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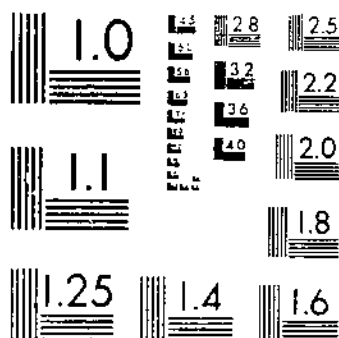
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DELIVERY OF IRRIGATION WATER
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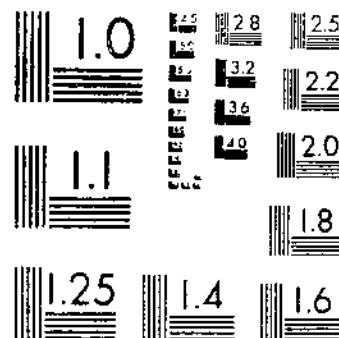
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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

DELIVERY OF IRRIGATION WATER

By WELLS A. HUTCHINS, *Associate Irrigation Economist, Division of Agricultural Engineering, Bureau of Public Roads*

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INTRODUCTION

A completed irrigation project, by whatever agency constructed, has normally encountered three more or less distinct periods of activity: (1) Preliminary investigations, financing, and organization; (2) construction of works; and (3) operation of the system. The operation period begins either before or upon completion of the irrigation system.

The field of irrigation management during the present century has broadened more and more as numerous enterprises have been brought from the construction to the operation stage. Under the most favorable conditions, irrigation management, involved so largely with human relations, is a perplexing matter calling for a certain type of personality to handle it successfully, but many of the manager's troubles can be avoided if he is able to give general satisfaction in distributing water. The type of canal construction in many cases determines the method of delivering water and prevents the use of other and possibly better methods without making expensive changes. In designing an irrigation system, therefore, it is important that the method of delivery best suited to local conditions be taken into consideration.

A bulletin of this department published in 1910 contained a description and review of the water-delivery systems of a number of typical enterprises in the West.¹ Since then numerous enterprises have come into operation, and much experience in delivering water has been gained that should prove of value both to prospective and

¹ ADAMS, F. DELIVERY OF WATER TO IRRIGATORS. U. S. Dept. Agr., Off. Expt. Stas. Bul. 220, 90 p., illus. 1910.

existing organizations. For the purpose of securing and making available information on this subject, a study was made in 1923 of the delivery methods and other important phases of the management of nearly 100 irrigation enterprises in 13 of the 17 Western States, the results of which are published in this bulletin. Projects of four principal types were included: Mutual companies, irrigation districts, commercial companies (public utilities), and Federal projects. Districts and mutual companies together included about 75 per cent of the total, which is thought to be a fairly representative proportion as the present trend is toward cooperative ownership and operation of irrigation works.

DEFINITION OF TERMS

Irrigation terms often have different meanings in different parts of the country. Such terms appearing in this bulletin may be defined briefly as follows:

Lateral.—A branch of the main canal of an enterprise. A main lateral leads from the main canal and serves a group of sublaterals. A farmers' lateral is a ditch, controlled by the users of such ditch, leading from an enterprise canal or lateral to a farm or group of farms. A farm lateral is the distributing ditch within the boundaries of a farm.

Head or stream.—The flow of water delivered to an individual irrigator or group of irrigators is called in some communities a head, in others a stream. These terms are used interchangeably in this bulletin.

Continuous delivery.—Delivery of water continuously to all users under a project throughout the irrigation season.

Rotation delivery.—Delivery of water to users in turn, at regular or irregular intervals.

Demand delivery.—Delivery of water to users whenever requested by them.

Ditch tender.—An irrigation employee who patrols canals and delivers water. Also called ditch rider or ditch walker, ditch agent, canal rider, water tender, patrolman, and zanjero. The terms "ditch tender" and "ditch rider" are most commonly used, but zanjero is general in southern California and some other parts of the Southwest. Patrolman sometimes designates one who patrols canals but does not deliver water.

CONTROL AND OPERATION OF LATERALS

In the construction of every new irrigation enterprise a decision must be made as to whether water shall be delivered by the enterprise only out of the main canal, or whether main laterals and sublaterals shall be built for delivery to each small subdivision of land, or whether some unit of delivery intermediate between these extremes shall be adopted. On many older systems only the main canal, or the main canal and main laterals, were constructed by the enterprise, the water users being required to build the sublaterals to their farms, often miles away, which added materially to the difficulties of bringing the land under cultivation. In later years the more general and much more liberal practice has been to construct distributing systems to serve relatively small units of

land, such as every 40 or 80 or 160 acres; or to reach within a definite distance, such as one-fourth or one-half mile. from each subdivision.

CONSTRUCTION

BY INDIVIDUALS

Where the irrigation company or other organization has built only the main canals and main laterals, neighboring settlers have clubbed together in building a common lateral to supply their farms. In many cases, however, the entire first burden has fallen upon some one man who has had to build a ditch probably several miles long, other settlers coming in later and making arrangements with the original owner to enlarge the lateral and thus eventually coming to own it in common.

The burden of building long ditches is a heavy one to place upon the individual settlers. They must, of course, pay for the laterals sooner or later, but are confronted with sufficiently heavy first costs in subdividing their land and can get under way much more readily if the canals with which they are to connect are not too far away. Furthermore, there is too much opportunity for such ditches to be laid out poorly and with little or no relation to the needs of the system as a whole. Instances have been noted of parallel ditches—in an extreme case in Montana four ditches bordering a single road—built independently of each other, where a single ditch would have served the purpose. The only sound arguments in favor of construction of laterals by the users are the smaller cash outlay and the assurance that ditches will not be built until needed.

BY MAIN ENTERPRISE

Organizations that have built laterals have sometimes gone to the extreme of building all sublaterals and structures at one time. This is thought to have stimulated development in a few cases, owing to the attractiveness of a system completed to every farm unit and ready for immediate use. Nevertheless, on certain other projects where this was done, development proceeded slowly, with the result that structures deteriorated before being used, while maintenance costs were running high and interest was being paid on capital invested in works not in use. The wiser course would have been to defer the construction of at least the smaller sublaterals and structures.

MAINTENANCE

UNORGANIZED LATERALS

The upkeep of an unorganized community lateral is often a vexatious matter. It is a common saying that 75 per cent of the users do all the work; certainly the experience of having a few men avoid doing their share is widespread. Collection from such water users of their pro rata cost of operation and maintenance is a troublesome proceeding, and forcing them to pay for improvements to which they object is usually impossible. The ditch must be kept clean, for neglect results in decreased carrying capacity and is cause for

refusal on the part of the management to turn water in. Hence the upkeep devolves upon the conscientious users.

ORGANIZED LATERALS

An organized lateral offers greater opportunity for satisfactory maintenance, as responsibility may be fixed and assessments for upkeep may be levied and collected.

DESIRABILITY OF LOCAL MAINTENANCE

The farmers' ideas on proper maintenance are often at variance with those of the manager, and too frequently the amount of work they do on the ditch is no more than just enough. Less trouble is experienced with early cleaning than with upkeep after the opening of the irrigation season, when the farmers are busy with other matters. On the other hand, the farmers have the time to handle much of the maintenance work, at least early in the season, and by doing the work themselves they can avoid much of the heavy annual outlay necessary where all maintenance work is done by the project management. The most effective plan is to place final responsibility for maintenance of all the important sublaterals upon the project management, giving the farmers opportunity to do the work if they so desire but under the direction of a foreman responsible solely to the manager.

OPERATION

Responsibility for maintenance and for operation should not be divided. Certain enterprises are able to control the delivery of water to the individual user through laterals owned and maintained by the users; but elsewhere this procedure has proved to be a great mistake owing to the difficulty of operating ditches not always kept in satisfactory condition. A manager who has no control over the condition of a ditch he is required to operate may be placed at a disadvantage at any time, and the practice is not to be recommended.

However, there is no objection to outlining a method of distribution on a lateral and allowing the users to carry it out so long as they can work together amicably, reserving the right to have the ditch rider adjust any unsatisfactory situation. In fact, water users who are disposed to cooperate can be of material assistance in reducing the cost of operation by making changes of water under rotation schedules at hours when it is not practicable for the ditch tender to be on hand.

Control by the central management over individual deliveries, or at least a measure of supervision, is distinctly beneficial in its assurance that the lower users on a ditch will receive their just share of water and in accomplishing in many cases a more disinterested division of water than could be made by a local man.

LATERAL ORGANIZATIONS

UNINCORPORATED COMPANIES

The rights and liabilities of owners of an unincorporated lateral are determined by the contractual relations of the members, by the laws of cotenancy and copartnership, and by any special statutes

relating to ditches of this character. The irrigation laws of many States include provisions governing the operation and maintenance of such laterals. Much trouble may be avoided if the original members prepare and sign specific articles of agreement, indicating clearly the nature of the association and the rights and responsibilities of members.

An unincorporated lateral-ditch company does not possess the direct remedies of a corporation against obstinate members and is consequently a satisfactory arrangement only so long as all members are disposed to cooperate. The available legal remedies against delinquents are adequate, but are often troublesome to follow out.

INCORPORATED COMPANIES

A corporation, on the other hand, possesses a quick, simple method of enforcing collection of assessments—by sale of delinquent stock—and is able to effect needed improvements even though opposed by an obstreperous minority. Water users can not be forced into a corporation against their will; but once the corporation is formed, the majority of stockholders are in control. In some sections of the country, notably in northeastern Colorado, incorporation of laterals is quite common and is thought to have had much to do with the successful operation of farmers' laterals in those sections.

The basis of most of these lateral incorporations is the share of stock representing a carrying right in the lateral, so that a water user on such a lateral owns stock in the parent company entitling him to water from the main canal and also owns stock in the lateral company entitling him to have such water carried from the main canal to his land. Such stock is assessed to cover costs of operation and maintenance of the lateral and may be sold for nonpayment of assessments, as in other corporations. These companies are governed by boards of directors who appoint the local ditch rider. To facilitate the handling of accounts, it is frequently customary for the secretary of the main company to act as secretary for some of the lateral companies.

LOCAL-IMPROVEMENT DISTRICTS

The irrigation-district laws of several States permit the formation of subdistricts within irrigation districts for the purpose of making local improvements and assessing the cost against the lands benefited, bonds being issued which, so far as the bondholders are concerned, are an obligation of the entire irrigation district. The consent of only a portion of the landowners within a proposed local district is sufficient to authorize its formation and subjection of all lands to an obligation to pay for the cost of the improvement. The irrigation-district law of Washington, where these subdistricts were first authorized and where most of them have been formed, has served as a model for the adoption of this feature in certain other States.

Numerous local-improvement districts have been formed in Washington, principally for lining community ditches, replacing earth ditches with pipe, installing measuring devices, and in some cases for building new ditches, operation and maintenance not being contemplated. There is no local government, all affairs being handled by the directors of the parent irrigation district. The principal

advantage of the local-improvement district is in accomplishing needed improvements over the objections of a small minority who could successfully resist being drawn into a possible incorporated company and who could therefore in many cases defeat the proposed improvements altogether. Its use is, of course, limited to organized irrigation districts in a few States.

MAINTENANCE DISTRICTS

A unique organization originating with Sunnyside Valley Irrigation District, Wash., is the maintenance district, initiated by petition of owners of at least 25 per cent of the acreage affected and formed by the board of directors after an opportunity for a hearing. If such a district is formed, a local foreman is chosen by the landowners (the action being subject to ratification by the Sunnyside district directors). This local foreman is considered to be the agent of the irrigation district, and his duties are to hire men (preferably local water users) to clean the lateral and keep it in shape. Payments for labor and material are made by the Sunnyside district, and the cost is assessed against the lands in the maintenance district and collected as a part of the general district taxes. The maintenance district is considered to be a distinct improvement over the unorganized lateral in that it forces the "slacker" to pay his proportion of the cost of maintenance.

DESIRABILITY OF LOCAL CONTROL OF LATERALS

Control of lateral and sublateral systems by the water users has worked admirably under some circumstances, notably those surrounding the development of the Union Colony² and other communities of the same type in northeastern Colorado, Utah, and elsewhere, where the people were bound by ties of sympathy and in numerous cases by family kinship, thought along the same lines, and were disposed to work together for their common welfare. On the other hand, local control is not practicable where the users are of varied nationalities, speaking different languages, thinking differently and not willing to be responsible for each others' doings. In any event it is essential that there be a few men competent to take the lead and to see that the work is properly done, and the safest plan is for the users to organize.

