MOUNTAIN SNOWFALL OBSERVATIONS AND EVAPORATION INVESTIGATIONS IN THE UNITED STATES.

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INTRODUCTION.

The United States Weather Bureau has been conducting, under the supervision of the writer, a series of investigations of a practical kind in two directions. The first is the invention of an apparatus for catching and conserving the snowfall, especially in remote mountainous places, where observers are not regularly on hand, with the purpose of reporting a season's fall of snow in the form of its water equivalent. The second is an investigation of the laws of evaporation over lakes and storage reservoirs, wherein the snow water from the mountains is held for distribution by irrigation during the summer. These two problems have assumed unusual significance during the past decade in connection with the development of the irrigation projects in the Rocky Mountain and Pacific States under the United States Reclamation Service and private companies, as well as the study of the water resources for power sites by the United States Geological Survey.

COOPERATIVE WORK.

In order to facilitate the study of these interrelated problems and avoid the duplication of work, an arrangement was perfected in 1908, whereby these bureaus of the Government mutually assist each other in establishing stations, securing observers, and discussing the records. In a general way the Weather Bureau comes first in the program, because its duty is to collect the records of precipitation, temperature, and evaporation as part of the meteorological work in the United States. This duty is assigned to the Climatological Division, which has charge of the work of about 4,000 observers and the publication and scientific discussion of the recorded facts of observation. The other bureaus make use of these climatological data in many ways, the engineers of the Reclamation Service in connection with the erection of dams for storage reservoirs and the distribution of the water for farming purposes.

RELATION OF SNOWFALL TO AGRICULTURE.

The amount of snow in the high mountains varies greatly from year to year in consequence of the action of the great currents of moisture-bearing wind, which deposit more or less snow and rain, according to the general laws of circulation in the earth's atmosphere. If there is much snow in the mountains the rivers, the reservoirs, the ditches, and the farms will be abundantly supplied; if there is comparatively little snow on the high levels, then the engineer must economize all along the line. If a contract is made to supply so many acre-feet of water to a given district and water is not available on account of the causes in the great atmospheric circulation beyond man's control, it is important for the engineer to have his figures of probable water supply before signing the contract. This water once spread out in a great storage reservoir loses a large mass by atmospheric absorption, especially in the arid regions of the West. The water from a pan may evaporate anywhere from 10 inches to 200 inches a year, according to circumstances, and for a given reservoir in a particular climate the annual evaporation will be a certain number of inches. In the humid Eastern States the reservoirs lose by evaporation from 2 to 4 feet of water; in the arid Western States similar reservoirs would lose from 4 to 7 feet of water; the open irrigated land would lose from 6 to 10 feet, and some small elevated areas might lose as much as 15 feet of water annually. When an engineer goes into a new country to construct a reservoir, he wishes to know the general climatic conditions, the temperature, the humidity, and the prevailing wind velocity that he may determine how much water will be lost by evaporation, before he begins to build the dam. If the dam is too high and spreads out the water over too great an area, there will be too much loss by evaporation; if the dam is too low, its storage power will not be great enough for practical purposes.

THE ENGINEER'S INTEREST IN SNOWFALL.

The engineer needs such information in planning the dam for the project and the network of dependent distributing canals. Similarly, for power sites there is an economic connection between mountain snow supply and electric or waterfall power distribution. The Forest Service has much interest in the relations of the growth of trees on the mountains to the moisture-bearing winds; and the Bureau of Plant Industry has a strong reason for studying soil evaporation and plant transpiration. Hence it is easily perceived how wide a field of scientific research is open to the Government bureaus connected with this cooperative work.

THE SNOW FIELDS OF THE WEST.

