MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY

VOL. 56, No. 6
W. B. No. 959

JUNE, 1928

CLOSED AUGUST 3, 1928
ISSUED AUGUST 31, 1928

WATERSPOUTS

By WILLIS EDWIN HURD

[Weather Bureau, Washington, June 25, 1928]

In an article prepared especially for seamen and shortly to be published on one or more of the monthly Pilot Charts of the United States Hydrographic Office (**1**), the writer has discussed the subject of the waterspout at some length. There the reports of marine observers are quoted freely to illustrate not only the individual behavior of numerous spouts, but also the varying conditions under which they occur. References of this character are omitted from the present paper, which is a summary of the more important facts only.

While waterspouts closely resemble true tornadoes in most phases of outward appearance, and both have many other features in common, yet in method of origin, and in some individual characteristics, they are often distinctly different.

The true tornado, as Doctor Humphreys points out (**2**), is a "joint product of cyclone and anticyclone," and occurs just in advance of the squall line which marks the change from the equatorial winds of the low-pressure region to the polar winds that succeed them. This characteristic, together with its probably invariable contraclockwise wind circulation in the Northern Hemisphere, must be considered as wholly typical of the disturbance.

The sand pillar of the Central and Southwestern States is frequently called a tornado. But since its origin is entirely convectional, the whirl rising from the heated surface and rotating either to right or left, while the tornado forms at or near the cloud level, the whirl thence being communicated earthward in what we see as a left-handed rotation, it becomes apparent that the two have well-marked points of dissimilarity.

Now the waterspout partakes in great measure of the nature and behavior of the tornado, or of the sand pillar, as the case may be, probably obeying the impulse to complete a contraclockwise whirl downward from the cloud, in the one instance, or tending to obey the convectional impulse to rise in one way of whirl or the other, in the second. Whence we may properly style them as tornado spouts and convection spouts. Sometimes the spout will be formed by a combination of conditions, in which case the rotation will be clockwise or counterclockwise, according to the local conditions prevailing at the place and moment of the inception of the eddy. Only about 1 in 15 of all waterspout observations—whether made by seamen or by land observers—mentions the direction of rotation, but from these comparative few it is shown that slightly more than half are of the tornadic, or left-handed, type.

Waterspouts that go ashore.—Many waterspouts on touching land are almost immediately dissipated, the base breaking up and the upper part of the funnel withdrawing into the cloud. Others—doubtless strongly of the tornado type—give up much of their liquid content as they go ashore, and, gaining new rotational energy, may become dangerous land tornadoes. Similarly, tornadoes, upon passing over a water surface of moment and perhaps taking up liquid, may change their name, though not their characteristics, and become known as waterspouts. An interesting example of a spout going ashore is found in the violent local storm known as the Goulds tornado, which did much damage southwest of Miami, Fla., September 10, 1919, during the prevalence of the West Indian hurricane of the 6th–14th. This originated as a waterspout, so called, over the near-by ocean or in Biscayne Bay.

Localities of occurrence.—While the waterspout is often considered to be a phenomenon only of the salt-water bodies of the world, yet it is not so confined in its activities, since true vortices of this type occasionally make their appearance on the lakes and rivers of many lands. Numerous instances are given of those of the mountain lakes and of the larger quiet streams of Europe. They are found occurring in the United States, more especially on Lake Erie, and reports of them sift in now and then from African, Asiatic, and other continental localities.

On the North Atlantic Ocean, including its contiguous gulfs, bays, and seas, waterspouts have been observed from the Baltic to the Gulf of St. Lawrence; from the eastern end of the Mediterranean to the farthest Caribbean and the Gulf of Mexico, and in fact over almost all the ocean, though they are rather uncommon in the most settled regions of the northeast trades, where the general regularity of the weather conditions is not favorable to their formation. The principal region of activity is embraced between the tropical African coast and the Central American and Mexican coasts, with an extension northward from the West Indies to the upper limit of the Gulf Stream. In this considerable area a band of maximum activity extends from the Gulf of Mexico through the Florida Strait past the Bahamas and up the coastal waters to, and to the eastward of, Cape Cod.

