Texas Water Development Board

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A Water Resource Assessment of the Playa Lakes of the Texas High Plains

by

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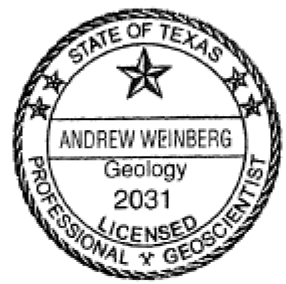

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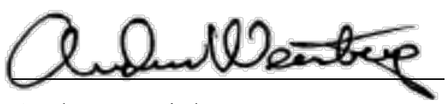

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1.0 Executive Summary

Texas Water Development Board (TWDB) staff are studying the water-resource potential of playa lakes in the Texas High Plains in partnership with the U.S. Department of Agriculture–Agricultural Research Service and Texas Tech University. Phase 1 of the research seeks to measure the volume of water available in playas and current recharge rates from playas into the underlying Ogallala Aquifer. As part of Phase 1, we reconstructed the flooding history of 73 playas for an 18 year period of record using geographic information systems (GIS) analysis of Landsat imagery. The results indicate an average annual total volume of water collected in all playas of 200,000 acre-feet. The average daily volume of water in playas declined from approximately 90,000 acre-feet in 1996 to approximately 20,000 acre-feet in 2014.

The playa water volumes estimated by this study are significantly lower than previous estimates, which ranged from two million to five million acre-feet per year. Changes in irrigation technology and agricultural practices may account for some of the difference in water volume between the current estimate and studies conducted in the 1950s and 1960s; however, changes in agricultural practices are not likely responsible for the observed decrease in playa water volume between 1996 and 2014.

Increasing evaporation rates appear to be the major factor affecting the volume of water contained in the playas over the long-term but do not provide a clear explanation of the observed decline between 1996 and 2014. TWDB data indicate that average evaporation rates have increased nearly 40 percent over the period from 1954 to present while average precipitation rates have stayed constant. Increased evaporation likely reduces runoff from playa watersheds. And because of the broad, shallow nature of playa lakes and the relatively impervious sediments in the playa bottoms, evaporation is the dominant route of water loss from playas. Together, reduced runoff volume and increased water loss result in lower water volumes in Texas playas.

The current research program has developed screening tools to estimate playa water budgets and help select playas that may be suitable for recharge modification. A simple regression model using the mapped playa size, watershed area, and geographic longitude explains seventy percent of the observed variation in the volume of water captured by individual playas. More detailed long-term water budgets for individual playas can be developed based on a simple topographic survey coupled with analysis of existing Landsat records. These tools allow us to identify the playas that consistently capture the most water and therefor represent the best candidates for recharge modification.

2.0 Introduction

Storm-water runoff collected in ephemeral wetlands, locally known as playa lakes, on the Texas High Plains has long been viewed as a potential water resource for local producers. Irrigation development on the Texas High Plains expanded rapidly during the drought of the 1950s. Newly drilled wells and turbine pumps pulled many farmers through the 1950's drought. But even in those boom years the idea of water conservation was widely circulated. The High Plains Underground Water Conservation District No. 1 was created in 1951 and charged with conserving, preserving, protecting, and preventing waste of groundwater. Its monthly newsletter, The Cross Section, featured frequent articles promoting various artificial recharge schemes to 'salvage' playa water by moving it underground, where it would not be lost to evaporation.

Early estimates of the volume of water collected in playas raised the prospect of reclaiming millions of acre-feet of water. The April 1957 issue of The Cross Section featured an article on artificial recharge that estimated total annual runoff to playas using "computations based on the soil-cover complex data from the SCS [Soil Conservation Service] Field Office and the rainfall–runoff relationship in the SCS Hydrology Guide," arriving at 0.84 inches of runoff per year over 20,000,000 acres, or 1.4 million acre-feet per year. Schwiesow (1965) cites a "recent calculation by the High Plains Underground Water Conservation District No.1 [that] places the average annual runoff at 3 million acre-feet per year." Templer and Urban (1996) cite "various estimates of runoff collecting in the playas [that] range from 1.8 to 5.7 million acre-feet per year" and selected a value of 2 million acre-feet per year as a conservative estimate.

Two previous field-based studies of playas suggested somewhat lower average playa water volumes. The U.S. Geological Survey conducted detailed field studies of playas in the late 1950s and the U.S. Bureau of Reclamation performed additional studies in the 1980s. Cronin and Meyers (1964) studied a sample of 50 playas in a 1,470 square mile area covering parts of Castro, Lamb, Hale, and Swisher counties in 1957 and 1958 measuring lake volumes and evaporation losses. They estimated the total annual water volume captured by the 1,348 playas in the study area at 199,096 acre-feet in 1957 and 37,025 acre-feet in 1958. Recognizing the highly local and variable nature of rainfall in the High Plains, which is dominated by summer-time convective thunderstorms, the authors did not attempt to project their results to the entire population of Texas playa lakes. Clyma and Lotspeich (1966) used the 1957 and 1958 data to estimate runoff for the entire area 25 million acre area of the Southern High Plains, concluding that "annual runoff into playas ranges between 1.8 and 5.7 million acre-feet." If we assume that some of the land area does not contribute runoff to playas and use the ratio of 35,668 acres of playa in the Cronin and Meyers study region to the 361,007 acre total Texas playa area, we get a water volume of 2.02 million acre-feet in 1957 and 0.4 million acre-feet in 1958. The U.S.

Bureau of Reclamation (1982) monitored a sample of 36 playas in 17 counties from 1979 through 1981 and used early Landsat imagery to estimate water volumes in all playa lakes in the study area for representative wet and dry periods between 1972 and 1980. They found that only about 15 percent of the playas contained water at any given time even under ‘wet’ conditions and estimated a total water daily volume of about 100,000 acre-feet. Less than two percent of the playas in the study area contained water under ‘dry’ conditions, with a total daily volume of about 7,000 acre-feet.

In 2009, the Texas Legislature approved funding for the Texas Water Development Board to conduct research on playa lakes in the Texas High Plains with the goal of increasing recharge to the Ogallala Aquifer. The current project is designed to evaluate the effectiveness of landowner-implemented playa modifications or land management changes for increasing the fraction of playa flood water that contributes to recharge. The project includes two phases: Phase 1 consists of three years of monitoring to determine initial conditions and Phase 2 consists of playa modifications and an additional three years of post-modification monitoring. Phase 1 goals are to determine the average annual volume of water available from playas regionally and to estimate pre-modification recharge rates at selected playas. The Phase 2 goal is to determine the effectiveness of playa modifications for increasing recharge. Phase 1 monitoring started in April 2011 and was completed in late 2014.

The current study represents an update and extension of previous work, reflecting environmental and technological changes since the early 1980s when the U. S. Bureau of Reclamation study was conducted. On the environmental side, the widespread adoption of high efficiency center-pivot irrigation systems, coupled with declining well yields, has reduced the amount of ‘tailwater,’ or irrigation runoff, to playas on the High Plains since the 1970s. Technologically, improvements in the Landsat satellites themselves, and the GIS software and computer hardware for processing the data, coupled with free distribution of Landsat imagery via the internet, greatly facilitates analyzing large volumes of satellite data. Geographic positioning system (GPS) technology improvements also facilitate the rapid acquisition of high-quality topographic data on playa basins, providing the current study with much more accurate measurements of water volumes than previous estimates, which were based on published topographic maps. Finally, the Landsat imagery archive now contains far more usable data than it did in the early 1980s, providing a longer period of record over which to evaluate the playa lakes as a potential water resource. The current study provides a well-documented, long-term analysis of a representative sample of playa lakes to determine the average annual volume of water they collect and trends and variability in that expected volume over time. The results will help focus playa modifications on locations where they can achieve maximum benefit.

3.0 Study Design

The current Phase 1 field study includes three components: (1) satellite observations, (2) field topographic surveys, and (3) field measurements of playa water levels and weather data. We used Landsat satellite observations to estimate water areas in selected playas for each image date. We used topographic surveys to convert water areas to water elevation and water volume estimates. We used field measurements of playa water levels to calibrate and validate estimates from the remote sensing data.

We selected the Landsat Path 30, Row 36 image area for evaluation in this study because it includes the highest density of playas. The image area, approximately 106 miles north to south by 115 miles east to west, includes 45 percent of all Texas playas and 53 percent of the mapped playa area. The 73 playas included in the study (Figure 3-1) are generally representative of all playas in the image area except in terms of size. The 73 playas studied range in size from 4.4 to 181 acres, with an average of 34 acres, compared with a mean size of 19 acres for all Texas playas, reflecting a bias towards larger features with greater amounts of water available for management. The sample includes 34 playas in predominantly rangeland watersheds, 23 in irrigated farm watersheds, and 16 in dry-land farm watersheds, broadly reflective of the land-use patterns in the area. The sample includes several clusters of playas; analysis of these clusters may help evaluate the variability of infiltration independent of other factors.

