HYDROLOGY, CONSERVATION, AND MANAGEMENT OF RUNOFF WATER IN PLAYAS ON THE SOUTHERN HIGH PLAINS

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CONTENTS

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HYDROLOGY, CONSERVATION, AND MANAGEMENT OF RUNOFF WATER IN PLAYAS ON THE SOUTHERN HIGH PLAINS

By VICTOR L. HAUSER, *research agricultural engineer, Soil and Water Conservation Research Division, Agricultural Research Service*

INTRODUCTION

Ground water pumped from wells irrigates more than 5.4 million acres in the Texas part of the southern High Plains [1] and additional large acreages in eastern New Mexico and the Oklahoma Panhandle. A map of the area discussed is shown in figure 1. The area's economy is heavily dependent on irrigated agriculture. Ground-water development since 1945 has resulted in rapid decline of the water table over most of the region. Cronin (*11*) [2] stated, "The estimated amount of water withdrawn from the Ogallala formation (the principal aquifer in the region) in the Southern High Plains of Texas each year so greatly exceeds even the most optimistic estimates of recharge that it must be concluded that ground water is being 'mined,' that is, it is coming from storage." He estimated that the pumping rate from the Ogallala formation was 5 million acre-feet annually in that part of the southern High Plains located in Texas, south of the Canadian River. Significant volumes of water are also pumped annually in the southern High Plains in New Mexico, north of the Canadian River in Texas, and in the Oklahoma Panhandle.

The only known water source for recharging the aquifer is precipitation, most of which is evaporated or transpired by plants. Cronin (*11*) concluded that natural recharge from precipitation is only a small fraction of an inch each year.

Numerous natural lakes called playas dot the southern High Plains. These playas are usually dry, but they do impound most of the surface runoff. This impounded water is the only available water supply for ground-water recharge. Estimates of runoff volume accumulated in the playas in the Texas and New Mexico part of the southern High Plains range from 1.8 to 5.7 million acre-feet annually (*10*). Broadhurst (*5*) stated that "prac-

[1] SHERRILL, D. W. HIGH PLAINS IRRIGATION SURVEY. Tex. Agr. Ext. Serv. mimeo. rpt., 10 pp. 1964.

[2] Italic numbers in parentheses refer to Literature Cited, p. 24.

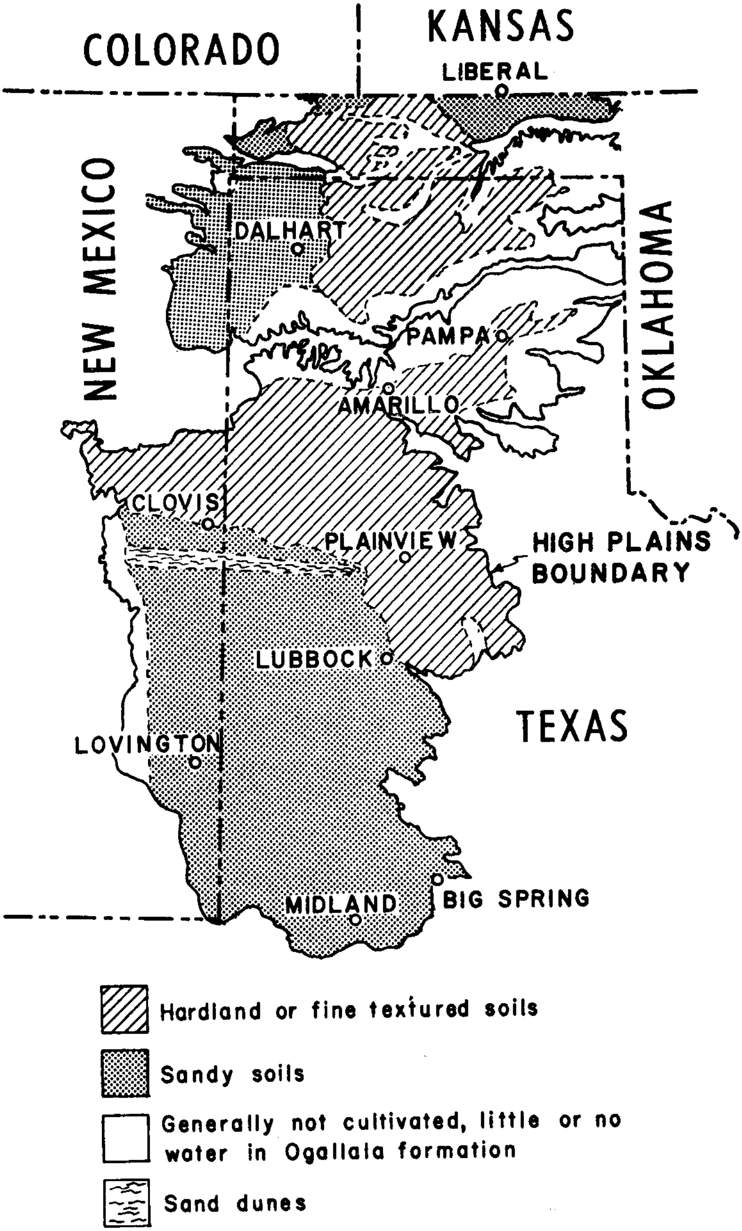

FIGURE 1.—The southern High Plains, showing the area discussed and the major soil types.

tically all the water from the playas is lost through evaporation," and other sources estimate that 90 percent is lost by evaporation (*2*).[3] Although the estimates lack precision, it is apparent that conservation of the water now being wasted by evaporation from playas would greatly extend the period of profitable pumping from the aquifer.

The cost of pumping irrigation water from wells in the Texas High Plains ranges from about $6 to $20 per acre-foot (*19*, *20*). Since irrigation water must return a profit, it may be assumed that the water is worth more than $20 per acre-foot for at least some of the area. Hartman and Anderson (*17*) concluded that the value of irrigation water ranged from about $21.50 to $25.70 per acre-foot in northeastern Colorado.

The land as well as the water in the playas has potential value. On most farms the flooding hazard prevents optimum use of land in the playas. It is estimated that in the "hardlands" within the Texas High Plains (see fig. 1) 500,000 acres of land is classed as Randall clay, which is found only in the bottom of playas (*36*). Van Doren[4] found that Hereford steers grazing the native vegetation in a playa gained up to 3 pounds per day for 60 days. This high rate of gain indicates very nutritious forage, which requires fertile soil.

The numerous shallow playas provide excellent breeding places for mosquitoes. Harmston (*16*) found that 75 percent of the mosquitoes produced in his study area in the southern High Plains were produced in playas. The major cities of the area have enough playas, either within their borders or nearby to make the annoyance from mosquitoes a major problem. In addition, mosquitoes from playas present a serious health hazard to people because they transmit the viruses that cause encephalitis (sleeping sickness) (*14*).

The main purposes of this paper are (1) to discuss playa hydrology, (2) to present different methods for managing and conserving runoff, and (3) to compare the efficiency and usefulness of these methods.

RAINFALL-RUNOFF RELATIONS

Rainfall and surface runoff are important segments of the hydrologic cycle. Rainfall—total amount and distribution—directly influences the total amount of ground water used for irrigation each year. Runoff determines the quantity of water available to supplement the ground-water supply by recharge or by pumping directly from playas for irrigation.

Point rainfall amount, distribution, and frequency of occurrence may be estimated with reasonable accuracy from the published records of the U.S. Weather Bureau, State agricultural experiment stations, and other sources. There are, however, few published data

[3] HIGH PLAINS UNDERGROUND WATER CONSERVATION DISTRICT. PROPOSAL FOR GROUND WATER RECHARGE HIGH PLAINS OF TEXAS. Mimeo. rpt., 16 pp. 1957.

[4] Van Doren, C. E., superintendent, Southwestern Great Plains Research Center, Bushland, Tex. Private communication. June 1964.

that may be used to estimate runoff in the southern High Plains. Runoff estimates have been made from runoff measurements made in other parts of the United States (*1, 39*). Cronin (*11*) reported runoff measurements for a 2-year period in the study area near Plainview, Tex.

The writer recorded runoff measurements over a 6-year period at the Southwestern Great Plains Research Center, Bushland, Tex. (near Amarillo).[5] Runoff was measured from field-size (5 to 10 acres) terraced dryland plots, described by Zingg and Hauser (*39*), located on Pullman silty clay loam soil described by Taylor and coworkers (*36*). The land slope is about 1.5 percent. The fields were cropped in a wheat-fallow-sorghum-fallow, dryland crop sequence. After sorghum harvest, one plot was fallow each year for about 11 months until wheat was planted the following fall.

