TEXAS WATER COMMISSION

BULLETIN 6413 A

APPENDICES TO BULLETIN 6413

WATER-SUPPLY LIMITATIONS ON IRRIGATION FROM THE RIO GRANDE IN STARR, HIDALGO, CAMERON, AND WILLACY COUNTIES, TEXAS

By

John T. Carr, Jr., I. G. Janca,
Robert L. Warzecha, Ralph B. Hendricks,
Allen E. Richardson, Henry H. Porterfield, Jr.,
and Paul T. Gillett

August 1965

Published and distributed
by the
Texas Water Commission
Post Office Box 12311
Austin, Texas 78711

FOREWORD

These appendices are the reports on the separate investigations and studies undertaken to obtain pertinent data and to develop bases for the selection of criteria for use in the comprehensive study summarized in the Texas Water Commission Bulletin 6413, "Water-Supply Limitations on Irrigation From the Rio Grande in Starr, Hidalgo, Cameron, and Willacy Counties, Texas," November 1964, and are supplementary thereto.

The criteria and assumptions used in the various phases of the computations made in this comprehensive study were selected and determined by John J. Vandertulip, Chief Engineer; Louis L. McDaniels, Research Program Coordinator; and C. Olen Rucker, Hydrology Program Coordinator in collaboration with the personnel engaged in this study.

The appendices were prepared in final form by Mr. McDaniels in collaboration with each of the authors of the separate reports.

TEXAS WATER COMMISSION

Joe D. Carter, Chairman

TABLE OF CONTENTS

APPENDIX I

CLIMATE OF THE LOWER RIO GRANDE VALLEY

By

John T. Carr, Jr.

TABLE OF CONTENTS

ILLUSTRATIONS

Figures

C L I M A T E   O F   T H E   L O W E R
R I O   G R A N D E   V A L L E Y

INTRODUCTION

The uniqueness of the climate and the characteristics of climatic factors in the Lower Rio Grande Valley of Texas were cause for a separate climatic study as a part of the comprehensive Valley study of the limitation on irrigation with waters of the Rio Grande.

The climate of the Valley varies from east to west. Average annual rainfall decreases westward from the Gulf Coast while air temperature and potential evaporation increase. Because of these variations, the Valley can best be studied as three separate climatic areas in transition from subhumid to semiarid conditions.

The effect of these variations in climatic characteristics in the Valley on agriculture is to increase the amount of water required for comparable crop production from the east to the west. For this reason, three study areas in the Valley were selected for separate climatic analysis and investigation of irrigation requirements. The boundaries of the three areas are not rigidly defined but do approximate Starr County as Area 1, Hidalgo County as Area 2, and Cameron and Willacy Counties as Area 3. Generally representative central points for the irrigated portions of these areas are respectively Rio Grande City, Edinburgh, and Harlingen.

PHYSIOGRAPHY

Physiographically, the Lower Rio Grande Valley below Falcon Dam lies wholly within the West Gulf Coast Plain Section of the Coastal Plain Province--altogether within the Atlantic Plain Major Division(1) of North America. The major physiographic feature of the area is that it is young land grading inland to mature coastal plain. Most of the Lower Rio Grande Valley is less than 200 feet above mean sea level. The mature coastal plain becomes the dominant feature beyond the Bordas Escarpment, which is located in Starr County about 100 miles inland from the Gulf of Mexico. Here the topography begins to become more rugged as it rises toward the Edwards Plateau to the north. Elevations of 400 to 600 feet above mean sea level are then more common.

CLIMATOLOGY

Rainfall

Linking climate classification to humidity and rainfall and using the distribution of the precipitation as a basis for climate classification, the reach of the Valley below Falcon Dam may be described as subhumid near the Gulf Coast grading to semiarid toward Falcon Dam. In this study, the 20-inch isohyet has been arbitrarily designated as a line separating the semiarid from the subhumid region. An area of transition between subhumid and semiarid divides the Lower Rio Grande Valley into three climatic areas. During some years, the average rainfall over the eastern area (Area 3) has a total annual accumulation exceeding 40 inches. During the 30-year period preceding 1960 there were at least 3 such years, but the overall climate for Area 3 is classified subhumid. Area 2, the transition area (17.5- to 22.5-inch average annual rainfall) between the subhumid and semiarid climates, has been subhumid 13 of the 30 years prior to 1960, semiarid 15 years, and has had less than 10 inches of rainfall each year during 2 of the years. The western portion of the Valley (Area 1), while semiarid in climate classification, has been subhumid about 5 years during the 30-year period preceding 1960. About 20 of the 30 years, Area 1 has experienced rainfall amounts of less than 20 inches per year. In 1950, 1952, and 1956 some places in Area 1 had a total rainfall of less than 10 inches.

Wind, Humidity, and Warm Air

During all months of the year, the winds in all three areas of the Lower Rio Grande Valley prevail generally from a southeasterly direction bringing with them maritime-tropical or "modified" maritime-tropical air and Gulf of Mexico moisture in greater or lesser amounts, depending mainly on the path taken by the air after it leaves the Gulf.

The wind prevails in all three areas generally from a southerly direction, but specifically: the prevailing wind in Area 3 comes from a little more of a southeasterly direction than does the wind in Area 2; the prevailing wind in Area 2 is from a little more of a southeasterly direction than is the wind in Area 1. These little differences in prevailing wind direction exert a much greater influence on rainfall and potential evaporation that is immediately apparent. Because moisture-laden air from the Gulf of Mexico provides the water vapor that in turn provides the moisture for rain and high humidities, the terrain over which the air travels and the distance it must travel before reaching the three Lower Rio Grande Valley areas (with which we are concerned here) are of prime importance.

Air has the quality that the hotter it becomes the more moisture it can hold in vapor form (humidity). When once-moist Gulf air passes over land that is hotter than the air, such as the Mexican countryside south of the Rio Grande, the effect is for the air to be heated by the land--thereby increasing the capacity of the air to hold its moisture, or, in other words, decreasing the relative humidity. The same air that was once high in humidity, therefore, becomes relatively low in humidity after passing over hot land even though no rain has fallen from the air along the way.

Much of the wind in Areas 2 and 3 comes from the Gulf of Mexico by an almost direct route, hence has travelled only a short distance. It, therefore, retains much of its original moisture. On the other hand, much of the wind reaching Area 1 and the western portion of Area 2 has first passed over hot and dry Mexican terrain, and has travelled a longer distance--therefore, has lost much of its original moisture and has picked up considerable heat. This "modified" maritime-tropical air arrives in Area 1 hotter and drier in the summer than does air that has undergone less "modification" enroute to Area 3.

The mild winter air temperatures of the Valley are favorable to citrus production and to successive cropping, especially winter vegetables. The favorableness of temperatures in the areas is demonstrated by the annual minimum temperature for the 45 years, 1919-63, being 32°F or higher for 15 years in Harlingen and for 11 years in Edinburg. During the 36 years, 1928-63, at Rio Grande City, the annual minimum temperature was higher than 32°F for 1 year.

Cold Air

While the winds prevail from a general southerly direction, the strongest winds recorded are usually from a northerly direction during the few winter months when dry, cold-air masses of continental origin invade the area from the north. These invasions of cold air are locally termed "northers." Severe northers may cause significant crop loss from freezing.

In describing microclimatological conditions affecting freezes, Hildreth and Orton[2] discuss many factors that affect heat transmission by radiation and conduction, and that act individually or in combination to produce an uneven temperature distribution over a small area resulting sometimes in very localized freeze or frost conditions, even on the same farm. Among the items for consideration as contributors to localized minimum-temperature conditions are: [1] net outward radiation from the earth; [2] elevation and slope of terrain; and [3] type and condition of soil.

Hildreth and Orton point out that because the thermometers in standard instrument shelters are 5 feet above the ground the temperatures occurring simultaneously at the ground level, 2, 3, or 7 feet above the ground, or at any level other than 5 feet, are not known (unless measured at those levels). In making allowances for temperatures occurring on the ground or at levels other than the 5-foot level, the factors affecting freezes, which were previously discussed, must be considered.

Frosts and freezes can and do occur at ground level and in low "pockets" in the topography when the 5-foot high instrument shelter temperature never goes below 32°F. On a clear night with calm wind, a ground-level temperature 4°F lower than the 5-foot level temperature is not uncommon, and under ideal conditions, a ground-level temperature 6°F below the temperature at 5 feet may occur.

SUMMARY

Progressing inland and westward up the Valley and when examining the climate with respect to moisture, the following characteristics become apparent, and can be credited mainly to the path taken by the wind after it leaves the Gulf of Mexico enroute to Areas 1, 2, and 3:

1. The percentage relative humidity becomes less and less, providing drier air into which surface water can evaporate;

2. The average summertime wind speed increases a little--more efficiently removing the envelope, or dome, of moist air forming over the water surface as it evaporates;

3. Summertime maximum temperatures become hotter and hotter, permitting the air to absorb more water; and,

4. Total average annual rainfall becomes less and less because the once-moist Gulf of Mexico air has pretty much "dried out" over the Mexican countryside before it arrives in Area 1 and parts of Area 2.

Regional analyses of climatic data disclose the following information for the areas shown:

	Area 1	Area 2	Area 3
Average annual rainfall depth, in inches	17	19	26
Average annual temperature, in degrees Fahrenheit	74.5	74.1	74.3
Lowest temperature of record, in degrees Fahrenheit	10 (1962)	18 (1962)	14 (1962)
Average annual potential lake evaporation depth, in inches	62	60	58
Highest official rainfall depth, in inches	41 (1958)	46 (1933)	60 (1855)
Lowest official rainfall depth, in inches	3 (1950)	7 (1956)	9 (1956)

Among the better-known meteorological conditions affecting freezes, Hildreth and Orton, q.v., discuss:

1. The invasion of a cold air mass;

2. Low humidity, absence of clouds, and comparatively little wind movement;

3. The "sinking" quality and stratification of the bottom layers of cold air;

4. The characteristically (under ideal conditions) lower ground-level temperature in comparison with the 5-foot high standard instrument shelter temperature; and,

5. The fact that if the invading air mass is cold enough, a freeze will occur in spite of wind movement, clouds, humidity, windbreaks, etc.

Based on Hildreth and Orton's "Freeze Probabilities in Texas," characteristic freeze data applicable to the Valley areas are as follows:

	Area 1	Area 2	Area 3
First usual occurrence of freezing temperature in the fall	Dec. 11	Dec. 14	Dec. 16
Last usual occurrence of freezing temperature in the spring	Feb. 20	Feb. 6	Feb. 9
Usual number of freeze-free days per year	345	348	350
Percent probability of no freeze occurring during the autumn	29	40	59
Percent probability of no freeze occurring during the spring	10	20	25

Based on the consecutive yearly records of air temperature for 36 years (1928-63) at Rio Grande City and 45 years (1919-63) at Edinburg and at Harlingen, there is a 45-percent probability of having an annual minimum free-air temperature equal to or less than the average annual minimum of 26°F at Rio Grande City; a 42-percent probability of having an annual minimum free-air temperature equal to or less than the average annual minimum of 28°F at Edinburg; and, a 40-percent probability of having an annual minimum free-air temperature equal to or less than the average annual minimum of 28°F at Harlingen.

The following Figures 1 through 7 depict the characteristic monthly distribution of climatic elements and historical annual climatic data for the Valley study Areas 1, 2, and 3 for the standard climatological 30-year base period 1931-60, and the Lower Rio Grande Valley as a whole.

