UNIVERSITY OF ARIZONA
College of Agriculture
Agricultural Experiment Station

USE AND WASTE OF IRRIGATION WATER
By G. E. P. SMITH

An irrigation canal near Tempe, Arizona

PUBLISHED BY
University of Arizona
UNIVERSITY STATION
TUCSON, ARIZONA
ORGANIZATION

BOARD OF REGENTS

EX OFFICIO MEMBERS

H.E. EXCELLENCY, GEORGE W. P. HUNT, Governor of Arizona
HONORABLE CHARLES O. CASE, State Superintendent of Public Instruction

APPOINTED MEMBERS

ANTHONY A. JOHNS
THEODORE MARSH, Treasurer

JOHN M. CAMPBELL, LL.M
EVERETT E. ELLIWOOD, LL.B., Chancellor
CLIVE W. VAN DYKE, Secretary

CHARLES M. LAYTON
JOHN J. COUGHLAN
ROSE KIRKPATRICK

CLOYD K. MARTIN, Ph.D., LL.D

President of the University

AGRICULTURAL EXPERIMENT STATION

JOHN J. THOMAS, A.M.
JAMES C. BROWN, M.S.
WALTER E. BRYAN, M.S.
PAUL H. BURGESS, Ph.D.
WALTER S. CUNNINGHAM, B.S.
GEORGE E. SMITH, C.E.
CHARLES T. VORISHER, Ph.D.

CLIFFORD N. CATLIN, A.M.
NARRY EMBLETON, B.S.
RALPH J. HAWKINS, M.S

FRANK B. STANLEY, M.S.
DAVID W. ALBERT, B.S.
SAM W. ARMSTRONG, B.S.
CARL A. KIRSCH, M.S.
STANLEY F. CLARK, B.S.
RICHARD N. DAVIS, B.S.
ALLEN F. KERNISCH, B.S.
C. GORDON FORREST, M.S.
ELIAS H. FRESSLY, M.S.

NARDO C. SCHWALB, B.S.

EVERETT L. SCOTT, M.S.
HOWARD W. SMITH, M.S.
ROBERT B. STREET, Ph.D.
MALCOLM F. WHARTON, M.S.

EXPERIMENT FARM FOREMEN

C. J. WOOD
T. L. STAPLEY
J. G. HAMILTON, B.S.
CARL CLARK, B.S.
F. G. GRAY

AGRICULTURAL EXTENSION SERVICE

J. E. REED

AGENTS

SPOTUS H. ROSS, B.S.
ALANDO B. BALLANTINE, B.S.
STELLA MATHERN, M.A.
LOUISE A. BOGS, B.S.
RICHARD N. DAVIS, B.S.
DONALD A. GILCHRIST, B.S.

BYRON J. SHOWERS, B.S.
CHARLES U. PICKELLE, B.S.

COUNTY HOME DEMONSTRATION AGENTS

FALLEN A. BENFIELD, B.S.
ROSA BOUTON, A.M.
CRACK RYAN
LAURA M. SEWARD, B.S.
ELIZABETH MURPHY, B.S.

COUNTY AGRICULTURAL AGENTS

CORNELIUS B. BROWN, B.S.
FRANCIS A. CHERRIS, B.S.
ROGER H. COGHLAN, B.S.

CHARLES R. FURR, B.S.
LS. H. GUILFORD, B.S.
JAN E. MIGLIORE, B.S.

DAVID W. ROGERS, B.S.
CHARLES A. SMITH, B.S.

KARL A. STEWART, B.S.
EDWIN W. TURVILL, B.S.
JOHN W. WRIGHT, B.S.

Tucson
Phoenix
Yuma
Cochise
Gila
Pima
Pinal
Pima
Pima
Pima
Pima
Pima
Pima
Pima

CONTENTS

INTRODUCTION .......................................................................................... 273
TRANSPIRATION ....................................................................................... 274
WATER LOSSES ....................................................................................... 277
  Losses from canals and field laterals ........................................... 277
  Evaporation from irrigated fields ................................................. 279
  Seepage loss from irrigated fields .............................................. 281
  Willful or careless waste .............................................................. 286
EFFICIENCY OF IRRIGATION ................................................................. 287
IRRIGATION RULES ............................................................................... 291

