LLANO ESTACADO

PLAYA LAKE WATER RESOURCES STUDY

A SPECIAL INVESTIGATION

Prepared by

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SOUTHWEST REGIONAL OFFICE
AMARILLO, TEXAS

NOVEMBER 1982

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CHAPTER IV - HYDROLOGY

This chapter concentrates on the hydrological characteristics of playa lakes in the study area--the quantity of water in the lakes and the dependability of that water. Many lakes in the study area were investigated individually.

Selection of Playa Lakes to be Monitored

The main goal in selecting the playa lakes to be monitored was to establish the relationship between precipitation and runoff for the monitored lakes. This relationship would then be applied to the entire study area. Other goals were to determine the relationship between drainage area and runoff and the effect of irrigation on runoff.

Criteria for selecting playa lakes included providing a large number of soil types, varying levels of precipitation, and a range in the percentages of irrigated land in the playa lake drainage areas. Modified and unmodified lakes were included.

Maps at 1:250,000 scale were studied and candidate playa lakes were selected. Because of distance, time, and expense limitations, an elimination process was begun to reduce the number of playas to be monitored. One of the main considerations was accessibility of the lakes. Local water conservation district offices were contacted to obtain information for each lake. Many candidate lakes were eliminated after these contacts. Maps at 1:24,000 scale were obtained for the remaining lakes and field checking for established criteria was begun.

In choosing lakes to be monitored, all States in the study area were considered, but only lakes in Texas fulfilled the criteria for selection. Ultimately, 36 playa lakes were selected for the monitoring program (figure IV-1).

The Monitoring Program

The 1:24,000 maps (U.S. Geological Survey (USGS) 7-1/2 minute quadrangles) for the 36 lakes were assembled and the latitude and longitude of each lake was determined. These coordinates were sent to the Bureau's Engineering and Research (E&R) Center for its use in LANDSAT evaluation of the lakes. The E&R Center provided major assistance in the conduct of the Llano Estacado study. Table IV-1 lists the coordinates of each lake, the county and State locations, and the covering USGS quadrangle. The drainage area of each playa was delineated on the quadrangles and planimetered (table IV-2)*.

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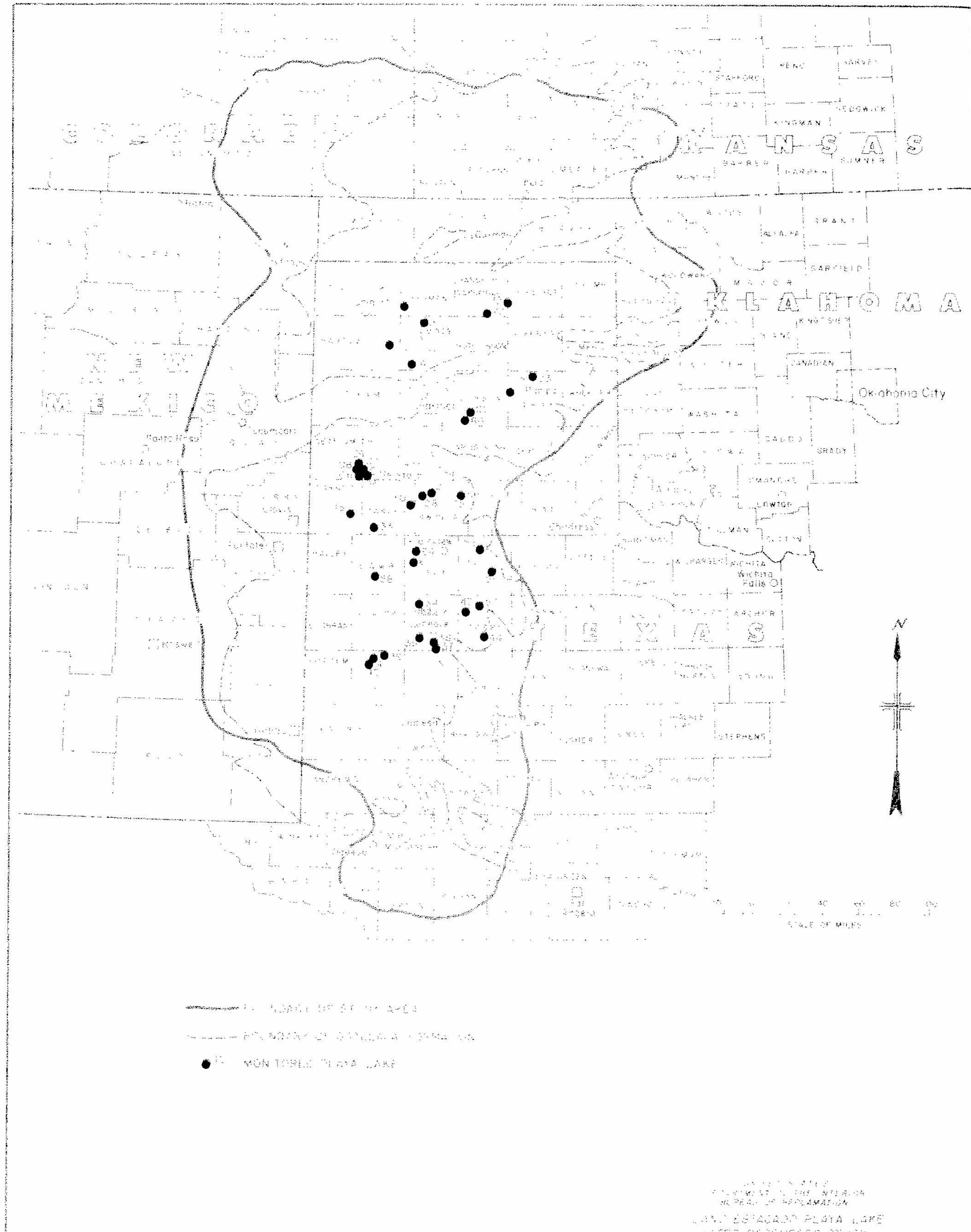
* See Data Packages for Monitored Playa Lakes in Appended Material.



MONITORING PROGRAM

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Figure IV-1

Table IV-1
Monitored Playa Lake Locations

Playa Lake number	County and State	USGS Quad	Latitude	Longitude
1	Gray, TX	Kingsmill, TX	35°27'44"	101°03'14"
3	Gray, TX	Hoover, TX	35°32'30"	101°51'48"
5	Deaf Smith, TX	Hereford, TX	34°46'30"	102°28'58"
6	Deaf Smith, TX	Westway, TX	34°47'16"	102°30'54"
7	Deaf Smith, TX	Hereford, TX	34°50'02"	102°29'04"
8	Deaf Smith, TX	Westway, TX	34°49'58"	102°32'12"
9	Deaf Smith, TX	Westway, NE, TX	34°54'08"	102°32'16"
13	Parmer, TX	Tam Anne, TX	34°30'08"	102°38'06"
14	Moore Co., TX	Bautista, TX	35°41'30"	102°02'30"
15	Moore Co., TX	Dumas, North, TX	35°59'08"	101°55'08"
16	Sherman Co., TX	Conlen, TX	36°07'59"	102°08'40"
17	Hartley Co., TX	Hartley, SE, TX	35°49'26"	102°15'18"
21	Ochiltree Co., TX	Spearman, NE, TX	36°11'10"	101°04'50"
22	Hansford Co., TX	Holt, TX	36°05'43"	101°14'11"
25	Swisher, TX	Tam Anne, TX	34°37'00"	101°32'12"
27	Swisher, TX	Tulia, TX	34°37'20"	101°35'36"
28	Swisher, TX	Lakeview, TX	34°35'18"	101°55'06"
30	Castro, TX	Nazareth, TX	34°32'34"	102°03'14"
33	Castro, TX	Dodd, NE, TX	34°22'30"	102°20'00"
34	Lubbock Co., TX	Shallowater, TX	33°44'04"	101°54'55"
36	Lubbock Co., TX	New Home, TX	33°29'56"	101°50'03"
37	Lubbock Co., TX	Slaton, TX	33°24'50"	101°42'57"
38	Lubbock Co., TX	Slaton, TX	33°25'08"	101°43'27"
39	Terry Co., TX	Sundown, SE, TX	33°20'30"	102°17'24"
41	Terry Co., TX	Pool, TX	33°19'33"	102°22'48"
42	Terry Co., TX	Pool, TX	33°18'29"	102°24'35"
44	Crosby Co., TX	Ralls, SE, TX	33°33'32"	101°17'12"
47	Crosby Co., TX	Ralls, TX	33°40'38"	101°28'11"
50	Crosby Co., TX	Ralls, NE, TX	33°44'17"	101°17'32"
51	Floyd Co., TX	Lockney 4, SW, TX	34°03'00"	101°13'50"
53	Floyd Co., TX	South Plains, TX	34°13'04"	101°18'48"
58	Lamb Co., TX	Cofferville, TX	34°00'40"	102°18'22"
61	Hale Co., TX	Hale Center, SW, TX	34°04'26"	101°57'22"
64	Hale Co., TX	Halfway, TX	34°11'18"	101°57'04"
65	Carson, TX	Panhandle, West, TX	35°17'30"	101°27'34"
66	Carson, TX	Panhandle, West, TX	35°15'00"	101°28'40"

Table IV-2
Drainage Areas of Monitored Playa Lakes*

Playa lake number	Drainage area (acres)	Playa lake number	Drainage area (acres)
1	1,174	33	1,280
3	1,878	34	912
5	982	36	816
6	1,450	37	834
7	2,766	38	690
8	1,300	39	590
9	2,342	41	708
13	1,758	42	658
14	1,194	44	1,338
15	3,080	47	721
16	4,257	50	935
17	2,012	51	345
21	5,922	53	685
22	922	58	663
25	942	61	530
27	1,835	64	674
28	886	65	3,456
30	918	66	1,541

* Drainage areas from USGS 1:24,000 quadrangles.

Three types of instruments were then placed at the lakes: automatic recording rain gages, nonrecording rain gages, and staff gages for measuring water levels in the lakes. Twelve lakes had recording gages, all lakes had 2 to 3 nonrecording gages, and all lakes had one staff gage. All lakes were monitored in 1979 and 1980, and some were monitored in 1981.

Upon each visit to a playa lake, monitoring personnel estimated air temperature, wind velocity, percentage of cloud cover, general weather conditions, and obtained precipitation and water level readings from the gages. Periodically, the owner or lessee was contacted for information so that playa lake usage and tailwater volumes could be determined. Information was obtained about irrigation schedules, when irrigation occurred, acreage irrigated, and length of irrigation. From this and other information, volumes of tailwater were estimated. Once per growing season, irrigation practices in playa lake drainage areas were recorded. Such practices included irrigation systems in use and operation schedules of the systems.

LANDSAT

A major use of LANDSAT was for estimating playa lake water volumes during wet and dry periods beginning in 1972, when LANDSAT information became available. Six types of data were provided the E&R Center for use in estimating the volumes:

1. Curves of time versus surface area, from August 1980 through October 1980, for all 36 playa lakes were provided. These curves were used in the correlation of LANDSAT and aerial photography.

2. The surface areas for all 36 lakes on October 13, 1980, and October 30, 1980, were provided.

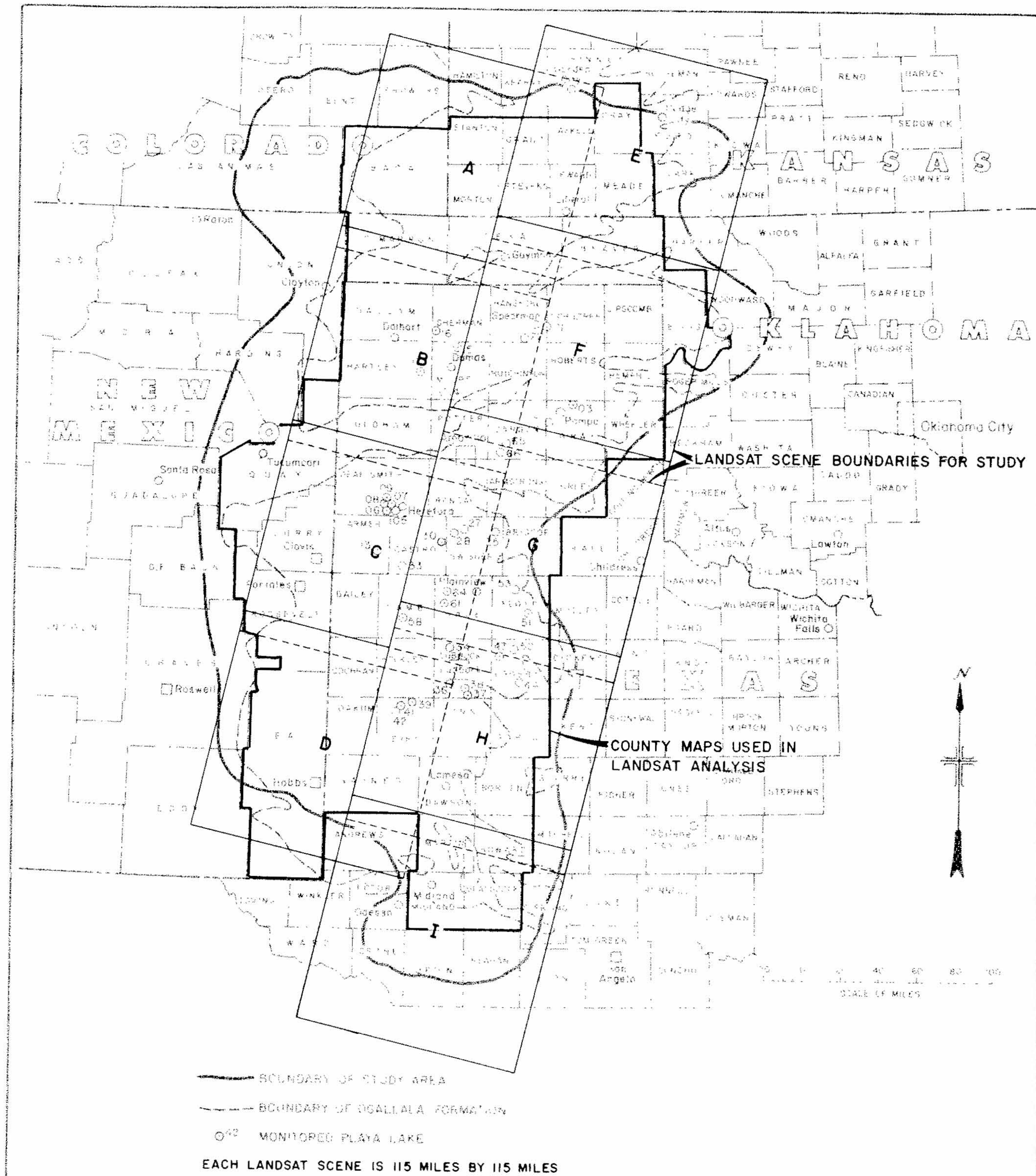
3. The wettest and driest periods since the start of LANDSAT imagery for scenes (photographs) containing all 36 lakes were provided.

4. For use in correlating monitored data and LANDSAT imagery the wettest and driest periods in 1979 or 1980 were provided.

5. For use in map-generation control, county maps for the study area were provided (figure IV-2).

6. Surface area versus capacity data for several lakes were grouped. Equations for the groups were developed and provided the E&R Center.

These six types of data are discussed in detail below.



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LANDSAT SCENE AND COUNTY MAP BOUNDARIES

JUNE 1982

AMARILLO, TEXAS

Figure IV-2

Time versus surface area curves

Staff gage readings from August to October 1980 were obtained. Based on these readings, surface areas were obtained from the area-capacity tables developed from field surveys for each lake. Then curves of time versus surface area for each lake from August through October 1980 were drawn. If necessary, surface areas between data points were estimated using evaporation, automatic rain gage, or weather station data. At another point in the study, time versus surface area curves were developed again from operation studies of each lake.

Surface areas during October 1980

The surface areas for all playa lakes on October 13 and 30, 1980, were taken from the above curves. LANDSAT images for these dates were available to the E&R Center.

Determination of wettest and driest LANDSAT periods

LANDSAT scene boundaries were drawn on a map showing locations of monitored playa lakes. Then, all lakes within a scene were grouped. Precipitation records for the weather station closest to each lake were obtained. Only records for these 20 stations from the beginning of LANDSAT imagery were used. Monthly precipitation at each station was recorded. Average precipitation and rough evaporation estimates were used to determine the wettest and driest months during this period for each station so that corresponding LANDSAT scenes could be selected.

The 5 wettest months and the 5 driest months for each station within each scene were determined. The wet months for all stations in a scene were compared and the 5 wettest months common to the stations in the scene were determined. The 5 driest months were based on the last month in a long period of below average precipitation. The total number of dry months determined the relative dryness. As with the 5 wettest months per scene, the 5 driest months common to all stations in a scene were determined.