Only a small amount of organic residue remained on the soil surface through the summer following sorghum harvest, even though the plots were tilled with large sweeps to conserve residue. Sweep tillage left the land surface essentially flat.

For the purpose of this study, it was assumed that the fallow plots (after sorghum) represented an "average" runoff condition for the "hardlands." The soil of the fallow plot is much wetter during the summer than where dryland crops are growing, where dryland wheat has been harvested in June, or where native grass is grown. The soil of the fallow plot is not as wet as irrigated cropland during much of the summer. The research data verified the validity of the assumptions about the relative amount of runoff from dryland.

The relation between total monthly precipitation and runoff is shown in figure 2 for flat fallow, for wheatfields where wheat was harvested during the summer, and for contour-listed fallow on the fields planted to sorghum in June. The data for flat fallow are for the period between sorghum harvest and wheat seeding. The runoff data for wheatfields are for the period May through October and should be representative for continuous dryland wheat. The data for listed fallow are for the period when sorghum fields have essentially no cover, are listed, and sorghum plants are small and use little water. The sorghum is planted in lister furrows that are parallel to graded terraces. Most deviation of points from the curves shown in figure 2 can be attributed to rainfall intensity variations that were not considered in the relations shown.

The relation between monthly rainfall and runoff can be checked by data obtained by Van Doren[6] during October 1941. Rainfall measured at the Southwestern Great Plains Research Center was 9.14 inches for October 1941. On October 1 the playa on the Research Center was dry; at the end of October the playa contained water 5 feet deep. Figure 11 (discussed later) shows that when the playa at the Research Center is 5 feet deep it contains 535 acre-feet of water or about 2.6 inches of runoff from the 2,500-acre watershed. The runoff from flat fallow is predicted to be 2.7 inches for

[5] Unpublished data.

[6] Van Doren. C. E. Personal communication, unpublished data, July 1964.

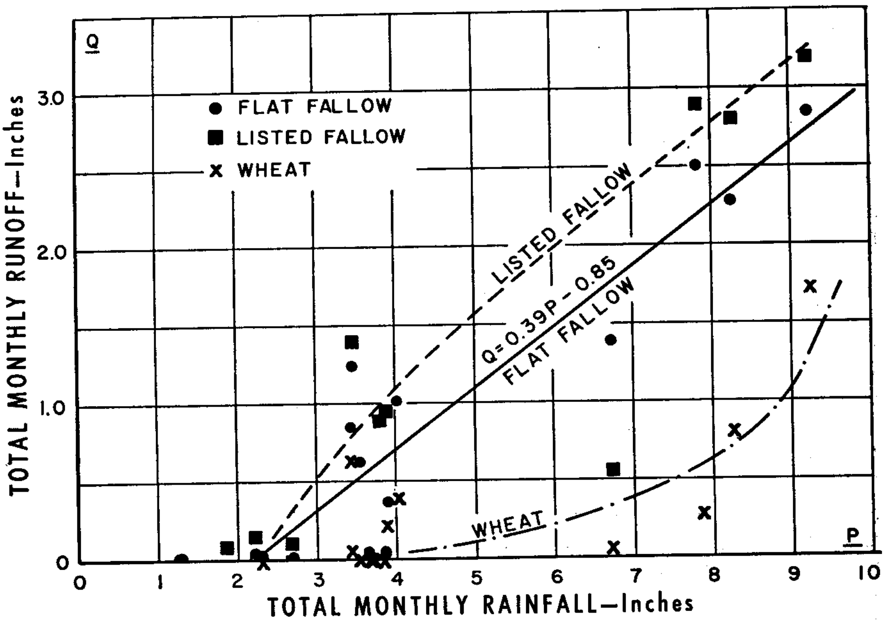

FIGURE 2.—Relation between monthly precipitation and monthly runoff on dryland farmed "hardlands" for flat fallow after sorghum, for wheat, and for contour-listed fallow, at the Southwestern Great Plains Research Center, Bushland, Tex.

9.14 inches of rain (fig. 2). These data seem to verify the assumptions made earlier that runoff from the flat fallow fields approximates runoff from the "hardlands."

The available runoff data for "hardlands" may be used to show the relative effect of irrigation on runoff amount. Runoff is related to soil moisture content immediately before a storm (*3, 28, 33, 37*). Frequent soil moisture measurements are not available for the study watersheds. Therefore, an "antecedent precipitation index" (*API*) (*3, 28, 31*) was derived from rainfall data for the period preceding a storm, and presumed to be proportional to actual soil moisture content.

For this analysis *API* was computed by the formula:

$$API = P_0 + M_1P_2 + M_2P_2 + \ldots\ldots\ldots\ldots + M_{20}P_{20} \qquad (1)$$

(which is similar to formulas suggested in the literature (*3, 28, 31*))

where: P_0 = precipitation on day of runoff event,

P_1, P_2, P_3, etc., = precipitation on first, second, third, etc., day before the runoff event, through 20 days, and

M_1, M_2, etc., are constants determined by the equation:

$$\text{Colog } M_i = \left\{ \frac{D_i - (0.088)}{19.912} \right\} \qquad (2)$$

which is similar to relations found in the literature (*3, 28, 31*)

where: D_i = number of days preceding the storm ($D_1 = 1.0, D_2 = 2.0, \ldots . D_{20} = 20.0$).

The *API* was calculated for each runoff-producing storm during the period of record on flat fallow drylands. Figure 3 presents data for the relation between daily rainfall and runoff with a family of curves drawn for *API* = 0 to 1.0, 1.0 to 2.0, and more than 2.0. Most deviation of the plotted points from the fitted curves can be explained by rainfall intensity variations or tillage immediately before a storm, which were not included as variables.

The relative effect of soil moisture on runoff for the "hardlands" is shown in figure 3. The curve for *API* greater than 2.0 approximates irrigated conditions, and the curves for *API* from 1.0 to 2.0 and less than 1.0 represent moist and dry sites, respectively, for dryland cropped conditions. Figure 3 shows that 1 inch of daily rainfall may produce significant runoff on wet (irrigated) soil but little or none on dry (drylands) soil. For 2 inches of daily rainfall, runoff is over twice as large when *API* is greater than 2 (irrigated) as when *API* is less than 1 (dryland).

The justifiable expense and the capacity of pumps, reservoirs, and other facilities to manage playa water will be determined by the frequency of different runoff amounts. Frequency estimates made directly from short-term runoff records may not be accurate. Therefore, the monthly rainfall-runoff relation shown in figure 2 for flat fallow was used to predict runoff for past rainfall events when no runoff measurements were made. These predications were then used for frequency estimates.

Jensen and Hildreth (*23*) summarized 69 years of rainfall records for Amarillo, Tex. Their data were plotted on log-probability paper, curves were fitted by eye, and the frequency estimates shown in figure 4 were read from the smoothed curves. The numbers on the curves of figure 4

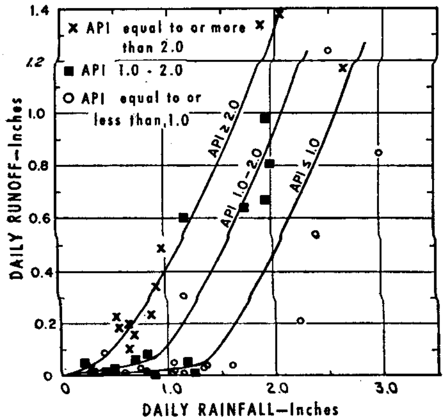

FIGURE 3.—Relation between daily rainfall and daily runoff as affected by antecedent precipitation index (*API*) on fallow dryland at the Southwestern Great Plains Research Center, Brushland, Tex. (typical of "hardlands" area).

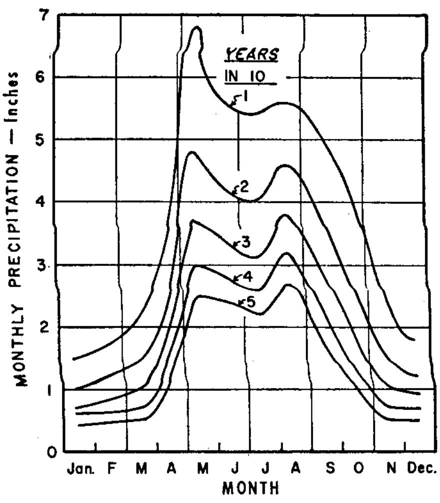

FIGURE 4.—Years in 10 that monthly precipitation at Amarillo, Tex., equals or exceeds amount shown.

show the number of years in 10 years when total monthly precipitation will equal or exceed the amount shown (example: 2 years out of 10, July rainfall equals or exceeds 4 inches).