In the North Pacific Ocean the region of maximum waterspout activity lies off the Mexican and Central American coasts, within a great triangular region of prevailing variable winds and calms. Extending northward from it is a band of occasional occurrence which conforms closely in area to the long fog bank stretching from Cape San Lucas to Puget Sound. Thence westward to the Kuro Siwo waterspouts are reported very infrequently. At Honolulu the only occurrences of record are three spouts that formed in the harbor on January 1, 1927. A secondary area of considerable activity embraces the China and other seas adjacent to the Asiatic coast.

In the Indian and South Pacific Oceans waterspouts form most frequently in East Indian and Australian waters and about the various archipelagoes both far and near to the eastward.

For the South Atlantic Ocean little information is available, although ships' reports make occasional mention of spouts in many localities.

Monthly and seasonal occurrence.—While waterspouts are likely to occur at any time of the year in waters appreciably subject to them, yet a more or less pronounced average seasonal shift with latitude is observed in the Northern Hemisphere, the greater number forming in the Tropics during the fall and winter months, and in the Temperate Zone during the late spring, late summer, and early fall months. For the tropical waters of the Atlantic, between latitudes 10° S. and 20° N., Hellmann (**3**) found that three-fourths of the waterspouts studied by him from the ships' reports of 26 years in these latitudes occurred from October to March. Gibson, in a special study (**4**) based upon waterspout data appearing on the United States Pilot Charts of the Hydrographic Office from January, 1884, to March, 1886, inclusive, found that out of 245 spouts observed along the American coast from Panama to Cape Cod, 70 per cent occurred during the summer half of the year, with the greatest monthly occurrence, 14½ per cent, in May. The least number for the year was credited to November.

In the present writer's more general treatment, about 65 per cent of waterspouts plotted for the entire North Atlantic were for the warmer months, May to October, inclusive. The months of maximum frequency for the year were found to be April, May, August, September, and October, with the greatest number occurring in August. The months of minimum occurrence were shown to be March, July, November, and December. That the adjoining months of July and August should present the minimum and maximum extremes of frequency is of peculiar interest. While no figures of spout frequency, owing to scantiness or incompleteness of data for the periods covered, are sufficient to make for desirable accuracy, yet they do point out reasonably well the times of rise and fall in waterspout production on the North Atlantic Ocean. Off the coast of Florida the greatest number for any month seems to occur in May, and to the northward, in August. In connection with the occurrence of spouts in winter, it is interesting to note that the North Atlantic Pilot Chart for March, 1888, describes about 40 that were reported between Cuba and the Grand Banks during the preceding January and February.

In a study covering the period from December 17, 1888, to June 30, 1898, Russell (**5**) mentions 38 waterspouts observed off Eden, on the coast of New South Wales. These were fairly well distributed according to seasons, with March the month of greatest frequency. Of the entire number, over half, or 20, made their appearance during a period of five hours on May 16, 1898.

American fresh-water spouts.—During the search for data bearing upon the general subject of waterspouts, records were discovered of some 36 vortices of this type occurring in the inland waters of, or waters contiguous to, the United States. Of this number 20 were observed on Lake Erie, 4 on Lake Ontario, 1 on Lake Michigan, 1 on Lake Newcomb, N. Y., 2 on Lake Monroe, Fla., 2 on the St. Johns River, Fla., 2 on the Mississippi River, 2 on the Chester River, Md., and 1 each on the Potomac and St. Lawrence Rivers. Seven of these were observed upon one occasion on Lake Erie, August 13, 1898, between 7.30 and 9 a. m. All but three occurred during the months, May to September, with the majority in August. One of the three formed February 11, 1907, during very cold weather, over a small stretch of open water at the eastern end of Lake Erie. Another formed in the St. Johns River, near Jacksonville, on April 18, 1888, and the third appeared in the Potomac River, at Washington, D. C., November 17, 1927. The spouts enumerated are doubtless scarcely more than casual findings, and the subject is worthy of a careful study. Such information regarding them as appeared in the reports indicates that fresh-water spouts rotate in either sense, as do their neighbors of the salt water and the sand whirls of the desert.

