PLAYA LAKE MONITORING FOR THE LLANO ESTACADO TOTAL WATER MANAGEMENT STUDY TEXAS, OKLAHOMA, NEW MEXICO, COLORADO, AND KANSAS

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Cooperators: TEXAS DEPARTMENT OF WATER RESOURCES
TEXAS NATURAL RESOURCES INFORMATION SYSTEM
U. S. BUREAU OF RECLAMATION

TEXAS DEPARTMENT OF WATER RESOURCES

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FOR THE
LLANO ESTACADO
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Prepared by
Texas Department of Water Resources and
Texas Natural Resources Information System
in cooperation with
U.S. Bureau of Reclamation

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INTRODUCTION

The High Plains of Texas covers an area of about 35,000 square miles in the northwest section of the State. All or parts of 46 counties are included within this region. Inasmuch as agriculture represents the major source of income in the area, water is a very precious commodity. Four major rivers, the Canadian, Red, Brazos, and Colorado, drain the High Plains, yet sparse annual rainfall (14 to 22 inches) forces the region to depend almost completely on ground water pumped from the Ogallala Formation for its municipal, industrial, and irrigation water supply.

Annual records show that the ground-water supply in the Ogallala aquifer is being depleted. The aquifer is thought to have contained as much as 600 million acre-feet of water before large-scale irrigation began in the 1930's. Subsequent years have produced withdrawal rates that greatly exceed the natural recharge to the aquifer. In 1974 an estimated 8 million acre-feet of ground water was pumped in the area. Most of this water was from the Ogallala. The declining supply of ground water in the High Plains region is one of the most severe water-supply problems in Texas.

This critical problem has been the prime factor in stimulating efforts to seek alternative water supplies for the High Plains. While importation seems to be the most direct means of solving this water problem, every effort is being made to encourage conservation of existing water supplies and reevaluation of potential water supplies in the High Plains.

The many playa lakes that dot this region of Texas have long been discussed as one such potential source of water. An overview of the High Plains after a recent rain impresses on the observer that a large volume of water lies virtually untapped below him. In reality, neither the quantity of water available or its frequency of occurrence has yet been substantiated. This effort initiates study in that direction.

PURPOSE

The Texas Department of Water Resources and its predecessor agencies have long been concerned about the water resources of the Texas High Plains. Various types of studies directed toward identifying a water-supply alternative to the depleting Ogallala aquifer have been conducted.

These studies recognized that the large number of playa lakes in the High Plains might constitute a resource to meet some of the water needs of the area. Utilization of water from the playas for aquifer recharge or as a surface supply has been considered. Unfortunately, the data available to adequately evaluate the potential of the playas for such purposes is insufficient. Several inventories of the playa lakes have been contracted for by this agency. Texas Tech University completed one such study in 1965, and A. C. Bowden, Consulting Engineer, made a 1967 inventory of playa lakes in

23 Texas counties. Although these studies provided valuable data, they fell far short of providing the means to adequately assess the potential of the playas as a water supply.

In June 1973 the Texas Natural Resources Information System (TNRIS) and predecessor agencies of Texas Department of Water Resources (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 procedure 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 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), in the Spring of 1975, to initiate work on a project to determine the feasibility of using digital data from LANDSAT imagery to determine the surface areas of playa lakes. This work continued until October 1977 at which time the U. S. Bureau of Reclamation contacted the TDWR to outline the Llano Estacado Total Water Management Study. The continued interest of the U. S. Bureau of Reclamation, the Texas Department of Water Resources, and the Texas Natural Resources Information System resulted in a cooperative project to develop a methodology for inventorying and determining the availability of water in the playa lakes. The following report presents the results of this project.

FORMULATION OF THE STUDY

The study was formulated based on two major work areas. Task "A" consists of development of a computer-aided methodology to analyze LANDSAT data as a means to map playas which contain water. Task "A" was divided into the four steps.

Step 1 - Develop a procedure to analyze LANDSAT data using the DAM package which would map each playa, identify each playa, and provide a means to store the data. The procedure would have the ability to update the data files of previously stored data, and provide tabulations of each playa by county and summary tabulations of all playas in a particular county.

Step 2 - Develop all existing data on playas in the study area.

Step 3 - Compare results of the method developed using LANDSAT data with aerial photo interpretation of the same area and time.

Step 4 - Develop method for computing playa volume from surface area, and develop a procedure to estimate the quantity and availability of playa water in the High Plains.

Task "B" consists of evaluating the methods developed. This task was outlined as a two-step process which:

Step 1 - Prepares cost of LANDSAT mapping techniques.

Step 2 - Evaluates results of Task "A" and makes recommendations regarding the feasibility of continuing the study.

DEVELOPMENT OF METHODOLOGY

This study develops a methodology for using LANDSAT data to determine the amount of playa lake water available for beneficial use. The study area selected for this work was Lubbock County, Texas. This limited area was selected to provide a manageable level of data that would require evaluation. Also, TDWR and TNRIS conducted other work in this area which could be used to supplement the effort. In the original agreement, two LANDSAT scenes covering the area were required to develop the methodology; however, by using the Lubbock study area two additional scenes were utilized to improve the study.

Method to Develop Computer System

Texas Natural Resources Information System has developed a computer system which estimates the area and geographic location of water bodies detected by LANDSAT using the DAM package.

LANDSAT consists of a series of land satellites that circle the earth in near-polar, sun-synchronized orbits. The National Aeronautics and Space Administration (NASA) launched LANDSAT-1 in July 1972, LANDSAT-2 in February 1975, and LANDSAT-3 in March 1978. The satellites orbit the earth at an altitude of 900 kilometers (560 miles), thus providing an ideal vantage point for surveying earth resources. On board each satellite is a scanner which records images of the earth in four spectral bands and transmits them in digital form to ground receiving stations. One scene covers an area 185 by 185 kilometers (116 by 116 miles). With LANDSAT-1 out of operation, each of the remaining satellites covers the same area every 18 days with a nine day interval between satellites. The U. S. Army Corps of Engineers, working with NASA/JSC scientists, formulated the requirements for an acceptable LANDSAT based water detection procedure. They determined that an operation procedure should utilize a general purpose digital computer with standard peripheral equipment and generate surface water maps meeting the following criteria:

1) Correct identification of surface water bodies 4 hectares (10 acres) or larger should be greater than 90 percent.

