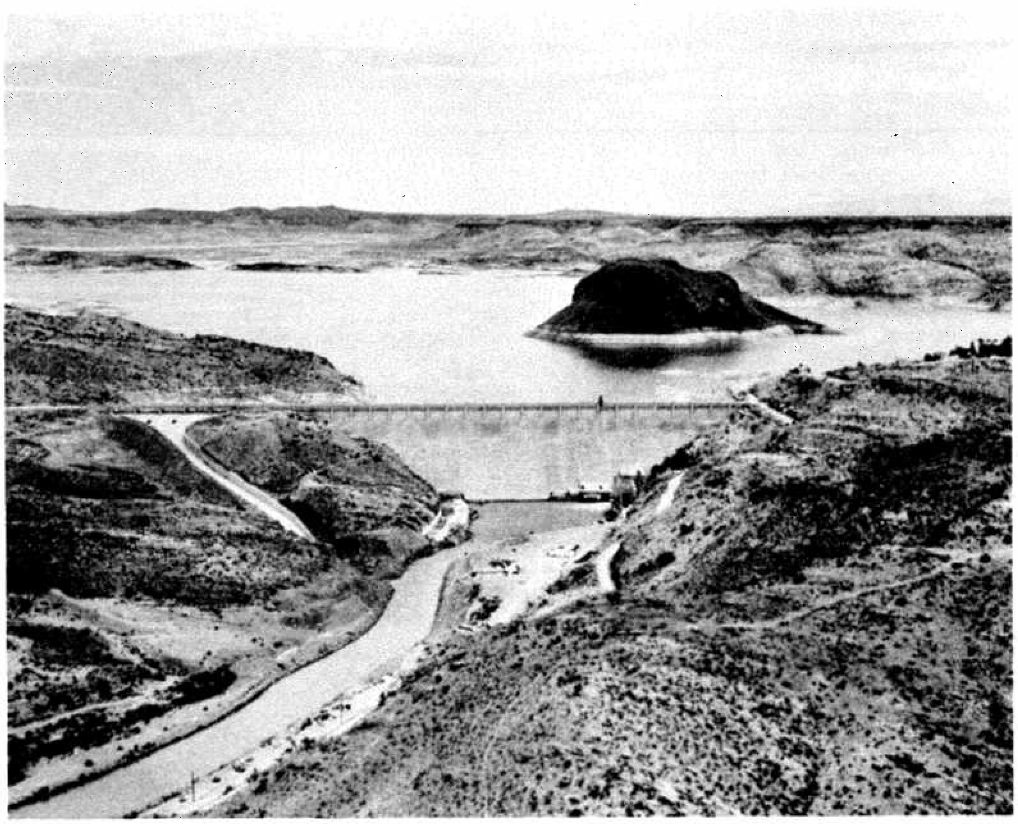
United States
Department of the Interior
Bureau of Reclamation

THE 1957 SEDIMENTATION SURVEY OF ELEPHANT BUTTE RESERVOIR



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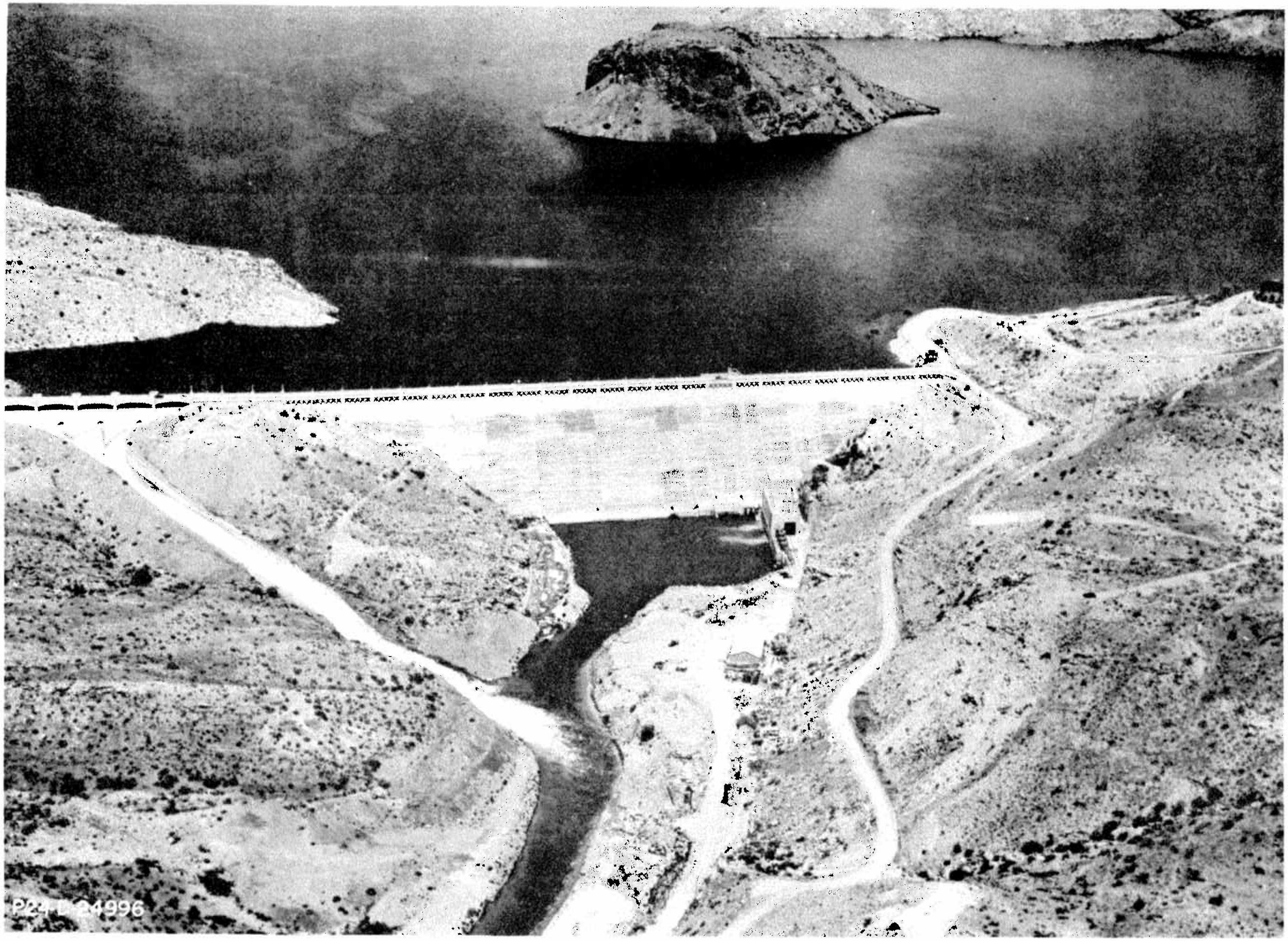

ELEPHANT BUTTE DAM

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THE 1957 SEDIMENTATION SURVEY OF ELEPHANT BUTTE RESERVOIR RIO GRANDE PROJECT, NEW MEXICO-TEXAS

INTRODUCTION

This report presents the results of the 1957 sedimentation survey conducted of Elephant Butte Reservoir on the Rio Grande near Truth or Consequences, New Mexico. The primary purpose of the survey was to determine the amount of reservoir storage depletion. Other data gathered in the course of this survey were used to investigate additional sediment features such as:

a. Quantitative sediment yield rates for the drainage area above the reservoir

b. Sediment distribution within Elephant Butte Reservoir

c. Trap efficiency of the reservoir

d. Density currents

e. Evaluation of the quantity of sediment deposited in the reservoir based on the suspended sediment measured at the San Marcial sampling station

f. Study of the grain size and unit weight characteristics of the stream and reservoir sediments

g. Practicability of measuring densities of reservoir deposits with a radioisotope densitometer (Timblin and Florey, 1957)

h. Effects of the conveyance channel on sediment deposition in the reservoir

i. Influence of salt cedar infestation on reservoir sedimentation

The 1957 survey of Elephant Butte Reservoir was begun on October 1, 1956, by personnel of the Rio Grande Project, Bureau of Reclamation. Personnel from the office of the Assistant Commissioner and Chief Engineer, Denver, Colorado, assisted in the review and completion of the survey during intermittent periods from October 16 to October 23, 1956, and February 4 to February 14, 1957. Two additional days were needed in March 1957 to obtain field data of areas which were inaccessible during the course of the survey. By that time, the reservoir waters had risen high enough to allow a boat to be piloted in these areas. Data obtained during this investigation were analyzed and new area-capacity charts were prepared by the office of the Project Manager, El Paso, Texas.

Since there are numerous other reports published or written concerning the sedimentation aspects of the Rio Grande and Elephant Butte Reservoir, general information pertaining to the river, reservoir, and drainage area is presented briefly herein. Some of the previous reports are cited for reference.

Purpose and Scope

The primary purpose of this investigation was to obtain the required data for defining a new area-capacity curve. This, in turn, provides basic information needed to compute water delivery by New Mexico into Elephant Butte Reservoir as provided in the Rio Grande Compact. Surveys of this nature are to be performed whenever the capacity curves and tables appear to be as much as 5 percent in error because of sediment accumulation in the reservoir.

Sediment data from these surveys also provide information needed for secondary purposes. Among them are:

a. Furnish information necessary in the study of control measures on the Rio Grande and its main tributaries upstream to reduce sediment contribution to the reservoir.

b. Serves to maintain a progressive check of the unit weights of sediments deposited in the reservoir. The lateral and longitudinal sediment depositional patterns are both important.

c. Various sedimentation features of general interest can be investigated such as the particle size characteristics of the inflowing sediments and the yield rates determined for the drainage area.

GENERAL INFORMATION

Location and Ownership

Elephant Butte Reservoir is located in Sierra and Socorro Counties, New Mexico. The dam on the Rio Grande is approximately 4 miles east of Truth or Consequences, New Mexico, and 125 miles north of El Paso, Texas. The dam and reservoir are owned by the United States and operated by the Bureau of Reclamation, Department of the Interior.

Date of Completion

Construction of the dam began with foundation excavations in 1911 and was completed in 1916. Storage of water, however, began on January 6, 1915. At the time of its completion, the storage capacity of Elephant Butte Reservoir was the largest in the United States. As of 1957 there were four other Bureau of Reclamation reservoirs larger than it.

Description of the Dam and Dike

The type of dam is straight gravity, Cyclopean rubble concrete (Photograph No. 1, Frontispiece). The structural height is 301 feet, hydraulic height 193 feet, base width 228 feet, crest width 18 feet, and the crest length 1, 162 feet. The total length including the spillway and abutments is 1, 674 feet. Elevation of the roadway on the dam is 4419. A drawing of the general plan and sections of the dam is shown in Figure 1.

The spillway is a chute at the west end of the dam. There are five 51-foot spans of overflow weir crest, with a concrete arch bridge; 4-cylinder drum gates, 10 feet in diameter by 4 and 3/4 feet in height, with sills 11 feet below the overflow crest. Elevation of the overflow crest is 4407 and the elevation of the sill of the cylinder drum gates is 4396.

The Elephant Butte Dam outlet works, in addition to the spillway, consist of two sluicing conduits through the dam, each with a 47-inch by 60-inch sluice gate, four 5-foot diameter service conduits, each with a 60-inch balanced valve control, and six 5-foot diameter power penstocks each with a 47-inch by 60-inch gate.

Total discharge capacities of the spillway and the lower and upper service outlets are as follows:

Elevation (feet)	Discharge (cubic feet per second)
4,407	12,760
4,415	39,770

Discharge curves for spillway, outlets, sluice gates, and powerplant are shown in Figure 2. The sluice gates are operated only for removing sediments from in front of the penstock openings and also at heads not exceeding 80 feet.

Elephant Butte Dike, erected in 1915 and 1916, is located along a low gap in the hills 1 mile west of the dam. It is constructed of earth and rock fill and paved with concrete on the upstream slope. The crest altitude is at elevation 4,425 feet with a crest width of 20 feet and 2,000-foot length. The dike has no spillway.

Reservoir

At crest stage (elevation 4407) the length of lake measures approximately 41 miles along its axis. Its original area was 40,060 acres. The area in 1957 was 36,584 acres which shows a loss of 3,476 acres because of sedimentation during the 1915-1957 period.

The original storage capacity of the lake was 2,634,800 acre-feet and the 1957 capacity was 2,206,780 acre-feet, indicating a loss of 428,020 acre-feet from January 6, 1915 to February 12, 1957, (42.1 years). The percent of capacity lost was 16.2 which amounts to 0.39 percent annually.

Use or Purpose

Elephant Butte Reservoir of the Rio Grande Project (Figure 3) provides water storage for irrigation uses and the generation of power for several New Mexico communities and for the El Paso area in Texas. There are three identical units located in the powerplant having a total kva rating of 27,000 and total kilowatt capacity of 24,300. A regulating reservoir 25 miles downstream from the dam at Caballo, New Mexico supplements Elephant Butte Reservoir.

Approximately 159,650 acres of lands are irrigated in New Mexico and Texas from the Rio Grande waters resulting from the Elephant Butte storage and regulation and other smaller downstream structures not mentioned herein. Additional acreages are irrigated in the Juarez Valley of Mexico opposite El Paso, by the use of 60,000 acre-feet of water allowed annually as provided by the treaty with Mexico proclaimed January 16, 1907.

The principal crops grown in the irrigated areas include cotton, alfalfa, truck, pecans, and small grains. Photograph 2 shows a view of one of the cotton fields.

Additional factual data relative to the location description, water supply, major structure features of the project plan, general conditions on the project, and historical facts about the Rio Grande Project are contained on the reverse side of Figure 3.

Datum

All of the elevations quoted are based on the project datum. To adjust these elevations to mean sea level datum, 43.3 feet should be added.

DRAINAGE AREA

The drainage area above Elephant Butte Dam for the Rio Grande at San Marcial, New Mexico, is 27,700 square miles which includes 2,940 square miles in the closed basin in the northern part of the San Luis Valley, Colorado. In this report, however, the drainage area above the dam (Figure 4) is determined to be 25,923 square miles. The area can be divided into two major parts:

a. The main drainage area above San Marcial, New Mexico, is 24,176 square miles.

b. The side drainage area which drains directly into the sides of the lake and lies below San Marcial is 1,747 square miles.

The drainage areas of the San Luis Valley in Colorado and parts of Catron and Socorro Counties, New Mexico, are not included in the total drainage area quoted above. These areas are considered as noncontributors of sediment.

Table of Land Ownership

Land Status	Percent of Watershed
National forests	20
Indian lands	12
Public domain	12
State lands	6
Private lands	40
Miscellaneous, urban, and railroad	10
TOTAL	100

Geology

The Rio Grande rises in the San Juan Mountains of Colorado and flows between the Conejos Mountains and La Garita Hills. Water surface slopes in the mountainous headwater region are steep, but most of the rocks are igneous or metamorphic and are not easily erodible. Lateral erosion occurring in the alluvium of the San Luis Valley is insignificant. Just above the New Mexico state line the river enters a deep canyon. It flows through lava-capped canyons of low sediment contribution until it enters Espanola Valley near the confluence with Rio Chama.

Upon leaving the Espanola Valley, it enters White Rock Canyon in the vicinity of Otowi Bridge. The unconsolidated sediments of the

Santa Fe formation (Miocene and Pliocene continental deposits) have been eroded to form the valley of the Rio Grande from the lower end of White Rock Canyon near Cochiti Diversion Dam, to near San Acacia. The flood plains and terraces of the valley are composed of alluvium which is available for transport and which contributes large quantities of sediment to the Rio Grande.

From the mouth of Rio Salado, just upstream from San Acacia, to the headwaters of Elephant Butte Reservoir, the Palomas formation of the Quaternary Period has been eroded to form the river valley.

The major geologic formations of the Rio Grande Valley are of the Cenozoic Era.

Topography

The topography of the drainage area is varied. The extreme upper portion is mountainous and rugged. South of Santa Fe, New Mexico, the topography is less rugged and consists of isolated mountains, separated by desert plains and the Rio Grande Valley. The ranges of the drainage area elevation vary from 12, 000 feet at the Continental Divide in the upper portion to 4, 210 feet stream bed elevation at the dam.

Land Cover

The higher elevations are forested with pine and fir trees; the slopes are sprinkled with cedars along the foothills. The natural cover of plains consists chiefly of creosote bush, sagebrush, greasewood, cactus, and natural grasses. There are thick growths of salt cedar (tamarisk), willows, and cottonwoods along the river banks above the reservoir and particularly at the head of the reservoir.

Rainfall (U. S. Department of Commerce, 1956)

The annual rainfall in the watershed varies from less than 9 inches in the lower altitude to over 20 inches in the mountainous area. The mean annual rainfall for New Mexico weather stations in the mountains, foothills, and valley of the drainage area is listed below:

Name of Station	Average Annual Rainfall--Inches
Wolf Canyon	22.35
Chama	21.49
Red River	21.22
Regina	16.67
Santa Fe	14.39
Albuquerque	8.68
Socorro	9.85

Most of the precipitation in the higher altitude occurs during winter as snowfall. The greatest precipitation in the lower altitude usually occurs during the spring and summer months. Frequently the rainfall for 1 month is equal to a third or a fourth of the yearly total. A large proportion of rainfall for 1-month periods in the lower altitude is often attributable to cloudbursts.

Inflow (U. S. Geological Survey, 1958)

The average annual discharge of the Rio Grande at San Marcial, New Mexico, for 60 years of record (1896-1956) is 1,004,000 acre-feet. The run-off at San Marcial is affected by many upstream diversions for irrigation.

During the period between the 1947 and 1957 surveys, an average discharge of 427,000 acre-feet per year was recorded at the San Marcial gaging station on the Rio Grande. This amounts only to 43 percent of the long-term average quoted above.

Outflow (U. S. Geological Survey, 1958)

Based on 40 years of record, the average annual discharge of the Rio Grande below Elephant Butte Dam amounted to 784,100 acre-feet. For the 1947-1957 period, this average was 487,000 acre-feet or 62 percent of the preceding 40-year mean value. Average annual releases were 701,500 acre-feet from Caballo Dam (25 miles downstream from Elephant Butte Dam) for 18 years of record.

The Elephant Butte Reservoir hydrographic record in Figure 5 shows the inflow, outflow, and storage for the period 1915 to 1956, inclusive.

Slope of River Channel

Average slopes of the Rio Grande above Elephant Butte Dam as determined from the 1951 to 1954 surveys are as follows:

Miles above Elephant Butte Dam	Slope feet per mile
50-55	3.47
55-65	3.90
65-75	4.28
75-90	5.07

The decreasing slopes indicated above tend to reduce or flatten the peak flows, thus, retarding rapid run-off. This, along with normal diversions for irrigation has caused bank caving, stream braiding, meandering, or aggrading of the main channel. The general over-all meander pattern of the Rio Grande is very characteristic of a stream heavily laden with sediment.

The slopes of many of the tributaries and arroyos flowing into the Rio Grande are generally much higher than those cited above for the main stem. Bank caving (Photographs 3 and 4) is often severe in these tributaries during high flows which are capable of moving large quantities of coarse sediments into the main river channel of the Rio Grande.

SURVEYS, SAMPLING, AND EQUIPMENT

History of Surveys

The original survey of Elephant Butte Reservoir was made by the Bureau of Reclamation during the periods 1903-1904 and 1907-1908. Additional level lines run by the same agency in 1916 and 1917 provided data which were used to correct maps made from the original survey.

In 1925, the upper two-thirds of the reservoir was resurveyed by this Bureau. The capacity curve, drawn from these data, was extended to cover the lower portion of the reservoir.

The Soil Conservation Service, United States Department of Agriculture, resurveyed this reservoir during the period March 2 to May 15, 1935 (Eakin, 1936). Final computations of the data from this survey were made by the Bureau of Reclamation.

The Bureau also conducted the following reservoir resurveys subsequent to 1935:

a. In 1940 the lower two-thirds was surveyed with curve extension for the upper portion.

b. A complete resurvey in 1946-1947 (Seavy, 1949).

c. Estimate and partial survey for silt deposits in 1951.

d. A complete resurvey in 1957 (subject of this report).

Area and capacity curves, dated September 17, 1957, prepared by the Rio Grande Project office, El Paso, Texas, are plotted in Figure 6 for the original 1935 and 1957 surveys. This figure also shows a table of the areas and capacities for all records of survey.

Present plans call for the continuation of partial resurveys of the reservoir about every 5 years and a complete instrument survey each 10-year period.

Method of Survey

The method of surveying the inundated area of the reservoir involved taking soundings generally along each range line and at other random points necessary for defining the contours. A plane table was cut in at the various points near the shoreline as necessary, using secondary horizontal control which had been previously established. Vertical control was obtained by using the reservoir water surface elevation which was read at the dam at the beginning and end of each survey period generally consisting of 1 day. Two men worked the table; one man locating the boat as to direction with the alidade and the other man obtaining distances to the boat by shooting stadia with a transit. The boat party, consisting of three men, proceeded along flagged sedimentation ranges or at random locations as determined from inspection of the plane table sheets. Soundings were taken as necessary. At the instant each sounding was made, a member of the boat party signaled the tablemen so that its location could be plotted on the plane table sheet. Soundings were reduced to elevations and plotted on the plane table sheets. Additional shots above shoreline were taken in several areas where it appeared that a significant amount of sediment deposition had occurred.

Between sedimentation Ranges 73 and 68 there were large swamp areas of extremely unstable and dangerous silt beds which could not be traversed by foot. An air boat (Photograph 5) and another small, flat-bottomed boat equipped with a Clinton air-cooled outboard motor were used to travel over these areas. Both horizontal and vertical secondary controls established from the primary system were run in on each side of these silt beds. A plane table traverse was then run along the accessible shoreline of the silt beds and into them as required.

The remainder of the "lower reservoir" or that area located between Range 59 and Elephant Butte Dam was surveyed by plane table. The area through the Narrows, Ranges 59 to 50, was profiled along the sedimentation ranges and a plane table traverse was run along the axis to locate the river channel and side sediment deposits. Secondary control in the "upper reservoir" area from sedimentation Ranges 50 to 9 was established from the head of the reservoir and along the conveyance channel (discussed later in the report) down to about Range 50. From Range 50 to the Nogal Canyon area in the vicinity of Range 38, regular plane table topography and range profiles were taken.

Heavy brush and dense undergrowth were observed above Range 38 to the head of the reservoir and between the conveyance channel and the west side of the reservoir. Accordingly, a tractor with a dozer attachment was needed to clear the range lines. Intermediate lines roughly parallel to the sedimentation ranges were also cleared at intervals of from 1,500 to 2,000 feet. These sediment ranges and intermediate lines were run in with a plane table or profiled with a level.

Topography was taken in the San Marcial vicinity and the 4420 contour established in the extreme upper limit of the reservoir area.

The reservoir elevation and capacity varied during the survey periods as follows:

Year	Month	Day	Elevation (feet)	Capacity (acre-feet)
1956	October	16	4, 269. 51	28, 000
1956	October	23	4, 269. 75	28, 500
1957	February	4	4, 277. 90	50, 400
1957	February	14	4, 279. 41	55, 900
1957	March	7	4, 283. 78	74, 400
1957	March	8	4, 283. 91	75, 000

Because the reservoir was at such low levels, the echo sounder could not be used in performing the survey.

Sampling of Reservoir Deposits and Equipment Used

Samples of the reservoir sediment deposits were obtained with four different instruments:

a. Subaqueous sampler

b. Radioisotope densitometer or RSD (Timblin and Florey, 1957)

c. Piston sampler

d. Pipe sampler

Photographs 6, 7, 8, and 9, show views of each type sampler used.

The subaqueous and pipe samplers were used to secure a total of 75 samples in March 1952. The results of the laboratory analysis made of these samples are listed in Table 1. Data for each sample include: sample number, unit weight, percentage gradation within specific micron ranges, and location where the sample was taken.

In the 1957 resurvey a total of 39 samples was taken using the subaqueous, piston, radioisotope densitometer, and pipe-driven samplers. Twenty of the samples were obtained from within the inundated area of the reservoir, 17 in the exposed deposits, and 2 in San Marcial Lake. Table 2 contains the information compiled for these samples. The radioisotope densitometer and subaqueous sampler were used to obtain a total of 16 samples at relatively the same location. The information pertinent to these samples is recorded in Table 3. The piston sampler was used to take three samples, two of which were in the San Marcial Lake area and the third at Range 68. The pipe-driven sampler was used to remove samples in the exposed areas of the reservoir delta.

The maximum sample depth obtained by the subaqueous sampler was about 6 feet in a recorded 10-foot penetration. Reasons for this incomplete recovery were not immediately evident because the instrument could not be observed as it traveled downward through the water and when it penetrated the reservoir deposits. Factors contributing to such poor recoveries include compaction, tube plugging, nonvertical penetration, and excessive friction between the sampler and sampler tube. The point of compaction in this instrument is described as a pressure bulb formed below the tube sampler. When a slight amount of compacted sediment is captured in the sampling tube, it acts as a plug in the lower end. As the sample plunges to a lower depth, there is an increase in the intensity of the pressure bulb below the tube sampler.

Practically full recovery was obtained for the 2-foot penetration samples that were taken for the purpose of comparing with those measured of in-place deposits by the radioisotope densitometer. Penetration depths of samples taken by the subaqueous sampler equaled or exceeded those taken by the radioisotope instrument. Retraction of the RSD from the deposits, however, was sometimes difficult. This was primarily due to the physical structure of the instrument. Because of the consolidated, dried-out condition of the exposed deposits, the depth of penetration was limited for samples taken with the pipe sampler. In most cases, the top 3 inches to 1 foot of overlying material in the exposed deposits was removed before taking the sample. Full recovery (8 inches) was accomplished for all samples taken by the piston sampler.

A sounding weight operated by a reel was used to measure the depths at intermediate points along the range lines and at other locations as required. Photograph 10 shows how this apparatus was rigged for operation.

Photograph 5 shows the special air boat used to traverse the shallow areas of mud deposits at the head end of the reservoir for survey and sampling purposes. Another boat was rented for these same purposes during the survey. No photographs are shown for this second boat, but it is described as a small aluminum boat with a shallow draft and propelled by a small air-cooled outboard motor.

Density Currents

Periodic observations of density flows have been made throughout the history of the Elephant Butte Reservoir operations. Table 7 contains the record of all inflowing and outflowing density currents that have been observed to the present time.

METHODS OF COMPUTATION

Reservoir Area and Capacity

Personnel of the El Paso, Texas office were responsible for computing the area and capacity of Elephant Butte Reservoir from the 1957 survey data.

It was first necessary to retrace a new topographic map of the reservoir from the original topography sheets used in making the 1935 map. The new map having a contour interval of 10 feet, furnished the base for computing areas and volumes of the reservoir.

The reservoir areas were determined by planimetric measurement. First, the contour lines taken from the plane table sheets were plotted on the new reservoir topographic map. Next, the areas bounded by each 10-foot contour were planimetered beginning at elevation 4230 and ending at elevation 4410. A special measurement was also made of the area encompassed by elevation 4407 which is at the spillway crest level. An areal table and curve resulting from these planimetric measurements are presented in Figure 6.

To determine the reservoir volume it was necessary to read the area values (a_1, a_2) at each 2-foot contour from the area curve of Figure 6. The average end-area formula was used to compute volumes, thus: Volume = $(a_1 + a_2)(ci/2)$ where ci is the 2-foot contour interval.

Since ci = 2, the formula reduces to: Volume = $a_1 + a_2$. Totaling these computed incremental volumes resulted in the capacity curve and table also shown in Figure 6 for the 1957 survey.

From Figure 6, total sediment volume accumulated for any survey period can be determined by subtracting the differences in capacities at the reservoir level and period involved. For example, the sediment volume at spillway crest elevation (4407) between the original and 1957 surveys is 2,634, 800 - 2,206, 780 = 428,020 or about 428,000 acre-feet.

Unit Weights of Deposited Sediments

Unit weights of reservoir deposits were determined by laboratory analysis of the samples obtained with the subaqueous, piston, and pipe samplers. Grain size analyses were also made of each sample. Unit weights computed from this grain size information were compared with the unit weights determined by laboratory analyses of the collected field samples. Miller's (1953) computational procedure was followed.

An example of the computation for one of the samples is illustrated below. First, the unit weight of the sediments for a 1-year period is computed. Next, a computation is made to determine a compaction correction for the sediments in a reservoir of specified operation. In the example a 5-year compaction period is considered.

Given:

Sample No. 46

a. Unit weight determined by laboratory analysis = 35.5 pounds per cubic foot.

b. Size analysis shows composition of sample as follows:

Material	Micron Range	Percent
Clay	less than 4	63.2
Silt	4 to 62.5	33.3
Sand	62.5 to 2,000	3.5
	Total	100.0

c. Reservoir operation: Sediments always submerged or nearly submerged.

Computations:

Unit weight (1 year) = (0.632 x 13) + (0.333 x 67) + (0.035 x 88)
= 33.6 pounds per cubic foot

Compaction correction:

$$K = (0.632)(16) + (0.333)(5.7) = 12.0$$

$$W \text{ (average 5 year)} = 33.6 + 0.4343K \left[\left(\frac{5}{5-1}\right)(\ln 5) - 1\right]$$

$$= 33.6 + (0.4343)\left[(12.0)(1.25)(1.61) - 1\right]$$

= 38.9 pounds per cubic foot (compared to to 35.5 pounds per cubic foot--unit weight by laboratory analysis)

Unit weights from radioisotope measurements were determined from the equation:

$$D = \frac{G\,(W - 62.4)}{(G - 1)}$$

where:

D = dry density or unit weight in pounds per cubic foot
G = specific gravity
W = wet density as determined by the radioisotope densitometer

A nomograph (Timblin and Florey, 1957, page 27) has been constructed (Figure 7) to show the above relationship. To use this nomograph the wet density of the saturated sediment field sample is determined by the RSD which indicates the relative proportions of two materials, water and sediment. Knowing the specific gravity of these two constituents and their proportion, the dry density or unit weight of the sediment can be determined through the scaler relationships of Figure 7.

An average unit weight of 54 pounds per cubic foot was computed by using the data of all samples taken in 1952 and 1957.

Approximately 577 million tons of suspended sediment were measured at the San Marcial gaging station for the period covering 1915 through the end of 1957 resurvey. Using the 428,000 acre-feet sediment volume in the reservoir, another estimate of the unit weight was made as follows:

$$\frac{577 \times 10^6 \times 2,000}{428 \times 10^3 \times 43,560} = 62 \text{ pounds per cubic foot}$$

This computation neglects any correction for the unmeasured load which may amount to 10 percent which, if included, would increase the unit weight only a half a pound per cubic foot.

An evaluation of the results of each of the methods to determine unit weights will be discussed subsequently in this report.

ANALYSIS OF SEDIMENTATION

General

The various factors influencing sedimentation in Elephant Butte Reservoir, are similar to those characteristic of other reservoirs in the southwestern United States, where extreme variation in both inflow and concomitant sediment loads is common. The manner and rate of sediment deposition are dependent on numerous interrelated factors characteristic of the watershed above the reservoir, influence by man, and type of reservoir operation. Some of these factors are as denoted below:

a. Effects of sediment sources including vegetation and extent of source areas, geology and soils, and land use

b. Frequency and magnitude of run-off transporting sediment

c. Size of available material for transport

d. Total capacity, area, and sediment volume of reservoir

e. Effects of reservoir stage fluctuations

f. Effectiveness of vegetation along the channel and in the reservoir headwaters

g. Effectiveness of such other factors as follows:

   (1) Longitudinal distribution

   (2) Lateral distribution

   (3) Sediment disposition

   (4) Trap efficiency

   (5) Unit weight analysis

   (6) Conveyance channel

   (7) Density currents

Data are not sufficient to make a thorough quantitative evaluation of each factor listed. The following discussion, however, presents a practical analysis of some of these factors.

Effects of Sediment Sources

The source areas producing sediment above Elephant Butte Reservoir have been generally described in a previous section (page 6) discussing the drainage area. Use of land in the Rio Grande watershed is limited primarily to agricultural development. This is classified either as irrigated farming or as ranching. A relatively minor amount of dry farming is done in the higher elevations. Some mining and timber production are present, but in small quantity. Highways and railroads have been constructed through the most accessible and scenic portions. Towns are scattered and numerous dams and irrigation systems have been constructed. A considerable amount of grazing is also carried on.