The playas in the Landsat Path 30, Row 36 area are an imperfect representation of the population of Southern High Plains playas. Soil conditions and rainfall distribution are not uniform across the Southern High Plains, and playas outside of the study area will likely behave somewhat differently. In particular, average rainfall decreases to the west, and playas on the western edge of the Southern High Plains will likely have smaller volumes of runoff than playas in the Landsat Path 30, Row 36 area along the eastern side of the region. The surface soil texture also becomes sandier to the west and southwest, which may result in smaller runoff volumes to playas in these areas. Finally, as noted above, the sample of playas included in this study is biased towards larger playas based on the expectation that they will make more water available for recharge purposes than smaller lakes. For all these reasons, the 73 playas included in this study likely over-estimate the total volume of runoff available in playas across the Southern High Plains.

We selected 73 playas for the study, based on location within the footprint of Landsat Path 30, Row 36 imagery, accessibility, and landowner willingness to participate. Thirteen of the playas in this study are part of an on-going monitoring program initiated by the U.S. Department of Agriculture-Agricultural Research Service and Texas Tech University in 2006. In 2011, TWDB staff equipped 14 sites with weather stations and installed water level recorders at another 14 sites. TWDB staff surveyed an additional 32 sites where no field water level data were collected.

Results from this sample of 73 playas were scaled up to estimate the water volume in all Texas playas based on the ratio of the total playa area overlying the Ogallala Aquifer in Texas to the playa area in the sample. Playa locations, classifications, and areas were taken from the playa wetland database compiled by Mulligan, Barbato and Seshadri (2014). The area of the 19,835 playa lakes over the Ogallala in Texas totals 374,587 acres. The total area of playas included in this study is 2,503 acres, giving a ratio of approximately 150.

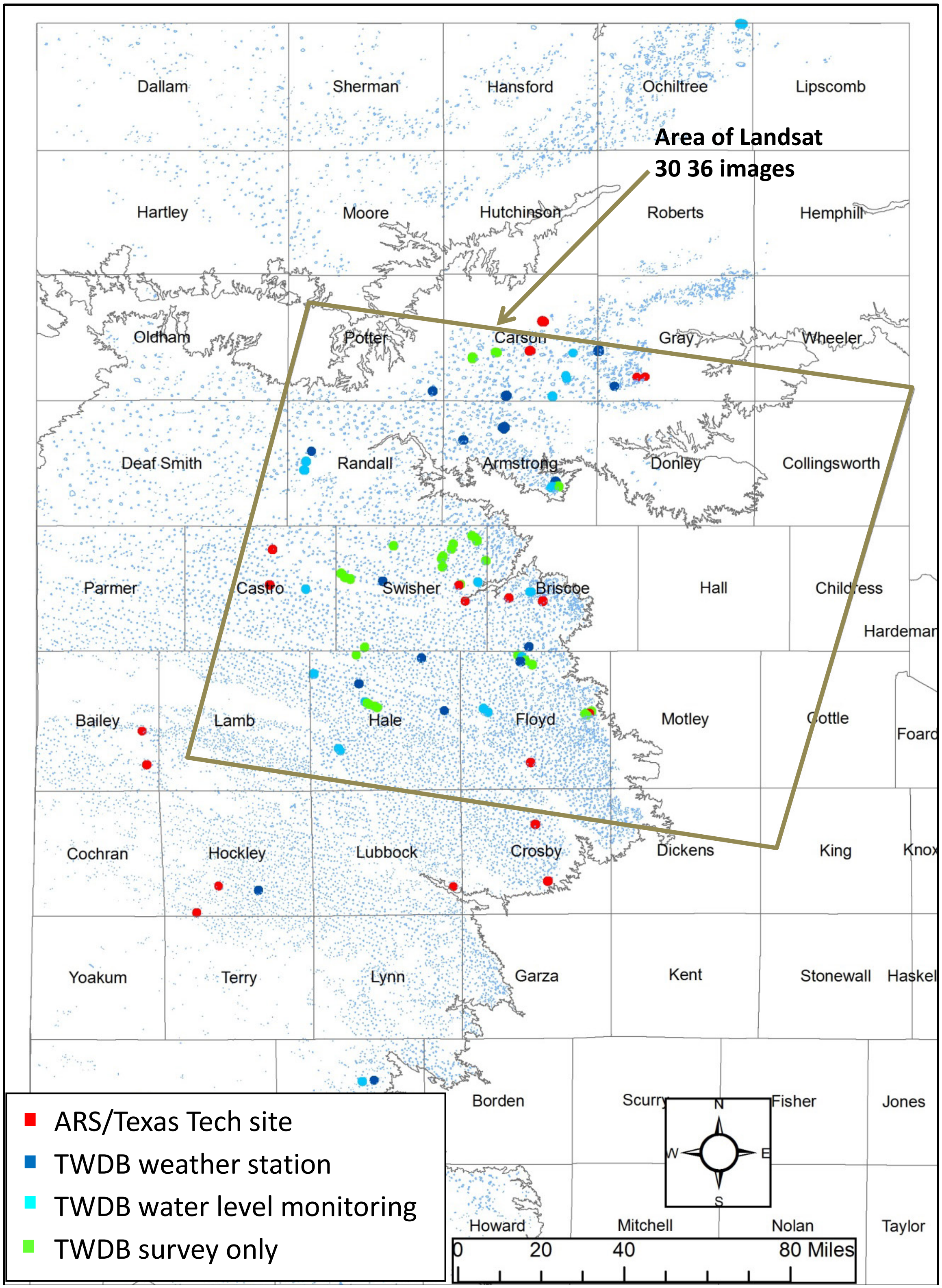

Figure 3-1. Locations of study-area playas
(ARS = Agricultural Research Service; TWDB = Texas Water Development Board)

4.0 Methods

We used a combination of field and GIS techniques to develop a continuous record of water levels in each of the 73 playas over an 18 year period from 1996 to 2014. The process workflow included field GPS surveys; watershed delineation and land-use classification; image classification; water area, elevation and volume estimation; and field water level measurement. Each of these steps is described in the following sections

4.1 Field Surveys

We conducted field surveys of each playa basin using a Trimble R-6 GPS with the rover unit mounted on a Honda Rancher all-terrain vehicle (Figure 4-1). We collected real-time kinematic position information at 15-foot intervals with sub-centimeter accuracy relative to the base. We gridded the GPS data using default kriging algorithms in Golden Software Surfer 9.1 and used the grid to generate contour maps of each playa (Figure 4-2). We developed elevation-area and elevation-volume curves from field survey data using the grid volume function of Surfer 9.1 and fit polynomial trend lines to the data in Microsoft Excel.

4.1.1 Survey Accuracy

We evaluated the accuracy of GPS survey data by performing repeat surveys at one site, with the second survey employing a much denser array of radial survey lines. Results are essentially identical up to an elevation of approximately 3,089 feet (Figure 4-3). The maximum water elevation observed in this playa is 3,090 feet.

The effects of micro-topographic variation associated with repeated shrink-swell movement and gilgai development in the vertisol soils that characterize High Plains playas were not resolved in the surveys, but the amounts of water contained in these depressions are too small to affect water resource management decisions.

4.1.2 Watershed Delineation

We delineated playa watersheds using publicly available datasets. It was impractical to perform field surveys of the entire watershed areas, which included cultivated areas, fence lines, and other obstructions. We used a Python-based collection of tools for hydrologic and terrain-based analysis of high resolution elevation data in the ArcGIS environment developed by the Minnesota and Wisconsin Natural Resource Conservation Service offices (NRCS, 2013) together with 1/3 arc-second elevation data from the US Geological Survey (USGS) National Map (USGS, 2014a). Playa watersheds ranged from 21 to 4,820 acres in area. Several very small,