ILLUSTRATIONS

An irrigation canal near Tempe, Arizona Cover Cut
Fig. 1.—Border irrigation from a concrete-lined ditch Frontispiece
Fig. 2.—Cleaning a canal with a giant "Vee" ......................... 276
Fig. 3.—Lining an irrigation ditch with concrete ............... 278
Fig. 4.—Class A evaporation station, Salt River Valley Farm ... 280
Fig. 5.—An orchard ruined by a rising water table .............. 282
Fig. 6.—Cotton field with poor stand due to shallow water table 283
Fig. 7.—An alfalfa field irrigated in corrugations ............... 284
Fig. 8.—Diagram showing distribution of irrigation water into
  useful portion and various losses ........................................... 287
Fig. 9.—Layout of an irrigated field for efficient irrigation .......... 289
Fig. 10.—Division gates on the Main Consolidated Canal near
  Mesa, Arizona ........................................................................... 290
Fig. 1.—Irrigation by flooding from a concrete-lined ditch on the ranch of B. A. Fowler near Phoenix. The "head" of water is evenly divided into three "lands". There is no seepage loss from the ditch, no ditch cleaning, and the water is easily controlled.
USE AND WASTE OF IRRIGATION WATER

By G E P Smith

INTRODUCTION

What becomes of the irrigation water? The irrigator knows that in a general way the water is beneficial, in fact, is necessary; he does not know just where the water goes after it sinks into the ground, nor does he know just how much of the water applied to the land actually does useful service and how much of it is wasted. In the early days of irrigation in any country, the chief interest and energy are exerted in developing the water. But when the water supplies are so fully developed as they are in Arizona at the present time, then farmers and others interested in agriculture must study the efficiency of irrigation in order that waste of water may be reduced and the water supplies may be made to serve as large an acreage as possible. It must be confessed that in some communities the various losses of irrigation water aggregate as high as 80 percent of the total quantity of water diverted from the stream. If the losses in such a community can be cut down to 60 percent, the remaining useful portion is increased from 20 percent to 40 percent, that is, it is increased two-fold. There are, indeed, inviting possibilities of doubling the irrigated area in certain Arizona valleys where already the entire water resources are assumed to be fully developed.

A survey of the water supplies of the State (March, 1925) indicates a shortage in the supply for the coming season on all streams except the Colorado. The Roosevelt Reservoir contains about one-fourth of its full capacity. Reservoir supplies must be conserved as far as possible, in the fear that the dry year just past may be followed by another equally dry. It is very pertinent, therefore, that this year the farmers should make a special study of their methods of irrigation in the effort to conserve the water supplies to the utmost.
Plants, like animals, breathe. The surfaces of leaves, and to a less extent of stems, are covered with innumerable minute breathing pores. Through these small openings, carbonic acid gas is taken in from the atmosphere and moisture is given out. It is a vital function of all plants to gather moisture through their roots and to expire the moisture through the minute stomatal pores into the air. Plant growth is dependent in large measure upon the presence of an abundant supply of soil moisture. Surely the irrigating water which actually passes through the plant in this way does a most useful service; all that portion of the irrigating water which does not pass through the plant is wasted, so far as crop production is concerned.

The transpiration rate, even for the same plants, varies greatly according to climatic conditions, being least in humid countries and increasing greatly with aridity. The rate must be high in Arizona. Like the evaporation rate, it depends upon the temperature, the wind movement, and the relative humidity. The characteristic of high transpiration rate in this State must be acknowledged.

Many investigators have measured the quantity of water transpired by various plants. Briggs and Shantz of the United States Department of Agriculture* conducted extensive tests of this kind in northeastern Colorado. Some of their results are given in the following table, in which the transpiration is stated as the number of pounds of water required to produce a pound of dry matter. This is sometimes called the transpiration ratio. The soil used was "rich, dark loam."

When the production of grain alone was considered, the water requirement of wheat was found to be 1,357 pounds of water per pound of dry matter, and of sorghum 790 pounds of water. The sorghum

<table>
<thead>
<tr>
<th>Crop</th>
<th>Pounds of water per pound of dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>1,068</td>
</tr>
<tr>
<td>Barley, average of 4 varieties</td>
<td>539</td>
</tr>
<tr>
<td>Wheat, average of 5 varieties</td>
<td>507</td>
</tr>
<tr>
<td>Potato</td>
<td>448</td>
</tr>
<tr>
<td>Corn, average of 3 varieties</td>
<td>369</td>
</tr>
<tr>
<td>Sorghum, average of 5 varieties</td>
<td>306</td>
</tr>
</tbody>
</table>

family of plants is specially adapted to arid climates and in particular to those localities where the limitations of water supply are felt seriously. It is evident, too, that alfalfa is the water gourmand, which suggests, therefore, that farmers, especially those under pumping plants with high lifts, should restrict their alfalfa to the amount needed for feeding their necessary stock.