Hour of occurrence.—Whenever the meteorological conditions are favorable, waterspouts may occur, whatever the time of day. Such conditions usually exist only during the daylight hours, but on several occasions the phenomenon has taken place during the hours of darkness, both before and after midnight. In the Tropics of the Atlantic, Hellmann (**3**) records 34 spouts in which the hour of occurrence was given by the observers. Of these, 21 formed before and 13 after noon, with times of most frequent appearance between 6 and 7 a. m. and near noon. The present study of hundreds of spouts observed for the Atlantic as a whole shows that they are most frequent during the early forenoon, late afternoon, and midday hours, but with only slight intermediate lessenings. There seems to be little difference in the numbers formed during the a. m. and p. m. hours.

Weather conditions under which waterspouts occur.—A much wider range of weather conditions favorable to waterspout formation exists at sea than is equally favorable to the production of all combined types of local whirls on land. The waterspout originates not only along or near the squall line separating cyclones from anticyclones, or over quiet and considerably heated tropical sea areas, but it occurs at almost any point within distinctive high or low pressure regions; also wherever fairly well-developed squalls occur along discontinuity surfaces, though unmarked by barometric changes of moment, either in the doldrums, or wherever the atmosphere exists in a state of unstable equilibrium. Spouts also occur, and quite frequently, in connection with ordinary thunderstorms.

While waterspouts are usually associated, at least in popular conception, with warm, sultry weather, yet they are by no means uncommon during the prevalence of low air temperatures, especially if over a warm-water surface. Gibson (**4**) found that out of 51 cold-weather spouts definitely assigned to low-pressure areas, 36 formed in the southwest quadrants and 15 in the southeast. Of 46 warm-weather spouts, the condition was reversed, 18 occurring in the southwest quadrants and 28 in the southeast. Winter spouts during the three years under study were most abundant when low temperatures prevailed and winds were from a north to west direction, and summer spouts, when the winds were south to east. As an example of the former: On February 21, 1886, 10 waterspouts formed in and near the Gulf Stream, following the passage of a cyclone center, during the prevalence of squally and violent winds which sometimes attained to hurricane force from the north-northwest. Less frequently spouts occur in winter over portions of the sea quite remote from a warm current, when temperatures of both air and water are below 50°, with atmospheric conditions tending toward the production of local squalls, though with no marked cyclonic weather necessarily prevailing.

Unless formation occurs under changing cyclonic or anticyclonic conditions, the weather preceding, during, and following a waterspout exhibits little change, temperature, pressure, wind, and humidity usually remaining practically undisturbed. In close proximity to the whirl, however, there is often accelerated wind, and sometimes, though not always, slight barometric fluctuations, pressure disturbances being ordinarily confined to the spout proper.

Windspouts and waterspouts: Water content.—While a majority of all fully developed sea spouts carry a greater or less quantity of water in suspension, yet many are mere wind whirls of convectional origin which contain no more water vapor than would be found in a bank of dry to ordinary fog. The latter are usually of no great violence, perhaps no greater than the dust whirls which they resemble, although capable of doing some damage to a small vessel. They occur for the most part during quiet weather over areas of considerably heated water. While sometimes little disturbing to the surface over which they travel, more often they throw up a small cloud of spray—the usual cascade—for a few feet into the air.