2) "False alarms" should not exceed 10 percent.

3) Results should not be affected significantly by water quality and turbidity.

4) The absolute positional error of computer maps should be less than ± 300 meters (1,000 feet) at least 90 percent of the time.

5) Scales, formats, and symbols of computer maps should be selectable to match user requirements.

6) The procedure should be usable by personnel with little background in computer processing or remote sensing.

7) Procedure costs should be competitive with those of techniques that utilize conventional interpretation from existing aerial photography.

Originally, NASA scientists expected to modify existing research-oriented computer programs to produce an operational procedure. However, the first phase evaluation demonstrated that none of the existing programs came even close to meeting the defined criteria in an operational environment.

In the phases that followed, a totally new procedure was developed and successfully transferred to the users. This procedure, called the Detection and Mapping (DAM) package, is a documented, integrated system of manual operations, special graphic devices, and computer programs. Evaluation by users indicated that it met or exceeded all original criteria.

Recognizing the deficiencies and limitations of the DAM package, work in progress at the Department indicated that water collected in Playas could be detected. Therefore, the decision was made to use DAM as a basis for inventorying the playas in this study.

Utilizing output from DAM package analysis of LANDSAT data, TNRIS developed a computer system which estimates and reports the area and geographic location of water bodies detected. LANDSAT data are obtained in the form of computer magnetic tapes from the Earth Resources Observation Systems Data Center in Souix Falls, South Dakota. LANDSAT tapes are analyzed by twelve major computer programs developed by TNRIS for the study. The programs, listed in the order in which they are run, are as follows:

DAM: A large system of programs developed by NASA/JSC that will detect water bodies from LANDSAT data and produce scaled, registered printer output maps. The map program in DAM has been modified to save the registered map output on a tape file for further processing. DAM is the basis for detecting water bodies in this study and is explained in detail in NASA publications. This study will not entail a description of DAM.

PLTH2O: This program generates pen plots using registered output from DAM.

EXTRACT/DAM: This program converts DAM's registered maps output from a grid system to a point-polygon system by extracting the boundary of each water body. Output from this program can be processed by the Geographic Information System (GIS) developed by TNRIS.

EXPAND/GIS: This program expands each water body at its boundary using an emperically determined factor to adjust for boundary pixel problems. (DAM tends to underestimate the area of water bodies slightly since boundary pixels containing part water and part land are classified as non-water). Present procedure utilizes an expansion factor of one-half pixel along the boundary of each water body. This factor can be adjusted as additional results may justify.

FIT/GIS: This program utilizes the expanded polygon file output by EXPAND and a control point network (the corners of the quad) to produce a file registered to Universal Transverse Mercator (UTM) coordinates.

PLAYAID: Using the registered file from FIT, this program calculates the Lat-Lon identifiers (centroids) of each water body (playa). It also calculates the area of each playa and checks the identifier of each playa against a user exclusion file to determine if the water body is a playa. It also allows the user to establish tolerance limits between identifiers.

ADCNTY: This program checks the centroid of each playa lake against a file of digitized county boundaries. Using a point-polygon test, it determines the county in which the playa lies and adds the county code to the record.

LOADUP: This program utilizes the information from PLAYAID either to load data into the master file or to update the master file.

PLRPT: Reports from the master file are generated by this program. Several selection options are available, and statistical summaries are given in each report.

CHKMST: This program checks the user exclusion file to make sure no excluded identifier appears in the master file.

ADDVOL: This program calculates and adds the volume to each record on the master file.

LOADX: This program loads and updates the user exclusion file.

The products of these programs are:

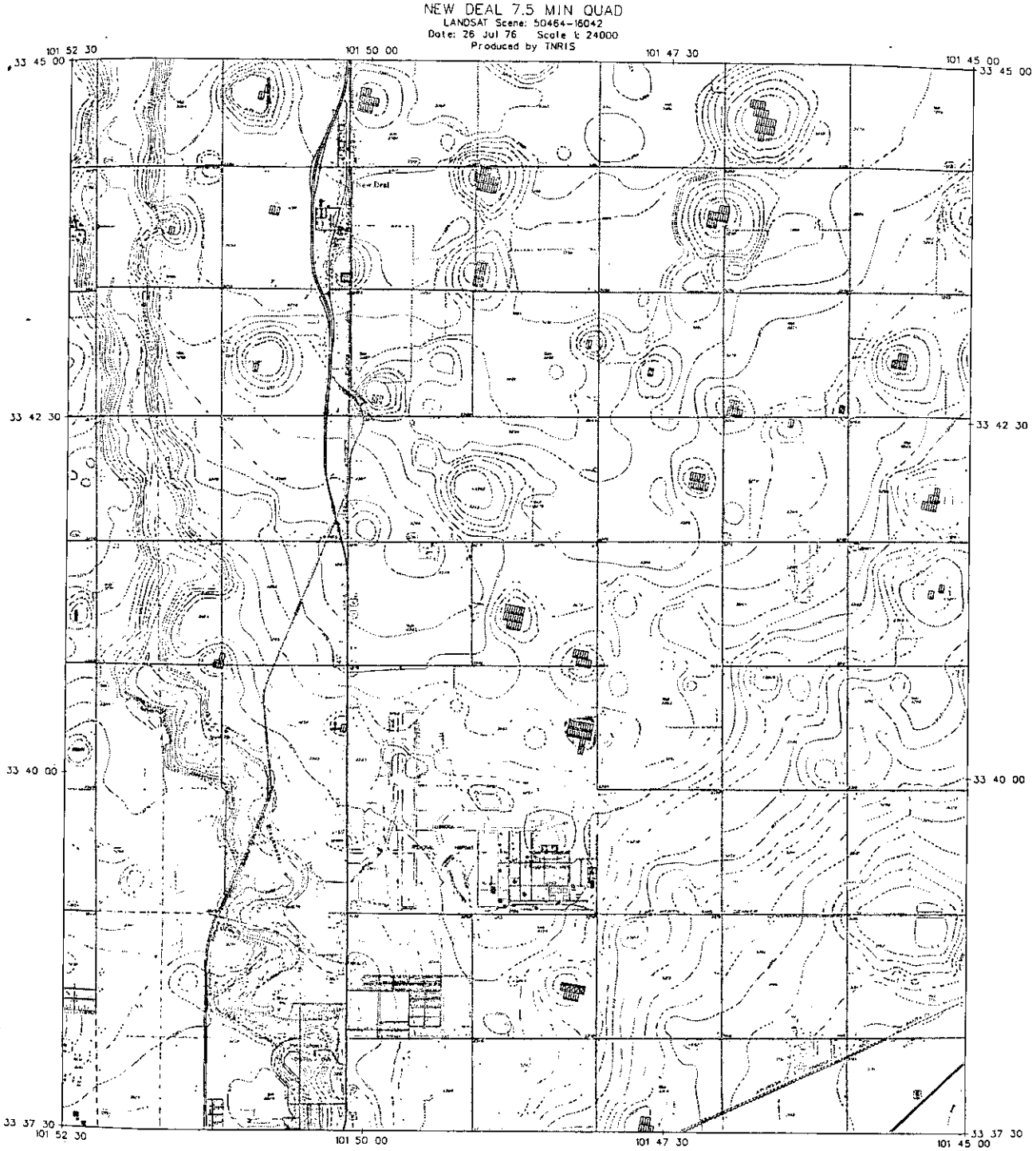
a. Computer-generated maps showing playa lake locations. Exhibit 1 is a pen plot map of the New Deal 7½-minute quadrangle showing water bodies as detected from the July 26, 1976 LANDSAT scene and a topographic map of the same area.

