



By SAMUEL FORTIER,  
*Chief of the Division of Irrigation Investigations,  
Bureau of Public Roads.*

THE distinguishing feature of the climate of the far western States is its low rainfall. Over the greater part of this extensive territory the annual precipitation in normal years is less than 15 inches and over large areas it is less than 10 inches. The exceptions to this rule are to be found mainly on the higher ranges of mountains, which intercept moisture-laden winds and where there is a larger precipitation, chiefly in the form of snow. This snow, when lodged and compacted in deep mountain recesses, forms the chief source of water supply for irrigation.

If the snow which falls on the elevated ranges melted gradually so as to maintain a fairly equable stream flow during the irrigation season, much larger areas could be watered. Actually, the bulk of the snow melts quickly and the resultant run-off creates floods which carry large quantities of valuable water to the sea. In consequence there is a wide seasonal fluctuation in the natural flow of streams. For instance, the maximum flow of the South Platte River at Denver, Colo., is over 24,000 second-feet, while the minimum flow is 40 second-feet. That of the Rio Grande at Del Norte, Colo., is 14,000 second-feet in flood periods and 70 second-feet in low-water periods. The Salt River at Granite Reef, Ariz., has been known to carry 143,000 second-

feet, but 300 second-feet is the minimum. The Sacramento River at Red Bluff, Calif., carries 254,000 second-feet in flood as compared with a minimum flow of 4,000 second-feet in midsummer.

The greater part of the land of the western States is utilized chiefly for grazing purposes. The arable lands of the Rocky Mountain and Pacific Coast States constitute, it is believed, less than one-fourth of the total area. A part of these arable lands is irrigated, another part is farmed dry, while the remainder is still in its natural condition and is used chiefly for grazing. As closely as it can be estimated, the area at present irrigated in this country is, in round numbers, 18,000,000 acres, and the area for which water is available throughout the 17 western States does not exceed 50,000,000 acres, or less than 5 per cent of the total area. It follows that more than one-third of the total area of western lands susceptible of irrigation has already been reclaimed, that in a broader sense the revenue to be ultimately derived from irrigated products will be largely dependent upon economical use of water, and that the utilization of the limited water supply sets a fixed limit to further production under irrigation. It likewise follows that if only 5 acres out of every 100 acres can be ultimately irrigated, owing to the lack of water, a premium will be placed on the relatively small areas for which water is available. Such lands will be called upon to produce sufficient forage to feed range stock during severe storms in winter; and when droughts occur and dry-land crops partially fail, the crops grown on irrigated fields will constitute the farmer's main dependence. At present the trend is in this direction. In recent years the farmers of the West have depended more on their irrigated holdings. The prevalence of droughts, the small average yearly returns from dry farming, the high prices of many irrigated products, and the scarcity of labor have exerted more or less influence in causing farmers to concentrate their efforts to a greater degree on relatively small irrigated tracts and to bring these to the highest state of production. This, in turn, has created a greater demand for water, increased its value, enhanced the price of irrigated land, and awakened a desire to lessen the waste of water by the adoption of better appliances and by more skillful use.

## Two Kinds of Irrigation Farmers.

The irrigators of the West may be classed in two groups, those under Government projects and those under private irrigation enterprises. The reclamation act, under which Government projects have been built, provided, as first passed, for the repayment of the cost of the water right in not more than 10 yearly installments. This was found to be impracticable, and by an amendment passed in 1914 the period of paying for a water right was extended to 20 years. In no case is any interest charged. The interest exemption is important. The interest at 4 per cent per annum on deferred payments, if compounded annually, would amount to over 80 per cent of the construction charge. Furthermore, several years intervene, on an average, between the time of construction and settlement. If the interest for this period were similarly computed and added, it would increase the total charge to over 100 per cent. In other words, the United States grants a bonus to all settlers on projects operating under the reclamation act, equaling, if not exceeding, the construction cost of the works by the exemption of all interest charges on deferred payments. Over 400,000 people living on or dependent on Government reclamation projects are at present receiving the benefits of these liberal terms. They pay no interest whatever on an expenditure of nearly \$125,000,000 made by the Federal Government in their behalf.