An equation relating monthly rainfall and runoff for fallow was derived from the data (fig. 2) by the method of averages:

$$Q = 0.39\,P - 0.85 \quad (3)$$

where: Q = total monthly runoff, in inches;
P = total monthly precipitation, in inches.

Runoff computed by equation 3 and rainfall frequency estimated from figure 4 were combined to estimate runoff frequency for dryland fallow as shown in figure 5. The data points fall closer to the trend lines for the monthly rainfall versus runoff (fig. 2) than for the daily values of figure 3. Therefore, the trends shown in figure 2 were used for estimating runoff in this study. The frequency estimates shown in figure 5 are for individual months, and it is assumed that each month is independent of the others. This assumption may not be valid, because rainfall in the preceding month may affect runoff amount during the next month. Large amounts of runoff are most likely in May, but the more frequent, smaller amounts of runoff may be expected in any month from May through August. Runoff exceeding one-half inch may be expected on the average 3 times in 10 years in both May and August (fig. 5).

Figure 6 was derived from the data of Jensen and Hildreth (*23*) and equation 3, and shows the number of months in 10 years when a given rainfall or runoff amount may be equaled or exceeded on flat fallowed dryland in the hardlands area. Figure 6 shows that 1 inch or more runoff may be expected during 10 months in 10 years, and that one-fourth inch or more runoff may be expected in 24 months in 10 years. Runoff volume accumulated from 1 inch of runoff is about 210 acre-feet for the playa on the Southwestern Great Plains Research Center. Runoff of one-half inch would produce 105 acre-feet of

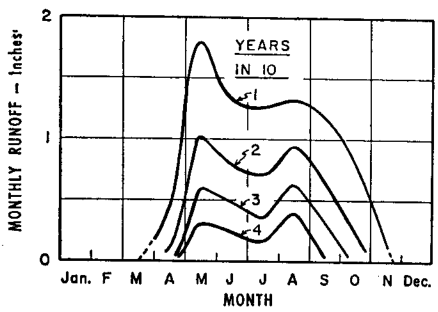

FIGURE 5.—Estimated frequency of monthly runoff from dryland flat-fallowed "hardlands" for April through November, at Amarillo, Tex. (Years in 10 when runoff for any particular month equals or exceeds the amount shown.)

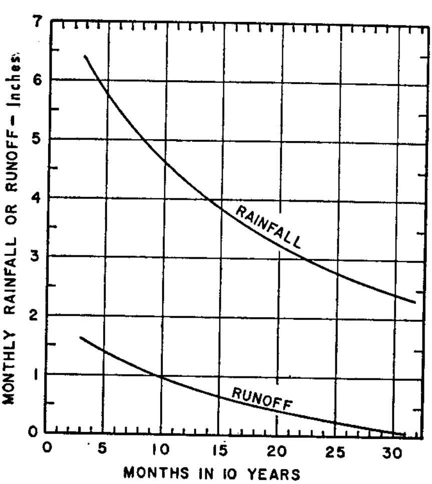

FIGURE 6.—Number of months in 10 years when rainfall or runoff equals or exceeds given amount on flat-fallowed dryland (hardlands), at Amarillo, Tex.

runoff and one-fourth inch runoff would produce 52 acre-feet of water.

The curves presented in figure 3 indicate that large amounts of runoff tend to occur during periods when rain falls on several successive days on "hardlands." During 1960, the runoff was higher at Bushland than for any other year during the 6-year period of runoff records. Figure 7 shows daily rainfall and runoff for June through October 1960. It is apparent from these data that a large percentage of runoff is likely after several days of rain and that very large daily rainfall is not necessary to produce large runoff volume. Figure 8 shows daily rainfall and daily volume of water stored in selected lakes in the sandy soil areas near Lubbock, Tex., in 1963 (*35*). These data support the statement that significant amounts of runoff are most likely after several days of rain. They also show that rains exceeding 2 inches per day are likely to cause runoff into playas even on the sandy loam soil near Lubbock, Tex.

Two inches of daily rainfall will probably produce some runoff on hardlands even when the soil is relatively dry (fig. 3). If the storm is preceded by other rains or irrigation, then the runoff amount should be over 0.5 inch. Figure 9 shows that, on the average, a 24-hour rainfall of 2 inches is likely once each year in the area between Amarillo and Lubbock, Tex. Therefore, some runoff is likely once each year, on the average, in the central part of the study area.

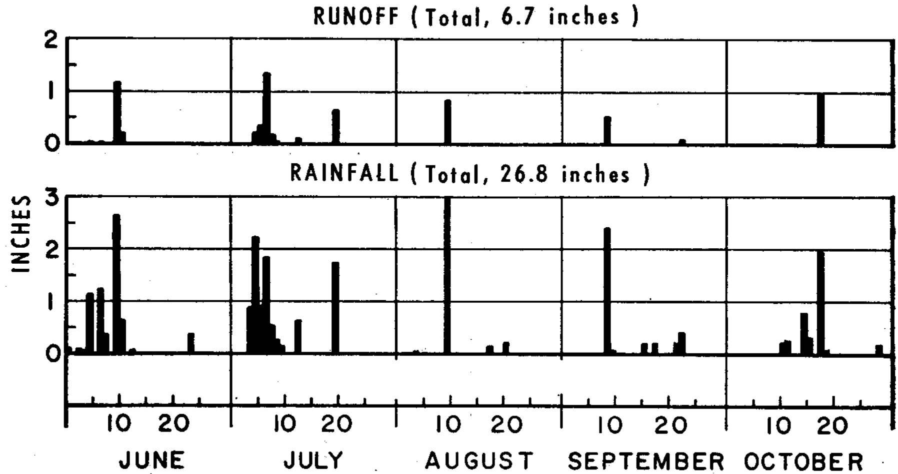

FIGURE 7.—Daily rainfall and runoff from flat-fallowed dryland (hardlands) at Southwestern Great Plains Research Center, Bushland, Tex., during June to October 1960.

SHAPE-AREA-VOLUME RELATIONS OF PLAYAS

The playas are generally flat-bottomed, shallow lakes, and cover a relatively large area in comparison to the volume of water stored. Figure 10 shows the shape of the playa on the Southwestern

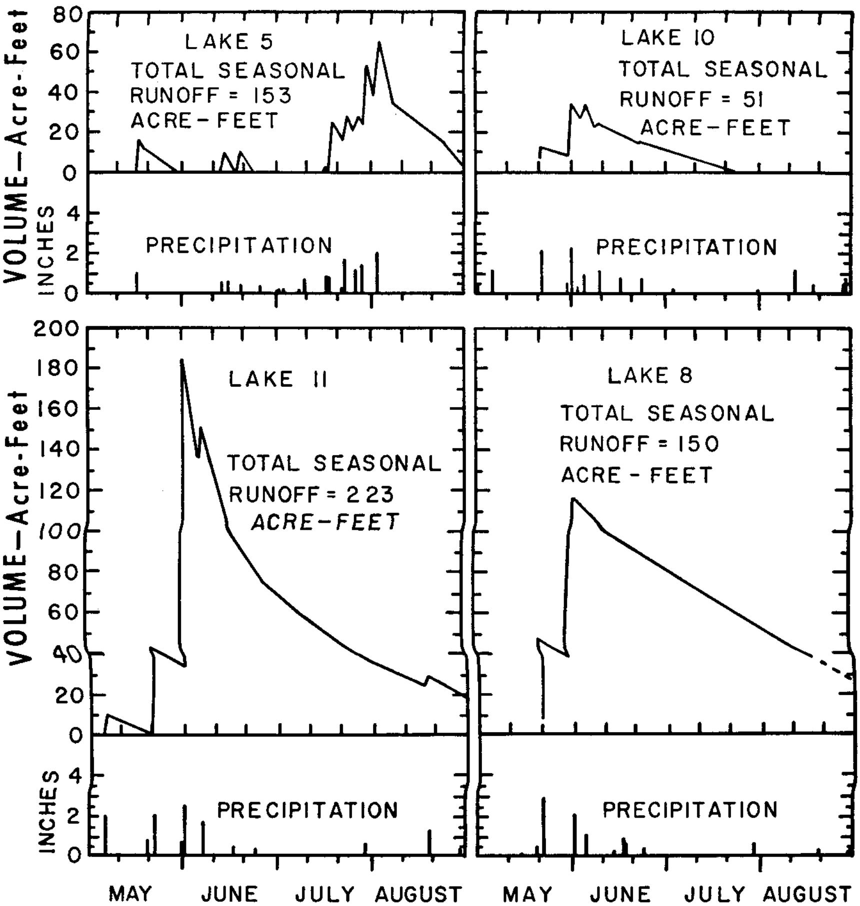

FIGURE 8.—Daily rainfall and runoff water volume in selected playas in Lubbock County (sandy soil area) in 1963. (Redrawn from Reddell and Rayner (*35*).)