The 5 wettest and driest months for each scene were compared to determine the wettest and driest months for the entire study area. The wettest month was August 1974. It occurred in 4 of the 5 scenes* and included 33 of the 36 monitored playas. In the fifth scene, it was the sixth wettest month. Wetness was based on the cumulative precipitation at all stations (within one scene). The driest month, which terminated the longest dry period, was April 1978. It occurred in all five scenes. Dryness was based on the number of cumulative consecutive below normal rainfalls at all stations (within one scene).

* The five scenes covering the monitored playa lakes were used to develop the wettest months.

Correlation of monitored data with LANDSAT

Data from monitored lakes were collected in 1979 and 1980. The wettest month and driest period during those years for the entire study area was determined in the following manner.

Precipitation records during 1979 and 1980 were obtained for the 20 weather stations previously mentioned. Then the stations were grouped on the basis of playa lakes closest to the stations within a scene. The totals of monthly precipitation, using the grouped stations, were compared and the 5 wettest months per scene were determined. When evaluated, the 4 wettest months were common to all 5 scenes.

The recorded data from monitored lakes were evaluated to determine which month had the most recorded data. ~~June 1979~~ had the greatest precipitation but only half the recorded data of May 1980 (the second wettest month for precipitation but the best month for field data). May 1980 was investigated to determine when in May to evaluate wet scenes. Half the rainfall occurred on May 15th and 16th and 25 percent on May 27-29. LANDSAT imagery for the same area occurs every 18 days, so the optimum LANDSAT data would be obtained from May 19-26 or May 30-June 7.

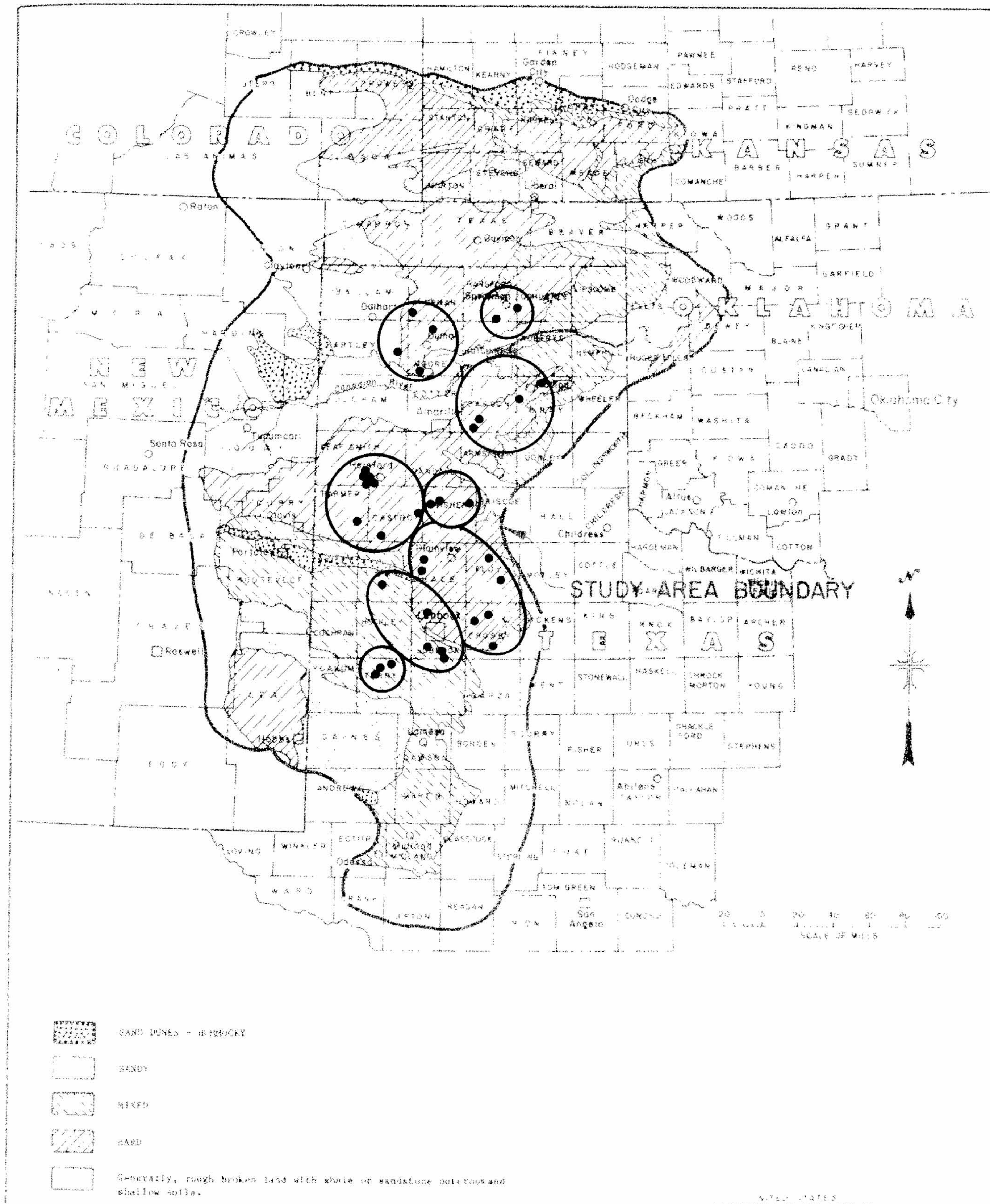
The driest months occurred when field equipment was not monitored. As before, dry months were based on the last month in a long period of below average precipitation. The dry periods for the scenes were compared to determine the end of the dry periods common to all scenes. Then daily precipitation records were evaluated to determine which LANDSAT data would best display the driest scenes. LANDSAT data from February 17-March 22 were selected.

County maps

Output by the E&R Center's computer would be by county. Therefore, county maps were provided for use as control in establishing county corners and latitude and longitude of playa lakes and for use in eliminating nonplaya lake water bodies. Maps for counties beyond the boundary of the Ogallala, partially contained in the study area, or not having any playa lakes were not provided. The latitude and longitude of each monitored lake and of all nonplaya lake water bodies were also provided.

Area-capacity equations

To translate surface areas into volumes using LANDSAT data, equations were developed from playa lakes grouped within subareas of the study area. The monitored lakes were divided into three areas based on soil type: hard lands soil north of the Canadian River, hard lands soil south of the Canadian, and mixed lands soil south of the Canadian. The three areas were divided into a total of eight subareas, based on changing precipitation in the study area (figure IV-3; see also figure II-3 for average annual precipitation). Also



GROUPING OF MONITORED PLAYA LAKES FOR DEVELOPMENT OF AREA-CAPACITY EQUATIONS

AMARILLO, TEXAS

Figure IV-3

considered in the assignment of lakes to subgroups were various conditions which affect playa lake behavior such as percent of drainage area irrigated and whether the lake was modified.

Area and capacity data for each playa lake were plotted and a smooth curve drawn through the points. Using coordinates from the curve, areas were determined for the lakes for selected capacities. All area values for a subarea and capacity were totaled and average areas for given capacities were plotted. A smooth curve was drawn through the averaged data and used to develop the area-capacity equation, $y = ax^b$, where y equals the capacity, x equals the area, and a and b are constants.

Four equations were developed for each subarea. For most lakes, the capacity increased sharply at about 50 acres and again, but to a lesser degree, at about 100 acres. Beyond 100 acres, most curves approached a straight line, but for consistency all third equations ranged from 100 to 150 acres and the fourth equation from 150 to 200 acres. The equations were used by the E&R Center to determine the range in capacity, based on area, for wet and dry scenes.

Analysis

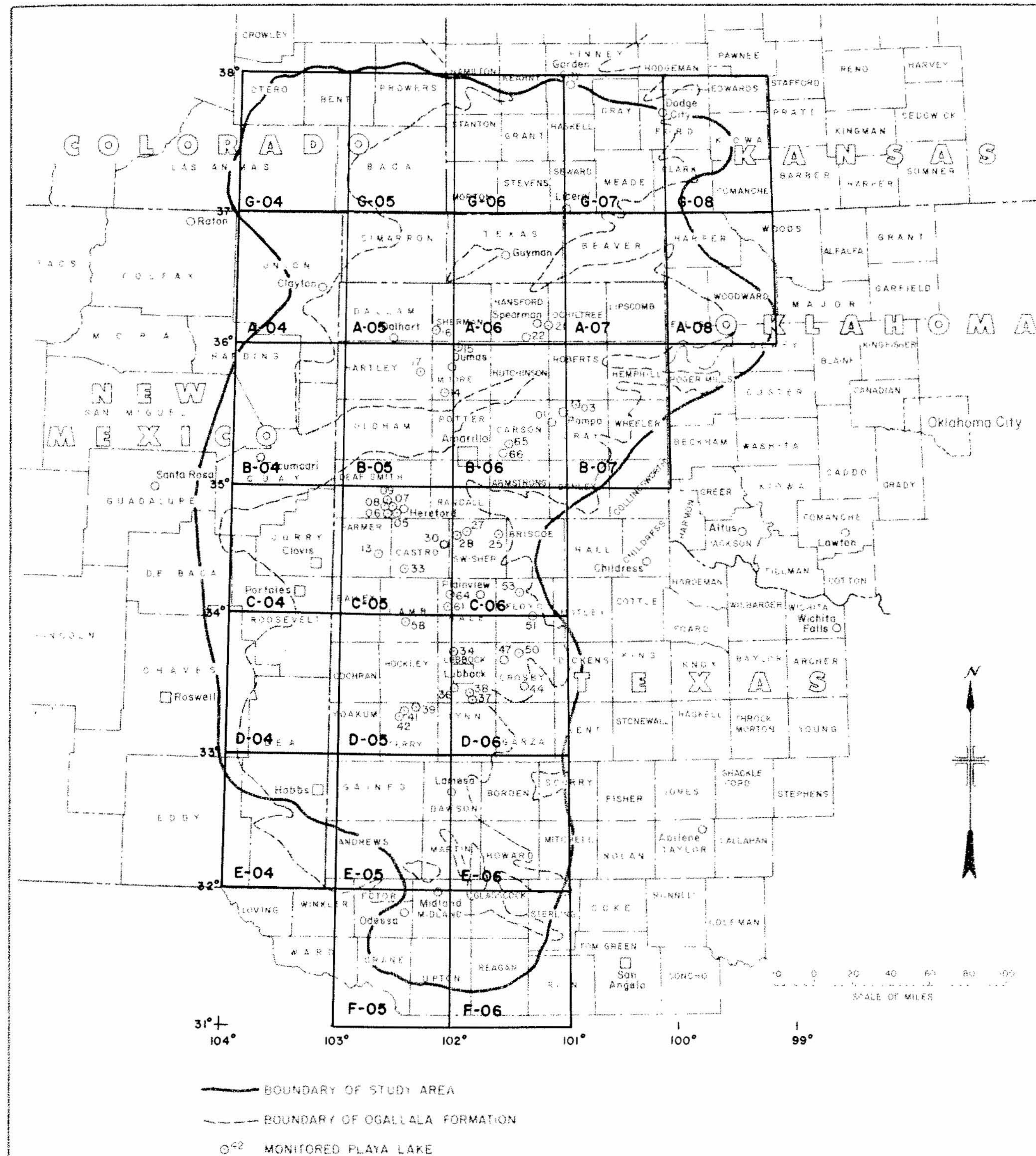
The goal of the analysis was to determine the reliability* of runoff into the playa lakes for the entire study area. The analysis included evaluation of the monitored lakes, LANDSAT data interpretations, and areal extension of findings on monitored lakes to the rest of the study area based on information such as soil type and precipitation-runoff relationships.

The data base required for the analysis was developed from field data and historic records. All monitored data were placed in computer files; the files were used to develop curves (see Graphs developed below) for each playa lake.

The study area was divided into quadrangles of one degree of latitude by one degree of longitude (figure IV-4). Then data from two or three precipitation stations and all evaporation stations within each quadrangle were stored in computer files. A computer program (SYMAP) determined the average monthly precipitation and evaporation for each quadrangle. There were 102 precipitation stations and 66 evaporation stations in the study area. Study area data from January 1940 to July 1981 were combined into a master file for precipitation and a master file for evaporation. Monthly precipitation or evaporation for any year at any playa lake in the study area can be estimated by using the two files. The files were used to develop precipitation-runoff curves.

Completion of two tasks facilitated the analysis of the data. The first task was to estimate how wet and dry the LANDSAT scenes were, based on precipitation-duration curves. Duration is the percent of the time a given amount of a parameter (in this case precipitation) can be expected to occur. The second task was to estimate playa lake reliability using evaporation-duration curves.

* Reliability measures how long water in a lake remains available for use.



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QUADRANGLES ESTABLISHED FOR HYDROLOGICAL ANALYSIS

JUNE 1982

AMARILLO, TEXAS

Figure IV-4

The final task in completing the data base for the analysis was the development of area-capacity equations for each of the 36 playa lakes. These equations were used in generating operation studies for the lakes. Although area-capacity equations were developed for subareas of the study area to assist LANDSAT data interpretation, they were not developed on an individual basis for each monitored lake. Therefore, area and capacity monitored data were input to a computer program which developed the least squares fit for a nonlinear regression power curve. The equation used was $y = ax^b$, where x equals area and y equals capacity. To obtain the best correlation coefficient, some lakes required two equations. For the lakes with two equations (area-capacity curves broke sharply), the equations were solved to determine which equation to use for a given area.

Upon completion of these tasks, operation studies for each playa lake were developed.

Operation Studies

An operation study of each monitored playa lake was compiled by the computer.* The monitoring program had resulted in weekly records of lake content (water volume) and precipitation for all playa lakes during the 1979-1980 period and selected representative lakes in 1981. Pan evaporation was also available for each quadrangle (figure IV-4) in which the lakes are located. Using this information, a historic operation study was made for each monitored playa lake to determine change in content, average content, average water-surface area, evaporation, runoff, and seepage. The average water-surface area was computed using the area-capacity equations developed for each playa lake. The free-water-surface evaporation rate was assumed to be .7 times the pan evaporation rate. The net evaporation rate used was free-water-surface evaporation minus precipitation. Evaporation equaled average area times the net evaporation rate. Unadjusted runoff was change in content plus evaporation. Seepage was derived from the correlation (discussed below) between average content and negative unadjusted runoff. Adjusted runoff was unadjusted runoff plus seepage.

Precipitation versus unadjusted runoff curves

The first set of operation studies were run to determine unadjusted runoff. A thorough examination of the operation study of each lake was made. Events that appeared to be the result of incorrect staff or precipitation data were eliminated and the reason recorded. Plots of data** versus time and of runoff versus precipitation were made which did not include the eliminated data. The operation studies show all of the data, including the eliminated data.

* See Data Packages for Monitored Playa Lakes in Appended Material.
** Content, average water-surface area, free-water-surface evaporation rate, precipitation, net evaporation rate, seepage, and runoff per mi^2.

Unadjusted runoff per square mile (mi^2) versus precipitation data points were plotted on a graph by the computer for 23 playa lakes.* Overlays of the unadjusted runoff per mi^2 versus precipitation graph were made. Lines were drawn on the overlays beginning at .5 inch precipitation and zero runoff per mi^2 indicating 100, 50, 33-1/3, 25, and 20 percent, respectively, of excess precipitation (runoff). These overlays were used for each playa lake. Any data point greater than the 50 percent excess line was eliminated as impossible.

Next, the correlation between seepage and content was determined. The seepage (Negative unadjusted runoff) versus content data points were plotted on graphs by the computer. A best-fit straight line, starting at zero content and zero seepage, was drawn manually through the points to develop the seepage versus content correlation.

Precipitation versus adjusted runoff curves

The operation studies were rerun to compute seepage using the above correlation and omitting data previously eliminated. As before, the operation studies show all data, including eliminated data.

The precipitation versus adjusted runoff per mi^2 plots were examined with the overlays. Any data point greater than the 50 percent excess line was eliminated. A best-fit line was drawn manually through these plots of precipitation versus adjusted runoff per mi^2. Values for the equation $y = ax^b$ were developed using a Wang calculator. A straight line equation, $y = a+bx$, was used from the point assumed to be 100 percent runoff.

Historical runoff

Within certain areal limits (see General results below and figure IV-7 (later in this chapter)), the equations discussed in the above paragraph were used to extend (by quadrangle) the adjusted runoff per mi^2 versus precipitation correlation to all playa lakes, monitored and unmonitored, for the January 1940-June 1981 period. In addition, adjusted runoff-duration curves were constructed for each of the 23 playa lakes with monitored runoff, and precipitation-duration and evaporation-duration curves were constructed for all quadrangles in the study area (although the adjusted runoff-precipitation relationships were projected areally only to a limited extent).

Graphs developed

In general, the graphs listed below, which cover the period 1979-1981, were developed for each monitored playa lake from the operation studies. Because of insufficient data, not all graphs were generated for each lake. The graphs are not included in this report; however, an example of the graphs for one lake is included in the Appended Material (Data Packages for Monitored Playa Lakes). Copies of the graphs for other monitored lakes are available upon request.