Most investigators believe that the texture and tilth of the soil and the fertility have a pronounced effect on the transpiration ratio. Thus, on clayey soils and very sandy soils, plants transpire more water per unit of crop produced than on good loam; and comparative tests have shown the water requirement on sand and clay to be reduced more than 50 percent by the addition of fertilizers. On rich loams, however, the addition of fertilizer appears to have little effect upon the ratio of water transpired to crop produced.

It is not likely that the actual transpiration ratios in broad fields are so high as given in the table. Nevertheless, the table indicates the relative transpiration ratios of different crops and the possibility of tremendous demands for water by plants under adverse soil and climatic conditions.

The water requirements of crops in Arizona have not been determined in an entirely adequate manner. Observations and certain records indicate that, for the Salt River Valley, alfalfa that is grown continuously through the summer should have about eight 6-inch irrigations per year on medium loam soil, and about twelve 4-inch or 4½-inch irrigations on sandy soils. Cotton requires from 2 or 2½ acre-feet per acre on fertile loam soil to 3 acre-feet on light sandy soil and new desert soil. Wheat or barley requires about 1½ or 2 acre-feet per acre, and milo requires 1½ or less. The yield of alfalfa increases almost in proportion to the amount of water applied. The yields are about 5 tons per acre for 3 acre-feet, and 8 tons per acre for 6 acre-feet, even up to 7 acre-feet per acre. With grain and other crops, the yield is reduced by applying more than the optimum amount. The duty of water is higher in some cases due to subirrigation from a shallow water table.

There is one school of irrigators in the Valley who do not irrigate alfalfa during part of July and through August. Allowing the alfalfa to rest during this period tends to keep out water grasses and tends to avoid damage by insects. Under this system the water requirements are less than the amounts stated above, and the total yields also are reduced.

The climatic conditions vary somewhat from year to year. In 1918 and again in 1924, the summers were notably dry and the water requirements of crops were more than during normal years.
WATER LOSSES

The water transpired by plants constitutes, ordinarily, but a small part of the total water diverted for irrigation. Beginning at the point of diversion, the supply stream suffers continuous losses. The sequence of these losses is as follows: (1) seepage (and evaporation) from canals, and seepage from the field laterals; (2) evaporation from the irrigated fields; (3) seepage from the fields; and (4) willful or careless waste. These losses will be discussed separately and suggestions will be offered as to how they can be reduced.

LOSSES FROM CANALS AND FIELD LATERALS

Earthen canals are more or less porous; new canals in sandy soils are sometimes little better than sieves. Most of the irrigating waters taken from streams in Arizona carry considerable fine silt; and this silt, settling in the canals, forms a blanket and reduces to some extent the excessive losses which occur in new canals. Since the construction of the Roosevelt Reservoir, the proportion of clear water carried in the canals of Maricopa County has increased greatly, and the loss by seepage from the canals has increased correspondingly.

Measurements of seepage losses on scores of ditches and canals in the Western states have been compiled and published.* The results are startling. Losses of over 10 percent per mile are not infrequent, and it is concluded that "a large percentage of the water, estimated at 40 percent of the amount taken in at the heads of the main canals, is lost by absorption and percolation along the routes." The records of the United States Reclamation Service in the Salt River Valley** state that during the years 1912 to 1917 inclusive, the canal losses between the Granite Reef and Joint Head diversion dams and the points where water is delivered to the water users were from 40 to 45 percent of the total amount diverted. While the losses as given in the records are much overstated, it is estimated that one-third of the water diverted is lost in the canals. The loss from the Avondale Canal was shown in one test to be 40 percent in the first 4 miles.

Practically all of the loss in canals is by seepage, for the loss by evaporation is small. The evaporation from a free water surface during the summer months at Tucson averages 10 inches per month in depth. On that basis a canal with a water surface 10 feet wide and carrying 2S

---

*U. S. Dept. Agric., Bull. No. 126, 1914. This bulletin, designed for irrigation engineers and superintendents, contains descriptions of many concrete linings.

**Reclamation Record, Vol 9, No. 11, Nov., 1918, p. 532.
second-feet of water would lose just 1 acre-foot per month per mile by evaporation, while the total discharge in the same time would be 1500 acre-feet.