ASSUMPTION OF CONTROL BY MAIN ORGANIZATION

Cases are rather numerous in which enterprises have assumed control of laterals built by the farmers; much more numerous, probably, than where a reverse procedure has occurred. These changes have been due mainly to the desire of the farmers to be relieved of the responsibility of maintenance or of costs out of proportion to those incurred in neighboring communities; to a need for more efficient operation; and in some cases to the feeling that a more impartial distribution of water would result. Money has seldom been paid for such canals. In some cases they have been leased to the enterprise or given in trust, in others deeded outright, and in still other instances they have been the subject of change of control only without formal change of ownership. Important examples of the taking over of

² HEMPHILL, R. G. IRRIGATION IN NORTHERN COLORADO. U. S. Dept. Agr. Bul. 1026, 85 p., illus. 1922.

numerous farmers' laterals are found on Umatilla project, Oregon; Boise project, Idaho; and Fresno and Consolidated irrigation districts, California.

Assuming control over farmers' laterals is necessarily an individual transaction on each lateral and for that reason usually progresses over a period of years. A very general requirement is that the lateral be put in good repair before being turned over to the main organization.

DESIRABLE UNIT OF DELIVERY

Under the favorable circumstances indicated above under Desirability of Local Control of Laterals, the water users may be able to handle operation and maintenance efficiently and with a smaller cash outlay than could the central organization. The builders of a new project, however, have usually no assurance that such conditions will obtain. For this reason, and to relieve settlers of the burden of building long distributing ditches, the more advisable course on a new project is to arrange for deliveries to relatively small units.

The most desirable unit will depend, in general, upon the character of the country, size of land holdings, and probable type of agriculture. In an orchard or small-fruit country, where the holdings are relatively small and the users numerous, the desirable unit is smaller than in a general-crop region, and in some sections of this type deliveries may be profitably made from underground pipe lines at the highest corner of each 10-acre tract. In a new country, particularly where the agricultural practices are likely to be less intensive, deliveries are made more satisfactorily at the highest point of each 40 or 80 or even 160 acres.

METHODS OF DELIVERING WATER

The object of the farmer in applying irrigation water is to make possible the most profitable production of his crops. This does not always mean the greatest production, for there is always a point beyond which a further application of water will result in decreased yields and a point beyond which it will bring diminished net returns, the two points not necessarily being identical. The human and economic variables involved in crop production throughout an irrigation system can not be reduced to any exact basis in the original design of the system; yet with the increasing availability of information as to the water requirements of soils and crops, and with the practical experience gained on so many irrigation projects, it is certainly possible to plan, within closer limits than heretofore, for the delivery of those quantities of water which will best serve the needs of anticipated crops.

The selection of a method of delivering water which will best serve this purpose is therefore an important consideration in the design of the distribution system. Once in effect, the method may be difficult to change, for the type of canal construction, size of delivery boxes and farm laterals—as well as the preparation of land for irrigation and habits of the irrigators—frequently prove to be limiting factors. Before the character and capacity of the system are finally determined upon, study can very profitably be devoted to the moisture requirements of anticipated crops, effective water-holding

capacity of soils, and the more readily ascertained factors of character of water supply and topography.

Water is delivered to the individual irrigator either in a continuous flow or at intervals. Water delivered at intervals is served in turn to each of a group of irrigators, or is delivered to the individual whenever he calls for it. According to this classification, there are three basic methods of water delivery, which are called (1) continuous, (2) rotation, and (3) demand.

ELEMENTS OF A DELIVERY METHOD

The use which may be made of water delivered to a farm depends upon the frequency with which the water is delivered, the duration of the delivery, and the size of head or stream delivered. These points are the principal elements of a mode of water delivery, and the degree of success with which they meet the requirements of the irrigators, taking into account the physical limitations of the project and without undue waste of water, is the measure of the efficiency of the method in question.

FREQUENCY OF DELIVERY

The frequency with which water is needed by the irrigator will depend upon his crop and soil requirements, an important factor being the capacity of the soil to retain moisture. With certain soils it is feasible to irrigate heavily and to depend upon the availability of the water for plant use over many days; while with other soils which can hold less water in the root zone, frequent light applications are preferable and irrigation turns many days apart are not sufficient. With a given soil type, there is a wide range in the water requirements of the crops which may be grown, certain crops for their highest yield needing water much more frequently than other crops. These varying needs of crops and soils present a complicated problem, but one which must be solved if the highest use of the water delivered is to be obtained.

DURATION OF DELIVERY

The duration of the delivery is a factor in determining the completeness of the irrigation, and a delivery method which cuts the period short or which prolongs it unnecessarily is to that extent inefficient.

HEADS OR STREAMS OF WATER

An element of the utmost importance is the size of the irrigation head or stream. The capacity of the project distribution system, preparation of the land for irrigation, and methods of applying water to the land are made to depend upon the size of head selected. Hence a mistake is very difficult to correct. Necessarily there is usually some latitude in the size of head which may be delivered.

Large heads of water require careful, and in many cases, expensive preparation of land for irrigation, else they can not be handled at all, whereas smaller streams may be guided over relatively uneven surfaces. On the other hand, careful preparation of land often pays for itself in uniformity of water applications and decreased labor costs. If a stream of 2 second-feet is as much

as an irrigator can handle on unprepared land, and if such stream proves too small for economical irrigation, it will pay him to prepare his land to receive a larger one. Of course, large streams are not feasible on steep slopes, regardless of preparation of land.

The adequacy of any irrigating stream will depend upon soil and topographic conditions and will seldom be the same throughout a large project. In general, an "adequate" head will be a stream of water large enough to cover the ground without excessive loss of water by deep percolation, yet not so large as to result in a movement of water across the field so rapid that it does not become available to the plants. The absorption of water is much more rapid by some soils than by others, and a stream large enough for the proper irrigation of a fairly impervious soil might be wholly insufficient for an open-textured soil with similar slope. Conversely, where impervious soils are encountered, the problem is to get the water into the soil, rather than to get it over the ground without loss by deep percolation; so that in such case any increase over the size of an effective head will result simply in wasting the water at the end of the field.

To illustrate this matter further, reference is made to certain experiments to determine the effect of applying heads of various size to porous soils, made in 1910 and 1911 by W. G. Steward, of the United States Reclamation Service, in Boise Valley, Idaho,³ and in 1915 by agents of this department in cooperation with the State department of engineering and the University of California at Davis, Calif.⁴ The two groups of experiments were made with heads of very different ranges in size—1 to 4 second-feet in Boise Valley and 4.6 to 17.8 second-feet at Davis—but showed similar results, namely, that the amount of water per acre required to get over the ground in each case decreased markedly with the increase in head; or expressed differently, that doubling the head resulted in covering the ground in considerably less than half the time. The inverse ratios between size of stream and depth of application of water necessarily apply only to the conditions under which the experiments were made, but are valuable in that they point out the extent of loss of water that may occur where inadequate heads are used on porous soils.

CONTINUOUS DELIVERY

PRINCIPAL FEATURES

This method involves the delivery of a stream of water, usually very small, to each irrigator constantly throughout the season. If a given amount of water is served continuously to each user over a period of several months, the head or stream of water needs to be smaller than if the same total amount is delivered at intervals. Likewise, if the use of very small heads for one reason or another is necessary, then continuous delivery follows as a matter of course. An exception to the above appears under some combinations of circumstances, such as on canals with late priorities delivering water

³ BARK, D. H. EXPERIMENTS ON THE ECONOMICAL USE OF IRRIGATION WATER IN IDAHO. U. S. Dept. Agr. Bul. 339, 58 p., illus. 1916. These experiments are discussed by Mr. Steward in a paper in "Report of Boise Conference of Operating Engineers, 1911."

⁴ ADAMS, F., ROBERTSON, R. D., BECKETT, S. H., HUTCHINS, W. A., and ISRAELSEN, O. W. INVESTIGATIONS OF THE ECONOMICAL DUTY OF WATER FOR ALFALFA IN SACRAMENTO VALLEY, CALIFORNIA, 1910-1915. Calif. Dept. Engrs. Bul. 3, 78 p., illus. 1917.

not appurtenant to the land, where heads of several second-feet in size are delivered continuously throughout the relatively short period during which water is available.

WHERE CONTINUOUS DELIVERY IS NECESSARY

In some situations there is no course other than to deliver water continuously. On the steep slopes of the Sierra foothills of California the use of large heads is impracticable on account of the washing of soil that would result, and it has proved necessary to use very small heads—sometimes as small as 1 to 3 miner's inches. Heads of this size make continuous use necessary. The same situation holds in other parts of the country where water is applied on very steep slopes, as well as on gentler slopes where the soil is easily washed. Where water is to be applied constantly to rice, continuous delivery is required.

WHERE CONTINUOUS DELIVERY MAY BE ADVANTAGEOUS

There are other situations where continuous delivery may not be absolutely necessary, but where it will accomplish the desired end better than other methods. On slopes where the soils are either so light or so shallow that irrigation is required frequently, and for soils so impervious that long runs with small heads furnish the only means of effecting penetration of water, the continuous use of a small head of water will often be more satisfactory than the use of a larger head at intervals. The real determining factor in such cases is the necessity, resulting from the slope and soil, for using very small heads; the need for frequent irrigation being a secondary consideration because in so many cases it can be readily accomplished by a method of rotation at frequent intervals.

From the standpoint of irrigation farming, water is needed so much of the time for small fruits and truck gardens that the continuous delivery of a small stream for such crops is a decided advantage, particularly as it will add little to the labor burden in growing them.

WHERE CONTINUOUS DELIVERY IS NOT DESIRABLE

Continuous delivery is not adapted to soils so light as to prevent small streams of water from getting over the ground without excessive loss through deep penetration of moisture. In such a situation the only effective method of accomplishing irrigation, without excessive waste of water by deep percolation at the upper ends of fields and the drainage troubles so occasioned, is to use an irrigation head sufficiently large to bring about a fairly uniform application of water to all parts of the field. Continuous delivery under such circumstances is likely to provide water when needed and in the quantities needed, but only at the expense of an unjustifiable waste of water. Where this method of delivery is practiced, as it is so extensively in the Northwest, under conditions of soil, topography, and crop production which do not require its use to the exclusion of other methods, the test of its usefulness will be: Does it provide streams of sufficient size to irrigate the soils of the particular project without undue waste?

To answer this question with any degree of accuracy requires a study of the soils of a given project and of what becomes of the water

applied with heads of different ranges in size. There are countless situations in which waste of this character is apparent from the difficulty with which small streams are forced over the ground and from the ease with which irrigation is accomplished with larger streams, without a decrease in yields of crops traceable to the smaller quantity of water applied with the larger streams.

The size of heads delivered continuously in the Northwest has usually resulted from contract or water right. Streams are frequently one-half or five-eighths inch per acre and seldom exceed 1 inch per acre, where an inch represents one-fiftieth or one-fortieth second-foot, according to the laws and customs of the State. A tract of 10 acres may be entitled to a delivery of only 5 miner's inches, which under the conditions obtaining on most of those projects is too small to be at all practicable. The owners of small tracts are forced to combine their streams with those of neighbors and thus operate a local system of rotation in use. Owners of 40 acres or more may command irrigation heads of one-half to 1 second-foot, which they often consider adequate for proper irrigation but which nevertheless is not adequate on the more porous soils of light slope. Heads of 2 or 3 second-feet have almost invariably given greater satisfaction when substituted for the smaller streams. This has necessarily involved the installation of a limited system of rotation.

MODIFICATION OF CONTINUOUS DELIVERY

Even relatively small changes in size of delivery stream have proved difficult to bring about on well-established projects, owing to the reluctance of the farmer to giving up the right to a constant stream of water, and have been limited mainly to small groups of users. However, there are notable examples of complete or fairly complete changes that have proved very beneficial. Minidoka Irrigation District, Idaho, is an example of a project laid out for continuous deliveries, with laterals not equipped to carry the large heads of water that a completely coordinated system of rotation would make necessary, but on which local schedules of rotation have been effected. On Tieton division of Yakima project, Washington, continuous deliveries were abandoned in 1914 in order to conserve the water supply, for it developed that the use of less water resulted with larger individual streams. Continuous deliveries on Umatilla project, Oregon, were given up as being unsuited to sandy soils and rotation heads of 2 to 2½ second-feet for heavy soils and 4 to 5 second-feet for sandy soils were adopted. Efforts along the same line, with varying degrees of success, are being made by irrigation managers on several smaller projects.

RESULTS OF CONTINUOUS USE

Continuous delivery does not always involve the constant use of water by each irrigator, but at least gives him the right to use it constantly. An unfortunate result is a heavier use of water than necessary in many cases, due primarily to the fact that the water is at all times available. It is even charged in some localities that water users seldom close their head gates, preferring to waste the water when not needed, for fear that turning it back into the canal would be

a confession that they need less than they receive. With the increasing demand for water throughout the West, such practices can not be countenanced indefinitely.

