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HYDROMETEOROLOGICAL REPORT NO. 27

# ESTIMATE OF MAXIMUM POSSIBLE PRECIPITATION
# RIO GRANDE BASIN, FORT QUITMAN TO ZAPATA



Special Study Prepared For

The International Boundary Commission

by

The Hydrometeorological Section
Division of Climatological and Hydrologic Services
U. S. Weather Bureau, Department of Commerce
In Cooperation with
The Corps of Engineers, Department of the Army

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## INTRODUCTION

### Authorization

The Office of the Chief of Engineers, in a memorandum dated February 26, 1951, requested the Hydrometeorological Section of the United States Weather Bureau to prepare an estimate of maximum possible precipitation for a portion of the Rio Grande basin in Texas and Mexico to meet the needs of the International Boundary and Water Commission (IBWC).

### Assignment

The IBWC requested "the maximum possible storm rainfall expressed in terms of time, area, and quantity". A letter dated June 27, 1951, specified that the final report include estimates of maximum possible precipitation for the following areas:

1. "Above Diablo Dam and below the Nichols site on the Rio Grande and below Red Bluff Dam on the Pecos River," 24,470 sq. mi.
2. "Above Nichols site and below Fort Quitman on the Rio Grande, including the Rio Conchos in Mexico," 42,900 sq. mi.
3. "The Rio Grande Basin between Diablo Dam and Zapata, Texas, which is just above the mouth of the Mexican tributary Rio Salado," 12,250 sq. mi.

In addition, it was verbally requested that the Hydrometeorological Section offer comments as to whether it is meteorologically possible for these maximum possible conditions to be preceded at an interval of ten days to two weeks by conditions comparable to the maximum observed snow melt and/or rainfall on the Rio Grande above Elephant Butte Dam and on the Pecos above Red Bluff Dam.

Aspects of the problem

The portion of the Rio Grande Basin considered in the report is that between Fort Quitman and Zapata, including the drainage basins of the Conchos and Devils Rivers and the Pecos River Basin below Red Bluff Reservoir, figure 2.

Lack of data over much of the region proved to be a handicap which was overcome by means of more liberal transposition than might be used in a region where the storm sample was more extensive. For example it was considered that there were insufficient data to eliminate the possibility of a maximum possible storm over the Rio Conchos in June, even though June is usually a comparatively dry month.

The eastern portion of the basin has been subject to much more severe flooding than the western part, the western part being generally protected by mountain barriers from invasions of moist air. The effect of the Balcones Escarpment on the major Texas storms has been studied extensively by the Section and the conclusion has been reached that the Escarpment - a comparatively minor barrier - may have caused a greater frequency of storms. In the maximum possible case, however, the necessary lift could originate from convective or frontal activity just as well elsewhere.

Acknowledgments

We are indebted to Engineer Isom H. Hale, IBWC, for valuable briefing on hydrologic and other pertinent engineering aspects of the assignment. The excellent presentation of data in IBWC Water Bulletins Nos. 1-19, were of invaluable help. Mr. W. W. Swayne was project leader for the study; principal professional contributors were J. F. Appleby, R. E. Helbush, and G. A. Lott. The entire project was under the guidance of C. S. Gilman, Section Chief, R. W. Schloemer, and D. R. Harris. Drafting was done by the Weather Bureau's C&HS Division Drafting Section; editing by Mrs. L. K. Rubin. The manuscript was typed by Miss M. I. Hammer and Mrs. V. B. Fowler.

Chapter II

# CLIMATOLOGY OF THE RIO GRANDE BASIN

## Climatic controls

Factors which exert climatic control over the basin region are: (1) topography, (2) latitude, (3) land and water, including ocean currents, (4) prevailing winds, and (5) storms.

## Topography

The great diversity of climatic characteristics with regard to temperature, rainfall, wind, cloudiness, and humidity which exist in the Basin is due in no small part to the great topographic variations to be found there. The topography of the Basin is shown in figure 1. The Balcones Escarpment, a fault zone which lies outside the northeastern boundary of the Basin, separates the Coastal Plains from the Edwards Plateau, which forms the northeastern portion of the Basin. In the main, this is a region of gentle rise not exceeding 5 or 6 feet to the mile, at times interrupted by low ranges of hills. The southeastern part of the Basin lies in the Rio Grande Plain.

The Trans-Pecos region, which consists of the remainder of the basin area lying within Texas, is a section which is geologically complex. It consists of high plains, deep canyons, and mountains formed in conjunction with the Rockies, of which they are a part. Many peaks in this section are 5,000 to 8,000 feet above sea level. The Davis and Guadalupe Mountains form the principal chains in this portion of the Basin, while the southeastern portion of the Trans-Pecos region is a high, rugged, dissected pleateau extending beyond the Rio Grande far into Mexico

The topography of the Basin on the Mexican side of the Rio Grande is even more varied than its Texas counterpart. Innumerable local variations in the climate exist over most of this region because of the topographical controls. The Mexican portion of the Basin divides itself naturally into three sections, the Sierra Madre Occidental, the Central Plateau, and the Sierra Madre Oriental regions.

The Sierra Madre Occidental forms the western boundary of the Conchos Basin. This is a region of rugged topography, much of it above 7,000 feet with the mountains reaching more than 9,000 feet in the southern portion. This imposing range is a barrier to the moisture-bearing winds from the Pacific.

On the extreme eastern boundary of the Rio Conchos Basin lies the Sierra Madre Oriental. Less majestic than its western counterpart, it nevertheless plays an important part in the determination of the climate of the surrounding area. The forced ascent of the on-shore winds from the Gulf of Mexico up the flanks of these mountains often produces very heavy rainfalls just outside the Basin. Although there may be some spill-over into the basin area, the air advancing farther into the Basin is dried.

Between the two ranges lies the high Central Plateau of Mexico. This is the "tierra templada" or temperate region; temperate in climate because of its elevation, although sub-tropical in latitude.

Latitude

The Rio Grande Basin, lying as it does between latitudes

26° and 32° N, should, as far as its latitude is concerned, be mainly a region of subtropical climate. However, much of the Basin is at an elevation sufficiently high to counteract the temperature effect of latitude. The latitude is, nevertheless, an important factor in the distribution and occurrence of storms and, consequently, the amount and distribution of rainfall.

Bodies of water

Another factor which exerts control over the climate of the Basin is the distribution and temperature of the large bodies of water which lie to the west and east (the Gulf of California and the Gulf of Mexico), and locally, lakes and marshes. The larger bodies of water have, by supplying an abundant quantity of water vapor a very profound influence upon the rainfall.

Winds

Maps of the prevailing surface winds in the basin area for January and July are shown in figures 3a and 3b. The map for January shows that the winds tend to blow from continental sources during the winter season as the Basin comes under the influence of the westerly winds and their associated cyclonic storms. Surface winds with an easterly component are prevalent during the remainder of the year, especially during the summer months when the continental high-pressure areas have largely dissipated, and sluggish low-pressure areas are traversing the southern portion of the Basin. There is, therefore, a pronounced monsoon wind movement over this section, i.e., movement from the continental interior toward the Gulf of Mexico during the cold months and from the Gulf toward the interior in spring, summer, and autumn.

Storms

One of the most interesting phenomena to occur in the Basin is the strong, cold, and often humid wind which blows in the winter. This wind, known as the "norther", has been the object of study and investigation by various people;[1,2] some have compared it to the Bora of the Dalmatian coast, and the Mistral of France. A norther may occur whenever a well-developed cyclone moves across the northern part of the Basin with a pronounced anticyclone over the north-central part of the United States.

Types of storms which cause widespread rains over the Basin during the main rainy season from May to October are enumerated and described in Chapter III of this report. Therefore, no discussion of summer rainfall will appear here, except for a few remarks concerning hurricanes. Tropical storms enter the Basin most frequently in the summer and fall months, the Carribean Sea and the Pacific being favorable areas for the formation and growth of these storms.

A map showing the general course of hurricanes which affect Mexico appears as figure 4. Paths (2) and (4) may enter the Basin area.

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[1]Cleveland Abbe, The Northers of Tampico and Vera Cruz, (MWR, v. 21, 1893).

[2]W. E. Hurd, Northers of the Gulf of Tehuantepec, (MWR, v. 57, 1929).

The climatic elements

Precipitation. The average monthly precipitation at certain selected stations in the Basin appears in figure 6. The western portion of the Basin has a pronounced seasonal variation of rainfall. July to September are the rainy months, with June and October the transitions. Some rain, however, falls in all months. Much of the winter precipitation, especially in the desert, comes from extra-tropical cyclones that take a southerly course across North America, some of it coming as snow. Most summer rainfall is the result of afternoon convection. On an average, a half to a third of the rainfall in the region comes in one heavy shower each month.

Rainfall in the extreme eastern portion of the Rio Grande Basin is distributed somewhat differently than in the western section. There is a September maximum of rainfall with a secondary maximum in May. Much of the September rainfall is due to tropical storms, which at times bring very heavy rains to this region.

The central portion of the Basin forms a transitory region between the other two parts, with most of its rainfall occurring during the half year from May through October. As mentioned previously, much of the area is desert, especially in the southern part. The aridity is attributable both to its location within the sub-tropical, high-pressure belt and to its protected location. The Sierra Madre Occidental is too high and unbroken to permit much moisture to enter from the west, and the Sierra Madre

Oriental is sufficiently elevated and unbroken to form a considerable barrier to rain-bringing winds from the east.

Figures 7 and 8 show the mean annual precipitation and the maximum observed 24-hour precipitation in the Basin. The data for the figures are based on regular observing stations in the Basin. Since local sparsity of stations and shortness of records render the construction of an accurate precipitation map of the Basin difficult, these limitations should be kept in mind when attempting to draw specific conclusions from the charts.

Examination of the mean annual chart (figure 7) shows that topography plays a major role in establishing the precipitation pattern with the largest mean annual amounts over the Sierra Madre Occidental and Oriental and the Davis Mountains, and the least amounts over the desert regions of northern Mexico. Very little north-south gradient is evident; the isohyets and isohyetal centers in general are oriented north-northeast-south-southwest in the direction of the mountain ranges. The variation in amount of mean annual precipitation in the Basin is moderately large, ranging from less than eight inches annually at Ojinaga, Chih., to more than twenty-seven inches at Creel, Chih.

The maximum 24-hour precipitation map (figure 8) exhibits much the same distribution as the annual chart, as does figure 9a, which shows the mean annual number of rainy days in the Basin, that is, days in which 0.01 inches of rain or more are recorded. Again, the largest amounts occur on the western, eastern, and northern sections of the basin boundaries, while the least occurs over the south-central part.

Figure 9b shows the average annual number of days with thunderstorms in the Basin. The maximum number of recorded thunderstorms, in excess of 35 per year, occur on the southeastern edge of the Conchos Basin, while a minimum of less than 15 per year occurs near Dryden, Tex. An interesting feature of the map is that in some areas, notably in the extreme northeastern section of the Basin, more days with thunderstorms than days with rainfall are reported. This may be accounted for by the fact that many of the thunderstorms in the region occur in the higher elevations surrounding the station and give no rainfall at the station or else are dry thunderstorms, i.e., no rain reaches the ground.

Snow is infrequent over most of the Basin, and except on the mountains is confined to the period from November to April. It increases generally to the westward and northwestward, being heaviest in the higher elevations of the Trans-Pecos region. Fort Davis, Marathon, and Kent, Tex., are the only stations reporting average annual amounts of snow in excess of six inches, although greater depths no doubt occur in the mountain ranges. Snowfall in the Basin is generally dissipated quickly by the warmth, sunshine, and dessicating winds of the region.

Temperature

The temperature regime in the Rio Grande Basin is continental in character with marked variation between winter and summer average temperatures. (See figure 10). June is the hottest month in the western area of the Basin; July and August, the hottest months in the eastern portion. In the central section the highest average temperatures are to be found during the months of June, July, and August, with little variation in the monthly averages at each station during this period. December and January are the coldest months throughout the Basin. The summer to winter temperature range is emphasized when extremes are considered. Temperatures in excess of 110° are not uncommon, especially in the central portion of the Basin, while subzero temperatures have been recorded at many points in the Basin.

During the summer months altitude exercises a more dominant control than latitude over temperatures in the Basin. In winter, however, a more pronounced north-south mean temperature gradient becomes established as the Basin comes under the influence of the winter polar air masses from the north. The mean annual range of temperature is most marked in the northern portion of the Basin, some stations having ranges of nearly 40°F.

Sunshine and cloudiness. Sunshine data for the Rio Grande Basin are presented in figure 5. The percent of the possible sunshine ranges from more than 80 at El Paso to less than 60 near Del Rio. The mean annual number of cloudy and clear days are shown in figures 11a and 11b. The least cloudiness, as might be expected, occurs over the arid Central Plateau region and the maximum cloudiness over the high mountains of the western Conchos Basin.

Moisture. Graphs showing the maximum observed precipitable water from the surface to the five-kilometer level at Mazatlan, Mex., and Brownsville and El Paso, Tex., for the two rainy months (in the Basin) of July and September appear in figure 12. Upper-air soundings for five years of record were used in the compilation of the graphs, and the 30 highest values at each station during the month were selected, representing approximately the top 10% of the precipitable-water values. The abscissa of the graphs indicates the number of cases in which the maximum precipitable water values equalled or exceeded the values shown by the ordinate.

The Gulf of Mexico and the Pacific Ocean are the principal moisture sources for air entering the Basin area as mentioned previously. Southwesterly winds transport moist air from the Pacific into the Basin across the Sierra Madre Occidental. Moist air from the Gulf of Mexico, is transported into the Basin by southeasterly winds, and, in general, must cross the Sierra Madre Oriental or the Davis Mountains before entering the Basin. The maximum moisture available at the Pacific source-region is depicted by the Mazatlan precipitable-water curves,[1] while the curves for Brownsville typify the maximum moisture available from the eastern source-region.

A comparison can thus be made between the maximum moisture content present at the source regions with that which reaches El Paso, a station selected to exemplify the maximum moisture values

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[1]A. L. Shands, Mean Precipitable Water in the United States, Weather Bureau Technical Paper No. 10 (Washington, D. C., 1949)

to be found in the protected area of the Basin. It may be noted that the maximum amounts of precipitable water available in both source regions are nearly equivalent. The graphs for El Paso illustrate, however, that as the air enters inland and traverses the Sierra Madre Occidental or Oriental the effect of these ranges is to deplete sharply the amount of moisture by causing precipitation on the windward slopes before the air enters the basin area. The average amount of depletion, as can be seen from the graphs, is nearly an inch of water.

Evaporation power. A study of evaporation from Lake Conchos (Lago Toronto), Chih., has been made by Duryea and Haehl.[2] The Lake, located in the Basin about 90 miles south of the city of Chihuahua, is an artificial reservoir formed by impounding the waters of the Rio Conchos. The Lake, about 4300 feet above sea level, lies in a region having a mean temperature of about 67°F. Duryea and Haehl estimated a value of 55 inches for the yearly evaporation depth from the surface of the Lake. Measurements taken in circular pans, four feet in diameter, at La Boquilla Dam by the IBWC during the period 1938-1949, show an average pan-evaporation depth of 102.29 inches. Other average pan measurements of evaporation in the Rio Grande appear in IBWC Water Bulletin No. 19. In Texas they range from 55.80 inches at Weslaco to 120.76 inches at Dryden; in Mexico, from 62.83 inches at Montemorelos, N. L., to 112.58 inches at Villaba, Chih.

[2] E. J. Duryea and H. L. Haehl, A Study of Annual Evaporation from Lake Conchos, Mexico, (Proceedings ASCE, September, 1915).

## Chapter III

## STORMS TYPES AND TRANSPOSITION LIMITS

This chapter deals with the typing of heavy rain situations within the shaded area shown in figure 13. The area represents, roughly, the limits of transposability of storms to the Rio Grande Basin, although certain storms can occur within the delineated limits (usually near the eastern edge) that may not be transposed into the Basin. Generally, the storms typed have been those of the warmer half of the year (May through October), since nearly all important flood-producing storms have occurred within this period.

Storms occurring in the Rio Grande Basin fall into four general types:

| | |
|---|---|
| Type I - Frontal | Type III - Induced trough aloft |
| Type II - Tropical | Type IV - Stagnant cold plateau trough aloft |

Many of the very largest flood-producing storms are composed of a combination of two or more storms of different types. The most common combination is that of a tropical storm followed or preceded by frontal rain. Synthesized combinations of storm types and intervals of occurrence are discussed in Chapter V if this report.

The following is a list of representative storms grouped according to type:

Table 1

Type I - Frontal

| U.S.E. Number | Date | Rainfall Center |
|---|---|---|
| SW 1-6 | Sept. 26-30, 1904 | Rociada, N. Mex. |
| GM 3-13 | July 21-25, 1905 | Elk, N. Mex. |
| SW 1-14 | June 6-12, 1913 | Ft. Union, N. Mex. |

| Number | Date | Rainfall Center |
|---|---|---|
| -- | August 6, 1920 | O2 Ranch, Tex. |
| GM 4-21 | May 27-29, 1925 | Eagle Pass, Tex. |
| GM 5-1 | June 30-July 2, 1932 | Kerrville, Tex. |
| -- | Sept. 5-10, 1932 | Hormiguero, Chih., Muzquiz, Coah., Mex. Coates Ranch, Tex. |
| SW 2-11 | Apr. 3-4, 1934 | Cheyenne, Okla. |
| GM 5-10 | July 19-25, 1938 | Eldorado (nr), Tex. Chihuahua, Chih., Mex. |
| *SW 2-18 | Sept. 2-6, 1940 | Hallet, Okla. |
| GM 5-18 | May 20-25, 1941 | Prairieview, N. Mex. |
| SW 3-1 | Sept. 27-30, 1941 | Tularosa, N. Mex. |
| -- | Sept. 3-6, 1944 | B. H. Davis Ranch, Tex. |
| -- | July 1-3, 1945 | Kingston Ranch, Tex. |
| -- | Oct. 3-6, 1946 | Pandale, Tex. |
| -- | May 9-10, 1947 | Stone, Tex. |
| | **Type II - Tropical** | |
| -- | Aug. 29, 1909 | Monterrey (nr), N.L., Mex. |
| GM 3-22 | June 29, 1913 | Montell, Tex. |
| GM 5-15B | Sept. 15-17, 1919 | Meek, N. Mex. |
| -- | June 16-17, 1922 | Coahuila (State), Mex. |
| -- | Sept. 19-22, 1936 | Marfa, Tex. |
| SW 2-29 | Aug. 31-Sept. 1, 1942 | Rancho Grande, N. Mex. |
| | **Type III - Induced trough aloft** | |
| -- | June 14-15, 1899 | Ft. Clark, Tex. |
| GM 4-12 | Sept. 9-10, 1921 | Thrall, Tex. |
| GM 5-16A | Aug. 31-Sept.1, 1932 | Substation No. 14, Tex. |
| -- | June 24, 1948 | Wardlaw's Ranch, Tex. |
| | **Type IV - Stagnant Cold Plateau Trough Aloft** | |
| GM 5-20 | May 31, 1935 | D'Hanis, Tex. |
| GM 5-19 | Sept. 20-23, 1941 | McColleum Ranch, N. Mex. |
| | **Observed Combination Storms** | |
| GM 3-4 | June 29-July 1, 1899 (Type II followed 1 day later by Type I) | Hearne, Tex. |
| -- | Sept. 3-10, 1904 (Type I and II concurrent) | Chihuahua, Chih., Mex. |
| -- | Sept. 17-20, 1917 (Type I and II concurrent) | Chihuahua (State), Mex. |

*Air mass contrast weak, but isobaric pattern similar to other Type I storms.

| Number | Date | Rainfall Center |
|---|---|---|
| -- | Aug. 30-Sept. 5, 1932 (Type II followed 3 days later by Type I) | Balmorhea, Tex. |
| GM 5-7 | Sept. 14-18, 1936 (Type II followed 3 days later by Type I) | Broome and Roosevelt, Tex. |
| -- | June 23-26, 1938 (Type II followed 1 1/2 days later by Type I) | Toyahvale, Tex. |
| -- | Sept. 13-15, 1938 (Type II followed by Type I 2 days later) | Chihuahua, Chih., Mex. |
| -- | Aug. 23-28, 1944 (Type II followed by Type I in 3 days) | B. Bunton Ranch, Tex., Mariposa, Coah., Mex. |
| -- | Sept. 6-7, 1944 (Type I followed by Type II 2 days later) | Hormiguero, Chih., Mex. |
| -- | July 1-7, 1945 (Type I followed 3 days later by Type I) | Kingston Ranch and J. F. Runge Ranch, Tex. |

Type I - Frontal

One of the most potent heavy-rain-producing synoptic situations that can occur over any part of the Rio Grande Basin is the frontal type. Modified polar air lies to the north of the front and is over-run by tropical maritime air, usually from the Gulf of Mexico, but under some conditions from the Pacific Ocean.

Strictly frontal storms are rare in the southern part of the Rio Conchos Basin during the middle of the summer season (July). The maximum frequency of this type of storm is reached in September and October.

Nearly all frontal storms are characterized by a quasi-stationary front; and a few, by moving cold fronts or frontal waves. Probably, the mountainous terrain prohibits wave development of the type seen in the central United States. The moving system, even when accompanied by a squall line, results in smaller rainfall amounts than the quasi-stationary fronts, other things being equal. The orientation of the front may vary, ranging, counter-clockwise, between northwest-souteast and north-northeast-south-southwest (with the cold air always north of the front).

Figure 14a illustrates the surface synoptic map during a Type I storm, that of May 1947 at Stone, Tex. The area of principal total storm rainfall is indicated by shading. Upper-air charts are included (figures 14b and 14c), showing the approximate trajectory of moist air at the upper levels. (Height lines on upper level charts are labeled in tens of feet).

Type I storms are not primarily orographic in nature, although location of the rain center itself may be influenced by topography. Heaviest rainfall is likely to occur on mountain slopes facing east and southeast - direction at right angles to the low-level wind.

<u>Transposition limits of Type I storms</u>

Type I storms have been observed in all parts of the Rio Grande Basin and, therefore, may be considered fully transposable. Placement of the rainfall center, however, must be confined to slopes with an exposure similar to that of the center of the storm as it originally occurred. The relative orientation of the isohyetal pattern to major topographic barriers in the transposed location must be similar to that in the observed location.

<u>Type II - Tropical storm</u>

A large number of flood-producing storms are attributable, at least in part, to decadent tropical storms coming from either the

Gulf of Mexico or the Pacific Ocean. Approximately one third of the storms studied are connected directly or indirectly with decadent tropical storms. On crossing the Continental Divide in Mexico, the Pacific tropical storms are broken up in the surface layers, but the high-level cyclonic circulations can be traced as they cross the Divide and move into the Rio Grande Basin. Tropical storms from the Gulf of Mexico usually preserve their identity better, occasionally retaining a symmetrical surface circulation even into New Mexico.

Rainfall amounts over the Basin are smaller in the Pacific storms because of the higher mountain barrier to the west, but in combination with fronts, the resulting storm may be very large. The center of the tropical storm from the Pacific need not cross the mountain barrier to give heavy rain over the Rio Conchos Basin. Pacific storms deposit most of their rain on the western slopes of the mountains. However, if the Rio Conchos Basin is filled with cool air (a front lying along the Continental Divide) the ascending moist currents from the Pacific can rise further, yielding flood-producing rains within the Basin.

Figure 15 shows a typical decadent storm from the Gulf of Mexico over the Trans-Pecos with the rainfall center at Meek, N. Mex. An example of a decadent Pacific tropical storm that crossed the Divide in Mexico is that of the September 1938 storm centered at Chihuahua, Mexico (figure 16).

Tropical storms have been observed to give rain in all parts of the Rio Grande Basin, although the Rio Grande Basin above Del Rio, including the Rio Conchos, is beyond the limit of destructive winds associated with these storms. A large quantity of moist air, however, is carried aloft to great heights over the Rio Grande Basin by the decadent tropical storm. This moisture is frequently precipitated in heavy afternoon showers. But, if a frontal system lies over the Basin, the combination of very moist air plus frontal activity has produced great floods in the Rio Conchos Basin, for example, the floods of September 1904 and September 1917.

Transposition limits of Type II storms

The tropical storm may be transposed to any portion of the Rio Grande Basin, but proper allowance for moisture depletion must be made for the barrier over which the moist air is lifted.

Type III - Induced trough aloft

It has long been recognized that many of the very heavy rains in Texas cannot be explained by frontal activity, tropical storms, or squall lines. Previously, in reports issued by the Section, the change in curvature from more anticyclonic upwind to more cyclonic downwind has been stressed as a cause of convergence associated with some Texas storms. Further study has shown that an accompanying feature to this change in curvature is frequently an induced trough aloft. The characteristic synoptic situation of these anomalous storms is a deep flow of warm air from the Gulf of Mexico associated with a strong subtropical cell of high pressure over the southeastern United States. Prior to the heavy rain, the air may be rather dry aloft but very moist near the surface. Aloft, a sharp trough between two subtropical Highs is observed, while at the surface a change in curvature from anticyclonic to straight or cyclonic isobars over the rainfall area is characteristic. The trough aloft is quite similar to the induced or westerly trough in the subtropics as discussed by Riehl.[1]

Although the presence of a tropical storm in the Gulf of Mexico contributes to the intensity of the observed storm over Texas, the existence of such a tropical disturbance is not necessary for the production of heavy rain.

It is probable that orographic lifting aids in the release of instability and, within limits, may influence the location of the rainfall center. However, in one of the storms studied (Thrall, Tex., Sept. 9-10, 1921) the rainfall center was located on the Plains at an elevation of 563 feet.

Wardlaw's Ranch, Tex., storm of June 24, 1948, has been chosen to represent the group because of the relatively large amount of upper level data. Certain surface synoptic characteristics are noted, however, so as to permit typing of older storms with limited upper air data.