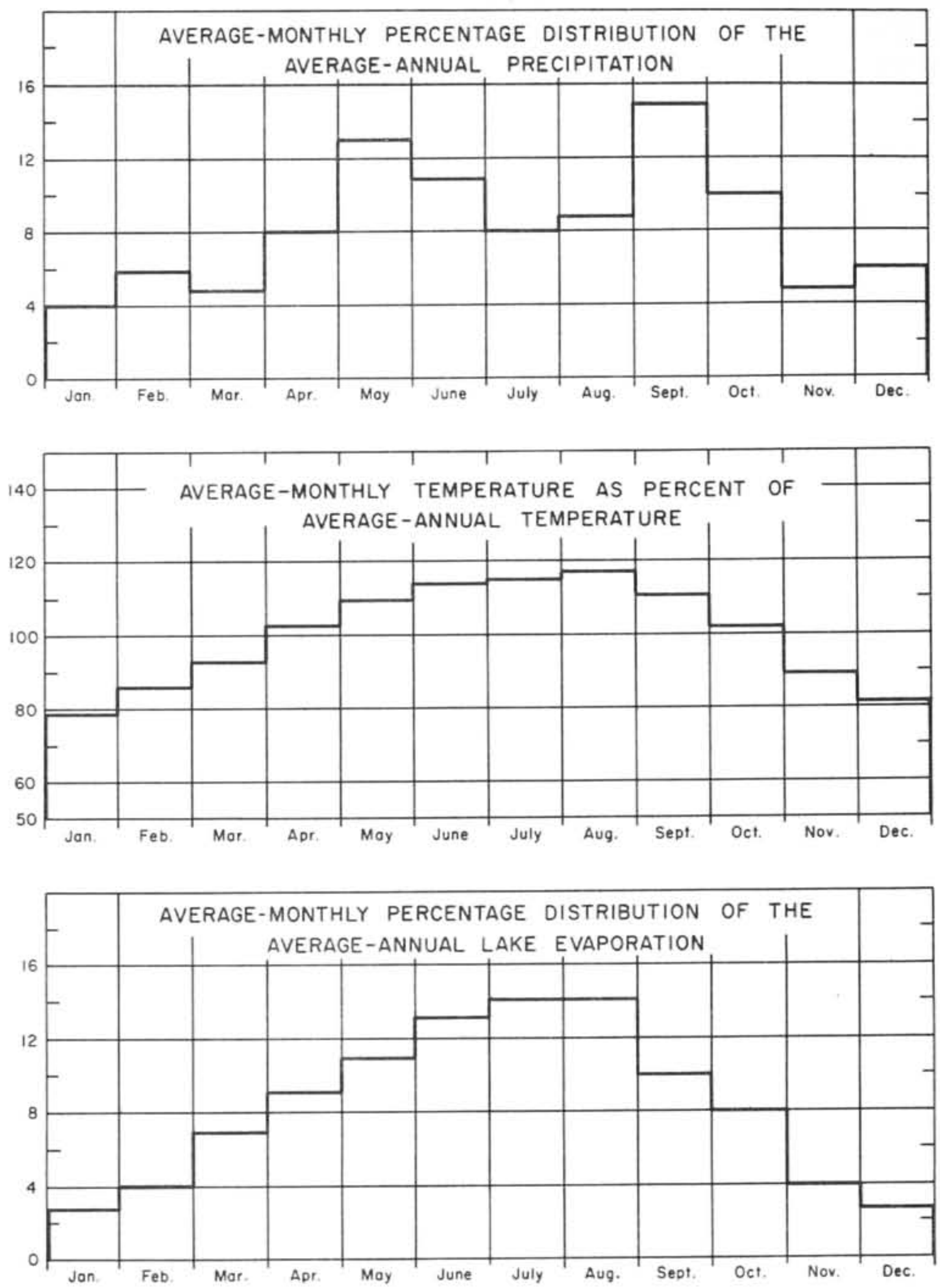

Figure 1

Characteristic Distribution of Climatic Elements, Valley Area I

Texas Water Commission

186

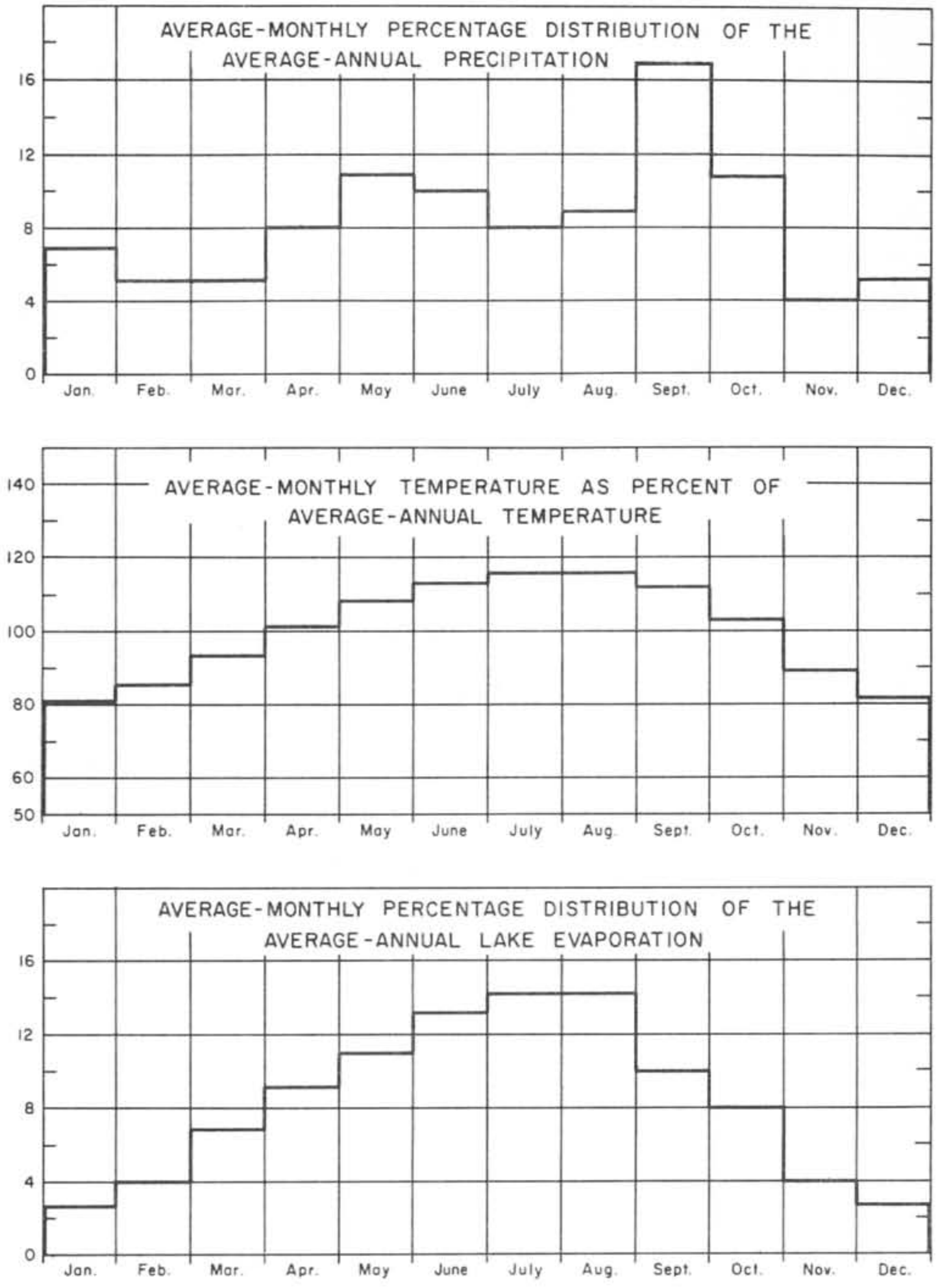

Figure 2

Characteristic Distribution of Climatic Elements, Valley Area 2

Texas Water Commission

186

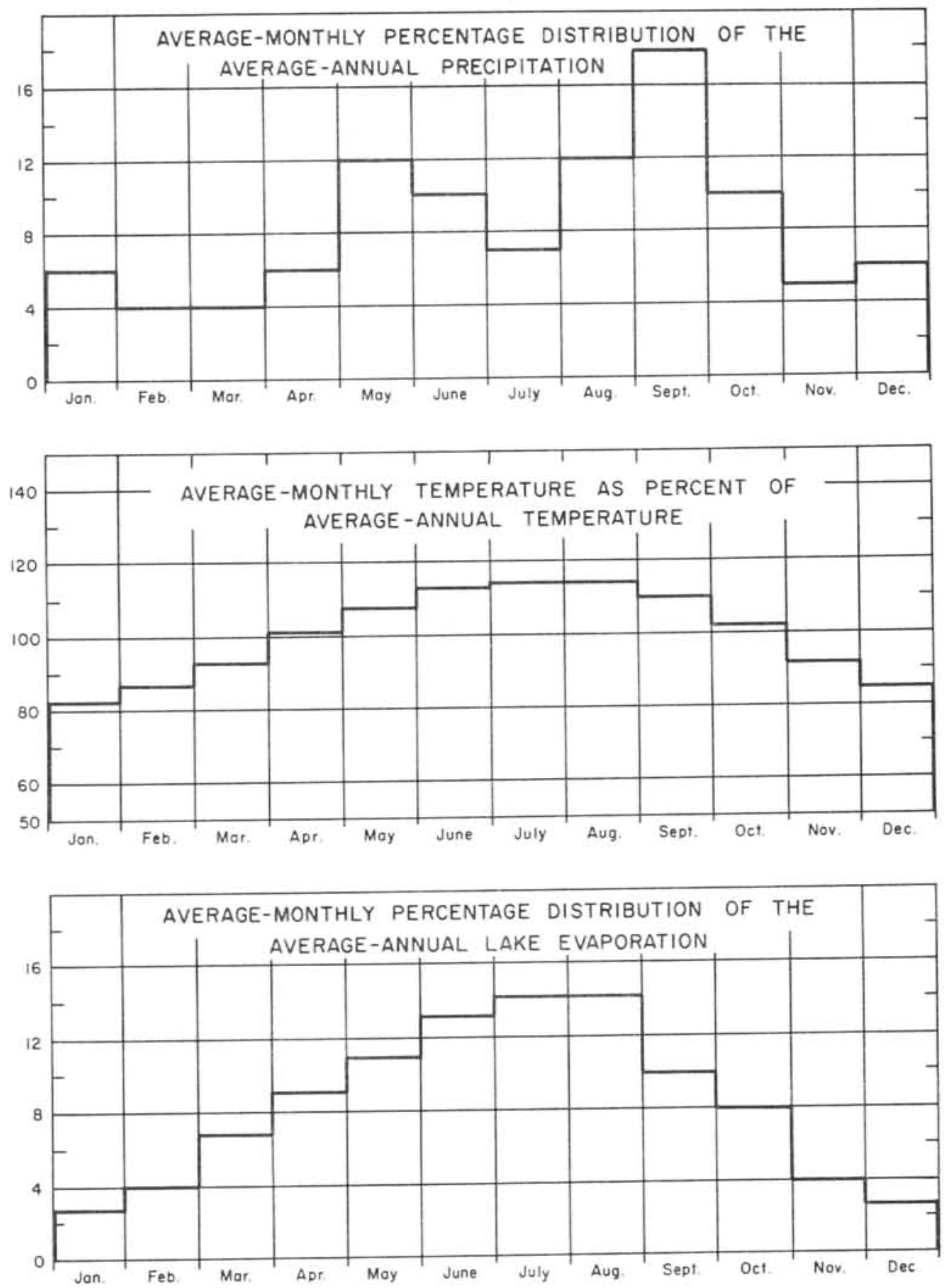

Figure 3

Characteristic Distribution of Climatic Elements, Valley Area 3

Texas Water Commission

186

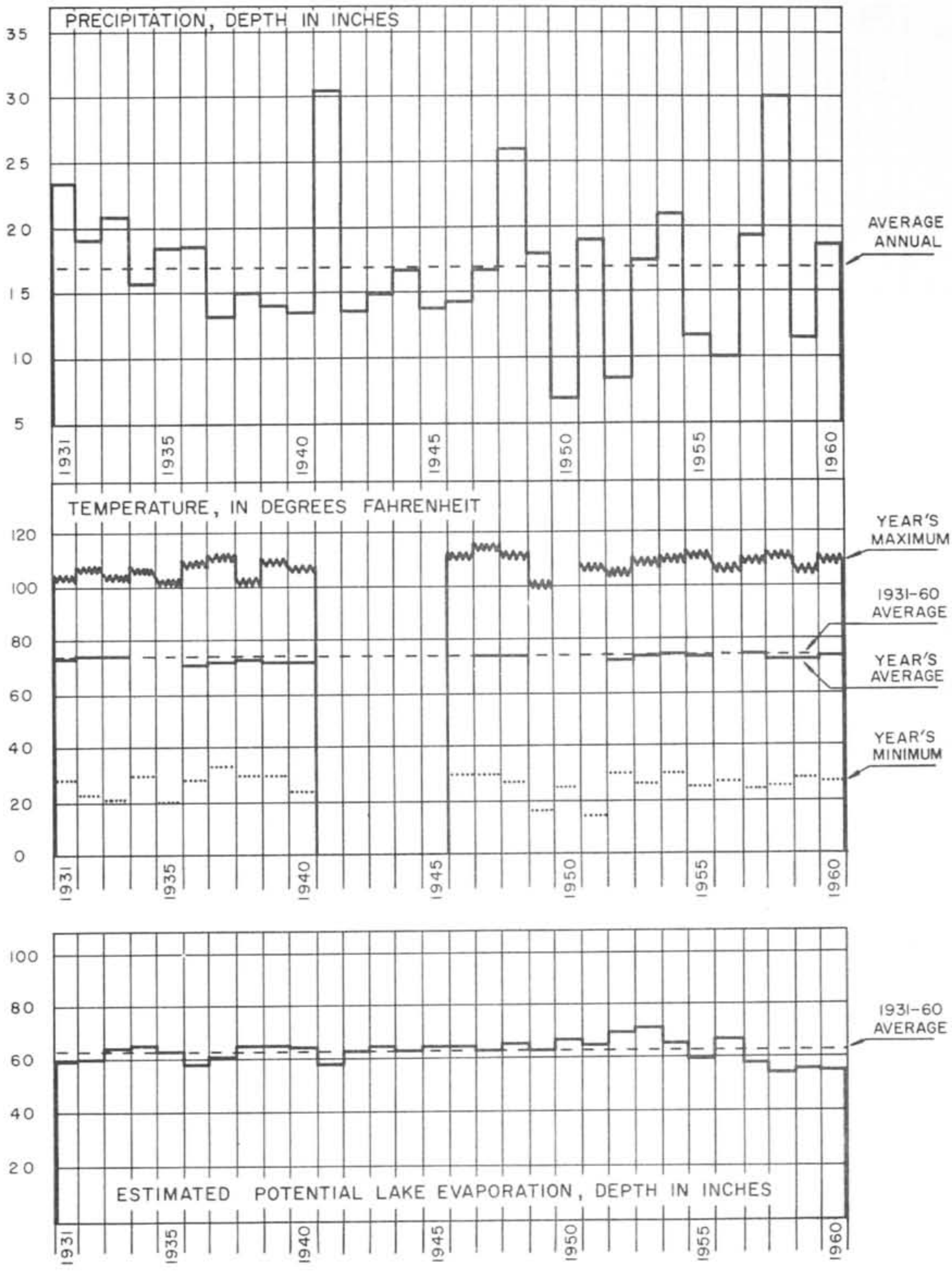

Figure 4

Historical Annual Climatic Data for Valley Area I, Base Period 1931-60

Texas Water Commission

186

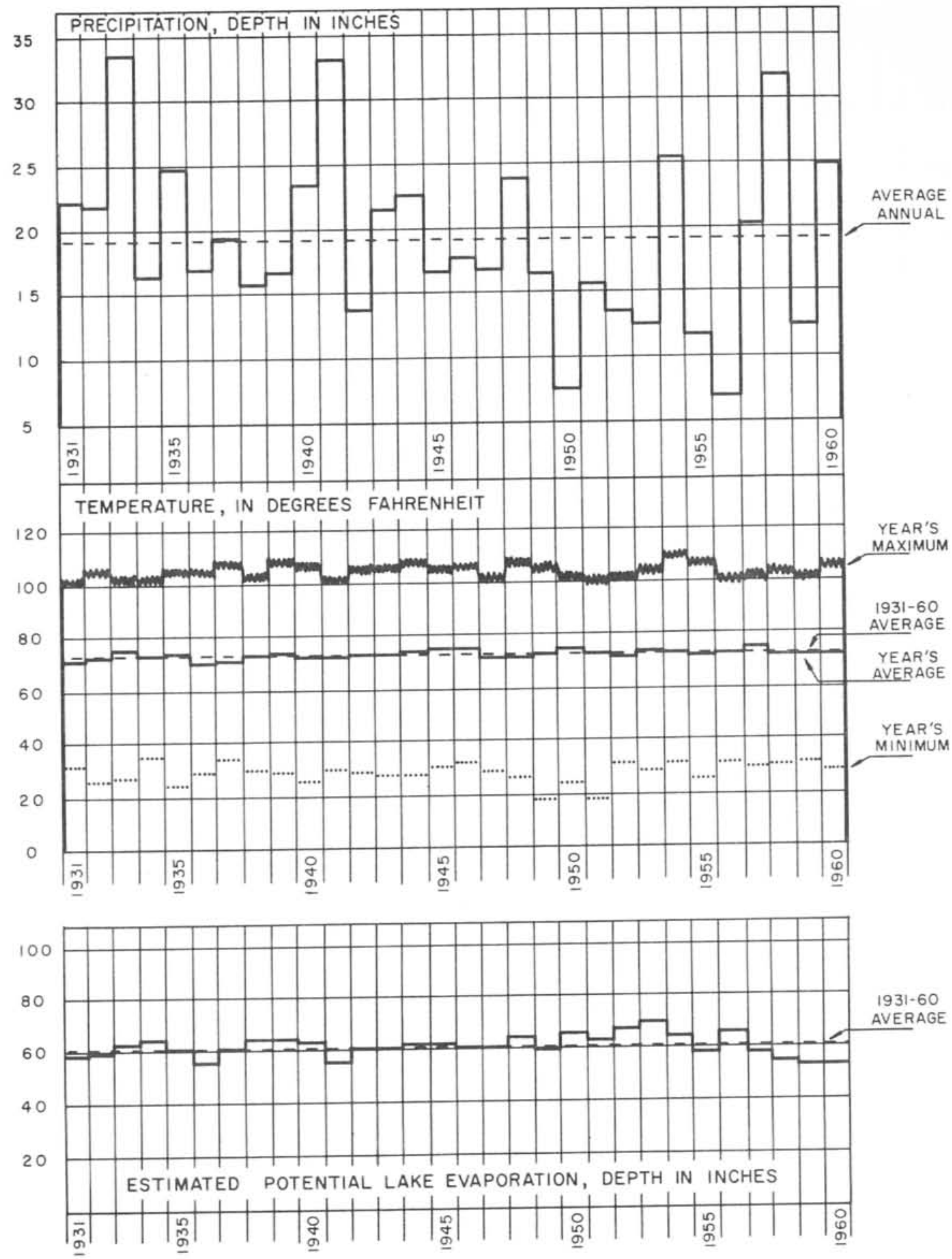

Figure 5

Historical Annual Climatic Data for Valley Area 2, Base Period 1931-60

Texas Water Commission

186

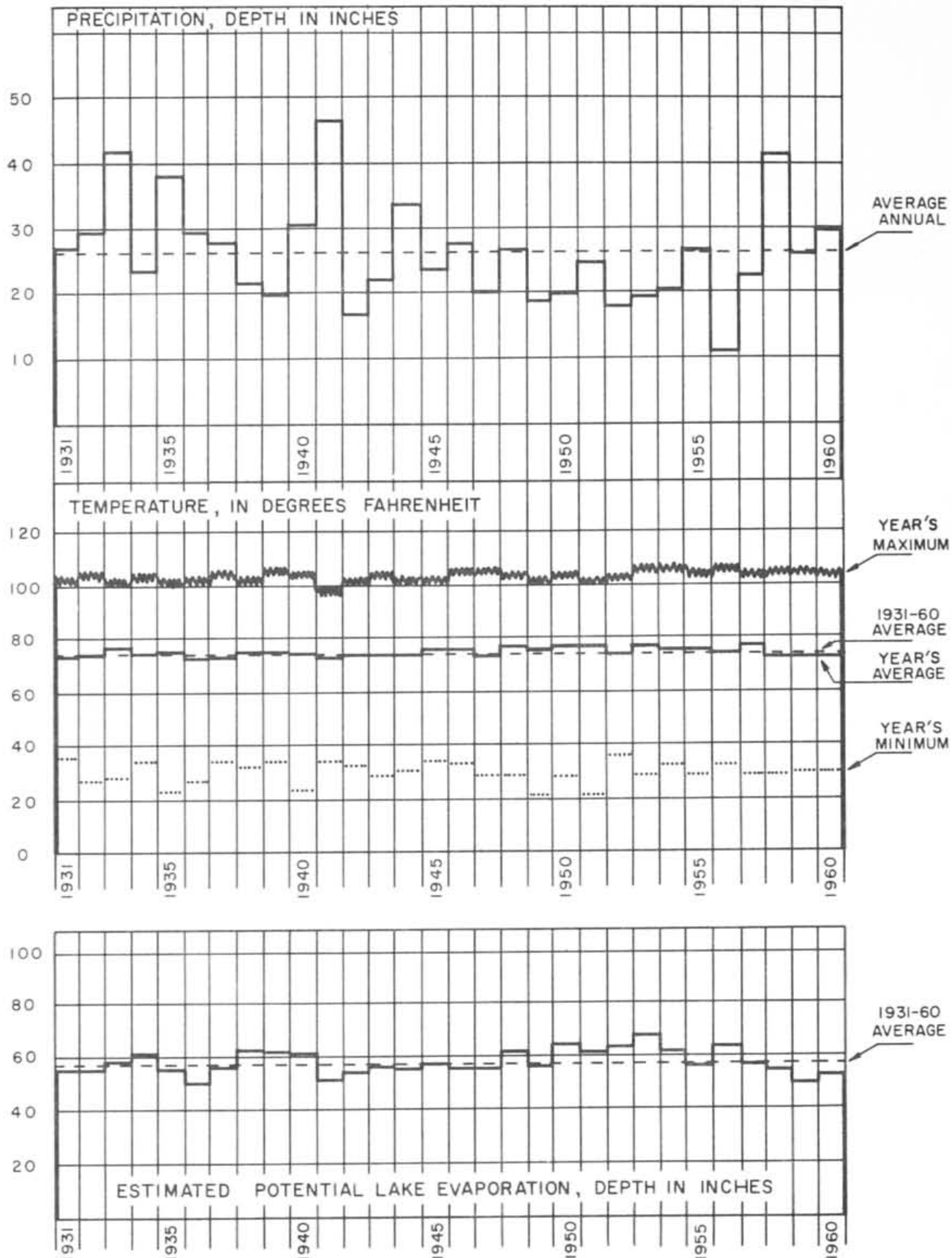

Figure 6

Historical Annual Climatic Data for Valley Area 3, Base Period 1931–60

Texas Water Commission

186

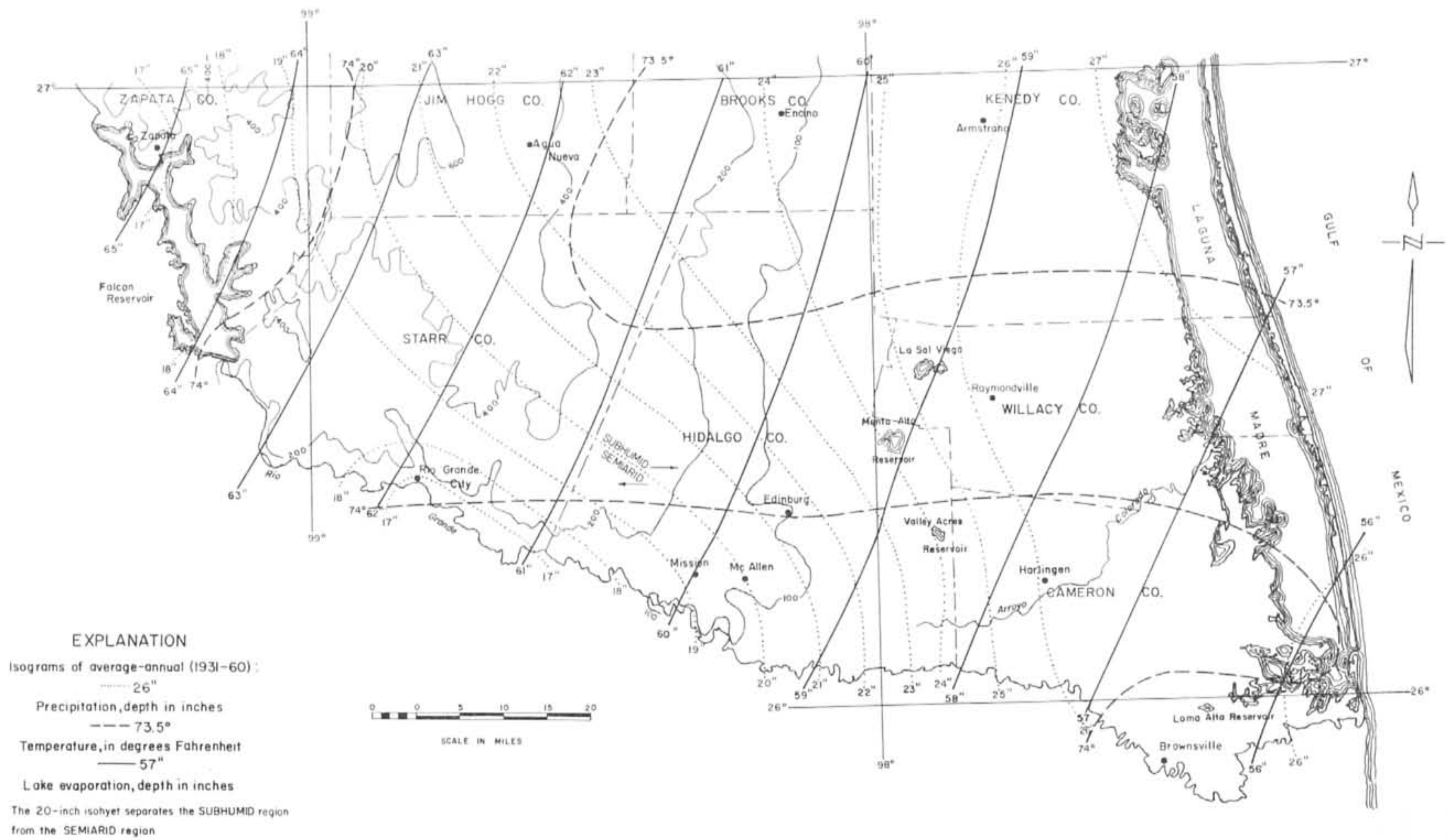

Figure 7

Climate Characteristics of the Lower Rio Grande Valley

Texas Water Commission

186

REFERENCES

1. "Physical Divisions of the United States," by N. M. Fenneman and D. W. Johnson, in cooperation with Physiographic Committee of the U.S. Geological Survey, Washington, a map, 1 p.

2. "Freeze Probabilities in Texas," by R. J. Hildreth and R. B. Orton, Texas Agricultural Experiment Station, MP-657, College Station, Texas, May, 1963, 19 p.

APPENDIX II

SOILS OF THE LOWER RIO GRANDE VALLEY

By

I. G. Janca

TABLE OF CONTENTS

TABLES

S O I L S   O F   T H E   L O W E R
R I O   G R A N D E   V A L L E Y

INTRODUCTION

Purpose

The purpose of this report is to present and explain the results of studies of the soils of the Valley as made to provide a basis for use in a soil-moisture accounting computation of irrigation water requirements for Valley crops.

Scope of Study

The scope of this study was the grouping of soils into categories having similar characteristics of texture, available moisture-holding capacity, and moisture-replacement depth as based on soil survey and classification data published by the Texas Agricultural Experiment Station and the U.S. Soil Conservation Service. The study also covered the relation of these soil characteristics to crop production under irrigation.

DISCUSSION

General

The soils of the Valley are mainly comprised of the Willacy, Brennan, Hidalgo, Victoria, Harlingen, Laredo, Cameron, Medio, Delfina, and Orelia series. Their surface texture ranges from heavy clays to fine sandy loams, and includes intermediate gradations of sandy clays, silty clays, clay loams, sandy clay loams, silty clay loams, silt loams, and sandy loams.

These soils vary in depth and profile with surface textures as named overlying subsoils of similar textures in varying combinations, having varying available moisture-holding capacities and other characteristics. These overlie substrata principally comprised of calcareous materials including deltaic and marine earths, deltaic clays, sandy clays, sediments from the Rio Grande Basin, and stratified sandy and silty alluviums.

Basic Soil Grouping

Soil Types

Soils in the Lower Rio Grande Valley were placed into three groups based primarily on the soil-unit classification system of the U.S. Soil Conservation Service (SCS). A soil unit is described by the SCS(1) as follows:

> A soil unit will include all soils within a land resource area that have similar profile characteristics such as depth, texture, structure, permeability, and consistence of the various horizons. All variations of the unit under similar conditions should have similar crop adaptabilities, be about equally productive, and require and respond to the same conservation practices. Any soil unit may include several types or soil series, providing there is a similarity as described above and regardless of whether or not they are adjoining or in close association.

Identification of the various soil types in the Valley has been a function of the Soil Conservation Service for many years. Detailed soil surveys were made of Willacy County(2) in 1926, Cameron County(3) in 1923, Hidalgo County(4) in 1925, and a reconnaissance soil survey of South Texas including Starr County(5) was made in 1909. These were published by the SCS in conjunction with the Texas Agricultural Experiment Station.

These original studies have been reviewed from time to time; and the SCS in conjunction with the Texas Agricultural Experiment Station has published general soil maps of Hidalgo County, 1963; Cameron County, 1960; Willacy County, 1963; and Starr County, 1957.

In grouping the soils for this study, some of the soils within the same soil unit were placed in a different group based on their available moisture-holding capacity and moisture-replacement depth. Specifically, the clay soils, for purposes of this study, were placed in Group I and include soils units 2 and 4 as classified by the SCS. The clay loam soils that are designated as soil unit 2 soils were placed in Group II because their available moisture-holding capacity and moisture-replacement depth are more nearly that of the 2x, 4x, and 6 soil units. Therefore, Group II includes soil unit 2 soils, which are clay loams; 2x, sandy clay loams, silty clay loams; 4x, silty clay loams; and 6, fine sandy loams. The soil unit 6 soils, which are fine sandy loams, were placed in Group II for the same reasons some of the soil unit 2, clay loam soils, were placed in this group. Group III soils include soil units 7, fine sandy loam, and 9, very fine sandy loam. The available moisture-holding capacities and moisture-replacement depths used in the soil moisture accounting procedure are shown for each group in Table 1.

This grouping of the soils was patterned after Table 1 in the Texas Agricultural Experiment Station's Bulletin 937.(6) The groups were modified to fit the conditions in the Lower Rio Grande Valley, and approximately 95 percent of the soils in the Valley fit directly into the three groups. Discussions concerning the soils in the Valley and this grouping in particular were held with the author of Bulletin 937, the State soil scientist for the SCS, Texas Agricultural Experiment Station personnel at Weslaco, and an SCS soil scientist at Harlingen. Their suggestions and recommendations were followed.

Even though the soils in the Lower Rio Grande Valley have been mapped and placed in the various soil units, there are limiting factors to be considered that affect land use. The primary limiting factor in the Valley is the soluble salt in some of the soils. The presence of salt does not change the soil unit classification of a particular soil, but affected areas are mapped separately and identified. These soils were not placed in special groups because the salt concentrations were not known. The additional water required for leaching would vary from 15 to 75 percent in excess of the normal irrigation requirement.[6]

Available Moisture-Holding Capacities

The available moisture-holding capacity of a soil is the amount of water held by a soil that is available to plants. It is the difference between the total water held by a soil at field capacity and the permanent wilting percentage. Field capacity is the quantity of water retained in the soil after gravitational water has drained away following an irrigation or rain, usually 1 to 3 days later.[6] The permanent wilting percentage is the quantity of water remaining in the soil after plants have withdrawn all they can and permanent wilting occurs.

The column titled "Average available moisture-holding capacity" in Table 1 is the average of the soil types listed in that group, and is expressed by foot increments of depth.

The available moisture-holding capacities for the various soil types were obtained from the SCS publications titled "Irrigation Guide for Rio Grande Plain Land Resource Area - Texas, Zone 2[8] [and] Zone 3[9]." These publications give this capacity in 1-foot increments of depth for the entire soil profile from which the various crops utilize water. Unpublished field data reviewed from the Texas Agricultural Experiment Station in Weslaco corresponded to the data used.

Moisture-Replacement Depth

Data from the above listed SCS publications were used for the average depth to which moisture should be replaced for the various soil types and for various crops grown. These data were compiled by the SCS from studies that have been conducted by several other agencies.

Basically the moisture-replacement depth is determined by the root concentrations in the soil profile of the various crops when grown on different soil types. The depths used are designed to replace moisture in the entire root zone of a plant even though a large percentage of the roots may be concentrated near the surface. Water will be lost from the upper portion of the root zone rapidly after a rain or an irrigation, but the plant will continue to utilize water from the entire root zone. Therefore, when irrigating, the entire root zone should be replenished with moisture.

The various soil types included in the soil groups, average available moisture-holding capacities, and moisture-replacement depths are listed in Tables 1 and 2.

Table 1.--Lower Rio Grande Valley soil groupings

Soil type[1/]	Average available moisture-holding capacity	
	Foot of depth	Capacity in inches
Soil Group I		
Banquete - c Montell - c Monteola - c Victoria - c Harlingen - c	1st 2nd 3rd 4th 5th 6th	2.7 2.2 2.2 2.2 2.2 1.7
Soil Group II		
Clareville - cl Raymondville - cl Rio - cl Hidalgo - cl Brennan - scl Runge - scl Uvalde - scl Willacy - scl Hidalgo - scl Laredo - scl Uvalde - sicl Karnes - cl Frio - cl Blanco - sicl Delfina - fsl Webb - fsl	1st 2nd 3rd 4th 5th 6th	2.0 2.0 2.0 1.7 1.6 1.6
Soil Group III		
Brennan - fsl Crystal - fsl Duval - fsl Runge - fsl Willacy - fsl Hidalgo - fsl Laredo - vsl	1st 2nd 3rd 4th 5th 6th	1.4 1.8 1.7 1.6 1.6 1.6

1/ Soil types are classified as follows: c, clay; cl, clay loam; sicl, silty clay loam; fsl, fine sandy loam; vsl, very fine sandy loam.

Table 2.--Moisture-replacement depth by crop groups

Crop group	Moisture-replacement depth in feet
Soil Group I	
1	2
2	3
3	2
Soil Group II	
1	4
2	5
3	2
Soil Group III	
1	5
2	6
3	3

Table 3 shows the distribution of irrigated land by counties and by study groupings as shown in Tables 1 and 2. Table 3 includes only irrigated land.(7)

Table 3.--Percentage of irrigated land within each soil group

Soil group	By counties				Average for Valley
	Cameron	Hidalgo	Willacy	Starr	
I	25	12	6	8	17
II	68*	61*	84*	41	63
III	7	27	10	51	20

*Includes 17 percent of the soil in soil units 2 and 4; based on best estimates of the SCS area conservationist in Harlingen.

Irrigation Frequency

Irrigation frequency is determined by the maximum depletion of the available soil moisture-holding capacity that can be tolerated before plant stress occurs.

The generally recommended practice of the SCS and the Experiment Station is to irrigate when moisture in the root zone has been depleted to 50 percent of available soil moisture-holding capacity. It has been found that if soil moisture is depleted below 50 percent throughout the root zone, plant stress will occur and a possible reduction in yield will result.

The following excerpts from the SCS Texas Engineering Handbook[10] explain the basis of the 50 percent factor shown above and the general recommendations followed by the SCS. Normal irrigation usually should be made by the time 50 percent of the total available moistures in the root-zone depth has been depleted.

> Irrigation should be delayed until there is sufficient storage capacity available in the soil within the root zone depth to hold an amount of water which can be applied efficiently. However, the irrigation should be completed before a recession in plant growth occurs. When essentially all the available moisture is removed from 20 to 30 percent of the root zone profile, a recession in plant growth can be expected to occur. Since most all irrigated crops have a fairly common moisture extraction pattern (40 percent from the upper quarter of the root zone, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the bottom quarter) the top one-fourth of the root zone depth is usually the most critical for most soils and can be used as a 'guide' for determining when to irrigate. Irrigation water should be applied by the time 75-80 percent of available moisture in this zone has been depleted. As pointed out before, the second and third quarter of the root zone depth can be the critical portion depending upon the available moisture holding capacity of the subsoil. However, even in such cases, a recession in plant growth would not be expected to occur if irrigation water is applied when the top quarter of the root zone depth contains as much as 25 percent of its available moisture.