Where continuous delivery is practiced, much preventable waste of water may be eliminated by measuring the water and charging for it on a quantity basis where legally possible to do this. On those Federal projects which make use of this system, the schedules of rates provide for a minimum payment for a certain quantity of water per acre, and for a certain charge for each acre-foot delivered in excess of the minimum, with the result that an irrigator pays for what he wastes as well as for what he uses.

CONTINUOUS DELIVERY TO LATERALS

The management of a project may deliver water to a lateral and allow the users under the lateral to effect their own distribution. In such case continuous delivery to a lateral does not preclude the users from rotating the water among themselves if such practice is better suited to their needs. Desirable changes may thus be effected over large portions of a project without making material changes in the main distribution system.

USE OF CONTINUOUS-DELIVERY HEAD ON THE FARM

Under a continuous head the farmer must rotate the entire stream or portions of it, depending upon the size, from one part of his farm to another, cutting hay or harvesting other crops from portions not then being irrigated. This raises the objection that he is always irrigating, instead of having periods of time devoted to irrigating and the balance of the time for other farming operations. Just how objectionable this is will depend partly upon the farm routine occasioned by the character of crops grown and partly upon the temperament of the individual farmer, and should not be permitted to weigh against the method if it is best for crop production.

FINAL TEST OF EFFICIENCY

The use which can be made of the continuous head of water on the farm provides the final test of efficiency of this method of delivery from the standpoint of maximum crop production. The frequency and duration of irrigation are not necessarily under the irrigator's control because of his having a constantly flowing stream of water at his command, but only in case he has the use of an irrigating stream large enough to cover the ground properly, without undue waste, whenever any portion of his farm requires irrigation. A method of delivery that gives him an adequate irrigation stream during just such times and no longer can well be said to have served its purpose. This, however, is an ideal that in actual practice is very difficult to reach. Continuous delivery under many circumstances fails to reach it on one or both of two counts—inadequate head of water and unnecessarily long duration of use—each contributing to a form of waste that is often in large measure preventable.

ROTATION DELIVERY

ESSENTIAL FEATURES OF ROTATION DELIVERY

Rotation is essentially the delivery of water by turns to various portions of a project, with larger irrigation streams than are available for the individual user under the continuous-delivery method. Irrigation turns are based on some form of schedule which governs the frequency and duration of irrigation. With a given water supply, the planning of the schedule and the size of irrigation head necessarily depend upon each other, and on both depends the advisability of a rotation method of delivery under any set of conditions.

COMPARISON OF ROTATION DELIVERY AND CONTINUOUS DELIVERY

Rotation in water delivery is desirable in many cases where continuous delivery is inefficient. Where the irrigation heads are too small for efficient application to the soil, and where water supplies must be conserved more carefully, the combining of heads to a degree sufficient to get over the ground properly and the delivery of this combined stream to different tracts at different times is desirable. Except under circumstances of considerable slope and light soils, or other local conditions unfavorable to this method, the larger heads will cover the ground faster, with smaller quantities of water applied to the soil, but with a larger percentage of the application retained where it is needed. It has been the experience of many canal managers who have campaigned in the interest of rotation on small laterals, that those farmers who have reluctantly made the change have become readily converted after a trial with the larger streams. Rotation involves cooperation and consequently a sacrifice of the farmer's complete independence in handling his water, but this objection should carry little weight against the advantage of securing an adequate irrigating head. Furthermore, a saving in the labor of irrigating often results from the use of larger heads.

From an operation standpoint, rotation and demand deliveries undoubtedly increase the difficulties of canal regulation, and through the alternate wetting and drying of the sides and bottoms of canals they may cause the loss of a larger percentage of the water carried than would be the case if the canals were kept in constant use.⁵

On the other hand, canals used for rotation and demand deliveries are necessarily larger than for continuous deliveries under otherwise similar conditions; in which connection a summary of seepage measurements made in various sized unlined canals shows a fairly constant decline in the average loss as the capacity increases, ranging from an average loss of 25.7 per cent per mile for canals of less than 1 second-foot capacity down to 1.0 per cent for those of capacities of 800 second-feet and over.⁶

⁵ Experiments (unpublished) by O. V. P. Stout, irrigation engineer, and Carl Rohrer, associate irrigation engineer, in pooled channel sections in San Joaquin Valley, Calif., showed a constant increase in the length of time required to absorb a given quantity of water in a channel not theretofore used. In sandy soil, the first experiment being made while the soil was dry and succeeding experiments while it remained wet, with a drop in the curve for a further test made after the channel had stood empty for 13 days. Tests in a channel that had been in use almost to the time of the experiments in a heavier soil showed a similar trend, but not so pronounced.

⁶ FORSTER, S. CONCRETE LINING AS APPLIED TO IRRIGATION CANALS. U. S. Dept. Agr. Bul. 120, 83 p., illus. 1914.

VARIATIONS IN LOCAL-ROTATION METHODS

Of the many types of rotation delivery found in practice, the simplest forms—and the least removed from continuous deliveries—are those participated in by small groups of users on systems where continuous delivery has been previously the rule and where deliveries to laterals are still continuous. These arrangements are sometimes limited to two farmers, and in other cases affect an entire lateral serving many farmers. They are usually voluntary on the part of the farmers concerned.

Necessarily these local arrangements vary widely in character and cover many different situations. Two examples of the simpler forms in Snake River Valley, Idaho, may be cited. In the first case, four adjoining 80-acre tracts are served by a lateral carrying a continuous stream of 160 miner's inches, each tract using the entire stream for two days at a time, the rotation period thus being eight days. In the second case two 80-acre tracts and three 20-acre tracts are entitled to a combined stream of 110 inches, which is given for four days to each 80 acres and for one day to each 20 acres, the total period thus being 11 days. The schedules in both cases are proving very satisfactory wherever the ground has been properly prepared—much more so than when heads of smaller size were being tried—although the smaller head and longer interval between waterings in the second example are somewhat less desirable than the first schedule. Obviously the most satisfactory schedule under such circumstances will depend upon the happiest combination of farms and farming conditions.

Local-rotation methods left entirely to the initiative of landowners who would otherwise take water continuously lead to a more efficient use of the water so far as they go, but frequently they do not go far enough. The actual help and encouragement of the project manager are necessary in developing methods that will yield the greatest good from the greatest number of lateral streams on a project. Where deliveries to the individual are under the manager's control he can, of course, accomplish much more than where he is limited to making suggestions. The Minidoka irrigation district, in Idaho, has been zoned on the basis of its water requirements as affected by soil and topography. With these zone allotments as a starting point, and with due regard for the crops and wishes of the landowners, rotation schedules are drawn up for the several laterals by the manager so as to give irrigation heads ranging from about 2 to 6 second-feet for lengths of time proportioned to the respective areas of the users.

In all of these cases cited the arrangements are local in effect because of the present capacities of ditches and structures, and have been worked out to improve conditions so far as practicable without occasioning a great outlay of money for new ditch work. Under such practical limitations, where the larger irrigation heads are feasible and beneficial and where the local schedules have a really substantial basis of soil and crop requirements, it is difficult to conceive of a better method of water delivery.

COMPLETE ROTATION SCHEDULES

Many irrigation systems are operated with completely coordinated schedules of water delivery. Rotation schedules are ordinarily de-

signed to meet the needs of soils or crops so far as they are known, and to this end different schedules are sometimes planned for different parts of a project. At best this is a difficult matter where crops are diversified, except under happy combinations of early and late season crops; and when diversification is extreme, rotation deliveries fall farthest short of supplying water when needed and in the quantities needed.

With a given supply of water, rotation in delivery accomplishes, under most circumstances, a better use of the water than does continuous delivery. This is generally true from the standpoints of both the project and the individual user. Water delivered on demand of the user can usually be put to an even better use by the individual, but in many cases will not accomplish so much throughout the project as a whole. Under such circumstances a properly designed rotation schedule will fit the situation best.

Schedules on the portions of a California project in which relatively heavy soils predominate are based on the delivery of 1 second-foot to 10 acres for 24 hours each 15 days. This plan was adopted as being the most equitable in view of the capacity of the distribution system and the fact that soils and crops were fairly uniform over a large area. Obviously the plan would not be equitable if no deviation were allowed. A schedule is prepared on the above basis for each ditch in the area, but departures are arranged for, or are permitted as between neighbors, to the extent allowed by the ditch capacity. On account of the original layout of this project, the management could not provide for varying local needs to the extent desired.

Contracts for the delivery of water on a Montana project provided for a maximum of $2\frac{1}{2}$ acre-feet per acre per year, or one-half acre-foot per acre in any one month. This required delivery at the rate of 1 second-foot to 120 acres, and led to the adoption of a schedule on substantially the following basis: 1 second-foot continuously to 120 acres, or for a full week every other week to each 60 acres, or for three and one-half days every other week to each 30 acres, with double the length of run each fourth week for orchard tracts. The contract requirements were faulty in providing equal monthly quantities of water over a five-month season, because the grain and orchard crops particularly needed water over a much shorter period, and often needed more than the monthly allotments. In the enforcement of this schedule the general arrangement has been followed, but not too much diligence has been exercised in holding down the June and July deliveries to the scheduled figures. As more of the land in this project becomes developed and the water requires more careful regulation, it will probably become necessary to revise the delivery schedule to conform more closely to the crop needs.

Many cases could be cited of schedules based solely upon two or more soil classifications. In general, these schedules provide for deliveries at relatively frequent intervals to porous or shallow soils and less frequently to the tighter, more retentive soils, with heads of water shown by experience to be necessary to get over the ground. Very few attempts at greater refinement are known. Where crops are uniform—for example, on projects or units of projects composed entirely of orchards—it has been possible to work out rotation

schemes that satisfy the irrigators and that apparently make good use of the water supply.

It is a difficult matter to work out a schedule that will make the most complete use of the water supply and at the same time fulfill individual requirements. Except under the most favorable conditions of uniform soil and crop requirements, a rotation schedule can not meet fully all local needs, and to do the greatest good will necessarily strike a balance between the limitations of water supply and of the irrigation system, if already constructed, on the one hand and the needs of the irrigators on the other. To accomplish this, it is entirely feasible to divide many projects into units and to treat the units separately. Therefore, where continuous delivery is out of the question, and where delivery on demand, for reasons that will be brought out later, is less practicable than in rotation, that schedule which most closely approaches the above requirements will provide the most efficient method of delivery.

FRAMING THE SCHEDULE

Comprehensive schedules are least difficult to prepare for systems designed to carry large heads of water and where the water supply is fairly well sustained throughout the season.

The point of departure in designing the schedule is to ascertain the water requirements of the soils, and so far as practicable those of the anticipated crops. It may then be decided to what extent the water can be made to meet these requirements. For example, it is determined that 365 acres of silt-loam soils under lateral X require water every 10 days with an irrigation head of 5 second-feet, making a total annual application of 3 acre-feet per acre over an irrigation season of 150 days, or an application of 0.2 acre-foot per acre per irrigation. To irrigate this area at this rate will require 7.3 days and 2.7 days of each 10-day period will be left during which the head of 5 second-feet may be used elsewhere. The requirements of all other units have been similarly determined. Then, can the water deliveries throughout the irrigation system be so coordinated that all units may receive their allotments regularly? If not, how close an adjustment can be made? All crops will not require the same total quantities of water, nor will their monthly requirements be the same. It will often be possible to favor certain crops at those times when their needs are greatest, using such crops as alfalfa, which is irrigated over relatively long periods, to balance the seasonal deliveries. In this way the diversification of early and late season crops lends itself to the rotation method of delivery.

USE OF SHORT-SEASON WATER SUPPLY

Irrigation systems in some parts of the country depend upon the direct flow of streams which are commonly dry by midsummer. In those situations, where continuous delivery is not practicable, the most effective plan is to keep the canals full while water is available in order to serve users practically on demand as long as possible, and then to rotate the diminishing supply until it gives out entirely. When the supply is very short—for example, only enough to give each irrigator one thorough irrigation—rotation is more economical

at the outset. If demands are slow in coming in and the project management can not afford to wait for them, rotation at the start is necessary. As a usual thing under such circumstances there is plenty of demand for the water while it is on hand, so that rotation may be postponed until the supply is such that demand deliveries are no longer feasible.

ROTATION IN COMBINATION WITH OTHER METHODS

Rotation may sometimes be combined profitably with some other method of water delivery, as indicated in the preceding paragraph. This method may also be employed during the times of heaviest use of water to ease the strain on the method usually employed and thereby increase the efficiency of the water supply.