The Nation has not been so liberal in dealing with the second group, those under private irrigation enterprises, and yet this class constitutes more than 90 per cent of the total. Before the war Congress granted to the Department of Agriculture, for the investigation of irrigation problems, an annual appropriation of \$102,440, but this amount has since been reduced, and for the current year it is \$62,440. When this fund is distributed over the 17 western States, not to speak of the irrigation of rice in the Gulf States and the irrigation of truck crops along the Atlantic coast, the amount available for any one State is quite small. In many cases, however, Federal funds are augmented by State funds under cooperative agreements. Before the war, when a larger appropriation was available, it was possible to contribute dollar for dollar with the States cooperating. Since the funds for

this purpose were reduced, it is seldom that this can be done, but several States and State institutions, rather than abandon the cooperative investigations, are now contributing more than is allotted by the Department of Agriculture.

### The Need of Stored Water.

In the irrigation of over 16,000,000 acres under private enterprises of one kind or another little storage has been provided. The greater part of the canal systems are dependent on the natural flow of the streams for their water supplies. During periods of high water large quantities are diverted and wastefully used, while in July, August, and September, when the most profitable crops require the largest amount of water, little is available. In many localities in the West the storage of a relatively small quantity of water to tide the farmers over the low-water period would result in a doubling of the area irrigated and a like increase in the profits obtained. The reasons that so few dams have been built to impound irrigation water are mainly the cost of such structures and the difficulties encountered in financing them.

Under private enterprises large numbers of independent canals and ditches divert water from the same stream, resulting in low efficiency and much waste. None of these small enterprises is financially able to build the usual type of storage dam costing up into the millions of dollars. It is seldom that a number of such enterprises, when cooperating, can undertake a work of such magnitude. About the only feasible solution of a problem of this kind is to induce all the water users on a stream to merge their interests in a single organization, such as an irrigation district, and in this way provide sufficient security to float long-term bonds with which to obtain money to build the necessary storage works. In work of this kind the human problem is the most difficult to handle. When hundreds, and in many cases thousands, of farmers must be persuaded to cooperate and come within the jurisdiction of a single governing body, it is difficult for local men, on account of animosities of long standing, to unite diverse interests. Such a task, as recent experiences have demonstrated, is much less difficult when undertaken by a representative of the Federal Government. The Govern-

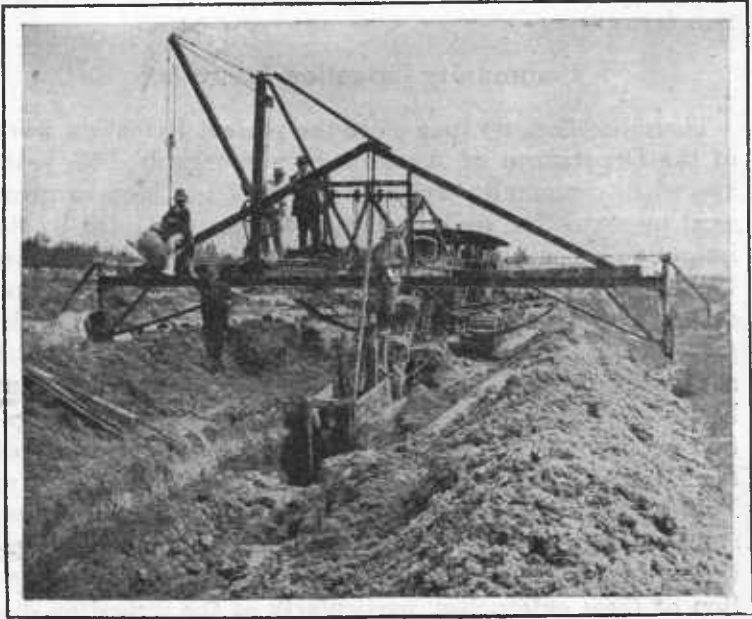
ment engineer is not supposed to know anything of local factions, jealousies, and disputes. He has no private interests to serve, and his best efforts are devoted to improving the condition of the community as a whole. A small amount of money expended in helping communities to make the right kind of start in this direction and in exercising a general supervision over their organization, management, and construction could not but result in lasting benefit to the irrigation farmers.