The influence of all of the fore-mentioned activities on sediment production in the Rio Grande watershed is not evaluated in this report, but they undoubtedly would have considerable effect upon such production.

The following is a rough estimate of the proportion of sediment carried by the Rio Grande contributed by each of the respective tributary sources:

Tributary	Percent
Rio Grande above Cochiti	19
Santa Fe Creek	1
Galisteo Creek	3
Rio Jemez	12
Rio Puerco	35
Rio Salado	13
Minor tributaries	17

Frequency and Magnitude of Run-off Transporting Sediment

The frequency and magnitude of run-off from the sediment producing areas above Elephant Butte Dam are extremely variable owing to the changes in elevation, channel length and slope, climate, rates of precipitation, soil types, vegetation, land use, and other causes. These factors have been described previously.

The action of surface run-off is the immediate source of all sediment. Frequency and magnitude of run-off, therefor, determine to a great extent the amount of sediment picked up from previously weathered material, the extent to which a surface may be cut by the moving water, and the ability of the stream to move sediment in the channel.

When an area is subject to intense rains for short durations, as is the case over most of the sediment contributing area above Elephant Butte Dam, sheet and gully types of erosion occur and large quantities of sediment may be moved during short periods. This is especially characteristic of the Rio Puerco (Photograph 11), a large upstream tributary, and numerous other arroyos. The stream beds of these tributaries become clogged with sediment and bank cutting is often severe. At the mouths of the short arroyos leading into the tributaries, debris cones are often formed, followed by lateral erosion and bank cutting which, in turn, feeds the tributary with readily available sediment. It is not uncommon to measure sediment concentrations of as much as 10 to 20 percent, by weight, in these streams, but the peaks are sharp and flow duration short. Photographs 11, 12, 13, 14, and 15 depict the material carried by streams of this type.

Sediment production from the mountainous areas of southern Colorado and northern New Mexico is governed to a great extent by the rate of weathering and would be considerably less than that for the plains portion where it is governed by the intensity of surface run-off acting upon previously weathered material and soft deposits.

Tributaries in the plains portion are generally longer and of much larger drainage area than those of the mountainous area. These areas are subject to thunderstorm activity and their flood peaks are sharp. Concentrations of sediment in these tributaries will vary, depending on antecedent conditions and duration of the storm. For example, a large flood following a period of low flow tends to have high concentrations during its rise on up to its peak flow, whereas there is considerably lower concentration on its recession. With the successive occurrence of a number of medium or high-peak flows, spaced only a few days apart, the sediment concentration pattern shows a marked decrease for the same discharge of successive flow on a rising and falling stage. Because of a diversity of soil types, vegetal cover, and other factors, there is much variation in relationship between the quantity of run-off and sediment concentration, even along the same tributaries.

Size of Available Material for Transport

The size of material available for transport is an important factor influencing the quantity of sediment and the manner of transport in the stream system. It also determines to a great extent where the sediments will be deposited along the stream channel and in the reservoirs. Sediment studies conducted on the Upper and Middle Rio Grande indicate that steep side tributaries and arroyos carry appreciable quantities of coarse material having variable effects on the stream regimen. Most of these streams lose a considerable amount of their coarse load before reaching the main stem; however, that part which does reach the Rio Grande is dropped mainly at the confluence where the sediment transport capacity changes owing to such factors as the change in slopes and average material size and the difference in hydraulic systems of the tributary and main channel. The remaining load is spread generally throughout the reach immediately downstream from the confluence. Photographs 13, 14, and 15 show some of the types of sediments carried by tributary streams.

The following tabulation shows the average for clay, silt, and sand in the suspended sediment load at six stations on the Rio Grande above Elephant Butte Reservoir. They are listed in downstream order.

Station	Suspended sediment samples*		
	Percent clay	Percent silt	Percent sand
Otowi Bridge	20.5	33.9	45.6
Bernalillo	26.1	40.5	33.4
Bernardo	25.6	38.6	35.8
San Acacia	33.6	44.9	21.5
San Antonio	45.9	37.7	16.4
San Marcial	45.4	31.9	22.7

*Using the American Geophysical Union Classification of soils.

The above suspended sediment data show a gradual increase of clay content progressing downstream with the silt content remaining fairly constant and the sand amounts decreasing. This indicates that the bulk of suspended sediments being in clay and silt range is carried in suspension downstream until they are either diverted from the river by irrigation works or are deposited in Elephant Butte Reservoir.

For the same stations, size analyses were made of the sediments representing the bed material. These results are shown below:

Station	Average bed material		
	Percent clay and silt	Percent sand	Percent gravel
Otowi Bridge	0.5	80.2	19.3
Bernalillo	2.0	96.0	2.0
Bernardo	2.0	97.4	0.6
San Acacia	1.1	96.0	2.9
San Antonio	7.2	92.7	0.1
San Marcial	11.8	88.0	0.0

Samples collected for compiling the above table were very meager for some of the stations. The size analyses performed in the laboratory were not carried out to determine the break-down between the clay and silt ranges because of the small amount available in these ranges. This is not too significant, however, as the greatest amount shown is only 11.8 percent. The above tabulation indicates a trend of reducing sand size quantities for stations in downstream order as was similarly indicated for the suspended sediments listed previously.

Using all 114 samples taken in 1952 and 1957 of the sediments deposited in the reservoir and averaging the gradation in the various size ranges gives the following results: clay, 54.6 percent; silt, 32.7 percent; and sand, 12.7 percent. Assuming this to be representative of the general gradation of the deposits, it can be reasonably concluded that most of the sediments are trapped by the reservoir. The increase in clay content indicates that the majority of fines are settling in the reservoir.

Total Capacity, Area, and Sediment Volume of Elephant Butte Reservoir

Results of the 1957 resurvey of Elephant Butte Reservoir indicate its present capacity is 2,206,800 acre-feet at spillway crest elevation 4,407 feet. This amounts to a depletion of 16.2 percent or 428,000 acre-feet considered as the total sediment volume. The current survey shows there was a net capacity gain of 9,200 acre-feet since the 1947 survey and a gain of 21,400 acre-feet since the partial survey of 1951.

Comparing the results of the 1957 and 1947 surveys shows greater volumetric deposits of sediment in the lower portion of the reservoir, particularly below elevation 4,290 feet at which there was a reduction in reservoir capacity of about 17 percent. In this 10-year interim period the reservoir was operated at rather low stages during which time it is apparent the main channel traversing the reservoir area seldom overflowed its banks and the bulk of incoming sediments consequently were conveyed to the lower reservoir levels.

The period between 1947 and 1957 also showed (Figure 6) there were areal gains in elevations ranging from 4,330 to 4,390 feet, with a maximum gain of 707 acres at elevation 4,370 feet. For this same range in elevations the period between the 1947 and the 1951 partial surveys showed generally the opposite, that is, a loss in areas. In 1951 reservoir conditions showed the entire upper lake was largely a swamp. The water table was lowered in this area upon construction of a conveyance channel which drained the area for a period of more than 5 years after the 1951 survey. Lowering the water table accelerated the compaction of sediments in the upper reservoir, particularly between the Narrows and Nogal Canyon. This lowering or settling of sediments by compaction, however, was not as severe in the upper end of the reservoir, as the areas above elevation 4,390 feet did not show any significant changes since the 1947 survey.

There was a decrease of 3,476 acres in the reservoir area at spillway crest elevation since the original survey. The present area at this same elevation is 36,584 acres (Figure 6).

The seemingly paradoxical gains both in reservoir capacity and area between the 1947 and 1957 surveys are presumably due to the compaction or settling of sediments as previously described. Inflows to the reservoir being far below average during this period would also tend to increase the compaction of sediments since they remain in a prolonged desiccated state.

Complete area and capacity data both in tabular and graphical form for all surveys are shown in Figure 6.

Effects of Reservoir Stage Fluctuations

The following table shows the average annual month-end elevations for Elephant Butte Reservoir from 1945 to 1956:

Year	Month-end elevations in feet
1945	4,374.63
1946	4,348.72
1947	4,321.37
1948	4,329.67
1949	4,338.02

Year	Month-end elevations in feet
1950	4,325.21
1951	4,283.38
1952	4,300.23
1953	4,296.25
1954	4,279.70
1955	4,287.79
1956	4,283.45

The average month-end reservoir elevation from 1945 to 1950 was 4,329.60 feet at which the capacity is less than 500,000 acre-feet based on the 1957 capacity curve. For the 1951 to 1956 period, the respective values were 4,288.47 at less than 200,000 acre-feet capacity. The maximum month-end elevation 4,384.74 feet during this period was in June 1945 and the minimum of 4,260.33 feet occurred in July 1954. In general, during these 12 years, drought conditions prevailed.

Since the 1947 survey, the reservoir has operated between a maximum stage of 4,351.30 feet on July 29, 1949, and a minimum of 4,258.03 feet on August 6, 1954. During the period between the 1947 and present surveys, the mean monthly reservoir stage was below elevation 4340, and the storage was confined to the lower reservoir during 101 months. Inflow at San Marcial during the period between the 1947 and 1957 surveys was 4,165,438 acre-feet. About 90 percent of this inflow, or 3,760,000 acre-feet, entered the reservoir while the stage was at or below elevation 4,340 feet.

The continual change in pool stage has a material effect on the depositional pattern of sediments entering the reservoir. There is a tendency for the finer-grained sediments to settle toward the dam with the coarser material depositing more at the head end of the reservoir. This condition is very evident from the samples of reservoir deposits collected in 1952 and 1957. The unit weight graphs in Figures 15 and 16 show the results of the samples taken during these years. The cluster of points of lower unit weights were of the samples gathered nearer the dam; those clustered at the higher unit weight range were taken from the head end of the reservoir. There are very few samples that appear between the 40- to 60-pounds-per-cubic-foot range.

The continual draw-down of the reservoir during this period undoubtedly had a significant effect on the compaction of reservoir sediments. The deposits were exposed to the sun for prolonged periods, hence, they tended to dry out which would increase the initial unit weight.

Effects of Vegetation--Elephant Butte Reservoir

There is a prolific growth of salt cedars at the head of the reservoir and along the upstream areas of the drainage basin as can be seen in Photographs 16 and 20. Prior to 1930, relatively few salt cedar plants were known to inhabit these upstream areas. Infestation of salt cedar in the Middle Rio Grande Valley increased significantly in both areal and density between 1935 and 1947. A study conducted in the reach of the Rio Grande between Bernardo Bridge and San Marcial showed there had been more than 3,000 acres equivalent area, or an increase of slightly more than 50 percent for the 1947 to 1955 period.

Salt cedar infestation is an important factor in the aggradation of the channel and flood plain of the Rio Grande. Its presence along the channel of the stream accelerates the natural levee-building process by causing a decrease or slackening of the stream velocity next to the banks. When overflow occurs, coarser sediments are deposited in the vegetated areas. In this manner, the rate of the natural levee building is increased and the slope of the natural levee away from the channel is steeper than it would be without the influence of vegetation. Vegetation causes immediate deposition of sediments adjacent to the stream and lessens the amount that will be deposited on the flood plain some distance from the stream. An avulsion can occur breaking through this levee which is strengthened by the presence of vegetation; the size of the avulsion is larger than it would be otherwise. Downstream from the avulsion, the river is effectively blocked from re-entering its old channel and is held to a new course by the natural levee. The presence of vegetation in the flood plain accelerates the deposition of sediment, and if the flood plain has a dense vegetative cover when the avulsion occurs, practically all of the sediment load of the stream will be deposited in this area.

The building of a natural levee and aggradation of the stream channel is frequently the cause of swamp or seeped areas that occur on the adjacent flood plain. These areas are conducive to a further growth of vegetation. If the vegetation is luxuriant, a sediment plug may be formed which splits the stream into many channels. This, in turn, encourages deposition and further increases the size of the sediment plug. The plug generally forms when there is a large flood and an avulsion occurs at a point where the stream channel is several feet above its flood plain. When the stream is split into different channels, it is unable to scour any one particular channel to convey the water through this reach.

No studies have been made to determine the amount of sediment which these salt cedars have prevented from flowing into Elephant Butte

Reservoir. From numerous field observation of the infested areas, it can be concluded that salt cedars and other vegetation play a significant part in the complex process of sediment transport and deposition. Determining how much sediment is deposited by action of salt cedars would make an interesting and useful study. Continued studies are also necessary in the development of newer and effective methods of controlling or preferably totally eradicating these nonbeneficial phreatophytes.

Longitudinal Distribution

The variation of the sediment thickness in Elephant Butte Reservoir is presented graphically in Figure 8. The original 1935, 1947, and 1957 longitudinal profiles of the main arm thalweg* are shown. It is noted that two profiles for the 1957 survey are shown beginning approximately at 22 miles upstream from the dam. One of the profiles is based on the thalweg as defined by the conveyance channel which was constructed in 1954 and extended down the reservoir to about this point. The other profile is based on the thalweg defined by the floodway contours above the 22-mile point.

This graph shows that between the 1947 and 1957 surveys considerable channel degradation occurred in the vicinity of the Narrows particularly between the elevations of 4300 and 4340. Degradation averaged about 3 feet from Range 21 to Range 40, below Nogal Canyon. Maximum vertical degradation of about 20 feet is noted at approximately 1 mile below Range 57. The area from the dam to about 10 miles upstream indicates some aggradation occured.

Below normal inflows prevailing in the last 10 years and the accompanying changes in reservoir operation had definite effect on the shape of the 1957 profile. A change in the climatic conditions causing sustained normal or above normal inflows with proportional changes in sediment movement would define another longitudinal profile for the main channel.

A further examination of the 1957 profile shows considerable movement of the top-set and fore-set bed sediments into the area occupied by bottom-set bed sediments. This movement, however, applies only to the thalweg as defined by the single profile shown for the reach between the dam and the 22-mile point upstream from which the floodway profile should be applied. Long-term movement of sediments in the valley areas follow a different pattern as discussed in the next section of this report on lateral distribution of sediments.

*Thalweg in this report is the trace defined by projecting each contour at its farthest upstream point normal to a pre-established base reservoir axis.

The following tabulation lists the 1915 (original) and 1957 thalweg elevations to the nearest 1/2 foot at 2-mile intervals up to spillway crest elevation. These values, scaled off Figure 8, typify the general trend of sediment movement within the reservoir:

THALWEG ELEVATIONS

Miles above Elephant Butte Dam	Elevation (feet) 1915	Elevation (feet) 1/ 1957	Elevation (feet) 2/ 1957
0	4,214.0	3/ 4,221.0	3/ 4,221.0
2	4,220.0	4/ 4,246.0	4/ 4,246.0
4	4,234.5	4,256.5	4,256.5
6	4,246.0	4,266.5	4,266.5
8	4,254.0	4,277.0	4,277.0
10	4,262.0	4,286.0	4,286.0
12	4,273.0	4,295.5	4,295.5
14	4,282.5	4,305.0	4,305.0
16	4,294.0	4,315.5	4,315.5
18	4,304.5	4,325.0	4,325.0
20	4,312.0	4,333.0	4,333.0
22	4,325.0	4,346.0	4,344.5
24	4,334.0	4,360.5	4,355.0
26	4,340.0	4,368.5	4,363.0
28	4,342.5	4,374.5	4,370.0
30	4,358.5	4,380.0	4,376.0
32	4,368.0	4,385.5	4,383.0
34	4,375.5	4,391.0	4,390.5
36	4,383.0	4,398.5	4,395.0
38	4,391.0	4,406.0	4,400.0
40	4,399.0	-	4,405.5
41.2	4,407.0	5/ 4,407.0	6/ 4,407.0

The above data indicates average slopes of 0.000888 and 0.000922 for the years 1915 and 1957 (based on floodway profile), respectively. General breaks in the profiles are noted at the following locations:

1/ Based on floodway contours above 22-mile point.
2/ Based on conveyance channel contours above 22-mile point.
3/ 1935 thalweg.
4/ 1947 thalweg.
5/ At 38.2 miles.
6/ At 40.6 miles.

Miles above dam (along reservoir axis)	Slopes in foot per foot 1915	1957 (based on floodway profile)
6	0.00110	0.000843
16	.000909	.000861
24	.000947	.000949
38	.000865	.000636

Photographs 17, 18, 19, 20, 21, and 22 show views typical of the upstream areas.

Lateral Distribution

The lateral distribution of sediments in the lake is depicted by typical cross sections of Ranges 89, 57, 29, 21, 12, and 10 in upstream order shown in Figures 9 and 10.

Examining the 1947 and 1957 profiles shows there has not been any extreme change in the cross-sectional areas of the ranges depicted. Range 57 in the Narrows area shows the greatest change that occurred and this was due to the degradation process described in the preceding section. Ranges 89, 21, and 29 show slight degradation in the western side of the valley cross section. Range 12 shows some aggradation in the eastern side of the valley and negligible changes in the western valley.

Cross-section profiles of Monticello and Nogal Canyons in Figure 11 also show very little change.

The upstream cross-sectional profiles remained practically unchanged primarily because of the drought conditions during the 1947 to 1957 period and the reservoir operating at levels considerably below the lower elevations of these ranges. A tabulation of the average annual month-end reservoir elevations discussed in a previous section shows the reservoir seldom exceeded the 4300 elevation during that period.

Sediment Disposition

The 1957 sediment disposition is portrayed by the curve plotted in Figure 12. This curve indicates that the sediment was deposited relatively uniform in the lower part of the reservoir with greater amount in the upper areas.

Initial sediment studies made of the reservoir when constructed in 1915 did not include the determination of a disposition curve. Studies in the sediment field at that time had not advanced to the stage of predicting the pattern of sediment distribution within the reservoir. As a matter of further practical interest, an analysis was made of the curve based on current procedures (Borland and Miller, 1958) using the 1915 data. A logarithmic plotting (Figure 13) was made of depth versus capacity to classify the reservoir by type. From this plotting, it was found that the reservoir would have been classified as Type I to a depth of about 60 feet and Type II above this depth. A study of the 1957 curve defined from observed data in Figure 12 shows a reversal of this classification. The plot in this figure shows the 1957 curve follows a Type II curve to about the 30-percent depth range, and from the 30- to 60-percent depth it is in transition to a Type I. It follows a Type I closely on upward to the 100 percent of the total reservoir depth.

The preceding analysis points up the need for considering factors other than just the depth-capacity relationship in sediment disposition studies. Among the other major factors to be considered are the following as quoted from the report (Borland and Miller, 1958) previously referred to:

a. Reservoir shape

b. Sediment characteristics:

   (1) Textures of sediments

   (2) Grain sizes and shapes

c. Reservoir operation

d. Sediment-reservoir volume ratio

e. Inflow-capacity relationship

Each of the above factors has an effect on the sediment disposition in Elephant Butte Reservoir. All of them, however, have not been quantitatively evaluated. Two additional important factors influencing the pattern of sediment deposition in this particular reservoir are the salt cedar infestation in the delta area and the sediment-laden flows of the side tributaries which drain directly into the reservoir.

Sediment distribution in various elevation intervals is represented by the bar graph in Figure 14. The elevation range in feet above and below crest elevation is plotted on the abscissa and there are two ordinates representing the sediment volume and percent of total sediment on the left- and right-hand scales, respectively. The percentage values are based on the 428,000 acre-feet total sediment volume for the 1915 to 1957 period.

The greatest percent of total sediment is accumulated in the upper area where it is noted that about 62 percent of the total lies above elevation 4340. The greatest sediment accumulation lies in the 4360 to 4380 elevation range which amounts to about 96,300 acre-feet.

By way of contrast, the longitudinal thalweg profile in Figure 8 shows some degradation in excess of 20 feet in the 4300 to 4340 elevation range; the bar graph of Figure 14 indicates that 13 percent of the total sediment has accumulated in this same range.

Trap Efficiency

A determination of the trap efficiency for this reservoir could not be made because of the insufficient records of sediment inflow and outflow available as of this resurvey. The capacity-inflow ratio for the reservoir computes to 2.17 based on the present storage capacity of 2,206,708 acre-feet. This ratio indicates a trap efficiency of 97 percent from Brune's (1953) median curve for normal ponded reservoirs. Brune determined a trap efficiency of 98.6 percent for Elephant Butte Reservoir in his original investigations.

A trap efficiency estimate of 95 percent is judged reasonable upon considering the slow rate of reservoir releases which, in turn, allows more time for the incoming sediments to settle out.

Unit Weight Analysis

Establishing a unit weight for Elephant Butte Reservoir has been a long sought and interesting objective. Follett (1914) who pioneered the work in this field arrived at a unit weight of 53 pounds per cubic foot. He based this determination on a single sample consisting of a 3-inch cube taken under carefully selected conditions. Admittedly he made a realistic appraisal of the results arriving at this unit weight as evidenced from his concluding remarks quoted below:

> "It may be objected that the results involved are too important to make them depend upon one single observation, as was done in this case. In reply it should be stated that the conditions under which the silt will settle in the reservoir are not well known and that there are enough other indeterminate factors in the problem to render it probable that this one sample, deliberately and intelligently chosen by two trained men (Follett and B. M. Hall) who were fully conversant with all the conditions confronting them and who were careful in their selection of the sample, would give a result fully as good as might come from

> the mean of many samples taken with less care. Moreover, the result appeared to be reasonable."

It is of further interest that Follett took this sample in 1904, 12 years before Elephant Butte Dam was completed.

Hemphill (1931) in a later survey further appraised Follett's results and summarized them as follows:

> "Follett made no estimate of the silt rolled along the bottom of the stream but stated the belief that it might possibly amount to as much as 25 percent of that suspended. Accepting this ratio as a maximum, the results of the survey gave a unit value of 65 pounds per cubic foot of deposit. It is believed that they (the Rio Grande sediment records) were accurate enough to indicate fairly that suspended silt in the Rio Grande will form deposits containing from 55 to 65 pounds per cubic foot of silt."

Seavy (1949) estimated the average unit weight to be 65.9 pounds per cubic foot based on the 1947 survey data and further predicted the ultimate unit weight of sediment deposits would be slightly more than 73.3 pounds per cubic foot. He arrived at these values applying the formula developed by Lane and Koelzer (1943). In the summary of his report, Seavy is quoted as follows:

> "When adequate sampling equipment is available for obtaining representative samples of the sediment deposited in Elephant Butte Reservoir, it would be very desirable to obtain samples in order that the average density (unit weight) of the deposited materials could be determined."

Mr. H. Stabler (1911) carried out studies on a unit weight assumption of 85 pounds per cubic foot. He believed this weight to be representative of the sediments carried by the Rio Grande flowing past San Marcial and down in the vicinity of the proposed Elephant Butte Dam known then as Engle Dam.

Coghlan and Lieb (1916) obtained 17 samples during 1916 at various locations in the delta area about 15 miles upstream from the dam. Their results are tabulated below:

Sample No.	Unit weight pounds per cu ft	Sample No.	Unit weight pounds per cu ft
A-1	90.99	B-3	94.59
A-2	91.03	B-4	92.25
A-3	93.36	B-5	88.21
A-4	88.58	B-6	94.09
A-5	101.18	C-1	94.83
A-6	66.38	C-2	90.68
B-1	87.90	C-3	90.22
B-2	91.74	C-4	99.57

They averaged the above results and obtained a 92.34-pounds-per-cubic-foot unit weight.

Mr. A. E. Fenz (Bureau of Reclamation, 1914) derived a unit weight of 97.6 pounds per cubic foot from analyses that were made of 96 samples collected in 1914. Unfortunately the analytical results of any of the observed samples were not recorded.

Mr. J. C. Stevens (1946) arrived at a unit weight value of 65 pounds per cubic foot by analysis of the San Marcial sediment records available covering the period from January 1915 to September 1940 or 25.75 years. To the total recorded sediment passing San Marcial, he added 15 percent for the bed load or 73.5 million tons and another 72 million tons for the sediment contributed by the tributary drainage area below San Marcial. From this total he subtracted an estimated 6.4 million tons of sediment outflow which determined a net sediment inflow of 629.2 million tons. Knowing the measured deposits to be 442,900 acre-feet he then performed the following computation to determine the unit weight:

$$\text{Unit weight} = \frac{629.2 \times 10^6 \text{ T}}{442,900 \text{ ac-ft}} \times \frac{2,000 \text{ lbs}}{43,560 \text{ cu ft}} = 65.3 \text{ pounds per cubic foot}$$

S. C. Happ (1944) conducted a study of the alluvial deposits in the Middle Rio Grande. His published results include a derivation of an average unit weight of 86 pounds per cubic foot for the Middle Rio Grande Valley sediments. A partial tabulation of the unit weights and size analyses of the samples collected during the year 1941 is shown in table 5. Over 600 samples were also gathered during the period 1937 to 1940, however, unit weight data of each sample were not readily available.

The International Boundary and Water Commission (1937), United States and Mexico, uses an average unit weight of 66.7 pounds per cubic foot. This value was arrived at by a study of the pertinent literature on unit weights available in 1937.

Table 4 summarizes the unit weight results obtained by all the fore-mentioned investigators.

The 114 samples of Elephant Butte Reservoir sediment deposits gathered by Bureau of Reclamation personnel in 1952 and 1957 are the most extensive of record. Results of the unit weight tests of these samples showed values varying from 16 to 100 pounds per cubic foot. The unit weights of all samples collected in these years were arithmetically averaged and resulted as follows:

Year	No. of samples	Average unit weight pounds per cubic foot
1952	75	53.0
1957	39	55.5

A comparison of the computed and observed unit weights is shown in Figures 15 and 16 for the 1952 and 1957 samples, respectively. The procedure set forth by Miller (1953) was used to compute the unit weights (example on page 16). It is noted in these graphs there is a cluster of data about each end of the 100-percent correlation curve somewhat in the form of a dumbbell pattern. Only a few samples lie in the 45- to 65-pounds-per-cubic-foot range. The relationship displayed by either curve is judged to be very good since the majority of points fall within a plus or minus range of 5 pounds per cubic foot which is well within practical limits. This relationship also tends to confirm the applicability of Miller's (1953) procedure to determine the theoretical unit weight of sediment deposits for this particular reservoir.

The graph in Figure 17 plotted from 1957 data in table 3 shows another comparison of unit weights between the observed as gathered by the subaqueous sampler and the unit weights determined by the radioisotope densitometer. Most of the samples were collected in the lower portion of the reservoir and all except one had a unit weight of less than 50 pounds per cubic foot indicating a high clay content.

The relationship in Figure 17 is remarkably well for the 16 samples tested. As a result of these tests and those conducted at other reservoirs, the RSD sampler has demonstrated that it is a highly practical instrument for determining in-place sediment unit weights. The principal advantage over the subaqueous sampler is its ability to secure the samples at a lower cost. Two major disadvantages, however, are the potential radiation hazard involved in operating the instrument and its inability to obtain the gradation of the deposited sediments which is important to the theoretical determinations of unit weight such as prescribed by Miller (1953) discussed previously. Timblin and Florey's (1957) report also includes the results of the samples taken by the radioisotope densitometer during this 1957 resurvey of Elephant Butte Reservoir. Their report contains a detailed description of the operation and applicability of the instrument. Future plans include further tests of the radioisotope densitometer.

In Figure 18, an attempt was made to investigate the occurrence of compaction of the deposited sediments which played an important part in the unit weight analyses and helped to explain the increase in capacity since the 1947 survey. This graph shows the unit weight results of 12 reservoir deposit samples gathered at the same ranges for the years 1952 and 1957. It is noted that all but two of the samples showed an increase in unit weight during this period substantiating the conclusion that the sediments were compacting. Table 6 containing the basic information for plotting the graph of Figure 18, shows: range location, sample number, unit weight, and the percentage gradation of clay, silt, and sand. Although the samples were not taken at precisely the same location on the range lines in either year, they are judged to be adequately representative of the sediment depositional characteristics and of the compaction conditions developed in the interim period between surveys.

Because of the extreme variance in unit weights of samples gathered in 1952 and 1957, it is difficult to estimate the unit weight representative of all inflowing sediments. Many factors are involved in a unit weight analysis such as the reservoir size (36, 600 acres), reservoir operation, size and texture of inflowing sediments, settlement rate or fall velocity, density currents, and compaction rates. In order to determine the representative unit weight for this reservoir further analyses were carried out based on the quantitive results of the 1952 and 1957 samples.

One calculation resulted in a unit weight of 62 pounds per cubic foot based on the total measured sediment load at San Marcial and the total volume of sediments (below spillway crest) in the reservoir for the period 1915 to 1957. Another computation showed a unit weight of 54 pounds per cubic foot on the basis of a straight arithmetic average of all samples collected in 1952 and 1957. Using Seavy's data (1949), a unit weight of 54 pounds per cubic foot was computed from total measured sediment loads at San Marcial and total sediment volume in the reservoir as of 1947. As mentioned previously, unit weights of 53 and 55. 5 pounds per cubic foot were calculated for the years 1952 and 1957, respectively.

Because of the varying conditions under which the samples were gathered, no quantitative adjustment could be made for such factors as differences in depth of penetration for each sample; granular settlement of some samples while in transit to the laboratory for analysis; and differences in compaction rates of in-place sediments. However, an upward correction in the unit weight is apropos to allow for some of the unaccountable factors, particularly that of compaction. As related before, the trend toward compaction is evident by analysis of the data in table 6 and Figure 18. Accordingly, a value of 60 pounds per cubic foot is selected to be representative of the over-all unit weight of the sediments in Elephant Butte Reservoir. This value does not agree with the conclusions reached by some of the previous investigators; however, it is judged to be reasonable owing to the fact that it is based on more expansive supporting data.

It is interesting to note that Follett's (1914) original unit weight of 53 pounds per cubic foot based on a single observed sample (table 4) is practically identical to the arithmetic average unit weight of all samples collected in 1952 and 1957. It is predicted that in 100 years the average unit weight of the sediment deposits in Elephant Butte Reservoir will be about 70 pounds per cubic foot. This value was arrived at by a review of the past records of the suspended sediment loads of the Rio Grande at San Marcial. Analyzing these records by plotting a relationship of the unit weights against time resulted in a trend which indicated the 70-pound value would be approached in the 100-year period. In the analysis, a 10-percent correction was made for the unmeasured load and it was assumed that 5 percent of the total incoming sediment load would deposit above spillway crest.

Conveyance Channel

The proposed channel rectification work from the head of the Espanola Valley to the backwaters of Elephant Butte Reservoir was approved by the Congress as part of a comprehensive plan for the Middle Rio Grande Project.

Prior to any channelization work in the backwater area of Elephant Butte Reservoir by the Bureau of Reclamation, the state of New Mexico financed some of this type of work through its Rio Grande Development Fund. The Elephant Butte Irrigation and Middle Rio Grande Conservancy Districts provided further assistance in the form of actually supervising the construction work and furnishing the equipment. The Bureau of Reclamation assisted in the engineering work. Under this plan, four channels of approximately 1,000 cubic feet per second and varying in length 1/2 to 3 miles were constructed in the San Marcial area. This area extends approximately 10 miles north of the old town of San Marcial to the Fish and Wildlife Refuge and south 20 miles into Elephant Butte

Reservoir. Many direct benefits resulted from this work including a considerable quantity of water saved and draining and drying of the area in which the first conveyance channel was constructed.

Construction of the first portion of the conveyance channel under the Bureau of Reclamation channelization plan previously mentioned was begun in 1951 and completed in 1954. It was designated as the San Marcial conveyance channel and covered the river stretch from San Marcial to the Narrows of Elephant Butte Reservoir, New Mexico. The construction work was performed under the contract awarded to McGinnes Brothers, Incorporated. Photographs 23 and 24 show two separate views of the channel in the initial construction stage. The conveyance channel was designed for a capacity of 2, 000 cubic feet per second and with a bottom width of 32 feet, side slopes of two to one, and average depth of approximately 11 feet.

In the original design of this channel, cognizance was taken of the difficulties involved in maintaining its stability in the future. Many complexities were faced, such as how to predict the amount of scour and fill for the channel. This, in turn, required some means of predicting the size of bed material that would eventually line the channel. Another factor was to predict the channel shape subsequent to its construction which presented difficulties because of the variable sediment transport loads and the effectiveness of vegetation to protect the banks. The original design was based on the assumption that the soil masses were homogeneous. Such assumption may not be realistic, but it is commonly done in problems of this nature. Photograph 25 shows a current view of extreme channel instability which has resulted in one of the areas of the conveyance channel. These results point up the need for continuing research work in the field of stable channels.

