

**REPORT ON THE CLIMATE OF  
ARIZONA, WITH PARTICULAR  
REFERENCE TO QUESTIONS OF  
IRRIGATION AND WATER  
STORAGE IN THE ARID REGION**

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Report on the Climate of Arizona, with Particular Reference to Questions of Irrigation and Water Storage in the Arid Region by W. A. Glassford & A. W. Greely

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**W. A. GLASSFORD & A. W. GREELY**

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#### PREFATORY NOTE.

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This report was prepared by the Chief Signal Officer prior to the transfer of the Weather Bureau from the War Department to the Department of Agriculture. In order to satisfy the great interest regarding the subject-matter which it covers, among residents of the region in question, the Secretary of Agriculture has ordered a considerable number of extra copies for distribution among them.

WAR DEPARTMENT,  
*Washington City, February 28, 1891.*

The Secretary of War has the honor to transmit to the House of Representatives a report from the Chief Signal Officer, with text, tables, and charts, prepared in response to the resolution of the House of Representatives dated May 23, 1890, that—

The Secretary of War be, and is hereby, requested to transmit to the House of Representatives the reports that have been prepared under the direction of the Chief Signal Officer of the Army upon the climate of Arizona and New Mexico and other parts of the arid region, together with such tables particularly of rainfall, temperature, evaporation, and other matters as relate thereto, with such corrections, alterations, and additions as may be deemed advisable by the Chief Signal Officer, who will also express his views as to the value and importance of said tables of temperature, precipitation, evaporation, etc., and their bearing upon the subject of irrigation and water storage.

The Chief Signal Officer expresses his opinion that the economic value of these reports is such as to justify their being printed by Congress for the information of the public.

REDFIELD PROCTOR,  
*Secretary of War.*

THE SPEAKER OF THE HOUSE OF REPRESENTATIVES,  
*Washington, D. C.*

SIGNAL OFFICE, WAR DEPARTMENT,  
*Washington City, February 28, 1891.*

SIR: Referring to the resolution of the House of Representatives of May 23, 1890, that "the Secretary of War be, and is hereby, requested to transmit to the House of Representatives the reports that have been prepared under the direction of the Chief Signal Officer of the Army upon the climate of Arizona and New Mexico and other parts of the arid region, together with such tables particularly of rainfall, temperature, evaporation, and other matters as relate thereto, with such corrections, alterations, and additions as may be deemed advisable by the Chief Signal Officer, who will also express his views as to the value and importance of said tables of temperature, precipitation, evaporation, etc., and their bearing upon the subject of irrigation and water storage." I have the honor to transmit herewith text, tables, and charts which illustrate Arizona, California, Colorado, New Mexico, Nevada, and Utah particularly with reference to temperature and rainfall, together with such other notes on the climatic conditions of the region as appear pertinent and important.

Owing to the multiplicity of duties which have lately surrounded the Chief Signal Officer this report has been delayed beyond the time at which he would have chosen to submit it. Even at the present time the Chief Signal Officer has been unable to give it all the personal attention he desired. In view of this fact he delegated to the officer in charge of the records division, First Lieut. W. A. Glassford, Signal Corps, certain portions of the region with which he was acquainted through residence and meteorological examination. Lieutenant Glassford's remarks appear as separate memoirs upon the climate of Arizona, New Mexico, California, and Nevada.

The Chief Signal Officer has treated the subject of the climate of the arid region in perhaps a drier and more practical manner, confining himself to a presentation of such facts and clear deductions as may be of greatest utility to investors and settlers, as well as of theoretical interest to the

## LETTER OF TRANSMITTAL

more exacting student of irrigation problems. The resulting deductions clearly confirm the Chief Signal Officer's theoretical opinion that the arid regions can not be treated as a climatic unit with an entire disregard of physical boundaries, and that no general statement or treatment can be outlined which will be of equal applicability in every State and Territory within the region under discussion.

The Chief Signal Officer expresses his opinion that the climatic data presented herewith are of great value and importance to any corporation or community contemplating investments in works of irrigation or for water storage, and recommends that they be printed for the general information of the public.

Very respectfully,

A. W. GREELY,  
*Chief Signal Officer.*

The SECRETARY OF WAR.

## REPORT ON THE CLIMATOLOGY OF THE ARID REGIONS OF THE UNITED STATES, WITH REFERENCE TO IRRIGATION.

By Gen. A. W. GREELY,  
*Chief Signal Officer, U. S. Army.*

The object of the resolution, in answer to which this report and accompanying charts and tables are submitted, calls for a consideration of this question from a standpoint indicated by the Chief Signal Officer three years since. In a previous report to the Senate (on the "Rainfall of the Pacific Slope," etc., Fiftieth Congress, first session, Senate Executive Document No. 91), in February, 1888, before Congress took legislative action regarding the arid regions of the United States, the Chief Signal Officer pointed out the magnitude of the irrigation question as affecting the future agricultural interests of the population over one-third of the area of the country, and also specifically expressed the opinion that this question could not be satisfactorily discussed and treated without an accurate knowledge of the rainfall over the area of each particular drainage basin.