b. The identification of each playa lake by the longitude and latitude of its centroid.

c. A tabulation of data by county for each playa lake. Exhibit 2 is a printout showing lake identifier, date of LANDSAT scene, lake location, lake area, and estimated volume of water in the playa. Also, a tabulation shows the number of playas containing water, total surface area of playas which contain water, maximum playa lake size, minimum playa lake size, and average playa lake size.

d. A master file of playa lake data. The program LOADUP, developed by TNRIS, updates and stores all playa lake data with the same identifier together on the file, sorted by date. With each update, new identifiers are listed so they can be verified by the user to insure that new water bodies detected are playas. Previously identified non-playa water bodies are automatically eliminated. The expansion

EXHIBIT 1



Computer-Generated Pen Plot is Shown Superimposed on USGS Topographic Map

EXHIBIT 2

T E X A S N A T U R A L R E S O U R C E S I N F O R M A T I O N S Y S T E M

PLAYA LAKE REPORT

STATE OF TEXAS

COUNTY: LUBBOCK

PLAYA ID	LATITUDE	LONGITUDE	DATE	AREA (ACRES)	VOLUME (ACRE-FT)
3352801880	33 31 40	101 52 47	74/02/25	4.42	2.58
3353801881	33 32 16	101 52 51	74/02/25	4.42	2.58
3355001755	33 33 00	101 45 17	74/02/25	4.44	2.04
3355301758	33 33 10	101 45 28	74/02/25	4.43	2.04
3355701769	33 33 25	101 46 08	74/02/25	24.57	65.31
3356001781	33 33 35	101 46 51	74/02/25	6.88	4.96
3356001783	33 33 35	101 46 58	74/02/25	4.43	2.04
3356201770	33 33 43	101 46 11	74/02/25	16.13	27.86
3356301774	33 33 46	101 46 26	74/02/25	11.77	14.72
3357001902	33 34 12	101 54 07	74/02/25	22.91	52.58
3358002031	33 34 47	102 01 51	74/02/25	20.01	31.45
3358202031	33 34 55	102 01 51	74/02/25	9.33	6.36
3358802027	33 35 16	102 01 37	74/02/25	4.44	1.34
3359601899	33 35 45	101 53 56	74/02/25	4.43	2.59
3359801900	33 35 52	101 53 59	74/02/25	4.43	2.59

COUNTY SUMMARY

VIMUM	4.42	1.34
KIMUM	24.57	65.31
MBER = 00015		
TAL	147.04	221.04
AN	9.80	14.74
D DEV	7.20	19.77

of the master file which results from the analysis of additional LANDSAT scenes will progressively reduce the number of new identifiers which must be verified.

Method to Develop a Data Base

The concept of this study involved two goals. One was an effort to determine the amount of water available from playas, and the other was verification of DAM's ability to use LANDSAT data for classifying playa water bodies. Satisfying these objectives meant developing data that would acurately reflect the topographical as well as climatic characteristics of Lubbock County, and provide a means of checking LANDSAT's capabilities to recognize playa water bodies.

Climatic tendencies of the region were developed through study of historical records of county precipitation events and evaporation rates. The topographic characteristics of Lubbock County were developed through examination of contour maps. A series of aerial photographs picturing a portion of Lubbock County on a date within a few days of a LANDSAT scene was obtained and inspected to lend credibility to DAM and LANDSAT techniques.

ANALYSIS OF DATA

Analysis of the data began with a review of previous works done on the subject of playa lakes. Information regarded as useful for background material to this study was retained. Using the 17 topographic maps that make up Lubbock County, curves were drawn to represent the relation between the surface area of depressions in the region and the approximate amount of water they are likely to contain. Inspection of precipitation and evaporation records resulted in graphical displays of their effects on water storage in the area. Finally, a comparison was made between aerial photographs and LANDSAT results in an attempt to verify the latter's detection ability.

Review of Reports, Studies, and Data on Playa Lakes

Numerous studies have sought to establish the number of playa lakes in the High Plains and evaluate their potential as a water source. Examinations at all levels, Federal, State, and local, have been directed toward these goals. Most studies pursued the evaluation of the hydraulic characteristics of several selected playas. Other efforts simply inventoried depressions. Neither approach satisfactorily confronts the problem of varying physical characteristics among the many playas or the fact that some depressions are unable to capture or hold water. In the past the magnitude of these problems was beyond methods available. Early estimates placed the number of playas at 37,000, while current approximations are nearer 19,250. Limited land surveys and subsequent projections of data across the entire High Plains provided these early guesses.

Similarly, attempts at defining the hydraulic characteristics of High Plains playas depended on limited data. Survey techniques applied to scattered, hand-picked depressions, and the resulting area-volume relationships can in

no way do justice to such a vast area and so many, varied playa formations. Texas Tech University, the U. S. Geological Survey, the High Plains Underground Water Conservation District No. 1, and the Texas Department of Water Resources did, however, conduct significant studies on this subject. Their efforts provided an information base from which to begin work on this report and should be recognized.