The elevation of the lower end of the conveyance channel is 4, 395 feet (4, 341. 7 feet using datum of Elephant Butte Reservoir surveys). Thus, should Elephant Butte Reservoir ever be filled to the spillway crest level (4, 407 feet), the channel would be inundated for a considerable distance above the Narrows which is its downstream termination point.

There has not been any quantitative estimate made of the sediment load being transported by the conveyance channel. Periodic sampling of the suspended sediment is continuing and as these records are compiled, some determination of the sediment load will be made in future studies. The effect of the conveyance channel on sediment inflow into Elephant Butte Reservoir, therefor, cannot be evaluated at this time although more sediment will be transported into the reservoir by the channel because it is more efficient.

A satisfactory measure of control of many sediment problems which heretofore have plagued the Rio Grande should eventually be brought about by the channel control program as proposed in the Middle Rio Grande comprehensive plan. These measures include the completion of all channelization work, levee construction, bank revetment, floodway excavation, and construction of dams on the main stem and tributaries of the Rio Grande. It is pointed out, however, that water salvage is another major aim of this comprehensive plan.

Change of Sediment Inflow Rate into Elephant Butte Reservoir

In the original studies in 1950, an average unit weight of 70 pounds per cubic foot was used to determine the change of rate of sediment inflow into Elephant Butte Reservoir. The results obtained by this original study are compared with the measured loads in the following tabulation. Another calculation of sediment tonnages is also included, based on a unit weight of 60 pounds per cubic foot as determined by the 1957 survey.

Annual Rate of Sediment Inflow into Elephant Butte Reservoir Below San Marcial, New Mexico

Period	Acre-feet	Tons x 10^6 * (computed)	Tons x 10^6 ** (computed)	Tons x 10^6 *** (measured)
1915-47	14,370	21.9	18.8	16.9
1935-47	7,806	11.9	10.2	9.9

It is noted that the computed exceed the measured tonnages. Assuming this difference to be the unmeasured load the following computations are made to determine the percentage of such load for the 1915 to 1947 period:

Based on 70 pounds per cu ft

$$\text{Percent unmeasured} = \frac{(21.9 - 16.9)\ (100)}{21.9} = 23 \text{ percent}$$

Based on 60 pounds per cu ft

$$\text{Percent unmeasured} = \frac{(18.8 - 16.9)\ (100)}{18.8} = 10 \text{ percent}$$

*Based on 70 pounds per cubic foot unit weight
**Based on 60 pounds per cubic foot unit weight
***Measured at San Marcial

Computations of the unmeasured load for the 1935 to 1947 period show 20 and 3 percent for the 70- and 60-pounds-per-cubic-foot unit weights, respectively.

The above calculations indicate that a 60-pounds-per-cubic-foot unit weight appears more representative of the reservoir sediments. An unmeasured load of 10 to 15 percent is judged to be reasonable for this river channel.

Assuming the average sediment inflow to Elephant Butte Reservoir to remain approximately 10, 200 acre-feet per year as indicated by this survey, the sediment volume would occupy 1, 020, 000 acre-feet of reservoir storage space at the end of a 100-year period at which time the original capacity would have been reduced to 1, 614, 800 acre-feet or by 61 percent. In view of this remaining capacity, it is concluded that the reservoir would have served a useful life (period 1915 to 2015) insofar as present-day Bureau project economic studies are concerned.

Density Currents

Lane and Carlson (1954) summarized the results of studies that were made of density currents observed in several reservoirs including Elephant Butte. A general discussion on density currents presented herein includes some of the information and data contained in their report.

It is very probable that flows from the Rio Puerco have been responsible for most of the density currents observed in Elephant Butte Reservoir. This ephemeral stream which joins the Rio Grande approximately 59 miles from the head end of the reservoir, carries one of the highest measured concentrations of sediment in the world; samples of 680, 000-parts-per-million concentration or weighing up to 68 percent of the total weight have been observed. The composition of sediments flowing from this stream is largely of clay-size particles.

In practically all cases it is noted from table 7 that concentrations of outflowing currents are less than those of the inflowing currents. Some observations show the reverse of this condition which is due probably to the variation of the sediment flow not being accurately defined, sediment samples not being taken often enough, or the flashy nature of the inflow.

Only one density current flow in Elephant Butte Reservoir has occurred since 1935. There were 13 flows in the first 20 years and only one in the second 20-year period. This is probably due to a variety of causes, among them being the growth of vegetation in the upper end of the basin and the shallow nature of the density flows occurring mainly as turbid underflows (Figure 19). Another reason is that present conditions show the channels in the reservoir area are filled. Therefor, the density currents no longer being able to concentrate in a channel must spread out in a thin sheet causing them to disintegrate.

Little data are available on the quantity of sediment carried by density currents. The outflow of July 1919, was estimated to carry 2,500 acre-feet of sediment. Up to about the year 1933, it was estimated that the total sediment outflow amounted to less than 4,000 acre-feet, or under 2 percent of the total sediment inflow for the 1915 to 1933 period. Since that time, the percent removed has been estimated to be less than 2 percent.

Periodic measurements and observations of density currents are being continued. No critical analyses of any of these observed data are contemplated because of the negligible amount of sediments passed through the dam by these density currents. Total sediment passing the dam as of this 1957 resurvey is probably between 4,500 and 5,000 acre-feet or less than 1 and 1/2 percent of the sediment inflow (428,000 acre-feet) for the 1915 to 1957 period involved.

Statistical and Data Summary

A detailed statistical summary shown in table 8 lists the sedimentation and capacity information for Elephant Butte Reservoir based on the 1957 resurvey. Only the sediment deposition below the crest elevation was considered.

Table 9 contains a special summary of additional reservoir sedimentation data. Information of this particular type is compiled for all reservoirs in the United States by the Inter-Agency Committee on Water Resources, Washington, D. C.

SUMMARY AND CONCLUSIONS

The period between the 1947 and 1957 resurveys of Elephant Butte Reservoir was characterized by severe drought conditions. Total water inflow into the reservoir during this period amounted to 4,165,438 acre-feet which averaged 427,000 acre-feet per year or about 43 percent of the long-term (60-year) mean annual of 1,004,000 acre-feet. It is noted from the hydrographic record in Figure 5 that the minimum inflow of record occurred during this period when in 1951 it amounted only to 114,100 acre-feet or 11 percent of the long-term mean. Critical irrigation shortages were experienced for several years.

Total sediment accumulated in the reservoir since the original survey amounted to 428,000 acre-feet. The present storage capacity is 2,206,780 acre-feet and the area is 36,584 acres. There has been a loss of 16.2 percent of the original capacity as of the time of this 1957 survey. The annual average sediment inflow is 10,200 acre-feet. Sediment yield per square mile per year is 0.39 acre-foot. It is reasonably concluded that compaction was one of the major factors causing an increase in the reservoir capacity and area since the last major survey of 1947. Pertinent information on sedimentation and capacity of this reservoir is shown in Figure 6 and Tables 8 and 9. Trap efficiency of Elephant Butte Reservoir is reasonably estimated to be greater than 95 percent. Based on the present trend, the trap efficiency should not reduce appreciably for the next 2 decades.

Analyses and study of the data from representative samples of the reservoir deposits collected in 1952 and 1957 indicate a unit weight of about 60 pounds per cubic foot as an average for Elephant Butte Reservoir. Averaging the gradation curves of the 114 samples collected, results in percentages of 54.6, 32.7, and 12.7 for clay (less than 4 microns), silt (4 to 62.5 microns), and sand (62.5 to 2,000 microns), respectively.

Of the various instruments used to obtain samples of the reservoir deposits, the radioisotope densitometer proved to be the most economical. The major shortcomings of this instrument, however, are its inability to determine the gradation of the deposited sediments and its specific operational technique, particularly with regard to the radiation hazard involved. The subaqueous sampler developed in 1950 secures a fairly representative sample although it is a cumbersome instrument to operate because of its bulky physical structure. The main advantage, however, is its ability to secure an actual physical sample which can be studied by observation for such features as type and texture of sediments and layer formations and can be analyzed in the laboratory for the two main sediment properties of unit weight and size gradation.

The continued salt cedar infestation of the upstream areas of the reservoir poses a menace that is becoming more difficult to overcome. One of the most vicious characteristics of this phreatophyte is its ability to consume excessive quantities of water without benefit to man. This exotic plant that develops a junglelike growth continues defying all efforts to eradicate it. It can be controlled only through considerable effort. A study conducted of an upper reach of the Rio Grande between Bernardo Bridge and San Marcial showed there had been an increase in salt cedar infestation amounting to 50 percent for the 1947 to 1955 period. Considerable channel and overbank aggradation can result from the screening action by the salt cedars of the sediments in transport by the stream. No studies have been conducted to determine the total sediment load intercepted by these phreatophytes.

The upstream channelization and other control works as proposed in the Middle Rio Grande comprehensive plan, when completed, should reduce sediment inflows to the Elephant Butte Reservoir. The principal purpose of the channelization program, however, is for water salvage which is estimated to amount to 170,000 acre-feet per year.

The next partial survey of this reservoir is scheduled for the year 1962 and a detailed instrument resurvey in 1967.

ACKNOWLEDGMENTS AND PERSONNEL

This report was prepared by Joe M. Lara under the supervision of Whitney M. Borland, Head, Sedimentation Section, Hydrology Branch.

The report was reviewed by Mr. Borland and Carl R. Miller, former Assistant Head, Sedimentation Section.

Acknowledgment is made to Mr. Harris R. McDonald, Head, Water Resources and Utilization Section, who provided the material in the section on salt cedar infestation.

Planning and organizing the 1957 resurvey of the reservoir was directed by Mr. William F. Resch, Project Manager, Rio Grande Project, El Paso, Texas. Personnel of the El Paso field office performed the work of drawing new reservoir topography maps and computing new area-capacity tables.

Mr. Lloyd O. Timblin, physicist of the Chemical Engineering Branch, and Carl R. Miller, former Assistant Head of the Sedimentation Section, were responsible for gathering samples of the reservoir deposits using subaqueous samplers and the radioisotope densitometer.

The resurvey was performed at the request of Robert W. Jennings, former Regional Director, Amarillo, Texas.

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Table 1

ELEPHANT BUTTE SEDIMENT SAMPLES OF RESERVOIR DEPOSITS
March 1952

Sample No.	Unit Weight pounds per cu ft	Percent Sediment Grain Size Ranges in Microns			Location
		<5	5-74	74-#4	
1	68.1	26	56	18	Approximately 1,000 feet below Range 25
2	87.8	13	44	43	Approximately 1,000 feet below Range 25
3	85.7	5	40	55	Approximately 1,000 feet below Range 25
4	76.0	55	44	1	Range 27 taken about 1,500 feet from east bank of stream
5	75.8	54	44	2	Range 27 taken about 1,500 feet from east bank of stream
6	69.9	88	12 1/	0	Range 27 taken about 1,500 feet from east bank of stream
7	66.6	72	27	1	Range 29E to Range 30W taken 150 feet west of west bank of new canal
8	90.0	24	12	64	Taken about 2,000 feet above Range 30, 40 feet west of west canal bank
9	66.8	76	22	2	Range 36
10	80.7	28	56	16	Range 36
11	88.5	12	80	8	Range 36
12	93.8	10	76	14	Range 36
13	76.9	57	41	2	Range 36
14	76.7	33	66	1	Range 4
15	66.2	89	10	1	Range 4
16	62.4	91	7	2	Range 4
17	81.6	22	33	45	Range 36 taken on east side of old stream channel about 300 feet from west side of reservoir
18	64.8	86	12	2	Range 36 taken on east side of old stream channel about 300 feet from west side of reservoir
19	58.0	82	16	2	Range 36 taken on east side of old stream channel about 300 feet from west side of reservoir
20	73.5	39	8	53	Range 36 taken on east side of old stream channel about 300 feet from west side of reservoir

Table 1--Continued

Sample No.	Unit Weight pounds per cu ft	Percent Sediment Grain Size Ranges in Microns <5	5-74	74-#4	Location
21	87.7	22	25	53	Range 19W to Range 18E taken about 1,000 feet from west edge of reservoir
22	82.5	37	28	35	Range 19W to Range 18E taken about 1,000 feet from west edge of reservoir
23	85.0	13	70	17	Range 19W to Range 18E taken about 1,000 feet from west edge of reservoir
24	88.8	8	19	73	Range 19W to Range 18E taken about 1,000 feet from west edge of reservoir
25	86.4	7	37	56	Range 19W to Range 18E taken about 1,000 feet from west edge of reservoir
26	72.6	45	41	14	Range 21 taken from left side over-flow or high water channel about 1.3 miles downstream from Range 19, 1,000 feet east of west bank
27	66.7	54	44	2	Range 21 taken from left side over-flow or high water channel about 1.3 miles downstream from Range 19, 1,000 feet east of west bank
28	71.1	40	57	3	Monticello Canyon taken about 1 mile above mouth of canyon, 100 feet from left bank
29	52.7	60	39	1	Monticello Canyon taken about 1 mile above mouth of canyon, 100 feet from left bank
30	82.1	15	39	46	Monticello Canyon taken about 1 mile above mouth of canyon, 100 feet from left bank
31	35.7	80	19	1	Range 66 (origin) to Range 66E taken 200 feet east of the farthest point extending into lake below mouth of Monticello Canyon
32	35.3	76	23	1	Range 66 (origin) to Range 66E taken 200 feet east of the farthest point extending into lake below mouth of Monticello Canyon
33	28.5	90	10	0	Range 66 (origin) to Range 66E taken 200 feet east of the farthest point extending into lake below mouth of Monticello Canyon
34	30.9	92	8 1/	0	Range 66 (origin) to Range 66E taken 200 feet east of the farthest point extending into lake below mouth of Monticello Canyon

Table 1--Continued

Sample No.	Unit Weight pounds per cu ft	Percent Sediment Grain Size Ranges in Microns			Location
		<5	5-74	74-#4	
35	76.8	17	56	27	Nogal Canyon taken about midpoint of canyon and 1 mile above mouth
36	100.0	2	7	76 2/	Nogal Canyon taken about midpoint of canyon and 1 mile above mouth
37	79.3	23	55	22	Nogal Canyon taken about midpoint of canyon and 1 mile above mouth
38	66.2	27	62	11	Nogal Canyon taken about midpoint of canyon and 1 mile above mouth
39	40.9	85	15 1/	0	Indian Grave to Three Cedars
40	39.0	94	6	0	Indian Grave to Three Cedars
41	16.3	83	17	0	Indian Grave to Three Cedars
42	29.9	87	13	0	Indian Grave to Three Cedars
43	40.9	90	10	0	Indian Grave to Three Cedars
44	34.4	89	11	0	Indian Grave to Three Cedars
45	31.8	65	35	0	Opposite Range 77W
46	35.5	79	21	0	Opposite Range 77W
47	40.1	91	9	0	Opposite Range 77W
48	28.3	73	27	0	Opposite Range 77W
49	34.7	89	11	0	Opposite Range 77W
50	40.2	85	15	0	Opposite Range 77W
51	38.8	93	7	0	Old Glory to Range 82W
52	32.9	86	14	0	Old Glory to Range 82W
53	39.7	89	11	0	Old Glory to Range 82W
54	24.8	85	15	0	Range 90 (origin) to Range 90E taken 100 downstream from range line
55	31.6	96	4	0	Range 90 (origin) to Range 90E taken 100 downstream from range line
56	39.0	92	8	0	Range 90 (origin) to Range 90E taken 100 downstream from range line
57	19.6	82	18	0	Grassy Hill to Range 89W
58	29.3	94	6	0	Grassy Hill to Range 89W
59	39.6	92	8	0	Grassy Hill to Range 89W
60	19.6	83	17	0	Range 86G

Table 1--Continued

Sample No.	Unit Weight pounds per cu ft	Percent Sediment Grain Size Ranges in Microns			Location
		<5	5-74	74-#4	
61	29.1	94	6	0	Range 86G
62	38.2	90	10	0	Range 86G
63	18.8	87	13	0	Range 84 to Range 85
64	29.9	91	9	0	Range 84 to Range 85
65	36.5	93	7	0	Range 84 to Range 85
66	30.4	88	12	0	Range 83 to Range 84
67	36.1	77	23	0	Range 83 to Range 84
68	41.0	90	10	0	Range 83 to Range 84
69	25.8	91	9	0	About 200 feet above Range 83
70	34.3	92	8	0	About 200 feet above Range 83
71	41.0	92	8	0	About 200 feet above Range 83
72	29.6	95	5	0	Range 81D to Eagle Point
73	35.9	73	27	0	Range 81D to Eagle Point
74	42.7	88	12	0	Range 81D to Eagle Point
75	39.0	87	13	0	Range 81D to Eagle Point

1/100 percent finer than No. 200 sieve size--samples Nos. 6, 34, and 39 to 75, inclusive
2/15 percent in range 4.7 mm to 3 inches

Table 2

ELEPHANT BUTTE SEDIMENT SAMPLES OF RESERVOIR DEPOSITS
February 1957

Sample No.	Unit Weight pounds per cu ft	Percent Sediment Grain Size Ranges in Microns			Location
		<5	5-74	74-4700	
1	37.90	63	37	0	Range 90 sampled at mid-channel
2	37.46	76	24	0	Range 90 sampled at mid-channel
3	35.69	85	15	0	Range 89 sampled at mid-channel
4	34.07	80	20	0	Range 89 sampled at mid-channel
5	33.44	88	12	0	Range 86 sampled at mid-channel
6	29.50	73	27	0	Range 86 sampled at mid-channel
7	33.96	75	25	0	Range 85 to Range 84D sampled at midchannel
8	30.24	85	15	0	Range 85 to Range 84D sampled at midchannel
9	36.23	88	12	0	Indian Grave to Three Cedars sampled at mid-channel
10	33.03	91	9	0	Indian Grave to Three Cedars sampled at mid-channel
11	34.07	84	16	0	Indian Grave to Three Cedars sampled at mid-channel
12	31.76	86	14	0	Range 72 sampled at approximately 1,000 feet from left bank
13	36.54	81	19	0	Range 72 sampled at approximately 1,000 feet from left bank
14	35.39	87	13	0	Range 68
15	42.50	72	28	0	Range 68
16	33.67	88	12	0	Old Glory to Range 82W
17	38.62	83	17	0	Old Glory to Range 82W
18	54.80	82	18	0	Range 68
19	65.41	82	18	0	Line C (San Marcial Lake)
20	67.48	72	28	0	Line C (San Marcial Lake)
21	77.40	24	46	30	Line C (San Marcial Lake)
22	38.40	86	14	0	Line F (San Marcial Lake)

Table 2--Continued

Sample No.	Unit Weight pounds per cu ft	Percent Sediment Grain Size Ranges in Microns			Location
		<4	4-62.5	62.5-250	
23	67.28	48.5	51.3	0.2	Range 12
24	76.63	17.0	47.2	35.8	Line F (San Marcial Lake)
25	64.17	32.8	66.7	0.5	Range 65 sampled at mid-channel
26	72.27	17.5	80.3	2.2	Monticello Canyon sampled at midchannel about 1,000 feet up canyon from origin to Canada range line
27	64.17	77.0	21.4	1.6	The Narrows sample obtained from silt deposits on right side of channel just below gaging station
28	71.65	74.5	25.3	0.2	Range 45
29	70.40	82.5	17.1	0.4	Range 38 sampled about midway on range line
30	82.86	11.6	59.7	28.7	Nogal Canyon sampled about midchannel on range line
31	74.14	84.3	15.5	0.2	Range 35 sampled at right side of conveyance channel about 200 feet from channel bank
32	58.56	75.1	24.5	0.4	Range 30 sampled at 1,000 feet west of conveyance channel on range
33	72.27	34.7	35.6	29.7	Range 25 sampled at 200 feet west of conveyance channel on range line
34	79.12	20.7	65.9	13.4	Range 27 sampled on range about 1,200 feet west of conveyance channel
35	77.25	67.2	32.3	0.5	Range 21 sampled about 300 feet from west side of conveyance channel
36	87.84	5.4	51.4	43.2	Range 19 sampled approximately 300 feet west of conveyance channel
37	87.84	3.1	32.1	73.8	Range 9 sample taken from lake between Black Mesa and railroad
38	74.14	18.1	73.3	8.6	Range 23 sampled at 200 feet from levee in floodway
39	85.97	14.1	18.8	67.1	Range 35 sampled at 300 feet from levee in floodway

Table 3

1957 Results of Unit Weight Data
Collected by Subaqueous and RSD Samplers

Sample Number	Subaqueous Sampler		RSD Sampler		Location
	γ 1/	D 2/	γ 1/	D 2/	
1	37.5	2.7	25.8	2	Range 90 sampled at mid-channel
2	34.1	2	23.9	2	Range 89 sampled at mid-channel
3	35.7	10	35.0	4	Range 89 sampled at mid-channel
4	29.5	2	31.0	2	Range 86 sampled at mid-channel
5	33.4	10	28.7	4.8	Range 86 sampled at mid-channel
6	30.2	2	29.6	2	Range 85 to 84 D sampled at midchannel
7	34.0	10	37.2	5	Range 85 to 84 D sampled at midchannel
8	33.6	1.9	31.1	2	Indian Graves to Three Cedars sampled at mid-channel
9	36.2	10.4	49.3	5	Indian Graves to Three Cedars sampled at mid-channel
10	31.8	2	32.8	2	Range 72 sampled at approximately 1,000 ft. from left bank
11	36.5	6.3	45.2	5	Range 72 sampled at approximately 1,000 ft. from left bank
12	67.5	2	59.0	2	Line C (San Marcial Lake)
13	35.4	2	29.8	2	Range 68
14	42.5	5	50.1	5	Range 68
15	33.7	2	39.3	2	Old Glory to R82W
16	38.6	10	35.8	5	Old Glory to R82W

1/ γ - Unit weight in pounds per cubic foot
2/ D - Depth of penetration in feet

Table 4

SUMMARY OF PREVIOUS STUDIES OF UNIT WEIGHTS

Investigator	Data used	Unit weight in pounds per cubic foot
R. R. Coghlan and V. E. Lieb	Seventeen samples observed in March 1916	92.34
A. E. Fenz	Ninety-six samples observed	97.6
W. W. Follett	One sample taken in 1904	53
S. C. Happ	Over 600 samples observed	86
R. G. Hemphill	Qualitative analysis	55-65
L. M. Seavy	Sediment records of the Rio Grande at San Marcial, New Mexico, from 1915 to 1947	65.9
H. Stabler	Same records as used by Seavy above except for period 1897-1908	85
J. C. Stevens	Same records as used by Seavy above except for period September 1915 to September 1940	65
International Boundary and Water Commission, United States and Mexico	Qualitative analysis	66.7

Table 5

Density and mechanical composition of Middle Rio Grande Valley sediment samples

Sample No.	Type of sample	Locality	Unit Weight	Mechanical composition by grade sizes in microns: >1,981	1,981 to 1,397	1,397 to 991	991 to 701	701 to 495	495 to 351	351 to 246	246 to 175	175 to 124	124 to 88	88 to 61	61 to 31.2	31.2 to 15.6	15.6 to 7.8	7.8 to 3.9	3.9 to 1.95	1.95 to 0.98	0.98 to 0.49	>61	<61	<1.95	<0.98	<0.49
			Lbs./cu. ft.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
35	Spot	Range 860.4, river bar	101.0		0.2	0.4	1.2	4.7	13.7	24.2	24.3	20.1	7.1	1.9								97.8	2.2			
36	Composite	Range 860.4, floodway		3.9	0.4	0.5	0.6	0.8	1.7	5.4	8.6	15.8	13.0	7.1	25.4	6.7	2.7	1.4	1.1			57.8	42.2	4.9		
37	Composite	Range 873, west overflow area		0.5	0.4	1.7		7.7			17.5	18.6		5.5	25.7	7.0	3.6	2.2	2.3			51.9	48.1	7.4		
38	Composite	Below Angostura Diversion, floodway			0.1	0.3		1.8			12.1	29.3		7.5	25.1	10.3	4.5	1.7	1.8			51.1	48.9	5.5		
39	Composite	Below Alameda Bridge, floodway						0.2			9.3	16.6		3.3	18.2	16.7	12.2	6.2	3.8	3.1	3.1	29.4	70.6			7.3
40	Composite	Range 907.6, west 1200' of valley		2 0	1.4	5.0		13.8			17.1	13.7		3.2	12.2	5.2	3.6	3.1	3.1	3.1	4.5	54.2	43.8			9.0
41	Composite	Range 907.6, 1000' west from highway			0 2	0.9		6.5			14.8	15.2		4.5	21.4	6.2	4.6	4.2	4.1	4.6	4.8	42.1	57.9			8.0
42	Composite	Range 907.6, 1000' west from floodway				0.3		1.0			7.6	15.9		4.6	16.9	8.2	8.2	6.3	5.0	5.5	5.3	29.4	70.6			15.2
43	Composite	Range 907.6, floodway				0.1		1.0			12.9	23.6		3.2	21.5	16.0	8.9	3.2	1.8			40.8	59.2	7.8		
44	Spot	Range 907.6, east floodway	86.1		0.1	0.1		0.1			0.3	4.4		6.2	66.8	12.0	3.1	0.9	0.9			11.2	88.8	5.1		
45	Composite	Range 922, floodway			0.3	0.1		0.4			4.9	35.5		7.2	21.3	9.8	6.3	4.1	1.4			48.4	51.6	8.7		
46	Spot	Range 922, floodway	86.9		TR.	TR.		0.1			0.3	21.4		11.2	39.5	15.5	5.1	1.4	0.9			33.1	66.9	4.5		
47	Spot	Range 922, floodway	73.2												8.7	33.3	27.5	10.0	5.2	4.9		1.7	98.3	8.7		
48	Composite	Range 934, floodway			0.1	0.2		1.2			5.0	12.8		5.3	37.2	10.0	5.5	3.8	3.4	2.8	3.9	24.6	75.4			8.8
49	Composite	Bosque Bridge, floodway			0.0	0.2		2.4			13.5	29.7		4.0	11.7	4.5	4.5	4.6	4.5	4.5	4.9	49.8	50.2			11.0
50	Composite	Range 945, east overflow area				0.1		0.5			4.3	25.2		9.8	30.6	12.2	5.5	2.3	1.8			39.9	60.1	7.7		
51	Spot	Range 945, east overflow area	103.5		TR.	0.0	TR	0.1	0.1	1.1	6.1	28.2	24.4	11.2	21.8	2.9	1.0	0.5	0.6			71.2	28.8	2.0		
52	Spot	Range 945, east overflow area	81.7									2.1		2.0	23.9	27.4	25.8	8.0	3.1			4.1	95.9	7.7		
53	Composite	Range 949, west overflow area			0.1	0.4		6.4			20.1	28.4		5.8	10.4	4.2	4.3	3.6	2.5	3.7	3.1	61.2	38.8			7.0
54	Spot	Range 949, west overflow area	76.4												3.2	35.5	36.8	11.3	3.5			1.2	98.8	8.5		
55	Spot	Range 949, west overflow area	90.3	0.0	0.0	0.8	0.2	0.6	1.3	4.5	11.4	17.3	15.1	8.4	23.8	5.7	1.9	1.9	0.9			59.6	40.4	6.2		
56	Composite	Range 949, floodway			0.0	0.1		0.3			5.0	25.5		7.1	24.1	11.0	8.1	4.4	3.4			38.0	62.0	11.0		
57	Composite	Range 949, east overflow area									0.5	5.6		2.2	17.4	18.5	19.8	11.7	5.8	4.7	3.9	8.3	91.7			9.9
58	Spot	Range 949, east overflow area	79.6												10.5	32.4	32.4	9.6	2.7	2.4		2.3	97.7		7.7	
59	Spot	Range 949, river bar	102.0		0.0	TR.	0.1	0.2	0.8	3.7	17.7	32.0	20.2	8.1								82.8	17.2			
60	Composite	Range 951, floodway					TR.	0.1			0.8	19.5		9.0	26.7	13.8	9.6	5.3	2.9	2.9		29.4	70.6		9.4	
61	Spot	Range 951, floodway	87.0		0.3	0.2	0.2	0.2	0.1	0.5	2.6	16.5	29.2	15.4	28.8	2.0	0.7	0.6	0.5			65.0	35.0	2.4		
62	Spot	Range 951, floodway	73.0												2.0	11.9	25.9	21.6	11.6	8.8	7.5	0.5	99.5			10.2
63	Composite	Range 951, west overflow area										10.7		3.3	16.1	11.4	11.3	9.6	7.5	7.2	6.3	14.0	86.0			16.6
64	Composite	Range 954, floodway						0.9			10.0	13.5		4.6	17.3	7.8	6.1	6.2	4.9	6.0	5.5	29.0	71.0			17.2
65	Composite	Range 966.7, west overflow area			0.1	0.1		1.1			10.5	23.9		8.0	28.1	8.6	4.6	3.0	2.6			43.7	56.3	9.4		
66	Spot	Range 966.7, west overflow area	83.1		TR.	0.1	0.1	0.4	1.2	5.6	18.5	34.6	21.9	7.6								90.0	10.0			
67	Spot	Range 966.7, west overflow area	91.4			0.0		0.1			0.3	11.5		7.9	52.6	13.2	4.6	1.6	1.0			19.8	80.2	7.2		
68	Composite	Range 966.7, floodway						0.2			2.4	12.6		5.1	29.8	15.9	9.2	2.6	5.1	2.6	4.1	20.3	79.7			10.4
69	Spot	Range 966.7, floodway	80.2		TR.	0.1	0.1	TR.	TR.	0.1	0.1	1.6	13.3	15.0	56.9	3.7	1.0	1.0	0.7			30.3	69.7	6.4		
70	Spot	Range 966.7, river bar	98.0		0.0	TR.	0.2	1.2	9.3	40.6	28.9	12.4	3.5	1.2								97.3	2.7			
71	Composite	Range 971.6, west overflow area									3.5	6.5		2.1	16.6	14.2	15.5	10.2	6.1	5.5	4.9	12.7	87.9			14.9
72	Spot	Range 971.6, west overflow area	87.0						TR.		1.8	22.9		2.7	5.6	11.0	16.4	13.0	6.5	5.3	4.8	27.4	72.6			10.0
73	Spot	Range 971.6, west overflow area	48.3												0.0	0.8	6.1	12.6	14.7	18.7	18.4	0.2	99.8			28.5
74	Composite	Range 973.5, east overflow area						0.2			0.9	13.7		5.7	27.1	13.8	8.1	5.4	4.2	4.3	4.4	20.5	79.5			12.2
75	Composite	Range 990.9, west overflow area			0.0	0.1		0.1			1.7	28.8		10.6	34.2	11.0	4.3	1.8	1.3			41.3	58.7	6.1		
76	Composite	San Antonio Bridge, floodway									0.4	6.9		2.9	20.9	10.7	8.2	7.3	7.4	7.1	7.3	10.2	89.8			20.9
77	Spot	San Antonio Bridge, floodway	94.2												0.3	0.8	4.1	11.7	18.8	24.0	19.9	0.2	99.8			20.2
78	Spot	San Antonio Bridge, floodway	81.4								0.3	1.8		3.2	45.2	22.7	9.0	3.8	2.9	2.3		5.3	94.7		8.8	
79	Spot	San Antonio Bridge, river bar	101.2		0.0	0.0	TR.	0.1	0.0	0.2	1.0	14.5	25.6	14.4	33.4	4.1	0.9	1.2	1.0			55.8	44.2	3.6		
80	Spot	San Antonio Bridge, floodway	88.5												25.9	32.9	18.3	6.6	3.2	1.8	3.8	1.0	99.0			6.5
81	Composite	Range 997(M), west overflow area			0.0	0.1		0.2			1.9	13.9		5.6	16.3	4.1	7.2	9.9	8.6	6.8	6.8	21.6	78.4			18.7
82	Composite	Range 997(M), east overflow area						0.1			1.5	18.4		8.3	47.5	10.5	4.0	1.6	1.7			28.4	71.6	6.3		
83	Spot	Range 998(L), east overflow area	80.8												0.7	13.3	30.1	21.0	9.9	6.6	6.3	0.3	99.7			11.8
84	Composite	Range 1001(I) overflow area			0.0	TR.	0.1	0.1	0.3	1.0	4.5	18.4	25.0	11.4	21.8	3.9	2.7	2.4	1.7			60.8	39.2	6.7		
85	Spot	Range 1002.4(2), east overflow area	78.6												11.1	22.0	20.7	9.9	6.6	6.9	8.0	0.2	99.8			14.6
86	Composite	Range 1004(F), east overflow area						0.1			1.3	15.3		4.9	27.2	16.9	10.3	5.1	4.0	2.5	3.0	21.6	78.4			9.4
87	Composite	Range 1005.7(C), west of railway													12.4	7.7	8.4	11.5	10.0	10.3	9.7	7.7	92.3			22.3
88	Composite	Range 1006.8(A), overflow area			0.0	TR.		0.2			3.8	19.9		8.2	36.5	8.7	4.6	2.6	2.8	2.2		32.1	67.9		10.5	
89	Spot	Range 1006.8(A), west overflow area	78.5					0.0			0.1	0.9		1.1	46.2	27.0	7.9	4.2	2.6			2.1	97.9	10.0		
90	Spot	Range 1006.8(A), west overflow area	80.9		TR	0.1	0.1	TR.	0.1	0.1	0.1	1.6	14.9	18.7	55.5	2.1	0.5	0.7	0.8	1.2		35.8	64.2		3.4	