True waterspouts contain, in addition to condensed water, an uncertain quantity of sea water drawn to a height which depends upon the intensity of the disturbance, and therefore the lifting power of the rising winds. Thus, under extreme circumstances, the quantity of surcharged vapor and free water is so great as to produce the equivalent of a cloud-burst, upon its discharge. This water has often been spoken of by seamen upon vessels struck by waterspouts as being wholly fresh, but by others as having a saline taste. A few reports are current of salt water having been carried in such quantities up the spout to the clouds as to be noticeable in the precipitation occurring at a distance. This was true of the Cottage City (Oak Bluffs) waterspout of August 19, 1896, some time following the disappearance of which, saline rains fell over Marthas Vineyard Island (**6**). Since this spout, the history of which was given much publicity, was estimated to have been at least 3,600 feet high, the vertical distance to which the sea water was raised is seen to have been considerable.

Simultaneous numbers.—While often only a single waterspout forms in a given instance, yet 2 to 10 quite frequently occur together, and 15 to 20 occasionally have been witnessed off the south and east coasts of the United States, and in mid-Atlantic. Groups of spouts in as great numbers have also been observed in various localities in other oceans.

Waterspout-bearing clouds.—In general the most vigorous spouts are associated with the heavy cloud masses of the cumulo-nimbus type and the almost equally dense nimbus of energetic cyclones. Less vigorous spouts as a rule form in connection with cumulus, strato-cumulus, and stratus clouds. Spouts occur most frequently in connection with cumulo-nimbus clouds, and least frequently with strato-cumulus. Group spouts in bunches or irregular formation are found most often in squall clouds, whether these accompany violent upper air changes in cyclones, or fair weather convective turbulence. Group spouts in line formation may sometimes be found in rows of long cumulus clouds, or in single strato-cumulus bands, and are most likely to occur in the tropics in such localities as, for instance, in the neighborhood of the Bahamas, or off the west coast of Mexico, during fair weather. Frequently many of these are immature, ranging from mere protuberances at the base of the cloud to half-formed pendants.

Occasionally low spouts are seen traveling along as mere tubes with no accompanying clouds. Other spouts, whether low or moderately high, sometimes induce the formation of a cloud summit in the over-flowing vapor, as a result of convection and vortical action.

Lightning.—Electrical phenomena occur in general with waterspouts only when the atmospheric conditions are such as to be favorable for thunderstorms.

Precipitation.—Rain is not invariable. When it does fall it may be extremely light to excessive. Upon the sudden disintegration of a spout, water sometimes falls as a cloudburst. In cold weather snow occasionally accompanies a spout cloud. Hail occurs as in thunderstorms, when convection is violent, and sometimes there is a fall of large and irregular ice chunks.

Sounds.—Faint and uncertain murmurings are sometimes heard prior to the completion of a spout, but when full development is reached, the sounds swell into roarings, grindings, and hissings, the volume depending upon the intensity of the disturbance.

Wind violence.—This is far less on the average than in the tornado, although the force exerted in the waterspout has not been determined as exactly as that in the land storm. Small vessels that have passed through spouts have often received only local damage, though sometimes there has been an overturning or a complete wrecking of the craft. Often the mischief wrought is as much due to the deluge of water as to the force and twist of the wind. The roarings which accompany a waterspout are occasionally sufficiently loud and terrific to indicate that the wind is rotating with great violence. Vessels, however large, do not take chances voluntarily with even the least formidable of these whirls.

Translatory speed.—Many spouts are practically stationary throughout their brief careers. Others are reported as traveling at a high rate of speed, estimated at from 50 to even 80 miles an hour. In the majority of instances the rate is in excess of 15 or 20 miles. The Cottage City waterspout had a speed of close to a mile an hour, as could be accurately determined, it being near land and under close observation with reference to known positions. The speed sometimes varies even among the members of a group, and regardless of the force of the surface wind, thus indicating differences in velocity of the adjacent air currents at the elevation in which formation occurs. It is observed that rapid forward movement sometimes occurs even though the surface air be calm.

Progression and verticality as related to wind direction.—The spout usually moves with, or nearly with, the current in which it has origin, the convection-formed type going with the surface wind, and the squall-formed variety with the upper current in which it becomes engaged. Therefore, the direction may be at any angle with or against the surface wind, whatever its force. When the wind is light, though variable, or steady and of the same direction from cloud to surface, the spout usually maintains a perpendicular position. Differences in wind velocity result in a backward or forward bending, which may be straight or curved. When the wind surfaces are strong and conflicting, the spout becomes variously contorted, or it may even be torn asunder at the weakest point, which is somewhere midway of the stem.