An excessive seepage loss can be reduced somewhat by puddling the canal with clay. This method, however, is not recommended for general practice, for it is a temporary, half-way measure, and the puddling must be repeatedly injured by ditch cleaning. Oil lining has been tried to some extent in California and is said to reduce the seepage about 50 percent, but it does not prevent the growth of weeds, and ditch cleaning becomes more difficult. The best method is to line the canal with concrete, or, in the case of small ditches, as from pumping plants, to convey the water in cement pipe lines. Concrete linings are coming into use widely, and they will be employed more extensively as projects become thickly settled and the value of the water increases. The Tucson Farms Company has lined 2½ miles of its canals with 3-inch reinforced concrete. The cost of this lining was about $18,000, while the value of the water saved is at least $40,000. More recently, the Pima Farms Company has lined 7 miles of main canal mostly with 2-inch (non-reinforced) concrete. An excellent example of concrete lining for field laterals is to be found on the B. A. Fowler ranch near Phoenix, as shown in the frontispiece. The Agricultural Products Corporation has used cement pipe lines throughout for its distribution system, 26 miles in all.

Fig. 3.—Lining earthen canals with a 2-inch lining of concrete at Lichton, Arizona. The total cost of such linings is about 10 cents per square foot.
The Southwest Cotton Company uses both canal linings and cement pipe lines and ultimately will carry all irrigation water in concrete.

Concrete linings and pipe lines have additional advantages. Ditch cleaning is nearly or quite eliminated; breaks, especially those caused by gopher holes, cannot occur; and the labor cost of irrigating is reduced.

EVAPORATION FROM IRRIGATED FIELDS

The direct evaporation of water from the ground surface may account for from 10 to 40 percent of the water applied. This loss is much larger on heavy loams and adobe soil than on sandy soil. It is greatest, of course, during and just after each irrigation and decreases gradually until the next irrigation. In the case of alfalfa, it is comparatively high after each cutting and decreases as the plants grow again and shade the ground. It is greater on an open, wind-swept area than on one protected by windbreaks.

Many methods for reducing the evaporation loss are available to the farmer. They are:

1. **Deep plowing.**—A shallow seedbed underlain by packed soil tends to cause a high evaporation loss. From 7 to 9 inches of soil should be turned over by the plow.

2. **Cultivation.**—In the case of crops planted in rows, such as corn, the ground between the rows should be cultivated as soon as possible after each irrigation. In the case of orchards, the ground should be furrowed just before irrigating and cultivated soon afterward. If the furrows are 6 inches or more in depth, one may expect to save a considerable percentage of the loss which would occur without the mulch. Even alfalfa needs cultivation at least twice a year, and particularly after the soil has been packed by winter pasturing.

3. **Increase in soil fertility.**—It is difficult to make a mulch when humus is lacking. A fertile soil takes water readily and, if mulched on top, retains it with comparatively little loss by evaporation. Straw should be spread on the ground and plowed in. Weeds, trash, and green manure crops can be utilized to improve the fertility. All stable manure should be spread and plowed into the soil.

4. **More thorough and less frequent irrigation.**—This practice, besides saving water, tends to establish deep root feeding, while frequent light irrigations encourage shallow roots. For alfalfa one irrigation per cutting is ample except for sandy soils, where two lighter irrigations are usually necessary.

5. **Irrigation at the right time.**—Irrigate heavily before planting, and withhold water after the planting for a considerable time. In the
Fig. 4.—Evaporation station on the Salt River Valley Farm near Mesa, Arizona. The evaporation from the 48-inch circular pan is about 9 inches per month during the summer. It has been found that where the soil is kept saturated nearly to the surface, the combined transpiration and evaporation loss is greater than from the free water surface of an open tank set in the soil.
case of alfalfa, irrigate about a week before cutting. This will supply the water when it is most demanded for plant growth, and after cutting, the ground being still moist, the new crop will spring up quickly and shade the ground. Wheat should be planted in thoroughly irrigated ground and, with the aid of good winter rains, no irrigation is needed until the boot or flower stage. Cotton should be irrigated sparingly in the early stages of growth.

6. Irrigation at night.—Evaporation is much restricted in the night as compared with the day time. It is a great mistake to shut down pumping plants each evening.

7. Elimination of weeds.—The waste of water to raise weeds should be included with evaporation losses. Weed farming is unprofitable.

8. Windbreaks.—They should be planted along the roadsides. Every farmer should raise his own fence posts and firewood. Wind movement in the Salt River Valley is greatly reduced by the long rows of trees which the landscape is checkered. The nearby fringes of fields require additional fertilization, but the net result of windbreaks is beneficial.

SEEPAGE LOSS FROM IRRIGATED FIELDS

As a rule, this loss is even greater than the preceding one. It is particularly severe on light soils. It could be avoided to a large extent if no more water were applied at each irrigation than the amount that can be held by the soil within reach of the plant roots.