Table 6

UNIT WEIGHT DATA--1952 VS. 1957 SAMPLES GATHERED AT SAME RANGES

Location	1952					1957				
	Sample no.	Unit weight #/ft^3	Gradation			Sample no.	Unit weight #/ft^3	Gradation		
			Clay	Silt	Sand			Clay	Silt	Sand
Range 90	R-7	31.8	73	26	1	1	37.7	64	34	2
Range 89	R-8	29.5	71	27	2	2	34.9	79	20	1
Range 86	R-9	29.3	72	26	2	3	31.0	76	23	1
Range 85 to 84D	R-10	28.4	72	26	2	4	31.6	75	24	1
Indian graves to three cedars	R-1, 2 & 3	33.4	70	28	2	5	34.4	82	17	1
Range 72	R-5	35.1	72	25	3	6	33.6	78	21	1
Old glory to range 82W	R-6	37.1	71	27	2	11	36.2	80	19	1
Range 38	8	69.5	46	25	29	16	70.4	82	17	1
Range 38I to creosote	13	80.6	14	41	55	17	82.9	11	60	29
Range 27	2 & 2A	73.9	53	41	6	20	79.1	21	66	13
Range 21	10	69.7	40	45	15	22	77.2	67	32	1
Range 19W to 18E	9	86.1	14	33	53	23	87.8	5	52	43
	Total	604.4	668	370	172		636.8	720	385	95
	Avg.	50.3	55	31	14		53.0	60	32	8

Table 7

DENSITY CURRENTS
Elephant Butte Reservoir

INFLOWING				OUTFLOWING							
Date	Water Discharge cfs	Concen-tration ppm	Sediment Discharge T/da	Date	Water Discharge cfs	Concen-tration ppm	Sediment Discharge T/da	Date	Water Discharge cfs	Concen-tration ppm	Sediment Discharge T/da
7-5-19	7,840	107,800	2,280,000	7-7-19	1,885	37,800	199,000	9-26-29	574	39,700	61,500
7-8-19	2,611	24,700	174,000	7-8-19	1,863	37,800	197,000	9-28-29	574	56,200	87,000
7-11-19	5,437	106,700	1,560,000	7-9-19	1,895	37,800	201,000	10-1-29	482	61,400	80,000
7-14-19	2,273	34,400	211,000	7-10-19	1,895	37,800	201,000	10-4-29	482	55,600	72,500
7-16-19	8,450	68,400	1,560,000	7-15-19	1,627	37,800	172,000	9-22-31	644	29,800	51,800
7-19-19	8,017	66,900	1,450,000	7-18-19	1,205	37,800	127,000	9-23-31	699	52,100	98,400
7-22-19	5,682	42,800	656,000	7-19-19	1,210	37,800	128,000	6-23-33	991	26,800	71,800
7-31-19	2,340	43,100	272,000	7-20-19	1,220	66,100	218,000	6-24-33	1,007	24,900	67,600
8-2-19	7,600	147,600	3,030,000	7-21-19	1,220	42,400	140,000	6-25-33	1,296	41,600	146,000
8-6-19	2,300	31,400	195,000	7-22-19	1,230	64,400	214,000	6-26-33	1,598	38,700	167,000
8-9-19	1,424	26,900	103,000	7-23-19	1,300	80,500	283,000	6-27-33	1,683	49,000	223,000
7-23-21	3,530	70,500	672,000	7-24-19	1,300	80,500	283,000	6-28-33	1,793	26,800	130,000
7-26-21	8,650	80,700	1,890,000	7-25-19	1,278	80,500	278,000	6-29-33	1,793	41,500	201,000
7-29-21	6,205	112,600	1,890,000	7-26-19	1,185	77,300	248,000	6-30-33	1,793	2,000	9,700
8-1-21	5,463	70,000	1,030,000	7-27-19	1,170	92,600	293,000	7-2-33	1,574	300	1,270
8-4-21	3,808	35,100	361,000	7-28-19	1,190	40,300	129,000	7-3-33	1,954	300	1,580
9-9-27	3,930	102,100	1,080,000	8-6-19	1,785	40,300	194,000	8-9-35	2,193	36,960	219,000
9-15-27	7,100	36,400	698,000	8-7-19	1,670	40,300	182,000	8-10-35	2,020	22,960	125,000
8-8-29	4,860	107,200	1,410,000	8-8-19	1,750	72,400	342,000	8-11-35	1,951	380	2,000
8-16-29	5,970	8,900	144,000	8-1-21	2,121	200	1,140	8-25-35	1,904	18,200	93,700
8-25-29	1,220	480	1,580	8-2-21	2,121	260	1,490	8-26-35	1,904	12,520	64,500
8-31-29	2,950	67,200	535,000	8-3-21	2,020	360	1,960	8-20-54	368	19,710	19,600
9-5-29	3,180	60,500	520,000	9-22-23	1,400	18,400	69,600	8-21-54	371	11,210	11,210
9-19-31	2,670	104,000	750,000	9-23-23	1,400	16,600	62,800				
9-25-31	4,950	72,200	965,000	9-24-23	1,400	8,700	32,900				
6-15-33	3,240	31,500	276,000	9-25-23	1,400	5,200	19,700				
6-17-33	2,755	13,300	99,000	9-26-23	1,400	3,000	11,300				
6-18-33	4,591	57,800	716,000	9-19-27	1,050	61,000	173,000				
6-19-33	6,446	91,600	1,600,000	9-20-27	1,050	59,500	169,000				
6-20-33	9,977	78,000	2,100,000	9-21-27	1,050	54,400	154,000				
6-23-33	11,246	42,600	1,290,000	8-13-29	675	21,600	39,400				
6-25-33	4,882	35,700	470,000	8-14-29	675	27,100	49,400				
6-26-33	5,744	26,500	410,000	8-15-29	675	24,100	43,900				
6-28-33	2,722	9,100	66,900	8-16-29	675	47,200	86,000				
7-1-33	1,371	5,800	21,500	8-17-29	740	43,900	87,600				
7-28-35	50	1,140	154	8-19-29	935	17,600	44,400				
8-5-35	5,700	33,130	510,000	8-21-29	1,094	25,200	74,500				
8-6-35	11,500	70,830	2,200,000	8-23-29	1,283	26,600	92,300				
8-18-35	1,050	20,320	56,200	8-25-29	1,283	7,500	26,000				
8-22-35	6,480	125,630	2,200,000	8-26-29	1,405	22,000	83,500				
8-20-54	368	19,710	19,600	8-29-29	1,700	22,100	103,000				
8-21-54	371	11,210	11,210	8-31-29	1,700	200	920				

Table 8

STATISTICAL SUMMARY
ELEPHANT BUTTE RESERVOIR

	Quantity	Unit
Age 1/	42.10	Years
Drainage Area 2/		
Total Area	25,923	Square miles
Below San Marcial, New Mexico	1,747	Square miles
Reservoir 3/		
Original area at crest stage	40,060	Acres
Present area at crest stage	36,584	Acres
Original storage capacity	2,634,800	Acre-feet
Present storage capacity	2,206,780	Acre-feet
Original storage capacity per square mile of drainage area	102	Acre-feet
Present storage capacity per square mile of drainage area	85.2	Acre-feet
Sedimentation		
(Below crest deposits) Total sediment	428,020	Acre-feet
Accumulation per year average	10,200	Acre-feet
Accumulation per year average (1915-1935)	18,225	Acre-feet
Accumulation per year average (1935-1957)	2,890	Acre-feet
Sediment yield per square mile per year (1915-1957)	0.39	Acre-feet
Sediment yield per square mile per year (1915-1935)	0.70	Acre-feet
Sediment yield per square mile per year (1935-1957)	0.11	Acre-feet
Depletion of Storage		
Loss of original capacity per year (1915-1957)	0.39	Percent
Loss of original capacity per year (1915-1935)	0.69	Percent
Loss of original capacity per year (1935-1957)	0.11	Percent
Loss of original capacity to date of survey (1957)	16.2	Percent

Table 8--Continued

	Quantity	Unit
Depletion of Storage (Continued)		
Loss of original capacity per year to date of survey (1957)	0.39	Percent

1/ Date storage began: January 6, 1915. Date of last survey: October 16, 1956 to February 14, 1957. Field work was not continuous during this period.
2/ Does not include the noncontributing sediment area, such as the San Luis Valley (Figure 4). The reservoir area, however, is included.
3/ The elevation at crest stage is 4,407.0 feet, project datum. Add 43.3 feet to adjust elevations to mean sea level datum.

UNITED STATES
DEPARTMENT OF THE INTERIOR

Table 9

BUREAU OF RECLAMATION

RESERVOIR SEDIMENTATION DATA SUMMARY

Elephant Butte
NAME OF RESERVOIR

57-
DATA SHEET NO.

DAM

1. OWNER Bureau of Reclamation	2. RIVER Rio Grande	3. STATE New Mexico 1/
4. SEC. 2/ TWP. 13S RANGE 4W	5. NEAREST TOWN Truth or Consequences	6. COUNTY Sierra
7. STREAM BED ELEV.	8. TOP OF DAM ELEV.	9. SPILLWAY CREST ELEV. 4407

RESERVOIR

10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. SURFACE AREA ACRES	13. STORAGE ACRE-FEET	14. ACCUMULATED ACRE-FEET	15. DATE STORAGE BEGAN
a. FLOOD CONTROL	4407	36,584		2,206,780	
b. POWER					Jan. 6, '15
c. WATER SUPPLY					16. DATE NORMAL OPER. BEGAN
d. IRRIGATION					
e. CONSERVATION					1915
f. INACTIVE	4231.5	Negligible	Negligible		

17. LENGTH OF RESERVOIR 41 MILES | AV. WIDTH OF RESERVOIR 1.69 MILES

WATERSHED

18. TOTAL DRAINAGE AREA 25,923 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 10 to 15 INCHES
19. NET SEDIMENT CONTRIBUTING AREA 25,866 SQ. MI.	23. MEAN ANNUAL RUNOFF INCHES
20. LENGTH 305 MILES | AV. WIDTH 85 MILES	24. MEAN ANNUAL RUNOFF 1,004,000 (60) AC.-FT.
21. MAX. ELEV. 12,000 | MIN. ELEV. 4407	25. CLIMATIC CLASSIFICATION Semi-arid

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA ACRES	32. CAPACITY ACRE-FEET	33. C/W RATIO AC.-FT. PER SQ. MI.
Jan. 6, 1915	0	0	Contour	10 feet	40,060	2,634,800	102
Dec. 1916	1.9	1.9				2,584,865	100
Aug. 1920	3.7	5.6				2,498,850	96
Aug. 1925	5.0	10.6	Contour		39,406	2,389,380	92
April 1935	9.7	20.3	Contour	5 feet	38,140	2,270,300	88
Oct. 1940	5.5	25.8	Contour		37,670	2,219,000	86

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW ACRE-FEET a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	36. WATER INFL. TO DATE AC-FT. a. MEAN ANNUAL	b. TOTAL TO DATE
Jan. 6, 1915						
Dec. 1916		1,573,665		3,005,700	1,573,665	3,005,700
Aug. 1920		1,413,845	2,250,100	5,188,810	1,463,305	8,194,510
Aug. 1925		1,130,348	1,690,900	5,651,742	1,306,250	13,846,252
April 1935		853,428	1,444,200	8,252,648	1,088,616	22,098,900
Oct. 1940		945,761	1,597,000	5,201,730	1,058,164	27,300,630

26. DATE OF SURVEY	37. PERIOD SEDIMENT DEPOSITS ACRE-FEET a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	38. TOTAL SED. DEPOSITS TO DATE ACRE-FEET a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
Jan. 6, 1915						
Dec. 1916	49,900	26,300	1.02	49,900	26,300	1.02
Aug. 1920	86,000	23,200	0.899	136,000	24,300	0.939
Aug. 1925	109,000	21,900	0.846	245,000	23,200	0.895
April 1935	119,000 (125,000)	12,300 (12,900)	0.475 (0.498)	365,000 (370,000)	18,000 (18,200)	0.694 (0.705)

26. DATE OF SURVEY	39. AV. DRY WGT. LBS. PER CU. FT.	40. SED. DEP. TONS PER SQ. MI.-YR. a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS PCT. a. AV. ANNUAL	b. TOT. TO DATE	42. SED. INFLOW PPM a. PERIOD	b. TOT. TO DATE
Jan. 6, 1915							
Dec. 1916				0.998	1.89		
Aug. 1920				0.922	5.16		
Aug. 1925				0.881	9.30		
April 1935	60 (est.)	621 (651)	907 (921)	0.683	13.9	13,900 (14,600)	15,900 (16,100)

Table 9--Continued

26. DATE OF SURVEY / 43. DEPTH DESIGNATION RANGE IN FEET ABOVE, AND BELOW, CREST ELEVATION — PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION

DATE OF SURVEY	193-175.5	175.5-167	167-147	147-127	127-107	107-87	87-67	67-47	47-27	27-11	11-Cr.	Cr.-3
Aug. 1925	1.26	-0.057	7.18	11.1	9.03	5.86	9.19	14.3	25.1	8.99	4.53	
April 1935	0.869	0.380	5.70	8.38	7.22	4.81	8.14	16.4	27.1	12.9	6.54	1.46
Oct. 1940	0.760	0.330	5.10	7.45	6.83	5.06	8.32	15.4	26.1	16.3	6.69	1.70
Apr. 28, 1947	0.719	0.321	4.75	7.07	6.53	5.64	8.66	15.0	24.9	16.0	8.14	2.21
Feb. 12, 1957	0.734	0.325	6.04	10.0	7.64	5.42	7.83	13.1	22.5	15.6	8.40	2.31

26. DATE OF SURVEY / 44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGH OF RESERVOIR — PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION

DATE OF SURVEY	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125

Data not available due to contour method of sediment computation.

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW AC.-FT.
1915	4321.81		1,443,900	1923	4374.20*	4368.3*	964,500
1916	4346.85	4307.29*	1,420,900	1924	4395.80	4370.4*	1,690,900
1917	4354.0	4331.0*	1,310,600	1925	4379.20	4354.7*	320,800
1918	4326.28	4290.30*	379,100	1926	4378.10	4355.68*	1,120,900
1919	4364.0	4267.70*	1,527,000	1927	4371.96*	4363.02*	1,178,400
1920	4393.87	4351.5*	2,250,100	1928	4379.10	4359.70*	772,700
1921	4392.5	4378.2*	1,607,300	1929	4374.80	4354.00*	1,238,900
1922	4389.50*	4377.5*	1,069,100	1930	4384.5	4372.27*	930,200

46. ELEVATION-AREA-CAPACITY DATA

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4220	1	1	4310	8,993	259,940	4390	29,226	1,642,790
4240	4	22	20	10,804	358,450	4396	32,140	1,826,570
50	312	1,298	30	12,556	475,150	4400	34,117	1,959,060
60	1,220	8,590	40	14,290	608,930	07	36,584	2,206,780
70	2,343	26,253	4350	16,506	762,940	4410	37,884	2,318,460
80	4,004	57,680	60	18,504	937,850			
90	6,005	107,730	70	21,328	1,135,660			
4300	7,698	176,810	80	25,455	1,369,870			

47. REMARKS AND REFERENCES

1/Headquarters for operation of dam located at El Paso, Texas.
2/Sections not determined--Located in Amendariz Grant No. 33.
*Mean monthly elevations

48. AGENCY SUPPLYING DATA Bureau of Reclamation

49. DATE Jan. 8, 1959

UNITED STATES
DEPARTMENT OF THE INTERIOR

Table 9--Continued

BUREAU OF RECLAMATION

RESERVOIR SEDIMENTATION DATA SUMMARY

Elephant Butte (Continued)
NAME OF RESERVOIR

DATA SHEET NO.

DAM

1. OWNER	2. RIVER	3. STATE
4. SEC. TWP. RANGE	5. NEAREST TOWN	6. COUNTY
7. STREAM BED ELEV.	8. TOP OF DAM ELEV.	9. SPILLWAY CREST ELEV.

RESERVOIR

10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. SURFACE AREA ACRES	13. STORAGE ACRE-FEET	14. ACCUMULATED ACRE-FEET	15. DATE STORAGE BEGAN
a. FLOOD CONTROL					
b. POWER					
c. WATER SUPPLY					16. DATE NORMAL OPER. BEGAN
d. IRRIGATION					
e. CONSERVATION					
f. INACTIVE					

17. LENGTH OF RESERVOIR MILES | AV. WIDTH OF RESERVOIR MILES

WATERSHED

18. TOTAL DRAINAGE AREA SQ. MI.	22. MEAN ANNUAL PRECIPITATION INCHES
19. NET SEDIMENT CONTRIBUTING AREA SQ. MI.	23. MEAN ANNUAL RUNOFF INCHES
20. LENGTH MILES AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF AC.-FT.
21. MAX. ELEV. MIN. ELEV.	25. CLIMATIC CLASSIFICATION

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA ACRES	32. CAPACITY ACRE-FEET	33. C/W RATIO AC.-FT. PER SQ. MI.
Apr. 28, 1947	6.5	32.3	Range	90 feet	36,772	2,197,600	85
Feb. 12, 1957	9.75	42.1	Contour	10 feet	36,584	2,206,780	85

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW ACRE-FEET a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	36. WATER INFL. TO DATE AC-FT. a. MEAN ANNUAL	b. TOTAL TO DATE
Apr. 28, 1947		1,154,862	2,440,000	7,506,600	1,077,623	34,807,230
Feb. 12, 1957		441,776	1,036,000	4,307,318	930,191	39,114,548

26. DATE OF SURVEY	37. PERIOD SEDIMENT DEPOSITS ACRE-FEET a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	38. TOTAL SED. DEPOSITS TO DATE ACRE-FEET a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
Oct. 1940	51,300	9,330	0.361	416,000	16,100	0.623
Apr. 28, 1947	21,400	3,290	0.127	437,000	13,500	0.523
	(43,000)	(6,620)	(0.256)	(465,000)	(14,400)	(0.556)
Feb. 12, 1957	3/			428,000	10,200	0.390

26. DATE OF SURVEY	39. AV. DRY WGT. LBS. PER CU. FT.	40. SED. DEP. TONS PER SQ. MI.-YR. a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS PCT. a. AV. ANNUAL	b. TOT. TO DATE	42. SED. INFLOW PPM a. PERIOD	b. TOT. TO DATE
Oct. 1940				0.611	15.8		
Apr. 28, 1947	65.9 (Est)	182	751	0.512	16.6	3,010	13,300
		(367)	(798)			(6,050)	(14,100)
Feb. 12, 1957	60.0	3/		0.463	19.4		

Table 9--Continued

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET ABOVE, AND BELOW, CREST ELEVATION											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW AC.-FT.
1931	4374.17	4351.66*	417,900	1948	4349.22	4313.08	1,036,000
1932	4384.5	4353.26*	1,444,200	1949	4351.30	4329.69	1,031,000
1933	4377.9	4365.02*	716,800	1950	4346.01	4315.46	364,100
1934	4367.2	4325.00*	298,300	1951	4315.79	4262.30	132,900
1935	4342.2	4324.50*	917,700	1952	4324.59	4261.64	487,500
1936	4354.90	4331.83	872,800	1953	4320.49	4283.19	286,800
1937	4380.7	4336.48*	1,597,400	1954	4297.30	4258.03	198,500
1938	4377.1	4365.6	1,003,500	1955	4295.46	4276.58	257,900
1939	4378.4	4348.6	615,700	1956	4304.40	4268.44	174,830
1940	4357.04	4323.2	333,100				
1941	4399.2	4324.3	2,440,500				
1942	4409.15	4397.00	2,322,000				
1943	4398.96	4380.82	441,600				
1944	4385.68	4369.16	982,500				
1945	4385.60	4372.28	851,500				
1946	4375.66	4339.52	224,900				
1947	4339.36	4311.94	419,200				

47. REMARKS AND REFERENCES

Values listed in parentheses include above crest deposits.

3/ Total storage shows a gain of 9,180 acre-feet since 1947 survey attributable primarily to compaction.

U.S.D.A. Technical Bulletin No. 524, August 1939, "Silting of Reservoirs."

Bureau of Reclamation, February 1949, "Sedimentation Surveys of Elephant Butte Reservoir." Only the upper two-thirds of the reservoir was surveyed in 1925 and 1940. Curves from these data were extended over the remaining lower one-third of the reservoir.

48. AGENCY SUPPLYING DATA

49. DATE______________

Table 9--Continued

Depth below crest	CAPACITY Original	1925	1935	1940	1947	1957	SEDIMENT VOLUME 1925	1935	1940	1947	1957	1925	1935	1940	1947	1957
193	0	0	0	0	0	0										
	3,215	0	0	0	0	0	3,215	3,215	3,215	3,215	3,215	1.26	0.869	0.760	0.719	.734
175.5	3,215	0	0	0	0	1										
	1,445	1,590	40	50	10	21	-145	1,405	1,395	1,435	1,424	0.057	0.380	0.330	0.321	.325
167	4,660	1,590	40	50	10	22										
	35,040	16,760	13,960	13,450	13,790	8,568	18,280	21,080	21,590	21,250	26,472	7.18	5.70	5.10	4.75	6.04
147	39,700	18,350	14,000	13,500	13,800	8,590										
	93,100	64,950	62,100	61,600	61,500	49,090	28,150	31,000	31,500	31,600	44,010	11.1	8.38	7.45	7.07	10.0
127	132,800	83,300	76,100	75,100	75,300	57,680										
	152,600	129,620	125,900	123,700	123,400	119,130	22,980	26,700	28,900	29,200	33,470	9.03	7.22	6.83	6.53	7.64
107	285,400	212,920	202,000	198,800	198,700	176,810										
	205,400	190,490	187,600	184,000	180,200	181,640	14,910	17,800	21,400	25,200	23,760	5.86	4.81	5.06	5.64	5.42
87	490,800	403,410	389,600	382,800	378,900	358,450										
	284,800	261,410	254,700	249,600	246,100	250,480	23,390	30,100	35,200	38,700	34,320	9.19	8.14	8.32	8.66	7.83
67	775,600	664,820	644,300	632,400	625,000	608,930										
	386,500	350,060	325,700	321,400	319,500	328,920	36,440	60,800	65,100	67,000	57,580	14.3	16.4	15.4	15.0	13.1
47	1,162,100	1,014,880	970,000	953,800	944,500	937,850										
	530,700	466,890	430,400	420,400	419,200	432,020	63,810	100,300	110,300	111,500	98,680	25.1	27.1	26.1	24.9	22.5
27	1,692,800	1,481,770	1,400,400	1,374,200	1,363,700	1,369,870										
	525,000	502,130	477,100	456,100	453,300	456,700	22,870	47,900	68,900	71,700	68,300	8.99	12.9	16.3	16.0	15.6
11	2,217,800	1,983,900	1,877,500	1,830,300	1,817,000	1,826,570										
	417,000	405,480	392,800	388,700	380,600	380,210	11,520	24,200	28,300	36,400	26,790	4.53	6.54	6.69	8.14	8.40
Crest	2,634,800	2,389,380	2,270,300	2,219,000	2,197,600	2,206,780	254,420									
	121,800		116,400	114,600	111,900	111,680		5,400	7,200	9,900	10,120		1.46	1.70	2.21	2.31
3	2,756,600		2,386,700	2,333,600	2,309,500	2,318,460		369,900	423,000	447,100	438,140					

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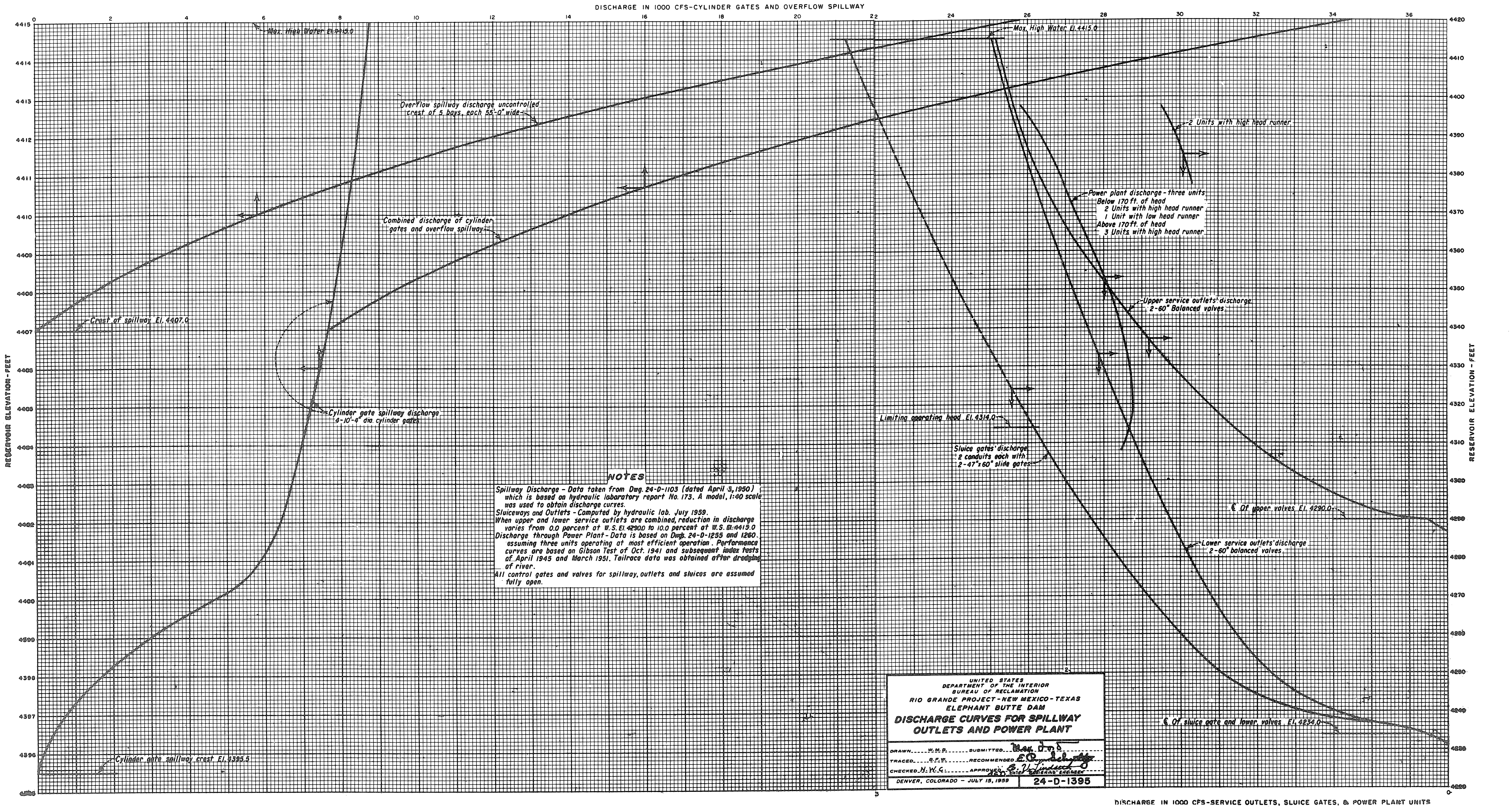

DISCHARGE IN 1000 CFS-CYLINDER GATES AND OVERFLOW SPILLWAY
RESERVOIR ELEVATION - FEET
DISCHARGE IN 1000 CFS-SERVICE OUTLETS, SLUICE GATES, & POWER PLANT UNITS
Max. High Water El. 4415.0
Overflow spillway discharge uncontrolled crest of 5 bays, each 55'-0" wide
Combined discharge of cylinder gates and overflow spillway
Crest of spillway El. 4407.0
Cylinder gate spillway discharge 4-10'-4" dia. cylinder gates
Cylinder gate spillway crest El. 4395.5
2 Units with high head runner
Power plant discharge - three units
Below 170 ft. of head
2 Units with high head runner
1 Unit with low head runner
Above 170 ft. of head
3 Units with high head runner
Upper service outlets' discharge 2-60" Balanced valves
Limiting operating head El. 4314.0
Sluice gates' discharge 2 conduits each with 2-47"x60" slide gates
℄ Of upper valves El. 4290.0
Lower service outlets' discharge 2-60" balanced valves
℄ Of sluice gate and lower valves El. 4234.0
NOTES
Spillway Discharge - Data taken from Dwg. 24-D-1103 (dated April 3, 1950) which is based on hydraulic laboratory report No. 173. A model, 1:40 scale was used to obtain discharge curves.
Sluiceways and Outlets - Computed by hydraulic lab. July 1959.
When upper and lower service outlets are combined, reduction in discharge varies from 0.0 percent at W.S. El. 4290.0 to 10.0 percent at W.S. El. 4415.0
Discharge through Power Plant - Data is based on Dwgs. 24-D-1255 and 1260. assuming three units operating at most efficient operation. Performance curves are based on Gibson Test of Oct. 1941 and subsequent index tests of April 1945 and March 1951. Tailrace data was obtained after dredging of river.
All control gates and valves for spillway, outlets and sluices are assumed fully open.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE PROJECT - NEW MEXICO - TEXAS
ELEPHANT BUTTE DAM
DISCHARGE CURVES FOR SPILLWAY OUTLETS AND POWER PLANT
DRAWN W.M.B. SUBMITTED
TRACED B.F.W. RECOMMENDED
CHECKED N.W.C. APPROVED CHIEF DESIGNING ENGINEER
DENVER, COLORADO - JULY 15, 1959
24-D-1395