There are many examples of this procedure, of which the practice on North Platte project, Nebr., is typical of a well-coordinated plan. Water is ordinarily delivered on demand, or continuously if the irrigator wishes, while water is plentiful. Then as the irrigation of sugar beets and other row crops starts, while alfalfa is growing fast, the demands for water accumulate to a point where the canal capacity is not sufficient to carry the quantity of water desired, and rotation is temporarily put into effect in the several divisions, the intervals between waterings being increased as the demands increase. After the peak has been passed and the demands grow lighter, the process is reversed until each division is back on its normal basis of demand or continuous deliveries.

ORDER OF ROTATION ON LATERALS

The order in which a single rotation head of water is delivered to farmers on a given lateral is of little consequence under many circumstances, but does make a difference in other cases. The most important reasons for adopting one end or the other as the starting point are:

In beginning at the upper end, the only loss of "backed-up" water occurs after the last user has completed his irrigation, whereas in working up the ditch there is some loss at every change. Furthermore, little time is lost in priming the ditch in a sandy country. There is also less likelihood that water will be stolen from a stream that is passing lands already irrigated.

In beginning at the lower end, however, the unirrigated farms above a break furnish an outlet for the water while repairs are under way: although the same effect may be had by leaving a small lateral or sublateral as a "safety valve" while rotating down the ditch and picking it up later. In working up the ditch no time is lost during changes of water—an advantage that tends to offset the additional time required to get water to the first user by this method. Under some circumstances the users at the lower end of a ditch may have greater assurance of receiving water if deliveries begin at that end.

Probably in the greater number of cases where the order of delivery makes a real difference, the advantage lies in beginning at the upper end of the lateral.

DELIVERY ON DEMAND

Situations in which continuous delivery either is not feasible or is uneconomical, and in which delivery at intervals is preferable, have been pointed out. Intermittent deliveries in rotation have been shown to be seldom entirely satisfactory from both of the two standpoints of individual soil and crop needs and best utilization of the project's water supply. It, therefore, is next in order to inquire in what situations the intermittent delivery of water on demand of the user will better suit all requirements.

DIFFERENCE BETWEEN DELIVERY ON DEMAND AND CONTINUOUS DELIVERY

The demand of the user is an element of continuous delivery, in that the irrigator may call for his allotted stream whenever he wants it and may keep it as long as he wants it. The fact that he and all other irrigators may keep their respective streams constantly limits the size of those streams. On the other hand, if the irrigation streams are large enough to render their constant use impracticable, intermittent delivery necessarily follows. Therefore, in the classification of delivery methods, it is important to emphasize the fact that the method commonly termed "delivery on demand" deals with irrigation heads which are of such size that they may not be used on the same tracts constantly and which are consequently subject to use by different irrigators at different times. To summarize, demand delivery, in common with the rotation method, differs fundamentally from continuous delivery in frequency of irrigation, duration of irrigation, and size of head or stream of water.

ESSENTIAL FEATURES OF DEMAND DELIVERY

The elements of the demand method are deliveries of water when requested by the user, in the quantities asked for, and, within reasonable limits, with the size of irrigation stream desired. Deliveries of this character are obviously most satisfactory to the individual user and best suited to his needs. Whether they also make the best use of the project's water supply is another matter.

ECONOMY OF DELIVERY ON DEMAND

To make the most complete use of a given water supply, deliveries must be made while the water is available and to the extent that it is available; in other words, the use must conform to the supply. On any project the supply and the needs of crops necessarily vary from year to year, and a perfect adjustment is an ideal that can seldom be carried out. There are conditions under which delivery on demand is either wasteful of water or uneconomical from an operation standpoint, where the benefits to the individual do not outweigh these objections; and there are also many situations in which the method is entirely feasible.

FAVORABLE CONDITIONS FOR DELIVERY

An ample water supply facilitates any method of delivery, but is particularly favorable to the use of the demand method under certain conditions. Where the water supply is just enough for the suitable irrigation of a project if diverted continuously, the management can

not always afford to wait for demands during parts of the season and can not properly fill the demands during other parts, in which event a plan of rotation conforming as closely as practicable to the soil and crop needs will make a better use of the water supply. In such case an increase in the supply will tend toward the feasibility of demand deliveries. The question of the economy of using an added supply of water for such purpose is, of course, local in every case.

Another feature of this method that is widespread in application is the opportunity to deliver water on demand in the early stages of a project's existence, while the water supply is in excess of the needs of the relatively small percentage of lands settled. Water may usually then be delivered whenever the irrigators want it. A result to be guarded against during such times is the tendency toward excessive use, which, in a number of cases, has led the irrigators into bad habits not easy to break. Latitude as to the time of delivering water is quite possible without undue laxity in the individual quantities delivered.

Delivery of water on demand while relatively few farms are under cultivation, is not feasible when the operation costs are too high in proportion to the area served. A pumping project is peculiarly subject to this condition. To bring the operation costs within reason under such conditions, it has proved necessary on some systems to limit the operation of the system to certain periods during the season within which deliveries are made to the extent desired by the irrigators. The extent to which limitations of this character are necessary depends upon local economic factors.

CONTROLLED WATER SUPPLIES

A water supply controlled by the project management to the extent that it may be drawn upon as needed lends itself in a peculiarly favorable way to deliveries on demand. In fact, the ideal situation from the standpoint of supplying water when needed and in the quantities needed, and at the same time making the supply go farthest, is the delivery on demand of water from a carefully regulated supply. It is not necessary that the supply be abundant. The demand method will function satisfactorily with a restricted water supply under close regulation as long as it is sufficient for the project lands.

Deliveries from reservoirs provide many examples of this character. Other examples are found on projects which obtain water from artesian wells and from pumped wells. In other cases water supplies derived from the direct flow of streams, that would ordinarily not be subject to economical demand deliveries, when supplemented by storage or by pumping are satisfactorily delivered on demand. Many growers under the Santa Ana Valley Irrigation Co., in California found their 28-day rotation schedule during the prorating periods unsatisfactory and formed the practice of obtaining small quantities of water from neighboring pumping plants, to fill out their needs. To remedy this condition the company itself began buying water from plants owned by stockholders to supplement its regular supply and thus became able to deliver on demand throughout the season.

The experience of Salt River Valley Users' Association, Arizona, is illuminating. This project has a regulated water supply. With

a large increase in area devoted to such crops as long-staple cotton, garden truck, and melons, the management tried out a demand service and concluded that the slightly increased cost over that of rotation delivery was an investment well worth while. It was found that increased crop production and a material saving of water, as well as improvement in service to the user resulted. With demand deliveries in effect the farmer knew that he could have water within a few days at any time and did not use more than immediately necessary even during the summer, whereas under an eight-day rotation schedule, while faced by the possibility of hot winds or high temperatures during the succeeding eight days, he had been accustomed to applying more than was actually needed at his turn.

ECONOMICAL TRANSMISSION

This feature may be subdivided into two parts: (1) Transmission without heavy losses regardless of the area served; and (2) transmission made relatively economical because of the close settlement of project units.

(1) A pipe system through which water is delivered under pressure involves minimum transmission losses and is convenient for the users, provided the capacity of the system is sufficient. No time is lost in transmitting the water, for on completion of a delivery the closing of the outlet valve makes that delivery stream immediately available in any other part of the project. Such systems necessarily are of high cost, and on many projects would not be justified by the agricultural production. Their installation has been confined mainly to orchard sections.

Transmission losses in open channels are sometimes so great that delivery on demand to scattered tracts of land involves losses of water and of time out of all proportion to the area served. In such cases canal linings to the extent of their effectiveness in preventing losses tend to bring demand deliveries within the range of economical operation.

(2) Where irrigated farms are widely scattered, rotation is more economical than delivery on demand because under rotation a number of users are served with a single run of water. The close settlement of an irrigation project means so many applications for water from a given territory within a short period of time that a method may be and frequently is used that combines the advantages of the rotation and demand methods, namely, rotation on a lateral to those users who have asked for the water. In well-settled districts, users may often have the benefit of deliveries practically whenever they want them without rendering the transmission of water on that account less economical.

BALANCING SUPPLY AND DEMAND

The problem of balancing supply and demand may be treated from the standpoints of (1) character of water supply, (2) demand as affected by size of project, and (3) demand as affected by diversification of soils and crops.

(1) An unregulated water supply that reaches its peak during the summer will often contribute to a sufficiently close balance between supply and demand to justify demand deliveries. The direct flow

of streams that are highest in the spring and drop rapidly during June is not adapted to this method.

(2) The size of the project is often an element to be considered in deciding the feasibility of the demand method, in that an increase in the number of irrigators tends to diversify more the times that water is wanted. On the larger projects, therefore, there exists greater opportunity for a uniform curve representing the number of requests for water throughout the season.

(3) A project on which the soils and crops are diversified is in greatest need of deliveries of water on demand and at the same time creates a situation favorable to demand deliveries. It has been shown that rotation deliveries do not completely satisfy the needs of projects on which soils and crops are greatly diversified, except where the early and late season crops tend to balance each other. Even in those cases demand deliveries conform more closely to individual needs. Where such diversification is pronounced the demands in turn tend to spread out over the season and in this way are better balanced with a continuing supply of water than if the soils and crops were more uniform.

The situation in Farmers irrigation district, Nebraska, illustrates this. The irrigation of small grains takes place early in the season and is largely completed before the irrigation of sugar beets begins. Alfalfa is watered at intervals throughout the season. The acreage in each of these crops is normally large. On a project containing as much irrigated land as this, such diversification goes far toward equalizing the demands for water and permits of smaller canal capacities than would be necessary otherwise.

On the other hand, as is the case in certain parts of the interior valley of California where large heads of water are desired at relatively infrequent intervals for alfalfa and orchard lands, demand deliveries would lead to considerable waste where only one person on a lateral needed water. Where these conditions are extreme a flexible rotation method is more economical and may be made reasonably satisfactory to the users, and demand deliveries will be justified only when such diversification takes place that smaller heads, more frequent irrigations, and smaller laterals will be called for, so that water may be kept practically constantly in the longer laterals and sufficient irrigation heads may be available to reach the users within a short time after they want them.

PRACTICAL LIMITATIONS ON DEMAND DELIVERIES

The delivery of water precisely when wanted is very difficult to accomplish owing to the distance water must be carried and the inadequacy of canal capacities for taking care of many irrigators at the same time. Consequently several days' notice from the user is usually necessary. Records kept by Salt River Valley Water Users' Association show that 84 per cent of all demands are filled within 24 hours, 96 per cent within 48 hours, 99 per cent in 72 hours, and 100 per cent in 96 hours; in other words, that a user on that project is almost certain to have his water within two days and in the vast majority of cases within one day.

Circumstances occasionally make it necessary to withhold deliveries pending the accumulation of demands. This is particularly

true when water is scarce and the most efficient carrying capacities of canals must be utilized to make the most of it, as well as when operation costs are so high as to require consideration.

Some restrictions as to the size of head or stream are, of course, necessary. Having determined the most efficient sizes for use in a given locality, the irrigator may have a choice within limits governed largely by canal capacities. Available heads on the Salt River project range in size from 25 to 600 inches, depending upon topography, soil, and crop; the only restriction is that on very small tracts the head must be such that it will not operate to waste water. On smaller projects it is frequently impracticable to deliver heads of such wide range in size.

COMPARATIVE SUMMARY OF METHODS

In its last analysis the method by which water may be delivered on any project is dependent upon the physical conditions under which delivery must be made and upon the water supply. Within these limitations, however, any choice that may be made should certainly favor the needs of the water users.

CHARACTER OF SOILS AND TOPOGRAPHY

Lands lying on very steep slopes require continuous delivery of water on account of the necessity for irrigating with very small heads. On slopes where the soils are light or shallow, frequent light applications of water are necessary, and continuous delivery to the farm or rotation deliveries at short intervals will fit the situation best. Soils of impervious character make continuous delivery advantageous, although frequent rotations will do in some cases, depending upon how small a stream is required and how long it must be used to saturate the soil.

Continuous delivery is wasteful where the soils are so light as to prevent a continuous stream from covering the ground without excessive loss of water due to deep percolation. In such cases the larger streams afforded by the rotation and demand methods are required.

Rotation deliveries are more feasible on projects or sections of projects in which the soils and crops are similar in water requirements than where they are diverse.

CAPACITY OF DISTRIBUTION SYSTEM

Laying out a system for the delivery of very small heads practically compels the use of continuous delivery, unless funds become available for enlarging canals and replacing structures at a later date. If small irrigating heads are not otherwise necessary or advisable on such system, local rotation programs or modified demand deliveries on laterals or sections of laterals will improve the situation. The flexibility of rotation or demand deliveries is distinctly limited by the capacities of distributing laterals.

Reduction of transmission losses in canals makes demand deliveries feasible in some cases where rotation would otherwise be required.