Great Plains Research Center, Bushland, Tex. This playa is representative of playas in the "hardland" or fine-textured soil areas. Figure 11 shows the relation between lake-surface elevation, lake-surface area, and water volume. When 50 acre-feet of water is impounded in the playa, it covers about 88 acres of land with a maximum depth of 0.94 foot.

The shape and area-volume relations for a playa in Lubbock County are shown in figure 12 (*34*). This playa is typical of the smaller, more cone-shaped playas that occur in the sandy soil of the "South Plains" of Texas. Fifteen acre-feet of water covers about 11 acres with a maximum depth of 2.1 feet.

EVAPORATION AND SEEPAGE FROM PLAYAS

Figures 10, 11, and 12 show that the evaporating surface of a playa is very large in comparison to the total water volume in the

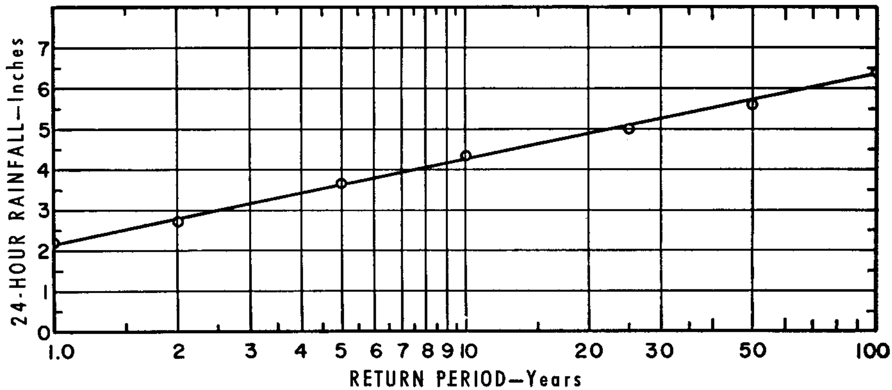

FIGURE 9.—The return period for 24-hour rainfall for the area between Lubbock and Amarillo, Tex. (Hershfield (*18*)). (The average number of years between 24-hour rainfall amounts is equal to the amount shown.)

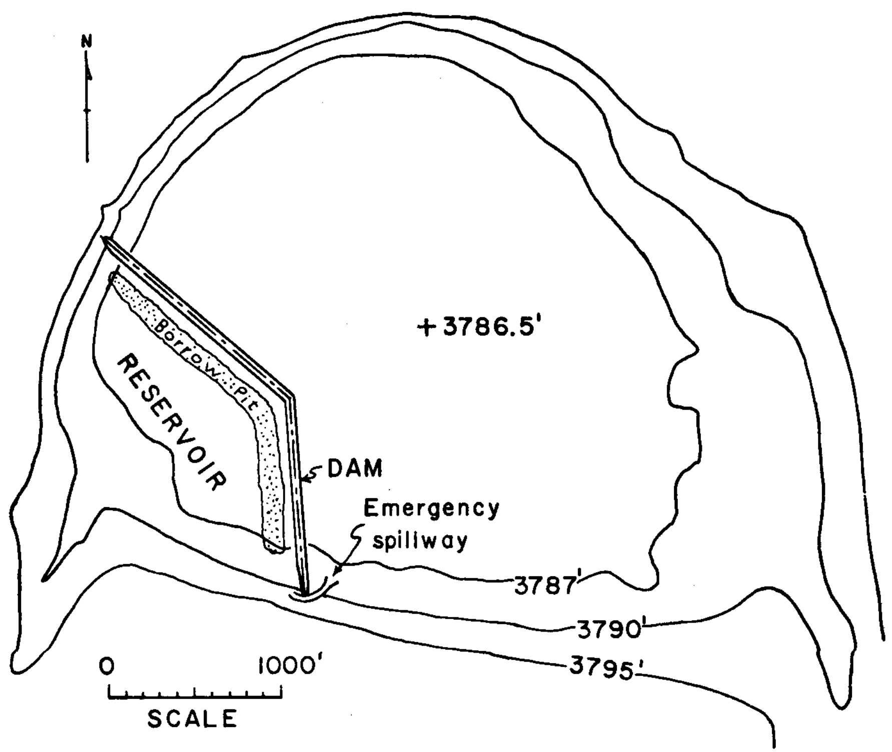

FIGURE 10.—Contour map of the playa on the Southwestern Great Plains Research Center, Bushland, Tex., showing the "detention reservoir."

lake. *Shallow depth and high* evaporation rate combine to make evaporation an important factor.

Lake evaporation is difficult to measure directly. No long-term lake evaporation data are available for the southern High Plains; however, estimates can be made from pan evaporation measured at weather stations in the area.

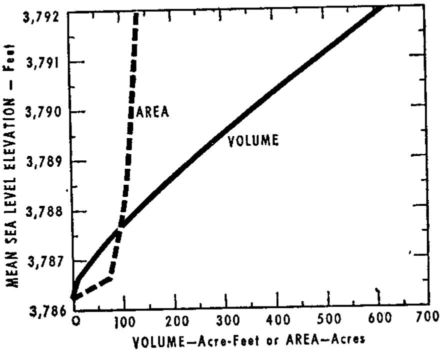

FIGURE 11.—Depth-volume and depth-area curvest for the playa, Southwestern Great Plains Research Center, Bushland, Tex.

Bloodgood, Patterson, and Smith (*4*) discuss evaporation from several types of evaporation pans in Texas and give specifications for each. The Young screen pan is 24 inches in diameter and is buried 33 inches deep in the earth. This pan should provide net heat storage in the water that is close to the actual net heat storage in playa lakes. The coefficient to convert Young screen pan data to lake evaporation should be between 0.96 and 0.98 (*4*). Several authors have discussed the estimation of annual lake evaporation from standard Weather Bureau Class A pan evaporation data (*26, 27, 30*).

Twenty-four years of Young screen pan evaporation data were

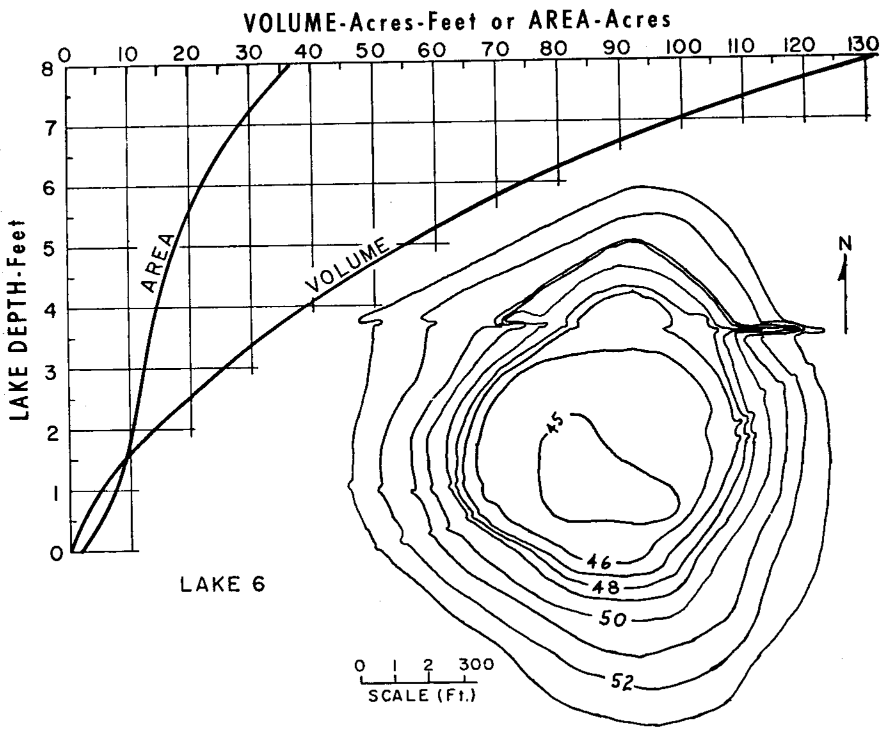

FIGURE 12.—Depth-volume, depth-area curves, and contour map of playa No. 6, Lubbock County, Tex. (Redrawn from Reddell and Rayner (*34*).)

obtained at the weather station at the Southwestern Great Plains Research Center. Mean monthly evaporation from a playa was estimated to be 97 percent of the mean monthly Young screen pan evaporation, as shown in figure 13 along with the 25-year average monthly precipitation.