Length of path.—Owing to lack of continued observation points, the length of the path can not be determined for any waterspout the beginning or ending of which is beyond the range of an individual vision. Many spouts break up almost at the spot of formation, and since the average spout lasts for only a few minutes, it can proceed for only a few miles at the utmost. The average length is apparently far less than that of the tornado.

Life period.—Very few individual spouts are known to have existed for more than an hour or so. Usually they last less than half that time; and the average length of existence is probably not far from 15 or 20 minutes. In the present study, largely based upon original data, the life period has ranged from three minutes to slightly over an hour, with neither the time of beginning nor ending of the longest observed one known. Favorable conditions for spout formation sometimes last for several hours, many individuals forming and dissipating within eye distance during the period.

Size.—While the average size of waterspouts is not so great as that of land tornadoes, individual spouts sometimes attain to considerable dimensions. Some have been measured with precision from both land and shipboard points of vantage. Professor Bigelow (**7**) computed the following measurements for the Cottage City waterspout of August 19, 1896:

	Feet
Approximate length of tube	3, 600
Diameter of tube at base of cloud	840
Diameter of tube at middle	144
Diameter of tube at water surface	240
Diameter of base of cascade	720
Height of cascade	420

Measurements of a spout in Mobile Bay, June 12, 1925, indicated that it was approximately 2,600 feet high and 26 feet in diameter throughout its length. The cascade was some 10 feet high and 60 feet in diameter. The highest spout of which the writer has found accurate mention occurred off New South Wales, May 16, 1898 (**5**). By eye measurement on shipboard it was estimated to be 5,000 feet high. Theodolite measurements from shore confirmed this estimate and gave it a height of 5,014 feet. Some 4,500 feet of the tube was estimated to have a practically uniform width of 10 feet, greater widths occurring only along about 250 feet each of base and summit. Short spouts 200 feet and less in length are fairly frequent, but the most common lengths will approximate perhaps 1,000 to 2,000 feet. Some of the shorter ones are remarkably thick. One observed near Blunts Reef Light Vessel, California, November 14, 1914, was estimated to be 100 feet high and 700 feet thick. The longer ones are usually very narrow in comparison with their lengths, as in the instance of that off New South Wales. A spout seen off Rabat, Morocco, December 18, 1917, was said to have been 1,050 feet high and only 3 feet in diameter.

The principal size-determining factors are height of cloud, method of formation, whether at the surface or above it, and atmospheric humidity. With low clouds, or strong convection with or without clouds, and high relative humidity, the shorter and thicker as a rule will be the spouts. With more elevated clouds, high wind-shift surfaces, and lower humidity, the loftier and slenderer will they be. In connection with the humidity, it must be understood that a moderately high vapor content, at least, is generally necessary to spout production.

Condensation along the spout line.—Waterspouts that are formed by purely convectional processes sometimes, though not always, first materialize in visible form at the water surface. Often at the beginning the swirl development does not intensify sufficiently, or the dew-point temperature is not first arrived at, except at the level of the cloud which it sometimes induces, to cause much condensation. Whence, except for certain circular stirrings of the sea at the base of the whirl, the first visible intimation of its presence is the feeble downward projection at the cloud base. As the wind velocity in the upper part of the whirl increases, the condensation level progressively lowers and elongation of the visible line occurs. Usually before it has reached halfway to the surface, the lower end of the whirl similarly becomes visible through condensation, and the two projections then approach each other, meeting at the point where humidity is lowest, or the attaining of dew-point temperature is most retarded. Should the first cloudy cone rise from the sea, a similar appendage sooner or later drops to meet it from above, unless the column be extremely short. Sometimes, indeed, no visible spout forms, although there is an increase of wind to some little elevation, and all that is seen is a water whirligig which rises no more perhaps than a half dozen feet or less above the surface.