Development of Area-Volume Relationship for Lubbock County

Using the 17 topographic maps--12 7½-minute quadrangles and 5 15-minute quadrangles--that provide coverage of Lubbock County, area-volume relationships were developed for depressions in the study area. The area-volume characteristics of a representative number of depressions on each quadrangle were determined by planimetering the area enclosed within each contour that defined the depression. Analyzing these data with curve fitting techniques, a power curve equation of the form

$$x = \sqrt[b]{\frac{y}{a}}$$

came reasonably close to approximating the reservoir area-capacity curve. In this equation "y" equals the area and "x" equals the volume. By using values from area-capacity tables developed for the selected depressions, a coefficient "a" and an exponent "b" were developed to provide a composite equation for each quadrangle. Two methods were considered in developing the area-capacity curve that would best represent the slope characteristics of the geographic area. A curve was developed for each of the quadrangle maps that cover Lubbock County employing the coefficients derived from data secured through examination of playas singular to that quadrangle. Using this technique, coefficients of determination ranged from 0.7759 to 0.9722. A list of the coefficients is given on Exhibit 3.

A curve was also developed for the entire county based on the composite of all quadrangles. Results from use of both methods varied under comparison to such a degree that the curve for each quadrangle was considered more accurate and therefore, was used in the study. Exhibit 3 is a summary of the resulting equations.

Precipitation

Four national weather stations record precipitation in the Lubbock County area. They are located at Abernathy, Lorenzo, Lubbock Airport, and Slaton. Initially, the estimations of rainfall depth across the county used in this report resulted from the combination of all station data by means of a Thiessen Polygon Network. These estimations, however, varied only slightly from readings taken at the centrally located Lubbock Airport Station. As a result, and for the sake of convenience, this report treats Lubbock Airport's precipitation record as representative of rainfall depth across the entire county.

The complete historical monthly record for the Lubbock Airport Station, 1911-1977, provides the basis for precipitation related topics herein. The

EXHIBIT 3

AREA-VOLUME RELATIONSHIPS
FOR
LUBBOCK COUNTY

Using the expression: $X = \sqrt[B]{\frac{Y}{A}}$

Y = Area in Acres

X = Volume in Acre-Feet

R^2 = Coefficient of Determination

A = Regression Coefficient

B = Regression Coefficient

Quadrangle	A	B	R^2
Slaton NE	1.040555045	0.732844931	0.820461497
Slaton	1.828916448	.637801765	.869094447
New Home	3.526729922	.504865256	.959563682
Meadow	3.144732941	.488019034	.821511665
Acuff	1.405179190	.672749296	.972236928
Buffalo Springs Lake	.940728450	.741129643	.775891516
Lubbock East	3.118389800	.493922813	.846566286
Lubbock West	2.638144037	.545504899	.894949700
Wolfforth	3.858693054	.477292138	.916854858
Shallowater	3.452328024	.487882036	.814279464
New Deal	2.463006438	.566460162	.875647276
Idalou	1.505232592	.651913930	.919755636
Lorenzo	1.166438365	.697145893	.953680265
Petersburg	1.380058923	.649342931	.942262755
Heckville	2.130880253	.594049324	.839902654
Abernathy	.882730870	.704908559	.926487291
Anton	2.848924381	.521536589	.834510000
Composite	2.088550546	.583342739	.876710854

record shows the county as receiving an average yearly rainfall of 18.6 inches. Monthly averages range from a minimum of 0.49 inch for January, to a maximum of 2.67 inches for May. The total for September, 1936, represents the largest monthly reading on record, 13.9 inches. A frequency analysis of the monthly precipitation record at Lubbock was made and the results are as follows:

Precipitation equaled or exceeded (inches)	Percent of time precipitation was equaled or exceeded
1	48.82
2	27.84
3	15.61
4	9.00
5	5.26
6	3.02
7	1.90
8	.65
9	.39
10	.26
11	.26
12	.26
13	.13
14	0

Evaporation

A Texas Department of Water Resources' station near Lubbock registers daily reading from a 4-foot evaporation pan. The record of this station provides a basis for this report's investigation of the effects of evaporation on the Playa Lakes in Lubbock County. In an effort to more realistically estimate evaporation on the surface of a Playa Lake, the data secured from the Lubbock station was converted to gross lake surface evaporation. The coefficients used for this procedure were generated in Texas Water Development Board Report 64, MONTHLY RESERVOIR EVAPORATION RATES FOR TEXAS, 1940 THROUGH 1965. The coefficients used are as follows:

Month	Weather Bureau Class A pan coefficient
January	0.77
February	.67
March	.64
April	.64
May	.68
June	.73
July	.79
August	.84
September	.88
October	.91
November	.92
December	.89

Comparing the records of precipitation and evaporation from 1946 through 1977, monthly precipitation exceeded evaporation on 10 months during the period. This represents only 3 percent of the time that precipitation exceeded evaporation. Generally, the region's precipitation is inadequate to offset the severe rate of evaporation. Therefore, the evaporation is so extensive that precipitation is lost in a short period of time.

Application of Area-Volume Relationship

The designation of a volume for each playa recorded by DAM from LANDSAT data is accomplished through use of formulas developed from the area-volume relationship curves. The computer program ADDVOL inspects the identification number of the detected water body, determines the quadrangle in which the body is located, and applies the proper equation to the body's area. In this manner, the playa capacities are calculated using coefficients derived from data taken in the actual vicinity of the depression. Exhibit 2 is a tabulation of the results of the LANDSAT scene for February 25, 1974. At this point it should be emphasized that the values presented in this report are presented to agree with values calculated using the methods developed for the study. The reader should realize these data are the actual calculated results based on these techniques.

Results of LANDSAT Data

Two major objectives of this study are the determination of LANDSAT accuracy in mapping playas, and a recommendation of a method for determining water availability in the playas. The desirable approach to determining availability is the establishment of a long term data base. LANDSAT's unavailability before July 1972 prohibits this. Availability studies, therefore, must begin at that date and be added to systematically with future scenes.

