and 2.0 feet on the bottom. Side slopes are 2-1/2:1. The canal has depth of 15.4 feet and a berm 10 feet wide on each side. The designed maximum water surface elevation in the earthlined canal follows the original ground surface closely for approximately the first half of its length, the departure varying between 2 feet above ground and 3 feet below. In the remaining portion, the water surface elevation is about 5.0 feet above the ground, on the average. Other dimensions of the earthlined portion of the canal, together with hydraulic properties, are as follows:

Sec.	Station	Bottom Width, Feet	Canal Depth, Feet	Water Depth, Feet	A	V	Q	R	N	S
10	4535-5218	62	15.4	13.9	1345	2.46	3310	9.83	.021	.00005
11	5218-5350	84	15.4	13.85	- -	- -	3310	- -	.021	.00005
12	5350-5485	60	15.4	13.85	1311	2.45	3211	9.74	.021	.00005

CHAPTER 2

CLOSED DRAINS

The closed drains along Delta-Mendota Canal in the Firebaugh area consist of 12-inch concrete pipe laid in the bottom of a trench approximately 28 inches wide and 7 to 15 feet deep. The total length of the drains is 35,485 feet (6.7 miles), extending along the right bank (uphill) side of the canal from station 4620 DMC to station 5143--a total distance of 52,215 feet (9.9 miles). The length of the canal through the investigation area, which is also the length of the earth-lined section, is 18 miles. It starts at station 4535 DMC and ends at station 5485+50, the terminus of the canal at Mendota Pool. The closed drains lead to 6 sumps from which electrically-powered sump pumps with automatic water level control discharge water into the canal. Manholes for cleaning and inspection, 64 in number, are located at average intervals of 500 to 600 feet along the drain lines. The following tabulation shows the length and slope of the drains and the location of the 6 sumps:

DELTA-MENDOTA CANAL CLOSED DRAINS, SLOPES, LOCATIONS AND LENGTHS, AS BUILT

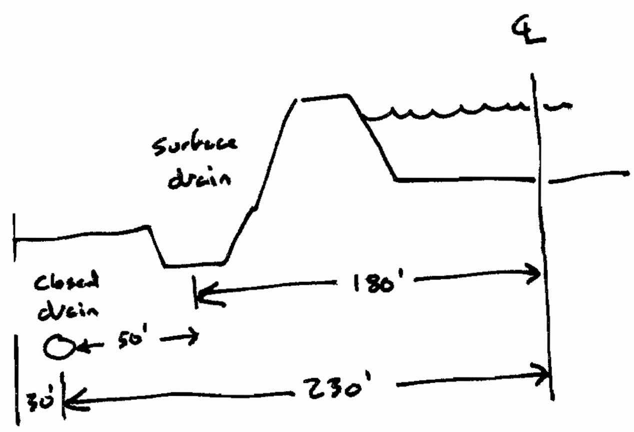
	Slopes	DMC Stations	Lengths in Feet: Drains	Lengths in Feet: Between Drains
Upper end "A"		4620+35		
	.00071		3,515	
Sump		4655+50		
	.00060		3,000	
Lower end "B"		4685+50		
				7,250
Sump		4758+00		
	.00060		3,700	
Lower end "C"		4795+00		
Upper end "D"		4796+50		150
	.00100		3,250	

DELTA-MENDOTA CANAL CLOSED DRAINS, SLOPES, LOCATIONS AND LENGTHS, AS BUILT (Cont.)

	Slopes	DMC Stations	Lengths in Feet: Drains	Lengths in Feet: Between Drains
Sump		4829+00		
	.00100		2,715	
Lower end "E"		4856+15		
				495
Upper end "F"		4861+10		
	.00061		4,230	
Sump		4903+40		
	.00060		1,500	
	.00270		2,100	
Lower end "G"		4939+40		
				60
Upper end "H"		4940+00		
	.0016		5,000	
Sump		4990+00		
	.00059		3,225	
Lower end "J"		5022+25		
				8,775
Sump		5110+00		
			3,250	
Lower end "K"		5142+50		
Total Length Drains			35,485	
Total Distance Between Drains				16,730
Total Distance, Upper to Lower End			52,215	

The drain tile are surrounded by a backfill of pit-run gravel, graded to 2-inch maximum stone size. Timber cradles are used to support the tile where the trench bottom soil is too soft. Where the soil is solid enough to support the tile and maintain proper alignment, the tile are underlain with just enough gravel for bedding. The depth of the gravel fill ranges from a minimum of 6 inches above the tile to within 3 feet of the ground surface. Where a water-bearing stratum intersects the drain trench above the tile, gravel core 12 inches wide is extended upward to the level of that stratum in order to provide a pervious channel to the tile. The balance of the trench volume is filled with original excavation material. The top 3 feet of back fill, obtained from original excavation material, is not compacted except where the drain intersects an irrigation canal or surface drain ditch. In these instances, the top back fill is compacted to a depth of 3 feet below the bottom of the canal or ditch.