### Community Irrigation Interests.

There has been no time since the present irrigation work of the Department of Agriculture was organized 21 years ago when community irrigation activity has been so great as at present. The seed of cooperation early planted by the irrigation pioneers of Utah, Colorado, and California has brought forth an abundant harvest of cooperative and mutual irrigation companies and irrigation districts. The principle of ownership and control by irrigators of the water and works upon which their agriculture depends has thus become so firmly established as to be a fixed western irrigation institution. In one way or another the specialists of the Division of Irrigation Investigations of the Bureau of Public Roads have studied at close range the organization and operation of nearly every important community irrigation enterprise in the country, and to a considerable proportion of these enterprises, particularly of the irrigation districts, they have rendered substantial help. Possibly even more important than the help rendered to individual irrigation districts has been the help rendered in revising and establishing our present body of irrigation-district laws. This has largely had to do with encouraging the strengthening of State supervision over the organization and the financial management of districts, which in turn has made at least home markets for irrigation district securities that but a decade back, because of early mistakes under noncontrol and nonsupervision by the States, were hardly salable at all.

In Utah the irrigation district problem is the consolidation into more efficient single systems of the numerous independent, wasteful, often paralleling ditches, shovel-built in early days by the sturdy followers of Brigham Young.

To cite only one instance, engineers of the Bureau of Public Roads are helping the farmers about Ogden in the formation of a single irrigation district of 93,000 acres within which over 40 independent systems, operating under 149 separate and distinct water rights, now furnish irrigation water. Through lack of storage of flood waters much of this area now receives water only in the early summer, much of it has



Modern Machines for Extensive Work.

Excavator at work on a trench for tile on a drainage district in Wyoming.

none at all, and much of it is so overirrigated in months of plenty and so affected by seepage from leaky ditches as to be unsuitable, until reclaimed. Specialists of the bureau have a thorough knowledge of the resources and latent wealth of this locality and, in conjunction with representatives of the State engineer's office, the Utah Agricultural College, and the local farm bureau, are awakening the interest of the community in the utilization, through united effort, of these neglected opportunities.

The more important present irrigation district movements in California are a little different from those in Utah just

described. They involve in some instances a similar consolidation of present smaller systems; but, more important, they involve cooperation in storage construction on a larger scale than heretofore attempted by community irrigation enterprises in this country. A representative of the Department of Agriculture has recently ascertained that the six California major irrigation districts now actively constructing or planning new or additional irrigation works expect to require more than \$100,000,000 for construction purposes during the next five years. In fact, the total reported as needed in the next 5 to 10 years by existing California irrigation districts and those far enough along in their organization plans to make them of live present interest is \$174,000,000. While all of the expenditures now under consideration are not likely to be made within the next decade, the mere statement of the amount shows the present importance of the community irrigation movement in this State and suggests the call that comes to the Division of Irrigation Investigations.

### The Drainage of Water-Logged Lands.

Community action is likewise necessary in the drainage of wet lands. It is seldom that the individual farmer can find, at a reasonable cost, an outlet for waste water. He must as a rule cast in his lot with his neighbors and with all those whose lands are being damaged. Thus the drainage district is very similar to the irrigation district in form of organization, but differs from it in the object to be attained.