Figure 4-1. Global positioning system

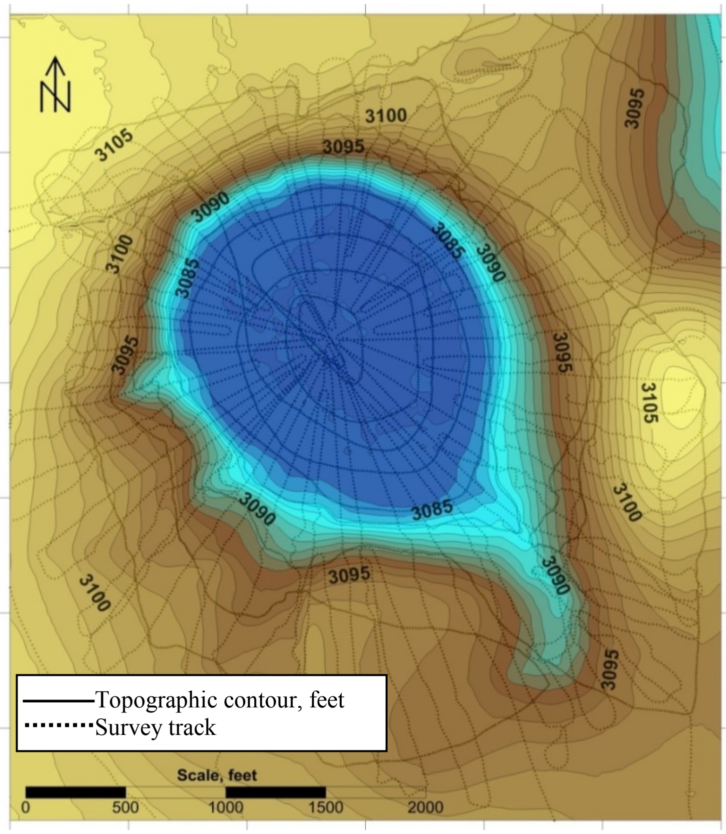

Figure 4-2. Topographic map of the FLRNG playa site showing survey tracks

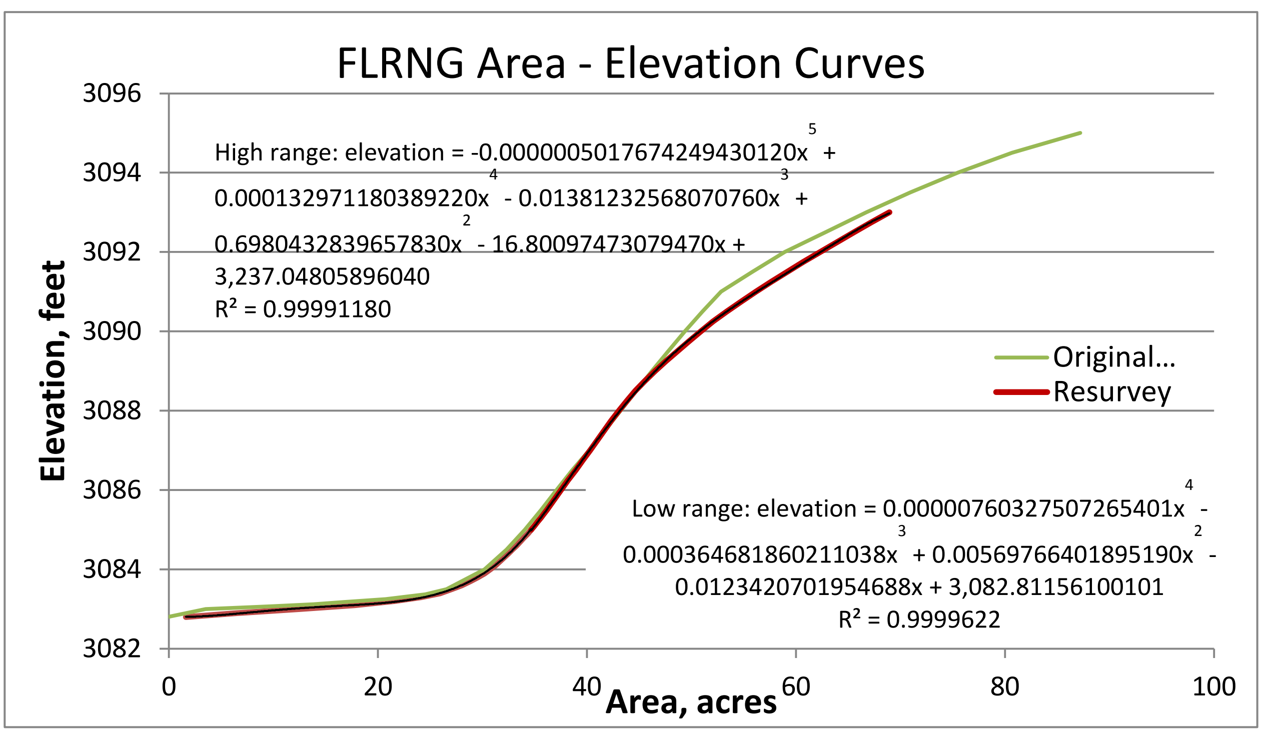

Figure 4-3. Area-elevation curves for survey accuracy check

shallow playas did not have any topographic expression in the 1/3 arc second dataset; we did not delineate watersheds for these playas.

4.2 Landsat Image Classification

We used Landsat near-infrared (Bands 5 and 6) imagery from the USGS Global Visualization Viewer (USGS, 2014b) to estimate water-covered areas in all reasonably cloud-free images between January 1996 and March 2014. We processed a total of 275 images from the Landsat 5,7, and 8 satellites using ESRI ArcGIS 10.1. We classified water areas in the images using the default Natural Breaks classification parameters in ArcGIS with the lowest reflectance class assigned as water. For Landsat 8, we used the Band 6 imagery to match the Band 5 spectrum of earlier satellites, with the numerical cutoff value for water areas determined by comparison with known water bodies. Figure 4-4 shows a natural color composite Landsat 8 image (top) from September 21, 2013, showing a thunderstorm track through Floyd County. The lower Band 6 image of the same area is classified to highlight water areas, shown in blue.

4.2.1 Water Area, Elevation, and Volume Estimation

We contoured the Landsat images at the water cut-off value determined in the classification step. This process interpolates shoreline location between the pixel values and produces smooth outlines of water areas (Figure 4-5). We converted water areas to polygons and tabulated numerical values for the water-covered area of each playa and each image date. We calculated water elevations and volumes from the water areas in Excel using the area-elevation and elevation-volume curves developed from the survey data. We summed peak water volumes representing new flood events over the period of record to determine the average annual flood volume for each playa. We summed water volumes by image date for all 73 playas to assess trends in daily water volume over the period of record.

4.3 Land Use Classification

Current land use around each playa was determined by inspection during field surveying. We classified playas according to the predominant land use in the watershed area as irrigated farm, dry-land farm, or range. We did not classify land in the Conservation Reserve Program separately from other range areas. Most of the irrigated farm areas use center-pivot sprinklers, but there are areas around some of the playas where furrow-flood or drip irrigation is used. We did not make any attempt to classify different types of irrigation separately.

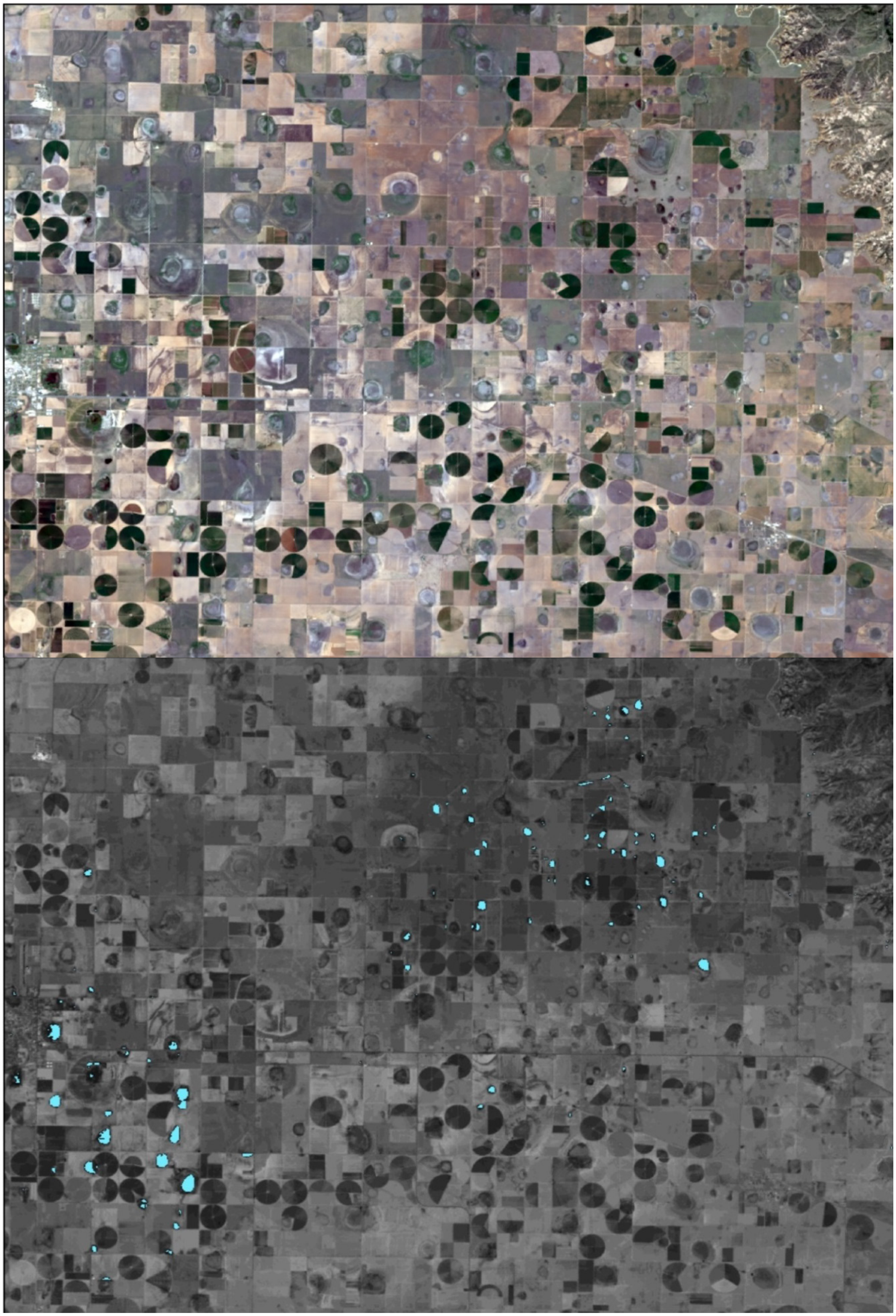

Figure 4-4. Landsat natural color composite and classified Band 6 imagery of Floyd County, 21 September 2013