In the instructions attending the SCS Irrigation Guide,[11] net moisture to be replaced each irrigation is explained as follows:

> Short cut method: For soils with uniform available moisture-holding capacity in the root zone depth, use 1/2 total available moisture capacity of root zone.

Although there is some variation in the available moisture-holding capacity in the root-zone depth within each of the three groups of soils designated in this report, the small differences within each group preclude differentiation by less than 1-foot depth increments.

The Texas Agricultural Experiment Station's Bulletin 937,[6] has the following on the above subject:

> Irrigation should start when about 50 percent and not over 60 percent of the available moisture has been used from the zone in which most of the roots are concentrated. The zone of root concentration will depend largely on the type and age of plant as well as the depth of soil for root development and distribution. The root zone should be kept moist, but not wet.

Previous Investigations and Reports

During the compilation of this report, various sources were examined for basic information that could be utilized. The Bureau of Reclamation, Agricultural Research Service (ARS), Soil Conservation Service, Texas Agricultural Experiment Station, and the Texas Agricultural Extension Service were contacted in the Valley and the project discussed.

Most of the basic information was obtained from the SCS and the Experiment Station. Information in the SCS manuals is, as stated by the State soil scientist, "...the best thinking available on this subject by the people in agricultural research," and is based on research results obtained by various State and federal agencies.

The project was discussed with personnel employed by the ARS in Weslaco, and their reports were reviewed. These reports have not been published, and the data contained therein were found to be generally inconclusive for the purposes of this study.

The Bureau of Reclamation has conducted studies in the Valley in connection with their various proposed projects.

In their rehabilitation reports[12-15] for the various districts in the Valley, the following general statement deals with the derivation and classification of Valley soils.

> The soils composing the Valley lands have developed under the influence of semi-arid, semi-tropical climatic conditions. The upland soils in the western portion of the area have been developed from light to medium textured, slightly calcareous materials, while in the central portion of the area they have developed from highly calcareous clays overlain in places with eolian sand and silt deposits. The alluvial soils have been derived from fine textured deltaic deposits of the Rio Grande. Immediately adjacent to the river there are areas of coarser depositions. The soils of the area may be divided as follows: dark colored upland soils, consisting chiefly of Victoria, Willacy, and Hidalgo soil series; light colored upland soils of the Brennan soil series; alluvial soils consisting of Harlingen, Cameron, Laredo, and Rio Grande soils, and semi-marshy soils along the coastal border of the Lomalta soil series.

Following this general description, the Bureau of Reclamation lists the predominant soil types found in the Valley, and gives a description of the physical characteristics of each. In addition, mention is made of the drainage characteristics and the major crops produced on each soil type.

The Texas A&M Research Foundation made a study for the U.S. Bureau of Reclamation of the Lower Rio Grande Valley, and included their findings in a report titled "Irrigation Potential of Selected Areas in Texas."[16] This study was conducted under the direction of Curtis L. Godfrey who at the time was Associate Professor of Agronomy at Texas A&M College. This study included soil resource data, farmer experience, soil and crop problems, economic input-output data relative to crop production, and other miscellaneous information related to irrigation agriculture. The data in this report were reviewed and found to be generally in agreement with that from other sources of information used.

A search of International Boundary and Water Commission literature revealed nothing that would contribute to the basic data needed for this study.

CONCLUSIONS

The soils in each of the three groups as shown in Table 1 were so grouped on the basis of their available moisture-holding capacity and moisture-replacement depth. Although these characteristics for each soil type within each group may differ somewhat from the other soils within the group, the differences are within reasonable limits considering the purpose for which these groupings were made.

These three soil groups adequately represent the diverse soil characteristics that must be considered in the operation of soil moisture reservoirs in determining irrigation requirements for Valley croplands.

REFERENCES

1. "Farm Planning Soil Conservation Surveys," U.S. Soil Conservation Service, Texas State Planning Manual, Planning Section, January 18, 1957.

2. "Soil Survey Willacy County, Texas," U.S. Soil Conservation Service and Texas Agricultural Experiment Station, 1926.

3. "Soil Survey Cameron County, Texas," U.S. Soil Conservation Service and Texas Agricultural Experiment Station, 1927.

4. "Soil Survey Hidalgo County, Texas," U.S. Soil Conservation Service and Texas Agricultural Experiment Station, 1929.

5. "Reconnaissance Soil Survey of South Texas," U. S. Department of Agriculture, Bureau of Soils, 1909.

6. "Some Principles and Practices in the Irrigation of Texas Soils," by M. E. Bloodworth, Texas Agricultural Experiment Station, Bulletin 937, September 1959.

7. "Texas Soil and Water Conservation Needs Inventory," U.S. Soil Conservation Service, July 1962.

8. "Irrigation Guide for Rio Grande Plain Land Resource Area-Texas, Zone 2," U.S. Soil Conservation Service, October 1962.

9. "Irrigation Guide for Rio Grande Plain Land Resource Area-Texas, Zone 3," U.S. Soil Conservation Service, October 1962.

10. "Texas Engineering Handbook, Section 15, Irrigation," U.S. Soil Conservation Service, 1958.

11. "Explanation of Material Contained in Irrigation Guides," U.S. Soil Conservation Service, Oklahoma, July 1955.

12. "Plan of Rehabilitation Harlingen Division," U.S. Bureau of Reclamation, February 1956.

13. "Plan of Rehabilitation Mercedes Division," U.S. Bureau of Reclamation, January 1956.

14. "Plan of Rehabilitation LaFeria Division," U.S. Bureau of Reclamation, January 1957.

15. "Plan of Rehabilitation El Jardin Division," U.S. Bureau of Reclamation, January 1957.

16. "Irrigation Potential of Selected Areas in Texas," Texas Agricultural Experiment Station, Texas A&M Research Foundation, Project 138, May 1957.

17. "Effect of Irrigation Differentials and Plant Spacings on Yield of Cotton on Harlingen Clay in the Lower Rio Grande Valley," by C. J. Gerard and L. N. Namken, Texas Agricultural Experiment Station, Progress Report 2216, October 1961.

18. "Cotton Irrigation in the Lower Rio Grande Valley," by C. J. Gerard, M. E. Bloodworth, C. A. Burleson, and W. R. Cowley, Texas Agricultural Experiment Station, Bulletin 916, September 1958.

19. "Conservation and Utilization of Soil Moisture," by C. E. Fisher and Earl Burnett, Texas Agricultural Experiment Station, August 1953.

20. "Water, the Yearbook of Agriculture," U.S. Department of Agriculture, 1955.

APPENDIX III

CROPPING PATTERN OF THE LOWER RIO GRANDE VALLEY

By

Robert L. Warzecha

TABLE OF CONTENTS

TABLE

CROPPING PATTERN OF THE LOWER RIO GRANDE VALLEY

GENERAL

The Lower Rio Grande Valley of Texas, comprised of Starr, Hidalgo, Cameron, and Willacy Counties, has a variety of soils under irrigation from the Rio Grande in an area extending from Falcon Dam to the Gulf of Mexico.

The Valley climate is favorable to the production of a wide variety of agricultural crops. Because of the long growing season and usually mild winter air temperatures, two or more crops grown on the same tract of land during a year are common in some areas.

The diversity of soils, the favorable climate, and the availability of water from the Rio Grande for irrigation afford stability in the Valley cropping.

PURPOSE AND SCOPE

The purpose of this study and the subsequent report was to develop and present a recent historical average annual cropping pattern for the principal crops grown on irrigated lands in the Valley. This cropping pattern was needed for use by the Texas Water Commission in a detailed study of the Valley irrigation diversion requirements at Falcon Dam.

The scope of this study was restricted to the deep-rooted and shallow-rooted vegetable crops as categories, and to specific crops involving 2 percent or more of the cropland.

Information used in developing an average annual cropping pattern for the Valley was obtained through personal interviews of technical personnel employed by several government agricultural agencies in the Valley, from publications containing Valley crop production and marketing data, and from studies and reports of irrigated agricultural production made by this and other agencies.

CROPPING DATA

An accurate yearly record of the percentage of irrigated area in each crop was not found. However, estimates of principal crop acreages irrigated were obtained for the years 1957[(1)] and 1959[(3)] from publications of the Texas Agricultural Extension Service, for 1958[(2)] from a publication of the Texas Board of Water Engineers, and also for 1959[(4)] from a survey made by the United States Bureau of the Census. Estimates of crop acreages for the years 1960-63 for some crops were obtained from the Statistical Reporting Service, United States Department of Agriculture.(5-11)

The estimates obtained for the years 1957-59 were used as a basis for developing the cropping pattern. The data obtained for the years 1960-63 were not complete, and were only used as a guide for slight adjustment of the derived cropping pattern determined for years 1957-59. This adjustment was done by determining whether a trend was apparent toward either increased or decreased acreages in recent years.

AVERAGE ANNUAL CROPPING PATTERN

The following percentage distribution of irrigated crops is the result of the above investigation.

Crop	Percent of acreage
Cotton	41
Corn	2
Sorghum	18
Citrus	10
Pasture	8
Vegetables	32
Other	1
Farmstead and waste	5
Total	117

The distribution above shows 5 percent of acreage as farmstead and waste. It includes such cropland losses as turning rows, canals, diversion ditches, buildings, etc.(12)

It will be noted also that the total of the above percentages exceeds 100 percent. This condition exists because of the long growing period, the availability of water for irrigation, and the double cropping practices in the Lower Rio Grande Valley.

Because of climatic conditions, marketing conditions, and farming practices in the Lower Rio Grande Valley, the planting and harvesting period of a crop may extend over several months. Data on planting and harvesting periods for the specific crops were taken from a publication of the Texas Water Commission,(13) and from information furnished by the Texas Crop and Livestock Reporting Service,(14) and the U.S. Bureau of Reclamation.(12) The crops, the average percentage of acreage in crops, and the estimated percentage of irrigable land in each crop by months are shown in Table 1.

The percentages for the various months shown in columns 2 through 9 of Table 1 represent the estimated average percentage of the irrigated land in that crop for each month. For example, it is estimated that 10 percent of the irrigated land has cotton growing on it in February. The sum of columns 2 through 9 as shown in column 10 is the total percentage of irrigated land cropped for each month. The sum of the percentages in columns 10 and 11 is subtracted from 100 percent to give the percentage of fallow land for each month.

Table 1.--Average annual cropping pattern for the Lower Rio Grande Valley

Based on the period, 1957-63

	Crop								Percent of total irrigated land			
	Cotton	Corn	Sorghum	Citrus	Pasture	Shallow-rooted vegetables	Deep-rooted vegetables	Other	Cropped	Farmstead and waste	Fallow land	Total
Percent of acreage in crop	41	2	18	10	8	10	22	1				
	Percent of land in individual crops, by months											
(Column 1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
January				10	8	4	10		32	5	63	100
February	10			10	8	3	8		39	5	56	100
March	30	2	9	10	8	3	6		68	5	27	100
April	41	2	9	10	8		5		75	5	20	100
May	41	2	9	10	8		5		75	5	20	100
June	41	2	9	10	8		3		73	5	22	100
July	41	1		10	8				60	5	35	100
August	20		9	10	8	1	1		49	5	46	100
September			9	10	8	3	8		38	5	57	100
October			9	10	8	6	13		46	5	49	100
November			9	10	8	7	15		49	5	46	100
December				10	8	6	13		37	5	58	100
Total	224	9	72	120	96	33	87		641	60	499	1,200

REFERENCES

1. "Irrigation Survey," Cooperative Extension Work in Agriculture and Home Economics, Agricultural and Mechanical College of Texas and the United States Department of Agriculture, Extension Service County Agent Work, June 1957.

2. "Irrigation in Texas in 1958," Texas Board of Water Engineers, Bulletin 6018, November 1960.

3. "Irrigation Survey," Cooperative Extension Work in Agriculture and Home Economics, Agricultural and Mechanical College of Texas and the United States Department of Agriculture, Extension Service County Agent Work, June 1959.

4. "United States Census of Agriculture-Texas," United States Department of Commerce, Bureau of the Census, Vol. 1, P. 37, 1959.

5. "Texas Cotton Statistics," United States Department of Agriculture, Statistical Reporting Service, Texas Crop and Livestock Reporting Service, Bulletin 10, June 1961.

6. "Texas Cotton Statistics," United States Department of Agriculture, Statistical Reporting Service, Texas Crop and Livestock Reporting Service, Bulletin 17, June 1962.

7. "Cotton County Estimates-Texas," United States Department of Agriculture, Statistical Reporting Service, Crop and Livestock Reporting Service, 1962 Crop Preliminary, June 1963.

8. "Sorghum County Estimates-Texas," United States Department of Agriculture, Statistical Reporting Service, Crop and Livestock Reporting Service, 1960 Crop, February 1962.

9. "Sorghum County Estimates-Texas," United States Department of Agriculture, Statistical Reporting Service, Crop and Livestock Reporting Service, 1961 Crop, April 1962.

10. "Sorghum County Estimates-Texas," United States Department of Agriculture, Statistical Reporting Service, Crop and Livestock Reporting Service, 1962 Crop, April 1963.

11. "Sorghum County Estimates-Texas," United States Department of Agriculture, Statistical Reporting Service, Crop and Livestock Reporting Service, 1963 Crop, April 1964.

12. "Texas Basins Project," United States Department of Interior, Bureau of Reclamation, Annex C-5, August 1960.

13. "Consumptive Use of Water by Major Crops in Texas," Texas Board of Water Engineers, Bulletin 6019, November 1960.

14. "Texas Crop Calendar," United States Department of Agriculture, Statistical Reporting Service, Texas Crop and Livestock Reporting Service, Bulletin 15, December 1961.

15. "Texas Vegetables," United States Department of Agriculture, Statistical Reporting Service, Texas Crop and Livestock Reporting Service, Bulletin 25, February 1964.

16. "Cotton Irrigation in the Lower Rio Grande Valley," by C. J. Gerard, M. E. Bloodworth, C. A. Burleson, and W. R. Cowley, Texas Agricultural Experiment Station, Bulletin 916, September 1958.

17. "Guide for Citrus Production in the Lower Rio Grande Valley," Texas Agricultural Experiment Station and Texas Agricultural Extension Service, Bulletin 1002, December 1963.

APPENDIX IV

WATER TRANSMISSION LOSSES TO IRRIGATORS OF THE LOWER RIO GRANDE VALLEY

By

Ralph B. Hendricks

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLES

ILLUSTRATIONS

Figures

WATER TRANSMISSION LOSSES TO IRRIGATORS OF THE LOWER RIO GRANDE VALLEY

INTRODUCTION

This report discusses investigations that were conducted in order to provide a portion of the criteria needed to determine diversion requirements at Falcon Dam. The diversion requirements under study are those needed to satisfy Valley crops that receive water from the Rio Grande.

One of the major considerations in determining the limitation of acreage that can be fully supplied with irrigation waters from Falcon and Amistad Reservoirs is that of estimating the losses from a given quantity of water to be encountered between the time of its release from Falcon Reservoir and its consumption by crops.

In analyzing this delivery system, it can be considered in three categories consisting of the river channel, the distribution systems, and finally the farms themselves. These categories are discussed in this report in that order.

Recognizing inefficiencies in many of the Valley canal systems, recent efforts have been made to line the earthen canals or replace them with closed conduits. An evaluation of this lining program required consideration of losses from facilities as they presently exist and as they are expected to exist after the lining programs are completed. For the purposes of this investigation, it was assumed that all systems will be 100-percent lined at some future date although it is recognized that the current rehabilitation programs in the Valley do not call for 100-percent lining in all cases.

RIVER CHANNEL LOSSES

General

Previous investigations conducted to estimate river channel losses below Falcon Dam generally have been in connection with specific projects, and extended only to the last point of diversion as determined in a particular plan. At present, diversions are made directly from the Rio Grande by various water districts and individuals as the river flows to the Gulf with only one river diversion control facility, the Anzalduas Dam.

Only the presently used method of diversion from the Rio Grande was considered in this study because there is no assurance that upstream diversion dams and the required distribution systems to transport water to downstream users will be built. The U.S. Bureau of Reclamation planned these facilities in 1948, and also planned alternate facilities later, in 1954. No construction has been authorized to date; therefore, none has been assumed in this study. These investigations included estimates of river channel losses for several reaches of the river. Reports of these studies were reviewed and abstracted to provide some indication of the methods of computation used and the loss rates thus determined. Experience since the construction of Falcon Dam has demonstrated that these loss rates were too high; therefore, none of the data from previous investigations were used in this report. Instead reliance was placed on records of the International Boundary and Water Commission, United States and Mexico (IBWC), which reflect channel losses for various reaches of the Rio Grande. The following analysis of these records constitutes the basis of river channel loss estimates utilized herein.

Average Annual Water Losses

The IBWC maintains monthly records of the use of the United States' share of water in the Rio Grande. These records, available for the period 1953 through 1963, show inflows, diversions, losses, and outflows for six separate reaches of the river from Falcon Dam to the Gulf of Mexico.

Losses encountered in each reach were designated as either "evapotranspiration" or "other" in the accounting. The method of computing evapotranspiration losses was not explained, nor was a description of "other" losses given. For purposes here, however, it was assumed that these losses are reliable.

From the IBWC's accounting it was determined that the average annual channel loss below Falcon Dam is about 73,800 acre-feet, based on the years 1954 through 1957 and 1960 through 1963. The omission of 1958 and 1959 was due to unusually high flows for those years. The average annual channel losses of the United States' share of water in the Rio Grande from Falcon Dam to the Gulf of Mexico during the period 1954-63 are shown by river reaches in Table 1 as percentages of the total losses and in acre-feet.

Table 1.--Average annual channel losses of water by river reaches, 1954-63

(From United States' share of water, Falcon Dam to the Gulf of Mexico)

River reach	Water loss		River reach	Water loss	
	Percent	Acre-feet		Percent	Acre-feet
Falcon Dam to Fort Ringgold Gage	16	12,100	Progreso Bridge Gage to San Benito Gage	8	5,900
Fort Ringgold Gage to Anzalduas Dam	32	23,600	San Benito Gage to Lower Brownsville Gage	7	4,900
Anzalduas Dam to Progreso Bridge Gage	34	25,000	Lower Brownsville Gage to the Gulf of Mexico	3	2,300
			Total...	100	73,800

Operational Losses

In addition to channel losses, water released from Falcon Dam is lost to the Gulf owing to operational inefficiency. These losses were described by the IBWC as either "ordinary" or "extraordinary" with ordinary wastes being defined as "...those due solely to the inherent impossibility of making releases from Falcon storage and deliveries to the numerous diversion points along 230 miles of river below the dam, precisely in accord with the diversion demands."(1)

Extraordinary wastes were defined as those portions of the waters released at Falcon Dam for domestic and irrigation use "...which are in transit to United States points of diversions at times when rain or cold weather suddenly develops, so that the anticipated requirement therefore is eliminated with the result that waters become excess to the needs and waste to the Gulf."(1)

In the IBWC accounting of United States' waters there was no differentiation between ordinary or extraordinary wastes. Wastes averaged about 88,100 acre-feet annually.

Inflow Below Falcon Dam

The operational wastes included runoff from the 3,874 square-mile drainage area below Falcon Dam. This constituted a considerable quantity on an average basis (98,100 acre-feet), of which only a portion was divertible "...since the runoff occurs as short-duration floods and, generally, at times when there are also rains in the Valley which reduce the irrigation demands."(2) Studies made by the United States section of the IBWC "...indicated that, under existing conditions, an average of about 29,000 acre-feet could be diverted annually."(2) This meant that only about 30 percent of the intervening inflow was available for diversion. The remaining 70 percent was considered as wasted to the Gulf.

Of the intervening inflows, 70 percent was wasted, comprising about 68,700 acre-feet of the 88,100 acre-feet wasted annually, leaving 19,400 acre-feet as operational losses. The remaining 30 percent of yearly intervening inflow more than offset the volume allowed for operational losses and eliminated consideration of reservoir releases as wastes. On this assumption, computations of channel losses were made without consideration of intervening inflow and wastes to the Gulf.

River Channel Loss Estimates

Based on past experience since the construction of Falcon Dam, it was found that the average annual river channel losses of water from Falcon Dam to the Gulf of Mexico amount to 73,800 acre-feet or 6.25 percent of the average annual releases from the reservoir (1,180,000 acre-feet). This percentage applied to the percentage of average annual water losses by respective river reaches shown in Table 1 provided a factor for determining estimates of water lost from specific Falcon Dam releases by river reaches. Those percentages, reduced to coefficients, are shown in Table 2.

Table 2.--Channel-loss coefficients by river reaches

(Applicable to United States' share of water in the Rio Grande below Falcon Dam)

River reach	Channel-loss coefficients	River reach	Channel-loss coefficients
Falcon Dam to Fort Ringgold Gage	0.16 x 0.0625 = 0.0100	Progreso Bridge Gage to San Benito Gage	0.08 x 0.0625 = 0.0050
Fort Ringgold Gage to Anzalduas Dam	0.32 x 0.0625 = 0.0200	San Benito Gage to Lower Brownsville Gage	0.07 x 0.0625 = 0.0044
Anzalduas Dam to Progreso Bridge Gage	0.34 x 0.0625 = 0.0212	Lower Brownsville Gage to the Gulf of Mexico	0.03 x 0.0625 = 0.0019

For the purpose of determining losses of water for channel reaches of the Rio Grande other than as shown in Table 2, coefficients of water loss per mile of river reach are presented in Table 3.

Table 3.--Water loss per mile of river channel as a function of releases

(From United States' share of water in the Rio Grande from Falcon Dam to the Gulf)

River reach	Length of reach in miles	Water loss per mile in reach
Falcon Dam to Fort Ringgold Gage..........	40	0.000250 Q*
Fort Ringgold Gage to Anzalduas Dam..............	63	.000318 Q
Anzalduas Dam to Progreso Bridge Gage........	47	.000453 Q
Progreso Bridge Gage to San Benito Gage.............	27	.000185 Q
San Benito Gage to Lower Brownsville Gage......	48	.000092 Q
Lower Brownsville Gage to Gulf of Mexico..............	49	.000039 Q

*Q is quantity of release from Falcon Reservoir.

Conclusion

Losses from the Rio Grande channel since the construction of Falcon Dam have varied from the estimates of losses made prior to the completion of the dam. It is recognized that the early estimates were ascertained by the best methods and information available at the time; however, the estimates used in this study are from the analysis of the IBWC records as reflected by the coefficients in Table 2.

DISTRIBUTION SYSTEM LOSSES

General

Although it is widely recognized that losses from the distribution systems of the Lower Rio Grande Valley are large enough to merit concern, very little data on the magnitude of these losses were found during this investigation. Presently the U.S. Bureau of Reclamation is undertaking a project to determine distribution system loss rates, but their data will not be available for some time.

Despite this handicap, efforts were made to estimate these losses during various studies by governmental agencies and by the distribution system owners or operators. The reports and data found during the investigation were reviewed, and the applicable information was summarized and used to arrive at a basis for estimating these losses.

Review of Rehabilitation Project Studies

Shortly after Falcon Reservoir came into operation, the U.S. Bureau of Reclamation conducted studies of several water districts in the Lower Rio Grande Valley, and presented plans for rehabilitating the water distribution systems. It was recognized that large losses did occur and that rehabilitation was necessary to improve the systems' efficiency. As of 1964, construction was almost completed on some of the systems, but the original plans have been somewhat changed. Nevertheless, the original plans were used as a basis for making new estimates of losses.

In order to determine the effect of rehabilitation on a given distribution system, the Bureau of Reclamation established a correlation relating items affecting the systems' performance. The correlation was established between the quantity of water diverted by each of nine valley districts per acre application delivered, miles of lined and unlined canals and laterals per 1,000 acre applications, and permeability of soil in each district.(3)

From this statistical analysis, irrigation diversion requirements were obtained for future conditions both with rehabilitation and with present facilities. The results of these analyses were usually adjusted slightly to reflect specific conditions existing in a particular district. The "with" and "without" results were then compared to estimate water savings for future conditions.