No census has ever been taken of the extent of irrigated lands needing to be drained, and, if attempted, such a census would be difficult to take on account of the large number of classes under which water-logged lands might be listed. It is perhaps not far from the truth to state that 10 per cent of the irrigated lands have been rendered well-nigh worthless through water-logging and the rise of alkali, and that a larger percentage of the remainder is being more or less injured from these causes. A community having a large percentage of what formerly constituted its most productive lands rapidly becoming practically worthless is in a pitiable condition. Without organization, money, or a knowledge of

the remedies to be applied, they are apt to stagnate. It is at this stage of proceedings that the drainage engineer of the Department of Agriculture can render the most effective service. By making a technical examination of the lands needing drainage as well as those menaced by a rising water table, estimating the cost, and outlining a drainage district and its organization, he can usually at small cost start such communities on the road to prosperity by pointing out what is needed, helping them to organize and exercising a general



Getting the Land Ready.

The tractor replaces a four-horse team in throwing up borders on land previously leveled.

oversight over the construction of a drainage system. Such supervision is being exercised to-day with satisfactory results in a dozen Western States, and might be greatly extended if more funds were available.

### The Preparation of Land for Irrigation.

After a water supply has been provided and conveyed to the highest corner of each farm, a large amount of labor and money have to be expended in grubbing out sagebrush, plowing, leveling, and grading the surface of fields, building the necessary supply and field ditches with their accompanying structures; in short, preparing the land for



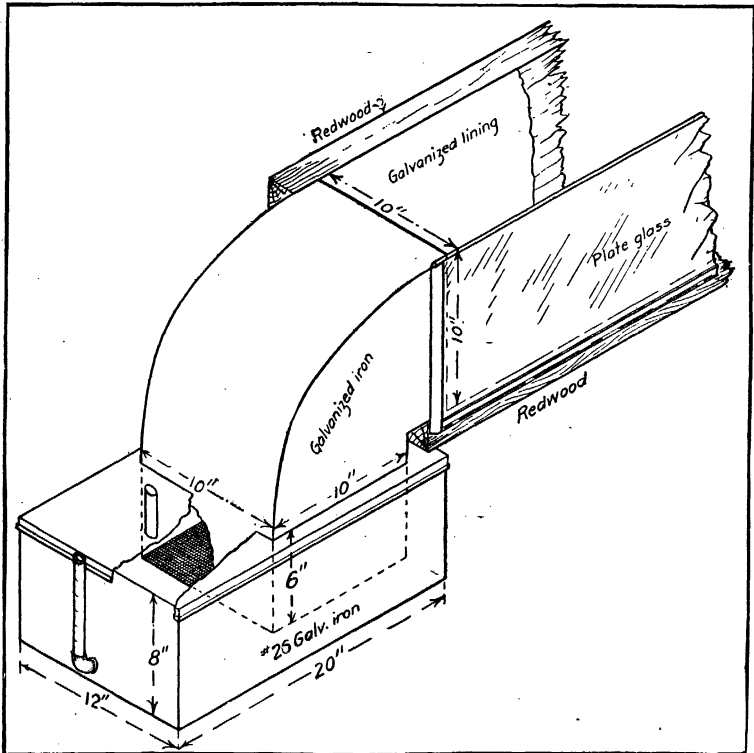
efficient irrigation and profitable crops. The manner in which this work is done determines in a large measure the profits derived from irrigation farming. It pays to prepare the surface of fields in a thorough manner. Measured in capital invested for the betterment of the irrigated farm, the difference between a field poorly prepared and one well prepared would not exceed, as a rule, \$12 an acre. The interest on this investment at current rates would be about \$1 a year. The benefits to be derived from this investment, which costs \$1 per acre per annum, would consist in larger yields, a better quality of crops, a reduction in the waste of water, labor saved in irrigating, lessening the risk of water-logging soil, and enhancing the value of the farm.

Efforts have been made to adapt the methods used to local conditions. At least nine standard methods have been developed and put in practice for the preparation of land and the application of water. It is no easy task to choose the right one, and any assistance offered to water users either in the form of published reports or advice bearing on this subject is not only gladly received but put to good use.