Prior to the very heavy rain at Wardlaw's Ranch early on the morning of the 24th no fronts had passed through the area for ten days. A steady south-southeasterly flow of moist air was well established east of the Presidio-Lubbock line. To the west of this line, continental tropical air prevailed. At the 700-mb level (about 10,000 feet) a single large subtropical high cell was predominant (figure 17b).

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[1] Riehl, H., Waves in the Easterlies and the Polar Front in the Tropics, Institute of Meteorology Miscellaneous Report No. 16, Univ. of Chicago, 1945.

A few days before the rain period, a polar trough appeared over the northwestern United States. A vigorous wave developed on the attendant cold front about 36 hours preceding the Texas storm. The wave development took place to the north of Texas, and moved north-northeastward. A strengthening of the upper westerly flow accompanied the wave development, and at the same time a split was observed in the subtropical high cell to the south. The split, or induced trough, traveled eastward on the 23rd (figure 17c), becoming stationary along the Abilene-Del Rio-Muzquiz line on the evening of the 23rd (figure 17d).

The trough remained over the Del Rio area for about 18 hours and then moved slowly westward. The surface map a few hours prior to the heavy rain (figure 17a) shows a stationary front oriented northeast-southwest to the south of Amarillo. This approximate position of the surface polar front is quite characteristic of the induced trough type of storm, representing the southern limit of the westerly winds aloft. The surface pressure in the vicinity of the storm tends to become lower when the induced trough moves overhead, and isobars become cyclonic or straight rather than anticyclonic.

Convective activity extended about 200 miles to the east of the induced trough line, but the greatest intensity was observed within a few miles east of the line. Normally the induced trough moves eastward at about 10 to 15 mph and produces nominal point-rainfall amounts, but when it becomes quasi-stationary, very heavy local rains are possible.

Transposition limits of Type III storms

As pointed out previously, areas of upslope are favored places for the location of heaviest rain, although upslope itself is not a sufficient condition for the generation of the heavy rain. On the other hand, none of the four storms studied was observed to center on a downslope. With this in mind, a study of the orography to the south of the Rio Grande Basin was undertaken. The problem was to find the western limit of upslope wind using the inflow wind direction in the observed storms. A value of 160° was obtained for the wind direction at the 700-mb level over the storm area at the time of the heavy rain. Identical directions occurred in the 1948 and 1932 storms (those which occurred farthest west among the storms for which upper air data were available). The effect of orography, therefore, is to limit transposition of storms of this type in the maximum possible case to the Devils River and lower Pecos Basins. A line extending, approximately, from Wink to Dryden, Tex., was found to delineate the western limit of upslope winds from the mountains south of the Rio Grande. For hydrologic trials rotation of the isohyetal pattern to a maximum of 20° in either direction is allowable.

Type IV - Stagnant, cold, plateau trough aloft

Type IV storms, associated with pronounced cold, slowly moving, polar troughs aloft over the plateau region are not so numerous in the Rio Grande Basin as are other types of storms.

The McColleum Ranch storm of September 1941 is the most extensive storm of this type. Inflow winds approached record velocities, and temperatures aloft to the northwest of the storm area reached record lows for the date. The deep cold trough caused unusually moist and warm air, advancing from the Gulf of Mexico in the lower layers and from the Gulf of California at upper levels, to envelope the Rio Grande Basin. A hurricane was situated near the southern tip of Lower California, while another tropical storm was centered off the Yucatan peninsula in the Gulf of Mexico. The presence of the Pacific hurricane produced a sharp anticyclonic ridge aloft over the northwestern portion of Mexico. See figure 18b. The moist air, when it left this ridge, encountered a strong south-southeasterly current over western Texas and eastern New Mexico. The Texas current was part of the circulation about a strong subtropical High aloft over the eastern part of the United States. Evidence of convergence was observed in connection with the confluence of the two currents over eastern New Mexico. Orography contributed to the intensity and the placement of the rainfall center on the Guadalupe Mountains in the McColleum Ranch storm. Figures 18a and 18b show the surface and the 10,000-ft. charts at the time of the first burst of rain. Approximate trajectories of the moist air are also shown.

<u>Transposition limits of Type IV storms</u>

Type IV storms may be transposed to any portion of the Rio Grande Basin under consideration in this study; however, the rainfall center of the McColleum Ranch storm should be placed in areas of similar altitude and mountain range orientation.

## Chapter IV

## STORM HISTORY

In this chapter, the location and a brief description of critical storms which have occurred in the Basin will be given along with preliminary depth-duration-area (DDA) curves wherever practicable. Figures 19 to 21 show the locations of the major Rio Grande storms discussed in the text along with the isohyet bounding the principal rain areas in each storm. It has not been feasible to construct maps and DDA curves in all cases because of the sparseness of the rain gage networks and the lack of a suitable time-breakdown of rainfall. Examples are the storms of Sept. 17-20, 1917, and June 16-17, 1922, over Mexico and the Fort Clark storm of June 14-15, 1899, over the Devils River Basin.

### Type I storms

July 1-3, 1945. Type I storms in the Rio Grande Basin are frontal storms, the front usually being quasi-stationary in nature, with tropical air overrunning the frontal surface. A characteristic Type I storm occurred in the Basin during the period of July 1-3, 1945. The area covered by this storm consisted of most of the Pecos and Upper Rio Grande drainage basins. The main isohyetal center was located at Kingston Ranch, along the east slopes of the Davis Mountains. In addition, two other centers occurred in the Conchos Basin; one at Hormiguero and the other at San Antonio, Chih. In this storm, the mountain slopes appeared to play a major part in intensifying and distributing the rainfall. This is generally the case in Type I storms in the Basin, where the major centers are ordinarily oriented parallel to the mountain slopes and tend to form along the Davis Mountains in western Texas and just east of the Sierra Madre Occidental in Mexico. DDA curves for the July 1945 storm are shown in figure 22a, with average depth of rainfall on a linear scale plotted against area as a logarithmic coordinate.

May 27-29, 1925. Another important storm of this type was that of May 27-29, 1925. The storm was centered at Eagle Pass, Tex., which received 11.2 inches of rain in 60 hours. Although this storm caused the fifth largest peak discharge on the Devils River, much of the rain fell outside the confines of that Basin. DDA curves for this storm have been reproduced in Figure 22b.

Aug. 6, 1920. A remarkable small-area and short-duration Type I storm occurred on Aug. 6, 1920, when 7.80 inches of rain fell at the 02 Ranch in a five-and-one-half-hour period. The rainfall, according to the observer at the Ranch, was mainly confined to an area of approximately 60 square miles.

May 9-10, 1947. Another short-duration storm of this type occurred in the Basin on May 9-10, 1947. This storm was centered at Stone Ranch, Tex., (figure 14a). Most of the rain in this storm fell during the 36-hour period following 6 a.m. of the 9th. DDA curves pertinent to the storm for that portion of the rain which fell in the Basin west of the 103d meridian are reproduced in Figure 22c.

July 19-25, 1938. A notable large-area storm of this type occurred over the Rio Grande Basin during July 19-25, 1938. The isohyetal map for this storm period showed three rainfall centers lying within the Basin limits. The main storm center lay along the eastern border of the Devils River Basin near Eldorado, Tex. Secondary centers occurred over the Conchos Basin near Chihuahua and to the north and east of the Big Bend country, from Ft. Stockton and Marfa southeastward to Palestina Camp. The orientation of the rainfall centers in this storm showed a definite tendency to lie parallel to the mountain ranges. DDA curves for the storm are shown in figure 23, representing the rainfall over all of the Rio Grande Basin except the Rio Conchos.

Oct. 3-6, 1946. Another important storm of this type was that of Oct. 3-6, 1946, which caused an increase of daily average flow at the Pecos River Station from 238 c.f.s. on October 5 to 28,100 c.f.s. on the 6th, with a peak flow of 65,000 c.f.s. being registered on the 6th. The major center of the storm was located at Pandale, Tex., and secondary centers occurred at A. L. Baugh Ranch, Tex., and Rosetilla, Chih. Thunderstorm activity occurred with the frontal passage and a rainfall of 9.25 inches was measured at Pandale during the period from the afternoon of the 5th to the morning of the 6th. This amount, so far as is known, is the largest 24-hour total ever recorded for any station in the Basin above Del Rio during the month of October. Rains totaling more than ten inches also fell in many parts of the Panhandle area during the storm period.

Sept. 5-10, 1932. The most noteworthy Type I storm to occur in the Rio Conchos Basin was that of Sept. 5-10, 1932, during which period a total of 10.47 inches fell at Hormiguero, Chih. In addition to the Hormiguero center, there was a secondary rainfall center of 5 inches at Coates Ranch, Tex. The storm resulted in a peak flow of 133,000 c.f.s. on September 12 at Lower Presidio, Tex., the fourth greatest discharge ever measured at that station.

Sept. 3-6, 1944. The Type I storm sometimes consists of the passage of a slowly-moving cold front across the Basin. Such storms may be preceded by a squall line, as was the case in the Sept. 3-6, 1944 storm. The rainfall center for the storm was at B. H. Davis Ranch, Tex. The rainfall pattern for the storm is similar to those of the other Type I storms with the major rainfall center in the Davis Mountains and oriented parallel to the mountain slopes. In figure 24a may be seen the DDA curves for the B. H. Davis storm.

Type II storms

Sept. 19-22, 1936. Type II storms consist of tropical storms which have entered the Basin either from the Pacific or the Gulf of Mexico. Many of these storms disappear at the surface after entering the coast and their future movements can only be traced aloft. Such a storm was that of Sept. 19-22, 1936 centered at Marfa, Tex. This tropical storm originated in the Carribean and moved aloft in a westerly direction across the Basin as shown by the upper-air winds. DDA curves for this Type II storm are depicted in figure 24b.

June 16-17, 1922. Another Type II storm to occur in the Basin was that of June 16-17, 1922, in the State of Coahuila, Mexico. This storm resulted in the greatest peak discharge of record at Langtry, Tex., 204,000 c.f.s. on June 18, 1922. As in the case of the preceding storm, the tropical storm which caused these heavy rains also had its origin in the Carribean. The storm entered the coast near Tampico on June 15, and moved across Mexico in a north-northeasterly direction. Although it is rather difficult to be certain because of the sparse meteorological network existing at this time, it would seem that the storm "rained out" in the mountains to the southwest of Langtry. Most of the discharge into the Rio Grande, therefore, was probably from the Arroyo del Cibolo and nearby streams.

Type III storms

Aug. 31-Sept. 1, 1932. The Type III storm, associated with an induced trough aloft, has been responsible for some of the most intense rains over the Devils River and Pecos drainage basins. The Aug. 31-Sept. 1, 1932 storm, which was of this type, caused floods of unprecedented magnitude on the Lower Rio Grande. The floods on the Devils and Pecos Rivers during this period were the greatest of record. On September 1, a peak discharge of 116,000 c.f.s. was measured at the Pecos River Station, and on the same date, a discharge of 597,000 c.f.s. was noted near the mouth of the Devils River. The two readings represent the greatest discharges ever to be recorded on these rivers.

The center of this storm was located at Substation No. 14 near Sonora, Tex. Here 7.66 inches of rain was measured on August 31 and 6.08 the next day, establishing new 24-hour and 48-hour precipitation records for the station. DDA curves for this storm for the area encompassed by the Devils River and Lower Pecos Basins are shown in figure 25.

June 24, 1948. Another memorable Type III storm was that of June 24, 1948. The principal center of this storm occurred at Wardlaw's Ranch, which received a total of 28 inches in less than 24 hours. As was the case in the Aug. 31-Sept. 1, 1932 storm, the orientation of the storm isohyetal pattern was north-south. A discharge of 475,000 c.f.s. was measured on the Rio Grande at Del Rio June 24. The peak discharge at the Devils River Station was 476,000 c.f.s., a record second only to that of the 1932 storm. However, if the June 1948 storm (figures 17a-d) had occurred about 40 miles further to the north-northwest with the same orientation, the amount of rain falling over the Devils River Basin would have been roughly doubled. Computations made by the IBWC have shown that if such had been the case, the Devils River would have reached a stage of approximately 50 feet, or 9 feet above the maximum stage of September 1932. DDA curves for the 1948 storm are shown in figure 26.

June 14-15, 1899. The copious rainfall of June 13-15, 1899 was also produced by a Type III storm. Eighteen inches of rain fell at Ft. Clark, Tex., in a period of 21½ hours during the 14th-15th. The storm is estimated to have caused a peak discharge of between 300,000 and 325,000 c.f.s. on the Devils River. This estimated discharge, is surpassed only by the measured discharges in the 1932 and 1948 storms. Because of the sparsity of rainfall reporting stations in the Basin in 1899, no DDA curves are presented for the storm.

Type IV storms

Sept. 20-23, 1941. The Type IV storm is associated with a stagnant, cold, plateau trough aloft and is best illustrated by the Sept. 20-23, 1941 storm (figures 18a and 18b). Although the storm center was at Dave McColleum Ranch, N. Mex., considerable rain fell over the upper Basin. In fact, most of the stations in this portion of the Basin received their maximum 24-hour amounts of record during the period of this storm. DDA curves for the portion of the storm rainfall which fell in the Basin will be found in figure 24c.

Combinations of storm types

Sept. 3-10, 1904 and Sept. 17-20, 1917. As has been pointed out previously, many of the large flood-producing rains result from storms which are composed of two or more storm types.

The storms of Sept. 3-10, 1904 and Sept. 17-20, 1917, were quite similar, meteorologically. Each resulted from a tropical storm from the Pacific acting in conjunction with a quasi-stationary front, (a combination of Types I and II). In addition, both storms caused severe flooding in the Rio Conchos. It has been calculated by the IBWC that the September 1917 flood produced the third highest flood on the Conchos, being exceeded only by the storms of 1829 and 1868, while the 1904 storm ranks fourth. According to IBWC Water Bulletin No. 8, the 1917 and 1904 storms would produce the two greatest discharges of record on the Rio Grande at Lower Presidio, assuming neither Boquilla nor Elephant Butte Dam was built.

Aug. 30-Sept. 5, 1932. This storm combination consisted of a Type II storm followed 3 days later by Type I. The storm period was initiated by a strong current of moist, convectively unstable tropical air which flowed around a decadent Pacific tropical storm in northern Mexico and was forced up the slopes of the Davis Mountains. On September 1, a different regime came into being with the entrance into the region of a quasi-stationary front. The upper-basin rainfall, coupled with the induced trough rainfall which occurred in the Lower Pecos during this period, resulted in the unprecedented floods on the Pecos which were discussed earlier in this chapter under the Type III heading. DDA curves for that portion of the rainfall which fell in the Upper Pecos have been prepared and may be found in figure 27a.

June 23-26, 1938. The Toyahvale, Tex., storm of June 23-26, 1938, is closely akin to the Upper Pecos storm of Aug. 30-Sept. 5, 1932. The June 1938 storm also consisted of a Pacific tropical storm followed by a Type I storm one and a half days later, however, in this case. Also, the rainfall centers in both storms occurred within a few miles of one another. In figure 27b will be found the DDA curves for the June 1938 storm.

Sept. 13-15, 1938. The storm of Sept. 13-15, 1938, (figure 16), consisted of a tropical storm followed two to three days later by passage of a cold front through the Basin, the tropical storm being of Pacific origin. The isohyetal map for the storm showed two rainfall centers; the main center, which was oriented north-south, occurred at Chihuahua. In addition, there was a secondary center at Big Bend State Park, Tex.

Aug. 23-28, 1944. The storm of Aug. 23-28, 1944, like the preceding storm of September 1938, consisted of a tropical storm followed by a cold front. The tropical storm associated with the 1944 storm entered the Basin from the Gulf of Mexico. The isohyetal pattern of this storm also lay in a north-south direction with the center at the Bill Bunton Ranch, Tex. Another center lay outside the confines of the Basin at Mariposa, Coah. DDA curves for the Bunton Ranch center are reproduced in figure 27c.

Sept. 6-7, 1944. The storm of Sept. 6-7, 1944, at Hormiguero, Chih., is the converse of the September 1938 and August 1944 storms which have just been discussed. The combination consisted of a Type I followed by a Type II. Passage of the cold front involved was mentioned previously under Type I in the description of the B. H. Davis Ranch storm of Sept. 3-6, 1944. The tropical storm came from the Gulf of Mexico.

# Chapter V

## MAXIMUM POSSIBLE STORMS AND CRITICAL SEQUENCES

The derivation of the design storm for a particular basin consists of two steps: (1) derivation of the maximum possible precipitation (MPP) values for the general region of which the basin is a part, and (2) adaptation of the observed time-areal distribution of precipitation in observed storms to the MPP values, the hydrologic characteristics of the basin, and meteorologically reasonable critical sequences. Since step (2) involves both meteorological and hydrologic judgment, the final adaptation is usually made by hydrologic engineers after the Hydrometeorological Section has suggested certain patterns for trials.

### Derivation of MPP curves

The MPP curves for the Rio Grande Basin are determined by a process of storm transposition and moisture adjustment. They are the smoothed envelopments of DDA values from all storms that can be transposed to the basin, adjusted for the maximum moisture that has been observed in the basin. The curves thus represent limiting values for many storms.

Transposition is the moving of rainfall values from the places in which they occurred to the general area of the basin, the values being raised or lowered according to differences in moisture in the two regions. Transposition assumes that the location of major storms is fortuitous within certain geographical limits. In effect, it increases the storm experience of the region.

Decision as to what storms are transposed to the basin is based on meteorological experience. Storms are typed as to their meteorological characteristics and, in general, a storm of large precipitation volume of a certain type is transposed to any basin in which storms of the same type have occurred even though of smaller precipitation volume. An exception is made to this general rule in cases where some topographic feature is important as a storm moves from sea to land or in the forced lifting of winds in a storm by a steep orographic barrier. In these cases transposition is limited to regions similar with respect to these important topographic features.

The moisture adjustment factor is obtained by multiplying the observed rainfall values by the ratio of the maximum possible effective precipitable water in the basin to the effective precipitable water in the storm. If there is a topographic barrier between the moisture source and the basin, the maximum effective precipitable water in the basin is limited by the amount that can pass over the barrier.

Further details on transposition and moisture adjustment together with a discussion of the basic assumptions involved, may be found in Hydrometeorological Report No. 23, Generalized Estimates of Maximum Possible Precipitation.

Fitting of a time-areal pattern

The MPP curves for the Rio Grande Basin do not necessarily define, within one storm, the areal distribution for a selected duration nor the time distribution for a selected area within the Basin. Over small basins within the general area the storm producing critical values will not necessarily be the same storm as that producing critical values over a large basin. Similarly, different storms will control for different durations over the same basin. The longer axis of the basin may be oriented in a direction that is impossible for the orientation of the longer axis of an isohyetal pattern; so that a basin-shape factor is necessary to reduce the rainfall values. Topography may determine the location of the major isohyetal centers within the basin.

For such reasons, the Section makes recommendations regarding the patterns that may realistically be applied to a basin. These are given in one of two forms: (1) One or more of the transposed storms may provide a suitable pattern or patterns. Such a choice applies especially when both the basin and the region of the observed storm are level or when both are topographically similar. The isohyetal values are determined by the moisture adjustment described above. A limitation is placed on the rotation of the isohyetal pattern. (2) A storm actually occurring in the basin may be selected as a pattern. The adjustment to be applied to the isohyetal values is determined by either of the following two methods of which the first is more accurate:

(a) The observed DDA curves and the maxumum possible DDA curves (MPP) are drawn on separate sheets of transparent log-log paper. The observed curves are superimposed on the maximum curves and shifted to the right until they meet at some point or along some segment of the curves. The ratio of the maximum to the observed rainfall value at that point or segment will be the adjustment factor applicable to all the observed data. Its use will increase the observed values to the maximum possible for at least one area and duration but will ensure that the maximum possible values are nowhere exceeded.

(b) The percentage ratios of the maximum possible to the observed storm data are computed for a selected set of area-duration combinations, e.g., those of Form S-2. The smallest of these ratios is the approximate equivalent of the adjustment obtained in procedure (a).

Either procedure, then, entails preparation of incremental isohyetal maps or their equivalent (the observed precipitation values being adjusted by one of the two ratios) and replanimetering on the total-storm map the areas not bounded by closed isohyets within the basin. A <u>basin-shape factor</u> is thus implicitly introduced, its value being dependent on storms that have actually been observed over the basin or that are believed transposable to the basin. The factor will be less than 1.0 if the orientation of the basin is much different from the orientation of major storms in the region, or if storms observed in the basin have isohyetal patterns that are of much different shape from those usual for major storms in the region.

Results for the Rio Grande Basin above the Diablo Dam site. below Nichols Dam site, 25,470 square miles

The final DDA values for the Rio Grande Basin above the Diablo Dam site are shown in figure 28. The controlling storms, their types, and adjustment are as follows:

Table 2

| Type | U.S.E. Number | Date | Center | Adjustment Ratio |
|---|---|---|---|---|
| I | GM 4-21 | May 27-29, 1925 | Eagle Pass, Tex. | 1.24 |
| I | SW 2-18 | Sept. 2-6, 1940 | Hallet, Okla. | 1.24 |
| I | GM 5-1 | June 30-Jul. 2, 1932 | Kerrville, Tex. | 0.95 |
| I | SW 2-20 | May 6-12, 1943 | Warner, Okla. | 1.14 |
| II+I | GM 5-7 | Sept. 14-18, 1936 | Broome, Tex. | 1.05 |
| I | GM 5-10 | July 19-25, 1938 | Eldorado (nr), Tex. | 1.04 |
| III | GM 4-12 | Sept. 8-10, 1921 | Thrall, Tex. | 0.92 |

Each of the controlling storms may be used for hydrologic trial in order to obtain patterns in time and space for the MPP over the Basin. Placement within the Basin should be confined to slopes open to the Gulf of Mexico. The patterns for GM 4-21, SW 2-18, GM 5-1, SW 2-20, GM 5-7, and GM 5-10 should, therefore, be centered over the gently sloping plateau area east of the Davis Mountains and Sierra Madre Oriental, and the major axis of the isohyetal pattern should not be rotated more than 20 degrees in either direction. Placement of the center of GM 4-12 must be restricted to a position east of the extension of the Wink-Dryden line, and the major axis of the isohyetal pattern should not be rotated more than 20 degrees in either direction.

The Rio Grande Basin above Nichols Dam site, below Fort Quitman, 18,159 sq. mi.

The final DDA values obtained for the 18,159 square miles above the Nichols Dam site are shown in figure 29. These values are controlled by the following storms:

Table 3

| Type | U.S.E. Number | Date | Center | Adjustment Ratio |
|---|---|---|---|---|
| I | GM 4-21 | May 27-29, 1925 | Eagle Pass, Tex. | 1.15 |
| I | SW 2-18 | Sept. 2-6, 1940 | Hallet, Okla. | 1.10 |
| I | GM 5-1 | June 30-July 2, 1932 | Kerrville, Tex. | 0.84 |
| II+I | GM 5-7 | Sept. 14-18, 1936 | Broome, Tex. | 0.93 |
| I | GM 5-10 | July 19-25, 1938 | Eldorado (nr), Tex. | 0.92 |
| I | SW 2-11 | April 3-4, 1934 | Cheyenne, Okla. | 1.13 |
| I | SW 2-20 | May 6-12, 1943 | Warner, Okla. | 0.94 |

Although it is felt that the rainfall values for the above storms are transposable to the Basin, it is doubtful that the isohyetal patterns of the controlling storms transposed to this Basin would give realistic areal distribution because of the Basin topography. It is recommended that the isohyetal patterns of the following storms which have occurred over the Basin be used to obtain patterns of the distribution in time and space for the maximum possible precipitation over the entire Basin, or a selected portion of it.

Table 4

| Date | Center | Adjustment Ratio |
|---|---|---|
| July 1-3, 1945 | B. H. Davis Ranch, Tex. | 2.86 |
| June 23-26, 1938 | Big Bend State Park, Tex. | 2.97 |
| July 19-25, 1938 | Marfa, Tex. | 3.84 |

Preliminary Part II's for these storms are being forwarded under separate cover to the IBWC. The distribution in time and space is determined by applying the adjustment factor given in Table 4 to the DDA values from the pattern storms, in the manner described under (a) on page 35.

Rio Conchos Basin above Presidio, 24,741 sq. mi.

The final DDA values obtained for this Basin are shown in figure 30. The values are controlled by the following storms:

Table 5

| Type | U.S.E. Number | Date | Center | Adjustment Ratio |
|---|---|---|---|---|
| I | GM 4-21 | May 27-29, 1925 | Eagle Pass, Tex. | 0.97 |
| I | SW 2-18 | Sept. 2-6, 1940 | Hallet, Okla. | 0.97 |
| I | GM 5-1 | June 30-July 2, 1932 | Kerrville, Tex. | 0.75 |
| II+I | GM 5-7 | Sept. 14-18, 1936 | Broome, Tex. | 0.83 |
| I | SW 2-20 | May 6-12, 1943 | Warner, Okla. | 0.79 |
| II | GM 5-15b | Sept. 15-17, 1919 | Meek, N. Mex. | 1.23 |
| I | GM 5-10 | July 19-25, 1938 | Eldorado (nr), Tex. | 0.82 |
| I | SW 2-11 | Apr. 3-4, 1934 | Cheyenne, Okla. | 0.93 |

The use of controlling storm patterns in the Conchos Basin is not recommended because of the orographic influences. The Hydrometeorological Section suggests the use of storm patterns which have occurred in the Basin, adjusted by the method described in (a) on page 35. A preliminary Part II for the storm of Aug. 25 to Sept. 10, 1932, is being forwarded under separate cover.

Rio Grande Basin above Zapata and below Diablo Dam site, 12,250 sq. mi.