Figure 2

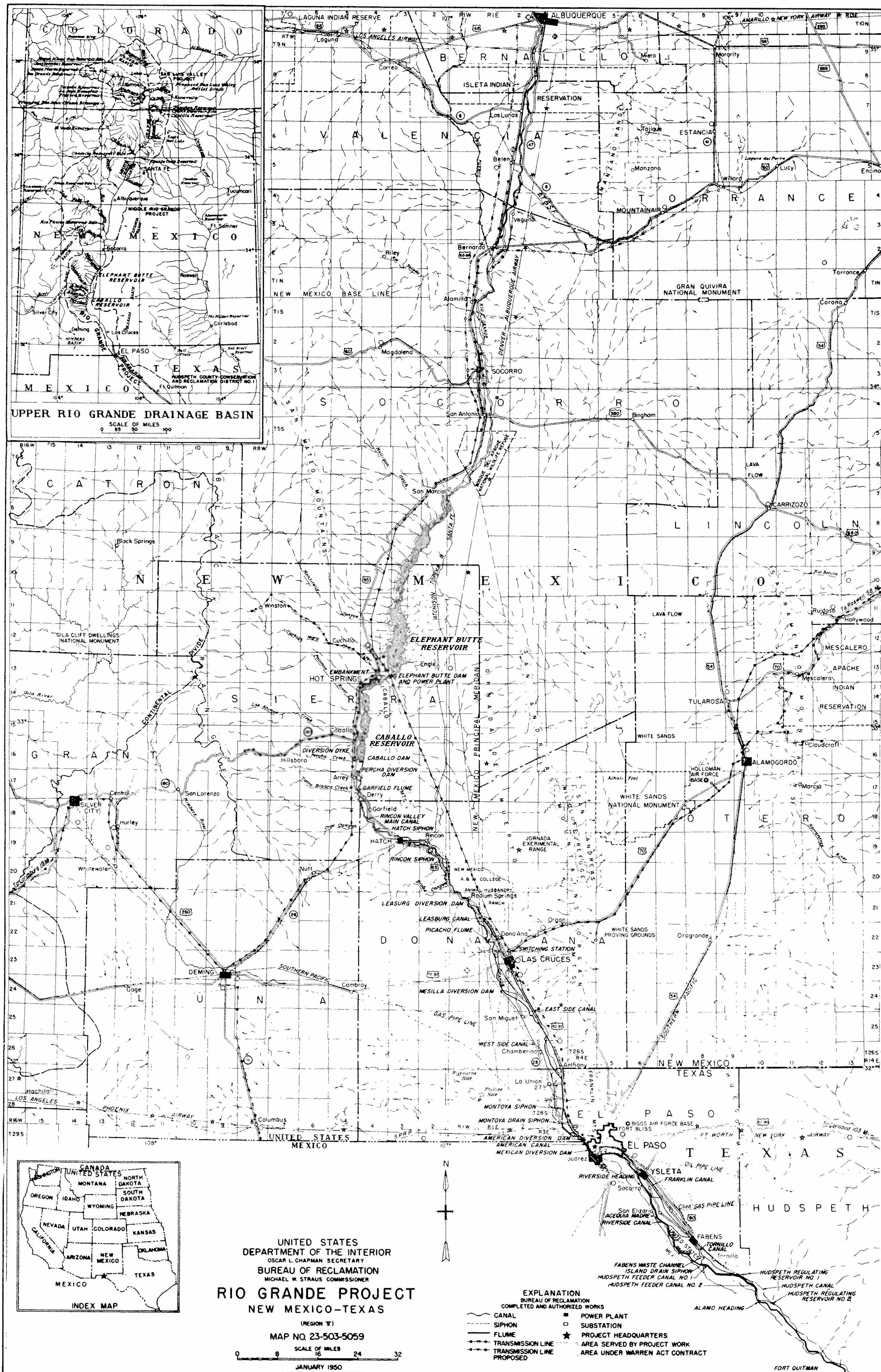
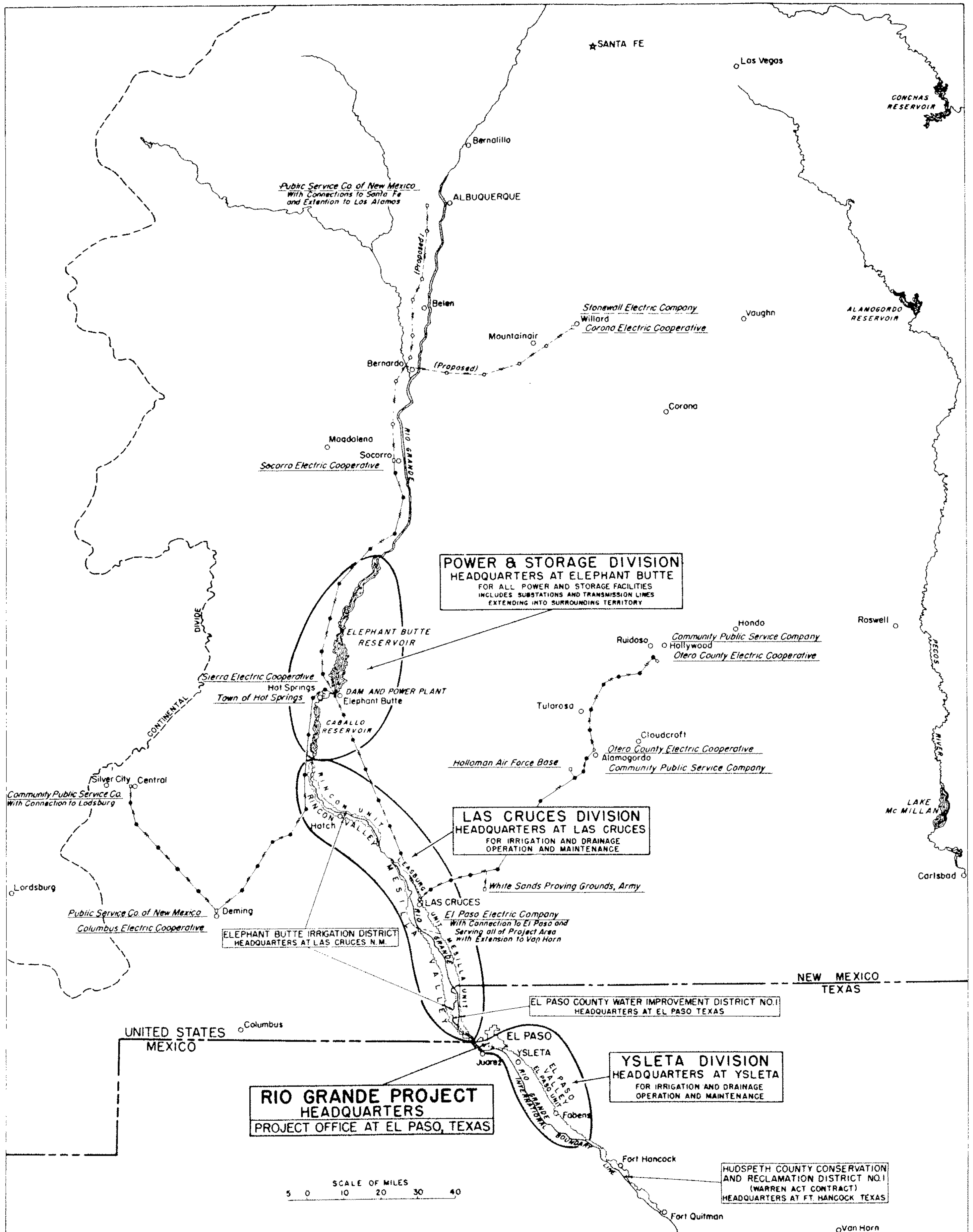

UPPER RIO GRANDE DRAINAGE BASIN
SCALE OF MILES
0 25 50 100
COLORADO
NEW MEXICO
TEXAS
MEXICO
SAN LUIS VALLEY PROJECT
MIDDLE RIO GRANDE PROJECT
ELEPHANT BUTTE RESERVOIR
CABALLO RESERVOIR
HUDSPETH COUNTY CONSERVATION AND RECLAMATION DISTRICT NO. 1
ALBUQUERQUE
BERNALILLO
VALENCIA
TORRANCE
SOCORRO
CATRON
LINCOLN
NEW MEXICO
SIERRA
GRANT
OTERO
DONA ANA
LUNA
EL PASO
TEXAS
HUDSPETH
ELEPHANT BUTTE RESERVOIR
ELEPHANT BUTTE DAM AND POWER PLANT
CABALLO RESERVOIR
CABALLO DAM
DIVERSION DYKE
PERCHA DIVERSION DAM
GARFIELD FLUME
RINCON VALLEY MAIN CANAL
HATCH SIPHON
RINCON SIPHON
LEASBURG DIVERSION DAM
LEASBURG CANAL
PICACHO FLUME
SWITCHING STATION
LAS CRUCES
MESILLA DIVERSION DAM
EAST SIDE CANAL
WEST SIDE CANAL
MONTOYA SIPHON
MONTOYA DRAIN SIPHON
AMERICAN DIVERSION DAM
AMERICAN CANAL
MEXICAN DIVERSION DAM
RIVERSIDE HEADING
FRANKLIN CANAL
ACEQUIA MADRE
RIVERSIDE CANAL
TORNILLO CANAL
FABENS WASTE CHANNEL
ISLAND DRAIN SIPHON
HUDSPETH FEEDER CANAL NO. 1
HUDSPETH FEEDER CANAL NO. 2
HUDSPETH REGULATING RESERVOIR NO. 1
HUDSPETH CANAL
HUDSPETH REGULATING RESERVOIR NO. 2
ALAMO HEADING
FORT QUITMAN GAUGING STATION
INDEX MAP
UNITED STATES
DEPARTMENT OF THE INTERIOR
OSCAR L. CHAPMAN SECRETARY
BUREAU OF RECLAMATION
MICHAEL W. STRAUS COMMISSIONER
RIO GRANDE PROJECT
NEW MEXICO–TEXAS
(REGION V)
MAP NO. 23-503-5059
SCALE OF MILES
0 8 16 24 32
JANUARY 1950
LAMBERT CONIC PROJECTION
EXPLANATION
BUREAU OF RECLAMATION
COMPLETED AND AUTHORIZED WORKS
CANAL
SIPHON
FLUME
TRANSMISSION LINE
TRANSMISSION LINE PROPOSED
POWER PLANT
SUBSTATION
PROJECT HEADQUARTERS
AREA SERVED BY PROJECT WORK
AREA UNDER WARREN ACT CONTRACT

Figure 3



FACTUAL DATA ABOUT THE RIO GRANDE PROJECT

LOCATION DESCRIPTION

The Rio Grande Project occupies the river bottom land of the Rio Grande Valley in south-central New Mexico and extreme west Texas with its irrigated area of approximately 155,000 acres of Project water-right land extending from 100 miles north to 40 miles southeast of the City of El Paso, Texas with a maximum width of only 4.5 miles. The Hudspeth County Conservation and Reclamation District, using Project operating waste and drainage return flow water reaching the lower end of the Project, extends a distance of 40 miles below the Project with an irrigable area of approximately 18,000 acres. By International Treaty, an annual allowance of 60,000 acre-feet of water from Project sources is made available for diversion to Mexico near the City of Juarez across the Rio Grande from El Paso.

Geographically, the Project is divided into five local or sub-valley units separated by short river canyon sections. These are the Elephant Butte Reservoir, Caballo Reservoir, and the Project agricultural areas consisting of Rincon, Mesilla, and El Paso Valleys, with the Mesilla Valley further subdivided into the Leasburg and Mesilla Units. The Power System radiates out over considerable of the surrounding territory.

The Project is operated in three Divisions. The Power and Storage Division with field headquarters at Elephant Butte, New Mexico; the Las Cruces Division with field headquarters at Las Cruces, New Mexico for the New Mexico portion of the Project area in Rincon and Mesilla Valleys, and about 10,000 acres of the Texas portion in the lower end of the Mesilla Valley; and the Ysleta Division with field headquarters at Ysleta, Texas for the El Paso Valley in Texas. The main Project administrative office is located at El Paso, Texas.

Contracts providing for the construction, operation and maintenance, and repayment of the costs on the irrigation system have been entered into with the Elephant Butte Irrigation District with office at Las Cruces, New Mexico for the New Mexico portion of the Project area of 88,000 acres of water-right land with a total construction cost repayment obligation of $5,509,135, and with the El Paso County Water Improvement District No. 1 with office at El Paso, Texas for the Texas portion of the Project area of 67,000 acres of water-right land with a total construction cost repayment obligation of $4,270,456.

A Warren Act contract with the Hudspeth County Conservation and Reclamation District No. 1 with headquarters at Ft. Hancock, Texas, provides for use by that district of Project operating waste and drainage return flow reaching the lower end of the Project on approximately 18,000 acres of land below the Project. As of June 30, 1949 there were 13 contracts for the wholesale delivery of electric energy to utility companies, municipalities, cooperatives, and two Army posts. Other agreements cover purchase, wheeling and exchange of energy. Further power contracts are contemplated. The cost of Power and Storage features is repayable from power and storage revenues.

WATER SUPPLY

The Project water supply is storage and regulated release of the flood waters of the Rio Grande. The Rio Grande drainage basin above Elephant Butte Dam contains 25,923 square miles and has an average annual run-off of about 1,060,000 acre-feet at San Marcial, the head of Elephant Butte Reservoir. The normal annual release from the Project's reservoirs for irrigation, including 60,000 acre-feet for Mexico, is 790,000 acre-feet. Project operating waste and drainage return flow is rediverted and used through the successive units of the Project.

MAJOR STRUCTURE FEATURES OF THE PROJECT PLAN

ELEPHANT BUTTE DAM AND RESERVOIR on the Rio Grande 125 miles north of El Paso, Texas, stores 2,197,600 acre-feet of water (1947 Silt Survey correction, original capacity was 2,638,000 acre-feet) to provide irrigation water and year-round generation of power. This is a rubble concrete structure 301 feet high, foundation to parapet, 200 feet old river bed to roadway, and 1674 feet long, including the spillway. This dam was completed in 1916, but storage operation began in 1915.

ELEPHANT BUTTE EMBANKMENT is an earth and rock fill, concrete faced structure, located across a saddle one mile northwest of the dam to help form the reservoir. It has a maximum height of 59 feet and is 2000 feet long. It was constructed in 1915-16.

ELEPHANT BUTTE POWER PLANT consists of a hydro-electric power plant at the dam with three identical generating units operated by water flow thru three penstocks. Each unit has a rated capacity of 8,100 kilowatts. The power plant was constructed during the period 1938-40.

CABALLO DAM AND RESERVOIR on the Rio Grande is 25 miles downstream from Elephant Butte Dam, with a capacity of 345,870 acre-feet. This is an earth fill, rock faced structure 96 feet high and 4,590 feet long. The dam was completed in 1938. Water used for winter generation of power at Elephant Butte is held here in storage for irrigation use during the summer.

PERCHA ARROYO DIVERSION DIKE AND CHANNEL are located one mile west of Caballo Dam for the diversion of flood waters of the Arroyo into the reservoir. The dike is an earth fill, 29 feet maximum height, 2489 feet long, constructed in 1938.

PERCHA DIVERSION DAM on the Rio Grande, 2 miles downstream from Caballo Dam diverts water into the Rincon Valley Main Canal for irrigation purposes. This is a rubble concrete weir 14 feet high and 350 feet long, ogee section with radial sluice gates and earth fill dikes. This structure was completed in 1917.

RINCON VALLEY MAIN CANAL for carrying water for the irrigation of 16,000 acres in the Rincon Valley is 26.8 miles long and has an initial capacity of 350 second-feet.

GARFIELD FLUME over the Rio Grande 4 miles south of Percha Diversion Dam is a steel truss structure carrying twin barrels 800 feet long for carrying the irrigation water of the Rincon Valley Main Canal over the Rio Grande.

HATCH SIPHON under the Rio Grande 9 miles south of the Garfield Flume is a concrete structure 6 feet in diameter and 650 feet long for carrying irrigation water of the Rincon Valley Main Canal under the Rio Grande.

RINCON SIPHON under the Rio Grande 8 miles southeast of the Hatch Siphon is a concrete structure 5 feet in diameter and 550 feet long for carrying irrigation water of the Rincon Valley Main Canal under the Rio Grande.

LEASBURG DIVERSION DAM on the Rio Grande 62 miles north of El Paso at the head of the Mesilla Valley is a rubble concrete weir, 10 feet high and 600 feet long with earth fill dikes. This structure diverts water into the Leasburg Canal for the upper 31,000 acres of the Mesilla Valley irrigation system. Completed in 1908 it, together with 6 miles of the Leasburg Canal, constituted the first construction work on the Project by the Bureau of Reclamation.

LEASBURG CANAL for carrying irrigation water in the Mesilla Valley is 16 miles long and has an initial capacity of 625 second-feet.

PICACHO FLUME over the Rio Grande 9 miles south of Leasburg Diversion Dam is a steel truss structure 502 feet long for carrying the irrigation water of the Picacho Branch of the Leasburg Canal over the Rio Grande.

MESILLA DIVERSION DAM on the Rio Grande 40 miles north of El Paso is a low concrete weir, radial gate structure, 22 feet high and 303 feet long, with bridge and earth fill dikes. This structure diverts water into the East Side and West Side Canals for the lower 52,000 acres of the Mesilla Valley irrigation system. It was completed in 1916.

EAST SIDE CANAL for carrying irrigation water in the Mesilla Valley is 18.4 miles long and has an initial capacity of 300 second-feet.

WEST SIDE CANAL for carrying irrigation water in the Mesilla Valley is 31.5 miles long and has an initial capacity of 650 second-feet.

MONTOYA SIPHON under the Rio Grande 22 miles downstream from the Mesilla Diversion Dam is a concrete structure 3 feet 9 inches in diameter and 468 feet long, for carrying irrigation water under the Rio Grande to the lower end of Mesilla Valley.

MONTOYA DRAIN SIPHON is a concrete structure 6 feet in diameter and 600 feet long to carry Mesilla Valley west side drain water under the river to a lower outlet at the extreme lower end of the valley.

AMERICAN DIVERSION DAM on the Rio Grande 2 miles northwest of El Paso and immediately above the point where the river becomes the International Boundary Line, is for the diversion of irrigation water to the El Paso Valley for use on the American side. This is a radial gate structure 18 feet high and 286 feet long with earth fill dikes; it was constructed in 1938 and is operated by the American Section of the International Boundary Commission to regulate delivery of water to Mexico in accordance with Treaty provisions.

AMERICAN CANAL also constructed and operated by the American Section of the International Boundary Commission in connection with the American Diversion Dam, carries the water for use on the American side from the dam to the head of the Franklin Canal, a distance of two miles, with a capacity of 1200 second-feet.

MEXICAN DIVERSION DAM on the Rio Grande at El Paso is for the diversion of irrigation water to Mexico. This is a rubble masonry and concrete structure with radial sluice gates 4.7 feet high and 320 feet long. It was also formerly used to divert water into the Franklin Canal. It is not now a part of the Project works.

FRANKLIN CANAL for carrying water in the El Paso Valley is 41 miles long and has an initial capacity of 325 second-feet to serve 17,000 acres in the upper portion of the valley. It was constructed about 1889 by an irrigation company, and was acquired by the Bureau of Reclamation in 1912 to become one of the Project's main canals.

RIVERSIDE HEADING, the lowest Project diversion located on the Rio Grande 15 miles southeast of El Paso, is for diversion of water into the Riverside Canal for irrigation purposes. This is a radial gate concrete structure 18 feet high and 268 feet long, with flood by-pass weir and earth fill dikes. It was constructed in 1927.

RIVERSIDE CANAL for carrying irrigation water in the El Paso Valley is 17.1 miles long and has an initial capacity of 900 second-feet, to serve 39,000 acres in the lower portion of the valley, and carry any available surplus through to the Hudspeth District.

TORNILLO CANAL, a continuation of Riverside Canal for carrying irrigation water to the lower end of El Paso Valley, is 12 miles long and has an initial capacity of 325 second-feet.

ISLAND DRAIN SIPHON is a concrete structure 6 feet in diameter and 571.5 feet long. It carries San Elizario Island drain water under the Fabens Waste Channel, formerly the River, to a lower outlet below the lower end of the project.

THE PROJECT IRRIGATION SYSTEM consists of a total of 604 miles of main canals and distribution laterals including the diversion canals listed above, 490 miles of deep open drainage ditches and 14 miles of waste ditches with several thousand appurtenant miscellaneous structures in addition to the major structures described above.

HUDSPETH DISTRICT IRRIGATION SYSTEM receives Project operating waste and drainage return flow water reaching the lower end of the Project under a Warren Act contract dated 1924, and irrigates about 18,000 acres thru a series of small reservoirs and canals extending down the Rio Grande Valley for a distance of 40 miles below the Project.

THE POWER SYSTEM consists of the 24,300 KW hydro-electric power plant at Elephant Butte Dam, and 365 miles of 115 KV 20,000 KW capacity transmission lines radiating from it. These are the Elephant Butte-Las Cruces-Alamogordo-Hollywood (Ruidoso) line with taps to White Sands Army Ordnance Proving Ground and Alamogordo Army Air Field, 173.78 miles, constructed to Las Cruces in 1940, extended 1945-47; the Elephant Butte-Deming-Central line with tap to Hot Springs, 119.52 miles, constructed 1941, Hot Springs tap 1950 to replace a 13.8 KV, 3.75-mile direct line constructed in 1940; and the Elephant Butte-Socorro line, 71.82 miles, constructed in 1947-1949. There are also two miles of distribution lines in the Elephant Butte Camp Area. Substations are located at the above-mentioned points except at Las Cruces where there is only a switching station, substation facilities there being owned by the El Paso Electric Company. Further extensions and connections to the transmission system are contemplated.

GENERAL CONDITIONS ON THE PROJECT

NUMBER OF IRRIGABLE ACRES IN THE PROJECT is approximately 155,000 acres of land, 88,000 acres in New Mexico, and 67,000 acres in Texas are irrigated in the Project, and approximately 17,886 acres are irrigated in Hudspeth County, Texas.

CHARACTER OF SOIL IN THE IRRIGABLE AREAS is fertile valley alluvium with variable texture ranging from adobe clay silt to light sandy loam, depending on manner of depositions during meandering of the river over the valley floor.

ALTITUDE OF IRRIGABLE AREAS of the Project ranges from 3600 to 4200 feet.

DUTY OF WATER averages approximately 3 acre-feet per acre per year dependent on type of soil and crop.

LENGTH OF IRRIGATION SEASON extends for approximately 201 days, March to September, plus some winter irrigation for short periods.

ANNUAL RAINFALL in the Project area averages approximately 8.9 inches, two-thirds of which usually occurs during late summer and early fall.

RANGE OF TEMPERATURE usually ranges from a minimum low of 14 degrees above zero in the winter to a maximum high of 103 degrees in the summer, with occasional years having record extremes of lowest near zero, and highest of 106 degrees.

PRINCIPAL PRODUCTS of valley crops are cotton and alfalfa; livestock feed, vegetables and fruits are also produced in abundance. Some products may be cropped twice a year. Cotton is now the predominating crop, producing yields of more than 2 bales per acre, with an average of around 1.4 bales. Some livestock feeding and dairying is being practiced.

PRINCIPAL MARKETS for products of the Project, not consumed locally, are thru the facilities available in El Paso to markets in the East, West and Gulf Coast. El Paso is a city of about 140,000 population. Fort Bliss, one of the largest permanent Army posts, is also located adjoining El Paso. Juarez, Mexico is located across the Rio Grande.

TRANSPORTATION is provided by six railroad lines, the Southern Pacific having two main east-west lines passing through El Paso, Texas and Pacific and a branch of the Santa Fe terminating in El Paso, Mexican Central (National) and Mexican Northwestern terminating in Juarez; six U.S. Highways, numbers 54, 62, 70, 80, 85 and 180, with a highly improved State and County system of local roads; also the American, Continental, Mexican and secondary airlines.

NOTE: While the net irrigable area which is limited to the area for which there is considered to be an adequate reliable water supply, being 155,000 acres plus a 3% margin, the gross area of valley bottom land within Project boundaries is approximately 210,000 acres, but this includes 18,500 acres of non-water-right (Suspended) land and all rights of way for canals, drains, roads, railroads, river, etc.

HISTORICAL

The Rio Grande Project is among the first of the projects to receive the attention of Federal Reclamation soon after the passage of the Reclamation Law in 1902. Investigation surveys were begun on the Project in 1903. A feasibility report was made in 1904. The Project was approved by the Secretary of the Interior on December 2, 1905. In 1906 the Reclamation Act was extended to Texas; a Treaty with Mexico was signed providing for International allocation of waters of the Rio Grande; a joint contract was entered into with Water Users' Associations providing for construction, including storage reservoir, diversion dams and canals; and Project construction work was begun on the building of Leasburg Diversion Dam and Canal. The dam and 6 miles of canal were complete in 1908 when first water was delivered through Project works to three old community ditches providing permanent diversion facilities for them, a major problem of irrigators at that time being the difficulty of maintaining their makeshift diversions from the river.

Construction of Elephant Butte Dam was authorized by Congress May 4, 1907 when a $1,000,000 non-reimbursable appropriation was made to apply against its cost on account of the Treaty allowance of water to Mexico. Preparatory work was begun in 1908 but progress was delayed when difficulty in obtaining reservoir land developed. Preparatory work finally being completed, construction of the dam proper progressed through the period 1912 to 1916 but storage operation began January 1915.

The Franklin Canal was constructed in 1889-90 by the El Paso Irrigation Company and after passing through several financial reorganizations was acquired by the Bureau of Reclamation by purchase in 1912 to be one of the Project's main canals. Additional diversion works consisting of reconstruction of the Franklin Canal, construction of Mesilla Dam and the East Side and West Side Canals, Percha Dam and Rincon Valley Canal, and extension of Leasburg Canal were accomplished during the period 1914-1919.

In 1917-1918 the Water Users' Associations were succeeded by the Irrigation Districts, and contracts were entered into for the construction of lateral distribution canals and drainage system in addition to storage and diversion works. A critical seepage condition having developed as a result of the rising ground water table, construction of the drainage system which was begun in 1916 was expedited as much as possible. During the period 1918-1929 taking over of old community ditches, their reconstruction and extension, and construction of new laterals to form a complete irrigation distribution system and the drainage system, was in progress. Improvements and betterments have been added from time to time since.

Caballo Dam became justified when it was included as a flood control unit in the Rio Grande Rectification Project and part of its cost allocated to that purpose. It made year-round power generation at Elephant Butte Dam possible and part of the cost was allocated to that purpose, but it also provided additional Project storage. It was built 1936-1938 followed by the construction of the power plant 1938-1940. Construction of the power transmission system has been in progress since 1940.

Irrigation on the Project antedates endeavors at an organized unified project by approximately 250 to 300 years, probably commencing with the establishment of Paso del Norte, now Juarez, Mexico, by the Spaniards as a way station on their travel route to and from Mexico in their conquest of New Mexico during the 17th century. It is not known whether any earlier irrigation was practiced in the area by Indians.

At the inception of the Project as a Federal undertaking, practically all of the land was in private ownership, title to most of it having originated in old Spanish Land Grants. Scattered areas in the vicinity of local community settlements constituting probably 25% to 30% of the total Project area were in cultivation, irrigating from numerous community ditches, each having its separate makeshift heading on the river which usually washed out during high water, frequently requiring replacement or a change in location.

Storage first began to be considered about 1890 when extensive settlement and irrigation development in southern Colorado, in addition to that which had already taken place in central New Mexico, absorbed the normal summer flow of the Rio Grande, causing it to be dry at El Paso during more frequent and longer periods. Several local and smaller storage developments were proposed, but conflicting interests prevented the culmination of any of them. These, including Mexico's claims for loss of water based on ancient prior right, were resolved by the proposed plan for Project development under the Reclamation Act when it was reported in 1904 that a reservoir could be created by construction of a dam at Elephant Butte which would provide sufficient water to meet the requirements of all interests, and by the Treaty of 1906.

A compact agreeing to the allocation of the Upper Rio Grande water between the States of Colorado, New Mexico and Texas, including the treaty allowance to Mexico, was entered into in 1938.

EARLY SETTLEMENT. Major periods and advents influencing settlement and development of the Project area may be reviewed as follows:

Expedition of Cabeza de Vaca through the Southwest in 1536 followed by the Coronado Expedition in 1540.

Journey of Juan de Onate up the Rio Grande from Mexico to colonize in Northern New Mexico, 1598.

Establishment of a mission at Paso del Norte in 1659.

Use of Paso del Norte, now Juarez, Mexico, by the Spaniards as a way station on their travel route to and from Mexico in their conquest and colonization of Northern New Mexico during the 17th and 18th Centuries.

Retreat of the Spanish conquerors and their Indian converts to Paso del Norte in 1680 when driven out of New Mexico by the Pueblo Indians in revolt, resulting in the establishment of several settlements below Paso del Norte, some of which, Ysleta and Socorro, are now on the American side of the river.

De Varga's reconquest of New Mexico 1692.

Increased endeavor at Spanish and Mexican colonization about 1800-1840 with establishment of settlements including Dona Ana and Mesilla above Paso del Norte; earlier colonization in Southern New Mexico was not accomplished because of Indian raids.

Mexico independence from Spain 1822.

Influx of Anglo-American settlers as result of the following occurrences about the middle of the 19th Century: Texas independence from Mexico 1836, followed by United States annexation 1845; Cessation of territorial claims west of the Rio Grande by Mexico at close of the Mexican War 1848; Gadsden Purchase from Mexico 1853. Westward migration following discovery of gold in California in 1848, and opening of mines in New Mexico and Arizona.

Establishment and occupation of a system of forts through the Southwest for protection against Indian raids and the operation of overland stage and wagon train routes 1848-1892.

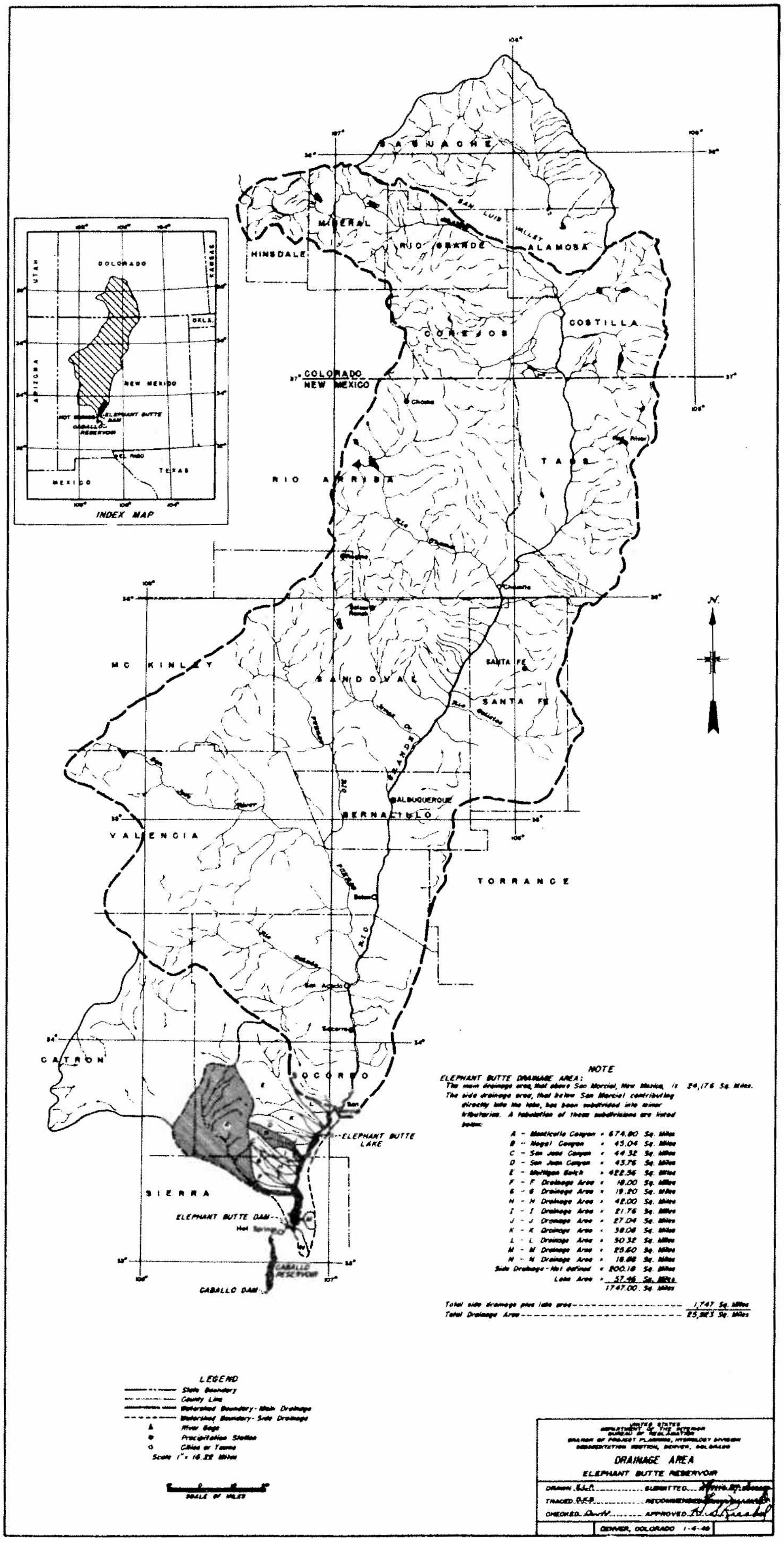
Fort Bliss, which has become a major permanent Army post, was originally located on the site of what became the City of El Paso. Other forts which were located on the Project area were Fort Quitman and Fort Hancock located 68 miles and 48 miles respectively southeast of the site of El Paso; Fort Fillmore and Fort Selden, 7 miles south and 14 miles north of the site of Las Cruces; Fort Thorn 6 miles north-west of the site of Hatch; Fort McRae and Fort Craig near the lower end and the upper end of the site of Elephant Butte Reservoir. These were occupied at various times and abandoned when no longer needed. Other sites as at San Elizario, Mesilla and Dona Ana were occupied at various times more temporarily as military posts.