For the purpose of a basic availability study, TNRIS secured three scenes that cover Lubbock County. These scenes correspond to the dates February 25, 1974, September 11, 1974, and July 26, 1976. They were selected based on the need to evaluate a "wet" scene and a "dry" scene. An investigation of precipitation records reveals that the "dry" scene, February 25, 1974, did represent a dry period and was helpful in compiling historical data on playa resources. On the other hand, the September 11, 1974 scene, selected to represent a "wet" scene, did not represent a true wet period for the area. The 12 months preceding the scene date (September 11, 1974) were relatively dry (13.79 inches) compared to average annual precipitation (18.6 inches). Although above normal rainfall occurred in August, the dry condition of the area and the extremely high evaporation rates of the summer and fall prohibited the playa content from being at a maximum when the scene was taken.

The July 26, 1976 scene showed to be the wettest scene of those analyzed. It was taken within 30 days of 6.54 inches of rainfall and detected 10,251 acre-feet of water contained in the playas.

An August 16, 1972 scene was obtained primarily for the purpose of verifying the mapping accuracy of LANDSAT data. It showed that 2,886 acre-feet of water was stored in the playas at that time. Exhibit 4 shows the summary of results of the analysis of LANDSAT data.

EXHIBIT 4

SUMMARY OF RESULTS OF LANDSAT SCENES

Date Landsat Scene	Number of Playas		Area (Acres)	Volume (Acre-Feet)
72/08/16	146	Minimum	4.44	1.35
		Maximum	37.29	196.79
		Total	1537.48	2886.00
		Mean	10.53	19.77
		STD DEV	7.25	29.37
74/02/25	15	Minimum	4.42	1.34
		Maximum	24.57	65.31
		Total	147.04	221.04
		Mean	9.80	14.74
		STD DEV	7.20	19.77
74/09/11	186	Minimum	4.42	1.34
		Maximum	52.28	326.98
		Total	2486.08	7124.83
		Mean	13.37	38.31
		STD DEV	10.09	53.05
76/07/26	296	Minimum	4.42	1.35
		Maximum	66.05	455.58
		Total	3879.08	10251.21
		Mean	13.10	34.63
		STD DEV	10.45	56.83

Comparison of LANDSAT Data to Aerial Photography

The examination of LANDSAT accuracy began with an attempt to obtain aerial imagery of Lubbock County taken at the same time as a LANDSAT scene. Verification of LANDSAT data would then involve comparison with the aerial photographs. TDWR reviewed LANDSAT-scene availability, precipitation records, and concurrent aerial photography. The optimum period to satisfy these conditions was August and September 1972. Aerial photographs were acquired and enlarged to a scale near 1:24,000. These photographs were taken September 10, 1972. The smaller colored infrared photographs were found to be easier to use, however.

The photographs cover approximately 149,570 acres through the center of Lubbock County, or about 26 percent of the total area. A LANDSAT scene for August 16, 1972 was compared with the photographs. Exhibit 5 is a comparison of the photographs with LANDSAT data. This comparison shows that on August 16, 1972, 938 acre-feet of water was stored in playas in the area of Lubbock County covered by the photographs. The estimated volume of water shown in the photographs was 3,532 acre-feet. This represents a 2,594 acre-feet difference in colume between August 16 and September 10. An evaluation of the precipitation record shows that 6.09 inches of rainfall fell during the period August 16 to September 10.

Since this comparison was not satisfactory, an evaluation of daily precipitation prior to each LANDSAT scene was made. It was determined that in the 30-day period prior to each scene the precipitation was as follows:

Date LANDSAT scene	Precipitation 30 days prior to scene
8/16/72	2.84 inches
*9/10/72 (Photographs)	6.16 inches
2/25/74	.01 inch
9/11/74	4.44 inches
7/26/76	6.54 inches

The precipitation of 6.16 inches before the September 10, 1972 photographs was 0.38 inch less than the 6.54 inches for the July 26, 1976 scene. A comparison was made of these two periods. Exhibit 6 shows this comparison. LANDSAT data showed 3,928 acre-feet of water in storage for the area covered by the photographs, while the photographs revealed 3,532 acre-feet of water in storage. This represents a difference of only 396 acre-feet of water in storage which can be accounted for by the difference of 0.38 inch of precipitation between the two periods. While there appears to be a slight difference in rainfall patterns for the two periods, the correlation of comparative rainfall over Lubbock County and the amount of water in storage in the playas appears to be very good. More scenes would have to be analyzed to better evaluate this conclusion, but the results are encouraging.

Development of Methodology for Predicting Water Availability from LANDSAT Data

Evaluation of the data shows that evaporation plays the major role in determining the volume of water stored in the playas. As previously noted, monthly precipitation exceeds monthly evaporation only about 3 percent of the time. Due to this high evaporation rate, analysis of the playas can best be done on a daily basis.

By comparing the volume of water in storage for the area covered by aerial photographs taken September 10, 1972 with the results of the August 16, 1972 LANDSAT scene for the same area, a change in storage of 2,594 acre-feet was noted. This change was caused by 6.09 inches of precipitation which fell during this time. To evaluate the significance of this variation, a water balance technique was developed in which the daily effects of evaporation were subtracted from the volume of playa water in storage and the runoff of daily precipitation was added. Exhibit 7 is a tabulation of the results of this computation. Using this technique, a volume of 3,472 acre-feet was computed for September 10, 1972 compared to 3,532 acre-feet estimated from aerial photographs. This represents less than a 2 percent variation between the volumes.

In order to draw a relationship between rainfall and water stored in the playas, an estimate of playa lake volume 30 days before each of the scenes was made. This was accomplished by means of a reverse water balance technique similar to the technique described for Exhibit 7. Starting with the volume of water in storage as determined using LANDSAT data, the effects of evaporation were added to the volume, and the runoff portion of daily precipitation was subtracted.

The runoff portion of daily precipitation was computed based on effective precipitation relationships developed in Net Reservoir Evaporation Rates by the Bureau of Reclamation for the United States Study Commission - Texas. This relationship was also used by Texas Water Development Board and Texas Department of Water Resources in computing monthly reservoir evaporation rates for Texas.

Generally, the relationship shows low percentages of runoff for low intensity precipitation and higher percentages of runoff for higher intensity precipitation. Exhibit 8 is a tabulation of percent of runoff for various levels of precipitation.