Land use changes were assessed by inspection of Landsat data from July 1998. False color composite images were constructed using Landsat bands 7, 4, and 2 for the red, green, blue components. This color composite provides a high contrast natural-look representation. Healthy vegetation is bright green, grasslands green, barren soil pink, sparsely vegetated areas are orange and brown. Images from the summer of 1998 were selected instead of 1996 because 1998 was a dry year where the difference between irrigated and non-irrigated crops was more apparent and areas using furrow-flood irrigation could be easily distinguished from non-irrigated fields. Center-pivot irrigated areas were determined by their characteristic shape and were classified as irrigated land even if no crop was present at time of the Landsat image in July 1998.

4.4 Field Water-Level Measurements

We used field measurements to validate Landsat-based playa water volume estimates. The Texas Tech University and U.S. Department of Agriculture-Agricultural Research Service team measured playa water levels as part of the U.S. Department of Agriculture-Agricultural Research Service Ogallala Aquifer Program and the Natural Resources Conservation Service's Conservation Effects Assessment Project at 13 of the 73 playas included in the current study starting in 2005. They measured water depth at these 13 sites using a 260-700 Ultrasonic Snow Depth Sensor (NovaLynx Corp.) mounted on a boom at a two-meter elevation. We also measured playa water levels during flood events at nine of the TWDB sites during the 2011 through 2013 period using Campbell Scientific CR450 and Onset Computer Corporation HOBO U20 pressure transducers set in stilling wells at the low point in the basin. We used barometric pressure data from nearby playa monitoring sites to correct the HOBO data for atmospheric pressure changes.

4.4.1 Accuracy of Water-Level Estimates

We compared Landsat water elevation estimates to field monitoring data collected by Texas Tech University and U.S. Department of Agriculture-Agricultural Research Service (Gitz, 2013) and the TWDB to assess the accuracy of the remote sensing process (Figure 4-6). The Landsat estimates typically under estimate the peak water elevation because the 16-day interval between satellite observations does not coincide with the timing of peak flooding. The remote sensing data accurately captures both the overall duration of flood events and the slope of the lake-level recession. Small, short-duration flood events may be missed completely if they fall between Landsat observations. These small flood events may play an important role in maintaining the characteristic wetland soils and plant communities in playa lakes but are not significant from a water management perspective. We will present additional findings on the role of small flood

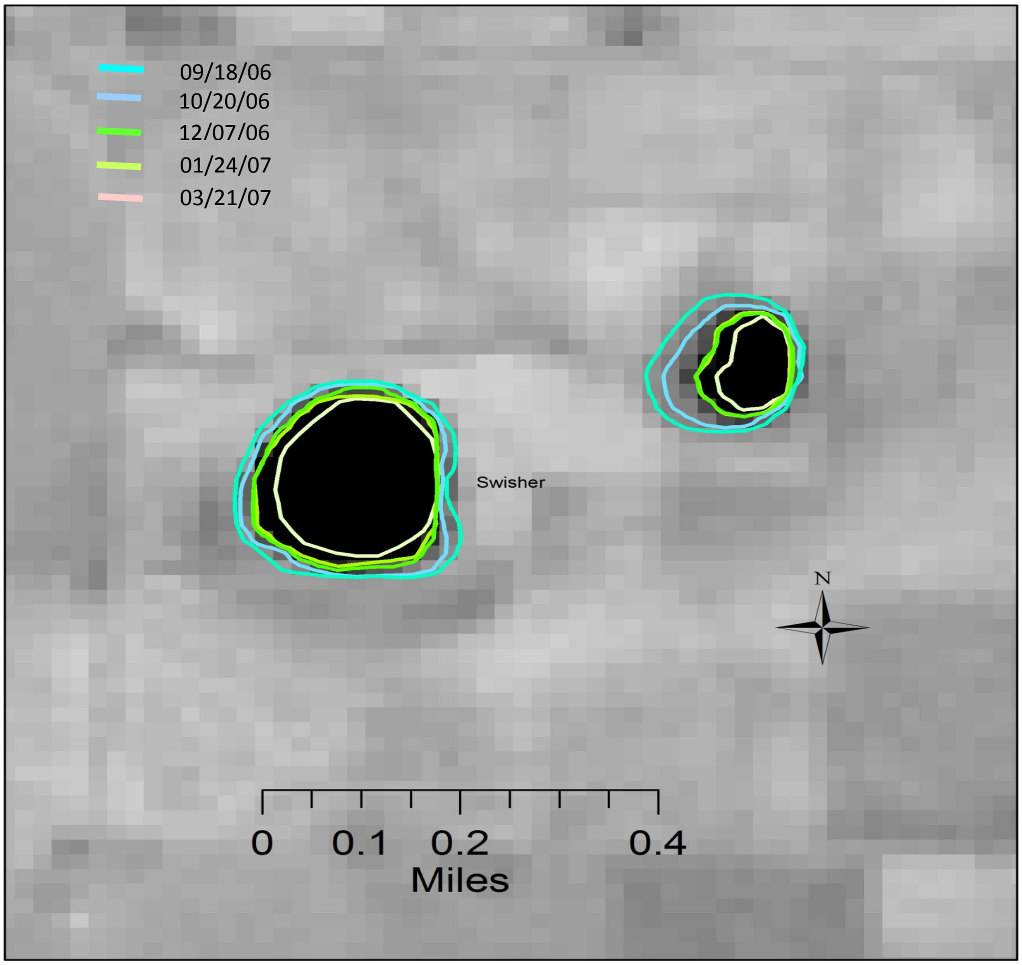

Figure 4-5. Water area polygons for successive image dates in 2006 and 2007

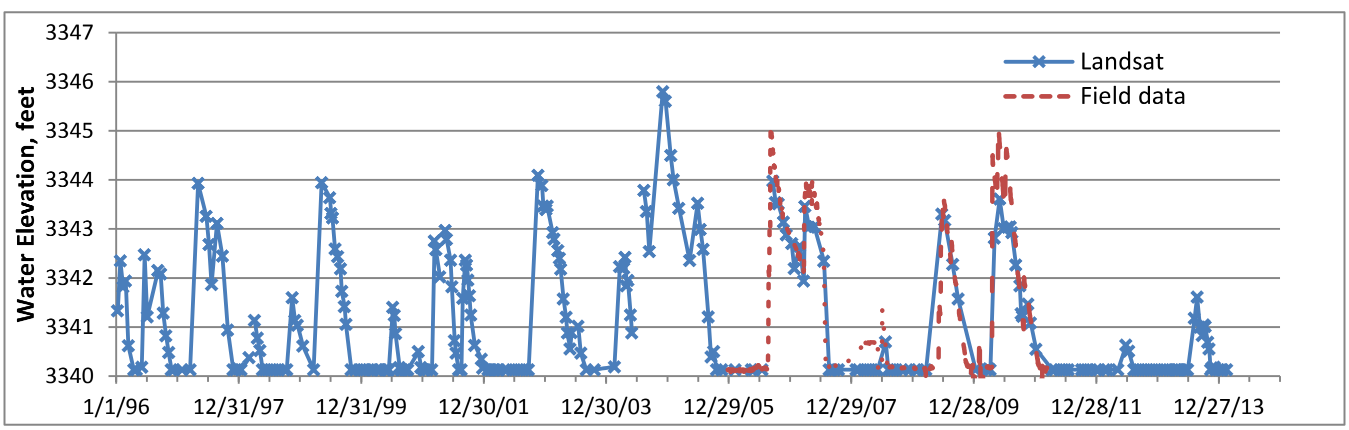

Figure 4-6. Comparison of Landsat estimates and field observations of playa water levels

events and storm-water runoff events that do not produce flooding as part of subsequent reports on Phase 1 of the current project.

We compared field water depth measurements with GIS water depth estimates for all 161 pairs of measurements where the measured water depth was greater than 0.25 centimeters. Five of the data points were discarded as outliers. On further examination of the Landsat imagery for these dates we identified thin clouds that interfered with the image classification process in some cases. Other outliers are for playas that have excavated pits where the field depth measurements represent a small area of water that is not well resolved in the satellite imagery. The remaining 156 data pairs were analyzed using PROC CORR and REG routines within the Statistical Analysis System (SAS) software. A plot of the data (Figure 4-7) shows a significant correlation (P < 0.0001) between the two measurement systems, with a slope of 0.888 and a correlation coefficient of 0.84.