An ideal irrigation consists in applying the right amount of water, evenly distributed over the field. Throughout the central and southern part of Arizona the practice for field crops is to lay out the field in long strips or "lands." In many observed cases the water, turned in at one end, requires from 1 to 3 hours to traverse a land to its lower end. As soon as the water reaches the lower end, the ditch water is turned to another land. For 1 or 2 hours, then, the head end of a land gets water, part of which soaks downward beyond the reach of, and beyond the needs of, the plant roots, while at the far end the land receives water for 15 to 40 minutes. Surely, this is not an ideal irrigation. The same conditions are observed frequently where the irrigation water is applied in furrows. In 1913, the author made several tests of the evenness of distribution of the water. In one case, on heavy loam, it was found that the percentage of soil moisture at the head of a land, for 6 feet depth, was increased from 24.1 to 26.3 percent by a 4-inch average irrigation, while at the tail end the soil moisture was increased from 15.4 to 18.2 percent. In another case, on sandy loam, the soil moisture at the head end
was increased from 14.3 to 21.1 percent and at the tail end from 8.3 to 12.2 percent. In both cases, therefore, the head end had more soil moisture before irrigating than the tail end had after irrigating—a preposterous condition. Inasmuch as the alfalfa near the foot of each land was making excellent growth, it follows that the head ends of the lands were getting unnecessarily large, wasteful amounts of water. On one of the fields thus tested the average depth of water applied in 1914 was 108.2 inches. Unquestionably, 50 percent of the water thus applied sank to the water table and was wasted. Many similar cases have been observed in alfalfa irrigation and in furrow orchard irrigation, where the quantity of water absorbed at the head ends of the furrows was found to be excessive and wasteful. When these conditions exist, the remedy is more rapid application of the water, by means of a larger head, or shorter runs, or steeper slopes.

As a result of the downward percolation of irrigation water from canals and from fields, nearly all irrigation projects are encountering difficulties due to water-logged or seeped lands or to the consequent rise of the alkali. The rising water table and the concentration of alkali are disastrous to crops, causing the death of orchards and alfalfa. On several
projects of the United States Reclamation Service the necessity for drainage works became urgent before the irrigation systems were fully completed. On one of the projects the water table over nearly 30,000 acres rose from 90 feet average depth to less than 5 feet depth in 6 years, and about 6,000 acres of the land became a marsh. Over 15 percent of the total area in the arid region irrigated by individuals and corporations in the past has been abandoned on account of water-logging. In the Salt River Valley the rise of the groundwater became threatening about 1918, and the Board of Governors of the Salt River Valley Water Users' Association in that year initiated extensive measures for holding the water table at a safe depth. During the years 1919-1924, the drainage project of the Association has involved the drilling and equipping of 123 wells; one open drain, 14 feet deep and 3 miles long; and three tile drains, 11 feet deep, aggregating nearly 6 miles in length. Several areas in the Upper Gila Valley have been reclaimed by tile drainage systems. At a school house near Pima the water table rose to the surface of the ground, and the alkali crept upward in the brick work to the top of the door. Extensive drainage works have been constructed in the Yuma Valley.

Although in general the head ends of the fields are given too much

Fig. 6.—A poor stand in a cotton field, where the water table is close to the surface.
water, yet there are exceptions to this rule. Thus, on clay loam and heavy adobe soils, if the lands have considerable fall, the irrigating water runs quickly to the lower ends of the lands without soaking into the ground more than a few inches. A similar effect is produced by very silty water, such as that of the Gila and Colorado rivers; a silt-blanket is formed at the upper ends of the lands and becomes almost impervious. In such cases the remedy is either to divide the head of water over more lands, or to use a flatter gradient, or longer runs; and silt-blankets must be broken up and mulched.

The frequently discussed problems of what slope to give the lands and what head of water is best are interrelated, and involve also a discussion of the length and width of lands and the character of the soil.

![Alfalfa field in Navajo County, irrigated by the corrugation method.](image)

Any one of these five factors can be taken as a function of the other four factors. The problem is complex and should be solved separately for each crop and for each locality. In some communities the lands are graded level or on a very slight gradient at an additional expense of $20 to $40 per acre. This outlay is of doubtful utility. The lands should be graded down the natural slope or approximately so. Surely any lands, except possibly heavy clay soil, with slope from 3 to 40 feet per mile can be laid out and irrigated without material change in the general direction of the slope, except for the purpose of squaring the borders with the sides of the field. The other factors, then, can be determined so as
to give the most uniform distribution of water. Thus, on light soil with a grade of 20 feet per mile, where a large head of water is available, perhaps the lands can be laid out 50 feet wide and 880 feet long. If the head of water is small, as from a No. 5 centrifugal pump, then the lands should be not over 30 feet wide and 440 feet long. If, however, the grade is only 10 feet per mile, the lands, perhaps, should be 660 feet long for the large head and 330 feet long for the small head. These values are intended to be suggestive; on shallow soils underlain by caliche the lands can be longer; in some cases lands 1300 feet long are irrigated successfully. For heavy loams the lands can be considerably longer than for sandy soil, and in general the flatter the grade, the shorter should be the runs and the larger should be the head of water.