The closed drains follow a line that is generally parallel to the canal and about 230 feet from its centerline on the right bank (uphill) side. This is about 30 feet inside of the right-of-way boundary. Along most of the canal through the investigation area, a Bureau constructed surface drain parallels the canal about 180 feet up hill from its centerline, or 50 feet below the closed drain.



in groundwater levels between March 1950 and March 1952, for the entire investigational area shows groundwater rise in some areas and recession in others. These changes are the result of changes in irrigation practice--generally the presence or absence of rice in the crop pattern. In instances where irrigation practice is the cause of a general groundwater rise in areas near the canal, it is only reasonable to expect that the same degree of rise is to be expected in observation wells on or immediately adjacent to the canal right-of-way, except for the alleviating effect of the Bureau's closed drain system. Groundwater depth and elevation maps for March 1952 are shown on Plates 12 and 13 in the Appendix. Depth and elevation maps for March and September of 1950, 1951 and 1952 are contained in the Exhibits volume.

Effectiveness of Closed Drains

The Bureau's closed drain system, described in detail in Chapter 2, is generally effective. This conclusion is demonstrated by the cross section profiles, many of which show a pronounced increase in groundwater gradient on the uphill side. Profiles which show little or no increase in gradient do not necessarily indicate ineffectiveness of the drain because this condition may be due to low permeability of the soil. Effectiveness of the closed drains is demonstrated further by the fact that the six sump pumps have been operating at a total average annual discharge rate of 1800 gpm, or 4 c.f.s. This rate is equivalent to 0.6 c.f.s. per mile for the 6.7 miles of drain length; and it is slightly greater than the estimated interception rate based on observed groundwater gradients and soil permeabilities.

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FIREBAUGH CANAL COMPANY

Los Banos, California

May 18, 1949

Mr. Oscar Boden, Construction Engineer
United States Bureau of Reclamation
Tracy, California

Dear Mr. Boden:

Pursuant to instructions from the Board of Directors, I am making a formal protest against the proposed construction of the Delta - Mendota Canal through the service area of this Company as an unlined section or one in which a compacted back-fill is substituted for a concrete lining.

Based on more than twenty year's experience with soil and ground-water conditions in this area, it is apparent to the Board that transportation of water through a canal not lined with concrete will, within a very few years, result in the destruction of at least one-third of the land within the service area. This would bankrupt the entire area for the remaining lands could not then carry the entire burden of maintenance and operation of the system.

The problem of drainage in this area has always been a difficult one. In many places within the area the subsoil is so fine that the separation of water from it is a very slow process. Because of this fact, it has been extremely difficult to keep the ground water at a safe depth below natural ground.

Construction of the Delta - Mendota Canal through the Firebaugh Canal Company area will, under any plan adopted, increase this burden tremendously and adequate measures must be taken to control seepage losses from the Delta - Mendota Canal into the ground water table and to permit the natural but slow flow of ground water out of the area.

It is the considered opinion of the Board that a tile drain of sufficient capacity, properly protected by a sand and gravel envelope and located on the center-line of the Canal just below the grade of the canal bottom, would give the area protection against a dangerous ground water table condition; and, at the same time, would eliminate the possibility of floating out the Canal lining during times when the Delta - Mendota Canal was not filled. This would require the installation of small pumping plants at proper places along the Delta - Mendota Canal to lift the water from the tile drain into either the Delta - Mendota Canal or one of the drains maintained and operated by this company.

Trusting that further consideration and study may be given this problem and a decision reached to construct a concrete lined canal with proper sub drainage facilities, I am

Yours very truly,

FIREBAUGH CANAL COMPANY

/s/ Thos. C. Mott
Thos. C. Mott, President

TCH:gc

DEPARTMENT OF THE INTERIOR (copy)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION II
Tracy, California

August 16, 1949

Mr. Thomas C. Mott, President,
Firebaugh Canal Company,
Los Banos, California

Dear Mr. Mott:

Reference is made to your letter of May 18, 1949, in which you submitted a formal protest of your company to the proposed construction of the Delta-Mendota Canal, through your service area, as an earth or earth-lined section as a substitute for a concrete-lined section. Considerable effort in the form of field and laboratory testing has been expended in an attempt to arrive at the most suitable type of construction for the canal reach from Station 4535 to the Mendota Pool. The major factors influencing our choice of type of construction for this reach are (1) groundwater conditions, (2) expansive clay soils within the section, and (3) cost.

Three types of construction have been investigated in detail for this reach of canal, namely: (a) earth section, with earth lining only as required to control seepage in sandy areas (approximately 60 percent would require lining), (b) continuous heavy compacted earth lining, and (c) continuous concrete lining, with under drains as required.