The maximum possible DDA curves for the Rio Grande Basin above Zapata and below the Diablo Dam site are shown in figure 31. The controlling storms and their maximum allowable adjustments are:

Table 6

| U.S.E. Number | Date | Center | Adjustment Ratio |
|---|---|---|---|
| GM 4-12 | Sept. 8-10, 1921 | Thrall, Tex. | 1.05 |
| GM 3-4 | June 27-July 1, 1879 | Hearne, Tex. | 1.16 |
| GM 4-21 | May 27-29, 1925 | Eagle Pass, Tex. | 1.48 |

The controlling storm patterns are recommended in order to obtain time-areal distribution of the rainfall. Placement of the center of the Thrall, Tex., storm (GM 4-12) within the Basin should be restricted to a position east of the Wink-Dryden line extended. The center of the Hearne, Tex., storm (GM 3-4) should not be moved farther inland from the coast than it occurred. The Eagle Pass, Tex., storm (GM 4-21) may be placed anywhere within the Basin. The isohyetal patterns may be rotated not more than 20° in either direction.

Critical storm sequences

The Hydrometeorological Section has investigated historical sequences of weather occurrences in and near the Rio Grande Basin in order to determine reasonable combinations of amounts and timing of flood-producing storms over contributing streams. The critical sequences were obtained by a synthesis of observed events and meteorological reasoning. In some cases observed sequences have been maintained, with appropriately adjusted storm values inserted at critical times in the sequence. In other cases, hypothetical sequences have been synthesized using storms and storm sequences which have been observed beyond the limits of the Basin, but which can, meteorologically speaking, occur over the Basin. The minimum time intervals allowed between storm occurrences in the synthesized sequences were based upon observed major storms in the vicinity of the Basin. The time interval is based on the length of time between maximum 24-hour periods of rainfall in the storms.

A. Above Diablo Dam site, below Nichols Dam site.

1. Any Type II storm may be transposed without moisture adjustment to the Pecos area, followed at any time by any controlling storm immediately above Diablo site adjusted and transposed. This sequence of events is based upon the observed sequence during the storm period of Aug. 29-Sept. 5, 1932.

2. Any Type I storm may be transposed to the Pecos area without moisture adjustment, followed three days later by any controlling storm critically located above Diablo Dam site adjusted and transposed. This sequence is based upon the storm period of July 1-7, 1945, during which a cold front produced heavy rain, stagnated, and was reinforced by a new polar surge three days later. The second surge could also have produced a Type III storm.

3. Any Type IV storm may be transposed to the Pecos area without moisture adjustment, followed at any time by any controlling

storm critically located above Diablo Dam site adjusted and transposed. Although no major storms establish precedent for this sequence, such a sequence is meteorologically reasonable.

Barrier reductions to be applied to Type I and II storms when transposed to the Upper Pecos area follow:

Table 7

| U.S.E. Number | Date | Center | Reduction Ratio |
|---|---|---|---|
| | | Type I | |
| SW 1-6 | Sept. 26-30, 1904 | Rociada, N. Mex. | 1.00 |
| GM 3-13 | July 21-25, 1905 | Elk, N. Mex. | 1.00 |
| SW 1-14 | June 6-12, 1913 | Ft. Union, N. Mex. | 1.00 |
| GM 4-21 | May 27-29, 1925 | Eagle Pass, Tex. | 0.84 |
| GM 5-1 | June 30-July 2, 1932 | Kerrville, Tex. | 0.76 |
| SW 2-11 | April 3-4, 1934 | Cheyenne, Okla. | 0.88 |
| GM 5-10 | July 19-25, 1938 | Eldorado (nr), Tex. | 0.81 |
| SW 2-18 | Sept. 2-6, 1940 | Hallet, Okla. | 0.84 |
| GM 5-18 | May 20-25, 1941 | Prairieview, N. Mex. | 0.92 |
| SW 3-1 | Sept. 27-30, 1941 | Tularosa, N. Mex. | 1.00 |
| | | Type II | |
| GM 5-15b | Sept. 15-17, 1919 | Meek, N. Mex. | 1.00 |
| SW 2-29 | Aug. 31-Sept. 1, 1942 | Rancho Grande, N. Mex. | 1.00 |

B. Above Nichols Dam site excluding the Rio Grande above Elephant Butte

In the absence of an extended storm history over the Rio Conchos, it is recommended that for a critical sequence the maximum possible precipitation over the Conchos, distributed in accordance with the pattern of the storm of Aug. 26 - Sept. 8, 1932, as shown in Special Flood Report of the IBWC, be followed in not less than three days by any of the adjusted storms critically placed above Nichols Dam site. During the period of Sept. 3-7, 1921, a quasi-stationary front remained over the Conchos Basin, producing moderate amounts of rainfall. This was followed by the Thrall storm of Sept. 9-10, 1921.

C. Entire Rio Grande Basin above Diablo Dam site

In accordance with the verbal request of the representative of the IBWC, the meteorological feasibility of peak flows above Elephant Butte and Red Bluff Dams in connection with downstream peak storms was investigated. For the Pecos River it is meteorologically possible to have such flows as those which occurred in May 1941 or April 1914, followed at a critical time downstream by the maximum possible storm.

Over the Upper Rio Grande it is considered possible that the maximum year of snowmelt run-off (1905 or 1941) above Elephant Butte may be followed at any critical time by a maximum storm sequence downstream.

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The following abbreviations are used:

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GPO - Government Printing Office
HMS - Hydrometeorological Section
H.O. - Hydrographic Office
IBWC - International Boundary and Water Commission (U.S. and Mexico)
MWR - Monthly Weather Review, U.S. Weather Bureau publication
USWB - U.S. Weather Bureau, Dept. of Commerce

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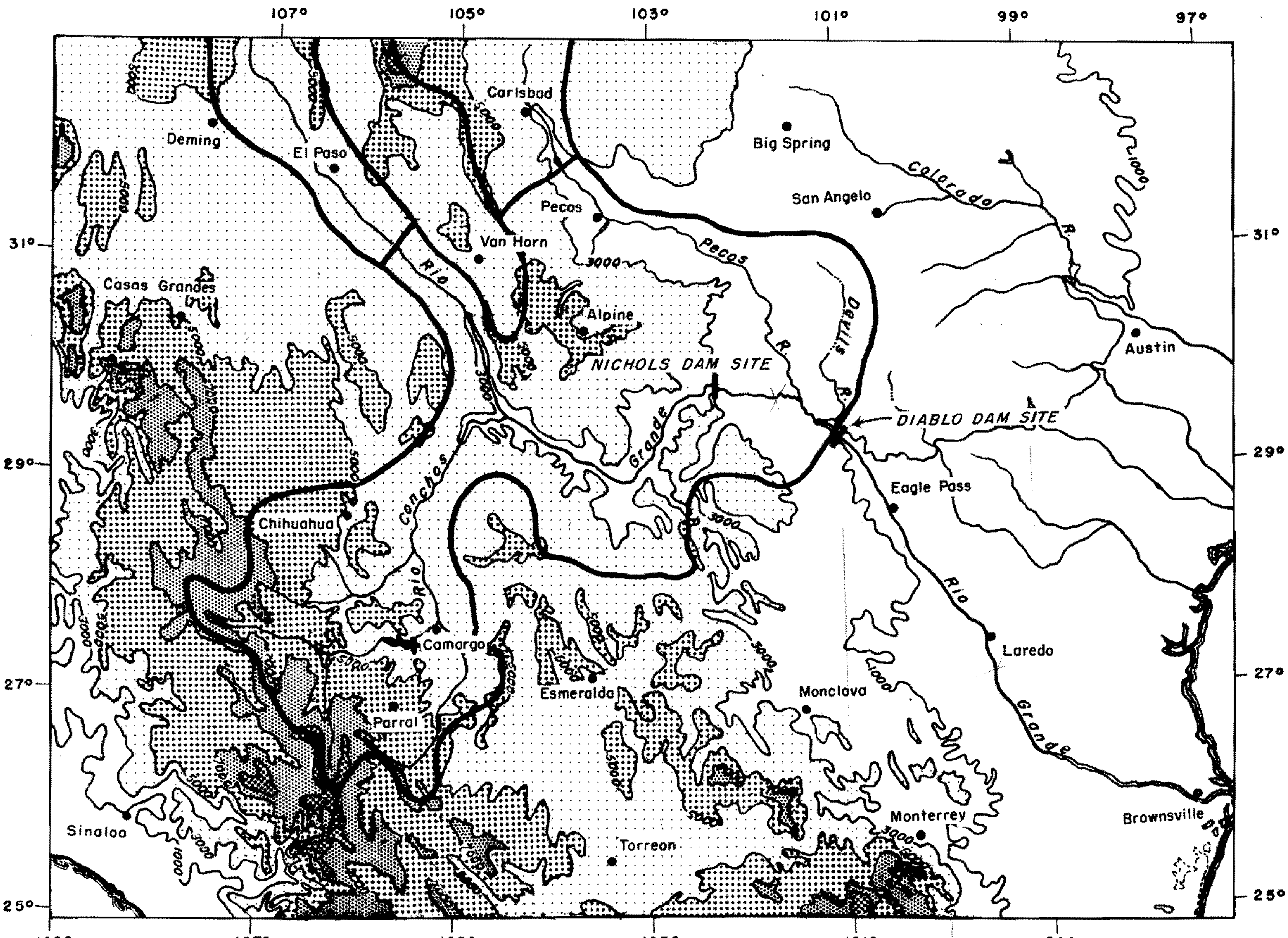