* Thirteen of the playa lakes had no runoff to plot.

1. Content versus time.

2. Water-surface evaporation rate versus time.

3. Free-water-surface evaporation rate versus time.

4. Precipitation versus time.

5. Net evaporation rate versus time.

6. Evaporation versus time.

7. Seepage versus time.

8. Runoff per mi^2 versus time.

9. Seepage versus content.

10. Precipitation versus adjusted runoff per mi^2.

Land-Use Patterns

Land-use patterns of the 36 monitored playa lakes and their watersheds were analyzed from low-altitude aerial photographs to determine whether land use affected inflow to the lakes and to provide ground-truthing information for checking the accuracy of LANDSAT data analysis. The analysis was conducted in the following manner.

Preliminary watershed boundaries were determined from 7.5-minute U.S. Geological Survey quadrangles. Field surveys conducted in February and March 1981 were used to adjust the boundaries. The adjustments were required because of alteration of the watersheds by human activity such as agricultural practices and construction.

The adjusted watershed boundaries were drawn on low-altitude photographs taken of the playa lakes and their watersheds in September and October 1980. Then, the photographs were studied and land-use areas drawn on them. Using information from the February and March 1981 field survey, the photographs were further marked to identify crops, condition of rangelands, types of human development, and other details not discernable on the photographs.

Land-use acreages were then calculated using a digitizer. Twenty-eight categories of land use were used. These categories were then grouped into seven categories to produce table IV-3.*

* In addition to these acreages, for reference purposes, wetland types and acreages occurring in the 36 water sheds were also determined from National Wetlands Inventory maps obtained from the U.S. Fish and Wildlife Service.

Table IV-3
Land Use on Monitored Playa Lake Watersheds
(in acres and percent of total acreage)

Playa Lake Number	Land Use Category: Permanent water		Wetlands 1/		Crops		Rangeland		Human development		Old fields		Shelterbelts, fencerows, orchards		Total Acreage 2/
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	
1	0.52	0.04	128.89	9.54	1,163.94	86.16	44.03	3.26	14.10	1.04	-	-	-	-	1,350.96
3	-	-	167.13	6.90	1,820.91	75.15	290.78	12.00	144.21	5.95	-	-	-	-	2,423.03
5	0.23	0.02	22.67	2.03	978.44	87.75	72.50	6.50	41.47	3.72	-	-	-	-	1,115.08
6	2.52	0.16	51.47	3.18	1,492.44	92.15	25.12	1.55	50.50	3.12	-	-	-	-	1,619.53
7	23.35	0.62	47.14	1.25	3,431.44	90.57	182.40	4.81	123.13	3.25	-	-	4.60	0.12	3,788.71
8	2.89	0.27	23.68	2.23	956.24	90.09	34.23	3.23	28.05	2.64	19.17	1.81	-	-	1,061.37
9	18.79	0.64	70.86	2.43	2,708.61	92.91	5.05	0.17	32.67	1.12	98.18	3.37	-	-	2,915.37
13	0.95	0.07	32.34	2.34	1,319.63	95.36	-	-	31.86	2.30	-	-	-	-	1,383.83
14	-	-	29.55	2.22	1,070.29	80.42	191.73	14.41	39.29	2.95	-	-	-	-	1,330.86
15	94.62	3.24	120.53	4.12	1,960.24	67.03	821.69	28.09	22.16	0.76	-	-	-	-	2,924.62
16	60.25	1.27	85.61	1.80	2,293.35	48.20	2,105.57	44.25	31.19	0.66	242.17	5.09	-	-	4,757.89
17	56.99	3.72	87.24	5.70	419.43	27.41	1,023.80	66.89	-	-	-	-	-	-	1,530.47
21	0.19	0.003	296.98	4.84	5,431.41	88.53	279.85	4.56	126.97	2.07	-	-	-	-	6,135.21
22	-	-	79.15	14.48	447.74	81.92	18.40	3.37	1.23	0.23	-	-	-	-	546.52
25	0.10	0.01	19.93	2.17	570.66	62.23	288.69	31.48	27.00	2.94	10.80	1.18	-	-	917.08
27	-	-	31.81	2.48	949.77	74.18	229.69	17.94	17.22	1.34	51.84	4.06	-	-	1,280.33
28	1.41	0.12	59.83	5.07	836.00	70.83	259.67	22.00	24.86	2.10	-	-	-	-	1,180.36
30	-	-	31.95	5.34	413.94	69.20	104.97	17.55	42.90	7.18	4.39	0.73	-	-	598.15
33	-	-	101.22	6.61	1,266.47	82.61	71.35	4.65	53.37	3.48	39.23	2.56	1.34	0.09	1,532.98
34	3.50	0.34	18.84	1.82	800.68	77.52	185.48	17.95	28.03	2.71	-	-	-	-	1,033.03
36	-	-	20.17	3.88	449.03	86.46	-	-	50.16	9.66	-	-	-	-	519.36
37	0.31	0.04	22.95	2.88	754.47	94.29	2.12	0.26	20.59	2.57	-	-	-	-	800.13
38	0.25	0.03	27.51	3.54	713.51	91.85	-	-	28.62	3.68	-	-	7.20	0.93	776.84
39	-	-	6.15	1.59	376.21	96.99	-	-	5.52	1.42	-	-	-	-	387.88
41	-	-	15.22	1.84	728.00	87.97	54.45	6.58	29.88	3.61	-	-	-	-	827.55
42	-	-	9.06	1.43	601.24	94.74	-	-	24.32	3.83	-	-	-	-	634.62
44	75.80	6.98	98.31	9.05	956.64	88.10	-	-	30.91	2.85	-	-	-	-	1,085.86
47	2.82	0.58	6.75	1.38	462.04	94.79	13.34	2.74	5.31	1.09	-	-	-	-	487.44
50	0.14	0.01	54.38	5.68	865.53	90.33	5.21	0.54	33.09	3.45	-	-	-	-	958.21
51	-	-	29.68	12.75	171.40	73.58	22.58	9.69	9.28	3.98	-	-	-	-	232.94
53	-	-	56.91	8.43	533.83	79.07	46.72	6.92	37.64	5.58	-	-	-	-	675.10
58	0.79	0.15	17.31	3.26	480.72	90.60	2.59	0.49	14.47	2.73	15.49	2.92	-	-	530.58
61	-	-	13.84	3.53	323.21	82.43	38.42	9.80	11.92	3.04	4.73	1.20	-	-	392.12
64	0.75	0.15	28.25	5.57	445.35	87.82	-	-	26.96	5.32	6.54	1.29	-	-	507.10
65	2.86	0.09	201.80	6.63	2,383.12	78.35	256.33	8.43	200.40	6.59	-	-	-	-	3,041.65
66	-	-	123.24	5.99	1,559.87	75.83	355.89	17.30	17.96	0.88	-	-	-	-	2,056.96

1/ Areas which showed evidence of having been wet at some time were considered to be wetlands.
2/ Acreage of playa lake watershed.

Analysis of the information in table IV-3 shows that watersheds in the north part of the study area were generally larger and had more rangeland than those in the south part.

Results of Hydrology Studies

General results

The results of hydrologic studies were dependent on the analysis of hydrologic data pertaining to playa lake reliability, on the areal extension of monitored data based on soil analysis, and on determination of playa lake surface areas and volumes by LANDSAT data interpretation.

After operation studies were developed for each playa lake, contents over time were evaluated to determine playa lake reliability. Modified and unmodified lakes, pumped lakes, and lakes without pumps were evaluated. To reduce pumping effects, pumped lakes were analyzed following a heavy rain and for only 2 weeks. To reduce the effects of modification, no data with known tailwater flows were used.

Reliability data were divided into three groups based on soil type. The data show that playa lakes decrease in reliability to the southwest. Lakes in hard lands soils north of the Canadian River lost nearly 25 percent of their content within 2 weeks. Lakes in hard lands soils south of the Canadian lost about one-third of their content. Lakes in mixed lands soils lost nearly 60 percent of their content. No monitoring occurred in sandy lands soils, but if the above trend continued, over two-thirds of the content would probably be lost within 2 weeks (table IV-4 and figure IV-5).

These reliability evaluations are based on all losses throughout the period of record. As such, they must be categorized as a general assessment based on conditional variables. This tends to obscure the causes of loss. The most notable variable that was observed, because of its persistence, was season. Reliability is greater in winter than in summer. That means that during times of high irrigation demand, when the water is most needed, the reliability may be somewhat less than these overall values indicate.

Since playa lake surface area and reliability are both related to soil type, observations of playa lake surface areas give an indication of reliability. Infrared (low-altitude) photographs of the 36 lakes were evaluated for total wetlands. Figure IV-6 shows the results of the analysis. These data indicate that reliability decreases to the south and west (from 117 to 18, as shown on figure IV-6).*

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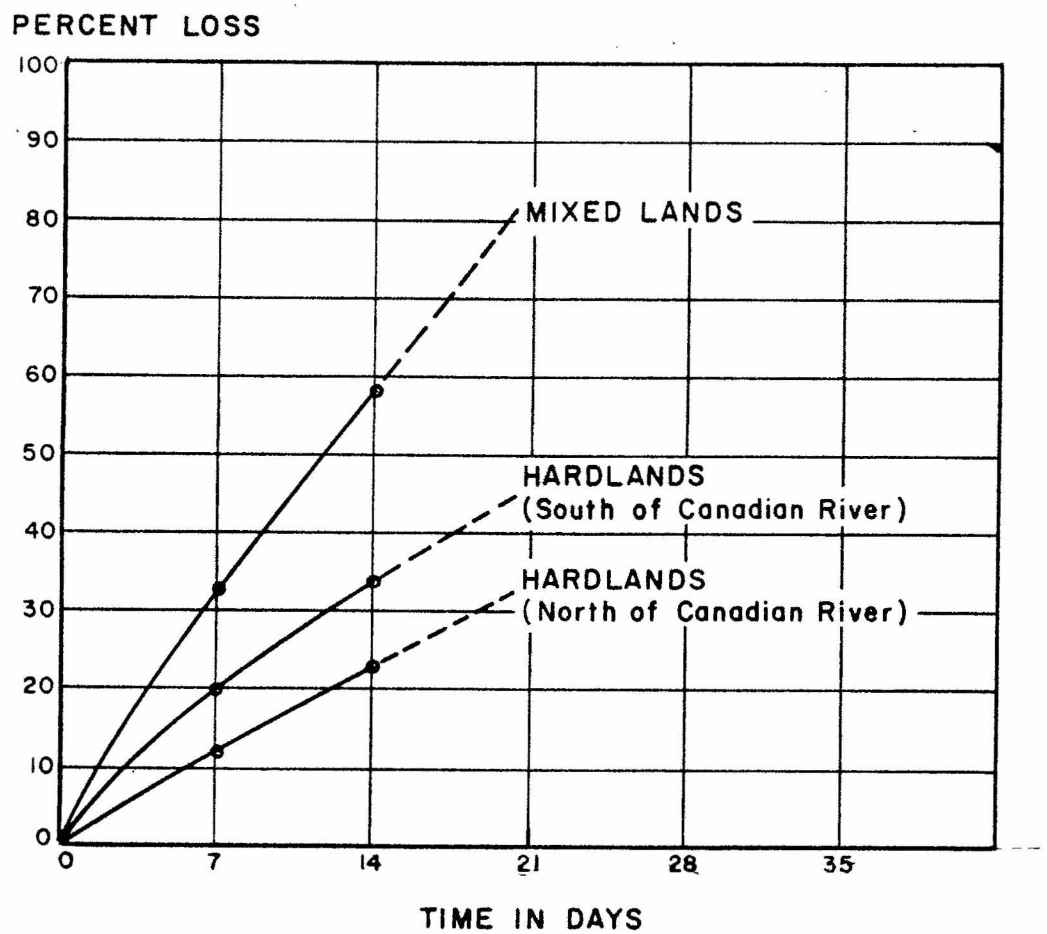
* The average surface area of typical playa lakes in New Mexico will be smaller than in other parts of the study area. Also, extrapolation of data from the monitored playa lakes to lakes in New Mexico will be inexact because of the recognized lower rainfall in New Mexico. (SCS 1982b)

Table IV-4
Reliability of Monitored Playa Lakes
(contents over time in acre-feet)

Playa lake number	Starting content	7-Day content	Percent loss	14-Day content	Percent loss over 2d week	Total percent loss
Hard lands north of the Canadian						
14	no data	-		-		
15	753	655		601		
16	504	419		355		
17	2,318	2,101		1,873		
21	733	627		514		
22	181	131		100		
	4,489	3,933	12	3,443	12	23
Hard lands south of the Canadian						
1	582	343		234		
3	358	290		173		
5	79	47		38		
6	57	35		22		
7	195	167		144		
8	140	99		60		
9	323	266		235		
13	472	370		302		
25	186	115		75		
27	22	11		0		
28	-	-		-		
30	152	133		119		
33	167	95		46		
34	98	42		14		
44	600	528		462		
47	2	2		0		
50	456	406		366		
51	74	51		34		
53	25	18		15		
61	-	-		-		
64	103	81		52		
65	1,175	1,023		900		
66	1,593	1,384		1,202		
	6,859	5,506	20	4,493	18	34
Mixed lands						
36	278	192		116		
37	73	38		20		
38	11	8		4		
39	-	-		-		
41	-	-		-		
42	66	47		38		
58	-	-		-		
	428	285	33	178	38	58



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

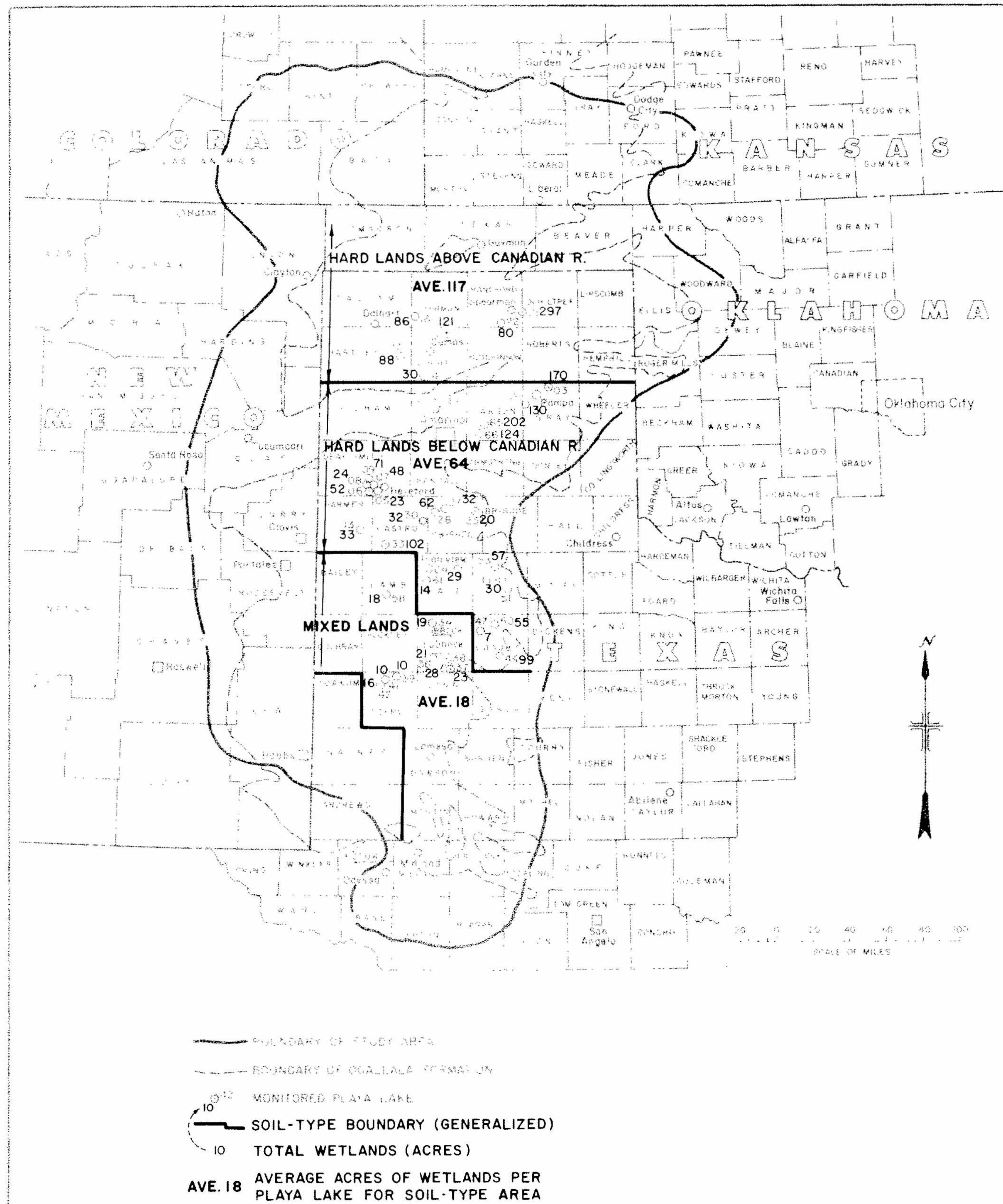
LLANO ESTACADO PLAYA LAKE
WATER RESOURCES STUDY

RELIABILITY (Content vs. Time) OF MONITORED PLAYA LAKES

JUNE 1982

AMARILLO, TEXAS

Figure IV - 5



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LLANO ESTACADO PLAYA LAKE
WATER RESOURCES STUDY

TOTAL WETLANDS AT MONITORED PLAYA LAKES

JUNE 1982

AMARILLO, TEXAS

Figure IV-6

Soil analyses were made to areally extend the hydrological analysis of the monitored lakes to the rest of the study area. It was hoped that, using precipitation, evaporation, and soil-type data, the findings for monitored lakes could be extended to other lakes in the study area with similar soil types.*

However, for general planning purposes, data collected in the monitoring program can be projected only on a limited basis to adjacent areas; to extend the data to the entire study area would be very questionable. Throughout the study area, soils of playa lake bottoms and of lands adjacent to the lakes are variable, especially where soil types adjoin or are intermixed. Specific playa lake modification will require specific soil analyses to determine the kind and extent of soils present. Figure IV-7 shows the area to which data from the monitoring program may be projected based on soil-type information.