The final adjustment to obtain an even distribution should be made by varying the head of water in each land or in each furrow. This adjustment should be made last because it is the easiest to make. An irrigator near Mesa complained that the stand of alfalfa was better in the lower part of his field than in the upper part. He wished to regrade the field so as to reduce the fall. But the remedy was much simpler than that. His head of water delivered by the Reclamation Service was 300 miner's inches. By changing his order and obtaining 275 miner's inches he would get a uniform irrigation and uniform crop. Many irrigators have difficulty in getting the water across their land. They require a larger unit head. They should order more water, or concentrate it in fewer lands or furrows, or if this cannot be done without increasing the unit head to a point where it will erode the soil, then the length of run should be reduced.

In cases where the distances between head ditches, especially cement pipe lines, prove to be too great, special methods of irrigating can be used. One method is to open an intermediate head ditch midway between the permanent ditches. The intermediate ditch can be used for the preliminary irrigation and possibly for the first irrigation after planting, after which the ground will become settled and packed and the ditch can be leveled off and planted. In the case of furrow irrigation, double heads can be run in alternate furrows and subdivided about two-thirds of the way down the field. Later, the intervening furrows can be treated the same way, and thus the proportion of water received by the lower end is increased. Another practice is to turn a large head down each furrow at first, and when the water reaches the lower end, to reduce the head to such an amount as will continue just to reach the lower end. On some alfalfa fields, the borders terminate 50 feet from the lower edge of the field, and the strip of land 50 feet wide lying along the lower edge is graded as a land extending down the cross-slope.

Good control over the division of the stream of water into furrow
EXPERIMENT STATION BULLETIN NO 101

Sometimes it is essential to divide the stream into two, three, or more parts by means of a division box. Then each part can be more readily divided into furrow-heads. Spiles, made of laths or of narrow boards, are effective in the final distribution. The spiles are set in the ditch bank at the natural ground surface. Sometimes the water is let into forebays and then distributed through spiles. Wooden spiles are much used in the Northwest; in Arizona, however, spiles should be of some other material than wood, which cannot long withstand the alternate wetting and drying in this climate. Galvanized iron, or clay tile, or cement tile would be preferable. The division of water from cement pipe lines can be made with ease and accuracy, an important argument for their use.

Frequency of irrigation is a related subject. The smaller the application at each irrigation, the more often the field must be irrigated. Investigations along this line have not been conclusive except for the peculiar set of conditions under which the tests were made. Many a test has been terminated by the untimely death of the young plants when the irrigations were too infrequent. Sandy soils or other soils that are shallow and underdrained by gravel need frequent applications, while a deep, rich loam, with its large capillary storage capacity, will require much fewer applications. Heavy clay soils, in some places, require frequent irrigations because it is impossible to make them take much water at an application, either because of their physical condition or because they are shallow and are underlain by hardpan that is nearly impervious.

There is much diversity in Arizona in methods of laying out fields and irrigating. Farmers in the Yuma Valley prefer to grade the lands level from end to end. Elsewhere in southern Arizona, the general custom is to run water down the slope parallel to the steeper side of the field, the lands varying from 30 to 100 feet in width, and the lengths of runs depending on the slope, soil, crop, and the available head of water. In northeastern Arizona the corrugation method is used without borders, and the water is run down the steepest slopes. In Yavapai County, the Colorado system of flooding from field laterals is used for alfalfa and grain.

Most Arizona soils take water readily. Uniformity of distribution is possible, but requires thought and skill on the part of the irrigator. The use of the proper unit head in each land or in each furrow will prevent waste of water at the upper or lower end of the field and will give an even appearance to the field of grain or other crop.

WILLFUL OR CARELESS WASTE

This loss includes allowing excess water from the lower end of a field to run onto unused land or, as sometimes happens, into the
highways. It is due sometimes to the absence of a good tail border, sometimes to gopher holes, sometimes to a sleepy or forgetful irrigator. On some irrigation projects the loss has been proved to exceed 10 percent of the water applied. On some mature, well established projects, waste ditches are constructed to collect waste water and lead it back into the canal system. In Arizona, and especially in the Salt River Valley, there is a strong public sentiment against willful or careless waste, and the total loss of this character is comparatively small. The method of measuring the water to each user and charging him for just what he uses has made the water user more diligent in distributing the water over his own fields, and somewhat loath to turn it back into the system or to let it run to waste. Would that he might take an equal interest in preventing the water from escaping downward beyond his control, or upward by evaporation from a crusted soil!