Fig. I. RIO GRANDE BASIN TOPOGRAPHY

File 5103

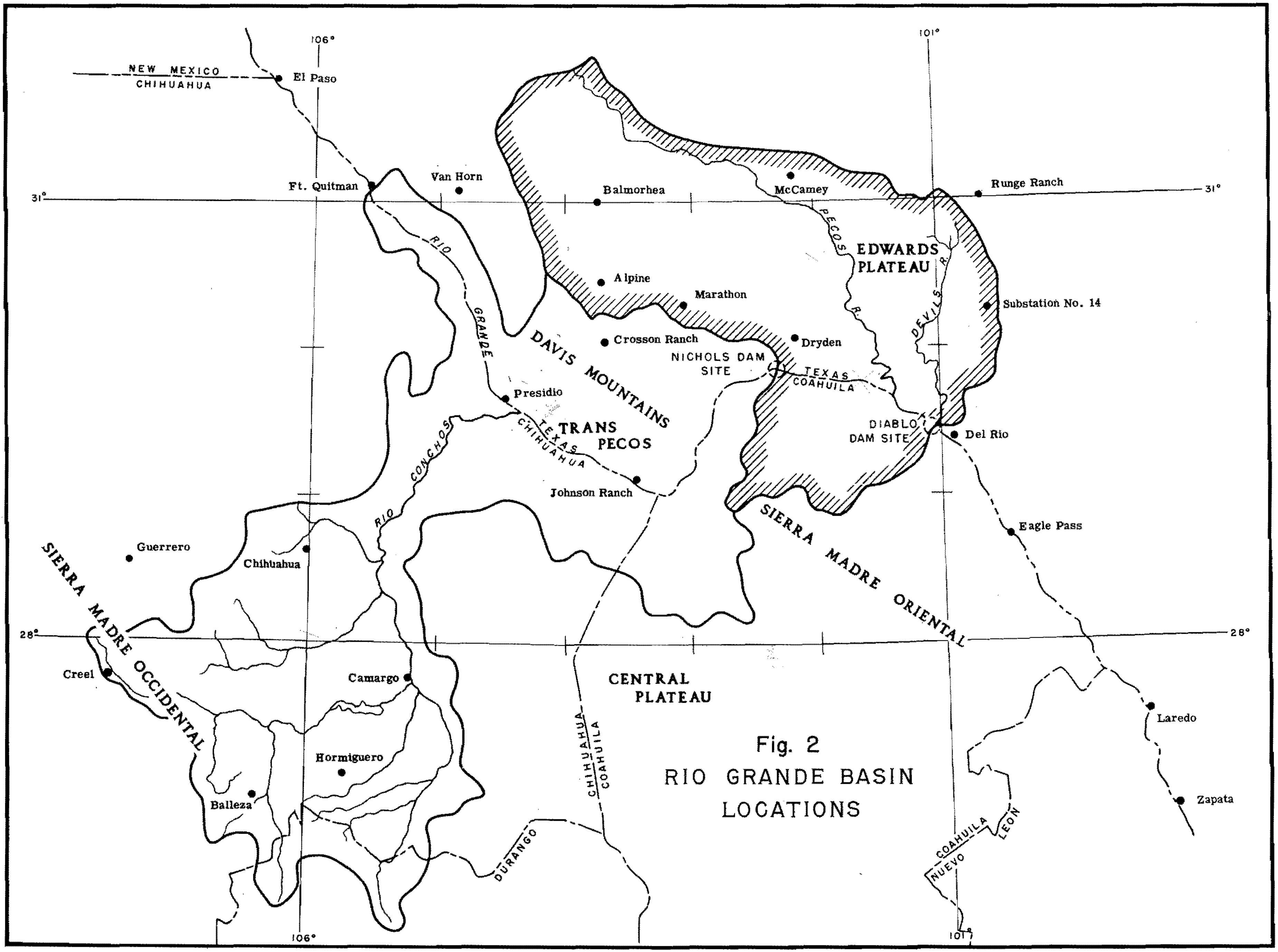



Fig. 2
RIO GRANDE BASIN
LOCATIONS

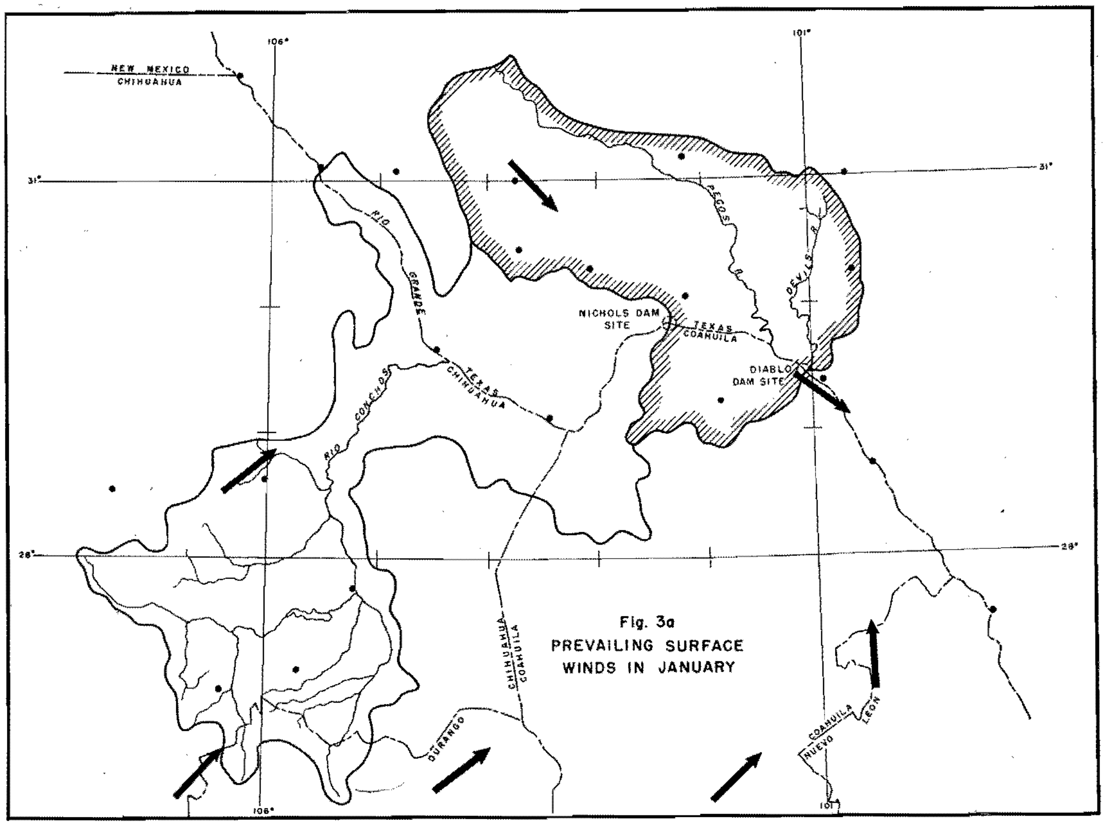



Fig. 3a
PREVAILING SURFACE WINDS IN JANUARY

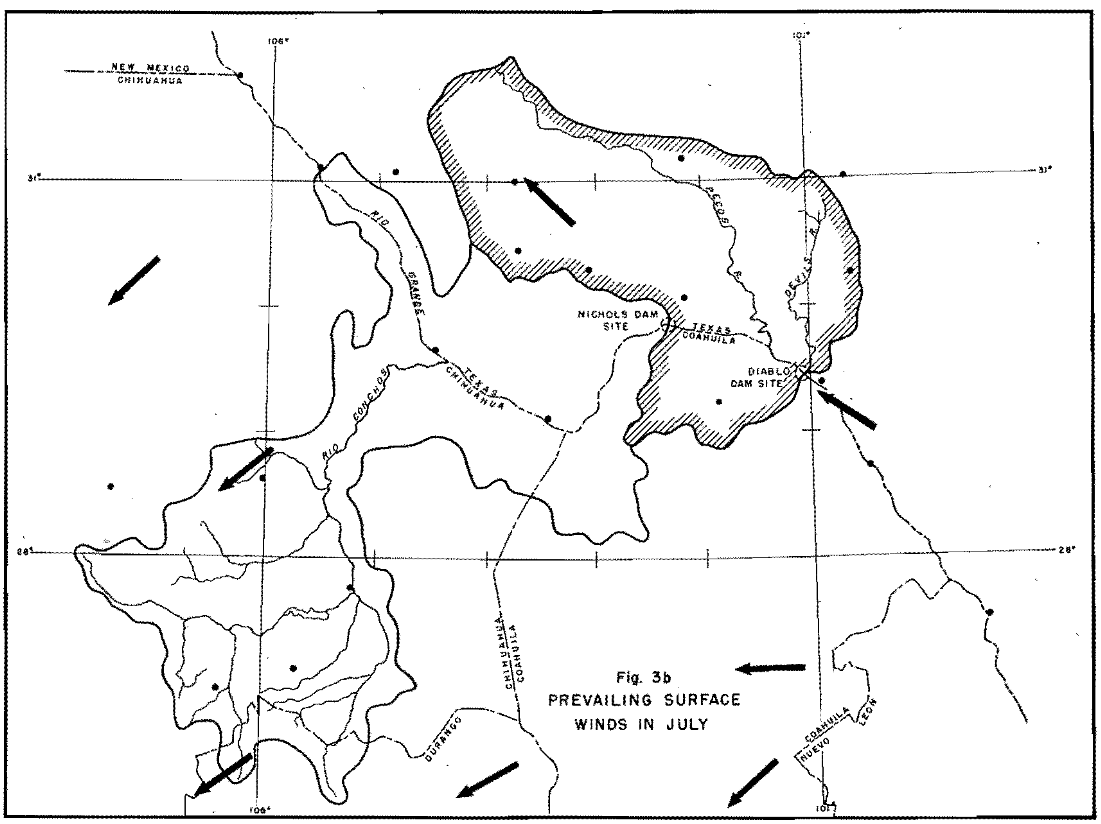



Fig. 3b
PREVAILING SURFACE WINDS IN JULY

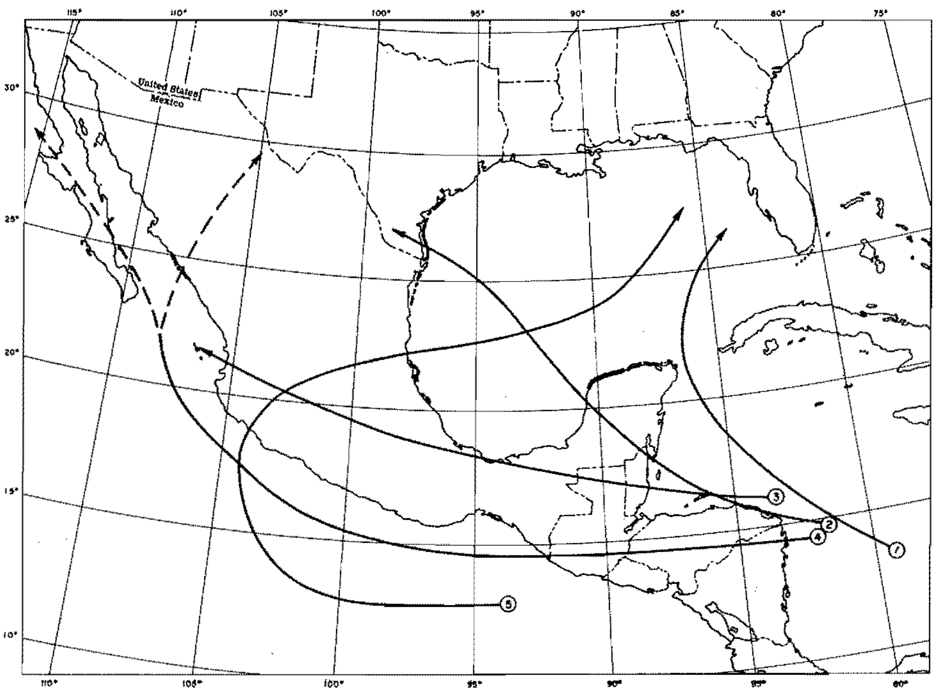



Fig. 4. TYPICAL TRACKS OF TROPICAL CYCLONES

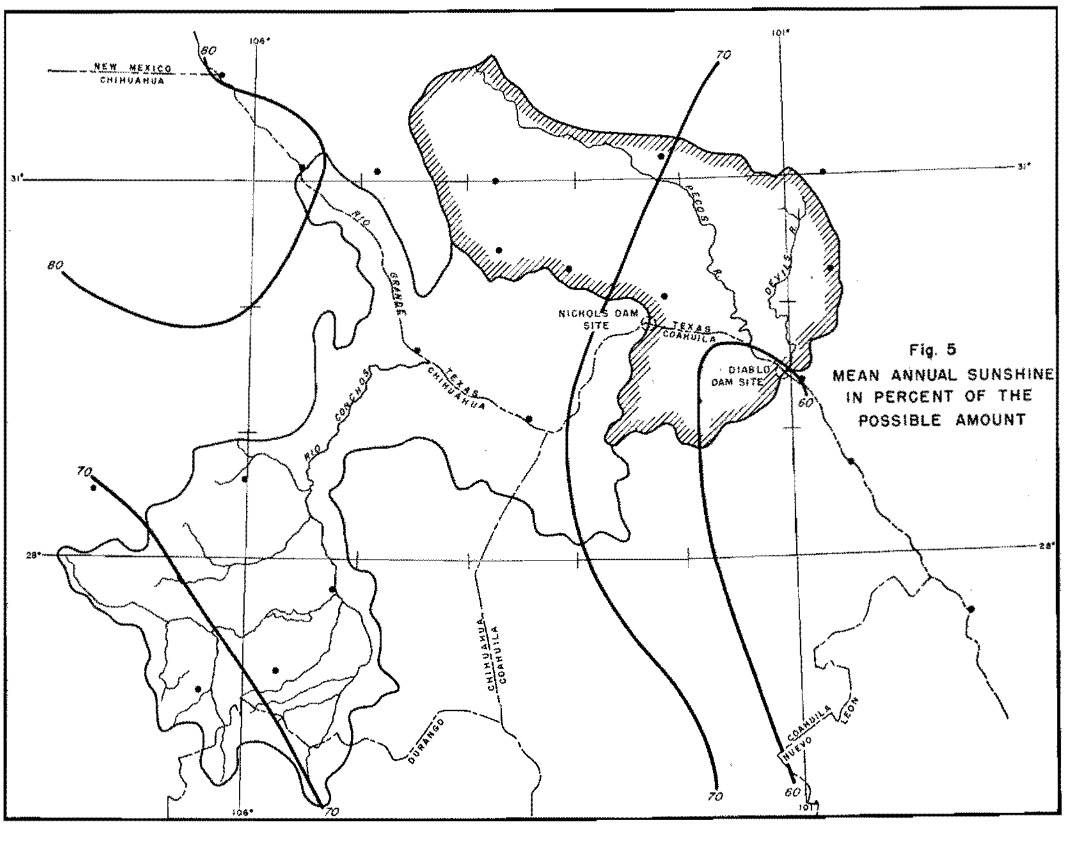



Fig. 5
MEAN ANNUAL SUNSHINE
IN PERCENT OF THE
POSSIBLE AMOUNT

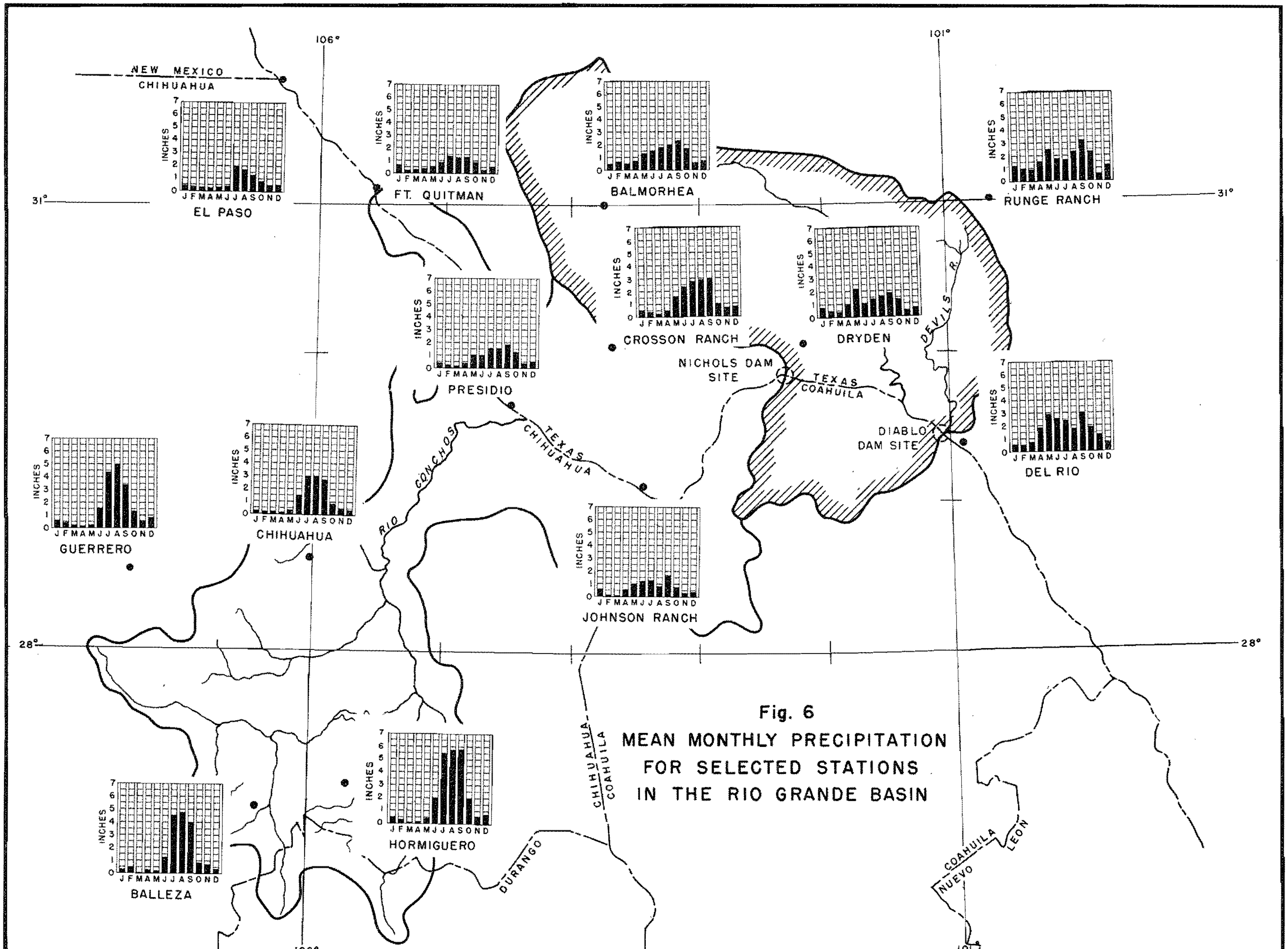



Fig. 6

MEAN MONTHLY PRECIPITATION FOR SELECTED STATIONS IN THE RIO GRANDE BASIN

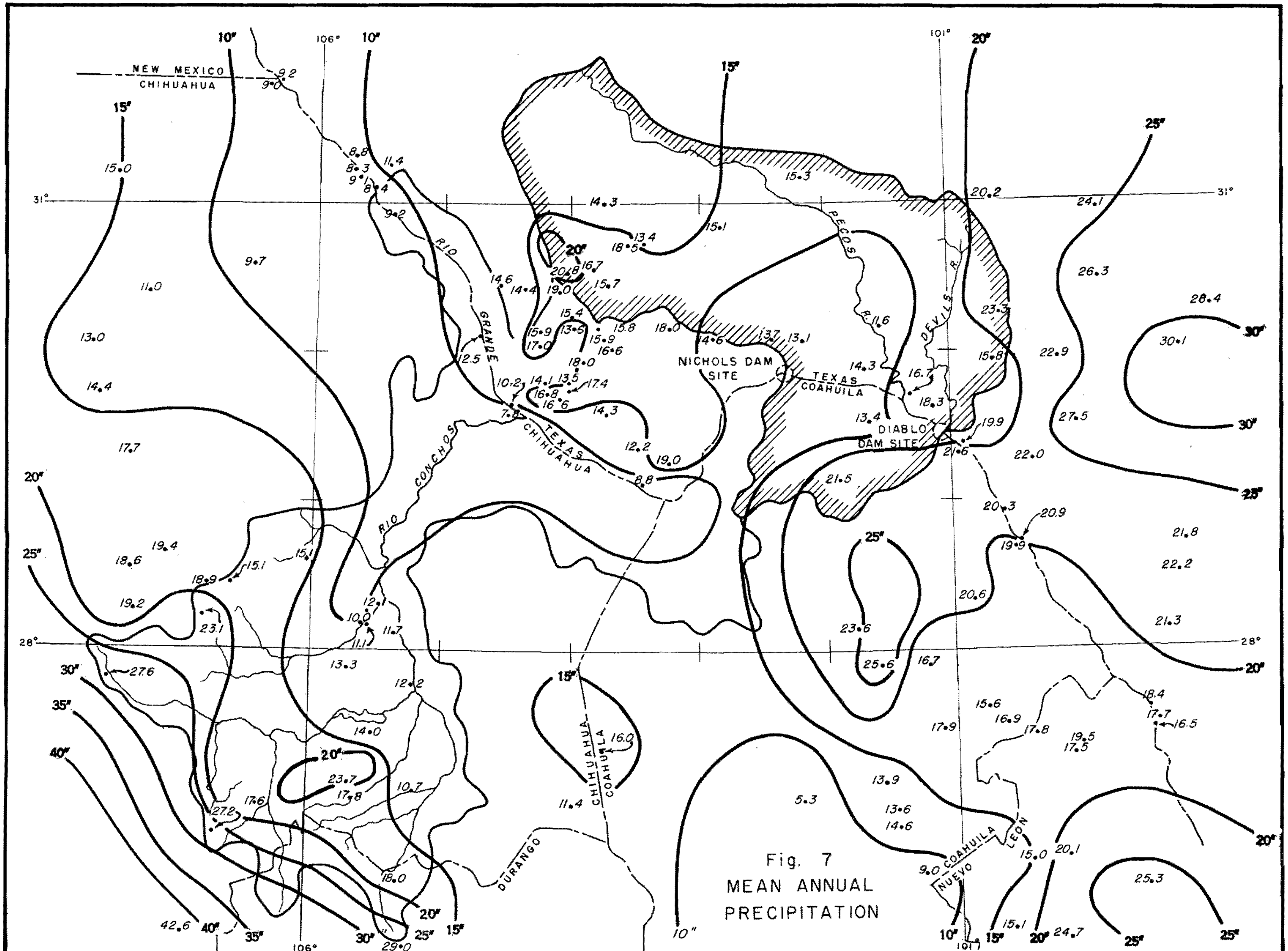



Fig. 7
MEAN ANNUAL PRECIPITATION

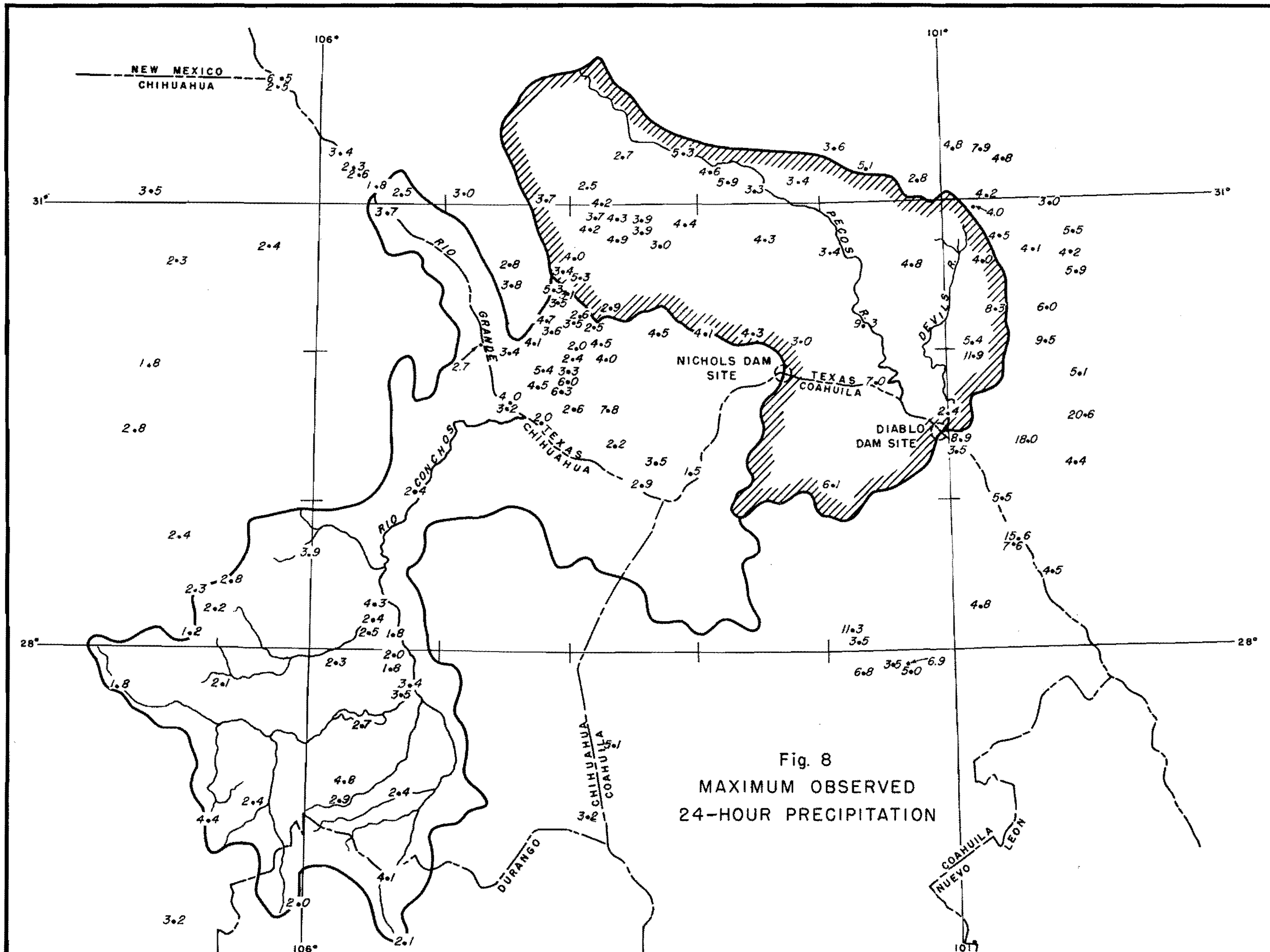
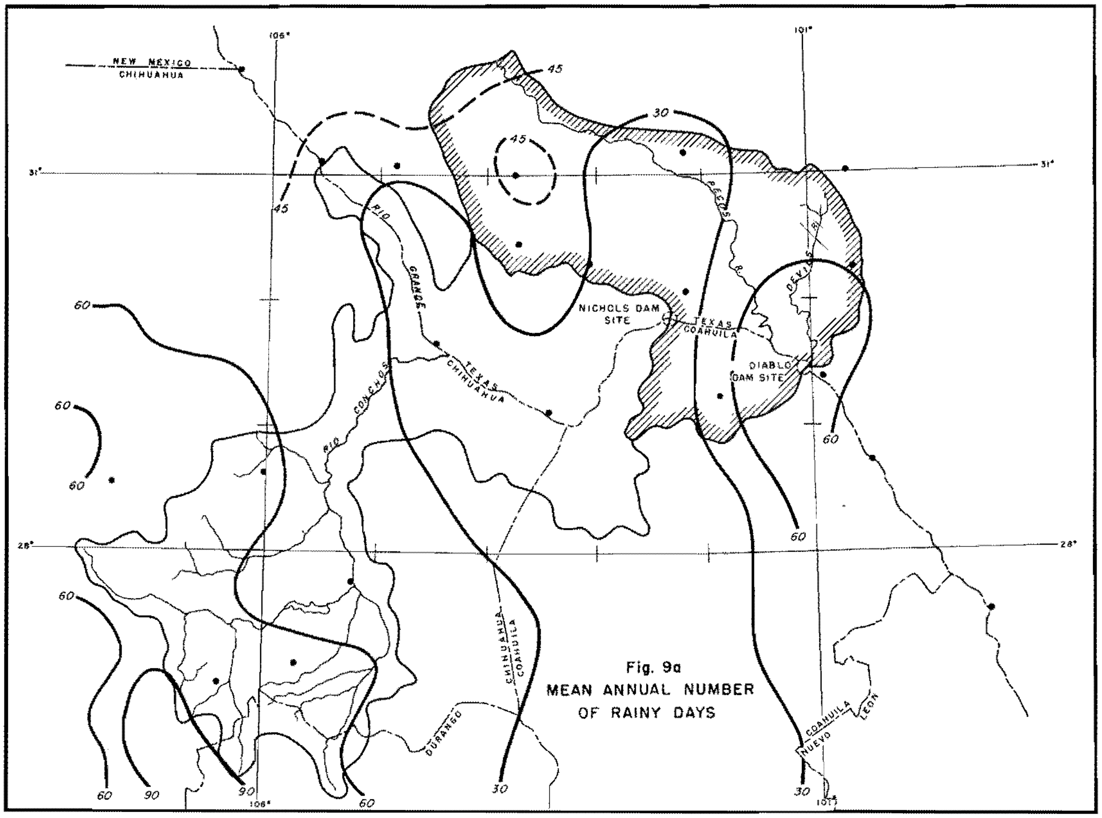
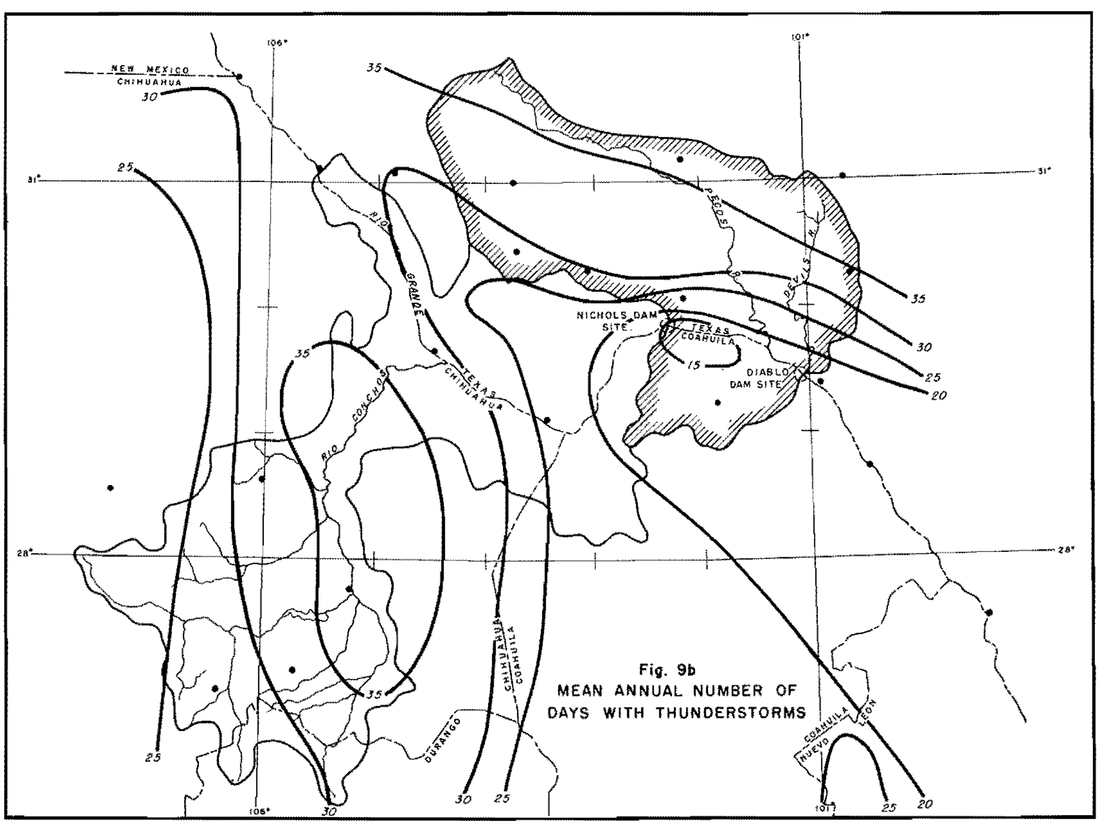



Fig. 8
MAXIMUM OBSERVED
24-HOUR PRECIPITATION


NEW MEXICO
CHIHUAHUA
NICHOLS DAM SITE
TEXAS
COAHUILA
DIABLO DAM SITE
RIO GRANDE
RIO CONCHOS
PECOS R.
DEVILS R.
DURANGO
NUEVO LEON
Fig. 9a
MEAN ANNUAL NUMBER
OF RAINY DAYS


NEW MEXICO
CHIHUAHUA
NICHOLS DAM SITE
TEXAS
COAHUILA
DIABLO DAM SITE
RIO GRANDE
RIO CONCHOS
PECOS R.
DEVILS R.
DURANGO
NUEVO LEON
Fig. 9b
MEAN ANNUAL NUMBER OF
DAYS WITH THUNDERSTORMS

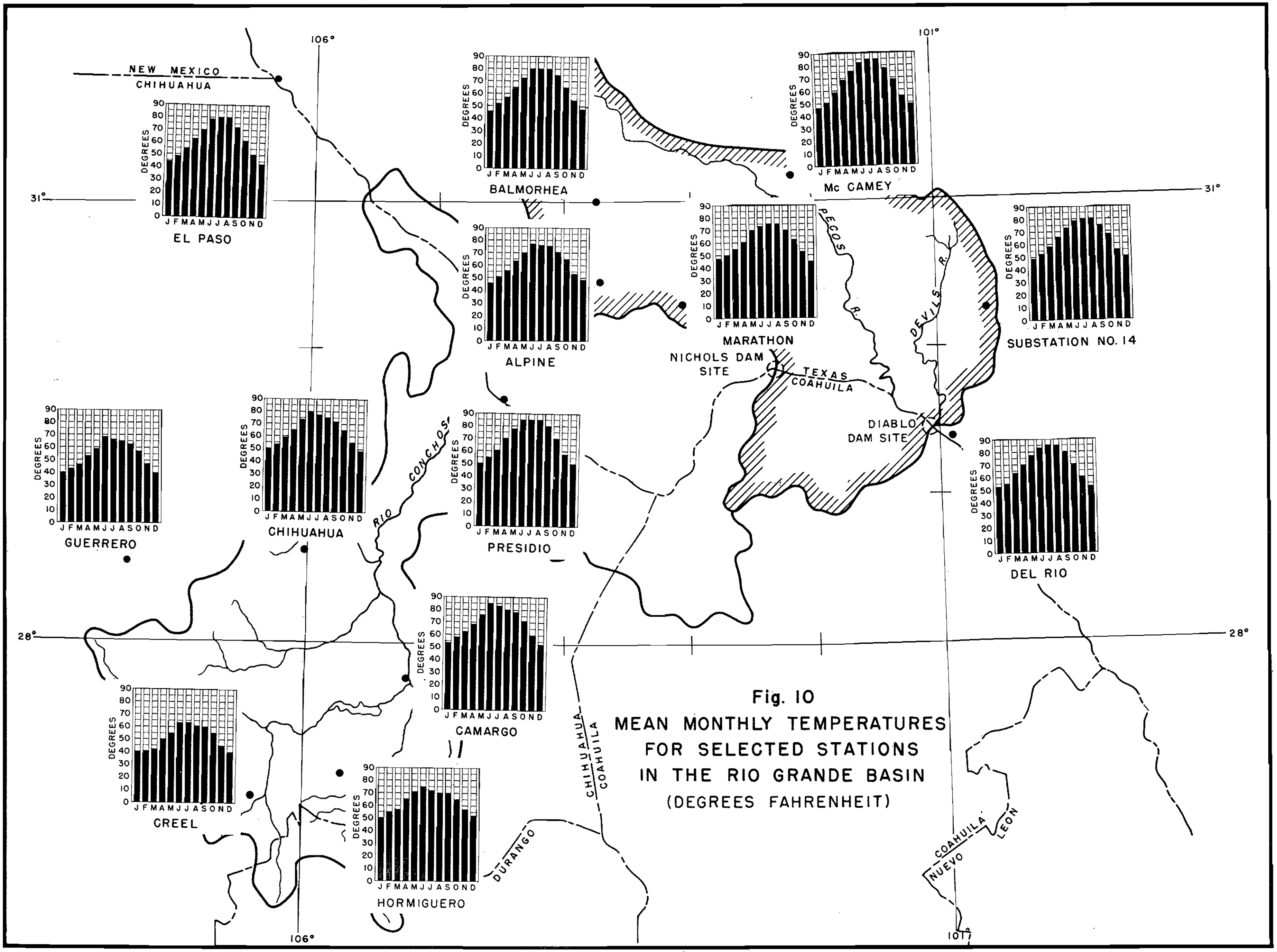



Fig. 10
MEAN MONTHLY TEMPERATURES
FOR SELECTED STATIONS
IN THE RIO GRANDE BASIN
(DEGREES FAHRENHEIT)