In the case of a spout originating at an elevated squall front most, if not all, of the column will invariably condense progressively downward, and only when the tip is near the surface will the cone from below sometimes rise to meet it. Thus there is frequently very little difference in the method by which condensation progresses, whether the wind-whirl originates at the surface or at the cloud level.

Waterspout shapes.—Like a pipestem, or a "huge circular tower," to quote from an observer, and of the same diameter throughout. These and similar descriptions apply to many. Others gradually narrow with descent until they come to comparatively little more than points at the surface. In some, but apparently in fewer instances, the reverse is true. Occasionally one bulges midway along the tube, seemingly breathing and throwing off vapor and water as it advances, though more frequently the diameter is least at some intermediate point, the narrowest portion occurring at the air layer where moisture content is least. Sometimes the width at both base and summit is much greater than along any other part of the tube, thus developing what is often spoken of as an hour-glass formation. Occasionally fantastic shapes and coils are observed, and if the latter occur, any contact of one part of the coil with another results in quick destruction to the whole.

Double-walled spouts.—There is no reason to assume that the usual waterspout has other than a single-walled tube, but that there are some with double walls is beyond question. An instance was reported by Dr. G. D. Hale Carpenter, of the Uganda Medical Service, as occurring on Lake Victoria (**8**). This waterspout was within 100 yards of the observer on shore, and the central core could be plainly seen, surrounded by a sheath, with a clear space separating the two walls. Several similar instances have been observed at sea. In one case on record, "after about 15 minutes the inner spout suddenly drew upward," while the outer one moved away and disappeared.

Currents in and about the core.—It is generally understood that the air rises spirally along the tube of the waterspout, although in many instances the circulation is invisible to the eye. The appearance of descending water, often noticed, probably is due to or results from the aqueous matter returning to the sea after being thrown out along the lower reach of the spout. Within the core itself ascending water has been reported on many occasions in instances where the envelope was more or less transparent, and descending air currents have likewise been reported. Franklin (**9**) makes reference to a calm-weather spout, the base of which came to within 8 feet of the sea surface. From its circular orifice issued a violent stream of wind, to quote, "which made a hollow of about 6 feet diameter in the surface of the water." Doctor Fassig (**10**) mentions the instance of a vessel which collided with and went through the center of a waterspout. During the passage several objects on deck were drawn upward, among them the captain's log, which went vertically into the air for 40 feet, or the entire length of the attached line.

The mound, or depression.—Within the base of the spout a mound of water has often been reported as observed rising to a height of two or more feet. This can be conceived of as caused by a forcing up of the sea water by reason of the lowered pressure within the spout wall, or by the violence of the winds; or the impression of rising water may be illusory, which is doubtful, considering the number of observations reporting it. Almost as frequently a basinlike depression has been mentioned, as though the water had been hollowed by rotary action, or by a violent descending air current, similar to the one already referred to in the preceding paragraph. While this depression sometimes apparently has been noticed in fully developed thin-walled spouts, yet it has been plainly seen on a few occasions in surface whirls that have passed in close proximity to vessels.

The cascade.—Similar to the débris-laden ground squall surrounding the foot of a tornado is the cascade, bush, or "bonfire," as it is sometimes called, enveloping the base of a waterspout. This is composed of dense vapor and spray hurled upward and outward from the agitated region, sometimes to the height of 100 feet or more.