Pertinent data from the rehabilitation studies are shown in Table 4.

Table 4.--Pertinent data on diversion requirements extracted from rehabilitation studies, in acre-feet

	Districts			
	Mercedes(3)	Harlingen(4)	El Jardin(5)	La Feria(6)
Average annual net diversions present facilities	137,000	80,900	23,600	68,400
Future average annual diversions without rehabilitation	176,000	103,000	34,000	81,000
Future average annual diversions with rehabilitation	145,000	81,000	26,000	66,000
Future annual saving	30,000	20,000	9,000	15,000

Estimate of Total Annual Loss

From the data shown in Table 4, the approximate losses from a particular system under pre-1951 cropping patterns and before rehabilitation were determined. This was required in order to determine losses in a system wherein the extent of facilities was known. For the Mercedes, Harlingen, and El Jardin Districts, the approximate loss before rehabilitation was computed under the assumption that if a particular system's losses were reduced by some amount with rehabilitation and under future cropping patterns, the losses were reduced by a proportional amount under pre-1951 cropping patterns. For these districts, the reduction in losses under present conditions (pre-1951 cropping patterns) obtainable by rehabilitation were computed as shown in Table 5.

Table 5.--Computation of annual reduction in losses, in acre-feet, by rehabilitation under pre-1951 cropping patterns

Item	Districts		
	Mercedes	Harlingen	El Jardin
A. Future* requirements with rehabilitation	145,000	81,000	26,000
B. Future* requirements without rehabilitation	176,000	103,000	34,000
C. Pre-1951* requirements without rehabilitation	137,000	80,900	23,600
D. Pre-1951 requirements with rehabilitation $(C \times \frac{A}{B} = D)$	113,000	63,600	18,000
E. Reduction of losses by lining (C - D = E)	24,000	17,300	5,600

*From Table 4.

For the La Feria District, the rehabilitation plan gave the estimated annual use assuming pre-1951 cropping patterns and a rehabilitated system as 52,000 acre-feet.(6) Present usage was shown to be 68,400 acre-feet annually, giving an annual saving of 16,400 acre-feet if the system were rehabilitated.

Effect of Rehabilitation

The extent of lining of the distribution systems was included in the statistical correlation used to determine annual savings. The districts investigated in this study were shown to have linings in existence as shown in Table 6, which also shows the extent of lining as planned for upon completion of rehabilitation.

Table 6.--Existing and proposed lining of distribution systems, at time of rehabilitation studies

Districts	Existing facilities			Proposed facilities		
	Lined (miles)	Unlined (miles)	Lined (percent)	Lined (miles)	Unlined (miles)	Lined (percent)
Mercedes (3)	134.0	181.5	43	291.0	24.5	92
Harlingen (4)	25.3	154.0	14	155.1	24.2	87
El Jardin (5)	21.0	95.0	18	109.0	7.0	94
La Feria (6)	67.0	94.0	42	140.0	21.0	87

In an effort to determine the annual losses from a rehabilitated distribution system, many of the system owners were consulted for opinions and pertinent data. As a result of this effort, reliable information was obtained, which was used in making estimates of losses from rehabilitated systems. From an analysis of these data it was found that the losses will approximate the figures shown in Table 7.

Table 7.--Estimated unavoidable annual loss

Percent lined	Loss-per-mile basis (acre-feet per mile)
100	21.8
96	24.1

In order to obtain an estimate of the loss rate for systems whose percent lining is less than 96 percent after rehabilitation, the relationship of Figure 1 will apply.

Assuming the data as shown in Tables 4, 5, and 6 to be correct, as well as that shown in Table 7 and Figure 1, total losses from the systems under study but with pre-rehabilitation facilities were determined as shown in Table 8.

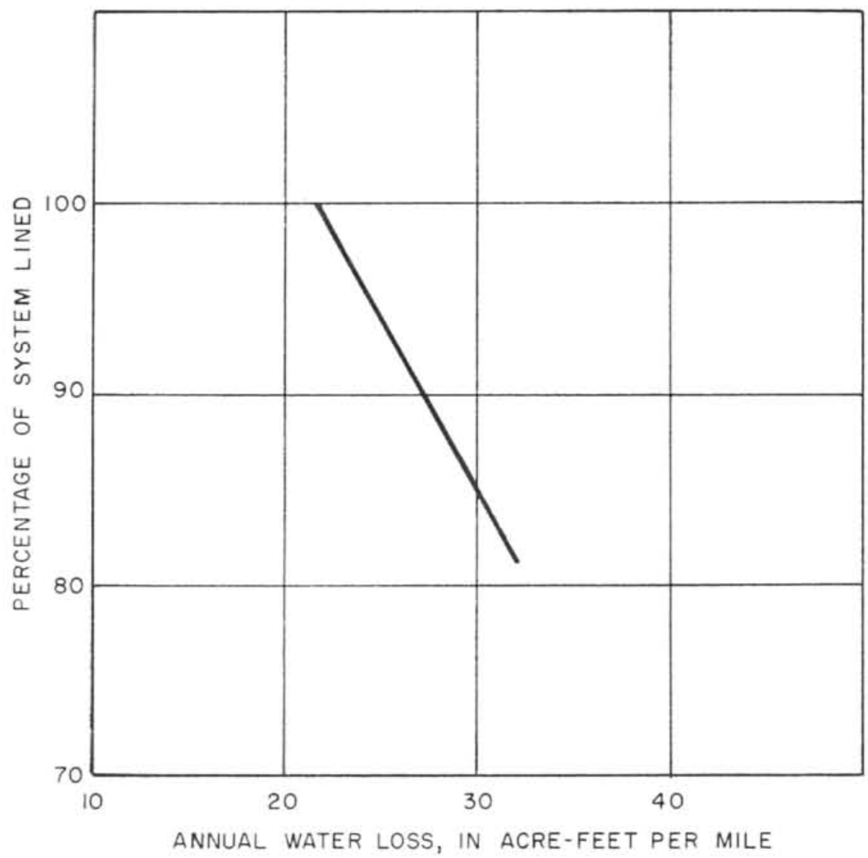

Figure 1

Unavoidable Losses of Water After Rehabilitation

Texas Water Commission

186

Table 8.--Estimated annual distribution system water losses, pre-rehabilitation facilities

	Districts			
	Mercedes	Harlingen	El Jardin	La Feria
Percent of system lined, without rehabilitation	43	14	18	42
Percent of system lined,* with rehabilitation	92	87	94	87
Length of system facilities, in miles	315.5	179.3	116.0	161.0
Quantity of water saved with rehabilitation, in acre-feet	24,000‡	17,300‡	5,600‡	16,400§
Quantity of water saved per mile of system (acre-feet per mile)	76.2	96.5	48.3	102.0
Unavoidable water loss† (acre-feet per mile)	26.2	29.0	25.0	29.0
Total loss rate on a per-mile basis (acre-feet per mile)	102.4	125.5	73.3	131.0
Total annual water loss in acre-feet	32,300	22,500	8,500	21,100
Number of acres under irrigation at time of studies	62,100	35,000	11,700	24,400
Total loss rate on a per-acre irrigated basis (acre-feet per acre)	0.520	0.644	0.727	0.865

*From Table 6
†From Figure 1
‡From Table 5
§From page 55

Losses to be expected in the systems on a per-mile basis are shown graphically in Figure 2 and on an acre-foot per acre irrigated basis in Figure 3.

Conclusion

Although the loss rates as shown in Figures 2 and 3 are not precise, they provide a practical basis for estimating water losses from Valley distribution systems. These loss rates are average values, and individual delivery system losses of water may vary from the amounts computed therefrom.

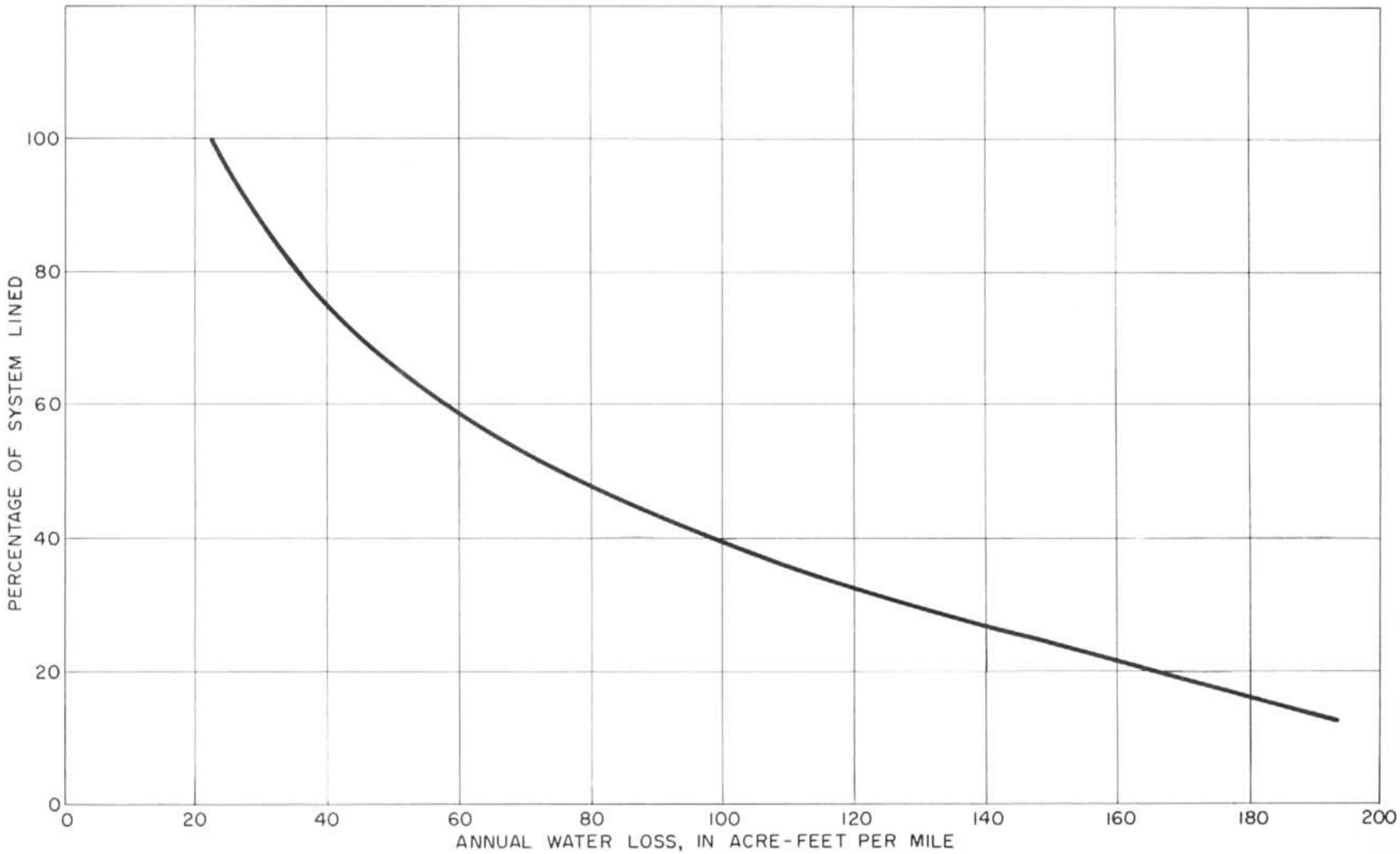

Figure 2

Distribution System Annual Water Loss Per Mile of Length

Texas Water Commission

186

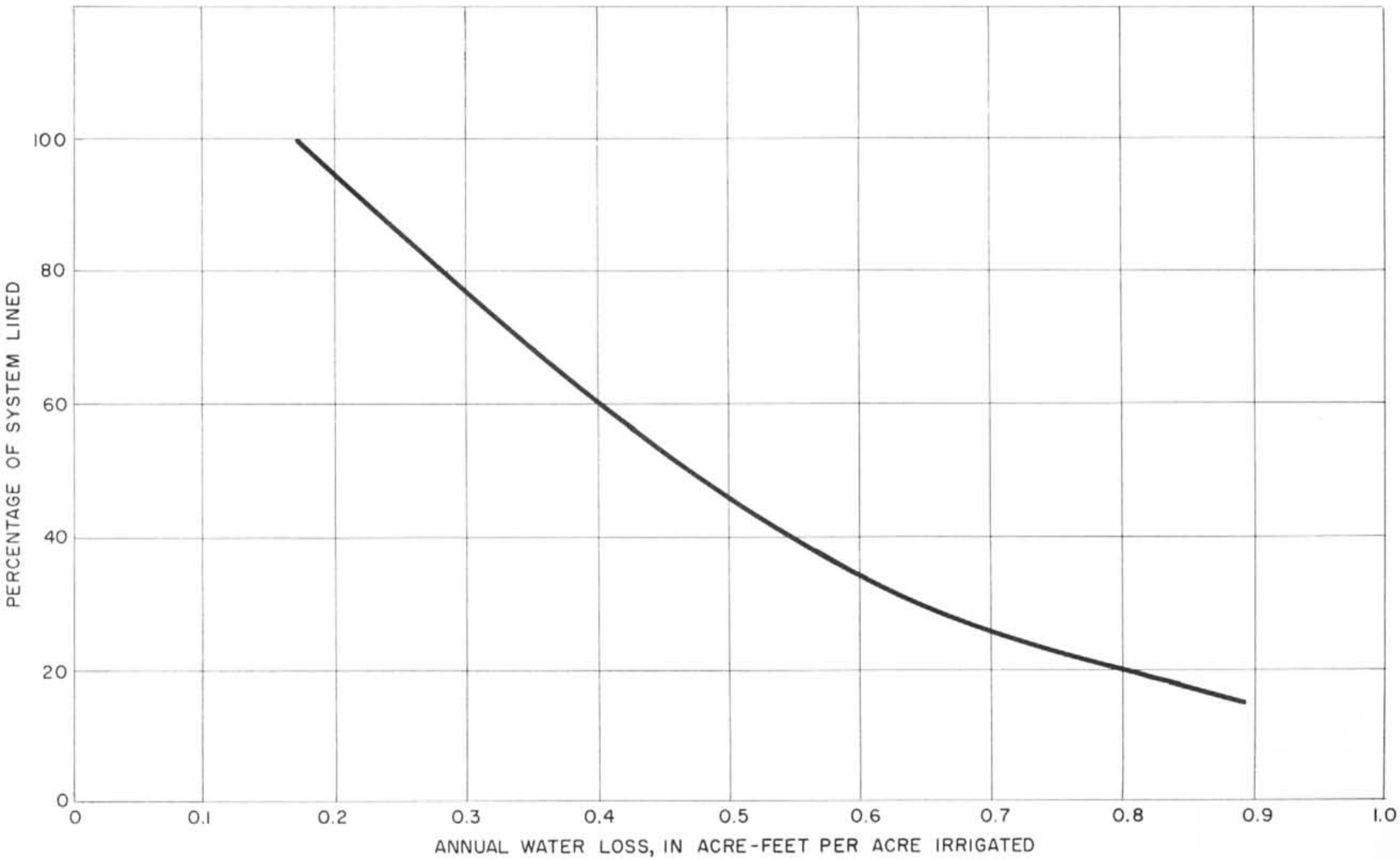

Figure 3

Distribution System Annual Water Loss Per Acre Irrigated

Texas Water Commission

186

FARM EFFICIENCY

General

The efficiency of use of irrigation water when it is applied to the land was of concern in this study in order to get a complete evaluation of the overall efficiency of the delivery of water from Falcon Dam to point of use. The efficiency of farm use, for purposes of this investigation, was based on the quantity of water diverted from the laterals of the supplier. Losses on the farms included those encountered in the small laterals used by the individual farmer to transport water to rows or other points of release, evaporation, deep percolation, and wastes from the ends of the rows or runoff from the fields.

Reviews of Prior Studies Used

Irrigation Water Requirements in U.S. Study Commission-Texas Area

In 1960 the U.S. Study Commission-Texas received Planning Report 30.9, which listed efficiencies of farm use and canals. These values were to be used for their planning purposes in connection with irrigation requirements throughout the State.

The estimate of farm efficiency presented in that report was based on an evaluation of the minutes of the 10th meeting of the Surface-Water Hydrology Collaboration Group, Committee Print No. 12 of the Select Committee on National Water Resources of the U.S. Senate, and other data, and was considered to have a value of 70 percent.(7)

The Irrigation Potential of Kinney, Uvalde, Medina, Bexar, Hays, and Comal Counties, Texas

In 1959, an investigation was made for the City Water Board of San Antonio regarding the irrigation potential of the counties listed above. Included in the report submitted to them was an estimate of farm efficiency in the area under study.

The lack of data on this aspect of irrigation requirements hampered the progress of the investigation but "...from general considerations of drainage conditions and from some knowledge of practices based on discussions of the problem with irrigators and county agents, it was concluded that for vegetables the farm irrigation efficiency may be as low as 50 percent and for feed crops may be anywhere from 50 to 70 percent. These efficiencies are within the usual range for general irrigation farming although slightly on the high side."(8)

A discussion of irrigation practices in the area indicated there was some waste of water under their present procedures. No change in these practices was foreseen, however, so a weighted efficiency of 60 percent(8) was estimated as applicable.

Irrigation Guide for Rio Grande Plain
Land Resource Area-Texas, Zone 3

In the subject report, the Soil Conservation Service published tables of design for various combinations of soil types, irrigation methods, land gradients, row lengths, rates of application, etc. Included in this information was the design efficiency of application, which for graded furrow irrigation was about 85 percent[9] for the area as a whole.

The efficiency of application on farms utilizing level border irrigation was somewhat higher, running about 90 percent.[9]

Conclusion

On the basis of the studies and reports reviewed, an overall average farm irrigation efficiency of 65 percent appears reasonable for use in the Lower Rio Grande Valley.

COMBINED CANAL AND FARM EFFICIENCY

Texas Basins Project

In recent years, the U.S. Bureau of Reclamation has conducted studies in connection with its Texas Basins Project. Among these was an investigation of the irrigation requirements of the Lower Rio Grande Valley, which took into consideration the efficiency of irrigation water use.

Since water deliveries in the Valley are made on an acre-application basis, it was difficult to separate delivery system efficiency and farm efficiency. As a result, the Bureau of Reclamation considered them as one in their investigation.

Overall efficiency was determined for those years in which no shortage occurred during the period 1938-55, and was estimated to be 55.5 percent after adjusting to recent conditions.

Texas Water Commission Estimate

In the discussion of farm efficiency in the preceding section, a figure of 65 percent for farm efficiency was recommended for use.

Efficiency of the canal system must be computed. From Figure 3, assuming the systems to be 56 percent lined, loss in acre-feet per acre irrigated was estimated to be 0.428 annually. Average acres under irrigation for the years as used by the Bureau of Reclamation in their efficiency estimate was 453,900, and average annual diversions amounted to 1,035,600 acre-feet. By use of these data and Figure 3, it was apparent that average annual losses amounted to 194,000 acre-feet, giving a canal efficiency of 81 percent.

Inasmuch as 81 percent of average diversions reach the farms and farm efficiency was estimated to be 65 percent of that quantity, overall efficiency was computed as 81 percent x 65 percent = 52.5 percent. This compared favorably with the 55.5 percent value determined by the Bureau of Reclamation for 56 percent of the canals being lined.

Conclusion

From the preceding discussion, it was apparent that there was considerable agreement between the two efficiency estimates. The use of Figure 3 along with data on acres irrigated and diversions for a particular year will provide reasonable estimates of the distribution system and farm efficiency.

REFERENCES

1. "Operational Wastes," Preliminary Examination and Survey Report-Feasibility of Channel Control Dams, Lower Rio Grande, House Document No. 233, 95th Congress, 1st Session, 1957, p. 12.

2. "Wastes Due to Runoff Below Falcon Dam," Preliminary Examination and Survey Report-Feasibility of Channel Control Dams, Lower Rio Grande, House Document No. 233, 95th Congress, 1st Session, 1957, p. 13.

3. "Plan of Rehabilitation for Mercedes Division," U.S. Bureau of Reclamation, 1956.

4. "Plan of Rehabilitation for Harlingen Division," U.S. Bureau of Reclamation, 1956.

5. "Plan of Rehabilitation for El Jardin Division," U.S. Bureau of Reclamation, 1957.

6. "Plan of Rehabilitation for La Feria Division," U.S. Bureau of Reclamation, 1957.

7. "Irrigation Water Requirements in U.S. Study Commission-Texas Area," by C. B. Thompson, U.S. Study Commission-Texas Planning Report 30.9, December 1960.

8. "The Irrigation Potential of Kinney, Uvalde, Medina, Bexar, Hays, and Comal Counties, Texas," by John R. Erickson, March 1959, p. 20.

9. "Irrigation Guide for Rio Grande Plain Land Resource Area-Texas, Zone 3," Soil Conservation Service, 1962.

APPENDIX V

REVIEW OF REPORTS BY THE UNITED STATES SECTION, INTERNATIONAL BOUNDARY AND WATER COMMISSION, UNITED STATES AND MEXICO, ON THE HYDROLOGY OF THE RIO GRANDE

1900-56

By

Allen E. Richardson

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

REVIEW OF REPORTS BY THE UNITED STATES SECTION, INTERNATIONAL BOUNDARY AND WATER COMMISSION, UNITED STATES AND MEXICO, ON THE HYDROLOGY OF THE RIO GRANDE

1900-56

INTRODUCTION

The purpose of the studies culminating in this report was to review and extract Rio Grande flow data from the hypothetical reservoir operation studies of Amistad and Falcon Reservoirs as made by the United States Section, International Boundary and Water Commission, United States and Mexico (IBWC). Where possible, comparisons were made of the methods and/or criteria used by the IBWC and those which have become standard in the Texas Water Commission's (TWC) Surface Water and Permits Division.

An integral part of the report is a summary of the procedures used by the IBWC in their hypothetical reservoir operation studies. The IBWC furnished the TWC with copies of their study sheets and special summary tabulations of data used in their feasibility studies of Amistad and Falcon Reservoirs, including water-supply studies for the United States along the Rio Grande below Fort Quitman.

The United States' share of the regulated releases from Falcon Reservoir as computed by the IBWC in their studies was extracted for use in the TWC studies of the water-supply limitations on irrigation from the Rio Grande in the Valley. These extracted amounts and the year-end content in conservation storage in Amistad and Falcon Reservoirs as shown in the IBWC study sheets were adjusted by the TWC for the estimated future domestic, municipal, and industrial water requirements to determine the United States' share of the Rio Grande waters that may be available for irrigational use below Falcon Dam. These computations were necessary because of the different procedures used by the TWC to determine consumptive use of water by Valley crops and the irrigation diversion requirements at Falcon Dam.

Estimated future domestic, municipal, and industrial water requirements for Valley cities were compiled from and projected on the basis of the Texas Board of Water Engineers (TBWE) (which became the Texas Water Commission in 1958) Bulletin 5910, "Water Requirements Survey for Texas."

Conservation Storage Reservoirs

Of the initial conservation storage capacities of Amistad and Falcon Reservoirs, the United States' shares were designated as follows:

Amistad - 1,986,700 acre-feet of usable conservation storage capacity. The United States' share of the dead storage at Amistad is 8,400 acre-feet. The flood-control storage capacity of Amistad will make the winter increase in conservation capacity of 234,400 acre-feet at Falcon permanent.

Falcon - 1,420,500 acre-feet of usable conservation storage capacity. During the winter this was increased by 234,400 acre-feet to a total usable capacity of 1,654,900 acre-feet. In addition, the United States' share of the dead storage was 9,600 acre-feet.

The total United States' share of the initial usable conservation storage capacity of the two reservoirs amounts to 3,641,600 acre-feet.

Reservoir Inflow

The IBWC estimated the future inflows to Amistad and Falcon Reservoirs on the basis of hydrologic records for the Rio Grande Basin. At several points on the river, there were streamflow records from the years 1900-14. The streamflow records are only fragmentary from 1914 to 1931 when the actual international stream-gaging program began. For these periods when records were available, the actual streamflows were used. If an area had no streamflow records for a particular time, and records were available for a similar area nearby, flow for that area was estimated on the basis of the runoff per square mile from the nearby area. When no streamflow records were available, the flows were estimated on the basis of correlations of streamflow and rainfall data.