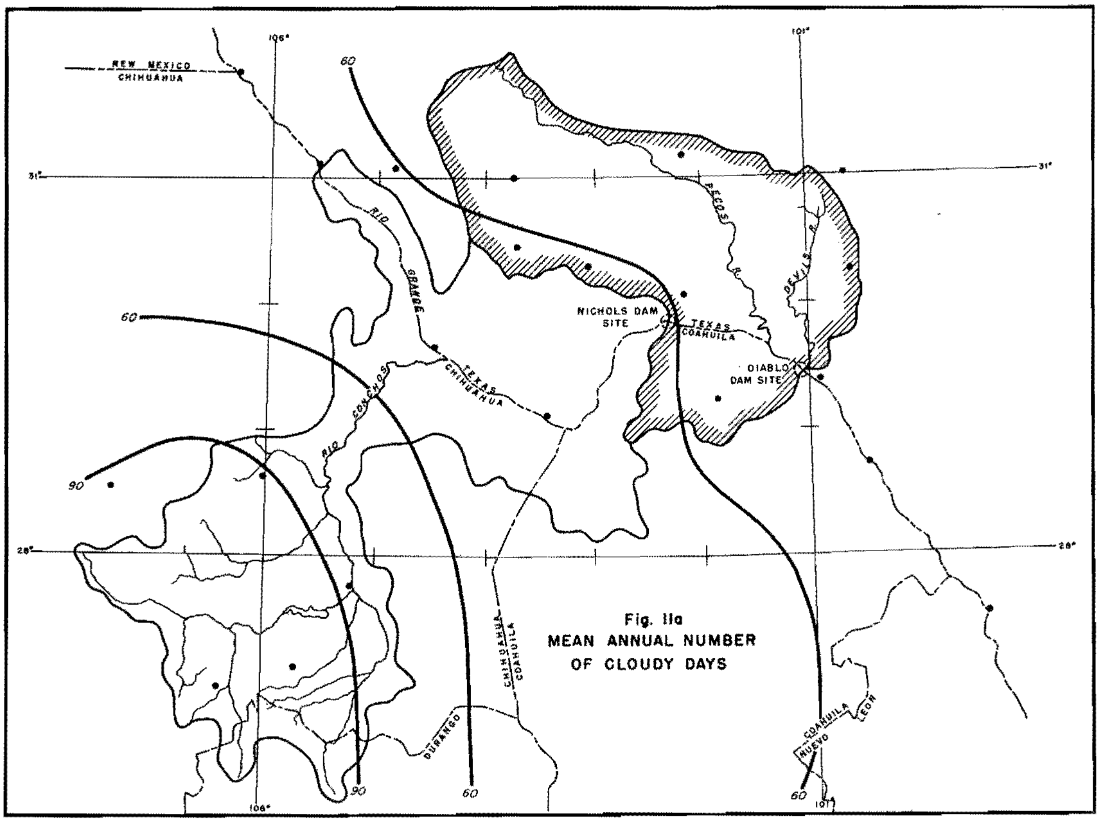



Fig. IIa
MEAN ANNUAL NUMBER
OF CLOUDY DAYS

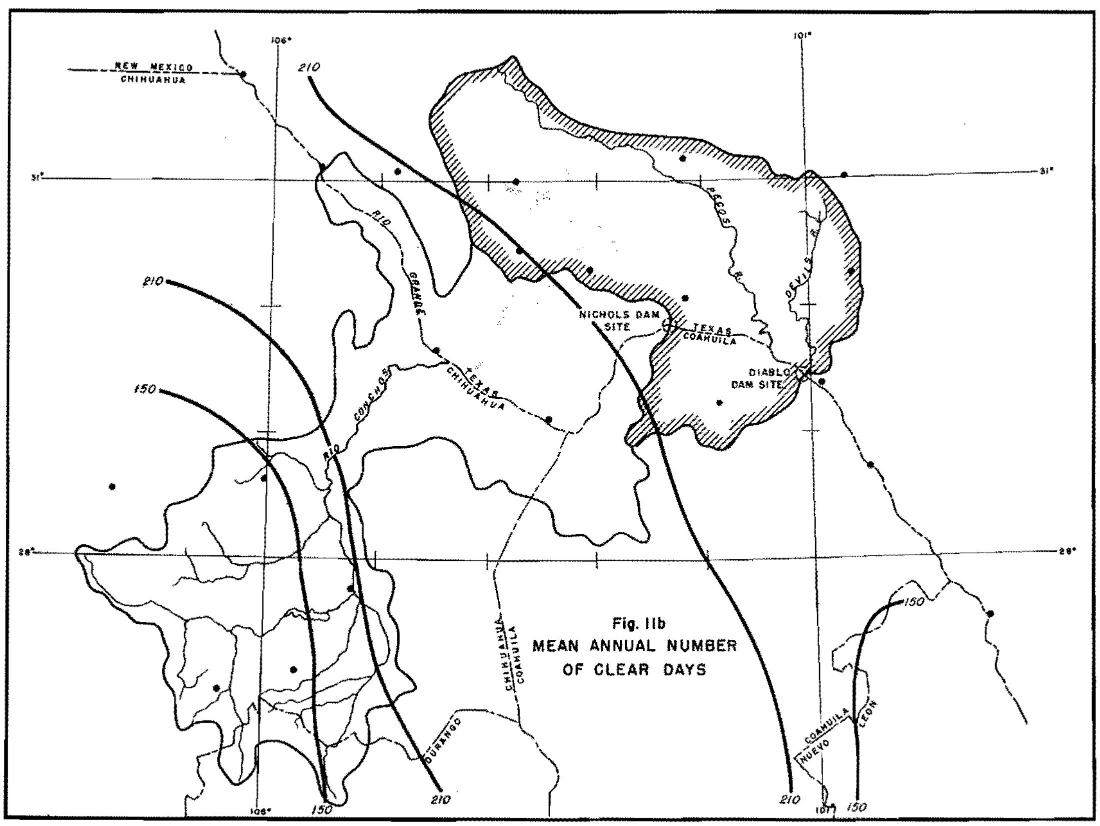
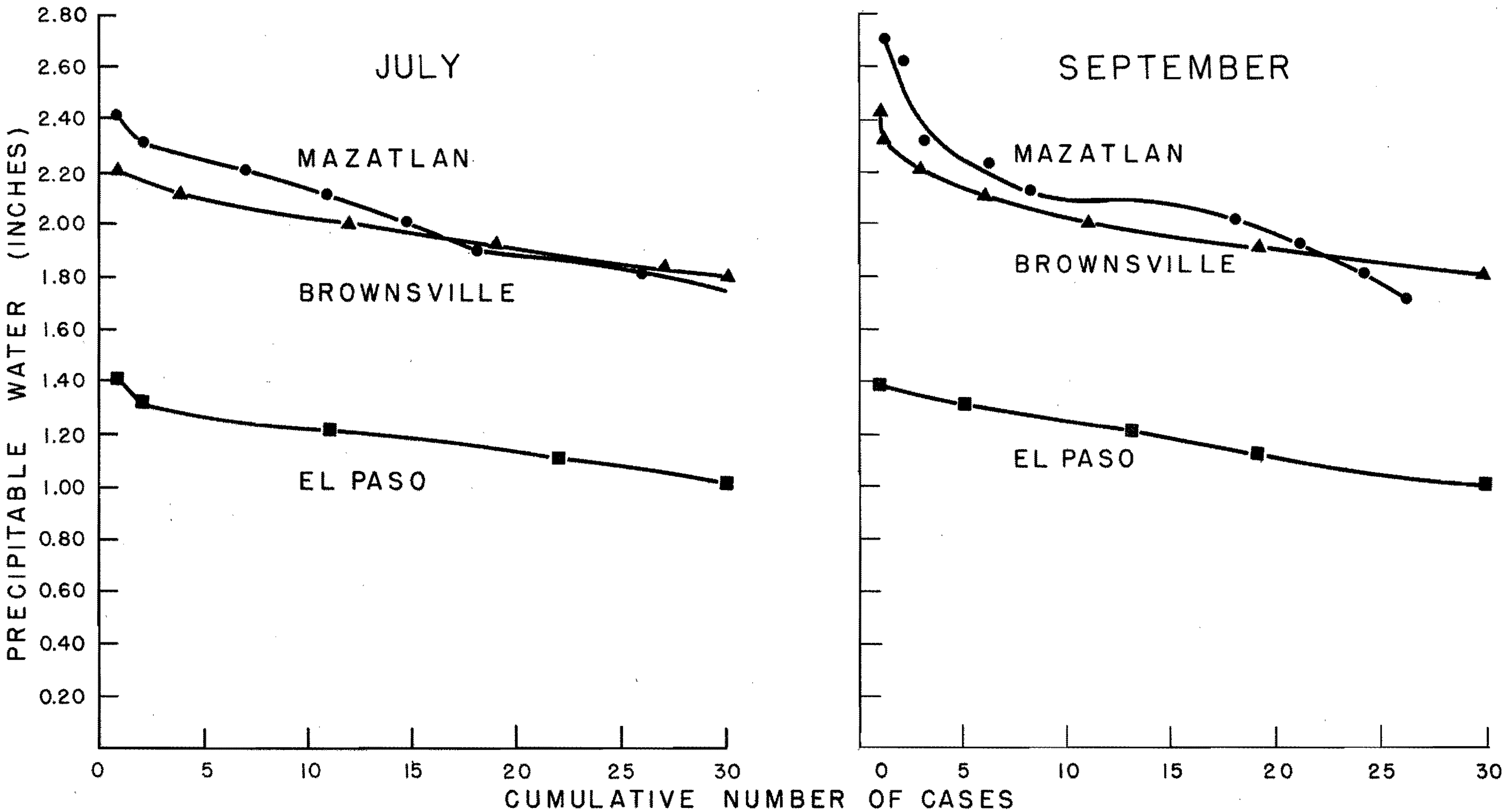



Fig. IIb
MEAN ANNUAL NUMBER
OF CLEAR DAYS

Fig. 12

# MAXIMUM OBSERVED PRECIPITABLE WATER (SURFACE TO 5 KM.)



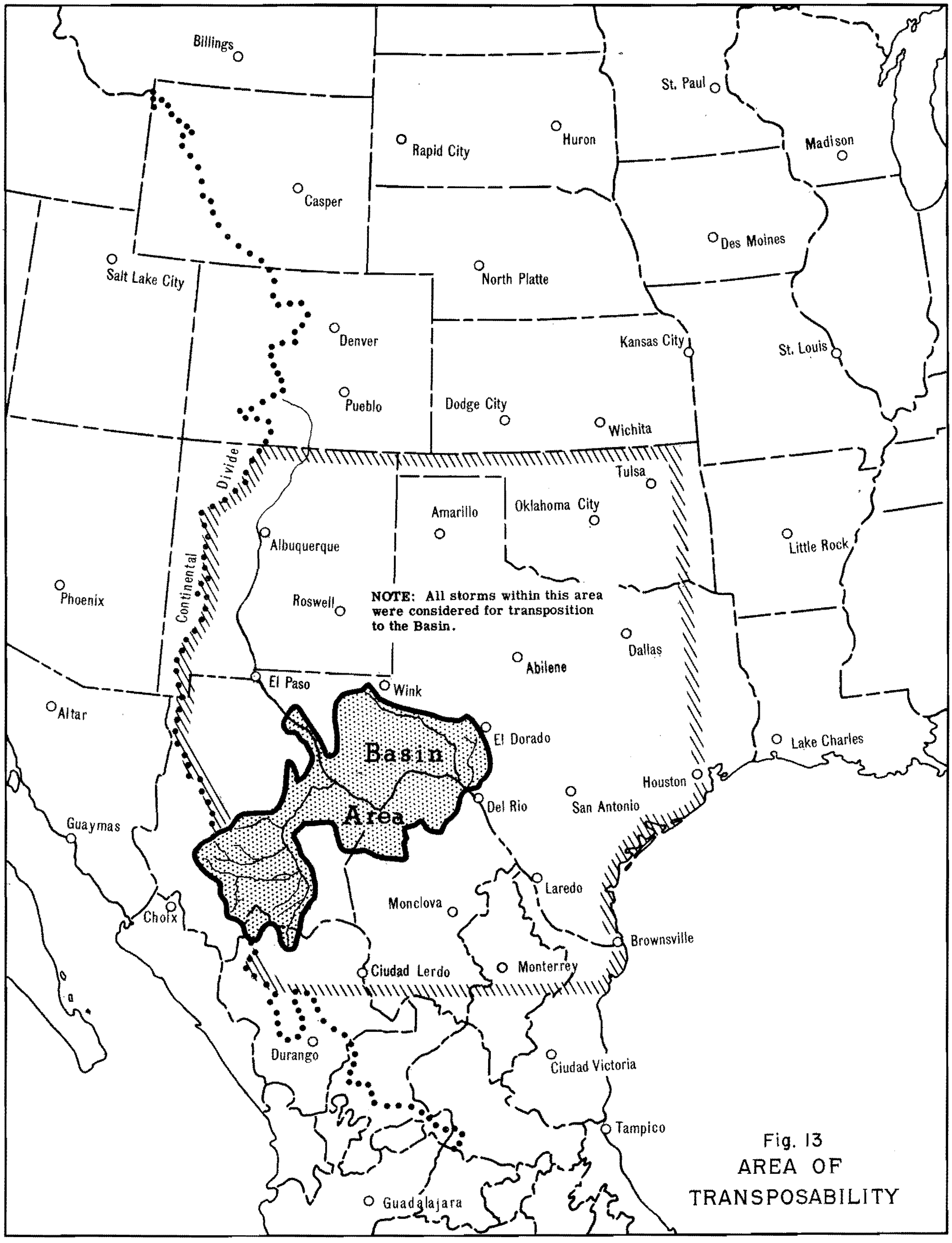



Fig. 13
AREA OF
TRANSPOSABILITY

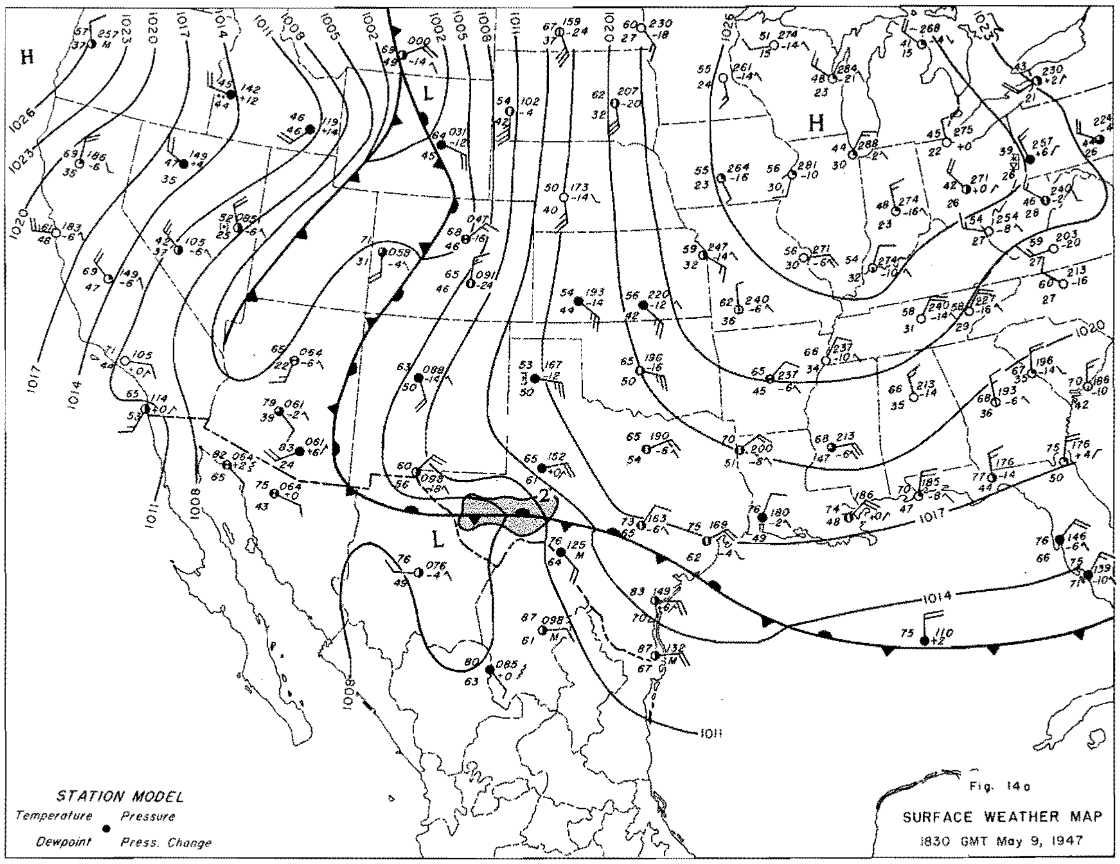



Fig. 14a
SURFACE WEATHER MAP
1830 GMT May 9, 1947

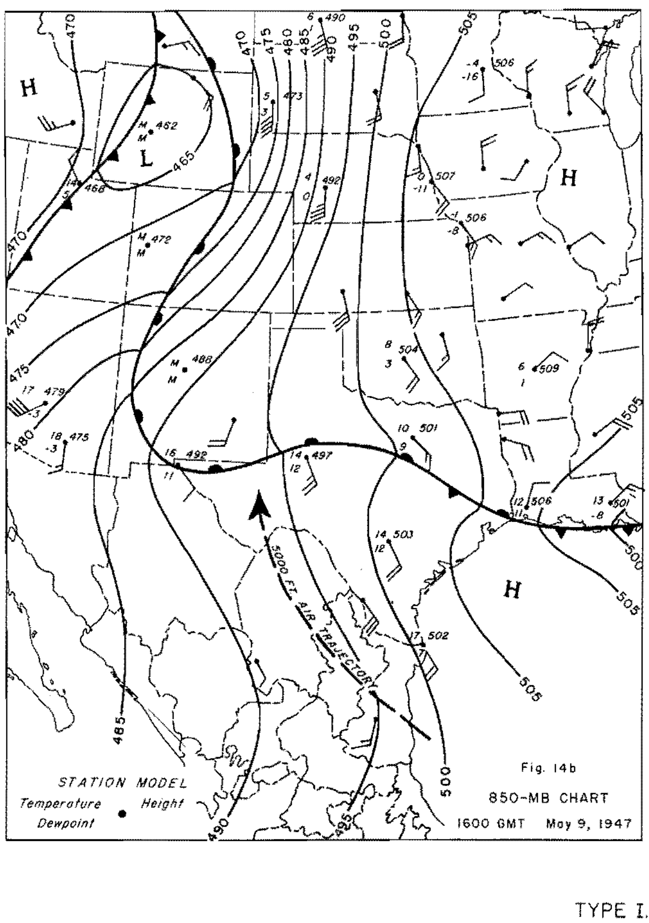



Fig. 14b
850-MB CHART
1600 GMT May 9, 1947

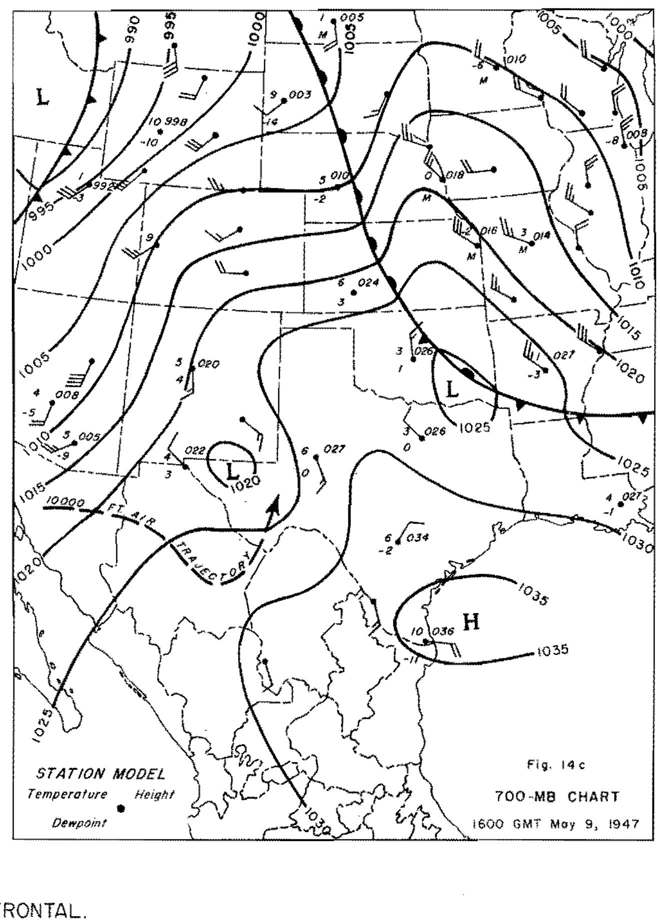
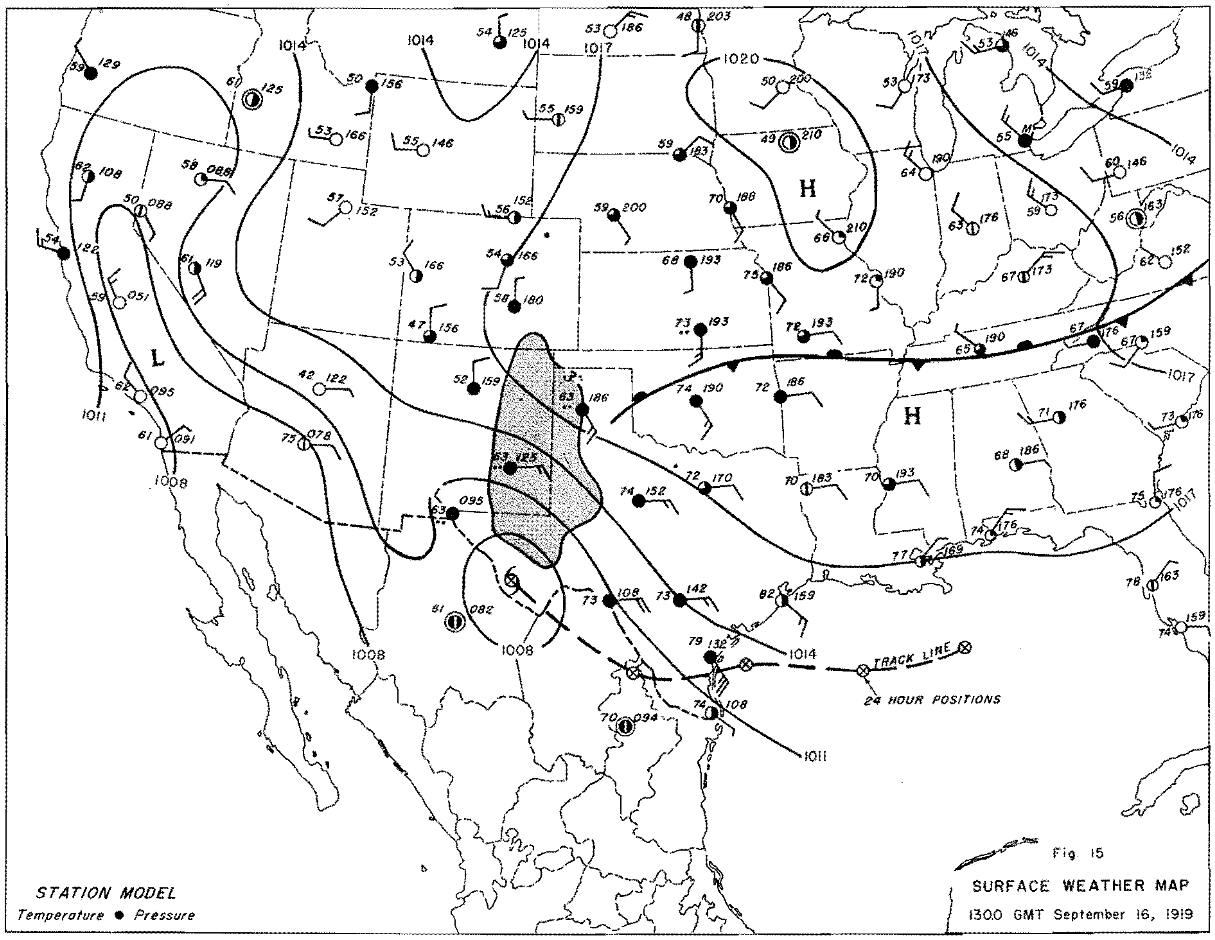
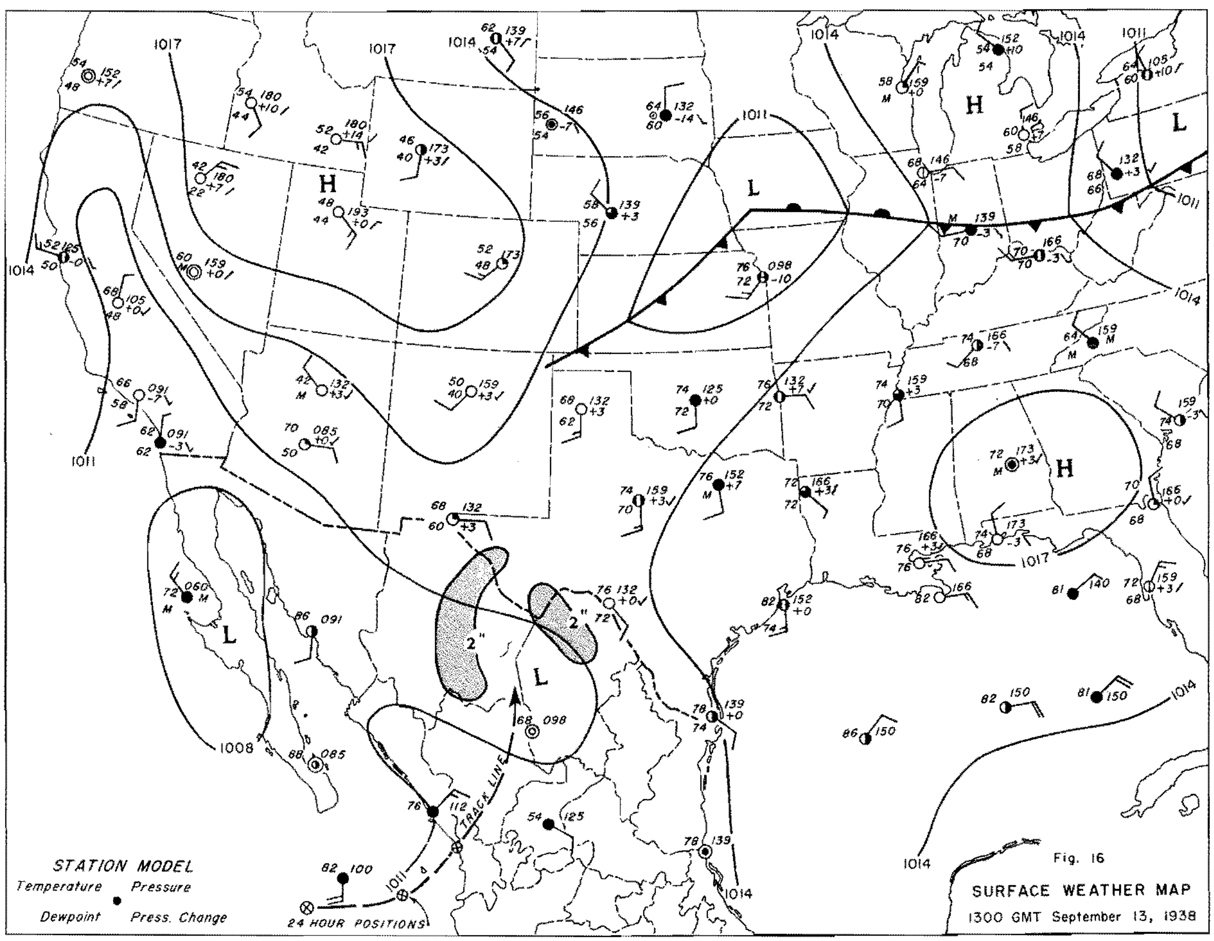


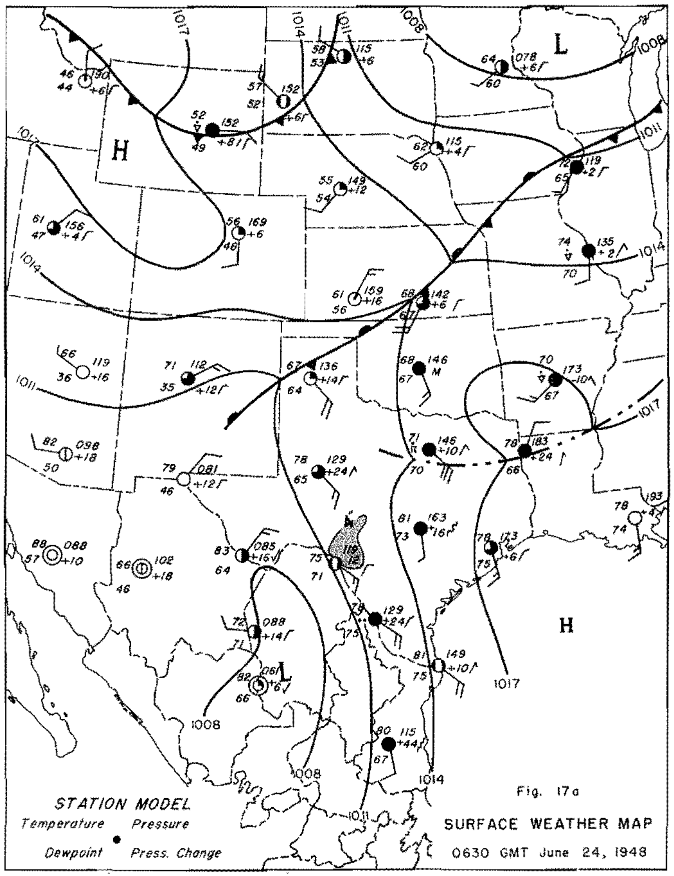

Fig. 14c
700-MB CHART
1600 GMT May 9, 1947

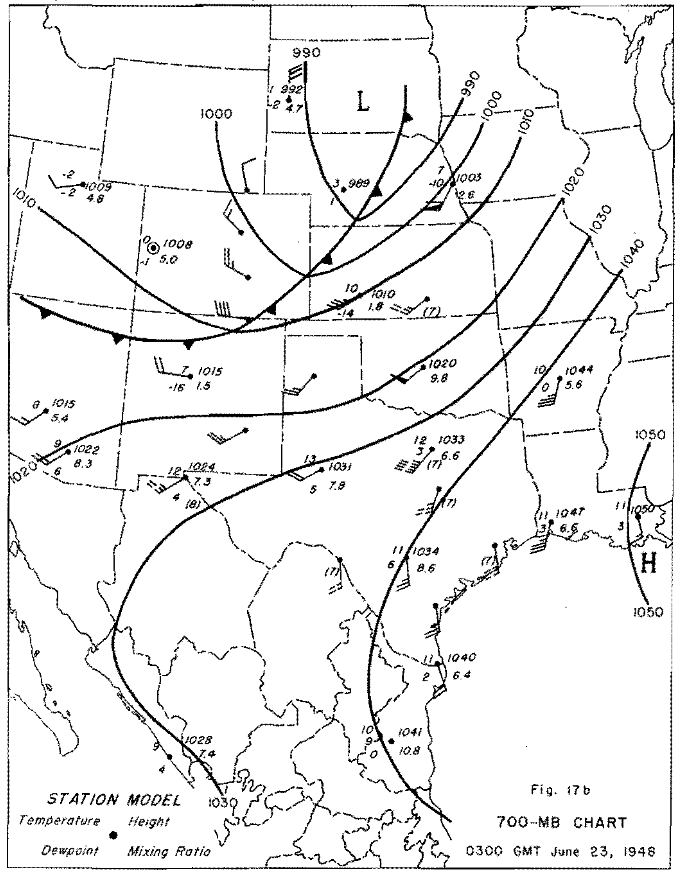
TYPE I. FRONTAL.