Relationship of hydrological results to LANDSAT results

Tables IV-5 and IV-6 give the total number of playa lakes per county as determined by Guthrey et al.** (1981)(see chapter VIII), the number of playa lakes shown by LANDSAT imagery during wet and dry periods, historic monthly precipitation prior to the date of the LANDSAT scene, and the probability of occurrence of that monthly precipitation during wet and dry periods. Wet scene data indicate that only about 15 percent of all playa lakes in the study area contain water during wet periods, for a total water volume for those lakes of about 100,000 acre-feet. Likewise, dry scene data show that less than 2 percent of all playa lakes contain water during dry periods, for a total volume for those lakes of about 7,000 acre-feet.

The above data indicate that wet scene LANDSAT values generally depict unusually wet periods and represent close to the maximum amounts of water which would be available. Table IV-7 shows only those monthly precipitation amounts (prior to LANDSAT flyover) with a 90 percent or better probability of being the maximum, yet these playa lakes represented only about 29 percent of the lakes with water. The 90 percent or better percent values represent the percentage of all monthly precipitation amounts for the 41 years of record which were drier than the monthly precipitation (prior to LANDSAT flyover) indicated.

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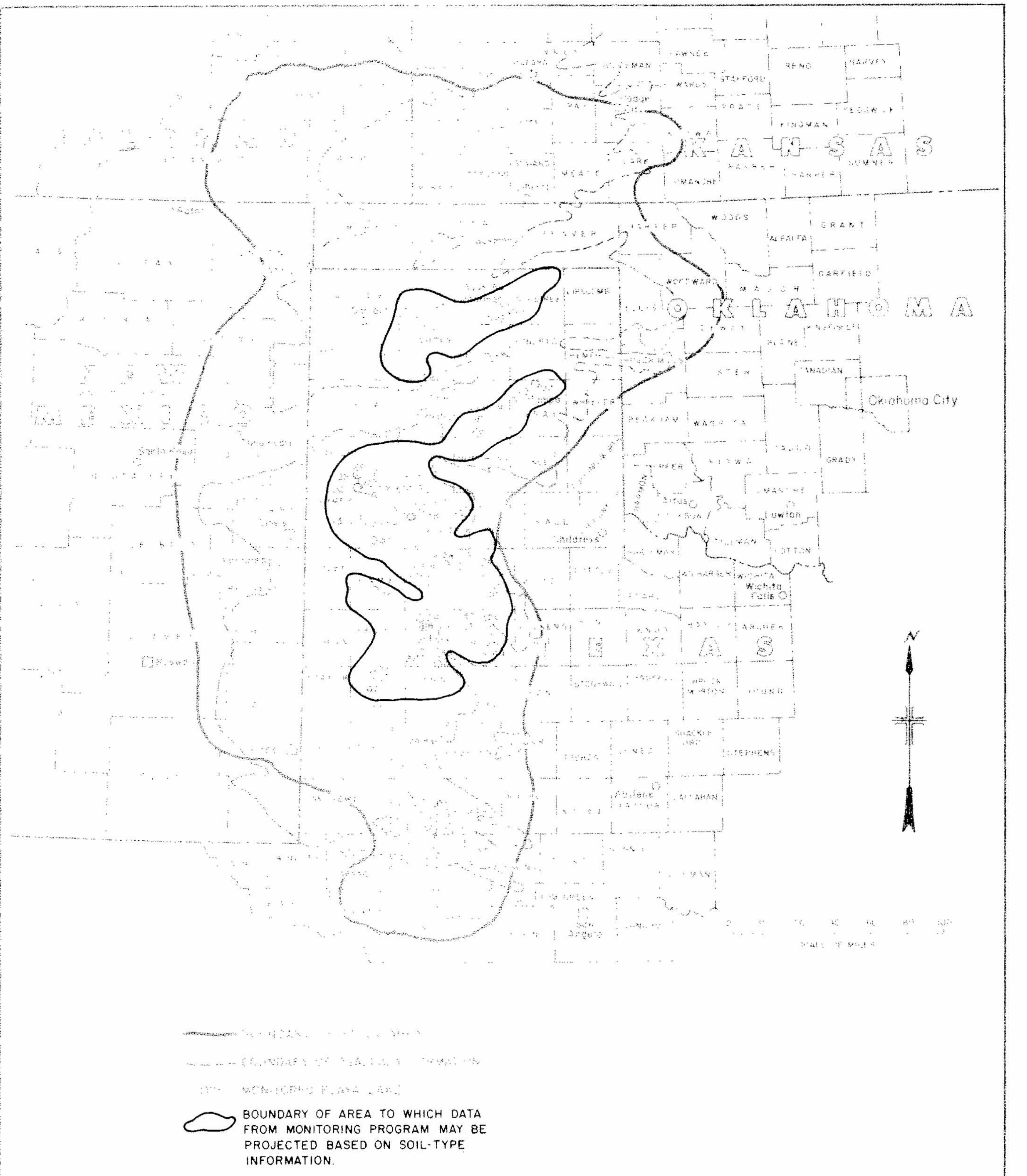
* The average surface area of typical playa lakes in New Mexico will be smaller than in other parts of the study area. Also, extrapolation of data from the monitored playa lakes to lakes in New Mexico will be inexact because of the recognized lower rainfall in New Mexico. (SCS 1982b)

** In both tables, the number of lakes determined by Guthrey et al. includes all lakes (wet and dry), and the number of lakes shown by LANDSAT includes only those with water.



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LLANO ESTACADO PLAYA LAKE
WATER RESOURCES STUDY

AREAL PROJECTION OF MONITORING PROGRAM DATA

JUNE 1982

AMARILLO, TEXAS

Figure IV-7

Table IV-5

Selected Analysis of Wet Scene LANDSAT Data

County	No. of playa lakes LANDSAT Column 1	Guthrey Column 2	Percent of all lakes (wet and dry) which contained water Col. 1 ÷ Col. 2	Monthly PPT prior to LANDSAT Flyover Column 3	Percent of time precipitation will be: < Col. 3	> Col. 3
LANDSAT scene of 9-11-74						
Beaver	20	84	23.8	2.24	72	28
Borden	20	-	-	4.91	96	4
Carson	50	535	09.3	2.75	79	21
Crosby	170	925	18.4	6.57	98.7	1.3
Dawson	6	702	00.9	2.96	84	16
Gaines	68	65	104.6	4.69	96.5	3.5
Garza	47	283	16.6	4.30	93	7
Gray, TX	43	752	05.7	2.37	72	28
Hansford	20	345	05.8	2.05	72	28
Hemphill	15	9	166.7	2.83	81	19
Hutchison	35	167	21.0	3.59	88	12
Lipscomb	2	18	11.1	4.92	95	5
Lubbock	214	934	22.9	4.44	94	6
Lynn	63	842	07.5	2.99	82	18
Ochiltree	13	590	02.2	2.62	77	23
Roberts	2	20	10.0	1.87	62	38
Terry	117	532	22.0	6.23	98.5	1.5
Texas	35	237	14.8	2.27	75	25
Wheeler	14	10	140.0	.90	39	61
Subtotal	934	7,050	13.2 (Av.)			
LANDSAT scene of 10-13-80						
Bailey	18	598	03.0	2.30	78	22
Castro	44	621	07.1	2.10	74	26
Cimarron	26	264	09.8	.00	.2	99.8
Curry	18	524	03.4	1.34	66	34
Dallam	22	220	10.0	.00	.2	99.8
Deaf Smith	106	451	23.5	3.02	87	13
Hartley	37	123	30.1	.75	43	57
Lamb	25	1,280	02.0	3.23	86	14
Moore	85	195	43.6	.43	30	70
Oldham	29	75	38.7	2.42	78	22
Parmer	49	455	10.8	2.80	85	15
Potter	78	69	113.0	.97	45	55
Quay	22	228	09.6	.74	50	50
Roosevelt	37	535	06.9	1.83	73	27
Sherman	48	219	21.4	.15	10	90
Texas	35	237	14.8	.00	.2	99.8
Subtotal	679	6,094	11.1 (Av.)			

Table IV-5 (Con.)

Selected Analysis of Wet Scene LANDSAT Data

County	No. of playa lakes LANDSAT Column 1	Guthrey Column 2	Percent of all lakes (wet and dry) which contained water Col. 1 ÷ Col. 2	Monthly PPT prior to LANDSAT Flyover Column 3	Percent of time precipitation will be: < Col. 3	> Col. 3
LANDSAT scene of 5-26-74						
Armstrong	78	676	11.5	2.61	78	22
Briscoe	144	787	18.3	3.52	89	11
Donley	23	114	20.2	3.60	85	15
Floyd	125	1,783	7.0	3.54	87	13
Hale	127	1,383	9.2	2.56	78	22
Randall	166	564	29.4	1.95	69	31
Swisher	156	910	17.1	2.38	76	24
Subtotal	819	6,217	13.2 (Av.)			
LANDSAT scene of 10-17-74						
Beaver	20	84	23.8	1.52	58	42
Glasscock	78	-	-	9.71	99.7	.3
Gray, KS	24	-	-	.87	48	52
Haskell	32	701	4.6	1.60	63	37
Howard	140	185	75.7	5.99	98.1	1.9
Martin	172	-	-	9.30	99.7	.3
Meade	36	712	5.1	1.53	61	39
Midland	149	-	-	8.13	99.8	.2
Seward	18	294	6.1	1.14	52	48
Texas	35	237	14.8	.91	49	51
Subtotal	281	2,213	12.7 (Av.)			
LANDSAT scene of 10-18-74						
Baca	23	198	11.6	1.67	72	28
Cimarron	26	264	9.8	1.94	74	26
Cochran	44	395	11.1	1.16	55	45
Gaines	68	65	104.6	1 0.55	99.8	.2
Grant	20	232	8.6	.11	12	88
Hockley	400	1,171	34.2	1 0.12	99.6	.4
Lea	425	1,175	36.2	9.05	99.6	.4
Morton	5	58	8.6	1.02	56	44
Roosevelt	37	535	6.9	4.01	96	4
Stanton	9	676	1.3	.75	46	54
Stevens	6	133	4.5	1.83	71	29
Terry	117	532	22.0	1 1.35	99.7	.3
Texas	35	237	14.8	.91	49	51
Yoakum	42	38	110.5	8.69	99.5	.5
Subtotal	1,257	5,709	22.0 (Av.)			
Total	3,970	27,283	14.6 (Av.)			

Table IV-6

Selected Analysis of Dry Scene LANDSAT Data

County	No. of playa lakes: LANDSAT Column 1	No. of playa lakes: Guthrey Column 2	Percent of all lakes (wet and dry) which contained water Col. 1 ÷ Col. 2	Monthly PPT prior to LANDSAT Flyover Column 3	Percent of time precipitation will be: < Col. 3	Percent of time precipitation will be: > Col. 3
LANDSAT scene of 4-20-74						
Beaver	3	84	3.6	.00	.2	99.8
Carson	7	535	1.3	.12	11	89
Gray, KS	-	-	-	.47	29	71
Gray, TX	10	752	1.3	.21	13	87
Hansford	8	345	2.3	.34	28	72
Haskell	-	701	-	.68	39	61
Hemphill	9	9	100.0	.22	13	87
Hutchison	19	167	11.4	.24	16	84
Lipscomb	1	18	5.6	.00	.2	99.8
Meade	-	712	-	.22	18	82
Ochiltree	4	590	.7	.82	43	57
Roberts	0	20	.0	.22	13	87
Texas	14	237	5.9	.03	.6	99.4
Wheeler	9	10	90.0	.32	17	83
Subtotal	84	2,767	3.0 (Av.)			
LANDSAT scene of 4-26-78						
Armstrong	2	676	.3	.37	23	77
Borden	7	-	-	.26	20	80
Briscoe	6	787	.8	.60	32	68
Crosby	13	925	1.4	.08	10	90
Dawson	2	702	.3	.54	33	67
Donley	3	114	2.6	.25	15	85
Floyd	5	1,783	.3	.13	13	87
Gaines	2	65	3.1	.28	26	74
Garza	6	283	2.1	.24	19	81
Glasscock	-	-	-	.00	.2	99.8
Hale	11	1,383	.8	.50	28	72
Howard	-	185	-	.26	20	80
Lubbock	18	934	1.9	.21	18	82
Lynn	9	842	1.1	.12	13	87
Martin	-	-	-	.10	9	91
Midland	-	-	-	.06	11	89
Randall	6	564	1.1	.55	29	71
Swisher	20	910	2.2	.28	16	84
Terry	13	532	2.4	.16	26	74
Subtotal	116	10,500	1.1 (Av.)			

Table IV-6 (Con.)

Selected Analysis of Dry Scene LANDSAT Data

County	No. of playa lakes: LANDSAT Column 1	No. of playa lakes: Guthrey Column 2	Percent of all lakes (wet and dry) which contained water Col. 1 ÷ Col. 2	Monthly PPT prior to LANDSAT Flyover Column 3	Percent of time precipitation will be: < Col. 3	Percent of time precipitation will be: > Col. 3
LANDSAT scene of 9-11-74						
Cimarron	0	264	.0	1.46	65	35
LANDSAT scene of 4-18-78						
Bailey	2	598	.3	.25	19	81
Castro	7	621	1.1	.71	40	60
Curry	4	524	.8	1.80	73	27
Dallam	2	220	.9	.24	20	80
Deaf Smith	18	451	4.0	.15	12	88
Grant	-	232	-	.21	21	79
Hartley	7	123	5.7	.61	38	62
Hockley	-	1,171	-	.31	40	60
Lamb	2	1,280	.2	.28	39	61
Lea	-	1,175	-	.44	39	61
Moore	10	195	5.1	.67	38	62
Morton	-	58	-	.05	7	93
Oldham	14	75	18.7	.56	36	64
Parmer	14	455	3.1	.71	41	59
Potter	4	69	5.8	.64	35	65
Quay	0	228	.0	.83	51	49
Roosevelt	4	535	.7	.30	22	78
Sherman	6	219	2.7	.13	11	89
Stanton	-	676	-	.09	11	89
Stevens	-	133	-	.48	36	64
Texas	14	237	5.9	.60	36	64
Subtotal	108	6,094	1.8 (Av.)			
Total	308	19,625	1.6 (Av.)			

Table IV-7
Selected Wet Scene LANDSAT Data

County	No. of playa lakes LANDSAT Column 1	Guthrey Column 2	Percent of all lakes (wet and dry) which contained water Col. 1 ÷ Col. 2	Monthly PPT prior to LANDSAT Flyover Column 3	Percent of time precipitation will be: < Col. 3	> Col. 3
All LANDSAT scenes						
Terry	117	532	22.0	11.35	99.7	.3
Gaines	68	65	104.6	10.55	99.8	.2
Hockley	400	1,171	34.2	10.12	99.6	.4
Lea	425	1,175	36.2	9.05	99.6	.4
Yoakum	42	38	110.5	8.69	99.5	.5
Crosby	170	925	18.4	6.57	98.7	1.3
Terry	117	532	22.0	6.23	98.5	1.5
Howard	140	185	75.7	5.99	98.1	1.9
Lipscomb	2	18	11.1	4.92	95	5
Gaines	68	65	104.6	4.69	96.5	3.5
Lubbock	214	934	22.9	4.44	94	6
Garza	47	283	16.6	4.30	93	7
Roosevelt	37	535	6.9	4.01	96	4
Total	1,847	6,458	28.6 (Av.)			