CHARACTER OF WATER SUPPLY

The character of the water supply is a potent factor in determining the method of water delivery.

Where the water supply is limited continuous delivery is inefficient because the prorated heads are too small. If conditions require the use of such small heads, there is no alternative. Otherwise rotation delivery is more efficient in giving larger streams to individuals and thus making the water supply go farther. Rotation can be used further to ease the strain on a program of continuous or demand deliveries during the periods of heaviest use of water. Deliveries of a limited water supply on demand are not efficient, unless the supply is regulated, because the management can not afford to wait for demands. Where the water supply is more abundant, continuous delivery often leads to extravagant use because the water is constantly on hand—a condition which may be ameliorated by charging for water on a quantity basis. Abundant water supplies are especially favorable to demand deliveries.

Uniform monthly diversions of water seldom coincide with crop requirements. With such a water supply, in case of a large project, demand deliveries are often most satisfactory owing to the diversity in times of wanting water created by a large number of users. A water supply that is highest in midseason is best balanced with the total demands and lends itself on that account to deliveries on demand. Water supplies that are greatest in the spring and that fall rapidly during the early summer are best distributed by demand deliveries during the first weeks of the season, followed by rotation.

A water supply subject to close regulation can be adjusted within reason to the needs of crops and soils and can be delivered most satisfactorily on demand, provided transmission losses are not too great.

CHARACTER OF CROPS

Continuous delivery is advantageous for small fruits and garden truck, which require water in small quantities very often throughout the season and require attendance much or all of the time, and for rice under the practice obtaining in many rice-growing sections of the West.

Uniformity of crops over large areas, in which also the soils are at least fairly uniform, tends to make possible the framing of a rotation schedule suitable to the needs of soils and crops. Great diversification of crops makes rotation unsatisfactory in that the water is not supplied when needed and in the quantities needed. In such case demand deliveries give far greater satisfaction to the users. If demand deliveries are not feasible, the only recourse is to seek a rotation schedule that strikes a balance between the needs of individual users and the limitations of water supply. Diversification of early and late-season crops, however, lends itself much more readily to rotation deliveries.

SETTLEMENT OF PROJECT

On a project only sparsely settled rotation deliveries are most economical because of the service of a number of users with a single run of water. Continuous deliveries entail heavy losses of water owing

to the attenuation of the streams. If the water supply is abundant and operation costs are not too high, demand deliveries, which suit the individual best, may be feasible. As the irrigated area and the total water requirements of the project increase, a point is reached where the supply no longer exceeds the demand, and rotation may become necessary in order that every user may have enough. Still later, with close settlement of the land and better knowledge of water requirements, it may become practicable again to deliver on demand.

CANAL OPERATION

Rotation and demand deliveries are more complicated than continuous delivery, and the alternate wetting and drying of canal banks cause the loss of more water than would be occasioned if the banks were kept wet. On the other hand, rotation and demand deliveries are made with larger streams, which have been shown to lose proportionately less water in transit than do the smaller streams.

FARMING OPERATIONS

Continuous delivery becomes a part of the regular farm routine and necessarily requires a great deal of the farmer's attention. With such crops as small fruits and truck continuous irrigation adds very little to the labor burden. A rotation schedule is burdensome to the extent that the farmer must take the water whether he is ready for it or not at the risk of losing his turn; yet it carries assurance that the water will be delivered at the appointed time, so that other farming operations may be planned to conform to it. Delivery on demand, provided requests for water are promptly complied with, can be made to satisfy individual needs as they arise.

CONCLUSIONS

Continuous delivery has a distinct field of usefulness, but a narrow one, and where circumstances do not require its use it should not be used. Rotation delivery not only puts the water supply of a project to a higher use but if properly planned may often be better for the individual. Demand deliveries are not always sufficiently economical to justify their use, but where they are feasible they are most satisfactory in providing water when and in the quantities needed and with irrigation heads large enough to eliminate much waste in applying the water.

TREND

Projects on which the method of water delivery has been changed in recent years are not numerous. Any trend that is observable at present is toward rotation, usually on small laterals, on some of the projects in the Northwest heretofore operating on a continuous-flow basis, and from rotation to demand deliveries on a few projects in other sections.

WATER-DELIVERY ORGANIZATION

One of the principal parts, and usually the largest, of the administrative organization of an irrigation enterprise is the water-delivery force. The importance of a loyal and efficient water-delivery or-

ganization can hardly be overestimated. These men are intrusted with the protection of the irrigation system and with the diversion and distribution of water to the irrigators, and while performing the last-named function they come into daily contact with the water users, who, in the greatest number of cases, are the owners of the irrigation works. The best opportunity for successful operation lies in thorough cooperation between the water users, employees, and officials, which in the last analysis depends mainly upon the efforts of the water-delivery force. They must go more than halfway.

SCOPE OF ORGANIZATION

Water delivery is the principal function of operation, which is directed by a manager or superintendent reporting to the board of directors or other general managing body of the irrigation enterprise. The operation force under the manager or superintendent includes water masters, ditch tenders, dam and head-gate watchmen, pump operators, hydrographers, and such office assistants as are necessary in receiving reports of canal stages, dispatching water, and keeping records. The water master is the operation field man in charge of all ditch tenders, watchmen, and other operation employees on a small project or division of a large project.

On large projects it pays to have separate organizations for operation and maintenance; small enterprises can not always afford it, and are content with a small maintenance force working under the water master. Likewise it is only the larger projects that have separate departments for handling routine engineering work.

RELATIONS WITH WATER USERS

Employees engaged upon water delivery—primarily the ditch tenders—are usually the only ones whom the farmers see frequently, and are consequently called upon to handle almost all relations between the enterprise and farmers. The board of directors is the ultimate source of appeal on disputed matters, but should not be required to participate in those minor controversies that necessarily arise in operating an irrigation system. Many trivial matters may be smoothed out by the ditch tenders, and more serious cases not involving questions of policy may be taken to the water master and superintendent.

As the population on an irrigation project increases and as land and water become more valuable, the water users are often found to demand the better service for which they can then afford to pay. Yet the early stages of a project's existence are the most critical, and abundant experience has shown that development may be seriously retarded if the irrigation needs of individuals during these early years are not given adequate attention.

PERSONALITY OF THE MANAGER

While the success of an irrigation enterprise is not necessarily determined by the character of the management, the irrigation manager may accomplish much by adopting the right attitude toward the farmers. Just what is the right attitude may depend to some extent upon the local situation, but the fundamentals are generally the same. Engineering training, executive ability, and business sense

are most valuable assets, but they are not enough. Ability to get along with the farmers and a real interest in their problems are equally important. Bulldozing tactics fail in the long run, and the irrigation managers who have been most successful and who have stayed longest have been both tactful and firm in dealing with the water users. The successful managers have found it important to get the farmer's point of view and to respect it; to listen to him when he comes to the office and to attempt to convince him if he is wrong; and to show a real interest in his crops, livestock, and other interests and problems while driving over the project, even at the cost of taking up valuable time. After all the water user pays the bills, and upon his individual success in the aggregate depends the success of the enterprise. This has not always been the point of view on irrigation projects, but it is coming to be more generally appreciated.

DITCH TENDERS

DUTIES

The operation of an irrigation system, involving as it does the carrying of water in artificial channels which lie in almost all cases above the natural drainage channels of the country, demands constant vigilance on the part of all employees from superintendent down. Even a small break is certain to cause some damage, and if not quickly stopped may result in great disaster. It is therefore necessary that the water-delivery force be available at a moment's notice to help repair a break at any point on the system. The ditch tenders are therefore on duty 24 hours a day throughout the irrigation season, even though their routine work may be accomplished in 8 or 10 daylight hours or even less.

Canals must be patrolled and water delivered on Sunday as on other days. Where the water supply is fairly continuous, however, the ditch rider's Sunday work can often be lightened by allowing no water changes on that day.

Patrolling canals.—Patrolling consists of traversing canal banks and watching carefully for gopher holes, leaks, and other potentially dangerous conditions. Most canals require frequent patrolling during the irrigation season to assure their safety. The amount of attention required in any case depends upon the location and condition of the ditch and is often learned as a result of bitter experience. The age of the canal has an important bearing upon the amount of patrolling required, for the danger of breaks often becomes less after years of service and constant attention to its condition. Under ordinary circumstances one daily inspection suffices for a well-seasoned unlined canal. An extreme instance was noted on a Nebraska system, where one section of a large canal, resting on a very unstable foundation, was being traversed 16 times each 24 hours.

Practically every ditch tender is called upon to do a certain amount of such work and is necessarily equipped with shovel, pitchfork, empty sacks for stopping breaks, and often a hook for manipulating flashboards and reaching floating wood and refuse. Canals that traverse many miles of unirrigated country—as is usually the case at the upper ends of large main canals—require the services of men who do nothing but patrol their banks periodically.

Delivering water.—Aside from guarding the safety of all ditches under his jurisdiction the ditch tender's most important duty is to deliver water to the irrigator. Each ditch tender is assigned certain ditches or sections of ditches for which he is solely responsible. His business is to take charge of all water flowing in these ditches, to distribute the proper quantities to the proper users through their respective delivery gates, and to pass on the surplus, if any, to the ditch tender or tenders next below him. Where measuring devices are installed it is his duty to measure the quantities received, delivered, and passed on by him; otherwise he has to use his judgment in estimating these amounts. The ditch rider, under the conditions to which he is accustomed, has an excellent opportunity to become a good judge of heads of water, and the experienced ones usually do so.

One concern of the ditch rider is to safeguard the interests of the last user on each ditch—the so-called "tailender"—who feels the effect of every change made on the ditch above him and can be protected only by careful regulation of the flow. One of the important and very difficult duties of the ditch tender is to get the right amount of water to the end of the ditch and thus avoid the tendency either to cut the last user short or to drown him out. An emergency waste gate at the tail end of a ditch is of material assistance in accomplishing this.

Daily routine.—It is apparent that the ditch tender's work involves much moving about and a great deal of routine. Where continuous delivery is practiced, his work may be very much the same day after day for weeks at a time, and may consist mainly in visiting each delivery gate and noting the water stage. Rotation delivery brings more variation and demand delivery considerably more.

It is important that the ditch tender keep in as close touch as practicable with the water master or superintendent's office to report his findings and receive instructions. As he is the one who moves about most, it is desirable that he report at a fixed time daily by telephone. His time of starting work in the morning is apt to be more regular than that of returning to his quarters in the evening; hence a morning report is often preferable. On the other hand, the intricacies of water regulation on a large project frequently call for daily information on total water deliveries in each division, which almost necessitates evening reports on account of the total time consumed. Inasmuch as operation conditions are subject to radical changes overnight, an additional morning call is advisable from ditch tenders who report in the evening.

A part of the daily work of these men is to watch for unnecessary waste of water and to take steps to remedy it; to trace down unauthorized use of water or use on land not entitled to receive it; and to receive complaints and adjust them or report them to those in charge. It is generally advisable for the ditch tender to ride his canals according to a reasonably definite schedule, so that the water users may have some idea as to when to expect him. Irritation on the part of the water user is easily caused by missing the ditch rider several days in succession. On the other hand, where the ditch tender has reasons to suspect tampering with the water supply, an unannounced change in itinerary may enable him to apprehend the guilty party.

Reading gage heights on main canals and main laterals is a routine duty.

MAINTENANCE

During the irrigation season patrolling, delivering water, and incidental work are as much as the ditch tender can handle properly. He can do the superficial canal cleaning necessary to keep the canals open, such as clearing trash from structures and removing other obstructions, but his other work requires such connected, concentrated attention that it is not wise to saddle much maintenance work upon him during the irrigation season, except of course in case of emergency. It has proved better practice to confine the ditch tender to a full day's work as outlined above and to employ a separate maintenance force. The assistance of the ditch tender is available in case of a break and there can be little objection to using him on maintenance work during slack periods. During the nonirrigation season the more capable men can be used profitably as foremen in their respective territories on canal cleaning and general maintenance work.

QUALIFICATIONS

General.—The ditch tender's work requires tact and ability to get along with the farmers, at the same time strictly enforcing the rules. It is highly desirable that he shall have been an irrigation farmer or have acquired irrigation experience in some other way, and that he shall have lived in the country long enough to understand local conditions. The ditch tender should know his territory thoroughly, for he has always a responsibility in the care of his particular part of the irrigation system. One of the best qualifications is a reputation for impartiality. Needless to say, sobriety is a prime necessity.