It is difficult to comprehend the magnitude of evaporation from playas from data such as that shown in figure 13. The monthly average loss rate in gallons per minute from playa surface areas of 100, 50, and 25 acres was calculated and is shown in figure 14. When the playa on the Southwestern Great Plains Research Center is 1.5 feet deep, it covers 100 acres (fig. 11). During all months from May to August, inclusive, monthly average evaporation rate from 100-acre playa surface exceeds 500 gal. per minute.

Seepage from playas has not been measured directly. However, it may be calculated as the difference between playa surface decline and estimated evaporation

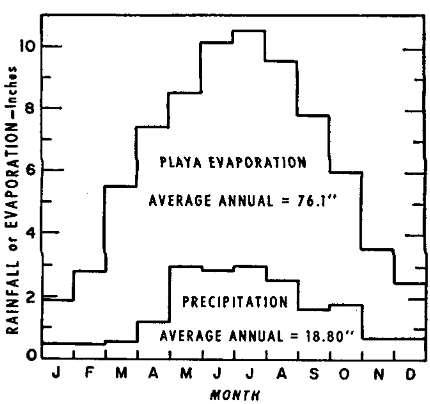

FIGURE 13.—Estimated monthly playa evaporation and average monthly precipitation at Bushland, Tex. (near Amarillo).

from the playa surface. Clyma[7] measured the water level decline for the playa on the Southwestern Great Plains Research Center in 1961. The results of these measurements are shown in figure 15. Evaporation from the playa was estimated from the Young screen pan data. These data indicate that the seepage loss for this playa in a "hardland" or clay soil area is about 14 percent. Since the class A pan evaporation data multiplied by published empirical coefficients indicate slightly lower evaporation, it was concluded that seepage loss would be adequately estimated at 15 percent of the total water in the playa.

Cronin (*11*) reported a 2-year intensive study of 50 playas in a clay loam soil area near Plainview, Tex. Data published in his

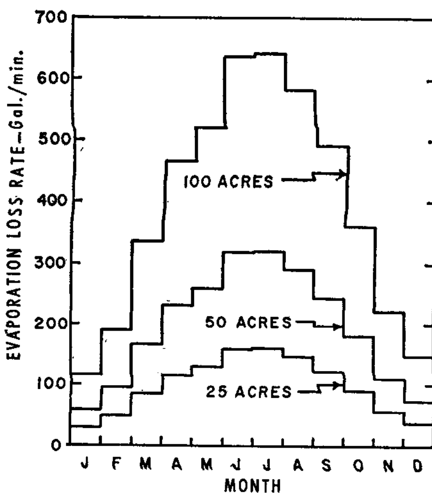

FIGURE 14.—Estimated monthly average rate of evaporation from playa surfaces, Texas High Plains near Amarillo, for 100-, 50-, and 25-acre *lake surfaces.*

[7] Clyma, Wayne, Southwestern Great Plains Research Center. Unpublished data.

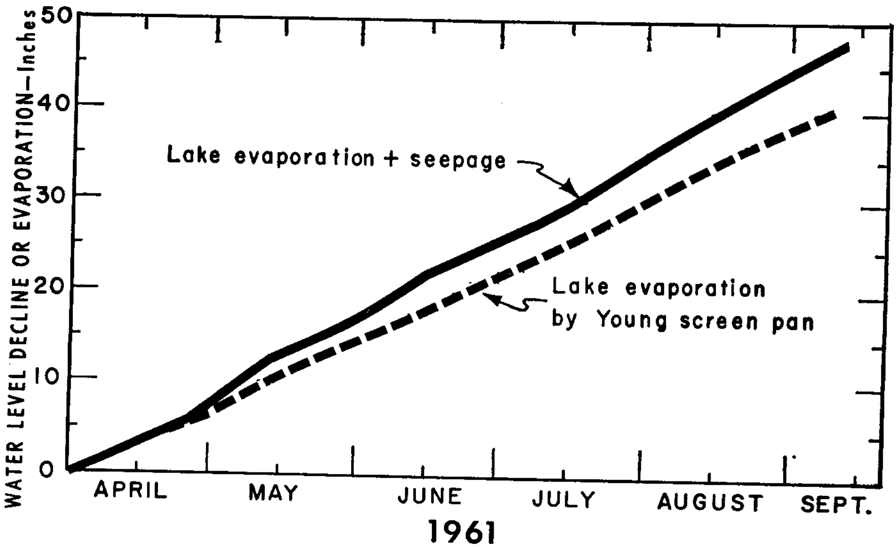

FIGURE 15.—Evaporation plus seepage measured on the playa at the Southwestern Great Plains Research Center, Bushland, Tex., with estimated evaporation loss. (Unpublished data from Wayne Clyma.)

report indicate that 35 percent of the water impounded by these playas was lost by deep percolation.

Data published by Reddell and Rayner (*35*) permit calculations of seepage loss from five playas near Lubbock, Tex., during 1963. These playas are located in a sandy loam soil area. The loss to seepage ranged from 84 to 54 percent of the total water caught. The relation between percentage of seepage loss and playa depth when full is shown in figure 16.

Cronin (*11*) stated that a sandy soil belt generally surrounds the relatively impermeable clay found in the bottom of playas on the "South Plains" near Lubbock. He also stated that water level measurements indicated high seepage rates when the water was deep in the playa and covered the sandy zone and low seepage rates when the playa did not cover the sandy zone. The data of

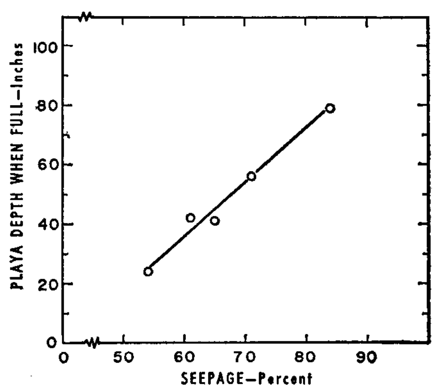

FIGURE 16.—Relation between depth of playa when full to seepage loss, for selected lakes in Lubbock County (sandy and mixed land soils). (Data from Reddell and Rayner (*35*).)

figure 16 may be explained by Cronin's observation.

Above-average rainfall caused the runoff into some playas reported by Reddell and Rayner (*35*); therefore, these playas probably were somewhat deeper than "normal." It is assumed that a playa depth of 36 inches represents a normal condition, and that evaporation would be about 40 percent and seepage 60 percent of the total water impounded in playas in Lubbock County.

CROP WATER REQUIREMENTS

The amount of runoff water that may be used by pumping directly from playas for irrigation is largely determined by crop water use. Data reported by Sherrill[8] shows that cotton, grain sorghum, and wheat are grown on about 90 percent of the irrigated land in the Texas part of the southern High Plains.

Cumulative evapotranspiration (total water use) for cotton, grain sorghum, and wheat is shown in figures 17, 18, and 19, respectively. The recommended average irrigation dates for high yields and the recommended preplant irrigation dates are shown. These figures were derived from data published on cotton by McDaniels (*29*) and Hughes and coworkers (*21*); on grain sorghum and on wheat by Jensen and Sletten (*24*), (*25*).

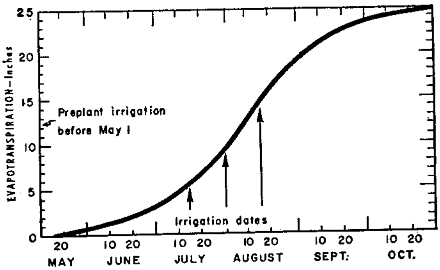

FIGURE 17.—Cumulative evapotranspiration and recommended irrigation dates for cotton, Texas High Plains (McDaniels (*29*) and Hughes(*21*)).

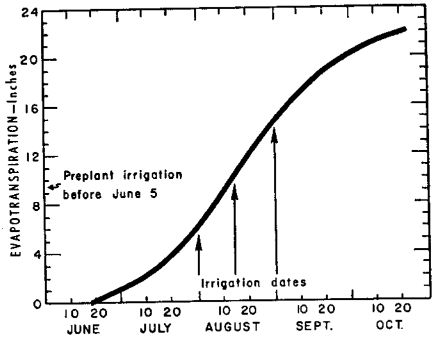

FIGURE 18.—Cumulative evapotranspiration and recommended irrigation dates for grain sorghum planted in mid-June, near Amarillo, Tex. (Jensen (*24*)).

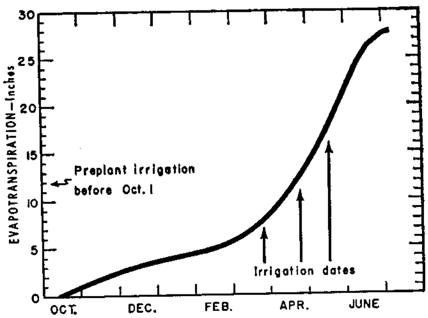

FIGURE 19.—Cumulative evapotranspiration and recommended irrigation dates for winter wheat near Amarillo, Tex. (Jensen (*25*)).