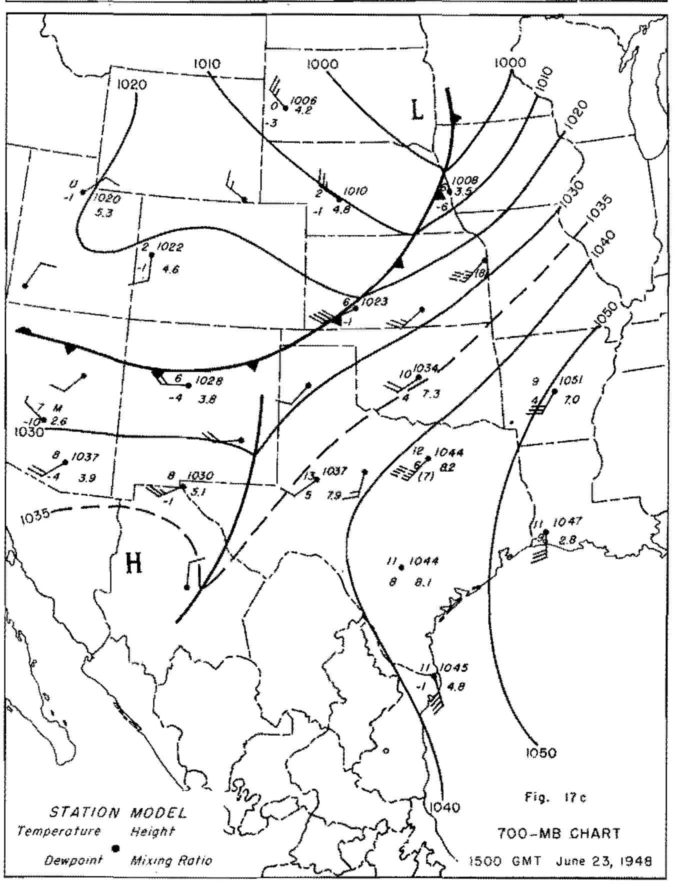


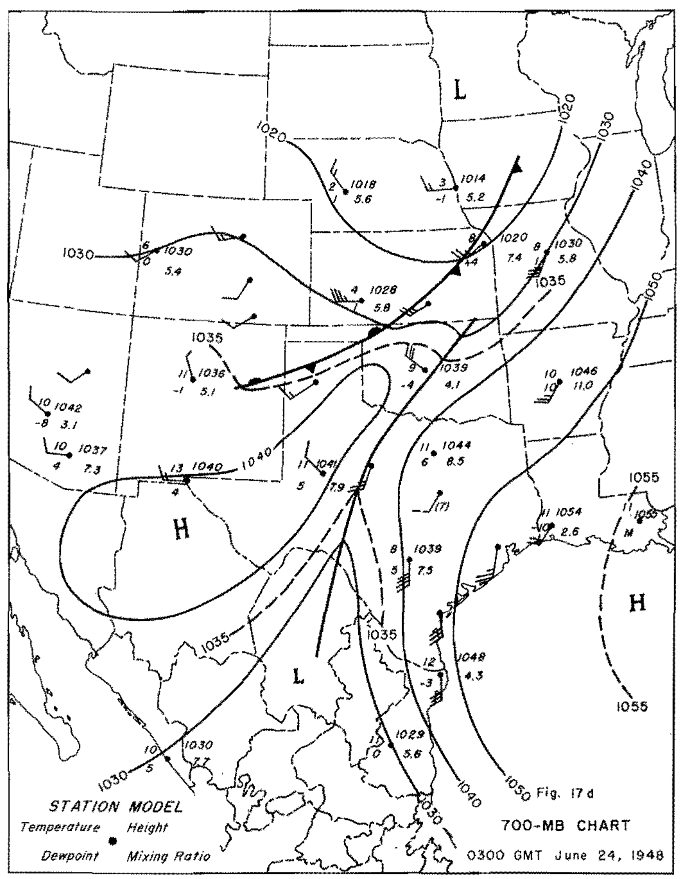




TYPE II. TROPICAL.

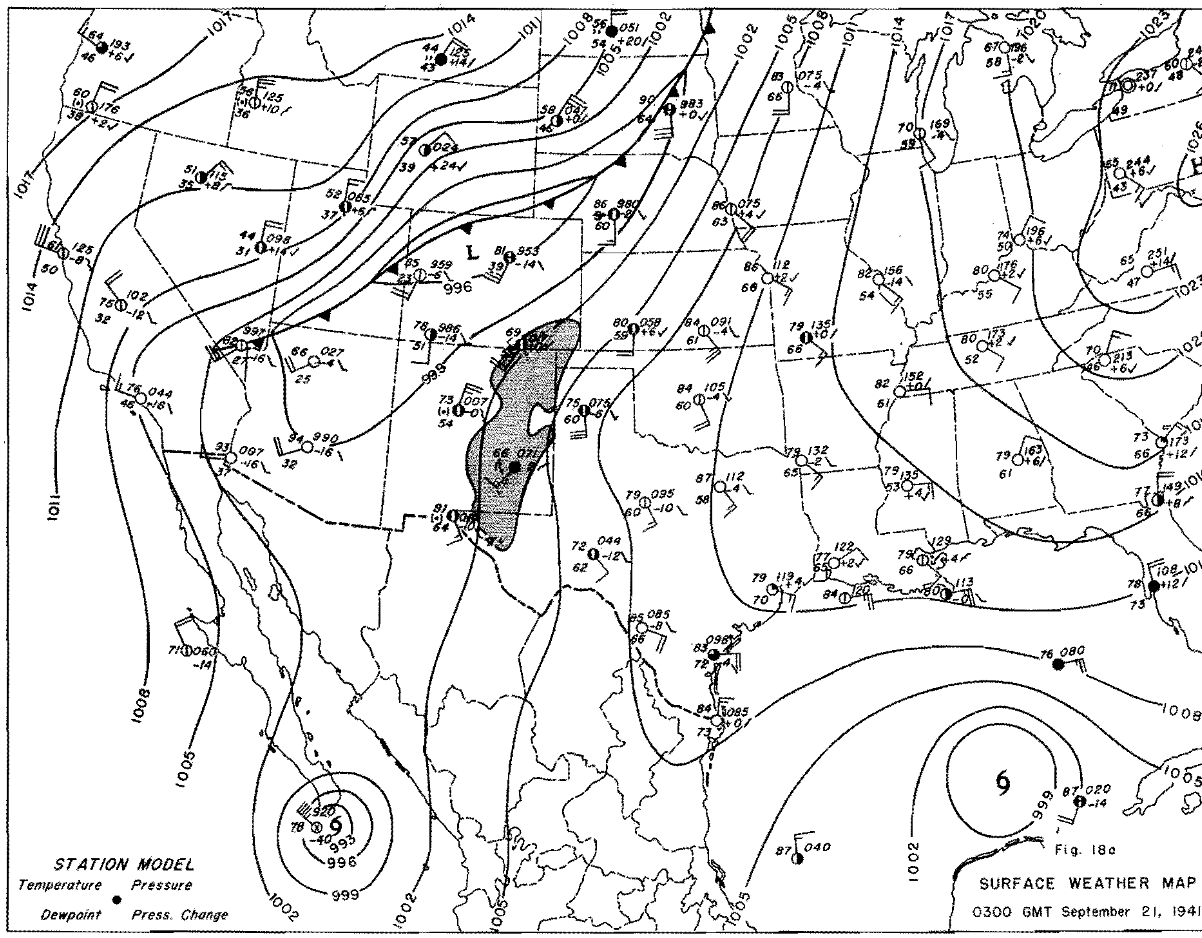


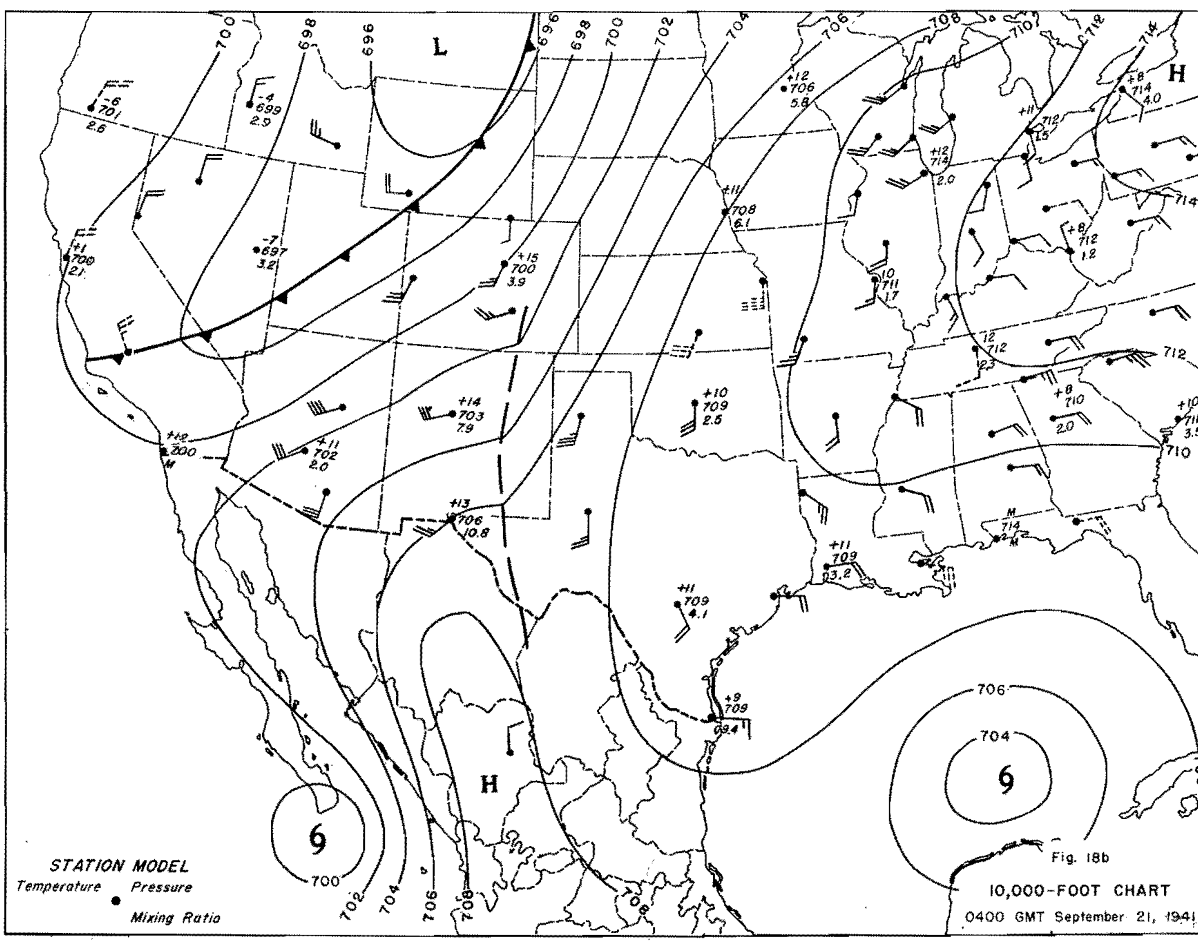




TYPE III. INDUCED TROUGH ALOFT.




TYPE IV. STAGNANT, COLD, PLATEAU TROUGH ALOFT.