The booklet entitled "Instructions to Operation Employees" of Farmers Irrigation District, Nebraska, may be quoted on this matter of qualifications:

The ditch rider holds a very important position in the delivery of water, and should possess certain qualifications to fill his position competently. He should have a good general education and some agricultural training or experience. He should be strong, healthy, energetic, resourceful, and tactful; able to make accurate computations in arithmetic and keep accurate records of water delivered. He should, by all means, be willing to perform hard manual labor, in case of breaks or on maintenance work, and should not be afraid to get into the water, if necessary. He should have some experience in miscellaneous construction work, to qualify him for foreman on maintenance work, which may be required at any time. He should also learn to use carpenter's tools, as considerable work on wooden structures will be required.

The ditch riders will be required to give their entire time to their work, and will not be allowed to devote a part of their time to farming or other private work. Loitering will not be tolerated, and the ditch rider should take pride in keeping his ditches in good operating condition, and in making a satisfactory record of water delivery for his division. He should become personally acquainted with all of the water users in his division, conditions of soil, crops, etc., and should know, or learn, much about irrigation. A copy of the booklet entitled "Measurement of Irrigation Water" will be furnished each ditch rider.

Ownership of farms.—A wide difference of opinion prevails among irrigation managers as to the wisdom of allowing ditch tenders to own farms and a hard-and-fast rule regarding farm-land ownership may easily lead to injustice, while no rule at all may cause trouble. Plans that have proved feasible in practice have involved allowing

the canal rider to own a small farm if not under a ditch controlled by himself; or if arrangements have been made to have all farm work done by hired labor or by other members of his family; or if the farm consists of only a few acres. In any case there should be a definite understanding that the ditch work is to come first and that the ditch tender shall remain subject to call at any hour of the day or night, for under no other circumstances will the ditch operation prove practicable.

Checking.—Systematic checking of the work of ditch tenders is practicable to only a limited extent and only on large projects, owing to the great expense involved. The most constructive service that can be rendered by "checkers" is in keeping individual measurements of water up to standard by instructing the ditch tender, rather than by following him at a later hour to duplicate his measurements, for two reasonably accurate measurements made at the same gate at different hours may show entirely different results. The checkers' work, consequently, is most valuable with new men.

Ratings.—Efficiency ratings of ditch riders involve exactly the same principles as those of employees in other lines of work. The most comprehensive rating called to the author's attention was that of Twin Falls Canal Co., Idaho. Ratings are made independently by the manager, superintendent of operation, and division water master. The following subjects are included: Natural adaptation, care of stream, use of due column, complete record, transfer from column, transfer to column, prompt response to orders, transfer of cards in boxes, care of company property, industry, expertness.

MEETINGS

Periodical meetings of ditch riders, presided over by the superintendent, have proved distinctly valuable in correlating methods of handling water, exchange of views between superintendent and ditch men, and generally in ironing out difficulties. On small projects it is often feasible for all operation employees to meet in the morning before the riders start out on their work, or for the superintendent to ring all ditch tenders simultaneously on a party telephone line, for the purpose of holding a general discussion of work done and to be done. On projects so large that these plans are not practicable, and where the territories and interests of ditch tenders are not sufficiently similar in character to justify daily meetings, gatherings at less frequent intervals are helpful.

CONVEYANCES

Where the roads are good more ground obviously can be covered by saddle horse or horse and cart than by walking, and still more by automobile. In certain situations, such as in canyons and some foothill or mountainous areas, walking is the only feasible way of getting around. Where the roads permit the use of either autos or horses, such factors as cost of conveyance, necessity of patrolling canals thoroughly, and ultimate distances to be covered will usually determine the most suitable means of conveyance. Where patrolling is especially important and where speed in covering the ground is consequently a minor consideration, horses and carts are preferable

to autos, and saddle horses are even more desirable, in requiring less of the driver's or rider's attention to the road and giving greater opportunity for examination of canal banks. Bicycles—which are seldom used—may be profitably employed in a level country where the distances traveled are not great. Motor cycles afford great speed in getting over the ground and may be used advantageously in rare cases, but are less adapted to general water-delivery work than are the more usual modes of conveyance and are not adapted to patrolling canal banks.

Table 1 shows the extent of use of various means of conveyance on 88 projects in 1922. The third column, giving the number of projects represented by each type, contains duplications, in that many projects use more than one type of conveyance. The fourth column shows a total less than 88, because on eight projects no single type predominated. This table does not include patrolmen not engaged in delivering water.

TABLE 1.—Extent of use of various types of conveyance by ditch tenders, 1922

Type of conveyance	Number of ditch tenders	Number of projects represented	Number of projects on which each type predominated
Automobile.....	435	57	37
Saddle horse.....	350	35	32
Horse and cart.....	122	19	7
Walking.....	51	9	4
Bicycle.....	6	3	
Motorcycle.....	2	2	
Total.....	946		80

Automobiles predominate in California, some other sections of the Pacific coast, and on the larger projects of the Southwest, while saddle horses are very generally used throughout the Rocky Mountain States and elsewhere in the Northwest.

QUARTERS

Ditch tenders gain by living close to their work. Often it is necessary that they live away from home or in some out-of-the-way place during the irrigation season, in which event the organization employing them is forced to provide quarters or to reimburse them for their outlay for rent. Quarters are necessarily provided for head gate and dam tenders.

EMPLOYMENT AND COMPENSATION

Term of employment.—On most irrigation projects the ditch tenders are employed only during the irrigation season and for 1 to 3 months additional on maintenance and canal cleaning. In other cases they are carried on the rolls through the winter, if they desire to remain, being used on maintenance, canal lining, and other repair and construction work. Of the projects included in this study, 30 per cent employed all ditch riders through the year, and an addi-

tional 8 per cent retained part of the force. The actual water-delivery season covers a wide range, being 3 months or less in some portions of the Rocky Mountain States and often 12 months in the extreme Southwest. Continuous employment is necessary in case of reservoir tenders and the more responsible diversion and pump attendants.

The desirable policy is to keep the water-delivery force intact throughout the year. All-year men are likely to be more satisfactory than those who must depend upon summer work only. It is often difficult to get back a man after he has been dropped, particularly if other opportunities arise; and the time required to break in new men and the loss of the older men's experience and intimate knowledge of their territories are distinct handicaps. On the other hand, the saving in salaries, where the irrigation season is short and where winter work is not sufficient to justify employment of ditch riders, is a vital matter that often requires first consideration, particularly where efforts are being made to lower the overhead costs.

In some cases ditch tenders are dismissed as the delivery work lessens late in the season, and the "beats" of the others are lengthened correspondingly. This policy, however, is not to be recommended. The addition of unfamiliar territory lessens the ditch rider's efficiency, and in any event there is usually ample late-season work on maintenance, crop reports, and other miscellaneous matters to occupy his spare time.

Compensation.—The compensation paid to ditch riders almost always includes a fixed allowance designed to cover the cost of conveyance furnished by themselves. In fact, of all projects included in this study, only four provided conveyance for all ditch tenders and three more for part of the force. The value of living quarters where furnished by the management is sometimes considered a part of compensation.

In 1922 the salaries paid ditch tenders on 33 projects, where automobiles were provided by the ditch tenders and where the value of living quarters was not included in their salaries, ranged from \$80 to \$225 per month and averaged \$132 per month, most of the salaries being from \$100 to \$150 per month.

On 40 projects, where saddle horses or horses and carts were provided by ditch tenders, the salaries (not including value of living quarters) ranged from \$50 to \$160 per month, with an average of \$110, most salaries running from \$90 to \$135 per month.

FACTORS INFLUENCING SIZE OF FORCE

The area which one ditch tender can serve efficiently depends directly upon the distance he must travel, number of stops, and length of time required at each stop. These three elements in turn are governed by many conditions, important among which are the following:

Unit to which water is delivered.—The unit to which water is delivered is probably the most decisive element in determining the number of ditch tenders required, for it directly involves the number of deliveries to be made by the organization and mileage of canals to be operated. The average irrigated area covered per ditch tender in 1922, on 41 projects delivering to individuals or to relatively small units, was 3,041 acres, although elimination of three exceptional cases

reduced the average to 2,702 acres. The figures were rather variable. Results from projects delivering to larger units were even more variable and offered no satisfactory basis for making averages.

Size of project.—The size of the project is a factor of some importance on projects delivering only into the heads of laterals, in that the multiplication and greater lengths of farmers' laterals on the larger projects provide a larger irrigated area for each main-ditch tender.

Number, size, and grouping of farms.—The irrigated area served per ditch tender tends to increase with the increase in the average number of farms served, average size of farms, and percentage of the whole project under irrigation. Irrigated areas that are well grouped usually require less time and travel per irrigated acre on the part of the ditch tender than is required by those widely scattered.

Method of water delivery.—The principal effect of method of delivery is in connection with deliveries that are really continuous, where fluctuations in flow of water are reduced to a minimum and ditch tenders are not required to visit each delivery gate daily.

Character of country.—Rough topography is apt to result in an increased number of delivery gates where delivery is made to a prescribed unit of land, to that extent adding to the ditch tender's work and cutting down the area he can serve.

Character of conveyance.—In general, as shown above, the use of an automobile increases the scope of a ditch tender's work.

Maintenance work required.—If ditch riders are required to spend much time on canal cleaning while delivering water the distance they travel will be proportionately reduced.

Frequency of irrigation and length of season.—Frequent irrigations necessarily increase the work of water delivery. On the other hand, a long irrigation season tends to lighten it, in that the use of water is spread over a longer time and demands for water are less concentrated.

Financial condition of project.—Whether the enterprise is hard pressed for finances and requires an unusually high degree of efficiency from the ditch riders has a practical bearing upon the amount of work done by them and upon the number of men required to cover the ground.

CONCLUSIONS

That no one condition of itself can be depended upon to determine the number of ditch tenders required to deliver water on a given project is apparent from a study of conditions on some 97 projects of all sizes, types, and degrees of efficiency scattered throughout 13 States. Certain general tendencies are apparent, as listed above, but are offset in specific cases by local conditions of greater influence. For example, other matters being equal, a system delivering water only into the heads of laterals requires fewer operators than one delivering to every farm, yet several systems which do not reach the individual user show small average areas covered by ditch tenders, because of the necessity of ditch tenders walking their beats, or the scattered location of irrigated areas, or the necessity for close patrolling. On the other hand, certain systems delivering to the individual show larger acreages per ditch tender because of infrequent changes

of water, or relatively large farms in compact groups, or in at least one instance because the sole ditch rider had more work to do than he could properly handle. About the only reasonably safe conclusion to draw from these studies is that where deliveries are made to the individual farm, the ditch tender can not be expected, except under the most favorable circumstances, to cover more than 3,000 acres.

RULES AND REGULATIONS

Rules and regulations have a distinct value in clarifying the policy of the management in conducting the internal affairs of an irrigation enterprise, but lose much of it if not consistently enforced. It is better to change a rule than to allow it to become a dead letter. Subjects which may be advantageously included in the rules and regulations follow.

CONTROL OF SYSTEM

It is advisable to state at the outset that the management will exercise exclusive control over all canals owned by the enterprise, and to state definitely the degree of control to be exercised by the management over private ditches and the extent, if any, to which the water users shall be permitted to regulate delivery gates. A statement should also be made reserving access to all irrigated lands for the purpose of controlling the flow of water.

LIABILITY OF MANAGEMENT AND WATER USERS

The management is responsible only for damage arising from its own acts; therefore, it is wise to call attention to the fact that its responsibility ceases at the point of delivery, and that each water user is liable for damage resulting from his own negligence or unauthorized acts.

METHOD OF WATER DELIVERY

The method and the circumstances surrounding water delivery should be described fully. If the method is rotation, state the basis of the schedule; for instance, the usual length of time allotted for the irrigation of an acre on each soil type or for each crop, and the frequency of delivery. If demand, state the number of days' notice required before delivery may be made. Available sizes of delivery heads may be stated. State the point at which delivery is to be made, point of measurement of water, and method of measurement. Measurement tables printed for distribution to users will go far toward establishing their confidence in the measuring device.

Conditions under which transfers of water from one user to another and exchanges on the rotation schedule may be permitted should be specified.

CONDITION OF PRIVATE LATERALS

A private lateral not cleaned or in proper condition to receive water, results in unsatisfactory delivery to the user and waste of

water, and may cause the water to back up dangerously in the canal from which it is delivered. The management should reserve the right to refuse delivery under such circumstances.

WASTE OF WATER

Waste of water, even where the user pays for it, is uneconomic, and where it results in flooding roads it becomes a public nuisance. Waste is often difficult to detect and to prevent. The rules and regulations of most enterprises contain an injunction against waste and a provision that where water is being wasted it will be cut off. A remedy that has proved effective is to reduce the delivery to an individual by the amount which the ditch tender estimates he is wasting.