In the grading of a field the lower 40 or 50 feet should be graded level in the direction of the irrigation. The lands should terminate in one common land running at right angles across the field, or the furrows should be connected so that the furrow streams will be equalized at their lower ends. Very few irrigators are able to gauge the irrigation and shut off the water from each land at just the right time; invariably, some lands receive too much, and frequently the water overflows the levee at the lower end of the land. A common crosswise land prevents this loss and usually has the heaviest alfalfa.

**EFFICIENCY OF IRRIGATION**

Every progressive farmer can easily investigate the general efficiency of his irrigation system. In the first place, he should set a weir, or other measuring device, and keep a record of the amount of water applied to each field. His records will serve as a basis for comparisons. There are
several simple means by which he can ascertain the nature and extent of his water losses. Some of the most useful are the following:

1. He can note with a watch the number of minutes during which the head end and the center and the tail end of land or furrow get water.

2. Pits dug to a depth of 6 feet with a posthole digger at different points in a field will show whether or not the irrigation is uniform, and whether the soil is wet amply or too much. The pits should be dug about 20 hours after the irrigation. In lieu of the pits, a sharp stick can be thrust into the ground at various points, and much can be learned thereby of the penetration of the water.

A better tool is a pointed metal rod with a groove 1 foot long in the side near the point. By driving the rod to any depth, rotating it there, and then withdrawing it, a sample of the soil at that depth is obtained. Better still is a soil auger; it is convenient and most useful, and every farmer can well afford to own one. (Consult the county agricultural agent.)

3. Observation of the water level in nearby wells may indicate whether the groundwater plane is rising, due to over-irrigation.

4. Does the soil surface bake? If so, there must be heavy loss of water by evaporation. A farmer can demonstrate to his own satisfaction how far evaporation losses can be reduced by cultivation by leaving a few rows uncultivated and observing the condition of the plants and the drying of the soil up to the time of the next irrigation.

Ditch losses are best measured by setting weir boards and measuring the quantity of water at two points.

The efficiency of irrigation can be defined as the ratio of that portion of the water actually utilized by the crop to the total quantity applied to the land. It is the farmer's province to endeavor to make this ratio as high as possible and thus to decrease the amount of water needed for his ranch.

The State Water Commissioner and the courts of Arizona have excellent opportunities in their decisions in cases establishing water rights to limit the diversion and application of irrigating water to the real needs of crops, plus a reasonable allowance for water losses which it is impractical to prevent. Usually the courts have established the duty of water much lower than it should be. The Kent decree in Maricopa County, and the Lockwood decree in Pinal County fix the limit of application at 5.5 acre-feet per acre annually, the water to be measured at the land. The records of the Salt River Valley Water Users' Association show that the average amount of water bought and paid for by farmers has been about one-half of that quantity. The decree of 1905, adjudicating water
Fig 9—Layout of cement-pipe distribution system for the northeast unit of the Agricultural Products Cooperatives, much new Tucson. The pipe sizes are 12, 14, and 16 inch. The total length of pipe lines in this unit is 33 miles and the unit irrigation 3,500 acres. The contours show elevations above sea level. The small arrows show the direction of irrigation. The dotted lines indicate temporary ditches for use on a new-to-graded field. With this layout the cost of grading was reduced to a minimum and the irrigation is made very efficient.
rights of Graham County, fixed the duty of water at "one-half miner's inches continuous flow to the acre." This is equivalent to 9 acre-feet per acre annually. Under the license of the decree, many farmers over-irrigated their lands at times and some localities became water-logged and alkalied. A temporary decree in Apache County in 1917 established the duty of water at St. Johns at 1 cubic foot per second for 75 acres, at Eagar at 1 second-foot for 100 acres, and at Greer at 1 second-foot for 150 acres. The distinction between the conditions at different altitudes is logical and is an important step forward. In 1918 the decree was changed so as to allow 1 second-foot per 90 acres at St. Johns, 110 acres at Eagar, and 180 acres at Greer. Inasmuch as rotation of water is practiced throughout Arizona, the duty of water should be stated in acre-feet per acre per year, or preferably a monthly schedule can be decreed for the limiting use of water.