CONSERVATION AND MANAGEMENT PLANS

At present, runoff water is stored in natural playas in the southern High Plains. This practice requires no investment and no expense, but such storage may be a liability as neither the water nor the soil is used efficiently. Several plans might be used to conserve and manage runoff water in the playas.

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[8] See footnote 1.

1. *Surface reservoir storage.*—As most playas are shallow and have large evaporating surfaces, evaporation loss would be reduced and water conserved by confining the runoff water in an artificial reservoir of small surface area and considerable depth. The chief disadvantage of this method is cost.

Two types of reservoirs have been proposed: (1) A deep hole or trench is dug in the playa and the spoil spread over the rest of the playa (hole type); or (2) a dam is built across one end or one corner of the playa (detention type). The detention reservoir may require diversion terraces to carry runoff water into the reservoir (see fig. 10). It would hold all runoff from small storms and release large floods through a spillway into the rest of the playa.

The relative cost of the two reservoir types differs greatly. A detention reservoir constructed on the Southwestern Great Plains Research Center (fig. 10) costs about $32.50 per acre-foot of water storage when full (69 acre-feet). No diversion terraces were constructed. For the same lake and same volume stored, a hole-type reservoir would cost about $400 per acre-foot of storage if earth-moving costs are assumed equal in each case.

2. *Ground-water recharge.*—Recharging aquifers with runoff water has been proposed by many individuals and agencies (*5, 7, 14, 15, 38*).[9] The advantages of recharge are that no water is lost by evaporation once it is in the aquifer and ample free storage space is available. The chief disadvantages are cost of water treatment and injection and cost of pumping water to the surface again. A special problem is introduced by the clay contained in the water, which must be either removed before recharge or removed from recharge wells by well redevelopment. It may not be possible to redevelop wells plugged by clay and silt (*7*). Several writers have discussed ground-water recharge in the southern High Plains (*6, 7, 8, 9, 22, 38*).

3. *Irrigation pumping from playa.*—Since irrigated fields are often located near playas, it has been proposed (*13*) that runoff water should be pumped directly from playas to irrigate crops. The chief advantage of this procedure is its relatively low pumping cost. When runoff-producing rains occur, however, the need for irrigation is low. This plan results in very high evaporation losses from the lake surface.

4. *Surface reservoir and irrigation pumping combined.*—This plan is a combination of plans 1 and 3. Evaporation losses are reduced by confining runoff water in a small reservoir until it is pumped for irrigation.

5. *Conservation system.*—This plan conserves the maximum quantity of water and it combines plans 1 and 2. If runoff water were available when needed for irrigation, this system would include plan 3. Small amounts of runoff water would be detained in the detention reservoir until it could be recharged to ground water; however, part of the large runoff volumes would be stored in the rest of the playa. The true concept of the detention reservoir would be achieved by draining the reservoir as rapidly as possible after each runoff event by recharge or by pumping; therefore, most runoff could be confined in a

[9] See also footnote 3.

relatively small capacity reservoir. Recharge to ground water would begin immediately from the rest of the playa, where evaporation rate is high, and continue until all water in the playa and detention reservoir was gone.

6. *All precipitation retained on the watershed.*—It is frequently proposed that the best use of precipitation is to retain all of it on the watershed where it falls. This idea has been advanced as one possible way to conserve runoff water which now accumulates in playas. On the hardlands of the southern High Plains, the only known feasible methods for holding all precipitation on the land are costly. The proven methods are (1) land leveling on the steeper slopes; and (2) either land leveling or level-closed-end terraces on flatter slopes.

MANAGEMENT PLAN EVALUATION

Several management plans are evaluated as compared with no management for the playa on the Southwestern Great Plains Research Center. The amount of runoff water beneficially used and that lost by evaporation were studied. It was assumed that runoff water was present in the playa on June 1, and there was no further runoff. Evaporation and seepage data presented earlier were used for estimation purposes. It was also assumed that seepage from the detention reservoir would be the same as from the playa. The systems were evaluated for 56 acre-feet of runoff volume (1.0-foot depth in playa) and for 152.5 acre-feet of runoff volume (2.0-foot depth in playa).

Runoff volume of 56 acre-feet represents an average runoff from the watershed of 0.26 inch. In 4 out of 10 years, runoff from flat fallow will exceed 0.26 inch during May (fig. 5).

Runoff volume of 152.5 acre-feet represents an average runoff from the watershed of 0.72 inch. In 2 (plus) years out of 10, runoff from flat fallow will exceed 0.72 inch during May (fig. 5).

Plans 1, 3, 4, and 5

The plans evaluated were (1) storage in a detention reservoir; (3) storage in playa with irrigation beginning on either July 1 or July 15; (4) storage in a detention reservoir with pumping for irrigation beginning on July 1 or July 15; and (5) the conservation system where 56 acre-feet of runoff was all stored in the reservoir and where 152.5 acre-feet of runoff was stored in the reservoir (69 acre-feet) and in the playa (83.5 acre-feet) — ground-water recharge beginning on June 1.

It was assumed that either irrigation pumping or ground-water recharge was continuous at the rate of 900 gallons per minute, and that for average conditions the daily evaporation was the average monthly rate divided by the number of days per month. Rainfall directly into the lake after June 1 was ignored in all calculations. It is recognized that some of the assumptions introduce error; however, the results give comparisons of management plans.

Daily water balance and runoff water disposition by the different management systems were calculated. Estimated water lost by evaporation, pumped for irrigation, or stored as ground water (either natural or artificial) is shown in figures 20 and 21. Evaporation loss under the various management systems ranged from 85 to 15 percent. It was assumed that any water pumped for irrigation, recharged, or lost from the playa by seepage (which presumably reaches the water table) was conserved or beneficially used.

Figures 22 and 23 show the daily volume of water remaining in surface storage through June and July for the management systems evaluated. Fifty-six acre-feet of water would keep the playa covered, prevent tillage, and produce mosquitoes until June 26 where the water was stored in the playa with no conservation. Where the reservoir held 56 acre-feet of water on June 1, the playa would never be flooded and all water should be removed from the surface by June 13 by recharge. Where the reservoir held 56 acre-feet on June 1 and with no recharge, irrigation would be possible on July 1 or July 15, with mosquito production to July 9 and 21, respectively (fig. 22).

Where the water is stored in the playa with no conservation and 152.5 acre-feet of water is stored on June 1, the playa would remain covered, tillage would be prevented, and mosquitoes would be produced past July 20. Pumping for irrigation provides only small improvement. The conservation system (plan 5) would remove all water from the playa area outside the reservoir by

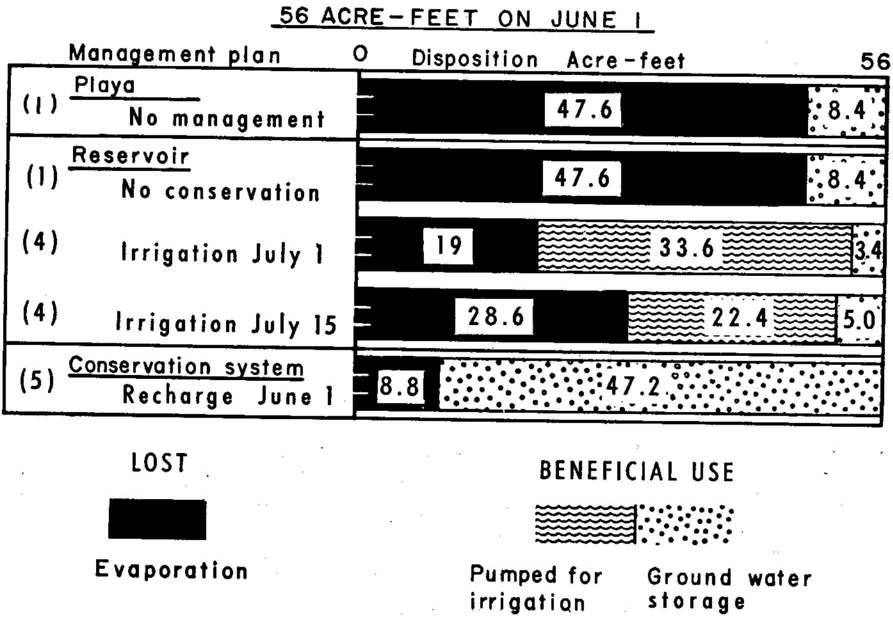

FIGURE 20.—Estimated evaporation loss, water pumped for irrigation, or stored as ground water by different management systems at the Southwestern Great Plains Research Center near Amarillo (hardlands soils) for 56 acre-feet of runoff available on June 1.