### Soil Moisture.

Soil moisture is that form of moisture held in the soil by capillarity and available for plant use. The popular conception is that this moisture may move around in the soil quite freely and somewhat rapidly. Especially is it thought to move upward to the soil surface freely and from considerable distances. Experimental work by the Division of Irrigation Investigations upon the capillary movement of soil moisture from a wet or damp soil to a dry soil has demonstrated that the popular idea is erroneous. This work showed that the lateral movement of soil moisture by capillarity during a period of 30 days through a distance of 6 inches in a loam soil was less than half enough to support an alfalfa crop. During the same period of time, moisture did not move from the wet soil 18 inches laterally into the dry soil. Barley plants, the roots of which were confined within a space 6 inches square, within a body of wet soil, thrived for about 30 days, then began to wilt, and within two weeks more were all but dead for lack of moisture. Analysis of the soil showed plenty of moisture at 2 inches from the roots.

The upward movement of soil moisture is not so rapid or extensive as the lateral movement. Numerous experiments gave results tending to show that the downward movement of soil moisture by capillarity over a period of 30 days was approximately one and three-fourths times as far, and that twice as much moisture moved down as up. Gravity is work-



Testing Movement of Soil Moisture.

Isometric view of open flume connected by wick to supply tank from which soil obtained moisture.

ing all the time upon soil moisture, tending to pull it down below the plant roots. The experiments have demonstrated that capillary moisture is influenced greatly by gravity and that soil moisture, once below the root zone, is all but entirely lost in so far as nourishing plants is concerned. Numerous tests have shown that capillarity will not move it through even a few inches rapidly enough or in sufficient quantity to grow and mature a grain crop or support an alfalfa hay crop.

The capillary movement of soil moisture from a body of free water into a body of dry soil differs only in degree from the movement of moisture from a wet soil into a dry soil. The upward movement of the moisture in a loam soil from ground water will be farther in one day than it would be in 30 days from a body of wet soil and the quantity of moisture moved would be even relatively greater. In a very fine loam soil of high capillary power it was found that if barley roots did not reach within less than 40 inches of the ground water, the plants would not mature. Sufficient moisture would not reach the roots to satisfy the plants' needs.

The downward movement of moisture by capillarity, when the source of moisture is free water, may extend indefinitely in distance and may be relatively quite large in quantity. In fact, bogs may be formed in this way.

The experiments indicate that gravity is a very potent factor in soil-moisture movement and that one great value of capillarity is to hold the moisture and cause its relatively slow transference from one soil particle to another.

### Irrigation Water from Underground Sources.

Water for irrigation from underground sources may be obtained from springs, flowing wells, or pumped wells. The irrigated area in the 17 western States in 1909 was reported at about 13,750,000 acres. Of this total, the surface-water supply irrigated an area of about 13,056,000 acres, spring-fed supplies about 200,000 acres, flowing wells about 140,000 acres, and pumped wells approximately 300,000 acres. It is thus evident that at that time pumped-well water was the second greatest source of supply for irrigation. At the present time there are no authentic data published showing the changed aggregate or the proportion of each of the above classifications, but the data obtained in the cooperation this division has extended to various outside agencies indicate a rate of development of irrigation from pumped-well supplies far exceeding that of any of the other three classifications. In California, which has done most in making use of underground water, records show that in 1909 there were 9,297 pumping plants in operation, irrigating 277,000 acres. In 1914, this number had increased to 24,589 plants, and to-day it is estimated that there are 30,000 pumping plants, irrigating between 750,000 and 800,000 acres. New Mexico

probably follows, with Utah, Colorado, Nevada, and Arizona showing rapid increase in development, though not in proportion to that of California. With proper encouragement and assistance, there are vast possibilities in the extension of irrigated areas from pumped supplies. Only about four years of extensive research in Utah has resulted in the sinking of wells in Cache Valley, Utah Valley, Uinta Basin, and in southern and southeastern Utah, with the development of the underground water of that State only begun. There are possibly more appeals from farmers for assistance and more requests for information on this subject addressed to the Department of Agriculture than on any other pertaining to irrigation. Cooperative agreements with 6 of the 17 western States include work on underground water supply, study, and development, and there are petitions from other States for such aid.