The earth section with intermittent lining would have 2-1/2:1 side slopes and would be earth-lined through areas where sandy or other permeable strata, having a high seepage rate, were encountered.

The earth lining for the continuous earth-lined section would consist of two-feet of compacted earth in the canal bottom and an eight-foot horizontal width of compacted earth on the side slopes. Lean clay soil obtained from the excavation would be used for the lining material. This material would be compacted in six-inch horizontal layers by sheepsfoot rollers to obtain a dense and impervious lining. Field densities equal to 95 percent of standard Bureau laboratory maximum density would be required to insure denseness and impermeability.

The concrete lining would be a standard concrete lined section similar to that used on the upper reaches of the canal, with underdrains as required, the construction details being those which you have no doubt observed.

Permeability characteristics for the earth sections have been studied in detail by analyzing field and laboratory test and drill-hole data. An estimate of the permeability for the concrete lining was based on recent ponding tests on the Friant - Kern Canal. These studies and tests indicate that the highest seepage loss would obtain in the partially lined earth section. The concrete lining comes next with an estimated seepage loss of about a third of that for the partial earth lining. Indicated seepage losses from the continuous earth lining are far lower than for either of the other types of construction, being estimated as a small fraction of the losses for concrete lining.

Preliminary estimates indicate that on the basis of initial construction cost the partially lined earth section was the cheapest type considered. The continuous earth lining was next with a cost of approximately 25 percent higher than for the partially lined section. The concrete lining was highest with a cost more than double that of the partially lined earth section. On the basis of annual cost the concrete lining is often favored over other types of lining sections because of the low maintenance. However, this area appears unfavorable to the construction of concrete lining from the standpoint of both initial cost and maintenance for the following reasons:

(a) High groundwater, up to eleven-feet above canal grade, has been encountered in numerous locations along this reach and field borings indicate that sloughing will occur in sandy strata in which water is encountered. It is recognized that any type of construction will be difficult and expensive in such an area. However, the construction of the earth-lined section with 2-1/2:1 side slopes will be much easier than the construction of a concrete-lined section with 1-1/2:1 side slopes. In addition, our experience with large canals, indicates that several longitudinal drain lines and suitable finger drains, rather than a single central drain, would be required in these areas of high groundwater to protect a concrete lining against uplift.

(b) It has been found that the clay materials which exist throughout this reach are very expansive. Samples submitted from the field for permeability tests expanded from 8 to 29 percent when saturated. Experience on both the Delta-Mendota and Friant-Kern Canal systems shows that expansive clays can be extremely harmful to concrete lining, especially if they occur in the bottom subgrade. This one factor would preclude the use of concrete lining until such time as economical corrective measures could be found.

After carefully considering all factors we have chosen the continuous heavy earth-lining as the type of construction best suited to the reach of canal under discussion. This type of construction has the following major advantages for use in this area: (a) the indicated percolation loss is negligible, being far less than for the other types considered, (b) the cost is within reason, and (c) concrete lining appears unsuitable for use in this area from both the construction and maintenance standpoint. I wish to emphasize that the above choice should in no way be construed as a substitute for concrete lining, but has been chosen because of superiority to concrete lining for this particular installation.

Very truly yours,

O. G. Boden,
Construction Engineer.

CC-Chief Engineer, Denver
Regional Director, Sacramento
District Manager, Stockton

The ground and water conditions can be readily seen in the section of the canal now being excavated and in which the lining has not been rolled. If drainage and pumping is not continuous, the water levels will recover and assert a hydrostatic pressure against the lining and any weakening of that lining through cracking or rupture will let the water into the canal when it is empty and out of the canal when it carries water. Should the canal lining be continuously moistened through being kept full of water, the weakening of the compacted earth through swell would be sufficient to allow rupture unless the water levels inside and outside are kept balanced.

While we understand that a closed drain is being installed at a level close to the bottom grade of the canal on the up slope side and about five hundred feet from the canal, our engineers feel it would be advisable while the ditch is open, to carry the filter up to its ultimate height the full width of the ditch.

The observations of our engineers convince us that the landowners down slope from the canal will not be safeguarded. It now appears apparent that the canal cannot be constructed and an earth lining compacted without the lining drying out, cracking, checking and weakening, subject to blowout and softening from low head water tables adjoining, and thus rendering it porous. It appears to us that the canal must be constructed so that no seepage will take place, otherwise the lands of the area lying below the canal will be rendered worthless. Our engineers are of the opinion that the canal will be constructed, and with adequate drainage provided, in a manner that will reduce the hazards expressed in this letter, to a minimum.

This letter is written to you in the hope that the weaknesses in the proposed construction can be rectified and the loss of land through seepage and improper drainage might be very substantially reduced.

We would appreciate having your views and would be glad to confer with you or your representatives at any time and place at your convenience.

Very truly yours,

DEARING, JERTBERG & AVERY

By /s/ Gilbert H. Jertberg
Gilbert H. Jertberg