Adjustment of Inflow

Where necessary, adjustments of streamflow were made to take into consideration the increased usage in reservoirs that were in existence at the time of the records, or in case of reservoirs that were not in existence during the entire period of record. Such records were adjusted to conditions that would have existed had the reservoirs been in existence during the entire period of record. Adjustments in streamflow were also made that would reflect the estimated future water uses along the streams.

Adjustment of Inflow--United States

Specific adjustments at specific sites along the river were as follows: the historical streamflow records at Fort Quitman were adjusted for operation of upstream reservoirs and for the present irrigation uses in the El Paso area and upstream. The most important adjustments for the streamflow records at

Fort Quitman were for the regulation at Elephant Butte Dam, which was constructed in 1915. Adjustments of the streamflow records from 1900-15 were necessary to reflect the effect of Elephant Butte Reservoir as estimated prior to 1915. The total adjustments resulted in the reduction of the average annual flow passing Fort Quitman from 335,300 acre-feet per year to 191,900 acre-feet per year for the period 1900-56.

With regard to flows originating on the Pecos River, the assumption was made that most of the flow reaching the Rio Grande from the Pecos River originated below Red Bluff Reservoir. Adjustments were made in this area that resulted in the reduction of the average historical flow of 393,000 acre-feet to 325,000 acre-feet annually.

Minor adjustments were made in the historical flows from Alamito, Terlingua, San Felipe, and Pinto Creeks for which the historical flow averaged 118,308 acre-feet annually. This was reduced to 109,100 acre-feet annually because of some small uses of water from these four creeks.

No adjustments to the historical flows from Devils River and Goodenough Springs were made because no irrigation works were on these tributaries. The average annual historical flows for this period of 515,600 acre-feet from the Devils River and 97,700 acre-feet from Goodenough Springs were used in those quantities in the operation studies.

Adjustment of Inflow--Mexico

The Mexican tributary, Rio Conchos, was adjusted for the effect of the following reservoirs: La Boquilla Dam, which began its operation in 1914; La Colina in 1940; and Rosetilla also in 1940. The Madero Reservoir on a tributary to the Rio Conchos began operation in 1948. The Mexican section of the IBWC made an operation study of the flow of the Rio Conchos taking into account these reservoirs and the present irrigation uses from the streams. This study indicated a reduction of the average annual flow of 1,064,400 acre-feet to the expected future average of 622,500 acre-feet. The Arroya Las Vacas, Rio San Diego, Rio San Rodrigo, Rio Escondido, and the Rio Salado together had an historical average annual flow of 670,800 acre-feet. This average flow was modified to 556,200 acre-feet annually.

Adjustment of Inflow--Unmeasured

Future uses along the unmeasured tributaries to the Rio Grande were estimated to reduce the flow by 108,000 acre-feet per year in the area from Fort Quitman to the Amistad site and 413,000 acre-feet per year from the Amistad Dam site to Falcon Dam. These uses are totals for both the United States and Mexico.

Future Total Inflow

The estimated future total Rio Grande flow at the Amistad Dam site for the period 1900-56 was 2,294,000 acre-feet per year and 2,887,000 acre-feet per year at the Falcon Dam site. This is the combined total of the United States and Mexican waters. The estimated future runoff below Falcon Dam was 226,000 acre-feet per year with no expected additional irrigation uses in this area.

Table 1 summarizes the conditions of future flow of the Rio Grande discussed herein.

Table 1.--Average annual total flow of the Rio Grande, in acre-feet, below Fort Quitman with estimated future conditions of upstream development

(Based on 1900-56 records except where noted)

Location	Historical flows	Estimated average increased depletions over historical depletions	Estimated probable future flows
1. At Amistad Dam site	2,985,000	691,000	2,294,000
2. At site of Falcon Dam	4,058,600	1,171,600	2,887,000
3. Inflows below Falcon Dam (excluding Rio Alamo and Rio San Juan), 1938-52	226,000	0	226,000
Totals (2 + 3)	4,284,600	1,171,600	3,113,000

These estimated future flows of the Rio Grande were divided into the United States share and the Mexico share in accordance with the Treaty of 1944 between the United States and Mexico concerning the waters of the Rio Grande. Table 2 shows the United States' share of the flow of the Rio Grande at the Amistad Dam site and at Falcon Dam.

Table 2.--United States' share of the average annual flow of the Rio Grande, in acre-feet, below Fort Quitman with estimated future conditions of upstream development

(Based on 1900-56 records except where noted)

Location	Total allotted waters less United States' share of channel losses	Estimated future upstream uses	Future flows	Percent of total
1. At Amistad site	1,536,000	50,000	1,486,000	80
2. At site of Falcon Dam	1,971,900	224,000	1,747,000	94
3. Inflows below Falcon, 1938-52	113,000	--	113,000	6
Totals (2 + 3)	2,084,000	224,000	1,860,000	100

Reservoir Demands

Domestic Water Demands

The IBWC computed the estimated domestic demands on the waters of the Rio Grande from Fort Quitman to the Gulf of Mexico for the United States as follows: domestic requirements were based on 120 gallons per day per capita for the area above Falcon Reservoir. This amounted to only 225 acre-feet per year from Fort Quitman to Amistad Reservoir. From Amistad Reservoir to Falcon Reservoir, the estimated domestic requirements were 10,000 acre-feet per year, with 5,000 acre-feet per year return flow resulting in a net requirement of 5,000 acre-feet per year. Below Falcon Reservoir the domestic and municipal diversions were included in the acre-feet per acre irrigation demand for the area because they were included in the measured diversions of the irrigation districts.

Irrigation Water Demands

The irrigation demands under reservoir operation DF-1 were based on 1957 conditions of irrigation. In the reach of the Rio Grande from Fort Quitman to Amistad Reservoir, there were 19,700 acres under irrigation from the river. Consumptive use in this area was estimated on the basis of temperature records. Curves relating consumptive use and degree days--that is, the summation of the differences between mean daily temperature and 32 degrees for a given year--were developed for the area from Fort Quitman to Presidio, from Presidio to Langtry, from Langtry to the Amistad Dam site, and Amistad Reservoir to Falcon Reservoir. These curves were based on measurements made in the El Paso area and another undesignated area in the Lower Rio Grande Valley.

The monthly distribution of the annual irrigation demands were based on the monthly distribution in the El Paso area. The average annual irrigation requirement for the area from Fort Quitman to Amistad Reservoir was 2.75 acre-feet per acre.

The Mexican Section of the IBWC computed the same consumptive-use figures for these areas using a little different formula but using the basic data essentially as the United States Section did. The formula used by the Mexican Section was not given. The consumptive-use data that were used in each of these areas were the result of averaging the monthly values computed by the two sections of the IBWC. These computations resulted in an estimated annual irrigation use above Amistad Reservoir of 54,000 acre-feet. As was stated earlier, the water requirements being discussed herein are for the United States side only.

For the area between Amistad and Falcon Reservoirs, consumptive use was based on temperature records and was varied by months and years according to the rainfall available to supply crop requirements. The 54,000 acre-feet per year computed for the area above Amistad was not varied by months and years according to the rainfall available, but was used every year. The consumptive use between Amistad and Falcon Reservoirs averaged 2.6 acre-feet per acre per year. This depth, applied to the 66,000 acres under irrigation works, resulted in an average of 170,000 acre-feet requirement per year.

For the area from Falcon Dam to the Gulf of Mexico, historical data on acres irrigated and diversions of water for irrigation were available for the period 1938-53. From these data, consumptive use in acre-feet per crop acre for each month was (could be) computed when there was sufficient water for diversion to satisfy all demands. During this period (1938-53), if the flow at Rio Grande City was less than 2,000 cubic feet per second (cfs) or less than 50 cfs at Brownsville, it was assumed that a shortage existed. This shortage was made up by increasing the demands on the reservoir sufficient to increase the flow at Rio Grande City to 2,000 cfs.

During periods of shortage after 1953, the consumptive use was based on the average throughout the previous period of record for those months. Prior to 1938, the irrigation demand was based on a correlation of consumptive use with temperature degree days.

Total Demands

The estimated average annual United States demand for water below Falcon Dam was 1,531,000 acre-feet. This included both irrigation, municipal, and domestic requirements.

The total estimated future United States demand for water from the Rio Grande for irrigation and domestic use from Fort Quitman to the Gulf of Mexico was 1,760,000 acre-feet per year. This was the demand that was used by the IBWC in their reservoir operation designated DF(1). Reservoir operation DF(2) was made under the assumption that demands would increase by 6 percent to an average of 1,810,000 acre-feet annually. Reservoir operation DF(3) assumed that demands would increase by 13 percent to an average of 1,934,000 acre-feet annually.

Reservoir Evaporation and Rainfall

The Treaty of 1944 between the United States and Mexico governing the waters of the Rio Grande presents an unusual situation with respect to evaporation from and rainfall on the reservoir surface. The rainfall on the reservoir is considered to be inflow to the reservoir, and is divided equally between the two countries. Evaporation from the reservoir surface is charged according to the ownership of the water stored in the reservoirs.

This situation necessitates accounting for the rainfall and evaporation from the reservoirs separately, and this is what the IBWC did in their reservoir operations made for the Senate Document No. 65 and in all studies since 1956. In studies made prior to the Senate Document, the net evaporation--evaporation minus rainfall--was used in the operations. The following are descriptions of the methods for computing monthly rainfall and evaporation, as used by the IBWC.

Amistad Reservoir Evaporation

During recent years, extensive pan-evaporation data have been collected at a number of places near the Amistad Dam site. Prior to 1938, however, there were only three stations near the reservoir site. These were Dilley and Balmorhea, Texas; and Palestina, Coahuila, Mexico. The types of pan from which data were available include the Class A Weather Bureau Pan, the Bureau of Plant Industry Pan, a 12-foot pan, and a 2-foot screened pan.

Coefficients for converting pan evaporation to reservoir evaporation were obtained from evaporation records at Dryden, Texas, and at Fort McIntosh in Laredo, Texas. At each of these locations a 2-foot screened pan, a 12-foot sunken pan, and a Class A pan were operated simultaneously. The 12-foot ground pan evaporation depths were assumed to be equal to reservoir evaporation depths. Comparison of the simultaneous records of the three pans at each site developed coefficients of 0.72 for the Class A pan and 0.89 for the 2-foot pan.

The evaporation values for the period 1900-13 were based on the relationship established during more recent years between monthly evaporation and monthly rainfall. This relationship was apparently developed for the climatological records collected at the Del Rio weather station and nearby stations.

For the period 1919-27, the evaporation depths were based on a correlation, also defined by data collected in recent years, between evaporation and the factor (T+W)/RH, where T is the average monthly observed temperature in degrees Fahrenheit, W is the average monthly wind movement in miles per hour, and RH is the average monthly observed relative humidity as established by readings each day at 12:30 p.m.

For the period 1928-30, evaporation depths were computed by adjusting the observed evaporation at Balmorhea and Dilley, Texas.

For the period 1931-45, the monthly evaporation depths were developed by adjustment of the Palestina, Coahuila, observed data. Such adjustment was made by the use of a correlation between the Palestina and Del Rio stations defined during later years.

The evaporation depths for the period 1946-56 were based on the observed data at Del Rio, Texas.

Amistad Reservoir Rainfall

The monthly average rainfall on Amistad Reservoir was computed from the records for the following rainfall stations: Langtry, Fort Clark, Comstock, Del Rio, Cabra, Devils River, Feeley, McKees, Shumla, Devils Lake, and Goodenough Springs Ranch. Appropriate stations for each year were used as records were available. As the runoff from the reservoir area, estimated to average 15 percent of the total rainfall, was included in the computed water supply at the Amistad Dam site, only 85 percent of the total rainfall--the percentage in excess of the portion estimated as runoff--was used as rainfall on the reservoir surface in the operation studies.

Falcon Reservoir Evaporation

In arriving at the monthly evaporation figures for Falcon Reservoir, use was made of the records at four pan-evaporation stations. These stations were: Laredo, Fort McIntosh, and Falcon Village, Texas, and Ciudad Guerrero, Tamaulipas, Mexico. The station at Laredo was operated by the U.S. Weather Bureau while the other three stations were operated by the IBWC. The evaporation depths from a 12-foot pan at Fort McIntosh were assumed equal to reservoir evaporation depths. Coefficients of 0.72 and 0.89 for the Class A Weather Bureau pans and the 2-foot screened pans at Ciudad Guerrero and Falcon Village, respectively, were applied to the observed records of pan evaporation depths to obtain evaporation depths for reservoirs.

These records cover only a small portion of the period 1900-56 for which evaporation data were required. Evaporation for most of the periods of no record was estimated from rainfall records and a rainfall-evaporation correlation curve derived from the 1946-54 evaporation and rainfall data. The gross annual evaporation depths were read from this rainfall evaporation curve with annual rainfall as the argument. The annual rainfall depths were ascertained by taking averages of various stations surrounding the reservoir. The gross annual reservoir evaporation depths thus obtained from the curve were distributed by months throughout the year according to the average monthly evaporation distribution, which had been recorded at the Laredo evaporation station.

Falcon Reservoir Rainfall

The monthly rainfall on the reservoir area was computed from various stations surrounding the reservoir. Some of these stations were: Fort Ringgold, Fort McIntosh, Hebbronville, Zapata, Laredo, Roma, and several stations in Mexico. Once again, 85 percent of the gross rainfall on the area was used as the rainfall for the reservoir operations since 15 percent of the rainfall was recorded in the runoff through August 1953, the date of closure of Falcon Dam. After that date the gross rainfall was used in the operation studies.

The average annual net evaporation loss for the period 1940-56 at the Amistad Reservoir site was 6.17 feet as computed by the IBWC, and 6.18 feet as given in Texas Board of Water Engineers Bulletin 6006, "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1957." The average annual net evaporation loss for the period 1940-56 at the Falcon Reservoir site was 7.08 feet as computed by the IBWC, while Bulletin 6006 gives an average of 6.33 feet, an average difference of 0.75 feet per year.

Criteria of Hypothetical Reservoir Operations

Some of the general criteria used by the IBWC in making the hypothetical reservoir operations were related back to the Treaty of 1944 between the United States and Mexico. Evaporation and other losses from the reservoirs were divided between the two countries in proportion to the ownership of waters in storage in each reservoir. Flood discharges and spills from Amistad Reservoir were divided between the two countries in the same proportion as the ownership of inflows occurring at the time of spills.

In Amistad Reservoir either country at its option may temporarily use unfilled conservation capacities of the other. They may do this provided that when spills occur at Amistad, while one country is temporarily using conservation capacity of the other, all spills are charged to the country using the other's capacity. All inflows are credited to the other country until the spills cease, or until the conservation capacity of the other country becomes filled with its own water.

As provided in Article 8 of the Treaty, storage of water in Amistad Reservoir throughout these studies was maintained at the maximum feasible water level consistent with flood control, irrigation use, and power requirements. This proved to have the important advantage of minimizing storage losses in a two-reservoir system comprised of Amistad and Falcon, as evaporation and seepage losses would be materially less in the reservoir at the Amistad site than at Falcon Reservoir. Also this assured the availability of conservation storage space in Falcon for flood waters originating below the Amistad site.

Except for the retention of 60,000 acre-feet of United States waters in Falcon Reservoir for domestic use, all waters belonging to this country were released from storage as needed for domestic and irrigation purposes with incidental use of such releases at Falcon Dam for generation of hydroelectric power. Releases from Amistad Reservoir were scheduled for optimum generation of hydroelectric energy consistent with domestic and irrigation requirements. These were re-regulated in Falcon Reservoir for such requirements.

The sediment inflow to Amistad Reservoir was estimated by the IBWC to average about 0.467 percent by volume of the inflows. Applying this percentage to the estimated total future river flow at the Amistad site amounting to an average of 2,294,000 acre-feet, the estimated future average annual volume of sediment at the reservoir site was computed to be 10,700 acre-feet. The total sediment capacity at the Amistad site was 550,000 acre-feet, of which 309,000 acre-feet was charged to the United States. In the reservoir operations the IBWC assumed no sediment in the sediment storage at the start of operations and sediment was accumulated yearly in proportion to the inflow.

Recent Domestic, Municipal, and Industrial Water Use in the Lower Rio Grande Valley

Based on annual water-use reports received by the Texas Water Commission's Electronic Data Processing Division as tabulated here, the present domestic, municipal, and industrial use in the Lower Rio Grande Valley is about 62,000 acre-feet per year as shown in Table 3.

Future Domestic, Municipal, and Industrial Water Requirements in the Lower Rio Grande Valley

Future domestic, municipal, and industrial water requirements for cities in the Valley for 1965, 1975, and the year 2000 were compiled from and projected on the basis of work done by the Bureau of Business Research, The University of Texas, and published as TBWE Bulletin 5910, "Water Requirements Survey for Texas." Population and water requirement projections for 1965, 1975, and 2000 are contained in Bulletin 5910 for cities with a population of more than 5,000 in 1957. Twelve of these cities are located in the Valley and are listed, with their population projections and their 1960 census count, in Table 5.

Twelve other Valley cities having less than 5,000 population in 1957 and therefore not included in Bulletin 5910 were added to those shown in Table 5. Water requirements for these 12 smaller cities were projected using as a basis the projections for the cities of Mercedes, Raymondville, and Rio Grande City. These three cities were considered as representative of the future growth of the smaller cities in the Valley. These 24 cities, their 1960 population, and their projected water requirements are shown in Table 6.

Table 3.--Domestic, municipal, and industrial water use in Valley cities as recently reported to the Texas Water Commission

Note: Water use is reported for 1963 except as noted.

Municipality	Population 1960	Ground-water use in acre-feet	Surface-water use in acre-feet	Total use in acre-feet
Roma	1,496	--	445	445
Mission	14,081	1,567[a]	2,480[a]	4,047[a]
McAllen	32,728	220	3,241	3,461
Edinburg	18,706	--	4,516	4,516
Pharr	14,106	2,006	--	--
San Juan	4,371	501	2,897	5,567
Alamo	4,121	163	--	--
Donna	7,522	--	1,173	1,173
Weslaco	15,649	--	--	--
Elsa	3,847	--	--	--
Edcouch	2,814	--	10,224[b]	10,224[b]
LaVilla	1,261	--	--	--
Mercedes	10,943	--	--	--
Lyford	1,554	--	--	--
Raymondville	9,385	--	1,598	1,598
Santa Rosa	1,572	49	--	49
LaFeria	3,047	484	960	1,444
Harlingen	41,207	3	11,900	11,903
San Benito	16,422	977	4,062	5,039
Rio Hondo	1,344	--	--	--
Los Fresnos	1,289	--	1,411[c]	1,411[c]
Brownsville	48,040	none	8,847	8,847
Hidalgo	1,078	90[b]	--	90[b]
Cameron County WCID #10,11,13	--	--	2,538	2,538
	TOTAL.....	6,060	56,292	62,352

[a] Reported in 1960.
[b] Reported in 1962.
[c] Includes use by Cameron Co. Fresh Water Supply District No. 1, Olmito, Immigration and Naturalization Service.

Table 4.--Water supplied for Valley domestic, municipal, and industrial uses in 1962

(Reported surface- and ground-water amounts, in acre-feet)

County	Domestic and municipal uses	Industrial uses	Total
Starr	830	860	1,690
Hidalgo	35,815	843	36,658
Cameron	30,200	4,630	34,830
Willacy	14	--	14
Four-county total..........................			73,192

Table 5.--1960 Census and projected population of Valley cities in TBWE Bulletin 5910

City	Population			
	Census	Projected		
	1960	1965	1975	2000
Brownsville	48,040	55,900	67,000	95,000
Donna	7,522	12,800	15,000	20,000
Edinburg	18,706	19,900	22,500	29,000
Harlingen	41,207	43,000	52,000	90,700
McAllen	32,728	36,300	43,800	76,400
Mercedes	10,943	14,700	16,900	21,100
Mission	14,081	20,900	25,000	35,000
Pharr	14,106	14,100	16,300	20,000
Raymondville	9,385	14,300	16,300	24,200
Rio Grande City	5,835	7,300	9,600	15,000
San Benito	16,422	20,000	23,400	29,500
Weslaco	15,649	15,000	16,300	21,600

Table 6.--Future domestic, municipal, and industrial water requirements in the Valley

City	Population 1960 census	Projected water requirements, in acre-feet		
		1965	1975	2000
Alamo	4,121	845	1,170	2,089
Brownsville	48,040	10,020	12,484	22,035*
Donna	7,522	2,925	4,048	7,422*
Edcouch	2,814	577	799	1,427
Edinburg	18,706	2,830	3,762	6,178*
Elsa	3,847	789	1,093	1,950
Harlingen	41,207	7,976	10,029	21,743*
Hidalgo	1,078	221	306	547
La Feria	3,047	625	865	1,545
La Villa	1,261	259	358	639
Los Fresnos	1,289	264	366	654
Lyford	1,554	319	441	788
McAllen	32,728	6,356	8,571	17,793*
Mercedes	10,943	2,084	2,863	4,570*
Mission	14,081	3,360	4,505	8,142*
Pharr	14,106	2,084	2,777	4,367*
Raymondville	9,385	2,164	2,876	5,466*
Rio Grande City	5,835	1,114	1,679	3,222*
Rio Hondo	1,344	276	332	681
Roma	1,496	307	425	758
San Benito	16,422	2,771	3,947	6,350*
San Juan	4,371	896	1,241	2,216
Santa Rosa	1,572	322	446	797
Weslaco	15,649	2,265	2,971	5,137*
TOTAL	262,418	51,649	68,404	126,516

* Projected water requirements given in TBWE Bulletin 5910. Other projections were made by Texas Water Commission staff.

The United States' Share of Water Available from the Rio Grande for Valley Use

The month-by-month summary tabulations of the results of the hypothetical reservoir operation studies of Amistad and Falcon Reservoirs for the period 1900-56 as made by the IBWC were used to derive and compile the total amount of United States water available yearly at Falcon Reservoir for use in the Valley. These yearly amounts were adjusted by subtracting 124,000 acre-feet annually to supply projected future domestic, municipal, and industrial uses. The adjusted or reduced amounts were then considered to be the annual amount of water available for irrigational use below Falcon Dam. These amounts as derived from the three IBWC conditions of operation, DF(1), DF(2), and DF(3), listed in Table 7.

The IBWC month-by-month summary was also used to derive the total end-of-year United States share of usable content in conservation storage in both Amistad and Falcon Reservoirs. The IBWC content figures for the two reservoirs included the sediment volume that had accumulated in the reservoirs since the start of the operation, plus the 60,000 acre-feet reserved in Falcon Reservoir for domestic use in the Valley. To arrive at the "usable" content, the 60,000 acre-feet plus 8,200 acre-feet per year for sedimentation of storage space was subtracted from the IBWC end-of-year total content figures. The total "usable" end-of-year contents of the two reservoirs are listed in Table 7.