Increased Anglo-American migration following advent of railroads into El Paso, Southern Pacific and Santa Fe 1881, Texas and Pacific, 1882, El Paso Northeastern-Southwestern 1899-1903, merged with the Southern Pacific 1924. The Mexican Central began operation from Juarez in 1882 and the Mexican Northwestern 1896.

Increased activity in land acquisition and improvements with assurance and inception of Reclamation Project development commencing about 1906.

Major construction of Project irrigation works 1906-1930, followed by power development 1938-1950.

Attainment of full agricultural development of Project area, following completion of Project works to serve the entire irrigable area 1930-1950, accelerated by the very profitable production of cotton following its highly successful introduction as a Project crop in 1917.



SAGUACHE
MINERAL
HINSDALE
RIO GRANDE
ALAMOSA
SAN LUIS VALLEY
CONEJOS
COSTILLA
COLORADO
NEW MEXICO
Chama
RIO ARRIBA
TAOS
Chamita
SANTA FE
MC KINLEY
SANDOVAL
ALBUQUERQUE
BERNALILLO
VALENCIA
TORRANCE
San Acacia
Socorro
CATRON
SOCORRO
ELEPHANT BUTTE LAKE
SIERRA
ELEPHANT BUTTE DAM
Hot Springs
CABALLO RESERVOIR
CABALLO DAM
INDEX MAP
UTAH
COLORADO
KANSAS
OKLA.
ARIZONA
NEW MEXICO
ELEPHANT BUTTE DAM
CABALLO RESERVOIR
EL PASO
TEXAS
MEXICO
NOTE
ELEPHANT BUTTE DRAINAGE AREA:
The main drainage area, that above San Marcial, New Mexico, is 24,176 Sq. Miles.
The side drainage area, that below San Marcial contributing directly into the lake, has been subdivided into minor tributaries. A tabulation of these subdivisions are listed below:
A - Monticello Canyon = 674.80 Sq. Miles
B - Nogal Canyon = 45.04 Sq. Miles
C - San Jose Canyon = 44.32 Sq. Miles
D - San Juan Canyon = 43.76 Sq. Miles
E - Mulligan Gulch = 422.56 Sq. Miles
F - F Drainage Area = 19.00 Sq. Miles
G - G Drainage Area = 19.20 Sq. Miles
H - H Drainage Area = 42.00 Sq. Miles
I - I Drainage Area = 21.76 Sq. Miles
J - J Drainage Area = 27.04 Sq. Miles
K - K Drainage Area = 38.08 Sq. Miles
L - L Drainage Area = 50.32 Sq. Miles
M - M Drainage Area = 25.60 Sq. Miles
N - N Drainage Area = 18.88 Sq. Miles
Side Drainage - Not defined = 200.18 Sq. Miles
Lake Area = 57.46 Sq. Miles
1747.00 Sq. Miles
Total side drainage plus lake area 1,747 Sq. Miles
Total Drainage Area 25,923 Sq. Miles
LEGEND
State Boundary
County Line
Watershed Boundary - Main Drainage
Watershed Boundary - Side Drainage
River Gage
Precipitation Station
Cities or Towns
Scale 1" = 16.22 Miles
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DRAINAGE AREA
ELEPHANT BUTTE RESERVOIR
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO 1-4-48

Figure 4

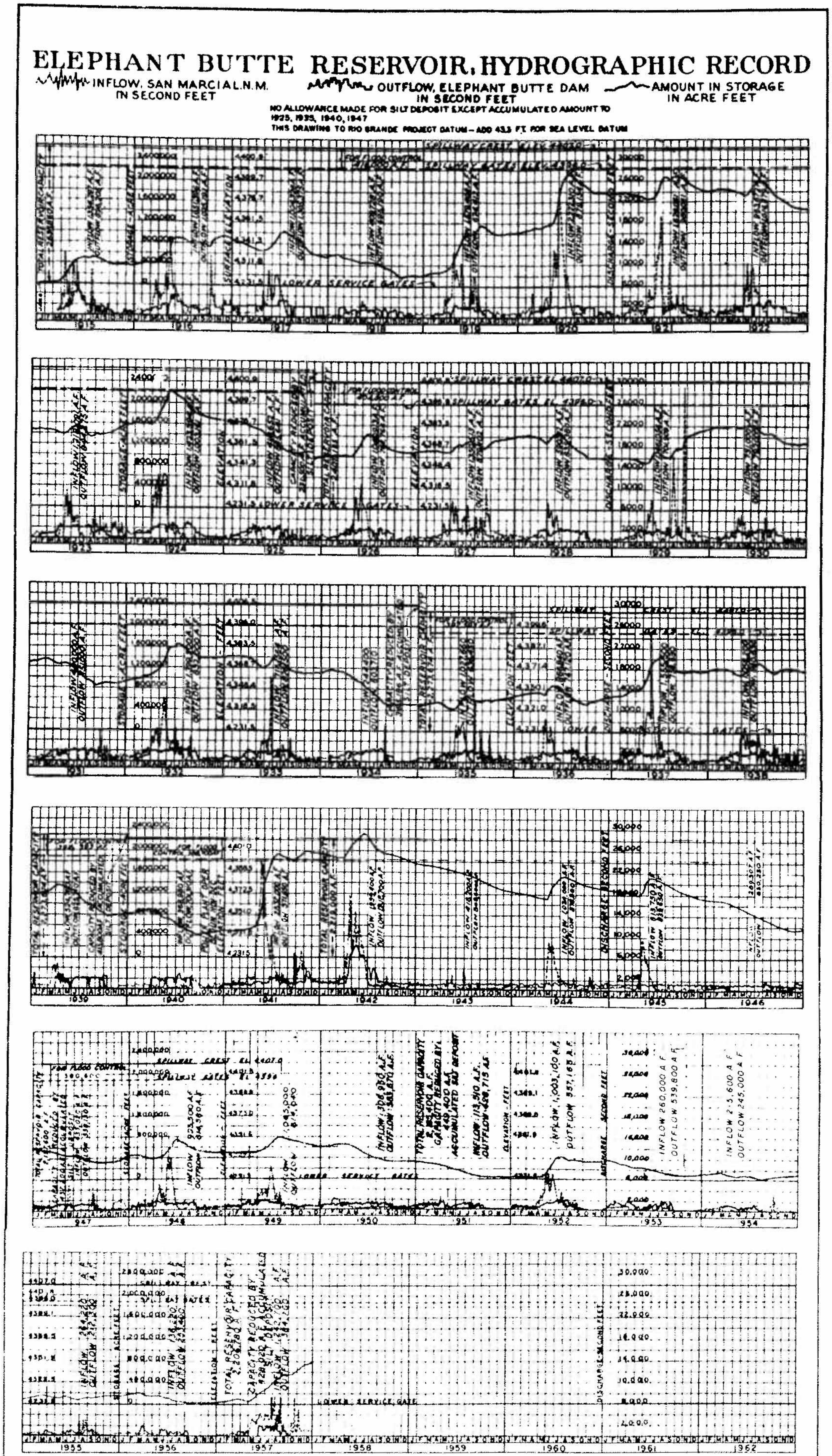
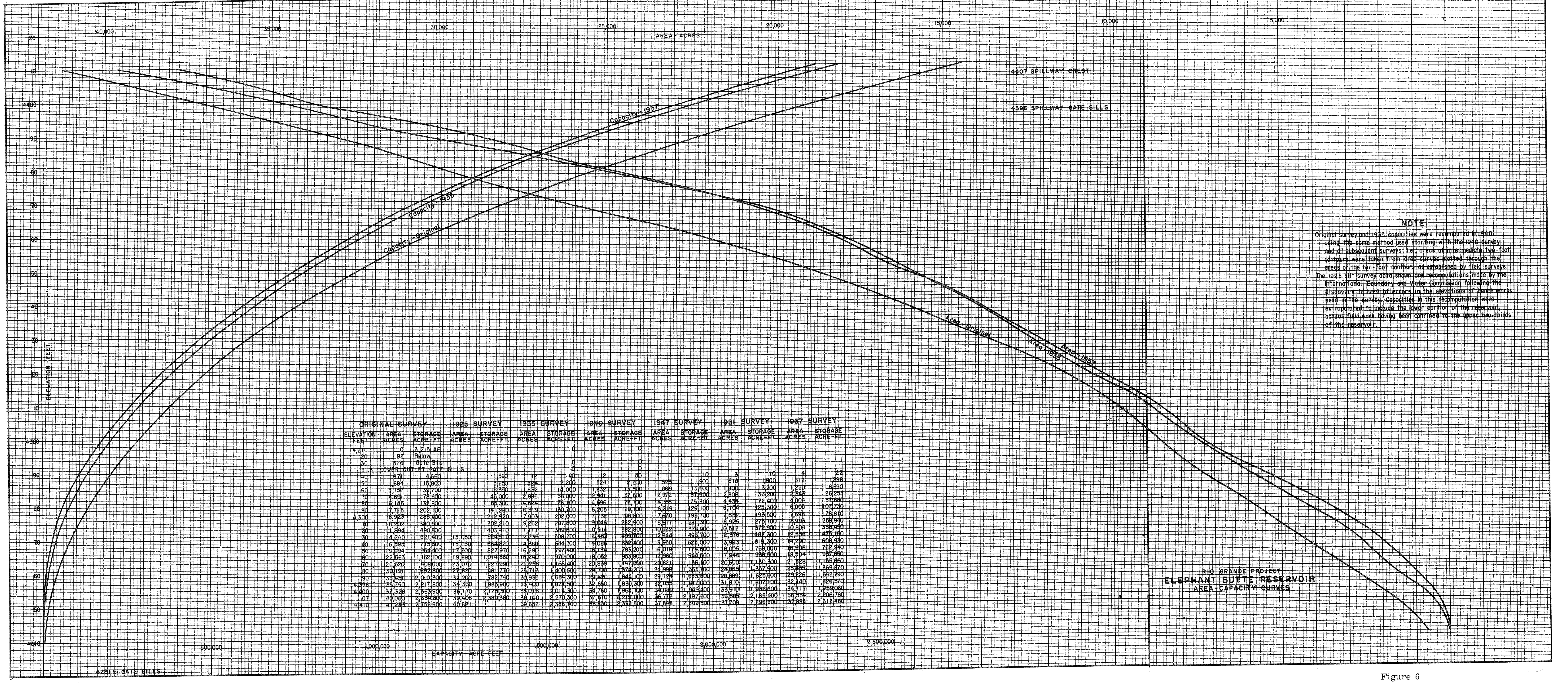

ELEPHANT BUTTE RESERVOIR, HYDROGRAPHIC RECORD
INFLOW, SAN MARCIAL, N.M. IN SECOND FEET
OUTFLOW, ELEPHANT BUTTE DAM IN SECOND FEET
AMOUNT IN STORAGE IN ACRE FEET
NO ALLOWANCE MADE FOR SILT DEPOSIT EXCEPT ACCUMULATED AMOUNT TO 1925, 1935, 1940, 1947
THIS DRAWING TO RIO GRANDE PROJECT DATUM – ADD 43.3 FT. FOR SEA LEVEL DATUM

Figure 5



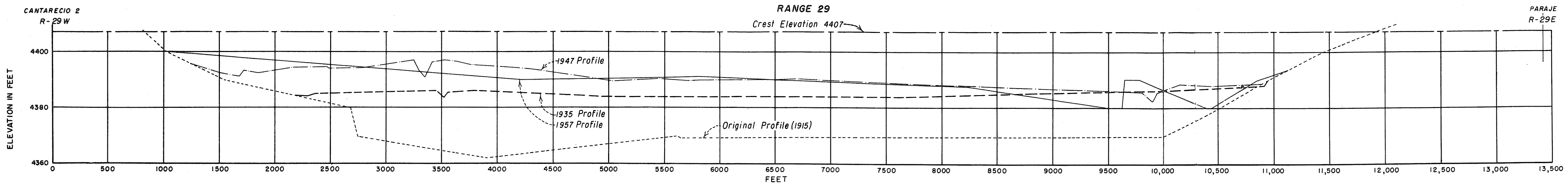
ELEVATION FEET	ORIGINAL SURVEY AREA ACRES	ORIGINAL SURVEY STORAGE ACRE-FT.	1925 SURVEY AREA ACRES	1925 SURVEY STORAGE ACRE-FT.	1935 SURVEY AREA ACRES	1935 SURVEY STORAGE ACRE-FT.	1940 SURVEY AREA ACRES	1940 SURVEY STORAGE ACRE-FT.	1947 SURVEY AREA ACRES	1947 SURVEY STORAGE ACRE-FT.	1951 SURVEY AREA ACRES	1951 SURVEY STORAGE ACRE-FT.	1957 SURVEY AREA ACRES	1957 SURVEY STORAGE ACRE-FT.
4,210	0	3,215 AF				0		0						
20	98	Below												
30	576	Gate Sills				0		0					1	1
31.5	LOWER OUTLET GATE SILLS			0		-0		0						
40	671	4,660		1,590	12	40	12	50	11	10	3	10	4	22
50	1,684	15,800		5,250	524	2,200	524	2,200	523	1,900	518	1,900	512	1,298
60	3,157	39,700		18,350	1,832	14,000	1,832	13,500	1,869	13,800	1,800	13,200	1,220	8,590
70	4,691	78,600		45,000	2,986	38,000	2,941	37,600	2,972	37,900	2,808	36,200	2,343	26,253
80	6,145	132,800		83,300	4,624	76,100	4,596	75,100	4,555	75,300	4,434	72,400	4,004	57,680
90	7,715	202,100		141,280	6,319	130,700	6,205	129,100	6,219	129,100	6,104	125,300	6,005	107,730
4,300	8,923	285,400		212,920	7,903	202,000	7,732	198,800	7,670	198,700	7,532	193,500	7,698	176,810
10	10,202	380,800		302,210	9,262	287,800	9,046	282,900	8,917	281,300	8,925	275,700	8,993	259,940
20	11,894	490,800		403,410	11,111	389,600	10,914	382,800	10,622	378,900	10,512	372,900	10,804	358,450
30	14,240	621,400	13,050	524,510	12,735	508,700	12,463	499,700	12,344	493,700	12,376	487,300	12,556	475,150
40	16,595	775,600	15,130	664,820	14,388	644,300	14,088	632,400	13,950	625,000	13,983	619,300	14,290	608,930
50	19,194	954,400	17,500	827,970	16,290	797,400	16,134	783,200	16,019	774,600	16,005	769,000	16,506	762,940
60	22,563	1,162,100	19,890	1,014,880	18,240	970,000	18,052	953,800	17,960	944,500	17,946	938,500	18,504	957,850
70	26,620	1,408,000	23,070	1,227,990	21,256	1,166,400	20,839	1,147,600	20,621	1,136,100	20,600	1,130,300	21,328	1,135,660
80	30,191	1,692,800	27,820	1,481,770	25,713	1,400,400	24,700	1,374,200	24,998	1,365,700	24,865	1,357,900	25,455	1,369,870
90	33,451	2,010,300	32,200	1,782,740	30,935	1,684,300	29,420	1,644,100	29,124	1,633,800	28,689	1,625,600	29,226	1,642,790
4,396	35,750	2,217,800	34,330	1,983,900	33,400	1,877,500	32,650	1,830,300	32,055	1,817,000	31,810	1,807,100	32,140	1,826,570
4,400	37,328	2,363,900	36,170	2,125,300	35,016	2,014,300	34,760	1,965,100	34,089	1,949,400	33,910	1,938,600	34,117	1,959,080
07	40,060	2,634,800	39,406	2,389,380	38,140	2,270,300	37,670	2,219,000	36,772	2,197,600	36,585	2,185,400	36,584	2,206,780
4,410	41,283	2,756,600	40,821		39,652	2,386,700	38,830	2,333,500	37,848	2,309,500	37,709	2,296,900	37,884	2,318,460

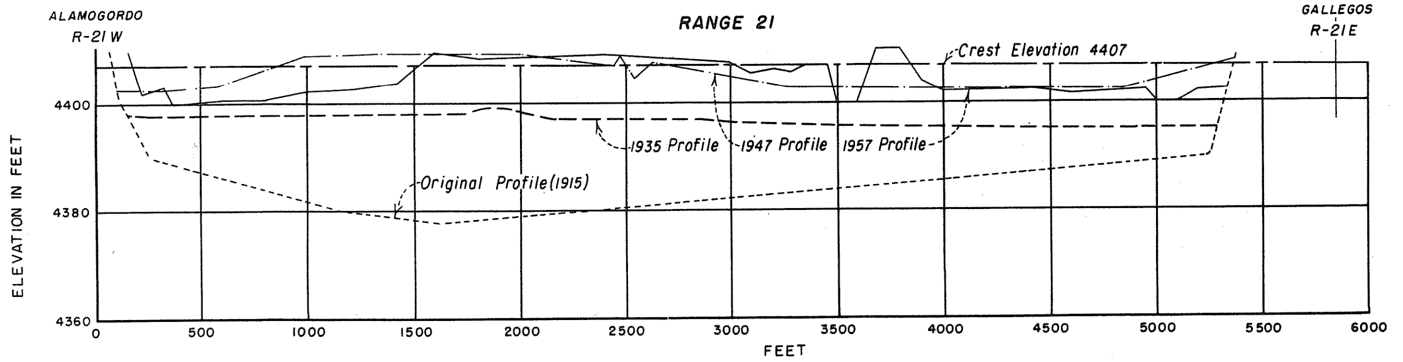
NOTE

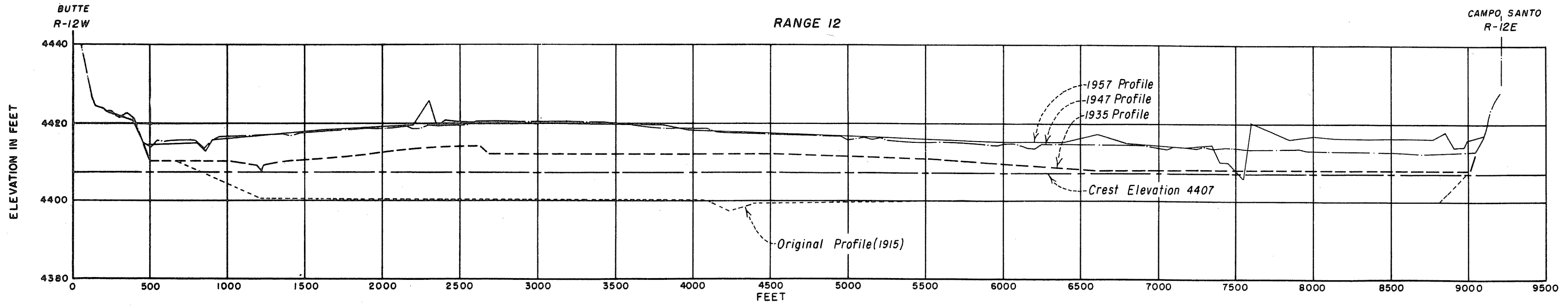
Original survey and 1935 capacities were recomputed in 1940 using the same method used starting with the 1940 survey and all subsequent surveys; i.e., areas of intermediate two-foot contours were taken from area curves plotted through the areas of the ten-foot contours as established by field surveys.

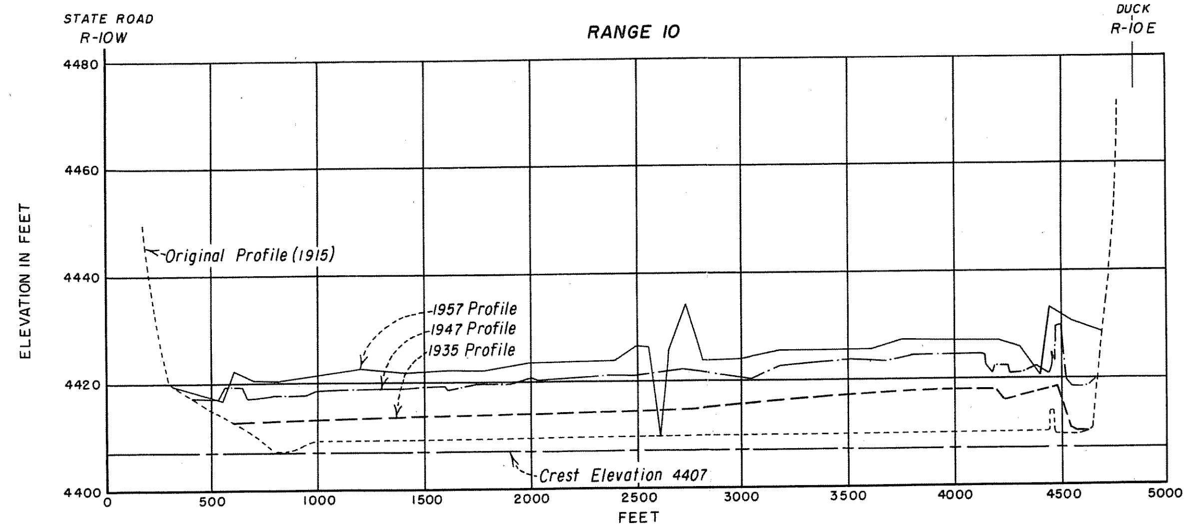
The 1925 silt survey data shown are recomputations made by the International Boundary and Water Commission following the discovery in 1929 of errors in the elevations of bench marks used in the survey. Capacities in this recomputation were extrapolated to include the lower portion of the reservoir, actual field work having been confined to the upper two-thirds of the reservoir.

Figure 6





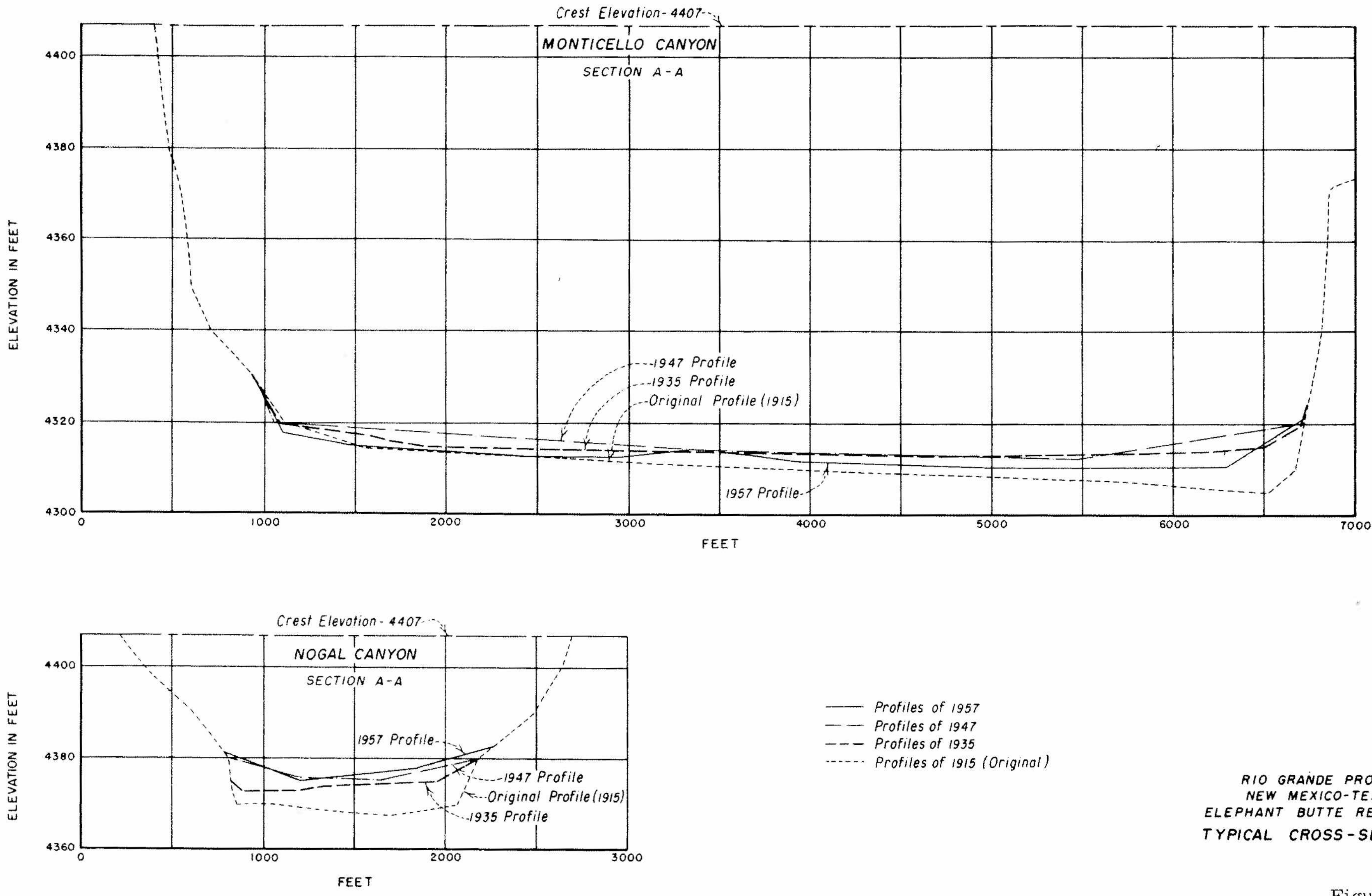




Profiles of 1957
Profiles of 1947
Profiles of 1935
Profiles of 1915 (Original)

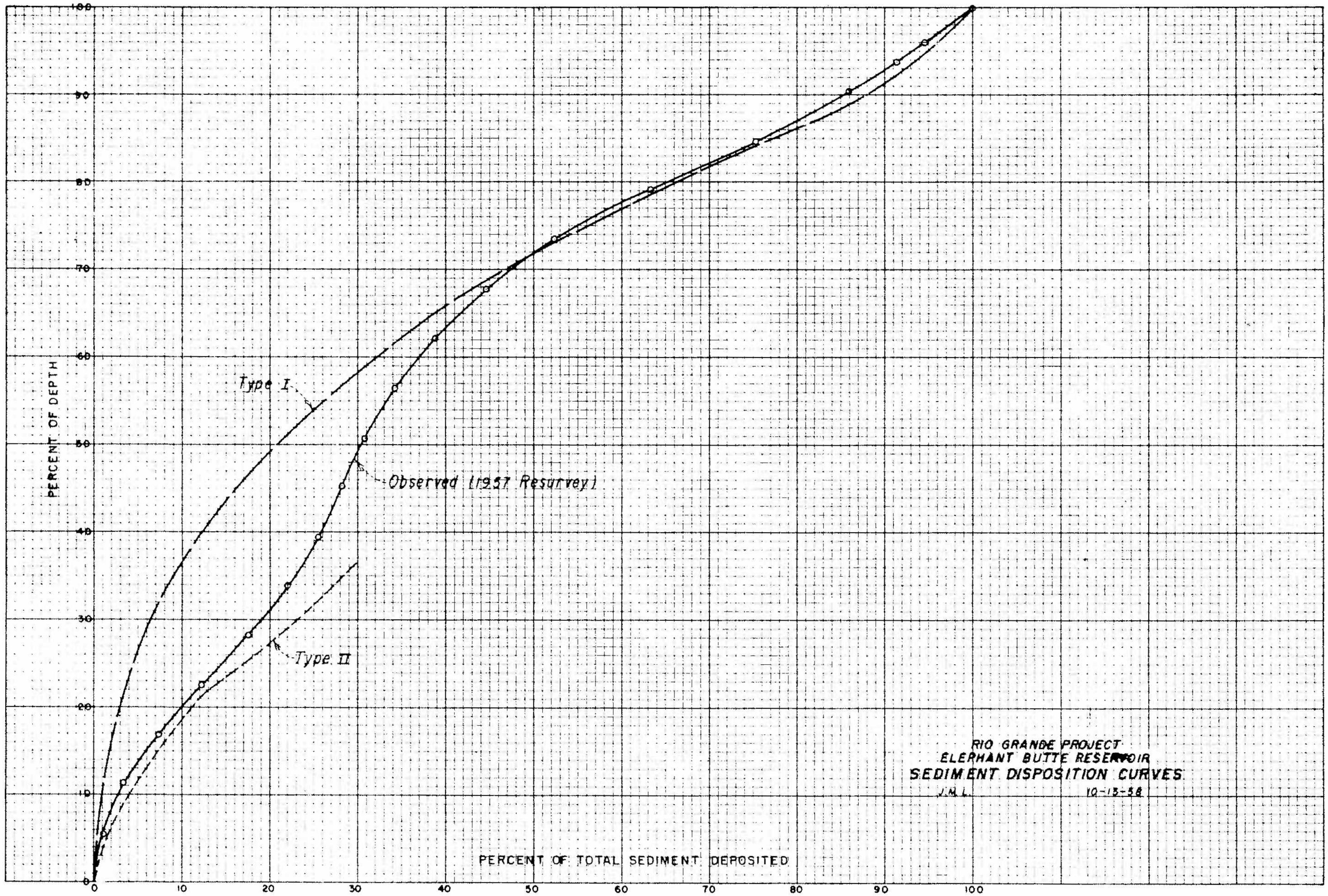
RIO GRANDE PROJECT
NEW MEXICO-TEXAS
ELEPHANT BUTTE RESERVOIR
TYPICAL CROSS-SECTIONS

Figure 10



RIO GRANDE PROJECT
NEW MEXICO-TEXAS
ELEPHANT BUTTE RESERVOIR
TYPICAL CROSS-SECTIONS

Figure 11



PERCENT OF DEPTH
PERCENT OF TOTAL SEDIMENT DEPOSITED
Type I
Type II
Observed (1957 Resurvey)
0
10
20
30
40
50
60
70
80
90
100
RIO GRANDE PROJECT
ELEPHANT BUTTE RESERVOIR
SEDIMENT DISPOSITION CURVES
J.M.L.
10-15-58