The productive snow fields of the Rocky Mountains center in two principal foci, the first in Colorado, embracing the headwaters of the Colorado, Platte, Arkansas, and Rio Grande rivers and other smaller streams; the second in Yellowstone Park, in northwest Wyoming, whence flow the Snake, Missouri, Yellowstone, and Shoshone rivers. The Columbia River comes down from the Canadian mountains; and the Cascades, with the Sierra Nevada ranges, are the sources of many short streams in Washington, Oregon, and California. The highest snow-capped peaks of the United States are in the neighborhood of the 14,000-foot level above the sea, and there are many ranges which reach from 10,000 to 12,000 feet in elevation. The snow fields on these ranges afford beautiful sights for the travelers on the several overland railroad routes that pass within easy view. The snow appears during the summer in long streaks stretching down the mountain canyons and ravines, where it has been blown by the wind and compacted into regular ice blocks often of great extent and considerable depth. Such a snow range is the rampart of the Sierra Nevada Mountains seen from the Owens Valley, stretching north and south for several hundred miles, the glittering white crests shining in the sunlight. The snow melts very slowly at the high elevations where the air is cold at night, and only the top layer feels the rays of the sun during the day.

SOME USES OF WATER FROM MELTING SNOW.

Small lakes are formed as the snow melts, and streams of water run down the gulches, useful for power in their descent and invaluable for irrigation when spread out on the floor of the valleys below. If the water seeps underground, as is largely the case in the Owens Valley, it is found by experiment that about 75 per cent of it evaporates through the surface soil and is lost in the dry atmosphere. The Owens River and the Los Angeles Aqueduct run along the floor of this valley 8 or 9 miles from the rampart of the mountains, and yet only 25 per cent of the water discharging into the valley is available for the supply to the aqueduct. At Bishop, in the same valley, a large power plant transmits electric energy across country to the Goldfield mining district in Nevada, nearly 200 miles distant.

THE FORMATION OF RAIN AND SNOW.

On the western side of the mountains referred to above the irrigation of lands depends upon the snows, which are deposited thereon in winter by the winds blowing in from the Pacific Ocean. The water rises from the surface of the sea or ground by invisible evaporation, the power from which is afterwards used in the form of falling water under the force of gravitation. This gaseous vapor is blown about by the winds from ocean to continent and, rising in the air currents on the mountain sides, is gradually cooled, so that the aqueous vapor turns back to water as snow or rain, and falls on the mountains to be drained off rapidly if rain, or more slowly if snow, till it finally returns to the sea whence it came. We can imagine some drops of water in the blue Pacific a thousand miles from shore changing into vapor, borne along in the balmy breeze across the steamer's deck, thence over the Coast Ranges of California to the slopes of the Sierra Nevadas, where a portion of it turns back to water and is dropped, while a great billow sweeps across the deserts and rises a second time, on the Rocky Mountain ranges of Colorado, where more of it is condensed. Here the drops divide their comradeship, some flowing to the Gulf of Mexico, gradually to seek their way to Europe and the mountains of the East, others flowing to the Pacific Ocean through the Gulf of California, and so on through an endless succession of migrations and transformations from water to vapor and vapor to water.

THE SALTON SEA IN SOUTHERN CALIFORNIA.

The Gulf of California in ancient days extended northward between the mountain ranges nearly 200 miles beyond its present shore line, and the Colorado River, after cutting its gorge through the high plateau, emptied into the Gulf near the present town of Yuma. The silt-laden waters gradually formed a broad delta across the Gulf opposite Yuma to the Cocopal Mountains, and the river flowed on the hog-back of its own construction with meandering channels, spreading more silt to the north and to the south in turn and thus broadening its own delta. The spring freshets tended to overflow the soft banks, now on one side and now on the other, irrigating the gentle slopes in the most approved though natural manner.