LITERATURE CITED

(1) Hurd, Willis Edwin. Waterspouts. North Atlantic Pilot Chart, August, 1928.
(2) Humphreys, W. J. The Tornado. Mo. Wea. Rev., Dec., 1926, **54**: 503.
(3) Hellmann, Von G. Wasserhosen auf dem Atlantischen Ozean.
(4) Gibson, H. B. Waterspouts in the Gulf Stream in Winter. American Meteorological Journal, vol. 3, pp. 119–127.
(5) Russell, H. C. Waterspouts on the Coast of New South Wales. (Paper read before the Royal Society of N. S. W., Aug. 3, 1898.)
(6) Bigelow, Frank H. The Waterspout seen off Cottage City, Mass. Mo. Wea. Rev., July, 1906, **34**: 309.
(7) Ibid, vol. 34, p. 314.
(8) Nature, vol. 110, Sept. 23, 1922, p. 414; Mo. Wea. Rev., April, 1923, **51**: 209.
(9) Franklin, Benjamin. Philosophical Papers, Vol. II, p. 53.
(10) Monthly Weather Review, vol. 30, 1902, p. 302.

THE COLORADO RIVER SITUATION

By JAMES H. GORDON,

[Weather Bureau Office, Yuma, Ariz]

The student of meteorology can hardly let his interest in precipitation cease with the fall of moisture to the ground. He must care something what becomes of it, what it does and what is done with it on its way back toward to sea. So we find the Weather Bureau studying streams and rivers. The forecasting of stream stages, especially at time of flood, is hardly less important than forecasting the weather. Interest extends to stream flow for the purposes of navigation, for power development, and, in arid regions, for irrigation.

The Colorado River has long been one of the streams in which the Weather Bureau has taken an interest. Its flood problems are complex and serious. Its possibilities for power development are tremendous. Its use for irrigation is very important. Its waters are so greatly desired in "the land of little rain" that great cities will lift them over a massive mountain range to supply their needs.

It is not to be expected that the development of a river in which seven States are directly interested can be accomplished without battles over conflicting rights. The past eight years have seen such battles waged over the waters of the Colorado. And the war is not yet ended. The following paper is an attempt to discuss, as fairly as one man may see them, the essential facts of the present situation as regards flood control and use of the waters of the Colorado River.

The Colorado River is a resource of tremendous importance not only in the Southwest but to the whole Nation. It is estimated that development in the lower basin alone, from hydroelectric power, from reclamation of desert land by irrigation and from growth of cities made possible, may well represent a potential wealth of $14,000,000,000. It is a big proposition. To get the utmost from it there is need of a carefully worked-out plan of development. It is already bringing up questions of national policy that are of the utmost importance. National and State rights are involved. Care must be taken that injustice does not creep in. So far nothing has been done that will interfere with the carrying out of a carefully-considered, well-ordered plan to make the most of what the river can give.

The base of the situation is, of course, the river. It is not one of the great rivers of the world or even of the United States. It carries no commerce. Its average annual discharge of some 17,000,000 acre-feet of muddy water is barely 2 per cent of what the Mississippi can boast. The flow of the Nile is four times as great. The importance of the Colorado River lies in the value of its water for irrigation in an arid land and its tremendous potentialities in the development of hydroelectric power.

In the Colorado River Basin are some 120,000,000 acres of arid land, (Fig. 1), land with precipitation averaging less than 10 inches a year. Over thousands of square miles the rainfall averages less than 5 inches a year. For the entire basin the average depth of run-off is less than an inch and a half a year. The flow of the stream varies greatly from season to season. The annual discharge, as measured at Yuma, has ranged from ten to twenty-six million acre-feet in the last 26 years. The maximum flow normally comes in June with discharges occasionally reaching 200,000 second-feet. Not infrequently the late summer flow is barely sufficient to meet present irrigation demands.

For a thousand miles through its vast desert empire the river flows at the bottom of mighty canyons, as useless to the thirsty land as one of its own mirages. Only in the river valleys through which tributaries flow to join the main stream are irrigable areas. Along the lower river, after it has emerged from the deep canyons, re other areas that may be irrigated to advantage. Of the 120,000,000 acres of arid land in the Colorado River Basin there are perhaps 10,000,000 acres which might be classed as irrigable.

In the early days the chief problem of the Colorado was one of transportation, getting the wagon trains across. As river traffic developed low water and shifting sand bars tried the souls of steamboat men. Bigger problems appeared with the development of the Imperial Valley. Early in the sixties an Army engineer had seen