Summary of Results

Generally the study shows that LANDSAT data can be used to inventory playa lakes located in the High Plains of Texas. While the correlations made for this study show encouraging results, additional work is needed to evaluate a greater number of scenes as well as scenes from other areas of the High Plains.

The results of the study do establish several points. Earlier studies have been focused on the number of depressions in the High Plains and not specifically on the number of depressions that contain water. While it is estimated that 19,250 depressions exist in the High Plains of Texas, there is wide variation in the number that contain water. Texas Water Development Board Report 10 estimated that of the 19,250 depressions in the High Plains, 1,500

are located in Lubbock County. Our current study showed that on July 26, 1976, only 296 of the depressions in Lubbock County contained water. This was an above normal rainfall period for Lubbock County. The 296 playas were estimated to contain a volume of 10,251 acre-feet of water. They ranged in size from a minimum of 1.35 acre-feet to a maximum of 455.58 acre-feet with an average of 34.63 acre-feet per playa.

Using relationships developed by this study concerning the volume of water that could be collected in the playas from various rainfall amounts and the precipitation frequency curve, a playa lake storage frequency curve was developed for Lubbock County (Exhibit 9). The result showed that 5 percent of the time the playas in Lubbock County would contain 4,500 acre-feet, 10 percent of the time 3,280 acre-feet, 15 percent of the time 2,620 acre-feet, 20 percent of the time 2,190 acre-feet, and 50 percent of the time 690 acre-feet. While the economics of utilizing this water resource is beyond the scope of this study, it does appear that the cost for collection and distribution of these waters would be prohibitive.

COST EVALUATION

The cost of any data collection program must be weighed against the value and need for the data. This study was devised to establish the cost of such a data collection program for utilizing LANDSAT data to inventory playa lakes in the High Plains of Texas. Since the project was the first effort to establish methods and develop techniques for handling the data, the cost developed as a result of this study should be conservative.

Cost to Collect Data Presented in Report

Through November 30, the study has cost $53,350. This includes $38,240 in direct cost and $15,110 in overhead. Most of this cost was incurred in the development of the 12 computer programs required to process each scene as well as the development of methodology to analyze the data. The operational cost to conduct future studies of an expanded area should be greatly reduced. This study evaluated only Lubbock County which covers an area of 903 square miles. The study required the analysis of only one LANDSAT scene and 17 topographic quadrangle maps to cover the county. Since each scene covers an area 116 miles x 116 miles and the 17 topographic maps cover an area larger than Lubbock County, more area could be analyzed than used in this study for the same cost.

There are several steps required to inventory the playas in any area.

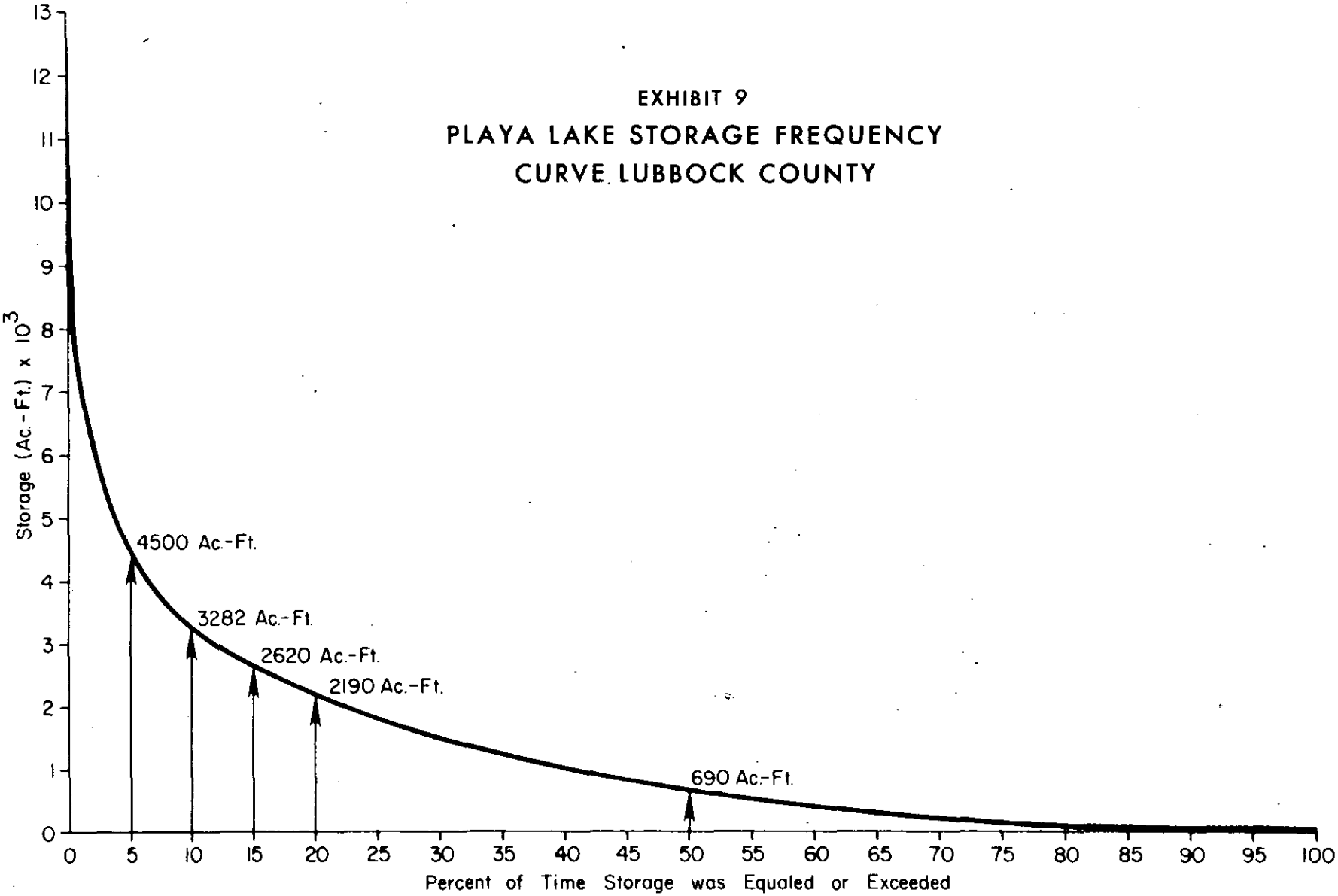
1. Develop area-volume relationships for area to be studied. This requires about one man-day to evaluate one 7½-minute quadrangle or $90 per quadrangle ($19,400 per LANDSAT scene). This step would only be required once.