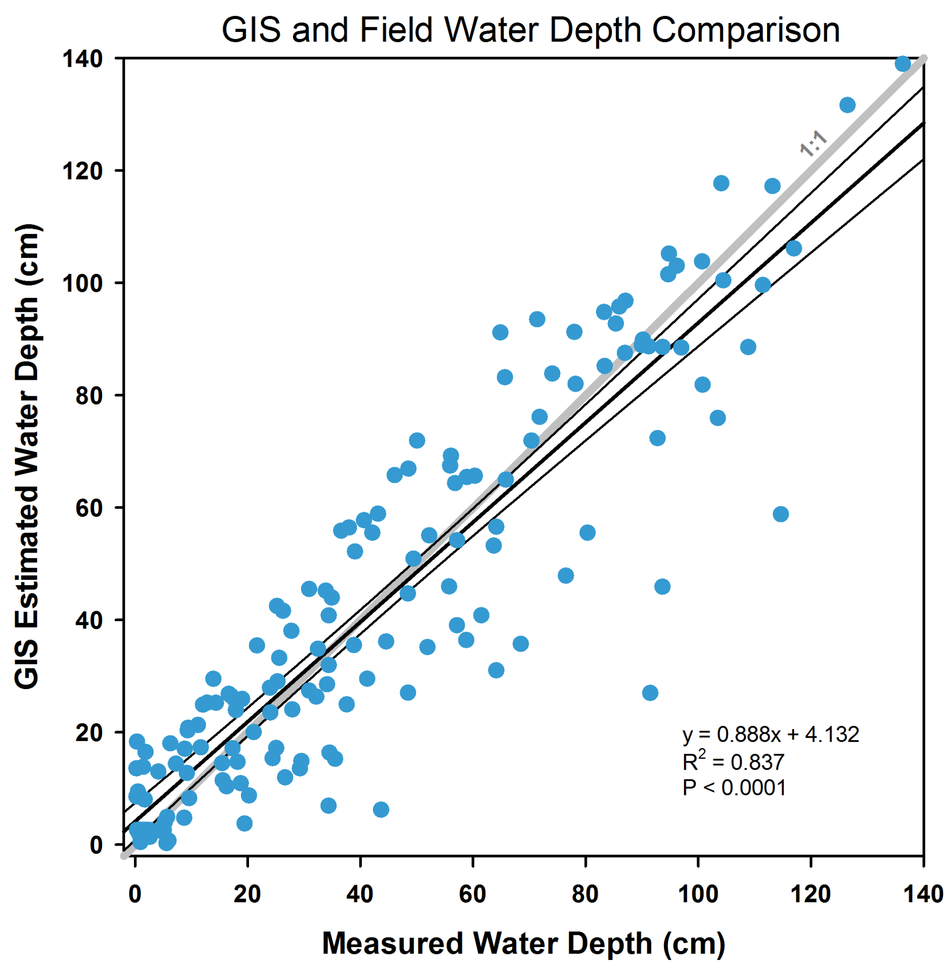

Figure 4-7. Correlation between field and GIS water depth measurements. Upper and lower 95percent confidence intervals are shown.

5.0 Results and Discussion

Over the 18 year period of study, the 73 playas contained some water an average of 17 percent of the time. The average hydroperiod (flood duration) was 92 days, and the annual average volume of water captured per playa was 21 acre-feet, or 0.51 acre-feet per acre of playa area. Projected over the entire population of 20,704 playas occupying 388,483 acres of the Texas High Plains gives an estimated average annual total volume of approximately 200,000 acre-feet of water captured in the playas. A summary table listing flood frequency, number of flood events, average hydroperiod, and average flood volume for each monitored playa is included as Attachment 1. Hydrographs showing water depth over the 18-year period of record for each playa are included as Attachment 2.

We developed a simple regression model to assess the importance of various factors in determining the total annual volume of water captured in any playa. We found that a model including the mapped playa wetland area, the playa watershed area, and the geographic longitude of the playa accounts for over 70 percent of the total variance in annual playa water volume. The average watershed slope was not a significant factor. Parameter values were not significantly different for the different land use classifications, given the relatively small sample size and high variance between individual playas. The estimated parameters for the regression model are shown in Table 5-1.

We summed estimated water volumes for all playas by date to evaluate trends in the overall water volume captured over time from 1996 through 2013 (Figure 5-1). The peak estimated playa water volume of 512,000 acre-feet occurred on May 5, 1999, when 93 percent of the monitored playas contained water. Smaller annual wet-season peaks occur in most years, except the drought years in 2002, 2011, and 2012. The longest period of dryness extends from mid-2011 through mid-2013; no water was present in any monitored playa for five months in 2012 and four months in 2013. A linear trend-line fitted to the data shows that the expected daily average water volume declined from 88,000 acre-feet at the beginning of 1996 to 21,000 acre-feet at the beginning of 2014. The water volume for playas in irrigated watersheds showed little change over time, with most changes in playa water volume occurring in range or dry land farm watersheds.

Regression Statistics						
Multiple R	0.850					
R Square	0.722					
Adjusted R Square	0.709					
Standard Error	16.240					
Observations	66					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	42538.6	14179.5	53.76	3.05E-17	
Residual	62	16352.5	263.75			
Total	65	58891.1				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1299.3	640. 3	2.03	0.0467	19. 4	2579
Longitude	-12.82	6.30	-2.03	0.0463	-25.4	-0.220
Watershed area, acres	0.01075	0.00393	2.74	0.00807	0.00291	0.0186
Playa area, acres	0.4776	0.111	4.29	6.48E-05	0.255	0.700

Table 5-1. Regression model parameters

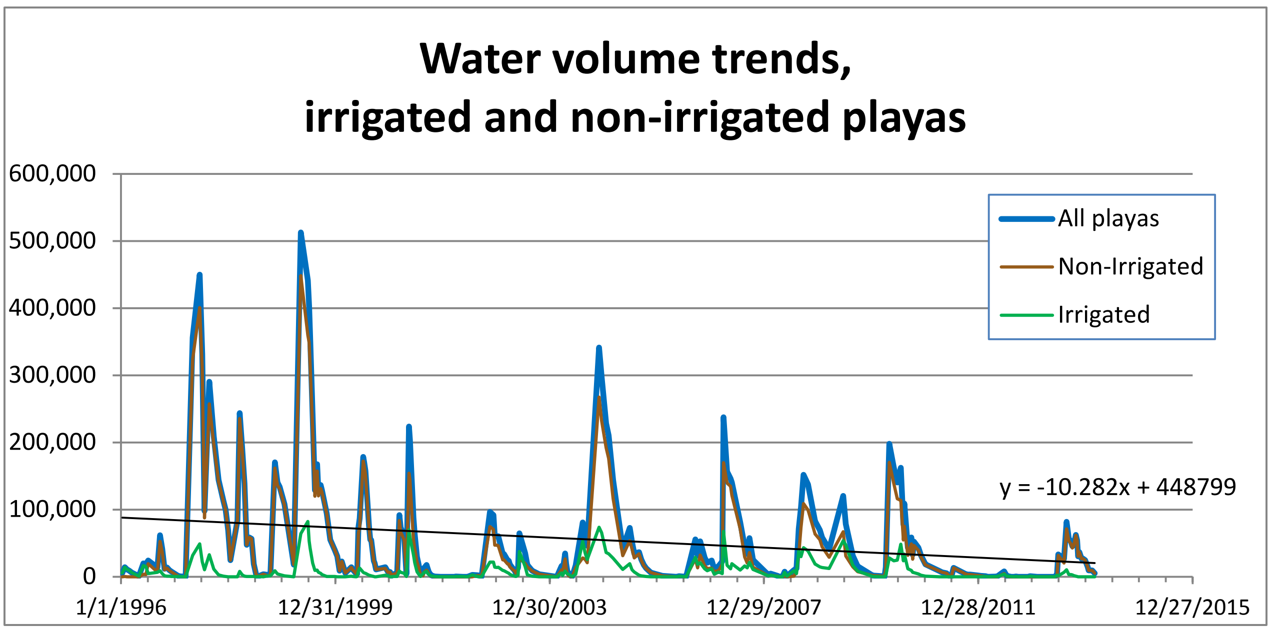

Figure 5-1. Trends in estimated total daily water volume over time for all Texas playas

Agricultural practices in the Texas High Plains have changed over time, altering the hydrological environment and potentially contributing to the observed decline in playa water volume. Furrow-flood irrigation was the dominant technology until the 1970s. Farmers plowed up and down the slopes, applied water at the tops of the fields, and collected 'tail-water' in the playas at the bottoms of the fields. As a result playas tended to flood deeper and stay wet longer than today. Producers are also using less water per acre of crops today than in the past. The average water use efficiency in the High Plains improved from about 40 percent in the 1950s to perhaps 50 percent in the mid-1970s through replacement of unlined ditches with buried pipe, construction of tailwater pits, and use of sprinkler irrigation (Blandford and others, 2003). By the year 2000, 72 percent of the irrigated area in the Texas High Plains used sprinkler systems (Collazi, 2009). Producers are irrigating fewer acres as energy costs rise and well yields decline in many parts of the Southern High Plains; the acreage of irrigated land in the study area reached a high of 1.92 million acres in 1978 before declining to 1.48 million acres in 1997 and 0.95 million acres in 2012 (National Agricultural Statistics Service, 1974, 1982, 2002, 2012). Agricultural practices such as contour plowing, furrow-dikes, and other measures to retain soil and water on the fields also limit runoff to the playas. All of these changes in agricultural practices tend to reduce the amount of runoff to playas and help explain why playa volume estimates from the 1950s and 1960s are much higher than the current estimate.