Recharge

Over the years, the possibility of using playa lake water to recharge the Ogallala Aquifer has been a subject of interest and study in the High Plains. Various methods of recharge have been evaluated. Because the methods are expensive or become inoperable (aquifer clogs with sediment) after a period of time, the economic feasibility of using playa lake water for ground water recharge appears questionable at this time.

Two basic methods of artificial recharge have been studied. One is the use of water-spreading basins from which water infiltrates to the water table; the second is the use of injection wells to pump water into the aquifer. Both methods are considered to have significant value in the High Plains area, but both methods are subject to limitations and failure.

Experiment and field tests indicate that spreading basins are probably the most economical method of recharge in many areas; however, in some areas this is not successful because of the low permeability of the surface material. The lake bottoms are blanketed with Randall clay which prevents measurable percolation, but the effectiveness of this method depends on a moderate to high rate of infiltration. (Brown et al. 1978) Although the clay can be removed to expose more permeable material, it tends to refill the excavated area when precipitation runoff recurs. An approach that seems to have merit is the use of water spreading to recharge water through certain permeable soils in selected areas near the playa lake. A February 1979 proposal (Wendt 1979) to evaluate this method was submitted by the Texas Water Resources Institute, Texas A&M University, to the Federal Office of Water Research and Technology. If possible, the basins would be situated near an irrigation well so that infiltrating water would move toward and remain near the well. Dvoracek and Wheaton (Dvoracek and Wheaton 1969 from Aronovici et al. 1972) recharged playa lake water through pits excavated in the bottom of a lake near Lubbock, Texas. The maximum percolation rate was 1.5 feet per day, but the recharge pits were inundated by large storms and required frequent maintenance to remove the sediment.

Where the spreading-basin method cannot be used because of the depth of the clay soil or absence of permeable soils, water can be recharged through injection wells. Several researchers have investigated dual-purpose wells for injecting playa lake water into the underlying aquifer. The main limitation of these dual-purpose wells is the formation sealing caused by suspended solids in the playa lake water. Recharging sediment-laden water into a fine sand formation rapidly reduces the effectiveness of the well for both pumping and recharging.

Because suspended sediment in playa lake water is of major concern (particularly if injection wells are the method of recharge), it must be reduced as much as possible to prevent clogging of the aquifer. One method of reducing the sediment load is through use of chemical flocculation. This operation has been used with varying degrees of success at several locations in the Texas Panhandle area. (Brown et al. 1978). However this operation is expensive.*

* Imported water would probably not contain problem levels of suspended solids. Therefore, if such water should become available in the study area, consideration could be given to use of the water to recharge the Ogallala Aquifer.

CHAPTER V - LANDSAT

Previous Studies

In June 1973, the Texas Natural Resources Information System (TNRIS) and predecessor agencies of the TDWR became closely associated with NASA-Johnson Space Center (JSC) in regard to the development of an operational remote sensing technique for the detection and mapping of surface water bodies. This technique was developed by JSC working cooperatively with the U.S. Army Corps of Engineers in support of the National Program of Inspection of Dams established by Public Law 92-367. The system used data from LANDSAT, a series of satellites each equipped with an onboard multispectral scanner for recording images of the earth. The success of this technique led the Texas Water Development Board (a TDWR predecessor agency) to initiate work in the spring of 1975 on a project to determine the feasibility of using digital data from LANDSAT imagery to determine the surface area of playa lakes. This work continued until October 1977, at which time the Bureau asked the TDWR to assess the utility of using LANDSAT data analysis technology for the Llano Estacado study. The continued interest of the Bureau, the TDWR, and TNRIS resulted in a cooperative project to develop a methodology for inventorying and determining the availability of water in the playa lakes. (TDWR 1980) The result of the project was the report (TDWR 1980) by the Texas Department of Water Resources (in cooperation with TNRIS and the Bureau) entitled "Playa Lake Monitoring for the Llano Estacado Total Water Management Study, Texas, Oklahoma, New Mexico, Colorado, and Kansas." This was a report on pilot studies, using LANDSAT imagery, of wet and dry periods in the Lubbock County, Texas, area. The report formed the basis for the LANDSAT studies (described below) conducted by the Bureau's E&R Center.

Engineering and Research Center Procedures *

This study required several years of intensive research and development of the techniques required to perform the inventory of playa lakes using LANDSAT data.

Because of the large area to be studied, the Llano Estacado study has, from its inception, emphasized use of LANDSAT imagery. Further, because various unofficial estimates had placed the number of playa lakes as high as 30,000, it was realized that computer analysis of the imagery would be required. This method should provide an accurate, reasonably timely, and cost effective means to inventory the playa lakes that contain water and provide a measure of water availability in wet and dry periods.

The E&R Center used a computer system for LANDSAT image analysis called Interactive Digital Image Analysis System (IDIAS). The course of investigation using IDIAS for the study consisted of two phases, a technique development and feasibility demonstration phase and a playa inventory phase.

* This section was abstracted from the April 29, 1982, E&R Center memorandum from Head, Remote Sensing Section, to Chief, Applied Sciences Branch, Subject: "Summary of Results of the Playa Lakes Inventory in the Llano Estacado Using Digital Image Processing," principal investigator, G. A. Teter. The entire memorandum is included in the appended material.

Data Packages for Monitored Playa Lakes

The items listed below were prepared for each playa lake. The items for Playa Lake No. 9 follow this page. Copies of the items for other monitored playa lakes are available upon request.

1. Graphs of various parameters versus time for playa lake. (Note that items 1 and 2 were prepared following preparation of item 7.)

2. Seepage vs. content and adjusted runoff vs. precipitation for playa lake.

3. Map showing location of playa lake within the study area.

4. County map showing location of playa lake.

5. Map showing drainage area of playa lake based on aerial photographs and field checking.

6. Characteristics of the playa lake.

7. Precipitation-duration curve for quadrangle in which the playa lake is located.

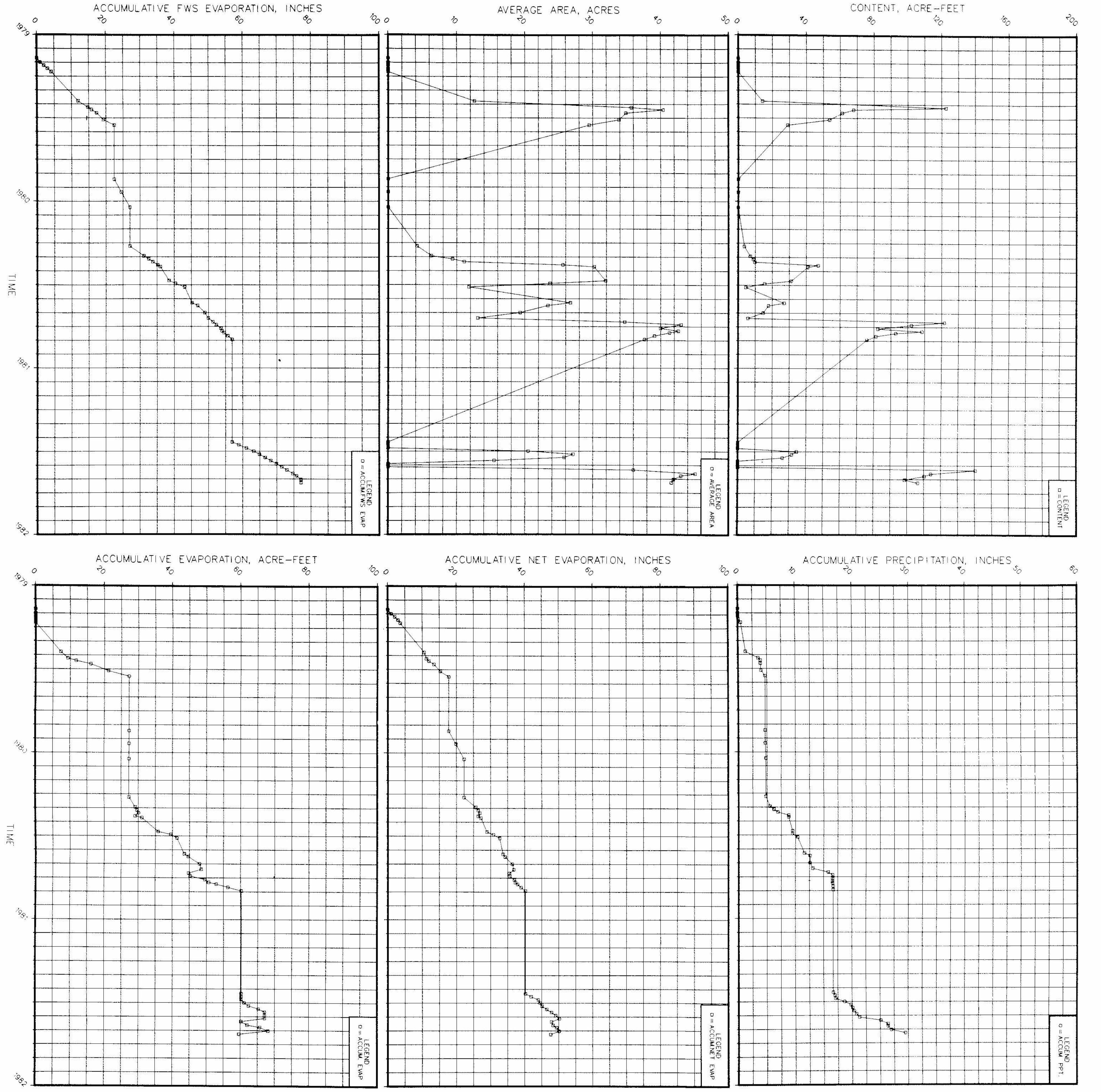
8. Evaporation-duration curve for quadrangle in which the playa lake is located.

9. Operation study of playa lake.

10. Table of historical precipitation for playa lake.

11. Table of estimated historical runoff for playa lake (corresponding to 8).

12. Estimated runoff-duration curve for playa lake.



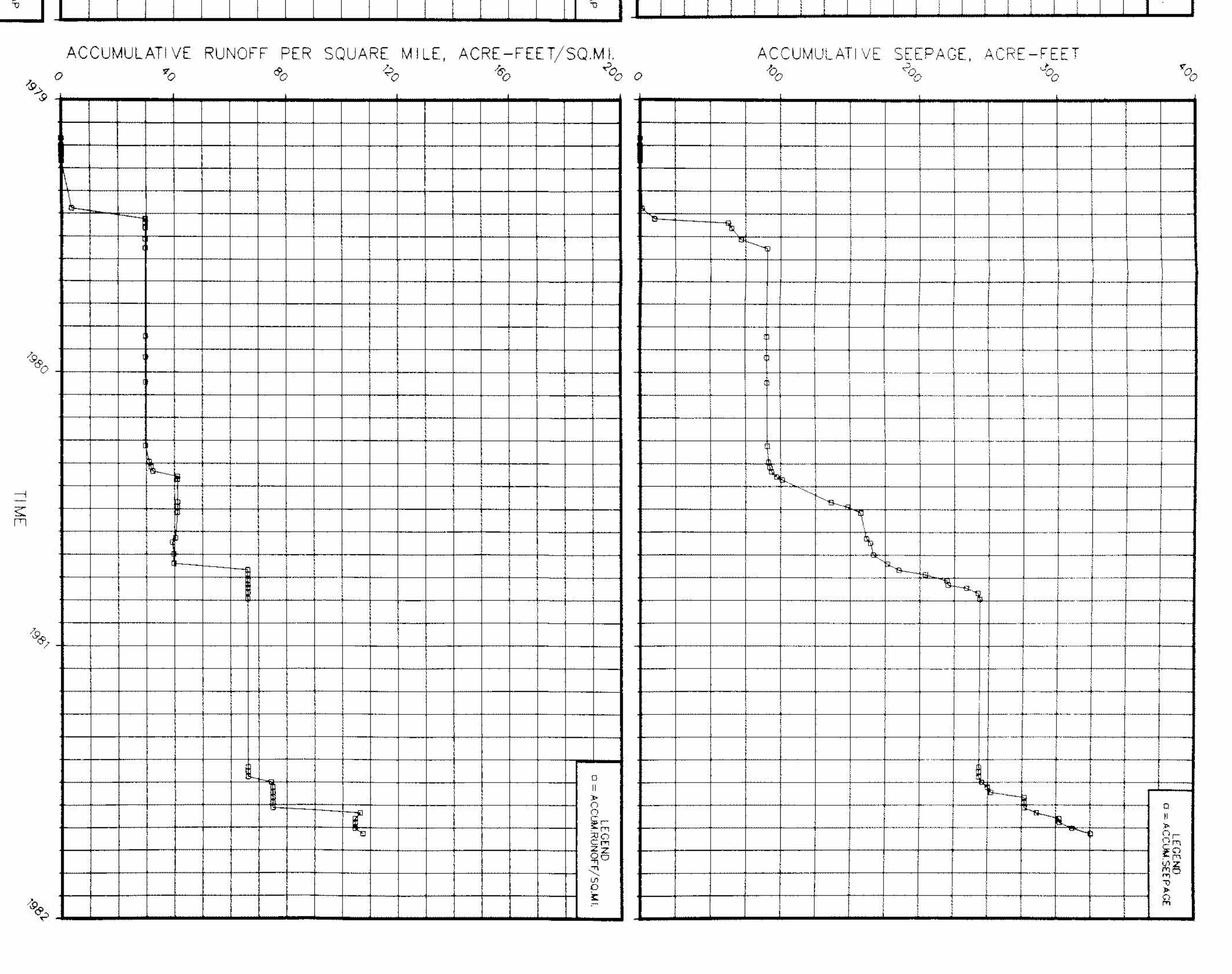
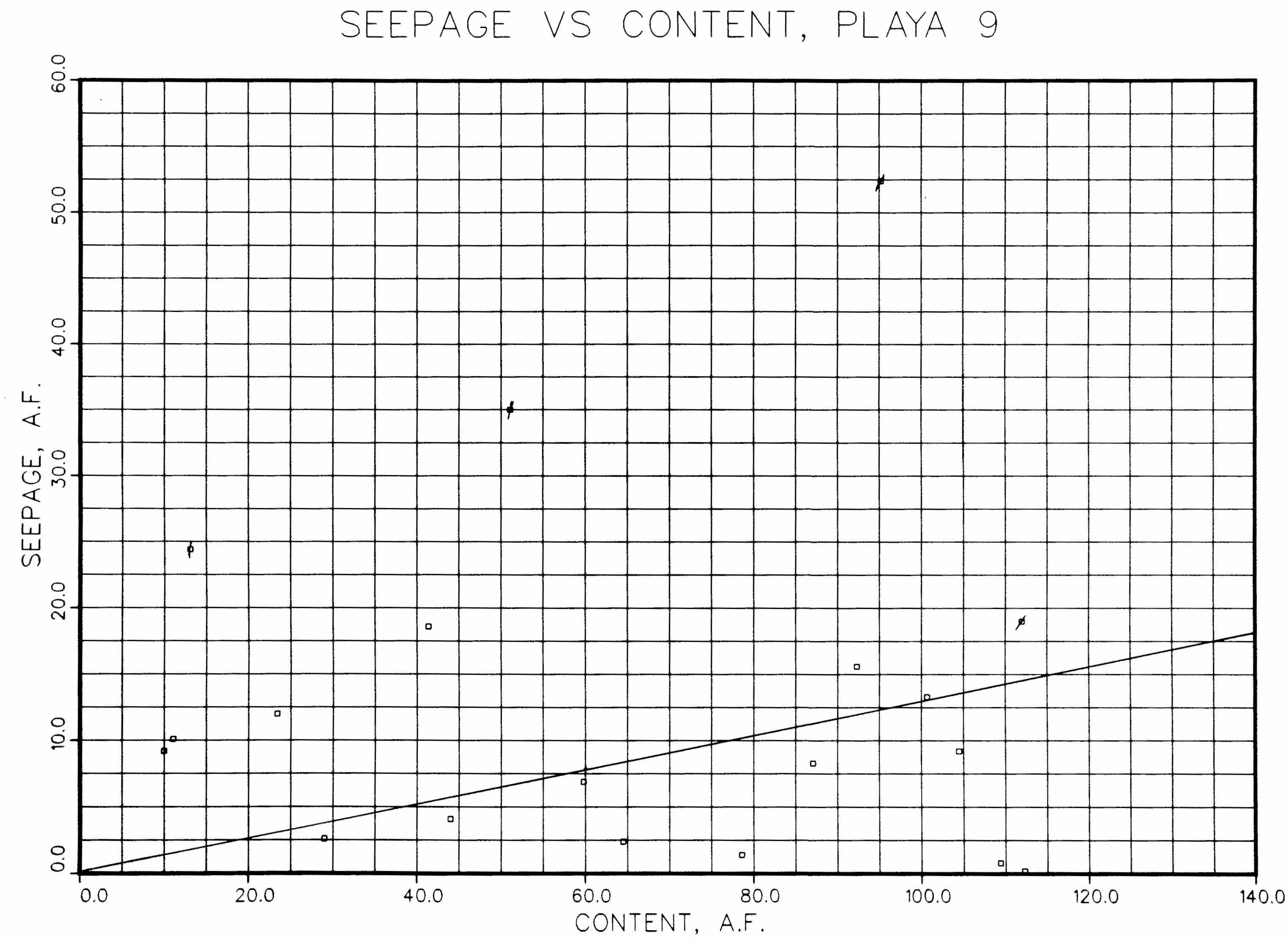