In this way were formed the Salton Basin, whose lowest point in 1904 was 273 feet below sea level, and the fertile Imperial Valley, destined in that hot climate to be a garden spot for early fruits and vegetables. The Colorado broke its banks in 1904–5 and flooded the basin to a depth of 76 feet by 1906, making the Salton Sea, a lake 45 miles in length, 10 to 15 miles in width, and containing 440 square miles of surface. The ancient beaches are still distinctly seen on the land all around the sea at the height of 60 feet above the waters, showing where antique waves washed the shores. The entire country has also undergone elevations and depressions in the geological uplifts and subsidences. The Salton Basin has been filled numerous times with the Colorado floods and emptied again by the processes of evaporation. It is now losing water at the rate of 6 feet annually by evaporation; and is being replenished by inflows from the Blanco and New rivers, with what is practically Colorado River water, to the amount of 12 inches, and by natural precipitation to the amount of 6 inches, so that the actual annual loss is about 4.5 feet or 54 inches. In June, 1910, there was 62 feet of water in the Salton Sea, a loss of 13 feet since June, 1907. It is evident that in fifteen years the Salton Sea will be reduced to small dimensions, though the present annual supply of 18 inches will of course finally feed a small lake as fast as it evaporates, so that if the overflow from the Imperial Valley canals goes on indefinitely there is likely to be maintained a little lake at the lowest depression. The Liverpool Salt Company for years had been mining salt in the lower levels of the basin, deposited from the ancient evaporations, and the present waters are somewhat brackish.

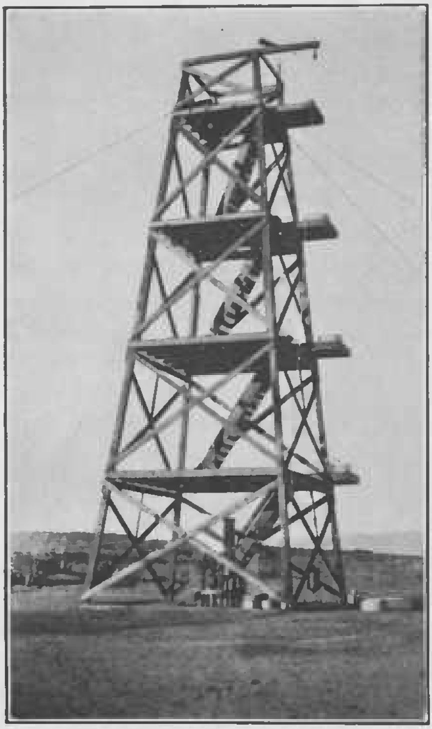

FIG. 1.—TOWER NO. 1, 1,500 FEET INLAND.

FIG. 2.—TOWER NO. 4, 7,500 FEET AT SEA.

TOWERS FOR STUDYING THE LAWS OF EVAPORATION AT THE SALTON SEA, SOUTHERN CALIFORNIA.

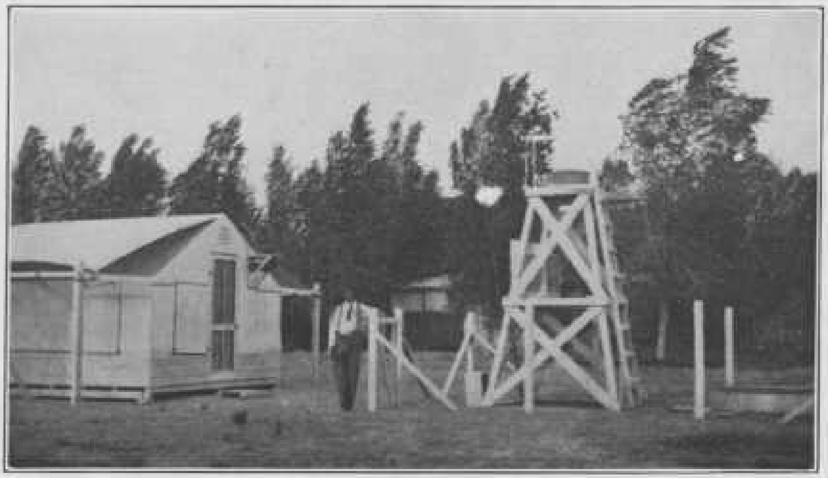

FIG. 3.—OBSERVING STAND, 10 FEET HIGH, FOR STUDYING THE FACTS OF EVAPORATION IN THE UNITED STATES.

In a geographic sense it is a long distance from the lofty, snow-clad crests of the Sierra and Rocky Mountains, where condensation and precipitation as snow and rain occur, to the Salton Sea, where vigorous evaporation is going on. The endless cycle is in process continually in nature on large and on small scales, on continents and oceans, on hills and lakes, on farm lands or on artificial evaporation pans. The scientific study of the laws controlling these physical processes can be conducted in nature's open laboratories in the field, or in man's laboratories beneath a roof. In the one the conditions are free and unrestricted, in the other constrained and incomplete.