Table 7.--The adjusted United States' share of the available water supply

[For DF(1), DF(2), and DF(3) conditions and end-of-year contents of Amistad and Falcon Reservoirs, 1900-56]

Year	TWC adjusted supply[1/] in 1,000's acre-feet			End-of-year usable content of Amistad and Falcon Reservoirs under DF(1) conditions
	DF(1)	DF(2)	DF(3)	
1900	1,526	1,618	1,728	1,103
1901	1,658	1,779	1,925	435
1902	1,364	1,185	982	6
1903	1,129	1,193	1,270	460
1904	1,289	1,386	1,502	1,223
1905	1,157	1,244	1,347	2,335
1906	1,197	1,285	1,392	3,352
1907	1,669	1,792	1,937	2,707
1908	1,426	1,529	1,655	2,503
1909	1,598	1,712	1,854	2,028
1910	1,603	1,719	1,860	1,261
1911	1,608	1,729	1,280	629
1912	1,263	854	830	137
1913	1,134	1,148	1,161	458
1914	1,194	1,283	1,390	2,127
1915	1,497	1,609	1,739	1,925
1916	1,454	1,560	1,688	1,467
1917	1,975	2,117	2,007	535
1918	1,358	1,028	905	206
1919	1,167	1,252	1,298	2,489
1920	1,536	1,651	1,785	3,466
1921	1,668	1,790	1,934	2,189
1922	1,171	1,259	1,365	2,725
1923	1,354	1,454	1,575	2,650
1924	1,437	1,541	1,669	2,166
1925	1,056	1,136	1,231	2,981
1926	1,052	1,132	1,228	2,904
1927	1,561	1,677	1,837	1,950
1928	1,215	1,307	1,416	1,800
1929	1,265	1,359	1,471	1,186
1930	843	910	988	1,534
1931	1,240	1,335	1,444	1,343
1932	1,166	1,254	1,360	3,519
1933	1,185	1,156	1,254	3,308
1934	1,362	1,463	1,583	2,212
1935	1,137	1,224	1,325	3,448
1936	1,301	1,162	1,239	3,377
1937	1,404	1,505	1,629	2,459
1938	1,451	1,558	1,686	2,473
1939	1,441	1,548	1,674	1,728
1940	1,293	1,388	1,504	1,582
1941	651	703	766	3,412
1942	1,628	1,637	1,728	3,251
1943	1,329	1,429	1,546	2,605
1944	1,289	1,383	1,499	2,292
1945	1,569	1,684	1,822	1,523
1946	1,447	1,553	1,681	1,180
1947	1,538	1,649	1,246	465
1948	1,521	1,239	1,225	479
1949	1,371	1,474	1,594	1,007
1950	1,784	1,681	1,520	0
1951	605	606	606	0
1952	202	208	208	0
1953	383	383	383	0
1954	1,077	1,151	1,243	2,364
1955	1,635	1,756	1,899	1,548
1956	1,421	1,520	1,353	204

1/ United States' share of IBWC regulated releases from Falcon Reservoir less 124,000 acre-feet per year for future domestic, municipal, and industrial requirements.

REFERENCES

1. "Rio Grande International Storage Dams Project: Proposed Amistad Dam and Reservoir," Senate Document No. 65, 86th Congress, 1st Session, 1959.

2. "The Court's Interrogatories and Appropriator's Answers to the Interrogatories and the Statements of Fact," Vols. I and II, Proceedings of the 93rd District Court of Hidalgo County, "State of Texas, et al., versus Hidalgo County Water Control and Improvement District No. 18, et al."

3. "Hypothetical Reservoir Operations of Amistad and Falcon Reservoirs," International Boundary and Water Commission, 1900-56.

4. "Treaty between the United States of America and Mexico: Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande," February 3, 1944.

5. "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1957," Texas Board of Water Engineers, Bulletin 6006, May 1960.

APPENDIX VI

COMPUTATIONAL PROCEDURES AND IRRIGATION DIVERSION REQUIREMENTS IN THE LOWER RIO GRANDE VALLEY 1904-56

By

Henry H. Porterfield, Jr.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLES

COMPUTATIONAL PROCEDURES AND IRRIGATION DIVERSION REQUIREMENTS IN THE LOWER RIO GRANDE VALLEY 1904-56

INTRODUCTION

This report contains explanations and examples of the selection of criteria, the computational procedures, and the results as obtained from this portion of the comprehensive study made by the Texas Water Commission (TWC) to determine the water-supply limitations on irrigation from the Rio Grande in Starr, Hidalgo, Cameron, and Willacy Counties, Texas, on the basis of the TWC methods.

Purpose

The purpose of this study was to determine the irrigation diversion requirements for water at Falcon Dam as needed to satisfy the water requirements for consumptive use by Valley crops not fully provided for by rainfall, and to provide a basis for determining the Valley acreages irrigable annually over a long period of time with the United States' share of the Rio Grande waters regulated by management of the conservation storage afforded by Amistad and Falcon Reservoirs. Criteria for this study were to be derived from separate studies and reports of the Valley climate, soils, cropping patterns, and water transmission losses comprising this set of appendices to the TWC Bulletin 6413 (Appendices I, II, III, and IV, respectively).

Summary

Detailed water-balance accountings were made on a month-by-month basis for the 53-year period 1904-56 for three Valley study areas. This was necessary partly because of the characteristic variation in climate, ranging from subhumid to semiarid according to rainfall, east to west, as explained in Appendix I. Basic climatic data for Rio Grande City, Edinburg, and Harlingen were used as being representative of the annual average areal climatic data and characteristic variation and range in quantity for Areas 1, 2, and 3 in transition from Falcon Dam to the Gulf of Mexico.

Determinations were made of the irrigation diversion requirements for water at Falcon Dam that would have satisfied the water requirements for Valley crops under historical conditions on a month-by-month basis during the period 1904-56 for an average annual cropping pattern as explained in Appendix III.

Soils grouped by type and by characteristics, with particular selection by texture, available moisture-holding capacity, and moisture-replacement depth as described in Appendix II, were used in the computations for Areas 1, 2, and 3.

Irrigation requirements for the Valley crops on the farm were determined as unit requirements for the three areas by accounting the consumptive-use requirements of the crops, the rainfalls, the potential evaporation, the available moisture in the soil reservoirs, and the resulting shortages of water during each month of the study period. These requirements at the crop were consolidated into annual figures, and were increased by the amounts of transmission losses from Falcon Dam to the crop unit in each area as derived from Appendix IV to determine the respective irrigation diversion requirements at Falcon Dam. The annual irrigation diversion requirements for the three study areas were combined into a Valley requirement on the basis of the respective percentage of irrigation requirement in each.

Having determined the irrigation diversion requirements at Falcon Dam to satisfy Valley crop water needs for each year of study, the Valley acreages irrigable each year were determined on the basis of the available water supply. The available water supply and total water resources comprised of the United States' share of the Rio Grande waters and the conservation storage capacities of Amistad and Falcon Reservoirs were derived in a separate study as described in Appendix V.

Additional studies of the acreages irrigable on a project basis--an established acreage to be irrigated annually--with consequent shortages were made on the basis of the United States' total water resources. The acreages included in these studies were 600,000; 650,000; 700,000; 750,000; and 800,000. The results from these studies covering the 57-year period 1900-56 provided the basis for the analyses and conclusions summarized in Bulletin 6413.

The selection of the criteria and data used in these computations was made jointly by Messrs. Vandertulip, McDaniels, Rucker, and this writer in agreement with the authors of Appendices I, II, III, IV, and V.

BASIC DATA

Rainfall

Rainfall data collected by the U.S. Weather Bureau; the International Boundary and Water Commission, United States and Mexico; the Texas Agricultural Experiment Station; and the Texas Water Commission (formerly the Texas Board of Water Engineers, TBWE) were used to develop the continuity of monthly rainfall data for each study area for the period 1904-56.

Area 1: Rio Grande City

Monthly rainfall data for Area 1 were used as recorded for the rainfall gaging station at Rio Grande City. For periods of no record at the Rio Grande City gage, rainfall records for Mission, Roma, Ringgold Barracks, and Fort McIntosh were used and transferred to Rio Grande City by correlations to provide complete data for the period 1904-56.

Area 2: Edinburg

Monthly rainfall data for Area 2 were used as recorded for the rainfall gaging station at Edinburg. Rainfall data for periods of missing record at Edinburg were substituted directly from records for Mission because the rainfall correlation between Edinburg and Mission was very close. For periods of no record at either Edinburg or Mission, recorded data for Mercedes and Llano Grande were substituted. For rainfall data prior to the period of record at the cited stations, averages of Fort McIntosh and Brownsville data were used. Because the Edinburg area lies in transition between a maritime climate and a semiarid climate, it was necessary to choose a rainfall station to represent each climate. These were Fort McIntosh and Brownsville, and it was found that the average rainfall at these two stations correlated well with the areally representative records of rainfall taken at Edinburg.

Area 3: Harlingen

The rainfall data for Area 3 were taken from Harlingen rainfall gaging station records except for periods of missing record, which were taken from Brownsville. Harlingen and Brownsville have similar climatic characteristics, and rainfall averages correlated closely. No adjustments to rainfall records for Brownsville were considered necessary for use at Harlingen in this study.

Climatic Indices

The monthly climatic indices used in the determination of consumptive use of water by Valley crops in Areas 1, 2, and 3 were taken from studies and computations made by the Texas Water Commission. These monthly climatic indices provide a basis for the determination of estimates of evapotranspiration (consumptive use) by agricultural crops and other beneficial vegetation, consumptive waste by non-beneficial vegetation, and evaporation from land and water surfaces. Monthly climatic indices for the entire State have been computed and compiled for the period 1903-63 by the Commission's staff for each area of Texas for use in computing these estimates.

The climatic indices for each area were taken from monthly isogrammatic charts based on Valley and adjacent area air temperature, dew point temperature, wind movement, and solar radiation data. The procedure for computing the climatic indices is outlined and referenced in TBWE Bulletin 6019, "Consumptive Use of Water by Major Crops in Texas," November 1960.

Soil Moisture Reservoirs

The data on soils, and their grouping and characteristics as used in the hypothetical soil-moisture reservoir operation studies to determine the extent to which rainfall and available moisture held in the various soils would provide for the consumptive-use requirements of Valley crops, were used as given in Appendix II.

Table 1 shows the available moisture-holding capacity for the moisture-replacement depth supporting the principal root growth for three respective crop groups, combined in relation to their root depths, for each of the three soil groups used in each study area.

Table 2 shows the percentage of irrigated cropland in each soil group in each area. These data provide the basis for deriving weighted average irrigation requirements for each area.

Cropping Pattern

The average annual cropping pattern used in this study throughout the period 1904-56 was derived from Appendix III. The computations of consumptive use and irrigation requirements by the crops included were made on the basis of an annual percentage crop use of the irrigated acreage as being representative of each monthly cropping. Varying the month-by-month percentages of acreage planted in accordance with the data derived and shown in Table 1 of Appendix III in these computations was prohibitive in time and cost required. The annual percentages of crop acreages shown in Appendix III were modified by shifting 2 percent of the deep-rooted vegetable acreage to the shallow-rooted vegetable acreage, and by deleting the 1 percent of "other" crops and the 5 percent land use for farmsteads and waste. The deep-rooted vegetables, comprising 22 percent cropping of the acreage annually, were used as 11 percent for each of two crops, early and late.

Table 3 shows the average percentage distribution of the Valley crops used in this study. The total of 111 percent reflects the multiplicity of cropping a land unit as afforded by a water supply for irrigation and favorable climatic conditions, and does not include land use for farmsteads, waste, and minor crops.

Consumptive-Use Data

Consumptive-use coefficients for Valley crops, included in the average annual cropping pattern used in this study, were taken directly from TBWE Bulletin 6019 in sub-areas 4A and 4B, and were used in the manner prescribed in that publication. For convenience of computations, the average planting dates for Valley crops shown as the 16th day of a month in Bulletin 6019 were changed to the first day of a month. The programming for the IBM 1401 Electronic Computer was therefore expedited without loss of accuracy in the results obtained.

The consumptive-use coefficients by months for each Valley crop included in this study are shown in Table 4.

Irrigation Water Losses

Farm Losses

Losses of water in transmission from Falcon Dam to the crops in Areas 1, 2, and 3 were based on data given in Appendix IV. The farm efficiency of 65 percent was used as a coefficient to increase the amounts of water required for irrigation of the crops by the amount lost through application and other causes on the farm. This increase for farm losses amounts to 54 percent of the irrigation requirement at the crop.

Table 1.--Valley soil group moisture capacities

Soil group	Crop group	Moisture replacement depth, in feet	Available moisture holding capacity, in inches
I	1	2	4.9
I	2	3	7.1
I	3	2	4.9
II	1	4	7.7
II	2	5	9.3
II	3	2	4.0
III	1	5	8.1
III	2	6	9.7
III	3	3	4.0

Table 2.--Percentage of irrigated cropland in each soil group in Valley study areas

Area	Soil group	Percentage in irrigated cropland
1	I	8
1	II	41
1	III	51
2	I	12
2	II	61
2	III	27
3	I	23
3	II	70
3	III	7

Table 3.--Average cropping pattern in the Valley, 1957-63

Crop	Distribution, in percent
Corn......................	2
Cotton....................	41
Pasture, perennial.........	8
Vegetables, deep-rooted:	
1st crop................	11
2nd crop................	11
Vegetables, shallow-rooted (two crops or more)......	10
Sorghum, grain:	
1st crop................	9
2nd crop................	9
Citrus (mixed)............	10
Total effective unit cropping....111	

Distribution System Losses

In this study, the assumption was made that future distribution systems would be concrete-lined canals, or the equivalent, and closed conduits. Therefore the distribution system loss rate per acre irrigated was used as shown for 100-percent lined in Figure 3 in Appendix IV.

Because of the multiplicity of cropping on the irrigated acreage, the losses of water through the distribution system was readily accountable as a constant amount per acre irrigated each year. Under single or less complex cropping, distribution system efficiency percentages or coefficients can be used in computations to increase the amount of water required at a farm headgate by the amount lost in transit from the point of diversion.

The data on which the loss rates shown in Appendix IV were based, were equivalent to the loss of 0.17 acre-feet per acre irrigated per 128 acres served per mile of canal. From studies of Valley irrigation made by the U.S. Bureau of Reclamation, the acreage served per mile of canal in Areas 1 and 2 was derived as 200, and the acreage served per mile of canal in Area 3 was derived as 150. By proportion to the per acre loss for 128 acres served per mile of canal, the loss rates for Areas 1 and 2 were computed as 0.145 acre-feet per irrigated acre per year, and the loss rate for Area 3 was computed to be 0.109 acre-feet per irrigated acre per year.

Table 4.--Crop consumptive-use coefficients for Valley Study Areas 1, 2, and 3.

(Data from TBWE Bulletin 6019 for sub-areas 4A and 4B)

Crop	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Corn, Planted on 1st of month.........	--	--	0.15	0.45	0.81	1.35	1.00÷2*	--	--	--	--	--
Cotton, Planted 1st of month.......... (5-1/2 month growing period)	--	--	.23	.24	1.03	.83	.61	0.10÷2*	--	--	--	--
Pasture, perennial....................	0.53	0.53	.74	.69	1.03	.90	.93	.64	0.94	0.92	0.74	0.43
Vegetables, deep-rooted:												
1st crop............................	.38	.48	.93	.78	.57	--	--	--	--	--	--	--
2nd crop............................	--	--	--	--	--	--	--	.38	.48	.93	.78	.57
Vegetables, shallow-rooted, Planted 1st of September............	.81	.58	.53	--	--	--	--	--	.25	.70	1.03	.75
Sorghum, grain:												
1st crop............................	--	--	.43	.84	1.01	.60	--	--	--	--	--	--
2nd crop............................	--	--	--	--	--	--	--	.43	.84	1.01	.60	--
Citrus (mixed)......................	.60	.66	.56	.69	.61	.67	.57	.64	.72	.65	.66	.68

* Applicable for half a month; applied to climatic index for a month.

River Channel Losses

The reaches of the Rio Grande, within which the diversion works principally serving Areas 1, 2, and 3 were located, were delineated by inspection of maps of the Valley which showed the distribution systems and the locations of the diversion works.

The lengths of the three reaches of the river determined by inspection were correlated with the river reaches compiled in Table 3 of Appendix IV, and the proportional loss rates per mile of river channel were determined for the overlapping portions.

The loss rates determined for the three river reaches were applied to the average quantity of United States water released from Falcon Dam as computed by the IBWC in order to compute a quantity of annual loss for each of the three reaches. These computations were made on the basis that flows in the respective reaches were reduced by the upstream losses and diversions. The proportion of the resulting quantities lost within each reach to the estimated flow through that reach, combined with the proportional loss in the upstream reach or reaches, was determined to be the channel transmission-loss coefficient applicable to that reach. The coefficients expressed as river channel transmission efficiencies, in percentage, were determined to be: Area 1, 98 percent; Area 2, 94 percent; and Area 3, 92 percent. The percentage of the total Valley irrigation requirements served in each area and subject to the effects of these losses were estimated to be: Area 1, 4.4 percent; Area 2, 55.8 percent; and Area 3, 39.8 percent. These percentages provided a basis for determining the weighted Valley unit diversion requirement at Falcon Dam.

Effective Rainfall

Only a portion of some rainfall amounts are effective in providing water for consumptive use by crops. Generally, in the accounting procedure used in this study involving the operations of soil moisture reservoirs with crops, the determination of effective rainfall is not of material consequence because of uncertainties in some of the less precise data and because of the use of monthly data. However, effective rainfall, allowing for some surface runoff, was computed throughout the study. The bases for these computations were derived from Watershed Experiment Station data collected by the Agricultural Research Service, U.S. Department of Agriculture, at Reisel and Tyler, Texas. The soils at these Experiment Stations are similar to the soils grouped for this study in the Valley. These rainfall-effective rainfall relations were used by the U.S. Study Commission-Texas (USSC-T) in irrigation requirement studies. The data so derived were contained in the USSC-T Planning Report 30.9 as a curve. Points defining this curve as compiled for use in this study are shown in Table 5.

Table 5.--Rainfall-effective rainfall relationships, in inches, for the Lower Rio Grande Valley*

Rainfall	Effective rainfall	Rainfall	Effective rainfall
0.01	0.01	8.00	5.41
1.00	1.00	8.50	5.63
2.00	1.90	9.00	5.82
3.00	2.65	9.50	6.01
4.00	3.32	10.00	6.20
5.00	3.93	11.00	6.51
6.00	4.50	12.00	6.88
6.50	4.75	13.00	7.22
7.00	5.00	14.00	7.53
7.50	5.22	20.00	9.65

* Based on data contained in USSC-T Planning Report 30.9.

COMPUTATION PROCEDURES

General

The computations of the irrigation diversion requirements for the Lower Rio Grande Valley were divided into three phases. Most of these computations were done on the IBM 1401 Electronic Computer, and were programmed and processed by the TWC Electronic Data Processing Division. Computer and tabulation "print-outs" of pertinent data in these computations were made and are on file in the Commission offices.

Multiphase Computations

First Phase Computations

The first phase computations were made to determine the irrigation requirement for crops in each study area. These include preplanting irrigation requirements and irrigation requirements during the crop growing season.

In these computations the soil moisture reservoirs were operated under crops and during periods of fallowing or rest in a manner similar to computation of hypothetical reservoir operations. The soil moisture-replacement depth for each crop in each soil group was selected and the available moisture-holding capacity tabulated as contained in Table 1. Month-by-month accounting of rainfall, effective rainfall, evaporation from fallow land, consumptive-use requirements for crops, the soil reservoir available moisture content, the pre-planting irrigation requirement, and the irrigation requirement during the crop growing season were made for each crop on each soil group in each area for the 53-year period, 1904-56.

The fallow land monthly evaporation coefficient was used as 0.30 throughout the study. This was applied to the monthly climatic-index number as the estimate of water lost from the soil reservoir by evaporation. Comparison of studies made on loss of water by evaporation from fallow land, expressed as total water lost by evaporation in relation to soil moisture depletion and rainfall, indicates this coefficient is reasonable.

The soil moisture reservoir available moisture-holding capacities were not depleted below 50 percent of capacity during cropping (see Appendix II) but were allowed to be depleted as much as 100 percent during fallowing.

Step by step details of this procedure are shown in Table 6 and Table 7.

Second Phase Computations

The second phase of these computations was the tabulation of individual crop consumptive use and irrigation requirements for the period of study, and the computation average figures. These tabulations were reviewed to determine the range in variations of these amounts. The third phase computations were then designed to minimize the work requirement and maintain a minimum allowable difference between combined amounts and individual amounts.

Third Phase Computations

The third phase computations were made to determine the irrigation diversion requirements at Falcon Dam to satisfy the irrigation requirements at the crop for the 53-year period 1904-56. These computations were made as follows:

1. The annual irrigation requirement for each crop for each soil group was combined as a weighted average in each area on the basis of the percentage of each soil group in each area (Table 2);

2. The annual weighted average irrigation requirement for each crop in each area obtained under Step 1 was combined into a weighted annual average cropping-pattern irrigation requirement on the basis of the cropping pattern percentages (Table 3);

3. Each area weighted cropping-pattern irrigation requirement was divided by 0.65 to adjust for the farm efficiency and determine the farm headgate requirement;

4. The distribution system loss of 0.145 acre-feet per irrigated acre in Areas 1 and 2, and the loss of 0.109 acre-feet per irrigated acre in Area 3, were added to the annual weighted average irrigation requirement as a constant in the respective areas to obtain the annual distribution system diversion requirements;

Table 6.--Crop consumptive-use requirements: Soil moisture reservoir operations criteria

---

Data involved:

Monthly gross rainfall (P) for each of 3 areas.
Effective rainfall (P_E) relationships for area.
Monthly climatic-indices (I_C) for each of 3 areas.
Consumptive-use coefficients (K_U) for area.
Fallow land evaporation coefficients (K_F).
Soil moisture reservoir capacities (M_C) for 3 soil groups and for 3 crop-group root depths each for area.
Criteria for operation.

Criteria for soil moisture reservoir operations for 8 capacities (M_C):

1. Begin with soil moisture reservoir content (M_A) at end of December 1903 as 50 percent of M_C for each crop and respective root depth in each soil group.

2. During months lands are fallow, account total depletion of M_A by fallow-land consumptive use (U_F) and bring M_A to M_C at end of month just prior to month in which crop is planted--whether on 1st of month or 16th of month.

3. The amount of water required to bring M_A to M_C in the month prior to planting of crop is the PREPLANTING-IRRIGATION REQUIREMENT (Irr_P).

4. Deplete M_A during months lands are fallow by amounts as determined by an evaporation coefficient (K_F) applied to I_C--for the Rio Grande Study, use K_F=0.30.

5. During months lands are cropped, allow a maximum depletion of M_A as 50 percent of M_C before refilling reservoir to M_C; except for the last month or half month of the cropping period, refill reservoir to 50 percent of M_C only.

6. When the crop consumptive use (U_C) is greater than P_E plus the M_A in excess of 50 percent M_C, account the difference as the IRRIGATION REQUIREMENT (Irr) for that month.

7. When a crop period begins or ends in the middle of a month, account U_C for half a month and U_F for half a month.

Note.--IRRIGATION DIVERSION REQUIREMENTS are determined by dividing Irr_P and Irr by a selected IRRIGATION COEFFICIENT (K_I) after 1st, 2nd, and 3rd phase of program is completed in which irrigation requirements are computed.

Table 7.--Example of computations of crop irrigation requirements: Lower Rio Grande Valley, 1904-56

Study Area I--Crop: Corn; Soil Moisture Reservoir Capacity: M_C = 4.9 inches; Fallow Land Evaporation: K_F = 0.30.

Calendar year	Item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	The year
1904:	K_U	--	--	0.15	0.45	0.81	1.35	1.00÷2	--	--	--	--	--	--
	1. P	1.48	1.22	1.03	1.66	3.14	2.58	1.89	3.08	4.57	2.68	1.25	1.51	26.09
	2. P_E	1.45	1.21	1.03	1.61	2.67	2.32	1.82	2.62	3.20	2.41	1.24	1.48	23.06
	3. I_C	2.4	3.0	4.2	5.4	6.6	7.2	8.4	7.2	5.4	4.8	3.0	2.4	60.0
	4. U_F	.72	.90	--	--	--	--	1.26	2.16	1.62	1.44	.90	.72	9.72
	5. U_C	--	--	.63	2.43	5.34	9.70	4.20	--	--	--	--	--	22.30
	6. M_AU_F	3.18	4.90	--	--	--	--	2.10	2.56	4.14	4.90	4.90	4.90	--
	7. Irrp	--	1.41	--	--	--	--	--	--	--	--	--	--	1.41
	8. M_AU_C	--	--	4.90	4.08	4.90	4.90	2.45	--	--	--	--	--	--
	9. Irr	--	--	0	0	3.49	7.38	.84	--	--	--	--	--	11.71
	10. Irrp+Irr	--	1.41	0	0	3.49	7.38	.84	--	--	--	--	--	13.12
1905:	1. P	.37	3.92	.29	.47	.98	4.76	1.11	2.22	3.21	2.56	.79	.33	21.01
	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀
	10. Irrp+Irr	--	2.10	0	3.42	4.56	3.45	0	--	--	--	--	--	13.53
1906:	**And continuing** in a like manner year by year	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀
1956:	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀

Note: Units are inches except for consumptive-use coefficients K_U.
Item 10 is used in Second Phase Computations for determination of Irrigation Diversion Requirements.