2. Process DAM Package. For one scene would cost $1,275. This step would be required for each scene processed.

3. Process DAM output using programs developed by the study. This step would cost $2,020 and would be required for each scene processed.

EXHIBIT 9

PLAYA LAKE STORAGE FREQUENCY CURVE, LUBBOCK COUNTY



4. Evaluate DAM output to exclude non-playa water bodies. This would require about ½ man-day per 7½-minute quadrangle or $45 per quadrangle ($9,680 per LANDSAT scene). The cost of this step would decrease as more scenes are processed of the same area.

In order to analyze the playas covered by one scene, a schedule of the cost using the procedure developed by this study for 4 scenes per year would be as follows.

	1st Year	2nd Year and successive years
Develop area-volume relationships	$19,400	-
Process DAM 4 scenes per year	5,100	5,100
Process Playa Computer Programs 4 scenes per year	8,080	8,080
Evaluate Playa Maps (4 sets of maps)	18,150	1,000
Total Cost	$50,730	$14,180

Formulation of Method to Continue Use of LANDSAT

There are several methods that can be used which utilize LANDSAT data and techniques resulting from this study. These methods are primarily a function of the number of scenes to be analyzed and the extent of the area to be covered. Naturally, better results can be expected when more scenes are analyzed. Costs, however, also rise as more scenes are inspected.

The most difficult problem to overcome in the formulation of any further study of the playas using LANDSAT is that the playas do not contain water most of the time. Also, the large area of the High Plains requires nine LANDSAT scenes each time the playas are inventoried. The cost to process the nine scenes to cover the area one time would be $29,700. Since the High Plains area does not normally receive evenly distributed rainfall, a number of scenes would have to be processed before adequate statistics could be developed that would establish the availability of water stored in the playas.

To analyze and develop area-volume relationships for the High Plains of Texas using the detail developed for this study would require the evaluation of about 640 topographic maps. This would cost $57,600. A program to completely map and inventory the playas in the High Plains in the detail used in this study would be significant. A summary of the cost is as follows:

	1st Year Cost	2nd Year and Successive Years
Develop area-volume relationships using 640 maps of Texas High Plains (this would be required one time)	$57,600	- 0 -
Process DAM 9 scenes to cover High Plains Assume 4 times per year (this would involve 36 scenes)	45,900	$45,900
Process Playa Computer Programs 9 scenes to cover High Plains Assume 4 times per year (this would involve 36 scenes)	72,720	72,720
Evaluate Playa Maps 9 scenes to cover High Plains Assume 4 times per year (this cost would decrease as new scenes are processed)	54,000	1,800
	$230,220	$120,420

The bulk of the cost would be in the development of area-volume relationships and evaluation of playa maps to determine non-playa water bodies that should be excluded. As scenes of the same area are processed, the need to evaluate each map would be reduced and eventually eliminated. Also, it is quite possible that some streamlining could be accomplished with the computer playa mapping programs and the scene processing techniques which would reduce the cost to some extent.

Cost to Use LANDSAT Data Collection Program for Entire Llano Estacado

The results of this study indicate that it is probably not justified to expand this work to the entire Llano Estacado. It is doubtful that the playas in the Llano Estacado would yield sufficient water on an annual basis to be considered as a dependable water supply.

The cost of expanding the study appears to be prohibitive at this time. A full scale playa data collection project for the High Plains could cost in excess of $230,000 for the initial effort. This commitment is extensive for the expected results.

However, it does seem appropriate that some effort be made to obtain some results that would provide an indication of the number of playas that possibly might contain water. By scaling down the detail used in this study, a "ball park" estimate of the number of playas that contain water would be beneficial. By evaluating the rainfall over the High Plains, a set of scenes could be selected which would provide an indication of the number of playas that contain water.

Then, by selecting topographic maps that represent the north, middle, and south High Plains, a 10 percent sample area could be used to develop area-capacity relationships that would provide adequate results. Using this approach, area-volume relationships could be developed for about $6,000, LANDSAT scenes processed for $29,700, and maps of the playa lakes evaluated for $28,800. The cost to survey the High Plains one time would then be $64,500.

CONCLUSIONS

Generally, the study has provided some beneficial and interesting results on playa lakes not utilized before. For the most part inventories of the playas have been based on ground surveys which take a long period to conduct. With the vast number of depressions in the High Plains and the short duration of time that they may hold water, no dependable means has been available to physically observe all the playas at the same time. LANDSAT, within a period of four days, can provide images of the entire High Plains.

The study shows that the playa lakes in Lubbock County are not a dependable water supply. Fifty percent of the time only 690 acre-feet or less is available for use. The uneven distribution of playas which contain water over the county makes the playas even less of a potential water supply. For the most part, the property owners are probably utilizing the playas to the maximum extent possible at this time.

Evaporation rates in the High Plains are excessive. Rainfall exceeds evaporation only a small portion of the time. Therefore, water that is captured in a playa remains in storage only for a very short period of time before it evaporates. In order to utilize a major portion of these waters, they must either be emplaced below ground as recharge to the underground reservoir, or otherwise stored where evaporation can be minimized.

Suitability of LANDSAT to Estimate Volume

Based on the results of the study, LANDSAT appears to be the most accurate means to estimate the volume of water in storage in the playas. With more study of the area-volume relationships in each area, the accuracy should improve. The cost of any land based operation or aerial photo interpretation to inventory the volume of water in storage is prohibitive. Aerial photos of the High Plains could not be obtained that would adequately estimate water availability. Aerial photos would also have to be manually interpreted which would drastically add to the cost.

Predictability of LANDSAT to Estimate Water Availability

LANDSAT scenes on a recurring basis are the best known means to collect the large volume of data required to properly analyze the availability of water in the playa lakes. Based on the results of the study it is felt that LANDSAT is the only means to cover the vast number of playa lakes in the High Plains. However, with some additional refinements of area-volume relationships and correlations with evaporation and precipitation, reasonable estimates of the

quantity of water stored in the playas can be made. No other method appears to be more economical.