Irrigation districts and cooperative companies can influence the use and waste of water under their canals by their method of charging for water. The old flat rate, a fixed amount per acre per year, was a constant challenge to each irrigator to use as much water as he could obtain. It was as unreasonable as a proposition to buy the family flour supply at a fixed

Fig. 10.—Division gates on the Main Consolidated Canal near Mesa.
sum per annum. The water should be measured to each water user, and each user should pay on the basis of the amount which he uses. The Irrigation District Act of Arizona provides for a uniform assessment rate per acre, and the tendency is for landowners to demand a pro rata division of the water, regardless of the real needs of the various farms. In the Salt River Valley, the change from the old flat rate to the new basis in 1912 resulted immediately in a decreased use of water. What remains to be done is the installation of weirs or other measuring devices so that the measurements can be made more accurately than they are at present.

With the exception of some projects which will require Federal or State aid, surface water supplies in Arizona are quite thoroughly appropriated, and the limit of development of ground water supplies will be reached in a few years. But the water supplies must be made to serve more land, and this must be brought about through a reduction of the water losses. No longer is it considered justifiable for appropriators to divert and use excessive amounts of water, even though they may have been doing so for many years. The modern viewpoint of courts in the arid states is that no man has a right to take more water than he can put to beneficial use together with a reasonable allowance for conveyance and other losses. But each appropriator is expected to make such expenditures on his ditches, and in the preparation of his land, and in his care of the land, that his losses will be small and the general water supply thereby conserved. As Judge J. H. Kibbey said in his decree covering water rights in the Salt River Valley, "No man has a right to waste a drop of water."

IRRIGATION RULES

1. Keep the ditches in order. A sluggish current increases the water loss.

2. Line the ditches with concrete, or lay cement pipe lines. This settles the problem of seepage loss permanently, and almost eliminates ditch maintenance.

3. Grade the land surface evenly. High places become "slick"; low places invite watergrass, sun scald, and puddling of the soil. The "lands" should be level crosswise, but with adequate fall lengthwise.

4. Plow deeply. Deep-plowed soil utilizes all of the rainfall, takes the irrigation water more readily, forms a mulch more quickly, and permits better aeration.

5. Use short lands for light soils. The best length depends mainly upon the character of the soil but also on the slope and on the head of water available.
6. Divide a large head of water into "unit heads" of such size as to give uniformity of irrigation throughout the length of furrow or land. If the upper ends of lands get too much water, divide the head into fewer lands, or order a larger head from the sanjero; if the upper ends get too little, irrigate more lands at the same time. Larger unit heads are needed on lighter soils, flatter slopes, or longer lands or furrows.

7. Test the soil the day after irrigating to determine the depth of water penetration. Use a soil augur, a pointed rod, or a shovel. Ascertain if the water penetration is about right, and whether it is uniform from end to end of lands or furrows.

8. Irrigate before planting. Have the soil well stored with water to a depth of 4 or 5 feet. Then allow a good root development before the next irrigation.

9. Do not over-irrigate. An excess of water is an injury. Many crops do not require heavy irrigations. Even alfalfa can be given too much at a time.

10. Do not hesitate to irrigate at night. The big projects run water continuously; why should not a pump irrigator also? The evaporation loss is much less at night. Pumping plants should be operated night and day through the hot, growing months.

11. Irrigate at the most favorable time. Irrigate alfalfa when two-thirds grown, but not just after cutting; grains when just out of boot, and corn when in tassel and silk.

12. Examine the soil occasionally. Bore or dig into it at least 3 feet. Does it pack nicely in the hand? Irrigate when soil and crop indicate the need of water, and not according to calendar. There should be always some reserve moisture in the soil to prevent wilting and to assure a profitable yield.

13. Cultivate. A loose soil mulch prevents baking and cracking of the soil and permits aeration of the roots. Cracks permit heavy losses by evaporation. Use an alfalfa renovator in August, in late fall, and in spring if alfalfa has been pastured. Row crops need cultivation after each irrigation, though in cases of cotton, corn, and milo, cultivation is not possible in the latter part of the season.

14. Fight the weeds; eradicate them. Weeds rob the crop of water, sunshine, and plant food.

15. Rotate the crops; keep the soil fertile. Use alfalfa in the rotation; grow legumes and plow them under; all crop residues, straw, and stalks should be plowed under.
16. Do not irrigate the roads. Your neighbors do not appreciate this. Keep the gophers out of the ditch banks, shut off the water in time, and the highways will not become bogs.

17. Measure the water. Set a weir on your supply ditch. Are you getting as much water as you pay for? Do you know how much each crop is using? You measure everything else; why not the water supply?