Furthermore, there are areas in several of these States where water applied from surface sources has percolated through the soil of the higher lands and water-logged the lands of the lower levels. Pumping from wells or trenches sunk on these lower areas not only lowers the water table of the water-logged lands and therefore reclaims them, but in addition furnishes water for higher lands supplied from the surface water system.

### The Distribution of Irrigation Water.

As has been pointed out, the bulk of the water supply for the irrigated farms falls upon elevated ranges. If uncontrolled this water would flow down natural channels unutilized and eventually would be lost in the ocean or would evaporate. For its utilization laws are passed, regulations formulated, administrative officers appointed, and water courts created. So important has legislation regarding water become in many of the western States that a large part of the laws on the statute books relate to this subject. Much money has likewise been expended in building diversion works and channels. If the main canals and laterals built to convey irrigation water in this country were placed end to end, they would encircle the globe six times. Some of these structures and canals are well designed and built, but the large majority are mere makeshifts.

As an aid to the proper control and distribution of irrigation water, the engineers of the Division of Irrigation Investigations have sought to improve the laws relating to the control of public waters, render State administrative systems more effective, determine the water requirements of different types of soils, design better structures, and increase the carrying capacity and efficiency of channels. In investigations of this character the main object sought has been to benefit the many rather than the few. The data collected regarding the service which water performs in irrigating crops and the quantities of water which should be allotted to definite tracts of land have been widely disseminated, and all are at liberty to make free use of this information. The same is true of the results of experiments to ascertain the carrying capacities of canals, pipes, and other conduits. All conduits should be large enough to satisfy the requirements of the lands they serve. On the other hand, all money expended in making conduits larger than necessary is wasted. Although the farmer may have no part in making these highly technical adjustments, he is always an interested party, since he pays the bills. At first thought it would appear that water has been conveyed from place to place for so long a time that all the fundamental facts relating to flow have become known to hydraulic science. While this is true in a degree, the new materials used and the new types of conduits which have been devised and introduced into general practice during the past two or three decades have rendered many of the old formulæ obsolete.

Transmission losses in earthen channels being one of the largest sources of waste, the use of concrete has recently been investigated with a view of making a stronger, more uniform and more serviceable pipe of this material. A cooperative arrangement was entered into with the State engineer of California and the California Concrete Pipe Association, by which the materials used in making pipe have been carefully investigated, the proportions of the several ingredients, including water, standardized, and numerous specimens and joints of pipe tested. As a result the weak, porous, and improperly made pipe can no longer be classed as good pipe, and a much higher standard has been adopted for all pipe made by the association.

### The Economical Use of Water.

In many of the western States fertile raw land is cheap and abundant, but water is valuable and scanty. This fact can not be too often reiterated or too strongly impressed upon all. As a result of long-continued and carefully conducted experiments the amount of water which different crops require under any given set of conditions of soil and climate has been fairly accurately determined, but much remains to be done in conveying water to the place of use with the least possible loss and in spreading it over the surface of soil so as to minimize the losses due to evaporation and deep percolation. Notwithstanding all the improvements brought about in the past 20 years, it is doubtless still true that on the average for every 3 gallons of water diverted from streams only 1 gallon serves to nourish plant growth. Were it possible to convey and use water in irrigation with the same degree of efficiency that electric current is transmitted and applied the water now used and wasted might serve double the present area. Here, too, the activities of the Division of Irrigation Investigations are accomplishing beneficial results. The demonstration in all the larger irrigated centers that larger yields and a better quality of crops can be grown with a medium rather than an excessive amount of water is leading farmers to realize that the use of too much water is a detriment in that it water-logs their soil, causes the alkali to rise, and otherwise injuriously affects both crops and soil. However, the waste of water is not wholly due to the farmer's carelessness or lack of skill. It arises from absorption and percolation losses in canal systems, in too liberal allowances granted by judges in issuing decrees, and in defective State laws and administrative systems.