Figure A-1

GRAPHS OF VARIOUS PARAMETERS VS. TIME
for
PLAYA LAKE NO. 9


SEEPAGE VS CONTENT, PLAYA 9
SEEPAGE, A.F.
0.0
10.0
20.0
30.0
40.0
50.0
60.0
CONTENT, A.F.
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0

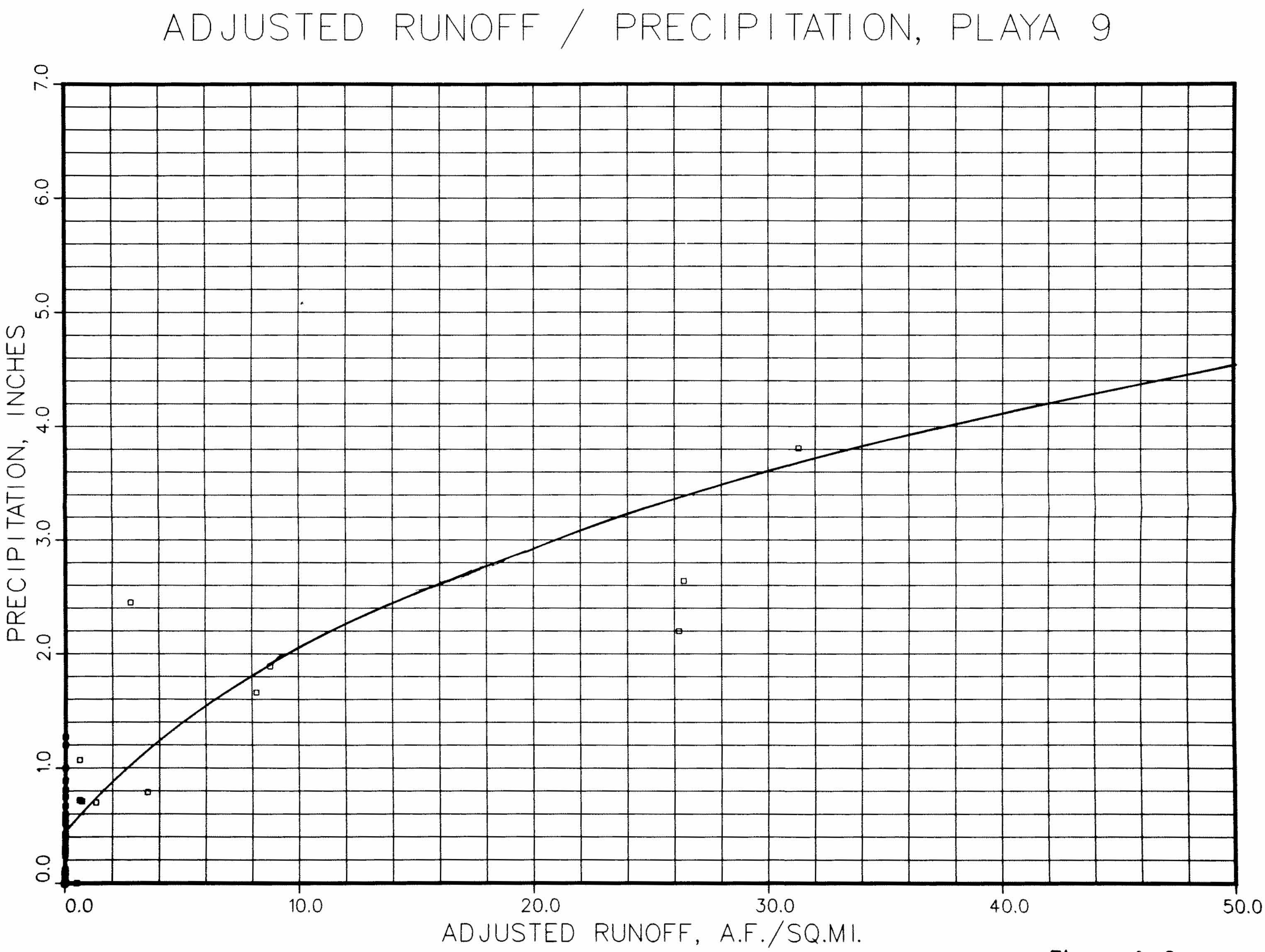
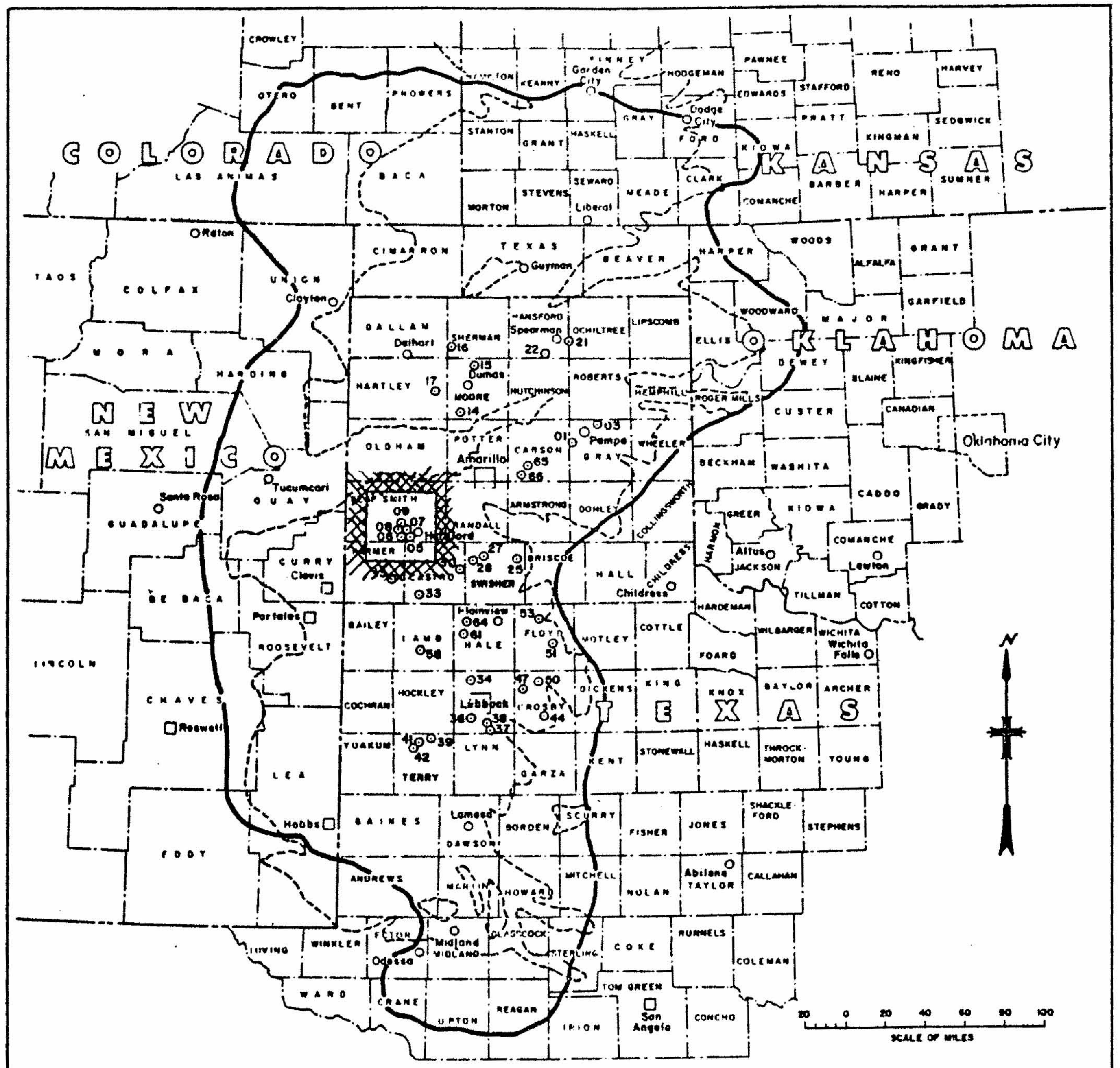

ADJUSTED RUNOFF / PRECIPITATION, PLAYA 9
PRECIPITATION, INCHES
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
ADJUSTED RUNOFF, A.F./SQ.MI.
0.0
10.0
20.0
30.0
40.0
50.0

Figure A-2



BOUNDARY OF STUDY AREA

BOUNDARY OF OGALLALA FORMATION

○42 MONITORED PLAYA LAKE

Box highlights location of playa lake no. 9

UNITED STATES
DEPARTMENT OF THE INTERIOR
WATER AND POWER RESOURCES SERVICE
LLANO ESTACADO PLAYA LAKE
WATER RESOURCES STUDY

MONITORING PROGRAM

JANUARY 1980

AMARILLO, TEXAS

Figure A-3

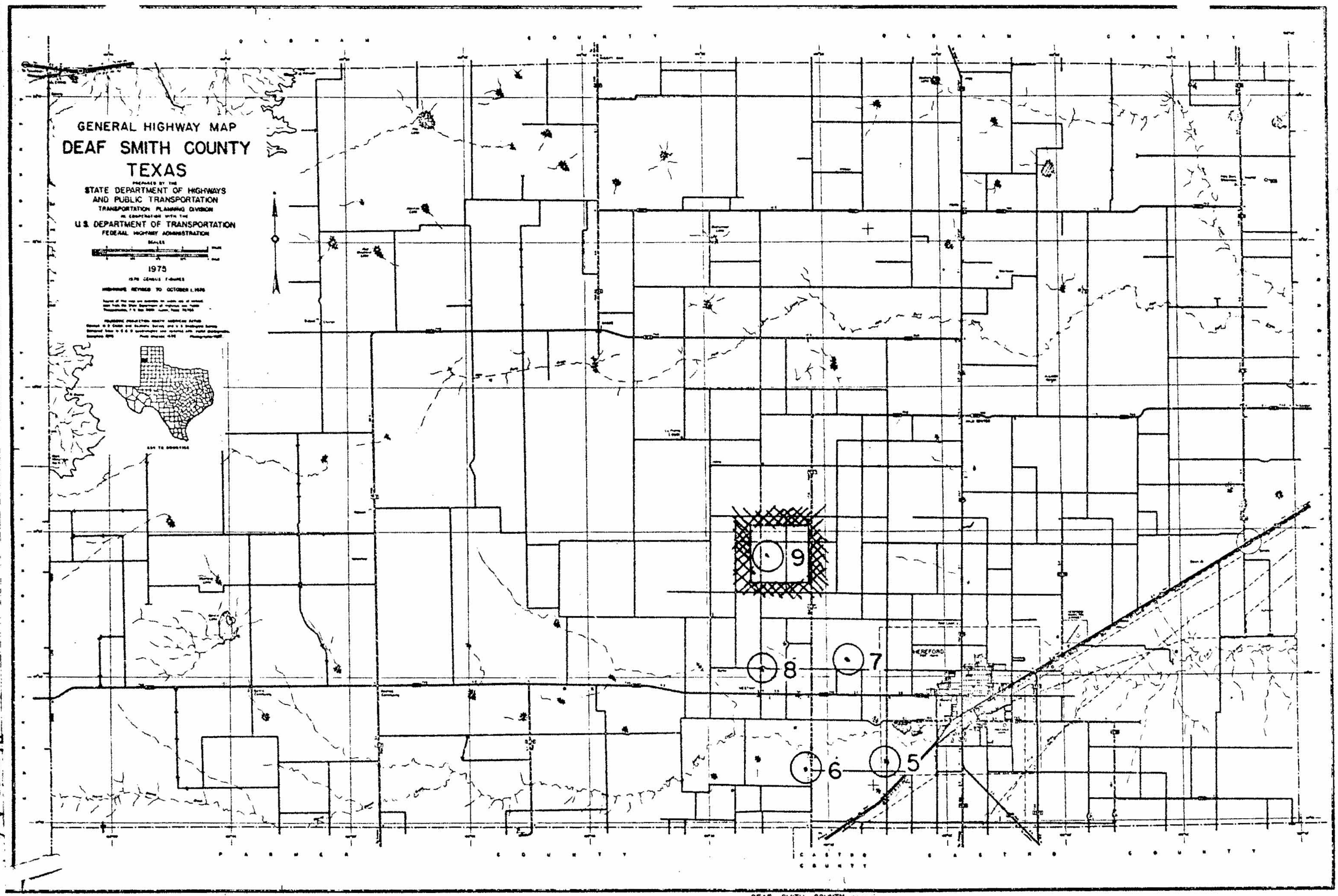


Figure A-4

Box highlights location of playa lake no. 9

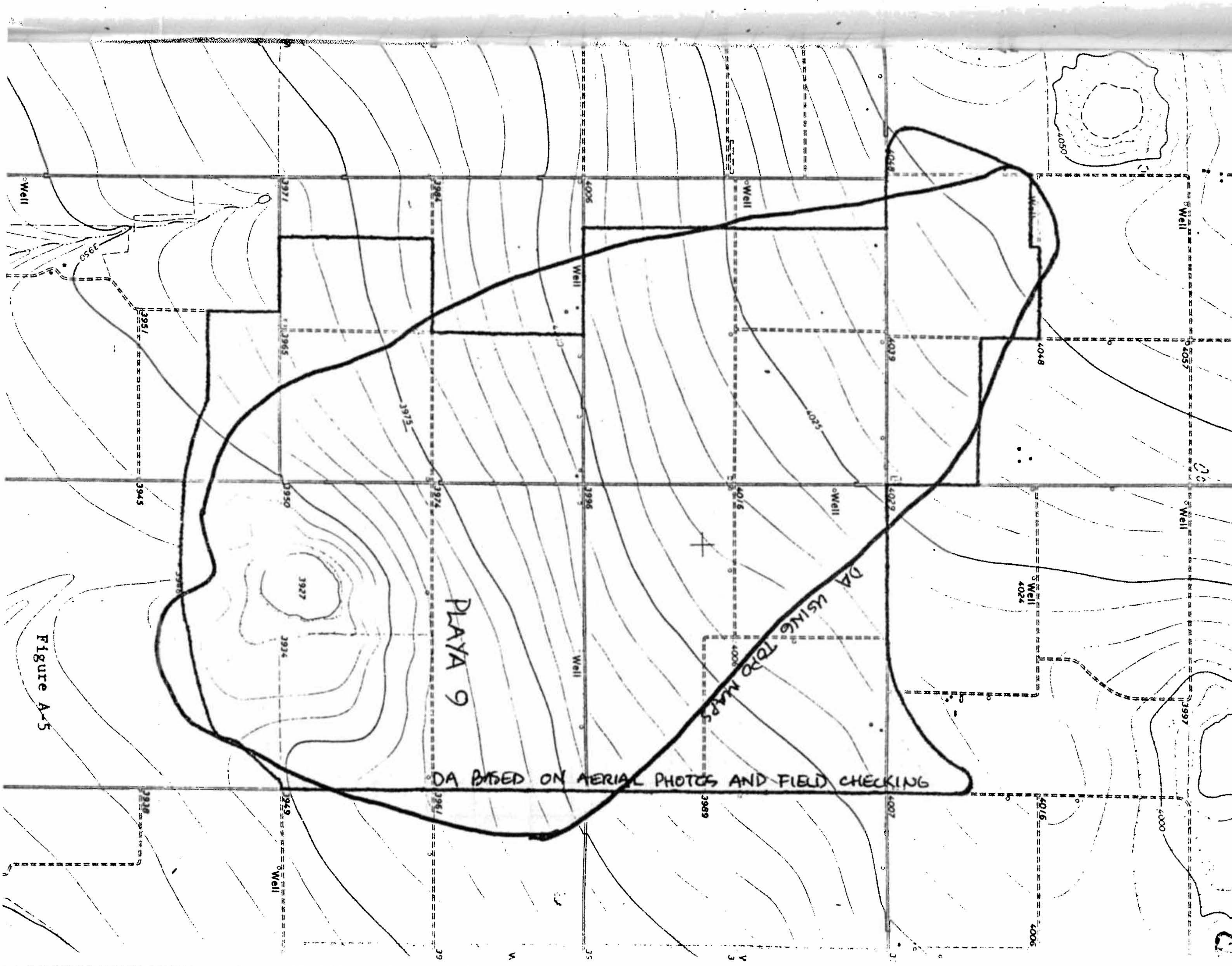


Figure A-5

Playa No. 9 is found in the south-central portion of Deaf Smith County. It is found in hardlands (clay) soils with the drainage area for the playa covering about 2,900 acres. The playa is modified and pumps are used to withdraw water from the playa. About 93 percent of the drainage area is used as cropland with furrow irrigation as the principal irrigation practice. Playa No. 9 does receive tailwater; but based on infrared photography of the soil and vegetation, total wetlands have not exceeded 71 acres.