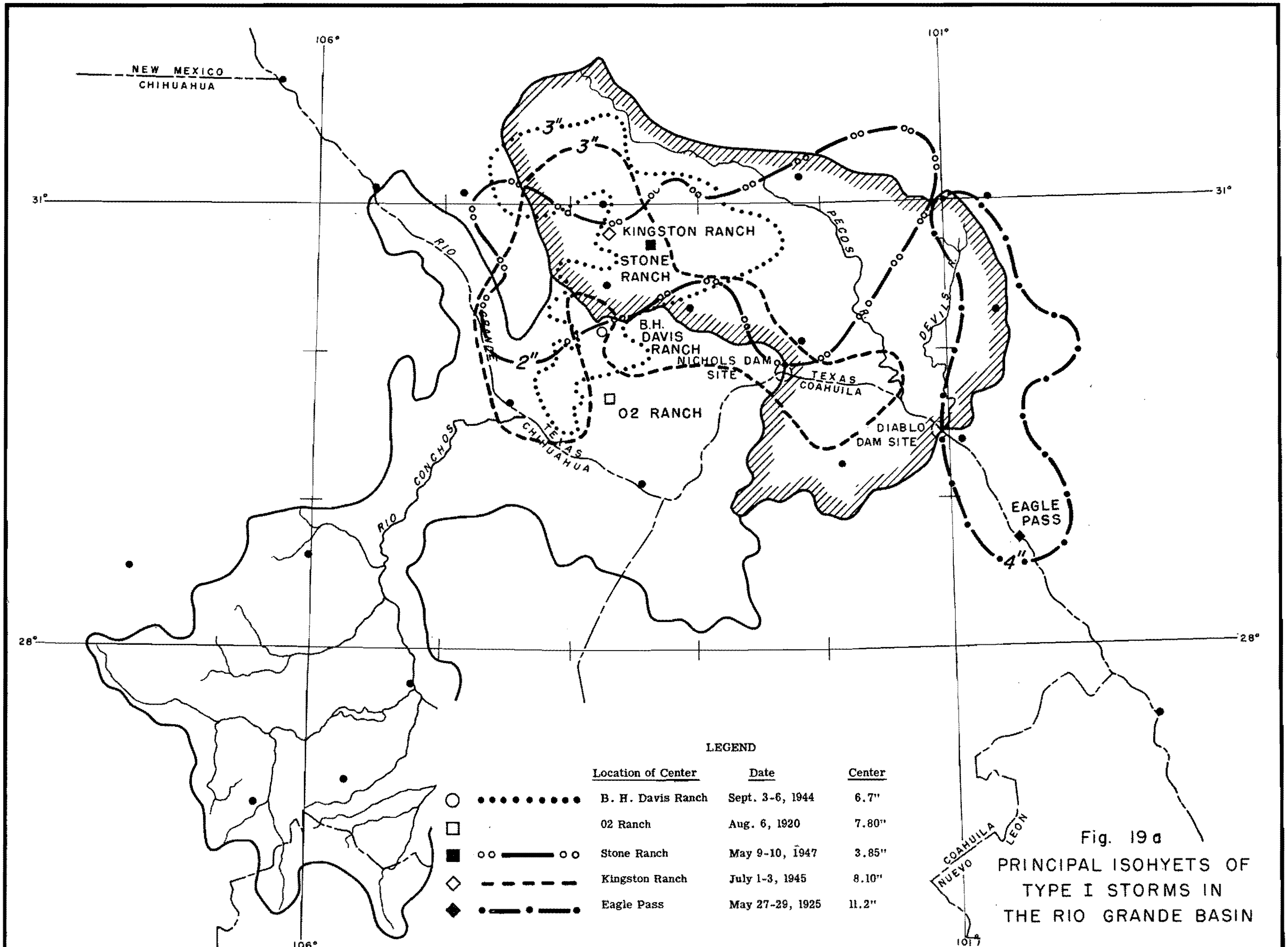



Fig. 19a
PRINCIPAL ISOHYETS OF TYPE I STORMS IN THE RIO GRANDE BASIN

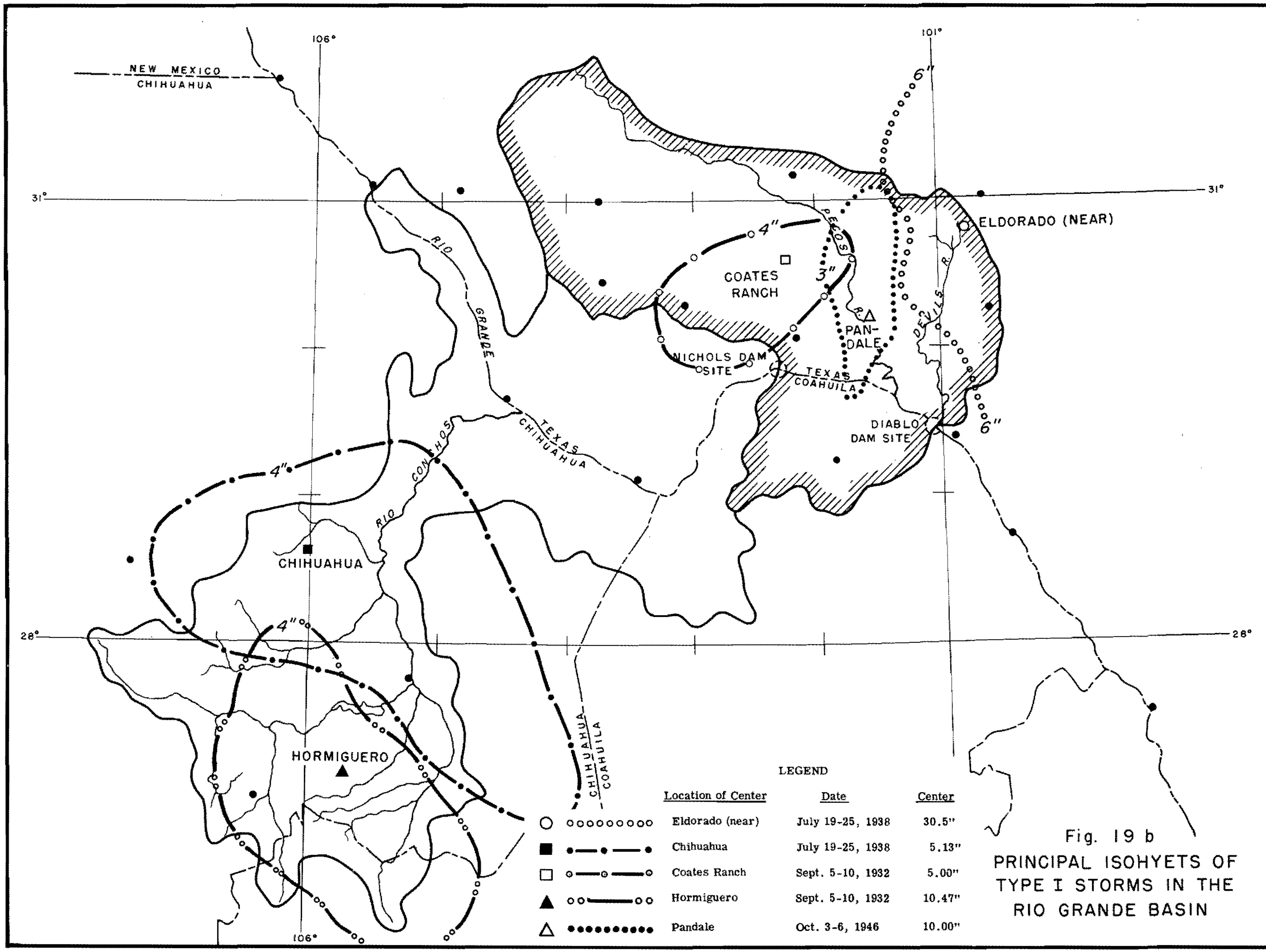



Fig. 19 b
PRINCIPAL ISOHYETS OF TYPE I STORMS IN THE RIO GRANDE BASIN

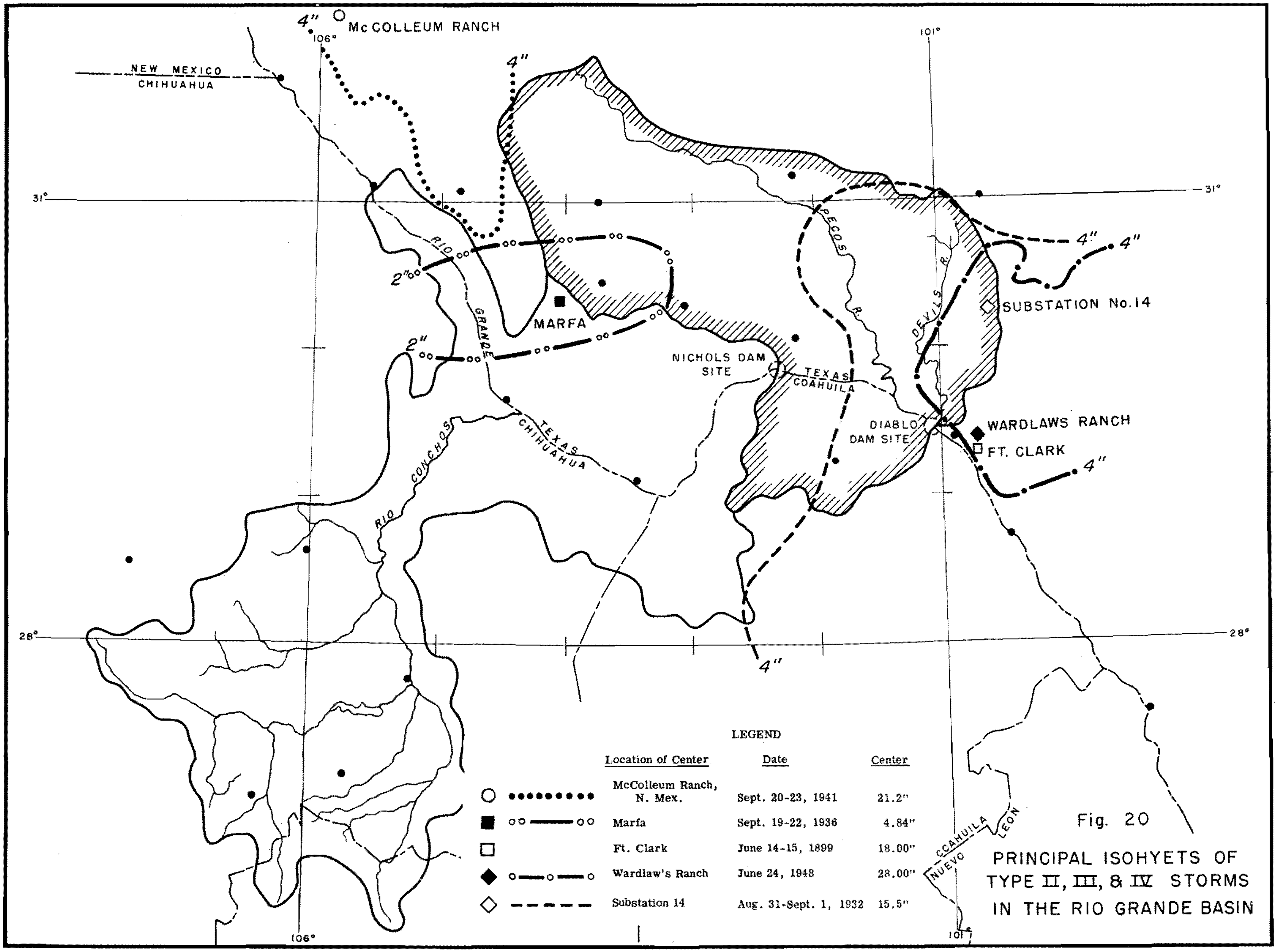



Fig. 20

PRINCIPAL ISOHYETS OF TYPE II, III, & IV STORMS IN THE RIO GRANDE BASIN

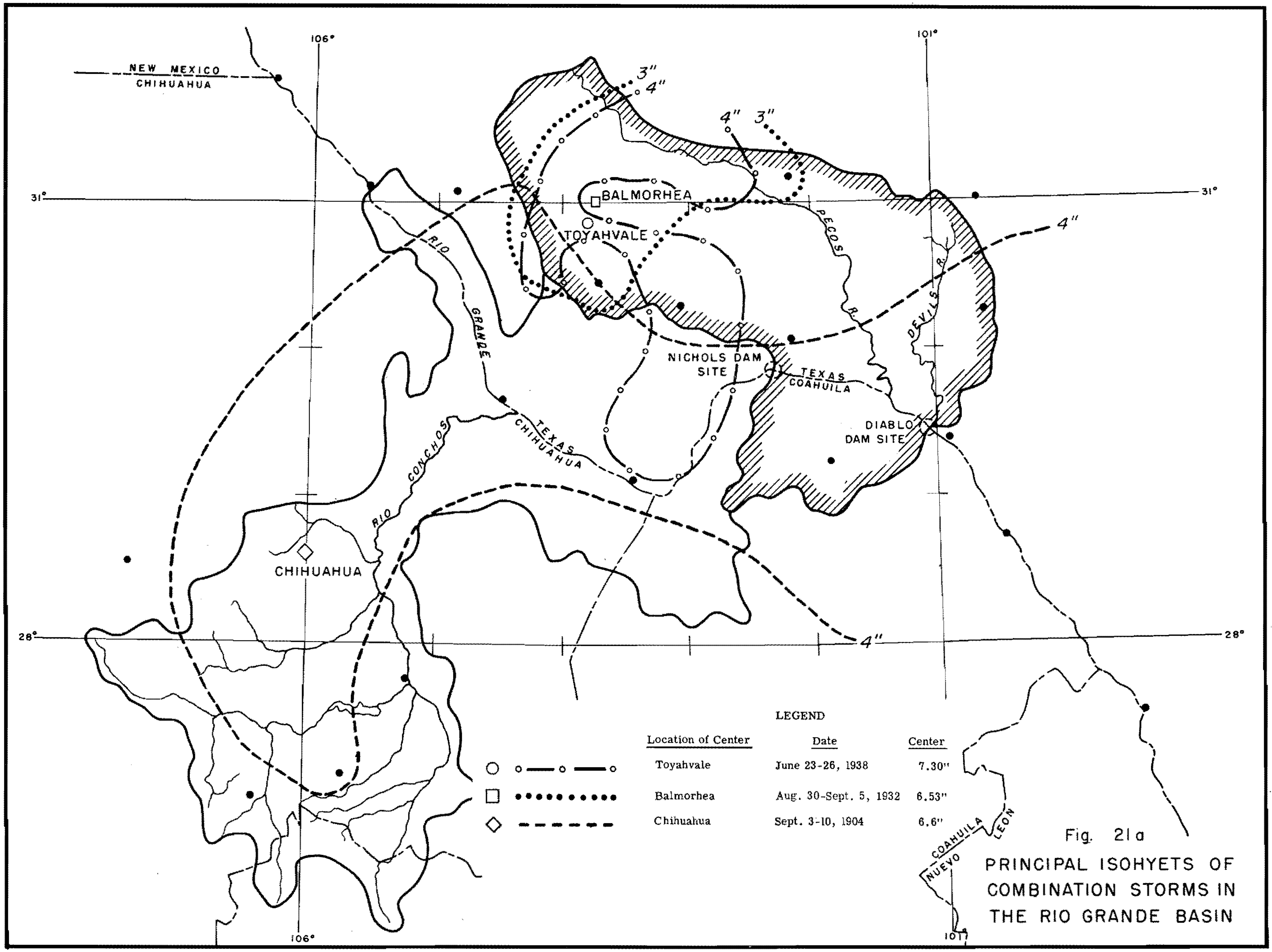



Fig. 21a
PRINCIPAL ISOHYETS OF COMBINATION STORMS IN THE RIO GRANDE BASIN

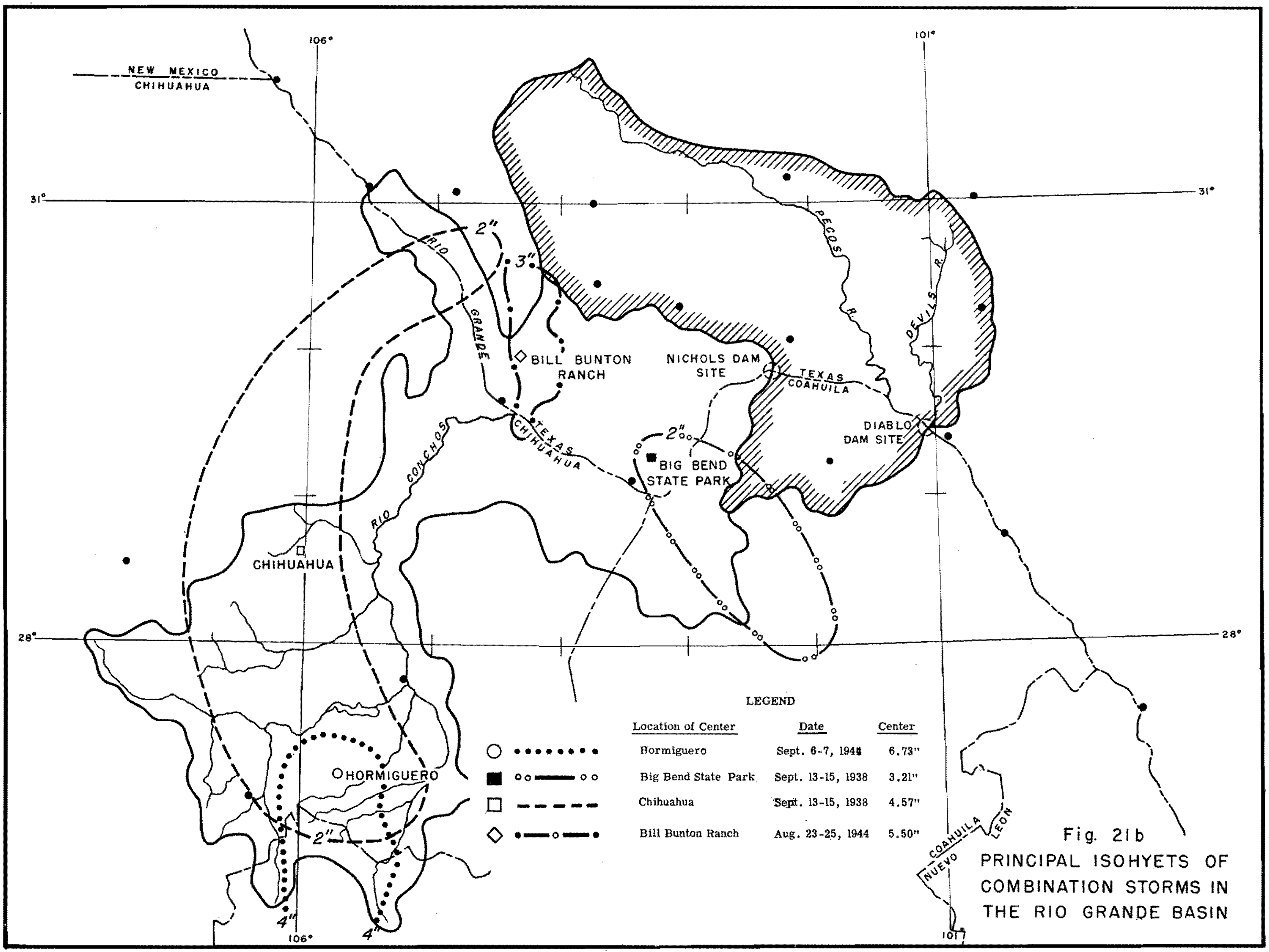



Fig. 21b
PRINCIPAL ISOHYETS OF COMBINATION STORMS IN THE RIO GRANDE BASIN

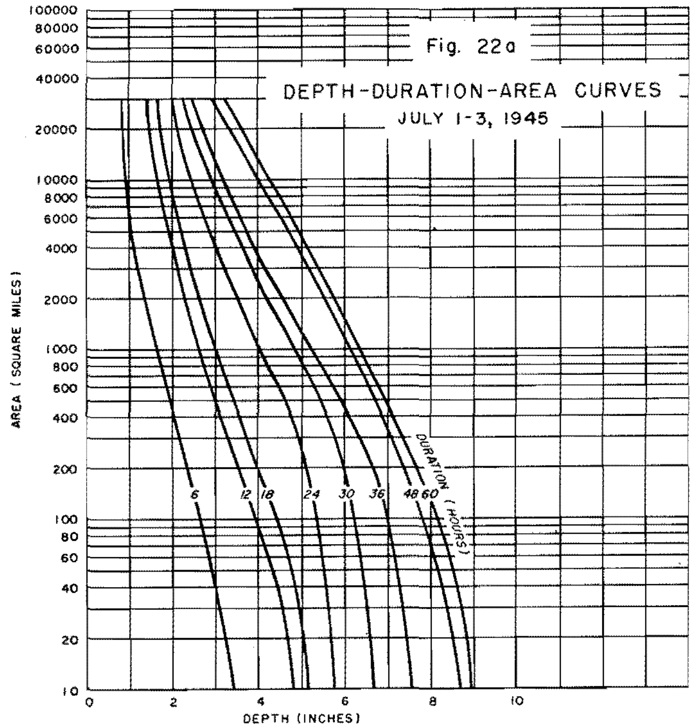
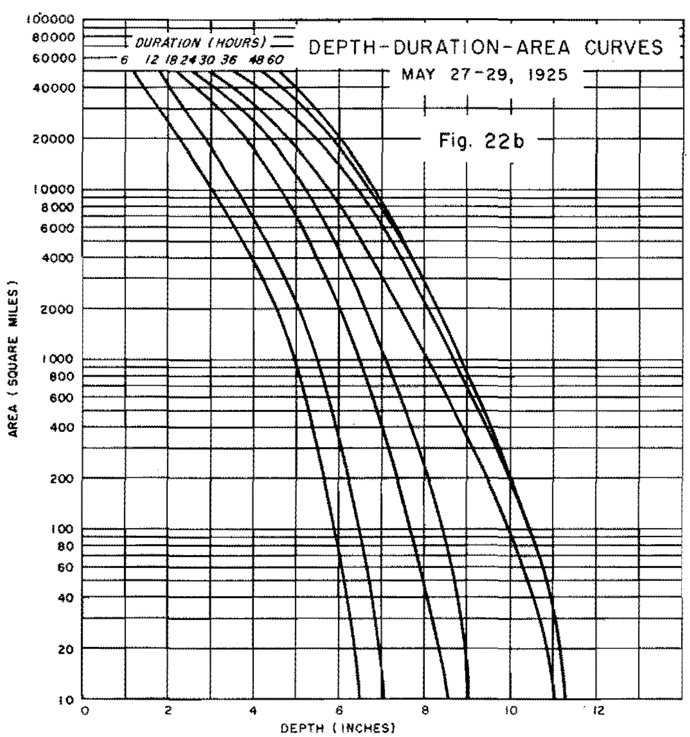


Fig. 22a
DEPTH-DURATION-AREA CURVES
JULY 1-3, 1945
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
DEPTH (INCHES)
0
2
4
6
8
10
6
12
18
24
30
36
48
60
DURATION (HOURS)


DEPTH-DURATION-AREA CURVES
MAY 27-29, 1925
Fig. 22b
DURATION (HOURS)
6
12
18
24
30
36
48
60
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
DEPTH (INCHES)
0
2
4
6
8
10
12

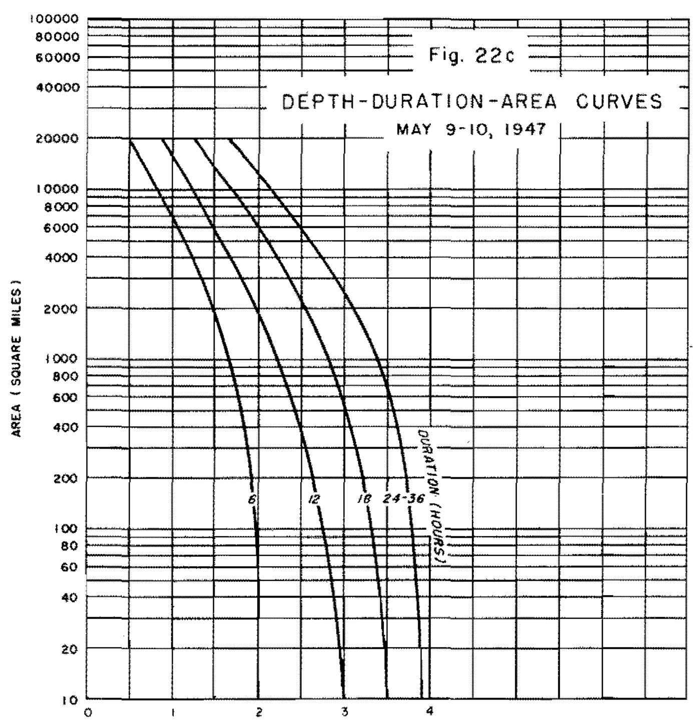


Fig. 22c
DEPTH-DURATION-AREA CURVES
MAY 9-10, 1947
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
DEPTH (INCHES)
0
1
2
3
4
6
12
18
24-36
DURATION (HOURS)

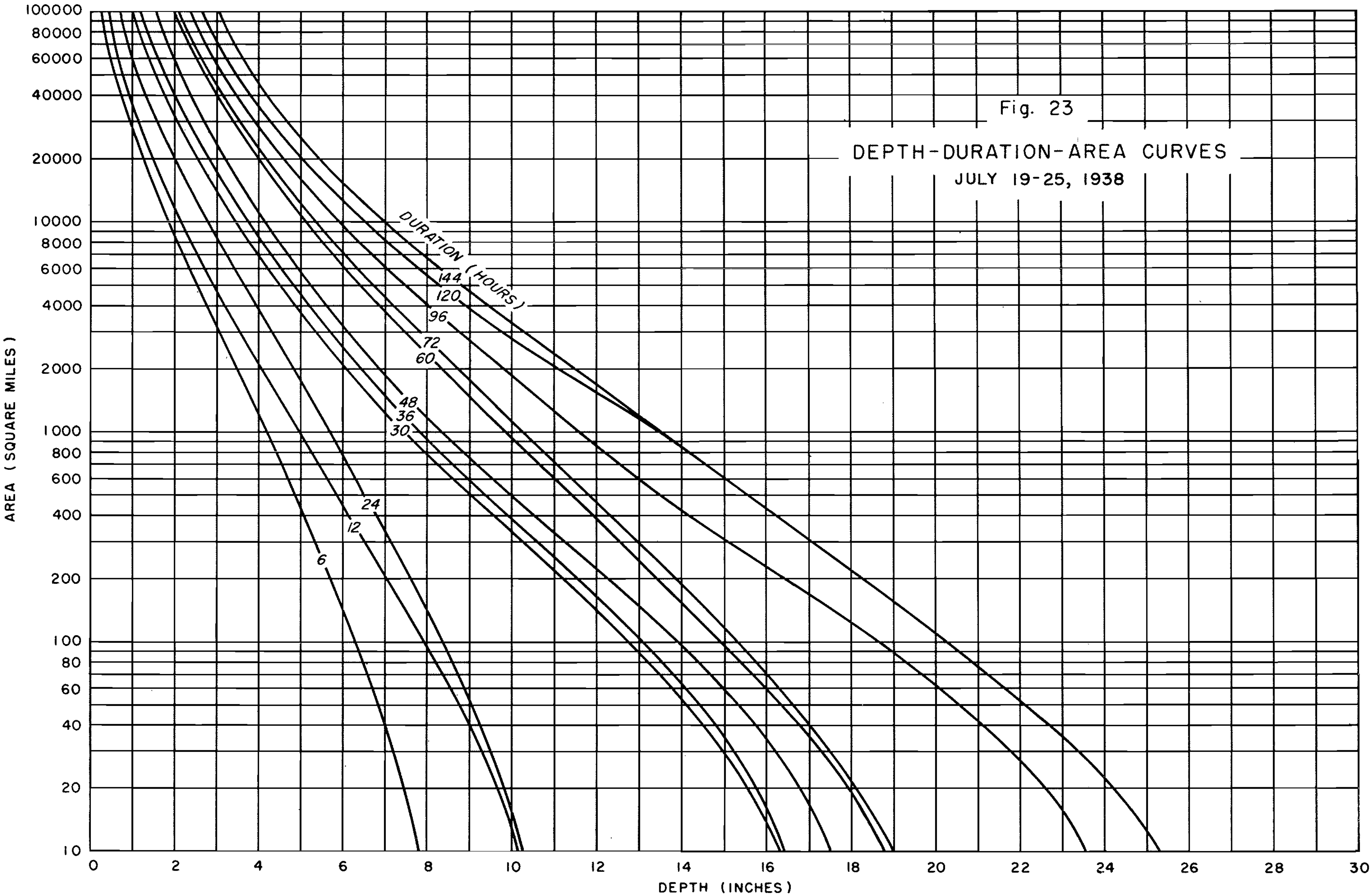


Fig. 23
DEPTH-DURATION-AREA CURVES
JULY 19-25, 1938
DURATION (HOURS)
144
120
96
72
60
48
36
30
24
12
6
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
DEPTH (INCHES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

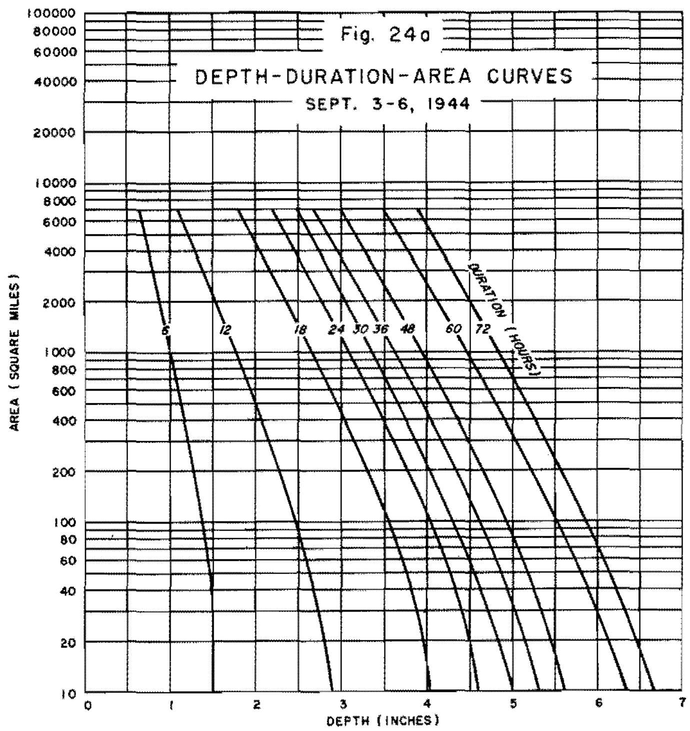


Fig. 24a
DEPTH-DURATION-AREA CURVES
SEPT. 3-6, 1944
DURATION (HOURS)
6
12
18
24
30
36
48
60
72
AREA (SQUARE MILES)
DEPTH (INCHES)

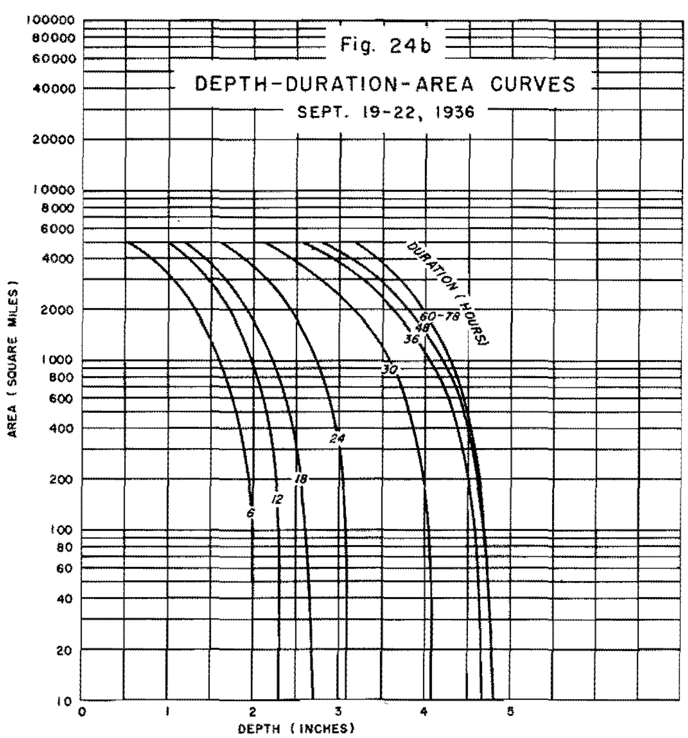


Fig. 24b
DEPTH-DURATION-AREA CURVES
SEPT. 19-22, 1936
DURATION (HOURS)
6
12
18
24
30
36
48
60-78
AREA (SQUARE MILES)
DEPTH (INCHES)

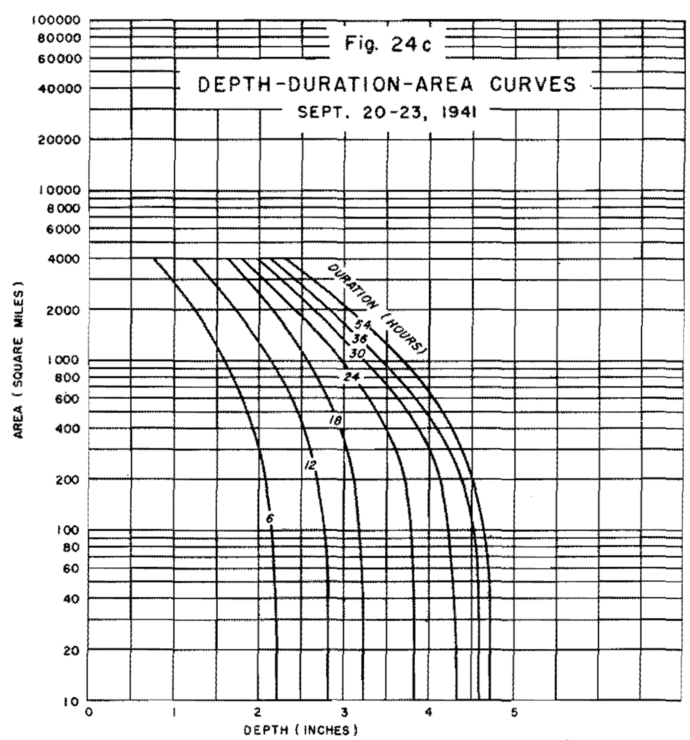


Fig. 24c
DEPTH-DURATION-AREA CURVES
SEPT. 20-23, 1941
DURATION (HOURS)
6
12
18
24
30
36
54
AREA (SQUARE MILES)
DEPTH (INCHES)

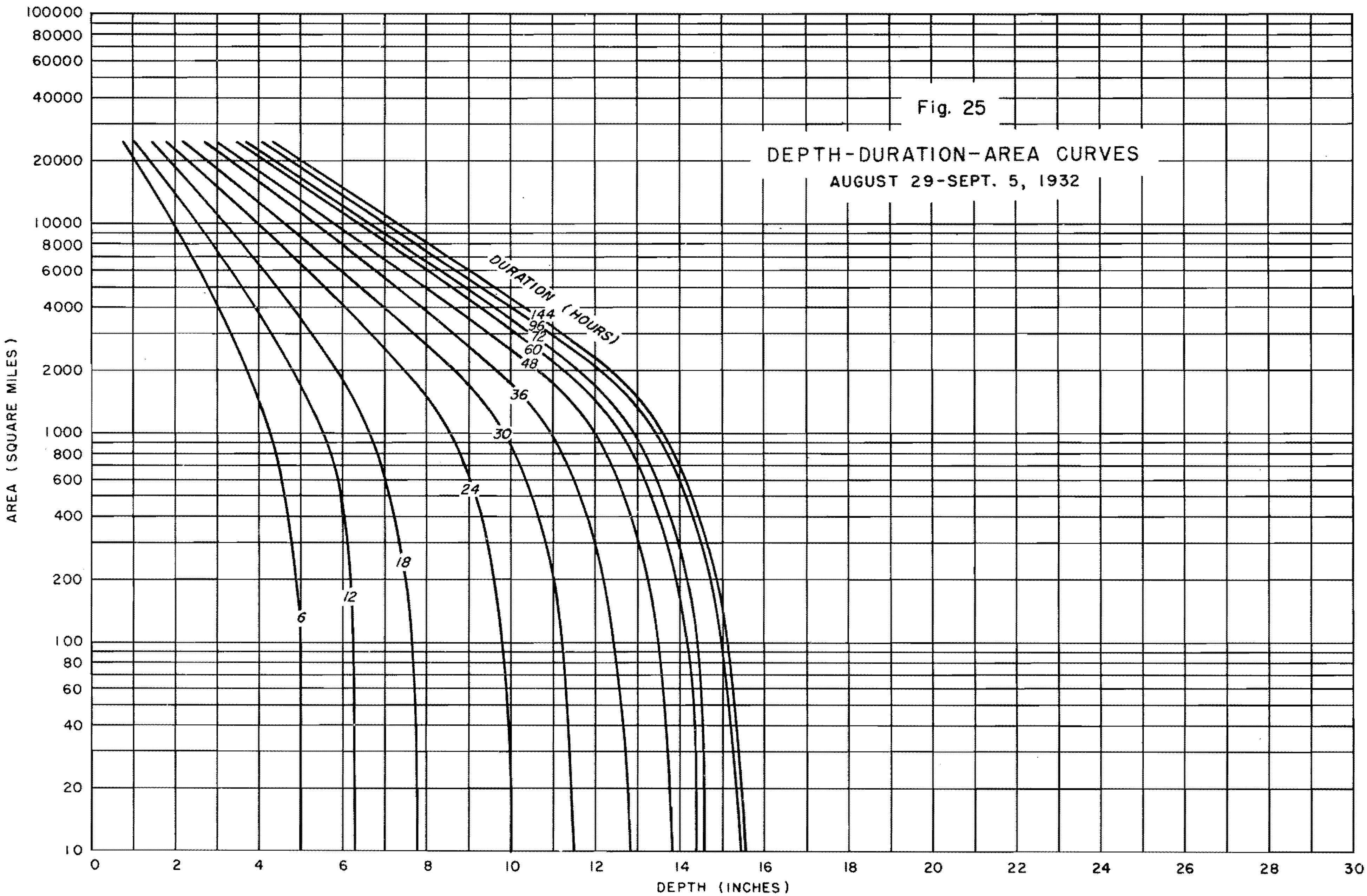


Fig. 25
DEPTH-DURATION-AREA CURVES
AUGUST 29-SEPT. 5, 1932
DURATION (HOURS)
144
96
72
60
48
36
30
24
18
12
6
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
DEPTH (INCHES)