Changes in land use and agricultural practices since 1996 do not appear sufficient to explain the observed changes in playa water volume, especially since most changes occur in non-irrigated watersheds. Land use changes in the watersheds of the playas included in this study have been modest over the period between 1998 and 2014 and do not appear to reflect the regional trend of decreasing irrigated acreage. In 1998 the predominant land use around the playas in this study was dry-land farming at 23 sites, irrigated farming at 16 sites, and range at 34 sites. By 2014, seven of the dry-land farming watersheds had converted to irrigated farming, with 34 playas still classified as range land. While water use efficiency has continued to improve since 2000, recent changes in technology typically result in smaller improvements than in previous decades. For example, upgrading irrigation systems from center pivots with spray heads to low energy precision application heads only increases water use efficiency by about five percent (Howell, 2003). Such changes are probably not enough to account for the observed decline in runoff to playa lakes from 1996 to 2014, although more detailed land use histories in the watersheds of the playas included in this study would be needed to quantitatively assess the role of changes in irrigation practices.

Larger watersheds in the southwestern United States and in the High Plains, including Lake Meredith and Lake Mackenzie, also exhibit a trend of declining water yield since about 2000 (TWDB, 2014a). Cyclical changes in rainfall distribution associated with the Pacific Decadal Oscillation and Atlantic Multi-decadal Oscillation have been proposed as factors contributing to drought in the southwestern United States (McCabe and others, 2004). However there has not been any significant long-term change in precipitation in the study area.

Increased evaporation may play a role in the observed changes in playa watersheds. Texas Water Development Board staff have collected monthly precipitation and gross lake evaporation rates for one-degree quadrangles that cover Texas from 1954 to present. The quadrangular precipitation and evaporation rates are based on daily precipitation and pan evaporation rates measured at monitoring stations from Texas, Louisiana, Arkansas, Oklahoma, and New Mexico. The number of stations available varies from year to year. In 2013, 76 evaporation stations and more than 2,400 precipitation stations were used to develop evaporation and precipitation estimates for Texas (TWDB, 2014b); many fewer records were available for estimating precipitation and evaporation earlier in the period of record. Long-term moving average evaporation trends were examined because the soil column and watershed store significant volumes of water year to year and respond slowly to cumulative changes in hydrological conditions. Three-year moving average monthly precipitation data for quadrangle 306, corresponding to the Landsat Path 30 Row 36 image area, show little evidence of long-term cyclical change or overall trend, either positive or negative. However evaporation rates show a significant increasing trend over time (Figure 5-2), rising almost 40 percent over the 60 year period of record.

The evaporation trend observed in Quadrangle 306 was verified through an independent analysis of evaporation data from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NOAA, 2014). We retrieved all available evaporation data for sites between 32 and 37 degrees north between 100 and 104.5 degrees west, representing stations in Bushland, Lake J.B. Thomas, Lubbock, and Plainview, TX; Clovis and Conchas, NM, and Goodwell, OK. The period of record for these sites varied from 78 years for Conchas, NM to one year for Lake J.B. Thomas. We performed rudimentary quality control on the data, correcting errors such as apparent changes in units and multi-day evaporation recorded on Mondays, then aggregated the results to monthly averages for comparison with the Quadrangle 306 data. The aggregated NOAA data show a 22 percent increase in evaporation over the period 1954 to 2014. The only notable deviations between the NOAA and Quadrangle 306 trends occur after 2000, when additional local cooperator data are included in the Quadrangle 306 estimates.

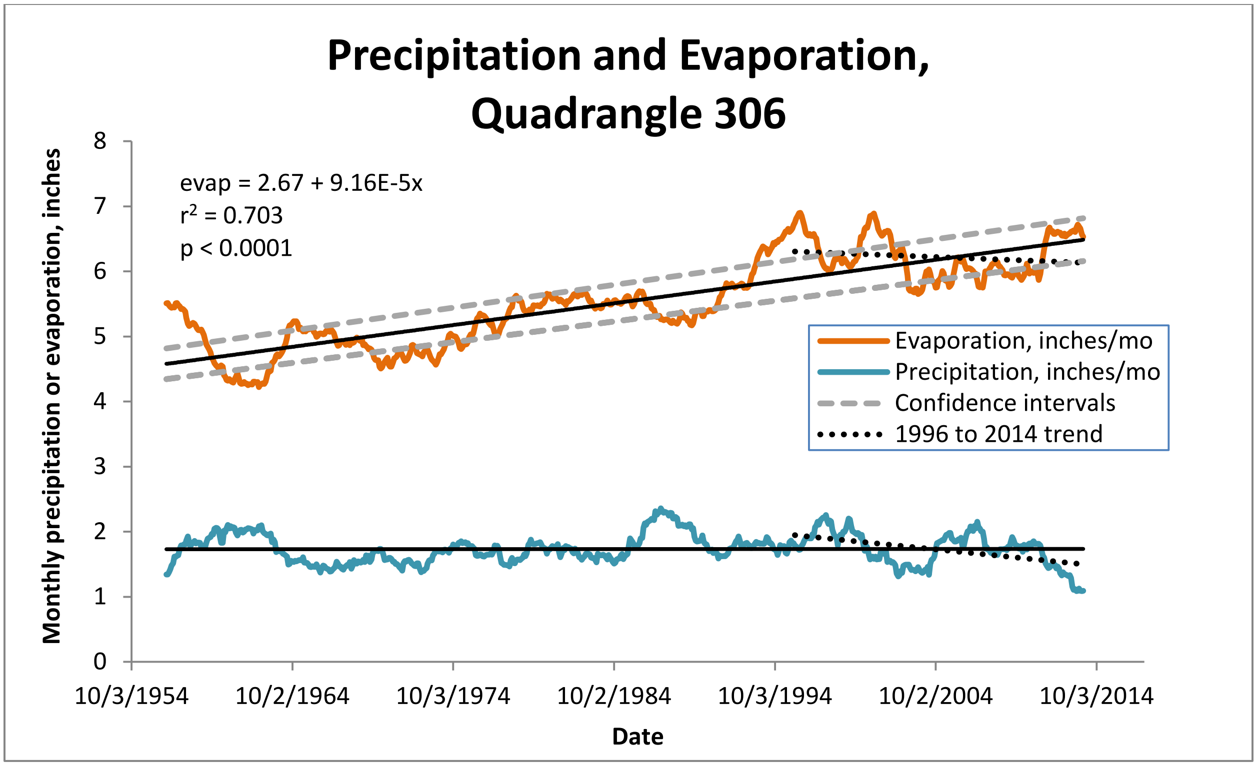

Figure 5-2. A 36-month moving average precipitation and evaporation for Quadrangle 306 (Randall, Armstrong, Swisher, Briscoe, Hale, and Floyd counties)

The volume of runoff to playas is likely influenced by multi-year trends in evaporation; playas flood in response to intense storm events, but that response is strongly affected by factors like the moisture content of the soil profile in the watershed and whether the playa flooded the previous year. Increased evaporation with constant rainfall will tend to decrease soil moisture content in the playa watersheds, reducing the volume of runoff produced by a given storm event. Drier soils in the playa basins will absorb more water into desiccation cracks before they flood. The hydroperiod of the playas will also be reduced as evaporation increases because evaporation is the primary route of water loss from most playas. The long-term trend of increasing evaporation may be a major factor responsible for the declining water volume in Texas playas.

But increasing evaporation may not be the primary cause of the observed decline in playa water volume between 1996 and 2014. The 36-month moving average evaporation rate and precipitation have both decreased over this interval (dashed trend lines), with a somewhat steeper decline in precipitation than evaporation. Rainfall effects may dominate the shorter term records even though changes in evaporation are more significant over a time period of several decades.

6.0 Conclusions

The average annual volume of water available from playa lakes on the Texas High Plains is significantly lower than suggested by previous studies. The current study indicates a long-term average annual volume of less than 200,000 acre-feet, an order of magnitude lower than Templer and Urban's "conservative" estimate from 1996. Several factors likely contribute to the decline in playa water volumes, including changes in agricultural practices and increased evaporation rates.