5. The annual distribution system diversion requirement for Areas 1, 2, and 3 were divided by the respective channel transmission coefficients of 0.98, 0.94, and 0.92 to determine the annual irrigation diversion requirement at Falcon Dam for each area;

6. The annual irrigation diversion requirement at Falcon Dam for each area was combined into an annual weighted average irrigation diversion requirement at Falcon Dam for the Valley on the basis of the percentage of the irrigation requirement in Areas 1, 2, and 3--4.4, 55.8, and 39.9 percent, respectively.

The annual irrigation diversion requirements for each area and for the Valley as a whole for the period 1904-56 are shown in Table 8.

VALLEY ACREAGES IRRIGABLE

From the Available Supply Based on IBWC Regulated Releases

The Valley acreages irrigable from the United States' share of the Rio Grande adjusted available water derived from the IBWC computations of regulated releases were determined for IBWC DF(1), DF(2), and DF(3) conditions by dividing each respectively by the Valley composite-acre irrigation diversion requirement. These data are shown in Table 9.

From the Water Resource

The water resources as previously described consist of the annual regulated releases of United States water at Falcon Dam as determined for the DF(1) studies plus the contents in conservation storage in Amistad and Falcon Reservoirs at the end of each year during the 57-year period, 1900-56.

The Valley composite-acre irrigation diversion requirement for each year during the period 1904-56 was multiplied by 600,000; 650,000; 700,000; 750,000; and 800,000 acres to obtain the annual irrigation diversion requirements in acre-feet for those acreages. For the period 1900-03, the average annual requirement of 2.21 acre-feet per acre was used with the respective acreages to obtain Valley irrigation diversion requirements for the full 57-year period, 1900-56. Detailed monthly computations for 1900-03 were not made in this study because of lack of data.

Subsequently, hypothetical annual reservoir operations at Amistad and Falcon Reservoirs were made, using total United States water resources previously described. The combined initial conservation storage capacities of the two reservoirs were depleted yearly by sedimentation and 60,000 acre-feet of water for domestic use reserved in storage as explained in Appendix V. The total usable end-of-year content of the two reservoirs and the adjusted regulated supply for irrigation as explained previously (124,000 acre-feet subtracted annually for domestic, municipal, and industrial water requirements in the Valley) were combined to supply the demands for the annual requirements for each of the five acreages stated.

When the annual water resources exceeded the annual demand, the difference between the supply and demand was accrued in a revised total end-of-year usable content in storage. Content in conservation storage was not allowed to exceed

Table 8.--Irrigation diversion requirements for the Lower Rio Grande Valley at Falcon Dam, 1904-56

Year	Acre-feet per acre			
	Area 1	Area 2	Area 3	Valley
1904	2.14	2.43	2.20	2.33
1905	2.42	1.44	1.51	1.51
1906	2.01	1.42	1.65	1.54
1907	3.02	2.21	2.06	2.19
1908	2.54	1.85	1.89	1.90
1909	3.24	2.21	1.95	2.16
1910	3.31	2.66	2.30	2.55
1911	3.16	2.68	2.26	2.54
1912	2.22	1.74	1.79	1.78
1913	2.39	1.80	1.65	1.76
1914	2.27	2.12	1.61	1.92
1915	2.59	2.77	1.99	2.45
1916	2.91	2.40	2.13	2.32
1917	3.05	3.21	2.29	2.84
1918	2.74	2.74	2.02	2.45
1919	2.13	1.75	1.40	1.63
1920	2.79	2.53	2.47	2.52
1921	3.36	2.97	1.89	2.56
1922	2.55	2.71	1.38	2.17
1923	2.91	2.44	2.22	2.38
1924	2.64	1.97	2.04	2.03
1925	2.85	2.87	1.94	2.50
1926	2.15	1.36	1.30	1.37
1927	2.91	2.79	1.92	2.45
1928	2.58	2.59	2.15	2.41
1929	2.58	2.27	1.69	2.05
1930	1.87	1.19	1.22	1.23
1931	1.49	1.70	1.31	1.53
1932	2.53	1.62	1.41	1.58
1933	2.34	1.59	1.71	1.68
1934	2.59	2.84	2.28	2.61
1935	2.55	2.01	.85	1.57
1936	1.99	1.96	1.33	1.71
1937	2.58	2.41	1.83	2.19
1938	2.75	2.75	2.29	2.57
1939	3.16	2.41	2.25	2.38
1940	3.00	2.59	2.25	2.47
1941	1.21	1.15	.71	.98
1942	2.73	2.48	1.66	2.17
1943	2.75	2.42	2.33	2.40
1944	2.59	2.13	1.20	1.78
1945	2.85	2.54	1.97	2.33
1946	2.86	2.56	1.80	2.27
1947	2.71	2.72	2.12	2.48
1948	2.24	2.52	1.96	2.28
1949	2.28	2.55	2.23	2.41
1950	3.48	3.29	2.39	2.94
1951	2.91	2.97	2.21	2.67
1952	3.61	2.93	2.72	2.87
1953	3.42	3.75	3.21	3.52
1954	2.57	2.46	2.48	2.47
1955	2.69	2.88	2.13	2.58
1956	3.39	3.51	3.02	3.31
Average yearly	2.65	2.37	1.94	2.21

Table 9.--Valley cropland irrigable from adjusted IBWC water supply at Falcon Dam

Year	TWC adjusted supply[1] in 1,000's acre-feet			TWC irrigation diversion requirements in acre-feet per acre	Total cropland irrigable in acres		
	DF(1)	DF(2)	DF(3)		DF(1)	DF(2)	DF(3)
1904	1,289	1,386	1,502	2.33	553,200	594,800	644,600
1905	1,157	1,244	1,347	1.51	766,200	823,800	892,100
1906	1,197	1,285	1,392	1.54	777,300	834,400	903,900
1907	1,669	1,792	1,937	2.19	762,100	818,300	884,500
1908	1,426	1,529	1,655	1.90	750,500	804,700	871,100
1909	1,598	1,712	1,854	2.16	739,800	792,600	858,300
1910	1,603	1,719	1,860	2.55	628,600	674,100	729,400
1911	1,608	1,729	1,280	2.54	633,100	680,700	503,900
1912	1,263	854	830	1.78	709,600	479,800	466,300
1913	1,134	1,148	1,161	1.76	644,300	652,300	659,700
1914	1,194	1,283	1,390	1.92	621,900	668,200	724,000
1915	1,497	1,609	1,739	2.45	611,000	656,700	709,800
1916	1,454	1,560	1,688	2.32	626,700	672,400	727,600
1917	1,975	2,117	2,007	2.84	695,400	745,400	706,700
1918	1,358	1,028	905	2.45	554,300	419,600	369,400
1919	1,167	1,252	1,298	1.63	716,000	768,100	796,300
1920	1,536	1,651	1,785	2.52	609,500	655,200	708,300
1921	1,668	1,790	1,934	2.56	651,600	699,200	755,500
1922	1,171	1,259	1,365	2.17	539,600	580,200	629,000
1923	1,354	1,454	1,575	2.38	568,900	610,900	661,800
1924	1,437	1,541	1,669	2.03	707,900	759,100	822,200
1925	1,056	1,136	1,231	2.50	422,400	454,400	492,400
1926	1,052	1,132	1,228	1.37	767,900	826,300	896,400
1927	1,561	1,677	1,837	2.45	637,100	684,500	749,800
1928	1,215	1,307	1,416	2.41	504,100	542,300	587,600
1929	1,265	1,359	1,471	2.05	617,100	662,900	717,600
1930	843	910	988	1.23	685,400	739,800	803,300
1931	1,240	1,335	1,444	1.53	810,500	872,500	943,800
1932	1,166	1,254	1,360	1.58	738,000	793,700	860,800
1933	1,185	1,156	1,254	1.68	705,400	688,100	746,400
1934	1,362	1,463	1,583	2.61	521,800	560,500	606,500
1935	1,137	1,224	1,325	1.57	724,200	779,600	843,900
1936	1,301	1,162	1,239	1.71	760,800	679,500	724,600
1937	1,404	1,505	1,629	2.19	641,100	687,200	743,800
1938	1,451	1,558	1,686	2.57	564,600	606,200	656,000
1939	1,441	1,548	1,674	2.38	605,500	650,400	703,400
1940	1,293	1,388	1,504	2.47	523,500	561,900	608,900
1941	651	703	766	.98	664,300	717,300	781,600
1942	1,628	1,637	1,728	2.17	750,200	754,400	796,300
1943	1,329	1,429	1,546	2.40	553,800	595,400	644,200
1944	1,289	1,383	1,499	1.78	724,200	777,000	842,100
1945	1,569	1,684	1,822	2.33	673,400	722,700	782,000
1946	1,447	1,553	1,681	2.27	637,400	684,100	740,500
1947	1,538	1,649	1,246	2.48	620,200	664,900	502,400
1948	1,521	1,239	1,225	2.28	667,100	543,400	537,300
1949	1,371	1,474	1,594	2.41	568,900	611,600	661,400
1950	1,784	1,681	1,520	2.94	606,800	571,800	517,000
1951	605	606	606	2.67	226,600	227,000	227,000
1952	202	208	208	2.87	70,400	72,500	72,500
1953	383	383	383	3.52	108,800	108,800	108,800
1954	1,077	1,151	1,243	2.47	436,000	466,000	503,200
1955	1,635	1,756	1,899	2.58	633,700	680,600	736,000
1956	1,421	1,520	1,353	3.31	429,300	459,200	408,800

[1] U.S. share of IBWC regulated releases from Falcon Reservoir less 124,000 acre-feet per year for future domestic, municipal, and industrial requirements.

the United States' share of conservation storage capacity in the two reservoirs. Involuntary spills occurred only under demands for 600,000 and 650,000 acres during these operations.

When the annual demand exceeded the IBWC usable content in storage and the adjusted regulated release, water was withdrawn from the revised total end-of-year usable content in storage.

When the revised content and the adjusted regulated supply was inadequate to supply the demand, the difference between the total demand and the portion supplied was tabulated as a shortage in acre-feet.

These annual operations were assumed to reflect compensating differences in evaporation and other losses from the two reservoirs, which might occur because of differences in monthly demands and contents in storage from those for which losses were computed monthly by the IBWC.

The computations for the reservoir operations supplying the five acreages are shown in Tables 10, 11, 12, 13, and 14.

Table 10.--Water-supply limitations for a 600,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1900	3593	1103	1526	1326	200	1303	--	--
1901	3585	435	1658	1326	332	967	--	--
1902	3577	6	1364	1326	38	576	--	--
1903	3568	460	1129	1326	-197	833	--	--
1904	3560	1223	1289	1398	-109	1487	--	--
1905	3552	2335	1157	906	251	2850	--	--
1906	3543	3352	1197	924	273	3543	--	597
1907	3536	2707	1669	1314	355	3253	--	--
1908	3527	2503	1426	1140	286	3335	--	--
1909	3519	2028	1598	1296	302	3162	--	--
1910	3511	1261	1603	1530	73	2468	--	--
1911	3503	629	1608	1524	84	1920	--	--
1912	3494	137	1263	1068	195	1623	--	--
1913	3486	458	1134	1056	78	2112	--	--
1914	3478	2127	1194	1152	42	3478	--	255
1915	3470	1925	1497	1470	27	3303	--	--
1916	3462	1467	1454	1392	62	2907	--	--
1917	3453	535	1975	1704	271	2246	--	--
1918	3445	206	1358	1470	-112	1805	--	--
1919	3437	2489	1167	978	189	3437	--	840

(Continued on next page)

Table 10.--Water-supply limitations for a 600,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1920	3429	3466	1536	1512	24	3429	--	1009
1921	3421	2189	1668	1536	132	2284	--	--
1922	3412	2725	1171	1302	-131	2689	--	--
1923	3404	2650	1354	1428	-74	2540	--	--
1924	3396	2166	1437	1218	219	2275	--	--
1925	3388	2981	1056	1500	-444	2646	--	--
1926	3380	2904	1052	822	230	2799	--	--
1927	3371	1950	1561	1470	91	1936	--	--
1928	3363	1800	1215	1446	-231	1555	--	--
1929	3355	1186	1265	1230	35	976	--	--
1930	3347	1534	843	738	105	1429	--	--
1931	3339	1343	1240	918	322	1560	--	--
1932	3330	3519	1166	948	218	3330	--	624
1933	3322	3308	1185	1008	177	3296	--	--
1934	3314	2212	1362	1566	-204	1996	--	--
1935	3306	3448	1137	942	195	3306	--	121
1936	3298	3377	1301	1026	275	3298	--	212
1937	3289	2459	1404	1314	90	2470	--	--
1938	3281	2473	1451	1542	-91	2393	--	--
1939	3273	1728	1441	1428	13	1661	--	--

(Continued on next page)

Table 10.--Water-supply limitations for a 600,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1940	3265	1582	1293	1482	-189	1326	--	--
1941	3257	3412	651	588	63	3219	--	--
1942	3248	3251	1628	1302	326	3248	--	146
1943	3240	2605	1329	1440	-111	2491	--	--
1944	3232	2292	1289	1068	221	2399	--	--
1945	3224	1523	1569	1398	171	1801	--	--
1946	3216	1180	1447	1362	85	1543	--	--
1947	3207	465	1538	1488	50	878	--	--
1948	3199	479	1521	1368	153	1045	--	--
1949	3191	1007	1371	1446	-75	1498	--	--
1950	3183	0	1784	1764	20	511	--	--
1951	3175	0	605	1602	-997	0	486	--
1952	3166	0	202	1722	-1520	0	1520	--
1953	3158	0	383	2112	-1729	0	1729	--
1954	3150	2364	1077	1482	-405	2651	--	--
1955	3142	1548	1635	1548	87	1748	--	--
1956	3134	204	1421	1986	-565	969	--	--

Table 11.--Water-supply limitations for a 650,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1900	3593	1103	1526	1436	90	1193	--	--
1901	3585	435	1658	1436	222	747	--	--
1902	3577	6	1364	1436	-72	246	--	--
1903	3568	460	1129	1436	-307	393	--	--
1904	3560	1223	1289	1514	-225	931	--	--
1905	3552	2335	1157	982	175	2218	--	--
1906	3543	3352	1197	1001	196	3431	--	--
1907	3536	2707	1669	1424	245	3031	--	--
1908	3527	2503	1426	1235	191	3018	--	--
1909	3519	2028	1598	1404	194	2737	--	--
1910	3511	1261	1603	1658	-55	1915	--	--
1911	3503	629	1608	1651	-43	1240	--	--
1912	3494	137	1263	1157	106	854	--	--
1913	3486	458	1134	1144	-10	1165	--	--
1914	3478	2127	1194	1248	-54	2780	--	--
1915	3470	1925	1497	1592	-95	2483	--	--
1916	3462	1467	1454	1508	-54	1971	--	--
1917	3453	535	1975	1846	129	1168	--	--
1918	3445	206	1358	1592	-234	605	--	--
1919	3437	2489	1167	1060	107	2995	--	--

(Continued on next page)

Table 11.--Water-supply limitations for a 650,000-acre irrigation demand below Falcon Dam based on adjusted Unites States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1920	3429	3466	1536	1638	-102	3429	--	441
1921	3421	2189	1668	1664	4	2156	--	--
1922	3412	2725	1171	1410	-239	2453	--	--
1923	3404	2650	1354	1547	-193	2185	--	--
1924	3396	2166	1437	1320	117	1818	--	--
1925	3388	2981	1056	1625	-569	2064	--	--
1926	3380	2904	1052	890	162	2149	--	--
1927	3371	1950	1561	1592	-31	1164	--	--
1928	3363	1800	1215	1566	-351	663	--	--
1929	3355	1186	1265	1332	-67	0	18	--
1930	3347	1534	843	800	43	391	--	--
1931	3339	1343	1240	994	246	446	--	--
1932	3330	3519	1166	1027	139	2761	--	--
1933	3322	3308	1185	1092	93	2643	--	--
1934	3314	2212	1362	1696	-334	2449	--	--
1935	3306	3448	1137	1020	117	2566	--	--
1936	3298	3377	1301	1112	189	2584	--	--
1937	3289	2459	1404	1424	-20	1746	--	--
1938	3281	2473	1451	1670	-219	1541	--	--
1939	3273	1728	1441	1547	-106	690	--	--
1940	3265	1582	1293	1606	-313	231	--	--

(Continued on next page)

Table 11.--Water-supply limitations for a 650,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1941	3257	3412	651	637	14	2075	--	--
1942	3248	3251	1628	1410	238	2152	--	--
1943	3240	2605	1329	1560	-231	1275	--	--
1944	3232	2292	1289	1157	132	1094	--	--
1945	3224	1523	1569	1514	55	380	--	--
1946	3216	1180	1447	1476	-29	8	--	--
1947	3207	465	1538	1612	-74	0	731	--
1948	3199	479	1521	1482	39	3	--	--
1949	3191	1007	1371	1566	-195	336	--	--
1950	3183	0	1784	1911	-127	0	798	--
1951	3175	0	605	1736	-1131	0	1131	--
1952	3166	0	202	1866	-1664	0	1664	--
1953	3158	0	383	2288	-1905	0	1905	--
1954	3150	2364	1077	1606	-529	1835	--	--
1955	3142	1548	1635	1677	-42	977	--	--
1956	3134	204	1421	2152	-731	0	1098	--

Table 12.--Water-supply limitations for a 700,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1900	3593	1103	1526	1547	-21	1082	--	--
1901	3585	435	1658	1547	111	525	--	--
1902	3577	6	1364	1547	-183	0	87	--
1903	3568	460	1129	1547	-418	36	--	--
1904	3560	1223	1289	1631	-242	557	--	--
1905	3552	2335	1157	1057	100	1769	--	--
1906	3543	3352	1197	1078	119	2905	--	--
1907	3536	2707	1669	1533	136	2396	--	--
1908	3527	2503	1426	1330	96	2288	--	--
1909	3519	2028	1598	1512	86	1899	--	--
1910	3511	1261	1603	1785	-182	950	--	--
1911	3503	629	1608	1778	-170	148	--	--
1912	3494	137	1263	1246	17	0	327	--
1913	3486	458	1134	1232	-98	223	--	--
1914	3478	2127	1194	1344	-150	1742	--	--
1915	3470	1925	1497	1715	-218	1322	--	--
1916	3462	1467	1454	1624	-170	694	--	--
1917	3453	535	1975	1988	-13	0	251	--
1918	3445	206	1358	1715	-357	0	686	--
1919	3437	2489	1167	1141	26	2309	--	--

(Continued on next page)

Table 12.--Water-supply limitations for a 700,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1920	3429	3466	1536	1764	-228	3058	--	--
1921	3421	2189	1668	1792	-124	1657	--	--
1922	3412	2725	1171	1519	-348	1845	--	--
1923	3404	2650	1354	1666	-312	1458	--	--
1924	3396	2166	1437	1421	16	990	--	--
1925	3388	2981	1056	1750	-694	1111	--	--
1926	3380	2904	1052	959	93	1127	--	--
1927	3371	1950	1561	1715	-154	19	--	--
1928	3363	1800	1215	1687	-472	0	603	--
1929	3355	1186	1265	1435	-170	0	784	--
1930	3347	1534	843	861	-18	330	--	--
1931	3339	1343	1240	1071	169	308	--	--
1932	3330	3519	1166	1106	60	2544	--	--
1933	3322	3308	1185	1176	9	2342	--	--
1934	3314	2212	1362	1827	-465	781	--	--
1935	3306	3448	1137	1099	38	2055	--	--
1936	3298	3377	1301	1197	104	2088	--	--
1937	3289	2459	1404	1533	-129	1041	--	--
1938	3281	2473	1451	1799	-348	707	--	--
1939	3273	1728	1441	1666	-225	0	263	--

(Continued on next page)

Table 12.--Water-supply limitations for a 700,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1940	3265	1582	1293	1729	-436	0	582	--
1941	3257	3412	651	686	-35	1795	--	--
1942	3248	3251	1628	1519	109	1744	--	--
1943	3240	2605	1329	1680	-351	746	--	--
1944	3232	2292	1289	1246	43	476	--	--
1945	3224	1523	1569	1631	-62	0	355	--
1946	3216	1180	1447	1589	-142	0	485	--
1947	3207	465	1538	1736	-198	0	913	--
1948	3199	479	1521	1596	-75	0	61	--
1949	3191	1007	1371	1687	-316	212	--	--
1950	3183	0	1784	2058	-274	0	1069	--
1951	3175	0	605	1869	-1264	0	1264	--
1952	3166	0	202	2009	-1807	0	1807	--
1953	3158	0	383	2464	-2081	0	2081	--
1954	3150	2364	1077	1729	-652	1712	--	--
1955	3142	1548	1635	1806	-171	725	--	--
1956	3134	204	1421	2317	-896	0	1515	--

Table 13.--Water-supply limitations for a 750,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1900	3593	1103	1526	1658	-132	971	--	--
1901	3585	435	1658	1658	0	303	--	--
1902	3577	6	1364	1658	-294	0	420	--
1903	3568	460	1129	1658	-529	0	75	--
1904	3560	1223	1289	1747	-458	305	--	--
1905	3552	2335	1157	1132	25	1442	--	--
1906	3543	3352	1197	1155	45	2504	--	--
1907	3536	2707	1669	1642	27	1886	--	--
1908	3527	2503	1426	1425	1	1683	--	--
1909	3519	2028	1598	1620	-22	1186	--	--
1910	3511	1261	1603	1912	-309	110	--	--
1911	3503	629	1608	1905	-297	0	819	--
1912	3494	137	1263	1335	-72	0	564	--
1913	3486	458	1134	1320	-186	135	--	--
1914	3478	2127	1194	1440	-246	1558	--	--
1915	3470	1925	1497	1838	-341	1015	--	--
1916	3462	1467	1454	1740	-286	271	--	--
1917	3453	535	1975	2130	-155	0	816	--
1918	3445	206	1358	1838	-480	0	809	--
1919	3437	2489	1167	1222	-55	2228	--	--

(Continued on next page)

Table 13.--Water-supply limitations for a 750,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1920	3429	3466	1536	1890	-354	2851	--	--
1921	3421	2189	1668	1920	-252	1322	--	--
1922	3412	2725	1171	1628	-457	1401	--	--
1923	3404	2650	1354	1785	-431	895	--	--
1924	3396	2166	1437	1522	-85	326	--	--
1925	3388	2981	1056	1875	-819	322	--	--
1926	3380	2904	1052	1028	24	269	--	--
1927	3371	1950	1561	1837	-276	0	961	--
1928	3363	1800	1215	1808	-593	0	743	--
1929	3355	1186	1265	1538	-273	0	887	--
1930	3347	1534	843	922	-79	269	--	--
1931	3339	1343	1240	1148	92	170	--	--
1932	3330	3519	1166	1185	-19	2327	--	--
1933	3322	3308	1185	1260	-75	2041	--	--
1934	3314	2212	1362	1958	-596	349	--	--
1935	3306	3448	1137	1183	-46	1539	--	--
1936	3298	3377	1301	1282	19	1487	--	--
1937	3289	2459	1404	1642	-238	331	--	--
1938	3281	2473	1451	1928	-477	0	132	--
1939	3273	1728	1441	1785	-344	0	1089	--

(Continued on next page)

Table 13.--Water-supply limitations for a 750,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1940	3265	1582	1293	1852	-559	0	705	--
1941	3257	3412	651	735	-84	1746	--	--
1942	3248	3251	1628	1628	0	1585	--	--
1943	3240	2605	1329	1800	-471	468	--	--
1944	3232	2292	1289	1335	-46	109	--	--
1945	3224	1523	1569	1748	-179	0	839	--
1946	3216	1180	1447	1702	-255	0	598	--
1947	3207	465	1538	1860	-322	0	1037	--
1948	3199	479	1521	1710	-189	0	175	--
1949	3191	1007	1371	1808	-437	91	--	--
1950	3183	0	1784	2205	-421	0	1337	--
1951	3175	0	605	2002	-1397	0	1397	--
1952	3166	0	202	2152	-1950	0	1950	--
1953	3158	0	383	2640	-2257	0	2257	--
1954	3150	2364	1077	1852	-775	1589	--	--
1955	3142	1548	1635	1935	-300	473	--	--
1956	3134	204	1421	2482	-1061	0	1932	--