Figure 12

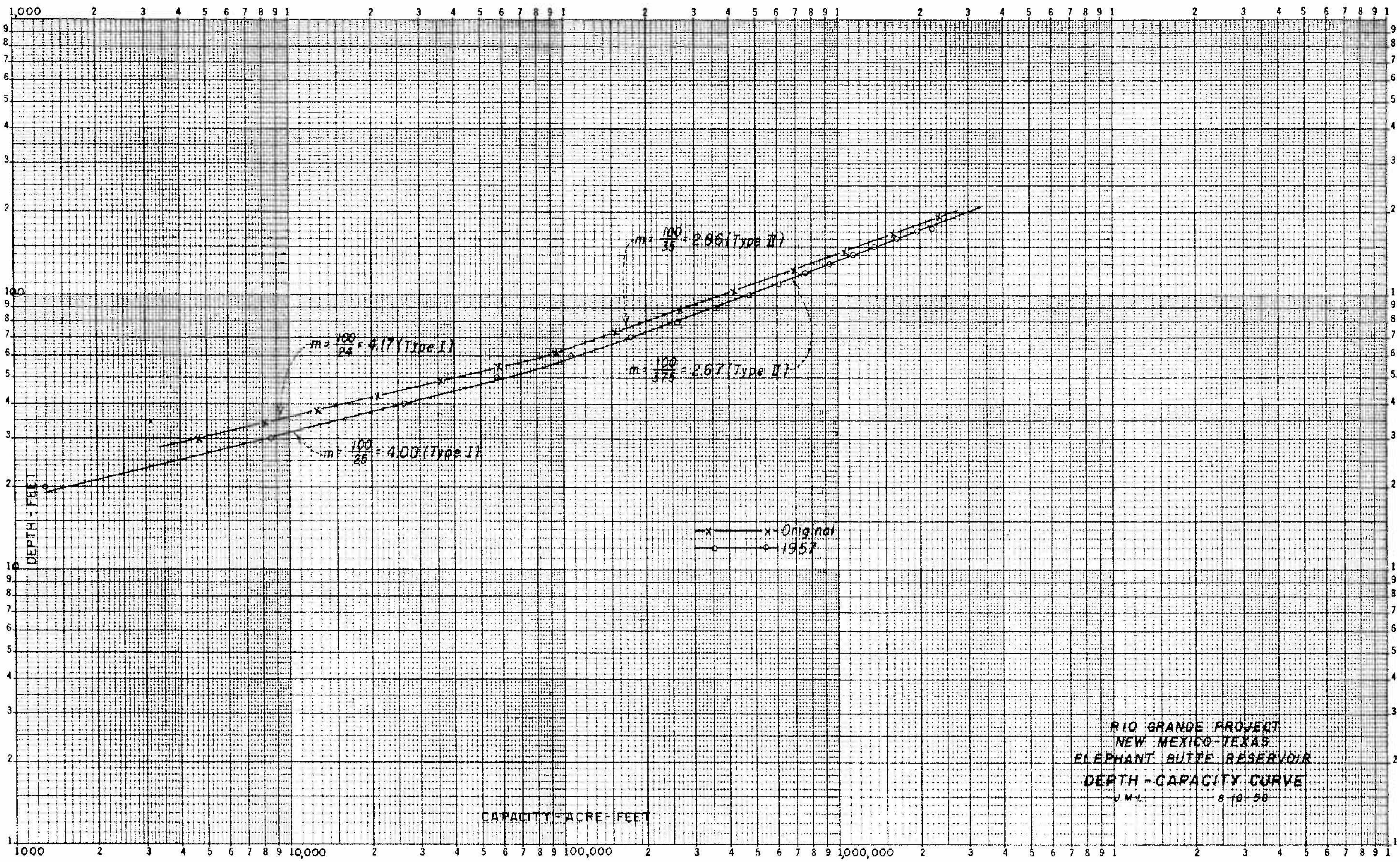

m = 100/24 = 4.17 (Type I)
m = 100/25 = 4.00 (Type I)
m = 100/35 = 2.86 (Type II)
m = 100/37.5 = 2.67 (Type II)
Original
1957
DEPTH - FEET
CAPACITY - ACRE-FEET
1000
10,000
100,000
1,000,000
RIO GRANDE PROJECT
NEW MEXICO-TEXAS
ELEPHANT BUTTE RESERVOIR
DEPTH - CAPACITY CURVE
J.M.L. 8-18-58

Figure 13

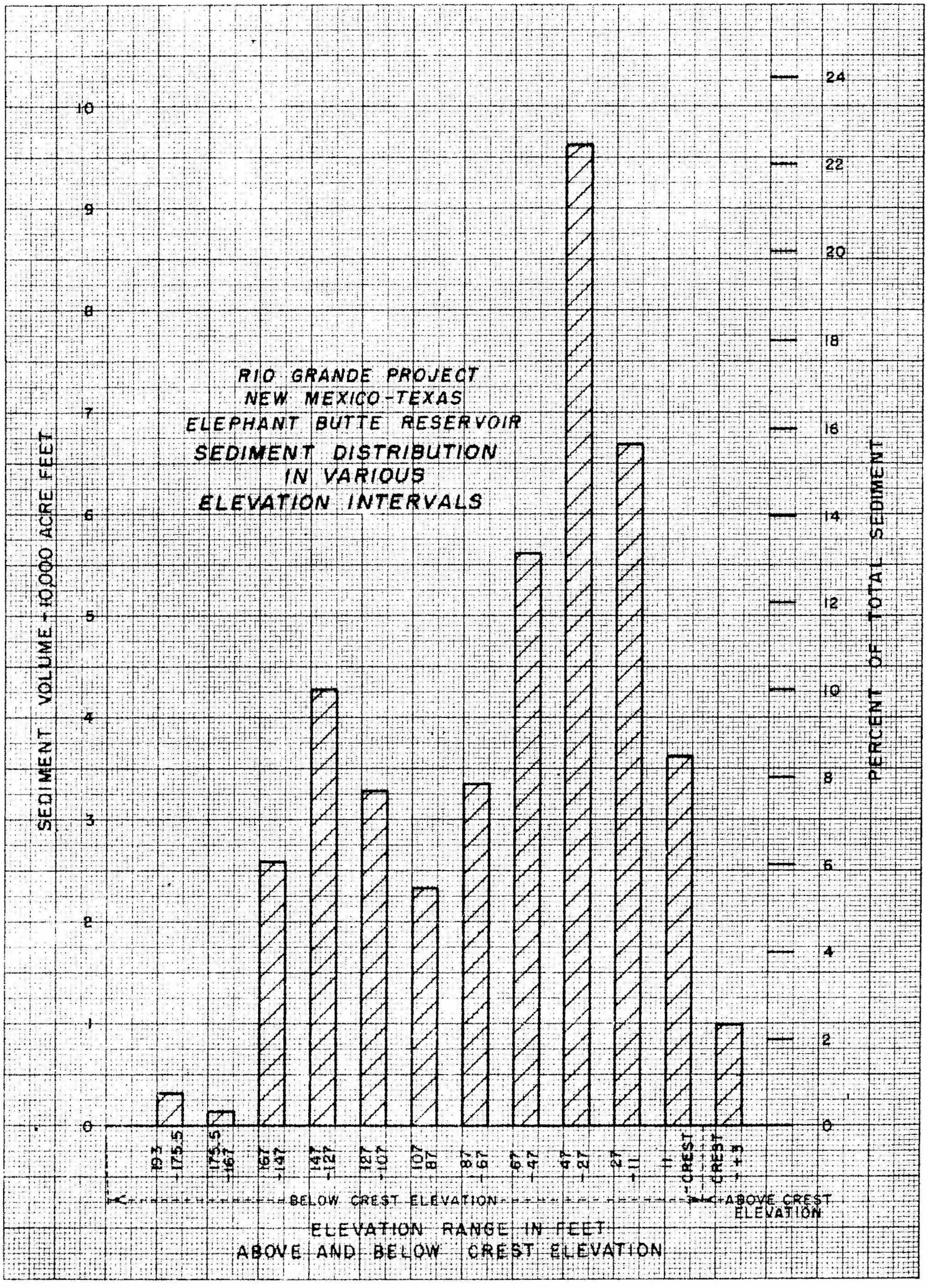

RIO GRANDE PROJECT
NEW MEXICO-TEXAS
ELEPHANT BUTTE RESERVOIR
SEDIMENT DISTRIBUTION
IN VARIOUS
ELEVATION INTERVALS
SEDIMENT VOLUME - 10,000 ACRE FEET
PERCENT OF TOTAL SEDIMENT
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14
16
18
20
22
24
193 -175.5
175.5 -167
167 -147
147 -127
127 -107
107 -87
87 -67
67 -47
47 -27
27 -11
11 -CREST
CREST -+3
BELOW CREST ELEVATION
ABOVE CREST ELEVATION
ELEVATION RANGE IN FEET
ABOVE AND BELOW CREST ELEVATION

Figure 14

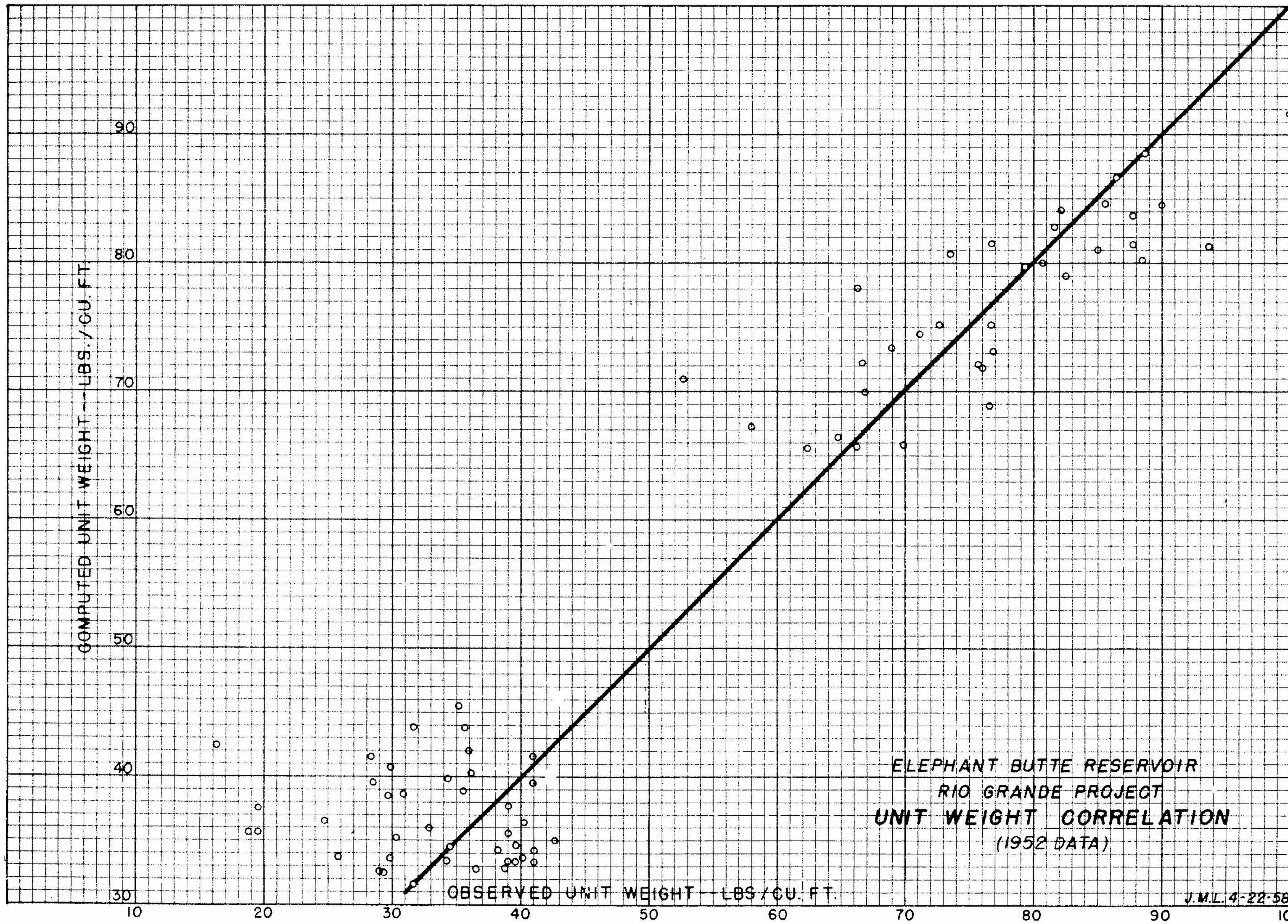

ELEPHANT BUTTE RESERVOIR
RIO GRANDE PROJECT
UNIT WEIGHT CORRELATION
(1952 DATA)
COMPUTED UNIT WEIGHT--LBS./CU. FT.
OBSERVED UNIT WEIGHT--LBS./CU. FT.
30
40
50
60
70
80
90
10
20
30
40
50
60
70
80
90
100
J.M.L. 4-22-58

Figure 15

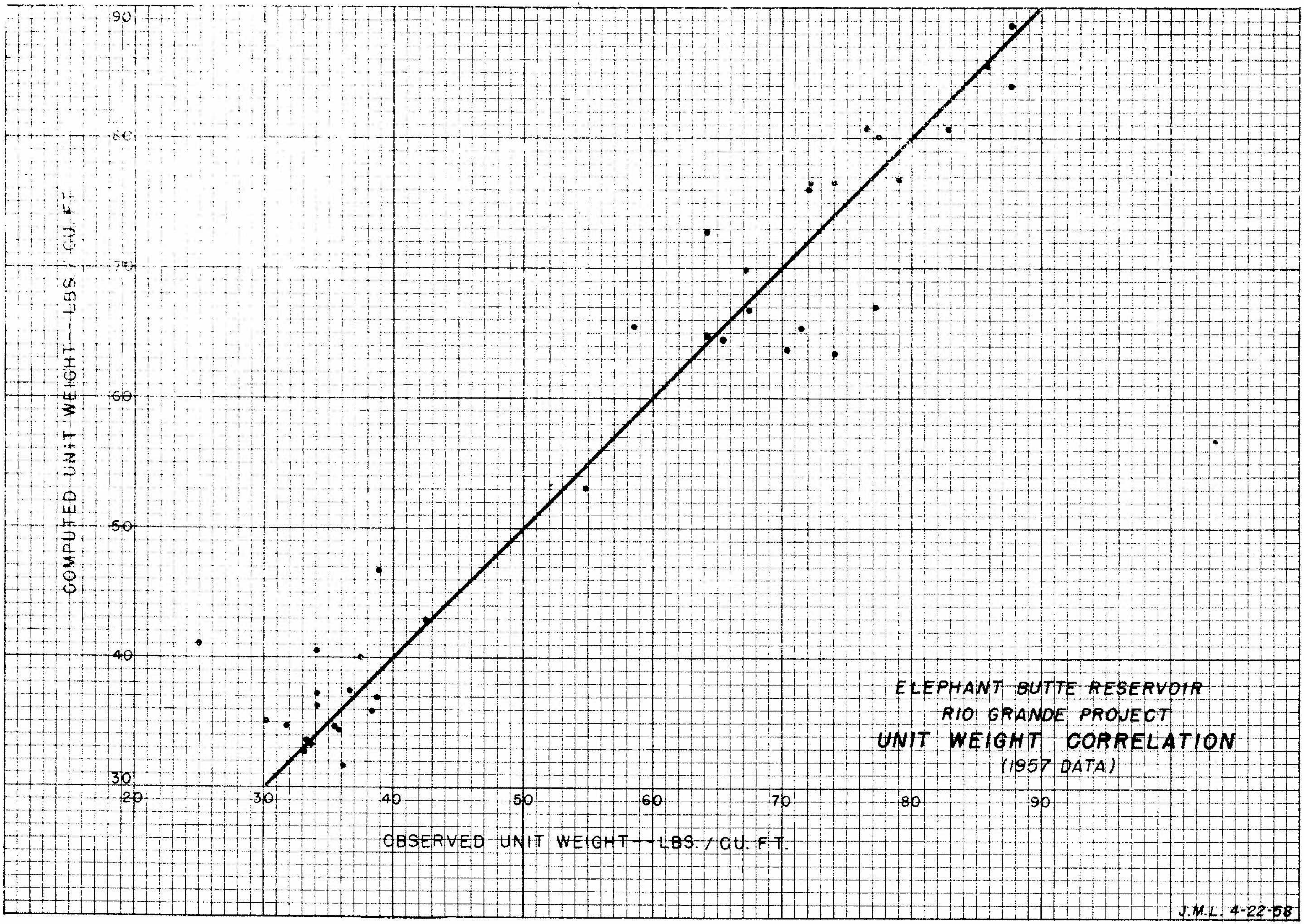

ELEPHANT BUTTE RESERVOIR
RIO GRANDE PROJECT
UNIT WEIGHT CORRELATION
(1957 DATA)
COMPUTED UNIT WEIGHT--LBS./CU.FT.
OBSERVED UNIT WEIGHT--LBS./CU.FT.
20
30
40
50
60
70
80
90
J.M.L. 4-22-58

Figure 16

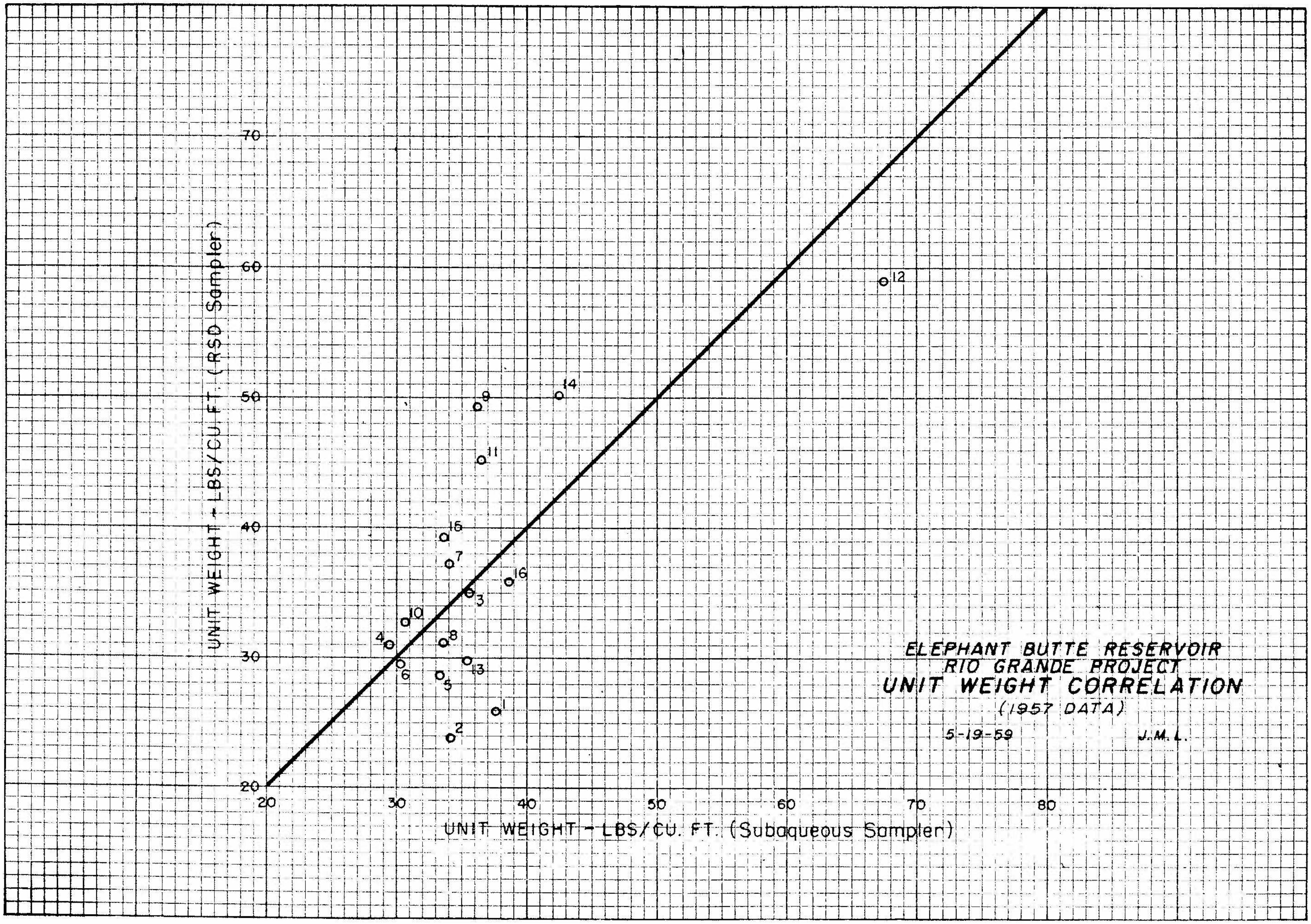
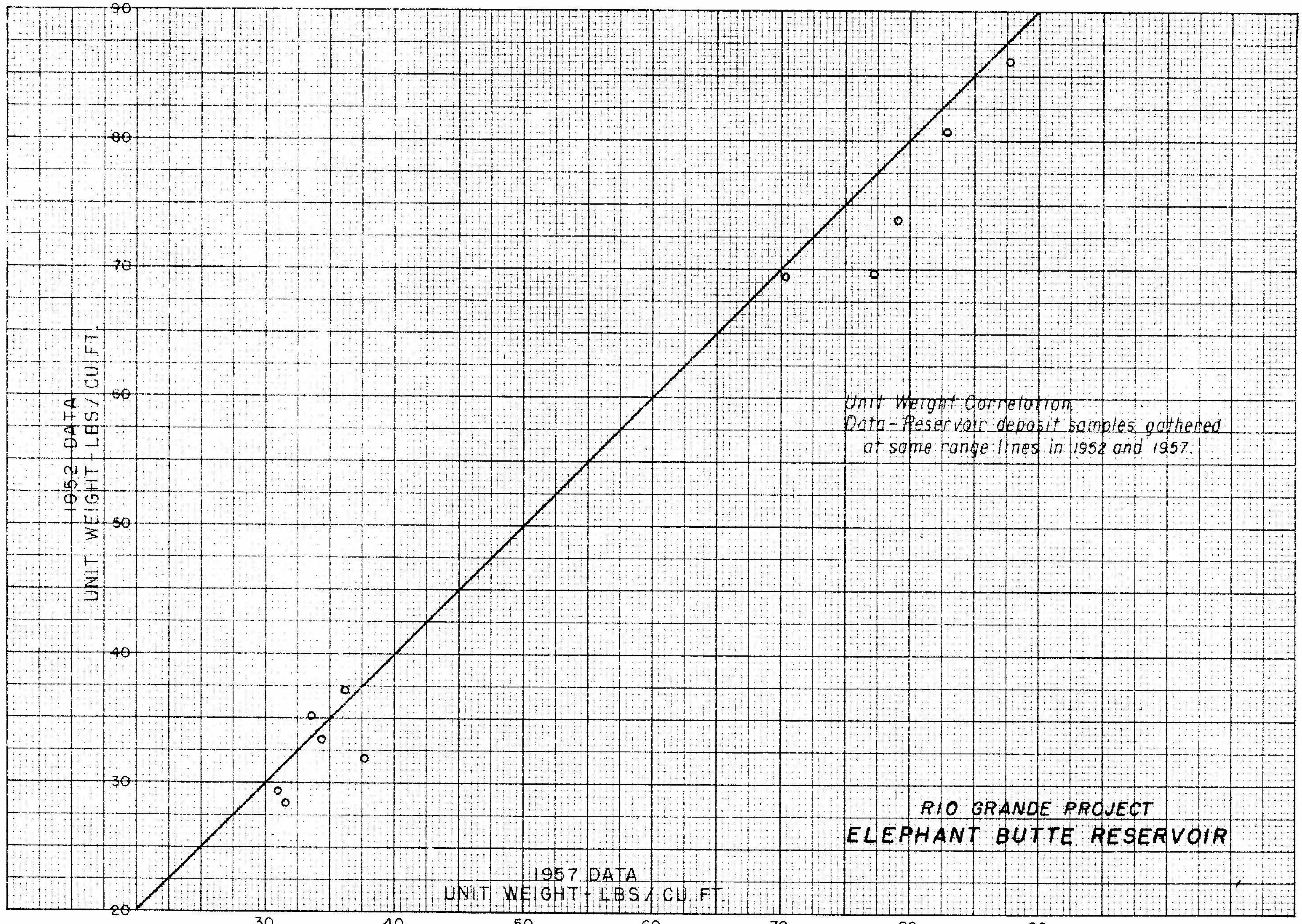

ELEPHANT BUTTE RESERVOIR
RIO GRANDE PROJECT
UNIT WEIGHT CORRELATION
(1957 DATA)
5-19-59
J.M.L.
UNIT WEIGHT - LBS/CU. FT. (RSD Sampler)
UNIT WEIGHT - LBS/CU. FT. (Subaqueous Sampler)
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 17



90
80
70
60
50
40
30
20
1952 DATA
UNIT WEIGHT-LBS/CU.FT.
Unit Weight Correlation
Data-Reservoir deposit samples gathered
at same range lines in 1952 and 1957.
RIO GRANDE PROJECT
ELEPHANT BUTTE RESERVOIR
1957 DATA
UNIT WEIGHT-LBS/CU.FT.
30
40
50
60
70
80
90

Figure 18

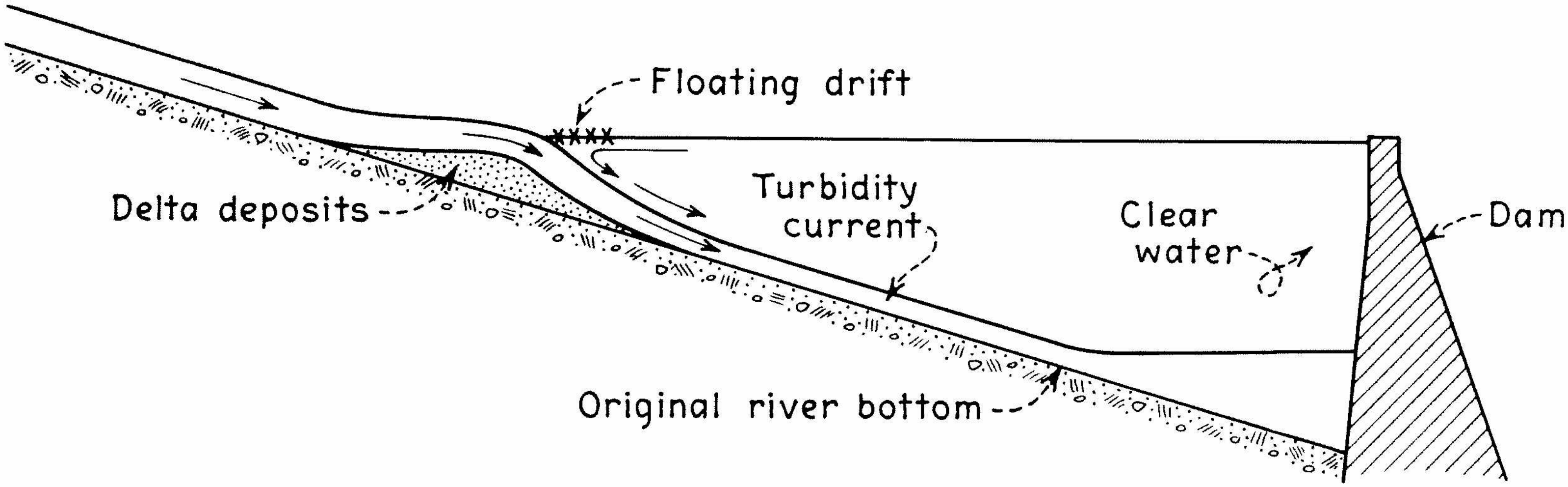
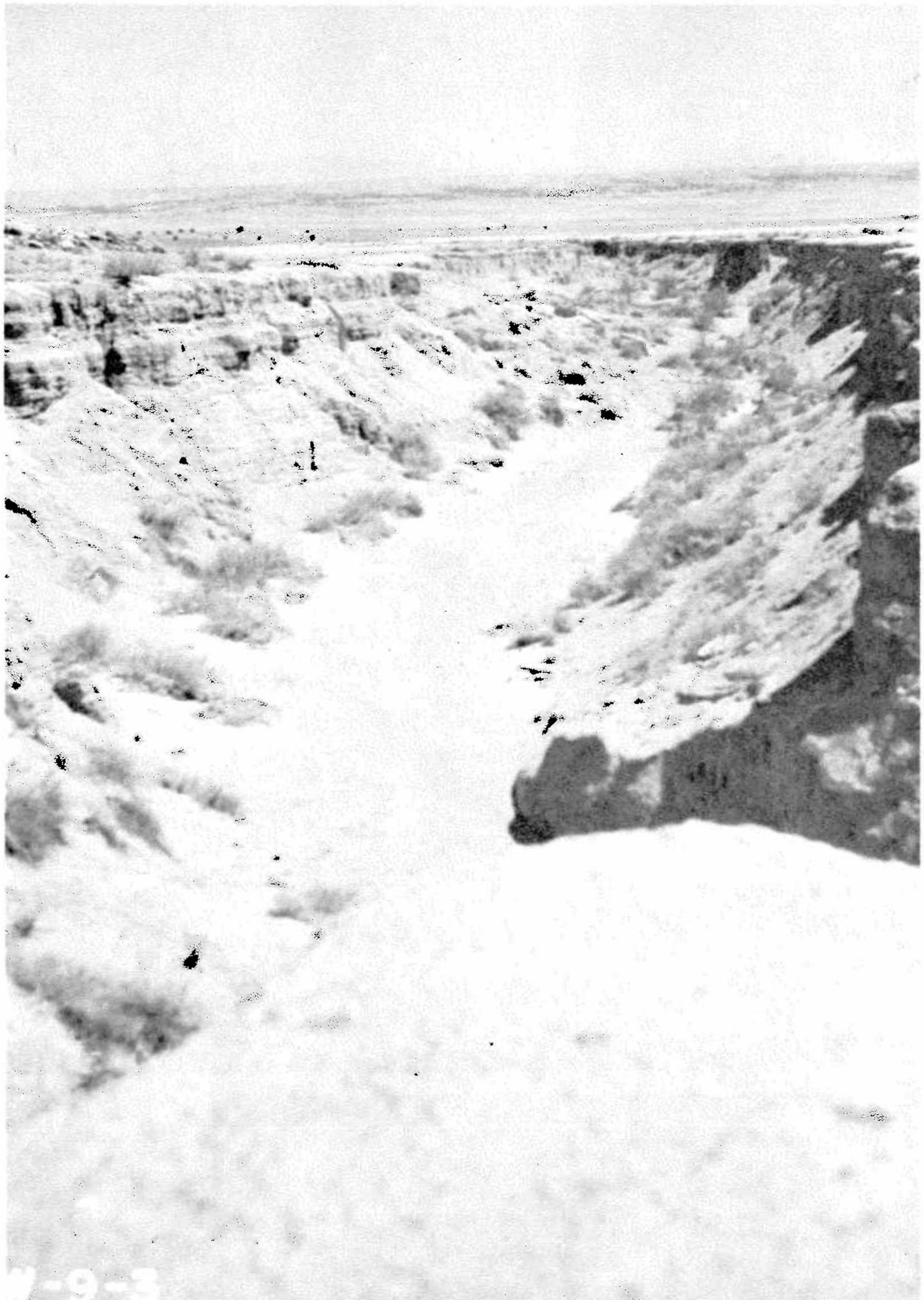


FIGURE I - UNDERFLOWING TURBIDITY CURRENT IN A RESERVOIR

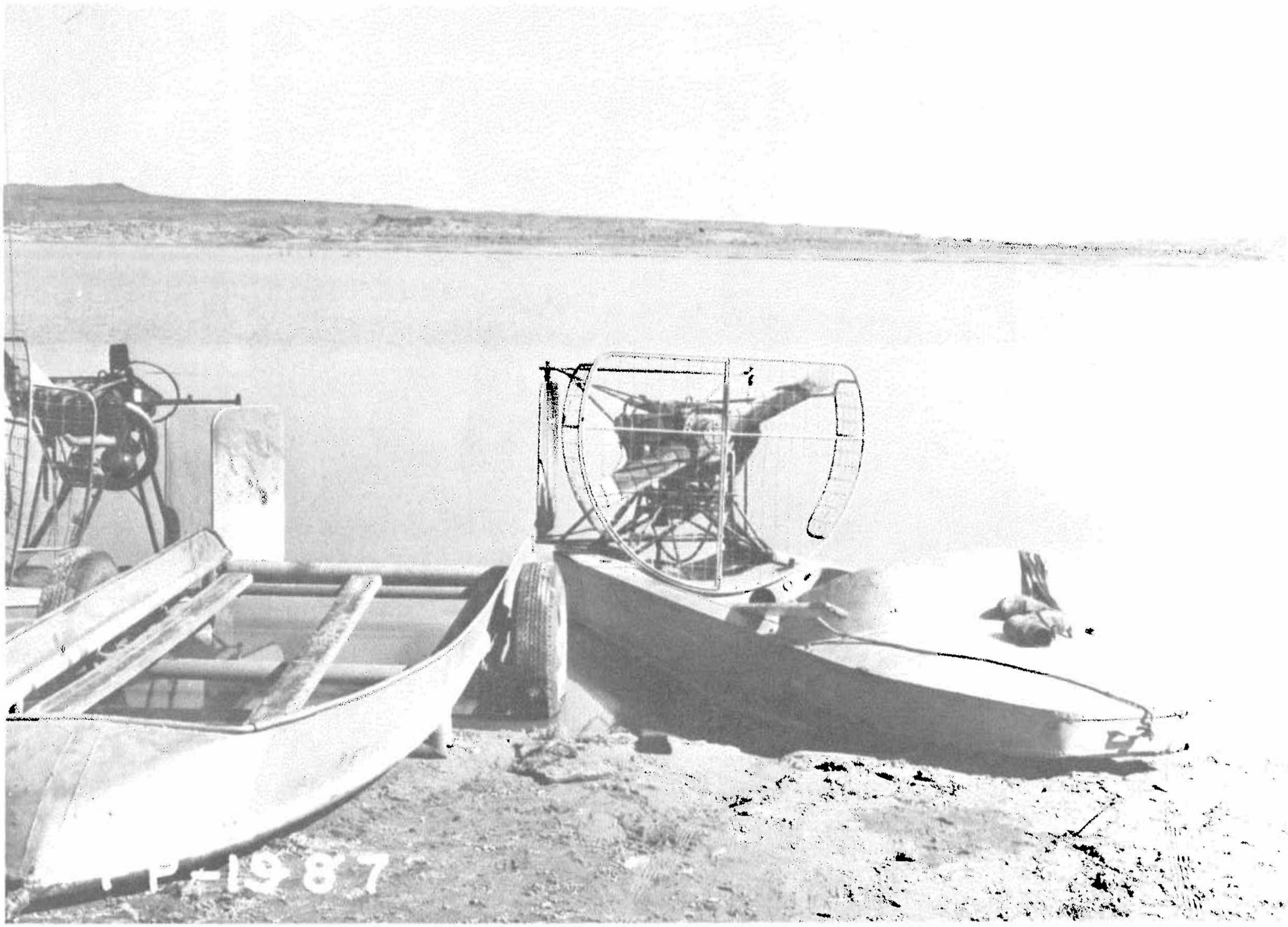
PLUNGING TYPE

Photograph No. 2 - View of one of the cotton fields in one of the irrigated areas of the Rio Grande Project. Cotton is the predominant crop produced.