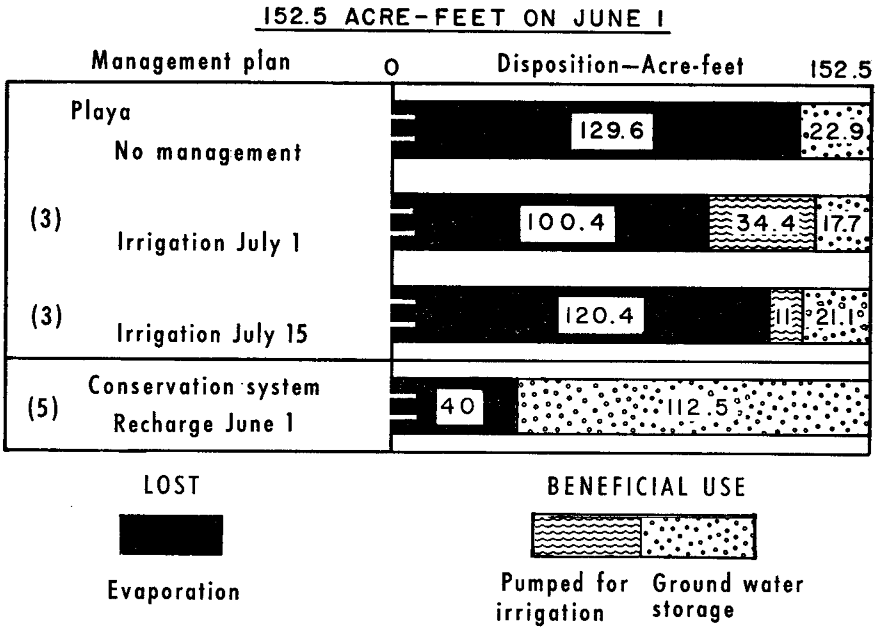

FIGURE 21.—Estimated evaporation loss, water pumped for irrigation, or stored as ground water by different management systems at the Southwestern Great Plains Research Center near Amarillo (hardland soils) for 152.5 acre-feet of runoff available on June 1.

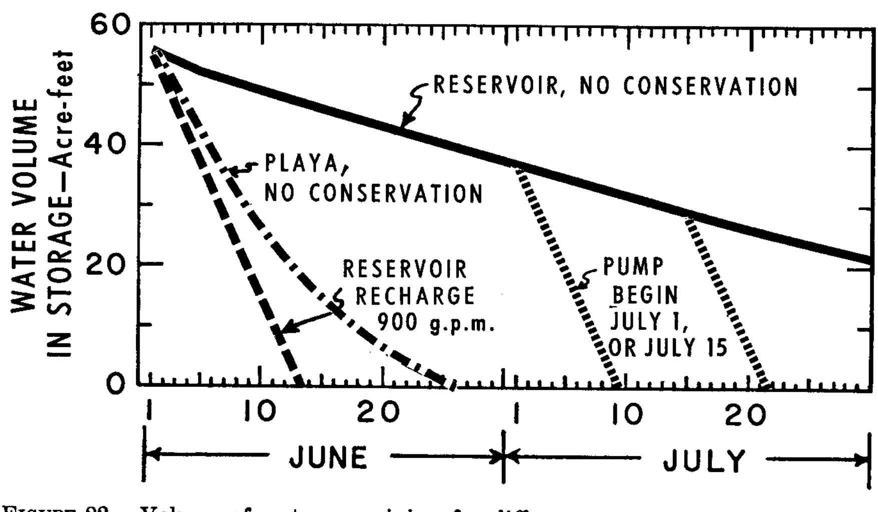

FIGURE 22.—Volume of water remaining for different management systems of the playa, Southwestern Great Plains Research Center, Bushland, Tex.; 56 acre-feet available on June 1 (1-foot depth in playa).

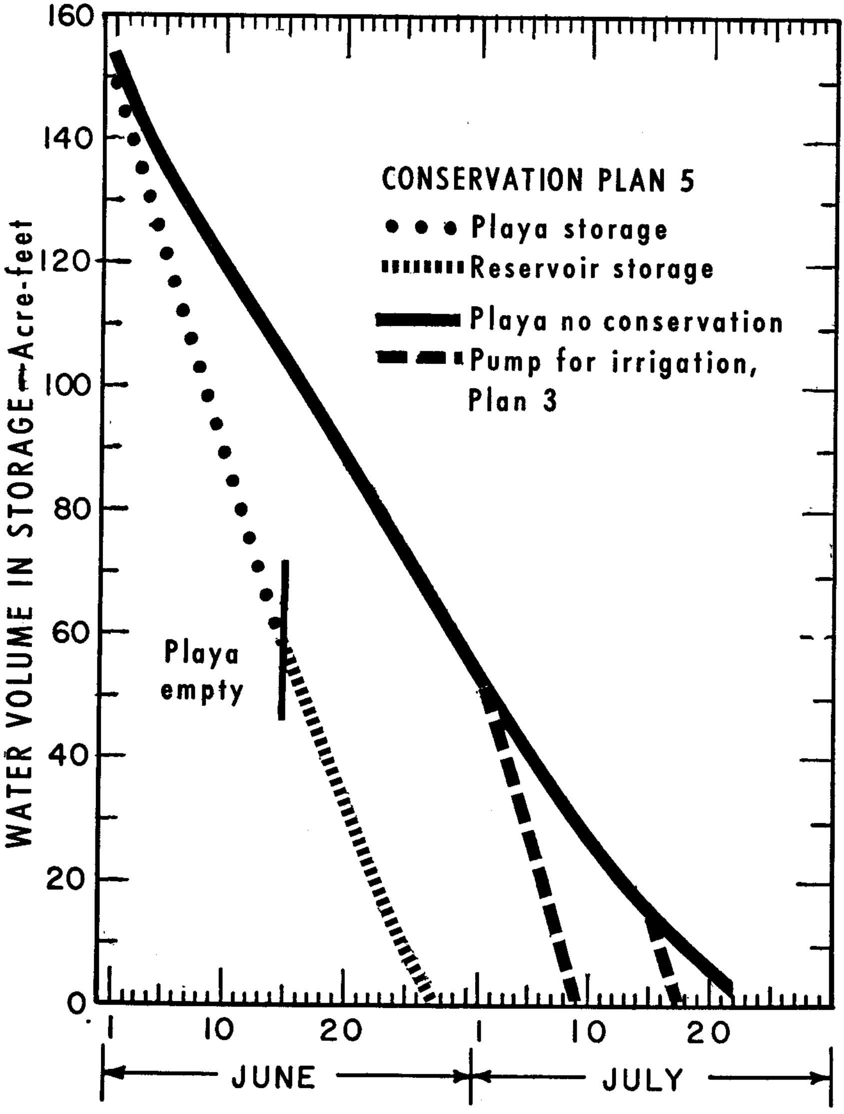

FIGURE 23.—Volume of water remaining for different management systems of the playa, Southwestern Great Plains Research Center, Bushland, Tex.; 152.5 acre-feet available on June 1 (2-foot depth in playa).

June 14, reducing mosquito production and making cultivation and planting of summer crops possible on the land (fig. 23).

The data shown in figures 14, 20, 21, 22, and 23 show that a reservoir is required to conserve water if pumping for irrigation from surface storage is practiced. The data shown in figures 22 and 23 show that pumping directly from a playa or a reservoir for irrigation cannot remove all water soon enough for profitable crop production in the playa. The addition of the reservoir prevents flooding of the rest of the playa for small runoff volumes (56 acre-feet) and makes it possible to drain the rest of the playa in 14 days (plan 5) for 152.5 acre-feet of runoff.

The data shown in figures 20 to 23 emphasize the substantial loss of water due to evaporation from playas. Pumping for irrigation from the playa would be impossible for the case of 56 acre-feet, because all of the water would be gone by June 26 and only about 15 acre-feet remain on June 15 (fig. 22). Pumping for irrigation from the playa resulted in very inefficient water use for the case of 152.5 acre-feet, because most of the water was lost by evaporation (figs. 21 and 23). Even with the maximum conservation system (plan 5), 26 percent of 152.5 acre-feet was lost by evaporation (fig. 21), indicating the need for a much higher ground-water recharge rate.

Plan 6

It is often taken for granted that management plan 6, "All precipitation retained on the watershed," is the best way to use potential runoff water. This is not always true for the southern High Plains.