On this account the formation of the Salton Sea afforded a large laboratory on a grand scale for studying evaporation, and the mountains a limitless workshop for investigating snow action, stream formation, and water resources generally. It is this vast field of investigation that is now occupying the serious attention of at least five great bureaus of the Federal Government. The procedure is the classification of the laws and the purpose is the practical advantage to the people of the United States. If a small percentage of the capital to be invested in these enterprises be applied to an intelligent study of the problems involved, it will become an insurance against unwise expenditures and improvident projects. This work has been advanced somewhat in three years, and a good beginning has been made, which should encourage further development and more profound study of the numerous difficult scientific questions coming to the front.

RESEARCHES REGARDING THE LAWS OF EVAPORATION.

Many investigations have been made regarding the phenomena and the theory of the evaporation of water from lakes and storage reservoirs in the past 50 years, but—although the amount of literature is very great—very few definite conclusions have been reached. In 1907 the United States Weather Bureau began an extensive study of this subject in cooperation with the United States Reclamation Service and the United States Geological Survey. The principal work was done at the Salton Sea in 1909–10, and at several neighboring stations, while other stations were operated in the Pacific and Rocky Mountain States, as well as in the Atlantic States. There have been about 125 evaporation pans under observation at 25 different localities, some near sea level, some on high plateaus, some in very dry climates, some in very humid climates, in all the latitudes, longitudes, and elevations of the United States, from Eastport and Key West to the Salton Sea and North Yakima. Hundreds of thousands of observations have been made, and their records classified and discussed. The method of attack was to adopt towers and stands with pans at the several elevations from the surface of the water or the ground up to the height of 40 feet. The lower atmosphere is characterized by considerable changes in the wind velocities from the surface upwards, increasing with the height; in the vapor pressure, decreasing with the height; and some lowering of the temperatures, so that pans placed at the several stages were evaporating under conditions slightly different and gradually changing. At Reno, Nev., five 50-foot towers were erected in 1907 at the city reservoir, and some practical experiences were acquired regarding the facts of evaporation and the formulas to express them. In 1909 a camp was established at the Salton Sea, and heavy towers were erected there, one on the land and three in the water, the farthest in being 7,500 feet from shore. At the subordinate stations 10-foot observing stands were raised, with a pan of water on the ground and another 10 feet above it. The research has been exceedingly complicated and difficult, but many new and valuable facts have been discovered.

A number of special pieces of apparatus have been used and tested. A simple burette tube gives excellent results for general field work, but the micrometer hook gauge is perhaps the most accurate instrument with a very efficient still well. Several pieces of magnifying gauges have been tried, but these need further consideration. An efficient automatic self-register has been in successful operation where a solid support is available. It will be necessary to adopt a standard pan, as a 4-foot pan, and a standard method of observing, since accurate readings of all pieces of apparatus depend upon the kind and the efficiency of the illumination of the water when measured, which is a difficult matter in rough weather and high winds, when evaporation is at a maximum.

A number of interesting special phenomena have been observed, as the change of the vapor pressure from a single diurnal period at the surface of the Salton Sea to a fine semidiurnal period at 40 feet above the water. The vapor blanket from the Salton Sea extends into the desert so as to begin to retard the rate of the evaporation at 1,000 feet inland in the middle of summer. The relative humidity over the sea changes from 75 per cent at the water to 50 per cent at the top of the towers and to 10 or 20 per cent at 1,000 feet inland.

It is found that perfectly satisfactory results can be obtained by observations at 6 a. m. and 2 p. m., the times of minimum and maximum meteorological influences, instead of every four hours of the day (2, 6, and 10 a. m., and 2, 6, and 10 p. m.) at which the regular program of 1909 was executed.

Plate XXVI shows the style of tower adopted both for the sea and land and the observing stands used in the evaporation investigations at the Salton Sea.