The downward trend in playa water volumes from 1996 to 2014 suggests that even 200,000 acre-feet per year may be an optimistic estimate of surface-water availability from playas under current conditions. Similar trends of declining water yield are observed for larger watersheds in the southwestern United States and in High Plains, including Lake Meredith and Lake Mackenzie (TWDB, 2014a). Increasing evaporation rates likely influence playa volume over the long term but do not correlate well with observed changes in playa water volume from 1996 to 2014.

We are continuing to collect data on the playa lakes to assess potential connections between these small, isolated watersheds and large-scale, long-term weather patterns. Playas serve as excellent indicators for changes in the hydrological cycle. Because playas are so shallow and are set in such a low-relief landscape, even small changes in atmospheric conditions or land management practices in the surrounding watersheds can have a major effect on the volume of water playas receive.

The scarcity of surface-water resources on the High Plains suggests that any playa modification program should be carefully focused on sites where a sufficient volume of water is available and where the water can be used in a manner that maximizes its productive value. Given the wide range in annual average water volumes between playas, we propose to focus site selection on playas that represent the top 10 to 15 percent in terms of annual average water volume. For example, only 11 of the 73 monitored playas receive at least an acre foot of water per acre of playa area per year, but these playas account for 44 percent of the total observed flood volume.

The regression model developed as part of this study offer a means to quickly screen candidate playas on the basis of publicly-available information on playa size, location, and topography using GIS systems. More detailed assessment with Landsat image analysis can be performed following a field topographic survey of selected sites. The playa water level records derived from Landsat analysis should be sufficient to support final selection of Phase 2 sites and to determine the effectiveness of any playa modifications that are implemented.

7.0 References

Blandford, T. N., D. J. Blazer, K. C. Calhoun, A. R. Dutton, T. Naing, R. C. Reedy, and B. R. Scanlon, 2003; Groundwater Availability of the Southern Ogallala Aquifer in Texas and New Mexico: Numerical Simulations Through 2050. Unnumbered Texas Water Development Board report, http://www.twdb.texas.gov/groundwater/models/gam/ogll_s/OGLL_S_Full_Report.pdf accessed April 2, 2013.

Clyma, W. and F.B. Lotspeich, 1966, Water Resources in the High Plains of Texas and New Mexico: Uniter States Department of Agriculture Agricultural Research Service paper ARS 41-114, https://archive.org/details/waterresourcesin11clym, accessed November 5, 2014.

Colaizzi, P. D.; P. H. Gowda; T. H. Marek and D. O. Porter, Irrigation in the Texas High Plains: a brief history and potential reductions in demand: Irrigation and Drainage, Volume 58, Issue 3, pages 257–274, July 2009.

Cronin, J. G., and Meyers, B. N., 1963, A summary of the occurrence and development of ground water in the Southern High Plains of Texas: U.S. Geological Survey Water Supply Paper 1693, 88 p.

Gitz, Dennis, USDA-ARS Lubbock, Texas, personal communication. June 2013.

Howell, Terry A., 2003. Irrigation Efficiency: Encyclopedia of Water Science; Marcel Dekker, Inc., New York, NY.

McCabe, G.J., Palecki, M. A., and Betancourt, J. L., 2004, Pacific and Atlantic ocean influences on multidecadal drought frequency in the United States: Proceedings of the National Academy of Sciences of the United States of America, v. 101, no. 12, pp. 4136–4141.

Mulligan, K. R., L. S. Barbato, and S. Seshadri, 2014. Playas and wetlands database.Texas Tech University, Lubbock, Texas. http://gis.ttu.edu/pwd/PlayasDocument.pdf, accessed April 2014.

National Agricultural Statistics Service, 1974, United States Census of Agriculture, 1974. Accessed October 21, 2014 at http://usda.mannlib.cornell.edu/usda/AgCensusImages/1974/01/43/306/Table-03.pdf

National Agricultural Statistics Service, 1982, United States Census of Agriculture, 1982. Accessed October 21, 2014 at http://usda.mannlib.cornell.edu/usda/AgCensusImages/1982/01/43/121/Table-02.pdf

National Agricultural Statistics Service, 2002, United States Census of Agriculture, 2002. Accessed October 21, 2014 at http://www.agcensus.usda.gov/Publications/2002/ Volume_1,_Chapter_2_County_Level/Texas/

National Agricultural Statistics Service, 2012, Census of Agriculture, 2002. Accessed October 21 2014 at http://www.agcensus.usda.gov/Publications/2012/ Volume_1,_Chapter_2_County_Level/Texas/

National Oceanic and Atmospheric Administration – National Climatic Data Center, http://www.ncdc.noaa.gov/cdo-web/search, accessed December 4, 2014.

Natural Resource Conservation Service, 2013. NRCS Engineering Tools: Field Office Toolset, ftp://ftp.lmic.state.mn.us/pub/data/elevation/lidar/tools/NRCS_engineering/ENGINEERING _TOOLS_WORKFLOW.pdf, accessed October 2014.

Schwiesow, W. F., 1965, Playa lake use and modification in the High Plains: Contribution No. 65-3 of the Texas Technological College Water Resources Center, Texas Water Development Board Report 10, 16 p.

Templer, O. W. and Urban, L. V., 1996, Conjunctive use of water on the Texas High Plains: Water Resource Update, v. 106, pp. 102-108.

TWDB (Texas Water Development Board), 2014a, Water Data for Texas: http://www.waterdatafortexas.org/reservoirs/statewide, accessed April 8, 2014

TWDB (Texas Water Development Board), 2014b, Precipitation and gross lake evaporation data on TWDB Website: http://www.twdb.texas.gov/surfacewater/conditions/evaporation/ evapinfo/index.asp, accessed October 6, 2014.

U. S. Bureau of Reclamation, 1982, Llano Estacado playa lakes water resources study, a special investigation, U.S. Department of the Interior, Bureau of Reclamation, Southwest Regional Office, Amarillo, TX.

U. S. Geological Survey, 2014a, The National Map Viewer and Download Platform, http://nationalmap.gov/viewer.html, accessed September 2014.

U. S. Geological Survey, 2014b, USGS Global Visualization Viewer, http://glovis.usgs.gov/, accessed April 2013.

Attachment 1: Summary of Image Analysis Results by Playa

Playa ID	Primary wetland description	Wetland area, acres	Number of flood events	Percent time flooded	Average flood duration, days	Total water volume, acre feet	Annual volume, acre feet	Annual volume, acre feet/ acre	Land use	Lat-itude	Long-itude	Watershed area, acres
BKFD	Lacustrine, semipermanently flooded	30.35	13	19	97	226.9	12.5	0.41	Dry	34.53	102.10	706.60
CRKS 4	Lacustrine, seasonally flooded	40.38	10	13	85	337.2	18.6	0.46	Dry	34.67	101.60	769.60
CRKS 5	Palustrine, temporary flooding	7.01	19	14	49	14.8	0.8	0.12	Dry	34.68	101.59	21.00
CRKS 5W	Palustrine, seasonally flooded	9.29	16	16	65	28.9	1.6	0.17	Dry	34.69	101.59	173.30
DRRT	Lacustrine, temporary flooding	61.4	11	23	140	709.2	39.2	0.64	Dry	35.05	101.55	1,025.00
GLZR	Lacustrine, temporary flooding	49.56	12	24	135	916.2	50.5	1.05	Dry	34.97	102.10	1,761.00
HLSTN	Palustrine, temporary flooding	17.57	13	20	104	176	9.7	0.45	Dry	35.01	102.08	613.8
MDTN N	Lacustrine, seasonally flooded	59.99	6	11	127	382.1	21.1	0.35	Dry	34.58	101.98	721.70
MDTN S	Lacustrine, seasonally flooded	48.56	7	14	136	361.3	19.9	0.46	Dry	34.57	101.97	714.80
MRE	Lacustrine, seasonally flooded	39.89	12	27	151	472.2	26.1	0.65	Dry	34.33	101.33	462.90
MTN-N	Lacustrine, seasonally flooded	36.05	16	23	95	270.9	14.9	0.41	Dry	34.29	101.35	404.00
MTN-S	Lacustrine, semipermanently flooded	67.59	14	34	161	910	50.1	0.63	Dry	34.28	101.36	795.20
PULM	Lacustrine, seasonally flooded; w excavated pond	52.23	17	21	83	512.5	28.2	0.54	Dry	34.56	101.95	1,182.00
STKS E	Palustrine, temporary flooding	12.9	11	5	33	37.3	2.1	0.16	Dry	34.11	101.86	376.70
STKS W	Lacustrine, temporary flooding; partially drained	53.26	13	13	65	398.5	22	0.41	Dry	34.13	101.89	1,868.00
YNGR	Lacustrine, seasonally flooded	47.75	11	18	108	278.5	15.4	0.32	Dry	35.22	101.66	743.80
B HRRL	Palustrine, seasonally flooded	32.14	11	6	36	15.2	0.8	0.03	Irr	34.14	101.90	NA
B HRRL S	Lacustrine, seasonally flooded; partially drained	25.69	13	9	44	70.3	3.9	0.15	Irr	34.13	101.89	NA
CRWL	Lacustrine, temporary flooding	25.81	24	21	58	200.9	11.1	0.40	Irr	35.24	101.03	132.00
CSCROP	Lacustrine, semipermanently flooded	24.9	9	26	189	457.3	25.2	1.01	Irr	34.54	102.23	1,315.00
FLCROP	Lacustrine, semipermanently flooded	30.27	9	32	237	691.8	38.2	1.20	Irr	34.07	101.31	613.80
FLDS	Lacustrine, Littoral, temporary flooding, w excavated basin	70.8	17	20	79	756.9	41.7	0.70	Irr	35.20	101.24	976.10
FNCR	Palustrine, seasonally flooded	16.32	20	14	45	117.1	6.5	0.13	Irr	34.23	102.08	723.10