RECOMMENDATIONS

While the study only addressed Lubbock County, the same general result is expected over the High Plains. To verify this, other counties need to be evaluated to develop relationships between rainfall and the resulting runoff stored in the playas. The cost of processing recurring LANDSAT scenes over a long period of time are more than can be justified at this time. This implies that the nine scenes to cover the High Plains would be analyzed four times each year or a total of 36 scenes would be analyzed each year.

The best means of determining water availability for the entire High Plains using the methods developed in this study are through correlations with precipitation. Since LANDSAT data are only available from July 1972, precipitation records which have been collected for a long time are the best means of estimating the amount of water available in playas.

A generalized computer model should be developed that would use precipitation adjusted to reflect that part of precipitation which becomes runoff, evaporation rates that would reduce the water stored in the playas for a region, and the area-volume relationship for the region. The model would basically be a simplified water balance equation in the form:

> Volume in storage at beginning of period + Inflow (computed from precipitation records for the region) - Evaporation (computed from evaporation rates acting on the playa lake surface area) = Volume in storage at end of the period.

The model should have the flexibility to process the entire High Plains, and should have the ability to be modified as better data are available. LANDSAT data would supply storage volumes as checks to the water balance computations and also initial volumes in storage for predicting future conditions. Two scenes of the middle High Plains and two scenes of the northern High Plains should be processed to compare the area-volume relationships with those for Lubbock County.

The model could be used to generate information on long term playa storage and provide a means for revision and refinement as more research is accomplished. Data from the model would be used to project availability of water stored in the playas for the entire High Plains of Texas.

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EXHIBIT 5

COMPARISON OF AUGUST 16, 1972 LANDSAT SCENE WITH SEPTEMBER 10, 1972 AERIAL PHOTOGRAPHS

Quadrangle	Photo Playas	LANDSAT Playas	LANDSAT Area	LANDSAT Vol	Estimated Values Photo Area	Photo Vol	DIFFERENCES Area	Vol
New Home (3301-230)	36	28	288 ac	311 ac-ft	538 ac	957 ac-ft	250 ac	646 ac-ft
Lubbock W. (3301-322)	18	11	100 ac	131 ac-ft	201 ac	358 ac-ft	101 ac	227 ac-ft
Lubbock E. (3301-321)	22	9	125 ac	277 ac-ft	184 ac	247 ac-ft	59 ac	-30 ac-ft
New Deal (3301-324)	30	8	61 ac	72 ac-ft	220 ac	273 ac-ft	159 ac	201 ac-ft
Shallowater (3301-323)	11	1	7 ac	4 ac-ft	85 ac	77 ac-ft	78 ac	73 ac-ft
Abernathy (3301-330)	23	3	37 ac	143 ac-ft	377 ac	1620 ac-ft	340 ac	1477 ac-ft
Totals	140	60	618 ac	938 ac-ft	1605 ac	3532 ac-ft	987 ac	2594 ac-ft

EXHIBIT 6

COMPARISON OF JULY 26, 1976 LANDSAT SCENE WITH SEPTEMBER 10, 1972 AERIAL PHOTOGRAPHS

Quadrangle	Photo Playas	LANDSAT Playas	LANDSAT Area	LANDSAT Vol	Estimated Values Photo Area	Photo Vol	Differences Area	Vol
New Home (3301-320)	36	23	283 ac	370 ac-ft	538 ac	957 ac-ft	255 ac	587 ac-ft
Lubbock W. (3301-322)	18	11	135 ac	184 ac-ft	201 ac	358 ac-ft	66 ac	174 ac-ft
Lubbock E. (3301-321)	22	13	114 ac	153 ac-ft	184 ac	247 ac-ft	70 ac	94 ac-ft
New Deal (3301-324)	30	20	243 ac	426 ac-ft	220 ac	273 ac-ft	-23 ac	-153 ac-ft
Shallowater (3301-323)	11	10	171 ac	318 ac-ft	85 ac	77 ac-ft	-86 ac	-241 ac-ft
Abernathy (3301-330)	23	27	515 ac	2477 ac-ft	377 ac	1620 ac-ft	-138 ac	-857 ac-ft
Totals	140	104	1461 ac	3928 ac-ft	1605 ac	3532 ac-ft	144 ac	-396 ac-ft

EXHIBIT 7

DAILY SUMMARY OF WATER BALANCE, 8-16-72 to 9-10-72

Date	Precipitation (in.)	Gross Lake Evaporation (in.)	Area (ac.)	Volume in Storage (ac-ft)
8-16-72			618	938
8-17-72	0	0.24	490	926
8-18-72	0	.24	486	916
8-19-72	0	.25	481	906
8-20-72	0	.24	477	896
8-21-72	.18	.23	493	932
8-22-72	.23	.27	514	978
8-23-72	0	.18	510	970
8-24-72	0	.18	507	962
8-25-72	.18	.19	524	999
8-26-72	.94	.22	623	1223
8-27-72	2.72	.14	1485	3352
8-28-72	0	.19	1476	3328
8-29-72	0	.21	1466	3302
8-30-72	0	.21	1456	3276
8-31-72	0	.28	1443	3242
9- 1-72	.20	.20	1453	3268
9- 2-72	.12	.19	1455	3275
9- 3-72	0	.19	1447	3252
9- 4-72	.66	.19	1501	3394
9- 5-72	0	.17	1493	3373
9- 6-72	.13	.14	1498	3388
9- 7-72	.56	.19	1543	3504
9- 8-72	.17	.16	1551	3525
9- 9-72	0	.19	1541	3500
9-10-72	0	.22	1530	3472

EXHIBIT 8

PERCENT OF PRECIPITATION REFLECTED AS RUNOFF

Precipitation (inches)	Seasonal Distribution			
	December January February March	April May October November	June September	July August
0	0.02	0.02	0.02	0.02
1	.02	.02	.02	.02
2	.08	.06	.04	.03
3	.19	.14	.11	.09
4	.31	.25	.20	.17
5	.40	.35	.30	.25
6	.48	.42	.37	.33
7	.56	.49	.43	.39
8	.56	.56	.50	.45
9	.56	.56	.56	.50
10	.56	.56	.56	.56