In treating this subject exhaustively, a large volume could be prepared which would undoubtedly be of great value as a standard work of reference in connection with tentative enterprises for the development of the natural resources of the United States west of the one hundredth meridian, but in a report of this kind to Congress brevity is an essential feature, even if the limited time available for the preparation of the accompanying data did not, as it does, impose it upon the Chief Signal Officer.

In answering the resolution, the attention of the Chief Signal Officer has been directed to the States and Territories of Arizona, California, Colorado, Nevada, New Mexico, and Utah. The States and Territories enumerated comprise in their limits those sections of the United States over which the rainfall is the smallest, the prevailing temperatures the highest, the evaporation of moisture most decided, and the amount of sunlight the greatest; thus presenting, and in some localities combining, such maximum meteorological phases as are of an adverse character to the regular and successful prosecution not only of agricultural enterprises, but, indeed, to the development of any other industry wherewith an abundant supply of water is an essential factor, and for which in these regions the adventitious aid of irrigation is indispensable. The above-mentioned meteorological conditions are less marked and less unfavorable in the remainder of the arid regions, viz, northern California, Wyoming, Montana, the eastern parts of Oregon and Washington, and western portions of Nebraska, Kansas, Indian Territory, Texas, and the Dakotas.

It is a serious error and somewhat prevalent that one can predicate the necessity of irrigation by simply ascertaining and comparing the annual rainfalls of various localities. It needs no elaborate discussion to demonstrate not only the practical inutility of such comparisons, but also the certainty that deductions therefrom must be nearly always misleading and frequently detrimental.

To illustrate this point may be quoted the annual rainfall of Pittsburgh, Pa. (36.71 inches), and that of Julian, San Diego County, Cal. (37.68). As these rainfalls are almost identical in amount, it would naturally be assumed by one not conversant with the peculiar distribution of



meteorological conditions of the United States, which conditions depend almost as much on peculiar locality as on latitude, that any industry or pursuit in which rain is an important element would succeed as far as water is concerned equally well at either place. There could be no greater mistake, however, as the following data of average rainfall for Julian, Cal., and Pittsburgh, Pa., clearly indicate.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.	Length of record.
	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>Years.</i>
Julian.....	4.81	2.35	2.85	5.98	0.73	0.00	0.00	0.00	0.55	2.23	5.28	37.63	37.63	8
Pittsburgh.....	3.21	2.62	2.85	2.61	3.07	3.59	4.96	3.45	2.53	2.49	2.58	2.75	36.71	18

The rainfall at Pittsburgh is substantially uniform throughout the entire year; the greatest differences between the separate amounts for any two months being only 6 per cent. of the entire amount for the year. At Julian, however, during seven consecutive months, from the first of May to the last of November, only 9 per cent. of the annual amount falls, while nearly one-half (48 per cent.) of the entire precipitation of the year occurs during the months of February and March.

This leads up to the main point, evident to every farmer, that the most important characteristic of the rainfall, apart from quantity, is its proper distribution throughout the year. Over the greater part of the United States the rainfall of the winter months is not of such direct and vital importance to the agriculturists as are the rains of the late spring and of the early summer. This has been illustrated in a report of the Chief Signal Officer (see Senate Ex. Doc. 115, Fifty-first Congress, first session), wherein he has pointed out that the disadvantages of Nebraska, with a rainfall from one-half to one-third below that of the States of Maryland, New York, Pennsylvania, and the interior of Virginia, are neither as extensive nor as material as might seem evident to one casually considering the effect of the annual rainfall. In this respect the great advantage of Nebraska, and this advantage likewise obtains in parts of Kansas and South Dakota, is in the suitable distribution of rainfall throughout the year, particularly during the months of April, May, June, and July, which may be called, not inappropriately, the critical agricultural months from the standpoint of staple crops grown in Nebraska. Over this State as a whole, the percentage of rainfall in each of these four months closely agrees, that for April being about 11 per cent. of the entire annual rainfall; that for May, 17; for June, 16; and for July, 16 per cent.; in other words, substantially 60 per cent., or three-fifths of the rainfall for the year falls during the four months mentioned, the period when such rainfall is most needed for the growth and development of the staple crops.