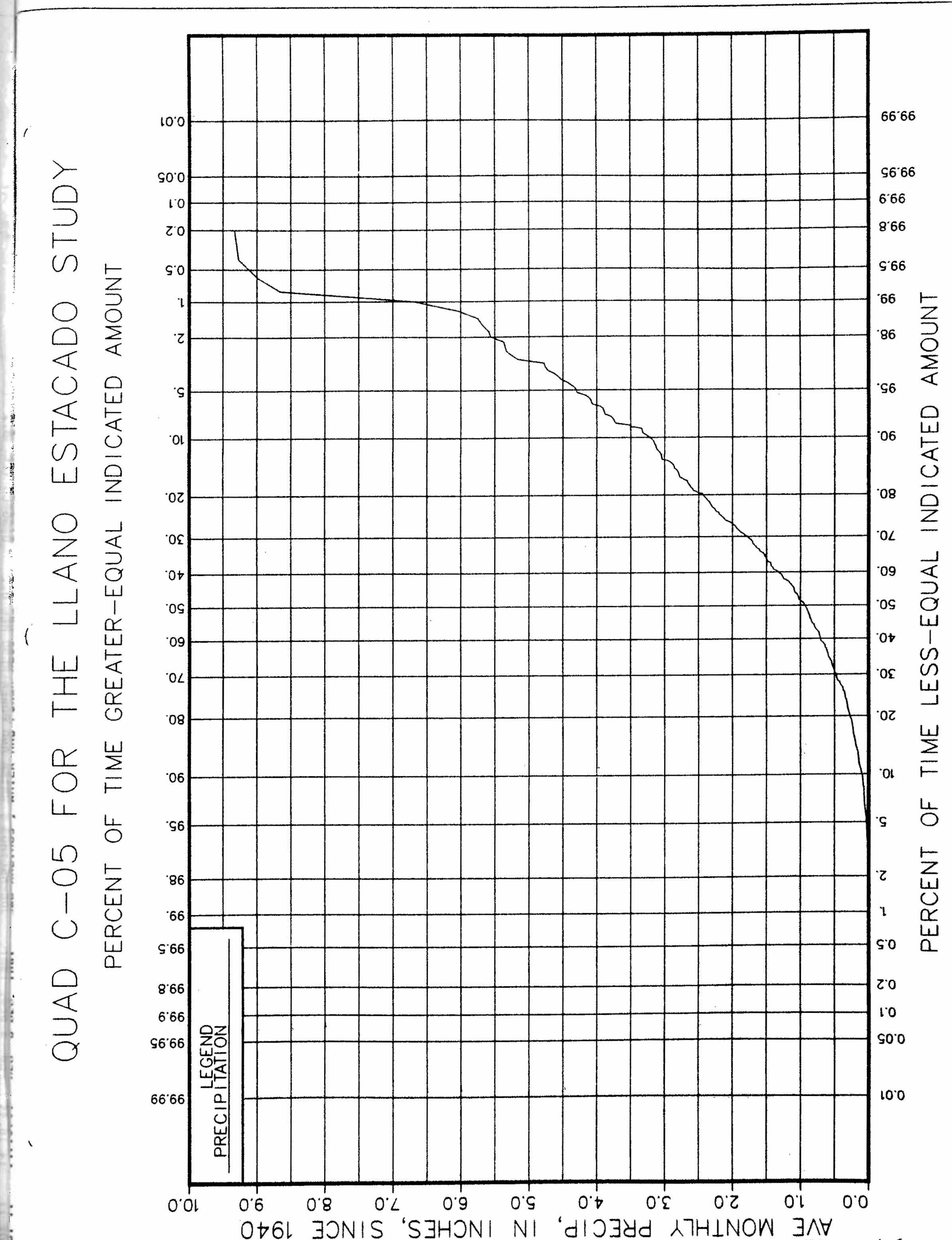
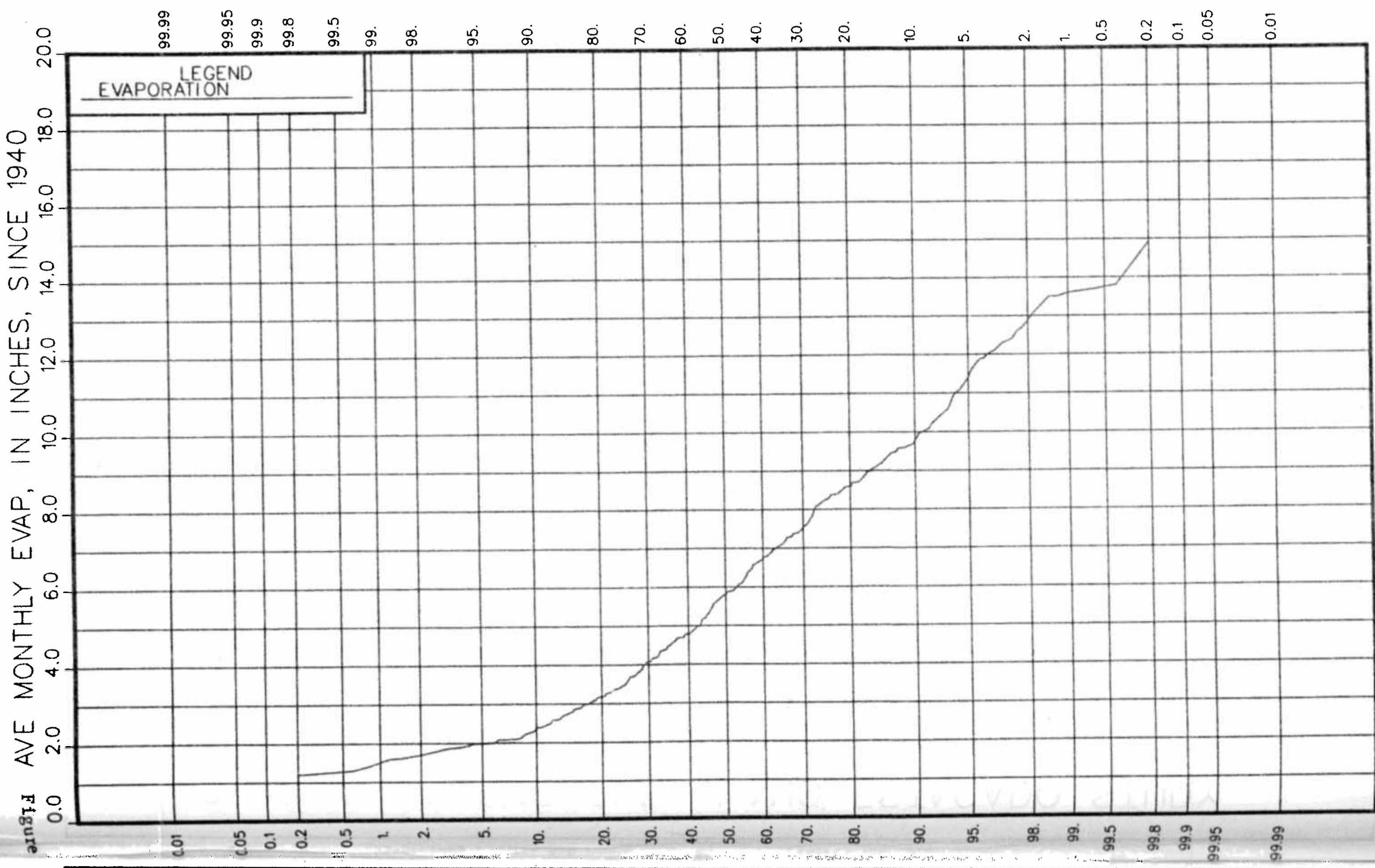


Figure A-6

PLOT 11 13.06.06 WED 16 DEC, 1981 JOB-AAEYDZM , WATER AND POWER RESO REL-8.2 DISSPLA VER 8.2

QUAD C-05 FOR THE LLANO ESTACADO STUDY

PERCENT OF TIME GREATER-EQUAL INDICATED AMOUNT



82/03/24 OPERATION STUDY OF PLAYA 9 DRAINAGE AREA = 4.56 SQ.MI.

DATE	CONTENT	CHANGE IN CONTENT	AVERAGE CONTENT	AVERAGE AREA	PAN EVAP.	FWS EVAP.	TOTAL PRECIP.	NET EVAP. RATE	EVAP.	UNADJUSTED RUNOFF	SEEPAGE	ADJUSTED RUNOFF	RUNOFF /SQ.MI.
	A.F. (1)	A.F. (2)	A.F. (3)	A.F. (4)	IN. (5)	IN. (6)	IN. (7)	IN. (8)	A.F. (9)	A.F. (10)	A.F. (11)	A.F. (12)	AF/SQ.MI (13)
2-21-79	0.0												
3- 1-79	0.0	0.0	0.0	0.0	1.38	.97	0.00	.97	0.0	0.0	0.0	0.0	0.0
3- 8-79	0.0	0.0	0.0	0.0	1.52	1.06	0.00	1.06	0.0	0.0	0.0	0.0	0.0
3-15-79	0.0	0.0	0.0	0.0	1.52	1.06	.10	.96	0.0	0.0	0.0	0.0	0.0
3-22-79	0.0	0.0	0.0	0.0	1.52	1.06	.43	.63	0.0	0.0	0.0	0.0	0.0
~~4-12-79~~	~~7.1~~	~~7.1~~	~~3.6~~	~~4.2~~	~~4.77~~	~~3.34~~	~~.12~~	~~3.22~~	~~1.1~~	~~8.2~~	~~.5~~	~~8.7~~	~~1.9~~
5-25-79	14.2	7.1	10.7	12.6	11.09	7.76	.79	6.97	7.3	14.4	1.4	15.8	3.5
6- 8-79	122.6	108.4	68.4	35.7	4.08	2.86	2.20	.66	2.0	110.4	8.9	119.3	26.2
6-13-79	67.8	-54.8	95.2	40.4	1.52	1.06	.36	.70	2.4	-52.4	52.4	0.0	0.0
6-20-79	61.1	-6.7	64.5	34.9	2.13	1.49	0.00	1.49	4.3	-2.4	2.4	0.0	0.0
~~6-27-79~~	~~65.8~~	~~4.7~~	~~63.5~~	~~34.7~~	~~2.13~~	~~1.49~~	~~0.00~~	~~1.49~~	~~4.3~~	~~9.0~~	~~8.3~~	~~17.3~~	~~3.8~~
7- 5-79	53.7	-12.1	59.8	33.9	2.78	1.95	.10	1.85	5.2	-6.9	6.9	0.0	0.0
7-17-79	29.0	-24.7	41.4	29.5	4.49	3.14	.67	2.47	6.1	-18.6	18.6	0.0	0.0
11-14-79	0.0												
12-12-79	0.0	0.0	0.0	0.0	2.98	2.09	0.00	2.09	0.0	0.0	0.0	0.0	0.0
1-15-80	0.0	0.0	0.0	0.0	3.62	2.53	.12	2.41	0.0	0.0	0.0	0.0	0.0
4- 8-80	3.6												
4-29-80	7.1	3.5	5.4	6.3	5.87	4.11	.70	3.41	1.8	5.3	.7	6.0	1.3
5- 6-80	8.9	1.8	8.0	9.4	2.01	1.41	.71	.70	.5	2.3	1.0	3.3	.7
5-12-80	9.8	.9	9.4	11.1	1.73	1.21	.72	.49	.5	1.4	1.2	2.6	.6
5-19-80	47.0	37.2	28.4	25.6	2.02	1.41	1.89	-.48	-1.0	36.2	3.7	39.9	8.8
5-23-80	40.9	-6.1	44.0	30.2	1.16	.81	0.00	.81	2.0	-4.1	4.1	0.0	0.0
~~6- 8-80~~	~~56.4~~	~~15.5~~	~~48.7~~	~~31.4~~	~~5.91~~	~~4.14~~	~~.54~~	~~3.60~~	~~9.4~~	~~24.9~~	~~6.3~~	~~31.2~~	~~6.8~~
~~6-14-80~~	~~70.9~~	~~14.5~~	~~63.7~~	~~34.7~~	~~2.70~~	~~1.89~~	~~.08~~	~~1.81~~	~~5.2~~	~~19.7~~	~~8.3~~	~~28.0~~	~~6.1~~
6-22-80	31.2	-39.7	51.1	31.9	3.60	2.52	.75	1.77	4.7	-35.0	35.0	0.0	0.0
6-28-80	15.5	-15.7	23.4	23.7	2.70	1.89	0.00	1.89	3.7	-12.0	12.0	0.0	0.0
7- 6-80	4.5	-11.0	10.0	11.8	3.79	2.65	.81	1.84	1.8	-9.2	9.2	0.0	0.0
~~7-12-80~~	~~4.5~~	~~0.0~~	~~4.5~~	~~5.3~~	~~2.89~~	~~2.02~~	~~0.00~~	~~2.02~~	~~.9~~	~~.9~~	~~.6~~	~~1.5~~	~~.3~~
~~8- 2-80~~	~~36.5~~	~~32.0~~	~~20.5~~	~~22.6~~	~~9.93~~	~~6.95~~	~~0.00~~	~~6.95~~	~~13.1~~	~~45.1~~	~~2.7~~	~~47.8~~	~~10.5~~
8-10-80	27.0	-9.5	31.8	26.7	3.11	2.18	1.20	.98	2.2	-7.3	4.1	-3.2	-.7
8-16-80	17.8	-9.2	22.4	23.4	2.33	1.63	1.00	.63	1.2	-8.0	2.9	-5.1	-1.1
~~8-24-80~~	~~17.8~~	~~0.0~~	~~17.8~~	~~21.1~~	~~3.11~~	~~2.18~~	~~.02~~	~~2.16~~	~~3.8~~	~~3.8~~	~~2.3~~	~~6.1~~	~~1.3~~
~~9- 1-80~~	~~14.7~~	~~-3.1~~	~~16.3~~	~~19.3~~	~~2.97~~	~~2.08~~	~~0.00~~	~~2.08~~	~~3.3~~	~~.2~~	~~2.1~~	~~2.3~~	~~.5~~
~~9- 7-80~~	~~16.4~~	~~1.7~~	~~15.6~~	~~18.4~~	~~1.45~~	~~1.02~~	~~0.00~~	~~1.02~~	~~1.6~~	~~3.3~~	~~2.0~~	~~5.3~~	~~1.2~~
9-13-80	5.8	-10.6	11.1	13.1	1.45	1.02	.56	.46	.5	-10.1	10.1	0.0	0.0
9-21-80	121.7	115.9	63.8	34.7	1.94	1.36	2.64	-1.28	-3.7	112.2	8.3	120.5	26.4
9-27-80	102.2	-19.5	112.0	43.0	1.45	1.02	.89	.13	.5	-19.0	19.0	0.0	0.0
10- 5-80	82.3	-19.9	92.3	40.0	1.85	1.30	0.00	1.30	4.3	-15.6	15.6	0.0	0.0
~~10- 9-80~~	~~110.3~~	~~28.0~~	~~96.3~~	~~40.6~~	~~.90~~	~~.63~~	~~.64~~	~~-.01~~	~~0.0~~	~~28.0~~	~~12.5~~	~~40.5~~	~~8.9~~
10-11-80	108.4	-1.9	109.4	42.6	.45	.32	0.00	.32	1.1	-.8	.8	0.0	0.0
10-15-80	92.9	-15.5	100.7	41.3	.90	.63	0.00	.63	2.2	-13.3	13.3	0.0	0.0
10-22-80	81.2	-11.7	87.1	39.1	1.57	1.10	.06	1.04	3.4	-8.3	8.3	0.0	0.0
10-30-80	75.9	-5.3	78.6	37.6	1.79	1.25	0.00	1.25	3.9	-1.4	1.4	0.0	0.0
6-11-81	0.0												
6-17-81	0.0	0.0	0.0	0.0	2.74	1.92	.28	1.64	0.0	0.0	0.0	0.0	0.0

1. RUNOFF EXCEEDS AMOUNT EXPECTED FOR PRECIPITATION.

82/03/24

OPERATION STUDY OF PLAYA 9

DRAINAGE AREA = 4.56 SQ.MI.