INTERFERENCE WITH FLOW OF WATER

Interfering with the flow of water in a canal is a serious matter. The regulation of a large canal system is a delicate operation, easily thrown out of adjustment, and tampering with structures may possibly injure the system and adjoining lands. Stealing water and taking water out of turn are phases of the same problem. These matters should be emphasized in the rules and appropriate penalties provided.

In some cases of stealing water or breaking locks on canal structures a criminal prosecution has been found to be a deterrent for a while at least, though it is difficult to secure a conviction unless the defendant is seen in the act of taking the water.

RIGHT OF WAYS AND BRIDGES

Provisions should be inserted against placing any obstruction on the canal right of ways or fouling the canals and structures. The bridge policy should also be stated; that is, the conditions under which bridges may be constructed across canals, payment of the cost, and maintenance.

CROP PREFERENCES DURING WATER SHORTAGE

Taking water from certain crops in times of shortage for the purpose of assisting other crops less able to withstand drought is a problem that sometimes arises. Such procedure may often be illegal, and in any case is an extreme measure to be taken only in case of real necessity. Where it is practiced, the rules should give the order of priority; for example: First, garden crops; second, young trees, vines, and cuttings; and so on through the list.

WATER CHARGES

All information regarding water rates, including time and conditions of payment, should be stated.

COMPLAINTS

It has proved wise to require that all complaints be made in writing. Some persons, especially if quick-tempered, are ready to make oral complaints on little or no provocation, but are more restrained

when required to reduce their grievances to writing. Written complaints are more likely to be really justified.⁸

PENALTIES

A good rule is to consider violation of any rule sufficient cause for shutting off water until, in the opinion of the manager, the condition has been remedied. In actual practice this penalty is applied in case of flagrant violations. It is well also to call attention to State laws under which action may be taken against waste of water, tampering with structures, and other penal offenses.

INSTRUCTIONS TO EMPLOYEES

Brief general instructions to employees engaged in delivering water, particularly instructions in which the users are directly interested, may be included with the rules and regulations.

LOCAL INFORMATION

Items of information for local water users may often be profitably included with the rules, but should not be made too lengthy or they will not be read.⁹

IMPORTANT FEATURES OF WATER DISTRIBUTION

APPLICATIONS FOR WATER

Rotation deliveries under fixed schedules seldom require formal demands for water, for it is ordinarily presumed that the user will take his turn when it comes around. Continuous deliveries in practice are not strictly continuous, and therefore call for applications from the user when he wants the water turned on or off. Deliveries on demand require applications from the user prior to each irrigation.

Where the request for the delivery of water involves any possibility of uncertainty or error, it should be made in writing, preferably on a form provided for that purpose. Under the continuous-delivery method, where the user's irrigation stream is definite and its use independent of the use of any other person's stream, a simple verbal order to turn the water on or off is sufficient. However, if water is being paid for on a quantity basis, the safer rule is to require written orders even where delivery is continuous.

Seasonal applications for water service are required at the beginning of each year on a number of projects from those users entitled to service. (Fig. 1, p. 40.) The value of such application lies in the

⁸The method of handling complaints adopted by the Salt River Valley Water Users' Association is worthy of note. A water user dissatisfied with a *zanjero's* work is advised to lay the case directly before the general superintendent, who orders an investigation, two men with motorcycles being detailed to such work. If the complaint proves to be justifiable it goes against the *zanjero's* record; otherwise the water user is advised as to the circumstances, some action being taken on every complaint. The number of complaints that have proved to be just has decreased markedly since the inauguration of this procedure.

⁹In this connection a section of valuable advice is included with the rules and regulations of Lethbridge Northern Irrigation District, of Alberta, Canada, entitled "Sterilizing Water." This section emphasizes the danger of using untreated ditch water for drinking, laundering, and other such domestic purposes, and gives the details of two methods of treating ditch water, one method using chloride of lime and the other iodine. In a new country, where ditch water is likely to be used for household purposes, information of this character is of great importance.

information it gives to the management concerning the probable water requirements of the project for the forthcoming season. Information of this character is especially valuable in framing rotation schedules.

WATER TRANSFERS

Water that is appurtenant to a definite tract of land can be delivered only to such tract, irrespective of its ownership. Where not appurtenant, however, as in many mutual companies, the water follows the stock ownership and may be transferred freely from one tract to another, either by sale or by rental.

Water transfers from one lateral to another during the irrigation season may cause serious trouble in delivering water and for that reason on many systems are either prohibited during the season or restricted in some way. Unlimited transfers, where the canal capacities are sufficient to take care of them, are much more readily handled under the demand system than under either continuous or rotation deliveries, and are most disturbing under strict rotation schedules where the heads of water and hours of use are blocked out in advance. A possible danger in permitting too much water to be transferred from a lateral would lie in leaving an insufficient head in the lateral for practical use. On the other hand, a practical limitation is always to be found in the capacity of the lateral to which a user wishes water changed. In old established communities, lands served by a particular lateral are usually well defined, and infrequent transfers may be permitted without greatly upsetting the delivery routine.

WATER DISPATCHING

Distribution of water, which forms a continuous stream from the point of diversion to the place of ultimate use, is in some respects comparable to the distribution of gas and electricity in that it requires close control all along the line, and presents entirely different problems from the distribution of most commodities. Regulating reservoirs are most useful, but do not eliminate the necessity for control of all ditches carrying water. Water dispatching, therefore, is a very essential function of the operation of all systems, particularly large ones, and is usually a one-man task because of the danger of divided responsibility. On the other hand, where water is secured from different reservoirs or other sources for different portions of a system, or where the systems are small and only one or two ditch tenders are involved, dispatching may be more readily decentralized, each ditch tender being allowed to order what water he needs daily from the head gate or reservoir tender and being held solely responsible for its proper distribution.

Two examples of centralized dispatching may be cited. The irrigation manager of the interstate unit of the North Platte project, Nebr., calls the water master of each division by telephone each evening—beginning with the lowest division so that each water master in turn may be instructed as to the amount of water to pass to the next lower division—secures from each a report of deliveries and gage readings, and gives instructions for the next day's diversion and distribution of water. The plan used by Strawberry High Line Canal Co., Utah, is to prepare a hydrograph, which is developed

continuously throughout the season. As demands for water come into the office the dispatcher plots upon the hydrograph all deliveries to be made into each sublateral, making the necessary adjustments according to lateral capacities, and in this way is able to keep the laterals running as nearly as possible to capacity, thus avoiding much canal fluctuation.

The Farmers Reservoir and Irrigation Co., Colorado, affords an excellent example of decentralized water dispatching with its independent reservoirs, to which the rights of users in the several districts are separately allocated.

REGULATING RESERVOIRS

Reservoirs in which water may be held temporarily near the place of use are of great value in canal operations, not only because of the storage facilities provided but because of the aid they give in regulating the distribution of water and thus in getting the water where it is wanted when it is wanted. Small reservoirs along the canal lines are most valuable in making the lower divisions practically independent of the rest of these systems so far as canal regulation is concerned, for they become sources of supply for the lower areas and also provide places to turn water not needed above. Strawberry High Line Canal Co. has two very small reservoirs, with combined capacity of about 50 acre-feet, for the purpose of taking up a large part of the inevitable fluctuations in canal flow that result even with the use of the hydrograph mentioned above.

The use of the reservoirs in canal regulation is necessarily subject to any restrictions that may result from the need for satisfying river priorities. This matter is of particular importance in northeastern Colorado, where reservoirs are used extensively under strict State supervision.

STORAGE RESERVOIRS

A storage reservoir is in the nature of things an equalizing reservoir, and is a potent factor in making water available for the user when he needs it most. The water-supply curve coinciding with the demand curve makes for the most efficient irrigation.

SPILLWAY FACILITIES

Canal operation is greatly simplified if the system is well provided with spillways. The geography and topography of some projects are such that spillways are not practicable within the irrigated area, and under such circumstances close regulation is necessary to prevent disastrous breaks. In a large California district, which is insufficiently provided with spillways and in which the users are permitted to change their own head gates, an unusually large number took occasion to shut down one Saturday night, with the result that the water dispatcher was kept at his telephone practically all night switching the water around from place to place to prevent its breaking away.

CONTROL OF DELIVERY GATES

The management of an irrigation enterprise is the judge of the desirability of allowing water users to adjust the delivery gates,

Under some circumstances the water users can be of material assistance in changing the gates; for example, under rotation systems where only a single head of water is involved and where the hours of change are irregular, the ditch tender notifying each user as to the time he can have the water and allowing him to open his gate at that hour. It is seldom practicable for the ditch tender to change a gate oftener than once a day, so that it is practically impossible for him to handle personally all changes on a system delivering large heads of water for short periods of time. He must keep in close touch with the situation at all times, and so arrange matters that when one user is through with the water another will be on hand to receive it.

On the other hand, the management can not afford to allow water users to turn back their streams of water unless there is ample canal capacity to provide for any emergency, for on closely controlled systems, especially those delivering a multitude of small heads, and where the discharges through many gates are closely interrelated, the balance can be easily upset, with resulting inconvenience to irrigators and possible damage due to overloading the canals. Under such circumstances the irrigators must be required to figure their needs accurately enough to conform to a single daily gate adjustment by the ditch tender. Shutting down over Sundays and holidays, where the water supply holds up well during the season, is a practice sufficiently general in some communities to require careful watching.

Complete control of the flow of water is impossible without the use of locks on all delivery gates. If proper apportionment of water, rather than safety of the system, is the objective, gates may be locked in such a way that they may be shut down by the irrigator at any time and raised again to that point, but no higher. An advantage of using locks lies in the confidence of the farmers that deliveries are really supervised.

MEASURING DEVICES

On many systems water is not measured to the irrigators at all, inasmuch as the comparatively undeveloped state of the community has not demanded measurement, or the supply of water is considerably in excess of its need. Apportionment of water in such cases is necessarily made by rule-of-thumb. It is sometimes felt that the experienced ditch-tender's judgment is as dependable as a measurement made under improper conditions, prevalent, unfortunately, in so many places. Generally speaking, however, in the interest of economical use of water and in justice to those who pay for it, the adoption of a measuring device that will provide at least reasonable accuracy is strongly recommended.

Water sold on a quantity basis should always be measured with as close an approach to accuracy as practicable. Whether the installation of new measuring devices on old systems is justified depends largely upon the value of the water. Theoretically the increasing value of water calls for greater and greater accuracy in its measurement. In actual practice it is often found difficult to install a new method of measurement owing to its cost and to the unfamiliarity of the farmers with the new device. Where conditions are

favorable for the use of an inexpensive measuring device, its adoption in the early stages of a project's existence may save considerable trouble later.

Weirs and submerged orifices are the devices most commonly used to measure water to irrigators on the projects included in this study. Cipolletti weirs are extensively used in the Northwest.

TRANSMISSION LOSSES

Transmission losses, as indicated above in the discussion of methods of delivering water, have an important bearing upon canal operation, and must be taken into account in figuring the quantity of water to deliver from most canal systems as at present constructed. The individual's water right determines the point at which the organization delivering the water ceases to bear such losses. That is, if the individual right calls for a stated amount of water delivered at the highest point of each quarter section, the irrigation enterprise must bear the conveyance losses in getting the water to that point. Again, if the right is for a certain quantity or proportionate quantity of water carried in the main canal of an enterprise, the individual must stand the losses from the main canal to his land. Any ambiguity as to this point will cause trouble sooner or later.

TELEPHONES

Telephones are indispensable to the safe and successful operation of an irrigation system. Private lines reaching every important point of operation are of great advantage in the direct and independent service made possible. Private lines connecting with the ditch-tenders' homes are undoubtedly desirable, but their extra cost may not be justified in those cases in which commercial lines are available, particularly in view of the annual changes in personnel of ditch tenders that may always be looked for. It goes without saying that some form of reliable telephone service should connect the office and the ditch-tenders' and reservoir-tenders' quarters at all times.

RIGHT OF WAYS

FENCES

Trouble has frequently been experienced because right of ways along canals were not made wide enough or kept free from obstructions. It is very important that the road be free and clear and that the ditch rider in patrolling the canal should not be compelled to open and close gates constantly. The use of a limited number of sheep and goats in pasturing a right of way has proved advantageous in some sections in keeping down vegetation and in consolidating the embankment, but uncontrolled access of stock will often result in damage. The cost of fencing the right of way, while a large item, may be fully justified in saving the ditch-tenders' time and in protecting the canal banks.

BRIDGES

Agreements on the part of irrigation enterprises to maintain farmers' bridges on right of ways have led to so much trouble and expense

that the wiser policy has been to pay more for the right of ways in the first place and then require the farmers to maintain their own bridges. The management should reserve the right to approve construction of all farmers' bridges, to limit their number where necessary or advisable, and to require the removal of any bridge found to be interfering with the operation and maintenance of the canal.