Although the distribution of rainfall in certain portions of the Atlantic coast States is nearly uniform for the different months, and although the annual distribution on the Pacific coast is known to be peculiar and marked, yet there has been a popular tendency to ignore these widely varying rainfall characteristics and attribute the same climatic conditions to immense areas with widely differing physical features, and also at greatly varying distances from the ocean, the source of rain. Particularly has misapprehension existed as regards general scarcity of rain and its unequal distribution throughout the year, since the same rainfall conditions have often been attributed to the entire arid regions of the United States, which by general consensus of opinion cover the entire United States west of the one hundredth meridian.

Even among the better informed and casual observers of meteorological conditions, the tendency has been to concur substantially with this popular opinion, excepting so far as it relates to the coast region of northern California, Oregon, and Washington. While the belief of the casual observer as to the scarcity of water west of the one hundredth meridian may be considered true in a general sort of way, yet it is not so in many specific and important cases, for the latest rainfall maps of the United States compiled at the office of the Chief Signal Officer show that there are enormous areas of country in the so-called arid regions where the rainfall exceeds 15 inches (by which isohyetal, or line of equal rainfall, the arid region is, by some, limited), and even very large areas over which the annual precipitation exceeds 20 inches, and in lesser areas 25 inches.

The opinion also obtains among many that the rainfall of the arid regions is typically represented by the California rainfall, with a wet season from November to March, and a practically, if not totally, rainless season for the rest of the year. Such a typical curve may not be inappropriately represented by San Francisco, where the average rainfall is as follows: January, 5.10 inches; February, 3.60; March, 3.26; April, 1.93; May, 0.67; June, 0.15; July, 0.02; August, 0.02; September, 0.16; October, 0.98; November, 2.87; December, 5.33; year, 24.08 inches; length of record, 42 years. The data show that 43 per cent. of the annual precipitation occurs at San Francisco during the months of December and January, while only 2 per cent., or substantially no rain, falls between the 1st of June and the 1st of October.

This peculiar distribution of rainfall, however, is not characteristic of the entire arid region, and it obtains definitely only in California (with slight exceptions) and a portion of Nevada. In Oregon and Washington the autumnal rains begin gradually earlier, as one goes northward, commencing nearly a month earlier in Washington, where, however, they cease somewhat earlier in the spring.

These peculiarities as to the annual distribution of rain being so marked and varying, even on the bordering coast of the Pacific Ocean, strongly evidence the necessity of a most careful examination of the annual precipitation régime for the rest of the arid region, over which the rainfalls, as a rule, are less plentiful and more dependent on exceptional causes, and consequently more liable to extreme and unusual fluctuations.

This examination and comparison the Chief Signal Officer has personally attempted as far as the limited time at his disposal would permit, and the general distribution for different States is shown on Chart No. 1 where the typical rainfall curves are what may be called composite, being made up from selected stations, with long records, in the State or Territory to which the curve applies. The values here given are drawn from stations selected with reference to their geographical position as well as to their agreement with the common rainfall régime, and so may be considered as fairly representative of adjacent regions as well as of their immediate locality.

It will appear clearly from these curves, as is more evident by detailed examination of the original data for separate stations, that the varying periods of *wet*\* and *dry* or *very wet* and *very dry* months are almost as many in number as the States to which they obtain. These curves also make it apparent that, in order to insure in the arid regions economic and successful crops by irrigation, the growth of only such crops should be attempted or encouraged in different sections as are suited to the character of the local soil, the varying local seasonal temperatures, and which by their seasonal period of germination and development would have the advantage of the rainfall of those months in which the greater part of the general precipitation occurs. The advantage of this plan would be that it thus reduces to the minimum the quantity of water, absolutely essential to the success of the crops, which must be caught, impounded, preserved, and delivered on the ground at a considerable expenditure of labor and material.

The general distribution of rainfall throughout the year over the region west of the one hundredth meridian may briefly be defined as follows:

*January*.—This is a *very wet* month over all of California except the southeastern portion, where it is *wet*. In Oregon and Washington the coast region is *very wet* and the eastern parts of the States *wet*. It is also a *wet* month over Nevada and the greater part of Idaho. It is a *dry* month over western Texas and the western half of the Dakotas. It is *very dry* over the eastern half of the two Dakotas, the eastern parts of Nebraska, and over the greater part of Kansas. Over Montana, Wyoming, Colorado (except the eastern half, where it is *very dry*), New Mexico, and Arizona the amount of precipitation is either about the proportional amount with reference to annual rainfall, or deviates slightly therefrom.