DATE	CONTENT A.F. (1)	CHANGE IN CONTENT A.F. (2)	AVERAGE CONTENT A.F. (3)	AVERAGE AREA A.F. (4)	PAN EVAP. IN. (5)	FWS EVAP. IN. (6)	TOTAL PRECIP. IN. (7)	NET EVAP. RATE IN. (8)	EVAP. A.F. (9)	UNADJUSTED RUNOFF A.F. (10)	SEEPAGE A.F. (11)	ADJUSTED RUNOFF A.F. (12)	ADJUSTED RUNOFF /SQ.MI. AF/SQ.MI (13)
6-24-81	0.0	0.0	0.0	0.0									
7- 1-81	34.5	34.5	17.3	20.5	3.20	2.24	.09	2.15	0.0	0.0	0.0	0.0	0.0
7- 8-81	31.7	-2.8	33.1	27.1	3.08	2.16	1.66	.50	.9	35.4	2.2	37.6	8.2
7-15-81	26.2	-5.5	29.0	25.8	2.37	1.66	1.07	.59	1.3	-1.5	4.3	2.8	.6
7-22-81	0.0	-26.2	13.1	15.5	2.37	1.66	.31	1.35	2.9	-2.6	2.6	0.0	0.0
7-29-81	0.0	0.0	0.0	0.0	2.37	1.66	.24	1.42	1.8	-24.4	24.4	0.0	0.0
8- 5-81	0.0	0.0	0.0	0.0	2.23	1.56	.41	1.25	0.0	0.0	0.0	0.0	0.0
8-12-81	140.6	140.6	70.3	36.0	2.17	1.52	.52	1.04	0.0	0.0	0.0	0.0	0.0
8-20-81	114.2	-26.4	127.4	45.1	2.49	1.74	3.81	-2.29	-6.9	133.7	9.1	142.8	31.3
8-25-81	110.3	-3.9	112.3	43.0	1.55	1.09	1.27	.47	1.8	-24.6	16.6	-8.0	-1.8
9- 2-81	98.7	-11.6	104.5	41.9	1.86	1.30	.05	1.04	3.7	-.2	.2	0.0	0.0
9- 9-81	106.5	7.8	102.6	41.6	0.00	0.00	.60	.70	2.4	-9.2	9.2	0.0	0.0
							2.45	-2.45	-8.5	-.7	13.3	12.6	2.8

1. RUNOFF EXCEEDS AMOUNT EXPECTED FOR PRECIPITATION.

82/04/15

PRECIPITATION FOR PLAYA 9

UNIT = INCHES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	.48	.81	.28	1.44	2.28	1.41	1.03	2.66	.72	.54	3.77	.95	16.37
1941	.22	.30	2.34	2.01	9.27	5.37	3.80	2.64	5.16	8.66	.23	.61	40.61
1942	.09	.29	.64	4.44	.35	2.78	1.97	5.25	3.13	3.91	0.00	1.59	24.44
1943	.03	.03	.01	1.50	1.52	1.78	2.86	.87	1.27	.14	.55	3.12	13.68
1944	.60	.66	.01	1.27	2.82	3.05	2.24	2.41	2.30	.99	.50	1.04	17.89
1945	.62	.26	.23	.73	.25	.55	1.85	3.89	2.80	.79	0.00	.07	12.04
1946	.92	.07	.31	.89	.70	1.10	1.26	2.77	2.81	5.33	.52	.41	17.09
1947	.38	.04	.56	1.48	4.57	1.26	1.19	2.02	.21	.17	.64	1.05	13.57
1948	.49	1.64	.47	.33	3.16	1.96	1.34	3.91	1.64	.80	.93	.15	16.82
1949	1.88	.71	.43	1.78	5.59	4.32	3.24	2.63	1.67	1.49	.06	.35	24.15
1950	.04	.07	.01	.57	1.03	2.67	8.99	2.72	4.07	1.03	.01	.09	21.30
1951	.64	.90	.32	.33	6.05	2.26	2.67	1.14	.98	1.60	.30	.52	17.71
1952	.50	.16	.35	3.07	.73	2.52	2.80	1.52	.73	0.00	1.07	.47	13.92
1953	.40	.15	.71	1.23	1.44	.12	2.53	2.21	.22	3.04	.37	.28	12.70
1954	.11	.13	.19	.94	2.46	1.59	1.10	3.74	.35	1.82	.04	.16	12.63
1955	.23	.01	.03	.91	2.90	1.45	2.59	1.04	2.59	.32	.08	.07	12.22
1956	.07	1.41	0.00	.09	2.31	2.14	1.14	1.09	.28	.84	0.00	.07	9.44
1957	.16	.86	2.11	1.44	3.34	2.17	.84	1.76	1.38	2.85	.91	.03	17.85
1958	1.53	.43	2.25	1.69	1.28	1.73	3.88	1.66	3.50	.67	.72	.24	19.58
1959	.10	.09	.31	.91	2.62	4.09	3.08	2.96	.69	2.20	.11	3.32	20.48
1960	1.41	.89	.60	.96	.80	4.76	9.33	1.71	1.95	5.37	0.00	1.32	29.10
1961	.46	.48	2.10	.19	1.02	2.80	3.34	2.33	1.31	.73	2.16	.38	17.30
1962	.73	.47	.41	.72	.62	4.09	4.73	.87	3.10	1.25	.54	.37	17.90
1963	.07	.86	.05	.28	3.23	5.56	2.61	3.52	.90	.40	.78	.21	18.47
1964	.05	1.10	.16	.02	1.11	3.13	.34	1.52	2.41	.20	1.73	.47	12.24
1965	.20	.51	.80	.60	2.10	6.67	2.34	1.84	1.23	1.34	.01	.49	18.13
1966	.48	.32	.01	.61	.83	3.75	1.55	5.75	1.74	.06	.31	.07	15.48
1967	0.00	.31	.26	.84	.54	4.78	4.32	1.54	1.12	.24	.19	.59	14.73
1968	1.49	.38	.87	.63	1.90	1.14	1.99	2.26	.85	.60	.59	.15	12.85
1969	.02	.77	.89	1.17	4.53	2.87	2.32	1.66	3.17	3.95	.57	.62	22.54
1970	.25	.16	1.16	.87	.35	2.66	1.70	1.95	1.61	.95	.08	.01	11.75
1971	.06	.77	.12	1.10	1.29	1.81	1.94	4.38	3.72	1.61	2.13	.86	19.79
1972	.24	.21	.20	0.00	2.58	2.42	2.86	2.44	3.15	2.88	2.03	.54	19.55
1973	.71	.64	2.73	2.44	1.09	1.54	4.17	.83	1.44	.97	.03	.29	16.88
1974	.46	.19	.71	.23	.45	1.54	1.17	5.68	2.37	4.63	.27	.55	18.25
1975	.25	1.08	.35	1.71	1.28	2.19	3.15	1.36	1.52	.04	.61	.14	13.68
1976	.01	.10	.58	1.09	1.10	1.89	1.79	3.34	2.92	.88	.42	0.00	14.12
1977	.23	.38	.53	1.71	3.05	1.69	.78	4.12	.80	.75	.15	.09	14.28
1978	.52	.75	.25	.51	3.05	3.05	1.40	2.38	3.19	.30	2.20	.33	17.93
1979	.71	.14	.93	1.44	2.31	4.29	2.12	2.80	.95	1.03	.32	.35	17.39
1980	.59	.65	.33	.85	3.28	1.01	.53	1.94	2.36	.67	.88	.20	13.29
1981	.24	.24	1.43	1.16	1.05	1.91	--	--	--	--	--	--	6.03
TOTALS	18.67	20.42	27.03	46.18	92.23	109.87	104.88	103.11	78.31	66.04	26.81	22.62	716.17
AVERAGES	.40	.50	.60	1.10	2.20	2.60	2.60	2.50	1.90	1.60	.70	.60	17.26

82/04/15 ESTIMATED RUNOFF FOR PLAYA 9 UNIT = AF/SQ.MI.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	.6	1.7	.2	5.2	12.5	5.0	2.7	16.8	1.4	.8	32.9	2.3	82.1
1941	.1	.3	13.2	9.8	268.1	77.0	33.4	16.6	69.8	235.5	.2	1.0	725.0
1942	0.0	.2	1.1	48.3	.3	18.3	9.5	72.8	23.0	35.3	0.0	6.3	215.1
1943	0.0	0.0	0.0	5.6	5.8	7.8	19.4	2.0	4.1	.1	.8	22.9	68.5
1944	1.0	1.2	0.0	4.1	18.8	21.9	12.1	13.9	12.7	2.5	.7	2.8	91.7
1945	1.0	.2	.2	1.4	.2	.8	8.4	34.9	18.6	1.6	0.0	0.0	67.3
1946	2.2	0.0	.3	2.1	1.3	3.1	4.0	18.2	18.7	75.6	.7	.5	126.7
1947	.4	0.0	.8	5.5	51.8	4.0	3.6	9.9	.1	.1	1.1	2.8	80.1
1948	.7	6.7	.6	.3	23.4	9.4	4.5	35.3	6.7	1.7	2.2	.1	91.6
1949	8.7	1.3	.5	7.8	84.9	45.1	24.6	16.5	6.9	5.5	0.0	.3	202.1
1950	0.0	0.0	0.0	.9	2.7	17.0	253.1	17.6	39.0	2.7	0.0	0.0	333.0
1951	1.1	2.1	.3	.3	103.1	12.3	17.0	3.3	2.5	6.4	.3	.7	149.4
1952	.7	.1	.3	22.2	1.4	15.2	18.6	5.8	1.4	0.0	2.9	.6	69.2
1953	.4	.1	1.3	3.8	5.2	0.0	15.3	11.8	.1	21.8	.4	.2	60.4
1954	0.0	.1	.1	2.3	14.5	6.3	3.1	32.4	.3	8.1	0.0	.1	67.3
1955	.2	0.0	0.0	2.2	19.9	5.3	16.0	2.8	16.0	.3	0.0	0.0	62.7
1956	0.0	5.0	0.0	0.0	12.9	11.1	3.3	3.0	.2	1.8	0.0	0.0	37.3
1957	.1	1.9	10.8	5.2	26.1	11.4	1.8	7.6	4.8	19.2	2.2	0.0	91.1
1958	5.8	.5	12.2	7.1	4.1	7.4	34.7	6.8	28.5	1.2	1.4	.2	109.9
1959	0.0	0.0	.3	2.2	16.4	39.4	22.3	20.7	1.3	11.7	0.0	25.8	140.1
1960	5.0	2.1	1.0	2.4	1.7	57.2	271.3	7.2	9.3	77.0	0.0	4.4	438.6
1961	.6	.6	10.7	.1	2.7	18.6	26.1	13.1	4.3	1.4	11.3	.4	89.9
1962	1.4	.6	.5	1.4	1.0	39.4	56.4	2.0	22.6	4.0	.8	.4	130.5
1963	0.0	1.9	0.0	.2	24.4	83.8	16.2	28.8	2.1	.4	1.6	.1	159.5
1964	0.0	3.1	.1	0.0	3.2	23.0	.3	5.8	13.9	.1	7.4	.6	57.5
1965	.1	.7	1.7	1.0	10.7	131.1	13.2	8.3	3.8	4.5	0.0	.7	175.8
1966	.6	.3	0.0	1.0	1.8	32.5	6.0	91.0	7.5	0.0	.3	0.0	141.0
1967	0.0	.3	.2	1.8	.8	57.8	45.1	5.9	3.2	.2	.1	.9	116.3
1968	5.5	.4	2.0	1.1	8.8	3.3	9.7	12.3	1.9	1.0	.9	.1	47.0
1969	0.0	1.6	2.1	3.5	50.7	19.5	13.0	6.8	23.6	36.2	.9	1.0	158.9
1970	.2	.1	3.4	2.0	.3	16.8	7.1	9.3	6.4	2.3	0.0	0.0	47.9
1971	0.0	1.6	0.0	3.1	4.2	8.1	9.2	46.7	32.0	6.4	11.0	1.9	124.2
1972	.2	.1	.1	0.0	15.9	14.1	19.4	14.3	23.3	19.6	10.0	.8	117.8
1973	1.3	1.1	17.7	14.3	3.0	5.9	41.4	1.8	5.2	2.4	0.0	.2	94.3
1974	.6	.1	1.3	.2	.6	5.9	3.5	88.3	13.5	53.5	.2	.8	168.5
1975	.2	3.0	.3	7.2	4.1	11.6	23.3	4.7	5.8	0.0	1.0	.1	61.3
1976	0.0	0.0	.9	3.0	3.1	8.7	7.9	26.1	20.1	2.0	.5	0.0	72.3
1977	.2	.4	.8	7.2	21.9	7.1	1.6	40.2	1.7	1.5	.1	0.0	82.7
1978	.7	1.5	.2	.7	21.9	21.9	4.9	13.6	23.9	.3	11.7	.3	101.6
1979	1.3	.1	2.2	5.2	12.9	44.4	10.9	18.6	2.3	2.7	.3	.3	101.2
1980	.9	1.1	.3	1.9	25.2	2.6	.8	9.2	13.4	1.2	2.0	.1	58.7
1981	.2	.2	5.1	3.4	2.8	8.9	--	--	--	--	--	--	20.6
TOTALS	42.0	42.3	92.8	197.0	895.1	940.0	1094.7	802.7	495.9	648.6	105.9	79.7	5436.7
AVERAGES	1.0	1.0	2.2	4.7	21.3	22.4	26.7	19.6	12.1	15.8	2.6	1.9	131.0

ESTIMATED RUNOFF FOR PLAYA 9

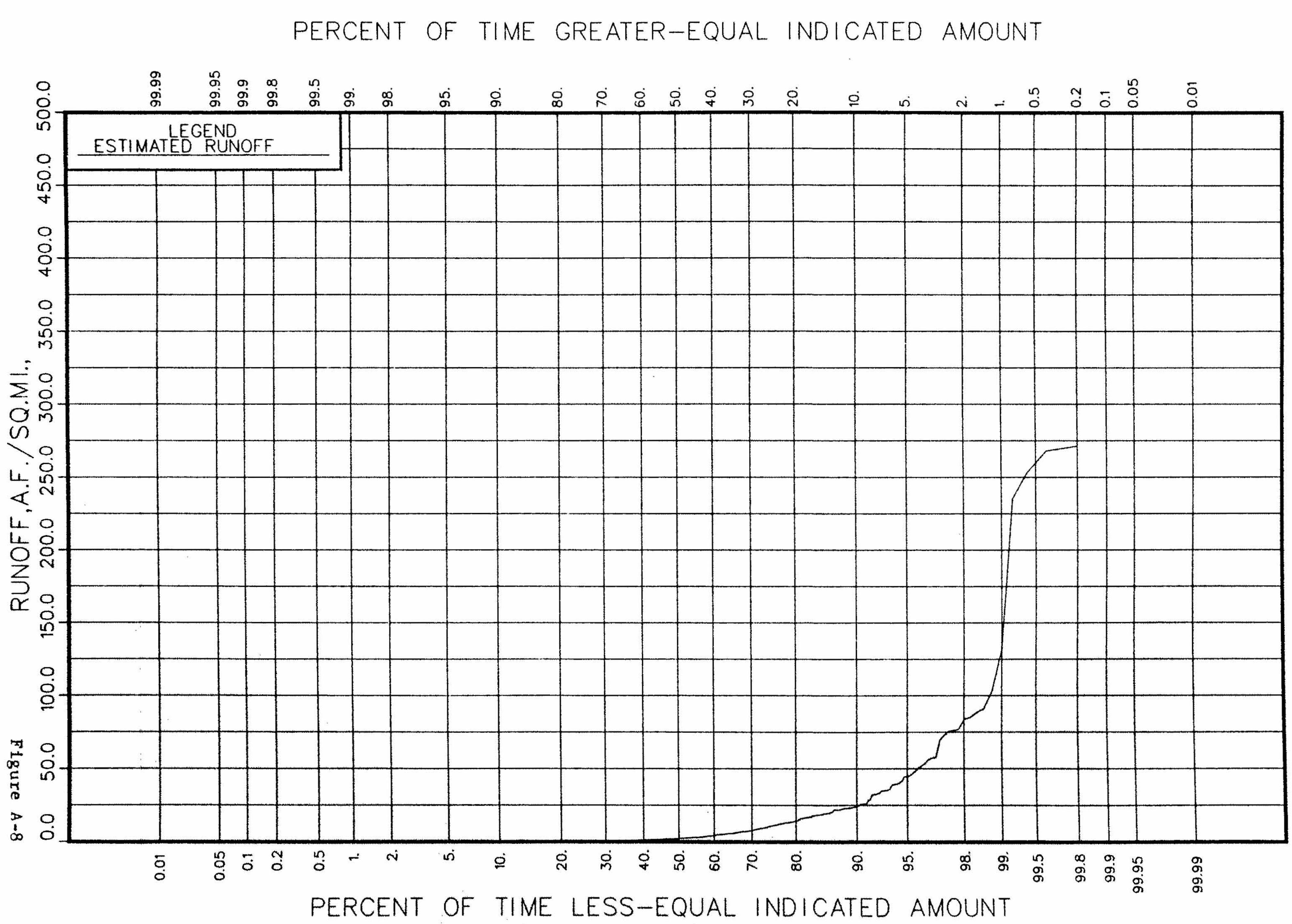


Figure A-8