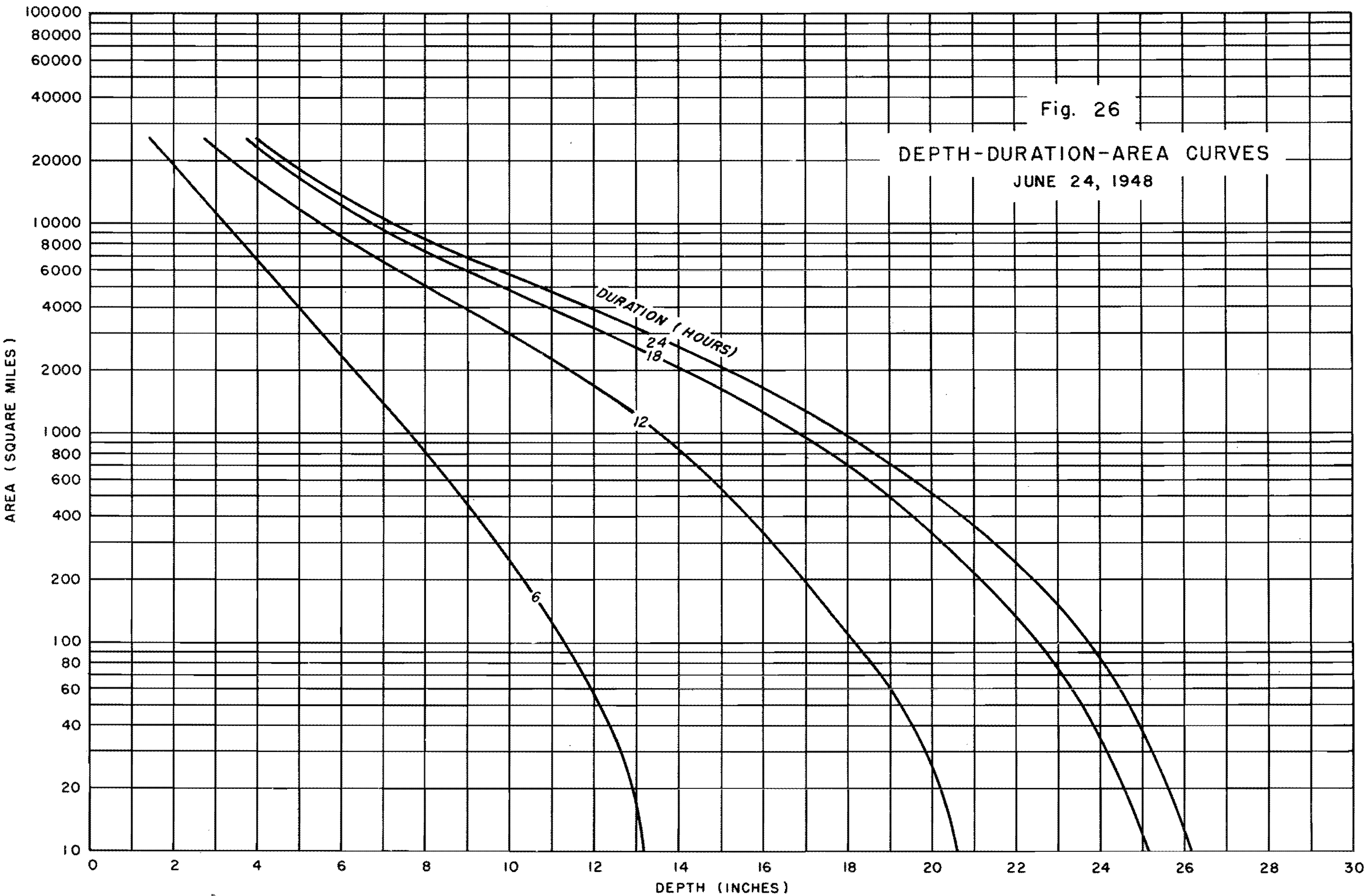
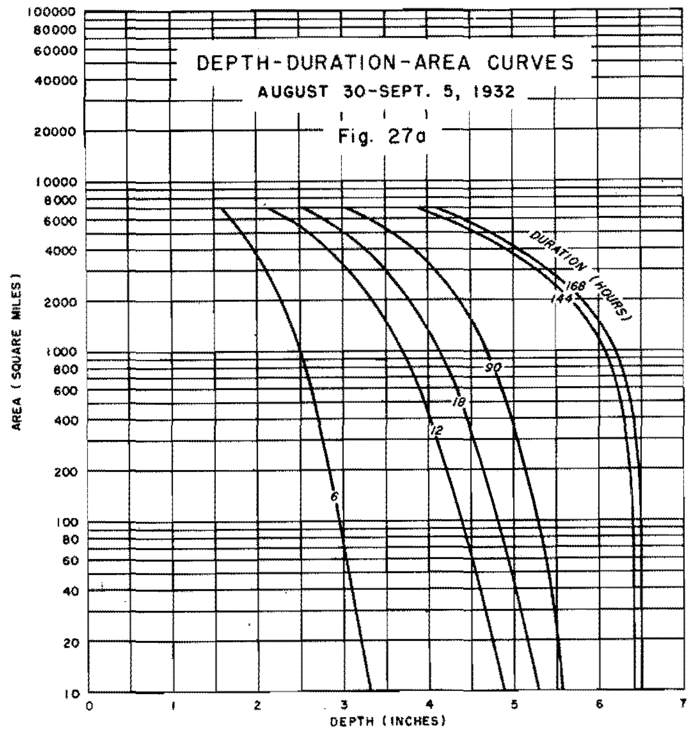
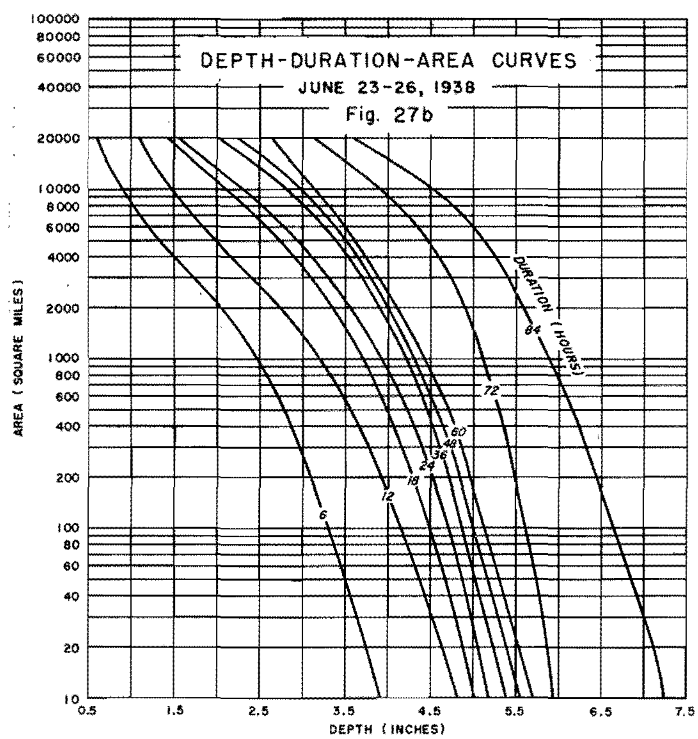
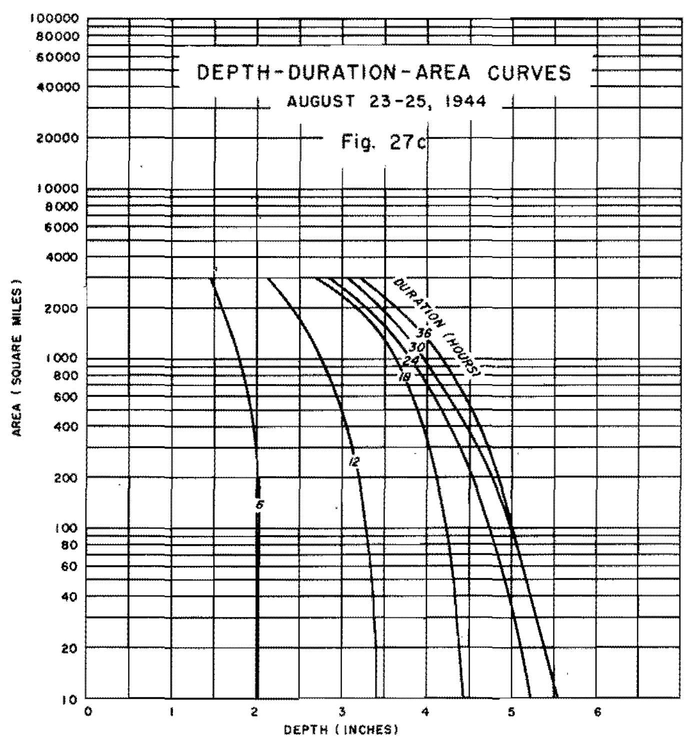


Fig. 26
DEPTH-DURATION-AREA CURVES
JUNE 24, 1948
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
DEPTH (INCHES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
DURATION (HOURS)
24
18
12
6


DEPTH-DURATION-AREA CURVES
AUGUST 30-SEPT. 5, 1932
Fig. 27a
AREA (SQUARE MILES)
DEPTH (INCHES)
DURATION (HOURS)
6
12
18
90
144
168
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
0
1
2
3
4
5
6
7


DEPTH-DURATION-AREA CURVES
JUNE 23-26, 1938
Fig. 27b
AREA (SQUARE MILES)
DEPTH (INCHES)
DURATION (HOURS)
6
12
18
24
36
48
60
72
84
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
0.5
1.5
2.5
3.5
4.5
5.5
6.5
7.5


DEPTH-DURATION-AREA CURVES
AUGUST 23-25, 1944
Fig. 27c
AREA (SQUARE MILES)
DEPTH (INCHES)
DURATION (HOURS)
6
12
18
24
30
36
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
0
1
2
3
4
5
6

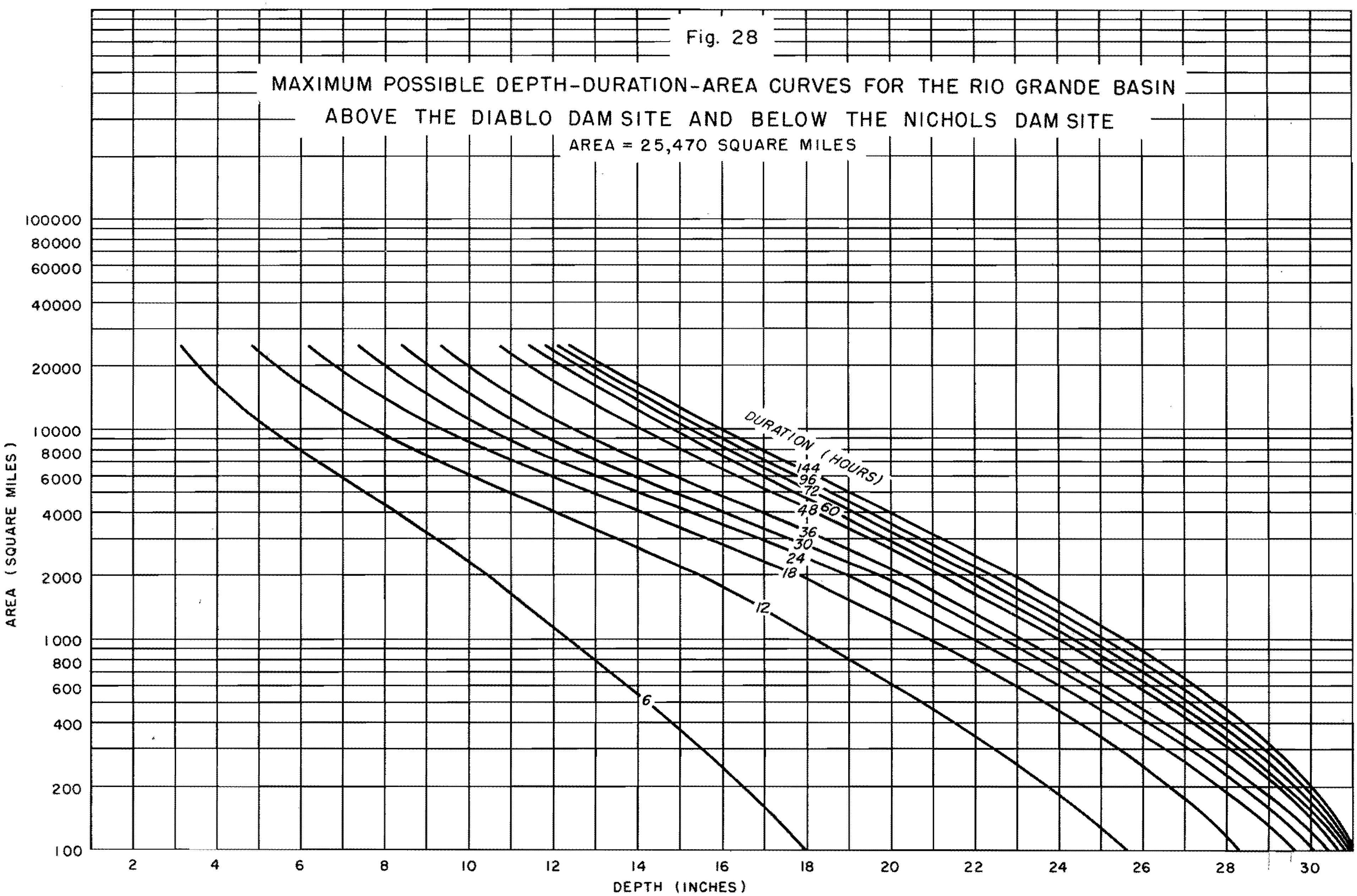


Fig. 28
MAXIMUM POSSIBLE DEPTH-DURATION-AREA CURVES FOR THE RIO GRANDE BASIN
ABOVE THE DIABLO DAM SITE AND BELOW THE NICHOLS DAM SITE
AREA = 25,470 SQUARE MILES
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
DEPTH (INCHES)
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
DURATION (HOURS)
144
96
72
60
48
36
30
24
18
12
6

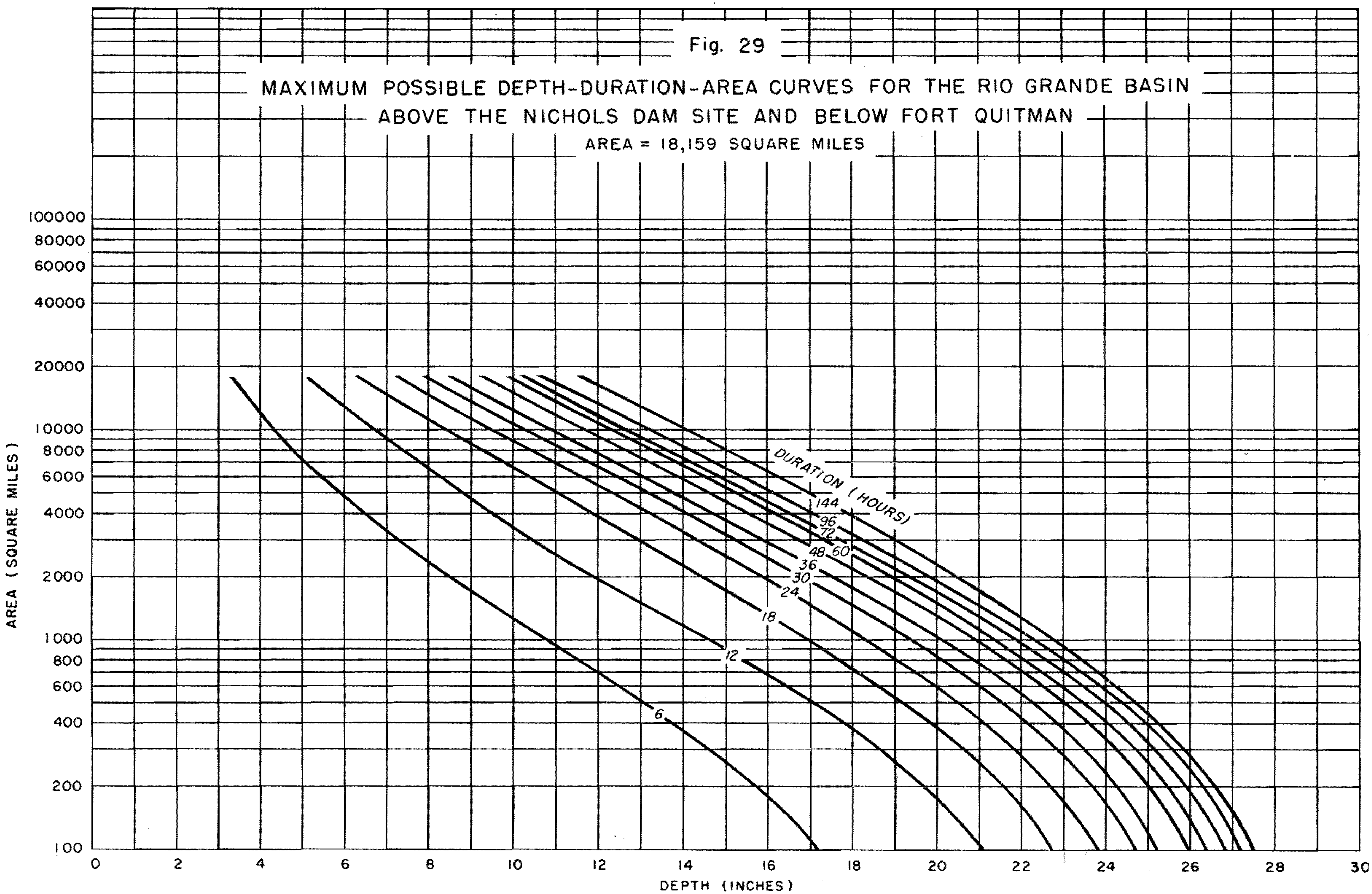


Fig. 29
MAXIMUM POSSIBLE DEPTH-DURATION-AREA CURVES FOR THE RIO GRANDE BASIN
ABOVE THE NICHOLS DAM SITE AND BELOW FORT QUITMAN
AREA = 18,159 SQUARE MILES
DURATION (HOURS)
144
96
72
60
48
36
30
24
18
12
6
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
DEPTH (INCHES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

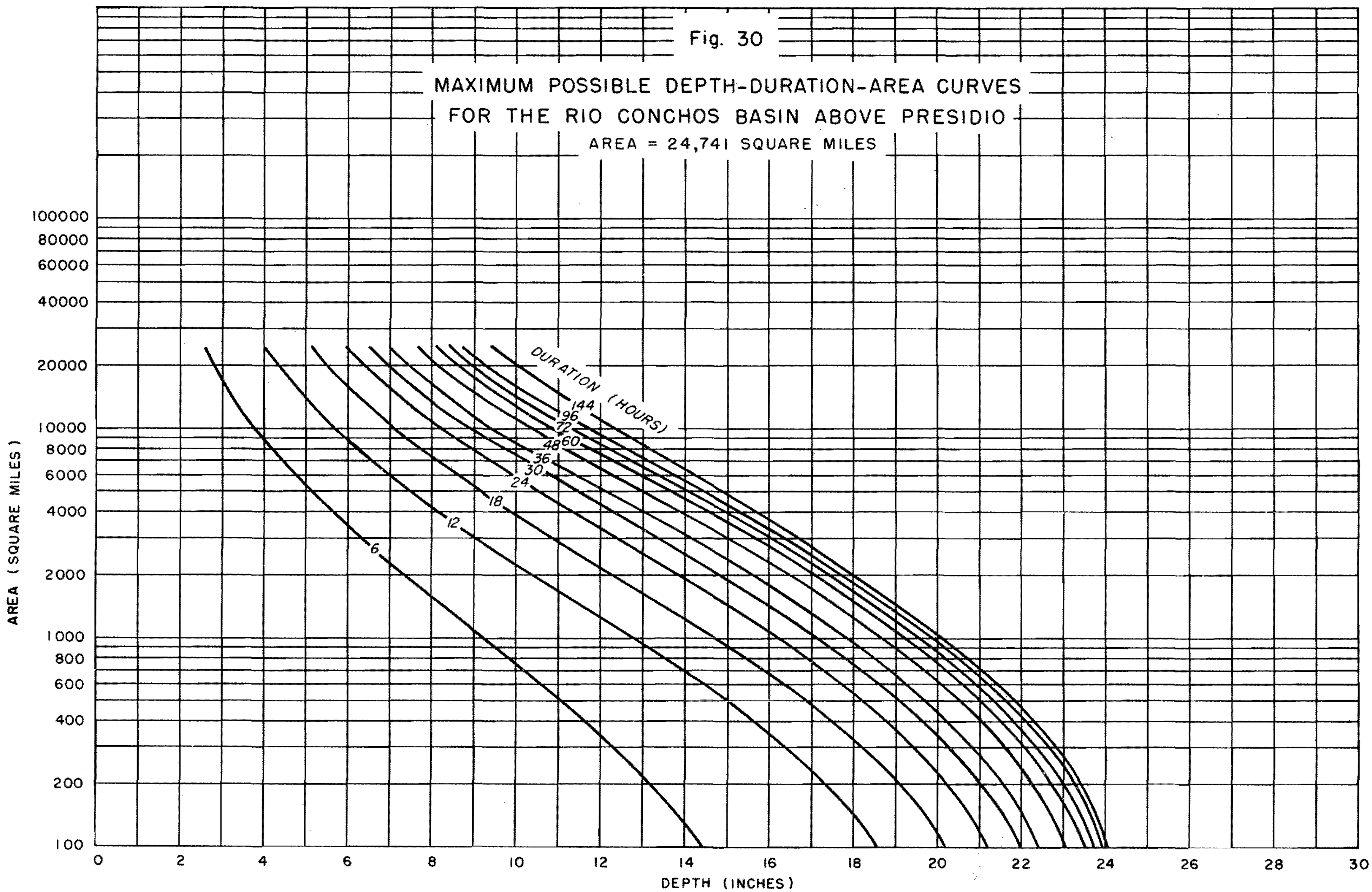


Fig. 30
MAXIMUM POSSIBLE DEPTH-DURATION-AREA CURVES
FOR THE RIO CONCHOS BASIN ABOVE PRESIDIO
AREA = 24,741 SQUARE MILES
DURATION (HOURS)
144
96
72
60
48
36
30
24
18
12
6
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
DEPTH (INCHES)

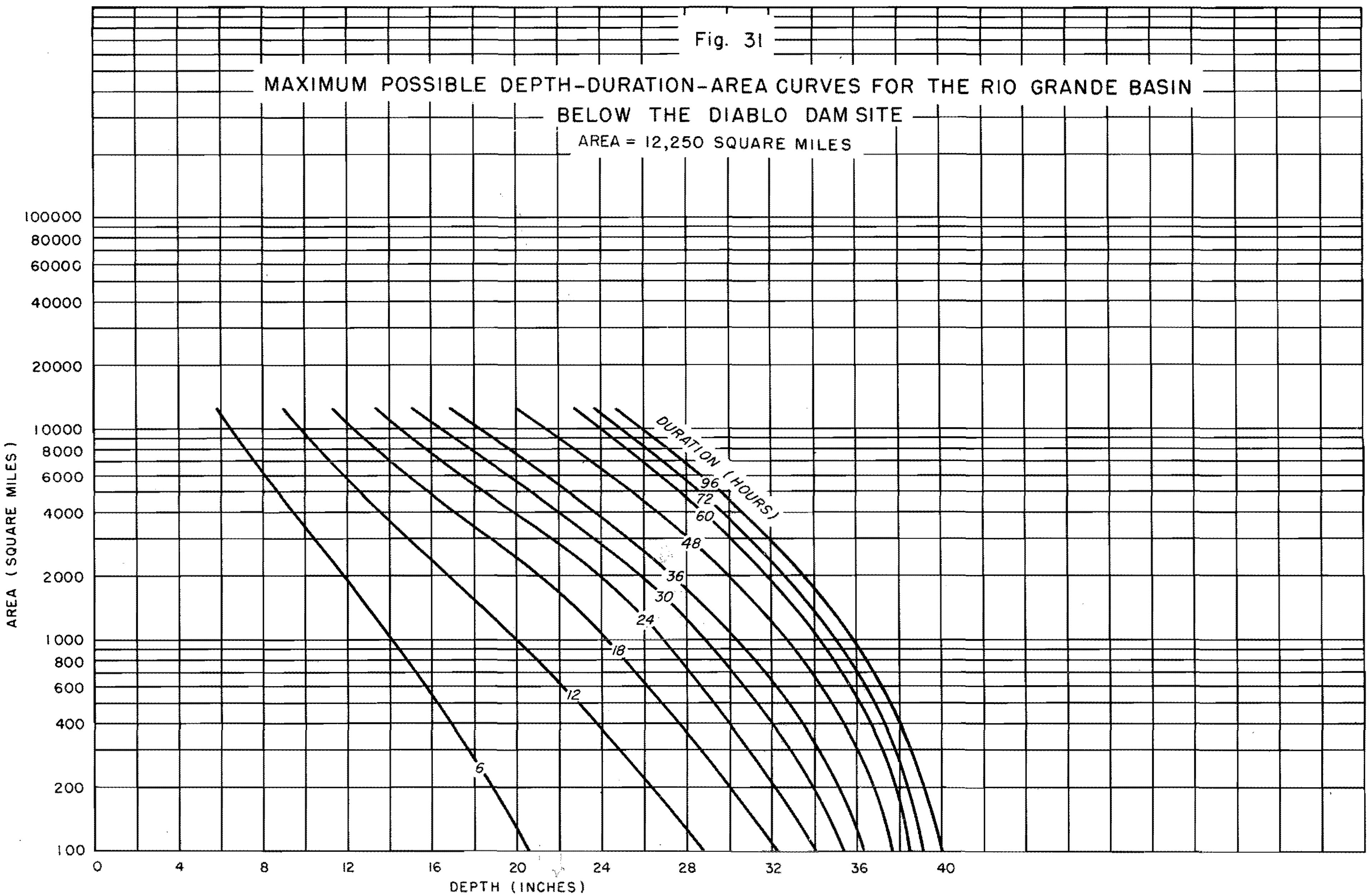


Fig. 31
MAXIMUM POSSIBLE DEPTH-DURATION-AREA CURVES FOR THE RIO GRANDE BASIN BELOW THE DIABLO DAM SITE
AREA = 12,250 SQUARE MILES
DURATION (HOURS)
96
72
60
48
36
30
24
18
12
6
AREA (SQUARE MILES)
100000
80000
60000
40000
20000
10000
8000
6000
4000
2000
1000
800
600
400
200
100
0
4
8
12
16
20
24
28
32
36
40
DEPTH (INCHES)