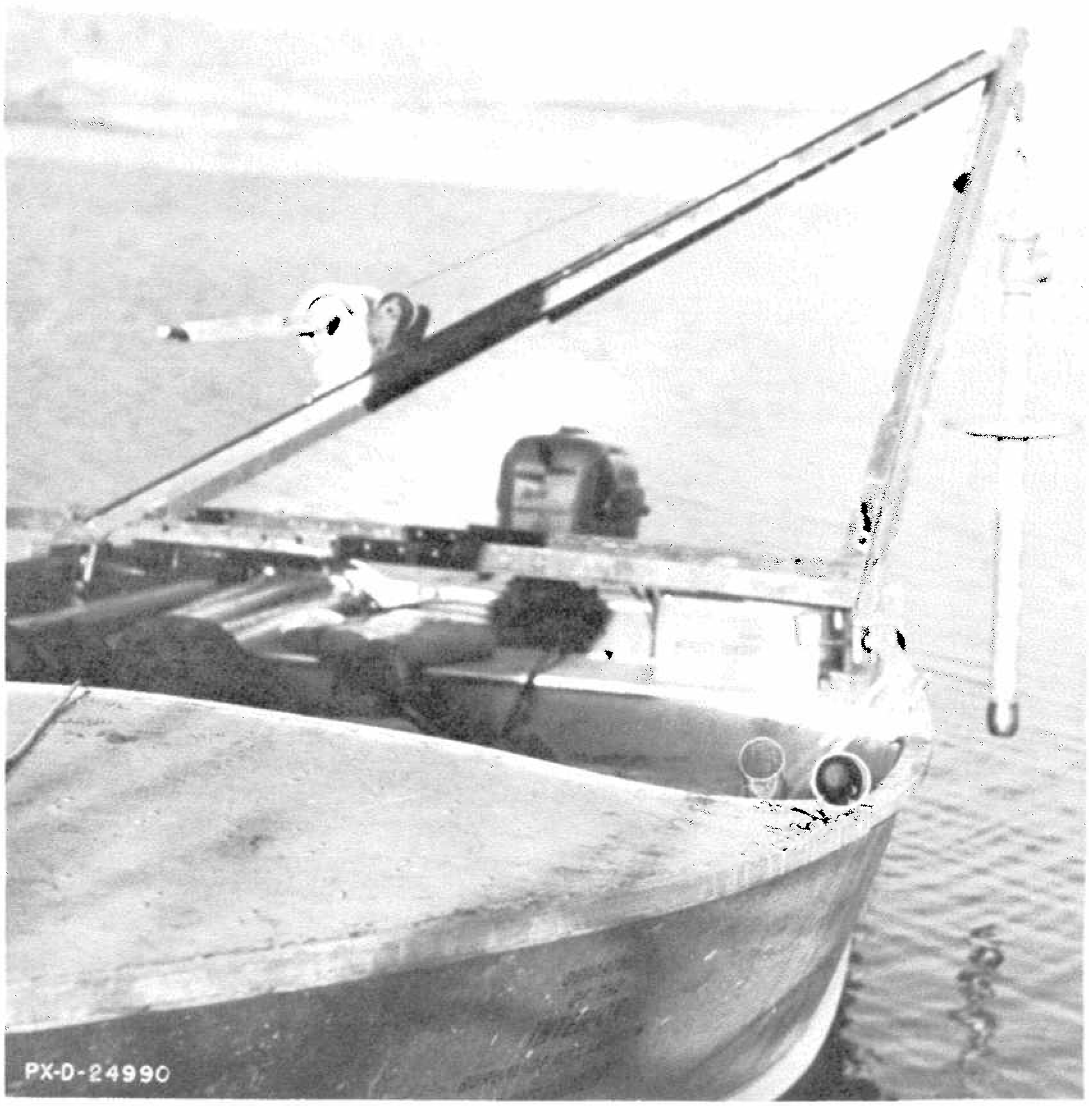
Photograph No. 3 - Torreon Arroyo in the Rio Puerco Basin. Rock ledge in the picture controls the stream gradient.



Photograph No. 4 - Montano Grant gully--Tributary to Rio Puerco.

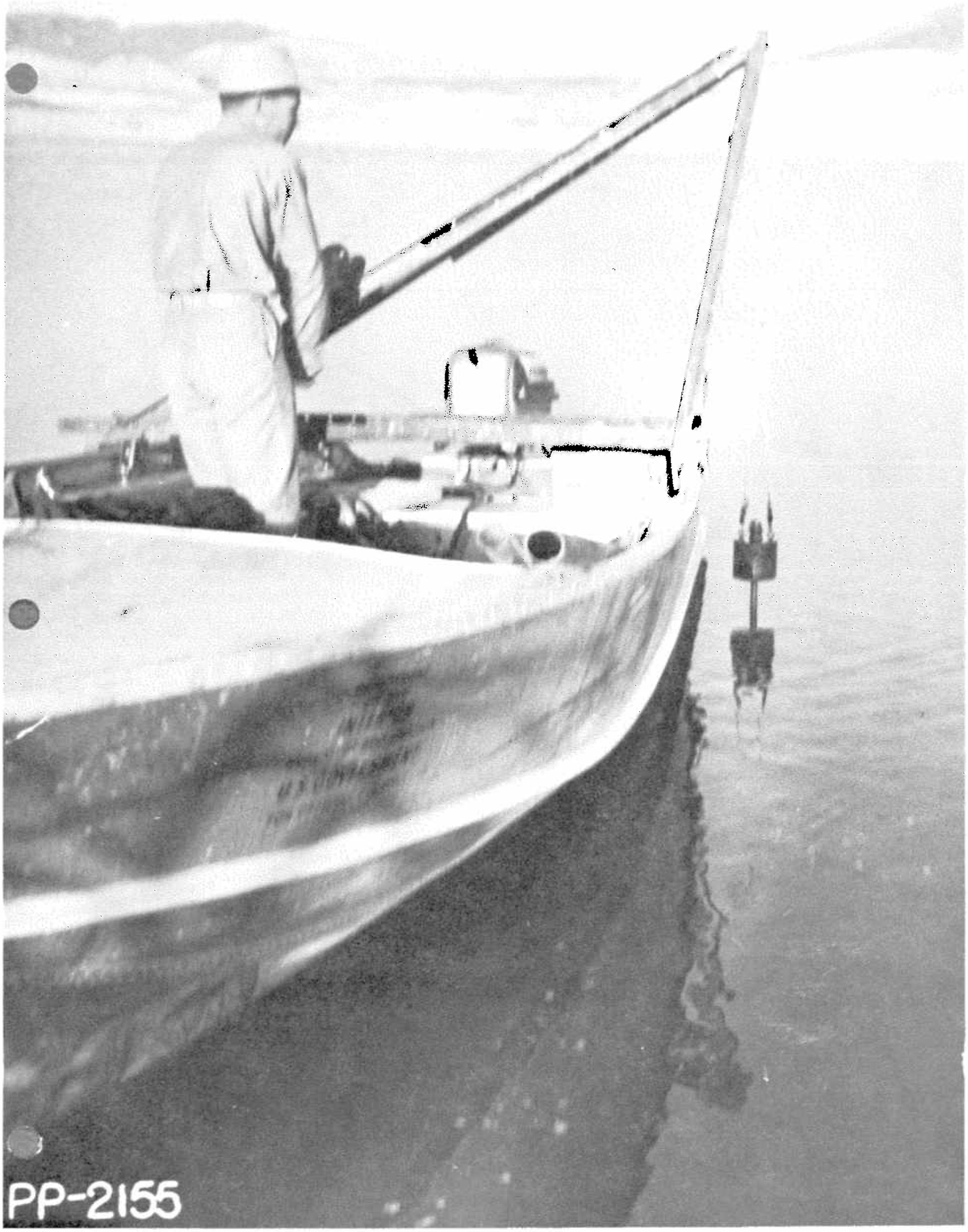


Photograph No. 5 - Small aluminum flat-bottomed boat used for traversing shallow areas of mud deposits. The boat is powered by an airplane-type outboard motor.



Photograph No. 6 - View of the subaqueous sampler with a 2-foot length pipe attachment. Five-and ten-foot pipes are also used in securing samples at greater depths. The sampler consists essentially of a steel pipe, inner plastic tube, valve, lead weights, and cutter head.

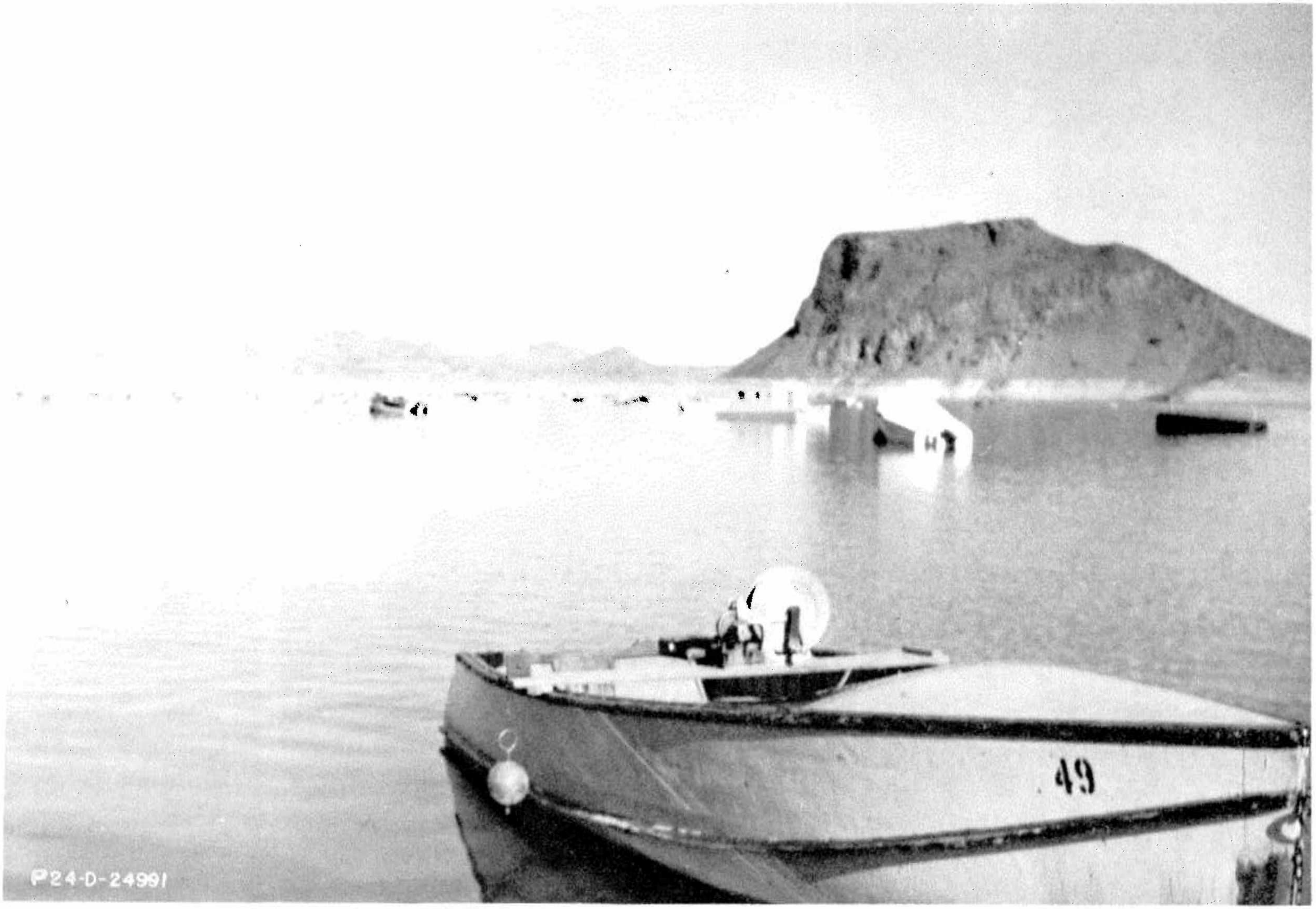
Also seen in this photograph is the apparatus used for raising and lowering the subaqueous and radioisotope densitometer samplers. A Class "B" reel is attached to a plate on the "A" frame. The "A" frame is adjustable to fit boats having beams as wide as 8 feet. The cantilevered section is also adjustable.



Photograph No. 7 - View of the radioisotope densitometer used for determining the in-place densities of reservoir deposits. Major components of the sampler are storage shield, working shield, dosimeter charger, probe shell, lead column to separate source and detector, dosimeter, and dosimeter holder.

Photograph No. 8 - Photograph of the piston-type sampler used to obtain some of the samples of the reservoir deposits in areas that were accessible by foot. The sampler is generally used for securing samples of the bed material of stream channels.

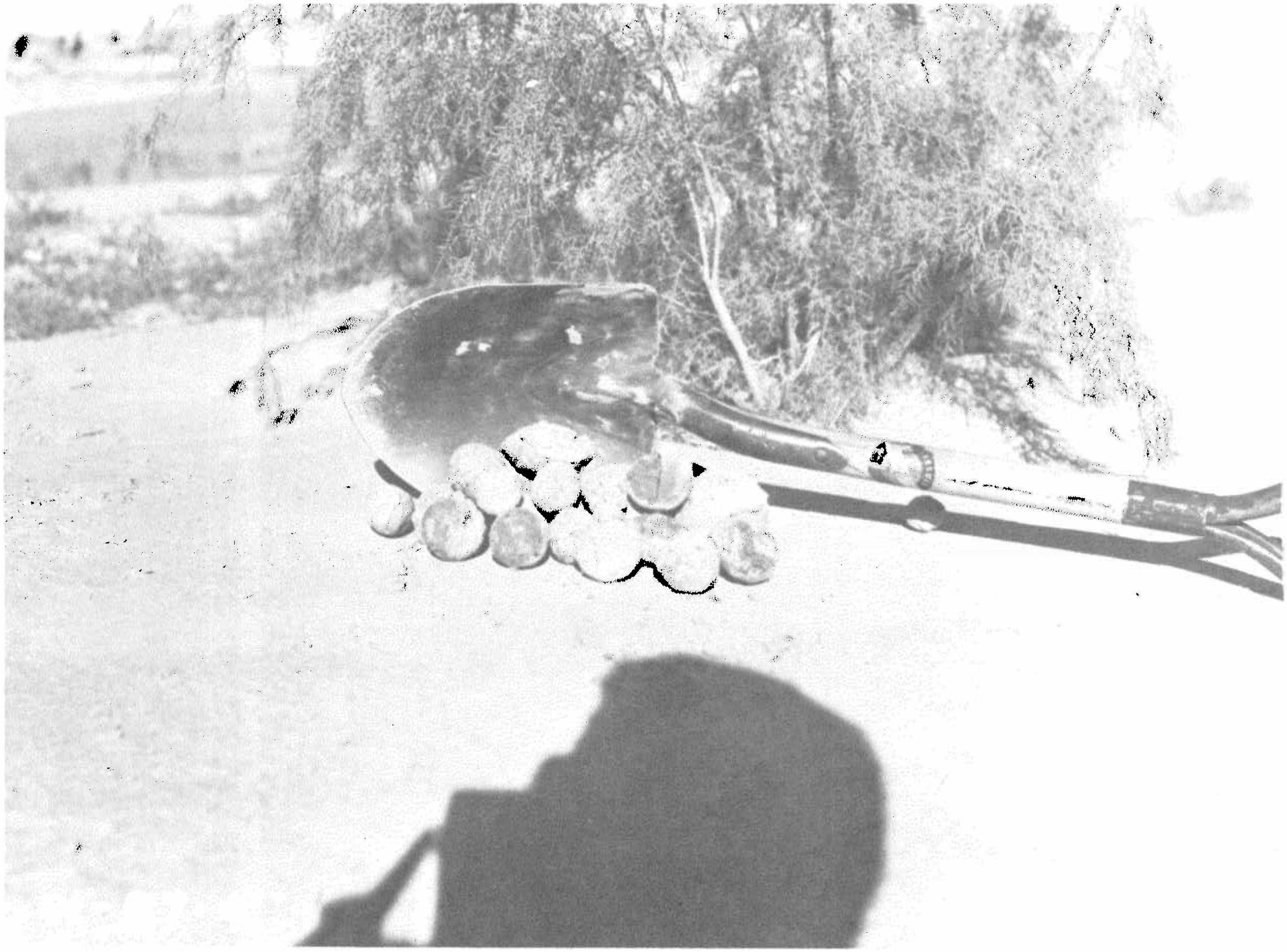
Photograph No. 9 - View of the pipe-driven sampler used to obtain samples of the sediment deposits in the exposed areas of the upper end of Elephant Butte Reservoir. The sampler is simply an 8-inch steel tube driven into the deposits by a rubber hammer. It is a common practice to remove the top soil mantle before sampling.



Photograph No. 10 - View of the sounding apparatus used in the survey of Elephant Butte Reservoir. The steel ball suspended over the side of the boat is lowered to determine the reservoir depth.

Photograph No. 11 - Photograph of the Rio Puerco taken downstream from bridge of U.S. Highway No. 85 near mouth of the river.

Photograph No. 12 - The Rio Salado photographed from a bridge on U.S. Highway 85. A flood had just passed down the channel a few days previous.



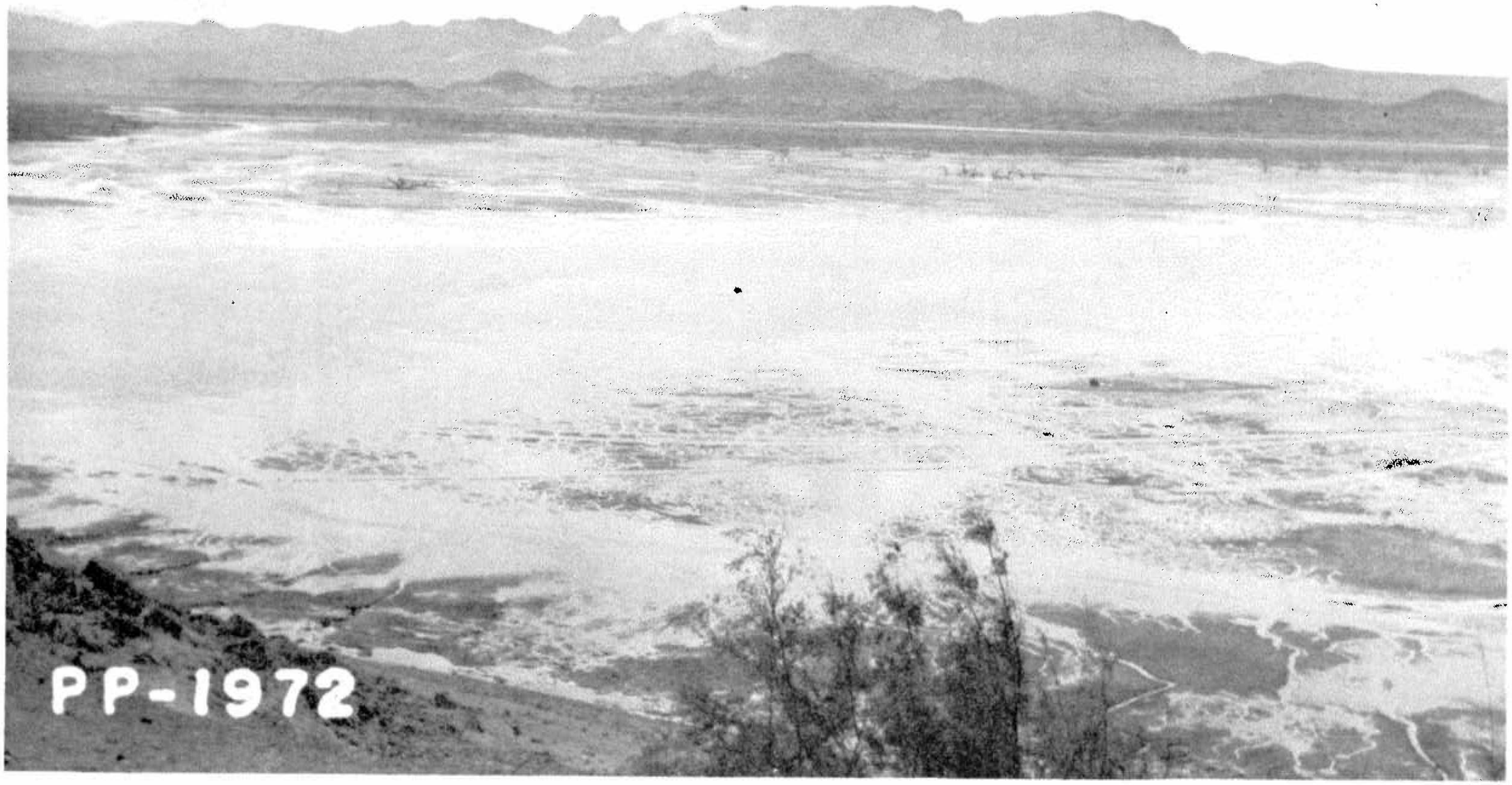
Photograph No. 13 - Mud balls collected from the Rio Puerco channel. Armoring of the sand and gravel is particularly evident.

Photograph No. 14 - A view of the sediments on the channel bottom of Rio Puerco.

Photograph No. 15 - Upstream view of the Rio Puerco. Three types of sediment movement along the channel bed are portrayed by this photograph--sand dunes, ripples, and over a smooth hard surface.

Photograph No. 16 - Typical view of the salt cedars growing in the delta and backwater areas of the reservoir.

Photograph No. 17 - Ash Canyon arm of Elephant Butte Reservoir as seen from a point near the dam.
Taken October 16, 1956.



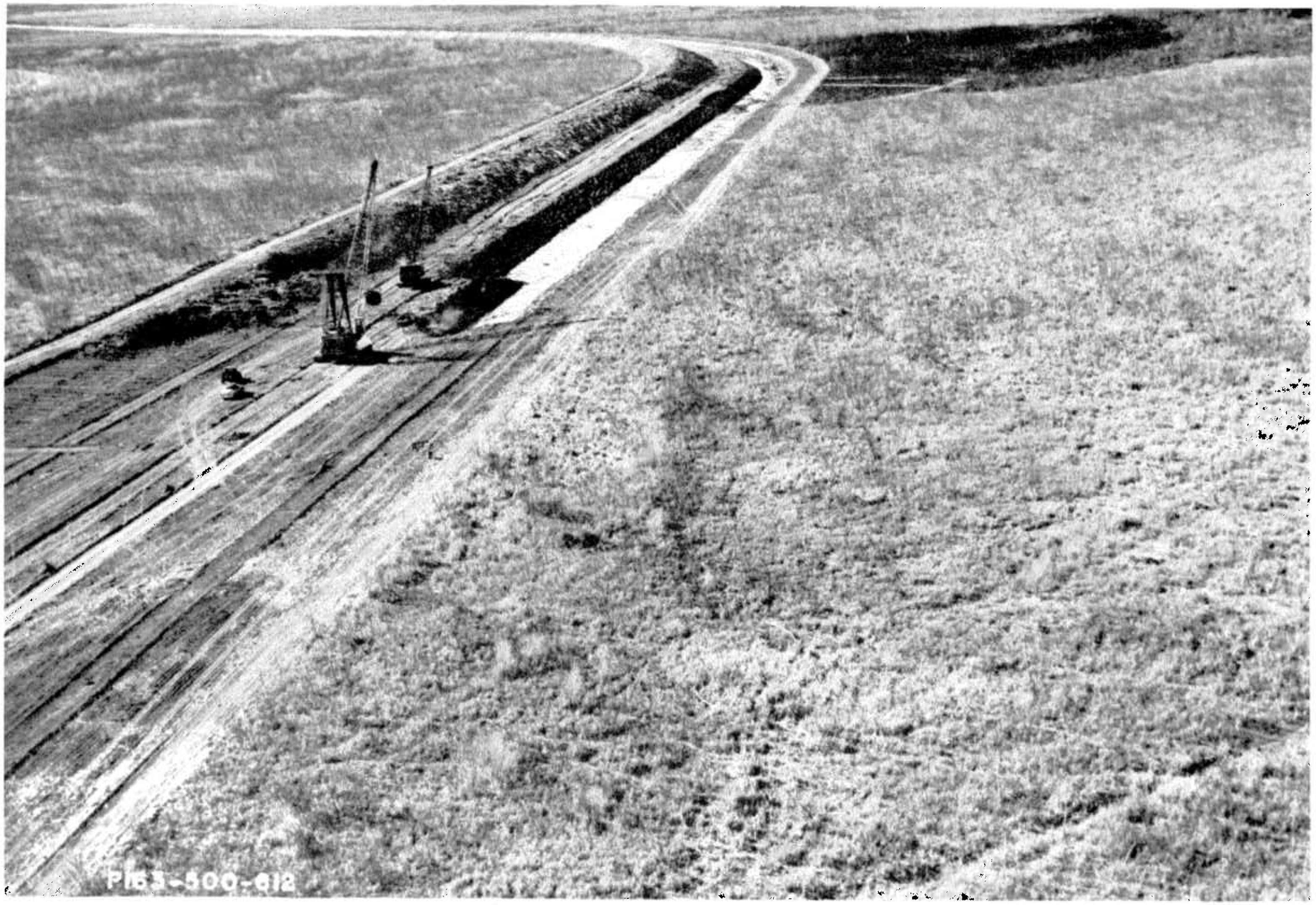
Photograph No. 18 - Elephant Butte Reservoir near Hidden Cove--Present head end of reservoir storage. Extent of mud flats can be noted. This is a view looking across and upstream from the right bank. Elephant Butte Reservoir was at elevation 4269. 5. Taken October 16, 1956.

Photograph No. 19 - Elephant Butte Reservoir area as seen from Three Sisters triangulation station. Salt cedars are among the types of vegetation growing in this area. Taken October 17, 1956.

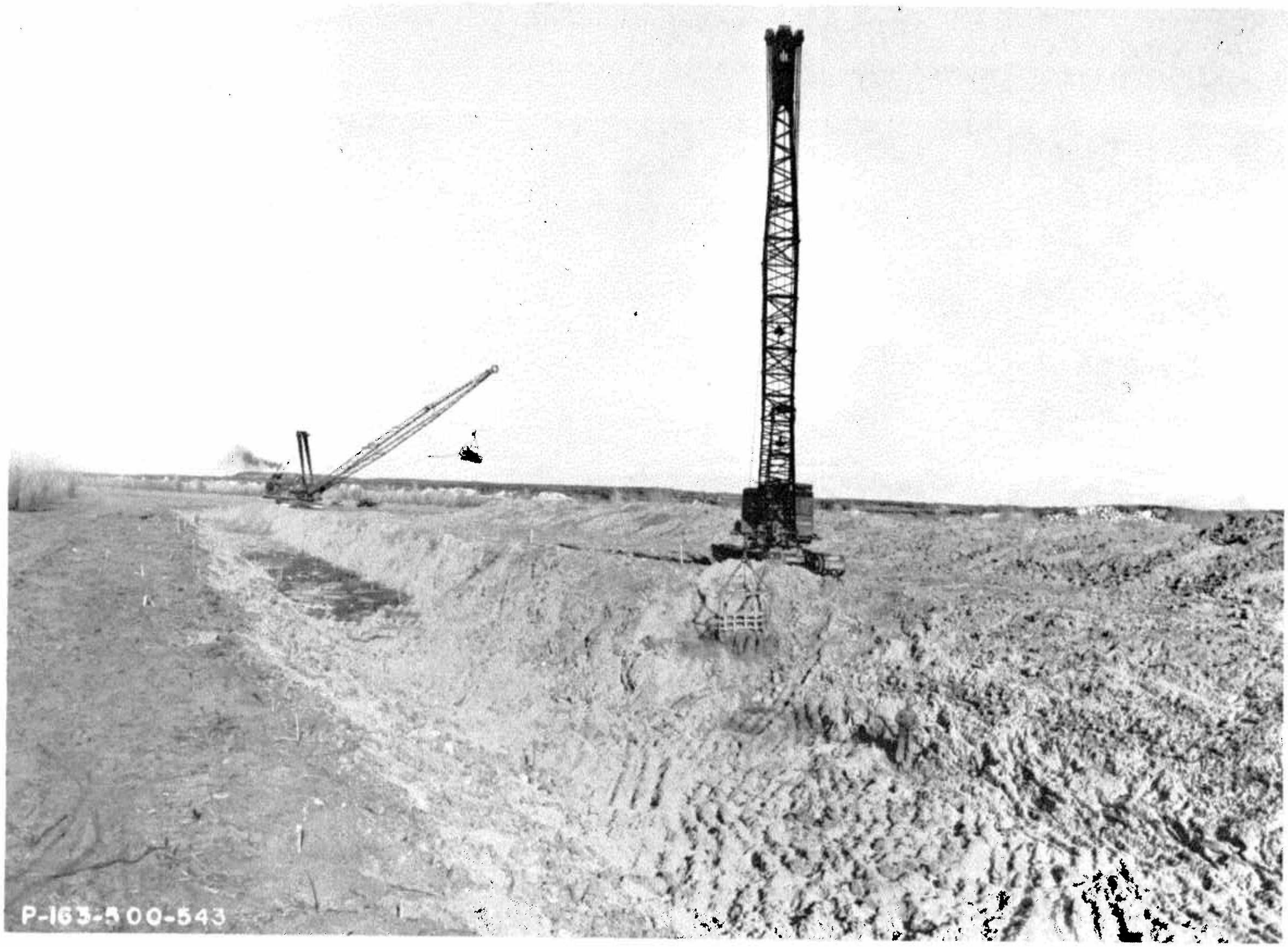
Photograph No. 20 - Mouth of Monticello Canyon as seen from Olguin Point. Heavy salt cedar growth is prevalent in this area. Taken October 17, 1956.

Photograph No. 21. - Elephant Butte Reservoir as seen from Eagle Point triangulation station. Elephant Butte rock is at left center of the photograph. Reservoir water level elevation was about 4,279 feet at the time this photograph was taken. Photographsed on February 9, 1957.

Photograph No. 22 - Elephant Butte Reservoir at the Narrows gaging station. This is a view looking upstream and across from the right bank. This area is inundated at higher reservoir stages. The gaging station is operated in conjunction with the upstream channelization work. Taken February 11, 1957.



Photograph No. 23 - An aerial view of the conveyance channel taken from an altitude of 200 feet looking downstream at initial excavation operations. Photograph was taken January 1952.



Photograph No. 24 - A view of the initial excavation operations looking upstream from one of the stations of the conveyance channel. A 6-cubic-yard dragline is working in the background excavating 20 feet of west side of channel. A 3-cubic-yard dragline shown in the foreground is excavating the remainder of the channel prism.

Photograph No. 25 - View looking downstream toward the extreme lower end of the conveyance channel in the reservoir headwater area. Instability of the banks is very evident as one of the residual effects of the channelization. Taken October 1956.