\* NOTE.—The terms "wet" and "dry" with reference to months is something more than relative as used in this report. Here it is defined fully with reference to average rainfall, the same rule being followed as has been employed elsewhere. A *wet* month is one in which 50 per centum more rain falls than the average, and in like manner a *very wet* month is one in which double the usual amount of rain occurs, that is to say, 8.33 per cent. of the annual rainfall is the proportional amount for each month, so that under the definition here given a month with 12.5 of the average yearly rainfall is a *wet* month and one with 16.7 is a *very wet* month. In like manner a *dry* month is one in which the average rainfall does not exceed 4.2 per centum of the annual rainfall, and a *very dry* month is one in which 2.1 per centum, or less, of the annual amount occurs.

*February.*—This month is *wet* over Washington, Oregon, and California (except the southwestern part of the State, where it is *very wet*). It is *dry* over the Dakotas southward to western Texas; elsewhere the rainfall for February shows but slight deviations from its proportional amount with reference to the yearly range.

*March.*—A *wet* month for the western parts of Washington, Oregon, and California. A *dry* month over western Texas, the eastern part of New Mexico, Nebraska, the Dakotas, and Montana.

*April.*—A *dry* month in the southern half of Arizona and New Mexico with tendencies in localities to be *very dry*. A *wet* month in the interior valleys of southern California, over western Colorado and parts of eastern Utah, in South Dakota, and over considerable portions of the Indian Territory and northern Texas.

*May.*—A *dry* month over the western parts of Washington and Oregon, over all California, the western half of New Mexico, and the northern half of Arizona, and a *very dry* month in southern Arizona. A *wet* month over Texas (except in the neighborhood of El Paso) northward to include the Indian Territory, northeastern Colorado, Kansas, Nebraska, North and South Dakota, Wyoming, and the greater part of Montana. However, in northeastern Wyoming, western Nebraska, western Kansas, southeastern Colorado, and the western part of the Indian Territory the month is *very wet*.

*June.*—The month is *very dry* over California, southern Nevada, southern Utah, and Arizona, and is *dry* over western Colorado, northern Utah, central Nevada, and the western parts of Oregon and Washington. It is a *very wet* month over Montana, North and South Dakota, Nebraska, and Kansas. It is *wet* over Indian Territory, northwestern Texas, extreme eastern Colorado, and all of Wyoming except the extreme southwestern part, and over northern Idaho.

*July.*—A *very dry* month over California, Oregon, Washington, Idaho, and a *dry* month over northern Utah. A *very wet* month over the eastern parts of North and South Dakota, southwestern Nebraska, extreme western Kansas, eastern Colorado, western Texas, New Mexico, and the eastern part of Arizona. It is a *dry* month over western Arizona (except in the extreme southwestern part), southern Utah, northern Nebraska, and northern Montana.

*August.*—A *very dry* month over California (where it is practically rainless), Nevada, Oregon (where it is nearly rainless), Washington, and western Idaho. It is *dry* over eastern Idaho and extreme northwestern Montana. It is *very wet* over Arizona, New Mexico, and the mountain region of Colorado and southern Utah. It is *wet* over western Kansas, the panhandle of Texas, western Nebraska, and the eastern parts of North and South Dakota.

*September.*—*Very dry* and nearly rainless in California; *dry* over Nevada, southwestern Utah, Idaho, southern Oregon, and the greater part of Wyoming. It is a *wet* month over all of Texas (except the panhandle and southeastern part) and also in extreme southern Texas, along the coast where the month is *very wet*.

*October.*—The month is *dry* over western Arizona, southern California, southern Nevada, and in portions of the interior of southern Oregon and northern California. Elsewhere about the proportional amount of the annual rainfall occurs.

*November.*—A *wet* month in western parts of Oregon, Washington, and northern California. A *very dry* month over the panhandle of Texas, thence northward through western Kansas and western Nebraska, and the eastern parts of the two Dakotas; but elsewhere from the one hundredth meridian to the crest of the Rocky Mountains it is a *dry* month.

*December.*—A *dry* month over western Texas, western New Mexico, Kansas, eastern Colorado, Nebraska, North and South Dakota, with a tendency to be *very dry* in the extreme eastern portion of New Mexico, extreme southeastern Colorado, and extreme northwestern Kansas. The month is *very wet* over western Arizona, California, the greater part of Nevada, Oregon, and Washington.

It must be clearly understood that these terms, *wet*, *very wet*, *dry*, and *very dry*, refer not to the absolute quantity of rainfall over the regions mentioned, but to the average monthly quantities with reference to the proportional part of the annual rainfall, that is, if equitably distributed, 8.33 per cent. of the year's rain would fall in each month.

Attention is especially called to the fact that a paper of this kind must generally deal with averages, but in connection with the subject of irrigation it is of particular importance to briefly consider the question of excessive rainfalls and also of prolonged periods of drought.