Data from research plots at the Southwestern Great Plains Research Center may be used to compare water use efficiency of (1) conventional continuous dryland grain sorghum, runoff permitted; (2) continuous dryland grain sorghum grown on bench leveled land, no runoff; and (3) continuous grain sorghum grown under irrigated conditions. The plots were all on the same soil type with essentially equal water-holding capacity, native fertility, and soil depth. In all cases, cultural practices, planting rate, planting date, sorghum variety, soil fertility, and other factors affecting yield were carefully selected or controlled to give maximum yield under either dryland or irrigated conditions.

Efficiency of the dryland practices was determined by calculating pounds of grain produced per inch of total precipitation between November 1 and October 31. Efficiency of the irrigated treatments was determined by calculating pounds of grain produced per inch of total water use from any source during the growing season.

Table 1 shows the results of this study. It is apparent that water is used much more efficiently if applied when the crop needs it rather than when supplied at random by rainfall.

The data from Musick and coworkers (*32*), showing a water use efficiency of 620 pounds of grain per inch of water applied at milk stage, emphasize the importance of water application timing on grain sorghum. Water use efficiency is low on the dryland grain sorghum because the moisture supply is controlled by weather factors and not by crop needs. Retention of all rainfall by bench leveling does not improve water application timing or water use efficiency.

TABLE 1.—*Comparison of water use efficiency for continuous grain sorghum at the Southwestern Great Plains Research Center, Bushland, Tex. Efficiency is compared for conventional dryland practice where runoff is allowed, bench leveled dryland where no runoff is allowed, and adequate irrigation for high yields*

System	Water use efficiency	Reference
	Pounds of grain per inch of water	
DRYLAND:		
Conventional (runoff allowed), total annual	80	([1])
Bench leveled (no runoff allowed), total annual	90	—
IRRIGATED:		
Adequate water, total seasonal	360	(*24*)
Adequate water, total seasonal	320	(*32*)
Adequate water-efficiency of milk stage, irrigation only	620	(*32*)

[1] Johnson, W. C. Unpublished data.

FEASIBILITY OF PUMPING FROM PLAYAS FOR IRRIGATION

Several factors influence the feasibility of pumping runoff water directly from lakes for irrigation, including crop growth stage, crop water use from the soil, probable timing of runoff storage in playas, and water-holding capacity of the soil.

When significant volumes of runoff occur in playas, cropped watershed fields probably will be too wet for efficient storage of runoff water pumped from playas. Significant runoff volumes are produced by rainfall periods of several days' duration, with some rainfall on most days of the period (figs. 3, 7, and 8). Therefore, the soil moisture reservoir should be full immediately after the storage of significant volumes of runoff water in playas on either "hardland" or "sandy" soils. Isolated high-intensity storms may produce runoff without completely refilling the soil moisture reservoir; however, these events do not occur frequently.

Winter Wheat

It is unlikely that significant volumes of runoff water could be profitably pumped directly from playas to irrigate growing wheat. Water storage in playas through the late summer for fall irrigation would result in very high evaporation losses. However, runoff water might be efficiently used to preirrigate winter wheatland.

Growing winter wheat requires most water during April, May, and early June, and requires irrigation to about May 15 for high yields (fig. 19). If the soil moisture reservoir is full on May 15, additional irrigation increases yield little or none (*25*) and increases the hazard of wet ground at harvesttime, which could delay harvest and reduce yield.

Figure 5 shows that significant runoff is not likely before May. Since watershed soils are likely to be relatively dry on May 1 and storms are less intense and produce lower rainfall during early May as compared with late May, most runoff is likely to occur too late for effective winter wheat irrigation.

Cotton or Grain Sorghum

Preplant irrigation of cotton or sorghum fields should fill the soil moisture reservoir through the entire root zone. A soil profile initially full of water and seasonal rainfall usually provide adequate water for cotton until July 15, and for grain sorghum until August 1 (figs. 17 and 18).

Runoff before the first cotton or grain sorghum irrigation is most likely in May or June, with most runoff in May. The data shown in figures 20, 21, 22, and 23 clearly show the large evaporation loss where water is stored on the surface for irrigation on July 1 or 15. Conservation of runoff water accumulating in May or June will require a reservoir as a minimum conservation measure; however, ground-water recharge would be preferred.

During July and August, both cotton and grain sorghum use large amounts of water and in all but the wettest years, irrigation is required for high yields (*21, 24, 29*). After rainfall that produces runoff, the soil profile under irrigated cotton or grain sorghum is likely to be filled to maximum water-holding capacity. Therefore, a minimum of 10 to 14 days would be required before the soil dried enough to store a 4-inch irrigation efficiently (figs. 17 and 18). During 10 days in July or August, over 3 inches of water (25 acre-feet from a 100-acre playa) will evaporate from a playa surface (fig. 13), indicating that a reservoir is the minimum conservation method.

Irrigation is normally not needed on cotton after August 15, or grain sorghum after September 5; however, runoff after these dates is possible (fig. 5). Ground-water recharge would be the only available and feasible method for conserving runoff water occurring late in the summer.

It is concluded that only a limited amount of the total runoff water accumulating in playas could be pumped directly for cotton or grain sorghum irrigation.

Two serious objections to storing water in playas for later pumping to irrigate crops are the loss of production potential in the playa and mosquito production.

DISCUSSION

It may be argued that the cost of ground-water recharge plus the cost of pumping recharged water to the ground surface again prohibit ground-water recharge as a feasible practice. However, there are some important facts that disprove this argument. First, if runoff water in playas is not recharged, then most of it will be lost by evaporation, representing a total loss. Second, mosquito production remains a problem where runoff water is confined in a playa or reservoir for any purpose. Third, playas are essentially lost for useful production or use without ground-water recharge. Therefore, ground-water recharge is a necessary part of an effective and efficient plan to manage runoff water accumulated in playas.

Data presented in figure 16 indicate a seepage loss higher than 50 percent on some playas in the sandy soil areas of the Texas High Plains. Where the natural seepage loss is so high, storage of significant amounts of water for direct pumping from playas to irrigated fields would be nearly impossible. Artificial ground-water recharge to increase playa drainage rate would make crop production on the playa beds feasible in most years.

Mosquito control requires very good management and a high rate of playa drainage. Mosquitoes require a minimum of 5 days to complete the water stage in warm water, to a maximum of 18 days in cool water (*12*). Mosquitoes die if deprived of water during the water stage of their life cycle (*12*). Elimination of shallow water by storing runoff in reservoirs should reduce mosquito production (*14*). Maximum mosquito control will require a combination of reservoirs and ground-water recharge on most playas. The reservoir would reduce mosquito production during the period required for recharging the playa water because the area of shallow water is reduced in a reservoir. In addition, the rate of ground-water recharge must be higher than the assumed 900 gal./min. rate for large playas and must be at least 900 gal./min. for medium-sized playas, to drain them in sufficient time to deprive the mosquito larva of water.

Since recharge or other beneficial use must begin immediately after runoff water is impounded in playas to prevent evaporation losses, runoff water management systems should be designed to handle smaller runoff volumes that occur frequently, as well as large runoff volumes. If conservation measures are delayed until a large runoff volume accumulates in the playa, evaporation losses will be very high. The detention reservoir could accumulate small runoff amounts and hold the water for recharge or direct pumping for irrigation.

SUMMARY AND CONCLUSIONS

On the average, some runoff may be expected each year in the southern High Plains. Monthly runoff from fallow may be expected to equal or exceed 1 inch during 10 months in 10 years, and equal or exceed one-fourth inch during 24 months in 10 years.

Evaporation rate is, on the average, higher than 500 gal./min. from a 100-acre playa surface during May to August, inclusive. The very high rate of water loss from playas by evaporation demands efficient management systems to conserve runoff water impounded in playas.

The most efficient method for conserving runoff water impounded in playas is a combination detention reservoir and ground-water recharge. The next most efficient system is runoff water storage in a reservoir for later pumping directly to irrigated fields.

Water loss by evaporation was reduced from 47.6 acre-feet for a playa only to 8.8 acre-feet for a reservoir and ground-water recharge combined where 56 acre-feet was available on June 1. Evaporation loss was reduced from 129.6 acre-feet for a playa only to 40 acre-feet for a conservation system where 152.5 acre-feet was available on June 1.

Ground-water recharge appears to be the most effective method for control of mosquitoes originating in playas, and the most effective method for water conservation. Mosquito numbers should be reduced by impounding runoff water in a reservoir.

Runoff water management systems must be designed to handle relatively small runoff volumes that occur frequently as well as large volumes that occur infrequently.

Retention of all precipitation on the land where it falls is not the best water management or conservation plan for the southern High Plains.

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