Table 14.--Water-supply limitations for an 800,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1900	3593	1103	1526	1760	-234	869	--	--
1901	3585	435	1658	1760	-102	99	--	--
1902	3577	6	1364	1760	-396	0	726	--
1903	3568	460	1129	1760	-631	0	177	--
1904	3560	1223	1289	1864	-575	188	--	--
1905	3552	2335	1157	1208	-51	1249	--	--
1906	3543	3352	1197	1232	-35	2231	--	--
1907	3536	2707	1669	1752	-83	1503	--	--
1908	3527	2503	1426	1520	-94	1205	--	--
1909	3519	2028	1598	1728	-130	600	--	--
1910	3511	1261	1603	2040	-437	0	604	--
1911	3503	629	1608	2032	-424	0	1056	--
1912	3494	137	1263	1424	-161	0	653	--
1913	3486	458	1134	1408	-274	47	--	--
1914	3478	2127	1194	1536	-342	1374	--	--
1915	3470	1925	1497	1960	-463	709	--	--
1916	3462	1467	1454	1856	-402	0	151	--
1917	3453	535	1975	2272	-297	0	1229	--
1918	3445	206	1358	1960	-602	0	931	--
1919	3437	2489	1167	1304	-137	2146	--	--

(Continued on next page)

Table 14.--Water-supply limitations for an 800,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1920	3429	3466	1536	2016	-480	2643	--	--
1921	3421	2189	1668	2048	-380	986	--	--
1922	3412	2725	1171	1736	-565	957	--	--
1923	3404	2650	1354	1904	-550	332	--	--
1924	3396	2166	1437	1624	-187	0	339	--
1925	3388	2981	1056	2000	-944	0	129	--
1926	3380	2904	1052	1096	-44	0	121	--
1927	3371	1950	1561	1960	-399	0	1353	--
1928	3363	1800	1215	1928	-713	0	863	--
1929	3355	1186	1265	1640	-375	0	989	--
1930	3347	1534	843	984	-141	207	--	--
1931	3339	1343	1240	1224	16	32	--	--
1932	3330	3519	1166	1264	-98	2105	--	--
1933	3322	3308	1185	1344	-159	1740	--	--
1934	3314	2212	1362	2088	-726	0	82	--
1935	3306	3448	1137	1256	-119	1117	--	--
1936	3298	3377	1301	1368	-67	979	--	--
1937	3289	2459	1404	1752	-348	0	287	--
1938	3281	2473	1451	2056	-605	0	591	--
1939	3273	1728	1441	1904	-463	0	1208	--

(Continued on next page)

Table 14.--Water-supply limitations for an 800,000-acre irrigation demand below Falcon Dam based on adjusted United States share of available water from IBWC DF(1) condition and contents of Amistad and Falcon Reservoirs, 1900-56: TWC requirements--Continued

Year	1. Total usable capacity	2. Total usable content at end-of-year	3. TWC adjusted IBWC regulated supply	4. Irrigation diversion requirement	5. Column 3-4	6. Revised end-of-year usable content	7. Shortages	8. Spills
1940	3265	1582	1293	1976	-683	0	829	--
1941	3257	3412	651	784	-133	1697	--	--
1942	3248	3251	1628	1736	-108	1428	--	--
1943	3240	2605	1329	1920	-591	191	--	--
1944	3232	2292	1289	1424	-135	0	257	--
1945	3224	1523	1569	1864	-295	0	1064	--
1946	3216	1180	1447	1816	-369	0	712	--
1947	3207	465	1538	1984	-446	0	1161	--
1948	3199	479	1521	1824	-303	0	289	--
1949	3191	1007	1371	1928	-557	0	29	--
1950	3183	0	1784	2352	-568	0	1575	--
1951	3175	0	605	2136	-1531	0	1531	--
1952	3166	0	202	2296	-2094	0	2094	--
1953	3158	0	383	2816	-2433	0	2433	--
1954	3150	2364	1077	1976	-899	1465	--	--
1955	3142	1548	1635	2064	-429	220	--	--
1956	3134	204	1421	2648	-1227	0	2351	--

APPENDIX VII

ECONOMIC EVALUATION OF AGRICULTURAL WATER USE IN STARR, HIDALGO, CAMERON, AND WILLACY COUNTIES

By

Paul T. Gillett

TABLE OF CONTENTS

TABLES

ECONOMIC EVALUATION OF AGRICULTURAL WATER USE IN STARR, HIDALGO, CAMERON, AND WILLACY COUNTIES

INTRODUCTION

This report was made to show the extent to which agriculture, particularly irrigation farming, has contributed to the overall economy of the Lower Rio Grande Valley. Also, this report was developed to provide basic values that can be useful in appraising the economic advantages of having a water supply for irrigation under variable future cropping and rainfall conditions, or the economic consequences of not having such a resource.

Historical dollar values of past agricultural production, shown herein, are given in terms of dollar values for the years involved, unadjusted to a constant value. Indices of prices received can be used if adjusted values are desired.

Future agricultural values make use of long-term projected indices of prices received as developed by the Agricultural Research Service and the Agricultural Marketing Service, U.S. Department of Agriculture, for use in making benefit and cost analyses of land and water resources projects. As approved for use by the U.S. Bureau of Reclamation, the long-term projected index for prices received for all farm products in the United States is 250 (1910-14=100). Indices for Texas prices of individual crops as used in this study and report were computed on that basis.

The agricultural value projections herein represent the level of prices that may be expected to prevail over <u>an extended period of years</u> (not necessarily in any particular year or time period, such as the year 2000 or 2020) under assumptions of relatively high employment, a trend toward world-wide peace, continued population and economic growth, and a stable general price level. In general, the projections reflect the long-term levels that might reasonably be expected with production and requirements in balance, under competitive conditions.

Under such conditions, as described in the preceding paragraph, the general economic level of prices received by farmers and cost-price relationships in the future are not expected to be much different from those prevailing in the 1953-55 period. Values derived on the basis of these indices establish only the <u>relative</u> relationship between the present values used in the analyses and future values. Variations from these average future values can be expected to the same extent that present actual values may range above or below the present average values shown in this report. It should be noted, therefore, that the price projections are not designed for use as a basis for evaluating any individual farm business or for predicting the absolute price of a farm commodity in a particular future time period.

AGRICULTURAL GROSS VALUES

Historical Values, 1957-63

Total Irrigated and Dryland Agricultural Production Values

There are about 1-3/4 million acres of cropland and pastured lands in the four-county area (Starr, Hidalgo, Cameron, and Willacy) comprising the Lower Rio Grande Valley of Texas.[1] During the period 1957-63, about 3/4 million acres of this area was producing crops, livestock, and livestock products with the aid of irrigation--using water largely diverted from the Rio Grande below Falcon Dam, but also using smaller amounts from ground water and other surface-water sources.[2,3] A portion of the irrigated land produces two or more irrigated crops annually.

The annual farm gross cash income from all agricultural production in the Lower Rio Grande Valley during the period 1957-63 was as follows:[4]

Year	Gross value
1957	$ 134,234,964
1958	161,975,770
1959	178,625,317
1960	156,772,530
1961	153,053,000
1962	171,739,716
1963	142,955,068
7-Year average	$ 157,050,909

These amounts include farm income from all crop and livestock sources, exclusive of government subsidies, both with irrigation and without. Income values from Valley farming during this period, except for temporary setbacks caused principally by adverse weather conditions, follow the same vigorous upward trend that has existed for many years, having grown steadily from an annual value in 1927 of only 13-1/2 million dollars.

Since 1944, gross cash farm income value in these four counties has exceeded 100 million dollars annually. This constitutes a major segment of the overall economy of the Lower Rio Grande Valley, not only as direct farm income values but especially as large values derived from agriculturally dependent services and machinery, equipment, materials, processing, marketing, and transportation businesses that agriculture supports or helps to support. As of 1962, these include: canneries, 15; wholesale fruit and vegetable shippers, 97;

frozen-food processors, 7; fruit package shippers, 19; agricultural chemical formulators, 12; concrete pipe manufacturers, 4; plastic bag and tube manufacturers, 2; cotton compresses, 12; cotton gins, 81; tin can plants, 1; meat packing plants and fabricators, 18; plus box factories, food machinery plants, etc., combining to produce a large part of an additional $90,000,000 annual industrial income.(5) The direct farm cash income alone provides 35 percent of the nearly half a billion dollar annual economy of the Valley--a greater amount than from any other source.

Estimated Irrigated Agricultural Production Values

Irrigation farming provides much of the nearly $160,000,000 annual direct farm income. Over 95 percent of the annual farm income derived from production of citrus fruit, vegetables, and nursery stock was produced from irrigated lands. Irrigated improved pastures provided over 88 percent of the cash farm income from all improved pastures. About 82 percent of the farm income value of corn, hay, and ensilage production, and 73 percent of the farm income value of cotton production was derived from irrigated crop acreage. Nearly 38 percent of the farm income from grain sorghum production came from irrigated land, while about 44 percent of the farm cash income value of all livestock and livestock products is estimated to have been produced with the aid of irrigated pasture and feed production. Overall, 72 percent of all cash farm income values in the Lower Rio Grande Valley were derived from irrigated farming for the 1957-63 period. During this period, releases of water from Falcon Reservoir for irrigation were made under water master supervision.

The irrigated farming production values during the period 1957-63 were estimated as follows:

Year	Estimated gross value
1957	$ 99,723,388
1958	117,306,950
1959	130,687,776
1960	115,290,525
1961	110,836,846
1962	120,190,554
1963	98,285,404
7-Year average	$ 113,188,777

These estimates for irrigation farming were computed on the basis of:

1. Relationships between irrigated- and nonirrigated-crop acreages for the four Valley counties as tabulated in the Agricultural Census for the 1959 crop year,(1) and

2. Yield relationships between irrigated and nonirrigated crops grown in the Rio Grande Plain area as developed by the U.S. Department of Agriculture Economic Research Service for the U.S. Study Commission-Texas.[6]

Based on average diversion of the United States' share of water from the Rio Grande below Falcon Dam during the period 1957-61,[7] a period that includes several water-short years, irrigation farming has been producing agricultural commodities with a farm gross cash income value of about $119 for each acre-foot diverted (non-agricultural use of some of the diversions is a compensatory factor for agricultural use of relatively small amounts of water from sources other than Rio Grande flows).

The gross values given above and used in the analyses that follow measure more clearly than would net farm income values the size of the Valley farming business. These values reflect the extent to which the secondary services and business, dependent on Valley agriculture, augment the economy. Although net farm income values are highly variable and are affected by numerous production efficiency factors, efficient producers can usually obtain returns over chargeable operating expense (exclusive of unallocated costs for such expenses as interest on farm real estate, insurance, depreciation charges on farm buildings, and farm taxes) amounting to from a third to a half of the gross farm income value of the crops produced.[8,9]

Irrigation farming in the Lower Rio Grande Valley is important, also, to Texas and the nation. Five percent of the State's agricultural production comes from the Lower Rio Grande Valley,[10] and in 1959 its irrigated acreage was 11 percent of all Texas irrigated acreage.[1]

Of the gross farm income value from irrigation in the Lower Rio Grande Valley during the period 1957-63, cotton provided about 43 percent, vegetables--largely tomatoes, carrots, cabbage, onions, sweetcorn, lettuce, snapbeans and green peppers[11]--accounted for 23 percent, and citrus fruit nearly 12 percent. Livestock and livestock products make up over 11 percent of irrigated production values, while all other commodity groups constitute the remainder. These percentages are based on U.S. Agricultural Census data,[1] Economic Research Service data,[6] and data furnished by the Lower Rio Grande Valley Chamber of Commerce.[12]

Future Farming in the Lower Rio Grande Valley

Relatively low production costs and high quality fruit gives the Valley a potential for citrus fruit production that compares favorably with other United States citrus-producing areas. Yields per tree generally are lower than in Florida or California, but this factor is offset by low production costs.[13] The Valley, with its capability of producing fruit of superb quality with relatively low production costs, maintenance of soil fertility, and other production factors, would have distinct regional advantages for citrus growing if it were not for damage caused periodically by freezing--experts are optimistic about lessening this problem. Even with the hazard of killing freezes, the area is competitive with other citrus-producing areas. Grapefruit, early and midseason oranges, and late oranges will share the acreage and almost all citrus fruit will be produced with irrigation.

Likewise, vegetable-growing, largely with irrigation, will continue to be important in the Lower Rio Grande Valley, furnishing a significant part of the growing national demand for fresh market and particularly processed vegetables. Acreages are likely to fluctuate from year to year and from season to season for given vegetables, with emphasis on winter-harvested vegetables and others required to fulfill market needs at times when supplies are not generally adequate or not available from other producing areas.

Cotton production can be expected to continue as a major farming enterprise in this area, and undoubtedly a large percentage of it will continue to be produced with irrigation. Livestock producers are finding that irrigated improved pastures offer opportunities to improve their income from livestock and livestock products, and are developing a growing acreage of these pastures. Alfalfa, other hay, corn, grain sorghum, and other commodities will continue to be produced in the Valley with some use of irrigation.

The Economic Research Service in conjunction with specialists of Texas A&M University and the Texas Agricultural Experiment Station, and the Soil Conservation Service, in 1960 and 1961 made an analysis of irrigated and nonirrigated crop yields and production values for the U.S. Study Commission-Texas.(6) Yields from these studies, shown in Table 1, are consistent with basic yield projections for 1975 provided by specialists at Texas A&M University.(14) These yields are in close agreement with yields obtained by the Soil Conservation Service in an inventory made for the production study, reflecting yield levels that were being equalled or exceeded in 1959 by the 5 to 10 percent of all producers in the Rio Grande Plain area who were using the best management techniques and conservation practices.(15) These levels were expected to be generally attained by all producers by 1975 under average climatic and other agricultural production limitations expected to prevail at that time.

In Tables 15, 16, 34, and 35 of the aforementioned studies by the Economic Research Service for the U.S. Study Commission-Texas, 1975 projections of production values for Rio Grande Plain irrigation farming showed an estimated per-acre dollar output on a composite acre, made up of proportionately weighted areas of each crop, ranging from 3 to over 10 times the dollar output from nonirrigated production on corresponding soils.(16) Most of these differences are due to different land usage and cropping pattern, with and without irrigation, with high value crops being produced on the highest producing soils when and where irrigation can be given. When the same soil is not irrigated, range, pasture, feed, and other lower investment and lesser risk enterprises are relied on. Because the yields and values in Table 1 do not reflect this difference in use and cropping of the same soil, with and without irrigation, values shown are conservative. Too, there are new techniques--improved varieties, cultural methods, knowledge of fertilizer needs and usage, and others--that already have been developed and are undergoing testing that can become "break-throughs" to additional production increases for irrigated crops.

Applying the irrigated and nonirrigated per acre values of each commodity shown in Table 1 to the proportionate irrigated acreages of each that has been grown in the Lower Rio Grande Valley as indicated by the average annual cropping pattern for 1957-63 (Appendix III), the composite irrigated acre production value is $305.16; the composite nonirrigated acre production value is $83.19--a difference in value of $221.97 per acre as shown in Table 2.

Table 1.--Projected yields and production values for major crops* in Starr, Hidalgo, Cameron, and Willacy Counties

Item	Cotton	Corn	Grain sorghum	Citrus fruit	Vegetables		Improved pastures
					Shallow-rooted	Deep-rooted	
Unit	Lbs of lint[a]	Bu	Cwt	Ton	Cwt	Cwt	AUM[b]
Irrigated yield/acre	860	75	49	12.4 [c]	276.4 [d]	132.2 [e]	14.0 [f]
Nonirrigated yield/acre	327	30	25	--	--	--	2.5 [f]
Difference in yield/acre	533	45	24	12.4	276.4	276.4	11.5
Unit price (dollars)[g]	.26[h]	1.48	2.40	32.90	1.90[i]	1.95[j]	10.92
Irrigated value/acre[k] (dollars)	278.71	111.00	117.60	407.96	525.16	257.79	152.88
Nonirrigated value/acre[k] (dollars)	105.97	44.40	60.00	--	--	--	27.30
Difference in value/acre[k] (dollars)	172.74	66.60	57.60	407.96	525.16	257.79	125.58

* Except as noted below, yields are derived from 1975 yield and acreage projections developed for the U. S. Study Commission-Texas by the Economic Research Service, USDA, working cooperatively with specialists of Texas A&M University and the Soil Conservation Service.

a/ Also 1.8 lbs seed per lb of lint.

b/ An AUM (animal unit month) is equal to the feeding value of approximately 450 lbs of corn and is the amount of grazing required for a cow and calf, steer (over yearling), or equivalent for one month.

c/ Irrigated yields based on data from Texas A&M Bulletin 1002, Guide for Citrus Production in the Lower Rio Grande Valley, Table 16, assuming 25-year tree age, prorating yields to full 25-year (nonbearing and bearing) period. Based on 1/3 acreage each of grapefruit, early and midseason oranges, and late oranges. All future citrus assumed to be irrigated.

d/ Yields for cabbage, onions taken from Texas A&M University MP-719, Production and Production Requirements, Costs and Expected Returns....Loam Soils--Lower Rio Grande Valley of Texas, and weighted by proportionate 1958 normalized acreage.

e/ Yields for tomatoes, carrots (from MP-719, cited above) and snap beans (from Snap Beans for Canning, Texas Agricultural Extension Service) weighted by proportionate 1958 normalized acreage.

f/ Based on SCS technical guide estimates, Harlingen Area work units, following good pasture management practices and complete conservation treatment.

g/ Unit prices are projected, using projections currently being used by the Bureau of Reclamation: Index of Prices Received By Farmers, 250 (1910-14=100).

h/ Plus $71.20 per ton for seed.

i/ Based on cabbage and onions.

j/ Based on tomatoes, carrots, snap beans.

k/ Values given are for a single crop: multiple cropping will increase proportionately value per acre.

Table 2.--Production values*--composite acre, Starr, Hidalgo, Cameron, and Willacy Counties

Crop	Percent of total acres of crops[a]	Value per crop acre (dollars)	Proportionate value-composite (dollars)
	Irrigated		
Cotton	41	$278.71	$114.27
Corn	2	111.00	2.22
Grain sorghum[b]	18	117.60	21.16
Citrus	10	407.96	40.80
Pasture	8	152.88	12.23
Vegetables[b] (shallow-rooted)	11	525.16	57.77
Vegetables[b] (deep-rooted)	22	257.79	56.71
Production value (weighted) - composite irrigated acre......			$305.16
	Nonirrigated[c]		
Cotton	60	$105.97	$ 63.58
Corn	3	44.40	1.33
Grain sorghum	25	60.00	15.00
Pasture	12	27.30	3.28
Production value (weighted) - composite nonirrigated acre...			$ 83.19
Difference - irrigated and nonirrigated acre...............			$221.97

* Projected prices as currently used by Bureau of Reclamation. Base: 1910-14=100; Index, Prices Received by Farmers - 250.

a/ Percentages include double-cropped acreages, with irrigation only. "Irrigated" percentages reflect the same cropping pattern used for water requirement computations.

b/ Double-cropped acreage of these crops included in percentage.

c/ Acreage that would be used for citrus and vegetables, if irrigated, has been prorated to the nonirrigated crops shown, with no double cropping, without irrigation.

Future Irrigation Appraisal

The composite irrigated-acre production values can be used to derive conservative estimates of the agricultural production values attainable with irrigation at any levels of irrigation water availability, based on the acreage that can be fully irrigated with water that is available. The difference between composite irrigated and nonirrigated production values can be used to estimate conservatively the economic significance of decreases or increases in irrigation water availability and to establish unit values of water that is made available for irrigation (value added, with irrigation). Table 3 gives these values per acre-foot of water diverted from Falcon Reservoir, based on diversion requirements to satisfy the composite-acre irrigation needs.

Table 3.--Future agricultural value estimates attainable from diversions from Falcon Reservoir for irrigation in Starr, Hidalgo, Cameron, and Willacy Counties

Note:--Precipitation records since 1903 were used in computations, assuming the fulfillment of total irrigation needs of crops grown, and district and farm irrigation system efficiency that will hold transmissional and water management losses low.

1. Total Production Value, Composite Acre	
a. Irrigated	\$ 305.16
b. Not irrigated	83.19
2. Value Added Through Irrigation (1a - 1b)	\$ 221.97
3. Diversion Requirements, in acre-feet, Irrigation of Composite Acre	
a. Maximum	3.52
b. Minimum	0.98
c. Average	2.21
4. Total Production Value Per Acre-Foot of Diversion	
a. With maximum diversion requirement (1a ÷ 3a)	\$ 86.69
b. With minimum diversion requirement (1a ÷ 3b)	311.39
c. With average diversion requirement (1a ÷ 3c)	138.08
5. Value Added Through Irrigation Per Acre-Foot of Diversion	
a. With maximum diversion requirement (2 ÷ 3a)	\$ 63.06
b. With minimum diversion requirement (2 ÷ 3b)	226.50
c. With average diversion requirement (2 ÷ 3c)	100.44

REFERENCES

1. "United States Census of Agriculture, 1959," U.S. Department of Commerce, Vol. 1 (Counties), Part 37 (Texas).

2. "Irrigation in Texas In 1958," Texas Board of Water Engineers, Bulletin 6018, November 1960.

3. "Irrigation Inventories for 1957 and 1959," Texas A&M University, (two mimeographed tabulations).

4. "Farm Cash Income, Cameron, Hidalgo, Starr, and Willacy Counties," Lower Rio Grande Valley Chamber of Commerce, Weslaco, Texas, (a mimeographed tabulation based on data from The University of Texas, Bureau of Business Research, 1927-1955, and County Agent estimates, 1956-1962).

5. "The Strangest Street In America," Texas Daily Press League, Inc., 1962.

6. Supplement to "Resource Requirements For Meeting Projected Needs For Agricultural Production, Texas River Basins," U.S. Department of Agriculture, Economic Research Service, (prepared for the U.S. Study Commission-Texas as a report of part of work assignment 1.3) 1961 [unpublished].

7. "Flow of the Rio Grande and Related Data, 1961," U.S. Department of State, International Boundary and Water Commission, United States and Mexico, Water Bulletin Number 31.

8. "Production and Production Requirements, Costs, and Expected Return, Clay Soils, Lower Rio Grande Valley of Texas," Texas A&M University, MP-694, February 1964.

9. "Production and Production Requirements, Costs, and Expected Returns, Loam Soils, Lower Rio Grande Valley of Texas," Texas A&M University, MP-719, March 1964.

10. "Water Requirements for Irrigation in Texas," by Edward Lincoln Harrington, Texas Agricultural Progress, Vol. 9, No. 4, July-August 1963, pp. 5-7.

11. "Texas Vegetables Acres Harvested By Areas," U.S. Department of Agriculture - Statistical Reporting Service, Texas Crop and Livestock Reporting Service Bulletin 25, February 1964.

12. "Farm Cash Income in Dollars By Commodity, Cameron, Hidalgo, Starr and Willacy Counties," Lower Rio Grande Valley Chamber of Commerce, Weslaco, Texas, (five annual tabulations, 1957 to 1963, inclusive) [unpublished].

13. "Guide For Citrus Production In The Lower Rio Grande Valley," Texas A&M University, Bulletin 1002, December 1963.

14. "Crop Yields and Livestock Feeding Efficiencies For Texas," Texas Agricultural Experiment Station, (a supplemental report to the Economic Research Service's report on work assignment 1.3 to the U.S. Study Commission-Texas), College Station, Texas, July 1960.

15. "Present Crop Yields, Acreages, and Land Use for River Basins and Land Resource Areas, Texas," U.S. Department of Agriculture, Soil Conservation Service, (a supplemental report to the Economic Research Service's report on work assignment 1.3 to the U.S. Study Commission-Texas), Temple, Texas, August 1960.

16. "Resource Requirements for Meeting Projected Needs for Agricultural Production, Texas River Basins," U.S. Department of Agriculture, Economic Research Service, (report to U.S. Study Commission-Texas on work assignment 1.3) June 1961.