Playa ID	Primary wetland description	Wetland area, acres	Number of flood events	Percent time flooded	Average flood duration, days	Total water volume, acre feet	Annual volume, acre feet	Annual volume, acre feet/ acre	Land use	Lat- itude	Long- itude	Watershed area, acres
GRCROP	Palustrine, farmed	11.16	13	19	95	75	4.1	0.37	Irr	35.27	100.95	NA
KNKD E	Palustrine, temporary to seasonal flooding	27.22	15	17	74	218.1	12	0.44	Irr	34.32	101.90	538.80
KNKD W	Lacustrine, seasonally flooded	19.65	16	18	77	243.5	13.4	0.68	Irr	34.30	101.93	568.70
MCHA	Palustrine, seasonally flooded	32.2	14	8	39	100.3	5.5	0.17	Irr	34.29	101.70	979.80
MHARR	Lacustrine, seasonally flooded	30.55	8	12	101	202	11.1	0.36	Irr	34.20	101.92	684.50
MHGN	Palustrine, seasonally flooded	15.26	19	18	62	214.5	11.8	0.77	Irr	34.10	101.62	413.10
OBRT M	Palustrine, temporary flooding	10.91	15	16	69	74.6	4.1	0.29	Irr	35.26	101.20	507.60
OBRT N	Palustrine, temporary flooding	12.15	15	14	64	82.6	4.6	0.58	Irr	35.27	101.20	52.80
OBRT S	Palustrine, temporary flooding	9.46	15	17	76	73.7	4.1	0.30	Irr	35.26	101.19	175.50
RFF 1	Lacustrine, semipermanently flooded	32.23	18	25	90	320	17.6	0.54	Irr	33.97	101.99	806.54
RFF 2	Palustrine, semipermanently flooded	17.3	24	23	62	161.6	8.9	0.51	Irr	33.96	101.98	340.70
SCHT	Palustrine, seasonally flooded	33.96	22	17	51	655.6	36.2	0.91	Irr	34.11	101.49	829.90
SCHT 2	Palustrine, farmed	35.61	6	3	33	23	1.3	0.05	Irr	34.1	101.47	NA
STKS M	Palustrine, temporary flooding	25.82	19	15	56	515.9	28.4	1.10	Irr	34.12	101.87	1,268.00
SWCROP	Lacustrine, semipermanently flooded	26.18	19	45	156	835.5	46.2	1.98	Irr	34.54	101.57	336.70
SWCROP E	Lacustrine, semipermanently flooded	22.34	15	32	142	310.8	17.2	0.76	Irr	34.54	101.56	665.90
BRCRP	Palustrine, seasonally flooded	14.62	12	14	75	54.5	3	0.30	Rng	34.49	101.33	162.70
BRRNG	Lacustrine, semipermanently flooded	39.93	15	36	158	470.8	26	0.83	Rng	34.50	101.40	391.90
BVN N	Lacustrine, temporary flooding	157.24	10	23	150	2993	164.9	1.66	Rng	34.90	101.23	4,329.00
BVN S	Lacustrine, seasonally flooded	135.23	11	9	52	1042	57.4	0.44	Rng	34.88	101.25	2,320.00
BVNS A	Palustrine, temporary flooding	5.07	9	5	39	3.2	0.2	0.04	Rng	34.89	101.23	NA
BVNS B	Palustrine, temporary flooding	4.44	9	7	48	6.4	0.4	0.08	Rng	34.89	101.23	80.99
BVNS C	Palustrine, temporary flooding	4.94	9	7	51	7.2	0.4	0.08	Rng	34.89	101.22	33.78
BVNS D	Palustrine, temporary flooding	6.87	9	8	56	12	0.7	0.09	Rng	34.89	101.22	NA
BVNS E	Palustrine, temporary flooding	5.84	9	7	54	13.5	0.7	0.12	Rng	34.88	101.22	54.93
BWRS	Palustrine, intermittent flooding	10.38	12	13	73	41	2.3	0.17	Rng	35.27	101.20	100.93
CRKS 1	Lacustrine, seasonally flooded	42.91	8	9	71	103.7	6.1	0.14	Rng	34.63	101.63	441.00
CRKS 2	Lacustrine, seasonally flooded	43.83	6	7	77	195.9	10.8	0.25	Rng	34.64	101.63	961.60
CRKS 3	Lacustrine, seasonally flooded	24.96	13	16	79	207.7	11.4	0.46	Rng	34.63	101.62	453.40

Playa ID	Primary wetland description	Wetland area, acres	Number of flood events	Percent time flooded	Average flood duration, days	Total water volume, acre feet	Annual volume, acre feet	Annual volume, acre feet/ acre	Land use	Lat-itude	Long-itude	Watershed area, acres
CRKS 6	Lacustrine, seasonally flooded; partially drained	80.85	12	30	165	2075	114.3	1.41	Rng	34.63	101.48	1,956.00
CSCRP	Lacustrine, seasonally flooded	37.72	6	6	64	70.3	3.87	0.11	Rng	34.58	102.22	1,113.00
CSRNG	Palustrine, semipermanently flooded	30.47	15	27	117	557.1	30.7	1.01	Rng	34.67	102.22	4,119.00
DOAN N	Lacustrine, seasonally flooded	31.14	13	34	175	477.1	26.3	0.84	Rng	34.71	101.53	479.60
DOAN NE	Palustrine, temporary flooding	16.24	11	13	80	85.7	4.7	0.29	Rng	34.71	101.52	198.40
DOAN SE	Palustrine, temporary flooding	5.94	13	9	45	9.8	0.5	0.09	Rng	34.71	101.52	335.60
DVPT A	Palustrine, temporary flooding	7.04	10	8	58	25.26	1.4	0.13	Rng	34.10	101.13	151.60
DVPT B	Palustrine, temporary flooding	5.36	7	4	37	10.1	0.56	0.04	Rng	34.09	101.13	72.50
DVPT C	Palustrine, temporary flooding	10.61	9	14	103	55.9	3.1	0.55	Rng	34.09	101.12	539.20
DVPT D	Lacustrine,seasonally flooded	37.67	11	39	236	1409	77.8	1.78	Rng	34.10	101.11	1,077.00
FLRNG	Lacustrine, seasonally flooded	27.9	11	33	200	991.3	54.8	1.68	Rng	34.10	101.12	536.33
FNLY	Lacustrine, seasonal to temporary flooding	180.64	10	24	156	2147	118.6	0.66	Rng	35.09	101.41	4,820.00
GRCRP	Lacustrine, seasonally flooded	24.12	13	16	81	127.5	7	0.29	Rng	35.24	100.96	121.30
GRGG	Lacustrine, temporary flooding	43.25	16	16	67	124	6.8	0.16	Rng	34.28	101.34	573.40
GRRNG	Palustrine, temporary flooding	6.31	13	16	82	16.3	0.9	0.14	Rng	35.27	100.92	22.10
HRNG 1	Lacustrine, seasonally flooded	33.33	15	28	124	686.4	37.8	1.12	Rng	34.56	101.84	504.30
HRNG 3E	Lacustrine, seasonally flooded	25.88	12	12	67	156.5	8.6	0.38	Rng	34.52	101.32	466.90
HRNG 3W	Palustrine,seasonally flooded	11.64	15	11	46	50	2.8	0.22	Rng	34.52	101.32	NA
SWCRP	Paulstrine, seasonally flooded	14.69	12	18	97	131.7	7.8	0.31	Rng	34.39	101.59	226.70
SWRNG	Lacustrine, semipermanently flooded	23.49	10	11	74	120.6	6.7	0.38	Rng	34.49	101.55	651.80
WRGT	Lacustrine, temporary flooding	111.71	12	21	117	1024	56.5	0.47	Rng	35.20	101.41	3,216.00
	AVERAGES	**34.03**	**12.81**	**17.44**	**92.37**	**382.9**	**21.13**	**0.51**				**830.0**

Notes: Irr = irrigated farm land
Dry = non-irrigated farm land
Rng = range land
NA = not available; shallow playa not resolved by available digital elevation model data
[1] Playa area listed does not include additional areas mapped as intermittently flooded