FORMS AND RECORDS

Operation of an irrigation system is facilitated by the use of standard forms for reporting activities and keeping permanent records. The most valuable forms contain space for all essential information, simplified as much as possible. The record should be complete in

South San Joaquin Irrigation District
APPLICATION FOR WATER
SEASON 192

Rotation No. _____ Division No. _____

Owner _____

Tenant _____

Lateral and Sta. _____

CROPS TO BE IRRIGATED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CROPS NOT IRRIGATED

--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Total acreage owned _____

Sec. _____ T. _____ S. _____ R. _____ E. _____

Condition of land _____

Signed _____ Irrigator _____

Ditch tender _____

Put Remarks on Other Side

South San Joaquin Irrigation District
WATER RECEIPT FOR SEASON OF 192

Rotation No. _____ Division No. _____ Irrigation No. _____

Owner _____

Tenant _____

Lateral and Sta. _____

WATER TURNED ON		WATER TURNED OFF		ACRES
Time	Date	Time	Date	

CROPS IRRIGATED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

SECOND CROP IRRIGATED

--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Sec. ft. Delivered _____ Total Hours _____

Signed _____ Irrigator _____

Ditch tender _____

Remarks _____

FIG. 1.—Seasonal application for water and water receipt, each 4¼ by 7 inches, used by South San Joaquin Irrigation District, California

order that management and water users may be informed of what is going on, that unnecessary trouble over quantities of water delivered may be averted, and that data be provided on which to base desirable changes and economies. Typical forms used in connection with the several functions of water delivery are shown below.

APPLICATIONS FOR WATER

SEASONAL APPLICATIONS

Figure 1 shows the form of application used by a district to establish rotation turns on laterals and to provide a crop forecast. In the same figure is shown the water receipt signed by both irrigator and ditch tender after every turn, on which are also entered the acreages

of various crops watered at that irrigation. Space for "2d crop" is for a second planting on the same land, as corn following barley.

EACH IRRIGATION

The water request shown in Figure 2 is a concise yet comprehensive form that may be used for ordering water for a stated length of time or without stating it; or for ordering a change from one head gate to another, either stating or not stating the length of time water is wanted at the new head gate; or for turning the water off altogether. It is a standardized form for use on Federal projects of differing requirements and is well adapted to continuous deliveries or to deliveries on demand where the periods of use are protracted. For demand deliveries covering only short periods of time, the orders beginning "Change.... sec.-ft." and "Close turnout" may be omitted from the form.

DEPARTMENT OF THE INTERIOR UNITED STATES RECLAMATION SERVICE WATER REQUEST		7-307 January, 1914
U. S. Reclamation Service: _____, 19____		
Please make the following changes in the water for my land:		
Deliver _____ sec.-ft. to turnout _____ on _____		
lateral beginning _____ until _____		
Change _____ sec.-ft. from turnout _____ on _____		
lateral to turnout _____ on _____ lateral beginning _____		
until _____		
Close turnout _____ on _____ lateral on _____		
Received: _____	Water User. _____	
_____ <i>Canal Rider.</i>		
To the Water User: In requesting water service give at least two days advance notice of your needs, using one of these cards for each run of water from each turnout.		

FIG. 2.—Water-request card, 3½ by 5½ inches, used on Federal projects

Figure 3 shows another water-request form used on Federal projects for demand deliveries, containing information on crop acreages.

DITCH-TENDER'S REPORTS

WATER DELIVERIES

A record of the time and quantity of water delivered to each irrigator is of prime importance to an irrigation manager, particularly where deliveries are charged for on a quantity basis. Every delivery report should be signed and dated by the ditch tender before being turned in to the office, in case the matter should be brought into court. Cases are on record in which users have disclaimed their signatures to applications for water, but are extremely rare, for a water user confronted with his own signature or with the ditch-tender's record of delivery to him seldom makes further protest.

A simple form of individual report, on the reverse side of an application card, is shown in Figure 4. This provides the management with the necessary information regarding each delivery, upon which to base charges for water, but does not provide details of the ditch-tender's measurement, which should be recorded in order to be

DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
WATER REQUEST

January, 1914
7-3071a

U. S. RECLAMATION SERVICE: _____, 192

I hereby request delivery of water at the rate of _____ (second-foot *)
for _____ (days*) beginning _____, 192, at turnout
(hours) _____
No. _____ on _____ lateral or canal to irrigate
the following crops: _____ acres of _____, _____ acres of _____;
_____ acres of _____

Water User's Farm Unit or Holding	
Sec. _____ T. _____ R. _____	
Sec. _____ T. _____ R. _____	
Sec. _____ T. _____ R. _____	
Sec. _____ T. _____ R. _____	
(To be filled out by Water User.)	

Water User, _____

To the WATER USER.—In requesting water service, give at least two days' advance notice of your needs, using one of these cards for each run of water from each turnout.
* Cross out word that does not apply.

GOVERNMENT PRINTING OFFICE 6-4508

FIG. 3.—Water-request card, $3\frac{1}{2}$ by $5\frac{1}{2}$ inches, used on Federal projects

available in case of dispute and is valuable principally as a ready check upon the filling of each order.

A typical daily report of all deliveries made by a canal rider, which may also be used for reporting total deliveries to laterals, is shown in Figure 5. Where fluctuations are common it will be advisable to

Date _____ 192

Turned on _____ Sec.-Foot at _____ M.

Turned off _____ Sec.-Foot at _____ M., _____ 192

REMARKS

DITCH TENDER _____

FIG. 4.—Ditch-tender's report of delivery, on reverse side of order card, 3 by 5 inches, used by the Farmers Reservoir and Irrigation Co., Colorado

have an additional column so that the gauge height may be recorded on the canal rider's arrival and again on his departure after he has made the necessary adjustment. If measuring devices are all of one kind, this form may be simplified.

A form of report covering a week's operations is shown in Figure 6. The

enterprise using this particular form delivers water mostly to rice lands, in streams which are continuous during long periods of time. Under such circumstances a weekly report is convenient.

The monthly report used on many Federal reclamation projects is reproduced in Figure 7. The pages for each account face each other

and are bound in books 4 by 7¼ inches in size. This form, and that shown in Figure 6, contain space for more information than is neces-

[illegible]

FIG. 5.—Daily water report, $4\frac{1}{2}$ by $8\frac{1}{2}$ inches, used by Medford Irrigation District, Oreg.

sary to apprise the management of the ditch rider's operations, but, on the other hand, the columns into which the results of measure-

[illegible]

FIG. 6.—Ditch rider's weekly report, 7 by 3½ inches, used by Western Canal Co., California.

ments may be extended make it possible to use these forms as permanent office records of deliveries, or original books of entry, from

BREAK REPORTS

A written report of each break or flood is valuable. Such report should give the location, description, and cause of the break, with full information as to damage done to land, crops, or roads, and time the water was turned out of the canal and estimated time it may be turned back again. Ample space should be provided for all descriptive matter and notes.

OFFICE FORMS

Forms on which office records of delivery are kept will necessarily depend largely upon water credits and charges. A system selling water on a quantity basis will require records and financial accounts different from the records of one delivering on an acreage basis, and a system apportioning its water and crediting each user with a water dividend will need even different forms. Hence the water-

JOHN DOE IRRIGATION COMPANY									
DITCH TENDER'S GAGE RECORD									
Measurements of Water for Week Ending Saturday, _____ 19__									
Station or Lateral	Time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Remarks
		Gage Rec'd	Cape Rec'd	Gage Rec'd	Cape Rec'd	Gage Rec'd	Cape Rec'd	Gage Rec'd	
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								
	A.M.								
	P.M.								

Telephone these figures in daily
Forward this report to office at end of week

Ditch Tender

FIG. 8.—Suggested form of ditch-tender's gage record, 5 1/4 by 9 1/2 inches

ledger and financial-ledger accounts with users may be one and the same thing, or may have no connection whatever.

Office records of water delivery often duplicate more of the information called for on ditch tenders' reports than is necessary. That is, where details of water measurements are reported by the ditch tender it is seldom really necessary to transfer such details to another record, for only on rare occasions would these figures be referred to. But it is helpful to keep a filing card for each user on which may be summarized dates of irrigation and acre-feet delivered, together with other necessary information, after having made all computations of quantities delivered on the ditch tenders' reports in columns provided for that purpose. Such cards are a convenient medium through which total monthly deliveries may be ascertained.

A typical system of accounts with users who are charged for water on an acre-foot basis is that of the Imperial Irrigation District, Calif. The monthly water bills, made up from the zanjeros' records of delivery, are entered in numerical order in a "Water Rentals Accounts Receivable Register," from which bills and payments are posted to a

those of drainage, canal clearing, repairs, replacements, depreciation of structures and machinery, and other commonly recurring items, which are all factors in determining the cost of water for irrigation, but are not strictly a part of the cost of distributing water. It was not practicable, however, to segregate the time spent by ditch tenders

Schedule No. _____		UTAH-IDAHO SUGAR CO.	
District _____		Garland, Utah, _____ 19__	
<p>Box No. _____ Dear Sir:— Your schedule of time for irrigating _____ Acres in Sec. _____</p> <p>Contract No. _____ Tp _____ N. Rg _____ W. During the irrigating season 19__ will be from _____ M _____</p> <p>Acres by Contract _____ Flow _____ Second Feet _____</p> <p style="text-align: right;">UTAH-IDAHO SUGAR CO.</p>			

FIG. 10.—Rotation notice, $3\frac{1}{4}$ by $8\frac{5}{8}$ inches, used by Utah-Idaho Sugar Co. on Bear River canal system, Utah

in taking care of canals while making their daily rounds. Furthermore, as both pumping and gravity systems are involved, the salaries of pump operators are included, inasmuch as these men occupy positions equivalent to those of dam tenders on gravity projects; but the cost of power for pumping is not included, depending as it does upon

Form 7-312 (July, 1922)		DEPARTMENT OF THE INTERIOR UNITED STATES RECLAMATION SERVICE MONTHLY WATER STATEMENT	
DEAR SIR:		_____, 192	
The records of this office show that you have received water this season as follows:			
	ACRE-FeET OF WATER.		
	TOTAL	PAID ACRES	
Entitled to (based on minimum charge).....			
Delivered:			
Previously reported			
During			
Total			
Balance unused (based on minimum charge).....			
Excess over minimum			
Description of land:	Serial or Reference No. _____		
____ Acres, ____ Sec. ____ T. ____ R. ____	____ Acres, ____ Sec. ____ T. ____ R. ____		
____ Acres, ____ Sec. ____ T. ____ R. ____	____ Acres, ____ Sec. ____ T. ____ R. ____		
Very truly yours, _____ Project Manager.			
No objections as to error in this statement will be considered unless filed in writing in the project office within 10 days from date of this statement.			

FIG. 11.—Monthly water-statement card, $3\frac{1}{4}$ by $5\frac{1}{4}$ inches, used on Federal projects

factors which are highly important in determining the cost of water, but which have no bearing upon a comparison of distribution costs. In other words, the purpose of presenting these data is to make known to irrigation managers and others the average cost of distributing water to various delivery units in 1922 on a number of

representative projects. For the purpose of ascertaining the cost of water delivery the following items were arbitrarily selected:

Salaries of water-delivery employees, such as ditch tenders, dam tenders, pump operators, patrolmen, during the irrigation season only, with value of conveyance and living quarters if furnished by the enterprise in addition to salaries. Costs in this group were found to average 69 per cent of the total costs for all enterprises.

Portions of salaries of manager, secretary, and other field and office employees chargeable to water delivery averaged 19 per cent of the total.

Other operation costs properly chargeable to water delivery, such as office and field expenses, field telephones, and proportion of overhead, but not including power for pumping water, averaged 12 per cent of the total costs.

The total costs of the above items on the 61 enterprises are summarized according to unit of water delivery in Table 2.

TABLE 2.—*Cost of water delivery for the year 1922, on 61 projects*

Unit of delivery	Number of projects	Cost of delivery—	
		Per acre irrigated	Per mile of canal operated
Individuals or small units	26	\$0.36	\$100.02
Individuals and laterals	13	.82	128.00
One-half mile from quarter section	4	.78	76.80
Heads of laterals only	18	.30	93.73

Little difference appears in the average costs per irrigated acre of the first three groups, but as would be expected the cost of delivering only into the heads of laterals is much lower. The cost of delivering to individuals or small units ranged from \$0.31 to \$2.89 per acre; to individuals and laterals, \$0.17 to \$2.09; to a point within one-half mile from each quarter section, \$0.23 to \$1.59; and to laterals only, \$0.06 to \$0.72 per acre.

The average cost of delivery per mile of canal operated on all projects was \$102.86.

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